Disentangling Majorana fermions from conventional zero energy states in semiconductor quantum wires

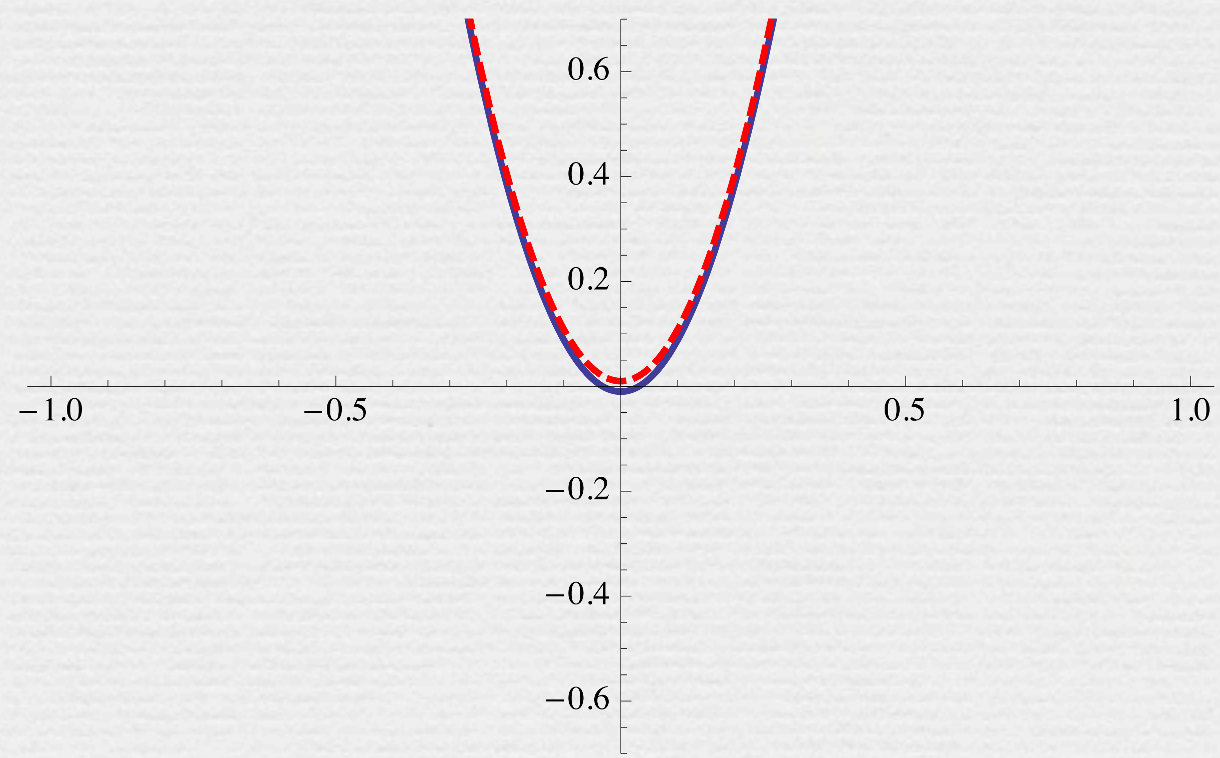
arXiv:1208.6298

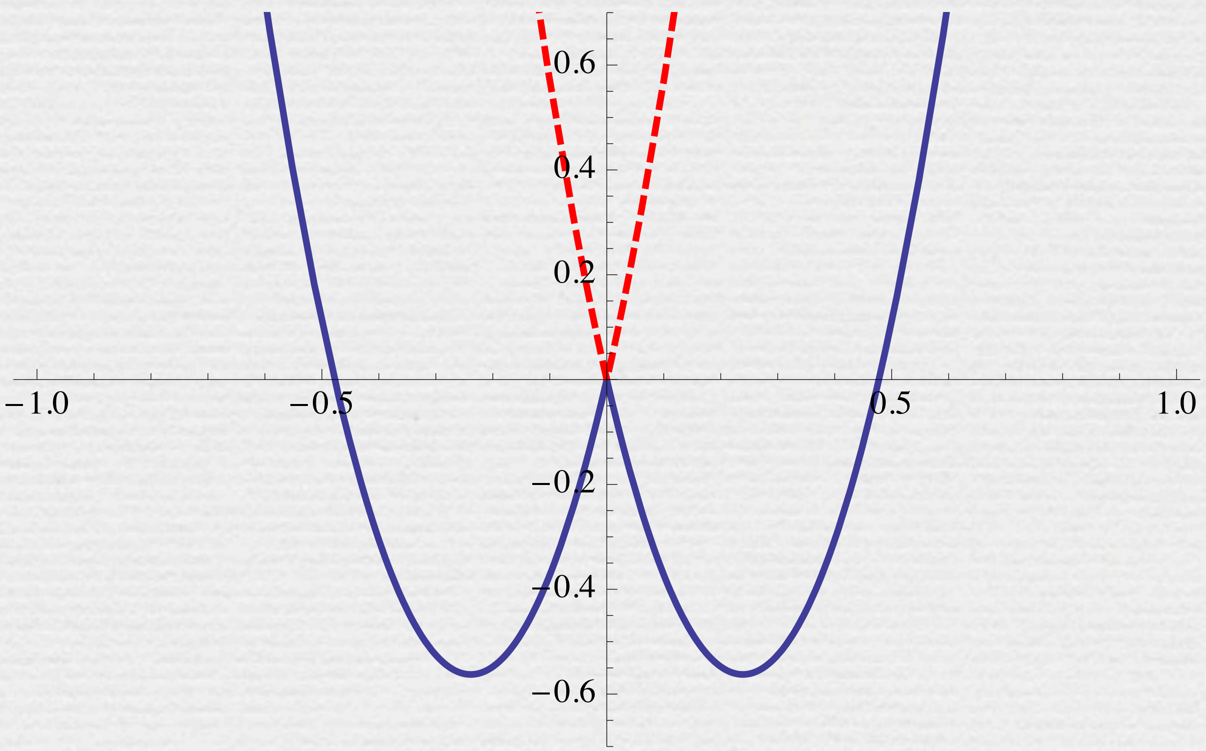
Tudor D. Stanescu (West Virginia University, Morgantown)
and Sumanta Tewari (Clemson University, Clemson)

Diego Rainis

Journal Club 11.09.2012

$$H_0 + H_{\mathrm{so}} + H_{\mathrm{SC}} + H_{\mathrm{Z}}$$





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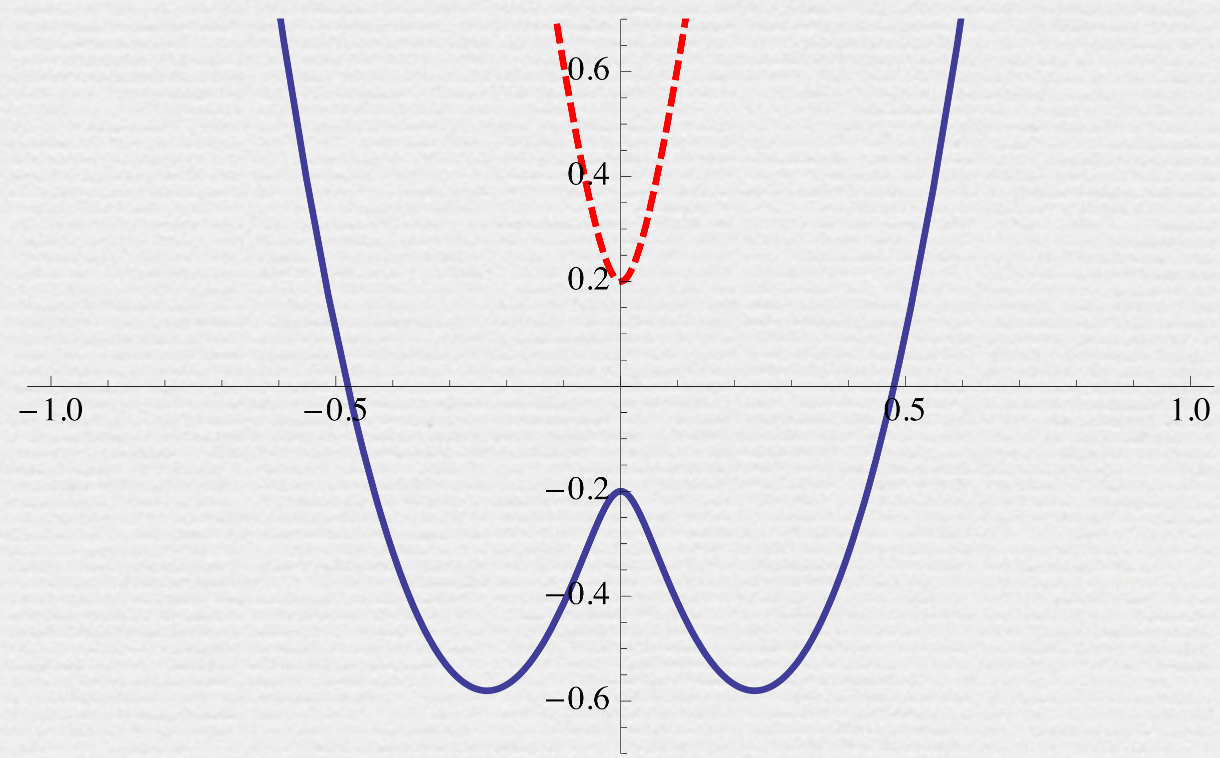
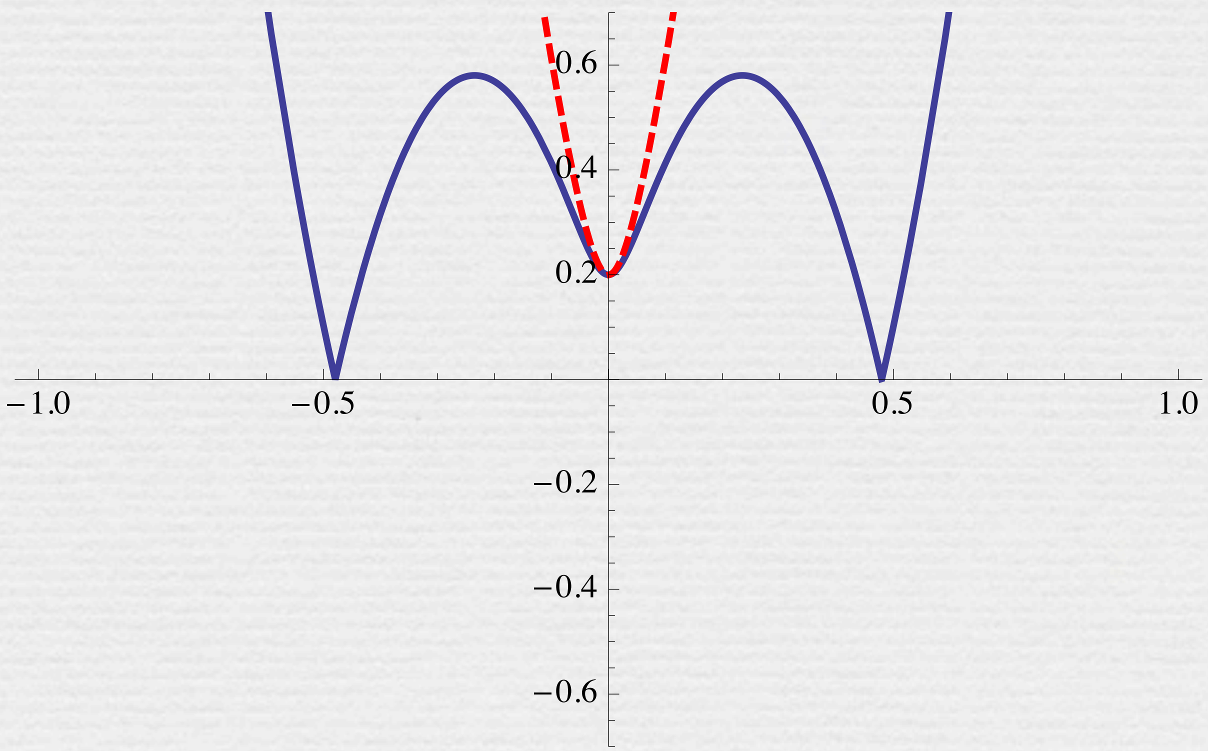
$$H_0 + H_{\rm so} + H_{\rm SC} + H_{\rm Z}$$





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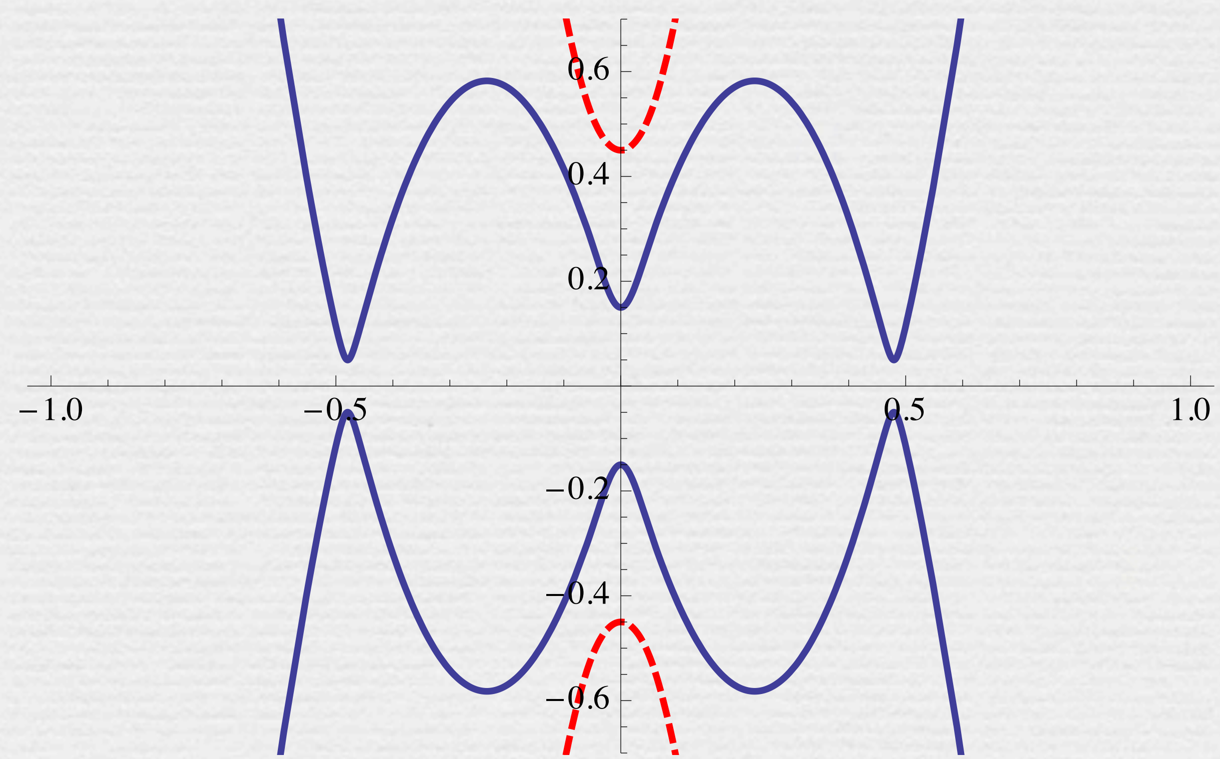

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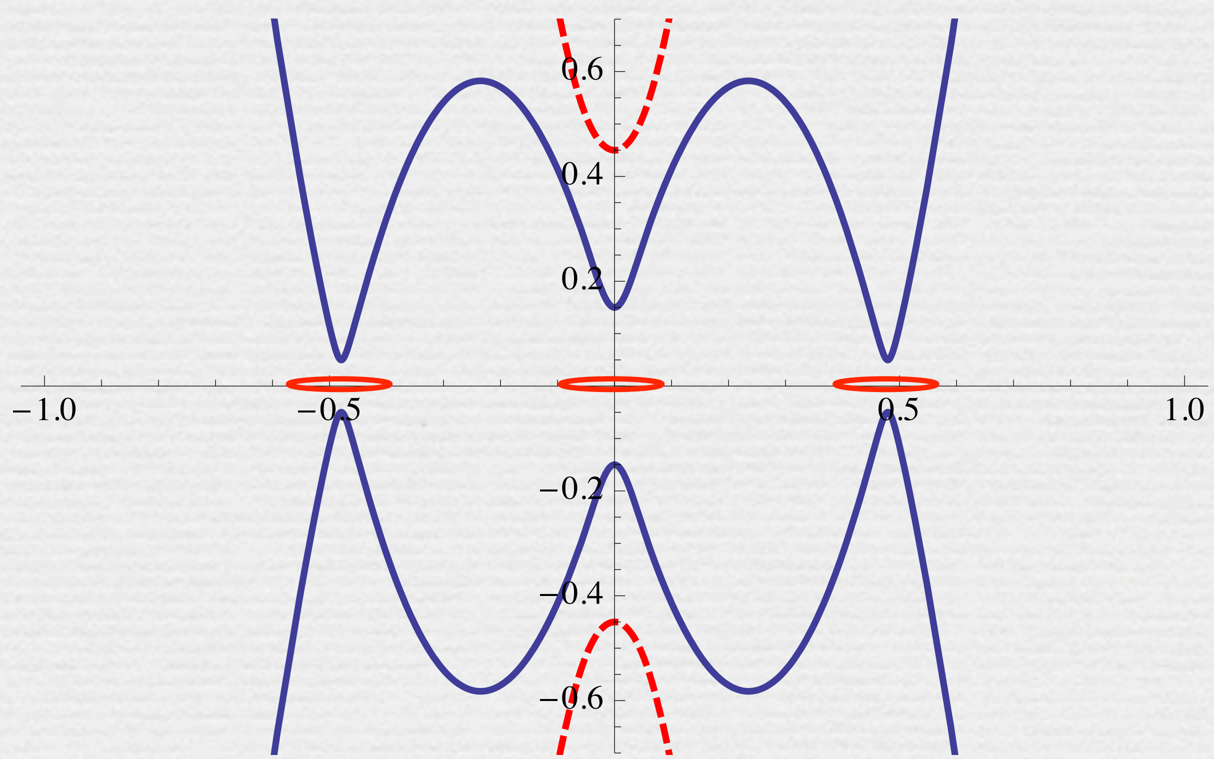

