Group meeting

Henok Weldeyesus
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Direct observation of anyonic braiding statistics at the ν=1/3 fractional quantum Hall state

J. Nakamura,[1,2] S. Liang,[1,2] G. C. Gardner,[2,3] and M. J. Manfra[1,2,4,3,5,*]

[1] *Department of Physics and Astronomy, Purdue University*
[2] *Birck Nanotechnology Center, Purdue University*
[3] *Microsoft Quantum Purdue, Purdue University*
[4] *School of Electrical and Computer Engineering, Purdue University*
[5] *School of Materials Engineering, Purdue University*
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Utilizing an electronic Fabry-Perot interferometer in which Coulomb charging effects are suppressed, we report experimental observation of anyonic braiding statistics for the $\nu = 1/3$ fractional quantum Hall state. Strong Aharonov-Bohm interference of the $\nu = 1/3$ edge mode is punctuated by discrete phase slips consistent with an anyonic phase of $\theta_{anyon} = \frac{2\pi}{3}$. Our results are consistent with a recent theory of a Fabry-Perot interferometer operated in a regime in which device charging energy is small compared to the energy of formation of charged quasiparticles [17]. Close correspondence between device operation and theoretical predictions substantiates our claim of observation of anyonic braiding.

Overview

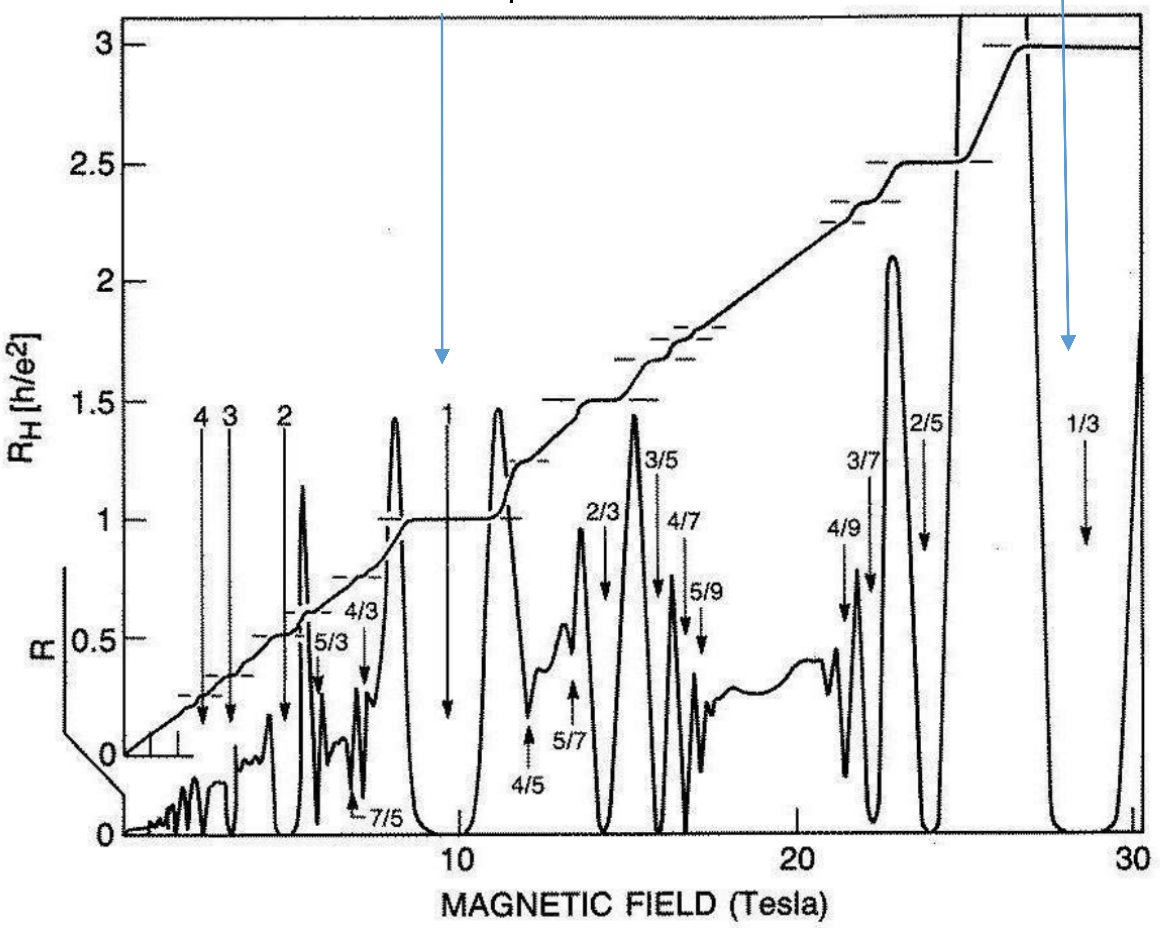
- Introduction
- Anyonic braiding statistics
- Fabry-Pero Interferometry
  - Problems
  - Device Design
  - Signatures of Anyon statistics
- Summary

Introduction

- Electrons in2D + perpendicular B-field
  - Quantum-Hall effect
- Filling factor $\nu = \frac{N_e}{N_\phi}$

  N_e number of electron
  $N_\phi$number of fluxquanta
- Integer states:
  - Described by non-interacting electrons
- Fractional states:
  - Strongly interacting electrons
    - Description in terms of quasiparticles with exotic properties (fractional charge, anionic statistics, etc.)

$N_e = N_\phi$ $3N_e = N_\phi$



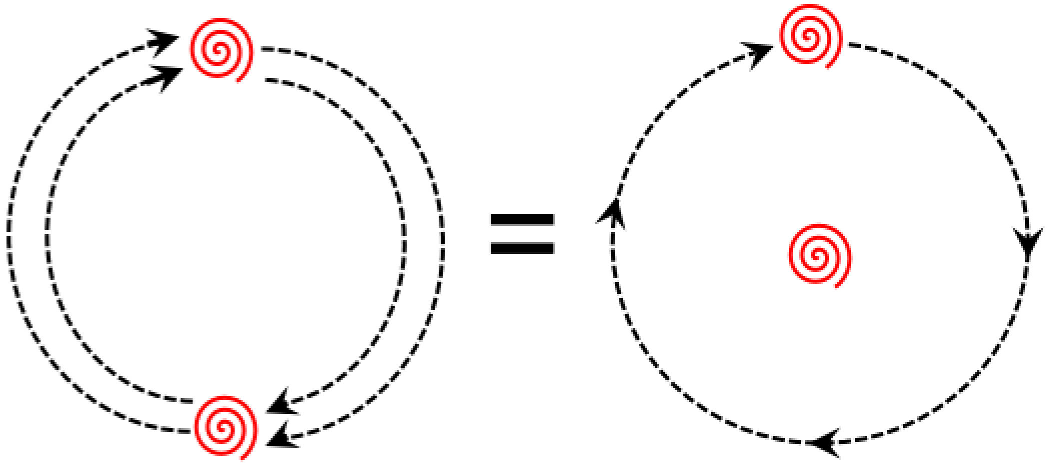
Anyon braid statistics

- Generally: $\psi(r_1, r_2) = e^{i\theta}\psi(r_2, r_1)$
- Two options in 3D:
  - Bosons ($\theta = 2\pi$) Or Fermions ($\theta = \pi$)
- In 2D:
  - Anyons: $0 < \theta < \pi$

Example:
Braiding Laughlin states in FQHE

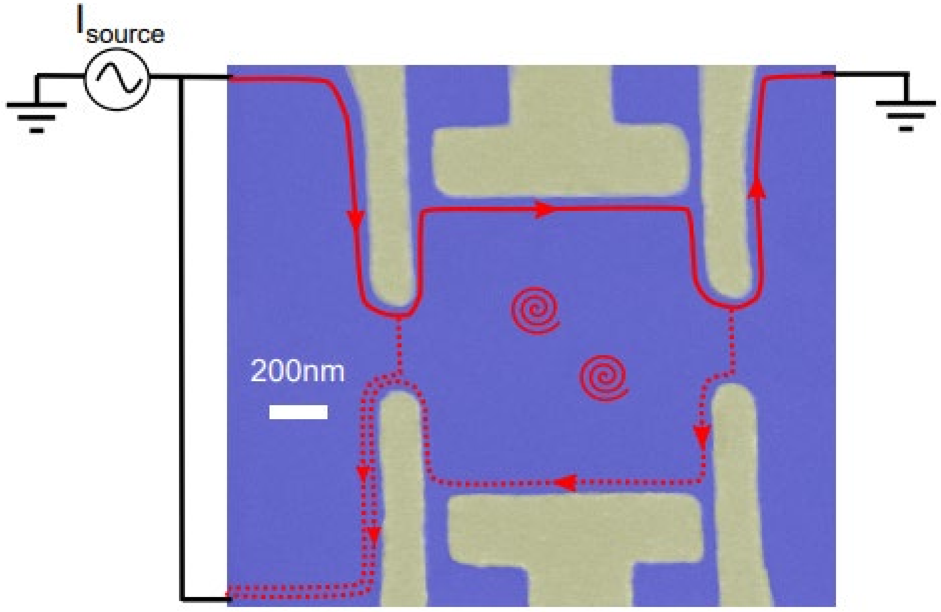
$\nu = \frac{1}{2p+1}$ for p = 1,2,3...

