ECT*

Annual Report
2013

European Centre for Theoretical Studies in Nuclear Physics and Related Areas
Trento

Institutional Member of the European Science Foundation Expert Committee NuPECC

FONDAZIONE BRUNO KESSLER

Edited by
Susan Driessen and Gian Maria Ziglio

1 Preface

The European Centre for Theoretical Studies in Nuclear Physics and Related Areas (ECT*) is one of the Research Centres of the Fondazione Bruno Kessler (FBK) and an Institutional Member of the European Science Foundation Expert Committee NuPECC (Nuclear Physics European Collaboration Committee). Its objectives – as stipulated in its statutes – are:

- to arrange in-depth research at the forefront of contemporary developments in nuclear physics;
- to foster interdisciplinary contacts between nuclear physics and neighboring fields such as astrophysics, condensed matter physics, particle physics and the quantal physics of small systems;
- to encourage talented young physicists to participate in the activities of the ECT* and
- to strengthen the interaction between theoretical and experimental physics.

Altogether 850 scientists from 41 countries have visited the ECT* in 2013 and have participated in the activities of the Centre. This demonstrates once again impressively ECT*'s worldwide visibility and its key importance for the European and international communities.

In 2013 ECT* held:

- 20 Workshops and 3 Collaboration Meetings on new developments in nuclear and hadronic physics from the lowest to the highest energies, nuclear astrophysics, topics in QCD, many-body systems and physics at the borders of the Standard Model;

- a Doctoral Training Programme on “Neutron-Rich Matter: Constraints from Nuclear Physics and Astrophysics” lasting for 6 weeks and attended by 22 students;

  In addition to these 24 scientific events, ECT* supported:

- basic theoretical research on nuclear structure and reactions, non-perturbative QCD and hadron physics, hadronic and nuclear collisions at high energy, phases of strongly interacting matter, nuclear astrophysics and neutron stars, many-body theory and computational physics. This research was performed by the in-house group of Junior Postdoctoral Fellows and Senior Research Associates in close interaction with each other and with the Director of the Centre, and with scientific visitors and collaborating physicists elsewhere. The research activities of the Centre are documented in detail in Chapter 4 of this Annual Report. More than thirty publications by the ECT* researchers in refereed (impact factor) journals in 2013 represent a substantial fraction of all publications produced within the Fondazione Bruno Kessler in the same year.

New cooperation agreements, signed in 2013 with the RIKEN Nishina Centre, with the National Astronomical Observatory of Japan and with the Technical University of Munich provided further international stimulation to the scientific program at ECT*. This year has also seen a welcome enhancement of cross-disciplinary activities between ECT* and LISC, the Interdisciplinary Laboratory for Computational Science at FBK, in terms of joint seminars and publications. In the near future we expect furthermore that the cooperation with TIFPA, the recently founded Trento Institute for Fundamental Physics and Applications, will add to the ECT* profile.

Maintaining ECT*´s high level of scientific activity and visibility in 2013 has only been possible through a stable operating budget. We gratefully acknowledge the local support from the FBK/PAT, the contributions from European funding agencies and research centres in Belgium, the Czech Republic, Denmark, Finland, France, Germany, Hungary, Italy, Poland, Romania, and the UK, and funds provided through the European FP7 projects Hadron Physics, ENSAR, QUIE2T and Qute-Europe. Within FP7 ECT* plays an important role as a Trans-National Access (TNA) facility. ECT* also acknowledges partial support for its workshops from the ExtreMe Matter Institute EMMI and from the Helmholtz International Center (HIC for FAIR).

The year 2013 was in several respects a very special one for ECT*. The 20th Anniversary of its foundation was celebrated in a memorable event on September 14. On that same day members of ECT*'s multinational Joint Finance Review Committee (EJFRC) came together and signed a new Memorandum of Understanding that coordinates financial contributions to ECT* for coming years. The agenda of the EJFRC was supported by the favorable report of the international ECT* Review Committee, chaired by Paul Hoyer (Helsinki), that held its assessment meetings on 21-22 June 2013 at Villa Tambosi.

Finally, it is a great pleasure to thank the members of the Scientific Board, the coordinator of the Doctoral Training Programme, Georges Ripka, the scientific staff – and last but not least – the highly competent administrative and technical staff of the ECT* for their dedicated cooperation.

As its predecessors the Annual Report of 2013 is also available on the ECT* web site (www.ectstar.eu).

Trento, March 2014

Wolfram Weise
*Director of ECT**

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2 ECT* Scientific Board, Staff and Researchers

2.1 ECT* Scientific Board and Director

Baha Balantekin (from January 2010, Chairman)	University of Wisconsin, Madison, USA
Angela Bracco (from June 2012)	NuPECC/University of Milano, Italy
Jens Jørgen Gaardhøje (until January 2013)	Niels Bohr Institute, Copenhagen, Denmark
François Gélis (from September 2012)	CEA Saclay, France
Maria-Paola Lombardo (from September 2012)	INFN Frascati, Italy
Judith McGovern (from January 2013)	University of Manchester, UK
Piet Mulders (from June 2012)	VU Amsterdam, Netherlands
Arturo Polls (from June 2011)	University of Barcelona, Spain
Achim Schwenk (until September 2013)	TU Darmstadt, Germany
Johanna Stachel (from June 2013)	University of Heidelberg, Germany

Honorary Member of the Board

Ben Mottelson	NORDITA, Copenhagen, Denmark

ECT* Director

Wolfram Weise (from November 01, 2012)	ECT*, Italy and TU München, Germany

2.2 ECT* Staff

Ines Campo (part time)	Technical Programme Co-ordinator
Serena degli Avancini	Technical Programme Co-ordinator
Barbara Curro' Dossi	Systems Manager
Susan Driessen (part time)	Assistant to the Director
Tiziana Ingrassia (part time)	Accounting Assistant
Mauro Meneghini	Maintenance Support Manager
Gian Maria Ziglio	Technical Programme Co-ordinator and Web Manager

2.3 Resident Researchers

- **ECT* Postdocs**

Daniele Binosi, Italy
Marco Cristoforetti, Italy
Alexis Diaz-Torres, Germany
Daniel Gazda, Czech Republic (from 01/11/13)
Thomas Hell (TUM-ECT*), Italy (until 30/09/13)
David Ibañez Gil de Ramales, Spain (from 01/10/13)
Ahmad Idilbi, Israel (until 30/09/13)
Vincent Mathieu, Belgium (until 30/09/13)
Abhishek Mukherjee, India
Dionysis Triantafyllopoulos, Greece

- **PhD Students**

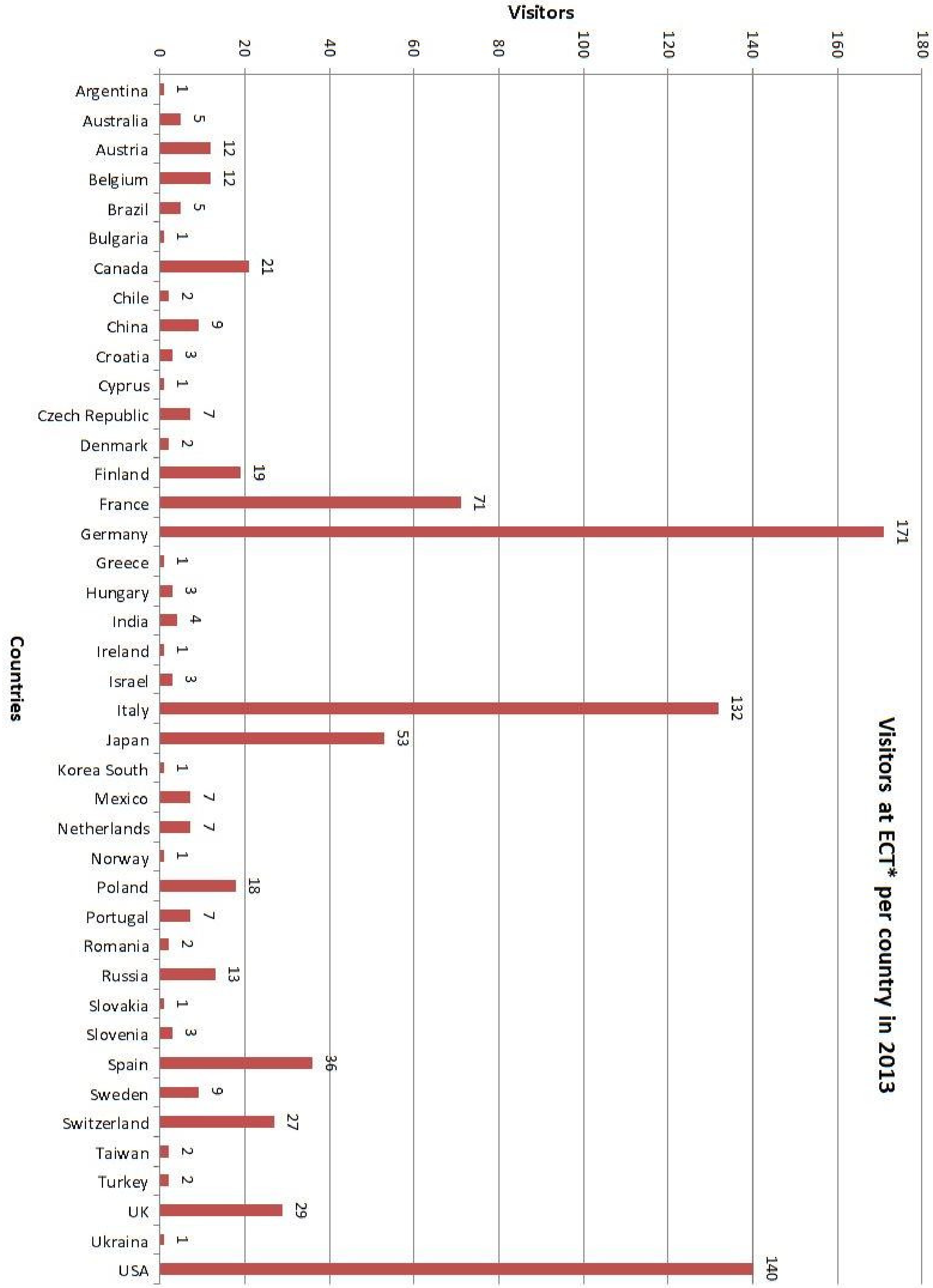
Maddalena Boselli, Italy
Matthias Drews, Germany

2.4 Visitors in 2013

This list includes Visiting Scientists (VS) who typically spent from a few days up to several weeks at the Centre, as well as participants and lecturers of the Doctoral Training Programme (TP).

Paolo Giuseppe Alba (09/05-25/05)	INFN Torino, Italy (TP)
Wanda Alberico (20/06-23/06)	University of Torino, Italy (VS)
Michael Altenbuchinger (17/02-23/02, 02/12-06/12)	TU München, Germany (VS)
Andreas Bauswein (12/05-17/05)	Max Planck Institute for Astrophysics, Germany (TP)
Gordon Baym (30/06-15/07)	University of Illinois, USA (VS)
Sanjin Benic (14/04-25/05)	Zagreb University, Croatia (TP)
Jean-Paul Blaizot (27/04-12/05, 20/06-23/06)	CEA Saclay, France (VS)
Peter Braun-Munzinger (13/05-17/05)	GSI, Germany (TP)
Marco Brenna (21/04-26/04, 19/05-24/05)	Università degli Studi di Milano, Italy (TP)
Sandeep Chatterjee (10/11-13/11)	Indian Institute of Science, Bangalore, India (VS)
Wei-Chia Chen (13/04-26/05)	Florida State University, USA (TP)
Giuseppe Colucci (14/04-25/05)	Goethe-Universität Frankfurt am Main, Germany (TP)
Madhumita Dhar (13/04-26/05)	Universität Giessen, Germany (TP)
Matthias Drews (15/04-24/05, 29/10-31/10)	TU München, Germany (TP)
Kevin Ebinger (14/04-25/05)	University of Basel, Switzerland (TP)
Victor Efros (01/05-29/05)	Kurchatov Institut, Moscow, Russia (VS)
Maria Isabel Ferretti Bondy (13/04-26/05)	Johannes Gutenberg Univ. Mainz, Germany (TP)
François Gélis (11/06-15/06)	CEA Saclay, France (VS)
Lisheng Geng (14/07-16/07)	Beihang University, China (VS)
Arturo Gomez Comacho (07/07-03/08)	ININ, Mexico (VS)
Carlo Guaraldo (20/06-23/06)	INFN LNF, Italy (VS)
Miguel Gullon (15/04-17/05)	Universidad de Alicante, Spain (TP)
Tetsuo Hatsuda (09/09-16/09)	RIKEN, Japan (VS)
Wick Haxton (20/06-23/06)	University of California, Berkeley, USA (VS)
Paul-Henri Heenen (20/06-23/06)	Université Libre de Bruxelles, Belgium (VS)
Emiko Hiyama (17/10-19/10)	RIKEN, Japan (VS)
Jeremy Holt (19/03-22/03)	University of Washington, USA (VS)
Paul Hoyer (23/04-13/05, 20/06-01/07)	University of Helsinki, Finland (VS)
Tetsuo Hyodo (14/10-18/10)	Yukawa Institute for Theoretical Physics, Kyoto, Japan (VS)
David Ibanez (25/02-08/03)	Universitat de València, Spain (VS)
Yoichi Ikeda (14/10-20/10)	RIKEN, Japan (VS)
Norbert Kaiser (19/03-20/03)	TU München, Germany (VS)
Jim Lattimer (19/05-24/05)	Stony Brook University, USA (TP)
Yuri Litvinov (28/04-02/05)	GSI, Germany (TP)
Thomas Krüger (14/04-25/05)	TU Darmstadt, Germany (TP)
Gwendolyn Lacroix (06/01-09/02, 05/05-25/05)	University of Mons, Belgium (VS&TP)
Robert Lang (17/02-23/02, 29/05-31/05)	TU München, Germany (VS)
Jiajie Li (14/04-25/05)	IPNO, France (TP)
Diego Lonardoni (15/04-24/05)	Università degli Studi di Trento, Italy (TP)
Kota Masuda (14/04-26/05)	RIKEN, The University of Tokyo, Japan (TP)
Thomas Mehen (04/08-11/08)	Duke University, USA (VS)
Heiko Möller (15/04-24/05)	TU Darmstadt, Germany (TP)

Shota Ohnishi (14/04-25/05,14/10-20/10)	RIKEN, Japan (TP&VS)
Cem Ozen (28/08-07/09)	Kadir Has University, Istanbul, Turkey (VS)
Joannis Papavassiliou (07/09-11/09)	University of the Basque Country, Leioa, Spain (VS)
Stefan Paul (16/07-19/07)	TU München, Germany (VS)
Owe Klaus Philipsen (05/05-11/05)	Universuty of Frankfurt, Germany (TP)
Alessia di Pietro (22/04-23/04)	INFN LNS, Italy (VS)
Andrea Quadri (20/01-21/01)	INFN Milano, Italy (VS)
Sanjay Kumar Reddy (21/04-26/04)	INT and University of Washington, USA (TP)
Achim Richter (07/06-14/06, 13/09-20/09)	TU Darmstadt, Germany (VS)
Georges Ripka (11/04-29/05)	CEA Saclay, France (VS)
Robert Rutledge (28/04-05/05)	McGill University, Canada (TP)
Christian Schmidt (01/04-06/04)	Universität Bielefeld, Germany (VS)
Achim Schwenk (14/04-19/04)	TU Darmstadt, Germany (TP)
Roshan Sellahewa (14/04-10/05)	University of Surrey, UK (TP)
Ingo Tews (14/04-25/05)	TU Darmstadt, Germany (TP)
Anthony Van Eysden (14/04-26/05)	NORDITA, Sweden (TP)
Daniele Viganò (14/04-27/05)	Universitat d'Alacant, Spain (TP)
Jochen Wambach (20/06-23/06)	TU Darmstadt, Germany (VS)
Corbinian Wellenhofer (14/04-26/05)	TU München, Germany (TP)



Visitors at ECT* per country in 2013
Visitors
Countries
0
20
40
60
80
100
120
140
160
180
Argentina 1
Australia 5
Austria 12
Belgium 12
Brazil 5
Bulgaria 1
Canada 21
Chile 2
China 9
Croatia 3
Cyprus 1
Czech Republic 7
Denmark 2
Finland 19
France 71
Germany 171
Greece 1
Hungary 3
India 4
Ireland 1
Israel 3
Italy 132
Japan 53
Korea South 1
Mexico 7
Netherlands 7
Norway 1
Poland 18
Portugal 7
Romania 2
Russia 13
Slovakia 1
Slovenia 3
Spain 36
Sweden 9
Switzerland 27
Taiwan 2
Turkey 2
UK 29
Ukraina 1
USA 140

3 Scientific Projects in 2013

3.1 Summary

Altogether 23 scientific projects have been run in 2013: 20 workshops, two collaboration meetings, and a Doctoral Training Programme. This chapter collects the scientific reports written by the workshop organizers. The report of the Doctoral Training Programme was prepared by Georges Ripka who assisted the Director in coordinating and running this extended programme.

3.2 Workshops, Collaboration Meeting and School (Calendar)

Feb 04 – 13	**Physics at a Fixed Target Experiment using the LHC Beam** Frédéric Fleuret *(Laboratoire Leprince Ringuet École Polytechnique CNRS/IN2P3)* Andry Rakotozafindrabe *(IRFU/SPhN CEA Saclay)* Ingo Schienbein *(LPSC – Université Joseph Fourier - CNRS/IN2P3)* Ulrik Uggerhøj *(Department of Physics and Astronomy - University of Aarhus)* Stanley J. Brodsky *(SLAC National Accelerator Laboratory)* Jean-Philippe Lansberg *(IPNO - CNRS/IN2P3)* Elena G. Ferreiro *(Departemento de Fisica de Particulas Universitade de Santiago de Compostela)*
Feb 18 - 22	**Scattering and Annihilation Electromagnetic Processes** Marco Maggiora *(Università di Torino)* Simone Pacetti *(Università di Perugia)* Egle Tomasi-Gustafsson (*IPN Orsay*) Rinaldo Baldini *(Centro Fermi)* Francesco Iachello *(Yale University)* Frank Maas *(Mainz University)*
Apr 01 - 05	**Heavy Quarks and Quarkonia in Thermal QCD** Mikko Laine *(University of Bern)* Seyong Kim *(Sejong University)*
Apr 10 - 12	**Constraining the Hadronic Contributions to the Muon's Anomalous Magnetic Moment** Marc Vanderhaeghen *(Universität Mainz)* Achim Denig *(Universität Mainz)* Graziano Venanzoni *(LNF)* Henryk Czyz *(Kattowice)*
Apr 15 – May 24	**Neutron-Rich Matter: Constraints from Nuclear Physics and Astrophysics** **(Doctoral Training Programme)** Achim Schwenk *(TU Darmstadt)* Arturo Polls (*Univ. Barcelona*)

May 06 - 10	**Proton–Nucleus Collisions at the LHC** Francois Arleo *(LLR, École polytechnique)* David d'Enterria *(CERN)*
May 20 - 24	**Electromagnetic Probes of Strongly Interacting Matter: Status and Future of Low-Mass Lepton-Pair Spectroscopy** Volker Koch *(Lawrence Berkeley National Laboratory)* Xin Dong *(Lawrence Berkeley National Laboratory)* Tetyana Galatyuk *(Technische Universität Darmstadt)* Ralf Rapp *(Texas A&M University)* Joachim Stroth *(Goethe-Universität Frankfurt)*
Jun 10 - 14	**From Few-Nucleon Forces to Many-Nucleon Structure** Robert Roth *(Institut für Kernphysik, TU Darmstadt)* Bruce Barrett *(University of Arizona)* Ruprecht Machleidt *(University of Idaho)*
Jun 17 - 21	**h3QCD (High Energy, High Density and Hot QCD)** Dionysis Triantafyllopoulos *(ECT*)* Francois Gélis *(CEA Saclay)* Edmond Iancu *(CEA Saclay)* Cyrille Marquet *(CPhT - École Polytechnique)*
Jul 01 - 05	**Flavor Structure of the Nucleon Sea** Gerald A. Miller *(University of Washington, Seattle)* Mary Alberg *(Seattle University)* Jen-Chieh Peng *(Physics Department - UIUC)* Matthias Grosse-Perdekamp *(University of Illinois at Urbana-Champaign)*
Jul 08 - 12	**Nuclear Structure and Astrophysical Applications** Paul-Henri Heenen *(Université Libre de Bruxelles)* Jacek Dobaczewski *(Warsaw University)* Helmut Leeb *(University of Vienna)* Friedrich-Karl Thielemann *(University of Basel)*
Jul 16 - 18	**HASPECT ECT*:** **Hadron Spectroscopy Collaboration Meeting at ECT*** Vincent Mathieu *(ECT*)*
Jul 22 - 26	**Nucleon Matrix Elements for New-Physics Searches** Huey-Wen Lin *(University of Washington, Seattle)* Susan Gardner *(University of Kentucky)* Felipe Llanes-Estrada *(Univ. Complutense de Madrid)*
Jul 29 – Aug 02	**Compton Scattering off Protons and Light Nuclei: Pinning Down the Nucleon Polarizabilities** Vladimir Pascalutsa *(University of Mainz)* Barbara Pasquini *(University of Pavia)* Evangeline J. Downie *(George Washington University)* Helene Fonvieille *(Université Blaise Pascal)*

Sep 02 - 06	**QCD-TNT-III From Quarks and Gluons to Hadronic Matter: a Bridge too Far?** Daniele Binosi (*ECT**) Cristina Aguilar (*UNICAMP*) Joannis Papavassiliou (*Univ. of Valencia*) John Cornwall (*UCLA*)
Sep 16 - 20	**LC13: Exploring QCD from the Infrared Regime to Heavy Flavour Scales at B-factories, the LHC and a Linear Collider** Giulia Pancheri *(INFN Frascati)* Gennaro Corcella *(INFN Frascati)* Francois Richard *(LAL - IN2P3 Université de Paris Sud)* Stefano Moretti *(University of Southampton)* Stefania De Curtis *(INFN Firenze)* Rohini Godbole *(Indian Institute of Science)*
Sep 23 - 27	**MICRA 2013** Filippo Galeazzi *(Universidad de Valencia)* H.-Thomas Janka *(Max Planck Institute for Astrophysics)* Christian Ott *(California Institute of Technology)* Almudena Arcones *(TU Darmstadt)*
Sep 30 – Oct 04	**Neutron-Rich Matter and Neutron Stars** Christopher J. Pethick *(Niels Bohr International Academy and NORDITA)* Achim Schwenk *(TU Darmstadt)* Anna Watts *(Anton Pannekoek Astronomical Institute)*
Oct 07 - 11	**Reactions Involving 12C: Nucleosynthesis and Stellar Evolution** Alexis Diaz-Torres *(ECT*)* Leandro R. Gasques *(University of São Paulo)* Michael C. Wiescher *(University of Notre Dame)*
Oct 14 - 18	**Advances in Time-Dependent Methods for Quantum Many-Body Systems** Arnau Rios Huguet *(University of Surrey)* Pavel Danielewicz *(Michigan State University & National Superconducting Cyclotron Laboratory)*
Oct 21 - 25	**Strangeness in the Universe? Theoretical and Experimental Progress and Challenges** Carlo Guaraldo *(LNF – INFN)* Johann Marton *(SMI-Vienna)* Johann Zmeskal *(SMI-Vienna)* Jiri Mares *(Nuclear Physics Institute ASCR)* Catalina Curceanu *(LNF – INFN)*
Nov 04 - 08	**From Nuclear Structure to Particle-Transfer Reactions and Back** Jacek Dobaczewski *(University of Warsaw)* Marek Ploszajczak *(GANIL)*

Nov 14 - 15	**Nuclear Fusion with Polarized Nucleons** Paolo Lenisa *(Università di Ferrara and INFN)* R. Engels *(FZ-Jülich)* A. Vasiliev *(PNPI)* R. Milner *(MIT)*
Dec 5 - 6	**CRC 110 Collaboration Meeting on Strangeness and Related Topics** Ulf-G. Meissner - *(Universität Bonn)*

3.3 Reports on all Workshops and three Collaboration Meetings

3.3.1 PHYSICS AT A FIXED TARGET EXPERIMENT USING THE LHC BEAMS

DATE: February 3 – 13, 2013

ORGANIZERS:

Jean-Philippe Lansberg *(IPNO - CNRS/IN2P3, France)*
Stanley J. Brodsky *(SLAC National Accelerator Laboratory, Stanford U., USA)*
Elena G. Ferreiro *(U. de Santiago de Compostela, Spain)*
Frédéric Fleuret *(Laboratoire Leprince Ringuet, École Polytechnique, CNRS/IN2P3, France)*
Andry Rakotozafindrabe *(IRFU/SPhN, CEA Saclay, France)*
Ingo Schienbein *(LPSC – Université Joseph Fourier - CNRS/IN2P3, France)*
Ulrik Uggerhøj *(Department of Physics and Astronomy, University of Aarhus, Denmark)*

NUMBER OF PARTICIPANTS: 39

MAIN TOPICS:

This was an exploratory workshop aiming at studying in detail the opportunity and feasibility of a fixed-target experiment using the LHC beams extracted by a bent crystal.
Complementarity with existing experiments at the LHC, at SPS, at CEBAF, at Fermilab and RHIC was also the cornerstone of the discussions.
The workshop consisted of morning sessions with invited speakers and afternoon sessions devoted to work in groups on the following themes:

- nucleon and nucleus pdf extraction in hadronic processes
- spin physics
- QGP physics
- nuclear matter studies in pA
- diffractive physics and ultra-peripheral collisions
- heavy-quark dynamics and spectroscopy at high |xF|
- beam extraction and secondary beams
- studies of the crystal-extraction influence on the machine and detector performance
- target polarization
- modern detector technologies
- event generator and detector simulation

SPEAKERS:

M. Anselmino (Torino University & INFN Torino, Italy)

R. Arnaldi (INFN Torino, Italy)

E.C. Aschenauer (BNL, Upton, NY, USA)

S. Bodsky (SLAC National Accelerator Laboratory, Menlo Park, USA)

G. Cavoto (INFN Roma, Italy)

D. D'Enterria (CERN, Genève, Switzerland)

O. Denisov (INFN Torino, Italy)

J.P. Didelez (IPNO - CNRS/IN2P3, France)

J. Engelfried (U. Autonoma de San Luis Potosi, Mexico)

N. Estrada (UVM Campus San Luis Potosi, Mexico)

E. Ferreiro (U. de Santiago de Compostela, Spain)

M.C. Guclu (Istanbul Technical University, Istanbul, Turkey)

I. Hrivnacova (IPNO - CNRS/IN2P3, France)

V. Kartvelishvili (Lancaster University, Lancaster, U.K.)

L. Kluberg (LLR/IN2P3 - Ecole Polytechnique, France)

J.-P. Lansberg (IPNO - CNRS/IN2P3, France)

C. Lorce (IPNO - CNRS/IN2P3, France)

L. Massacrier (Subatech, Ecole des Mines, Nantes, France)

S. Melis (University of Torino, Italy)

S. Montesano (CERN, Switzerland)

J.-C. Peng (University of Illinois, USA)

C. Pisano (University of Cagliari, Italy)

S. Platchkov (IRFU/SPhNFrance)

M. Ploskon (Lawrence Berkeley National Laboratory, USA)

S. Porteboeuf-Houssais (LPC, France)

A. Rakotozafindrabe (CEA Saclay, IRFU, France)

B. Saghai (CEA Saclay, IRFU, France)

H. Satz (Univ. Bielefeld, Germany)

S. Sawada (KEK, Tsukuba, Japan)

I. Schienbein (LPSC Grenoble, France)

M. Schlegel (University of Tübingen, Germany)

G. Schnell (University of the Basque Country UPV/EHU, Spain)

E. Scomparin (INFN Torino, Italy)

J. Sexias (CERN, Switzerland)

T. Stavreva (LPSC, France)

L. Szymanowski (National Centre for Nuclear Research, Poland)

O. Teryaev (JINR, Russia)

N. Topilskaya (Institute for nuclear research RAS, Russia)

R. Vogt (LLNL and UC Davis, USA)

SCIENTIFIC REPORT:

Within the Standard Model of elementary-particle physics, Quantum ChromoDynamics (QCD) is the theory of strong interaction – one of the four fundamental interactions in physics. It binds quarks and gluons inside the nucleons as well as the nucleons inside the nuclei. While one understands QCD at short distances (the perturbative domain), phenomena such as confinement of quarks and gluons in the nucleons are still not understood at a fundamental level. There is also no ab initio understanding of their dynamics within both nucleons and nuclei.

With the advent of the Large Hadron Collider (LHC) at CERN, a new era of particle and nuclear physics has begun. The LHC allows us to delve into QCD dynamics with protons and lead ions accelerated to a record nominal collision energy of 14 TeV and 5.5 TeV respectively – one order of magnitude beyond the previous colliders. The primary goals of the LHC were the discovery of the Higgs boson and the search for physics beyond the Standard Model. Two years after the first recorded collisions, the LHC has however also been recognized as an outstanding machine to study QCD with a remarkable precision, thanks to its large reaction rates and the modern detection techniques of its detectors.

Nevertheless, these detectors do not permit us to study processes producing very high longitudinal momentum particles. Such reactions are, however, particularly important in understanding the dynamics and confinement of quarks and gluons which carry the largest momentum fraction of the projectile particles.

By extracting a small fraction of the intense LHC beams to collide it with fixed targets, we can study produced particles without restrictions since the beam comes from one side only. Using the unprecedented energies of the LHC beams, the project AFTER, for “A Fixed-Target ExpeRiment”, gives access to new domains of particle and nuclear physics complementing that of collider experiments, in particular the Brookhaven's Relativistic Heavy Ion Collider (RHIC) and the to-be Electron-ion colliders (EIC).

The multi-TeV energy of the LHC beams would make this fixed-target physics program unique. As simple as it seems, the high energy LHC beams will allow for the most energetic fixed-target experiments ever performed. We believe that such a facility will be of much interest to a wide range of hadron, nuclear and particle physicists. The collision of the high energy LHC beams with fixed targets, including polarized and nuclei targets will greatly expand the range of fundamental physics phenomena accessible at CERN.
The fixed-target mode will permit us to carry out unprecedented precision measurements of hard QCD processes. In particular, our aim is to study:

- rare configurations of the proton wave function which contain gluon or heavy-quarks with high momentum fraction;
- the gluon content in the deuteron and neutron in a wide momentum-fraction range;
- the correlation between the proton spin and the gluon angular momentum through the Sivers effect and novel spin correlations;
- the production of W and Z bosons in their threshold domain;
- the melting of excited heavy-quark bound states in the deconfined QCD phase in heavy-ion collisions;
- the nucleus structure function for momentum fractions close to and above unity;
- the deconfinement dynamics in the target-rest frame;
- ultra-peripheral collisions in a fixed-target mode.

Compared to the RHIC experiments, which benefit from similar center-of-mass energies, AFTER will bear upon a huge luminosity –typical of a fixed-target set-up– and upon a complete versatility of target species. Compared to Electron-ion collider projects, AFTER will certainly be highly competitive in terms of cost and it will be of complementary design, with a specific focus on the study of parton content at large momentum fractions – in particular that in terms of gluons.

High-energy fixed-target experiments have already been discussed in the 90's, both at the European LHC and the American SSC. The main differences between AFTER and earlier proposals are:

- the fact that the LHC is now built and runs –very well indeed–,
- bent-crystal beam-extraction techniques have now been successfully tested at the SPS and the Tevatron up to nearly 1 TeV and they will be tested on the LHC beams,
- a number of modern detection techniques have been developed in the meantime –in particular, ultra-granular detectors– and, finally,
- AFTER is, in essence, a multipurpose experiment, not only focusing on one specific aspect of particle physics, as it was the case for the LHB project, for instance.

We believe it is well worth exploring this option and bringing our nuclear and particle physicist colleagues' attention to all these new physics opportunities. To do so, the principal aim of the workshop was to prepare the ground in order:

- to work out the detail of the physics case in adequacy with the current experimental possibilities –and limitations– ,
- to develop a first robust –but ambitious– design of the experiment and its assembly compliant to the physics case, and
- to advertise our project all over the world-physics community to create an experimental collaboration large enough to make this project viable and fruitful for the years to come.

Results and Highlights

The workshop was divided in 3 parts:

1. the morning session of the 5 first days with invited review talks;
2. the afternoon sessions of the 5 first days with work in 3 groups;
3. the 3 last days with talks followed by extended discussion sessions.

<u>Morning sessions:</u>

The morning sessions were very useful to update the participants about the state-of-the-art activities in the different topics relevant for a fixed-target experiment on the LHC beams. These topics are belonging to particle physics, spin physics, hadronics physics, nuclear physics as well as to detector technologies. The review talks were very general, accessible and of high quality.

<u>Afternoon sessions:</u>

During the afternoon sessions, we have formed 3 working groups:

1. topics related to simulations and detectors
2. spin physics
3. topics related to PDF, nPDF and GQP

The activities of the first group were very focused and efficient. They resulted in the setting of a first simulation framework based on ALIROOT and MOKKA, in the generation of samples of minimum bias collisions at AFTER energies with PYTHIA and in some conclusions about the geometry of the possible detector. The members of this working group will remain in contact and will continue developing the simulation framework, set up a wiki webpage where the event files will be made available and elaborate a list of constrains for the detector.

The activity of the second group was focused on mostly theoretical and phenomenological aspects of spin physics at AFTER. They critically discussed the pertinence of studying the gluon Sivers effects with single photon, photon-photon and heavy flavours. They have also discussed the complementarity with other experiments in particular at RHIC and at Fermilab (E906). During the discussion, we have decided to investigate more specifically the spin

asymmetry in the production of a J/psi with an isolated photon. A note has been written after the workshop and a paper on this topic is likely.
The third group discussed the extraction of PDF and nPDF with gluon sensitive probes, the opportunity of studying W and Z production near threshold as well as some specific aspects related to QGP studies. The idea of updating, at AFTER energies, a recent study by some participants has emerged; it will be pursued in the coming months. We have also reached the agreement that proton-nucleus studies at negative xF will indeed be unique and some participants proposed to make some predictions.

Three last days:

During the 3 last days, we have discussed the synergies with the (L)UA9 experiment using bent crystals. A consensus has emerged that both projects can gain a lot from such synergies. We have then discussed the schedule of both LUA9 and AFTER projects and how they can be matched. We have had intense and very interesting discussions on the role of open heavy-flavour studies in the context of the study of Quark-Gluon Plasma at RHIC, the LHC and AFTER. In particular, we had discussions about the optimization of the contribution from AFTER. We have also discussed the future of the project AFTER, in particular, the next milestones. The possibility of writing a Letter of Intent has been discussed and will seriously be considered in the future.

3.3.2 SCATTERING AND ANNIHILATION ELECTROMAGNETIC PROCESSES

DATE: February 18 – 22, 2013

ORGANIZERS:

Simone Pacetti *(Università di Perugia, Italy)*
Marco Maggiora *(Università di Torino, Italy)*
Egle Tomasi-Gustafsson *(IRFU/SPhN and IN2P3/IPN Orsay, France)*
Rinaldo Baldini Ferroli *(LNF-Frascati, Italy)*
Franco Iachello *(Yale University, United States)*
Frank Maas *(Mainz University, Germany)*

NUMBER OF PARTICIPANTS: 30

MAIN TOPICS:

The theme of the workshop concerned the electromagnetic form factors of hadrons and their theoretical and experimental investigation in the whole domain of definition, i.e. in all the kinematical regions. Particular emphasis is placed on: radiative corrections, which are crucial to extract data, since the form factors parameterize the one-photon exchange vertices, and polarization techniques that allow to disentangle electric and magnetic components of the hadronic four-current in space-like region and to determine their relative phase in the time-like region.

The main topics were:

- Historical aspects on nucleon form factors.
- Radiative corrections to electromagnetic processes: methods, reactions and kinematics.
- Vector-meson-dominance models. Constituent quark models. Soliton models.
- Phenomenological interpretations of time-like nucleon form factors.
- Nucleon form factors in the unphysical region.
- Low energy electron-proton scattering.
- High-energy proton-polarimetry.
- Nucleon-antinucleon cross section at BESIII and VEPP-2000.
- Proton-antiproton cross section via initial state radiation at BaBar.
- Baryonic time-like Form Factors at HADES.
- Nucleon form factor experiments at Jefferson Lab.
- Perspectives at FAIR.

