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Participant	Title	Abstract
Carles Altimiras	Dynamical Coulomb blockade of the high frequency noise of a tunnel junction	C. Altimiras, O. Parlavecchio, P. Joyez, D. Vion, P. Bertet, P. Roche, D. Esteve and F. Portier Service de Physique de l'Etat Condensé (CNRS URA 2464), IRAMIS, CEA Saclay, 91191 Gif-sur-Yvette, France The transport properties of a quantum conductor are deeply modified when it is embedded in a circuit. Quantum fluctuations of the electromagnetic environment can trigger inelastic electron scattering giving rise to non-linear I(V) characteristics for the embedded conductor. This phenomenon, called Dynamical Coulomb Blockade (DCB), has been thoroughly investigated for tunnel junctions in the past decade [1], but only focusing on the corrections to the mean current. However, recent experiments carried on atomic contacts [2] and quantum point contacts [3,4] have shown that the corrections to the non-interacting I(V) characteristics do not only depend on the strength of the environment phase fluctuations, but also on the shot noise triggered by the conductor itself, in agreement with recent theoretical work [5-8]. A question that naturally arises is therefore: how does the DCB modify the current fluctuations of the conductor? To investigate this question, we have embedded a tunnel junction in a microwave quarter-wave resonator which implements a "single-mode" electromagnetic environment. With such circuit, we can both measure the I(V) characteristic of the junction and the shot noise emitted by the junction at microwave frequencies (~6GHz). But obtaining strong DCB effects requires the resonator to display a characteristic impedance comparable to the resistance quantum (h/e^2~26kOhm), which is hardly achievable by exploiting plain geometric considerations. We have taken advantage of the kinetic inductance of an array of Josephson junctions, to increase up to ~1.5 kOhm the characteristic impedance of an otherwise standard coplanar waveguide. The resulting coupling is strong enough to observe DCB corrections to the shot noise emitted by the tunnel junction, interpreted as spontaneous two-photon emission processes. Thanks to an independent calibration of the resonator, we can reproduce the DCB corrections to the shot noise with the help of recent theory [Joyez private comm.]. References: [1] Ingold & Nazarov, in Single Charge Tunneling; Coulomb Blockade Phenomena in Nanostructures Ch. 2 (Plenum, 1992). [2] R. Cron et al., in Electronic Correlations: From Meso to Nano-Physics, (EDP Sciences, Les Ulis, 2001), p. 17. [3] Altimiras et al., PRL 99, 256805 (2007). [4] Parmentier et al., Nature Physics 7, 935–938 (2011). [5] Yeyati et al., PRL 87, 046802 (2001). [6] Golubev, & Zaikin, PRL 86, 4887–4890 (2001). [7] Kindermann, & Nazarov, PRL 91, 136802 (2003). [8] Safi & Saleur, PRL 93, 126602 (2004). [9] Joyez, private comm.
Adam Bednorz	Violation of time reversal symmetry in weak measurements	It is a common belief that the laws of physics respect the time reversal symmetry (generally CPT symmetry) while it is broken only by the second law of thermodynamics due to information loss. In the quantum case, it depends on the type of measurements. Strong measurements certainly cause information loss but weak measurements should not. Surprisingly, weak measurements still violate the time reversal symmetry indicating that either they are not really weak or there is a new fundamental arrow of time.
Tobias Brandes	Feedback control and fluctuations in quantum transport	I plan to give an overview of our recent results on quantum feedback control and fluctuation relations in transport through nanostructures.
Christoph Bruder	Interferometric and noise signatures of Majorana fermions	Recently, the possibility to realize Majorana-like quasiparticles on the surface of a three-dimensional topological insulator has attracted a lot of attention. It has been theoretically predicted that the domain wall of two superconducting regions support transport channels for Majorana fermions and the interface of superconducting and magnetic regions give rise to transport channels for chiral Majorana fermions. We propose to study noise correlations in a Hanbury Brown-Twiss type interferometer and find three signatures of the Majorana nature of the channels [1]. First, the average charge current in the outgoing leads vanishes. Furthermore, we predict an anomalously large shot noise in the output ports for a vanishing average current signal. Adding a quantum point contact to the setup, we find a surprising absence of partition noise which can be traced back to the Majorana nature of the carriers.
