Electron optics experiments in quantum conductors: from single electrons to anyons

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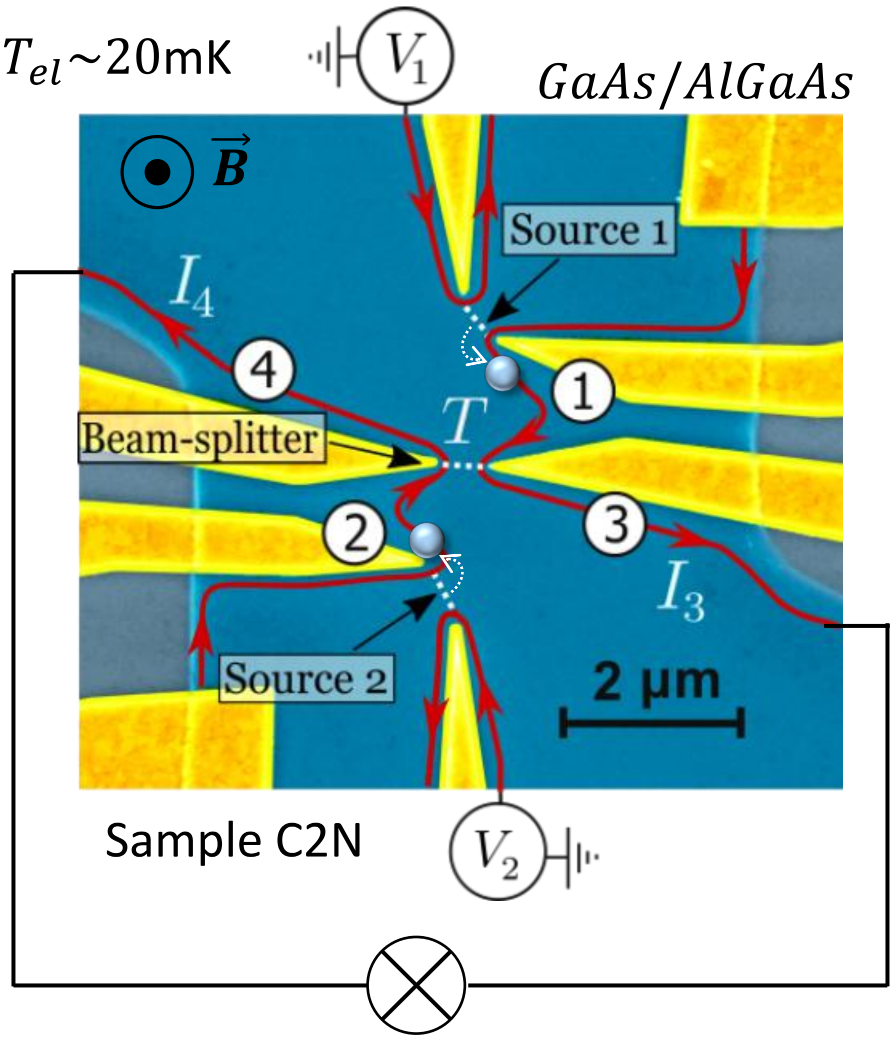
Electron optics experiments in quantum Hall conductors

B~few T

T_{el}~20mK



Sample C2N

Current correlations $\langle \Delta I_3 \Delta I_4 \rangle$

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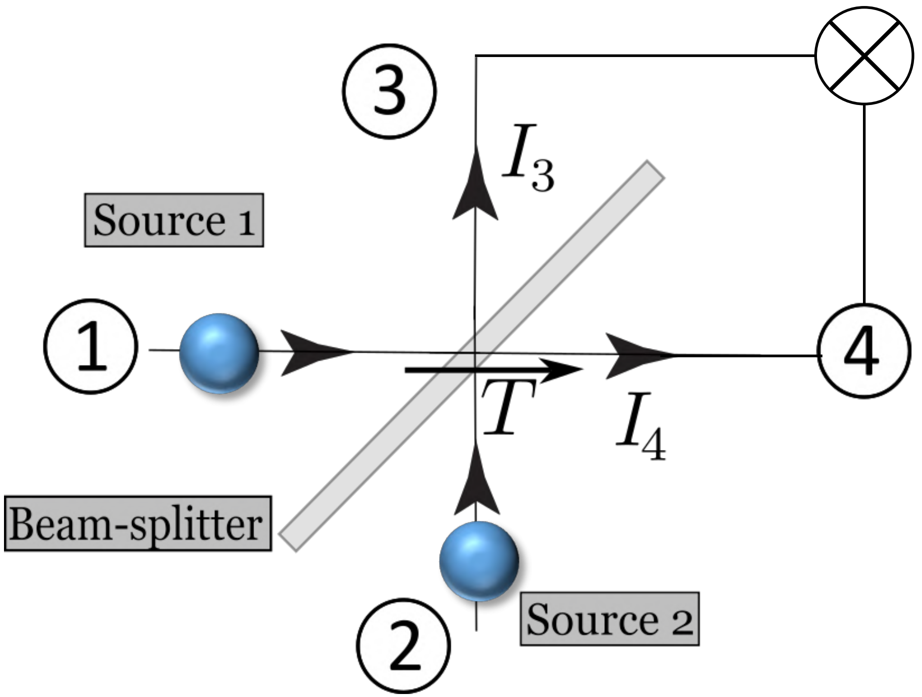
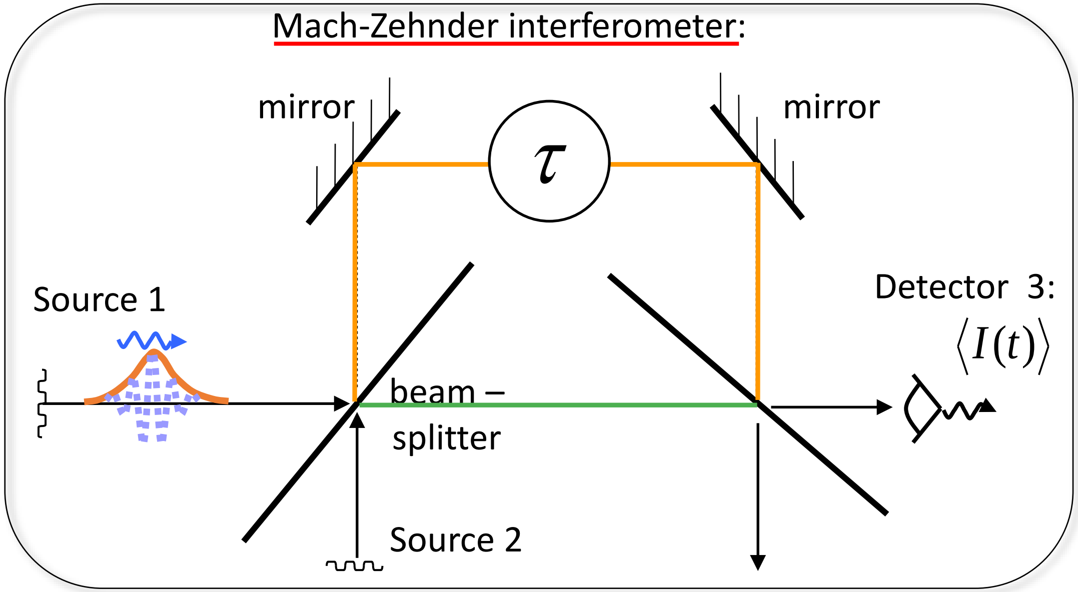


Single-particle vs two-particle interferometry (optics)

Single particle interferometer

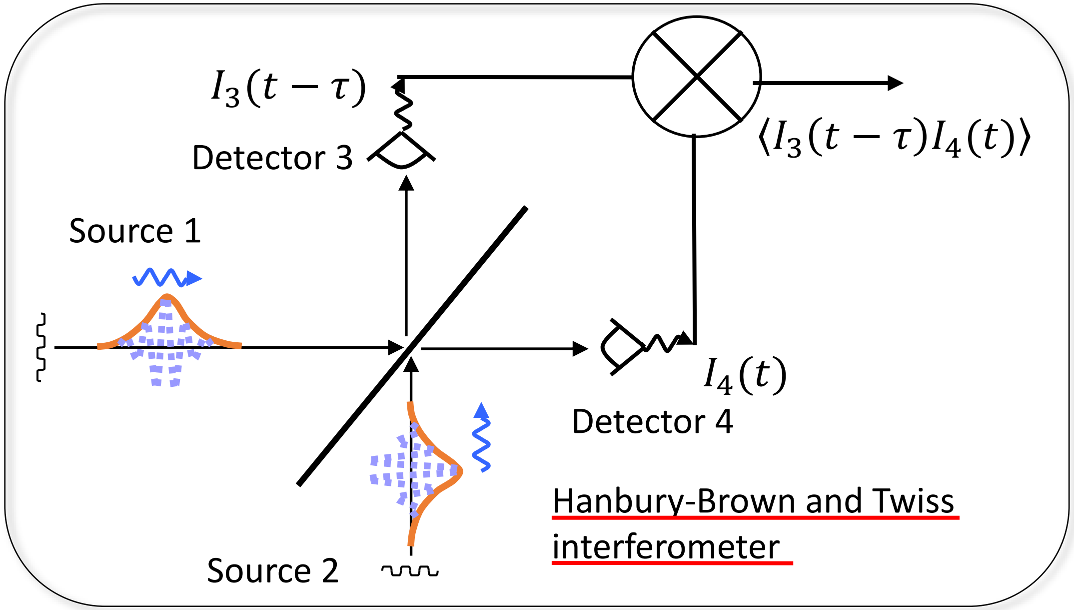
$G^{(1)}(t+\tau,t) \propto \langle E^*(t-\tau)E(t)\rangle$

Coherence of electric field



Two-particle interferometer

HBT interferometry $\langle I_3(t-\tau)I_4(t)\rangle$



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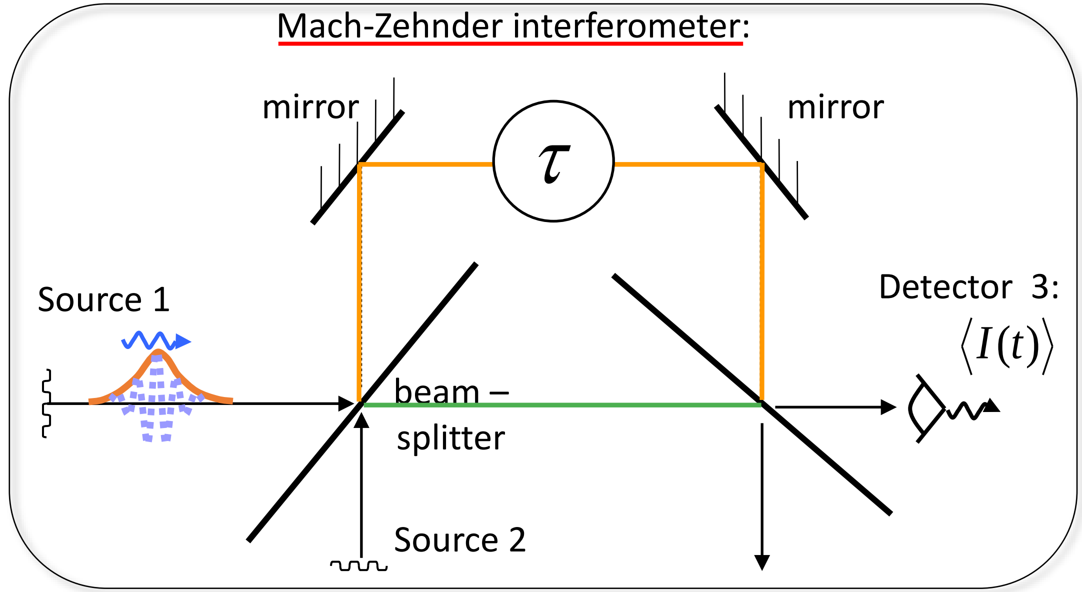
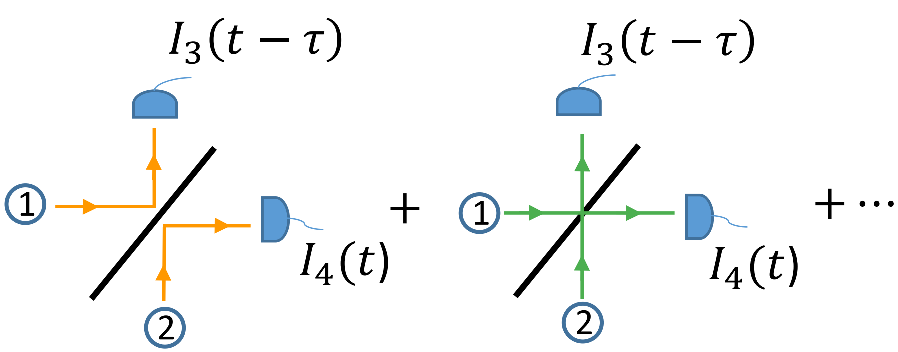
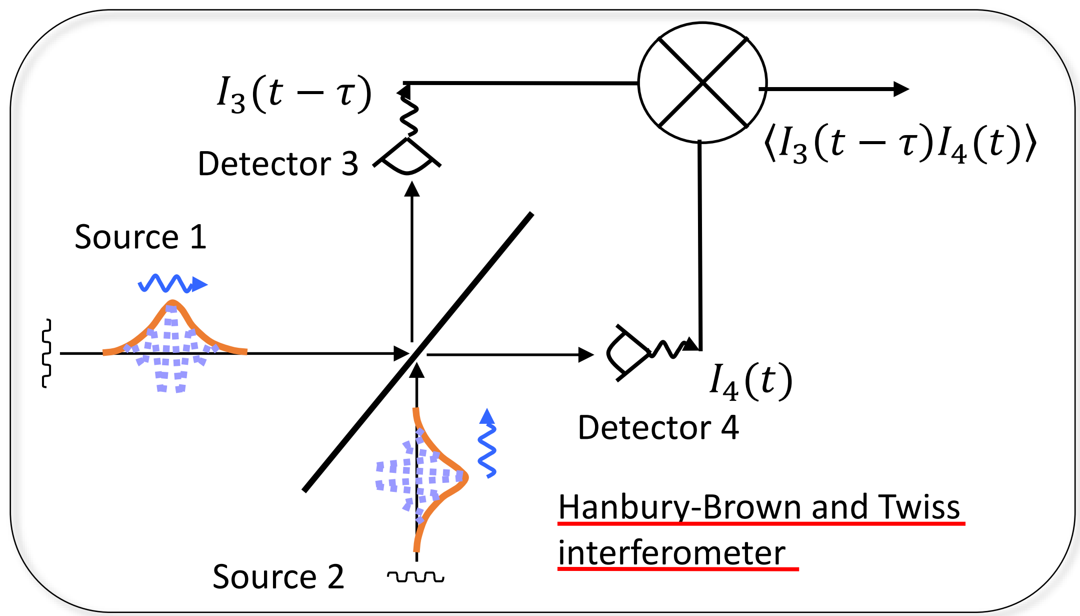


Two-particle interferometer

HBT interferometry $\langle I_3(t-\tau)I_4(t)\rangle$

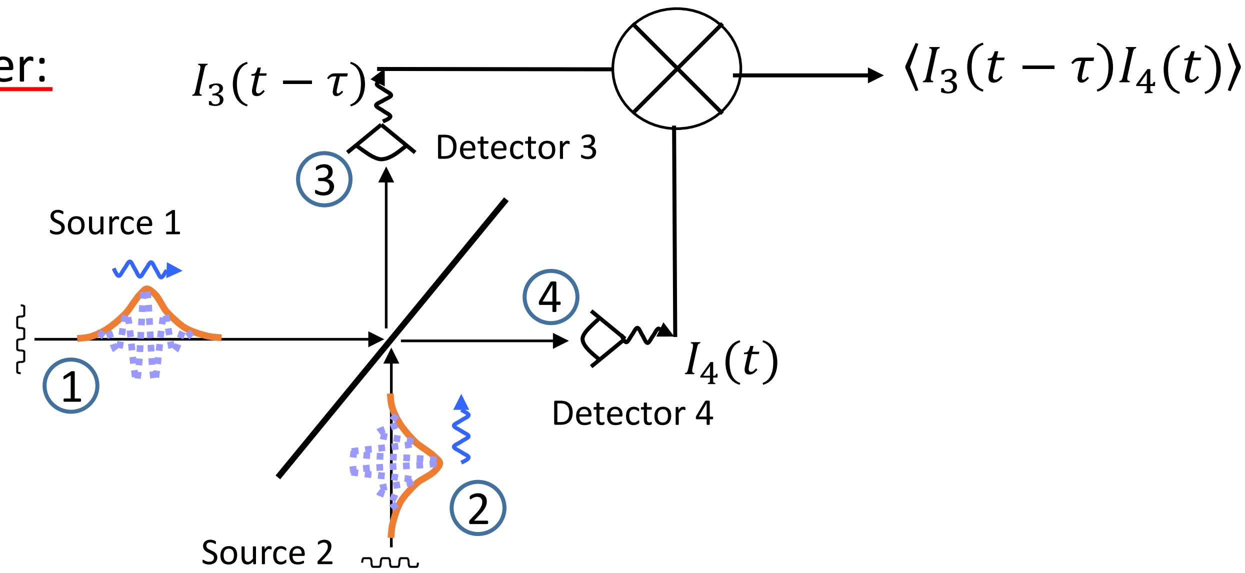


$$\propto \langle E_1^*(t-\tau)E_1(t)\rangle\langle E_2(t-\tau)E_2^*(t)\rangle$$

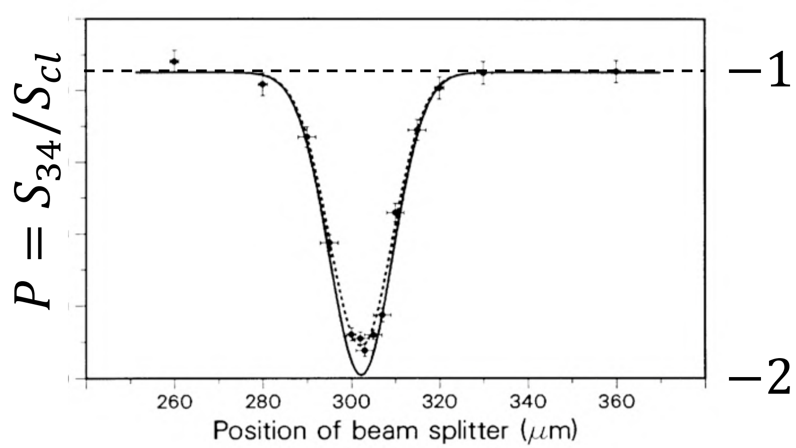


Single-particle vs two-particle interferometry (optics)

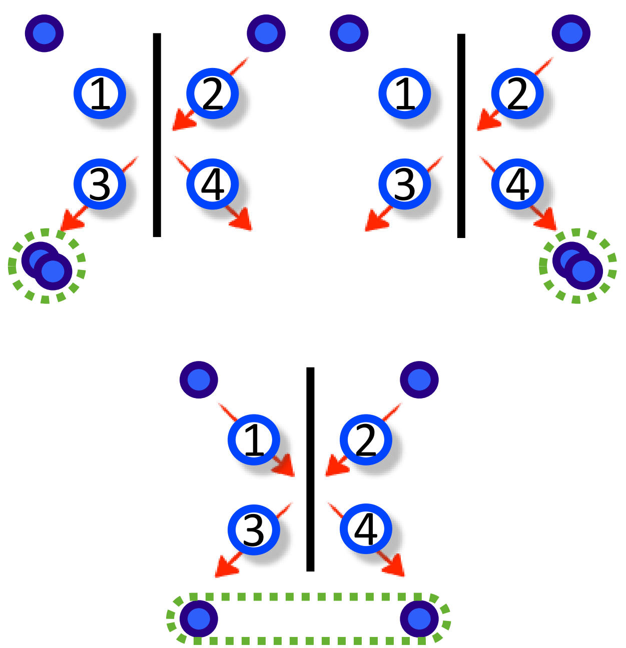
Two-particle interferometer:



Cross-correlations: $S_{34} = 2\int d\tau \overline{\langle \Delta I_3(t-\tau)\Delta I_4(t)\rangle}^t$



C. Hong *et al.*, PRL **59**(18), 2044 (1987)



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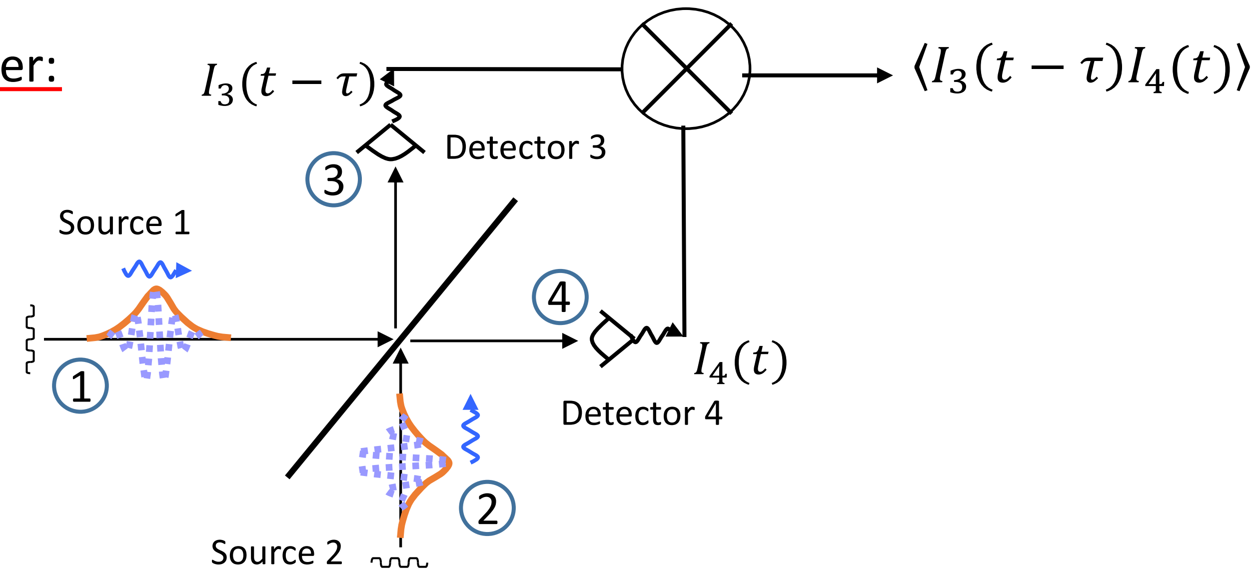
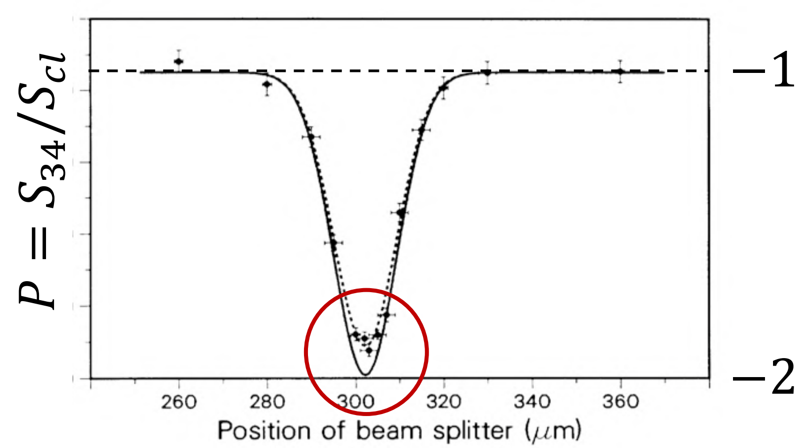
Single-particle vs two-particle interferometry (optics)

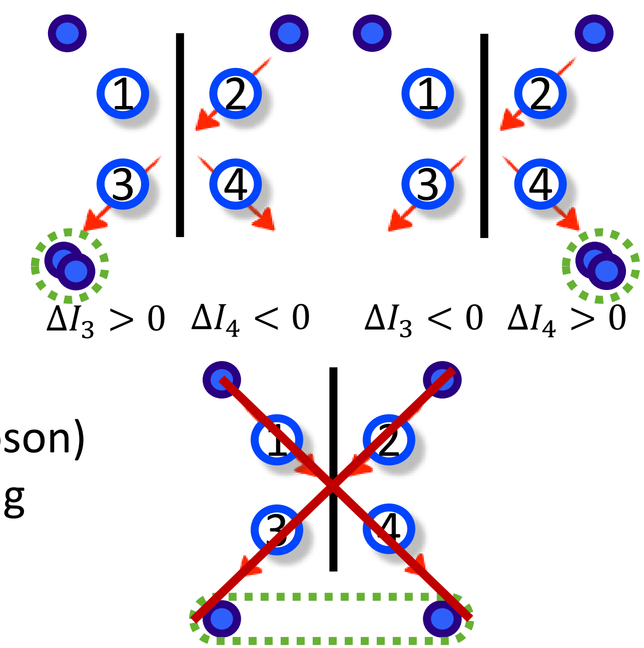
Two-particle interferometer:



Cross-correlations: $$S_{34} = 2\int d\tau\,\overline{\langle \Delta I_3(t-\tau)\Delta I_4(t)\rangle}^{t}$$

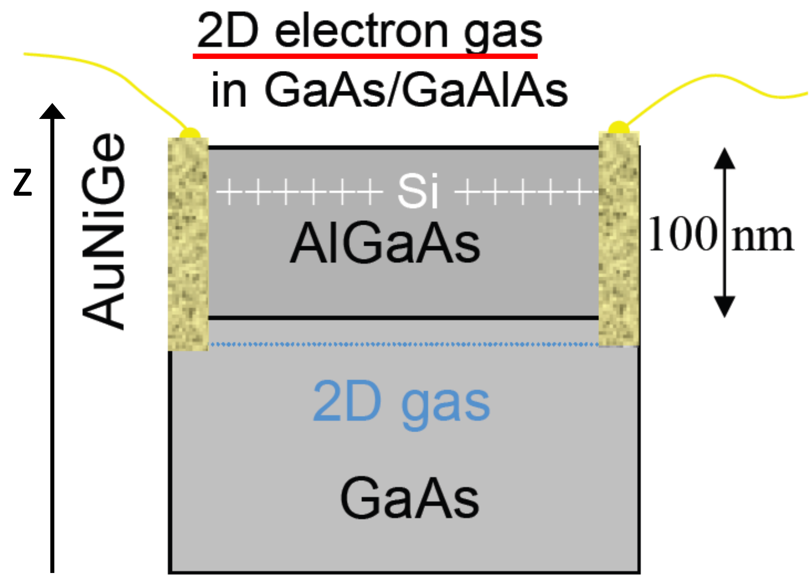


C. Hong *et al.*, PRL **59**(18), 2044 (1987)

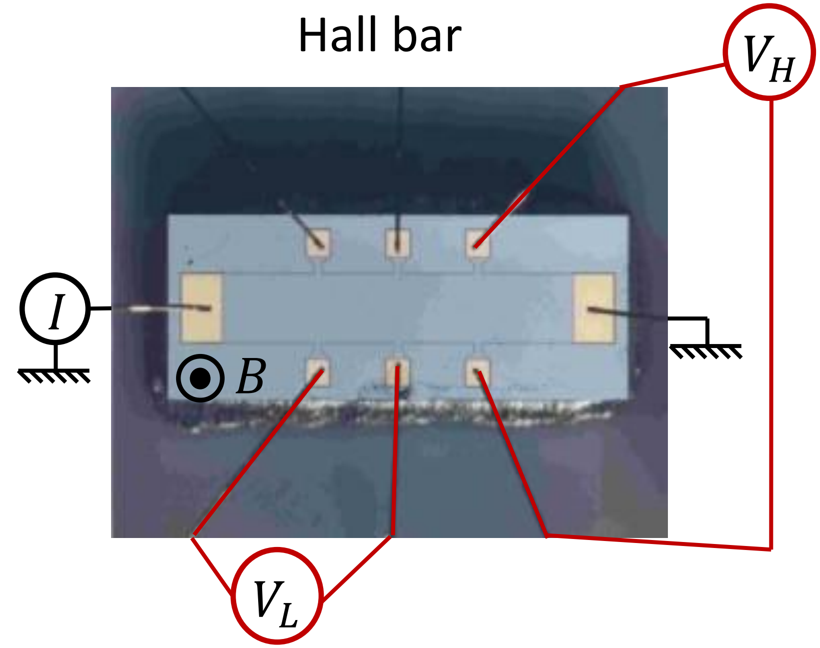


Photon (boson) bunching

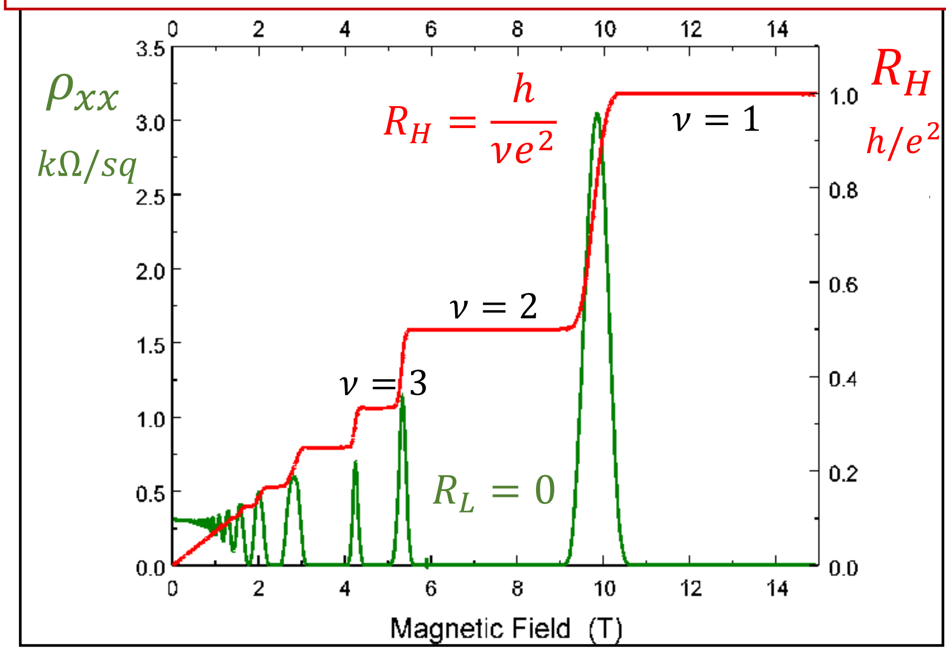
Electron optics: the integer quantum Hall effect



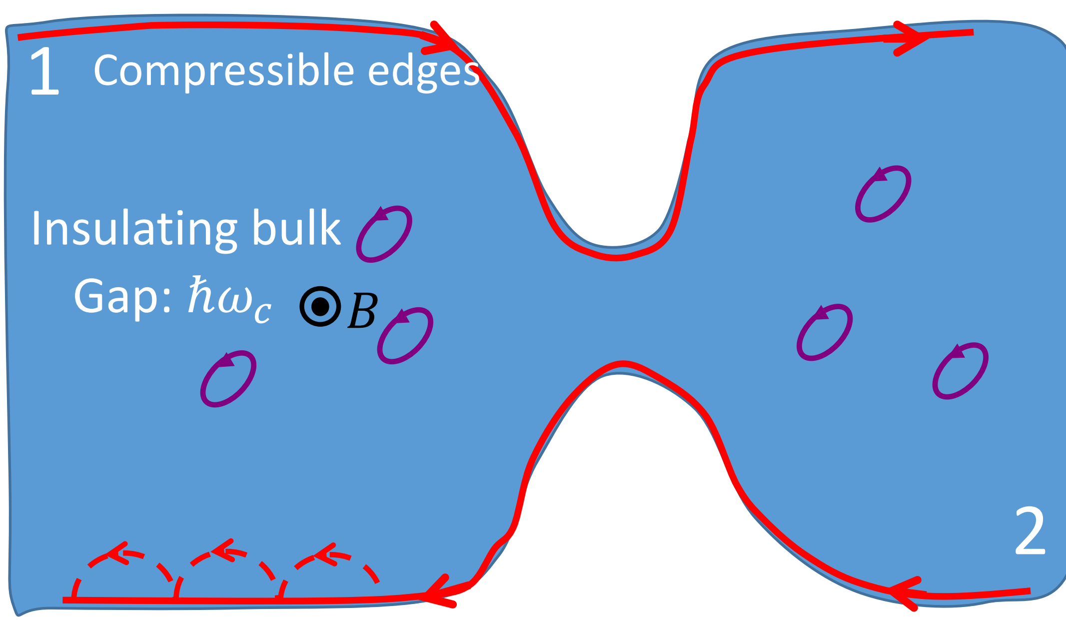
Hall bar



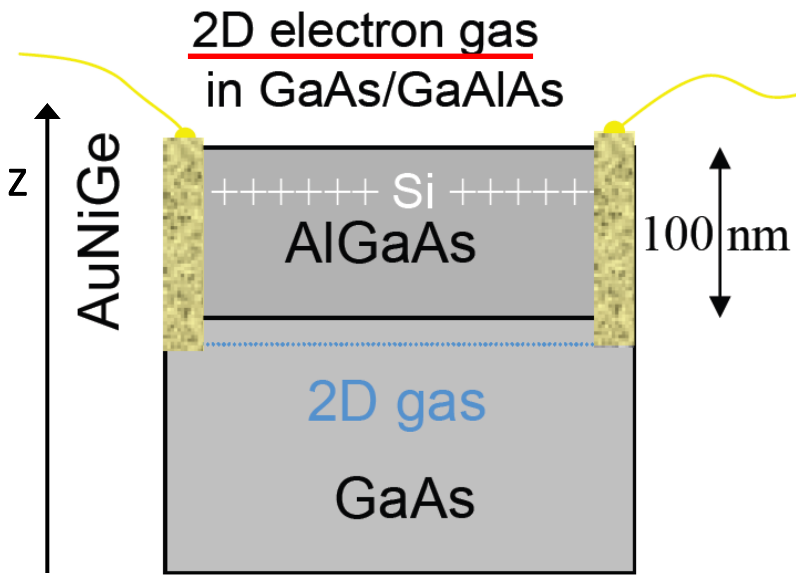
K. v. Klitzing, G. Dorda, and M. Pepper, PRL **45**, 494 (1980).

