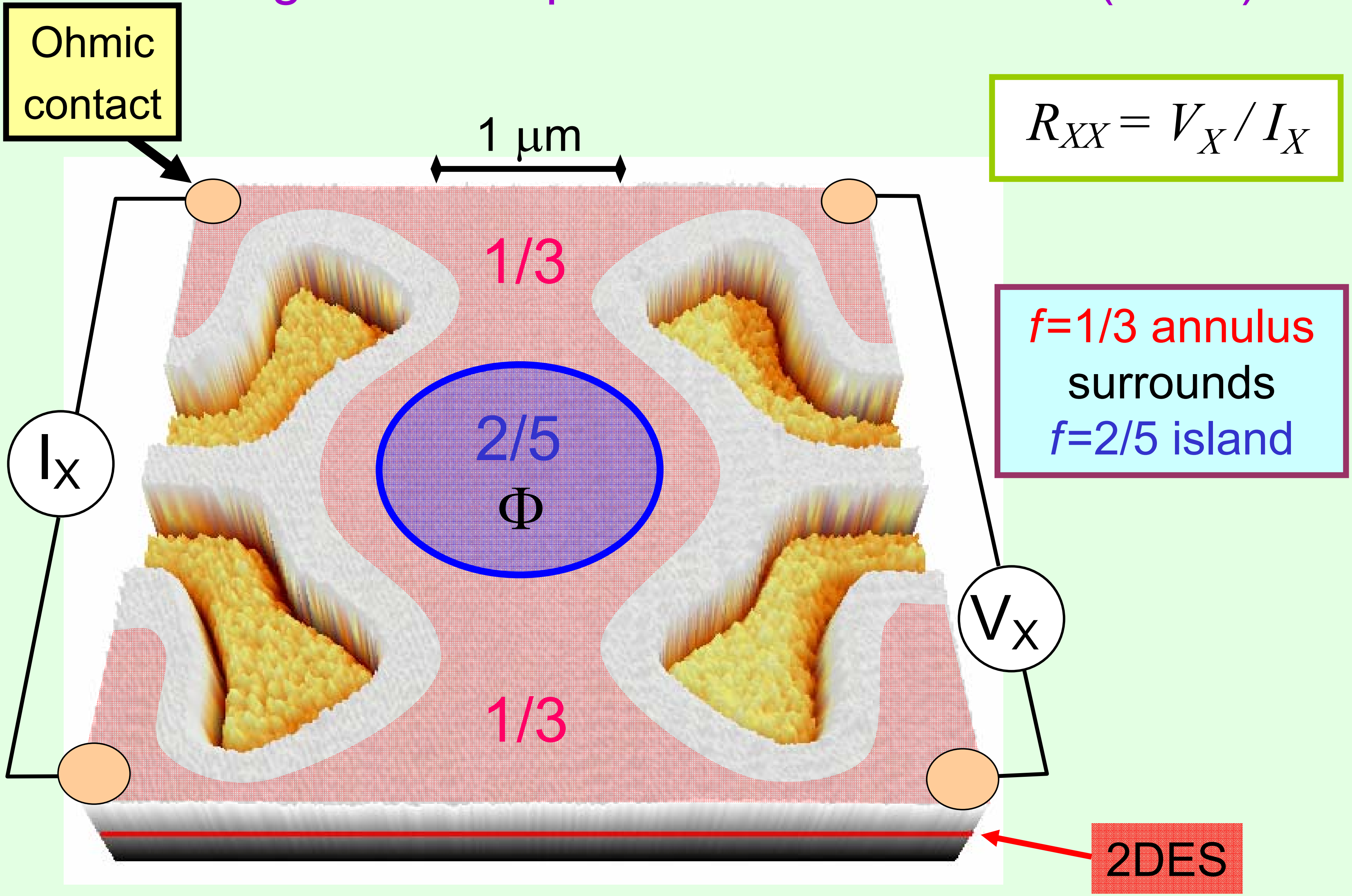
Thermal Dephasing in the Laughlin Quasiparticle Interferometer

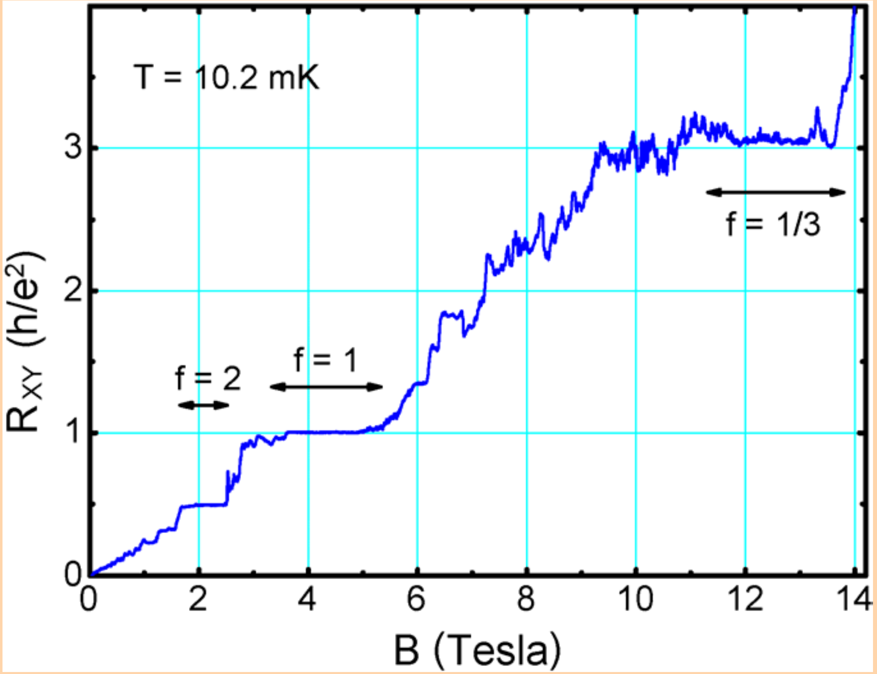
F. E. Camino, W. Zhou and V. J. Goldman

Stony Brook University

Laughlin Quasiparticle Interferometer (LQPI)



