凝聚态物理-北京大学论坛

北京大学物理学院
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Measurements of Quasi-Particle Tunneling in the $\upsilon = 5/2$ Fractional Quantum Hall Regime

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2. Princeton University

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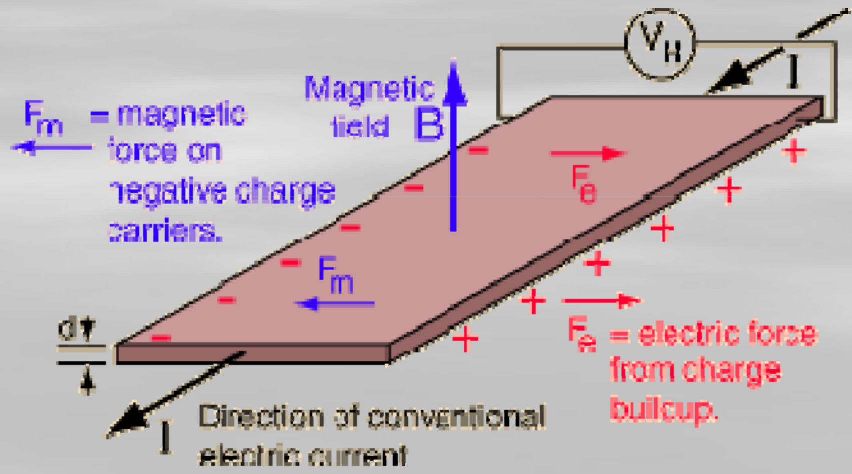
Outline

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

Introduction to QHE

- Classical quantum Hall effect
  - Edwin Hall，1879



http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/hall.html

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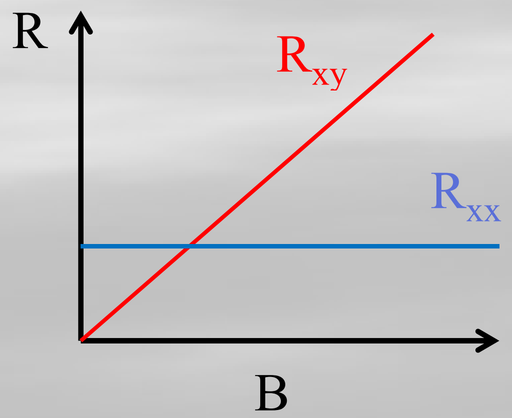
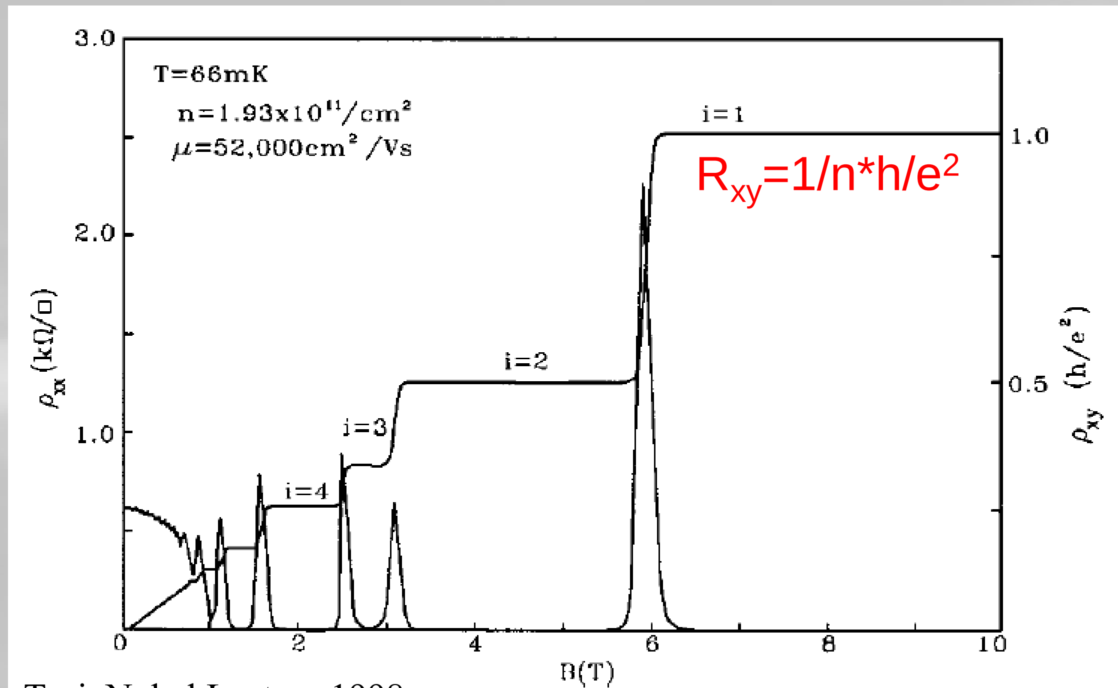
Introduction to QHE

