



凝聚态物理-北京大学论坛

北京大学物理学院

林熙

2012/11/01



Measurements of Quasi-Particle Tunneling in the $\nu = 5/2$ Fractional Quantum Hall Regime

Cooperator: C. Dillard¹, M. A. Kastner¹, L. N. Pfeiffer², and K. W. West²

1. Massachusetts Institute of Technology
2. Princeton University

Thanks to Claudio Chamon, Dmitri Feldman, Paul Fendley, Charles Marcus, Chetan Nayak, and Xiao-Gang Wen for helpful discussions.



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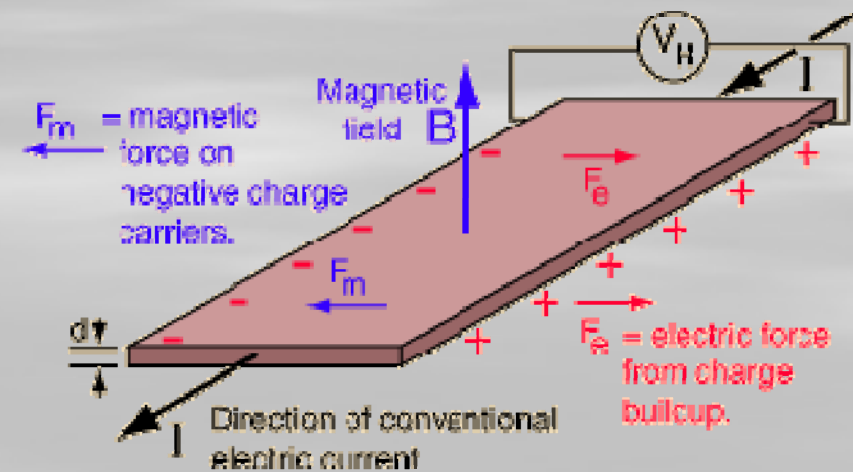
Outline

- Introduction to quantum Hall effect
- Motivation
- Details of the experiment
- Results
- Summary



Introduction to QHE

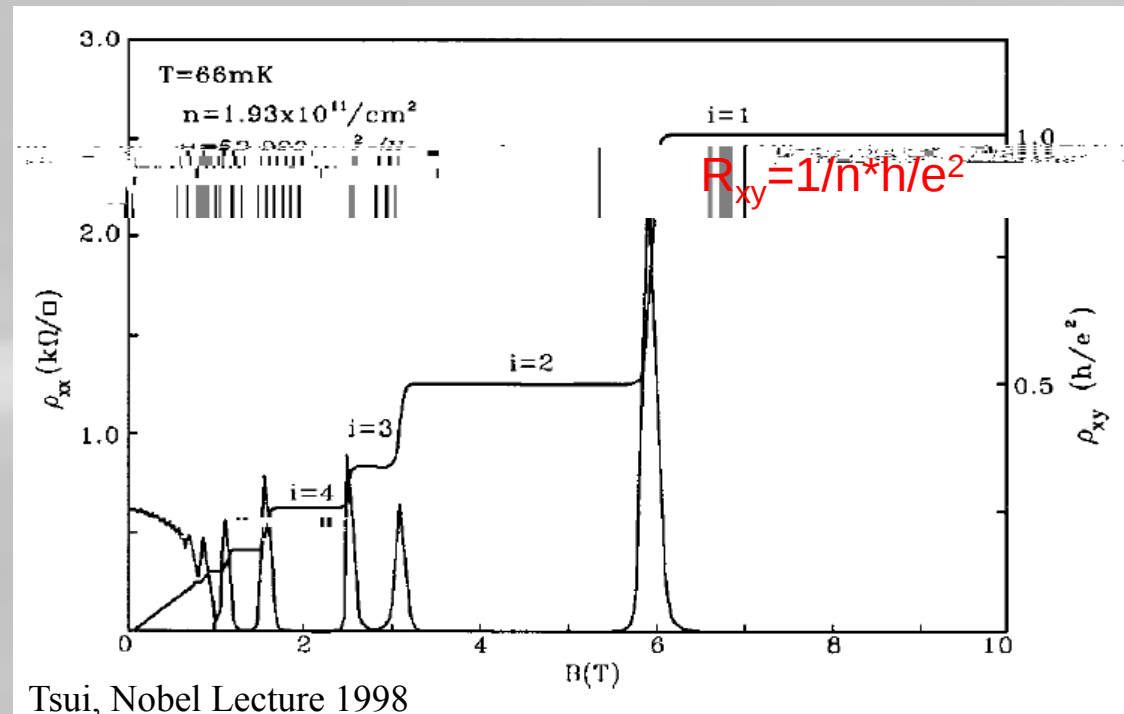
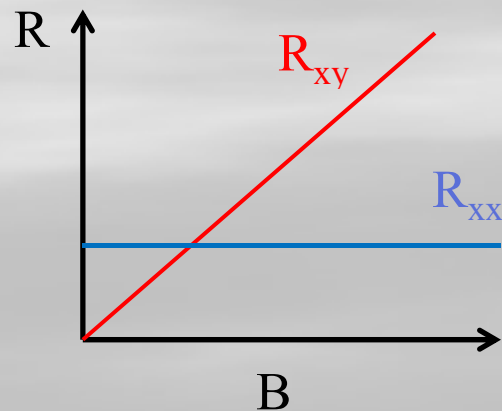
- Classical quantum Hall effect
 - Edwin Hall, 1879





Introduction to QHE

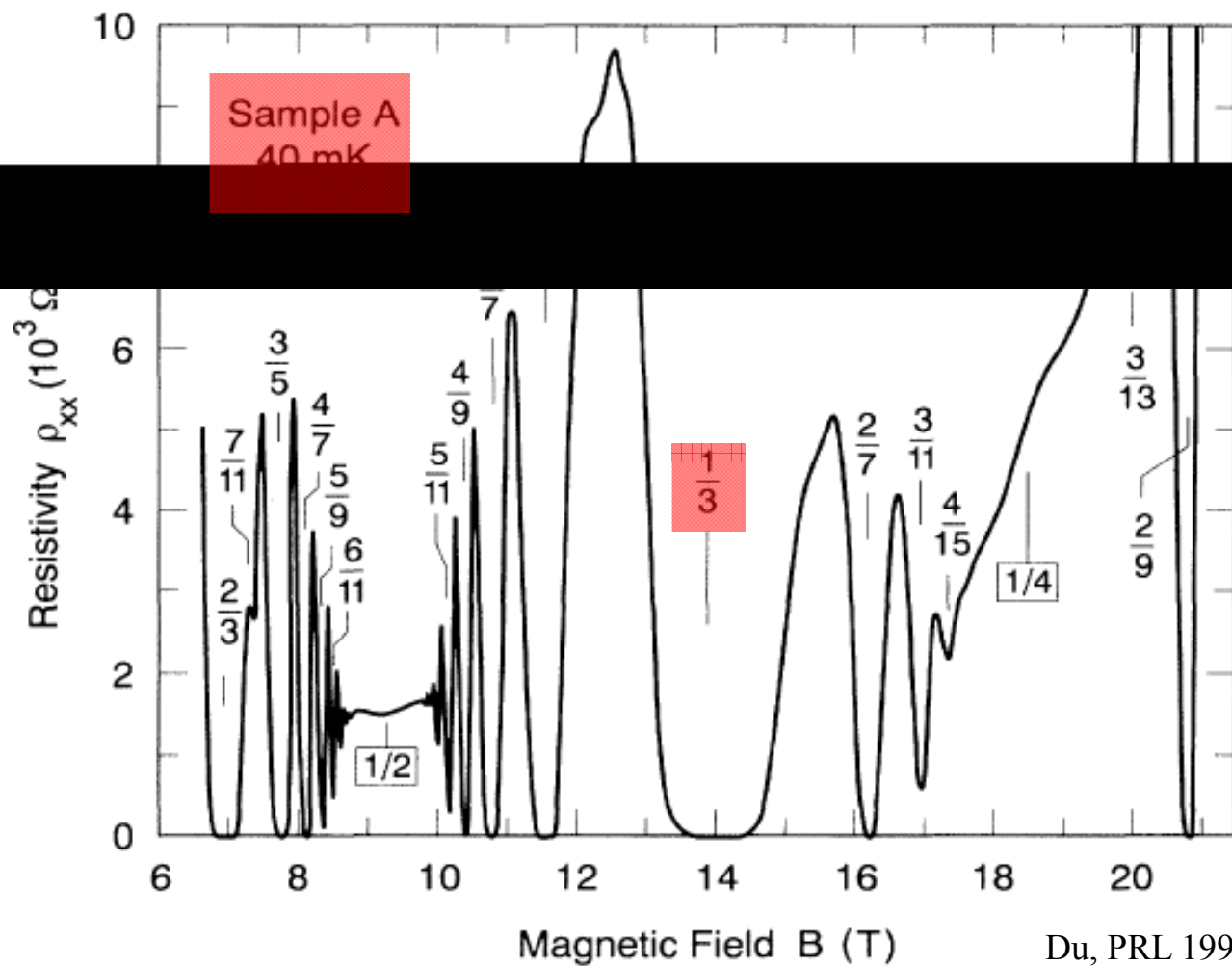
- Quantum Hall effect (QHE)
 - discovered by Klitzing(1980)





