MESA+
INSTITUTE FOR NANOTECHNOLOGY

UNIVERSITY OF TWENTE.

Josephson supercurrent through a topological insulator surface state

Nb/Bi_2Te_3/Nb junctions

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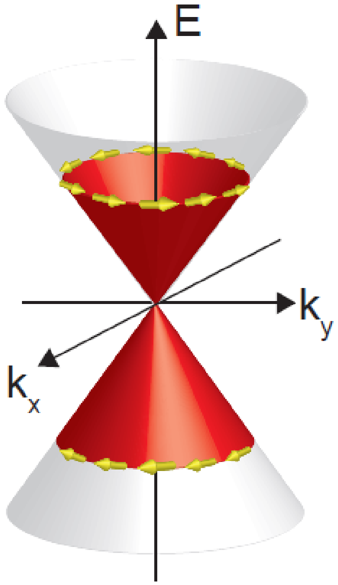
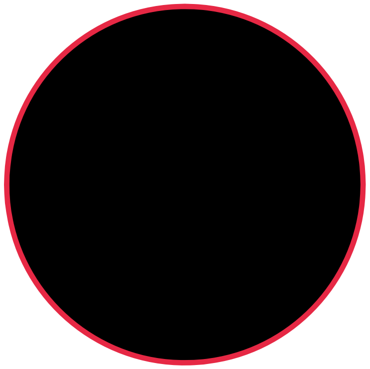
Motivation



TI surface states

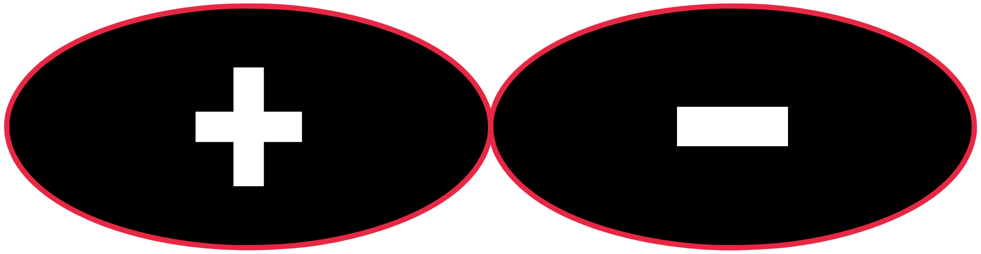
+



S-wave
Superconductor

=

Motivation



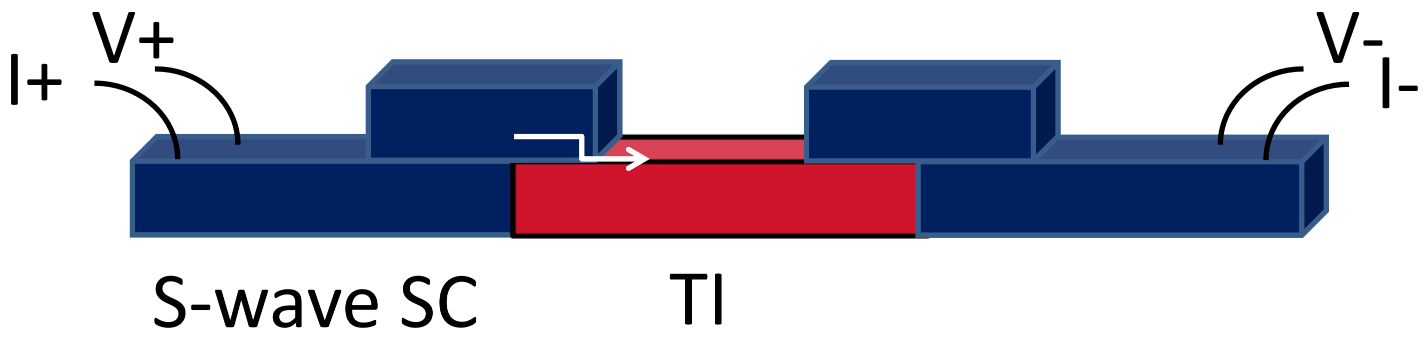
P-wave Superconductor

Natural place to look for Majorana fermions
(single zero-energy modes)

Motivation

Essential: supercurrent must couple to surface states

Characterize junction



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Part 1	Bi_2Te_3
Part 2	S/TI/S junctions
Part 3	Josephson supercurrent through the surface states

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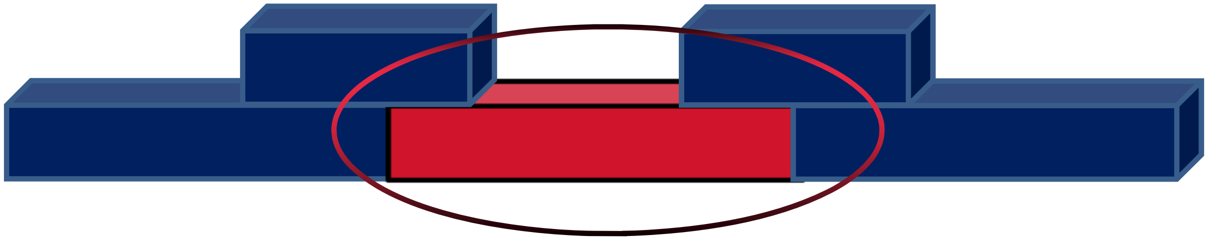
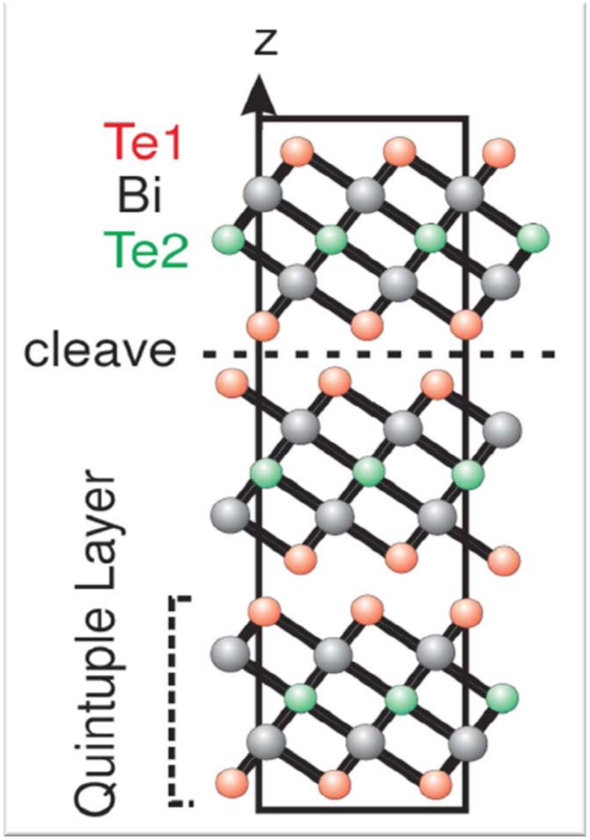
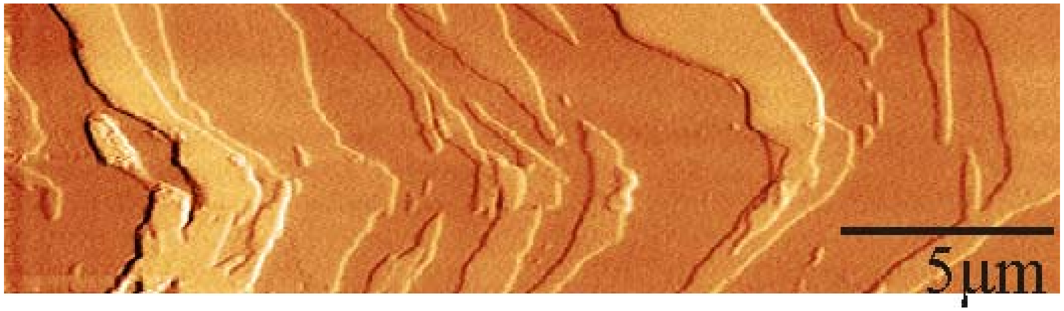
Bi_2Te_3