For $\nu = \frac{1}{3}$ the phase is $\theta = \frac{2\pi}{3}$



Fabry-Perot Interferometer

- Qpc's at ~ 90% transmission
- Interference of backscattered channels
- $T \sim \cos\left(2\pi \frac{AB}{\phi_0}\right) \quad ; \phi_0 = \frac{h}{e}$



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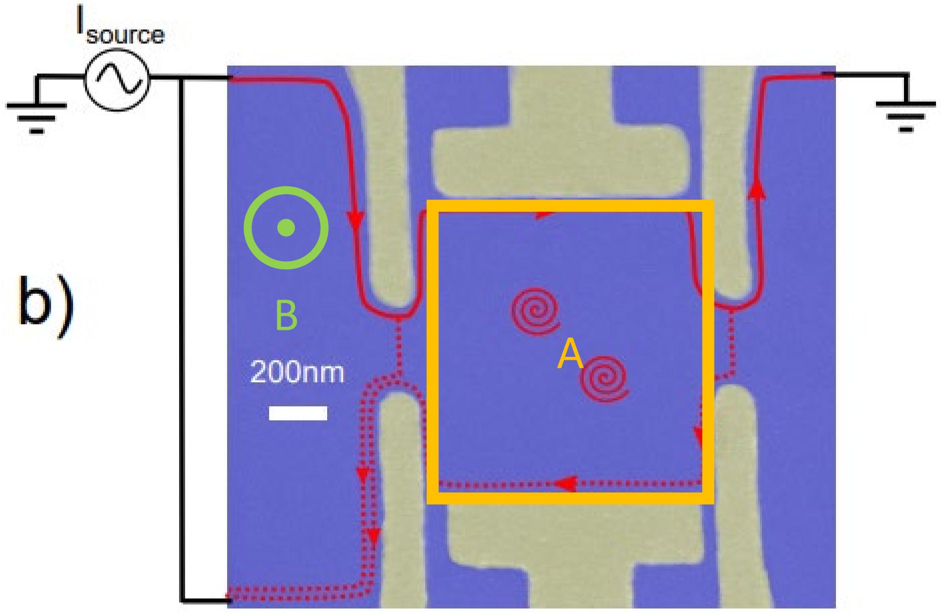
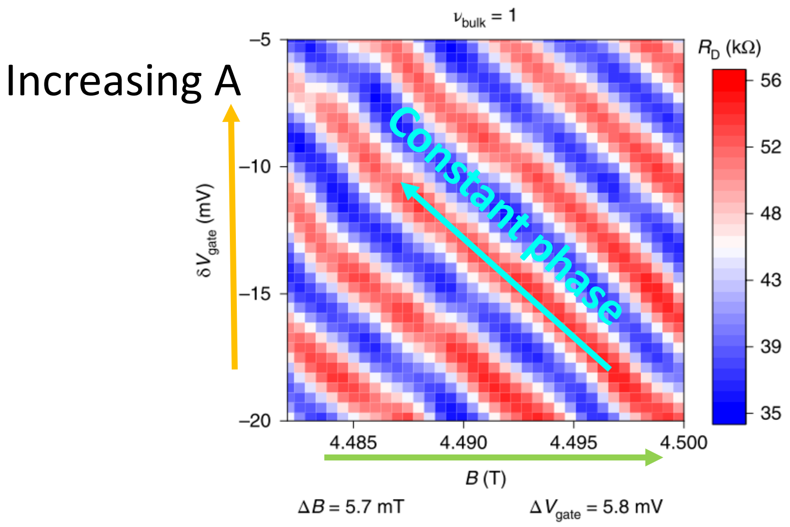
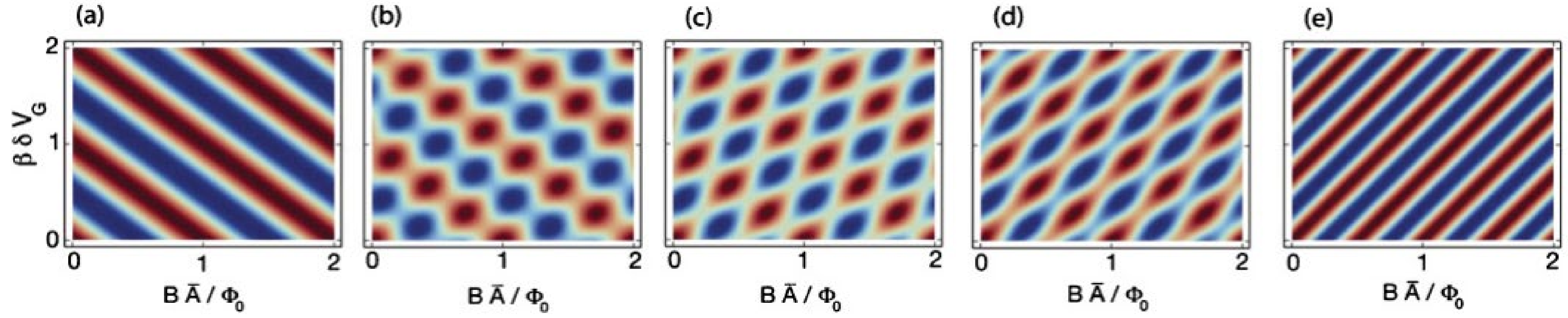




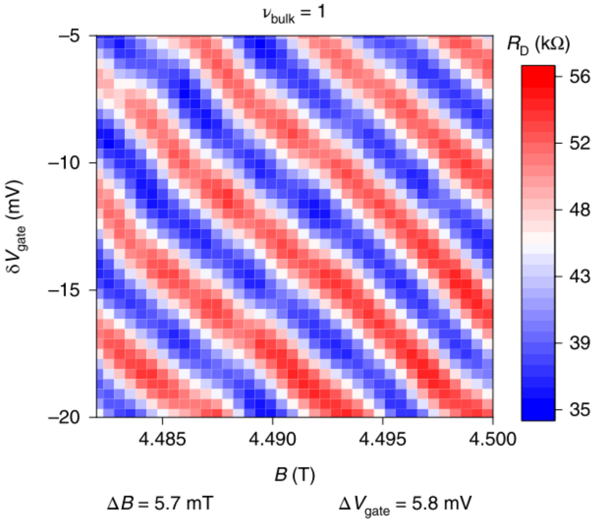
Nakamura, J. et al. Nat. Phys (2019)

The charging problem

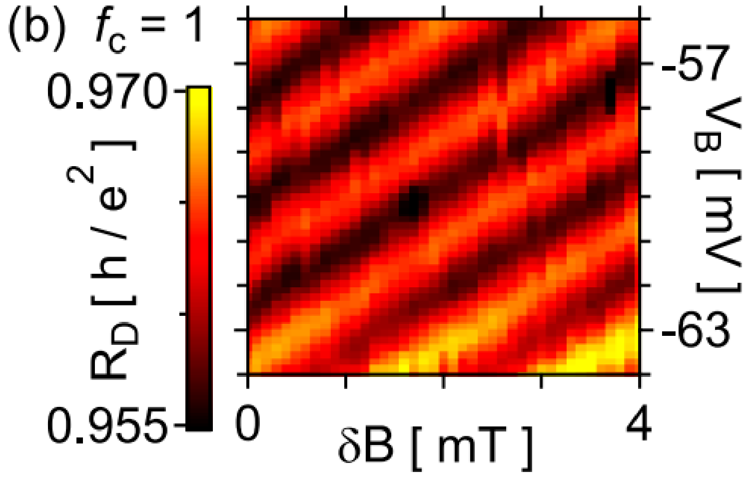


Aharonov-Bohm Dominated

Coulomb



Anyon statistics only observable in AB-regime!



