Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA
NQSTI National Quantum Science and Technology Institute

Missione 4 Istruzione e Ricerca

Spoke 5

A5.2 Novel nanomaterials for hybrid architectures

A5.2.1

15-16 January 2024

Highly transmissive InSb nanoflag Josephson junctions

Andrea Iorio[1], Bianca Turini[1], Sedighe Salimian[1], Alessandro Crippa[1], Elia Strambini[1], Valentina Zannier[1], Matteo Carrega[2], Luca Chirolli[1], Fabio Beltram[1], Lucia Sorba[1], Francesco Giazotto[1], **Stefan Heun[1]**

1. NEST, Istituto Nanoscienze-CNR and Scuola Normale Superiore, Piazza San Silvestro 12, 56127 Pisa, Italy

2. CNR-SPIN, Via Dodecaneso 33, 16146 Genoa, Italy

Why InSb?

Small bandgap E_g=0.23 eV

Low effective mass m/m_0 = 0.018

Strong SOC $E_{SOC} \sim 200\ \mu eV$

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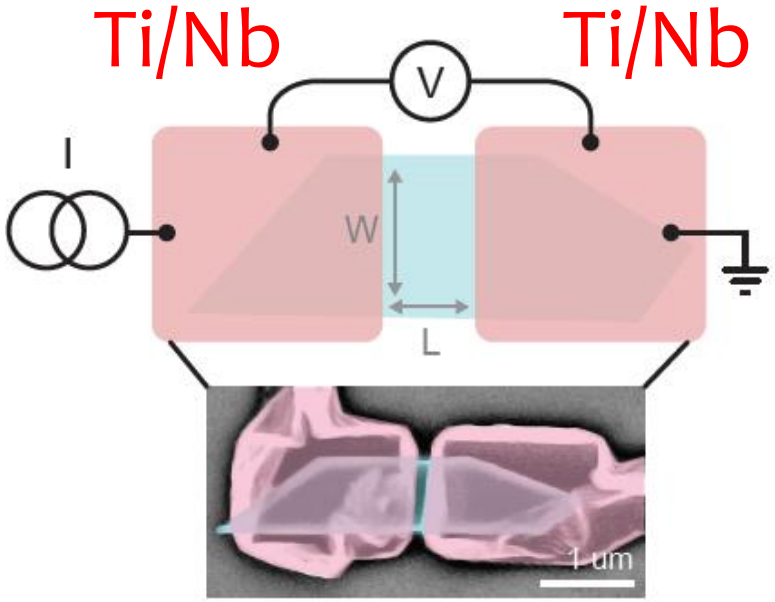
High-mobility 2D nanostructures

Lucia Sorba

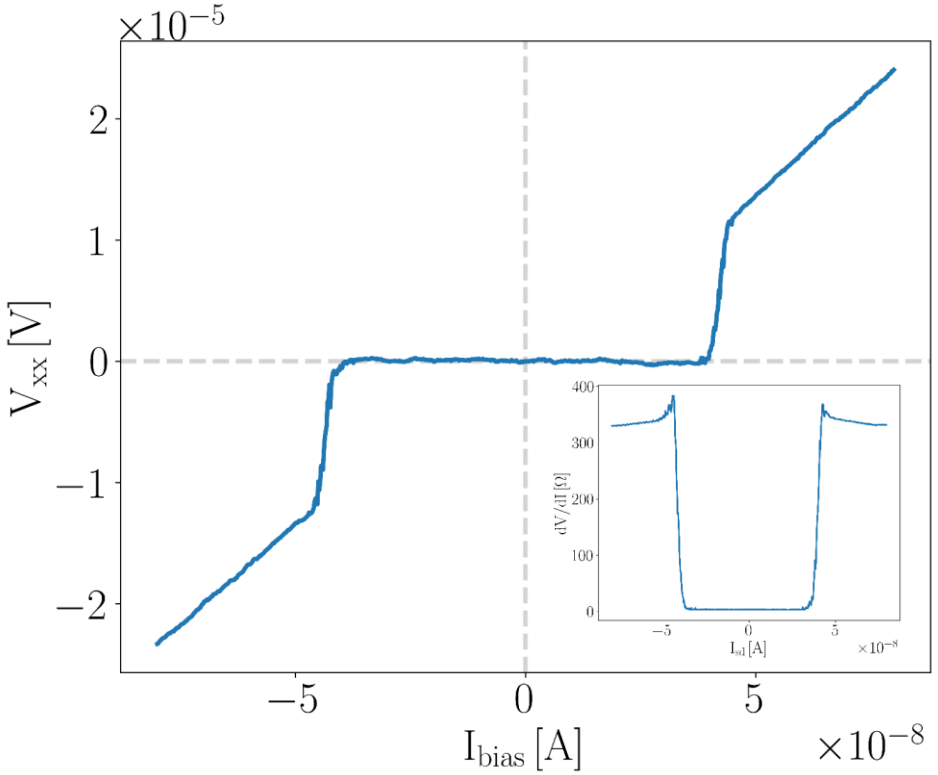
National Enterprise for nanoScience and nanoTechnology

InSb nanoflag-based Josephson junctions



λ_{mfp}	500 nm
L	200 nm
ξ_S	750 nm

short-ballistic junction



Sedighe Salimian

S. Salimian et al., Appl. Phys. Lett. 119, 214004 (2021).

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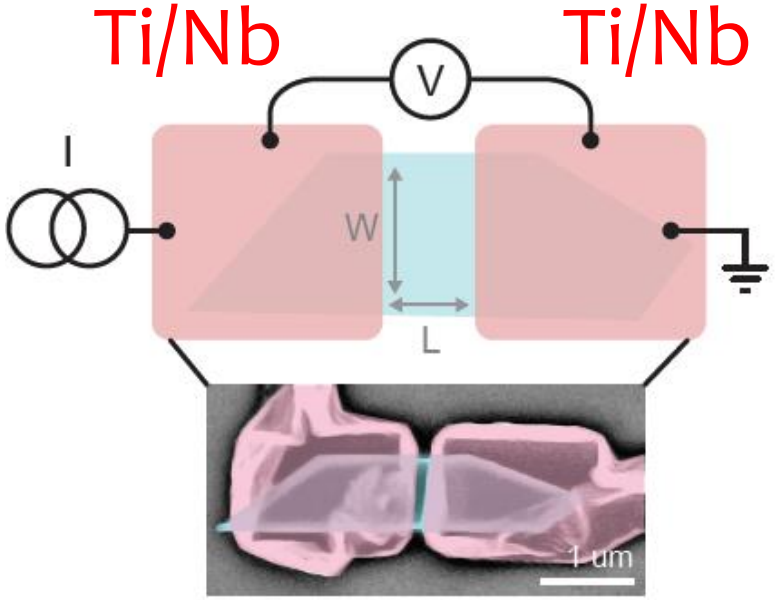
Gate-tunable supercurrent