SPEAKERS:

R. Baldini Ferroli (Laboratori Nazionali Frascati – INFN, Italy)

M. Bertani (Laboratori Nazionali Frascati – INFN, Italy)

D. Bettoni (INFN Ferrara, Italy)

Y. Bystritskiy (JINR, Dubna, Russia)

A. Calcaterra (Laboratori Nazionali Frascati – INFN, Italy)

M. C. (Mainz University, Germany)

P. Dalpiaz Ferretti (INFN and University of Ferrara, Italy)

A. Dbeyssi (IPN Orsay, France)

M. Destefanis (University of Turin and INFN Turin, Italy)

A. Drago (Università di Ferrara, Italy)

V. Fadin (JINR, Dubna, Russia)

A. Gramolin (BINP, Russia)

D. Khaneft (Mainz University, Germany)

E. Kuraev (JINR, Dubna, Russia)

F. Maas (Helmholtz-Institute Mainz, Germany)

C. F. Perdrisat (College of William and Mary, USA)

M. Radici (INFN – Pavia, Italy)

B. Ramstein (IPN Orsay, France)

P. Rossi (Jefferson Lab, USA)

E. Santopinto (INFN Genova, Italy)

K. Seth (Northwestern University, USA)

O. Teryaev (JINR, Dubna, Russia)

E. Tomasi-Gustafsson (IPN Orsay, France)

G. Venanzoni (Laboratori Nazionali Frascati – INFN, Italy)

U. Wiedner (RUB Bochum, Germany)

SCIENTIFIC REPORT:

The purpose of the workshop was to gather experimentalists and theoreticians working in the field of hadron electromagnetic form factors. New interest recently aroused in this field, due to the experimental possibilities opened at Jefferson Laboratory, the improvement of the beams and the detection at electron-positron experiments, such as BESIII and VEPP-2000, and the possibilities offered with high intensity anti-proton beams at PANDA, FAIR in the future. These experiments access different kinematical regions and provide different pieces of information on the same physics issue: the dynamics of the internal structure of the hadron. General introductory talks allowed to get acquainted with the state-of-the-art and the different issues of the ongoing experiments. The goal of the workshop was to connect the information coming from different experiments, and to elaborate a common view on form factors. We think this message has been caught, and some links have been found. Special emphasis was given to the models that work in all the kinematical regions. The issues related to analyticity and asymptotic properties were analyzed.
Common problems such as radiative corrections, which have to be applied in any experiment involving electrons in initial or final state, where discussed and a critical comparison of different methods was presented. It appeared that Monte Carlo generators are unavoidable in coincidence measurements, therefore the calculations embedded in the generators should be carefully handled.

The perspectives opened with the JLab 12 GeV upgrade, PANDA, and BESIII were subject of dedicated discussions.

Results and Highlights

Models: The surprising results from the GEp experiment, which showed that the electric and magnetic form factor of the proton do not follow the same dependence with the transfered momentum squared, triggered a review of the nucleon models. However, it is evident now that a good model should reproduce all four nucleon form factors: electric, magnetic, of proton and neutron. Moreover, an effort is undertaken to extend the models to the time-like region. Apart from models based on vector-meson-dominance or dispersion relations, which incorporate the necessary analytical properties, an example of an extension of covariant light front descriptions of form factors has been presented. An attempt to apply soliton-based model in time-like region was also discussed.

Radiative corrections: Coincidence experiments require multidimensional corrections, which go beyond corrections depending on the inelasticity cut, as used in earlier elastic electron-positron experiments. Dedicated programs embedded in the physics analysis are necessary. An example of a stand-alone Monte Carlo for first order corrections, which is freely available, was presented. The limits of the approximations inherent to radiative correction calculations, used in the literature, were pointed out. In particular, radiative corrections will be a critical issue for JLab at 11 GeV, where initial state emission from the incident electron will be significant. Polarized antiprotons: The possibility of polarizing anti-proton beams was illustrated. The spin-filtering technique seems the most promising method to build up polarization in a re-circulating beam. Experiments in Jülich and CERN are ongoing.

Time-like region: Interesting features of the cross section behavior in the threshold region seem to show that the form factors behave like those of point particles. The proton-antiproton cross section from BaBar data shows a constant behavior close to threshold where it is not vanishing. Such unexpected behavior is compatible with other neutral baryon cross sections, as those of the Lambda and Sigma. High precision results will soon be available from BESIII.

3.3.3 HEAVY QUARKS AND QUARKONIA IN THERMAL QCD

DATE: April 2 – 5, 2013

ORGANIZERS:

Seyong Kim *(Sejong University, South Korea)*
Mikko Laine *(Bern University, Switzerland)*

NUMBER OF PARTICIPANTS: 31

MAIN TOPICS:

The workshop concentrated on the current status of lattice methods and field theoretical approaches to heavy quarks and quarkonia in thermal QCD. Subtopics included:

- heavy quark transport in quark-gluon plasma
- quarkonia in thermal environment
- technical developments: lattice simulations, analytic approaches
- new observables and ideas related to heavy quarks in hot QCD

An experimental overview talk was included as well.

SPEAKERS:

G. Aarts (Swansea University, United Kingdom)

Y. Akamatsu (Nagoya University, Japan)

D. Banerjee (Bern University, Switzerland)

A. Beraudo (CERN, Switzerland)

D. Bodeker (Bielefeld University, Germany)

Y. Burnier (Bern University, Switzerland)

S. Kumas Das (Catania University, Italy)

S. Datta (TIFR, India)

M. Escobedo (TUM, Germany)

W. Evans (Swansea University, United Kingdom)

C. Ewerz (EMMI, Germany)

J. Ghiglieri (McGill University, Canada)

P. Gubler (RIKEN, Japan)

T. Hayata (Tokyo University, Japan)

O. Kaczmarek (Bielefeld University, Germany)

R. Katz (Subatech, France)

M. Panero (Helsinki University, Finland)

B. Patra (IIT Roorkee, India)

P. Petreczky (BNL, United States)

A. Rothkopf (Bern University, Switzerland)

H. Satz (Bielefeld University, Germany)

F. Scardina (Catania University, Italy)

J.-I. Skullerud (NUI Maynooth, Ireland)

E. Scomparin (INFN Torino, Italy)

A. Vairo (TU Munich, Germany)

L. Scorzato (ECT*, Italy)

SCIENTIFIC REPORT:

Recently, there has been rapid progress both in the theoretical and in the experimental study of "heavy quarks and quarkonia in thermal QCD". The theoretical progress has originated from the application of modern effective field theories, Non-Relativistic QCD (NRQCD), potential Non-Relativistic QCD (pNRQCD), and Heavy Quark Effective Theory (HQET) to a finite-temperature environment. Effective field theories allow for a separation of difficult non-perturbative IR physics from perturbative UV physics at heavy quark mass scale and permit a systematic non-perturbative study of the former. On the experimental side, the heavy ion programmes of ALICE and CMS at LHC are in their full swing. For example, ALICE has shown that high transverse momentum D-meson jets get quenched in central lead-lead collisions, and CMS has shown that the production of Upsilon excited states (2S and 3S) in lead-lead collisions is sequentially suppressed, compared to proton-proton collisions at the same energy. In view of these developments, we considered it timely to review the theoretical understanding of heavy quarks and quarkonium at non-zero temperature, and to chart possible future directions. Thus this workshop concentrated on the current status of lattice methods and field theoretical approaches to heavy quarks and quarkonia in thermal QCD. Collaborative discussions among the participants were highly encouraged.

Results and Highlights

The workshop had a relaxed atmosphere and schedule, and involved lots of discussions, both during the seminars as well as in more informal settings afterwards. Among the most discussed topics were the use of Maximum Entropy Method and other techniques for the determination of spectral functions fro m Euclidean correlators; the use of NRQCD techniques, both analytic and numerical, for a systematic study of the fate of quarkonium resonances in the quark-gluon plasma; methods to study the chemical equilibration of heavy quarks, possibly with the help of lattice simulations; as well as phenomenological and theoretical progress in the understanding of the kinetic equilibration and hydrodynamic flow of open heavy flavour.

In addition, Prof. Satz put forward an important new idea for experimentalists to judge the fate of heavy quarkonium without relying on model assumptions, and Prof. Scomparin gave a beautiful and exhaustive overview of the recent experimental results on heavy quarks and quarkonia from the Large Hadron Collider.

3.3.4 CONSTRAINING THE HADRONIC CONTRIBUTIONS TO THE MUON'S ANOMALOUS MAGNETIC MOMENT

DATE: April 10 - 12, 2013

ORGANIZERS:

Henryk Czyz *(Univ. Silesia, Katowice, Poland)*
Achim Denig *(Univ. Mainz, Germany)*
Marc Vanderhaeghen *(Univ. Mainz, Germany)*
Graziano Venanzoni *(LNF, Frascati, Italy)*

NUMBER OF PARTICIPANTS: 33

MAIN TOPICS:

The collaboration meeting brought together the experimental e+e- collider communities from BABAR, KLOE, BES-III, BELLE, CMD2/SND, with theorists working in the fields of meson transition form factors, of hadron physics contributions to the muon's anomalous magnetic moment and on the development of Monte Carlo generators. The meeting discussed the plans for the accompanying experimental programs aimed at reducing the dominating hadron physics uncertainties in the standard model prediction to $(g-2)_\mu$ and $\alpha_{em}(M_Z)$.

The main topics were:

- Monte Carlo generators for luminosity
- Monte Carlo generators for e+e- annihilation into leptons and hadrons
- Monte Carlo generators for e+e- annihilation into hadrons plus an
- Energetic photon from initial state radiation (ISR)
- Monte Carlo generators for tau production and decays
- Hadronic vacuum polarization, $(g-2)_\mu$ and $\alpha_{em}(M_Z)$
- Gamma-gamma physics
- Meson transition form factors and sum rules
- Modelling of photon hadron interaction

SPEAKERS:

H. Czyz (University of Silesia, Katowice, Poland)

M. De Stefanis (Università degli Studi di Torino, Italy)

A. Denig (University Mainz, Germany)

S. Eidelman (Novosibirsk State University, Russia)

K. Griessinger (Stanford University, USA)

M. Gunia (University of Silesia, Katowice, Poland)

A. Hafner (University Mainz, Germany)

H. Hu (Institute of High Energy Physics, Beijing, China)

F. Jegerlehner (Humboldt University, Berlin and DESY, Zeuthen, Germany)

T. Johansson (Uppsala University, Sweden)

B. Kloss (University Mainz, Germany)

K. Kolodziej (University of Silesia, Katowice, Poland)

J. Kühn (Institut für Theoretische Teilchenphysik, Karlsruhe, Germany)

A. Kupsc (Uppsala University, Sweden)

E.A. Kuraev (Bogoliubov Laboratory of Theoretical Physics, Russia)

P. Masjuan (Universty Mainz, Germany)

S. Müller (Helmholtz-Zentrum Dresden-Rossendorf, Germany)

V. Pauk (University Mainz, Germany)

A. Penin (University of Alberta, Canada)

C. Redmer (University Mainz, Germany)

M. Ripka (University Mainz, Germany)

P. Roig (Universitat Autonoma de Barcelona, Spain)

P. RongGang (Institute of High Energy Physics Beijing, China)

P. Sanchez-Puertas (University Mainz, Germany)

O. Shekhovtsova (Institute of Nuclear Physics Cracow, Poland)

H. Spiesberger (University Mainz, Germany)

E.Tomasi-Gustafsson (CEA, IRFU, SPhN, Saclay, France)

T. Teubner (University of Liverpool, UK)

M. Unverzagt (University Mainz, Germany)

M. Vanderhaeghen (University Mainz, Germany)

G. Venanzoni (Laboratori Nazionali di Frascati dell'INFN, Italy)

Y. Wang (Laboratori Nazionali di Frascati dell'INFN, Italy)

B. Zhang (Institute of High Energy Physics, Beijing, China)

SCIENTIFIC REPORT:

The importance of continuous and close collaboration between the experimental and theoretical groups is crucial in the quest for precision in hadronic physics. This is the reason why the Working Group on “Radiative Corrections and Monte Carlo Generators for Low Energies” was formed a few years ago bringing together experts (theorists and experimentalists) working in the field of low-energy e+e-. Its main motivation is to understand the status and the precision of the Monte Carlo generators used to analyse the hadronic cross section measurements obtained as well with energy scans as with radiative return. The development of these tools then allows to extract from the data information on meson transition form factors, and to estimate the hadron physics contributions to the muon’s anomalous magnetic moment, (g-2)μ. The 13th such meeting was held as an ECT* Collaboration Meeting with the aim to bring together the experimental e+e- collider communities from BABAR and KLOE with theorists working in the field. Specifically, this meeting also included for the first time the experimental community from BES-III. The present meeting was very timely in view of a newly planned (g-2)μ experiment at Fermilab in 2015, that will improve the accuracy on the (g-2)μ determination by a factor of around 4. A major aim of this collaboration meeting was to discuss and plan the accompanying experimental program at BES-III aimed at reducing the dominating hadron physics uncertainties in the standard model prediction to (g-2)μ .

Results and Highlights

The workshop brought together over 30 physicists (about equal number of theorists and experimentalists) who presented the latest achievements in the different subfields. A particular emphasis has been put on the recent evaluations of the hadronic contributions to the anomalous magnetic moment (g-2) of the muon. For the hadronic vacuum polarization contribution, the necessity to have a database with an easy general access of hadronic cross section measurements with clear indication of the treatment of Radiative Corrections and systematic errors was discussed. For the hadronic Light-by-Light contribution different theoretical models were presented and the possibility to constrain some of them by data was discussed. Finally, a proposal for a white book on meson transition form factors was presented.

Web proceedings of all the presentions given during the collaboration meeting have been published on the arXiv, with reference arXiv:1306.2045.

All the information on the working group can be found at the web page: http://www.lnf.infn.it/wg/sighad/

We would like to thank the ECT* staff for the warm hospitality and technical support. We are especially grateful to Dr. Ines Campo for her very professional help in organizing this meeting!

3.3.5 WORKSHOP ON PROTON-NUCLEUS COLLISIONS AT THE LHC

DATE: May 06 - 10, 2013

ORGANIZERS:

François Arleo *(LLR, École polytechnique, France)*
David d'Enterria *(CERN, Switzerland)*

NUMBER OF PARTICIPANTS: 36

MAIN TOPICS:

The first proton–lead collisions run at the CERN Large Hadron Collider (LHC) took place in Jan-Feb 2013 after a successful pilot run of Sept 2012. The aim of the workshop has been to discuss experimental and theoretical issues connected to the physics of proton-nucleus collisions at the LHC. The first results obtained by the ALICE, ATLAS, CMS, LHCb, LHCf and TOTEM experiments were discussed as well as the future measurements to be carried out. The main topics of the workshop include:

- p–A benchmark measurements for interpreting A–A collisions results,
- Constraints of nuclear parton distributions functions (PDF),
- Small-x QCD and gluon saturation physics,
- Forward physics, diffractive and electromagnetic (ultra-peripheral) collisions,
- Impact of collider p–A measurements for ultra-high energy cosmic rays physics.

SPEAKERS:

J. Adam (Czech Technical University, Czech Republic)

F. Arleo (LLR, France)

R. Arnaldi (INFN Torino, Italy)

W. Broniowski (Wojciech, Institute of Nuclear Physics PAN, Poland)

M. Csanad (Eötvös University, Hungary)

D. D'Enterria (CERN, Switzerland)

K. Eskola (Department of Physics, Finland)

I. Helenius (University of Jyväskylä, Finland)

P. Hoyer (University of Helsinki, Finland)

J. Jalilian-Marian (Baruch College, USA)

F. Jing (Tsinghua University, China)

K. Jung (Purdue University, USA)

R. Kolevatov (Subatech, France)

K. Kutak (Instytut Fizyki Jadrowej Polskiej Akademii Nauk, Poland)

J.-P. Lansberg (IPN Orsay, Paris Sud U. / IN2P3-CNRS, France)

J.G. Milhano (Universidade de Santiago de Compostela, Spain)

M. Misiura (University of Warsaw, Poland)

G. Mitsuka (Nagoya University, Japan)

S. Mohapatra (Stony Brook University, USA)

H. Mantysaari (University of Jyväskylä, Finland)

S. Oh (Yale University, USA)

S. Ostapchenko (SINP MSU - D.V. Skobeltsyn Nuclear Physics Institute, Moscow State University, Russia

H. Paukkunen (University of Jyväskylä, Finland)

T. Pierog (KIT, IKP, Germany)

R. Preghenella (Università and INFN Bologna, Italy)

A. Rezaeian (Universidad Tecnica Federico Santa Maria, Chile)

M. Rybar (Charles University, Czech Republic)

F. Sikler (Wigner RCP, Hungary)

M. Strikman (Penn State, USA)

D. Triantafyllopoulos (ECT*, Italy)

S. Tuo (Vanderbilt University, USA)

R. Venugopalan (Brookhaven National Laboratory, USA)

R. Vogt (LLNL and UC Davis, USA)

K. Werner (Univ. of Nantes, France)

A.J. Zsigmond (Wigner RCP, Hungary)

M. Zurita (USC, Spain)

SCIENTIFIC REPORT:

In January 2013 the first proton–lead collisions took place at the Large Hadron Collider (LHC) at CERN. This p–A physics run is essential in many aspects. First of all, the data collected in p–Pb collisions serve as baseline measurements for the experimental results obtained in Pb–Pb collisions at the LHC. It allows for a better, less ambiguous, interpretation of the main discoveries of the 2010 and 2011 LHC heavy-ion runs, for instance the spectacular "jet quenching" measurements or the heavy-quarkonium results, performed by ALICE, ATLAS and CMS. Therefore, part of the Pb–Pb measurements collected at LHC were discussed from the perspective of the first data of the LHC p–Pb run.
Data in p–Pb collisions at the LHC also shed some light on the expected phenomenon of parton saturation at small values of Bjorken-x. In particular, the LHC p–Pb collisions reach a collision energy never obtained with nuclear targets ($\sqrt{s} \simeq 5$ TeV), almost twice as large as the LHC Pb–Pb collisions ($\sqrt{s} = 2.76$ TeV). This allows for testing parton densities in Pb nuclei at Bjoren-x as low as x ~ 10–6–10–5. Closely related to the topic of saturation, the nuclear parton distribution functions can be studied in a new kinematical regime and with a degree of precision never attained so far. The inclusion of p‑Pb data ‑ for instance prompt photons, jets, or large $p_\perp$ hadrons ‑ in a new generation of nuclear PDF sets were also an important subject of debate during this workshop. In turn, this will improve the quantitative predictions of hard QCD processes in heavy-ion collisions. The first p–Pb LHC data also proved an ideal playground for testing phenomena in a controlled QCD medium, whose dynamics is less complex than that of an evolving quark-gluon plasma. It is for instance the case of parton propagation and medium-induced gluon radiation in cold nuclear matter, which understanding is key to interpret the abundant results from all LHC experiments on jet quenching. The data collected at the LHC clarify some of the puzzles observed in p–A

collisions over the years, for instance the strong suppression of heavy-quarkonium states and high pT hadrons at forward rapidities.

Results and Highlights

The workshop was a very useful opportunity to balance the above-mentioned competing approaches, and this was appreciated by all the participants. Every talk was followed by lively debates among the various participants.

Several experimental results were presented for the first time. In particular:

- Measurement of J/psi suppression in p–Pb collisions, by the ALICE and LHCb collaborations
- Measurement of dijet rapidity distribution in p–Pb collisions, by the CMS collaboration

The new data triggered intense discussions regarding the origin of the effects reported experimentally. The role of nuclear PDF effects on these measurements – as well as large pT hadron spectra –have been discussed in detail, also during a specific session on Wednesday afternoon. The possible effects of parton energy loss in cold matter have also been mentioned as a source of heavy-quarkonium suppression in p–Pb collisions at the LHC.

Many discussions also followed the presentation of experimental results on hadron distributions and correlations. Large azimuthal asymmetries (e.g. values of v2 and v3 coefficients) were either interpreted as a sign of gluon saturation (initial-state effect) or rather coming from final-state interaction. More data are therefore needed in order to resolve this puzzle.

Many other facets of proton–nucleus collision physics were mentioned, such as multi-parton interaction, diffraction and forward physics, as well as ultra-peripheral collisions. Finally, future experiments have been discussed using the LHC beam on fixed targets (AFTER experiment).

The full agenda of the workshop can be found at this link:

http://indico.cern.ch/conferenceTimeTable.py?confId=216368 - all.detailed

3.3.6 ELECTROMAGNETIC PROBES OF STRONGLY INTERACTING MATTER: STATUS AND FUTURE OF LOW-MASS LEPTON-PAIR SPECTROSCOPY

DATE: May 20 - 24, 2013

ORGANIZERS:

T. Galatyuk *(Technical University of Darmstadt, Germany)*
R. Rapp *(Texas A&M University, USA)*
X. Dong *(Lawrence Berkeley National Laboratory, USA)*
J. Stroth *(Goethe-University of Frankfurt, Germany)*
V. Koch *(Lawrence Berkeley National Laboratory, USA)*

NUMBER OF PARTICIPANTS: 44

MAIN TOPICS:

- Thermal radiation of dileptons and photons from hot hadronic and partonic matter
- In-medium modifications of hadrons in dense matter, their relation to the QCD phase structure, in particular to the chiral phase transition
- Assessment of (multi-) differential measurements of photon and dileptons.

SPEAKERS:

J. Aichelin (University of Nantes)

H. Appelshäuser (University of Frankfurt)

A. Ayala (University of Mexico City)

E. Bratkovskaya (University of Frankfurt)

S. Campbell (University of Ames)

G. David (University of Brookhaven)

A. Drees (Stony Brook University)

S. Endres (University of Frankfurt)

A. Francis (University of Bielefeld/Mainz)

T. Galatyuk (University of Darmstadt)

C. Gale (University of Montreal)

F. Guerts (Rice University)

M. Harada (University of Nagoya)

C. Hoehne (University of Giessen)

P. Hohler (College Station)

B. Kämpfer (University of Dresden)

S. Leupold (University of Uppsala)

V. Metag (University of Giessen)

U. Mosel (University of Giessen)

M. Mueller (University of Bielefeld)

M. Nanova (University of Giessen)

E. Oset (University of Valencia)

B. Ramstein (University of Orsay)

D. Rischke (University of Frankfurt)

T. Rodrigues (University of Sao Paolo)

P. Salabura (University of Cracow)

E. Shuryak (Stony Brook University)

V. Skokov (University of Brookhaven)

H.-J. Specht (University of Heidelberg)

A. Uras (University of Lyon)

G. Usai (University of Cagliari)

H. van Hees (University of Giessen)

G. Vujanovic (University of Montreal)

Q. Wang (USTC)

J. Weil (University of Frankfurt)

M. Wilde (University of Münster)

Z. Xu (BNL)

SCIENTIFIC REPORT:

This workshop was the fifth in the series on “Electromagnetic Probes of Strongly Interacting Matter” at ECT* (March 1999, June 2005, June 2007, September 2010). The purpose of the workshop was to assess the state-of-the-art in experimental measurements and their theoretical understanding, discuss strategies for advancing the interpretation of data, and identify future key measurements. The goal is to develop a common description for electromagnetic radiation emanating from matter under the different conditions realized in heavy-ion collisions with center of mass energies from 2.4 GeV per nucleon (SIS 18) to 200 GeV (FAIR, SPS, RHIC), and at 2.76 and 5.5 TeV (LHC). The workshop benefited from the interactions between the high- and intermediate-energy heavy-ion communities. Fruitful connections to results in elementary proton- and photo-induced reactions have been moved forward as well. Following the tradition of this workshop series, the scheduled talks were followed up by 1-2 hour evening discussion sessions (moderated by B. Friman, J. Wambach, V. Koch and R. Rapp), which reiterated and often clarified pressing questions raised in the talks.

Results and Highlights:

Dileptons from elementary and heavy-ion collisions at low beam energies:

- A re-analysis of CBELSA/TAPS data on ω production off nuclei in the $\pi^0\gamma$ decay channel does not exhibit a mass shift anymore; the ω line shape is now believed to have little sensitivity to potential broadening effects. On the other hand, data on the nuclear transparency ratio indicate a strong ω absorption, translating into a width of ~150MeV at saturation density (ρ_0), whose theoretical and phenomenological interpretation remains under debate. The multi-collisional Monte Carlo (MCMC) intra-nuclear cascade model extracts an in-medium ω width of 63 MeV/c^2 for $\rho\sim0.8\rho_0$, a factor of ~2 smaller than the Valencia and Giessen models. Recent data for e^+e^- production by the CLAS collaboration suggest even stronger ω absorption when analyzed with the Giessen, Valencia and Glauber models. On the other hand, preliminary MCMC analysis suggests that CLAS and CBELSA/TAPS data are mutually consistent with a collisional broadening of $\Gamma^*_{ave}\sim64$ MeV using $\sigma_{inel}\sim39$ mb. These model discrepancies need further study. Microscopic calculations for the in-medium ω width using linear-density approximations predict (well) below 100 MeV, but the importance of non-linear effects has been pointed out.

- Recent data from HADES on inclusive and exclusive e^+e^- production in heavy-ion and elementary reactions show substantial contributions to the low invariant-mass spectrum from decays of baryonic resonances. HADES presented their final e^+e^- results in p+Nb reactions at 3.5 GeV, including a first high-statistics measurement with good mass resolution (2%) of dielectrons emitted from cold nuclear matter at low pair momentum where strong medium effects are expected. In comparison to p+p data, the spectra in p+Nb spectra show marked modifications for pair momenta $P_{ee}< 0.8$ GeV/c in terms of an excess yield below the free ρ/ω pole mass and a reduced ω yield at its pole mass. These trends hint at a strong coupling of the ρ meson to baryonic resonances and absorption of the ω meson, with both being manifestations of in-medium modifications of vector mesons.

  HADES also presented results for the exclusive channels $pp \rightarrow pn\pi^+$, $pp \rightarrow pp\pi^0$ and $pp \rightarrow ppe^+e^-$ measured with 3.5 GeV protons. These data will provide further constraints of the baryon resonance contributions (Dalitz decays) to the dilepton spectrum.

- Transport model calculations are generally in fair agreement with the e^+e^- invariant-mass and transverse-momentum spectra, but model assumptions are not always well controlled (e.g., the authors of GiBUU model stated that "the obtained results should be regarded as an educated guess because both resonance production processes and their dielectron decays are poorly known and more precise data are needed to pin them down."). Rather large differences in the treatment of $R \rightarrow N\gamma^*$ decays in various transport models have been reported and actively discussed, including the difference in string and resonance-based production approaches and their relevance as a function of colliding energy. The problem of off-shell transport simulations was re-iterated, exhibiting differing treatments in the different codes. It was apparent from the discussion that progress in this area requires a detailed comparison of the models, which in turn calls for open-access to all codes. Within the resonance-based approach, a good description of the e^+e^- spectra in p+Nb (as well as pp and pd) has been achieved by Weil, van Hees and Mosel, including a proper continuation below the 2-pion threshold. The baryonic resonances employed in this calculation largely overlap with those figuring into the in-medium ρ spectral function which successfully describes dilepton data at high energies (SPS and RHIC), where effects due to anti-/baryons remain important.

- As a prototype process, the opportunity to directly assess the dilepton yields from the N*(1520) by π-induced reactions doable with HADES was considered to be a valuable proof of principle.

Spectral functions / lepton pair production at various beam energies:

- A new approach to in-medium spectral functions from holographic mean-field theory for baryon many-body systems was presented. It provides a framework of gauge/gravity duality for finite-density systems of baryons in the confined phase. Within a scalar mean-field model the decrease of the effective nucleon mass is found to be comparable to Walecka-type models. The sensitivity of this result on the partitioning of the free nucleon mass into chirally-broken and -invariant mass is surprisingly small.

- New lattice-QCD results for thermal dilepton rates at vanishing 3-momentum are not far from hard-thermal loop calculations for not too-small masses. A systematic analysis with multiple lattice spacings facilitated to take the continuum limit of the correlation functions. The electric conductivity has been extracted using a Breit-

Wigner ansatz for the low-energy transport peak. The spectral functions and the conductivity (normalized to temperature, T), show little variation between T=1.1Tc and 1.45Tc in the quenched case, and moderate variations for 2-flavor QCD. An “uncharted territory” in the ρ-meson mass region cannot be reliably assessed yet.

- The connection between dilepton measurements and chiral symmetry restoration has been studied in the Massive-Yang-Mills approach of implementing axial/vector mesons into the chiral Lagrangian; it turns out to be difficult to obtain a quantitative fit to the vacuum τ decay data in the axial-vector channel. Similar difficulties arise in a more comprehensive effective SU(3) approach with global chiral symmetry, which otherwise gives a good overall description of hadronic masses and decay data. This approach has also been used to discuss strategies for the implementation of baryons.

  In a phenomenological approach, the properties of the axial-vector channel (a_1) have been investigate through quantitative analysis of QCD and Weinberg-type sum rules, using as input established in-medium spectral functions in the vector channel (ρ) and temperature dependent condensates from lattice QCD. Solutions were found leading to a gradual melting of the a_1 showing a clear tendency for degeneration with the vector channel, demonstrating that the ρ-meson melting scenario is compatible with chiral restoration.

- The time-honored vector meson dominance (VMD) model has been revisited. The leading-order Lagrangian of chiral perturbation theory has been augmented with a non-linear sigma model in the sector of even pion number and Wess-Zumino-Witten structures for odd pion numbers. It was found that the agreement of VMD with the pion form factor can be maintained while deviations from VMD improve the description of the NA60 data for the omega form factor.

- Fully acceptance corrected $\mu^+\mu^-$ *invariant*-mass spectra in ^{115}In+In collisions at $\sqrt{s}$ = 17.3 GeV by NA60 were analyzed with the Rapp-Wambach model of the in-medium ρ propagator, updated with recent lattice-QCD input for the QGP dilepton rates and equation of state. The lower pseudo-criticial temperature (T_{pc}=170MeV) and nonperturbative QGP EoS resulted in an increase of partonic radiation compared to the previous calculation. At low masses, the duality of the QGP and in-medium hadronic rates around T_{pc} implied that the total yield changed very little, thus maintaining good agreement with the Lorentz-invariant NA60 mass spectra and corroborating the melting of the ρ around T_{pc}. At intermediate masses, larger temperatures induced by the lattice-EoS render QGP radiation dominant over multi-pion processes, describing the NA60 data well with an extracted average temperature of T≈210MeV.

Dilepton production at LHC, RHIC, SPS:

- PHENIX presented e^+e^- mass spectra for ^{197}Au+Au at $\sqrt{s}$ = 200 GeV at RHIC, which show a striking low-mass enhancement for M=0.2–0.7 GeV that is entirely concentrated in the most central collisions. This enhancement is not seen in the preliminary data presented by the STAR collaboration. Further insight into this tension is expected once PHENIX has completed its analysis with the hadron blind detector (HBD). So far, PHENIX presented HBD data only for p+p as well as peripheral and semi-central Au+Au collisions. These results essentially agree with STAR, but residual discrepancies of up to ~40-50% are present in the decay cocktail.

- STAR showed first preliminary measurements of the elliptic flow of thermal dileptons. This measurement will eventually help to disentangle the emission history and provide valuable cross checks to current photon measurements. The present STAR data are statistics limited; an increase by more than a factor of two is required before any conclusion can be drawn.

In addition, the correlated charm background needs to be understood. STAR presented strategies to address this issue: The new HFT and MTD detector systems will significantly enhance their capability of measuring heavy-flavor production at RHIC. This setup will allow to measure open-charm spectra down to small transverse momenta and enable to tag correlated c-cbar decays (i.e., their modification in medium) via electron-muon pairs.

- A first calculation of the dilepton yields and elliptic flow v_2 from viscous (3+1)D hydrodynamic simulations was presented. This calculation indicated that $v_2(p_T)$ for different invariant masses is promising for separating QGP and hadronic contributions. The dilepton yields are essentially unaffected by finite fluid viscosities, while the v_2 exhibits considerable dependence on viscosity, more so in the QGP than in the hadronic phase. Two calculations of the correlated charm contribution to intermediate-mass dileptons indicate that its v_2 is larger than for thermal radiation (mostly QGP), reiterating the importance of using realistically modified heavy-flavor spectra. First results of implementing in-medium dilepton rates into coarse grained transport simulation at SIS and SPS energies have been reported. This is a promising approach for systems in which viscous hydrodynamics breaks down.

Direct photons at RHIC and LHC:

- The state of the art for calculations of photons production in heavy ion collisions has been presented. In the perturbative sector, most aspects of the calculations appear to be under control. A comprehensive approach to parton jet quenching and e.m. emissivity at high p_t was presented, yielding binary scaling for the direct photon R_{AA}.

- Measurements of direct photon p_t spectra and v_2 have been reported by PHENIX and ALICE. In central AA collisions, the high-p_t (hard photon) R_{AA}'s exhibit the expected binary scaling, while within current uncertainties, no significant direct photon signal can be extracted in pp and peripheral Pb+Pb at 2.76 TeV nor in pp and d+Au at top RHIC energy.

  For the low-p_t ("thermal") photon excess inverse slopes of T_{eff} =221±19(stat)±19(syst) MeV in Au+Au at RHIC and T_{eff} =304±51(stat+syst) MeV in Pb+Pb at LHC have been extracted. In addition, a significant direct photon v_2 for p_t>1GeV was measured, similar in magnitude to that of pions(!). These results suggest late production times for direct photons and raise the question of blue-shift effects in the extracted slopes of the thermal spectra. Calculations using a thermal fireball expansion, constrained by bulk-hadron spectra and v_2, predict an appreciable direct photon-v_2 due to large emission contributions from around T_{pc} and below, with significant contributions from baryonic sources. It will be interesting to see whether viscous hydro calculations yield similar results when including baryonic sources and systematic studies of initial conditions.

Dilepton production at RHIC Beam Energy Scan, future experiments

- STAR presented preliminary e^+e^- spectra data the RHIC Beam Energy Scan (BES). Their data at $\sqrt{s_{NN}}$=19.6 GeV are found to be consisted with former CERES data. The predictions of hadronic many-body calculations with melting vector mesons plus QGP emission, which describe CERES and NA60 data at SPS, are in fair agreement with the STAR data from $\sqrt{s_{NN}}$=200GeV down to $\sqrt{s_{NN}}$=19.6GeV. The prevalent low-mass emission source remains at temperatures around T_{pc}, which provides an intriguing connection to the large direct-photon v_2. A significant increase in experimental precision of low- and intermediate-mass dileptons will be required to discriminate current model calculations which differ in their input for the emission rates and the underlying space-time evolution. While this is likely possible at 200 GeV, it would be very important to achieve sufficient statistics also at lower energies within the planned luminosity upgrade for a continued BES program at RHIC. In addition, a fixed target program will be needed to assess dilepton production at lower energies, $\sqrt{s}$<15 GeV.

- To address this issue plans, for dilepton measurements with NA60' at SPS, CBM at FAIR (although not a dedicated dilepton spectrometer), and MPD at NICA were presented and discussed. Feasibility studies with NA60', proposing to measure dimuons in the beam energy range 20-158 GeV/u, demonstrated very good performance, with further work to be done to optimize the detector setup. Ion beams with sufficient intensity exist and will be available for experiments at the SPS in the upcoming years (presently scheduled up to 2021). CBM aims to measure e^+e^- and $\mu^+\mu^-$ for E_{beam} from 10 GeV (SIS100) to 38 GeV (medium ions, e.g., In or Cu, at SIS300). Construction of FAIR has started, with first beams (SIS100) expected in 2018. R&D for CBM is well under way and the detector is expected to be ready at that point.

New ideas and future*:*

- New theoretical ideas regarding dilepton and photon production have been presented, including the effect of strong magnetic fields on pre-equilibrium photon production. Another idea was to monitor parton equilibration in heavy-ion collisions via dilepton polarization. The pertinent anisotropy parameter, $\alpha(M)$, is predicted to exhibit a characteristic dilepton mass dependence, starting with complete positive polarization (α=1) for primordial high-mass Drell-Yan pairs (M>4GeV), evolving into negative anisotropy at intermediate mass ($\alpha\approx$-0.2) due to a small longitudinal pressure in pre-equilibrium phases, while for small masses (M<1GeV) no polarization typical for thermal emission is expected (α=0). It would be particularly interesting to measure this observable at varying beam energies.

- ALICE presented preliminary e^+e^- and $\mu^+\mu^-$ spectra at LHC in p+p collisions at $\sqrt{s}$ = 7 TeV, p+Pb at 5.02 TeV (world premiere) and Pb+Pb at 2.76 TeV. In p+p, the S/B ratio at M_{ee}=0.5 GeV/c^2 is about 3×10^{-2}, decreasing to ~10^{-3} for 0-10% central Pb+Pb, giving rise to large systematic errors. ALICE upgrade plans for the ITS address this issue and are proceeding well. A new set of data from ALICE is expected after the upgrade in 2018. Detailed e^+e^- simulation studies based on the ρ melting plus QGP scenario show that only the full upgrade will achieve a data quality near the NA60 "gold standard". A forward muon tracker will be installed which will largely expand the low-mass/low-momentum dimuon capabilities in future ALICE runs.

