EFFECT OF THE ELECTROSTATIC ENVIRONMENT IN MAJORANA NANOWIRES

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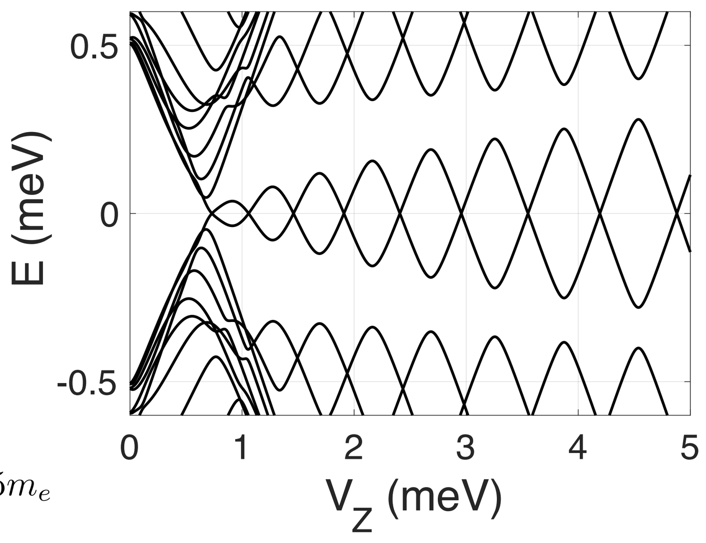
ABSTRACT: Spectroscopic measurements in real Majorana nanowires exhibit some features that cannot be explained by simple theoretical models, such as zero-energy pinning of the lowest lying modes or quantum dot-like behavior. In this work, we show that these features could be explained taking into account the interaction with the bound charges which arise in the electrostatic environment of these nanowires. They make Majorana states more stable under magnetic and electrostatic perturbations, and they may also lead to the formation of quantum dots at the edges of the nanowires.

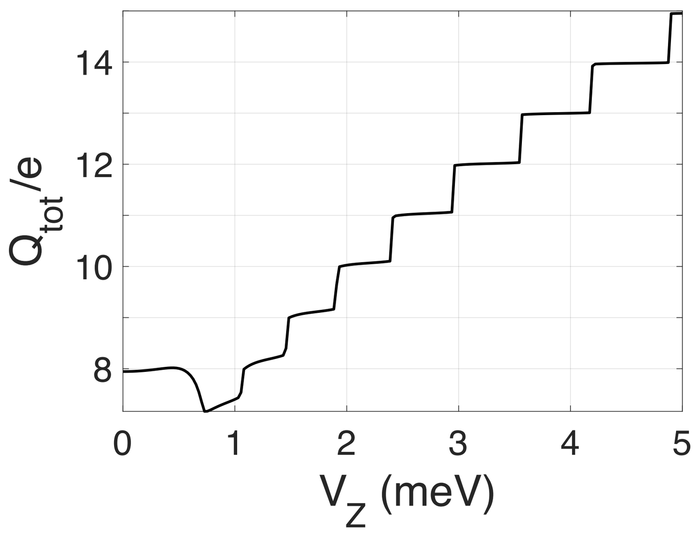
1. INTRODUCTION AND MOTIVATION

The effective Hamiltonian for a Majorana nanowire and its corresponding energy spectrum…

$$\hat{H}_0 = \left[\left(\frac{\hbar^2 k_x^2}{2m} - \mu\right)\sigma_0 + \right.$$
$$\left. + \alpha\sigma_y k_x + V_Z\sigma_x\right]\tau_z +$$
$$+\Delta\sigma_y\tau_y$$

