TT 9: Transport: Quantum Coherence and Quantum Information Systems

Time: Monday 14:00–18:15 Location: H 2053

TT 9.1 Mon 14:00 H 2053

Control of two coupled Josephson persistent current qubits at the degeneracy point — •Marcel Manheller[1,2], Pieter de Groot[1], C. J. P. M. Harmans[1], and J. E. Mooij[1] — [1]TU Delft, Netherlands — [2]IFF, FZ, Juelich, Deutschland

A Josephson persistent current qubit is created by a superconducting loop, which is interrupted by three Josephson junctions. A quantum mechanical two level system is generated, if a magnetic field close to half a flux quantum is applied at the qubit loop. Two qubits are coupled inductively, while sharing a piece of line. The two qubits are operated via two control lines, which can produce a gradient in electromagnetic field over the qubits. Thereby we are able to control a two qubit system at the degeneracy point. At this point is the theoretical lifetime of a qubit a factor of 35 higher then at the usual operation point. This promises us to apply a simple algorithm on this device.

TT 9.2 Mon 14:15 H 2053

Probing the States of a High-T$_c$ Intrinsic Phase Qubit — •X. Y. Jin, J. Lisenfeld, Y. Koval, A. V. Ustinov, and P. Müller — Institut für Physik der Kondensierten Materie, Universität Erlangen-Nürnberg

We report our results on fabricating and probing high-T$_c$ intrinsic phase qubits. An intrinsic phase qubit is a superconducting ring made of a $Bi_2Sr_2CaCu_2O_{8+\delta}$ single crystal, intercepted by two intrinsic Josephson junction stacks. Macroscopic quantum tunneling was observed in these qubits, and the crossover temperature was around 600 mK. An intrinsic phase qubit is generally regarded as a multi-junction system, i.e. a system of many degrees of freedom in phase space. However, we discovered that as long as the two stacks are uniform, the intrinsic phase qubits behaves like a system with only two degrees of freedom, independent of the number of junctions in the stacks. Due to the large self-inductance, the potential of an intrinsic phase qubit has several minima in which the system can stay. In order to perform quantum operations, a technique using low-frequency microwaves is developed to assure that the system stays inside the chosen potential well.

Invited Talk TT 9.3 Mon 14:30 H 2053

Coherent Oscillations in Josephson Phase Qubits — •Jürgen Lisenfeld, Alexander Lukashenko, and Alexey V. Ustinov — Physikalisches Institut III, Universität Erlangen, D-91058 Erlangen

A phase qubit uses as its logical states discrete energy eigenstates of the Josephson phase of a current-biased tunnel junction. By embedding the junction in a superconducting loop, the qubit can be controlled by a magnetic bias flux, while its state is then read out by measuring the magnetic moment of the loop using a dc-SQUID. A maximum readout contrast is hereby achieved by strong coupling to the dc-SQUID detector, which acts as a source of decoherence.

We present a new method of data evaluation to restore the full 100 % readout contrast for a weakly coupled detector. The same technique is used to compensate for a loss of contrast induced by thermal fluctuations in the dc-SQUID. We applied this method to measure the temperature dependence of coherence times in phase qubits of different origins and featuring different materials. By observing Rabi oscillations, energy relaxation and Ramsey fringes, we find that the coherent qubit response of a sample operated in the two-level limit vanishes rapidly as soon as the thermal energy $k_{\mathrm{B}}T$ becomes larger than the energy level spacing. In contrast, a sample which was operated in the multi-level limit displayed semi-classical oscillations similar to Rabi oscillations, but showed qualitatively different temperature dependence. Our experimental data shed new light on the origin of decoherence in superconducting qubits and suggest that contemporary phase qubits can be operated at temperatures of up to several 100 mK.