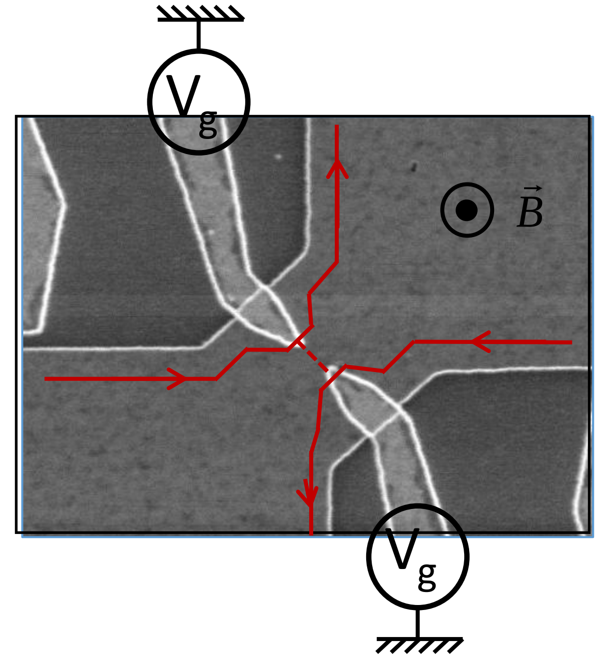


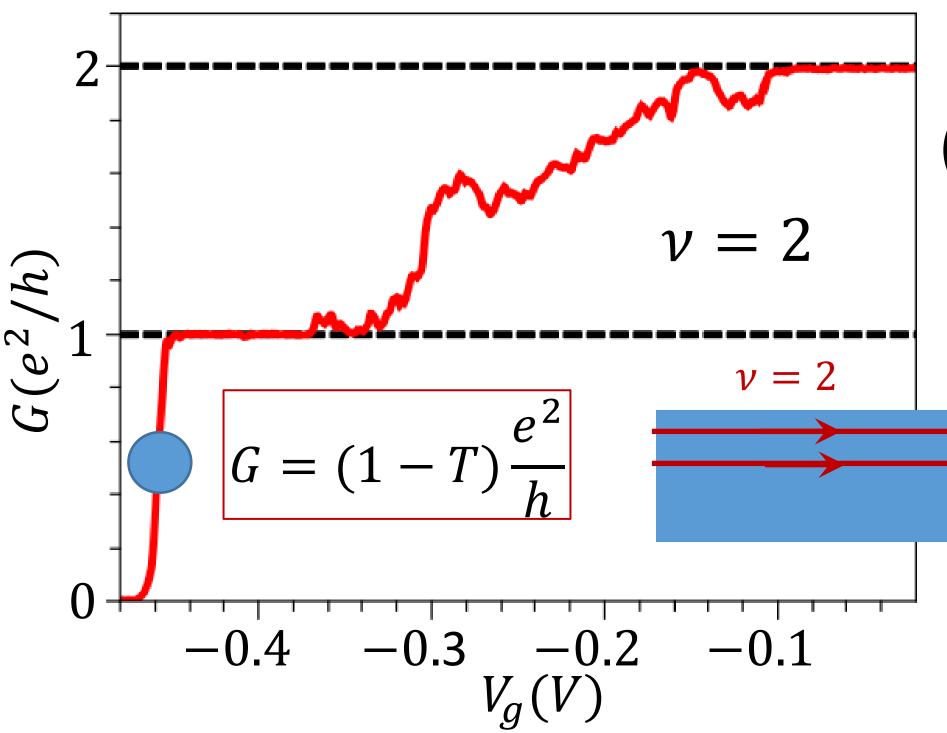
Ballistic propagation along ν edge channels

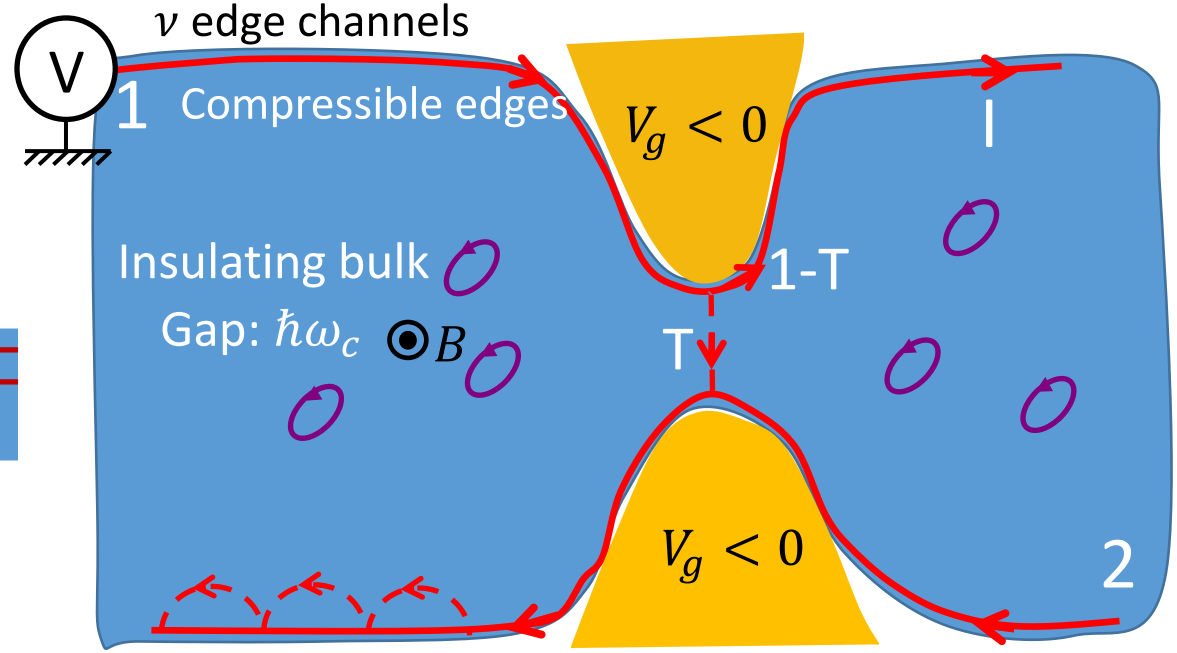


The quantum point contact: tunable beam-splitter

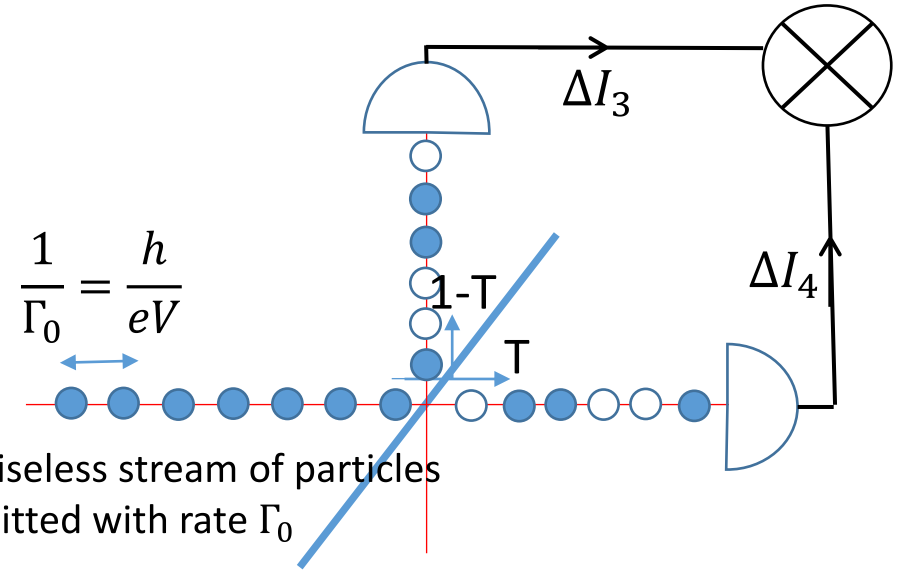




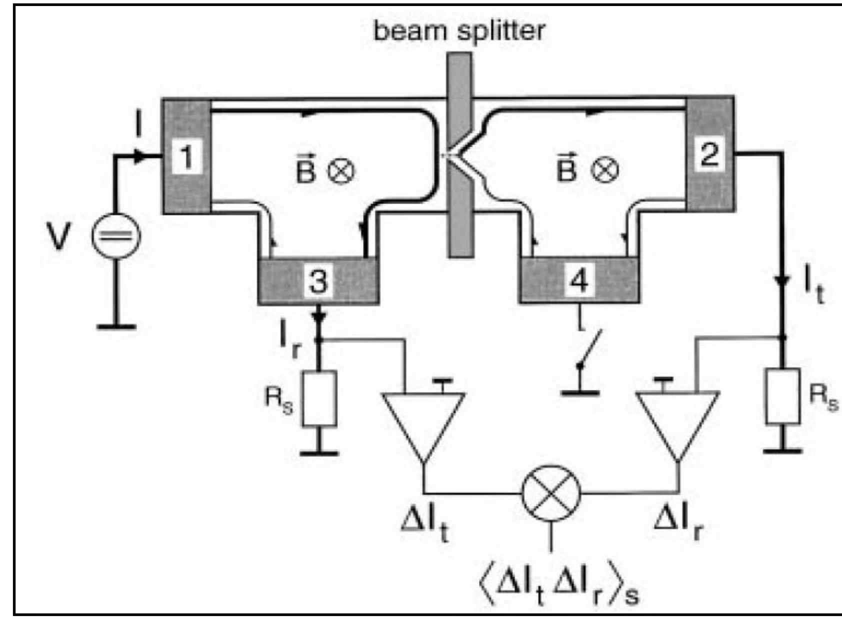




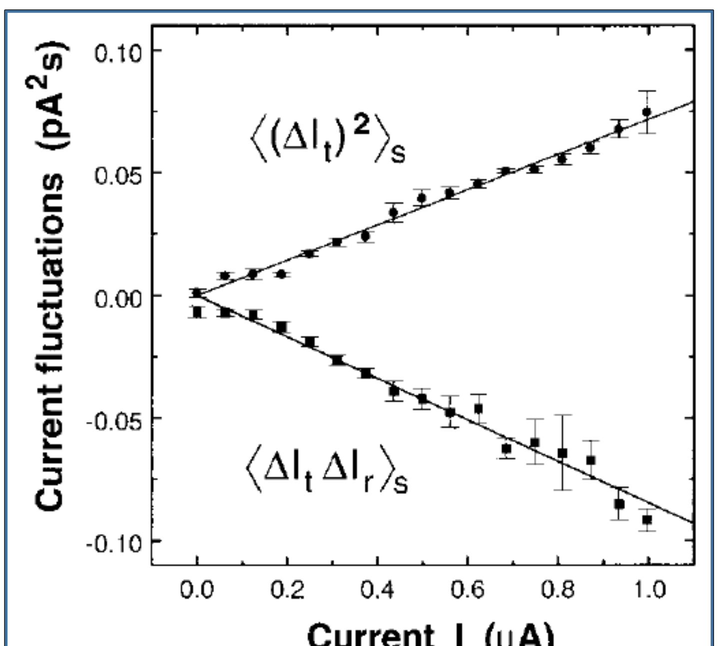
Electron optics experiments: random partitioning of electron beams



Noiseless stream of particles emitted with rate Γ_0



M. Henny et al., Science **284** 296 (1999)
W.D. Oliver et al., Science **284** 299 (1999)
A. Kumar et al., PRL **76** 2778 (1996)



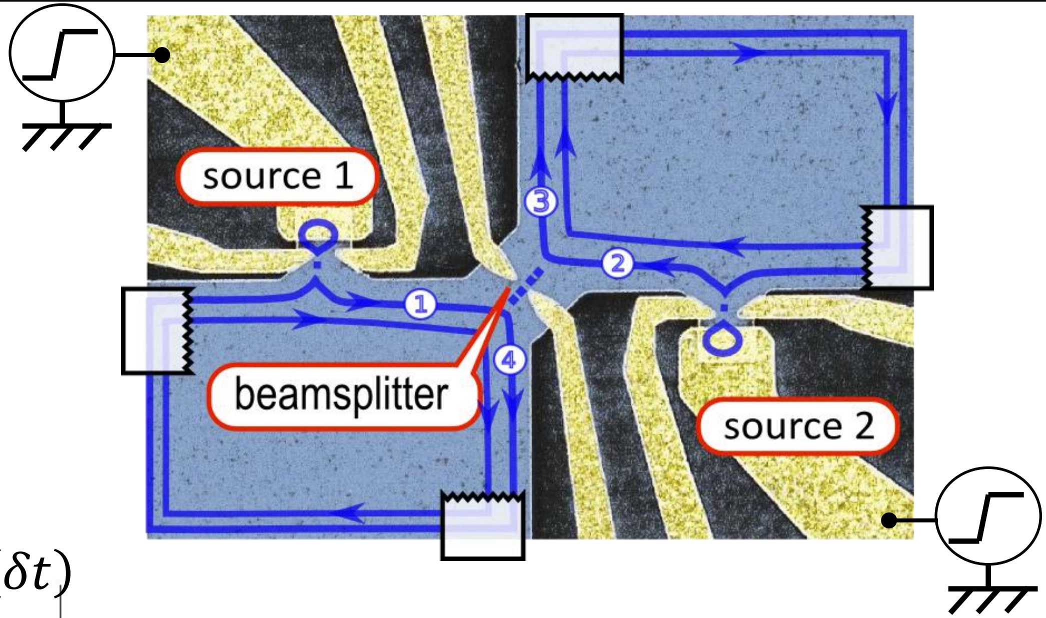
Binomial law: $\langle \Delta N_4^2 \rangle = T(1-T)\, N_0$

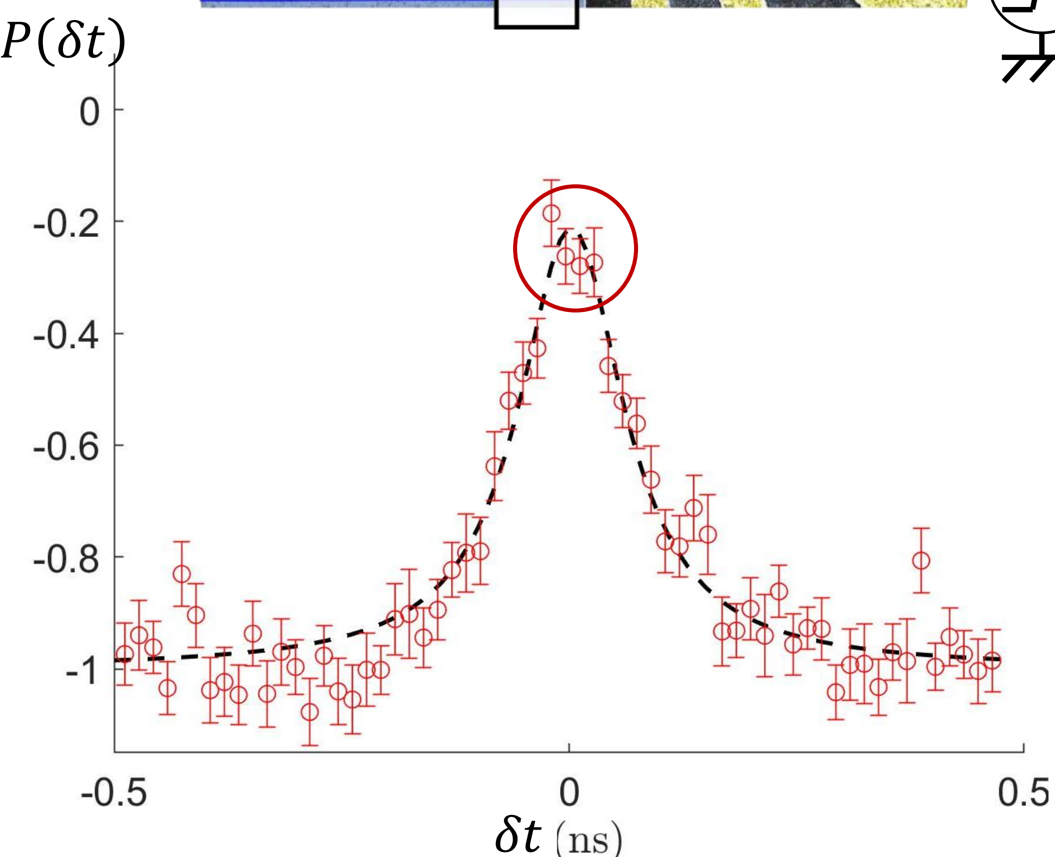
$$S_{44} = \frac{2q^2}{T_{meas}} \langle \Delta N_4^2 \rangle = 2qT(1-T)I_0 \equiv S_{cl}$$

$$S_{34} = -S_{44} = -\,S_{cl}$$

$$P = S_{34}/S_{cl} = -1$$

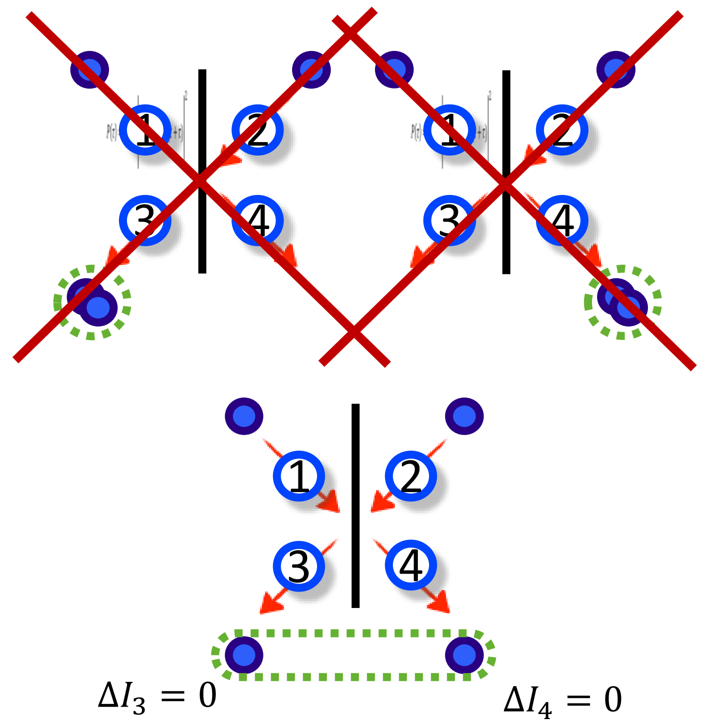
$\nu = 2$: Two-particle interferometry with single electrons





$$\langle \Delta I_3(t-\tau)\Delta I_4(t)\rangle$$
$$\propto \langle \psi_1^{+}(t-\tau)\psi_1(t)\rangle\langle \psi_2(t-\tau)\psi_2^{+}(t)\rangle$$

Electron interferometry



Fermion antibunching

S. Ol'khovskaya et al., PRL **101**, 166802, (2008).

E. Bocquillon et al., Science **339**, 1054 (2013).

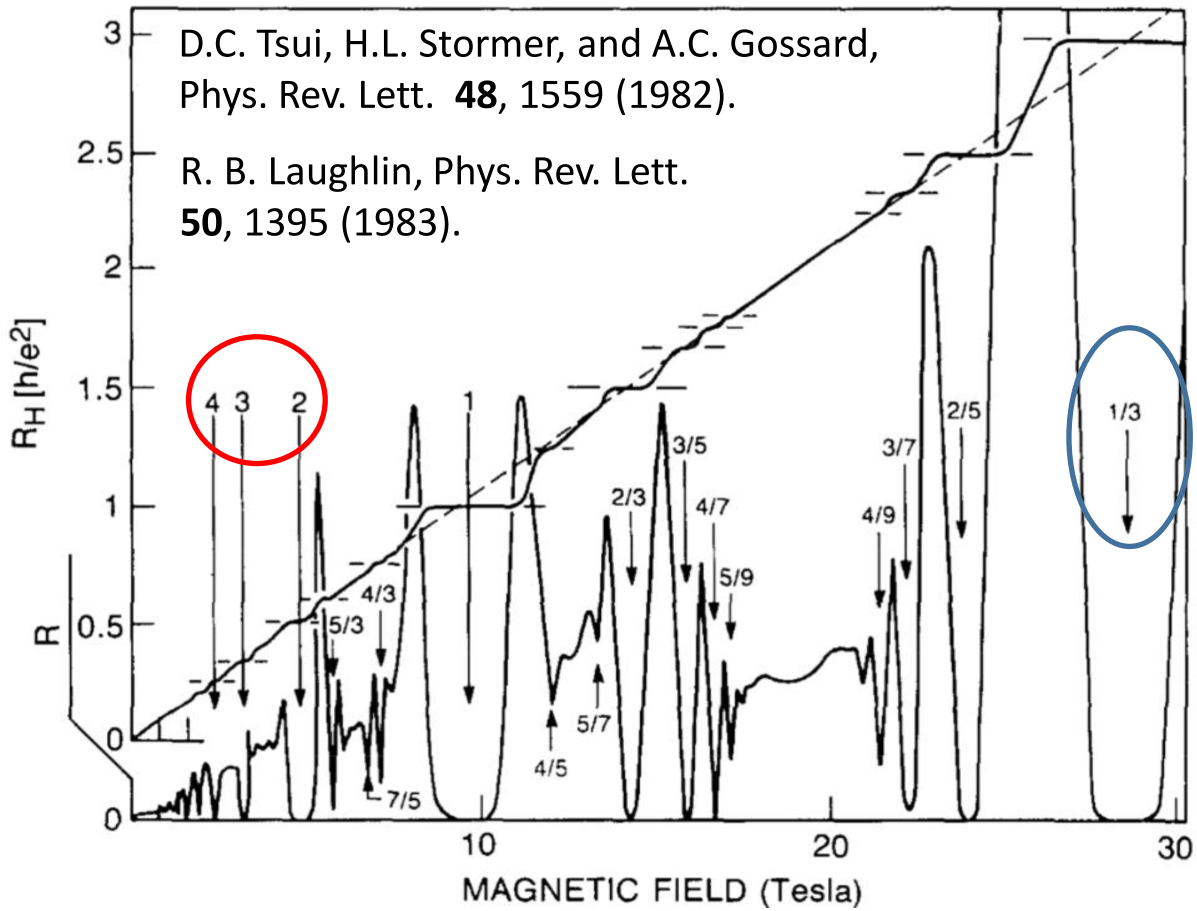
Anyons and the Fractional Quantum Hall Effect (FQHE)

$\nu = N$

$q = e$

$\varphi = \pi$

$\theta = 2\varphi = 2\pi$



$G = \frac{1}{3}\frac{e^2}{h}$

$\nu = 1/3$

$q = e/3$

$\varphi = \pi/3$

$\theta = 2\varphi = 2\pi/3$

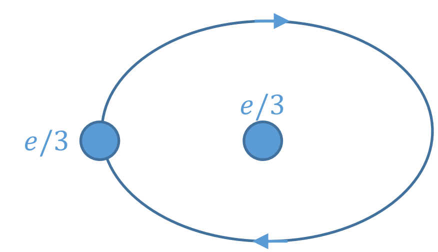
Each FQHE phase hosts a specific variety of anyons characterized by their fractional charge q and their fractional statistics φ

Halperin, PRL **52** 1583 (1984)

Arovas, Schrieffer, Wilczek PRL **53** 722 (1984)

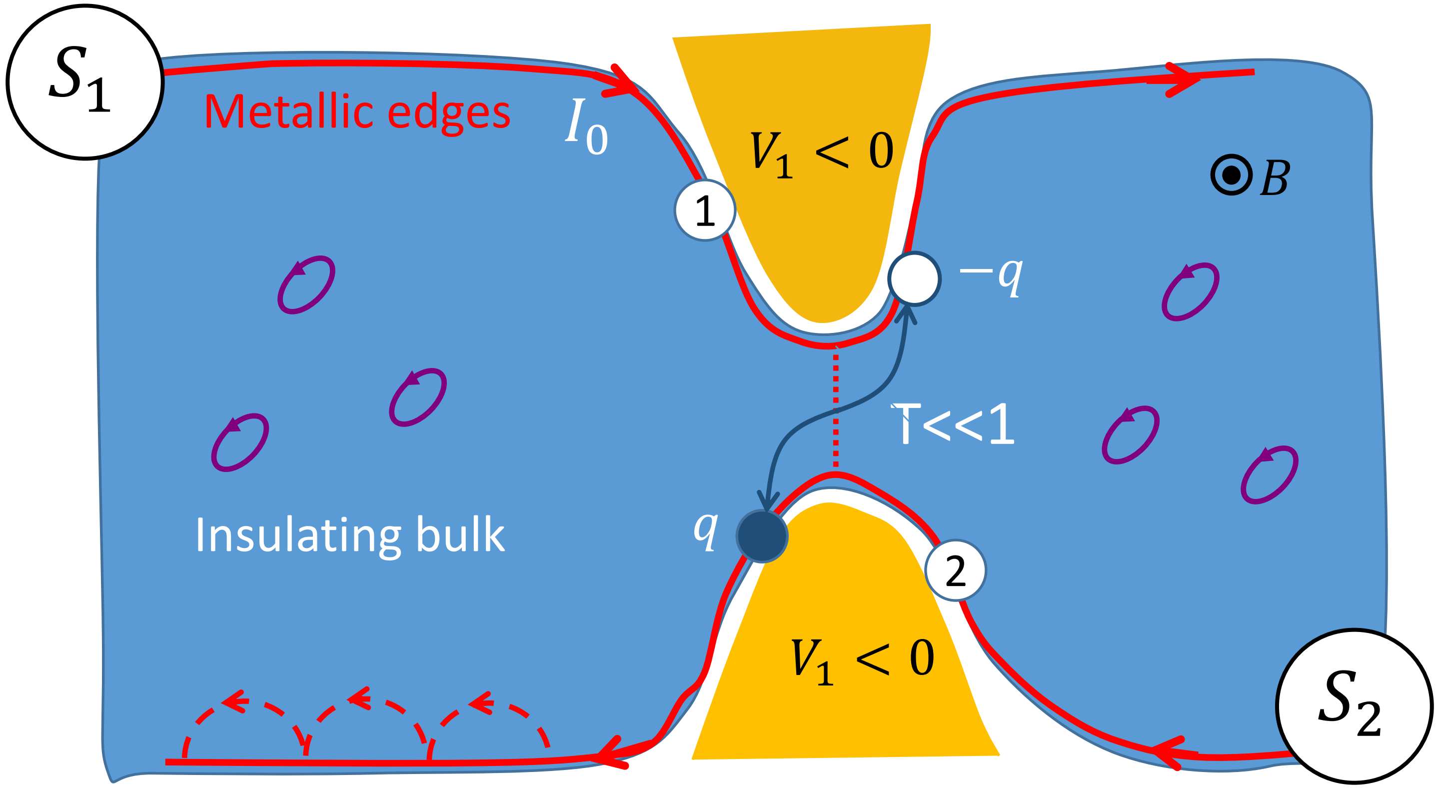
J. K. Jain, PRL **63**, 199 (1989).

