Nanodevices and Microsystems Research Foundation

Non-Abelian Fractional Quantum Hall Effect for Fault-Resistant Topological Quantum Computation

Wei Pan (01123)

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Outline

- *Motivation*
- *Results*
  - **tunneling in the 5/2 state in quantum point contacts**
  - **long coherent 5/2 edge state**
- *Future* direction

why quantum computer?

Modern encryption is based on the assumption that it is impossible to prime-factorize a large digit number within a reasonable time frame.

Classical computer: A 200-digit number was prime-factorized after **170 CPU years**.

Peter Shor in 1994
algorithm for prime factorization using a *quantum computer*

A 600-digit number can be prime-factorized in 6 CPU days!

35th Annual Symposium on Foundations of Computer Science, Santa Fe, NM, Nov. 20-22, 1994.

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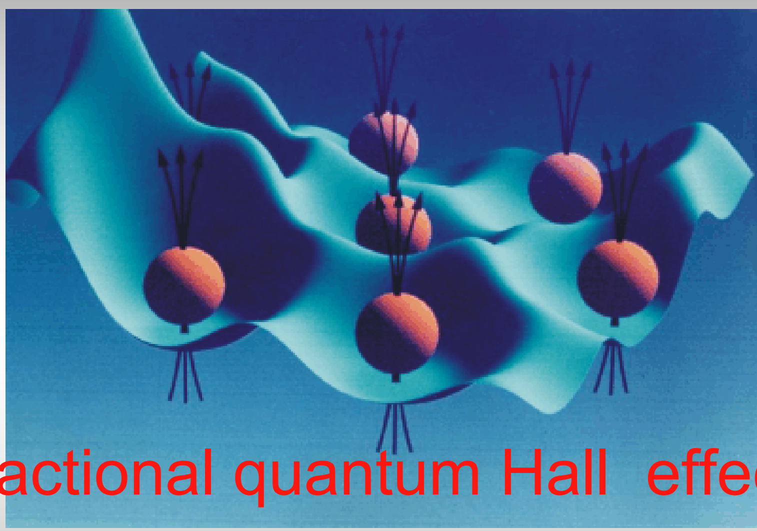
topological quantum computation (TQC)

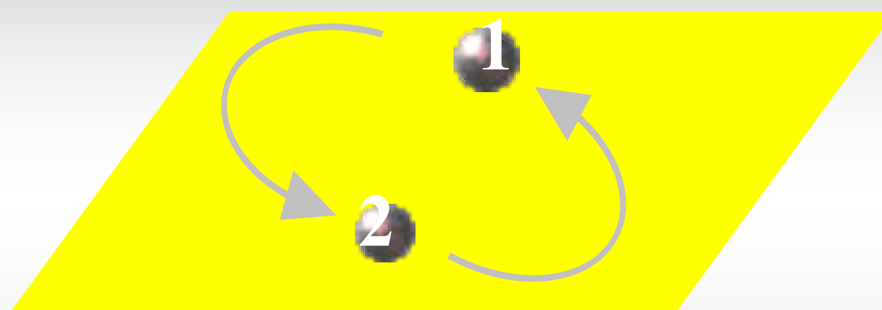
- utilizing non-Abelian quantum particles.
- global operation thus immune from local disturbance processes.
- error rate < 10^{-30}.

elementary particles



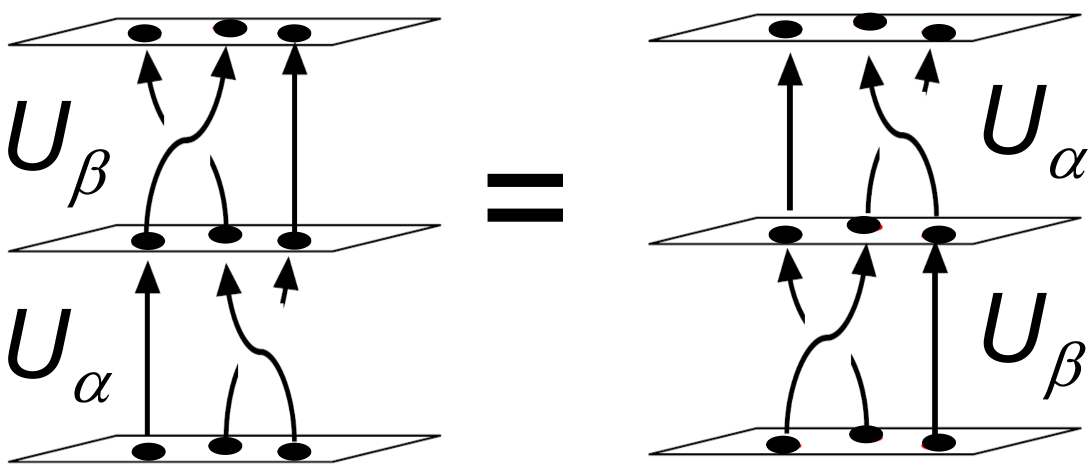
fractional quantum Hall effect

Anyons



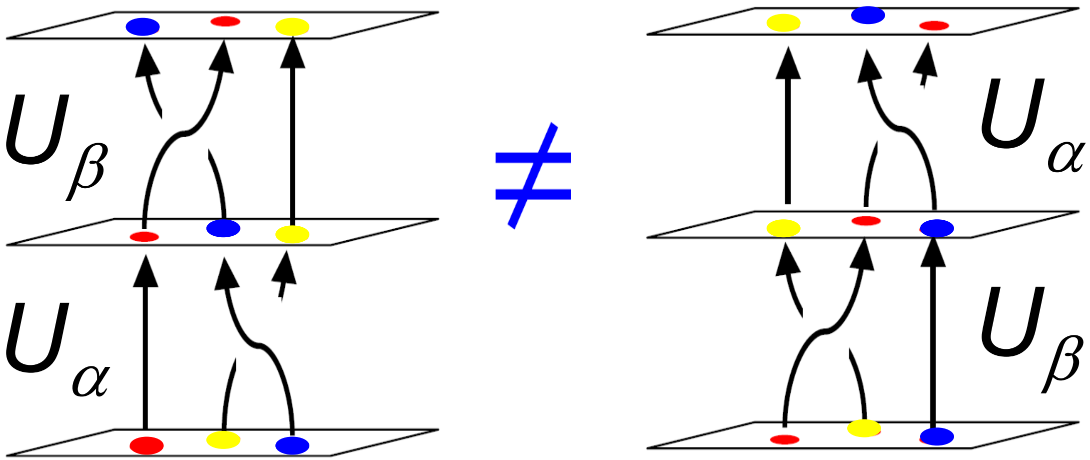
$$\Psi(2,1) = e^{i\theta}\,\Psi(1,2)$$

Abelian particles



$$U_\beta U_\alpha = U_\alpha U_\beta$$

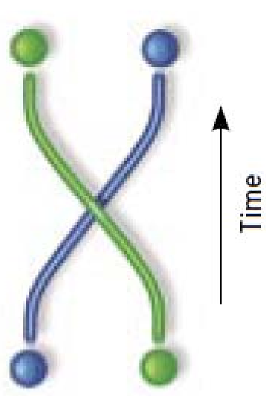
non-Abelian particles



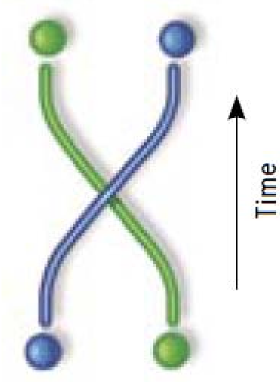
$U_\beta U_\alpha \neq U_\alpha U_\beta$

