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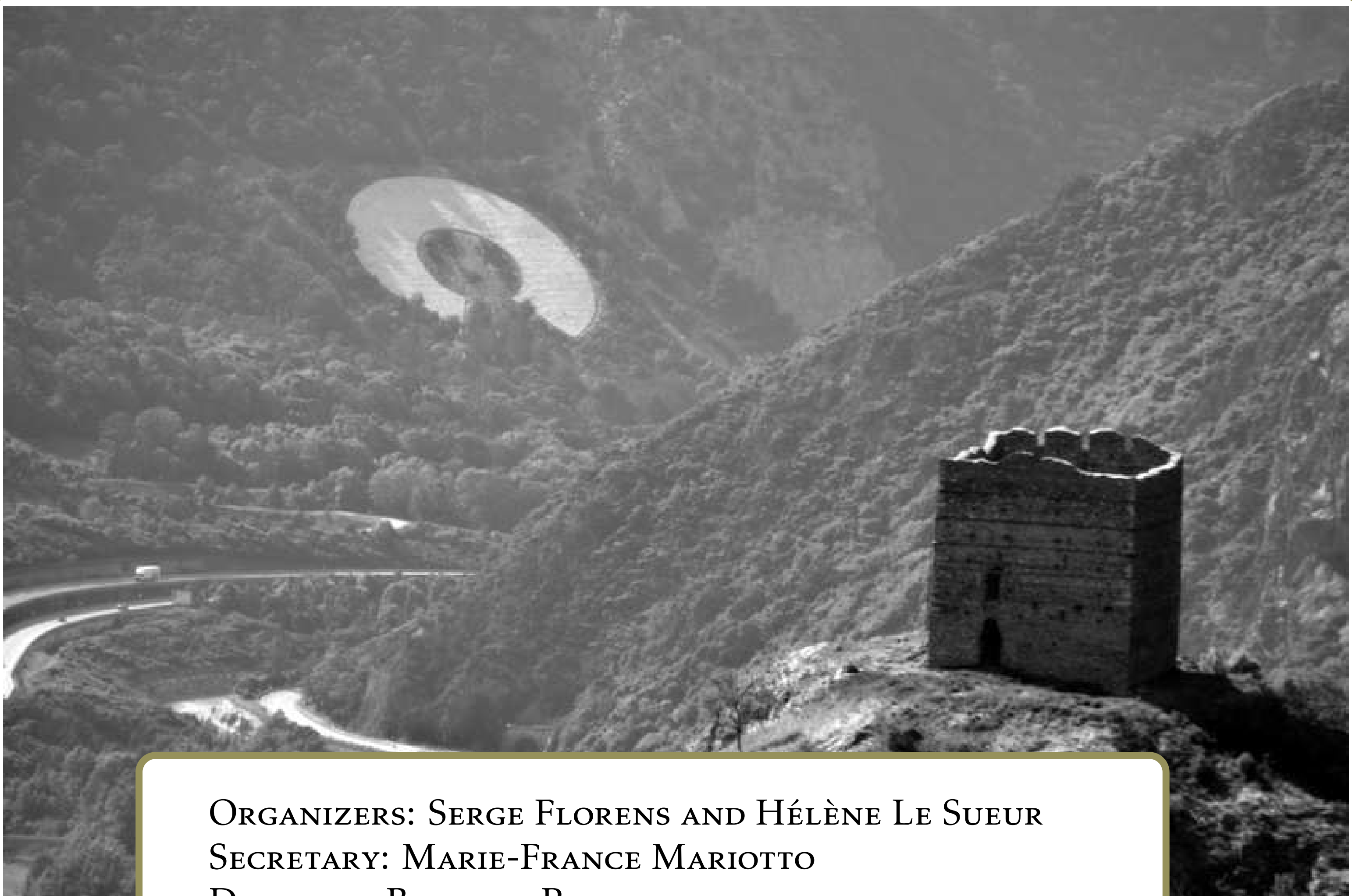
Abstracts of poster sessions (alphabetical order)



Organizers: Serge Florens and Hélène Le Sueur
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Phase-driven collapse of the Cooper condensate in a nanosized superconductor

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Abstract (max 1/2 page including references+ 1 illustration if needed)

We show experimental evidence of complete suppression of the energy gap in the local density of quasiparticle states (DOS) of a superconducting nanowire upon establishing a phase difference equal to the π over a length scale comparable to the superconducting coherence length. These observations are consistent with a complete collapse of the pairing potential in the center of the wire, in accordance with theoretical modeling based on the quasiclassical theory of superconductivity in diffusive systems. Our spectroscopic data, fully exploring the phase-biased states of the condensate, highlight the profound effect that extreme phase gradients exert on the amplitude of the pairing potential. Moreover, the sharp magnetic response observed near the onset of the superconducting gap collapse regime can be exploited to realize ultra-low noise magnetic flux detectors

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Single photon radiation scheme based on inelastic Cooper pair tunneling

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Usually, Cooper pair tunneling through a Josephson junction is elastic: the dc voltage across the junction has to be zero. Nonetheless, tunneling can also occur at non-zero bias if the difference of potential can be dissipated somewhere [1]. By coupling the junction to a transmission line, it can be dissipated as photons [2]. At first sight, the photons have the same statistics as the tunneling Cooper pairs: poissonian, i.e. tunneling events are independent. We show that photons statistics can also be non-classical [3]: by designing the electromagnetic environment, we are able to emit antibunched photons on demand.

Our project is built around a voltage-biased Josephson junction and a quarter-wave resonator as the electromagnetic environment. Cooper pair tunneling can occur inelastically at non-zero bias, leading to photons dissipated through a transmission line. This phenomenon has been explained by P(E)-theory [4, 5] in the early nineties and some experiments have measured Cooper-pair current at non-zero voltages [1]. More recently, experiments have also probed the emitted radiation [2]. Our project is focused on the question whether the emitted radiation can be non-classical [3], that we investigate using an Hanbury Brown and Twiss scheme [6].

In this scheme, each time a Cooper pair tunnels, a photon is created in the resonator, so the statistics of photons will be the same as that of the Cooper pairs: Poissonian. To go below this statistics, we block tunneling events before the resonator relaxes. To do so we use a high-impedance RC circuit slower than the resonator, so that the second tunneling event has to pay a higher energy than the first one, resulting in single photon statistics. Using tunable Jospehson energy, this blocking mechanism can be transformed into a latching mechanism alowing us to obtain a very bright on demand single photon source.

Moreover, we build this source from niobium nitride, a wide gap superconductor, which should allow us to scale this source to mm-wave or THz frequencies.

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Andreev spectrum with high spin-orbit interactions: revealing spin splitting and topologically protected crossings.