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

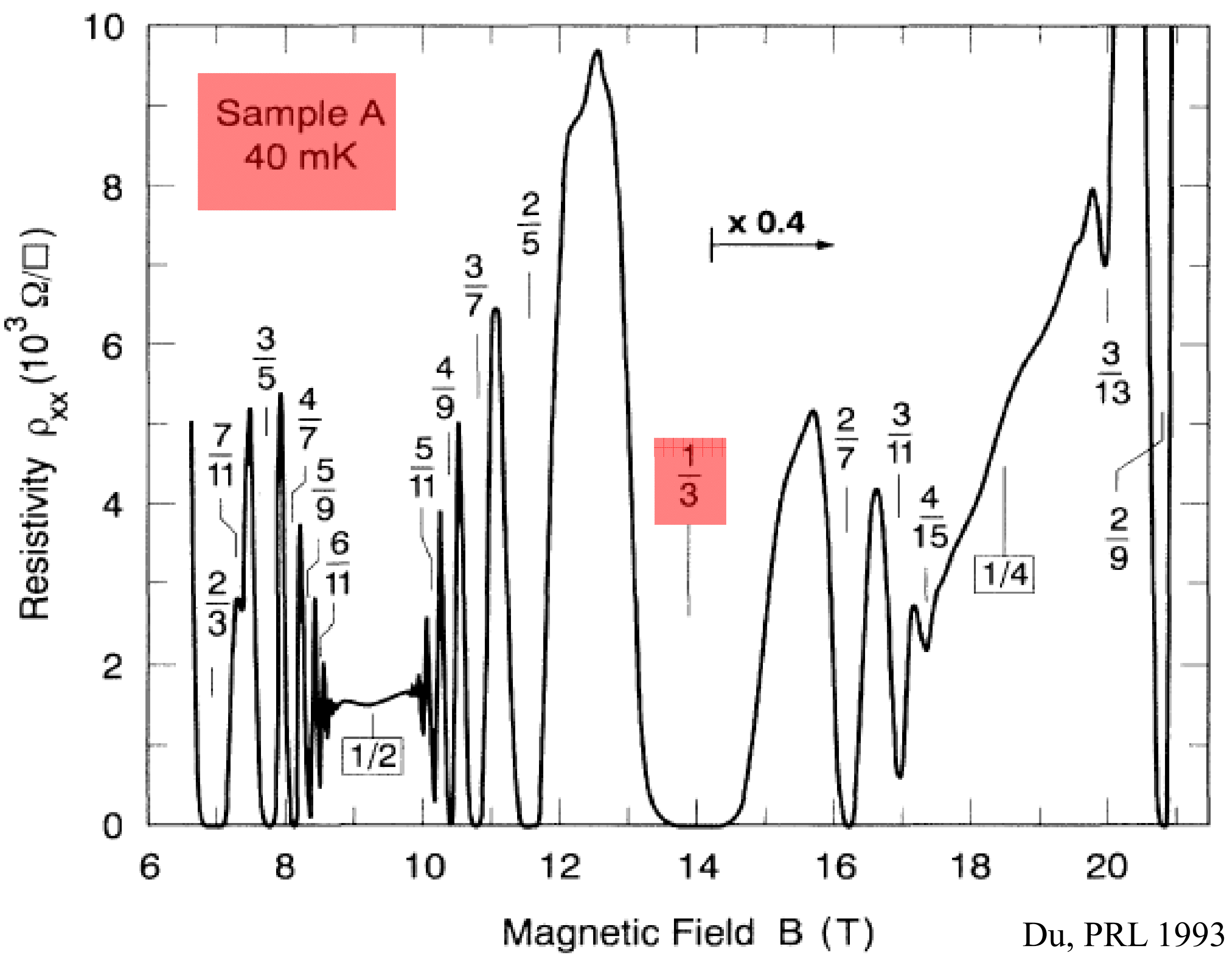




Tsui, Nobel Lecture 1998

Introduction to QHE

- FQHE



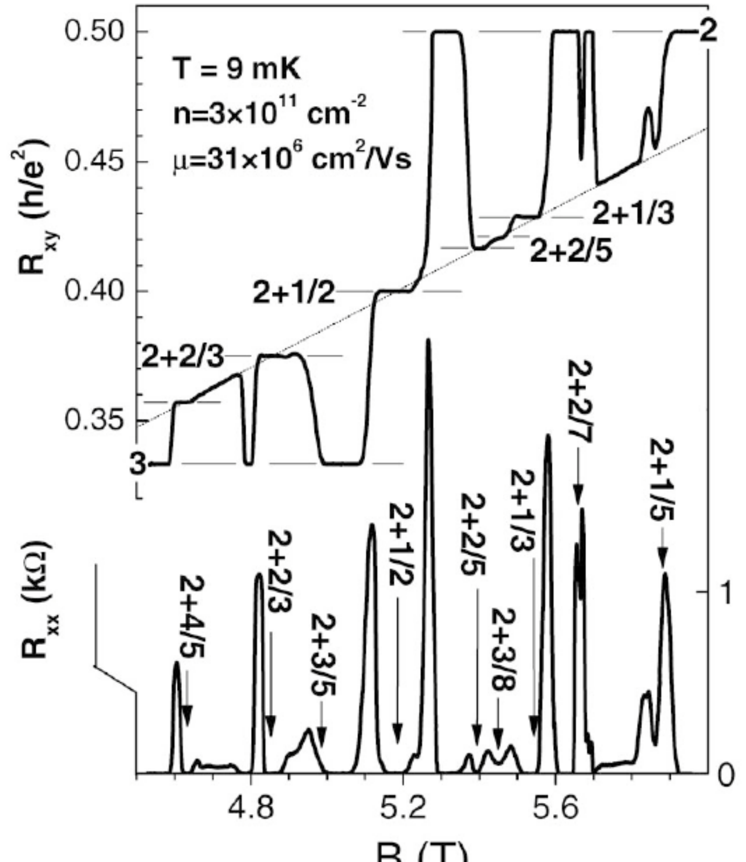
Du, PRL 1993

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

Motivation

$$\upsilon = \frac{p}{(2q \pm 1)} \;\; ?$$

- 5/2 FQHE
  - Willett, PRL 1987



Xia, PRL 2004

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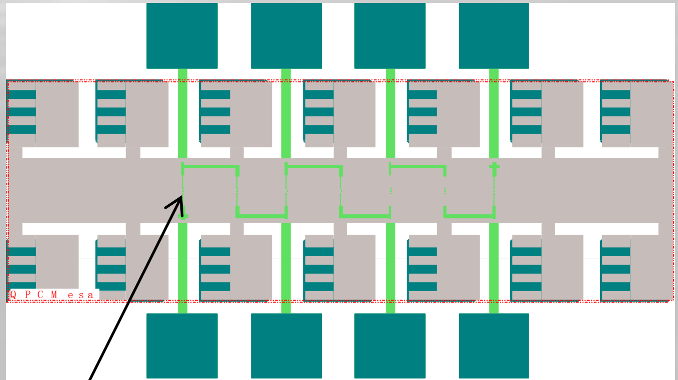
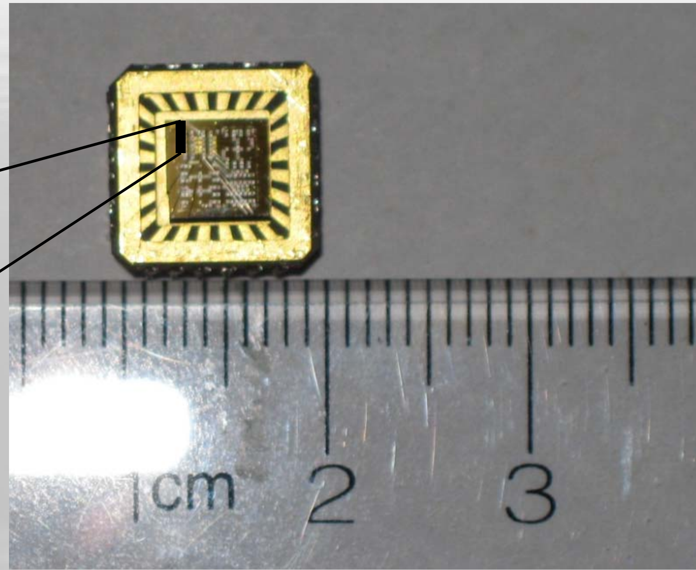
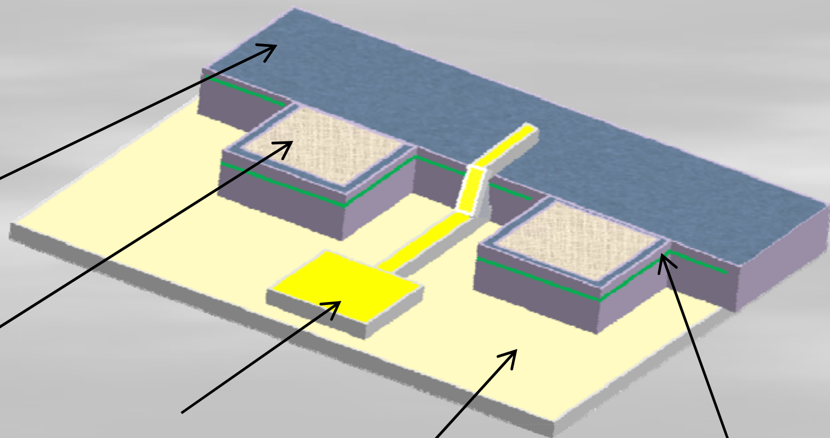
Details of the experiment

