Squeezing of edge magnetoplasmon states in Quantum Hall edge channels

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Summary

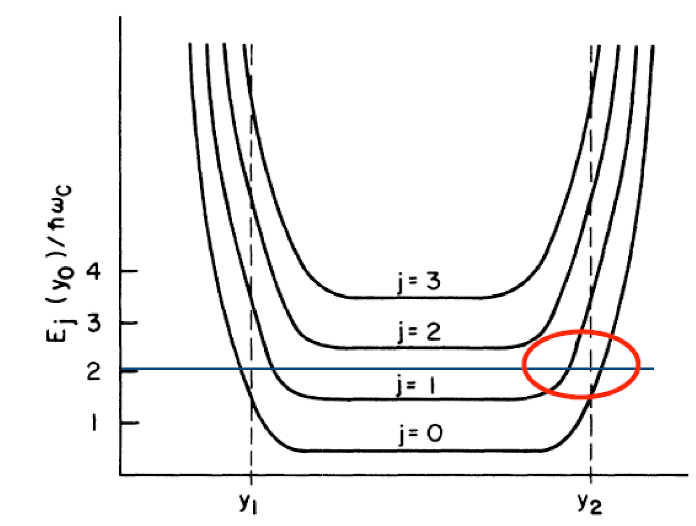
In quantum Hall conductors, charge excitations propagate ballistically along chiral one dimensional waveguides at the edge of the sample. These edge channels have been used to propagate non-classical fermionic states of matter by manipulating electron wavefunctions in electronic interferometers for example. However, one dimensional charge propagation can also be described in terms of bosonic collective excitations called edge magnetoplasmon (EMP).

The tools of quantum electronics, such as the quantum point contact (QPC), allow for the generation of non-classical EMP states such as squeezed states. In that study, we show that the partitioning of a high frequency (few GHz) AC signal on top of a DC voltage can be used to generate squeezed EMP states, in analogy with a previous experiment performed on tunnel junctions [1].

This technique opens the possibility to generate non-classical bosonic states in high impedance transmission lines, with a strong coupling to mesoscopic systems.

QHE interferometry and Noise measurements

Quantum electron optics toolbox



A 2DEG in Quantum Hall regime is a Topological insulator: transport occurs through 1D edge channels

=>Chiral ballistic transport along the edge

electronic 1D waveguide

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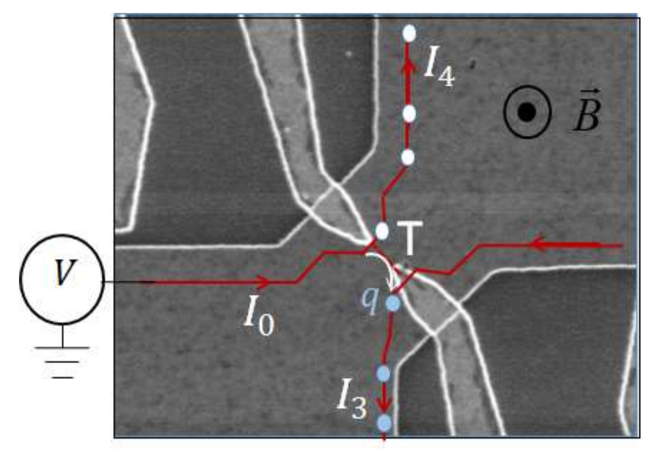

A quantum point contact is made of two top gate. We can tune back reflection from one edge to the other

electronic beam splitter

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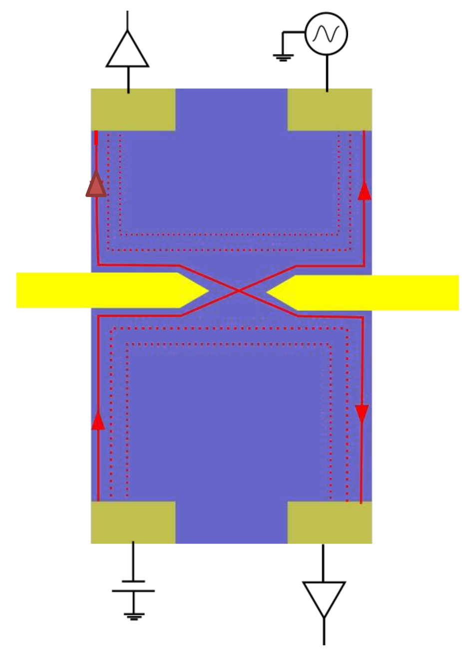
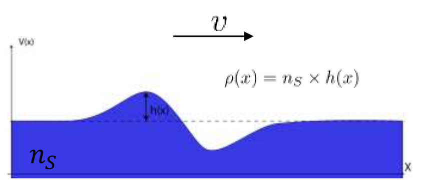


