Zero-Bias Peaks and their Splitting in Al-InAs Nanowires

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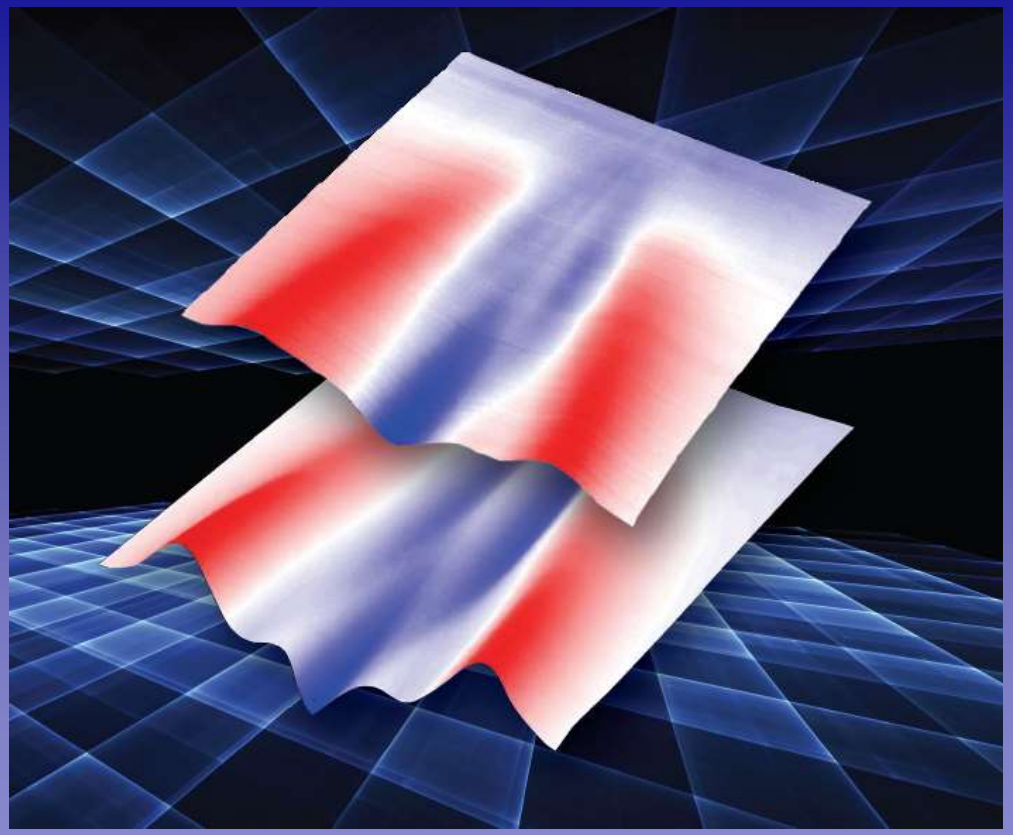


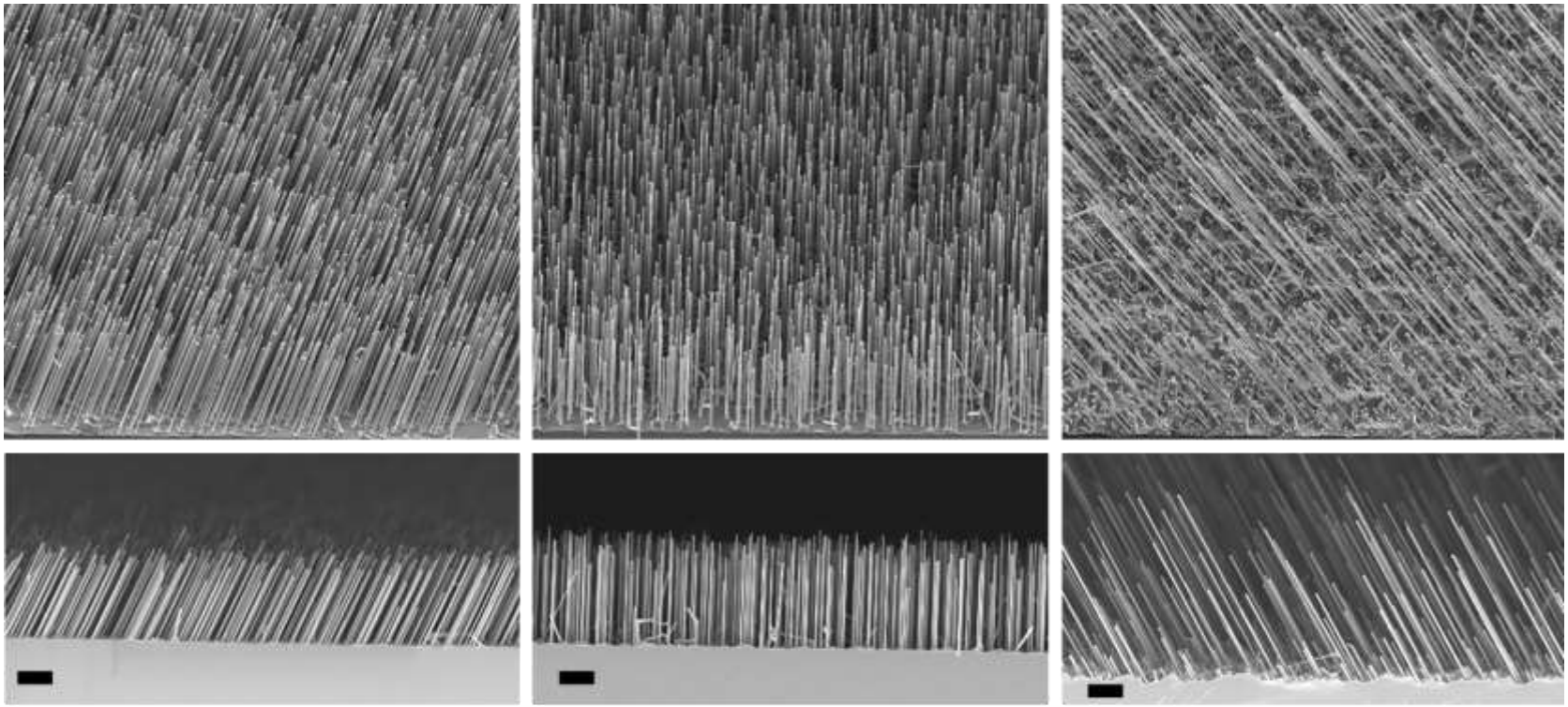
מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

Braun Center for Submicron Research
Weizmann Institute of Science

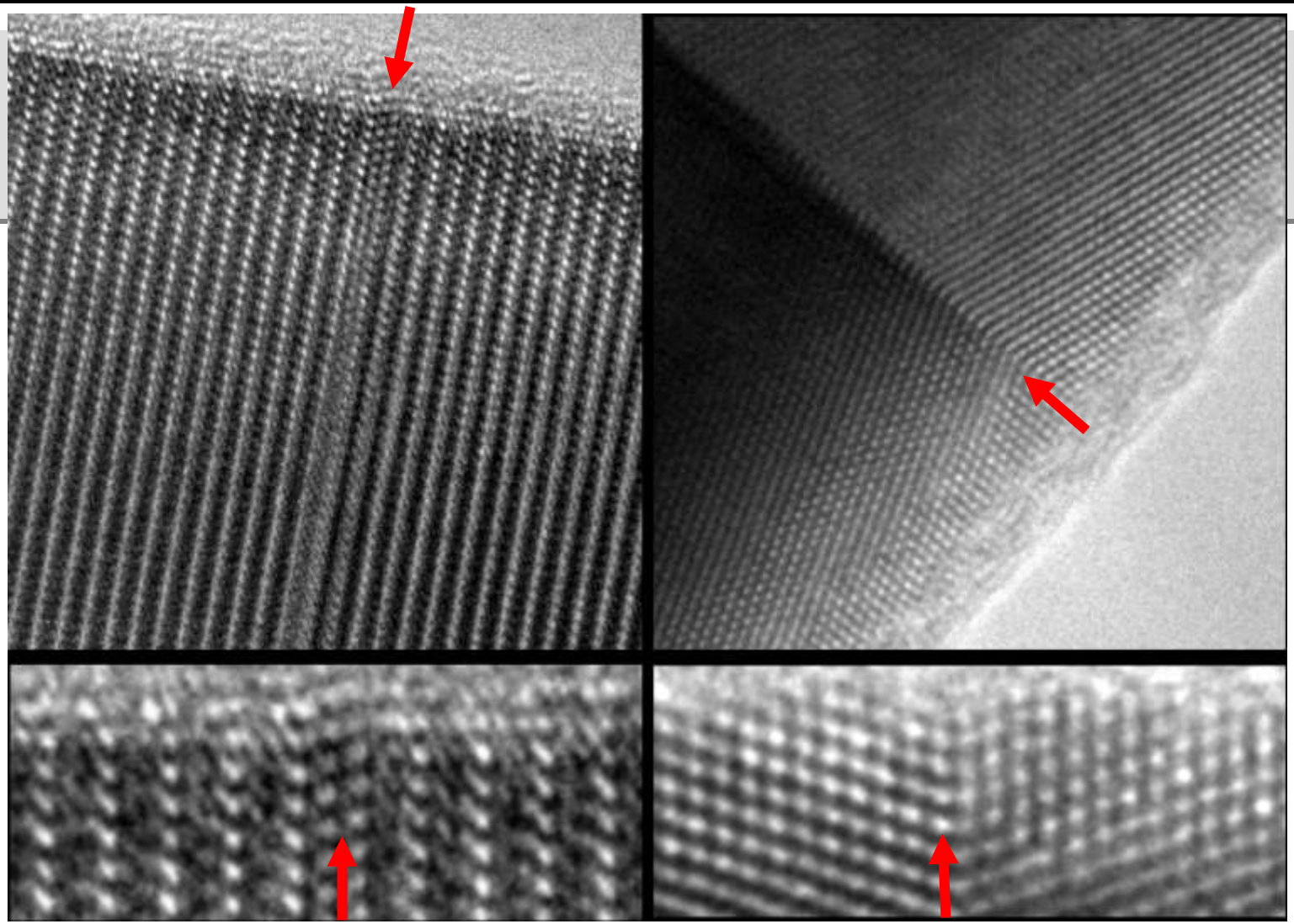
why entering this field?

