2D to 3D crossover in topological insulators

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Résumé

At the heart of the study of topological insulators lies a fundamental dichotomy: topological invariants are defined in infinite systems, but their main footprint, surface states, only exists in finite systems. In systems in the slab geometry, namely infinite in two dimensions and finite in one, the 2D topological invariant was shown to display three different types of behaviours. In the limit of zero Dirac velocity along z, these behaviours extrapolate to the three 3D topological phases: trivial, weak and strong topological insulators. We show analytically that the boundaries of these regions are topological phase transitions of particular significance, and allow one to fully predict the 3D topological invariants from finite-thickness information. Away from this limit, we show that a new phase arises, which displays surface states but no band inversion at any finite thickness, disentangling these two concepts closely linked in 3D.

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A hybrid cavity-superconducting qubit-magnon haloscope for dark matter detection in the microwave range.

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Résumé

We will present our original setup for detecting axion dark matter using quantum microwaves. In particular, we will describe how we can use the resources of superconducting qubits and cavity photons hybridized with magnons in order to downconvert possible axions signals. In addition, we will discuss how magnetic materials can be used for enlarging the mass scanning range for axion dark matter.

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Amorphous topological insulators in theory and experiment

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Résumé

A central goal of contemporary material science is to find new, robust, and universal phenomena that can be technologically useful. Topological phases of matter are one of the most robust phases of matter, and host such potential. However, topological materials are often predicted using crystal symmetries, although topological phases don't rely on them to exist. By doing so we seem forced to exclude all amorphous materials, which are ubiquitous in technology and can display properties that surpass those of crystals. In this talk I will review new topological properties that are only possible in amorphous systems, discuss ways how to predict materials that are both amorphous and topological, and present signatures of topological surface states seen in ARPES experiments on amorphous bismuth selenide. At the end, I will touch upon the many remaining open questions that remain unanswered, with the aim of sparking discussion.

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Andreev spin qubit in nanowire Josephson junction

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Résumé

In a Josephson junction, the transfer of Cooper pair from one superconductor to the other one can be described by the formation of discrete bound states known as Andreev Bound States (ABS). Breaking the spin degeneracy, thanks to the presence of a spin-orbit coupling and a finite phase difference between the two superconducting electrodes, opens the way to the realization of Andreev spin qubits. Here we show, using the formalism of scattering matrices, how spin-flip processes allowed by time-reversal symmetry (TRS) can couple opposite spin states. In particular, the non vanishing current matrix elements between them then allow the manipulation of the spin of ABS.

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Asymmetric and spatially resolved power dissipation in quantum transport

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Résumé

Dissipation is a natural byproduct of quantum transport caused by various inelastic scattering events of electrons and their lost energy stimulates in turn the temperature profile of the underlying bulk material. Importantly though, electronic current may run only through a narrow part of the sample as, for instance, happens in the quantum Hall regime of graphene due to chiral edge channels (1). Henceforth, dissipation has to be seen as a local quantity yielding to "hotter" areas of the sample. The still rather recent invention of the Squid-on-tip technique in 2016 (2), paved the way to experimental access this challenge, where the temperature increases by merely a few hundred micro Kelvin on length scales of the order of nanometers.
Quantum point contacts (QPC's) are of particular interest in nanoscale transport, as electrons experience now a -perhaps energy dependent- transmission probability. On a hand waving level, QPC's increase the resistance electrons face from the sample locally, which is accompanied by areas of higher dissipation. These heat spots have well defined size and occur on characteristic length's away on both sides of the QPC (3, 4). Furthermore, the total dissipated power before and after the QPC may differ depending on the transmission probability (5).

In our recent project, we aim on the simulation of spatially resolved dissipation in quasi 1d systems before we turn towards experimentally more realistic 2d transport geometries. In particular, we predict where and how much power is dissipated.

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Berezinskii-Kosterlitz-Thouless transition in the type-I Weyl semimetal PtBi2

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Résumé

Symmetry breaking in topological matter has become in recent years a key concept in condensed
matter physics to unveil novel electronic states. In our work, we predict that broken inversion symmetry and strong spin-orbit coupling in trigonal PtBi2 lead to a type-I Weyl semimetal band
structure. Transport measurements show an unusually robust low dimensional superconductivity in
thin exfoliated flakes up to 126 nm in thickness (with Tc $\sim 275 - 400$ mK), which constitutes the
first report and study of unambiguous superconductivity in a type-I Weyl semimetal. Remarkably,
a Berezinskii-Kosterlitz-Thouless transition with TBKT $\sim$ 310 mK is revealed in up to 60 nm thick
flakes, which is nearly an order of magnitude thicker than the rare examples of two-dimensional superconductors exhibiting such a transition. This makes PtBi2 an ideal platform to study low
dimensional and unconventional superconductivity in topological semimetals.

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Bolometric detection of Josephson current in a highly dissipative environment

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Résumé

The Josephson junction is a building block of quantum circuits. Its behavior, well understood when treated as an isolated entity, is strongly affected by coupling to an electromagnetic environment. In 1983 Schmid predicted that a Josephson junction shunted by a resistance exceeding the resistance quantum Rq = h/4eˆ2 for Cooper pairs would become insulating since the fluctuations caused by the dissipative environment on the junction's phase difference destroy the Josephson coupling. Although this prediction has been confirmed in charge transport experiments (1), recent microwave measurements have questioned this interpretation (2). Here, we insert a small junction in a Johnson-Nyquist type setup, where it is driven by weak current noise arising from thermal fluctuations. Our heat probe minimally perturbs the junction's equilibrium, shedding light on features not visible in charge transport (3). We find that while charge transport through the junction is dissipative as expected, thermal transport is determined by the inductive-like Josephson response, unambiguously demonstrating that a supercurrent survives even deep into the expected insulating regime of the Josephson junction. The discrepancy between these two measurements highlights the difference between the low frequency and the high frequency response of a junction and calls for further theoretical and experimental inputs on the dynamics of Josephson junctions in a highly dissipative environment.

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Charge noise influence on SiMOS electron spin qubits

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Résumé

Electron spins in semiconductor quantum dots hold great promise as building blocks of quantum processors (1). Trapping them in SiMOS transistor-like devices eases future industrial scale integration (2). In this prospect, it becomes of paramount importance to understand noise effects inferring with the qubit behavior.
One way to address an electron spin qubit is to synthesize an artificial spin-orbit interaction (3). Placing it in an inhomogeneous magnetic field by patterning micromagnets on top of the device enables to drive the qubit through periodic displacement with electric gate voltages. While this method offers more individual qubit addressability and less device heating, it opens a new decoherence channel by coupling the electron spin to the surrounding charge noise.

In this work, we study the origin and the effect of charge noise in typical SiMOS devices meant to trap electron spin qubits. At low frequencies, by using relaxometry to probe the valley splitting, we study the relative influence of Johnson noise and phonon noise on the electron spin (4). At high frequencies, we implement dynamical decoupling pulse sequences on an electron spin to refocus nuclear magnetic noise and obtain a qubit limited by charge

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noise (5). The extrapolation of the noise power spectral density obtained with this technique coincides with low frequency noise probed by simple measurements of current fluctuations in a single-electron transistor (6), most likely coming from fluctuators located in the top interface of the transistor.

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Chiral Discrimination in Helicity-Preserving Fabry-Pérot Cavities

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Résumé

We theoretically investigate the circular dichroism of a helicity-preserving Fabry-Pérot cavity made of two dielectric metamirrors. The latter are designed to act, in a narrow frequency range, as efficient polarization cross-converters in transmission for one polarization, and almost perfect reflectors for the other polarization. The resulting cavity mode is circularly polarized and decoupled (at resonance) from the outside of the cavity. Despite this decoupling, a Pasteur medium hosted inside the cavity can still couple efficiently to both the outside of the cavity and the helicity-preserving mode, inheriting a partial chiral character. The consequence of this mechanism is twofold: it increases the intrinsic chiroptical response of the molecules by two orders of magnitude and it allows for the formation of chiral polaritons upon entering the regime of strong light-matter coupling.

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Coherent coupling of a microwave photon to a hole spin in silicon

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Résumé

Recently, hole spins in silicon and germanium have shown increasing interest for quantum information processing owing to
the advantage of manipulating their state with electric instead of magnetic microwave fields (1, 2). This is possible due to the
strong spin-orbit interaction intrinsically present in the valance band of these materials. Spin-orbit coupling should as well offer

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the possibility to couple a hole spin to the electric field component of a microwave photon, paving the way for a hybrid cQED platform.

Here we show a strong hole spin-photon interaction in gate-defined quantum dots in silicon. We find a coupling strength on the order of 300 MHz, exceeding the combined spin-photon decoherence rate by a factor 27 (3). Our coupling largely exceeds the best figures reported so far in the case of electrons in silicon (4, 5), opening the door for hybrid cQED experiments with hole spins including high-fidelity two qubits gates between distant spins.

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Comparing fractional quantum Hall Laughlin and Jain topological orders with the anyon collider

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Résumé

Anyon collision experiments have recently demonstrated the ability to discriminate between fermionic and anyonic statistics. However, only one type of anyons associated with the simple Laughlin state at filling factor =1/3 has been probed so far. It is now important to establish anyon collisions as quantitative probes of fractional statistics for more complex topological orders, with the ability to distinguish between different species of anyons with different statistics. In this work, we use the anyon collider to compare the Laughlin =1/3 state, which is used as the reference state, with the more complex Jain state at =2/5, where low energy excitations are carried by two co-propagating edge channels. We demonstrate that anyons generated on the outer channel of the =2/5 state (with a fractional charge

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e⋆=e/3) have a similar behavior compared to =1/3, showing the robustness of anyon collision signals for anyons of the same type. In contrast, anyons emitted on the inner channel of =2/5 (with a fractional charge e⋆=e/5) exhibit a reduced degree of bunching compared to the =1/3 case, demonstrating the ability of the anyon collider to discriminate not only between anyons and fermions, but also between different species of anyons associated with different topological orders of the bulk. Our experimental results for the inner channel of =2/5 also point towards an influence of interchannel interactions in anyon collision experiments when several co-propagating edge channels are present. A quantitative understanding of these effects will be important for extensions of anyon collisions to non-abelian topological orders, where several charged and neutral modes propagate at the edge.