QHE interferometer



One dimensional transport at the edge can be described by edge magneto_plasmon (EMP) bosonic excitation, which are related to electron hole pairs creation. The propagation of charge density along the edge is given by a bosonic field, that can be written in the EMP basis:

$$\Phi(x,t) = \frac{-i}{\sqrt{4\pi}} \sum_\omega \sqrt{\frac{2\pi}{\omega T_{mea}}} [b_\omega e^{i\omega(x/v - t)} - h.c.]$$

For one EMP mode bw we define the quadratures of the bosonic field at pulsation ω:

$$X_{\omega,\phi} = \frac{b_\omega e^{i\phi} + b_\omega^\dagger e^{-i\phi}}{\sqrt{2}}$$

with

$$[\hat{X}_{\omega,\phi}, \hat{X}_{\omega',\phi+\pi/2}] = [\hat{X}_{\omega,\phi}, \hat{Y}_{\omega',\phi}] = i\delta_{\omega,\omega'}$$

=> X and Y are conjugated

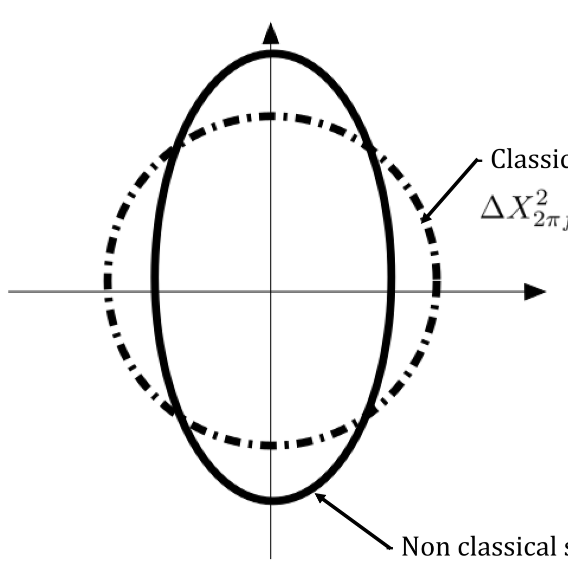
We can recover the Current and the current fluctuation at a given phase and frequency through the relations:

$$\begin{cases} < \overline{I_{f,\phi}(t)}^t >= -e\sqrt{\frac{2f}{T_{meas}}} < X_{2\pi f,\phi} > \\ S_{f,\phi} = e^2 f < \Delta X^2_{2\pi f,\phi} > \end{cases}$$

Edge transport and EMP states

Heisenberg principle: $\Delta\hat{X}_{\omega,\phi}\Delta\hat{Y}_{\omega,\phi} \geq 1/2$