Anyons have non-trivial braiding



$e^{i\theta} = e^{i2\pi/3}$ $(\nu = 1/3)$

Electron/anyons tunneling at quantum point contact



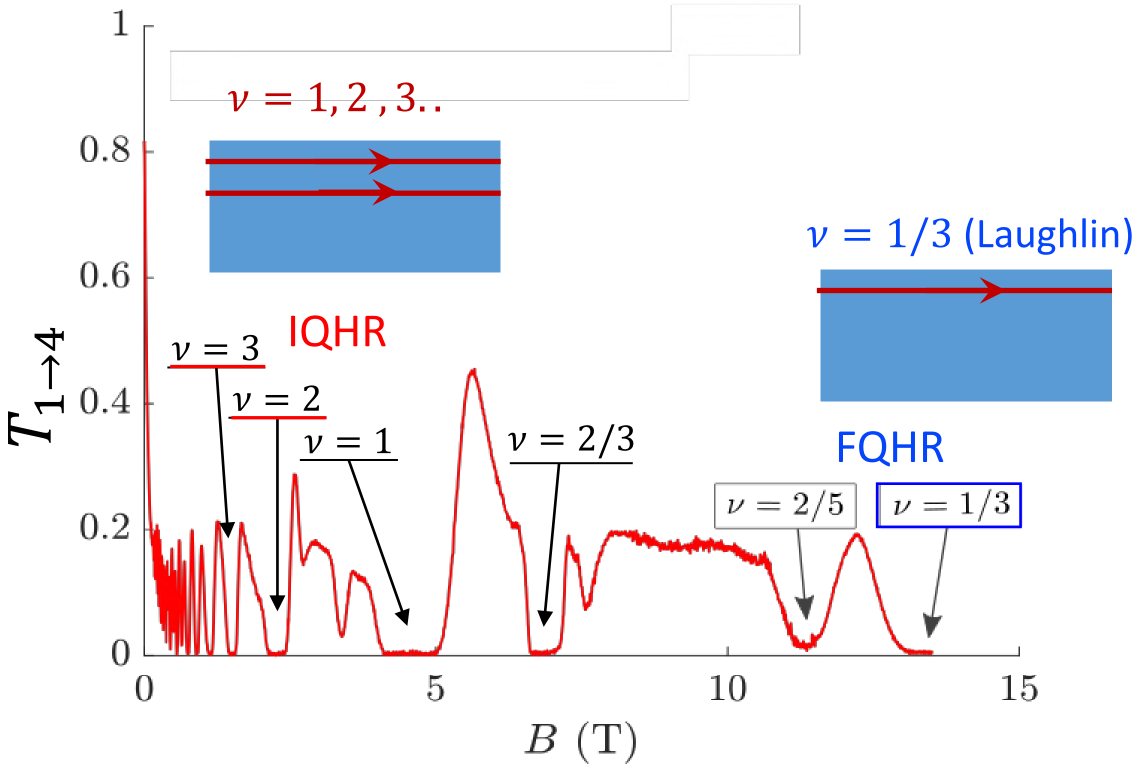
Random tunneling of electrons in the integer quantum Hall regime: $H_T \propto \psi^{+}_{2,e}\psi_{1,e} + h.c$

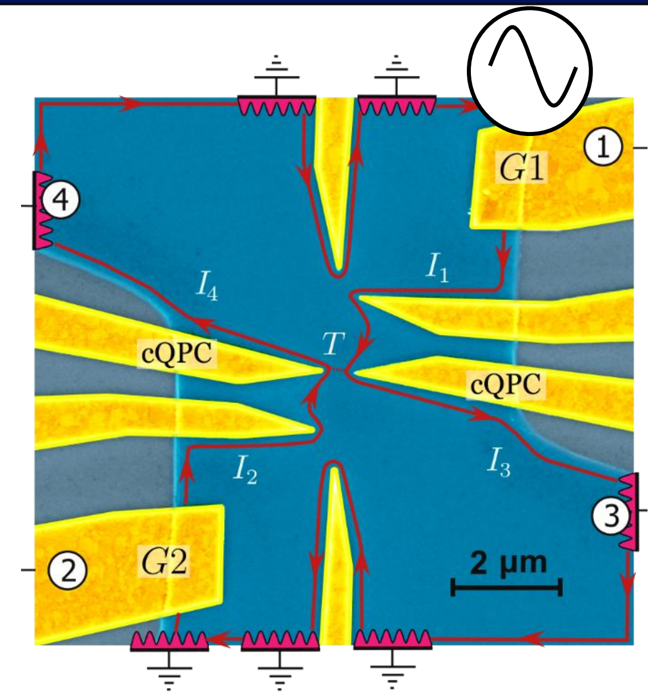
$\nu = 2, \nu = 3 \quad q = e \quad \varphi = \pi$

Random tunneling of anyons in the fractional quantum Hall regime: $H_T \propto \psi^{+}_{2,a}\psi_{1,a} + h.c$

$\nu = 1/3 \quad q = e/3 \quad \varphi = \pi/3 \quad \theta = 2\varphi = \frac{2\pi}{3}$

Electron/anyon beam splitters: random partition noise and charge measurement





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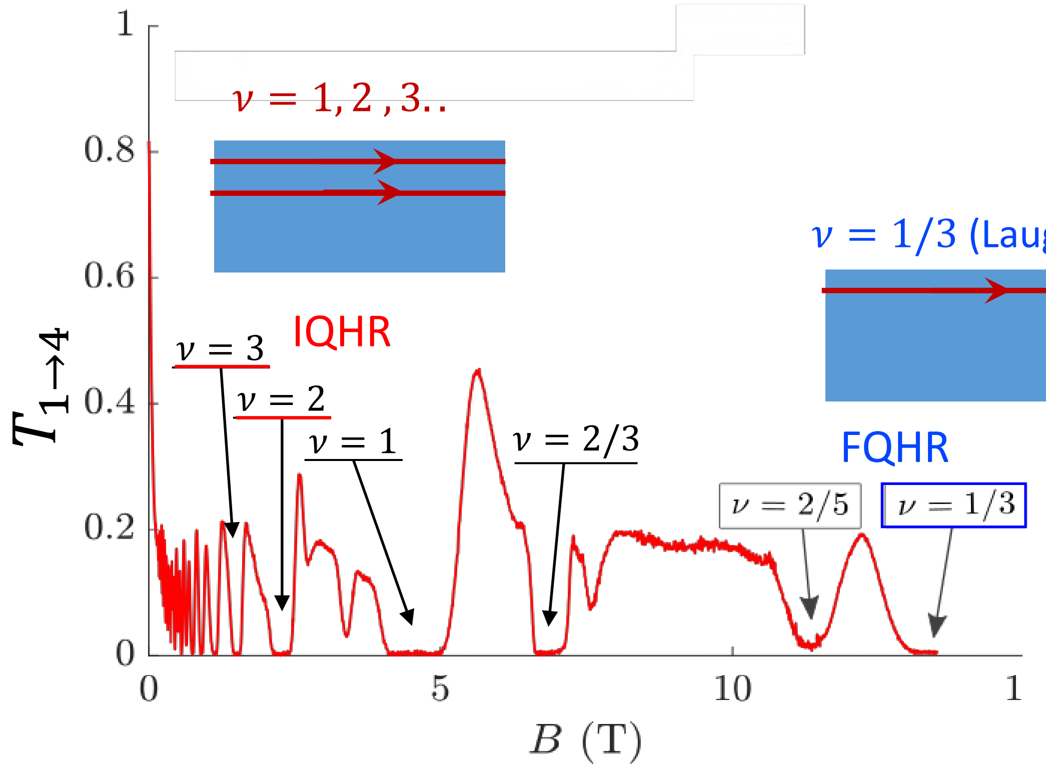
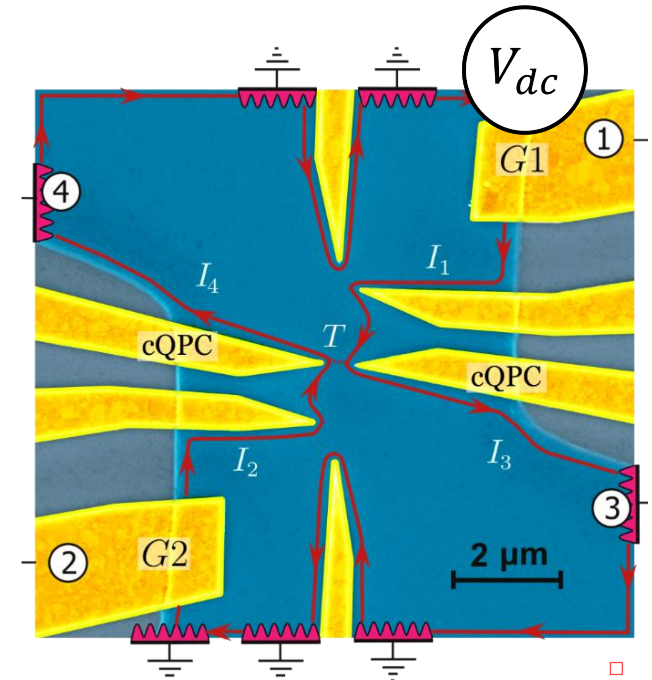
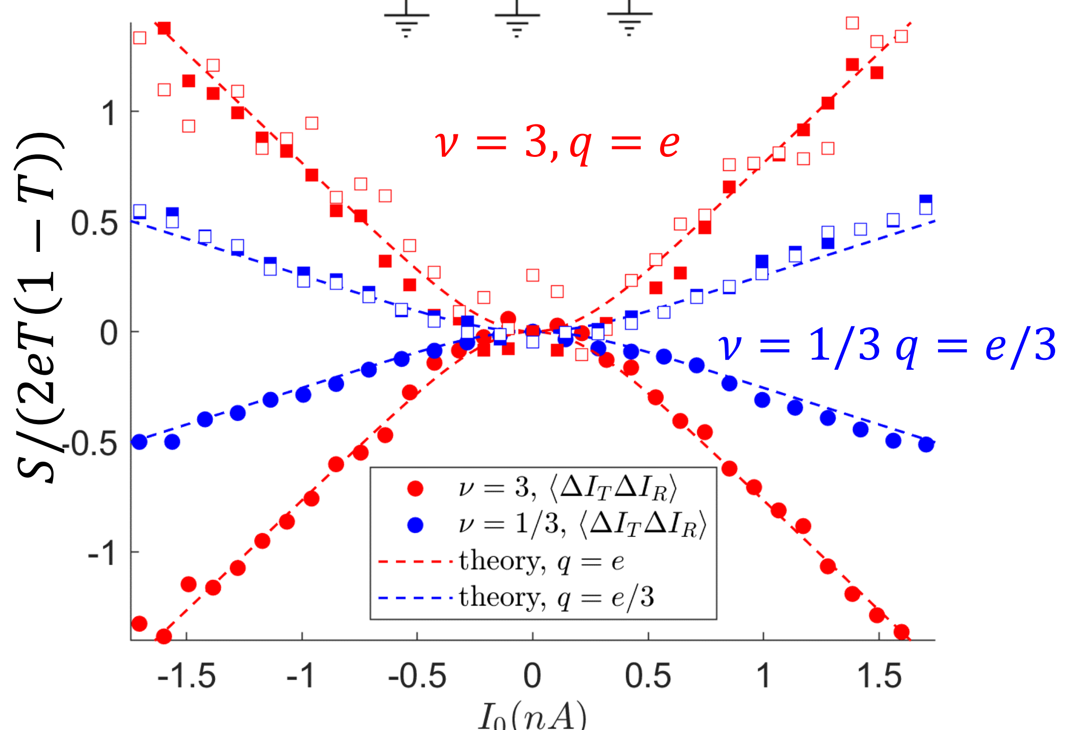
Electron/anyon beam splitters: random partition noise and charge measurement







$$S_{33} = 2qT(1-T)I_0 \equiv S_{cl}$$

$$S_{34} = -S_{cl}$$

R. de Picciotto et al., Nature **389**, 162 (1997).

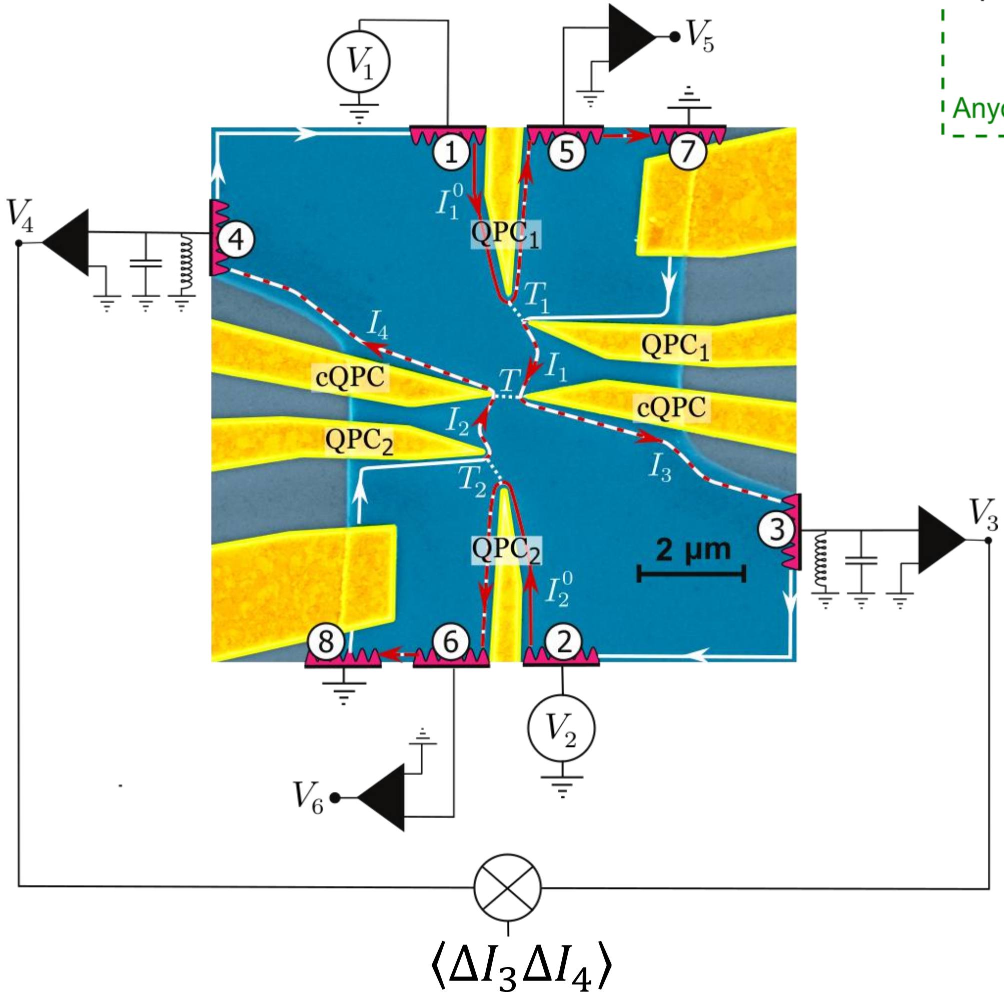
L. Saminadayar et al., Phys. Rev. Lett. **79**, 2526 (1997).

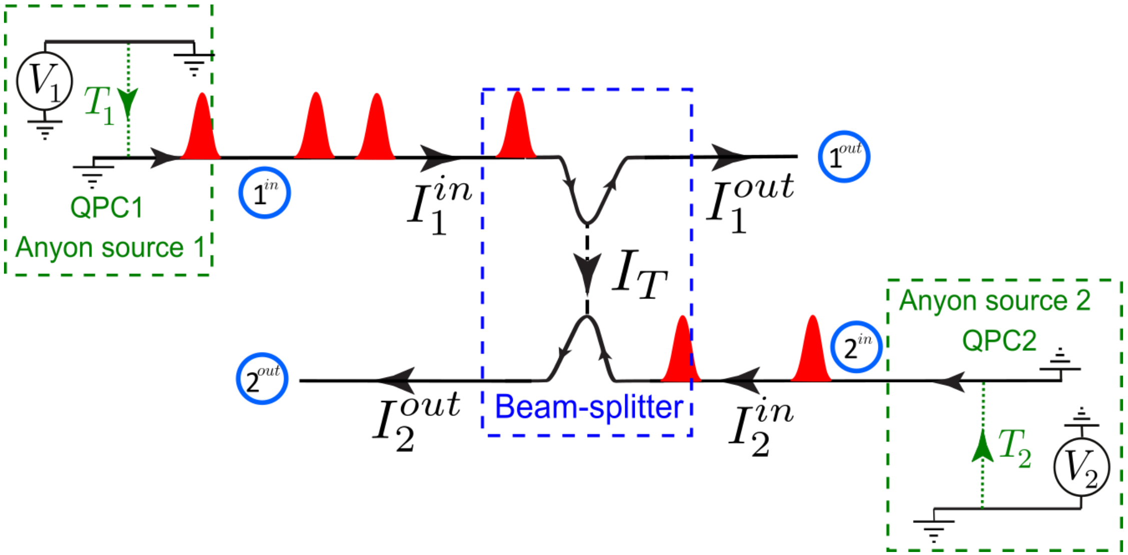
C. L. Kane and M. P. A. Fisher, Phys. Rev. Lett. **72**, 724 (1994)

The anyon collider

B. Rosenow, I.P. Levkivskyi, B. Halperin PRL **116**, 156802 (2016)

H. Bartolomei et al., Science **368**, 173 (2020)





Random emission of particles: probabilities $T_1 = T_2 = T_S$

Poissonian limit, $T_S \ll 1$

Fano factor: $P = \dfrac{S_{34}}{S_{cl}}$

$S_{cl} = 2qT(1-T)I_+$

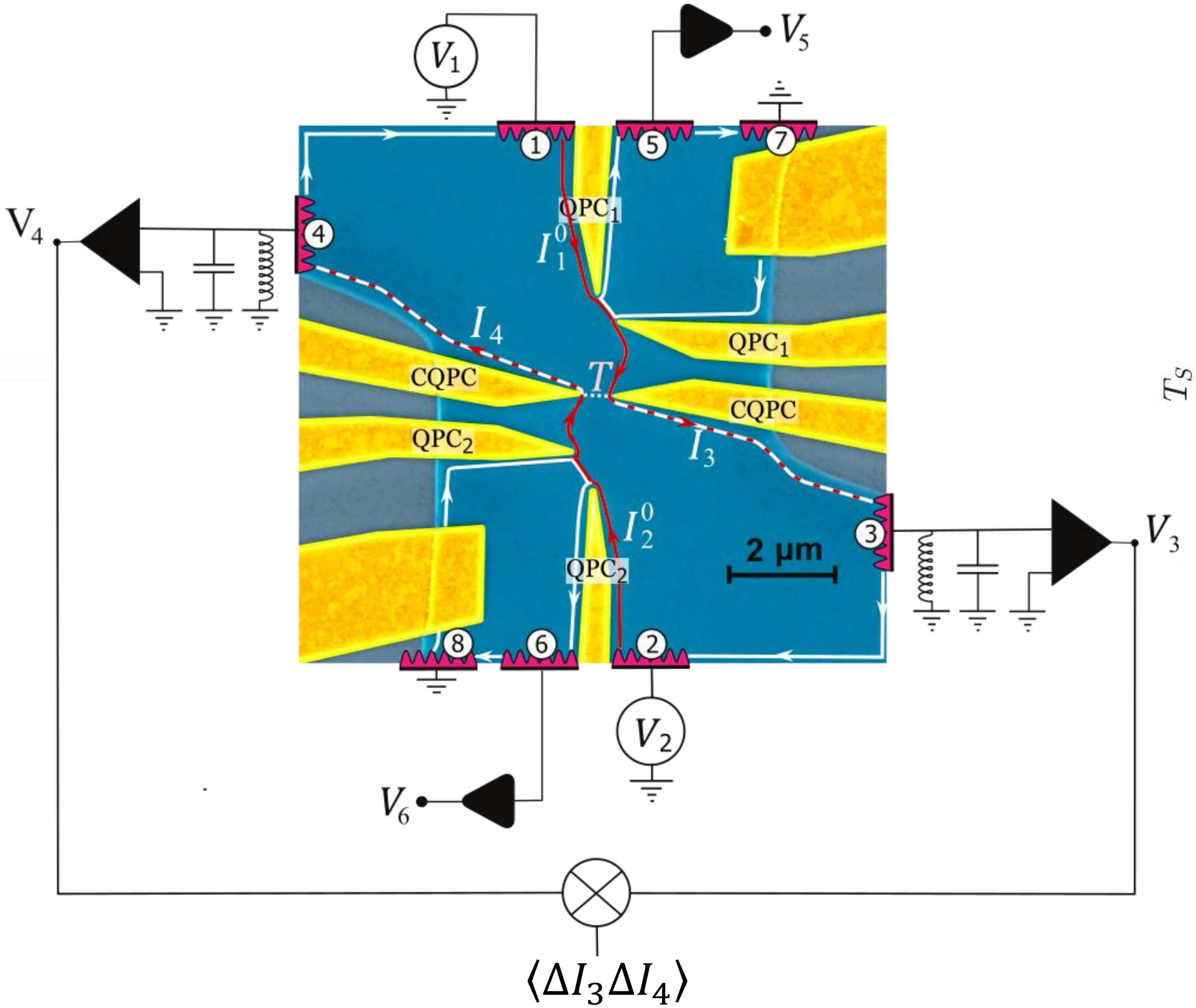
Total input current: $I_+ = I_1^{in} + I_2^{in}$

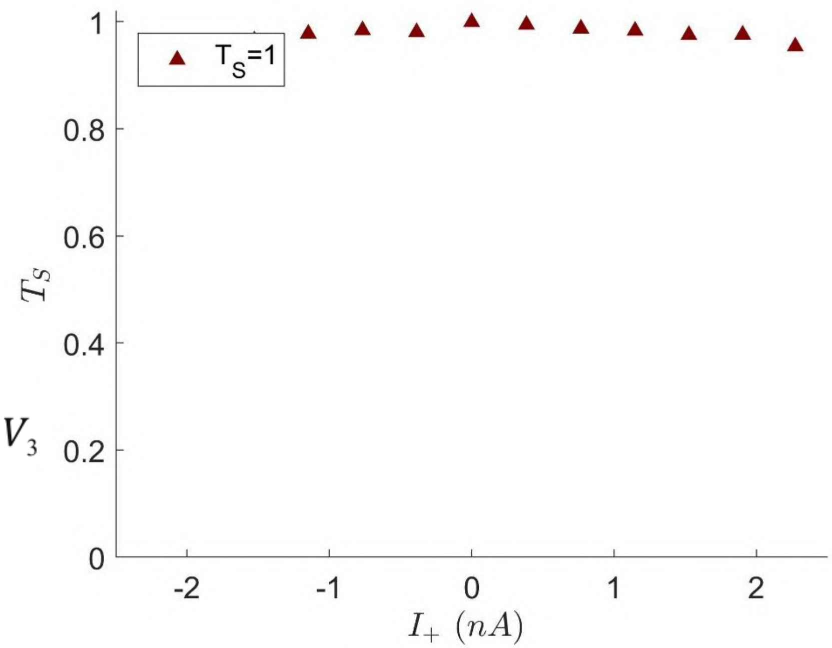
Balanced collider, $I_1^{in} = I_2^{in}$, electron case, $\nu = 2$

Balanced case: $I_1^{in} = I_2^{in}$

Integer case: q $= e$, fermions

$\nu = 2, T = 0.4, T_S = 1$





H. Bartolomei, M. Kumar et al., Science **368** 173 (2020)

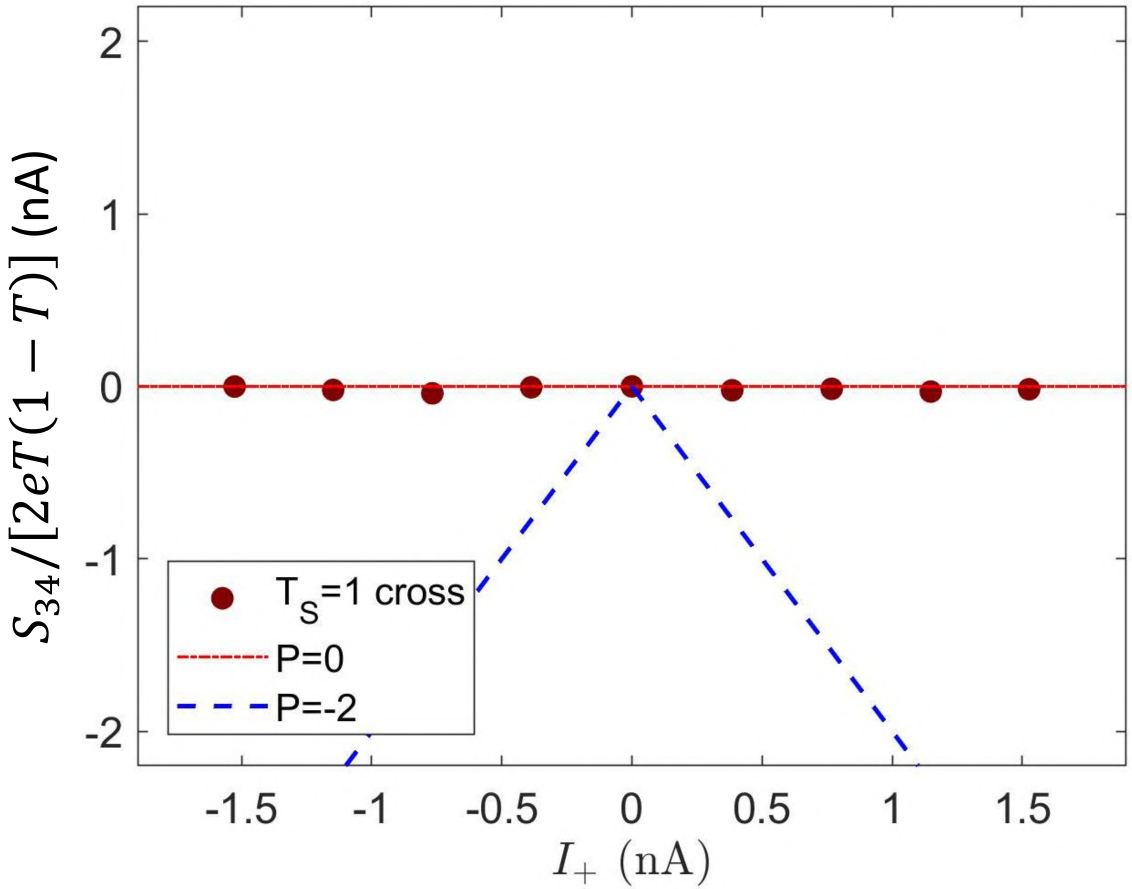
M. Ruelle et al., PRX **13**, 011031 (2023)

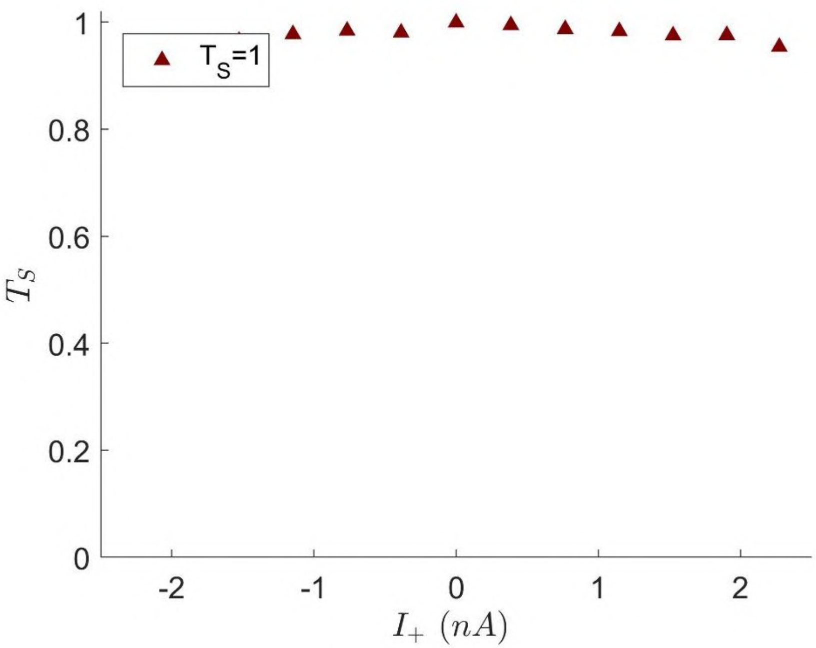
Balanced collider, $I_1^{in} = I_2^{in}$, electron case, $\nu = 2$

Balanced case: $I_1^{in} = I_2^{in}$

Integer case: $q = e$, fermions

$\nu = 2, T = 0.4, T_S = 1$





H. Bartolomei, M. Kumar et al., Science **368** 173 (2020)

M. Ruelle et al., PRX **13**, 011031 (2023)

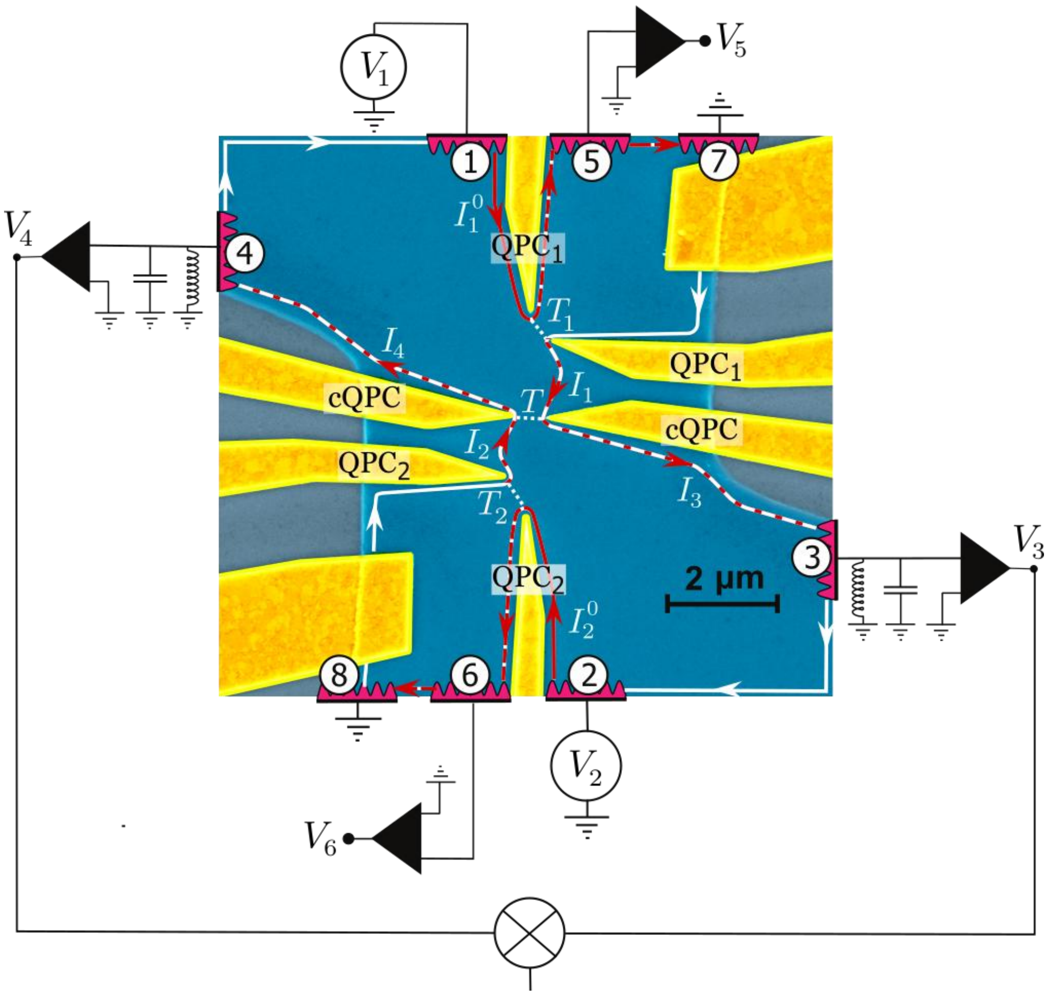
$P \approx 0$ fermions

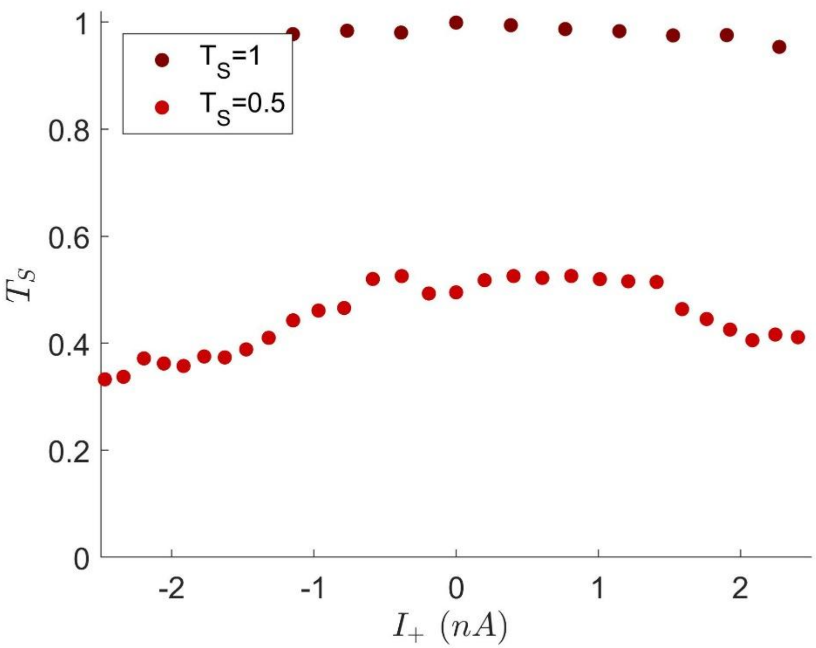
Balanced collider, $I_1^{in} = I_2^{in}$, electron case, $\nu = 2$