Characterization of the Experimental Scenario

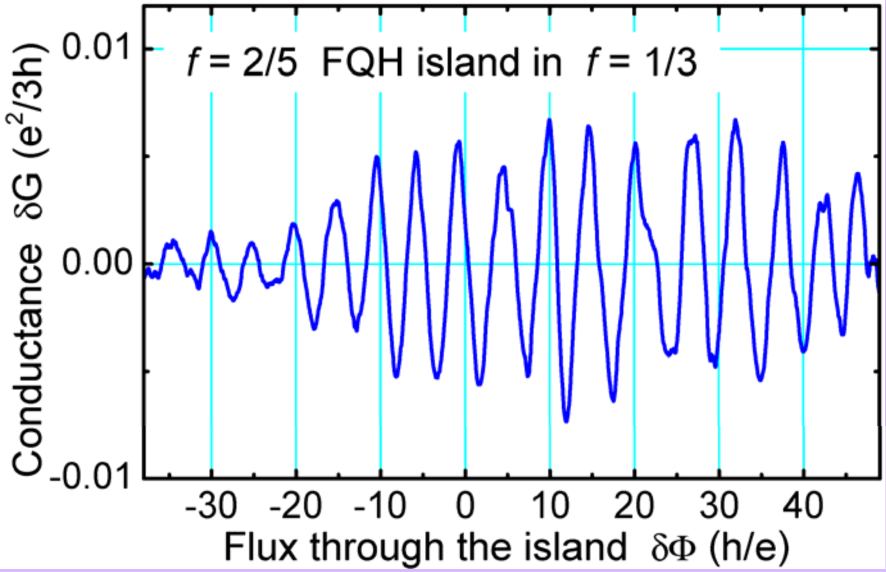


$R_{XY} = 3\ h/e^2$, then current is transported by $f = 1/3$ fluid

Aharonov-Bohm conductance oscillations with flux period

$\Delta_\Phi = 5\ h/e$ (*)

(*) Camino *et al.*, PRB **72**, 075342 (2005); PRL **95**, 246802 (2005)
Zhou et al., cond-mat/0512329 (2005)

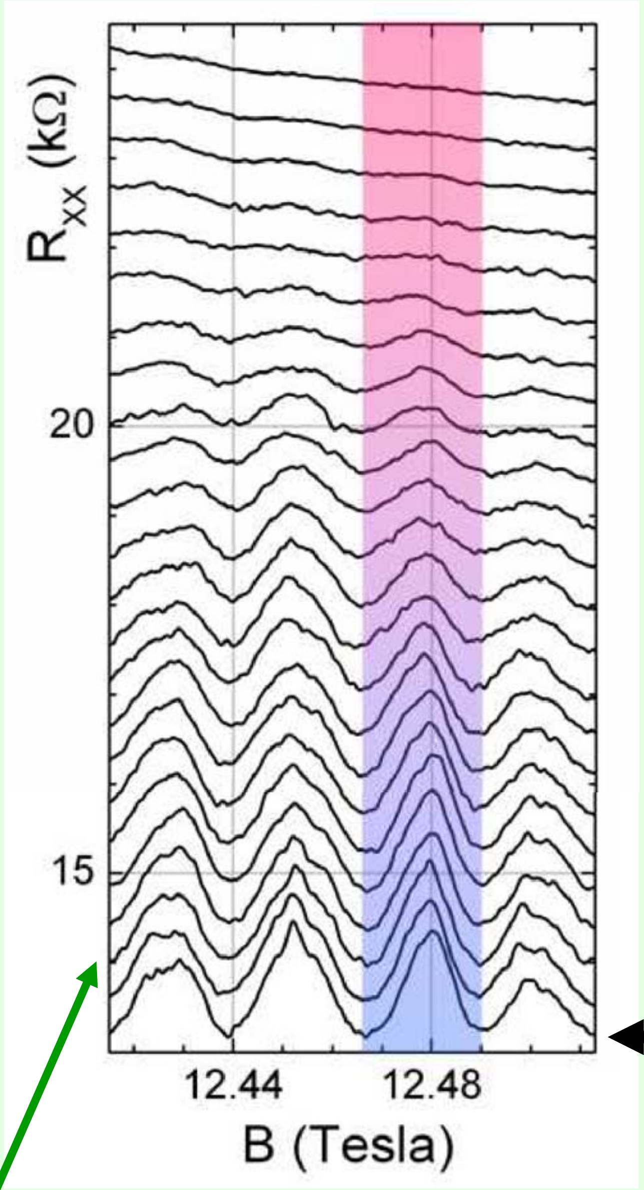


Temperature Dependence of Oscillations

141 mK

increasing temperature

10.2 mK



traces shifted vertically by 0.4 kΩ

Analysis steps:

1) measure $\delta R_{XX}(T)$ for 6 regular oscillations

2) calculate δG using

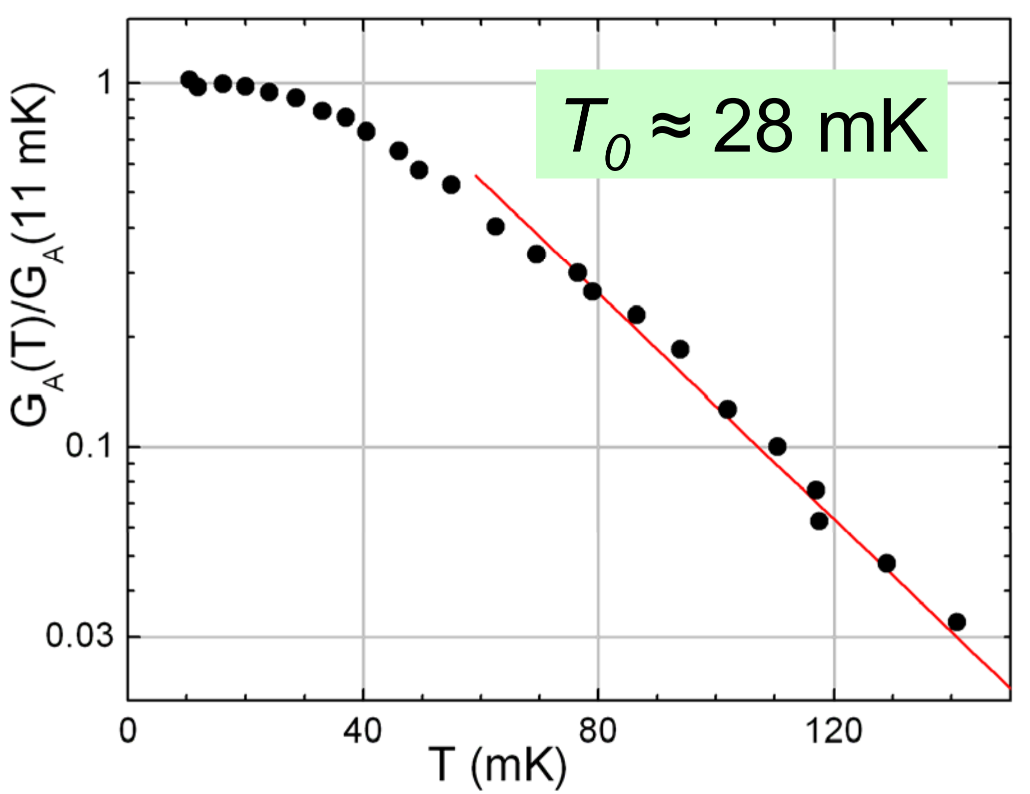
$$\delta G = \delta R_{XX} / (R_{XY}^2 - \delta R_{XX} R_{XY})$$

where $R_{XY}=3h/e^2$

~12.9 kΩ background comes from R_{XX} quantization:

$$R_{XX} = R_{XY}(\tfrac{1}{3}) - R_{XY}(\tfrac{2}{5}) = \tfrac{1}{2} h/e^2$$

T-dependence of Oscillation Amplitude $G_A(T)$



- high-T asymptotics:

$$G_A(T) \propto \exp(-T/T_0)$$

- Aharonov-Bohm oscillations persist for $T > T_0$

<u>very different from</u>:

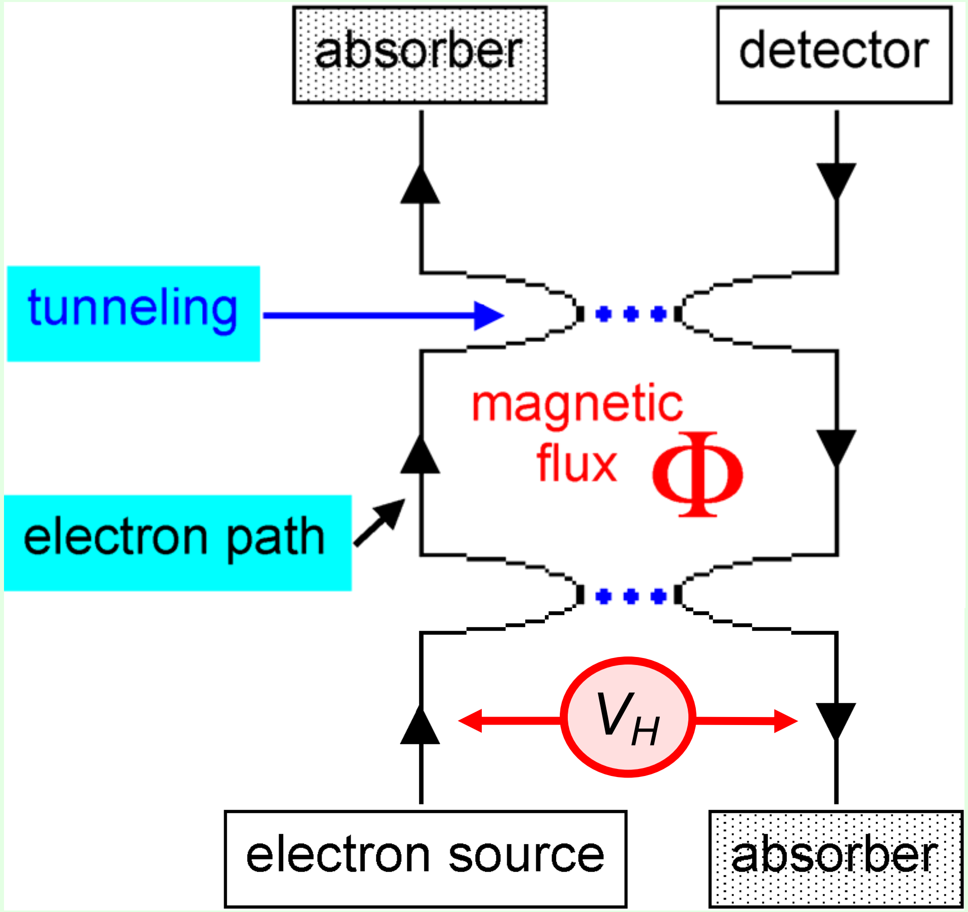
- thermal activation

$$G_A(T) \propto \exp(-T_0/T)$$

- <u>Fermi liquid behavior in</u>:
  - resonant tunneling in quantum dots
  - Coulomb blockade devices

oscillations vanish at a $T < T_0$

Theoretical Model of a Quantum Interferometer (*)