Introduction to QHE

■ FQHE



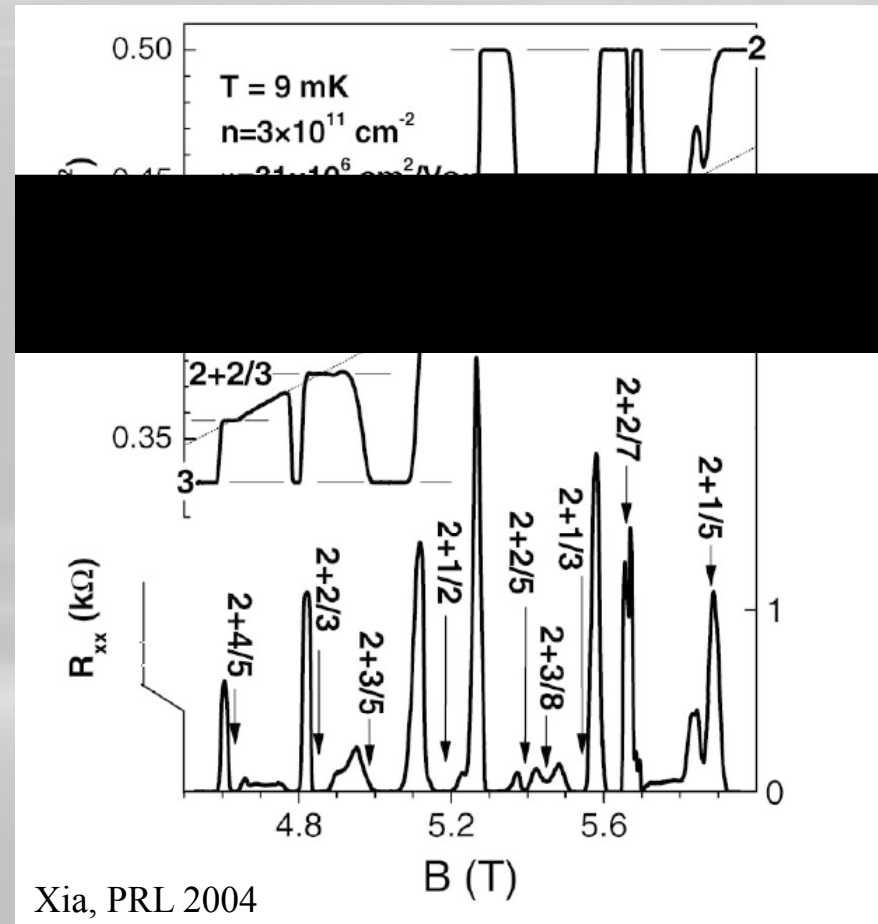
$$\nu = \frac{p}{(2q \pm 1)}$$

Motivation

■ 5/2 FQHE

– Willett, PRL 1987

$$\nu = \frac{p}{(2q \pm 1)} \quad ?$$



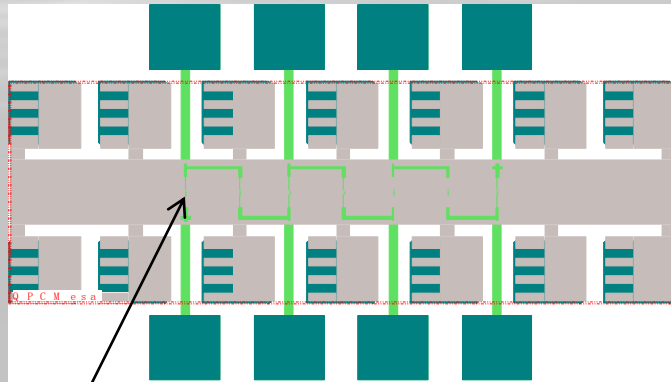
Xia, PRL 2004



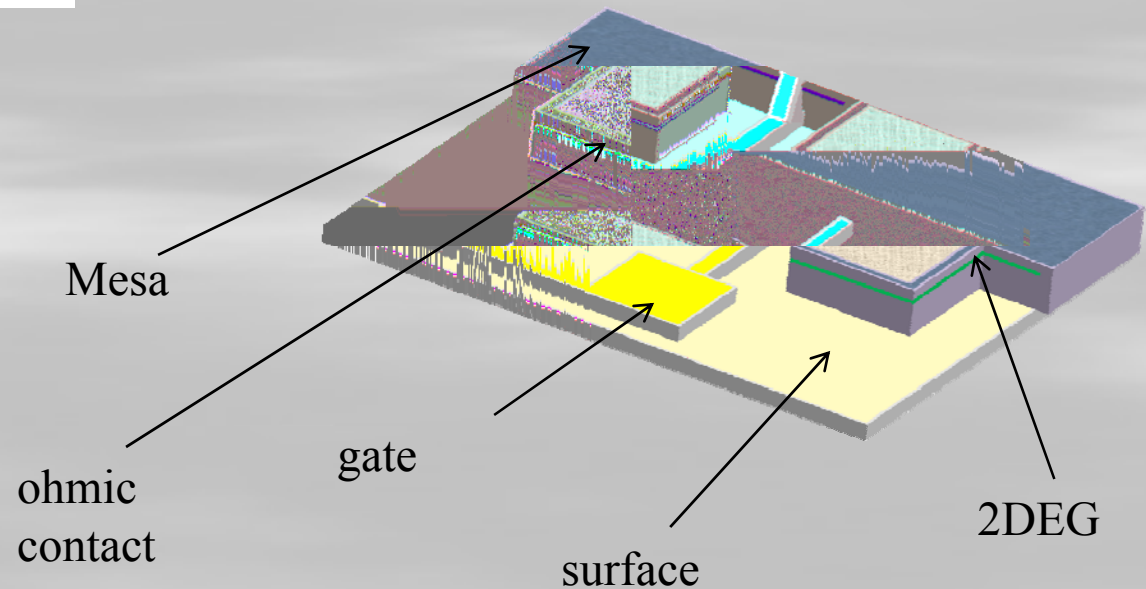
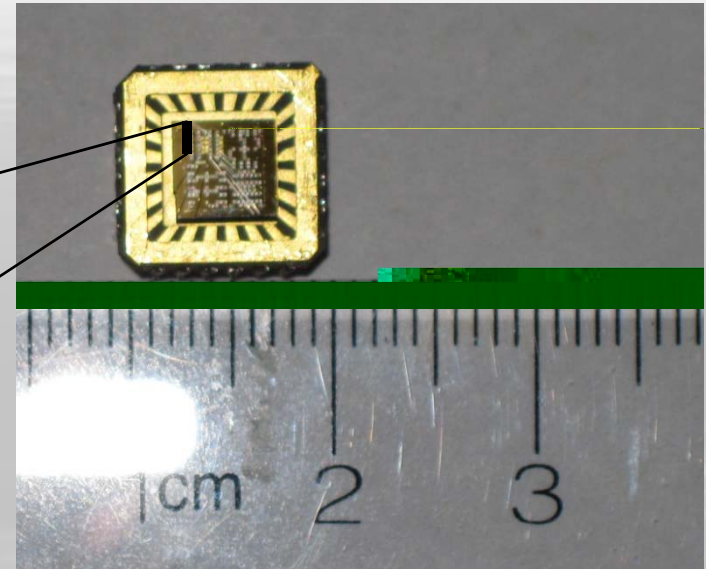
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Details of the experiment