braiding non-Abelian particles

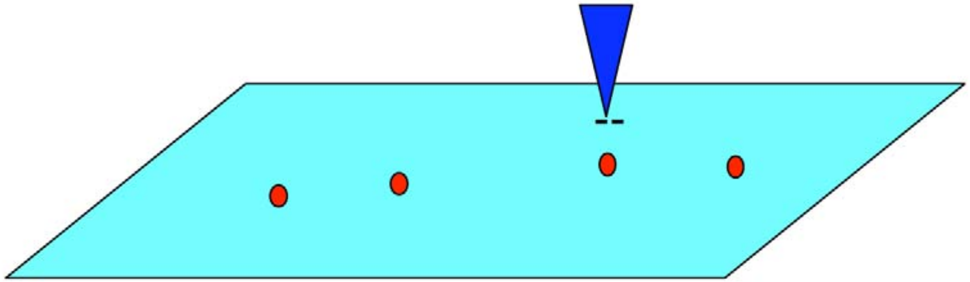
qubit 0



qubit 1

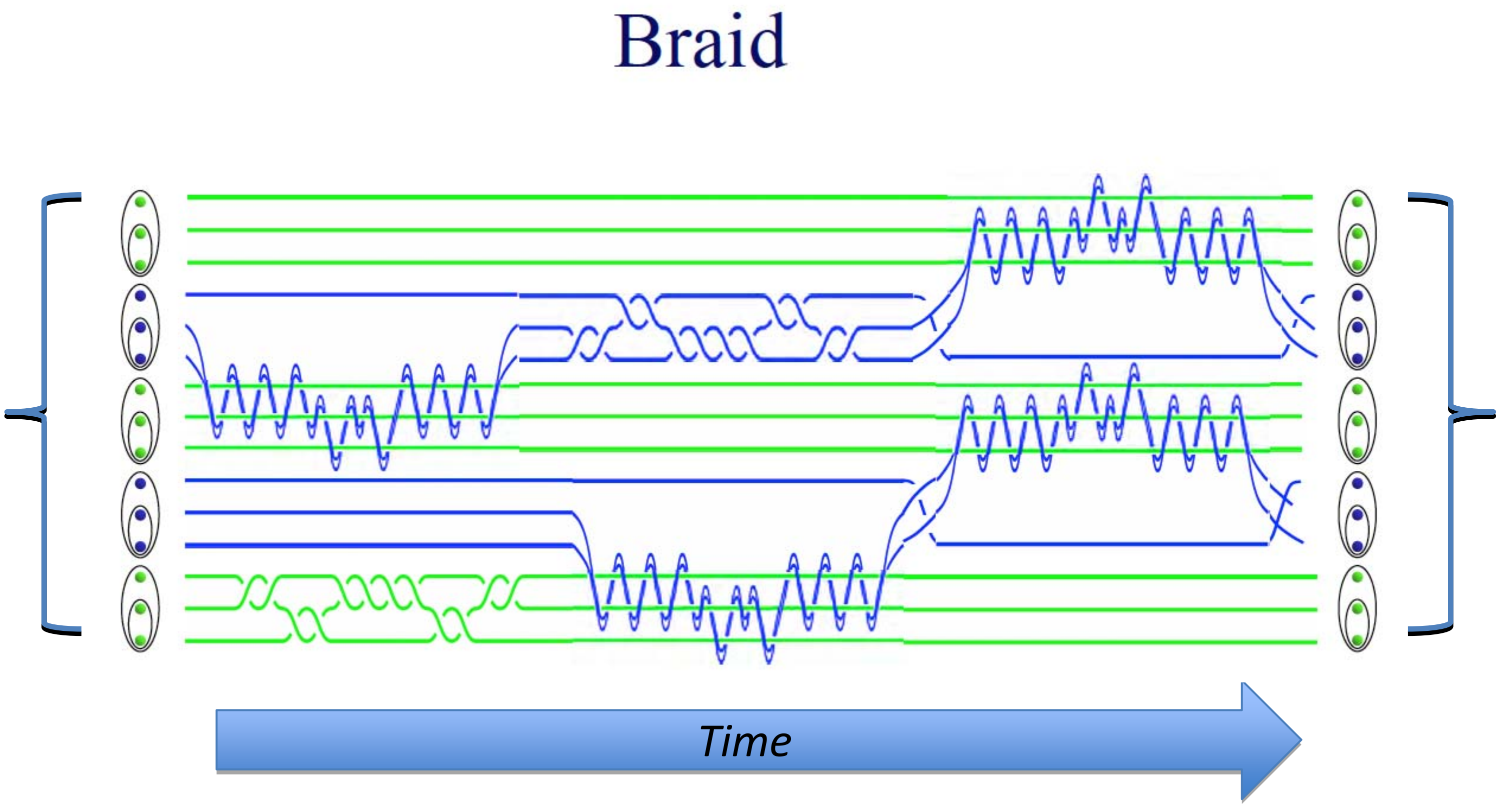


braiding = qubit



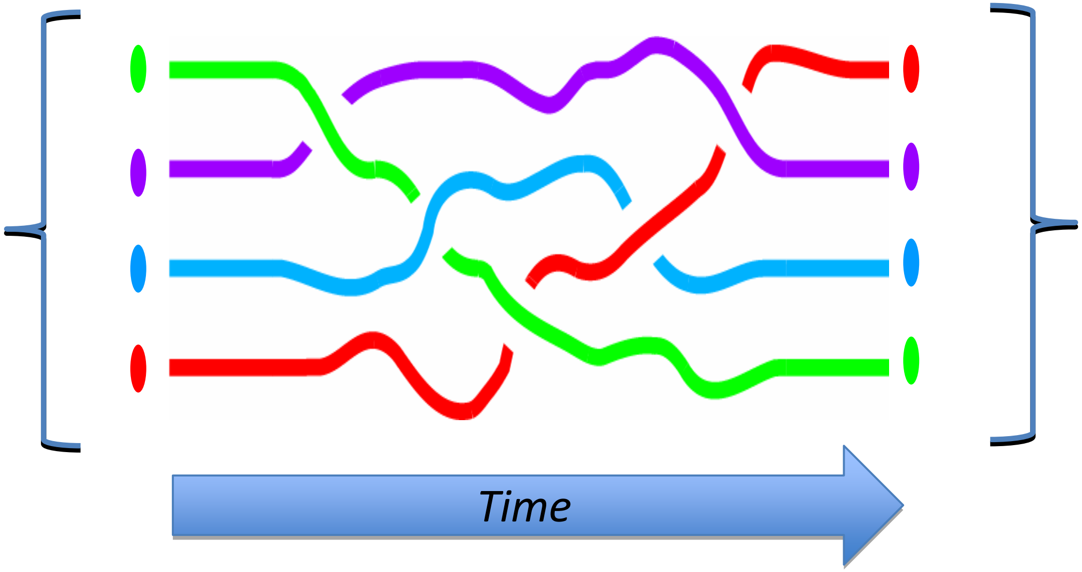
(Kitaev, 1998)

TQC



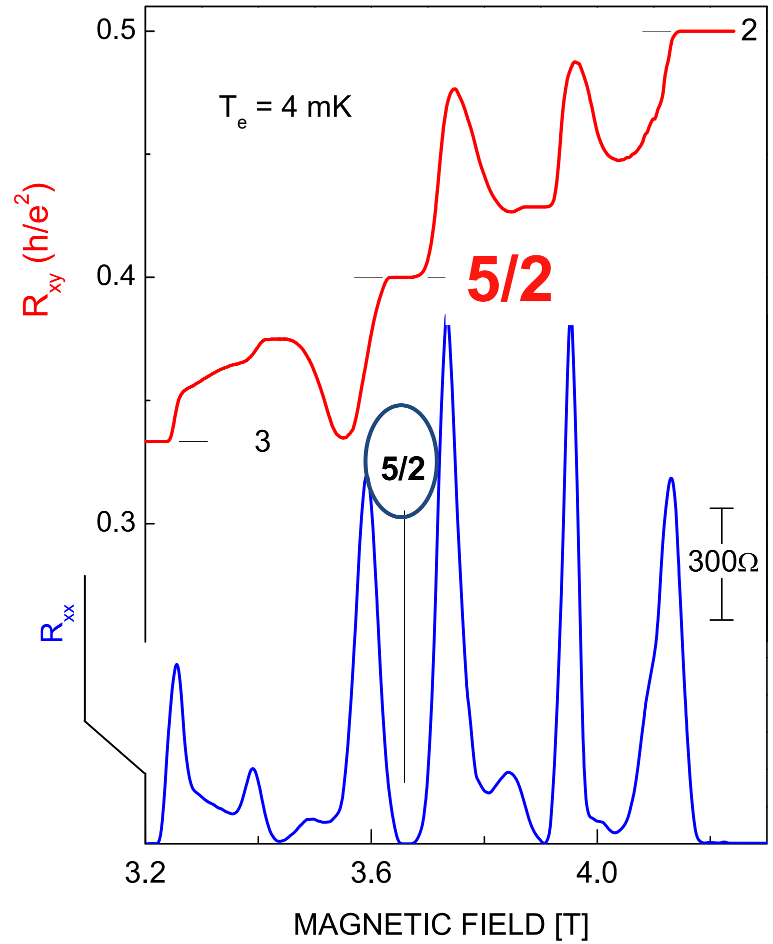
Bonesteel et al, PRL 2005

topological robustness



non-Abelian FQHE

Quasiparticles of a special fractional quantum Hall effect state, the so-called 5/2 state, in a 2D electron system are believed to be non-Abelian particles!



