Fractional quantum Hall spectroscopy investigated by a resonant detector

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I. INTRODUCTION

In recent years a great attention has been devoted to the study of strong correlations in low dimensional systems. Among them the fractional quantum Hall effect (FQHE) plays a major role, in which correlations can induce the emergence of excitations with fractional charges and fractional statistics.[1,2] Several works focussed on the experimental detection of these peculiar features. In particular, fractional charges can be revealed by means of shot noise measurements in a quantum point contact (QPC) geometry.[3] Indeed, the zero frequency current-current correlation, in the weak-backscattering regime, is predicted to be proportional to the induced backscattering current via the fractional charge associated to the tunnelling excitation between the opposite edges of the Hall bar. Clear experimental signatures of this fact have been reported for the Laughlin sequence. In the case of composite edges, such as in the Jain sequence the situation is more involved since at low energies, various excitations with different fractional charges can contribute to the transport.[4,5] Moreover, zero frequency noise may be not enough in order to extract in a univocal way the values of the fractional charges when many of them contribute, with comparable weight to QPC transport. A possible way to overcome this limitation is to look at the finite frequency (f.f.) properties.[6–8]. In particular, for quantum Hall QPC transport, the f.f. noise is predicted to show resonances in correspondence of Josephson frequencies, which are proportional to the fractional charges.

II. PROPOSED DETECTION SCHEME

In the context of current-current correlations Lesovik and Loosen[9] introduced a model based on a resonant LC circuit as prototypical scheme for f.f. noise measurement. It has been shown that the measured quantity for the LC detector setup can be expressed in terms of the non-symmetrized f.f. noise which reflects the emission and adsorption contributions of the active system under investigation, *i.e.* the QPC. The non-symmetrized noise has been considered in literature for different systems as the ultimate source of information of quantum noise properties.[10–12]
Here[13] we consider the f.f. detector output power of a resonant circuit coupled to a QPC in the fractional quantum Hall regime. A schematic view of the proposed setup is shown in Fig.(1). The measurable quantity, in

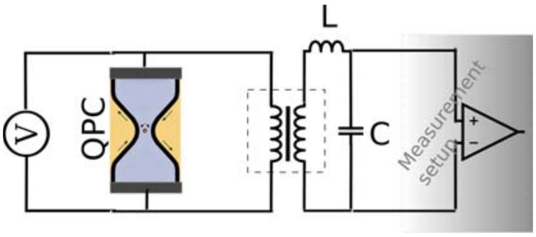

FIG. 1. Schematic view of the proposed setup.

this scheme, is the variation of the energy (at frequency $\omega = \sqrt{1/LC}$) stored in the LC circuit before and after the switching on of the LC-QPC coupling, i.e. the circuit element in the dashed line of Fig.(1). We will indicate it as measured noise S_{meas}. At lowest perturbative order in the coupling $K \ll 1$ it can be expressed in terms of the non-symmetrized noise spectrum of the QPC.[9,10] Finally, this quantity may be eventually expressed in terms of the difference of the output LC power, at finite bias V, subtracted with the same quantity measured at equilibrium, $V = 0$.[13]

III. RESULTS

Hereafter we will discuss this detector model coupled with a QPC kept in the fractional Hall regime in the limit of weak back-scattering. This realistically measurable noise power will be analyzed, at fixed frequency ω, as a function of QPC bias V, measured in terms of the Josephson frequency $\omega_0 = e^*V/\hbar$ associated to the fundamental fractional charge e^* of the considered Hall state. We will assume that the temperature T_c of the detector could be controlled and kept, eventually, at different temperature from the QPC circuit T. We will mainly consider the quantum limit for the detector, $\hbar\omega \gg k_BT_c$, where the output power is proportional to the non-symmetrized noise. The QPC, will be investigated by scanning the bias out of equilibrium (shot noise limit $e^*V \gg k_BT$). These limits represent the best conditions to extract information about fractional multiple quasiparticles (qps), in particular, their charge me^* and their scaling properties.[14]