Balanced case: $I_1^{in} = I_2^{in}$

Integer case: $q = e$, fermions

$\nu = 2, T = 0.4, T_S = 0.5$





H. Bartolomei, M. Kumar et al., Science **368** 173 (2020)

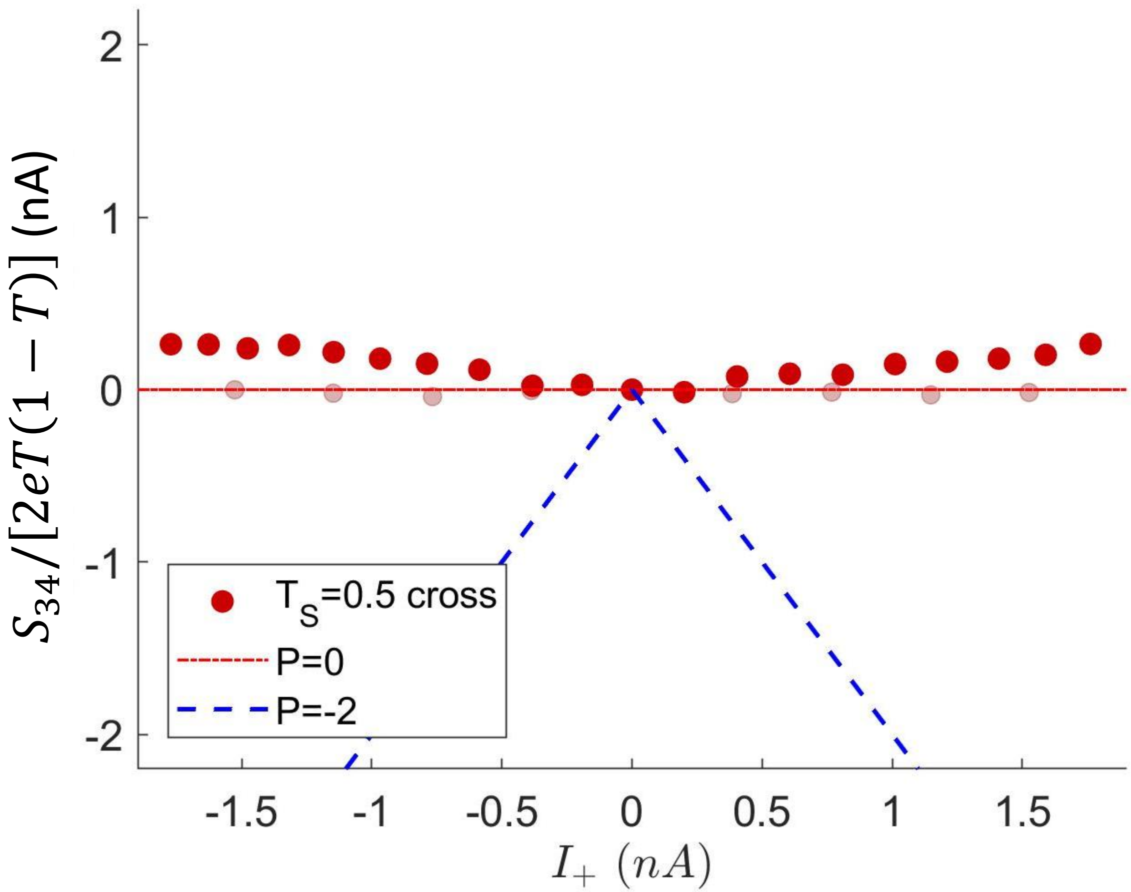
M. Ruelle et al., PRX **13**, 011031 (2023)

Balanced collider, $I_1^{in} = I_2^{in}$, electron case, $\nu = 2$

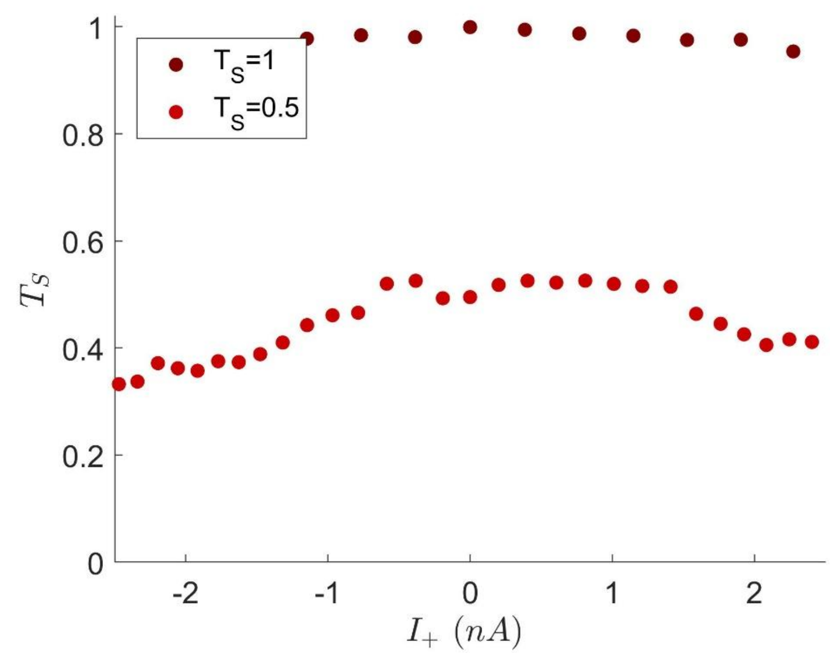
Balanced case: $I_1^{in} = I_2^{in}$

Integer case: q $= e$, fermions

$\nu = 2, T = 0.4, T_S = 0.5$



$P \approx 0$ fermions



H. Bartolomei, M. Kumar et al., Science **368** 173 (2020)

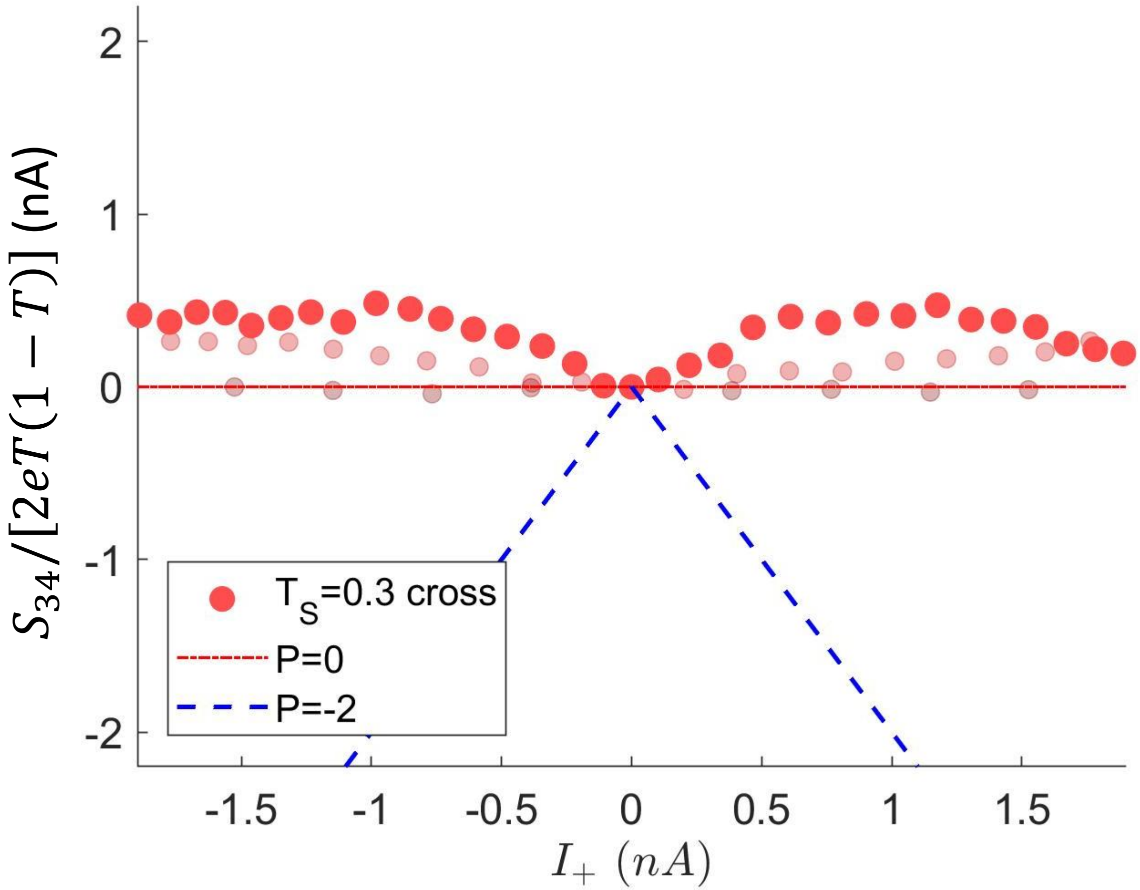
M. Ruelle et al., PRX **13**, 011031 (2023)

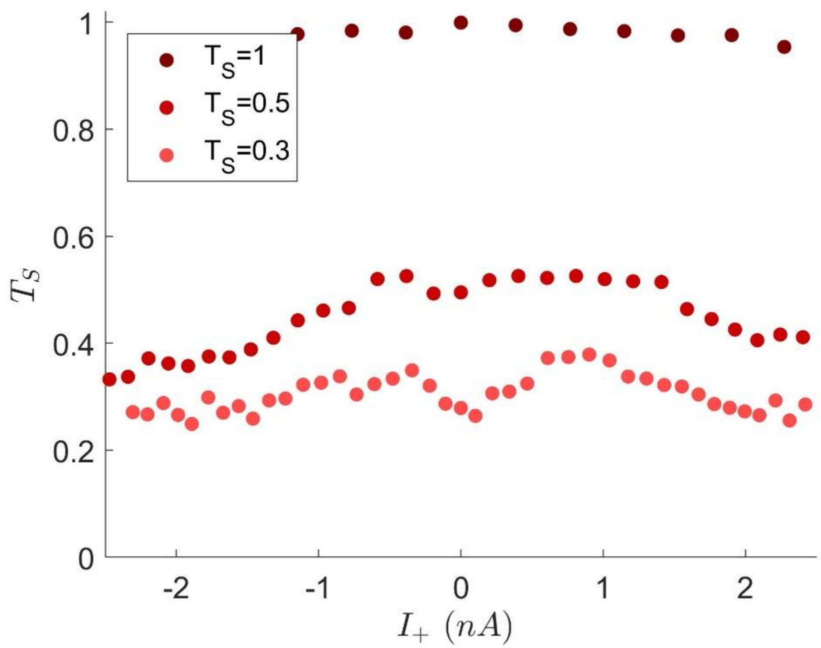
Balanced collider, $I_1^{in} = I_2^{in}$, electron case, $\nu = 2$

Balanced case: $I_1^{in} = I_2^{in}$

Integer case: $q = e$, fermions

$\nu = 2, T = 0.4, T_S = 0.3$





$P \approx 0$ fermions

H. Bartolomei, M. Kumar et al., Science **368** 173 (2020)

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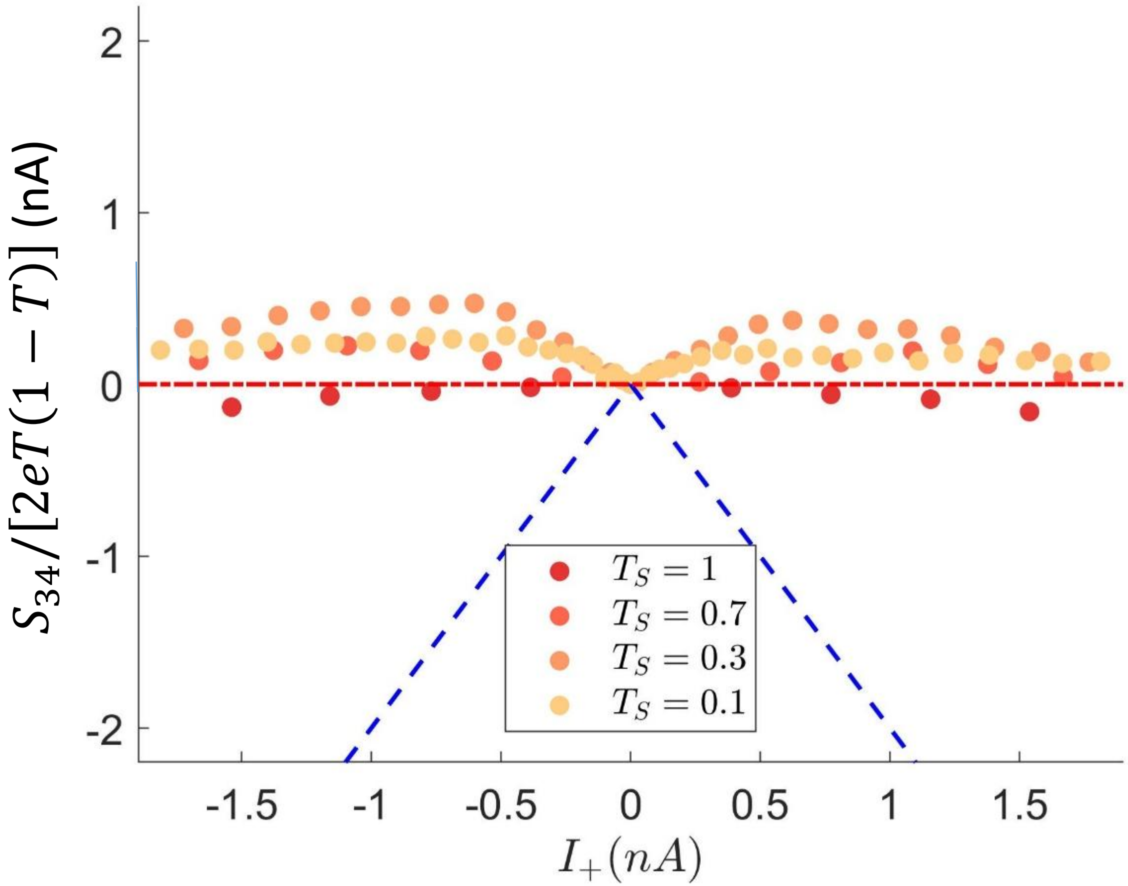
Balanced collider, $I_1^{in} = I_2^{in}$, electron case, $\nu = 3$

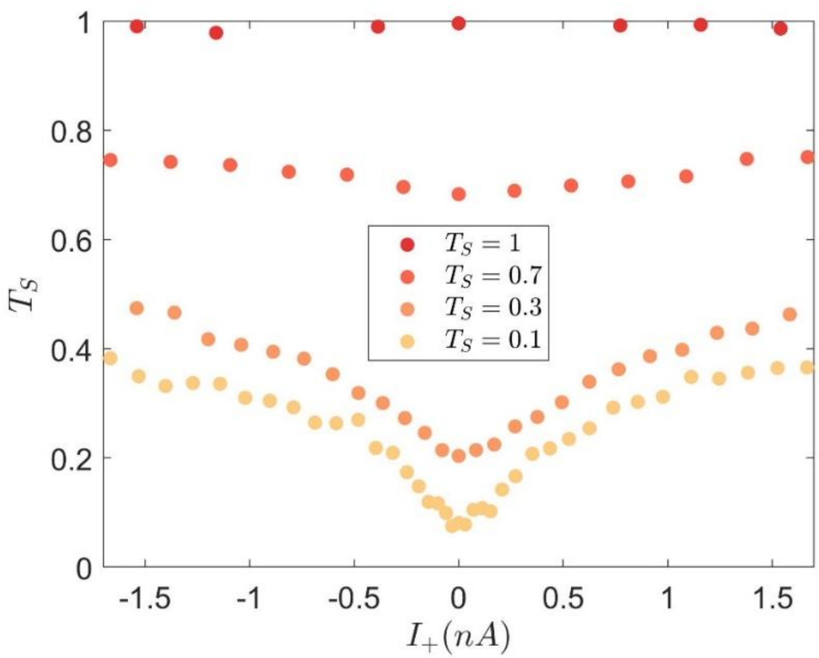
Balanced case: $I_1^{in} = I_2^{in}$

Integer case: $q = e$, fermions

$\nu = 3, T = 0.4, T_S = \{1; 0.7; 0.3; 0.1\}$



$P \approx 0$ fermions



H. Bartolomei, M. Kumar et al., Science **368** 173 (2020)

M. Ruelle et al., PRX **13**, 011031 (2023)

Other experiment in F. Pierre and A. Anthore group

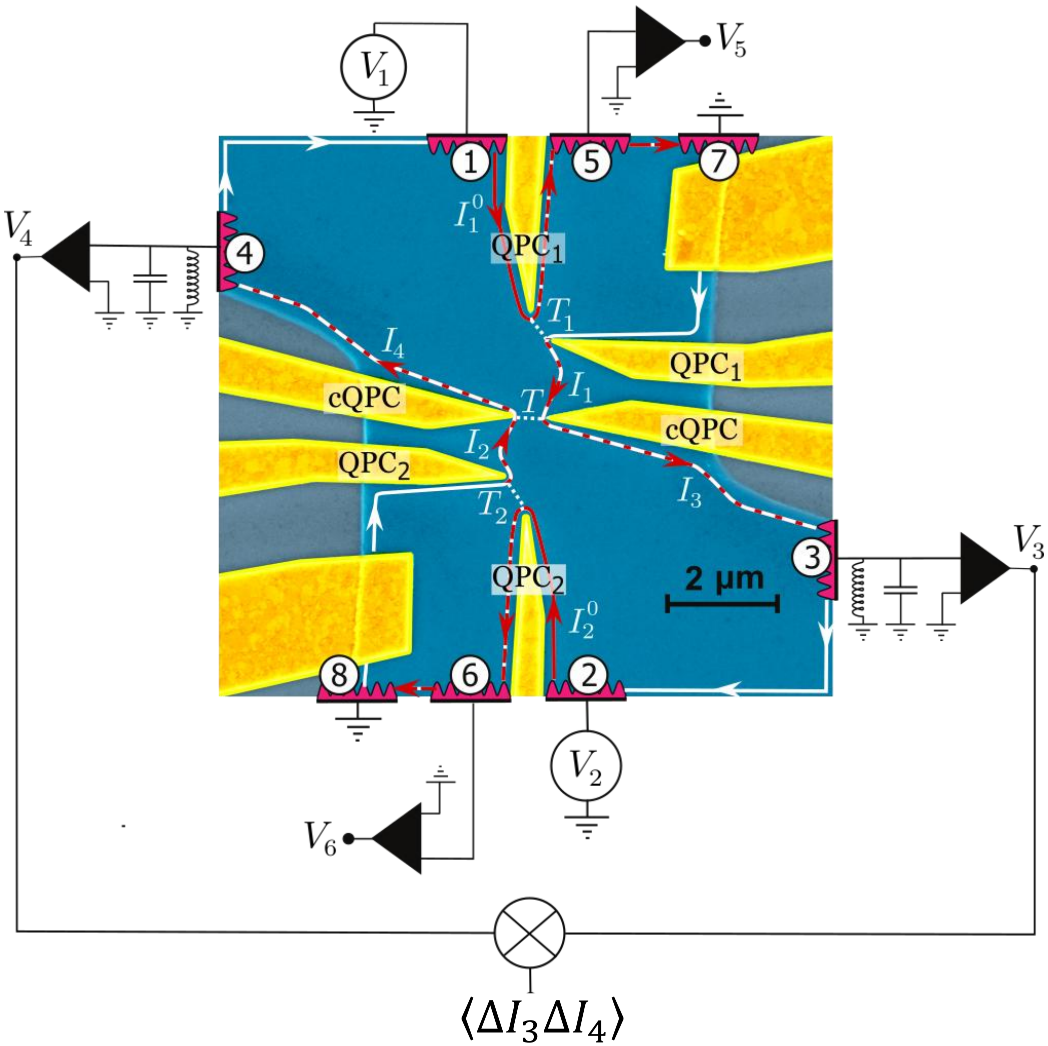
P. Glidic et al., Phys. Rev. X **13**, 011030 (2023).

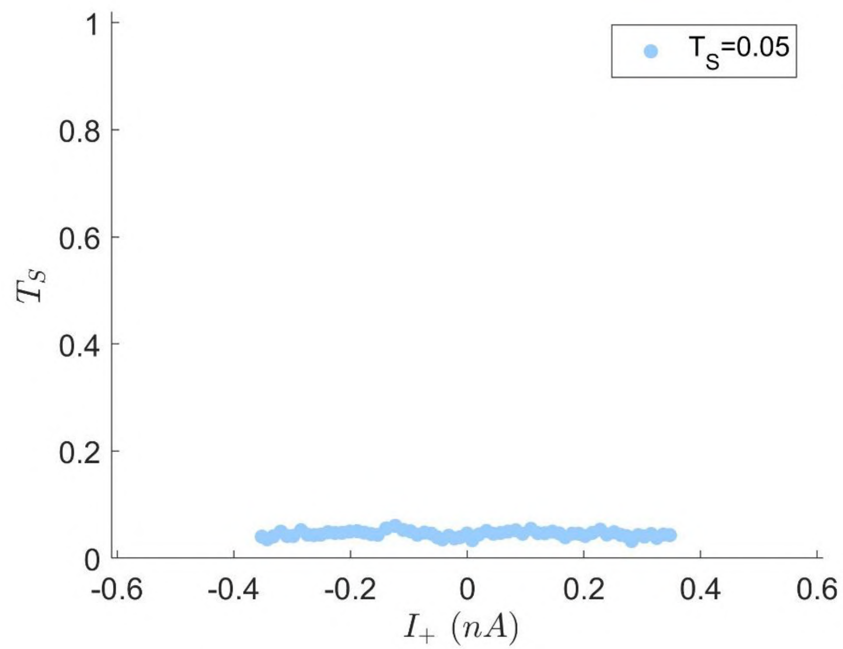
Balanced collider, $I_1^{in} = I_2^{in}$, anyon case, $\nu = 1/3$

Fractional case: q $= e/3$, anyons

$\nu = 1/3, T = 0.3, T_S = 0.05$

Balanced case: $I_1^{in} = I_2^{in}$





H. Bartolomei, M. Kumar et al., Science **368** 173 (2020)

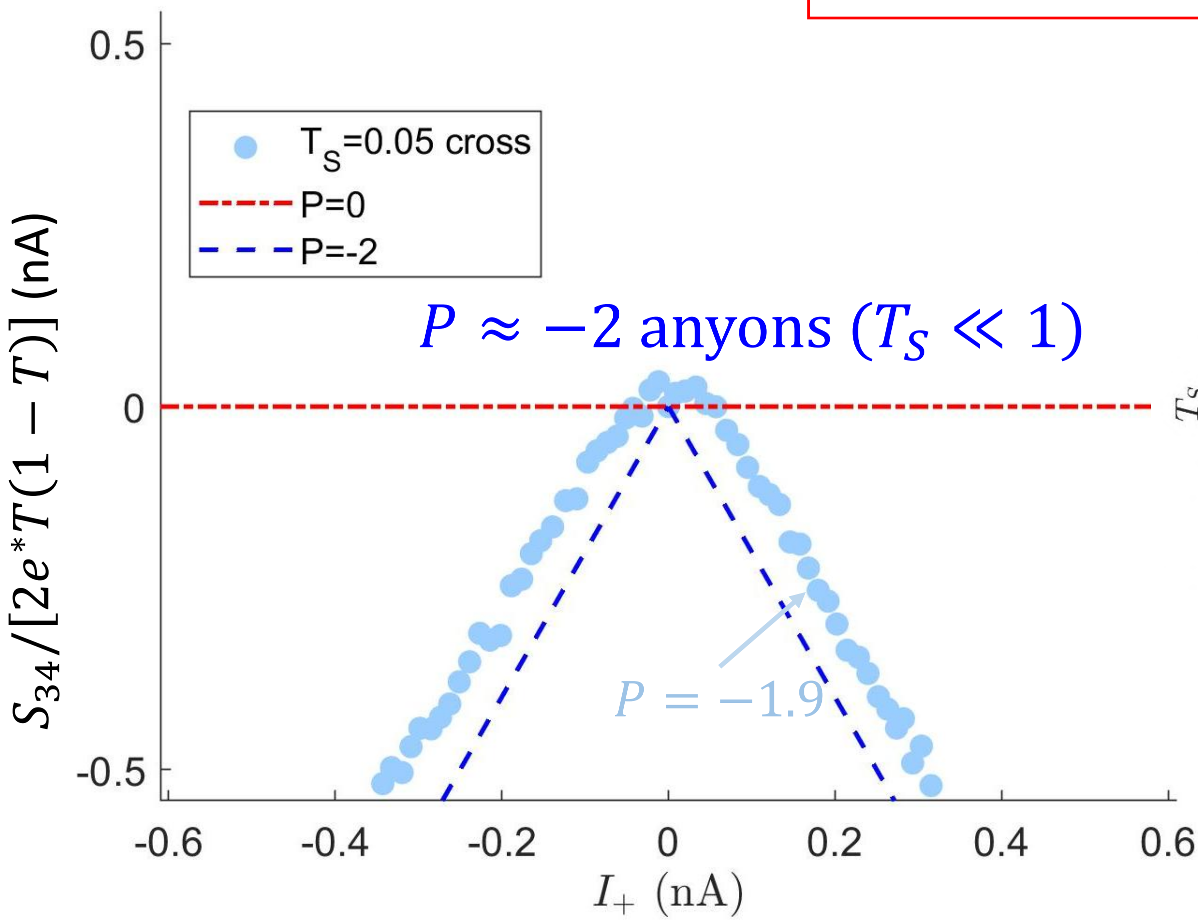
M. Ruelle et al., PRX **13**, 011031 (2023)

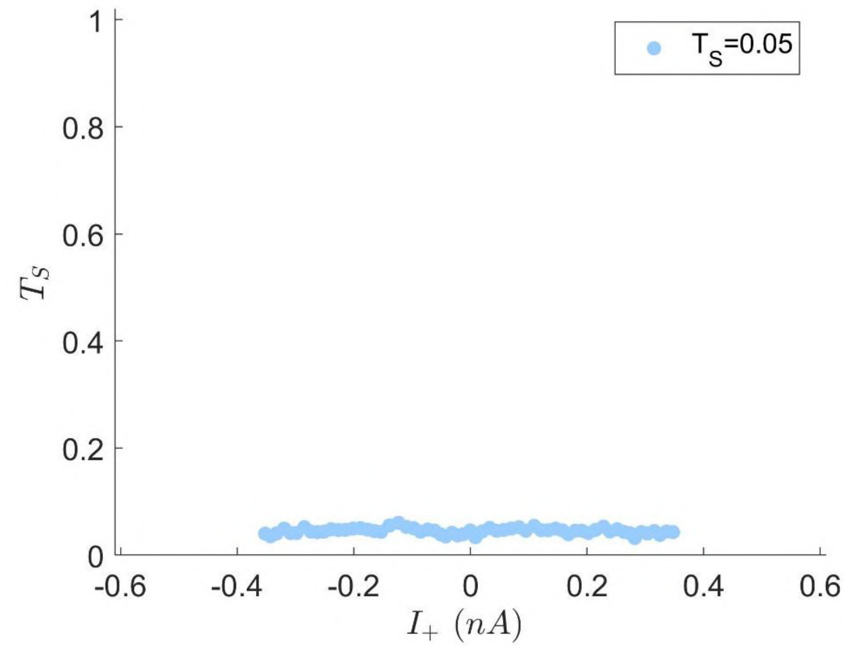
Balanced collider, $I_1^{in} = I_2^{in}$, anyon case, $\nu = 1/3$

Balanced case: $I_1^{in} = I_2^{in}$

Fractional case: $q = e/3$, anyons

$\nu = 1/3, T = 0.3, T_S = 0.05$





H. Bartolomei, M. Kumar et al., Science **368** 173 (2020)
M. Ruelle et al., PRX **13**, 011031 (2023)

$P(\theta = 2\pi/3) = -2$, Rosenow et al. PRL 2016

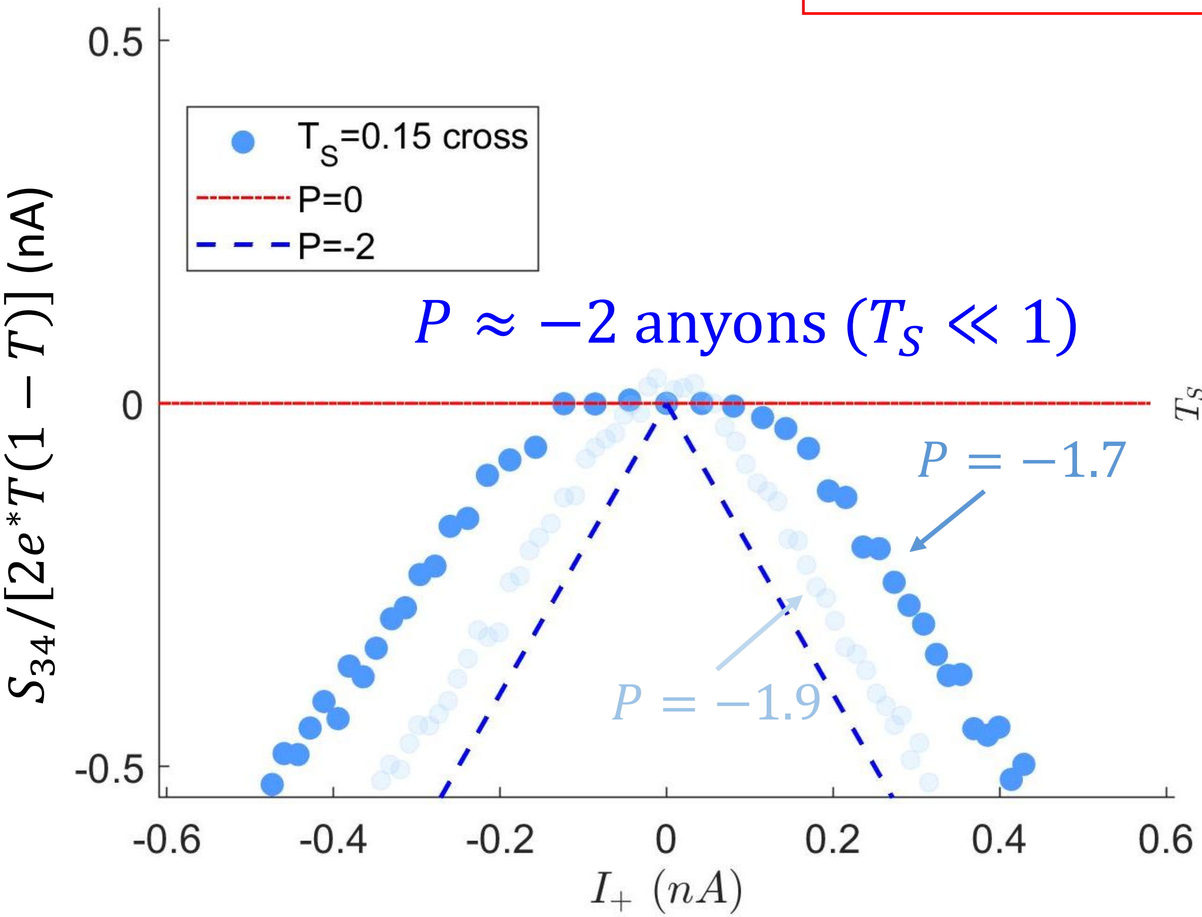
$T_S \ll 1$: standard bunching (similar to photons) $\propto T_S^2$ can be excluded!