■ GaAs Heterostructures



QPC: quantum point contact
width: a few 100 nm



Details of the experiment

$$I_{AC} = 0.4 \text{ nA at } 17 \text{ Hz}$$

$$R_{XY} = dV_{XY} / dI_{AC}$$

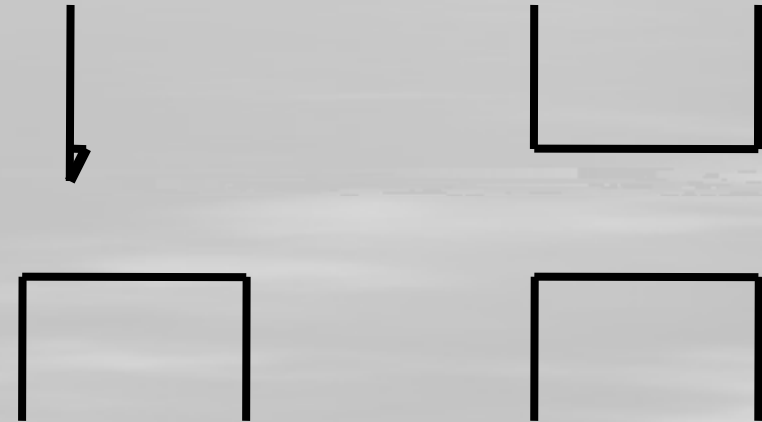
$$R_D = dV_D / dI_{AC}$$

Geometry A: short QPC of nominal width $\sim 0.6 \mu\text{m}$,

Geometry B: a long channel of nominal width $\sim 1.2 \mu\text{m}$ and length $\sim 2.2 \mu\text{m}$.

Geometry A

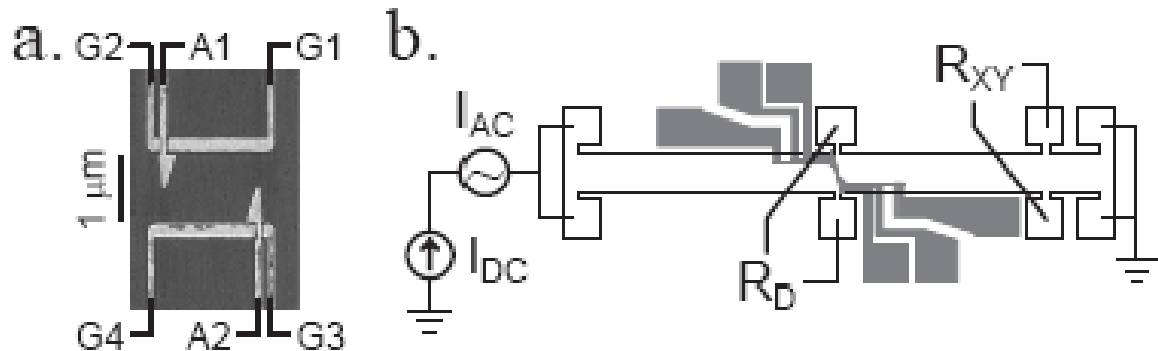
Geometry B



$$g_T(T, I_{DC}) = AT^{(2g-2)} F\left(g, \frac{e^* I_{DC} R_{XY}}{k_B T}\right) \quad g_T = (R_D - R_{XY}) / R_{XY}^2$$

$$F(g, x) = B\left(g + i\frac{x}{2\pi}, g - i\frac{x}{2\pi}\right) \left\{ \pi \cosh(x/2) - 2 \sinh(x/2) \text{Im} \left[\Psi\left(g + i\frac{x}{2\pi}\right) \right] \right\},$$

Wen, *Phys. Rev. B.* **44**, 5708 (1991).



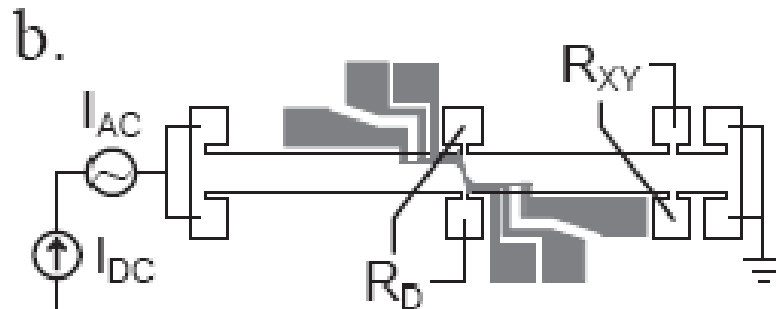
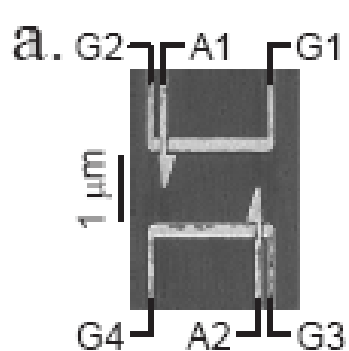
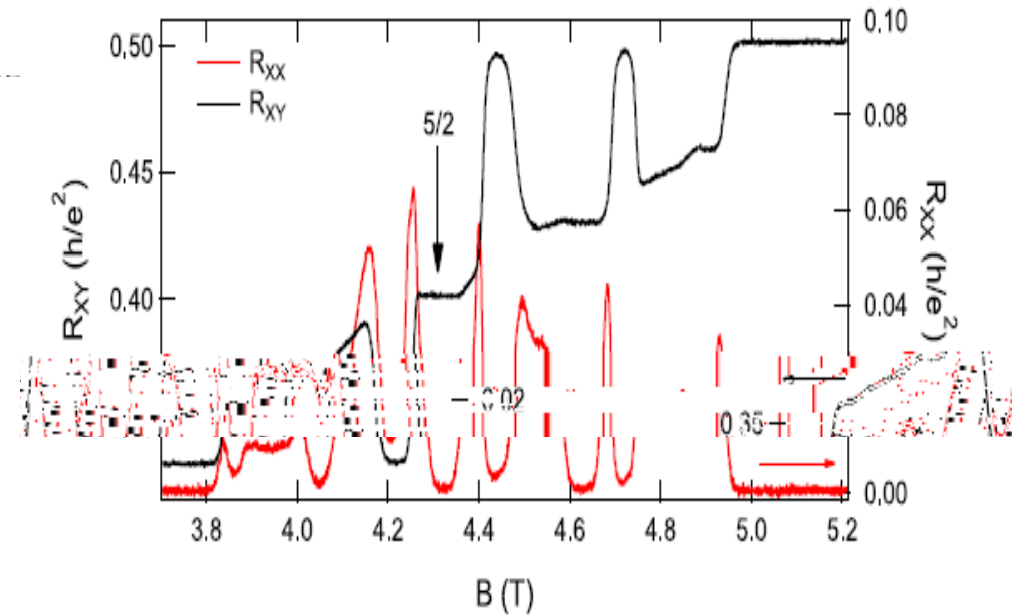
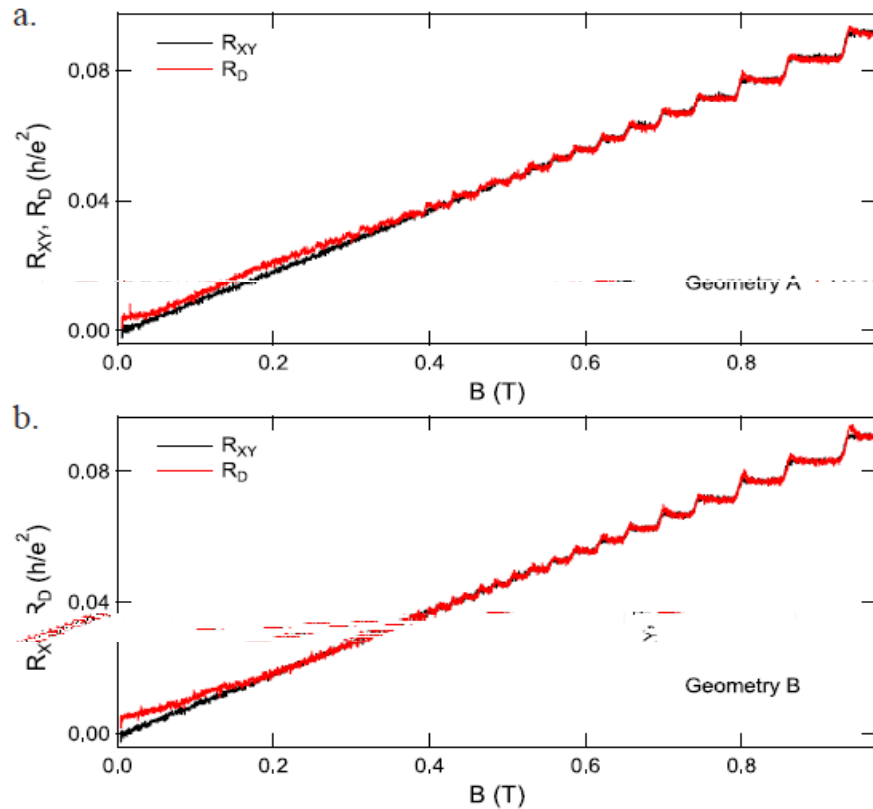
Mobility: $1 \times 10^7 \text{ cm}^2/\text{Vs}$

