ECT*

Annual Report 2012

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
Gian Maria Ziglio and Susan Driessen

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.

As shown on p. 4 of this Annual Report, altogether 684 scientists from 39 countries worldwide have visited the ECT* in 2012 and have participated in the activities of the Centre. This demonstrates once again impressively ECT*'s high visibility and its key importance for the European and international communities.

In 2012 ECT* held:

- 17 Workshops and 1 Collaboration Meeting 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 “The Three-dimensional Nucleon Structure” lasting for 6 weeks and attended by 15 students;

- the first TALENT course on Computational Many-Body Methods for Nuclear Physics lasting for 4 weeks and attended by 22 students.

  In addition to these 20 scientific events, ECT* supported

- fundamental research on low energy nuclear theory, models of nuclear structure, reaction dynamics and phase transitions, nuclear many-body theory, pion-nucleon interactions, chaos in hadrons, structure of the nucleon, partons, quarks and gluons, non-perturbative QCD, hadron-nucleus-nucleus collisions at high energy and QCD in hot and dense matter. 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, with scientific visitors and collaborating physicists elsewhere. These activities 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 2012 represent a substantial fraction of all publications produced within the Fondazione Bruno Kessler in the same year.

Furthermore, ECT* has

- administered scientifically the AuroraScience project, a collaboration of the FBK with the Istituto Nazionale di Fisica Nucleare (INFN) and several local and national institutions. ECT* has utilized the high performance computing (HPC) system AURORA – a joint research and development project of Eurotech and AuroraScience – optimized for a number of highly relevant scientific computing applications in physics. Phase one of this project finished by the end of the year 2012. The activities are foreseen to become part of the larger Exascale computational network in the near future.

Maintaining ECT*´s high level of scientific activity and visibility in 2012 has only been possible through a stable operating budget. We are very grateful for the local support from the FBK/PAT, for the contributions from European funding agencies and research centres in Belgium, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, the Netherlands, Poland, Romania, Spain and the UK, and for funds provided through the European FP7 projects Hadron Physics, ENSAR and QUIE2T. Within FP7 ECT* plays an important role as a Trans-National Access (TNA) facility. ECT* also acknowledges partial support of its workshops from the ExtreMe Matter Institute EMMI and from the Helmholtz International Center (HIC for FAIR).

On 31 October 2012 Achim Richter's term as ECT* Director ended, shortly after a memorable farewell event celebrated at the headquarters of the Fondazione Bruno Kessler. On 1 November the present Director took office. All of us at ECT* join in expressing our deep gratitude to Achim for directing the Centre over a period of four very productive years and leaving it so well prepared to his successor.

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 2012 is also available on the ECT* web site (www.ectstar.eu).

Trento, March 2013 *Wolfram Weise*
*Director of ECT**

Contents

2 ECT* Scientific Board, Staff and Researchers

2.1 ECT* Scientific Board and Director

Baha Balantekin (from January 2010)	University of Wisconsin, Madison, USA
Angela Bracco (from June 2012)	NuPECC/University of Milano, Italy
Jens Jørgen Gaardhøje (from January 2010)	Niels Bohr Institute, Copenhagen, Denmark
François Gélis (from September 2012)	CEA Saclay, France
Simon Hands (until September 2012, Chairman)	Swansea University, UK
Kris Heyde (until June 2012)	University of Gent, Belgium
Maria-Paola Lombardo (from September 2012)	INFN Frascati, Italy
Piet Mulders (from June 2012)	VU Amsterdam, Netherlands
Jean-Yves Ollitrault (until June 2012)	CEA Saclay, France
Arturo Polls (from June 2011)	University of Barcelona, Spain
Achim Schwenk (from October 2010)	TU Darmstadt, Germany

Honorary Member of the Board

Ben Mottelson	NORDITA, Copenhagen, Denmark

ECT* Director

Achim Richter (until October 31)	ECT*, Italy and TU Darmstadt, Germany
Wolfram Weise (from November 01)	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 (part time)	Technical Programme Co-ordinator and Web Manager

2.3 Resident Researchers

- **ECT* Postdocs**

Massimiliano Alvioli, Italy (until 31/08/12)
Daniele Binosi, Italy
Alexis Diaz-Torres, Germany
Thomas Hell (TUM/ECT*), Germany (from 02/11/12)
Ahmad Idilbi, Israel (from 01/10/12)
Vincent Mathieu, Belgium
Stefano Melis, Italy (until 30/09/12)
Abhishek Mukherjee, India (from 03/09/12)
Laura Muñoz, Spain (until 30/09/12)

Pavel Stransky, Czech Republic (until 30/11/12)
Dionysis Triantafyllopoulos, Greece

- **AuroraScience**

Marco Cristoforetti, Italy
Luigi Scorzato, Italy
Enrico Tagliavini, Italy (until 21/11/12)

- **PhD Students**

Maddalena Boselli, Italy (from 01/11/12)
Matthias Drews (TUM/ECT*), Germany (from 02/11/12)

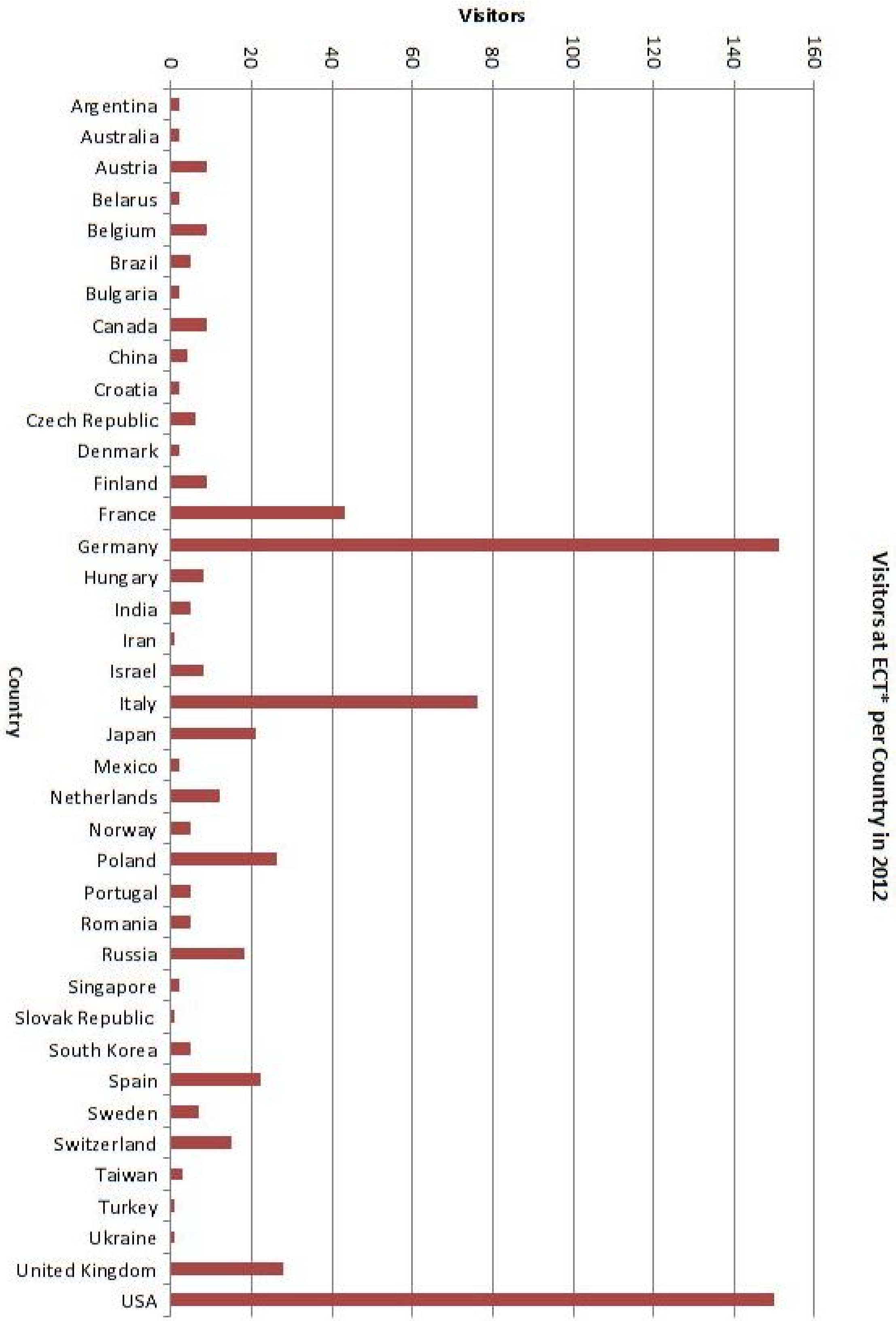
2.4 Visitors in 2012

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) and participants and lecturers of the TALENT school (TS).

Michael Altenbuchinger (26/11)	TU München, Germany (VS)
Mauro Anselmino (29/04, 01/05, 07/05, 11/05, 13/06,15/06)	University of Torino, Italy (TP)
Gustav Baardesen (24/06-13/07)	University of Oslo, Norway (TS)
Alessandro Bacchetta (27/05 - 01/06)	INFN Pavia, Italy (TP)
Eduardo Basso (29/04-18/06)	Univ. Fed. do Rio Grande do Sul, Porto Alegre, Brasil (TP)
Michael Beaumier (29/04-18/06)	University of California, Riverside, USA (TP)
Jean-Paul Blaizot (23-30/06)	CEA Saclay IPhT, France (VS)
Nino Bratovic (26/11)	TU München, Germany (VS)
Irina Brodski (29/04-16/06)	Universität Giessen, Germany (TP)
Carmen Carbonell-Coronado (23/06-13/07)	University Pablo de Olavide de Seville, Spain (TS)
Francesco Catalano (25/06-13/07)	Università degli Studi di Trento, Italy (TS)
Andrea Cipollone (24/06-13/07)	Università La Sapienza di Roma, Italy (TS)
Lorenzo Contessi (25/06-13/07)	Università degli Studi di Trento, Italy (TS)
Abhay Deshpande (10/06 - 16/06 - 25/06 - 29/06)	Stony Brook and Riken BNL, USA (TP)
Markus Diehl (06-12/05)	DESY, Germany (TP)
Cesar Fernandez-Ramirez (15-29/08)	Universidad Complutense de Madrid, Spain (VS)
Salvatore Fiorilla (26/11)	TU München, Germany (VS)
Kevin Fossez (24/06-14/07)	GANIL, France (TS)
Ilnur Gabdrakhmanov (29/04-16/06)	Bogoliubov Lab. of Theor. Phys., Dubna, Russia (TP)
Gautam Gangopadhyay (23/04-21/05)	University of Calcutta, India (VS)
Yuan Gao (23/06-15/07)	University of Jyväskylä, Finland (TS)
Jasone Garay (29/04-16/06)	University of the Basque Country, Leioa, Spain (TP)
Jonathan Gaunt (06-13/05)	University of Cambridge, UK (TP)
Arturo Gomez-Camacho (23/09-14/10)	ININ, Mexico (VS)
Delia Hasch (12-18/05)	LNF, INFN, Italy (TP)
Dieter Heiss (29/05 – 15/06)	University of Stellenbosch, South-Africa (VS)
Morten Hjorth-Jensen (25/06-13/07)	Mich. State Univ., USA and Univ. of Oslo, Norway (TS)
Istvan Hornyak (24/06-14/07)	MTA-ATOMKI, Hungary (TS)
David Ibañez (22/01-04/02)	University of Valencia, Spain (VS)
Hye-Ran Jang (25/06-14/07)	Soongsil University, South Korea (TS)
Robin Salomon Matthew Jodon (23/06-14/07)	Inst. de Physique Nucl. de Lyon, France (TS)
Calvin Johnson (02-13/07)	San Diego State University California, USA (TS)

Norbert Kaiser (26/11)	TU München, Germany (VS)
Viacheslav Khandramai (30/04-16/06)	Gomel State Technical University, Belarus (TP)
Bertram Klein (26/11)	TU München, Germany (VS)
David Kleinjan (29/04-16/06)	University of California, Shoreham, USA (TP)
Gwendolyn Lacroix (01/05-09/06)	University of Mons, Belgium (VS)
Robert Lang (26/11)	TU München, Germany (VS)
Alexander Laschka (26/11)	TU München, Germany (VS)
Tianbo Liu (29/04-16/06)	Peking University, Beijing, China (TP)
Diego Lonardoni (25/06-13/07)	Università degli Studi di Trento, Italy (TS)
Hongliang Lu (24/06-14/07)	GANIL, France (TS)
Mauricio Martinez Guerrero (05-08/06)	Universidade de Santiago de Compostela, Spain (VS)
Tom Mertens (29/04-16/06)	University of Antwerp, Belgium (TP)
Titus Dan Morris (24/06-14/07)	Michigan State University, USA (TS)
Leticia Palhares (25-30/06)	Universidade Federal do Rio de Janeiro, Brasil (VS)
Fabrizio Palumbo (01-02/10)	INFN Frascati, Italy (VS)
Barbara Pasquini (03/06 - 08/06)	INFN Pavia, Italy (TP)
Francesco Pederiva (25/06-13/07)	Università degli Studi di Trento, Italy (TS)
Joshua Perry (30/04-16/06)	Iowa State University, Ames, USA (TP)
Stefan Petschauer (26/11)	TU München, Germany (VS)
Irina Potapova (30/04-16/06)	Bogoliubov Lab. of Theor. Phys., Dubna, Russia (TP)
Andrea Quadri (02-05/01, 12-13/02, 03-04/06, 02-13/07 & 19-24/08)	INFN Milano, Italy (VS)
Sarah Maria Reimann (24/06-14/07)	University of Oslo, Norway (TS)
Felix Ringer (29/04-16/06)	University of Tübingen, Germany (TP)
Georges Ripka (23/04-04/07)	CEA Saclay IPhT, France (VS)
Alessandro Roggero (25/06-13/07)	Università degli Studi di Trento, Italy (TS)
Julia Michelle Rossi (23/06-14/07)	San Diego State University, USA (TS)
Guillaume Jules Edouard Scamps (24/06-14/07)	GANIL, France (TS)
Kevin Schmidt (25/06-13/07)	Arizona State University, Phoenix, USA (TS)
Sigve Bøe Skattum (23/06-15/07)	University of Oslo, Norway (TS)
William Mathew Spinella (24/06-14/07)	San Diego State University, USA (TS)
Paul Springer (26/11)	TU München, Germany (VS)
Marco Stratmann (29/04 - 04/05)	BNL, USA (TP)
Kemper Dyar Talley (24/06-14/07)	UTK/ORNL, USA (TS)
Lukas Theussl (12-16/11)	Slovak Academy of Science, Bratislava, Slovak Republic (VS)
Marco Traini (23/05/2012)	Università degli Studi di Trento, Italy (VS)
Frederik Van der Veken (29/04-16/06)	University of Antwerp, Belgium (TP)
Jochen Wambach (29/04-04/05)	TU Darmstadt, Germany (VS)
Daniel Erwin Ward (24/06-14/07)	Lund University, Sweden (TS)
Wolfram Weise (11-12/01, 23/05)	TU München, Germany (VS)
Corbinian Wellenhofer (26/11)	TU München, Germany (VS)
Kyle Andrew Wendt (24/06-14/07)	The Ohio State University, USA (TS)
Guenter Wunner (29/05 – 15/06)	University of Stuttgart, Germany (VS)
Jiacai Zhu (29/04-16/06)	Peking University, Beijing, China (TP)

The following histogram gives an overview of all visitors to ECT* in 2012, including workshop participants.



Visitors at ECT* per Country in 2012
Visitors
0
20
40
60
80
100
120
140
160
Country
Argentina
Australia
Austria
Belarus
Belgium
Brazil
Bulgaria
Canada
China
Croatia
Czech Republic
Denmark
Finland
France
Germany
Hungary
India
Iran
Israel
Italy
Japan
Mexico
Netherlands
Norway
Poland
Portugal
Romania
Russia
Singapore
Slovak Republic
South Korea
Spain
Sweden
Switzerland
Taiwan
Turkey
Ukraine
United Kingdom
USA

3 Scientific Projects in 2012

3.1 Summary

Altogether 20 scientific projects have been run in 2012: 17 workshops, one collaboration meeting, a Doctoral Training Programme and the first TALENT course on Computational Many-Body Methods for Nuclear Physics. 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. Morton Hjorth-Jensen reported on the TALENT course.

3.2 Workshops, Collaboration Meetings and Schools (Calendar)

Feb 27 – Mar 02	**Exclusive and Diffractive Processes at High Energy Proton-proton and Nucleus-nucleus Collisions** Antoni Szczurek *(Institute of Nuclear Physics, Cracow)* Rainer Schicker *(Universität Heidelberg)* Wolfgang Schäfer *(Institute of Nuclear Physics, Cracow)*
Mar 26 - 27	**SARFEN – Structure and Reactions for Exotic Nuclei (Collaboration Meeting)** Marek Ploszajczak *(GANIL)*
Apr 02 - 06	**Beautiful Mesons and Baryons on the Lattice** Matthew Wingate *(DAMTP, University of Cambridge)* William Detmold *(College of William and Mary)* C.-J. David Lin *(National Chiao Tung University)*
Apr 30 – June 15	**The 3-dimensional Nucleon Structure (Doctoral Training Programme)** Mauro Anselmino *(Universita' di Torino and INFN)*
May 14 - 18	**Hadrons in the Nuclear Medium** Steffen Strauch *(University of South Carolina)* Chaden Djalali *(University of South Carolina)* Ulrich Mosel (*Universität Giessen*)
May 21 - 25	**Drell-Yan Scattering and the Structure of Hadrons** Paul Reimer *(Argonne National Laboratory)* Oleg Denisov *(INFN - Torino)* Marco Radici *(INFN - Pavia)* Oleg Teryaev *(Joint Institutes for Nuclear Research)*
Jun 18 - 22	**The Nuclear Dipole Polarizability and its Impact on Nuclear Structure and Astrophysics** Paul-Gerhard Reinhard *(Universität Erlangen/Nürnberg)* Achim Schwenk *(TU Darmstadt)* Witold Nazarewicz *(UT Knoxville)* Peter Von Neumann-Cosel *(TU Darmstadt)*

Jun 25 - 29 — **Electro-Weak Probes: from Low-Energy Nuclear Physics to Astrophysics**
Doron Gazit *(Hebrew University of Jerusalem)*
Sonia Bacca *(TRIUMF)*
Sofia Quaglioni *(Lawrence Livermore National Laboratory)*

Jun 25 - Jul 13 — **ECT* Nuclear TALENT School**
Jacek Dobaczewski *(University of Warsaw and University of Jyväskylä)*
Morten Hjorth-Jensen *(Michigan State University and University of Oslo)*
Giuseppina Orlandini *(University of Trento)*
Francesco Pederiva *(University of Trento)*
Marek Ploszajczak *(GANIL)*

Jul 02 - 06 — **Initial State Fluctuations and Final State Correlations in Heavy-Ion Collisions**
Matthew Luzum *(CEA Saclay)*
Hannah Petersen *(Duke University)*
Andrew Adare *(Yale University)*

Jul 16 - 20 — **Scattering Amplitudes: from QCD to Maximally Supersymmetric Yang-Mills Theory and Back**
Andrei Belitsky *(Arizona State University)*
Gregory Korchemsky *(CEA Saclay)*

Jul 23 - 27 — **Spectral Properties of Complex Networks**
Dima Shepelyansky *(CNRS Toulouse)*
Nelly Litvak *(University of Twente)*
Thomas Guhr *(University of Duisburg-Essen)*
Guido Caldarelli *(Institute for Complex Systems, CNR)*

Sep 03 - 07 — **Towards a Resolution of the Double Beta Decay Problem**
Sabin Stoica *(Horia Hulubei National Institute of Physics and Nuclear Engineering)*
Mihai Horoi *(Central Michigan University)*
Jouni Suhonen *(University of Jyväskylä)*
Kai Zuber *(TU Dresden)*

Sep 24 - 28 — **Many-Body Open Quantum Systems: From Atomic Nuclei to Quantum Optics**
Marek Ploszajczak *(GANIL)*
Wolfgang Schleich *(Universität ULM)*

Oct 01 - 05 — **EDM Searches at Storage Rings**
Andreas Wirzba *(FZ Jülich)*
Hans Stroeher *(FZ Jülich)*
William Marciano *(Brookhaven National Lab.)*
Yannis Semertzidis *(Brookhaven National Lab.)*
Mei Bai *(Brookhaven National Lab.)*
Frank Rathmann *(FZ Jülich)*

Oct 08 - 12

Mathematical Aspects of Hadron Physics
Craig Roberts *(Argonne National Laboratory)*
Kurusch Ebrahimi-Fard *(Instituto de Ciencias Matematicas, CSIC, Madrid)*
Frederic Patras *(University of Nice)*

Oct 15 - 19

New Trends in Low-Energy QCD in the Strangeness Sector: Experimental and Theoretical Aspects
Catalina Curceanu *(LNF – INFN, Frascati)*
Carlo Guaraldo *(LNF – INFN, Frascati)*
Johann Marton *(SMI - Vienna)*
Laura Fabbietti *(TU München)*
Jiri Mares *(Nuclear Physics Institute ASCR)*

Oct 22 - 24

Reactions of Exotic Nuclei and the Impact of Nuclear Structure
Helmut Leeb *(University of Wien)*
Paul-Henri Heenen *(Université Libre de Bruxelles)*
Jacek Dobaczewski *(Warsaw University)*
Friedrich-Karl Thielemann *(University of Basel)*
Achim Richter *(ECT* and TU Darmstadt)*

Oct 29 – Nov 02

The Proton Radius Puzzle
Randolf Pohl *(Max-Planck-Institut für Quantenoptik, Garching)*
Gerald A. Miller *(University of Washington)*
Ronald Gilman *(Rutgers University)*

Nov 12 - 16

QCD in Strong Magnetic Fields
Andreas Schäfer *(Universität Regensburg)*
Gergely Endrödi (*Universität Regensburg*)
Kenji Fukushima *(Keio University)*
Mikhail Polikarpov *(ITEP)*

3.3 Reports on all Workshops and one Collaboration Meeting

3.3.1 EXCLUSIVE AND DIFFRACTIVE PROCESSES AT HIGH ENERGY PROTON-PROTON AND NUCLEUS-NUCLEUS COLLISIONS

DATE: February 27 – March 2, 2012

ORGANIZERS:

Rainer Schicker *(University of Heidelberg, Germany)*
Antoni Szczurek *(Inst. of Nuclear Physics, Polish Academy of Sciences, Cracow, Poland)*
Wolfgang Schäfer *(Inst. of Nuclear Physics, Polish Academy of Sciences, Cracow, Poland)*

NUMBER OF PARTICIPANTS: 40

MAIN TOPICS:

- elastic proton-proton, pion-proton and pion-pion scattering
- exclusive production of Higgs, P-wave quarkonia, vector mesons, gluonic jets, Z-boson, W^+ W^- pairs, single mesons and pairs of mesons, glueballs, dileptons
- inclusive single, double and central diffraction
- inclusive diffractive production of jets, gauge bosons, Drell-Yan
- production of jets with large rapidity gaps
- exclusive production of beyond Standard Model particles
- gamma-gamma processes
- gamma-proton and gamma-nucleus processes
- large angle scattering in elastic and exclusive processes

SPEAKERS:

S. Chung *(TU Munich, Germany and BNL, USA)*

J. Figiel *(Inst. Nucl. Phys., Cracow, Poland)*

M.-B. Gay-Ducati *(UFRGS, Porto Alegre, Brazil)*

B. Giacobbe *(INFN Bologna, Italy)*

L. Goerlich *(Inst. Nucl. Phys., Cracow, Poland)*

P. Grafstrom *(CERN, Switzerland)*

G. Gustafson *(Lund U, Sweden)*

L. Harland-Lang *(Cavendish Laboratory, Cambridge, UK)*

J. Hollar *(UC Louvain, Belgium)*

D. Ivanov *(Novosibirsk State U, Russia)*

J. Pinfold *(U of Alberta, Canada)*

L. Jenkovszky *(BITP, Kiev, Ukraine)*

N. Kaiser *(TU Munich, Germany)*

H. Kowalski *(DESY, Germany)*

P. Kroll *(U Wuppertal, Germany)*

V. Kus *(Inst. of Physics, Prague, Czech Republic)*

P. Lebiedowicz *(Inst. Nucl. Phys., Cracow, Poland)*

M. Luszczak *(U of Rzeszow, Poland)*

R. Maciula *(Inst. Nucl. Phys., Cracow, Poland)*

C. Mayer *(Inst. Nucl. Phys., Cracow, Poland)*

H. Menjo *(Nagoya U, Japan)*

C. Mesropian *(Rockefeller U, USA)*

M. Mieskolainen *(Helsinki Inst. of Physics, Finland)*

D. Moran *(University of Manchester, UK)*

O. Nachtmann *(Inst. Theor. Phys, U Heidelberg, Germany)*

R. Orava *(Univ. of Helsinki/Helsinki Inst. of Physics, Finland)*

R. Pasechnik *(Lund U, Sweden)*

A. Pilkington *(IPPP Durham/Manchester U, UK)*

F. Reidt *(Phys. Inst., Heidelberg, Germany)*

C. Royon, (*CEA Saclay, France)*

A. Sandacz *(NCBJ, Warsaw, Poland)*

W. Schäfer *(Inst. Nucl. Phys., Cracow, Poland)*

R. Schicker *(U Heidelberg, Germany)*

R. Staszewski *(Inst. Nucl. Phys., Cracow, Poland)*

A. Szczurek *(Inst. Nucl. Phys., Cracow, Poland)*

M. Tasevsky *(Phys. Inst., Prague, Czech Republic)*

O. Teryaev *(JINR, Dubna, Russia)*

M. Trzebinski *(Inst. Nucl. Phys., Cracow, Poland)*

J. Wagner *(Nat. Centre for Nuclear Research, Warsaw, Poland)*

D. Werder *(Uppsala U, Sweden)*

SCIENTIFIC REPORT:

Aim and Purpose/ Objectives and Achievements

The workshop was dedicated to fostering the communication between experimentalists and theorists in the field of diffractive physics. The workshop is in many ways a continuation of the 2010 Trento workshop on diffractive and electromagnetic processes and the 2011 W.E. Heraeus summerschool on diffraction in Heidelberg.

Differently from more formal conferences, talks were scheduled with a lot of discussion time and not merely devoted to the dissemination of results. Such a format was perceived very useful by participants, and we believe that the aims of the meeting were met successfully. For a fact new ideas for future work were taken home by participants, and we hope that new collaborations have been formed.

Results and Highlights

The program of the workshop consisted of 20 talks on experimental results and methods and 19 presentations devoted to theory and/or phenomenology.

On Monday, C. Mesropian started with reviewing the results on diffractive physics from the Tevatron. The Tevatron has (had) a mature diffractive physics program and a wealth of results was shown. These included the t-dependence of elastic scattering, the inclusive diffractive production of W bosons as well as central exclusive production of vector mesons, p-wave quarkonia (chi-states) and digamma pairs. New results from 300 and 900 GeV runs can be expected for the summer conferences.

R. Orava then presented an overview on how to measure diffraction and elastic scattering with the TOTEM experiment at the LHC. He showed the recent results on the t-dependence of elastic scattering and discussed the determination of the integrated elastic cross section from extrapolation to t=0. Orava discussed plans to extend measurements into the Coulomb-nuclear interference region of very small t, where a determination of the real part would be possible, as well as an interesting idea of independently measuring elastic scattering in exclusive Bremsstrahlung events. Prospects for other diffractive observables in collaboration with the CMS detector were also discussed and especially the importance of low-mass diffraction was stressed.

New results are still flowing out of the analysis of data from the no longer operating HERA accelerator. J. Figiel presented the main findings of the large program on exclusive vector meson production and then turned to the discussion of QCD factorization and its possible breaking in inclusive hard diffraction and diffractive jet production. The H1 and ZEUS collaborations are now combining their datasets, and as Figiel stressed, the experimental errors appear to become smaller than the systematic uncertainties of theoretical approaches.

A. Sandacz presented the results and future prospects on diffraction from the STAR experiment at RHIC. Ultraperipheral collisions of heavy ions give access to a lot of interesting physics. As heavy nuclei are strong sources of Weizsaecker-Williams photons, these include photon-photon collisions as well as high-energy photon-nucleus interactions. Sandacz discussed the results on coherent photoproduction of various final states. High energy polarized protons are unique to RHIC, and open up the unique possibility of studying the spin dependence of diffraction. Preliminary results on a single spin asymmetry will allow to extract/bound the Pomeron spin flip coupling to unprecedented precision.

The afternoon was then devoted to electromagnetic interactions. The first part was devoted to the bound-free production process. The large charges of heavy ions leads to copious production of electron-positron pairs, and in a small fraction of events (but still with huge cross-section!), an electron may be captured by one of the ion beams, while the positron escapes. P. Grafstrom presented the experimental situation of the bound-free production and a related process with electron capture on an atomic target.

R. Schicker continued on bound-free production and presented an innovative idea to use the latter as a trigger for ultraperipheral collisions, in conjunction with possible Roman pots for

the ALICE experiment. Schicker emphasized the rich program on strong-coupling QED as well as photon-photon cross sections into hadrons that would become accessible.
J. Wagner contributed a careful discussion of timelike Compton scattering on a proton or nucleus, which gives rise to a mechanism of exclusive lepton-pair production. He discussed how its amplitude may be extracted from an interference with the QED Bethe-Heitler process.
N. Kaiser then gave an hour-long lecture on low energy photon-pion interactions in the framework of chiral perturbation theory and its appropriate unitarizations. Such an introduction had been demanded by some experimentalists, and was perceived as very useful.
On Tuesday morning, O. Nachtmann presented a framework for soft high-energy interactions. Nachtmann develops effective field-theoretic Feynman rules for hadronic scattering amplitudes in the high energy limit. In particular he argued against a modelling of the Pomeron exchange as an effective vector and favoured a rank-two symmetric tensor. Nachtmann also discussed vertices for the fusion of Pomerons to various hadronic states, as well as effective vertices for Odderon exchange. It appears that a number of interesting predictions for central exclusive production processes can be obtained.
Returning to the reviews from experimental collaborations, B. Giacobbe spoke for the ATLAS collaboration. He presented results for inclusive single diffraction as a function of the gap size. Existing Monte-Carlos fail to describe especially the rise at large gap-size, which is however consistent with a typical soft Pomeron in a triple-Regge analysis. Giacobbe also gave an outlook to a future measurement of elastic scattering with the ALFA detector.
J. Pinfold then gave an interesting introduction to the MoEDAL experiment at the LHC which aims to search for magnetic monopoles. As Pinfold stressed, magnetic monopoles are expected to have a large electric charge, and potentially might be produced in photon-photon collisions.
C. Royon gave a detailed account of the experimental apparatus of the ATLAS Forward Physics Project (AFP). Its realization will be a major step forward for the diffractive community. The installation of forward detectors at 210 m downstream the main detector is foreseen for 2013.
M. Hiroaki gave an account of the LHCf experiment which aims at an investigation of particle production in the very forward region. Great interest into this physics is driven by various puzzles in the description of cosmic ray air showers. Results for forward single and inclusive photons as well as neutral pions were presented.
S.U. Chung turned our attention to hadron spectroscopy. He discussed the large data sample of diffractive $\pi \to 3\pi$ excitation on the proton as well as lead target obtained by the COMPASS experiment at CERN. Chung emphasized that it is crucial to perform the partial wave analysis of production amplitudes to come to firm conclusions. He strongly argued for an exotic 1^{-+} $\pi_1(1600)$ meson in COMPASS data.
Connecting to Orava's talk from Monday, L. Jenkovszky reviewed the theoretical treatment of low-mass diffraction, in particular the production of resonances using Regge theory and duality ideas. The day finished with a talk by P. Lebiedowicz who discussed in great detail the Pomeron-fusion mechanism for exclusive central production of pion and Kaon pairs. He paid special attention to the continuum production in the vicinity of the $\chi(c)$-resonance.
Wide angle processes were the topic of P. Kroll's presentation. He focused in particular on meson pair production in gamma-gamma collisions within the pQCD motivated handbag approach. Differently from the Brodsky-Lepage pQCD factorization it is also applicable in the experimentally accessible pre-asymptotic region.
O. Teryaev then had a look at certain conceptual issues regarding different QCD factorization formulas valid in different kinematic regions and suggested "dualities" between them. In particular Teryaev hinted at a possible collinear factorization formalism for the much discussed exclusive diffractive Higgs production.
A Monte-Carlo approach for high energy collisions based on a color-dipole picture was discussed by G. Gustafson. As the model involves effectively the multiperipheral wave-

functions of the colliding hadrons, diffractive processes could be dealt with at the amplitude level.

