

Josephson effect in full-shell hybrid nanowires

Carlos Payá

APS Global Physics Summit – March 18th, 2025



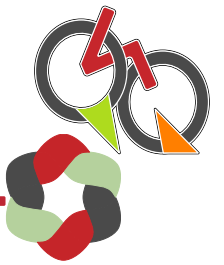
CSIC



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About us



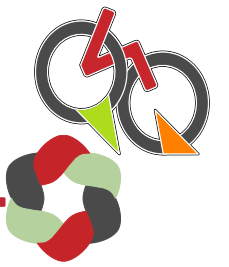
Josephson effect and critical currents in trivial and topological full-shell hybrid nanowires

C. Payá, R. Aguado, P. San-Jose and E. Prada
arXiv:2503.09756



Phenomenology of Majorana zero modes in full-shell hybrid nanowires

C. Payá, S. D. Escribano, A. Vezzosi,
F. Peñaranda, R. Aguado, P. San-Jose and E. Prada
Phys. Rev. B **109**, 115428

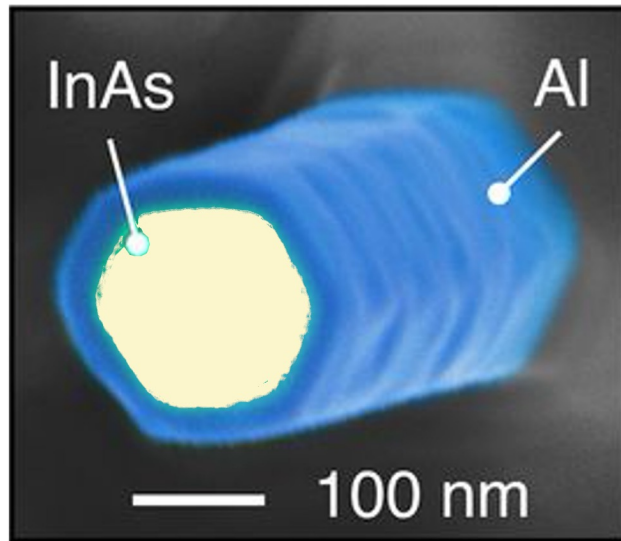
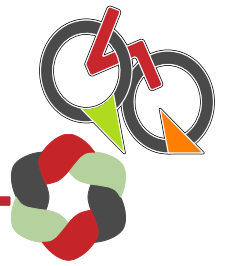


What does the **critical current** of a full-shell Josephson junction look like?

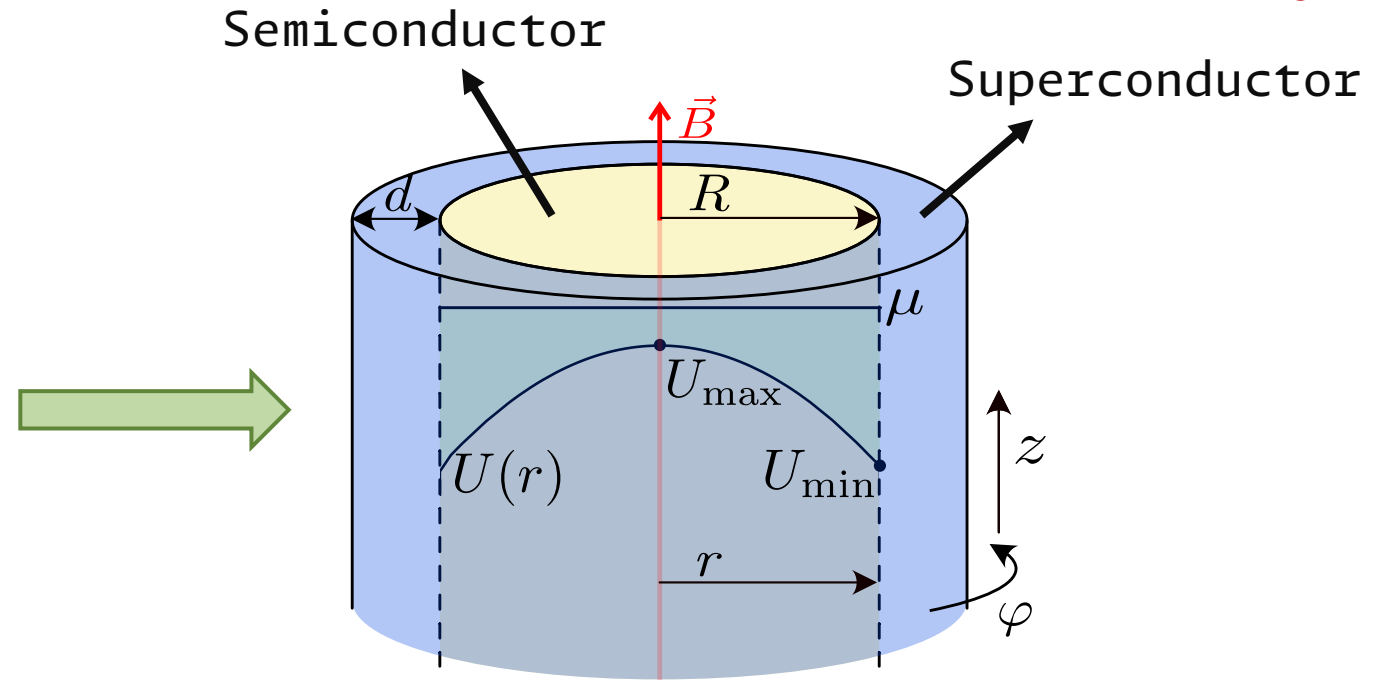
How do **non-topological** sub-gap states contribute?

What about **Majoranas**?

A full-shell hybrid nanowire



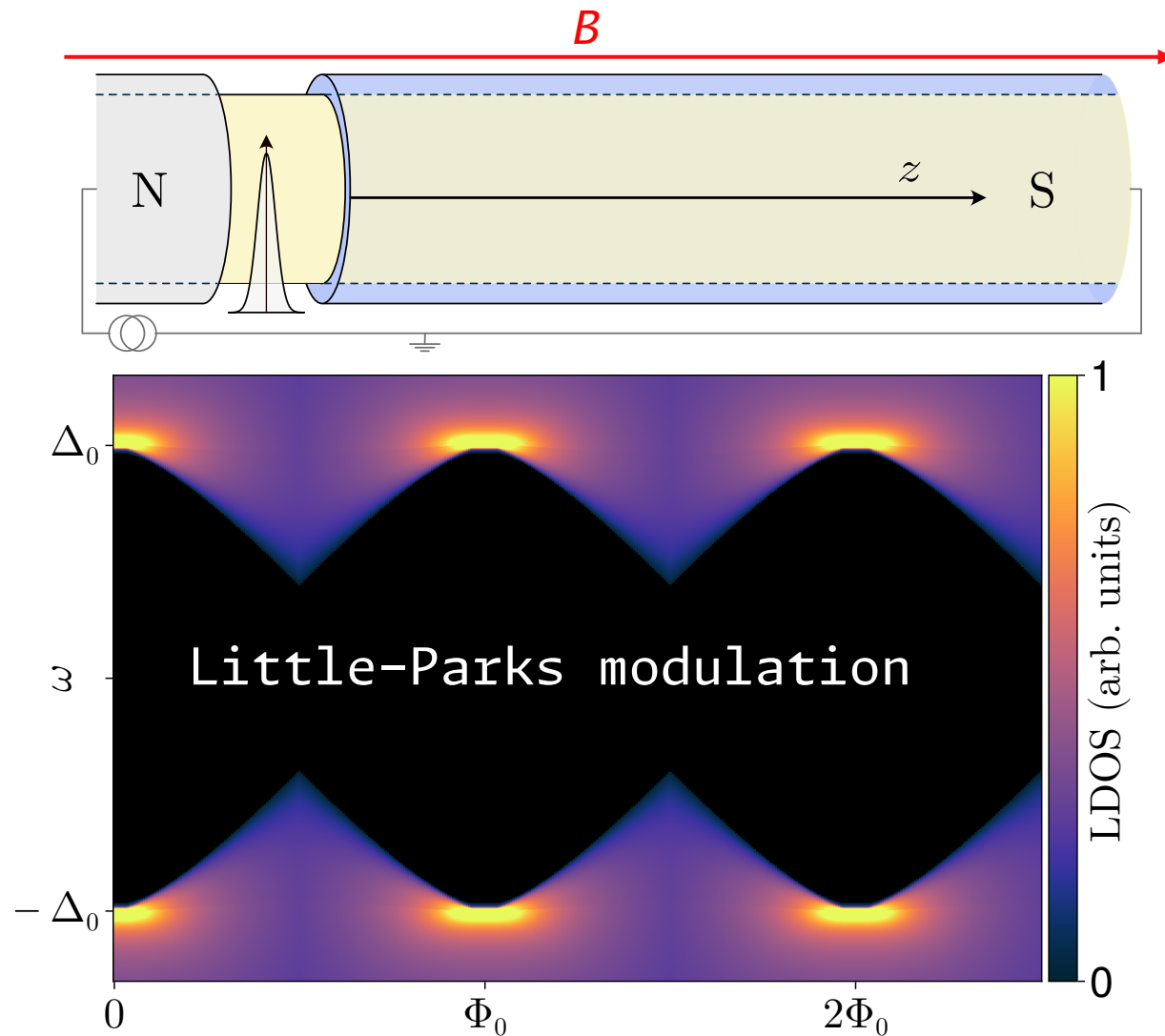
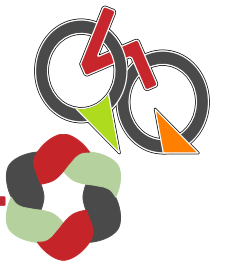
S. Vaitiekėnas *et al.*, *Science*, 2020