- available home grown of nanowires
- we were looking for entangled electrons
- having difficulties with the FQHE 5/2 fraction

our InAs nanowires reached maturity



(110) (111)B (311)B



single staking fault
wurtzite (hexagonal) structure

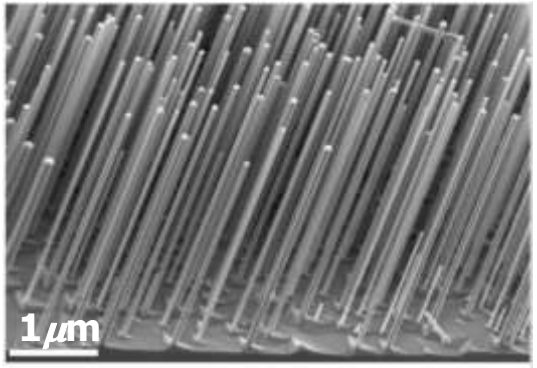
single staking fault
zinc blende (cubic) structure

curtsey of Ronit Popovitz-Biro

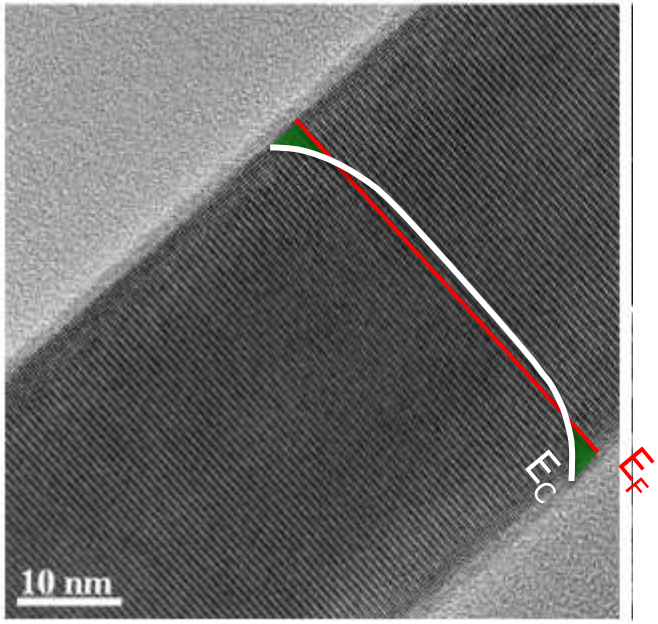
the nanowires

Au-assisted MBE growth

InAs nanowires <111>



InAs substrate (110)



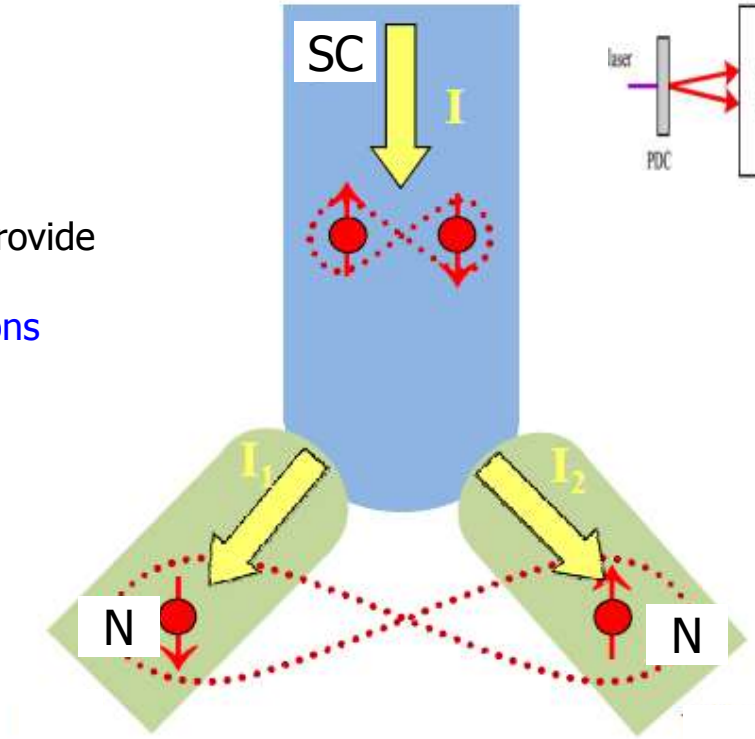
Wurtzite InAs nanowire

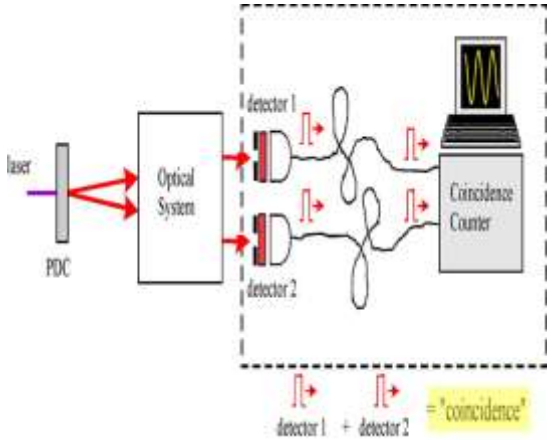
- InAs ~50nm diameter nanowires
- carriers likely on the surface (good and bad)
- *g* ~15 & spin-orbit energy ~70μeV
- large *spin-orbit* energy (50-150 μV)

entanglement via splitting Cooper pairs

splitting pairs may provide

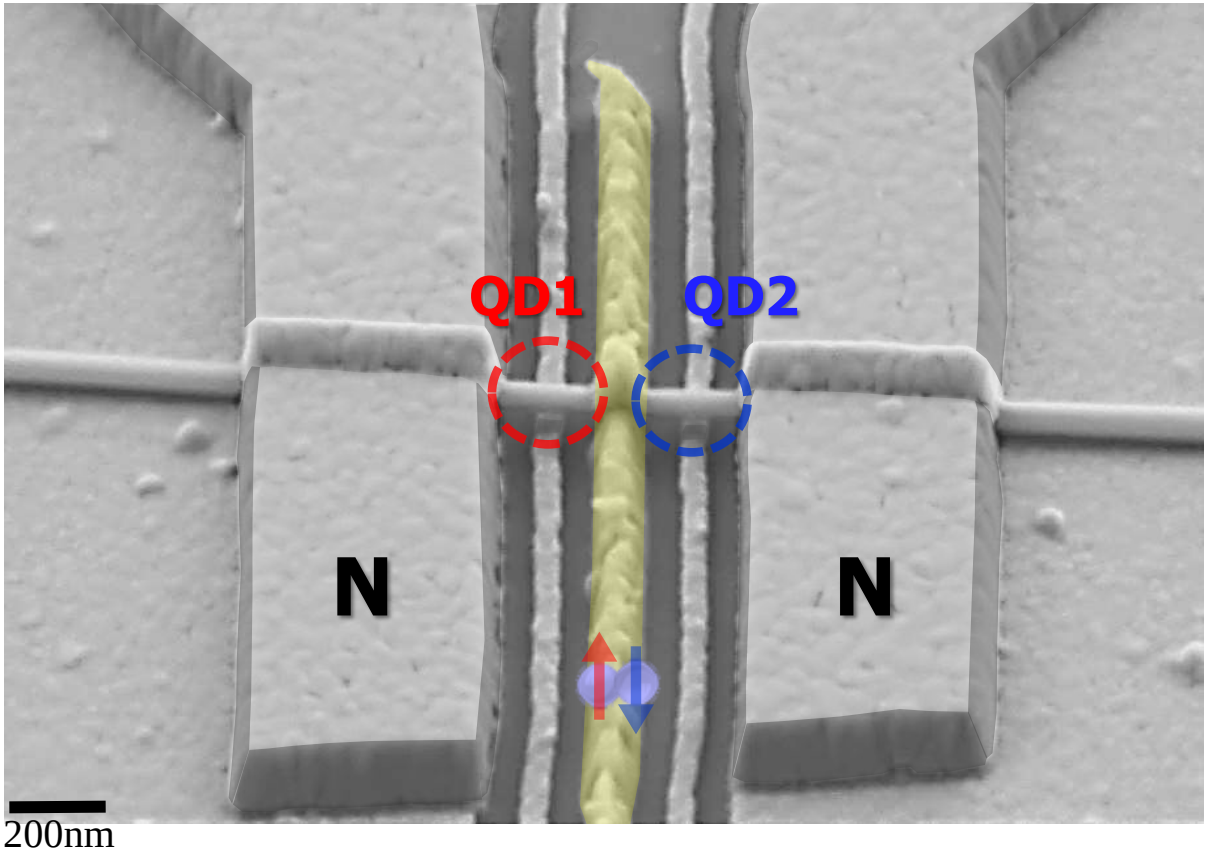
entangled electrons





Loss, Martin
Schonenberger

actual splitter (useful configuration)



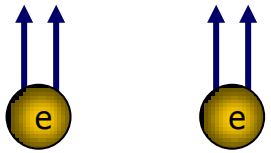
Majorana quasiparticles in ν=5/2 FQHE state

$\nu = 5/2 \rightarrow 2 + 1/2$

$R_{xx} = 0$

R_{xy} quantized

$\rightarrow$ energy gap



composite fermions at $B^* = 0$

spinless (high field)

we failed to observe AB interference

in 5/2 (and at any fraction)

why entering this field?

