TT 44: Transport: Quantum Coherence and Quantum Information

Time: Thursday 14:00–19:15 Location: HSZ 304

TT 44.1 Thu 14:00 HSZ 304

Entanglement in driven spin chains — •David Zueco, Fernando Galve, Sigmund Kohler, and Peter Hänggi — Institut für Physik, Universität Augsburg, Universitätsstraße 1, D-86135 Augsburg, Germany

One-dimensional spin chains are ubiquitous in condensed matter physics and represent one of the basic models in quantum information. Therefore, insight to their behavior is rather valuable and, eventually, allows the development of methods for controlling their dynamics. Among a variety of tasks, the directed transfer of quantum entanglement through the chain presents an important challenge. In this sense we could use them as "quantum wires" pretty much like copper wires carrying electrons in the electrical circuits.

In this talk we present our recent results on the generation and control of entanglement dynamics in 1D driven spin chains. We demonstrate the feasibility of generating entanglement between the first and the last spin of a chain via applied time-dependent fields [1]. Moreover, once the entanglement has been created, the driving even allows further control of its dynamics. In particular we propose guiding entanglement into a direction of choice, which corresponds to a rectification of quantum information transfer. Finally, we will discuss how to quench the dynamics in order to preserve the entanglement during a substantial time interval.

[1] F. Galve, D. Zueco, S. Kohler, E. Lutz, and P. Hänggi arXiv:0809.3712

TT 44.2 Thu 14:15 HSZ 304

Electron and nuclear spins in double quantum dots — •Björn Erbe and John Schliemann — Institute for Theoretical Physics, University of Regensburg

Apart from fundamental interest, double quantum dots play a central role in the realization of solid state quantum computers. In the relevant set-ups, the spins of the confined electrons are controllable coupled to each other and, via hyperfine interaction, to the surrounding nuclear spins. On the one hand these can be regarded as a decohering environment for the electron system, on the other one they themselves can serve as a quantum information processing resource [1,2].

Just like the well-studied Gaudin type Hamiltonian of a single quantum dot [3], in general the Hamiltonian of a double quantum dot is very difficult to treat. We will present analytical as well as numerical results concerning simplications of the full Hamiltonian, appropriate for the different roles of the nuclear system.

[1] J.M. Taylor et al., cond-mat/0407640 (2006)

[2] D. Loss and D. DiVincenco, Phys. Rev. A 57, 120 (1998)

[3] J. Schliemann et al., J.Phys.: Condens. Matter 15 (2003) R1809-R1833

TT 44.3 Thu 14:30 HSZ 304

A quantum interface between light and nuclear spins in quantum dots — Heike Schwager, Juan Ignacio Cirac, and •Geza Giedke — Max-Planck-Institut für Quantenoptik, D-85748 Garching

We show how to exploit the hyperfine interaction of an electron in a quantum dot to realize a quantum interface between the polarized nuclear spins in a dot strongly coupled to a high-finesse optical cavity and a traveling-wave optical field. By adiabatically eliminating the electronic degree of freedom different effective couplings can be achieved that enable write-in, read-out, and the generation of entanglement between the nuclei and the output field of the cavity. Such a coherent coupling of flying photonic qubits to stationary matter-based qubits is an essential building block for quantum communication networks.

TT 44.4 Thu 14:45 HSZ 304

Quantum Simulator with Electrons Floating on a Helium Film — •sarah Mostame[1] and Ralf Schuetzhold[2] — [1]MPI-PKS, Dresden, Germany — [2]Fachbereich Physik, Universitaet Duisburg-Essen, Duisburg, Germany

We propose a physical setup that can be used to simulate the quantum dynamics of the Ising model in a transverse field. Building on currently available technology, our scheme consists of electrons which float on a superfluid helium film covering a suitable substrate and interact via Coulomb forces. At low temperatures, the system will stay near its ground state where its Hamiltonian is equivalent to the Ising model and thus shows phenomena such as quantum criticality.