Continuous and Efficient Microwave photon to electron conversion using a high impedance circuit

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Résumé

We use granular aluminum to build a high impedance microwave resonator strongly coupled to a hybrid single electron transistor (SINIS based SET). The engineered Fabry-Perot cavity has a large bandwidth set by the finite impedance mismatch on one side and by the transistor on the other. By adjusting the dc-voltage bias and the gate voltage applied to the SET, we tune the photon to electron conversion rate up to a point where it matches the microwave coupling rate of the resonator on the other side. At this critical coupling, microwave photons are efficiently and continuously converted into a flow of electrons across the SET. Remarkably, the quantum efficiency estimated from the measured photo-assisted current approaches unity.

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Controlling topological phases of matter with quantum light

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Résumé

Controlling the topological properties of quantum matter is a major goal of condensed matter physics. A major effort in this direction has been devoted to using classical light in the form of Floquet drives to manipulate and induce states with non-trivial topology. A different route can be achieved with cavity photons. In this talk, I will discuss a prototypical model for topological phase transition, the one-dimensional Su-Schrieffer-Heeger (SSH) model, coupled to a single mode cavity (1). I will demonstrate that quantum light can affect the topological properties of the system, including the finite-length energy spectrum hosting edge modes and the topological phase diagram. In particular, I will show that depending on the lattice geometry and the strength of light-matter coupling one can either turn a trivial phase into a topological one or vice versa using quantum cavity fields. Furthermore, the polariton spectrum of the coupled electron-photon system contains signatures of the topological phase transition in the SSH model.

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Coulomb-mediated antibunching of an electron pair surfing on sound

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Résumé

A surface acoustic wave (SAW) can transfer a single electron via a surface-gate-defined channel between distant quantum dots with very high fidelity (1,2). This acousto-electric transport technique offers an original platform for quantum-optics-like experiments with single flying electrons exploiting their spin (3) or charge degree of freedom (4,5). Here we

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present a SAW-assisted single-electron circuit that consists of two tunnel-coupled transport channels and perform investigations on electron-electron interaction via Hong-Ou-Mandel (HOM) interferometry (6). We transfer a pair of flying electrons from independent sources towards a coupling region calibrated at half transmission. Employing a triggered-sending process, we control the synchronization between the electrons that allows us to contrast the full-counting statistics of the single-shot events with and without interaction. Only when the electron pair is synchronized, we observe an excess in the probability P11 (arrival of one electron at each detector) up to 30%. To unveil the underlying interference mechanism, we perform numerical simulations where Coulomb interaction plays the dominant role. The presented investigation sheds light on the in-flight electron-electron interaction and thus paves the way to implement controlled phase gates in electron-quantum-optics experiments driven by sound. If time allows, I will also briefly highlight our recent results on SAW wave engineering for scalable single-eletron transport (7).

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Coulomb-mediated pairing in a graphene Fabry-Pérot quantum Hall interferometer

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Résumé

Fabry-Pérot quantum Hall Interferometer (FPI) are prototypical devices to achieve anyon braiding and access anionic statistics (1-2). However, Coulomb interaction strongly modifies the non-interacting picture with the emergence at filling factor bigger than 2 of an exotic regime of electron pairing (3). In this talk I will present recent data on graphene-based FPI where bias voltage and plunger gate dependent interferences are used as a new tool to identify and discriminate contributions of each channel to the interference. We evidence a common synchronized pairwise motion between channels stemming from inter-channel electron-electron interaction, which leads to the halving of the Aharonov-Bohm period. Our works clarifies the origin of electron pairing in FPI and demonstrates a new technique of plunger-gate spectroscopy, which will be of great interest for anyon interferometry.

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Creating adiabatic cat states of topologically coupled quantum modes

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Résumé

The simplest topological pump consists in a two level system periodically driven in time at two frequencies (1, 2). We consider a quantum analog of such a pump : two quantum electromagnetic modes strongly coupled to a qubit. We show that any initial state of this system decomposes into a pair of adiabatic states. In a generic adiabatic state, the qubit is entangled with the two quantum modes. We characterize this entanglement in terms of a quantum metric tensor of the model. The time evolution of each adiabatic state induces a topologically quantized energy transfer either from mode 1 to mode 2, or from 2 to 1. Hence, as a consequence of this topological pumping, the pair of adiabatic states splits into states with distinguishable energy content of mode 1 and mode 2, thereby realizing a new kind of cat state (3).
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Determination of the disorder inside an heterostructure using machine learning

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Résumé

The aim of our research is to determine the disorder potential seen by electrons in a two-dimensional electron gas formed inside a semiconductor heterostructure. We have shown that a machine learning approach can be used to characterize the full disorder of a sample from its transport properties (1). While this study was based on simulations only, the next step is to apply our method to a real sample. This implies additional difficulties to tackle, such as the need to have simulated training data that are as close as possible to real samples, and the resulting limitation of the size of the training dataset. We present strategies and techniques to overcome those difficulties and to make progress towards the determination of the disorder in a real sample from scanning gate microscopy conductance measurements. (1) G. J. Percebois and D. Weinmann Phys. Rev. B 104, 075422 (2021)

*Intervenant

Diamagnetic and paramagnetic orbital magnetism in graphene

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Résumé

The recent detection of the singular diamagnetism of Dirac electrons in a single graphene layer(using a highly sensitive Giant Magnetoresistance sensor (GMR)) paved a new way of probing topological materials through the measurement of equilibrium orbital currents (which cannot be accessed in usual transport experiments) Among the predictions, is an intriguing orbital paramagnetism at saddle points of the Fermi surface of 2D materials which can be tested.

In order to reveal this unusual orbital paramagnetism, we present magnetisation measurements in a wide range of Fermi energy of a graphene monolayer encapsulated between two hexagonal boron nitride (hBN) crystals. One of these is nearly alined with the graphene lattice and gives rise to a large period moiré potential.

Beside the sharp diamagnetic McClure response at the Dirac point, followed by de Haas-van Alphen oscillations at larger doping, we detect extra diamagnetic singularities at the satellite Dirac points (SDP) of the moiré lattice. We also find, surrounding these satellite diamagnetic peaks, paramagnetic peaks located at the energy of the saddle points of the Graphene moiré band structure and related to van Hove singularities in the density of states. These findings reveal the existence of an intriguing paramagnetic orbital response in 2D systems, though predicted long ago, when the Fermi energy is tuned to the vicinity of saddle points.

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Disorder-enhanced transport in a chain of lossy dipoles strongly coupled to cavity photons

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Résumé

Over the past several years, strong coupling of matter excitations with confined electromagnetic modes has been shown to significantly modify material properties. In particular, polaritonic excitations are known to exhibit long-range energy transport characteristics. Moreover, while Anderson localization suppresses transport in one-dimensional systems with short-range interaction (1), such hybrid light-matter excitations have been proven robust against disorder (2). Surprisingly, in recent studies of disordered polaritonic systems (3,4), an improvement of the transport characteristics has been observed when increasing the disorder strength, instead of an expected suppression. The interplay between disorder and strong light-matter coupling is therefore highly nontrivial, and its understanding is of primary importance, since disorder is always present in experimental setups.
In this work, we address such interplay by considering a disordered one-dimensional chain of lossy dipoles coupled to a multimode optical cavity through a microscopically-derived Hamiltonian. Such a disordered system hosting polaritonic excitations may be realized experimentally in a wide range of systems with strong light-matter coupling, from plasmonic and dielectric nanoparticles to ultracold atoms or molecules embedded in a photonic cavity.

By analyzing both the eigenspectrum and the driven-dissipative transport properties of our system, we find that in the strong-coupling regime, increasing disorder leads uncoupled dark states to acquire a photonic part, allowing them to inherit polaritonic long-range transport characteristics. Crucially, we show that this disorder-enhanced transport mechanism is increasingly noticeable when the considered dipoles are lossier.

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Dissipative stabilization of squeezing beyond the 3dB limit in a microwave resonator

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Résumé

While a propagating state of light can be generated with arbitrary squeezing by pumping a parametric resonator, the intraresonator state is limited to 3 dB of squeezing. Here (1), we implement a reservoir-engineering method to surpass this limit using superconducting circuits. Two-tone pumping of a three-wave-mixing element implements an effective coupling to a squeezed bath, which stabilizes a squeezed state inside the resonator. Using an ancillary superconducting qubit as a probe allows us to perform a direct Wigner tomography of the intraresonator state. The raw measurement provides a lower bound on the squeezing at about 6.7±0.2 dB below the zero-point level. Further, we show how to correct for resonator evolution during the Wigner tomography and obtain a squeezing as high as 8.2±0.8 dB. Moreover, this level of squeezing is achieved with a purity of 0.91±0.09. (1) Dassonneville et al, PRX Quantum **2**, 020323, (2021)

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Driven Andreev molecule

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Résumé

We study the three terminal S-QD-S-QD-S Josephson junction biased with commensurate voltages. In the absence of an applied voltage, the Andreev bound states on each quantum dot hybridize forming an Andreev molecule. However, understanding of this system in a non-equilibrium setup is lacking. Applying commensurate dc voltages on the bijunction makes the system time-periodic, and the equilibrium Andreev bound states evolve into a ladder of resonances with a finite lifetime due to multiple Andreev reflections (MAR). Starting from the time-periodic Bogoliubov-de Gennes equations we use Floquet theory to map the problem to an infinite tight-binding chain. We calculate the spectrum of the Floquet-Andreev resonances which could be experimentally probed by performing local tunneling spectroscopy on one of the dots. A second observable we consider is the subgap current, which is known to exhibit steps at odd subdivisions of the superconducting gap. We show how the Floquet resonances leave a trace in the current, determining the position of the MAR steps. Proximity of the two dots causes splitting of the steps, while at large distances we observe interference effects which cause oscillations in the I–V curves. The latter effect is similar to the Tomasch effect and should persist at distances much larger than the supercoduncting coherence length.

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Dynamics of Transmon Ionization

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Résumé

Superconducting circuit quantum electrodynamics (circuit QED) is one of the most promising platforms for quantum information processing. In typical circuit QED experiments, the quantum state of the qubit is measured by monitoring a readout resonator weakly and off-resonantly coupled to the qubit. As drive power is increased to achieve a higher fidelity and faster measurement, unwanted transitions occur, which, for example, decrease the qubit's energy relaxation time *T1*. In this talk, focusing on the ubiquitously used transmon qubits, we address the phenomenon of escape into unconfined states (1,2), and unveil a mechanism for rate enhancement during measurement: by interactions between the low-lying states defining the qubit subspace and high-energy chaotic states (3). This analysis can help impose parameter constraints in current experiments.