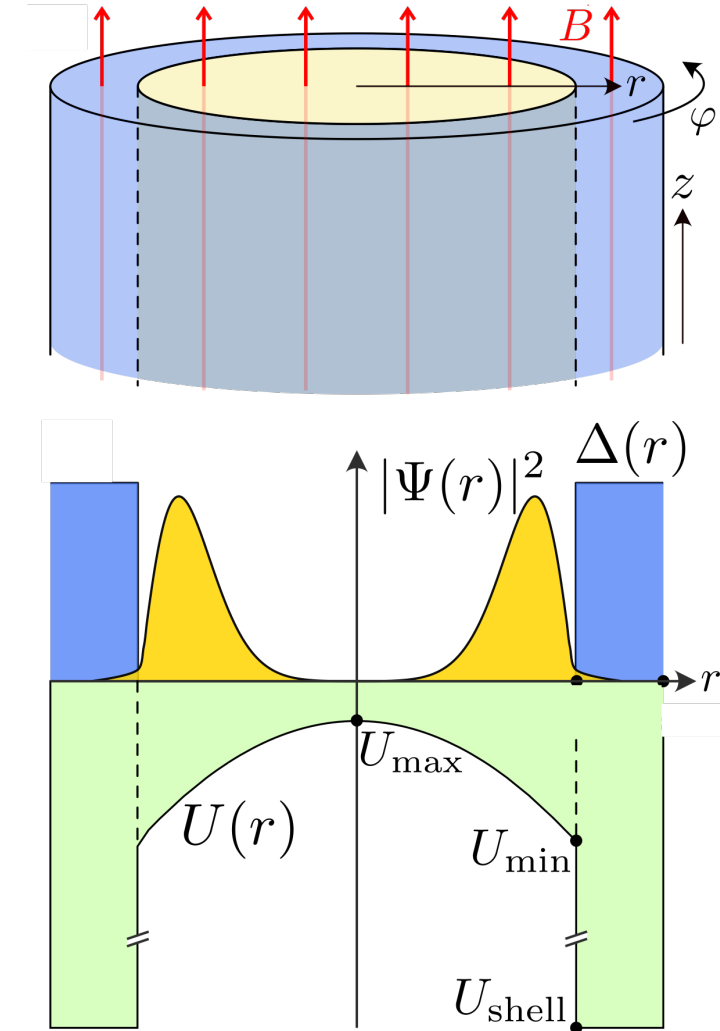
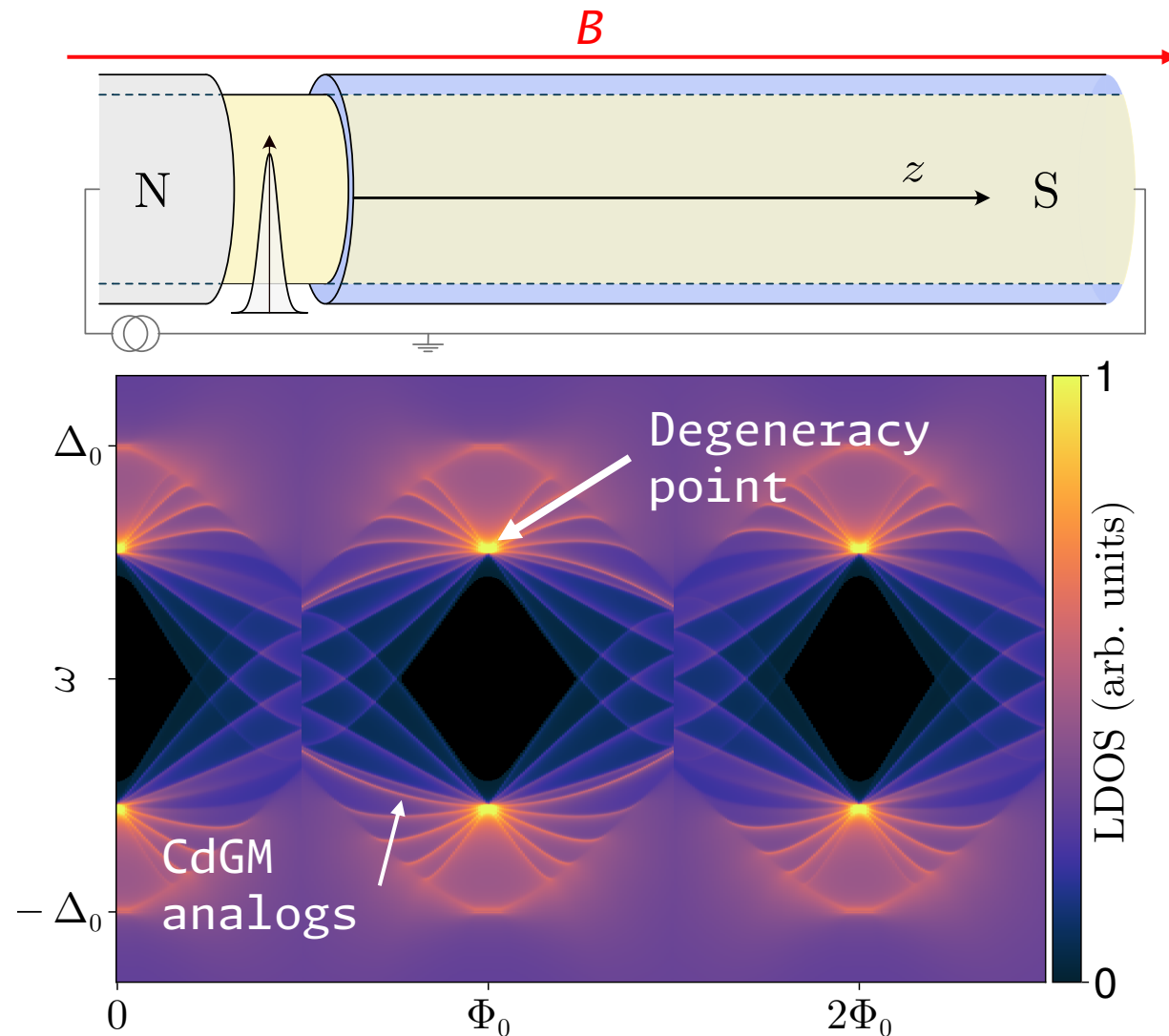
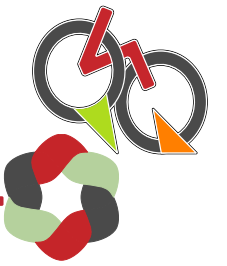
- Topological at lower magnetic fields
- Protected from charge noise