Fabrication





Mechanical cleavage

Photolithography contacts

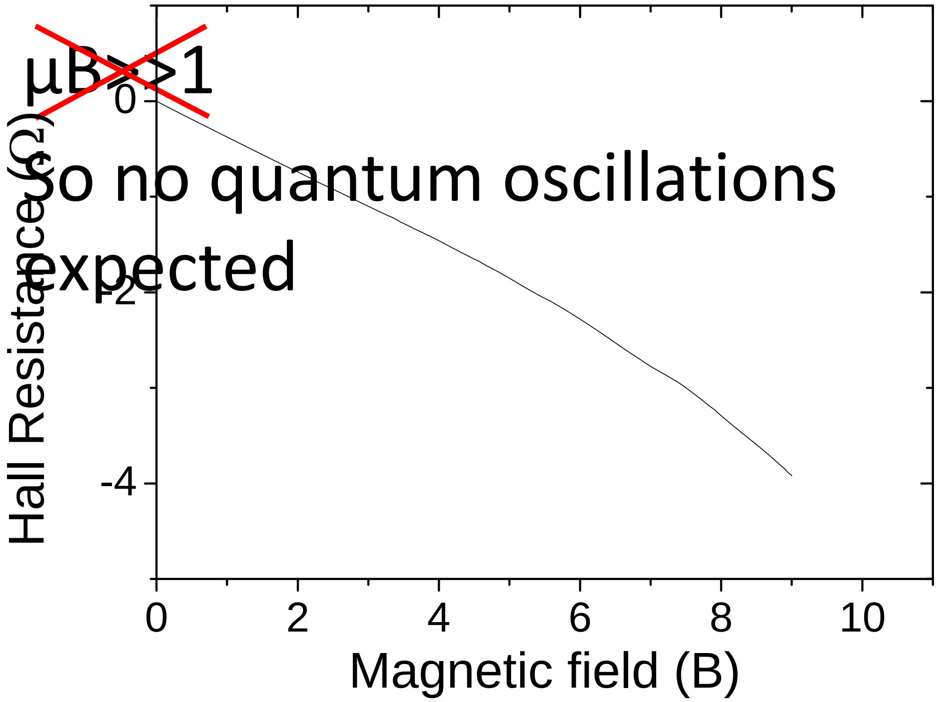
Hall measurements

$n=8.3 \times 10^{19}$ cm^{-3}

$\mu=250$ cm^2/Vs

(bulk is conductive)