=> Define vacuum fluctuation due to quantum nature

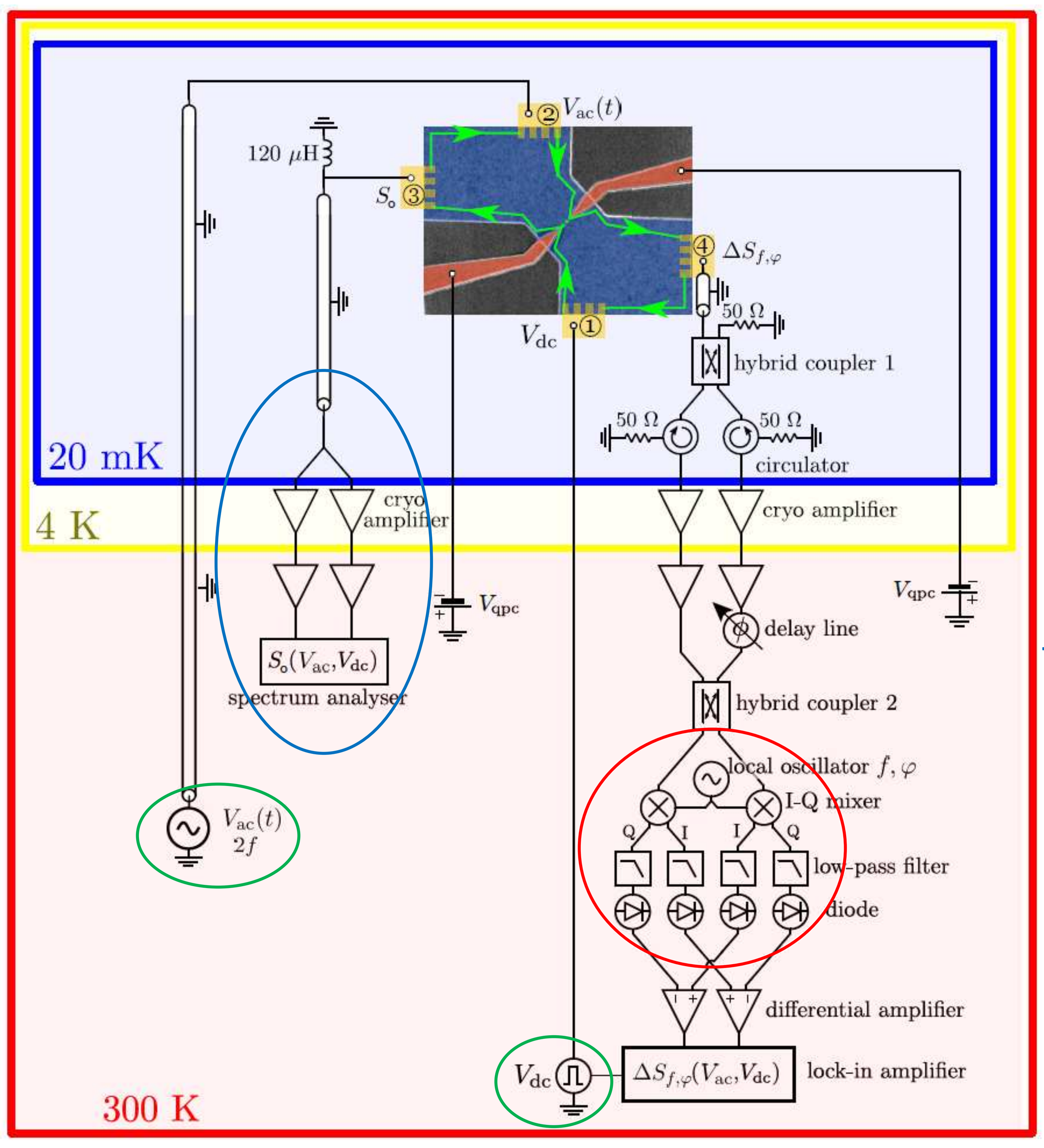


Classical/coherent states: $\Delta X^2_{2\pi f,\phi} = \Delta Y^2_{2\pi f,\phi} = 1/2$

Non classical squeezed states:
$$\begin{cases} \Delta X^2_{2\pi f,\phi_0} < 1/2 \\ \Delta Y^2_{2\pi f,\phi_0} > 1/2 \end{cases}$$

=> For a given phase a quadrature shows lower fluctuations than vacuum state

Set up for RF noise measurements



- Sample: AlGaAs/GaAs heterostructure

- Charge density: $n_S = 1.9 \times 10^{15} m^{-2}$
- Mobility: $\mu = 2.4 \times 10^6 cm^{-2} V^{-1} s^{-1}$
- IQHE @ ν=3 ($B = 2.4T$)

- QPC: $T = 0{,}42$ for outter channel

- Sources:

- DC bias V_{dc}, step modulated @ 234 Hz
- AC pump $V_{ac}(t)$ @$2f = 15.5\ GHz$

- Low frequency Noise:

- $S_0(V_{ac}, V_{dc})$ @ $f = 1{,}1 MHz$ (Δf =200kHz)

- High frequency noise

- Down conversion (IQ mixer @ $f = 7{,}75 GHz$)