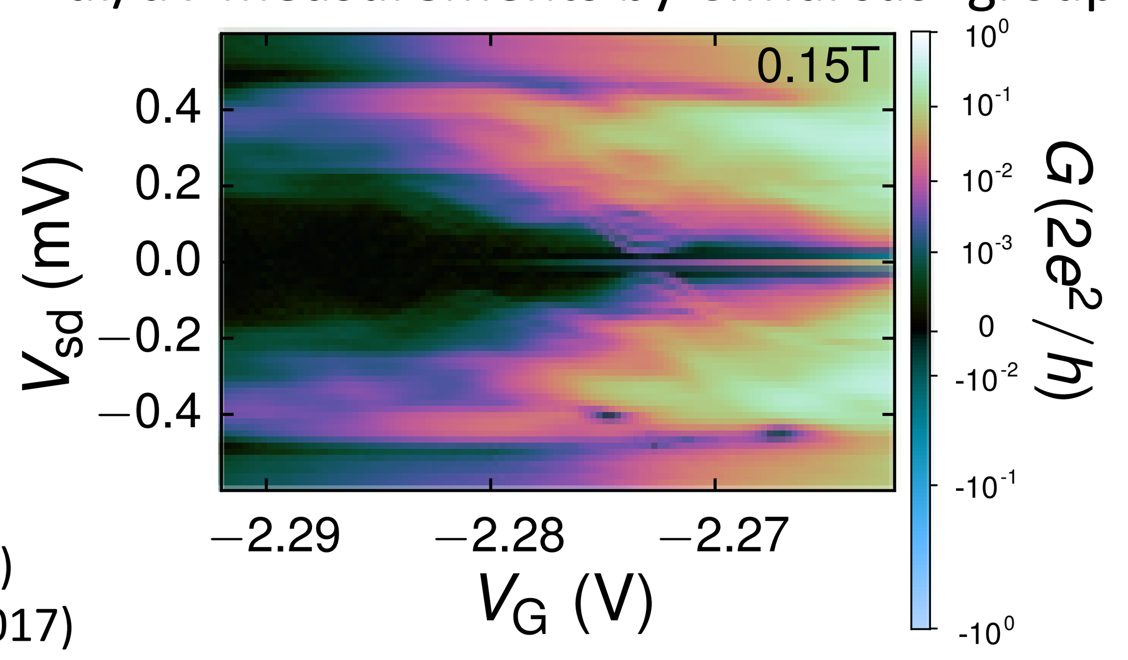
Where: $\Delta = 0{,}5\mathrm{meV}$ $\mu = 0{,}5\mathrm{meV}$
$L = 1\mu\mathrm{m}$ $\alpha = 20\mathrm{nm}\cdot\mathrm{meV}$ $m = 0{,}015 m_e$





…do not describe properly some observed experimental features, like zero-energy pinned regions[2] and energy levels approaching zero energy after the topological transition.

dI/dV measurements by C.Marcus[1] group



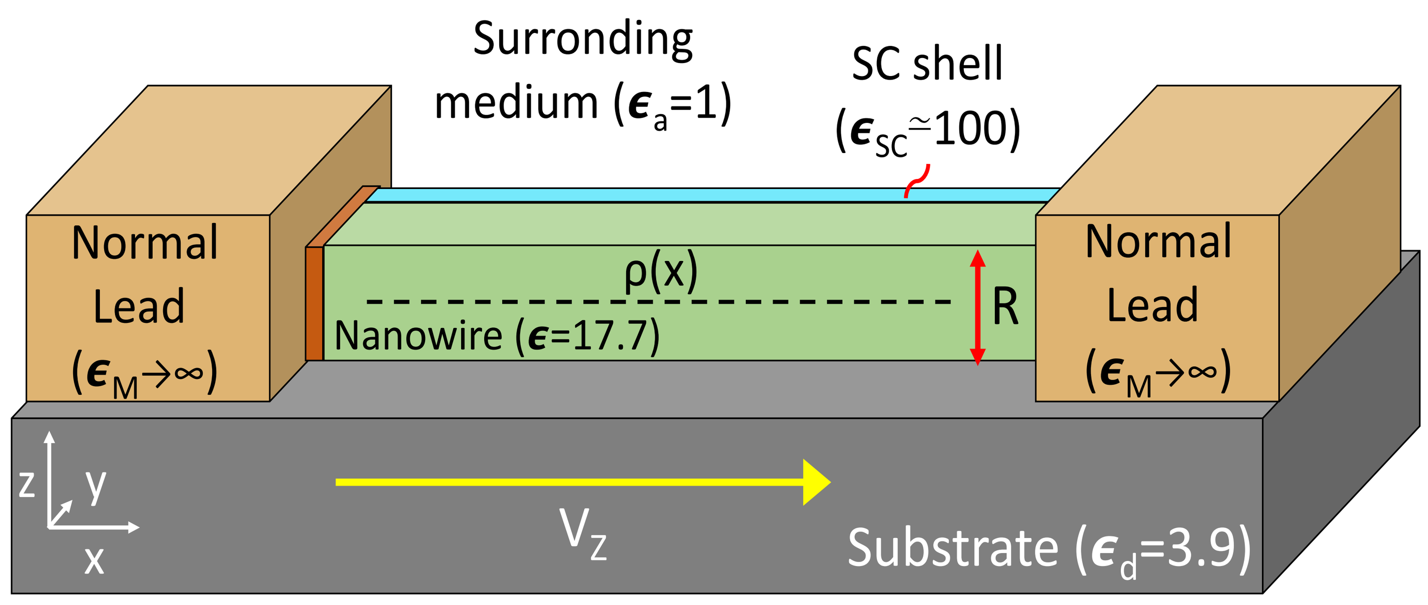
[1]H.J.Suominen *et al.*, arXiv:1703.03699 (2017)
[2]F.Domínguez *et al.*, npj Quant. Mat. 2, 13 (2017)