- GaAs Heterostructures





QPC: quantum point contact
width: a few 100 nm



Mesa

ohmic contact

gate

surface

2DEG

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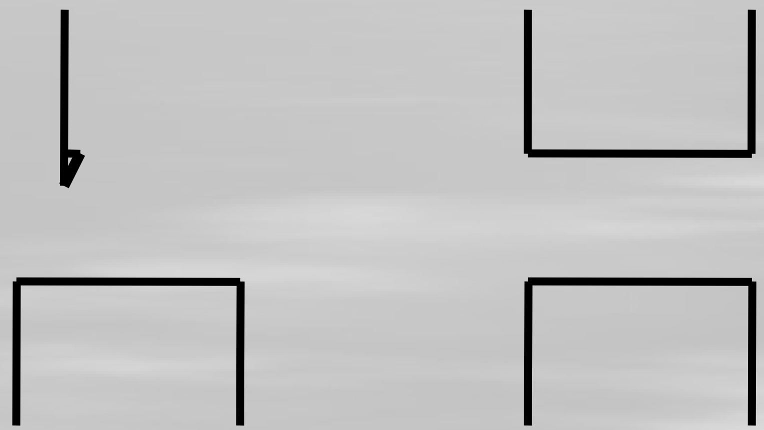
Details of the experiment

I_{AC}= 0.4 nA at 17 Hz
$R_{XY}=dV_{XY}/dI_{AC}$
$R_D=dV_D/dI_{AC}$

Geometry A: short QPC of nominal width ~0.6 μm,
Geometry B: a long channel of nominal width ~1.2 μm and length ~2.2 μm.

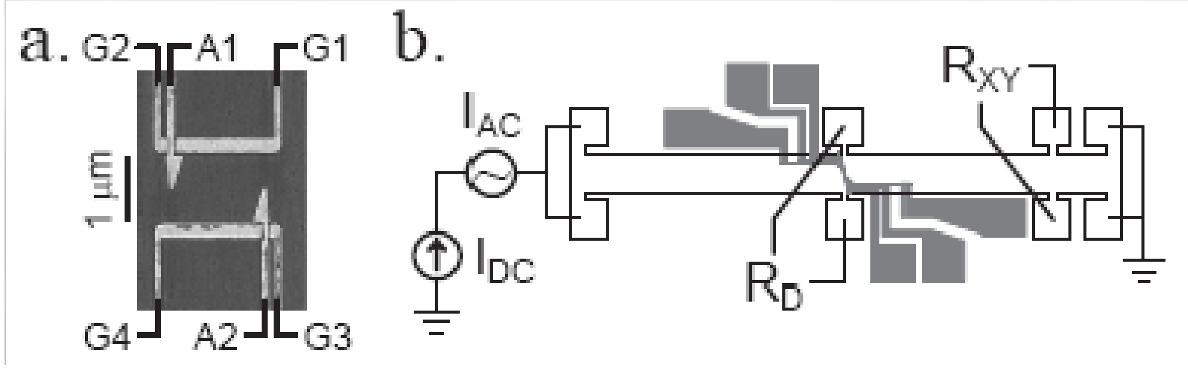
Geometry A Geometry B



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

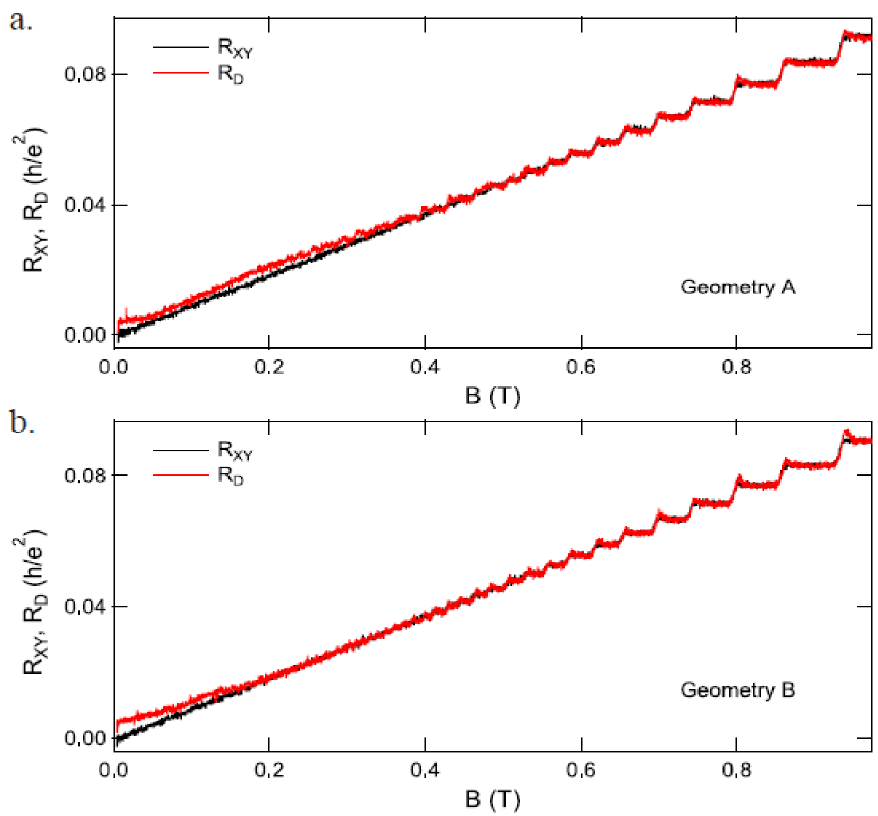
$$F(g,x)=B\left(g+i\frac{x}{2\pi},g-i\frac{x}{2\pi}\right)\left\{\pi\cosh(x/2)-2\sinh(x/2)Im\left[\Psi\left(g+i\frac{x}{2\pi}\right)\right]\right\},$$

