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Group Seminar

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Zumbühl Group

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ARTICLES

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Aharonov–Bohm interference of fractional quantum Hall edge modes

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The braiding statistics of certain fractional quantum Hall states can be probed via interferometry of their edge states. Practical difficulties—including loss of phase coherence—make this a challenging task. We demonstrate the operation of a small Fabry–Perot interferometer in which highly coherent Aharonov–Bohm oscillations are observed in the integer and fractional quantum Hall regimes. Careful design of the heterostructure suppresses Coulomb effects and promotes strong phase coherence. We characterize the coherency of edge-mode interference by the energy scale for thermal damping and determine the velocities of the inner and outer edge modes independently via selective backscattering of edge modes originating in the $N = 0, 1, 2$ Landau levels. We also observe clear Aharonov–Bohm oscillations at fractional filling factors $\nu = 2/3$ and $\nu = 1/3$, which indicates that our device architecture provides a platform for measurement of anyonic braiding statistics.

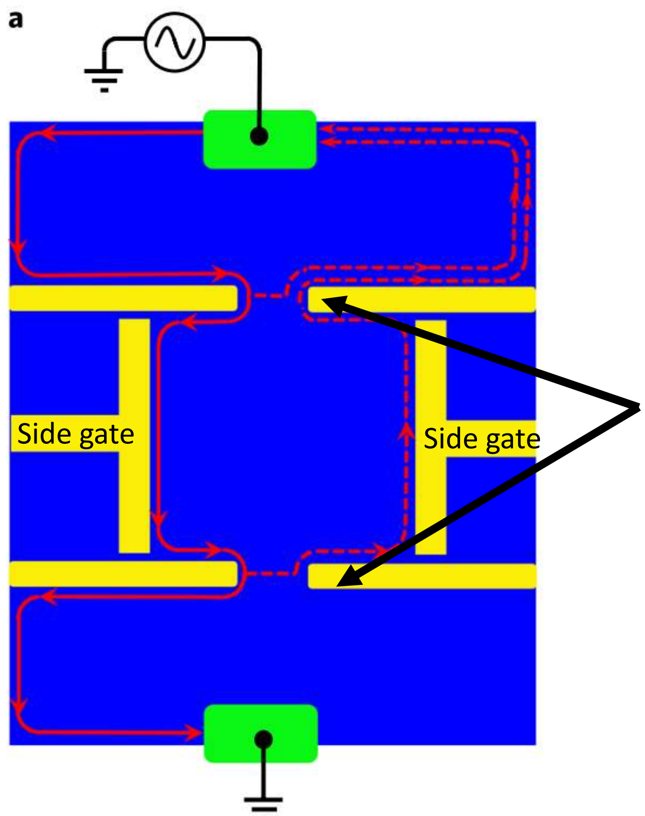
Outline

- Aharonov-Bohm interference
- Interferometer Regimes
- Device Properties
- Results
  - Fractional edge state interferometry
  - Edge state velocities

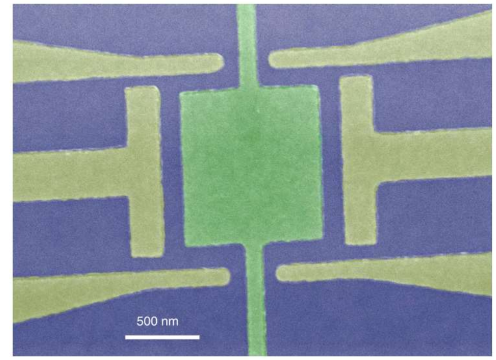
Aharonov-Bohm Interferometry

- Investigation of (fractional) quantum Hall effect
  - Edge state velocities
  - (non)-Abelian fractional statistics
- Problems with Aharonov-Bohm interferometry
  - Small coherence length of fractional edge states requires small interference area
  - Small interference Area causes larger coulomb charging energy

Aharonov-Bohm inerferometer



Quantum point contact (QPC)



AB-interference at weak backscattering (r~ 0.03)

$$G / G_0 = 1 - 2r^2\left[1 + \eta \cos\left(2\pi \frac{AB}{\Phi_0}\right)\right]$$

r = QPC reflectivity
η =coherence factor
A = interference Area
Φ_0 = Flux quantum (h/e)