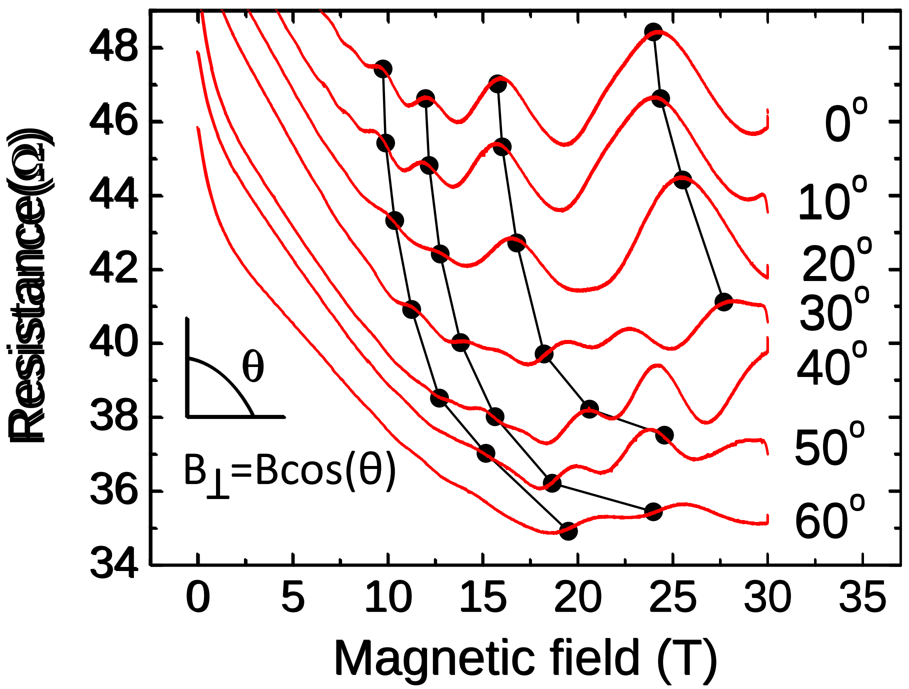
$l_{mfp}=22$ nm

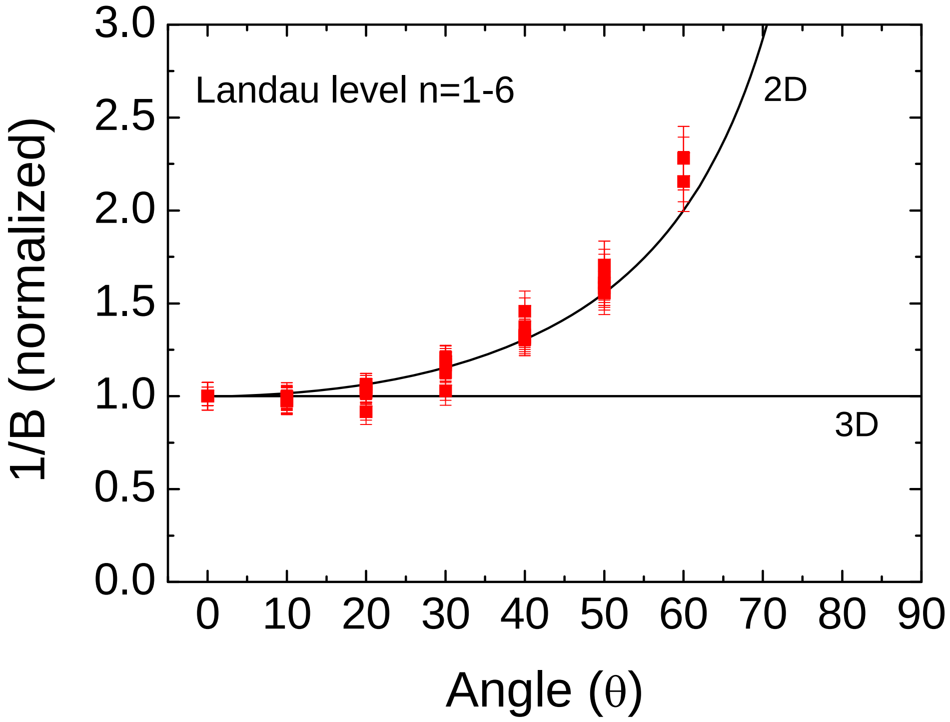


~~$\mu B>>1$~~

So no quantum oscillations expected

Shubnikov-de-Haas oscillations

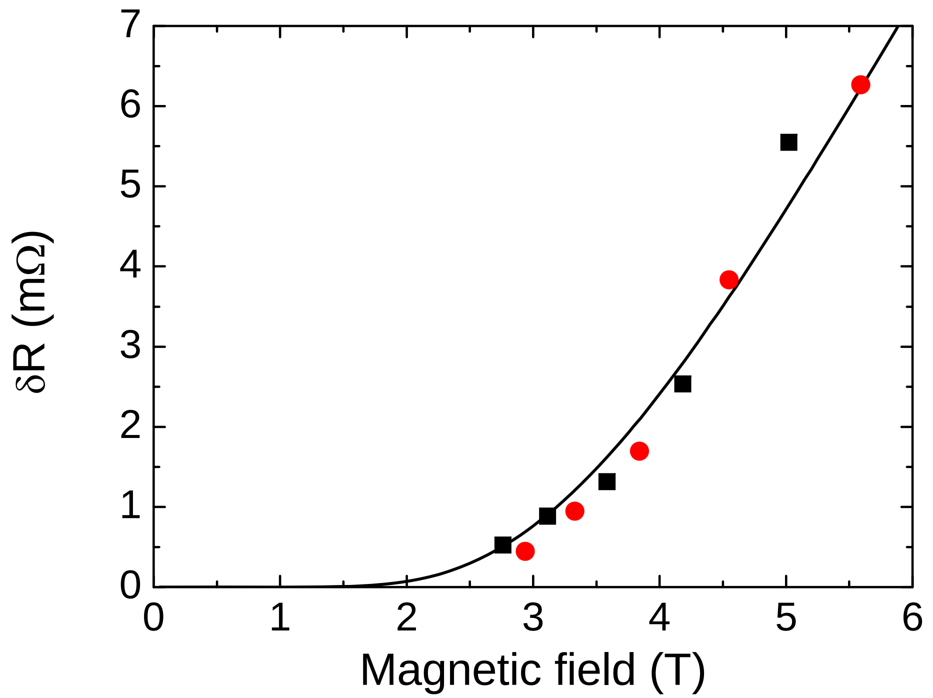


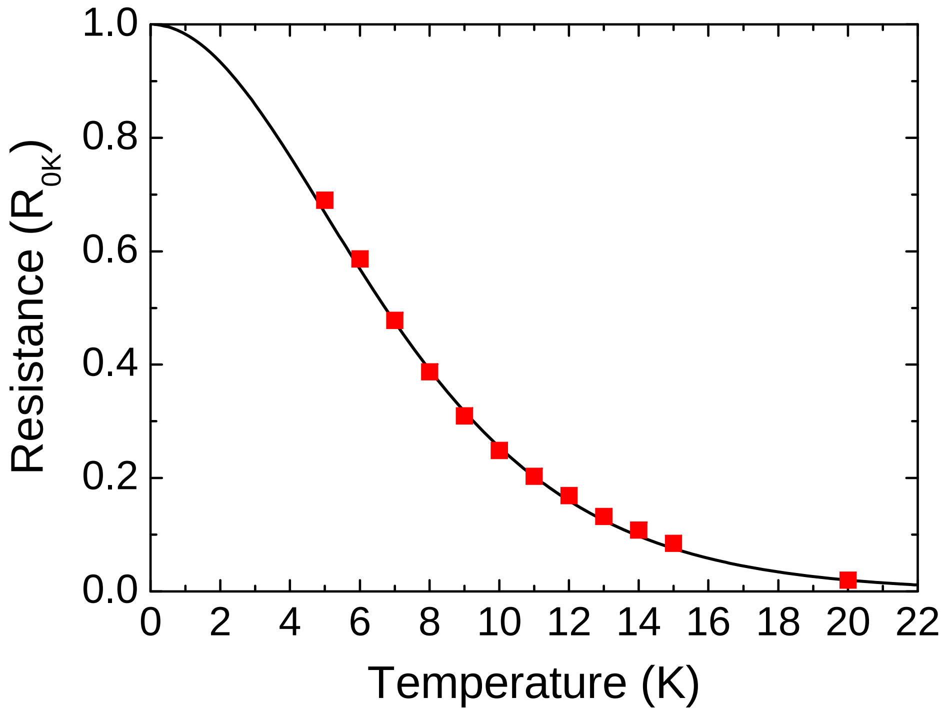


Left graph: Quantum oscillations @T=4.2K

Right graph: Oscillations from 2D channel

Shubnikov-de-Haas oscillations

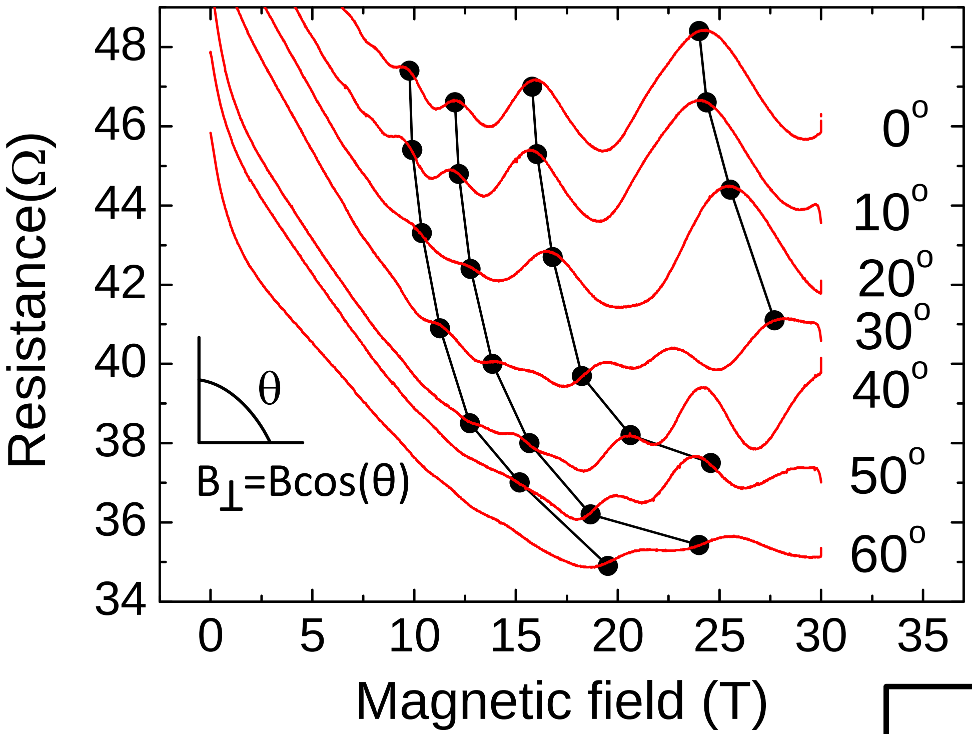




Left graph: Dingle temperature 1.65 K, μ=8300 cm^2/Vs

Right graph: Effective mass 0.16m$_0$