(*) Chamon *et al*., PRB **55**, 2331 (1997)

- interferometer formed by χLL edge channels
- single QH filling in device
- amplitude of oscillations:

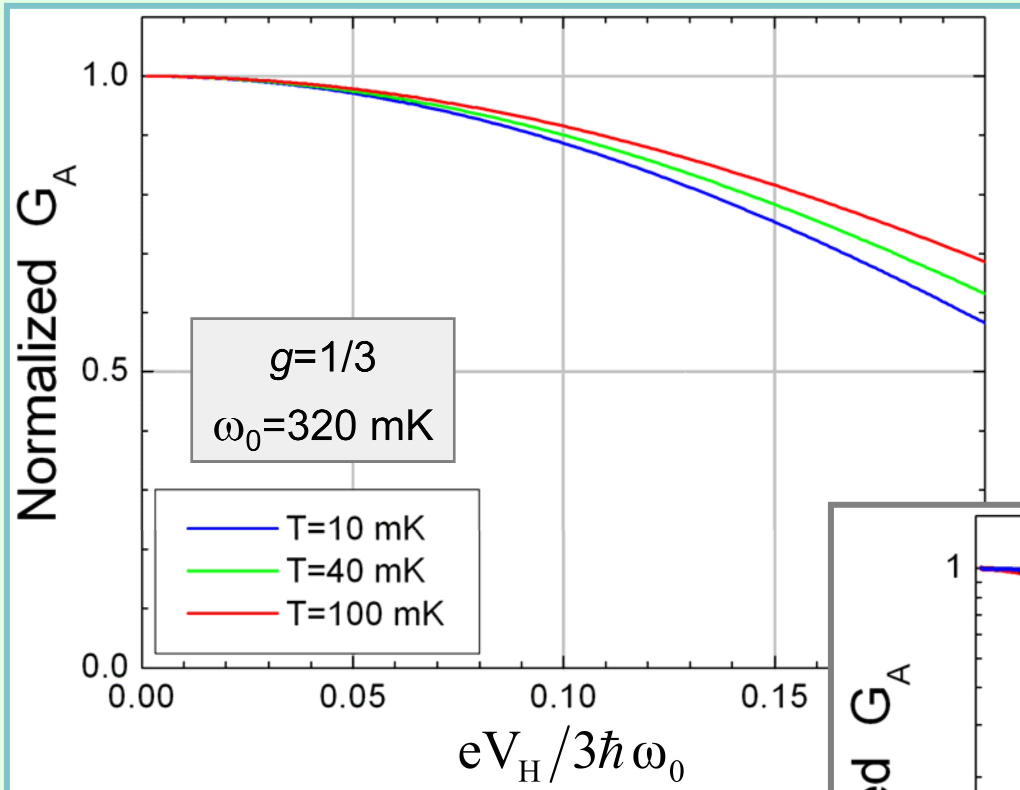
$$G_A(T) \propto H_g\left(\frac{2\pi\omega_J}{\omega_0}, \frac{\omega_J}{2\pi T}\right)$$

- g =1/3 for f =1/3 FQH fluid

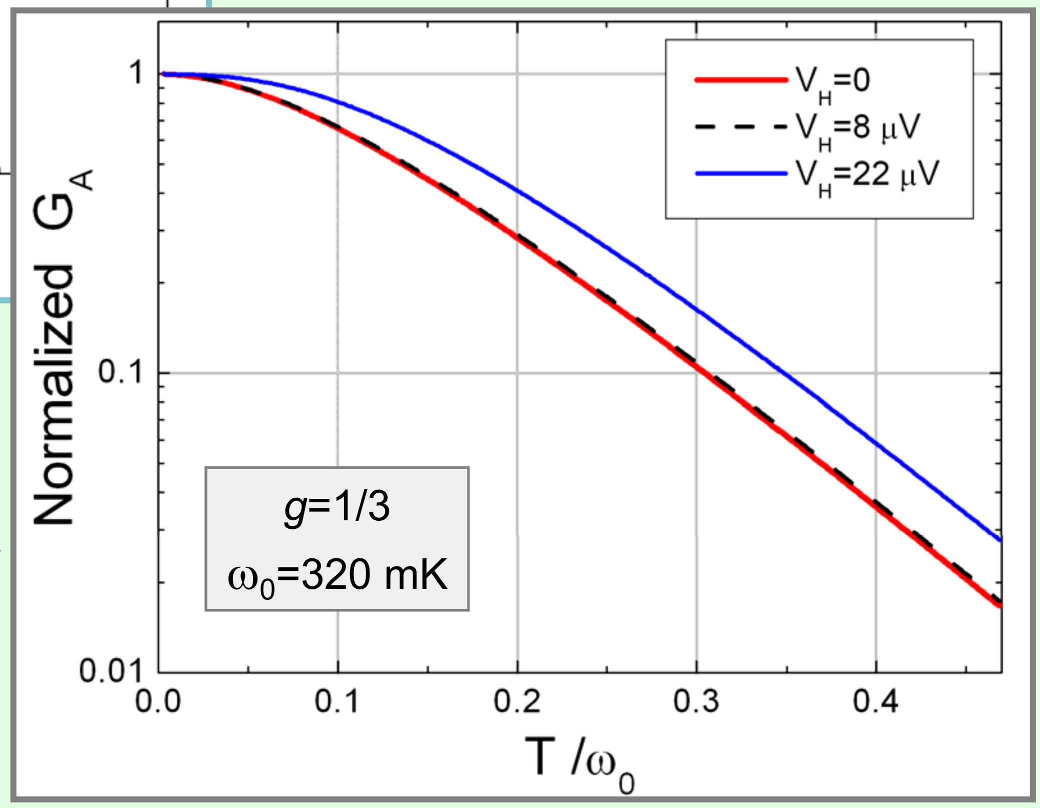
Josephson: $\omega_J = qV_H / \hbar$ q = e/3 is the quasiparticle charge