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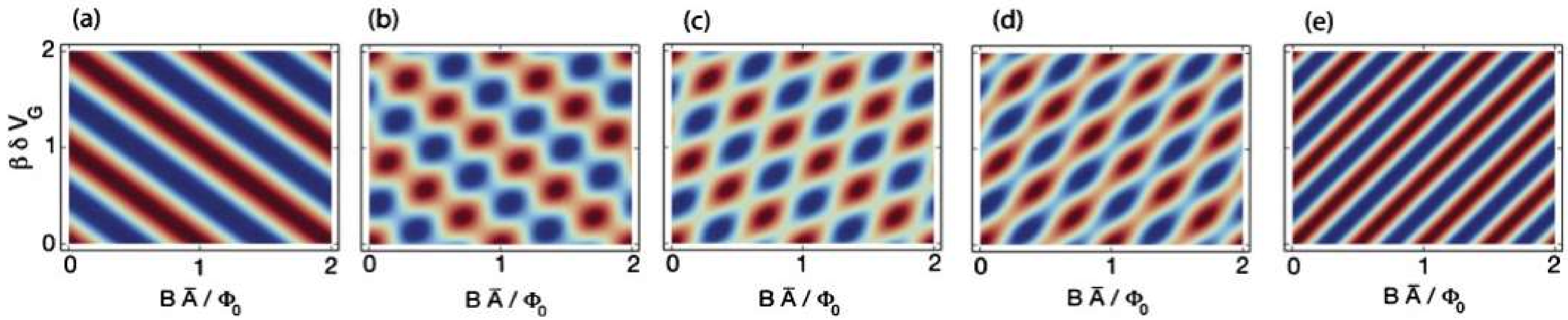
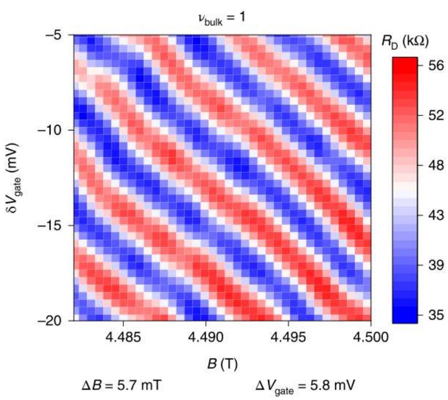
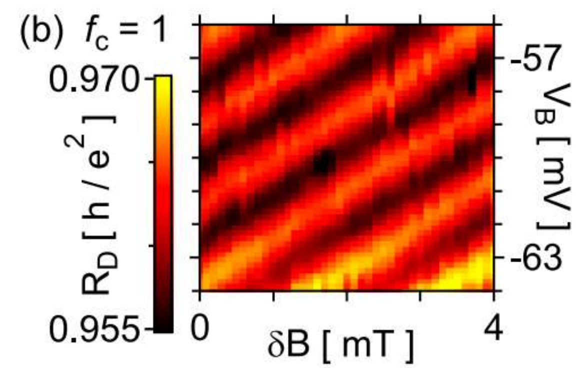
Interferometry regime