- Cylindrical symmetry
- Charge at interface
- SOC induced by band bending

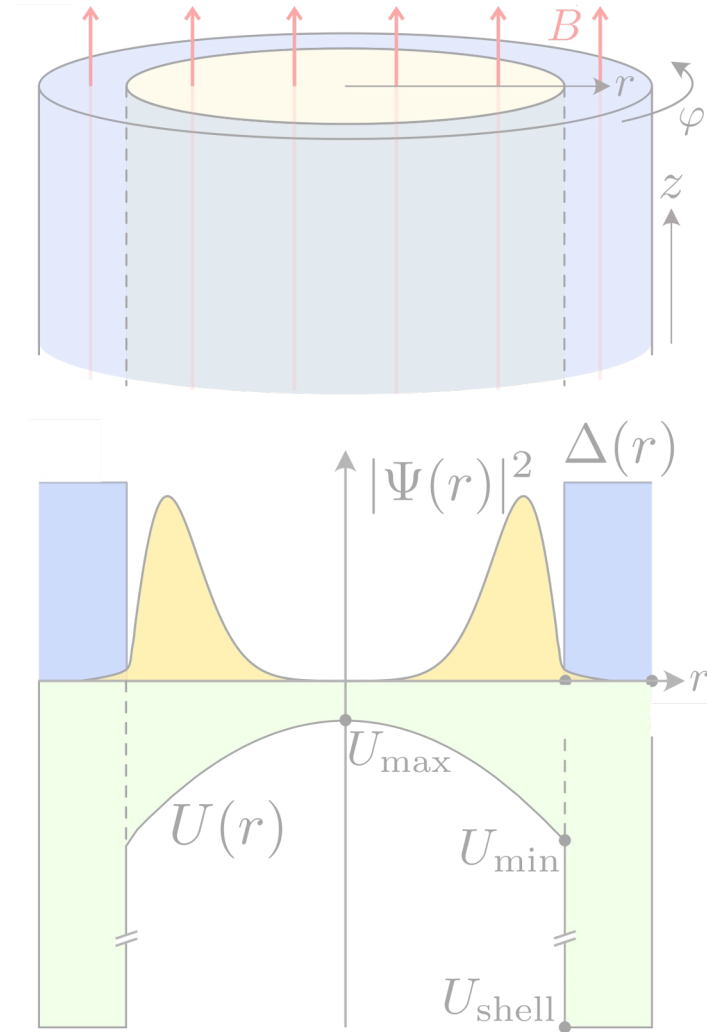
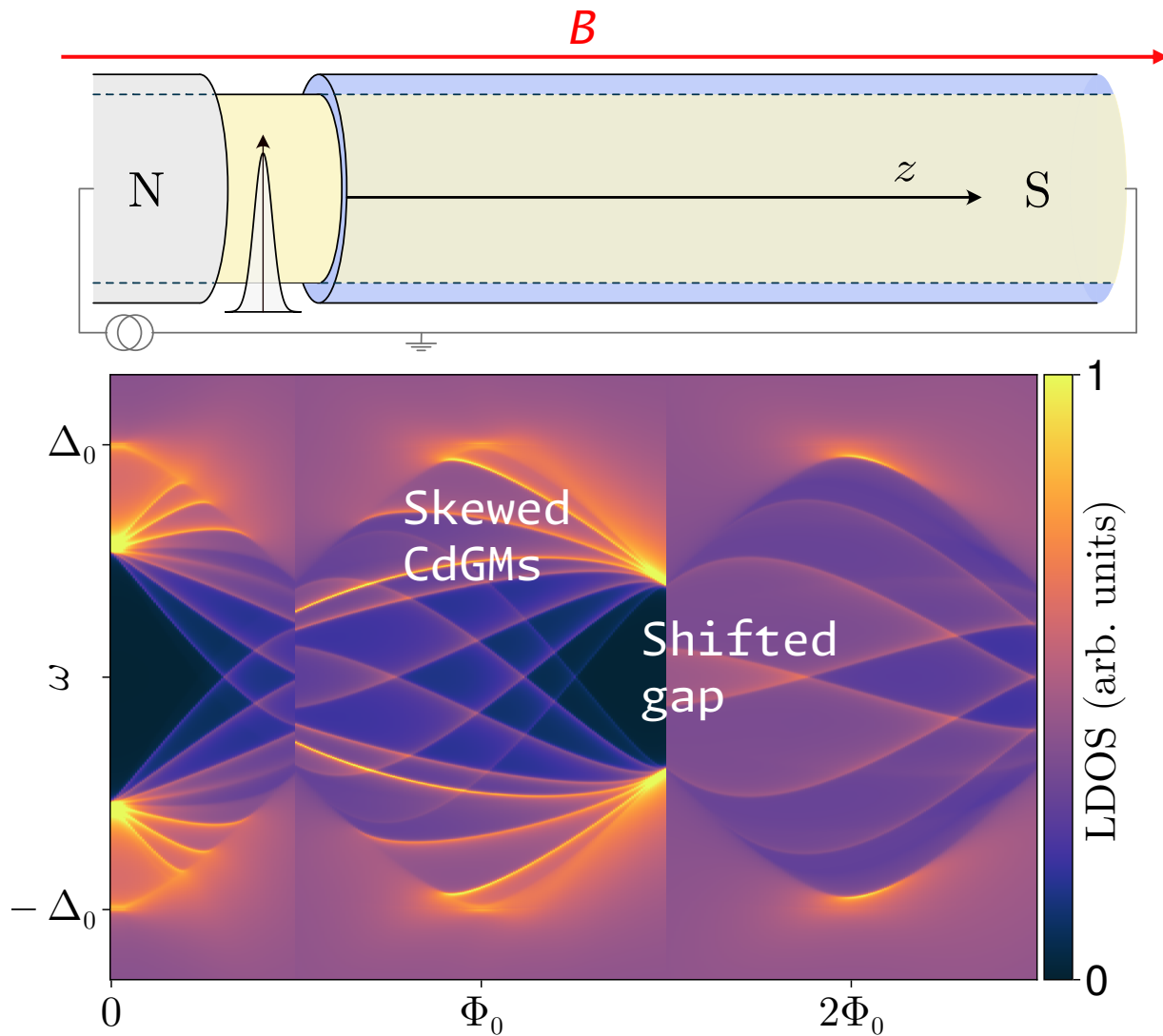
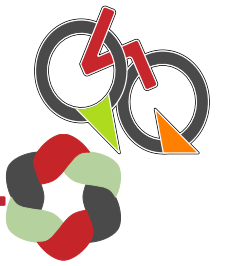
Sub-gap levels skewness at the edge



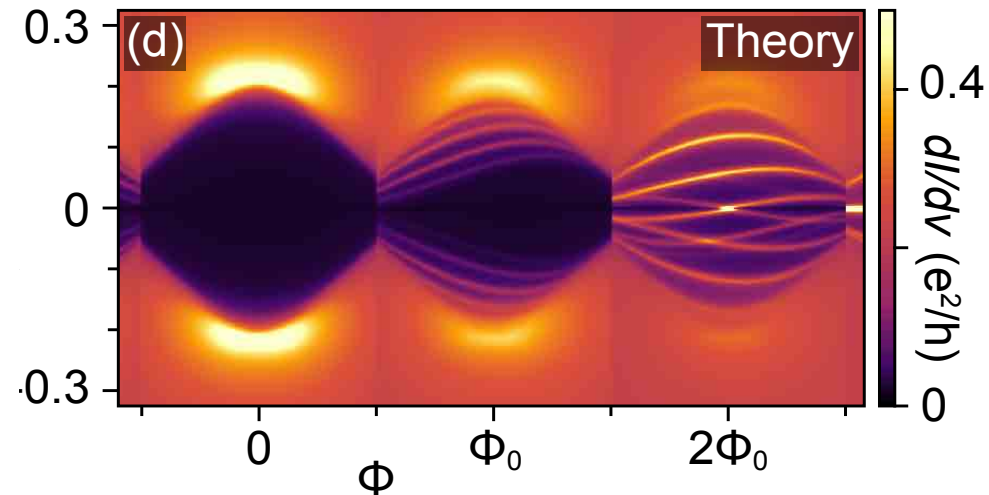
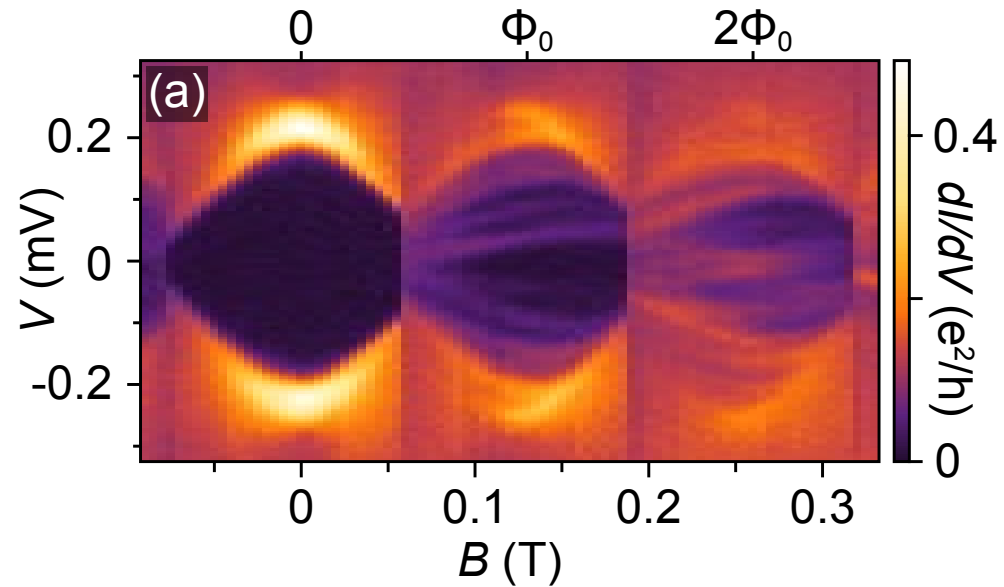
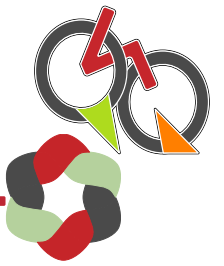
Sub-gap levels skewness at the edge



