

2<sup>nd</sup> VIENNA SYMPOSIUM  
ON THE FOUNDATIONS  
OF MODERN PHYSICS  
2009

in honour of  
Daniel Greenberger and Helmut Rauch

June 11-14, Vienna, Austria

**Information  
Program  
Abstracts**

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# FOREWORD



# GENERAL INFORMATION

## 1.1. CONFERENCE VENUE

All lectures are located at:

The Faculty of Physics  
Lise Meitner Lecture Hall, 1<sup>st</sup> floor  
Strudlhofgasse 4  
A-1090 Vienna



## 1.2. REGISTRATION

The **Meeting point** as well as the **reception desk** are located in front of the Lise Meitner lecture hall at the Faculty of Physics, Strudlhofgasse 4, 1090 Vienna. In order to get there please follow the signposting! Registration opens on Thursday, June 11<sup>th</sup> at 8 am.

## 1.3. INTERNET ACCESS

Open WLAN access available. You will also find computers with standard browsers at your service.

## 1.4. PRESENTATION EQUIPMENT

- Connection for your own laptop (incl. sound)
- Beamer (VGA 800x600)
- MS-Powerpoint & Word up to Office 2003
- Acrobat Reader 7.0
- Our conference Notebook will accept your
  - USB stick (1.0 and 2.0)
  - CD/DVD (ISO9001)
- Overhead projector

Please test your presentation the day of your talk before all presentations start, at least during the coffee break.

## 1.5. POSTERSESSION

**Thursday, June 11<sup>th</sup> 2009, 7.30 pm**

The Postersession is located at the Faculty of Physics, 2<sup>nd</sup> and 3<sup>rd</sup> floor  
Strudlhofgasse 4, A-1090 Vienna

- Posters are accepted up to format A0 (841mmX1189mm/33"x46,8")
- Refreshments will be served during the Postersession

## 1.6. LAB TOURS

**Saturday, June 13<sup>th</sup> 2009, 6.30 pm**

On Saturday evening we offer you to see our labs at the University of Vienna (Quantum Optics, Quantum Nanophysics, Quantum Information) and at the IQOQI (Institute of Quantum Optics and Quantum Information) of the Academy of Science.

Meetingpoint: registration desk in front of the Lise Meitner Lecture Hall.

## 1.7. CONFERENCE DINNER

**Friday, June 12<sup>th</sup> 2009, 7 pm**

The conference dinner will be held at the traditional Viennese restaurant, "Heuriger" Hengl-Haselbrunner: <http://www.hengl-haselbrunner.at/>

A bus-transfer will leave at **18.30h** in front of the Faculty of Physics, Strudlhofgasse 4

## 1.8. LUNCH & COFFEE BREAKS

There are several restaurants in the surrounding of the Faculty of Physics for your choice during the lunch breaks.

Refreshments will be served in the Cafeteria of the Faculty of Physics during the coffee breaks.

## 1.9. Vienna Exploration Day

**Sunday , June 14<sup>th</sup> 2009**

The last day of the conference is dedicated to Vienna's culture. It's an optional offer to enjoy Vienna. The entry fee is not included to the conference fee. You can choose out of three programs:

(A) guided tour (in English) through the *Schatzkammer* (Hofburg); starting at 10 am



Schatzkammer, Hofburg - Schweizerhof , 1010 Wien

<http://www.khm.at/de/schatzkammer>

(B) guided tour (in English) through *Albertina* (Rembrandt exhibition); starting at 10 am



Albertina, Albertinaplatz 1, 1010 Wien

<http://www.albertina.at/jart/prj3/albertina/main.jart?rel=en&reserve-mode=active>

(C) Concert with the Wiener Sängerknaben and the Wiener Philharmoniker at the *Hofmusikkapelle* (F. L. Gassmann: Missa in C); starting at 9:15



Wiener Hofmusikkapelle , Hofburg-Schweizerhof, 1010 Wien

<http://www.bmukk.gv.at/kultur/musik.xml>

## 1.10. TRAVEL INFORMATION

- **Arrival at the airport :**

The **CAT** and the Railway System **S7** will take you directly into the city of Vienna. They terminate at the city air terminal within the “**Wien-Mitte**” railway station.

In order to reach our institute you can either take a **taxi**, or you take the **underground** line **U3** (direction “Ottakring”) until the station “**Volkstheater**” and change onto the line **U2** (direction “Stadion”).

Get off at the station “**Schottentor-Universität**”. From there take a tram (lines **37, 38, 40, 41** or **42**), to the station “**Währingerstraße/Nußdorferstraße**” (2 stops). Walk along Währingerstrasse (back in the direction from which the tram has come.) The entrance to the conference venue is at Strudlhofgasse 4, on the right-hand side of the street.

**By taxi:**

You can find a taxi stand directly in front of the arrival hall of the airport. It takes you about 30 minutes to get to the conference venue, the costs are about € 30.– to € 35.–

- **Arrival at the railwaystation Westbahnhof**

**By taxi:** Journey time approx. 10 minutes.

**By tram:** From Westbahnhof take the tram number **5** (direction Praterstern) and get out at the station “**Währingerstrasse/ Nußdorferstrasse**”. Walk along Währingerstrasse and take the first street to the left (Strudlhofgasse). The entrance is at Strudlhofgasse 4.

- **Arrival at the railwaystation Südbahnhof:**

**By taxi:** Journey time approx. 20 minutes

**By tram:** take the tramway line **D**, which stops across the street, if you leave the railway-building. From there it takes you about 30 minutes until you arrive at the station “**Schottentor-Universität**”. Take a tram (lines **37, 38, 40, 41** or **42**), to the station “**Währingerstraße/Nußdorferstraße**” (two stops). Walk along Währingerstrasse (back in the direction from which the tram has come.) The entrance is at Strudlhofgasse 4, on the right-hand side of the street.

# PLENARY TALKS

# On mass and complexity limits of matter wave interferometry: strategies and fantasies

**Markus Arndt**

Faculty of Physics, University of Vienna, Austria

The physics of de Broglie waves has been essential in triggering the Schrödinger equation and matter waves have found applications in many tests on the foundations of physics as well as in the materials sciences. This year we celebrate the birthdays of two outstanding scientists, Daniel Greenberger and Helmut Rauch, who have been pioneers in the field of theoretical and experimental quantum optics, respectively.

We will therefore take the occasion to extrapolate their early research on neutron interferometry [1,2] and we will explore the ultimate mass and complexity limits for matter wave experiments in general. About a decade ago, our own research started with the interference of C<sub>60</sub>, i.e. an object containing 360 neutrons and 360 protons [3].

We will now present considerations on an 'ultimate' interferometer arrangements [4,5,6], discuss decoherence and dephasing mechanisms as well as the most pressing technological challenges on the way towards interferometry with objects in the mass range between  $10^6$  and  $10^{10}$  amu or potentially even beyond.

[1] Rauch, H.; Treimer, W. & Bonse, U. Test of a Single Crystal Neutron Interferometer, *Phys. Rev. A*, 47, 369-371 (1974).

[2] Greenberger, D. The neutron interferometer as a device for illustrating the strange behavior of quantum systems, *Rev. Mod. Phys.* 55, 875-905 (1983).

[3] Arndt, M.; Nairz, O.; Voss-Andreae, J.; Keller, C.; der Zouw, G. V. & Zeilinger, A. Wave-Particle Duality of C<sub>60</sub> Molecules, *Nature*, 401, 680-682 (1999).

[4] Clauser, J.; in Cohen, R.; Horne, M. & Stachel, J. (ed.) De Broglie-Wave Interference of Small Rocks and Live Viruses, in: *Experimental Metaphysics*, Kluwer Academic, 1-11 (1997).

[5] Reiger, E.; Hackermüller, L.; Berninger, M. & Arndt, M. , Exploration of gold nanoparticle beams for matter wave interferometry, *Opt. Comm.* 264, 326 (2006).

[6] Gerlich, S.; Hackermüller, L.; Hornberger, K.; Stibor, A.; Ulbricht, H.; Gring, M.; Goldfarb, F.; Savas, T.; Müri, M.; Mayor, M. & Arndt, M., A Kapitza-Dirac-Talbot-Lau interferometer for highly polarizable molecules, *Nature Physics*, 3, 711 - 715 (2007).

# Testing Bose-Einstein statistics for photons using atomic

*Dmitry Budker and Damon English*

Department of Physics, University of California at Berkeley, USA

Is particle statistics, the fundamentally quantum aspect of ensembles of identical particles that gives the periodic table of elements its structure and shapes the spectrum of black-body radiation, a perfect symmetry of nature? After all, all other discrete symmetries are now known experimentally to be violated (albeit, some at a very small level; and with the one notable exception of CPT symmetry). We are putting the principle to the test with photons.

Photons, being particles of integer spin (spin-one), are supposed to obey Bose-Einstein statistics, as opposed to half-integer-spin particles such as electrons that should follow Fermi statistics, of which a corollary is the Pauli Exclusion Principle, which forbids any two electrons from having all quantum numbers the same.

How can an experiment testing quantum statistics be designed?

It turns out (see Ref. 1 and references therein) that certain two-photon atomic transitions are forbidden by the Bose-Einstein statistics of photons. When two lasers drive such a transition in barium, the atoms make fewer and fewer transitions as the frequencies of the lasers approach each other. Finally, when the two lasers' frequencies are the same, the barium atoms make no transitions at all, even though transitions would be permitted by energy and angular-momentum conservation.

This last year our group improved its 2007 limit [2] on possible Bose-statistics violation in photons by a factor of 30 (which, in turn, was a factor of 100 better than the previous result from 1999 [3]) to a level of  $10^{-10}$ . In the course of the experiment, some interesting atomic physics has also been uncovered – for example, we have observed hyperfine-interaction-induced two-photon transitions [4].

1 D. DeMille, et al, How we know that photons are bosons: experimental tests of spin-statistics for photons, in: Proceedings of the International Conference on Spin-Statistics Connection and Commutation Relations: Experimental Tests and Theoretical Implications, Anacapri, Italy, May 31-June 3, 2000, R. C. Hilborn and G. M. Tino, Eds., AIP Conf. Procs. #545, 2000, p. 227.

2 Damon English, Ph.D. Thesis, University of California, Berkeley, 2007.

3 D. DeMille, D. Budker, N. Derr, and E. Deveney, Search for Exchange-Antisymmetric Two-Photon States, Phys. Rev. Lett. 83(20), 3978 (1999).

4 M. G. Kozlov, D. English, and D. Budker, in preparation.

# Macroscopic state-independent quantum contextuality

***Adan Cabello***

Departamento de Física Aplicada II, Universidad de Sevilla, Spain

By "quantum contextuality" we mean the impossibility of reproducing quantum mechanics with models in which the outcomes of measurements on individual systems have precise values which are independent of which other compatible measurements are jointly performed. We have shown that a state-independent experimental test of quantum contextuality is possible [Phys. Rev. Lett. 101, 210401 (2008)]. This test has been successfully performed with ions (G.Kirchmair et al., arXiv:0904.1655) and photons (E. Amselem et al.).

However, so far, for all known state-independent tests of noncontextuality, the amount of violation of the noncontextuality inequality decreases as the complexity of the quantum system increases. Here we prove that the violation can increase exponentially with the number of qubits in the system, suggesting that state-independent quantum contextuality would be observable in "macroscopic" systems.

## **Independent Nonlocalities**

***Nicolas Gisin***

GAP-Optique, Université de Genève, Switzerland

# **The Tic-Tac-Toe Theory of Gravity**

***Daniel Greenberger***

Physics Department, The City College of New York, USA

The Tic-Tac-Toe theory is a qualitative, phenomenological theory, that automatically explains many of the features of the universe that we see, such as dark matter and dark energy. In that sense it is a Copernican theory, that gives an alternate approach that immediately and intuitively explains phenomena whose explanations are essentially ad-hoc in accepted standard theories.

The basic concept is to take the possibility of negative masses seriously, and generalize this to counter the unconvincing treatment of negative masses by the equivalence principle. Surprisingly, this automatically solves all sorts of other problems at the same time. I doubt that many people will be willing to accept this clean and simple, though different solution, but it is presented to help convince students that there are many new ideas available to them, and they should not let themselves be intimidated into believing that we are close to understanding nature.

# Clifford Algebras as a vehicle for Quantum Mechanics without wave functions: The Bohm Model of the Dirac Equation

***Basil J. Hiley***

Birkbeck, University of London, Theoretical Physics, UK

I will outline how it is possible to formulate quantum mechanics entirely within a hierarchy of Clifford algebras taken over the reals. This enables us to dispense with wave functions since all the information normally contained within the wave function is encoded in the minimal ideal structure of the algebra itself. In this way we have the Schrödinger, Pauli and Dirac particles described naturally within the sequence of Clifford algebras,  $C(0,1) \subset C(3,0) \subset C(1,3) \subset C(4,2)$ , the latter is included to indicate the link with the Penrose twistor. This approach has the bonus that the Bohm approach emerges without the need to appeal to classical mechanics at any stage. In this new approach the so-called Bohm energy and Bohm momentum is identified as arising directly from the standard energy-momentum tensor. This insight enables us, for the first time, to give a complete account of the Bohm model of a Dirac particle, which includes a relativistic expression for the quantum potential. These results give an entirely new insight into meaning of the Bohm approach.

# **The Flavor of Matter**

***Gudrun Hiller***

Theoretical Physics III, Dortmund University of Technology, Germany

Known fundamental matter comes in (3) generations, leading to the breakdown of CP-symmetry and a multitude of microscopic interactions and reactions among different kinds of matter, called flavors. We review the status and prospects of this phenomenon, and comment on its possible explanations.

## **Quantum entangled states in a deterministic cellular automaton.**

***Gerard 't Hooft***

Institute for Theoretical Physics, University of Utrecht, The Netherlands

Cellular automata are the prototypes of deterministic systems. Yet their statistical features can be studied as if they were quantum mechanical. One can then construct states that are as entangled as in real quantum mechanics, apparently violating Bell's inequalities just as much. Of course, these systems differ from the 'real' quantum world in important ways, but the similarities are striking, and one wonders whether these distinctions survive all the way to the Planck length.

# **On Classical Fields and Quantum Phases**

***Michael Horne***

Physics and Astronomy, Stonehill College, USA

## **Adventures in Neutron Interferometry**

***Anthony George Klein***

University of Melbourne, Australia

A brief history of Neutron Interferometry will be presented, from a personal perspective. Additional comments and a message from Professor Sam Werner will be included.

# **A Reconstruction of Quantum Mechanics**

***Simon B. Kochen***

Department of Mathematics, Princeton University, USA

A conceptually simple general principle together with some experimental results from interferometry are used to construct the formalism of quantum mechanics. This construction allows us to transform the natural definitions of states, observables, symmetries, and dynamics of classical physics into the density, Hermitian, and unitary operators of the quantum formalism, and derive the Schrödinger equation and the von Neumann-Luders Projection principle. We discuss a resolution of the Measurement Problem through this approach.

