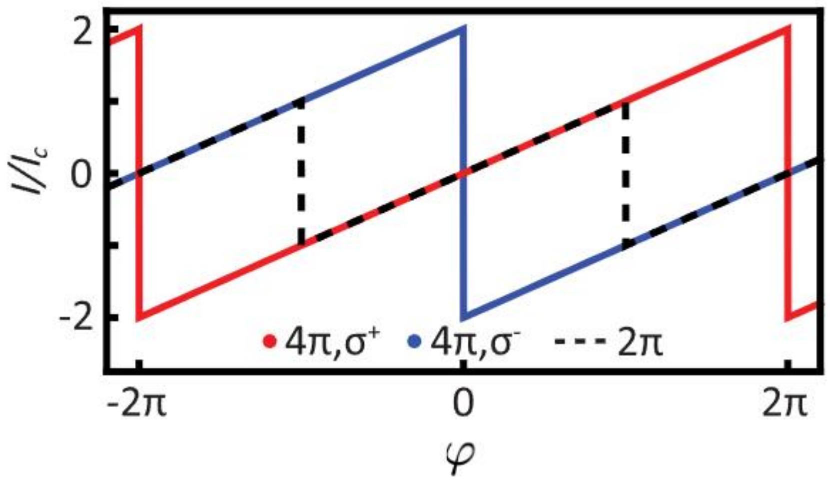
Current–Phase Relation of a WTe_2 Josephson Junction

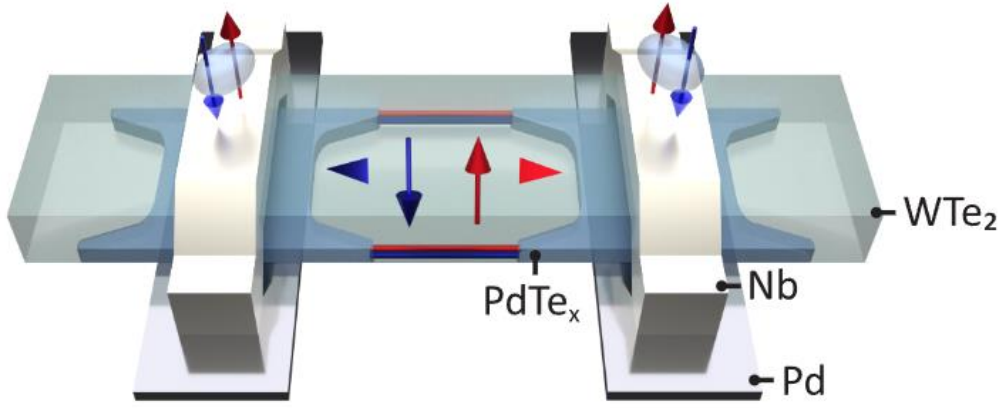
Martin Endres,* Artem Kononov, Hasitha Suriya Arachchige, Jiaqiang Yan, David Mandrus, Kenji Watanabe, Takashi Taniguchi, and Christian Schönenberger

Outline

- The goal
- The Current Phase Relation of a Josephson Junction
- Superconducting Quantum Interference Device
- The Counter Technique
- The result & Model
- EMP project

The goal





Fermion-Parity Anomaly of the Critical Supercurrent in the Quantum Spin-Hall Effect

C. W. J. Beenakker,[1] D. I. Pikulin,[1] T. Hyart,[1] H. Schomerus,[2] and J. P. Dahlhaus[1]

[1]*Instituut-Lorentz, Universiteit Leiden, Post Office Box 9506, 2300 RA Leiden, The Netherlands*

[2]*Department of Physics, Lancaster University, Lancaster LA1 4YB, United Kingdom*

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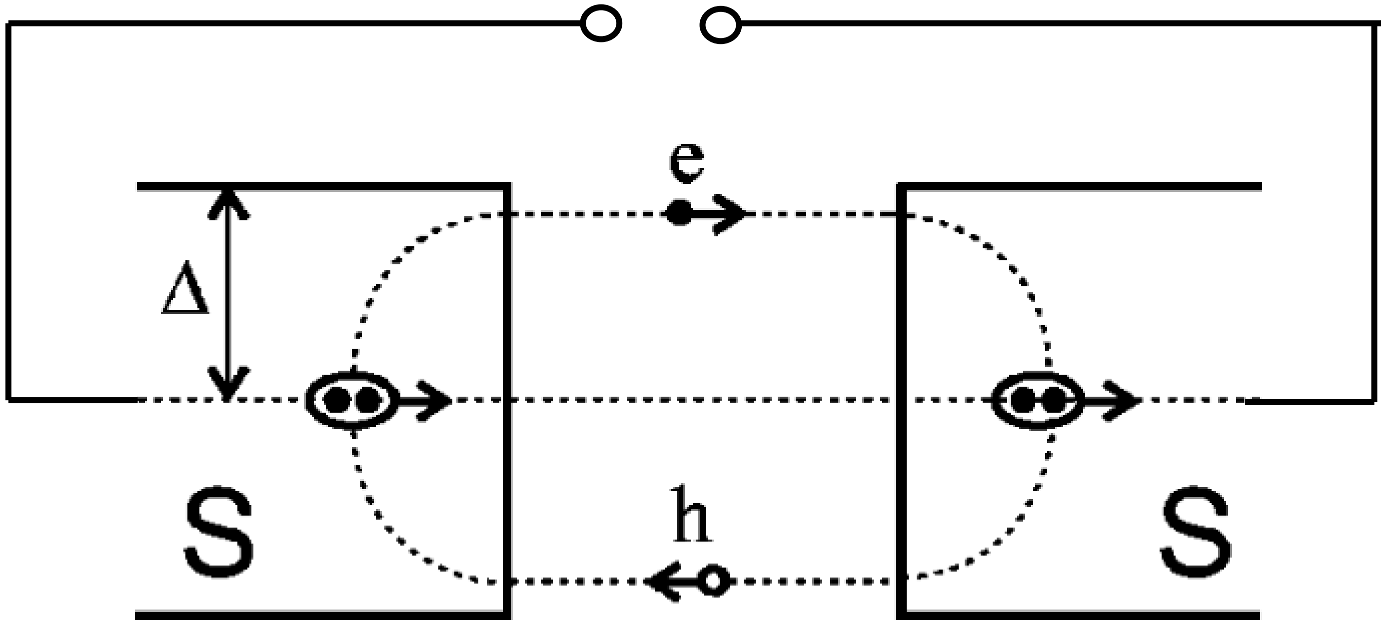
The helical edge state of a quantum spin-Hall insulator can carry a supercurrent in equilibrium between two superconducting electrodes (separation L, coherence length ξ). We calculate the maximum (critical) current I_c that can flow without dissipation along a single edge, going beyond the short-junction restriction $L \ll \xi$ of earlier work, and find a dependence on the fermion parity of the ground state when L becomes larger than ξ. Fermion-parity conservation doubles the critical current in the low-temperature, long-junction limit, while for a short junction I_c is the same with or without parity constraints. This provides a phase-insensitive, dc signature of the 4π-periodic Josephson effect.