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*Intervenant

Electron flying qubits using ultrashort electronic charge pulses.

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Résumé

Flying qubits – usually associated with photons – are originally intended to serve as a communication link within a quantum computer and represent a vital part of global roadmaps towards secure data transmission. An alternative approach for flying qubits are single electrons propagating in a semiconductor quantum device (1,2,3). Here we present the development of a flying qubit architecture, based on an electronic Mach-Zehnder interferometer (MZI) using ultrashort electronic charge pulses. Injecting such ultrashort wave packets in a MZI allows manipulation of the quantum state of the qubit in flight, while it is being transferred coherently by means of electrostatic gates. We demonstrate time of flight measurements with electron wave packets with a temporal width down to 25 ps. Furthermore, we observe for the first-time controlled quantum interference when injecting such ultrashort charge pulse into the MZI of a length of 14μm. Strikingly, we observe an increase of the visibility of the Aharonov-Bohm oscillations when the temporal width of the charge pulses are reduced. These results pave the way for the first demonstration of a flying electron qubit with ultrashort charge pulses at the single electron level.

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*Intervenant

Emission of photon multiplets by a dc-biased superconducting circuit

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Résumé

In nature the emission of photon from electronic relaxation is a well known phenomenon. The rate at which this process happens is controlled by the fine structure constant alpha=1/137. Because of this small value, the emission of more than one photon from a single relaxation event is a very rare event in nature and in optical experiments. In order to increase the probability of emission of photon multiplets it is necessary to increase the light-matter coupling intensity which can be done in the context of circuit QED by properly designing an RF resonator (1). I will discuss here the result obtained on a device with a coupling factor alpha = 2 (2). By biasing a SQUID in series with a microwave resonator with a strong inductance coil we observe the emission of k photons for dc voltages Vdc=khf/2e which allows us to witness the emission of photon multiplets up to k=6. In order to investigate the statistic of the emission we compute the Fano factor from measurements of a second order correlator and find that for small enough Josephson energies the Fano factor coincides with k. We also perform a theoretical analysis of our system in order to understand the role of the bias noise as well as the detuning from the resonance condition and find a good agreement between theory and experiment.

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*Intervenant

Encapsulation of carbon nanotubes with hexagonal boron nitride for the fabrication of hybrid quantum circuits

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Résumé

A milestone in the world of 2D materials was the use of hexagonal boron nitride (hBN), a wide band gap insulator, as a protective layer to pick up and encapsulate two-dimensional materials in order to build heterostructures in a contamination-free way (1). Besides the protection against polymers involved in nanofabrication, hBN-encapsulation also prevents subsequent contamination or degradation, allowing the study of air-sensitive materials (2). In this work, we demonstrate the clean hBN-encapsulation of individual carbon nanotubes. We present two different methods to contact carbon nanotubes electrically with normal and superconducting electrodes. These techniques offer new possibilities for the fabrication of hybrid quantum circuits based on carbon nanotubes, such as gatemons (3) or Andreev qubits (4). Our ultra-clean fabrication could reduce the charge noise inherent to these devices and thus surpass the best coherence times obtained so far.

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Enhancement of Kondo effect in a quantum dot formed in a full-shell nanowire

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Résumé

We analyze results of an experiment (D. Razmadze et al., PRB 125, 116803 (2020)) and argue that observed effects cannot be explained by the presence of Majorana bound states but are caused by Kondo effect enhancement due to nontrivial geometry (magnetic flux in a full-shell nanowire). Moreover, we propose that such setup presents a unique and convenient system to study competition between superconductivity and Kondo effect and has significant advantages in comparison to other known approaches, as the important parameter is controlled by the magnetic flux through the full-shell nanowire, which can be significantly varied with small changes of magnetic field, and does not require additional gates. The corresponding competition is of fundamental interest as it results in quantum phase transition between the unscreened doublet and many-body Kondo singlet ground states of the system

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Evidence of dual Shapiro steps in a Josephson junctions array

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Résumé

The modern primary voltage standard is based on the AC Josephson effect and the ensuing Shapiro steps, where a microwave tone applied to a Josephson junction yields a constant voltage hf/2e (h is Planck's constant and e the electron charge) determined by only the microwave frequency f and fundamental constants. Duality arguments for current and voltage have long suggested the possibility of dual Shapiro steps–that a Josephson junction device could produce current steps with heights determined only on the applied frequency. In our setup we embed an ultrasmall Josephson junction in a high impedance array of larger junctions to reveal dual Shapiro steps. For multiple frequencies, we detect that the AC response of the circuit is synchronised with the microwave tone at frequency f, and the corresponding emergence of flat steps in the DC response with current 2ef, equal to the transport of a Cooper pair per tone period. This work sheds new light on phase-charge duality, omnipresent in condensed matter physics, and extends it to Josephson circuits. Looking forward, it opens a broad range of possibilities for new experiments in the field of circuit quantum electrodynamics and is an important step towards the long-sought closure of the quantum metrology electrical triangle.

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Exact Lindbladian spectrum of a dissipative qubit-oscillator system in the dispersive regime

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Résumé

Any quantum system should be treated as an open quantum system in describing its dynamics. It is not only because perfect isolation of a quantum system is unrealistic, but also because control and measurement of a target quantum state are mostly achieved by coupling a target system to another one. For theoretical description of open quantum systems, various approximation methods have been developed so far. In studies of quantum control, one usually assumes a time evolution that is Markovian and completely positive. These assumptions lead to a Lindblad master equation, whose generator is called Lindbladian (1). Since it is a linear differential equation, the time evolution can in principle be computed if spectrum and eigenvectors of the Lindbladian are obtained.
As a well-studied system in the context of quantum control, we consider a qubit-oscillator system in the dispersive regime, where the coupling strength is much smaller than the magnitude of the qubit-oscillator detuning frequency. In the dispersive regime, the oscillator frequency is shifted depending on the qubit state. This behavior makes it possible to perform a quantum non-demolition measurement of the qubit state, which has been realized, for instance, for a transmon qubit in a circuit quantum electrodynamics architecture (2). To readout the qubit state, the qubit-oscillator system is coupled to a transmission line. This coupling inevitably leads to dissipation, effects of which can be simulated with a Lindblad master equation.

Understanding of the Lindbladian for a dispersive qubit-oscillator system has been limited so far. Recently, the authors of (3) proposed a basis on which the matrix form of the Lindbladian becomes block diagonal. Although this facilitates numerical computation of the spectrum greatly, one still needs truncation of the oscillator Fock states. In this talk, we will present exact and analytic expressions of full Lindbladian spectrum. To solve the eigenvalue problem, we will use the third quantization technique (4), which enables to diagonalize a quadratic Lindbladian for a bosonic system. While the original formulation is applicable only to trace-preserving generators, it is necessary for the present problem to diagonalize a non-trace preserving generator. For this reason, we will discuss an extension of the formulation. We will then find analytic expressions of full spectrum and eigenvectors. We will utilize those results to obtain the Kraus map form of the time evolution and to discuss the long-time decoherence rate of the qubit.
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Gapful electrons in a vortex core of granular superconductor

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Résumé

We generalize classical solution for electron density of states (DoS) inside vortex core of
a
disordered superconductor for the case of granular superconductors. Discrete version of the
Usadel
equation for a vortex is derived and solved numerically for a broad range of parameters.
Electron
DoS is found to be gapful when the vortex size ξ becomes comparable to the grain size a.
Minigap
magnitude Eg grows from zero at $\xi \approx 1.4$a to nearly half of superconducting gap at $\xi \approx$
0.5a.
The absence of low-energy excitations explains strong suppression of microwave dissipation
in a
mixed state of granular Al.

*Intervenant

Giant Chirality Induced Spin Selectivity of Polarons

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Résumé

The chirality-induced spin selectivity (CISS) effect gives rise to strongly spin-dependent transport through many organic molecules and structures. Its discovery raises fascinating fundamental questions as well as the prospect of possible applications. The basic phenomenology, a strongly asymmetric magnetoresistance despite the absence of magnetism, is now understood to result from the combination of spin-orbit coupling and chiral geometry. However, experimental signatures of electronic helicity were observed at room temperature, i.e., at an energy scale that exceeds the typical spin-orbit coupling in organic systems by several orders of magnitude. In this talk I will first introduce the experimental observations of the CISS effect. Then, I will show that a new energy scale emerges for currents carried by polarons, i.e., in the presence of strong electron-phonon coupling. In particular, we found that polaron fluctuations play a crucial role in the two manifestations of CISS in transport measurements—the spin-dependent transmission probability through the system and asymmetric magnetoresistance.

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Graphene based superconducting quantum circuits

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Résumé

In the last decades, the size of the electronic components has shrunk to a point where current devices are smaller than 10 nm. At this scale, the quantum behaviour of those systems must be taken into account. It is now possible to engineer reproducible and controllable quantum devices thanks to recent researches in this field. The more advanced devices to date are based mostly on superconducting materials but the issue is that they rely on magnetic fields to be manipulated. While it is not an industry standard, it also starts to be a problem in large scale circuits because of crosstalk issues. Two building blocks for possible future quantum computers are the quantum bit (qubit), which is a quantum system allowing quantum calculation and the parametric amplifier, a device that is able to perform a low noise readout of a quantum system. The goal of this project is the integration of a one atom-thick sheet semiconductor material, graphene, in the Josephson junction : the core element of superconducting quantum circuits. The integration of this material will make the devices tunable thanks to an electric field. Therefore, we will be able to control these building blocks by a simple gate voltage.