# Quantum non-local effects with independent Bose-Einstein effects: the role of the quantum angle

***Franck Laloë***

Laboratoire Kastler Brossel, Département de physique de l'ENS, France

Quantum measurements performed with systems made of a small number or entangled particles can lead to the observation of violations of quantum realism: Bell inequalities, Greenberger-Horne-Zeilinger (GHZ) contradictions, Hardy impossibilities. Similar violations can also be obtained with large systems in quantum Fock states (number states with perfectly well defined populations). It turns out that the violations are as large as for small systems, and do not tend to zero when the number of particles tends to infinity. A condition, nevertheless, is that all particles be measured: if a single particle is missed, the violations of local realism disappear.

A standard quantum mechanical calculation of these effects introduces two angles: (i) the usual phase angle, which can be called the Anderson phase (introduced as a consequence of spontaneous symmetry breaking taking place in superfluid systems), but can also be seen as an additional variable ("hidden variable") appearing naturally in the formalism of standard quantum mechanics; (ii) the "quantum angle", which roughly speaking controls the "degree of quantumness" in the probabilities. When this angle vanishes, quantum non local effects do not occur; when it takes non zero values, the probabilities become quasiprobabilities (which may be negative), and violations of local realism become possible. The talk will describe a few thought experiments illustrating the role of this quantum angle, in particular a new version of the GHZ experiment with highly populated Fock states.

## Towards metastable helium condensates in optical lattices

J. Simonet, J. Dugué, Sanjukta Roy, J. Beugnon, E. Arimondo, **M. Leduc**  
Ecole Normale Supérieure, Département de Physique, France

Interfering optical laser beams is a way to trap cold atoms in the wavelength-size regions of the resulting patterns. The domain of BEC in optical lattices is a rich field related to the possibility of 1D, 2D and 3D atomic confinement, and it provides simulation tools for solid state systems. A breakthrough occurred with the experimental observation of the superfluid-Mott insulator quantum transition with Rb atoms [1]

In this context using metastable helium atoms ( $\text{He}^*$ ) in the  $23S1$  excited state offers some specific exciting detection strategies, related to their high internal energy (20eV) which can be released through Penning and associative ionization during interatomic collisions and through ejection of electrons when the atoms strike a surface.  $\text{He}^*$  atoms are usually spin-polarized, which induces a strong reduction of the Penning rate due to total spin conservation during the collision. Monitoring ions with a channeltron electron multiplier (CEM) allows a fast detection (response time of a few ns).

We shall first recall how we performed a very precise measurement of the s-wave scattering length between two colliding  $\text{He}^*$  atoms using spectroscopic methods based on photoassociation [2]. The presentation will then develop prospects of studying  $\text{He}^*$  condensates loaded into 3D optical lattices (produced with counter-propagating lasers beams at  $\lambda=1.5\mu\text{m}$ , red detuned from the resonant helium transition at  $\lambda=1.08\mu\text{m}$ ), using ion monitoring with CEM as a tool to follow the real-time dynamics of the superfluid-Mott insulator quantum phase transition. The  $\text{He}^*$  Mott insulator phase will differ from the case of alkali atoms : each lattice site will contain no more than one atom and the presence of helium losses by Penning ionization will produce a “dissipative” Mott insulator, for which orders of magnitudes will be discussed. The tight confinement is expected to produce changes in the Penning ionization rate, strongly dependent on the trap frequency [3]. The case of a 1D lattice will also be discussed and prediction will be given for the changes in the interparticle interaction attributed to the tight 2D confinement [4].

[1] M.Greiner et al, Nature 415, p39 (2002)

[2] S.Moal et al, Phys.Rev.Lett.96, 023203 (2006)

[3] T.J.Beams et al, J.Phys.B, 37, p4561 (2004)

[4] D.S.Petrov et al, Phys.Rev.A64, 012706 (2001)

# Quantum physics with neutrons: from spinor symmetry to Kochen-Specker phenomena

***Helmut Rauch***

Atominstutue of the Austrian Universities, Vienna, Austria

In 1974 perfect crystal interferometry has been developed and immediately afterwards the  $4\pi$ -symmetry of spinor wave-functions has been verified. Then efforts have been made to separate and measure various dynamical and geometrical phases. In this connection non-cyclic and non-adiabatic topological phases have been identified and their stability against various fluctuations and dissipative forces has been investigated by means of ultra-cold neutrons. An entanglement between different degrees of freedom in a single neutron system demonstrated the contextuality feature of quantum mechanics. In its continuation this yields to Kochen-Specker like investigations providing a new basis for information processing and for the understanding of quantum physics in general. All investigations show the equivalence of various phase spaces and show how physical phenomena are correlated by quantum laws. Some curiosa occurred during the experiments and some epistemological aspects will be discussed as well.

## Looking for quantum diffusion in gravitational waves backgrounds

***Serge Reynaud***

Laboratoire Kastler Brossel (CNRS, ENS, UPMC), France

The value of the Planck mass ( $22\mu\text{g}$ ) suggests that intrinsic fluctuations of spacetime may be responsible in some manner for the existence of a natural borderline between quantum and classical worlds.

Some quantitative answers to this question are obtained by considering the diffusion mechanism induced on quantum systems by the stochastic gravitational waves backgrounds generated at galactic and cosmic scales. This universal fluctuating environment blurs quantum interferences on macroscopic systems (large masses), while leaving essentially untouched those on microscopic systems (small masses). Some relevant numbers are given in the context of ongoing progress towards more and more sensitive matter-wave interferometry.

Similar ideas are also worthy of attention in the context of quantum information. For example EPR correlations encoded on photon polarizations are affected by the exposition to GW backgrounds, and one can calculate whether or not, and to what extent, the correlations survive propagation on long distances.

# Factorization of numbers, Schrödinger cats and the Riemann hypothesis

***Wolfgang P. Schleich***

Institut für Quantenphysik, University of Ulm, Germany

In this talk we connect the three different topics of factorization of numbers, Schrödinger cats and the Riemann hypothesis. The bridge between these areas is the concept of a Gauss sum.

Gauss sums manifest themselves in various phenomena such as the Talbot effect, wave packet dynamics or quantum carpets. Moreover, Gauss sums can be used to efficiently factor numbers. In the meantime five experiments have used such an approach. They rely on NMR techniques, the physics of cold atoms and femtosecond pulses. At the moment the largest number that was factored using a Gauss sum algorithm is a 17 digit number. The talk summarizes these activities.

Moreover, we propose an elementary quantum system which provides us with the Riemann Zeta function. We show that its zeroes are a consequence of the interference of two quantum systems with opposite phases. However, the preparation of such a superposition state (Schrödinger cat) is impossible unless one takes advantage of entangled quantum systems. In this sense analytic continuation familiar from complex analysis finds entanglement as its analogue in quantum mechanics.

## **Experiments on Quantum Mechanics and Mind**

***Abner Shimony***

Department of Philosophy, Boston University, USA

An experiment was proposed and performed by J. Hall, C. Kim, B. McElroy, and A. Shimony (Found. of Phys. 7, 1977, 759) testing the theory that a definite reduction of a superposition does not occur in a measurement process prior to an act of consciousness of an observer. Their data conflicted with this theory. S. Whitmarsh and D.J. Bierman carried out some refinements of this experiment (reported in D. Radin (ed.), Entangled Minds (Simon and Schuster, 2009), with results that are inconclusive.

Two further refinements are now proposed, straightforward in design, which envisage definitive results.

## Quantum theory and reality

***Stig Stenholm***

Department of Physics, KTH, Alba Nova University Centre, Sweden

Quantum theory is our most successful physical theory. We know how to apply it but we do not know why. The theory does not even tell us which entities it talks about. If I assign a state vector to a system, is this an element of reality? As such it would have to reside in the phenomena we observe. Some claim that it represents our knowledge only. This opens the question: "Whose knowledge?"

I consider observations provided by the conventional quantum formalism and, in particular, the clues they reveal about the character of reality. Considering physical Gedankenexperiments, I claim that the state vector must somehow be a genuine attribute of the real world. However, for it to be able to concomitantly carry its information aspects, we are forced to assert that also the knowledge has to have real presence independent of who the observer happens to be. Such a concept of knowledge is in agreement with modern quantum information considerations but lacks a role in the standard formulation of empirical quantum physics.

## **False decoherence**

***William G. Unruh***

Department of Physics and Astronomy, University of British Columbia, Canada

Decoherence is usually measured by examining the reduced density matrix. This talk will argue that this leads to wrong intuitions in some cases, especially at longer time scales, by showing that, despite almost complete decoherence of some simple systems (entropy of the density matrix large), interference experiments show almost perfect coherence. This will, I hope, act as a cautionary tale for a too naive approach to many problems in decoherence.

# The most popular hidden variable theory ever

***Reinhard Werner***

Institut für Mathematische Physik, TU Braunschweig, Germany

We show that the widespread idea which associates a wave function with each individual particle amounts to a hidden variable theory. Einstein called this the "orthodox view of the wave function", and contrasted it with an ensemble point of view. None of his Copenhagen opponents seems to have protested that this was a misrepresentation of their views. In any case, even today, a majority of physicists probably think that way, which justifies the title of this talk.

Looking at the individual state interpretation as a hidden variable theory sheds some new light on traditional paradoxes of quantum mechanics, some of which then appear as the non-locality problems all such theories provably share. As an illustration, some examples of non-locality bugs in the second most popular hidden variable theory, i.e. the Bohm-Nelson theory, are also given.

# Observing Nonspecular Reflection of a Light Beam

*Han Woerdman*

Institute of Physics, University of Leiden, The Netherlands

The Law of Reflection of a light ray incident upon a planar mirror was first formulated by Euclid around 300 BC in his book *Catoptrics*; it has been a tenet of geometrical optics ever since.

However, more recently a small angular deviation of the Law of Reflection has been predicted for a physical light beam, when this is regarded as the implementation of a ray. The deviation is a diffractive consequence of the angular dependence of the reflectivity; it should occur for any mirror with  $<100\%$  reflectivity. We report here experimental proof of this angular deviation, by determining the direction of an optical beam after reflection from an air-glass interface, using an optical position detector with nanometer resolution. The angular deviation displays a dispersive Lorentzian resonance near the Brewster angle. Our results are relevant for angular metrology in general and cantilever-based surface microscopies in particular. Analogous angular deviations are expected for reflection of acoustic waves and quantum matter waves.

## Quantum metrology based tests of gravitation at small and large scale

**P. Wolf**, M-C Angonin, S. Bize, A. Clairon, K. Djerroud, L. Duchayne, A. Landragin, P. Lemonde, F. Pereira dos Santos (LNE-SYRTE, Observatoire de Paris, CNRS, UPMC, Paris, France)

A. Lambrecht, B. Lamine, S. Reynaud (*Laboratoire Kastler Brossel, UPMC, ENS, CNRS, France*)

Gravitation is one of the fundamental interactions of physics. It is well described by General Relativity in the macroscopic world, where the gravitational interaction plays a dominant role. However, General Relativity remains a classical theory incompatible with the standard techniques of quantization. Unification models, lead to modifications of the theory that have observable consequences. They can become apparent, for example, in violations of Lorentz invariance, of the equivalence principle, or of the distance dependence of gravitation.

Concerning the last point, it is essential to experimentally test gravitation at all accessible length scales. While present tests at scales ranging from a few mm to Earth-Moon and planetary distances show impressive sensitivities, the constraints at very short ( $< \text{mm}$ ) and very large distances ( $\geq$  solar system) remain relatively weak. On the theoretical side many unification theories suggest some deviations from the known laws of gravity at very short range, whilst at very large scales astronomical observations (galaxy rotation curves, supernovae redshifts, ...) can only be reconciled with General Relativity by invoking dark matter and energy that constitute about 96% of the total mass of the universe.

We report on two projects that aim at experimentally testing the shortest and largest scales accessible in the laboratory and the solar system. The FORCA-G project [1] under construction at SYRTE uses atoms trapped in an optical standing wave to probe the gravitational interaction between a macroscopic surface and the atoms in the 100 nm to 10 micron range, using atom-interferometry techniques. The SAGAS project [2] aims at flying an optical atomic clock and an accelerometer based on atom-interferometry to  $> 50 \text{ AU}$  (beyond Pluto orbit) to precisely map gravitation in the outer solar system and search for possible deviations. The two projects are briefly described, including their present status and related activities.

[1] P. Wolf et al., PRA 75, 063608, (2007)

[2] P. Wolf et al., arXiv: 0711.0304, (2008); Exp. Astr. 23, 651, (2009)

# Quantum Mechanics as a Real-Vector-Space Theory with a Universal Auxiliary Rebit

*William K. Wootters*

Department of Physics, Williams College, USA

In a 1960 paper, E. C. G. Stueckelberg showed how one can obtain the familiar complex-vector-space structure of quantum mechanics by starting with a real-vector-space theory and imposing a superselection rule. In effect, the role of the complex phase is played in this construction by a single auxiliary real-vector-space binary object (a rebit). In this talk I interpret Stueckelberg's superselection rule as a limitation on our knowledge of the auxiliary rebit and on our ability to use this object in state transformations. I also show how standard complex-vector-space entanglement can be expressed in terms of real-vector-space entanglement involving ordinary objects and the special auxiliary rebit.

# POSTERS

# Postponing the Past: An Operational Analysis of Conceptual Foundations of Delayed-Choice Experiments

M. Bahrami, A. Shafiee

*Presented by: Mohammad Bahrami*  
Sharif University of Technology

The prominent characteristic of a delayed-choice effect is to make the choice between complementary types of phenomena after the relevant interaction between the system and measuring instrument has already come to an end [1]. Here, we first represent a detailed comparative analysis of some early delayed-choice propositions and also most of the experimentally performed delayed-choice proposals in a coherent and unified quantum mechanical formulation. On the lines of probability theory, we know that all probabilities are conditional. On the other hand, quantum theory enables us to formulate probabilistic predictions about the outcomes of measurements in which the conditions are determined by state preparations. That is, the  $\psi$ -function (i.e., the quantum state) can be interpreted as a catalog of probability [2]. Taking into the account the represented quantum mechanical descriptions and also the rules of probability theory, we discuss that there are two fundamentally different descriptions concerning the physical mechanism of the delayed-choice between the complementary types of phenomena in these experiments. In this regard, we finally conclude that the delayed-choice experiments can be classified into two main groups where the temporal aspect of each group is characterized differently within their probabilistic descriptions.