The Current Phase Relation of a Josephson Junction



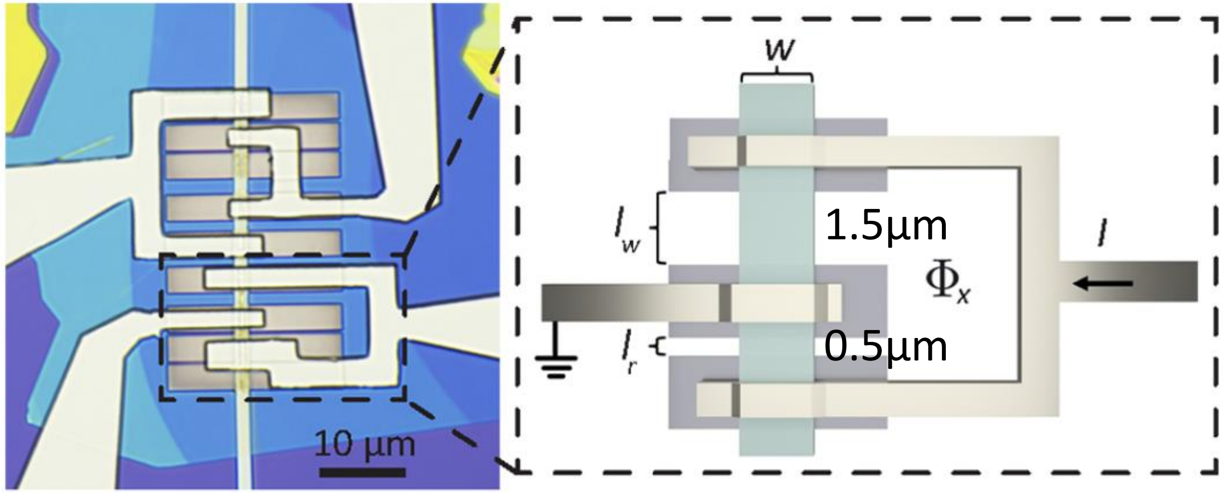
$\Delta_1 \exp(i\phi_1)$

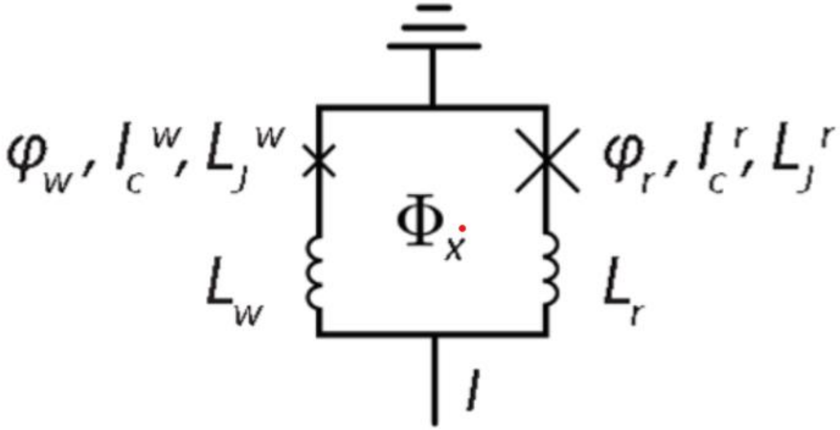
$\Delta_2 \exp(i\phi_2)$

$V \propto d(\phi_1 - \phi_2)/dt$

$I_s(\phi_1 - \phi_2) = I_c f(\phi_1 - \phi_2)$

Superconducting Quantum Interference Device (SQUID)





$$I_c(\varphi_w, \varphi_r) = I_c^w f_w(\varphi_w) + I_c^r f_r(\varphi_r)$$

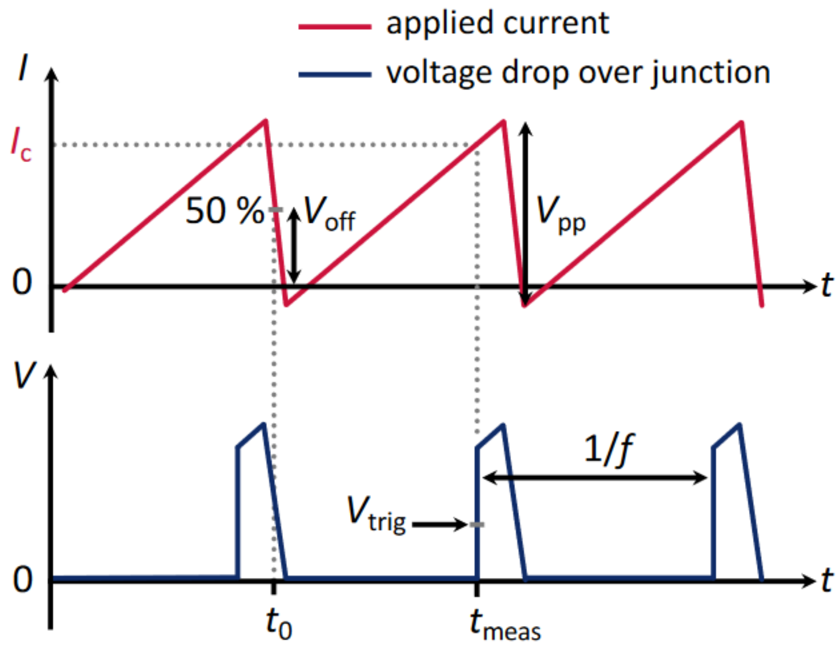
$$\varphi_w - \varphi_r = 2\pi\Phi_{tot}/\Phi_0 = \phi_{tot}$$

when $I_c^r \gg I_c^w$

$$I_c(\phi_x) \approx I_c^w f_w(\varphi_r^{max} + \phi_x) + I_c^r f_r(\varphi_r^{max})$$