Halperin, B. et al. Phys. Rev. B 83, 155440 (2011).
McClure, D. T. et al. Phys. Rev. Lett. 108, 256804 (2012).
Nakamura, J. et al. Nat. Phys (2019)

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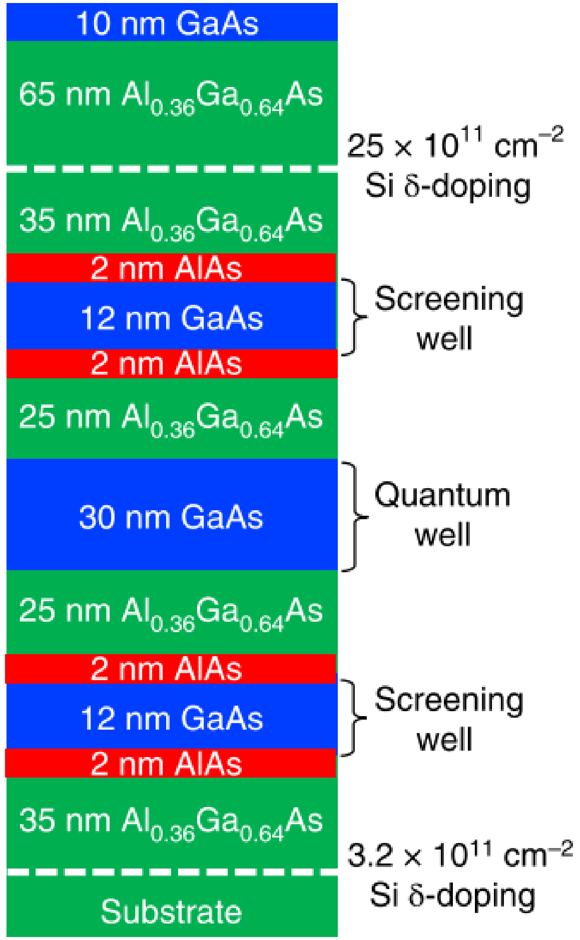
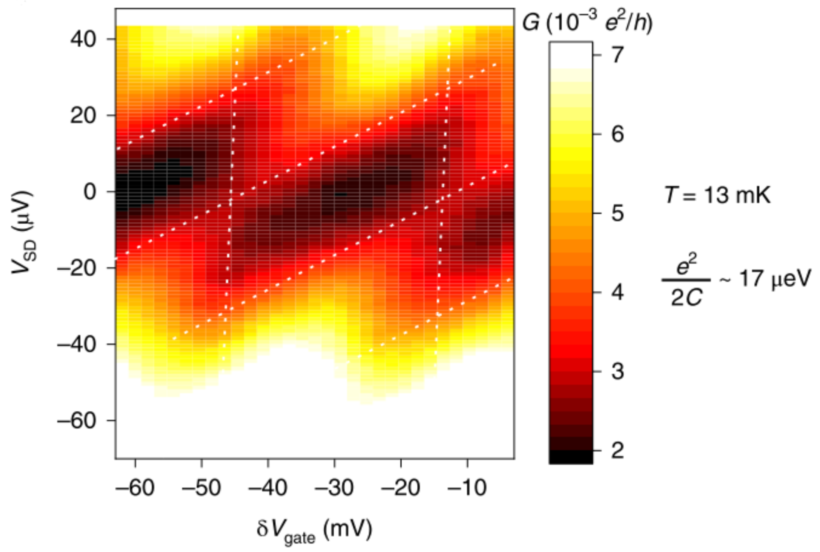
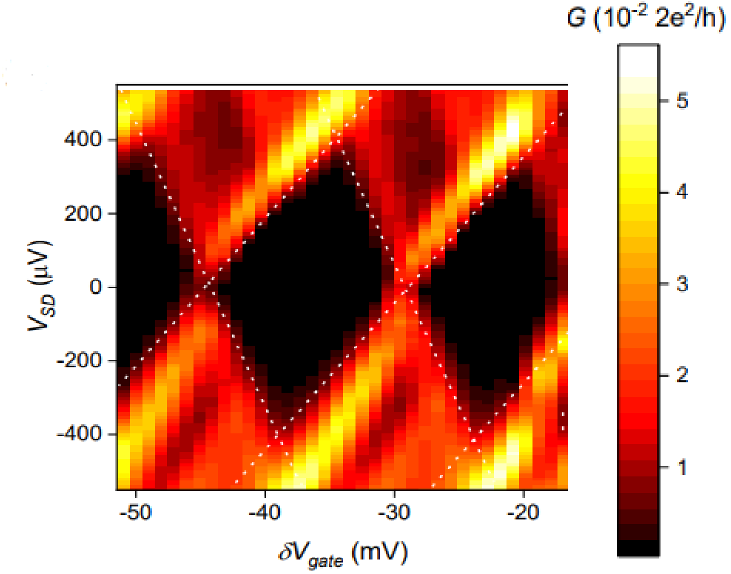


Growth profile

With screening wells



Without screening wells



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

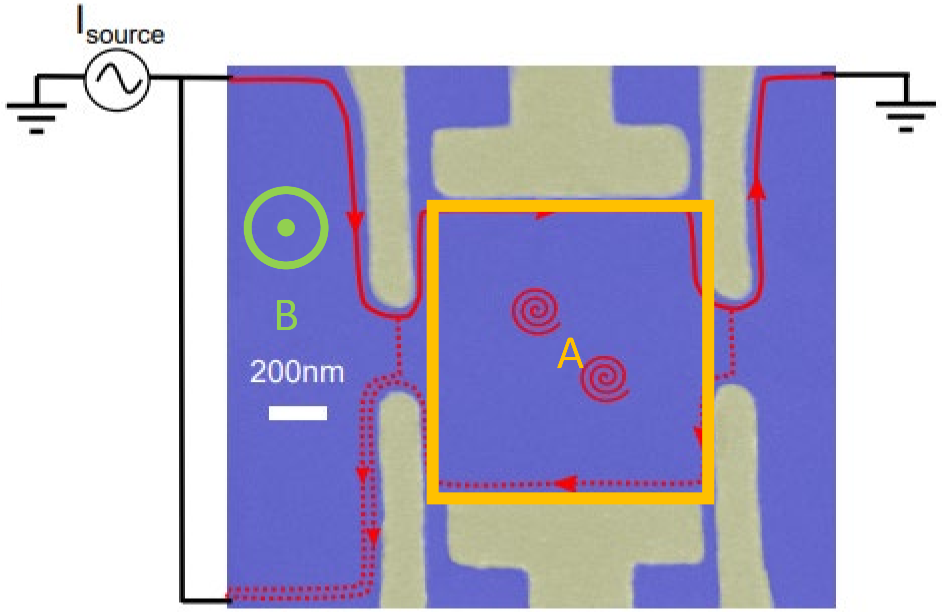
Nakamura, J. et al. Nat. Phys (2019)

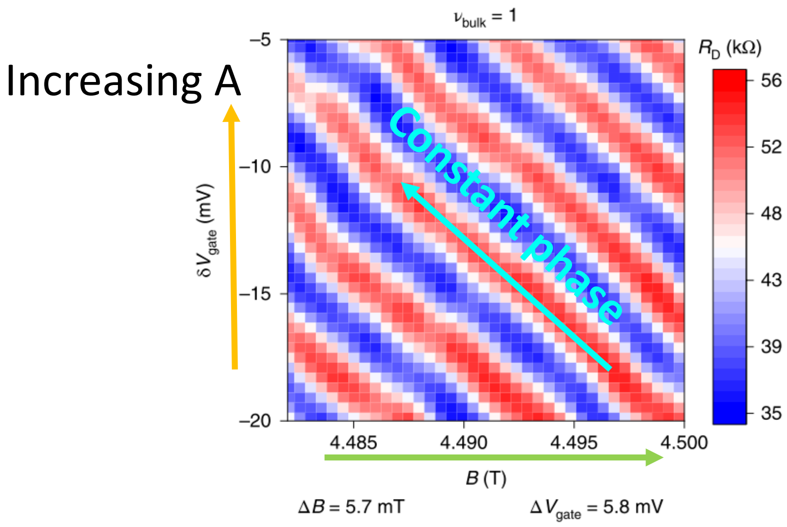
Fabry-Perot Interferometer (for Anyons)

- $T \sim \cos\left(2\pi \frac{e^*}{e} \frac{AB}{\phi_0} + N_{qp}\theta_{anyon}\right)$

Fractional charge!