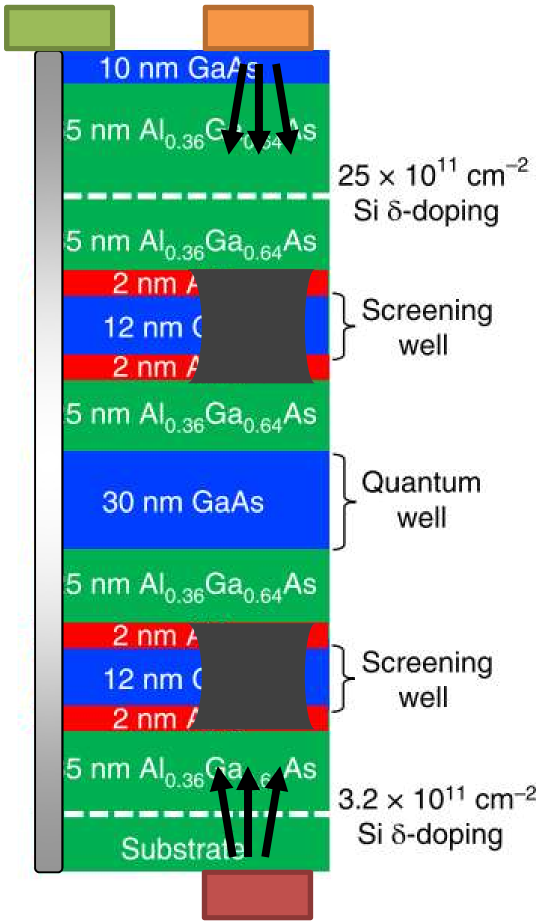
Aharonov-Bohm **Coulomb Dominated**





Halperin, B. et al. Phys. Rev. B 83, 155440 (2011).
McClure, D. T. et al. Phys. Rev. Lett. 108, 256804 (2012).

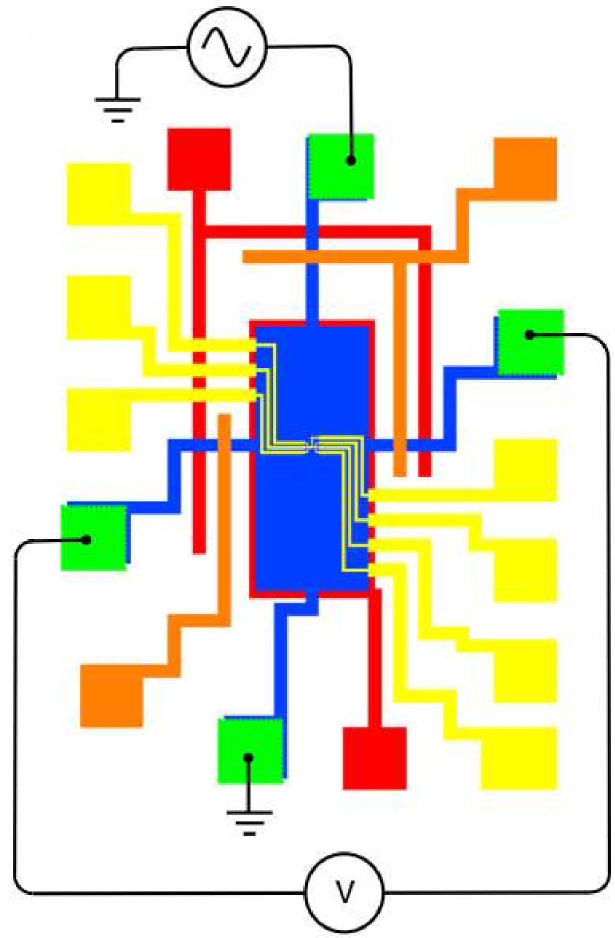
Device



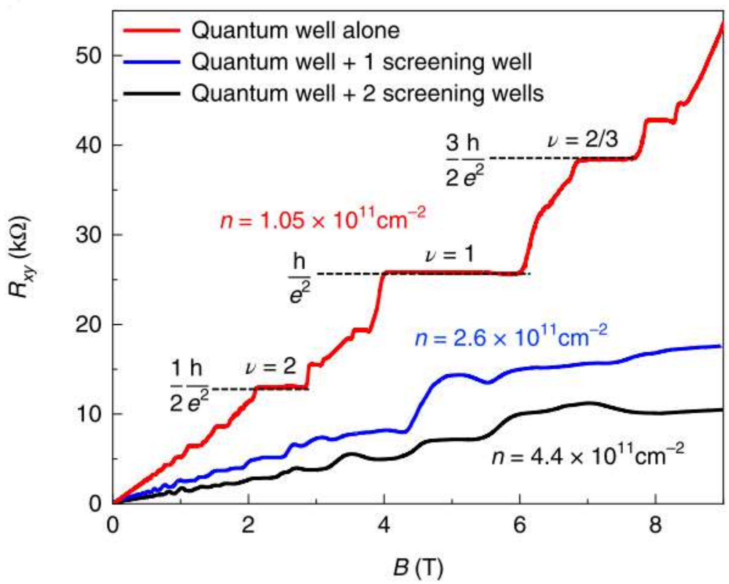
Ohmic contacts (green)

Top gates (orange)

Back gates (red)