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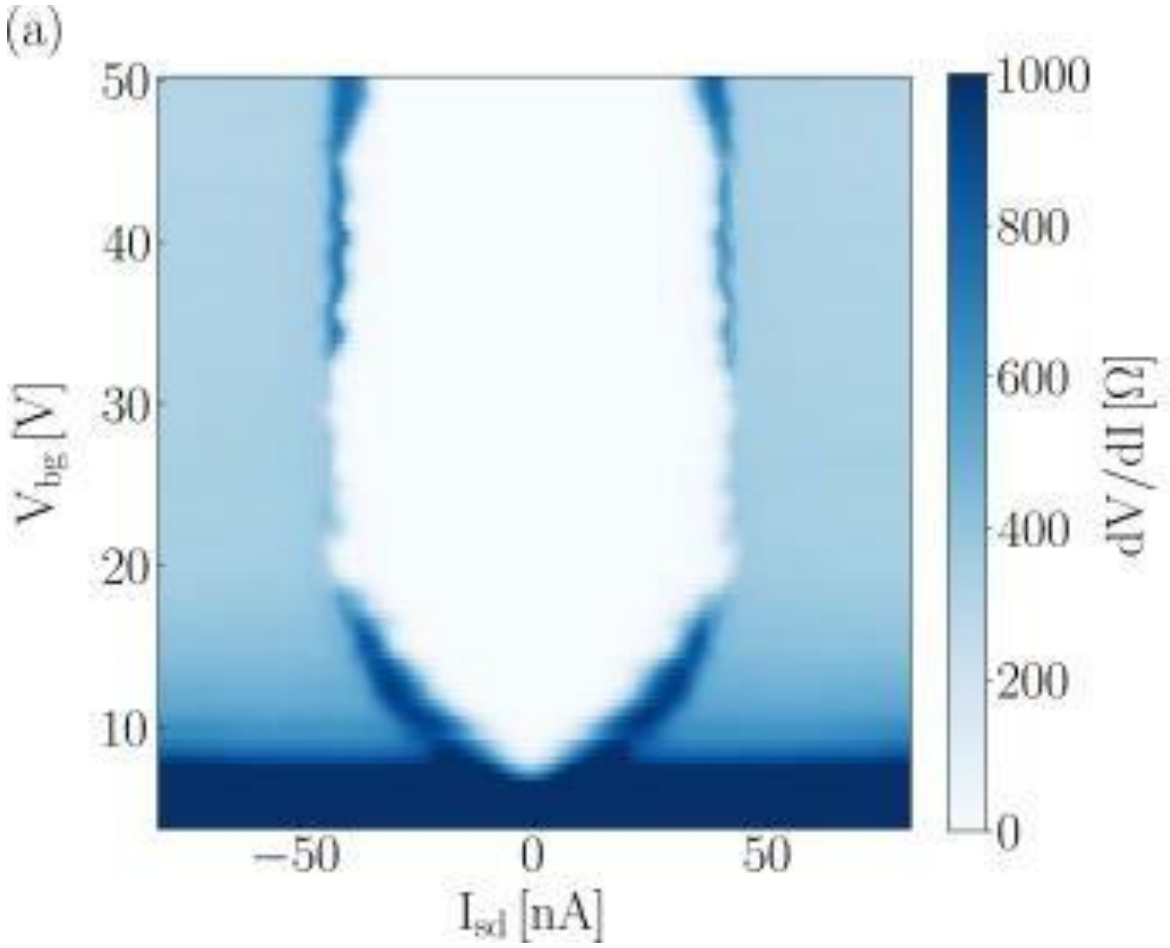

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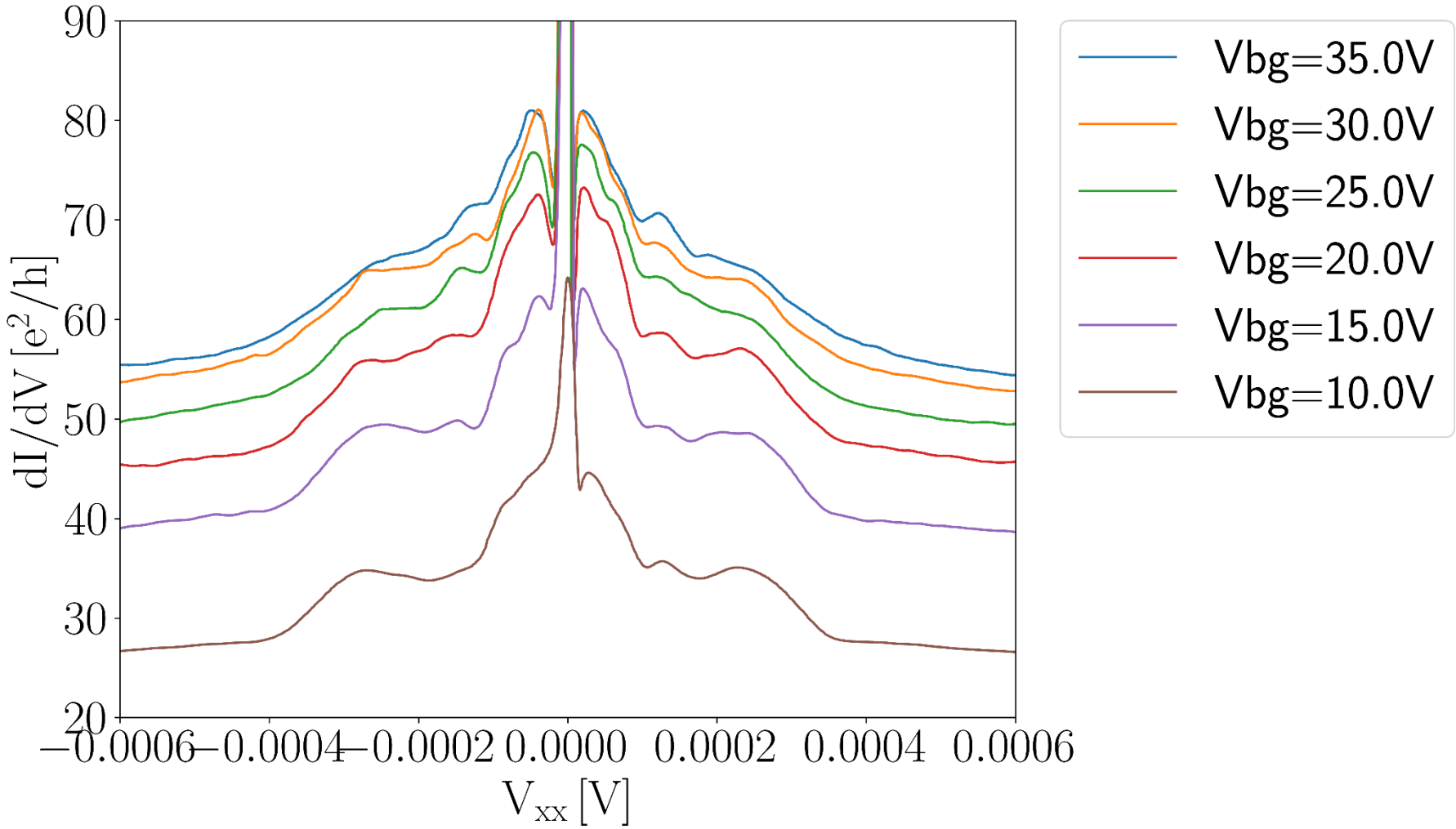
Multiple Andreev Reflections



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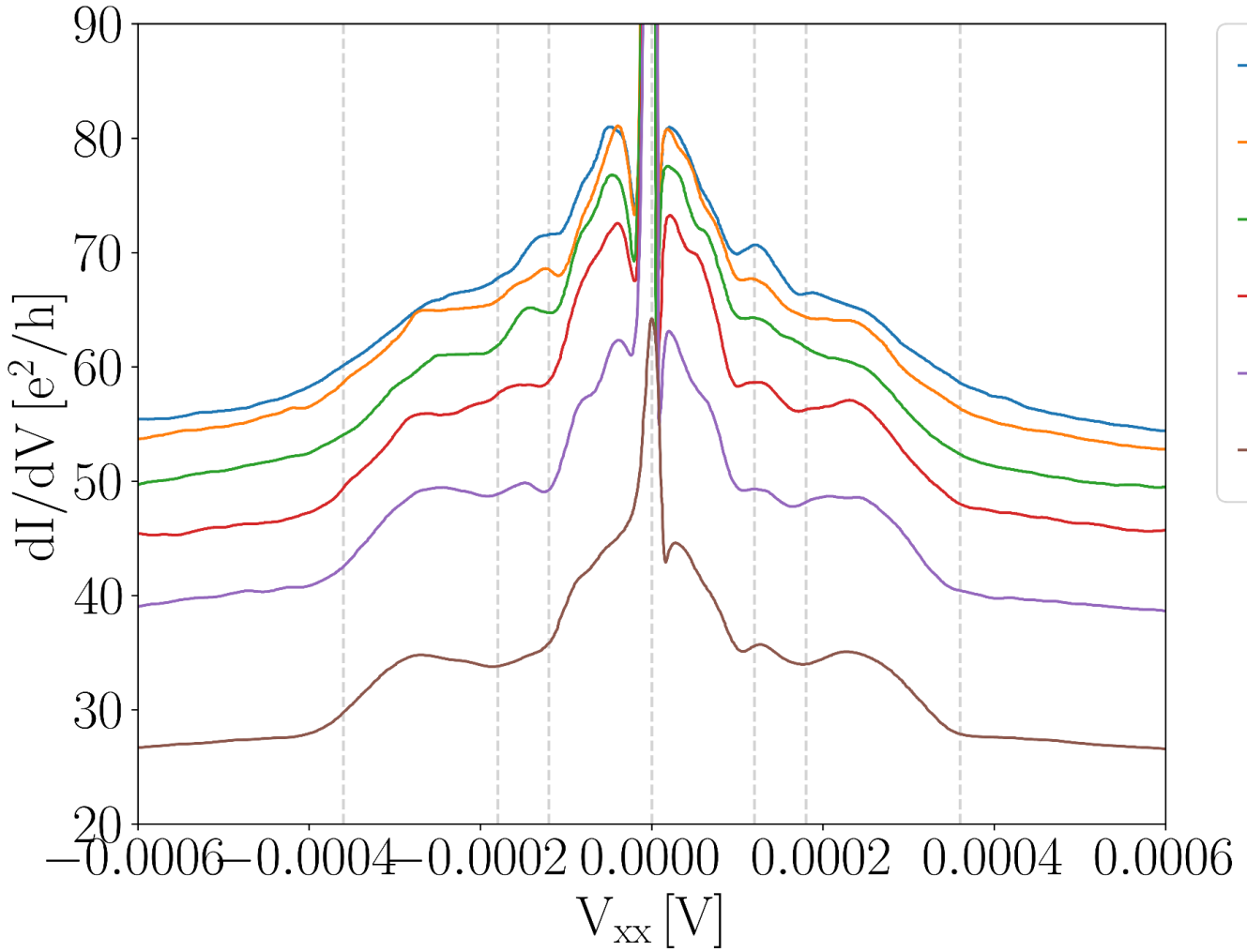