The delayed-choice proposals can be categorized into two main groups which both of them characterize the delayed-choice effect in a way that the choice between complementary patterns is made after the particle is prepared in a superposition of states. The first group includes the experiments in which the complementary phenomena are recorded within exclusive contexts, and hence their corresponding probabilities are calculated under exclusive conditions. The change of conditions which are characterized by transformation of the states is occurred due to the local interaction between the particle and measuring instrument. The only expectation, in which the transformation is a free evolution, is the delayed-choice double-slit experiment with swinging door detector plate [1] which has no experimental counterpart, yet. The second group contains the experiments in which the coincident results of measuring the entangled degrees of freedom of two entangled systems are considered. Here, the corresponding probabilities are joint probabilities that are calculated under the same given condition, and these joint probabilities are symmetric respect to the time sequence of measurements on two entangled systems. The marginal probability for a system that results from integrating over these joint probabilities is independent from any measurement or any change on its entangled system. We believe that of most intriguing question is whether or not it is possible to propose an experiment in which the marginal probability, that describe the results of measurement on a system, to be dependent upon the interactions (e.g., measurement) with some other system with which it is entangled. If we could give a positive answer to this question, then it seems to us that it would vigorously enlighten the conception of non-locality based on standard formalism of quantum theory.

[1] J. A. Wheeler, in *Mathematical Foundations of Quantum Theory*, edited by A. R. Marlow (Academic, New York, 1978).

[2] (a) E. Schrodinger, *The Present Situation in Quantum Mechanics*, translated in *Quantum Theory and Measurement*, J. A. Wheeler and W. H. Zurek edit., (Princeton University Press, 1984), p.152; (b) *The Structure of Physics*, C. F. von Weizsäcker, (Springer, 2006), pp. 280-291.

## **Error Suppression in a Quantum Register with Non-ideal Control**

Gernot Alber, Pavel Bazant, Igor Jex, Oliver Kern

*Presented by: Pavel Bazant*  
Czech Technical University

Unwanted interactions among qubits in a quantum register can be effectively suppressed by means of external control operations. However, if the control is non-ideal, it acts as an additional error source. This poster shows that if this additional error remains constant among different applications of the same control operation, it can be suppressed together with the interqubit interactions.

## **Combinatorics of Creation-Annihilation**

P. Blasiak, P. Flajolet, G.H.E. Duchamp, A. Horzela, K.A. Penson, A.I. Solomon

*Presented by: Pawel Blasiak*  
Polish Academy of Sciences

The Heisenberg-Weyl algebra, underlying virtually all physical representations of Quantum Theory, is considered from a combinatorial point of view. We provide a concrete model of the algebra in terms of graphs and discuss its relation to the classical lie algebras. Special emphasis shall be put on the efficient methods of discrete mathematics such as generating functions and graph decomposition. In this way, by drawing attention to the algebraic structure of Quantum Theory, we intend to shed light on the combinatorial nature hidden behind its formalism.

## **Is two-photon resonance optimal for STIRAP?**

I.I. Boradjiev, A.A. Rangelov, N.V. Vitanov

*Presented by: Iavor Boradjiev*  
Sofia University

The technique of stimulated Raman adiabatic passage is a highly efficient tool for coherent population transfer in a chainwise-connected three-state quantum system, 1-2-3.

It is widely accepted that the two-photon resonance between the two end states of the chain, 1 and 3, is crucial for the success of the process.

This assumption, which is almost never questioned, is perfectly justified when the two driving pulses --- pump and Stokes --- produce nearly equal couplings for the two transitions, 1-2 and 2-3.

We show, numerically and analytically, that when the pump and Stokes couplings differ significantly, the two-photon excitation profile is distorted and asymmetric with respect to two-photon resonance.

We present examples when the line profile is shifted from the two-photon resonance so much that the optimal operation of STIRAP demands significant two-photon detuning.

The results are of potential importance for a number of applications of STIRAP, particularly in situations when the pump and Stokes fields are of different nature.

## **New experiments: a revolution in quantum foundations**

María C. Boscá

*Presented by: María C. Boscá*

University of Granada

In this poster we display a recapitulation of some recent experiments whose consequences have a deep impact on the foundations of quantum physics, discussing the profound conceptual revolution involved. The topics covered would include:

- Updates of the concept of Bohr's complementarity, which must become understood as a continuous concept(1)after experimental intermediate observational situations in some double slit experiments(2), or when we have experiments where complementarity is not due to an unavoidable disturbance during observation(3)or, also, experiments in which a contradiction with the notion of mutual exclusiveness of classical wave and particle pictures emerges(4).
- Delayed choice experiments that demonstrate that the behaviour of the photon in the interferometer depends on the choice of the observable that is measured, even when that choice is made at a position and a time such that it is separated from the entrance of the photon into the interferometer by a space-like interval(5).
- Experiments in quantum teleportation involving two distant experimenters, that "demonstrates some of the salient features of entanglement and quantum information and raises deep questions about the nature of reality in the quantum world"(6).
- Discussion about whether some non-local realistic models can be considered refuted by before-before experiments(7).

(1)P.D.D. Schwindt, P.G. Kwiat and B-G. Englert, Phys. Rev. A60 (1999) 4285-4290; Y. Abranyos, M. Jacob and J. Bergou, Phys. Rev. A61 (1999) 013804; A. Zeilinger, Rev. Mod. Phys. 71,2 (1999) S292.

(2)F. Bardou, Am. J. Phys. 59 (1991) 458-461.

(3)M.O. Scully, B-G. Englert y H. Walther, Nature 351 (1991) 111-116.

(4)P. Ghose and D. Home, Found. Phys. 22,12 (1992) 1435-1447.G. Brida et al, Phys. Lett. A328 (2004) 313-318.

(5)V. Jacques et al, Science 315 (2007) 966-968.

(6)A. Zeilinger, Rev. Mod. Phys. 71,2 (1999) S295.

(7)A. Suarez, Found. Phys. 38 (2008) 583-589.

## **Loss and regain of coherence in neutron and atom interference experiments with internal states**

Mirjana Bozic

*Presented by: Mirjana Bozic*

Institute of Physics

The origin of loss and regain of coherence in neutron interference experiments with internal state labeling [ 1,2] and in atom interference experiments with resonant photon-atom scattering [3,4] is studied and compared. In this study we use the time evolution of a wave function of an atom or neutron as it passes through the interferometer [5,6]. The consideration of a transverse wave function in momentum representation is essential in our study. A role of coupling to an environment versus correlations between external (translational) and internal states is elucidated.

[1] G. Badurek, H. Rauch and J. Summhammer, Time-dependent superposition of spinors, Phys. Rev. Lett. 51, 1015 (1983),

[2] H. Rauch and S.A Werner, 2000, Neutron Interferometry (Oxford University Press).

[3] M.S. Chapman, T.D. Hammond, A. Lenef, J. Schmiedmayer, R.A. Rubestein, E. Smith and D.E. Pritchard, Photon Scattering from atoms in and atom interferometer: coherence lost and regained, Phys. Rev. Lett. 75, 3783 (1995).

[4] A. Cronin, J. Schmiedmayer, D. E. Pritchard, Atom Interferometers, arXiv:0712.3703v1 [quant-ph] 21 Dec 2007

[5] Mirjana Božić and Dušan Arsenović, Emergence of an interference pattern in numerical simulation of quantum particles, Acta Phys. Hung. B 26/1-2, 219 (2006).

[6] D. Arsenović, M Božić, A S Sanz and M. Davidović, Evolution of the wave function of an atom hit by a photon in a three-grating interferometer, Phys. Scr. T134 (2009) to appear, doi:10.1088/0031-8949/2009/134/to appear

## **Perfect state transfer in networks of arbitrary topology**

I. Jex, V. Kostak and G. M. Nikolopoulos

*Presented by: Thomas Brougham*  
Czech Technical University

The task of constructing a quantum computer has many technical challenges associated with it. One such example is transferring the state of a quantum system between different components of a quantum computer [1]. A common approach to this problem is the use of a quantum wire, i.e. a chain or network of coupled quantum systems where the interactions are such that the quantum state is transferred through the wire. Many different realizations of such perfect state transfer (PST), using quantum wires, have been proposed [2-4].

The approach that is often taken to the problem of PST is to construct a Hamiltonian and show that this allows the state to be perfectly transferred. An alternative approach has been proposed that enables a broad class of Hamiltonians to be constructed [5]. This approach does not make any assumptions about the coupling or the topology of the network. Instead, a class of Hamiltonians that lead to a particular permutation are derived. This work was developed for the task of transferring a single excitation between two points in a network. We will show how one can use the formalism outlined in [5] to control quantum information in a more general manner. For example, we may wish to transfer a state to several different nodes within a network, at different times. This would enable us to generalize the problem of PST to networks with a nontrivial logical bus topology. The formalism can also be used to find Hamiltonians that enable PST when we have multiple excitations.

[1] D. P. DiVincenzo, Fortschr. Phys. 48, 771 (2000).

[2] S. Bose, Phys. Rev. Lett. 91, 207901 (2003).

[3] G. M. Nikolopoulos, D. Petrosyan and P. Lambropoulos, Europhys. Lett. 65, 297 (2004).

[4] M. Christandl, N. Datta, A. Ekert, A. Kay and A. J. Landahl, Phys. Rev. Lett. 92, 187902 (2004).

[5] V. Kostak, G. M. Nikolopoulos, and I. Jex, Phys. Rev. A 75, 042319 (2007).

## **Observers, Agents and Kochen-Specker's Theorem**

Eric G. Cavalcanti

*Presented by: Eric Cavalcanti*

Griffith University

One of the most important foundational questions in quantum mechanics is on the nature and role of observers, or more generally, of agents, within the theory. Is an agent a fundamentally distinct kind of system, or can it be fully represented within the quantum formalism? If so, what kinds of systems can be said to be agents?

While a fully satisfactory quantum representation of agents is still elusive, agents can and have been traditionally represented within classical decision theory. It is common for example to speak of "rational agents" and other idealisations. Those concepts can be given well-defined formal meaning within decision theory, as corresponding to certain patterns of behaviour, given some background information and a system of values.

Assuming that the world is fundamentally quantum, it would be natural to expect that agents can be represented as quantum systems, even if in practice it suffices to describe their behaviour through classical concepts. I will make a parallel between decision theory and quantum mechanics interpreted as a theory of information, and show that Kochen-Specker's theorem has surprising implications for the decision-theoretic concept of "ideal agent".

## **Dimension driven accelerating Universe**

S. Chatterjee

*Presented by: Sujit Chatterjee*

New Alipore College

Observation evidences from large redshift supernova suggest that our Universe is at present accelerating. Grvitation ,being always attractive, this phenomenon is counter intuitive. Possible explanation includes,among other things -scalar tensor theories,higher derivative theory and various quintessential models.We argue that higher dimensional models have inbuilt mechanism to account for early deceleration and late acceleration without forcing ourselves to invoke different types of hypothetical matter field.

## **Nonlinear Continuum Mechanics of Space and the Foundations of Electromagnetism**

Ch. Christo

*Presented by: Christov Christo*

University of Louisiana at Lafayette

We prove that, when linearized, the governing equations of an incompressible elastic liquid yield Maxwell's equations as corollaries. The divergence of the deviator stress tensor is interpreted as the electric field, while the vorticity (the curl of velocity field) is interpreted as the magnetic field. Thus we establish that the electrodynamics can be fully explained if one assumes that it is the manifestation of the internal forces of an underlying elastic material which we term the metacontinuum. Through judicious distinction between the referential (Lagrange) and local (Euler) descriptions, the principle of material invariance (frame indifference) is established and shown to be a true covariance principle, unlike the Lorentz covariance, which is valid only for non-deforming frames in rectilinear relative motion. The new nonlinear formulation of the electrodynamics incorporates the Lorentz force as an integral part of Faraday's law, rather than as an additional empirical observable relation. We show that the Ampere-Oersted and Biot-Savart laws can be derived from the frame-indifferent modification of the Maxwell displacement current. A viscous term in the

constitutive relation can explain quantitatively Ohm's law. The material invariance of the model entails Galilean invariance as a limiting case. The main objection against the presence of an absolute medium stems from the perception that the particles and charges (the matter) move through it. We propose a new concept in which the particles and charges are considered as localized nonlinear waves (solitons) of the metacontinuum. They do not move through, but rather propagate over the surface of the metacontinuum. We show that a localized screw deformation in the metacontinuum possesses a topological charge and for all practical purposes can be interpreted as the charge. A most important property of a propagating phase pattern is that it is contracted in the direction of propagation by the Lorentz factor (which is a well established fact in soliton theory). This means that the Lorentz contraction is an intrinsic property of the proposed model. Thus one does not need the Lorentz Transformation to explain the Lorentz contraction. We address also the conundrum connected with the detectability of the absolute continuum. The phase change concept of Michelson interferometer proved unable to detect the first-order Doppler effect, while the second-order is exactly cancelled by the Lorentz contraction. The difficulties stem from the fact that any observational frame is composed by localized patterns while the electromagnetic waves propagate in the absolute medium. Keeping this in mind, we reexamine the famous experiment of Ives and Stilwell using a modified Bohr-Rydberg formula for the emitted frequencies which formula accounts for the motion of the emitting atom. We show that the results of Ives and Stilwell are fully compatible with the presence of an absolute medium, without the need to assume time dilation. Finally, we propose a new two-beam interferometry concept based on the beat frequency which can produce results for the first-order Doppler effect, allowing detecting the relative speed with respect to what is called the preferred frame.

## **Entanglement detection with bounded reference frames**

Fabio Costa, Nicholas Harrigan, Terry Rudolph, Caslav Brukner

*Presented by: Fabio Costa*  
University of Vienna

Quantum experiments usually assume the existence of perfect, classical, reference frames, which allow for the specification of measurement settings (e.g. orientation of the Stern Gerlach magnet in spin measurements) with arbitrary precision. If the reference frames are "bounded" (i.e. are quantum systems themselves), only limited precision can be attained. Using spin coherent states as bounded reference frames we have found the minimal size needed to violate local realism for entangled spin systems. For composite systems of spin-1/2 particles reference frames of very small size are sufficient for the violation; however, to see this violation for macroscopic entangled spins, the size of the reference frame must be at least quadratically larger than that of the spins. This gives a possible explanation for the non-observance of entanglement at macroscopic scales, that is, the emergence of classicality.

## **Experimental realization of Dicke states of up to six qubits for multiparty quantum networking**

G. Croneneberg

*Presented by: Gunther Cronenberg*  
University of Vienna

We report the first experimental generation and characterization of a six-photon Dicke state and demonstrate its remarkable versatility by projecting out four- and five-photon Dicke states, in addition to four-photon GHZ- and W-states. These multipartite states are studied by developing experimentally favorable characterization tools. Furthermore, we show that Dicke states have interesting applications in multiparty quantum networking protocols such as open-destination teleportation, telecloning and quantum secret sharing.

