Fluxoid-induced pairing suppression and near zero-modes in quantum dots coupled to full-shell nanowires

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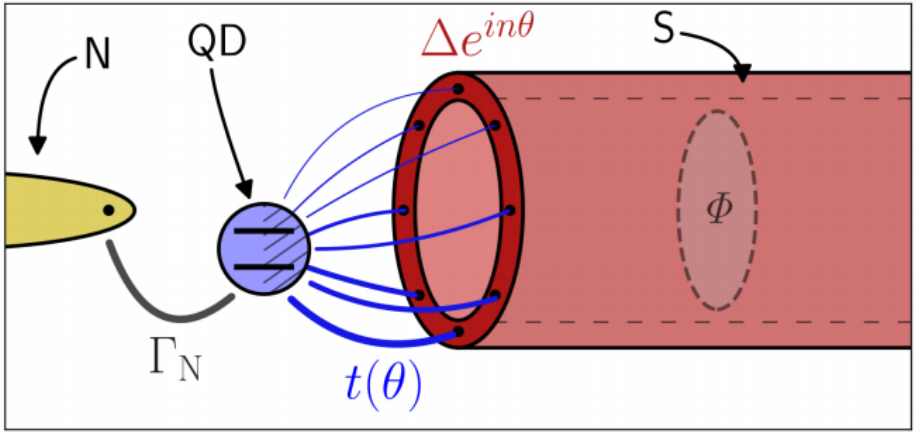

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Arxiv:2107.13011

Introduction

Co-authors




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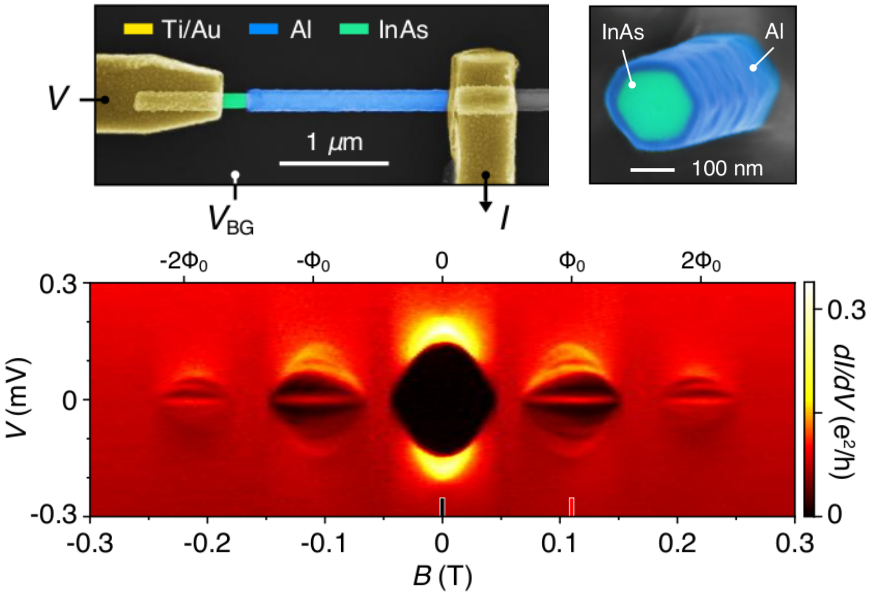
Introduction

N-QD-S with full-shell superconductors are now a possible experimental platform in semiconductor/superconductor heterostrucures.