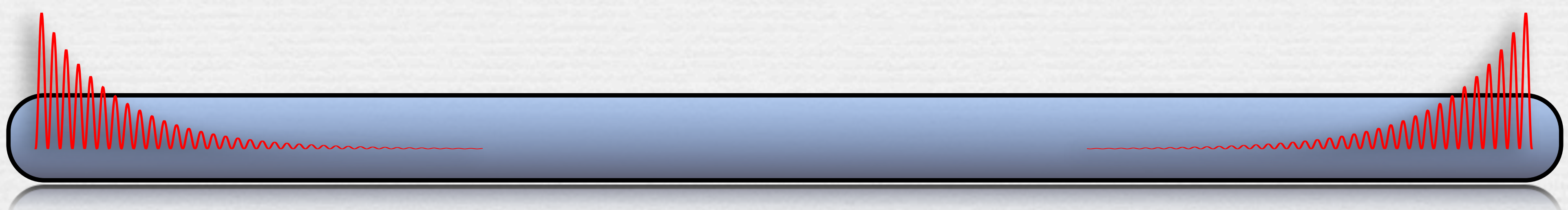

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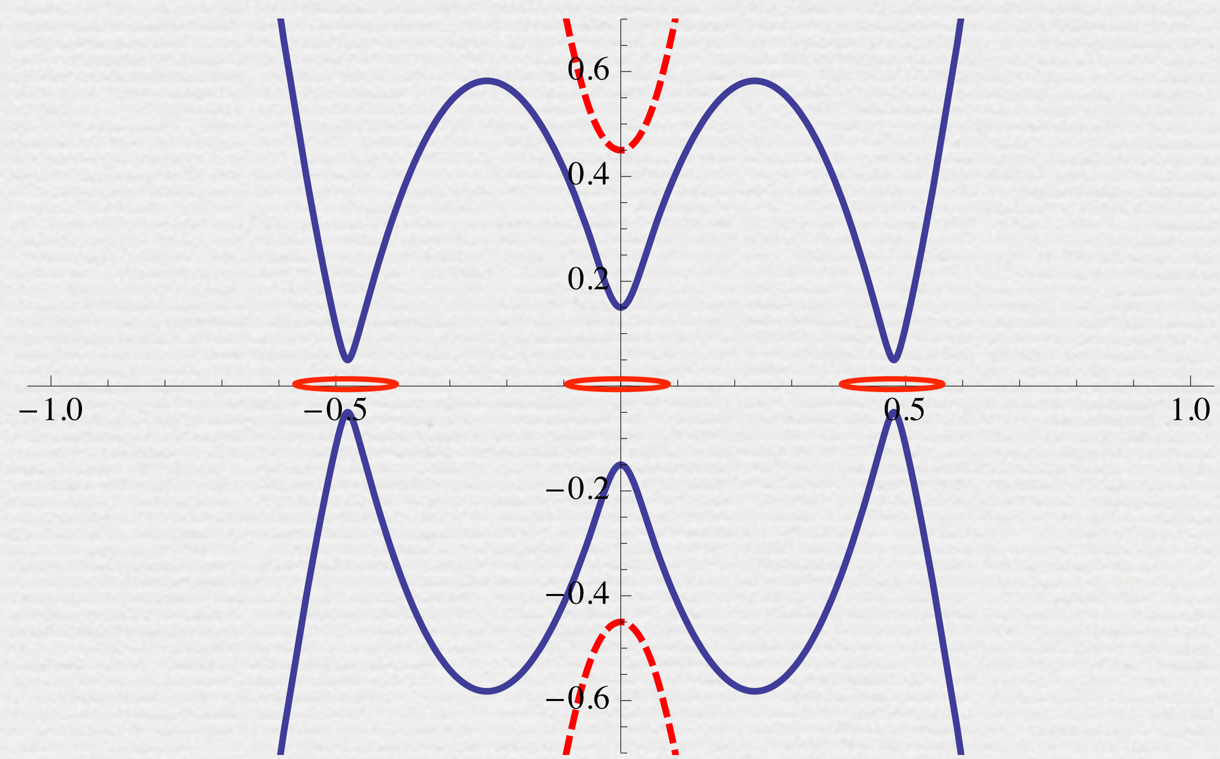

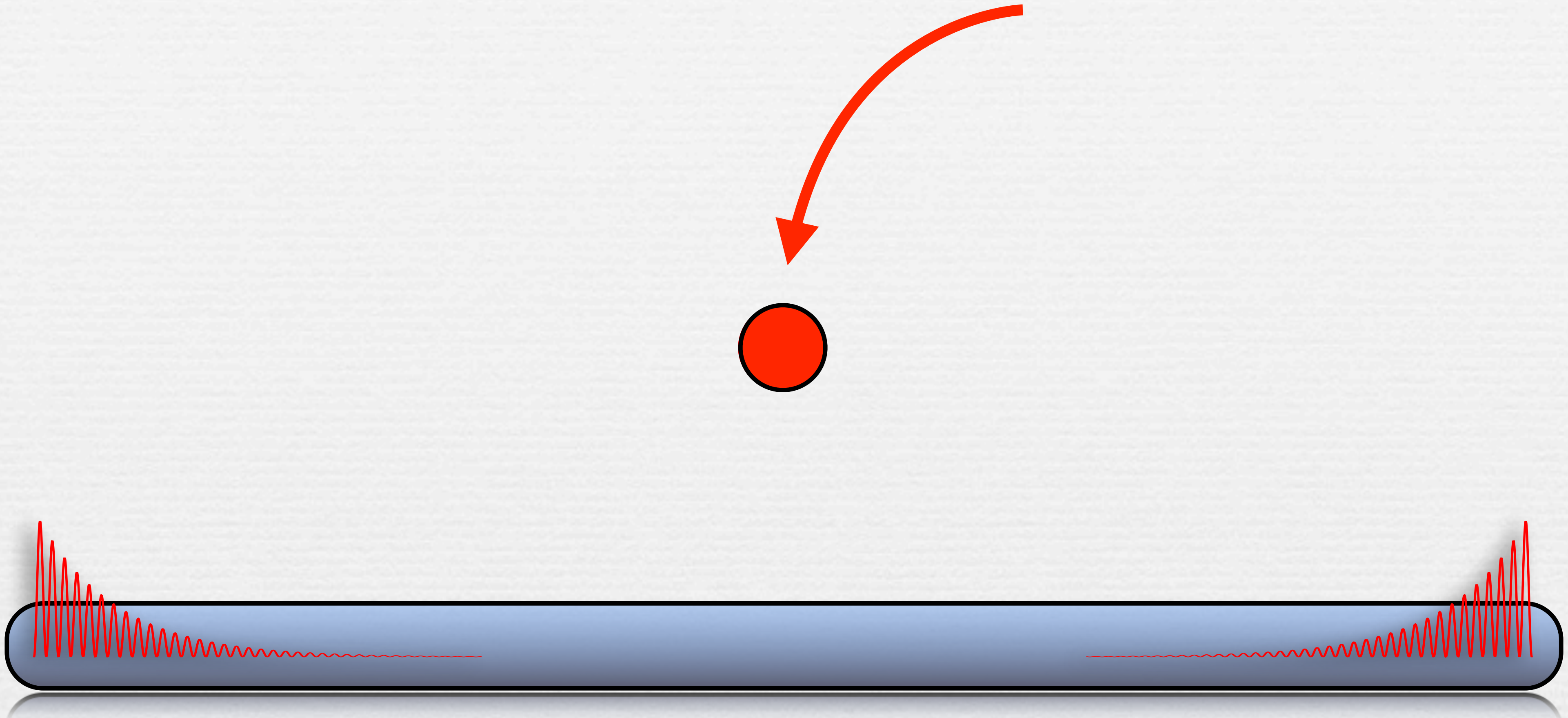

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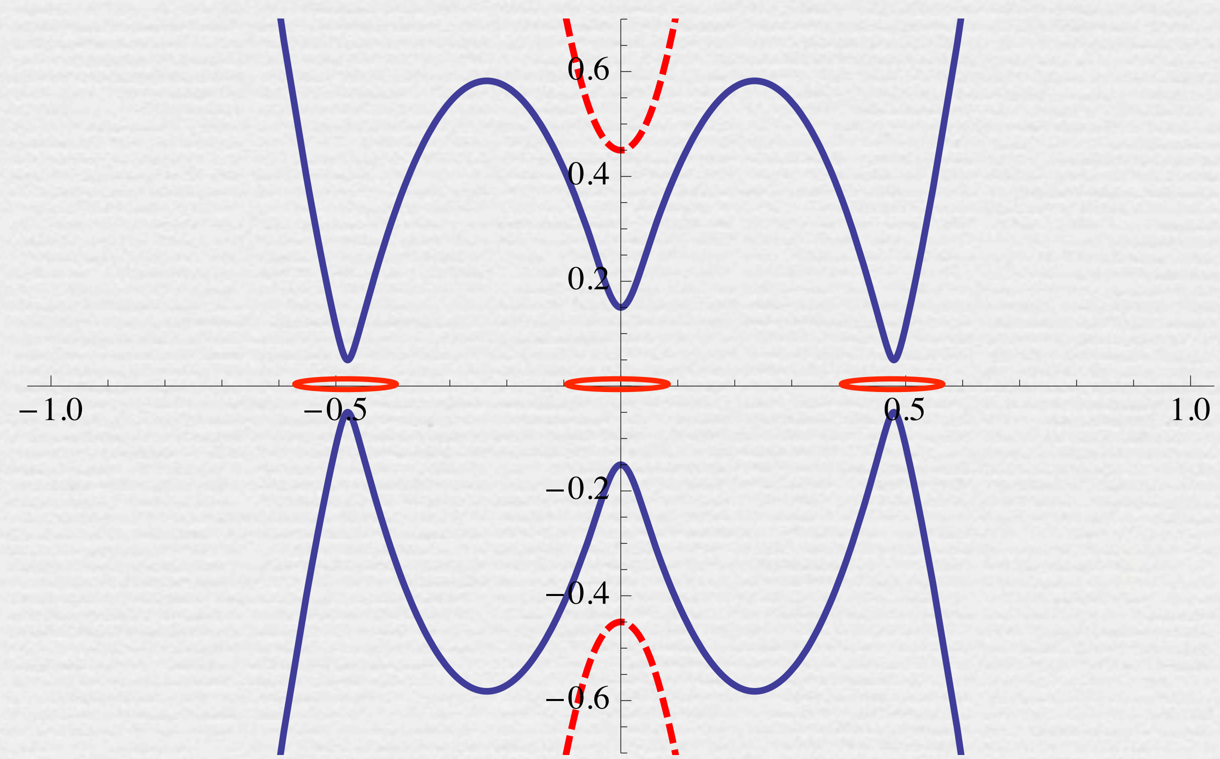

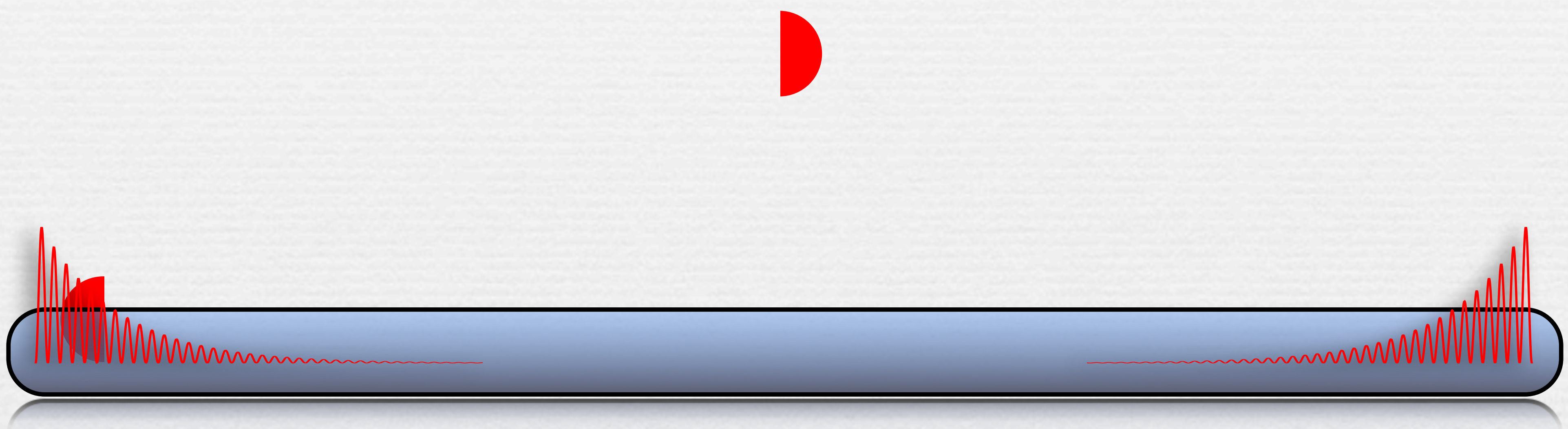

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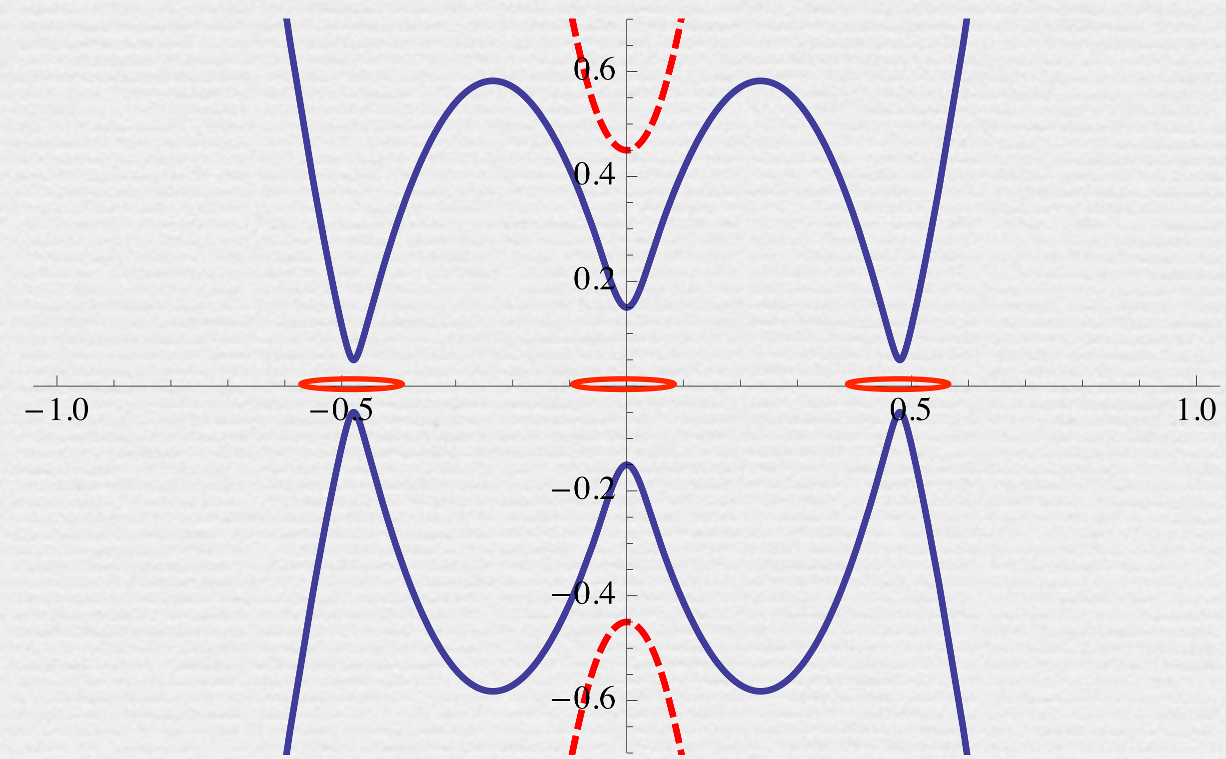