## **On the near horizon approximation for the Schwarzschild black hole**

Hristu Culetu

*Presented by: Hristu Culetu*  
Ovidius University

An anisotropic fluid with a negative radial pressure  $p_r = -\rho$  is supposed to exist near the horizon of a black hole spacetime. The constant energy density  $\rho$  depends only on the black hole mass. The structure of the stress tensor is similar with that obtained previously for the interior of a black hole excepting the time dependence.

## **Efficient Hidden-Variable Simulation of Measurements in Quantum Experiments**

Borivoje Dakic, Milovan Suvakov, Tomasz Paterek, Caslav Brukner

*Presented by: Borivoje Dakic*  
University of Vienna

According to hidden-variable theories (HV) quantum state is a classical mixture of states with deterministic outcomes, so called hidden variables (HVs). How plausible these theories are in terms of resources, i.e. how many classical bits are required, for such a classical description of quantum mechanics (QM)? For an infinite number of measurement settings, already a single qubit requires infinitely many HVs, the result proved by Hardy [1] and, in a different context, by Montina [2]. However, these authors did not consider the scaling of the number of HVs with the number of measurements. Total number of HVs grows exponentially with the number of measurements. A natural question arises, is it possible to simulate quantum mechanical results consuming only a polynomial number of HVs?

## **Observing the evolution of a quantum system that does not evolve**

Simone de Liberato

*Presented by: Simone De Liberato*  
Ecole Normale Supérieure

I studied the problem of gathering information on the time evolution of a single metastable quantum system whose evolution is impeded by the quantum Zeno effect. I found it is in principle possible to obtain some information on the time evolution and, depending on the specific system, even to measure its average decay rate, even if the system does not undergo any evolution at all.

These results have been published in [1] and reviewed in a News & Views in [2].

- [1] S. De Liberato,  
Observing the evolution of a quantum system that does not evolve,  
Phys. Rev. A 76, 042107 (2007).  
[2] L. Vaidman,  
Quantum mechanics: Evolution stopped in its tracks,  
Nature 451, 137 (2008).

## **Decoherence, Neutron Interferometry and Geometry**

Katharina Durstberger, Reinhold A. Bertlmann, Yuji Hasegawa, Helmut Rauch

*Presented by: Katharina Durstberger-Rennhofer*  
Atominstytut der Österreichischen Universitäten

Decoherence arises in quantum systems which can not be perfectly isolated from the surrounding environment. Then we are faced with a modification of the state of the system described by an effective master equation. In choosing different Lindblad generators for the master equation it is possible to study different decoherence modes for a two qubit system.

Neutron interferometry is a very proper tool to test experimentally the behaviour of spin 1/2 systems, and even entanglement between different degrees of freedom (e.g., spin and path) can be established. We propose an experimental realization of several decoherence modes within neutron interferometry where the sources of decoherence are fluctuating magnetic fields. In particular we study the effects of decoherence for maximally entangled states - the Bell singlet states.

The time dependent solutions for different decoherence modes are depicted in the so-called spin geometry picture which allows to illustrate the evolution of the (nonlocal) correlations stored in a certain state.

## **P, C and T for Truly Neutral Particles**

V. Dvoeglazov

*Presented by: Valeriy Dvoeglazov*  
Universidad de Zacatecas

## **Communication Complexity in Hidden Variable Theories Augmented by Non-Local Effects**

A. Fahmi-M.Golshani

*Presented by: Akbar Fahmi Hashiyani*  
Institute for Research in Fundamental Sciences

Bell proved that quantum entanglement enables two space-like separated parties to exhibit classically impossible correlations. Nevertheless these correlations are causal and stronger than anything classically achievable. Recently, Brassard *et al.* considered Popescu and Rohrlich's non-local box and showed that in the non-local box that works correctly with probability greater than  $\frac{1}{2} \approx 90.8\%$ , every Boolean function has trivial probabilistic communication complexity. This bound is an improvement over the previous knowledge that nonlocal boxes could not exactly approach the actual bound  $\frac{1}{2} \approx 85.4\%$  imposed by quantum mechanics and the lower bound  $\frac{5}{6}$  which is given by von Neumann. Then, they asked: the obvious open question is to close the gap between these probabilities. In this poster, we give a partial answer to this question by suggesting a non-local version of Toner and Bacon (NTB-box) model and show that a slightly stronger correlations greater than  $\frac{5}{6}$ , would result in a world in which probabilistic communication complexity becomes trivial.

## **Gazeau-Klauder Coherent States for Quartic Energy Spectrums**

Omid Faizy

*Presented by: Omid Faizy Namarvar*  
Sahand University of Technology

The Gazeau-Klauder coherent states for quartic energy spectrums are constructed. It is shown that the resolution of unity, temporal stability and action identity conditions are satisfied for the coherent states.

## **Information complementarity for general bipartite quantum states**

Alessandro Fedrizzi, Bojan Skerlak, Tomasz Paterek, Marcelo de Almeida and Andrew G. White

*Presented by: Alessandro Fedrizzi*  
University of Queensland

We formulate an exact complementarity relation for general bipartite quantum states based on the limited information content of quantum systems. We demonstrate this relation experimentally for pure states and various classes of mixed states.

## **The necessity of negativity in quasi-probability representations of quantum mechanics**

Ch. Ferrie and J. Emerson

*Presented by: Christopher Ferrie*  
University of Waterloo

Several finite-dimensional quasi-probability representations of quantum states have been proposed to study various problems in quantum information theory and quantum foundations. These representations are often defined only on restricted dimensions and their physical significance in contexts such as drawing quantum-classical comparisons is limited by the non-uniqueness of the particular representation. Here we show how the mathematical theory of frames provides a unified formalism which accommodates all known quasi-probability representations of finite-dimensional quantum systems. Moreover, we show that any quasi-probability representation is equivalent to a frame representation and then prove that any such representation of quantum mechanics must exhibit either negativity or a deformed probability calculus.

## **Conservation rules for entanglement transfer between qubits**

S. Chan, M.D. Reid, Z. Ficek

*Presented by: Zbigniew Ficek*  
King Abdulaziz City for Science and Technology

We consider an entangled but non-interacting qubit pair where each qubit is independently coupled to a set of local qubit systems. We derive two general rules to describe the transfer of entanglement from a give to an another pair of qubits, for the case where the initial entanglement is given by the two different Bell states,  $\Psi$  and  $\Phi$ , corresponding to anti-correlated and correlated qubits respectively. We find that for  $\Psi$ , the non-local pairwise entanglement is conserved, but this manifests in the square of the concurrence, not in the concurrence itself. For this case, we will prove an additivity of constituent entanglement, that the entanglement shared between any two nonlocal partitions is the sum of the nonlocal

pairwise entanglement of the constituents of the partitions. For  $\Phi$ , the sum of the square of the concurrences is reduced, even to zero in some cases, to reveal a complete and abrupt loss of all non-local pairwise entanglement. This rule applies to closed systems, and will be also investigated for open systems.

## **Entanglement and the Feynman Propagator**

J.D. Franson

*Presented by: James Franson*  
University of Maryland

The propagation of virtual particles is described by the Feynman propagator, which has nonzero components outside of the light cone. This does not allow messages to be transmitted outside the light cone, but it does allow entanglement and mutual information to be generated between two distant points in less time than would be required for light to travel between them [1]. This raises some fundamental issues, including whether or not any feasible experiments can be designed to test these predictions of quantum field theory.

## **Optimizing the quantum random walk search of the hypercube**

V. Potoček, A. Gábris, T. Kiss and I. Jex

*Presented by: Aurel Gabris*  
Czech Technical University

It is known that the quantum random walk search algorithm proposed by Shenvi, Kempe and Whaley (SKW algorithm) can be used to search a hypercube of  $N$  vertices using  $O(\sqrt{N})$  oracle queries. The overall time complexity of the SKW algorithm differs from the best achievable on a quantum computer only by a constant factor. We present improvements to the SKW algorithm regarding query complexity, achieving also the relevant theoretical limit of  $(\pi/4)\sqrt{N}$ , by boosting the success probability of single runs. We point out which improvements can be applied to the case when more than one elements are marked.

## **Mechanical analogue of quantum search for relativistic speeds**

Juan Carlos Garcia-Escartin, Pedro Chamorro-Posada

*Presented by: Juan Carlos Garcia-Escartin*  
Universidad de Valladolid

Grover's algorithm for quantum search can be expressed as a classical collision problem with  $N$  elements. After about  $\sqrt{N}$  collisions, most of the energy of the system is transferred to one marked element.

We examine the behaviour of the same procedure for relativistic collisions. As the initial speed of the elements approaches the speed of light, the maximum transfer of energy is achieved in less steps, but the energy that the marked element receives is a smaller fraction of the total.

## **How much does distinguishable particles destroy coherence of qubit?**

M. Gavenda, L. Bartuskova, M. Dusek and R. Filip

*Presented by: Miroslav Gavenda*  
Palacky University

We investigate the coherence of qubit disturbed by another particle or particles temporally presented in the qubit system. The disturbing particles are uncontrollably created and subsequently intentionally annihilated in the subsystem of the qubit. We quantitatively predict how much coherence of the qubit can be preserved in the qubit system. The coherence depends just on a degree of principal and technical distinguishability between the qubit and the particle(s).

For fully indistinguishable particles the unit visibility can be achieved, whereas for distinguishable particles the maximal visibility  $1/\sqrt{2}$  is achieved. We tested our predictions using two photon experiment based on the coupling of the photon with variable distinguishability into Mach-Zehnder interferometer.

## **Molecule Interferometry: The influence of molecular properties**

Stefan Gerlich, Tarik Berrada, Sandra Eibenberger, Michael Gring, Lucia Hackermüller, Klaus Hornberger, Marcel Mayor, Marcel Müri, Stefan Nimmrichter, Jens Tüxen, Hendrik Ulbricht, Markus Arndt

*Presented by: Stefan Gerlich*  
University of Vienna

Kapitza-Dirac-Talbot-Lau interferometry (KDTLI) has recently been established as an ideal method to perform quantum matter wave experiments with large, highly polarizable molecules in the so far inaccessible mass range of beyond 1000 atomic mass units [1]. We present new and improved data on organic molecules in the range of 1600-3000 amu and high-contrast interference fringes with functionalized azobenzenes, the currently most extended polyatomic structure to have shown quantum interference [2]. Hot and complex molecules show a vivid internal dynamics which influence the interference pattern, both as coherent phase shifts and as visibility reducing dephasing. In both cases, the interference visibility reveals important information about the properties of the diffracted particles and KDTLI turns out to be a potent tool for precision metrology of neutral molecules [3]. Mass, optical and static polarizability as well as dynamic and static dipole moments become accessible. They are closely related to the molecular conformation and structure. Here, quantum interferometry offers an interesting solution to a challenge that is not readily met using conventional techniques.

[1] S. Gerlich et al., Nat. Phys. 3, 711 - 715 (2007)

[2] K. Hornberger et al., New J. Phys. 11, 043032 (2009)

[3] S. Gerlich et al., Angew. Chem. Int. Ed. 47, 6195 -- 6198 (2008)

## **Motional Bell test with dissociated Feshbach molecules**

Clemens Gneiting and Klaus Hornberger

*Presented by: Clemens Gneiting*  
Arnold Sommerfeld Center for Theoretical Physics

The controlled dissociation of Feshbach molecules permits one to generate pairs of counterpropagating atoms that are entangled in their motional degrees of freedom. In particular, a sequence of dissociation pulses may result in delocalized single-atom states, in analogy to photonic time-bin entangled states. The distinct spatial components of this dissociation-time entangled state can be addressed individually by subsequent Mach-

Zehnder interferometric devices, which then permits to perform a Bell test analogue based on the dispersing motional state of the dissociated atoms. An implementation of the scheme with macroscopic extensions of both the interatomic separation and the single-atom states seems to be within reach of present day technology.

## **Linguism as a Key to Physics**

H.H. Grelland

*Presented by: Hans Herlof Grelland*  
University of Agder

Two epistemological approaches to physics is outlined: positivism or intuitionism (Hume, Mach, Husserl, Bohr) and linguism (Locke, Hertz, Boltzmann, Wittgenstein, Dirac). The linguistic position is defended as the key to an adequate understanding of symbolic, non-intuitive theories like Minkowski space relativity or quantum physics.

## **Entanglement in 1D thermal cluster chains**

Michal Hajdusek, Vlatko Vedral

*Presented by: Michal Hajdusek*  
University of Leeds

We present a systematic way of constructing the closest separable state to a one-dimensional cluster state. This state minimizes the relative entropy and can therefore be used to quantify the entanglement of cluster states. We confirm the correct known scaling for pure cluster states and obtain analytic expression for the scaling of entanglement at finite temperature. We also calculate the critical temperature of entanglement and show how states at this temperature can be used to construct the closest separable state. We consider finite cluster states with open boundaries and investigate the different behavior and form of the closest separable states for even and odd number of qubits.

## **Quantum theory of classical properties**

P. Hajicek

*Presented by: Petr Hajicek*  
University of Berne

Properties of individual quantum objects that can be assumed real without contradiction to standard quantum mechanics are listed. They are different from, and logically subtler than, single values of observables. Averages and variances of quantum operators in prepared states belong to them and can model classical properties for macroscopic quantum systems. Difficulties due to Bub-Clifton-Goldstein theorem that afflict, e.g., quantum decoherence theory or Leggett-Garg inequality are thus avoided and the emergence of classical properties and of classical realism in quantum world are explained (arXiv:0806.4437). Statistical models of internal (thermodynamic) and external (mechanical) classical properties are calculated. In the models of mechanics, Jaynes' generalisation of statistical physics is further developed (arXiv:0901.0436).

## **Understanding and applications of cold atom "cat state"**

David Hallwood, Jess Cooper, Thomas Ernst, Joachim Brand, Jacob Dunningham

*Presented by: David Hallwood*  
University of Leeds

The exploration of possible applications of quantum states has only just begun. Already promising applications in understanding fundamental physics, phase transitions and quantum technologies such as precision measurements and quantum computing have been made. By theoretical investigation we have shown how different types of "cat states" with different robustness can be made. We then show how these can be used to understand their nature and used to make precision measurements of rotation. The system comprises of a quasi-1D loop that is either continuous with a barrier, or an optical lattice, that can be rotated. This goes beyond mean field analysis by studying small systems at a microscopic level using second quantized formalism.