CONCLUSIONS

This workshop was a resounding success (confirmed by feedback from participants), featuring high-quality presentations and discussions. It progressed the understanding of thermal emissivities and their manifestation in experiment, stimulated new directions for future research projects and "homework" to be conducted. We enthusiastically suggest a continuation of this series in 2016 to push further progress in the wake of this meeting and to take advantage of the growing momentum in this field. Most of the talks can be browsed on the website: http://www.ectstar.eu/node/92

3.3.7 FROM FEW-NUCLEON FORCES TO MANY-NUCLEON STRUCTURE

DATE: June 10 – 14, 2013

ORGANIZERS:

Bruce Barrett *(Univ. of Arizona, USA)*
Ruprecht Machleidt *(Univ. of Idaho, USA)*
Robert Roth *(TU Darmstadt, Germany)*

NUMBER OF PARTICIPANTS: 38

MAIN TOPICS:

The goal of this workshop is to foster the exchange between research groups developing QCD-based nuclear interaction, e.g., using chiral effective field theory (EFT), and groups developing and applying ab initio many-body techniques employing those interactions. It comes at a critical time, where we see decisive advances in both sub-areas: The development of nuclear interactions from chiral EFT is reaching a stage of consistent high-precision NN plus 3N plus 4N interactions at N3LO, which will soon be ready for application in nuclear structure theory. At the same time the next-generation chiral interactions, e.g., including explicit Δ degrees-of-freedom or N4LO contributions, is under development. The progress in nuclear many-body theory and computational techniques makes it possible to use 3N (and possibly 4N) interactions systematically for exact and approximate ab initio calculations. We are now able to quantify the impact of 3N interactions for a range of nuclei and nuclear structure observables and to establish constraints and provide guidance for the construction of next-generation interactions. As a long-term outcome of the workshop we aim to establish a continued exchange and feedback cycle between the two areas, promoting the use of QCD-based interactions for precise and predictive nuclear structure and reaction calculations.

SPEAKERS:

T. Abe (Univ. Tokyo, Japan)

C. Barbieri (Univ. Surrey, UK)

S. Binder (TU Darmstadt, Germany)

A. Calci (TU Darmstadt, Germany)

L. Coraggio (INFN Naples, Italy)

A. Covello (Univ. Naples, Italy)

A. Deltuva (Univ. Lisbon, Portugal)

D. Entem (Univ. Salamanca, Spain)

E. Epelbaum (Univ. Bochum, Germany)

G. Hagen (Oak Ridge, USA)

K. Hebeler (TU Darmstadt, Germany)

H. Hergert (Ohio State Univ., USA)

J. Holt, Jeremy (Univ. Washington, USA)

N. Kalantar (KVI Groningen, Netherlands)

H. Krebs (Univ. Bochum, Germany)	G. Papadimitriou (Univ. Arizona, USA)
J. Langhammer (TU Darmstadt, Germany)	E. Ruiz Arriola (Univ. Granada, Spain)
D. Lee (North Carolina State Univ., USA)	F. Sammarruca (Univ. Idaho, USA)
W. Leidemann (Univ. Trento, Italy)	A. Schwenk (TU Darmstadt, Germany)
P. Maris (Iowa State Univ., USA)	W. Tornow (Duke Univ., USA)
K. Moghrabi (Univ. Paris-Sud, France)	T. Varese (UNICAMP, Brazil)
A. Mukherjee (ECT* Trento, Italy)	J. Vary (Iowa State Univ., USA)
P. Navratil (TRIUMF, Canada)	R. Vesely (INFN Napoli, Italy)
G. Orlandini (Univ. Trento, Italy)	M. Viviani (Univ. Pisa, Italy)
T. Otsuka (Univ. Tokyo, Japan)	H. Witala (Univ. Cracow, Poland)

SCIENTIFIC REPORT:

Nuclear structure theory has entered a new era of ab initio predictions of the full range of nuclear structure and reaction observables starting with input from low-energy quantum chromodynamics (QCD). Several key developments are at the heart of this novel view on nuclear structure and reaction physics. They can be grouped in four topical areas: (i) chiral effective field theory for nuclear Hamiltonians and currents; (ii) interfacing chiral EFT with nuclear many-body methods; (iii) ab initio nuclear structure methods; (iv) ab initio nuclear reaction theory. We briefly highlight the most relevant elements of each area in the following:

(i) The foundation of our modern view on low-energy nuclear physics is defined by chiral effective field theory (chiral EFT) for the description of the interactions among nucleons. It allows for the derivation of consistent and systematic nuclear Hamiltonians containing two-, three- and many-nucleon terms as well as the corresponding electroweak current operators. At present, chiral two-nucleon (NN) interactions up to order N3LO are used in a variety of many-body calculations. Three-nucleon (3N) interactions have been worked out up to order N3LO, but so far only 3N interactions at N2LO are available in a partial-wave representation suitable for ab initio structure calculations. A number of developments have already started to go beyond the level of N3LO Hamiltonians. It is anticipated that important and sizable contributions to the nuclear interaction will emerge at N4LO. Strategies and criteria for a selective inclusion of N4LO contributions were discussed. Furthermore, the construction of NN and 3N interactions in a chiral EFT containing explicit Δ degrees-of-freedom is already at an advanced stage. Ongoing discussions on the foundations of chiral EFT as well as power counting and regularization issues were covered as well.

(ii) The output of chiral EFT is not necessarily suitable as a direct input for nuclear many-body methods. A number of intermediate and sometimes technical elements are needed to interface chiral EFT and the nuclear many-body machinery. These elements are crucial for precise and efficient many-body calculations. Recently, several innovations in this area have pushed the frontier of ab initio calculations to significantly heavier nuclei and larger model spaces.

The main issue is the efficient inclusion of 3N interactions into various many-body schemes. For configuration-space methods, the starting point are matrix elements of the chiral 3N interaction in a partial-wave representation. The computation of those matrix elements, e.g. in a partial-wave momentum representation, for 3N interactions at N3LO or N4LO is a challenge in itself - at present numerical partial-wave decompositions seem to be the only viable route from a huge number of chiral EFT terms to partial-wave matrix elements. A typical bottleneck for all many-body methods using basis expansions is the computation and handling of the 3N matrix elements. New coupling and “recompute instead of store” techniques have been developed were discussed. Obviously, all of the aforementioned elements are even more critical for 4N interactions. Once the matrix elements of the initial or 'bare' Hamiltonians are available, one can employ unitary transformations to enhance the convergence behavior of the many-body calculation by pre-diagonalizing the Hamiltonian or by decoupling the model space (low energy, low momentum) from the excluded space (high energy, high momentum). Apart from the Lee-Suzuki-Okamoto transformation that is employed widely in the context of the no-core shell model, only the similarity renormalization group (SRG) approach has been used so far for a consistent transformation of chiral NN+3N Hamiltonians. We discussed recent developments and open issues with these unitarily transformed interactions, e.g. regarding the role of induced many-body contributions and the transformation of observables.

(iii) Starting from chiral Hamiltonians including 3N and possibly 4N interactions as universal input, the ab initio solution of the nuclear many-body problem poses a formidable challenge. Nonetheless, there has been amazing scientific advance in this area over the past few years. It has been driven by novel conceptual and methodological developments on the one hand, and by the increased and refined utilization of supercomputing resources, on the other.
Traditionally, few-body methods have provided the most rigorous ab initio calculations with NN and 3N interactions and they continue to be an indispensable tool for accurate and precise predictions in the era of chiral Hamiltonians. Beyond the few-body domain, the no-core shell model (NCSM) has a pioneering role in adopting chiral 3N interactions for ab initio calculations up to the mid p-shell. It provides the complete set of observables for low-energy structure and spectroscopy. Through advances regarding the computational algorithms, the handling of 3N interactions, and the importance-truncation scheme, the range of applicability of the NCSM has increased significantly. Today, it is the ab initio workhorse for ground states, spectra, and spectroscopy with chiral NN+3N Hamiltonians throughout the p-shell and beyond. A powerful complement to the NCSM are coupled-cluster (CC) methods, which have been reintroduced into nuclear structure theory as an efficient tool for ab initio calculations for ground states of closed-shell nuclei throughout the nuclear chart. Supplemented by equations-of-motion techniques, excited states and nuclei near closed-shells can be described as well. A frontier in the CC framework is the inclusion of 3N interactions. In addition to approximate schemes, e.g. using normal-ordering techniques to include parts of the 3N interaction, the exact inclusion of 3N interactions was discussed. The status of related approaches, e.g. the so-called in-medium SRG and the self-consistent Green's function method, was reviewed as well. In the context of chiral EFT, a new approach to the nuclear many-body problem based on lattice Monte Carlo simulations was recently proposed. These lattice EFT simulations, like the well-known Green's Function Monte Carlo method, do not rely on a basis representation and thus circumvent some of the problems of NCSM or CC.
In addition to the discussion of advances and connections of the different many-body methods, the workshop addressed the topic of uncertainty quantification in many-body calculations. We also highlighted the connection to present experiments and try to identify key observables suitable for constraining chiral Hamiltonians.

(iv) Following the example of few-body methods that are used to address structure and reactions on the same footing, more and more of the ab initio nuclear structure tools are extended towards low-energy nuclear scattering and reaction calculations. The NCSM was combined with the Resonating Group Method (RGM) to a powerful framework for addressing scattering and reactions of light nuclei keeping the full ab initio description of the structure of the reaction partners. This approach is presently being extended to the so-called no-core shell model with continuum (NCSMC), which is able to cover structure and reactions on equal footing. Similar developments towards reaction and continuum calculations have started in the CC framework.

Results and Highlights

The workshop succeeded in bringing together experts from the different sub-fields contributing towards a QCD-based ab initio description of nuclear structure and reaction observables. Each of the sub-communities presented exciting new developments and identified major research directions for the coming years.

In the topical area (i), focussing on chiral EFT for constructing nuclear Hamiltonians and currents, the completion of derivation, partial-wave decompositions, and LEC fits for consistent Hamiltonians at N3LO without and with explicit Δ degrees-of-freedom is one of the immediate goals for the near future. In parallel various formal developments towards renormalizable interactions, where cutoffs can be removed to infinity, are underway and may lead to new schemes for deriving future chiral Hamiltonians. In a new development, comprehensive numerical fitting strategies for the determination of LEC from phase shifts or cross section data are investigated as well as alternative schemes for the propagation of error from scattering data to the nuclear Hamiltonian.

In area (ii), the interface between chiral EFT Hamiltonians and nuclear many-body methods, new developments regarding the computation of three- and four-body matrix elements of the Hamiltonian in different basis representations and their Similarity-RG transformation were reported. Whereas the inclusion of 3N interactions has become a standard already, the work on the inclusion of SRG-induced and initial 4N terms is only starting and first steps have been reported.

Many different efforts have been reported in area (iii) on ab initio nuclear structure methods, making this a very dynamic field. Among the new developments and results reported at the workshop, two topics were particularly interesting: First, the advent of different many-body methods (coupled-cluster theory, in-medium SRG, self-consistent Green's function) using chiral NN+3N interactions for the description of medium-mass nuclei. Second, the advances of Monte Carlo and lattice methods for the ab initio description of finite nuclei and infinite matter using chiral EFT as starting point.

On the area (iv), the ab initio description of nuclear reactions, progress was reported in both the few-body and the many-body domain. First (incomplete) results on few-body reactions with consistent chiral NN+3N-Hamiltonians at N3LO show indications that the notorious discrepancies regarding polarization observables (Ay-puzzle, etc.) are not resolved by including N3LO contributions to the 3N interaction. Progress on the description of scattering and continuum observables beyond A=4 was reported, both using resonating group method, Lorenz integral transform or Berggren bases in conjunction with powerful bound state methods.

One of the big overarching discussions was concerned with uncertainty quantification and error propagation. This is viewed as a key challenge for future research in this field. Efforts in this direction are starting right now, but are still far from a consistent propagation of uncertainties in the chiral EFT inputs to nuclear many-body observables.

As a long-term outcome of the workshop we aim to establish a continued exchange and feedback cycle between the groups developing chiral EFT interaction and the nuclear structure and reaction 'users community'. We envision to propose a follow-up workshop in about two years time to critically assess the advances and perspectives along the lines mentioned above.

3.3.8 H3QCD (HIGH ENERGY, HIGH DENSITY AND HOT QCD)

DATE: June 17 – 21, 2013

ORGANIZERS:

Dionysis Triantafyllopoulos *(ECT*, Italy)*
Francois Gélis *(Saclay, France)*
Edmond Iancu *(Saclay, France)*
Cyrille Marquet *(Ecole Polytechnique, France)*

NUMBER OF PARTICIPANTS: 48

MAIN TOPICS:

The workshop mostly focused on the semi-hard region of high energy nucleus-nucleus collisions. In particular, we were interested in the QCD description of all the stages of such collisions: starting from the initial condition which can be determined by looking at proton-nucleus collisions, moving to the problem of thermalization and ending with the in-medium jet evolution of produced hard particles.

The main topics were:

- Experimental review of QCD studies in high energy hadronic collisions
- The Color Glass Condensate in heavy ion collisions
- Thermalization of the Quark-Gluon Plasma
- In-medium modification of jet formation and evolution

SPEAKERS:

P. Arnold (U of Virginia, USA)

M. Attems (Frankfurt IAS, Germany)

I. Balitsky (Old Dominion U and JLAB, USA)

S. Bathe (Baruch College, USA)

G. Beuf (U of Santiago de Compostela, Spain)

J. Bielcikova (NPI, Prague, Czech Republic)

G.A. Chirilli (Ohio State U, USA)

B. Cole (Columbia U, USA)

F. Dominguez (Saclay, France)

A. Dumitru (Baruch College, USA)

T. Epelbaum (Saclay, France)

M.A. Escobedo (TU Munich, Germany)

A. Flacchi (CENTRA, Lisbon, Portugal)

H. Fujii (U of Tokyo, Japan)

K. Fukushima (Keio U, Japan)

E. Iancu (Saclay, France)

A. Kovner (U of Connecticut, USA)

A. Kurkela (McGill U, Canada)

K. Kutak (NINP, Cracow, Poland)

J. Laidet (Saclay, France)

T. Lappi (U of Jyväskylä, Finland)

Y.-J. Lee (CERN, Switzerland)

J.D. Madrigal (U of Madrid, Spain)

H. Mantysaari (U of Jyväskylä, Finland)

M. Martinez-Guerrero (U of Santiago de Compostela, Spain)

Y. Mehtar-Tani (Saclay, France)

J.G. Milhano (U of Santiago de Compostela, Spain)

G. Moore (McGill U, Canada)

S. Munier (Ecole Polytechnique, France)

E. Petreska (Baruch College, USA)

E. Scapparone (INFN Bologna, Italy)

S. Schlichting (Heidelberg U, Germany)

A. Taliotis (Vrije U of Brussels, Belgium)

N. Tanji (Saclay, France)

D. Toton (NINP, Cracow, Poland)

D. Triantafyllopoulos (ECT*, Italy)

K. Tywoniuk (U of Barcelona, Spain)

A. Vuorinen (Bielefeld U, Germany)

B. Wu (Saclay, France)

The following people participated for the full or most of the workshop period without contributing with a talk

J. Albacete (U of Granada, Spain)

N. Armesto (U of Santiago de Compostela, Spain)

J.-P. Blaizot (Saclay, France)

J. Casalderrey-Solana (U of Barcelona, Spain)

F. Gélis (Saclay, France)

T. Gorda (U of Colorado, USA)

C. Marquet (École Polytechnique, France)

A. Quadri (INFN Milan, Italy)

M. Torres (Saclay, France)

SCIENTIFIC REPORT:

Quantum Chromodynamics (QCD) has been very successful in describing not only qualitatively, but also quantitatively, hard phenomena in high energy hadronic and nuclear collisions characterized by a large transverse momentum scale. In such a regime parton distributions are small, the perturbative expansion is very accurate and one can calculate the observables of interest, like jet cross-sections.

However, semi-hard processes are sensitive to the small-x components of the hadronic or nuclear wavefunction and in this limit the gluon density becomes so large that higher twist effects are of leading order. A scale, called the saturation momentum, is dynamically generated and modes below that scale get saturated. At high-energy the saturation momentum is sufficiently above the confinement scale, and it allows the application of weak coupling techniques in a proper reorganization of the perturbation series in the presence of a strong background field. In that sense the Color Glass Condensate (CGC) has emerged as a well-motivated effective theory within QCD. It serves as the most practical and successful option in order to understand many aspects of the experiments carried out at hadron colliders, especially those related to its own existence and the formation of the Quark Gluon Plasma. The significant jump in collision energy from RHIC to LHC clearly provides new opportunities for a systematic study of these phases.

Observables for studying the CGC are mainly related to total, diffractive, single inclusive and double inclusive cross sections. From a phenomenological point of view, in relation to the "ridge" effect observed both at RHIC and LHC, a lot of interest has been given during the recent years to rapidity correlations in multi-particle production. We sought for a review of recent experimental data and at the same time for a discussion of the phenomenological approaches and the theory behind them.

A more quantitative description of this initial state of ultrarelativistic heavy ion collisions needs to incorporate various kind of corrections. These include going beyond the leading order non-linear evolution equations, taking into account pomeron loops and modifying the MV (McLerran-Venugopalan) model initial conditions when solving the aforementioned equations. Thus, it was planned to address all these issues.

The CGC also provides a natural framework to study the initial stages of heavy ion collisions, and in particular to assess how fast and to what degree the quark-gluon plasma approaches local thermal equilibrium. Indeed, hydrodynamical models have been very successful in reproducing many observables in heavy ion collisions, but for doing that they require that the system be close enough to locally thermal. But explaining this from first principles in QCD has so far proven very challenging. Many studies suggest that this may be driven by the instabilities that affect the QCD dynamics, but an implementation of these ideas in a realistic description of the collision dynamics is still missing.

The heavy ion experiments also provide direct information about the intermediate stages of the nucleus-nucleus collisions, where a transient state of quark-gluon plasma is expected to exist. This information is carried by `hard probes', i.e. hadrons or leptons with relatively large transverse momenta, which are created via quasi-local partonic processes at the early stages and then cross the surrounding medium on their way towards the detectors. From their measured spectra, one can infer the properties of the medium, provided we have a good understanding of their interactions with this medium. A useful observable in that sense is `jet quenching', which refers to the ensemble of the modifications in the properties of a jet (jet shape, energy distribution, energy loss…) triggered by its interactions with a QCD plasma. Calculations of jet quenching in perturbative QCD are extremely challenging because of the complexity of the interactions between an evolving system of partons (the jet) and a dense, dynamical, medium. Over the last couple of years, there was some significant theoretical progress on this topic, which was partly triggered by the discovery of `di-jet asymmetry' at the LHC and led to a statistical picture for in-medium jet evolution. It was a main purpose of the workshop to summarize this progress and clarify the relation between the various approaches.

Results and Highlights

There were 48 participants, out of which 5 experimentalists representing the ALICE, ATLAS, CMS, PHENIX and STAR collaborations and 43 theorists many of which are leading experts of the field worldwide. The workshop lasted four and a half days and 39 participants contributed with a total of 41 talks (each of the ATLAS and CMS representatives gave two talks). The 7 experimental talks were typically given in the beginning of a session. All talks

lasted 25 + 5 minutes, but there was a certain amount of flexibility when critical questions led to interesting and important discussions.
Regarding both single inclusive gluon production and double inclusive gluon production at the same rapidity, it is understood that one needs to go beyond kT factorization, but this is hardly a problem and in fact it is well under control. For the single inclusive cross section in deuteron-gold and proton-lead collisions one can get quantitative results by using the BK equation. Predictions have been made for the RpA ratio at the LHC and they predict a suppression in the mid-rapidity region. The double inclusive cross section and when the two-jets are produced forward is also interesting due to the attenuation of the away-side peak in the transverse plane. The technical tools to calculate such a cross-section have been recently available and a nice description of the RHIC data has been achieved. For multi-gluon inclusive production at different rapidities in pA collisions, a promising proposal based fully on the JIMWLK evolution equation has been given, and it remains to see its numerical implementation.
NLO corrections were extensively discussed and perhaps in the near future we may have a more accurate BK equation which takes the most dominant ones into account and with a proper prescription for the running of the coupling. Extensions of the MV-model initial condition already exist and are available to use. Not much progress has been done regarding Pomeron loops, but it is a general belief that they should not give large contribution in pA collisions.
In this workshop, there were several talks reporting on recent results on the problem of thermalization in heavy ion collisions. Most of these talks revolved around the effect of instabilities in the early collision dynamics. Many of the works presented in this session used the so-called "classical statistical field theory" approach, which amounts to solving classical equations of motion with fluctuating initial conditions. With the appropriate choice of fluctuations, this method is exact at NLO, and resumes an infinite subset of all the higher orders. Moreover, in the case of QCD, it has the advantage of being a resummation that preserves gauge invariance.
Using this method, it was shown that the behavior at later times in QCD may be somewhat independent of the starting point. In the much simpler case of a scalar toy model, it has been shown that the instabilities are sufficient to lead to the isotropization of the pressure, a condition which is thought to be sufficient for hydrodynamics to be applicable.
The workshop session devoted to jet quenching has addressed two main topics: (i) the in-medium jet evolution via successive medium-induced branchings, and (ii) the next-to-leading-order (NLO) quantum corrections to the `jet quenching parameter' (the relevant transport coefficient). Concerning topic (i), there were several talks and many discussions about a recently proposed effective theory – a classical branching process which generates the soft components of the jet which propagate at large angles. This picture is in at least qualitative agreement with the phenomenon of di-jet asymmetry observed at the LHC. It also provides an interesting example of wave turbulence in the context of QCD. Concerning topic (ii), the presentations emphasized the existence of large, positive, NLO corrections, which have the right trend to agree with the phenomenology. These results and their conclusions comfort the idea that the physics of jet quenching can be understood within perturbative QCD.
Last, but not least, we would stress that we received very positive comments from many workshop participants, some of them mentioning that it was the best workshop they have ever been.

3.3.9 FLAVOR STRUCTURE OF THE NUCLEON SEA

DATE: July 01- 05, 2013

ORGANIZERS:

Mary Alberg *(Seattle University, USA)*
Matthias Grosse-Perdekamp *(University of Illinois at Urbana-Champaign, USA)*
Gerald Miller *(University of Washington, USA)*
Jen-Chieh Peng *(University of Illinois at Urbana-Champaign, USA)*

NUMBER OF PARTICIPANTS: 29

MAIN TOPICS:

The workshop covered both the spin-averaged and the spin-dependent sea quark contents in the nucleons. The status and open issues of various theoretical approaches, including lattice QCD, light-cone formulation, intrinsic sea, meson cloud, perturbative QCD, chiral quark, soliton, etc., were discussed at this workshop. This workshop also attempted to identify new experiments which could effectively test these theories at existing or future facilities

SPEAKERS:

M. Alberg (Seattle Univ., USA)

D. Boer (Univ. Groningen, Netherlands)

W.-C. Chang (Academia Sinica, Taiwan)

M. Contalbrigo (Ferrara, Italy)

O. Denisov (INFN Torino, Italy)

M. Grosse Perdekamp (Univ. Illinois, USA)

M. Guzzi (DESY, Germany)

A. Guffanti (Niels Bohr Institute, Denmark)

E. Henley (Univ. Washington, USA)

P. Hoyer (Helsinki, Finland)

X. Ji (Univ. Maryland, USA)

B. Kopeliovich (Santa Maria, Chile)

S. Kumano (KEK, Japan)

H.-W. Lin (Univ. Washington, USA)

K.-F. Liu (Univ. Kentucky, USA)

B.-Q. Ma (Peking Univ., China)

M. Maggiora (INFN Torino, Italy)

S. Melis (INFN Torino, Italy)

Z.-E. Meziani (Temple Univ., USA)

J. Miller (Univ. Washington, USA)

J.-C. Peng (Univ. Illinois, USA)

B. Povh (Univ. Heidelberg, Germany)

J. Qiu (BNL, USA)

P. Reimer (ANL, USA)

M. Rosina (Univ. Ljubljana, Slovenia)

S. Sawada (KEK, Japan)

P. Schweitzer (Univ. Connecticut, USA)

R. Seidl (RIKEN-BNL, Japan)

J. Soffer (Temple Univ., USA)

M. Stratmann (BNL, USA)

M. Wakamatsu (Osaka Univ., Japan)

SCIENTIFIC REPORT:

The existence of sea quarks in the nucleons was first observed in Deep Inelastic Scattering at SLAC. While the gluon splitting into a quark-antiquark pair provide the mechanism for generating quark and antiquark seas in the framework of perturbative QCD, it is now clear that nonperturbative QCD must also play a crucial role. The observation of the pronounced flavor asymmetry of the anti-up and anti-down light-quark sea, which is not expected from perturbative QCD, provides a clear evidence for the presence of nonperturbative QCD effects in the nucleon sea.

Although the flavor asymmetry of the anti-up and anti-down light-quark sea can be qualitatively explained by a variety of theories including the meson-cloud, Pauli-blocking, chiral-quark soliton, instanton, and intrinsic sea, the underlying mechanisms are often quite different among these theories. The advent of lattice QCD also allows the calculation for the “connected" and “disconnected" seas. The connections as well as differences between the various theories remain to be better understood. The implications of different theoretical models for other yet unmeasured flavor structures of the nucleon sea also need to be worked out. These yet unmeasured or poorly known quantities include the flavor dependence of the polarized anti-up and anti-down light-quark sea, the anti-up and anti-down ratios at the large Bjorken-x region, the possible difference between the strange-quark seas s(x) – s_bar(x), the existence of so-called “intrinsic" sea corresponding to the five-quark Fock states, the possible connections between the flavour asymmetries of the sea quarks and the valence quarks, the possible connection between the flavor asymmetry of the sea and the flavor structure of the transverse momentum dependent (TMD) parton distributions, etc.

The goal of the workshop is to first review the status of our current understanding of the flavor structure of the sea-quark contents in the nucleons, and then to address various outstanding unresolved theoretical issues in this subject, followed by discussions of key experiments at various existing and future facilities.

Results and Highlights

The talks presented at the workshop were of excellent quality, reflecting significant efforts by the workshop participants in preparing and delivering their talks. Many of these presentations were greeted with enthusiastic and interesting discussions afterwards. While it is impossible to summarize all these interesting results and discussions at this workshop, we list below some of the highlights.

- Significant progress has been made in the formulation of lattice QCD, allowing for the calculation of the shape (in Bjorken-x) of quark distributions, rather than their moments only. First numerical results were presented, showing the x-dependence of the light-quark flavour asymmetry (both the unpolarized and the helicity distributions) in qualitative agreement with the experimental data.

- A recent global fit using the neural network approach led to the interesting finding that s-quarks very likely carry more momentum than the sbar-quarks. This has important implication on explaining a long-standing puzzle in neutrino experiment called the

NuTeV anomaly. It also lends support to theoretical models (such as meson-cloud and chiral-quark soliton models) predicting such an s-quark sbar-quark asymmetry.

- The ratio of the strange-sea over non-strange light quark sea appears to have intriguing Bjorken-x and Q2 dependences, as suggested by the semi-inclusive kaon production at HERMES and the W/Z production in p-p collision at LHC. The x-dependence of this ratio could be qualitatively explained by the quark-flavour dependence of the connected and disconnected seas.

- Recent data on the single-spin asymmetry of W boson production at RHIC and the latest global fits to extract the polarized light-quark sea have revealed that the u-quark sea has positive net helicity while the d-quark sea has negative polarization. This result is in good agreement with the prediction of the chiral-quark soliton model.

- While many models can explain the excess of d-quark sea over the u-quark sea, so far none of them would predict a possible sign-reversal of this flavour asymmetry at x~0.3, as suggested by the Fermilab E866 Drell-Yan data and a recent analysis of the NMC DIS data. The Fermilab E906 experiment is expected to provide a definitive measurement. If this sign-reversal is confirmed, it could lead to qualitatively new insight on the flavour structure of the nucleon sea.

- The flavour structure of the sea-quarks for various transverse-momentum-dependent structure functions, such as the Silvers functions, Boer-Mulders functions, and transversity distributions are practically unknown. These are among the topics to be studied in various existing or future facilities, including COMPASS at CERN, polarized Drell-Yan at Fermilab, FAIR, JLab 12 GeV upgrade, J-PARC, EIC, etc. New information on the flavour structure of fragmentation functions is also expected from electron-positron colliders (Belle and Super-Belle).

In conclusion, this workshop has made very positive contributions to the on-going effort to improve our understanding on the substructure of the nucleons through the unique window of the flavour structure of the nucleon sea. Judging from the response from many participants, this workshop is a success.

3.3.10 NUCLEAR STRUCTURE AND ASTROPHYSICAL APPLICATIONS

DATE: July 08 - 12, 2013

ORGANIZERS:

P-H Heenen *(Université Libre de Bruxelles)*
J. Dobaczewski *(University of Warsaw)*
H. Leeb *(University of Wien)*
F. Thielemann *(University of Basel)*

NUMBER OF PARTICIPANTS: 46

MAIN TOPICS:

- Definition of key quantities for a meaningful comparison between theory and experiment
- Density Functionals and Correlations
- Mass measurements and predictions
- Equation of state of nuclear matter

SPEAKERS:

M. Bender (CEN Bordeaux)
K. Bennaceur (IPNL)
M. Block (GSI Darmstadt)
M. Brodeur (U of Notre Dame, USA)
G. Carlsson (U of Lund)
N. Chamel (U of Brussels)
A. Chbihi (GANIL)
G. Colò (U of Milano)
M. Colonna (INFN-LNS Catania)
T. Duguet (CEA Saclay)
J.P. Ebran (CEA Saclay)
T. Eronen (MPIK Heidelberg)
A. Gade (MSU, USA)
M. Harakeh (KVI, Netherlands)
R. Julin (U of Jyväskylä)
A. Kankainen (U of Edinburgh)
M. Kowalska (CERN)
H. Liang (RIKEN)
J.A. Maruhn (U of Frankfurt)
T. Nakatsukasa (RIKEN)
M. Oertel (Luth Meudon)
J.M. Pearson (U of Montreal)
D. Pena-Artega (CEA-DAM)
P.G. Reinhard (U of Erlangen)
D. Rossi (NSCL, USA)
P. Russotto (INFN Catania)
D. Tarpanov (U of Warsaw)
N. Timofeyuk (U of Surrey)
S. Typel (GSI Darmstadt)
X. Vinas (U of Barcelona)
D. Vretenar (U of Zagreb)
M. Zielinska (CEA Saclay))

SCIENTIFIC REPORT:

The aim of the workshop was to put together theoreticians and experimentalists to present and discuss the progress made in THEXO and in experiments since the beginning of ENSAR. The discussion was centered on four topics for which a full day of presentations and discussions was devoted. The talks were balanced between theory and experiment, with the aim to analyse in depth the way results from theory and experiment are confronted.
The first day was devoted to spectroscopy. There were in particular several talks on the experimental and the theoretical definitions of single-particle energies and of spectroscopic factors. This topic generated several discussions on specific topics on which there was a pre-conceived opinion, in particular on the interpretation of results obtained by COULEX experiments. The difficult problem of constructing density functionals, whether correlations should be included in the functionals and which ones should be taken explicitly into account, was the topic of the second day. This topic has some overlap with the one discussed the next day on masses. There is huge experimental progress in the determination of masses far from stability. Nuclear models have also gained in predictivity and they are now based on more fundamental grounds. However, some phenomenology has still to be eliminated and the progress achieved in beyond-mean-field models has still to be transposed to mass predictions. In particular, the description of nuclei with an odd number of particles and of low-energy spectra should be significantly improved in coming years. The fourth day was devoted to the equation of state of nuclear matter and applications to neutron stars. The connection between the study of heavy-ion reactions at high energy and the general properties of nuclear interactions have in particular been discussed, together with the best way to extract them from experiment. The future of ENSAR and the place of a theory activity within a big European program of support of the experimental facilities were discussed during the last day. There was a general consensus that the support brought by the actual program THEXO should be continued and amplified and that there is further need for detailed discussions between theoreticians and experimentalists to define model-independent confrontations between data and calculations.

3.3.11 HASPECT ECT*: HADRON SPECTROSCOPY COLLABORATION MEETING AT ECT*

DATE: July 16 - 18, 2013

ORGANIZERS:

V. Mathieu *(ECT*, Italy)*

NUMBER OF PARTICIPANTS: 16

MAIN TOPICS:

- The topics will cover hadron spectroscopy, amplitude analysis, tools for cooperative development,... in the perspective of the 12 GeV upgrade at Jefferson Lab.
- The main topics were
- Light flavour spectroscopy
- Meson photoproduction
- Amplitude analysis
- Tools for cooperative development
- Regge phenomenology
- Perspective at CLAS12 and GlueX

SPEAKERS:

M. Battaglieri (INFN-Genova)

A. Celentano (INFN-Genova)

R. De Vita (INFN-Genova)

M. Doering (Bonn U.)

S. Fegan (INFN-Genova)

C. Fernandez Ramirez (Madrid Complutense U.)

A. Filippi (INFN Torino)

G. Galata (ICN-UNAM, Mexico)

P. Guo (JLab)

S. Hughes (U. Edinburgh)

S. Lombardo (Indiana U.)

V. Mathieu (ECT*, Trento)

A. Rizzo (U. of Rome)

A. Szczepaniak (Indiana U.)

D. Watts (U. Edinburgh)

L. Zana (U. Edinburgh)

SCIENTIFIC REPORT:

A quantitative description of the hadron spectrum is essential for a complete understanding of Quantum Chromodynamics (QCD), the theory of the strong interactions. Numerous experiments devoted to hadron spectroscopy are currently underway e.g. COMPASS and BESIII, or are planned for the near future e.g. GlueX and CLAS12 at Jefferson Lab, and PANDA at GSI. Those new generations of high statistics and precision experiments demand a level of detailed partial wave decomposition and amplitude analysis never achieved before. Thus theoretical underpinning of data analysis and resonance parameter extraction is urgently needed. The purpose of this collaboration meeting was to meet theorists and experimentalists from CLAS to join their forces in the perspective of the 12 GeV upgrade at the Jefferson Lab. One of the goals of the CLAS12 and GlueX experiments is to identify new kind of resonances, such as hybrid mesons. According to lattice results the lightest hybrid mesons has quantum numbers JPC = 1-+. Since these quantum numbers are forbidden by the valence quark model, a resonance in this partial wave would be a smoking gun signal of a non-quark model state. There are experimental signals by E852 of such exotic partial waves, however to be able to draw firm conclusions it is necessary to perform a comprehensive and comparative study of the amplitudes extracted from experiments with those expected from hadron reaction theory and QCD. Such an approach was layout in the early days of hadron spectroscopy, but due to the lack of precision data, was never systematically implemented. Today’s large data sets call for such a systematic approach. This should be contrasted with unconstraint fits often performed in the context of the pure resonance dominance models, i.e. the isobars model. The one size fits all approach, which the isobar model is a good example of, should be avoided.

Results and Highlights

In this spirit, all participants agree to follow the following three steps procedure for the analysis: i) Theoretical amplitudes are proposed and constrained by fitting the experimental data. ii) These amplitudes are tested against various constraints that are used to minimize unresolved ambiguities in amplitude determination. iii) The amplitudes are extrapolated (analytically continued) to the unphysical kinematical region of energy and angular momentum to determine properties of resonances.

CLAS12 will start recording data in the next couple of years but, in order to start in the best conditions, we decided to apply this procedure on the available CLAS6 data. The maximum invariant mass available at CLAS6 is 1.5 GeV. It will rise to 2.5 GeV at CLAS12 and will allow to investigate resonances in the 2.0 GeV mass region. Nevertheless CLAS6 data analysis could lead to publications and is the ideal framework to develop new tools for cooperative development. We identified the interesting channels on the CLAS6 data sets and assigned them on a volunteer basis.

The three pions (neutral and charged), the five pions and the omega + two pions channels were assigned to the Edinburgh group (L. Zana and S. Hughes). The eta + two pions channel was assigned to A. Rizzo. A. Filippi agrees to analyse the two kaons + one charged pion and the two kaons + two charged pions channels. S. Fegan will analysed the two kaons + one neutral pion and the two kaons + one eta channels. A. Celentano already started recently the analysis of the eta + pion (charged and neutral) channels. In all cases the interesting observables that could lead to a publication are the total cross section and the Dalitz plots (of three mesons sub systems).

On the theoretical side, the two main fields to be studied are the Khuri-Treiman approach and the Regge theory. Indeed the Dalitz plot can be divided in different regions according to their resonance population. Where resonances in two invariants overlap, the unitarization of the amplitude is provided by the Khuri-Treiman equations. Where resonances do not overlap or in the region without resonance, the Regge theory applies.

P. Guo presented the general methodology for the Khuri-Treiman approach to the eta decay into three pions. V. Mathieu presented a Regge model for two-to-two processes and the general method for the extension to multiple mesons production. The objective is to eventually provide, to the experimental groups, theoretical parametrizations of amplitudes. The theorists were invited to collaborate on these two fields. The interested people can contact P. Guo and V. Mathieu to join this on-going project.