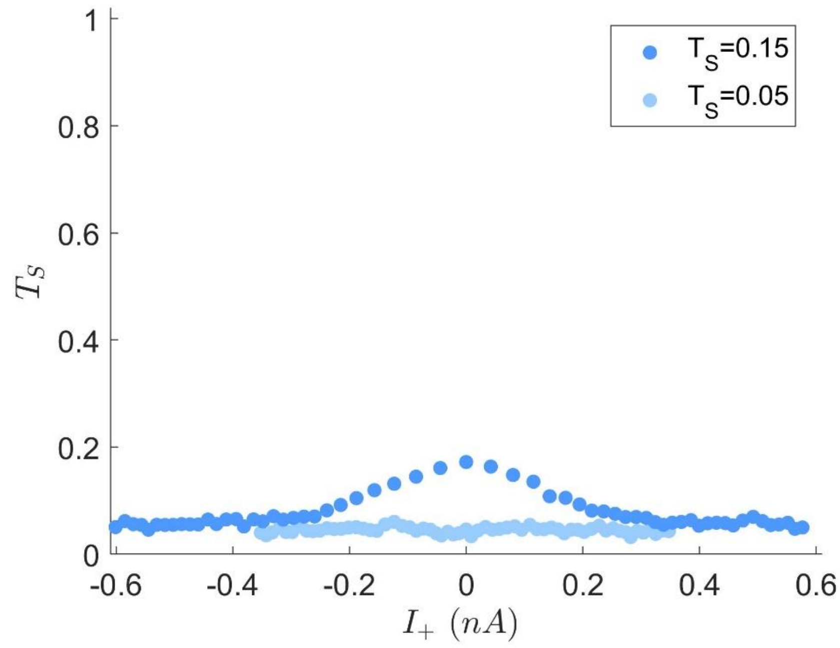
Balanced collider, $I_1^{in} = I_2^{in}$, anyon case, $\nu = 1/3$

Balanced case: $I_1^{in} = I_2^{in}$

Fractional case: $q = e/3$, anyons

$\nu = 1/3, T = 0.3, T_S = 0.15$





H. Bartolomei, M. Kumar et al., Science **368** 173 (2020)

M. Ruelle et al., PRX **13**, 011031 (2023)

$P(\theta = 2\pi/3) = -2$, Rosenow et al. PRL 2016

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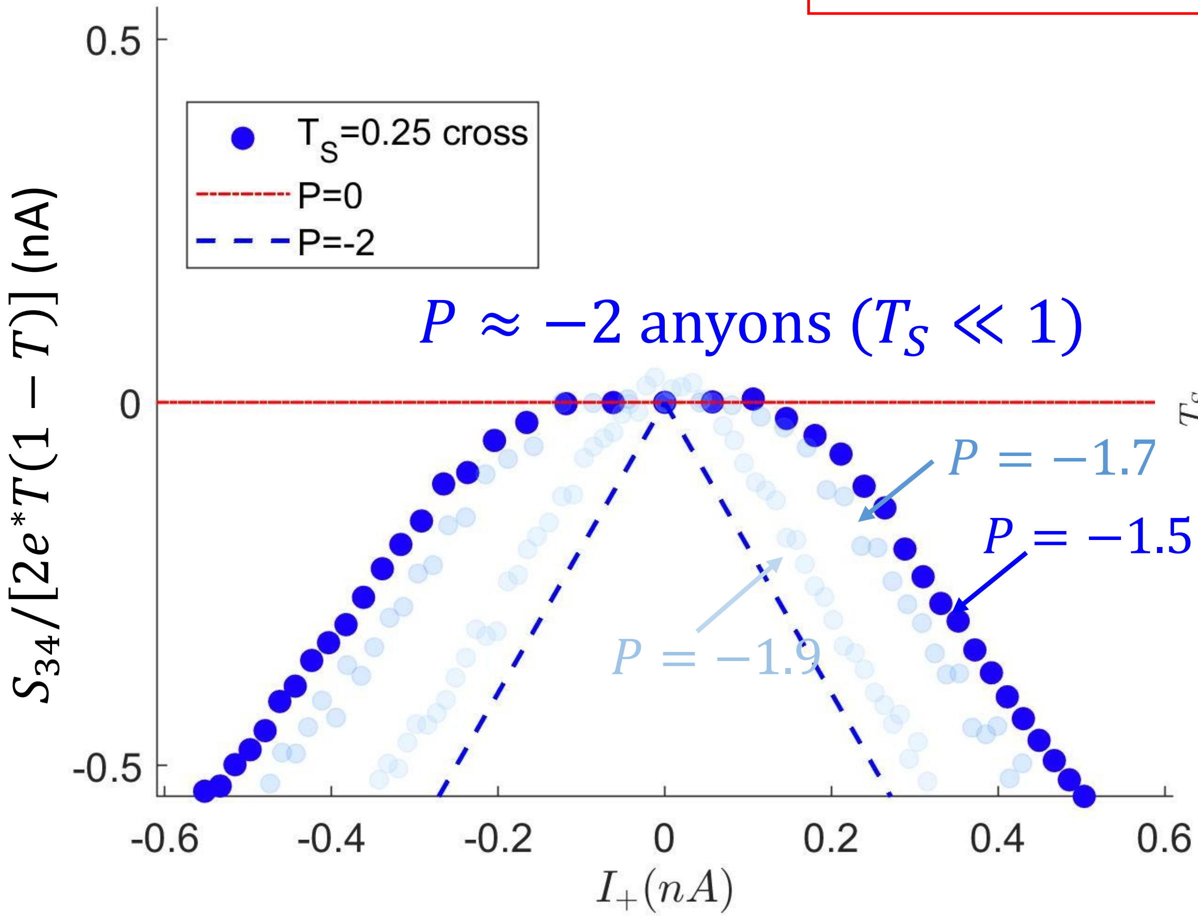
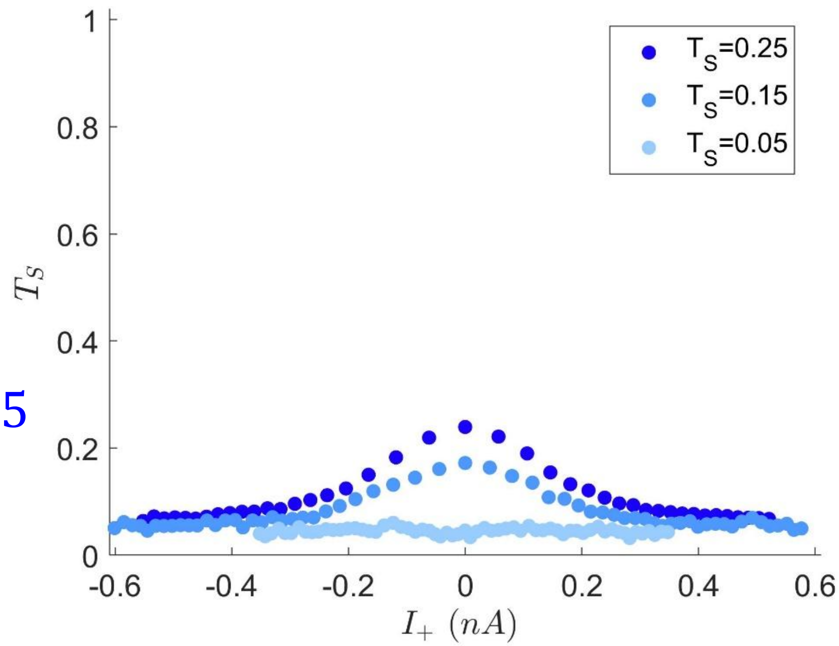
Balanced collider, $I_1^{in} = I_2^{in}$, anyon case, $\nu = 1/3$

Balanced case: $I_1^{in} = I_2^{in}$

Fractional case: q $= e/3$, anyons

$\nu = 1/3, T = 0.3, T_S = 0.25$





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M. Ruelle et al., PRX **13**, 011031 (2023)

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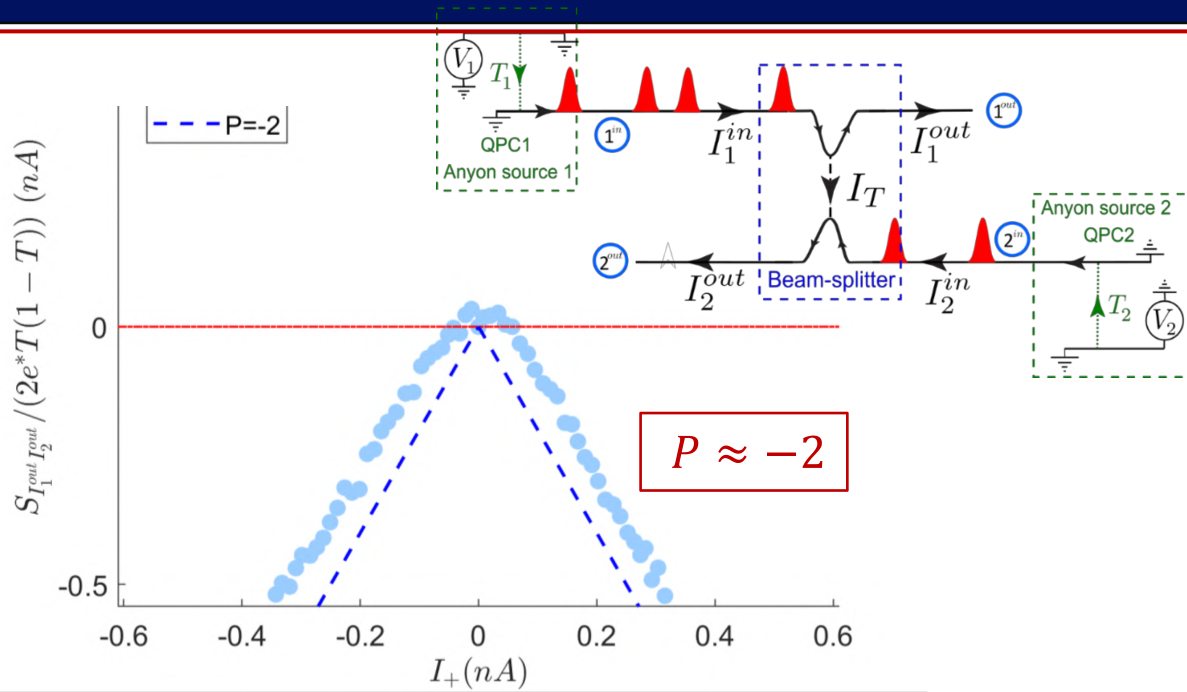
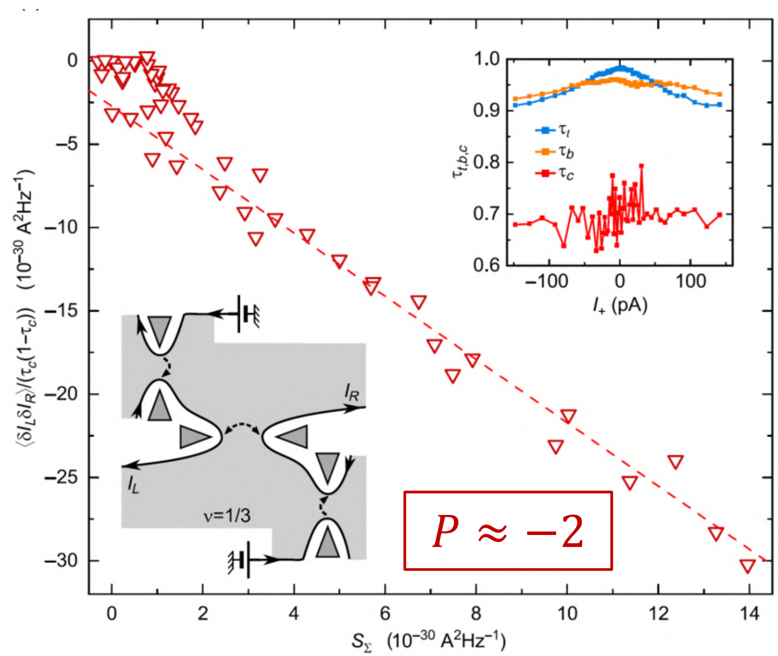
Partitioning of diluted anyon beams, $\nu = 1/3$

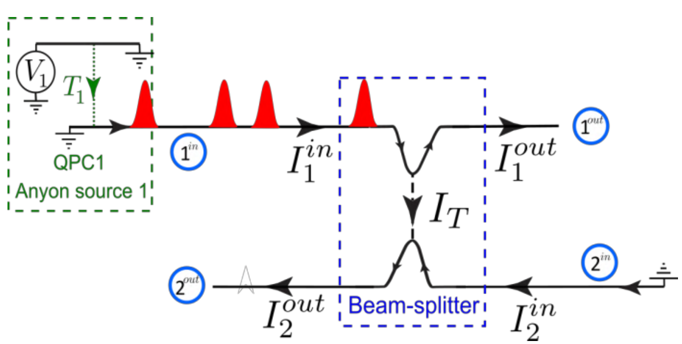


H. Bartolomei et al., Science **368** 173 (2020)

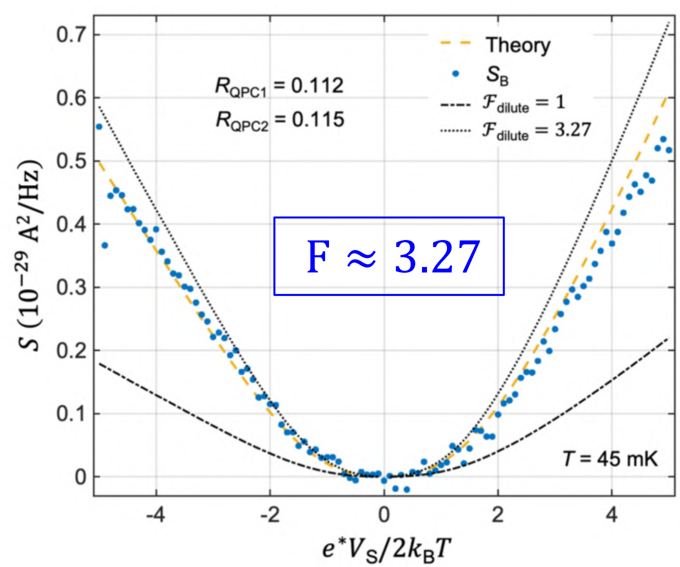
M. Ruelle et al., PRX **13**, 011031 (2023)



P. Glidic et al., PRX **13**, 011030 (2023).



J.Y.M. Lee et al., Nature **617**, 277 (2023).



Two-particle interferometry at a QPC

Time-domain braiding:

H.S Sim KAIST

Han et al., Nat. Commun. **7**, 11131 (2016)

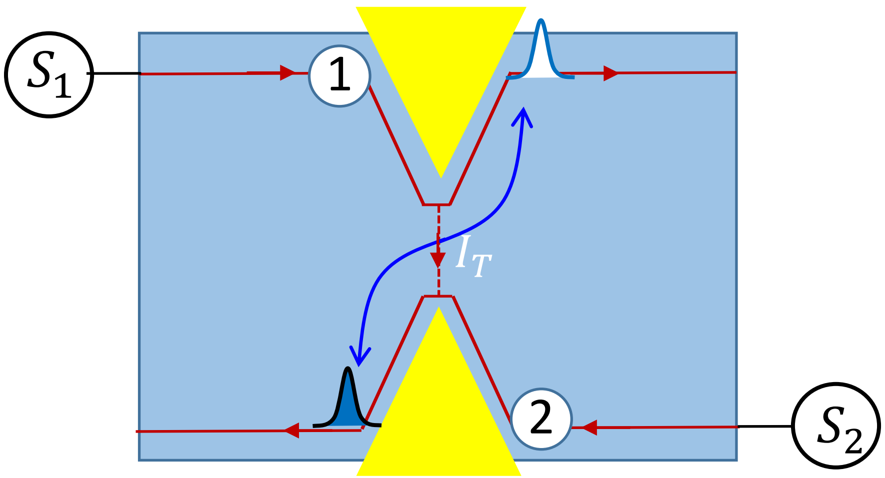
Morel et al., PRB **105**, 075433 (2022)

Lee et al., Nat. Commun. **13**, 6660 (2022)

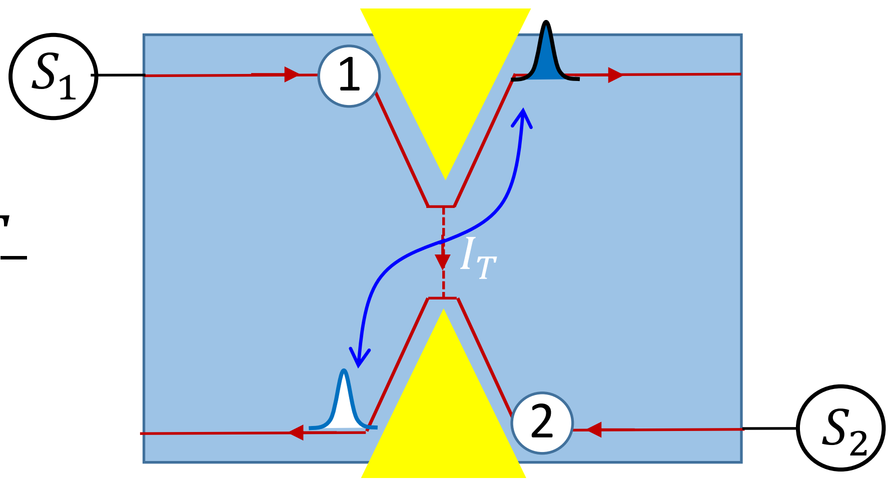
Schiller et al., PRL **131** 186601 (2023)

Weak backscattering regime: lowest order in tunneling $H_T = \zeta \psi_{2,a}^{+} \psi_{1,a} + \zeta^* \psi_{1,a}^{+} \psi_{2,a}$

Γ_+



Γ_-



$I_T = q(\Gamma_+ - \Gamma_-)$ Tunneling current

$S_{I_T} = 2q^2(\Gamma_+ + \Gamma_-)$ Noise of tunneling current

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Two-particle interferometry at a QPC

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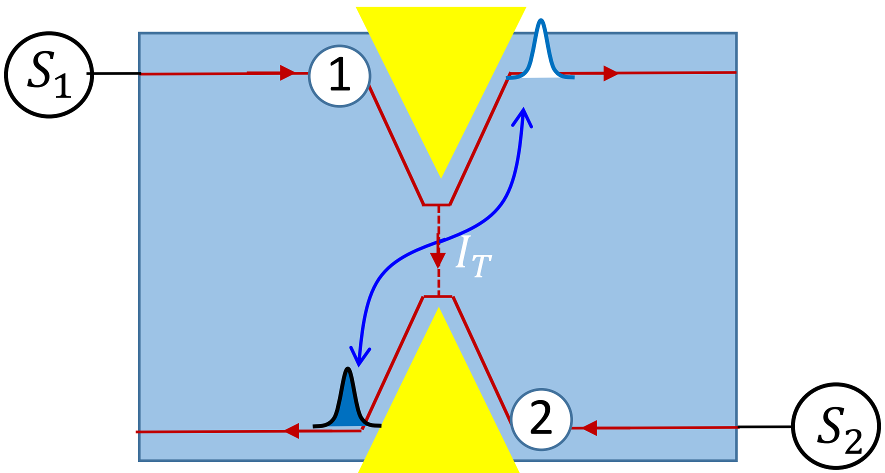
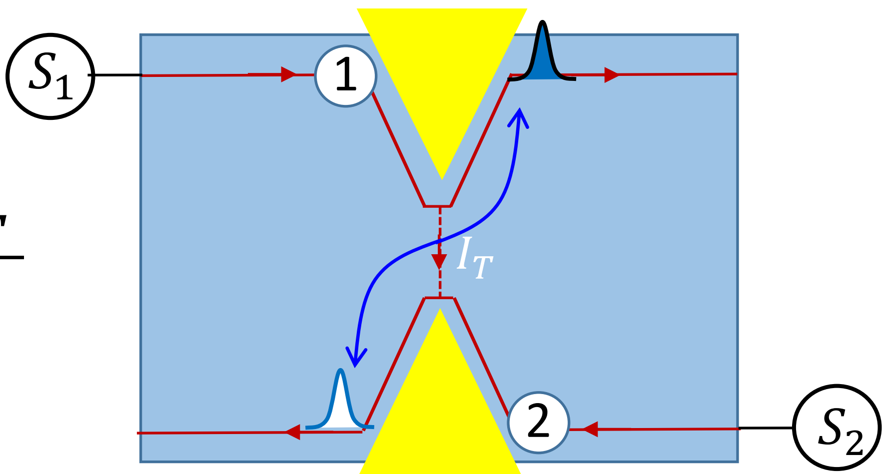


Γ_-



$I_T = q(\Gamma_+ - \Gamma_-)$ Tunneling current

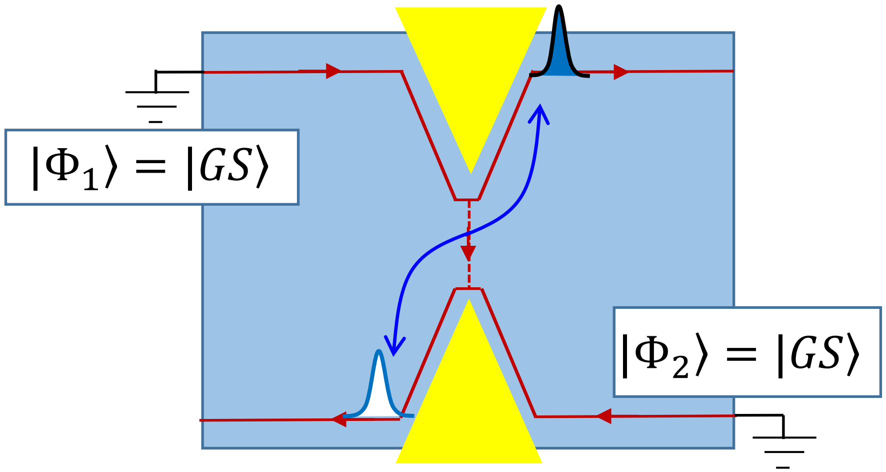
$S_{I_T} = 2q^2(\Gamma_+ + \Gamma_-)$ Noise of tunneling current

$$\Gamma_-(t) \propto \int_0^{+\infty} d\tau \; \underbrace{\langle \psi_{1,a}(t)\psi^{+}_{1,a}(t-\tau)\rangle\langle \psi^{+}_{2,a}(t)\psi_{2,a}(t-\tau)\rangle}_{\text{Two particle interferometry}} + h.c.$$

$\Gamma_+(t) \propto \cdots$

Equilibrium case

- Rate Γ_-



Han et al., Nat. Commun. **7**, 11131 (2016)

Morel et al., PRB **105**, 075433 (2022)

Lee et al., Nat. Commun. **13**, 6660 (2022)

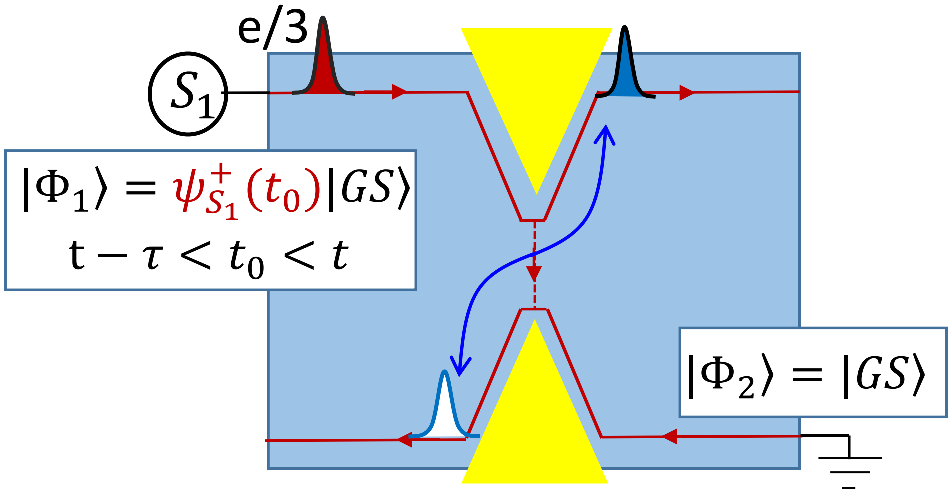
Schiller et al., PRL **131** 186601 (2023)

$$\langle GS|\psi_1\,(t)\psi_1^+(t-\tau)|GS\rangle = \langle GS|\psi_2^+(t)\psi_2\,(t-\tau)|GS\rangle = G_{eq}(\tau)$$

Equilibrium correlations

Time-domain braiding, single anyon in 1

- Rate Γ_-



Han et al., Nat. Commun. **7**, 11131 (2016)

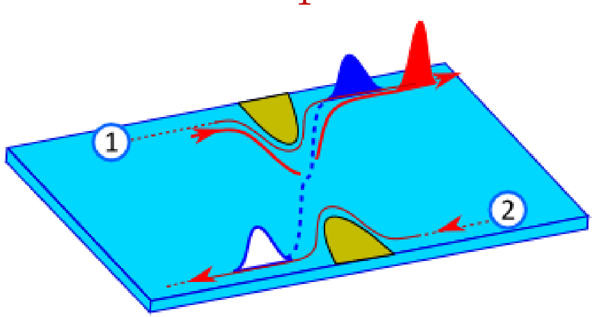
Morel et al., PRB **105**, 075433 (2022)

Lee et al., Nat. Commun. **13**, 6660 (2022)

Schiller et al., PRL **131** 186601 (2023)

$$\langle \Phi_1|\psi_1(t)\psi_1^+(t-\tau)|\Phi_1\rangle = \langle GS|\psi_{S_1}(t_0)\psi_1(t)\;\psi_1^+(t-\tau)\psi_{S_1}^+(t_0)|GS\rangle$$

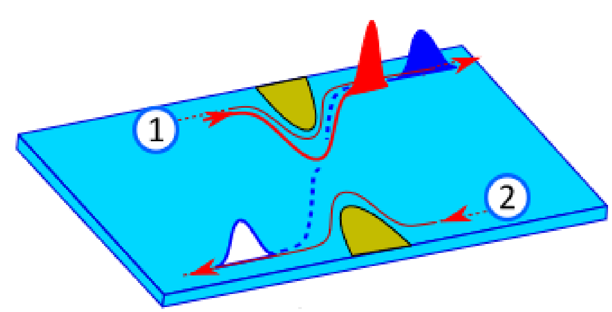
$\psi_1^+(t)\psi_{S_1}^+(t_0)|GS\rangle$



Tunneling $1 \rightarrow 2$ at $t > t_0$

+

$\psi_1^+(t-\tau)\psi_{S_1}^+(t_0)|GS\rangle$

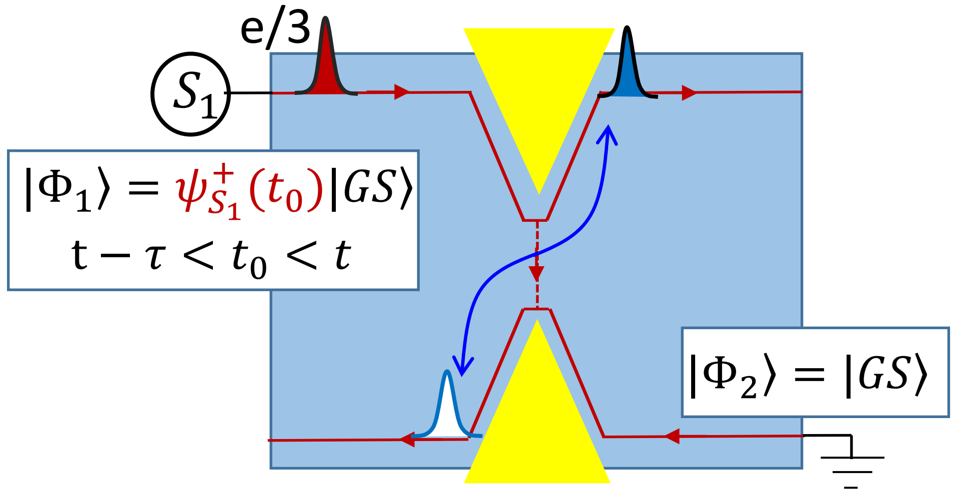


Tunneling $1 \rightarrow 2$ at $t - \tau < t_0$

Interferences between tunneling of blue anyon at times t and $t - \tau$

Time-domain braiding, single anyon in 1

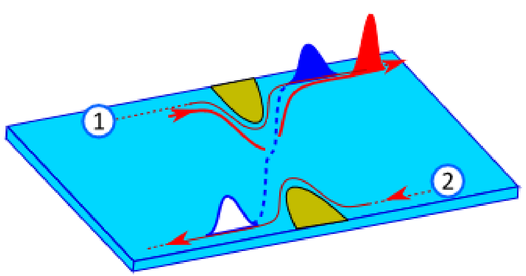
- Rate Γ_-



Han et al., Nat. Commun. **7**, 11131 (2016)
Morel et al., PRB **105**, 075433 (2022)
Lee et al., Nat. Commun. **13**, 6660 (2022)
Schiller et al., PRL **131** 186601 (2023)

$$\langle \Phi_1 | \psi_1(t) \psi_1^+(t-\tau) | \Phi_1 \rangle = \langle GS | \psi_{S_1}(t_0) \psi_1(t) \, \psi_1^+(t-\tau) \psi^+_{S_1}(t_0) | GS \rangle$$

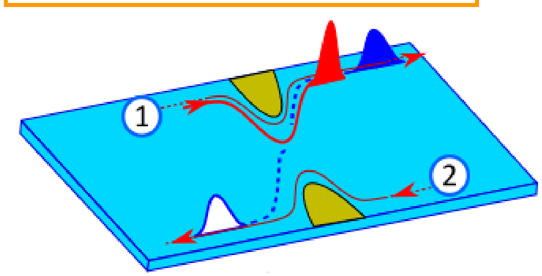
$\psi_1^+(t)\psi^+_{S_1}(t_0)|GS\rangle$



