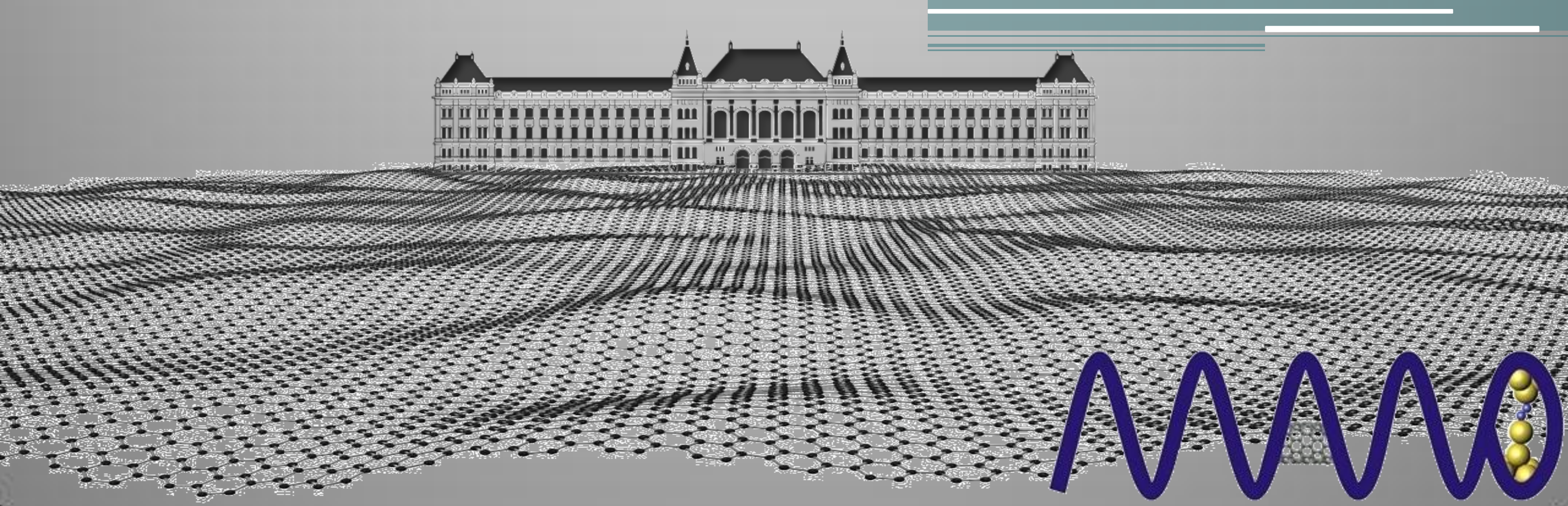
Signatures of Majorana Fermions in S-TI-S devices

Journal Club

Attila Márton
MSc student

BUTE, Department of Physics, 2012
Supervisor: Dr. Szabolcs Csonka (Dept. Of Physics, BUTE)



Journal Club

Signatures of Majorana Fermions in Hybrid Superconductor-Topological Insulator Devices

J. R. Williams,[1] A. B. Beswick,[1] P. Gallagher,[1] Seung Sae Hong,[2] Y. Cui,[3,4]
Andrew S. Bleich,[5] J. G. Analytis,[2,4] I. R. Fisher,[2,4] and D. Goldhaber-Gordon[1]
[1] *Department of Physics, Stanford University, Stanford, CA 94305, USA*
[2] *Department of Applied Physics, Stanford University, Stanford, CA 94305, USA*
[3] *Department of Material Science, Stanford University, Stanford, CA 94305, USA*
[4] *Stanford Institute for Materials and Energy Sciences, SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA.*
[5] *Geballe Laboratory for Advanced Materials, Stanford University, Stanford, CA 94305, USA*

(Dated: February 13, 2012)

Majorana fermions:

- Predicted by E. Majorana[1](1934): neutral spin-1/2 particles can be described by a real wave equation; M.E:

$$-i\partial\!\!\!/\psi + m\psi_c = 0$$

- Ψ – E.M.F. → charge neutrallity
- Particle that it is its own antiparticle

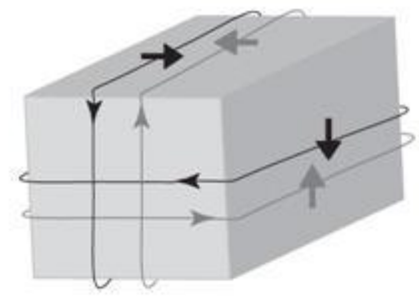
Candidates:

- Neutrinos been proposed to be of a Majorana nature →?
- Supersymmetry’s hypotetical neutralinos ???
- Theoritical prediction in solidstate materials: middle of a 2nd SC vortex, end of SC NW, etc.