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We investigate numerically the Andreev spectrum of a normal multichannel mesoscopic quantum wire (N) with high spin orbit interactions coupled to superconducting electrodes (S), contrasting topological and non topological behaviors.In the non topological case with no Zeeman field, we find that as soon as the normal quantum wires can host several conduction channels, the spin degeneracy of Andreev levels is lifted by a phase difference between the S reservoirs which breaks time reversal symmetry. The Andreev states remain degenerate at phases multiple of pi for which time reversal symmetry is preserved, giving rise to level crossings which are not lifted by disorder. Whereas the Josephson current is nearly insensitive to the level crossings, we show that the finite frequency admittance (susceptibility) is extremely sensitive to these crossings More interesting is the case of the hexagonal lattice with next nearest neighbor spin-orbit interactions which exhibit 1D topological helical edge states [1]. The finite frequency admittance exhibits at low temperature a very specic signature of a protected Andreev level crossing at pi and zero energy in the form of a sharp peak split by a Zeeman field.

Admittance of quantum Hall conductors

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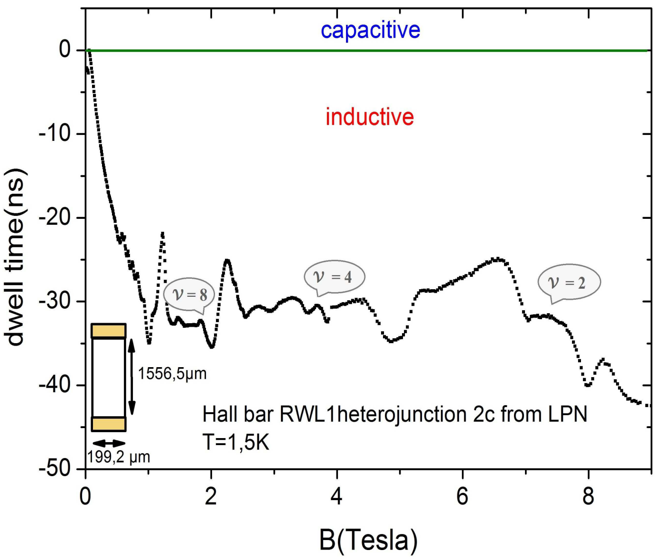
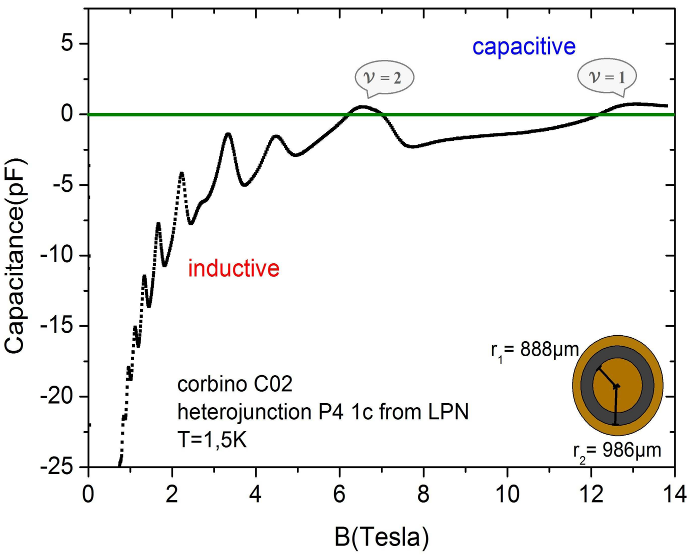
In a two dimensional electron gas in presence of a magnetic field, low energy transport occurs in 1D channels located on the edges of the sample (chiral quantum hall edges states). In AC measurement an emittance appears [1] which depends on the topology of the meso-circuit and wich is related to the Fermi velocity and to the quantum capacitance of the edge states.

We present direct measurements of the admittance in quantum Hall conductors as a function of the frequency in the kHz range. We study samples having only two contacts and no gate on top or on the side. Two topologies are studied: Hall bars and corbino rings. We observe two different behaviours depending on the geometry.

For our Hall bars, instead of a capacitance behaviour which is not a natural image for a two contact channel, the emittance can be interpreted as the dwell time between these two contacts as initially discussed in Ref[2]. At low filling factor, this time is related to the Fermi velocity. In the left figure the dwell time, in nano seconds, is plotted as a function of the magnetic field B.

In the case of the corbino geometry, we clearly measure a capacitance signature in the integer quantum Hall regime. However we observe a transition when entering the quantum regime. At small magnetic field (high filling factor) the corbino ring behaves like a Hall bar, i.e. an inductive meso-circuit described by a dwell time. Contrarily, at high magnetic field (low filling factor) the corbino ring behaves like a true capacitance whose value is directly the quantum capacitance of edge states(see the figure at right).





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Superconducting Silicon Devices

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When boron-doped above 1 at.%, cubic silicon turns into a BCS superconductor even at ambient pressure. However, the extreme doping concentration required to trigger superconductivity is more than three times the boron solubility limit in silicon. This concentration is impossible to reach using conventional micro-electronic techniques, but epitaxial superconducting Si:B thin films can be realised using Laser Doping [1].
The superconducting critical temperature Tc of thin Si:B films only depends on the boron dose, increasing above a threshold value up to a maximum of 0.7 K [2]. However, the initial linear increase reaches a saturation for a boron dose corresponding to the strain-induced Si:B crystal relaxation. We are thus investigating the role of the strain in the onset of superconductivity.
The doping-tunable Tc and the silicon technology are coupled in Si:B to the possibility of a large range of nanodevices, made of superconductors, metals and semiconductors coupled through extremely clean, transparent epitaxially grown interfaces [3]. We have thus realised the first silicon superconducting devices: SNS Josephson junctions where long-range proximity effect has been demonstrated [3], and superconducting quantum interference devices (dc-SQUID) [4].
Finally, we have started the investigation of the high frequency properties of Si:B, through the study of coplanar wavelength resonators. The multiple GHz resonant modes show an important kinetic inductance, expected from Si:B high resistance and low Tc.

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High frequency quantum noise measurement of a carbon nanotube in the Kondo regime

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The Kondo effect is a many body phenomenon that results from the interaction between a localized impurity and the conduction electrons in a metal. It leads to the screening of the spin moment of the impurity and to the appearance of a resonance at the Fermi energy. Quantum dots are famous realization of Kondo effect, in which it is possible to measure transport properties through a single impurity. In particular, this situation allows to probe the Kondo resonance out of equilibrium and its competition with superconductivity if the quantum dot is contacted with superconducting leads.

While DC properties of the Kondo effect have been widely studied, its AC behavior is less understood. In this work, we investigate high frequency transport in a carbon nanotube quantum dot, by coupling it to an on-chip quantum detector through a micro-wave resonator with a resonance frequency of the order of the Kondo Temperature. The on-chip detector, made of a Josephson tunnel junction, enables to probe the high frequency noise of the system separating emission and absorption processes, through a measurement of DC photo-assisted current in the detector.

We have investigated the emission noise at frequencies where the Kondo effect may be affected due to its dynamics or by out of equilibrium effects. We have probed two different situations: in the first one, we measured the emission noise of a nanotube contacted by normal electrodes, and investigated the influence of the asymmetry of the contacts on the decoherence of the Kondo effect. In the second one, the nanotube is contacted to superconducting reservoirs, allowing to investigate the AC Josephson emission in the Kondo regime thanks to its interplay with the superconducting proximity effect.