Density: $2.6 \times 10^{11} \text{ cm}^{-2}$



Details of the experiment

Annealing at -2.7 V for 60 hours at 4K to match the density of the QPC and the bulk



Details of the experiment

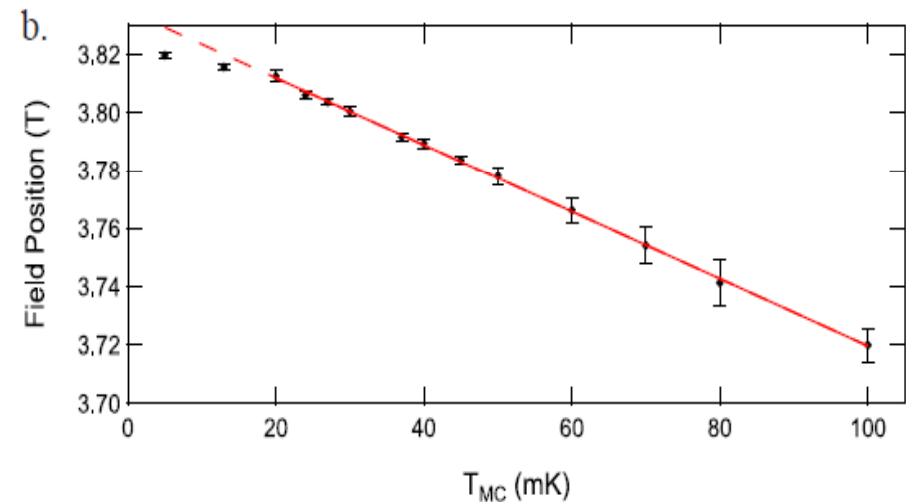
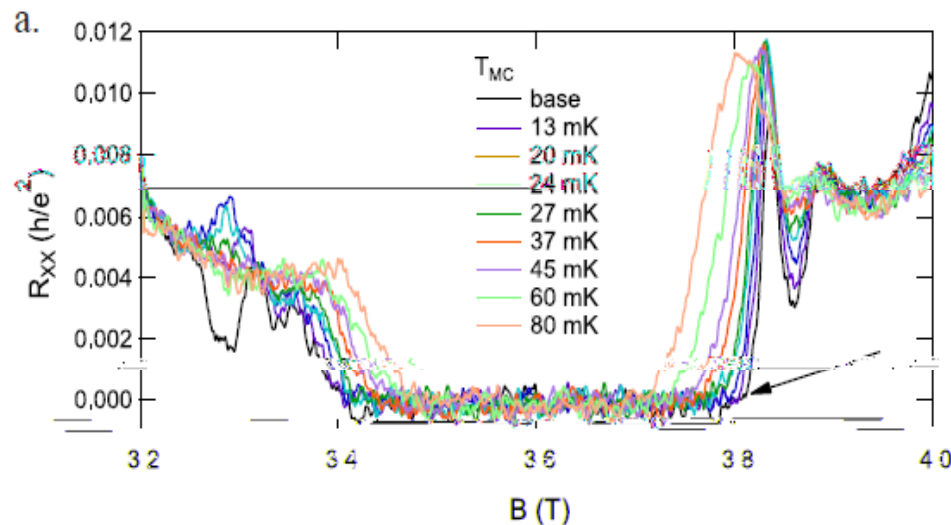
$$g_T(T, I_{DC}) = AT^{(2g-2)} F\left(g, \frac{e^* I_{DC} R_{XY}}{k_B T}\right) \quad g_T = (R_D - R_{XY}) / R_{XY}^2$$

$$F(g, x) = B\left(g + i\frac{x}{2\pi}, g - i\frac{x}{2\pi}\right) \left\{ \pi \cosh(x/2) - 2 \sinh(x/2) \operatorname{Im} \left[\Psi\left(g + i\frac{x}{2\pi}\right) \right] \right\},$$

Electron temperature vs Mixing chamber temperature?

Electron temperature measured directly from thermally broadened Coulomb blockade peaks of a quantum dot.