Braiding around N anyons (discrete changes)



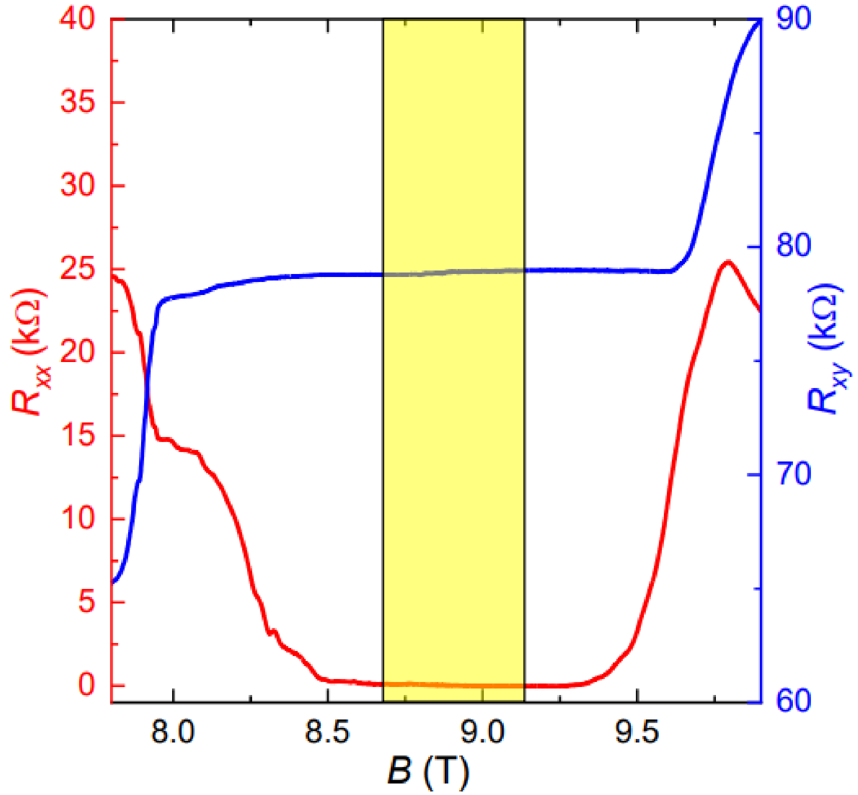


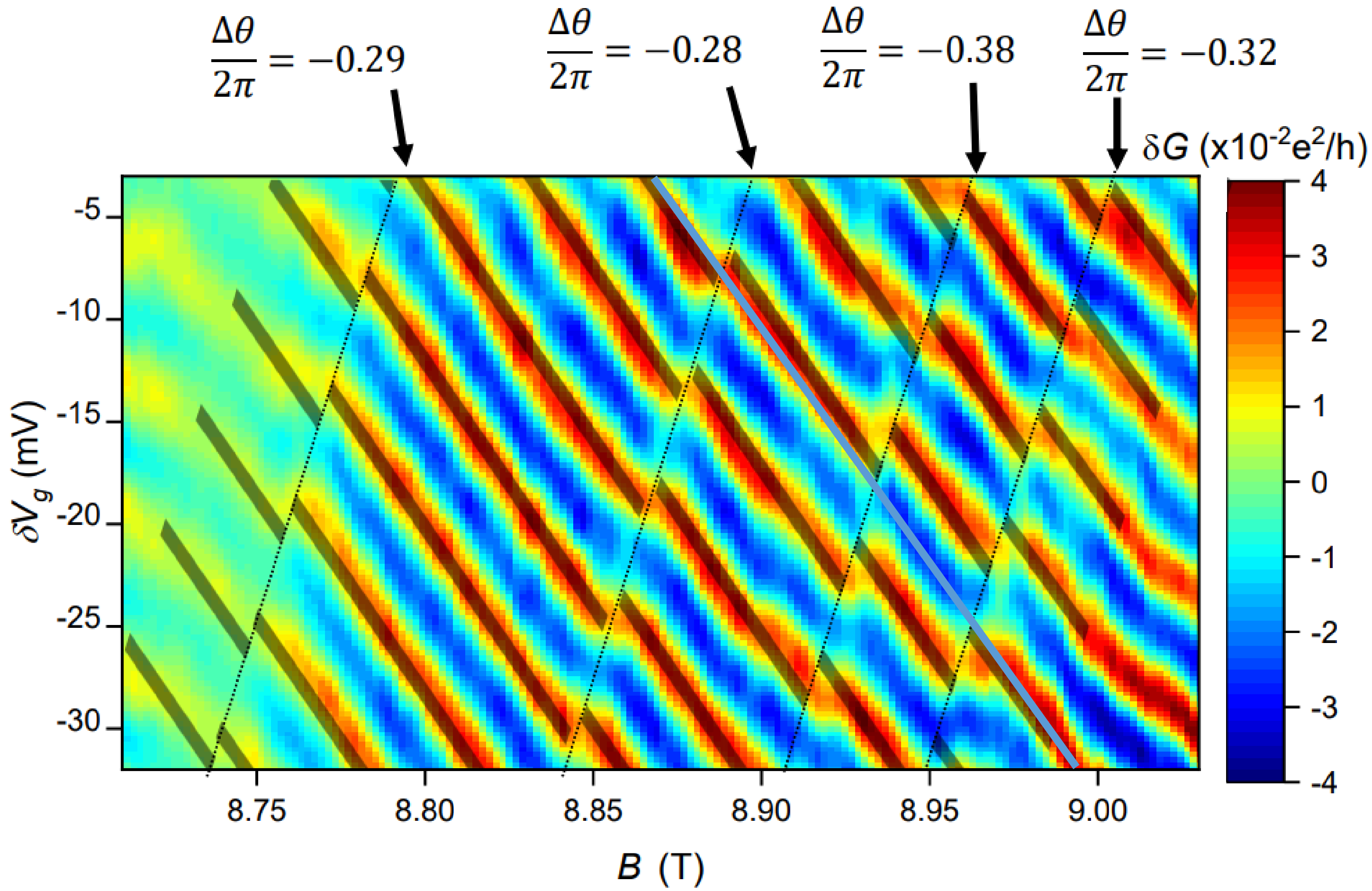
$$\theta_{anyon} = 2\pi \frac{1}{2p+1} \qquad p = 1 \text{ for } \nu = \frac{1}{3}$$

