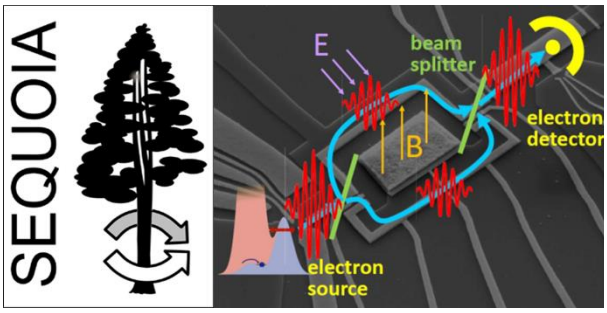
Single-Electron Quantum Optics for Metrology Workshop

(SEQUOIA Final Online Meeting)

11-12 october 2021



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The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

The **SEQUOIA project (single-electron quantum optics for quantum-enhanced measurements)** aimed at developing new metrological tools for quantum technology and quantum enhanced sensing harnessing single-electron wave-packet coherence. SEQUOIA - Project (ptb.de). It received funding from the European Metrology Program for Innovation and Research (EMPIR), co-financed by the Participating States, and from the European Union's Horizon 2020 research and innovation program. It involves six funded institutes: Physikalisch-Technische Bundesanstalt (PTB)-Germany, Laboratoire national de métrologie et d'essais (LNE)-France, National Physical Laboratory (NPL)-United Kingdom, Commissariat à l'énergie atomique et aux énergies alternatives (CEA)-France, Centre National de la Recherche Scientifique (CNRS)-France, Latvijas Universitate (LatU)-Latvia.

This Online workshop proposes not only presentations by the members of the SEQUOIA project but also presentations by external scientists having research activities related to the project.

Speakers:

Frank Hohls (PTB, Germany), Vyacheslavs Kashcheyevs (LatU, Latvia), Jonathan Fletcher/Masaya Kataoka (NPL, United Kingdom), Akira Fujiwara (NTT BRL, Japan), Myung-Ho Bae (KRISS, South Korea), Janine Splettstoesser (Chalmers, Sweden), Niels Ubbelohde (PTB, Germany), Michael Moskalets (DMSP, NTU "KhPI", Ukraine), Wilfrid Poirier (LNE, France), Preden Roulleau (CEA, France), Masayuki Hashisaka (NTT, Japan), Michihisa Yamamoto (RIKKEN, Japan), Christian Glattli (CEA, France), Gwendal Fève (ENS, France), Shintaro Takada (AIST, Japan), Pascal Degiovanni (ENS-Lyon, France), Heung-Sun Sim (KAIST, Korea).

Day 1 : 11/10/2021

Time (CEST=UTC+2)	Speaker	Presentation title
9h00-9h10	**W. Poirier**	Welcome speech
9h10-9h30	**F. Hohls**	SEQUOIA project introduction
Chairman: G. Fève		
9h30-10h00	**V. Kashcheyevs**	Theoretical introduction/Tutorial
10h00-10h40	**J. Fletcher/M. Kataoka**	Probing wavepackets emitted from on-demand single-electron sources
10h40-11h15	**A. Fujiwara**	Electron dynamics and device simulation of silicon single-electron pumps
Break:11h15-11h30		
11h30-12h05	**M-Ho Bae**	Parallelization of single electron pumps
12h05-12h40	**J. Splettstoesser**	Readout of quantum screening effects using a time-dependent probe
Break: 12h40-13h40		
Chairman: F. Hohls		
13h40-14h20	**N. Ubbelohde**	A counting scheme for single-electron wave packets
14h20-15h00	**V. Kashcheyevs**	Measures of coherence and interactions in few-electron optics
15h00-15h40	**G. Fève**	Single-electron interferences in Fabry-Perot cavities