Gate tunable transition from diffusive to ballistic regime in graphene Josephson junction

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We study graphene Josephson junction, where the graphene is encapsulated between boron nitride flakes. This leads to a large mean free path resulting in large critical current density of 180 nA/µm in our 1.5 µm long device. Recent works on boron nitride encapsulated graphene Josephson junction also show similar high critical current density over long device. We have a different device geometry which not only allows two-probe measurements but also 4-terminal measurements. The Josephson junction is defined by the superconducting electrode niobium nitride and the normal probe of gold is used to measure the four-probe resistance.

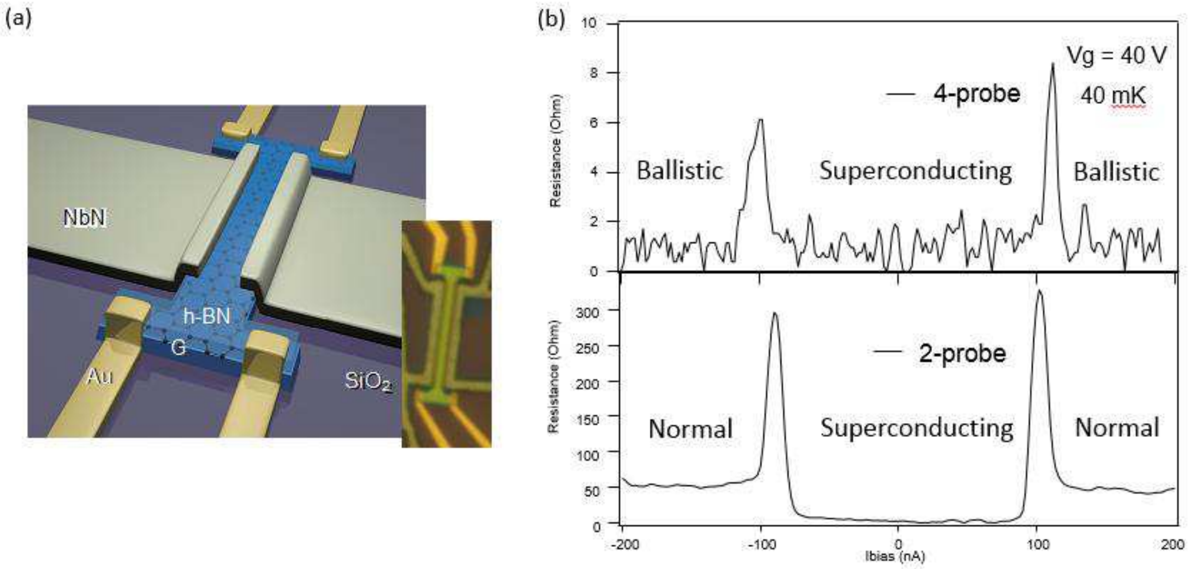

Figure: (a) Device schematic and optical image (b) Simultaneous measurement of two-probe and four-probe resistance as a function of bias current

Low temperature charge transport measurement showed that we can easily detect ballisticity in our device using four-probe measurement. Ballisticity is seen at high electron doping away from the Dirac point. By changing the gate voltage towards the Dirac point, we can tune to the diffusive regime. By measuring the two-probe resistance as a function of bias current, we can determine the superconducting and the normal regime, and simultaneously, measuring the four-probe resistance, we can distinguish between ballistic (vanishing resistance) and diffusive (finite resistance) regime in the normal state. We have also studied temperature evolution of critical current in the diffusive and the ballistic regime in our long graphene Josephson junction.

Experiments on Heat transport through a Single Electron Transistor

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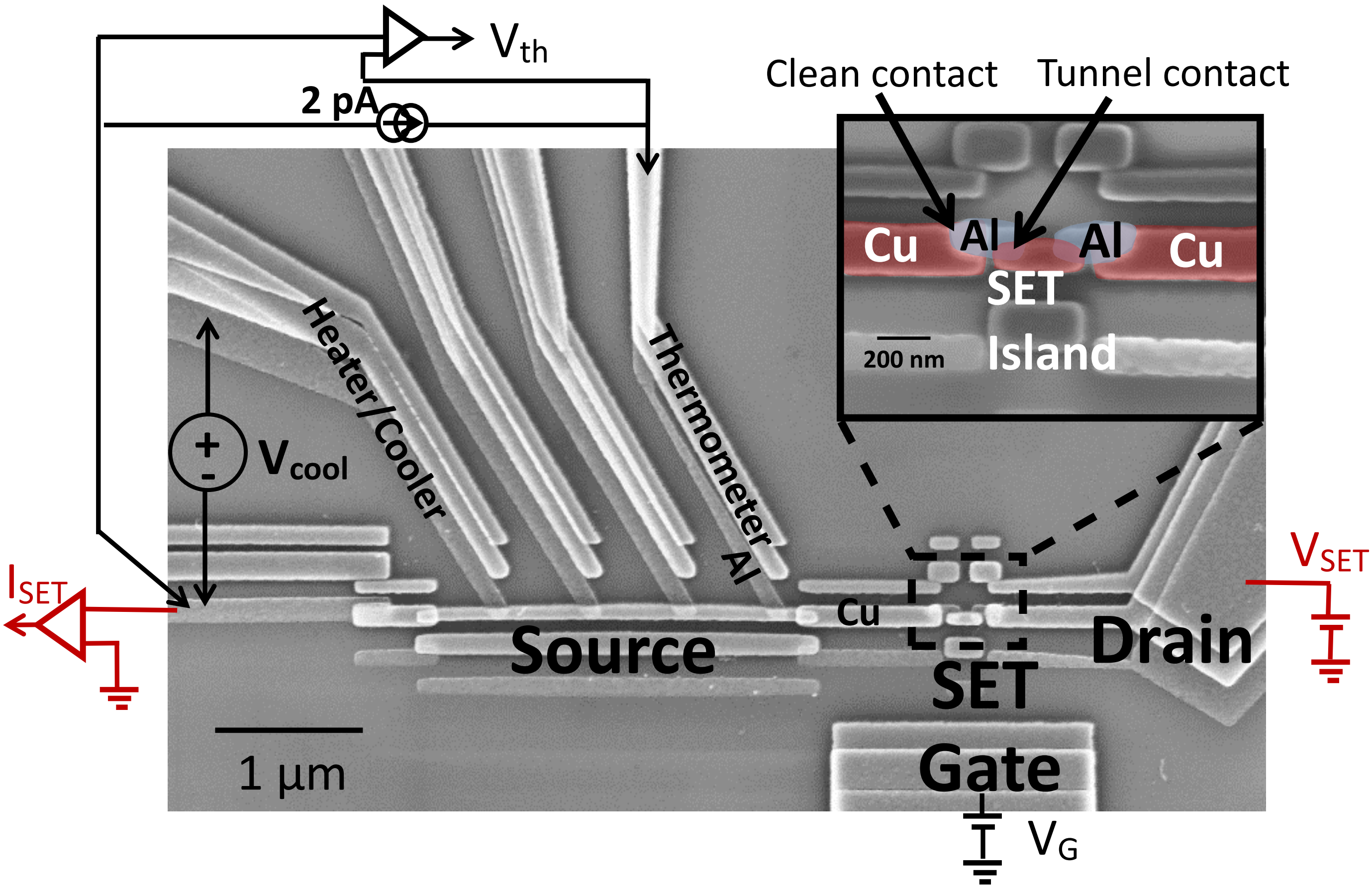
We have carried out thermal transport measurements through a single electron transistor (SET) [1]. The thermal transport properties of a SET is an interesting and yet vastly unexplored topic of research. Theory predicts a violation of some fundamental law of physics in this kind of system [2]. In our experiment, to perform thermal transport measurement, we create a thermal gradient across the SET (charging energy ~140 μeV) by cooling/heating the source of the SET (left side), with a properly biased NIS junction connected to it, while the drain (right side) is thermalized to bath temperature (T_b). Simultaneously we measure the temperature of the source as function of the applied gate voltage, by another NIS junction connected to the source. We observed a periodic temperature modulation of the source by the applied gate voltage. Specifically, we found temperature peaks at gate open position (charge degeneracy) when the source side is colder than T_b and temperature dips at gate open position when source is hotter than T_b. We fit the data with a thermal model (which uses the master equation of SET to calculate the heat flow through the SET) and extract the heat current flowing through the SET. The analysis indicates a significant deviation of temperature-heat flow relation from T^2 law (Wiedemann-Franz law) as we go away from the charge degeneracy point.