Sub-gap levels skewness at the edge

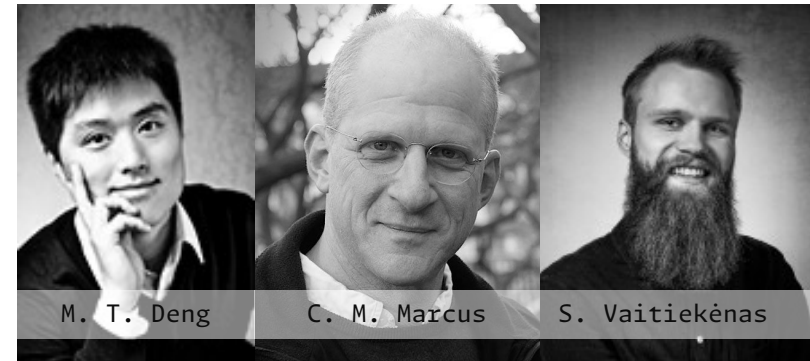


CdGMs experimental demonstration



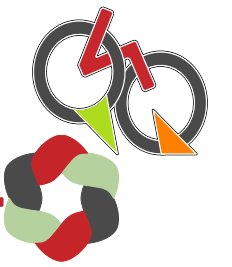
Caroli-de Gennes-Matricon analogs in full-shell hybrid nanowires

M. T. Deng, C. Payá, P. San-Jose, E. Prada,
C. M. Marcus and S. Vaitiekėnas
arXiv:2501.05419



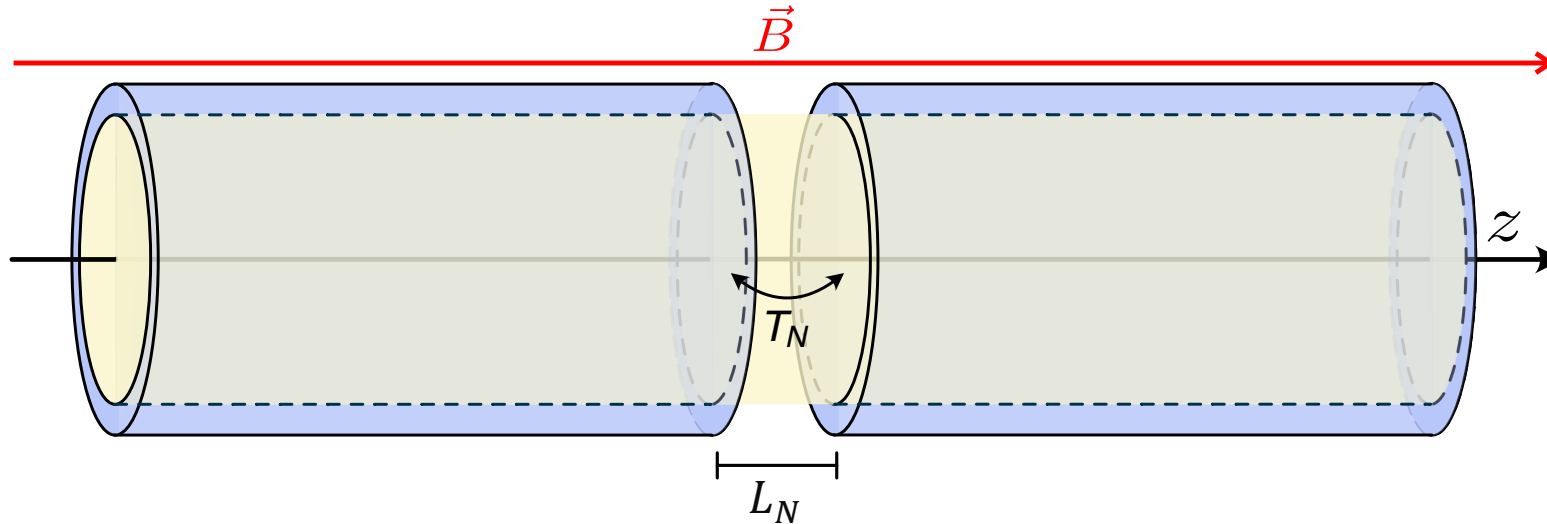
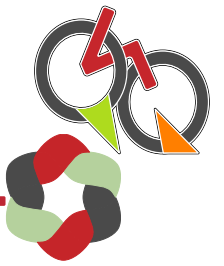
UNIVERSITY OF
COPENHAGEN





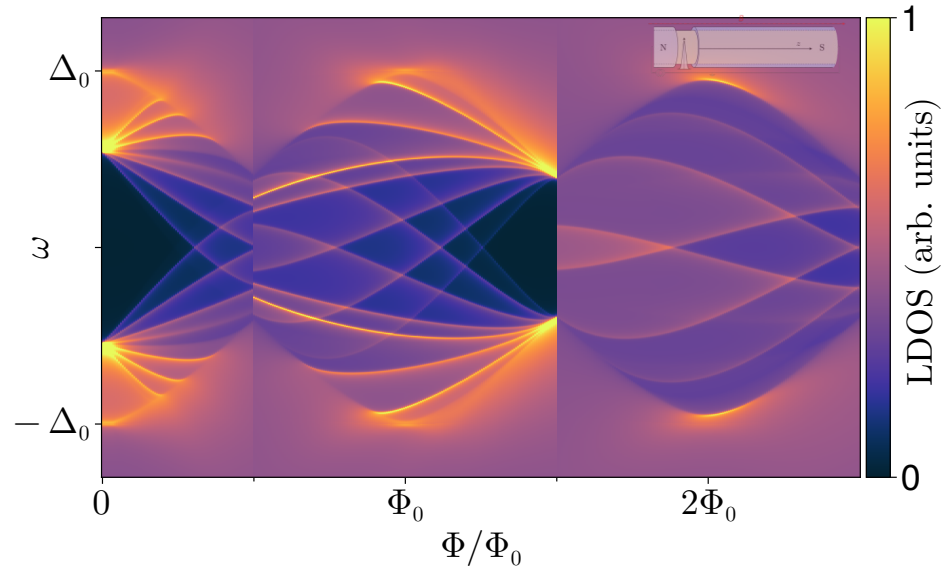
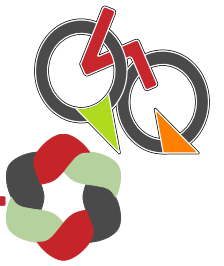
What do we expect in a Josephson junction?

A full-shell Josephson junction

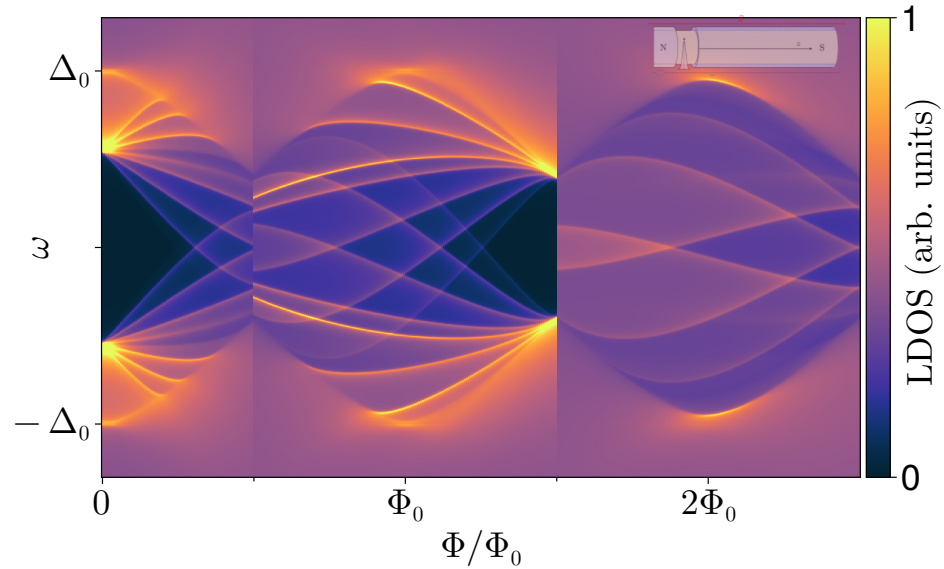
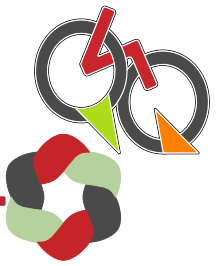