The diffractice physics program of the CMS collaboration was reviewed by J. Hollar, who showed results on diffractive W-production as well as diffractive dijets and exclusive lepton-pair production in photon-photon fusion. Hollar gave an optimistic outlook regarding future diffractive analyses even in the presence of sizeable pile-up.

Ch. Mayer then discussed how coherent photoproduction of rho and J/Psi-mesons can be studied at the ALICE experiment.

D. Moran spoke for the LHCb collaboration and presented results on the exclusive central production of charmonium states J/ψ, ψ(2S), χ(c) as well as the dilepton production via the gamma-gamma channel.

The pQCD motivated models for production of vector mesons in proton-proton as well as nucleus-nucleus collisions were discussed by W. Schäfer. In particular he showed predictions for coherent J/ψ and ϒ production on nuclei.

M. Luszczak presented her calculations on the diffractive production of charm in proton-proton collisions as well as inclusive photon-induced production.

R. Staszewski suggested that a charge asymmetry of diffractively produced W-bosons can distinguish between Pomeron-fusion and soft-color interaction approaches to inclusive diffraction.

Multivariate methods which can amongst other things be used to classify diffractive events were the topic of M. Mieskolainen's presentation.

Diffractive physics is by itself a multifaceted field. In exclusive diffraction we are dealing with very clean events which are of special interest for searches/studies of the Higgs or certain physics beyond the standard model. The first half of Thursday was devoted to these topics.

M. Gay-Ducati presented calculations on the exclusive production of Higgs bosons in ultraperipheral collisions. She proposed to look for Higgs bosons in events with an additional photon and argued that the gap survival probability will be relatively large in this case.

A very detailed analysis of the central diffractive production of beyond-the-Standard Model Higgs bosons was presented by M. Tasevsky. He argued for central exclusive production as an essential tool to determine e.g. the CP properties of Higgs bosons and stressed the importance of additional forward detectors.

Out of the broad physics opportunities of the ATLAS forward physics project, C. Royon mainly concentrated on the possibility to measure/constrain anomalous gauge couplings in the W-apir production in gamma-gamma collisions.

A. Szczurek also addressed the exclusive production of W-pairs, but in a Pomeron-fusion mechanism, which appears as a background to the anomalous coupling studies. Szczurek optimistically concluded that the strong interaction background is under control.

The QCD description of the Pomeron, which is the driving mechanism of diffractive processes, was the topic of H. Kowalski's talk. He emphasized that with inclusion of the running coupling, the BFKL possesses a discrete spectrum of Pomeron poles. Kowalski presented numerical solutions of "wave-functions" and intercepts, and made a provocative claim, that the former are sensitive to new physics, favouring SUSY particles at the 10 TeV scale.

D. Ivanov continued on the topic of BFKL physics, and showed how impact factors at the next-to-leading approximation enter the calculation of Mueller-Navelet jets. He emphasized that analytic results can be obtained for a "truncated" BFKL approximation, which may serve to control complicated numerical calculations.

L. Goerlich showed HERA results for the azimuthal correlation between the scattered positron and a forward jet in the proton fragmentation region. Cross sections appear to favour a BFKL approach, while the correlations themselves are consistent with several evolution approaches.

A. Pilkington discussed a model for the underlying event of a hard collision which is to be implemented in the Monte-Carlo Sherpa. Here various inelastic events from the cuts of Pomerons in multiple-Pomeron exchange graphs are accounted for.

M. Trzebinski gave a discussion of how to implement jet processes with gaps from BFKL dynamics into a forward physics Monte Carlo. Measurements within the ATLAS forward physics program are foreseen.
Following up, V. Kus spoke about the measurement of diffractive dijets and dijets with gaps within the ATLAS experiment.
The last day started with a presentation by L. Harland-Lang on recent developments of the Durham/Cambridge/Gatchina group within the so-called "Durham"-model of exclusive central diffraction. Harland-Land discussed a wealth of processes and in particular concentrated on how existing measurements ("standard candles") can fix ambiguities in the theoretical treatment.
R. Pasechnik presented an approach to diffraction within the soft-color interaction model. Here no explicit reference to a Pomeron is made. Pasechnik demonstrated how gap-survival effects can be evaluated in such an approach.
D. Werder then showed how the framework presented by Pasechnik can be applied to the HERA data on inclusive diffraction.
Finally, R. Maciula presented his calculations of central exclusive production of dijets. Besides an intrinsic interest, those processes are important as an irreducible background to central exclusive Higgs production.
Instead of a summary talk, the workshop ended with a discussion session.

3.3.2 SARFEN

STRUCTURE AND REACTIONS FOR EXOTIC NUCLEI - COLLABORATION MEETING

DATE: March 26 – 27, 2012

ORGANIZERS:

Marek Płoszajczak *(GANIL, France)*

NUMBER OF PARTICIPANTS: 14

MAIN TOPICS:

The objective of the SARFEN Theory Collaboration, supported by national funding agencies in 8 European countries and involving physicists from 13 different research centres is (i) to advance the reaction theory and its methods for the description of spectroscopic properties of rare isotopes, (ii) to provide a microscopic input for transfer reactions from most advanced nuclear structure models, and (iii) to study nucleon-nucleon correlations in exotic nuclear systems that are close to the break-up 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 RNB facilities in Europe and elsewhere.
In this Collaboration Meeting participated 14 physicists who presented the physics program of their teams and discussed future means to realize the scientific program of the SARFEN. Individual presentations have been ordered according to the work-package structure of the project.

SPEAKERS:

N. Pilliet (*Bruyeres-le-Chatel, France*)

M. Ploszajczak (*GANIL, France*)

K. Sieja (*IPHC Strasbourg, France*)

E. Simpson (*U. of Surrey, UK*)

J. Dobaczewski (*U. of Surrey/U. Jyväskylä, Poland/Finland*)

W. Satula (*U. of Warsaw, Poland*)

P. Magierski (*Technical U. of Warsaw, Poland*)

J. Okolowicz (*INP Krakow, Poland*)

S. Lenzi (*INFN Padova, Italy*)

J. Toivanen (*U. of Jyväskylä, Finland*)

D. Delion (*IFIN-HH Bucharest, Romania*)

A. Petrovici (*IFIN-HH Bucharest, Romania*)

N. Tsoneva (*INRNE BAS Sofia/U. of Giessen, Bulgaria/Germany*)

Ch. Stoyanov (*INRNE BAS Sofia, Bulgaria*)

SCIENTIFIC REPORT:

The first work package (WP1) “Reaction theory for neutron-proton asymmetric nuclei" was presented by (i) E. Simpson (Univ. of Surrey) who discussed the direct reaction mechanism approach for studies of exotic nuclei and detailed the necessary nuclear structure input for eikonal studies of nuclear reactions, (ii) M. Ploszajczak (GANIL) who presented the unified description of nuclear structure and reactions within the Gamow Shell Model framework, (iii) S. Lenzi (INFN Legnaro) who outlined the project of the Padova group to study effects of the continuum coupling in simple models of nuclear structure and reactions, and (iv) P. Magierski (Technical Univ. of Warsaw) who discussed the recent progress in the time-dependent superfluid Density Functional Theory for large amplitude nuclear collective motion and reactions.
In the second work package (WP2) “Nuclear structure models for the use in transfer reactions" we heard presentations of (i) N. Pilliet (Bruyeres-le-Chatel) on the calculation of radial overlap functions for transfer reaction using multiparticle-multihole Energy Density Functional (EDF), (ii) J. Toivanen (Univ. of Jyväskylä) on the QRPA description of low-energy correlations and two-particle strength functions, (iii) J. Dobaczewski (Univ. of Warsaw and Univ. of Jyväskylä) on two-particle transfer matrix elements within the EDF method, (iv) D. Delion (IFIN-HH Bucharest) on probing nuclear interaction by two-proton emission. Discussion between speakers of WP1 and WP2 lead to the definition of optimal strategy to provide the microscopic input for direct reaction models.
The lecturers of the third work package (WP3) “Nucleon-nucleon correlations in exotic nuclei at the vicinity of continuum” presented various microscopic nuclear structure approaches to study correlations in exotic nuclei. Near threshold configuration mixing and evolution of pairing matrix elements and mirror energy differences was discussed in the presentations by J. Okolowicz (INP Krakow), S. Lenzi (INFN Padova) and K. Sieja (IPHC Strasbourg). Beyond mean-field approach to nuclear structure and dynamics of medium mass nuclei was outlined in the talk of A. Petrovici (IFIN-HH Bucharest). Pygmy resonances at low-energy excitations were discussed by N. Tsoneva (INRNE BAS Sofia and Univ. of Giessen). Finally, Ch. Stoyanov (INRNE BAS Sofia) discussed nuclear structure calculations of valence shell excitations including mixed symmetry states, low-lying isovector modes and Pygmy resonances.

Results and Highlights

On the basis of intense discussions, it was concluded that the strong focusing on practical objectives of the SARFEN program is necessary to ensure the success of this program, its utility for experimental programs, and good prospects for future theory initiatives financed in part by the experimental programs. This requires targeting the production of specific tools, codes, and/or tables of calculated results that could be of direct use to external users. It was decided that a Trento workshop would be proposed to the Board of the ECT* for the beginning of 2013, with focus on various most recent achievements and modern developments in the low-energy nuclear structure and reaction theory covered within SARFEN. This workshop, if accepted by the ECT* Board for 2013, would allow to broaden the scientific objectives of SARFEN Collaboration. A list of key participants should be prepared very soon and their participation secured well before the formal proposal to ECT* is due. Later in 2013, a general SARFEN collaboration meeting will be organized, possibly in conjunction with the Varna School, to enhance the coherence between activities of different thematic subgroups. Small-scale meetings of various subgroups within SARFEN are also planned. The project exit meeting should be envisaged for the end of 2014.
It has also been decided to create the webpage of SARFEN project to resemble and disseminate main scientific results, reports, and publications within the collaboration and outside of it.

It was an unanimous opinion of all participants that the meeting was a great success, also due to a perfect organisation of our stay at the ECT*. The whole SARFEN Collaboration is most grateful to the ECT* for hosting their first scientific meeting.

3.3.3 BEAUTIFUL MESONS AND BARYONS ON THE LATTICE

DATE: April 2 – 6, 2012

ORGANIZERS:

Matthew Wingate *(DAMTP, University of Cambridge, UK)*
William Detmold *(College of William & Mary, USA)*
C.-J. David Lin *(National Chiao Tung University, Taiwan)*

NUMBER OF PARTICIPANTS: 26

MAIN TOPICS:

Recent advances in lattice QCD methods and computational power have made possible the accurate calculation of hadronic quantities to an unprecedented precision. Many properties of the B meson are now well-known but require advancement in techniques to further reduce uncertainties. Following on from the success of the Tevatron experiments, the LHC will present new opportunities to study the properties of the Bs meson and beautiful baryons such as the Λb. Therefore this was a good time to review the current status of relevant recent lattice calculations as well as to map the route ahead for new lattice calculations.
This workshop aimed to bring together experts from the following communities with the goal of directing lattice QCD efforts so that the most can be made of experimental measurements involving beautiful mesons and baryons:

- b quarks on the lattice
- baryons on the lattice
- chiral perturbation theory, especially for beautiful hadrons
- phenomenology of B, Bs, Λb decays (leptonic, semileptonic, and rare decays)

SPEAKERS:

T. Blake *(CERN, Switzerland)*

C. Bobeth *(Technische U Muenchen, Germany)*

V. Braun *(U of Regensburg, Germany)*

J.-W Chen *(National Taiwan U, Taiwan)*

C.T.H Davies *(U of Glasgow, UK)*

W. Detmold *(College of William & Mary, USA)*

P. Dimopoulos *(U "Tor Vergata", Rome, Italy)*

R. Dowdall *(U of Glasgow, UK)*

T. Feldmann *(U of Siegen, Germany)*

P. Fritzsch *(Humboldt U Berlin, Germany)*

E. Gamiz *(U of Granada, Spain)*

D. Hesse *(U of Parma, Italy)*

A. Khodjamirian *(U of Siegen, Germany)*

A. Kronfeld *(Fermilab, USA)*

A. Lenz *(CERN, Switzerland)*

R. Lewis *(York U, Canada)*

C.-J. D Lin *(National Chiao Tung U, Taiwan)*

Z. Liu *(Institute of High Energy Physics, China)*

S. Meinel *(College of William & Mary, USA)*

C. Monahan *(College of William & Mary, USA)*

K. Seth *(Northwestern U, USA)*

R. Sommer *(DESY, Germany)*

N. Uraltsev *(Notre Dame, USA)*

M. Wingate *(DAMTP, U of Cambridge, UK)*

O. Witzel *(Boston U, USA)*

M. Yip *(U of Durham, UK)*

SCIENTIFIC REPORT:

For decades understanding electroweak symmetry breaking has been the underlying goal of most research in elementary particle physics. The Standard Model description is given by the (Brout-Englert)-Higgs mechanism. In addition to explaining why the weak force is so weak, the Higgs mechanism gives the quarks masses in a way that couples the 3 generations of up-down, charm-strange, and top-bottom quarks. Without the Higgs field, the bottom (*b*) quark would be stable, for example. By studying the decays of the *b* quark, then we hope to further our understanding of electroweak symmetry breaking.
There are good reasons to expect more to the story than is described by the Standard Model. The theoretical calculations for the Higgs boson mass require the cancellation of two large numbers in order to arrive at a value which is sufficient to explain precision electroweak data. The Standard Model does not contain in it a particle which could make up the dark matter inferred from astronomical observations. The Standard Model appears to be too balanced to explain the observed matter-antimatter asymmetry of the Universe. All sorts of experiments are being done to try to detect hints of physics beyond the Standard Model. Looking for non-standard evidence of *b* quark decays is one of many search strategies being pursued by particle physics around the world.

Experiments do not detect *b* quarks by themselves, but instead measure the decays of their bound states, *b* hadrons. In order to determine the decay properties of the quarks, one must have rigorous theoretical methods for understanding how they decay while at the same time interacting strongly within their hadronic state, as described by the part of the Standard Model called QCD.

Strong interactions between quarks and gluons within hadronic states are difficult to describe theoretically. However, there has been tremendous progress which relies on the combined efforts of numerical and analytical calculations. The main focus of this workshop was the use of lattice field theory and Monte Carlo computations to precisely describe the decays of *b* hadrons. The workshop attracted experts from several lattice QCD collaborations who shared their recent, in some cases preliminary numerical data. Lattice QCD experts shared opinions regarding the merits of various methods, and non-experts were able to ask detailed questions about lattice approaches, achievements and difficulties.

While large-scale computations are a vital ingredient, they alone are not sufficient to solve the problems faced. Effective field theory has long aided the analysis of systematic uncertainties present in the brute-force computations. Combining the theoretical with the numerical efforts in many cases allows one to make reliable estimates of the effects of discretization, finite volume, extrapolation in mass parameters, for example. We were lucky that some experts in effective field theories, in particular in heavy quark effective theory, could be present.

The workshop welcomed theorists using non-lattice methods such as QCD sum rules. Historically these methods often led the way, providing first estimates of hadronic quantities. With increased computing power and improvement techniques, lattice QCD can surpass the precision of sum rules in some cases, but not all. In particular the kinematics of decays of *b* hadrons to light hadrons with large-recoil velocity are inaccessible to lattice approaches, so semileptonic form factors are often fit to a combination of lattice and sum rule results. This workshop provided a useful forum for theorists and phenomenologists to discuss optimal strategies of analysis.

We were given updates of recent measurements at the LHC, the Tevatron, and elsewhere by experimentalists and phenomenologists.

In addition to the need to study how *b* quarks decay, it is important to understand the many ways they can combine to form bound states. Comparison between lattice QCD computations and experimental measurements of the spectrum of b hadrons is an important test of lattice QCD methods. We had several talks from lattice theorists with new results and were excited to receive the announcement of the first measurement of the $\eta_b(2S)$ meson.

Three of the days had talks scheduled throughout, with an atmosphere that welcomed questions and discussions. The fourth full day had an unstructured afternoon session, during which participants broke into smaller groups for collaborative work or more detailed discussion. This schedule seemed to work well balancing the desire to allow any who wished to speak with the informal exchange of ideas generated through conversation.

3.3.4 HADRONS IN THE NUCLEAR MEDIUM

DATE: May 14 - 18, 2012

ORGANIZERS:

Chaden Djalali *(University of South Carolina, USA)*
Ulrich Mosel *(Justus-Liebig Universität Giessen, Germany)*
Steffen Strauch *(University of South Carolina, USA)*

NUMBER OF PARTICIPANTS: 39

MAIN TOPICS:

The goal of the workshop was to bring together experimentalists and theorists studying medium modifications of structure functions, form factors, mesons in the medium, mesonic atoms, etc. to create a synergy between these topics. A comprehensive assessment of the current understanding of medium modifications of hadrons is needed to plan and optimize the next round of experiments. Topics to be discussed during the workshop include:

- Vector and pseudoscalar meson properties in the medium
- Nuclear quark distributions: unpolarized, polarized, flavor dependence, anti-quarks
- In-medium nucleon form factors: Coulomb sum rule, polarization measurements
- Impact of short-range structure of nuclei: y-scaling, short-range correlation studies
- In-medium interactions: energy loss in nuclei, hadronization, color transparency
- Hadrons at high temperatures
- QCD phenomenology
- Unified descriptions of in-medium particle properties including form factors, polarized and unpolarized structure functions
- Consistent description of nuclear interactions in electromagnetic, neutrino-induced, heavy-ion, and Drell-Yan reactions
- Future experiments

SPEAKERS:

A. Accardi *(Hampton University & Jefferson Lab, USA)*

L. Alvarez-Ruso *(IFIC Valencia, Spain)*

O. Benhar *(INFN Rome, Italy)*

C. Ciofi degli Atti *(U of Perugia, Italy)*

I. Cloet *(U of Adelaide, Australia)*

D. Day *(U of Virginia, USA)*

D. Dutta *(Mississippi State U, USA)*

T. Galatyuk *(Technical U Darmstadt, Germany)*

D. Gaskell *(Jefferson Lab, USA)*

S. Gilad *(MIT, USA)*

R. S. Hayano *(U of Tokyo, Japan)*

B. Kämpfer *(Dresden, Germany)*

O. Lalakulich *(Justus-Liebig U Giessen, Germany)*

Y. Leifels *(GSI, Germany)*

C. Markert *(U of Texas at Austin, USA)*

K. S. McFarland *(U of Rochester, USA)*

W. Melnitchouk *(Jefferson Lab, USA)*

V. Metag *(U of Giessen, Germany)*

G. Miller *(U of Washington, USA)*

J. Miguel Nieves Pamplona *(IFIC Valencia, Spain)*

E. Oset *(U de Valencia, Spain)*

M. Paolone *(U of South Carolina, USA)*

J. C. Peng *(U of Illinois at Urbana-Champaign, USA)*

R. Petti *(U of South Carolina, USA)*

G. Ramalho *(Instituto Superior Tecnico, Lisbon, Portugal)*

A. Ramos *(U de Barcelona, Spain)*

P. Reimer *(Argonne National Lab, US)*

G. Ron *(U of Jerusalem, Israel)*

J. Ryckebusch *(Ghent U, Belgium)*

M. Sargsian *(Florida International U, USA)*

S. Schlimme *(Johannes Gutenberg-U Mainz, Germany)*

K. Schweda *(Ruprecht-Karls-U, Heidelberg, Germany)*

M. Strikman *(Penn State, USA)*

H. van Hees *(U of Frankfurt, Germany)*

W. Weise *(TU München, Germany)*

G. Zeller *(Fermi National Accelerator Laboratory, USA)*

SCIENTIFIC REPORT:

That particles can change their properties when they are embedded in a medium is a well-known fact of many-body physics. In nuclear physics interest in such phenomena started about 20 years ago when it was realized that electromagnetic properties of nucleons inside nuclei were different from those of free nucleons, the so-called EMC effect. At first sight unrelated to this phenomenon were predictions based on QCD-sum rules that hadrons should change their masses in the nuclear medium. More recently, neutrino long- and short-baseline experiments had found a remarkable change of the axial coupling of gauge-bosons to nucleons.
Due to partly historical reasons the EMC effect and its variants have captured the interest of scientists working in electronuclear physics, the masses of hadrons in dense and hot matter have created excitement among heavy-ion physicists and the modified axial couplings observed in the neutrino experiments had not found any serious interest outside the neutrino-physics community dominated by high-energy physicists.

All of these phenomena are closely related and it was, therefore, the purpose of this workshop to bring scientists from the three different communities together to start what would hopefully be a fruitful discussion among all of them. The discussion brought together theorists working in the QCD-based partonic picture and in more phenomenological approaches based on hadrons as the relevant degrees of freedom. On the experimental side, the meeting brought – often for the first time – experimenters together from JLab, MAMI, ELSA, Fermilab, RHIC/LHC and FAIR and provided ample opportunities for discussions among them.

In very broad outlines the main topics of this workshop were:

- EMC effect and connections to color transparency and short range correlations, changes of electromagnetic form factors
- Reaction Mechanisms of neutrino interactions with nuclei, relation to inclusive electron scattering reactions, interplay of reaction mechanism and electroweak couplings

- In-medium properties of hadrons, in particular spectral functions. Extraction of imaginary parts of self energies from transparency measurements

In addition, questions such as effects of in-medium changes of hadrons on nuclear structure and the phase-properties of nuclear matter were discussed.

Results and Highlights

From the talks and discussions it was obvious that the EMC effect still awaits a generally accepted explanation. The general consensus in the community is now that this effect is related to short-range correlations (SRC) and various talks dwelled on this issue. The recent experiments and phenomenological analyses from JLab suggest some relation between EMC effect, SRC, and inclusive electron scattering on nuclei at Bjorken $x > 1$. On the theory side, most explanations still invoke changes of the electromagnetic form factors of bound nucleons, either due to 'classical' binding (off-shell) effects, or to 'novel' binding effects on partons inside nucleons. For all these models Drell-Yan data provide a necessary constraint.

Since SRC are connected with high-momentum components of bound nucleons that can be resolved only with high momentum-transfer probes it is obvious that there must be also a connection with experiments aiming at the verification of color transparency (CT). The problems here are often on the experimental side: while the pion data obtained at JLab seem to be rather conclusive, the more recent rho meson production data exhibit a delicate interplay of CT and kinematical cuts employed in the experiment. Since any verification of CT needs data on the nucleon for comparison, such cuts, if they - due to Fermi motion – act differently for nucleons and nuclei, can mimic CT effects. This was discussed and here comments from theorists and experimenters alike were helpful.

While electron data are determined by vector couplings the neutrino experiments can yield important information on the axial couplings in addition. Here the general consensus has emerged that the large axial masses observed by two different neutrino experiments can be reconciled with the significantly lower world-average values if the experimental extraction of these quantities is carefully scrutinized. Here, indeed, the reaction mechanism has to be understood very well and more recent analyses have indeed shown that the high axial masses are due to a shortcoming in their extraction, and not a genuine physical effect. A similar careful reaction-theoretical treatment of CT, SRC, and the EMC effect is still missing. Speakers from the neutrino community have emphasized the urgent need for a much better modelling of neutrino-nucleus reactions that has to proceed in close collaboration with nuclear physics in order to be able to extract, e.g., the CP violating phase from planned long-baseline experiments.

For the question of hadronic properties in medium, a consensus has emerged that the spectral functions themselves are not observable as soon as hadronic decay channels are used; this is simply due to final state interactions. In that sense dileptons are the optimal probe to look for any in-medium properties; the 'ideal' experiments also uses photons in the initial state. So far experiments all agree in their observation of a significant broadening of hadronic spectral functions in medium, but no mass shift has been observed; this is the outcome of experiments from JLab, ELSA/MAMI and RHIC. The observed broadening can give useful information on the interactions of hadrons with the surrounding medium; here again information gained from photonuclear experiments turns out to be very useful for the search for penetrating probes in ultra-relativistic heavy-ion reactions.

The workshop presented a very rare opportunity for nuclear and high-energy physicists from very different subfields to exchange ideas and information. Often scientists from different fields met each other for the first time. Such an 'interdisciplinary' approach is very rare in this age of usually highly specialized workshops.

3.3.5 DRELL-YAN SCATTERING AND THE STRUCTURE OF HADRONS

DATE: May 21 - 25, 2012

ORGANIZERS:

Paul Reimer *(Argonne National Laboratory, USA)*
Oleg Denisov *(INFN – Torino, Italy)*
Marco Radici *(INFN – Pavia, Italy)*
Oleg Teryaev *(Joint Institutes for Nuclear Research, Russia)*

NUMBER OF PARTICIPANTS: 45

MAIN TOPICS:

Since it was first observed, the Drell-Yan process has been an important tool, used to determine the substructure of both the beam and target hadrons. Experimentally, we are now extending our knowledge of hadron structure from a single dimension—longitudinal momentum described by x_{Bj}—to include transverse degrees of freedom in the hadron as well.

Traditional deep inelastic scattering (DIS) experiments have offered some hints about the transverse structure of the hadron, but they necessarily leave some questions unanswered, with a complete answer requiring other measurements, most prominently Drell-Yan measurements, as well. The ability to measure the transverse structure of hadrons in both DIS and Drell-Yan will enable a test of the universality of transverse momentum dependent parton distributions (TMD) and, more generally, of the present understanding of (TMD) factorization theorems and color charge flow in QCD. The Sivers function which arises from final-state interactions in DIS, but initial-state interactions in Drell-Yan is believed to have opposite sign in the two processes. Experimentalists have only recently been able to extract the Sivers function from DIS scattering. Soon, a new generation of Drell-Yan experiments will also be able to address this distribution.

Questions addressed by this workshop included:

- What is the theoretical basis for expecting a change in sign of the Sivers function when probed with Drell-Yan scattering? What are the implications of an experimental evidence for no sign change?
- Is there only a sign change, with a universal magnitude for the Sivers function?
- How much do we know the shape of the Sivers function? In order to reconcile the outcome of calculations in TMD- and collinear-factorization, does the Sivers function need to have a node?
- What do violations of the Lam-Tung relation for Drell-Yan imply, in general and in terms of the TMD?
- What can be measured about the structure of the pion and kaon with Drell-Yan?
- How is the EMC effect manifest in Drell-Yan scattering?
- What is the underlying mechanism of the generation of the hadron's sea quark distributions?

While the first of these questions is focused on polarized Drell-Yan experiments, it is important to remember that there still remain issues of hadron structure that can only be directly addressed with unpolarized (polarization averaged) Drell-Yan measurements.

SPEAKERS:

W. Vogelsang *(U of Tübingen, Germany)*

J.-C. Peng *(U of Illinois at Urbana-Champaign, USA)*

V. Barone *(U of Piemonte Orientale and INFN, Italy)*

M. Garcia Echevarria *(U of Complutense de Madrid, Spain)*

C. Roberts *(Argonne National Laboratory, USA)*

A. Prokudin *(Thomas Jefferson National Accelerator Facility (JLab), USA)*

A. Bacchetta *(U of Pavia and INFN, Italy)*

S. Melis *(ECT*, Italy)*

K. Nakahara *(U of Maryland, USA)*

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

R. Pasechnik *(Lund U, Sweden)*

I. Belotelov *(Joint Institute for Nuclear Research Dubna, Russia)*

B. Pasquini *(U of Pavia and INFN, Italy)*

Z. Lu *(U of Southeast China)*

K.O. Eyser *(U of Brookhaven National Laboratory, USA)*

C. Dutta *(U of Michigan, USA)*

M. Destefanis *(U of Torino and INFN, Italy)*

R. Akhynzyanov *(Joint Institute for Nuclear Research, Dubna Russia)*

M. Schlegel *(U of Tübingen, Germany)*

C. Quintans *(LIP Lisboa, Portugal)*

O. Nachtmann *(U of Heidelberg, Germany)*

E. Roberto Nocera *(U of Milano, Italy)*

P. Zavada *(Institute of Physics Prague, Czech Republic)*

I. Gabdrakhmanov *(Joint Institute for Nuclear Research, Dubna Russia)*

M. Radici *(INFN – Pavia, Italy)*

N.C.R. Makins *(U of Illinois at Urbana-Champaign, USA)*

SCIENTIFIC REPORT:

As the title suggests, the unifying theme of this workshop was probing hadronic structure with the Drell-Yan process. The workshop began and ended with excellent summaries of the experimental and theoretical situation regarding hadron structure and the Drell-Yan reaction, and the presentations in between showed clear details of the theoretical and experimental status of individual aspects of hadron structure that can be measured with the Drell-Yan process.
Through choices in kinematics, beam hadron and beam or target polarization, experimentalists can "selectively" study these effects in either sea or valence quarks. We were reminded of how this has been exploited in past and current Drell-Yan experiments to measure the longitudinal partonic structure of the proton

Much of the workshop concentrated on transverse momentum distributions (TMDs). Significant time was spent discussing TMD factorization and collinear factorization. TMD factorization is clearly an emerging but rapidly growing field of study.

Much of the TMD discussion was focused on the Sivers function as measured by the Drell-Yan process and the implications of this measurement on the understanding of QCD. Several collaborations presented their plans to measure the transverse single-spin asymmetry with Drell-Yan from which the Sivers function can be extracted. Again, depending on the beam species and kinematics, the Sivers function can be determined separately for valance and sea quarks. Other TMD measurements possible with the Drell-Yan reaction include the Boer-Mulders distribution that can be measured through angular distributions from unpolarized Drell-Yan reactions. There already exists some data on angular distributions and future experiments, both unpolarized and polarized (spin averaged), will be able to greatly contribute to determining the Boer-Mulders distribution.

We were reminded that there are still important aspects of pion and kaon structure, which can be predicted by theory, to be measured. Given the lack of a stable pion or kaon target, pion- or kaon-induced Drell-Yan is the only practical way to make these measurements.