Markus Buttiker	Electron waiting time distributions in electrical conductors	The statistics of electron transport in mesoscopic conductors has been a subject of intense theoretical and experimental efforts for more than two decades. We develop a novel approach which focuses on the distribution function of the waiting time between the arrival of charge carriers. Of particular interest are quantum pumps for which the waiting time distribution describes the crossover from poissonian electron transfer to electron emission which is synchronized to the pump signal up to the uncertainty limit required by the escape-time [1]. For quantum mechanical transmission through a quantum point contact under dc bias we have to consider a many body state. We find that the waiting time distribution exhibits a crossover from a Wigner-Dyson distribution at full transmission to Poisson statistics close to pinch-off. We discuss several analogies with energy level statistics and random matrix theory [2]. [1] M. Albert, C. Flindt, M. Büttiker, Phys. Rev. Lett. 107, 086805 (2011). [2] M. Albert, G. Haack, C. Flindt, M. Büttiker, Phys. Rev. Lett. (unpublished). arXiv: 1202.3152
Aashish Clerk	Quantum measurement with non-linear cavities: beyond weak coupling	
Richard Deblock	Quantum Noise Measurement of a Carbon Nanotube Quantum Dot in the Kondo Regime	Probing the fast dynamics of many-body correlated systems has been the subject of a long-standing research activity. In this regard, nanoscale devices oer unique possibilities. Due to recent progress in nanotechnology, it is now feasible to design nanoscale devices in which correlated eects appear under out-of-equilibrium conditions. The Kondo eect in quantum dots constitutes in this respect a paradigmatic model system, where a single electron spin of the quantum dot is dynamically screened by the conduction electrons, leading to a many-body resonance. This eect has been studied extensively in transport and, more recently, by current uctuation measurements. However, all previous studies focused exclusively on the low frequency limit, while the high frequency regime, i.e. the dynamics remained experimentally unexplored. In this work [1], we present the rst measurements of the high frequency current uctuations of a carbon nanotube quantum dot in the Kondo regime by resonantly coupling it to an on-chip detector [2]. Our experiment allows to probe many-body correlations at frequencies of the order of the inverse timescale associated with the creation of the correlated state. The results are in good agreement with theoretical calculations provided that an additional spin decoherence rate is included .This experiment constitutes a new original tool for the investigation of the nonequilibrium dynamics in nanoscale devices. [1] J. Basset, A. Kasumov, P. Moca, G. Zarand, P. Simon, H. Bouchiat, R. Deblock, Phys. Rev. Lett. 108, 046802 (2012). [2] J. Basset, H. Bouchiat, R. Deblock, Phys. Rev. B 85, 085435 (2012).
Leonardo DiCarlo	Real-time observation of quasiparticle tunneling in a transmon qubit using feedback	
Klaus Ensslin	Dipole-coupling of a double quantum dot to a microwave resonator	A hybrid solid-state quantum device is realiozed, in which a semiconductor double quantum dot is dipole coupled to the microwave field of a superconducting coplanar waveguide resonator. The double dot charge stability diagram extracted from measurements of the amplitude and phase of a microwave tone transmitted through the resonator is in good agreement with that obtained from transport measurements. Both the observed frequency shift and linewidth broadening of the resonator are explained considering the double dot as a charge qubit coupled with a strength of several tens of MHz to the resonator. In another experiments the dynamic admittance of a single quantum dot coupled to a single lead is measured. Again positive and negative frequency shifts are observed which are interpreted as inductive and capacitive coupling. Microwave techniques give a new handle to investigate the dynamic electronic properties of quantum dots.
Yuval Gefen	Weak Measurement in electronic Systems	