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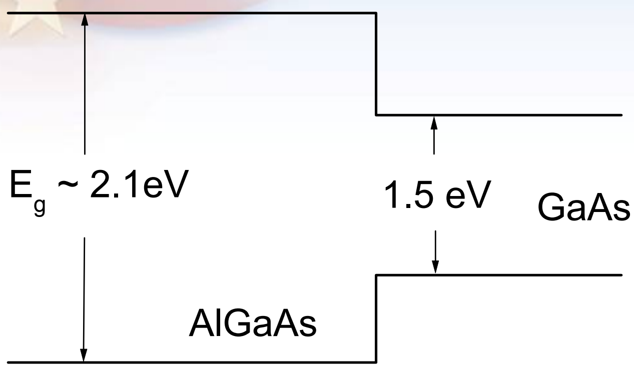
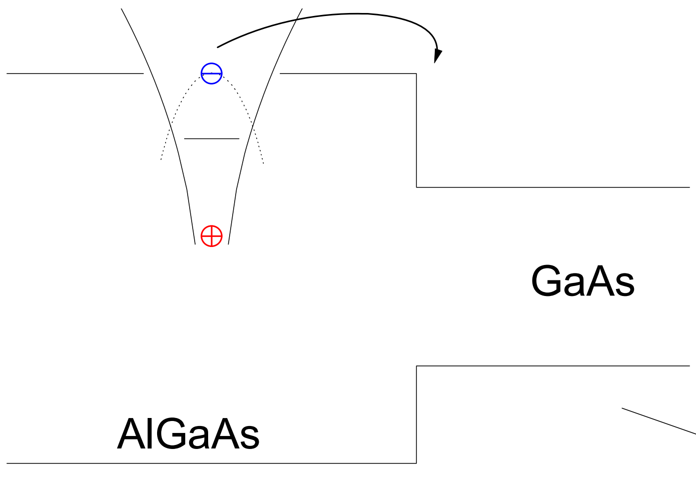
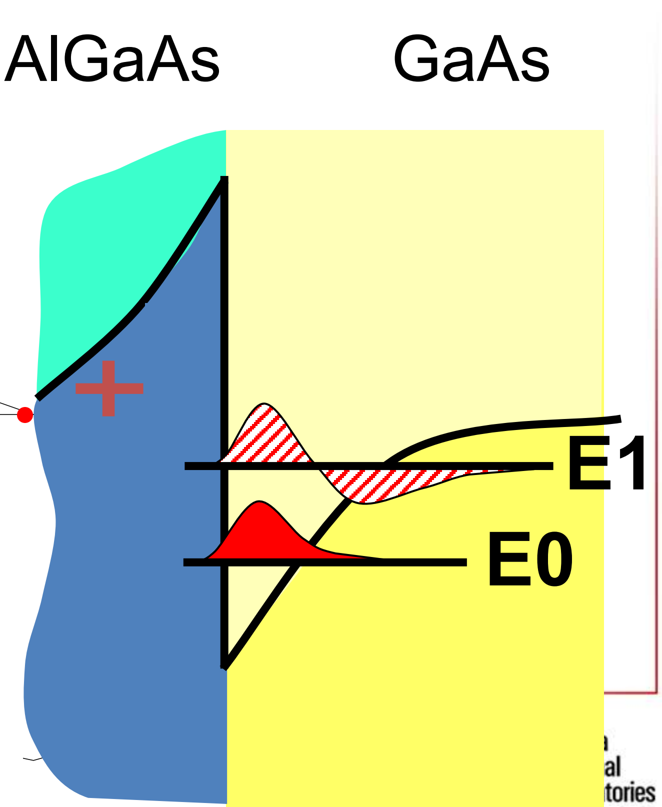
2D electron system in modulation-doped GaAs/AlGaAs heterostructures





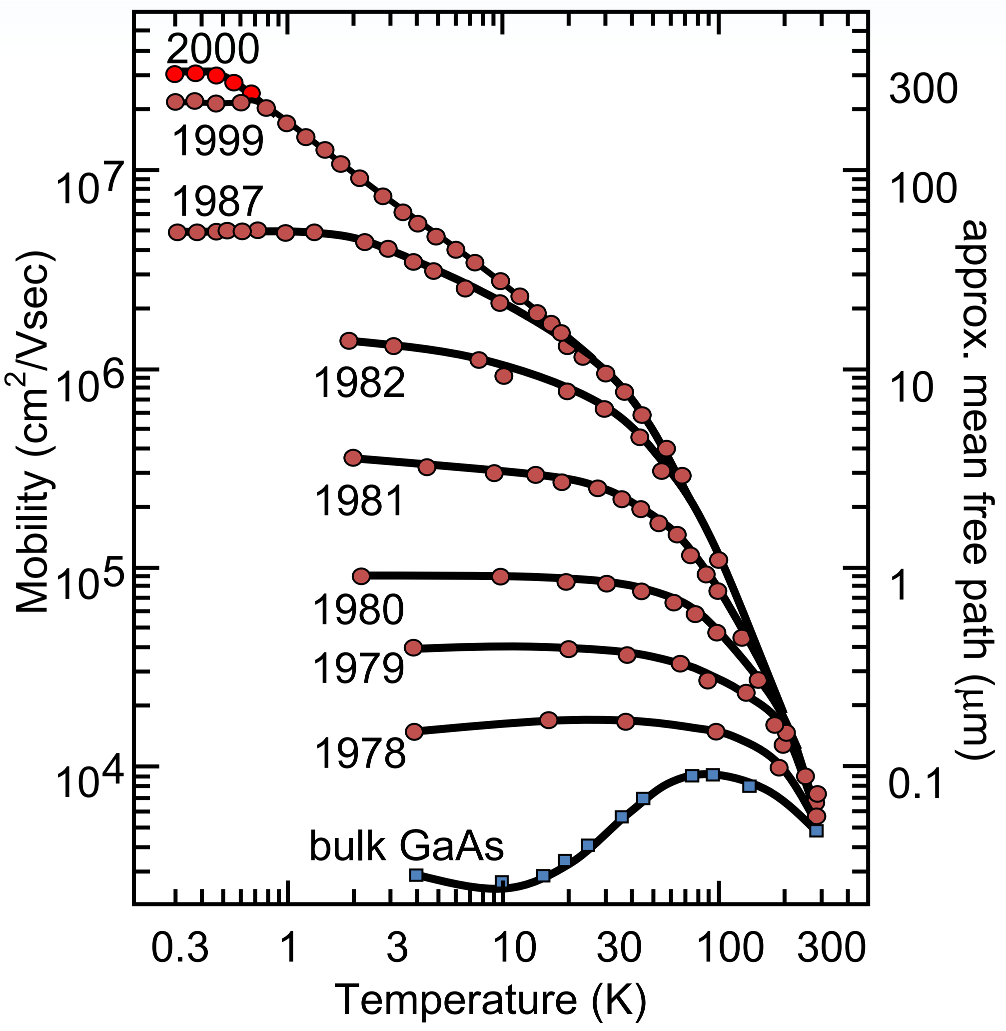


$E1 - E0 \gg k_B T$

z-motion quantized

two-dimensional electrons

mobility in modulation-doped material *vs* year



electrons travel for 300 μm "without" scattering

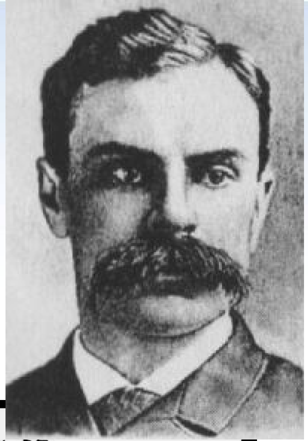
modern transistors

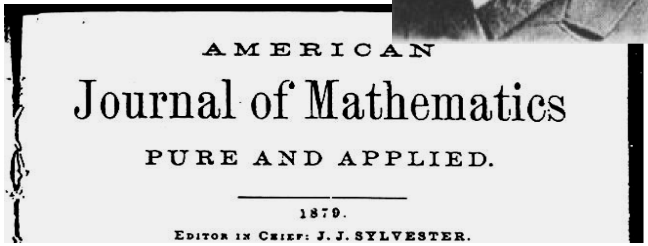
Cellular phone base station

VLA Socorro, New Mexico, USA

The Hall Effect

Edwin Hall
(1879)



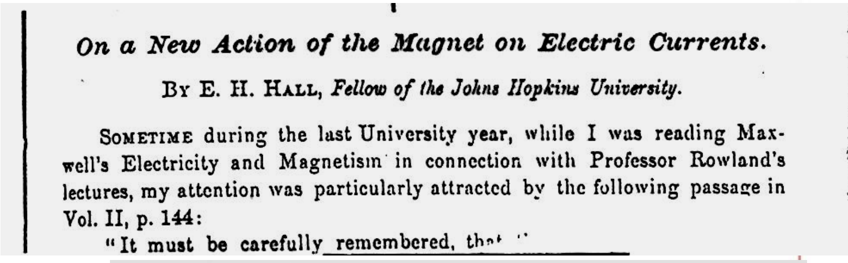

AMERICAN

Journal of Mathematics

PURE AND APPLIED.

1879.