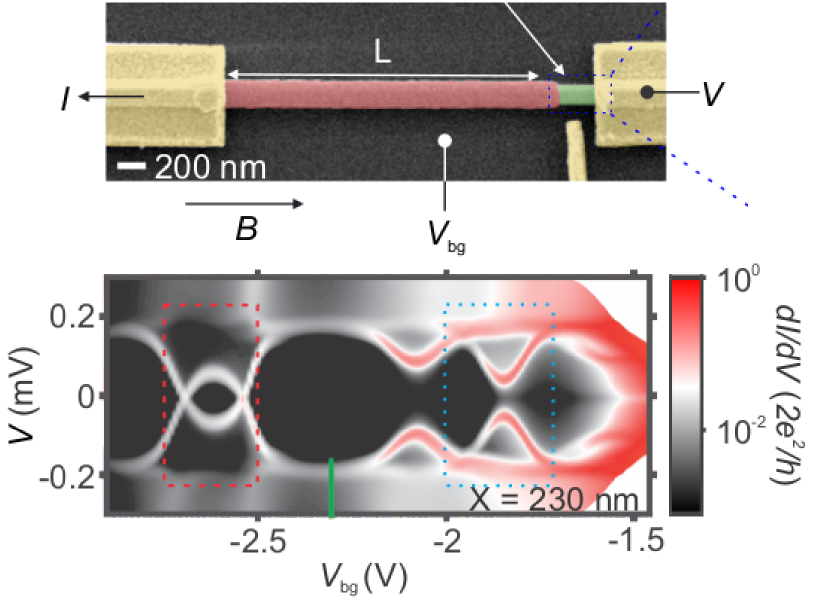
C. Marcus' group

S. Vaitiekenas et al., Science 367, 1442 (2020)

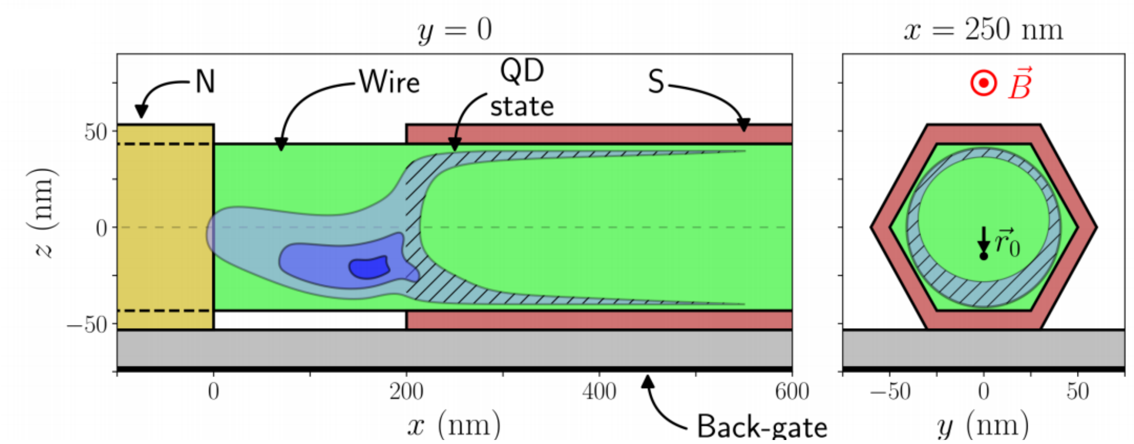


G. Katsaros' group

M. Valentini, arXiv:2008.02348 (2020)



Introduction

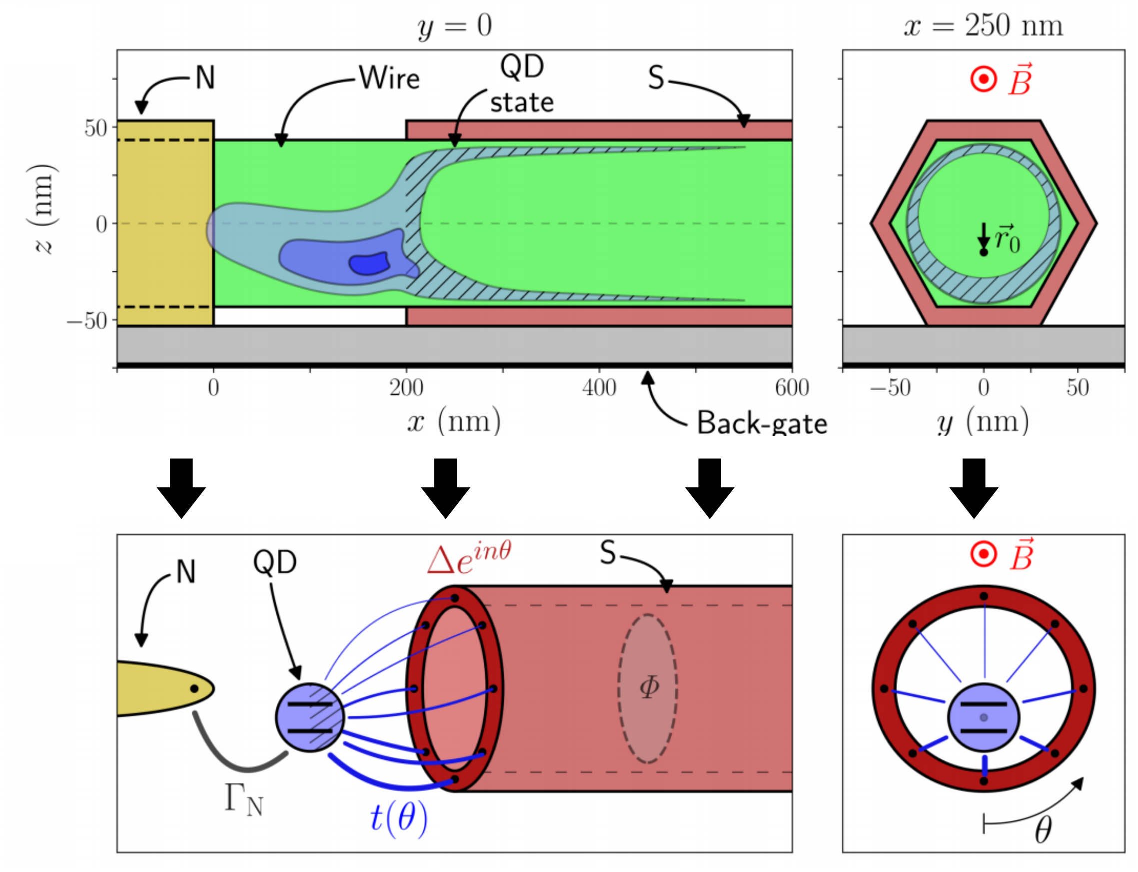


Longitudinal cut

Cross-section cut

Scheme of the real situation

Introduction



$$H = H_D + H_S + V_{SD}$$

$$H_D = \sum_\sigma (\epsilon_0 + \sigma V_Z) d_\sigma^\dagger d_\sigma + U n_\uparrow n_\downarrow$$

$$H_S = \int dz\, d\theta \sum_\sigma \left[\psi_{\sigma\theta z}^\dagger \frac{\boldsymbol{p}^2}{2m^*} \psi_{\sigma\theta z} \right.$$

$$\left. + \Delta(n_\Phi) e^{in\theta} \psi_{\sigma\theta z}^\dagger \psi_{-\sigma\theta z}^\dagger + \text{h.c} \right]$$

Little-Parks effects

Winding of the phase!

$$n = \text{int}\left(\frac{\phi}{\phi_0}\right)$$

$$V_{SD} = \int d\theta \sum_\sigma t(\theta) \psi_{\sigma\theta 0}^\dagger d_\sigma + \text{h.c}$$

$$t(\theta) = t_0 \exp\left(-\alpha \frac{|\vec{r}_0 - r_{SC}(\theta)|}{R}\right)$$

Introduction

We write the Green's function for the QD:

$$G_\sigma^{QD}(\omega,\phi) = \left(\left(G_{0,\sigma}^{QD}(\omega,\phi)\right)^{-1} - \Sigma_\sigma^S(\omega,\phi) - \Sigma_\sigma^N - \Sigma_\sigma^{HFB}\right)^{-1}$$

$$\Sigma^{\mathrm{HFB}} = U\begin{pmatrix} \langle n_{-\sigma}\rangle & \langle d_\sigma d_{-\sigma}\rangle \\ \left\langle d_\sigma^\dagger d_{-\sigma}^\dagger\right\rangle & -\langle n_\sigma\rangle \end{pmatrix}$$

$$\Sigma^N = i\Gamma_N \mathbb{1}$$

Σ^S = (Large expression)

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$$\Sigma^N = i\Gamma_N \mathbb{1}$$

$$\Sigma^S \approx -\frac{\Gamma_S}{\sqrt{\Delta^2 - \omega^2}} \begin{pmatrix} \omega & \Delta\delta_n \\ \Delta\delta_n & \omega \end{pmatrix} \longleftarrow$$

Axial symmetric case $\begin{cases} \vec{r}_0 = (0,0) \\ t(\theta) = \mathrm{cte.} \end{cases}$

Introduction

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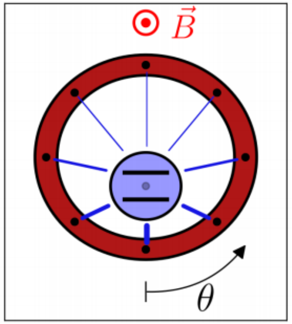


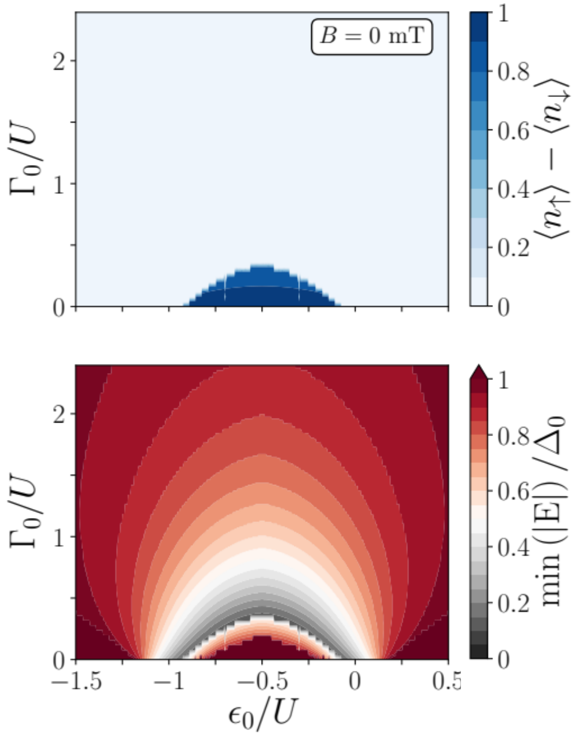
$$\Sigma^{\mathrm{S}} = \int d\theta d\bar{\theta} t(\theta+\bar{\theta}) g_{\mathrm{S}}(\theta+\bar{\theta},\theta-\bar{\theta}) t(\theta-\bar{\theta})$$

$$g_{\mathrm{S}} \sim \begin{pmatrix} \omega & \Delta e^{in\theta} \\ \Delta e^{-in\theta} & \omega \end{pmatrix}$$

Pairing term is zero for n>0 when the integral is done!
(in the symmetric coupling)