2. MODEL

They could be explained including the self-consistent mean field interaction…

$$\hat{\phi}_b(x) = \sigma_0\tau_z \int dx' V_b(x,x')\langle\hat{\rho}(x')\rangle$$

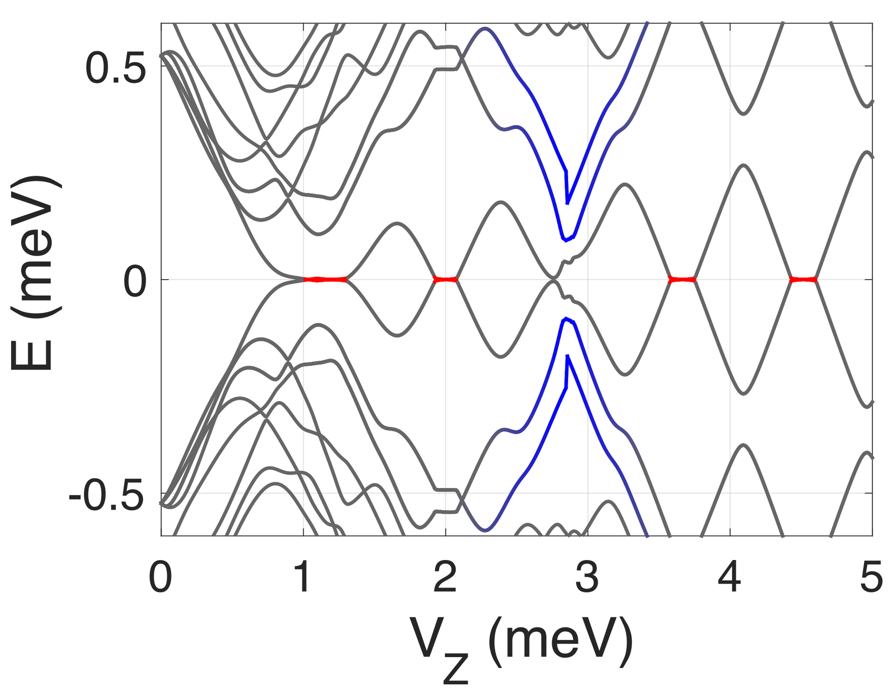
…between the nanowire charge density ρ(x) and the bound charges which arise in the electrostatic environment