A biweekly Skype meeting was set up to report on the progress of the different groups. The next meeting will be held in Camogli September 27th where the experimental groups will discuss the technical details on the feasibility on their analysis and theorists will report their progress and share their affinity concerning the two theoretical approaches.

3.3.12 NUCLEON MATRIX ELEMENTS FOR NEW-PHYSICS SEARCHES

DATE: July 22 – 26, 2013

ORGANIZERS:

Huey-Wen Lin *(University of Washington, USA)*
Susan Gardner *(University of Kentucky, USA)*
Felipe Llanes-Estrada *(Univ. Complutense de Madrid, Spain)*

NUMBER OF PARTICIPANTS: 24

MAIN TOPICS:

The goal of our workshop was to probe the intersections of QCD with new physics in the context of low-energy precision experiments with neutrons and protons. A wide variety of experiments of this type, including improved measurements of neutron beta decay, as well as searches for proton decay, neutron-antineutron oscillations, dark matter, and permanent electric dipole moments (EDMs) would benefit from a renewed look at the QCD theory inputs required to set limits on models of BSM physics. Our plan was to collect a group of phenomenologists, lattice gauge theorists, and a few key experimentalists, to discuss the constraints on theories probed by the experiments we consider and the manner in which these constraints are entwined with QCD physics, both perturbative and nonperturbative. We hope to help to advance our collective understanding of the theory needed to maximize the impact of low-energy, precision measurements in search of BSM physics.

The main topics were:

- Neutron Beta-Decay Studies of Non-V−A Currents and CKM Unitarity
- Nucleon Matrix Elements for Dark-Matter Searches
- Neutron-Antineutron Oscillations/Proton Decays
- Nucleon Electric Dipole Moments
- Other New-Physics Searches

SPEAKERS:

C. Alexandrou (U. Cyprus, Cyprus)

Y. Aoki (KMI, Nagoya, Japan)

T. Blum (U. Connecticut, USA)

M. Buchoff (Lawrence Livermore NL, USA)

V. Cirigliano (Los Alamos NL, USA)

S. Cohen (U. Washington, USA)

S. Collins (U. Regensburg, Germany)

A. Czarnecki (U. Alberta, Canada)

P. Fierlinger (TUM, Germany)

G. Fleming (Yale U., USA)

J. Giedt (Rensselaer Polytechnic Institute, USA)

M. Gorshteyn (U. Mainz, Germany)

R. Gupta (Los Alamos NL, USA)

R. Hill (U. Chicago, USA)

Y. Kamyshkov (U. Tennessee, USA)

A. Kronfeld (Fermilab, USA)

B. Maerkisch (U. Heidelberg, Germany)

U.-G. Meissner (U. Bonn & FZ Jülich, Germany)

R. Mohapatra (U. Maryland, USA)

M. Pospelov (U. Victoria, Canada)

A. Ritz (U. Victoria, Canada)

G. Schierholz (DESY, Germany)

SCIENTIFIC REPORT:

Upcoming low-energy experiments will provide valuable insights into the violation or preservation of fundamental symmetries beyond the Standard Model (BSM). Ongoing and planned experiments include neutron probes of weak-decay correlations (at LANL, NIST, ILL, and worldwide), searches for a permanent neutron electric dipole moment (EDM) (at ORNL, TRIUMF, ILL, PSI, TUM, and worldwide), as well as a suite of Project-X experiments at FNAL, including experiments to probe baryon-number violation, test fundamental symmetries through rare decays, search for EDMs of nucleons and nuclei, search for charged lepton flavor violation with nuclei, and measure the anomalous magnetic moment of the muon. Even though direct new-physics searches at colliders are well suited to the direct production of new, high-mass particles, low-energy precision experiments are designed to identify new physics through the discovery of the breaking of Standard Model (SM) symmetries, or through the failure of an experiment to confront the precision computation of an observable in the SM.

The discovery of a Higgs-like particle at the LHC and the particular value of its mass constrains many new-physics models, but many of our fundamental questions remain unaddressed. What is the nature of dark matter? Why is strong CP violation so small? A variety of low-energy, precision experiments can provide insight, crosschecking multiple BSM scenarios and exclusion regions, and can help identify suitable new-physics models through the use of an effective field theory framework. Furthermore, these experiments complement high-energy collider studies, indicating where to look for new physics and what the energy scales could be.

The subject of new-physics searches at low energies naturally gathers people expert in both nuclear and high-energy physics. A wide range of energy scales are involved in these problems, and much work is required to narrow down possible scenarios for new physics.

Low-energy studies of new physics invariably require precision calculations of nonperturbative hadronic matrix elements at the QCD scale, employing operators both within and beyond the SM. They are needed to characterize parameters in new-physics searches such as the nucleon axial form factors for neutrino physics, the flavor content of the nucleon or nuclei for dark matter searches, and the hadronic light-by-light matrix element which appears in the SM contribution to g−2 of the muon, and more. These matrix elements derive from the properties of QCD at low energies, and special techniques are needed to address the theoretical issues that arise within QCD. For the enterprise to be successful phenomenologists, computational theorists, and experimentalists are required to combine efforts. Our workshop was set up to advance our understanding of the physics necessary to maximize the impact of precision experiments at low energies through lively discussions between EFT and lattice gauge theory practitioners.

Precision measurements at low energies not only provide constraints on the SM complementary to those produced by high-energy experiments but are also able to discern the presence of physics beyond the SM. The most likely scenarios for new physics should be able to explain more than one precision experiment's discrepancy from the SM. Thus, the consideration of a range of experiments is key to realizing a coherent program for the discovery of new physics. Our workshop structure, with its array of topics, is meant to mirror that sensibility. Many ideas were proposed to control the currently assessed SM uncertainties, and we look forward to the progress made due to the discussions in this workshop.

Results and Highlights

To advance searches for new physics, interactions between phenomenologists, who suggest and provide motivation for what needs to be computed, and theorists who can calculate nonperturbative hadronic matrix elements are crucial. This workshop provided a unique opportunity for a small number of participants from various backgrounds to interact extensively with each other, commenting on the results and direction of each other's research.

Surprisingly, although there has been a relative increase in the number of conferences at the intersection between subfields, often researchers do not have the chance to have in-depth discussions with people across those intersections. Many participants have commented that although they know the results of calculations from other fields, they have never fully appreciated how or why the results are obtained. The workshop recruited a group of highly social participants, who are not shy to discuss ideas and ask questions throughout the workshop. Physics discussions continued throughout the day and extended to the dinner table. Our discussion sections also allowed people to discuss their ongoing research ideas, exchange experiences working on similar topics but using different theoretical tools, and many suggested novel matrix elements for the lattice-QCD community to attempt in the next couple years.

Lattice QCD can in principle help reduce the uncertainties in relevant matrix elements and improve the empirical constraints on the new-physics sources which could give rise to them. Similar logic applies to other matrix elements, such as the isoscalar tensor and scalar charges. Outside of the workshop main topics, the discussions also extended to possibilities of determining the proton radius using a non-uniform electric background field directly at zero transfer momentum to resolve the problem of access to sufficiently small momenta on the lattice.

Even though the workshop seems to cover an ambitious number of physics topics within one week, such diversity is necessary to constrain new physics models. Useful models of new physics should be able to confront multiple BSM observables. For example, the observation of n- n— oscillations would provide complementary information on the origin of the neutrino masses, as well as test some dark-matter hypotheses, such as certain models containing dark-matter candidates with a "dark" asymmetry, which mirrors the baryon asymmetry of the visible sector. Thus, a multifocal program is absolutely necessary, and we were glad that such a workshop can take place in a beautiful and culturally rich city like Trento.

This workshop was not designed to solve any one problem, but to open the door for future research opportunities — to permit disparate communities to collaborate on problems. In the precision era, we need to have the SM inputs under control, and there is much more to do for upcoming precision experiments. With the needed matrix elements being determined on the lattice in the near future, we will see more sensible BSM models taking advantage of the fruits of this workshop to better constrain future experimental data.

Last but not least, the participants were delighted by the facilities, and the center staff was extremely helpful regarding local information needed. Some participants also found the stay to be very productive for small collaboration meetings.

3.3.13 COMPTON SCATTERING OFF PROTONS AND LIGHT NUCLEI: PINNING DOWN THE NUCLEON POLARIZABILITIES

DATE: 29 July – 2 August, 2013

ORGANIZERS:

Evangeline Downie *(George Washington University, USA)*
Helene Fonvieille *(Laboratoire de Physique Corpusculaire of Clermont-Ferrand, France)*
Vladimir Pascalutsa *(University of Mainz, Germany)*
Barbara Pasquini *(University of Pavia, Italy)*

NUMBER OF PARTICIPANTS: 50

MAIN TOPICS:

The main topics were:

- Real and Virtual Compton Scattering off the proton and light nuclei
- Nucleon polarizabilities, extractions and interpretations
- Chiral perturbation theory and lattice QCD for polarizabilities and Compton scattering
- Dispersion theory of Compton scattering and meson production
- Nuclear polarizabilities in muonic atoms and the proton charge radius puzzle

SPEAKERS:

J. M. Alarcon (KPH Mainz, Germany)

A. Aleksejevs (Grenfell U, Canada)

A. Alexandru (GWU Washington, USA)

J. Annand (Glasgow U, UK)

A. Antognini (ETH Zurich, Switzerland)

H.-J. Arends (KPH Mainz, Germany)

J. Bericic (Ljubljana U, Slovenia)

M. Birse (Manchester U, UK)

A. Blomberg (Temple U Philadelphia, USA)

C. Carlson (CWM Williamsburg, USA)

C. Collicot (St-Mary's U, Canada)

L. Correa (LPC Clermont-FD, France)

E. Downie (GWU Washington, USA)

D. Drechsel (KPH Mainz, Germany)

G. Eichmann (Graz U, Austria)

G. Feldman (GWU Washington, USA)

H. Fonvieille (LPC Clermont-Fd, France)

A. Gasparyan (Bochum U, Germany)

M. Gorshteyn (KPH Mainz, Germany)

H. Griesshammer (GWU Washington, USA)

F. Hagelstein (KPH Mainz, Germany)

J. Hall (Adelaide U, Australia)

C.-W. Kao (Chung Yuan Christian U, Taiwan)

S. Karshenboim (MPI Garching, Germany)

H. Krebs (Bochum U, Germany)

N. Krupina (KPH Mainz, Germany)

A. L'vov (LPI Moscow, Russia)

P. Martel (MIT Cambridge, USA)

J. Mc Govern (Manchester U, UK)

G. Miller (Washington U, Seattle, USA)

D. Mueller (Bochum U, Germany)

A. Mushkarenkov (KPH Mainz, Germany)

L. Myers (TUNL U, Durham, USA)

M. Paolone (Temple U Philadelphia, USA)

V. Pascalutsa (KPH Mainz, Germany)

B. Pasquini (Pavia U, Italy)

G. Ron (Hebrew U, Jerusalem, Israel)

K. Savvidis (Nanjing U, China)

S. Schlesser (KVI Groningen, Netherlands)

S. Sirca (Ljubljana U, Slovenia)

K. Slifer (New Hampshire U, Durham, USA)

V. Sokhoyan (KPH Mainz, Germany)

L. Tiator (KPH Mainz, Germany)

M. Vanderhaeghen (KPH Mainz, Germany)

W. Weise (ECT*, Italy & TU Munich, Germany)

SCIENTIFIC REPORT:

The workshop opened with a talk of the ECT* director, Wolfram Weise, who welcomed the participants, introduced the ECT*, and gave a historical perspective on the subject of the workshop. The rest of the first day was devoted to the theory of Compton scattering and the review of the new efforts to determine the scalar polarizabilities of pions and nucleons. The 2nd day was predominantly devoted to Compton scattering on light nuclei, such as the deuteron, and to the virtual Compton scattering (VCS) on the proton. During the 3rd day the lattice QCD results on the magnetic polarizability of the neutron were presented in the talks of A. Alexandru and J. Hall. The new developments in the dispersion theory of Compton processes were discussed in the talks of A. Lvov, L. Tiator and B. Pasquini. The 4th day was devoted to the effects of nucleon and nuclear polarizabilities in atomic spectra. In the last session we have considered various QCD-inspired models (e.g., based on Dyson-Schwinger approach) of Compton scattering which serve as alternatives to the chiral PT and dispersion frameworks. On the 5th and last day, we have reviewed two-photon exchange effects in elastic electron scattering, and concluded with experimental and theoretical summaries of the workshop. The slides of all the talks are available from the ECT* website, http://www.ectstar.eu/node/98.

Results and Highlights

A main outcome of the lively discussions and debates during the workshop became a memorandum outlining the future progress in this field. We can summarize it as follows.

In recent years Compton scattering off the nucleon in different kinematical regimes has become a very powerful tool for analysing nucleon structure. It provides access to the nucleon polarizabilities -- the structure constants that define the extent to which the nucleon acquires dipole moments (i.e., deforms) in external electromagnetic fields. These constants are of interest to many branches of physics, ranging from precision atomic physics to astrophysics. Besides being fundamental properties of the nucleon, they play an important role in the Lamb shift of muonic Hydrogen as well as in radiative corrections to the proton charge radius, and provide the biggest source of uncertainty in theoretical determinations of the proton-neutron mass shift. Spin polarizabilities parametrise the optical activity of the nucleon which depends on its spin degrees of freedom. Scattering on light nuclei allows one to differentiate between proton and neutron values, and thus to study isospin symmetry breaking. As highlighted in the Long-Range Plans in the USA (NSAC 2007, NAS 2012) and Europe (NuPECC 2010), this vibrant and renewed theoretical interest prompted a new generation of high-accuracy facilities with unpolarized and polarized photon beams and targets to focus on Compton scattering. Interpreting such data needs commensurate theoretical support for interpretations with minimal theoretical bias. Compton scattering up to the first resonance region can roughly be divided into three regimes of different theoretical interest. The transition from one regime to another is of course gradual rather than sudden. In the first regime, comfortably below the single pion production threshold, our theoretical approaches contain very similar physics. Therefore, an extraction of static polarizabilities by running cross sections and other observables down to zero energy suffers only from minimal discrepancies between the different theoretical approaches. At these scales, this running is dominated by the physics of the pion cloud, which is for these energies adequately captured by each approach. We therefore anticipate that when the same data is used by different approaches, their values for the static polarizabilities will agree very well. Scalar polarizabilities should be extractable with high theoretical accuracy and minimal theory error. The same holds for the spin-polarizabilities -- if the necessary experimental accuracy can be reached. At present, single and double polarised data is sorely missed. In the second regime, around and above the pion production threshold, the sensitivity to the spin polarizabilities is increased. The different theoretical approaches still largely agree, but different physics at this scale leads to some discrepancies. Data in this regime will help to understand and resolve these issues and provide first values for the spin polarizabilities, triggering even more theoretical efforts. In the third regime, around and above the Delta(1232) resonance, all theoretical approaches gradually become less reliable for different reasons. In Dispersion Relations, an accurate inclusion of the two-pion production process in present formulations becomes crucial and is subject to further investigation. In Effective Field Theories, the dimensionless expansion parameter starts to approach unity, indicating increasingly worse convergence. At present, all theoretical approaches must thus resort to well-motivated but not fully controlled approximations. Concurrently, sensitivity to the static polarizabilities decreases substantially. Taken together, this makes their extraction from data at these energies less reliable. Instead, one gains access to details of Delta(1232) resonance properties, as well as potential information on the degrees of freedom exchanged between photons and the nucleon in the t-channel. We agreed on strong support of experimental programs which goal is to provide accurate data on real and virtual Compton scattering below and around the pion threshold. In the longer term, one expects a complete set of experiments up to the pion production threshold to disentangle detailed information from the energy dependence of the Compton multipoles.

We would like to thank the ECT* staff for the warm hospitality and technical support. We are especially grateful to Ines Campo for her patience and passion in organizing this meeting!

3.3.14 QCD-TNT-III: FROM QUARKS AND GLUONS TO HADRONIC MATTER: A BRIDGE TOO FAR?

DATE: September 02 - 06, 2013

ORGANIZERS:

D. Binosi *(ECT*, Italy)*
J. Papavassiliou *(University of Valencia, Spain)*
A.C. Aguilar *(Universidade Estadual de Campinas, Brasil)*
J.M. Cornwall *(University of California at Los Angeles, US)*

NUMBER OF PARTICIPANTS: 48

MAIN TOPICS:

The announced theme of the workshop was to demonstrate progress toward understanding observable hadronic degrees of freedom from QCD, while continuing work that was the subject of the first two QCD-TNT workshops, such as first-principles understanding of confinement, chiral symmetry breaking, QCD at finite temperature and density, and other non-perturbative manifestations of QCD. As at the first two workshops there were several presentations of lattice simulations and theory. A number of talks covered aspects of hadronic phenomenology, including exotic hadrons, glueballs, and Reggeism, using, in some instances, phenomenological approximations to the fundamental dynamical equations of QCD to relate quarks and gluons to hadrons. There were also new topics not represented in earlier workshops, including the simulation of certain quantum field theories with ultra-cold atoms and QCD calculations with methods motivated by string theory.

Topics included:

- Off-shell string-inspired methods for QCD calculations
- Cold-atom experimental realizations of gauge-theoretic phenomena
- Glueballs, exotic hadrons, Regge phenomenology, quark-hadron duality
- Lattice simulations in covariant gauges
- Models of the QCD vacuum and confinement
- Chiral symmetry breaking
- QCD Schwinger-Dyson equations for propagators and vertices
- From phenomenological Schwinger-Dyson equations to hadrons
- QCD at finite temperature and density
- Gauge theories with non-trivial backgrounds

SPEAKERS:

A. Aguilar (Universidade Estadual de Campinas, Brasil)

N. Ahmadiniaz (Michoacan University, Mexico)

R. Alkofer (University of Graz, Austria)

M. Asorey (University of Zaragoza, Spain)

R. Bellweid (University of Houston, USA)

D. Binosi (ECT*, Trento, Italy)

J.I. Cirac (Max Planck Institute for Quantum Optics, Germany)

J. Cornwall (University of California at Los Angeles, US)

A. Courtoy (INFN - Sezione di Pavia, Italy)

M. Creutz (Brookhaven National Laboratory, US)

M. Cristoforetti (ECT*, Trento, Italy)

M. Dalmonte (Inst. Quant. Optics and Quant. Information, Austria)

M. D'Elia (University of Pisa, Italy)

G. Eichman (University of Giessen, Germany)

W. Eshraim (University of Frankfurt, Germany)

R. Ferrari (University of Milan, Italy)

Ch. Fischer, (University of Giessen, Germany)

L. Fister (University of Heidelberg, Germany)

J. Greensite (San Francisco State University, US)

T.K. Herbst (University of Heidelberg, Germany)

M.Q. Huber (University of Darmstadt, Germany)

D. Ibanez (University of Valencia, Spain)

K.-I. Kondo (Chiba University, Japan)

G. Krein (University of São Paulo, Brazil)

K. Langfeld (University of Plymouth, UK)

B. Lucini (University of Swansea, UK)

A. Maas (Friedrich-Schiller-University Jena, Germany)

V. Mathieu (ECT*, Trento, Italy)

M. Mueller-Preussker (Humboldt University, Germany)

S. Olejnik (Inst. Phys., Slovak Acad. Sci., Bratislava, Slovakia)

J. Papavassiliou (University of Valencia, Spain)

O. Philipsen (University of Frankfurt, Germany)

A. Quadri (University of Milan, Italy)

C. Ratti (University of Turin, Italy)

H. Reinhardt (University of Tuebingen, Germany)

D.H. Rischke (University of Frankfurt, Germany)

M. Rizzi (University of Mainz, Germany)

J. Rodriguez-Quintero (University of Huelva, Spain)

J. Serreau (University of Paris, Diderot, France)

A. Shibata (KEK, Japan)

P. Silva (University of Coimbra, Portugal)

A. Slavnov (Steklov Mathematical Institute, Russia)

H. Suganuma (Kyoto University, Japan)

A. Szczepaniak (Indiana University, US)

T. Tomboulis (University of California at Los Angeles, USA)

L. von Smekal (University of Darmstadt, Germany)

P. Watson (University of Tuebingen, Germany)

D. Zwanziger (New York University, USA)

SCIENTIFIC REPORT:

This was the third in a series of workshops on non-perturbative quantum chromodynamics (QCD); the first two were held in 2009 and 2011. Originally there was no particular intent to go beyond the first workshop, but the enthusiastic support of the participants for more dialogue on non-perturbative QCD led to the second workshop and then to the present workshop. Some of the problems raised in the first two workshops are still with us, and there is still uncertainty in the QCD community about the first-principles answer to such questions as confinement and chiral symmetry breakdown.

However, over the years there has been progress: The old claim that the gluon of QCD has a non-perturbative mass generated by quantum effects is now widely accepted, even by some who dissented in the earlier workshops. Acceptance comes from the ever-increasing power and accuracy of QCD lattice simulations (as evidenced at the workshop), as well as from first-principles investigations of the dynamic equations governing QCD gluons. All simulations over the past few years unambiguously show dynamical mass generation. A number of talks at the present workshop, by authors previously not engaged in the subject, explored different ways of thinking in theoretical terms about modeling this dynamical mass, but none seem to improve on the original idea of finding the mass as an inevitable consequence of the QCD Schwinger-Dyson equations. There is also progress in "unquenching" lattice simulations (adding dynamic quarks) with results in agreement with theoretical expectations.

Although all recent simulations of lattice QCD show a dynamical gluon mass, there is one drawback of these simulations which deal with the gluon propagator: In order to define that propagator, it is necessary to fix a gauge, almost always the Landau gauge. Ordinarily, fixing a gauge would seriously compromise the possibilities for extracting gauge-invariant physics, but the existence of a gluon mass is one gauge-invariant manifestation that can be directly extracted from lattice simulations. There is a potential remedy for the problem that the conventionally-defined lattice gluon propagator depends on a choice of gauge, but unfortunately the leading lattice simulators who are exploring this remedy were unable to attend the workshop. In any event, several talks, including some by the organizers, continued to explore the well-known continuum procedure (the pinch technique) for finding a gauge-invariant propagator and gluon mass.

There were a number of talks tying detailed QCD theory to phenomenology, which includes comparison with not only accelerator experiments but also lattice simulations. These addressed glueballs, exotic hadrons (those not makeable from a quark-antiquark pair, or of three quarks) such as tetraquarks, and a couple of talks dwelt on the entire spectrum of known low-energy hadrons. Unfortunately, the wider the scope of a phenomenology the harder it seems to be to connect it directly to first-principles QCD. Moreover, phenomenological approaches that seem quite different in principle often yield equivalently good fits to hadronic data. There were a few talks relating experimental results directly to QCD theory, including one that extracted from data a reasonably accurate value of the low-energy running coupling of QCD, with results in good agreement with theoretical pinch-technique arguments.

There is an analog of this for the lattice, where hadronic data are replaced by simulation data. Lattice practitioners pretty much agree on the Landau-gauge gluon propagator, but we have little knowledge of the propagator spectral function, basically because to recover it from lattice data an ill-posed inverse Laplace transform is needed. Two attempts were presented, using apparently equally good phenomenological propagator fits but yielding quite different spectral functions. Similarly, several rather different phenomenological models of monopole confinement were shown, claiming to be equally good in reproducing confinement on the lattice. There are still widely-divergent views, represented at the workshop, on semi-phenomenological models of the QCD vacuum; none of these models can claim to pass successfully a few crucial tests of QCD confinement. One talk challenged the conventional views of what it means on the lattice to have a massless quark, along with massive ones, and hence challenged conventional ideas on chiral symmetry and its breaking.

As at the first two workshops a good number of continuum-theory papers were given on solutions using various approximations to the (first-principle) Schwinger-Dyson equations of gluonic Green's functions, in some cases making direct use of lattice data as input. This is a particularly hard problem, but the approximation algorithms and scope of the studies continue to improve. For example, a couple of papers on unquenching QCD gluonic Green's functions were presented. Theoretical studies of the gluon propagator yield a gluon mass of around 600 MeV, consistent with lattice data, but so far neither theory nor simulations really probe the detailed nature of the gluon mass as affected by adjoint-string breaking, a subject discussed in one workshop talk.

In recent years some authors have revived interest in the old subject of string-inspired methods for calculating QCD amplitudes; one such talk on this subject was given at the workshop (we had invited others, who were unable to come). The essence of such methods is to formulate QCD loop amplitudes in terms of proper-time Schwinger-Feynman propagators. For reasons of simplicity all such formulations use the background field Feynman gauge, which (as two of the organizers proved long ago) is equivalent to enforcing gauge invariance on these amplitudes. These string-inspired methods were explored further in a paper showing how to re-state them in various interesting ways.

One highlight of the workshop was an afternoon devoted to studies of certain quantum field theories, including QCD, with a combination of theory and experiments on ultracold atoms confined to, for example, an optical lattice. Some non-gauged field theories yield fairly straightforwardly to such techniques, but QCD is a hard case, at present reaching only the proposal stage. There are, however, cold-atom methods involving spin ices that speak directly to the solitons that are expected to occur in the QCD vacuum; these could be presented at a future workshop. It is impossible to recapitulate all the papers presented at the workshop, which had a far-reaching scope covering essentially all actively-researched areas of QCD. In an all-too-brief summary, the quality of research presented was uniformly high and all sessions were quite well-attended. The organizers believe, and apparently (judging by comments at the end of the workshop) the participants as well, that QCD-TNT-III was a success, as were its two predecessors. Many participants would be eager to see a fourth workshop. Although there is still no consensus on the basic details of confinement and chiral symmetry breakdown, considerable progress has been made, with the existence of a dynamical gluon mass of about 600 MeV confirmed both theoretically and on the lattice. This mass plays a critical role in confinement and other non-perturbative phenomena. We expect more progress in two years, perhaps with consensus on the mechanisms for confinement and growing understanding of exactly how chiral symmetry breaking works. As the power and scope of lattice simulations continues to grow, that may make it worthwhile to consider a fourth non-perturbative QCD workshop.

3.3.15 LC13: EXPLORING QCD FROM THE INFRARED REGIME TO HEAVY FLAVOUR SCALES AT B-FACTORIES, LHC AND LINEAR COLLIDERS

DATE: September 16 – 20, 2013

ORGANIZERS:

Gennaro Corcella *(INFN Frascati National Laboratories, Italy)*
Stefania De Curtis *(INFN Florence, Italy)*
Rohini M. Godbole *(Indian Institute for Science and Technology, Bangalore, India)*
Stefano Moretti *(University of Southampton, UK)*
Giulia Pancheri *(INFN Frascati National Laboratories, Italy)*
Francois Richard *(Laboratoire de l'Accelerateur Lineaire d'Orsay, IN2P3, Orsay, France)*

NUMBER OF PARTICIPANTS: 51

MAIN TOPICS:

This workshop was part of a series on physics at Linear Colliders (LCs), organised in Italy every one or two years to stimulate and gather together the Italian community interested in LCs. The workshop invited scientists from everywhere in the world to discuss topical arguments related to LCs.

This workshop explored physics prospects at very high energy LCs and the uncertainties from the infrared regime of QCD, which affect high energy precision measurements in particle physics.

The workshop was organised along the following main topics:

- Status of the LC projects
- Review of LHC results and future prospects
- SuperB factories and other new projects in particle physics
- Flavour physics
- Top physics measurements and uncertainties
- Theoretical updates on the infrared structure of QCD
- Total and elastic proton-proton cross-section: LHC and cosmic ray results
- Phenomenological aspects of the QCD infrared regime at the LHC and LC
- Infrared effects in low energy precision physics
- QCD Tools in the infrared region

SPEAKERS:

E. Accomando (Southampton University, UK)

P. Azzi (INFN Padova, Italy)

A. Baroncelli (INFN Rome3, Italy)

M. Beneke (TUM, Germany)

S. Biondini (TUM, Germany)

F. Borzumati (Tohoku University, Japan)

M. Caccia (Insubria University, Italy)

M. Chiesa (University of Pavia, INFN Pavia, Italy)

P. Ciafaloni (INFN Lecce, Italy)

D. Comelli (INFN Ferrara, Italy)

G. Corcella (INFN Frascati, Italy)

M. Dasgupta (Mancherster University, UK)

A. Deandrea (Université de Lyon, France)

S. De Curtis (INFN Firenze, Italy)

G. De Grassi (University of Rome3, Italy)

D. D'Urso (INFN Perugia, Italy)

Lyndon Evans (CERN, Switzerland)

R. Ferrari (University of Milan, Italy)

M. Ferrario (INFN Frascati National Laboratory, Italy)

M. Gagliardi (University of Torino, Italy)

M. Gomez (Helva University, Spain)

H. Hoorani (National Center for Physics, Quaid-I-Azam University, Pakistan)

F. Jegerlehner (Humboldt-University, Berlin, Germany)

L. Jenkovszky (University of Kiev, Ukraine)

S. Kanemura (Toyama University, Japan)

E. Kato (Tohoku University, Japan)

M. Kikuchi (Toyama University, Japan)

E. Kou (LAL Orsay, France)

C. Langenbruch (CERN, Switzerland)

S. Leone (INFN Pisa, Italy)

O. Mattelaer (UCL, Belgium)

B. Mele (INFN Rome1, Italy)

S. Moretti (Southampton University, UK)

H. Murayama (University of California at Berkeley, USA and IPMU, Japan)

A. Nyffeler (Harish-Chandra Res. Inst., Allahabad, India)

N. Orlando (INFN Lecce, Italy)

G. Pancheri (INFN Frascati, Italy)

O. Panella (INFN Perugia, Italy)

L. Panizzi (University of Southampton, UK)

P. Paradisi (CERN, Switzerland)

M. Passera (INFN Padova, Italy)

R. Petronzio (University of Tor Vergata, Italy)

F. Piccinini (INFN Pavia, Italy)

G.- M. Pruna (Paul Scherrer Institut, Switzerland)

E. Re (Oxford University, UK)

F. Richard (IN2P3, France)

I. Scimemi (UC University of Madrid, Spain)

A. Texeira (LPC Clermont Ferrand, France)

S. Valentinetti (INFN and University of Bologna, Italy)

A. Urbano (SISSA, Tireste, Italy)

G. Venanzoni (INFN Frascati National Laboratory, Italy)

SCIENTIFIC REPORT:

With the discovery of the Higgs boson at LHC, a new era is starting for particle physics: the community needs to plan for future explorations, to reach higher energies and luminosities, in order to improve experimental precision. At the same time, theoretical progress has to keep pace so as to be able to confront with data when this will become available.

In this connection, in our workshop we have addressed the following key points. What is the future of particle physics? There are a number of different projects, which were examined, and which span the physics of hadron collisions, versus several electron positron options, both at very high energy and at extremely high luminosity. The audience gained a very good overview of the current situation regarding planned experimental facilities and their physics scope.

At the present stage, the road to the future needs both theoretical and experimental input. At the LHC, a vast amount of data is showing that the Standard Model works very well, and the discovery of the Higgs completes a path started fifty years ago. At the workshop, experimental groups from all the LHC experiments reported their results on top physics, flavour physics in general, and hadronic physics.

The International LC (ILC) in Japan is by now a mature project supported by the whole Japanese scientific community. The best site for its constructions has already been selected. The project is at the moment under discussion by the Japanese government. This is expected to approve it shortly if negotiations with possible partner nations for the sharing of costs and technical expertise will have a successful outcome. All nations interested in the advancement of elementary particle physics need to contribute to this project, following the model of international collaborations carried out at the LHC, and will be soon asked at the governmental level to state an official agreement to its starting. In this sense, ILC meetings in Europe, and in particular in Italy, as ours, are therefore timely and important.

The Top and Heavy-Flavour session had a number of interesting presentations and discussions. The LHCb Collaboration presented its latest results, taking particular care about the implications of the flavour-related measurements on the searches for physics beyond the Standard Model at the LHC. Likewise, the most interesting results on the top-quark properties (total and differential cross sections, top mass, spin correlations and W helicity in top decays) at the LHC (ATLAS and CMS) and the Tevatron (CDF and D0) were reported.
On the theory side, we had a review on flavour physics within and beyond the Standard Model, stressing the interplay between theoretical models and LHC data in the flavour sector. As for top-quark phenomenology, the role of the top quark in determining the stability of the Standard Model Higgs potential, as well as progresses in higher-order calculations and Monte Carlo simulations for top production and decays at hadron and lepton colliders, were discussed. Moreover, the theoretical and experimental challenges concerning the electroweak couplings of top quarks at a LC were presented.

At present, the Higgs boson properties have been determined with increasing precision: its mass has been measured at the per mille level and evidence for its scalar nature has been given. The coupling tests are compatible with SM predictions by now, but the possible presence of some New Physics (NP) is not excluded yet. In fact, there is no fundamental principle for the minimal Higgs sector of the SM. Non-minimal scalar sectors are provided by many theories and provide sources for baryogenesis, dark matter and neutrino masses. Beside the direct search, precision measurements of the Higgs couplings, using the k-V –k-F parameterisation, could profile the underlying theory and even give an estimate of the mass scale of possible extra Higgs bosons. In this respect, the role of a LC will be fundamental in finding evidence of NP via the analysis of the SM-like Higgs couplings and decays, even before the possible discovery of the extra Higgs bosons. Accuracy of the order of percept or below, that only LCs can provide, is in fact necessary for finding evidence of new physics.

Low energy precision physics is another basic building block of our knowledge of the world of particle physics. Precision measurements, such as g-2 of the muon, are sensitive to physics beyond the Standard Model and can give glimpses of possible deviations from SM expectations. The problem in comparing theoretical expectations with experiments however lies in our poor knowledge of QCD in the infrared regime. This follows from the extreme precision of experiments and the large contribution to the errors coming from hadronic contributions. Attempts to reduce these errors lie in more and more refined measurement of the total electron-positron cross-section in the region from the two pion threshold up to the charm threshold. Another source of uncertainty is related to the very unique contribution from the light-by-light scattering amplitude. Models have given results with different signs in the past and more theoretical efforts are still under way to pinpoint this contribution with the required precision.

The QCD session has been devoted to present an update of recent theoretical efforts on three main subjects:
1) the jet substructure methods as a set of tools to enhance the discovery potential at very high energy collisions, where possible new heavy particles give rise to very boosted and rich final states;
2) Transverse Momentum Dependent (TMD) parton distribution functions, which will play a crucial role in the low momentum tail of vector boson/Higgs production, where non pertubative effects become dominant. Such studies have direct impact also on the definition of TMD fragmentation functions at leptonic colliders;
3) next-to-leading order (NLO) parton level calculations, properly interfaced to parton shower techniques for accounting higher order corrections.
The present state of the art on these techniques for multi-scale processes at the LHC has been discussed, with the prospects of reaching next-to-NLO (NNLO) predictions interfaced to parton shower. Part of this technology is already in use for theoretical predictions in high intensity leptonic collisions.

Hadronic physics, after LHC measurements, is gaining understanding. However, in most analyses performed on LHC data, a lingering problem remains: precision interpretation of data at hadronic colliders requires simulations of background processes and understanding of hadronic interactions at very low momenta. This is particularly true for all the studies of elastic, total and inelastic cross-sections. The LHC has measured all these quantities at an unprecedented centre-of-mass energy, with very good precision, as seen at this workshop: the ALICE, CMS and ATLAS collaborations showed their results, compared them with those obtained by TOTEM, the experiment dedicated to the measurement of the total and elastic cross-section.
The total cross-section keeps on rising, and it seems to be rising at a faster rate than what was predicted by many models. However, many models can accommodate these results within their band of predictions. Models incorporate analyticity, and, in some case, contributions from the infrared regime and QCD minijets to the rise.
Studies of the differential elastic cross-section have received a great boost by the beautiful TOTEM measurement, which shows the reappearance of the dip and a structure still to be

fully described without ad hoc parameters. A model-independent parameterisation of this structure shows that it can be fitted very well by a two component model, with a phase and two momentum dependent slopes. Many other models, initially missing both the position of the dip and the shape of the tail to follow it, have now adjusted their parameters and fit the data. However, a real understanding of the dynamics leading to the observed shape is not yet reached. It is to be hoped that the LHC at higher energies might provide some more insight.

Results and Highlights

We should emphasise the following outcomes from this workshop:

- A renewed strong interests and furthering awareness of the Italian and European communities in the physics case for building a LC.
- A strong contribution from the community as a whole to bring to focus the present Japanese effort for the future of LCs.
- A competent update of recent results in particle physics experiments at the LHC in order to maintain awareness of the strong correlations between LHC outcomes and LC possibilities.
- Several contributions of phenomenological and theoretical input to the ongoing discussion about the road map and options for a future LC.
- In-depth discussions about phenomenological and theoretical approaches to precision QCD studies, which affect both LHC and LC physics, including in the search for new physics beyond the SM.
- Publication of the workshop proceedings in both electronic and paper format as a means to contribute to the literature on LC physics. The Proceedings will be published by Nuovo Cimento. (Proceedings were published for LC09 and LC10 from the Societa' Italiana di Fisica and by the INFN, as VoL. LIII of the Frascati Physics Series, for LC11.)