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

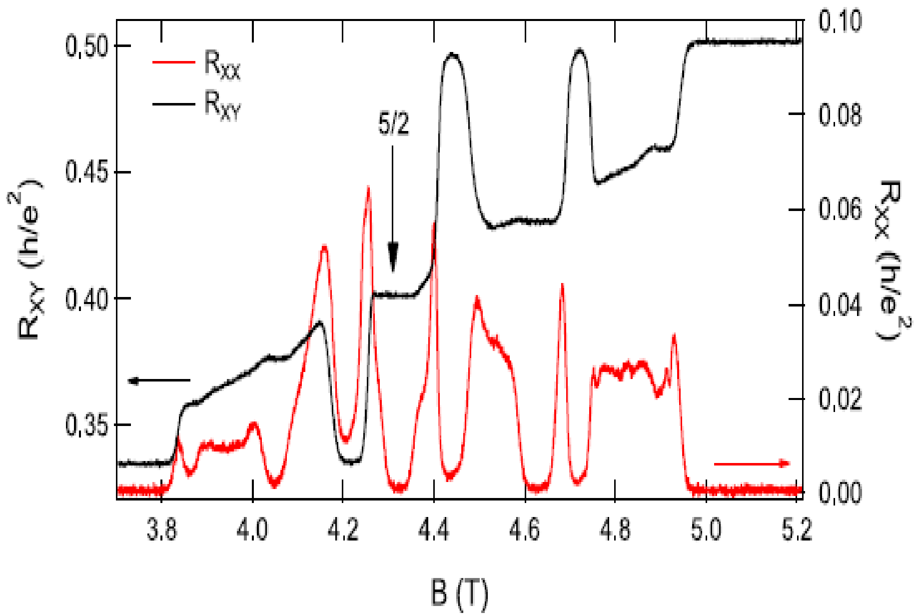


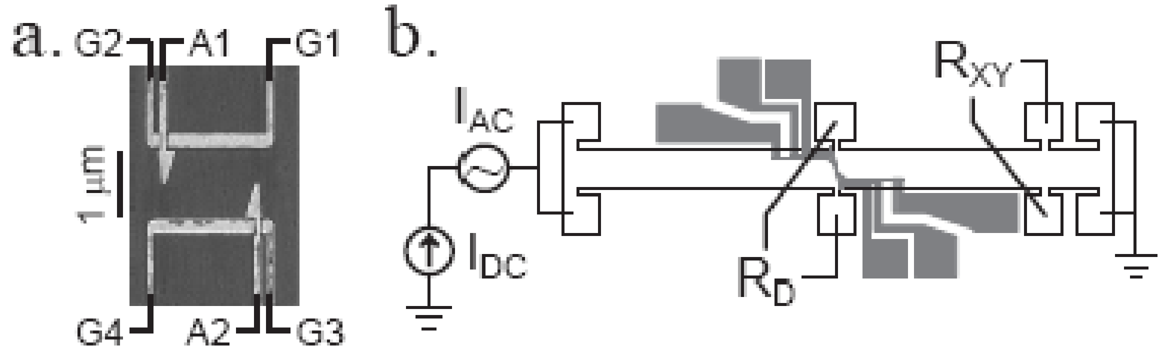
Mobility:1 × 10^7 cm^2/Vs
Density: 2.6 × 10^{11} cm^{-2}

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

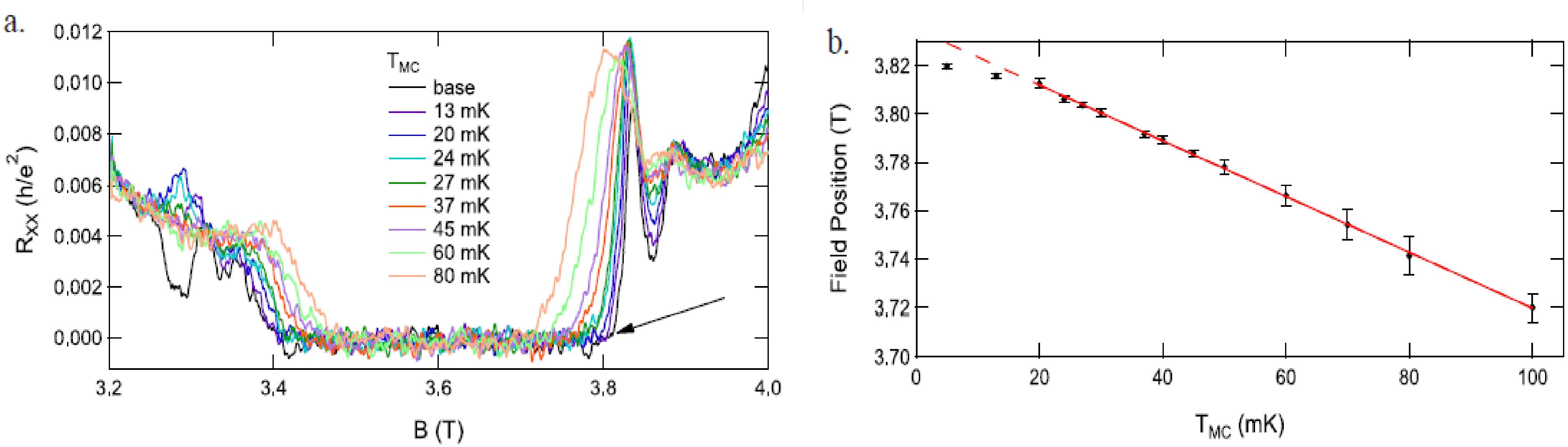
$$g_T(T, I_{DC}) = AT^{(2g-2)} F\left(g, \frac{e^* I_{DC} R_{XY}}{k_B T}\right) \qquad g_T = (R_D - R_{XY}) / R_{XY}^2$$

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

Electron temperature vs Mixing chamber temperature?

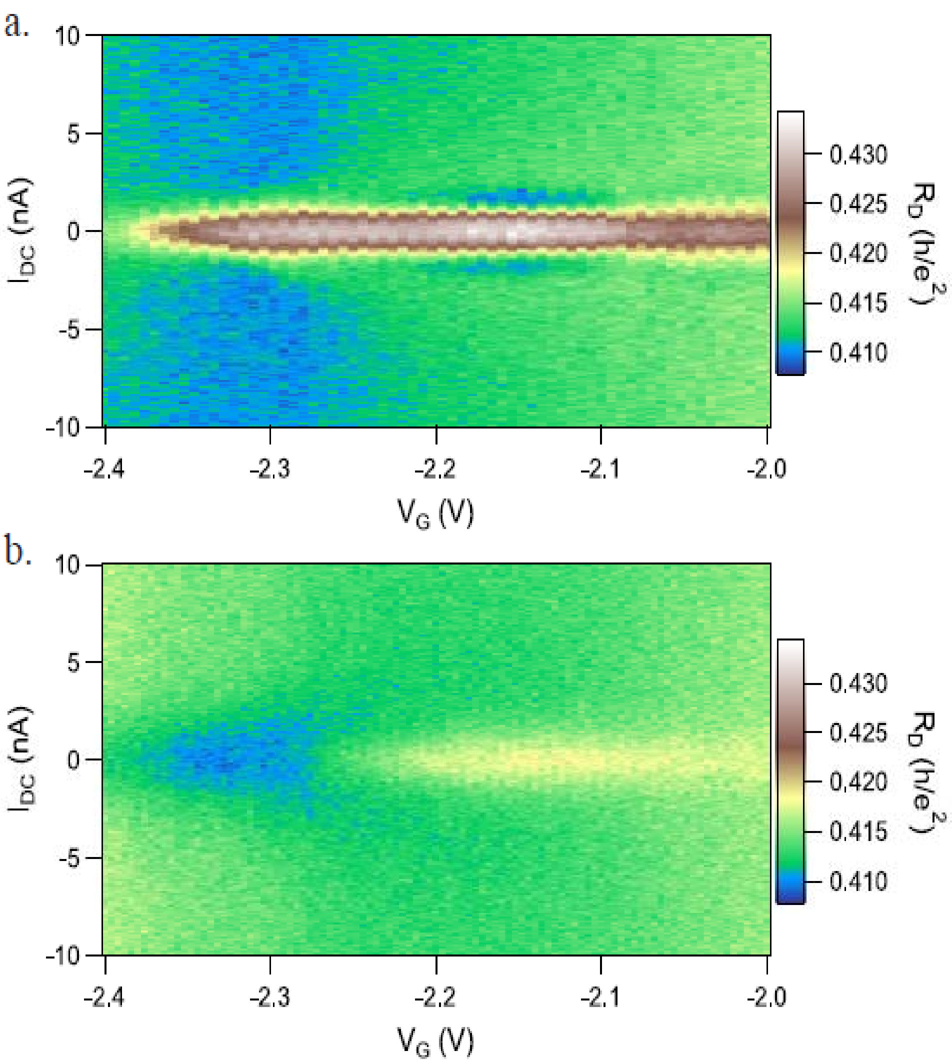
Electron temperature measured directly from thermally broadened Coulomb blockade peaks of a quantum dot.