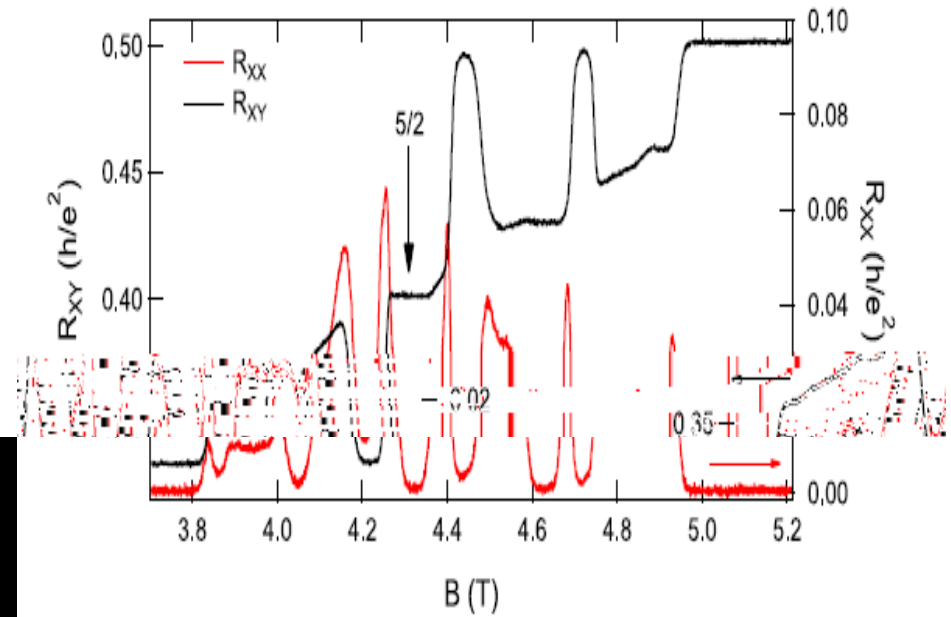
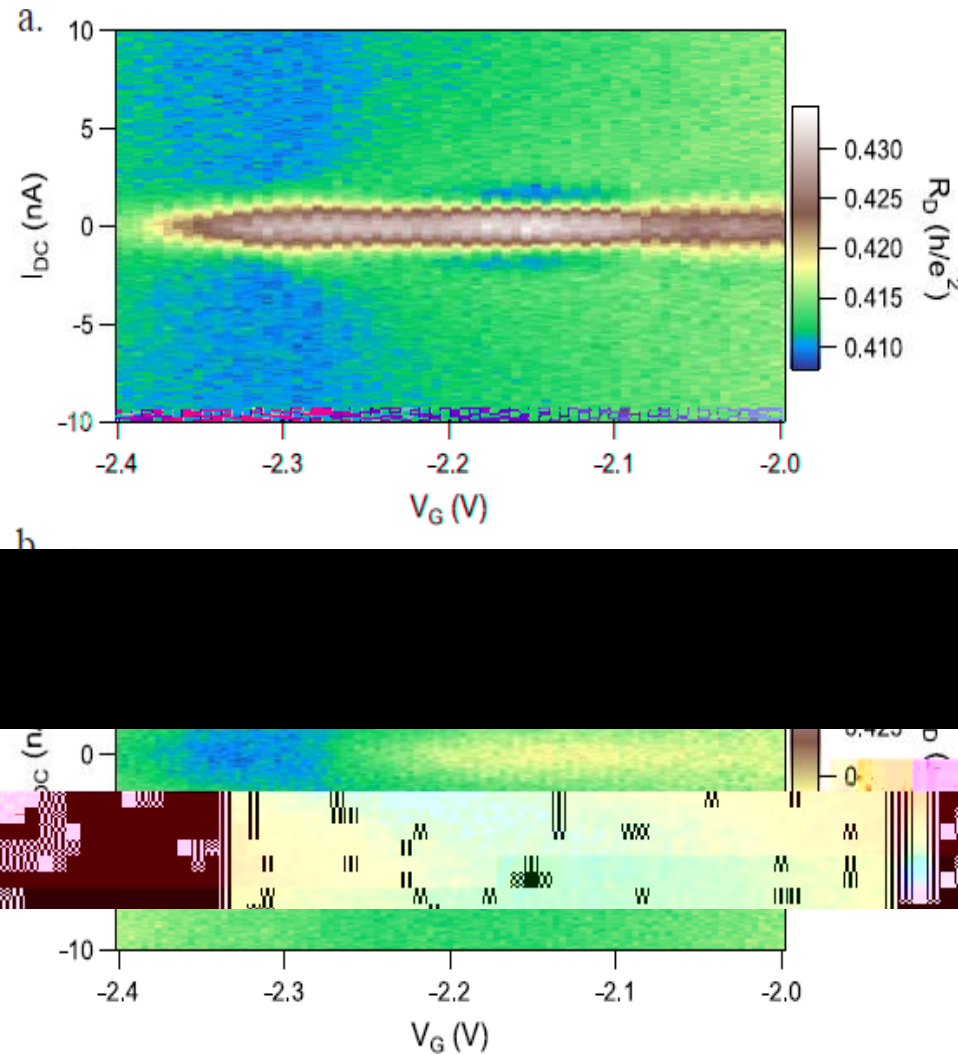
A convenient way to determine electron temperature. All the measurements reported here is above 20mK.





Details of the experiment

Tunneling at different gate voltages.

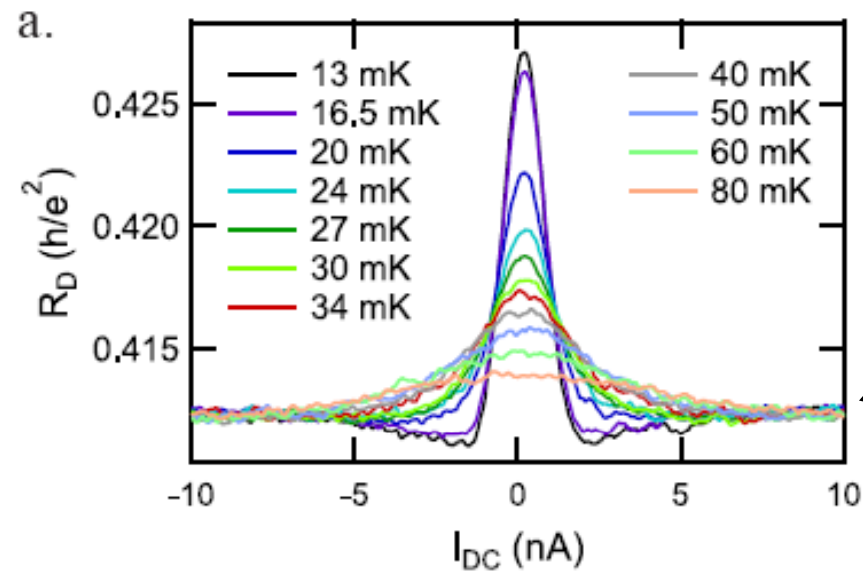




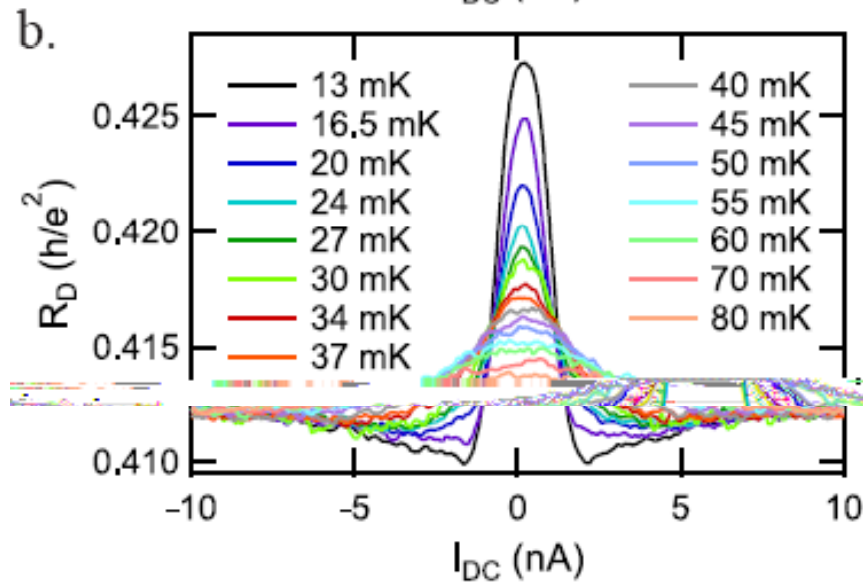
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Results

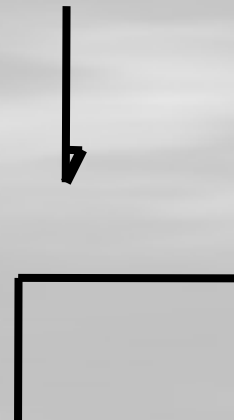
Tunneling at different temperatures.