$\frac{2}{3}\pi$ phase jump for change in quasiparticle number

Anyon signature

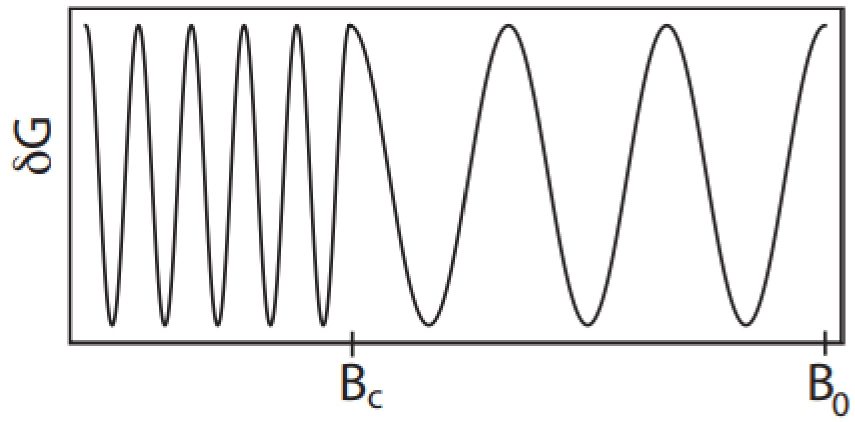
Bulk Hall-trace





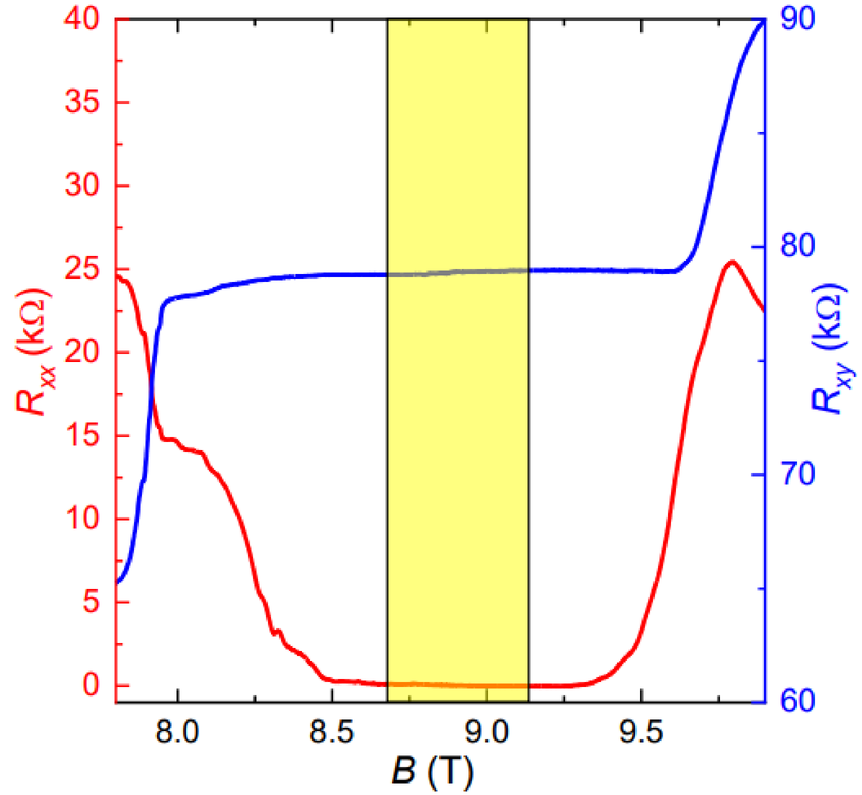
Further evidence

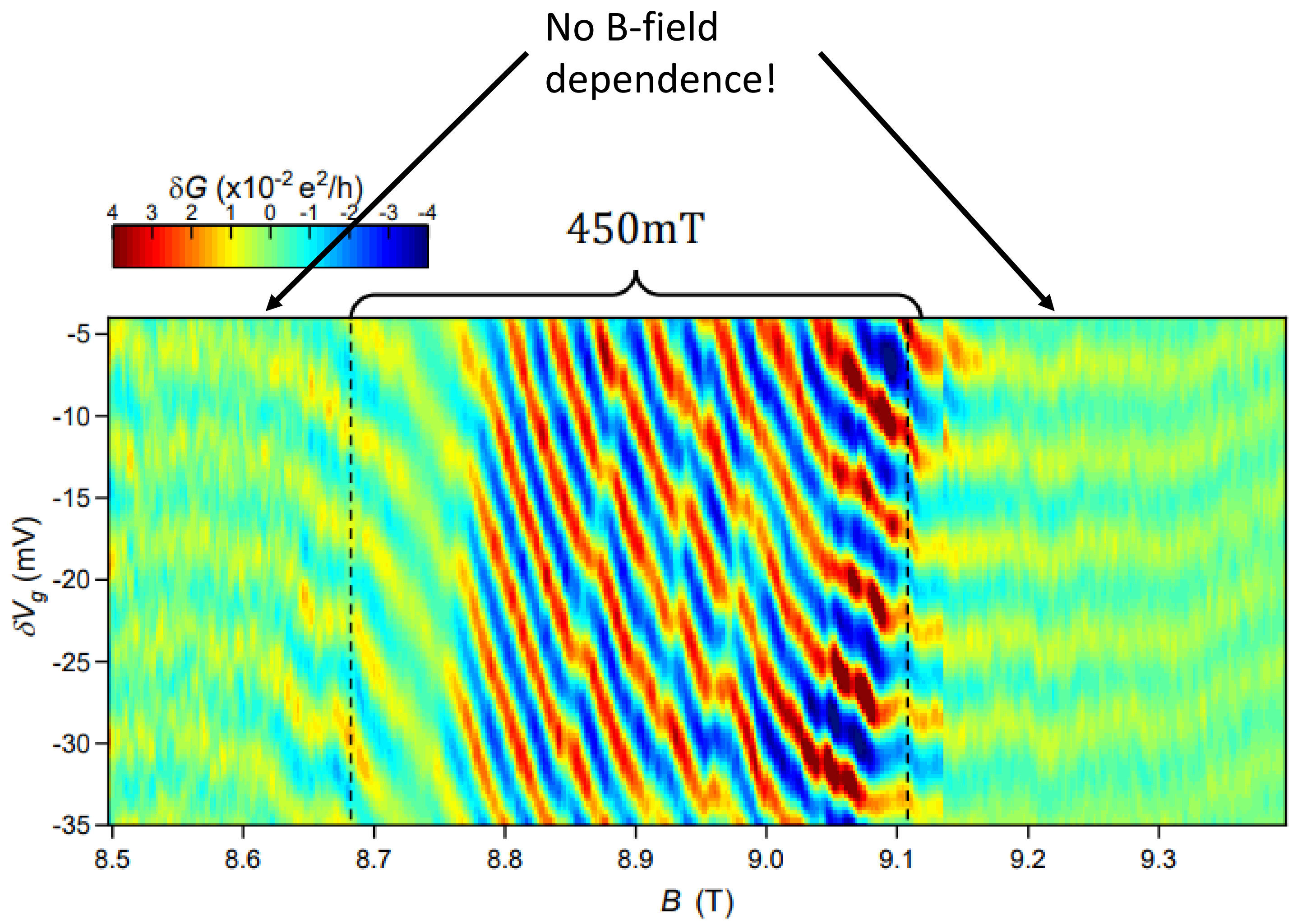
- FQH states have Quasiparticle gap for exitations
- Rosenow & Stern *Flux Superperiods and Periodicity Transitions in Quantum Hall Interferometers*. PRL (2020)
  - FP interferometer with strong screening
  - If Quasiparticle gap is bigger than Charging energy
    -> two interference regimes
  - Period trippling expected outside the gap