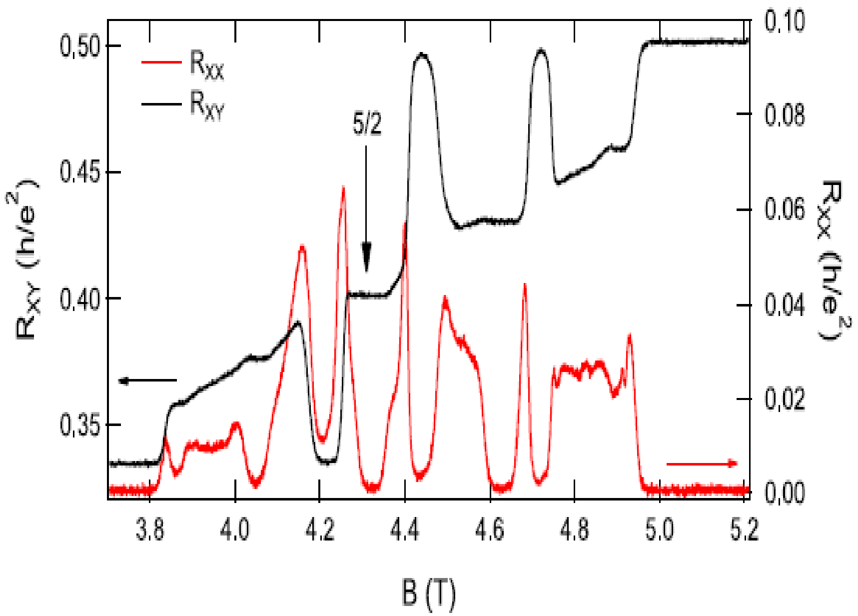
A convenient way to determine electron temperature. All the measurements reported here is above 20mK.



Details of the experiment

Tunneling at different gate voltages.





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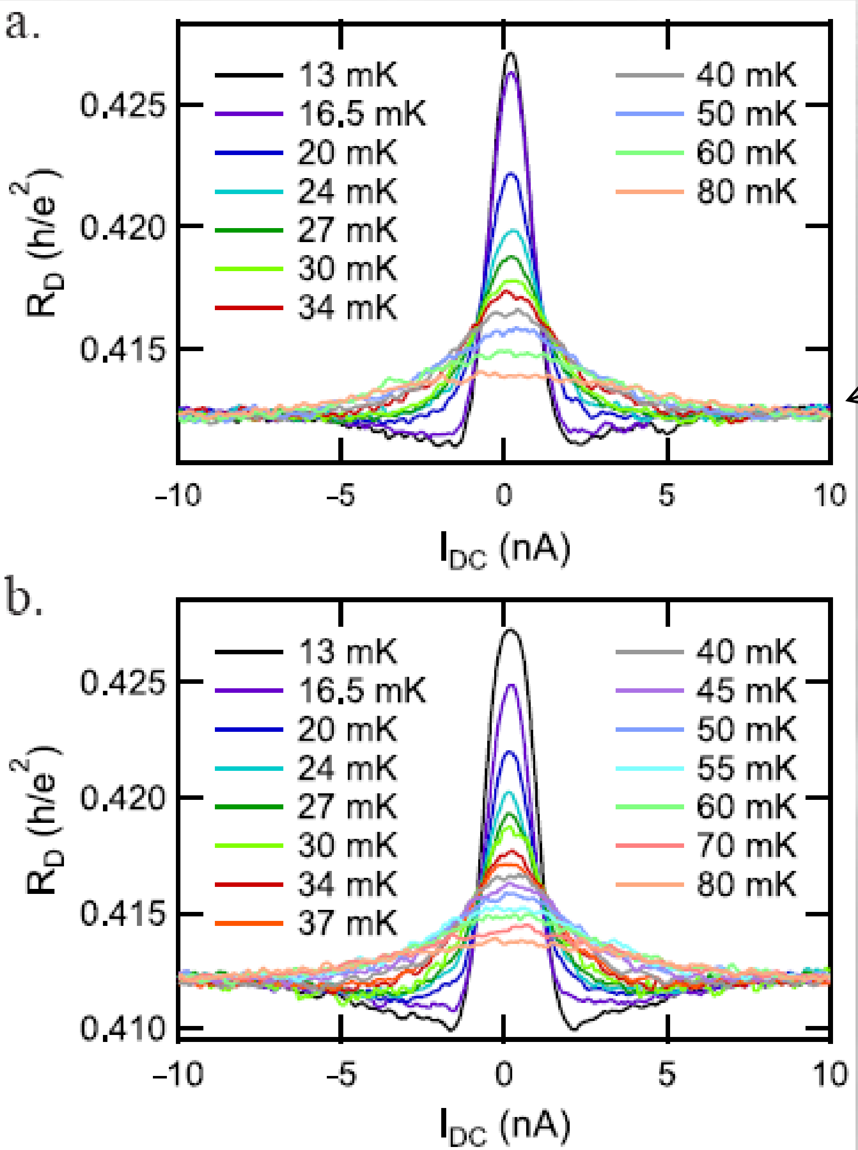
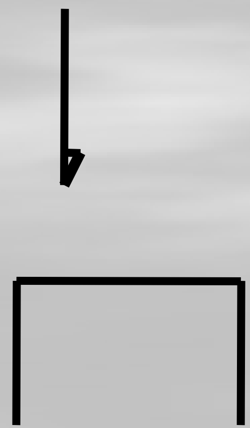
Results

Tunneling at different temperatures.