Results

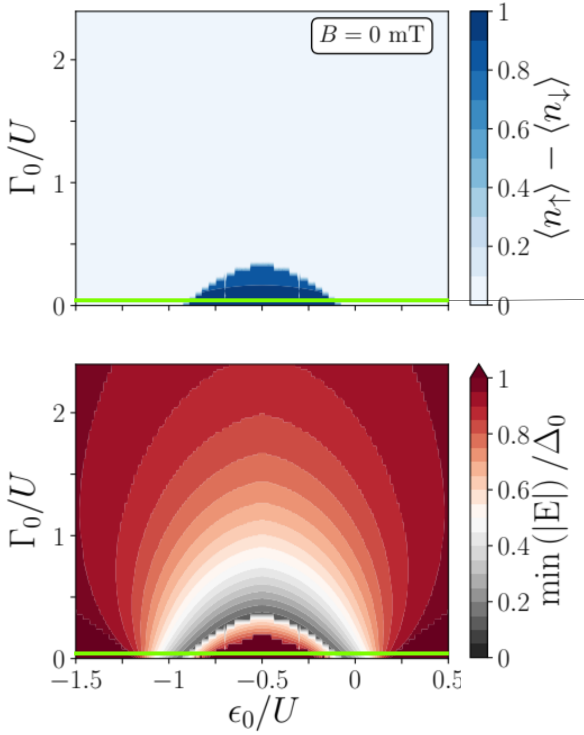
n=0
Symmetric case

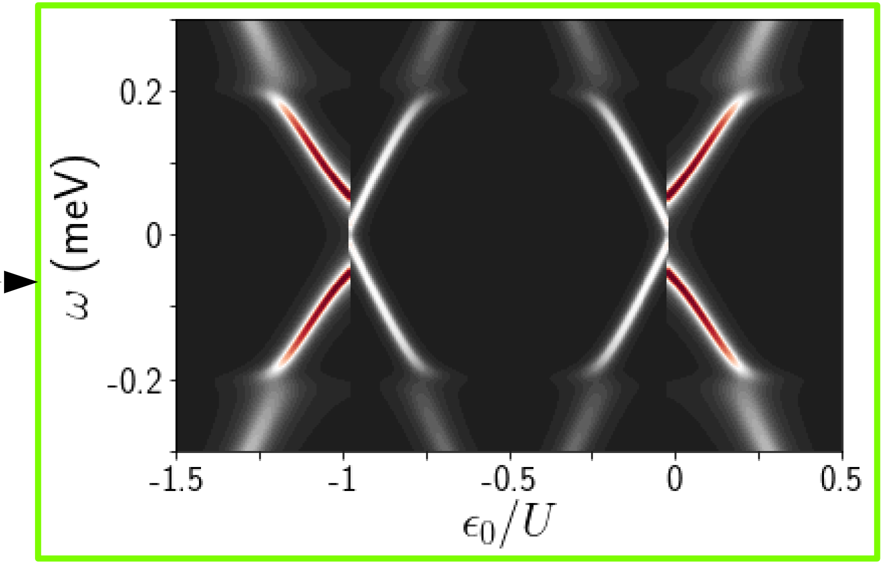


Results

LDOS versus QD energy level
LDOS versus magnetic field
Electrostatic simulations

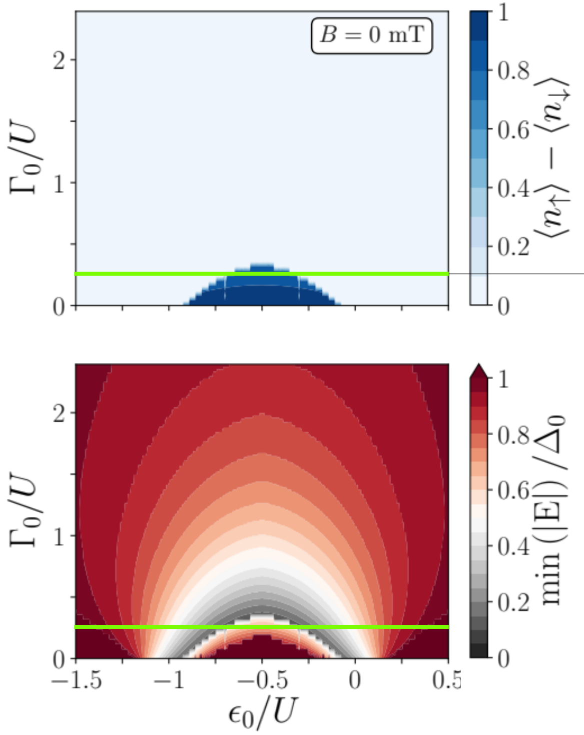
n=0
Symmetric case

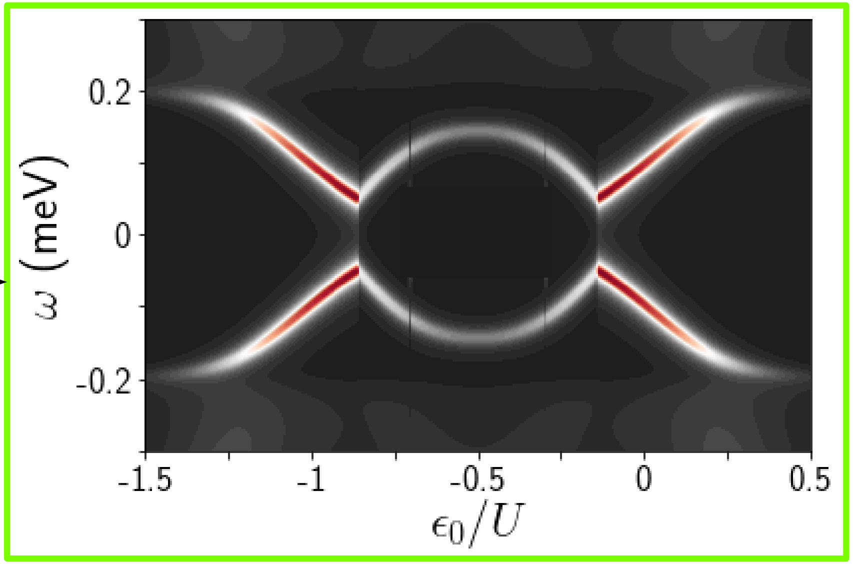




Results

n=0
Symmetric case





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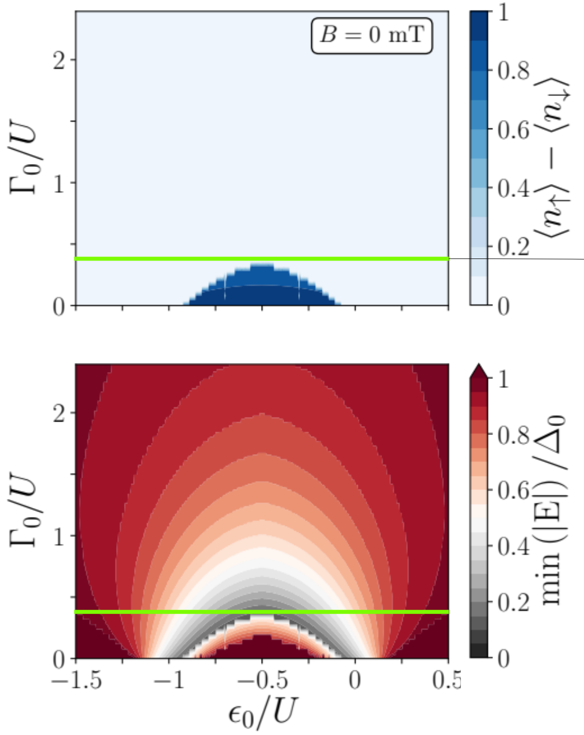
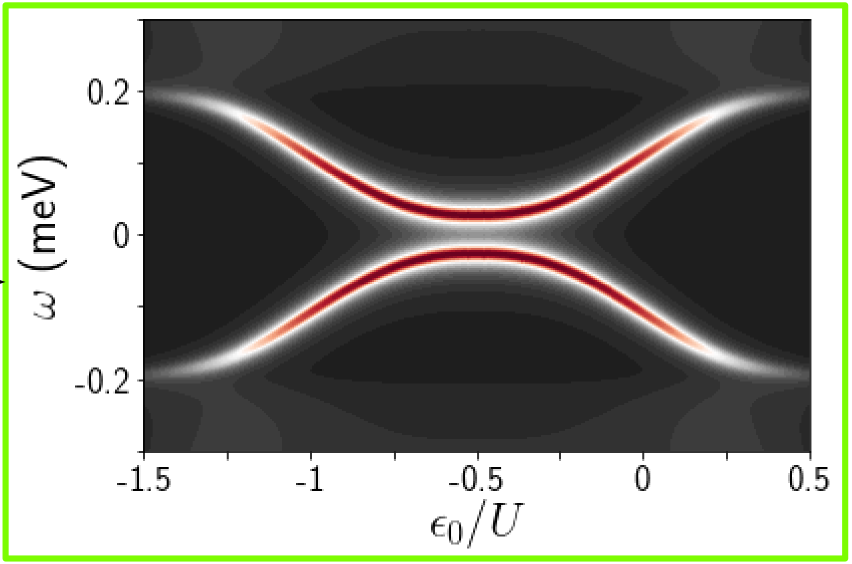
n=0
Symmetric case