- Equal nanowires
- Short junction, $L_N \ll \xi_{SC}$
- Controlled transparency T_N
- No voltage bias \Rightarrow dc Josephson

Critical current skewness

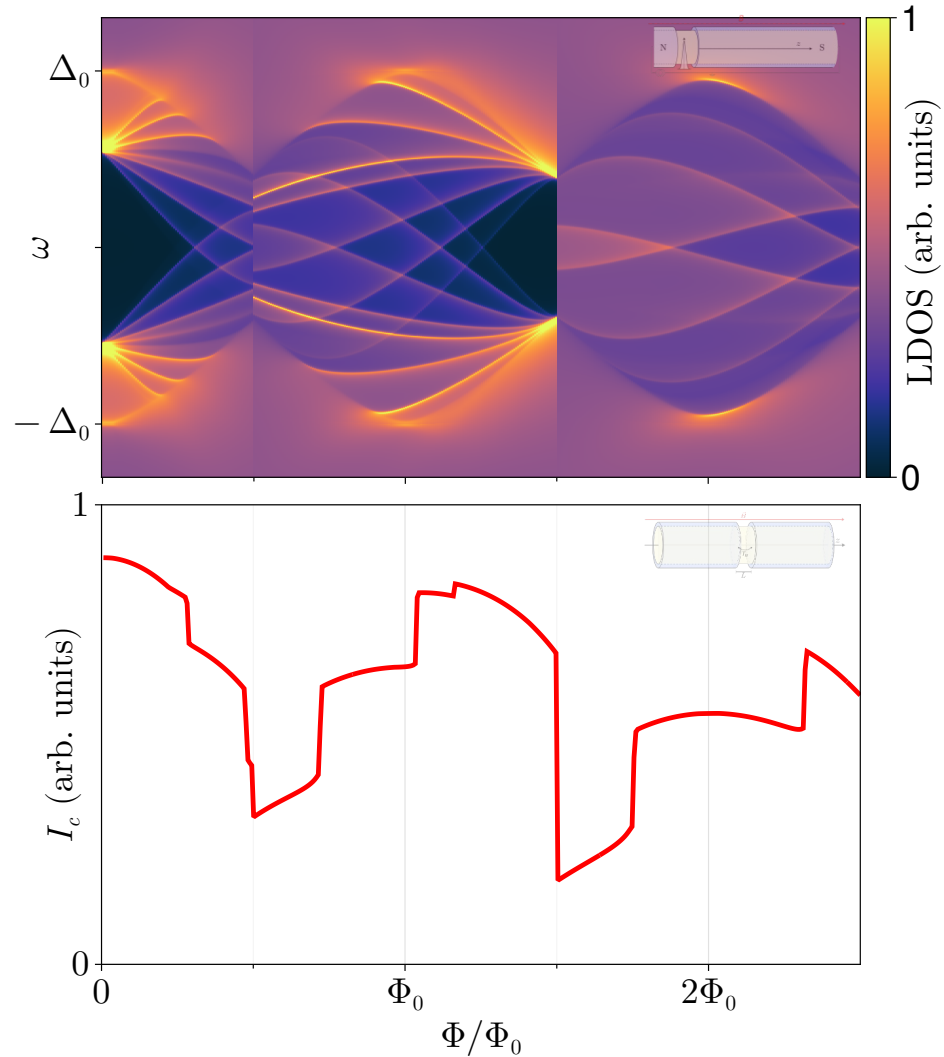
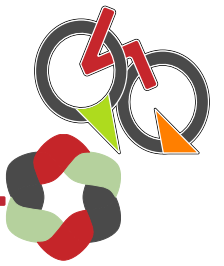


Critical current skewness



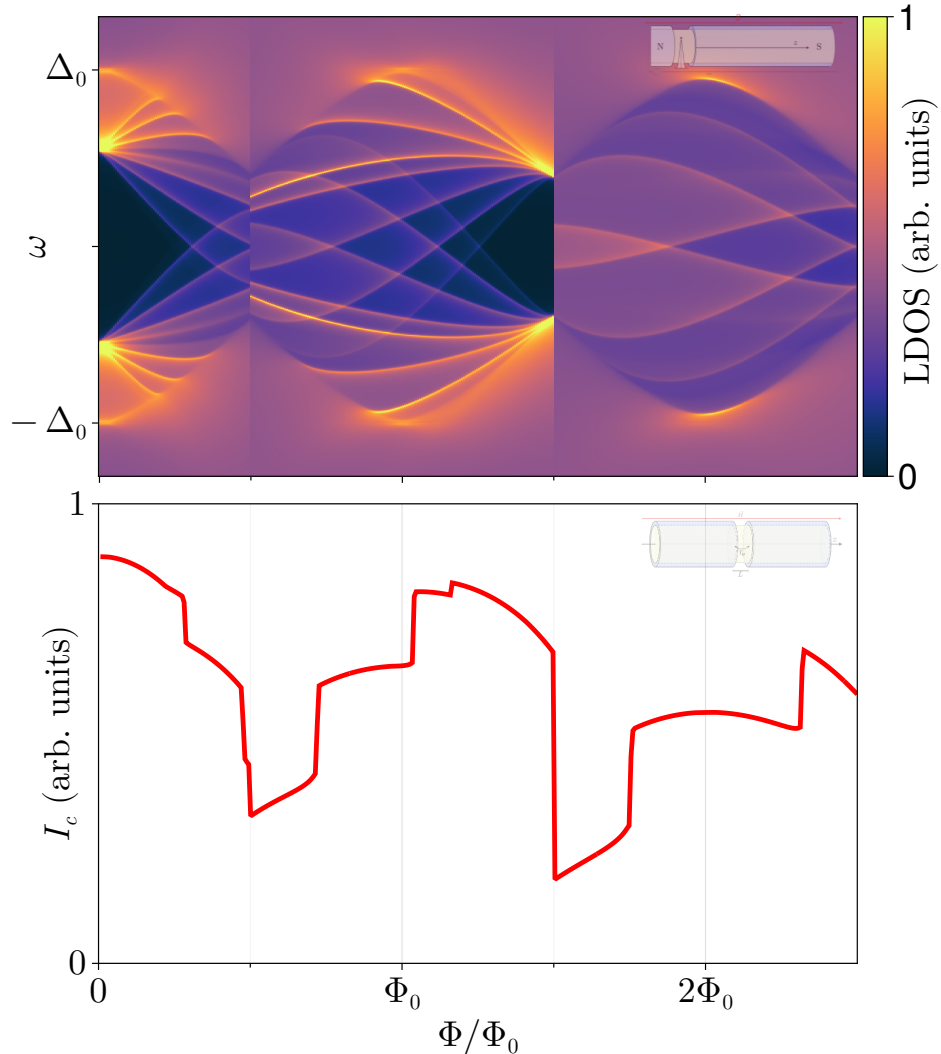
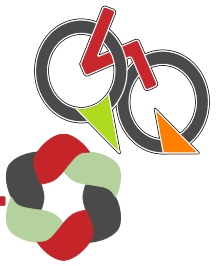
$$J_S(\phi) = \frac{2e}{h} \text{Re} \int d\omega f(\omega) 2\text{Tr}[(\Sigma^r G^r - G^r \Sigma^r)\tau_z]$$
$$I_c = \max_{\phi} \{J_S\}$$