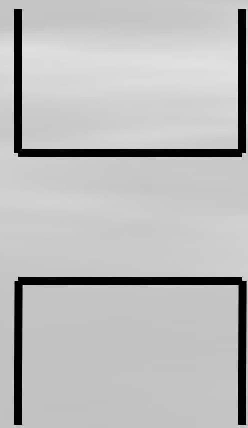


R_∞, background resistance, larger than the expected quantized value 0.4 h/e^2

Geometry A



Geometry B

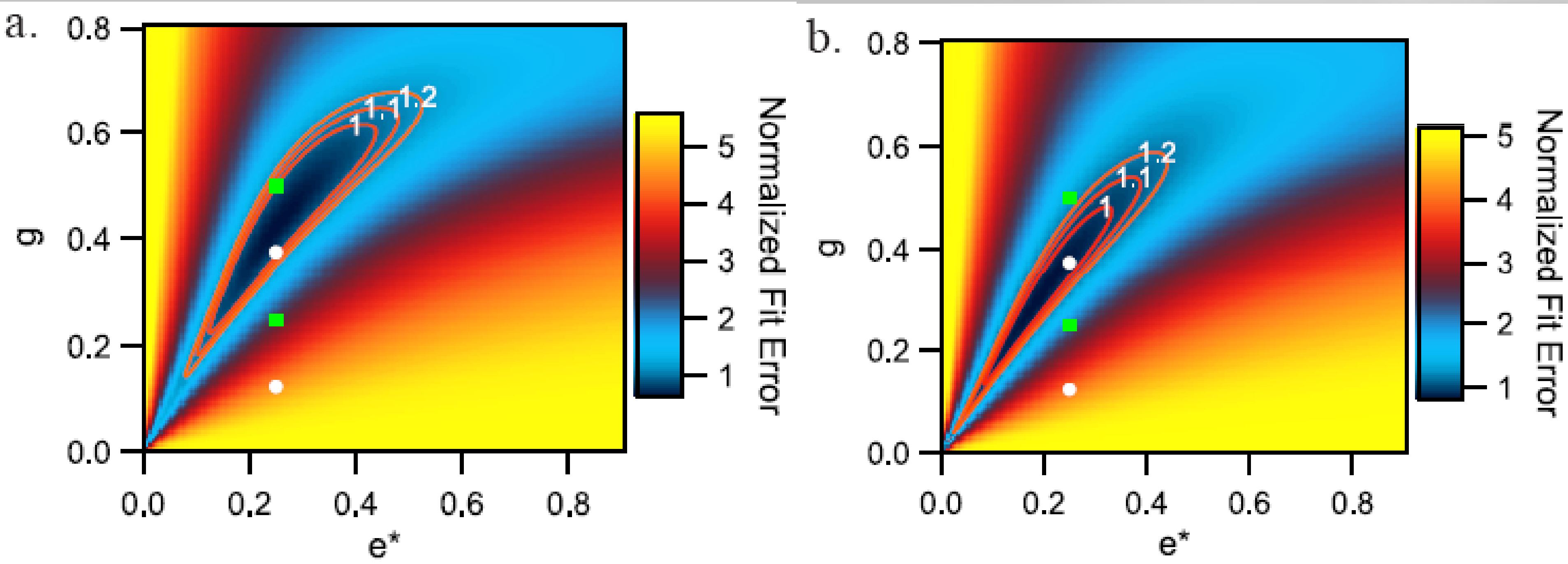


Results

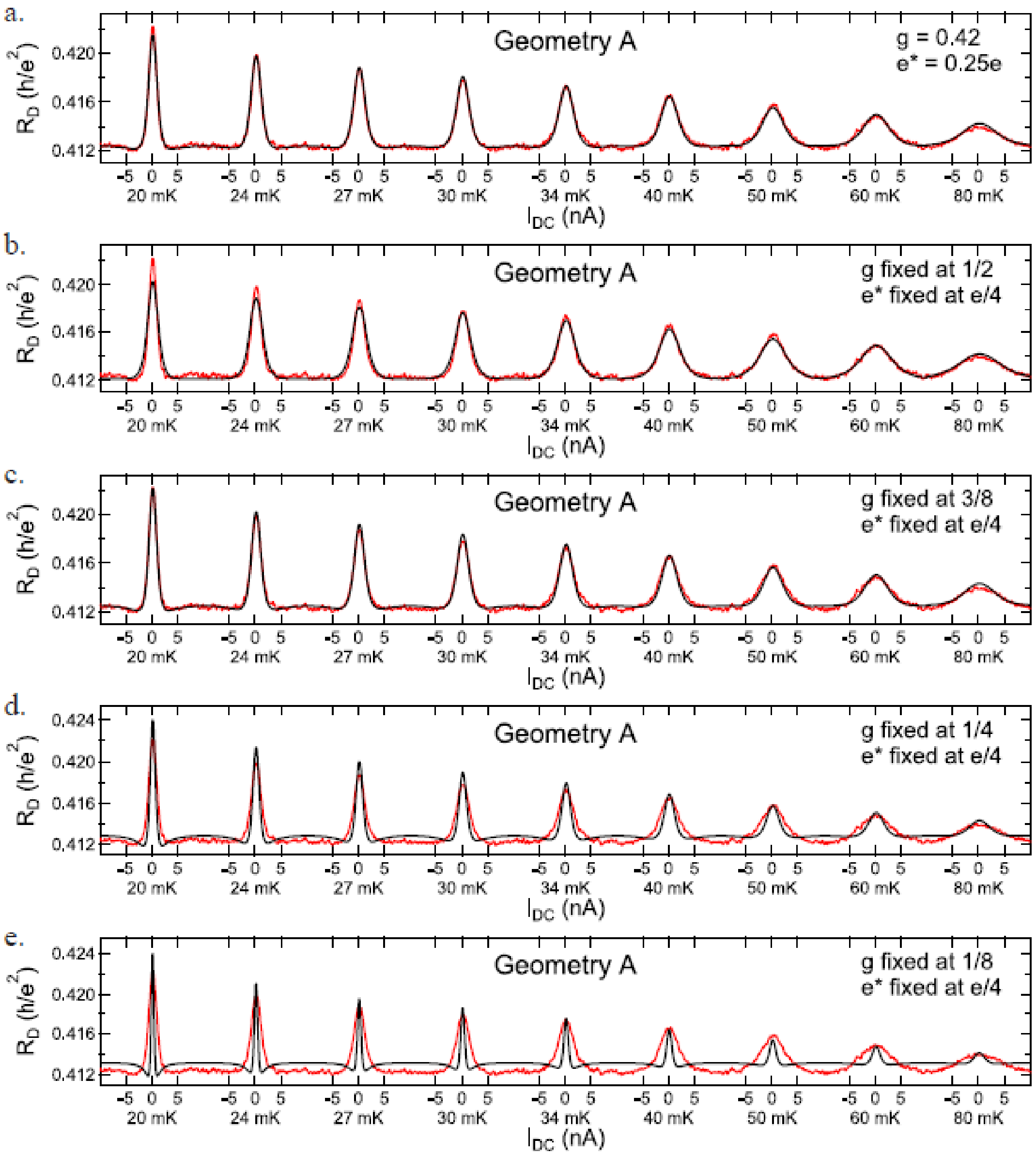
$$g_T(T, I_{DC}) = AT^{(2g-2)} F\left(g, \frac{e^* I_{DC} R_{XY}}{k_B T}\right) \qquad g_T = (R_D - R_{XY}) / R_{XY}^2$$