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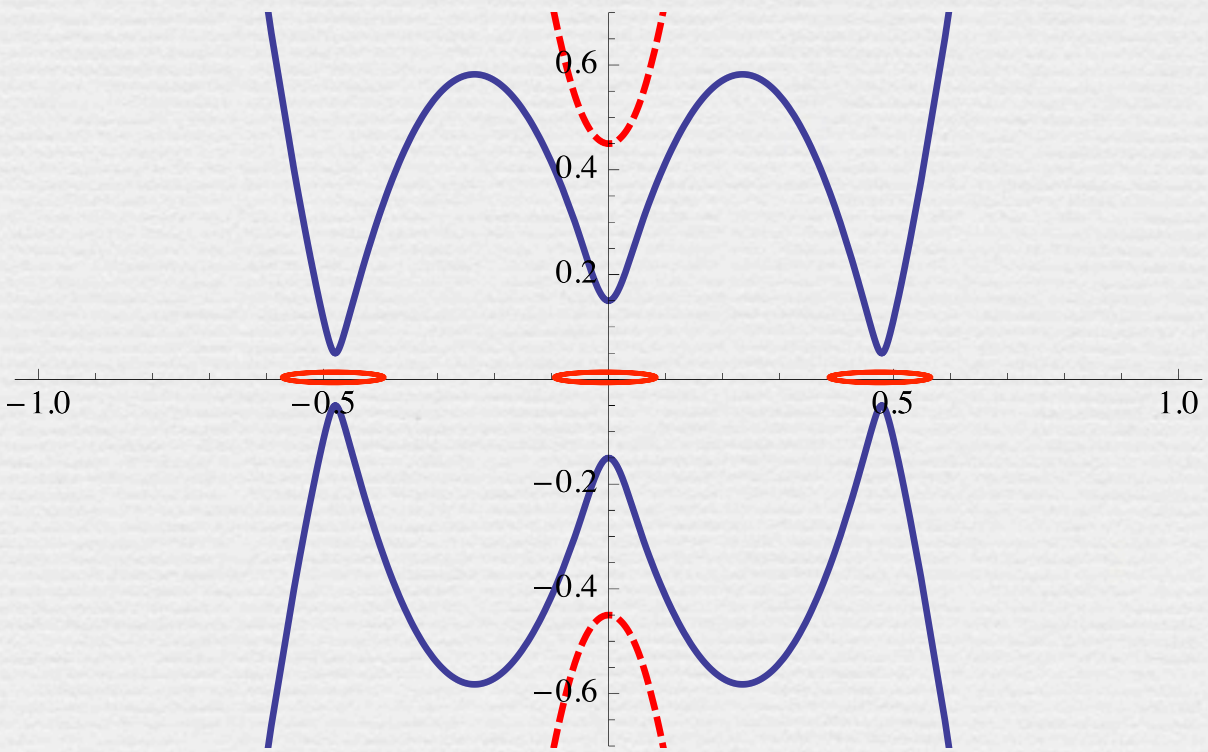
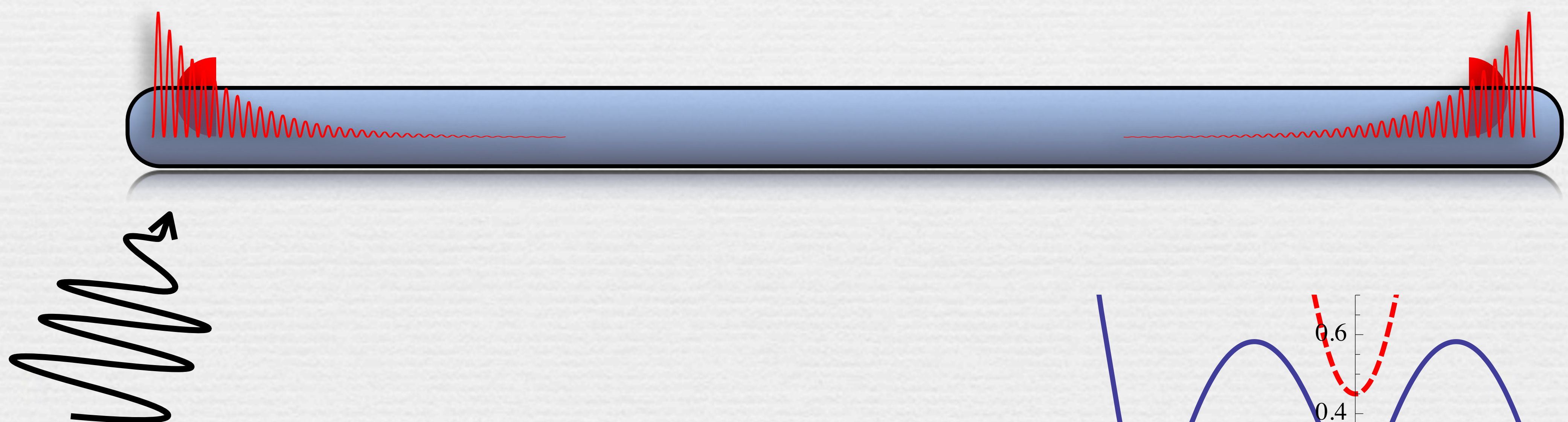
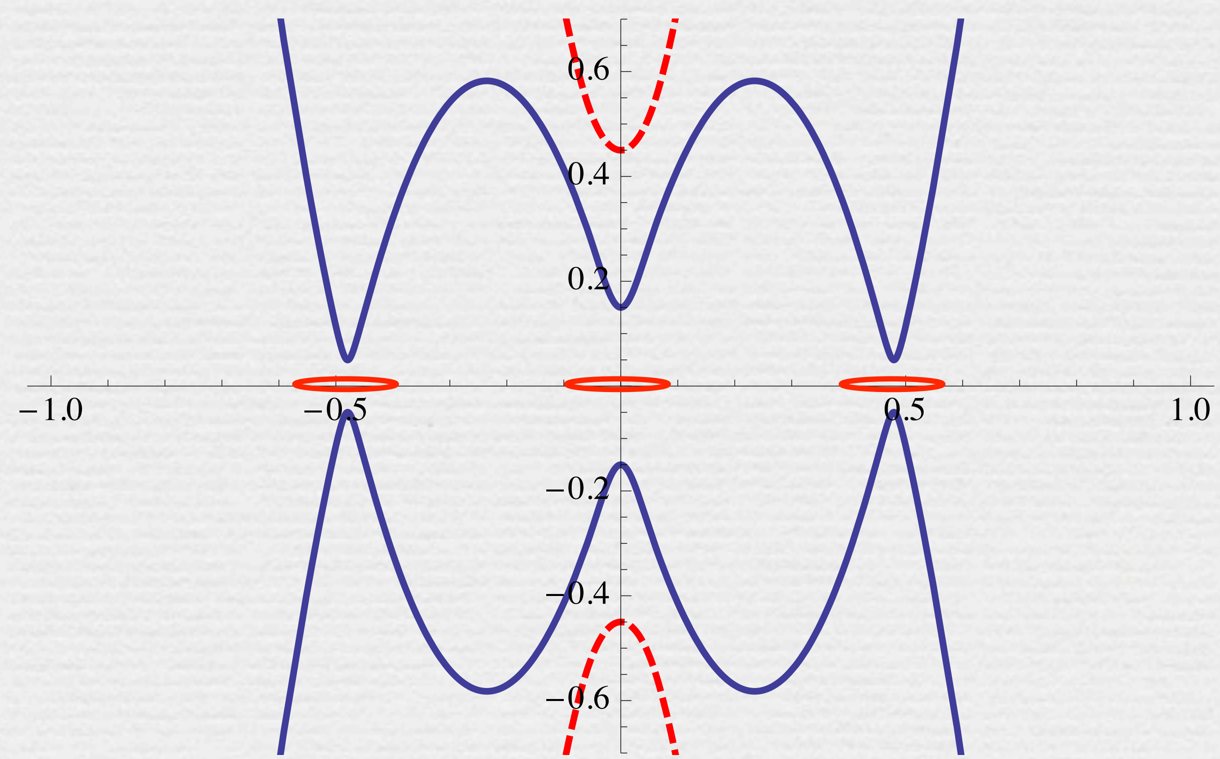
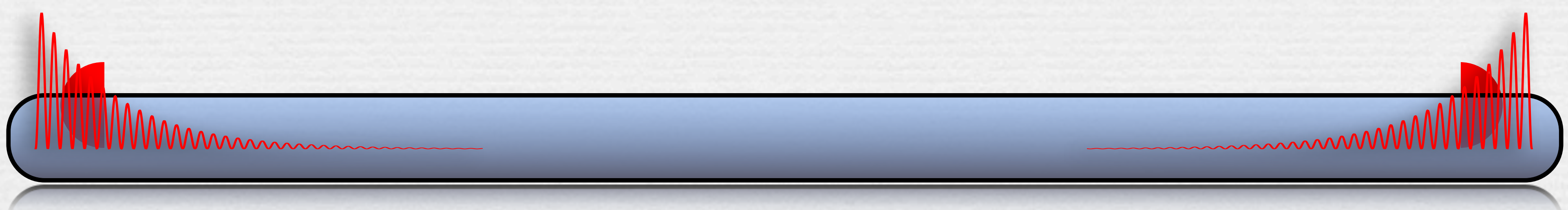




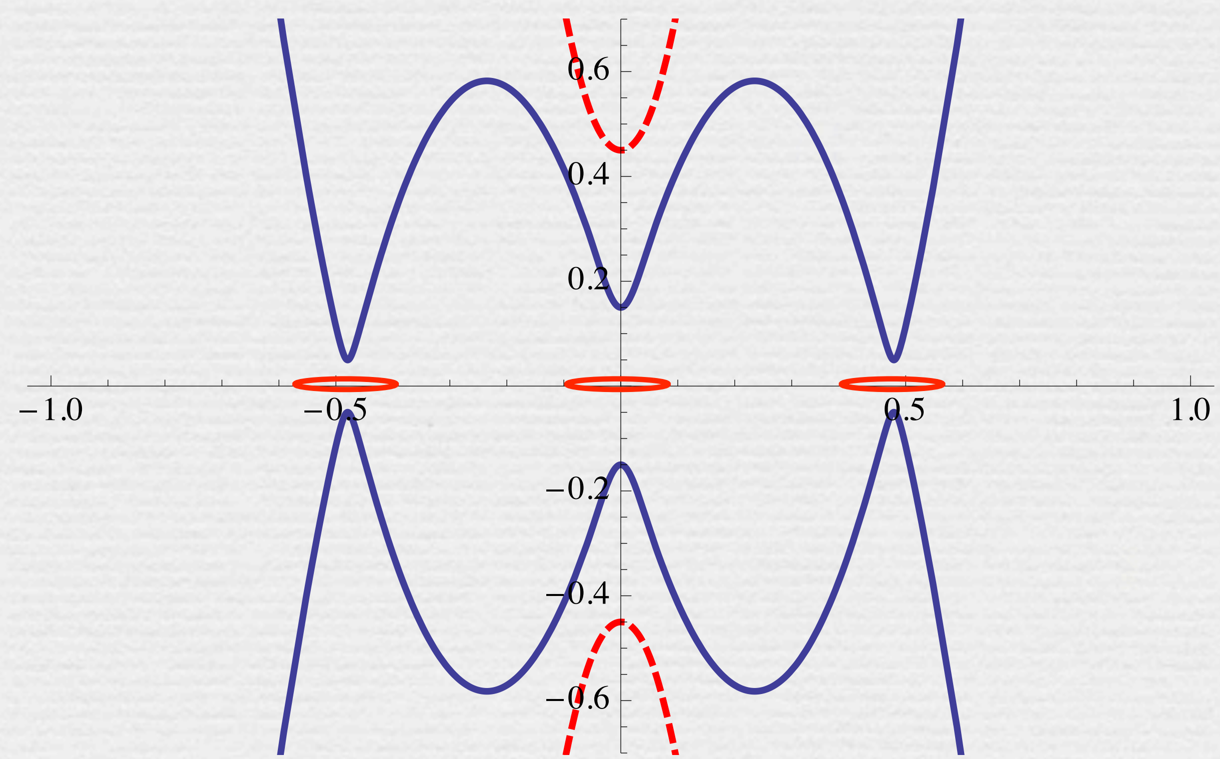
$$H_0 + H_{\rm so} + H_{\rm SC} + H_{\rm Z}$$



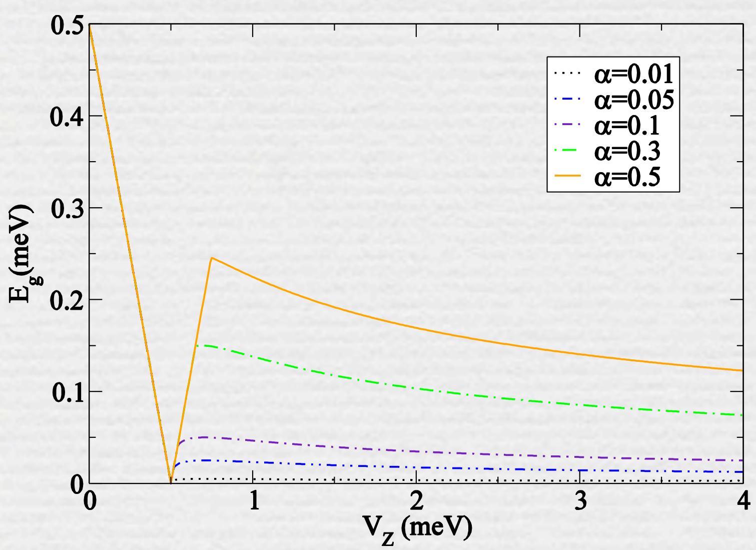
$$V_Z > \sqrt{\mu^2 + \Delta_\star^2}$$



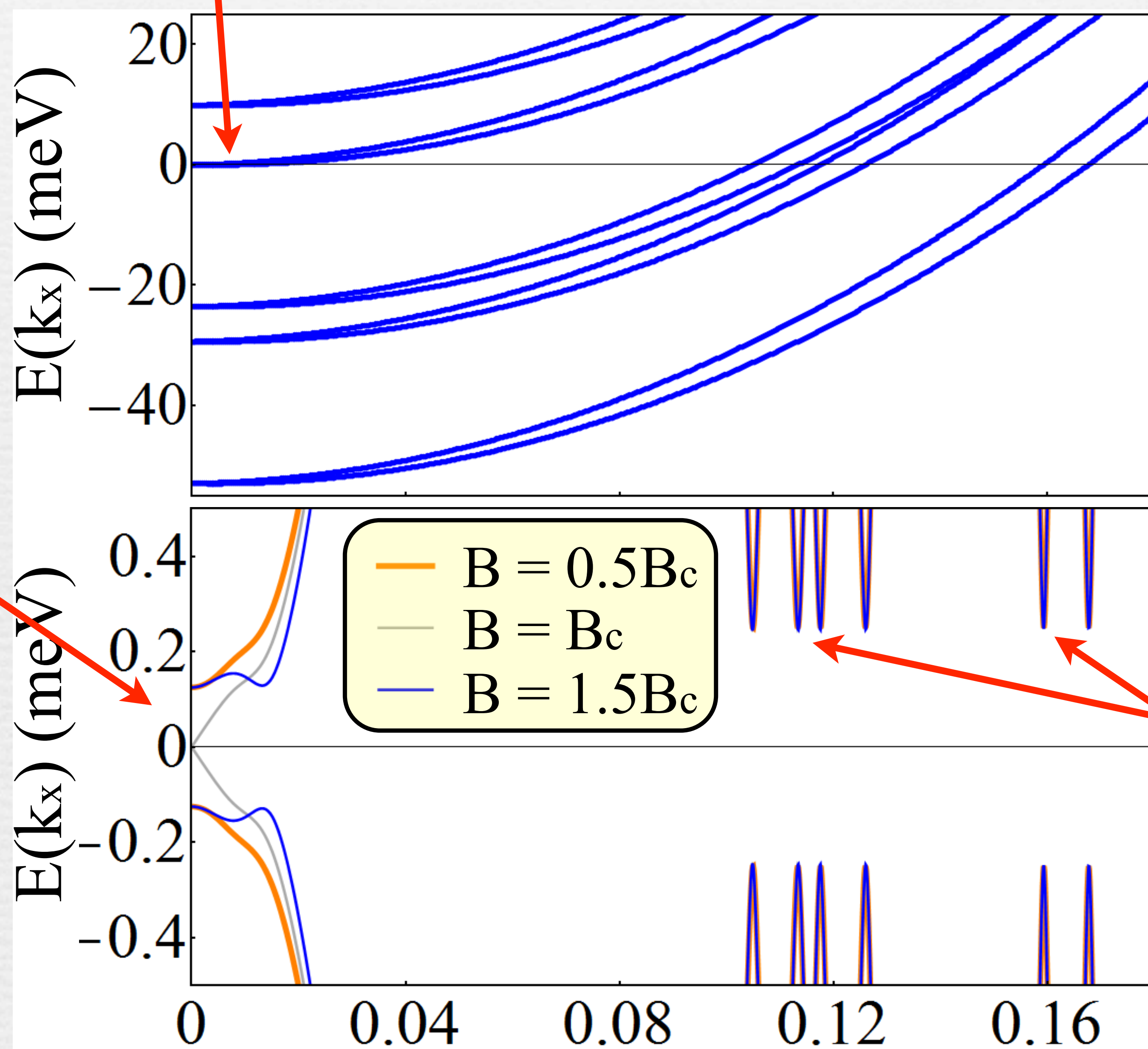
$$H_0 + H_{so} + H_{SC} + H_Z$$



“topological band”