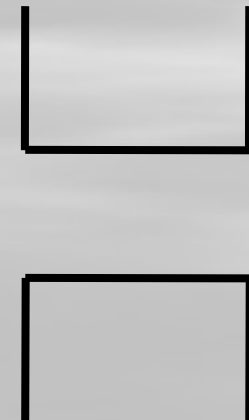
R_∞ , background resistance, larger than the expected quantized value $0.4 h/e^2$



Geometry A



Geometry B

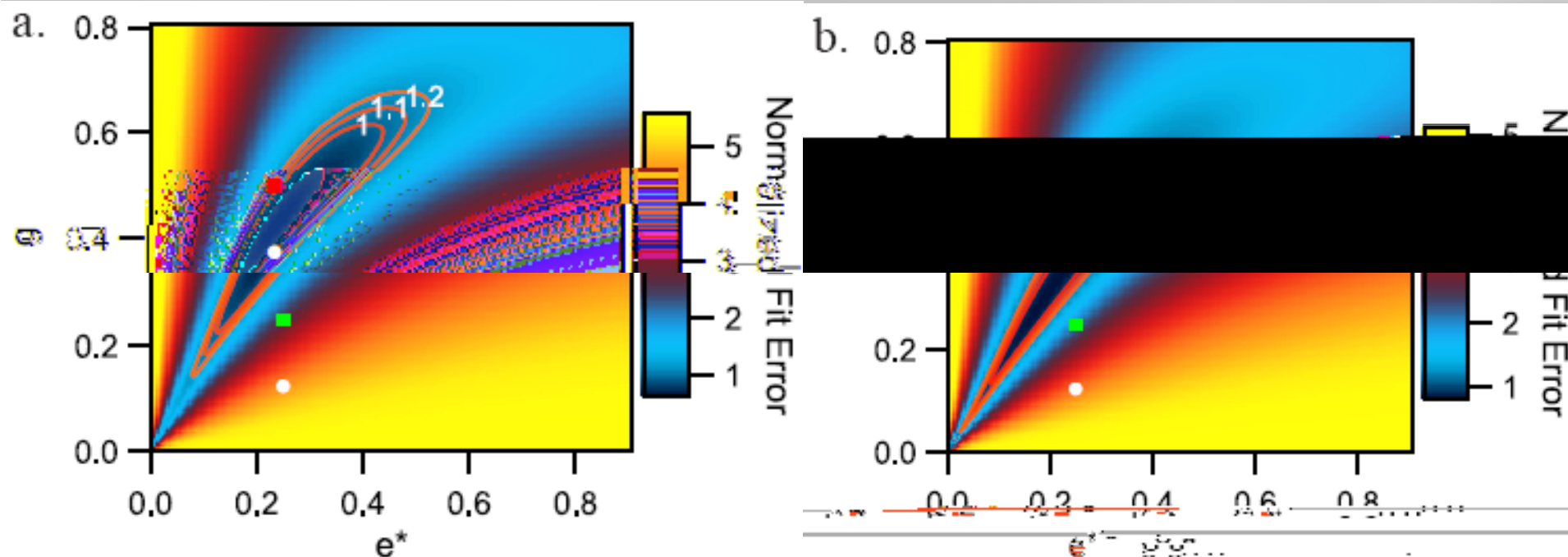


Results

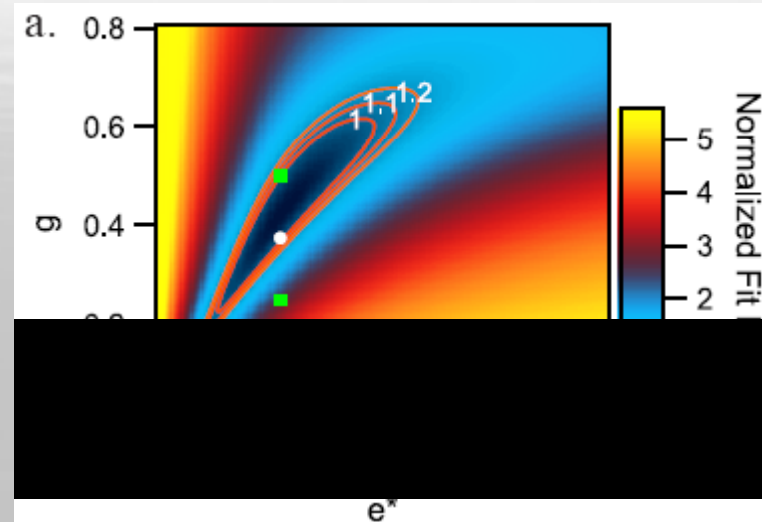
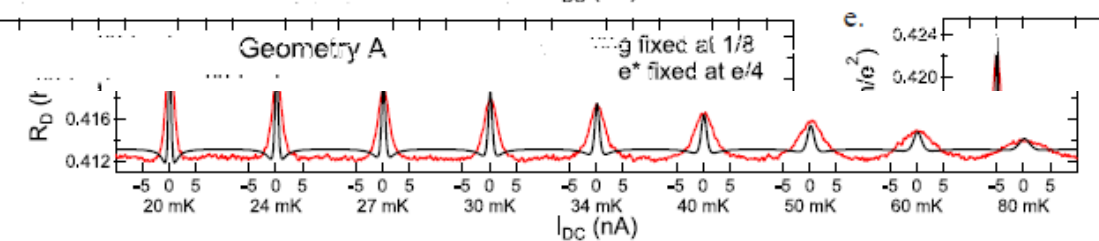
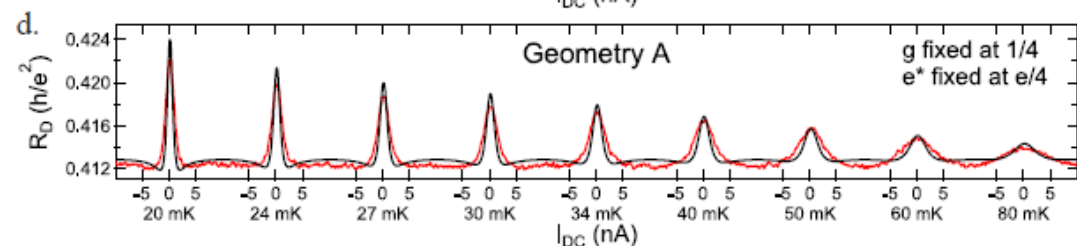
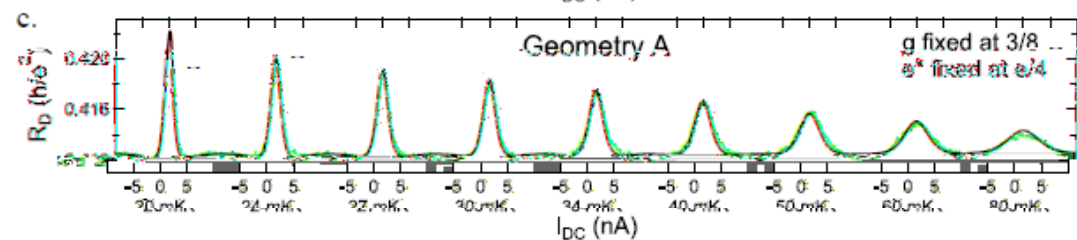
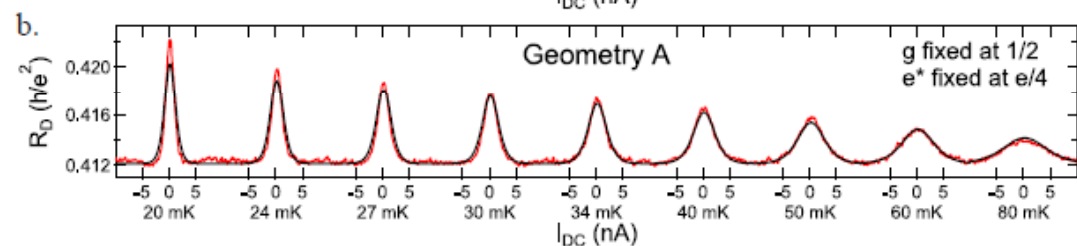
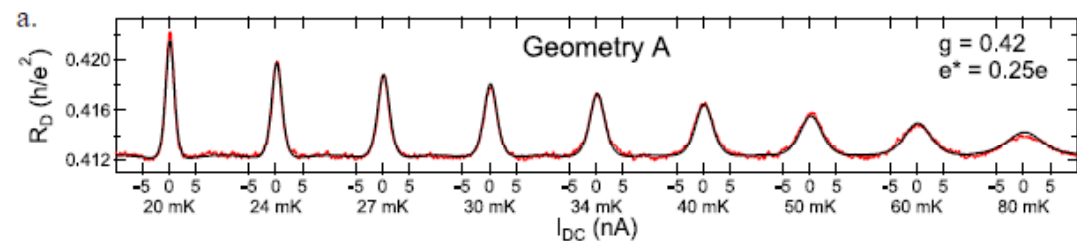
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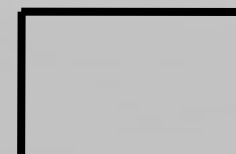
	K=8	331	Pfaffian	Anti-Pfaffian	U(1) x SU(2)
e^*	$e/4$	$e/4$	$e/4$	$e/4$	$e/4$
g	$1/8$	$3/8$	$1/4$	$1/2$	$1/2$