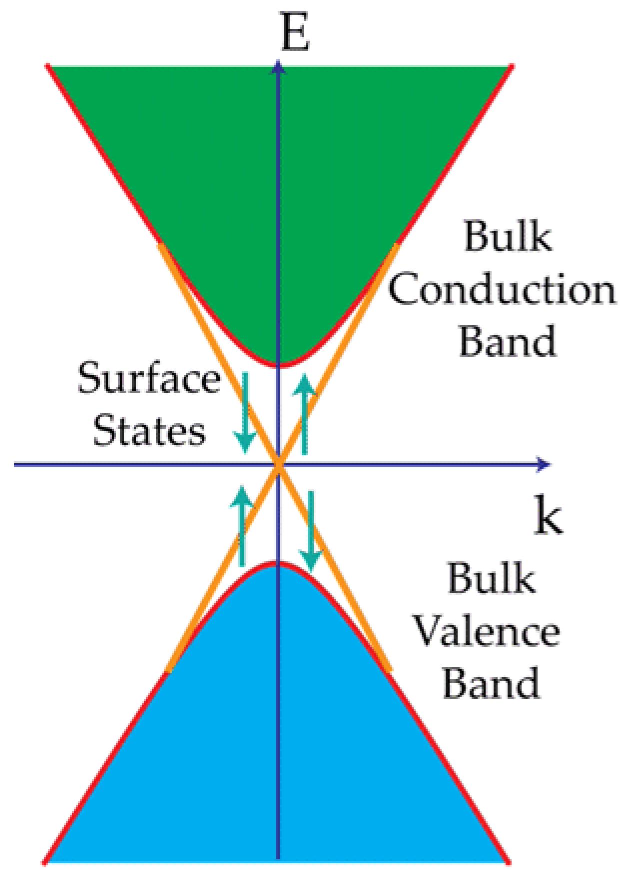
[1] E. Majorana, *Teoria simmetrica dell’elettrone e del positrone*, Nuovo Cimento **14**, 171 (1937)

Signatures of MF

Signatures of MF found in SC-TI-SC JJs



- **Topological Insulators (TIs)[2]:**
  - Insulating @ bulk
  - Permitted charge movements on surface (meta

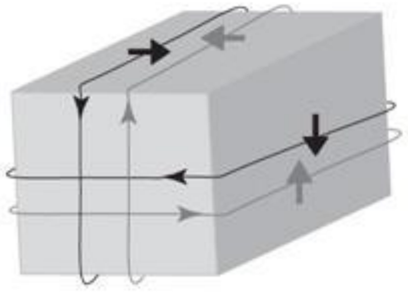


(appl.:surface 2DEGs w/ locked spin momentum)

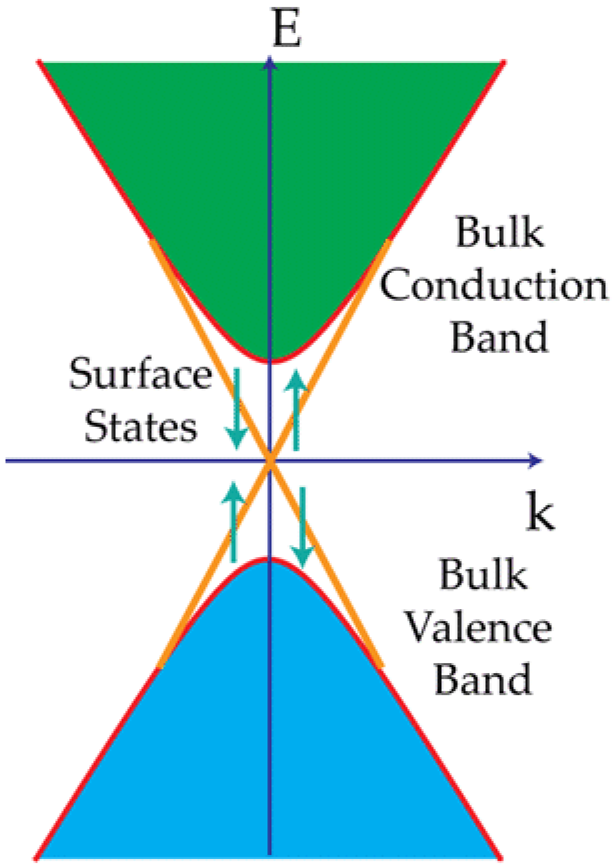
[2] Phys. Rev. Lett. 95, 146802 (2005)