$\Delta_{\mathrm{T}}(B)$

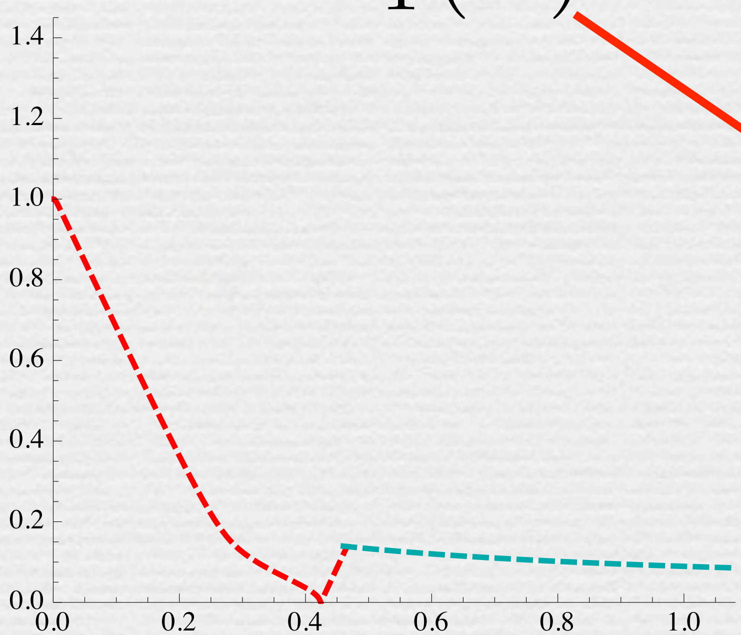


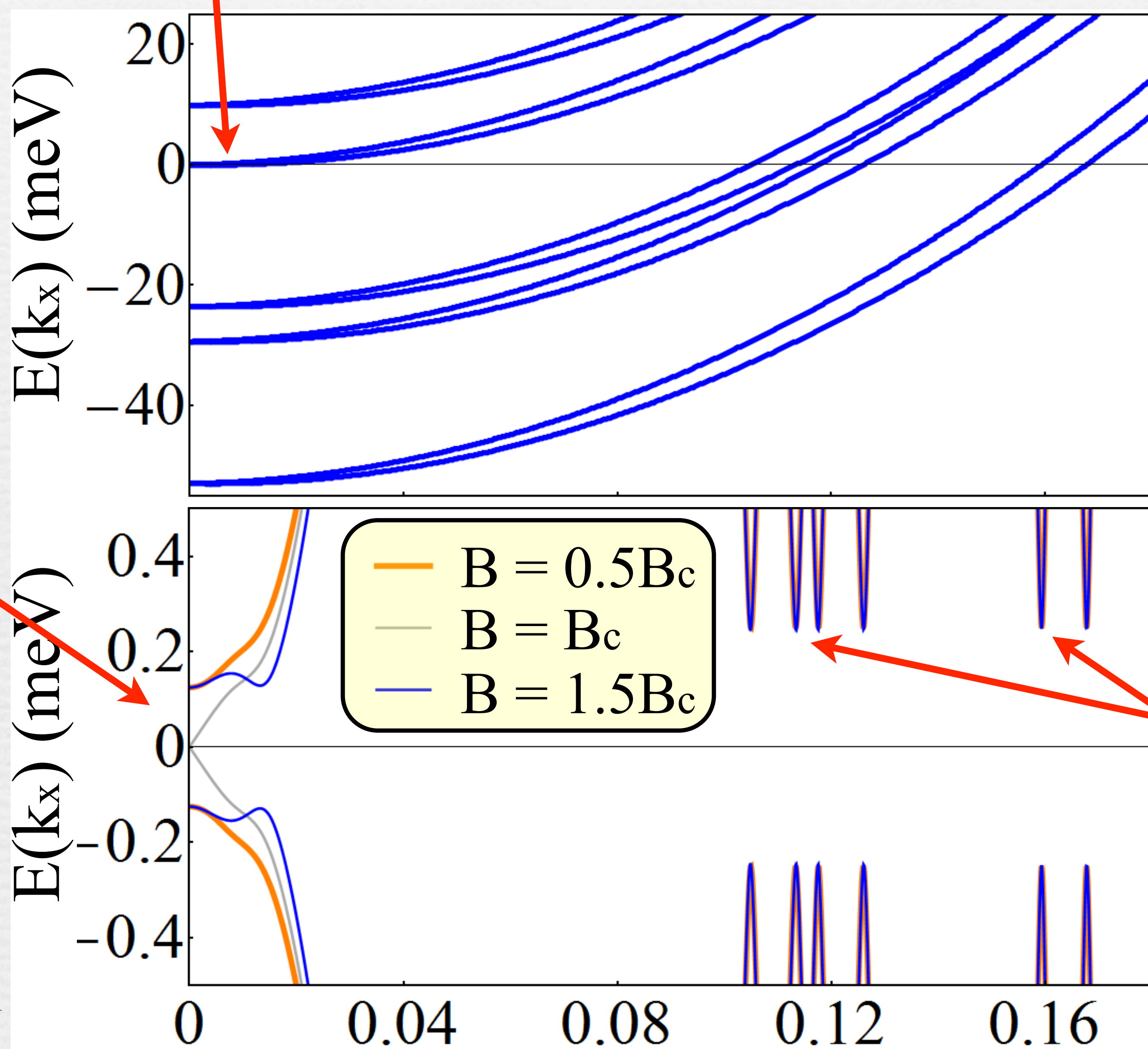
$\Delta_n(B) \simeq \Delta_\star$

T.D. Stanescu, S. Tewari, J.D. Sau, and S. Das Sarma, arXiv:1206.0013

“topological band”

$\Delta_{\mathrm{T}}(B)$





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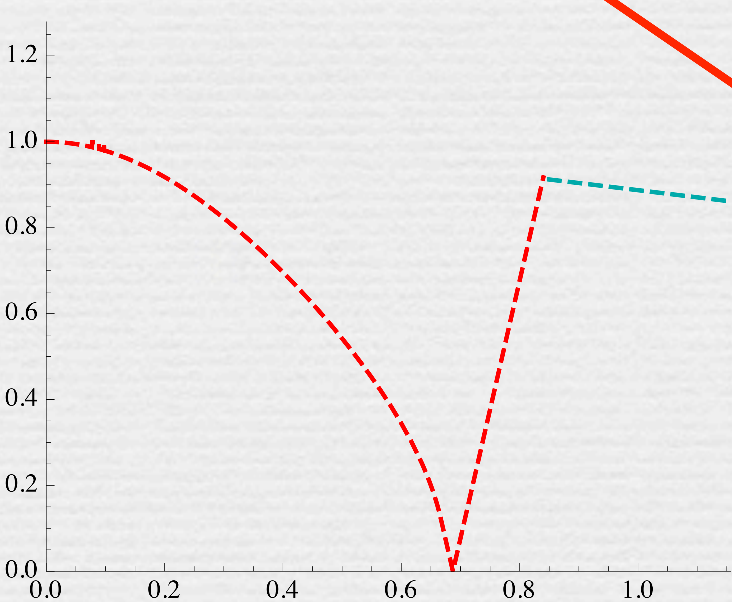

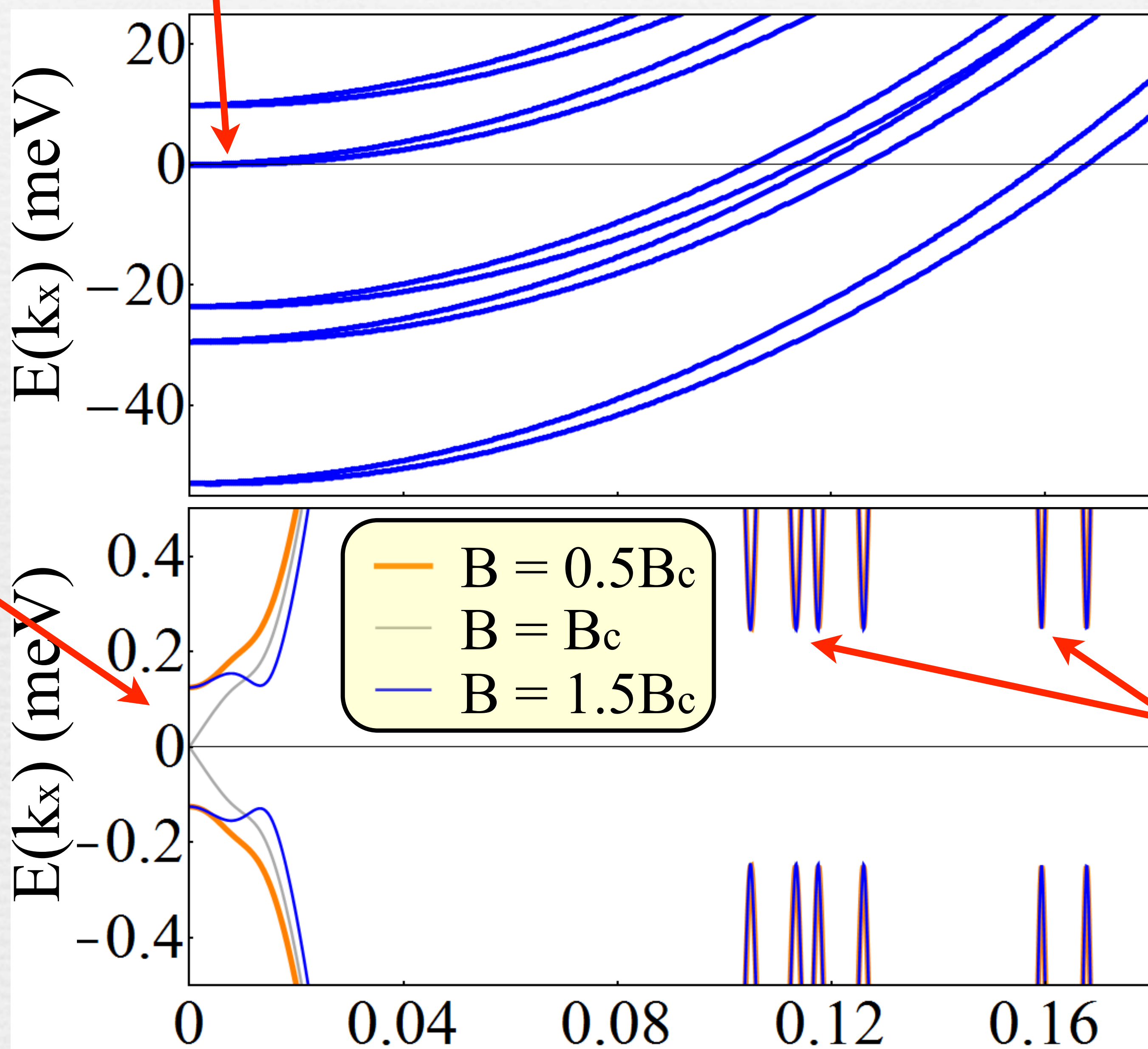

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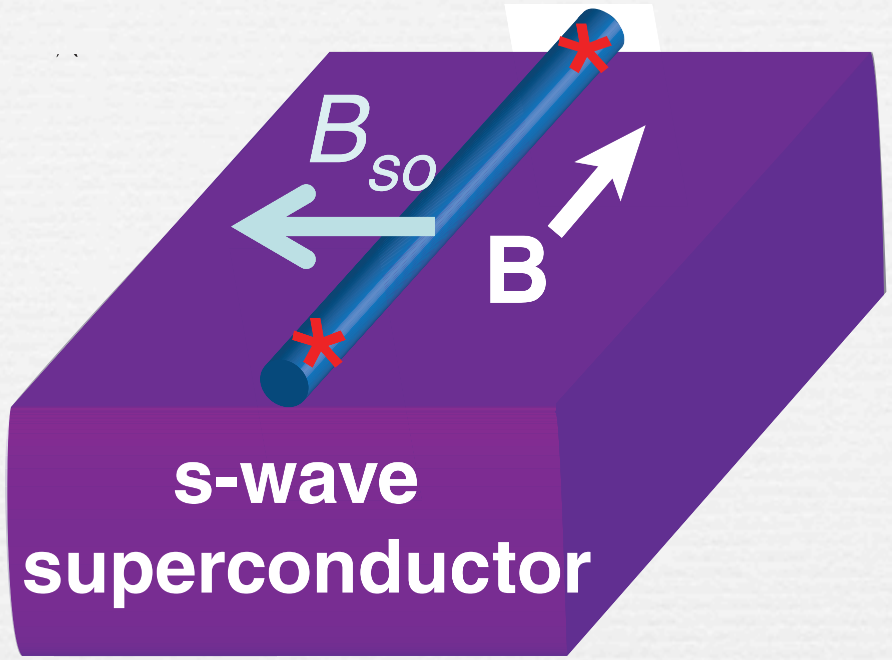
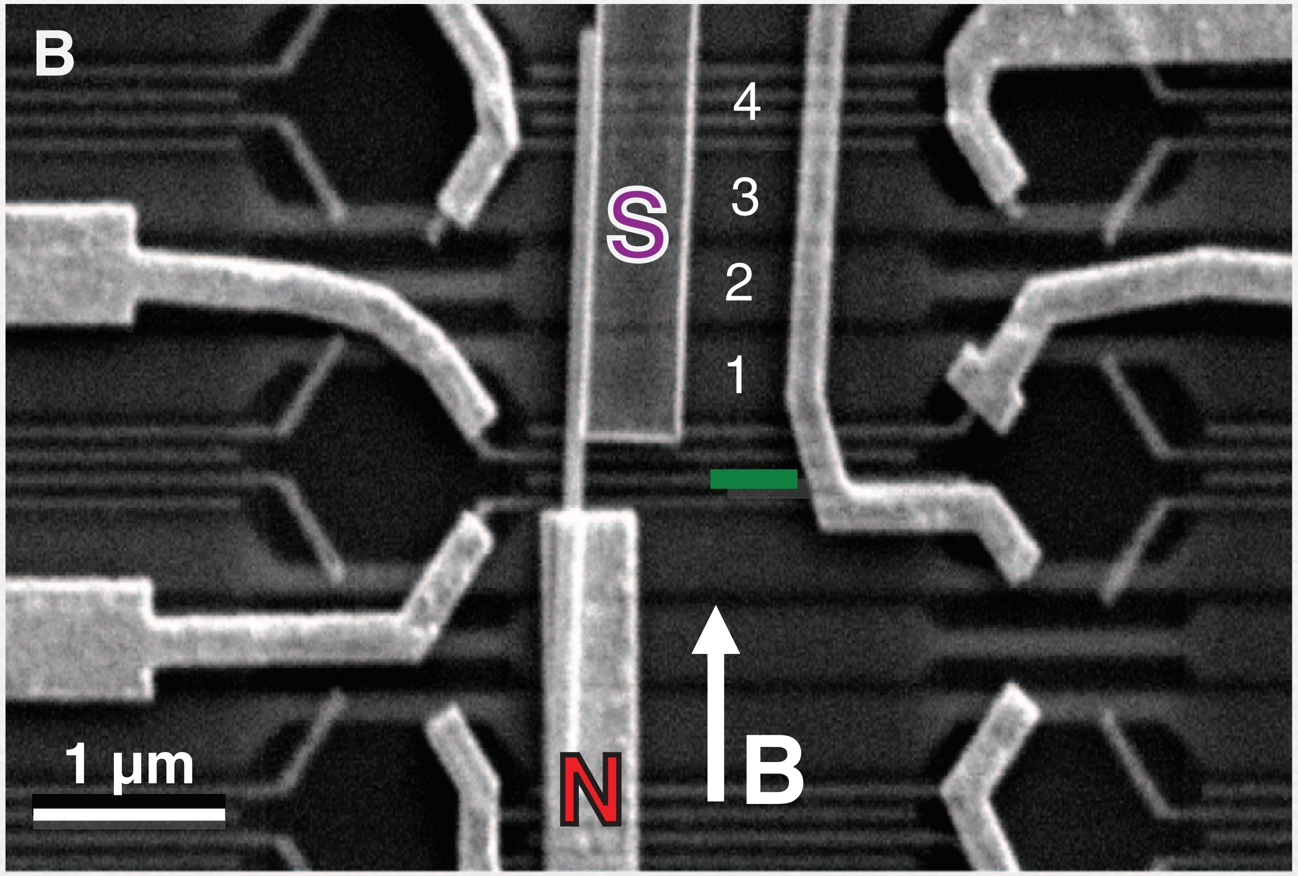
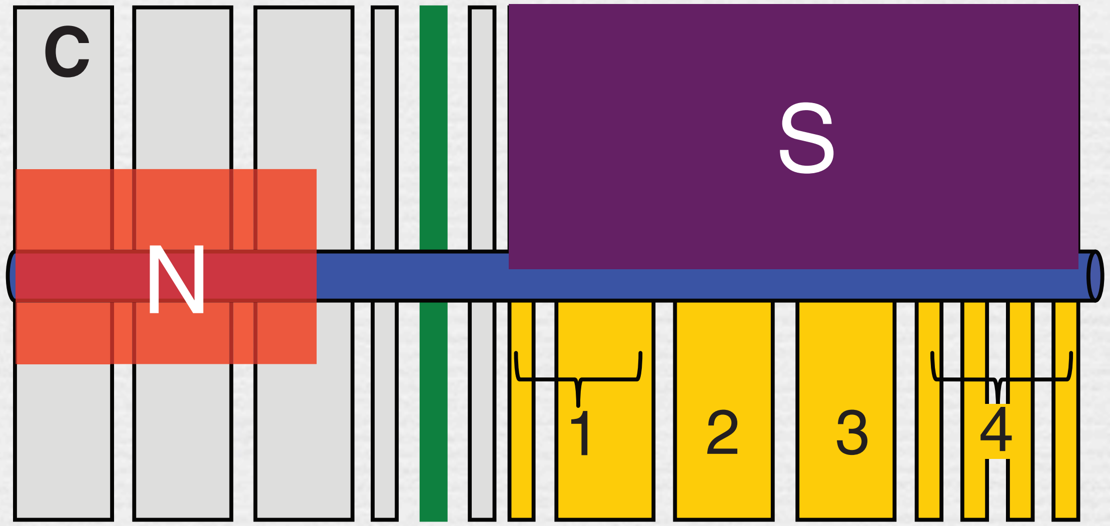
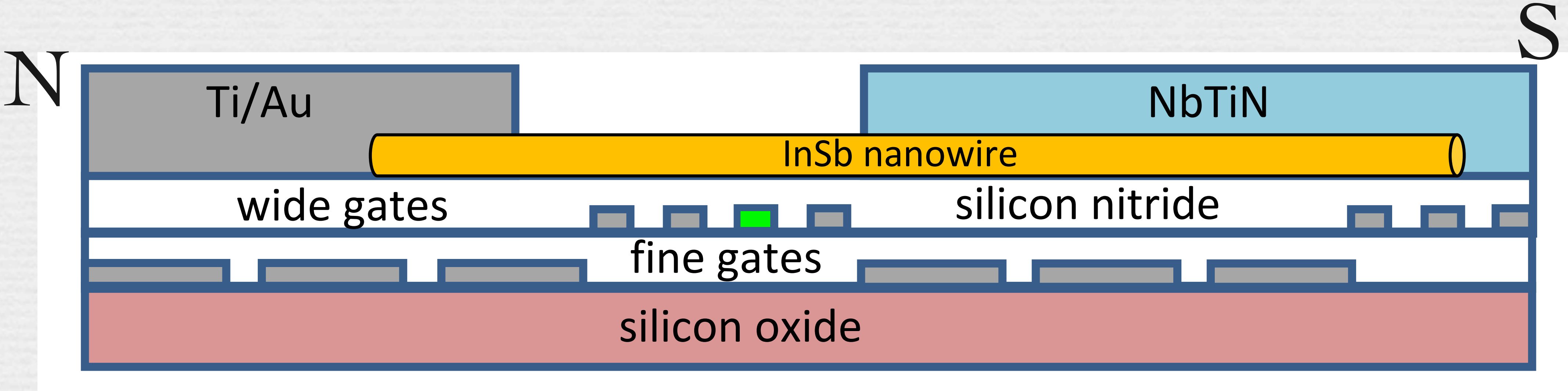
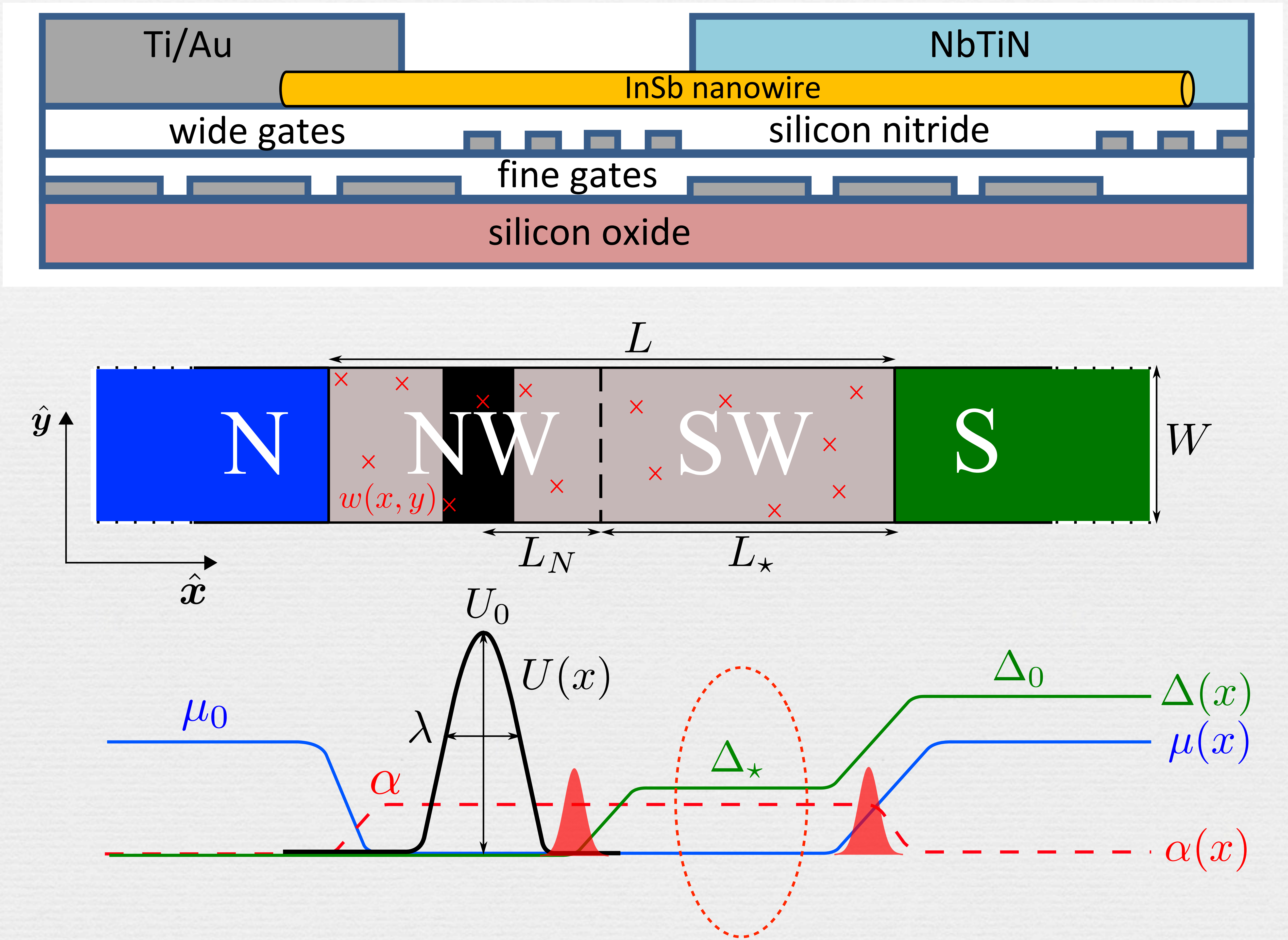