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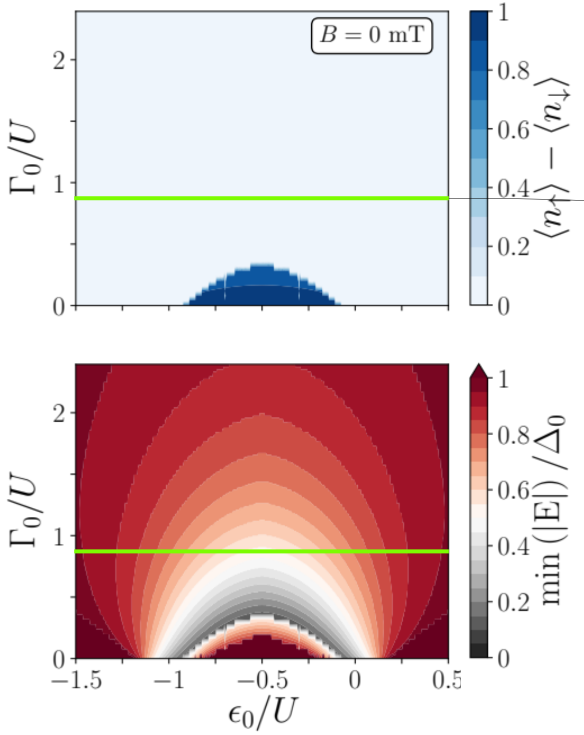
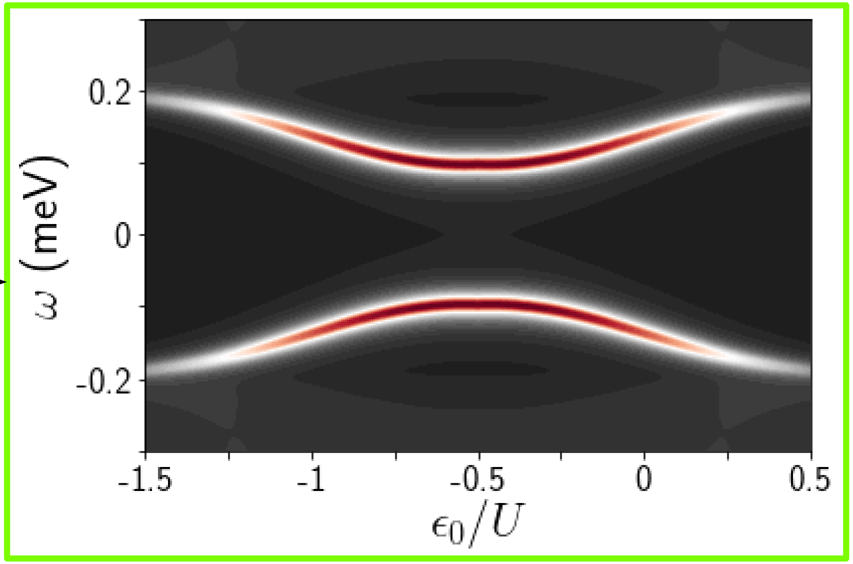
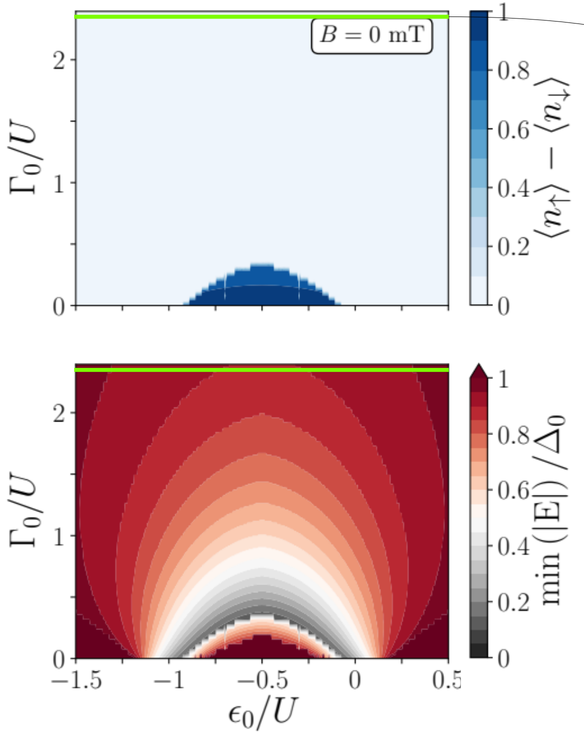
n=0
Symmetric case