Tunneling $1 \to 2$ at $t > t_0$

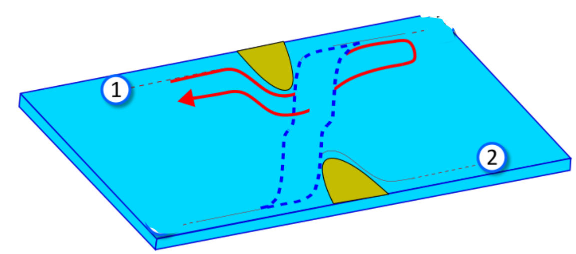
+

$\psi_1^+(t-\tau)\psi^+_{S_1}(t_0)|GS\rangle$



Tunneling $1 \to 2$ at $t - \tau < t_0$

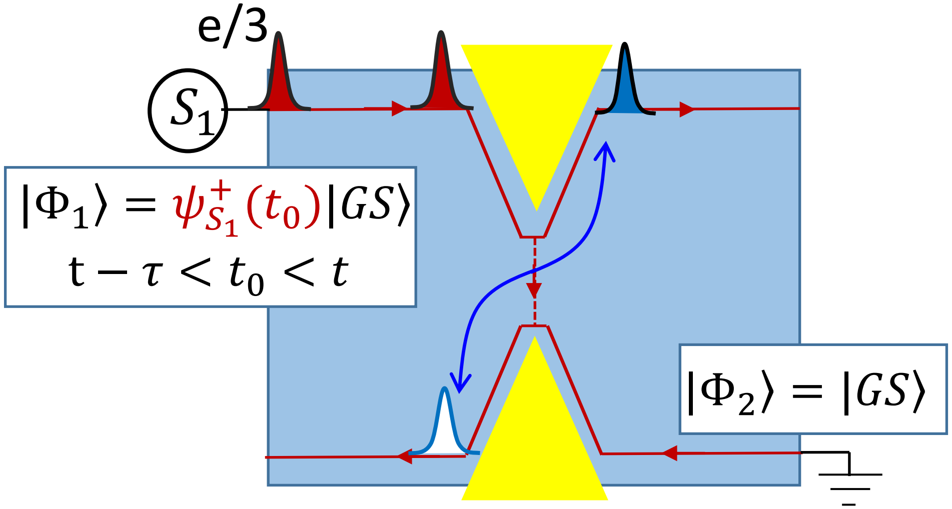
$$\langle \psi_1(t) \psi_1^+(t-\tau) \rangle = e^{-i\theta_{rb}} G_{eq}(\tau)$$



θ_{rb}: braiding phase between red and blue anyons: $\nu = 1/3$, $\theta_{rb} = 2\pi/3$

Time-domain braiding, N_1 anyons in 1

- Rate Γ_-



Han et al., Nat. Commun. **7**, 11131 (2016)
Morel et al., PRB **105**, 075433 (2022)
Lee et al., Nat. Commun. **13**, 6660 (2022)
Schiller et al., PRL **131** 186601 (2023)

$$\Gamma_\pm(t) \propto Re\left[\int_{-\infty}^{t} e^{\pm i\theta N_1(t,t')} G_{eq,\delta}(t-t')^2 dt'\right]$$

$N_1(t,t')$ set by the nature of the source S_1 (stochastic in «collider»)

θ: braiding phase (one expects $\theta = 2\pi/3$ at $\nu = 1/3$)

δ: scaling dimension, time-correlations at the edge $G_{eq,\delta}(t-t') \sim \frac{1}{|t-t'|^\delta}$

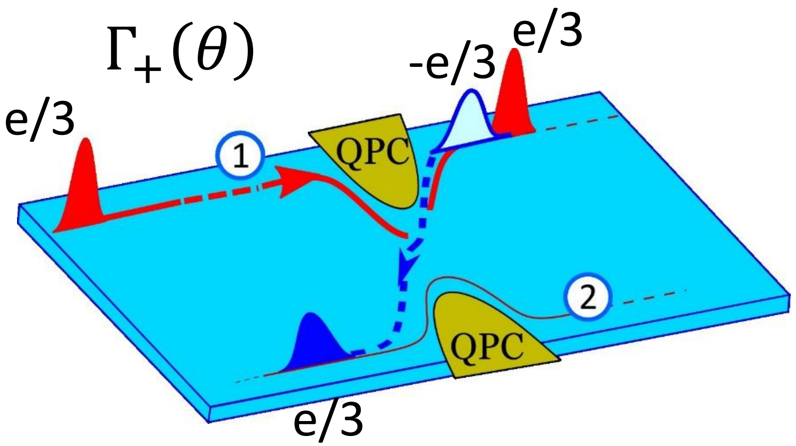
one expects $\delta = 1/3$ at $\nu = 1/3$

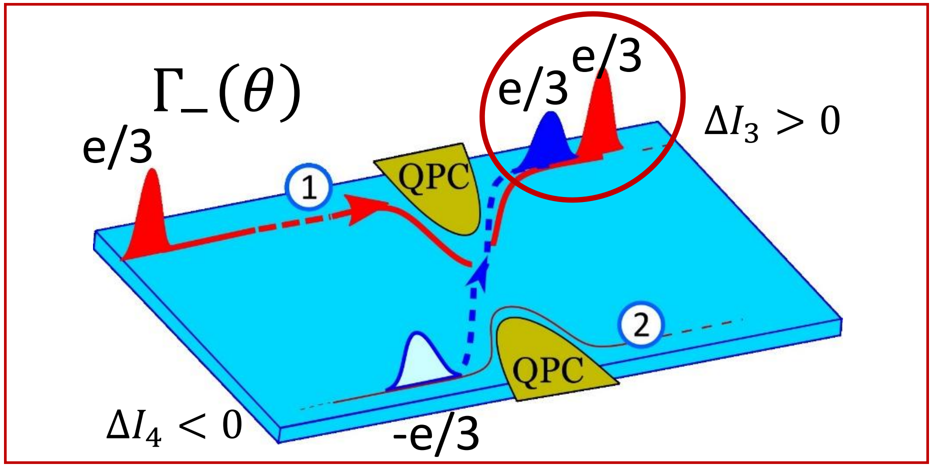
X. G Wen, Advances in Physics, 44, 405 (1995)
I. Safi, arXiv:2510.10525
A. Latyshev and I. Safi, arXiv:2510.2059

$\delta = 1/3$ at $\nu = 1/3$ observed in

A. Veillon et al., Nature **632**, 517–521 (2024).
R. Guerrero-Suarez et al, Nat. Phys. **21**, 1787 (2025)

Time-domain anyon braiding at a QPC

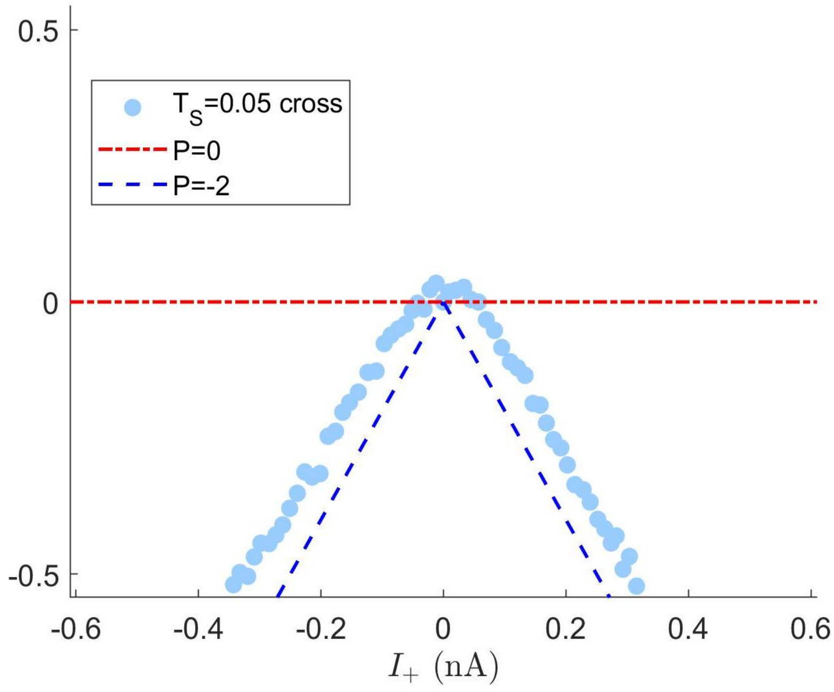




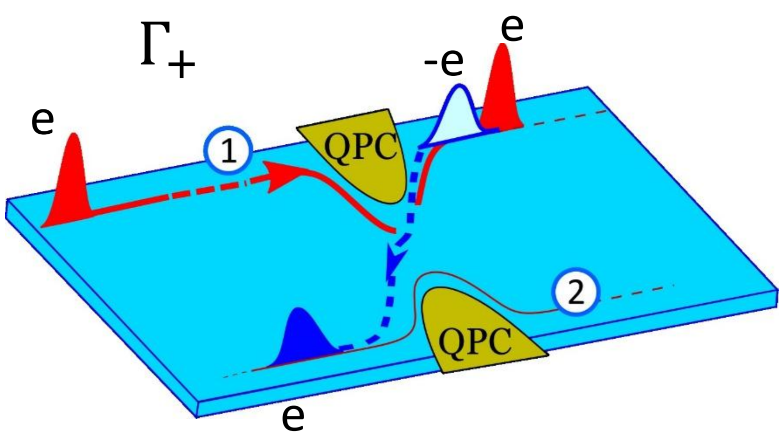
Anyons: $\Gamma_-(\theta \neq 2\pi) \neq 0$: bunching

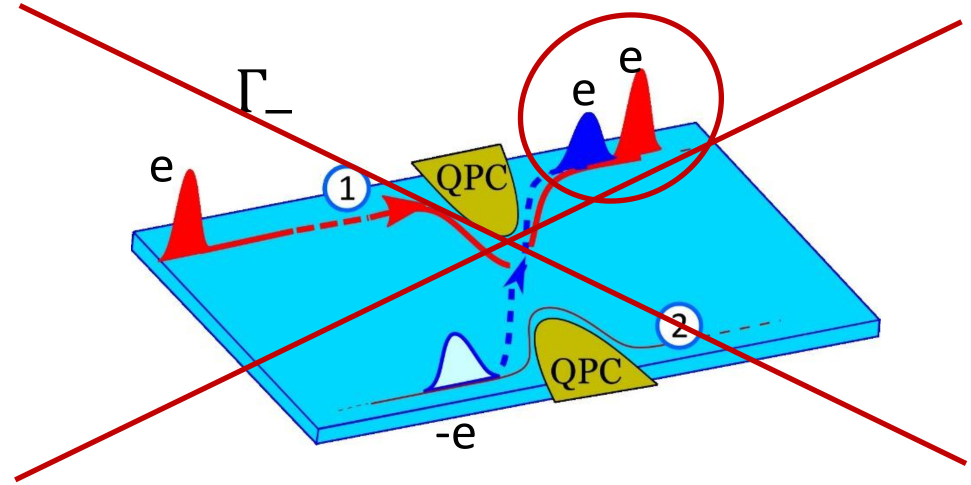
$P < 0$ and $P(\theta = 2\pi/3) = -2$

One anyon in 1 is enough to produce a pair of anyons in 1 together with an anyon hole in 2



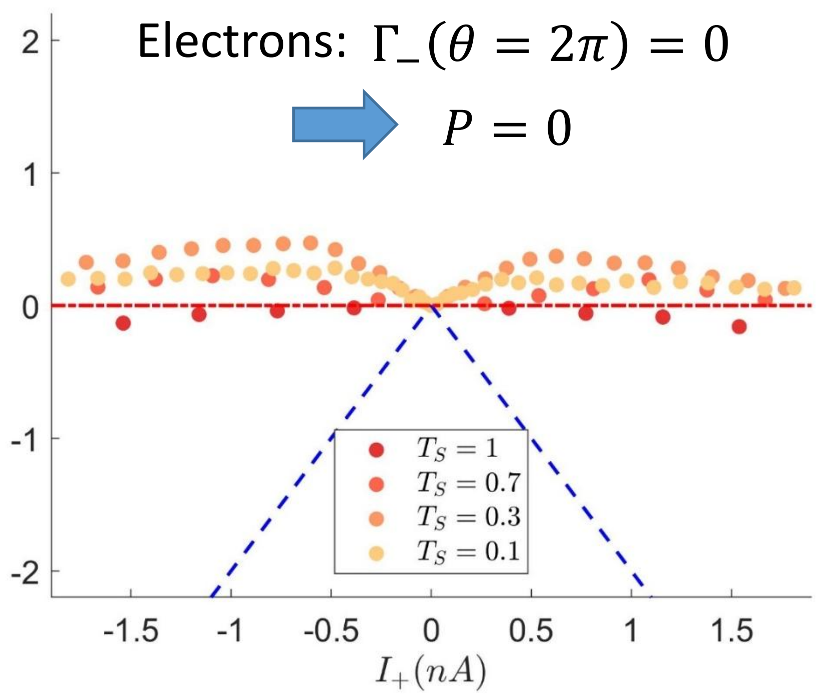
Electron case, integer filling: $\theta = 2\pi$



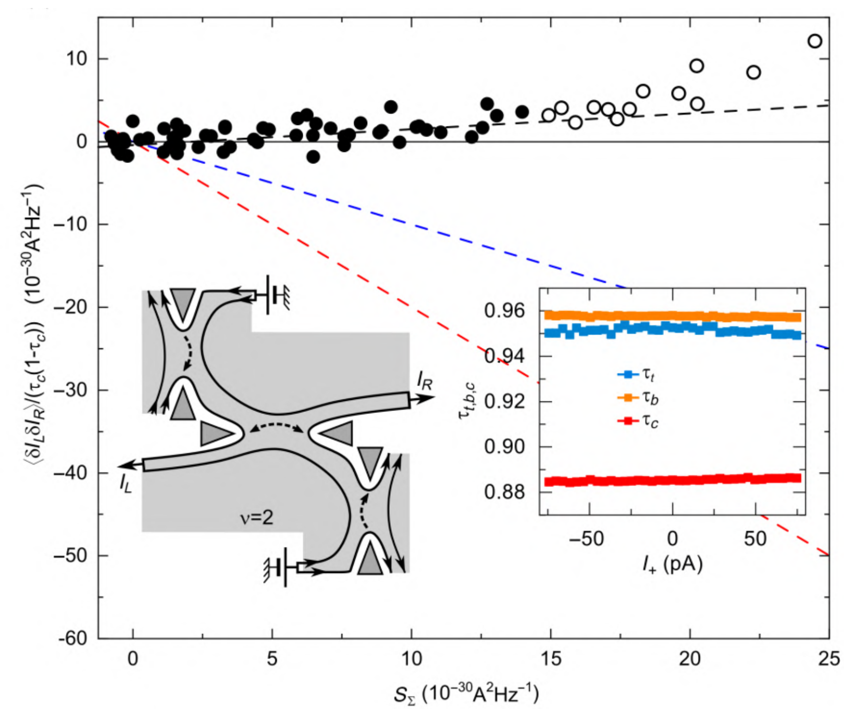


Electrons: $\Gamma_-(\theta = 2\pi) = 0$

$P = 0$

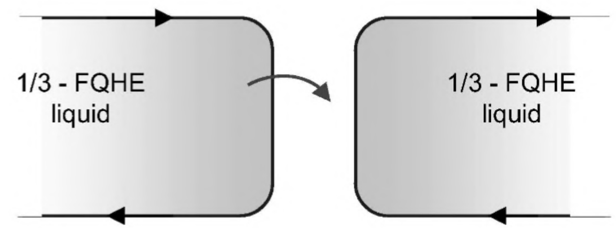


H. Bartolomei, M. Kumar et al., Science **368** 173 (2020)

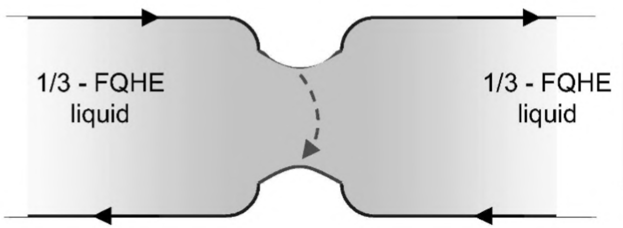


P. Glidic et al., Phys. Rev. X **13**, 011030 (2023).

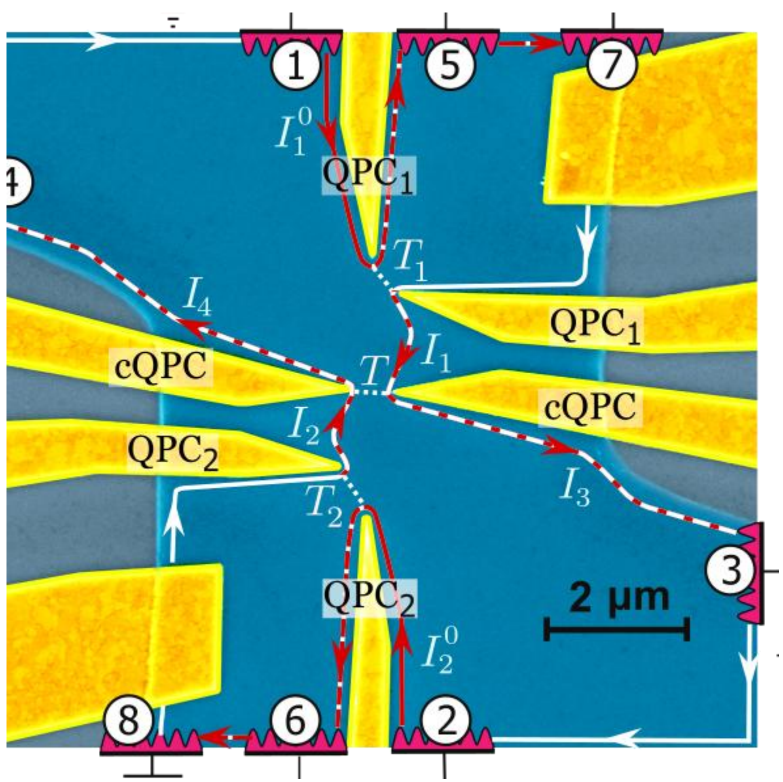
Electron and anyon tunneling, $\nu = 1/3$

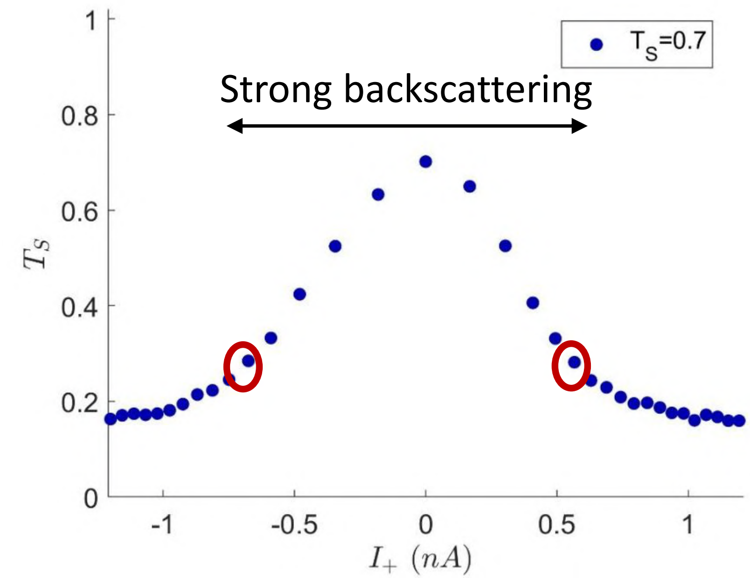


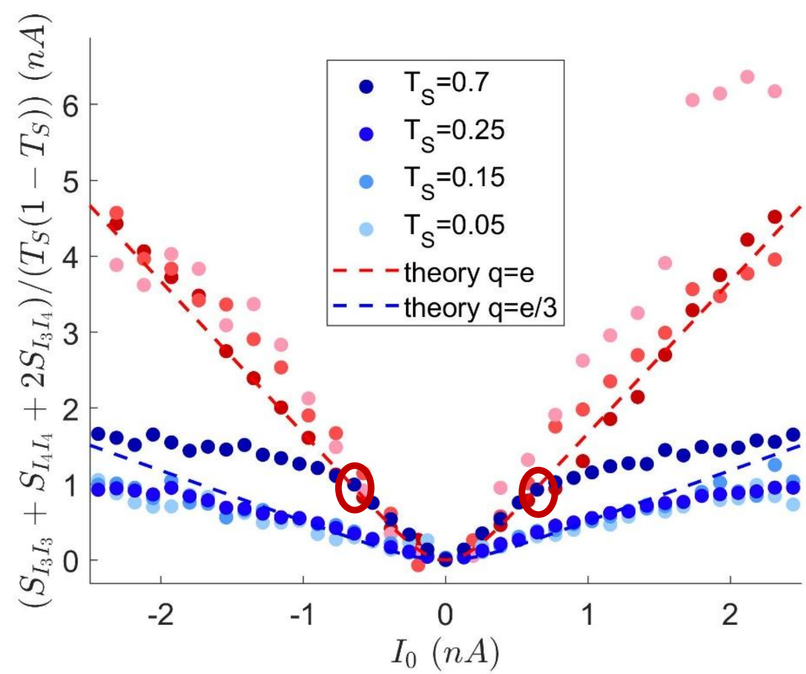
Strong backscattering,
Electron tunneling,
q=e



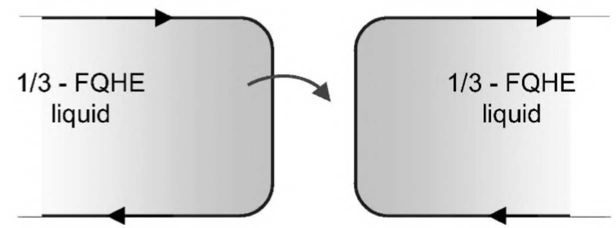
Weak backscattering,
Anyon tunneling,
q=e/3



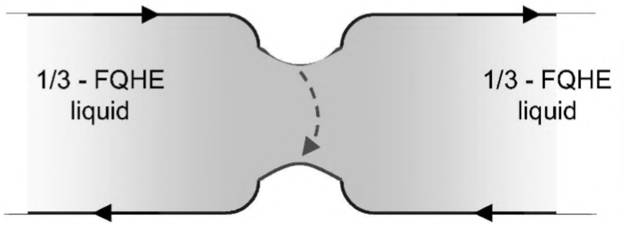




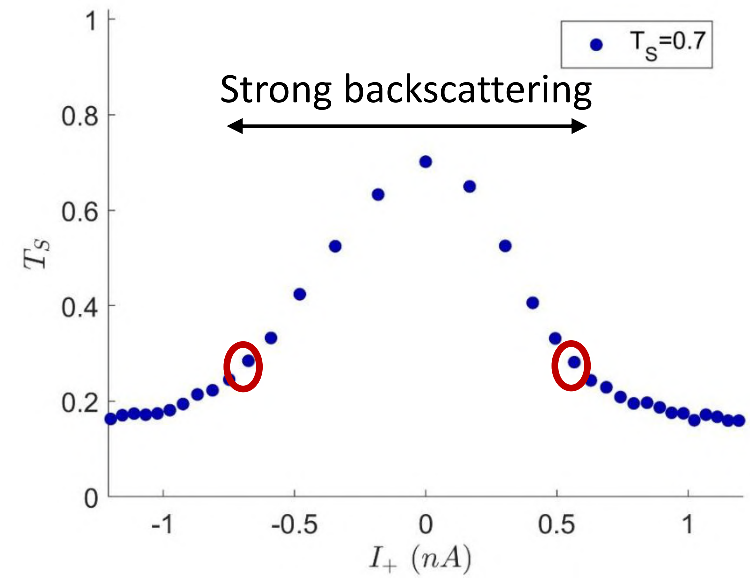
Electron and anyon tunneling, $\nu = 1/3$

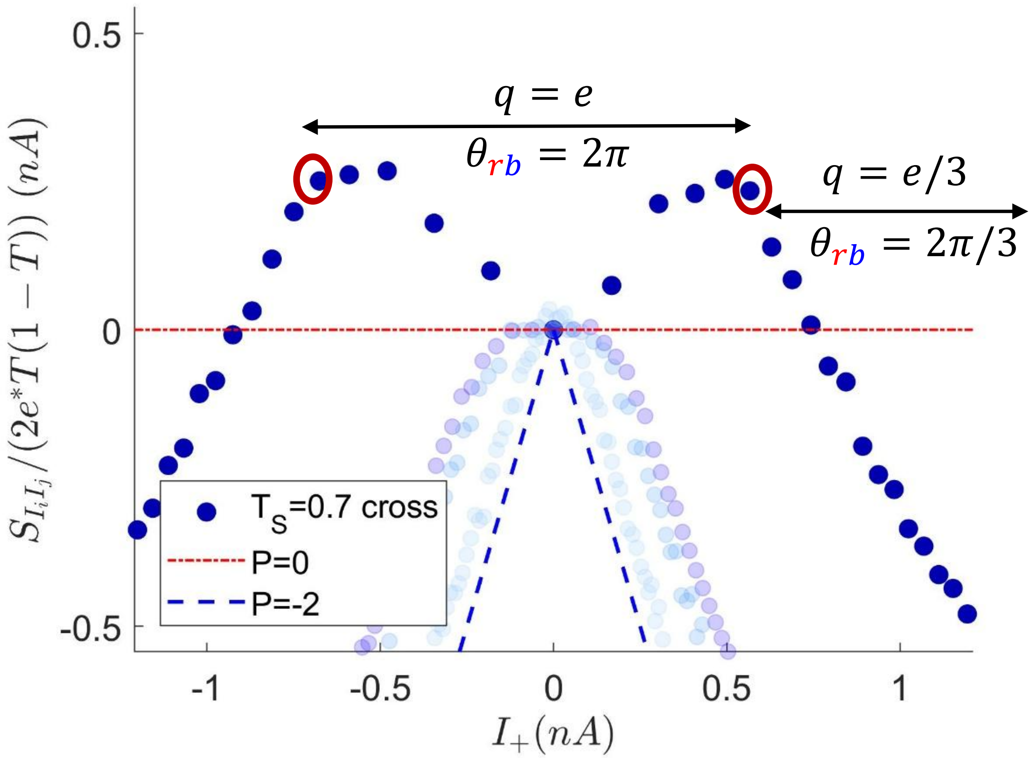


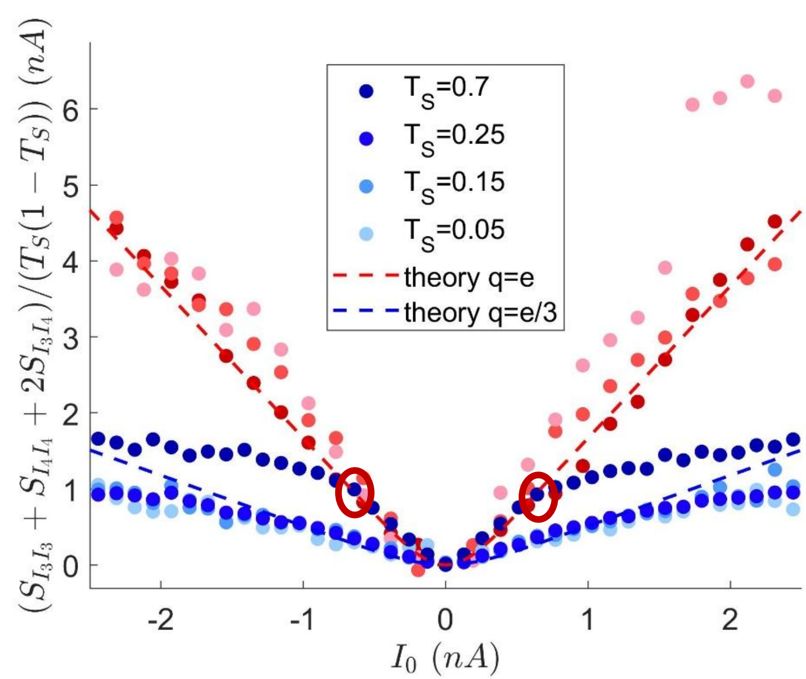
Strong backscattering,
Electron tunneling,
q=e



Weak backscattering,
Anyon tunneling,
q=e/3

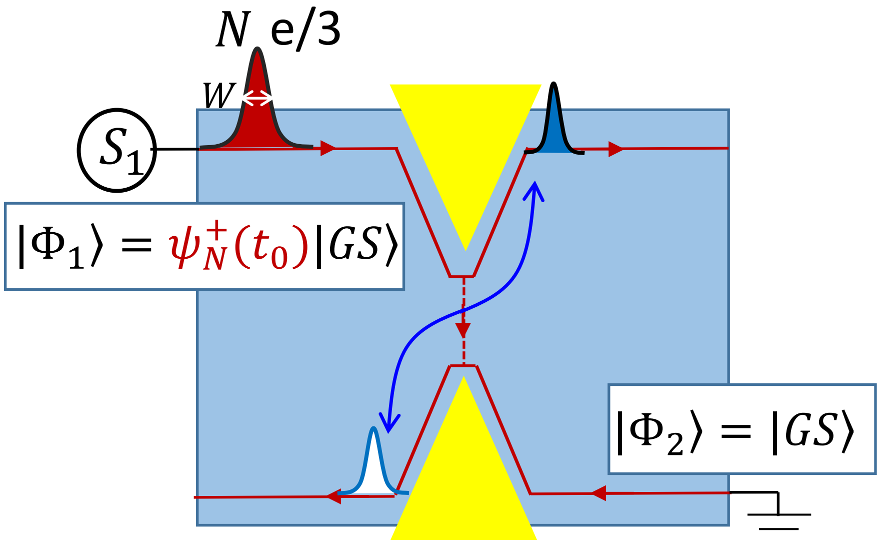






Anyon braiding with a trigerred anyon source

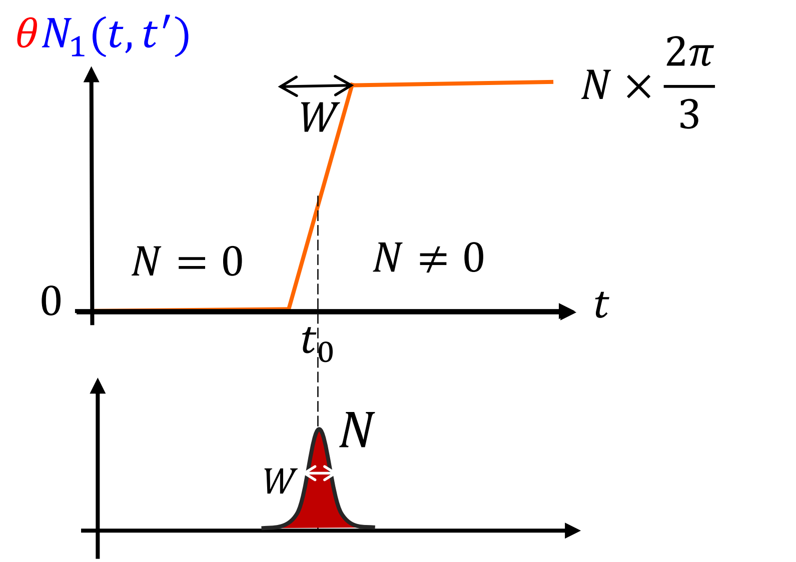
T. Jonckheere, et al., PRL **130**, 186203 (2023).