looking for Majorana quasiparticles seemed fitting

Lutchyn, Sau & Das Sarma PRL 2010 (1d)

Oreg, Rafael & von Oppen PRL 2010 (1d)

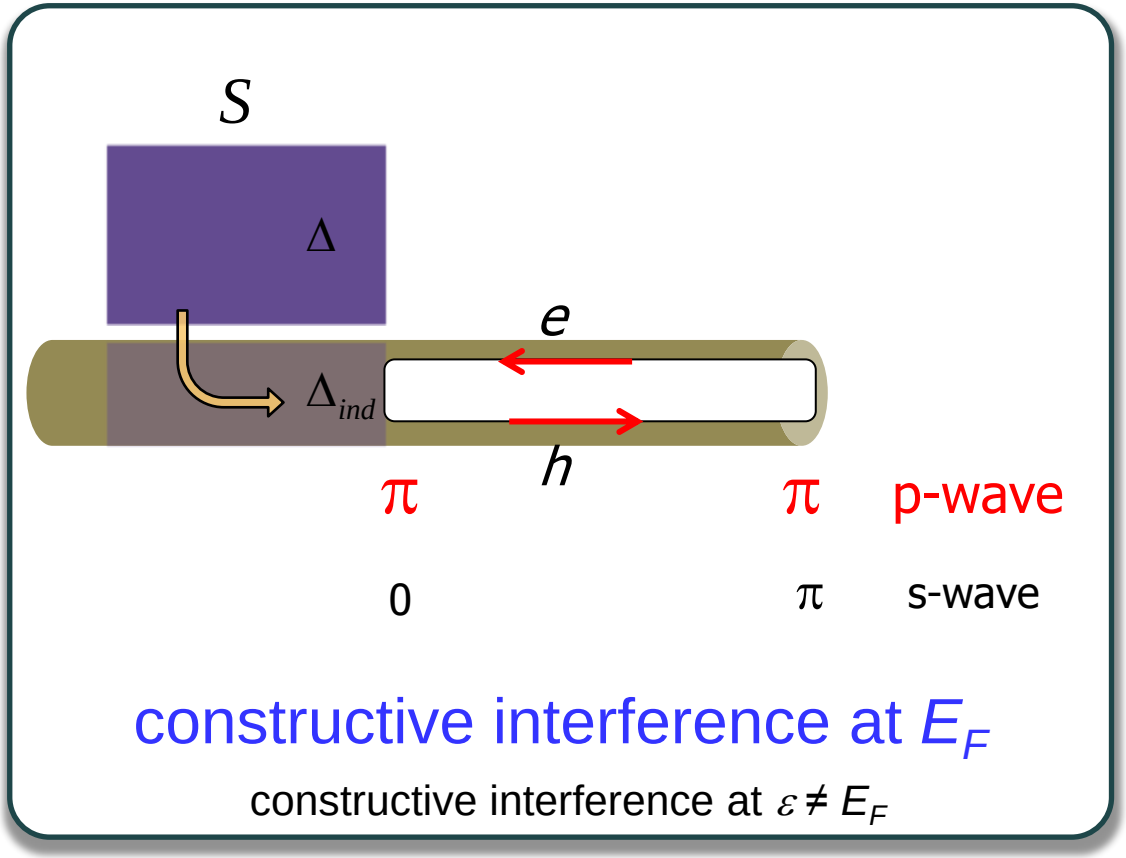
and the pioneering work of Kouwenhoven

what were we looking for ?

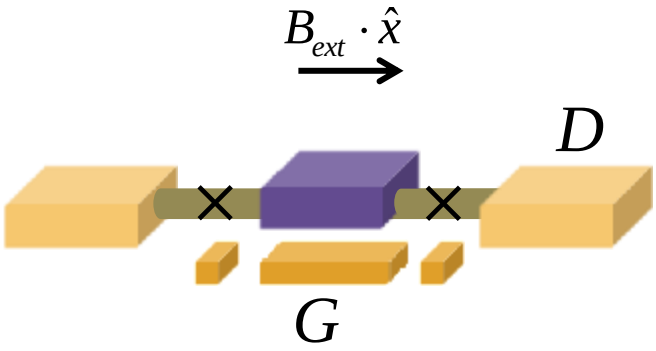
robust zero bias conductance peak

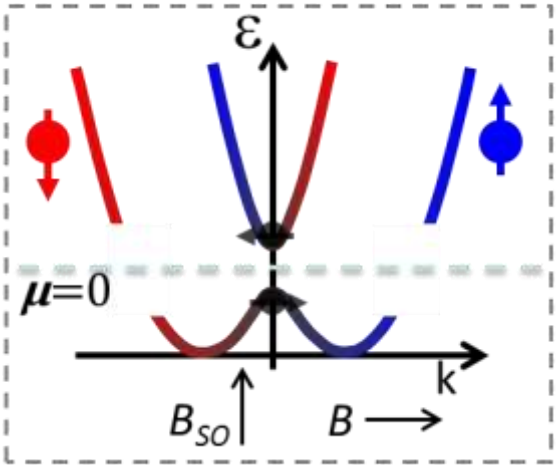
conductance $2e^2/h$

Majorana state → Andreev bound state at E_F



- terminated p-wave 1d SC
- E_F in the topological gap via V_G

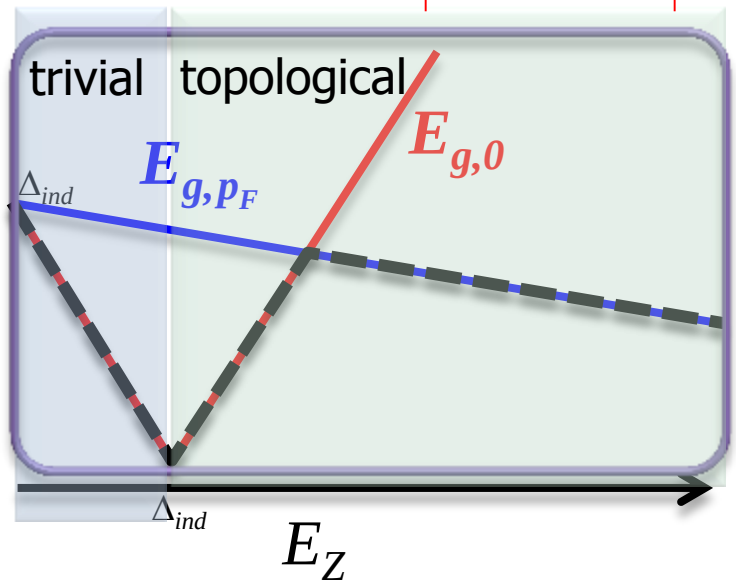




two localized Majorana states

energy gaps

$$E_{g,0} = 2\left|E_z - \sqrt{\Delta_{ind}{}^2 + \mu^2}\right|$$



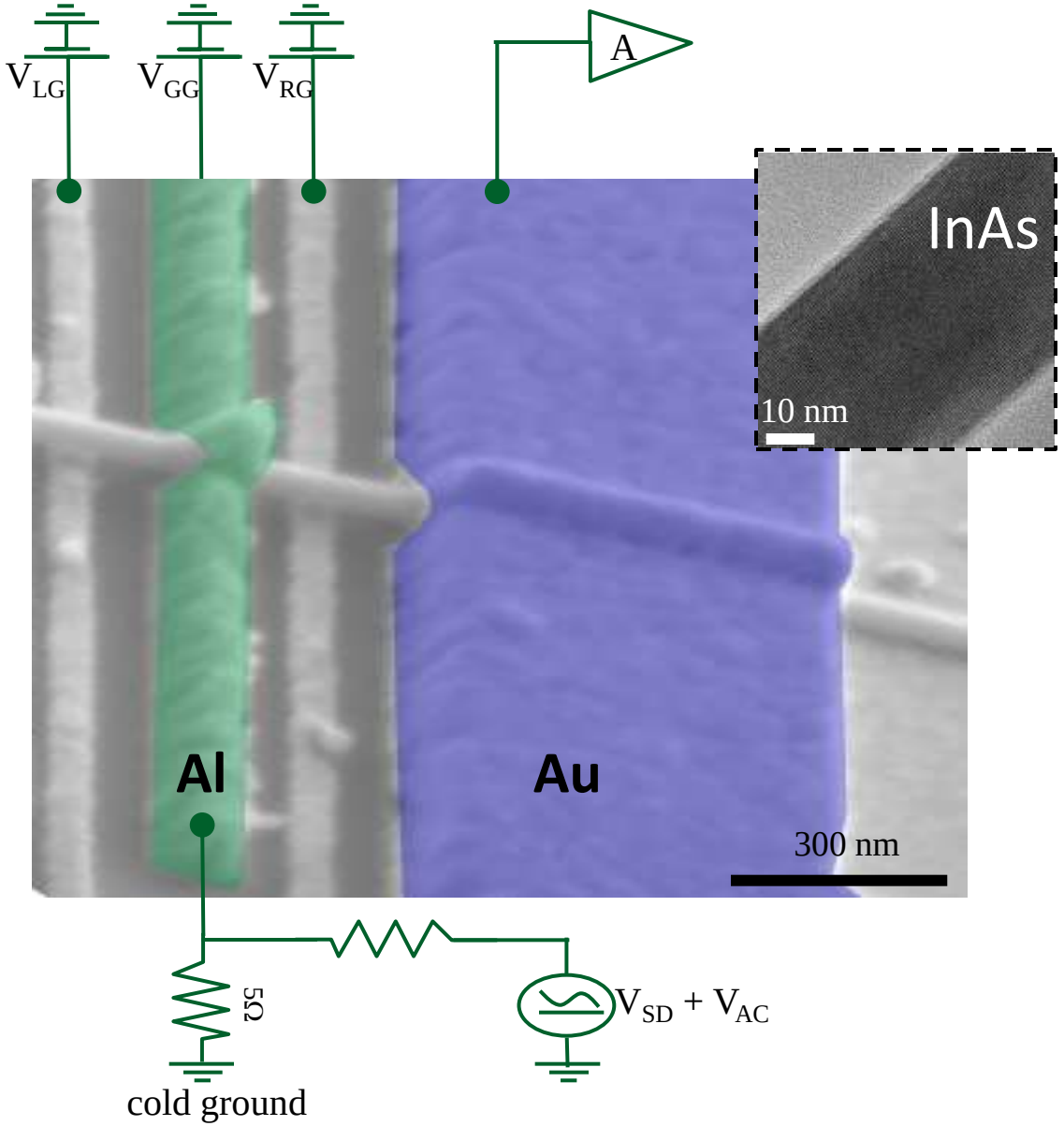
$$E_{g,p_F} = 4\Delta_{ind}\sqrt{\Delta_{so} / E_z}$$