TT 44.5 Thu 15:00 HSZ 304

Spin dehoherence of a heavy hole coupled to nuclear spins in a quantum dot — •Jan Fischer[1], William Anthony Coish[1,2], Denis Bulaev[1,3], and Daniel Loss[1] — [1]Department of Physics, University of Basel, Switzerland — [2]Institute for Quantum Computing and Department of Physics and Astronomy, University of Waterloo, Ontario, Canada — [3]Institute of Solid State Physics, Russian Academy of Sciences, Chernogolovka, Moscow District, Russia

We theoretically study the interaction of a heavy hole with nuclear spins in a quasi-two-dimensional III-V semiconductor quantum dot and the resulting dephasing of heavy-hole spin states. It has frequently been stated in the literature that heavy holes have a negligible interaction with nuclear spins. We show that this is not the case. In contrast, the interaction can be rather strong and will be the dominant source of decoherence in some cases. We also show that for unstrained quantum dots the form of the interaction is Ising-like, resulting in unique and interesting decoherence properties, which might provide a crucial advantage to using dot-confined hole spins for quantum information processing, as compared to electron spins.

[1] Jan Fischer, W. A. Coish, D. V. Bulaev, and Daniel Loss, Phys. Rev. B 78, 155329 (2008)

15 min. break

TT 44.6 Thu 15:30 HSZ 304

Weak Values in solid state physics — Vadim Shpitalnik[1], Yuval Gefen[1], and •Alessandro Romito[1,2] — [1]Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot 76100, Israel — [2]Institut für Theoretische Festkörperphysik, Universität Karlsruhe, 76128 Karlsruhe, Germany

The measurement of any observable in quantum mechanics is a probabilistic process described by the projection postulate. As opposed to projective (strong) measurement, weakly measuring an observable (i.e., measuring it while weakly disturbing the system), provides only partial information on the state of the system. It has been proposed that a weak measurement on pre and post-selected ensembles – i.e. a weak measurement followed by a strong one, where the outcome of the first measurement is kept provided a second post-selected outcome occurs – leads to a weak value [1]. Such a weak value may lie well beyond the range of strong values and may happen to be complex.

Here we study a weak value protocol in the context of a solid state setup, specifically, an electronic Mach-Zehnder interferometry [2] presenting the first specific proposal for full tomography of weak values. We generalization of weak values to non-pure states, and we further analyze the manifestation of many-body physics in the weak value, including finite temperature and shot-noise-like contributions.

[1] Y. Aharonov, D. Z. Albert, L. Vaidman, Phys. Rev. Lett. 60, 1351-1354 (1988).

[2] V. Shpitalnik, Y. Gefen, and A. Romito, Phys. Rev. Lett. 101, 226802 (2008).

TT 44.7 Thu 15:45 HSZ 304

Time-Resolved Measurement of a Charge Qubit — •Georg M. Reuther, David Zueco, Peter Hänggi, and Sigmund Kohler — Institut für Physik, Universität Augsburg, Universitätsstr. 1, 86159 Augsburg

We propose a scheme for monitoring coherent quantum dynamics with good time-resolution and low backaction. It relies on the response of the considered quantum system to a high-frequency ac drive. We find that the phase of the outgoing signal, which can directly be measured in an experiment with lock-in technique, is proportional to the expectation value of a particular system observable. We present explicit results for a charge qubit realized with a Cooper-pair box, where we focus on monitoring coherent oscillations and Landau-Zener transitions.

TT 44.8 Thu 16:00 HSZ 304

$Bi_2Sr_2CaCu_2O_{8+\delta}$ intrinsic SQUIDs as candidates of high-T_c phase qubits — •X. Y. Jin[1], J. Lisenfeld[1,2], Y. Koval[1], A. Lukashenko[1,2], C. Bergmann[1], A. V. Ustinov[1,2], and P. Müller[1] — [1]Department of Physics, Friedrich-Alexander-Universität Erlangen-

Nürnberg, Erwin-Rommel-Strasse. 1, D-91058 Erlangen, Germany — [2]Physikalisches Institut, Universität Karlsruhe (TH), Wolfgang-Gaede-Str. 1, D-76131 Karlsruhe, Germany