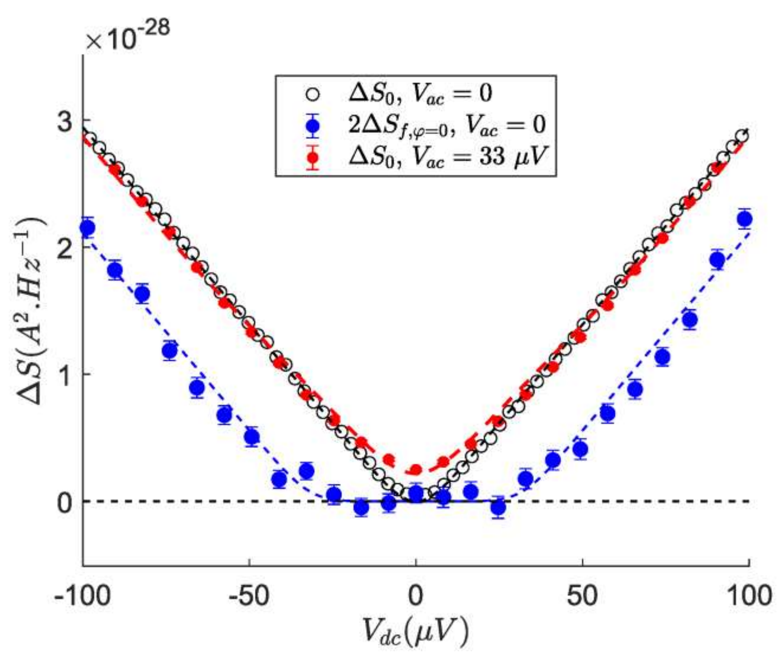
$i_0(t) \sim cos(2\pi f t + \phi)$

$i(t) \longrightarrow \otimes \longrightarrow i_{f,\phi}(t) = i(t)cos(2\pi f t + \phi)$

- Integrate with power diode over 800 MHz band (LP filters)

EMP squeezing in the QHE

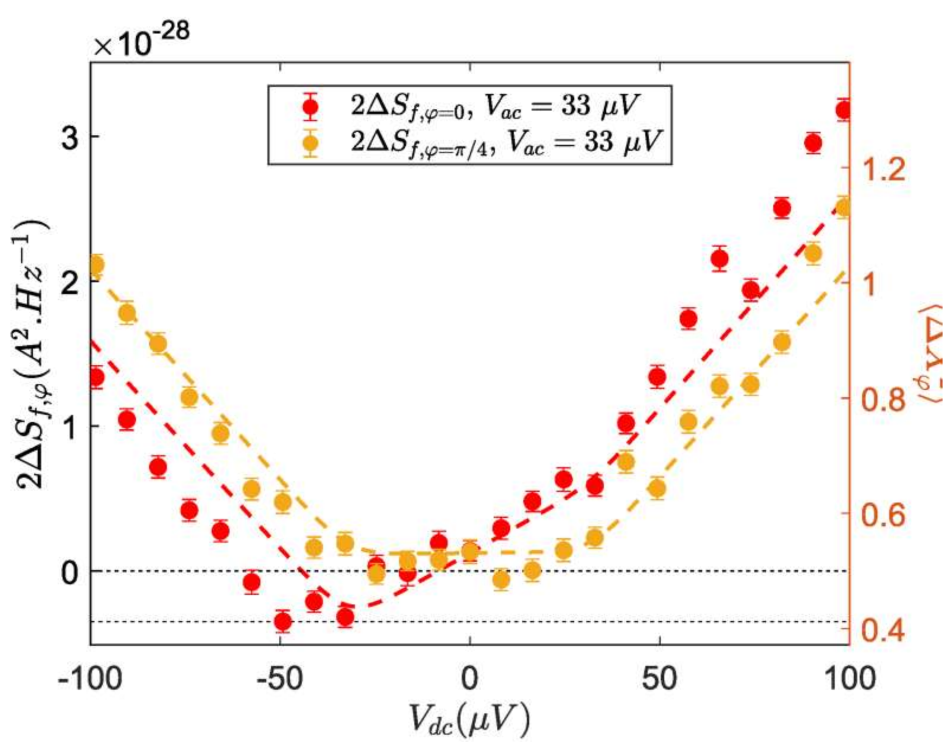
HF and LF noises



$$\Delta S_0(V_{dc}) = \frac{2e^3}{h} RTV_{dc}[coth(\frac{eV_{dc}}{2k_BT_{el}}) - \frac{2k_BT_{el}}{eV_{dc}}]$$

$$\Delta S_{f,\phi}(V_{dc}) = \frac{\Delta S_0(V_{dc} + hf/e) + \Delta S_0(V_{dc} - hf/e)}{4}$$