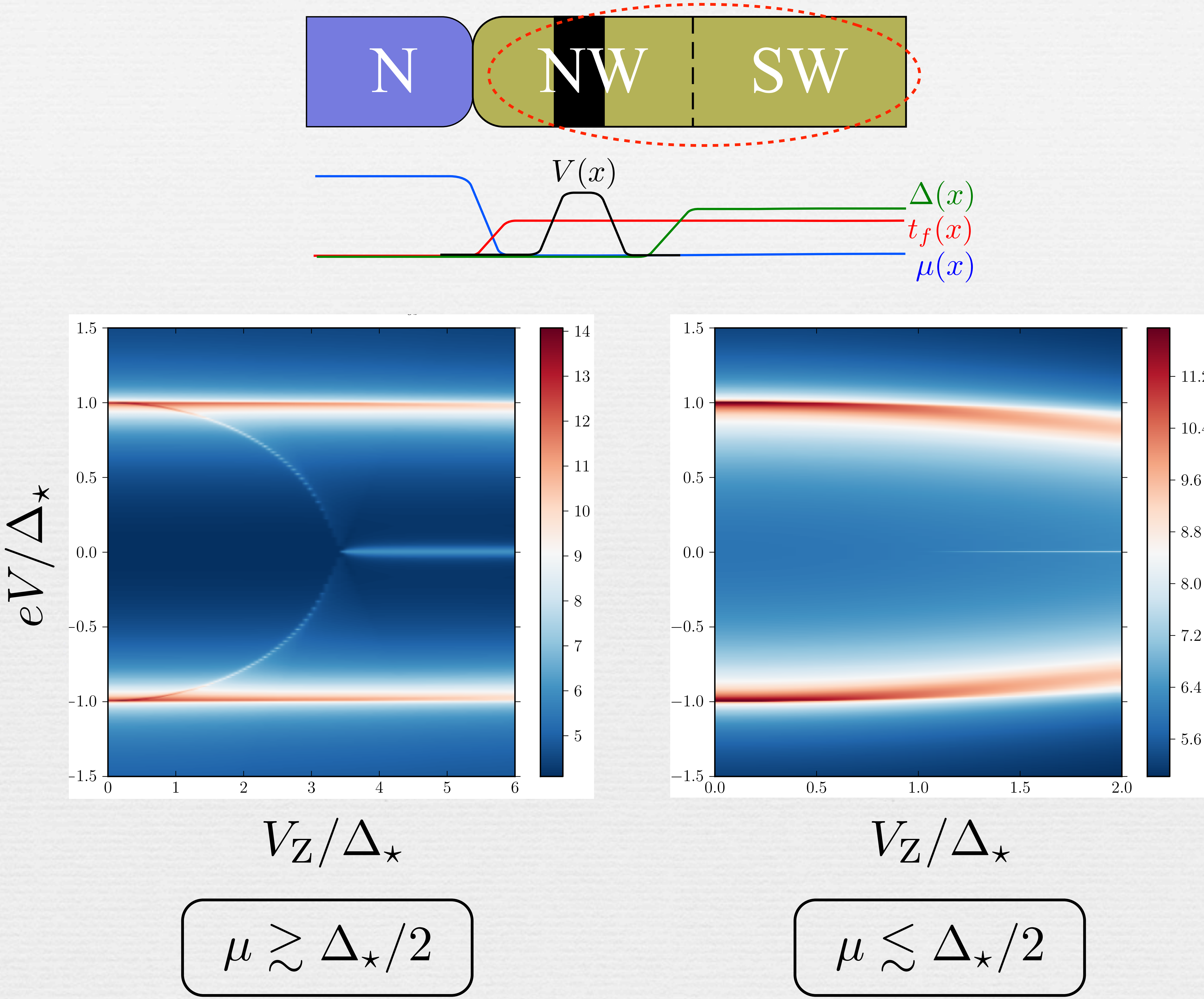


V. Mourik, K. Zuo, S.M. Frolov, S.R. Plissard,
E.P.A.M. Bakkers, L.P. Kouwenhoven,
Science **336,** 1003 (2012)





Ti/Au
NbTiN
InSb nanowire
wide gates
silicon nitride
fine gates
silicon oxide
L
$\hat{y}$
N
NW
SW
S
W
$w(x,y)$
L_N
$L_\star$
$\hat{x}$
U_0
$U(x)$
λ
μ_0
α
Δ_0
$\Delta(x)$
$\mu(x)$
$\Delta_\star$
$\alpha(x)$



N
NW
SW
$V(x)$
$\Delta(x)$
$t_f(x)$
$\mu(x)$
$eV/\Delta_\star$
$V_Z/\Delta_\star$
$V_Z/\Delta_\star$
$\mu \gtrsim \Delta_\star/2$
$\mu \lesssim \Delta_\star/2$

To close or not to close: the fate of the superconducting gap across the topological quantum phase transition in Majorana-carrying semiconductor nanowires

Tudor D. Stanescu[1], Sumanta Tewari[2], Jay D. Sau[3], and S. Das Sarma[4]

[1]*Department of Physics, West Virginia University, Morgantown, WV 26506*

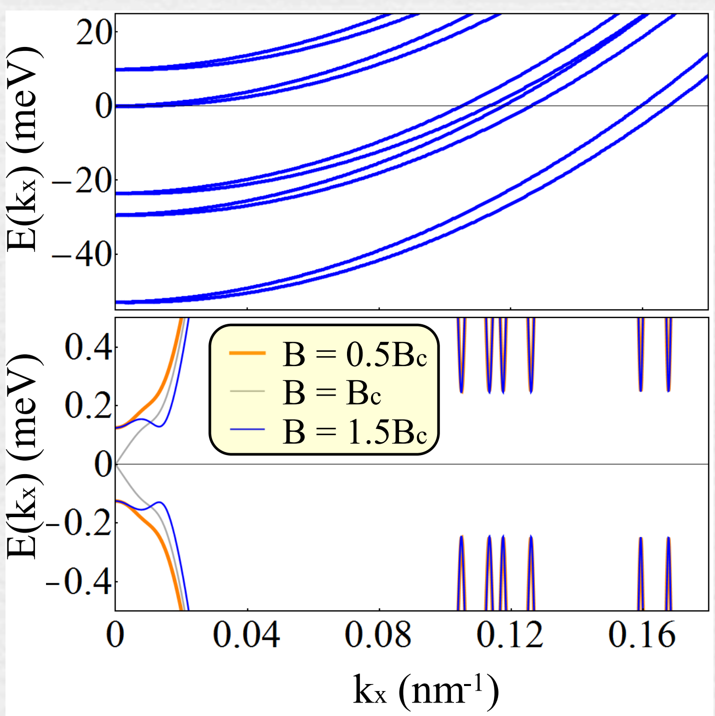
[2]*Department of Physics and Astronomy, Clemson University, Clemson, SC 29634*

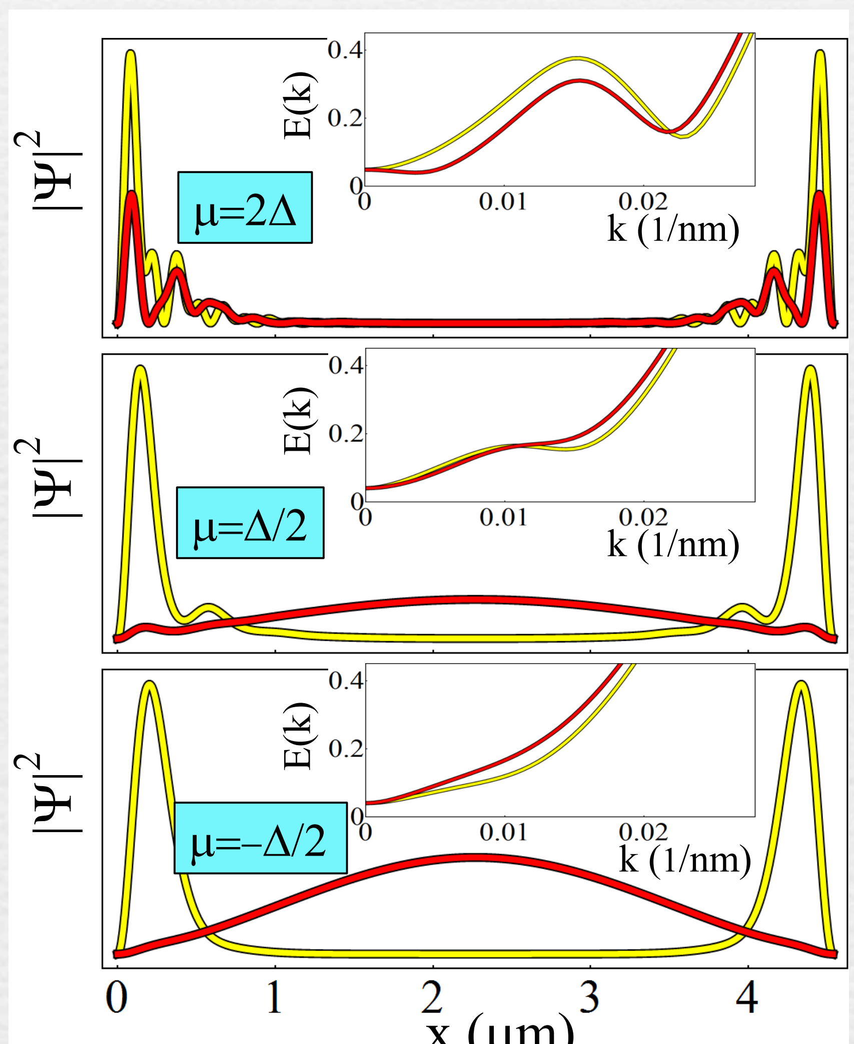
[3] *Department of Physics, Harvard University, Cambridge, MA 02138*

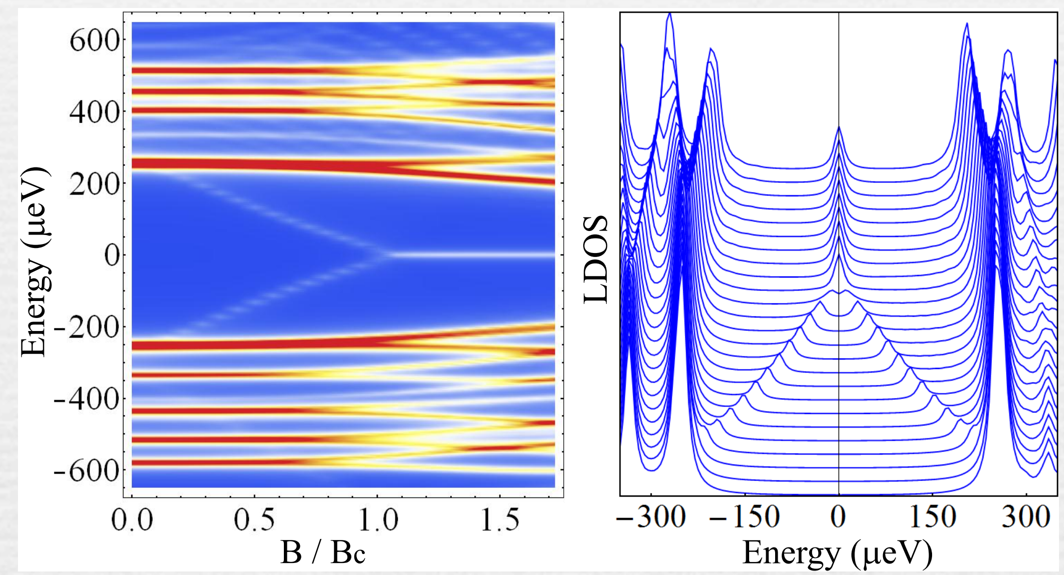
[4]*Condensed Matter Theory Center and Joint Quantum Institute, Department of Physics, University of Maryland, College Park, Maryland, 20742-4111, USA*

