TT 34: TR: Quantum Coherence and Quantum Information Systems 2 (jointly with MA and HL)

Time: Wednesday 14:00–18:45 Location: HSZ 03

TT 34.1 Wed 14:00 HSZ 03

Multiplexing Readout of a Qubit Array via a Single Transmission Line — •Markus Jerger[1], Stefano Poletto[1], Pascal Macha[1,2], Uwe Hübner[2], Alexander Lukashenko[1], Evgeni Il'ichev[2], and Alexey V. Ustinov[1] — [1]Physikalisches Institut, Karlsruhe Institute of Technology, D-76128 Karlsruhe, Germany — [2]Institute of Photonic Technology, PO Box 100239, D-07702 Jena, Germany

A resonant circuit coupled to a qubit displays a shift of its resonance frequency depending on the quantum state of the qubit. The qubit state can be thus measured by probing the resonator near its resonance frequency. By coupling every qubit to its individual resonator of distinct frequency, one can read out the state of an array of many qubits through a single microwave line coupled to all resonators. Moreover, this readout can be performed simultaneously by using a multi-tone microwave pulse with frequency-division multiplexing. We will present measurements on an ensemble of 7 superconducting flux qubits located on one chip and each coupled to an individual transmission-line resonator. We performed spectroscopy of all qubits and determined their parameters in a single measurement run. Our latest experiments on simultaneous preparation and readout of the 7-qubit array will be presented.

TT 34.2 Wed 14:15 HSZ 03

A flux-driven Josephson parametric amplifier for experiments with propagating quantum microwaves — •Edwin P. Menzel[1], Alexander Baust[1], Frank Deppe[1], Peter Eder[1], Thomas Niemczyk[1], Elisabeth Hoffmann[1], Max Haeberlein[1], Achim Marx[1], Rudolf Gross[1], Enrique Solano[2], Kunihiro Inomata[3], Tsuyoshi Yamamoto[3,4], and Yasunobu Nakamura[3,4] — [1]Walther-Meissner-Institut and TU München, Garching, Germany — [2]Universidad del Pais Vasco and Ikerbasque Foundation, Bilbao, Spain — [3]RIKEN, Wako-shi, Japan — [4]NEC Corporation, Tsukuba, Japan

For the detection of propagating quantum microwaves in circuit QED linear amplifiers are key ingredients. Phase sensitive amplifiers [e.g., Josephson parametric amplifiers (JPA)] in principle allow for the amplification of one signal quadrature without adding noise. In practice, however, internal losses often introduce a finite amount of noise. We have recently shown that, despite such a residual noise, signals on the quantum level can be fully characterized using two amplification chains and suitable correlations [E.P. Menzel et al., PRL 105, 100401 (2010)]. In this work, we characterize a flux-driven JPA. At 5.64 GHz the maximum degenerate gain is 25.5 dB and the signal bandwidth is 1.8 MHz. Phase-insensitive measurements yield a noise temperature of 100 ± 20 mK, which is below the standard quantum limit of 135 mK.

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TT 34.3 Wed 14:30 HSZ 03

Generation of non-classical states for microwave photons in networks of circuit cavities — •Martin Leib and Michael J. Hartmann — TU München,Munich,Germany

State of the art fabrication of superconducting microwave resonators coupled to Josephson qubits provides us with an architecture where strong coherent interaction of individual microwave photons with individual two-level systems (qubits) has been realised with exceptional control over both, photons and qubits. Here we consider a network of multiple microwave resonators each equipped with a Josephson qubit and analyse the quantum states of the output photons at several ports of the network. With time independent [1] or sequential driving one can generate highly non-classical states of the microwave field in specific network nodes. We investigate the generation, propagation and dissipation of these states along branches of the network. As a signature for the non-classical nature of the microwave field we quantify the generation of entanglement between various output ports of these networks of circuit QED systems.

[1] M. Leib and M.J. Hartmann *Bose-Hubbard dynamics in a chain of circuit QED cavities* **New Journal of Physics** Vol. 12 Nr. 9 pp. 093031

TT 34.4 Wed 14:45 HSZ 03

Probing decoherence through Fano resonances — •Stefan Rotter[1], Andreas Bärnthaler[1], Florian Libisch[1], Joachim Burgdörfer[1], Stefan Gehler[2], Ulrich Kuhl[2], and Hans-Jürgen Stöckmann[2] — [1]Institute for Theoretical Physics, TU Vienna, Austria — [2]Fachbereich Physik, Philipps-Universität Marburg, Germany

We investigate the effect of decoherence on Fano resonances in wave transmission through resonant scattering structures [1]. We show that the Fano asymmetry parameter q follows, as a function of the strength of decoherence, trajectories in the complex plane that reveal detailed information on the underlying decoherence process. Dissipation and unitary dephasing give rise to manifestly different trajectories. Our predictions are successfully tested against microwave experiments with metal cavities and against previously published data on the temperature dependence of transport through quantum dots [2].