Day 2 : 12/10/2021

Time (CEST=UTC+2)	Speaker	Presentation title
9h00-9h10	**W. Poirier**	Welcome speech
Chairman: M. Kataoka		
9h10-9h50	**W. Poirier**	Dissipation in the quantum Hall effect regime in h-BN encapsulated graphene
9h50-10h30	**P. Roulleau**	Excitonic nature of magnons in a quantum Hall ferromagnet
10h30-11h05	**M. Hashisaka**	Charge dynamics at a fractional-integer quantum Hall interface
Break: 11h05-11h20		
11h20-11h55	**M. Yamamoto**	Coherent beam splitter for flying electrons driven by a surface acoustic wave
11h55-12h30	**D. C. Glattli**	Principle of a Capacitive Single Shot detector for Electronic Flying Qubits
Break: 12h30-13h30		
Chairman: P. Roulleau		
13h30-14h05	**M. Moskalets**	Neutral excitations produced on-demand in the Fermi sea
14h05-14h40	**S. Takada**	A single-electron toolbox for quantum applications assisted by sound
14h40-15h15	**P. Degiovanni**	The electron radar: taking into account interaction effects
15h15-15h50	**H.-S Sim**	Anyons on integer quantum Hall edges
15h50-16h00	**F. Hohls**	Concluding Remarks

Abstracts

Frank Hohls (PTB): Project Introduction. The project SEQUOIA connects the basic science of single electron quantum optics with the domain of metrology. This talk gives a brief overview on the motivation, the main research questions and the status of this collaborate research project.

Vyacheslavs Kashcheyevs (LatU): Theoretical introduction/Tutorial. A little tutorial on some useful concepts from quantum optics adapted to electronic excitations: first order coherence and its Wigner representation, quantum purity, types of elementary fermionic excitations, single-particle scattering as transformation of coherence etc.

Jonathan Fletcher/Masaya Kataoka (NPL): Probing wavepackets emitted from on-demand, single-electron sources. Single electron sources are promising for both fundamental electrical metrology and as components in 'single electron optics' experiments. Using a tomographic technique we have visualised the energy, time distribution of electrons injected into high energy edge states in GaAs by 'on demand' single electron sources. This is an important step towards the preparation of pure quantum states for interferometry. Using two sources it is also possible to directly collide single electrons and thus directly probe their interactions at a barrier in geometry similar to the Hong Ou Mandel configuration in quantum optics.

Akira Fujiwara (NTT BRL): Electron dynamics and device simulation of silicon single-electron pumps. The talk will introduce ultrafast sampling of internal electron dynamics in a silicon single-electron pump as well as device simulation to extract critical parameters of the dynamic quantum dot and optimize the device design for a high accuracy pump.

Myung-Ho Bae (KRISS): Parallelization of single electron pumps. The parallelization of tunable-barrier electron pumps has been adopted as a strategy to achieve a nA current level. In my talk, I will introduce a progress in development of the parallelization of electron pumps, including high-accuracy current measurement results.

Janine Splettstoesser (Chalmers): Readout of quantum screening effects using a time-dependent probe. I will show that ac-sources side-coupled to a mesoscopic conductor via a third terminal can act as novel probes for hitherto unexplored quantum screening effects. We find that screening of charges induced by the static biases impacts already the standard linear thermoelectric response coefficients of the mesoscopic conductor due to nonlinear effects when accounting for the frequency of the time-dependent driving.

Niels Ubbelohde (PTB): A counting scheme for single-electron wave packets. The ballistic transport of hot electrons generated by non-adiabatic single electron pumps is studied to develop a counting scheme by trapping the ballistic electrons via controlled energy relaxation. This scheme makes it possible to measure counting statistics and coincidence correlations in single-electron circuits with Hong-Ou-Mandel and Mach-Zehnder configuration.

Vyacheslavs Kashcheyevs (LatU): Measures of coherence and interactions in few-electron optics. We will discuss adaptation of electron quantum optics concepts such as Wigner representation of coherence and Hong-Ou-Mandel interferometry to 'solitary electronics' driven by tunable-barrier quantum-dot on-demand sources. Two particular features open up new regimes compared to coherent Fermi-sea perturbations: strong energy-dependence of the beam-splitter transmission probability and Coulomb interaction between chiral electrons.

Gwendal Fève (ENS-Paris): Single electron interferences in Fabry-Perot cavities. I will present the transfer of single electron wavepackets generated by Lorentzian current pulses through a Fabry-Perot (FP) cavity. By applying a dc voltage to a plunger gate controlling the potential of the FP cavity, oscillations of the transmitted current are observed resulting from single electron interferences within the cavity. By modulating the plunger gate voltage in time, the ac potential can be sampled by tuning the time delay between single electron emission and the ac potential modulation.