Michal P. Nowak

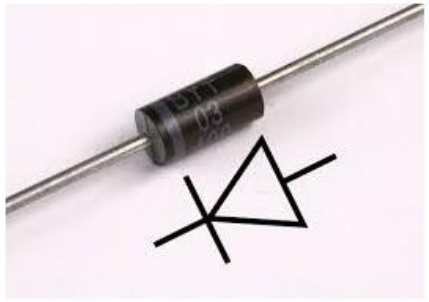
eV(n) = 2Δ*/n (n=1, 2, 3 . . .)

Δ* ~ 160 μeV

transparency τ = 0.94

S. Salimian et al., Appl. Phys. Lett. 119, 214004 (2021).

Josephson Diode Effect



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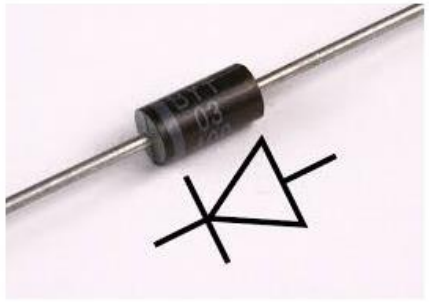

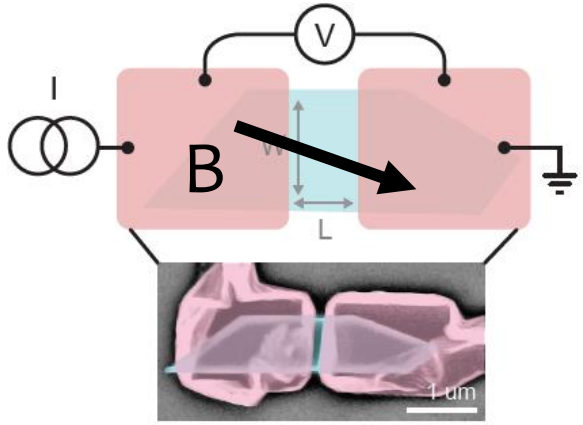

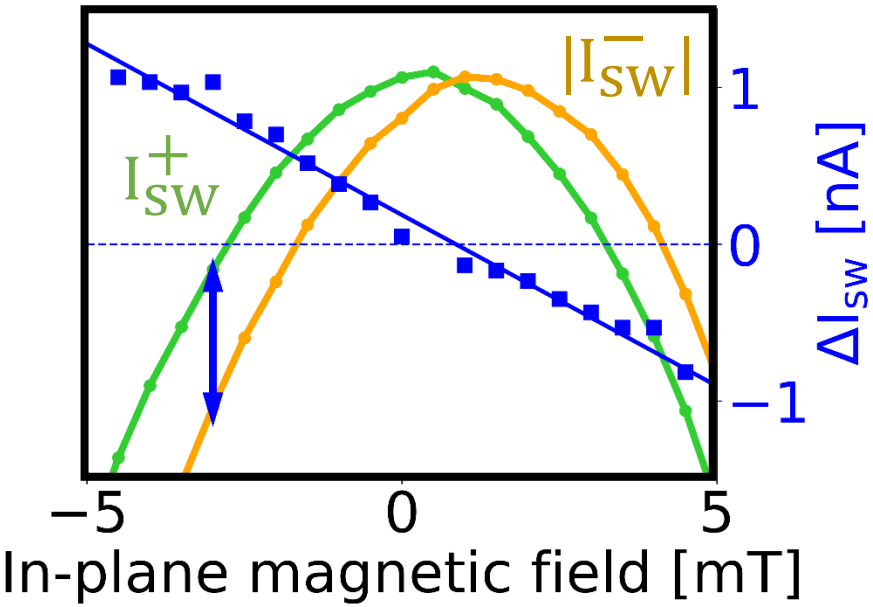

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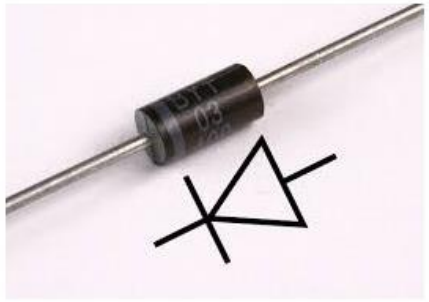