$E_z > \Delta_{so}, \Delta_{ind}, |\mu|$

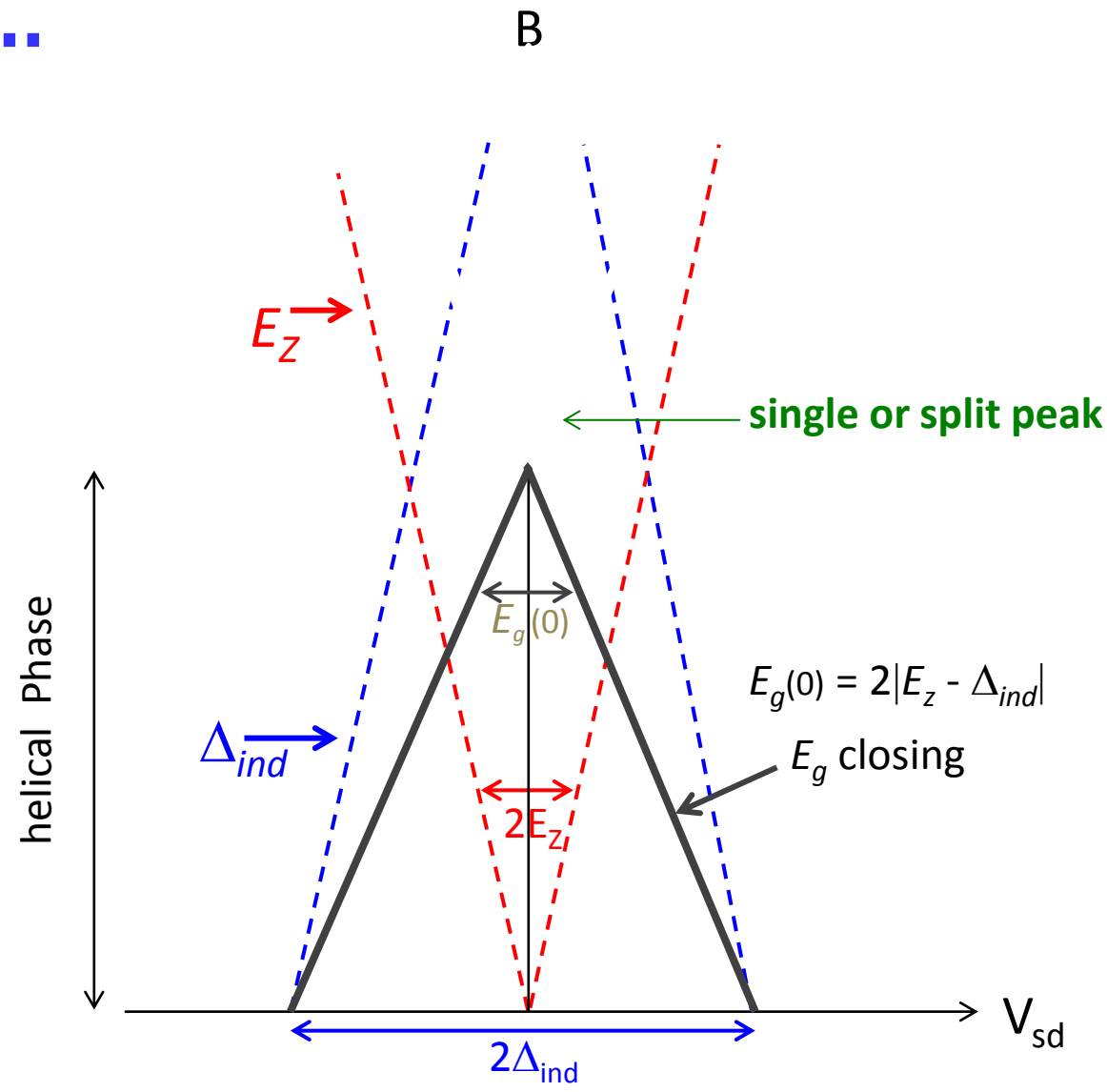
closing and opening gap !

we look for:

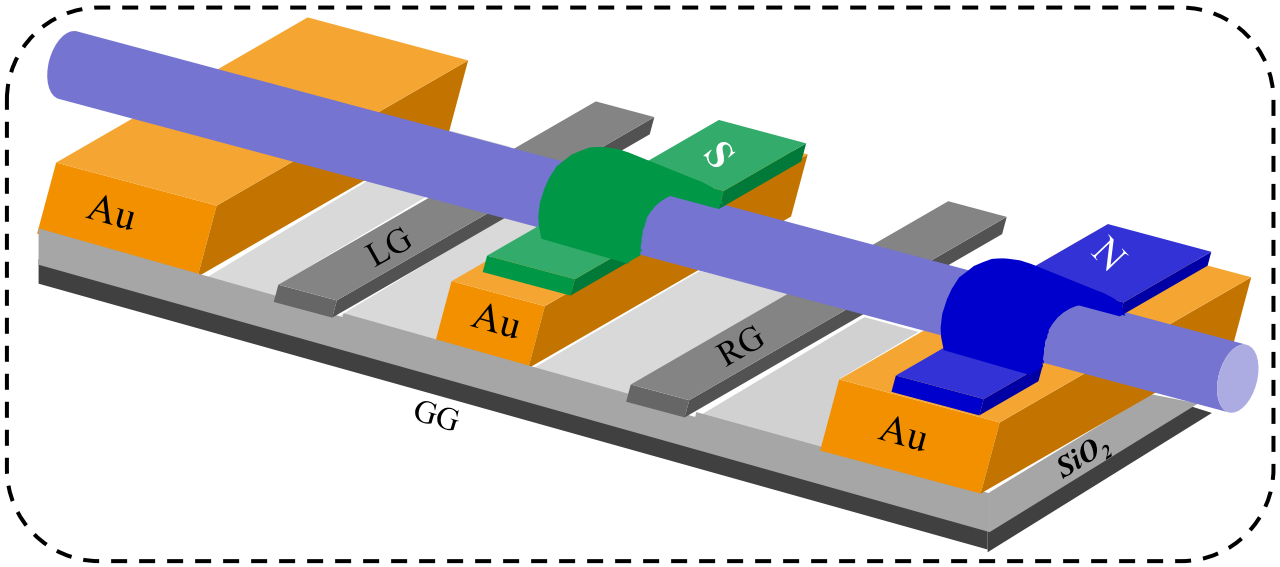
- ZBP only at finite magnetic field
- closing $E_g(0)$ gap
- splitting of the ZBP
- dependence on direction of Zeeman field
- temperature dependence