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Demonstration of a directional coupler for single flying electrons transferred by surface acoustic waves

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Over the past decade an important effort has been made in the field of low dimensional electronic conductors towards single electron electronics with the goal to perform quantum interference experiments at the single electron level. Here we present an experiment aiming at the coherent manipulation of single flying electrons transferred by surface acoustic waves. For this purpose we connect 4 quantum dots to a tunnel coupled wire via 4 quantum rails. We demonstrate single electron transfer between quantum dots over a distance of 20 µm with efficiency above 99%. Controlling the energy detuning of the tunnel-coupled wire we succeeded in partitioning a single flying electron into the two paths with arbitrary probability. This allows the realization of a directional coupler for single flying electrons and represents an important step forward towards coherent beam splitter operation. Finally, we show the possibility of loading an electron on demand into a specific potential minimum of the surface acoustic waves using sub-nanosecond voltage pulses opening the way to collision experiments with single electrons.

Single quasiparticle and electron emitter in the fractional quantum Hall regime

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We propose a driven anti-dot as the fractional quantum Hall counterpart of the celebrated single electron source. We characterize the setup as an ideal emitter of individual quasiparticles in the Laughlin sequence. This quasiparticle/quasihole emission involves only two charge states of the anti-dot, allowing for an analytic treatment. We show the precise quantization of the emitted charge and we compute the noise as a function of the escape time from the emitter. The periodic emission of one electron followed by one hole can also be achieved, and the overall shape of the noise spectrum is similar to that of the quasiparticle source. However, the presence of additional quasiparticle processes call for a full numerical treatment and leads to an enhancement the noise amplitude.

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Superconducting Silicon Devices

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In this project, we want to take advantage of the silicon technology and superconductivity by fabricating nanoMOSFETs with superconducting source and drain contacts. Two approaches were followed. The first one uses superconducting boron doped silicon [1], which is a promising candidate for a large amount of applications, as it inherits its potential from the highly developed silicon technology. The silicon superconductivity will be obtained by doping it beyond its solubility limit with boron, using Gas Immersion Laser Doping (GILD) or Pulse Laser Induce Epitaxy (PLIE) [2]. The second approach includes silicide materials, and especially PtSi which is very interesting due to its high critical temperature of 1K.

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Multiple van Hove singularities in moiré superlattices of stressed graphene

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Graphene consists of a 2D honeycomb lattice of carbon atoms with a unique electronic band structure (Dirac cones). Multilayers of graphene grown on carbon-faced silicon carbide (SiC(000-1)) is known to stack with a rotational disorder [1] inducing the superposition of atomic lattices with one rotated with respect to the other. This gives rise to a moiré pattern that was observed by Scanning Tunnelling Microscopy (STM) but also to van Hove singularities (vHs) in the density of states (DOS) of the graphene due to the crossing of the Dirac cones in the reciprocal space of each layer [2] that were probed by STS. These recent experiments in our group [3] showed that reproducible multiple peaks arise and a possible explanation could be the strain-induced lifting of the vHs degeneracy [4].
The poster will show the STM and STS measurements done on twisted graphene layers grown on SiC(000-1). To evaluate the internal stress in the graphene layers, a commensurability analysis [5] of the moiré observed in the STM images was realized. Using this analysis, atomic positions of the experimental system were generated for tight-binding calculations of the DOS to account for the effect of stressed carbon bonds. We find that the resulting DOS calculations show several van Hove singularities in good agreement with the STS experimental data.

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Enhancement of the paramagnetic limit in transition metal dichalcogenide monolayers

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A new kind of 2D materials have been recently synthesized – monolayers composed of a transition metal and a chalcogenide (TMDC) with a structure similar to graphene, but with two different atoms per unit cell. They exhibit a particularly strong intrinsic spin-orbit coupling, acting as an effective Zeeman field which takes opposite orientations in two different valleys. Intrinsic superconductivity has been experimentally confirmed in several of these compounds, with high critical in-plane magnetic fields that greatly surpass the Pauli limit – a consequence of the 2D nature of these materials and their spin-orbit coupling [1].

The goal of our study is to theoretically investigate the interplay between superconductivity and spin-orbit coupling in TMDC monolayers, both in the bulk and in Josephson junctions. Many interesting physical phenomena might arise, such as helical and topological superconductivity, or the anomalous Josephson effect . We will present a simple model we have constructed for superconductivity in these materials which successfully describes the magnitude of the critical magnetic field. The effect of disorder on the superconducting state is also considered.

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Junction between two topological superconductors
Josephson current and noise calculations from Bogoliubov - de Gennes wavefunctions

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We calculate equilibrium current, zero and finite frequency noises in a junction between two 1D superconductors from wavefunctions that are solutions of the Bogoliubov - de Gennes equation. The topological nature of the superconductors can be encoded in the transfer matrix at the contact. All calculations are performed in parallel with the case of a contact between two normal superconductors and coincide in the case of perfect transparency of the junction. The Josephson current is linked to the derivative of the Andreev energy with respect to the phase difference between the two superconductors. Zero-frequency noise is only due to Andreev bound states while the finite frequency noise has three parts: one part only due to the Andreev states vanishes in the topological case, another one is only due to continuum states, and then a last one is due to transitions between Andreev bound states and continuum energy levels.