oscillatory: $\omega_0 = 4\pi u / C$ u is the edge velocity; C is the closed path circumference

Chamon et al. Model Predictions

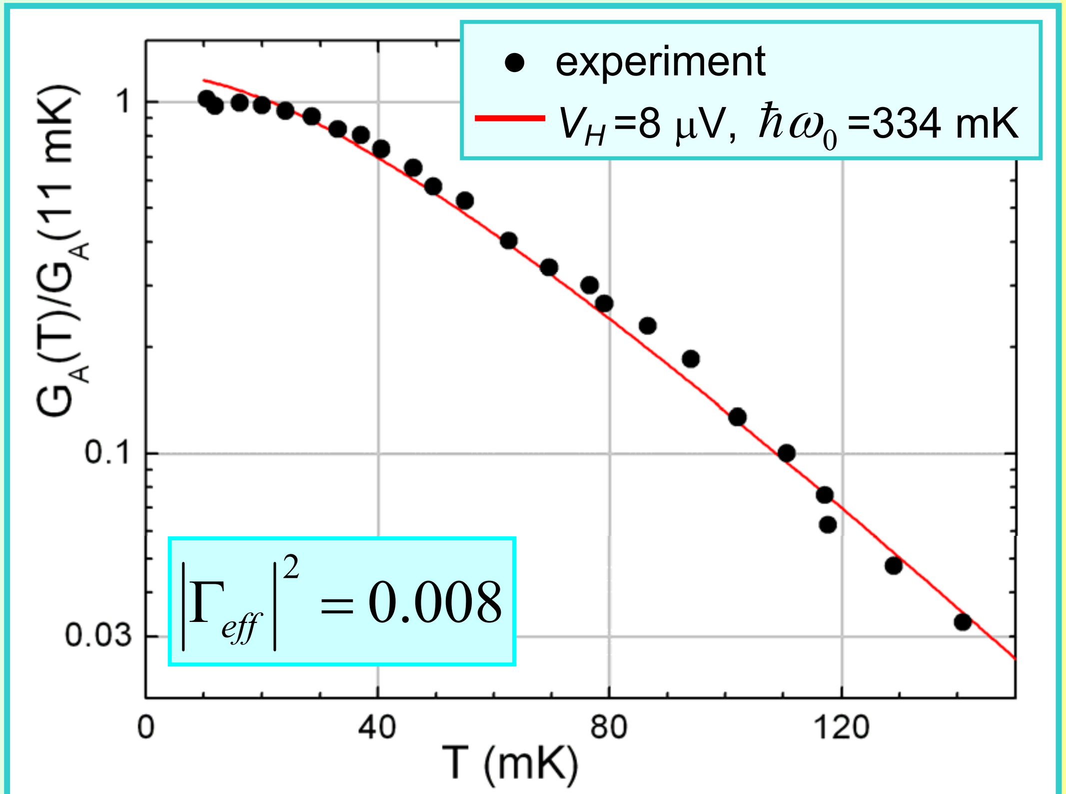


fixed temperature
variable bias V_H



fixed bias V_H
variable temperature

Comparison with Quantum Interferometer Model



- fit is very good!
- V_H =8 μV from experiment

$$V_H = \sqrt{7.2^2 + 2^2} = 7.5\ \mu\text{V}$$

applied bias

noise voltage

- fit is very similar for

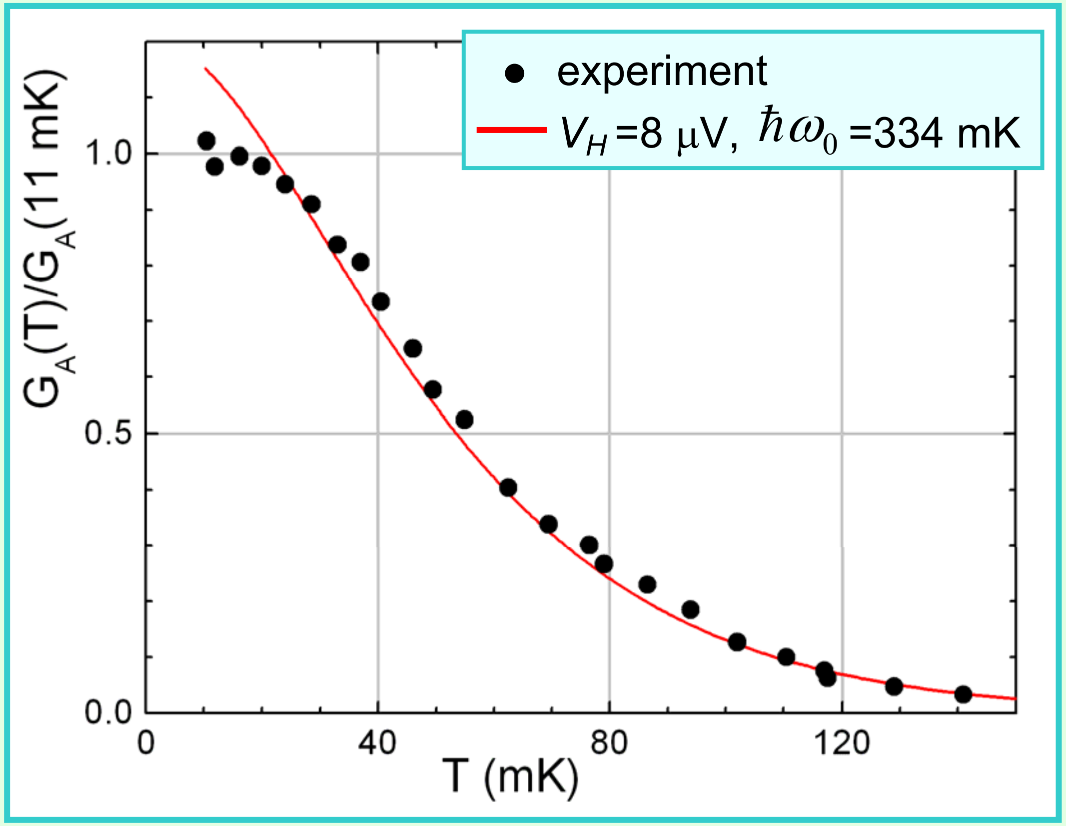
$V_H \rightarrow 0$

- Chamon et al. theory is first order in Γ
- experimental Γ_{eff} << 1

Using $\omega_0 = 4\pi u / C$ from fit (C=4.0 μm): u =1.4×10^4 m/s