Results and Highlights

This Workshop provided a very useful opportunity for the community of physicists who study the structure of hadrons using the Drell-Yan reaction as a probe to discuss their research, both experimental and theoretical, focusing on currently and future measurements. This meeting was especially useful in that experimentalists could discuss with theorists what *could* be measured and theorists could discuss with experimentalists what *should* be measured. In addition, all participants gained a historical perspective by being reminded of what *has* been measured in experiments, primarily at CERN and Fermilab.

Much of the workshop concentrated on the understanding and measurement of Transverse Momentum parton Distributions (TMDs). Experimentalists benefited from the theoretical discussion of TMD factorization and obtaining TMD's from unpolarized Drell-Yan data. Two experimental highlights of the workshop were the upcoming COMPASS measurements of pion induced Drell-Yan on a polarized target, which will allow the Sivers function to be extracted with Drell-Yan, and the possibilities of an additional polarized Drell-Yan experiment at Fermilab later this decade.

It was observed that in the Drell-Yan reaction, in addition to the existence of several "center-of-mass" frames of reference (*e.g.* the Collins-Soper or Gottfried-Jackson frames) there exists and ambiguity in the definitions of angles. A convention was adopted by the participants, extending the Trento convention [Bacchetta *et al.* Phys. Rev. D70 117504 (2004)] and the INT Transverse Momentum notations [arXiv:1108.1713] to include definitions of the angular variables relative to the spin of the polarized hadron. We plan to post this convention on the arXiv server soon.

Finally, this workshop was informally the third in a series of Drell-Yan workshops that have taken place at CERN in 2010 and at Brookhaven in 2011. With the sustained interest in measurement of hadronic structure with the Drell-Yan process, there was now a discussion of making this workshop a regular series.

3.3.6 THE NUCLEAR DIPOLE POLARIZABILITY AND ITS IMPACT ON NUCLEAR STRUCTURE AND ASTROPHYSICS

DATE: June 18 - 22, 2012

ORGANIZERS:

Witold Nazarewicz *(Department of Physics & Astronomy, USA)*
Peter von Neumann-Cosel *(Institut für Kernphysik, TU Darmstadt, Germany)*
Paul-Gerhard Reinhard *(Universität Erlangen, Germany)*
Achim Schwenk *(TU Darmstadt, Germany)*

NUMBER OF PARTICIPANTS: 44

MAIN TOPICS:

The workshop concentrated on reporting and understanding recent measurements of the nuclear dipole excitation strength, particularly at low energies, with a focus on electric excitations. The related observables have relations to the neutron radius and neutron skin in nuclei, which are also currently under investigation. Both quantities play a key role in improving the predictive power of nuclear structure theory in the isovector channel. In turn, this has a strong impact on understanding the structure of neutron stars and neutron-rich environments in astrophysics. The following topics have been discussed in detail at the workshop:

- Experimental methods
- Pygmy dipole resonance and low-energy electric dipole strength
- Electric dipole polarizability: properties and relations to other observables
- Symmetry energy and the electric dipole response
- Low-energy magnetic dipole strength
- Impact on astrophysics
- Impact on fundamental symmetries

SPEAKERS:

B. Agrawal *(U of Kolkata, India)*

A. Bauswein *(MPA München, Germany)*

K. Boretzky *(GSI, Germany)*

M. Brenna *(U of Milan, Italy)*

B.A. Brown *(MSU, USA)*

F. Crespi *(U of Milan, Italy)*

J. Dobaczewski *(U of Warsaw, Poland)*

J. Endres *(Cologne, Germany)*

J. Engel *(UNC, USA)*

S. Frauendorf *(U of Notre Dame, USA)*

K. Hebeler *(OSU, USA)*

C. Horowitz *(U of Indiana, USA)*

T. Inakura *(RIKEN, Japan)*

M. Kortelainen *(U of Jyväskylä, Finland)*

K. Kumar *(U of Mass, USA)*

J. Lattimer *(Stony Brook, USA)*

H. Lenske *(U of Gießen, Germany)*

E. Litvinova *(GSI, Germany)*

M. Matsuo *(U of Niigata, Japan)*

N. Paar *(U of Zagreb, Croatia)*

P. Pakanstontantinou *(U of Orsay, France)*

I. Poltoratsa *(U of Darmstadt, Germany)*

V.Y. Ponomarev *(U of Darmstadt, Germany)*

J. Piekarewicz *(FSU, USA)*

N. Pietralla *(U of Darmstadt, Germany)*

X. Roca Maza *(U of Milan, Italy)*

C. Romig *(U of Darmstadt, Germany)*

H. Sagawa *(U of Aizu, Japan)*

W. Satula *(U of Warsaw, Poland)*

D. Savran *(GSI, Germany)*

R. Schwengner *(U of Rossendorf, Germany)*

S. Siem *(U of Oslo, Norway)*

P.A. Souder *(U of Syracuse USA)*

A. Tamii *(RCNP, Japan)*

I. Tews *(U of Darmstadt, Germany)*

A. Tonchev *(HIGS, USA)*

A. Zilges *(U of Cologne, Germany)*

SCIENTIFIC REPORT:

Recent experiments have provided high quality information on the distribution of electric and magnetic dipole strength in nuclei. Of particular interest is the low-energy strength, below the giant resonance. There are, in fact, various independent experimental techniques: inelastic photon, proton and alpha scattering, and heavy-ion Coulomb excitation. Each method has its strengths and weaknesses concerning sensitivity, background problems, and possible model dependence in the analysis. The related open problems were discussed extensively. In spite of the experimental difficulties, it has become apparent that high quality experimental data on electric isovector and isoscalar dipole strength are now available. Moreover, the photon and proton scattering experiments deliver at the same time the magnetic dipole strength, which provides very useful information on spin excitations.

Measurements of the neutron radius in heavy nuclei represent a long-standing challenge, which has been tackled by several methods such as particle scattering, anti-protonic atoms, and parity-violating electron scattering. In particular, the parity-violating electron scattering is very promising, as it allows a nearly model independent analysis. The method is, however, extremely demanding. The experimental requirements for a reliable measurement and a careful error estimate on the extracted neutron radius were discussed in detail.

All these new data constitute invaluable input for theoretical developments, in particular based on nuclear density functional theory and its extensions, and ab-initio chiral effective field theory. The experimental information is particularly important because it addresses isovector properties, which are not so well controlled by existing data on nuclear ground-state properties. Some global features can be summarized by two bulk properties: symmetry energy J and the slope of the symmetry energy L. It has been extensively discussed what experimental information sets limits on these two key properties of nuclear matter. It has been concluded that the polarizability and the neutron radius are crucial in this respect. Less direct is the information on the low-energy dipole strength, often called “pygmy strength”. It has some impact on J and L, but also on other bulk properties such as incompressibility, effective mass, and sum rule enhancement. Thus the “pygmy strength” can perhaps be useful in a large-scale analysis surveying bulk isovector and isoscalar properties. A major task for the near future remains to provide a robust definition of the low-energy strength to allow clear comparisons between theory and experiment.

Neutron matter in neutron stars and other extreme environments plays a crucial role in astrophysics. For neutrons, all many-body forces are predicted in chiral effective field theory, and, therefore, microscopic calculations can provide key constraints for neutron matter and for the symmetry bulk properties J and L. These have a strong impact on the structure of neutron stars, but the connections go both ways. On one hand, observations (e.g., of neutron star radii and masses) set limits on isovector parameters. On the other hand, neutron matter calculations and isovector information from experiment provide better constraints on astrophysical properties.

Results and Highlights:
The workshop brought together experts from different research groups and different areas of physics. Much time was devoted to discussions, both during the presentation and dedicated discussion sessions. The major benefit of the workshop is a deeper understanding of experimental results and theoretical interpretations, defining outstanding open questions and paths forward. The major outcome is a number of homework problems and formation of new collaborative efforts. In the following, we list briefly the most debated topics:

1) There exists a strong, most probably direct, relation between the dipole polarizability and the symmetry bulk properties J and L. The same holds for the neutron radius. It needs yet to be worked out in more detail how experimental and theoretical uncertainties on these observables impact errors on J or L and subsequently influence uncertainties of astrophysical predictions.

2) Photo-excitation and de-excitation cross sections at low energy constitute important input for astrophysical r-process simulations. The new data allow to constrain theoretical models which are then used to predict crucial cross sections in r-process nuclei. A non-trivial problem is the proper treatment of temperature in evaluating the cross sections.

3) An involved question at the theoretical side is the impact of complex configurations (2ph, 3ph, ...) on the strength distributions at low and medium energies below the GDR. Large effects have been seen due to Landau damping. However, to be meaningful, the computations should yet be carefully scrutinized for the effects of center-of-mass and particle number breaking. Furthermore, one has still to develop robust integrated observables for comparison with data as a one-to-one correspondence of the spectral details cannot be expected.

4) Probably the most intensely discussed topic was the interpretation of low-lying E1 strength as “pygmy resonance”. Opinions differ widely from associating the “pygmy” with a well-developed collective mode to calling the low lying strength the “ashes” of former one-particle-hole states. The discrepancy is due to a different understanding of collectivity. On the experimental side, separation of the “pygmy” strength from the lower tail of the GDR strength is difficult.

5) A new interesting topic was the interpretation of the observed low-energy isoscalar E1 strength observed in, e.g., alpha-alpha studies. The theoretical challenge is to relate the new data to other nuclear observables and to bulk properties of nuclear matter.

6) Many experimental evaluations rely on the Brink-Axel hypothesis to disentangle ground-state gamma transitions from the swamp of other transitions in the gamma cascade. Theorists question that hypothesis when applied to all states in the spectrum and not only to the selected collective ones. New tests based on excitation data linked to the decay by the principle of detailed balance are likely to put this matter to rest.

Support
In addition to ECT* funding, this ECT* workshop was supported by funds of the ExtreMe Matter Institute (EMMI) and by the Helmholtz International Center for FAIR (HIC for FAIR). The organizers would also like to thank Ines Campo for the local organization, kind assistance, and wonderful friendliness.

3.3.7 ELECTRO-WEAK PROBES: FROM LOW-ENERGY NUCLEAR PHYSICS TO ASTROPHYSICS

DATE: June 25 – 29, 2012

ORGANIZERS:

Sonia Bacca *(TRIUMF, Canada)*
Doron Gazit *(Hebrew University of Jerusalem, Israel)*
Sofia Quaglioni *(LLNL, USA)*

NUMBER OF PARTICIPANTS: 28

MAIN TOPICS:

The main goal of the workshop was to present the state of the art results from the theoretical and experimental communities studying electro-weak reactions on nuclei for low-energy nuclear physics, fundamental symmetries, and nuclear astrophysics. From the theoretical side, the emphasis was on the effective field theory (EFT) approach to the subject. Many examples of EFT based forces and scattering operators were given, allowing predictive calculations. From the experimental side, the new experiments worldwide studying electro-weak interactions with nuclei were presented, emphasizing new measurements as well as needed theoretical contributions.
The main topics were:

- Theoretical and experimental efforts regarding precision studies of electro-weak reactions.
- Exotic reactions and halo nuclei.
- Beta decays probing beyond the standard model physics.
- New facilities and their prospect for studying nuclear electro-weak reactions.
- Studies of fundamental symmetries with low-energy nuclear reactions.

SPEAKERS:

N. Barnea *(Hebrew U of Jerusalem, Israel)*

B. Davids *(TRIUMF, Canada)*

P. Descouvemont *(ULB Brussels, Belgium)*

M. Distler *(U of Mainz, Germany)*

J. Enders *(TU Darmstadt, Germany)*

G. Feldman *(George Washington U, USA)*

C. Giusti *(U of Pavia, Italy)*

P. Grabmayr *(U of Tübingen)*

V. Gudkov *(U of South Carolina, USA)*

A. Guglielmetti *(U of Milano, Italy)*

M. Hass *(Weizmann Institute, Israel)*

W. Horiuchi *(Hokkaido U, Japan)*

S. Koelling *(U of Bochum, Germany)*

W. Leidemann *(U of Trento, Italy)*

J. Menendez *(TU Darmstadt, Germany)*

D. Middleton *(U of Mainz, Germany)*

G. Orlandini *(U of Trento, Italy)*

E. W. Ormand *(Lawrence Livermore National Laboratory, USA)*

T.-S. Park *(SKKU, Korea)*

S. Pastore *(ANL, USA)*

L. Platter *(ANL, USA)*

T. Shima *(RCNP, Osaka U, Japan)*

E.Truhlik *(Institute of Nuclear Physics, Academy of Sciences of the Czech Republic)*

P. Vogel *(Caltech, USA)*

V. Zamfir *(IFIN-HH Bucharest-Magurele, Romania)*

SCIENTIFIC REPORT:

Low energy nuclear physics has reached a certain maturity these days due to advancements in both experimental and theoretical efforts, especially in studies of electro-weak reactions of nuclei with fundamental probes. The theoretical part has been heralded by the development of EFT based forces as well as consistent electro-weak scattering operators, alongside with the developments in few- and many- body methods for strongly interacting systems, such as nuclei. These provide two needed ingredients for a predictive theory, i.e., a relation to the fundamental theory and an accurate mathematical solution.

The experimental part is reflected in worldwide facilities, some already operating and some under constructions. The former group was represented in the workshop by MAMI, S-DALINAC, Hiγs, S-Dalinac, TRIUMF facilities, LUNA, and $0\nu\beta\beta$ searches. The latter were covered by FAIR, FRIB, Saraf, and ELI-NP. These have a common feature: all are unique, allowing them to probe accurately nuclear reactions needed for pin-pointing the properties of nuclei, and a synergetic contribution to the needs of other branches of physics, from the fundamental symmetries of QCD and the validity of the Standard Model, to the nuclear reactions which are the microscopic motors of astrophysical phenomena.

The workshop hosted an equal amount of key-experimentalists and theorists, with expertise covering the areas of EFT, nuclear many-body problems with EFT potentials/currents, electro-weak excitations of nuclei, nuclear astrophysics. We explored theory-experiment connections that have the potential to advance the study of electro-weak probes and bring cross-fertilization between low-energy nuclear physics and other branches of physics. We made an effort to emphasize:

- The abilities and limitations of the theory.
- The uncertainties and assumptions in experiments.
- The differences and disagreements between similar measurements/calculations.
- The theory needs of on-going and planned experiments.

Results and Highlights

The Workshop was a very useful opportunity to exchange ideas and views between theory and experiments. This was acknowledged by many participants, which seemed to value the very good, as well as unusual, theoreticians to experimentalists ratio.

We emphasize a few of the many highlights of the workshop:

- It seems like the long-standing disagreement between SUBARU measurements of ^{4}He photodisintegration and other measurements can be related to a systematic error in the effort. This is hinted in a 26 MeV measurement of New SUBARU which, at this stage, seems inconsistent with the older SUBARU experiments.
- Minor differences, if any, were resolved in the workshop, regarding various EFT derivations of electro-magnetic scattering operators. These reactions seem to be dominated by long-range operators and three low energy constants. Some

differences were found in the incorporation of the non-relativistic reduction into the power counting.

- The six-body systems, ^{6}Li and ^{6}He, attract vast activity. Worldwide efforts exist to precisely study the electron-neutrino correlation in ^{6}He beta-decay, which is a window to beyond the standard model physics. The halo-structure of these nuclei is a window to the exotic possibilities of the nuclear regime. Compton scattering measurements are being published.
- Novel theoretical approaches now allow probing resonances and continuum states. The accurate theory can select between contradicting experiments and pave the direction for experiments.
- There are many needs for nuclear physics predictions in nuclear astrophysics, $0\nu\beta\beta$ searches, and in nuclear astrophysics.

At the end of the workshop it was widely agreed that a new dawn of precision era for low energy physics is rising, and that nuclear physics is a synergetic bridge between many fields of physics, as well as a viable problem in physics itself.

3.3.8 INITIAL STATE FLUCTUATIONS AND FINAL STATE CORRELATIONS IN HEAVY-ION COLLISIONS

DATE: July 2 – 6, 2012

ORGANIZERS:

M. Luzum (*IPhT Saclay, France*)
H. Petersen (*Duke, USA*)
A. Adare (*Yale, USA*)

NUMBER OF PARTICIPANTS: 32

MAIN TOPICS:

The general theme of the workshop concerned bulk observables in relativistic heavy-ion collisions, and especially recent developments regarding event-by-event fluctuations.
The main topics were

- Initial state physics in heavy ion collisions
- Transport coefficients of the quark gluon plasma
- Bulk evolution of the collision system and event-by-event approaches
- Exploration of higher harmonic flow observables and other long-range correlations
- Longitudinal dynamics and correlations
- New experimental results from RHIC and LHC

SPEAKERS:

M. Alvioli (*ECT*, Italy*)

A. Bilandzic (*Copenhagen, Denmark*)

P. Bozek (*Rzeszow U, Poland*)

W. Broniowski (*J Kochanowski U, Poland*)

A. Dumitru (*Baruch College*)

S. Gavin (*Wayne State*), USA

C. Gale (*McGill U, Canada*)

U. Heinz (*OSU, USA*)

C.-M. Ko (*TAMU, USA*)

R. Lacey (Stony Brook, USA)

W. Li (*MIT, USA*)

M. Luzum (*IPhT Saclay, France*)

S. Mohapatra (*Stony Brook*, USA)

G. Moschelli (*Frankfurt, Germany*)

B. Mueller (*Duke U, USA*)

K.i Murase (*U of Tokyo, Japan*)

Y.i Nara (*Akita International U, Japan*)

J.-Y. Ollitrault (*IPhT, CEA Saclay, France*)

A. Poskanzer (*LBNL, USA*)

Z. Qiu (*OSU, USA*)

E. Retinskaya (*IPhT, CEA Saclay*, France)

G. Roland (*MIT*, USA)

B. Schenke (*BNL*, USA)

M. Stephanov (*UIC, USA*)

D. Teaney (*Stony Brook, USA*)

X.-N. Wang (*LBN, USAL*)

K. Werner (*Nantes, France*)

SCIENTIFIC REPORT:

Relativistic heavy-ion collisions probe the extreme high-temperature regime of the strong interactions. Specifically, the goal is to create and characterize a deconfined state of matter – the quark-gluon plasma (QGP) – and investigate the nature of a deconfinement phase transition. In addition, many other aspects of QCD can also be studied, such as low-x physics and mechanisms for fast thermalization.

The Relativistic Heavy Ion Collider (RHIC) has been studying these topics experimentally since 2000, and was joined last November by the Large Hadron Collider (LHC), whose inaugural heavy-ion run produced collisions at an order of magnitude higher energy than at RHIC. In short, this workshop will focus on interpreting and understanding some of the first heavy-ion data from the LHC as well as brand new data still coming from RHIC, and providing direction for future measurements.

Since the very first data were taken at RHIC, one of the most important experimental signatures of the QGP has been the azimuthal anisotropy in correlations between detected particles. In particular, the large value of the so-called "elliptic flow" observable, indicating strong collective behaviour of the collision system, has been one of the most important and most studied measurements. It provided one of the strongest pieces of evidence leading to the conclusion that a strongly-coupled, low-viscosity, QGP medium is created in these collisions.

Elliptic flow refers to a second Fourier component of the azimuthal distribution of emitted particles. When two identical nuclei collide at a finite impact parameter, the overlap region is an oblong shape in the transverse plane. In the standard picture, the system comes to an approximate local equilibrium and expands according to (viscous) hydrodynamics. The elliptic asymmetry in the initial state is transformed during the collective expansion into an asymmetry in the final momentum distribution of the detected particles. The efficiency of this transformation is sensitive to medium properties such as viscosity.

Random variations in the initial distribution of nucleons, due to quantum fluctuations, lead to event-by-event fluctuations in the initial geometry. Naively, in a symmetric collision system, odd harmonics in the azimuthal momentum distribution are expected to be negligible. It has only recently been realized that these fluctuations are not, in fact, negligible, and that by taking them into account one can explain all long-range pair correlation data, which was previously not understood. Further, with this realization comes new potential "flow" observables – e.g., the natural extension of elliptic flow to odd harmonics such as "triangular flow", as well as a number of other correlations.

These new developments were the major highlight of Quark Matter 2011 – the largest and most important conference in the field. Every active experimental collaboration from both LHC and RHIC presented brand new (preliminary) measurements of some of these new observables. There has been much excitement about the potential for these new measurements to provide tight constraints on theory and to extract precise quantitative properties of the QGP, as well as to shed light on the (as-yet poorly understood) non-equilibrium QCD dynamics of the initial stage of the collision.

Since these developments are in such an early stage of maturity, however, there was a strong need for a workshop such this one, to construct a consistent picture of the current understanding of the community and set a course for future investigation.

Specific questions addressed during this workshop included:

- What is the best model for the initial state? What constraints can we already put on it from new data?
- How exactly is the initial spatial anisotropy converted to final-state momentum anisotropy? Can we understand the hydrodynamic response in general, or do we need to run event-by-event hydrodynamic simulations for every candidate initial condition?
- What is the current uncertainty in the viscosity of the QGP, and what is the best strategy for reducing it?
- What else can the newly-measured observables teach us, and what other flow observables should be measured?
- What are the prospects for experimentally and/or theoretically distinguishing between initial-state and collective effects?
- Can one disentangle various sources of fluctuations?

What are other open issues?

Results and Highlights

Highlights of the workshop include the following results:

It is agreed that all known sources of fluctuations should be included in models of the initial stages of heavy-ion collisions. In particular, implementations of fluctuations in particle production into Monte Carlo models should be continued, making sure to obey experimental constraints like multiplicity distributions in proton-proton collisions, and differences in recent implementations should be better understood.

Much progress has been made in characterizing the hydrodynamic response to the initial conditions in terms of simple relationships between properties of the initial density and flow correlations in the final particle distributions. This is providing us with much insight, but it is an open question how far this can be taken and whether brute-force event-by-event calculations will always be necessary for describing certain data.

More standardization is necessary in the field. Examples include definitions of initial anisotropies epsilon_n, variations of Glauber Monte Carlo models, and experimental flow analyses.

Subtleties are present in comparing theoretical calculations to experimental data and more care needs to be taken in the future in order to compare the correct quantities.

3.3.9 SCATTERING AMPLITUDES: FROM QCD TO MAXIMALLY SUPERSYMMETRIC YANG-MILLS THEORY AND BACK

DATE: July 16 – 20, 2012

ORGANIZERS:

Andrei Belitsky *(Arizona State University, USA)*
Gregory Korchemsky *(Institut de Physique Théorique, Saclay, France)*

NUMBER OF PARTICIPANTS: 40

MAIN TOPICS:

The last several years had witnessed tremendous advances in the development of perturbative and nonperturbative techniques for gauge theories, specifically targeting the theory of strong interaction, Quantum Chromodynamics. A remarkable progress was achieved in calculating anomalous dimensions governing scaling violations of high-energy processes based on integrability and multiparticle scattering amplitudes relying on techniques such as unitarity and dualities. The goal of the workshop was to bring together physicists working on different aspects of QCD and related gauge theories ranging from multiloop perturbative calculations to gauge/string correspondence to discuss recent discoveries, share ideas and create fruitful atmosphere for establishment of new collaborations. The main topics were:

- Multigluon and multiloop amplitudes and LHC Physics;
- Dualities in N=4 super Yang-Mills theory and their potential use for QCD;
- Integrability in QCD and cousin gauge theories as a tool for calculation of observables.

SPEAKERS:

B. Basso *(Princeton U, USA)*

N. Beisert *(ETH, Zurich, Switzerland)*

R. Boels *(U of Hamburg, Germany)*

A. Brandhuber *(Queen Mary, United Kingdom)*

S. Caron-Huot *(IAS, USA)*

I. Cherednikov *(JINR, Dubna, Russia)*

N. Drukker *(King's College, Great Britain)*

V. del Duca *(Frascati, Italy)*

C. Duhr *(ETH, Zurich, Switzerland)*

B. Eden *(Humboldt U, Germany)*

E. Gardi *(Edinburgh U, United Kingdom)*

A. Goncharov *(Yale U, USA)*

A. Gorsky *(ITEP, Moscow, Russia)*

S. He *(AEI, Potsdam, Germany)*

J. Henn *(IAS, USA)*

P. Heslop *(Durham U, United Kingdom)*

H. Johansson *(IPhT, Saclay, France)*

V. Khoze *(IPPP, Durham U, United Kingdom)*

D. Kosower *(IPhT, Saclay, France)*

L. Magnea *(INFN, Turin, Italy)*

Y. Makeenko *(ITEP, Moscow, Russia)*

L. Mason *(Oxford U, United Kingdom)*

H. Nastase *(IFT, San Paulo, Brazil)*

D. O'Connell *(NBI, Copenhagen, Denmark)*

R. Roiban *(Penn State, USA)*

E. Sokatchev *(LAPTH, Annecy, France)*

G. Sterman *(YITP, Stony Brook, USA)*

C. Thorn *(Florida U, USA)*

G. Travaglini *(Queen Mary, United Kingdom)*

J. Trnka *(Princeton U, USA)*

A. Tseytlin *(Imperial College, United Kingdom)*

P. Vanhove *(IHES and IPhT, Saclay, France)*

C. Vergu *(ETH, Zurich, Switzerland)*

Y. Yang *(Hamburg U, Germany)*

SCIENTIFIC REPORT:

High precision tests of the Standard Model (SM) at LHC and discovery of the physics beyond SM require accurate estimates of contaminating backgrounds. The LHC results call for a theoretical understanding of strong-interaction rates of multiparticle production. While at these energies QCD is amenable to perturbative treatment, traditional computational techniques based on Feynman diagrams hit a brick wall due to factorial explosion in the number of contributing graphs when one attempts to go to two loop order in the strong coupling and/or more than two particles produced in the final state. These calls were answered over a decade ago when dedicated efforts were directed towards development of systematic tools for calculation of multiparticle multiloop amplitudes in QCD. One of the crown jewels of these studies was the elaboration of unitarity-based methods which allowed one to bypass Feynman graph calculations. More recently, starting with Witten's work on twistor-string theory, there were important advances on the front of recursive techniques for construction of multiparticle scattering amplitudes. Many more important discoveries had occurred in last few years. These include but are not limited to the use of: AdS/CFT for the supersymmetric sibling of QCD to probe the string coupling limit of scattering amplitudes and realization of the latter as minimal surfaces spanned on piecewise Wilson loops in space-time; discovery of dual superconformal symmetry of the tree S-matrix and its controlled breaking by ultraviolet divergencies due to cusps present on the contour once one is turning on the quantum corrections; realization that dual and ordinary superconformal algebras can be merged into a Yangian and that there is a natural Grassmanian representation of planar amplitudes making the former explicit. Some of the more universal properties uncovered in recent years relate quantum corrections to scattering amplitudes and motivic structure of the polylogarithms. These findings, together with earlier discoveries of integrability of the spectrum of anomalous dimensions of gauge invariant operators in maximally supersymmetric theory, point out that N=4 might the first example of an exactly solvable four-dimensional gauge theory. Since one has strong evidence pointing towards this, the hope is that one may draw lessons for QCD in order to tackle its strong-interaction dynamics.

The workshop brought together QCD practitioners and experts on formal aspects of gauge theories with a stress on applications to scattering amplitudes and mathematicians. The goal was to bring them together for cross fertilization and bolster further developments in this rapidly developing field. The main emphasis was focused on the following topics: integrals and integrands of perturbative quantum field theories and their motivic structure; gauge/gravity dualities and strong coupling results; Wilson loops/Correlation functions/Amplitudes dualities; scattering amplitudes in (super)gravity and string theory and their ultra-violet behavior. All materials from the Workshop including the program and the list of talks can be found at the web site: https://sites.google.com/site/trentoworkshop/.

Results and Highlights

The conference was a true success. The venue and the structure of the meeting triggered productive discussions among the participants and led to a number of new research efforts. For instance, the analysis of integro-differential equations for scattering amplitudes though the super-Wilson loop/superamplitude duality received a further boost. The study of energy-energy correlations, which are infrared-safe weighted differential cross sections, was pursued through their relation to Euclidean correlation functions. The application of integrability techniques to scattering amplitudes was discussed using the dilatation operator of theory as a building block driving the form of leading discontinuities of scattering amplitudes. A framework that would allow one to predict the entire amplitude calls for understanding of the so-called impact factors within integrability-related formalism. Also the workshop managed to set up a crosstalk between QCD practitioners and mathematicians, highlighted by Alexander Goncharov's talk. More generally, the meeting allowed participants to get acquainted with general challenges of the modern approach to weak and strong coupling phenomena and the emphasis was made on refocusing the current efforts of workers in the field from model gauge theories, like N=4 super Yang-Mills theory, to QCD, based on recent advances made in the former.

The results of collaborations and discussions initiated at the meeting yielded publications that acknowledge ECT* as a venue where these ideas were pursued.

3.3.10 SPECTRAL PROPERTIES OF COMPLEX NETWORKS

DATE: July 23 - 27, 2012

ORGANIZERS:

G. Caldarelli *(CNR, Roma, Italy)*
T. Guhr *(U of Duisburg-Essen, Germany)*
N. Litvak *(U of Twente, Netherlands)*
D. Shepelyansky *(CNRS-IRSAMC, U of Toulouse, France)*

NUMBER OF PARTICIPANTS: 39

MAIN TOPICS:

Topics discussed included:

- Complex networks
- Markov chains
- Perron-Frobenius operators
- Google matrix
- Spectral analysis
- Disordered systems
- Information retrieval
- Search engines
- PageRank analysis
- Random matrix theory
- Quantum chaos
- Directed flow in economy
- Bio-cell networks

SPEAKERS:

A. Benczur, (*Hungarian Academy of Sciences, Hungary*)

G. Bianconi (*Northeastern U, USA*)

P. Blanchard (*U of Bielefeld, Germany*)

A. Chepelianskii (*Cambridge U, U.K.*)

S. Dorogovtsev (*U of Aveiro, Portugal*)

Y.-H. Eom (*ISI foundation, Italy*)

L. Ermann (*CNEA, Argentina*)

S. Fortunato (*Aalto U, Finland*)

K. Frahm (*U Toulouse, France*)

A. Gabrielli (*ISC –CNR, Italy)*

J. Galtier (*Orange Labs, France*)

B. Georgeot (*CNRS/U Paul Sabatier, France)*

K.-I. Go (*Korea U, South-Korea*)

T. Guhr (*U Duisburg-Essen, Germany*)

T. Hasegawa (*Tohoku U, Japan*)

E. Izhikevich, E. (*Brain Corporation, USA*)

H. Jeong (*KAIST, South-Korea*)

A. Kaltenbrunner (*Barcelona Media, Spain*)

B. Li (*NUS, Singapore*)

N. Litvak (*U Twente, Netherlands*)

M. Olvera-Cravioto (*Columbia University, USA*)

A. Panconesi (*U Sapienza, Italy*)

F. Radicchi (*Universitat Rovira i Virgili, Spain*)

A. Scala (*CNR-ISC, Italy*)

F. Silvestri (*ISTI - CNR, Italy*)

L. Sirko (*Institute of Physics PAS, Poland*)

S. Thurner (*Medical University of Vienna, Austria*)

P. Van Mieghem (*TU Delft, Netherlands*)

S. Vigna (*U of Milano, Italy*)

Y. Volkovich (*Barcelona Media, Spain*)

V. Zlatic (*U Zagreb, Croatia*)

SCIENTIFIC REPORT:

On the scale of the past ten years, modern societies have developed enormous communication and social networks. Their classification and information retrieval becomes a formidable task for the society. Various search engines have been developed by private companies which are actively used by Internet users. Due to the recent enormous development of World Wide Web, social and communication networks, new methods have been invented to characterize the properties of these networks on a more detailed and precise level. It is highly important to discuss and develop new tools to classify and rank enormous amount of network information in a way adapted to internal network structures and characteristics. New characterization of complex networks will allow to manage in an efficient and rapid way information extraction for social networks, communication, biocell and other networks. Such type of problems of complex networks and Markov chains appear in various fields of science. The development of interdisciplinary approach to complex networks, which combines expertise from computer science, theoretical physics, mathematics economy and biology, was the aim of this workshop.