TT 9.4 Mon 15:00 H 2053

Coherent oscillations in a superconducting flux qubit without microwave pulses — •Stefano Poletto[1], Jürgen Lisenfeld[1], Alexander Lukashenko[1], Maria Gabriella Castellano[2], Fabio Chiarello[2], Carlo Cosmelli[3], Pasquale Carelli[4], and Alexey V. Ustinov[1] — [1]Physikalisches Institut III, Universität Erlangen-Nürnberg, Germany — [2]Istituto di Fotonica e Nanotecnologie del CNR, Roma, Italy — [3]Dipartimento di Fisica and INFN, Universita' di Roma La Sapienza, Italy — [4]Universita' degli Studi dell'Acquila, Italy

We report on observation of coherent oscillations in a superconducting flux qubit by using no microwave excitation but only nanosecond-long dc flux pulses. The investigated circuit is a double-SQUID consisting of a superconducting loop interrupted by a small dc-SQUID, which we control via two bias fluxes ϕ_c and ϕ_x. The potential energy profile of the qubit has the shape of a double well, where the flux ϕ_c controls the height of the barrier between the two minima and the flux ϕ_x changes the potential symmetry. The two computational states of the qubit are identified with the two energy minima and physically correspond to clockwise or anticlockwise circulating currents in the double-SQUID main loop. We observed coherent oscillations, in the frequency range between 8 and 20 GHz, induced by fast pulses of the control flux ϕ_c modulating the barrier between the two potential wells. The quantum dynamics that leads to this kind of oscillations is composed of a non-adiabatic and adiabatic evolution of the two lowest energy states.

TT 9.5 Mon 15:15 H 2053

Theory of quantum non-demolition measurements of a flux qubit — •Luca Chirolli and Guido Burkard — Institute of Theoretical Physics C, RWTH Aachen University, D-52056 Aachen, Germany

Recently a new technique for a quantum non demolition measurement (QND) of the state of a flux qubit based on the coupling to a circuit oscillator has been proposed and experimentally realized (A. Lupascu *et al.*, Nature Physics **3**, 119 (2007)). In our theoretical description of the experiment, we use the positive operator value measurement (POVM) formalism to describe the qubit measurement. Two mechanisms lead to deviations from a perfect QND measurement: (i) the quantum fluctuations of the measurement oscillator, and (ii) quantum tunneling between the qubit states $|0\rangle$ and $|1\rangle$ during measurement.

TT 9.6 Mon 15:30 H 2053

2D cavity grid quantum computing — Ferdinand Helmer[1], Matteo Mariantoni[2], Austin Fowler[3], Jan von Delft[1], Enrique Solano[1], and •Florian Marquardt[1] — [1]Arnold-Sommerfeld Center for Theoretical Physics, Center for NanoScience and Department of Physics, Ludwig-Maximilians Universität München, Germany — [2]Walther-Meissner Institut, Bayerische Akademie der Wissenschaften, Garching b. München, Germany — [3]Institute for Quantum Computing, University of Waterloo, Waterloo, ON, Canada

We propose a novel scheme for scalable solid state quantum computing, where superconducting microwave transmission line resonators (cavities) are arranged in a two-dimensional grid on the surface of a chip, coupling to superconducting qubits (charge or flux) at the intersections. We analyze how tasks of quantum information processing can be implemented in such a topology, including efficient two-qubit gates between any two qubits on the grid and elements of fault-tolerant computation.

TT 9.7 Mon 15:45 H 2053

Exact Results on Dynamic Decoupling by π-Pulses in Quantum Information Processes — •Götz S. Uhrig — Lehrstuhl für Theoretische Physik I, TU Dortmund, 44221 Dortmund

The aim of dynamic decoupling consists in the suppression of decoherence by appropriate coherent control of a quantum register. Effectively, the interaction with the environment is reduced and hence the decoherence rate. In particular, a sequence of π-pulses is considered. Here we present exact results on the suppression of the coupling of a quantum bit to its environment by optimized sequences of π-pulses along the storage time t. The more pulses are used the higher is the order in t in which decoherence occurs [1]. To which extent the optimization pays is discussed for different high-energy cutoffs. We show that the results for a spin-boson model hold generally for any kind of bath.