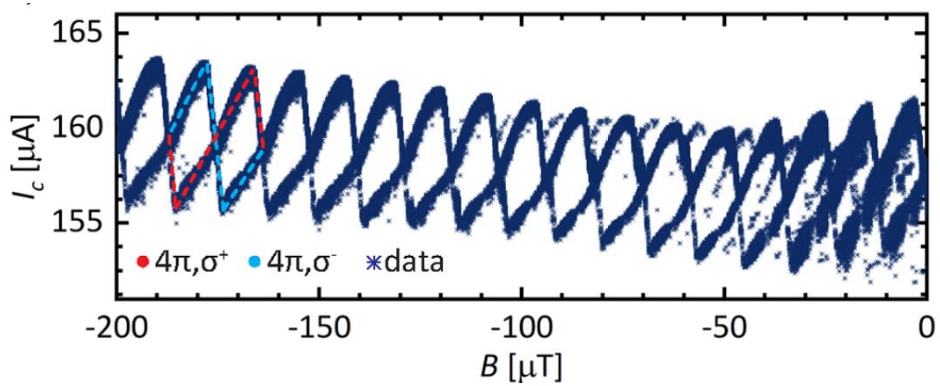
So by sweeping the magnetic through the SQUID, we can measure the critical current as a function of flux, it has the shape of current phase relation of the weak Junction.

The Counter Technique (supplementary material)

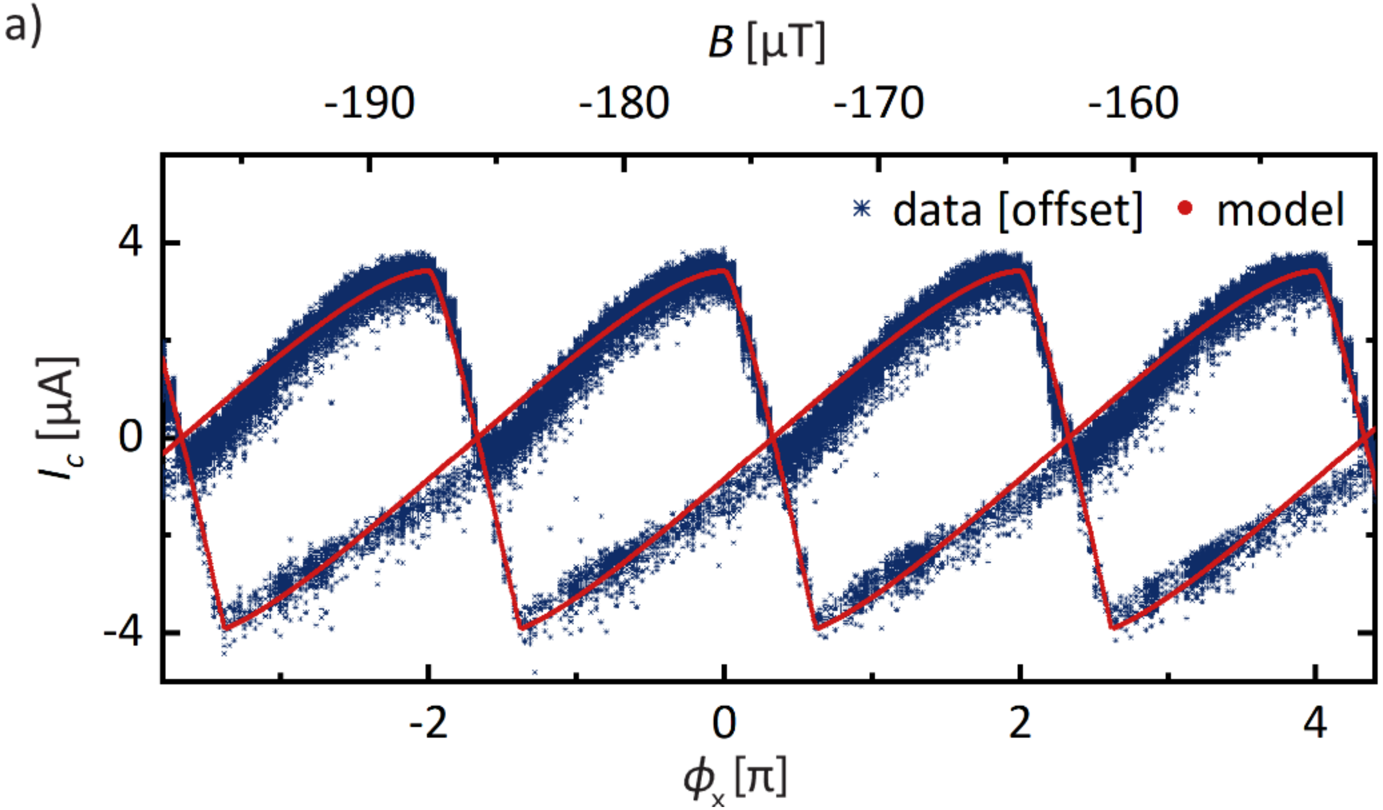


R_{bias} = 10KOhm

The result



$$\Phi_x = BA_o$$
$$A_o = 186 \ \mu m^2$$



Plot Twist

- “However , the amplitude of the signal deems this explanation unlikely.”

$$I_{c,4\pi} = E_{Th}e/\hbar = v_F e/l$$

$$I_c^w l_w/(ev_F) \approx 116$$

“We conclude that it is unlikely for the current to be carried purely by ballistic hinge states.”