Steven Girvin	Quantum Measurements and Back-Action (Spooky and Otherwise)	The topic of measurements and measurement back-action in quantum mechanics was endlessly confusing to the founders of quantum mechanics who were forced to argue in terms of gedanken experiments. Now we must face this confusion because real experiments are happening. This talk will present an introductory tutorial on how real measurements work and how they affect the state of the quantum system under observation. The basic concepts will be illustrated with the Stern-Gerlach experiment and then extended to include dispersive coupling of atoms or qubits to resonant cavities.
D. Christian Glattli	Minimal excitation charged states based on Lorentzian voltage pulses	Applying a voltage pulse, whose quantum of action is n X h, on a contact of a ballistic conductor is expected to inject n charges in the conductor [1]. In general this procedure simultaneously creates extra neutral electron and hole excitations due to the perturbation of the whole Fermi sea. However for Lorentzian time shape of the pulse, Levitov et al predicted that the n charges correspond to n electrons only : a so-called coherent n-electronic state with minimal excitations [2]. We present the first implementation of an on-demand electron source periodically injecting electrons using Lorentzian voltage pulses [3]. The quality of the source is studied by injecting the electron pulses to a Quantum Point Contact (QPC) which partitions all incoming excitations. This results in a low frequency shot noise which count the number of excitations. We demonstrate that, within finite temperature limitation, Lorentzian voltage pulses indeed produce minimal excitation. This is compared with sine and square wave voltage pulses which expectedly are shown to involve extra excitations. In addition the nature of the excitation spectrum of the pulses is analyzed by shot noise spectroscopy. Further characterization is obtained by colliding two n-electron pulses with a time shift on the QPC in a HOM like scheme. From zero time-shift where a maximal electron anti-bunching leads to zero shot noise, increasing the time delay restores a shot noise whose value probes the wavefunction overlap and thus provides a time-domain characterization of the electron wavefunction. [1] Lee, Levitov, Arxiv Cond-mat, 9507011v1, (6 Jul 1995) [2] Ivanov, Lee and Lesovik, Physical Review Letters B, Vol. 56 (1997), pp. 6839-6850; Keeling, Klich and Levitov, Physical Review Letters, Vol. 97, No. 11. (6 Sep 2006), 116403 [3] J. Dubois, Th. Jullien, P. Roulleau, P. Roche, F. Portier, W. Wegsheider and D.C. Glattli, submitted.
Peter Hänggi	The role of measurements for quantum fluctuation relations	
Fabian Hassler	Statistics of radiation at Josephson parametric resonance	Motivated by recent experiments, we study theoretically the full counting statistics of radiation emitted below the threshold of parametric resonance in a Josephson junction circuit. In contrast to most optical systems, a significant part of emitted radiation can be collected and converted to an output signal. This permits studying the correlations of the radiation. To quantify the correlations, we derive a closed expression for full counting statistics in the limit of long measurement times. We demonstrate that the statistics can be interpreted in terms of uncorrelated bursts each encompassing 2N photons, this accounts for the bunching of the photon pairs produced in course of the parametric resonance. We present the details of the burst rates. In addition, we study the time correlations within the bursts and discuss experimental signatures of the statistics deriving the frequency-resolved cross-correlations.
Michael Hatridge	Determining the quantum back-action of an individual variable-strength measurement	Measuring a quantum system randomly perturbs its state. Remarkably, the nature of this 'back-action' depends on the choice of quantity which is measured, even if that choice is delayed until after the system has stopped interacting with the measurement apparatus. Yet, in a partial measurement performed by an ideal apparatus, quantum physics predicts that the system remains in a pure state whose evolution can be tracked perfectly from the measurement record. We demonstrate this striking property using a superconducting qubit dispersively coupled to a microwave signal. We observe the predicted back-action on the qubit state of a single measurement of both signal quadratures and show that the back-action produces a random but unitary quantum gate whose action is fully determined by the measurement result. This accurate monitoring of a qubit state despite measurement back-action is an essential prerequisite for measurement-based feedback control of quantum systems.
Moty Heiblum	Shot noise measurements in mesoscopic systems	
Tobias J. Kippenberg	Quantum coherent coupling of a mechanical oscillator to a cavity mode	