[1] G.S. Uhrig, PRL 98, 100504 (2007)

15 min. break

TT 9.8 Mon 16:15 H 2053

Design of short coherent control pulses for quantum information processing — •Stefano Pasini, Tim Fischer, Peter Karbach, and Götz S. Uhrig — Technische Universität Dortmund

A systematic technique is presented to design short pulses for the coherent control of a two-level system coupled to a bath. The problem can be solved as the one for an ideal pulse, instantaneous pulse up to some order of approximation, which our π and $\frac{\pi}{2}$ optimized pulses make vanish. Their effectiveness is tested numerically on a specific spin model.

TT 9.9 Mon 16:30 H 2053

Nuclear spin dynamics in quantum dots — •Daniel Klauser, William Anthony Coish, and Daniel Loss — Departement of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland

The hyperfine interaction between the electron spin and the nuclear spins within a quantum dot has been established as the main source of decoherence for the electron spin. The decay of transverse and longitudinal spin components show rich dynamics including exponential, gaussian and power-law decay. Further, a universal phase-shift for driven single spin oscillations has been predicted and experimentally observed recently [1]. In this context of hyperfine induced electron spin decoherence also the dynamics of the nuclear spin system (Overhauser field dynamics) have come into focus. We discuss the dynamics of the nuclear spin system and how measurements of the Overhauser field [2] alter this dynamics.

[1] F.H.L. Koppens, D. Klauser, W.A. Coish, K.C. Nowack, L.P. Kouwenhoven, D. Loss and L.M.K. Vandersypen, Phys. Rev. Lett. 99, 106803, (2007).
[2] D. Klauser, W.A. Coish and Daniel Loss, Phys. Rev. B 73, 205302, (2006).

TT 9.10 Mon 16:45 H 2053

Exponential Decay in a Spin Bath — William Anthony Coish[1,2], •Jan Fischer[2], and Daniel Loss[2] — [1]Institute for Quantum Computing and Department of Physics and Astronomy, Waterloo, Ontario, Canada — [2]Department of Physics, University of Basel, Switzerland

We show that the coherence of an electron spin interacting with a bath of nuclear spins can exhibit a well-defined purely exponential decay for special ('narrowed') bath initial conditions in the presence of a strong applied magnetic field. This is in contrast to the typical case, where spin-bath dynamics have been investigated in the non-Markovian limit, giving super-exponential or power-law decay of correlation functions. We calculate the relevant decoherence time T_2 explicitly for free-induction decay and find a simple expression with dependence on bath polarization, magnetic field, the shape of the electron wave function, dimensionality, total nuclear spin I, and isotopic concentration for experimentally relevant heteronuclear spin systems.

TT 9.11 Mon 17:00 H 2053

Spin dynamics in InAs-nanowire quantum-dots coupled to a transmission line — •Mircea Trif[1], Vitaly N. Golovach[2], and Daniel Loss[3] — [1]Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland. — [2]Department of Physics, Ludwig-Maximilians-Universität, Theresienstr. 37, D-80333 Munich, Germany. — [3]Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland.

We study theoretically electron spins in nanowire quantum dots placed inside a transmission line resonator. Because of the spin-orbit interaction, the spins couple to the electric component of the resonator electromagnetic field and enable coherent manipulation, storage, and read-out of quantum information in an all-electrical fashion. Coupling between distant quantum-dot spins, in one and the same or different nanowires, can be efficiently performed via the resonator mode either in real time or through virtual processes. For the latter case we derive an effective spin-entangling interaction and suggest means to turn it on and off. We consider both transverse and longitudinal types of nanowire quantum-dots and compare their manipulation timescales against the spin relaxation times. For this, we evaluate the rates for spin relaxation induced by the nanowire vibrations (phonons) and show that, as a result of phonon confinement in the nanowire, this rate is a strongly varying function of the spin operation frequency and thus can be drastically reduced compared to lateral quantum dots in GaAs. Our scheme is a step forward to the formation of hybrid structures where qubits of different nature can be integrated in a single device.