[1] A. Bärnthaler, S. Rotter, F. Libisch et al., Phys. Rev. Lett. 105, 056801 (2010).
[2] I. G. Zacharia, D. Goldhaber-Gordon, G. Granger et al., Phys. Rev. B 64, 155311 (2001).

TT 34.5 Wed 15:00 HSZ 03

Dissipative Landau-Zener Transitions at High Temperatures — •Peter Nalbach and Michael Thorwart — I. Institut für Theoretische Physik, Universität Hamburg, Jungiusstraße 9, 20355 Hamburg, Germany

We study Landau-Zener transitions in a dissipative environment including excitation survival probability [1,2] by a numerically exact approach. Competition between relaxation and the external driving results in nonmonotonic behaviour of the ocupation probabilities which we explain in terms of an appealing phenomenological model. We furthermore show that the nonmonotonic behaviour survives up to very high temperatures where so far monotonic behaviour due to dominant dephasing was expected.

[1] P. Nalbach and M. Thorwart, Phys. Rev. Lett. 103, 220401 (2009)
[2] P. Nalbach and M. Thorwart, Chem. Phys. 375, 234 (2010)

TT 34.6 Wed 15:15 HSZ 03

Feedback Control of a Transport Charge Qubit — •Christina Pöltl, Clive Emary, and Tobias Brandes — TU Berlin, Institut für Theoretische Physik, Hardenbergstr. 36, D-10623 Berlin, Germany

We study a simple feedback control operation acting on a transport double quantum dot instantaneously after an electron jumps into the dot. A qubit system such as a double quantum dot is affected by decoherence once it is coupled to an environment. An electronic transport system always experiences decoherence and the projection on the qubit-state relaxes into a statistical mixture. However, we show that feedback qubit rotations enable the generation of pure states as steady states of the system.

We use a master equation jump approach in order to include the feedback which allows us to investigate the steady state as well as the full counting statistics of the transport qubit with feedback.

15 min. break

Invited Talk TT 34.7 Wed 15:45 HSZ 03

Coupled evolution and coherence of two-electron spin qubits — •Hendrik Bluhm — Harvard University, Cambridge, USA and RWTH Aachen, Germany

One of the fundamental requirements for quantum computing is to coherently couple qubits in order to generate entanglement. For semiconductor qubits, such entangling gates have yet to be demonstrated in fully operational devices. I will give a brief overview of our recent experiments on enhancing the coherence of two-electron spin qubits in GaAs double quantum dots, and then focus on current progress towards the realization of two-qubit entangling gates.

By manipulating a qubit in a way that decouples its evolution from the fluctuations of its nuclear spin bath, we extended its coherence time to more than 200 μs, two orders of magnitude longer than previously measured. Operating the qubit as a feedback loop that controls the nuclear bath enables universal single qubit control with greatly improved gate fidelities.

Using the Coulomb interaction between two adjacent double dots, we demonstrate a dependence of the coherence of one qubit on the state of the other, which results in strong correlations in a joint single shot readout of the two qubits. In this operation, the control qubit completely dephases due to low frequency electrical noise. Using a spin echo pulse, the single-qubit dephasing time can be extended by an amount that is expected to enable a fully coherent cPHASE gate, which would entangle the two qubits.

TT 34.8 Wed 16:15 HSZ 03

Dynamical switching of a driven nonlinear resonator caused by a two-level fluctuator — •Stephan André[1,2], Michael Marthaler[1,2], and Gerd Schön[1,2] — [1]Institut für Theoretische Festkörperphysik, Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany — [2]DFG Center for Functional Nanostructures (CFN), Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany

In recent "circuit QED" experiments, a nonlinear resonator was used to perform a quantum non-demolition readout of a superconducting qubit with a high contrast [1,2]. A driven nonlinear resonator can show bistability; increasing the driving strength will lead to switching from a state of low amplitude to a state of high amplitude oscillations. As the switching of the resonator occurs at a driving strength which depends on the state of the qubit, the resonator can be operated at a working point where, depending on the qubit state, it will switch to high amplitude oscillations or not, which provides a digital readout of the qubit.

