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Levitons : minimal excitations states of Fermions for electron quantum optics or cold atomic gases

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1. Abstract:

The on-demand generation of pure quantum excitations is a key issue to operate quantum systems. For Fermions this is particularly difficult as any perturbation affects all states below the Fermi energy resulting in a complex superposition of particles and holes excitations. However, it was predicted nearly twenty years ago [1] that a Lorentzian time dependent potential with quantized flux generates a minimal excitation with only one particle and no hole: a new quasi-particle called a leviton. Here, we report the on-demand generation of levitons in a conductor by applying voltage pulses on a contact [2]. Partitioning the excitations with an electronic beam-splitter generates a current noise used to measure their number. Minimal excitation states are observed for Lorentzian pulses while other pulse shapes show significant holes contribution. Further identification of levitons is provided in energy domain with shot noise spectroscopy and in time-domain with electronic Hong-Ou-Mandel noise correlation. The latter, obtained by colliding synchronized levitons on a beam-splitter, exemplifies the potential use of levitons for quantum information. Finally, we will present the first experimental tomography of an electron wavefunction in mesoscopic physics [3]. This is obtained by mixing levitons in the QPC beam-splitter with a weak fermion field prepared by applying a small ac sine-wave voltage on the opposite contact, following the theoretical work of ref.[4]. The anti-bunching of electrons and holes with the leviton provides a measure of the energy density matrix $\langle \psi^+(\epsilon) | \psi(\epsilon \pm k v_0) \rangle = \varphi(\epsilon) \varphi(\epsilon \pm k v_0)$ via excess shot noise measurements (v_0 is the Leviton frequency injection, $\varphi(\epsilon)$ its wave-function in energy representation). The present work demonstrates that, using levitons and linear electron quantum optics in ballistic conductors, let envisage flying qubit operation where the Fermi statistics is exploited to entangle synchronized electrons emitted by distinct sources. Compared with electron sources based on quantum dots, the generation of levitons does not require delicate nanolithography, considerably simplifying the circuitry for scalability. Finally, the principle of generation only exploiting fermionic properties can be applied to cold atomic gases [5,6] where atomic levitons could be implemented.

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2. Figures

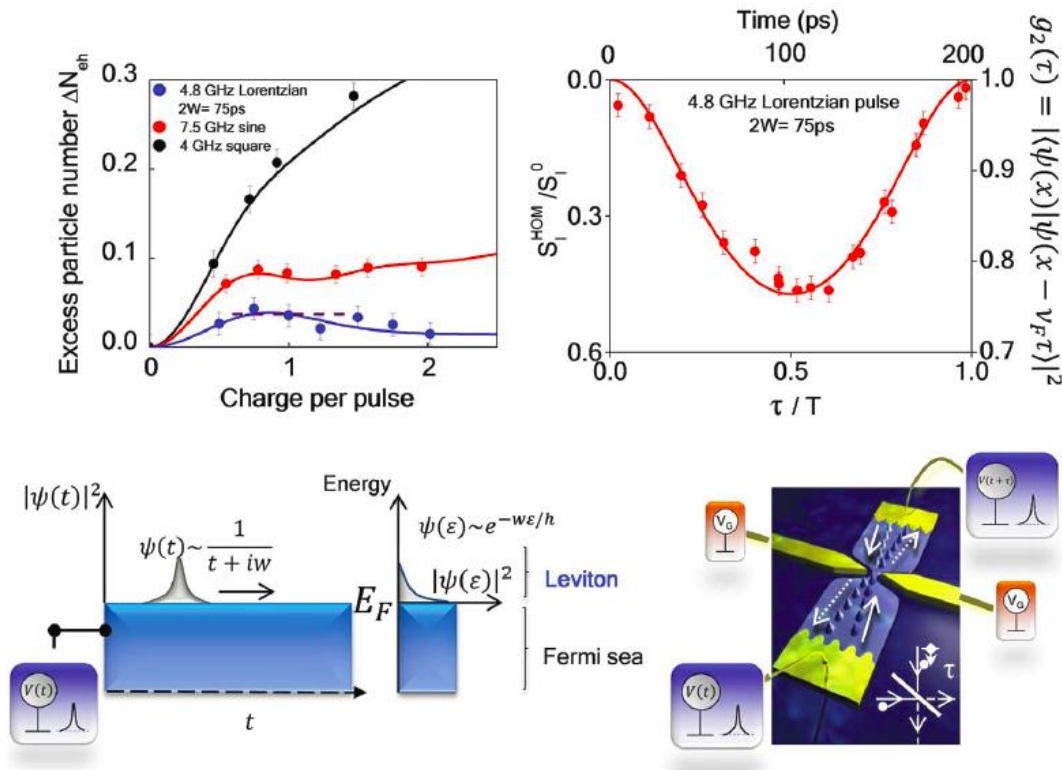


Figure : Upper left: partition noise of periodic charge pulses versus the charge carried per period observed for the application of various pulse shapes. The Lorentzian voltage pulse generates the minimal excitation. The residual noise observed for $q=1$ and 2 is entirely due to thermal excitations. Lower left: schematics of the leviton wave-function in time and energy domain. Upper right: electronic Hong Ou Mandel noise correlation provides a direct measure of the convolution of the Leviton wave-function in the time-domain. The principle is shown in the lower right figure. τ is the delay between the injection of synchronized indistinguishable levitons injected at opposite contact of the QPC-beam-splitter. (all figures from J. Dubois et al , Nature 2013, ref. [2]).