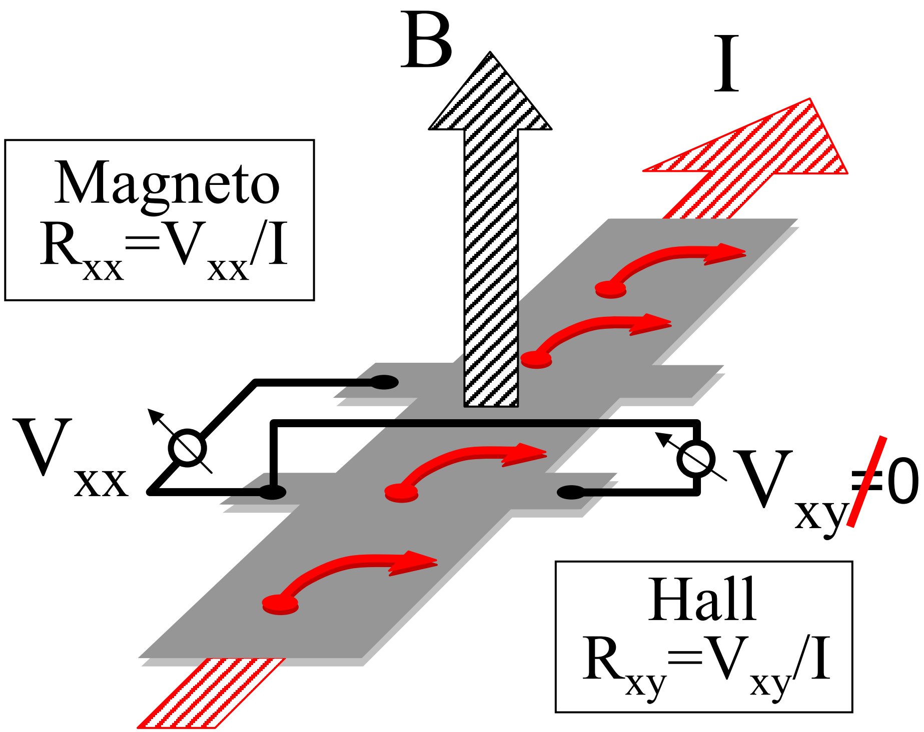
EDITOR IN CHIEF: J. J. SYLVESTER.


On a New Action of the Magnet on Electric Currents.

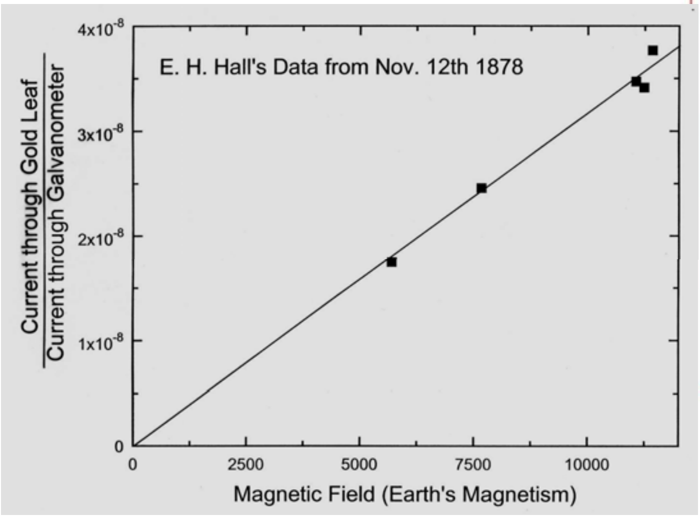
BY E. H. HALL, *Fellow of the Johns Hopkins University.*

SOMETIME during the last University year, while I was reading Maxwell's Electricity and Magnetism in connection with Professor Rowland's lectures, my attention was particularly attracted by the following passage in Vol. II, p. 144:

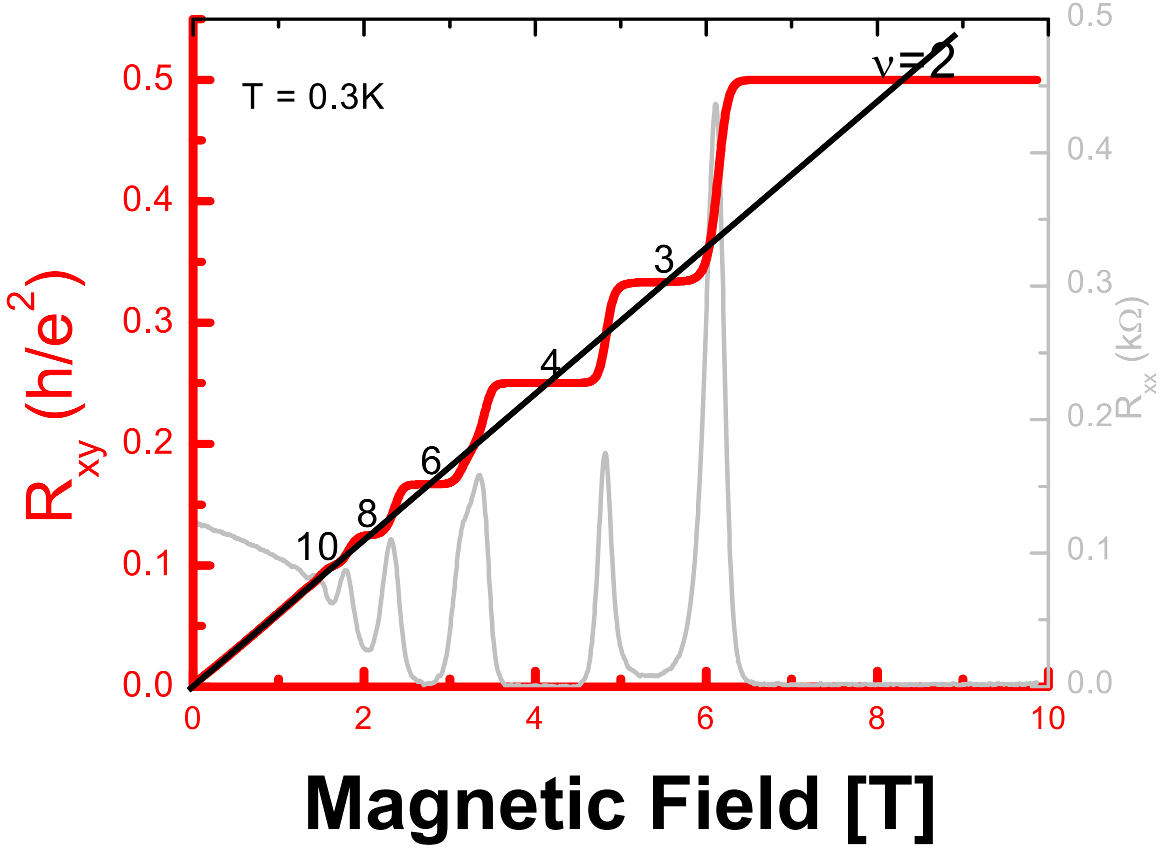
"It must be carefully remembered, that



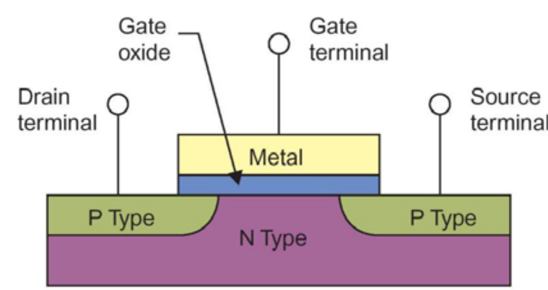
$$R_{xy} = \frac{B}{en}$$



quantized Hall effect



K. von Klitzing
(1985 Physics Nobel Laureate)

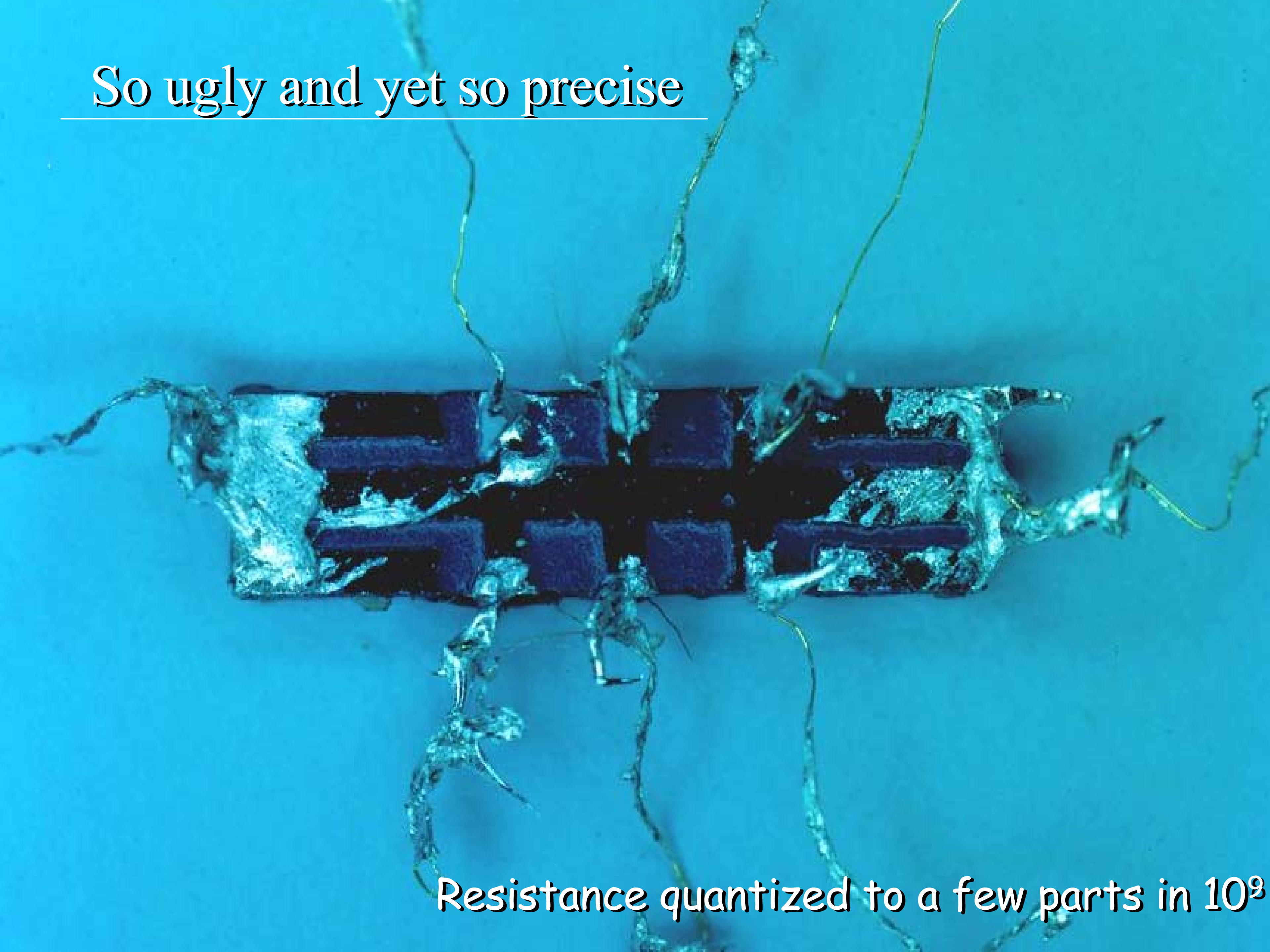


Si-MOSFET

quantized R_{xy}, $\mathbf{R_{xy}=(h/e^2)/\nu}$

ν, Landau level filling factor

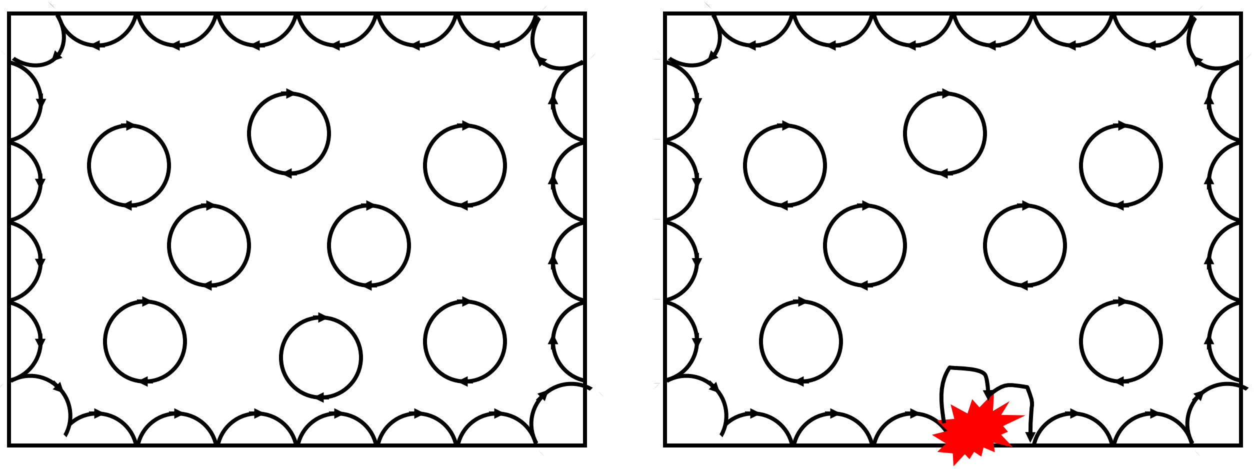
So ugly and yet so precise



Resistance quantized to a few parts in 10^9

edge state

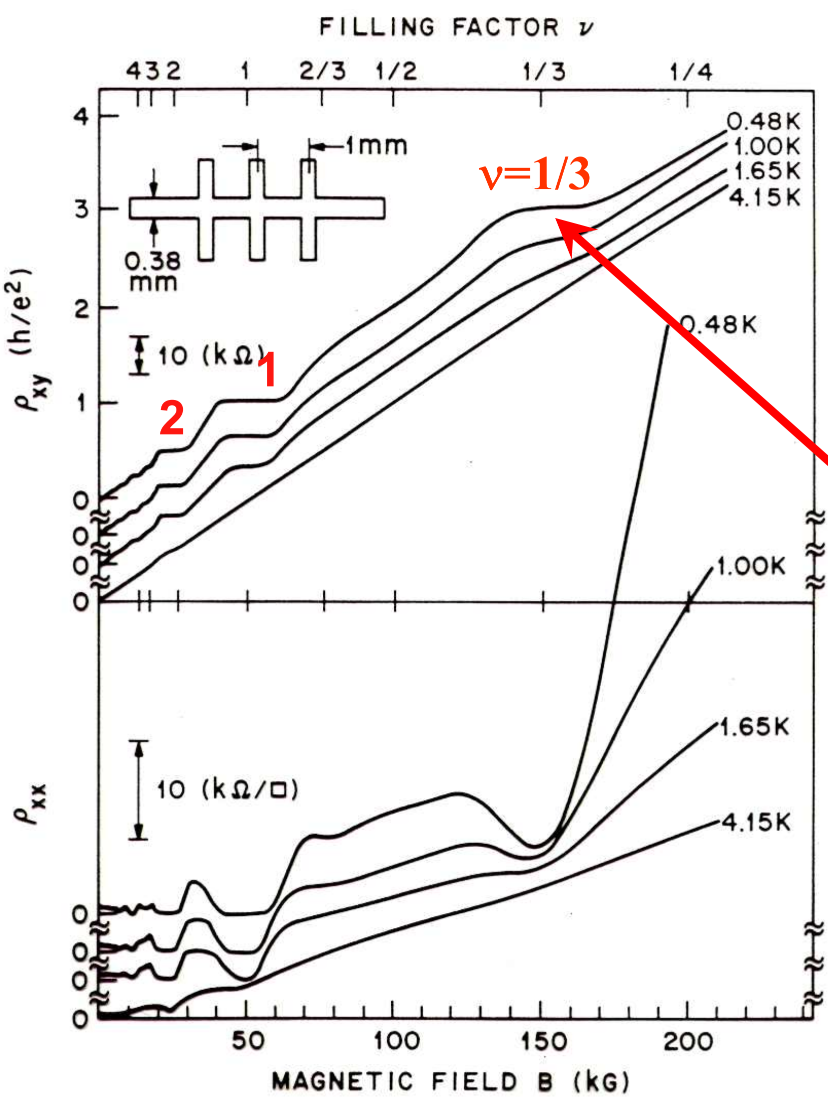
$B \neq 0$



skipping motion at the edge

impurity does NOT destroy the skipping mode

fractional quantum Hall effect



D.C. Tsui and H.L. Stormer
(1998 Physics Nobel Laureates)