Anyon signature

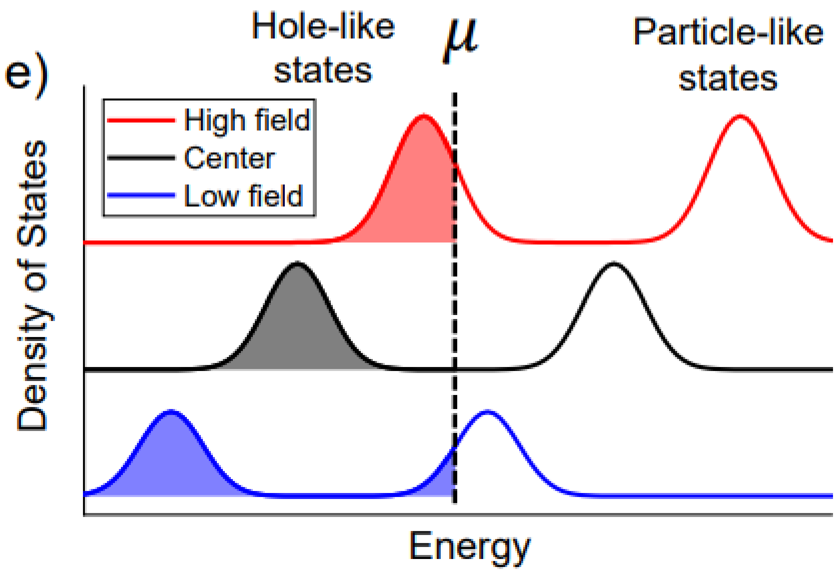
Bulk Hall-trace



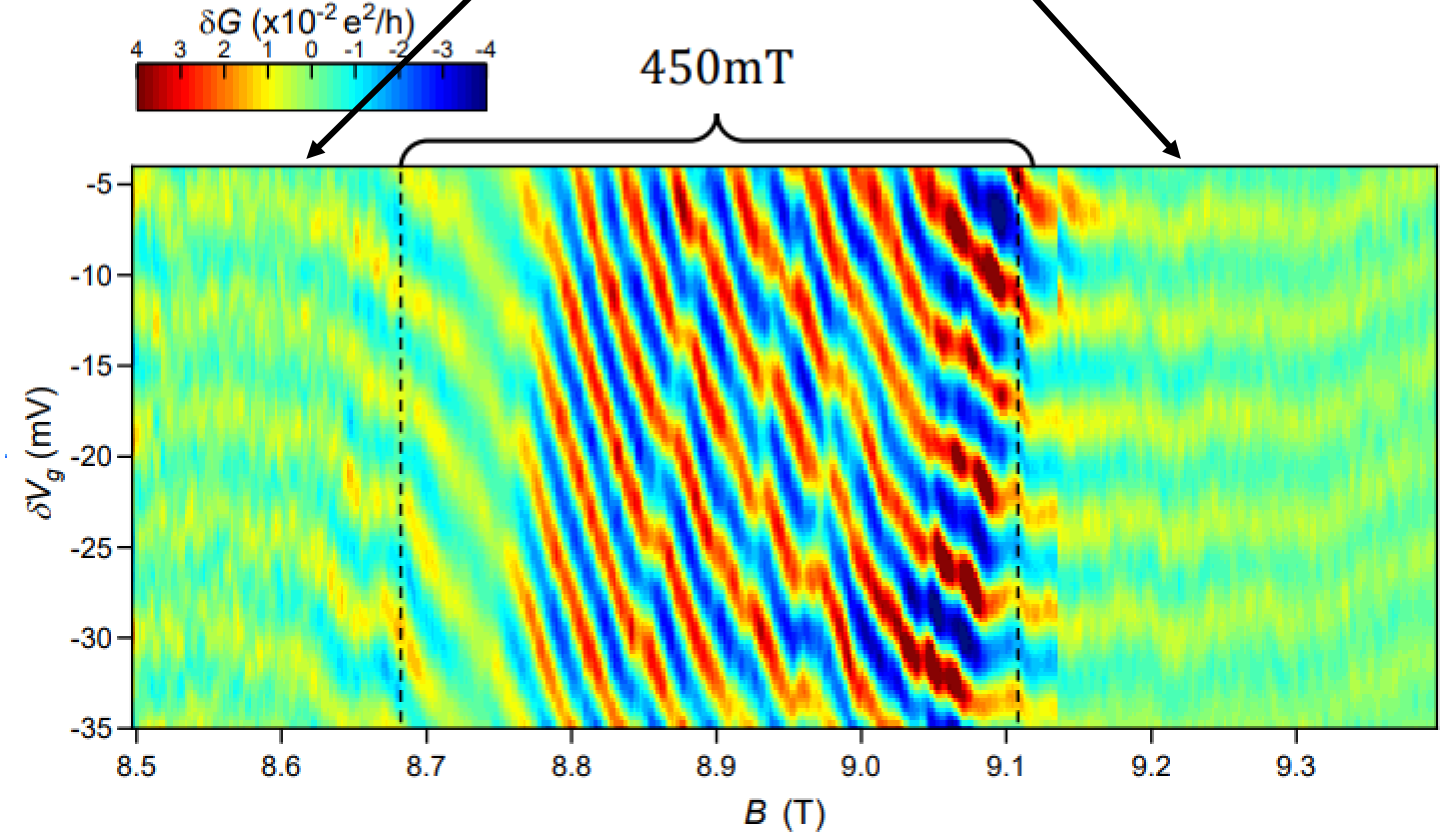


Anyon signature

Quasiparticle density of states

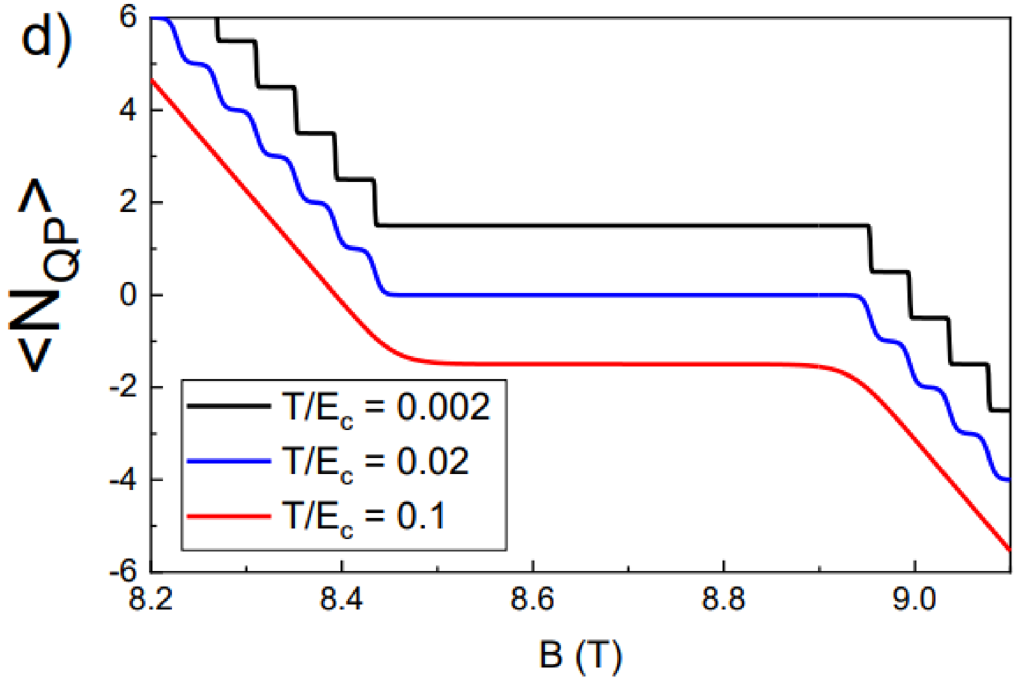


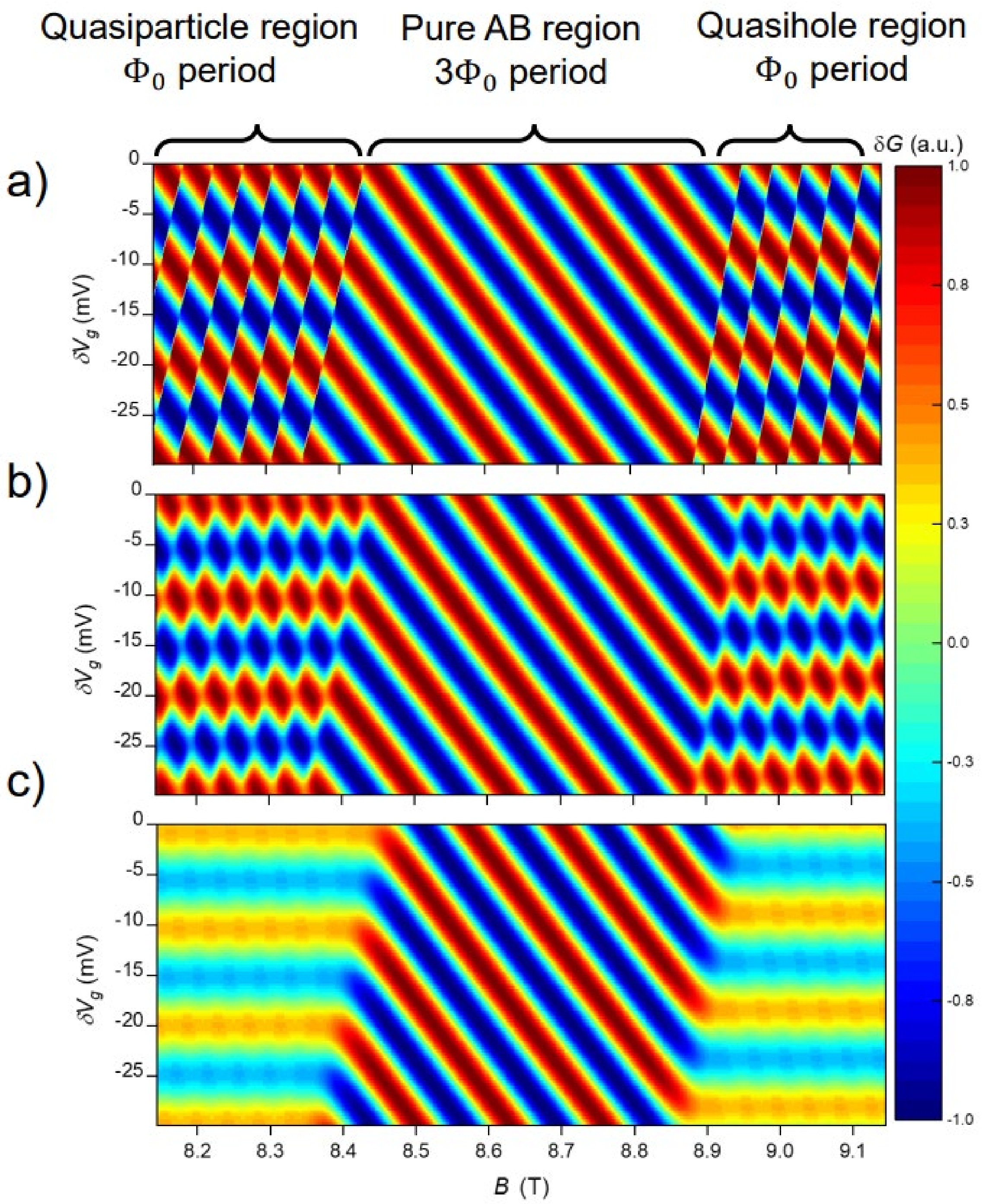
No B-field dependence!