Shubnikov-de-Haas oscillations



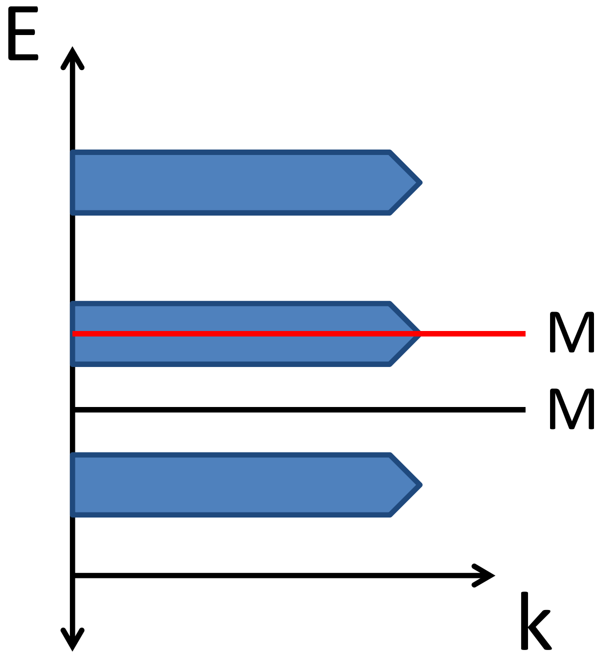
$$\delta\rho_{xx} \sim \cos\left(\frac{2\pi E_f}{\hbar\omega_c} + \pi + \varphi_B\right)$$

I.M. Lifshitz and A.M. Kosevich**,** Sov. Phys. JETP 2, **636** (1956)

Lifshitz-Kosevich formalism

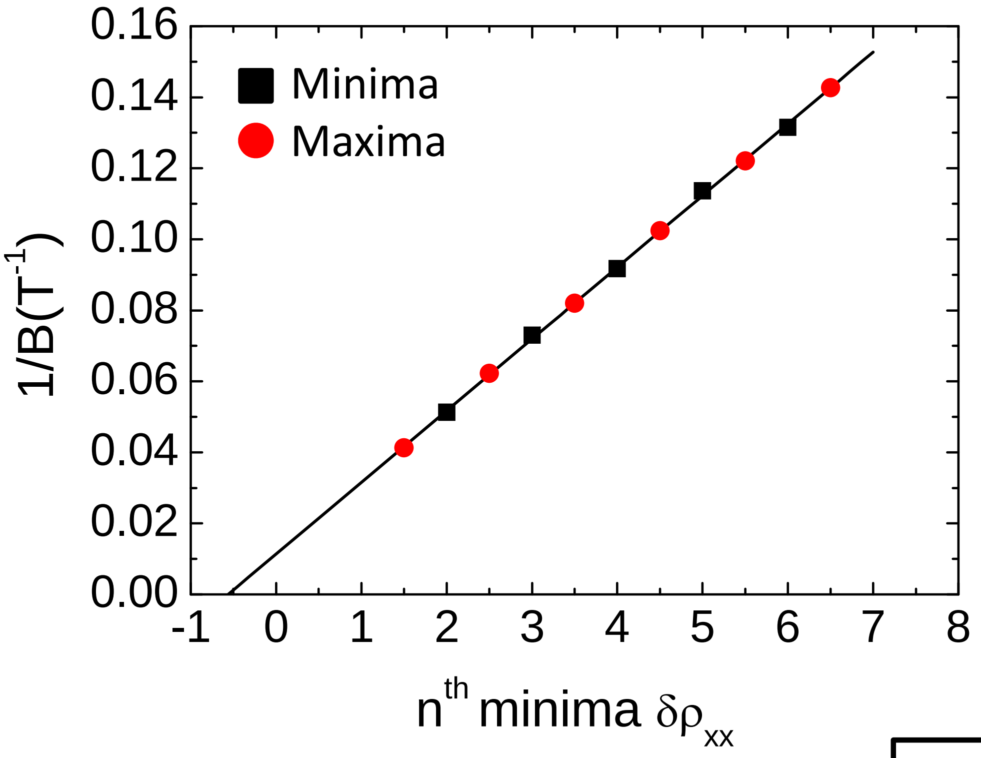
$$\boxed{\delta\rho_{xx} \sim \cos\left(\frac{2\pi E_f}{\hbar\omega_c} + \pi + \varphi_B\right)}$$

Extrapolating till 1/B=0
→
nth minima in resistivity is zero at 1/B=0 in ‘normal case’ (Berry phase=0)



