Fractional-Quasiparticle Creation

in a Local Fractional Quantu... ...tem
measured using cross-correlation noise mea...

Take-Home Message

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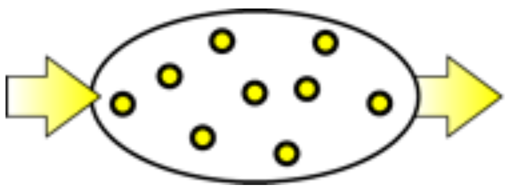
Introduction: Target of this work

Electron transport in mesoscopic systems

Quantum mechanics

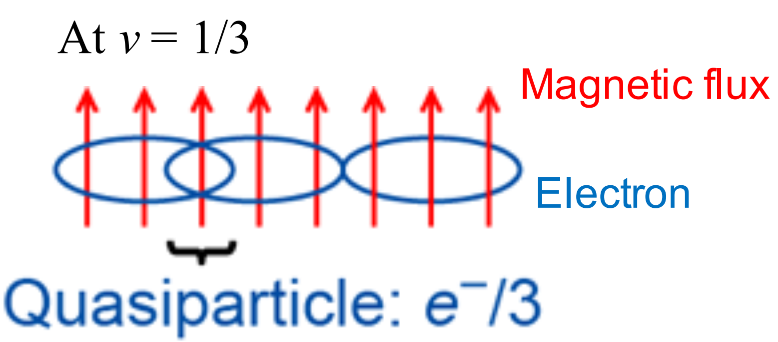
Many-body physics

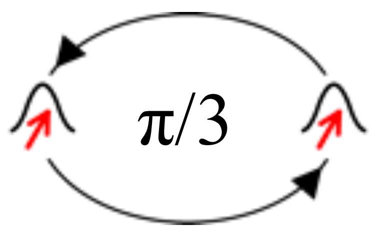


1 nA Typ. ~10^{10} electrons/s (~ GHz)

Fractional quantum Hall (FQH) effect

- Fractional charge
- Anyon statistics





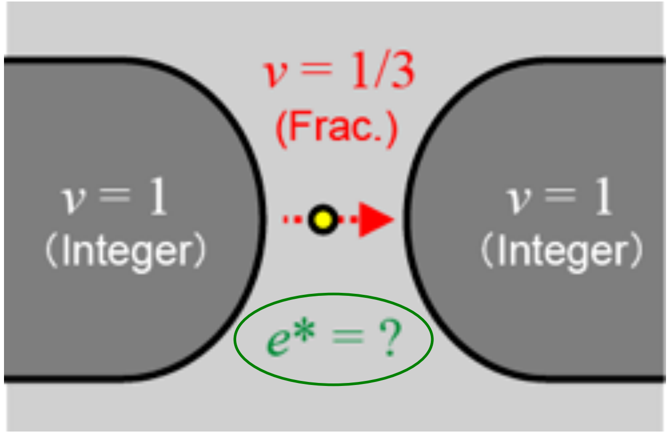
Aharonov-Bohm phase

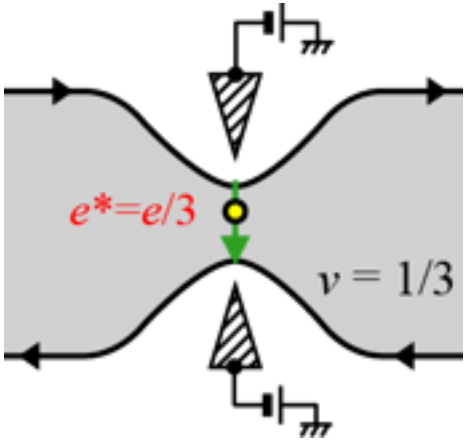
$\gamma(C) = 2\pi/3eBS/h$

Fractional-quasiparticle Creation in a local FQH system

Hashisaka *et al*., Phys. Rev. Lett. **114**, 056802 (2015).

Measurement of “Fractional charge”

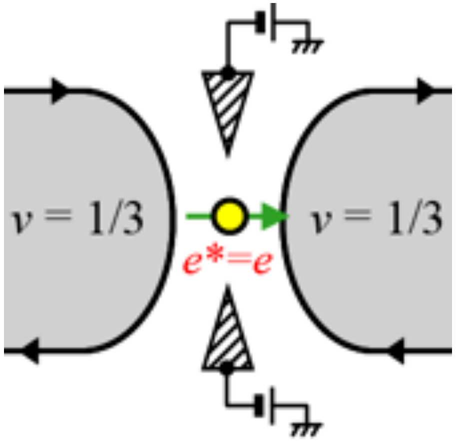




Weak backscattering

$e^* = e/3$

Saminadayar *et al*., PRL1997.
de-Picciotto *et al*., Nature 1997.



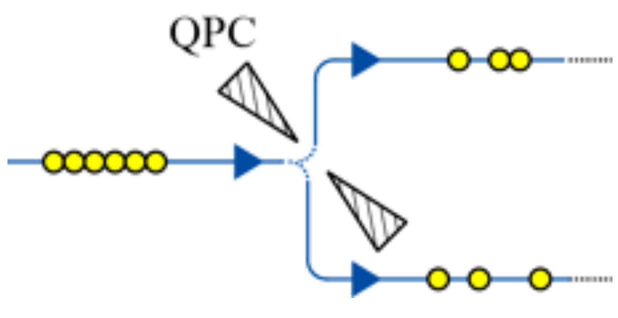
Strong backscattering

$e^* = e$

Griffiths *et al*., PRL **85**, 3918 (2000).

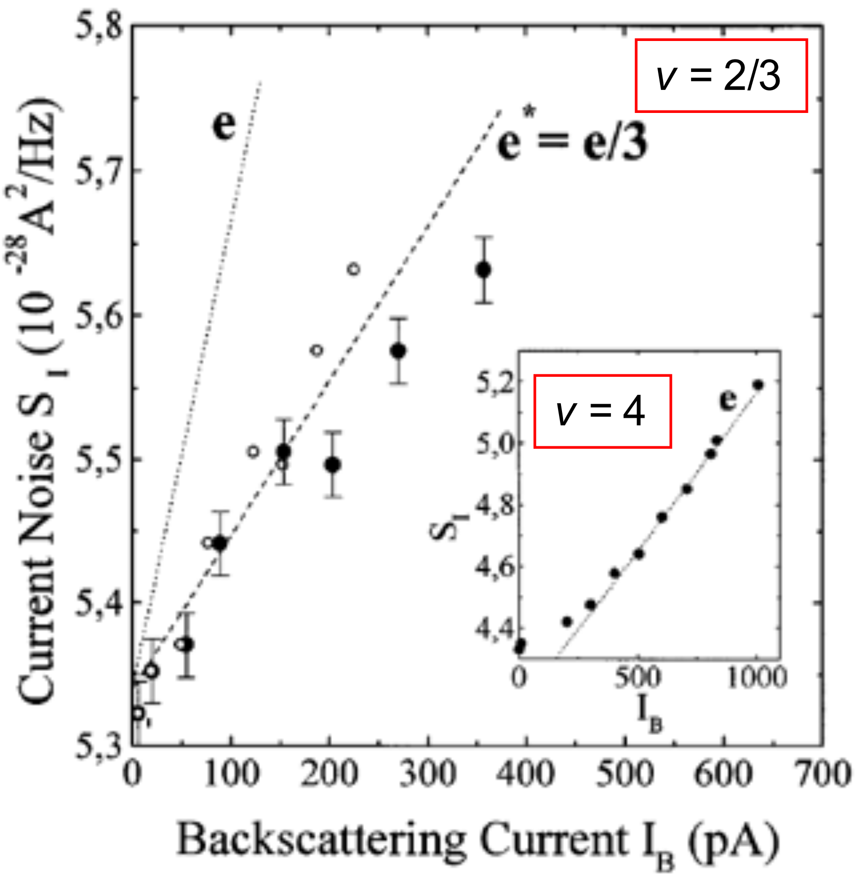
Introduction: Shot-noise measurements

Evidence of Fractional quasiparticles



One-by-one partitioning

We use "Cross-correlation" Shot-noise measurement



L. Samidanayar *et al.*, PRL **79**, 256 (1997).

Outline

Noise Measurement on a Mesoscopic Device

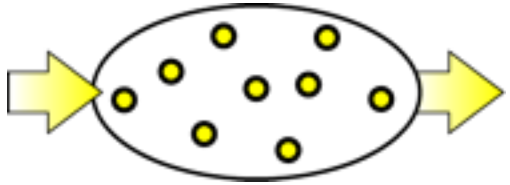
- ✓ Cross-correlation noise measurement
- ✓ Experimental technique

Creation of Fractional Quasiparticles

- ✓ Local fractional quantum Hall system
- ✓ Fractional-quasiparticle tunneling
- ✓ Tomonaga-Luttinger-liquid behavior

Noise measurement

An "Ideal detector" for mesoscopic devices



1 nA Typ.