An intrinsic SQUID is a superconducting ring made of $Bi_2Sr_2CaCu_2O_{8+\delta}$ single crystal, intercepted by two intrinsic Josephson junction stacks. When biased with dc current, the device is a typical hysteretic dc-SQUIDs with huge inductance. The inductance parameter β_L can be tuned in a wide range between 4 and 30 by changing the height and the cross-section area of the stacks. When a device was coupled with a coil and a Nb readout dc-SQUID, typical rf-SQUID behavior was observed. By applying a proper reset field, quantum escape from a single minimum has been measured on a sample of $\beta_L \sim 10$. The escape rate can be fine-tuned by applying short pulses down to 1 ns, which allows a fast readout technique. With these prerequisites, our experiments have opened the path to directly using these intrinsic SQUIDs as high-T_c phase qubits. The first attempts to measure Rabi oscillations on these devices will be discussed.

TT 44.9 Thu 16:15 HSZ 304

Relaxation of Josephson qubits due to strong coupling to two-level systems — •Clemens Müller and Alexander Shnirman — Institut für Theorie der Kondensierten Materie, Universität Karlsruhe, 76128 Karlsruhe, Germany

Naturally formed two-level systems (TLS) present in the oxide layer of nm-sized Josephson junctions pose a strong complication in the design of superconducting qubits. Recently an experiment used the coherent dynamics of a strongly coupled TLS to demonstrate its uses as a naturally formed quantum memory [1]. We calculate the effect of strongly coupled TLS on the relaxation rate Γ_1 of the qubit. In addition to providing results for single TLS we analyse the effects of an ensemble of TLS.

[1] M. Neeley at al, Nature Physics **4**, 523 (2008)

TT 44.10 Thu 16:30 HSZ 304

Renormalization of the dephasing by zero point fluctuations — •Swarnali Bandopadhyay[1] and Doron Cohen[2] — [1]Physics Department, Norwegian University of Science and Technology, NO-7491, Trondheim, Norway, — [2]Department of Physics, Ben-Gurion University, Beer-Sheva 84105, Israel

One of the most fundamental properties of an quantum particle is to maintain its phase-coherence. When an quantum particle is coupled to a fluctuating environment its wave-function gets phase-randomised. During the last decade a controversy has emerged in the mesoscopic literature regarding the role of zero-point-fuctuations (ZPF) in low temperature dephasing. We propose an exactly solvable model for dephasing due to short range scattering with environmental modes in dephasing at low temperature. Unlike the Caldeira-Leggett model where the interaction is with an homogeneous fluctuating field of force, here we consider the environment consisting of infinitely many localized fluctuating modes with (say) Ohmic spectral function and the interaction is local as in “s-scattering”. We find that in low temperature ZPF can enhance the inelastic cross-section. Our study shows [Phys. Rev. B 77, 155438 (2008)] we need finite temperature to see the effect. Thus indirectly ZPF might contribute to the dephasing at low temperature.

15 min. break

TT 44.11 Thu 17:00 HSZ 304

Driving-induced bistability in the Jaynes-Cummings model — •Vittorio Peano[1], Vicente Leyton Ortega[2], and Michael Thorwart[3,1] — [1]Universität Düsseldorf — [2]Universidad del Valle, Cali (Colombia) — [3]FRIAS, Universität Freiburg

As a consequence of nonlinearity and external driving, the generalized Jaynes-Cummings model exhibits a dynamical bistability. This can be conveniently investigated by introducing a quasipotential in phase space. We study the dissipative dynamics in this bistable quasipotential by means of a simple Markovian master equation and we interpret the results in terms of a quasiclassical analysis. We prove the existence of a metastable squeezed amplitude state and find resonant and antiresonant behavior of the lineshape in correspondence to multiphoton transitions. They are due to a sizeable occupation of the metastable state. We discuss similarities to the quantum Duffing oscillator [1] and also explain the lineshape of the recently observed vacuum Rabi supersplittings [2] in the superconducting transmon qubit set-up.

[1] V. Peano and M. Thorwart, New J. Phys. **8**, 21 (2006). [2] Lev S. Bishop, J. M. Chow, Jens Koch, A. A. Houck, M. H. Devoret, E. Thuneberg, S. M. Girvin, R. J. Schoelkopf, arXiv:0807.2882.