Signatures of MF

Signatures of MF found in SC-TI-SC JJs

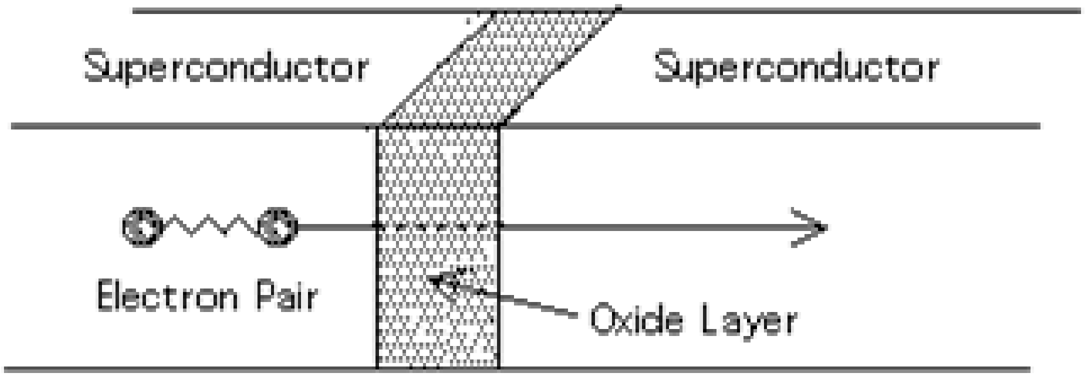


- **Topological Insulators (TIs)[2]:**
  - Insulating @ bulk
  - Permitted charge movements on surface (metallic)



(appl.:surface 2DEGs w/locked spin momentum)

- **Josephson Junctions (JJs)** (S-I/N/s/TI-S):

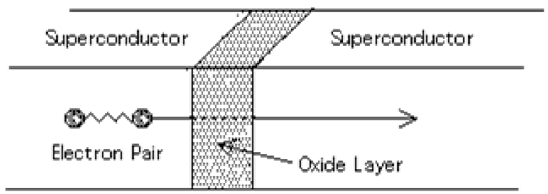


[2] Phys. Rev. Lett. 95, 146802 (2005)

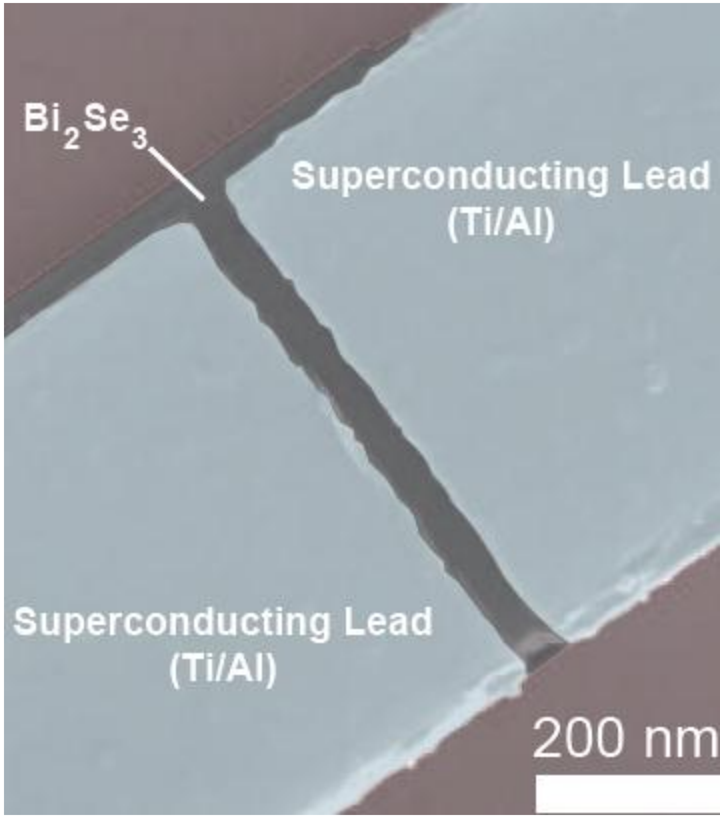
Signatures of MF

Signatures of MF found in SC-TI-SC JJs

- **Josephson Junctions (JJs)** (S-TI-S):