~10^{10} electrons/s

(~ GHz)

- Sensitivity << *e*
- High speed (No loss of events)

(Impossible in today's technology)

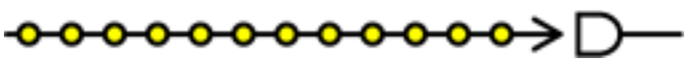
✓ DC transport meas.

✓ RF (GHz) measurement

✓ **Noise measurement**

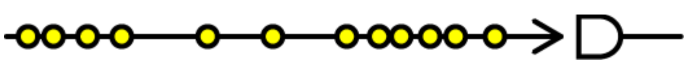
(MHz frequencies)

Ya. M. Blanter and M. Büttiker,
Phys. Rep. **336**, 1 (2000).



DC: $I = ne$

Noise: $(\quad I)^2 = 0$

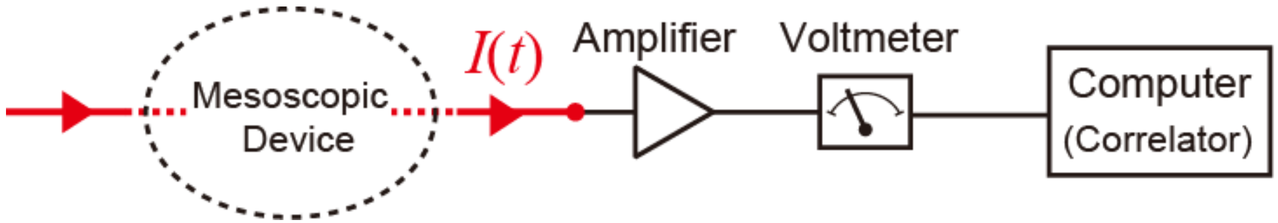


DC: $I = ne$

Noise: $(\quad I)^2 > 0$

Cross-correlation noise measurement

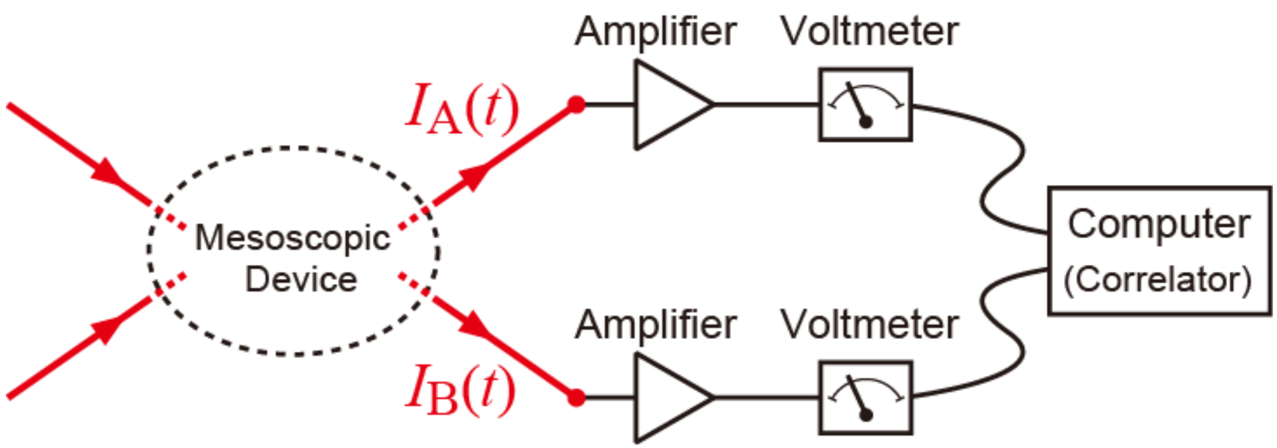
Auto correlation



$(\quad I)^2$

Variance of
a single current

Cross correlation



$I_A \quad I_B$

Correlation between
two currents

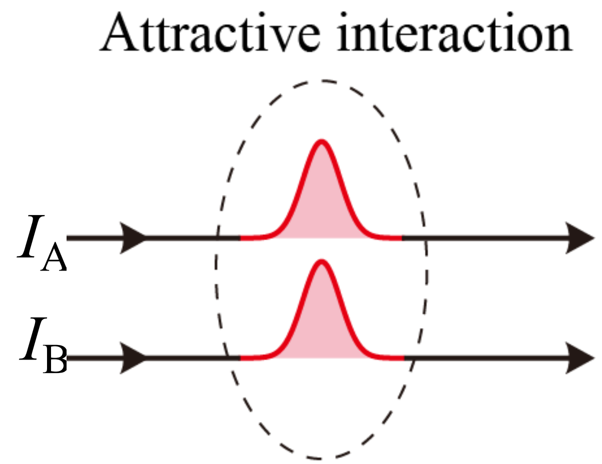
Sign of cross-correlation

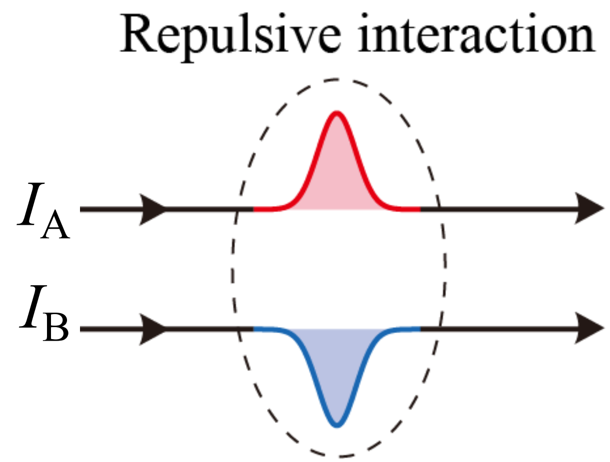
Noise cross-correlation

Not only the **amplitude**,
But also the **sign**.

Attractive: $I_A \quad I_B \quad > 0$

Repulsive: $I_A \quad I_B \quad < 0$





Quantum statistics

Boson / Fermion / Anyon

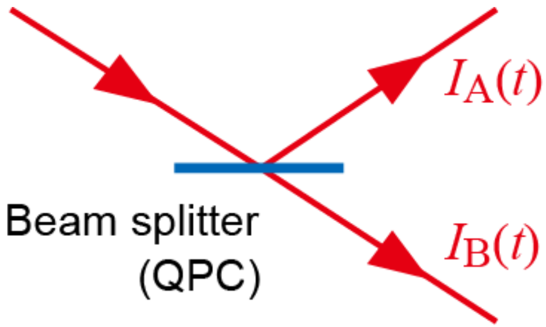
(Bunching / Anti-bunching)

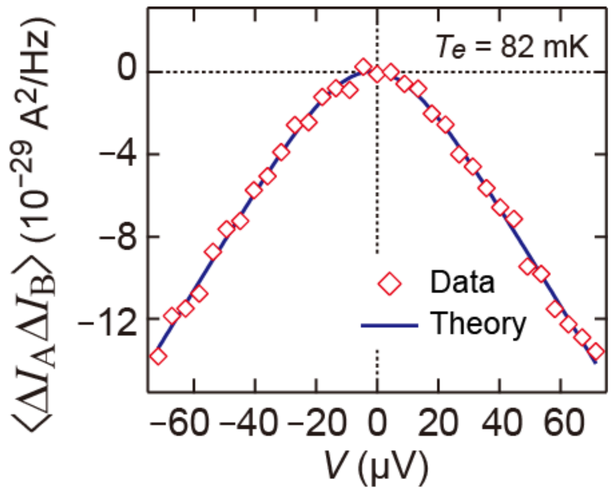
Ya. M. Blanter and M. Büttiker,
Phys. Rep. **336**, 1 (2000).