Results and Highlights

The workshop was attended by 39 participants from USA (3), Japan (1), S. Korea (2), Singapore (2), Argentina (1), France (6), Germany (2), UK (1), Italy (9) and other EU countries. However, the most important point is that the workshop attracted participants from very diverse sciences including theoretical and experimental physics, mathematics, computer science, engineering, sociology, econophysics, as well as industrial/commercial/social companies like Orange Labs (France), Brain Corporation (USA) and Barcelona Media (Spain). Thus, this workshop probably covered the largest number of related areas during the whole history of ECT*.

The program and slides of the workshop presentations are available at the Workshop website http://www.quantware.ups-tlse.fr/complexnetworks2012/

The main scientific research lines represented at the workshop included complex network analysis, links characterization, mathematical properties of graphs, PageRank and CheiRank algorithms for information retrieval, spectral analysis of the Google matrix of such directed networks as Twitter, Wikipedia, world trade network, graph-based ranking algorithms, large-scale modelling of the brain and epidemia propagation on networks.

During the week of the workshop the following useful applications of network analysis were discussed in a variety of systems by the speakers listed in parenthesis:

1st day:
PageRank analysis of network of Hollywood actors network (Vigna), mathematical aspects of disassortativity in large scale-free networks (Litvak), eigenvector properties of complex networks (Wang), entropy on complex networks (Thurner), aspects of degree distributions (Olvera-Cravioto), features of noise on complex networks (Li), multiplexity of networks (Go)

2nd day:
spectrum and eigenstates of Google matrix of directed networks with links to the problems of quantum chaotic scattering, fractal Weyl law and Ulam networks (Frahm), two-dimensional ranking of software codes, Wikipedia and other directed networks (Chepelianskii), democratic ranking of world countries via UN COMTRADE database of world trade (Ermann), ranking of trade products and countries (Gabrielli), analysis of universal features of citation networks(Fortunato and Eom), dynamics for assortative and disassortative networks (Scala), analysis of rumour spreading in social networks (Panconesi)

3rd day:
analysis of the SIS N-intertwined epidemic model (van Mieghem), tennis players ranking (Radicchi), links analysis of complex networks (Benczur), game of go as a complex network (Georgeot), large-scale modeling of the brain (Izhikevich), percolation on complex networks (Hasegawa)

4th day:
localization and spreading of diseases in networks (Dorogovtsev), statistical analysis of online discussions on social networks (Kaltenbrunner), experiments with quantum microwave graphs (Leszek), structural and geographic properties of online social interactions (Volkovich), dynamics and communities on directed complex networks (Jeong), critical phenomena on complex networks (Bianconi), spectral decomposition and community detection (Galtier)

5th day:
credits and the instability of the financial systems from a physics point of view (Guhr), random walks on graphs and spectral gap (Zlatic), spectral methods of network analysis (Silvestri), random walks and diffusion on networks (Blanchard).
It is clear that such a broad range of research aspects of modern network analysis requires exchange of expertise from various sciences and the ECT* provided this opportunity with its staff which created a family friendly atmosphere, easy internet access, nice lunches and dinners during the whole workshop period.

The opinion of the organizers is that such kind of interdisciplinary workshops fits very well in the scope of ECT*: nuclear physics opens here new research directions in various sciences (that happened already many times during the development of nuclear physics), it projects its prestige to these interdisciplinary workshops and at the same time it establishes new links between nuclear physics and related areas. This will thus be profitable in future both for nuclear physics and other sciences.

3.3.11 TOWARDS A RESOLUTION OF THE DOUBLE BETA DECAY PROBLEM

DATE: September 3 – 7, 2012

ORGANIZERS:

Sabin Stoica *(Horia Hulubei National Institute of Physics and Nuclear Engineering, Romania)*
Mihai Horoi *(Department of Physics,Central Michigan University, USA)*
Jouni Suhonen *(Department of Physics, University of Jyväskylä, Finland)*
Kai Zuber *(TU Dresden, Institut fuer Kern- und Teilchenphysik, Germany)*

NUMBER OF PARTICIPANTS: 26

MAIN TOPICS:

The general goal of the workshop was to review and debate the recent theoretical and experimental progress in the DBD searches and its connections with other neutrino investigations like neutrino oscillation data and possible LHC results.
Particularly, we wanted: 1) to review the recent theoretical developments for the computation of the NMEs, have a critical comparison between the different methods, with the goal to understand the discrepancies and reduce the errors in the obtained results; 2) to make an analysis of the mechanisms of occurrence of the $0\nu\beta\beta$ decay, with the goal to identify methods/ways to determine the leading one, e.g. by exploiting novel ways to compute the associated NMEs; 3) to review the present status and the future of DBD experiments, with the goal to understand the perspectives and the experimental limitations of the $0\nu\beta\beta$ decay searches; 4) to review the most recent neutrino oscillation data and future perspectives of accurate measurements of the neutrino mixing parameters.

The main topics were:

- Review and discuss recent progress of the double beta decay experiments.
- Review the methods of calculation of the DBD matrix elements and discuss their recent progress.
- Review and discuss other possible mechanisms which can contribute to DBD
- Low and high energy experiments in connection with DBD
- Present and future of DBD.

SPEAKERS:

J. Suhonen *(U of Jyväskylä, Finland)*
H. Ejiri *(RCNP Osaka, Japan)*
R. Bernabei *(U of Rome, Italy)*
Th. Rodriguez *(Darmstadt, Germany)*
S. Stoica *(FHH & IFIN-HH, Romania)*
F. Iachello *(Yale U, USA)*
S.R. Elliot *(LANL, USA)*
O. Civitarese *(U of La Plata, Argentina)*
M. Horoi *(Central Michigan U, USA)*
J. Menendez *(U of Darmstadt, Germany)*
J. Engel *(U of North Carolina, USA)*

A. Neacsu *(HHF and IFIN-HH, Romania)*

J. Kotila *(Yale U, USA)*

F. Piquemal *(CNBG, France)*

S. Petcov *(SISSA, Italy)*

J. Schiffer *(ANL, USA)*

B. Kay *(York U, UK)*

V. Lozza *(TU-Dresden, Germany)*

K. Zuber *(TU-Dresden, Germany)*

A. Poves *(Autonomous U of Madrid, Spain)*

S. Freeman *(University of Manchester, UK)*

D. Frekers *(U of Muenster, Germany)*

V.K.B Kota *(Ahmedabad U, India)*

R. Sahu *(Berhampur U, India)*

M. Redshaw *(Central Michigan U, USA)*

W. Rodejohann *(MPIK Heidelberg, Germany)*

SCIENTIFIC REPORT:

Double beta decay (DBD) is a rare radioactive process by which an even-even nucleus undergoes a transition into another even-even nucleus with the same mass number, but with the nuclear charge changed by two units. This process is attracting much attention due to the neutrinoless double beta ($0\nu\beta\beta$) decay mode, which can only occur by violating the conservation of the total lepton number. Thus, its discovery will definitely imply new physics beyond the Standard Model (SM). A strong interest for the $0\nu\beta\beta$ searches is related to the investigation of the neutrino properties. Particularly, it is the only known experiment capable of distinguishing between the Dirac and Majorana neutrinos, and it provides a method to determine the absolute mass of the electron neutrino in connection with neutrino oscillation data. Until now there is no confirmed experimental evidence for $0\nu\beta\beta$ decay (although a claim for detection was made around 2001) and currently there are many theoretical and experimental efforts to resolve the DBD problem.

Theoretically, the decay rate for $0\nu\beta\beta$ decay mode can be expressed as a product between a phase space factor (which depends on the decay mode), a nuclear matrix element (which depends on the mechanism and the nucleus) and an effective Majorana mass term. While the phase space factors are generally calculated with a good precision, the key ingredient for accurately extracting the neutrino mass is a precise knowledge of the nuclear matrix elements (NMEs). Different methods have been used to calculate them, based on different approximations/models: Quasi Random Phase Approximation (QRPA), the Interacting Shell Model (ISM), the projected Hartree Fock Bogolibov (PHFB) mean field, the Generating Coordinate Method (GCM) with energy-density functionals, Interacting Boson Model (IBM), each with its advantages and its drawbacks. Lately there has been significant progress of these calculations, with clear signs of convergence and with a validation of the traditional methods through improved approaches. However, there are still uncertainties that have to be understood and reduced, for a complete interpretation of the $0\nu\beta\beta$ decay results.

Another important open issue is related to the possible mechanisms that may contribute to $0\nu\beta\beta$ decay. The most analyzed is the process mediated by the exchange of light massive Majorana neutrinos (presented above), but other lepton violating processes might contribute as well.

On the experimental side, Heidelberg-Moscow, Cuoricino, NEMO3 and EXO-200 experiments have set limits on the Majorana neutrino mass term of the order of 0.2- 0.4 eV (equivalent to a half-life sensitivity of about 10^{25} y). Other experiments like GERDA, COBRA, CUORE, MAJORANA, SuperNEMO, SNO+ are either in the commissioning phase or in the final years of construction, aiming to improve the sensitivity with about one order of magnitude. Different experimental techniques are used and proposed, and different isotopes are under investigation. The general goal is to fully explore in the next future the degenerate and inverted mass hierarchy regions, in accordance with the neutrino oscillation data analysis.

Thus, the main themes which were addressed during the workshop referred to:

1) how reliable are the NMEs calculated with different methods and which ways to reduce the uncertainties?

2) which are other elements of uncertainty in estimating the $0\nu\beta\beta$ decay half-lives?

3) how would it be possible to identify the dominant mechanism of occurrence of the $0\nu\beta\beta$ decay?

4) which is the preset status of the $\beta\beta$ decay experiments and what sensitivity will be reached in the next future?

5) how complementary information from other experiments can help in the study of $0\nu\beta\beta$ decay?

Results and Highlights

The Workshop was a very useful opportunity to discuss and exchange ideas on the above mentioned themes and this was in fact perceived by all the participants.

The theoretical aspects of the $0\nu\beta\beta$ decay discussed during the workshop included the accurate calculations of the phase spaces, the nuclear structure part and the neutrino mass parameter, quantities which enter the half-lives. Accurate calculations of the phase spaces are still needed and the calculations should use an appropriate axial vector coupling constant (which effective value is essentially model dependent) g_A=1.25(1.269) and include a proper treatment of the atomic physics ingredients, like improved electron wave functions.

Concerning the nuclear aspects of the DBD several conclusions came out: i) there was a consensus on the form of the transition operator in the mass mode. It must include higher order terms in the nuclear current, proper nucleon dipole form factors, isovector and isoscalar. The consensus extends to the validity of the closure approximation for the calculation of the NMEs and to the use of soft (or no) short range correlations; ii) the discrepancies in the values of NMEs, obtained with different approaches, come mainly from the different structure of the wave functions used, particularly in the seniority structure of the wave functions that they produce; iii) in view these arguments, one can conclude that the QRPA, IBM and GCM tend to overestimate the NMEs, while the ISM give smaller values. On the other side, increasing the valence space of the ISM calculations tends to increase the NMEs, thus, one could see closer results between the two kind of approaches in the next future.

The particle physics aspects of $0\nu\beta\beta$ decay are related to the neutrino mass parameter. The “standard” interpretation is that the $0\nu\beta\beta$ decay is mediated by light and massive Majorana neutrinos and all other mechanisms potentially leading to $0\nu\beta\beta$ give negligible or no contribution. In this case, using the experimental half-lives limits and theoretical values for the phase spaces and NMEs, one can extract limits for the mass of the light Majorana electron neutrino. There is also a “non-standard interpretations, saying that there is at least one other mechanism leading to $0\nu\beta\beta$ and its contribution is at least of the same order as the light neutrino exchange mechanism. In this case one needs a multi-isotopes experimental determination in order to distinguish between different mechanisms. The $0\nu\beta\beta$ decay multidimensional analysisi is good for three reasons: credibility, test of NMEs and test of mechanisms. Important for the extraction of the neutrino properties are also complementary data coming from other experiments, like neutrino oscillation experiments and cosmic data. Further, it is worth to mention that lepton number violating processes can now be searched at LHC as well, and it the future there will be an interesting competition between low($0\nu\beta\beta$ decay) and high energy experiments for searching such beyond SM processes.

Experimental aspects of the DBD were also discussed extensively during the workshop. One interesting aspect is that the limit on $\langle m_{ee} \rangle$ provided by the Heidelberg-Moscow experiment has just been reached by EXO-200. Accurate calculations of the NMEs for ^{136}Xe can decide if the Klapdor's result will be ruled out or not. On the other side, there are several DBD experiments like GERDA, COBRA, CUORE, MAJORANA, EXO, SuperNEMO, KamLAND-Zen, SNO+, either in the commissioning phase or in the final years of construction, with the goal o fully explore in the degenerate and inverted mass hierarchy regions, in accordance with the neutrino oscillation and cosmic data analysis. Thus, the next years will be very interesting ones concerning our expectation of new results on the neutrino properties through the study of the DBD process.

3.3.12 MANY-BODY OPEN QUANTUM SYSTEMS: FROM ATOMIC NUCLEI TO QUANTUM OPTICS

DATE: September 24 - 28, 2012

ORGANIZERS:

Marek Płoszajczak *(GANIL, France)*
Wolfgang P. Schleich *(Ulm University, Germany)*

NUMBER OF PARTICIPANTS: 33

MAIN TOPICS:

Small open quantum systems (OQSs), whose properties are profoundly affected by environment, i.e., continuum of decay channels, are intensely studied in various fields of Physics (nuclear physics, atomic and molecular physics, mesoscopic physics, quantum optics, etc.). These different many-body systems, in spite of their specific features, have generic properties which are common to all weakly bound/unbound systems close to the threshold. These include: properties of the exceptional points and related topological phases, crossings and avoided crossings of resonance energies, redistribution of widths, symmetry-breaking effects in different regimes of resonance densities, S-matrix fluctuations, width distributions, etc. Comprehensive modern many-body theory of weakly bound/unbound states has been advanced recently in the time-asymmetric quantum mechanics using the complete ensemble of single-particle states consisting of resonant states and the complex-energy, non-resonant continuum of scattering states from which the complete many-body basis of OQSs can be obtained. This leads to the OQS formulation of the configuration mixing model (e.g. the nuclear shell model) and puts a foundation for the OQS community across the frontiers of various fields of physics. In other fields, like quantum optics, OQSs are usually modelled using a density operator equation represented as a Schrödinger equation with damping and quantum jumps. The non-Hermitian formulation of quantum mechanics plays the central part in both approaches to the microscopic description of OQSs in different regimes

The main topics were:

- Foundation of quantum mechanics and measurement process
- Rigged quantum mechanics and imaginary potentials
- Quantum trajectory method; density operator equations with damping and quantum jumps
- Reaction theory for weakly bound/unbound participants
- Time-dependent continuum shell model
- Properties of metastable states, resonances, and many-body continuum
- Threshold phenomena and channel coupling
- Channel alignment and clustering
- Statistical features of spectra; overlapping resonances
- Bound states in the continuum
- Nature of exceptional points
- Entanglement between continuous and discrete variables

- Unstable resonators; open microwave billiards
- Electron correlations in arrays of coupled quantum dots
- Optical lattices and cold atoms

SPEAKERS:

C. Bender *(Washington U, St. Louis, USA)*

L. Celardo *(U Cattolica, Brescia, Italy)*

M. DeKieviet *(U of Heidelberg, Germany)*

B. Dietz-Pilatus *(TU Darmstadt, Germany)*

P. Dömötör *(U of Szeged, Hungary)*

M. Efremov *(Ulm U, Germany)*

C. Forssén *(Chalmers U of Technology, Gothenburg, Sweden)*

K. Fossez *(GANIL, France)*

E. Garrido *(CSIC Madrid, Spain)*

B. Gertjerenken *(U of Oldenburg, Germany)*

M. Gianfreda *(U del Salento, Lecce, Italy)*

E. Giese *(Ulm U, Germany)*

G. Hagen *(Oak Ridge National Laboratory, USA)*

N. Hatano *(U of Tokyo, Japan)*

R. Kaiser *(Institut Non Linéaire de Nice, DR2 at CNRS, Valbonne, France)*

W. Loeffler *(U of Leiden, Netherlands)*

R. de la Madrid *(Lamar U, Beaumont, USA)*

P. Magierski *(Warsaw U of Technology, Poland)*

N. Michel *(Oak Ridge National Laboratory, USA)*

F. Narducci *(Naval Air Systems Command, USA)*

M. Oberthaler *(U of Heidelberg, Germany)*

G. Papadimitriou *(U of Arizona, Tucson, USA)*

M. Płoszajczak *(GANIL, France)*

I. Rotter *(MPG Dresden)*

J. Rotureau *(Chalmers U of Technology, Gothenburg, Sweden)*

W. P. Schleich *(Ulm U, Germany)*

S. Stenholm *(Kungl. Tekniska Högskolan, Stockholm, Sweden)*

A. Streltsov *(U of Heidelberg, Germany)*

V. Tamma *(Ulm U, Germany)*

A. Volya *(Florida State U, Tallahassee, USA)*

J. von Delft *(U of München, Germany)*

K. Yabana *(U of Tsukuba, Japan)*

W. Żurek *(Los Alamos, USA)*

SCIENTIFIC REPORT:

The workshop was dedicated to many-body aspects of quantum systems which interact with a reservoir. Situations of this kind arise in many different branches of physics. However, here we have focused on nuclear physics and quantum optics. In particular, cold atoms represent a prime example of a many-body open quantum system. Moreover, also in solid state physics similar phenomena occur. A bridge between nuclear physics and cold atoms are Efimov states in which three particles form a bound state due to two-particle interactions. Needless to say, even questions at the foundations of quantum mechanics were discussed. These topics give an impression of the depth and breadth of our workshop. More than 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 and the atomic physics community we have chosen three talks to bring out the new ideas presented at ECT*.

Robin Kaiser studied experimentally the scattering of light by cold atoms. This enterprise is driven by the goal to achieve Anderson localization, that is, trapping of photons by an arrangement of cold atoms. Here we have many photons trapped in a “cavity” formed by cold atoms. At the same time the photons can leak out into free space. In this sense the experiments by Kaiser are a prime example of a many-body open quantum system.

A totally different topic is represented by the field of microwave resonators. Here a resonator could be completely closed but also be open on one side. In open sharply-bent wave guides bound states can form and, of course, experience a coupling to the reservoir provided by free space. Such devices are analogue systems of nuclei. Barbara Dietz-Pilatus reported the results of recent experiments on this topic and on a new theoretical approach for the understanding of these unusual bound states.

Even the universe is an open system. Here Wojciech Zurek addressed the Zurek-Kibble mechanism which also arises in the physics of cold atoms. The fragmentation of a Bose-Einstein condensate in a ring resonator as a function of an appropriate change in the external parameters was shown in several impressive movies based on the numerical integration of the Gross-Pitaevski equation.

The last decade has witnessed a tremendous progress in *ab initio* description of atomic nuclei using many-body interactions derived from low-energy Quantum Chromodynamics. Christian Forssén reported the description of ground state properties and clustering in halo nuclei using *ab initio* No-Core Shell Model. This same many-body approach was also applied to describe clusters of atoms in the traps.

The significance of continuum and three-nucleon forces was discussed by Gaute Hagen in an *ab initio* Coupled-Cluster (CC) theory which was recently generalized to describe spectra of nuclei at the edge of stability. Impressive examples of the role of continuum induced correlations were shown for spectroscopic factors and the evolution of shell structure in neutron-rich calcium isotopes. The CC theory, which was developed in nuclear physics, has become now a tool of reference in quantum chemistry.

A simultaneous understanding of the structural and reaction aspects is at the very heart of understanding short-lived nucleonic matter. It can be considered in the extension of nuclear Shell Model based on the Berggren ensemble. Nicolas Michel has shown how to describe the proton induced reactions in this framework and reported a first *ab initio* study in medium-heavy nuclei.

A particular highlight was the talk by Stig Stenholm in which he compared and contrasted writings of the philosopher Ludwig Wittgenstein and the physicist Niels Bohr on topics such as “states”, “open systems” and “measurement”. Although the two have never read each other’s articles and might not even have been aware of each other, the statements they made, however, were rather similar.
All talks lead to extensive and intensive discussions in which both communities participated.

Results and Highlights

The present workshop was the third in this series. Through these workshops the ECT* has provided a unique opportunity for different communities sharing an interest in many-body open quantum systems to meet and exchange ideas. It is now noticeable that the “language barrier” that existed when these workshops started is no longer there anymore. The communities now can communicate with each other and have found joint projects of mutual interests. For example, Maxim Efremov who works on Efimov states in Bose-Einstein condensates has started a collaboration with Nicolas Michel who works on similar problems in nuclear physics.

Although a transfer of knowledge has already taken place due to these workshops 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 newly emerging field of PT symmetric quantum mechanics which has become very popular and certainly has strong ties to open quantum systems. Likewise, tunnelling of interactive many-boson systems represents another new development and will need more attention. The tunnelling control by external driving would open new perspectives in physics of atomic nuclei and atom condensates. Continuum induced correlations and clustering in dilute (neutron) matter is another topic of great interest in physics of exotic nuclei, molecular physics and physics of neutron stars.

There was a general agreement that this series should be continued. Robin Kaiser and Christian Forssén have been asked by the present organizers to plan a new workshop which shall take place in two years from now. They have kindly agreed to submit in due time a proposal to ECT*.

It is a pleasure for us to thank the ECT*, in particular Prof. Dr. Achim Richter for 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.

3.3.13 EDM SEARCHES AT STORAGE RINGS

DATE: October 01 – 05, 2012

ORGANIZERS:

Hans Ströher *(Jülich, Germany)*
William Marciano *(BNL, USA)*
Yannis Semertzidis *(BNL, USA)*
Mei Bai *(BNL, USA*)
Frank Rathmann *(Jülich, Germany)*
Andreas Wirzba *(Jülich, Germany)*

NUMBER OF PARTICIPANTS: 50

MAIN TOPICS:

The main topics were:

- Physics beyond the Standard Model
- Physics case for EDM searches
- Status of ongoing EDM searches
- New EDM projects for charged hadrons in storage rings
- Dynamics of polarized beams in storage rings

SPEAKERS:

M. Bai *(BNL, USA)*

D. Barber *(DESY, Hamburg, Germany)*

J. Bsaisou *(FZ Jülich, Germany)*

D. Chiladze *(FZ Jülich, Germany)*

M. Conte *(U of Genua, Italy)*

J. De Vries *(KVI Groningen, NL)*

D. Eversheim *(U of Bonn, Germany)*

A. Fedotov *(BNL, USA)*

R. Gebel *(FZ Jülich, Germany)*

M. George *(U of Sussex, UK)*

R. Golub *(North Carolina State U, USA)*

G. Guidoboni *(U of Ferrara, Italy)*

S. Haciomeroglu *(BNL, USA)*

T. Izubuchi *(BNL, USA)*

K. Jungmann *(KVI Groningen, NL)*

A. Kacharava *(FZ Jülich, Germany)*

D. Kawall *(U of Massachusetts, USA)*

I. Koop, *(Budker Institute, Novosibirsk, Russia)*

A. Lehrach *(FZ Jülich, Germany)*

A. *Luccio (BNL, USA)*

W. Marciano *(BNL, USA)*

U. Meissner *(U of Bonn and FZ Jülich, Germany)*

F. Meot *(BNL, USA)*

W. Morse *(BNL, USA)*

N. Nikolaev *(FZ Jülich, Germany)*

G. Onderwater *(KVI, Groningen, NL)*

Y. Orlov *(Cornell, USA)*

M. Ramsey-Musolf *(U of Wisconsin, USA*)

F. Rathmann *(FZ Jülich, Germany)*

L. Roberts *(Boston U, USA)*

B. Sauer *(Imperial College, UK)*

G. Schierholz *(DESY, Hamburg, Germany)*

P. Schmidt-Wellenburg *(PSI, Villigen, Switzerland)*

Y. Semertzidis *(BNL, USA)*

A. Silenko *(Belarusian State U, Minsk, Belarus)*

H. Soltner *(FZ Jülich, Germany)*

E. Stephenson *(U of Bloomington, USA)*

H. Stockhorst *(FZ Jülich, Germany)*

H. Ströher *(FZ Jülich, Germany)*

R. Talman *(Cornell, USA)*

R. Timmermans *(KVI Groningen, NL)*

N. Uraltsev *(U of Siegen, Germany)*

U. Van Kolck *(U of Tucson, USA)*

D. Weiss *(Penn State, USA)*

C. Welsch *(Cockroft Laboratory, UK)*

L. Willmann *(KVI Groningen, NL)*

A. Wirzba *(FZ Jülich, Germany)*

Z. Zavattini *(U of Ferrara, Italy)*

SCIENTIFIC REPORT:

The Standard Model (SM) of Particle Physics fails to explain the reason for our very existence since it is not capable to account for the apparent matter-antimatter asymmetry of our universe. Physics beyond the SM is required and searched for by (i) employing highest energies (e.g. at LHC), and (ii) by striving for ultimate precision and sensitivity (e.g., in the search for electric dipole moments (EDM)). Permanent EDMs of particles violate both time reversal (T) and parity (P) invariance, and are - via the CPT-theorem - also CP-violating. Finding an EDM would be the smoking gun for physics beyond the SM, and lowering the upper limits further provides crucial tests for any corresponding theoretical model. In fact, past EDM limits have already excluded or restricted several theoretical models. Precision physics in the form of EDM searches is thus complimentary to parts of the energy frontier at LHC.
Neutron EDM (nEDM) measurements are pursued at many labs worldwide, trying to reduce the already impressive experimental upper limits further. Searches for EDMs of the proton, the deuteron (and heavier nuclei) will provide even higher sensitivity, but the corresponding measurements have yet to be conducted. Since it is essential to perform EDM measurements on different targets in order to unfold the underlying physics, responsible for the baryogenesis in the early universe, pEDM and dEDM searches are must-do experiments. The experimental approach to perform this search is based on the particle's spin precession due to its magnetic and electric dipole moments in external electromagnetic fields. Freezing the horizontal spin motion, i.e., forcing the spin to always point along the direction of motion, cancels the (g-2) precession. The build-up (or absence) of a vertical polarization component will then indicate the signal of a finite EDM (an upper limit). Such measurements will be conducted with polarized beams stored in a new class of storage rings (SR): for protons a purely electrostatic SR can be used, while deuterons (and 3He) require SRs with both E- and B-fields. Such SRs pose an exceptional scientific and technological challenge, which can only be met by a strong experienced group of scientists and engineers. The storage ring COSY at Forschungszentrum Jülich provides the ideal test facility and starting point for this long-term enterprise.

The aim of the workshop was to highlight the physics potential of the search for permanent electric dipole moments (EDM) for the discovery/establishment of new physics (i.e. physics beyond the Standard Model (BSM) of Elementary Particle Physics) and to present (and discuss) the different approaches to search for EDMs in leptons, hadrons and more complex systems (e.g. nuclei, atoms and molecules). Emphasis was given to the presentation and discussion of a new experimental proposal/approach to use polarized charged particles in storage rings. Technological and metrological challenges were described and scrutinized. In addition the theoretical background and methods in order to calculate EDMs and to identify the CP-violating sources were presented and discussed.

Results and Highlights

In 49 talks (10 theory, 15 experiment, and 24 accelerator/metrology) as well as 2 outlook presentations, the above mentioned objectives of the meeting were all covered. The achievements can be summarized as follows:

- The physics case (baryogenesis, CP violation beyond CKM, new physics BSM) is most compelling: discovery of a finite EDM for any fundamental particle would be a major milestone and the smoking gun for physics beyond the Standard Model.

- EDMs must exist, but the question is whether they can be observed – in case of an EDM discovery, a series of observations (e.g. for neutron, proton and the deuteron) will be necessary to disentangle the source.

- Current EDM upper limits for electron, muon and neutron are impressive and new projects are underway to improve these limits by at least an order-of-magnitude during the next decade.

Although technological and metrological challenges for storage ring EDM measurements (srEDM) are severe, the current proposals – an all-electric srEDM ring for proton (pursued by BNL, US-srEDM collaboration) and an all-in-one combined E/B srEDM ring (Jülich, JEDI-collaboration) – exploiting counter-rotating beams seem the right track to tackle these problems. It seems obvious, however, that the final sensitivity goal of 10-29 e cm (or even beyond) can/will not be achieved in one gigantic leap: JEDI therefore proposes to use the conventional storage ring COSY at FZ-Jülich for a precursor EDM-experiment with the aim to obtain a proof-of-principle as well as first directly measured EDM-limits for proton and deuteron.

3.3.14 MATHEMATICAL ASPECTS OF HADRON PHYSICS

DATE: October 08 – 12, 2012

ORGANIZERS:

Kurusch Ebrahimi-Fard *(Instituto de Ciencias Matemáticas, Spain)*
Frédéric Patras *(Laboratoire J.-A. Dieudonné, France)*
Craig D. Roberts *(Physics Division, Argonne National Laboratory, USA)*

NUMBER OF PARTICIPANTS: 17

MAIN TOPICS:

The general themes of this workshop concerned the Hopf algebra structure of Dyson-Schwinger equations (DSEs) and renormalisation in quantum field theory; bridging the gap between perturbative- and nonperturbative-QCD; and the application of DSEs to phenomena in hadro-nuclear and -particle physics. The immediate goal was to open a dialogue between mathematicians and physicists, so that each can come to appreciate the challenges and needs of the other.

The main topics were

- Hopf algebra structure of renormalisation in quantum field theory and its relationship to Dyson-Schwinger equations
- QCD's β-function and its computation within the Hopf algebra representation of renormalisation in quantum field theory
- Constraining truncation schemes for the Dyson-Schwinger equations via practical demands of perturbation theory
- Predictions for hadron physics based on systematic truncations of Dyson-Schwinger equations

SPEAKERS:

J. Ablinger *(U. of Linz, Austria)*

A. Bashir *(U. of Michoacán, Mexico)*

M. Bellon *(CNRS, Paris 6, France)*

K. Ebrahimi-Fard *(ICMAT, Madrid, Spain)*

T. Grandou *(CNRS, Nice, France)*

J. Kock *(U Aut. Barcelona, Spain)*

T. Krajewski *(Centre de Physique Théorique, Marseille France)*

G. Landi *(INFN Trieste, Italy)*

F. Patras *(CNRS, Nice, France)*

M. Pennington *(Thomas Jefferson National Accelerator Facility, USA)*

A. Quadri *(INFN Milano, Italy)*

C. Roberts *(Argonne National Laboratory, USA)*

J. Rodriguez-Quintero *(U Huelva, Spain)*

A. Tanasa *(U Paris 13, France)*

P. Tandy *(Kent State U, USA)*

J. Unterberger *(U Henri Poincaré, Nancy, France)*

S. Weinzierl *(U Mainz, Germany)*

SCIENTIFIC REPORT:

QCD presents a fundamental problem that is unique in the history of science. Never before have we been confronted by a theory whose elementary excitations are not those degrees-of-freedom readily accessible via experiment; i.e., whose elementary excitations are confined. Moreover, there are numerous reasons to believe that QCD generates forces which are so strong that less-than 2% of a nucleon's mass can be attributed to the so-called current-quark masses that appear in QCD's Lagrangian; viz., forces capable of generating mass from nothing, a phenomenon known as dynamical chiral symmetry breaking (DCSB).