$$R_{xy} = \frac{h/e^2}{\frac{1}{3}}$$

HEMT

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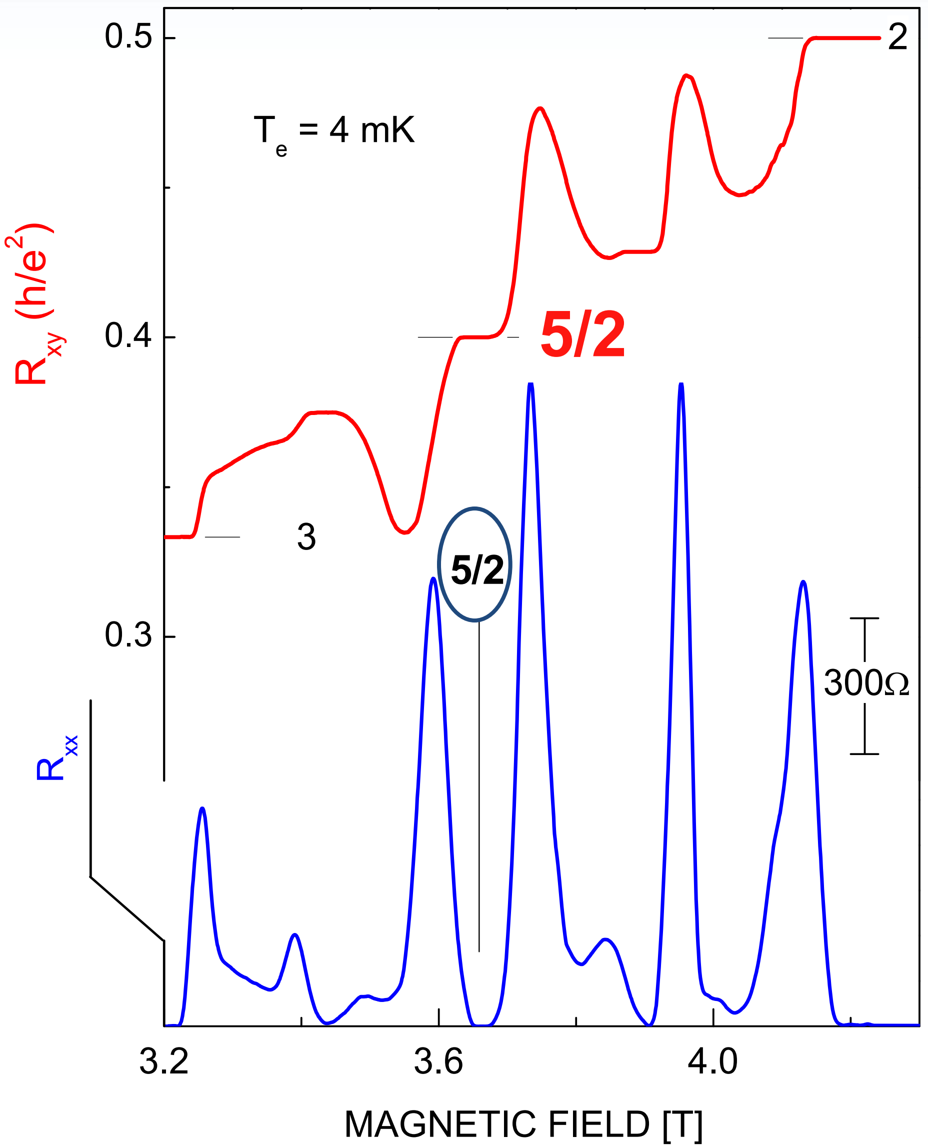
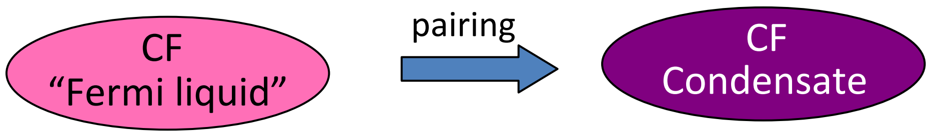
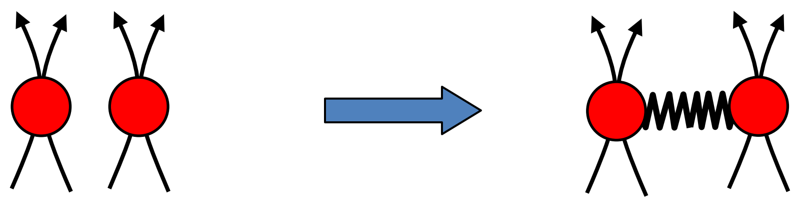
1/3	1/5	1/7	1/9	2/11	2/13	2/15	2/17	3/19	5/21	6/23
2/3	2/5	2/7	2/9	3/11	3/13	4/15	3/17	5/19	10/21	6/25
4/3	3/5	3/7	4/9	4/11	4/13	7/15	4/17	9/19		
5/3	4/5	4/7	5/9	5/11	5/13	8/15	5/17	10/19		
7/3	6/5	5/7	7/9	6/11	6/13	11/15	6/17			
8/3	7/5	9/7	11/9	7/11	7/13	22/15	8/17			
	8/5	10/7	13/9	8/11	10/13	23/15	9/17			
	9/5	11/7	14/9	16/11	19/13					
	11/5	12/7		17/11	20/13					
	12/5									
	13/5									
	14/5									

lots of FQHE states observed

the 5/2 FQHE state



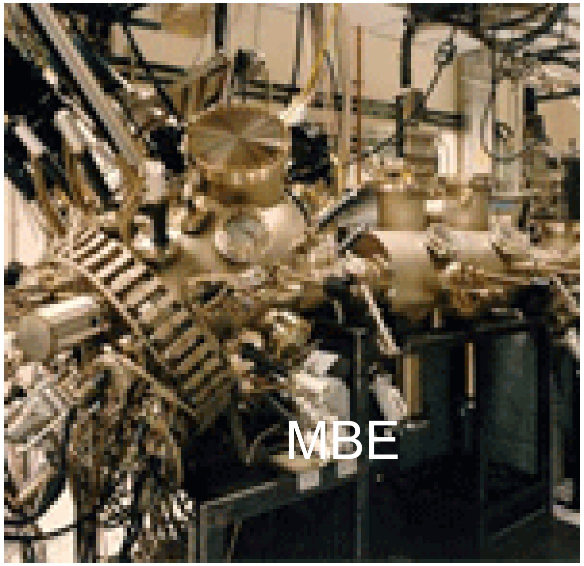

CF
"Fermi liquid"
pairing
CF
Condensate



project goal

To establish scientific foundation for topological quantum computation

facilities



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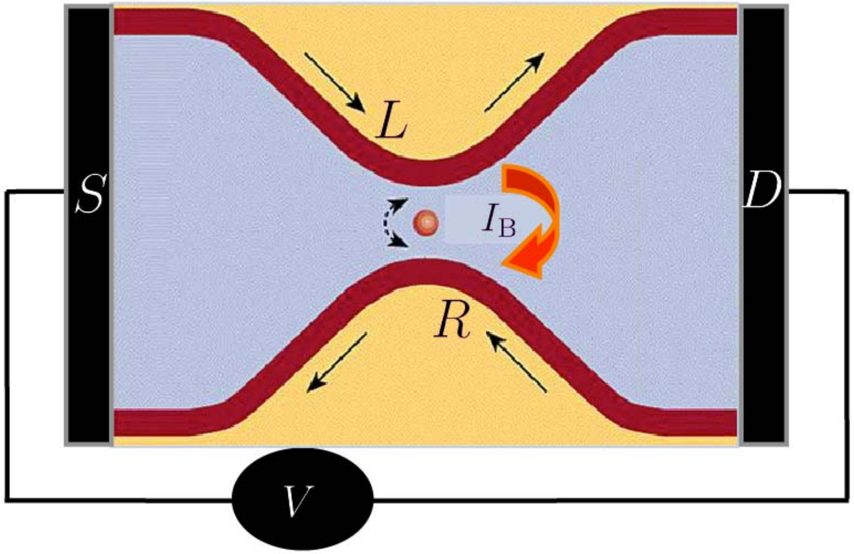
tunneling in quantum point contacts – non-Abelian physics