[redacted]

Lifshitz-Kosevich formalism



Extrapolating till 1/B=0

→

Berry phase is π

$$\boxed{\delta\rho_{xx} \sim \cos\left(\frac{2\pi E_f}{\hbar\omega_c} + \pi + \varphi_B\right)}$$

[redacted]

Lifshitz-Kosevich formalism

Conductivity is the response function

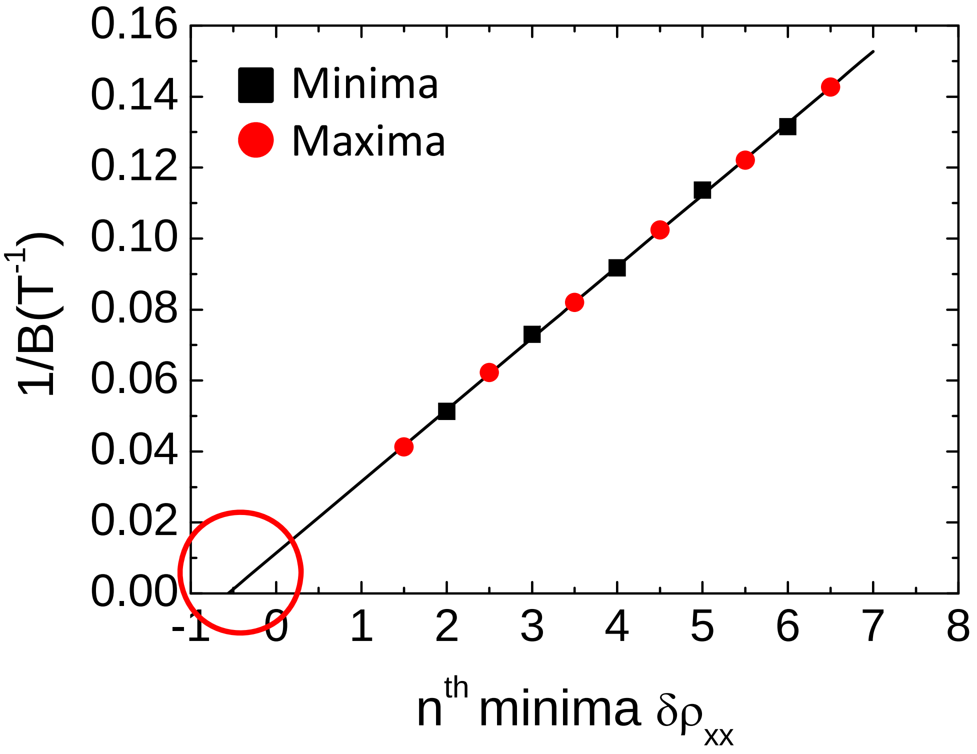
$$\rho_{xx} = \frac{\sigma_{xx}}{{\sigma_{xx}}^2 + {\sigma_{xy}}^2}$$

I.M. Lifshitz and A.M. Kosevich formalism applies if:

$\frac{\delta\sigma_{xx}}{\langle\sigma_{xx}\rangle} \ll 1$ or $\frac{\sigma_{xy}}{\sigma_{xx}} \gg 1$;Former is 0.01, later is 10

Then $\delta\rho_{xx} \sim \delta\sigma_{xx}$ So in normal case nth minima=0 through 1/B=0

Lifshitz-Kosevich formalism



- Surface states present
- @ 1/B=0, n=-1/2

(Berry phase of π)