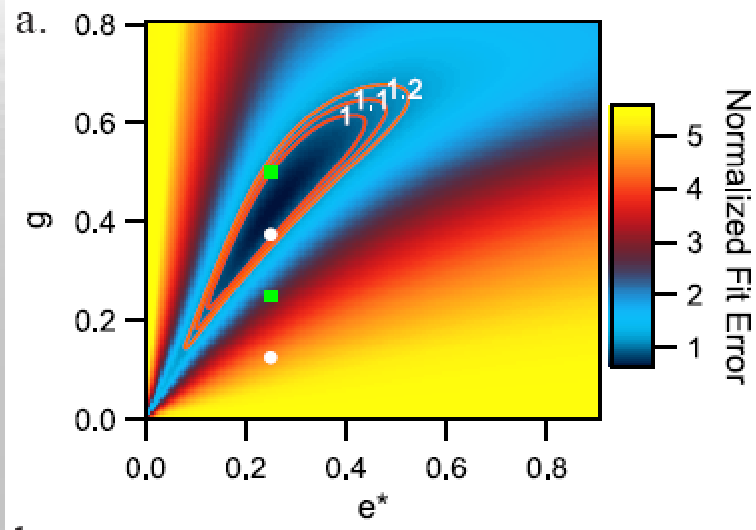
$$F(g,x) = B\left(g+i\frac{x}{2\pi}, g-i\frac{x}{2\pi}\right)\left\{\pi\cosh(x/2) - 2\sinh(x/2) Im\left[\Psi\left(g+i\frac{x}{2\pi}\right)\right]\right\},$$

	K=8	331	Pfaffian	Anti-Pfaffian	U(1) x SU2(2)
e*	e/4	e/4	e/4	e/4	e/4
g	1/8	3/8	1/4	1/2	1/2