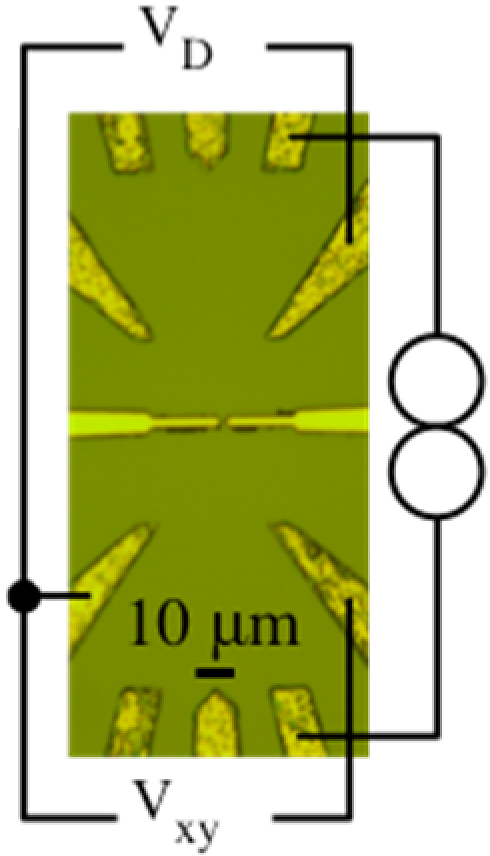
non-Abelian FQHE

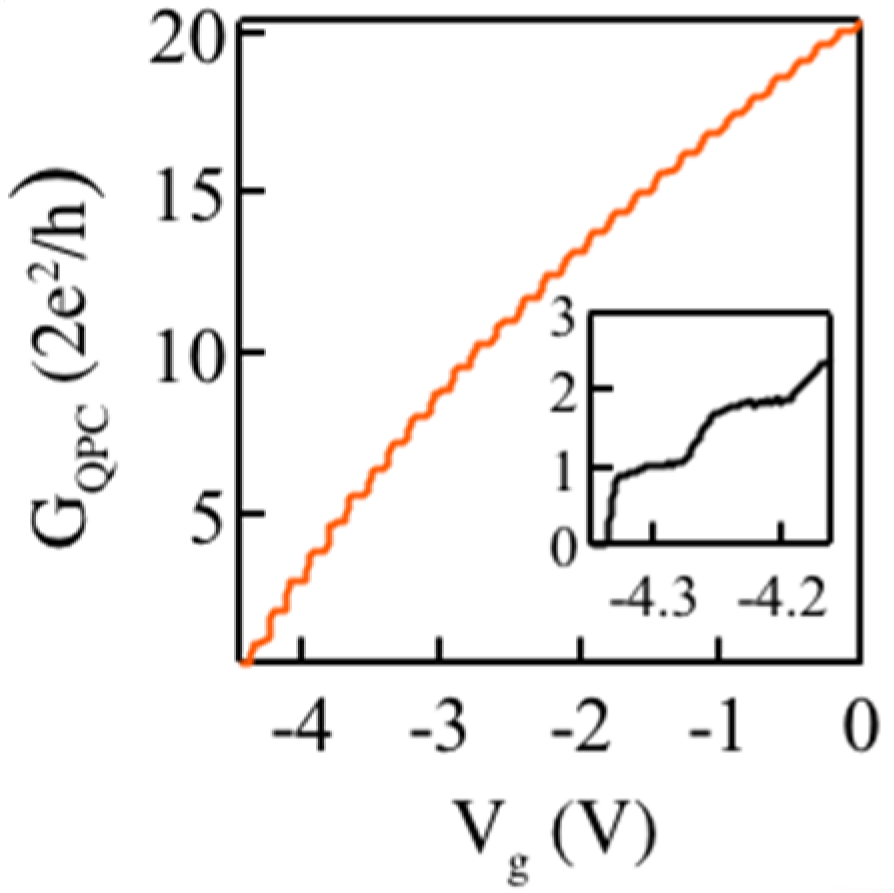
$e^* = e/4$

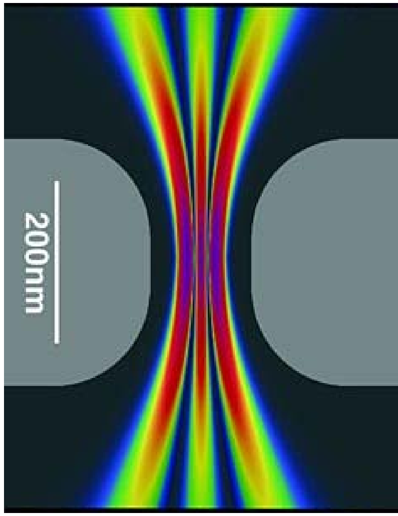
$g = 1/2$

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

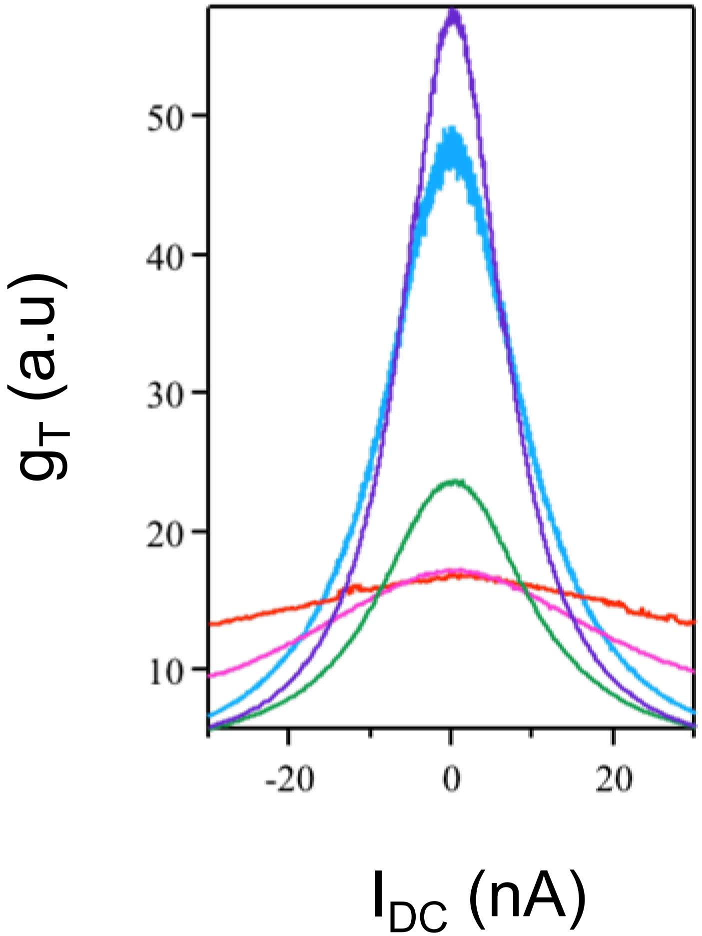
characterization of QPC







tunneling at 5/2



$e^* \sim e/4$

$g \sim 0.7$

$e^* = e/4$
$g = 1/2$

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

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extremely long coherent 5/2 edge channel

it is very important to know the coherence length of the 5/2 edge state, i.e., how long it can travel before losing its non-abelian properties?

Experimental results:

5/2 edge state can travel at least 1mm.

(from non-local transport measurements)

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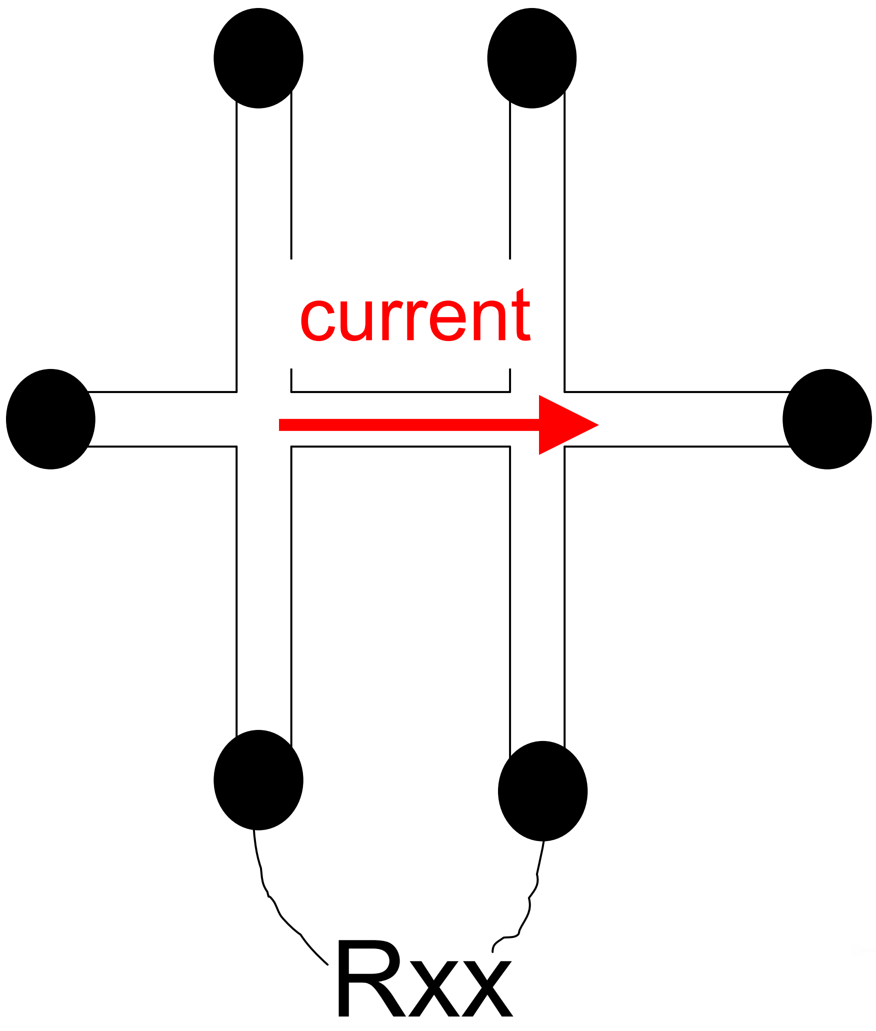
local measurement