V_{LG}
V_{GG}
V_{RG}
A
InAs
10 nm
Al
Au
300 nm
50
$V_{SD} + V_{AC}$
cold ground

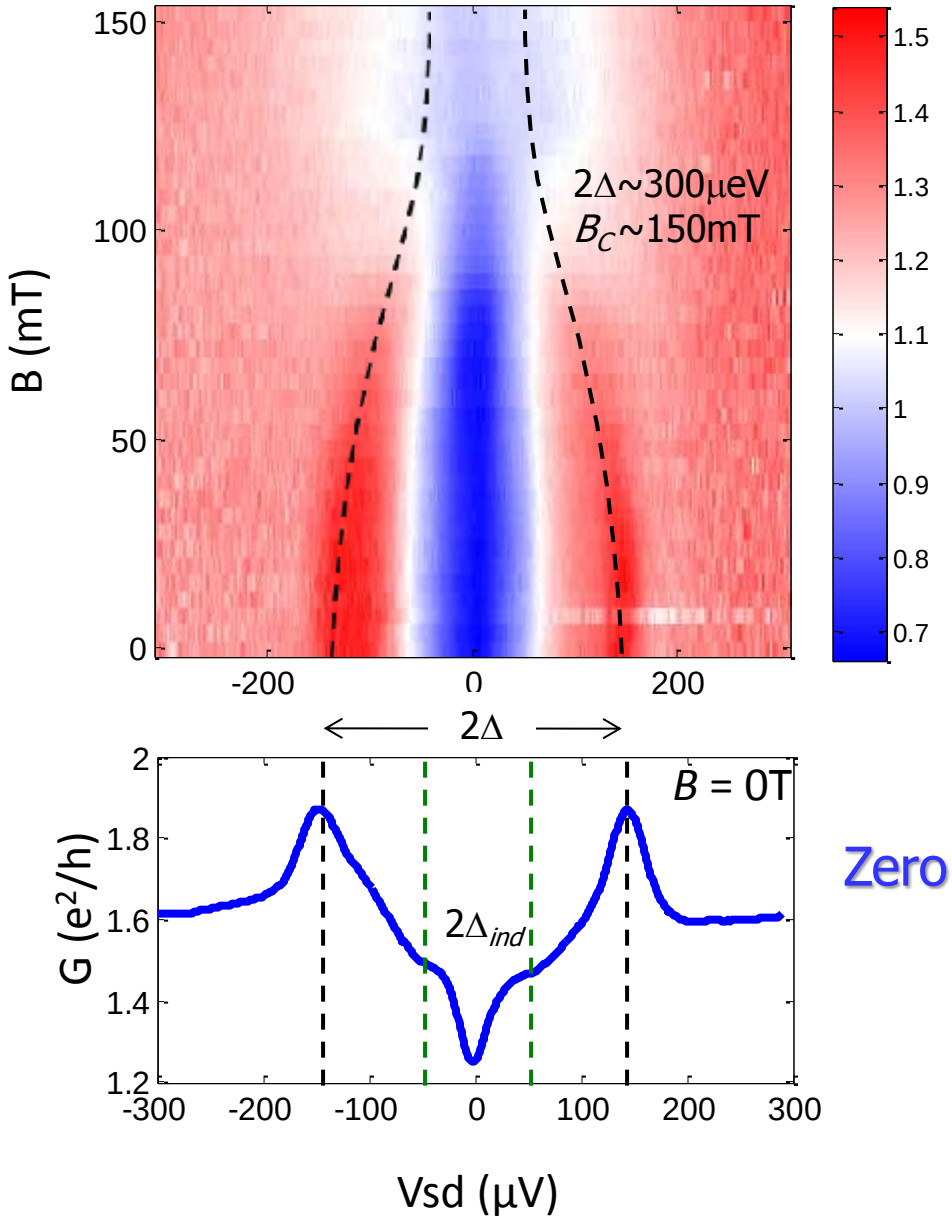
namely…


B
E_Z
single or split peak
helical Phase
$E_g(0)$
$E_g(0) = 2|E_z - \Delta_{ind}|$
Δ_{ind}
E_g closing
$2E_Z$
V_{sd}
$2\Delta_{ind}$

starting with the splitter device…

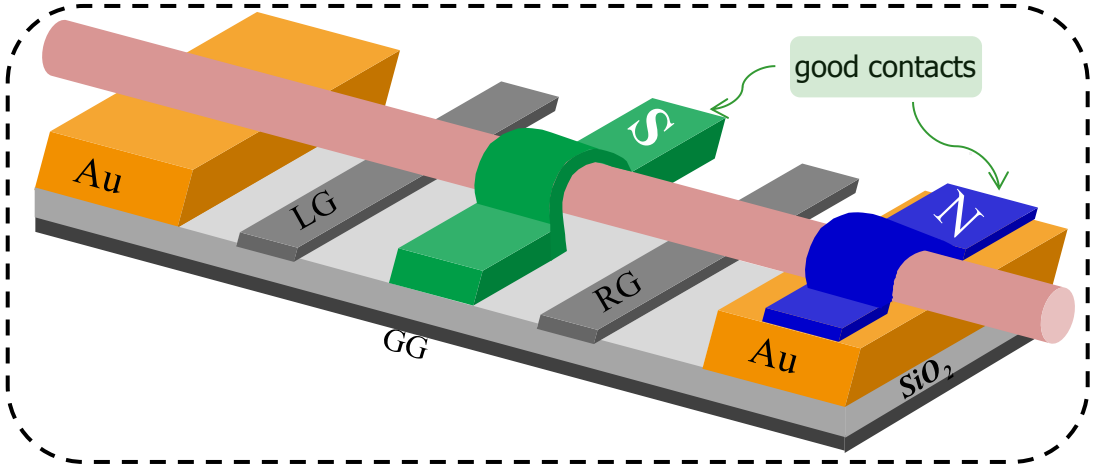


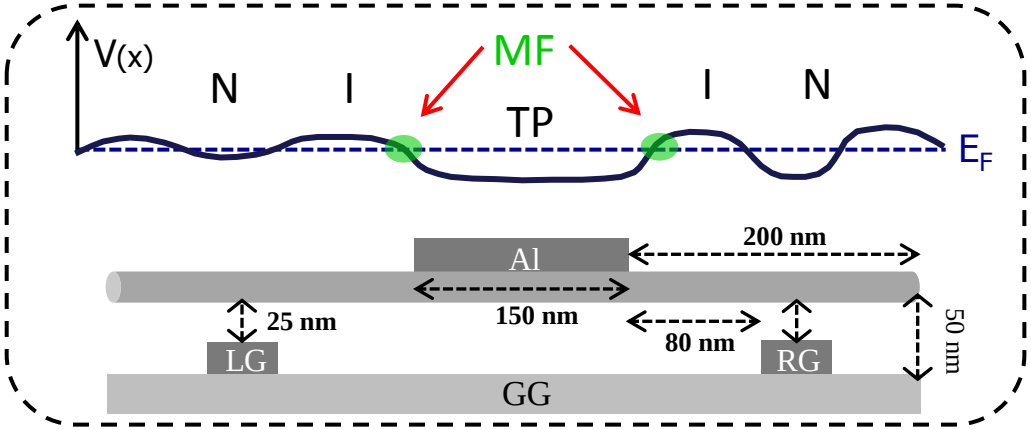
chemical potential could not be w/ GG



Zero Bias Peak - not observed

removing the middle pedestal...