We theoretically study the influence of a two-level fluctuator (TLF) coupled to a driven nonlinear resonator. TLFs have frequently been observed in superconducting circuits and generally affect the dynamics of the system. We investigate how the presence of a TLF influences the switching of the driven resonator between the two dynamical states. This will lead to a change in the readout contrast when the resonator is used to measure a qubit.

[1] M. Metcalfe *et al.*, Phys. Rev. B **76**, 174516 (2007)
[2] F. Mallet *et al.*, Nature Physics **5**, 791 (2009)

TT 34.9 Wed 16:30 HSZ 03

Measuring the temperature dependence of individual two-level systems by direct coherent control — •Jürgen Lisenfeld[1,4], Clemens Müller[2,4], Jared H. Cole[3,4], Pavel Bushev[1,4], Alexandr Lukashenko[1,4], Alexander Shnirman[2,4], and Alexey V. Ustinov[1,4] — [1]Physikalisches Institut, Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]Institut für Theorie der Kondensierten Materie, Karlsruhe Institute of Technology, Karlsruhe, Germany — [3]Institut für Theoretische Festkörperphysik, Karlsruhe Institute of Technology, Karlsruhe, Germany — [4]DFG-Center for Functional Nanostructures (CFN), Karlsruhe Institute of Technology, Karlsruhe, Germany

We demonstrate a new method to directly manipulate the state of individual two-level systems (TLSs) in phase qubits. It allows one to characterize the coherence properties of TLSs using standard microwave pulse sequences, while the qubit is used only for state readout. We apply this method to measure the temperature dependence of TLS coherence for the first time. The energy relaxation time T_1 is found to decrease quadratically with temperature for the two TLSs studied in this work, while their dephasing time measured in Ramsey and spin-echo experiments is found to be T_1 limited at all temperatures.

TT 34.10 Wed 16:45 HSZ 03

Defect models in superconducting phase qubits — •Clemens Müller[1,2], Jared H. Cole[3,2], Pavel Bushev[4,2], Grigorij J. Grabovskij[4], Jürgen Lisenfeld[4], Alexey V. Ustinov[4,2], and Alexander Shnirman[1,2] — [1]Institut für Theorie der Kondensierten Materie, KIT, Karlsruhe, Germany — [2]DFG Center for Functional Nanostructures (CFN), Karlsruhe, Germany — [3]Institut für Theoretische Festkörperphysik, KIT, Karlsruhe, Germany — [4]Physikalisches Institut, KIT, Karlsruhe, Germany

Superconducting qubits often show signatures of coherent coupling to intrinsic two-level systems (TLS), which manifest themselves as avoided level crossings in spectroscopic data. We use detailed theoretical models to determine the form of the coupling between a superconducting phase qubit and a TLS. Fitting the experimental data with our theoretical model allows us to determine all relevant system parameters. A strong qubit-defect coupling is observed, with a nearly vanishing longitudinal component. Using these estimates, we quantitatively compare several existing theoretical models for the microscopic origin of TLS.

TT 34.11 Wed 17:00 HSZ 03

Holonomic transformations with superconducting qubits — •Ingo kamleitner and Alexander Shnirman — Institut für Theorie der kondensierten Materie, Karlsruher Institut für Technologie, Karlsruhe, Germany

Holonomic transformations are known to be robust to small variations of the Hamiltonian and are therefore a promising method to achieve fault tolerant quantum gates for quantum information processing. Here we propose an experimentally feasible holonomic transformation using three superconducting qubits of the transmon type coupled to a cavity. The Hamiltonian in the one-excitation subspace is of the tripod type, which naturally has a degenrate subspace and is well suited for holonomies. The effective cavity transmon couplings are achieved via external driving of the transmons and are tunable.

TT 34.12 Wed 17:15 HSZ 03

Deterministic creation and stabilization of entanglement in circuit QED by homodyne-mediated feedback control — Zhuo Liu[2], Lülin Kuang[2], Kai Hu[2], Luting Xu[2], Suhua Wei[2], Xinqi Li[2], and •Lingzhen Guo[1,2] — [1]Institut für Theoretische Festkörperphysik, Karlsruhe Institute of Technology, D-76128 Karlsruhe, Germany — [2]Department of Physics, Beijing Normal University, Beijing 100875, China

In a solid-state circuit QED system, we demonstrate that a homodyne-current-based feedback can create and stabilize highly entangled two-qubit states in the presence of a moderate noisy environment. Particularly, we present an extended analysis for the current-based Markovian feedback, which leads to an improved feedback scheme. We show that this is essential to achieve a desirable control effect by the use of dispersive measurement.