Quantum Zeno Dynamics in 3D circuit-QED

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We present our observation of the quantum Zeno dynamics [1] in a 3D circuit-QED [2] system, where an artificial atom, consisting of a superconducting circuit called a transmon [3], is coupled to the electric field of a microwave cavity resonator. The transmon and resonator energy levels are aligned in a novel way enabling the manipulation of individual Fock states of the cavity, while minimizing its transmon-induced Kerr non-linearity [4]. We induce the QZD as in [5] by displacing classically the cavity field while continuously driving strongly a transmon transition specific to a particular Fock state, which keeps this Fock state population at zero. The QZD is then observed by measuring the Wigner function of the fields at regular time intervals, by standard quantum tomography and reconstruction of the density matrix. We observe three examples of QZD proposed in [6], and analyze the observed decoherence with the help of quantum simulations of the system.

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4π-Periodic Josephson supercurrent in ballistic Dirac-semimetal based Josephson junctions

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Abstract

Only when either time reversal symmetry or inversion symmetry is broken, a 3D Dirac semi-metal can turn into a Weyl semimetal. One Dirac cone splits into two Weyl cones with opposite chirality at opposite momenta k_0 and $-k_0$. The separation k_0 is proportional to the applied magnetic field. It is shown that a 3D Dirac semimetal can be found in Bi-based materials at the transition point from a band insulator to a topological insulator. For Sb-doped Bi, the phase diagram is well known and the transition point is ~3%.

By standard e-beam lithography, we fabricated various devices on $Bi_{0.97}Sb_{0.03}$ flakes and . $Bi_{0.97}Sb_{0.04}$.The high field results of Hall-bar shaped samples consistently show a negative longitudinal magnetoresistance (LMR) with B parallel to I. This Adler-Bell-Jackiw anomaly is a strong indication of a Weyl semimetal Heon-Jung Kim, et al. PRL 111, 246603 (2013) Furthermore, the Hall curves indicate low carrier densities of both electrons and holes.

We investigated the Nb/$Bi_{0.97}Sb_{0.03}$/Nb junctions in different regimes by making junctions with different lengths. We observed normal Fraunhofer patterns and Shapiro steps in long junctions, and irregular Fraunhofer patterns and a missing n=1 Shapiro step at low RF in short junctions. The missing n=1 Shapiro step is considered to be one of the major indications of the presence of Majorana fermions Wiedenmann. J, et al. Nat. comms. 7, 10303. We also show the theoretical calculation for the possible Dirac-bound states.

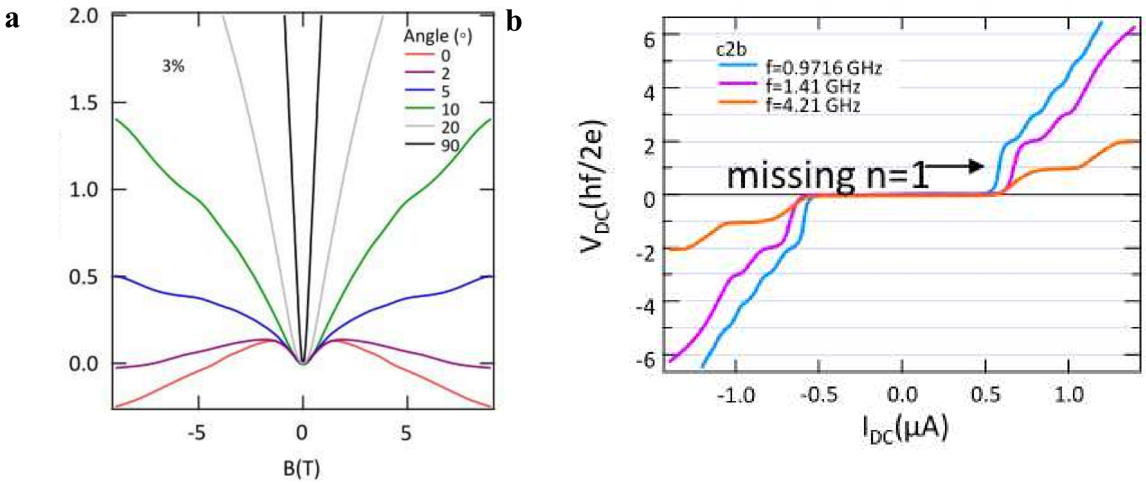

Figure 1 a. angle dependence of 3% doping sample. Negative longitudinal magneto-resistance is observed when the B field is parallel to the current direction. b. Shapiro steps at different frequencies. The missing step is observed only at low frequencies.

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On the disorder-driven transition in d=3 semimetals

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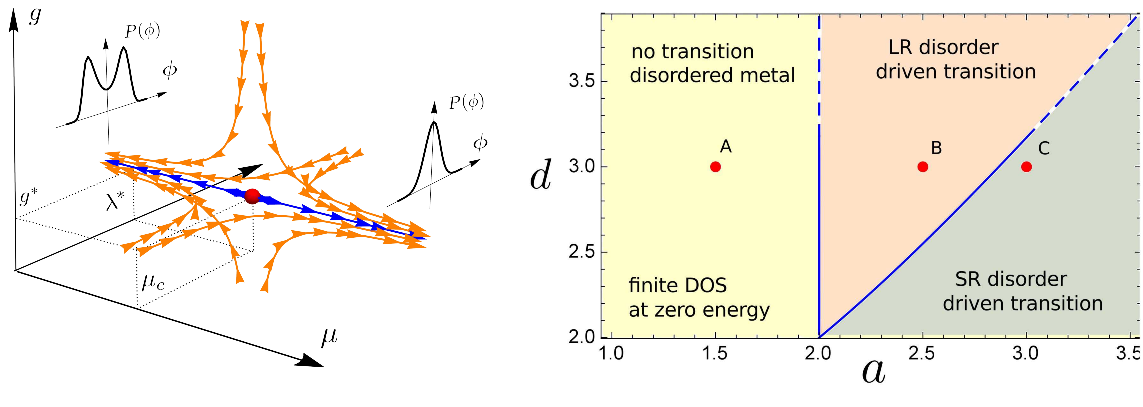
After discovering graphene the materials with relativistic-like spectrum of electronic excitations have become a popular subject which currently drives several hot topics in physics. Among them there are three dimensional materials which have been recently identified as Weyl semimetals and which provide a new universality class of phase transitions. The Weyl semimetallic phase is topologically protected against small perturbations such as presence of disorder. For a weak disorder, the system remains in a semimetallic phase: the density of states vanishes linearly at the band crossing, where electronic transport is pseudoballistic. However, for a critical disorder strength a transition occurs towards a diffusive metallic phase, characterized by a finite density of states at the nodal point [1]. This transition has been studied numerically and using renormalization group in d = 2 + eps [2] without consensus on the values of the critical exponents.