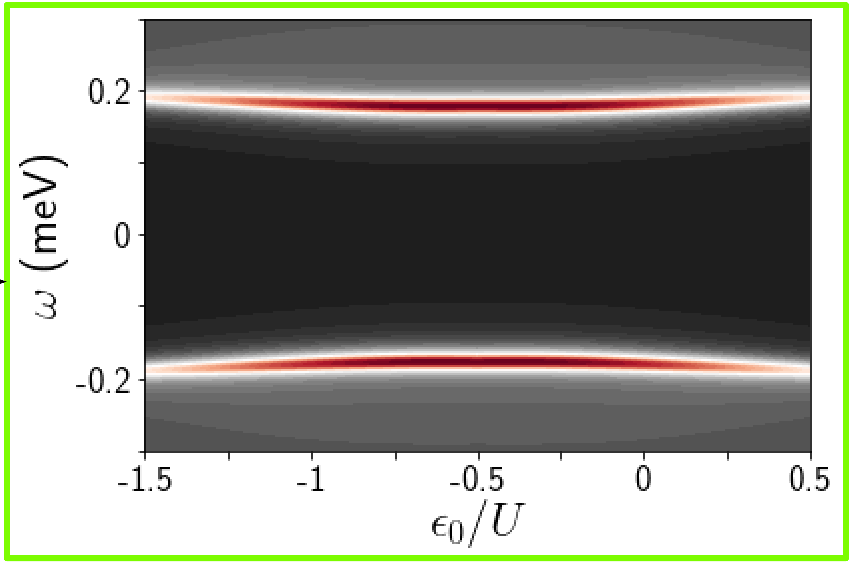




Results

n=0
Symmetric case

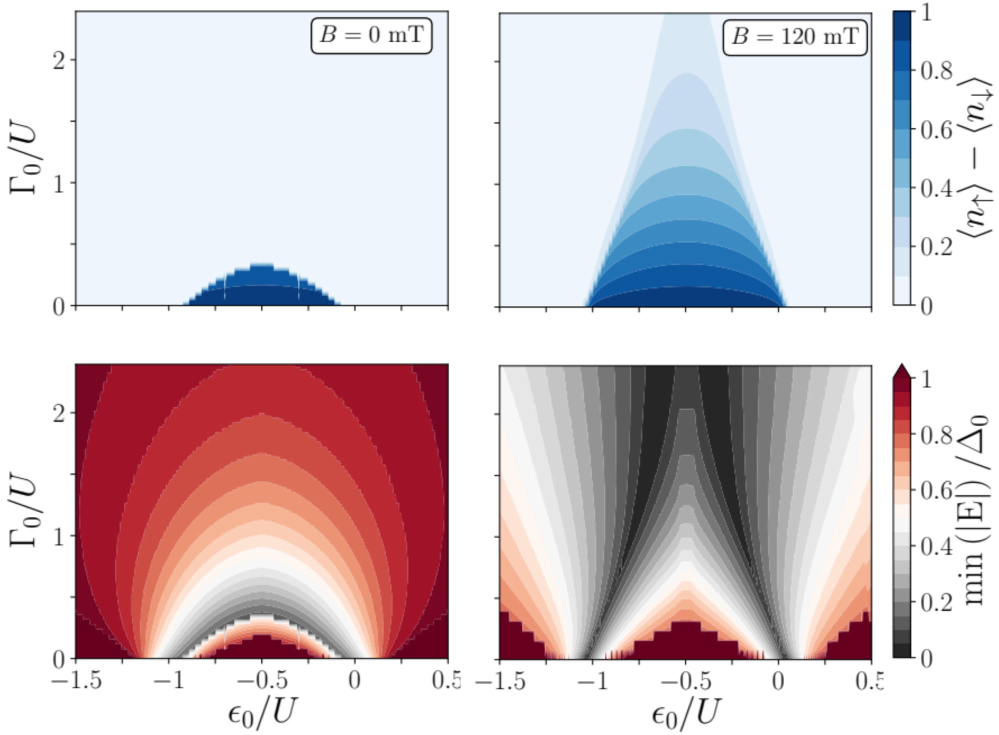




Results

n=0
Symmetric case

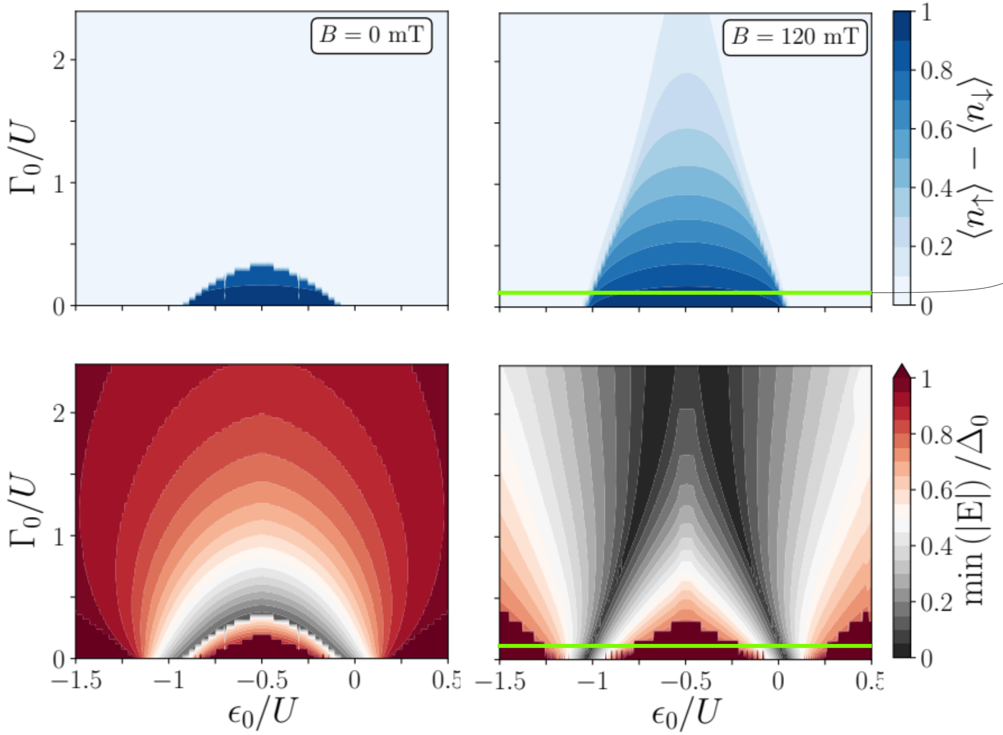
n=1
Symmetric case

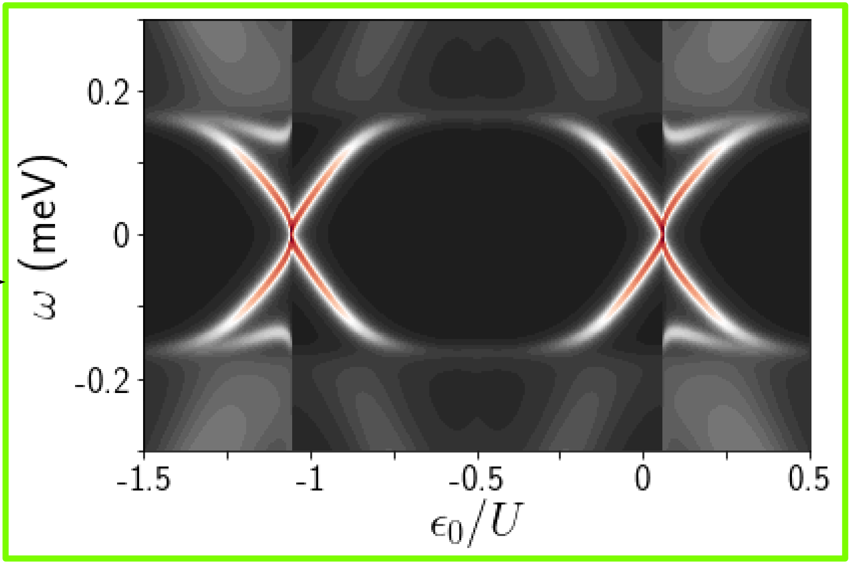


Results

LDOS versus QD energy level
LDOS versus magnetic field
Electrostatic simulations

n=0	**n=1**
Symmetric case	**Symmetric case**

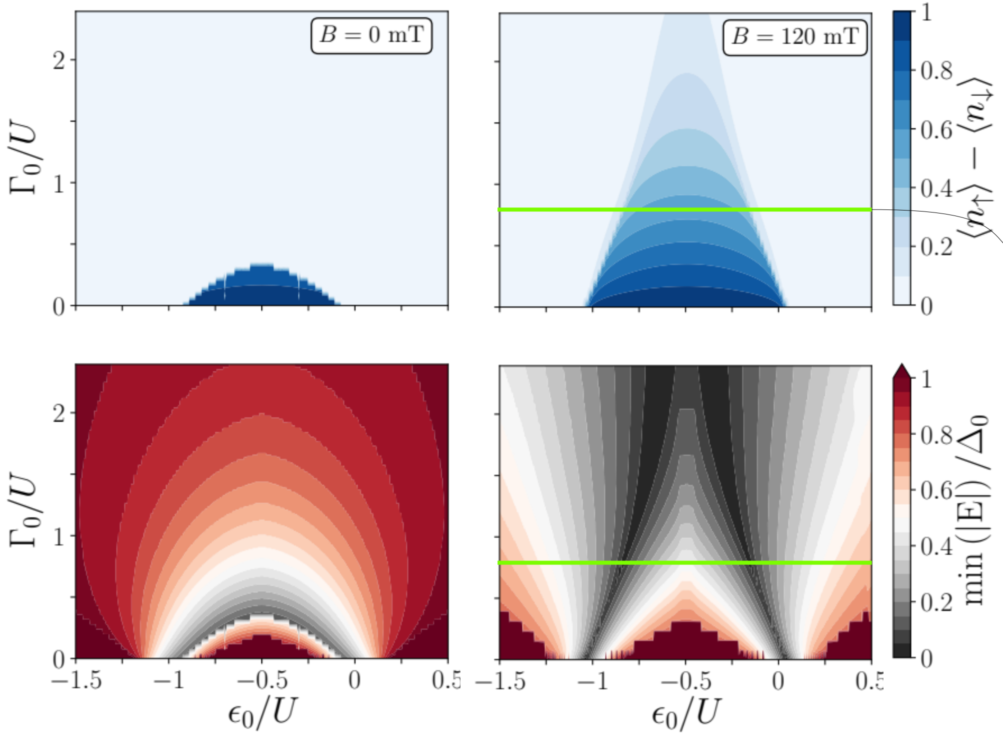


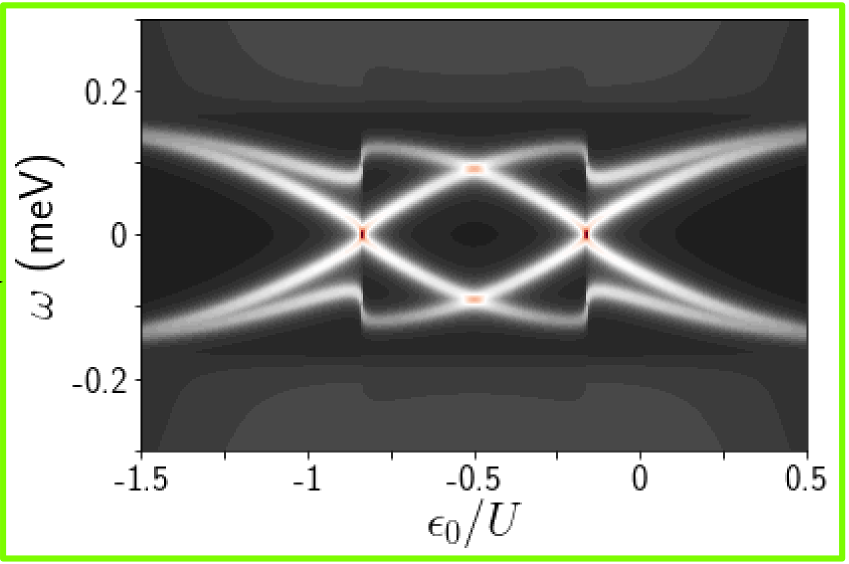


Results

n=0
Symmetric case

n=1
Symmetric case



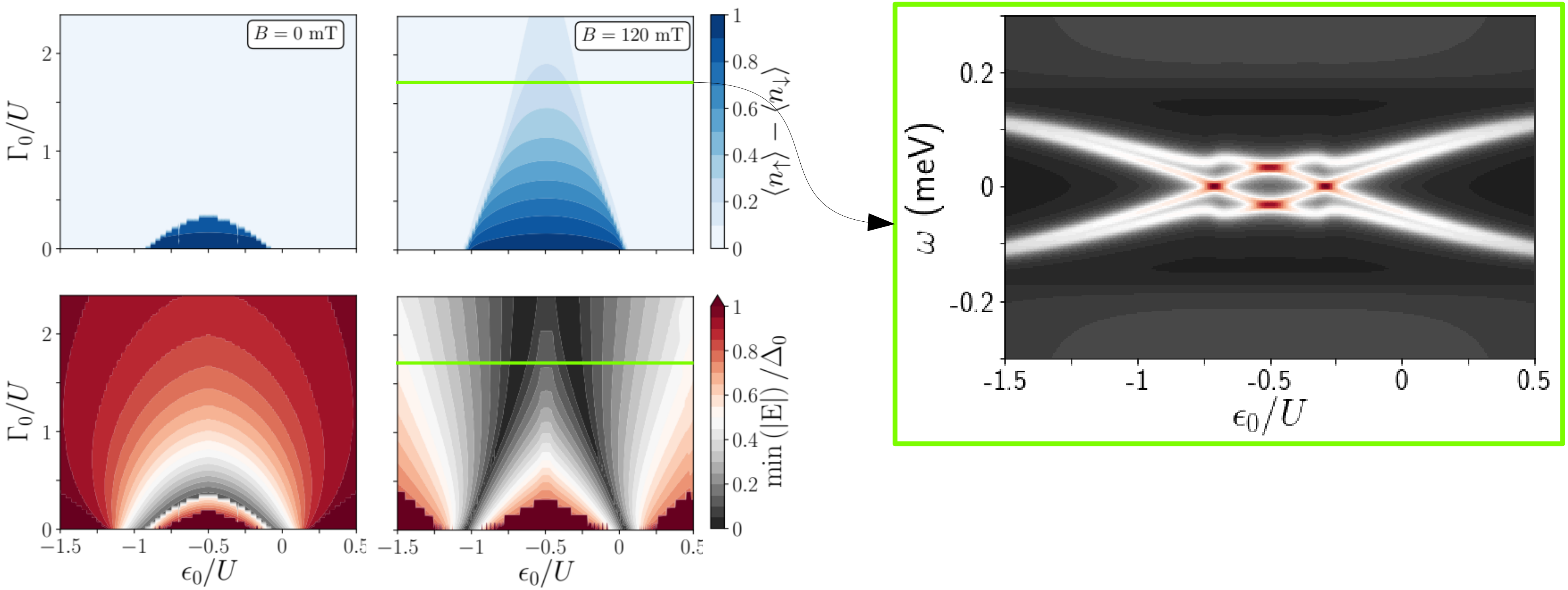


Results

LDOS versus QD energy level
LDOS versus magnetic field
Electrostatic simulations