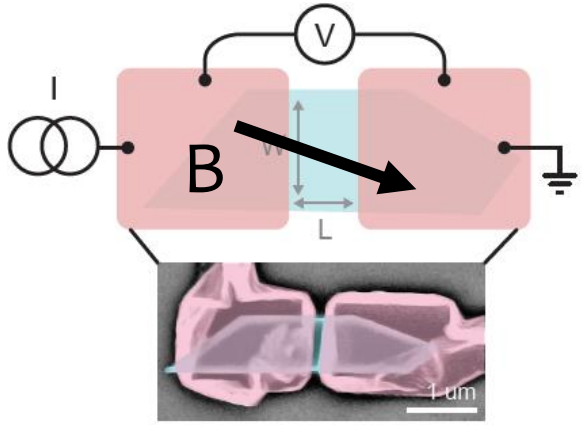

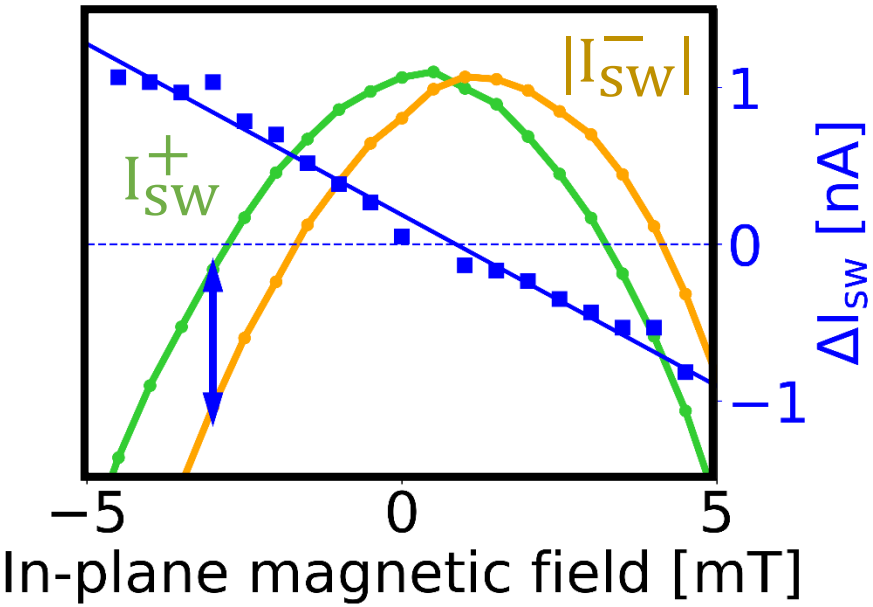

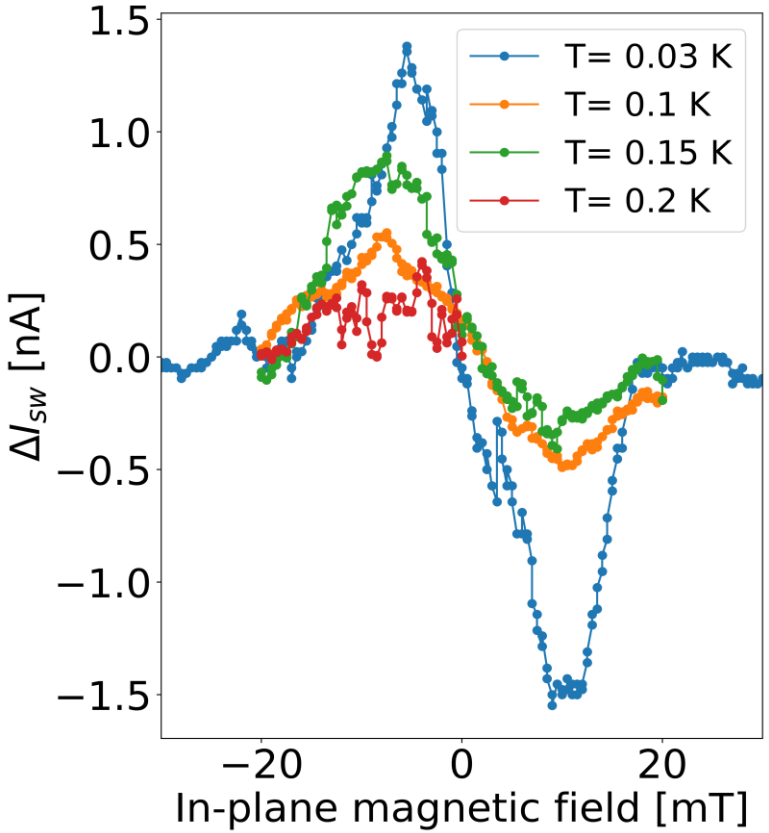

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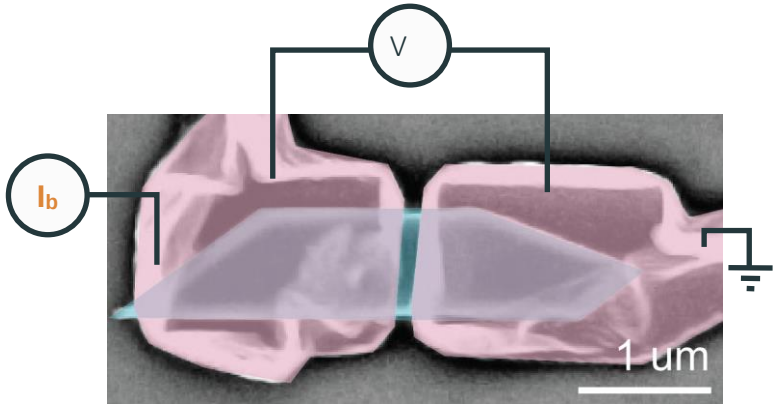
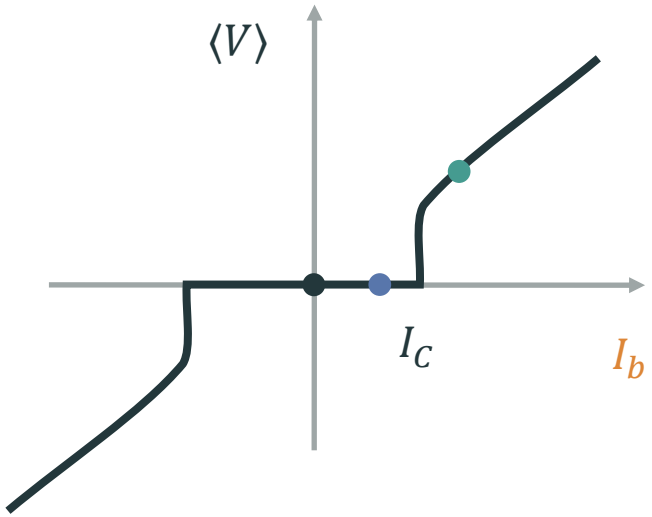
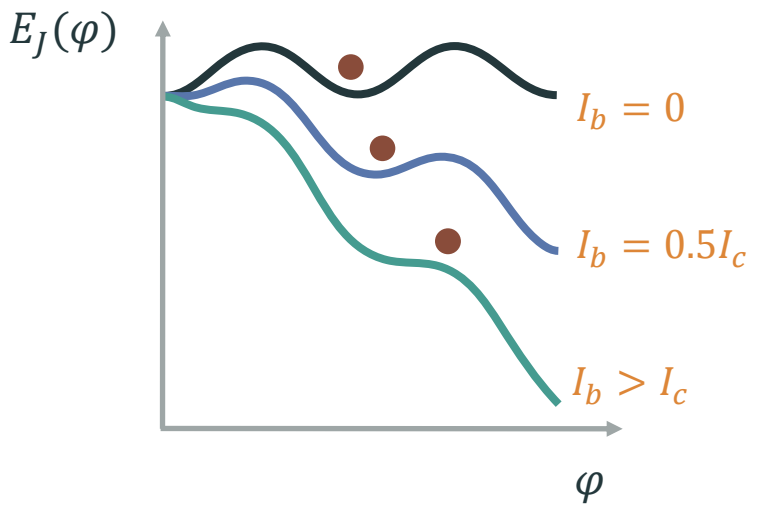
Half-integer Shapiro steps



$$V = \frac{\hbar}{2e}\dot{\varphi}$$





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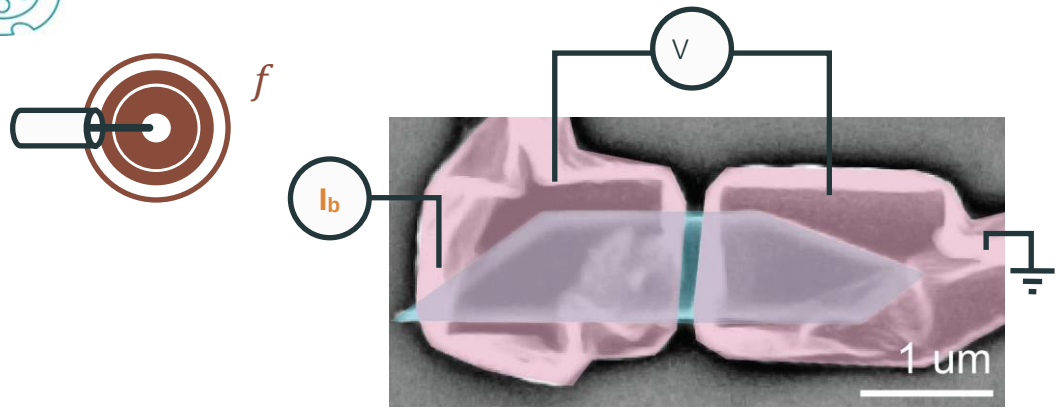
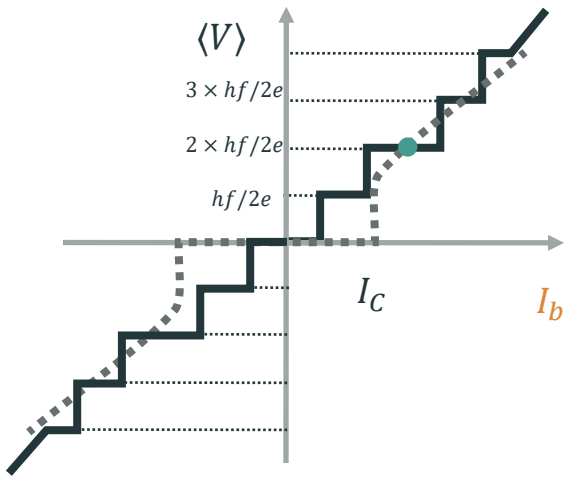
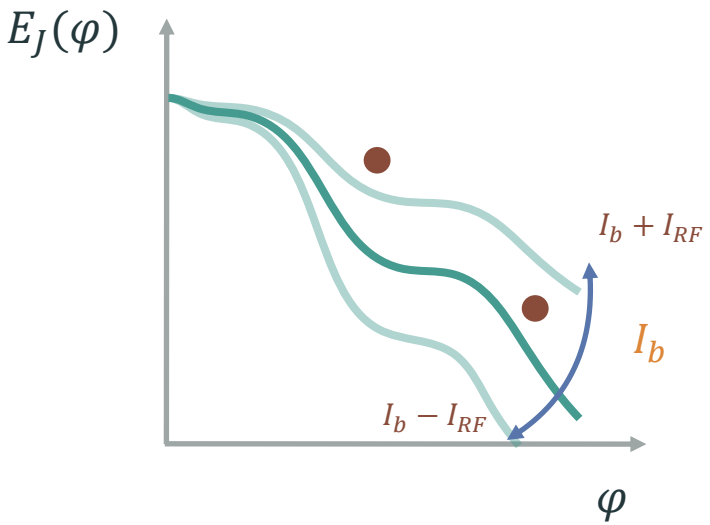


