SIGN PROBLEMS AND COMPLEX ACTIONS

DATE: 2009, March 2-6

ORGANISERS:
Gert Aarts (Co-ordinator) (*Swansea University*)
Shailesh Chandrasekharan (*Duke University*)

NUMBER OF PARTICIPANTS: 26

MAIN TOPICS:

- Nature of sign problems
- Worldline formulations
- Complex Langevin methods
- Diagrammatic Monte Carlo
- Extrapolation methods
- Reweighting methods

SPEAKERS:

Gert Aarts (*Swansea University*),
Bartolome Alles (*INFN Pisa*),
Jacques Bloch (*Universität Regensburg*),
Barak Bringoltz (*University of Wahington*),
Shailesh Chandrasekharan (*Duke University*),
Philippe de Forcrand (*ETH Zürich and CERN*),
Massimo D'Elia (*University of Genova*),
Francesco Di Renzo (*University of Parma*),
Shinji Ejiri (*Brookhaven National Labs*),
Gergely Endrodi (*Eötvös University*),
Dean Lee (*North Carolina State University*),
Maria-Paola Lombardo (*Frascati*),
Atsushi Nakamura (*Hiroshima University*),
Owe Philipsen (*Universität Münster*),
David Reeb (*University of Oregon*),
Erhard Seiler (*Max-Planck Institute Munich*),
Denes Sexty (*Universität Darmstadt*),
Kim Splittorff (*NBI Copenhagen*),
Ion Stamatescu (*Universität Heidelberg*),
Boris Svistunov (*University of Massachusetts Amherst*),
Urs Wenger (*Bern University*).

SCIENTIFIC REPORT:

Aim and Purpose – The understanding of strongly interacting matter and a variety of strongly correlated materials requires a nonperturbative analysis employing numerical simulations. In the conventional formulations of these problems, introduction of a chemical potential makes the action complex. Hence, the standard Monte Carlo method to evaluate the path integral through importance sampling fails, since there is no clear probability distribution to sample from. This problem is commonly known as the sign problem and is an outstanding problem in field theory and many-body physics. One prime example of a theory in particle physics where the sign problem arises is QCD at nonzero baryon density. There are also many condensed matter materials of interest where sign problems have hindered progress. This includes frustrated quantum spin systems and strongly correlated electronic systems away from half filling. Fortunately, in recent years radical new approaches have been developed which can handle the sign problem or even eliminate it altogether. For a class of field and many-body theories, these methods are based on rewriting the partition function in a dual set of variables, similar to worldline (WL) representations. In many cases, the WL-approach suggests new solutions to the sign problem. Promising results have also been obtained using stochastic quantization and complex Langevin dynamics. In this case the sign problem is potentially circumvented by complexifying all degrees of freedom, so that the theory's phase space is explored in an inherently different fashion. The aim of this workshop was to learn about sign problems that arise in lattice field theory, understand what has been done in recent years and explore what can be done in the future.

Results, Highlights and Conclusions – The format of the workshop was chosen to optimize two requirements often lacking in larger-scale conferences: sufficient time for speakers to explain their ideas and maximal discussion time. In practice this meant that we scheduled four talks per day, with the opening talks being semi-introductory in nature. The morning sessions concluded with a half hour discussion. For the afternoons we organized discussion sessions of at least one hour, moderated by a chair who prepared a 10 minute introduction and list of open questions. This format was well-appreciated by all participants and allowed for lively discussion continuing into the night.

We had in mind an interdisciplinary yet technical meeting, giving participants the opportunity to learn developments outside their own field of

expertise. This goal was achieved by having among the participants several researchers from the nuclear and condensed matter physics community (the majority of the participants are interested in the physics of QCD at nonzero baryon density). In combination with the discussion sessions, this allowed the workshop to be constructive and interdisciplinary. Moreover, many participants used the meeting to advance existing collaborations and possibly start new ones.

Two days were spent on the most promising directions to tackle the sign problem: complex Langevin dynamics and worldline methods. The possibility to focus a full day on one approach, with extensive discussions throughout, has allowed us to clarify aspects of the methods which were more obscure before. Two important insights have emerged from this conference: (1) In the context of complex Langevin dynamics, the possible relevance of stochastic gauge fixing was emphasized by several participants, (2) In the context of world line formulations, the sign problem in QCD with a finite baryon density may be alleviated through a partial averaging over gauge field configurations especially in relation to the Polyakov loop fluctuations.

In conclusion, the workshop was considered a success, by many of the participants and the organizers.

All talks are available at `http://pyweb.swan.ac.uk/~aarts/ect.html`