We reconsider this problem in view of relevance of disorder correlations and rare events. We find that the renormalization flow generates new terms in d = 2 + eps and propose an alternative route based on 4 - epsilon expansion [3]. Our method allows one to calculate the critical exponents in a systematic way opening an interesting perspective on several issues related to the transition. Besides, we show that in three dimensions, three scenarios are possible depending on the disorder correlations [4]. While the same transition is recovered for short range correlations, for disorder decaying slower than 1/r 2 , the Weyl semimetal is unstable to any weak disorder and no transition persists. In between, a new phase transition occurs. This transition still separates a disordered metal from a semi-metal, but with a new critical behavior that we analyze to two-loop order.



Left: RG flow diagram of the 4-eps expansion. Right: phase diagram depending on dimension and disorder correlations.

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Interpretation of scanning gate microscopy in quantum point contacts

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Abstract:

After having revealed new and fascinating phenomena like interference fringes and branched electronic flow in nanostructures, scanning gate microscopy (SGM) has been considered as a very promising tool to investigate quantum transport [Sellier et al, Semicond. Sci. Technol. (2011)].
In SGM, the conductance of a sample is measured while an AFM tip modifying the potential landscape is scanned above its surface. Despite the interesting features it has revealed, a rigorous physical picture of what is measured is still missing. However, a perturbative approach has demonstrated that, in the limit of weak and local tip potential, the SGM response in a perfectly symmetric quantum point contact (QPC) tuned to a conductance plateau is unambiguously related to the electronic local density of states, as well as the local current density.
Since the real physical systems are not perfectly symmetric, we present numerical simulations [KWANT: Groth et al New J. Phys (2014)] of the correspondence between the SGM response and the local electronic properties in symmetric and asymmetric structures.

Wigner function of a quantum Hall edge channel excited at GHz frequency

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In the rapidly evolving field of quantum computing, tremendous efforts have been made to realize phase-coherent electronics in the hope to process quantum information encoded on the electronic degrees of freedom. It is now possible to create and propagate quantum states with finite temporal and energy extensions. Although differential conductance or current fluctuations enable to recover energy distribution averaged in time of these states, it does not permit a complete reconstruction of a quantum state. To access, for instance, its Wigner distribution[1] a quasi-probability distribution that encodes both energy and temporal information, one needs a tomography protocol[2]. It has already been implemented but mainly on bosonic or discrete fermionic systems. One experiment successfully reconstructed the Wigner function of a single charge excitation by measuring its overlap with a probe state at a quantum point contact (QPC)[3], enabling a clear reconstruction of the quantum state. However, it was realized in a 2 terminals geometry where the source can not be distinguished from the probe and only for a peculiar class of states.

We will present the implementation of a tomography protocol in a 2 dimensional electron gas in the regime of integer quantum Hall effect where the 4 terminals geometry allows to separate the source from the probe. Although the protocol is fully universal, we tested it on an edge channel excited with a sinusoidal drive. This creates a many excitations state that, for $hf > k_b T_{el}$, differs from a simple Fermi sea with a time-varying chemical potential. Indeed, we were able to measure negativities in the Wigner function at a frequency drive f = 9GHz (see figure). This is a manifestation of photo-assisted absorption events [4] which are quantized by nature. We are able to distinguish between a “classical” time varying Fermi potential and a “quantum” many body state.

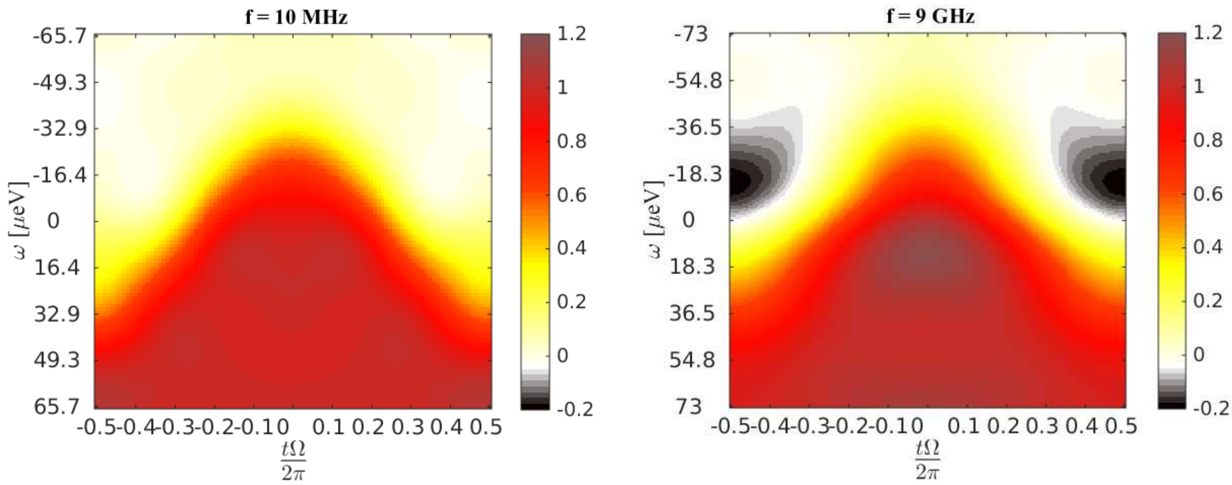

Figure: Wigner function of a Fermi sea driven at f = 10 MHz (left) and f = 9 GHz (right)

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Charge Control of a Nine Quantum Dot Array

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The spin degree of freedom of an electron is a very promising candidate as quantum bits for processing and storing quantum information. However, important questions concerning the system scalability remain to be addressed before building a large scale spin-based quantum nanoprocessor. So far, only classical spin transfer over linear arrays of three and four dots has been demonstrated, whereas slow electron displacement on a closed loop has been demonstrated in a four-quantum-dot system.

To demonstrate the scaling up capabilities of tunnel-coupled lateral quantum dots, we have investigated an array of nine lateral quantum dots defined in a 3x3 matrix geometry within an AlGaAs heterostructure. The system is tuned in the isolated configuration where the coupling to the reservoir can be ignored. We demonstrate the efficient loading into the isolated positions of up to ten electrons. We also show a complete set of measurements showing the nine possible charge configurations for one electron, allowing electron displacement on closed loops. The tunnelling rates between the nine dots are discussed.

Nano-mechanical transitions in Quantum Dots

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Transport measurements allow sensitive detection of nanomechanical motion of suspended carbon nanotubes. It has been predicted that when the electromechanical coupling is sufficiently large a bistability with a current blockade appears. Unambiguous observation of this transition by current measurements may be difficult. Instead, we investigate the mechanical response of the system, namely, the displacement spectral function, the linear response to a driving, and the ring-down behavior. We find that by increasing the electromechanical coupling the peak in the spectral function broadens and shifts at low frequencies while the oscillator dephasing time shortens. These effects are maximum at the transition where nonlinearities dominate the dynamics. These strong signatures open the way to detect the blockade transition in devices currently studied by several groups [1,2].