Critical current skewness



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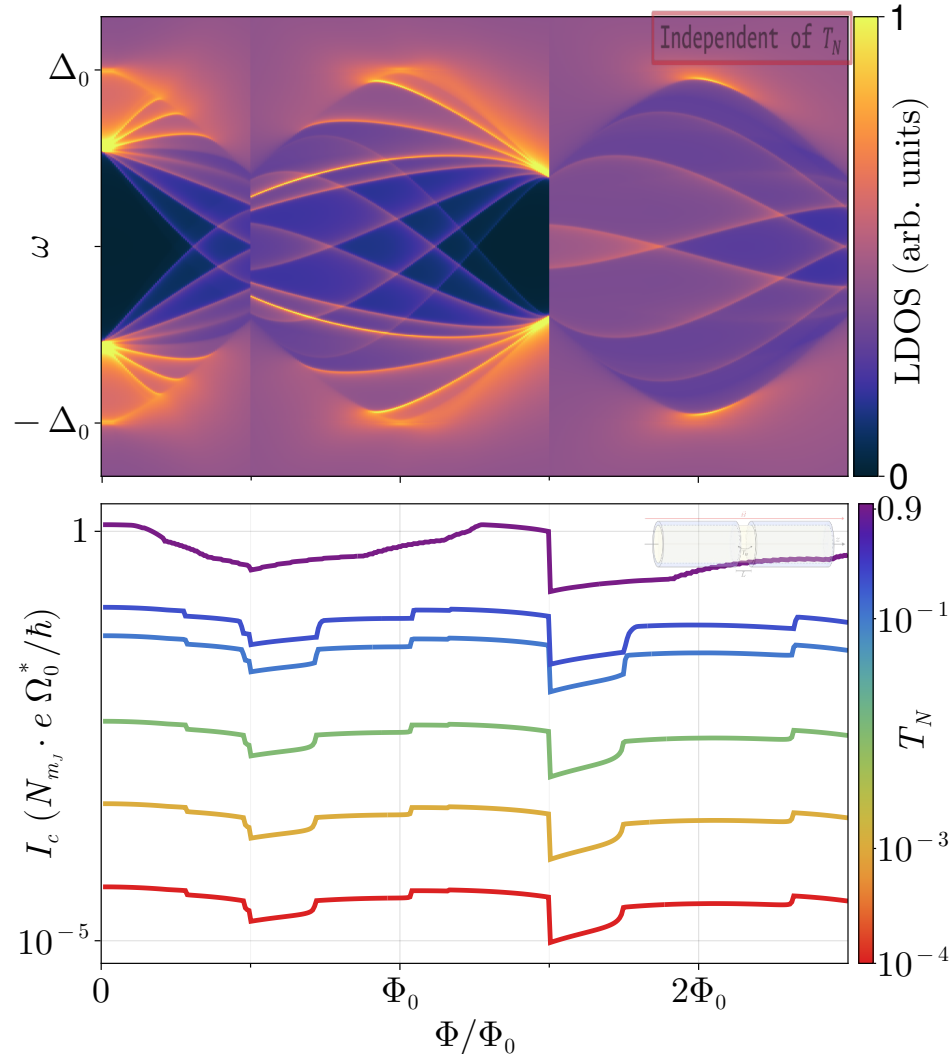
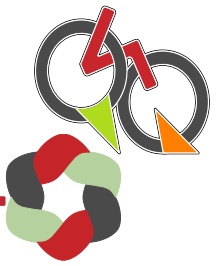


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- ➡ Little-Parks modulation
- ➡ Skewness to right within LP lobes
- ➡ Due to CdGM crossings at 0 energy
- ↔ Current steps

Critical current skewness



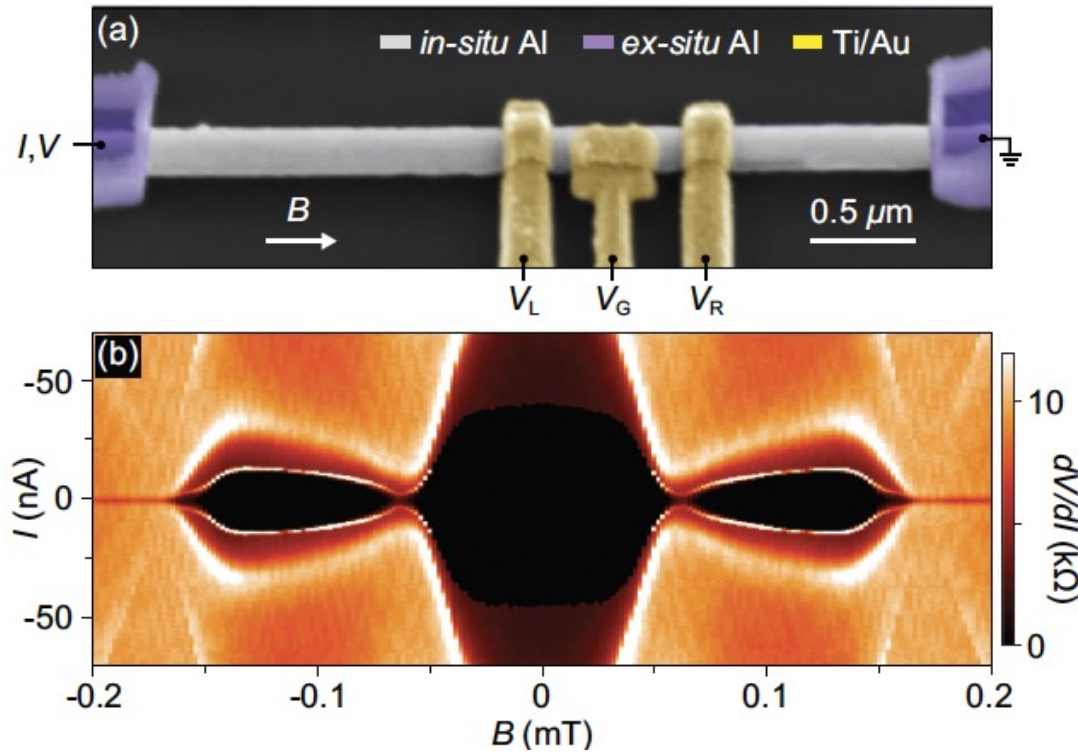
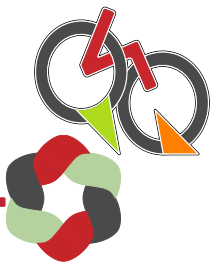
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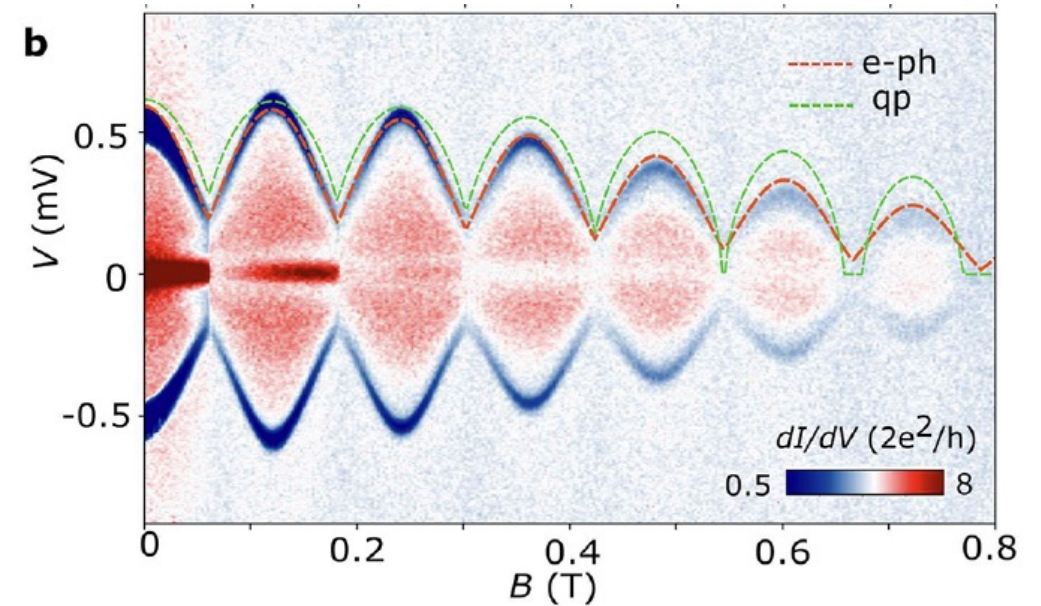
- ➔ Little-Parks modulation
- ➔ Skewness to right within LP lobes
- ➔ Due to CdGM crossings at 0 energy
- ↔ Current steps

Independent of T_N

Skewness experimental signatures



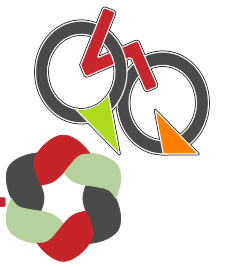
D. Razmadze *et al.* Phys. Rev. B **109**, L041302