n=0
Symmetric case

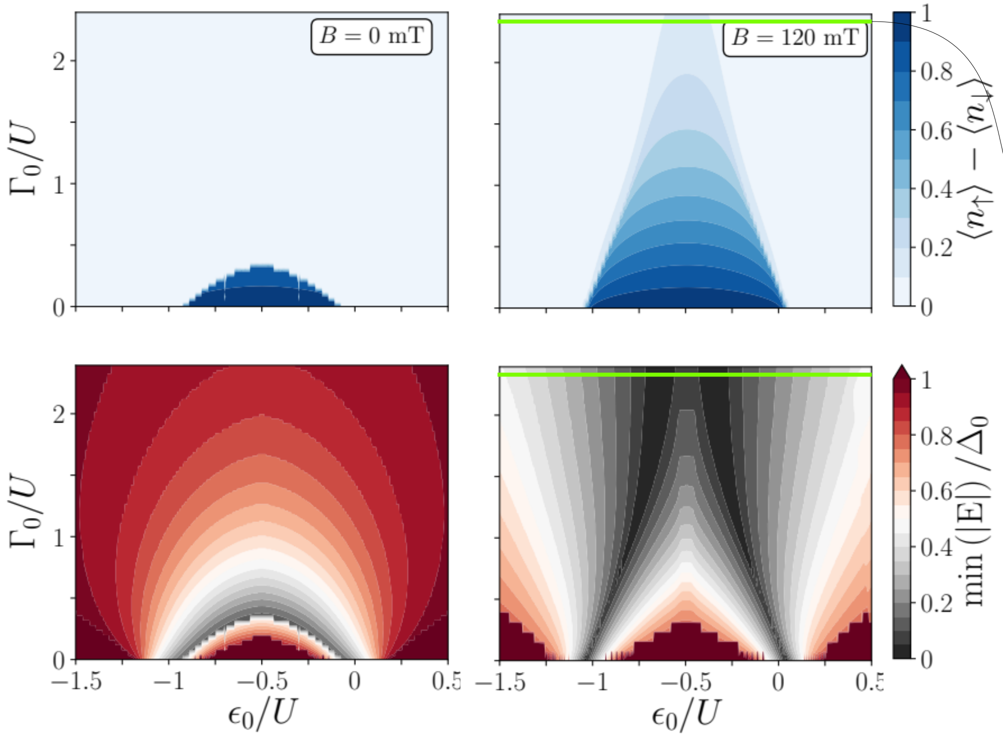
n=1
Symmetric case

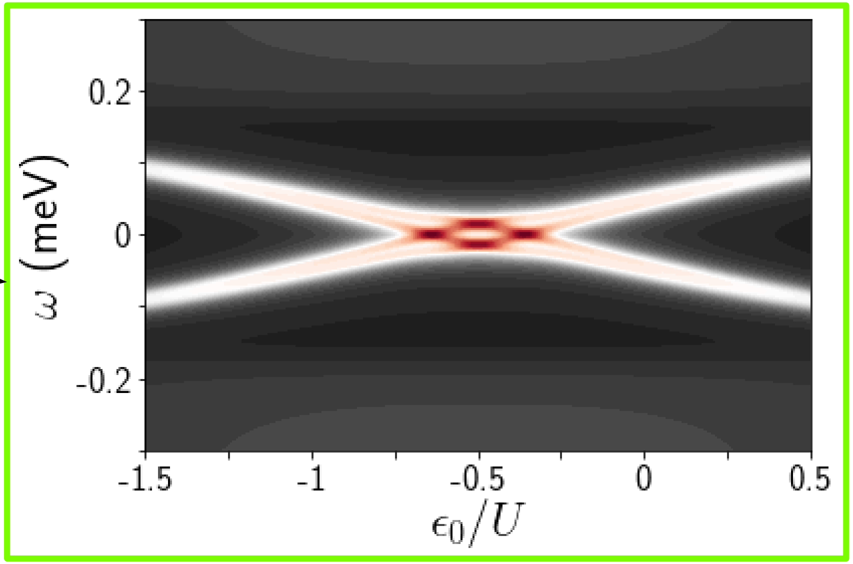


Results

n=0
Symmetric case

n=1
Symmetric case

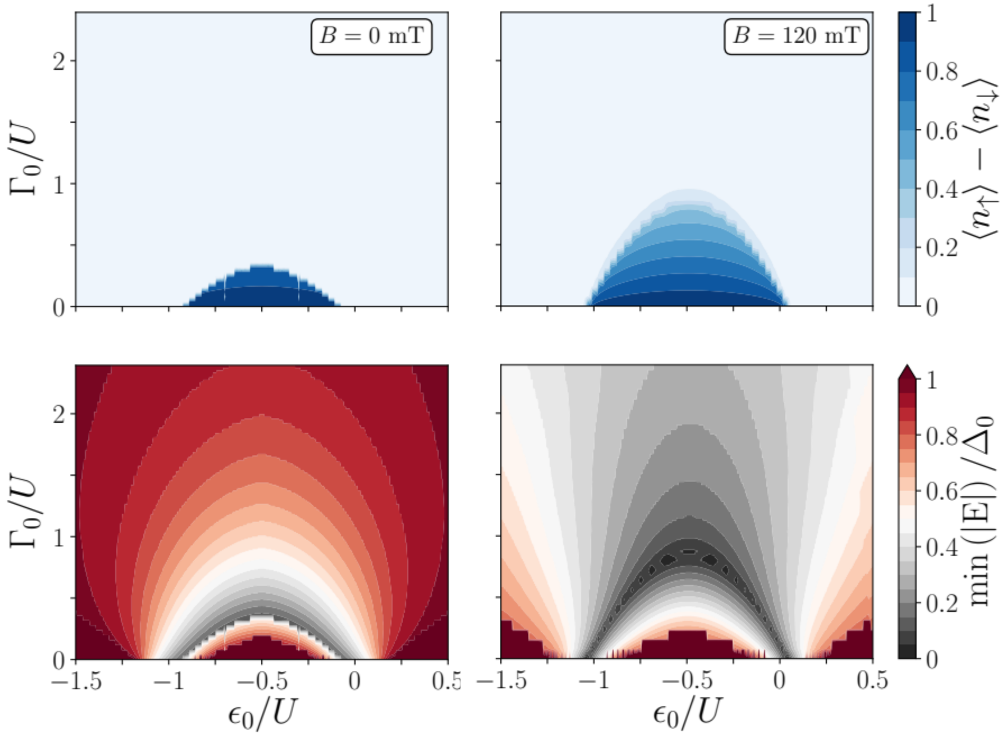




Results

n=0
Asymmetric case

n=1
Asymmetric case

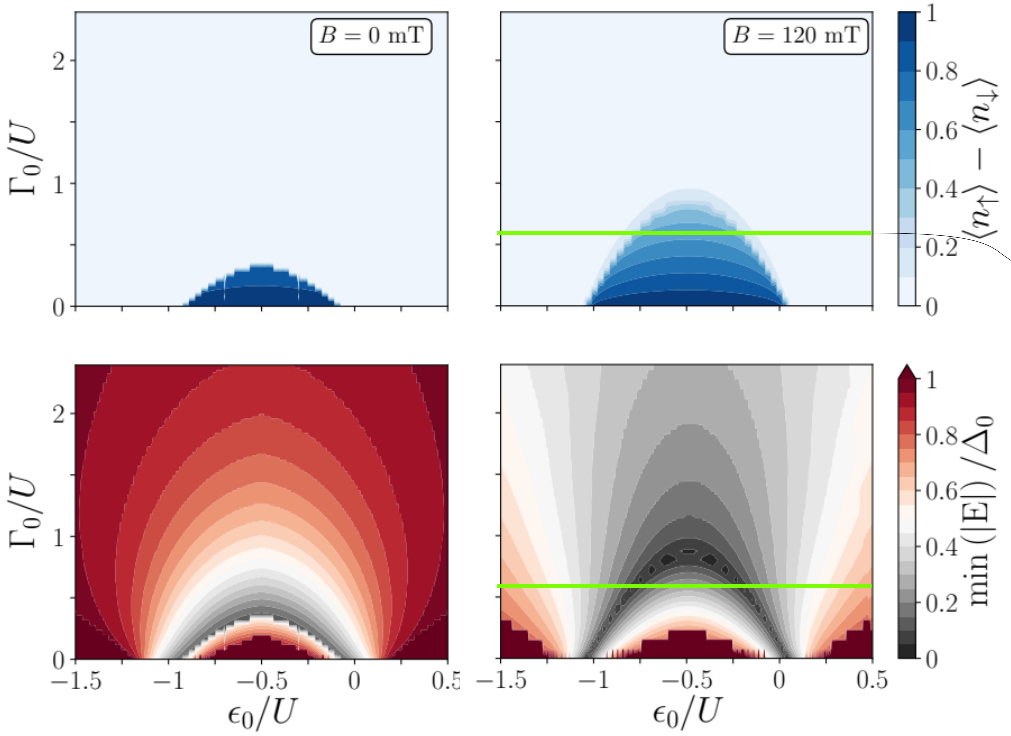


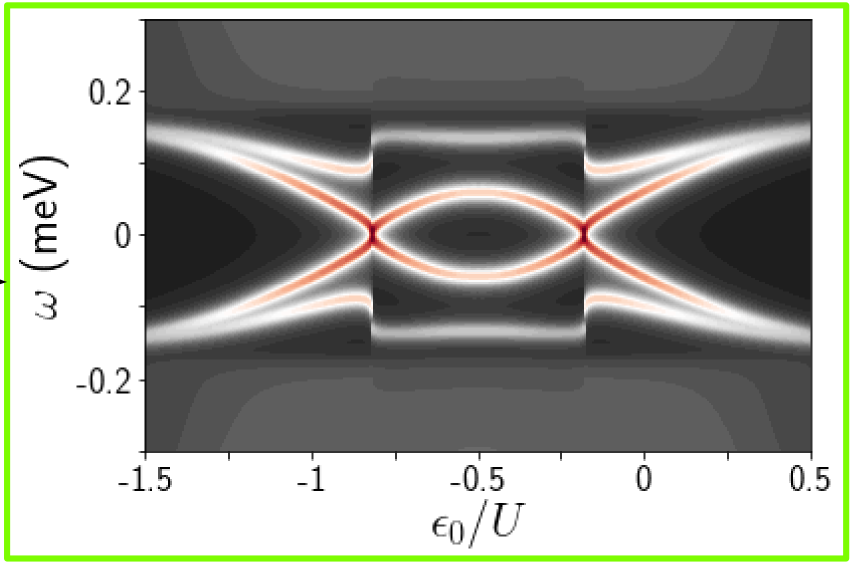
Results

LDOS versus QD energy level
LDOS versus magnetic field
Electrostatic simulations

n=0
Asymmetric case

n=1
Asymmetric case

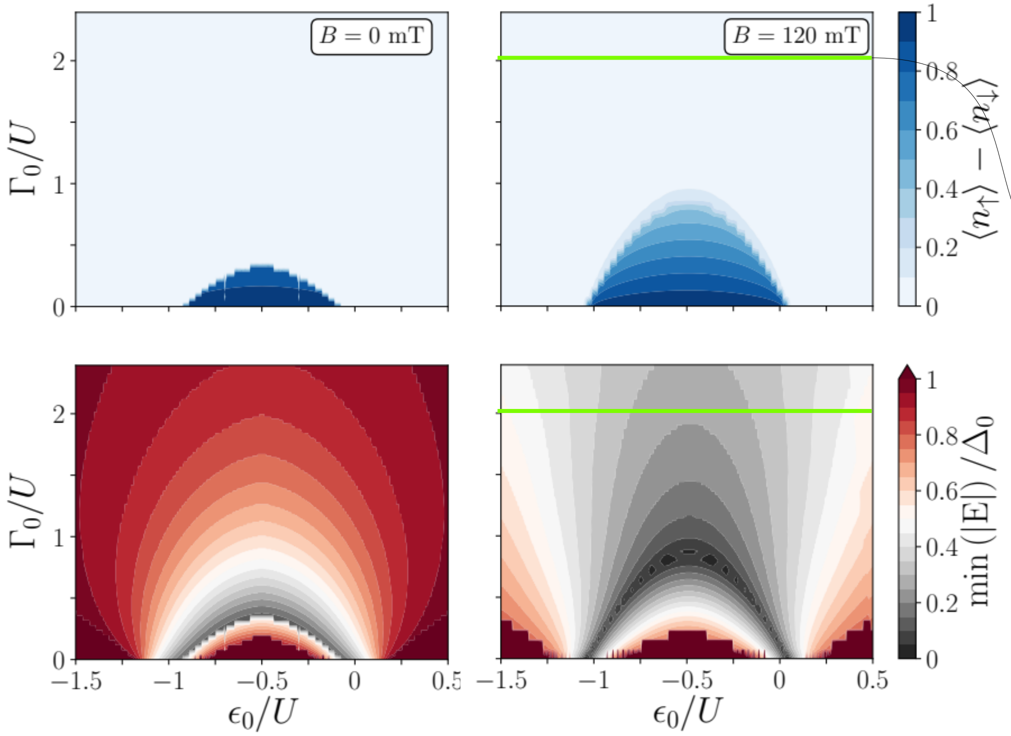


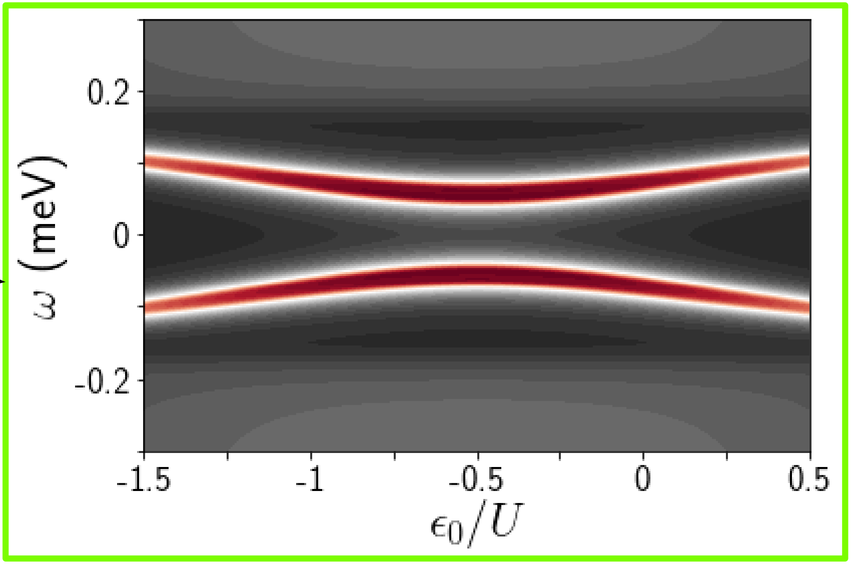


Results

n=0
Asymmetric case

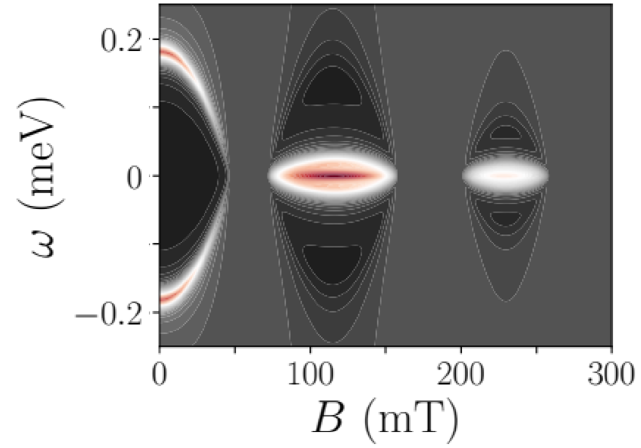
n=1