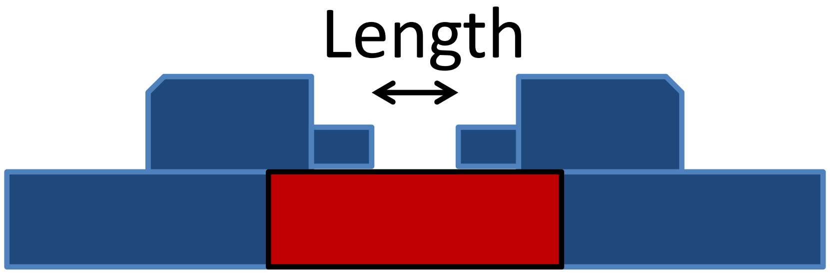
→ linear dispersion relation

- l_{mfp}=105 nm

Non-trivial surface states present

Content

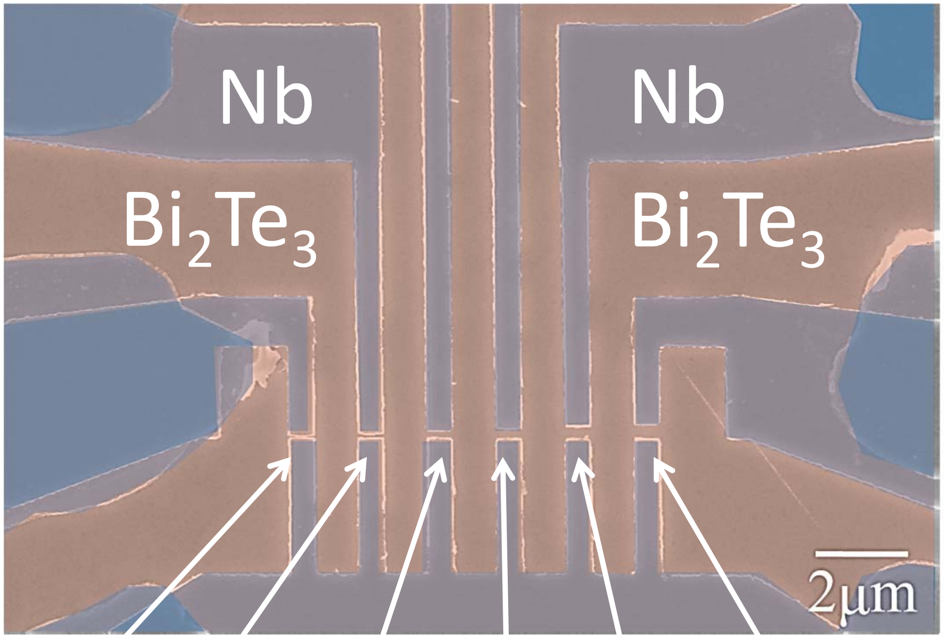
S/TI/S junctions



Nb: blue

Bi_2Te_3: red

Width=500 nm



50 100 150 200 250 300 nm

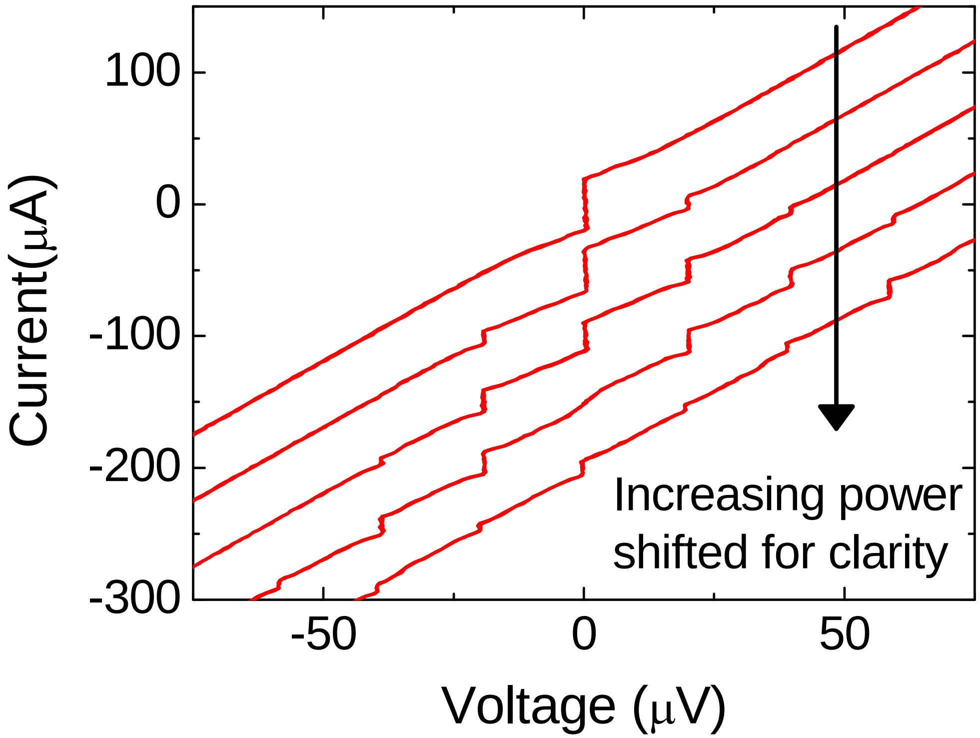
Junction lengths

Josephson supercurrent

Hallmarks for a Josephson junction:

1) Shapiro steps
2) Modulation I_c versus B-field

First hallmark – Shapiro steps



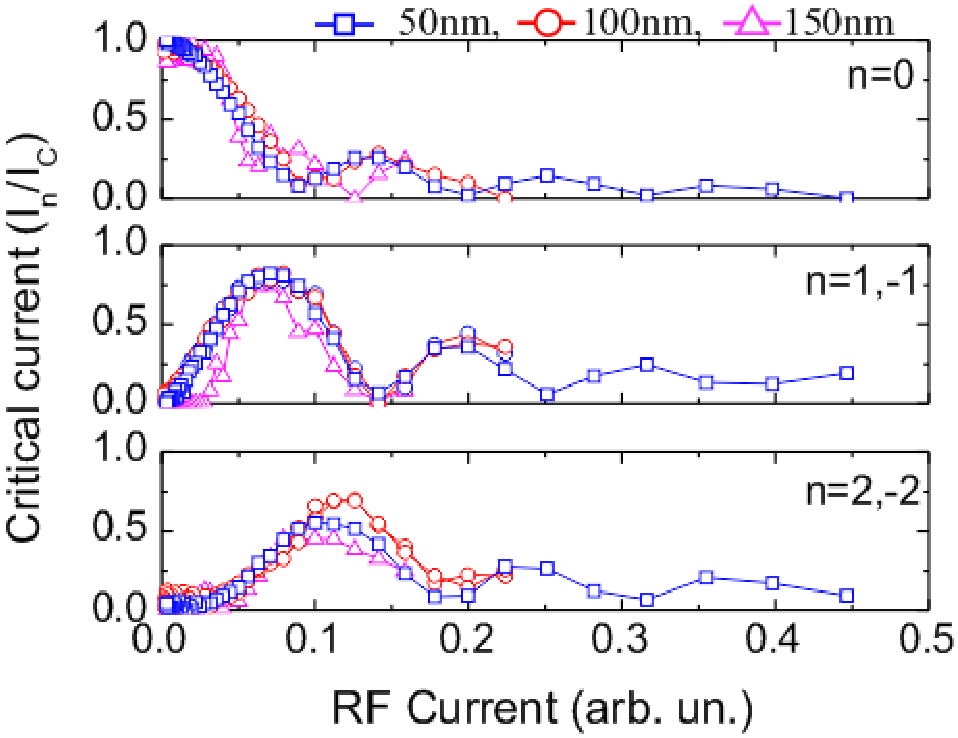
- Microwave frequency ω
- @2eV/ħ=nω Shapiro steps
- (Energy Cooper pairs resonant to energy microwave)