TI: 75nm Bi_2Se_3 synthetized slow cooling of binary melt of Bi and Se or VLS growth
+mechanical exfoliation



SC leads: 3nm Ti – 60-100nm Al
+EBL, deposition

Measurements:

-in $^3He/^4He$ dilution refrgirator (~12mK)
-standard DC and lock-in meas. setup

Signatures of MF

Signatures of MF found in SC-TI-SC JJs

- **Josephson Junctions (JJs)** (S-TI-S):

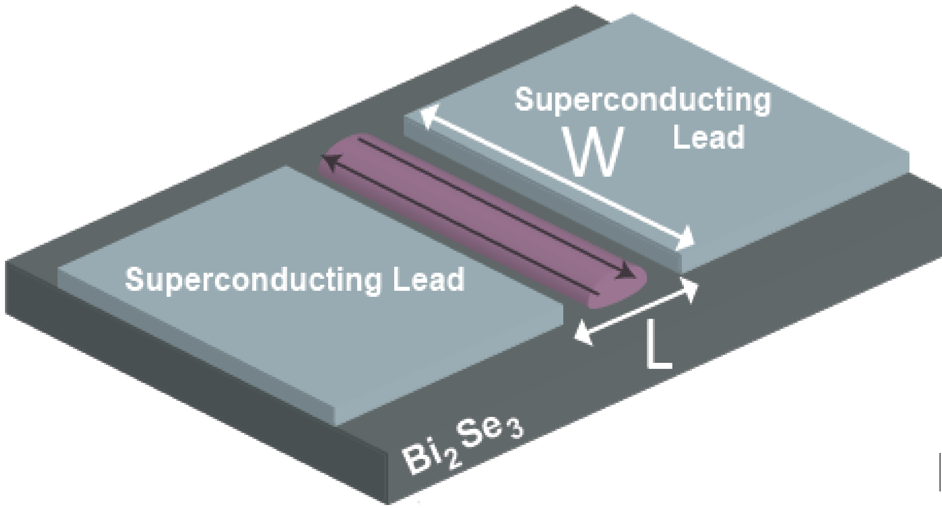
Characteristic prop. of conventional JJs:

- product of $I_C R_N \sim \Delta/e$ + independent from device geometry
- „Frauhofer-like” magnetic diffraction pattern – first minimum in I_C @ $B=B_C$ ($\Phi_0=h/2e$)

Report:

- small value of $I_C R_N \sim 1/W$
- B_C is 5 times smaller than expected

→no theoritical prediction or report



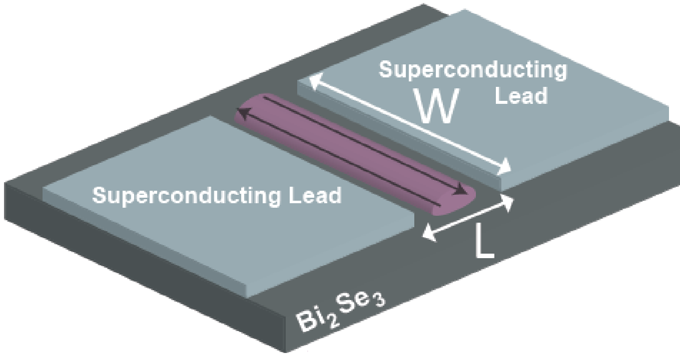
Signatures of MF

Signatures of MF found in SC-TI-SC JJs

- **Josephson Junctions (JJs)** (S-TI-S):

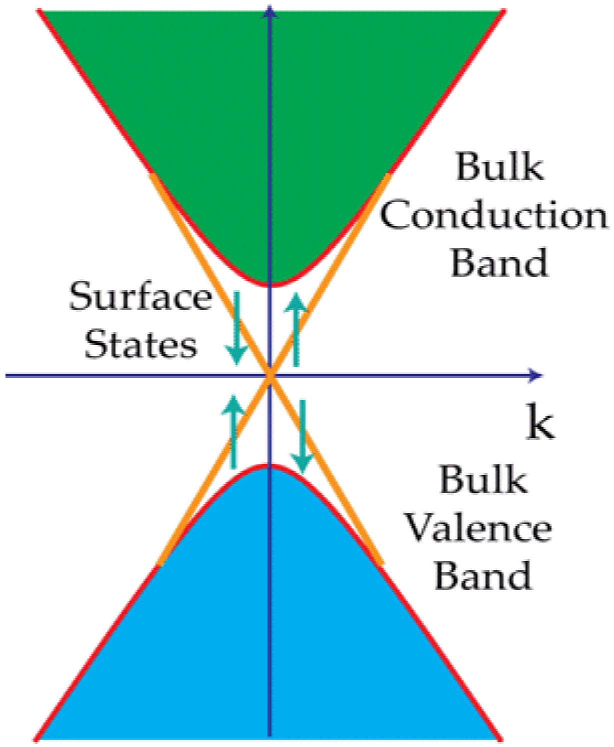
→theoritical work [3]