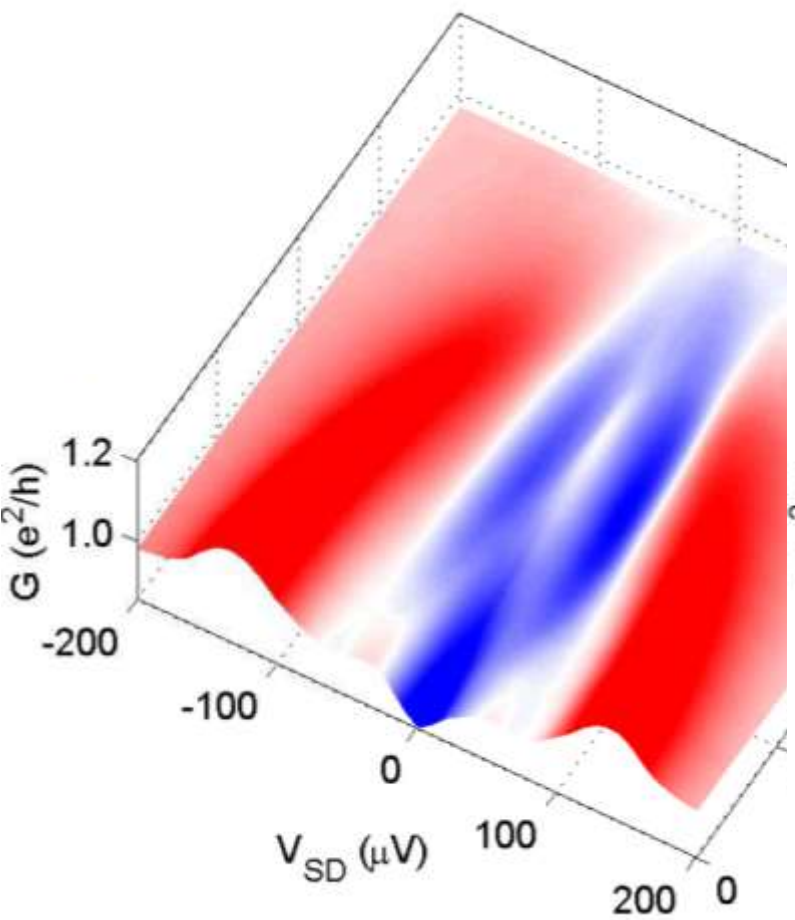


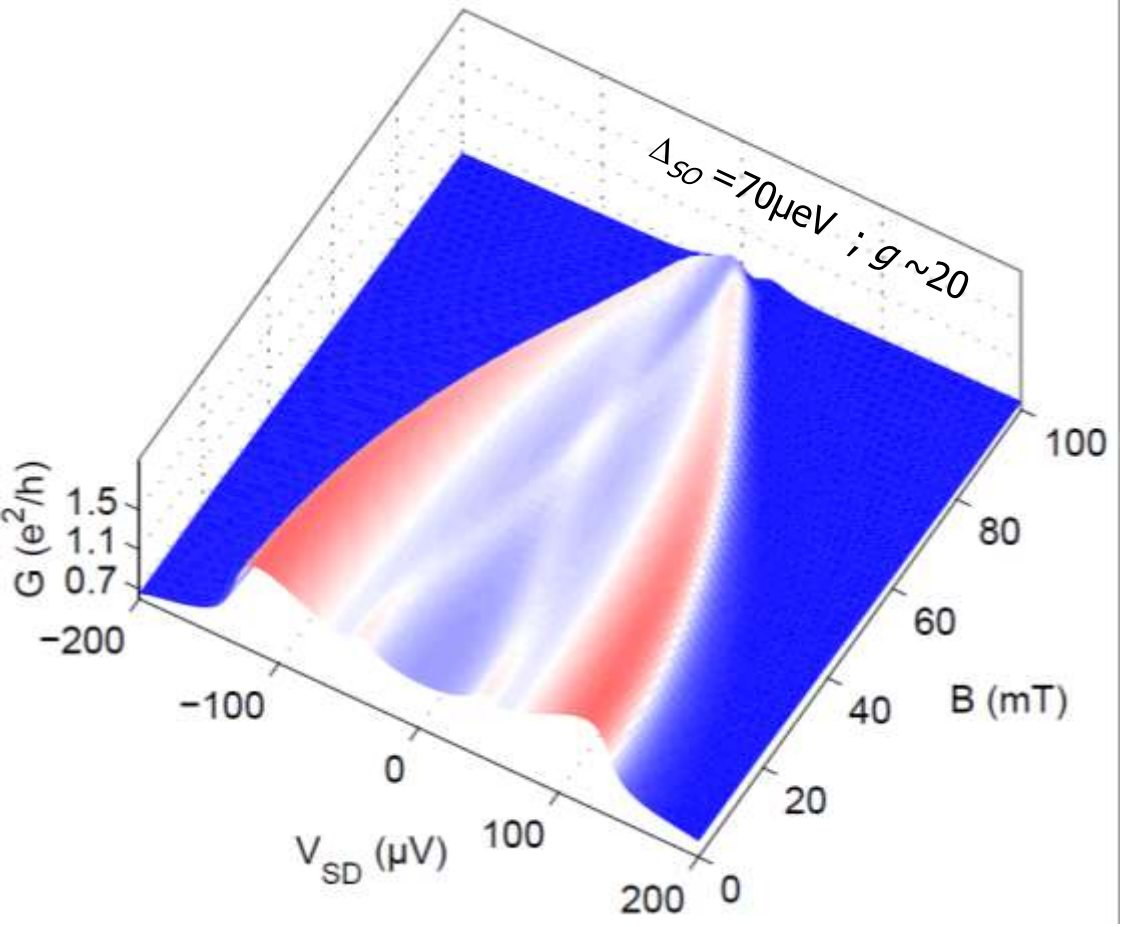


$\mu \sim 0$

experiment

simulation

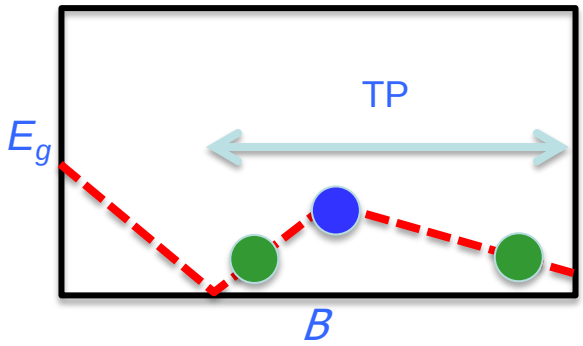




ZBP and **splitting** B dependence

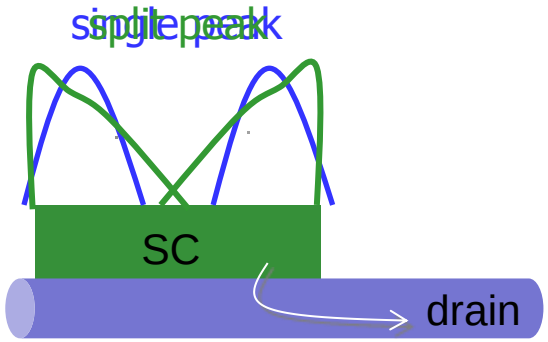
coherence length of Majorana state

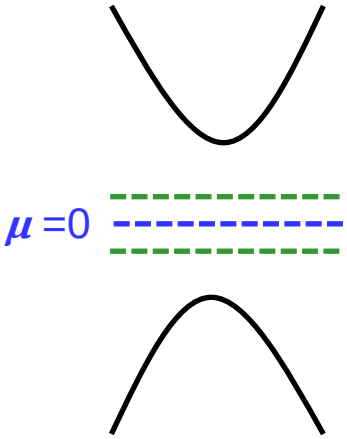
$$\xi \sim h\upsilon_F \,/\, E_g(B)$$



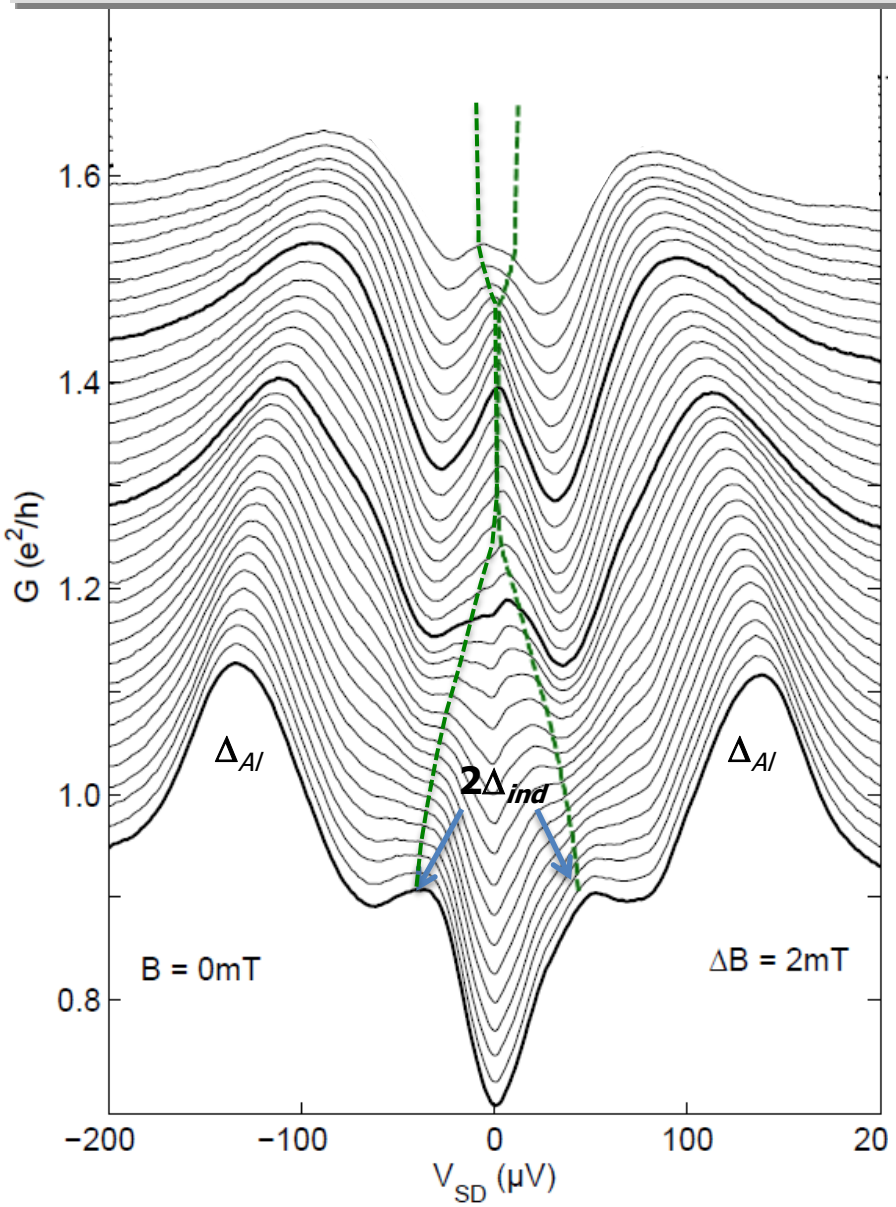
B = 50mT $\rightarrow \xi \approx$ small

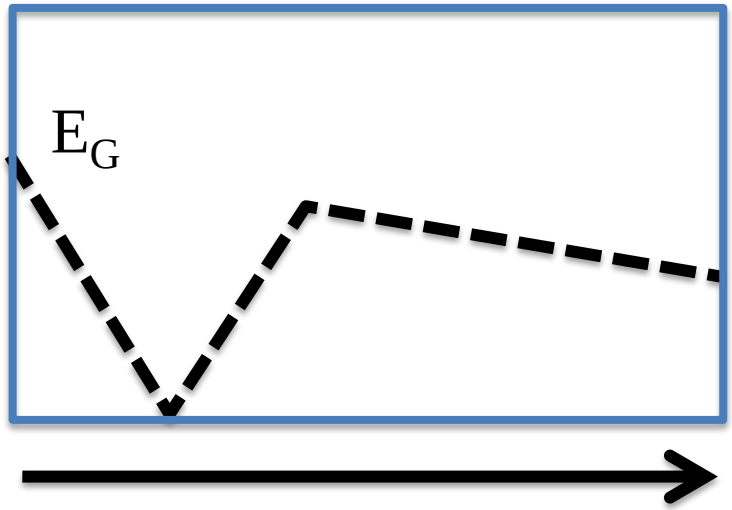
B = 30mT & 80mT $\rightarrow \xi \approx$ large





