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EDGE TRANSPORT IN QUANTUM SPIN HALL INSULATOR-SUPERCONDUCTOR HETEROSTRUCTURES

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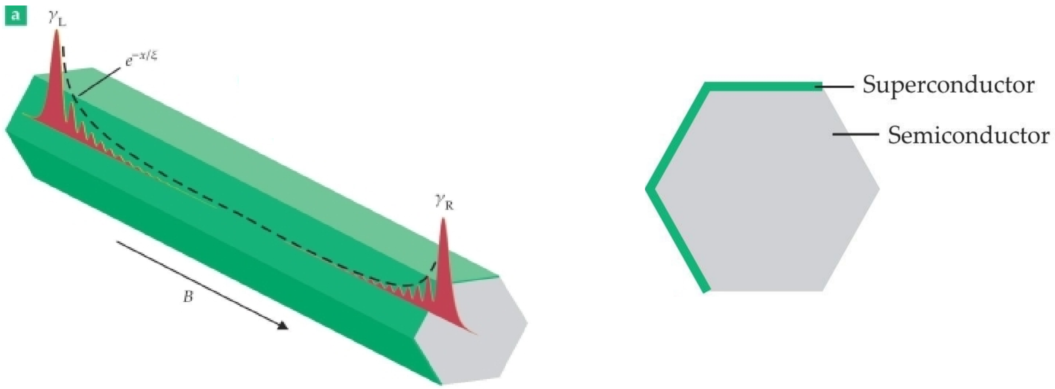
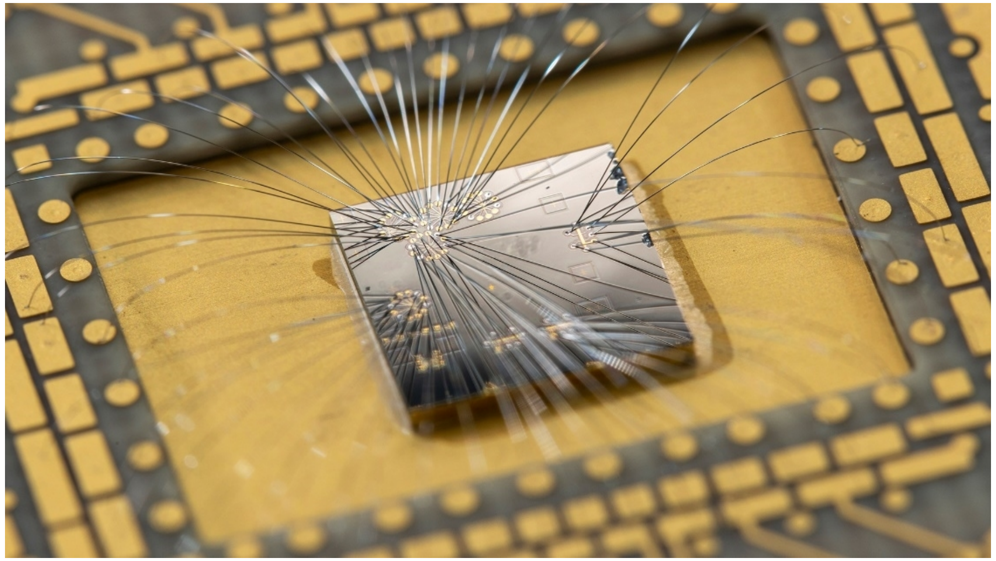
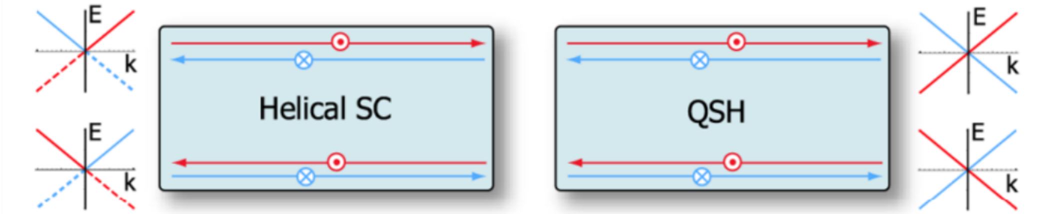
MOTIVATION