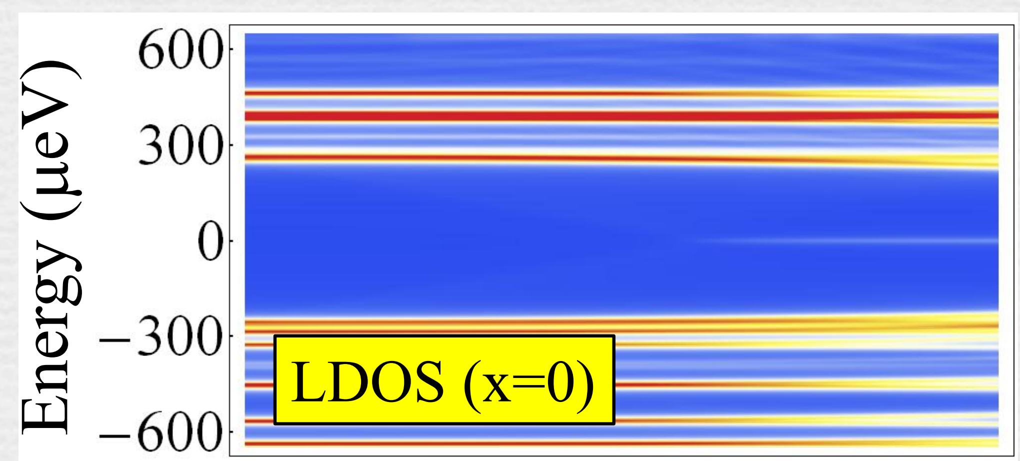
arXiv:1206.0013

$$\frac{dI}{dV} \propto \mathrm{LDOS}(x=0)$$









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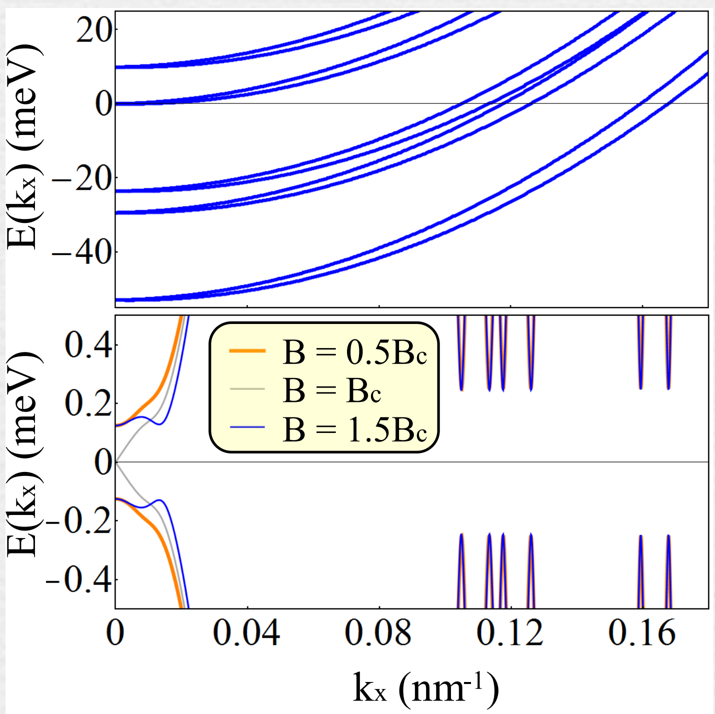
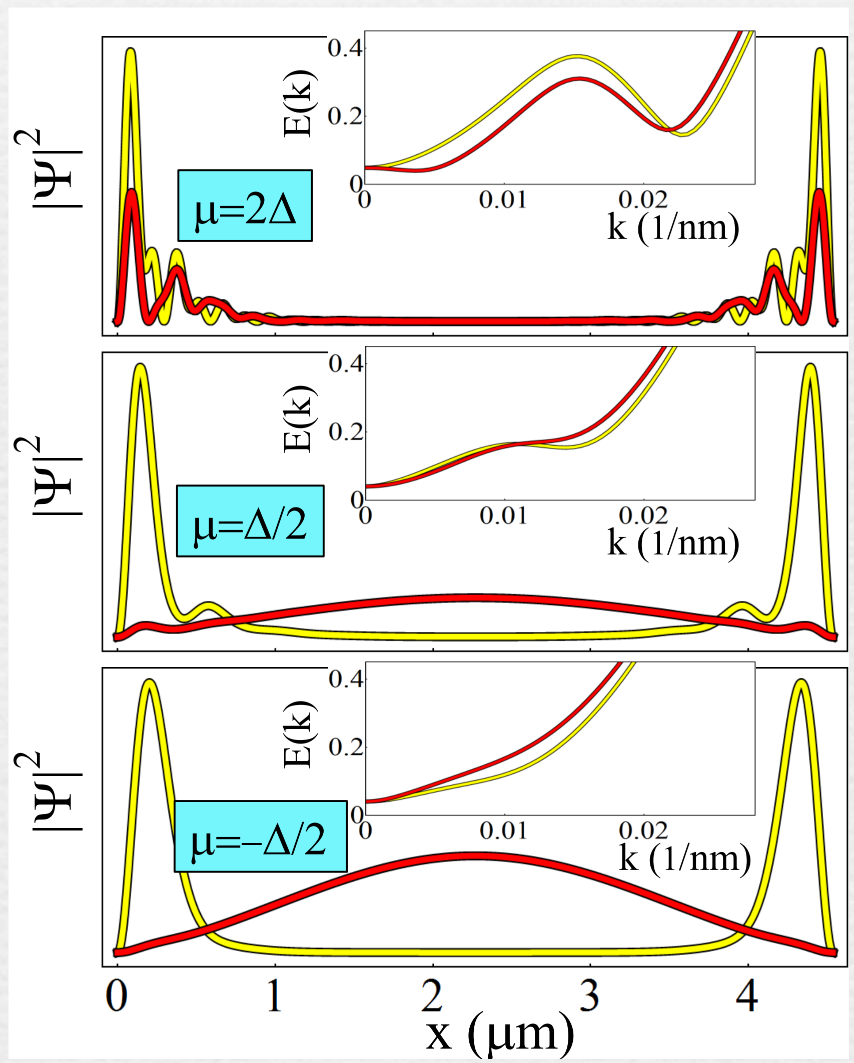
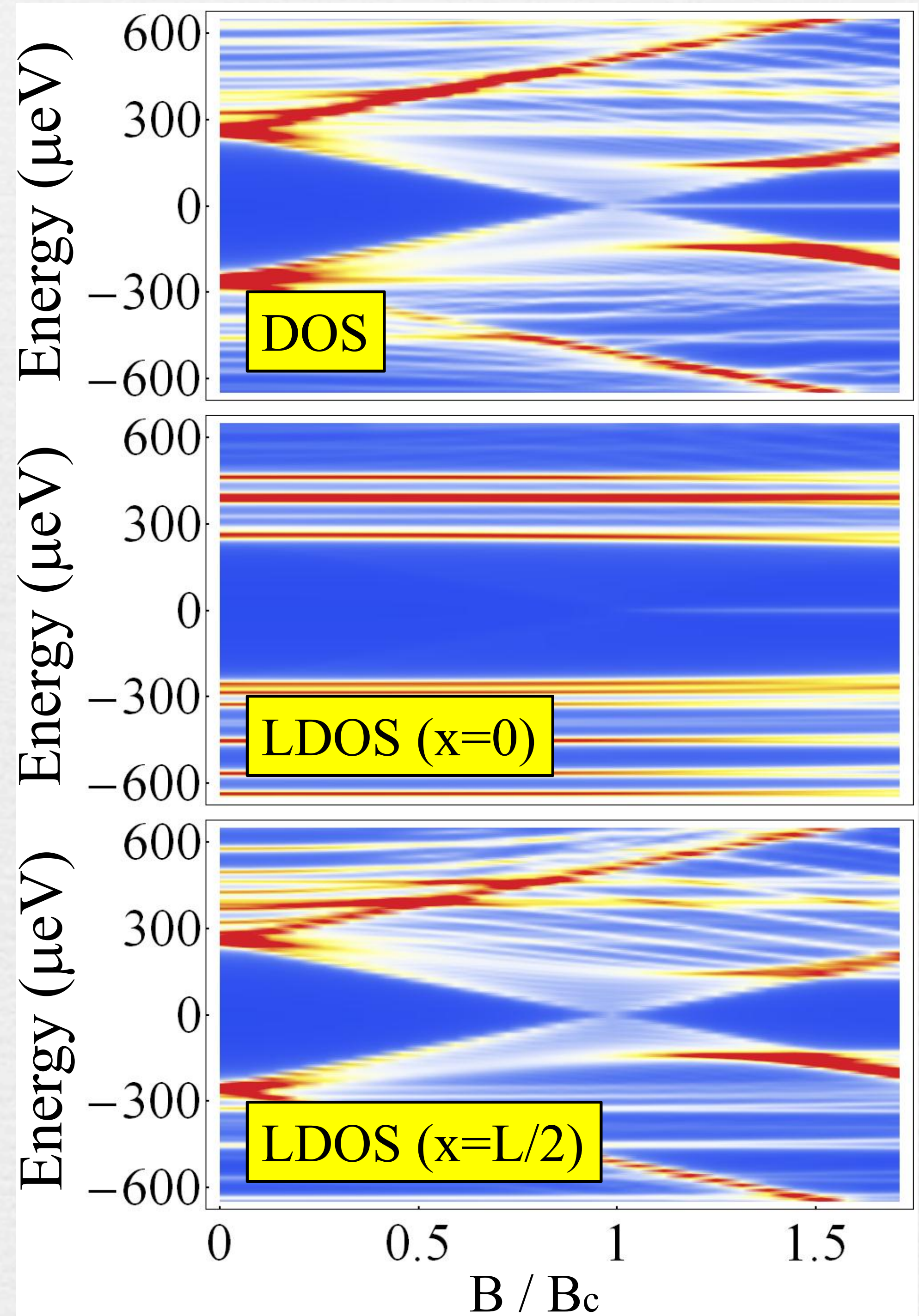
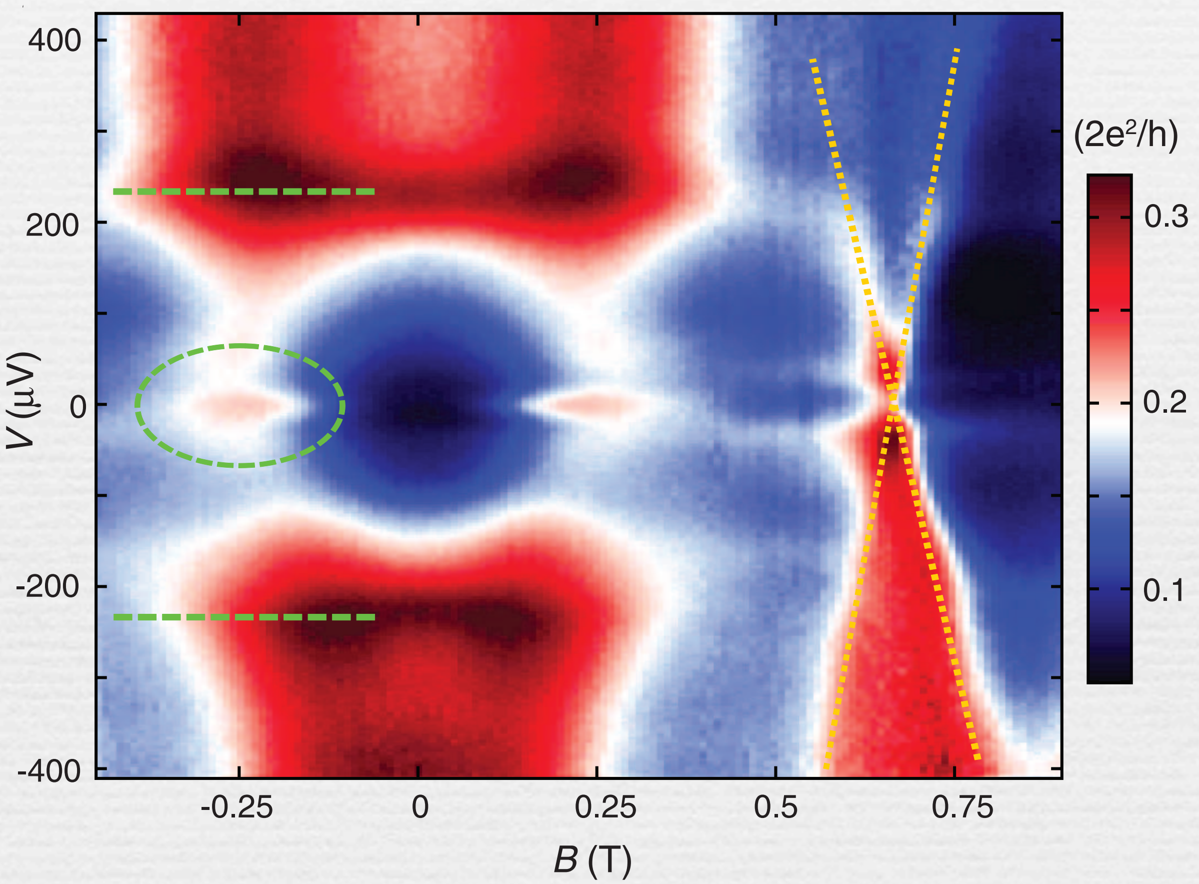
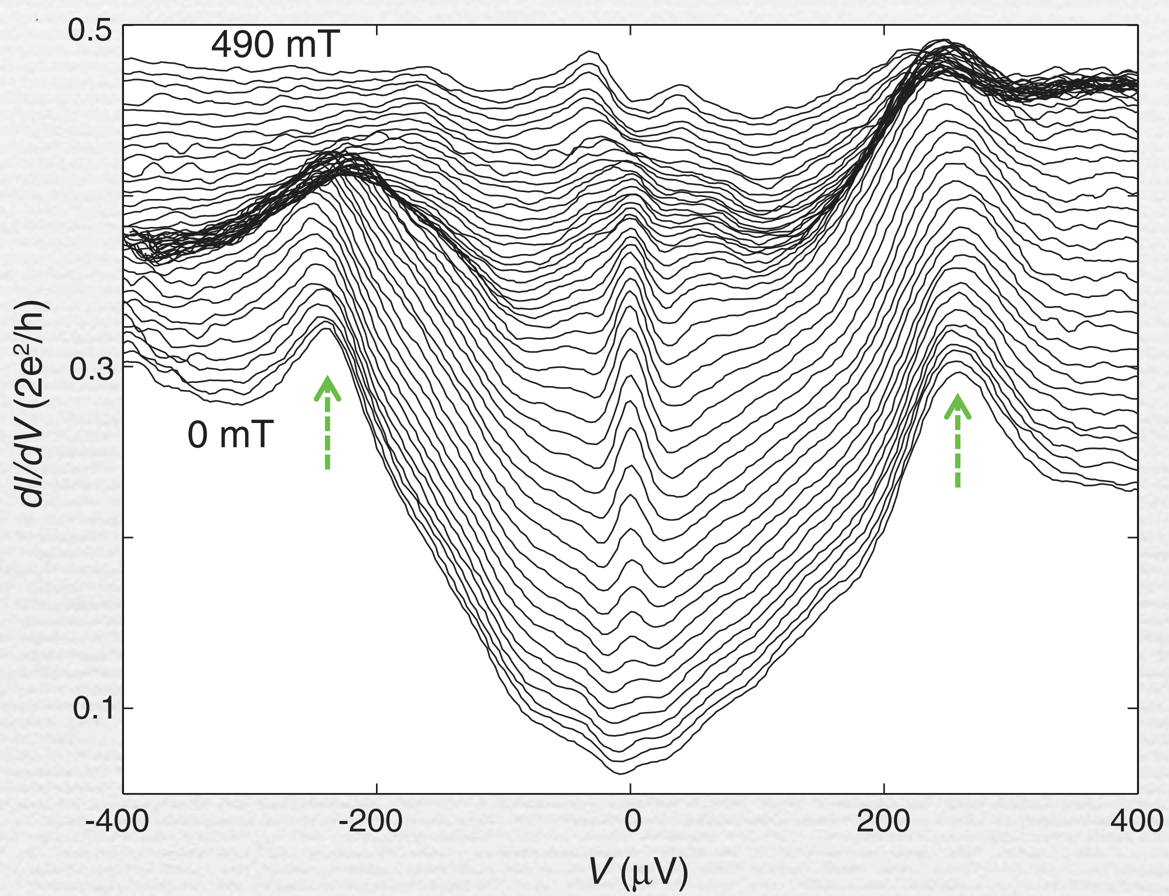






What is observed in the experiment?