Sign of cross-correlation

Current partitioning at a beam splitter

Henny *et al.*, Science **284**, 296 (1999).
Oliver *et al.*, Science **284**, 299 (1999).





One-by-one electron partitioning
(Anti-bunching of electrons)

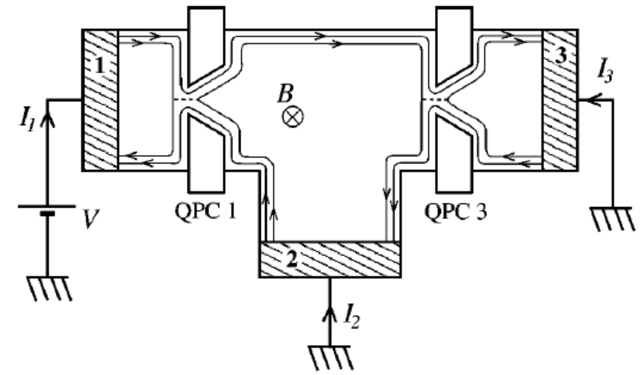
→ Negative correlation

Hashisaka *et al.*, Rev. Sci. Instrum. **85**, 054704 (2014).

Another interesting example:

Detection of Inelastic scattering in an edge channel

(in preparation)



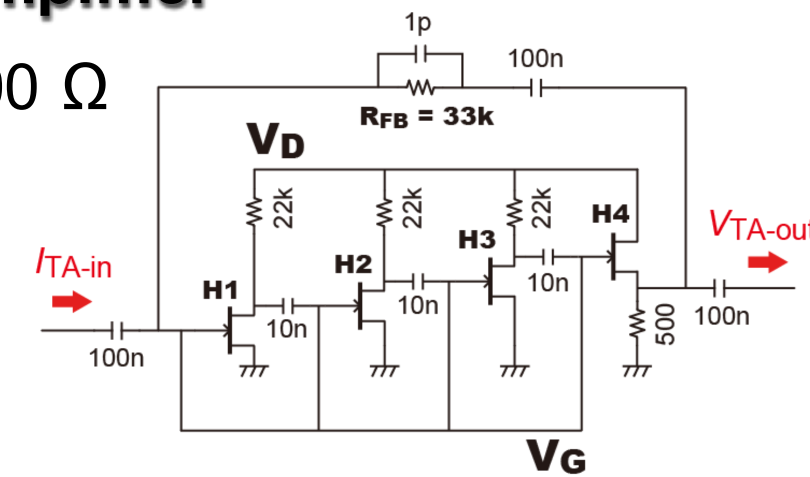
Texier and Büttiker PRB **62**, 7454 (2000).

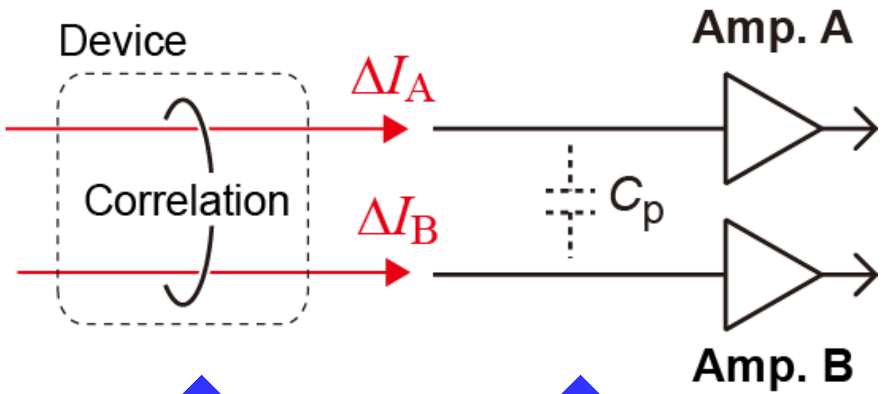
Homemade Transimpedance amplifier

Sensitivity ~ 10^{-30} A^2/Hz

- ✓ **Low input impedance** Z_{in} ~ 100 Ω
- ✓ Low noise floor

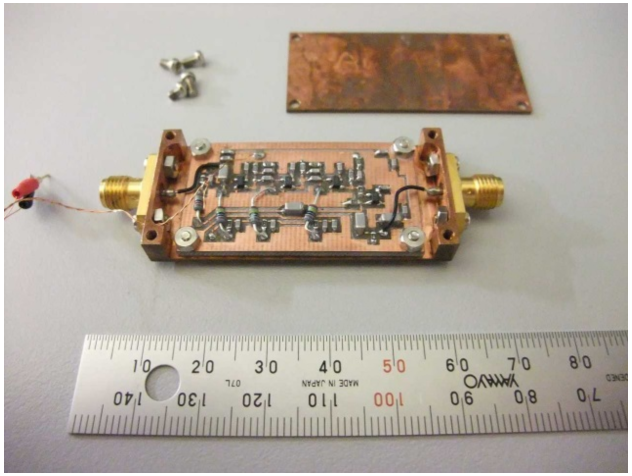
➡ Suppression of the extrinsic crosstalk





Intrinsic correlation

Extrinsic crosstalk



Hashisaka *et al.*,
Rev. Sci. Instrum. **85**, 054704 (2014).

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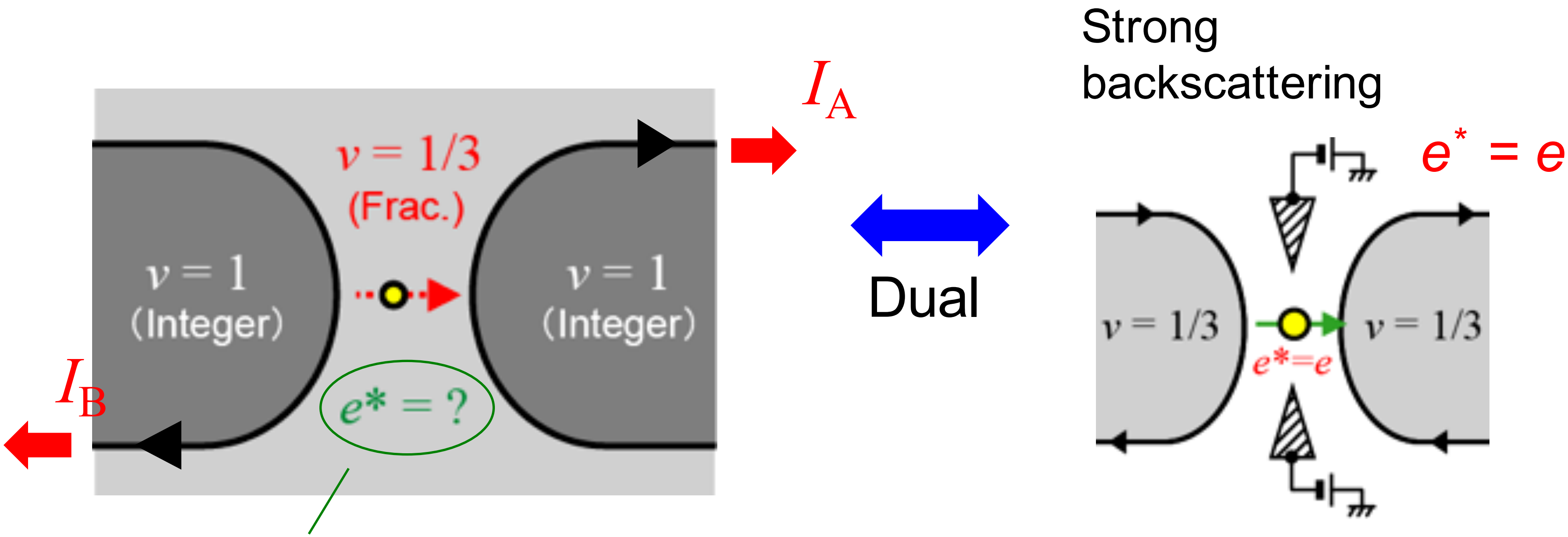
- ✓ Tomonaga-Luttinger-liquid behavior

Quantum Hall junction

"Integer / Fractional / Integer" QH junction



Laughlin quasiparticle creation?