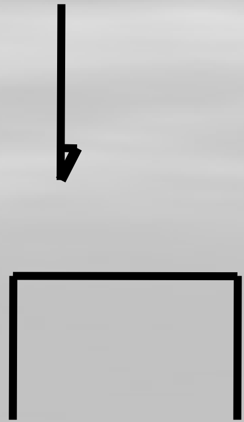


Results

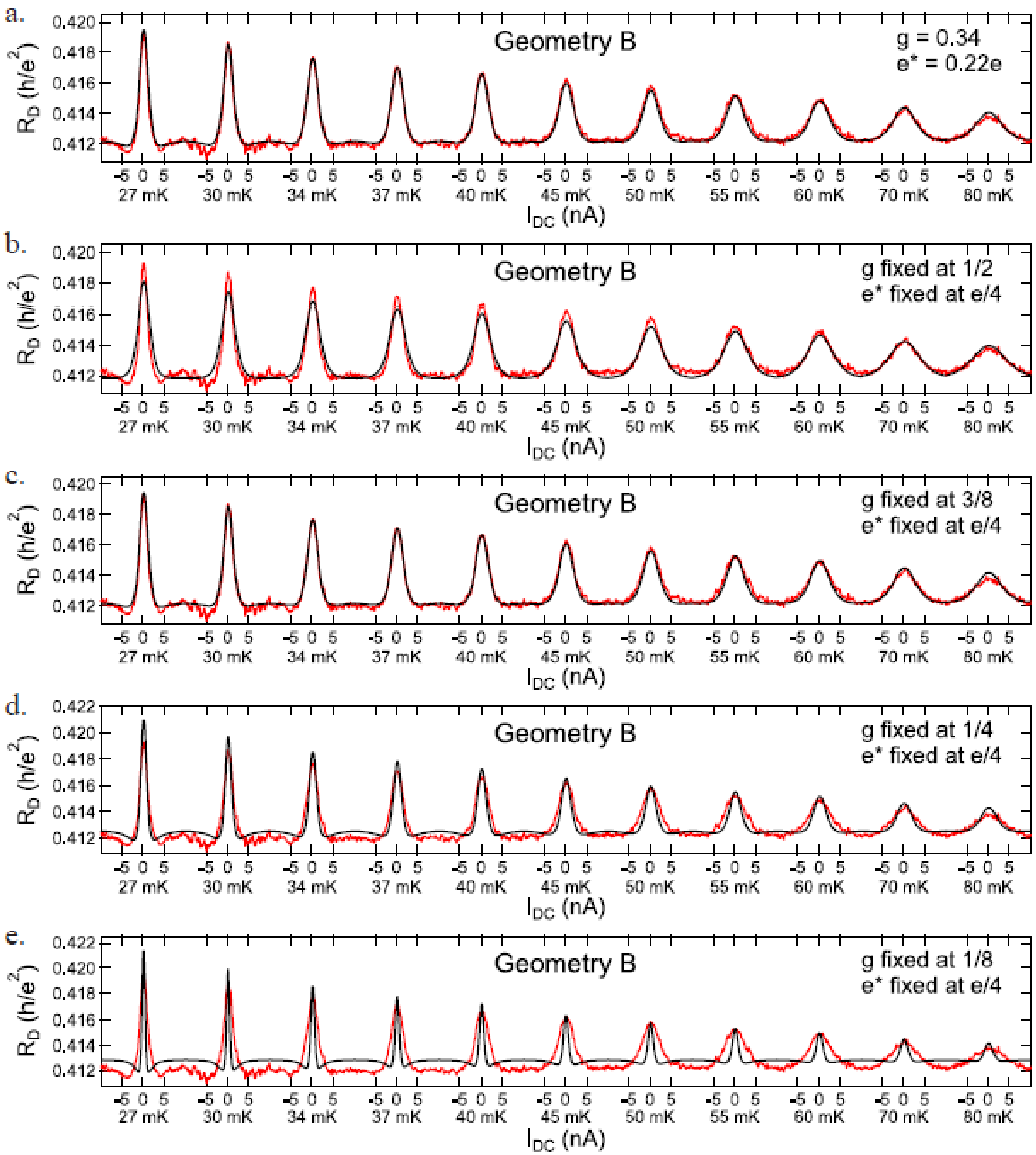


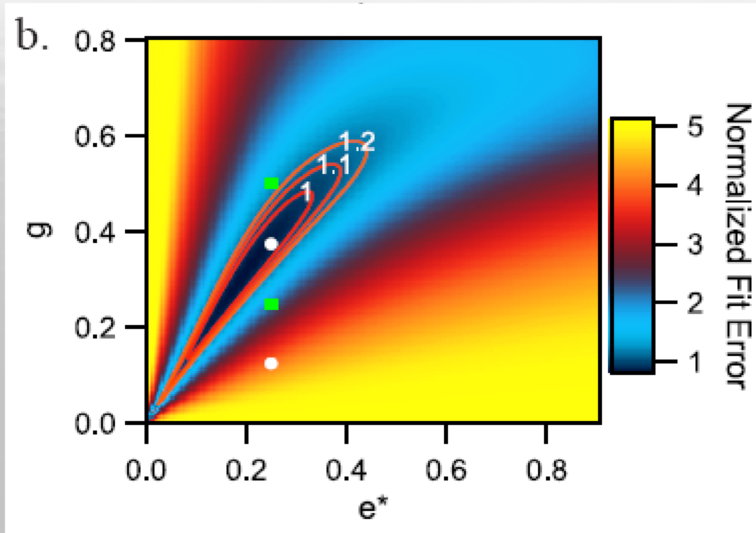


Geometry A

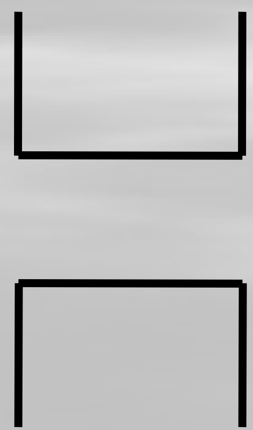


Results



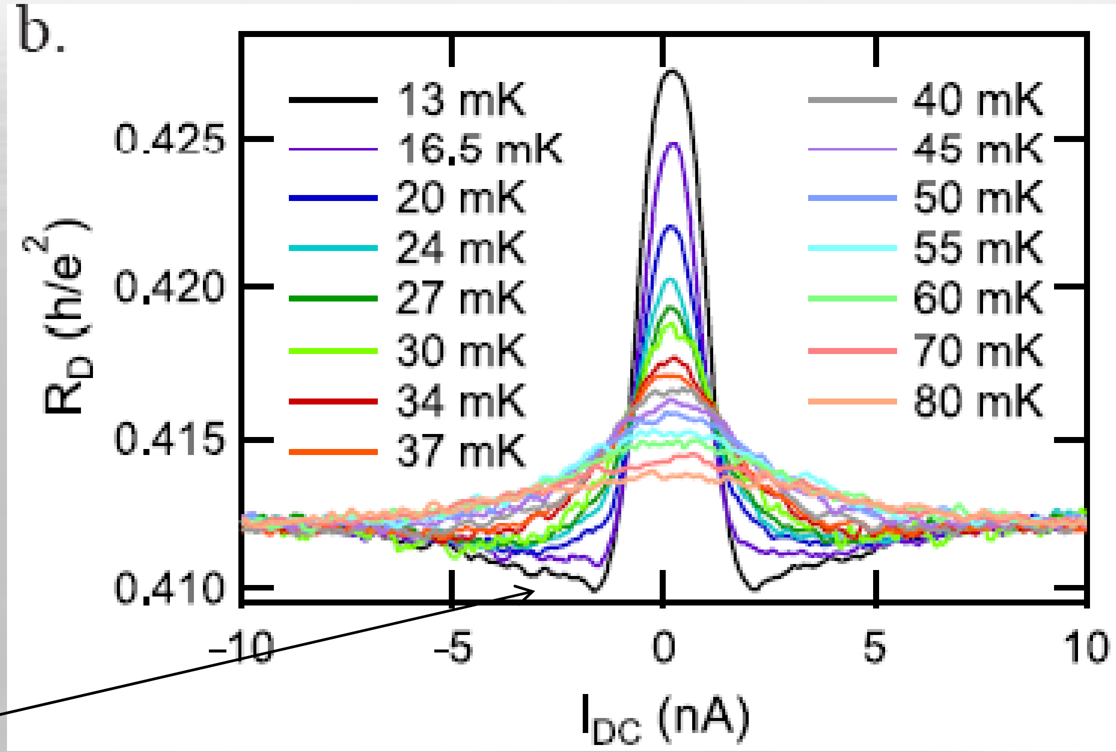


Geometry B

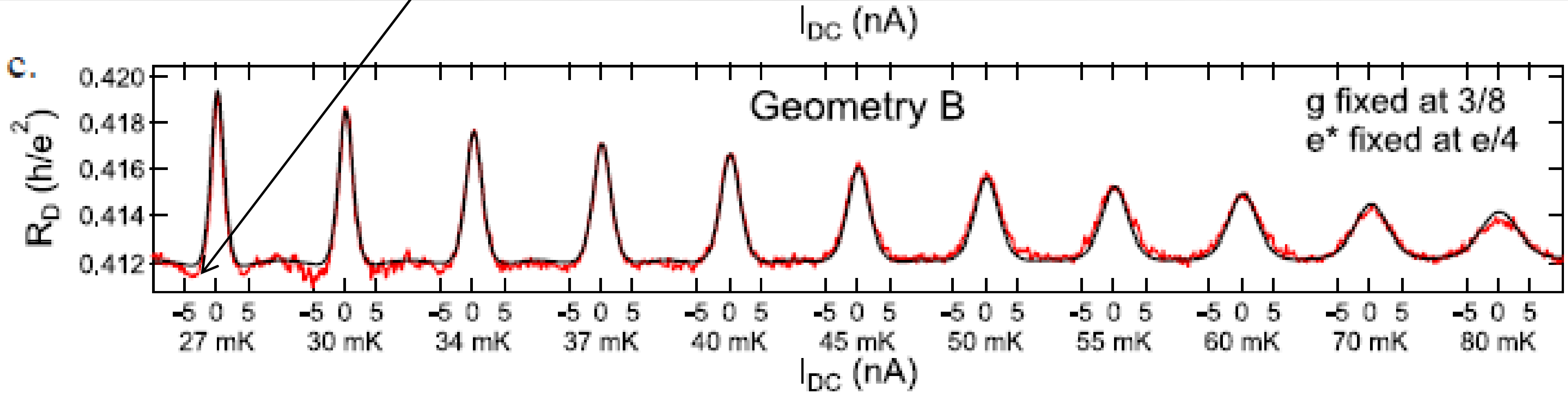


Results

g<0.5 or g=0.5?



Dip?



Results

g<0.5 or g=0.5?

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

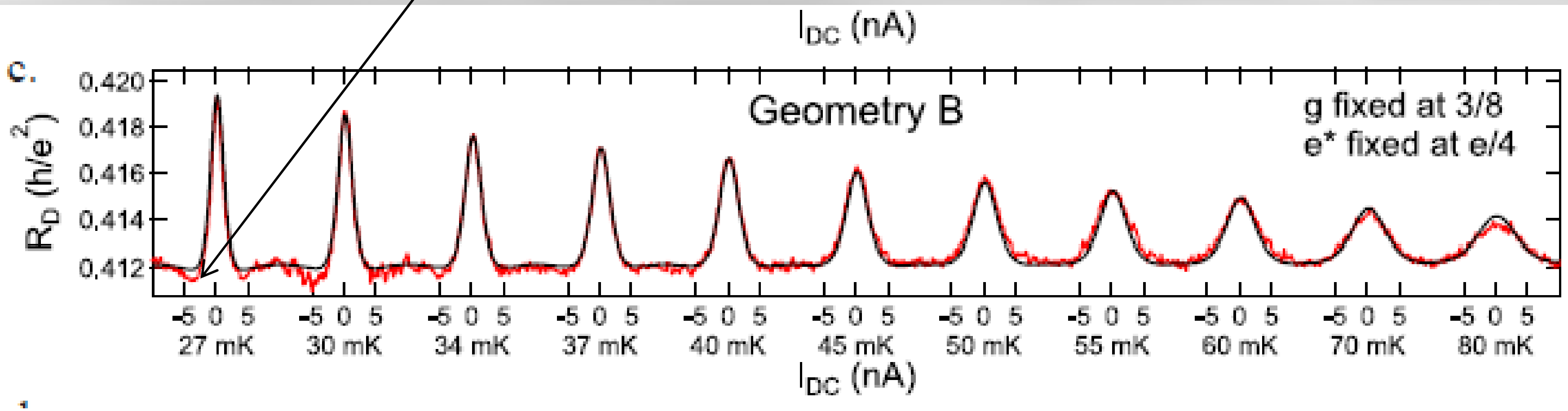
Fendley, *PRB* **52**, 8934 (1995).

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.

Dip?



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 $\upsilon = 5/2$ 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. $\upsilon = 1/3$