## **Neutron as a quantum system: Exploring multi-entanglement in a single-neutron system**

Y. Hasegawa, G. Badurek, J. Klepp, R. Loidl, S. Sponar and H. Rauch

*Presented by: Yuji Hasegawa*  
Atominstytut

Non-local correlations between subsystems sufficiently separated in spacetime have been extensively discussed in the light of the Einstein, Podolsky, and Rosen (EPR) paradox, together with the Bell's inequality. Within quantum terminology, such a non-locality can be interpreted as a consequence of the entanglement of subsystems as well as commuting observables due to the different position. Thus, a more general concept, i.e., contextuality, compared to non-locality can be introduced to describe other striking phenomena predicted by quantum theory. As an example of quantum contextuality, we report a neutron interferometer experiment which clearly demonstrates the violation of a Bell-like inequality. Entanglement is achieved not between particles, but between the degrees of freedom i.e., spin and path, in this case, for a single-particle. Appropriate combinations of the direction of spin analysis and the position of the phase shifter allow an experimental verification of the violation of a Bell-like inequality. In addition, Kochen-Specker-like phenomena and so-called state tomography, tomographic analysis of the density matrix of a quantum system, are presented to characterize neutrons' entangled states. Furthermore, we accomplished a coherent energy manipulation scheme with a radio-frequency (RF) spin-flipper. This scheme allowed the use of (total) energy degree of freedom to be added: peculiarity of a triply entangled GHZ-like state as well as higher violation of Bell-like inequality was demonstrated.

## **Towards the limits of cluster interferometry**

Philipp Haslinger, Stefan Nimmrichter, Nadine Dörre, Philipp Geyer and Markus Arndt

*Presented by: Philipp Haslinger*  
University of Vienna

The idea of Talbot Lau interferometry has been identified as one of the key concepts enabling matter wave interferometry with very massive particles [1,2]. We here discuss the concepts and theoretical limits of pulsed matter wave interferometers for high mass clusters and molecules in the mass range between 1.000 and 1.000.000 amu [2] and contrast it to other successful ideas for large particles [3,4].

A pulsed absorptive light wave grating with a period of about 79 nm is proposed to be the central diffractive element in the most compact matter interferometer that can be realized for very massive clusters.

It will reduce the size by a factor of 10 compared to recent matter-wave-experiments [4] and it allows to put the entire interferometer on a single two-inch mirror.

This tiny setup facilitates the alignment and it is expected to intrinsically reduce the sensitivity to a number of otherwise important dephasing mechanisms.

## **Sagnac-based asymmetric down-conversion source of entangled photons**

M. Hentschel, H. Huebel, A. Poppe, A. Zeilinger

*Presented by: Michael Hentschel*

IQOQI Vienna

We demonstrate a compact and stable source of polarization-entangled photons working at 810 & 1550 nm. Due to a novel Sagnac-based design of the interferometer no active stabilization is needed. Using only one 30mm ppKTP crystal the source produces photons with a spectral brightness of  $1.13 \times 10^6$  pairs/(s·mW·THz) with an entanglement fidelity of 98.2 %. Both photons are single-mode fiber coupled and ready to be used in optical network applications like QKD. The whole source is mounted on a custom milled aluminum block of dimensions  $5 \times 5 \times 5$  cm<sup>3</sup>.

## **'Full-state realism' as a foundation for quantum computing**

C. Hewitt-Horsman

*Presented by: Clare Hewitt-Horsman*

HP-Laboratories

Quantum computation and Everett-style 'many worlds' interpretations of quantum mechanics have long shared a special relationship. However, recent work in both areas has increasingly problematized their joint usefulness, if not compatibility. A major strand of modern Everett theories defines worlds only under decoherence - the applicability to (generally) coherent computations being therefore in doubt. On the side of quantum computing, there is the development of measurement-based algorithms which appear not to fit neatly into a 'many worlds' description. I will present an Everett-style foundational picture for quantum computation that aims to resolve these issues by significantly reducing the role played by a 'world' - indeed, we will find it becomes all but irrelevant for quantum computing. The name 'full-state realism' reflects that, while not forgetting the measurement problem, the emphasis is instead on the complete state. This view finds a natural formalism in a generalised version of stabiliser theory, which in turn aids the application of this picture to measurement-based quantum computing (where the stabiliser formalism is commonly used). The results of formulating measurement-based computing in this interpretive picture will be presented, highlighting the significant differences between this understanding and the usual model. I will discuss implications of this both for measurement-based algorithms and quantum computing more generally, in particular the resources needed to perform computation. Finally, I will show how this foundational perspective can be used to integrate both quantum and classical elements into a single, unified, model of computation.

## **Detecting Non-equilibrium Entanglement**

Jenny Hide and Vlatko Vedral

*Presented by: Jenny Hide*

University of Leeds

Real systems are not, in general, in equilibrium. We present a method of detecting entanglement in non-equilibrium systems using the relative entropy of entanglement and the concept of quantum mechanical work. We consider an example of a driven three qubit XXZ spin chain.

## **Bell Inequalities for Systems in High Energy Physics**

B.C.Hiesmayr, R.A. Bertlmann

*Presented by: Beatrix Hiesmayr*

University of Vienna

Also for systems in high energy physics entangled states can be produced. We show two types of Bell inequalities. One type shows that nonlocality is related to the violation of a symmetry in particle physics, the CP symmetry (C...charge conjugation, P...parity). The other one shows that the maximal violation of the Bell inequality is surprisingly not obtained for the maximal entangled states.

## **Multipartite Entanglement Measures**

M. Huber, B.Hiesmayr

*Presented by: Marcus Huber*

University of Vienna

We present two new Multipartite Entanglement Measures, one for pure and one for mixed states. They are applicable to an arbitrary number of systems and dimensions. The mixed state measure allows even to detect and measure some bound entangled states and is easily computable.

## **Entanglement Measures for Intermediate Separability of Quantum States**

Tsubasa Ichikawa, Toshihiko Sasaki, Izumi Tsutsui

*Presented by: Tsubasa Ichikawa*

Kinki University

We present a family of entanglement measures  $R_m$  which act as indicators for separability of  $n$ -qubit quantum states into  $m$  subsystems for arbitrary  $2 \leq m \leq n$ . The measure  $R_m$  vanishes if the state is separable into  $m$  subsystems, and for  $m = n$  it gives the Meyer-Wallach measure while for  $m = 2$  it reduces, in effect, to the one introduced recently by Love et al. The measures  $R_m$  are evaluated explicitly for the GHZ state and the  $W$  state (and its modifications, the  $W_k$  states) to show that these globally entangled states exhibit rather distinct behaviors under the measures, indicating the utility of the measures  $R_m$  for characterizing globally entangled states as well.

## **Scalable quantum search using trapped ions in thermal motion**

Ian Linington, Peter Ivanov, Nikolay Vitanov

*Presented by: Peter Ivanov*  
Sofia University

We propose a new approach to quantum search in which the scalable implementation of Grover's algorithm is a trapped-ion information processor, which does not require precise control over the ions' motional state. The system is initialized in an entangled Dicke state and the 'inversion-about-average' operator takes the form of a single off-resonant pulse along the trap axis. The oracle query is synthesized using a small number of laser pulses addressing individual ions. A significant advantage of our proposal is that each logical iteration requires only a few physical interaction steps, in contrast to the large number of concatenated gates required by previous approaches. We predict that the algorithm could be performed with high fidelity using current technology for databases comprising several hundred elements.

## **Decoherence-based macromolecules conformational transitions**

J Jeknić-Dugić, M. Dugić

*Presented by: Jasmina Jeknic-Dugic*  
Faculty of Science

We present the, so-called, elementary the decoherence-based processes governing the macromolecules conformational transitions.

## **Can quantum-mechanical no-signaling proofs be considered complete?**

Raymond Jensen

*Presented by: Raymond Jensen*  
Lake Superior State University

Here, we examine one kind of theorem forbidding superluminal signals. The proofs of such theorems generally consider two observers: a "sender" and a "receiver," together with a quantum system, and demonstrate that the receiver's eigenvalue statistics from the system do not change with respect to two possible actions committed by the sender. The two possible sender actions considered are (1) making a measurement and (2) taking no action. Here we show that these two sender actions cannot be the only two, on the basis of a 1986 experimental result by Aspect and co-workers involving a Mach-Zehnder interferometer: If (1) and (2) were the only two possible actions, then no interference patterns should be observed in that experiment. This contradicts the experimental results. Thus it is asserted that the possibility of superluminal signaling remains open, since there must be a third kind of action which a sender may perform (which would give rise to the interference patterns observed in the experiment). This third kind of action needs to be considered in proving such no-signaling theorems.

## **Can quantum mechanics be an emergent phenomenon?**

Petr Jizba, Massimo Blasone

*Presented by: Petr Jizba*

Freie Universität Berlin

We raise the issue whether conventional quantum mechanics, which is not a hidden variable theory in the usual Jauch-Piron's sense, might nevertheless be a hidden variable theory in the sense recently conjectured by G. 't Hooft in his pre-quantization scheme. We find that quantum mechanics might indeed have a fully deterministic underpinning by showing that Born's rule naturally emerges (i.e., it is not postulated) when 't Hooft's Hamiltonian for be-ables is combined with the Koopmann - von Neumann operatorial formulation of classical physics.

## **Wave-particle duality of large molecules revealed.**

Stefan Truppe, Thomas Juffmann, Philipp Geyer, Sarayut Deachapunja, Andras Major, Hendrik Ulbricht and Markus Arndt

*Presented by: Thomas Juffmann*

University of Vienna

Molecular interferometry has proven to be a suitable tool for testing the wave-particle duality of large, heavy and hot molecules.

We report on a new detection scheme for molecular interferometry: the near-field interference pattern is deposited onto a detection surface, which is subsequently imaged using various microscopic techniques.

Scanning tunneling microscopy even allows to image every single molecule with nanometer resolution within the interference pattern, revealing the wave-particle duality in its clearest form.

First interferograms of C<sub>60</sub> molecules deposited onto reconstructed Si(111) 7x7 are presented.

This method is not only intuitive and most sensitive, but also intrinsically scalable to larger molecules or clusters.

## **No-Broadcasting Theorem and Its Classical Counterpart**

Amir Kalev, Itay Hen

*Presented by: Amir Kalev*

National University of Singapore

Although it is widely accepted that “no-broadcasting” — the nonclonability of quantum information — is a fundamental principle of quantum mechanics, an impossibility theorem for the broadcasting of general density matrices has not yet been formulated. In this work, we present a general proof for the no-broadcasting theorem, which applies to arbitrary density matrices. The proof relies on entropic considerations, and as such can also be directly linked to its classical counterpart, which applies to probabilistic distributions of statistical ensembles.

## **Feynman's Path Integrals as Model of Extended Newtonian Dynamics**

Timur F. Kamalov

*Presented by: Timur Kamalov*  
Moscow State Open Universita

Newton's physics describes macro-objects sufficiently well, however it does not describe microobjects. A model of extended Newtonian dynamics (MEND) is based on an axiomatic generalization of Newton's classical laws to non-inertial reference frames postulating the description of body dynamics by differential equations with higher derivatives of coordinates with respect to time but not only of second order ones. In that case the Lagrangian  $L=L(q, \dot{q}, \ddot{q}, \dots, q^{(n)})$  depends on higher derivatives of coordinates with respect to time and corresponds to Feynman's multiple path integrals. The kinematic state of a body is considered to be defined if  $n$ -th derivative of the body coordinate with respect to time is a constant (i.e. finite). First, kinematic state of a free body is postulated to be invariable in an arbitrary reference frame. Second, if the kinematic invariant of the reference frame is the  $n$ -th order derivative of coordinate with respect to time, then the body dynamics is described by a  $(n+1)$ -order differential equation. For example, in a uniformly accelerated reference frame all free particles have the same acceleration equal to the reference frame invariant, i.e. reference frame acceleration. These bodies are described by third-order differential equation in a uniformly accelerated reference frame.

arXiv:0708.1584v3 [physics.class-ph]

## **Simulating the BCS Hamiltonian on a qubus quantum computer**

Katherine Brown, Viv Kendon and Bill Munro

*Presented by: Viv Kendon*  
University of Leeds

We look at performing a simulation of the BCS Hamiltonian on a qubus quantum computer by building on previous work from Wu et al. [PRL 89 057904 2002] and Brown et al. [PRL 97 050504 2006]. We have shown that it is possible to efficiently implement the time evolution of the BCS Hamiltonian on a qubus quantum computer and found the gates required for this. In the most general case, if the first order Trotter approximation is used, the number of gates required scales to the order of  $n$  squared where  $n$  is the number of qubits.

## **Quantum Erasure and Complementarity in Neutron Optics**

J. Klepp, S. Sponar, H. Bartosik, S. Filipp, H. Rauch, C. Schmitzer and Y. Hasegawa

*Presented by: Jürgen Klepp*  
University of Vienna

Since the early days of quantum physics, the mystery of complementarity has been intensively discussed, typically in the light of 'wave - particle duality'. In the nineties a possible explanation for the loss of interference contrast in quantum experiments was given by consideration of entanglement of the quantum system with an ancilla system. By using the ancilla as a marker of the path, one can gain which-path information that is responsible for the loss of contrast. In the 'quantum-erasure' concept, which-path information can be erased, so that interference contrast is regained. We have carried out a perfect-crystal neutron interferometer experiment and a neutron polarimeter experiment, both exhibiting typical complementarity and quantum-erasure behavior.

## **En Route to Quantum Biology: Non-trivial Quantum Effects in Radical-Ion-Pair Reactions**

I. Kominis

*Presented by: Iannis Kominis*  
University of Crete

Non-trivial quantum effects in biology have been sought after for a long time. It was recently discovered that a familiar biological system, namely radical-ion pairs and their reactions, exhibits a number of quantum effects such as quantum coherence, quantum jumps and the quantum Zeno effect. Radical-ion pairs, at the basis of photosynthesis and avian magnetic navigation, are shown to be a paradigm biological system where the full machinery of quantum measurement theory can be fruitfully applied. On the one hand, this opens the way to several vistas in theoretical and experimental quantum biology, from the understanding of the fundamental connections between quantum-dynamic effects and biology, to the design and experimental demonstration of novel quantum-limited biochemical-reaction magnetometers and last but not least to the exploration of quantum information processing at the biological level. On the other, the exploration of non-trivial quantum effects in the rich and complex biological environment will trigger and require progress in the mathematical and physical concepts of quantum physics.

## **Multipartite entanglement witnesses via structure factors**

Philipp Krammer, Hermann Kampermann, Dagmar Bruss, Reinhold A. Bertlmann, Leong Chuang Kwek, Chiara Macchiavello

*Presented by: Philipp Krammer*  
University of Vienna

We provide an analytical construction of multi-qubit entanglement witnesses, using static structure factors. Thus, we establish a relation between diffractive properties of a many-body system, and its entanglement properties. The proposed witnesses contain two-point correlations for up to three measurement settings. They detect symmetric states with a fixed number of excitations (so-called Dicke states), but also "Dicke-like" states with changed phases of the constituting terms. We further study the robustness of the witnesses with respect to noise.