$\Rightarrow$ confining electric field (at chemical potential) = $u\,B$ =1.7×10^5 V/m

Effective Electron Temperature (T_e)



a) No saturation of oscillation amplitude down to lowest T's

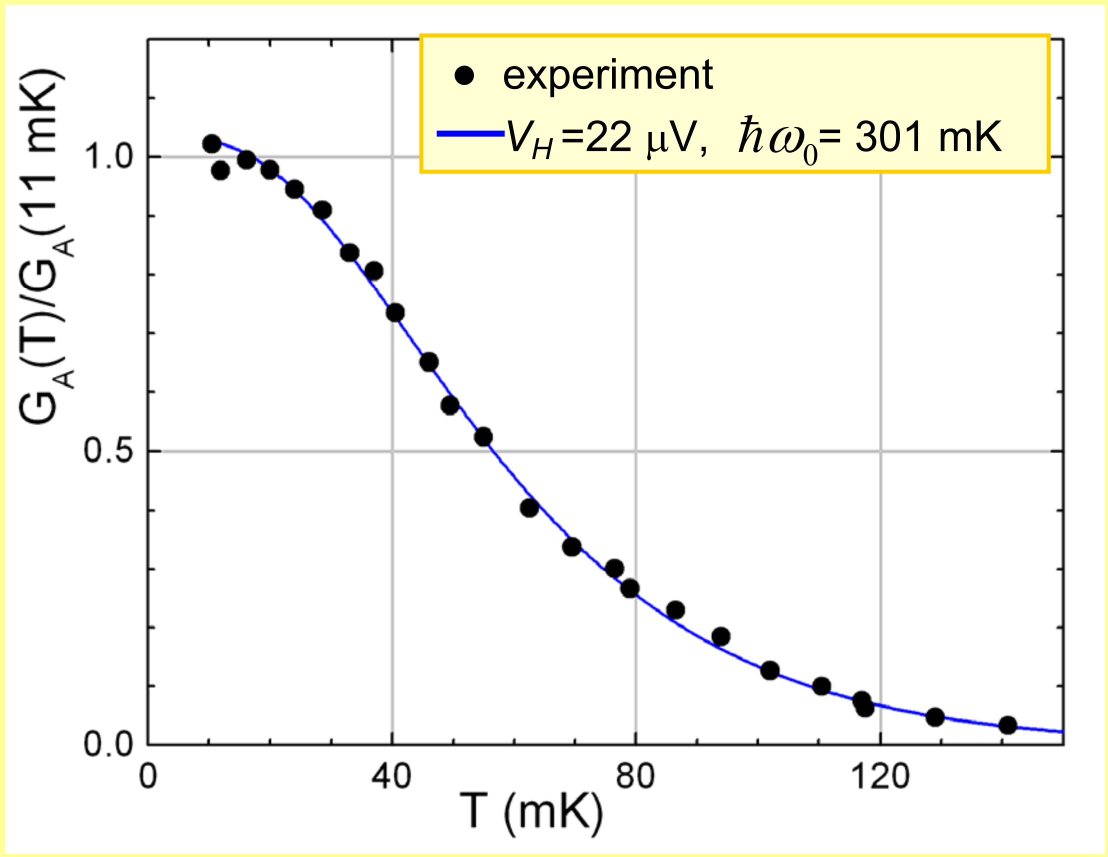
- amplitude changes by:
  40% from 40 to 10 mK
  5% from 20 to 10 mK

b) noise voltage 2 μV and T_e = 18 mK obtained from QAD experiments using almost identical experimental conditions

- we expect less heating in LQPI, since LQPI (2000 *e*) is larger than QAD (300 *e*). Also, tunneling amplitude Γ is less in LQPI

$\Longrightarrow$ in LQPI, T_e should be less than 18 mK observed in QAD

Adding V_H as a fitting parameter



V_H = 22 μV
fit is extremely good!
however, 22 μV is
not likely in our set-up!