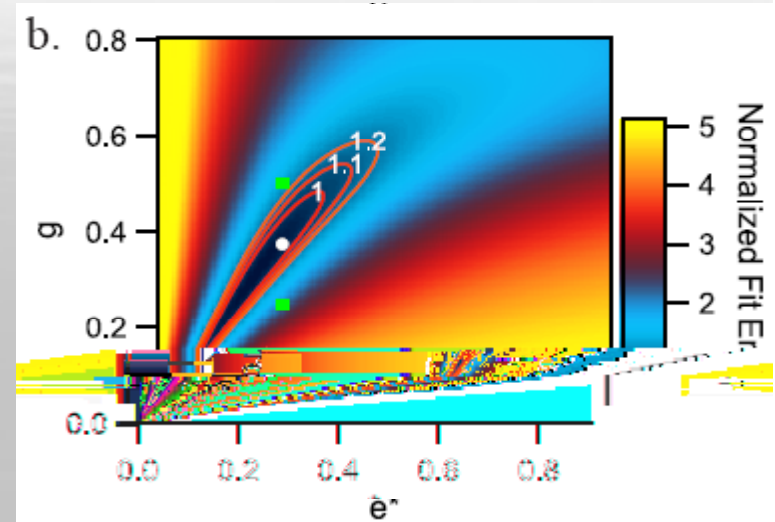
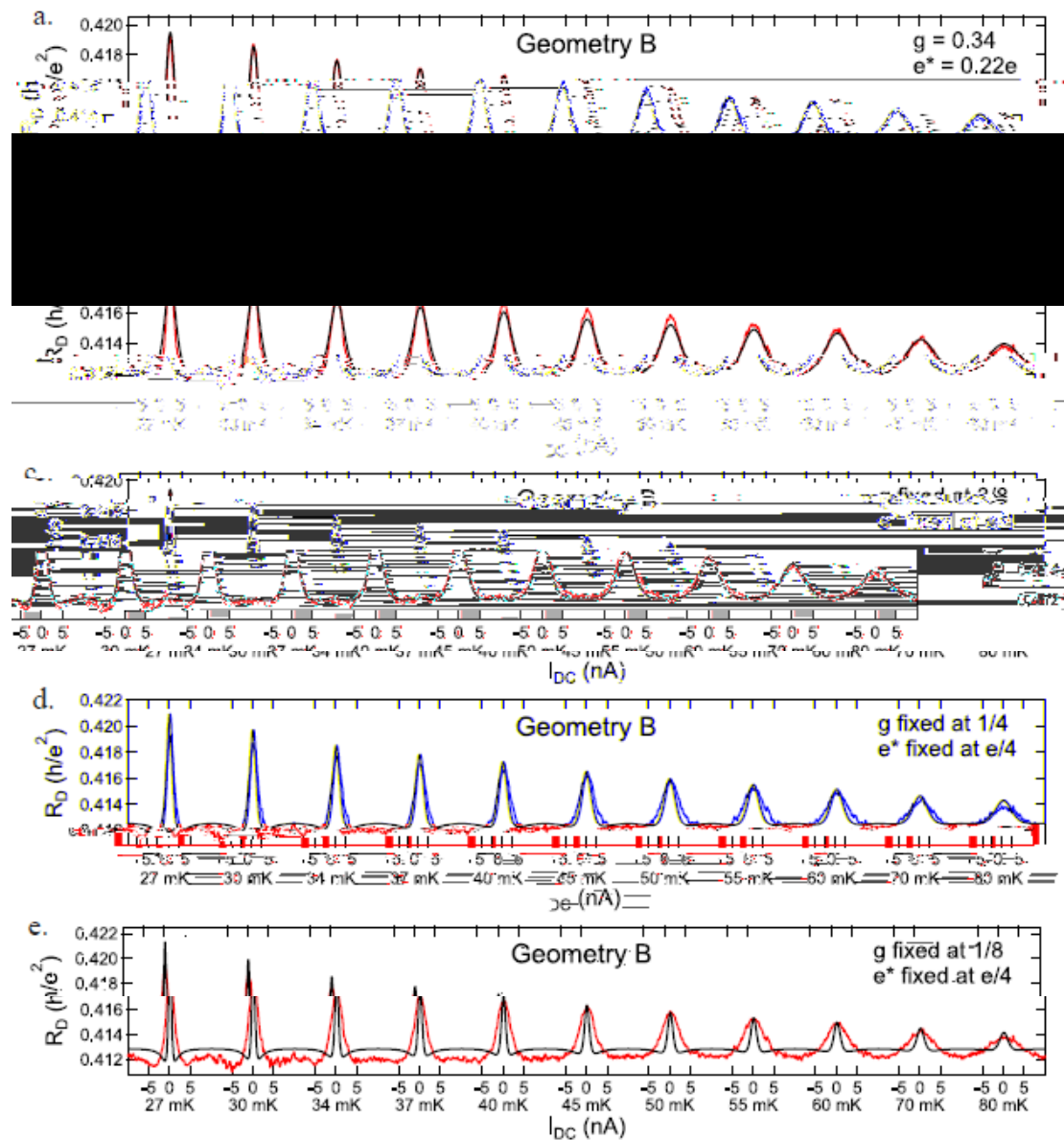
Results



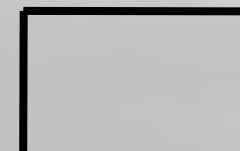
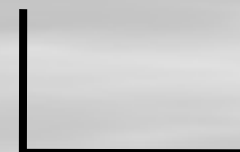
Geometry A