All the participants expressed their appreciation of both the format and the content of the workshop. The interplay between future projects, present experimental results and advances in phenomenology and theory, are seen as a great strength of this series of workshops and contribute to make it a unique opportunity to capitalise on the LC community as a whole, which is growing in size year after year. Main actors in the field presented the European, Japanese and International programs and the high quality of these presentations, including a Colloquium by Prof. Hitoshi Murayama, allowed an immediate high level update of the present status of particle physics as a whole.

3.3.16 MICROPHYSICS IN COMPUTATIONAL RELATIVISTIC ASTROPHYSICS (MICRA) 2013

DATE: September 22 – 27, 2013

ORGANIZERS:

Christian D. Ott *(Caltech, USA)*
Almudena Arcones *(TU Darmstadt, Germany)*
Filippo Galeazzi *(U. Valencia, Spain)*
H.-Thomas Janka *(MPA Garching, Germany)*

NUMBER OF PARTICIPANTS: 41

MAIN TOPICS:

The purpose of the MICRA workshop was to bring together leaders and young researchers in the fields of microscopic physics (nuclear/neutrino physics, nuclear astrophysics) and numerical modeling to investigate what input is needed, where approximations can be employed, and where a sophisticated treatment of microphysical details is most important.

See also the independent MICRA 2013 web page: http://micra2013.org
The main topics were:

- Astrophysics: neutron star merger and core-collapse supernova simulations; new observational developments.
- The nuclear EOS in core-collapse supernovae and neutron star mergers.
- Neutrino interactions and oscillations.
- Nucleosynthesis in mergers and core-collapse supernovae.
- Numerical simulation methods

SPEAKERS:

W. D. Arnett (U Arizona, USA)

A. Bartl (TU Darmstadt, Germany)

P. Cerda-Duran (U Valencia, Spain)

S. Couch (U Chicago, USA)

T. Fischer (U Wroclaw, Poland)

F. Foucart (CITA, Canada)

C. Frohlich (NCSU, USA)

B. Giacomazzo (Trento, Italy)

M. Hempel (U Basel, Switzerland)

C. Horowitz (Indiana, USA)

W. Kastaun (MPI for Gravitational Physics, Germany)

K. Kiuchi (Yukawa Inst., U Kyoto, Japan)

O. Korobkin (Stockholm, Sweden)

J. Lattimer (Stony Brook, USA)

E. Lentz (ORNL, USA)

A. Lohs (TU Darmstadt, Germany)

G. Martinez-Pinedo (GSI, Germany)

G. McLaughlin (NCSU, USA)

B. Metzger (Columbia, USA)

P. Moesta (Caltech, USA)

E. O'Connor (CITA, Canada)

D. Radice (MPI for Gravitational Physics, Germany)

L. Rezzolla (MPI for Gravitational Physics, Germany)

L. Roberts (Caltech, USA)

A. Schwenk (TU Darmstadt, Germany)

Y.-I. Sekiguchi (Yukawa Inst., U Kyoto, Japan)

A. Steiner (U. Washington, USA)

Y. Suwa (Yukawa Inst., U Kyoto, Japan)

M. Ugliano (TU Darmstadt, Germany)

C. Volpe (Paris, France)

SCIENTIFIC REPORT:

Modern astronomical instruments, both ground-based and in space, have revealed many energetic phenomena in which the physics and astrophysics of matter and radiation at high densities and the effects of general relativity play a central role. Understanding these phenomena is a great challenge, and over the past two decades much progress has been made in developing numerical methods for simulating dynamical general-relativistic gravitational fields, magnetohydrodynamic processes, and radiation transport. There has also been significant progress in understanding nuclear and particles physics at a fundamental level, but there has not been a corresponding improvement in many aspects of the microscopic physics input, such as the equation of state of hot dense matter and rates of neutrino processes, used in simulations.

The purpose of the MICRA workshop was to bring together leaders and young researchers in the fields of microscopic physics (nuclear/neutrino physics, nuclear astrophysics) and numerical modelling to investigate what input is needed, where approximations can be employed, and where a sophisticated treatment of microphysical details is most important. MICRA 2013 was the third in a series of workshops on this topic. The first one was held at the Niels Bohr International Academy, Copenhagen, Denmark, in 2009 and the second one was held at the Perimeter Institute for Theoretical Physics, Waterloo, Canada, in 2011.

The MICRA 2013 workshop held at ECT* focused on core-collapse supernova and neutron star mergers on the modelling side and on the nuclear EOS, neutrino interactions, and nucleosynthesis on the nuclear (astro)physics side.

In the following we present the topics that were discussed and provide details on the various discussions.

- The newest three-dimensional models of core-collapse supernovae and neutron star mergers were presented as well as detailed analyses how nuclear and neutrino physics influence the simulation outcomes. While there has been much progress on the modelling front, current models still lack many details that are potentially important. Core-collapse supernova models are now 3D, but the 3D simulations available at this point are either parameterized (so not from first principles) or underresolved and often use only crude neutrino transport. The current merger models still mostly use simple polytropic EOS, but the first small set of simulations using finite-temperature microphysical EOS are now available and were presented at MICRA 2013.
- A number of speakers presented overviews and phenomenological interpretations for recent observational astrophysics results and astrophysical constraints on the nuclear EOS:

(1) Thanks to time-domain astronomy, a number of supernova explosions have been shown that had pre-cursor outbursts only months to weeks before the actual explosion. It may be that these precursor outbursts are caused by unstable nuclear burning in shell burning episodes. (2) There is a big international effort to understand the possible electromagnetic (EM) counterpart signal to gravitational waves from double neutron star and neutron-star—black-hole mergers. Finding such an EM counterpart, which is potentially powered by decay of r-process nuclei, would be important for adding detection confidence for gravitational wave observatories. It will also be important for understanding r-process nucleosynthesis in mergers. (3) There is a growing amount of data from observations of quiescent and bursting neutron stars that allows astronomers to put statistical constraints on both neutron star mass and radius. This combined with the very certain knowledge that 2-solar-mass neutron stars exist, puts rather stringent constraints on the cold nuclear EOS.

- Recent progress in computing the nuclear EOS from chiral effective field theory and other approaches was summarized and discussed. Chiral effective field theory can compute the low-density neutron equation of state with very good accuracy. Fits to observational constraints then yield estimates for the softest and stiffest allowed cold nuclear EOS and corresponding neutron star mass-radius curves. These “extremal” EOS are of great interest to the modelling community.
- Neutrino interaction physics for mergers and core-collapse supernovae was discussed with an emphasis on medium corrections to the cross-sections and the influence of the nuclear symmetry energy, which have recently gained considerable interest in the community. There are still significant uncertainties surrounding the neutrino emission and nucleosynthetic impact of protoneutron star cooling. The overall interaction physics needed for core-collapse supernovae and neutron star mergers turns out to be rather similar.
- Nucleosynthesis results (r-process, explosive, nu-p process) in mergers and core-collapse supernovae were presented and the underlying nuclear physics and numerical approaches were discussed. Neutron star mergers are more and more recognized as a robust source for r-process nuclei, but it is still not possible to completely exclude core-collapse supernovae as r-process sites.
- Methods for improving the microphysical details in core-collapse supernova and neutron star mergers were discussed at length and the pro/cons of various approximations were weighed. There has been much work in improving simple neutrino leakage schemes to more accurately reproduce the results of very expensive full radiation-hydrodynamics simulations. On the latter, there has been progress as well, and a first full 3D implementation of a two-moment neutrino transport scheme was presented.

Results and Highlights

The workshop, as the previous MICRA workshops, was very successful in starting and furthering discussions between nuclear (astro)physicists and modelers. Both groups attended and contributed to the break-out discussion sessions and a number of new collaborations were started. Bringing together these communities in a single workshop again proved very fruitful. The workshop has also had an impact within the individual communities: due to the low-key, hierarchy-free setting, many informal and open technical discussions between modelling groups took place. The same happened between nuclear/neutrino physics groups.

An important result of the workshop for the modelling community is the agreement of several groups to work together to better understand systematic problems inherent to the various hydrodynamic schemes used by the community for modelling core-collapse supernovae and neutron star mergers. For this a collaborative github repository was set up by participant Sean Couch: https://github.com/smcouch/veracity/ . The idea is that code tests will be published in a frequently updated arXiv.org document.

On the microphysics side, an important highlight was the overview talk by Achim Schwenk on new results from chiral effective field theory for the nuclear EOS and the three new cold microphysics EOS of Hebeler et al. 2013, representing the softest possible, the stiffest possible, and an intermediate EOS for neutron stars. These are available in tabular form and are being rapidly incorporated into neutron star merger codes.

3.3.17 ECT*-EMMI WORKSHOP ON NEUTRON-RICH MATTER AND NEUTRON STARS

DATE: 30 September – 4 October, 2013

ORGANIZERS:

Christopher J. Pethick *(The Niels Bohr International Academy and Nordita)*
Achim Schwenk *(Institut für Kernphysik and ExtreMe Matter Institute EMMI)*
Anna Watts *(Anton Pannekoek Astronomical Institute)*

NUMBER OF PARTICIPANTS: 30

MAIN TOPICS:

The workshop brought together observational astrophysicists and nuclear physicists to develop an improved understanding of the properties of dense neutron-rich matter. The main topics of the workshop were:

- Extracting neutron star radii from observations of X-ray bursts and burst oscillations.
- New developments on microscopic calculations of the equation of state of dense neutron-rich matter.
- Implications of the constraints from observations and nuclear theory for the equation of state at super-nuclear densities.
- Impact on astrophysical simulations of neutron-rich environments (neutron star mergers and proto neutron-star cooling).
- Constraints on superfluidity and other nuclear properties obtained from observations and simulations of neutron star cooling.

SPEAKERS:

A Arcones (TU Darmstadt & GSI, Germany)

D. Bandyopadhyay (Saha Institute of Nuclear Physics, India)

A. Bauswein (AUTH Thessaloniki, Greece)

Y. Cavecchi (API - UvA, Amsterdam, Netherlands)

N. Chamel (ULB, Belgium)

A. Drago (Univ. Ferrara, Italy)

P. Freire (MPIfR, Bonn, Germany)

A. Gezerlis (Guelph, Canada)

K. Hebeler (Univ, Darmstadt, Germany)

D. Kobyakov (Univ. Umeå, Sweden)

T. Krüger (TU Darmstadt, Germany)

B. Link (Montana State Univ. USA)

A. Mukherjee (ECT*, Italy)

E. O'Connor (CITA, Canada)

F. Pederiva (University of Trento, Italy)

J. Poutanen (Univ. Oulu, Finland)
L. Roberts (Caltech, Pasadena, California, USA)

R. Rutledge (McGill, Canada)

V. Somà (TU Darmstadt, Germany)

A. Steiner (INT/U. Washington, Seattle, USA)

V. Suleimanov (IAAT, Univ. Tuebingen, Germany)

I. Tews (TU Darmstadt, Germany)

L. Tolós (ICE, Barcelona, Spain)

I. Vidaña (Univ. Coimbra, Portugal)

M. Voskresenskaya (TU Darmstadt, Germany)

A. Watts (University of Amsterdam, Netherlands)

W. Weise (ECT*, Italy)

SCIENTIFIC REPORT :

Over the past few years much progress has been made on two fronts. One is the observations of neutron stars, and the other is microscopic calculations of properties of dense matter, ranging from Monte Carlo calculations at lower densities to developing an understanding of the theoretical uncertainties based on chiral effective field theory interactions.

Significant recent developments on the observational side include the discovery of neutron stars with well-determined masses of 2 solar masses, considerably greater than the previous record holder of 1.65 solar masses, and increasingly precise determinations of neutron star radii especially from X-ray observations. These observations impose significant constraints on the equation of state of neutron-rich matter at super-nuclear densities.

This workshop explored astrophysical and nuclear physics constraints for neutron star radii, and the implications for nuclear astrophysics. The main focus was to bring together different groups analyzing X-ray bursts with groups working on new theoretical developments on the nuclear physics side.

X-ray bursters are a particularly fruitful source of constraints on the equation of state, and are driving development of future X-ray missions. Various different techniques can be used to derive complementary constraints. These include pulse profile modeling of burst oscillations (asymmetries that develop during some bursts whose profile encodes information about mass and radius via relativistic effects on photon propagation); continuum burst spectroscopy of cooling tails and Photospheric Radius Expansion bursts; and the detection of absorption lines or edges as heavy ashes are thrown up into the photosphere by highly energetic bursts. The acquisition by GAIA of accurate distances to bursters will also help to reduce model uncertainties.

In theory, the application of chiral effective field theory has made possible systematic calculations of the equation of state and other properties of matter up to around nuclear saturation density. The challenge is to bring together all the pieces of information that can give insight into the properties of dense neutron-rich matter, and the objective of the workshop was to do just this.

The workshop topics covered different pillars of the ExtreMe Matter Institute (EMMI), the phase structure of strongly interacting matter and the structure of neutron matter, in an interdisciplinary nuclear physics and astrophysics setting. The ECT* workshop was supported financially with 5 k€ from EMMI. This amount was used according to the agreement between ECT* and EMMI.

SUMMARY

By all accounts, the ECT*-EMMI workshop was considered very successful. In the close-out session on Friday, the participants commented in particular that they enjoyed the mixture of observers and theorists, which gave a real chance for information transfer across nuclear physics and astrophysics. This was especially fruitful in the discussion of radius constraints from the different groups, which represented a main focus of the workshop. The participants also commented that it was very useful to have the main messages of the talks first and that they enjoyed the informal setting with plenty of time for questions and discussion.

Since one of the organizers (Watts) brought her family (her husband and children aged 3 years and 5 months, as she was breastfeeding) with her, the organizers were especially conscious of the need to provide suitable facilities and accommodation for families. ECT* was able to find accommodation for the family, and the atmosphere at the workshop was such that bringing along a breastfeeding infant was not a problem. In our view doing so made for a more human environment at the workshop, which was beneficial for all participants.

Finally, we would like to warmly thank the ECT* staff, especially Ines Campo, Barbara Curró Dossi and Gianmaria Ziglio, for their excellent support and kind help in the organization of and during the workshop days in Trento.

3.3.18 REACTIONS INVOLVING 12C: NUCLEOSYNTHESIS AND STELLAR EVOLUTION

DATE: October 07 -11, 2013

ORGANIZERS:

A. Diaz-Torres *(ECT*, Italy)*
L. R. Gasques *(University of Sao Paulo, Brasil)*
M. C. Wiescher *(JINA and University of Notre Dame, USA)*

NUMBER OF PARTICIPANTS: 30

MAIN TOPICS:

Nuclear astrophysics is a broad interdisciplinary field. The discussion of reaction rates requires new experimental data which usually cover a number of low energy reaction techniques. Since the data are typically taken at higher energies, often complemented by nuclear structure methods probing the lower energy range, reliable nuclear reaction theory methods need to be applied to low energy extrapolations of the data. Low energy reaction theory is indeed the key element on which this workshop has been focused. The impact of the newly derived results has been discussed in the framework of astrophysical environments where the reactions take place to study the impact and sensitivity of the experimental and theoretical improvements.

The main topics were:

- 12C(alpha,gamma)16O reaction
- 12C(p,gamma)13N reaction
- R-matrix extrapolation
- 12C three-alpha cluster structure and three-alpha reaction rate
- 12C+12C burning and its impact on core collapse and supernova progenitors
- White dwarf collisions as a possible type Ia supernova
- 12C+12C sub-Coulomb fusion and nuclear molecular resonances

SPEAKERS:

E. F. Aguilera (ININ, Mexico)

C. Brune (Ohio U, USA)

S. Courtin (IPHC Strasbourg, FR)

R. DeBoer (Notre Dame U, USA)

A. Diaz-Torres (ECT*, IT)

A. Dileva (Naples Federico II U, IT)

H. Esbensen (ANL, USA)

H. Feldmeier (GSI, GE)

M. Freer (Birmingham U, UK)

L. Gasques, Leandro (USP, BR)

L. Gialanella (Second University Naples & INFN, IT)

J. Goerres (Notre Dame U, USA)

K. Hagino (Tohoku U, JP)

G. Imbriani (Naples Federico II U, IT)

S. Ishikawa (Hosei U, JP)

Y. Kanada-Enyo (Kyoto U, JP)

T. Neff (GSI, GE)

G. Montagnoli (Padova U, IT)

L. Morales Gallegos (Edinburgh U, UK)

A. Palumbo (BNL, USA)

M. Pignatari (Basel U, CH)

K. E. Rehm (ANL, USA)

N. Rowley (IPN Orsay, FR)

V. Sargsyan (JINR Dubna, RU)

A. Stefanini (INFN-Legnaro, IT)

O. Straniero (INAF Teramo, IT)

X. Tang (Notre Dame U, USA)

F-K. Thielemann (Basel U, CH)

H. Weller (Duke U, USA)

M. C. Wiescher (Notre Dame U, USA)

SCIENTIFIC REPORT:

The understanding of the physics of low-energy nuclear reactions is essential for explaining the chemical evolution of the universe. Nuclear reactions are the engine of stars and control the formation of elements. Nuclear reactions characterize the different phases of stellar evolution, hydrogen burning in main-sequence stars, helium burning in red giants, and carbon, neon, and oxygen burning during the late stages of stellar evolution. Carbon is a key element, as it is the source of all organic materials, and it is one of the most abundant elements in the universe next to hydrogen and helium. The nucleosynthesis of carbon therefore plays a particular role in the chemical evolution of the universe.
The 12C(p,gamma)13N reaction triggers the CNO cycle, which is the predominant energy source for hydrogen burning in massive stars. Without carbon, massive stars could not stabilize as main sequence stars and would collapse straight towards the helium burning phase. This is anticipated for massive first generation stars which have to rely on primordial abundance distribution and therefore have a completely different stellar evolution trajectory than stars with core carbon abundances. The low energy cross sections of CNO reactions have been thoroughly re-investigated over the last few years using new experimental and theoretical techniques and methods. The resulting low energy cross sections are in many cases significantly different from those suggested by previous experiments. The new experimental methods include new low energy measurements which cover a broader energy range than previously available as well as new results from indirect studies such as the Trojan Horse Method (THM). Coupled with these new experimental results are novel theoretical techniques that have been developed for extrapolating the S-factor from the experimentally observed energy range down to the stellar energy range. The new methods have been presented and discussed together with the implications and consequences for the CNO abundance distribution resulting from stellar core hydrogen for main sequence stars. These discussions covered not only the latest results for the 12C(p,gamma)13N reaction but also other radiative capture reactions associated with CNO nucleosynthesis.

The 12C(alpha,gamma)16O reaction is crucial for stellar helium burning and the subsequent fate of stars since it determines the ratio of carbon to oxygen towards the end of the red giant phase. Low mass stars evolve to White Dwarfs and this ratio determines the final abundance composition in white dwarf matter and sets the trigger conditions for type Ia supernova explosions. The carbon oxygen ratio also dictates the subsequent sequence of burning processes during the final stages of stellar evolution for massive stars and therefore defines the abundance composition in outer shells of the star prior to core collapse which will be the seed for shock-front driven nucleosynthesis. The12C(alpha,gamma)16O reaction is of central importance and the reaction rate needs to be determined for core helium burning conditions in massive stars in their red giant phase. Despite many years of theoretical and experimental efforts, the reaction rate still represents one of the main uncertainties for modeling stellar evolution and explosion with sufficient accuracy. The reaction cross section at stellar energies is characterized by strong interference effects between broad resonances, sub-threshold states and non-resonant direct capture components in the reaction mechanism. A reliable extrapolation in the stellar energy range of 300 keV requires improved experimental results. New experimental results have been obtained through inverse kinematic techniques in the high energy range as well as through improved beta-delayed alpha decay studies of 16N. These results reduce substantially the present uncertainties in low energy R-matrix based extrapolation of the data towards the stellar energy range. This in turn reduces the uncertainties in the prediction for the carbon oxygen composition for white dwarf materials, which is one of the key uncertainties in the predictions of type Ia supernova simulations. The reliability of the new R-matrix approach and the implication for the S-factor extrapolation were discussed.

During the carbon burning phase, the most important reaction is the 12C+12C fusion, followed by the 12C+16O and 16O+16O reactions. It determines the timescale of carbon burning but also the production of secondary fuel elements, H, He, n, for building the final abundance distribution in core and shell carbon burning. Of particular relevance is the knowledge of the 12C+12C reaction rate for type Ia supernovae explosions. It is well understood that these events are driven by carbon ignition in cores of accreting massive CO white dwarfs. The ignition conditions are sensitive to the 12C and 16O abundances as defined by the 12C(alpha,gamma)16O rate and the 12C+12C reaction rate at the typically T ≃(1.57) x 108 K and density of about (25) x 109 g cm−3. The process takes place when the white dwarf exceeds 1.4 times the mass of the Sun (the Chandrasekhar limit). Another intriguing phenomenon is the observation of X-ray superbursts on accreting neutron stars. Explosive carbon burning in the crust of such binary systems has been proposed as a possible trigger and energy source for a recently observed new phenomenon in neutron star transients, the superbursts. The mechanism can be interpreted as the unstable ignition of carbon that has been formed during hydrogen burning in the SnSb cycle that characterizes the final phase of the rp-process. However, the required ignition conditions seem to disagree with the observed superburst light curves. The low energy cross section of the 12C+12C reaction has been a matter of great debate for the last five years, different projections for the cross section based on improved potential model or the new concept of the hindrance model have been discussed which lead to substantially different S-factor predictions for the energy range of carbon burning. The theoretical predictions are complemented by new experimental results of which most have been obtained in the analysis of the neutron channel. The direct measurements have been complemented by first THM measurements.

Results and Highlights

The participants agreed that this was an excellent meeting, presenting the latest results on the 12C(alpha,gamma)16O reaction which seem to merge now to an agreement value. It also discussed new avenues towards a solution of the 12C+12C problem, both experimentally and theoretically. New ideas were presented and recent not published new data were discussed. New models were shown and discussed, in the higher energy range it seemed more a consolidation of the results, while in the low energy range there is still a lot of debates regarding the possibility and, if really observed as the Caserta group in Naples claims, the nature of the low energy resonances. The workshop stimulated a lot of debate and even more important a number of new ideas and collaborations, since it brought people from different fields together that usually do not talk to each other. That leads to a merging of experimental and theoretical tools that hopefully will eventually lead to the solution of the 12C+12C problem. Everybody liked the long, interactive talks (one hour) as it stimulated extensive discussions. It was facilitated by a small number of participants. The Workshop Colloquium by Prof. Martin Freer (University of Birmingham, UK) was outstanding, attended by many external people (from ECT*, the University and FBK) who expressed a deep appreciation. JINA provided a very substantial financial support to a large number of delegates, as this was an ECT* - JINA Workshop

3.3.19 ADVANCES IN TIME-DEPENDENT METHODS FOR QUANTUM MANY-BODY SYSTEMS

DATE: October 14 - 18, 2013

ORGANIZERS:

A. Rios Huguet *(University of Surrey, UK)*
P. Danielewicz *(Michigan State University & National Superconducting Cyclotron Laboratory, USA)*

NUMBER OF PARTICIPANTS: 40

MAIN TOPICS:

The overarching topic of this multidisciplinary meeting was the theoretical description of the time evolution of quantum many-body systems. Fundamental concepts, new techniques and computational issues in the broad area of time-dependent quantum mechanics were discussed intensively. The purpose was twofold: to expose nuclear theorists to developments in other areas of quantum dynamics and to showcase to other areas the most recent advances in nuclear theory. Common interests were discussed and potential new synergies were identified. Among others, we highlight:

- Time-dependent Hartree-Fock: applications in nuclear reactions and astrophysics
- Time-dependent density functional (TDDFT) for superfluid systems
- Kadanoff-Baym dynamics in relativistic systems and lattice models
- Time-dependent coupled cluster theory
- Exact dynamics in quantum dots and bosonic systems
- Balian-Veneroni dynamics in nuclear systems
- Time-dependent density matrix renormalization group for cold atoms dynamics
- Numerical methods and implementation of many-body dynamics

SPEAKERS:

H. Appel (Fritz Haber Institut, Germany)

S. Ayik (Tennessee Technical University, USA)

M. Bonitz (University of Kiel, Germany)

A. Bulgac (University of Washington, USA)

W. Cassing (University of Giessen, Germany)

J. Corney (University of Queensland, Australia)

A. Daley (University of Pittsburgh, USA)

P. Deuar (Institute of Physics, Polish Academy of Sciences, Poland)

A. Diaz Torres (ECT*, Italy)

S. Ebata (University of Hokkaido, Japan)

P. Faccioli (University of Trento, Italy)

M. Forbes (Institute of Nuclear Theory, USA)

P. Goddard (PhD Candidate, University of Surrey, UK)

M. Garny (CERN, Switzerland)

T. Gasenzer (University of Heidelberg, Germany)

A. Harju (Aalto University, Finland)

S. Hermanns (PhD Candidate, University of Kiel, Germany)

C. Hinz (PhD Candidate, University of Kiel, Germany)

Y. Iwata (University of Tokyo, Japan)

B. Julia-Diaz (University of Barcelona, Spain)

S. Kvaal (University of Oslo, Norway)

D. Lacroix (Institut de Physique Nucleaire, Orsay, France)

P. Magierski (Warsaw University of Technology, Poland)

J. Maruhn (University of Frankfurt, Germany)

M. Ogren (Orebro University, Sweden)

C. Pardi (University of Surrey, UK)

P. Saalfrank (University of Potsdam, Germany)

G. Scamps (PhD Candidate, GANIL, France)

K. Sekizawa (PhD Candidate, University of Tsukuba, Japan)

C. Simenel (Australian National University, Australia)

A. Streltsov (University of Heidelberg, Germany)

S. Umar (University of Vanderbilt, USA)
R. van Leeuwen (University of Jyväskylä, Finland)

C. Verdozzi (Lund University, Sweden)

K. Washiyama (RIKEN, Japan)

K. Yabana (University of Tsukuba, Japan)

SCIENTIFIC REPORT:

Many nuclear processes must be fundamentally addressed in time rather than energy representation. For reactions with several participants, proceeding over a multitude of steps and/or populating multiple channels, a unique way to access and understand the dynamics is via simulations that include time as an explicit coordinate. The interplay of many-body physics, quantum phenomena and temporal evolution, however, poses conceptual and technical challenges that need to be addressed from a broad perspective.

The most widely used quantal approach for the many-body time evolution of nuclear systems is the Time-Dependent Hartree-Fock (TDHF) approach. In this context, 3D calculations are now commonplace and have been recently applied to study a variety of situations, from superheavy element formation to isospin equilibration or transfer. Extensions of TDHF incorporating pairing have led to developments in our understanding of the nuclear response or, in another domain of physics, the superfluid shock wave dynamics of unitary gases.

The advances in dynamical studies of nuclei are coupled to the success of density functional theory for nuclear structure. Both approaches are tied from a formal point of view, with structure being the “static” limit of dynamical TDHF-like calculations. The recent shift of nuclear structure theory towards ab initio approaches, however, has no time-dependent counterpart. As a matter of fact, very few among these static ab initio methods can be extended to study the dynamics of nuclei.

First principles time-dependent calculations, however, are progressing quickly in other fields of physics, where dynamical quantum many-body calculations are essential. The following methods were discussed in the meeting:
1. Non-equilibrium Green's functions approach, which provides a consistent dynamical description that can, in principle, be improved systematically. Application to inhomogeneous (i.e. finite-size) systems include molecules and atoms.
2. Multi-configuration TDHF calculations, which have allowed for substantial advances in quantum chemistry, but have not yet been applied within nuclear theory.
3. Time-dependent coupled cluster theory, which has re-emerged recently as a potentially applicable theory for many-body dynamics.
4. Stochastic mean-field dynamics methods, extensively used in model systems and nuclear dynamics applications.
5. Gaussian phase-space representation approach, as introduced for ultracold gases.
6. Time-dependent density matrix renormalization group, particularly useful in a variety of lattice models.
7. Lindblad dissipative dynamics, which has recently been employed to assess the impact of decoherence in nuclear systems.

With this workshop, we brought together experts on quantum dynamics to (a) review the state of the art in quantum simulations of many-body systems and (b) explore and assess whether (and which) ab initio methods can be applied to the study of time-dependent nuclear reactions and structure. The meeting provided a platform to discuss in depth the advantages, potential limitations and applicability of different, competing theories for structure and dynamics of nuclei and other microscopic systems.

Results and Highlights

The workshop was attended by 40 researchers from Europe, the US, Australia and Japan. 35 talks provided an extensive summary of recent breakthroughs, present challenges and future directions of research. Broadly speaking, the talks at the workshop could be divided between those devoted to applications of time-dependent calculations in nuclear physics, mostly within the time-dependent Hartree-Fock (TDHF) and density functional (TDDFT) approaches, and those dealing with other many-body systems, which provided a wide overview of different methods.

Within nuclear physics, TDHF (or TDDFT) is still the more vastly used theoretical approach to tackle dynamics. This is due to various reason: its practicality, its clear connection to nuclear structure (particularly via the Skyrme density functional) and its relatively modest computational demands. Unrestricted 3D calculations from various leading groups, including Frankfurt, Vanderbilt, Tsukuba, RIKEN, Tokyo, Warsaw/INT and ANU/Saclay, were described at the meeting.

TDHF-oriented research provided a very healthy picture of nuclear theory. This is not only due to enhanced of computational resources but, most importantly, due to applications of the method to a wider variety of physics scenarios. At the workshop, these applications included: nuclear astrophysics in neutron star crusts (by Maruhn), fusion reactions (either using constrained calculations [Umar] or via dissipative dynamics [Washiyama]), isospin equilibration (Iwata) and nuclear resonances (Ebata, Goddard).

These new TDHF-inspired research avenues often need substantial conceptual developments. Theoretical advances using the Balian-Veneroni formalisms were discussed by Simenel, in the context of particle number fluctuations in fusion reactions. Similarly, particle number projection has recently been employed to study transfer (Scamps, Sekizawa). New techniques, developed at Surrey by Pardi, have also allowed for the implementation of boundary-constraint-free methods. The coupling with electromagnetism, as explored by Yabana, leads to a good description of laser abrasion in solids.

Another widely-discussed TDHF aspect, and one that triggered the interest of other communities, is the connection to pairing. In analogy to the nuclear structure situation, different prescriptions are applied to implement pairing correlations in the dynamics. The Time-Dependent Superfluid Local Density Approximation was discussed in two different backgrounds by the INT/Warsaw groups (Bulgac, Magierski, Forbes): ultracold fermionic atoms (vortex dynamics, potential formation of domain walls, shock waves) and heavy nuclei (resonances). Alternatively, the canonical Hartree-Fock-Bogolioubov basis, as implemented by the RIKEN group (Ebata), has been employed in nuclear physics applications, mostly in the context of resonances.

A natural extension of TDHF to include further correlations in the dynamics is the so-called multi-configuration TDHF method. This involves using several Slater determinants, which intrinsically evolve and mix in time. Applications in quantum chemistry (as discussed by Saalfrank) and in photoionization (as discussed by Hinz) were mentioned in the meeting. This method has not yet been introduced in nuclear physics. One potential inconvenience is the inconsistency introduced with respect to the density functional when one goes beyond the mean-field approximation.

The workshop brought along a variety of experts from other communities to discuss different techniques. Dynamics using Kadanoff-Baym techniques, either relativistic or non-relativistic, were discussed in the context of the Hubbard model (by Bonitz), heavy ion collisions (by Cassing) and, interestingly, leptogenesis (by Garny). Recent advances on the numerical implementation of such approaches were explored, especially in the context of the Generalized Kadanoff-Baym Ansatz, which seems to treat correctly the damping in finite systems. The Kadanoff-Baym method was originally developed and implemented by nuclear physicists, but its computational application has been mostly followed by other fields. We expect new developments in the application of these nuclear techniques in the near future, more than two decades after their original implementations.

The coupled cluster method is also a widely used many-body formalism, originally developed (and now widely applied) within the nuclear community. Its extension to dynamics is possible and has been initially studied in quantum chemistry settings. A recent reformulation of the method, by Kvaal, has the potential to stimulate applications in a wider field. In particular, in view of the recent revival of coupled cluster techniques within nuclear theory, the time-dependent version seems quite promising. Time-dependent configuration interaction methods have also been used in specific situations of quantum chemistry, as discussed by Appel. The coupling between electron and photon dynamics have been studied and access to almost-exact dynamics is granted.

New techniques based on a combination between mean-field dynamics and stochastic time trajectories have provided useful insight in ultracold atoms, both for bosons and fermions (talks by Deuar, Corney and Ogren). Numerical instabilities can arise in strongly correlated systems as time proceeds, but, when applicable, the method is sound and provides correlations beyond the mean-field approach. Similar techniques have been implemented in nuclear physics in the past, with different flavours of stochasticity adapted to a variety of correlation and physical scenarios (talks by Ayik and Lacroix). Future applications to nuclear collisions are foreseen, with work being pursued by various groups at the moment.

On the one hand density-matrix-based methods provide a natural quantum mechanical description of the time evolution. Lindblad dissipative dynamics is based on such a density-matrix picture, providing a physical description of decoherence. In nuclear physics, Diaz-Torres's approach is to induce decoherence via the coupling of resonance states to well-defined low-energy modes. On the other hand, renormalization group techniques in lattice systems, as discussed by Daley, provide means to describe exact dynamics in controlled many-body systems. While static applications of the DMRG approach are already in place for nuclear theory, we are not aware of attempts to extend the method to dynamics.

On top of the different theoretical methods, fresh concepts for time-dependent systems were discussed in the meeting. Using techniques borrowed from one-body quantum mechanics, shortcuts to adiabaticity were discussed by Julia-Diaz, in the context of exact many-body solutions of Josephson junctions. Within this specific bosonic system, steady final states can be accessed faster than with an adiabatic switch-on. Similar techniques in other many-body systems could provide access to ground states with smaller computational demands. In a similar context, the potential application of optimal control theory in nuclear many-body systems is still an open issue.

An exciting connection between quantum information and quantum many-body dynamics was discussed by Harju, in the context of the dynamics of few-body quantum dots using full configuration interaction dynamics. In relation to solid state physics, disorder also plays a role in a variety of many-body systems. Particularly, recent developments in ultracold atoms by Verdozzi indicate that the dynamics can be particularly affected by the presence of controlled (or uncontrolled) disorder. Turbulence, as induced by the propagation of different energy modes in the dynamics by stochastic jumps, is being explored in Bose-Einstein condensates by Gasenzer.

On the technical side, there were several common issues identified in the meeting. The study of dynamics in many-body systems is almost always a numerically intensive activity. In particular, systematic studies of different systems are becoming available, rather than simple one-shot runs. Parallelization is capital in most cases. In this context, GPU computing was continually reported at the meeting as a source of substantial speed-ups in computations. Future breakthroughs will most likely exploit this technology to improve upon previously existing codes.

Concerning the wider impact, a world-leading researcher was chosen to deliver a colloquium to the wider Trento research community. Robert van Leeuwen, from the University of Jyväskylä, provided a compelling lecture that covered a variety of many-body approaches. This was a biographical account on the successes, failures and common issues of different methods and their application to the dynamics of many-electron and lattice systems. It was perfectly suited for the meeting and attracted a few researchers from the ECT* and the local university.

A website for the workshop has been prepared by the organizers. All talks are now uploaded, for the benefit of the community (and the wider public):

http://personal.ph.surrey.ac.uk/~m01088/ECT/ECT_Workshop/Talks.html

The meeting was a success in terms of participation and research discussions. However, the last-minute budget issues were challenging and unexpected. Several groups were kind enough to reshuffle their travel budgets in a short notice and we take this opportunity to thank them formally for their contribution to this workshop.

3.3.20 STRANGENESS IN THE UNIVERSE? THEORETICAL AND EXPERIMENTAL PROGRESS AND CHALLENGES IN THE ANTIKAON NUCLEAR PHYSICS

DATE: October 21 - 25, 2013

ORGANIZERS:

Catalina Curceanu *(LNF-INFN, Italy)*
Carlo Guaraldo *(LNF-INFN, Italy)*
Jiri Mares *(Nuclear Physics Institute, Rez Prague, Czech Republic)*
Johann Marton *(SMI-Vienna, Austria)*
Johann Zmeskal *(SMI-Vienna, Austria)*

NUMBER OF PARTICIPANTS: 42

MAIN TOPICS:

The workshop focussed on most recent developments, both in strangeness physics from theoretical and experimental points of view, in particular in the antikaon nuclear sector, and possible implications in astrophysics and cosmology. Present and future opportunities in this frontier field of research were discussed, together with new experimental methods and techniques, paralleled by theoretical progress.