The alternative model

2π periodicity and strong inductance.

$$\phi_{tot} = \phi_x + 2\pi(L_r I_r - L_w I_w)/\Phi_0$$

How ever we need to know the relation between Josephson Current and total flux $I_w(\phi_{tot})$ by an educated guess…

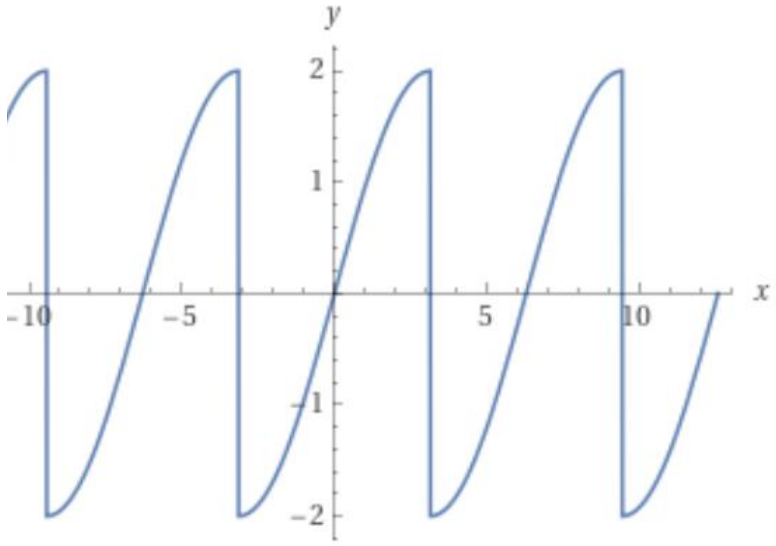
The alternative model

Suppression of the Josephson current through a narrow, mesoscopic, semiconductor channel by a single impurity

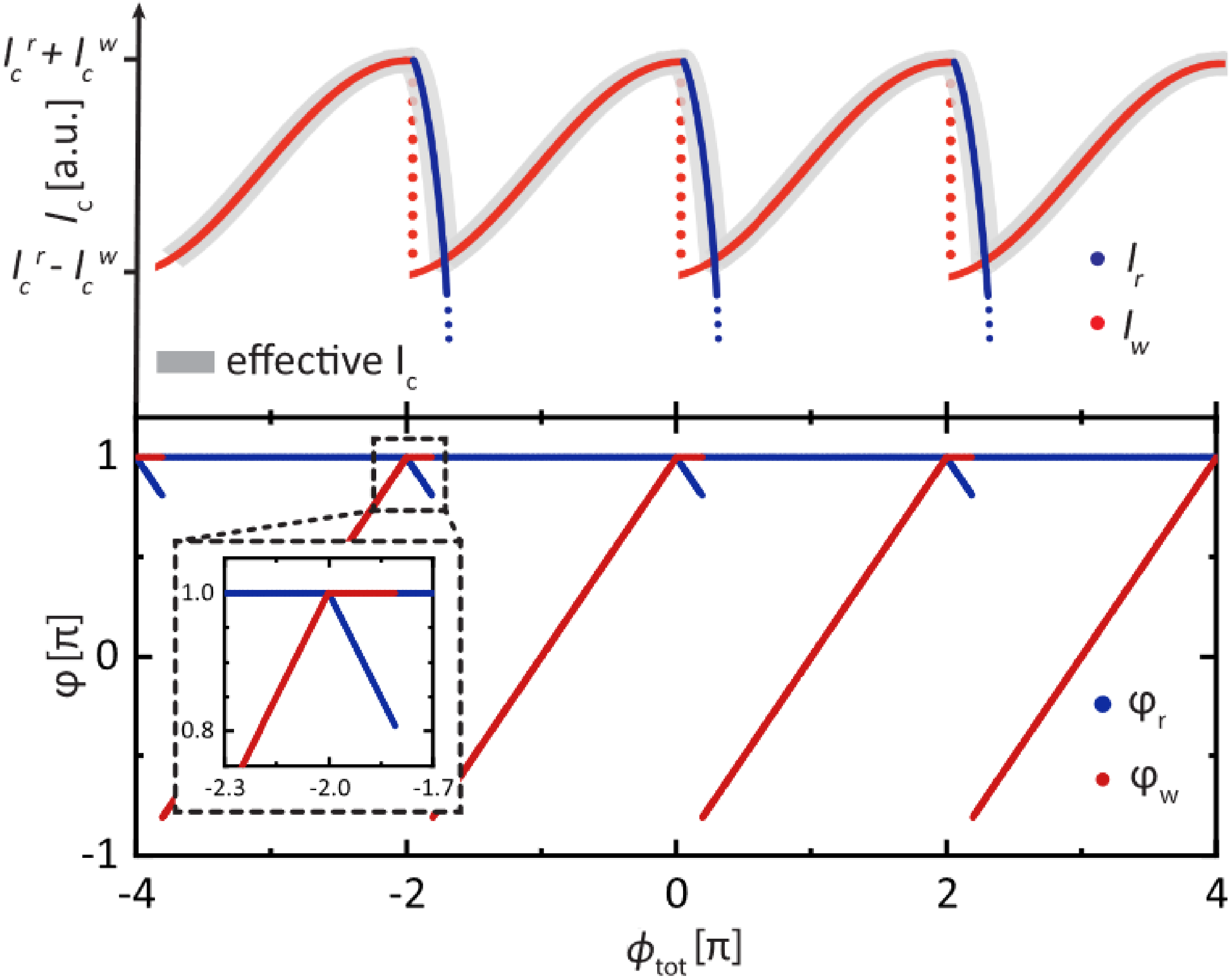
Philip F. Bagwell
School of Electrical Engineering, Purdue University, West Lafayette, Indiana 47907
(Received 2 June 1992)