If particle rolls n minima in a period $T = 2\pi/f$, then $\dot{\varphi} = 2\pi n f$

$$V = \frac{\hbar}{2e}\dot{\varphi} = \frac{hf}{2e}n$$





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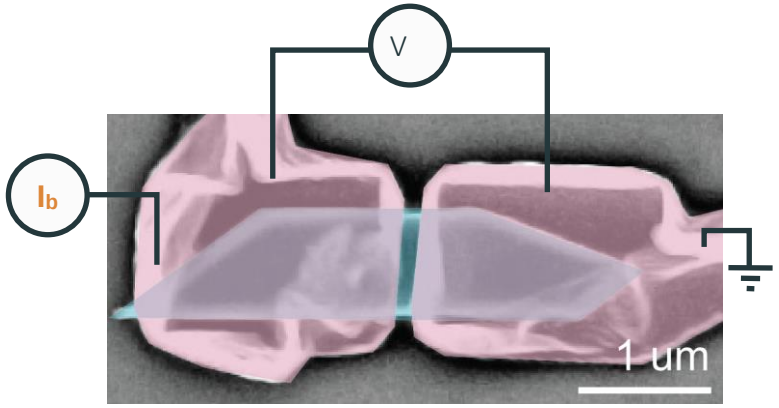

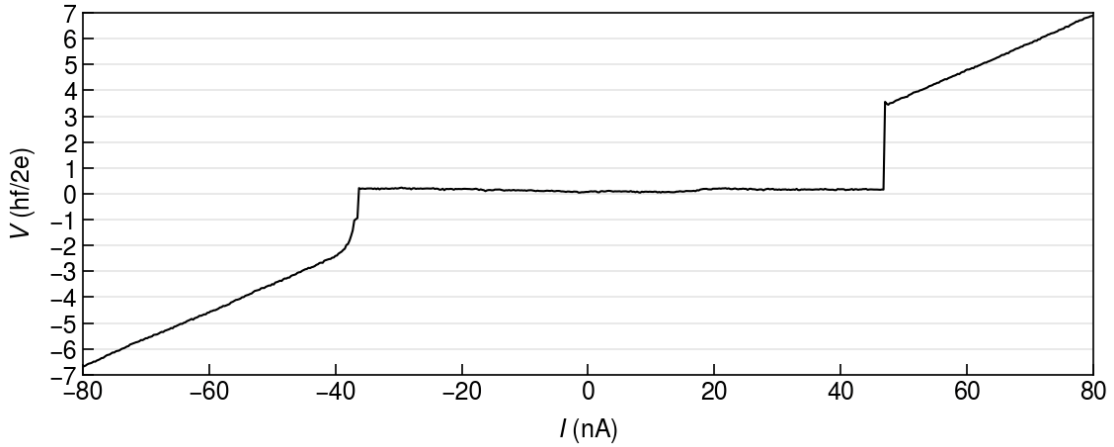

Shapiro steps – Quantized voltage plateaus $V = \frac{hf}{2e} n$

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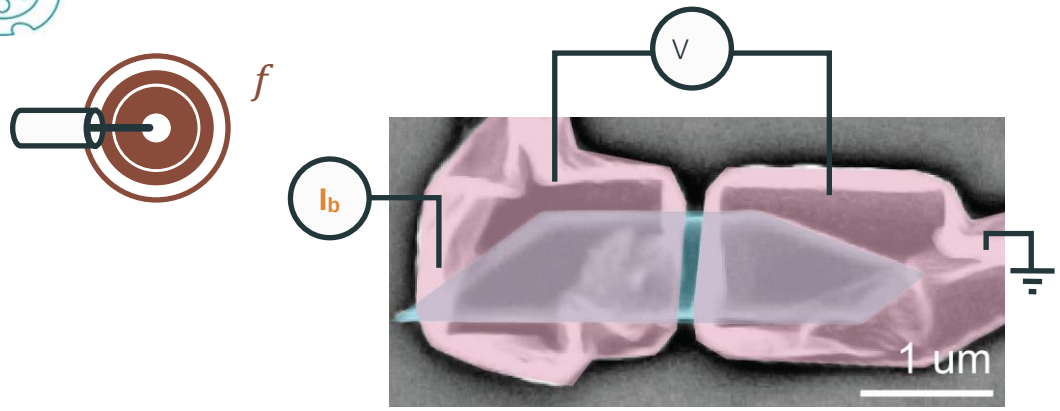

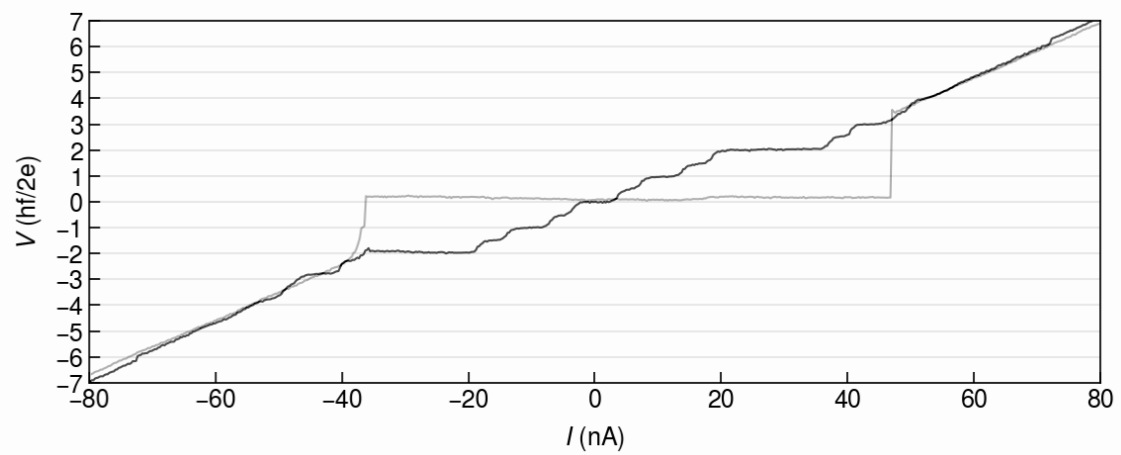

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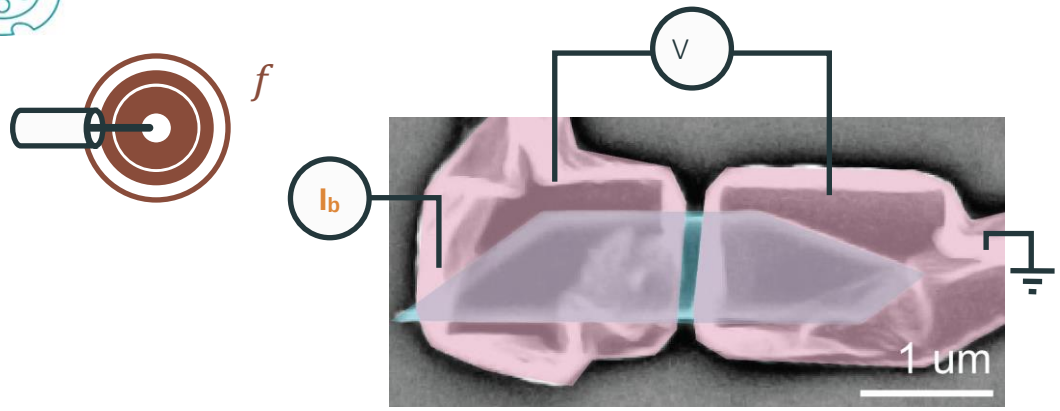