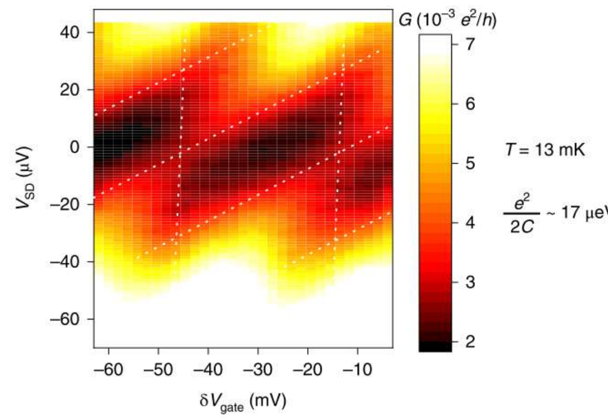
Device properties



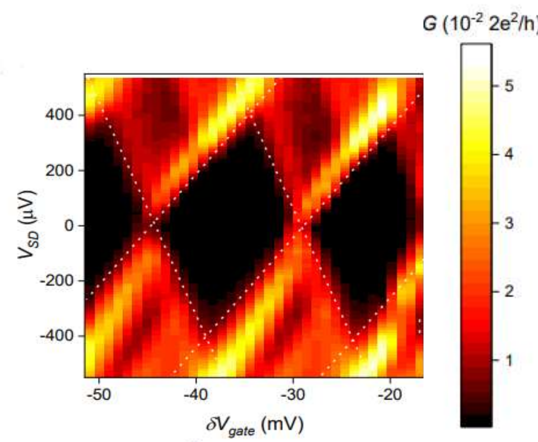
13 mK

300 mK

With screening wells



Without screening wells

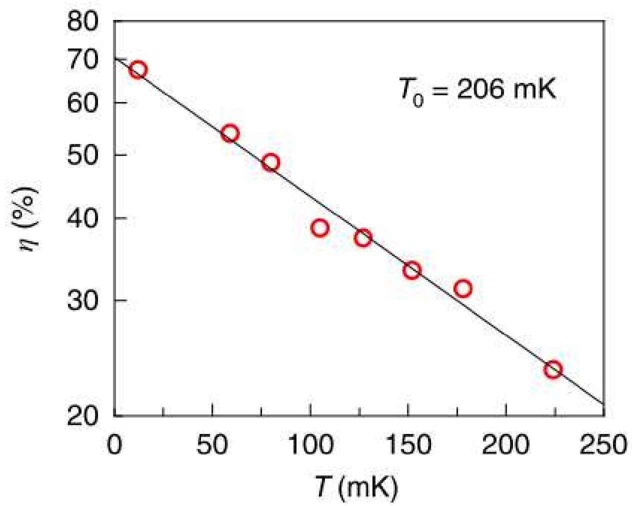


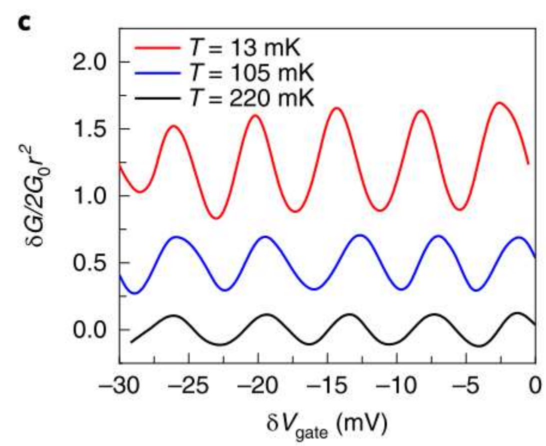
$\frac{e^2}{2C} \sim 200\ \mu V$

Device properties

coherence factor η

- Amplitude of normalized ν=1 oscillations





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Comparison

	Nakamura (2019)	Meclure (2009)	Meclure (2012)	Willet (2013)	Roulleau (2008)	
Area (μm^2)	0.7	17	2	0.1-0.6		
E_C (μeV)	17	-	(25)	-		
T_0(mK)	206	-	32	-	40	
Mobility (10^6 cm^2 /sV)	7	20	20	28		
Density (10^{11} cm^{-2})	1.05	2.7	1.7	2.4/4.2		
Regime	AB	AB	CD	AB/CD		
				Depending on illumination	Mach-Zender	