It is impossible to elucidate the origin of these phenomena using perturbation theory. Contributions are being made using the methods of lattice-regularised QCD. However, despite its promise, that approach has numerous limitations. An alternative is provided by QCD's Dyson-Schwinger equations (DSEs). There is a model-dependent element in the application of this method to the computation of real-world observables but that has been turned to advantage, so that now real predictions are being made and a feedback between experiment and theory is providing constraints on the infrared behaviour of QCD's β-function.

On the other hand, unknown to the bulk of physicists, there is progress in mathematics, which began roughly fifteen years ago with a realisation that the process of renormalisation in quantum field theory is naturally expressed via a Hopf algebra structure. Indeed, the Hopf algebra approach allows for a comprehensive description of the algebraic and combinatorial structures underpinning renormalisation. This enables a mathematically sound approach to the problem of computing the β-function that is based on two elements: the existence of quantum equations of motion, namely, the Dyson-Schwinger equations; and the consequences of the renormalisation group for local field theories. One needs the DSE umbrella in order to guarantee sufficient recursive structure in the theory such that a non-perturbative approach becomes feasible. The Hopf algebraic foundations of these phenomena make the approach possible. Finally, the Hopf algebra description permits mathematicians to comprehend and explore basic ideas of renormalisation, driving new applications of those ideas in the context of pure and applied mathematics. The progressive mathematical reformulation of the well-established physical procedure of renormalisation motivated mathematicians to imagine that this framework has the power to provide deeper insights into fundamental problems in quantum field theory. However, the majority lack an appreciation of just what those problems are, and of the physical connections between their formalism and phenomena. In the bulk, the framework is formally exact but practically inapplicable to the computation of an hadronic observable. Notwithstanding this, attempts have been made to compute the QCD β-function in the infrared.

This workshop gathered experts in: the Hopf algebra structure of Dyson-Schwinger equations and renormalisation in quantum field theory; perturbative- and nonperturbative-QCD; and the application of DSEs to phenomena in hadro-nuclear and -particle physics. The immediate goal was to open a dialogue between mathematicians and physicists, so that each can come to appreciate the challenges and needs of the other.

The discussions focused on the following questions:

1. What is the Hopf algebra structure of renormalisation and how is it related to the Dyson-Schwinger equations?
2. How does the Hopf algebra structure of renormalisation enable the computation of a theory's β-function, and what mathematical assumptions are necessary in order to provide relevant, falsifiable constraints on its real-world behaviour?
3. Can the practical demands of perturbation theory in QCD be expressed in mathematical constraints within the Hopf algebra structure of renormalisation? For example, can one formulate the selective resummation of a subclass of diagrams?

4. Can the need for truncations in the practical application of DSEs to the prediction of hadron phenomena be formulated mathematically within the Hopf algebra structure? For example, does the algebraic structure provide insight into the nonperturbative construction of a fermion-antifermion scattering kernel?

Results and Highlights

In a series of introductory lectures, Topics 1 and 4 above were clarified to the point that mathematicians and physicists could communicate in connection with Topics 2 and 3.

This represents significant progress because this group of people had never met before. Much was made of this first opportunity for the Hopf algebra developments in mathematics to be communicated to practicing physicists, and for mathematicians to be "grounded" in the realities of contemporary QCD physics. All participants agreed that there is significant potential for further positive feedback in identifying how these new tools and modern practice can be used to improve each another.

The organisers plan a review article. It aims to explain the Hopf algebra anatomy of rainbow-ladder truncation, which is the most widely used approximation in DSE studies of QCD. The article will

- Introduce Hopf algebra concepts for physicists;
- Show that the graphs of rainbow-ladder-truncation form a Hopf algebra, Hgrl;
- Explain under which circumstances Hgrl is a subalgebra of the Hopf algebra of QCD;
- Detail the significance of these results for mathematics, the physics of hadrons and the study of hadronic phenomena using DSEs.

It is anticipated that the article will be completed within nine months.

3.3.15 NEW TRENDS IN LOW-ENERGY QCD IN THE STRANGENESS SECTOR: EXPERIMENTAL AND THEORETICAL ASPECTS

DATE: October 15 – 19, 2012

ORGANIZERS:

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

NUMBER OF PARTICIPANTS: 40

MAIN TOPICS:

This workshop brought together international experts, young postdocs and Ph D students to discuss most recent developments in strangeness physics, as described by the low-energy QCD, both in theory and experiment. Present and future opportunities in this frontier field of research were discussed, together with new theoretical activities.

Main topics of discussions were:

- Antikaon—nucleon and –nucleus interaction at low energy
- The Λ (1405) case
- Kaonic atoms physics
- Antikaonic nuclei
- Double-antikaonic nuclei
- Hypernuclear spectroscopy
- Strange excited hyperons and their interactions with nuclei
- In medium modification of the properties of "strange" mesons
- Experimental results:
    - SIDDHARTA, KLOE and FINUDA at DAFNE
    - FOPI and HADES at GSI
    - COSY-TOF: COSY-ANKE
    - DISTO at SATURNE
    - MAMI status

- Next-generation experiments
    - AMADEUS at DAFNE
    - SIDDHARTA-2 at DAFNE
    - E15 and E17 at J-PARC
    - Future of MAMI
    - New experiments proposed at JPARC
    - New experiments with HADES
    - Experiments at FAIR

- Experiments at CERN
- Other proposals

SPEAKERS:

Y. Akaishi *(RIKEN, Nihon U, Japan)*

P. Aslanyan *(JINR Dubna, Russia)*

N. Barnea *(Hebrew U Jerusalem, Israel)*

J.-C. Berger-Chen *(TU Munich, Germany)*

T. Bressani *(U of Torino and INFN, Italy)*

M. Cargnelli *(SMI Vienna, Austria)*

A. Cieply *(NPI Rez, Czech Republic)*

C. Curceanu *(LNF-INFN, Italy)*

R. Dzhygadlo *(Juelich, Germany)*

E. Epple *(TU, Munich, Germany)*

L. Fabbietti *(TU Munich, Germany)*

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

A. Gal *(Hebrew U Jerusalem, Israel)*

M. Hassanvand *(Isfahan U, Iran)*

E. Hiyama *(RIKEN, Japan)*

M. Iwasaki *(RIKEN, Japan)*

M. Maggiora *(U of Torino and INFN, Italy)*

M. Mai *(U of Bonn, Germany)*

S. Marcello *(U of Torino and INFN, Italy)*

J. Mares *(NPI Rez, Czech Republic)*

J. Marton *(SMI Vienna, Austria)*

I. Mishustin *(U of Frankfurt, Germany)*

S. Okada *(RIKEN, Japan)*

A. Scordo *(LNF-INFN, Italy)*

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

K. Piscicchia *(LNF-INFN, Italy)*

J. Pochodzalla *(U of Mainz Germany)*

Ye Qiujian *(COSY, Germany)*

F. Sakuma *(RIKEN, Japan)*

M. Sato *(U of Tokyo, Japan)*

A. Scordo *(LNF-INFN, Italy)*

V. Shkylar *(U of Giessen, Germany)*

D. Sirghi *(LNF-INFN, Italy)*

O. Vazquez Doce *(LNF-INFN, Italy)*

W. Weise *(TU Munich, Germany)*

S. Wycech *(Soltan Institute for Nuclear Studies, Warsaw, Poland)*

T. Yamazaki *(U of Tokyo, Japan)*

J. Zmeskal *(SMI Vienna, Austria)*

SCIENTIFIC REPORT:

The field of strangeness physics is evolving very fast, with new experimental results coming from many recent experiments (HADES, FOPI, SIDDHARTA, KLOE, just to name few); other experiments are planned (such as those at DAFNE, GSI, FAIR or JPARC) and many others are in the proposal phase. On the theoretical side, refined calculations and methods (lattice QCD, many-body calculation methods, potential models etc.) are producing chiral perturbation theory and chiral unitary approaches accurate results which, combined with the experimental findings, are allowing to have a better and more detailed understanding of the processes governing the low-energy sector of QCD. Among the basic issues, some play a key-role: the nature of $\Lambda(1405)$, the possible existence of deeply bound kaonic nuclear states, the sigma and double strangeness hypernuclei and their binding energies, the kaon-nucleus and hyperon-nucleus interactions and their implications in astrophysics, just to name a few. These physics cases are approached with complementary experimental techniques that

range from employing kaons to heavy ions as beams creating a variety of different environments.
During the Workshop we discussed recent achievements in the strangeness low-energy sector, the theoretical findings “triggered” by the experimental results, and made a step forward in planning a global strategy in the field, based on the exchange among experimentalists and theorists in view of a deeper and more complete understanding of the underlying phenomena.
Going more in detail, in the framework of the workshop we focused on the following main themes: kaonic atoms studies; search for antikaonic nuclei; search for the double antikaonic nuclei; antikaon-nucleon and -nucleus interactions at low energy; the mystery of the Λ(1405); hypernuclear spectroscopy main themes; excited hyperons and their interactions with nuclei, in-medium modification of strange vector and scalar mesons. Both experimental and theoretical findings were discussed.
The following main items were presented and investigated:

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 governed by hyperon resonances near threshold which may lead 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 the analyses of KLOE data for kaon-nuclear interaction studies. In the future, opportunities will be exploited to study also low energy antikaon–nucleon and -nucleus scattering using advanced 4π-tracking detectors techniques for gaining precision data with the AMADEUS set up at DAΦNE. Experimental results were discussed together with theoretical findings and future opportunities.

The Λ (1405)

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

Kaonic Atoms

Kaonic atoms are fundamental tools for understanding low-energy QCD in the strangeness sector. Recently, the SIDDHARTA experiment has provided the most precise results on kaoni hydrogen transitions to the 1s level and of kaonic helium 3 and 4 transitions to 2p levels. The data on kaonic deuterium were as well discussed at the present Workshop. These results are presently being considered by the theoreticians working in the field in order to extract the scattering lengths for antikaon-proton and to make predictions for a future kaonic deuterium precision measurement. The SIDDHARTA-2 experiment at DAΦNE and the E17 experiment at JPARC are going to take data in the next year(s); these experiments are going to perform future precision measurements on kaonic atoms. Experimental results by SIDDHARTA were discussed, together with their use by theoreticians and future plans. Such discussions are vital for implementing the SIDDHARTA-2 and E17 future scientific programs.

Antikaonic Nuclei

The quest for of possible deeply bound kaonic nuclei is more vivid than ever. 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, AMADEUS, J-PARC with E15, and GSI using FOPI and HADES. First indications for of the existence of deeply bound ppK^- and $ppnK^-$ systems have been claimed 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; future experimental plans were well discussed.

Annihilation of stopped antiprotons in nuclei is considered to be a powerful method for studying strangeness production in nuclei. It is of special interest for the production of quasi-bound double strangeness systems, the most elementary ones being ppK^-K^- and pnK^-K^-. Missing mass spectroscopy in the annihilation of stopped antiprotons in ^3He using the produced K^+K^0 and K^+K^+ pairs, respectively, including a strangeness tracking of the ΛΛ decay products in the case of ppK^-K^- in an appropriate 4π-detector system is proposed to give unique evidence for the existence of such elementary double strangeness nuclear systems. In this double strangeness system one expects still higher binding energies and densities compared with single strangeness systems bound with one anti-kaon only. The production of K^+K^+ pairs in the annihilation of antiprotons at rest in ^4He with a probability of about 10^{-4} has been reported recently using OBELIX data. Plans to propose experiments in this directions (at JPARC and CERN) were presented and discussed.

Hypernuclear Spectroscopy

Many new results are coming in the hypernuclear physics sector; new experimental results and, in parallel, new theoretical ideas are coming 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 planned to be performed at J-PARC in the near future and at FAIR afterwards.
Results of existent experiments were discussed together with theoretical studies and future experiment proposals.

In-Medium Modification of the Properties of “Strange” Mesons

The in-medium mass modification of vector-mesons, such as Φ-mesons with hidden strangeness, has been studied using invariant mass spectroscopy in the *p+A* reaction by the KEK-PS experiment E325 to determine its mass shift and width. For the study of bound states of Φ-mesons in nuclei and by the ANKE Collaboration at COSY, missing mass spectroscopy using antiproton annihilation reactions with small momentum transfer has been proposed recently.
Apart from these experiments, where the so-called cold nuclear matter environment can be tested, the production of kaons and phi meson in heavy ion collisions is studied by the FOPI and HADES collaborations. In this case the kaon-nucleus potential for high nuclear density can be tested and the properties of vector mesons like phi studied.
Experimental results, future plans and theoretical findings were reviewed.

Results and Highlights

The field of *low-energy QCD in the strangeness sector* is a very active one, as was clearly demonstrated during this Workshop. On one side, there are many new and important experimental results coming from precision experiments performed or undergoing in/by GSI, DAFNE, KEK, COSY, MAMI or from re-analyses of existent older data from DISTO or JINR experiments, just to name a few. On the other side, theoretical approaches have performed important steps forward, motivated by the new coming results: not only at technical level, but, even more importantly, on the understanding of underlying physical processes or questions to be explored in the upcoming experiments.

There are many *solved (old) items*, as kaonic hydrogen and kaonic helium puzzles – which were understood, both due to the newer experiments (E570 and DEAR and SIDDHARTA at DAFNE) and to theoretical interpretation, but many *open problems* are still present. Actually, the number of open problems is increasing, theories are dealing with one or two $\Lambda(1405)$, with various potential models below the kaon-nucleon threshold, having as consequence the possibility or not to create deeply bound kaonic nuclear states. Important questions were targeted and formulated, but they still need both experimental results and a deeper theoretical understanding. Implications in astrophysics are as well explored with the tools coming from low-energy QCD in the strangeness sector (Weise's talk).
Future challenges in the field are many and were, during the Workshop, focussed and formulated in a unified framework.

The EU FP7 framework program for hadronic physics was as well presented: in particular a talk was dedicated to the LEANNIS Network (HadronPhysics3 FP7) by J. Marton, just dealing with physics discussed in the present workshop; future important contacts and modalities to optimize such contacts, in the view of future HORIZON2020 calls, were discussed.

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 (including Israel and Iran) – 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 ideal 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* (special thanks to Ines Campo, the Workshop secretary, and to the ECT* Director, Prof. A. Richter) was excellent.

3.3.16 REACTIONS OF EXOTIC NUCLEI AND THE IMPACT OF NUCLEAR STRUCTURE

DATE: October 22 – 24, 2012

ORGANIZERS:

Jacek Dobaczewski *(University of Warsaw, Poland)*
Paul-Henri Heenen *(University of Brussels, Belgium)*
Helmut Leeb *(TU Wien, Austria)*
Friedrich Thielemann *(University of Basel, Switzerland)*

NUMBER OF PARTICIPANTS: 26

MAIN TOPICS:

The workshop aims at a discussion of recent advances in nuclear theory related to the nuclear research at present and future radioactive ion beam facilities. In this workshop emphasis is given to the status and recent developments of theory for reactions and nuclear astrophysics.

The main topics were:

- Transfer Reactions: theory and experiment
- Coupled-Channel techniques and applications
- Breakup reactions and coupling to the continuum
- Nuclear reactions relevant for astrophysics
- Approaches to optical potentials
- Symmetry energy and effective interactions
- Nuclear structure information for reaction calculations

SPEAKERS:

A. Bonaccorso *(U of Pisa)*
H-T Chau *(CEA-DAM)*
J. Dobacewki *(U of Warsaw)*
M. Gaidarov *(INRE)*
M. Gal *(TU Wien)*
G. Gyurky *(OMKI, Debrecen)*
P-H Heenen *(U of Brussels)*
M. Hempel *(U of Basel)*
G. Imbriani *(U of Napoli)*
T. Kröll Thorsten *(TU Darmstadt)*
A. Krasznahorkay *(ATMKI Debrecen)*
H. Leeb *(TU Wien)*
W. Leidemann *(U of Trento)*
H. Lenske *(U of Gießen)*
G. Martinez-Pinedo *(TU Darmstadt)*
J. Maruhn *(U of Frankfurt)*
T. Rauscher *(U of Basel)*
R. Reifarth *(U of Frankfurt)*
E. Simpsons *(U of Surrey)*

D. Tarpanov *(U of Warsaw)*
F.K. Thielemann *(U of Basel)*
J. Toivanen *(U of Jyväskylä)*
J. Tostevin *(U of Surrey)*
S. Typel *(GSI)*
D. Warjri *(TU Wien)*
H. Wolter *(U of München)*

SCIENTIFIC REPORT:

The 2nd Collaboration Meeting of the JRA THEXO took place at ECT*, Trento, Italy. It was organized as a mini-workshop with the title REACTIONS OF EXOTIC NUCLEI AND THE IMPACT OF NUCLEAR STRUCTURE**.** The meeting was devoted to review the various facets of reaction theory, to present recent progress and applications to nuclear astrophysics. In order to identify the current and future needs of novel developments and/or improved inclusion of nuclear structure information experimentalists have been invited to present recent activities and envisaged measurements at FRANZ, GSI, ISOLDE, LUNA and at the accelerator in Debrecen. The workshop was organized as follows: the first day was mainly focused on applications in nuclear astrophysics and relevant aspects. The presentations on the second day dealt with recent progress in reaction theory and important ingredients. The third day was devoted to discuss the status and future activities of the THEXO group. The program of the collaboration meeting is attached in Appendix A. The given presentations are accessible on the WebSite www.ectstar.eu/meetings/. In the following a summary of the various topics is given.

Nuclear Reaction Theory: The question of the current status and recent advances in reaction theory, the central topic of this workshop, has been subject of 8 presentations. An overview on theoretical approaches to nuclear reactions with exotic beams was given by A. Bonaccorso. The description of fast one-nucleon and two-nucleon removal reactions, a promising tool for nuclear structure studies of exotics nuclei in the future, has been outlined in the two presentations of J. Tostevin and E. Simpson, respectively. These theory developments are important at higher energies, e.g. at SPIRAL2. But certain aspects are of interest also for the analysis of transfer reaction studies of exotic nuclei, performed e.g. at HIE-ISOLDE. Th. Kröll gave an overview of the experiments envisaged at HIE-ISOLDE.
Methods to account for the coupling to the continuum, an important aspect in reactions with weakly bound exotic nuclei, were presented in the talks of Huu-Tai Chau, W. Leidemann and M. Gal. The former contribution dealt with an extension of the Continuum Discretized Coupled Channel method (CDCC), while the other 2 talks were focussed on the Lorentz Integral Transformation method, a promising technique to account for continuum contributions. The time-dependent Hartree-Fock Method together with interesting examples was reviewed by J.A. Maruhn.

Theory for Nuclear Astrophysics: Two sessions with 5 presentations were devoted to reactions in nuclear astrophysics. H. Lenske and G. Martinez-Pinedo presented the inclusion of nuclear structure methods for reactions in nuclear astrophysics, while St. Typel discussed simplified numerical programs for the estimation of radiative capture and photodissociation reactions. Recent and envisaged reaction experiments for nuclear astrophysics were subject of the talks of R. Reifarth and G. Imbriani. The latter reported on the experiments performed at the underground facility LUNA, while neutron-induced reactions were the focus of R. Reifarth.

Effective Interactions: In the absence of a quantitative description of the nuclear force, effective interactions are important for the quality of reactions calculations. The determination of the alpha-nucleus optical potential was the central subject of 3 presentations. G. Gyürky showed recently measured results on elastic scattering, which provided constraints on the alpha-nucleus optical potentials. The puzzle about the alpha-nucleus potential was discussed by Th. Rauscher, who proposed a plausible solution of this puzzle. In a short talk D. Warjri reported on ongoing theory work to determine alpha-nucleus optical potentials microscopically.

The second group of talks dealt with the nuclear symmetry term. In this session H. Wolter presented recent work on the density and momentum dependence of the nuclear symmetry energy from heavy-ion collisions, while M. Gaidarov considered the relationship of the symmetry energy with surface properties of neutron rich exotic nuclei. Measurements of giant resonances in exotic nuclei, which are related to the symmetry term, were reported by A. Krasznahorkay.

Nuclear Structure: One session was devoted to recent developments on recent achievements in nuclear structure physics within the JRA THEXO. D. Tarpanov presented recent calculations of polarization reactions, while J. Toivanen reported on beyond mean field calculations of nuclear binding energies within QRPA and the importance of many-body perturbation theory.

Collaboration Meeting: The third day was devoted to the monitoring, coordination and specific questions of the JRA THEXO. In the first session the status of the THEXO related work at Univ. Warsaw, Univ. Brussels, TU Wien and Univ. Basel was reported. In addition the requirements and envisaged developments of codes were discussed. These code developments are vital results of the JRA THEXO because they are the deliverables which are of interest for the infrastructures.

The 2nd session was devoted to the next year planning and the exploitation of synergies. Central point of discussion was the organisation of the next year workshop and the forthcoming THEXO work.

Results and Highlights

The workshop gave a concise overview on the current status of the research in reaction theory and its applications in astrophysics and the interpretation of experiments performed at radioactive ion beam facilities. The concept of the meeting allowed ample discussion of the various topics. This opportunity has been extensively used by the participants and was essential for the very positive and collaborative atmosphere. At the workshop additional synergies could be identified which have led to more intensified collaborations within the THEXO group. Especially, the increased collaboration between Basel, Vienna and Warsaw in the field of reactions and the strengthening of the exchange between Basel, Brussels and Vienna in the field of astrophysics should be mentioned here. In addition the contacts with experimentalists and external experts could be intensified

3.3.17 THE PROTON RADIUS PUZZLE

DATE: 29 October – 2 November, 2012

ORGANIZERS:

Randolf Pohl *(Max-Planck-Institute of Quantum Optics, Garching, Germany)*
Gerald A. Miller *(University of Washington, Seattle, WA, USA)*
Ronald Gilman *(Rutgers University, New Brunswick, NJ, USA)*

NUMBER OF PARTICIPANTS: 47

MAIN TOPICS:

The topic of the workshop was the determination of the rms proton charge radius Rp from three types of measurement: Elastic electron-proton scattering, spectroscopy of "regular" electronic hydrogen H, and the recent measurement of the Lamb shift (2S-2P energy difference) in the muonic hydrogen atom. The latter differs by 7 standard deviations from the "traditional" value of Rp obtained in scattering and H. This so-called "proton radius puzzle" has attracted a lot of interest (e.g. about 180 citations of the muonic hydrogen paper in just 2½ years), but no satisfactory explanation has been found. The workshop has brought together the leading researchers in the field who discussed all aspects of the puzzle:

- Recent experiments: Muonic hydrogen; Elastic electron-proton scattering
- Extraction of proton form factors from electron scattering
- Polarizability of the proton, deuteron and helium nuclei
- Theory of muonic hydrogen energy levels
- Physics beyond the Standard Model
- New projects:
- Rydberg constant from hydrogen and H-like ions
- Electron scattering at very-low Q2, new polarization transfer and strucure function measurements
- Elastic muon-proton scattering

The workshop encouraged lively discussions during the talks as well as in the Q&A session that followed each talk. Additional discussion sessions in the evenings produced many new insights.

SPEAKERS:

A. Afanasev *(George Washington, USA)*

A Antognini *(ETH Zurich, Switzerland)*

J. Arrington *(Argonne National Laboratory, USA)*

J. Bernauer *(MIT, Cambridge, USA)*

A. Beyer *(Max-Planck-Institute of Quantum Optics, Germany)*

M. Birse *(U of Manchester, UK)*

P. Blunden *(U of Manitoba, Canada)*

E. Borie *(Karlsruhe Institute of Technology, Germany)*

P. Brax *(Institut de Physique Théorique, CEA, France)*

C. Carlson *(College of William&Mary, USA)*

J. D. Carroll *(U of Adelaide, Australia)*

M. Distler *(Johannes-Gutenberg Universität, Germany)*

M. Eides *(U of Kentucky, USA)*

K. Eikema *(LaserLaB, Netherlands)*

A. Gasparian *(NC A&T State U, USA)*

S. Gilad *(MIT, USA)*

R. Gilman *(Rutgers U, USA)*

M. Gorshteyn *(Johannes-Gutenberg Universität, Germany)*

K. Griffioen *(College of William&Mary, USA)*

N. Guise *(NIST, USA)*

E. Hessels *(York U, Canada)*

R. Hill *(U of Chicago, USA)*

P. Indelicato *(UPMC and CNRS, France)*

S. G. Karshenboim *(MPQ, Garching, & Pulkovo Observatory, Russia)*

M. Kohl *(Hampton U, USA)*

F. Kottmann *(ETH Zurich, and Paul-Scherrer-Institute, Switzerland)*

S. Krieg *(FZ Jülich and Wuppertal U, Germany)*

I. Lorenz *(HISKP, Germany)*

J. McGovern *(U of Manchester, UK)*

G. A. Miller *(U of Washington, USA)*

K. Pachucki *(U of Warsaw, Poland)*

V. Pascalutsa *(Johannes-Gutenberg Universität, Germany)*

G. Paz *(Wayne State U, USA)*

R. Pohl *(Max-Planck-Institute of Quantum Optics, Germany)*

M. Pospelov *(U of Victoria and Perimeter Institute, Canada)*

B. Raue *(Florida International U, USA)*

S. Schlesser *(KVI Groningen, Netherlands)*

I. Sick *(U of Basel, Switzerland)*

K Slifer *(U of New Hampshire, USA)*

D. Solovyev *(St. Petersburg State U, Russia)*

V. Sulkosky *(MIT CEBAF, USA)*

A. Vacchi *(INFN Trieste, Italy)*

I. Yavin *(Perimeter Institute, Canada)*

SCIENTIFIC REPORT :

The measurement of the Lamb shift (2S-2P energy difference) in the muonic hydrogen atom has created the “proton radius puzzle”: The rms proton charge radius R_p determined from the muonic hydrogen Lamb shift differs by 7 standard deviations from the accepted value of R_p which has been obtained from elastic electron-proton scattering and spectroscopy of electronic hydrogen and deuterium.

Traditionally, R_p has been determined from the slope of the measured electric form factor at zero momentum transfer. Since about 1995, precision laser spectroscopy of transition frequencies of the hydrogen atom have produced an even more accurate value of R_p which is in agreement with the scattering results. The PDG value of R_p originates from the CODATA least squares adjustment of the fundamental constants which takes into account both the analysis of the world data on elastic e-p scattering and 24 measurements of transition frequencies in hydrogen (H) and deuterium (D).

Recent experiments from MAMI at Mainz, $R_p = 0.879(8)$ fm, and Jefferson Lab E08-007, $R_p = 0.875(10)$ fm, have confirmed the accepted 2006 CODATA value $R_p = 0.8768(69)$ fm. The 2010 CODATA value is $R_p = 0.8775(51)$ fm.

A measurement of the Lamb shift (2S-2P energy splitting) in muonic hydrogen, μp, an H-like atom formed by a proton and a negative muon, has long been considered the most precise way to determine R_p. The muon's mass is 200 times the electron mass, therefore the muonic Bohr radius is about 200 times smaller than the Bohr orbit in regular hydrogen. Hence the finite size effect on the S states in muonic hydrogen is a 200^3 times larger than the finite size effect in regular hydrogen H and R_p can be determined from the 2S Lamb shift in μp with unprecedented accuracy.

In 2010, the first measurement of the Lamb shift in muonic hydrogen produced a ten times more precise value, R_p = 0.84184(67) fm, which astonishingly differs from the CODATA-2010 value by 7 standard deviations. A wealth of papers has investigated various ways to explain the discrepancy. The workshop covered all facets of the proton radius puzzle: Review of experiments and data, methods of fitting electron scattering data, theory in muonic hydrogen, aspects of nuclear polarizability, and physics beyond the standard model explanations of the discrepancy. The programme was completed with a variety of talks about new projects in atomic physics and scattering.

The workshop's opening session was dedicated to a review of the three recent experiments: The MAMI A1 experiment reported on their elastic e-p scattering measurements and their Rosenbluth separation fits. These result in values of the electric and magnetic form factors, $G_E(Q^2)$ and $G_M(Q^2)$, respectively, at the lowest Q^2 measured so far. The JLab experiment E08-007 used polarization transfer measurements to obtain accurate values of the form factor ratio $G_E(Q^2)/G_M(Q^2)$. And new data for a second transition in μp was presented which confirms the previous value from μp and improves the accuracy. From the two transition frequencies one can extract the Lamb shift and the 2S hyperfine splitting separately. The Lamb shift yields R_p = 0.84087(39) fm.

The methods used to fit the electron scattering data were reviewed on day 2, starting with various analyses using the Rosenbluth separation technique. Modern Rosenbluth fits parametrize the form factors and fit the cross sections directly, instead of $G_E(Q^2)$ and $G_M(Q^2)$ determined at fixed values of Q^2. The existing world data's sensitivity to R_p is highest in the region between Q^2 =0.5/fm^2 and 1.3/fm^2. Lower Q^2 data is not very sensitive to the r^2 term (i.e. R_p) if the fit is constrained to G_E=1 at Q^2=0. Data at larger Q^2 (between 1.5/fm^2 and 1.5/fm^2) are most sensitive to the curvature of G_E, i.e. to the r^4 term. There is a trade-off between statistical accuracy and an error due to truncating higher moments of $G_E(Q^2)$ when one attempts to fit only the lowest Q^2 data. Interestingly, fitting only the lowest Q^2 data from Mainz can yield R_p = 0.84 fm (in agreement with the value from muonic hydrogen) regardless of the G_E/G_M model, indicating that the low-Q^2 behaviour is decoupled from the curvature at larger Q^2. Great care must be taken in phenomenological Rosenbluth fits to avoid poles in the fit function. Good model-functions should ensure a sensible large-r fall-off of the charge density. A new trend is the use of a sum of Gaussians, instead of the continued-fraction parameterization used earlier. The z-expansion is a model-independent standard tool in the analysis of meson transition form factors, but it has only recently been applied to the proton form factor. Dispersion theory, using space-like and time-like nucleon form factors, has for a long time yielded R_p in agreement with the muonic hydrogen value. Also the Mainz data, when analyzed within the dispersion theoretical frame work, gives R_p = 0.84 fm. The overall reduced χ^2 is however worse, compared to the Rosenbluth fits.

Several talks were also concerned with the theory required to extract R_p from the measurement in hydrogen and muonic hydrogen. For the latter, no large missing or wrong theory terms have been identified. Non-perturbative all-order numerical calculations confirm the standard perturbative approach. Weak interaction contributions have been shown to be negligible. In summary, the QED part seems solid.