## **Geometric phase induced by polarizers**

J. Lages, R. Gisut, J.-M. Vigoureux

*Presented by: Jose Lages*  
CNRS

The quantum kinematic approach is used to revisit geometric phases associated with polarizing processes of a monochromatic light wave. We derive the expressions of geometric phases for any, unitary and non-unitary, non-cyclic transformations of the light wave state. Contrarily to the usually considered case of absorbing polarizers, we found that a light wave passing through a total reflection based polarizer acquires a non trivial geometric phase. This geometric phase, which is a direct reminiscence of the evanescent light wave component, exists despite the fact that initial and final polarization states are in phase according to the Pancharatnam criterion.

## **Position and momentum tomography**

J. Kiukas, P. Lahti, J. Schultz

*Presented by: Pekka Lahti*

University of Turku

We illustrate the use of the statistical method of moments for determining the position and momentum distributions of a quantum object from the statistics of a single measurement.

## **Experimental Quantum Process Discrimination**

Anthony Laing, Terry Rudolph, Jeremy O'Brien

*Presented by: Anthony Laing*

University of Bristol

Quantum states are described by a wavefunction that is subject to collapse, but this is not usually the case for our description of processes that act on quantum states. The surprising asymmetry between probing unknown states with known processes and probing unknown processes with known states has implications for our foundational understanding of quantum mechanics. Furthermore, given the emerging potential of quantum information science where devices including photonic quantum circuits are being miniaturized, making their identification challenging, quantum process discrimination has pragmatic considerations. Discrimination between unknown processes chosen from a finite set is experimentally shown to be possible even in the case of nonorthogonal processes. We demonstrate unambiguous deterministic quantum process discrimination of nonorthogonal processes using properties of entanglement, additional known unitaries, or classical communication. Single qubit measurement and unitary processes and multipartite unitaries (where the unitary acts nonseparably across two distant locations) acting on photons are discriminated with a confidence of at least 97% in all cases.

## **Time-bin entanglement and local realism**

J.A. Larsson

*Presented by: Jan-Åke Larsson*

Linköpings Universitet

In this paper, the question of time-bin entanglement and its implications for existence of local realist models will be investigated. We will have a look at some possible experimental setups and, in each case, a detailed account of assumptions needed to enable existence tests of local realist models. The examples will include a range of experiments from the original Franson proposal to the fairly recent setup by Cabello et al.

## **Quantum random walk with jumps**

H.Lavicka, I.Jex, M.Stefanak

*Presented by: Hynek Lavicka*

Faculty of Nuclear Sciences and Physics Engineering

We analyze a special class of one-dimensional quantum walks realized using optical multiports. We assume nonperfect multiports showing errors in the connectivity, i.e. with a small probability the multiports can connect not to its nearest neighbor but to another multiport at a fixed distance. We call such errors jumps. As initial states we assume that the test particle (photon) starts its walk from a given input channel of one particular multiport.

We show that fundamental differences in the properties of the output probability distribution exist between the propagation through a sequence of thin layers of multiports or through a bulky medium. In addition we demonstrate that in the case of a thin pattern differences between odd and even jumps exist. The probability distributions of the studied cases strongly differ - in the case of even jumps the distribution does exhibit a three peak profile around the position of the initial excitation. In contrast, probability distribution in the odd case follows a Laplace-like discrete distribution modulated by additional (exponential) peaks for long times. Finally, for bulky medium the distribution is Gaussian-like.

## **Phase Space, MUB's, Pauli Operators and All That**

Jay Lawrence

*Presented by: Jay Lawrence*  
Dartmouth College

We describe the relationships among three alternative bases in the space of operators acting on systems of  $N$  prime-state objects: The usual Pauli Operators, the phase point operators defined at points in discrete phase space, and the projectors of mutually unbiased basis sets (MUB's). We demonstrate the equivalence of two recent approaches, one that originates in discrete phase space based on finite fields (1), and another that originates with Pauli operators, whose compatibility patterns also conform to finite fields (2). We show that all known MUB structures may be obtained as linear foliations of phase space. We also show that the multiplicity of Wigner functions associated with a given MUB structure conforms to the multiplicity of admissible phase choices for Pauli operators.

(1) KS Gibbons et. al., PRA 70,062101 (2004).

(2) AB Klimov et. al., eprint quant-ph/0806.0726v1

## **Bounds for a class of multiple-setting, multiple-outcome Bell inequalities**

Yeong-Cherng Liang

*Presented by: Yeong-Cherng Liang*  
The University of Sydney

Starting from a Bell function analogous to that considered by Ji and collaborators [Phys. Rev. A 78, 052103], we derive some linear Bell inequalities for probabilities with both multiple settings and multiple outcomes. Computationally, we show that some of these inequalities are tight and therefore correspond to boundaries of the set of classical correlations. In contrast with most of the tight multiple-outcome Bell inequalities known to date, numerical results suggest that one of our tight inequalities is violated maximally by a maximally entangled state. Along with the derivation of our Bell inequalities, we show that many of the Bell correlation inequalities derived by Ji et. al. can be violated by pure classical strategies, and hence do not represent legitimate constraints on classical correlations. Moreover, we prove that any quantum state violating a legitimate correlation inequality derived by Ji et. al. must also violate the corresponding probability inequality that we derive using exactly the same local measurements.

## **Fisher and Jensen-Shannon divergences among one-particle densities of neutral and ionized atomic systems**

S. Lopez-Rosa, J. Antolin and J.C. Angulo

*Presented by: Sheila Lopez-Rosa*  
University of Granada

The Fisher divergence (FD) and Jensen–Shannon divergence (JSD) are used in this work with the aim of providing quantitative measures of the discrepancies between two arbitrary distribution functions, the FD being of local character and the JSD of global one. In doing so, the concepts of Fisher information and Shannon entropy associated to a distribution are the essential quantities for building up these comparative functionals. This kind of relative measures are here applied to the study of the one-particle densities in both conjugated spaces (position and momentum) of neutral atoms, singly charged ions and isoelectronic series, discussing the results as compared to those provided by other previous functional measures. It is clearly shown how these divergences provide relevant information on the atomic shell structure and the extremum values of the ionization potential, up to a level which depends on the considered space and measure.

## **Evolution of Quantum Wavepacket in a Box and Quantum States Forming**

Konstantin Lukin

*Presented by: Konstantin Lukin*  
National Academy of Sciences

Evolution of quantum wavepacket in a box is considered as a multiple reflection of localized wavefunction by quantum wells.

Transition to solution obtained with the help of standard approach is shown.

Two regimes of particle propagations, the ballistic one (quasi-classical) and quantum one, with self-interference and formation of quantum carpets have been considered.

Investigation of transients in the wavepacket propagation enables to discuss the issue of quantum states forming in the box.

## **Experimental Realization of Delayed Choice Entanglement Swapping**

Xiaosong Ma, Stefan Zotter, Thomas Jennewein, Anton Zeilinger

*Presented by: Xiaosong Ma*  
IQOQI Vienna

The spooky action at a distance (in Einstein's words) of entangled system is illustrated in a striking way by Peres's delayed-choice entanglement swapping Gedankenexperiment. In this experiment, which pair of particles is finally entangled of a four particles system is chosen at a time after they have been registered and don't even exist anymore: if one prepares two independent entangled photon pairs 1-2 and 3-4, either projects photon 2 and 3 into a entangled state and hence entangles photon 1 and 4 (entanglement swapping); or projects photon 2 and 3 into a separable state and hence photon 1-2 and 3-4 are still entangled as original case (entanglement non-swapping). Here we report an almost ideal realization of this Gedankenexperiment, where photon 2 and 3 are delayed with 104 m glass fiber respectively and are analyzed with an ultrafast bipartite state analyzer controlled by a quantum random number generator. The results, as characterized by the entanglement witness, are clearly in accordance of the prediction of quantum physics – the relative temporal order in this type of experiment is irrelevant.

## **Entanglement Measures for Pure States of N Identical Fermions**

A. R. Plastino, D. Manzano and J. S. Dehesa

*Presented by: Daniel Manzano Diosdado*  
Granada University

A necessary and sufficient criterion for separability of pure states of N identical fermions is obtained. This criterion, based on the verification of one single identity involving either the purity or the von Neumann entropy of the single-particle reduced density matrix, is drastically simpler than other criteria that have been previously advanced in the literature. That criterion gives two natural measures of entanglement that are compared.

## **Biomolecular beam source for matter wave interference**

Markus Marksteiner, Philipp Haslinger, Michele Sclafani, Hendrik Ulbricht and Markus Arndt

*Presented by: Markus Marksteiner*  
University of Vienna

In the last years matter wave interference of big molecules could shift the mass limit of particles, which show wave like behavior to a few thousand mass units. These experiments address one of the fundamental questions in modern physics: Does an upper mass limit for observing wave like behavior of massive objects exist?

In order to push this mass limit further we want to do interference experiments with high mass biomolecules, which demands also a source to produce beams of these biomolecules. Therefore we built a laser desorption source, which ejects a beam of neutral high mass particles, like amino acids and polypeptides. The detection of those molecules is done via VUV photoionization followed by a time of flight mass spectrometer. Beside the production of gasphase beams of the pure molecules also massive clusters of biomolecules could be observed. The source is able to produce Tryptophan-Calcium clusters (Trp\_nCa\_1) up to a mass of 6000amu. Replacing the calcium by other elements like barium, strontium, sodium and copper is also possible. Even clusters between different kinds of biomolecules could be produced, like for example Gramicidin-Tryptophan clusters.

Beside the access to high mass biomolecules for matter wave experiments these biomolecular complexes are also interesting candidates to do metrology. Since the combination of a Talbot-Lau interferometer with an electric field in the beam line allows to measure also internal properties of the molecules like polarizabilities, these clusters can be used to learn more of their internal structure and therefore also get some insight to their formation and growth-mechanism.

## **Lorentzian wormholes generalizes thermodynamics still further**

Prado Martin-Moruno and Pedro F. Gonzalez-Diaz

*Presented by: Prado Martin-Moruno*  
Instituto de Fisica Fundamental

This poster shows how the 2+2 formalism, first advanced by Hayward for spherically symmetric space-times, allows us to formulate the three main laws of wormhole thermodynamics as well as to consider a possible thermal emission made up of some sort of phantom radiation coming out from the wormhole at a negative temperature. Comments about a possible further generalization even beyond the already generalized gravitational thermodynamics are also included.

## **Characterization of PPT states and measures of entanglement**

Takashi Matsuoka, Wladyslaw A. Majewski, Masanori Ohya

*Presented by: Takashi Matsuoka*  
Tokyo University of Science

A detailed characterization of PPT states, both in the Heisenberg and in the Schrodinger picture, is given. Measures of entanglement are defined and discussed.

## **Quantum Information, Incompleteness and State Collapse**

S. Mayburov

*Presented by: Sergey Mayburov*  
Lebedev Inst. of Physics

Restrictions on information transfer in quantum measurements and their influence on the measurement results are explored. In information theory, any measuring system (MS) can be considered as the information channel, through which the information about studied object S is transferred from S to information system (observer) O. However, Holevo-Werner constraints reduce severely the information capacity of arbitrary quantum channels, in comparison with their classical analogs. As the example, the measurements of S observable Q is regarded for S states which can be the superposition or mixture of two Q eigenstates. In this case, such constraints result in the principal loss of information about S observable Q', which characterizes the purity of S state. It is shown that such incompleteness of information about S state results in the principal stochasticity of O final states for the measurement of S states superposition, i.e. it corresponds to S state collapse. O state decoherence by the interaction with environment E enlarges this information losses additionally.

## **Quantum Mechanics and Multiverse**

Aleksander Mikovic

*Presented by: Aleksandar Mikovic*  
Lusofona University

We describe how to implement the Many Worlds interpretation of quantum mechanics, as well as the De Broglie-Bohm interpretation, in the framework for the multiverse represented by mathematical structures realised in time.

## **State preparation in quantum mechanics**

K. Modi

*Presented by: Kavan Modi*  
National University of Singapore

I discuss the role of state preparation for quantum experiments that experience open dynamics. I show that the act of preparation cannot be treated trivially as it may affect the dynamics of the system.

## **Contextuality within quantum mechanics manifested in subensemble statistics**

A. Pan, D. Home

*Presented by: Alok Pan*

Bose Institute

For spin-1/2 particles, we argue that, it is a direct consequence of the quantum mechanical analysis that the experimentally verifiable subensemble statistics of a spin variable exhibit dependence on the choice of a commensurable 'path' observable, while the relevant expectation value pertaining to the whole ensemble remains unchanged. This, in turn, enables inferring the context-dependence of an individual measured value, irrespective of the way an outcome is specified using a hidden-variable(realist) model.

## **Information causality and the strength of quantum correlations**

M. Pawłowski, T. Paterek, D. Kaszlikowski, V. Scarani, A. Winter, M. Żukowski

*Presented by: Tomasz Paterek*

National University of Singapore

Quantum physics exhibits many remarkable features. For example, it gives probabilistic predictions (non-determinism), does not allow copying of unknown states (no-cloning), its correlations are stronger than any classical correlations but information cannot be transmitted faster than light (no-signaling). However, all the mentioned features do not single out quantum physics. A broad class of theories exist which share all of them with quantum mechanics and allow even stronger than quantum correlations. Here, we introduce the principle of Information Causality, stating that communication of  $m$  classical bits causes information gain of at most  $m$  bits. We show that this principle is respected both in classical and quantum physics, and that all stronger than quantum correlations violate it. We suggest that Information Causality, being a generalization of no-signaling, is one of the foundational properties of Nature.

## **Quantum Mechanics foundations investigation at INRIM: recent results**

G. Brida, I. Degiovanni, M. Genovese, F. Piacentini, V. Schettini, A. Migdall, S. Polyakov, N. Gisin

*Presented by: Fabrizio Piacentini*

INRIM

More than 40 years have passed since Bell's paper [1] stating that Local Hidden Variable Theories (LHVT) cannot reproduce all the results of Standard Quantum Mechanics (SQM). Since then, many experiments took place in order to discriminate between these two theoretical frameworks [2].

Recently, some papers appeared [3,4] proposing some inequalities satisfied only by restricted families of LHVT, but whose test, realizable by means of polarization-entangled photon pairs, would be free from detection loophole. These inequalities were then tested and successfully violated [5]. Furthermore, a nonclassicality test at single-particle level on a specific HVT was proposed [6] and realized [7,8]. Here we present the experiments performed at INRIM in order to test these particular HVTs, showing the interesting results obtained in our labs.

[1] J. Bell, *Physics* 1, pp. 195-200 (1964);

[2] M. Genovese, *Phys. Rep.* 413/6, pp. 319-398 (2005);

[3] E. Santos, *Phys. Lett. A* 327, pp. 33-37 (2004);

[4] E. Santos, *Eur. Phys. Journ. D* 42, pp. 501-509 (2007);

[5] G. Brida, M. Genovese, F. Piacentini, *Eur. Phys. Journ. D* 44, pp. 577-580 (2007);

- [6] R. Alicki and N. van Ryn, Journ. Phys. A 41, 062001 (2008);  
[7] G. Brida et al., Opt. Expr. 16, pp. 11750-11758 (2008);  
[8] G. Brida et al., Phys. Rev. A, in press.