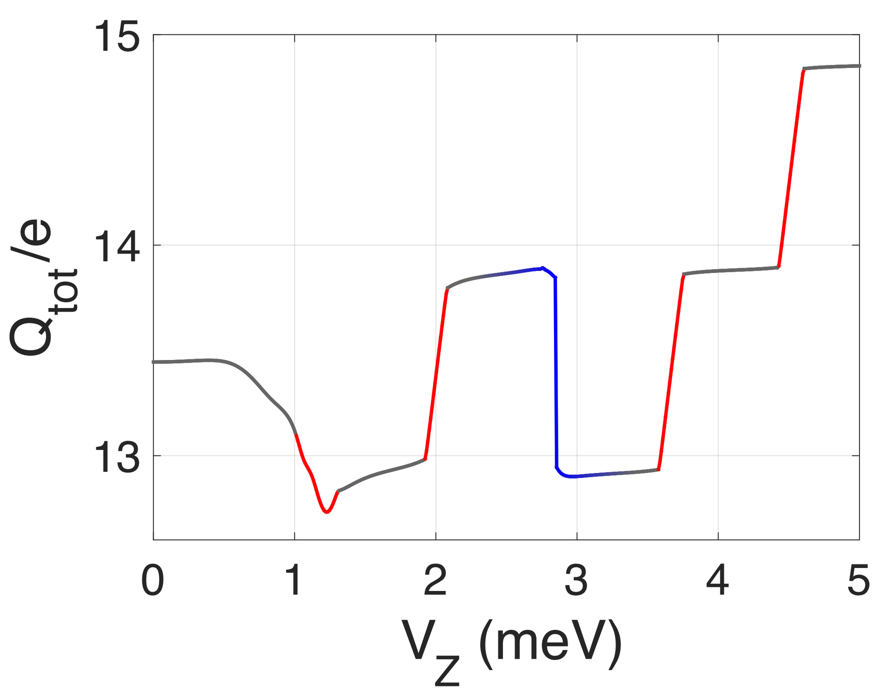


We assume that the dielectrical permittivity of the SC shell is finite. The kernel of the interaction $V_b(x,x')$ is obtained using the electrostatic image charge method.

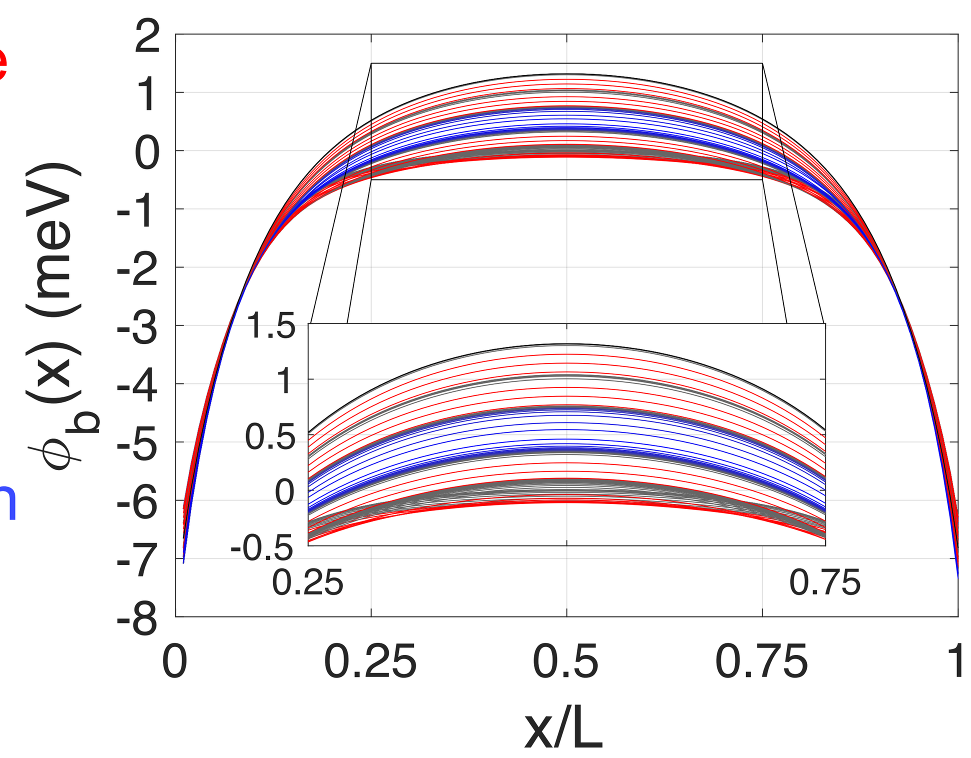
3. RESULTS

The energy spectrum is solved using self-consistent numerical methods, searching for the nanowire charge density convergence…