$$\Gamma_\pm(t) \propto Re\left[\int_{-\infty}^{t} e^{\pm i\theta N(t,t')} G_{eq}(t-t')^2 dt'\right]$$

N $=$ 1: single anyon emission at $\nu = 1/3$

N $=$ 3: single electron emission at $\nu = 1/3$



Stochastic source replaced by deterministic anyon source:

N anyons cross the QPC at time t_0

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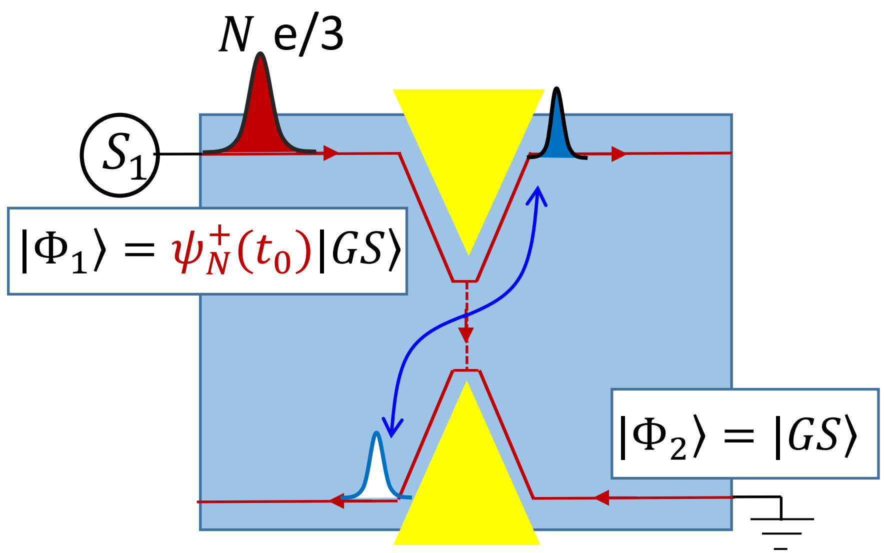
Anyon braiding with a trigerred anyon source

T. Jonckheere, et al., PRL **130**, 186203 (2023).



$$I_T = q(\Gamma_+ - \Gamma_-)$$

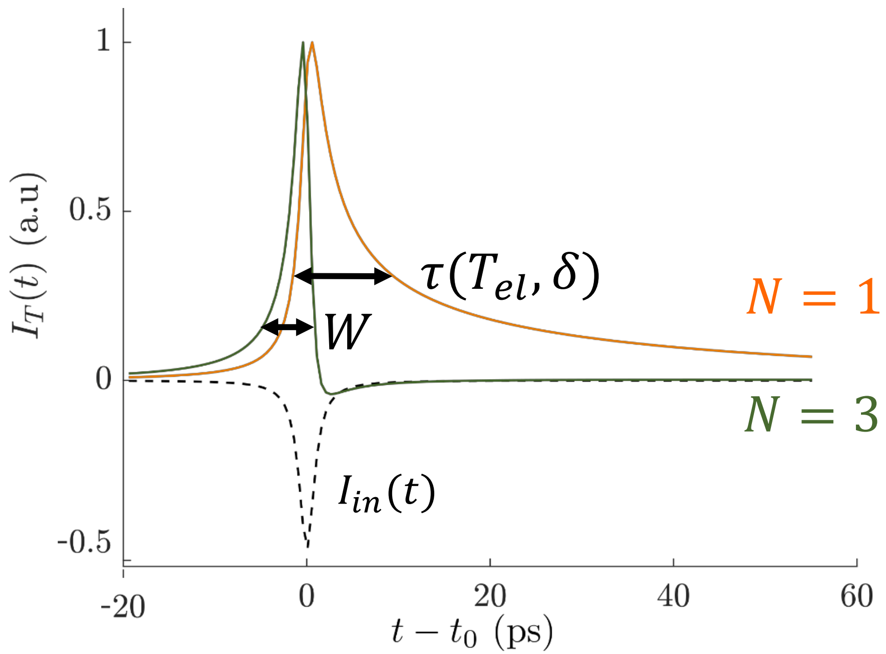
Braiding phase factor, varies on timescale W

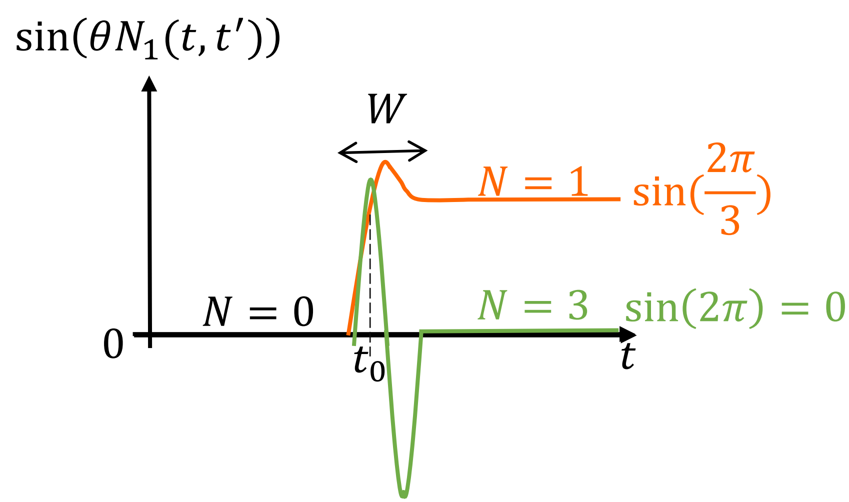
Memory or correlation time decays on $\tau(T_{el}, \delta)$

$$I_T(t) \propto \int_{-\infty}^{t} dt' \sin(\theta N_1(t,t')) Im[G_\delta(t-t')^2]$$

N = 1: single anyon emission at $\nu = 1/3$

N = 3: single electron emission at $\nu = 1/3$

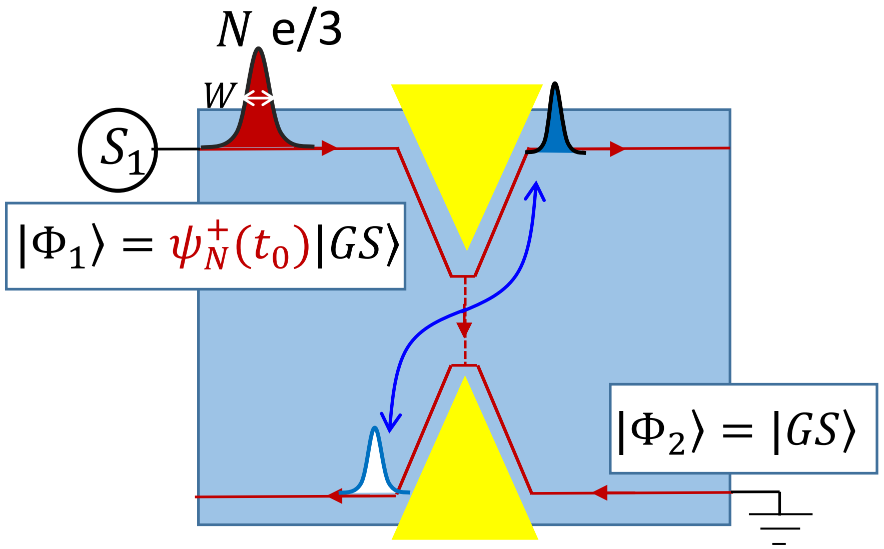


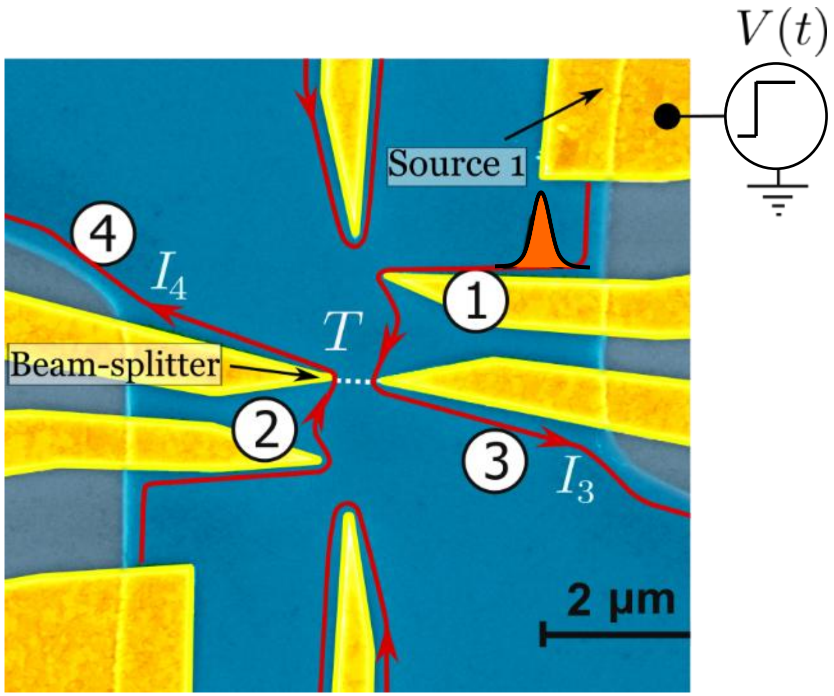


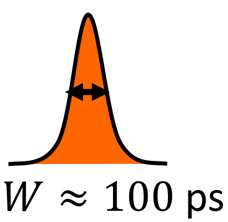
Brings information on both θ and δ

Anyon braiding with a trigerred anyon source

T. Jonckheere, et al., PRL **130**, 186203 (2023).







$N = CV/e^*$

Current pulse carrying charge $Ne/3$ emulates N −anyon source

J.Y. Lee, C. Han, H.S. Sim, PRL **125**, 196802 (2020)

C. Mora, arXiv:2212.05123 (2022)

M. Ruelle et al., Science **389**, eadm7695 (2025).

Calibrated capacitance…

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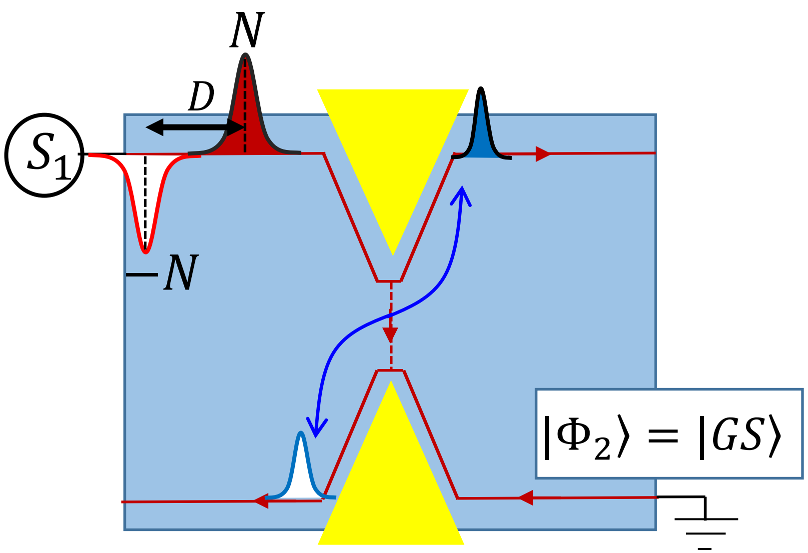
HOM with anyon pulses

T. Jonckheere, et al., PRL **130**, 186203 (2023).

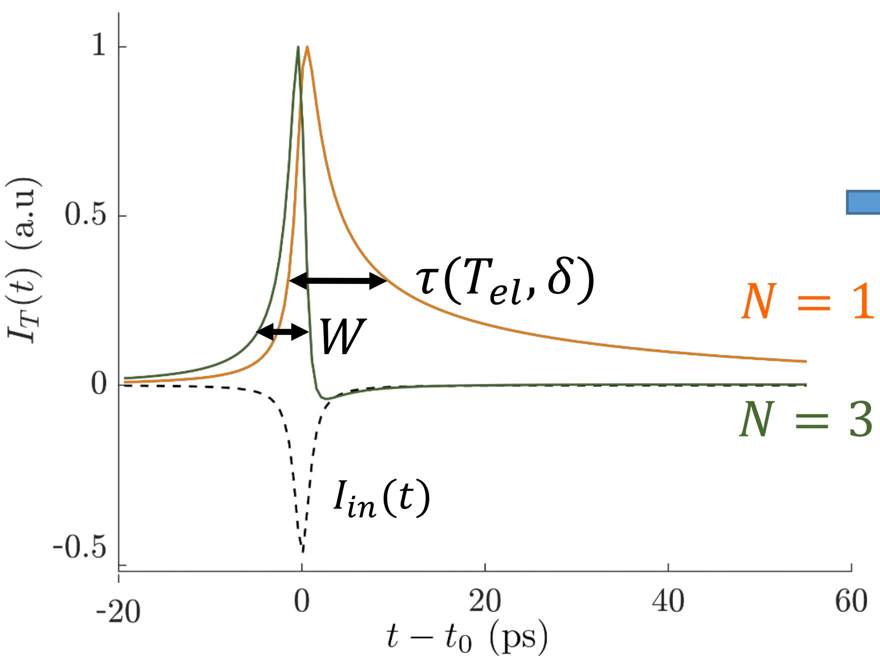
A. Latyshev et al., arXiv:2509.07875

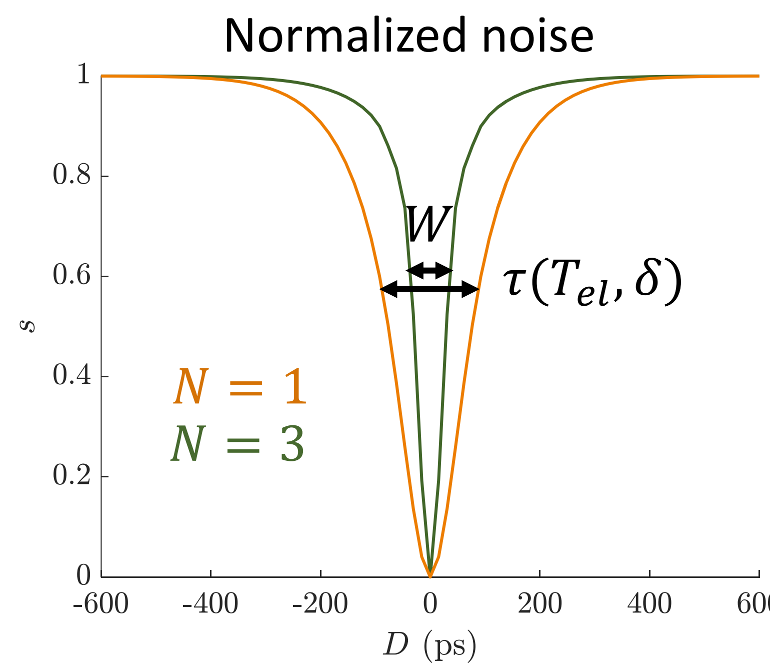
S. Varada et al., PRB **111** (20), L201407 (2025)



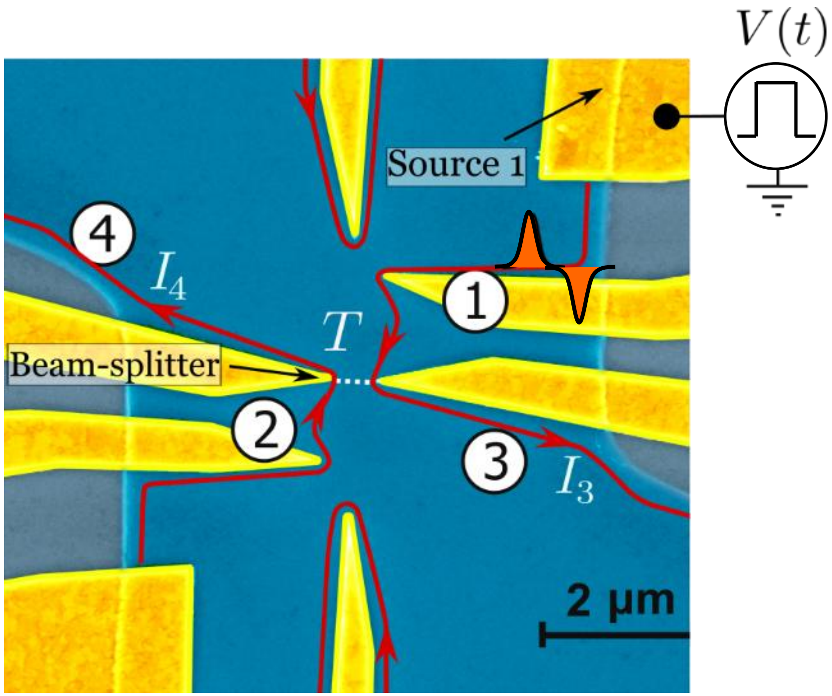
$N = 1$: single anyon emission at $\nu = 1/3$

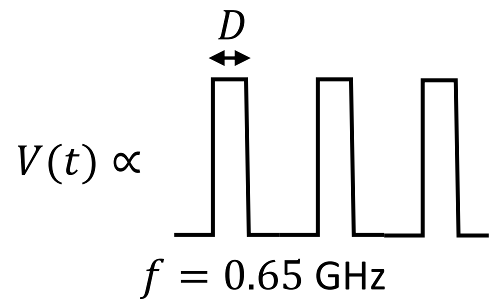
$N = 3$: single electron emission at $\nu = 1/3$

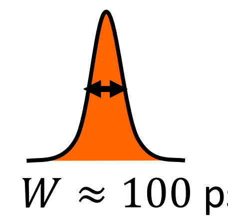


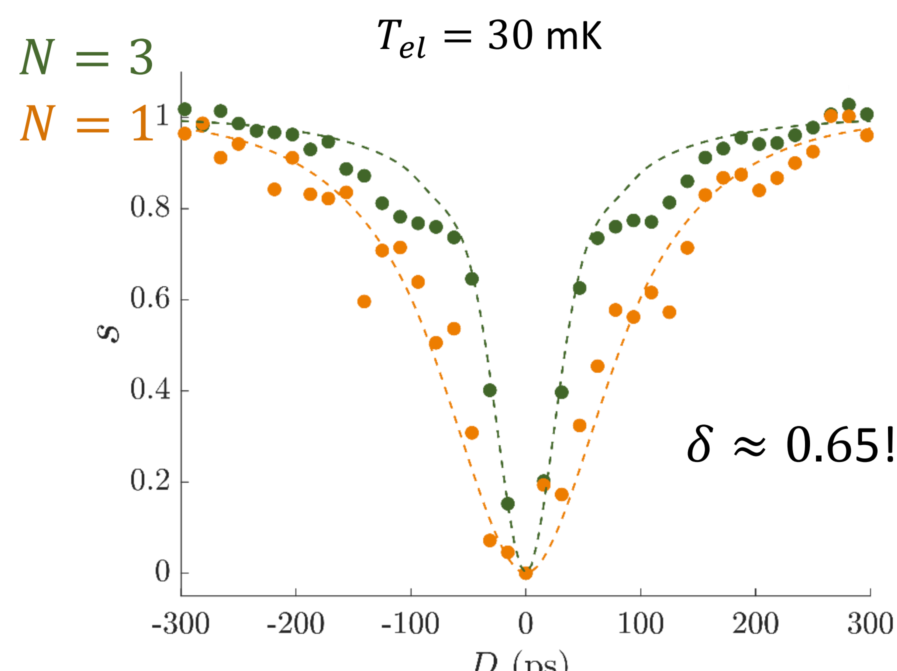


HOM experiment with anyon pulses









Current pulse carrying charge $Ne/3$ emulates N −anyon source

M. Ruelle et al., Science **389**, eadm7695 (2025).

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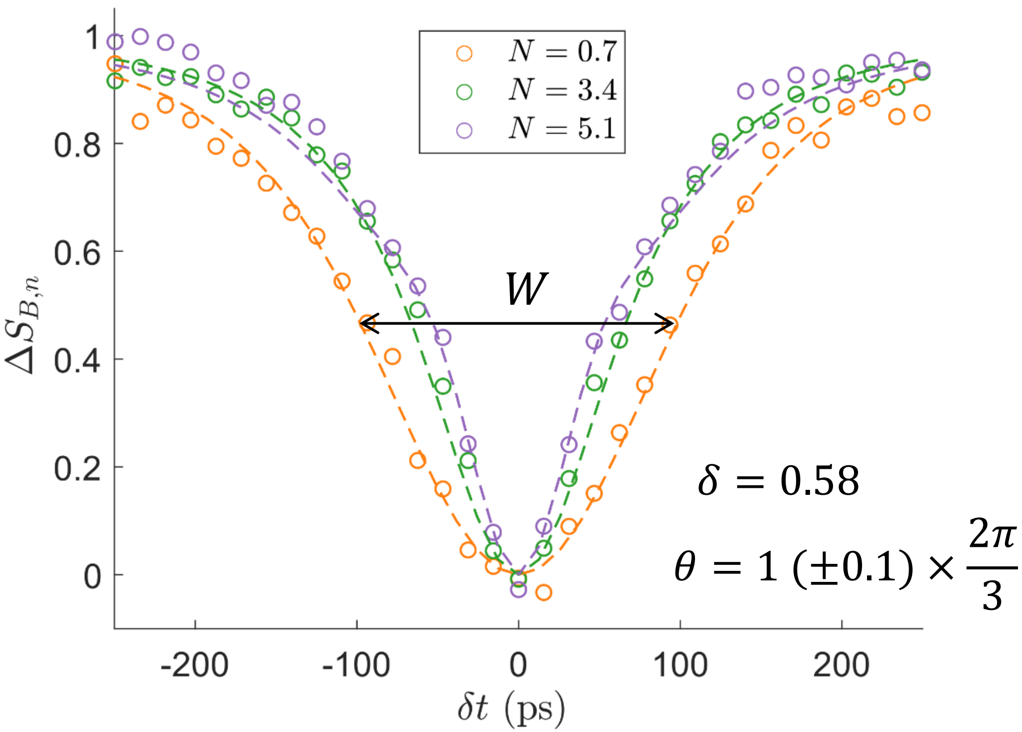
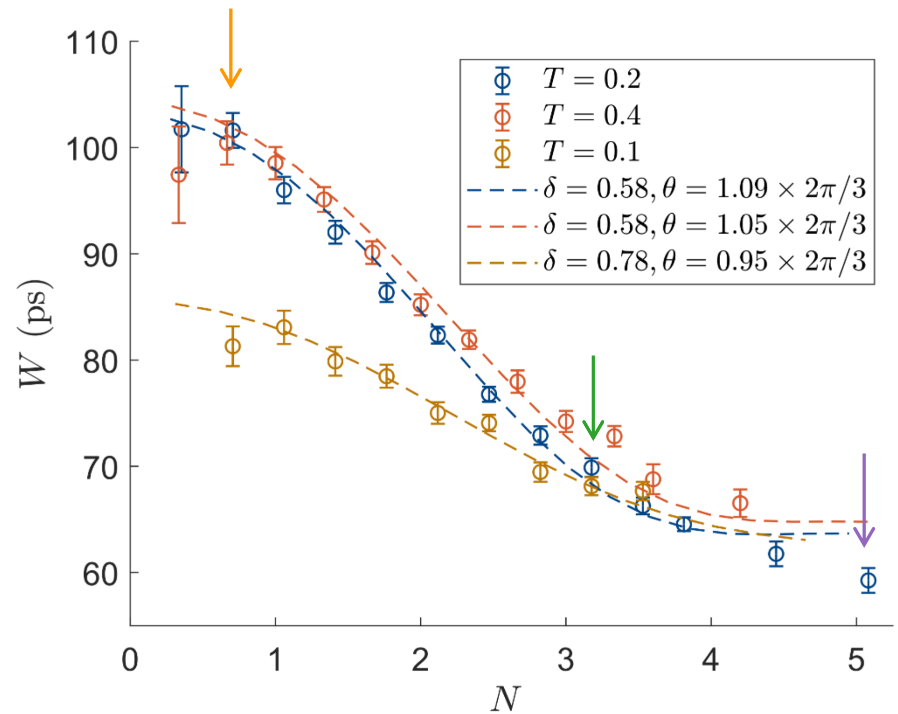
HOM experiment with anyon pulses:
$T_{el} = 45mK, W = 65\ ps$





Braiding phase has the expected value $\theta = \frac{2\pi}{3}$ for $\nu = 1/3$

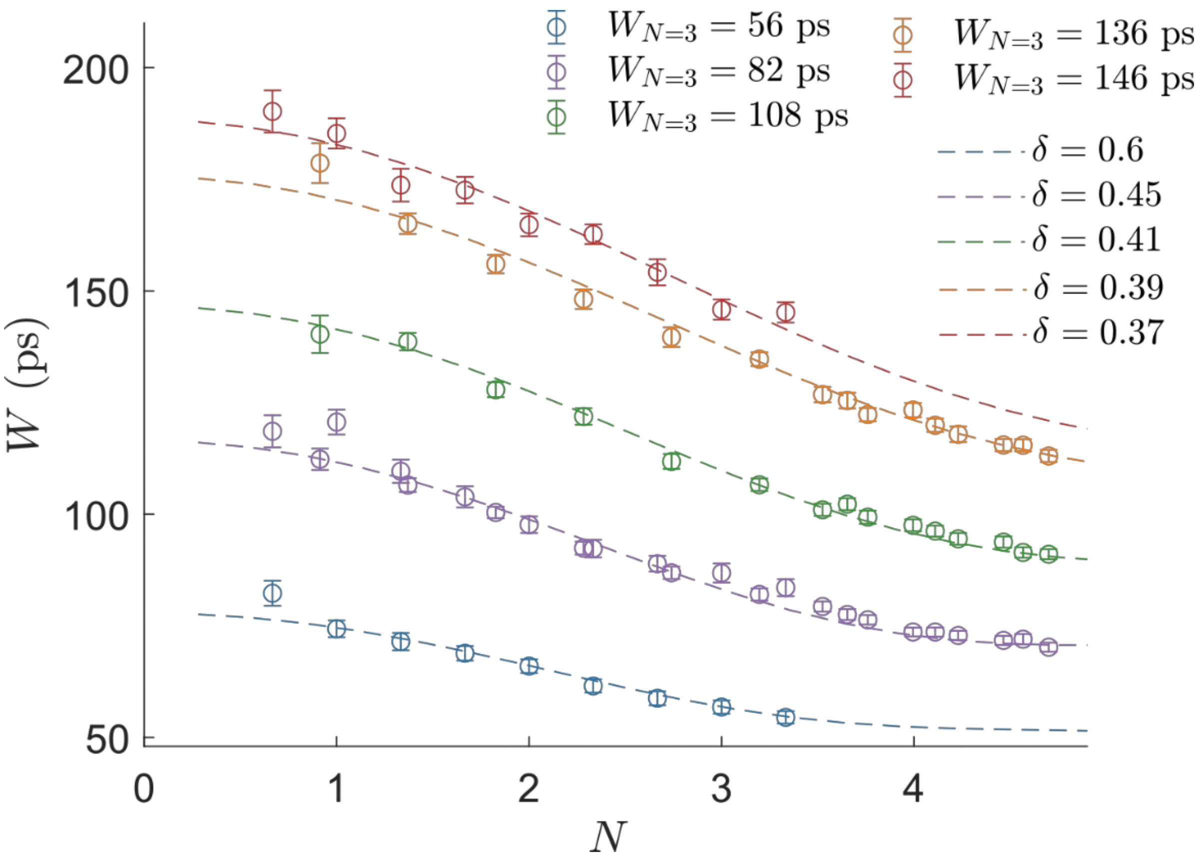
Not the scaling dimension! $\delta = 0.58$ instead of $\delta = 0.33$ expected

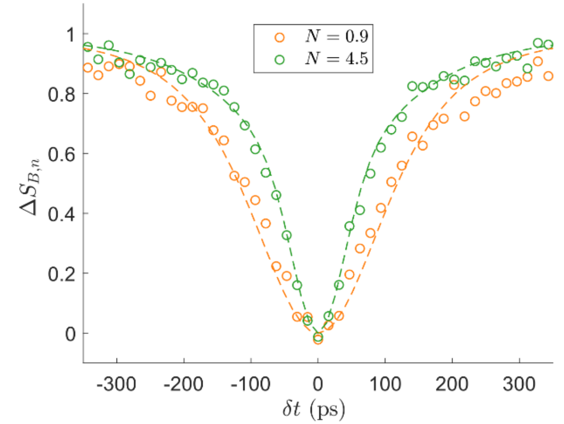
I. Safi, arXiv:2510.10525

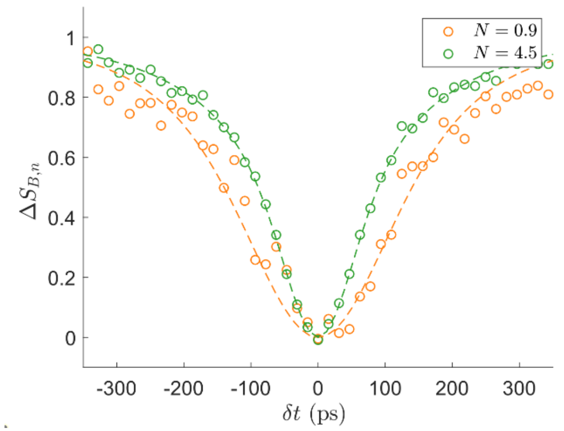
A. Latyshev and I. Safi, arXiv:2510.2059