R. M. Lutchyn, J. D. Sau, S. Das Sarma, *Phys. Rev. Lett.* **105**, 077001 (2010)

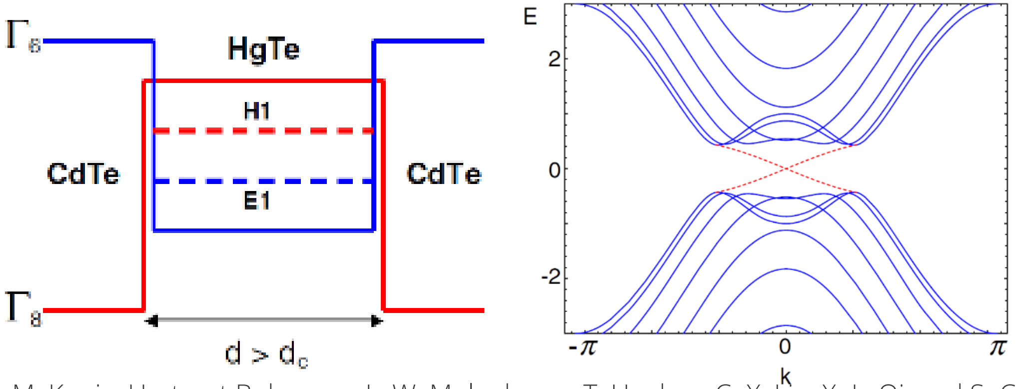


Microsoft Azure Quantum (2022)



Time-reversal invariant

X.-L. Qi, T. L. Hughes, S. Raghu, and S.-C. Zhang. PRL 102, 187001 (2009)