## **Creating and Verifying a Quantum Superposition In an Optomechanical System**

Igor Pikovski, Dustin Kleckner, Evan Jeffrey, Luuk Ament, Eric Eliel, Jeroen van den Brink and Dirk Bouwmeester

*Presented by: Igor Pikovski*  
University of Vienna

Different viewpoints about how the quantum-classical transition can be understood have been advocated since quantum mechanics was properly formulated. Among them is a proposal that gravitational effects will induce a collapse of the wavefunction, in particular favored by R. Penrose. Recent experimental advances in micro-optomechanical systems have allowed to think of a possible experiment that can put a mirror consisting of  $10^{14}$  atoms into a superposition, thus investigating quantum mechanics at an entirely new mass scale. Here we analyze various aspects of the proposed experiment. We discuss the effect of finite temperatures on the interpretation of the experimental outcome and obtain a lower bound on the degree of non-classicality of the mirror. We also investigate different sources of decoherence and their effect on the experiment.

## **MPS Algorithms for Translationally Invariant Spin Chains**

F. Verstraete, G. Vidal

*Presented by: Bogdan Pirvu*  
University of Vienna

We present a few MPS-algorithms for the simulation of translationally invariant (TI) 1D spin chains. Due to TI it is possible to get a very good scaling of the computational cost both in the system size and the virtual bond dimension. For chains with periodic boundary conditions we show how a definite momentum ansatz yields a large number of the lowest lying excitations.

## **Multifractality in Quantum Open Maps**

Sandra Prado, Fernando Kokubun, Marcel Novaes

*Presented by: Sandra Prado*  
Universidade Federal do Rio Grande do Sul

We study multifractal properties in phase space for an open map in the hyperbolic regime. We perform numerical computations showing that the fractal dimensions are directly related to the classical phase space.

## **The obstruction free quantization based on the operator version of Poisson bracket as the Lie product**

S. Prvanovic

*Presented by: Slobodan Prvanovic*  
Institute of Physics

The operator version of Poisson bracket for quantum mechanical observables is defined. It is shown that it has all properties of the Lie bracket and that quantum mechanical observables form the Lie algebra with this bracket as a product. Moreover, it is shown that operator version of Poisson bracket can substitute commutator in the von Neumann equation. Next, the algebraic product of quantum mechanics is defined as the ordinary multiplication followed by the application of superoperator that orders involved operators, with the ordering rule which coincides with Weyl ordering rule. This superoperator is defined in a way that allows obstruction free quantization when the observables are considered from the point of view of the algebra.

## **Stimulated Raman adiabatic passage analogues in classical physics**

A.A. Rangelov, N.V. Vitanov and B.W. Shore

*Presented by: Andon Rangelov*  
Sofia University

Stimulated Raman adiabatic passage (STIRAP) is a well-established technique for producing coherent population transfer in a three-state quantum system. We here exploit the resemblance between the Schrodinger equation for such a quantum system and the Newton equation of motion for a classical system undergoing torque to discuss several classical analogues of STIRAP, notably the motion of a moving charged particle subject to the Lorentz force of a quasistatic magnetic field, the orientation of a magnetic moment in a slowly varying magnetic field and the Coriolis effect. Like STIRAP, these phenomena occur for counterintuitive motion of the torque and are robustly insensitive to small changes in the interaction properties.

## **Poor man's renormalization in a perturbed stabilizer model**

Martin Veznik, Enrique Rico, Frank Verstraete

*Presented by: Enrique Rico Ortega*  
University of Vienna

We analyze the perturbed toric code on a hexagonal lattice. To get information about the low energy structures of this model we perform a decimation procedure where we apply symplectic transformations in such a way that we isolate plaquettes of six spins that in a latter step we will decimate, getting a new model with less degrees of freedom.

## **Quantum phase transitions in heavy-fermion compounds: a 'hidden disorder' scenario for complex ordering phenomena**

Tanja Rindler-Daller, Matthias Vojta

*Presented by: Tanja Rindler-Daller*  
University of Cologne

When investigating the low-temperature phase transitions in heavy-fermion compounds, one encounters a variety of complex ordering phenomena. One prominent example is the so-called 'hidden order' transition in URu<sub>2</sub>Si<sub>2</sub>, which is characterized by severe thermodynamical signatures, e.g. in the specific heat, and yet no associated order has been seen or unequivocally identified to it. We adopt an effective theory with two competing fields in order to explore the idea of 'hidden disorder', in which the ordering of one field suppresses the fluctuations of the other competing field, thereby enhancing the thermodynamical signatures of the first one. By performing a scaling analysis in the quantum critical regime of the second field, and studying a general model involving fluctuations in the fields, we can show that the proposed scenario is able to account for the observed anomalies in the specific heat under certain restrictions on the spatial dimension and scaling exponents.

## **The Schrodinger-Chetaev Equation in Bohmian Quantum Mechanics and Diffusion Mechanism for Alpha Decay, Proton, Cluster Radioactivity and Spontaneous Fission**

S. Cht. Mavrodiev, M.A. Deliyergiyev

*Presented by: Vitality Rusov*  
Odessa National Polytechnic University

In the framework of Bohmian quantum mechanics supplemented with the Chetaev theorem on stable trajectories in dynamics in the presence of dissipative forces we have shown the possibility of the classical (without tunneling) universal description of radioactive decay of heavy nuclei, in which under certain conditions so called noise-induced transition is generated or, in other words, the stochastic channel of alpha decay, proton, cluster radioactivity and spontaneous fission conditioned by the Kramers diffusion mechanism. Based on the ENSDF database we have found the parametrized solutions of the Kramers equation of Langevin type by Alexandrov dynamic autoregularization method (FORTRAN program REGN-Dubna). These solutions describe with high-accuracy the dependence of the half-life (decay probability) of heavy radioactive nuclei on total kinetic energy of daughter decay products. The verification of inverse problem solution in the framework of the universal Kramers description of the alpha decay, proton, cluster radioactivity and spontaneous fission, which was based on the newest experimental data of alpha-decay of even-even super heavy nuclei ( $Z=114, 116, 118$ ) have shown the good coincidence of the experimental and theoretical half-life depend upon of alpha-decay energy.

## **Determinism beneath composite quantum systems**

Massimo Blasone, Petr Jizba, Fabio Scardigli, Giuseppe Vitiello

*Presented by: Fabio Scardigli*

National Taiwan University

In the framework of 't Hooft's quantization proposal, we show how to obtain from the composite system of two classical Bateman's oscillators an interacting quantum system consisting of a quantum isotonic oscillator. In a specific range of parameters, such a system can be interpreted as a particle in an effective magnetic field interacting through a spin-orbital interaction term.

## **Violation of local realism with freedom of choice**

Thomas Scheidl, Rupert Ursin, Johannes Kofler, Sven Ramelow, Xiao-Song Ma, Thomas Herbst, Lothar Ratschbacher, Alessandro Fedrizzi, Nathan Langford, Thomas Jennewein, Anton Zeilinger

*Presented by: Thomas Scheidl*

IQOQI Vienna

Bell's theorem shows that local realistic theories place a strong restriction on observable correlations between different systems, giving rise to Bell's inequality. For its derivation, Bell made three equally important assumptions: realism, locality, and the freedom to choose between measurement settings. In experimental tests of Bell's inequality, "loopholes" arise which allow observed violations to still be explained by local realistic theories. Stringently closing all loopholes in one single experiment is one of the most significant still-unresolved challenges in fundamental physics and the focus of numerous experimental and theoretical efforts world-wide. While the locality loophole and the fair-sampling loophole have been closed individually, we present an experiment which closes for the first time an equally important loophole related to the freedom-of-choice assumption. Simultaneously closing the locality loophole and violating Bell's inequality by more than 16 standard deviations with entangled photons, this represents the most conclusive violation of local realism to date.

## **Experimental Direct Observation of Mixed State Entanglement**

Ch. Schmid, N. Kiesel, W. Wieczorek, H. Weinfurter, F. Mintert and A. Buchleitner

*Presented by: Christian Schmid*

Max-Planck-Institute of Quantum Optics

We report on the direct estimation of concurrence for mixed quantum states. The used method relies on joint measurements on two copies of an entangled state. In the experimental demonstration two polarization-entangled photon pairs emitted from spontaneous parametric down-conversion are analyzed together using a linear optics controlled phase gate. We demonstrate that the measured data, without need for further numerical processing, directly yield reliable estimates, despite experimental imperfections. (see Phys. Rev. Lett. 101, 260505 (2008))

## **Matching Lie and Markov Properties of Open Quantum Systems**

T. Schulte-Herbrüggen, G. Dirr, I. Kurniawan, and U. Helmke

*Presented by: Thomas Schulte-Herbrüggen*

TU Munich

The Lie properties and the Markov properties of open quantum systems (quantum channels) turn out to be 1:1 in the framework of Lie-semigroups. -- Optimal control of Markovian and non-Markovian open quantum systems cuts errors typically by one order of magnitude [1] in realistic settings. Yet open systems require more intricate theoretical concepts of controllability than their closed counterparts [2,3]. We present such new concepts in terms of Lie semigroups and Lie semialgebras [3]. On a general scale, Markovian quantum channels (with  $\det > 0$ ) recently characterised by their divisibility [4] can now be defined in the more general frame of invariant cones by their Lie-semigroup properties [3] with the GKS-Lindblad generators as Lie wedge. Its geometry proves powerful for addressing reachability as well as for numerical algorithms both in optimal control and in optimisation on various types of reachable sets within quantum state-space manifolds [2,3].

[1] Schulte-Herbrüggen, Spörl, Khaneja, Glaser, quant-ph/0609037;

Rebentrost, Serban, Schulte-Herbrüggen., Wilhelm, PRL 102, 090401(2009)

[2] Schulte-Herbrüggen, Dirr, Helmke, Glaser, arXiv:0802.4195

[3] Dirr, Helmke, Kurniawan, Schulte-Herbrüggen, arXiv:0811.3906

[4] Wolf and Cirac, Commun. Math. Phys. 279, 147 (2008);

Wolf, Eisert, Cubitt, Cirac, PRL 101, 150402 (2008)

## **A viable Silicon based Quantum Cellular Automata unit cell**

I. Shlimak

*Presented by: Issai Shlimak*

Bar-Ilan University

We discuss the problems of Silicon-based nano-structures for the Quantum Cellular Automata (QCA) computing. Since in QCA, there is no (static) flow of charges or particles and electrons solely change their position in a potential well, an ideal QCA circuit would, in principle, operate near the thermodynamic limit of information processing.

The talk is focused on the novel technology of molecular-beam-epitaxy (MBE) growth of isotopically engineered Si/SiGe structures subjected by neutron-transmutation-doping (NTD) to introduce phosphorous impurity atoms in 30-Si isotope. These structures will be developed into designing and fabrication of a scalable nano-size QCA unit cells.

## **Numerical and geometric studies of entanglement**

J. M. Leinaas, J. Myrheim, P. Ø. Sollid

*Presented by: Per Øyvind Sollid*

University of Oslo

Entanglement can be viewed as the key feature of quantum mechanics that describes its non-classical nature. It has been shown to be a useful resource in several aspects of quantum information theory, and one of the ongoing problems in the field is to understand and describe the full set of entangled (or equivalently, separable) states. We have taken a geometric approach and developed numerical tools to study these sets. We present here some results from these studies, with particular focus on results for the set of entangled PPT states for bipartite systems (i.e. states that remain positive under partial transposition).

## **Purity and quantum phase transition in many-body system**

Wonmin Son

*Presented by: Wonmin Son*

CQT Singapore

We discuss about the state structure of spectrums of the XX model on the view of quantum phase transition and entanglement. Especially, we compare the critical behaviour of the ground state and the thermal state of the XX model. With the solutions, we discuss about several physical properties of the states, purity (or mixedness) for example, which are found to be related to quantum phase transition, in various limits, at zero temperature as well as at a thermal equilibrium.

## **Berry phase in entangled systems: A Single-Neutron Interferometer Experiment**

S.Sponar, J. Klepp, R. Loidl, S. Filipp, K. Durstberger, R. A. Bertlmann, G. Badurek, Y. Hasegawa, H. Rauch

*Presented by: Stephan Sponar*

Atominstut

We have observed the influence of the geometric phase on quantum correlation (Bell) measurements, expressed by the Clauser-Horne-Shimony-Holt (CHSH) inequality, of a spin-path entangled neutron state in an interferometric setup, as proposed by Bertlmann et al. in (Phys. Rev. A 69, 032112 (2004)). The entanglement preparation is achieved by a appropriate adjustment of two radio-frequency (rf) - fields and a interferometer crystal. The systems time-dependent interaction with rf-fields is characterize by a modified Jaynes-Cummings Hamiltonian. It is experimentally demonstrated that the effect of the geometric phase, can be balanced by a change in the Bell angles. The value of the S function always exceeds the boundary between quantum mechanic and local realistic theories.

## **Decoherence in the neutron interferometer**

H. Rauch, Y. Hasegawa, J. Klepp, H. Lemmel

*Presented by: Georg Sulyok*

Atominstut

In the neutron interferometer the coherent motion of the two wavepackets can be fully destroyed by exposing the neutrons to magnetic noise fields. The contrast reduces to zero meaning that the off-diagonal terms in the density matrix vanish.

We performed measurements with different types of noise fields and studied their effects on interference pattern varying parameters like strength or frequency bandwidth. The wave function was manipulated in one or both arms of the interferometer. The loss of coherence was studied in position and in momentum space.

## **Cryptography with quanta and chocolate balls**

K. Svozil

*Presented by: Karl Svozil*

Vienna University of Technology

Some quantum cryptographic protocols can be implemented with specially prepared chocolate balls, others protected by value indefiniteness cannot. Similarities and differences of cryptography with quanta and chocolate are discussed. Motivated by these considerations it is proposed to certify quantum random number generators and quantum cryptographic protocols by value indefiniteness. This feature, which derives itself from Bell- and Kochen-Specker type arguments, is only present in systems with three or more mutually exclusive outcomes.

## **Quantum uniqueness**

Denis Sych and Gerd Leuchs

*Presented by: Denis Sych*

Max-Planck-Institute for the Science of Light

It is well known, that the quantum world can demonstrate fascinating phenomena which do not exist classically. In the area of quantum information the prominent examples are entangled states, violation of Bell inequality, no-cloning principle, etc. Initially they appeared as purely theoretical work, but later found important applications, e.g. in cryptography and computations.