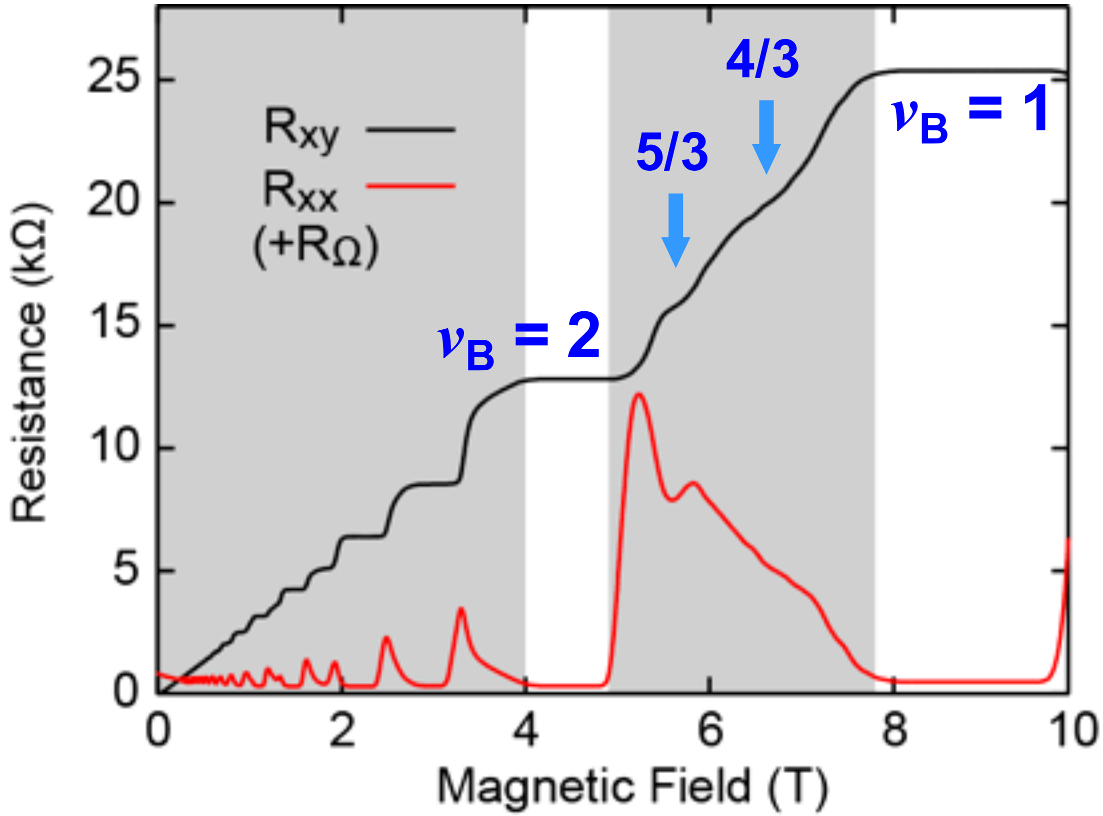
Griffiths *et al.*, PRL **85**, 3918 (2000).

Cross-correlation Shot-noise measurements

Bulk properties

Two-dimensional electron system

in a GaAs / AlGaAs heterostructure



Electron density:

$n_e = 2.3 \times 10^{11}$ cm^{-2}

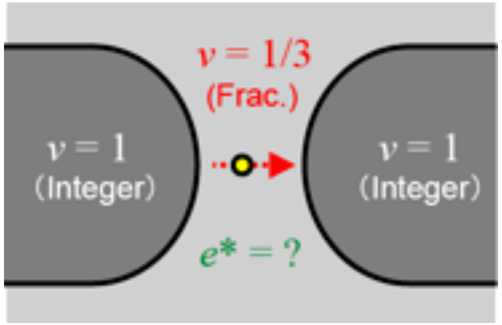
Mobility:

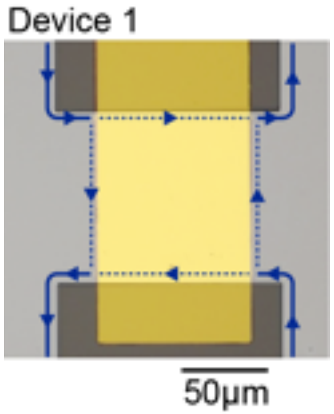
$\mu = 3.3 \times 10^{6}$ cm^2/Vs

Electron temperature:

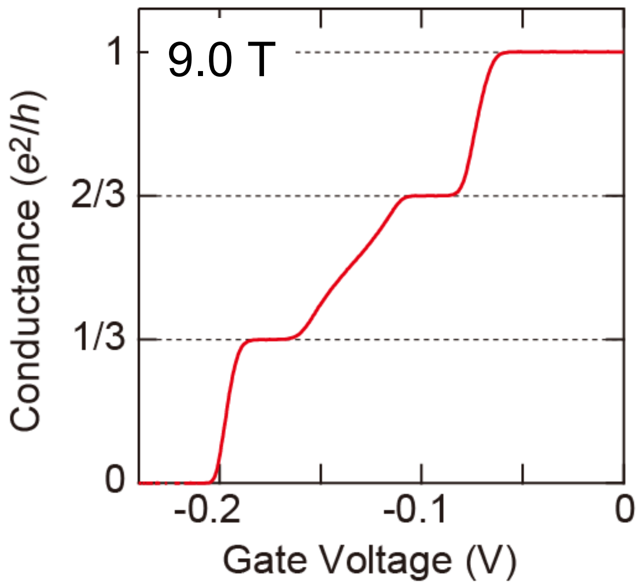
$T_e \sim 80$ mK

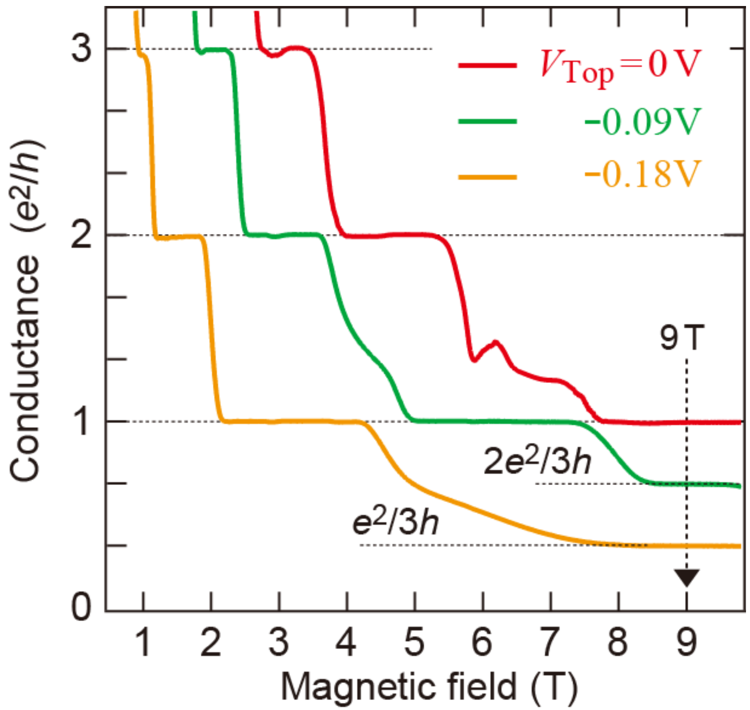
Tuning of
Local filling factor
by gate voltages



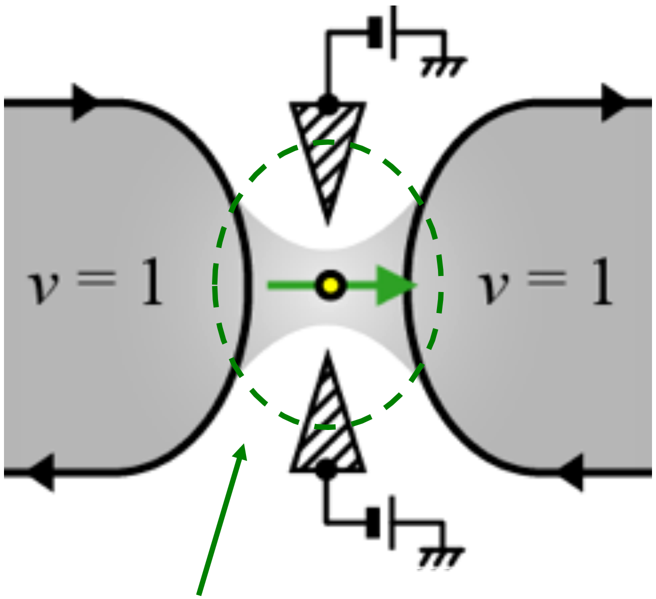


$\nu_{\text{local}} = 1/3$ FQH system
in a $\nu_{\text{bulk}} = 1$ IQH system





Quantum Point Contact (QPC)