M. Konig, Hartmut Buhmann, L. W. Molenkamp, T. Hughes, C.-X. Liu, X.-L. Qi, and S.-C. Zhang J. Phys. Soc. Jpn. (2008)

Quantum Computing with Majorana Kramers Pairs

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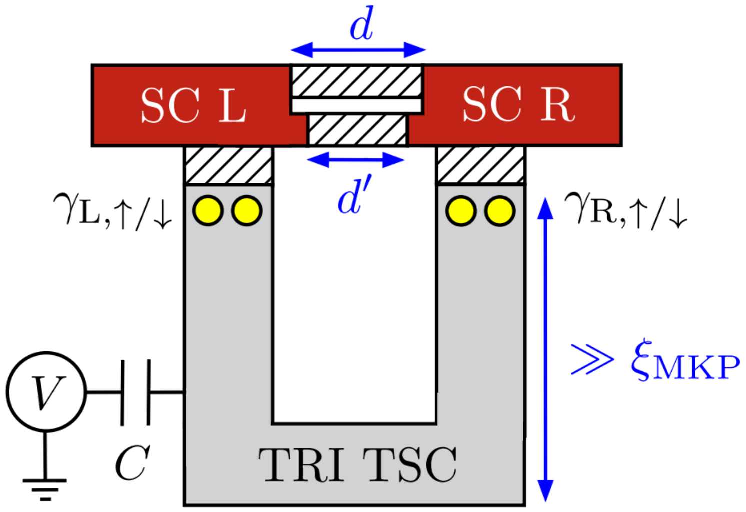
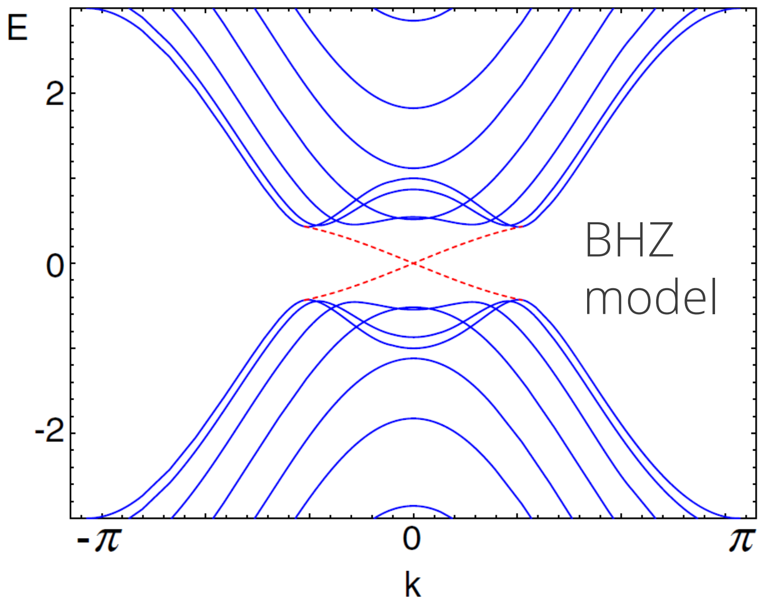
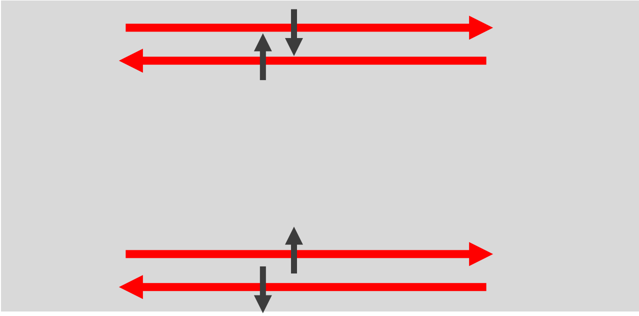
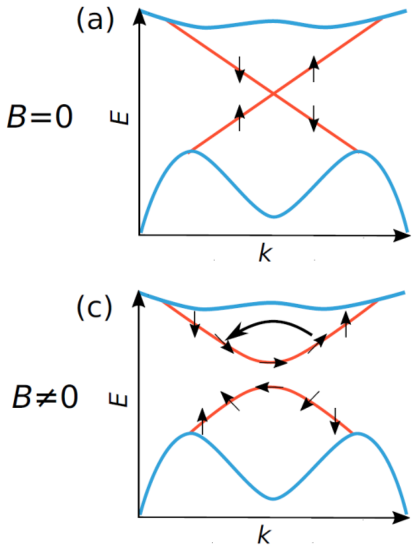
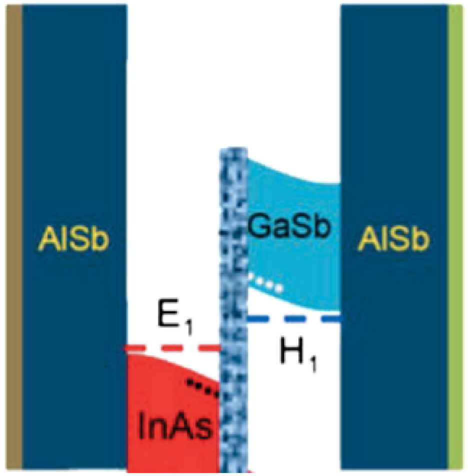