ω = 10 GHz

V= n x 20.7 μV

T=1.6 K

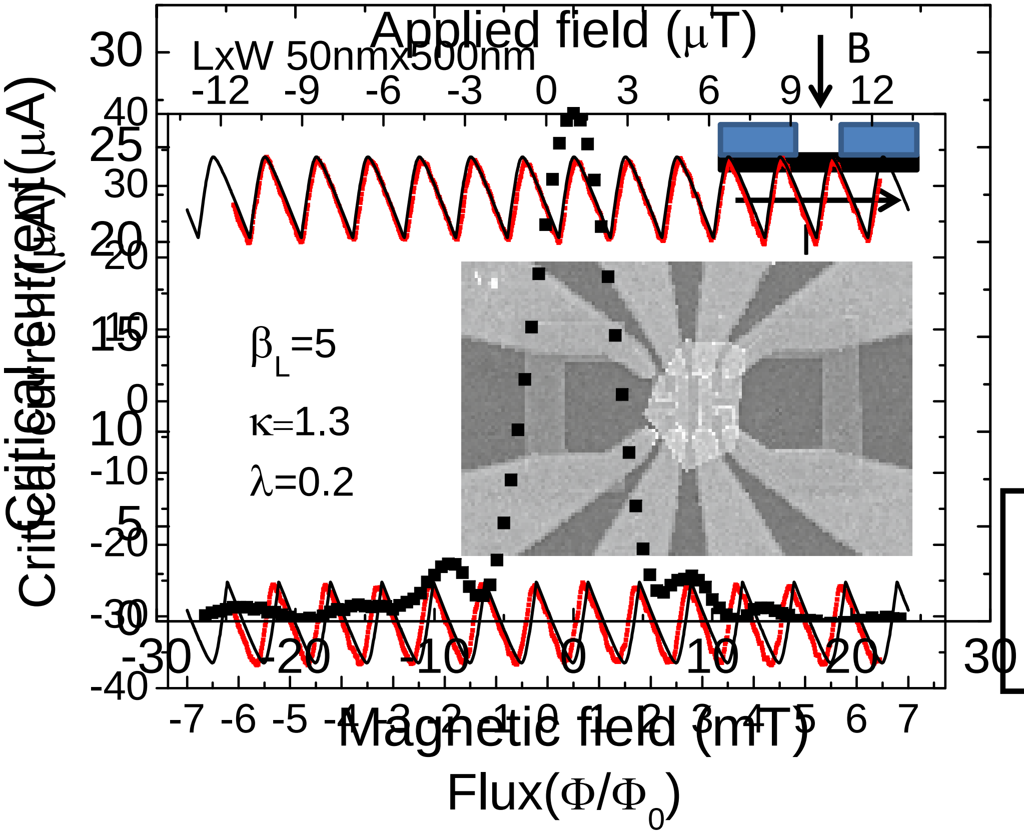
First hallmark – Shapiro steps



Fitting Shapiro steps with Bessel functions

Only can be done if I_cR_n product is larger than the position of the steps (20.7 μV in these measurements)

Second hallmark – I_c-B modulation



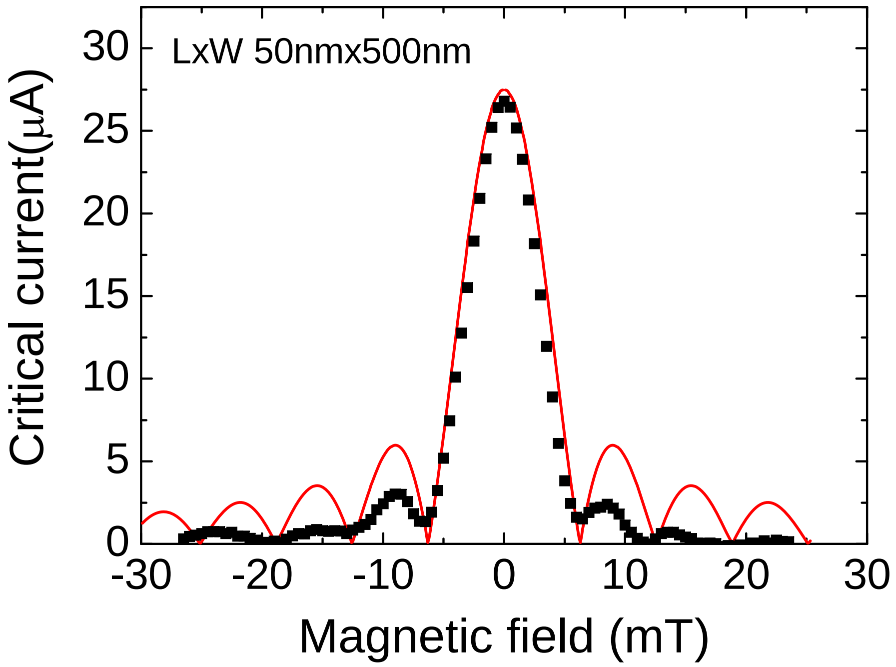
Modulation I_c

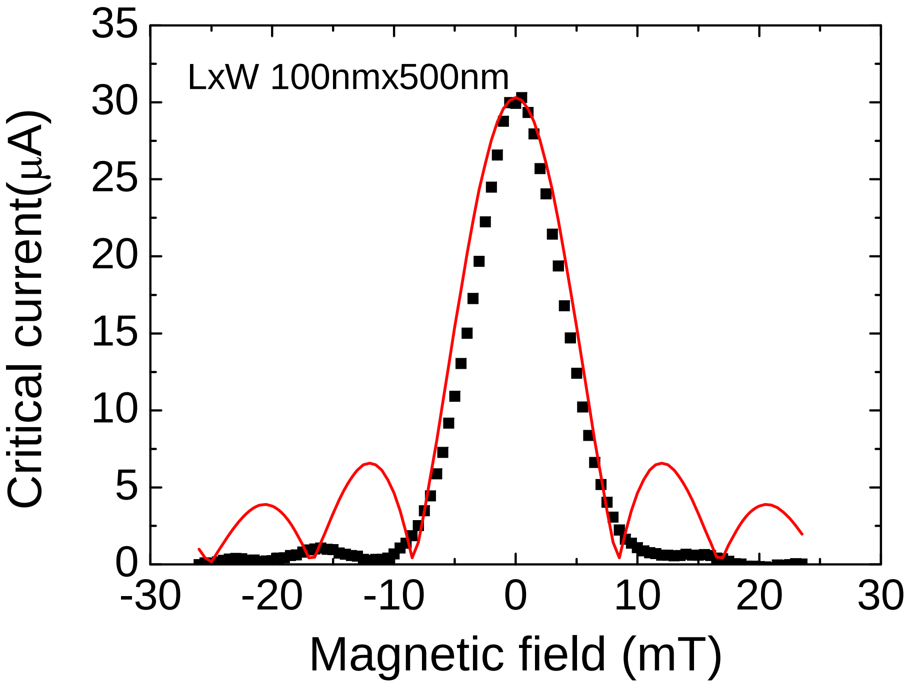
DC SQUID oscillations

Josephson supercurrent present

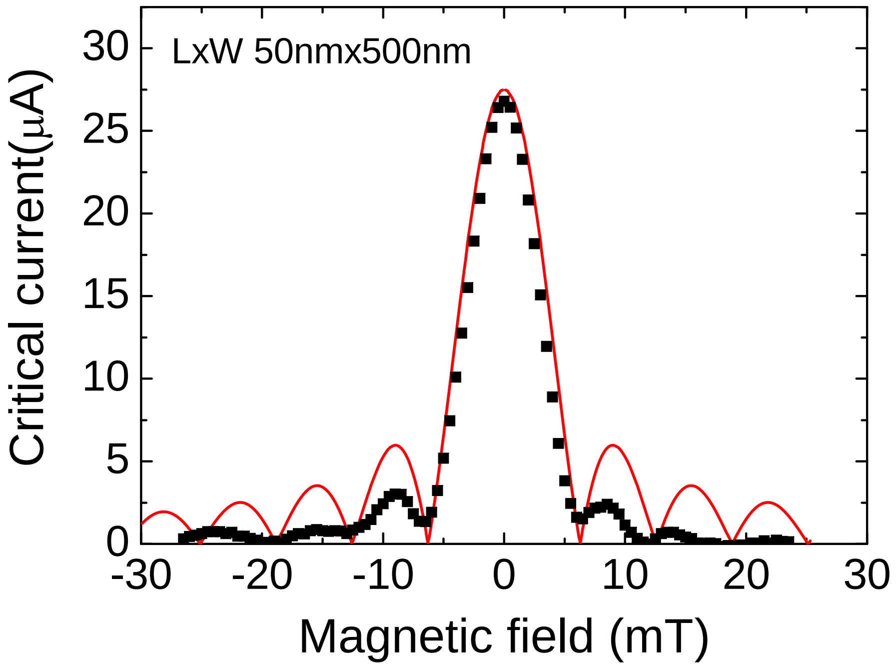
M. Veldhorst, C. G. Molenaar et al. Appl. Phys. Lett. **100**, 072602 (2012)