For hydrogen, some QED contributions exist which have only been calculated by one group. A confirmation of these results would be welcome. Of course, unexpectedly large

contributions from higher-order QED corrections can also only be excluded by new calculations. The need for a model-independent extraction of R_p also in atomic spectroscopy was highlighted.
Theory in neutral helium is becoming advanced enough to be able to extract the nuclear charge radii of the lightest helium isotopes from data measured in helium atoms. This may shed new light on the puzzle when combined with the planned measurement of the Lamb shift in muonic helium ions.

The situation concerning the effects of two-photon exchange (TPE) on the Lamb shift in muonic hydrogen (proton polarizability contribution) has received a lot of attention. Currently it seems that the proton polarizability is the only possibility to change R_p from muonic hydrogen. TPE has also been held responsible for the discrepancy between Rosenbluth and polarization transfer results on the form factor ratio. Hence, the 3rd day of the workshop was devoted to nucleon (proton) and nuclear (deuteron, helium nuclei) polarizability. The standard way of calculating the TPE contribution to the Lamb shift in muonic hydrogen gives a value of about ten times smaller than the 0.31 meV discrepancy in muonic hydrogen. There is however some concern about a subtraction term needed to make an integral in the dispersion relations converge. Several calculations, including a very recent result from heavy-baryon chiral perturbation theory, have evaluated the contribution of this subtraction term to be about 0.004±0.001 meV. However, the functional behaviour of the subtraction function is not known in a model-independent way for intermediate values of Q^2. (Only the value at $Q^2=0$ and the large-Q^2 behaviour $\sim 1/Q^2$ are known). It remains to be seen if a model can be presented in which the muonic hydrogen discrepancy is resolved, while not being in contradiction with other observables. In particular, the proposed elastic muon scattering experiment MUSE at PSI will be able to constrain some of these suggestions. Muonic deuterium may also be able to limit new ideas and a calculation of TPE effects in μd was presented at the workshop. Finally, the planned measurement of the Lamb shift in H-like muonic helium ions will require precise calculations of the polarizability contributions in μ^3He and μ^4He. The preliminary results of NLO calculation have been presented, and NNLO calculations are on the way.
Physics beyond the Standard Model (BSM) is required to explain the dark matter and dark energy in the universe. Not only high-energy experiments can find BSM physics, also precision measurements at low energies could be able to find new physics. BSM effects have been proposed to explain the proton radius puzzle, motivated also by the long-standing discrepancy between theory and experiment of the anomalous magnetic moment of the muon. Several constraints from experiment exists, e.g. from (g-2) of the electron, x-ray spectroscopy in muonic Si and Mg, neutron scattering, pion and kaon decay. A new scalar particle with a mass around 1 MeV or a new vector force coupling to right-handed muons could explain the muonic hydrogen discrepancy and be still compatible with all observations. They do, however, require fine tuning of couplings and cancellations. Testable predictions have been made for the Lamb shift in muonic deuterium and muonic helium ions. PNC experiments in muonic atoms, muon scattering or radiative muon capture experiments may be able to test the gauged right-handed muon hypothesis.

Lattice QCD has made spectacular progress in recent years and may be able to calculate R_p in not too distant future. New experiments are also on the way and will help solve the radius puzzle.
On the atomic physics side, several projects will soon provide improved values of the Rydberg constant, Ry, which is required to extract R_p using the ultra-precisely measured 1S-2S transition frequency in hydrogen. One- and two-photon transitions in hydrogen will improve the measurements that determine the present value of Ry. New ideas and techniques have been presented that will for the first time allow measurements of Ry in He, in H-like He^+ and in highly excited Rydberg states of H-like ions like Ne^{9+}. This will be complemented by a new measurement of the classical Lamb shift in electronic hydrogen

which will provide an improved value of the proton charge radius that does not depend on the Rydberg constant.
A wealth of new experiments will also give new data on (elastic) electron scattering. The CLAS TPE experiment and OLYMPUS at DESY have already taken data. They will measure the ratio of positron-proton to electron proton scattering and determine TPE effects with unprecedented accuracy, also giving new insights to the puzzling discrepancy between Rosenbluth and polarization transfer measurements. E08-007 will continue to provide polarization transfer data. The new experiment E12-11-106 has been proposed at JLab and will extend elastic electron scattering to even lower Q^2, down to 10^{-4} $(GeV/c)^2$. This will give important insights into R_p and the problem of having to extrapolate $G_E(Q^2)$ to $Q^2=0$. Low-Q^2 data on the deuteron will soon be measured at MAMI providing a better charge radius of the deuteron. The g2p experiment E08-027 will provide inelastic structure functions that are very relevant to the polarizability contribution in hydrogen and muonic hydrogen.
The MUSE experiment, recently proposed at PSI, will for the first time measure elastic muon scattering on the proton at low Q^2. This will be the crucial experiment to test both BSM physics and unexpected polarizability contributions. The MUSE experiment will use a superior differential measurement technique to both compare the scattering of electrons and muons, as well as positive and negative muons (electrons) on the proton. A complete theory calculation required for the understanding of elastic muon scattering at MUSE was presented, too.
Muonic atoms will also contribute new data. Lamb shift measurements in muonic deuterium will provide important cross checks. A measurement of the ground state hyperfine splitting in muonic hydrogen is being prepared. The Lamb shift in muonic helium ions is going to be measured in 2013/4.

Results and Highlights

The proton radius puzzle was not solved at this workshop. However, the combined expertise of experts from usually separated communities made the workshop a unique experience. Enthusiastic discussions during the talks and in dedicated discussion sessions produced many new insights and ideas for further studies.

3.3.18 QCD IN STRONG MAGNETIC FIELDS

DATE: November 12 – 16, 2012

ORGANIZERS:

Andreas Schäfer *(University of Regensburg, Germany)*
Gergely Endrődi *(University of Regensburg, Germany)*
Kenji Fukushima *(Keio University, Japan)*
Mikhail Polikarpov *(ITEP, Russia)*

NUMBER OF PARTICIPANTS: 34

MAIN TOPICS:

The general topic of the workshop was to discuss the various effects strong magnetic fields have on the dynamics of Quantum Chromodynamics (QCD). Such strong magnetic fields are present in physical systems such as the early universe, dense neutron stars and non-central heavy-ion collisions. The Chiral Magnetic Effect (CME) is the most frequently studied phenomenon in this context, and probably also the best understood effect. The magnetic field may also change the localization properties and induce a spin polarization of the thermal medium, which can generate a wide spectrum of other novel phenomena, including e.g. exotic effects like superconductivity caused by rho meson condensation.

The main topics were

- QCD phase diagram and magnetic fields
- Chiral symmetry breaking and (inverse) magnetic catalysis
- Chiral magnetic and chiral vortical effects
- Hadron spectrum in strong magnetic fields
- Effective theories for QCD in a magnetic field
- Observable effects in high-energy heavy-ion collisions
- Magnetic fields in other strongly interacting systems

SPEAKERS:

F. Bruckmann *(Regensburg, Germany)*
P. Buividovich *(ITEP, Moscow, Russia)*
N. Callebaut *(Gent, Belgium)*
M. Chernodub *(Tours, France)*
M. D'Elia *(Genoa, Italy)*
G. Dunne *(U of Connecticut, USA)*
G. Endrődi *(U of Regensburg, Germany)*
J. Erdmenger *(Munich, Germany)*
E. Fraga *(Rio de Janeiro, Brazil)*
P. Giudice *(Swansea, UK)*
Y. Hidaka *(RIKEN, Japan)*
D. Kharzeev *(BNL, USA)*
T. Kovács *(ATOMKI Debrecen, Hungary)*
K. Landsteiner *(Madrid, Spain)*
B. Müller *(Duke U, Durham, USA)*
J. Pawlowski *(Heidelberg, Germany)*

M. Polikarpov *(ITEP, Russia)*
A. Schmitt *(Vienna, Austria)*
V. Shevchenko *(Moscow, Russia)*
I. Shovkovy *(Arizona, USA)*
E. Shuryak *(Stony Brook, USA)*
V. Skokov *(BNL, USA)*
O. Teryaev *(Dubna, Russia)*
A. Yamamoto *(Tokyo, Japan)*
V. Zakharov *(ITEP, Moscow, Russia)*

SCIENTIFIC REPORT:

Quantum Chromodynamics (QCD) is the theory of the strong interactions. QCD is an asymptotically free theory, which implies that at large values of the thermodynamical state parameters such as the temperature or the density, the interaction strength between the elementary particles (quarks and gluons) decreases. Accordingly, at very high temperatures perturbation theory can be employed to study the strong force. On the other hand, at intermediate energies – which are most interesting for the discussion of the QCD phase transition scenario – the coupling is strong and essentially non-perturbative methods have to be used. The most successful of these methods is lattice QCD. It provides first principle results, which can be compared to those from perturbation theory at high temperatures, and from effective theories at low temperatures.
A set of interesting dynamical QCD phenomena is related to external magnetic fields, especially in heavy-ion collisions. In such high energy heavy-ion collisions the strongest magnetic fields in existence in our universe since the times of the Big Bang are produced. With $eB \sim (100\ \mathrm{MeV})^2$ being of a hadronic scale and due to the very strong time dependence of these fields one has to expect that they substantially influence QCD dynamics in the early phase of such collisions. Even more interestingly, QCD dynamics can generate topological charge changes, which in turn should lead to a coupling of magnetic to electric fields. The latter would modify the distribution of charged particles and thus should be experimentally accessible. Charged particle correlations of the expected type might have been observed by STAR, though the experimental situation is rather unsettled at present. These types of effects are usually discussed under the headlines 'Chiral Magnetic Effect' (CME) and 'Local Parity Violation' where the second is more generic and, therefore, more adequate. Motivated primarily by the early STAR data lattice QCD groups got interested in studying the QCD phase diagram for arbitrary constant magnetic background fields.
The phase diagram of QCD for nonzero magnetic fields is a particularly appealing topic for lattice simulations, since – contrary to the case of nonzero chemical potentials, where direct simulation is hindered by the infamous sign problem – finite magnetic fields are straightforwardly implemented on the lattice. The last year has seen a fast progress in simulating QCD in a magnetic background field on the lattice and now precise and reliable results for the phase diagram are present in the literature. Still, the underlying mechanisms which result in the effects observed by lattice QCD have yet to be understood better, especially, because existing effective theory predictions do not agree with the latest lattice results.
Another exciting possibility of the effect of external magnetic fields on the QCD vacuum is the existence of a superconducting phase at extremely high fields, where the rho meson is conjectured to become massless and create a condensate. There are indications both against and in favour of this mechanism, based on lattice simulations, the AdS/CFT correspondence or model calculations.

Results and Highlights

The workshop was generally regarded as a very successful one. Besides the invited talks, to facilitate lively and stimulating discussions, and to support exchange of ideas, each day of the workshop a session devoted to one controversial topic was organized. These topics included among others the Chiral Magnetic Effect signatures in heavy-ion collisions, the superconducting phase at large magnetic fields through rho meson condensation and an AdS/CFT – lattice field theory comparison. According to the feedback of the participants, these discussions were very useful and inspirational. Moreover, in the last year, the diverse subproblems of QCD in a magnetic field were studied using different theoretical techniques. The workshop allowed to identify in detail similarities, differences and complementarities of these approaches and thus helped to formulate a number of new project ideas and helped to start new collaborations.

At the end of the workshop, a list of interesting problems was collected for further study. The most pronounced and urgent items are:

- Lattice investigations of transport coefficients for the QCD medium in a magnetic field.
- Detailed simulations and model studies relating several intriguing experimental observations, on a more quantitative level, to the underlying QCD physics. A general approach to be pursued in the future is to develop comprehensive effective descriptions which allow to reliably describe dynamical effects, and then to fit the parameters of these to lattice results. An example for such an approach is the use of improved holographic QCD, which is a bottom-up version of the AdS/CFT duality, a topic also much discussed on the workshop.

One of the many possibilities still to be explored quantitatively on the lattice with higher precision, is the introduction of a chiral chemical potential. Ground-breaking lattice results were presented, but higher precision is necessary to reach a clear result. Consensus was reached that in general, precise lattice input is key to make progress, allowing for a quantitative determination of the dependence of various effects on quark masses and temperature.

3.4 ECT* DOCTORAL TRAINING PROGRAM IN 2012

"*The 3-dimensional nucleon structure*"

The 2012 ECT* Doctoral Training Program on *The 3-dimensional nucleon structure* started on April 30 and ended on June 15, 2012. The 7 weeks of the program consisted of two 3-week periods of lectures. After the first period, there was one week (May 14-18, 2012) without lectures, during which the students were invited to attend the ECT* workshop on *Drell-Yan Scattering and the Structure of Hadrons* because it concerned much the same subject.

The organizer of the Doctoral Training Program was Mauro Anselmino *(Universita' di Torino and INFN)*. 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**) acted as student coordinator.

The Doctoral Training Program was attended by 14 full-time students and 1 part-time student. The list of students is appended at the end of this report. Among the full time students 9 were theoreticians and 5 were experimentalists. The students were all working on their PhD.

There were six lecturers. Each one stayed and lectured during one week. Two 1-hour lectures were scheduled each morning and occasional exercise sessions were held in the afternoons. Two or three student seminars were scheduled each week. Some lecturers organized exercise sessions during the 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 project. Most lecturers put their slides on the internal Web site, thereby making them accessible to students but only from within ECT*. Some lecturers placed scanned hand-written notes there.

At the end of the program, the students were asked to write an informal report about the program. The reports, which were not required to be signed, were handed to the ECT* Director. The students appreciated the fact that afternoons were free to discuss with lecturers and to continue working on their PhD project. Some suggested shorter coffee breaks (usually ½ hour) so as to give lecturers more time. They also appreciated exercise sessions, which included Mathematica exercises, conducted by some of the lecturers. Some complained of excessive numbers of data plots, flashed on the screen with little explanation.

3.4.1 The Lecture Programme

Marco Stratmann (*Brookhaven National Laboratory, USA*)
QCD at work: from basic principles to current applications

The lectures concentrated on QCD calculations of deep inelastic collisions, factorization of scattering amplitudes, parton distributions and more. In spite of being essentially qualitative (meaning that results were flashed on the screen rather than being derived) they were very useful in that Stratmann gave a very critical account of what could or not be accurately calculated (singularities occurring in merging jets for example) and of the accuracy which could at present be obtained in calculating cross sections for jet production for example. He left some hand written notes in addition to his slides.

Markus Diehl *(Deutsches Elektronen Synchroton DESY, Germany)*
Theory of hard exclusive and semi-inclusive DIS processes
The lectures covered a large domain: deep inelastic scattering (DIS), semi-inclusive deep inelastic scattering (SIDIS), Drell-Yang reactions, parton models in QCD, deeply virtual Compton scattering (DVCS), short distance factorization, light-cone coordinates, fragmentation functions, one loop corrections, generalized parton distributions (GPD), twist 2 and 3 amplitudes, Wilson lines in short-distance factorization, and more.

All technical details in these lectures were shoved under the rug. It is most unlikely that, for example, the experimentalists, and I would guess some of the theorists, could understand the Wilson line which occurs in the parton distribution functions, other than hearing that it is needed for gauge invariance (an argument which does not specify the path of the Wilson line). Only easy things were occasionally explained on the board.

I believe that it is the opposite which should be done in the Doctoral Training Program. The students are already engaged in their PhD work but possibly have not worked out fully the theory. That is precisely why the difficult parts of the theory should be explained and not only the easy parts, such as the gauge invariance of the QCD Lagrangian which one lecturer took a full hour to derive.

Delia Hasch *(INFN, Laboratori Nazionali di Frascati, Italy)*
Data analysis of hard exclusive and semi-inclusive DIS processes

The lectures described experiments in HERA, deep inelastic scattering (DIS), data on the low *x* region, observation of scaling violation, extraction of parton distribution functions (PDFs), PDFs for the LHC, helicity distributions, polarization of quarks and polarized deep inelastic scattering (DIS), the need for polarized beams and targets, future experiments (COMPASS I at CERN, CLAS/HALL A at Jlab, PHENIX and STAR at RHIC,…), particle identification, event information and selection, getting inclusive observables, and considerably more. The lectures were completely descriptive accounts of experiments.

Alessandro Bacchetta *(Università di Pavia and INFN, Italy)*
Phenomenology of 3-dimensional partonic distributions

In contrast to this, the lectures of Bacchetta were outstanding and most useful. He took the trouble to explain in detail the theory, mostly on the board, including and stressing the somewhat more difficult parts. For example, he took great pains to explain the path used in the Wilson line mentioned above. In addition, Bacchetta organized afternoon sessions during which the students made Mathematica calculations on their laptops (he provided short term Mathematica licenses for those who needed them). Obviously such lectures and exercise sessions require far more work for the lecturer to prepare than powerpoint presentations and I believe that Bacchetta deserves special thanks for his efforts.

Barbara Pasquini *(Università di Pavia and INFN, Italy)*
Modeling partonic distributions in momentum and configuration space

Barbara Pasquini lectured much in the same spirit as Bachetta, mostly on the board. In her lectures she used simple models (such as a simple quark-diquark model of the nucleon) to work out various measured parton distribution functions. She also discussed, although on slides only, the contributions of quarks to the spin and angular momentum of the nucleon. She staged Mathemetica sessions and provided several programs.

Abhay Deshpande (*Stony Brook and RIKEN BNL, USA*)
Current and future experiments in pp and DIS at $\sqrt{s} < 1$ TeV

Abhay Deshpande talked about past, present and future experiments. In addition to an occasionally amusing history of spin physics, he spoke of polarized *pp* and transverse spin physics. He described mostly experiments at RHIC, the PHENIX and STAR detectors, as well as a proposal for a future electron ion collider.

3.4.2 List of the Participants

Basso Eduardo	Universitade Federal do Rio Brande do Sul, Porto Allegre, Brazil
Beaumier Michael (experimentalist)	U of California, Riverside, USA
Brodski Irina (experimentalist)	U of Giessen, Germany
Gabdrakhmanov Ilnur	Bogoliubov Laboratory of Theoretical Physics, Dubna, Russia
Garay Jasone (experimentalist)	U of the Basque Country, LEIOA, Spain
Gaunt Jonathan, May 6-13 (part-time student)	U of Cambridge, England
Khandramai Vlacheslav	Gomel State Technical U, Belarus
Kleinjan David (experimentalist)	U of California, Shoreham, USA
Liu Tianbo	U of Beijing, China
Mertens Tom	U of Antwerp, Belgium
Perry Joshua (experimentalist)	Iowa State U, USA
Potapova Irina	Bogoliubov Laboratory of Theoretical Physics, Dubna, Russia
Ringer Felix	U of Tübingen, Germany
Van der Veken Frederik	U of Antwerp, Belgium
Zhu Jiacai	U of Beijing, China

3.4.3 Seminars delivered by the students

The students were asked to give a seminar on their present research. Those which had just begun their PhD, could talk about their previous research. The seminars were announced on the ECT* website. Some students made their slides available on the internal ECT* website.

Tom Mertens
TMD's, Wilson Loops and the Makeenko-Migdal equation

David Kleinjan
Nucleon spin physics at RHIC in Brookhaven

Jonathan Gaunt
Elements of double parton scattering

Joshua Perry
Isolation of Collins fragmentation in proton-proton collisions at PHENIX

Michael Beaumier
W-physics at PHENIX

Jasone Garay
Analysis of semi-inclusive deep-inelastic scattering data from the HERMES experiment

Irina Brodski
Asymmetries with HERMES recoil detector as a link to GPD's

Frederik Van der Veken
Elements of the color-glass condensate

Eduardo Basso
Inclusive hadron production from color glass condensate

Ilnur Gabdrakhmanov
Finite subtraction for vector meson production

Felix Ringer
Resummation and hadronic W production

Tianbo Liu and Jiacai Zhu
Azimuthal asymmetries in unpolarized and single polarized Dell-Yang processes

Irina Potapova
Basics of analytic perturbative theory and its applications

3.5 Training in Advanced Low Energy Nuclear Theory (TALENT):

Course on Computational Many-body Methods for Nuclear Physics

The present document aims at given a summary, with background information as well, about the first Nuclear Talent course.
The course was held at the premises of the European Center for Theoretical Studies in Nuclear Physics and Related Areas (ECT*), Trento, Italy in the period June 25 to July 13, 2012.
This report contains first a general introduction to the Nuclear Talent initiative. Thereafter follows a detailed description of the course, with a summary of the experiences made.

3.5.1 Introduction to the TALENT courses

A recently established initiative, **TALENT: Training in Advanced Low Energy Nuclear Theory**, see www.nucleartalent.org, aims at providing an advanced and comprehensive training to graduate students and young researchers in low-energy nuclear theory. The initiative is a multinational network between several European and Northern American institutions and aims at developing a broad curriculum that will provide the platform for a cutting-edge theory for understanding nuclei and nuclear reactions. These objectives will be met by offering series of lectures, commissioned from experienced teachers in nuclear theory. The educational material generated under this program will be collected in the form of WEB-based courses, textbooks, and a variety of modern educational resources. No such all-encompassing material is available at present; its development will allow dispersed university groups to profit from the best expertise available.
The advanced training network in nuclear theory will provide students (theorists and experimentalists) with a broad background in methods and techniques that can be easily applied to other domains of science and technology. The characteristic feature of this initiative is training in multi-scale nuclear physics. This knowledge is crucial, not only for a basic understanding of atomic nuclei, but also for further development of knowledge-oriented industry; from nanotechnology and material science to biological sciences, to high performance computing. As such, the proposed training aims at providing an inter-disciplinary education when it comes to theories and methods.
The ultimate goal of the proposal is to develop a graduate program of excellence in low-energy nuclear theory. The program will build strong connections between universities and research laboratories and institutes worldwide and provide a unique training ground for the future needs of nuclear physics.

3.5.2 Report: First TALENT course on computational many-body methods for nuclear physics

Aims and Learning Outcomes

The aim of the course is to learn how to solve complicated quantum many-body problems beyond mean field approximations using advanced numerical methods. The course aims also at understanding and implementing numerical methods and modern computational facilities. The acquired skills will enable the participants to write their own codes and to work and understand existing codes for solving complicated many-body problems. This will give the participants the necessary knowledge for tackling a broader spectrum of research problems. The course will also focus on how to write a scientific report via a final assignment which will be graded.

Course Content
This is an advanced course on computational physics with an emphasis on quantum mechanical systems with many interacting particles. The applications and the computational methods are relevant for research problems in such diverse areas as nuclear, atomic, molecular and solid-state physics, chemistry and materials science. A theoretical understanding of the behavior of quantum-mechanical many-body systems - that is, systems containing many interacting particles – is a considerable challenge in that no exact solution can be found; instead, reliable methods are needed for approximate but accurate simulations of such systems on modern computers. New insights and a better understanding of complicated quantum mechanical systems can only be obtained via large-scale simulations. The capability to study such systems is of high relevance for both fundamental research and industrial and technological advances.
The aim of this course is to present, through various computational projects, applications of some of the most widely used many-body methods with pertinent algorithms and high-performance computing topics such as advanced parallelization techniques and object orientation. The methods and algorithms that will be studied may vary from year to year depending on teachers and the interests of the participants, but the main focus will be on nuclear physics related methods.

Detailed Course Content
The first course on computational methods was held at the ECT* in Trento, in collaboration with the University of Trento. The students arrived on June 24 (Sunday) and left on July 14 in 2012. The course had its focus on Monte Carlo methods (Variational and Diffusion Monte Carlo) and large-scale diagonalization methods (Configuration interaction) as solvers for the many-body problem. The chosen system was that of a simplified representation of nuclei, with protons and neutrons (or spin 1/2 fermions) described by a harmonic oscillator potential in three dimensions and interacting via central Yukawa and Coulomb interactions. This system contains the basic features needed to describe nuclei and is simple enough to let the students develop programs to solve Schrödinger's equation for many interacting (charged) particles with the above methods.
The detailed content of the course was (see also the webpage of the course)

First week
- The problem per se, basic many-body physics, hamiltonians, set up of Slater determinants and single-particle basis. Rehearsal of basic many-body physics and examples of computation of Hamiltonian matrices
- The Monte Carlo part: Basics of stochastic methods: Central Limit Theorem, sampling by Markov Chains, random numbers, covariance, auto-correlation functions and error estimates, blocking for data analysis.
- Wave functions: general structure of a correlated many Fermion wave function, Slater determinants and the Feenberg expansion for correlations. The concept of local energy and its computation: efficient calculation of Slater determinants, its derivatives, and the Jastrow factor. Improved Monte Carlo methods (force¬biased, Langevin).

Second week
- Parallelization: standard master-slave (using Message-passing interface (MPI)).
- Imaginary time propagators, Trotter-Suzuki method, analogy with the diffusion equation. Drift, diffusion and branching. Importance sampling in DMC. Fixed node approximation and applications to nuclear physics problems.
- The large-scale diagonalization part: Shell-model and no-core shell model, basic philosophies, effective interactions and similarity transformations.
- Diagonalization algorithms, basics of Krylov methods with Lanczos algorithm for symmetric matrices, Givens and Householder's algorithms for smaller systems,

typically with dimensionalities less than 10^5 basis states. Convergence properties and other mathematical properties of iterative methods.

Third week

- Set up of a Slater determinant in *m*-scheme. Discussion of different angular momentum recoupling schemes. Action of the Hamiltonian on the basis of Slater determinants, actual implementation of the Lanczos algorithm.
- Parallelization of the Lanczos algorithms and intermediate orthogonalization using MPI.
- Computation of expectation values, energies and transition operators.
- Summary of course and discussion of possible assignment.

The course ends with a final assignment. The final assignment will be graded with marks A, B, C, D, E and failed for Master students and passed/not passed for PhD students.

Learning outcomes

The main learning outcomes was within the time span of three weeks, to have the students write a large-scale diagonalization program based on the Lanczos algorithm using effective interactions provided by the teachers and a Variational Monte Carlo program for fermions and bosons. The system to be studied with these two many-body methods was that of neutrons (or protons) in a three-dimensional oscillator trap interacting with a modified Yukawa interaction fitted to reproduce $^1S_0$ scattering data (the so-called Malfliet-Tjon interaction). All students were able to program and implement the large-scale diagonalization method with the Lanczos algorithm. However, not all students (less than ten) were able to implement the fermionic part of the Variational Monte Carlo part.

Teaching

The course was taught as an intensive course of duration of three weeks, with a total time of 45 h of lectures, 45 h of exercises and a final assignment of 2 weeks of work. The total load is approximately 170 hours, corresponding to **7 ECTS** in Europe. The days were organized as follows: 9-12 lectures, time for exercises with assistance (including lunch) till 18 (3 hours of allocated exercise sessions per day). The course was held at the premises ECT* (Villazzano) in Trento, Italy, from June 25 to July 13 in 2012.
In addition, six students gave presentations of their own research.

Teachers

Morten Hjorth-Jensen (Michigan State University and University of Oslo), Calvin Johnson (San Diego State University, California), Francesco Pederiva (University of Trento) and Kevin Schmidt (Arizona State University, Tempe, USA)
The teachers were self-sponsored except for lunches that were provided by the ECT*. That is, own research funds were used for travels and meals. Hjorth-Jensen was hosted by friends in Povo, Trento. It is not very likely that this may happen in the future. This means that when setting up a final budget, one has to include eventual per diems, travel and housing expenses for the teachers.
Francesco Pederiva and Kevin Schmidt taught the Monte Carlo part, while Calvin Johnson and Morten Hjorth-Jensen taught the shell-model part, resulting in an approximately equal load for each teacher.

Participants and their home institution and nationalities

The target group for the Nuclear Talent courses is Master of Science students, PhD students and early post-doctoral fellows. There were no experimentalists among the applicants. Out of 26 applicants, 22 students were selected. Priority was given to Master of Science students

and early PhD students. The applicants who were not admitted, were either post-doctoral fellows or PhD students on the verge of finishing their theses.
The students were expected to have operating programming skills in Fortran/C++/Python and knowledge of quantum mechanics at an intermediate level, with basic knowledge of many-body physics. All students except one had the expected background knowledge. Of the 22 students, seven were Master of Science students. Of the PhD students, the majority were in their first two years. Ten nationalities (and three continents) and 16 different institutions/affiliations were represented. The students and their respective institutions are listed in the table below.

Name	Institution
Kyle Wendt	Ohio State U, USA
Julia Rossi	San Diego State U, USA
William Spinella	San Diego State U, USA
Titus Morris	Michigan State U, USA
Kemper Talley	U of Tennessee, USA
Sarah Reimann	U of Oslo, Norway
Gustav Baardsen	U of Oslo, Norway
Sigve Bøe Skattum	U of Oslo, Norway
Andrea Cipollone	U of Rome, Italy and U of Surrey, UK
Diego Lonardoni	U of Trento, Italy
Francesco Catalano	U of Trento, Italy
Alessandro Roggero	U of Trento, Italy
Lorenzo Contessi	U of Trento, Italy
Kevin Fossez	U of Caen and Ganil, France
Guillaume Scamps	U of Caen and Ganil, France
Hongliang Lu	U of Caen and Ganil, France
Robin Jodon	U of Lyon, France
Carmen Carbonell-Coronado	U of Sevilla, Spain
Istvan Hornyak	U of Debrecen, Hungary
Hye-Ran Jang	Soong Sill U, Seoul, Republic of Korea
Gao Yuan	U of Jyväskylä, Finland
Daniel Ward	U of Lund, Sweden

On average, the students performed very well. It was an excellent and very active group.

3.5.3 Summary and recommendations

Overall, the first Nuclear Talent course was a very positive experience for both teachers and students. The support from the ECT*, and its year-long experiences with running doctoral training programs, was central to the success of the course. Of uttermost importance was Serena Degli Avancini's help will all administrative matters, from housing to minor practicalities. Without her help and the other staff of the ECT*, and the director's (Prof. Achim Richter) enthusiastic support, it is unlikely that this course could ever have been organized. For the Talent initiative this startup help from the ECT* has been crucial. What follows here are various recommendations for new Talent courses based on the views of the organizers, teachers and the feedback from the students.

- The Talent initiative has the potential to develop new teaching material and modular course material that can aid university groups to design new nuclear physics curriculae. The students agreed that this initiative has the potential to broaden their background in nuclear theory.

- The experience of a well-established center like the ECT*, the INT in Seattle and/or universities and laboratories with large nuclear physics groups, is a central element in running a successful course. Established housing facilities, sponsoring of students and teachers, good teaching facilities and administrative experience are central issues for the outcome. The administrative support at the ECT* was simply excellent. An obvious improvement at the ECT* would be to have the possibility to broadcast and/or record the lectures. This is an important issue to consider and explore for future courses as this will allow students to attend remotely.

- Since students may wish to include the credits from different Talent courses in their respective course curriculae, one needs to consider the inclusion of the various Talent courses as parts of a given university's set of courses. This particular course is included as part of the package of advanced courses at the university of Trento. The University of Trento guarantees thus for the academic content and the quality. It issues also a documentation that asserts the given number of credits for each participant. In order to achieve this, in several cases one may need bilateral agreements with the institution of the student and the university that guarantees for the credits. Since nine Nuclear Talent courses are planned, one needs to consider where to locate the courses and eventually whether some centers (ECT* and INT) and/or laboratories and universities (FRIB at MSU, Ganil, GSI, Riken, etc) should take the responsibility of housing periodically different courses. These centers, laboratories and universities have the necessary infrastructure and experience needed for running these courses.