From our experimental set-up we determine

$$V_H = \sqrt{7.2^2 + 2^2} = 7.5\ \mu\text{V}$$

applied bias

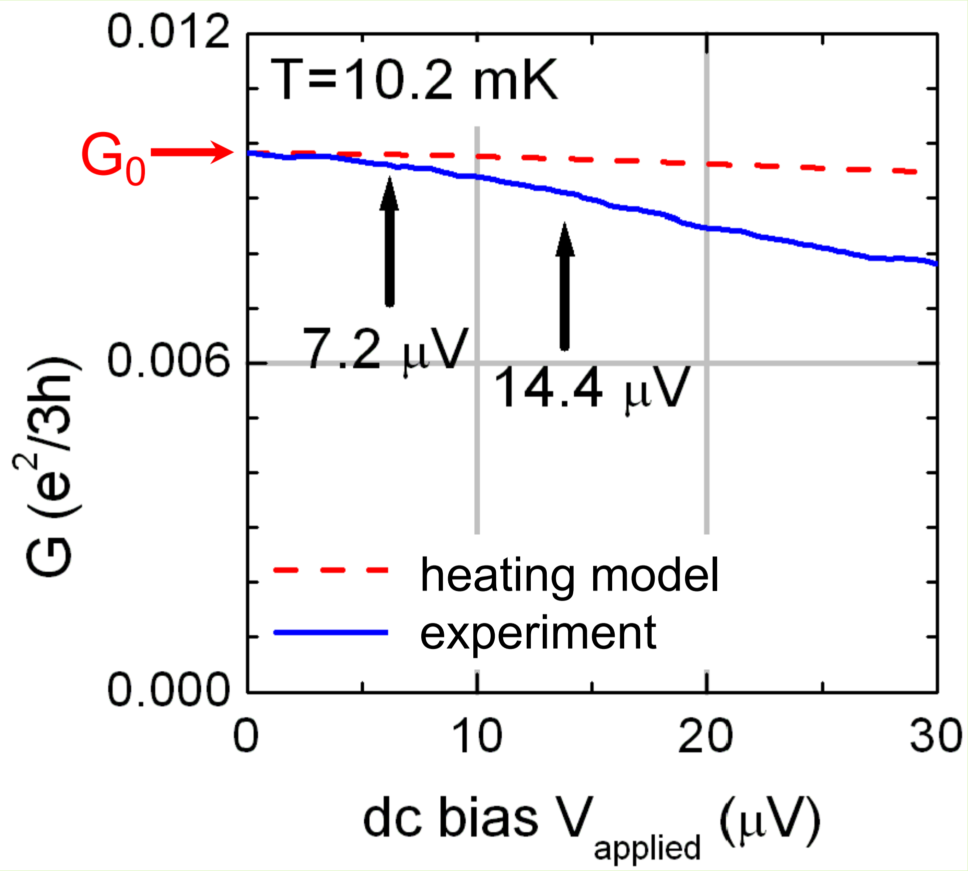
noise voltage

Tests that rule out V_H=22 μV from Heating

- <u>electron heating model:</u>

a) $P \propto V_H^2 = V_{applied}^2 + V_{noise}^2$ b) $T_e^5 - T_{bath}^5 \propto V_H^2$ c) $\frac{\delta G}{\delta T_e} = G_0 \frac{\partial H_g}{\partial T}$

- experiment vs. heating model (assuming V_{noise}=21 μV WRONG !)



$V_{applied}$		$\delta G/G_0$ heating model	$\delta G/G_0$ exp.
ac	×0.5	0.25%	**2-3%**
dc	7.2 μV	- 0.3%	**- 3%**
dc	14.4 μV	- 1%	**- 8%**

Conclusions

- T-dependence of the amplitude of conductance oscillations shows thermal dephasing, expected for an electron interferometer
- data fit very well the χLL theory of Chamon et al. for a two point-contact LQPI
- Topological nature of fractional statistics ($\Delta_\Phi = 5\,h/e$):

$f = 2/5$ island quasiparticles determine the period,

but do not affect T-dependence of the oscillation amplitude:

$\Delta_\Phi = 5\,h/e$ persists to the highest T

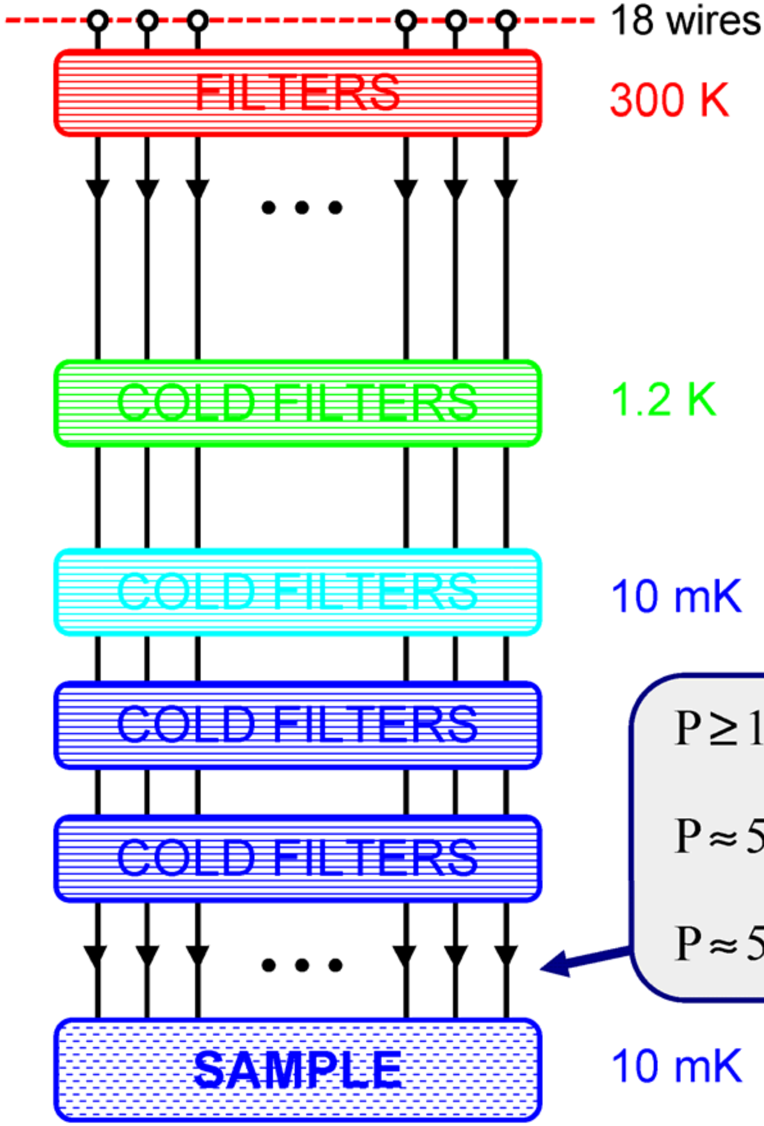
$\Rightarrow$ reveals robustness of statistical interaction due to its topological nature