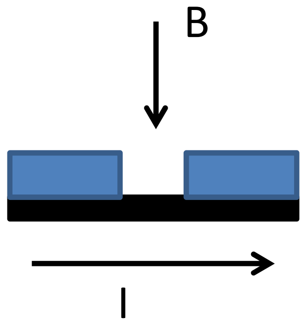
Second hallmark – I_c-B modulation





Second hallmark – I_c-B modulation





Area uncertain:

- Penetration depth
- Flux focussing

Sinc function only valid for large L and W ratio

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Link supercurrent and surface states

Surface states

Supercurrent

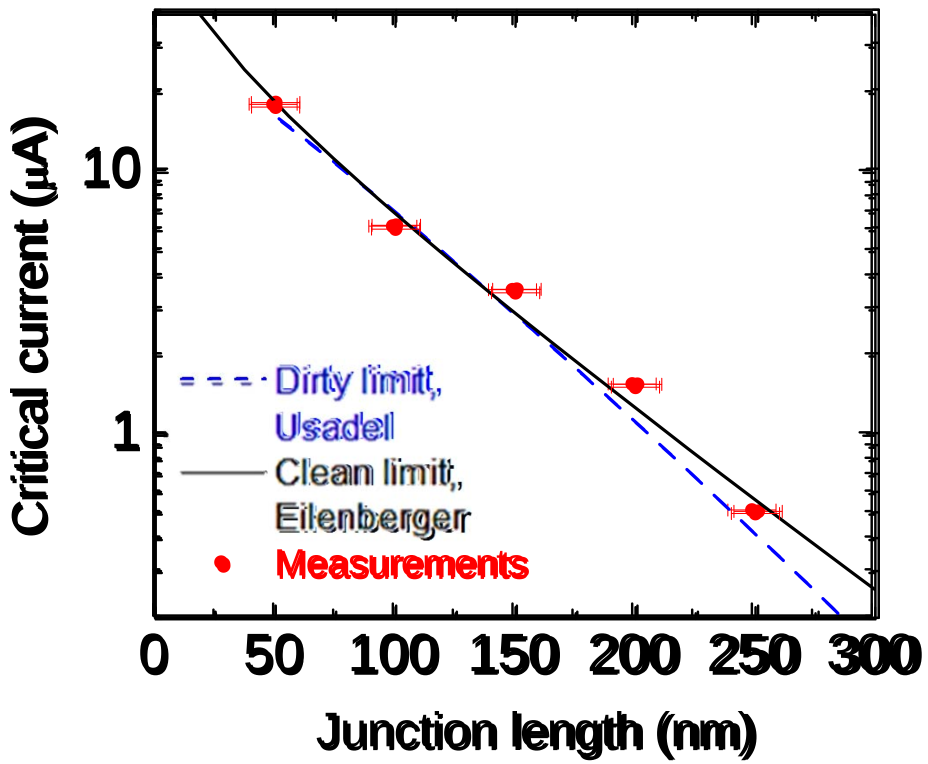
Do we have a supercurrent through the surface states?

We have junctions between 50 and 250 nm and:

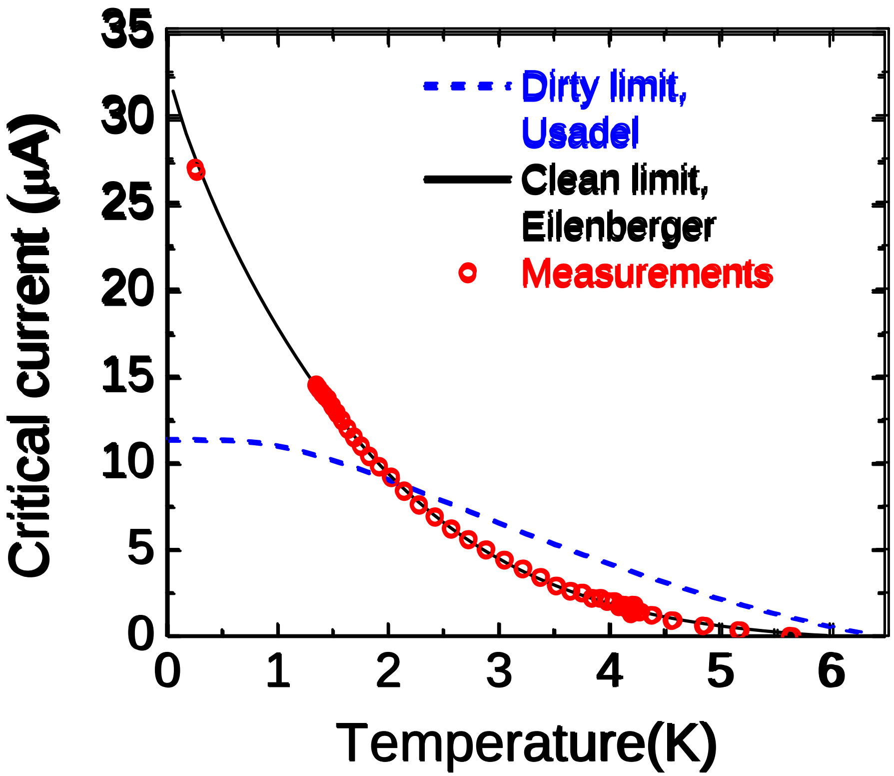
l_{mfp}=22 nm (bulk states) → diffusive transport

l_{mfp}=105 nm (surface states) → ballistic transport

Link supercurrent and surface states



Dirty or clean?



Definitely clean

Josephson supercurrent has been realized through the surface states of Bi_2Te_3

Provides prospects for Majorana devices……but

What is the best topological insulator for this purpose? (stability, insulating in the bulk, Dirac cone in the gap)

What is the smoking gun experiment with 3D topological insulators to observe Majorana fermions?

M. Veldhorst, M. Snelder et al. Nature Materials, 11, 417–421 (May 2012)