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Ground state cooling of an ultracoherent electromechanical system

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Résumé

Cavity electromechanics relies on parametric coupling between microwave and mechanical modes to manipulate the mechanical quantum state, and provide a coherent interface between different parts of hybrid quantum systems. High coherence of the mechanical mode is of key importance in such applications, in order to protect the quantum states it hosts from thermal decoherence.
We present the characterisation at milli-Kelvin temperatures of a microwave electro-mechanical system featuring an ultra-coherent phononic-crystal membrane (1). The mechanical dissipation rate is measured down to 30mK reaching a Q-factor of 1.5 billion, at 1.485MHz mode frequency. Then we perform resolved sideband cooling on the mechanical mode, cooling it to its motional ground state (nmin = 0.76 ± 0.16) (2).
We thus show the operation of an electromechanical system in the quantum regime, where its coherence time is estimated to be ∼ 100ms. We also show microwave-induced mechanical broadening up to 630Hz, reaching manipulation speeds on the order of state-of-the-art superconducting qubits coherence times (3) making our device a candidate for microwave quantum memories (4). (1) Y. Tsaturyan, A. Barg,E. S. Polzik and A. Schliesser "Ultracoherent nanomechanical resonators via soft clamping and dissipation dilution", Nature Nanotechnology 12 (June 2017), p. 776. doi:10.1038/nnano.2017.101
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Heat Equilibration of Integer and Fractional Quantum Hall Edge Modes in Graphene

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Résumé

Hole-conjugate states of the fractional quantum Hall effect host counterpropagating edge channels which are thought to exchange charge and energy. These exchanges have been the subject of extensive theoretical and experimental works; in particular, it is yet unclear if the presence of integer quantum Hall edge channels stemming from fully filled Landau levels affects heat equilibration along the edge. We present heat transport measurements in quantum Hall states of graphene demonstrating that the integer channels can strongly equilibrate with the fractional ones, leading to markedly different regimes of quantized heat transport that depend on edge electrostatics. Our results allow for a better comprehension of the complex edge physics in the fractional quantum Hall regime.
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Heat transfer modelling in the crossover regime between conduction and radiation

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Résumé

Fluctuational electrodynamics (FED) theory describes the near field radiative heat transfer for separation distances below the thermal wavelength (some microns at ambient temperature), where the heat flow between two solids at different temperatures can exceed the far field limit by several orders of magnitude, in particular when the bodies exchanging heat support surface resonant modes, such as surface phonon-polaritons or surface plasmons.
At even smaller distances, in the so-called extreme near field (distances in the nanometer range and below) the physics is expected to change radically. Interestingly, two recent scanning thermal microscopy (SThM) experiments, approaching gold tips to gold substrates, reach apparently opposite conclusions. While one of them shows large deviations from FED for separation distances of few nanometers, another experiment shows no deviations from FED even at sub-nanometer gaps, where acoustic phonons and electrons are expected to contribute as further channels to the heat exchange.
Here we introduce a theoretical framework to investigate the heat transfer mediated by photons, phonons and electrons between two metallic bodies. We quantify the role of electron tunnelling currents by paying attention to the role played by the shape of the electronic barrier in the presence of electron-electron screening interactions. Using an approach based on the elastic theory, we address the role of acoustic phonons coupled through the Van der Waals and the electrostatic forces. Finally, we employ FED to study the role played by photons, by taking into account the contribution of non-local effects. These theoretical approcahes allows us to outline the relative weight of the different carriers with respect to the separation distance, and to highlight the crucial role played by the external bias voltage on the heat flux carried by the three types of carriers.

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Josephson Diode effect and Bilinear Magnetoelectric resistance in Bismuth nanowires

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Résumé

We investigate the Josephson diode effect, namely the difference in critical current with opposite current orientation in finite magnetic field. This effect is often attributed to strong spin-orbit interactions combined with spatial inversion and time-reversal symmetry breaking, which induce a non-negligible triplet component in the Josephson current.
However other more trivial causes can also produce the same effect, such as self-field or inductive effects.

To investigate this question, we have probed magnetoelectric transport in crystalline nanowires of bismuth, a material with strong spin-orbit interactions, in both the normal state and in the proximity-induced superconducting state.

We have measured the field dependence of the critical current of Josephson junctions containing bismuth nanowires as their weak link for different field orientations. We find a strong field-asymmetry of the critical current (which has opposite sign for opposite current, as expected), the so-called Josephson Diode effect. We show that the shift in this Josephson interference pattern of the critical current can be interpreted in terms of an effective magnetic field superimposed to the applied one.

In order to investigate the role played by the strong spin-orbit coupling on this effect, we also performed magneto-electric experiments on the same nanowires in the normal state. This was done by measuring the second harmonic response in voltage to an AC current excitation. We find that this response varies linearly with field, which yields a bilinear magnetoresistance. This bilinear magnetoresistance is the signature of the Edelstein effect, (i.e.) the spin polarization induced in high-spin-orbit materials without inversion symmetry. Here as in the superconducting state, the current-induced spin-polarization can be interpreted as due to an effective field acting on the spins and proportional to the current.
We analyze this effective magnetic field for different orientations of the applied magnetic field. We find a similar behavior in the N state as in the S state, with however a different amplitude of the effective field. The combination of these experiments suggests that bismuth nanowires display an Edelstein effect both in the normal and the superconducting state

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Josephson two-tone spectroscopy in the Extremely High Frequency band

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Résumé

We have developed a novel two-tone spectrometer able to detect resonances of mesoscopic quantum systems up to unprecedented high frequencies (~100 GHz). We use a voltage-biased Nb Josephson junction as an on-chip source of high-frequency radiation to irradiate the System-of-Interest (SoI). Contrary to previous experiments (1)(2) where the absorption of energy by the SoI was detected by measuring the dc current through the junction, in our work we directly detect the excitation of the SoI through the dispersive shift of a coupled superconducting resonator. This simplifies the operation of our spectrometer as the detection part is separated from the excitation. We also benefit from the superior sensitivity of the high quality factor cavity.

Our spectrometer could be used to e.g. study the Andreev bounds states located in hybrid superconducting nanostructures (3) without destroying their quantum coherence. (1) Bretheau, L., et al. "Exciting Andreev pairs in a superconducting atomic contact." *Nature* 499.7458 (2013): 312-315

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Kondo Spin Universal Renormalization flow

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Résumé

The Kondo model is ubiquitous in the context of strongly correlated systems, underpinning a variety of phenomena from the emergence of exotic non-abelian particles to heavy fermions and high-Tc superconductivity. The central element of this model is a local 'Kondo' spin that effectively mediates interactions between itinerant electrons: As the temperature goes down, an initially weak antiferromagnetic coupling of the Kondo impurity with the spin of the electrons progressively grows, thereby giving rise to strong electronelectron correlations. While huge body of theoretical, numerical and experimental works focuses on this Kondo model for decades, thermodynamic observations and notably of the pivotal spin of the Kondo impurity remain elusive.

Here, with a novel 'charge' Kondo circuit implementation, we directly observe the progressive screening of the impurity. In our device, the Kondo (pseudo) spin is realized by two degenerate charge states of a metallic island. The use of a non-invasive, capacitively coupled charge sensor allows for the investigation of the thermodynamic properties of the (pseudo) spin. In the 'charge' implementation of the cardinal (1-channel) Kondo model, we establish the universal renormalization flow of both the spin magnetization and susceptibility coefficient from a free spin to a screened singlet. The flow is also associated to a relationship between scaling Kondo temperature and circuit parameters.

Such (pseudo) spin probe of an engineered Kondo system opens the way to the thermodynamic investigation of many exotic quantum states, including the clear observation of Majorana zero modes through their fractional entropy

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Local density of state fluctuations in 2d multifractal superconductor

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Résumé

The interplay of superconductivity and disorder is known to generate a wealth of new phenomena which have driven the history of superconductivity since its infancy. One of the major breakthroughs in the field was the celebrated quantum phase transition from superconductor to insulating state. Interestingly, the opposite effect has been reported several times: an increase of the superconducting critical temperature by disorder. One of the proposed mechanisms involves the peculiar structure of diffusive electronic wavefunctions whose multifractality can increase the superconducting pairing. Recent experiments in monolayer NbSe2 on graphene have reported Tc enhancement due to multifractal superconductivity but the field-theoretical models at our disposal fail to account for this effect at the relevant level of disorder.

In this work, we use an epitaxial monolayer of lead showing a simple band structure and homogenous structural disorder as a model system of a 2d multifractal superconductor in the weak-antilocalization regime. Then, we perform an extensive study of the emergent fluctuations of local density of states in this material and compare them with both analytical results and numerical solution of the attractive Hubbard model. We show that mesoscopic LDOS fluctuations allow to probe locally elastic scattering and dephasing rate in 2d weakly disordered materials in particular in the most interesting multifractal regime.

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Long-range nontopological edge currents in charge-neutral graphene

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Résumé

Van der Waals heterostructures display a rich variety of unique electronic properties. To identify novel transport mechanisms, nonlocal measurements have been widely used, wherein a voltage is measured at contacts placed far away from the expected classical flow of charge carriers. This approach was employed in search of dissipationless spin and valley transport, topological charge-neutral currents, hydrodynamic flows and helical edge modes. Monolayer, bilayer, and few-layer graphene, transition-metal dichalcogenides, and moire superlattices were found to display pronounced nonlocal effects. However, the origin of these effects is hotly debated. Graphene, in particular, exhibits giant nonlocality at charge neutrality, a prominent behavior that attracted competing explanations. Utilizing superconducting quantum interference device on a tip (SQUID-on-tip) for nanoscale thermal and scanning gate imaging, we demonstrate that the commonly-occurring charge accumulation at graphene edges leads to giant nonlocality, producing narrow conductive channels that support long-range currents. Unexpectedly, while the edge conductance has little impact on the current flow in zero magnetic field, it leads to field-induced decoupling between edge and bulk transport at moderate fields. The resulting giant nonlocality both at charge neutrality and away from it produces exotic flow patterns in which charges can flow against the global electric field. We have visualized surprisingly intricate patterns of nonlocal currents, which are sensitive to edge disorder. The observed one-dimensional edge transport, being generic and nontopological, is expected to support nonlocal transport in many electronic systems, offering insight into numerous controversies in the literature and linking them to long-range guided electronic states at system edges.

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Luttinger-liquid behaviour in quantum Hall tunnelling as seen through the tunnelling noise

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Résumé

One of the striking predictions of quantum Hall edge theory, alongside the fractional charge and fractional statistics of the quasiparticles, is the power-law dependence of the conductance of a tunnel contact. This power-law dependence is characteristic of Luttinger liquids and is tied to the quasiparticle property called "scaling dimension". Observing this behaviour is known to be problematic both in terms of achieving the qualitatively correct behaviour in experiments and quantitatively matching with theory (1–3).

I will present recent theory (4) that enables extracting the scaling dimension from the Fano factor – building upon the scheme long used to extract the fractional charge. I will further present the analysis of experimental data within this theoretical framework. I will demonstrate how it sheds light on the physics of quantum point contacts in the quantum Hall effect and opens new avenues to investigate renormalization of the Luttinger liquid behaviour.