Asymmetric case



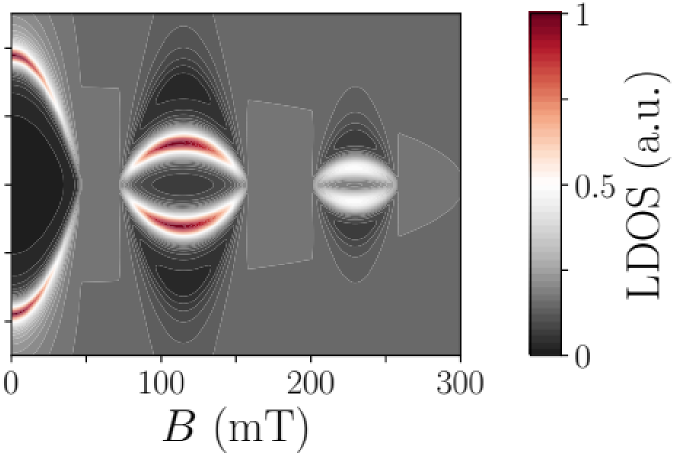


Results

**Strong coupling,
Symmetric case**

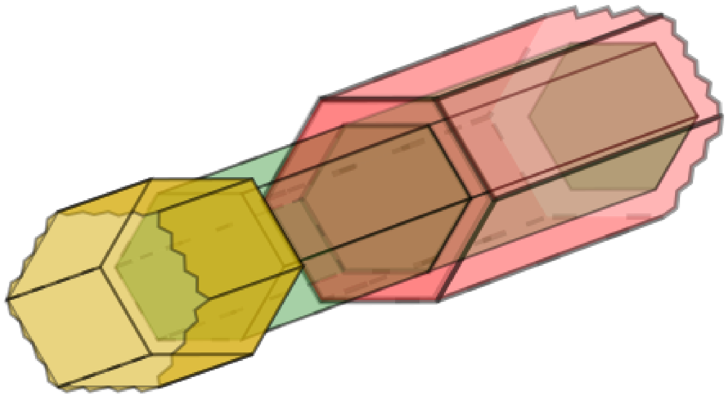


**Strong coupling,
Asymmetric case**



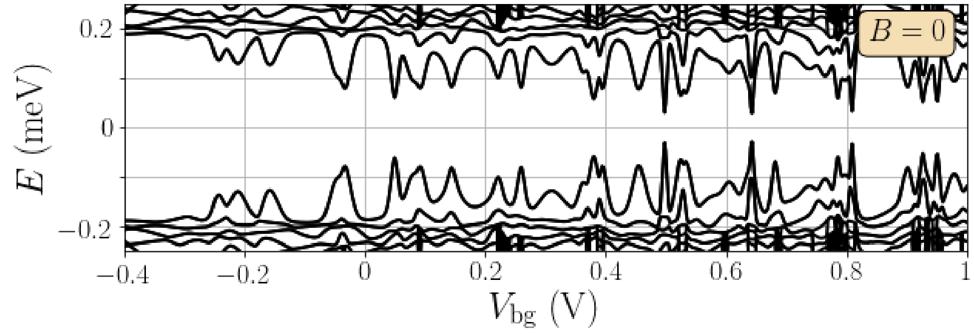
QD states may give rise to similar features to those of Majorana Bound States in full-shell wires

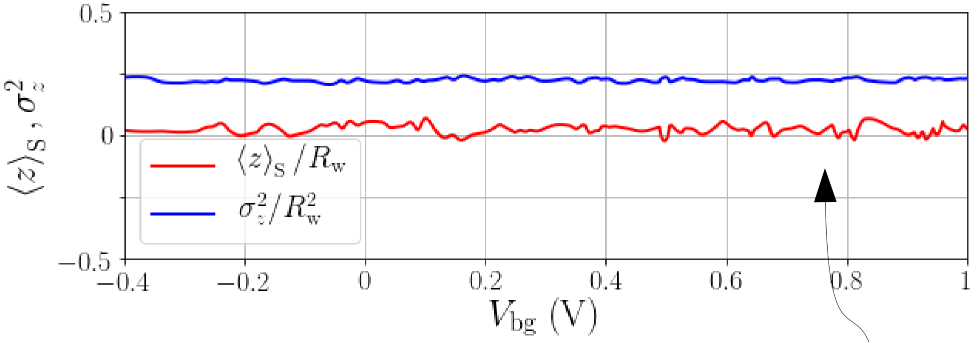
Results



$$H = \left(\frac{\hbar^2 \vec{k}^2}{2m^*} + e\phi(\vec{r}) \right) \sigma_0 \tau_z + \Delta(\vec{r}) \sigma_y \tau_y$$
$$+ \frac{1}{2} \left[\vec{\alpha}(\vec{r}) \cdot (\vec{\sigma} \times \vec{k}) + (\vec{\sigma} \times \vec{k}) \cdot \vec{\alpha}(\vec{r}) \right] \tau_z$$