AB = Aharonov-Bohm
CD = Coulomb dominated

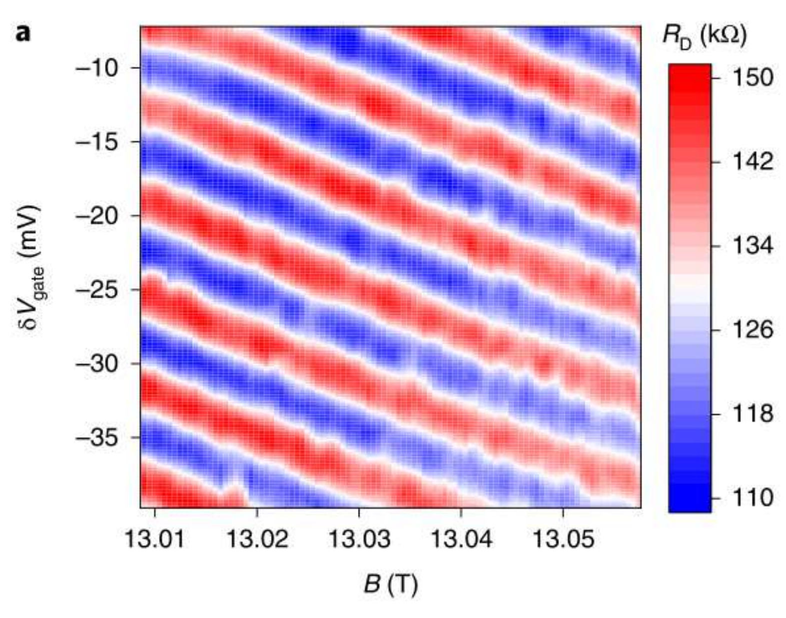
Fractional edge state interferometry

Modified AB-Phase $$\theta = 2\pi \frac{e^*}{e} \frac{A_I B}{\Phi_0}$$

e* fractional charge

- AB – interference of fractionally charged particles is observed
- No fractional braiding statistics
  - no expected phase jump $\Delta\theta_{anyon} = 4\pi/3$