Main topics of discussions were:

- Antikaon—Nucleon and –Nucleus Interaction at Low Energy
- Kaonic atoms physics
- Antikaonic (single and double strangeness) Nuclei
- The nature of the Λ (1405)
- Hypernuclear spectroscopy
- Excited Hyperons and their Interactions with Nuclei
- Equation of state for neutron stars including hyperons and strange quarks
- Experimental results:
    - SIDDHARTA, SIDDHARTA-2, AMADEUS and FINUDA at DAFNE
    - FOPI and HADES at GSI
    - E15 and other experiments at J-PARC
    - DISTO at SATURNE
    - MAMI status
    - Astrophysical observations

Next-generation experiments

- AMADEUS Step 1 at DAFNE
- SIDDHARTA-2 at DAFNE
- E15, E17 and other proposals at J-PARC

- Future of MAMI
- New experiments with HADES
- Experiments at FAIR
- Experiments at CERN
- Other proposals

In the framework of the Workshop a Special Event was organized on 23 October, dedicated to Paul Kienle's scientific heritage.

SPEAKERS:

Y. Akaishi (RIKEN, Nihon Univ., Japan)

M. Cargnelli (SMI Vienna, Austria)

A. Cieply (NPI Rez, Czech Republic)

T. Faestermann (TUM, Germany)

A. Filippi (Univ. and INFN Torino, Italy)

E. Friedman (Racah Institute of Physics, Jerusalem, Israel)

A. Gal (Hebrew Univ. Jerusalem, Israel)

J. Haidenbauer (FZ Jülich, Germany)

B. Hiesmayr (University Vienna Austria)

Y. Ioichi (RIKEN, Japan)

M. Iwasaki (RIKEN, Japan)

W. Kutschera (VERA Lab. Vienna, Austria)

M. Maggiora (Univ. Torino and INFN, Italy)

S. Marcello (Univ. Torino and INFN, Italy)

J. Mares (NPI Rez, Czech Republic)

J. Marton (SMI Vienna, Austria)

D. Myhailov (TUM, Germany)

S. Ohnishi (RIKEN, Japan)

S. Okada (RIKEN, Japan)

S. Piano (Sez. Trieste, INFN, Italy)

K. Piscicchia (Centro Fermi and LNF-INFN, Italy)

J. Pochodzalla (Univ. Mainz, Germany)

R. Quaglia (Politecnico and INFN Milano, Italy)

F. Sakuma (RIKEN, Japan)

K. Sasaki (Univ. Tsukuba Japan)

M. Sato (Univ. Tokyo, Japan)

A. Scordo (LNF.INFN, Italy)

K. Seth (Northwestern University, USA)

N. Shevcenko (NPI Rez Prague, Czech Republic)

M. Silarski (Jagellonian University, Krakow, Poland)

D. Sirghi (LNF-INFN, Italy)

H. Tamura (Tohoku University, Japan)

I. Tucakovic (Univ. Tor Vergata and LNF-INFN, Frascati, Italy)

I. Vidana (Univ. Coimbra, Portugal)

W. Weise (ECT*, Italy and TU Munich, Germany)

T. Yamazaki (Univ. Tokyo, Japan)

J. Zmeskal (SMI Vienna, Austria)

SCIENTIFIC REPORT:

The workshop focussed on the following main themes: antikaon-nucleon and -nucleus interactions at low energy; kaonic atoms studies; search for (single and double) antikaonic nuclei; the nature of the Λ (1405); excited hyperons; hyperon-nucleon and -nucleus interactions,=; hypernuclear spectroscopy; strangeness in heavy-ion collisions; equation of state for neutron stars including strangeness. Not only single topics were considered, but interconnections between them were as well discussed.

Antikaon-Nucleon and –Nucleus Interaction at Low Energy

A very active field of hadron physics in the strangeness sector is the study of low energy antikaon-nucleon interactions which are governed by hyperon resonances near threshold. The strong interaction of antikaons with the nuclear medium may give rise to very interesting phenomena in antikaonic nuclear systems with increased binding energy and density thus possibly giving access to high density, low temperature phases of hadronic matter. Many experimental results are emerging in this sector, for example from the analyses of KLOE 2002-2005 data and of the new data taken in 2012 with a dedicated carbon target, as well as from experiments at J-PARC. In the future, opportunities will be exploited to study also low energy antikaon–nucleon and -nucleus scattering using advanced 4π-tracking detector techniques for gaining precision data with the AMADEUS setup at DAΦNE. Experimental results were discussed together with theoretical findings and future perspectives.

Nature of Λ (1405)

In spite of being a well-established resonance, the nature of Λ (1405) is still not yet well-understood. It is currently described as a molecular state of the antikaon-proton and pion-Sigma states mixed together. This item is of fundamental importance- since it is connected with the strength of antikaon-proton interaction and, consequently, with the possible existence of deeply bound kaonic nuclei. The latest experimental results (FOPI, HADES and KLOE. data) were shown and discussed, together with theoretical findings. Future experiments were addressed too.

Kaonic Atoms

Kaonic atoms are fundamental tools for understanding low-energy QCD in the strangeness sector. The SIDDHARTA experiment has provided the most precise results on kaonic hydrogen transitions to the 1s level and kaonic helium 3 and 4 transitions to 2p level, and performed the first exploratory measurement on kaonic deuterium. These results are presently being considered by the theoreticians working in the field in order to extract the antikaon-proton scattering length and to make predictions for a future kaonic deuterium precision measurement. The SIDDHARTA-2 experiment at DAΦNE and future experiments at JPARC are going to take data in the next years; these experiments will perform future precision measurements on kaonic atoms. Experimental results were discussed, together with their use by theoreticians and future plans. Implications for the equation of state for dense hadronic matter was examined, as well.

Antikaonic Nuclei

The case of possible deeply bound kaonic nuclei is still at the stage of lively discussions. There are intensive ongoing searches for such deeply bound and dense systems with various reactions using stopped and in-flight K- beams, as well as proton and heavy ion induced reactions at various laboratories, such as at DAΦNE in Frascati using KLOE-data analyses, the carbon target in KLOE (2012) AMADEUS, J-PARC with E15, and GSI using FOPI and HADES. First indications for the existence of deeply bound ppK- and ppnK-systems have been found in stopped K- reactions with FINUDA at DAΦNE, E549 at KEK and proton induced reactions in the analysis of DISTO data from SATURNE and OBELIX at CERN, all of which need to be confirmed by planned future experiments. The scientific case of antikaonic nuclei was revised and updated based on latest experimental findings and theoretical calculations and future experimental plans were discussed.

Hypernuclear Spectroscopy

Many new results are coming in the hypernuclear physics sector; new experimental data but even more important, new theoretical ideas, are nowadays available and thus exerting pressure on existing and future experiments. The importance of hypernuclear physics is extending, in parallel with new accelerator and detector techniques, from strangeness -1 hypernuclei, to strangeness -2 systems and to high precision experiments. Experiments to search for single and double-Λ hypernuclei and cascade hypernuclei are undergoing or are planned at J-PARC and will be realized in the future at the FAIR.
Results of existent experiments were discussed together with theoretical studies and future experiment proposals. Relevant astrophysics aspects were considered.

Excited Hyperons and their Interactions with Nuclei

Recently various reactions produced excited hyperon states in the nuclear or hadronic medium, such as the Σ0 (1385) hyperon with a strong decay into the Λπ- -channel for which interesting effects can be expected in context of the π- propagation in the nuclear medium. In the future, these effects may be studied by invariant mass spectroscopy using the excited hyperon decay channel. First experiments to reconstruct the invariant mass of the Σ0 (1385) from the Λπ - channel have been performed recently with the FOPI detector in heavy ion and proton induced collisions. Another very interesting topic along this line is the study of the proposed double pole nature of an excited Λ-hyperon, Λ (1405) using various production reactions, such as pp-reactions at the HADES detector at GSI or reactions with stopped K- at DAΦNE. Such experiments have also been proposed at J-PARC. The solution of this pending double pole Λ(1405) problem is of utmost importance for our understanding of the interactions of antikaons with nuclei. Results of experiments and theoretical progress were reviewed.

Equation of state for neutron stars including strangeness

The composition of matter at high densities depends strongly on the details of the baryon-baryon interactions. For a long time, hyperons (and even kaons) have been considered relevant degrees of freedom of dense hadronic matter, realized in neutron stars. However, the hyperons embedded in nuclear matter cause softening of the corresponding equation of state. As a result, they lower drastically the maximum mass of neutron star. The mass of neutron star thus provides a strong constraint for hyperons (and kaons) in dense neutron star matter.
The latest observations of neutron stars with masses equal to two solar masses seem to be at odds with the understanding of hyperons as constituents of the composition of compact stars. Refined input is needed from strangeness nuclear physics for the hyperon-interactions (YY interactions, momentum dependence, hyperon 3-body forces) to reconcile experimental facts with models of dense hadronic matter with strangeness.
Possible theoretical scenarios for the structure of neutron stars, based on the current knowledge of the baryon-baryon interactions and information from heavy-ion collisions were discussed.

A special event dedicated to Paul Kienle's Scientific Heritage was organized on 23 October – see Appendix for details and for discussed items.

Results and Highlights

Strangeness nuclear physics bears a broad impact on contemporary physics. Lying at the intersection of nuclear and particle physics it has significant implications for astrophysics too. The field is evolving very fast, with new data coming from numerous recent experiments (HADES, FOPI, SIDDHARTA, KLOE, E15, just to name few); other experiments are planned (at DAFNE, GSI, FAIR or JPARC) and many others are in the proposal phase. On the theoretical side, refined calculations and methods (effective field theories, lattice calculations, few- and many-body approaches, etc.) are yielding results with steadily improving accuracy, which, combined with the experimental findings, yield a better and more accurate understanding of the processes undergoing in the low-energy QCD sector. There are, however, still many open problems to be solved. Among these, some play a key-role: the nature of the Λ (1405), the possible existence of deeply bound kaonic nuclear states with single or double strangeness, double strangeness hypernuclei and their binding energies, the kaon-nucleon/nucleus and hyperon-nucleon/nucleus interactions, just to name few. On the other side, a fast evolving field, based on more and more available experimental data in strangeness physics and advance in microscopic theories, together with new data coming from astronomy and astrophysics observations, is the study of the possible role of Strangeness in the Universe. Items such as: equation of state for neutron stars including strangeness (hyperons or kaons), or even (strange) quark stars or strangelets, are presently a flourishing field of research, with new rigorous constraints provided by the recently observed two-solar-mass neutron stars.

The successfully achieved aim of the Workshop was to discuss recent progress in the strangeness low-energy sector, in particular in antikaon nuclear physics, and to investigate the connection of these findings with the possible role of strangeness in the Universe, by bringing together specialists in various fields. The latest theoretical findings boosted by the experimental results were discussed in order to make a step forward in planning the future strategy aiming at deeper and more complex understanding of the underlying phenomena. The Workshop provided an excellent opportunity to trigger future collaborations which might then put forward new projects in the framework of the upcoming EU - Horizon2020 program.

The workshop gathered together world-leading experimental and theoretical experts in the field and young scientists and students, providing a state-of-the-art overview of the field of low-energy QCD in strangeness sector. The young participant's percentage was about 50%, which is one of the successes of the Workshop.
Moreover, participants from many countries took part, making it an occasion not only of scientific exchange, but of cultural and social significance too, proving once again scientists are part of society, and their role is an important one.

The future of the field looks bright and promising – in good health, with an optimal mixing of experts and young researches, theoreticians and experimentalists, understood items and puzzles.

The organization of this type of workshops in the ideal environment of ECT* contributes to the progress of the field.

Last but not least a note of merit: the organization of the workshop by ECT* was excellent (special thanks to Ines Campo, Barbara Curro' Dossi, Gian Maria Ziglio, and to the ECT* Director, Prof. W. Weise).

3.3.21 FROM NUCLEAR STRUCTURE TO PARTICLE-TRANSFER REACTIONS AND BACK

DATE: November 04 - 08, 2013

ORGANIZERS:

Jacek Dobaczewski *(University of Warsaw, Poland)*
Marek Ploszajczak *(GANIL, France)*

NUMBER OF PARTICIPANTS: 28

MAIN TOPICS:

Advances in the microscopic reaction theory are crucial for the science program at the existing and future Radioactive Ion Beam (RIB) facilities. The practical spectroscopic tools to study the shell evolution and nucleon-nucleon correlations can be advanced by interfacing nuclear structure models with reactions methods with a focus on unstable nuclei. The essential questions are how to (i) advance the reaction theory and its methods for the description of spectroscopic properties of rare isotopes, (ii) provide a microscopic input for transfer and knockout reactions from most advanced nuclear structure models, and (iii) study nucleon-nucleon correlations in exotic nuclear systems that are close to the breakup threshold and whose properties are determined by a combination of many-body correlations and couplings to the continuum. Acceleration of the process of development of practical tools, which are adapted for spectroscopic studies of rare-isotopes, will be decisive for the success of experimental programs at the existing and future RIB facilities in Europe and elsewhere.

The main topics were:

- Ab initio many-body calculations of reactions
- Faddeev/AGS equations including core excitations for (d,p), (p,d), (p,pn) and (d,d') reactions
- Time-dependent Hartree-Fock calculation of multinucleon transfer processes
- Density-independent effective interactions for structure and reaction calculations
- Medium polarization effects
- Spectroscopic factors of deep-hole states
- Signatures of pair correlations in transfer reactions
- Transfer and knockout to probe continuum states
- One nucleon transfer reactions at high neutron-proton asymmetry
- Radial overlap functions from transfer reactions
- Reaction theory to probe pairing interaction in transfer reactions
- Two-neutron transfer amplitudes with extended tail
- Core recoil effects in two-nucleon knockout reactions
- Pair rotation and giant pair vibration modes

SPEAKERS:

D. Beaumel (IPN Orsay, France)

K. Bennaceur (IPN Lyon, France)

R. Broglia (University of Milano, Italy)

W. Catford (University of Surrey, United Kingdom)

L. Corradi (INFN-Legnaro, Italy)

D. Delion (NIPNE-Bucharest, Romania)

A. Deltuva (University of Lisbon, Portugal)

E. Simpson (University of Surrey, United Kingdom)

F. Flavigny (KU-Leuven, Belgium)

L. Fortunato (University of Padova, Italy)

A. Gillibert (SPhN-Saclay, France)

M. Grasso (IPN Orsay, France)

M. Horoi (CMU-Mont Pleasant, USA)

M. Matsuo (Niigata University, Japan)

P. Navratil (TRIUMF, Canada)

N. Orr (LPC-Caen, France)

A. Petrovici (NIPNE-Bucharest, Romania)

M. Ploszajczak (GANIL, France)

K. Sekizawa (University of Tsukuba, Japan)

J. Tostevin (University of Surrey, United Kingdom)

B. Tsang (Michigan State University, US)

N. Tsoneva (University of Giessen, Germany)

E. Vigezzi (University of Milano, Italy)

SCIENTIFIC REPORT :

The workshop was dedicated to the discussion of the interface between nuclear structure models and nuclear transfer reaction methods with an emphasis on future advances needed to provide useful theoretical tools for weakly bound or unstable rare isotopes. In the last decade, nuclear theory has witnessed an unprecedented progress in ab initio nuclear structure and reaction theory of light nuclei and the unification of nuclear structure and reactions in a framework of the continuum shell model. An extension of the few-body techniques based on the Faddeev equation to include core excitations provided a new start for future studies of complex reactions with 3- or 4-body final states. New techniques of experimentation with radioactive isotopes lead to an explosion of results in transfer and knockout reactions about the shell structure and two-particle correlations in exotic nuclei.
These topics give an impression of the depth and breadth of our workshop. About 30 scientists participated and the average age was rather low. It goes without saying that a good mix of experimental and theoretical physicists have participated.
Space does not allow us to discuss the individual talks presented at the meeting. Here we restrict ourselves to a few that illustrate in a vivid way the diversity of the topic but in the same time illustrate the generality of the techniques used by the individual speakers. These talks also symbolized the main themes addressed at the workshop. Both, from the nuclear structure and the nuclear reaction community we have chosen three talks to bring out the new ideas presented at ECT*.
Petr Navratil presented a recent progress achieved by his group in ab initio calculations in nuclear physics using chiral 2- and 3-nucleon interactions. Starting from the No-Core Shell Model (NCSM), he demonstrated that many effects of the scattering continuum can be

included in the NCSM framework using techniques of the resonanting group method (RGM). Nowadays, NCSM/RGM allows for an ab initio description of proton radiative capture reaction, such as 7Be(p,g)8B from solar p-p chain, and transfer reactions 3H(d,n)4He, 3He(d,p)4He of astrophysical interest. Discussion of the structure of 9Be suggests an interplay between the induced 3-nucleon interaction and the continuum coupling which necessitates an improvement of the NCSM/RGM algorithm to deal with large number of excited states of the core. First NCSM/RGM calculations of 3-body cluster dynamics in 6He gives the hope that soon one will be able to quantify the role of 3-body forces in low-energy nuclear reactions.

A totally different approach to the few-body dynamics of complex nuclei was presented by Arnoldas Deltuva. He discussed exciting recent developments in Faddeev-type (Alt-Grassberger-Sandhas (AGS) equations) description of 3- and 4-body nuclear reactions including the core excitations. This 'tour de force' of the reaction theory opens exciting perspectives for the exact description of reactions in heavy nuclei combining the input of microscopic optical potentials with the exact treatment of continuum in few-body final states. The comparison of exact AGS solutions with core excitations in 10Be(d,p)11Be and 12C(d,p)13C reactions with those obtained using most advanced (approximate) models, such as CDCC and ADWA, demonstrated important differences between these approaches which remain to be understood.

If the reaction dynamics is complicated and involves different competing reaction mechanisms and/or many reaction channels, the application of the time-dependent methods with self-consistent potentials can be an interesting alternative. Kazuyuki Sekizawa presented the application of the Time-Dependent Hartree-Fock (TDHF) calculation for the description of multinucleon transfer processes in heavy reactions. The TDHF approach is a promising tool which accounts well for few-nucleon transfers to/from the projectile-like fragment. On the other hand, multiple transfer of nucleons cannot be described in this approach. It remains to be seen whether the fully microscopic description of nuclear dynamics including pairing correlations, as provided by the Time-Dependent Hartree-Fock-Bogolyubov calculation, will solve the problem of the massive multinucleon transfer. The difficulty of TDHF could be in part due to the failure of existing self-consistent potentials to reproduce separation energies for all considered transfer reaction channels.

New ideas to construct the density-independent effective interactions for mean-field and beyond mean-field calculations have been discussed by Karim Bennaceur. This promising approach is still at its infancy but future studies, including finite range 2- and 3-body effective interactions, will allow to construct ab initio energy functionals.

Particular aspects of the pair-transfer on neutron-rich nuclei have been discussed by Masayuki Matsuo. This process depends heavily on the neutron pair density and the asymptotic Cooper pair wave function as a function of the two-neutron separation energy. Since the pair condensate has a longer tail, pairing correlations and continuum induced spatial correlations of nucleons dominate the transfer processes far from the neutron drip line (Sn~S2n<2MeV). Detailed QRPA+DWBA calculations of the two-neutron transfer process confirm this assertion.

In a similar QRPA studies, Marcella Grasso pointed out a difficulty in extracting information from two-neutron transfer reactions about the surface/volume mixing in the effective pairing interaction.

Challenges and advances in the theory of nuclear structure and nuclear transfer reactions have been complemented by several presentations of up-to-date experimental data and discussions of the difficulties encountered in analyzing these data. Lorenzo Corradi gave an overview of experimental signatures of pair correlations. The difference in extracted spectroscopic factors from transfer and knockout reactions was pointed out as a major problem and discussed by many participants. Nigel Orr discussed how best to model transfer to continuum states and treat s-wave form factor. In the discussion of knockout/breakup reactions he pointed out that presently very crude description of the reaction to the continuum states puts severe limitation on the information that can be extracted from the

data. For example, when is a ‘bump’ a state?, or how to treat consistently background (core recoil, valence-n scattering, non-resonant continuum, etc.)?
All talks led to extensive and intensive discussions in which all communities participated.

Results and Highlights
The workshop capitalized on the new theoretical activity SARFEN (Structure And Reactions For Exotic Nuclei) established in Europe in 2011 in the framework of the recent ERANET-NuPNET [http://www.nupnet-eu.org/wps/portal/index.html] call for proposal. This collaborative 2012-2014 effort brings together theorists from 8 countries and 11 institutions with the common goal of providing experimental infrastructures with advanced modern theoretical tools. The present workshop went far beyond the structure of a simple collaborative meeting and aimed at discussing the subject matter with world-leading experts in theory and experiment. Through this workshop the ECT* has provided a unique opportunity for different communities, nuclear structure, nuclear reaction, experiment and theory, sharing an interest in learning about the structure of atomic nucleus from nuclear reactions to meet and exchange ideas. It is noticeable that the “language barrier” diminished and different communities can now communicate with each other on subjects of mutual interests. For example, Kazuyuki Sekizawa who is a theorist started a collaboration with Lorenzo Corradi, an experimentalist, on studies of multinucleon transfer processes in peripheral collision of heavy ions. Edward Simpson and Arnoldas Deltuva, both nuclear reaction experts, started two independent collaboration projects with Ricardo Broglia, the nuclear structure expert, on the transfer reaction involving a weakly bound 11Li which is described in Nuclear Field Theory.

Although a transfer of knowledge has taken place due to this workshop it is fair to say that only a beginning has been made. Many questions remain and give rise to many more fruitful discussions. Here we only mention the quenching of pure shell model spectroscopic factors for strongly bound nucleons, the effect of using realistic wavefunctions for transferred nucleon, the common sense approach in transfer reaction studies to identify strong single-particle states, measuring their spins and strength. Many still open questions remain, like (i) do the degrees of freedom and the corresponding matrix elements tested with stable beams hold with RIBs?, (ii) do the formfactors for one- and two-particle transfer and their strength need to be modified with RIBs?, or (iii) can one observe the tetraneutron correlations in transfer reactions as a dynamical near-threshold effect?
There was a general agreement that this ECT* workshop should initiate more frequent meetings of these diverse communities to accelerate progress in extracting useful information from transfer and knockout reactions with RIBs. It was suggested that a new workshop should be proposed to ECT* in two years from now.
It is a pleasure for us to thank the ECT*, in particular Prof. Dr. Achim Richter and Prof. Dr. Wolfram Weise for their support and the hospitality. Also we are grateful to Ines Campo for the administrative support. It was a real joy for us to work with both of them.

3.3.22 NUCLEAR FUSION WITH POLARIZED NUCLEONS

DATE: November 14 - 15, 2013

ORGANIZERS:

R. Engels *(FZ Jülich, Germany)*
P. Lenisa *(Università di Ferrara and INFN, Italy)*
A. Vasiliev *(PNPI, Russia)*
R. Milner *(MIT, USA)*

NUMBER OF PARTICIPANTS: 13

MAIN TOPICS:

The workshop was dedicated to the advantages of polarized fuel in nuclear fusion technology. That the total cross sections of the main fusion reactions d(t,4He)n and d(3He,4He)p can be increased by 50 % with double-polarized projectiles is undisputed. Even the modifications of the differential cross sections and, therefore, the control of the ejectiles is understood. But before the polarization of the fuel can be used for energy production a long list of questions must be answered:

- The situation for the d(d,t)p and d(d,3He)n reactions is discussed by theorists since many years. A first double-polarized measurement to investigate the necessary spin-correlation coefficients at energies below 100 keV is ongoing at the PNPI in Gatchina, Russia.

- That the polarization is preserved in the plasma of the different reactor concepts, magnetic confinement or inertial fusion, is a solid theoretical prediction, but it was never shown experimentally. Several measurements, especially for laser induced fusion, are now underway.

- The energy gain of a fusion reactor does not depend linearly on the total cross section. Calculations for inertial fusion experiments were discussed and the idea of a first experiment in a tokomak was presented.

- Today, polarized 3He is commercially available and even the production of polarized tritium seems to be in range. How to produce and store enough polarized deuterium is an unsolved problem. First ideas to use solid polarized HD targets or to store polarized D2 molecules were discussed in details.

SPEAKERS:

H. Paetz gen. Schieck (Univ. of Cologne, Germany)

P. Kravtsov (PNPI, Russia)

A. Deltuva (Univ. Lisboa, Portugal)

P. Kravchenko (PNPI, Russia)

R. Engels (FZ Jülich, Germany)
J. Biel (FZ Jülich, Germany)
M. Temporal (ENS Paris, France)
J.P. Didelez (IPN Orsay, France)
A. Holler (FZ Jülich, Germany)
A. Sandorfi (JLAB, USA)

SCIENTIFIC REPORT:

It was the first meeting in this field since more than 30 years and most of the active groups were represented in Trento. In the past years, there was not much progress in the field except of a few measurements of the analysing power and the spin-transfer coefficients for the dd reactions at low energies. An overview on this activities was given at the beginning of the conference by Hans Paetz gen. Schieck (University of Cologne), who was co-author of the only existung double-polarized measurement for the d(3He,4He)p reaction in Basel 1971. Afterwards, Arnoldas Deltuva (University of Lisboa) presented his calculation due to Alt, Grassberger and Sandhas (AGS) equations in momentum space on the dd reactions. He showed, that a small suppression of the neutrons in the d(d,3He)n reaction might be possible in the low keV regime. Other predictions expect a strong suppression of this reaction or even an increase of 50% or a factor 2.5 for the d(d,t)p reaction. To solve this basic questions a double-polarized dd experiment is under construction by a collaboration of the University of Ferrara, Italy, the reasearch center Jülich, Germany, and the PNPI in Gatchina, Russia. Peter Kravtsov (PNPI) showed in his report the actual status and explained that the polarized atomic beam source from the University of Ferrara for the polarized jet target just arrived in Gatchina. The polarized ion source, previously installed at the KVI in Groningen, The Netherlands, will deliver a polarized deuteron beam at the beginning of next year. Polina Kravchenko (PNPI) presented the programming of an algorithm for a partial wave representation of the four-body reaction amplitudes. With the additional results of the measurements at PNPI it might be possible to extract the matrix elements of all transitions for the dd reactions in the future. At the end of the day Ralf Engels (FZ Jülich) explained in his talk how it is possible to produce nuclear polarized molecules by recombination of polarized atoms on a wall covered by FOMBLIN. By freezing out these molecules in a cold storage cell it might be possible to collect enough polarized deuterium to feed a tokomak reactor for a short time.
The second day started with a talk of Wolfgang Biel (FZ Jülich) presenting the actual status of the ITER project. He finished his talk with the remark that the use of fully polarized fuel wouls allow to reduce the size of ITER by 10-15 % for the same energy gain. This would reduce the costs for ITER by a huge amount. Mauro Temporal (ENS Paris) showed in his calculation for a laser induced fusion reactor like “Megajoule” that the energy gain will be increased linearly with polarized fuel and at the same time the laser power can be reduced by 25 % to simplify the ignition and to reduce the costs. Such a powerful laser was used at the University of Düsseldorf to produce a fast and intense beam of accelerated 4He2+ ions at energies in the MeV range from a gas-jet target. Astrid Holler (FZ Jülich) discussed the plans to use a gas jet made from polarized 3He atoms to produce a polarized beam of 3He2+ ions. If the polarization will survive in the acceleration process it should survive in the laser induced fusion too. In the last talk Andrew Sandorfi (JLab) explained the idea to feed the DIII-D Tokomak in San Diego with polarized HD ice and polarized 3He gas to observe the changes in energy production as a function of the polarization and its direction. Even the modifications of the ejectile trajectories will be observed in a magnetic confinement plasma for the first time.

Results and Highlights

Due to the improvements of polarized sources and targets in the last decades the double-polarized measurements of the d(d,t)p and d(d,3He)n reactions at the low cross sections below 100 keV are now possible. Therefore, the planned investigations at the PNPI can solve basic question on the spin dependence of the differential and total cross sections for these reactions by testing the different predictions on the market.

The first 'real' experiment at a tokomak reactor for the double-polarized d(3He,4He)p reaction will allow to measure the lifetime of the polarization in such a high temperature plasma under the working conditions. If this experiment will be successful the door to use the advantages of polarized fusion is widely open.

3.3.23 CRC 110 COLLABORATION MEETING ON STRANGENESS AND RELATED TOPICS

DATE: December 5-6, 2013

ORGANIZERS:

U. Meissner *(University of Bonn, Germany)*

This short collaboration meeting focused on topics such as hyperon-nucleon interactions, hypernuclear physics and kaon-nuclear systems under the aspects of low-energy QCD and chiral effective field theories. The meeting was organized and financially supported within the framework of the Collaborative Research Centre 110 “Symmetries and the Emergence of Structure in QCD” (Bonn-Munich-Beijing). Speakers were: Stefan Petschauer (TU Munich), Johann Haidenbauer (FZ Jülich), Wolfram Weise (ECT* and TU Munich), Maxim Mai (Univ. of Bonn), Evgeny Epelbaum (Univ. of Bochum), Corbinian Wellenhofer (TU Munich).

3.4 ECT* DOCTORAL TRAINING PROGRAM 2013

Neutron-rich matter: constraints from nuclear physics and astrophysics

(Report written by Georges Ripka)

The 2013 ECT* Doctoral Training Program on neutron-rich matter: constraints from nuclear physics and astrophysics lasted 6 weeks, from April 15 to May 24, 2013. It was organized by Achim Schwenk (TU Darmstadt) and Arturo Polls (University of Barcelona). The finance, lodging and other administrative tasks of both the students and the lecturers were taken care of by Serena degli Avancini. Georges Ripka (IPhT, Saclay and ECT*) attended as student coordinator and advisor. One of the organizers (Schwenk) spent one week at ECT while lecturing, the other (Polls) was absent during the whole program.

The Doctoral Training Program was attended by 16 full-time and 6 part-time students: 8 students were from Germany, 3 from Italy (all part-time), 2 from Spain, 2 from Japan, and 1 from Belgium, Croatia, France, Sweden, Switzerland, United Kingdom and USA each.

There were altogether 9 lecturers during the 6 week period of the program: three weeks with one lecturer and three weeks with two. Two one-hour lectures were delivered each morning from Monday to Friday. Student seminars were held on Tuesday and Thursday afternoons. The fact that the afternoons were otherwise free and that the lecturers were present at ECT* allowed the students to discuss with the lecturers and to continue working on their PhD projects.

This 2013 Doctoral Training Program was shorter (6 weeks instead of 10-12 weeks) than most of the previous ones. Furthermore, the study of neutron stars involves many fields of physics. Because of this, possibly too much material was covered by the lectures and the presentation of the theory was often compressed. For example, slides showing the mass-radius relation of neutron stars were projected on the screen by practically all the lecturers. Some lecturers did mention the various ingredients required to obtain it, but they lacked time to explain how it actually is calculated. Another example is the use of effective chiral field theory. Most of the lecturers displayed a slide showing the leading order , , , … diagrams and how they lead to 3- and 4-body forces but they never explained really how the diagrams were calculated nor how they were used, except perhaps Schwenk, who estimated the order of magnitude of one or two of these diagrams. The lecturers often repeated and showed similar slides because of a lack of coordination among them. They all left lecture notes (mostly slides) which the students could download from the ECT* wks server.

Schwenk explicitly asked the lecturers to use, as much as possible, the blackboard rather than PowerPoint presentations. Few lecturers (Schwenk, Litvinov, Philipsen and Weise) did that, but the others paid no head to this recommendation. One lecturer asked the students whether they preferred slides or the blackboard. Only one student said he preferred slides. Others explicitly stated that they learned more from blackboard presentations. This problem is recurrent in the Doctoral Training Programs.

The students were all asked to give a seminar on their current research (the list of student seminars is given below). The student seminars, as well as the lecture program of each week were announced on the ECT web page. In the future, the student coordinator (myself in this instance) should insist more that the student seminars should deal essentially with the specific research the students are pursuing, rather than spending too much time on introductions and generalities.

At the end of the program, the students were asked to write an informal and personal report about the program. The reports, which were not required to be signed, were handed to the ECT* Director. In these reports, they all say that they learned a lot from the lectures and that they appreciated very much the Doctoral Training Program. Among other things, they mentioned that:

- the student seminars gave them an opportunity to interact with each other;
- attending the full program could be a problem for last year PhD students;
- it was useful that the lecturer was available for discussions in the afternoons;
- it would be great to have all the lectures on the blackboard;
- the ECT computers do not have a lot of programs which are often used, such as Kate, Grace, Texmaker, DjVu-reader and Jaxodraw;
- the accommodation in Agritur Ponte Alto in Povo was very good, but that the lodging in the San Dona Guest House was not clean enough (equipment to clean was missing) and that the internet connection was insufficient there (a few extra gigabytes on the internet sticks would help).

3.4.1 The Lecture Programme

Achim Schwenk *(TU Darmstadt, Germany)*
Neutron-rich matter: constraints from nuclear physics and ultra-cold atoms (10 lectures)

Schwenk gave a large part of his lectures on the board as well as exercises which were corrected the next day.

The lectures covered a wide range of topics: effective chiral field theory, how it generates three body forces, their impact on nuclear and neutron matter, on shell closures and magic numbers, on oxygen isotopes, on light nuclei, on neutron rich calcium isotopes, ultracold boson and fermion systems, universal properties of low density systems with large scattering lengths, universal thermodynamics, vortex lines in superfluids.

Sanjay Reddy *(INT and University of Washington, USA)*
Physics of the neutron star crust (10 lectures)

The lectures of Sanjay Reddy were PowerPoint presentations, with only trivial things presented on the blackboard.

He described the liquid drop model of nuclei, the energy of N=Z and pure neutron matter, nuclei immersed in a dense electron gas, non-spherical nuclei and pasta, pressure, free energy, phase transitions and cross-overs, the energy cost of local neutrality, strange nuggets and strange neutron stars, microscopic models of the nuclear crust, mean field models, local density approximations, high density solid phase, lattice phonons, elementary solid state physics, basic definitions in thermodynamics, path integrals, BCS theory and the neutron gap, superfluid gaps in strong coupling, microscopic structure of the crust, low energy theory of phonons, low energy effective theory, heat capacity in crust models, dissipative processes, thermal conductivity, impurities at low temperature, phonon thermal conductivity and conduction, superfluid conduction, nuclear reactions in accreting neutron stars, neutrino cooling and emissivity, crust thickness, outer crust equation of state, crustal heating, thermal relaxation, magnetar outbursts, shear oscillations of the crust, vortex model of glitches.

Yuri Litvinov *(GSI, Germany)*
Experimental constraints on neutron rich systems (5 lectures)

In spite of describing experiments, Litvinov took the trouble to explain most things on the board. He left hand-written notes for the students in addition to slides which he provided a few days later.

He described proton and heavy ion induced nuclear reactions, the ISOLDE facility in CERN, the secondary beam facility at GSI, the in-flight production and separation of exotic nuclei, electron beam ion traps, Penning and Paul traps, storage rings, the cooling of particles in ion traps, the storage ring ESR at GSI, electron and stochastic + electron cooling, R and S processes, rapid rotation capture, explosive H-burning, predictive power of mass calculations, the heavy ion research facility in Lanzhou, isochronous mass spectroscopy, radioactive decays of highly charged ions, the FAIR facility for antiproton and ion research, and more.

Robert Rutledge *(McGill University, Canada)*
Observations of neutron stars and outbursts (5 lectures)

The lectures of Rutledge were instructive, but purely descriptive. They consisted of a 159 page PowerPoint presentation of the properties and observations of neutron star systems, except for one lecture which concerned his work and which he partly described on the board. He explained that the goal of the lectures were to teach nuclear physicists how to speak to astronomers and to know what they are talking about when they respond to them.

His lectures consisted of a general introduction, the observational classes of neutron stars, the observational classes of neutron stars/radio pulsars, the observation of X-ray bursts, and the neutron star radius from QLMXBS.

Owe Philipsen *(Universität Frankfurt, Germany)*
Constraints on the phase diagram of quantum chromodynamics (10 lectures)

The lectures were presented on the blackboard and some, mostly the last ones, projected on the screen. The theory was sketched and described more than derived. He showed 10-15 slides per lecture, except the last lecture which had 41 slides.

His lectures concentrated on lattice QCD calculations: QCD at finite temperature and density, asymptotic freedom, Cooper pairing of fermions, composition of compact stars, a reminder of statistical mechanics (free energy, pressure, entropy, energy,…), Matsubara frequencies, ideal gases from the Gaussian path integral, ideal gases in QCD, infrared divergence of the Matsubara n=0 mode, Debye and magnetic screening, the Wilson Yang-Mills action, addition of fermions, chiral transitions, Goldstone bosons, phase transitions with water as an example followed by QCD, fluctuations of order parameters, critical temperature, a description of Monte Carlo 'history', first order as opposed to crossover transitions, the sign problem at finite baryon density and approximate methods to evade it.

Andreas Bauswein *(Max Planck Institute for Astrophysics, Germany)*
Neutron stars in astrophysical simulations (4 lectures)

Most of the lectures were carefully delivered on the board, with slides for some illustrations. He should have been among the first lecturers, together with Lattimer, who was unable to lecture at the beginning of the program.