- Black curve: LF noise pump off
- Red curve: LF noise pump on
- Blue curve: RF noise pump off



RF noise with pump on :

- φ=0 :
for $V_{dc} \simeq -V_{ac}$ **negative excess noise** / vacuum

=> Squeezing signature

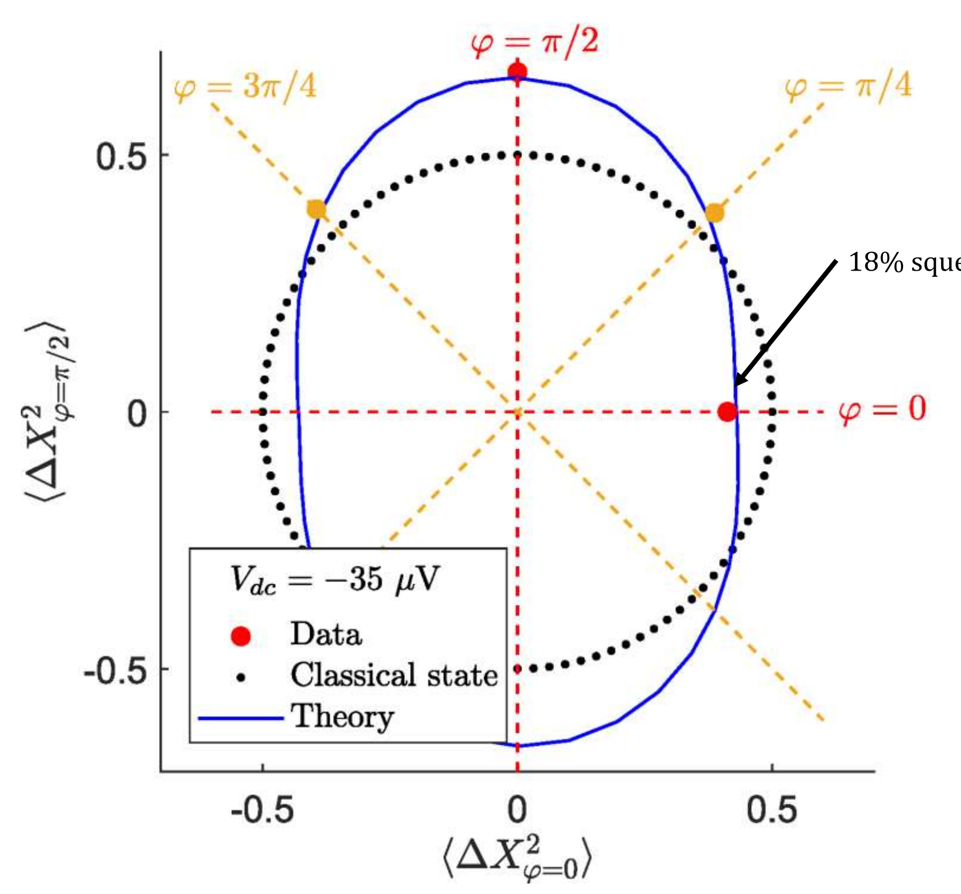
- φ=$\frac{\pi}{4}$: no effect of the pump !!

- φ=$\frac{\pi}{2}$: X and Y exchange (V_{dc} <-> $-V_{dc}$ symmetry)

Quadrature reconstruction

$< \Delta X^2_{2\pi f,\phi} >$ from $\Delta S_{f,\phi}$ measurement:

$$\boxed{< \Delta X^2_{2\pi f,\phi} > = \frac{1}{2} + \frac{1}{e^2 f} \Delta S_{f,\phi}}$$



-Thermal contribution can be ignored as $k_B T_{el} \ll hf$ ($\frac{k_B T_{el}}{h} \simeq 600 MHz$ @ 30mK)

- Squeezing parameter: $-10\log\left(\frac{\Delta X^2_{min}}{\Delta X^2_{vacuum}}\right) \simeq 1{,}9 dB$

- Squeezing rather small compared to optical set up but slighlty better than the one achieved in tunnel junctions

Perspectives

- **Increase squeezing by using higher order harmonics or increase the non linearity of the scatterer (QPC)**
- **This set up can be achieved on chip (high impedence) for implementation in interferometric devices, Q dots…**
- **Low coupling to the RF line (1%)=> RF impedence matching / tank circuit would strongly reduce acquisition time**

References

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