  - study of a SC-TI surface proximity effect
  - resembles 2D spinless p_x+ip_y superconductor



→phenomenological extensions:

1st: confinement along the 1D wire



[3] Phys. Rev. Lett. 95, 146802 (2005)

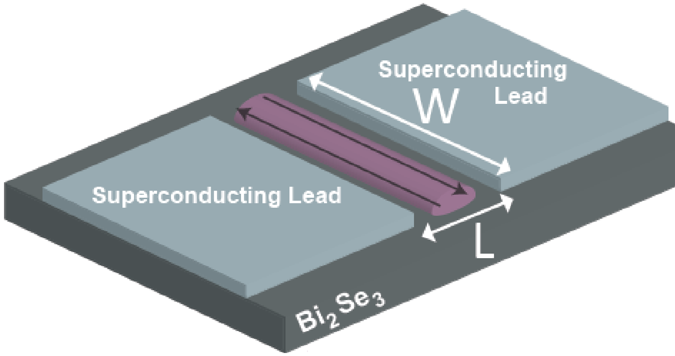
Signatures of MF

Signatures of MF found in SC-TI-SC JJs

- **Josephson Junctions (JJs)** (S-TI-S):

→theoritical work [3]

  - study of a SC-Ti surface proximity effect
  - resembles 2D pinless p_x+ip_y superconductor

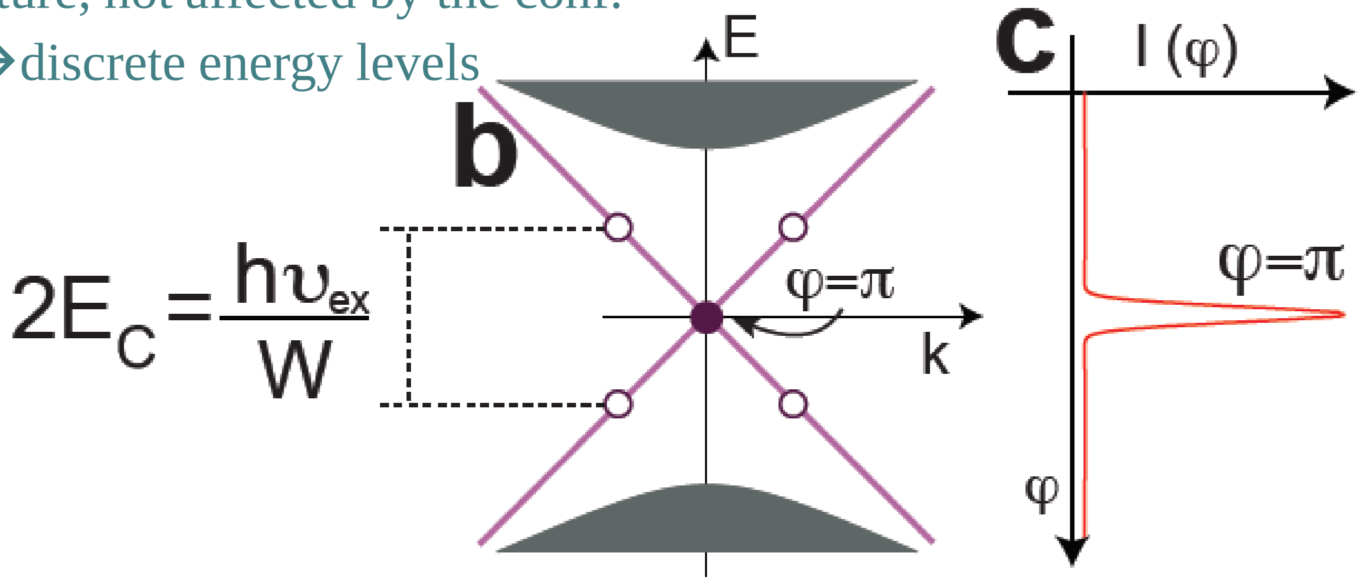


→phenomenological extensions:

1st: confinement along the 1D wire

E=0: topological nature, not affected by the conf.