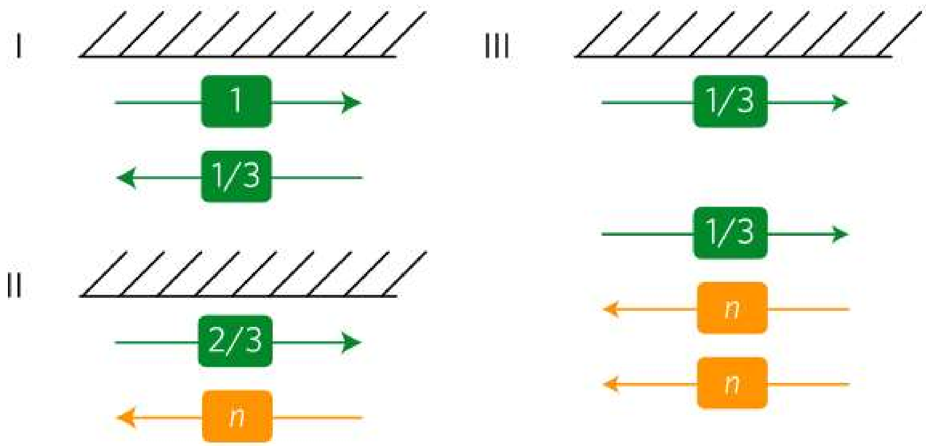
AB - interference of ν=1/3 edge states



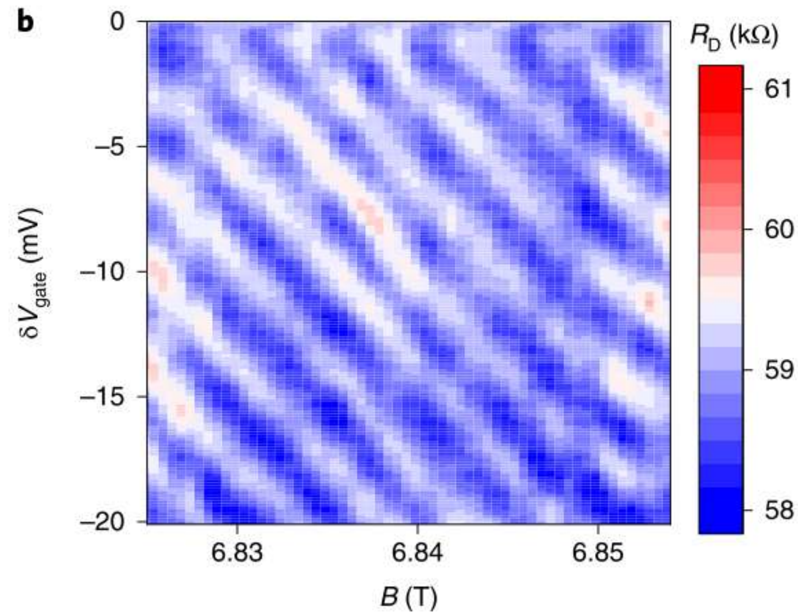
Charge fraction e*/ e = 0.29

Fractional edge state interferometry

Possible realizations of ν=2/3 edge states



AB – interference of ν=2/3 edge states



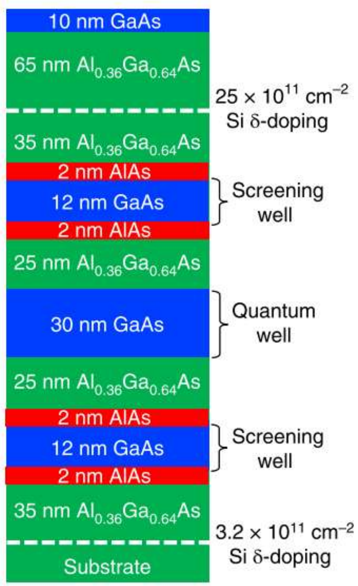
Measured charge fraction e*/ e = 0.93

Possible evidence towards I (MacDonald edge structure)

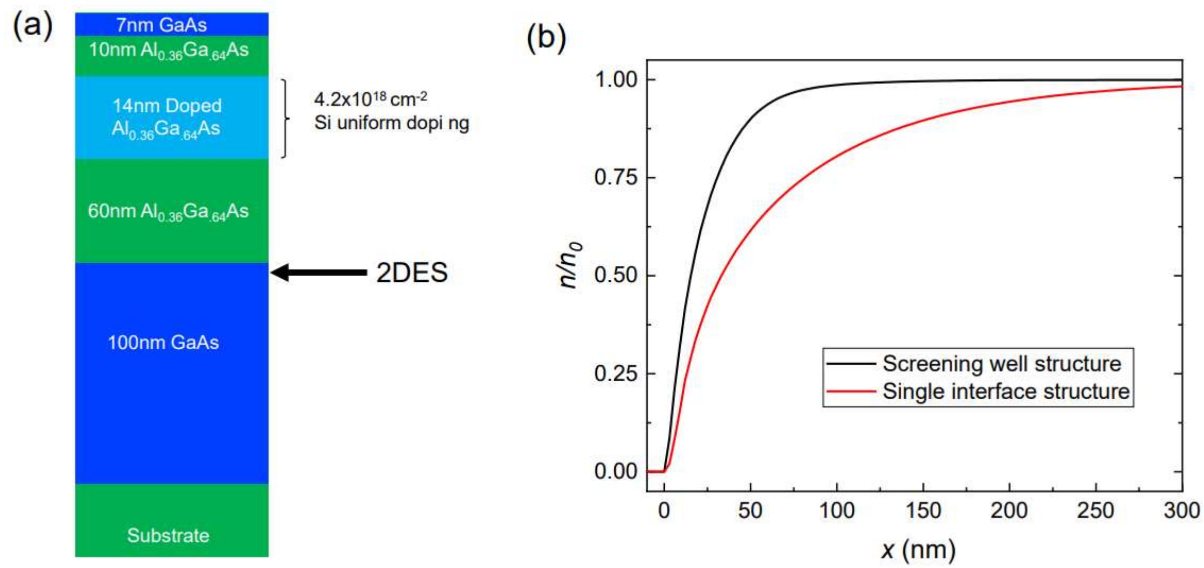
Sabo R., Gurman I., *Edge reconstruction in fractional quantum Hall states.* Nature Physics volume13, pages491–496 (2017)

Fractional edge state interferometry

Steeper confinement potential may favor MacDonald structure



With screening wells



Without screening wells

Meir, Y. *Composite edge states in the ν = 2/3 fractional quantum Hall regime.* Phys. Rev. Lett. 72, 2624–2627 (1993).