TT 9.12 Mon 17:15 H 2053

Cold bosonic atoms in a π – flux lattice — •Stephan Rachel and Martin Greiter — Institut für Theorie der Kondensierten Materie, Universität Karlsruhe, 76128 Karlsruhe

We present a model where the rare phenomenon of fragmented Bose–Einstein condensation occurs: we consider a system of neutral, bosonic atoms on a square lattice subject to an effective magnetic field. We focus on a magnetic flux of half a Dirac flux quantum through every lattice cell. The effective flux yields two minima in the lower single particle band. We show that in the many particle ground state, the particles are evenly distributed over both minima. The two macroscopically occupied minima correspond to two distinct Bose condensates.

Regarding the low-energy excitations of the system, we show that Josephson tunneling is only possible for pairs of bosons, while single particle tunneling between both condensates is absent. We further find a massive mode describing fluctuations in the relative density of the two condensates.

TT 9.13 Mon 17:30 H 2053

Migration of bosonic particles across a Mott insulator to superfluid phase interface — •Michael Hartmann[1,2] and Martin Plenio[1,2] — [1]Institute for Mathematical Sciences, Imperial College London, 53 Exhibition Road, London, SW7 2PG, United Kingdom — [2]QOLS, The Blackett Laboratory, Imperial College London, Prince Consort Road, London, SW7 2BW, United Kingdom

Effective many-particle systems in artificial structures have become an important testbed for the investigation of quantum many-particle and condensed matter physics.

Very recently it has been shown, that arrays of coupled microcavities can host effective Bose-Hubbard and spin models. As a new feature, this approach offers the possibility to control and address individual lattice sites. Besides being a prerequisite for quantum information applications, this possibility opens the door to the study of many-particle systems which are inhomogeneous or out of equilibrium.

Here we discuss one such possibility, an interface between a Mott insulator and a superfluid region.

TT 9.14 Mon 17:45 H 2053

Non-Abelian Statistics in a Quantum Antiferromagnet — •Martin Greiter and Ronny Thomale — Institut für Theorie der Kondensierten Materie, Universität Karlsruhe, D 76128 Karlsruhe

We propose a novel spin liquid state for a S=1 antiferromagnet in two dimensions. The ground state is a spin-singlet, fully invariant under the symmetries of the underlying lattice, and possess a threefold topological degeneracy. The spinon and holon excitations obey non-abelian statistics, with the braiding of half-quantum vortices governed by zero energy modes in the vortex cores. We present numerical evidence that the universality class of this topological liquid can be stabilized by a model Hamiltonian involving three-spin interactions. We discuss possible realizations with polar molecules in optical lattices as well as potential applications in quantum computing.

TT 9.15 Mon 18:00 H 2053

Preferred base for multiparticle states arising from subsequent two-particle scattering — •Ivo Knittel — Fachbereich Experimentalphysik, Campus, Geb. C6.3, 66041 Saarbrücken

For a quantum system coupled to its environment via a certain interaction operator, there exists a certain base, whose states exhibit minimal entanglement rate with environment states. For an interaction commuting with the position operator, this preferred base consists of highly localized states in position states.[1] This central result of decoherence theory is widely regarded as a solution of the 'preferred base' problem of the quantum theory of measurement [2]. However from decoherence theory it is not obvious how to construct the 'pointer states' for a given system. In this contribution, I investigate multiparticle states arising from a cascade of subsequent two-particle scattering events. This situation is met in a quasi-classical gas, or in the interaction of high-energy particles with a detector. A certain representation is constructed that is especially adapted to the multi-particle state arising from subsequent two-particle scattering events, and its time propagation.

[1] W. G Unruh, W. H. Zurek, Phys. Rev. D, 40, 1070 (1989) [2] M. Schlosshauer, Rev Mod. Phys. 76, 1267 (2004)