His lectures covered the effects of gravitation and general relativity, examples of metric tensors, the determination of the metric using the Einstein field equations, a list of astrophysical scenarios, and a list of challenges facing astrophysicists. He also discussed gravitational waves and their observation, laser interferometers, neutron star mergers, how the processes and observations depend on the equation of state (pressure against density), comparison of many (47) microphysical equations of state, star mass vs. radius plots, 3D relativistic smooth particle hydrodynamics, gravitational waves and the equation of state, gravitational wave spectra, mass ejection of neutron star mergers, nucleosynthesis by the R-process, existing codes, optical transients.

Peter Braun-Munzinger *(GSI, Germany)*
Experimental constraints on hot and dense matter (5 lectures)

The lectures, all on slides, were difficult to follow, about 35 slides in each lecture, often with several plots on each one and, more often than not, data shown with little or no time to define what was plotted against what.

The lectures covered far too much material, namely: the QCD phase diagram, phase transitions observed in lattice calculations, description of the LHC, detailed description of Alice, the time evolution of a collision, the formation of a quark gluon plasma and hadronization, angular distributions and particle multiplicities, thermal models of hadron yields, chemical freeze-out curves, a temperature now estimated close to 150 MeV for the freeze-out, universality of viscosity/entropy density ratio, viscosity and QCD, the quark gluon plasma as a nearly perfect fluid, elliptic flow, quantum fluctuations, measurement of the fireball temperature, the equation of state and thermodynamics in heavy ion collisions, charmonium as a probe, J/ψ identification in pp collisions with Alice, and more.

Jim Lattimer *(Stony Brook University, USA)*
Physics of neutron stars (5 lectures)

In spite of being entirely on slides, the students were lucky to have these lectures, which were extremely instructive, concerning up to date observations of neutron stars and simple models to estimate their motion and composition.

The lectures included a brief history of neutron star theory and observations, a flash of spherically symmetric general relativity, neutron star structure, what influences the shape of the mass-radius relation, the maximum energy density and causality, the mass-radius diagram and theoretical constraints, the equation of state of an ideal fermion gas, thermodynamics, relativistic gas with pairs, interacting Fermi gases, energy and pressure of bulk matter, free energy density, phase coexistence, nuclear symmetry energy and surface symmetry energy, nuclear mass formulae and droplet models, neutron skin thickness, inclusion of pasta phases, supernova matter, nuclei in dense matter, dipole polarizability, theoretical neutron Katter calculations, pulsars, pulsar flavors, magnetars, binary mass measurements, pulsar mass measurements, stellar triple systems, quiescent sources in globulars, consistency with neutron matter and heavy ion collisions, stellar moments of inertia, the location of the core-crust boundary, pulsar glitches.

Wolfram Weise *(ECT* Italy & TU Munich, Germany)*
Effective theories of quantum chromodynamics (5 lectures)

The lectures were for the most part delivered on the board. They consisted of a review of QCD, local gauge invariance, the running coupling constant, the hierarchy of quark masses, spontaneously broken chiral symmetry and the Goldstone theorem, the chiral quark condensate and its variation with temperature, the Gell-Mann,Oakes,Renner relation, lattice calculations of the chiral condensate as a function of temperature, chiral effective field theory, the non-linear sigma model and symmetry breaking mass terms, lattice calculations of chiral symmetry breaking, pion-pion scattering in chiral perturbation theory, chiral effective theory including nucleons, nuclear interactions from chiral effective field theory, inclusion of the Δ (1230 MeV), chiral dynamics in the nuclear many-body problem, in-medium chiral perturbation theory, nuclear thermodynamics, the phase diagram of nuclear and neutron matter, the equation of state and the mass-radius relation of neutron stars.

3.4.2 List of the Participants

Full time students:

Sanjin Benic	Zagreb University, Croatia
Wei-Chia Chen	Florida State University, USA
Giuseppe Colucci	Goethe Universität Frankfurt, Germany
Madhumita Dhar	Universität Giessen, Germany
Matthias Drews	TU München, Germany
Kevin Ebinger	University of Basel, Switzerland
Maria Isabel Ferretti	Johannes Gutenberg Universität Mainz, Germany
Thomas Krueger	TU Darmstadt, Germany
Jiajie Li	Institut de Physique Nucléaire d'Orsay, France
Kota Masuda	RIKEN, University of Tokyo, Japan
Heiko Moeller	TU Darmstadt, Germany
Shota Ohnishi	Tokyo Institute of Technology & RIKEN, Japan
Roshan Sellahewa	University of Surrey, UK
Ingo Tews	TU Darmstadt, Germany
Anthony Van Eysden	NORDITA, Sweden
Corbinian Wellenhofer	TU München, Germany

Part time students:

Paolo Giuseppe Alba	Università degli Studi di Torino, Italy
Marco Brenna	Università degli Studi di Milano, Italy
Miguel Gullon	Universidad de Alicante, Spain
Gwendolyn Lacroix	University of Mons, Belgium
Diego Lonardoni	Università degli Studi di Trento, Italy
Daniele Viganò	Universidad de Alicante, Spain

3.4.3 Seminars delivered by the students

Daniele Viganò (Universidad de Alicante, Spain): *Magneto-thermal evolution of neutron stars*.

Antony van Eysden (NORDITA, Sweden): *Pulsar glitch recovery and properties of bulk nuclear matter*.

Sanjin Benic (Zagreb University, Croatia): *Hybrid stars in the non-local PNJL model*.

Giuseppe Colucci (Goethe Universität Frankfurt, Germany): *Rescuing Hyperons in neutron stars*.

Ingo Tews (TU Darmstadt, Germany): *A local chiral EFT potential for Quantum Monte Carlo calculations*.

Thomas Krüger (TU Darmstadt, Germany): *Neutron matter from chiral EFT and applications for astrophysics*.

Heiko Moeller (TU Darmstadt, Germany): *Electron capture supernovae*.

Corbinian Wellenhofer (TU München, Germany): *Nuclear equation of state at finite temperatures.*

Wei-Chia Chen (Florida State University, USA) *Relativistic mean field theory – from finite nuclei to neutron stars*.

Madhumita Dhar (Universität Giessen, Germany): *Large-scale shell model calculations for the 100-132 mass region*.

Jiajie Li (Institut de Physique Nucléaire d'Orsay, France): *Self-consistent descriptions of the magic structures of superheavy nuclei*.

Maria Isabel Ferretti (Johannes Gutenberg Universität Mainz, Germany) *Experimental studies of neutron skin thickness of nuclei with coherent π_0 photoproduction.*

Miguel Gullon (Universidad de Alicante, Spain): *Population synthesis studies on isolated neutron stars*.

Gwendolyn Lacroix (University of Mons, Belgium): *Glueballs and the Yang-Mills plasma within quasiparticle approaches*.

Matthias Drews (TU München, Germany): *Dense matter and functional renormalization group*.

Shota Ohnishi (Tokyo Institute of Technology and RIKEN, Japan): *Production reaction of $\overline{K}$ NN-π YN and $\overline{K}$ N interaction*.

Kevin Ebinger (University of Basel, Switzerland): *Parameterized one-dimensional core-collapse supernova simulation*.

Kota Masuda (RIKEN, University of Tokyo, Japan): *Hadron-quark crossover and massive neutron stars with strangeness*.

Marco Brenna (Università degli Studi di Milano, Italy): *The symmetry energy and isovector giant resonances.*

4 Research at ECT*

In this chapter the activities of the scientific researchers at ECT* in 2013, i.e. of the Postdoctoral Fellows, the Director, the long-term Visitors and their collaborators are briefly summarized. The contributions are listed in alphabetical order of the researchers. Cooperations of the researchers within the Centre are as prominently visible as joint projects with colleagues at institutions elsewhere. Pursuing such collaborations, with ECT* as a “brain-storming” focal point, is an essential element of the scientific life at the Centre and of the activities conducted by the in-house research group. Among the ECT* Senior Scientists, Daniele Binosi continued his efforts in coordinating European projects in the field of quantum information parallel to his research in QCD. Alexis Diaz-Torres works on low-energy nuclear reaction dynamics relevant to astrophysical processes and acts at the same time as advisor of a PhD student at the University of Trento holding an ECT* fellowship. Dionysis Triantafyllopoulos directs his research primarily towards QCD at the highest energy densities and represents at the same time ECT* in the PhD Committee of the University.

4.1 Projects of ECT* Researchers

Daniele Binosi

Scalar resonances in the non-linearly realized electroweak theory

In collaboration with A. Quadri (INFN, Milan, Italy)

In [1] we introduced a physical scalar sector in a SU(2)xU(1) electroweak theory in which the gauge group has been realized non linearly (contrary to the standard Higgs mechanism). Then, by invoking theoretical as well as experimental constraints, we have built a phenomenologically viable model in which a minimum of four scalar resonances appear, and the mass of the CP even scalar is controlled by a vacuum expectation value; however, the masses of all other particles (both matter as well as vector boson fields) are unrelated to spontaneous symmetry breaking and generated by the Stueckelberg mechanism. We evaluated in this model the CP-even scalar decay rate to two photons and use this amplitude to perform a preliminary comparison with the recent LHC measurements. As a result, we find that the model exhibits a preference for a negative Yukawa coupling between the top quark and the CP-even resonance. This model turns out to have a very rich structure that is currently under active investigation.

QCD effective charge from the three-gluon vertex of the background-field method

In collaboration with D. Ibanez and J. Papavassiliou (University of Valencia, Spain)

In [2] we studied in detail the prospects of determining the infrared finite QCD effective charge from a special kinematic limit of the vertex function corresponding to three background gluons. This particular Green's function satisfies a QED-like Ward identity, relating it to the gluon propagator, with no reference to the ghost sector; consequently, its longitudinal form factors may be expressed entirely in terms of the corresponding gluon wave function, whose inverse is proportional to the effective charge. We considered a typical lattice quantity involving this vertex, and derive its exact dependence on the various form factors, for arbitrary momenta. Then, we focussed on the particular momentum configuration that eliminates any dependence on the (unknown) transverse form factors, projecting out only the desired quantity. A preliminary numerical analysis indicates that the effective charge is relatively insensitive to the numerical uncertainties that may afflict future simulations of the aforementioned lattice quantity. The numerical difficulties associated with a parallel determination of the dynamical gluon mass were finally briefly discussed.

Gluon mass generation in the presence of dynamical quarks

In collaboration with A. C. Aguilar (University of Campinas, Brazil)
and J. Papavassiliou (University of Valencia, Spain)

In [3] we studied in detail the impact of dynamical quarks on the gluon mass generation mechanism, in the Landau gauge, for the case of a small number of quark families. As in earlier considerations, we assumed that the main bulk of the unquenching corrections to the gluon propagator originates from the fully dressed quark-loop diagram; the nonperturbative evaluation of this diagram provided then the key relation for expressing the unquenched gluon propagator as a deviation from its quenched counterpart. This relation was subsequently coupled to the integral equation that controls the momentum evolution of the effective gluon mass, which contains a single adjustable parameter; this constitutes a major improvement compared to the analysis presented in the last year report [Phys. Rev. D86 (2012) 014032], where the behaviour of the gluon propagator in the deep infrared was estimated through numerical extrapolation. The resulting nonlinear system has been then treated numerically, yielding unique solutions for the modified gluon mass and the quenched gluon propagator, which fully confirmed the picture put forth recently in several continuum and lattice studies. In particular, an infrared finite gluon propagator emerged, whose saturation point was considerably suppressed, due to a corresponding increase in the value of the gluon mass. This characteristic feature becomes more pronounced as the number of active quark families increases, and can be deduced from the infrared structure of the kernel entering in the gluon mass equation.

AntiBRST symmetry and background field method

In collaboration with A. Quadri (INFN, Milan, Italy)

In [4] we have shown that the requirement that a SU(N) Yang-Mills action (gauge fixed in a linear covariant gauge) is invariant under both the Becchi-Rouet-Stora-Tyutin (BRST) symmetry as well as the corresponding antiBRST symmetry, automatically implies that the theory is quantized in the (linear covariant) background field method (BFM) gauge. Thus, the BFM and its associated background Ward identity naturally emerge from antiBRST invariance of the theory and need not be introduced as an ad hoc gauge fixing procedure. We also prove that treating ghosts and antighosts on an equal footing, as required by a BRST-antiBRST invariant formulation of the theory, gives also rise to a local antighost equation that together with the local ghost equation completely resolve the algebraic structure of the ghost sector for any value of the gauge fixing parameter. We have finally proved that the background fields are stationary points of the background effective action obtained when the quantum fields are integrated out.

Effects of divergent ghost loops on the Green's functions of QCD

In collaboration with A. C. Aguilar (University of Campinas, Brazil), D. Ibanez (ECT, Trento)*
and J. Papavassiliou (University of Valencia, Spain)

In [5] we discuss certain characteristic features encoded in some of the fundamental QCD Green's functions, whose origin can be traced back to the nonperturbative masslessness of the ghost field, in the Landau gauge. Specifically, the ghost loops that contribute to these Green's functions display infrared divergences, akin to those encountered in the perturbative treatment, in contradistinction to the gluonic loops, whose perturbative divergences are tamed by the dynamical generation of an effective gluon mass. In d=4, the aforementioned divergences are logarithmic, thus causing a relatively mild impact, whereas in d=3 they are linear, giving rise to enhanced effects. In the case of the gluon propagator, these effects do not interfere with its finiteness, but make its first derivative diverge at the origin, and introduce a maximum in the region of infrared momenta. The three-gluon vertex is also affected, and the induced divergent behavior is clearly exposed in certain special kinematic configurations, usually considered in lattice simulations; the sign of the corresponding divergence is unambiguously determined. The main underlying concepts are developed in the context of a simple toy model, which demonstrates clearly the interconnected nature of the various effects. The picture that emerges is subsequently corroborated by a detailed nonperturbative analysis, combining lattice results with the dynamical integral equations governing the relevant ingredients, such as the nonperturbative ghost loop and the momentum-dependent gluon mass.

High energy QCD evolution from Slavnov-Taylor identities

In collaboration with A. Quadri (INFN, Milan, Italy) and D. Triantafyllopoulos

The derivation of the JIMWLK equation which gives the evolution of the CGC is based on a separation of scales in the longitudinal momenta of the gluonic modes of a generic hadron. When integrating the harder modes to construct the Effective Field Theory (EFT) for the softer ones, a special choice of gauges is made; the background field is kept in the Coulomb gauge while the integrated modes are in the light-cone gauge. In [5], studying the BRST symmetry of the QCD action in the presence of a static source based on techniques developed by the authors, we show that there is a Slavnov-Taylor identity which indeed implies the existence of such an EFT (perhaps even beyond leading logarithmic accuracy) and explains why the aforementioned choice of gauges leads to certain simplifications.

Unquenching the infrared sector of QCD

In this first contribution to the Proceedings of the Xth Quark Confinement and the Hadron Spectrum, October 8-12 (2012), Munich (Germany) [7], I discuss the recent progress made in understanding how some fundamental results valid in the quenched infrared sector of non-Abelian Yang-Mills theories generalize to the unquenched case. In particular, we derive in the continuum an equation that allows to predict how the momentum dependence of the quenched gluon propagator is affected by the presence of a small number of dynamical quarks. In addition, I present the most recent lattice simulations of the (Landau gauge) gluon and ghost two-point sector obtained using gauge field configurations with two light and two light plus two heavy twisted-mass quark flavors. A comparison between the results obtained by these two complementary methods is then carried out.

Nonperturbative results on the quark-gluon vertex

In collaboration with A. C. Aguilar and J. C. Cardona (University of Campinas, Brazil) and J. Papavassiliou (University of Valencia, Spain)

In this second contribution to the Proceedings of the Xth Quark Confinement and the Hadron Spectrum, October 8-12 (2012), Munich (Germany) [8], We present analytical and numerical results for the Dirac form factor of the quark-gluon vertex in the quark symmetric limit, where the incoming and outgoing quark momenta have the same magnitude but opposite sign. To accomplish this, we compute the relevant components of the quark-ghost scattering kernel at the one-loop dressed approximation, using as basic ingredients the full quark propagator, obtained as a solution of the quark gap equation, and the gluon propagator and ghost dressing function, obtained from large-volume lattice simulations.

Nonlinearly realized gauge theories for LHC physics

In collaboration with D. Bettinelli (University of Milan, Italy) and A. Quadri (INFN, Milan, Italy)

In this contribution prepared for EPSHEP 2013 Stockholm, Sweden, 18-24 July, 2013 [9], we consider a minimal nonlinearly realized electroweak theory where mass generation happens a la Stueckelberg. Deformation of the nonlinearly realized gauge symmetry is controlled by functional methods. The Weak Power Counting allows to select uniquely the Hopf algebra of the theory and gives definite predictions on the Beyond-the-Standard Model (BSM) sector of the theory: the latter includes one CP-odd and two charged physical scalars (in addition to the Higgs-like CP-even resonance). The model interpolates between a purely Stueckelberg and a Higgs scenario. It can be used in order to check whether the presence of a Stueckelberg mass component can already be excluded on the basis of the existing LHC7-8 data.

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Maddalena Boselli

Reaction dynamics of weakly bound nuclei at near barrier energies: development of a quantum mechanical toy model

My PhD project consists in developing a quantum mechanical model to describe reaction dynamics of weakly bound nuclei at low energies and in implementing it. Due to breakup, at a given energy, various different processes can occur: no capture breakup, complete fusion and incomplete fusion. The first refers to the case when the projectile breaks but none of the fragment is captured by the target, the second refers to the opposite situation when all the fragments are captured and the latter to the case when only part of the fragments are fused with the target. A first aim is that to obtain cross sections as function of incident energy for all these processes individually.

A good understanding of the breakup role on the scattering of a weakly bound nucleus off a target is important because would allow theorist to calculate astrophysical reaction rates and experimentalists to plan and interpret measurements in radioactive ion beam facilities.
The key idea is to start dealing with a simplified problem building thus a toy model which allows to test the theoretical concepts as well as numerical methods used. Once every aspect of this toy model would be well understood, one will be able to move on towards a more realistic situation.
Up to now, a good part of the model has been implemented in a code and many theoretical concepts could have been tested. Still there are few aspects that need to be further investigated, as well as the structure of the code which needs to be improved in order to decrease the computing time. I am working on this and soon I think it could be the moment to increase the degree of complexity starting to use a more realistic Hamiltonian.

Marco Cristoforetti

Quantum field theories on the Lefschetz thimble.

M. Cristoforetti (ECT), A. Mukherjee (ECT*), F. Di Renzo (Parma U. & INFN, Parma), L. Scorzato (INFN)*

Many important physical systems are characterized by complex actions, when formulated in terms of a path integral. But, if the action S is not real, then the partition function is not positive semi-definite and it cannot be interpreted as a probability distribution. In these cases, Monte Carlo calculations are not applicable directly. This is the so called sign problem. Many techniques have been proposed to overcome this problem, with important partial successes, but the sign problem is still unsolved for a variety of important physical systems and parameter values.
In this context, any new idea that could improve our chances to simulate any of these models on larger lattices than are feasible today would be extremely valuable.

Recently, we proposed a new approach to control the sign problem in [1] and further developed in [2,3,4]. The approach consists in reformulating the quantum field theory (QFT) on a Lefschetz thimble [5,1]. The Lefschetz thimble, associated with a saddle point, is defined as the hypersurface formed by the union of all paths of steepest descent (SD) of the complex action ending in that saddle point at infinity. Both the Lefschetz thimble and the saddle point are constructed in an enlarged space obtained by complexifying each field component.

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Alexis Diaz-Torres

Low-energy reaction dynamics of weakly-bound nuclei

In collaboration with experimenters in Italy (INFN Legnaro and INFN Catania), France (GANIL & IPHC-Strasbourg), India (BARC), Mexico (ININ), Brazil (USP) and Australia (ANU)

In Refs. [1,2] a classical-trajectory Monte-Carlo model for treating low-energy reaction dynamics of weakly-bound nuclei was developed, which is implemented in an user-friendly code [3]. This is being exploited for planning, guiding and interpreting particle-gamma coincidence measurements, fusion measurements as well as breakup measurements in reactions induced by weakly-bound nuclei at energies near the Coulomb barrier [4,5]. The model has been developed further, which can now deal with both normal and inverse kinematics. A unified quantum description of relevant reaction processes of weakly-bound nuclei (breakup, transfer, complete and incomplete fusion) is being pursued, which is the central aspect of the work carried out by a PhD-student (Maddalena Boselli) at the ECT*. This PhD project is based on solving the time-dependent Schroedinger equation of a three-body scattering problem, and the first results obtained within a toy-model will be published in 2014 in a special issue of Journal of Physics G focused on open problems in nuclear reaction theory.

Quantum decoherence in low-energy nuclear collision dynamics

In collaboration with M. Dasgupta and D.J. Hinde (ANU, Canberra, Australia), E. Piasecki and A. Trzcinska (Warsaw University, Poland), M. Wiescher (JINA and Notre Dame, USA), A. Moro (Sevilla University, Spain) and J. Tostevin (Surrey, UK)

An investigation of quantum decoherence effects on low-energy heavy-ion fusion cross sections was initiated in Ref. [6]. It has been motivated by systematic disagreements between high-precision measurements of sub-Coulomb fusion cross sections and calculations based on the standard coupled-channel model [7]. An innovative approach [8] that is based on the time propagation of a coupled-channel density matrix (CCDM) is being developed, which includes decoherence and dissipation. These are caused by a high-density of single-particle states that affect the dynamics of low-lying collective states of the colliding nuclei. Decoherence is not included in the widely used optical potential model [9]. The developments allow one to quantify decoherence effects on both fusion and scattering [8]. Extensive CCDM calculations are planned for explaining very recent, precision measurements of fusion and quasi-elastic barrier distributions [10]. The microscopic foundation of the employed (phenomenological) Lindblad operators will be investigated. The model will also be developed for treating reaction dynamics of both weakly-bound rare-isotopes and heavy-ions in hot dense plasma environments. An analysis of very recent elastic scattering of $^{11}Be + ^{64}Zn$ at near-barrier energies [11] is being pursued from an open-quantum-system perspective.

Quantifying low-energy heavy-ion fusion with the time-dependent wave-packet method

In collaboration with M. Wiescher (JINA and Notre Dame, USA)

A number of critical heavy-ion reactions for stellar burning will be investigated within the time-dependent wave-packet method [12]. This method might be a more suitable tool for expanding the cross-section predictions towards lower energies than the commonly used potential-model approximation, as preliminary results for $^{12}C + {}^{12}C$ indicate [12]. The origin of resonance structures in the low-energy fusion excitation curve will be addressed. Calculations for the $^{12}C + {}^{16}O$ and $^{16}O + {}^{16}O$ heavy-ion fusion reactions at sub-Coulomb energies will be carried out as well.

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Matthias Drews

Study of nuclear matter with the functional renormalization group

The chiral nucleon-meson model as developed in Refs. [1,2] is designed to study the thermodynamics of nuclear matter and in conjunction with spontaneously broken chiral symmetry. In Refs. [3,4] we have extended the model beyond the mean field approximation using the functional renormalization group. In this way, mesonic and nucleonic fluctuations are treated in a self-consistent way. The thermodynamic properties are calculated and compared with results from chiral effective field theory [5,6]. Good agreement between these two approaches was found. Moreover, within the range of applicability of our model, no sign of chiral symmetry restoration is seen for temperatures below 100 MeV and densities below twice the nuclear saturation density. Susceptibilities around the critical endpoint of the liquid-gas phase transition are studied. Currently, the model is extended to asymmetric nuclear matter. Of particular interest is the equation of state of neutron star matter, as it must fulfill constraints from recent mass measurements of neutron stars [7,8].

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Daniel Gazda

No-core shell model for nuclear systems with strangeness

In collaboration with P. Navrátil (TRIUMF, Canada), J. Mareš (Nuclear Physics Institute, Czech Republic), R. Roth, and R. Wirth (TU Darmstadt, Germany)

Recently, we developed a novel *ab initio* approach for nuclear few- and many-body systems with strangeness. We formulated a no-core shell model technique [1] for nuclear systems with nonzero strangeness and successfully performed first calculations of the lightest Λ hypernuclei [2]. The use of a translationally invariant Jacobi-coordinate harmonic oscillator basis allows us to employ large model spaces, compared to traditional shell model calculations, and use realistic nucleon-nucleon and nucleon-hyperon forces, such as those derived from chiral effective field theory [3, 4]. Our first results for ${}_{\Lambda}^{3}H$, ${}_{\Lambda}^{4}H$ and ${}_{\Lambda}^{4}He$ look promising and give a reasonable description of experimental data. It is straightforward, and currently under development, to extend the no-core shell model methodology to heavier hypernuclei.

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Thomas Hell

Neutron-star constraints on the nuclear equation of state

In collaboration with N. Kaiser (TU München) and W. Weise (ECT)*

Reference [1] summarizes the results of our ongoing long-term project about the equations of state for nuclear matter, derived within several frameworks: from a chiral effective-field-theoretical approach [2] we obtain the energy per particle as a function of nuclear density for both symmetric nuclear matter and pure neutron matter; then we use the Polyakov-loop-extended Nambu and Jona-Lasinio model with three active quark flavors [3,4] to determine the equation of state of quark matter at high temperatures and baryon densities. We primarily use these two equations of state to compare the resulting mass-radius relations for neutron stars (calculated by solving the Tolman-Oppenheimer-Volkoff equations) with observations from astrophysics. Recently, the masses of the pulsars PSR J1614-2230 and J0348+0432 [5] have been measured with a one-percent accuracy to be about two solar masses. This, in addition to statistical analyses of neutron-star radii [6,7], allows us to impose tight constraints on the equations of state of dense baryonic matter inside neutron stars [1,8]. Combining a realistic phenomenological equation of state at low densities with the equations of state mentioned above we find from our analyses that a stiff equation of state of ordinary nucleonic matter, without the need of substantial exotic-matter admixtures, is able to reproduce the empirical observations for neutron stars.

Role of vector currents in a nonlocal Polyakov-loop-extended Nambu–Jona-Lasinio model

In collaboration with K. Kashiwa (RIKEN-BNL Research Center) and W. Weise (ECT)*

In Ref. [9] we investigate the effects of the nonderivative vector-type interaction which relates to the quark number density, using the nonlocal version of the Polyakov-loop-extended Nambu–Jona-Lasinio (PNJL) model at both real and imaginary chemical potentials. This model has been developed and extended in Refs. [4,10–12]. In particular, we discuss the extension of the approach to imaginary chemical potentials in Refs. [13,14]. The given model is useful for an investigation of the thermal properties of strongly interacting matter, and the phase diagram of quantum chromodynamics. Concerning the repulsive vector interaction between quarks, we observe the following impact on the chiral first-order phase transition: at imaginary chemical potentials it sharpens the transition at the so-called Roberge-Weiss (RW) end point [15] and moves the RW end point toward lower temperatures, in accordance with lattice simulations; at real chemical potentials, the critical end point moves on a trajectory towards larger chemical potentials and lower temperatures with increasing vector coupling strength. We also discuss the conditions at which the first-order chiral phase transition disappears and turns into a smooth crossover.

Thermodynamic phases and mesonic fluctuations in a chiral nucleon-meson model

In collaboration with M. Drews (TU München), B. Klein (TU München), W. Weise (ECT)*

In [16] we study the QCD phase diagram including nucleonic degrees of freedom and their thermodynamics in the range of baryon chemical potentials characteristic of nuclear matter. Relevant nuclear physics constraints are implemented by using a chiral nucleon-meson effective Lagrangian with inclusion of mesonic fluctuations using the functional renormalization group approach. The resulting description of the nuclear liquid-gas phase transition shows a remarkable agreement with three-loop calculations based on in-medium chiral effective field theory. No signs of a chiral first-order phase transition and its critical endpoint are found. Fluctuations close to the critical point of the first-order liquid-gas transition are also examined with a detailed study of the chiral susceptibility.

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David Ibáñez Gil de Ramales

Effects of divergent ghost loops on the Green's functions of QCD

In collaboration with A. C. Aguilar (Campinas State University, Brazil), D. Binosi (ECT, Trento) and J. Papavassiliou (Valencia University and IFIC, Spain)*

In this work [1] we discuss certain characteristic features encoded in some of the fundamental QCD Green's functions, whose origin can be traced back to the nonperturbative masslessness of the ghost field, in the Landau gauge. Specifically, the ghost loops that contribute to these Green's functions display infrared divergences, akin to those encountered in the perturbative treatment, in contradistinction to the gluonic loops, whose perturbative divergences are tamed by the dynamical generation of an effective gluon mass. In d = 4 dimensions, the aforementioned divergences are logarithmic, thus causing a relatively mild impact, whereas in d = 3 they are linear, giving rise to enhanced effects. In the case of the gluon propagator, these effects do not interfere with its finiteness, but make its first derivative diverge at the origin, and introduce a maximum in the region of infrared momenta. The three-gluon vertex is also affected, and the induced divergent behavior is clearly exposed in certain special kinematic configurations, usually considered in lattice simulations; the sign of the corresponding divergence is unambiguously determined. The main underlying concepts are developed in the context of a simple toy model, which demonstrates clearly the interconnected nature of the various effects. The picture that emerges is subsequently corroborated by a detailed nonperturbative analysis, combining lattice results with the dynamical integral equations governing the relevant ingredients, such as the nonperturbative ghost loop and the momentum-dependent gluon mass.

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Ahmad Idilbi

Transverse momentum dependence in polarized and un-polarized high-energy reactions

In collaboration with M. G. Echevarria (Nikhef) and Ignazio Scimemi (Univ. of Madrid)

Quantum Chromodynamics (QCD), the theory of the strongly interacting sector of the Standard Model (SM), is the most non-trivial and the most challenging of all other theories (or sectors) of the SM. Much of effort has been put in the last four decades in trying to understand the dynamics of QCD and many theoretical frameworks were developed to achieve that goal. Among others, perturbative QCD, Lattice QCD, Large N_c limit, effective field theories (chiral perturbation theory, heavy-quark effective theory, soft-collinear effective theory), small-x and large-x QCD, quark-hadron duality and ADS/CFT correspondence, have generated an impressive accomplishments in that regard. However, the basic question of how the observed properties of the hadronic spectrum (protons, neutrons, etc.) are generated by the dynamics of the basic constituents (or degrees of freedom) of QCD, namely, quarks and gluons, has so far been elusive and it is yet to be resolved.

A research venue that would be of much help to address that issue, as has been realized in the last two decades, is to try to explore the three-dimensional structure of the nucleon, both in momentum and in configuration space, and its momentum and spin distributions among quarks and gluons. This field of research is being actively pursued both theoretically and experimentally. The role of quarks and gluons in generating the nucleon's spin or the partonic angular momentum is being investigated at experimental facilities such as JLab and DESY and by HERMES and COMPASS collaborations, among others. As mentioned before, the ultimate goal of such endeavors is to try to understand how the dynamics of QCD generate the observed features of hadrons in general and of nucleons in particular.

To that end, it has been verified that one needs to identify an “irreducible” number of functions (or hadronic matrix elements) to study the spin and momentum distributions of a nucleon. In the collinear limit there are three parton distribution functions (PDFs): the momentum distribution, the helicity distribution and the transversity distribution. When the intrinsic partons' transverse momentum is also taken into account then one obtains, at leading twist, eight transverse momentum dependent PDFs (TMDPDFs) that characterize the nucleon's internal structure [1,2]. To be of any use, those matrix elements have to be properly defined at the operator level (in terms of QCD degrees of freedom) and then their properties (such as evolution or universality) should be carefully examined. Among that group of functions, the un-polarized TMDPDF has a special role. This function has no spin dependence, and thus it is considered as a ``simple'' generalization of the standard (integrated) Feynman PDF. However since the introduction of this quantity by Collins and Soper thirty years ago and despite many efforts (see [1-5]) there has not been so far any agreed-upon definition of it. This fact clearly has its bearings over the other, and more complicated, hadronic matrix elements as well, and over the whole field of spin physics.
My collaborators and myself have derived a factorization theorem for the q_T-dependent spectrum of the Drell-Yan lepton pair production and gave a new definition of quark-TMDPDF with all the features that one expects to have in such a quantity. These works open the door for a reanalysis of all processes where the "old" TMD-factorization theorems have been used so far. As a first step one needs to extend the given definition of quark-TMDPDF to gluon-TMDPDFs and to quark/gluon-TMD fragmentation functions (TMDFFs).This can only be achieved after a proper factorization theorems for the physical processes, where these quantities appear (such as semi-inclusive DIS, Higgs boson production or e+e-- annihilation), are obtained.

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Vincent Mathieu

Regge phenomenology for hadron spectroscopy experiments

In collaboration with A. Szczepaniak (Indiana University, USA)

A quantitative description of the hadron spectrum is essential for a complete understanding of Quantum Chromodynamics (QCD), the theory of the strong interactions. Numerous experiments devoted to hadron spectroscopy are currently underway e.g. COMPASS and BESIII, or are planned for the near future e.g. GlueX and CLAS12 at Jefferson Lab, and PANDA at GSI. Those new generations of high statistics and precision experiments demand a level of detailed partial wave decomposition and amplitude analysis never achieved before. Thus theoretical underpinning of data analysis and resonance parameter extraction is urgently needed.

According to the S-Matrix principles the analysis should follow a three-steps procedure: i) Theoretical amplitudes are proposed and constrained by fitting the experimental data. ii) These amplitudes are tested against various constraints that are used to minimize unresolved ambiguities in amplitude determination. iii) The amplitudes are extrapolated (analytically continued) to the unphysical kinematical region of energy and angular momentum to determine properties of resonances.

The theory of complex angular momenta, Regge theory, provides a model independent way of parameterizing amplitudes in the high mass region. Analyticity, via the finite energy sum rules, connects the high mass region to the low mass region. Hence the Regge parametrization constraints the resonance region one is interested in. We are performing a comprehensive analysis of high-energy two-to-two reaction with a Regge parametrization which will eventually leads to a better understanding of the resonances. We are also developing the technology for two-to-three reactions to parametrize data from CLAS and COMPASS on two mesons production.

Abhishek Mukherjee

Quantum Monte Carlo with non-local chiral interactions

In collaboration with F. Pederiva and A. Roggero (University of Trento, Italy)

Understanding the properties of nuclei from the underlying theory of strong interactions, viz. quantum chromodynamics (QCD), is one of the basic goals of nuclear physics. Chiral effective field theory (EFT) takes a huge step in this direction by providing a systematic expansion for strong interactions at low energies while incorporating the symmetries and symmetry breakings of QCD.

Quantum Monte Carlo (QMC) is currently one of the most successful computational methods for strongly correlated systems. However, continuum QMC methods cannot be used with chiral EFT interactions due to their non-local nature. We have developed a new QMC method, configuration interaction Monte Carlo (CIMC), that can be directly used with non-local interactions [1, 2]. This method is based on performing a random walk in the Fock space. Currently, calculations for neutron and nuclear matter with chiral EFT interactions are underway. In the very near future we hope to extend these calculations to finite nuclei.

Physics of neutron-rich nuclei

In collaboration with Y. Alhassid and M. Bonett-Matiz (Yale University, USA)

Nuclei with large neutron-proton asymmetry can fundamentally expand our knowledge of the shell structure of the nuclei. They also play a vital role in determining the abundances of heavy elements formed via explosive stellar nucleosynthesis. We are currently using the shell model Monte Carlo (SMMC) method to calculate pairing gaps and level densities for the vital iron-region nuclei [3, 4]. Recently, we solved a sign problem in SMMC arising out of particle number projection [3]. This now allows us to perform essentially exact calculations of thermodynamic observables for semi-realistic interactions for both even-even and odd-even nuclei. Currently, we are performing calculations for the heavier isotopes of the crucial Ni chain. The goal of this project is to provide accurate level densities, separation energies and pairing gaps for astrophysically important nuclei which are not experimentally accessible. These can be used as input into reaction network codes to predict elemental abundances.

Tackling the Monte Carlo sign problem in quantum field theories

In collaboration with M. Cristoforetti (ECT), F. di Renzo (University of Parma) and L. Scorzato (INFN)*

Monte Carlo simulations of many quantum field theories are plagued by the sign (or phase) problem due to the presence of a complex action. Important examples of theories with such sign problems include lattice QCD at finite chemical potential, the (repulsive) Hubbard model away from half filling and the lattice model of the unitary Fermi gas (attractive Hubbard model) with spin imbalance. Recently it was proposed that the sign problem can at least be significantly softened by working in a subspace, called the Lefschetz thimble, of the complexified fields [5]. We have successfully applied this method the U(1) one plaquette model [6] and the relativistic Bose gas at finite chemical potential [7]. Currently, we are applying this method to the repulsive and attractive Hubbard model.