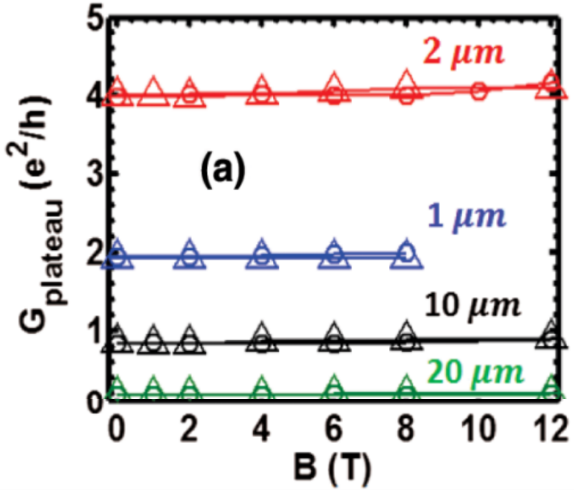
QUANTUM SPIN HALL INSULATORS



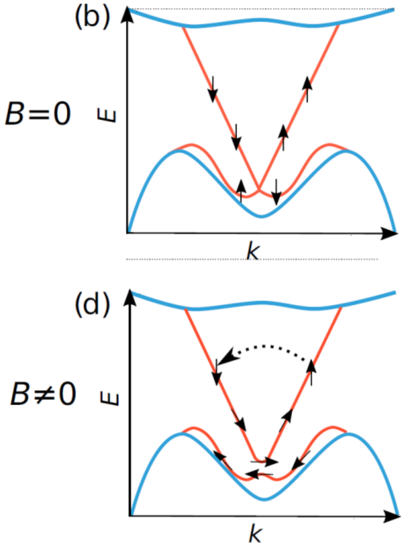


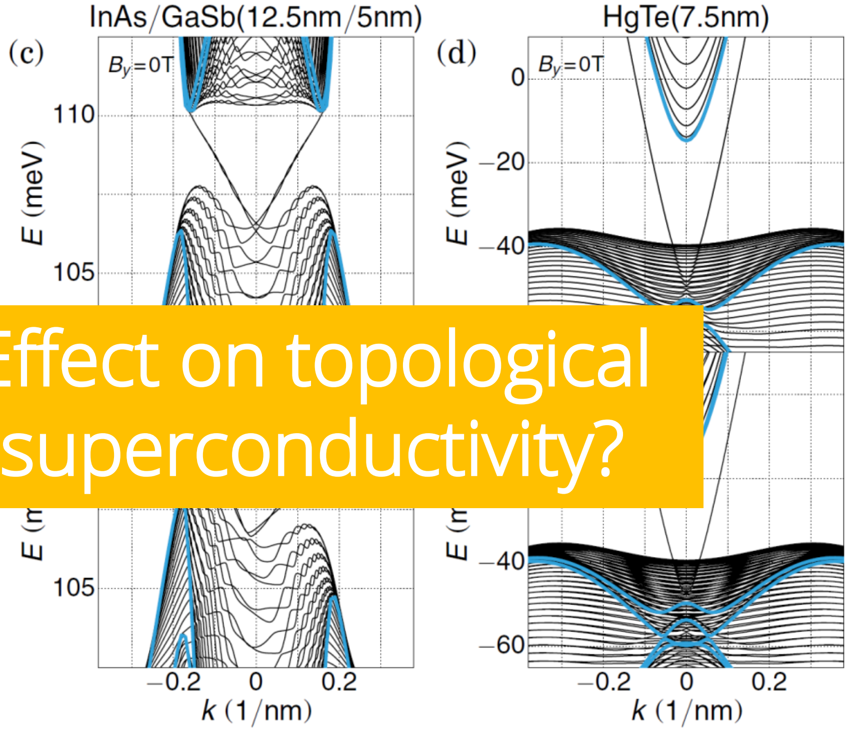






L Du, I. Knez, G. Sullivan, and R.-R. Du. PRL 114, 096802 (2015)