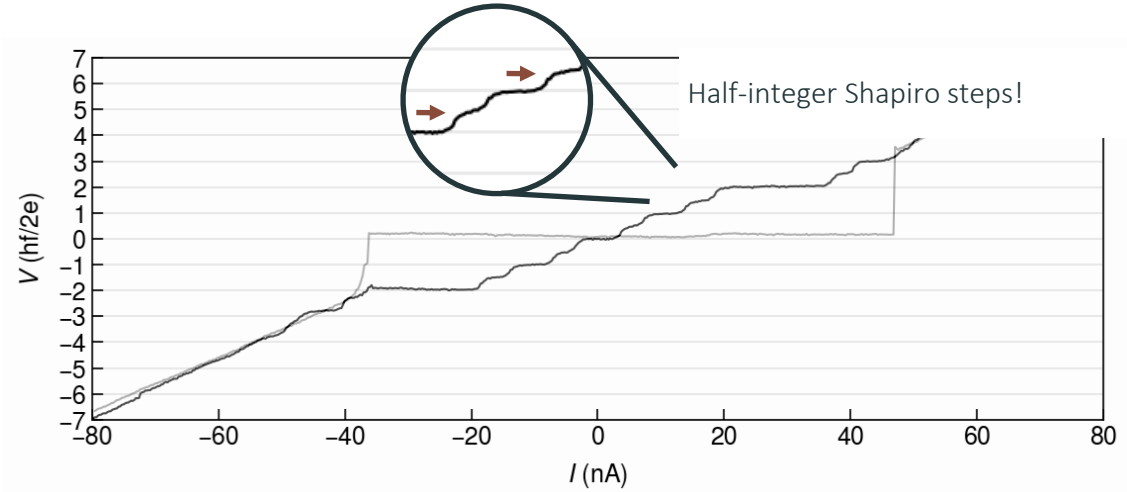

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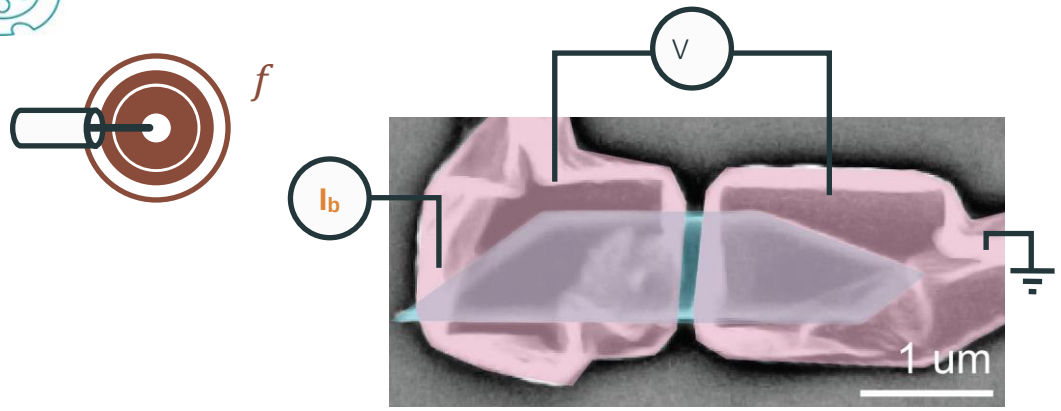

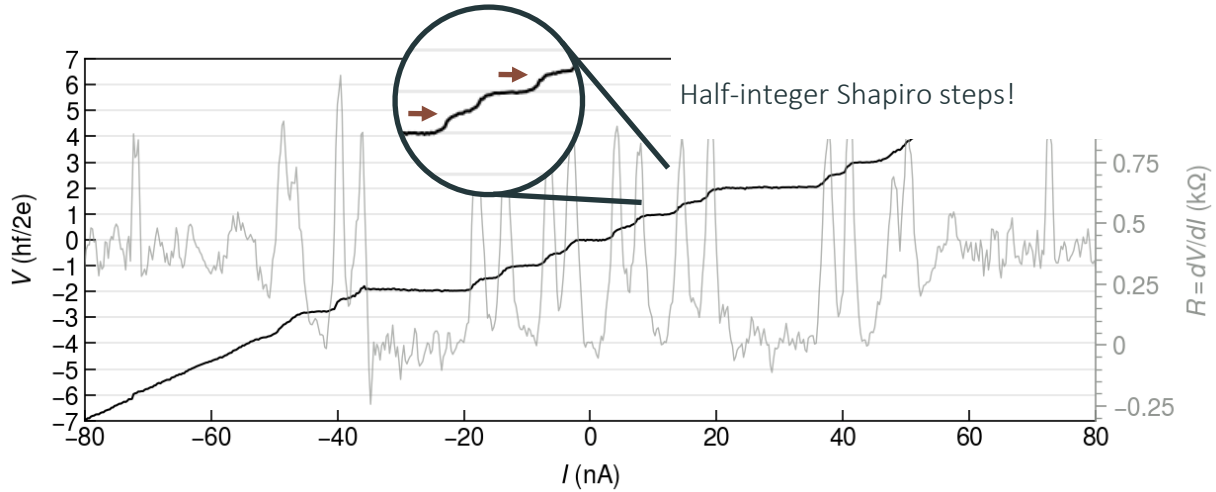

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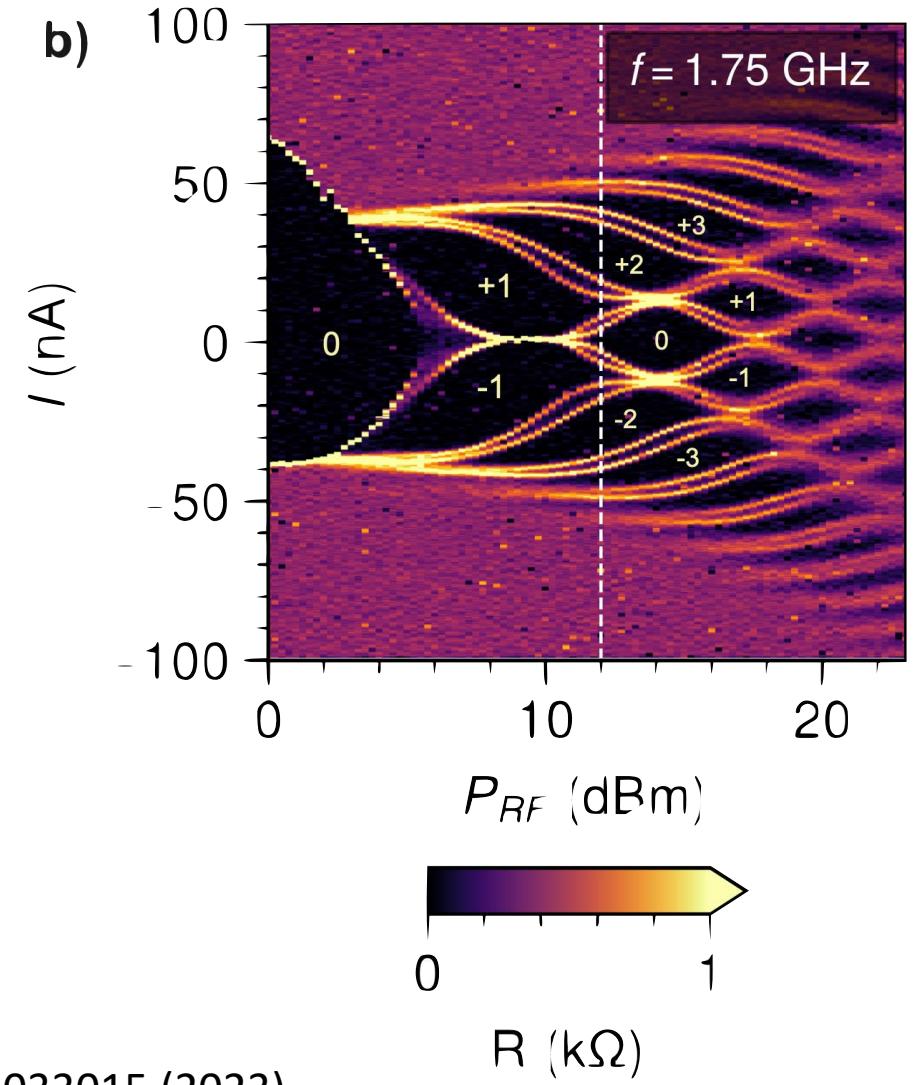

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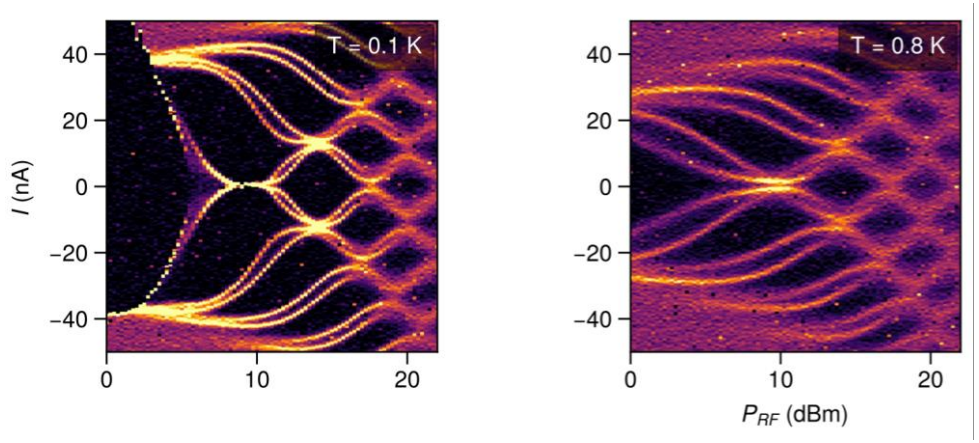
Half-integer Shapiro steps