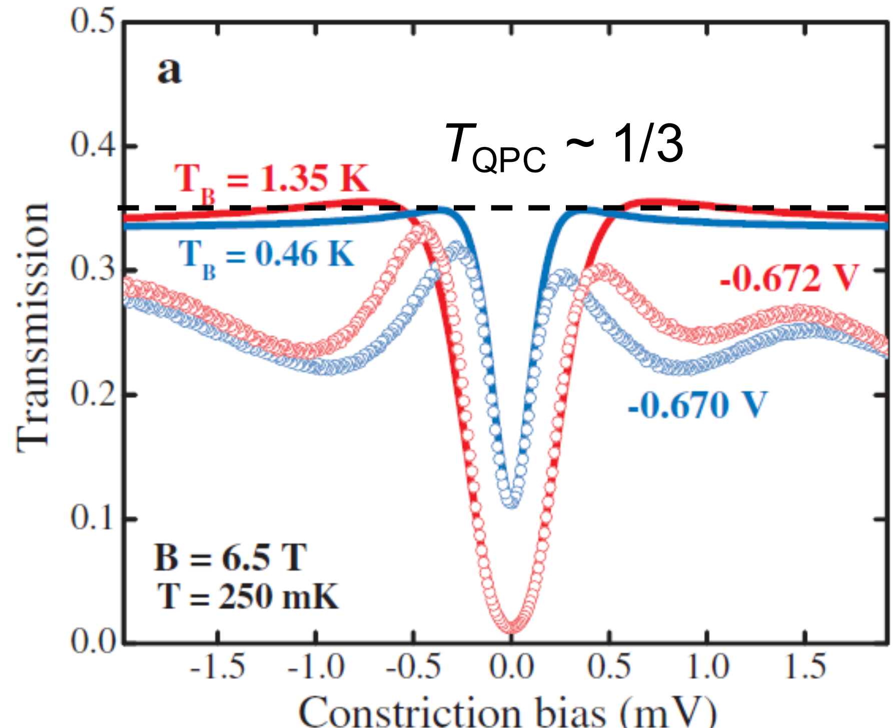
Modulation of electron density

Bulk: $\nu_B = 1$

QPC: $\nu_{QPC} \sim 1/3$

Luttinger liquid behavior

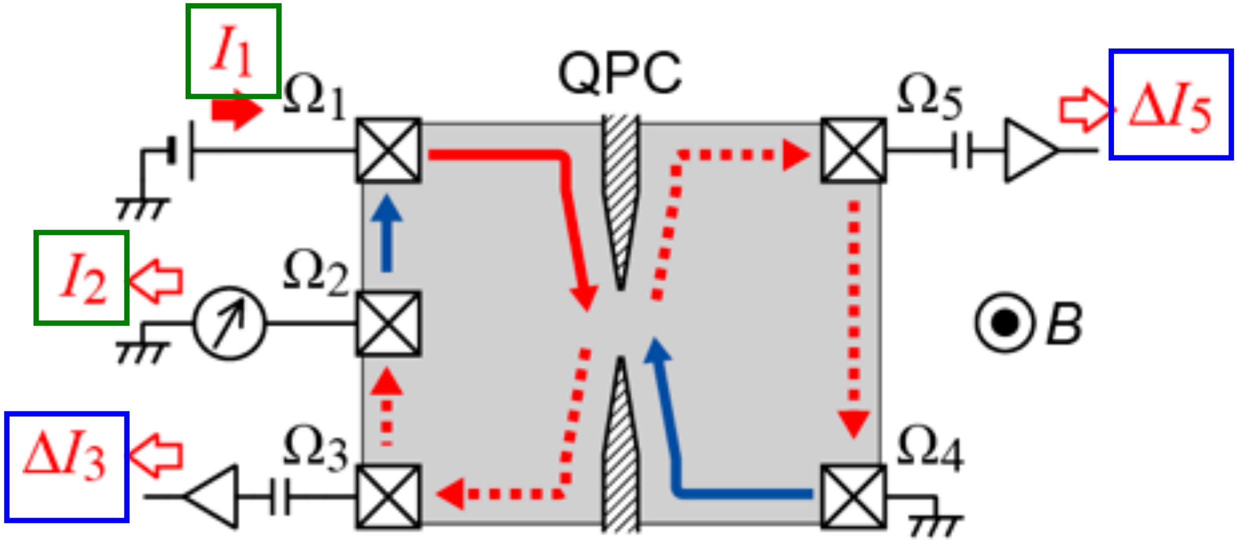
Power law behavior of
I-V characteristics (DC meas.)

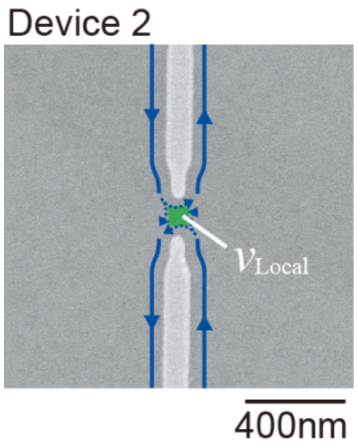


T: transmission probability of IQH edge channel
R: reflection probability of IQH edge channel

S. Roddaro et al., PRL **95**, 156804 (2005).

Experimental setup





n_e = 2.3 x 10^{11} cm^{-2}

μ = 3.3 x 10^6 cm^2/Vs

T_e ~ 80 mK

DC measurement: Input current I_1

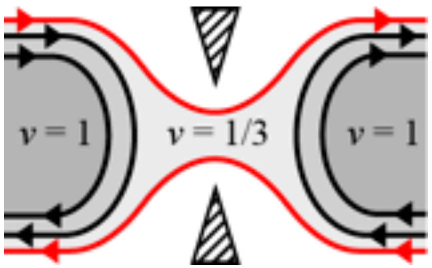
※Lock-in (V_{AC} = 40 uV) Backscattered current I_2

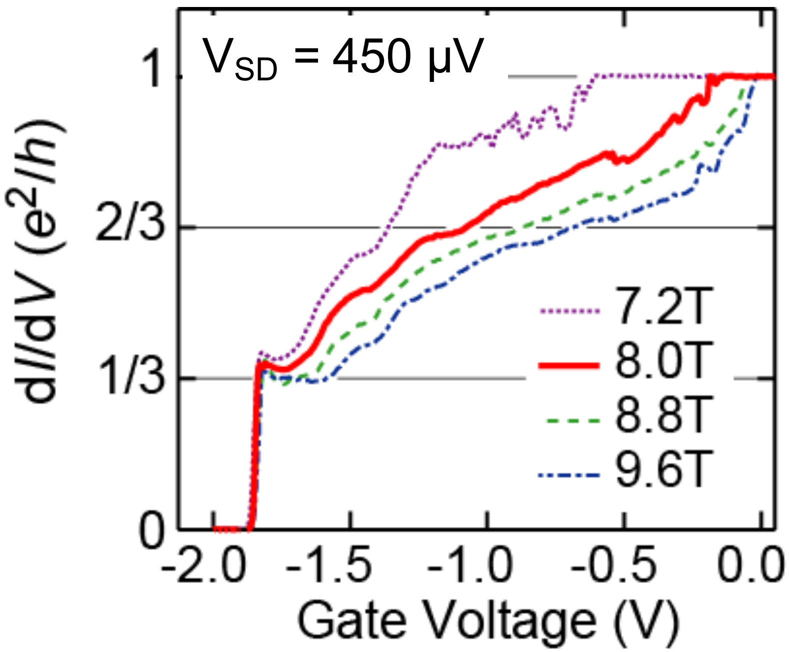
Shot noise: Cross correlation $\langle I_3 I_5 \rangle$