15 min. break

TT 34.13 Wed 17:45 HSZ 03

Monitoring and Markovian Feedback Control of a Solid-state Charge Qubit — •Gerold Kiesslich, Gernot Schaller, and Tobias Brandes — Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin

We investigate theoretically a charge qubit capacitively coupled to a single-electron transistor (SET). A quantum master equation approach [1] is used to address the question how it is possible to continuously monitor the qubit dynamics by SET transport observables. We further demonstrate analytically and numerically the qubit manipulation and control by instantaneous feedback of the SET current into qubit parameters. Feedback-induced qubit rotations and pure states as steady states can be generated.

[1] G. Schaller, G. Kießlich, and T. Brandes, Phys. Rev. B **80**, 245107 (2009). *ibid.* **81**, 205305 (2010). *ibid.* **82**, 041303(R) (2010).

TT 34.14 Wed 18:00 HSZ 03

Hybridization and spin decoherence in heavy-hole quantum dots — •Jan Fischer[1] and Daniel Loss[2] — [1]Institute for Theoretical Physics, University of Regensburg, 93040 Regensburg, Germany — [2]Department of Physics, University of Basel, 4056 Basel, Switzerland

We theoretically investigate the spin dynamics of a heavy hole confined to a III-V semiconductor quantum dot interacting with a narrowed nuclear-spin bath [1]. We show that band hybridization leads to an exponential decay of hole-spin superpositions due to hyperfine-mediated nuclear pair flips, and that the accordant single-hole-spin decoherence time T2 can be tuned over many orders of magnitude by changing external parameters. In particular, we show that, under experimentally accessible conditions, it is possible to suppress hyperfine-mediated nuclear-pair-flip processes so strongly that hole-spin quantum dots may be operated beyond the 'ultimate limitation' set by the hyperfine interaction which is present in other spin-qubit candidate systems.

[1] J. Fischer and D. Loss, arXiv:1009.5195 (2010).

TT 34.15 Wed 18:15 HSZ 03

Different types of integrability and their relation to decoherence in central spin models — •Bjoern Erbe and John Schliemann — Department of Physics, University of Regensburg, 93040 Regensburg, Germany

In a large variety of nanostructures spins couple to a bath of other spin degrees of freedom. Important examples are given by semiconductor and carbon nanotube quantum dots, phosphorus donors in silicon, nitrogen vacancy centers in diamond and molecular magnets. Commonly such systems are described by so-called central spin models [1,2].

We present recent results on the relation between integrability and decoherence in central spin models with more than one central spin [3]. We show that there is a transition between integrability ensured by Bethe ansatz and integrability ensured by complete sets of commuting operators. This has a significant impact on the decoherence properties of the system, suggesting that it is not necessarily integrability or non-integrability which is related to decoherence, but rather its type or a change from integrability to non-integrability.

[1] J. Schliemann, A. Khaetskii, and D. Loss, J. Phys.: Condens. Mat. 15, R1809 (2003).
[2] W. A. Coish and J. Baugh, phys. stat. sol. B 246, 2203 (2009).
[3] B. Erbe and J. Schliemann, Phys. Rev. Lett. 105, 177602 (2010).

TT 34.16 Wed 18:30 HSZ 03

Turning a vice into a virtue: Hyperfine induced nuclear spin dynamics in double quantum dots — •Bjoern Erbe and John Schliemann — Department of Physics, University of Regensburg, 93040 Regensburg, Germany

Electron spins confined in semiconductor quantum dots with an s-type conduction band, like for example GaAs quantum dots, interact with the surrounding nuclear spins via the hyperfine interaction [1]. With respect to possible future solid state quantum computation systems utilizing the electron spin as the qubit [2], these interactions act as a source of decoherence. We demonstrate that it is possible to turn vice into virtue by using the hyperfine interaction in order to utilize nuclear baths for quantum information purposes [3].

To this end, we numerically study the hyperfine induced nuclear spin dynamics in a system of two coupled quantum dots in zero magnetic field. Each of the electron spins is considered to interact with an individual bath of nuclear spins. Through quantitative investigations of several scaling behaviors we show that it is possible to swap the nuclear ensembles and indicate that it might even be possible to fully entangle them. It turns out that the larger the baths are, the more relevant they become as a ressource of quantum information.

[1] see e.g. J. Schliemann, A. Khaetskii, and D. Loss, J. Phys.: Condens. Matter 15, R1809 (2003).
[2] D. Loss and D. P. DiVincenzo, Phys. Rev. A 57, 120 (1998).
[3] B. Erbe and J. Schliemann, in preparation