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Dionysis Triantafyllopoulos

Langevin equation for rapidity correlations in multi-particle production

In collaboration with E. Iancu (IPhT, Saclay, France)

The ultra-relativistic heavy ion collision experiments at RHIC and LHC have put a significant part of their effort in studying rapidity correlations in multi-particle production [1], and interesting new phenomena, like the “ridge-efect” [2], have been observed. The proper framework to discuss observables at such high energies is the Color Glass Condensate (CGC) [3], which is a modern effective theory for parton saturation, and its associated JIMWLK equation [4]. In order to describe the aforementioned correlations in deuteron-gold or proton-lead collisions, a generalization of the JIMWLK equation for the simultaneous evolution of the strong nuclear color fields in the direct amplitude and the complex conjugate amplitude is needed. This functional equation can be used to derive ordinary evolution equations for the cross-sections [5] for particle production but the ensuing equations are too complicated to be useful in practice. In [6] we proposed an alternative formulation based on a Langevin process, which is better suited for numerical implementations, and we presented the stochastic equations appropriate for two-gluon production. In the same work we gave a clear explanation why factorization breaks down for two-gluon production (with the gluons produced at different rapidities). Our method also leads to, among other results, to a nice and easy derivation of the BFKL equation at finite number of colors [7].

The Boltzmann equation in classical Yang-Mills theory

In collaboration with V. Mathieu (ECT, Trento & Indiana University, USA) and A.H. Mueller (Columbia University, USA)*

The Boltzmann equation provides a tool for studying the approach to equilibrium after a collision between two heavy ions and when the occupation numbers are already small [8]. A derivation of the Boltzmann equation in a scalar classical field theory with quartic interactions was carried out in [9] by using a method based on the real time formulation of a statistical system. In [10] we give a detailed derivation, paying special attention to the collision integral, first in a scalar theory with both cubic and quartic interactions and subsequently in a Yang-Mills theory. Our method is not relied on a doubling of the fields, rather it is based on a diagrammatic approach representing the classical solution to the problem and it provides for a very intuitive derivation of the Boltzmann equation.

High energy QCD evolution from Slavnov-Taylor identities

In collaboration with D. Binosi (ECT, Trento) and A. Quadri (INFN, Milan, Italy)*

The derivation of the JIMWLK equation [4] which gives the evolution of the CGC is based on a separation of scales in the longitudinal momenta of the gluonic modes of a generic hadron. When integrating the harder modes to construct the Effective Field Theory (EFT) for the softer ones, a special choice of gauges is made; the background field is kept in the Coulomb gauge while the integrated modes are in the light-cone gauge. In [11], studying the BRST symmetry of the QCD action in the presence of a static source based on techniques developed in [12], we show that there is a Slavnov-Taylor identity which indeed implies the existence of such an EFT (perhaps even beyond leading logarithmic accuracy) and explains why the aforementioned choice of gauges leads to certain simplifications.

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Wolfram Weise

The topics of my research include:

- Studies in QCD and hadron physics;
- Effective field theory approaches to nuclear many-body systems;
- Investigations of the phases of QCD.

These projects are pursued in close collaboration with scientists from my home institution, Technische Universität München, and with colleagues from USA, Japan and China. Selected examples are reported in the following.

Structure and dynamics of hadrons with strangeness

In collaboration with Y. Ikeda, S. Ohnishi (RIKEN) and T. Hyodo (Yukawa Institute of Theoretical Physics, Kyoto)

Low-energy QCD in the sector of light (u, d and s) quarks is realized in the form of an effective field theory with spontaneously broken chiral symmetry. Hadrons with strangeness and their interactions are of special interest as they prominently involve the interplay of spontaneous and explicit chiral symmetry breaking, the latter induced by the mass of the s-quark which is intermediate between "light" and "heavy". We have systematically investigated antikaon-nucleon interactions close to threshold and extrapolated into subthreshold regions, using the framework of chiral SU(3) effective field theory combined with coupled-channels methods. Constraints from accurate measurements of kaonic hydrogen have been implemented and the physics of the Λ (1405) as an antikaon-nucleon quasibound state embedded in the pion-hyperon continuum has been clarified [1,2].

Hyperon-nucleon interactions and hypernuclei

In collaboration with Y. Funaki, E. Hiyama (RIKEN), and N. Kaiser (TU Munich)

Results for hyperon-nucleon interactions have been obtained at next-to-leading order in chiral SU(3) effective field theory, including all contributions at this order from one- and two-pseudoscalar meson exchanges. An excellent description of the hyperon-nucleon system can be achieved at the same level of quality as the one found with the best phenomenological hyperon-nucleon potentials [3].
Furthermore, selected light hypernuclei have been studied with a density-dependant hyperon-nucleon interaction based on chiral SU(3) effective field theory and including two-pion exchange processes combined with associated three-body mechanisms [4].

Heavy-quark systems

In collaboration with M. Altenbuchinger (TU Munich), L.S. Geng (Beihang Univ.)

Covariant chiral perturbation theory and its unitarized version with inclusion of coupled-channels dynamics is used to study low-energy interactions of Nambu-Goldstone Bosons (pions, kaons, …) with D, D* and B, B* mesons. Symmetry breaking corrections are systematically investigated. Decay parameters and other properties of heavy mesons such as scattering lenghts are explored in comparison with lattice QCD results. D* resonances can be dynamically generated from the DK coupled-channels interactions without a priori assumptions about their existence [5,6]

Nuclear chiral dynamics and thermodynamics

In collaboration with J.W. Holt (Univ. of Washington, Seattle) and N. Kaiser (TU Munich)

The aim of this extensive research program is to develop and apply in-medium chiral effective field theory – at the interface between low-energy QCD and nuclear physics – for the treatment of nuclear many-body systems. Previous work demonstrated that this approach successfully describes isospin-symmetric nuclear matter and (when transcribed into the form of an energy density functional) also finite systems from medium-weight to heavy nuclei throughout the nuclear chart. These investigations resulted in a systematic treatment of the thermodynamics of isospin-symmetric and asymmetric matter and the nuclear equation-of-state [7], including the liquid-gas phase transition. Further work focused on a series of currently important themes, such as the construction of the second-order quasiparticle interaction in nuclear matter with chiral two- and three-nucleon interactions [8], the derivation of the corresponding energy density functional, and the chiral Fermi liquid approach to neutron matter [9]. The state-of-the-art and results have been summarized in an extended review article [10].

Phases of QCD: strongly interacting matter under extreme conditions

In collaboration with M. Drews and T. Hell (TU Munich & ECT), R. Lang and N. Kaiser (TU Munich), T. Hatsuda (RIKEN), S. Imai and H. Toki (RCNP Osaka)*

Exploring the phase diagram of QCD with its variety of hadronic and quark-gluon sectors is one of the fundamental themes of modern nuclear and particle physics. The nature and properties of the chiral and deconfinement transitions, the possible existence of a critical point at which a chiral crossover turns into a first order phase transition at sufficiently large baryon chemical potential, the transport properties of hot and dense matter produced in high-energy heavy-ion collisions, and the constraints on the equation-of-state of cold dense matter provided by observations of neutron star properties – these are key issues of frontline research in this area. We contribute to these topics along several lines: modeling the phase diagram in terms of Nambu & Jona-Lasinio type approaches, both with local and non-local interactions and supplemented by Polyakov loop effective potentials [11,12]; constructing realistic equations-of-state for hadronic matter on the basis of in-medium chiral effective field [7,9,10]; investigating transport properties (such as the shear viscosity) in the vicinity of phase transitions [13,14]; and connecting hadronic and quark-gluon phases in a way consistent with empirical constraints both from nuclear physics and neutron stars at low temperatures and high baryon densities, and with conditions imposed by lattice QCD thermodynamics. The latter includes, in particular, conceptual studies within two-color QCD

[15]. Investigations of cold and dense baryonic matter are extended to incorporate empirical constraints from the accurate information provided by the recently discovered two-solar-mass neutron stars [16].

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4.2 Publications of ECT* Researchers in 2013

Daniele Binosi

Daniele Binosi, Andrea Quadri
AntiBRST symmetry and Background Field Method
Phys. Rev. D 88 (2013) 085036

D. Binosi, D. Ibanez, J. Papavassiliou
QCD effective charge from the three-gluon vertex of the background-field method
Phys. Rev. D 87 (2013) 125026

Authors: A. C. Aguilar, D. Binosi, J. Papavassiliou
Gluon mass generation in the presence of dynamical quarks
Phys. Rev. D 88 (2013) 074010

D. Binosi, A. Quadri
Scalar resonances in the non-linearly realized electroweak Theory
JHEP 1302 (2013) 020

Marco Cristoforetti

A. Mukherjee, M. Cristoforetti, L. Scorzato
Metropolis Monte Carlo on the Lefschetz thimble: application to a one-plaquette model
Phys. Rev. D 88 (2013) 051502(R)

M. Cristoforetti, F. Di Renzo, A. Mukherjee, L. Scorzato
Monte Carlo simulations on the Lefschetz thimble: taming the sign problem
Phys. Rev. D 88 (2013) 051501(R)

M. Cristoforetti, L. Scorzato, F. Di Renzo,
The sign problem and the Lefshetz thimble
J. Phys. Conf. Ser. 432 (2013) 012025

Alexis Diaz-Torres

D. H. Luong, M. Dasgupta, D. J. Hinde, R. du Rietz, R. Rafiei, C. J. Lin, M. Evers and A. Diaz-Torres
Predominance of transfer in triggering breakup in sub-barrier reactions of 6,7 Li with 144 Sm, 207,208 Pb, and 209 Bi
Physical Review C 88 (2013) 034609

D. H. Luong, M. Dasgupta, D. J. Hinde, R. du Rietz, R. Rafiei, M. Evers, C.J. Lin, A. Wakhle, K. Ramachandran, I.P. Carter, and A. Diaz-Torres
Breakup mechanisms for 7Li + 197Au, 204Pb systems at sub-barrier energies
EPJ Web of Conferences 63 (2013) 02004

A. Shrivastava, A. Navin, A. Diaz-Torres, V. Nanal, K. Ramachandran, M. Rejmund, S. Bhattacharyya, A. Chatterjee, S. Kailas, A. Lemasson, R. Palit, V.V. Parkar, R.G. Pillay, P.C. Rout, Y. Sawant
Dynamics of fragment capture for cluster structures of weakly bound 7Li
EPJ Web of Conferences 63 (2013) 02018

A. Shrivastava, A. Navin, A. Diaz-Torres et al.
Role of the cluster structure of 7Li in the dynamics of fragment capture
Phys. Lett. B 718 (2013) 931

Matthias Drews

M. Drews, T. Hell, B. Klein, and W. Weise
Dense nucleonic matter and the renormalization group
To appear in: Proceedings INPC2013; arXiv: 1307.6973

M. Drews, T. Hell, B. Klein, and W. Weise
Thermodynamic phases and mesonic fluctuations in a chiral nucleon-meson model
Phys. Rev. D 88 (2013) 096011

Victor Efros

V. D. Efros, P. von Neumann-Cosel, and A. Richter
Properties of the first excited state of ^{9}Be derived from (γ,n) and (e,e') reactions
arXiv: 1308.1563; Phys. Rev C 89 (2014) 027301

Thomas Hell

M. Drews, T. Hell, B. Klein, and W. Weise
Thermodynamic phases and mesonic fluctuations in a chiral nucleon-meson model
Phys. Rev. D88 (2013) 096011

M. Drews, T. Hell, B. Klein, and W. Weise
Dense nucleonic matter and the renormalization group
arXiv: 1307.6973 [nucl-th], to appear in EPJ Web of Conferences
Proceedings "INPC 2013"

T. Hell, B. Roettgers, and W. Weise
How neutron stars constrain the nuclear equation of state
arXiv: 1307.4582 [nucl-th], to appear in EPJ Web of Conferences
Proceedings "INPC 2013"

T. Hell, K. Kashiwa, and W. Weise
Impact of vector-current interactions on the QCD phase diagram
J. Mod. Phys. 4, (2013) 644

Ahmad Idilbi

Mi. G. Echevarria, A. Idilbi and I. Scimemi
Towards the Phenomenology of TMD Distributions at NNLL
To appear in: Proceedings "XXI International Workshop on Deep-Inelastic Scattering and Related Subjects" (April 2013, Marseille, France)

M. G. Echevarria, A. Idilbi and I. Scimemi
On Rapidity Divergences in the Soft and Collinear limits of QCD
To appear in: Proceedings "QCD Evolution 2013" (May, 2013, Jefferson Laboratory, Virginia)

Vincent Mathieu

V. Mathieu
Regge Amplitudes for Two-to-Two
arXiv: 1311.6366 [hep-ph], to appear in PoS Proceedings of the conference "From quarks and gluons to hadronic matter: A bridge too far?"[QCD-TNT-III]" (September 2013, Trento, Italy)

F. Buisseret, V. Mathieu and C. Semay
(2+1)-d Glueball Spectrum within a Constituent Picture
Eur. Phys. J. C 73 (2013) 2504

R. Perez-Ramos and V. Mathieu
Collimation of energy in medium-modified QCD
Phys. Lett. B 718 (2013) 1421

Abhishek Mukherjee

Alessandro Roggero, Abhishek Mukherjee, Francesco Pederiva
Quantum Monte Carlo with Coupled-Cluster wave functions
Phys. Rev. B 88 (2013) 115138

A. Mukherjee, M. Cristoforetti, L. Scorzato
Metropolis Monte Carlo on the Lefschetz thimble: application to a one-plaquette model
Phys. Rev. D 88 (2013) 051502(R)

Abhishek Mukherjee, Y. Alhassid
Configuration-interaction Monte Carlo method and its application to the trapped unitary Fermi gas
Phys. Rev. A 88 (2013) 053622

M. Bonett-Matiz, Abhishek Mukherjee, Y. Alhassid
Level densities of nickel isotopes: Microscopic theory versus experiment
Phys. Rev. C 88 (2013) 011302(R)

M. Cristoforetti, F. Di Renzo, A. Mukherjee, L. Scorzato
Monte Carlo simulations on the Lefschetz thimble: taming the sign problem
Phys. Rev. D 88 (2013) 051501(R)

Achim Richter

Y. Aksyutina, T. Aumann, A. Richter, et.al.
Momentum profile analysis in one-neutron knock-out from Borromean nuclei
Phys. Lett. B718 (2013) 1309

S. Bittner, B. Dietz, M. Miski-Oglu, A. Richter, C. Ripp, E. Sadurni, W.P. Schleich
Bound states in sharply bent waveguides: Analytical and experimental approach
Phys. Rev. E87 (2013) 042912

V. D. Efros, P. von Neumann-Cosel, and A. Richter
Properties of the first excited state of ^{9}Be derived from (γ,n) and (e,e’) reactions
arXiv: 1308.1563; Phys. Rev C 89 (2014) 027301

Dionysios Triantafyllopoulos

E. Iancu, D.N. Triantafyllopoulos
JIMWLK evolution for multi-particle production in Langevin form
JHEP 1311 (2013) 067

M. Alvioli, G. Soyez, D.N. Triantafyllopoulos
Testing the Gaussian approximation to the JIMWLK equation
Phys. Rev. D87 (2013) 014016

D.N. Triantafyllopoulos
Multi-gluon correlations in the Color Glass Condensate
Nucl. Phys. A910-911 (2013) 506

Wolfram Weise

J.W. Holt, N. Kaiser, W. Weise
Nuclear chiral dynamics and thermodynamics
Prog. Part. Nucl. Phys. 73 (2013) 35-83

J. Haidenbauer, S. Petschauer, N. Kaiser, U.-G. Meiβner, A. Nogga, W. Weise
Hyperon-nucleon interaction at next-to-leading order in chiral effective field theory
Nucl. Phys. A915 (2013) 24

J.W. Holt, N. Kaiser, G.A. Miller, W. Weise
Microscopic optical potential from chiral nuclear forces
Phys. Rev. C 88 (2013) 024614

T. Hell, K. Kashiwa, W. Weise

Impact of vector-current interactions on the QCD phase diagram
J. Mod. Phys. 4 (2013) 644

J.W. Holt, N. Kaiser, W. Weise
Chiral Fermi liquid approach to neutron matter
Phys. Rev. C87 (2013) 014338

N.M. Bratovic, T. Hatsuda, W. Weise
Role of vector interaction and axial anomaly in the PNJL modeling of the QCD phase diagram
Phys. Lett. B719 (2013) 131

S. Imai, H. Toki, W. Weise
Quark-hadron matter at finite temperature and density in a two-color PNJL model
Nucl. Phys. A913 (2013) 71

Y. Ikeda, T. Hyodo, W. Weise
Improved threshold constraints on coupled-channels chiral SU(3) dynamics from kaonic hydrogen
Few-Body Syst. 54 (2013) 1113

M. Drews, T. Hell, B. Klein, W. Weise
Thermodynamic phases and mesonic fluctuations in a chiral nucleon-meson model
Phys. Rev. D 88 (2013) 096011

4.3 Talks presented by ECT* Researchers

Daniele Binosi

Gauge theories with non-trivial backgrounds
Invited talk at conference "QCD-TNT-III. From quarks and gluons to hadronic matter: A bridge too far?"
2-6 September 2013, Trento, Italy

Alexis Diaz-Torres

Quantifying the 12C+12C sub-Coulomb fusion with the time-dependent wave-packet method
Invited Talk at the 36th International Symposium on Nuclear Physics, Cocoyoc, Mexico
09 Jan 2013

Quantifying the 12C+12C sub-Coulomb fusion with the time-dependent wave-packet method
Invited Talk at the Humboldt Kolleg, Tsakhgadzor, Armenia
05 Jul 2013

Low-energy reaction dynamics of weakly bound nuclei
Invited Talk at the Third International School on Symmetry in Integrable Systems and Nuclear Physics, Tsakhgadzor, Armenia
06 Jul 2013

Quantum decoherence in low-energy nuclear reaction dynamics
Invited Talk at the 33th Mazurian Lakes Conference, Poland
05 Sep 2013

Investigating the role of quantum decoherence in low-energy nuclear collision dynamics
Invited Seminar at the University of Padova, Italy
17 Sep 2013

Quantifying the 12C+12C sub-Coulomb fusion with the time-dependent wave-packet method
Talk at the ECT* Workshop on Reactions involving 12C: Nucleosynthesis and Stellar Evolution, Trento, Italy
09 Oct 2013

Quantifying low-energy nuclear collision dynamics within the coupled-channels density-matrix method
Talk at the ECT* Workshop on Advances in Time-Dependent Methods for Quantum Many-Body Systems, Trento, Italy
17 Oct 2013

Quantifying the 12C+12C sub-Coulomb fusion with the time-dependent wave-packet method
Invited Seminar at the IPHC Strasbourg, France
15 Nov 2013

Matthias Drews

Dense matter and fluctuations
Talk given at the DPG-Frühjahrstagung, Dresden, Germany
March 2013

Dense matter and the functional renormalization group
Poster presented at the International Nuclear Physics Conference (INPC), Florence, Italy
June 2013

Thomas Hell

Constraining the nuclear equation of state by neutron-star observables
Invited talk given at the "XLIV. Arbeitstreffen Kernphysik", Schleching, Germany
February 2013

How neutron stars constrain the nuclear equation of state
Talk given at the spring meeting of the German Physical Society, Dresden, Germany
March 2013

How neutron stars constrain the nuclear equation of state
Poster presented at the International Nuclear Physics Conference (INPC), Florence, Italy
June 2013

How neutron stars constrain the nuclear equation of state
Invited talk given at the "RIKEN Mini Workshop", Wako-shi, Tokyo, Japan
July 2013

Ahmad Idilbi

Transverse momentum distributions: matches and mismathes
Talk given at the conference "QCD Evolution 2013", Jefferson Laboratory, VA, USA
May 2013

From integrated to unintegrated hadronic matrix elements
Talk at the workshop "Structure of Nucleons and Nuclei", Como, Italy
June 2013

An overview of TMD factorization
Invited Talk at the Physics Department of Pavia University, Pavia, Italy
July 2013

Vincent Mathieu

Regge phenomenology
Invited Talk given at the workshop “Analysis Tools for Next Generation Hadron Spectroscopy [ATHOS2013]”, Trento, Italy
May 2013

Regge phenomenology
Invited Talk given at the collaboration meeting “Hadron Spectroscopy Meeting [HaSpect]”, Trento, Italy
July 2013

Regge phenomenology
Invited Talk given at the workshop “From quarks and gluons to hadronic matter: A bridge too far? [QCD-TNT-III]”, Trento, Italy
September 2013

Regge phenomenology
Invited Talk given at the conference “Meson-Nucleon Physics [MENU 2013]”, Rome, Italy
September 2013

Abhishek Mukherjee

Quantum Monte Carlo for the configuration interaction framework
Workshop on "From few nucleon forces to many nucleon structure", ECT*, Trento, Italy
11 Jun 2013

Quantum Monte Carlo in the momentum space and on the Lefschetz thimble
Program on "Advances in quantum Monte Carlo techniques for non-relativistic many-body systems", INT, Seattle, USA
25 Jul 2013

Quantum Monte Carlo calculations with nonlocal chiral interactions
Workshop on "Neutron rich matter and neutron stars", ECT*, Trento, Italy
03 Oct 2013

Dionysios Triantafyllopoulos

Parton saturation and particle production in pA collisions
Talk at the "Workshop on proton-nucleus collisions at the LHC", Trento, Italy
06 May 2013

JIMWLK evolution for multi-particle production
Talk at the Workshop "h3QCD (high energy, high density and hot QCD)", Trento, Italy
17 Jun 2013

JIMWLK evolution for multi-particle production in Langevin form
Talk at the "International conference on the initial stages of high-energy nuclear collisions", Illa da Toxa, Spain
12 Sep 2013

Wolfram Weise

Phases of nuclear matter
EMMI Workshop on Fluctuations and Correlations at the QCD Phase Transition, Darmstadt, Germany
11 Feb 2013

Strangeness in low-energy QCD and dense baryonic matter
LNF Seminar, Frascati
11 Mar 2013

Phases of nuclear matter
RIKEN Nishina Seminar, RIKEN, Japan
03 Apr 2013

Phases of strongly interacting matter
ICC Colloquium, Barcelona, Spain
22 Apr 2013

Effective field theories in QCD
Lectures at the ECT* DTP "Neutron-rich matter: constraints from nuclear physics to astrophysics"
20 May 2013

Hadron polarizabilities
ECT* Workshop on "Compton Scattering"
29 Jul 2013

Phases of nuclear matter and new constraints from neutron stars
Nuclear Theory Seminar, Stony Brook University, NY, USA
12 Aug 2013

Phases of nuclear matter and the EoS at high baryon density
ECT* Workshop Neutron-rich matter and neutron stars
03 Oct 2013

Phases of strongly interacting matter
(from quarks and gluons to nuclei and neutron stars)
INP Colloquium, Krakow, Poland
10 Oct 2013

Strangeness in baryonic matter and new constraints from neutron stars
ECT* Workshop "Strangeness in the Universe"
21 Oct 2013

Phases of strongly interacting matter
Colloquium, Univ of Bochum, Germany
18 Nov 2013

Nuclear chiral dynamics and thermodynamics
G.E. Brown Memorial Conference, Stony Brook Univ., NY, USA
24 Nov 2013

4.4 Courses taught by ECT* Researchers

Dionysis Triantafyllopoulos

Quantum Chromodynamics

In the spring of 2013 I taught, for a third consecutive year, a 21-hour course on Quantum Chromodynamics (QCD) at the PhD School of the University of Trento. The goal was to introduce and/or review QCD, study in detail some of its characteristic features and present the concept of parton evolution. It was a small class composed of three PhD students and the prerequisites to attend the course were knowledge of Quantum Field Theory and of basics of Group Theory. All lectures were done on the blackboard.

I started by presenting the reasons that lead to QCD, I introduced its Lagrangian and then discussed its symmetries. I reviewed the path integrals formulation of Quantum Mechanics and Quantum Field Theory including the case of fermions and the necessary introduction of Grassmann variables. Then I discussed the gauge fixing, the emergence of the Faddeev-Popov ghosts, and elaborated on covariant and light-cone gauges. I went on to describe briefly some formal and essential aspects like the BRST Symmetry. Focusing on the quark-antiquark-gluon vertex I emphasized the need of renormalization and presented most parts of the calculation which lead to the QCD β-function. Then I went to describe electron-positron to hadrons at NLO and how this process is infrared safe. Using this particular process and the β-function presented earlier I introduced the running of the coupling. I brought in the concept of a jet, focusing again on electron-positron annihilation. Finally I moved to DIS and discussed evolution of patrons via the DGLAP equations, the solution to the latter and the symmetries and properties of the splitting functions. I discussed elements of timelike evolution like Sudakov form-factors and angular ordering in jet evolution in the vacuum.

As an exam two students presented lectures on special topics. The two topics were “The Weizsäcker-Williams approximation” and “The operator product expansion”.

4.5 Seminars and colloquia at ECT*

Factorization theorems and hadronic matrix elements (part 1)
15 Jan 2013
Ahmad Idilbi (ECT*)

Factorization theorems and hadronic matrix elements (part 2)
22 Jan 2013
Ahmad Idilbi (ECT*)

Characterization of the pure-glue phase transition in QCD: Inclusion of the 2-body interactions thanks to the T-matrix formalism
29 Jan 2013
Gwendolyn Lacroix (Univ. of Mons)

Quantum Monte Carlo for momentum dependent interactions
06 Feb 2013
Abhishek Mukherjee (ECT*)

Quantum reaction dynamics of weakly bound nuclei at energies around the Coulomb barrier
19 Feb 2013
Maddalena Boselli (ECT*)

Shear viscosity in a large-Nc NJL model
19 Feb 2013
Robert Lang (TU Munich)

Heavy-light mesons in unitarized chiral perturbation theory
20 Feb 2013
Michael Altenbuchinger (TU Munich)

Time-like and space-like electromagnetic form-factors
ECT* Colloquium
21 Feb 2013
Egle Tomasi-Gustafsson (IPN Orsay)

Nuclear astrophysics (a few problems and perspectives)
27 Feb 2013
Maurizio Busso (INFN Perugia)

Dynamical gluon mass generation in pure Yang-Mills theory
02 Mar 2013
David Ibanez Gil de Ramales (Univ. Valencia)

The "Lefschetz thimble" and the sign problem
Joint ECT-BEC-LISC seminars*
06 Mar 2013
Luigi Scorzato (INFN)

Quantum fluctuations in Bose-Einstein condensates and nonlinear optical media
Joint ECT-BEC-LISC seminars*
06 Mar 2013
Stefano Finazzi (Univ. of Trento/BEC)

Quantum field theory approach to quantum transport in macromolecules
Joint ECT-BEC-LISC seminars*
06 Mar 2013
Pietro Faccioli (Univ. of Trento/LISC)

Nuclear structure and reactions from chiral effective field theory
20 Mar 2013
Jeremy W. Holt (Univ. of Washington, Seattle)

Deconfinement of strangeness and the strangeness content of the quark gluon plasma
04 Apr 2013
Christian Schmidt (Univ. of Bielefeld)

Review of ALICE and CMS result
ECT Colloquium*
05 Apr 2013
Enrico Scomparin (INFN Torino)

The role of sigma_hadronic for the future of the precision determinations of the muon g-2 and the running alpha_em
ECT Colloquium*
12 Apr 2013
Fred Jegerlehner (Humboldt-Univ. Berlin)

Reaction dynamics with halo nuclei
23 Apr 2013
Alessia Di Pietro (INFN Catania)

Hadrons at O(alpha_s^0) in QCD
03 May 2013
Paul Hoyer (Univ. of Helsinki)

Thermalization of the quark-gluon plasma and Bose-Einstein condensation in unusual circumstances
ECT Colloquium*
07 May 2013
Jean-Paul Blaizot (CEA Saclay)

An approach to solving Ill-posed problems
ECT Seminar*
15 May 2013
Victor D Efros (Kurchatov Inst., Moscow)

Probing cosmic matter in the laboratory with virtual photons
ECT Colloquium*
20 May 2013
Tetyana Galatyuk (TU Darmstadt)

From material science to astrophysics with electronic structure calculations
ECT Seminar*
12 Jun 2013
Simone Taioli (LISC-FBK)

Perspectives on the origins of nuclear structure
ECT Colloquium*
12 Jun 2013
James Vary (Iowa State Univ.)

Scattering of weakly bound nuclei at near-barrier energies: toy model and first observables
ECT Seminar*
13 Jun 2013
Maddalena Boselli (ECT*)

The Landau-Pomeranchuk Migdal effect, 1953 to today: cosmic rays to quark-gluon plasmas to string theory
ECT Colloquium*
19 Jun 2013
Peter Arnold (Univ. of Virginia)

Parton physics on a lattice in the Bjorken frame
ECT Colloquium*
01 Jul 2013
Ji Xiangdong (Shanghai Jiao Tong Univ. and Univ. of Maryland)

Neutron stars and the properties of matter at high density
ECT Colloquium*
11 Jul 2013
Gordon Baym (Univ. of Illinois, Urbana-Champaign)

Baryon-Baryon interactions in SU(3) chiral effective field theory
ECT - TUM Seminar*
15 Jul 2013
Stefan Petschauer (TU Munich)

Functional renormalization group and pionic fluctuations in nuclear matter
ECT - TUM Seminar*
15 Jul 2013
Matthias Drews (TU Munich-ECT*)

Regge phenomenology
ECT Seminar*
15 Jul 2013
Vincent Mathieu (ECT*)

Recent developments in SU(3) covariant Baryon chiral perturbation theory
ECT Seminar*
15 Jul 2013
Lisheng Geng (Beihang Univ., Beijing)

Single-particle potential from resummed ladder diagrams
15 Jul 2013
Norbert Kaiser (TU Munich)

Searches for new physics at low energy
ECT Colloquium*
22 Jul 2013
Andrzej Czarnecki (Univ. of Alberta)

Continuum discretized coupled channels (CDCC) calculations for reactions of 6Li with several targets
ECT Seminar*
24 Jul 2013
Arturo Gomez-Camacho (ININ, Mexico)

Compton scattering and the nucleon polarisabilities
ECT Colloquium*
29 Jul 2013
Evangeline Downie (George Washington Univ.)

Slavnov-Taylor identity for the effective field theory of the color glass condensate
ECT Seminar*
31 Jul 2013
Andrea Quadri (INFN Milano)

Nuclear collectivity in the shell model Monte Carlo approach
ECT Seminar*
30 Aug 2013
Cem Özen (Kadir Has Univ., Istanbul)

Simulating non-abelian gauge fields with cold atoms and ions
Special colloquium session of the workshop QCD-TNT-III
03 Sep 2013
J-I Cirac (MPQ, Garching)

Schrödinger- and Dirac-microwave billiards, photonic crystals and graphene
ECT 20th anniversary colloquium*
14 Sep 2013
Achim Richter (TU Darmstadt)

Nuclear force and nuclear matter from lattice QCD
ECT 20th anniversary colloquium*
14 Sep 2013
Tetsuo Hatsuda (RIKEN)

Hot and dense QCD matter
ECT 20th anniversary colloquium*
14 Sep 2013
Jean-Paul Blaizot (CEA Saclay)

Electron positron linear colliders: a project for the future of high energy physics
ECT Colloquium*
19 Sep 2013
Hitoshi Murayama (IPMU, Tokyo Univ.)

Testing general relativity for extreme densities and gravitational fields
ECT Colloquium*

02 Oct 2013
Paulo Freire (MPI for Radio Astronomy, Bonn)

Ashes to ashes, dust to dust: the story of the elements
ECT Colloquium*
07 Oct 2013
Martin Freer (Univ. of Birmingham)

Many-body approaches to interacting quantum systems out of equilibrium
ECT Colloquium*
16 Oct 2013
Robert van Leeuwen (Univ. of Jyväskylä)

Strangeness in baryonic matter and new constraints from neutron stars
ECT Seminar*
18 Oct 2013
Wolfram Weise (ECT* and TU Munich)

Research highlights from the HAL QCD collaboration
ECT Seminar*
18 Oct 2013
Yoichi Ikeda (RIKEN)

From lambda-hypernuclei to lambda-neutron matter: an AFDMC study
ECT Seminar*
18 Oct 2013
Francesco Pederiva (Univ. of Trento)

Quantum Monte Carlo with non-local interactions
ECT Seminar*
18 Oct 2013
Abhishek Mukherjee (ECT*)

Hyperons, quarks and neutron stars
ECT Colloquium*
22 Oct 2013
Isaac Vidana (Univ. of Coimbra)

Weakly-bound systems: clustering, correlations, and reactions
ECT Colloquium*
06 Nov 2013
Marek Ploszajczak (GANIL)

Sign structures of generalised susceptibilities in QCD like models
ECT Seminar*
11 Nov 2013
Sandeep Chatterjee (Indian Inst. of Sci., Bangalore)

Effects of divergent ghost loops on the Green's functions of QCD
ECT Seminar*
13 Nov 2013
David Ibanez (ECT*)

Reaction dynamics studies with the facility EXOTIC at LNL
ECT Seminar*
13 Nov 2013

Marco Mazzoco (INFN Padova)

Nuclear systems with strangeness
ECT Seminar*
20 Nov 2013
Daniel Gazda (ECT*)

Color glass condensate and particle production in pA collisions
ECT Seminar*
04 Dec 2013
Dionysis Triantafyllopoulos (ECT*)

Probing the open-quantum-system dynamics with elastic scattering of halo nuclei
ECT Seminar*
11 Dec 2013
Alexis Diaz-Torres (ECT*)

Recent development of chiral effective field theory and its application to nuclear structure calculations
ECT Seminar*
18 Dec 2013
Chieh Jen Yang (Univ. of Trento)

5 Quantum Information Processing and Communication activities at ECT*

- ECT* has been involved in the field of Quantum Information Processing and Communication (QIPC) over the last decade. Specifically, the QIPC field has been a so-called Proactive Initiative of the Future and Emerging Technologies Unit in DG Information Society and Media of the European Commission in the Framework Programme FP5 (1999-2002), FP6 (2003-2006), FP7 (2007-2013) and the just started H2020 (2014-2020) and ECT* have been a constant presence in QIPC consortia.
- This continue to be true at present, since during 2013 D. Binosi actively worked on the Coordination Action **QUTE-EUROPE** (Quantum Technologies for Europe) in which he contributes to Work-Package 2 (Coordination and Collaboration) and 3 (Dissemination). The funding for the ECT* node is 37,450.00€ for 3 years.

6 ECT* Computing Facilities

CONNECTIVITY

- The core of the computational infrastructure at ECT* has recently been improved.
- The main network infrastructure is a compound of three switches PoE - Power over Ethernet- (DELL Power Connect 5548P).
- 7 switches Dell Power Connect 5548 will be installed in order to improve the connectivity in the Villa Tambosi.
- The Rustico and the Villa are connected by two multi-mode optical fibers.
- Between ECT* and FBK the connection is also provided by fiber (1Gbps).

ECT* access to the Internet is transmitted through the FBK network (GARR and Trentino Network s.r.l.). The connection speed is 100 Mbps (by GARR) plus 100Mbps (by Trentino Network).

HARDWARE

Servers:
the virtual servers are running over the hardware in the FBK datacenter

PC clients:

20 PCs for staff and local research:
Workstation DELL Precision T1500
Workstation DELL Precision T1600
Apple iMac 27”

34 PCs for workshops and schools:
Workstation DELL Precision T1500
Workstation DELL Optiplex 755

IMPORTANT SOFTWARE: 1 Mathematica ver. 8 network server + 7 concurrent processes

MANAGEMENT
The PCs for the staff and for the local research are managed by FBK IT group.
The PCs for the schools and the workshops are managed directly by ECT*. The services on this network are distributed over the following virtual servers:

1) the Windows Server 2012 has the following most important roles and services: Active Directory server, Network Information Server (logins, groups, hosts database…), Domain Name Server, windows print server, Domain Name Server, Windows Server Update Services (for the windows client).
2) the linux server Red Hat 6.3 has the following services: Domain Name Server forwarder, e-mail server, Common Unix Print Server.
3) the gate server Red Hat 6.3 for the access from outside

7 20th Anniversary of ECT*

The 20th Anniversary of the foundation of ECT* in 1993 was celebrated on September 14, 2013. A meeting of the ECT* Finance Committee (EJFRC) was held on the same day. A new Memorandum of Understanding was signed, coordinating financial support for ECT* from contributing countries.

European Centre for Theoretical Studies in Nuclear Physics and Related Areas

20th Anniversary
of the Foundation of ECT*

14 September 2013
ECT* Auditorium
Tentative program and schedule

9 - 10:30	Massimo Egidi (President of FBK) Fernando Ferroni (President of INFN) Wolfram Weise (Director of ECT*) Sandro Stringari (University of Trento) Angela Bracco (NuPECC) Baha Balantekin (Chair, ECT* Scientific Board)
10:30 - 11	Coffee break
11 - 12	Scientific Colloquium, Part I Jean-Paul Blaizot (CEA Saclay) Achim Richter (TU Darmstadt)
12:30 - 14	Lunch at Villa Tambosi
14 - 15	Scientific Colloquium, Part II Morton Hjorth-Jensen (Michigan State Univ.) Tetsuo Hatsuda (RIKEN)
15:30 - 19	EJFRC Meeting (closed)
20	Dinner (Villa Tambosi)

FONDAZIONE BRUNO KESSLER