Wilfrid Poirier (LNE): Dissipation in the quantum Hall effect regime in h-BN encapsulated graphene. Graphene in the QHE regime is a good platform for single electron interferometry. As a support work, we have investigated at LNE the dissipation mechanisms driven by temperature and current in h-BN encapsulated graphene devices. Our work notably explores the quantization level of the Hall resistance, the sharpness of the breakdown transition and the role of the close graphite gate in these devices.

Preden Roulleau (CEA): Excitonic nature of magnons in a quantum Hall ferromagnet. Magnons enable the transfer of a magnetic moment or spin over macroscopic distances. In quantum Hall ferromagnets, it has been predicted that spin and charge are entangled, meaning that any change of the spin texture modifies the charge distribution. As a direct consequence of this entanglement, magnons should carry an electric dipole moment. Here we report evidence of this electric dipole moment in a graphene quantum Hall ferromagnet using a Mach-Zehnder interferometer.

Masayuki Hashisaka (NTT): Charge dynamics at a fractional-integer quantum Hall interface. I will introduce an experiment in which we observed the Andreev-like process of fractional charges at a fractional-integer quantum Hall interface. The result provides important insights for understanding the transport properties of counter-propagating fractional and integer edge channels.

Michihisa Yamamoto (RIKKEN): Coherent beam splitter for flying electrons driven by a surface acoustic wave. We demonstrate a coherent beam splitter for single electrons driven through two tunnel-coupled quantum wires by surface acoustic waves (SAWs). The output current through each wire oscillates with gate voltages to tune the tunnel coupling and potential difference between the wires. This oscillation is assigned to coherent electron tunneling motion that can be used to encode a flying qubit and is well reproduced by numerical calculations of time evolution of the SAW-driven single electrons.

Christian Glattli (CEA): Principle of a Capacitive Single Shot detector for Electronic Flying Qubits. We present the principle of a capacitive Single Shot detector for Electronic Flying Qubits. We estimate that the detector can reach sub-electron sensitivity. Originally conceived as a non-QND detector, we propose that its coupling to an interferometer can equally lead to QND detection. Preliminary measurements of the capacitive antenna performance, done in the Integer Quantum Hall regime, are presented.

Michael Moskalets (DMSP, NTU "KhPI"): Neutral excitations produced on-demand in the Fermi sea. I discuss single-particle injection from the Andreev level and how such injection is simulated using a voltage pulse.

Shintaro Takada (AIST): A single-electron toolbox for quantum applications assisted by sound. In this talk, I will present our recent advances in single-electron transport assisted by sound waves. This includes real-time measurements of in-flight distribution of an electron within a surface acoustic wave, the generation of acousto-electric chirp pulses as well as single-electron anti-bunching experiments.

Pascal Degiovanni (ENS-Lyon): The electron radar: taking into account interaction effects. The « electron radar » is a proposal for measuring electric or magnetic fields on a short time scale based on a Mach-Zehnder interferometer fed by single to few electron excitations. In the idealized case where interactions can be neglected, also called single particle or linear regime of the electron radar, itbasically compares the time dependent phase captured by the electrons on the two different arms. However, on realistic experiments, interactions have to be taken into account and the device may also be used to probe the quantum features of a radiation sent onto one of the arms of the interferometer. In this talk, I will present how to address both the effect of Coulomb interactions as well as the effect of an external quantum radiation. When the radar is fed with a single electron excitation, the main result is an effective radar equation that has the same form as the one obtained in the single particle or linear regime, therefore enabling a discussion along the same lines than the single particle or linear regime. I will conclude by discussing some of the open questions and perspectives opened by this work.

Heung-Sun Sim (KAIST): Anyons on integer quantum Hall edges. I will present a theoretical proposal on how to generate, engineer, and detect anyons in the integer quantum Hall regime (not based on the topological order of fractional quantum Hall states). Their fractional statistics or braiding with electrons can be observed with currently available experimental setups of a Mach-Zehnder interferometer or a mesoscopic collider.