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A Zener-Klein graphene on BN transistor with enhanced cooling capabilities

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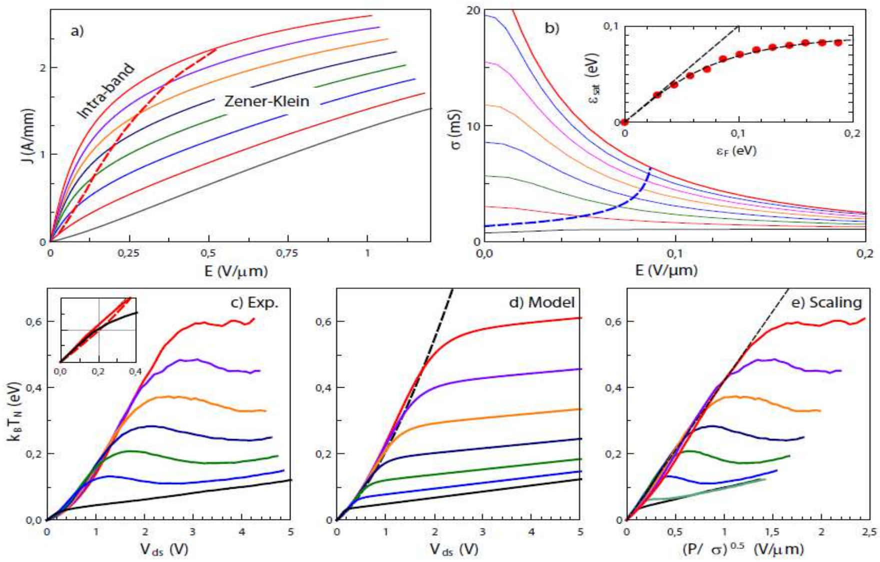
High mobility graphene on boron nitride transistors exhibit current saturation at finite electric fields (blue dotted line in the figure). Transport becomes governed by the interplay between intraband conductivity and interband Zener-Klein tunneling (ZKT), the later having a threshold E_{zk} set by Pauli blocking (red dotted line in the figure). Using sensitive RF noise thermometry we show that ZKT electron-hole pairs trigger 200 meV phonon emission in the substrate. Below E_{zk} Wiedemann-Frantz cooling prevails (black dotted line) with electron-electron relaxation and heat conduction to the leads. A switching of the heat conductance by two orders of magnitude is observed on acrossing E_{zk} that results in a clipping of the electronic temperature (see the noise temperature plot below). We attribute this remarkable cooling to the emission of hyperbolic phonon polaritons (HPP) of the h-BN substrate controlled by the ZK electron-hole pair density, creating a heat bridge between graphene and the gate. The combination of ZKT-transport and HPP-cooling promotes graphene transistors as a valuable nanotechnology for power devices and RF electronics.



Scanning gate microscopy signal enhanced by reflector

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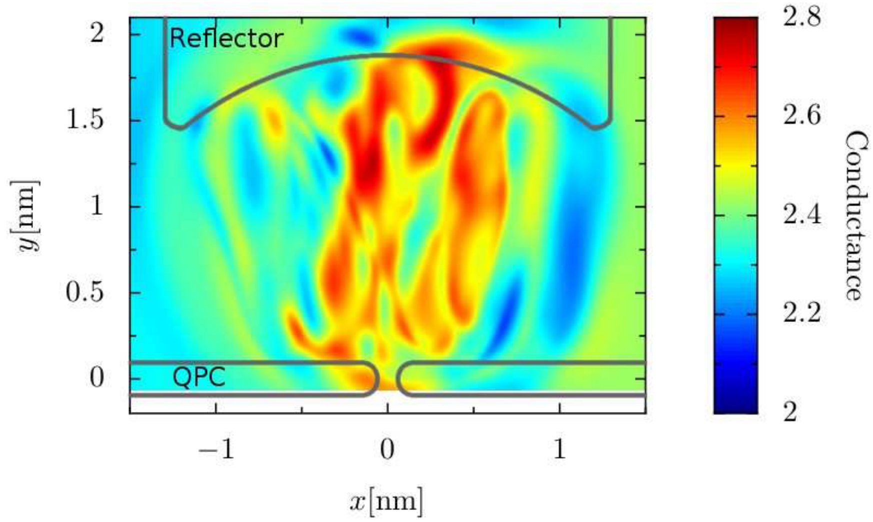

Calculated scanning gate microscope image at low tip strength

Scanning gate microscopy in confined geometries allows detailed studies of ballistic transport [1-2]. In particular, when a reflector is placed facing a quantum point contact (QPC) the scanning gate response is greatly enhanced. This effect would be strongest for an ideal reflector that can be designed to focus most of the electrons back into the QPC. However, we show that such behaviour would require disorder strengths much weaker than the ones typically encountered in state-of-the-art two-dimensional electron gases. We compute the tip position dependence of the conductance (see Figure above) for realistic disorder, finding strongly enhanced signals as compared with reflector-free samples, in quantitative agreement with recent experimental results [3].

Our results show that the introduction of a reflector can be a crucial tool to enhance the scanning gate response, enabling measurements at tip strength well below the ones normally used in experiments.

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Measurement of the channel's transmissions of an InAs Josephson junction

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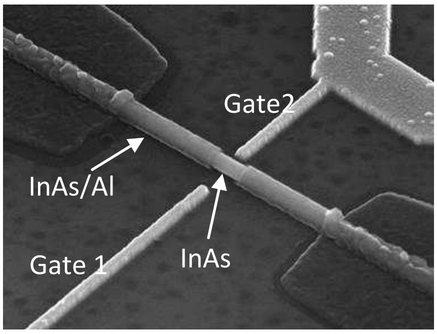
Semiconductor nanowires in good contact with superconductors allow obtaining Josephson junctions with low electron density and strong spin-orbit interaction, which are used in particular in the quest of Majorana physics. An important issue is the determination of the number of transport channels and of their transmissions.
Here, we present measurements of the current-voltage (*I*-*V*) characteristics of Josephson junctions obtained from epitaxial InAs–Al semiconductor–superconductor nanowires [1] in which an Al shell has been etched away over 150nm. A pair of metallic side gates is used to deplete the InAs and modulate the *I*-*V* characteristics. The number of channels of the junction and their transmissions are obtained by fitting the *I*-*V*s, assuming that their non-linearities are due to Multiple Andreev Reflections (MAR) [2]. It is found that the number of channels can be tuned from 4 to 1, with transmissions sometimes approaching unity.However, the MAR fits do not always reproduce all the observed features, in particular the asymmetry of the *I*-*V*s.



InAs Josephson junction: InAs nanowire covered with epitaxial Al, except in the 150-nm-long central region. Bright fingers are metallic gates.