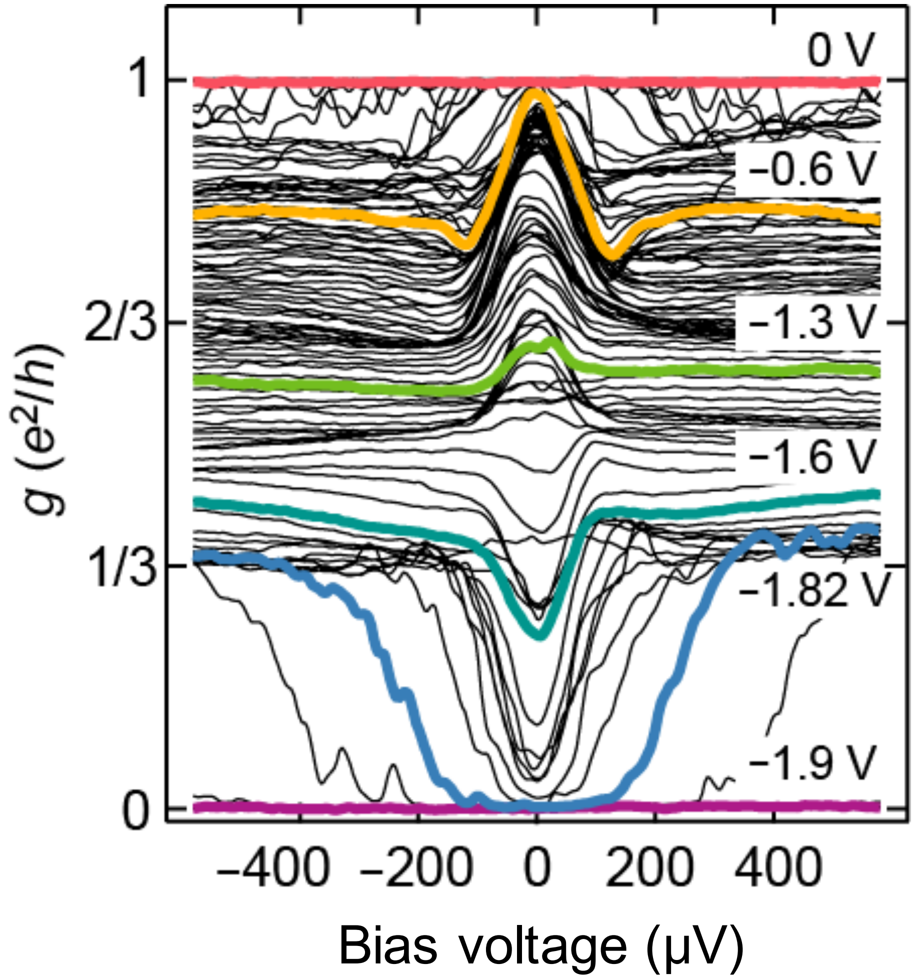
DC characteristics

Quantized differential conductance ($e^2/3h$)

Power law behavior







Shot noise of fractional quasiparticles

Shot noise: $S_{35} \quad \langle \quad I_3 \quad I_5 \rangle$

$$I_3 \quad I_5 \quad = \quad 2e^{*}I \times T_1\,(1 \quad T_1)$$

Negative correlation:

One-by-one tunneling

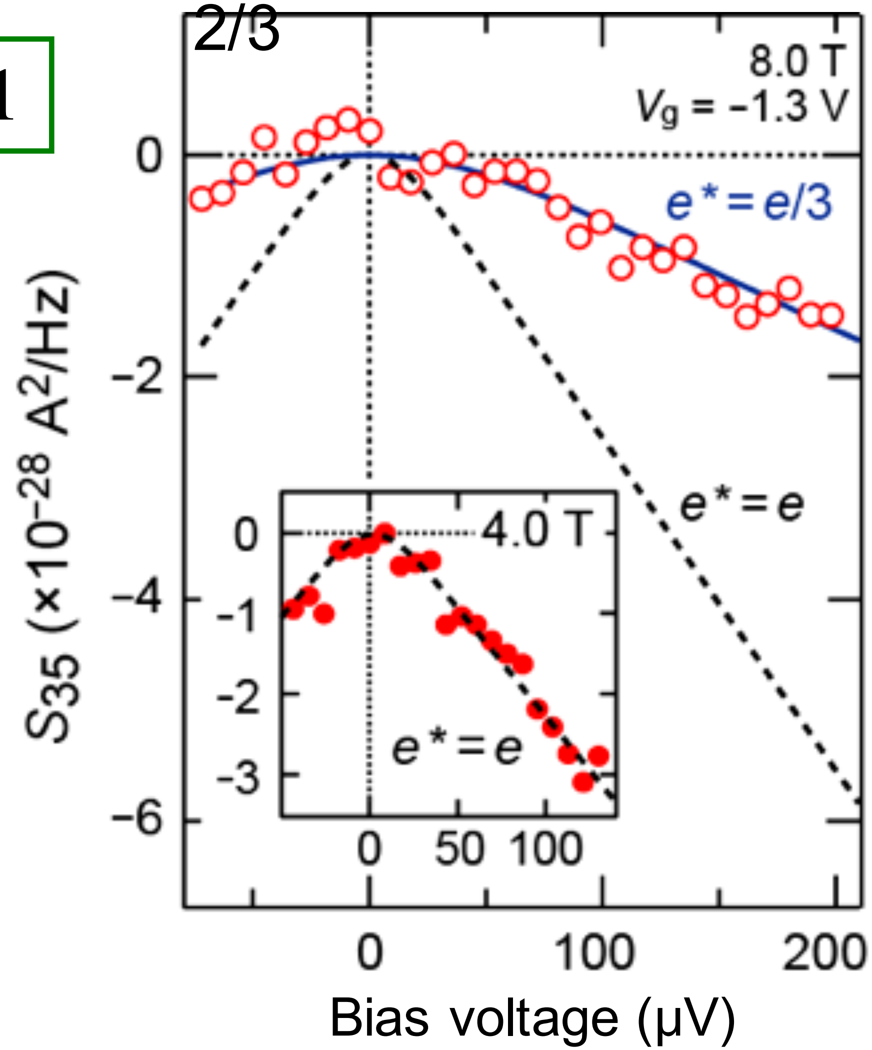
At a low magnetic field (4.0 T)

*e** = *e*:
scattering of electrons

At a high magnetic field (8.0 T)

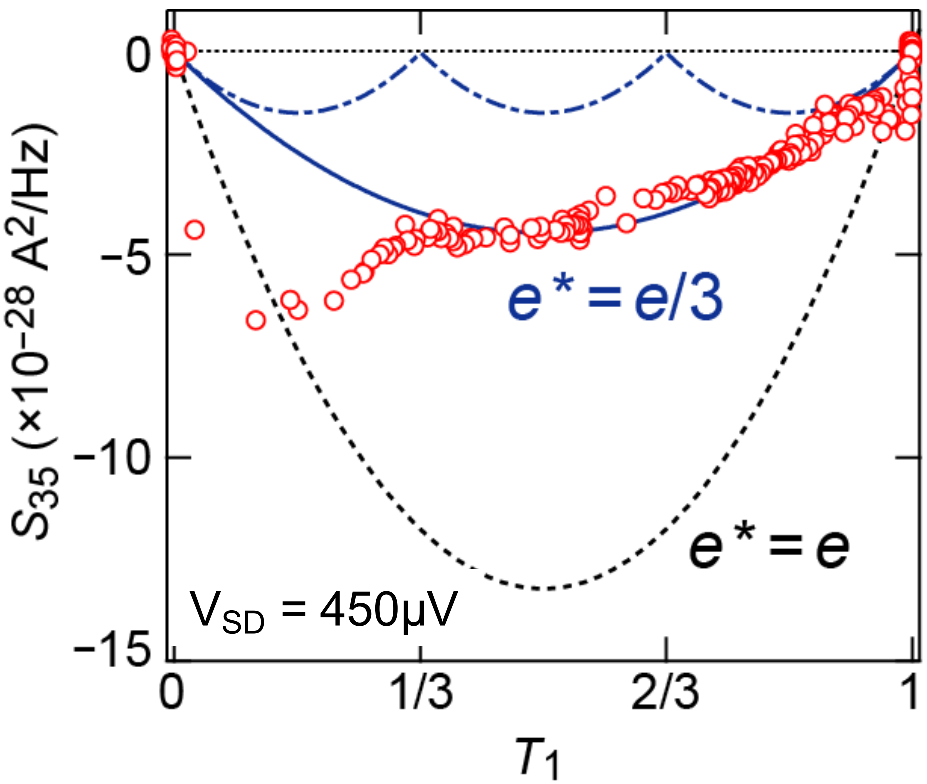
*e** = *e*/3:
scattering of *e*/3 quasiparticles