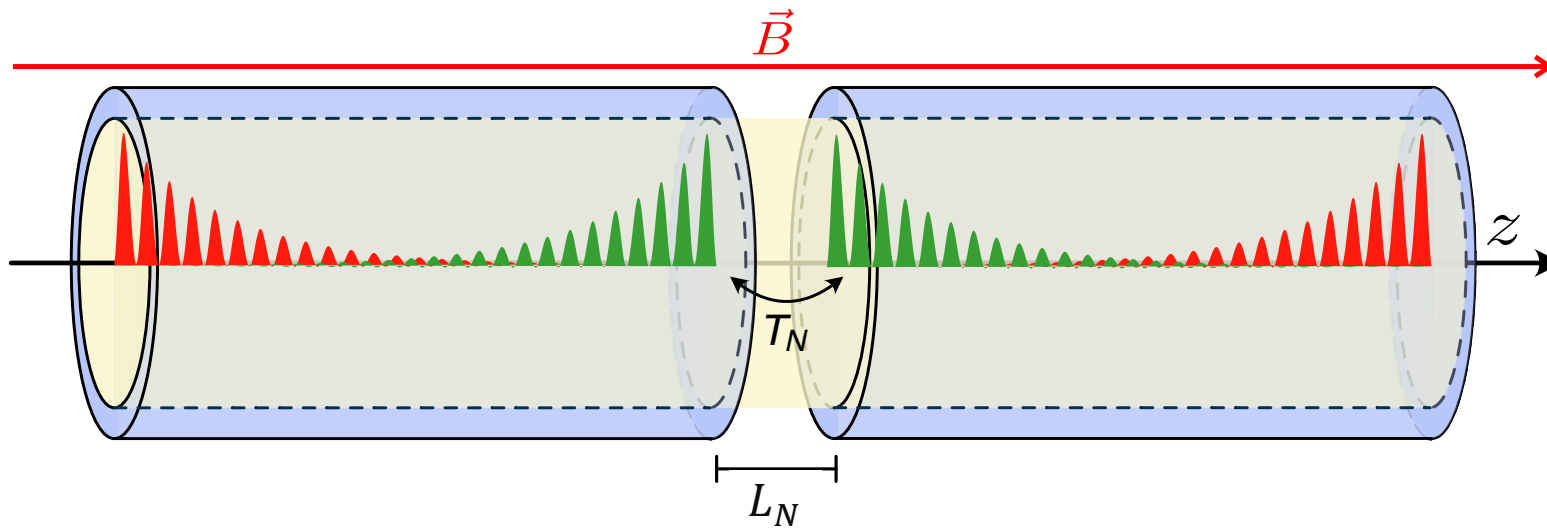
A. Ibabe *et al.* Nano Lett. 2024, 24, 22, 6488–6495

E. Lee group
IFIMAC, Madrid

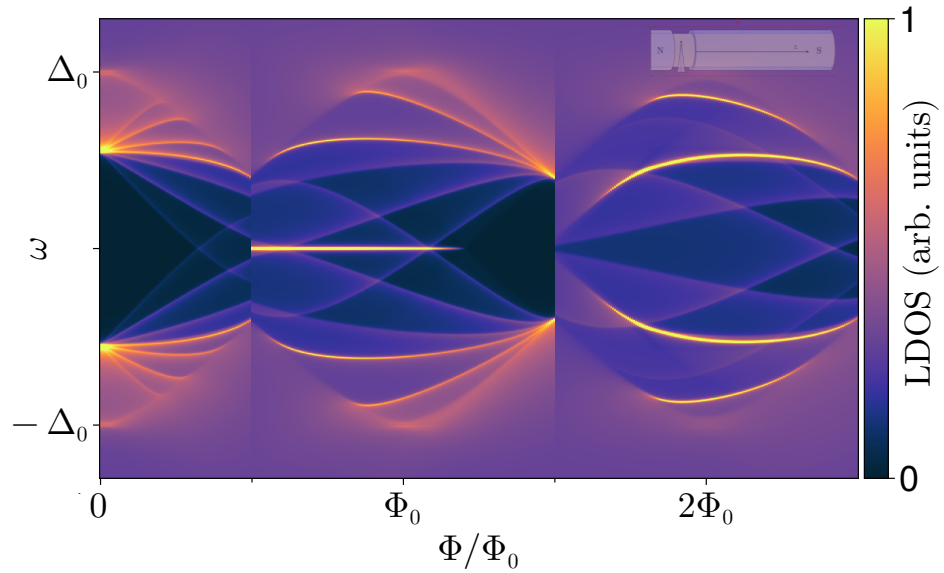
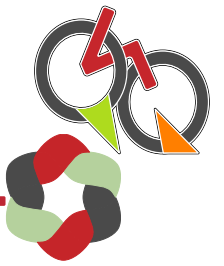
C. M. Marcus and S. Vaitiekėnas group
NBI, Copenhagen



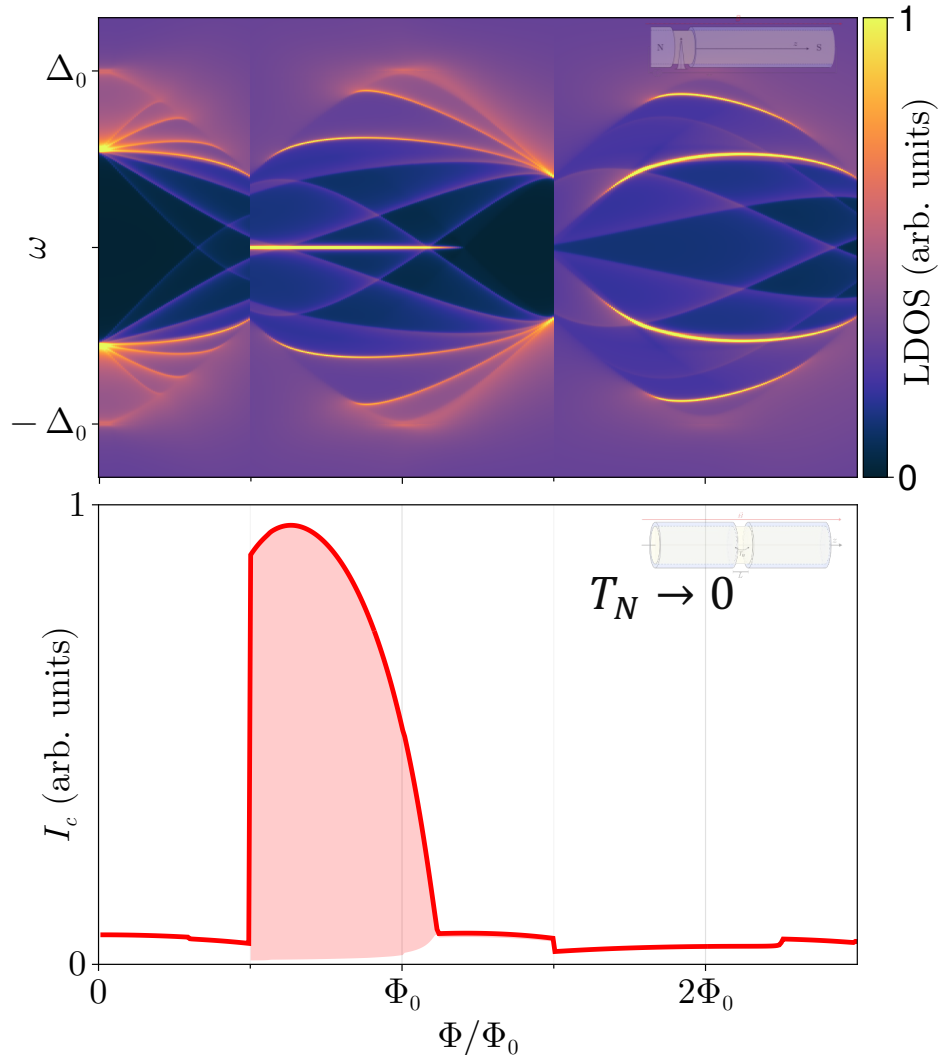
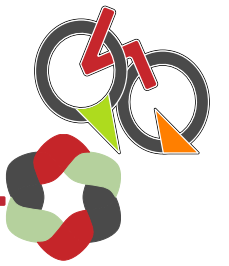
What if there are Majoranas?