First of all, we will analyze the well known case of non-

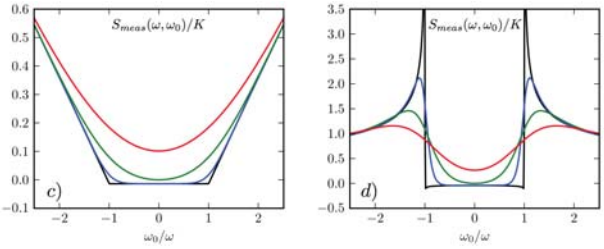

FIG. 2. Measured noise S_{meas} as a function of external bias for $\nu = 1$ (left panel) and $\nu = 1/3$ (right panel) (in units of $S_0 = e^2|t_1|^2/(2\pi\alpha)^2\omega_c$). Bias measured as ω_0/ω, with $\omega_0 = e^*V$. Temperatures are: $T = 0.1$ mK (black), $T = 5$ mK (blue), $T = 15$ mK (green) and $T = 30$ mK (red). Other parameters are: $T_c = 15$ mK, $\omega = 7.9$ GHz (60 mK), $\omega_c = 660$ GHz (5 K).

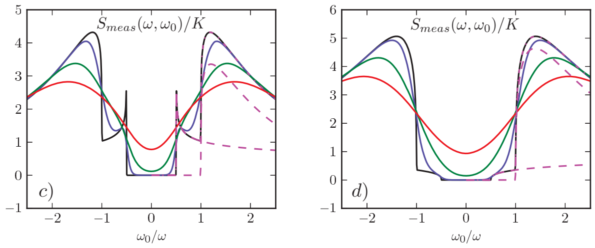

FIG. 3. Measured noise S_{meas} as a function of ω_0/ω for $\nu = 2/5$ (left panel) and $\nu = 2/3$ (right panel). All quantities are in units of S_0. The temperatures are the same of Fig.2. Other parameters are: $\omega = 7.9$ GHz (60 mK), $T_c = 0.1$ mK, $\omega_n = 6.6$ GHz (50 mK), $\omega_c = 660$ GHz (5 K). The dashed lines correspond to the rate contributions of the 2-agglomerate and the single-qp for $T = 0.1$ mK. They are calculated separately and fitted only by changing their prefactors. The dashed-dotted line is the sum of the two contribution and returns exactly the behaviour of S_{meas}.

interacting Fermi liquid ($\nu = 1$) and Laughlin ($\nu = 1/3$) to show some important and useful properties of the measurement setup. Differently from what usually considered in other theoretical papers, where the noise is shown at finite bias as a function of the frequency, here we will discuss the opposite case in which the bias is moved at fixed frequency. This allows us to be closer to realistic experimental situations representing by far the simplest measurement protocol for the system. We discuss in details the advantages of considering this measurement scheme in comparison to the simpler symmetrized noise.

In Fig.(2). we report the measured noise S_{meas} for the cases $\nu = 1$(left panel), 1/3(right panel) for different temperatures. It is easy to recognise in the behaviour of the output power directly the shape of tunnelling rates for the dominant excitation e (electron) and single-qp $e^* = \nu e$ (single-qp). Indeed in the Laughlin case the line-shape return immediately information of the investigated excitation, such as the scaling dimension from the shape of the peaks centred at ω_0. This information can be accessed in this setup and it may be crucial in order to validate the edge states theories.

The detector response will give the unique possibility to selectively address the emission contribution of QPC noise or its adsorptive part only by acting on the detector temperature. We also discuss the range of the detector temperatures in order to access the non-symmetrized noise contributions. In particular it is convenient that T_c is smaller than the considered frequency ω.

Finally, see Fig.(3), we apply the previous concepts to the measurement of multiple qps for two values of the Jain sequence ($\nu = 2/5$ and $\nu = 2/3$). In all cases we demonstrate how this setup is able to clearly address the different qps contributions separately and to quantitatively validate the hierarchical edge state models. In such cases we could distinguish the contribution of single-qp (e^*) or 2-agglomerate ($2e^*$) from the position of the corresponding Josephson resonances. From this we can separately address the contribution of the two excitations fitting their tunnelling rates and identifying their fundamental properties, such as the scaling dimensions. From these knowledges it is possible to validate various edge state models which in general differ in the prediction of these quantities. This possibility to separately address the different excitation contribution on the base of their different charges is unique resource of this setup and is deeply connected to the fact that analysis is done at finite bias (out-of-equilibrium) and at finite frequencies.

The same analysis can be repeated for other fractions, such as $\nu = 5/2$, with the factual possibility to identify which edge state model apply to the observed Hall state (Abelian, Pfaffian or anti-Pfaffian).[7,8]

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