Anyon signature

- Thermal smearing of quasiparticle number
- Temperature scale ~4mK (T_e ≈22mK)





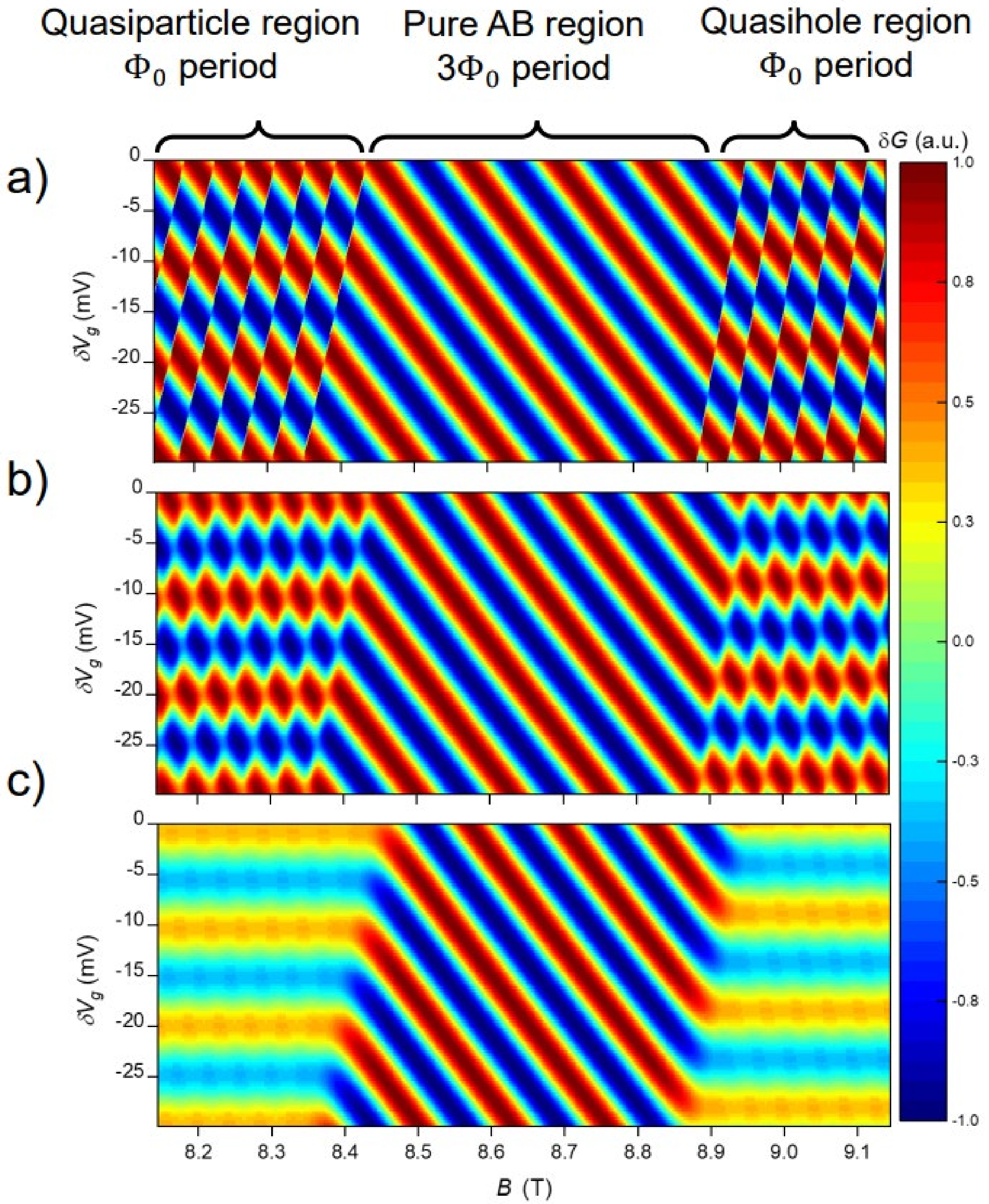
Anyon signatures

- $T \sim \cos\left(2\pi \frac{e^*}{e} \frac{AB}{\phi_0} + N_{qp}\theta_{anyon}\right)$
- At high T N_{qp} is continues

  $T \sim \cos\left(2\pi \frac{1}{3} \frac{AB}{\phi_0} + \frac{2\pi}{3}\langle N_{qp}\rangle \quad \right)$
- One particle per ϕ_0

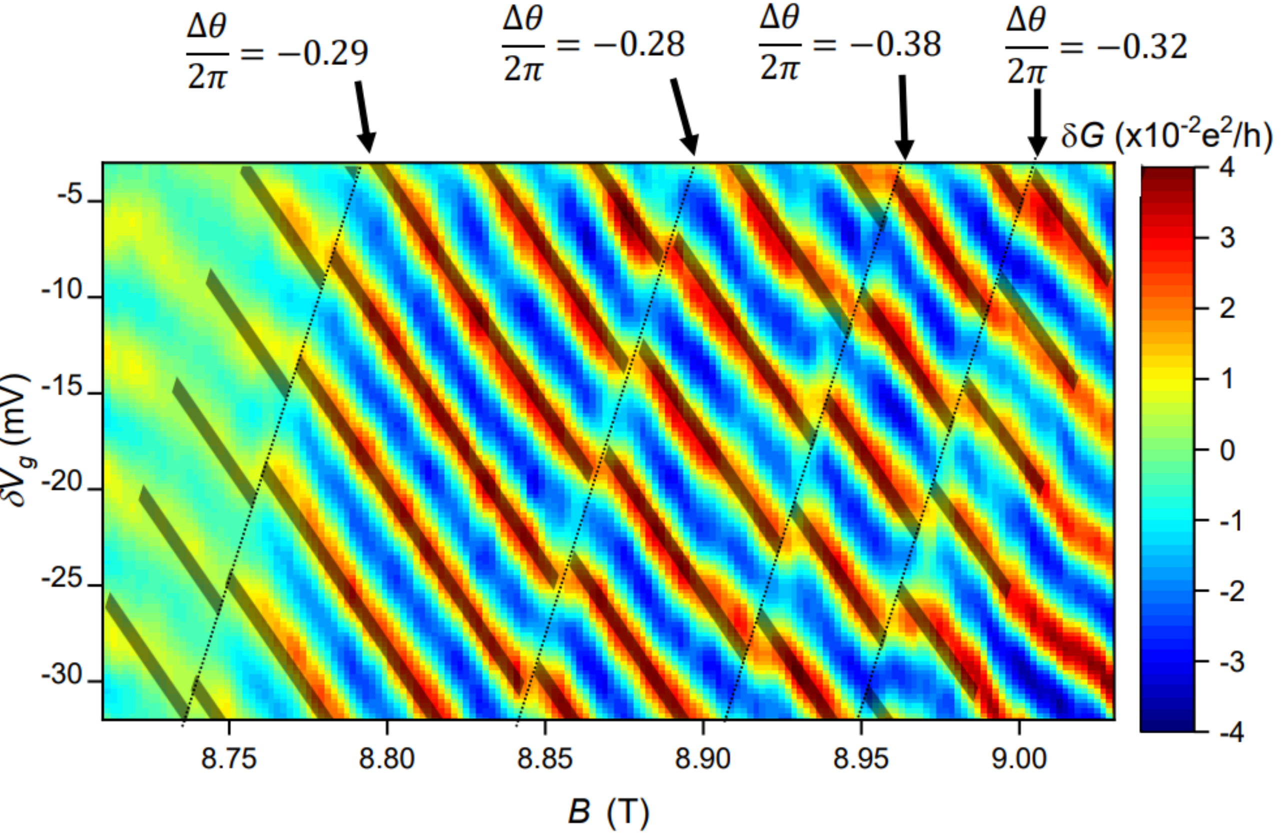
  $T \sim \cos\left(2\pi \frac{1}{3} \frac{AB}{\phi_0} - \frac{2\pi}{3} \frac{AB}{\phi_0}\right)$