Jürgen König	Mesoscopic Stoner Instability in Metallic Nanoparticles Revealed by Shot Noise	We study sequential tunneling through a metallic nanoparticle close to the Stoner instability coupled to parallel magnetized electrodes. Increasing the bias voltage successively opens transport channels associated with excitations of the nanoparticle's total spin. For the current this leads just to a steplike increase. The Fano factor, in contrast, shows oscillations between large super-Poissonian and sub-Poissonian values as a function of bias voltage. We explain the enhanced Fano factor in terms of generalized random-telegraph noise and propose the shot noise as a convenient tool to probe the mesoscopic Stoner instability. [1] B. Sothmann, J. König, and Y. Gefen, Phys. Rev. Lett. 108, 166603 (2012).
Takis Kontos	Quantum dot circuits in microwave cavities	
Leonid Levitov	Noiseless single particle source	
Florian Marquardt	Nonequilibrium quantum dynamics in circuit cavity QED	Circuit cavity QED is now evolving into a regime where many microwave cavities and/or qubits may be coupled, to form interesting interacting quantum many-body systems. Here we propose and analyze a design that implements a quantum transverse-field Ising chain coupled to a microwave cavity for readout. This can be used to study quench dynamics, the propagation of localized excitations, and other features of current interest in nonequilibrium physics, in a field theory displaying a quantum critical point. If such a design is experimentally realized, it could easily be extended to produce non-integrable model situations as well. This would help to establish circuit QED as a promising tool for performing quantum simulations of complex nonequilibrium phenomena.
Thierry Martin	Current correlations in the interacting Cooper-pair beam-splitter	We propose an approach allowing the computation of currents and their correlations in interacting multiterminal mesoscopic systems involving quantum dots coupled to normal and/or superconducting leads. The formalism relies on the expression of branching currents and noise crossed correlations in terms of one- and two-particle Green's functions for the dots electrons, which are then evaluated self-consistently within a conserving approximation. We then apply this to the Cooper-pair beam-splitter setup recently proposed [L. Hofstetter et al. Nature (London) 461 960 (2009); Phys. Rev. Lett. 107 136801 (2011); L. G. Herrmann et al. Phys. Rev. Lett. 104 026801 (2010)], which we model as a double quantum dot with weak interactions, connected to a superconducting lead and two normal ones. Our method not only enables us to take into account a local repulsive interaction on the dots, but also to study its competition with the direct tunneling between dots. Our results suggest that even a weak Coulomb repulsion tends to favor positive current cross correlations in the antisymmetric regime (where the dots have opposite energies with respect to the superconducting chemical potential).
Klaus Molmer	Quantum state control by quantum measurements	I will discuss how the unpredictable character of measurements in quantum theory can be used as a resource in the control and manipulation of quantum systems. I will present the underlying idea and simple examples of the stochastic master equation formalism, which describes quantum systems, subject to measurement, and I will then proceed to show how dissipation and loss, when adequately monitored, can drive quantum systems into states for which we have no other means of preparation, e.g., non-classical states of light from conventional light sources, entangled states of remote particles, squeezed states of many non-interacting particles, ... Physical examples will be given pertaining to recent research on superconducting qubits, solid state spin ensembles and microwave resonators.
Andreas Nunnenkamp	Synthetic gauge fields and homodyne transmission in Jaynes-Cummings lattices	Many-body physics is traditionally concerned with systems of interacting massive particles. Recent studies of effective interactions between photons, induced in the circuit QED architecture by coupling the microwave field to superconducting qubits, have paved the way for photon-based many-body physics. We derive the magnitude and intrinsic signs of photon hopping amplitudes in such circuit QED arrays. For a finite, ring-shaped Jaynes-Cummings lattice exposed to a synthetic gauge field we show that degeneracies in the single-excitation spectrum emerge, which can give rise to strong correlations for the interacting system with multiple excitations. We calculate the homodyne transmission for such a device, explain the generalization of vacuum Rabi splittings known for the single-site Jaynes-Cummings model, and identify fingerprints of interactions beyond the linear response regime.
Jukka Pekola	Fluctuation relations in driven electron tunneling	I discuss the concepts of work, heat and fluctuation relations in single-electron tunneling driven by a gate voltage. Our experiments confirm the validity of the most common fluctuation relations under isothermal conditions. Finally I discuss a feed back mechanism by which information can be converted into energy stored in a capacitor in a single-electron circuit.
Hugues Pothier	Photonic spectroscopy of Andreev bound states	In each conduction channel of a Josephson junction, there exist two localized states, on both sides of the Fermi energy, the Andreev Bound states. In standard Josephson circuits, only the properties of the ground state are exploited. In contrast, we