In this work we would like to highlight another interesting quantum feature which also has no classical analog: uniqueness of quantum systems. The no-cloning principle says that a perfect copy of an arbitrary a priori unknown quantum system cannot be created. The question we would like to discuss is in a certain sense complementary to it: if the perfect copy exist at all? Following everyday experience, we say that systems A and B are perfect copies of each other if there is no way to distinguish between them, i.e. the systems have absolutely the same properties and show absolutely the same manifestations. Otherwise, if for a given system A one cannot find such a perfect copy B, then we say that the system A is unique. In classical world existence of the perfect copy is possible in principle, and therefore no classical system is unique. As we show in this talk, the perfect copy of any quantum system doesn't exist even in principle, and thus all quantum systems are unique.

It is important to note, that we do not mean uniqueness of a quantum state. Nothing restricts us from producing identical states in general, e.g. if one a priori knows the state, then it is possible to create an arbitrary number of its clones. Speaking about uniqueness, we refer to the external characteristics which can be objectively observed, or measured. In other words, we address a question if it is possible that two quantum systems always show exactly the same measurement outcomes.

## **Feynman's path integral and MUBs**

J.Tolar, G.Chadzitaskos

*Presented by: Jiri Tolar*  
Czech Technical University

It was speculated by G. Svetlichny that the secret of the Feynman path integral may lie in the property of mutual unbiasedness of temporally proximal bases. He put it pregnantly in the following

questions:

1. For what unitary groups  $U(t)$  do the position bases at times 0 and  $t$  tend to mutual unbiasedness as  $t \rightarrow 0$  ?
2. Is there a discrete version of the previous question in a finite-dimensional Hilbert space which approximately simulates the propagation of a free particle?
3. What is the information-theoretic nature of the normalization factor  $A$  in the short-time propagator?

In our contribution we shall try to understand the meaning of these questions.

## **Entanglement and permutational symmetry**

Geza Toth, Otfried Gühne

*Presented by: Geza Toth*  
The University of the Basque Country

We study the separability of permutationally symmetric quantum states. We show that for bipartite symmetric systems most of the relevant entanglement criteria coincide. However, we provide a method to generate examples of bound entangled states in symmetric systems, for the bipartite and the multipartite case. These states shed some new light on the nature of bound entanglement.

## **Reliable hands-off entanglement-based QKD system for fibre networks**

A. Treiber, A. Poppe, M. Hentschel, T. Lorünser, H. Hübel, A. Zeilinger

*Presented by: Alexander Treiber*  
University of Vienna

We present a quantum key distribution system based on polarisation entanglement. The system is compact (19-inch) and allows an automatic start-up and hands-off long term key generation. The results of a two-week demonstration in a deployed fibre network are presented.

## **Optimum pulse shapes for stimulated Raman adiabatic passage**

A. Kuhn, N. V. Vitanov

*Presented by: Genko Vasilev*  
Oxford University

Stimulated Raman adiabatic passage (STIRAP), driven with pulses of optimum shape and delay has the potential of reaching fidelities high enough to make it suitable for fault-tolerant quantum information processing. The optimum pulse shapes are obtained upon reduction of STIRAP to effective two-state systems. We use the Dykhne-Davis-Pechukas (DDP) method to minimize nonadiabatic transitions and to maximize the fidelity of STIRAP. This results in a particular relation between the pulse shapes of the two fields driving the Raman process.

The DDP-optimized version of STIRAP maintains its robustness against variations in the pulse intensities and durations, the single-photon detuning and possible losses from the intermediate state.

### **Can single photons be detected on a screen after a double slit?**

A.I.Vistnes and B.Jagielski (possibly also J.Bergli)

*Presented by: Arnt Inge Vistnes*  
University of Oslo

When very low intensity light is passed through a double slit, we can observe how the interference lines slowly manifest themselves on a screen, dot after dot. However, it might be a flaw in the usual reasoning that each dot correspond roughly to one photon. We will, by using a different system, illustrate how we can be fooled in our reasoning.

### **Novel concepts of quantum search with trapped ions**

S.S. Ivanov, P.A. Ivanov

*Presented by: Nikolay Vitanov*  
Sofia University

The quantum search algorithm of Grover has been one of the driving forces behind the rapid expansion of the field of quantum computation. We review the implementations of Grover's algorithm, with a specific focus on trapped ions. The standard recipes demand the use of a large number of quantum gates, which require a very high fidelity of each single gate for a reliable computation. We have proposed several novel implementations of Grover's algorithm in a linear chain of trapped ions, which use the intrinsic symmetries of the system to realize the Grover operations --- the oracle call and the reflection about the mean --- in much fewer physical steps than in the standard approaches. The quantum register comprises all collective states with  $m$  ionic excitations, with examples for  $m=1, 2$  and  $N/2$ . The database is therefore nonclassical for its size scales as  $N^m$ ; for  $m=N/2$  the scaling is exponential vs  $N$ . The system is initialized in an even superposition of all register states, i.e. in the symmetric Dicke state with  $N$  ions sharing  $m$  excitations. The reflection-about-the-mean operator is produced merely by global addressing of the ion string by an off-resonant pulse with a suitable area, whereas the oracle operator is a conditional phase gate. This simplification should allow a demonstration of quantum search in databases of hundreds to thousands of elements without needing to synthesize multiple multi-qubit quantum gates.

### **On the Quantization Procedure in Classical Mechanics**

V.D. Rusov

*Presented by: Dmitry Vlasenko*  
Odessa National Polytechnic University

Basing on the Chetaev's theorem on stable trajectories in dynamics in the presence of dissipative forces we obtain a generalized stability condition for Hamiltonian systems that has the form of the Schrödinger equation. We show that the energy of the dissipative forces generating generalized Chetaev's stability condition coincides exactly with Bohmian "quantum" potential. Using the principle of least action of perturbation we prove that the Bohmian quantum mechanics complemented with the Chetaev's generalized theorem does not have hidden variables.

## **A quantum theory for a total system including a measuring apparatus**

Wen-ge Wang

*Presented by: Wen-ge Wang*

University of Science and Technology of China

We propose a quantum theory for a total system composed of a measuring apparatus and an environment. In such a theory, properties of measured systems should be derived from measurement records, which are given by some definite properties of the measuring apparatus, called reference properties here. Hence, the concept of reference property of measuring apparatus should be more fundamental than the concept of observable of measured system. Furthermore, the fact that properties of measured systems are derived from reference properties of the measuring apparatus, implies that the measuring apparatus also plays the role of a reference system. The proposed theory considers reference property of measuring apparatus and the concepts of reference system and frame of reference (FR) at the fundamental conceptual level. It is based on four basic postulates, which have, loosely speaking, the following contents. (i) States of the total system are associated with vectors in the total Hilbert space. (ii) A reference property of a measuring apparatus has the features of definiteness and stableness in the corresponding FR. (iii) Schrödinger equation is the dynamical law in each valid FR. (iv) Satisfying certain condition, a property of a measuring apparatus can be regarded as a reference property. The proposed theory has the following consequences, which are different from the usual quantum mechanics: (1) Under certain condition, a previously valid (invalid) FR may become invalid (valid); a change of the employed FR may induce an irreversible change to the description of the total system. (2) For some states of the total system, a vector description can be physically equivalent to some appropriate density-operator descriptions, in the sense that they give the same predictions for measurement results. (3) Some of the vectors in the Hilbert space can not be associated with any physical state of the total system. (4) Adopting appropriate density-operator description of the total system, the von Neumann entropy can increase with time. We also discuss relations between the proposed theory and some of the interpretations of quantum mechanics. In particular, in certain type of FR, the proposed theory gives a picture of evolution, which looks similar to that given in many-worlds interpretations of quantum mechanics; meanwhile, in some other type of FR, the description given in the proposed theory has some similarity to that given in consistent-histories interpretations of quantum mechanics.

## **Testing Born's Rule with a Triple Slit Experiment**

G. Weihs, U. Sinha, I. Söllner, C. Couteau, R. Laflamme

*Presented by: Gregor Weihs*

University of Innsbruck

Born's rule in quantum physics states that probabilities are the absolute squares of the wavefunctions. This entails that all interference terms are binary, i.e. between two of the possibilities in a superposition. A more general theory could potentially have tri-interference. With a triple slit diffraction experiment we test for the existence of a non-zero tri-interference term.

## **Uniform approximation for the overlap caustic of a quantum state**

E. Zambrano, A. M. Ozorio de Almeida

*Presented by: Eduardo Zambrano*  
Brazilian Center for Research in Physics

The Weyl-Wigner representation of quantum mechanics provides a tool to study a wide range of quantum phenomena. Particularly, the correlations within and between quantum states, including the interrelation of large and small (sub-Planck) structures, are optimally described in the frame of phase space.

Lately, this representation has been used to study evolution in a markovian environment. Density operators in phase space are represented by the Wigner function and its Fourier transform, i.e, the characteristic function or chord function. The simplest semiclassical approximation of these functions diverge at caustics.

In this work, we calculate semiclassical uniform approximations for both the Wigner and the chord function of pure states at regions near to the caustics.

We analyze their similarities and differences. We also calculate the correlation of a quantum state with its phase space translation.

## **Quantum fluctuations in spontaneous patterns**

M. Moreno, M. A. Garcia-March, D. Gomila and R. Zambrini

*Presented by: Roberta Zambrini*  
Campus University of Balearic Islands

Nonlinear media are known to transform the classical state of laser beams in quantum states, displaying, for instance, photon entanglement and squeezing. In the last decade quantum correlations have been studied also in the context of complex systems. Self-organization and spontaneous pattern formation in nonlinear optical systems are indeed often associated to quantum effects. This work shows the possibility to control and tune such quantum phenomena considering a parametric oscillator embedding a photonic crystal.

## **Two photon interference under Einstein's locality condition**

Stefan Zotter, Xiao-song Ma, Thomas Jennewein, Anton Zeilinger

*Presented by: Stefan Zotter*  
IQOQI Vienna

The quantum mechanics formalism tells us that a single particle can exhibit both, wave and particle nature. Which of this two properties is revealed depends on the measurement apparatus. To translate this into a single photon experiment, imagine that we have a Mach-Zehnder interferometer. If the observer chooses to measure the particle nature of the single photon wave-packet, he should remove the last beam-splitter and thus he acquires the which-path information by looking at the counts at the detectors Det1 and Det2 which are not sensitive to the relative phase change between the paths a and b. In 1984 J. Wheeler proposed his famous Gedankenexperiment in which "[...] the decision whether to put the final half-silvered mirror in place or to take it out at the very last picosecond, after the photon has already accomplished its travel." [1] His proposal was realized in several experiments [2,3].

Here we present an experiment which extends Wheelers Gedankenexperiment in two ways. First, complementarity is valid not only in the single photon experiment, but also in the two photon experiment; Second, independent of the space-time arrangement between the photon entry of the interferometer and the setting of the last beam-splitter complementarity is valid.

We use a ultrafast tunable polarization independent interferometrical switchable beam-splitter to perform a Hong Ou Mandel interference (HOM) measurement under Einstein's locality conditions. The tunable beam-splitter is realized by a Mach-Zehnder interferometer (MZI) with two Electro Optical Modulators (EOMs) in each arm. The phase of the MZI is actively locked by a counter-propagating He-Ne Laser and a ring piezo-transducer controlled by an analogue PID regulator. Depending the voltage applied to the EOMs, we are able to tune the relative phase of the interferometer. Hence the whole MZI is acting as a tunable beam splitter and the splitting ratio is controlled by the applied voltage of the EOMs. The highest switching contrast was 95% independent from the polarization of the single photon input. The maximal repetition rates of the EOMs are as high as 5 MHz with a short rising time of 6 ns.

In the experiment we use a collinear Type-II Spontaneous Parametric Downconversion source to create a time entangled photon pair. The horizontal and vertical polarized photons are splitted on a polarizing beam-splitter (PBS) and guided over single mode fibers to the two input modes of the MZI. The polarization was changed with bat-ear polarization controllers. The applied voltage of the EOMs was adjusted in such a way, that the whole MZI acts as a 50:50 beam-splitter. By looking at the coincidence detection events between the two output modes we are able to observe two different measurement scenarios. When the EOMs were ON, HOM type interference with 90% visibility shows up. But when the EOMs were OFF, path length difference insensitive flat lines were observed.

The choice of which measurement to perform was defined by our choice-maker, which was located in Lab2 with 40 m direct spatial distance to the interferometer and the source. It consisted of a home-built Quantum Random Number Generator (QRNG), which defined the choice for the experimental configuration fast and randomly. In order to exclude any communication between the QRNG and the photon pair source, there was no link between the QRNG and the photon source.

This tunable and fast optical beam splitter is also a crucial building block of modern quantum information processing science. One can utilize it for single photon multiplexing [1], quantum teleclone with active switching, one-way quantum computation with feed-forward [2,3]; 2) It is also an essential component for testing the fundamental concepts of quantum physics, e.g. delayed-choice entanglement swapping [4] and complementarity of two bipartite entangled system [5].

#### References

- [1] J. A. Wheeler, "Quantum Theory and Measurement, " (Princeton University Press, 1984)
- [2] T. Hellmuth, H. Walther, A. Zajonc, and W. Scheich. "Delayed-choice experiments in quantum interference, " Phys. Rev. A 35, 2532-2541 (1987).
- [3] V. Jacques, E. Wu, F. Grosshans, F. Treussart, P. Grangier, A. Aspect, J. F. Roch. "Experimental realization of wheeler's delayed-choice gedanken experiment, " Science 315, 966-968 (2007).
- [4] A. L. Migdall, D. Branning, S. Castelletto, "Tailoring single-photon and multiphoton probabilities of a single-photon on-demand source," Phys. Rev. A 66, 053805 (2002).
- [5] R. Prevedel, P. Walther, F. Tiefenbacher, P. Bohi, R. Kaltenbaek, T. Jennewein, A. Zeilinger, "High-speed linear optics quantum computing using active feed-forward, " Nature 445, 65-69 (2007)
- [6] K. Chen, C.-M. Li, Q. Zhang, Y.-A. Chen, A. Goebel, S. Chen, A. Mair, J.-W. Pan, "Experimental Realization of One-Way Quantum Computing with Two-Photon Four-Qubit Cluster States," Phys. Rev. Lett. 99, 120503 (2007)
- [7] A. Peres, "Delayed choice for entanglement swapping, " J. Mod. Opt. 47, 139 (2000)
- [8] C. Brukner, M. Aspelmeyer, A. Zeilinger, "Complementarity and Information in Delayed-choice for Entanglement Swapping, " Found. Phys. 37, 1909 (2005)

## **Bell's theorem and "non-locality(?)"**

Marek Zukowski

*Presented by: Marek Zukowski*

University of Gdansk

The assumptions behind Bell inequalities will be thoroughly discussed. It will be shown that violations of Bell inequalities do not necessarily imply non-locality. This may be so, but does not have to be so. Other issues concerning non-signalling in quantum mechanics will be discussed