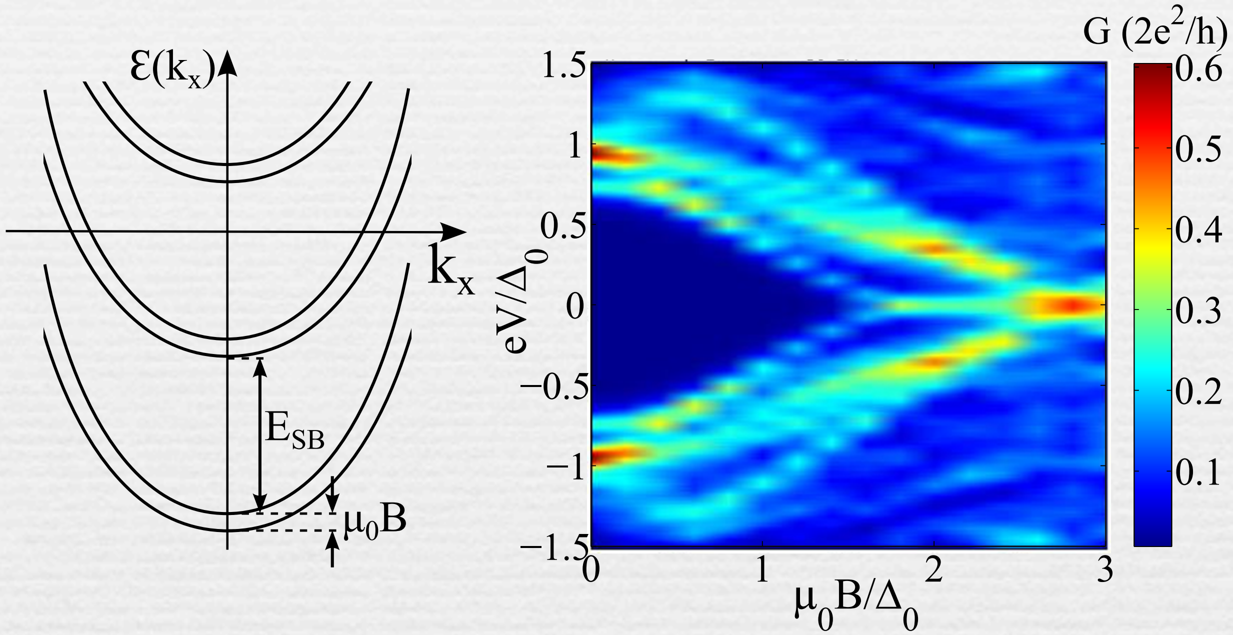


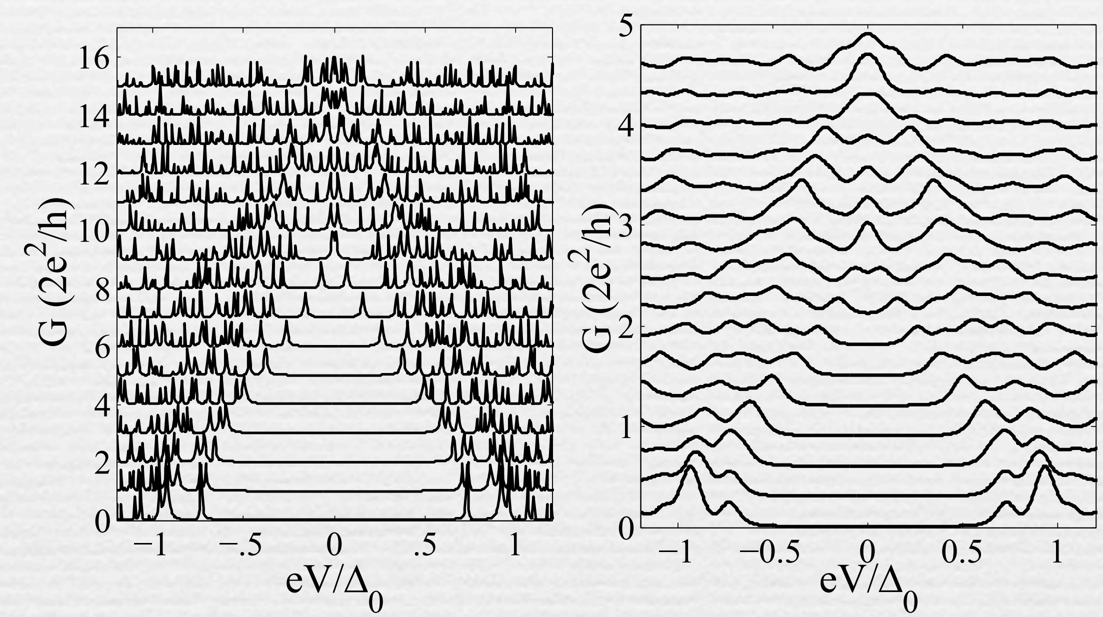


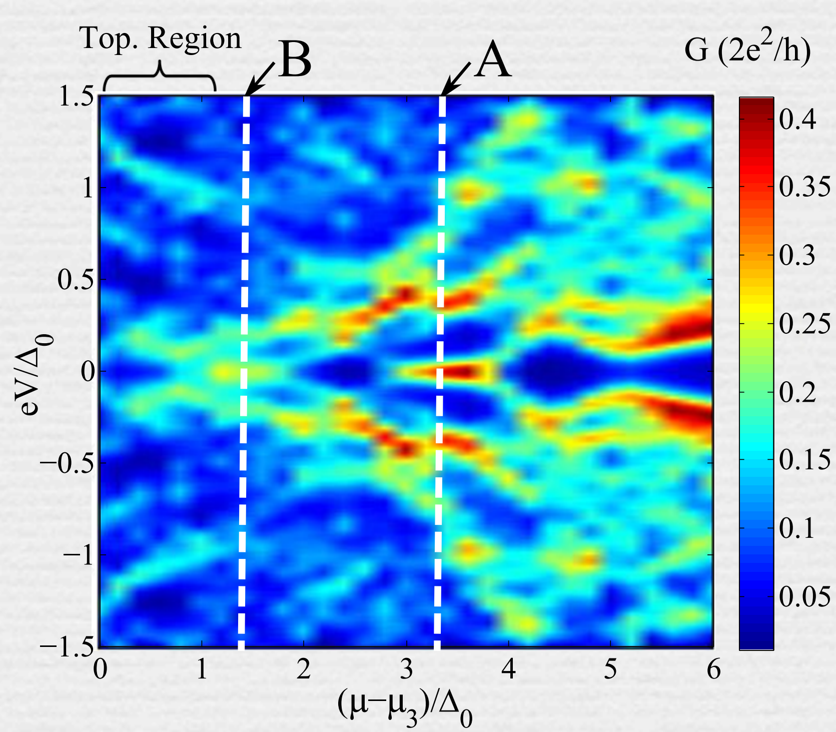
Zero-bias peaks in spin-orbit coupled superconducting wires with and without Majorana end-states

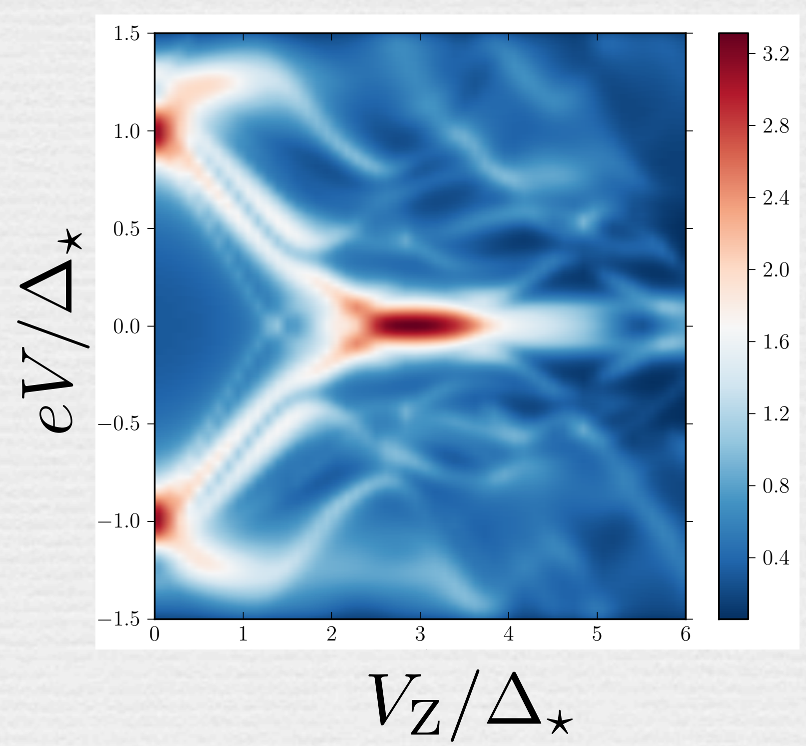
Jie Liu[1],* Andrew C. Potter[2],* K.T. Law[1], and Patrick A. Lee[2]
[1] *Department of Physics, Hong Kong University of Science and Technology, Clear Water Bay, Hong Kong, China and*
[2] *Massachusetts Institute of Technology 77 Massachusetts Ave. Cambridge, MA 02139*

arXiv:1206.1276







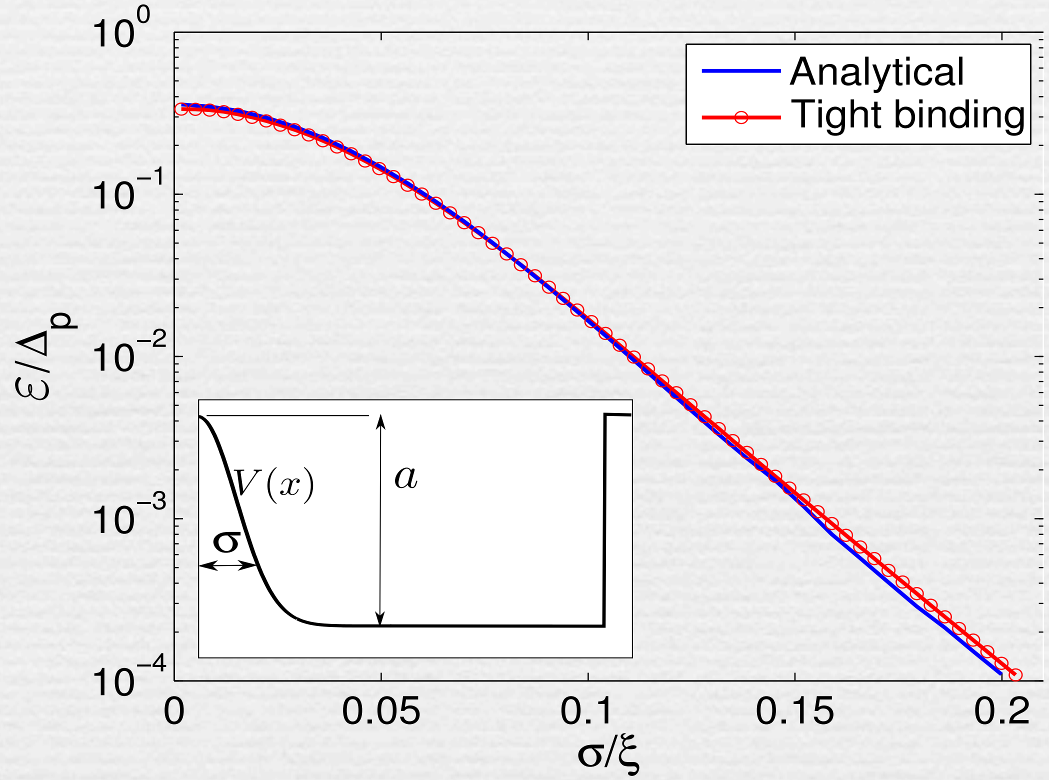


Near-zero-energy end states in topologically trivial spin-orbit coupled superconducting nanowires with a smooth confinement

G. Kells, D. Meidan, and P. W. Brouwer
Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany

arXiv:1207.3067
(Dated: July 13, 2012)

A one-dimensional spin-orbit coupled nanowire with proximity-induced pairing from a nearby s-wave superconductor may be in a topological nontrivial state, in which it has a zero energy Majorana bound state at each end. We find that the topological trivial phase may have fermionic end states with an exponentially small energy, if the confinement potential at the wire's ends is smooth. The possible existence of such near-zero energy levels implies that the mere observation of a zero-bias peak in the tunneling conductance is not an exclusive signature of a topological superconducting phase even in the ideal clean single channel limit.



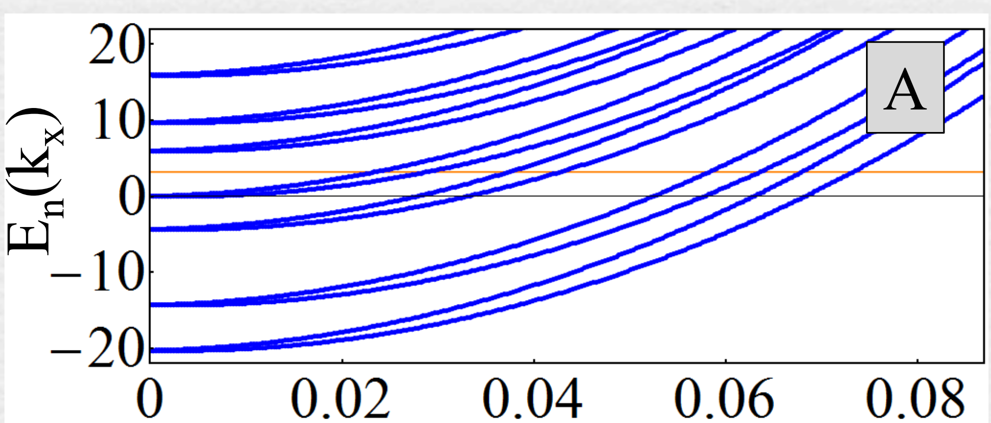
"The small energy ε of the Andreev end-states results from the ineffectiveness of a smooth potential to couple the two Majorana modes for the two spin channels. This near-degeneracy will be lifted in the presence of perturbations with an abrupt spatial dependence that couple the different spin-orbit bands.

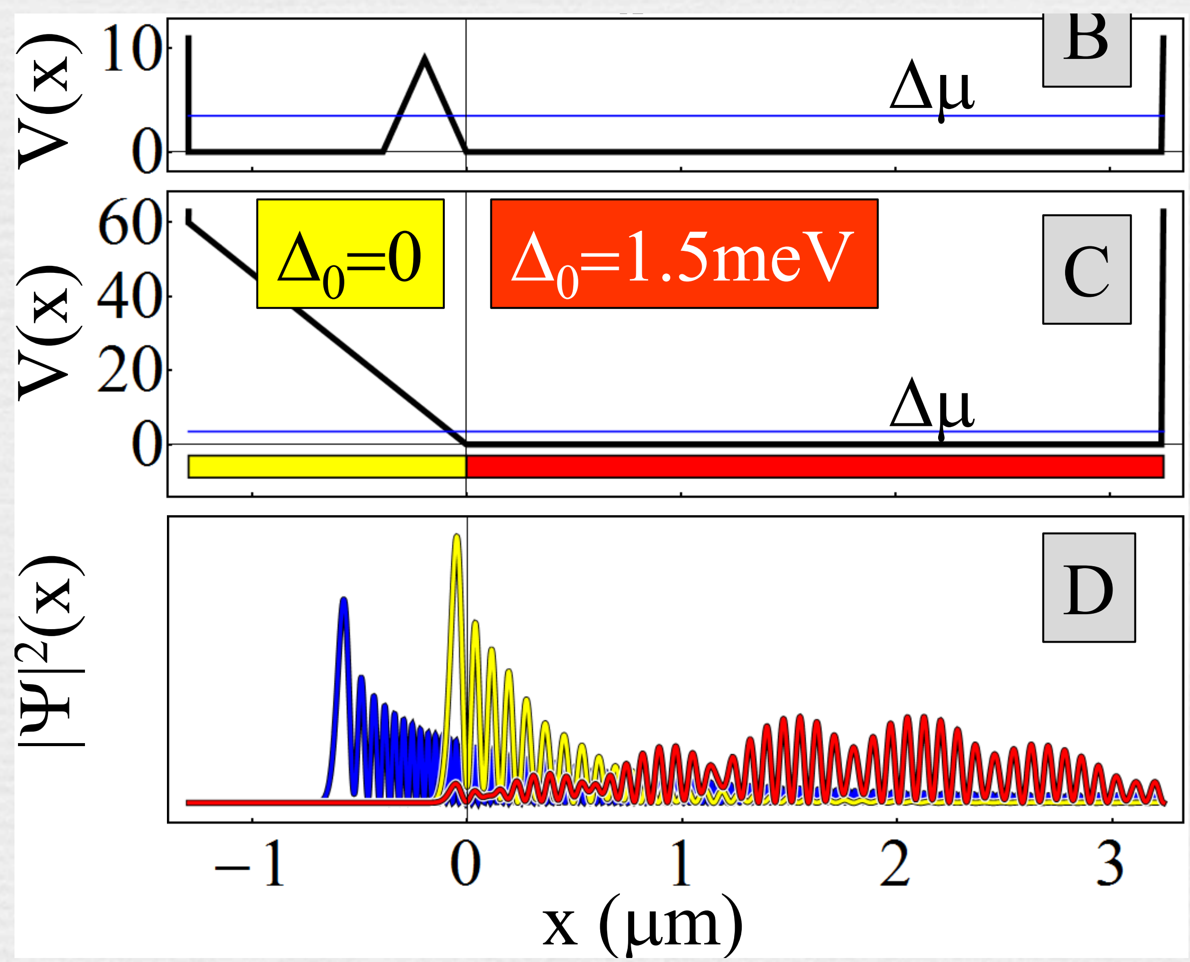
Examples of such perturbations are scattering from point-like impurities (which couple left-moving and right-moving particles), or a the abrupt vanishing of the pairing potential, which happens, e.g., if not all of the semiconducting wire is covered with the superconducting contact."

Disentangling Majorana fermions from conventional zero energy states in semiconductor quantum wires

T. D. Stanescu[1] and Sumanta Tewari[2]
[1] *Department of Physics, West Virginia University, Morgantown, WV 26506*
[2] *Department of Physics and Astronomy, Clemson University, Clemson, SC 29634*

A proposed signature for the Majorana zero-energy quasiparticle predicted to occur in semiconductor nanowires proximity-coupled to an s-wave superconductor is the zero-bias conductance peak (ZBCP) for tunneling into the end of the wire. Recently, it has been shown that, in the presence of a smooth confining potential, nearly ZBCPs can occur even in the topologically trivial phase. Here we show that, for a smooth confinement, the emergence of the nearly ZBCP at Zeeman fields corresponding to the topologically trivial phase is necessarily accompanied by a gap closing signature in the end-of-wire local density of state (LDOS). A similar behavior is found for nearly ZBCPs that appear in the presence of strong disorder. Our results strengthen the identification of the ZBCP observed in the recent Delft measurements, which show no gap-closing signatures, with topological Majorana fermions localized at the ends of the wire.