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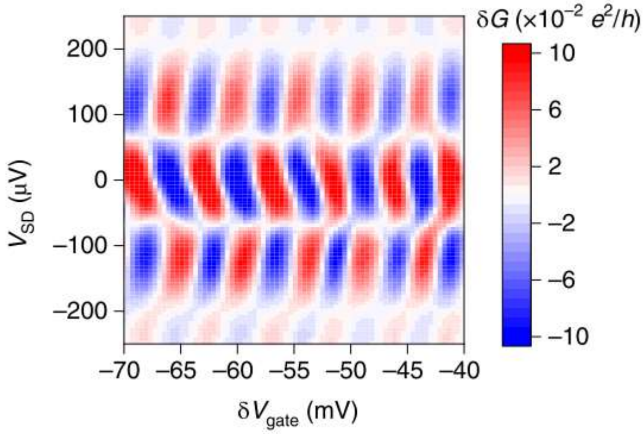
Edge state velocities

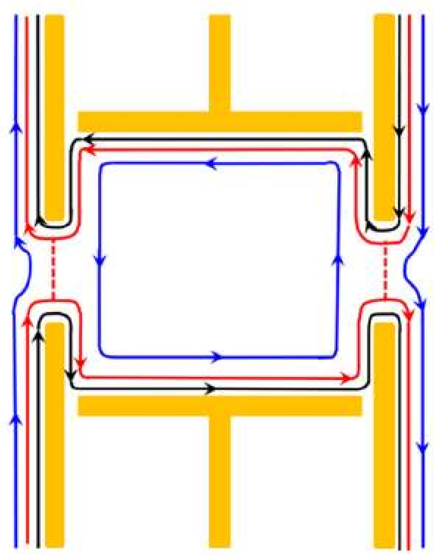
c

ν=1

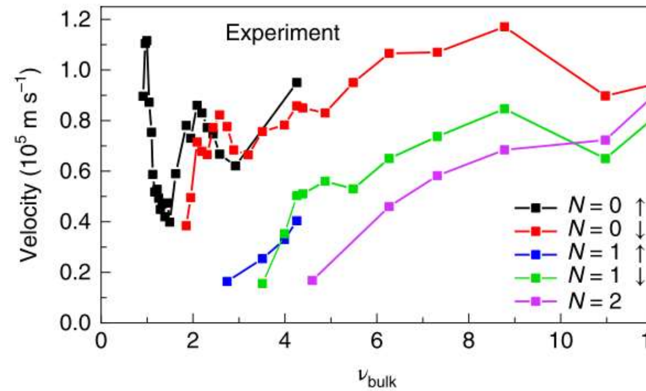


$$\delta G \propto \cos\left(2\pi \frac{AB}{\Phi_0}\right) \cos\left(\frac{eV_{SD}L}{2\hbar v_{edge}}\right)$$

$$v_{edge} = \frac{eL\Delta V_{SD}}{2\pi\hbar}$$



Completely backscattered
Partially backscattered (interference)
Completely transmitted



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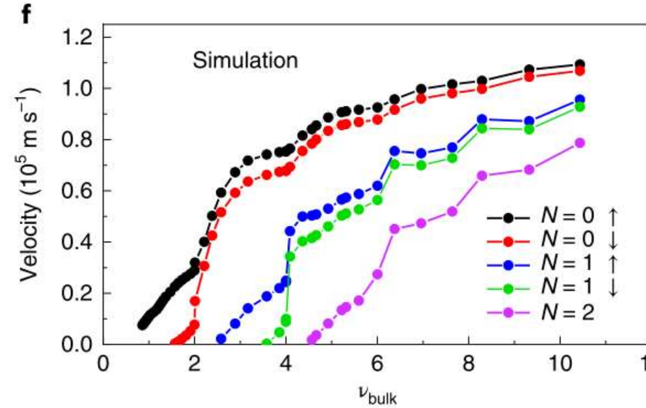

Summary

- Screening wells allow for AB - interferometry by screening coulomb interaction (despite lower density)
- Confirmation of fractional charge of $\nu=1/3$
- Hints of $\nu=2/3$ edge state structure where found
- Integer edge state velocities where investigated

Thank you

for your attention.