conductance – *B* field

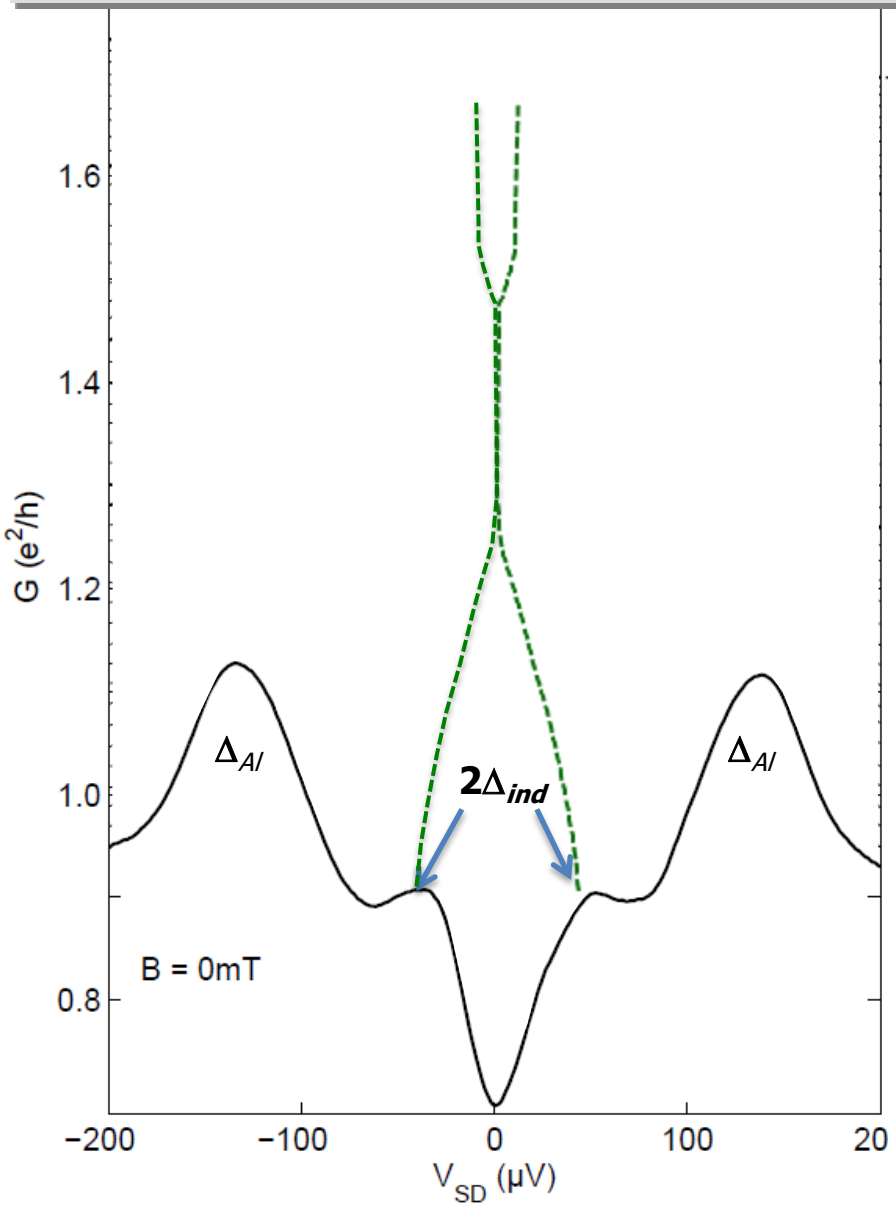




$E_Z \approx g\mu_b B,\ g = 20$

gap closing and splitting

conductance – *B* field

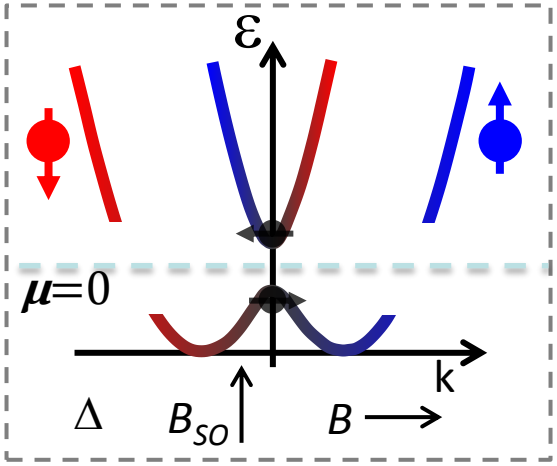


$E_Z \approx g\mu_b B,\ g = 20$

gap closing and splitting

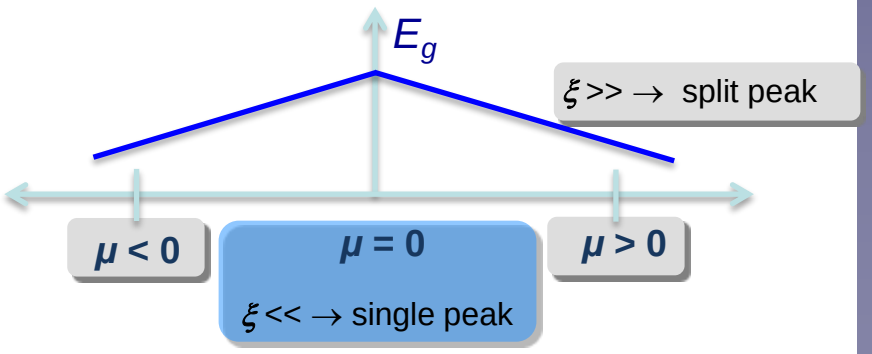
ZBP and splitting μ dependence

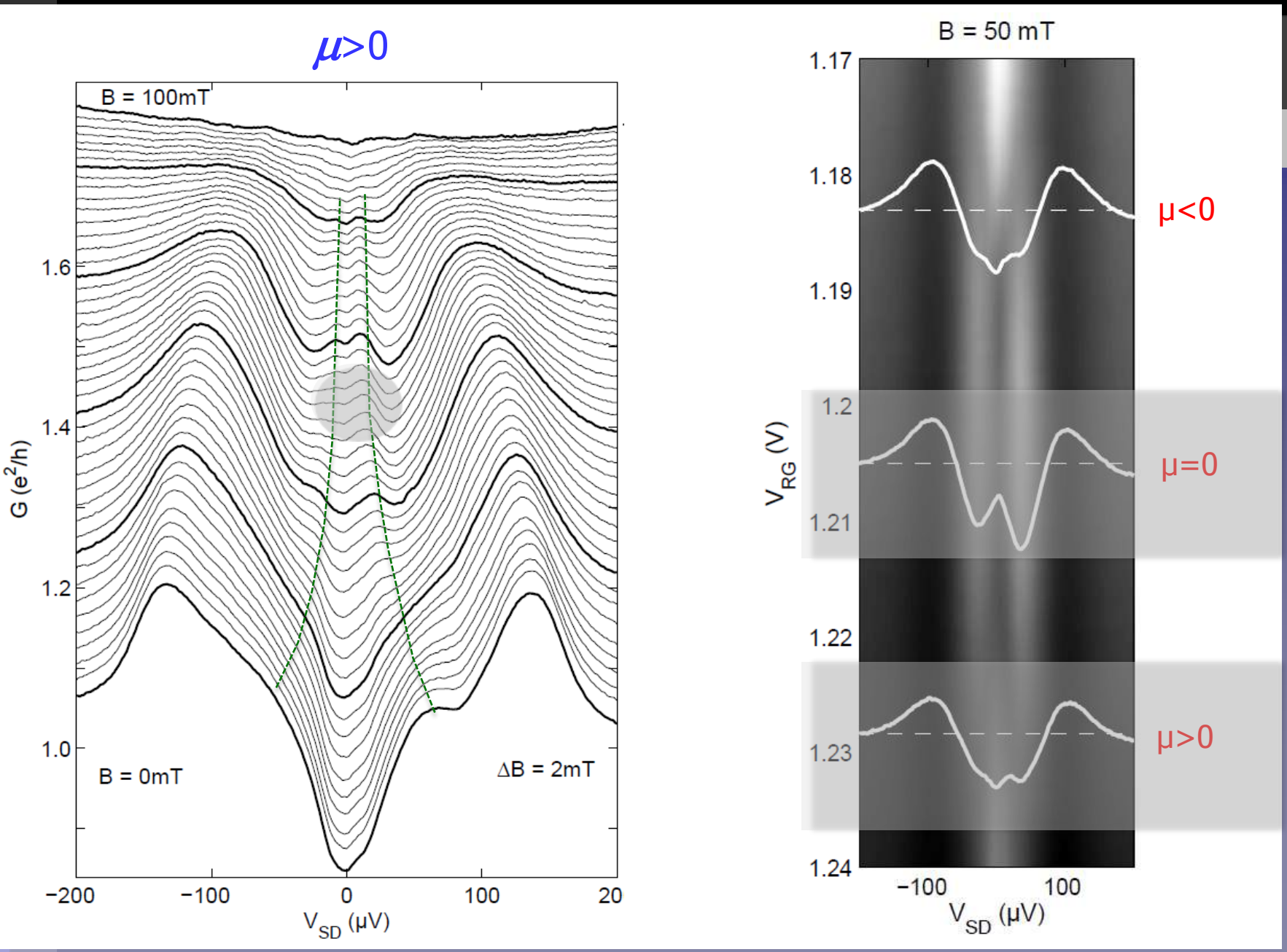
$$E_{g,0} = 2\left|E_z - \sqrt{\Delta_{ind}^{\ 2} + \mu^2}\right|$$