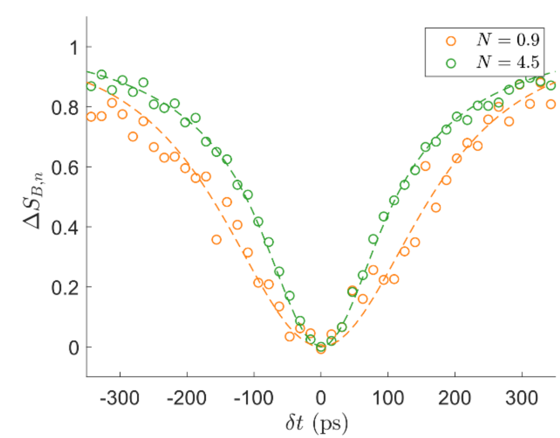
Varying the width of the pulse

$T_{el} = 60$ mK $\quad T = 0.45$









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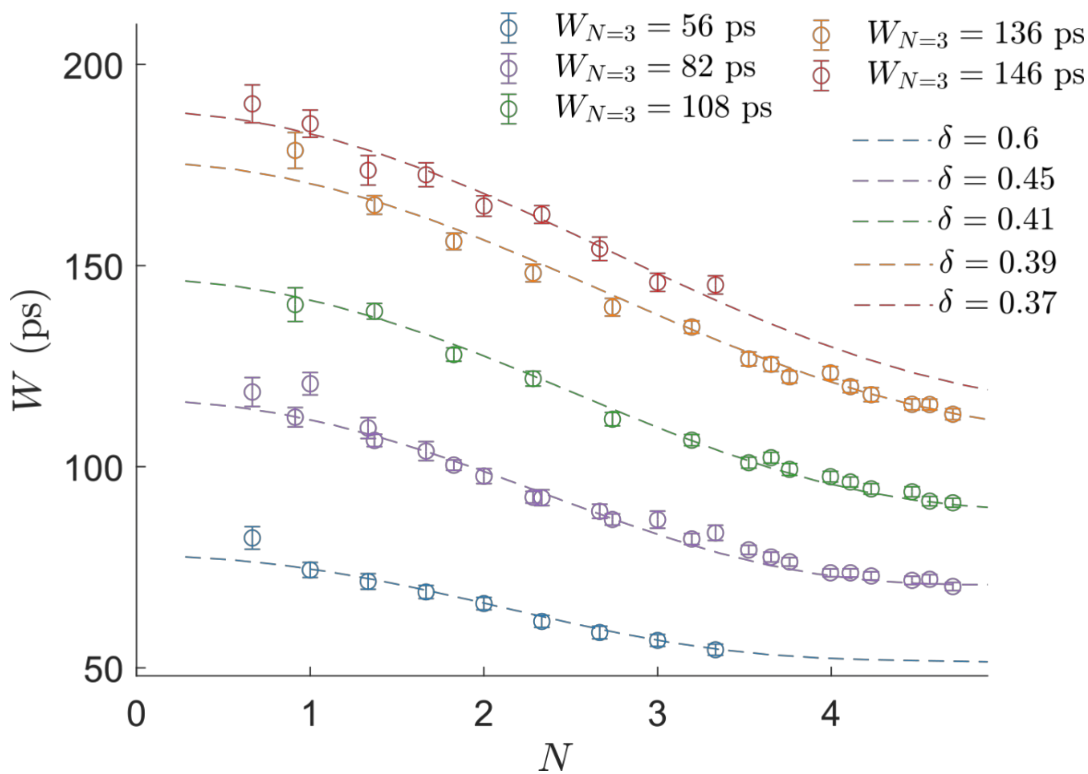
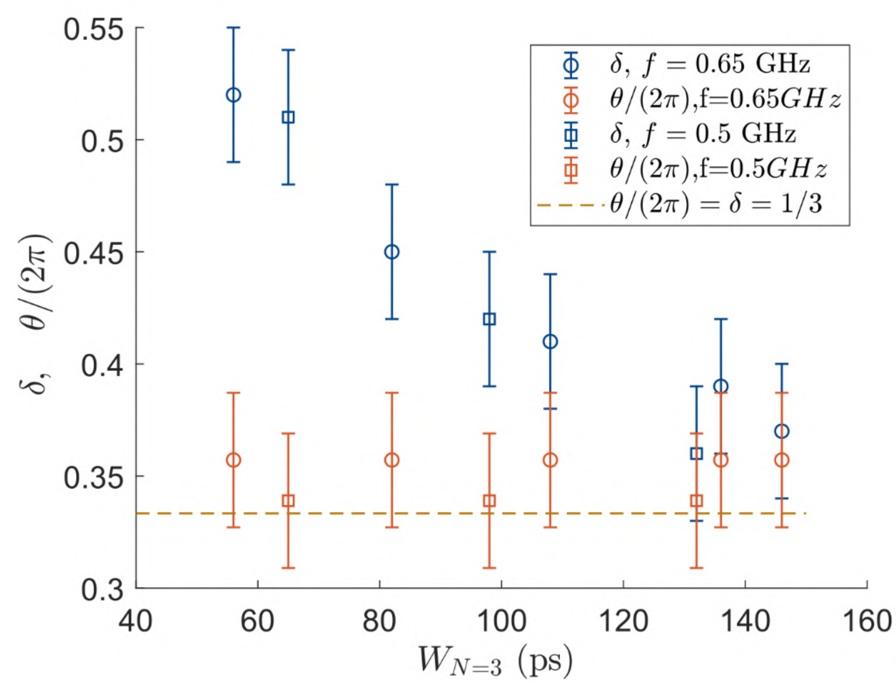
Varying the width of the pulse

$T_{el} = 60$ mK $\quad T = 0.45$





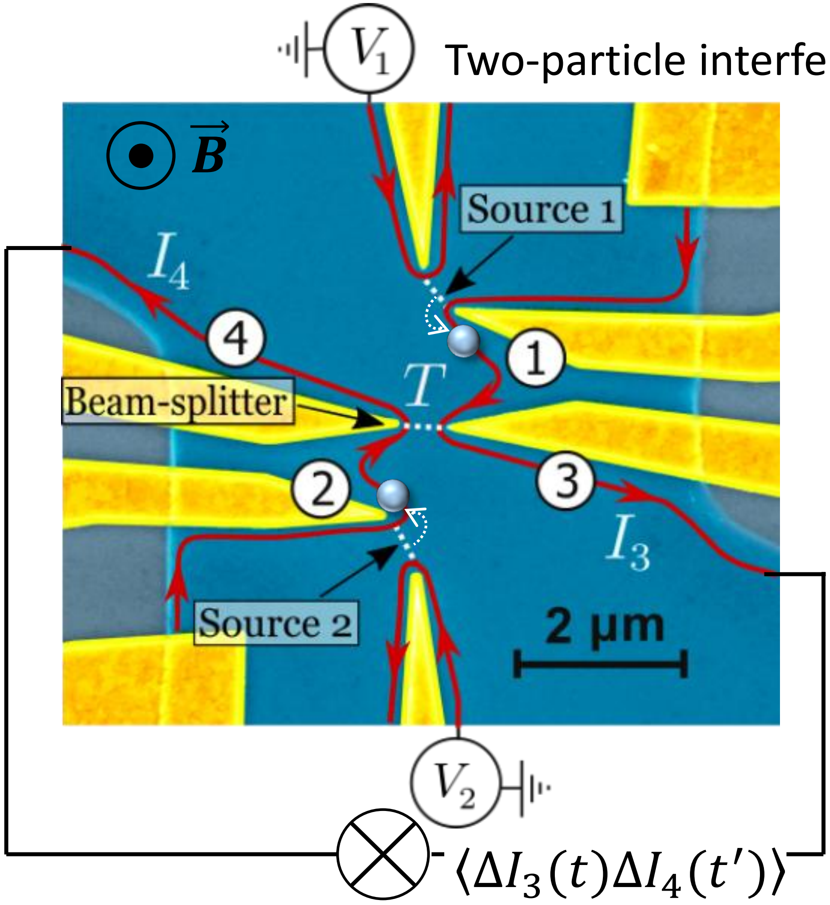
Deviations appear on short timescales

$\delta \approx 0.37$ recovered for larger pulses

Single and two particle interferometers in quantum Hall conductors

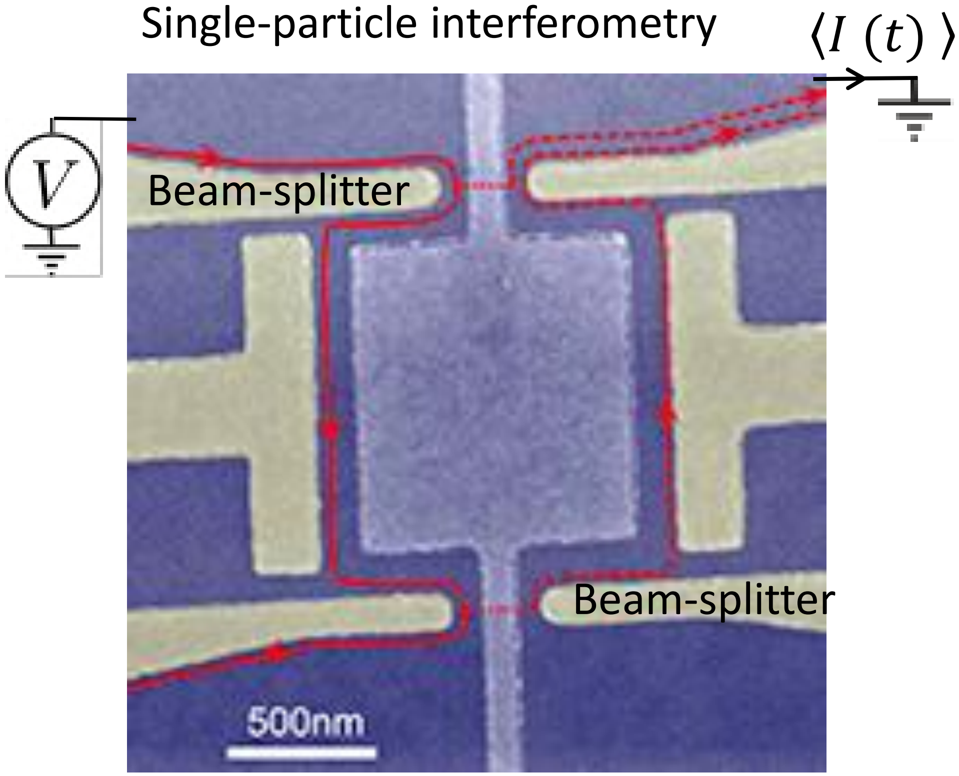
Electron optics experiments in quantum Hall conductors

Two-particle interferometry



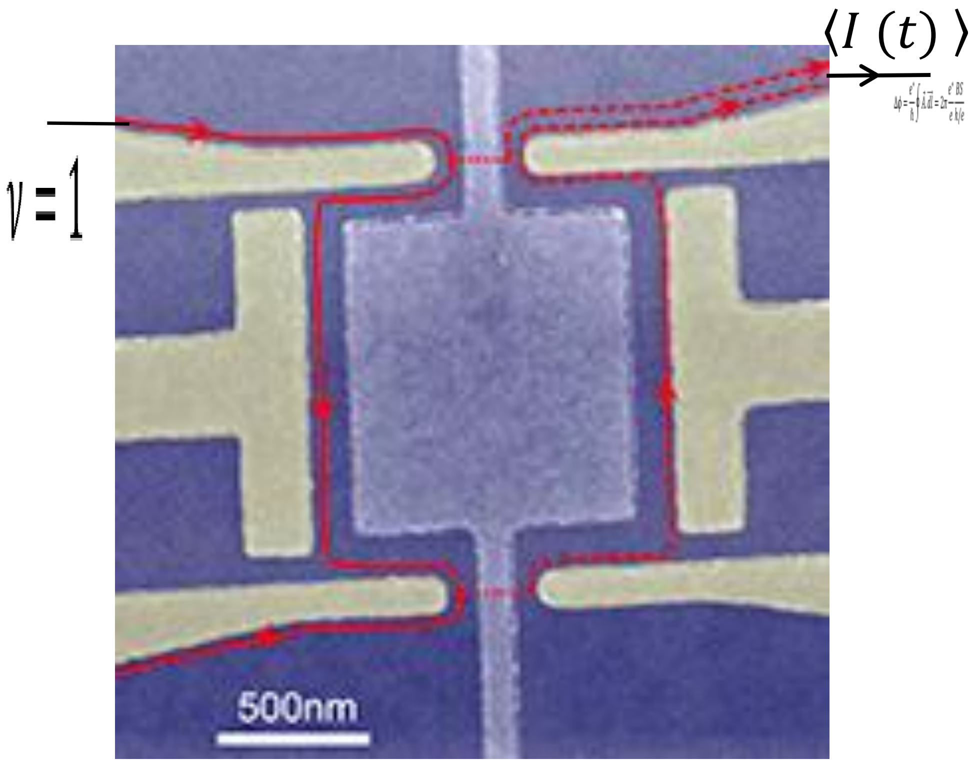
H. Bartolomei, M. Kumar et al., Science **368** 173 (2020)

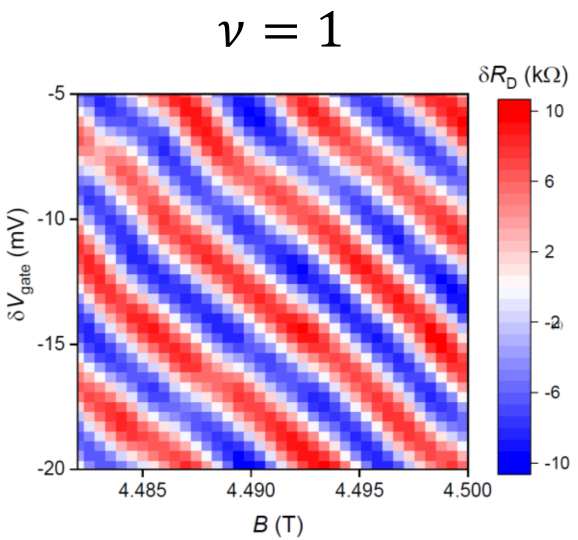
Single-particle interferometry

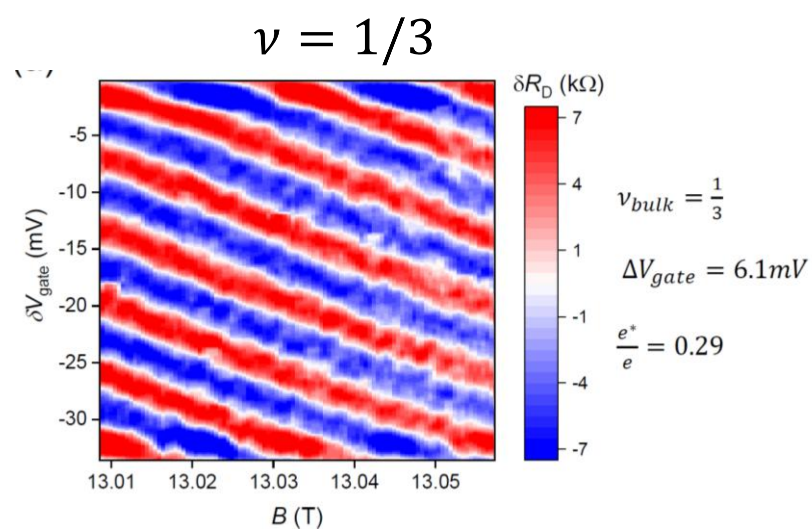


J. Nakamura, et al., Nature Physics **16** 931 (2020).

Anyon inteferometry in Farby-Perot interferometers





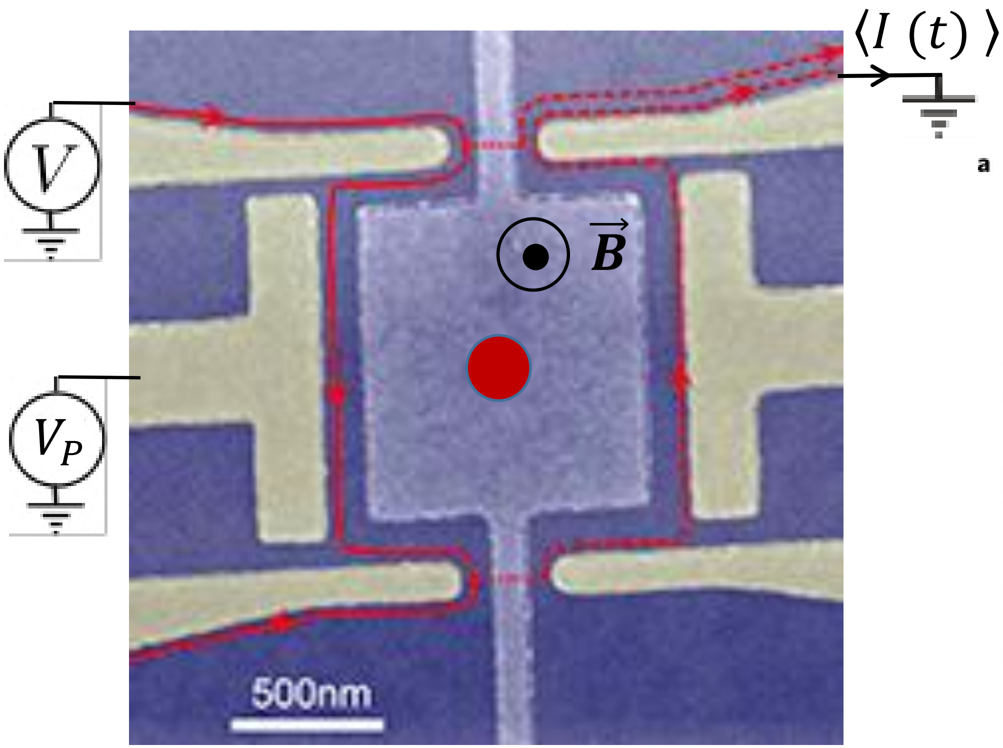


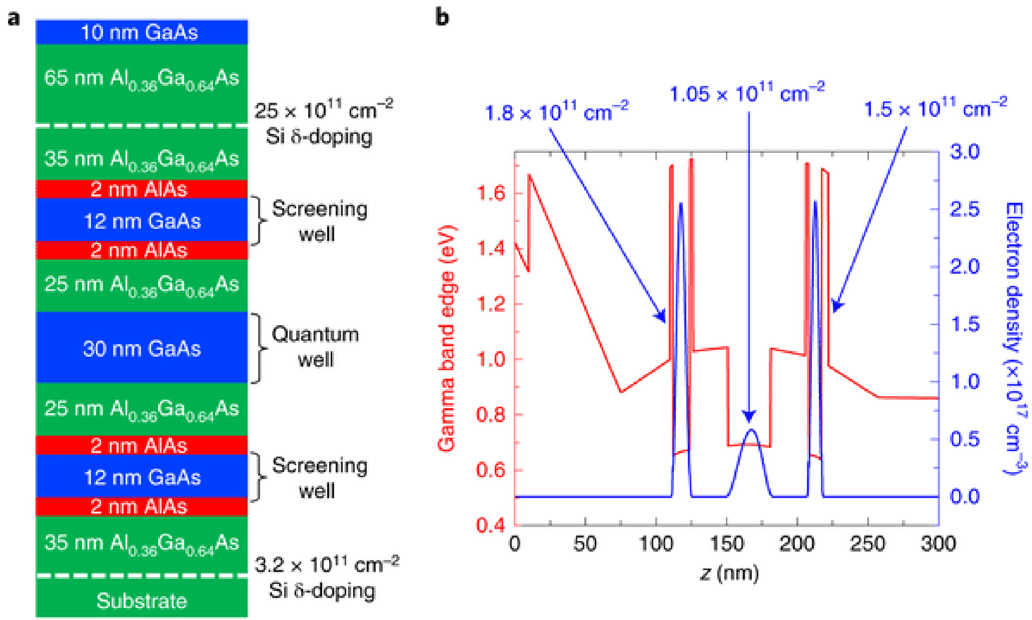
Interferometry of anyons of charge e^*

$$\Delta\phi = \frac{e^*}{\hbar}\oint \vec{A}.\overrightarrow{dl} = 2\pi\frac{e^*}{e}\frac{BS}{h/e}$$

J. Nakamura et al., *Nature Physics* **15**, 563–569 (2019)

Anyon interferometry in Fabry-Perot interferometers



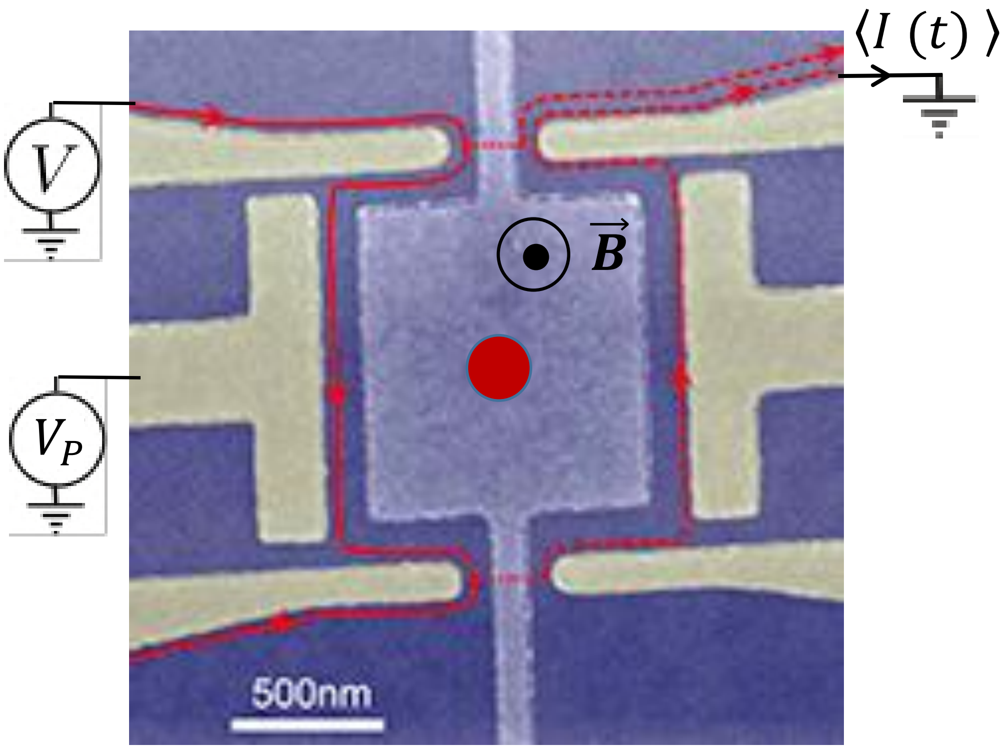


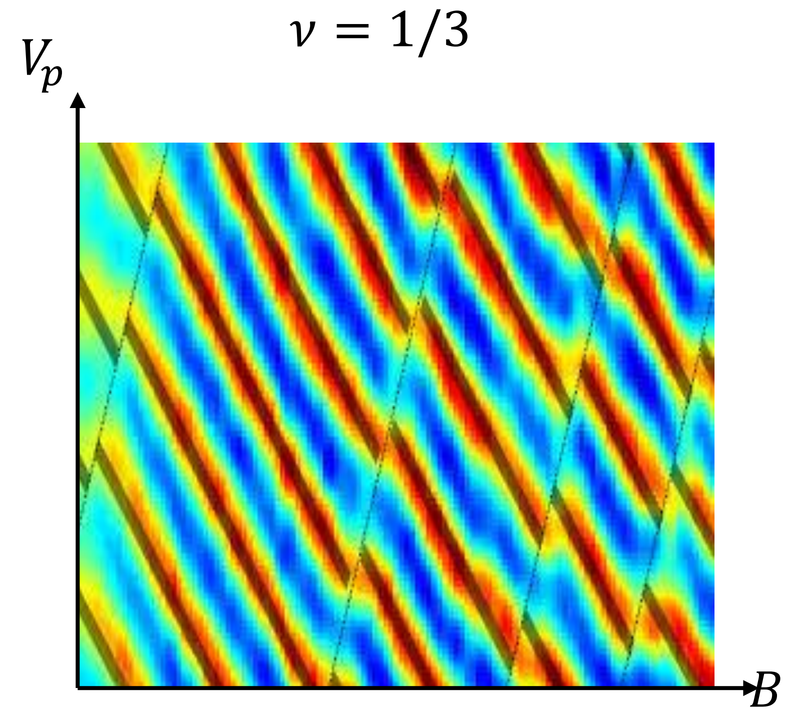
J. Nakamura, S. Liang, G.C. Gardner, M.J. Manfra, Nature Physics **16** 931 (2020).

$$\Delta\phi = 2\pi \frac{e^*}{e}\frac{BS}{h/e} + \theta\,\Delta N$$

Pb: real situation much more complex due to Coulomb interaction

Anyon interferometry in Fabry-Perot interferometers





$$\Delta\phi = 2\pi \frac{e^*}{e}\frac{BS}{h/e} + \theta\ \Delta N$$

Pb: real situation much more complex due to Coulomb interaction

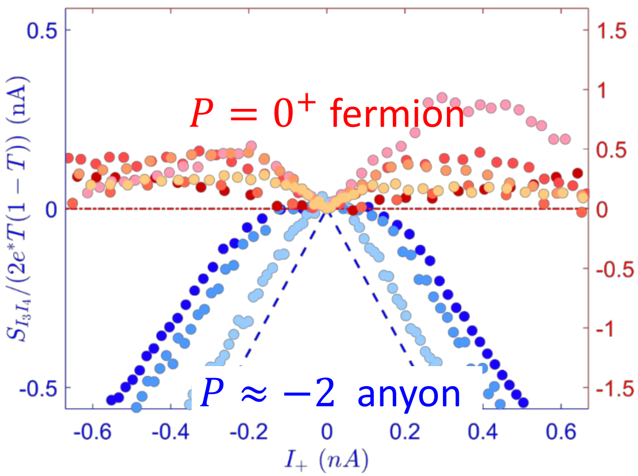
J. Nakamura, S. Liang, G.C. Gardner, M.J. Manfra, Nature Physics **16** 931 (2020).

$$\theta\ = 2\pi/3$$

Conclusion

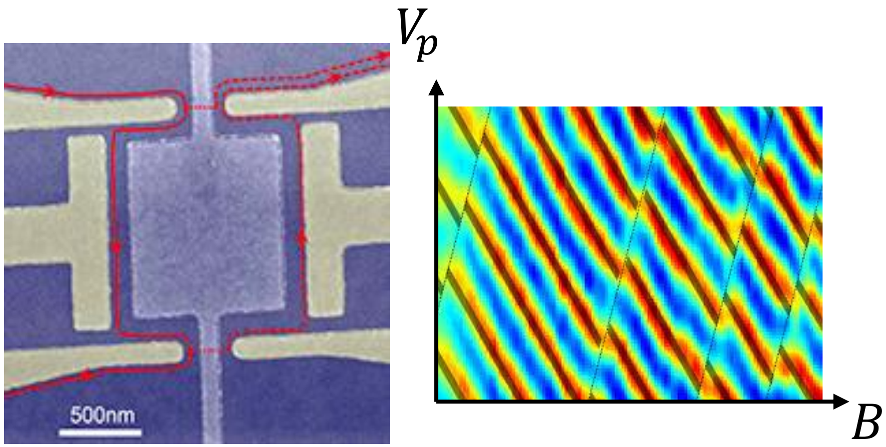
Interferometry for investigation of fractional statistics

- Two-particle interferometry



H. Bartolomei et al., Science **368** 173 (2020)
M. Ruelle et al., Phys. Rev. X **13**, 011031 (2023)
P. Glidic et al., PRX **13**, 011030 (2023).
J.Y.M. Lee et al., Nature **617**, 277 (2023).

- Single particle interferometry



J. Nakamura et al., Nature Physics **16** 931 (2020).
J. Kim et al., Nat. Nanotechnol. 19, 1619–1626 (2024)
T. Werkmeister et al., Science **388**, 730-735 (2025)
N.L. Samuelsson et al., arXiv preprint arXiv:2403.19628

- Braiding affects the dynamics of anyon tunneling

M. Ruelle et al., Science **389**, eadm7695 (2025).

- Anyon physics in the integer regime: charge fractionalization

P. Glidic et al., Nat. Commun. **15**, 6578 (2024)

- Other FQH states: 2/5, 2/3….. 5/2?

M. Ruelle et al., Phys. Rev. X **13**, 011031 (2023)
P. Glidic et al., PRX **13**, 011030 (2023).

- Thermal transport

Thermal conductance quantum

S. Jezouin et al., Science **342,** 601 (2013)

Thermal conductance for investigating FQH states

M. Banerjee et al., Nature **559,** 205 (2018)
G. Le Breton et al., PRL **129,** 116803 (2022)

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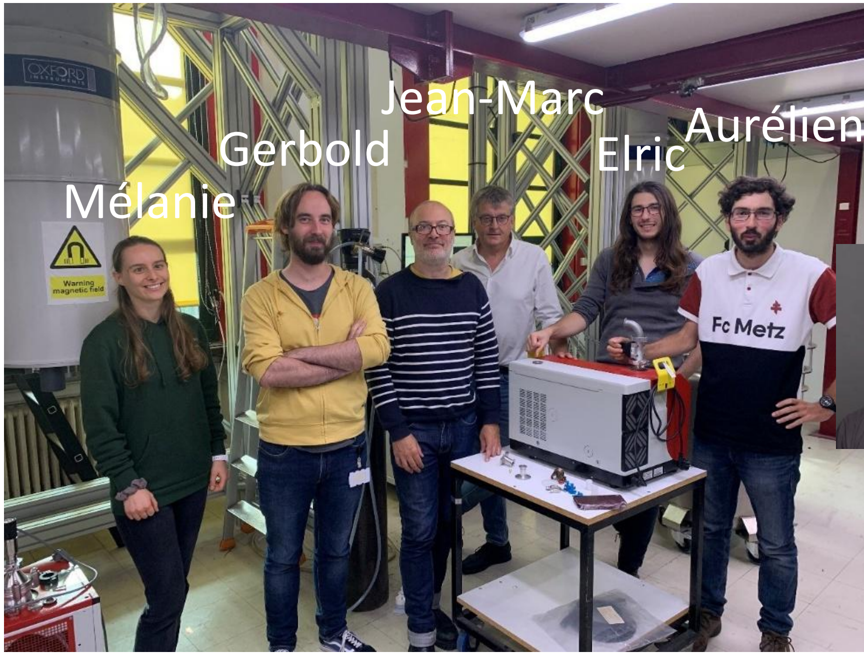
Many people involved



Hangyu

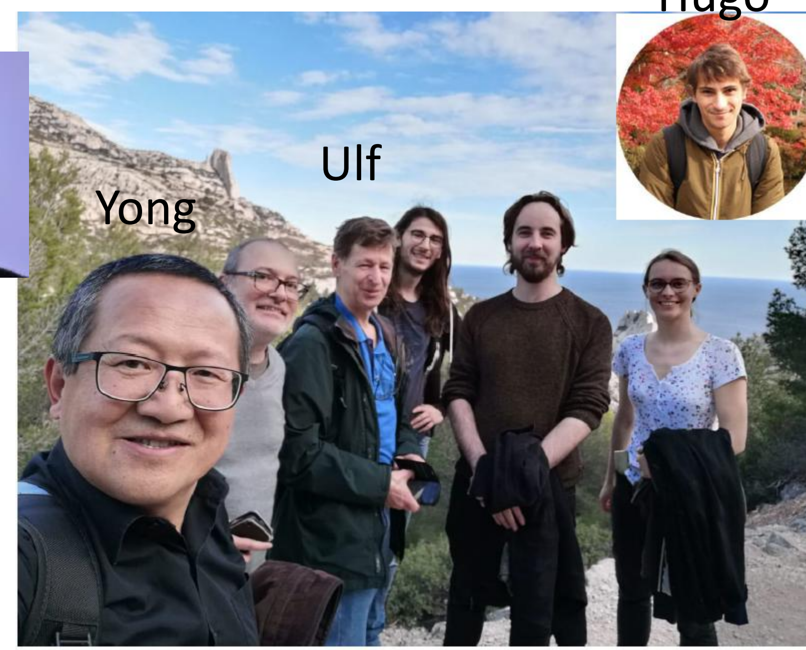
Bernard

LPENS : H. Bartolomei, M. Ruelle, H.Lyu, M. Kumar, S. Purkait, E. Frigerio, E. Baudin, J.M. Berroir, B. Plaçais, F.D. Parmentier, G. Ménard

C2N: Y. Jin, U. Gennser, A. Cavanna

Manohar

Hugo



Jin et al., Marseille 25/04 (2023)

ENS Lyon: P. Degiovanni, M. Paulet, G. Rebora, H. Souquet-Basiège, B. Roussel

LPS Orsay: A. Latyshev, I. Safi

CPT Marseille: K. Iyer, B. Gremaud, T. Jonckheere, T. Martin, J. Rech

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