A non-monotonic temperature dependance



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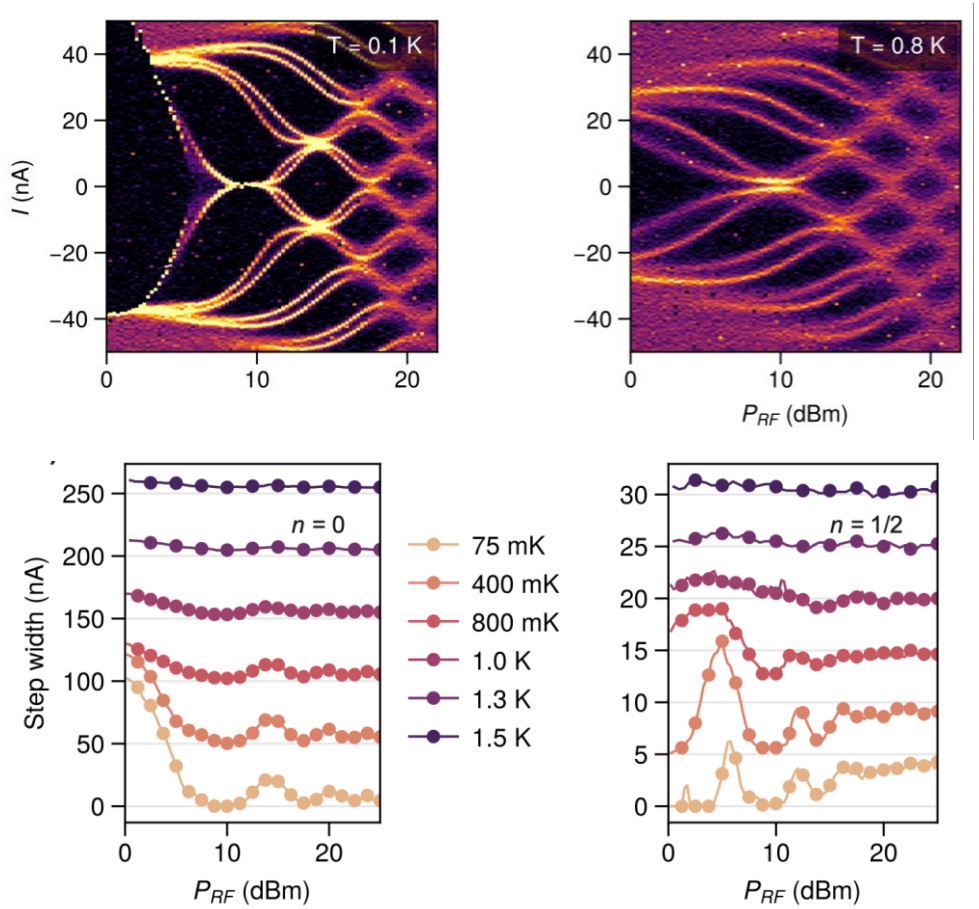

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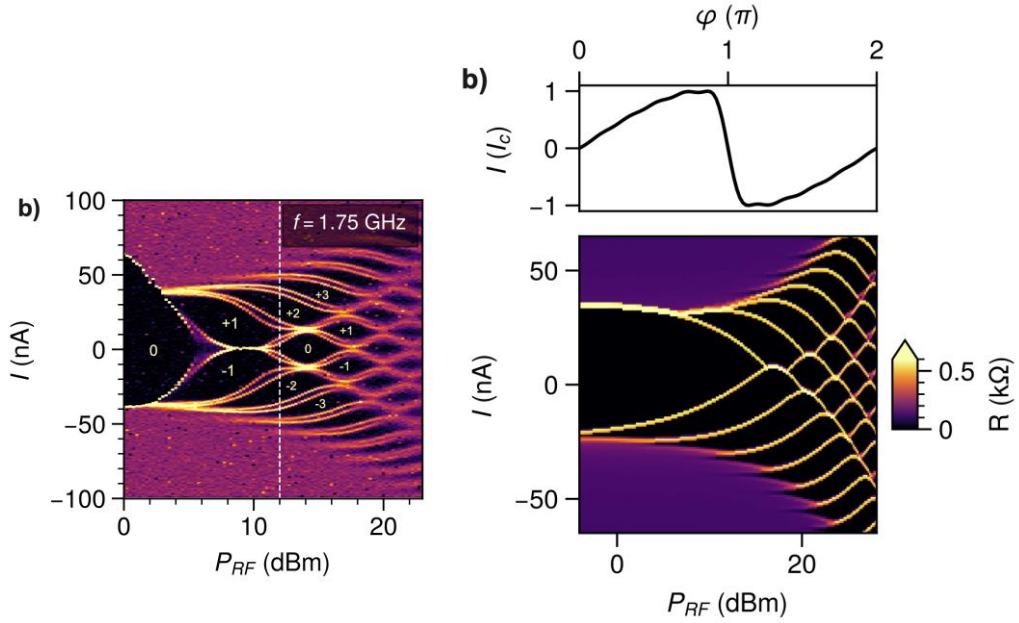
Half-integer Shapiro steps

How to have half-integer steps?

RCSJ simulations



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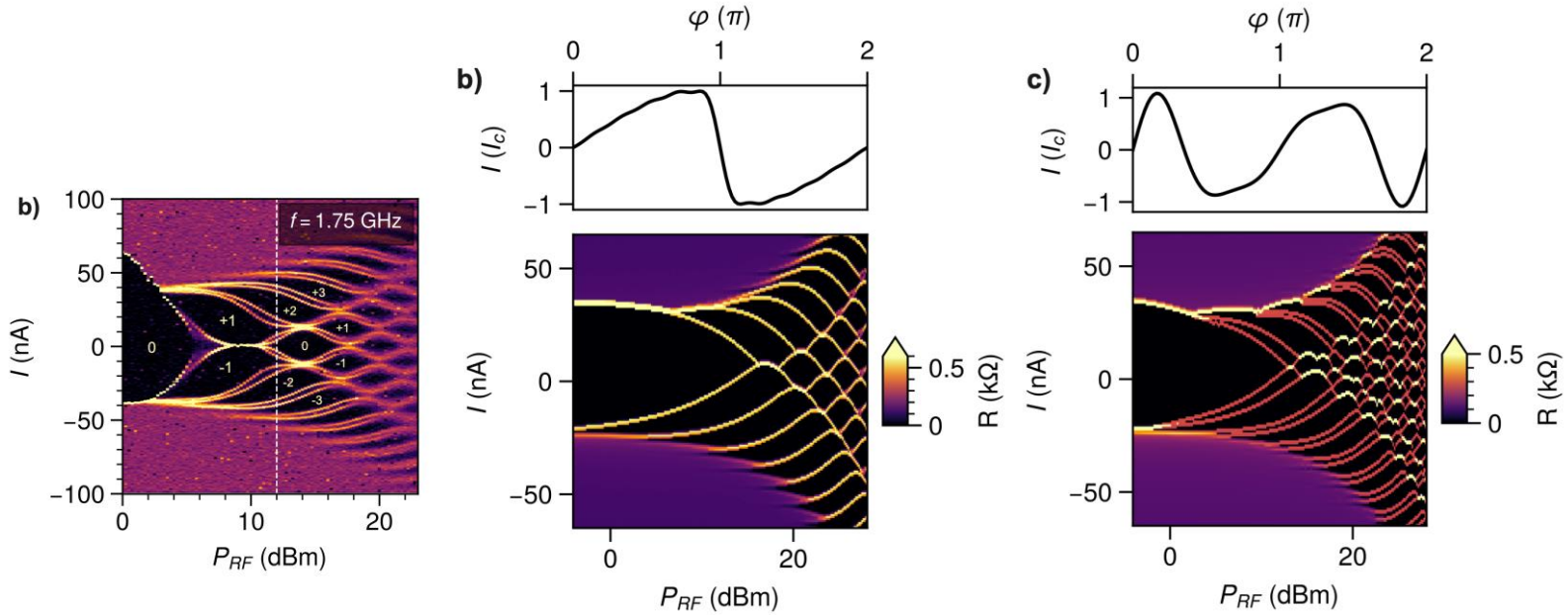
Half-integer Shapiro steps

How to have half-integer steps?