E≠0: quantization →discrete energy levels



[3] Phys. Rev. Lett. 95, 146802 (2005)

Signatures of MF

Signatures of MF found in SC-TI-SC JJs

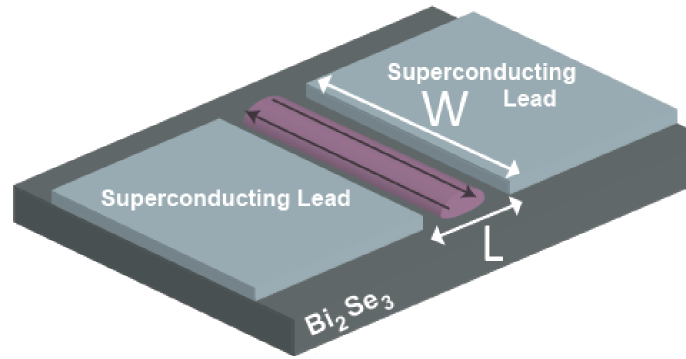
- **Josephson Junctions (JJs)** (S-TI-S):

→phenomenological extensions:

1st: confinement along the 1D wire

E=0: topological nature, not affected by the conf.

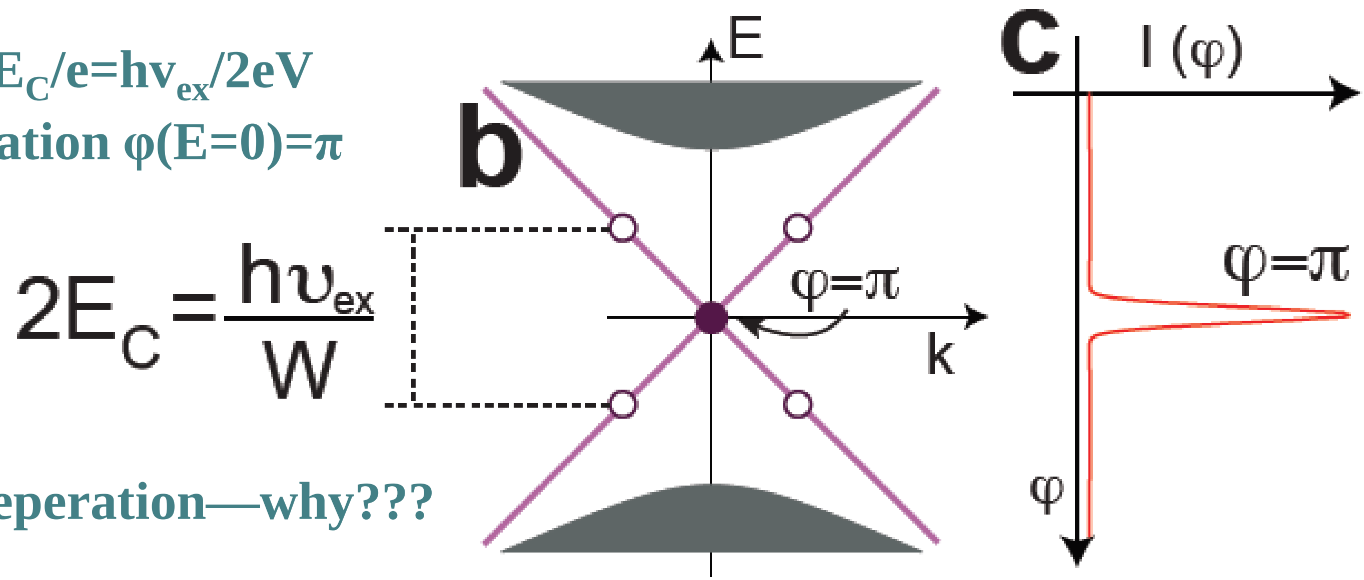
E≠0: quantization →discrete energy levels