$\Rightarrow$ potential application for implementing topological quantum computation

χLL=chiral Luttinger liquid

LQPI=Laughlin quasiparticle interferometer

Electromagnetic "Noise" Filtration



* typical QD work

* "very low noise"

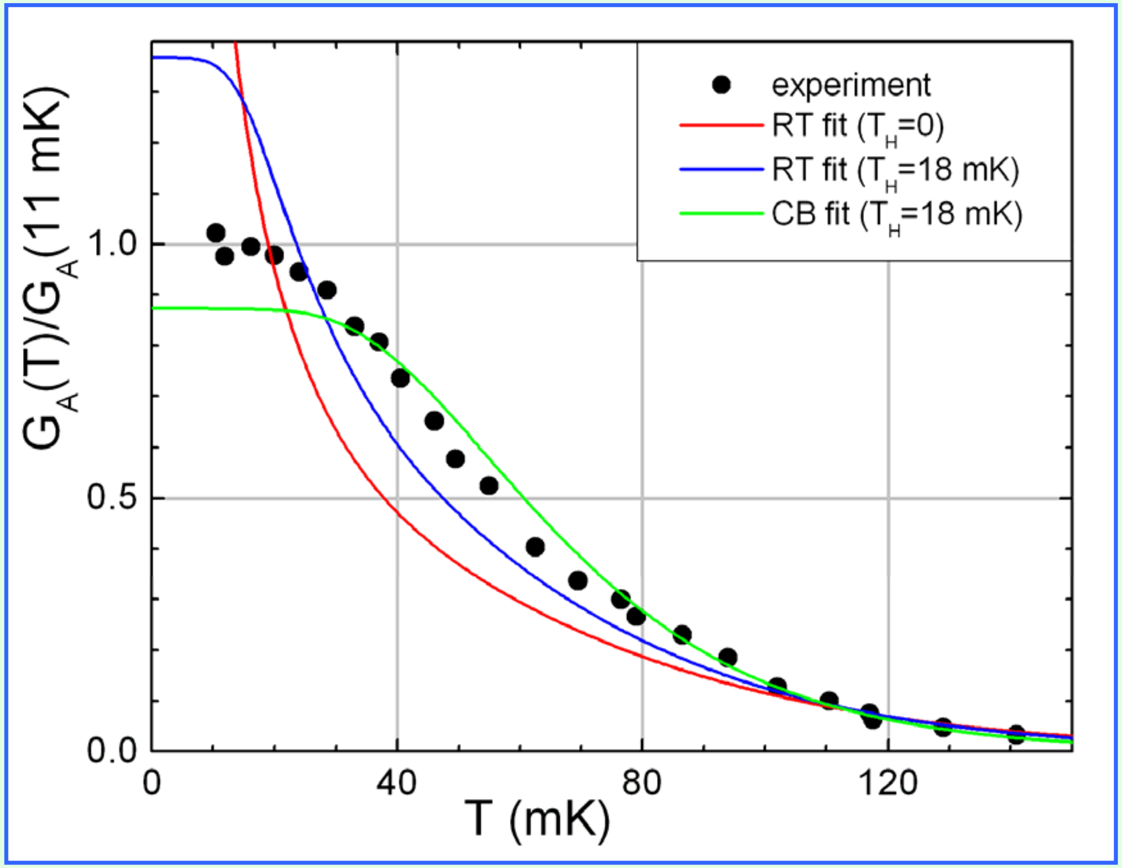
Roukes *et al.*, 2000
Webb *et al.*, 1996

* QTL/SBUniversity

Maasilta *et al.*, 1997
Karakurt *et al.*, 2000
Camino *et al.*, 2005

$P \geq 1\times10^{-14}$ W	**QD** *
$P \approx 5\times10^{-16}$ W	**VLN** *
$P \approx 5\times10^{-17}$ W	**QTL** *

Comparison with Resonant Tunneling and Coulomb Blockade Models



1) <u>resonant tunneling</u> (RT):

$$G(T) = G_0 / T \cosh^2(X/T)$$

no realistic T_H fits data

- fit saturates at ~32 mK, while experiment still rises

2) <u>Coulomb blockade</u> (CB):

$$G(T) = G_0 X / T \sinh(X/T)$$

- fit does not depend on T_H at this scale
- if CB, minima should rise while maxima remain const. as T is increased. This is not observed in experiment