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Magnetotransport in 3D topological insulator nanowires

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Résumé

In 3D topological insulator nanostructures low-temperature phase-coherent transport ideally takes place on a 2D Dirac metal wrapped around an insulating 3D bulk. These conditions are difficult to realise in BiSe-based samples – where the bulk typically behaves as a Coulomb glass, rather than as simple effective vacuum (1) – but are established in particular in high-quality HgTe systems (2).
In the ideal scenario magneto-transport is uniquely due to Dirac electrons propagating on a non-planar surface. It is thus strongly dependent on a peculiar conjunction of structural (real space) and spectral (reciprocal space) geometrical properties, which together determine the quantum channels available for electronic transmission. The latter essentially depend on the competition between quantum confinement and geometrical (Aharonov-Bohm and Berry) phases, and qualitatively different transport regimes – sensitive to the nanowire shape – become available by simply reorienting in space a field in the Tesla range (3, 4). Furthermore, if the surface Dirac electrons propagate on is curved, effective gravity will in general affect electronic transport.

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Mesoscopic Klein-Schwinger effect in graphene

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Résumé

Strong electric field annihilation by particle-antiparticle pair creation, described in detail by Sauter and Schwinger, is a basic non-perturbative prediction of quantum electrodynamics. Its experimental demonstration remains elusive as Schwinger fields E_s are beyond reach even for the light electron-positron pairs. Here we put forward a mesoscopic variant of the Schwinger effect in graphene, which hosts Dirac fermions with electron-hole symmetry. Using DC transport and RF noise, we report on universal 1d-Schwinger conductance at the pinch-off of ballistic graphene transistors. Strong pinch-off electric fields are concentrated in a length Lambda_˜0.1μm at the transistor drain, and induce Schwinger e-h pair creation at saturation, for a Schwinger voltage Vs=EsxLambda on the order of the pinch-off voltage. This Klein-Schwinger effect (KSE) precedes a collective instability toward an ohmic Zener regime, which is rejected at twice the pinch-off voltage in long devices. The KSE not only gives clues to current saturation limits in ballistic graphene, but also opens new routes for quantum electrodynamic experiments in the laboratory.

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Middle-infrared Electroluminescence of Graphene transistors

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Résumé

In this talk, I will present our recent discovery of graphene's electroluminescence in the mid-infrared spectral range. Electroluminescence is the phenomenon by which a material

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emits light in response to the passage of an electrical current. In solids, it is the prerogative of semiconductors and related organic materials, and it results from the radiative recombination of electrons and holes. The semi-metallic nature of graphene a priori forbids electroluminescence. Nonetheless, electroluminescence is possible, because (i) of the remarkable inefficiency of the non-radiative carrier relaxation in graphene, and (ii) thanks to an original carrier injection mechanism specific to 2D semimetals: the Zener-Klein tunneling conductance (1). We study high mobility graphene field-effect transistors at room temperature and ambient conditions. These transistors consist of a monolayer graphene flake encapsulated in a hexagonal Boron nitride (hBN) insulator, deposited on a gold backgate. When subjected to a large bias, we observe the appearance of a sharp emission peak at a photon energy of 167 meV (1350 cm-1) in the far-field radiation spectrum of the transistor (see Fig. (a)). Using a series of test experiments in the near-infrared and middle-infrared ranges, we show the electroluminescent nature of this emission (2). Using mid-infrared micro-spectroscopy, we observe the electroluminescent signal originating from the scattering of confined hyperbolic phonon-polaritons (3,4) close to the second reststrahlen band of hBN (Fig., panels (a) and (b)).

Mixed anomalies in inhomogenous tilted Weyl semimetals

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Résumé

We propose a non-dissipative transport effect and vortical response in Weyl semimetals in the presence of spatial inhomogeneities, namely a spatially varying tilt of the Weyl cones. We show that when the spectrum is anisotropic and tilted due to a spatial lattice variations, one is confronted with generalized quantum anomalies due to the effective fields stemming from the tilt structure. In particular, we demonstrate that the position-dependent tilt parameter induces a local vorticity, thus generating a chiral vortical effect even in the absence of rotation or magnetic fields. As a consequence, couples to the electric field and thus contributes to the anomalous Hall effect.

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Moiré-of-moiré low-energy effective theory of twisted trilayer graphene

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Résumé

Stacking three monolayers of graphene with a twist generally produces two moiré patterns. A moiré of moiré structure then emerges at larger distance where the three layers periodically realign. We devise here an effective low-energy theory to describe the spectrum at distances larger than the moiré lengthscale. In each valley of the underlying graphene, the theory comprises one Dirac cone at the _M point of the moiré Brillouin zone and two weakly gapped points at K_M and K_M. The velocities and small gaps exhibit a spatial dependence in the moiré-of-moiré unit cell, entailing a non-abelian connection potential which ensures gauge invariance. The resulting model is numerically solved and a fully connected spectrum is obtained, which is protected by the combination of time-reversal and twofold-rotation symmetries.

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Nature of electronic correlations in twisted bilayer graphene

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Résumé

The experimental discovery of insulating and superconducting states in magic-angle twisted bilayer graphene (MATBG) in 2018 has revolutionized the field of condensed matter physics, as it opens platforms for engineering tunable materials with unforeseen properties. Of particular interest is the enhanced importance of electronic interactions due to quenched electron kinetic energy. MATBG shows many signatures of strong electronic correlations, some of them sharing important similarities with cuprate high temperature superconductors. Still, a lot is unknown on the nature and the consequences of the electronic correlations in MATBG and the connection with other highly studied strongly correlated systems is also not clear. Using a Wannier-function based tight binding model, we investigate the nature of electronic correlations in TBG within a theoretical framework combining dynamical mean-field and Hartree calculations. We find a significant spectral weight reorganization in the correlated normal state at experimentally relevant interactions, giving an understanding of the so-called correlated insulating states with highly anomalous doping and temperature dependencies.

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Near-field heat transfer in many-body systems

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Résumé

In this lecture I will discuss how to handle the radiative heat exchanges in many-body systems consisting of thermal emitters interacting in the near-field regime. After briefly introducing the theoretical framework to describe these exchanges I will discuss some specific effects that occur in these systems and I will show how they can be used to control heat exchanges at nanoscale or to harvest the near-field energy confined close to a hot solid.

In the first part I will introduce a Landauer-like approach to describe the radiative heat exchanges in multi-terminal systems. I will deduce a general rule linking the pairwise transmission coefficients and I will show that supercurrents can exist at equilibrium particular many-body systems. In the second part I will introduce a thermal analog of Coulomb drag effect and I will show how this effect can be used to locally control the temperature gradients in many-body systems. Next I will show how the cooperative interactions between N> 2 thermal emitters held at different temperature can be used to control locally the Poynting vector. I will discuss the potential of this effect to focus and even amplify the heat flux in the close surrounding of these systems at a scale length which is much smaller than the diffraction limit. In the third part I will show that non-trivial topological behaviors have been highlighted in non-reciprocal systems (thermomagnetic effects and geometric pumping) and I will discuss how they could be exploited to control heat flux at nanoscale. Finally I will present a three-body energy converter of the near-field energy confined closed to a hot solid and I will show that that this technology could be an efficient alternative to the so called near-field thermophotovoltaic conversion at low grade temperature ($T <$ 500K) and small temperature differences (DT_˜100K).

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Observation of strong conversion in multi-mode circuit-QED

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Résumé

Non linear losses are ubiquitous in strongly interacting systems and are usually inferred through indirect measurements such as comparisons to phenomenological models. Leveraging the tools of circuit-QED, we designed a multi-mode resonator revealing strong conversion processes between modes of the latter. This strong conversion regime is characterised by a conversion rate greater than the intrinsic losses, then acting as the dominant loss channel. A fluorescence experiment enables us to directly measure the emitted converted photons and thus to directly measure non-linear dissipation in circuit-QED. This work opens prospects for the study of dissipation in quantum systems.

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Obstructed insulators and flat bands in topological phase-change materials

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Résumé

Phase-change materials are ubiquitous in technology because of their ability to transition between amorphous and crystalline phases fast and reversibly, upon shining light or passing a current. Here we argue that to fully understand their electronic properties it is necessary to define a novel electronic phase: the amorphous obstructed insulator. It differs from an obstructed insulator crystal in that it presents localized edge or surface states irrespective of the sample termination. Consequently, we show that obstructed amorphous insulators in three-dimensions host a surface two-dimensional flat band, detectable using ARPES. Our work establishes basic models for materials where topological and obstructed properties can be switched on and off externally, including two-dimensional surface flatbands.

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On-chip picosecond electrical pulses for flying qubits

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Résumé

In quantum information, flying qubits are usually associated with photons. An interesting approach is to use electrons instead of photons and by taking advantage of the Coulomb coupling to manipulate them. However, due to the short coherence time of electrons in a solid-state system, it is necessary to develop electronics working at the THz frequency scale. Flying electron qubits can be generated by applying short voltage pulses to a two-dimensional electron gas (2DEG) (1) and make them propagate in a Mach-Zehnder-type interferometer (2,3). The current state-of-the-art for electrical pulse generation is about 30 picoseconds, which limits to few quantum operations in a 10 micron long quantum device. To reach shorter pulses a radically different technology has to be developed.

Here we present the development of a cryo-optoelectronic setup to generate picosecond voltage pulses for quantum applications. The system consists of 4 optical fibres which are integrated into a a dilution refrigerator. A femtosecond laser pulse is converted on-chip (and at low temperature) into an electrical voltage pulse via a photo-switch (4) deposited onto a low temperature grown GaAs layer with picosecond photo response time. We demonstrate picosecond pulse generation via time-resolved pump-probe measurements. This ultra-short electronic pulse can be conveyed using a co-planar waveguide and injected into a high mobility 2DEG. This on-chip integration of picosecond voltage pulses into quantum nanoelectronic devices paves the way for ultrafast control of electronic flying qubits.