2nd: only E=0 superconducts, E≠0 states are dissipative

-$I_C R_N$!~Δ/e, $I_C R_N$~E_C/e=hv_{ex}/2eV

-current-phase-relation φ(E=0)=π

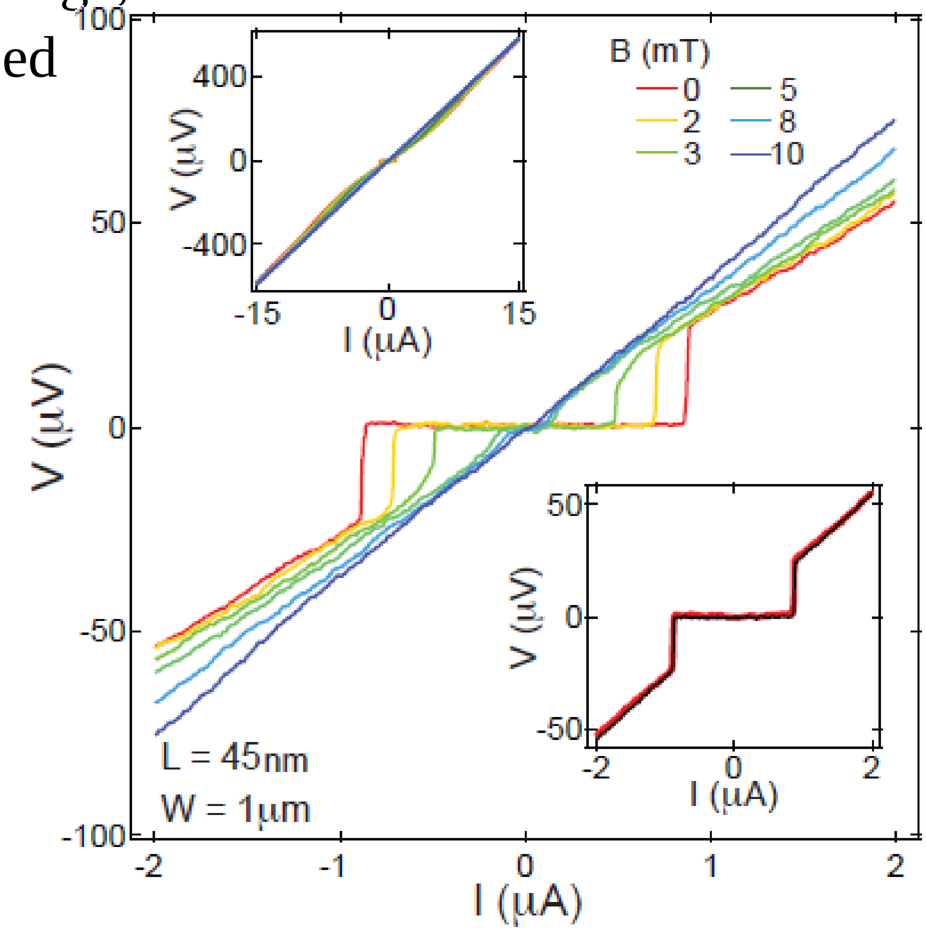


Confinement for seperation—why???

Signatures of MF

DC response:

→DC response, V(I,B) @ 12mK : I_C=850nA
→I>I_C excess current due to the CP leakage, V >2Δ/e
→no hysteresis – junction is overdamped



RN= 35Ohm, ICRN=30.6 uV

Theoritical prediction:
280-427uV !!!
Control sample w/ graphite weak link
244 uV !!!

Thermic reduction ruled out (~3.4K)

Signatures of MF

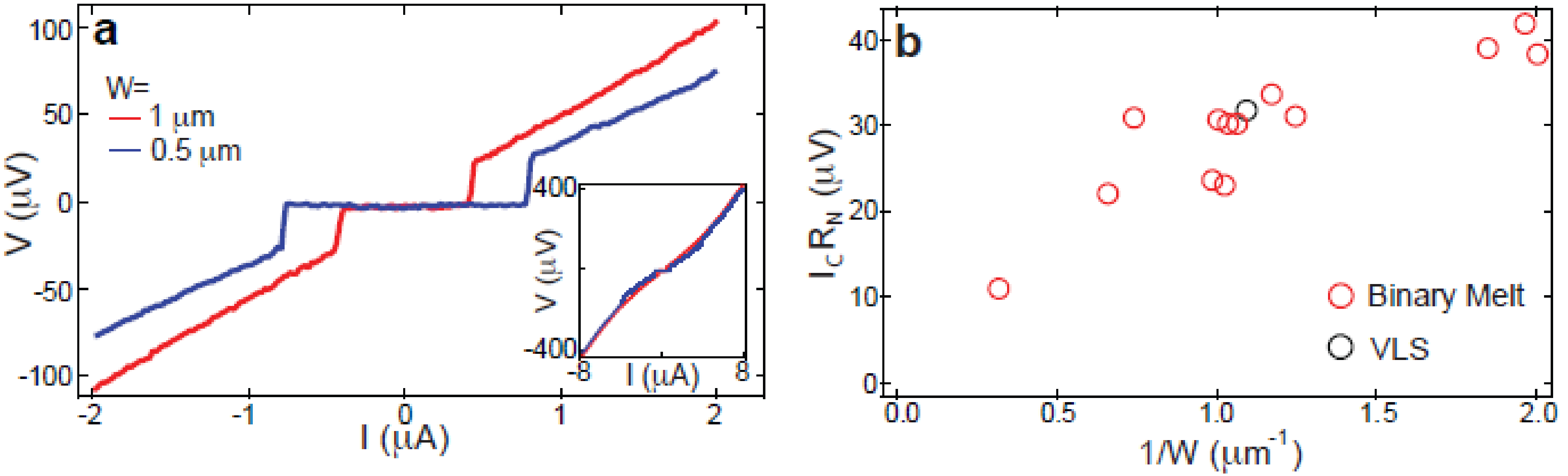
Width dependance: samples R_{N1}=56.1 Ohm, W_1=1um, R_{N2}=51.5Ohm, W_2=0.5 um