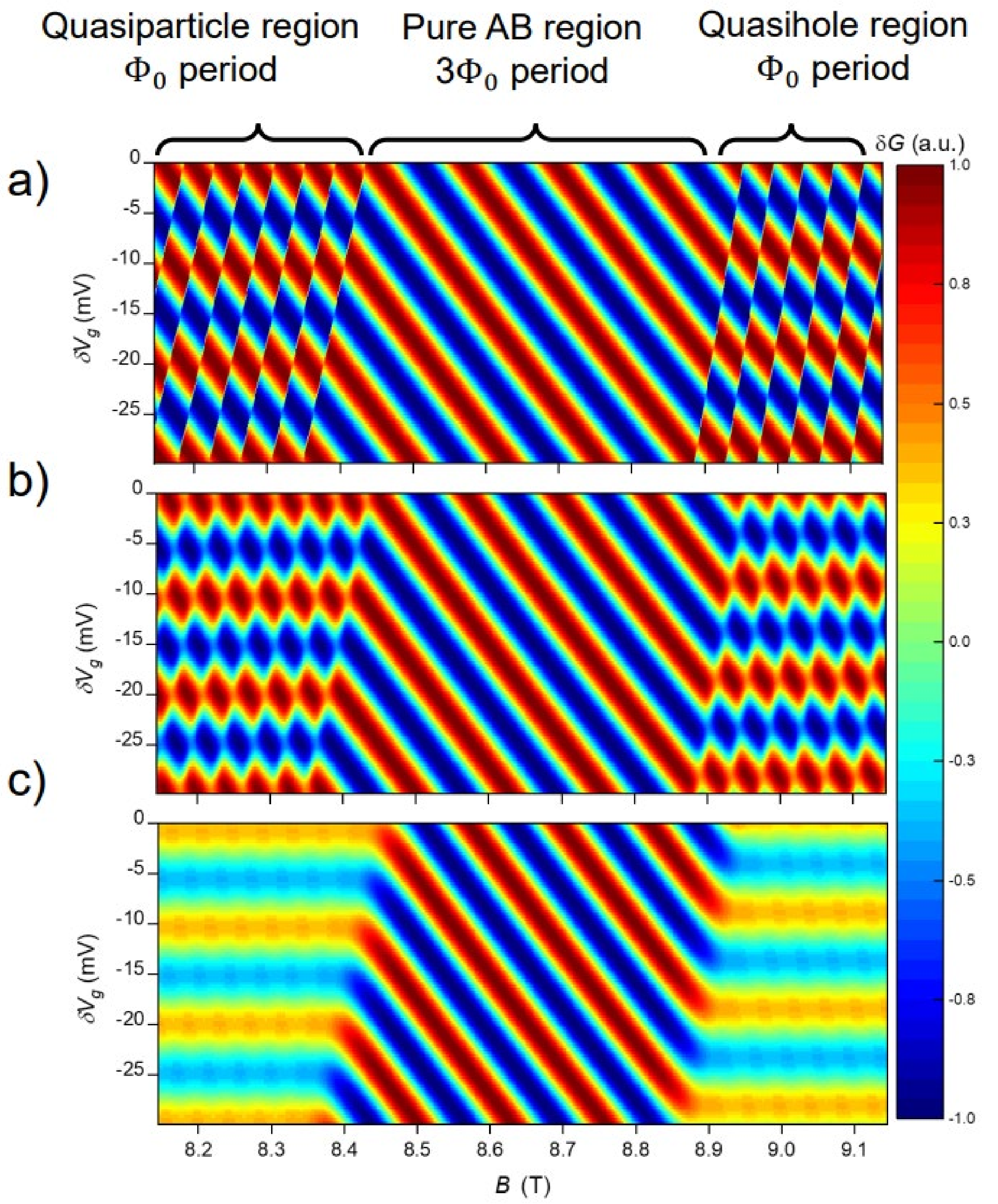
  no B-field dependence!



Anyon signature

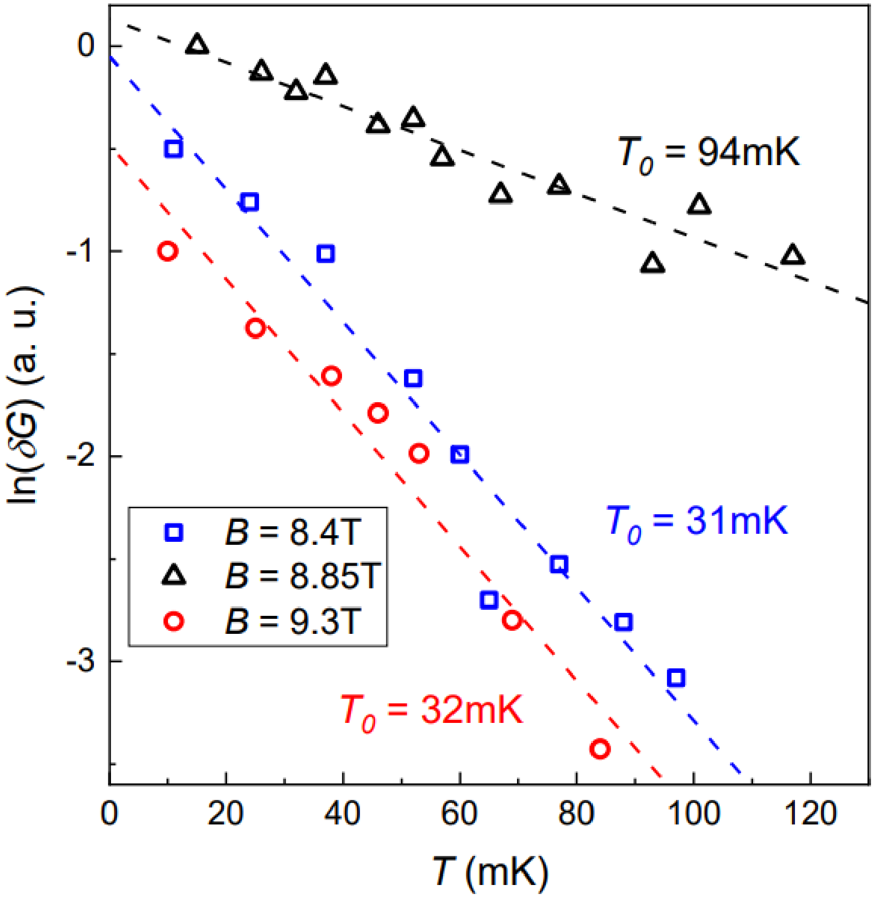
- Why phase jumps in center region?
  - Disorder





Temperature dependence

- Visibility of oscillations reduces slower in plateau center region
- Caused by thermal fluctuation of quasiparticle number



Summary

- Discrete phase jumps consistent with Anyon braiding
- B independent oscillations away from plateau center and thermal dephasing agree well with theory
- Strong evidence for first observation of Anyon braiding

Outlook

- Investigate other fractional states
  - Possibly non-Abelian(e.g. 5/2)