Results



Geometry B

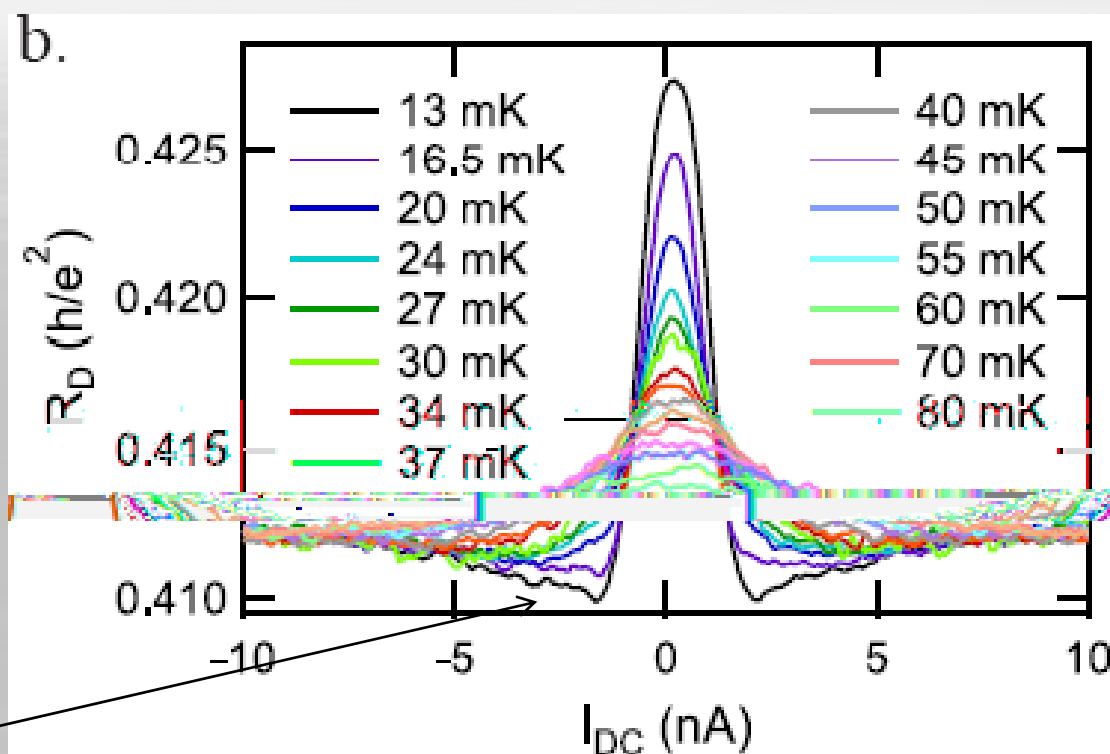




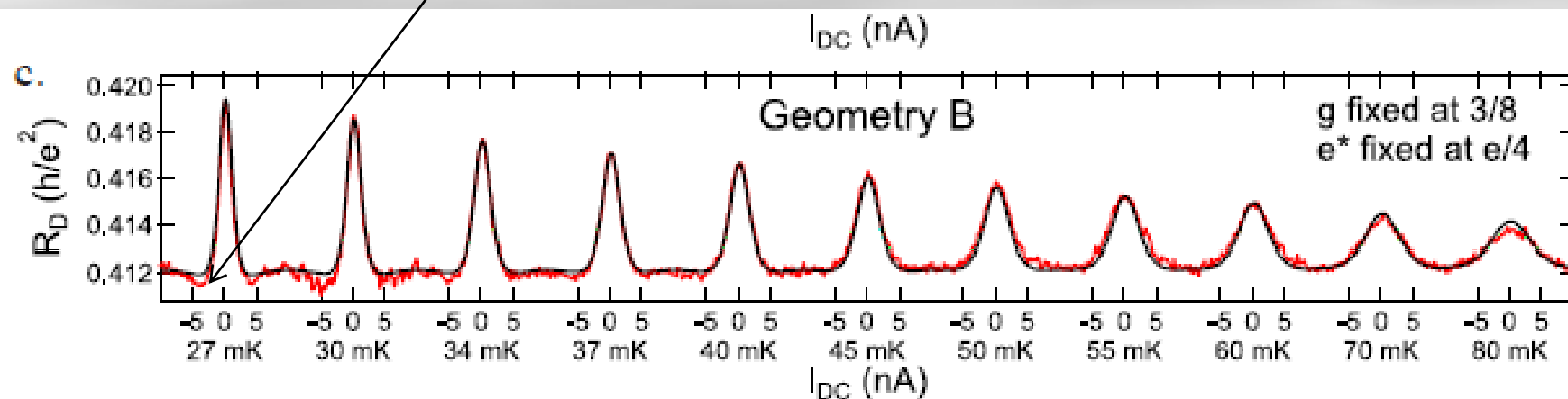
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Results

$g < 0.5$ or $g = 0.5$?



Dip?



Results

$g < 0.5$ or $g = 0.5$?

$$\frac{1}{R_D} = \frac{dI}{dV_D} = g + C \left(\frac{T_B}{V_D} \right)^{2(1-g)} (2g - 1) + \dots$$

Fendley, *PRB* **52**, 8934 (1995).

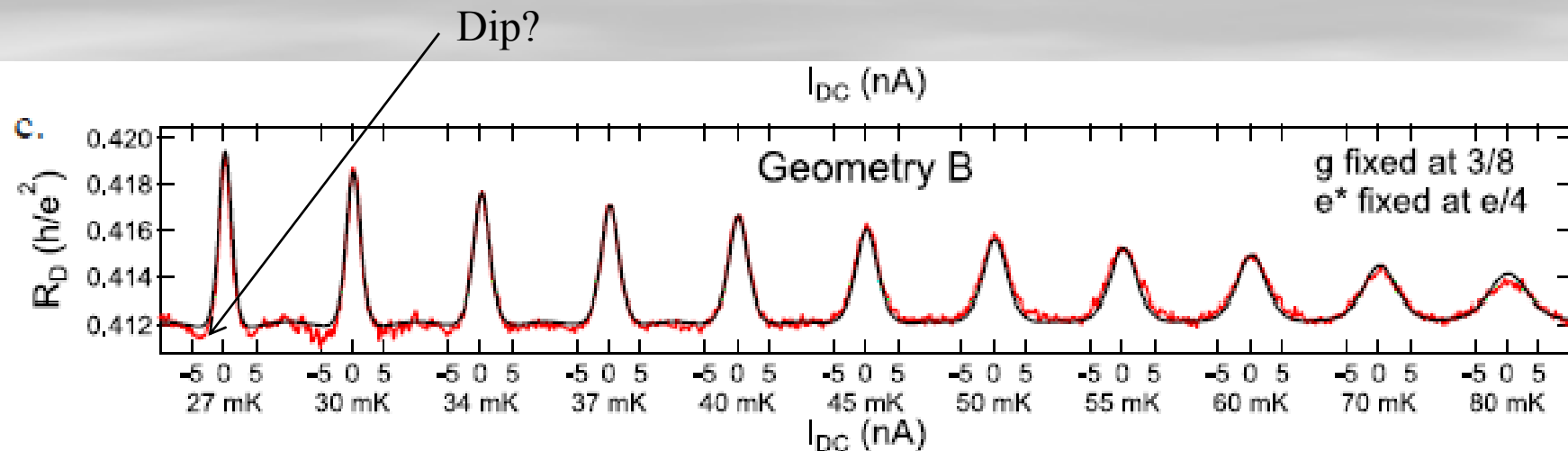
C : a negative constant,

T_B : reflecting the strength of the edge channel interaction

V_D : diagonal voltage.

As T_B/V_D increases (corresponding to decreasing from I_{dc} infinity), R_D decreases for $g < 1/2$, is constant for $g = 1/2$, and increases for $g > 1/2$. Since R_D eventually increases as the bias approaches zero, this produces a minimum in R_D only for $g < 1/2$.

This analysis neglects higher order terms, which could conceivably produce a minimum in R_D at $g = 1/2$, but to lowest order the presence of minima requires $g < 1/2$.



Summary

- Fits based on quasi-particle weak tunneling theory favor the presence of the 331 abelian wave function.
- Presence of minima in the DC bias dependence, which requires $g < 1/2$.
- Experiments favoring non-abelian states/Different states may be physically realizable at $\nu = 5/2$ due to device geometries or heterostructures?
- Unresolved Questions/Further Study:
 - Why is background resistance larger than the expected quantized value $0.4 h/e^2$?
 - Measurements at other filling fractions, i.e. $\nu = 1/3$