TT 44.12 Thu 17:15 HSZ 304

Cooling a Micro-Mechanical Resonator by Quantum Back-Action from a Noisy Qubit — •Yingdan Wang[1], Yong Li[1], Fei Xue[2], Kouich Semba[3], and Christoph Bruder[1] — [1]Department of Physics, University of Basel, Basel, Switzerland — [2]Department of Electrical Engineering, Technion, Haifa, Israel — [3]NTT Basic Research Laboratories, Atsugi, Japan

We study the different roles of qubit dephasing and relaxation in the process of cooling a mechanical resonator by quantum back-action. With a superconducting flux qubit as a specific example, we show that ground-state cooling of a mechanical resonator is possible under present experimental conditions. Our investigation suggests that the cooling limit is primarily determined by the dissipative nature of the qubit, including both relaxation and dephasing.

TT 44.13 Thu 17:30 HSZ 304

Two-Resonator Circuit QED: A Superconducting Quantum Switch — •Elisabeth Hoffmann[1,2], Matteo Mariantoni[1], Frank Deppe[1,2], Edwin P. Menzel[1], Achim Marx[1], Rudolf Gross[1,2], Frank K. Wilhelm[3], and Enrique Solano[4] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Walther-Meissner-Straße 8, 85748 Garching — [2]Physics Department, TU München, 85748 Garching — [3]University Waterloo, Canada — [4]Universidad del País Vasco-Eurskal Herriko Unibertsitatea, Spain

Coupling different kind of superconducting (sc) qubits to on-chip microwave resonators has strongly advanced the field of circuit QED. Regarding the application of circuit QED systems in quantum information processing it would be highly desirable to switch on and off the interaction between two resonators. We introduce a formalism for two-resonator circuit QED where two on-chip microwave resonators are simultaneously coupled to one sc qubit. In this three-circuit network, the qubit mediates a geometric and a dynamic second-order interaction between the two resonators [1]. These two coupling strengths can be tuned to be equal by varying the qubit operation point, thus permitting to switch on and off the interaction between the resonators. We discuss the effect of the qubit on the dynamic second-order coupling and how it can be deliberately manipulated to realize a sc quantum switch. Finally, we present a realistic design for implementing a two-resonator circuit QED setup based on a flux qubit and show preliminary experimental results. This work is supported by SFB 631 and NIM.

[1] M. Mariantoni *et al.*, Phys. Rev. B 78, 104508 (2008)

TT 44.14 Thu 17:45 HSZ 304

Mesoscopic Shelving Readout of Superconducting Qubits in Circuit QED — •Jens Siewert[1], Barbara Englert[2,3], Giuseppe Mangano[1,4], Matteo Mariantoni[3], Rudolf Gross[3], and Enrique Solano[2,5] — [1]University of Regensburg, 93040 Regensburg, Germany — [2]LMU München, 80333 München, Germany — [3]TU München und Walther-Meißner Institut, 85748 Garching, Germany — [4]DMFCI, Università di Catania, 95125 Catania, Italy — [5]University of the Basque Country, 48080 Bilbao, Spain

We present a method for measuring the state of a superconducting qubit inside a microwave cavity, where one qubit state is associated with the generation of a mesoscopic cavity coherent field while the other remains associated with a vacuum field. By measuring the outgoing cavity field with conventional devices, an efficient detection of the qubit state can be achieved. This method uses a cyclic transition in a three-level artificial atom configuration to build the large cavity field, enabling a high-fidelity measurement in the spirit of the successful electron-shelving readout for trapped ions. We expect that the proposed technique can be adapted to different superconducting qubit designs and contribute to further improve qubit readout fidelity.

15 min. break.

TT 44.15 Thu 18:15 HSZ 304

Noise in Circuit Quantum Electrodynamics — •Michael Marthaler[1], Gerd Schön[1], and Alexander Shnirman[2] — [1]Institut für Theoretische Festkörperphysik and DFG-Center for Functional Nanostructures (CFN), Universität Karlsruhe, 76128 Karlsruhe, Germany — [2]Institut für Theorie der Kondensierten Materie, Universität Karlsruhe, 76128 Karlsruhe, Germany

Qubits and superconducting single electron transistors (SSET) have been used to reproduce effects known from quantum optics in solid state based systems. In this type of system we have to consider noise sources which are different from known dissipation effects in quantum optics. We investigate the effect of the electromagnetic environment in circuit quantum electrodynamics (CQED) for a stripline pumped by a superconducting single electron transistor (SSET).