We study the Josephson current through a ballistic, normal, one-dimensional quantum channel in contact with two superconducting electrodes. A single point impurity having reflection coefficient R is placed in the normal conductor. The impurity couples the Andreev energy levels of forward and reverse moving electrons inside the junction, opening energy gaps in the quasiparticle level spectrum versus superconducting phase difference ϕ. These "Andreev" energy gaps suppress the Josephson current in much the same way as disorder suppresses the magnetic flux driven currents in a normal mesoscopic ring. Finite temperature "energy averages" the contribution of Andreev levels above the Fermi energy with those below μ, further suppressing the Josephson current. The portion of the Josephson current carried by scattering states outside the superconducting gap is similarly suppressed by disorder and finite temperature.

$$I_w(\varphi_w) = I_c^w \frac{\sin \varphi_w}{\sqrt{1 - \sin^2(\varphi_w/2)}}$$



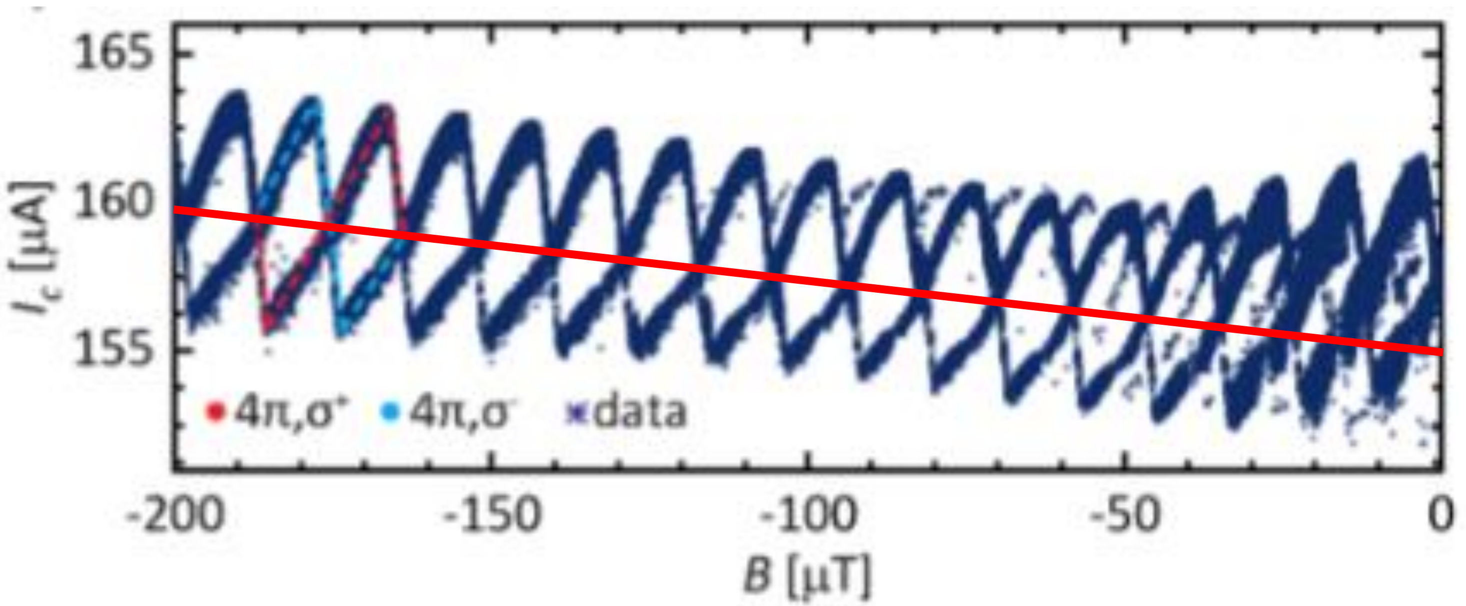
Quick dirty plot by letting Ic = 1


$I_c^{\,r} + I_c^{\,w}$
$I_c^{\,r} - I_c^{\,w}$
I_c [a.u.]
effective I_c
I_r
I_w
1
0
-1
φ [π]
1.0
0.8
-2.3
-2.0
-1.7
φ_r
φ_w
-4
-2
0
2
4
ϕ_{tot} [π]