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Optimizing resource efficiencies for scalable full-stack quantum computers

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Résumé

With the race to build scalable quantum computers, optimizing the resource consumption of the full stack becomes crucial. The full stack is everything from the qubits to the end-user, and includes the qubits, the quantum algorithm, error correction, cryogenics, wiring, control electronics, etc. Optimizing it requires a synergy of fundamental physics and engineering; the former for the microscopic aspects of computing performance, and the latter for the macroscopic resource consumption. With this aim, we propose a universal methodology dubbed Metric-Noise-Resource (MNR) to quantify inputs from different levels of description: quantum physics (e.g. noise on qubits), quantum information (computing architecture, type of error correction) and enabling technologies (e.g. cryogenics, control electronics, wiring). To show quantitative applications of MNR, we use it to minimize the power consumption of a full-stack quantum computer, performing noisy or fault-tolerant computing with a target performance. This holistic approach allows us to define and study resource efficiencies as ratios between performance and resource cost. Comparing a classical computer and a fault tolerant quantum processor in the execution of the same useful task, we identify a potential quantum advantage of energetic nature for regimes of parameters distinct from the usually targeted quantum computational advantage. This provides a new and so far overlooked practical argument for building quantum computers. While our simulations use parameters inspired from the superconducting platform and concatenated codes, our framework is versatile and easily applicable to various qubits and codes – providing experimenters with guidelines to build energy efficient quantum processors.

*Intervenant

Optomechanics of a suspended magnetic van der Waals heterostructure

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Résumé

The persistence of a magnetic order in a monolayer of van der Waals magnetic material has been established a few years ago, offering the perspective to embed a magnetic degree of freedom in heterostructures made of other bidimensional materials such as graphene or light-emitting transition metal dichalcogenides. The physical properties of van der Waals materials can be easily tuned by perturbations like strain or doping, inviting to the exploration of magnetism in two dimensions and its manipulation to unveil novel physical phenomena. We will present our current efforts on suspended magnetic van der Waals heterostructures, forming drum-like resonators, through optomechanics combined with optical spectroscopy to investigate the relations between magnetic order, strain and proximity effects in these systems.

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Probing Andreev States in ultra-clean carbon nanotube-based Josephson junctions

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Résumé

This poster presents the details and latest achievements in the novel fabrication of ultra-clean carbon nanotube-based junctions developed at the QCMX lab in Ecole polytechnique. When contacted to normal electrode, hundreds of Coulombs diamonds can be observed on a large gate span indicating the quality of our devices. Preliminary results will also be shown of a similar device contacted to superconducting electrodes.

*Intervenant

Probing entanglement in quantum processors with randomized measurements

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Résumé

First, I will introduce the concept of entanglement, in relation with quantum computers and quantum simulators.
I will then present the randomized measurement toolbox, which gives experimental access to entanglement-related quantities.
This will be illustrated with recent experimental works performed on quantum computers.
Finally I briefly mention recent upgrades of the toolbox for
- increasing the system sizes where the protocols can be applied.
- measuring new physical quantities with controlled statistical errors and efficient data processing.

*Intervenant

Purely quartic nonlinearity in cavity optomechanics

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Résumé

Introducing a controlled and strong anharmonicity in mechanical systems is a present challenge of nanomechanics. The anharmonicity allows one to generate non-classical states of the mechanical oscillator and, if the anharmonicity is sufficiently large, to address individually the mechanical excited states. It is well known that for sufficiently large laser power an optomechanical cavity exhibits a classical static instability. We investigated under which conditions the instability could be tuned in such a way that a smooth crossover could be observed from a harmonic potential to a purely quartic potential (see Figure). Unlike the previously studied optomechanical dynamical instability that comes about for large amplitude mechanical oscillations, the quartic nonlinearity appears to survive - and is perhaps even enhanced - for low laser power. The quadratic-quartic crossover could be exploited to tailor an anharmonicity in a precise way, in order to manipulate the state of the mechanical oscillator and, under certain conditions, fabricate non-classical quantum states.

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Quantum electron transport affected by cavity vacuum fields: breakdown of topological protection in quantum Hall systems and other effects

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Résumé

In this seminar, I will present recent results on how cavity vacuum fields can control quantum electron transport via the counter-rotating-wave terms of light-matter interaction, including quantum Hall systems (1,2,3) and beyond (3).
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Quantum phase slips in a resonant Josephson junction

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Résumé

We investigate the consequences of resonant tunnelling of Cooper pairs on the quantum phase slips occurring in a Josephson junction. The amplitude for quantum tunnelling under the Josephson potential barrier is modified by the Landau-Zener amplitude to excite an Andreev bound state, resulting in the suppression of 2π*phaseslips.Asaconsequence*, *closetoresonance*, 4π*phaseslipsbecomethedominanttunnellingprocess.W*

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Quantum plumbing: the mysteries of nanoscale flows

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Résumé

Liquids are usually described within classical physics, whereas solids require the tools of quantum mechanics. I will show how in nanoscale systems this distinction no longer holds. At these scales, liquid flows may in fact exhibit quantum effects as they interact with electrons in the solid walls. I will first discuss the quantum friction phenomenon, where charge fluctuations in the liquid interact with electronic excitations in the solid to produce a hydrodynamic friction force. Using many-body quantum theory, we predict that this effect is particularly important for water flowing on carbon-based materials, and we obtain experimental evidence of the underlying mechanism from pump-probe terahertz spectroscopy. I will then show how the theory can be pushed one step further to describe hydrodynamic Coulomb drag – the generation of electric current by a liquid in the solid along which it flows. This phenomenon involves a subtle interplay of electrostatic and electron-phonon interactions, and suggests strategies for designing materials with low hydrodynamic friction.

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Quasiparticle-induced errors in Kerr cat qubits

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Résumé

Understanding mechanisms of qubit decoherence is a crucial prerequisite for improving the qubit performance.
In this work we discuss effects of residual Bogoliubov quasiparticles in Kerr cat qubits.
The major difference from previous studies of quasiparticles in superconducting qubits is that the Kerr qubits are operated under non-equilibrium conditions. Indeed, an external microwave drive is needed to initialize "cat states", which are
coherent degenerate eigenstates of the effective stationary Hamiltonian in the rotating frame.
To analyze the impact of the external drive on the quasiparticles, we derive a kinetic equation from which we determine quasiparticles' dynamics and their effect on the qubit state.
We find that the main effect is probability leakage from the cat states to non-computational states, and we estimate the qubit lifetime associated with this process.

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Quasiparticles Andreev scattering in the =1/3 Fractional Quantum Hall regime

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Résumé

The scattering of exotic quasiparticles may follow different rules than electrons (1,2). In the fractional quantum Hall regime, a quantum point contact (QPC) provides a source of quasiparticles with selectable charges and statistics (3,4). These can then be scattered on a downstream 'analyzer' QPC to investigate these rules. Remarkably, for incident quasiparticles dissimilar to those naturally transmitted across the analyzer, electrical conduction conserves neither the nature nor the number of the quasiparticles. This contrasts with standard elastic scatterings where the quasiparticles are reflected or transmitted emulating an electronic beam splitter. Instead, theory predicts the emergence of a mechanism akin to the Andreev reflection at a normal-superconductor interface (5), but without interface with a superconductor or a different quantum Hall state.
Here, I will present direct observations of the predicted Andreev-like reflection of an $e/3$ quasiparticle into a $-2e/3$ hole accompanied by the transmission of a charge e quasielectron (6). Combining shot noise and cross-correlation measurements, the charge of the different particles is independently determined and the coincidence of quasielectron and fractional hole is demonstrated. This unconventional behaviour of a fundamental building block of quantum transport for fractional quasiparticles, may have implications toward the generation of exotic quasi-particles/holes and non-local entanglements. Given the multiplicity of quasiparticles accessible through the tuning of the filling factor, it is likely that the present observation develops into a family of Andreev-like mechanisms.

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Revealing topological hinge states in the second order topological insulator Bi4Br4

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Résumé

Topological Insulators (TIs) hold great promise for making novel electronic devices, thanks to the existence at their boundaries of topologically protected conduction channels. Unfortunately, the expected protection has revealed to be less robust than anticipated, notably due to inelastic processes involving bulk excitations. This complicates the fundamental study of the edge states, and motivates the search for different TIs with less non-topological bulk states. Among newly discovered TIs, Bi4Br4 appears to be a very promising material, with a large bulk gap (_˜ 230 meV), and experimental indications of a Second Order Topological Insulator (SOTI) character. SOTIs are topological insulators with (d-2)-dimensional topological states, d being the dimension of the bulk. Indeed, 1D states were visualized by STM at the hinges of a Bi4Br4 crystal, persisting up to 300K. Our work has been focused on evidencing these hinge states in transport experiments, both with non-superconducting and superconducting electrodes, as a function of magnetic and gate voltage. With normal electrodes, we have found signatures of phase coherence in μm-sized samples with surprisingly large characteristic fields, and a strongly anisotropic behavior. However, the analysis of those results has proven difficult, likely due to parasitic, non-topological channels that may coexist alongside the topological edge states. To better evidence the topological 1D edge states, we turned to superconducting contacts. Indeed, because they are ballistic, topological states can carry large supercurrents when proximitized with superconducting electrodes, hence magnifying their signatures in transport. In our most recent experiments, we find sizeable supercurrents in S-Bi4Br4-S Josephson junctions that persist up to extremely high fields (several Teslas).

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RF-Transport through Hall Bar coupled to Microwave Resonator

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Résumé

We present an experimental investigation of RF magneto-transport through a mesoscopic Hall bar (∼20x10 um
dimensions in the quantum Hall Effect. The Hall bar is galvanically coupled to two high impedance (Zc=1k) resonators
providing each a detection impedance of about 20k in a detection bandwidth of about 300 MHz around 5 GHz by
transforming the impedance of 50 detection line. The lines are connected to an external detection circuit enabling us to
measure the RF transmission through the Hall bar, but also to detect the RF noise emitted upon charge partitioning by the
QPC. Transport through the bar is modulated by applying a perpendicular magnetic field, but also by applying negative
voltages to top gates in switch, or split-gate geometry.

We first calibrate the detection circuit by measuring the transmission of the Hall bar as a function of the QPC
voltage at zero magnetic field, where the electrodynamics of the Hall bar are simpler to predict. We then apply quantizing

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magnetic fields and monitor changes in the RF transmission through the device. While DC magneto-transport shows usual
quantum Hall signature (large Hall plateaus with vanishing longitudinal resistances), RF transport though the Hall bar shows
a smoother evolution with magnetic field yet following 1/B oscillations on top of a continuous evolution.

We also present RF emission noise measurements in the =2 quantum Hall regime showing that the outer edge
channel is able to convey about 3 times more power than the inner edge channel within the probed length (L=10um) and
energy (hf=20 ueV) scales.