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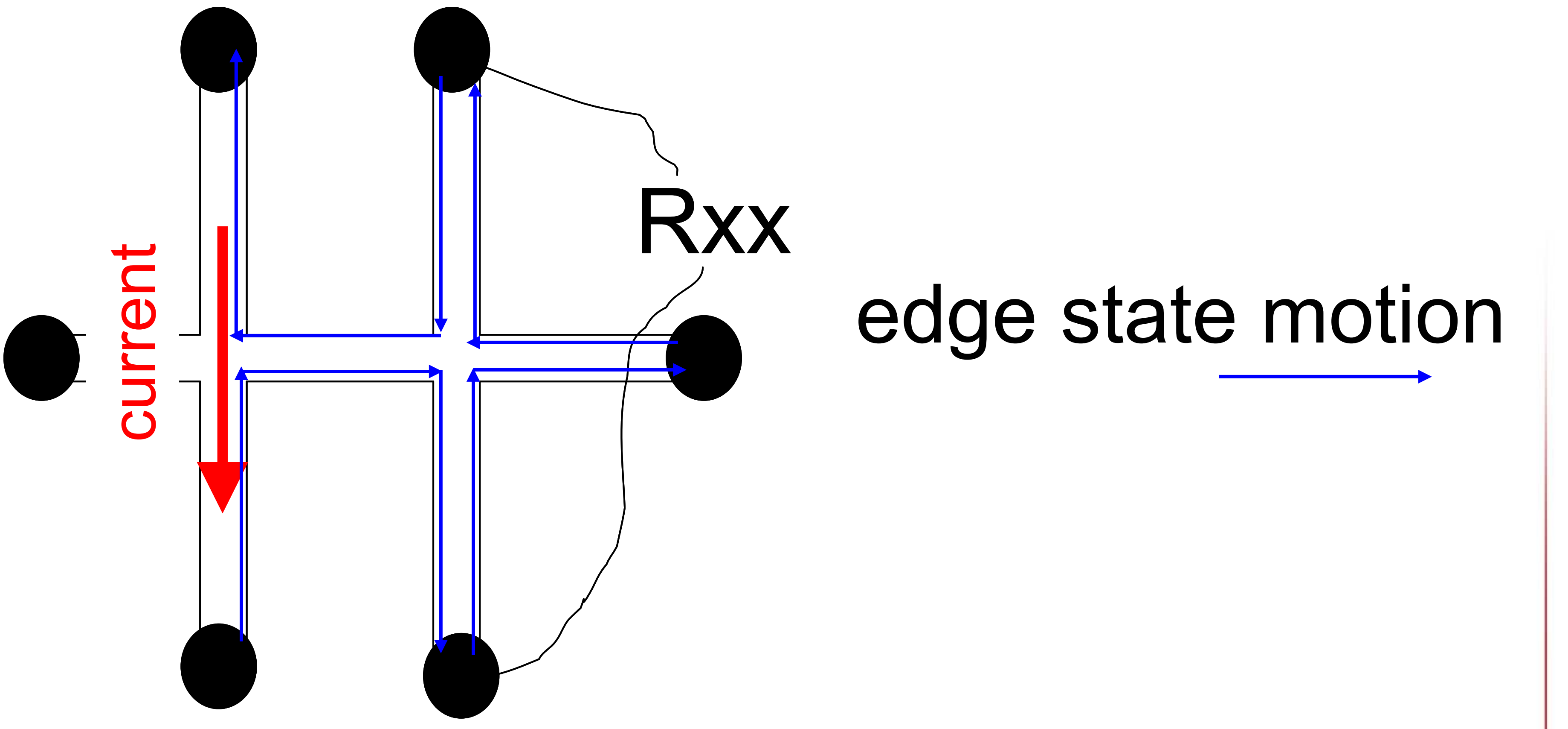
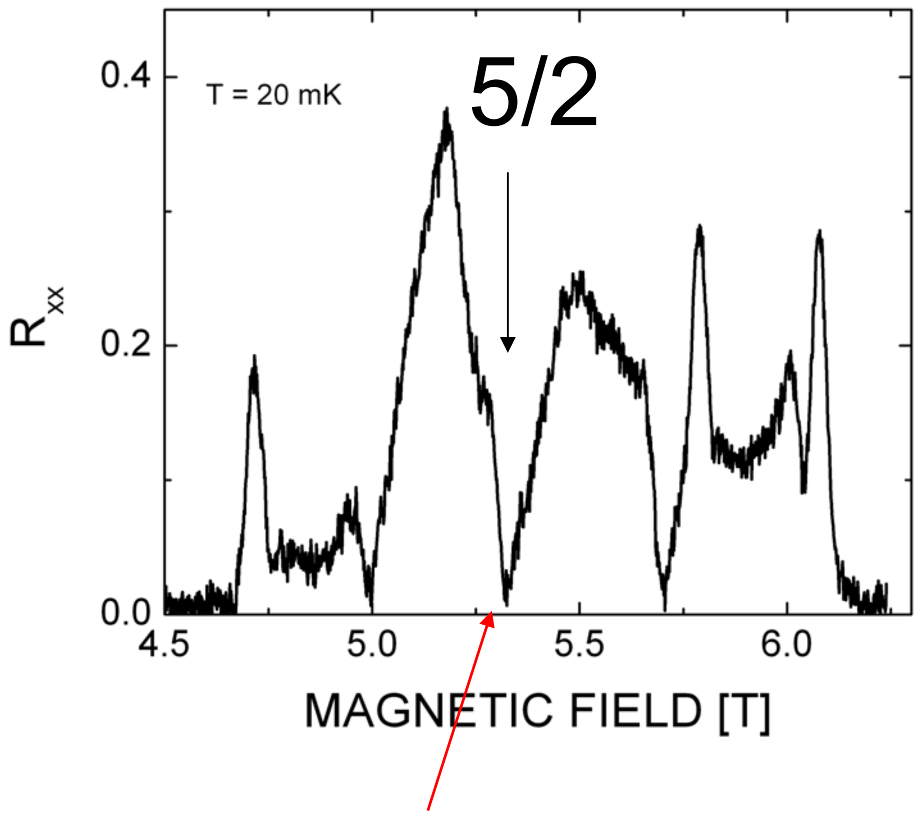
non-local measurement





well developed 5/2 state

coherent edge channel > 1mm

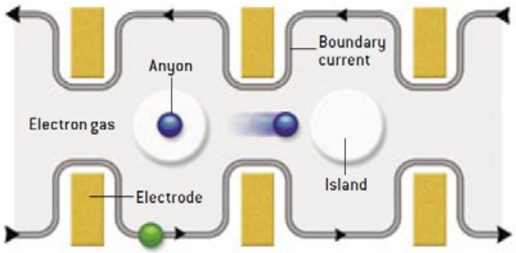
future direction

Das Sarma-Freedman-Nayak non-Abelian qubit

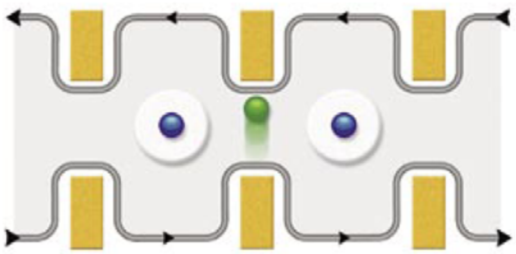
NOT GATE

This proposed anyonic NOT gate is based on a fractional quantum Hall state involving anyons having one-quarter the charge of an electron. Electrodes induce two islands on which anyons can be trapped. Current flows along the boundary but under the right conditions can also tunnel across the narrow isthmuses.

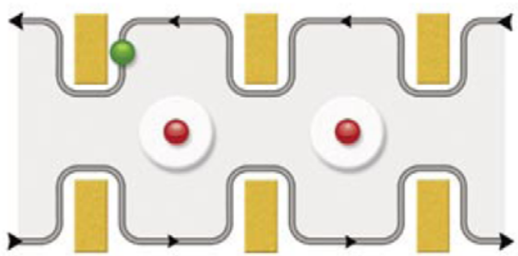
1 Initialize the gate by putting two anyons (*blue*) on one island and then applying voltages to transfer one anyon to the other island. This pair of anyons represents the qubit in its initial state, which can be determined by measuring the current flow along the neighboring boundary.



2 To flip the qubit (the NOT operation), apply voltages to induce one anyon from the boundary (*green*) to tunnel across the device.



3 The passage of this anyon changes the phase relation of the two anyons so that the qubit's value is flipped to the opposite state (*red*).



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summary

- Our tunneling results in QPCs support that the 5/2 state being a non-Abelian state

- The 5/2 edge state can travel at least 1 mm before losing its coherence.

Thank You !

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