Full Schrödinger-Poisson simulations



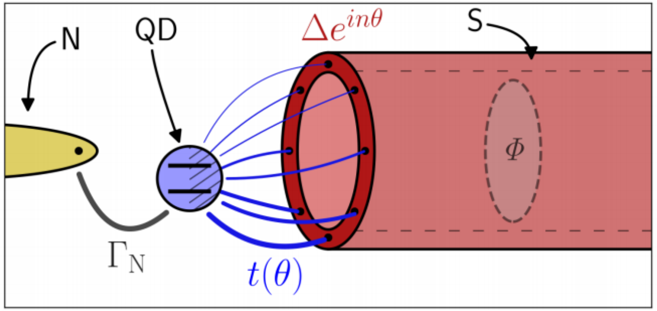


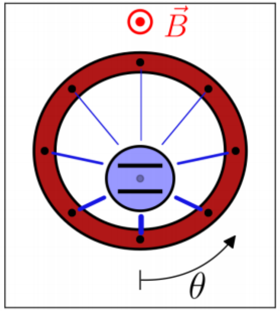
Symmetric case is a realistic situation!

Conclusions

Take-home messages

- N-QD-S junctions with full-shell superconductors develop quite different features and phase diagrams, specially in some cases.
- In the axial symmetric case, the superconducting pairing is always suppressed for the n>0 lobes.
- The YSR states are further pushed towards zero energy compared to a conventional N-QD-S junction.





Reference

Arxiv:2107.13011

Thank you for your attention!

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