Majorana critical current fin



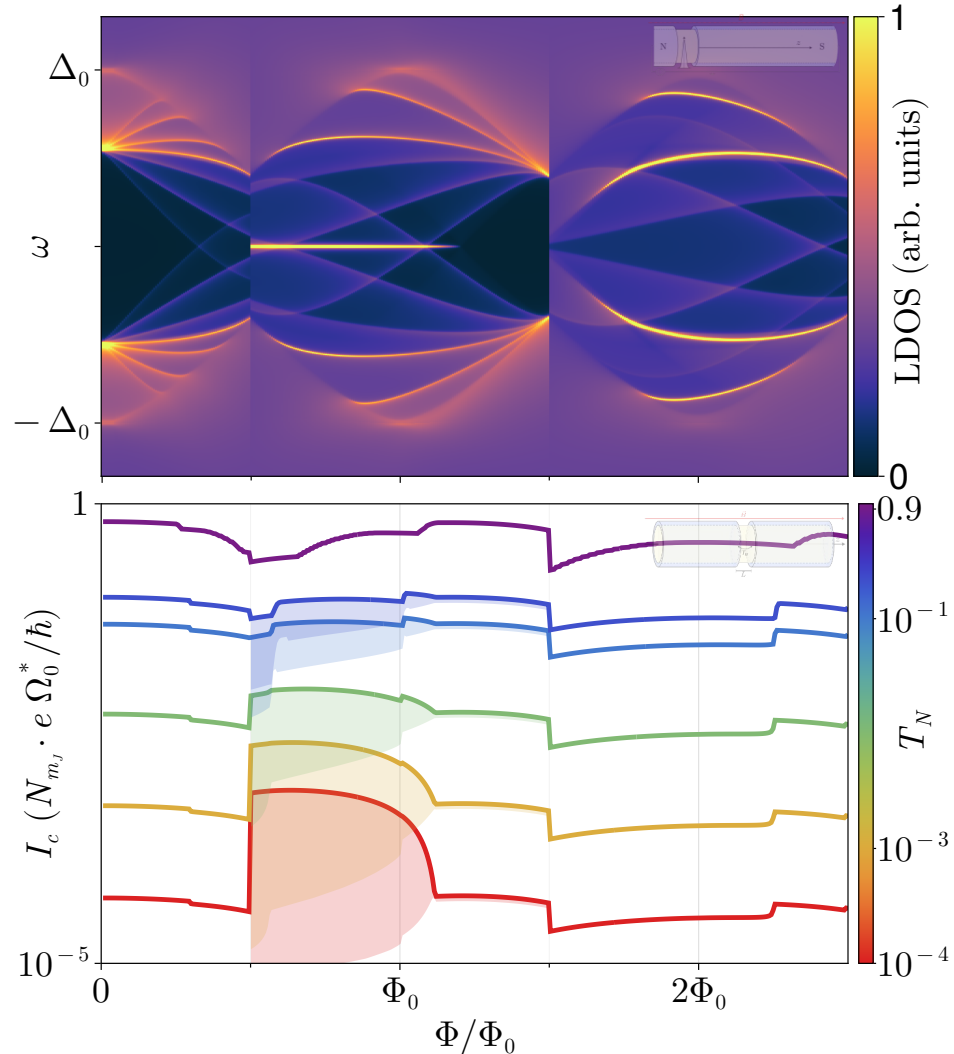
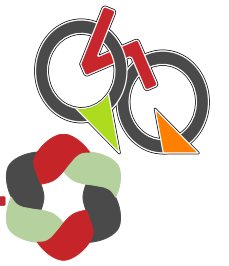
Majorana critical current fin



Majorana \longleftrightarrow Current fin

CdGMs \longleftrightarrow Skewness to right

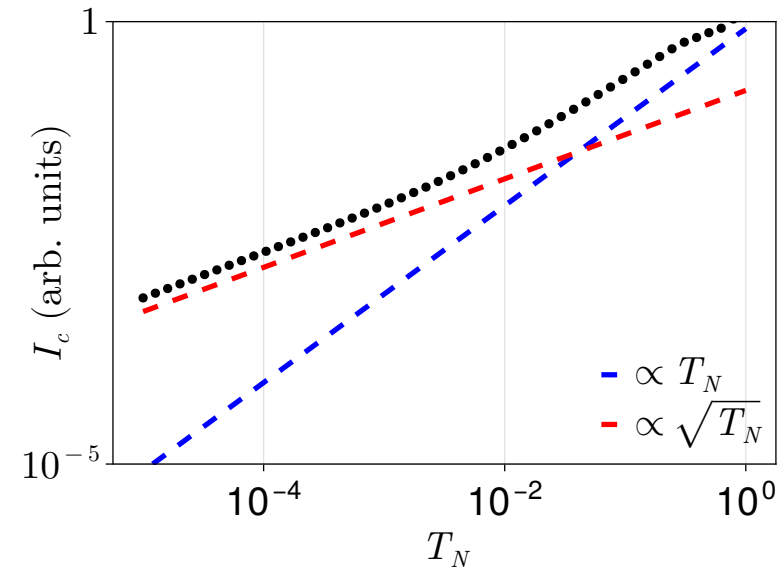
Majorana critical current fin



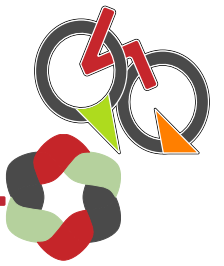
Majorana \longleftrightarrow Current fin

CdGMs \longleftrightarrow Skewness to right

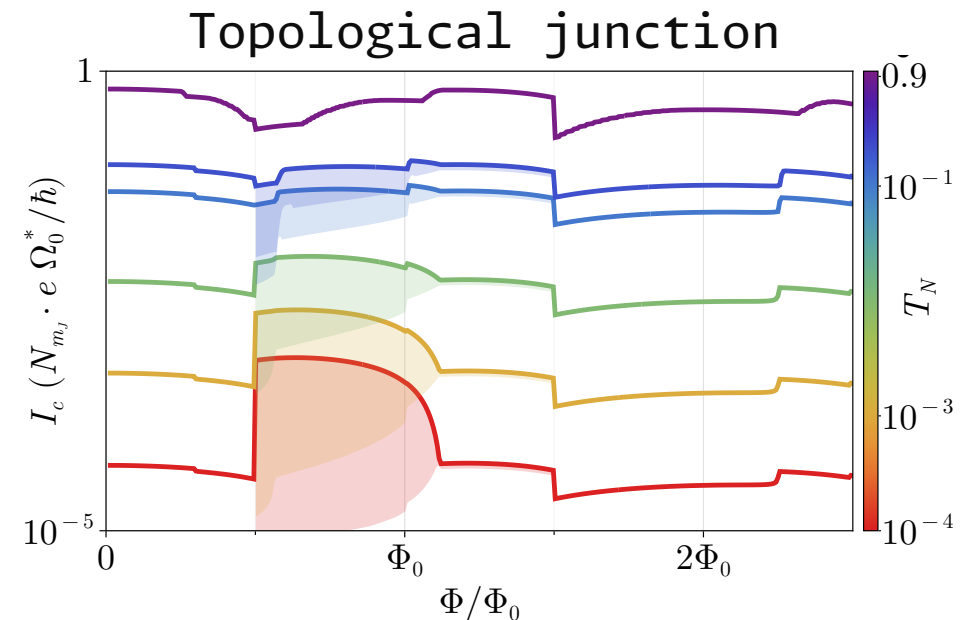
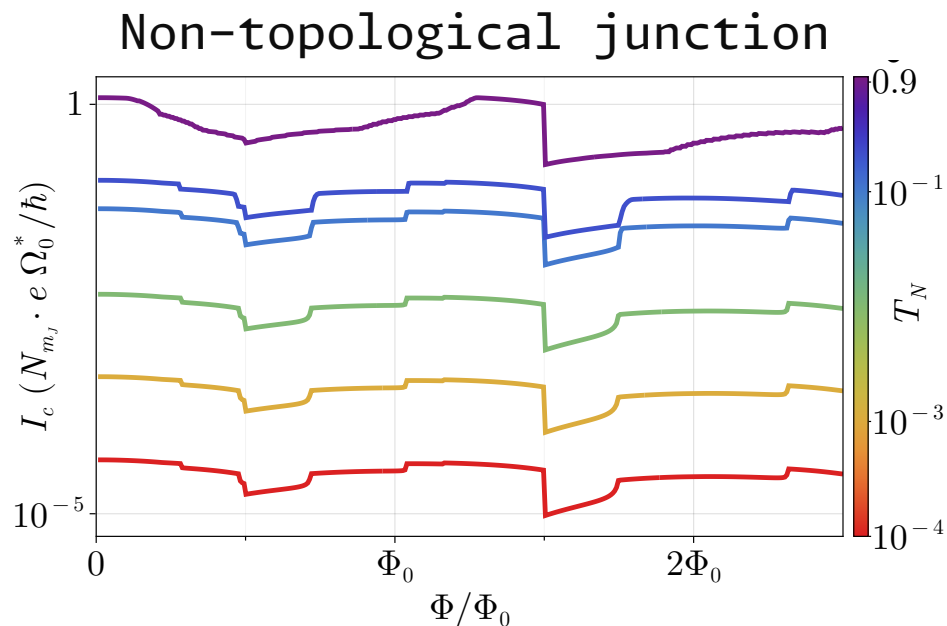
Crossover in transparency

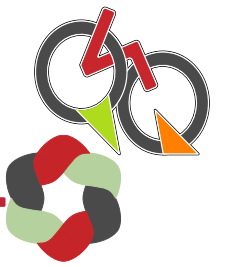


Conclusions



- ➔ Full-shell nanowires host **non-topological subgap states** ➔ CdGMs
- ➔ CdGMs **skew** Josephson critical current towards **higher fluxes** within all Little-Parks lobes for **all transparencies**
- ➔ Majoranas give the Josephson critical current a **fin shape** within odd Little-Parks lobes for **low transparencies**





Full story just appeared on arXiv!!

Josephson effect and critical currents in trivial and topological full-shell hybrid nanowires

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arXiv:2503.XXXXX

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PID2021-125343NB-I00
PRE2022-101362

