DECOHERENCE IN QUANTUM DYNAMICAL SYSTEMS

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ORGANISERS:
Alexis Diaz-Torres (Co-ordinator) (*U Surrey*), Irene Burghardt (*ENS, Paris*), Jeffrey Tostevin (*U Surrey*), Craig Martens (*U California, Irvine*)

NUMBER OF PARTICIPANTS: 29

MAIN TOPICS:

- What are the relative merits of alternative formulations of the quantum dynamical evolution in the presence of environmental couplings, in particular with reference to nuclear dynamical systems?
- How does the effective decoherence time and the entropy production depend on the collision energy, and how does this affect considerations in item above?
- How does the environment affect the reaction dynamics and which observables are needed to quantify the effects of environment-induced quantum decoherence? What specific or classes of measurements on nuclear dynamical systems might provide additional insights?

SPEAKERS:

Franz Hasselbach (*U Tübingen*),
Stefan Gerlich (*U Vienna*),
Klaus Hornberger (*MPIPKS, Dresden*),
David Hinde (*ANU, Canberra*),
Lorenzo Corradi (*INFN Legnaro*),
Alexis Diaz-Torres (*U Surrey*),
Mahir Hussein (*USP, Sao Paulo*),
Marek Ploszajczak (*GANIL, Caen*),
Aurelian Isar (*NIPNE, Bucharest*),
Peter Saalfrank (*U Potsdam*),
Ulrich Kleinekathöfer (*Jacobs U, Bremen*),
Jyrki Piilo (*U Turku*),
Barry Garraway (*U Sussex*),
Irene Burghardt (*ENS, Paris*),
David Coker (*UCD, Dublin*),
Angelo Bassi (*U Trieste*),
Guillaume Hupin (*GANIL, Caen*),
Denis Lacroix (*GANIL, Caen*),
Takashi Nakatsukasa (*RIKEN, Japan*),
Arnau Rios Huguet (*U Surrey*),
Walter Strunz (*TU Dresden*),
Ronnie Kosloff (*Hebrew U*),
Baha Balantekin (*U Wisconsin*),
Mahananda Dasgupta (*ANU, Canberra*),
Kouichi Hagino (*Tohoku U*)

In addition to the above speakers, Ronald Johnson (U Surrey), Alahari Navin (GANIL, Caen), Luca Ferialdi (U Trieste) and Jeffrey Tostevin (U Surrey) actively contributed to the discussions.

SCIENTIFIC REPORT:

Aim and Purpose

Nuclear physics research has entered a new era with the recent developments of facilities that provide access to high intensity radioactive nuclear beams; an area in which Europe is a major stakeholder (GSI, HIE-ISOLDE, GANIL). At these facilities it is nuclear collisions and reactions that provide the primary probes of the new physics, such as novel structural changes, through dynamical excitations of nucleonic, collective and cluster degrees of freedom. In parallel, new and innovative detection systems are allowing measurements of unprecedented exclusivity and precision, including those using intense stable beams. These and the increased intensity rare radioactive beam capabilities require investigations of the role of hitherto inaccessible degrees of freedom and new dynamical considerations in the nuclear structure and collision dynamics. Combining fully reaction dynamics and many-body structure information is a major outstanding problem across disciplines.

Quantifying the role and the importance of decoherence in quantum many-body systems is now pervasive in modern science and studies of quantum measurement and quantum information. The concept of a reduced (but not closed) quantum system evolving in the presence of weak couplings to complex states is common throughout disciplines. Collisions of composite nuclei have conventionally been treated as closed quantum systems, assuming a state-truncated model space. In reality however their evolution involves intrinsic excitations to innumerable available open channels. The assumed model space for any practical, conventional calculation is inevitably limited to a number of most relevant excitations, defining the reduced quantum system. All other states (each individually very weakly coupled to the reduced system by residual interactions) constitutes the external environment in this case and which may be specific to particular degrees of freedom of the system and the collision dynamics, such as weak binding or isospin asymmetry, and the collision energy. Among such environments are (i) high level-densities of one- and multi-nucleonic excitations, (ii) the breakup continua of decay channels (e.g. for weakly-bound nuclei).

Many of the key questions posed are common across disciplines and applicable techniques have been advanced very significantly in other areas of few- and many-body physics and chemistry. Molecular physics, for example, covers a wide range of regimes involving ultrafast electronic and vibrational decoherence, as well as situations where collective environmental modes create approximate decoherence-free subspaces. Recent experiments on photosynthetic light-harvesting systems provide strong evidence for the protection of excitonic coherence by the protein environment. Accordingly, the available theoretical approaches include Markovian and non-Markovian master equations as well as explicit, high-dimensional quantum and mixed quantum-classical calculations of the combined system and environment.

The main aims of the Workshop are:

- To both review and assess methods, recent investigations and implications of quantum decoherence in atomic, molecular and other areas, and to relate these to the nuclear physics context; providing both theoretical and experimental perspectives.
- To create essential links between the nuclear physics community and practitioners in other areas of science aimed at understanding fundamental aspects of quantum physics, such as the role of decoherence and the quantum-to-classical transition.
- To initiate inter-disciplinary exchanges and the transfer of expertise, to foster collaborations, and facilitate the formation of younger- researcher networks.

Results and Highlights The workshop brought together researchers (both theorists and experimenters) from a wide range of disciplines (electron and molecular interferometry, quantum optics, atomic and molecular physics, quantum information, quantum biology and nuclear physics) that span the subject of quantum decoherence in dynamics of few- and many-body quantum systems.

Researchers from fields other than nuclear physics presented methodologies and experiments for the study of decoherence in quantum dynamics. Nuclear scientists reported on theoretical methods and experimental capabilities in nuclear structure and reaction dynamics. They discussed, with researchers of other disciplines the use of specific techniques (their strengths and weaknesses) that might be used to identify nuclear scenarios where quantum decoherence may play a crucial role. E.g. complex atomic nuclei have proven to be outstanding laboratories for researching quantum decoherence effects, with the interplay of multiple, complicated degrees of freedom in the processes involved.

Conclusions The workshop was a great success, as expressed by many delegates. While quantum decoherence is topical across various disciplines, it is hardly investigated at all in low-energy nuclear physics phenomena. Thus, the workshop has opened a new window for the nuclear physics community. In the workshop, the communication between the participants was impressive, reflected in deep and stimulating discussions during and after the daily presentations. The workshop has been a very positive experience for everyone. New collaborations and exchange of ideas have been initiated, for instance, between nuclear theorists and researchers from other areas regarding methodologies for investigating the open (nuclear) system dynamics. A collaboration meeting on nuclear fusion (involving theorists and experimenters) has been planned, which could take place in 2011. It is expected that such a meeting will help tackle urgent (unsolved) problems in low-energy nuclear collision dynamics. It could also access, through realistic quantitative models, the usefulness of a consistent treatment of open (nuclear) system dynamics that includes quantum decoherence effects.

Optional The talks can be browsed from the website:
http://www.nucleartheory.net/Decoherence