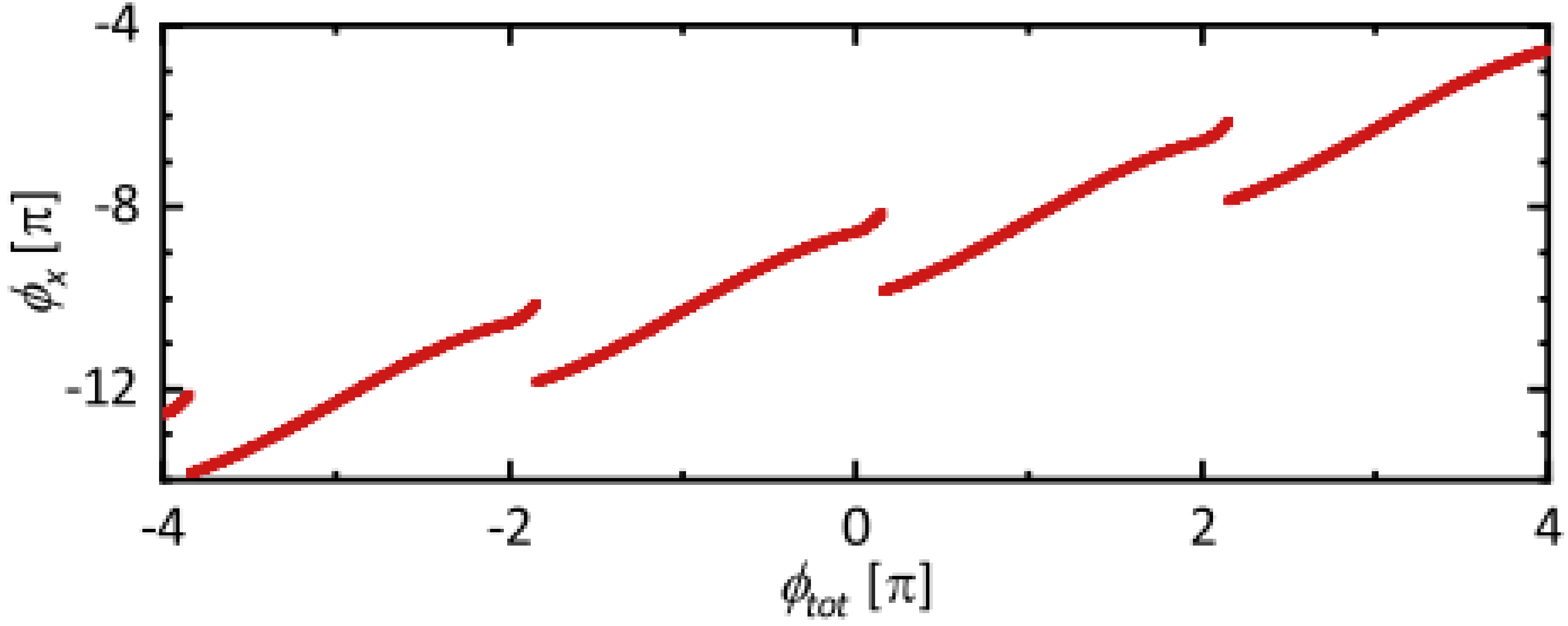
Inductance also affect the model

- We need to include the inductance of the Josephson Junctions…

$$\phi_{tot} = \phi_x + 2\pi(L_r I_r - L_w I_w)/\Phi_0 \qquad \mathrm{d}I_c/\mathrm{d}\varphi_x = \Phi_0/(2\pi(L_i + L_J^i))$$



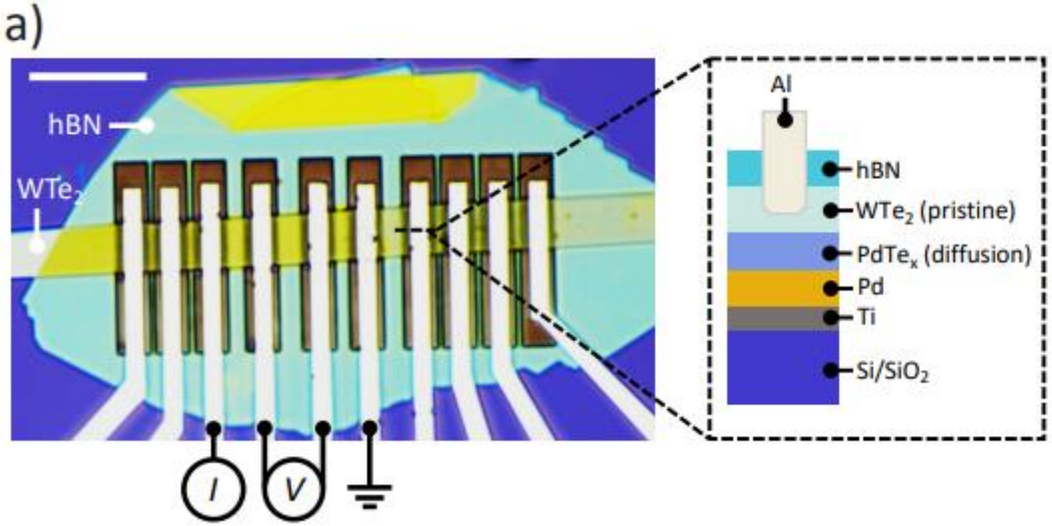
At any point, one applied flux correspond to multiple total flux