→DC response, V(I,B) @ 12mK : I_C=850nA

→$I>I_C$ excess current due to the CP leakage, V >2Δ/e

→no hysteresis – junction is overdamped

I_CR_N~1/W

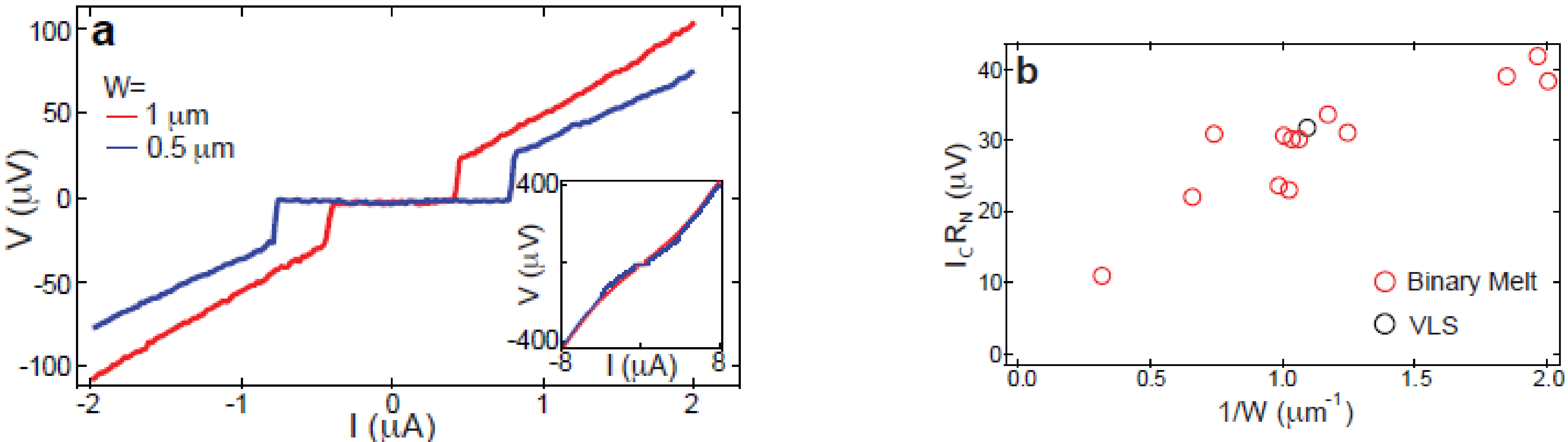


Signatures of MF

Width dependance: samples RN1=56.1 Ohm, W1=1um, RN2=51.5Ohm, W2=0.5 um

→DC response, V(I,B) @ 12mK : I_C=850nA
→$I>I_C$ excess current due to the CP leakage, V >2Δ/e
→no hysteresis – junction is overdamped

→I_CR_N~1/W →v_{ex} of dissipative excitations can be extracted frin slope
$v_F \sim 10^5\text{-}10^6 > v_{ex} = 1.4 \pm 0.2 \times 10^5$m/s ~Δ/e or $(\Delta/e)^2$ – good agreement



Signatures of MF

Magnetic diffraction pattern:

- B_C is 5 times smaller then expected:
  1.7mT ←→9.3 mT
- $I_C(B)$ deviates from typical FDP
- Existance of added features @ $I<I_C$