present broadband spectroscopic measurements of the transition between the two Andreev states in a superconducting atomic point contact. Not only do we clearly resolve the Andreev transition, but we also identify spectroscopic lines arising from anticrossings with the plasma modes of a Josephson junction placed in the environment.

Bertrand Reulet

Noise minimization, quantum oscillations, and the fourth cumulant of photo-assisted noise

We present several experiments related to photo-assisted noise: 1) by modifying the shape of the ac excitation we minimize shot noise; 2) we show that noise in the presence of increasing ac+dc excitation exhibits quantum oscillations; 3) we measure the fourth cumulant of current fluctuations and demonstrate its link with intensity-intensity correlations of light.

Robert Schoelkopf

Quantum Noise in Circuit QED

Gerd Schön

Fluctuation Theorem and Single-Electron Tunneling

Y. Utsumi, D. S. Golubev, M. Marthaler, and G. Schön

We study single-electron transport through a double quantum dot (DQD) monitored by a capacitively coupled quantum point-contact (QPC) electrometer. We derive the full counting statistics for the coupled DQD - QPC system and obtain the joint probability distribution of the charges transferred through the DQD and the QPC consistent with the fluctuation theorem (FT). The system can be described by a master equation with tunneling rates depending of the counting fields and satisfying a generalized local detailed-balance relation. Furthermore, we derive universal relations between the non-linear corrections to the current and noise, which can be verified in experiment.

Christian Schönenberger

Near unity Cooper-piar splitting with quantum dots

An elegant way of creating entangled electron pairs in a solid-state device is to coherently separate the two electrons of a Cooper pair in a conventional superconductor into two normal metal output terminals. It is expected that the efficiency of this process can be increased to very large values by using electrically tunable quantum dots (QDs) in the normal leads [1].

Cooper pair splitting (CPS) was demonstrated recently on such QD devices based on InAs nanowires [2-4] and carbon nanotubes (CNTs) [4] with efficiencies of several percent. Theoretical work shows that the maximum efficiency is limited to only 50% if electron-electron interactions are negligible [5,6].

Here we present experiments on a CNT-based device with unprecedented Cooper pair splitting efficiencies, signifficantly larger than 50%, reaching up to 90%. Such efficiencies suggest that electron-electron interactions are dominant and suppress the undesired local transport mechanisms. We observe CPS on a series of resonances of both QDs and compare the simultaneously recorded CPS currents in the two output terminals. Apparent discrepancies between the two signals suggest a competition between local and non-local processes and the presence of a higher-order tunnel coupling between the QDs.

A high CPS efficiency is a prerequisite for Bell-state measurements, a direct means of demonstrating the generation of spatially separated entangled electron pairs by Cooper pair splitting.

[1] Recher et al., Phys. Rev. B 63, 165314 (2001)
[2] Hofstetter et al., Nature 461, 960 (2009)
[3] Hofstetter et al., Phys. Rev. Lett. 107, 136801 (2011)
[4] A. Das et al. arXiv:1205.2455
[5] Herrmann et al., Phys. Rev. Lett. 104, 026801 (2010)
[6] P. Samuelsson and M. Büttiker, Phys. Rev. B 66, 201306(R) (2002)