- For courses which plan larger computational elements (this applies to several Talent courses), good computing facilities may be needed. However, since most students come with their own laptops (at this course only one out of 22 students did not bring a laptop), one may require that a laptop is needed and thus rely less on local computing facilities. The students used mainly the local computing facilities at the ECT* for printing.

- A student group of 20 to 30 students seems ideal and allows all teachers to get in touch with all participants. The students were asked to form working groups during the laboratory sessions, and more advanced students (or students which were already familiar with some of the methods) were asked to help less advanced students. Overall, the computer lab and the solution of the problems discussed during the lectures were perceived as very satisfactory and rewarding. The teachers rotated among the students during the computer lab sessions, discussing all possible aspects of the given problems.

- The tasks given to the students were rather ambitious. They were asked to develop a large-scale diagonalization program that could handle fermionic systems with a single-particle data table and an effective two-body interaction as input. All students succeeded in doing this and were able to reproduce various benchmarks. The final aim was to study a system of four neutrons with an effective no-core shell-model interaction defined by the single-particle states of the four lowest harmonic oscillator shells.

  The second task was to study the same system using the variational Monte Carlo method. Here, only half of the students achieved partly this goal. The conclusion of this goal was left as part of the completion of the final assignment. All students were however able to develop a variational Monte Carlo problem with the same interaction but for bosons only. The missing part was the development of functions that could handle the setup of a Slater determinant.

In order to achieve such ambitious tasks, it is crucial that the algorithms and the various programming steps are properly detailed in slides and lectures. A step-by-step recipe is almost mandatory as this makes the students operative in short time. If the tasks are not properly detailed from the beginning, the students end up wasting time searching for details (not all our tasks were properly spelled out and this caused some delay at the lab). In particular, since these are intensive courses, a clear recipe is needed in order to achieve the various tasks. The students were given daily programming tasks that followed the various lectures. Teachers and students discussed the various implementations during the lab sessions.

- Lecture notes for the first three days were provided approximately one week before the course started. The remaining lectures were provided gradually thereafter, after discussions among the teachers. This delay (we had hoped to present the full first draft of all lectures) was simply due to the need among us teachers to consult and discuss which material and which problems should be discussed. We were not able to meet physically before the course started. Although we were delayed with the final material, we still feel that the progression achieved by the students was within our aims. We were however not able to provide necessary background literature.

- Since the focus was more on computational methods and algorithms, we ended up using slides only. For courses with more theoretical details, one may opt for regular blackboard sessions. However, all material should be available as slides as well for later documentation.

- For such intensive courses, three weeks seem (at least from the student feedback) to be an optimal period.

4 Research at ECT*

In this chapter the activities of the scientific researchers at ECT* in 2012, i.e. of the Postdoctoral Fellows, the Director(s), the long-term Visitors and of their collaborators are briefly summarized. The different 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 to a PhD student at the University of Trento holding an ECT* fellowship. Luigi Scorzato is an expert in Lattice QCD and has simultaneously guided and coordinated the projects within the AuroraScience collaboration. 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

Massimiliano Alvioli

Color fluctuations in high energy hadron-nucleus and nucleus-nucleus collisions

In collaboration with M. Strikman (Pennsylvania State University, USA)

In Ref. [1] we started a program for the inclusion of short range nucleon-nucleon correlations in nuclear configurations to be used in hadron-nucleus and nucleus-nucleus high-energy collisions [2], motivated by the recent observation of the effects correlations [3], ascribed to the action of the tensor operator in the nuclear wave function [4]. The use of realistically correlated configurations has been shown to produce large fluctuations [1,5] on observables and we recently extended the implementation from central to realistic correlations [6]. In collaboration with Prof. Eskola (University of Jyväskylä, Finland) and H. Holopainen (FIAS, Frankfurt, Germany) we studied the effects of NN correlations and NN interaction models on the fluctuations of initial-state asymmetries of participant matter in ultrarelativistic heavy-ion collisions [7]. We recently applied our Monte Carlo method to the study of color fluctuations effects in proton-nucleus collisions [8], showing that such effects lead to a significant modification of the distribution over the number of nucleons involved in inelastic proton-nucleus collisions at collider energies. As a consequence, a trigger for low (high) mutliplicity of wounded nucleons selects smaller (larger) than average size configurations leading to a prediction of the impact dependence of the effective proton *pdfs* which can be checked in the forthcoming pA run at LHC.

Realistic many-body wave functions of medium-heavy nuclei

In collaboration with C. Ciofi degli Atti, S. Scopetta, L. P. Kaptari (University of Perugia) and H. Morita (Sapporo University, Japan)

In Ref. [11] we developed a many-body description of nuclei, within the cluster expansion method, which provides the expectation value of a given operator over the realistically correlated wave function. In particular, we produced basic one- and two-body quantities of interest in the calculation of nuclear reactions, namely one- and two-body densities and, most notably, momentum distributions [4,9]. These quantities have been shown to be relevant for many kinds of reactions at medium- and high-energies [6,12,13]. Universality of NN correlations and their A dependence are the object of current experimental investigations at JLab (USA) and other world facilities. We have recently shown that universal features can be found in one- and two-body quantities of few- and many-body nuclei [14,15,16]. One of the next goals of the collaboration is the extension of the method of Glauber multiple scattering in order to have a comprehensive description of final state interactions in A(e,e'p)X and A(e,e'pN)X reactions, with A ranging from few-to many-body nuclei and using realistic wave functions. Our recent findings about spin-isospin dependence of one- and two-body momentum distribution elucidates the role of pairs with deuteron-like quantum numbers in nuclei across a wide range of atomic numbers [15,16] and the relative and center of mass motion of such pairs in the nuclear medium. We obtained substantial computing time for the development of this project within the PRACE/DECI-8, the Partnership for Advanced Computing of the EU's FP7.

Parton correlations and multiple partonic interactions

In collaboration M. Filipuzzi and D. Treleani (University of Trieste & INFN) L. Fano' Illic (University of Perugia & INFN)

Multiple Partonic Interactions [17] are the tool to obtain information on the correlations between partons in the hadron structure. Partons may be correlated in all degrees of freedom and all different correlation terms contribute to the cross section. In the case of high energy proton-proton collisions, the effects of correlations in the transverse coordinates and in fractional momenta are mixed in the final observables, while the investigation of proton-nucleus collisions present advantages in order to disentangle such correlations [18]. It has been shown in [19] that the effects of longitudinal and transverse correlations may be disentangled investigating double parton interactions in high energy proton-deuteron collisions. The collaboration during the past year has led to a Master Thesis at University of Trieste co-supervised by Prof. Treleani and Dr. Alvioli [20], in which calculations have performed for the p-D reaction with usual parton distribution functions and modeling double-parton distribution functions. Work is in progress for the calculation of p-D to p-p cross ratios and their x-dependence [21] at possible kinematic conditions at the LHC. Investigation of the implementation of the model in a Pythia-based Monte Carlo simulation is also in progress.

High energy QCD evolution of the small x hadronic wave functions

with D.N. Triantafyllopoulos, ECT and G. Soyez (IPhT, Saclay, France)*

The high energy QCD evolution of the small-x components of a generic hadronic wave function is one of the main topics investigated at ECT*. We were interested in the numerical solutions of these non-linear evolution equations, and in particular in the Balitsky-Kovchegov equation [22, 23] which describes the evolution of the dipole-hadron interaction at high-energy. The solution of such an equation, which is integro-differential and nonlinear, is rather involved. We recently found the solution of new, approximate equations [24,25] which serve as a direct test of the Gaussian approximation. We found [26] that the Gaussian approximation provides a quasi-exact solution and in particular we have shown that this is the case independent of the prescription used to set the scale in the argument of the running coupling. This allows one to calculate easily higher-point correlations in the hadronic wave functions and it is of direct phenomenological interest, for example in calculating di-hadron correlations in light with heavy ion collisions.

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Daniele Binosi

Canonical transformations and renormalization group invariance in the presence of non-trivial backgrounds

In collaboration with A. Quadri (University of Milan, Italy)

In the paper [1] we continued the analysis started in [2] where an algebraic procedure for the evaluation of Green's functions in SU(N) Yang-Mills theory in the presence of a non-trivial background field was devised. In particular, we have shown that for a SU(N) Yang-Mills theory the classical background-quantum splitting is non-trivially deformed at the quantum level by a canonical transformation with respect to the Batalin-Vilkovisky bracket associated with the Slavnov-Taylor identity of the theory. This canonical transformation acts on all the fields (including the ghosts) and antifields, and, in addition, it uniquely fixes the dependence on the background field of all the one-particle irreducible Green's functions of the theory at hand. The important point of this study is that the approach developed is valid both at the perturbative and non-perturbative level, being based solely on symmetry requirements. To show the power of the method, we derived the renormalization group equation in the presence of a generic background and apply it in the case of a SU(2) instanton, determining also the one-loop deformation of the background-quantum splitting in lowest order in the instanton background.

The background field method as a canonical transformation

In collaboration with A. Quadri (University of Milan, Italy)

The paper [3] constitute the culmination of the studies carried out in [1,2]. There we construct explicitly the canonical transformation that controls the full dependence (local and non-local) of the vertex functional of a Yang-Mills theory on a background field. After showing that the canonical transformation found is nothing but a direct field-theoretic generalization of the Lie transform of classical analytical mechanics, we comment on a number of possible applications, and in particular the non perturbative implementation of the background field method on the lattice, the background field formulation of the two particle irreducible formalism, and, finally, the formulation of the Schwinger-Dyson series in the presence of topologically non-trivial configurations.

Unquenching the gluon propagator with Schwinger-Dyson equations

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

In the article [4] we use the Schwinger-Dyson equations to compute the nonperturbative modifications caused to the infrared finite gluon propagator (in the Landau gauge) by the inclusion of a small number of quark families. Our basic operating assumption is that the main bulk of the effect stems from the "one-loop dressed" quark loop contributing to the full gluon self-energy. This quark loop is then calculated, using as basic ingredients the full quark propagator and quark-gluon vertex; for the quark propagator we use the solution obtained from the quark gap equation, while for the vertex we employ suitable Ansätze, which guarantee the transversality of the answer. The resulting effect is included as a correction to the quenched gluon propagator, obtained in recent lattice simulations. Our main finding is that the unquenched propagator displays a considerable suppression in the intermediate momentum region, which becomes more pronounced as we increase the number of active quark families. The influence of the quarks on the saturation point of the propagator cannot be reliably computed within the present scheme; the general tendency appears to be to decrease it, suggesting a corresponding increase in the effective gluon mass. The renormalization properties of our results, and the uncertainties induced by the unspecified transverse part of the quark-gluon vertex, are discussed. Finally, the dressing function of the gluon propagator is compared with the available unquenched lattice data, showing rather good agreement.

Quark flavour effects on gluon and ghost propagators

In collaboration with A. Ayala and J. Rodriguez-Quintero (University of Huelva, Spain), A. Bashir (University of Michoacan, Mexico), and M. Cristoforetti (ECT, Italy)*

In the paper [5], which constitutes an ideal partner to [4], we compute the full non-perturbative ghost and gluon two-point Green functions by using gauge field configurations with two light and two light plus two heavy twisted-mass quark flavours. We use simulations with several different light quark masses, heavy quark masses close to that of the strange and charm quarks, and lightest pseudoscalar masses ranging from 270 to 510 [MeV]. Quark flavour effects on both the gluon and the ghost propagators are then investigated in a wide range of momenta, bridging the deep infrared and intermediate momenta domain of QCD interactions in the presence of dynamical quarks. The ghost-gluon vertex is also indirectly probed through a consistency requirement among the lattice data for the gluon and ghost propagators and the ghost propagator Schwinger-Dyson equation. The effective full QCD coupling is finally constructed, and its dependence on the presence of dynamical fermions scrutinized.

The all-order equation of the effective gluon mass

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

In the paper [6] we completed the work started in [7], and presented the general derivation of the full non-perturbative equation that governs the momentum evolution of the dynamically generated gluon mass, in the Landau gauge. The entire construction hinges crucially on the inclusion of longitudinally coupled vertices containing massless poles of non-perturbative origin, which preserve the form of the fundamental Slavnov-Taylor identities of the theory. The mass equation is obtained from a previously unexplored version of the Schwinger-Dyson equation for the gluon propagator, particular to the PT-BFM formalism, which involves a reduced number of "two-loop dressed" diagrams, thus simplifying the calculational task considerably. The two-loop contributions turn out to be of paramount importance, modifying the qualitative features of the full mass equation, and enabling the emergence of physically meaningful solutions. Specifically, the resulting homogeneous integral equation is solved numerically, subject to certain approximations, for the entire range of physical momenta, yielding positive-definite and monotonically decreasing gluon masses.

Scalar resonances in the non-linearly realized electroweak theory

In collaboration with A. Quadri (University of Milan, Italy)

Triggered by the CMD and ATLAS announcement of the discovery of Higgs-like particle with a mass of roughly 125 GeV, in [8] we developed a model in which a physical scalar sector is introduced in a SU(2)xU(1) electroweak theory in which the gauge group is realized non linearly. By invoking theoretical as well as experimental constraints, we build 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 Stückelberg mechanism. We evaluate 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.

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Marco Cristoforetti

The sign problem and the Lefschetz thimble

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

It is sometimes speculated that the sign problem that afflicts many quantum field theories might be reduced or even eliminated by choosing an alternative domain of integration within a complexified extension of the path integral (in the spirit of the stationary phase integration method). In this paper we start to explore this possibility somewhat systematically. A first inspection reveals the presence of many difficulties but - quite surprisingly - most of them have an interesting solution. In particular, it is possible to regularize the lattice theory on a Lefschetz thimble, where the imaginary part of the action is constant and disappears from all observables. This regularization can be justified in terms of symmetries and perturbation theory. Moreover, it is possible to design a Monte Carlo algorithm that samples the configurations in the thimble. This is done by simulating, effectively, a five dimensional system. We describe the algorithm in detail and analyze its expected cost and stability. Unfortunately, the measure term also produces a phase which is not constant and it is currently very expensive to compute. This residual sign problem is expected to be much milder, as the dominant part of the integral is not affected, but we have still no convincing evidence of this. However, the main goal of this paper is to introduce a new approach to the sign problem, that seems to offer much room for improvements. An appealing feature of this approach is its generality. It is illustrated first in the simple case of a scalar field theory with chemical potential, and then extended to the more challenging case of QCD at finite baryonic density [1].

Quark flavour effects on gluon and ghost propagators

A. Ayala (Huelva U.) , A. Bashir (IFM-UMSNH, Michoacan & Argonne & Kent State U.) , D. Binosi (ECT), M. Cristoforetti (ECT*) , J. Rodriguez-Quintero (Huelva U.)*

We compute the full non-perturbative ghost and gluon two-point Green functions by using gauge field configurations with Nf=2 and Nf=2+1+1 twisted-mass quark flavours. We use simulations with several different light quark masses, heavy quark masses close to that of the strange and charm quarks, and lightest pseudoscalar masses ranging from 270 to 510 [MeV]. Quark flavour effects on both the gluon and the ghost propagators are then investigated in a wide range of momenta, bridging the deep infrared and intermediate momenta domain of QCD interactions in the presence of dynamical quarks. The ghost-gluon vertex is also indirectly probed through a consistency requirement among the lattice data for the gluon and ghost propagators and the ghost propagator Schwinger-Dyson equation. The effective full QCD coupling is finally constructed, and its dependence on the presence of dynamical fermions scrutinized [2].

Are there hadronic bound states above the QCD transition temperature?

C. Ratti (Turin U. & INFN, Turin), R. Bellwied (Houston U.), M. Cristoforetti (ECT), M. Barbaro (Turin U. & INFN, Turin)*

Recent lattice QCD calculations, at physical pion masses and small lattice spacings that approach the continuum limit, have revealed that non-diagonal quark correlators above the critical temperature are finite up to about 2 Tc. Since the transition from hadronic to free partonic degrees of freedom is merely an analytic cross-over, it is likely that, in the temperature regime between 1-2Tc, quark and gluon quasiparticles and pre-hadronic bound states can coexist. The correlator values, in comparison to PNJL model calculations beyond mean-field, indicate that at least part of the mixed phase resides in color-neutral bound states. A similar effect was postulated for the in-medium fragmentation process, i.e. for partons which do not thermalize with the system and thus constitute the non-equilibrium component of the particle emission spectrum from a deconfined plasma phase. Here, for the first time we investigate the likelihood of forming bound states also in the equilibrated, parton dominated phase above Tc which is described by lattice QCD [3].

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Alexis Diaz-Torres

Low-energy reaction dynamics of weakly-bound nuclei

In collaboration with experimenters in 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 as well as fusion measurements in reactions induced by weakly-bound nuclei at energies near the Coulomb barrier [4]. The model will be developed further and fine tuned with the measurements. A unified quantum description of relevant reaction processes of weakly-bound nuclei (breakup, transfer, complete and incomplete fusion) will be pursued, which is the central aspect of the work by a PhD-student (Maddalena Boselli) at the ECT*.

Quantum decoherence in low-energy nuclear collision dynamics

In collaboration with M. Dasgupta and D.J. Hinde (ANU, Canberra, Australia), E. Piasecki (Warsaw University, Poland) and M. Wiescher (JINA and Notre Dame, USA)

An investigation of quantum decoherence effects on low-energy heavy-ion fusion cross sections was initiated in Ref. [5]. 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 [6]. An innovative approach [7] 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 [8]. The developments allow one to quantify decoherence effects on both fusion and scattering [7]. Extensive CCDM calculations are planned for explaining very recent, precision measurements of fusion and quasi-elastic barrier distributions [9]. 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.

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 [10]. 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 [10].

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Matthias Drews

Dense matter and functional renormalization group

In collaboration with W. Weise (ECT) and B. Klein (TU München)*

As a contribution to the ongoing discussion on the question of a critical endpoint of a chiral phase transition, a nucleon-meson model was studied recently [1]. There was no evidence of a first-order phase transition in the region of chemical freeze-out for larger chemical potential. We try to extend and solidify the calculations that were done at the mean field level by including mesonic fluctuations with help of the functional renormalization group equations.
The goal is to study the influences of these fluctuations through susceptibilities. As a long-term perspective, the goal is to extend the model to study neutron stars. The motivation comes from the recent observation of a two-solar-mass neutron star [2]. This high mass puts constraints on the equation of state of neutron star matter.

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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] is going to summarize the results of our ongoing long-term project about the equations of state for nuclear matter, derived within several frameworks: first, 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. Second, we use the Polyakov-loop-extended Nambu and Jona-Lasinio model [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 solution of the Tolman-Oppenheimer-Volkoff equations) with observations from astrophysics. Recently, the mass of the pulsar PSR J1614-2230 [5] has been measured at a one-percent accuracy to be roughly 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 very stiff equation of state of ordinary nuclear matter, without the need of exotic-matter admixtures, is in order 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 particularly useful for an investigation of the thermal properties of strongly interacting matter, and sketching to phase diagram of quantum chromodynamics. Furthermore, we can get in contact with first-principle Dyson-Schwinger calculations and lattice simulations without suffering from the notorious sign problem.
Concerning the repulsive vector interaction between quarks, we observe the following impact on the chiral first-order phase transition: at imaginary chemical potential 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 potential, 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 phase transition disappears and turns into a smooth crossover.

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Ahmad Idilbi

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

In collaboration with M.G. Echevarria (University of Madrid) and A. Schaefer (University of Regensburg)

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

Amplitude analysis for hadron spectroscopy

In collaboration with M. Battaglieri, R. De Vita (Genoa University, Italy)
and A. Szczepaniak (Indiana University, USA)

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 decomposition and amplitude analysis never achieved before. We started an ambitious project: to provide a comprehensive set of theoretical amplitudes that match the experimental data in order to extract physical properties of hadrons, to compare these properties with existing theoretical predictions, which possibly lead to discovery of new hadrons. We stated the analysis on eta-pi and 3 pi production since COMPASS have already recorded data on those channels [1]. Their data show a possible hybrid meson in J(PC) = 1(+-) partial wave. We are in parallel performing the same theoretical analysis with a photon beam for CLAS12 applications.

Dyson-Schwinger equations in hot QCD

In collaboration with D. Binosi (ECT, Italy)*
and G. Lacroix (Mons University, Belgium)

In Ref. [3] Binosi and Papavassiliou developed a formalism to recast Dyson-Schwinger (DS) equations for QCD Green's functions into a form where physical properties are more transparent. The new equation for the gluon propagators was solved numerically and the solution is found to be in agreement with the lattice calculations [4]. We have started to generalize this formalism, based on the pinch technique and its correspondence with the background field method, to the gluon propagator in finite temperature QCD.

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Stefano Melis

Transverse momentum dependent distribution and fragmentation functions

In collaboration with M. Anselmino (University of Torino)
M. Boglione (University of Torino), U. D'Alesio (University of Cagliari), F. Murgia (University of Cagliari), A. Prokudin (Jefferson Lab, USA)

In high energy processes, in the so called collinear parton model, a fast moving nucleon is described as a collection of constituents moving collinearly with it. The composite structure of nucleons in high energy processes is described by parton distribution functions (PDFs) which represent the number density of quarks (or gluons) with a certain polarization and momentum inside a moving nucleon at some given energy scale. Although many high energy observables can be successfully explained in the collinear approximation, several experimental evidences show the importance of the transverse components of the partonic momentum. Extending the QCD framework to a non-collinear picture introduces more degrees of freedom and new possible correlations among nuclear and partonic spin and momenta. Thus the nucleon is described by the so called Transverse Momentum Dependent distribution functions (TMDs). Transverse-momentum distributions, intuitively, give us a tridimensional representation of the nucleons (in momentum space). In the past forty years we have reached a good knowledge of collinear PDFs, which represent one-dimensional images of the nucleon. PDFs allow us to glance into the structure of matter at the highest resolution currently available. TMDs widen the perspective to embrace other dimensions. Their knowledge is fundamental to shed light on the parton dynamics inside the nucleon and to test lattice QCD predictions and model calculations, that is, to test our actual understanding of the hadron matter. For these reasons they are subject of an intense experimental investigation by several collaborations in many facilities in the world (HERMES at DESY, COMPASS at CERN, RHIC, JLAB, BELLE).
Our research represents a strong contribution to the knowledge of many TMDs and to our understanding of many experimental data. For instance, Ref. [1] is devoted to the extraction of the so called Sivers function in Semi-Inclusive Deep Inelastic Scattering processes (SIDIS) from the analysis of the HERMES and COMPASS data. The Sivers function is related to the probability to find an unpolarized quark in a transversely polarized hadron. It is naively time-odd, this means that the Sivers function, contrary to naive expectations, changes its sign if observed in Drell-Yan (DY) or in SIDIS processes. Moreover, many models connect this function to the partonic angular momentum, thus giving us invaluable information on parton dynamics. We found that the u and d Sivers distributions have opposite signs. This means that the parton distribution in momentum space of an unpolarized quark in a transversely polarized nucleon is distorted as if u and d quarks “rotate” in opposite directions. The way this distortion changes with the scale of the process is dictated by QCD evolution. Very recently, in the end of 2011, J. Collins and collaborators developed their TMD evolution equations for the unpolarized TMD PDF and the Sivers function. We tested their approach

applying TMD evolution to the analysis of polarized SIDIS [2] finding a remarkable agreement with data behavior.
Our studies are useful to test other important properties of the parton model and QCD in high energy processes, like the factorization. Recent studies pointed out that TMD factorization can be violated in inclusive hadron production. In Ref. [3], adopting a pure phenomenological approach we tried to understand whether present data can either confirm or disprove the factorization breaking while in Ref. [4] we reexamined the Collins effect in inclusive hadron production taking into account the experimental constraints coming from the SIDIS data.

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Abhishek Mukherjee

Configuration interaction Monte Carlo

In collaboration with Y. Alhassid (Yale University, USA), F. Pederiva and A. Roggero (University of Trento)

Projection Monte Carlo methods (e.g. diffusion Monte Carlo, Green's function Monte Carlo) have been applied very successfully in the past to strongly interacting systems ranging from liquid Helium to nuclei. They provide very accurate estimates of ground state energies and other ground state properties of systems with many interacting particles. Traditionally this projection Monte Carlo is formulated in real space. However, sometimes an economical description of the problem can be obtained in terms of an effective Hamiltonian in some finite configuration space, e.g. the shell model for nuclei and ultracold atoms in a trap.
We have developed a projection Monte Carlo algorithm which can be used with Fock space Hamiltonians. In order to circumvent the fermionic sign problem we use the particle number projected Hartree-Fock-Bogoliubov wave function as the parameter free guiding wave function for filtering out the ground state wave function through a stochastic random walk in the configuration space.
As a first application we calculated the ground state energies of a unitary Fermi gas in a harmonic trap. We find that this new method provides very tight upper bounds to the ground state energy and its accuracy is comparable to its real space counterparts [1].
Currently we are trying to generalize this method to uniform systems with more general interactions. In particular, for effective field theory based nuclear interactions

Shell model Monte Carlo for odd particle systems

In collaboration with Y. Alhassid (Yale University)

Shell model Monte Carlo (SMMC), i.e. auxiliary field Monte Carlo for the interacting shell model, is a very accurate method for calculating ground state and thermodynamic properties of finite systems. It is especially useful for systems with Hilbert spaces much larger than what is currently accessible with direct diagonalization methods. For a large class of interparticle interactions it can give exact results within statistical error.

For finite sized systems like nuclei, cold atomic gases in a trap etc., the correct thermodynamic description is the canonical ensemble, i.e., with a fixed number of particles. This *particle number projection* leads to a sign problem within SMMC for odd number of particles, resulting in exponentially growing statistical fluctuations in calculation of observables.

This sign problem had severely limited the application of SMMC to odd-particle systems in the past.

We have developed a method where we exploit the asymptotic behavior of the imaginary time Green's functions of even-particle systems to calculate the ground state energy of neighboring odd-particle systems [2,3]. Since, in this method, the calculations are performed for systems with an even number of particles, this method is free from any sign problem due to particle number projection. This method is somewhat similar to the technique used in lattice QCD to extract the hadron spectrum.

We have applied this method to calculate ground state energies and pairing gaps of iron region nuclei. We found very good agreement with the experimental pairing gaps for calculations done with a Hamiltonian with no adjustable parameters. Currently we are investigating the possibility of using this method to calculate the ground state energy of heavy rare earth nuclei.

Spin-parity projected level densities within the proton-neutron formalism of SMMC

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

Nuclear level densities are the key input to nuclear reaction theories where they govern the rates and decay patterns of astrophysical processes.

The iron region nuclei are especially interesting in this context since they are the heaviest nuclei formed by fusion inside stars and form the starting point for the synthesis of heavier nuclei.

Traditionally the level densities could be determined experimentally in very specific energy domains, e.g., at very low energies from level counting and at the neutron resonance energy from the level spacing of the resonances. Recent advances in experimental techniques (proton evaporation spectra) has made it possible to infer the level densities in the interesting intermediate energy regime.

The microscopic prediction of nuclear level densities is a long standing theoretical problem. The shell model Monte Carlo method provides an attractive alternative, in that, it can be used to calculate the level densities accurately within a given model space. For a fruitful comparison between theory predictions and experimental results it is necessary to be able to calculate the spin and parity resolved level densities microscopically. Currently, we are implementing spin and parity projection within the proton-neutron formalism of shell Model Carlo. This will be useful for not only the iron region nuclei but also for heavy rare earth nuclei. As a first step we will perform calculations for Ni isotopes were experimental results are already available.

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Achim Richter

In my fourth and last year at the ECT I have – as in the former years – continued working closely with collaborators from my home institution, the Institute of Nuclear Physics at the Technische Universität Darmstadt (TUD), and from institutions elsewhere mainly on problems in nuclear structure and on quantum and wave dynamical aspects in Schrödinger- and Dirac-microwave billiards. The names of the respective collaborators are listed in the references at the end of this section.*

Studies of the pygmy dipole resonance in ^{208}Pb

It has been demonstrated recently that high-resolution scattering of protons of several hundred MeV is a promising new spectroscopic tool for the study of electric dipole strength in nuclei. A case study of an experiment on ^{208}Pb performed at the RCNP in Osaka/Japan showed that under very forward angles 1^- states are strongly populated via Coulomb excitation. A clear separation from nuclear excitation of other modes has been achieved by a multipole decomposition analysis of the measured cross sections based on theoretical angular distributions calculated within the quasiparticle-phonon model [1]. The E1 strength distribution was extracted for excitation energies up to 9 MeV, i.e. in the region of the so called pygmy dipole resonance (PDR). The Coulomb-nuclear interference showed sensitivity to the underlying structure of the E1 transitions. The very precise results of this experiment [2] constitute a benchmark for future nuclear structure model predictions.

Momentum profile analysis in one-neutron knockout from Borromean nuclei

Previously taken data by our collaboration at the ALADIN-LAND setup at GSI Darmstadt on one-neutron knockout reactions from Borromean nuclei have been reanalysed using a so called profile function technique. The profile function that is derived as the square root of the variance of the measured fragment plus neutron moments is very sensitive to the angular momentum of the knocked out neutron. Three cases were studied: ^{7}He, where the profile function shows the presence of an $(s_{1/2})^2$ component in the ^{8}He ground-state wave function, ^{10}Li, where an 11 % d-wave contribution in the relative-energy spectrum above 1.5 MeV is found and, finally, the presence of a major s-wave contribution around 0.5 MeV in the ^{13}Be relative-energy spectrum. Furthermore, we confirmed an s-wave neutron decay from a $5/2^+$ state in ^{13}Be to the 2^+ state at 2.1 MeV in ^{12}Be. The results have just been published [3].

Experimental test of a trace formula for chaotic dielectric resonators

Resonance spectra of two stadium-shaped dielectric microwave resonators were measured and tested for the first time against predictions from a semi-classical trace formula for chaotic dielectric resonators [4]. We found good qualitative agreement between the experimental data and the predictions of the trace formula. Deviations were attributed to missing resonances in the measured spectra in accordance with results from previous experiments [5]. The numerical length spectrum of the periodic orbits was found to be in reasonable quantitative agreement with the trace formula. The application of a curvature correction to the Fresnel reflection coefficients entering the trace formula yielded, however, better agreement. The remaining deviations indicate the necessity of further investigations [6].

Analytical and experimental approach towards bound states in sharply bent waveguides

Quantum wires and electromagnetic waveguides have many features in common since their physics is governed by the same wave equation. We have exploited this fact to investigate theoretically and experimentally the occurrence of bound states in sharply bent quantum wires using flat wave guides excited by microwaves. In particular, we have studied the features of transitions from bound to unbound states caused by the variation of the bending angle. We have also – with the help of an effective potential approach – computed the bound states and the critical bending angles at which one of the states undergoes a transition from bound to unbound. Finally, the predictions were confirmed by numerical calculations and measurements of the spectra and electric field intensity distributions of electromagnetic waveguides. The results have been submitted for publication [7].

Schrödinger and Dirac-microwave billiards, photonic crystals and graphene

We have continued our experiments in 2012 with microwave photonic crystals modeling graphene.
By placing the photonic crystal into a closed resonator metal box a relativistic quantum billiard (called Dirac billiard) was produced. We have constructed a particular bounded photonic crystal of 888 metallic cylinders arranged in a triangular lattice, have made it

superconducting, and because of the unprecedented high resolution were able to detect and resolve altogether about 5000 resonances. From the complete spectrum we determined the local density of states (LDOS) at and around the Dirac point (in the relativistic regime) and away from it (in the non-relativistic regime). The results are presently prepared for publication [8].