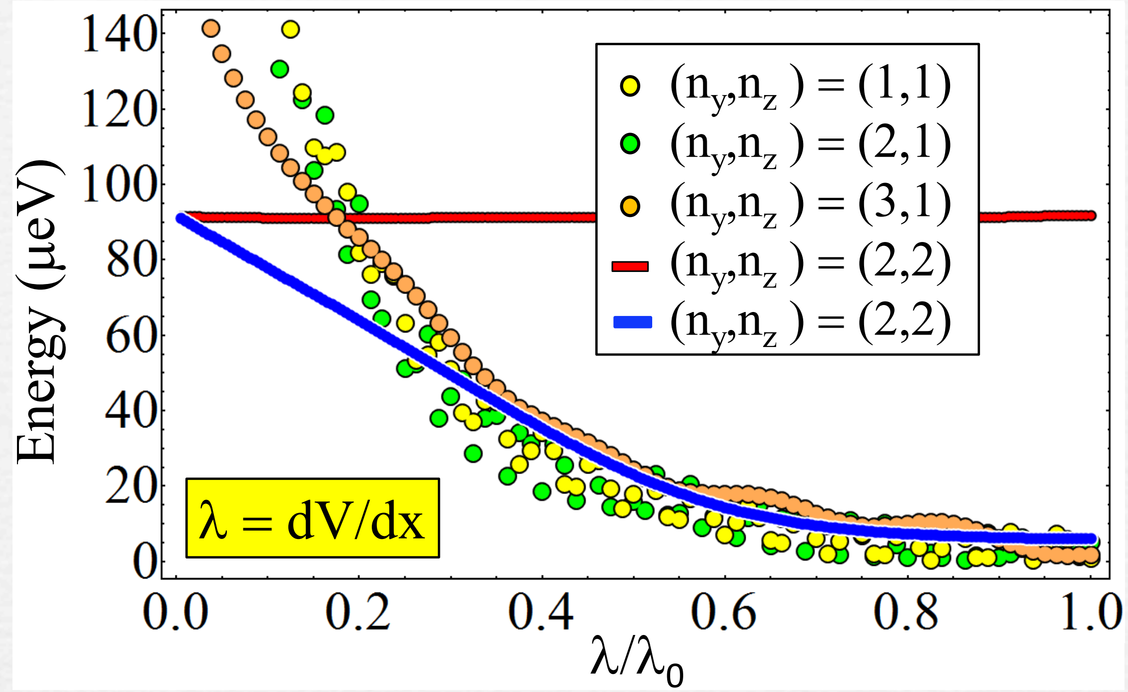




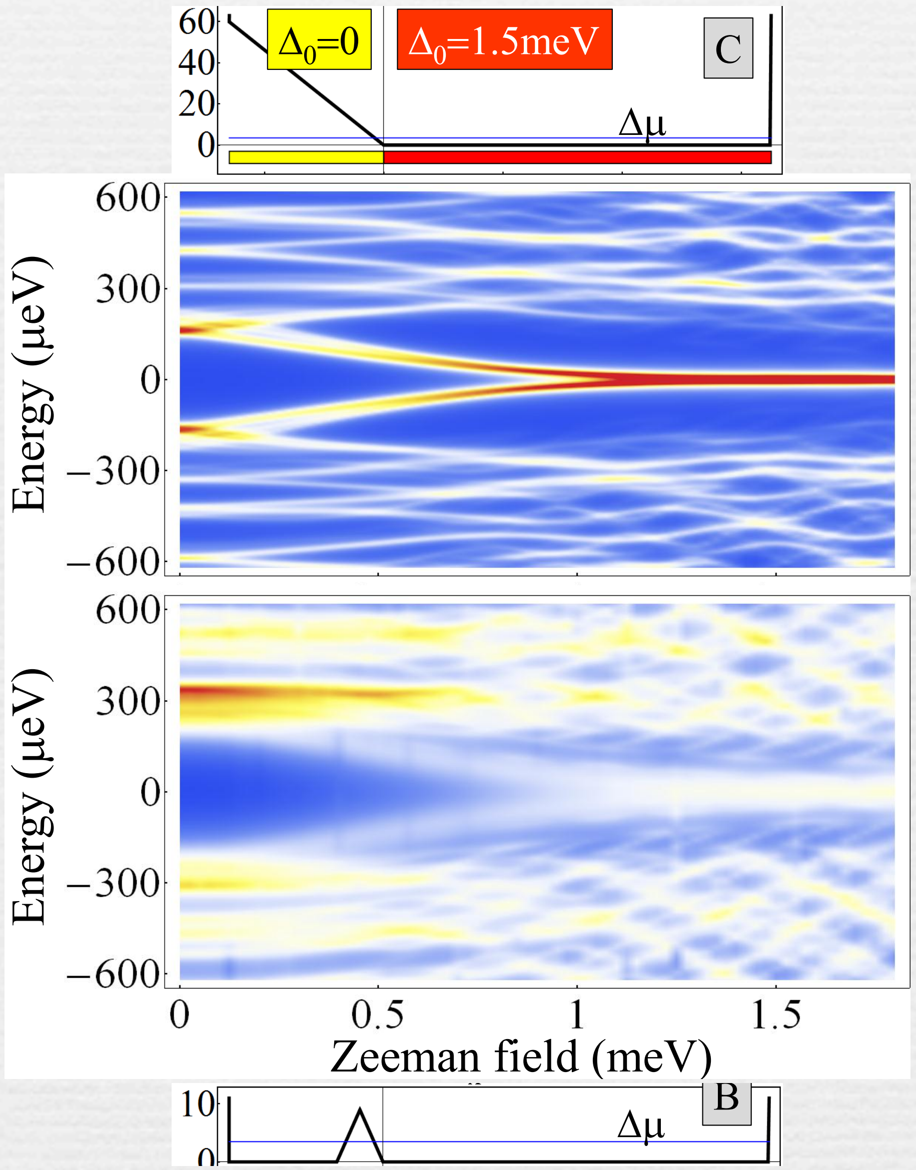
$$\mu \gg V_Z \gg \Delta$$

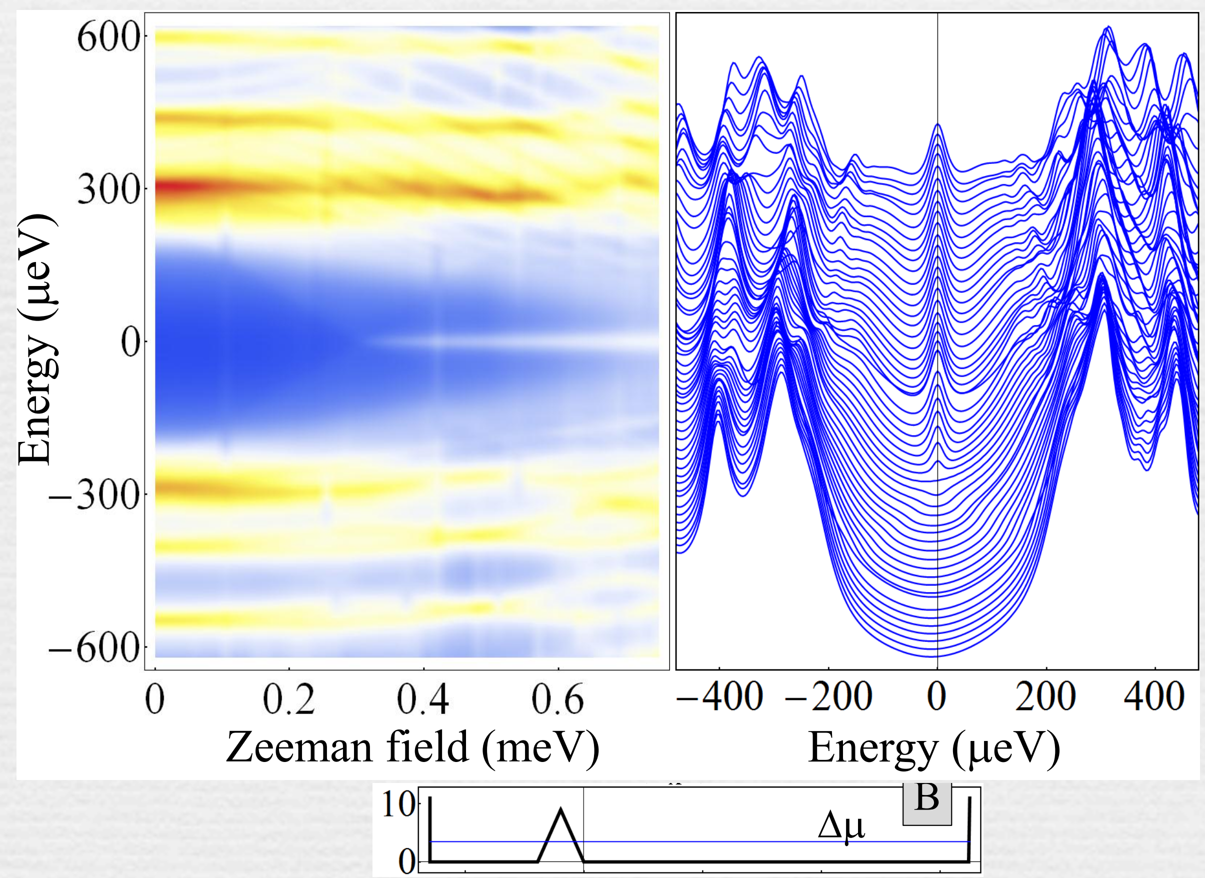
$$B = 0$$

Dependence on potential smoothness



$$V_Z > \sqrt{\mu^2 + \Delta_\star^2}$$

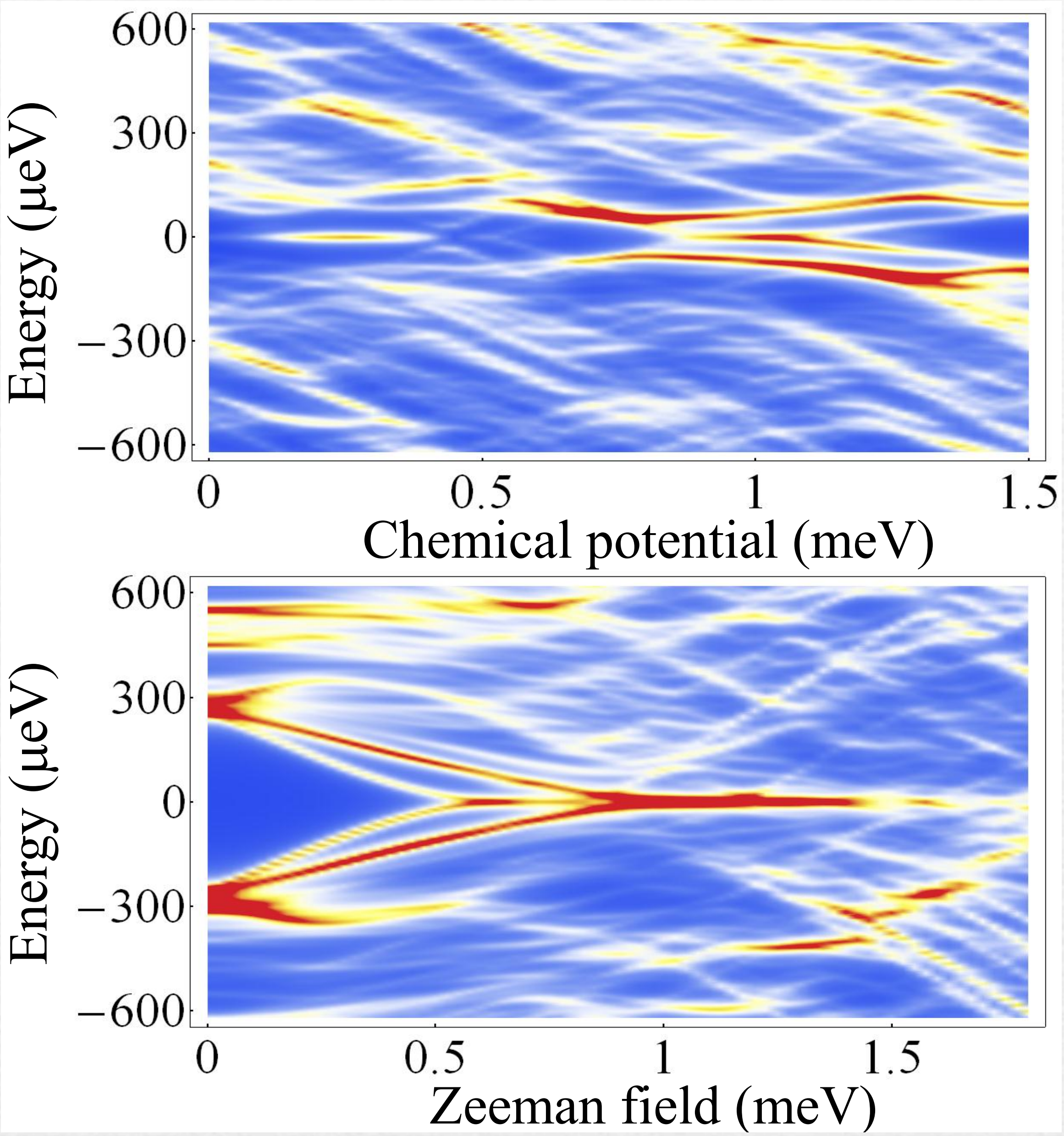




$\Delta\mu = 3.5$ meV

$\Delta\mu = 0$

Disorder-induced ZBP

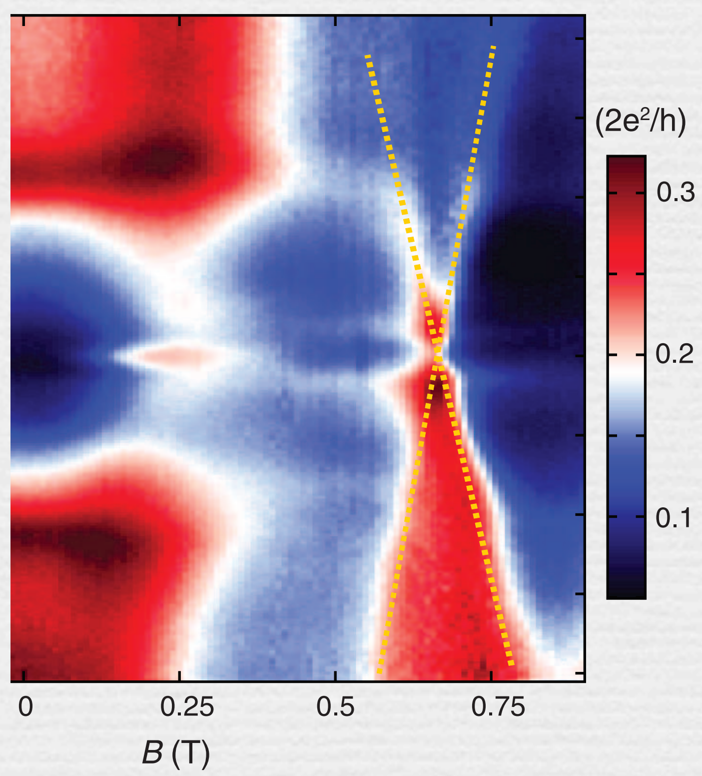


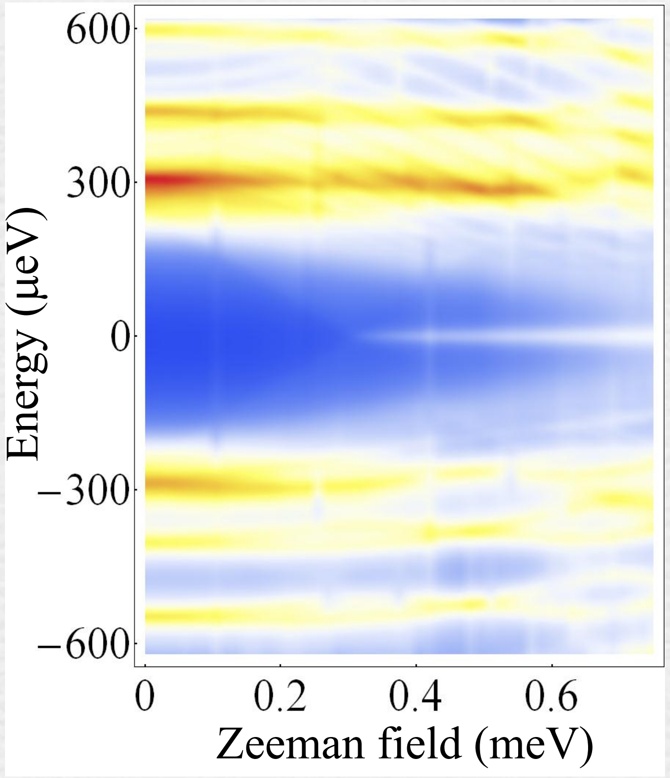
Also here the ZBP is accompanied
by the gap-closing signal

→ The observed ZBP is more likely to be induced by MF

BUT

There are still other features for which there is no agreement between theory and experiment, and even after fine tuning (in the theoretical models) it is not possible to "adjust" those features all TOGETHER.





Thank you for the attention