Need for a $\sin(2\varphi)$ CPR

RCSJ simulations



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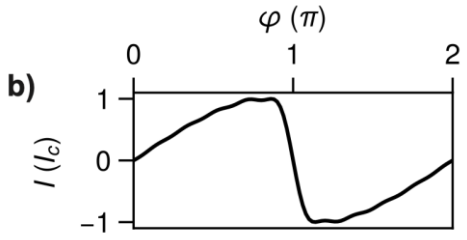
Half-integer Shapiro steps

Potential mechanisms for $\sin(2\varphi)$

Higher harmonic in the equilibrium CPR



- ✓ Common given explanation
- ✗ Weaker half-steps
- ✗ Half-steps decrease with T

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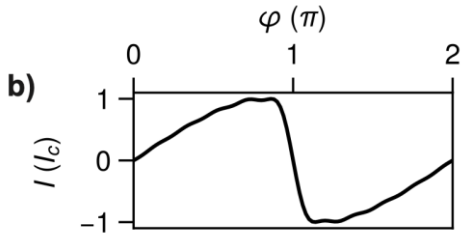
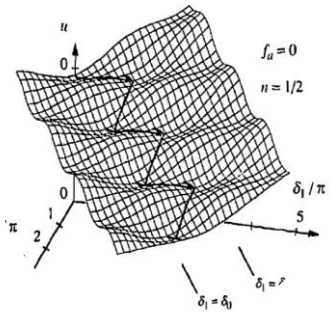


SQUID-like



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- ✓ Robust half-steps
- ✗ Different geometry
- ✗ B-field dependent

Physical basis for half-integral Shapiro steps in a dc SQUID. Physica C: Superconductivity 245.3-4 (1995)

A. Iorio et al., Phys. Rev. Research 5, 033015 (2023).

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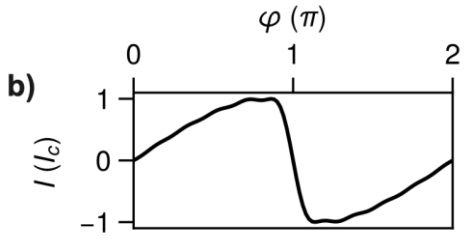

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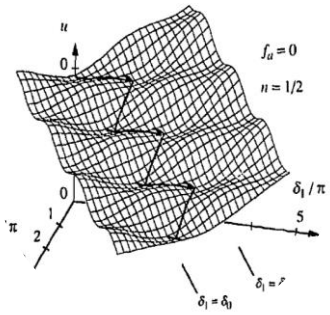

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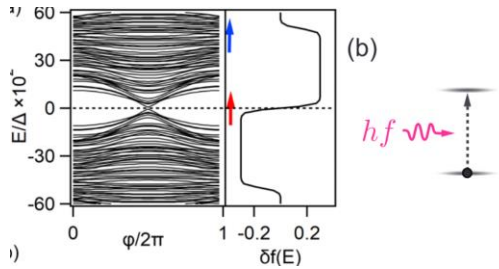
Non-equilibrium excitations



- $\sin(2\varphi)$ only when driving
- Half-steps non-monotonic in T
- ! Still some gaps with the theory

Physical basis for half-integral Shapiro steps in a dc SQUID. Physica C: Superconductivity 245.3-4 (1995)

Theory of microwave-assisted supercurrent in quantum point contacts. Physical review letters 105.11 (2010)

Microwave photoassisted dissipation and supercurrent of a phase-biased graphene-superconductor ring. Physical Review Research 3.3 (2021)

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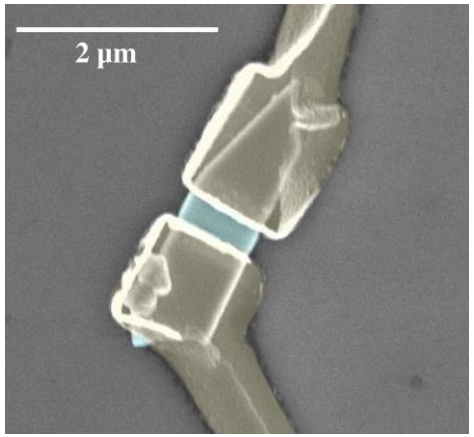
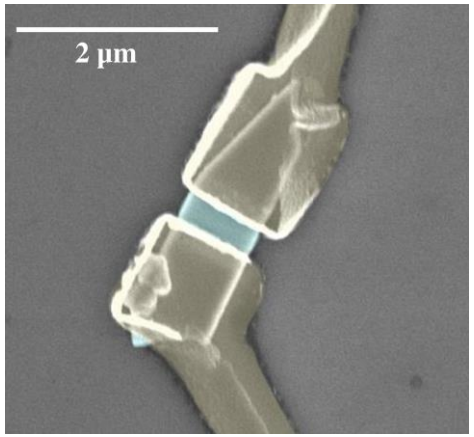
Summary



- InSb nanoflag-based Josephson junctions:
  - High-transparency of the interfaces
  - Ballistic transport
  - Gate-controlled supercurrent
- Josephson diode effect:
  - First observation of the JDE in InSb
  - Magnetic field-driven rectification
  - Relevance of Rashba SOC in the system
- Half-integer Shapiro steps:
  - Shapiro steps are still an open-topic in SNS devices
  - Controllable manipulation of bound states excitations (Andreev qubits)

Summary



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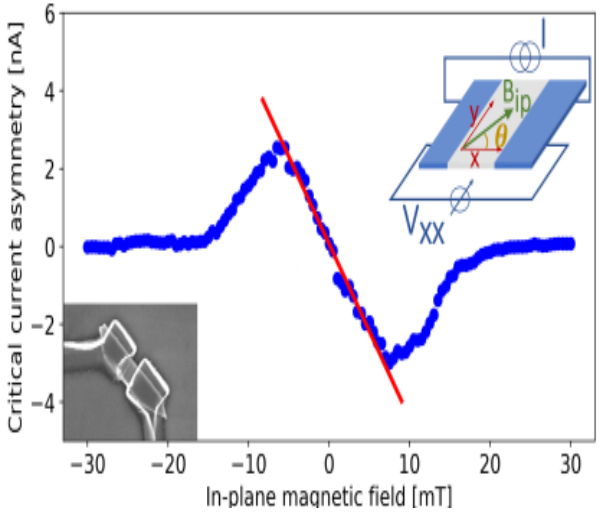

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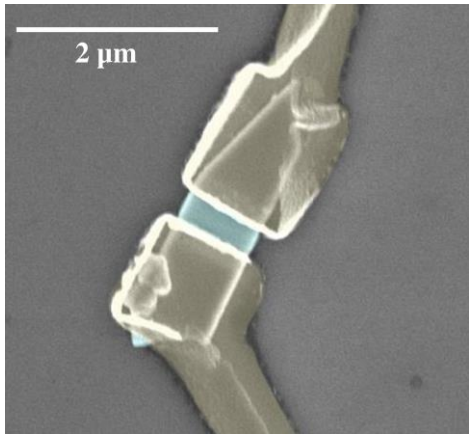

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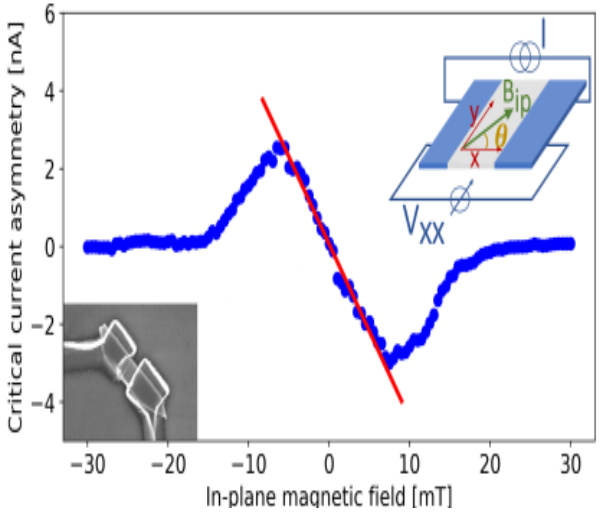

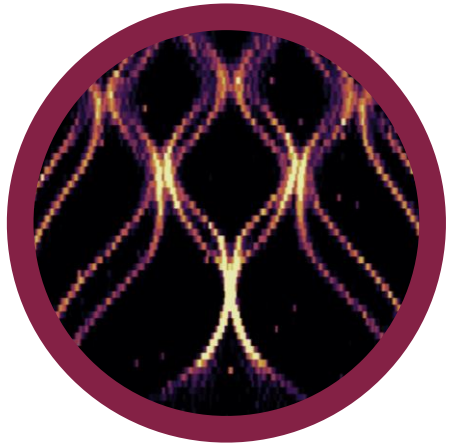

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