T_1
2/3



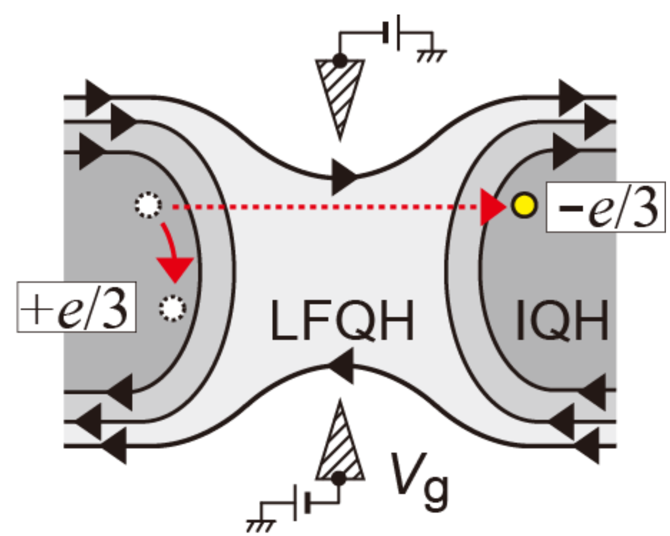
Creation of fractional quasiparticles

$$I_3 \quad I_5 \quad = \quad 2e^{*}I \times T_1\,(1 \quad T_1)$$



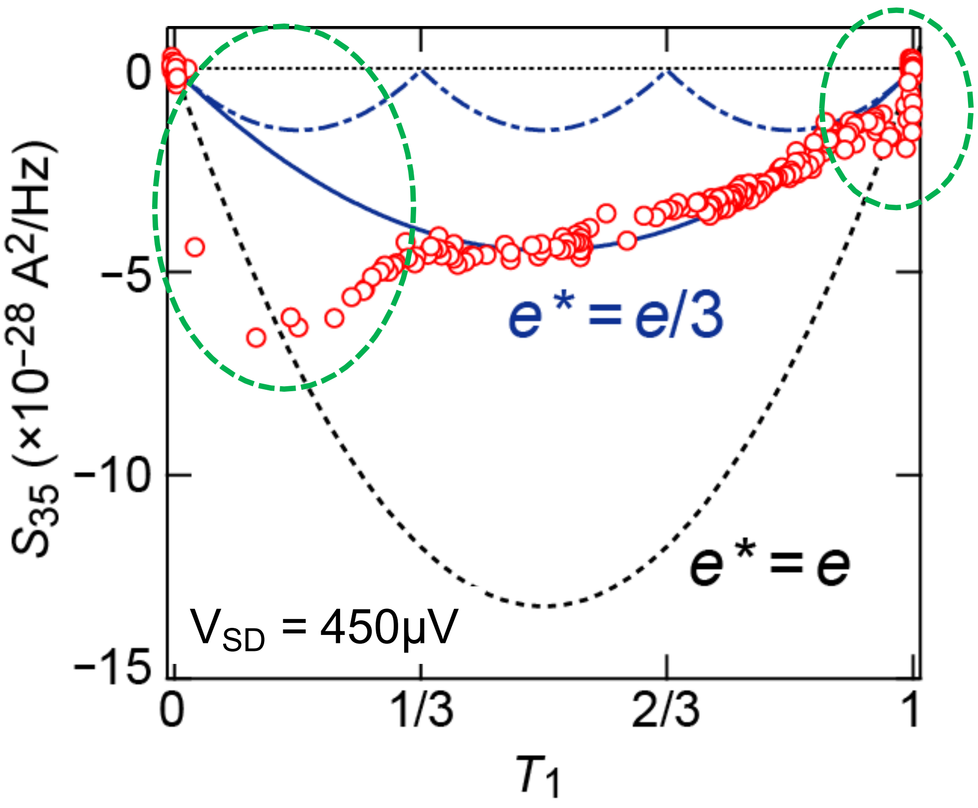
***T*$_1$:**
Transmission prob. between
ν = 1 Integer QH edge channels

**Fractional qps.
appear from IQH systems!**

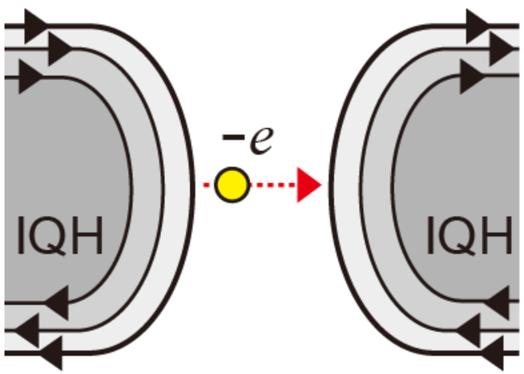


Strong- and Weak-backscattering limit

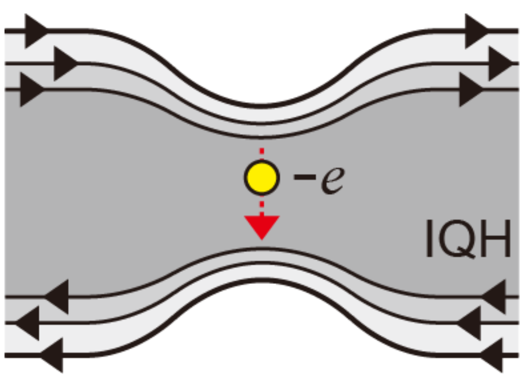
Electron tunneling through the vacuum or the IQH regime.



Strong backscattering



Weak backscattering



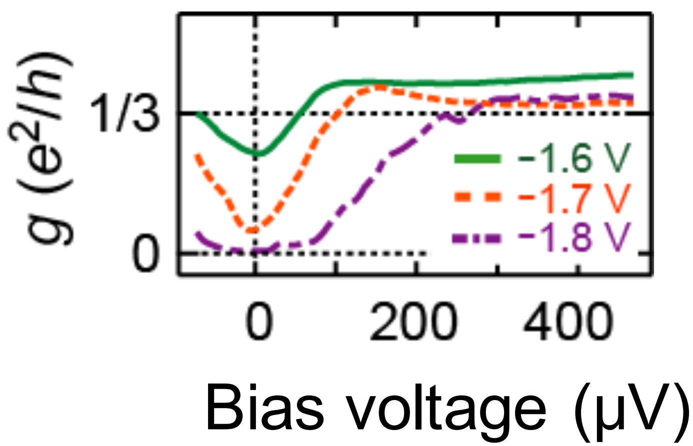
Strong-backscattering limit

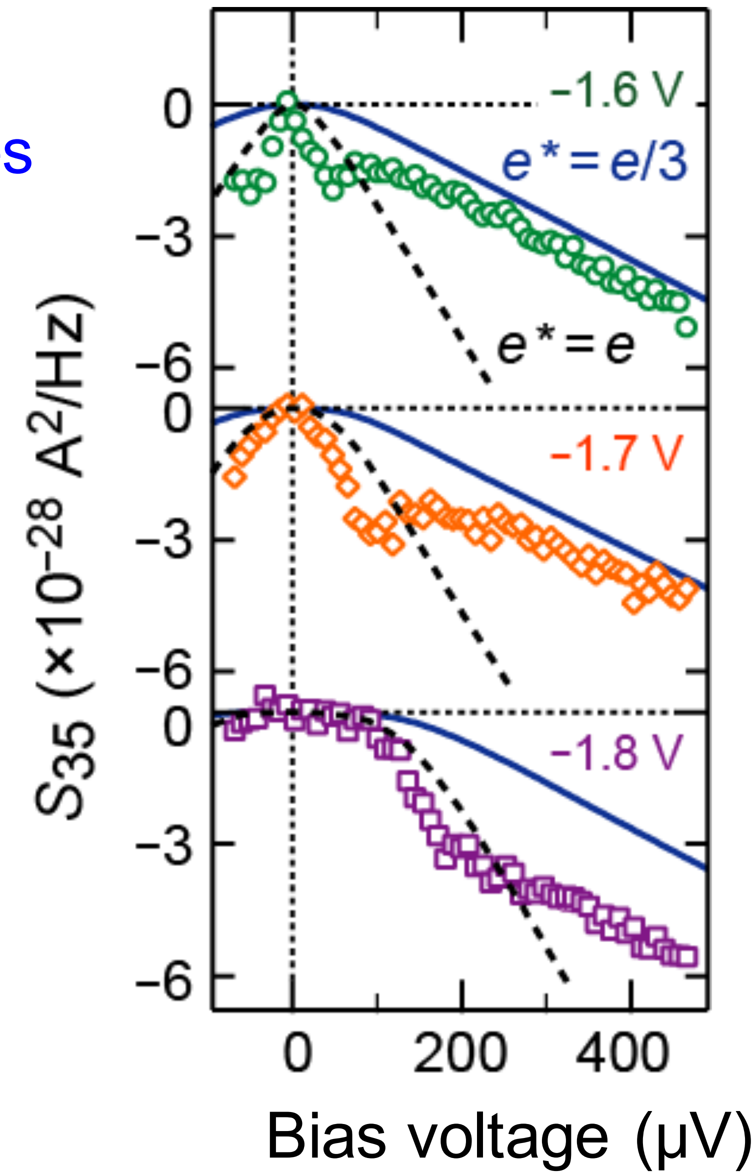
Suppression of *e*/3-charge tunneling
at low bias voltages