Role of optical rectification in photon-assisted tunneling current

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Résumé

Emission of light and conversely rectification of an optical signal using an all-metallic electronic device is of fundamental and technological importance for nano-optics. However despite recent experimental efforts in the development of electrically-driven plasmonic sources also related to progress to obtain highly confined optical modes, the interplay between quantum transport and optics is still under debate. Here, we measure the photon-assisted current in a planar tunnel junction under infrared illumination at $λ =
1.55 μ{m}$intheKretschmannconfiguration.Toaddressthemicroscopicmechanismattheoriginoftheopticalrectificatio
voltagecharacteristicsofthejunctionmeasuredonavoltagerangemuchgreaterthan$V_0 = {h c}{eλ} = 0.825 {V}$, previo
thermalout−of−equilibriumdistributionfunctionintheelectrodesandcorrespondingtotheexchangeofenergyquantabetw

*Intervenant

Shot Noise Measurements in Graphene Quantum Point Contacts in the Quantum Hall Regime

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Résumé

Quantum shot noise probes the dynamics of charge transfers through a quantum conductor, reflecting the nature of the flow of quasiparticles across the conductor. In this work, we have performed high-sensitivity shot noise measurements in Quantum Point Contacts (QPCs) on hBN-encapsulated Graphene systems in the Quantum Hall regime. The QPCs have been realised in the form of sub-100 nm features in graphite gates on Graphene, using a novel resist-free local anodic oxidation process. Using QPC as a benchmark device, we demonstrate selective partitioning of different integer quantum Hall edge modes at high magnetic fields, specifically at filling factor of =2. Furthermore, we find evidence for fragile interaction-driven edge reconstruction effects for =2, including the formation of a quantum dot at an electrostatic potential saddle point. Shot noise was then measured for the quantum dot-controlled QPC device and analysed, revealing a super-Poissonian nature of fluctuations in the system, which might be indicative of burst-like charge transport through the QPC.

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Single-shot electron detector for electron flying qubit operation

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Résumé

The recent realization of coherent single-electron sources in ballistic conductors let us envision performing time-resolved electronic interferometry experiments analogous to quantum optics experiments.One could eventually use propagating electronic excitations as flying qubits. However an important missing brick is the single-shot electron detection which would enable a complete quantum information operation with flying qubits. Here, we propose and discuss the design of a single charge detector able to achieve in-flight detection of electron flying qubits. Its sub-electron sensitivity would allow the detection of the fractionally charged flying anyons of the Fractional Quantum Hall Effect and would enable the detection of anyonic statistics using coincidence measurements.

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Single-Shot Electron detector with sub-electron sensitivity for electron flying qubit operation

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Résumé

The recent realization of coherent single-electron sources in ballistic conductors let us envision performing time-resolved electronic interferometry experiments analogous to quantum optics experiments. One could eventually use propagating electronic excitations as flying qubits. However an important missing brick is the single-shot electron detection which would enable a complete quantum information operation with flying qubits. Here, we propose and discuss the design of a single charge detector able to achieve "in-flight" detection of electron flying qubits. Its sub-electron sensitivity would allow the detection of the fractionally charged flying anyons of the Fractional Quantum Hall Effect and would enable the detection of anyonic statistics using coincidence measurements.

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Spin/photon interface for spins in carbon nanotubes

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Résumé

Abstract

Interface spin/photon and quantum gates for spins in carbon nanotubes

Electronic transport at the nanoscale is an important field of condensed matter physics. Thanks to nanofabrication improvements it is now possible to study conduction through confined electronic states. Among those new possibilities one can underline the possibility to build quantum bits using superconductors or electronic spins. One can also think about hybrid structures with different conductors to highlight exotics states of matter. Probing, manipulating and coupling individual quantum systems is feasible with cavity quantum electrodynamics (cQED) which deals with the interaction between light and matter at the most elementary level. Recently, these methods have been developed in the context of mesoscopic physics. In such mesoscopic quantum electrodynamics (mesoQED) architectures, the tools of cavity QED have been shown to allow us to probe with a very high sensitivity intricate charge or spin dynamics in nanoscale devices. In the HQC group of LPENS, we have developed such systems with carbon nanotubes as elementary conductor and CPW resonator as probe. This has enabled to show coherent coupling between individual spins and cavity photons (1,2).

(1) J.J. Viennot, M.C. Dartiailh, A. Cottet and T. Kontos Science 349, 408 (2015).
(2) T. Cubaynes et al. npj Quant. Inf (2019)

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The quantum transport states at 2D perovskite and Graphene interface

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Résumé

Halide Perovskite has been attractive as one of the most promising materials in optoelectrical devices. To improve the devices' efficiency and stability, The incorporation of graphene into perovskite-based optoelectronics has been exploited, in which the graphene acts as transport layers or electrodes and can tune the optical and electrical properties. Despite of a critical part in the graphene and perovskite integration, the states of graphene in this perovskite-centered devices are unclear and rarely researched. Here, quantum transport properties in molecularly thin 2D perovskite/Graphene heterostructure are experimentally investigated by Shubnikov-de Hass (SdH) oscillation in the magneto-resistance. We find strong charge transfer between the perovskite and graphene which induces a hole carrier density in graphene up to ~ 2.79×1013 cm-2. The perovskite layer also lowers the effective mass of graphene from ~0.12 *me* to ~ 0.08 *me*. Despite of the efficient charge transfer process, the graphene exhibits the carrier mobility ~550 cm2V-1s-1. The sign of the photoresistance SdH oscillations corresponds to a reduction of the hole density in graphene under illumination. This heavily dopped graphene implies the possibility of the interaction of carriers and excitons in the van der Waals heterostructure, and higher mobility enables the good performance of perovskite/graphene devices. Our findings unreal the effect of interfacial coupling on the transport properties of graphene imposed by 2D perovskite and give reference for design perovskite optoelectronic devices.

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Theoretical description of the superfluid density in strongly disordered superconductors

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Résumé

We develop an analytic description of the superfluid density ρ_S in strongly disordered superconductors at
low temperatures, following recent experiments performed by the groups of B. Sacépé and N. Roch at the Néel
Institute. The superconducting state in these materials is known to be strongly inhomogeneous, thus implying
the necessity to keep track of the distributions of local physical quantities, as opposed to just their mean values.
Our method describes the distribution of the order parameter and estimates the superfluid density ρS based
on the typical value of the local current-current response. The main result of our calculations is that the
dependence of the superfluid density defect ρ_S (T = 0) − ρ_S (T) features a behavior that could be described by
a power law A T^b at moderately low temperatures T_min ≤ T ≤ T_max. Here, b ∼ 2 is disorder-dependent and
the temperature scales T_min ∼ λ _typ , T_max ∼ _typ are defined by the typical superconducting scale _typ at
T = 0 and dimensionless Cooper coupling constant λ. The typical order parameter _typ itself follow a similar
temperature dependence. At very low temperatures, exponential BCS-like behavior of the form exp {−2T_min/T }
is expected for all quantities, although we cannot resolve this region with our method. At small disorder, the
temperature dependence gradually transitions from a power law to the exponential BCS-like behavior at all
temperatures, as expected.

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Title: Fabrication of a fractional Mach Zehnder interferometer in graphene

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Résumé

The Mach Zehnder interferometer is an experimental setup leading to the observation of interferences between two waves recombining on a beam-splitter. Initially applied to light waves and then to single photons by virtue of the wave-corpuscle duality, this experiment has recently been performed in the integer quantum Hall effect with electron currents (1) propagating along the edges of a graphene flake and interacting at the interface of a pn junction. In this poster, I will discuss our recent progress in fabrication to obtain a full graphite electronic Mach Zehnder interferometer. The goal of this experiment is to reveal interference oscillations with anyons (2).

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(2) Nakamura, J., Fallahi, S., Sahasrabudhe, H. *et al.* "Aharonov–Bohm interference of fractional quantum Hall edge modes". *Nat. Phys.* **15**, 563–569 (2019)

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Toward the control of tunnel coupling in silicon quantum dot array

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Résumé

Among the several possibilities for implementing qubits experimentally, spin qubits currently appear as one of the most promising. Indeed, this technology based on electron spins trapped in semiconductor quantum dots benefits from very high coherence times and can potentially leverage existing CMOS expertise to scale efficiently.

In order to demonstrate quantum processing, we need (among other things) high fidelity

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readout method on our qubit and a way to implement high fidelity quantum gates. Both of those requirements are related to our ability to effectively and selectively control the coupling of each quantum dots (QDs) both with each other and with the reservoirs.
Varying architectures have been used to satisfy this need and in this poster, we will show the versatility of QD arrays with two gate layers which have been fabricated by a process compatible with the existing CMOS industry methods. High quality control over the transition from single to double QD regimes will be demonstrated. Operating in the transport regime, we observe bias triangles with their excited states when two QDs are tune to be weakly coupled. As we increase the coupling strength, interdots become visible, forming a honeycomb pattern. Control of the coupling has been achieved both through exchange gates and through the use of the back gate. Preliminary results on the charge sensing in the few electron regime will also be presented.

Towards a quantum electrical calibrator

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Résumé

LNE has demonstrated operation of a programmable quantum current generator (PQCG) realizing the ampere from the elementary charge, e, with a 10ˆ{-8} relative uncertainty in the mA range down to the μA range (1). The high accuracy on the generated current is obtained by applying Ohm's law in a circuit connecting directly a quantum Hall resistance standard (QHRS) and a programmable Josephson voltage standard (PJVS) with a multiple connection scheme and by amplifying the quantized current with a cryogenic current comparator (CCC). After first improvements, the PQCG was used to calibrate ammeters with record uncertainties (2). Our goal is now to develop a more compact and even more accurate version of the PQCG in a laboratory dedicated to a new ampere traceability. An important target is the development of a new CCC which allows implementing the triple connection of the QHRS to the PJVS in order to reduce to a negligible value the cable correction which was amounting to a few parts in 10ˆ{7} in the double connection scheme previously implemented. We will present the details of the fabrication of the new CCC and its performance. Other on-going developments including a set of two PJVS implemented in a cryogen-free system, will be also presented. All these developments aims at using the PQCG to calibrate not only electrical currents but also resistances in conjunction with a quantum voltmeter, formed by a PJVS associated with a voltage null detector. Eventually, the whole system of quantum standards around the PQCG should form a quantum electrical calibrator of voltage, current and resistance (3). (1) J. Brun-Picard et al, Phys. Rev. X 6, 041051 (2016)
(2) S. Djordjevic et al, Metrologia 58 045005 (2021)
(3) W. Poirier et al, Comptes Rendus Physique, 20, 92 (2019)

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Towards coherent control of Andreev Bound States in ultraclean carbon nanotubes

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Résumé

Coherent manipulation has been achieved for a variety of superconducting devices, recently in particular in Josephson Junctions based on InAs nanowires. Similar to nanowires, quantum dots formed by carbon nanotubes host Andreev Bound States. Here we propose a superconducting quantum circuit to coherently control these states. Ultraclean manufacturing of the nanotubes and their intrinsic low-dimensionality promise long coherence times.