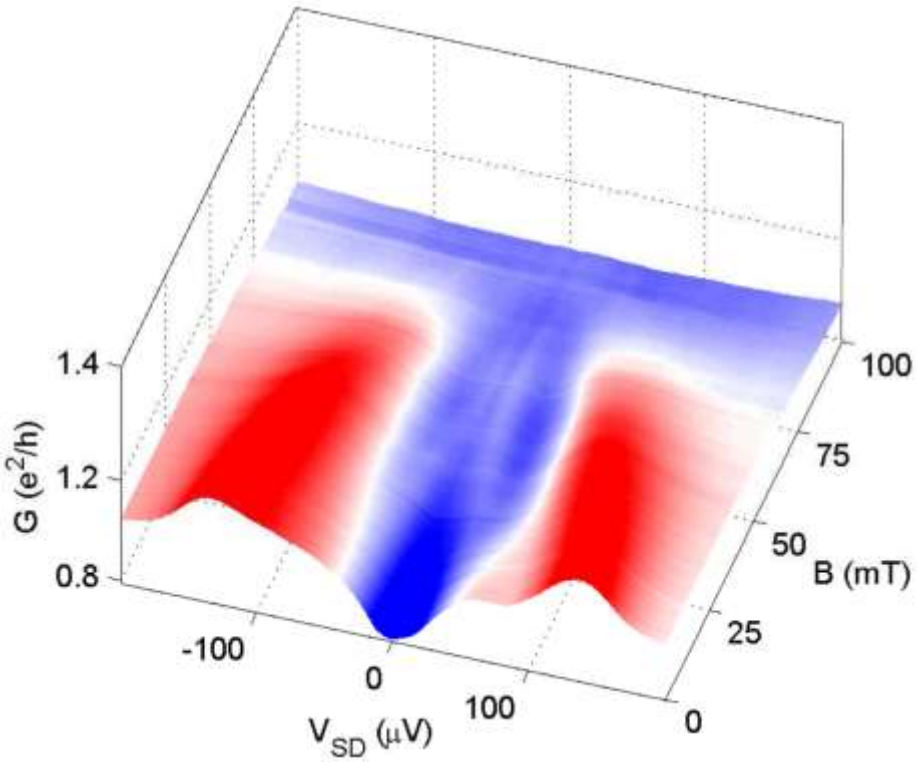
coherence length of Majorana state

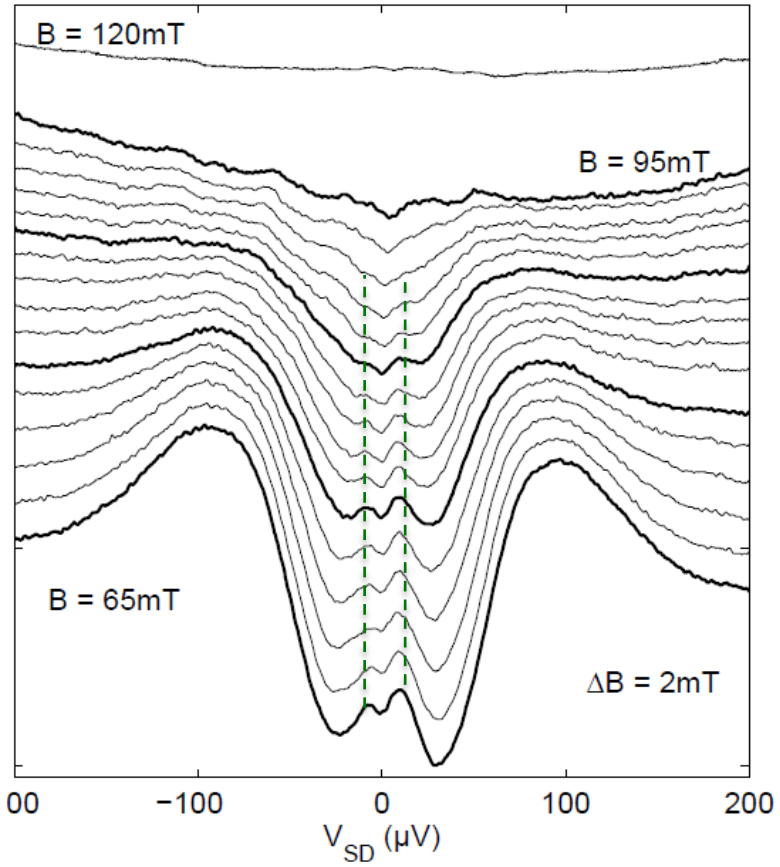
$\xi \sim h\upsilon_F / E_g(\mu)$




μ>0
B = 100mT
G (e²/h)
1.6
1.4
1.2
1.0
B = 0mT
ΔB = 2mT
−200
−100
0
100
20
V_SD (μV)
B = 50 mT
1.17
1.18
1.19
1.2
1.21
1.22
1.23
1.24
V_RG (V)
μ<0
μ=0
μ>0
−100
100
V_SD (μV)

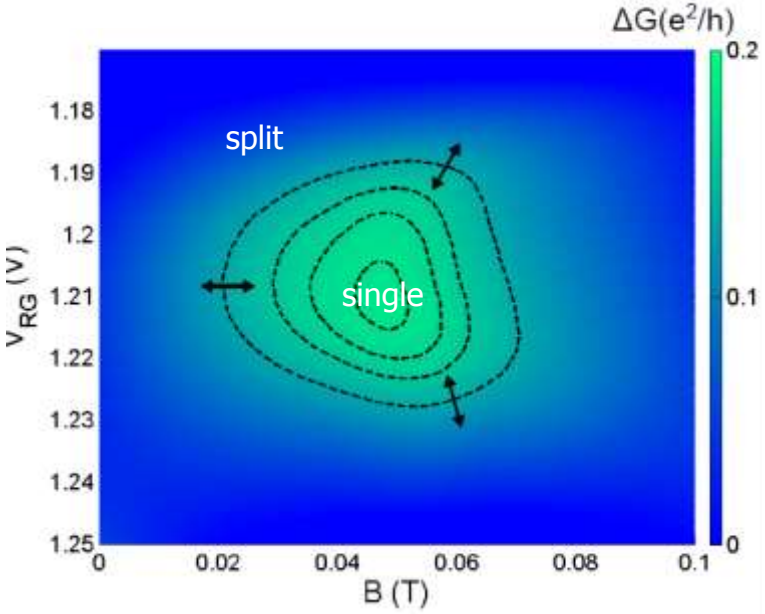
split ZBP ..... $\mu > 0$



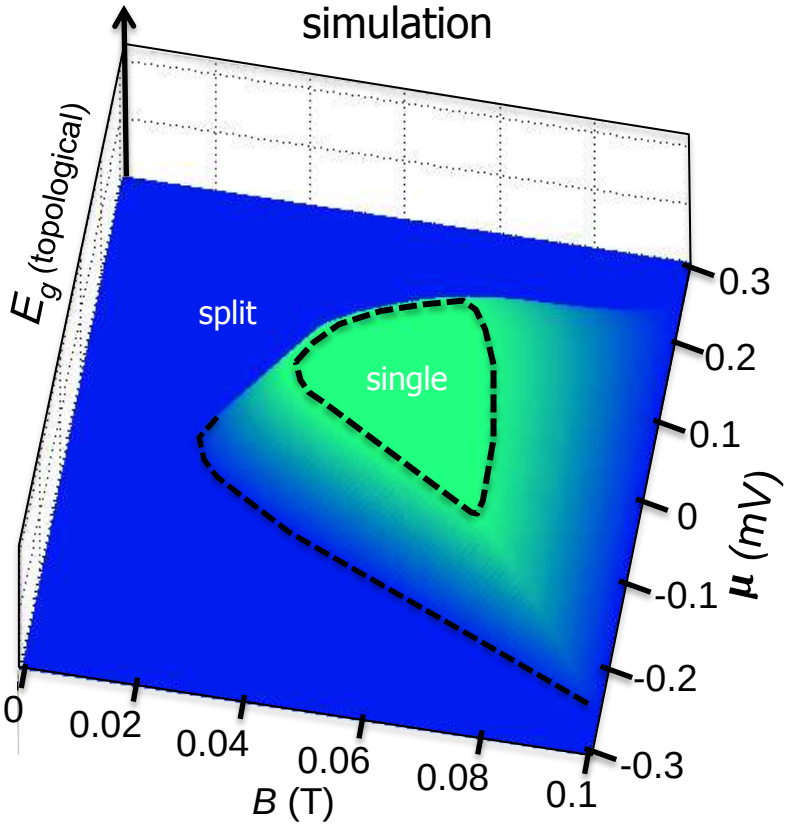


presence of a single ZBP

experiment



simulation



robust ZBP → with ***B*** & μ

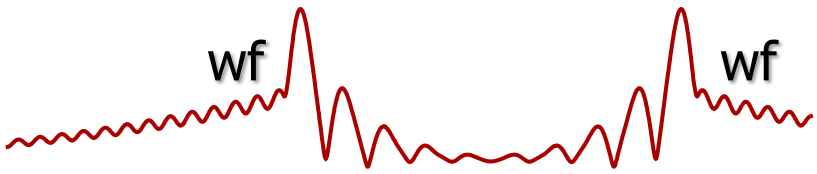
however,

- helical mode was not observed
- ZBP height is small….(0.1-0.4) $G_Q << 2G_Q$

  suppressing Cooper pair tunnelling $\rightarrow$ high barrier $\rightarrow$ small $\Gamma_{inverse\ lifetime}$

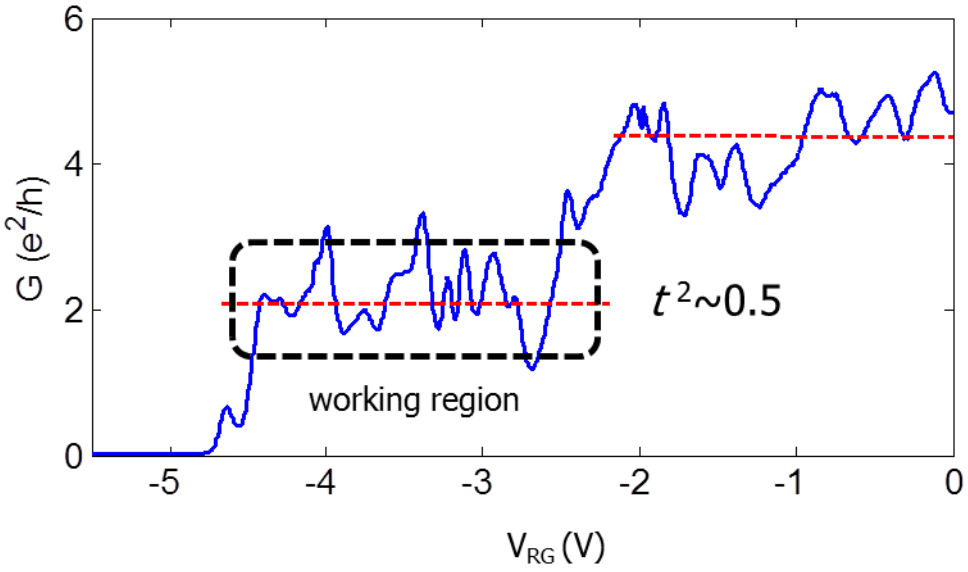
  peak height suppressed due to temperature…. $\Gamma_{inverse\ lifetime} / T_{temp}$

- splitting expected with μ (k_F periodicity)



moreover, the structures are far from ideal

strong disorder (carriers are likely on surface)



InAs channels in normal part ~1

InAs channels under superconductor ?

such zero bias peaks are not unique

rather than a ‘smoking gun’ experiment

data must be collected…