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Multimode circuit QED : Towards many-body physics

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The study of light matter interaction represents a key topic in fundamental physics. Over a decade ago this study got to another stage with the introduction of artificial atoms made of superconducting circuits. Because of their mesoscopic size they can couple much strongly to light than natural ones. This gave rise, for example, to the first observation of the ultra strong light-matter coupling regime in a cavity system [1].
In our work we follow a new approach consisting in coupling a superconducting artificial atom (namely a transmon qubit) to a meta-material made of thousands of SQUIDs. The latter sustains many photonic modes and shows a characteristic impedance close to the quantum of resistance. Thanks to this high characteristic impedance, we observe a coupling an order of magnitude higher than previously reported in multi-mode systems [2].
Thus, in our circuit the artificial atom is simultaneously coupled to many photonic modes, which, in return, all interact together. With this experiment we were able to push quantum optics towards the realm of many-body physics, where strong interactions between many particles is the norm. As a direct application, we use this circuit to explore quantum optics in the ultrastrong coupling regime, where new phenomena arise [3–5]. Moreover it provides a fully-tunable platform to study the spin-boson model in the strong dissipative regime [6] ; this is of prime importance since this model has remained so far a theoretical concept, despite its central role in condensed matter physics.

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Finite Energy Relaxation in the Integer Quantum Hall Regime

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We investigate the relaxation of electrons injected at a well defined energy above the Fermi sea in the edge states of the Integer Quantum Hall Effect obtained in a high mobility two dimensional electron gas.

The energy of the injected electrons is selected with a first Quantum Dot used as an energy filter by manipulating its discrete energy levels. After a propagation length of a few µ-meters, where relaxation mechanisms can take place changing the energy of the electrons, a second Quantum Dot is used to detect the energy at which electrons arrive. This experiment will provide the first accurate spectroscopy of the relaxation of quasiparticles in the IQHE regime.

As a preliminary result, a simpler experiment was performed in which a single QD is used as a spectrometer. A first QPC acting as a beam splitter is used to induce an out-of-equilibrium distribution in the edge channel. As a consequence of relaxation processes, the energy distribution evolves while electrons propagates along the edge of the sample. We checked that our setup allows to determine the out-of-equilibrium distribution and, that after a propagation along 4 µm the distribution partially relaxed to a hot electron distribution. This preliminary result, in agreement with the measurement of C. Altimiras *et al.* and H. le Sueur *et al.*, sets an upper limit to the distance between the two dots for the spectroscopy of a partially relaxed excitation.

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Shot noise in the Coulomb Blockade regime

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We report on shot noise measurements using Silicon nanowire field-effect transistors as a tunable quantum dot.Through the measurement of current noise in a Coulomb-blockadedquantum dot, we describethe transition between the Coulomb blockade and the diffusive regimes in a tunable quantum dot by observing super- and sub-Poissonian noise[1] which is related to the interplay between Coulomb interaction and Fermi statistics.[2, 3]

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A pseudopotential model for Dirac electrons in graphene

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Investigation of real two–dimensional systems with Dirac–like electronic behavior under a various types of perturbations is challenging and leads to many interesting physical results. It is possible to show that these perturbations, such as defects in the lattice structure or external field, can be modeled by an effective pseudopotential. Here we consider line defects [1] and Aharonov–Bohm vortex [2] as a two different types of perturbations. After determining the necessary boundary conditions, the transmission probability for electron transport through the defect line and the valley polarization are obtained. For the case of the Aharonov–Bohm vortex we additionally consider a homogeneous magnetic field and obtain the electronic wave functions, energy spectrum, and show that the magnetic Aharonov–Bohm vortex plays a role of a charge impurity. As a demonstration of vacuum properties of the system, vacuum current, as well as an electric current, is calculated and their representation for particular limiting cases of magnetic field is obtained.

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Giant Collective Magneto-Excitation in Spherical Clusters

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Bertsch et al have predicted a giant collective excitation ω_p at high energy in the C_{60} electromagnetic response spectrum using a RPA tight binding calculation. The present article extends the previous work to investigate the giant magneto-excitation for spherical clusters threaded by a magnetic field. The main effects due to a magnetic field increase are (1) the giant magneto-excitation ω_p is shifted to higher energy (2) the resonance shape appearing in the electromagnetic response is sharper. The size and the geometrical symmetry of the cluster play a role on the evolution of ω_p versus the applied magnetic field.

Quasiparticle dynamics in a hybrid Cooper-pair box

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In the context of a collaboration with the Edelweiss project for the direct detection of dark matter we have been working on the development of an electrometer based on the Cooper-pair box. As conceived, a dispersive read-out of this mesoscopic device though a rf-setup would allow an accurate measurement of the charge created by an incident particle in a semi-conductor crystal used as bolometer, with a sensitivity more than one order of magnitude below existing semiconductor electronics. However, as also happens in superconducting qubits, the performance of our device is limited by the presence of non-equilibrium quasiparticles in the superconductors which induce parity jumps in the box. Conventional strategies to handle quasiparticle "poisoning" are gap engineering of both, the box and the ground, and also the building of quasiparticle traps. We have chosen to fabricate a hybrid Nb/Al island connected to an Al ground through a tunnel junction. I will show that poisoning is still present, but with parity switching rates strongly reduced (of the order of the millisecond) compared to Al based devices, and with no observable difference between even and odd states. We believe that this study on the quasiparticle dynamics is a key step towards the realization of a robust detector.

Spin-orbit interaction in graphene induced by transition metal dichalcogenides

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In this study, we attempt to induce strong spin-orbit interaction into graphene by means of graphene-transition metal dichalcogenide (TMD) heterostructures. TMDs are also 2D materials similar to graphene, and they have strong intrinsic SOI. In our study, we use monolayer MoS_2 and multilayer WSe_2 as TMDs, and measure magnetoresistance of graphene on top of these TMDs. We observed weak-antilocalization behaviors for both samples at low temperatures, a clear signature of induced SOI in graphene. Temperature dependence of the weak-antilocalization signals show the difference in the amplitude of induced SOI depending of the TMD. We also found a significant difference between monolayer and multilayer TMDs to induce SOI in graphene in the carrier density modulation through the back gate. While the multilayer TMD strongly screens gate electric field, the monolayer TMD allows ambipolar transport in graphene. SOI in graphene can also be useful as a source for spin current generation. Our findings on introduction of SOI in graphene reveal that graphene can be a promising material for the QSH state and also spintronics.

Sensitivity of the mixing current technique to detect nano-mechanical motion

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Detection of nano-mechanical displacement by transport techniques has reached high level of sensitivity and versatility. In order to detect the amplitude of oscillation of nano-mechanical oscillator a widely used technique consists to couple this motion capacitively to a single-electron transistor and to detect the high-frequency modulation of the current through the non-linear mixing with an electric signal at a slighltly detuned frequency. The method known as current-mixing technique is employed in particular for the detection of suspended carbon nanotubes. In this paper we study theoretically the limiting conditions on the sensitivity of this method. The sensitivity is increased by increasing the response function to the signal, but also by reducing the noise. For these reasons we study systematically the response function, the effect of current- and displacement-fluctuations, and finally the case where the tunnelling rate of the electrons are of the same order or larger of the resonating frequency. We find thus upper bounds to the sensitivity of the detection technique.