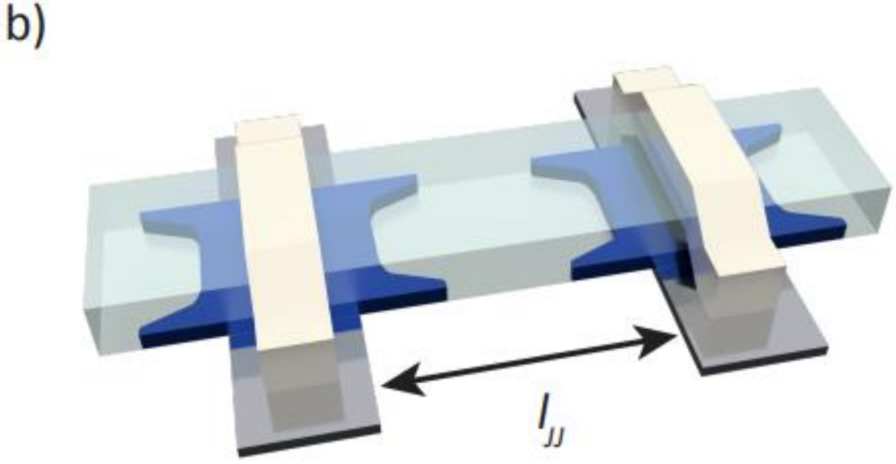


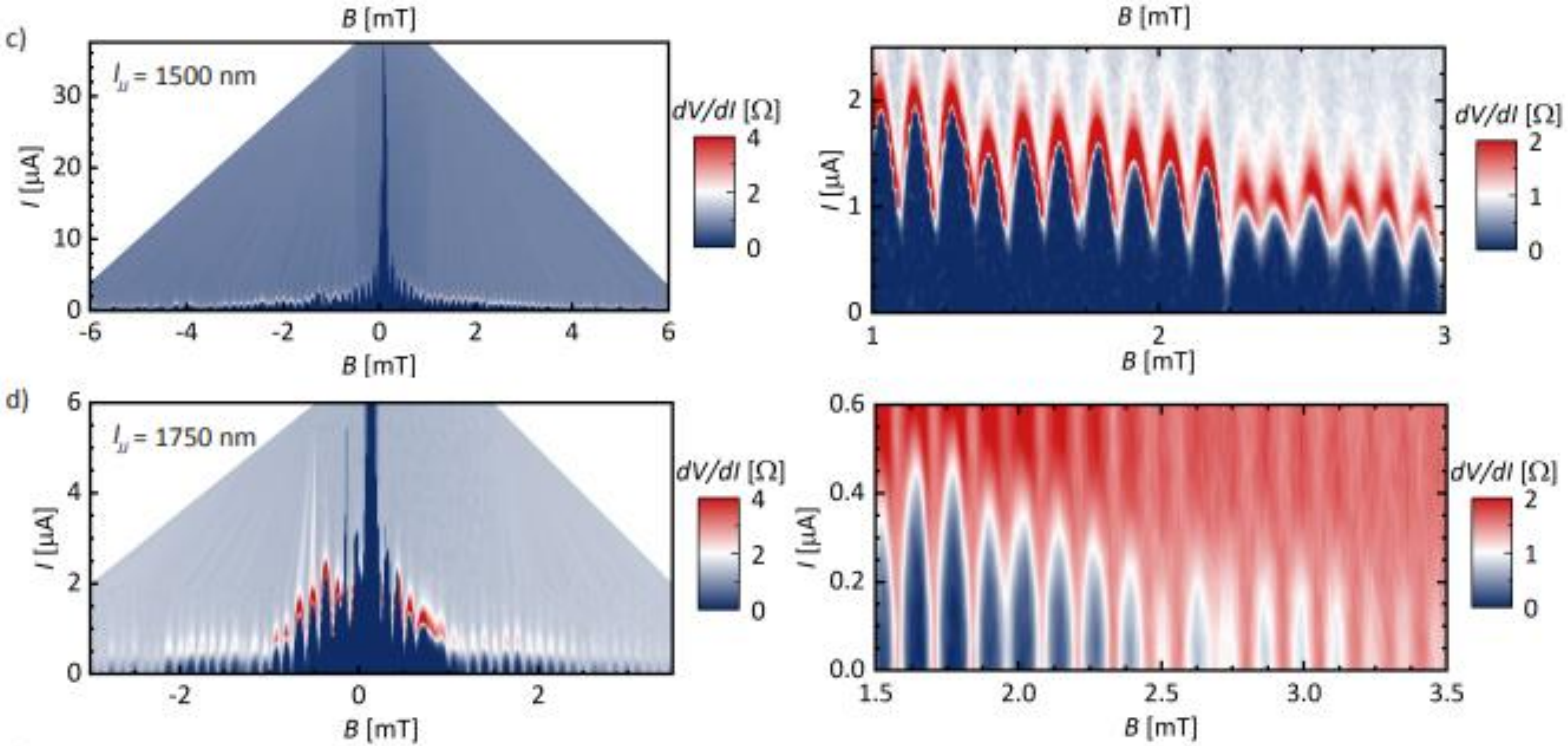
Moral of the day

- Seemingly 4π periodicity is insufficient for a topological Josephson Junction argument. The critical current needs to be quantized
- Strong self inductance of the device can cause multi-value current phase relation.

Why this is interesting to me?