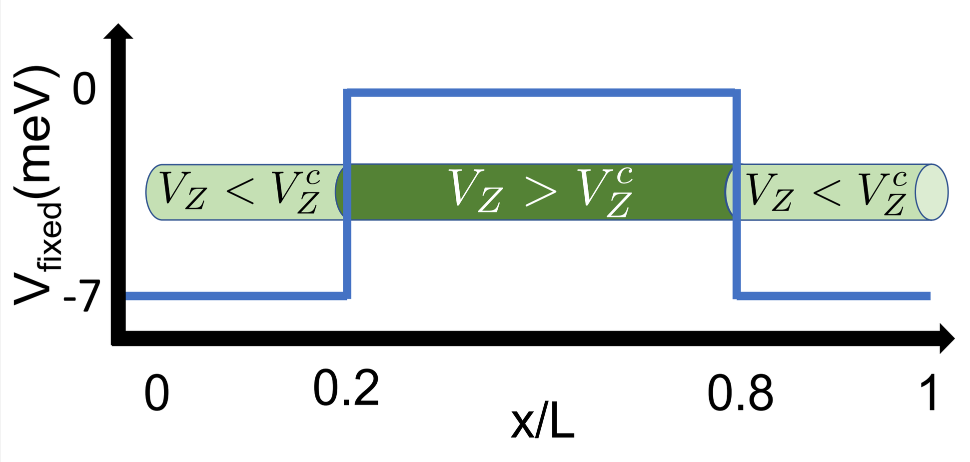
- The repulsive part of the interaction suppresses the charge entry into the nanowire, leading to zero-energy pinned regions.
- The attractive interaction at the nanowire edges increases the effective chemical potential in these regions. Only the central portion of the nanowire enters the topological phase at low fields.

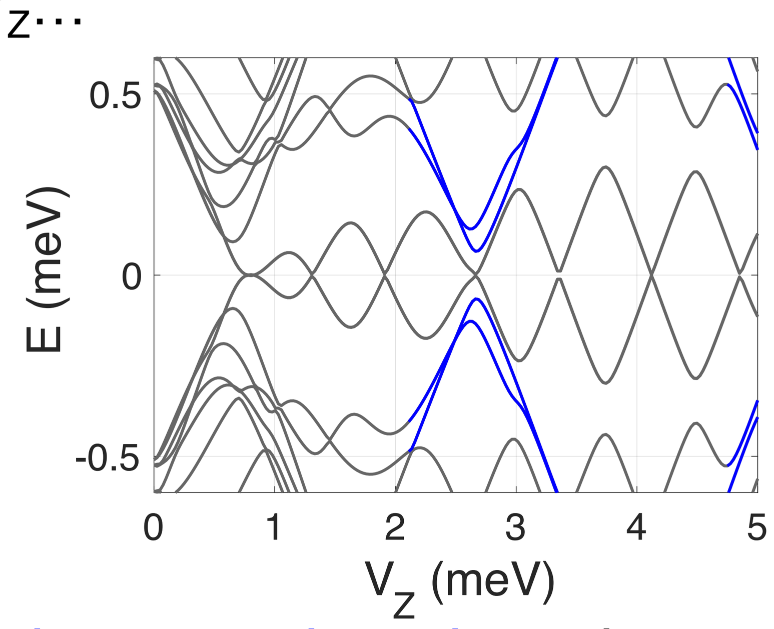


The energy levels approaching zero energy after the topological transition behave as quantum dot energy levels. They come from the outer nanowire regions outside the topological phase.

4. FIXED ELECTROSTATIC POTENTIAL MODEL

A fixed electrostatic potential with the shape of two quantum wells also creates regions in the nanowire that become topological for different V_Z…





It creates two quantum dots at the nanowire edges that reproduce qualitatively the results.

5. SUMMARY AND CONCLUSIONS

- The interaction with the electrostatic environment could explain some of the anomalous experimental features.
- The repulsive part of the interaction produces zero-energy pinning and makes Majorana modes more stable under magnetic and electrostatic perturbations.
- Quantum Dots are naturally built at the edges of the nanowire due to the attractive interaction created by the leads.
- Both features could help control Majorana qubits.