Irfan Siddiqi

Quantum Control of a Superconducting Qubit

We discuss both closed and open loop control of a superconducting transmon qubit. In the case of the former, we use a wide bandwidth, phase-sensitive parametric amplifier operating near the quantum noise limit to readout the state of a transmon qubit coupled to a linear resonant cavity. In the weak measurement regime where qubit transitions only result in a slight shift of the cavity resonance, we realize a partial measurement where the extracted information is used to feedback on the qubit state. We demonstrate this technique by phase-locking Rabi oscillations with respect to a classical reference. This allows the oscillations to persist indefinitely albeit with a reduced amplitude, indicative of the efficiency of the feedback protocol. As a demonstration of open loop operation, we prepare an arbitrary superposition state with high fidelity by applying strong drive pulses to engineer the dissipative environment seen by the qubit. For the specific case of an equal superposition, we are able to boost the contrast in a Ramsey like experiment and suppress the decay of coherent oscillations.

Jan van Ruitenbeek

Inelastic noise in nanowires: a two-electron effect

Shot noise carries information on the quantum mechanical electronic structure of nanoscale conductors. In atomic wires shot noise can be exploited for obtaining information on the number of conductance channels and their transmission probability. At bias voltage above the threshold for inelastic scattering corrections to noise are observed. The inelastic scattering we consider here is due to the excitation of a vibration mode. The inelastic correction can take a positive sign or a negative sign, depending on the transmission probablitity T of the conductance channel. The positve correction is found for T close to 1, and is the correction that would be expected from simple arguments. The negative correction is found for T<0.95 and is explained in terms of two-electron processes. This is a unique example of two-body effects in quantum conductors at high transmission.

Felix von Oppen

Current-induced forces in nanoelectromechanical systems

Andreas Wallraff

Quantum Optics with Superconducting Circuits: Exploring Propagating Microwave Photons

Using modern micro and nano-fabrication techniques combined with superconducting materials we realize quantum electronic circuits. We create, store, and manipulate individual microwave photons on a chip. The strong interaction of photons with superconducting quantum two-level systems allows us to probe fundamental quantum effects of light and also to develop components for applications in quantum information technology. In particular, I will discuss experiments in which we demonstrate first and second-order correlation function measurements of microwave frequency single photon sources integrated on the same chip with 50/50 beam splitters. In the absence of efficient single photon counters at microwave frequencies, linear amplifiers and quadrature amplitude detectors are used for correlation measurements [1]. Our data clearly displays single photon coherence in first-order and photon antibunching in second-order correlation function measurements of the propagating fields [2]. We have also used these techniques to investigate photon blockade in the context of cavity QED [3] and to reconstruct the Wigner function of itinerant single photon Fock states and their superposition with the vacuum [4]. To perform these measurements we have developed efficient methods to separate the detected single photon signal from the noise added by the amplifier by analyzing the moments of the measured amplitude distribution up to 4th order. Current experiments aim at using parametric amplifiers, for which we have observed two-mode squeezing [5], to perform nearly quantum limited simultaneous detection of both quadrature amplitudes of electromagnetic fields. The techniques and methods demonstrated in this work may find application in future linear quantum optics and quantum information processing experiments.

[1] M. P. da Silva, D. Bozyigit, A. Wallraff, and A. Blais, Phys. Rev. A 82, 043804 (2010)

[2] D. Bozyigit, C. Lang, L. Steffen, J. M. Fink, C. Eichler, M. Baur, R. Bianchetti, P. J. Leek, S. Filipp, M. P. da Silva, A. Blais, and A. Wallraff, Nat. Phys. 7, 154 (2011)

[3] C. Lang, D. Bozyigit, C. Eichler, L. Steffen, J. M. Fink, A. A. Abdumalikov Jr., M. Baur, S. Filipp, M. P. da Silva, A. Blais, A. Wallraff, Phys. Rev Lett. 106, 243601 (2011)

[4] C. Eichler, D. Bozyigit, C. Lang, L. Steffen, J. M. Fink and A. Wallraff, Phys. Rev Lett. 106, 220503 (2011)

[5] C. Eichler, D. Bozyigit, C. Lang, M. Baur, L. Steffen, J. M. Fink, S. Filipp and A. Wallraff, Phys. Rev. Lett. 107, 113601 (2011)