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Towards nonlocal Josephson effect using novel pinhole junctions

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Résumé

It has recently been predicted that bringing two Josephson junctions closer together gives rise to a nonlocal Josephson effect: their Andreev Bound States (ABS) overlap and hybridize, so that the ABS spectrum of one junction depends on the phase across the second. This Andreev molecule could implement a phi-junction and may have potential applications in quantum information, sensing and molecular simulation. A key requirement for its implementation is the ability to fabricate Josephson junctions with a few well-transmitted conduction channels separated by a distance of the order of the superconducting coherence length (~100 nm in aluminum).

A strong signature of the presence of a few well-transmitted conduction channels in a Josephson junction is the appearance of Multiple Andreev Reflections (MAR). Such features are usually observed in structures requiring complex fabrication, such as atomic contacts or hybrid junctions based on 2D materials or semiconducting nanowires.

We have developed a novel approach to fabricate all-aluminum pinhole junctions with a few well-transmitted conduction channels, using standard nanofabrication techniques only. Our method also allows us to realize asymmetric junctions (with two different superconductors), in which MAR have less been studied.

We present here direct evidence of MAR in the current-voltage characteristics of Aluminum/Aluminum and Aluminum/Titanium junctions as well as preliminary measurements in a device consisting of two junctions separated by 100 nm.

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Transport trought a quantum dot in the short-pulse limit

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Résumé

When nanoelectronic devices are operated at frequencies higher than the characteristic energies of the device, the transport properties change considerably compared to the steady-state DC limit. For that aim we investigate the transport of short electron pulses through a single impurity site on an infinitly long tight-binding chain. Considering first a non-interacing dot in the short pulse limit, approximate analytical expressions and numerically exact simulations show that the transferred charge has a periodic dependence on the number of injected electrons in the pulse. Extending this model with an additional onside interaction on the dot, the system is further investigated numerically with a mean-field and a diagrammatic real-time Green-function approach.

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Tuning the bandwidth of superconducting microwave resonators with kinetic inductance

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Résumé

Electron spin resonance (ESR) is a widely diffused technique to characterize unpaired electrons. The implementation of superconducting circuits in cryogenic regimes has allowed to probe samples down to the fL volume, increasing dramatically the sensitivity of such method. The results obtained so far are restricted to long-lived spins with narrow linewidths, limiting chemical and biological applications. We propose to address more spin species by dynamically acting on the ESR resonator linewidth to enlarge its excitation bandwidth. Firstly, we study the spin echo sequence numerically, showing an advantage in varying the resonator linewidth. Then we design an on-chip superconducting filter able to perform such task. Finally, we fabricate and measure the device, gaining important insights for future improvements.

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Tunnelling spectroscopy of few-monolayer NbSe$_2$ in high magnetic field: triplet superconductivity and Ising protection

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Résumé

In conventional Bardeen-Cooper-Scrieffer (BCS) superconductors, Cooper pairs of electrons of opposite spin (i.e. singlet structure) form the ground state. Equal spin triplet pairs (ESTPs), as in superfluid ^{3}He, are of great interest for superconducting spintronics and topological superconductivity, yet remain elusive. Recently, odd-parity ESTPs were predicted to arise in (few-)monolayer superconducting NbSe$_2$, from the non-colinearity between the out-of-plane Ising spin-orbit field (due to the lack of inversion symmetry in monolayer NbSe$_2$) and an applied in-plane magnetic field. These ESTPs couple to the singlet order parameter at finite field. Using van der Waals tunnel junctions, we perform spectroscopy of superconducting NbSe$_2$ flakes, of 2–25 monolayer thickness, measuring the quasiparticle density of states (DOS) as a function of applied in-plane magnetic field up to 33T. In flakes $\lesssim$ 15*monolayersthicktheDOShasasinglesuperconductinggap.Inthesethinsamples,themagneticfieldactsprimarilyonthe mentionedESTPs.*

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Two molecules coupled to a nano-mechanical oscillator

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Résumé

It has been predicted that the flexural mode of a carbon nanotube can couple strongly to an electronic two-level system present in single molecules. Detection and manipulation of the oscillator is possible by exciting the two-level system with a laser and measuring the fluorescence photons. The coupling is based on the (static) Stark effect, and the displacement dependence of the two-level system energy splitting. In this work we investigate how two two-level systems can be coupled by a single mechanical oscillator. We find that the effective interaction can entangle the two molecules. We also find that the effect of the electromagnetic and mechanical environment has to be reconsidered, in view of the strong coupling of the two-level system to the oscillator. Our preliminary results show that spectroscopic measurements could be used to observe the entanglement generated by the oscillator.

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Two-bands Ising superconductivity from Coulomb interactions in monolayer NbSe2

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Résumé

In conventional materials the presence of repulsive Coulomb interactions is in general detrimental to superconductivity. Nevertheless, it has long been known that when the Coulomb interaction in addition to repulsive short-range scattering processes generates also long-range attractive processes, the superconductivity can still arise (1). More recently, Roldan et al (2) have proposed another mechanism which may act in materials with fragmented Fermi surface, such as transition metal dichalcogenides (TMDCs). The competition between short and long range processes, both of them repulsive, can lead to an effective attraction which again induces superconducting pairing. This idea has been strongly developed by Shaffer et al (3), who have shown theoretically that, even with purely repulsive interactions, the application of the magnetic field and/or Rashba spin-orbit coupling can drive TMDCs such as NbSe2 into a multitude of non-trivial superconducting phases.
In the present work we follow the original idea of Roldan et al., starting from the premise of repulsive interactions and disjoint Fermi surfaces around the K points in NbSe2. Using a microscopic multiband BCS approach we derive and self-consistently solve the gap equation. We find two distinct superconducting gaps, one for the outer and one for the inner Fermi pockets, both consisting of a mixture of s-wave and f-wave components. The presence of two gaps is consistent with the recent observation of a collective Leggett mode in monolayer NbSe2 (4). Further, our results for the dependence of the gaps on temperature, as well as for the critical in-plane field as a function of temperature, are consistent with various sets of existing experimental data. Thus, the possibility of pairing due to purely electronic interactions relies now on a more quantitative analysis.

(1) Kohn, Luttinger PRL 15, 524 (1965)
(2) Roldan et al., PRB 88, 054515 (2013)
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Unconventional transport of Cooper pairs in topological Josephson junctions

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Résumé

It is well known that Josephson junctions (JJs) in presence of a perpendicular magnetic field exhibit qualitatively different interference patterns depending on the length of the junction and the current density profile. Two paradigmatic scenarios are the SQUID and the Fraunhofer patterns, corresponding to a current density sharply peaked at the edges of the junction or to a homogeneous current density profile, respectively. In these simple cases the electrons within the Cooper pair (CP) can be treated effectively as a single entity. However, it is not hard to run into physical mechanisms under which this assumption does not hold, leading to new features in the pattern. An example is the even-odd effect in SQUID patterns due to a non-local transmission of CPs, with the two electrons travelling along opposite edges. In fancier JJs, such as in presence of inter-edge tunnelling or broadened edge states, the two electrons can propagate and explore the junction independently. We analyse the consequences of a major role acquired by the single-electron physics in the superconducting context: the relevant flux quantum doubles, introducing unexpected periodicities, and new patterns arise.

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Universal fluctuations of the induced superconducting gap in an elemental nanowire

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Résumé

Proximity induced superconductivity in a normal conductor is a rich field of experimental and theoretical investigations in many systems. In the last decade, it has been particularly at the heart of the quest for realizing topological modes in hybrid superconductor-nanowire nanodevices. Yet it turns out that elemental systems have not been yet fully investigated, in particular as a function of magnetic field. In this work we therefore investigate an ultra-clean carbon nanotube coupled to a superconducting lead. We observe for the first time a long standing prediction of random matrix theory (RMT), dating back to 2001, that mesoscopic fluctuations of the mini-gap in a conductor follow a universal distribution (1). The statistical distribution of the mini-gap recorded over 60 charge states in our device unambiguously demonstrate a universal behavior with a clear transition when time reversal symmetry is broken, as predicted by RMT. Interestingly, mesoscopic fluctuations of the minigap were precisely predicted to lead to ubiquitous nontopological edge states clustering towards zero energy. We do indeed observe ubiquitous and robust zero bias conductance peaks under magnetic field in our device that cannot host topological modes by design. Since RMT predictions that are compatible with our observations are very general and should be present in any system showing disorder, even if it is weak, this shows that a general mechanism can lead to clustering of nontopological zero energy states mimicking the transport signatures of Majorana modes. It therefore calls for alternative probes than transport measurement to identify Majorana modes in 1D systems with microwave photons in a cavity as a promising powerful platform (2). References

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Why you should care about the electrostatics of your nanoelectronic device

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Résumé

In quantum transport, understanding the electrostatics of a device comes first. The electrostatic energy is the largest one at play, it defines where the charges are in the system. Essentially, it frames the environment into which the quantum phenomena take place. In this talk, I will showcase the importance of the self-consistent electrostatic-quantum problem (1) in two situations. First, we have recently showed (2) that electrostatics plays a major role in the reconstruction of the quantum Hall edge channels in Graphene. In particular, failing to take it into account leads to a qualitatively wrong prediction of the behavior of electronic interferometers recently measured in the group of Yacoby (3) and Roulleau (4). Second, electrostatics is a requirement for making quantitative predictions of the dependence of measured quantities (e.g conductance) on experimentally controlled parameters (e.g. gate voltages) (5). I will end this talk with an introduction of the python package I have developed during my PhD, PESCADO. It is a robust and easy to use tool to solve the self consistent Schrodinger-Poisson problem. PESCADO will be released as an open source software, much similar to KWANT (6). I will showcase how you can use PESCADO for your own problem.

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