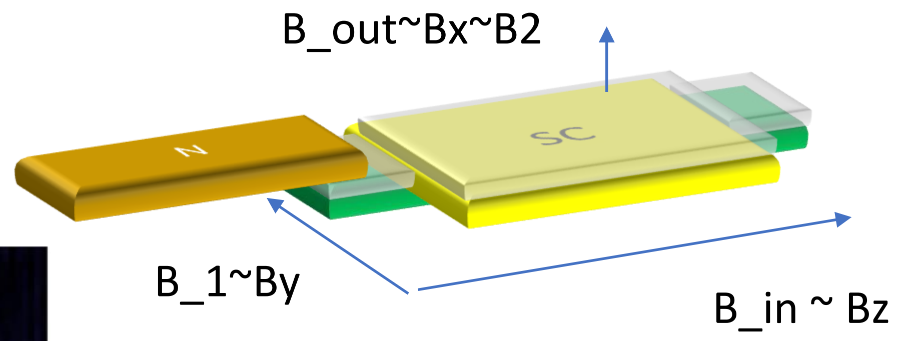


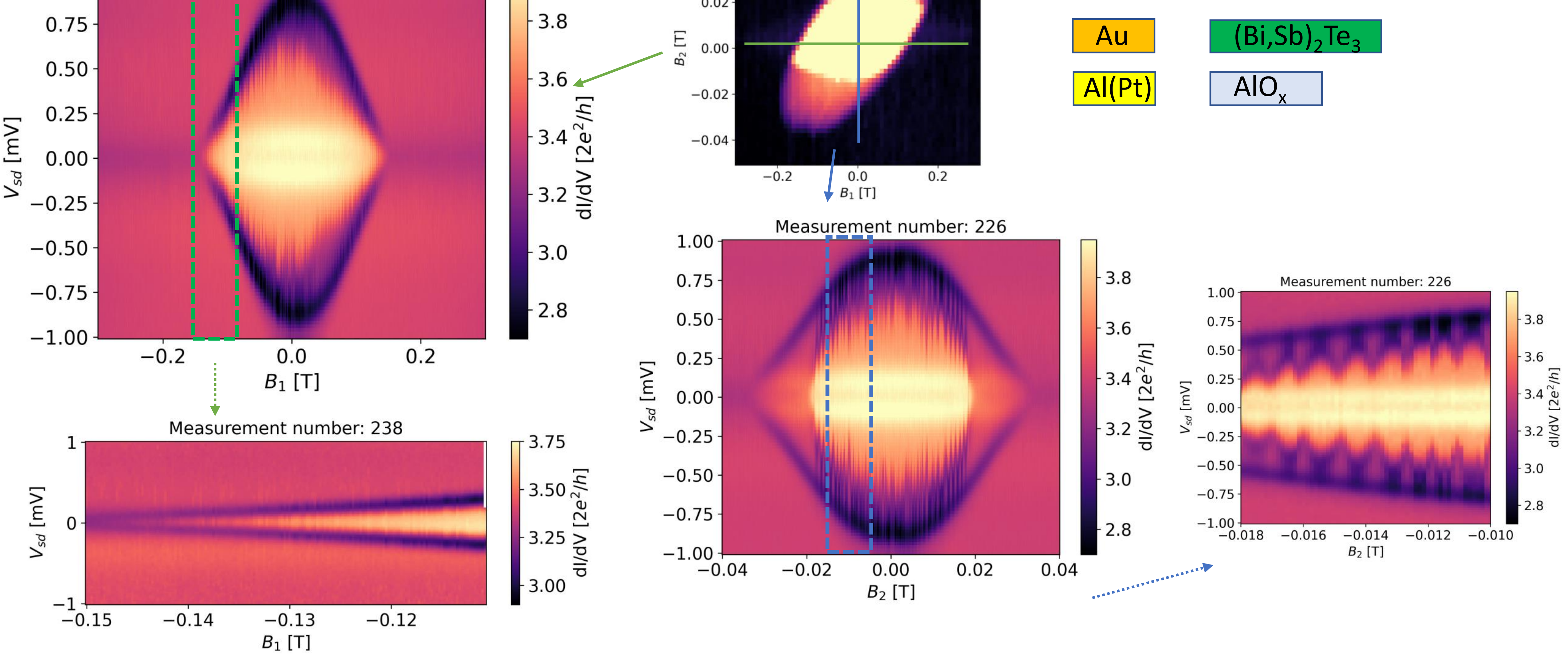


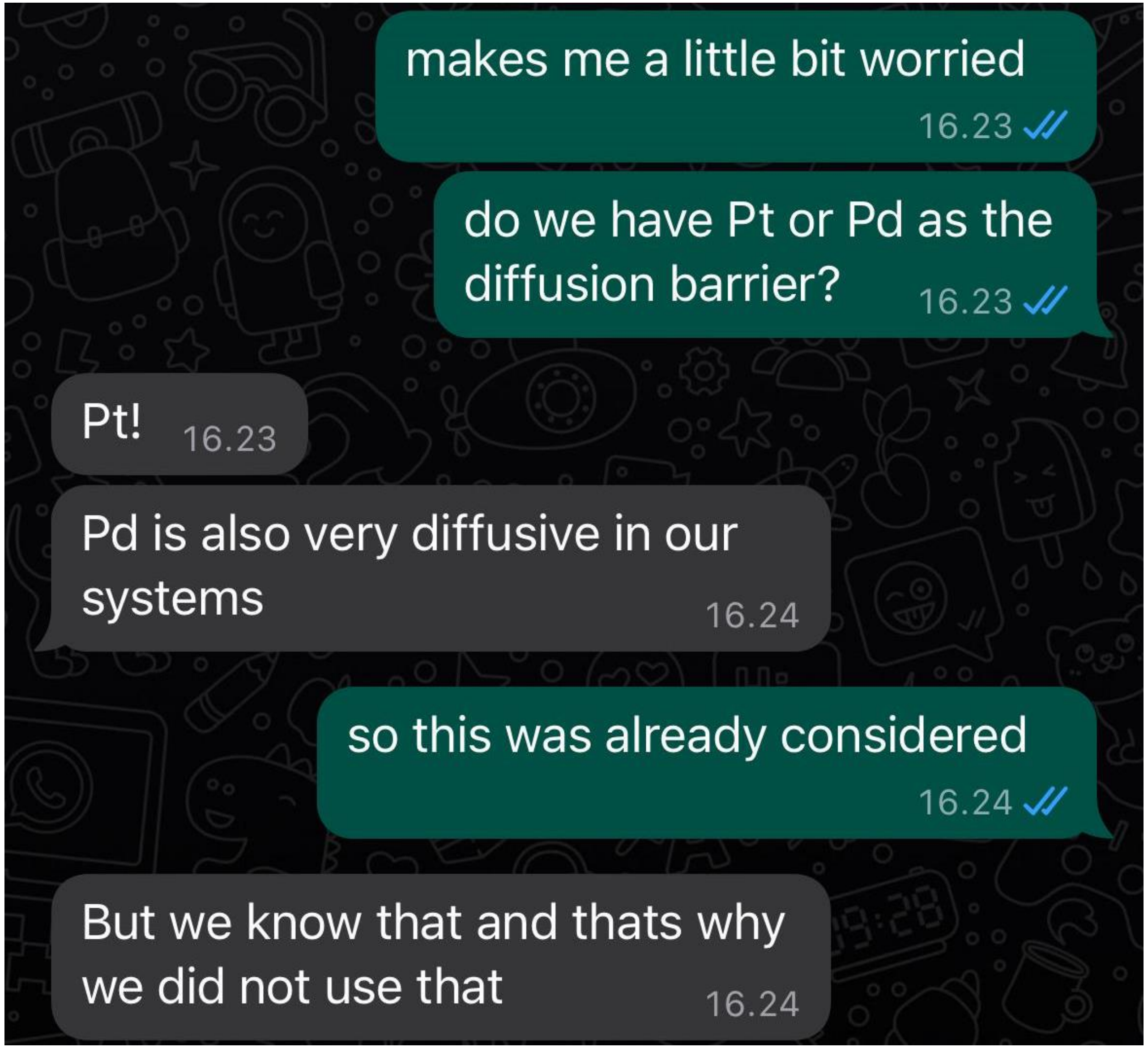


c)
B [mT]
l_{JJ} = 1500 nm
I [µA]
30
20
10
0
-6
-4
-2
0
2
4
6
B [mT]
dV/dI [Ω]
4
2
0
B [mT]
I [µA]
2
1
0
1
2
3
B [mT]
dV/dI [Ω]
2
1
0
d)
l_{JJ} = 1750 nm
I [µA]
6
4
2
0
-2
0
2
B [mT]
dV/dI [Ω]
4
2
0
I [µA]
0.6
0.4
0.2
0.0
1.5
2.0
2.5
3.0
3.5
B [mT]
dV/dI [Ω]
2
1
0

The EMP project






makes me a little bit worried
16.23
do we have Pt or Pd as the diffusion barrier?
16.23
Pt!
16.23
Pd is also very diffusive in our systems
16.24
so this was already considered
16.24
But we know that and thats why we did not use that
16.24