D. C. Glattli et al., Physica E **6**, 22 (2000),
Y. Chung et al., PRL **67**, 201104(R) (2003),
D. Ferraro et al., PRL **101**, 166805 (2008).

⇕

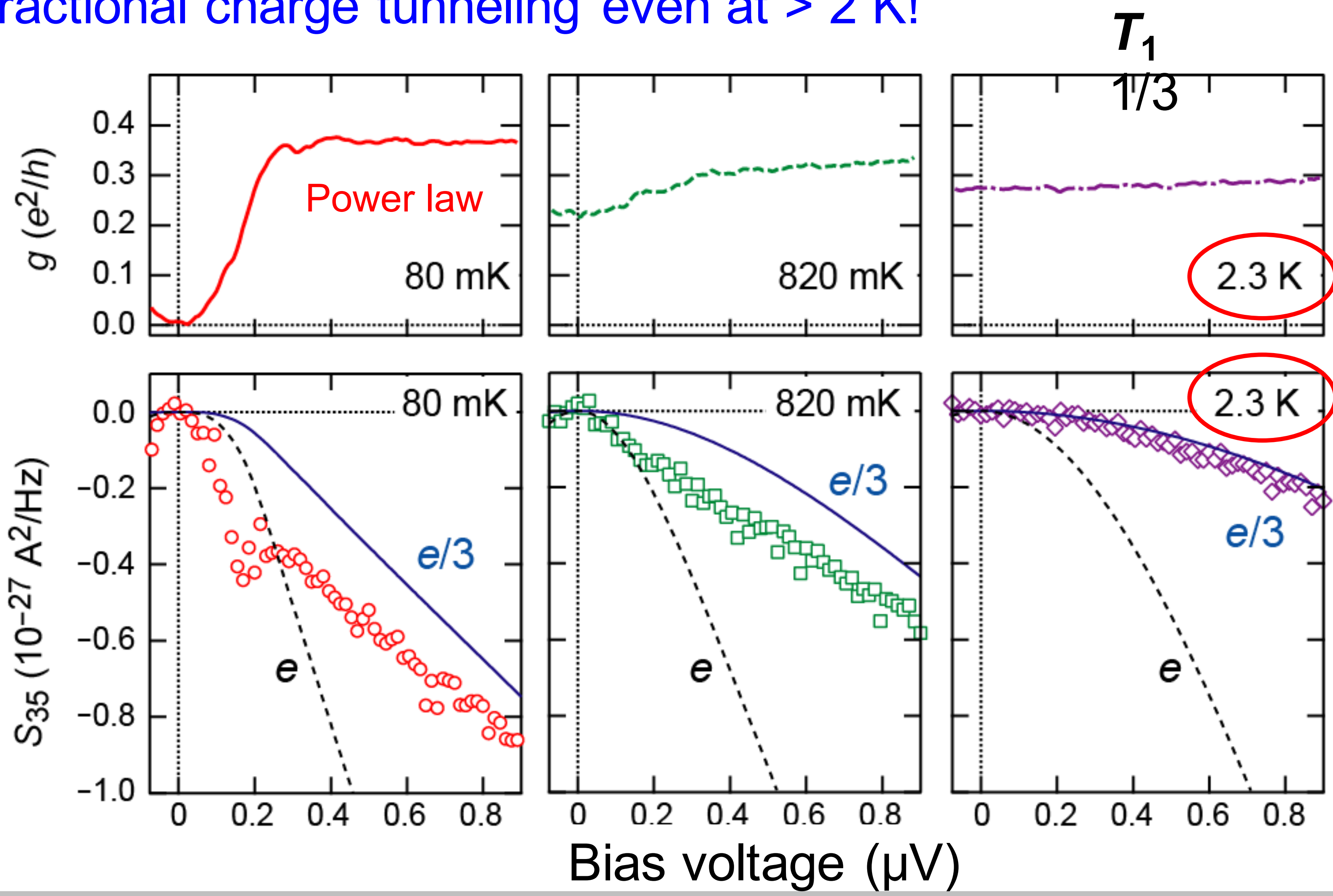
Power law behavior
in dc transport characteristics



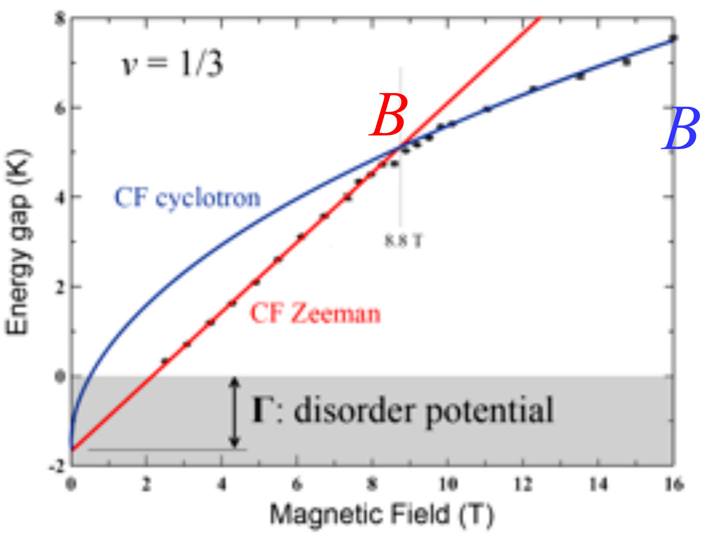


Temperature dependence

Fractional charge tunneling even at > 2 K!



Fractional quasiparticles at high temperatures



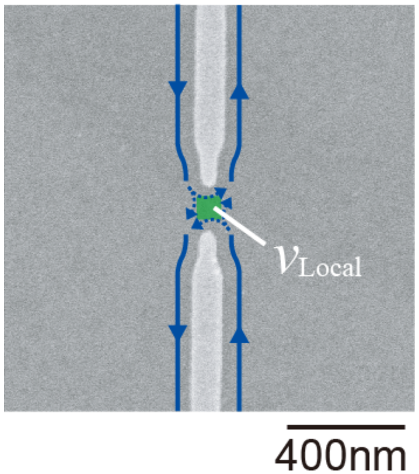
FQH gap D_F @ $\nu = 1/3$:

> 2 $K_{typ.}$ @ 3 T
> 7 $K_{typ.}$ @ 10 T

Dethlefsen et al., PRB 2006.

Disorder potential (G) prevents the observation of FQH effects.

Device 2



Disorder length scale: 100 $nm_{typ.}$

(depends on the spacer width)

J. Martin *et al.*, Science **305**, 980 (2004).

Comparable to QPC's size

Creation of Fractional Quasiparticles in a local fractional quantum Hall system

- ✓ Cross-correlation noise measurement

  Hashisaka *et al*., Rev. Sci. Instrum. **85**, 054704 (2014).

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  Hashisaka *et al*., Phys. Rev. Lett. **114**, 056802 (2015).

  Hashisaka *et al*., Phys. Rev. B **88**, 235409 (2013).