TT 44.16 Thu 18:30 HSZ 304

Losses in Microwave Resonators at Millikelvin Temperatures — •Pascal Macha[1], Simon H.W. van der Ploeg[1], Stefan Wünsch[2], Gregor Oelsner[1], Evgeni Il'ichev[1], Hans-Georg Meyer[1], and Michael Siegel[2] — [1]Institute of Photonic Technology, PO Box 100239, D-07702 Jena, Germany — [2]Universität Karlsruhe, Institut für Mikro– und Nanoelektronische Systeme, Hertzstraße 16, D-76187 Karlsruhe, Germany

We investigate the behaviour of a high-frequency coplanar waveguide resonator for low intensities of microwave power at low temperatures (20–700mK). In addition to the shift of the resonance frequency, we found a significant increase of losses in the resonator below 300mK. The temperature dependence correlates well with the expectation for a population of two level systems around the resonance frequency. Such two level systems have been identified as a major reason for decoherence in solid state quantum systems. We suggest that the increase of losses in our resonator is due to the coupling to such two level systems. In order to clarify the origin of the two level systems further investigations are necessary. This work is of great importance for the implementation of circuit QED and for detectors.

TT 44.17 Thu 18:45 HSZ 304

Cross-correlation heterodyne detection: Measuring the vacuum fluctuations at microwave frequencies — Matteo Mariantoni[1], Edwin P. Menzel[1], Miguel A. Araque Caballero[1], Frank Deppe[1], Elisabeth Hoffmann[1], Thomas Niemczyk[1], Achim Marx[1], •Rudolf Gross[1], and Enrique Solano[2] — [1]Walther-Meissner-Institut and TU Muenchen, Germany — [2]Departamento de Quimica Fisica, Universidad del Pais Vasco / Euskal Herriko Unibertsitatea, Spain

In order to gain a profound insight into the fundamental properties of quantum electrodynamics (QED), studying the zero-point fluctuations of microwave radiation represents an important task. Here, we present a full experimental characterization of the vacuum fluctuations by measuring the Planck distribution of its noise power at microwave frequencies and very low temperatures. We observe a cross-over from thermal noise to vacuum quantum noise and quantify the level of vacuum fluctuations for a narrow frequency band centered around 5.85 GHz. We demonstrate the change of the vacuum fluctuations level with the center frequency. Finally, we perform a new type of heterodyne detection particularly suitable for circuit QED systems. It is based on microwave beam splitters and cross-correlation measurements and allows for the reconstruction of the entire covariance matrix of the vacuum. We acknowledge support from SFB631, NIM, EuroSQUIP, and the Ikerbasque Foundation.

TT 44.18 Thu 19:00 HSZ 304

Cross-correlation heterodyne detection: Measuring microwave nontrivial propagating signals — Edwin P. Menzel[1], Matteo Mariantoni[1], Miguel Angel Araque Caballero[1], Frank Deppe[1], Elisabeth Hoffmann[1], Thomas Niemczyk[1], •Achim Marx[1], Rudolf Gross[1], and Enrique Solano[2] — [1]Walther-Meissner-Institut and TU Muenchen, Garching, Germany — [2]Departamento de Quimica Fisica, Universidad del Pais Vasco / Euskal Herriko Unibertsitatea, Bilbao, Spain

The accurate measurement of the first two moments of Gaussian states (e.g., coherent or squeezed states) allows for their complete characterization. This provides a tool to clarify the quantum nature of microwave radiation, an important issue for example in circuit quantum electrodynamics. We present a full experimental characterization of nontrivial microwave signals with an average photon number of the order of 1, whose variance exhibits an elaborate dependence on external control parameters. We experimentally access the entire covariance matrix by splitting the input signals via microwave beam splitters and performing cross-correlation measurements. In this manner, we are able to precisely resolve the first two moments, a challenging task at microwave frequencies. Furthermore, we succeeded to measure the third central moment of similar nontrivial signals. We acknowledge support from SFB631, NIM, EuroSQUIP, and the Ikerbasque Foundation.