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Luigi Scorzato

Exascale Lab

In collaboration with INFN, CINECA, Trento U., IASMA, ATreP, Padova U., Eurotech

I am the reference person in FBK concerning the new Exascale Lab initiative, that is developing scientific software able to exploit the HPC system that will be available in the near future. In particular, I am developing algorithms for Lattice QCD, designed to exploit modern HPC architectures. I am also advising other groups within the Exascale Lab on the porting of their applications to the new architecture. I have also managed, in collaboration with Enrico Tagliavini, the Aurora system installed at FBK, which is currently used by many scientific groups in Trentino and INFN. The publications resulting from calculations done in Aurora are listed in web.infn.it/aurorascience → publications.

Optimization of the Lattice Dirac operator on modern HPC architectures

In collaboration with F. Di Renzo and M. Brambilla (Parma U.)

I am studying optimization strategies for the application of the Lattice Dirac operator on modern HPC architectures. A very efficient version was developed for Aurora, and will be published soon.

Exotic mesons and tetraquarks on the lattice

In collaboration with M. Wagner (Frankfurt), M. Dalla Brida (TC Dublin), C. Alexandrou (Cyprus U.) M. Gravina (Cyprus U.), C. Urbach (U.Bonn)

We have computed the contribution of tetraquark states to the meson spectrum. We are using various noise reduction methods in which we are experts. The next step will be the extension of the method to the computation of hadron scattering.

Lattice QCD simulations at nearly physical quark masses

In collaboration with ETMC collaboration

We are doing simulations of Nf=2+1+1 lattice QCD in the twisted mass regularization, for nearly physical quark masses. In order to approach the physical limit on reasonably large and fine lattices, a delicate work of tuning is necessary, complemented the usage of a number of optimizations.

Lefshetz thimbles and the sign problem of QCD at finite baryonic density

In collaboration with F. Di Renzo, C. Torrero (Parma U.), M.Cristoforetti, A.Mukherjee (ECT)*

We are studying a new approach, which enables the definition of an algorithm that circumvents the sign problem that prevents the Monte Carlo simulation of a number of quantum field theories. The idea is based on representing the path integral as a sum along the manifold defined by the curves of steepest descent (Lefshetz Thimbles), and is applicable, in principle, also to QCD at finite density. We are currently applying the method to a scalar phi^4 model, to the XY model and to an electron gas model.

Pavel Stránský

Regular and chaotic dynamics and phase transitions in collective models of nuclei

In collaboration with P. Cejnar (Charles University in Prague, Czech Republic) and M. Macek (Racah Institute of Physics, The Hebrew University, Jerusalem, Israel)

Simple models of nuclear collective dynamics – the geometric collective model (GCM) and the interacting boson model (IBM) – exhibit a high degree of variability in regular and chaotic features with energy and control parameters [1,2,3]. The complex dynamics encoded in relatively simple Hamiltonians designate these systems to be laboratories for detailed investigation into classical-quantum correspondence and for testing methods of measuring and visualizing chaos [4]. In addition, the study of chaos can help in understanding the dynamical structure of the systems and allows for observation of new phenomena, such as the quantum phase transitions [5] and the separation of intrinsic and collective dynamics induced by increased regularity [6]. In the present work, we follow three branches of investigation. (i) Elaborate the method of associating a classical Hamiltonian with an appropriate metric tensor of a Riemannian space [7]. This method can be successively used as an indicator of the dynamical stability and can bring better understanding of the order-chaos-order transition in the parametric space of the system under study [8]. (ii) Continue the investigation of the quantum phase transitions, focusing mainly on the changes in the exited spectra (the so called excited state phase transitions [9,10]). (iii) Adopt the phenomenon of entanglement, known from solid-state physics [11], and apply it to study the quantum phase transition in nuclear physics.

Study of well-deformed nuclei by means of the Bohr Hamiltonian with different mass parameters for the rotational and vibrational modes

In collaboration with M.J. Ermamatov (Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México, and Institute of Nuclear Physics, Tashkent, Uzbekistan), P.R. Fraser (School of Physics, University of Melbourne, Australia), and P.C. Srivastava (Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México)

In recent works [12] it has been shown that taking into account the difference in the mass parameters of the rotational and the two vibrational modes in the Bohr Hamiltonian of the nuclear collective dynamics is very important when describing the properties of axially symmetric, well-deformed nuclei, especially when one in interested in the interband $E2$ transition probabilities. Choosing the Davidson potential to characterize the β vibrations, the excited-state energies and $E2$ transitions have been calculated for several even and odd nuclei [13]. We have explored the situation where K (the angular momentum projection onto the third symmetry axis) and Ω (the angular momentum projection of the external nucleon) are not conserved, as this leads to the inclusion of the Coriolis force [14]. In order to determine the correct value of the angular momentum of the external nucleon, large-scale shell-model calculations, using the ANTOINE code [15], are performed. The effect of staggering in the ground-state band and in the γ-band is observed [16], whose detailed study will be the subject of a future work.

Study of time series in complex physical and medical systems

In collaboration with A. Frank, E. Landa, I.O. Morales, J.-C. López Vieyra (Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México), V. Velázquez (Facultad de Ciencias, Universidad Nacional Autónoma de México), and R. Fossion (Instituto de Geriatría de la Secretaría de Salud, México)

Many dynamical systems from various areas of knowledge can be studied within the theoretical framework of time series, where the system can be considered as a black box. Certain dynamical systems auto-organize in a critical state that is characterized by 1/f noise in the power spectrum of the time series (for example the time series of the human heart inter-beat intervals of a healthy individual follows 1/f noise [17]). This noise has been also observed in physics both in classical and quantum systems [18-20], and could possibly offer a unifying bridge between the macroscopic and the quantum world. Besides the power spectrum, which assumes the time series to be stationary and periodic, and which uses an *a priori* given Fourier basis, we have adopted the Empirical Mode Decomposition (EMD) [21]. It decomposes a general nonstationary time series into few modes that can be regarded also as an *a posteriori* determined basis. The EMD method has been applied to improve the unfolding procedure [22], necessary for studying the fluctuating part of the quantum spectra. In addition, it has revealed a scaling law in the spectra of random matrices [23]. Currently, the EMD method is used to analyse time series originated from the spectra of diverse complex systems including collective (GCM and IBM) and microscopic (Shell model) models of atomic nuclei, and to study different modes in the heart inter-beat intervals and its correlation with breathing and other physiological time series.

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Dionysis Triantafyllopoulos

Jet evolution from weak to strong coupling

In collaboration with Y. Hatta (University of Tsukuba, Japan), E. Iancu (IPhT, Saclay, France) and A.H. Mueller (Columbia University, USA)

The strong coupling limit of certain gauge theories can be studied by using the gauge/gravity duality [1]. In particular, the radiation produced by a decaying system or by an accelerated charge has been calculated in the N=4 supersymmetric Yang-Mills theory at strong coupling and has led to a puzzling result: the supergravity backreaction, which is supposed to describe the energy density at infinitely strong coupling, yields the same result as at zero coupling [2,3,4]. Therefore, in contrast to the expectation from field-theoretical arguments, it does not show any trace of quantum broadening. In [5] we understood the origin of the confusion by showing that the backreaction calculation is unable to faithfully capture the space-time distribution of the radiation. This backreaction is tantamount to computing a three-point function in the gauge theory, but in order to study a localized distribution, one should rather compute a four-point function, as standard in deep inelastic scattering. We considered the decay of a time-like photon at both weak and strong coupling and we showed that, by computing four-point functions, the quantum evolution indeed broadens the energy distribution. This broadening is slow at weak coupling but it proceeds as fast as possible in the limit of strong coupling [5].

Higher-point correlations and di-hadron production in heavy ion collisions

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

In processes involving small-x partons, like in deep inelastic scattering and in hadronic collisions at high energy, the final state can be expressed in terms of correlators of Wilson lines [6,7,8]. These represent higher point-correlations in the Color Glass Condensate, and evolve according to the JIMWLK equation. We have explained the numerical findings of [8], by demonstrating that the JIMWLK equation admits a controlled mean field approximation of the Gaussian type, for any value of the number of colors N_c [9,10]. Thus, any higher n-point function can be computed in terms of the two-point function, the dipole S-matrix. As a byproduct, we also realized that, with increasing energy, a hadron is expanding its longitudinal support symmetrically around the light-cone, due to the invariance of scattering amplitudes under time reversal. At the practical level, our results opened the way for easy phenomenology [11], but at the same time more precise than the one of [12], in the case of di-hadron production when both particles are detected in the forward region. Currently, we are looking how the whole formalism can be extended to the case where the two hadrons are separated by a large rapidity interval, e.g. when one is detected at forward rapidity with the other at mid-rapidity.

Testing the Gaussian approximation to the JIMWLK equation

In collaboration with M. Alvioli (ECT, Trento) and G. Soyez (IPhT, Saclay, France)*

In the numerical solution in [8] only a couple of configurations for higher-point correlators were studied. Moreover, due to constraints imposed by the Langevin form of the JIMWLK equation, only a particular scheme for the running coupling was considered, a scheme which is not very physical [13,14,15]. In [16] we used an independent method to numerically test the validity of the Gaussian approximation, by solving appropriate mean field equations. We did confirm that this is the case for both fixed coupling and running coupling evolution, where in the latter the scale was set according to various prescriptions. In the same work, we also verified to high accuracy the validity of the law governing the behaviour of the dipole S-matrix close to the unitarity limit, the Levin-Tuchin formula, and we furthermore outlined how to calculate correlators with open color indices.

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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 (RIKEN) and T. Hyodo (Tokyo Institute of Technology)

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 recent measurements of kaonic hydrogen are 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].

Heavy-quark systems

In collaboration with M. Altenbuchinger (TU Munich), L.S. Geng (Beihang Univ.), N. Kaiser and A. Laschka (TU Munich)

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 are explored in comparison with lattice QCD results [3,4].
Another project under this general title has been focused on the matching of the perturbative QCD potential between heavy quarks at short distances to the potential found in lattice QCD at larger distances, both for the central and spin-dependent parts of the interaction [5,6].

Nuclear chiral dynamics and thermodynamics

In collaboration with S. Fiorilla (TU Munich), 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 (and hypernuclear) 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. Recent 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 has 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 [8,9], the derivation of the corresponding energy density functional [10], and the chiral Fermi liquid approach to neutron matter [11].

Phases of QCD: strongly interacting matter under extreme conditions

In collaboration with M. Drews and T. Hell (TU Munich & ECT), N. Bratovich, 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 recent 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 [12,13]; constructing realistic equations-of-state for hadronic matter on the basis of in-medium chiral effective field [7,11]; investigating transport properties (such as the shear viscosity) in the vicinity of phase transitions [14]; and – most importantly – 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].

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4.2 Publications of ECT* Researchers

Massimiliano Alvioli

M. Alvioli, C. Ciofi degli Atti, L.P. Kaptari, C.B. Mezzetti, H. Morita, S. Scopetta
Universality of nucleon-nucleon short-range correlations: two-nucleon momentum distributions in few-body systems
Phys. Rev. ***C 85****, 021001(R) (2012)*

M. Alvioli, H. Holopainen, K.J. Eskola, M. Strikman
Initial state anisotropies and their uncertainties in ultrarelativistic heavy-ion collisions from the Monte Carlo Glauber model
Phys. Rev. ***C 85****, 034902 (2012)*

M. Alvioli, H. Holopainen, K.J. Eskola, M. Strikman
Initial state anisotropies in ultrarelativistic heavy-ion collisions from the Monte Carlo Glauber model
PoS QNP2012 (2012) 172

M. Alvioli, H. Holopainen, K.J. Eskola, M. Strikman
Monte Carlo Glauber modeling of initial state anisotropies in ultrarelativistic heavy-ion collisions
in "Science and Supercomputing in Europe – report 2011", Monfardini Ed., CINECA, Bologna 2011 ISBN 978-88-86037-25-9, p. 112

M. Alvioli, D. Triantafyllopoulos, G. Soyez
Testing the Gaussian approximation to the JIMWLK equation
Phys. Rev. ***D 87****, 014016 (2013)*

M. Alvioli
Universality of short-range correlations in one- and two- nucleon momentum distributions of nuclei
in "Nuclear Theory '31", Eds. A. Georgieva, N. Minkov, Heron Press, Sofia (2012)

M. Alvioli, C. Ciofi degli Atti, L.P. Kaptari, C.B. Mezzetti, H. Morita
Universality of short-range correlations: nucleon momentum distributions and their spin-isospin dependence
arXiv:1211.0134 [nucl-th] – submitted to Phys. Rev. ***C***

M. Alvioli, M. Strikman
Color fluctuation effects in proton-nucleus collisions
arXiv:1301.0728 [hep-ph] – submitted to Phys. Lett.

Daniele Binosi

D. Binosi and A. Quadri
Scalar resonances in the non-linearly realized electroweak theory
arXiv:1210.2637 [hep-ph], to appear in JHEP

D. Binosi, D. Ibañez, J. Papavassiliou
The all-order equation of the effective gluon mass
*Phys. Rev. **D86,** 085033 (2012); arXiv:1208.1451 [hep-ph]*

A. Ayala, A. Bashir, D. Binosi, M. Cristoforetti, J. Rodriguez-Quintero
Quark flavour effects on gluon and ghost propagators
*Phys. Rev. **D86,** 074512 (2012); arXiv:1208.0795 [hep-ph]*

A.C. Aguilar, D. Binosi, J. Papavassiliou
Unquenching the gluon propagator with Schwinger-Dyson equations
*Phys. Rev. **D86,** 014032 (2012); arXiv:1204.3868 [hep-ph]*

D. Binosi, A. Quadri
The background field method as a canonical transformation
*Phys. Rev. **D85,** 121702 (2012); arXiv:1203.6637 [hep-th]*

D. Binosi, A. Quadri
Canonical transformations and renormalization group invariance in the presence of non-trivial backgrounds
*Phys. Rev. **D85,** 085020 (2012); arXiv:1201.1807 [hep-th]*

D. Binosi
Recent results in the infrared sector of QCD
arXiv:1208.5924 [hep-ph]
Proceedings of the conference "Excited QCD 2012" (6-12 May 2012, Peniche, Portugal)

D. Binosi, A. Quadri
Canonical transformations in gauge theories with non-trivial backgrounds
PoS QNP2012 (2012) 110; arXiv:1206.2151 [hep-th].
Proceedings of the "6th International Conference on Quarks and Nuclear Physics (QNP 2012)" (16-20 April 2012, Palaiseau, France)

D. Binosi, A. C. Aguilar, J. M. Cornwall, J. Papavassiliou, (eds.)
QCD Green's functions, confinement and phenomenology. Proceedings, International Workshop, QCD-TNT-II, Trento, Italy, September 5-9, 2011
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Marco Cristoforetti

C. Ratti, R. Bellwied, M. Cristoforetti, M. Barbaro
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*Phys. Rev. **D85,** 014004 (2012)*

M. Cristoforetti (ECT*), F. Di Renzo (Parma U. & INFN, Parma), L. Scorzato (ECT*)
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Alexis Diaz-Torres

A. Diaz-Torres, M. Wiescher
Quantifying the $^{12}C + ^{12}C$ sub-Coulomb fusion with the time-dependent wave-packet method
AIP Conf. Proc. ***1491****, 273 (2012).*
Proceedings of the conference "Nuclear Structure and Dynamics '12" (July 2012, Opatija, Croatia)

A. Shrivastava, A. Navin, A. Diaz-Torres et al.
Role of the cluster structure of ^{7}Li in the dynamics of fragment capture
Physics Letters ***B*** *(2012), in press.*
http://dx.doi.org/10.1016/j.physletb.2012.11.064

Thomas Hell

T. Hell, K. Kashiwa, W. Weise
Impact of vector-current interactions on the QCD phase diagram
arXiv: 1212.4017[hep-ph];J.Mod.Phys., in print

Ahmad Idilbi

M. G. Echevarria, Ahmad Idilbi and Ignazio Scimemi
Soft and collinear factorization and transverse momentum dependent parton distribution functions
arXiv:1211.1947 [hep-ph]

Vincent Mathieu

P. Gonzalez, V. Vento and V. Mathieu
Non perturbative one gluon exchange potential from Dyson-Schwinger equations
arXiv: 1207.4314 [hep-ph]
Proceedings of the conference "Charm 12" Hawai, USA

R. Perez-Ramos, V. Mathieu
Collimation of energy in medium-modified QCD jets
arXiv: 1207.2854 [hep-ph], to appear in Physics Letters B

Stefano Melis

A. Anselmino, M. Boglione, U. D'Alesio, E. Leder, S. Melis, F. Murgia, A. Prokudin
On the role of Collins effect in the single spin asymmetry A_N
Phys. Rev. ***D86,*** *074032 (2012)*

M. Anselmino, M. Boglione, S. Melis
Strategy towards the extraction of the Sivers function with TMD evolution
Phys. Rev. ***D86,*** *014028 (2012)*

M. Anselmino, M. Boglione, S. Melis
Extraction of the Sivers functions with TMD evolution
PoS QNP2012 (2012) 038

M. Anselmino, M. Boglione, S. Melis
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September 2012. To appear in the proceedings of DIS 2012

S. Melis, A. Anselmino, V. Barone, M. Boglione, U. D'Alesio, F. Murgia, A. Prokudin
Extracion of TMDs with global fits
Nuovo Cimento ***35C****, 165 (2012)*

Laura Muñoz

L. Muñoz, C. Fernández-Ramírez, A. Relaño, J. Retamosa
Spectral-statistics properties of the experimental and theoretical light meson spectra
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Achim Richter

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JHEP ***1212****, 114 (2012), arXiv: 1210.1534 [hep-th]*

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JHEP ***1204****, 025 (2012), arXiv: 1112.1104 [hep-ph]*

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Charmonium potentials: matching perturbative and lattice QCD
Phys. Lett. ***B 175****, 190 (2012)*

R. Lang, N. Kaiser, W. Weise
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Eur. Phys. J. ***A 48****, 109 (2012)*

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Phys. Rev. ***C 87****, 014338 (2013); arXiv: 1209.5296 [nucl-th]*

S. Imai, H. Toki, W.Weise
Quark-hadron matter at finite temperature and density in a two-color PNJL model
arXiv: 1210.1307 [nucl-th]; to appear in Nucl. Phys. A

T. Hell, K. Kashiwa, W. Weise
Impact of vector-current interactions on the QCD phase diagram
arXiv: 1212.4017 [hep-ph]; to appear in J. Mod. Phys.

4.3 Talks presented by ECT* Researchers

Massimiliano Alvioli

One- and two-body momentum distributions (and universality of NN short correlations)
Invited talk given at the 31st Int'l workshop on Nuclear Physics.
June 20-24, 2012, Rila Mountains (Bulgaria)

Correlations and fluctuations studies in a Glauber Monte Carlo approach
Talk given at the ECT* workshop “Initial State Fluctuations and Final State Correlations in Heavy-Ion Collisions”.
July 2–6, 2012, ECT, Trento (Italy)*

Daniele Binosi

Unquenching the gluon propagator with Schwinger-Dyson equations
Talk given at the 10-th Conference “Quark Confinement and the Hadron Spectrum”
8-12 October 2012, Garching, Germany

Recent results in the infrared sector of QCD
Invited talk at the conference “Excited QCD 2012”
6-12 May 2012, Peniche, Portugal

The all order gluon mass equation
Invited talk at the conference “Twin approached to confinement physics: experiments and strong QCD”
12-15 March 2012, Thomas Jefferson National Accelerator Facility, Newport News, VA, USA

A picture of the beginning - Big Bang and cosmic background radiation"
Invited talk at the “La notte dei Ricercatori 2012”
28 September 2012
In the context of "La notte dei Ricercatori 2012" (Researcher's night 2012) an event in which children and adults had the opportunity to understand science by experiencing its day-to-day practices, by frequenting the spaces and places where research is carried out and by coming into contact with its machinery and equipment, but above all by talking to those directly involved, Daniele Binosi gave a public lecture explaining the physics of the Cosmic Microwave Background radiation. The lecture, titled "A picture of the beginning - Big Bang and cosmic background radiation", was given on the 28 September 2012 at 10:00 PM and attracted around 100 people. In addition, ECT* had a stand featuring three-posters explaining in simple terms the physics research carried out at the institute. The entire event was sponsored by the European Commission and organized by Fondazione Bruno Kessler in collaboration with, among others, the University of Trento, the Municipality of Trento and the Autonomous Province of Trento.

Alexis Diaz-Torres

Quantifying quantum dynamics in slow collisions of atomic nuclei: Formation of new elements
Colloquium at the University of Notre Dame
February 2012, Notre Dame, USA

Quantum partner-dance of two interacting ^{12}C nuclei fuels stellar carbon burning
Selected talk at the conference "Nuclear Structure and Dynamics II"
July 2012, Opatija, Croacia

How could low-energy nuclear reaction dynamics in NIF-plasma environments be quantified?
Invited talk at the EMMI-JINA workshop "Nuclear Physics Processes in Dynamic High Energy Density Plasmas"
October 2012, London, UK

Quantifying the ^{12}C+^{12}C sub-Coulomb fusion with the time-dependent wave-packet method
Invited seminar at the University of Surrey
October 2012, Guildford, UK

Matthias Drews

Quark-meson-model and functional renormalization group
Talk given at the DPG spring meeting
March 2012, Mainz, Germany

Dense matter and functional renormalization
Invited talk given at the Brookhaven National Laboratory
August 2012, BNL, Brookhaven, USA

Thomas Hell

Constraining the nuclear equation of state by neutron-star observables
Talk given at Technische Universität München
May 2012, Munich, Germany

New constraints from neutron stars
Invited talk at "Brookhaven National Laboratory"
August 2012, Upton, NY., U.S.A.

New constraints from neutron stars
Talk at "Neutron-Star Mini-Workshop", ECT*
December 2012, Villazzano (Trento), Italy

What can we learn from a two-solar-mass neutron star?
Invited talk given at "PSI Seminar", Technische Universität München
December 2012, Munich, Germany

Vincent Mathieu

Properties of exotic hadrons
Invited talk given at Nuclear Theory Centre, Indiana University
February 2012, Bloomington, USA

Meson spectroscopy
Invited talk at Mons University
April 2012, Mons, Belgium

Meson spectroscopy
Invited talk at Louvain University
April 2012, Louvain, Belgium

Summary talk of ATHOS 2012
Invited talk at the “International Workshop on New Partial Wave Analysis Tools for Next Generation Hadron Spectroscopy Experiments” (ATHOS 2012)
June 2012, Camogli, Italy

Amplitude analysis
Invited talk for the collaboration meeting of HASPECT
November 2012, Genoa, Italy

Stefano Melis

Overview of TMD phenomenology
invited talk at QCD`N 2012, Bilbao
22-26th October 2012, Spain.

Overview of transversity
invited talk at the Advanced Studies Institute, SPIN-Praha-2012.
1st-8th July 2012 Prague, Czech Repulic

Boer-Mulders and Sivers effects in the Drell-Yan process
Drell-Yan scattering and the structure of hadrons
21st-25th May 2012, ECT, Trento, Italy*

Phenomenology of the Sivers effect with TMD evolution
QCD evolution 2012, JLAB, Newport News
14-17th May 2012, Virginia (USA)

Laura Muñoz

Spectral-statistics properties of the light meson spectrum
Talk given at “Wave Chaos from the Micro- to the Macroscale”
October 2012, Dresden, Germany

Achim Richter

Dipole response in 208Pb: polarizability, fine structure and level density
Invited seminar at the University of Illinois
March 26, 2012, Urbana-Champaign, USA

Playing billiards with microwaves - quantum manifestations of classical chaos
Twenty-sixth Annual Peter Axel Memorial Lecture at the University of Illinois
March 28, 2012, Urbana-Champaign, USA

Beautiful graphene, photonic crystals, Schrödinger and Dirac billiards and their spectral properties
Invited talk at the International Conference "Beauty in Physics: Theory and Experiment"
May 14 – 18, 2012, Cocoyoc, Mexico

Graphene and playing relativistic billiards with microwaves
Invited talk at the International Workshop "Wave chaos from the micro- to the macroscale"
October 22 – 26, 2012, Dresden, Germany

Luigi Scorzato

QCD optimization within AuroraScience
Invited talk at the PRACE face to face meeting on "Preparing community codes for future supercomputer architectures".
February 2 – 3, 2012, Barcelona, Spain

High density QCD on a Lefschetz thimble?
Presentation at the Extreme QCD 2012 workshop.
August 21 – 23, 2012, Washington DC, USA

High density QCD on a Lefschetz thimble?
Talk at the Simposium: "Quantum Chromodynamics: History and Prospects"
September 3 – 8, 2012, Oberwöltz, Austria

High density QCD on a Lefschetz thimble?
Talk at the Workshop: "Sign 2012"
September 19 – 22, 2012, Regensburg, Germany

Simplicity and measurability in science.
Talk at the mid-term conference of the Società Italiana di Logica e Filosofia della Scienza
November 20 – 21, 2012, Milano, Italy

Pavel Stránský

Interplay between regularity and chaos in simple physical systems
Invited talk at the workshop "Complexity and multidiscipline: new approaches to health".
April 2012, UNAM, México D.F., Mexico

Dionysis Triantafyllopoulos

Higher-point correlations in the Color Glass Condensate
Seminar at the University of Santiago de Compostela
March 2012, Santiago de Compostela, Spain

The Color Glass Condensate and some applications
Invited talk at the workshop “Excited QCD 2012”
May 2012, Peniche, Portugal

Multi-gluon correlations in the Color Glass Condensate and an analytical solution to the JIMWLK equation
Talk at the conference “Hard Probes 2012”
May 2012, Gagliari, Italy

4.4 Courses taught by ECT* Researchers

Dionysis Triantafyllopoulos

Quantum Chromodynamics

In the spring of 2012 I tought 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 one PhD student and two Master 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. I concluded by presenting the BFKL equation and the physics behind it.

4.5 Seminars at ECT*

Chaotic dynamics and quantum state patterns in collective models of nuclei
January 13
Pavel Stransky

Quantum partner-dance of two interacting 12C nuclei fuels stellar carbon burning
April 11
Alexis Diaz Torres

Phenomenological approaches to the pure-glue phase transition in QCD
May 25
Gwendolyn Lacroix

Low energy reactions in medium mass region and semi-microscopic optical model
May 30
Gautam Gangopadhyay

The physics of exceptional points
June 6
W. Dieter Heiss

Interference pattern between the initial and final state in a QCD medium
June 7
Mauricio Martinez

A Bose-Einstein condensate in a PT-symmetric double-well potential
July 13
Günter Wunner

High density QCD on a Lefschetz thimble?
June 29
Luigi Scorzato

Canonical transformations in gauge theories with non-trivial backgrounds
November 05
Andrea Quadri

Simultaneous calculation of fusion barriers, elastic and fusion cross sections of weakly-bound/halo nuclei using the optical model and the Continuum Discretised Coupled Channels method
October 11
Arturo Gomez-Camacho

The Color Glass Condensate (part 1)
November 06
Dionysis Triantafyllopoulos

The Color Glass Condensate (part 2)
November 7
Dionysis Triantafyllopoulos

Understanding the IR sector of QCD (part 1)
November 8
Daniele Binosi

Understanding the IR sector of QCD (part 2)
November 14
Daniele Binosi

Meson spectroscopy at JLab and SPS
November 16
Vincent Mathieu

Role of vector interaction in a non-local PNJL model
November 26
Thomas Hell

Dense matter and functional renormalization group
November 26
Matthias Drews

Transport properties in NJL-type models: Large N_c analysis
November 26
Robert Lang

The sign problem and the Lefschetz thimble
November 28
Luigi Scorzato

Relativistic Bose gas on a Lefschetz thimble
November 30
Marco Cristoforetti

Realistic many-body calculation of the neutron and nuclear matter equation-of-state
December 04
Francesco Pederiva

Many body physics of neutron stars and supernovae
December 04
Abhishek Mukherjee

New constraints from neutron stars
December 04
Thomas Hell

Low-energy reaction dynamics of weakly bound nuclei
December 06
Alexis Diaz-Torres

Quantifying low-energy nuclear reaction dynamics in plasma environments
December 12
Alexis Diaz-Torres

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 QIP 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) and FP7 (2007-2013), and ECT* have been a constant presence in QIPC consortia.
- This continue to be true at present, since during 2012 D. Binosi actively worked on the Coordination Action **QUIE^{2}T** (QUantum Information Entanglement- Enabled Technologies) in which, in addition to contributing to Work-Package 2 and 3 (Dissemination activities), he acts also as the Executive Secretary (the funding for the ECT* node is 89k€ for 3 years).

6 Aurora Science

AuroraScience is a project managed by ECT*/FBK, and has been described in detail in previous reports. Here we briefly recall the idea and provide a short update.
AuroraScience is a research project at the crossroad of Computational Sciences and Computer Architecture. It builds on the combined know-how collectively available to the members of the collaboration on:

- design, development and operation of application-driven high-performance computer systems (e.g., the series of APE machines, developed by INFN).

- algorithm development and physics analysis in computational areas of physics (Lattice Gauge Theory, Computational Fluid-Dynamics, Molecular Dynamics), Quantitative Biology (Protein Folding), Bioinformatics (Gene Sequencing) and Medical Physics.

AuroraScience is a scientific project enabled by leading-edge computational systems and by specific competences in the useful operation of these systems. The results of the project in 2012 are summarized here:
The prototype AURORA system was installed in 2010 and upgraded in 2011. During the year 2012 it has been used intensively by various groups especially at ECT*/FBK, the University of Trento and INFN. The scientific results obtained thanks to the AuroraScience project and to the Aurora prototype are listed in web.infn.it/aurorascience → publications. We do not provide details on the many scientific activities considered within the project, since they have been introduced in previous reports, and more details can be found in the publications above. What is not found there is an update on the management of the computing system. During the year 2012, the computing system was maintained by the system administrator Enrico Tagliavini, under the supervision of Luigi Scorzato. Dr. Tagliavini brought a number of improvements to the system, the more significant one is the installation of a very efficient Lustre parallel filesystem. Dr. Tagliavini also offered technical assistance to the scientific users, that was very much appreciated. Towards the end of 2012, Enrico accepted an offer from the National Irish Computing Center.
Thanks to the experience and visibility gained with the AuroraScience project, FBK will be now part of the upcoming Exascale Lab, coordinated by CINECA and including Italian research institutions with special competences in the efficient use of modern HPC systems.

7 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 trough 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:
1 Virtual Server DELL PowerEdge R900

PC clients:

20 PCs for staff and local research:
Workstation DELL Precision T1500
Workstation DELL Precision 390
Workstation DELL Optiplex GX620
Workstation DELL Optiplex 755
Workstation DELL Optiplex SX270
Apple iMac 27”

34 PCs for workshops and schools:
Workstation DELL Precision T1500
Workstation DELL Optiplex GX280
Workstation DELL Optiplex GX620
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) Windows Server 2008 R2 with the following most important roles and services: Active Directory server, Network Information Server (logins, groups, hosts database…), Domain Name Server, Windows print server, Windows Server Update Services (for the Windows clients).

2) Linux server Red Hat 6.3 provides the following services: Domain Name Server forwarder, e-mail server, Common Unix Print Server.

3) Gate server Red Hat 6.3 for the access from outside.