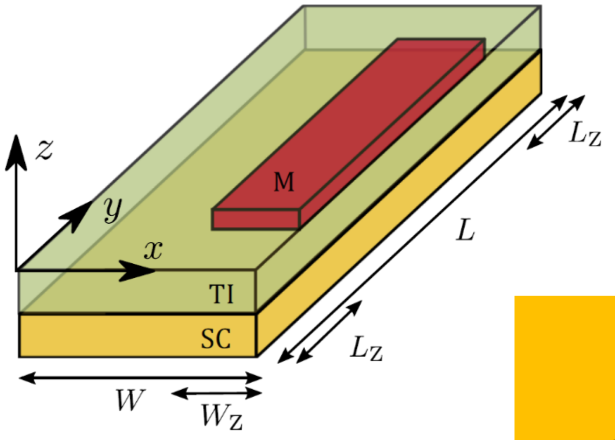


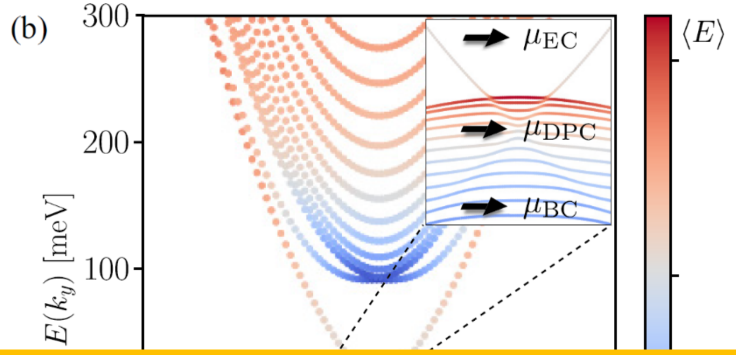


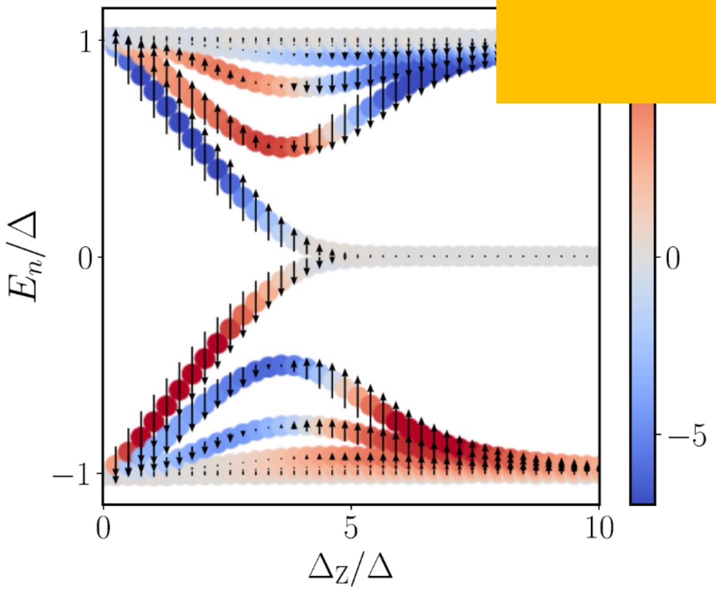
Effect on topological superconductivity?

R. Skolasinski, D. I. Pikulin, J. Alicea, and M. Wimmer PRB 98, 201404(R) (2018)

TOPOLOGICAL SUPERCONDUCTIVITY



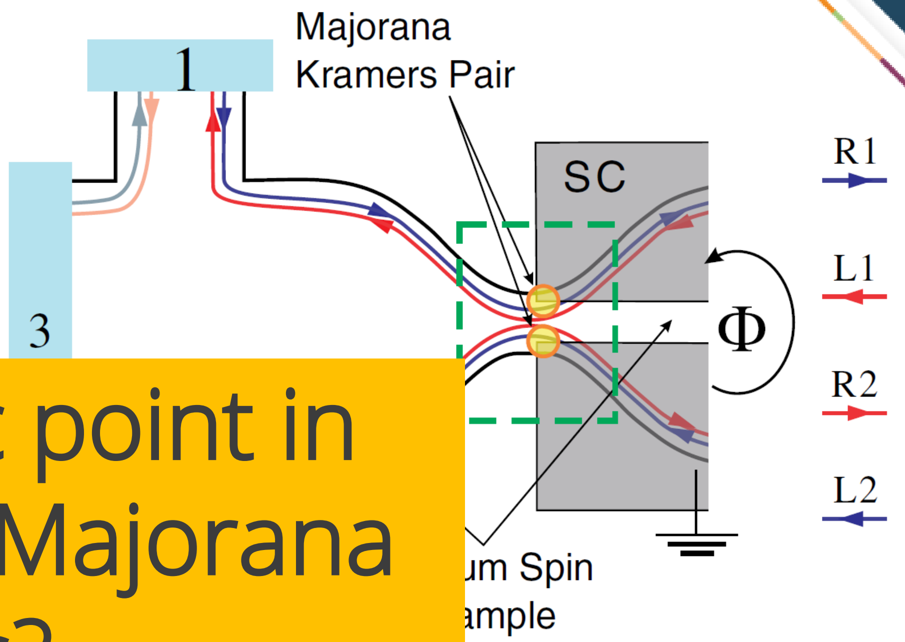


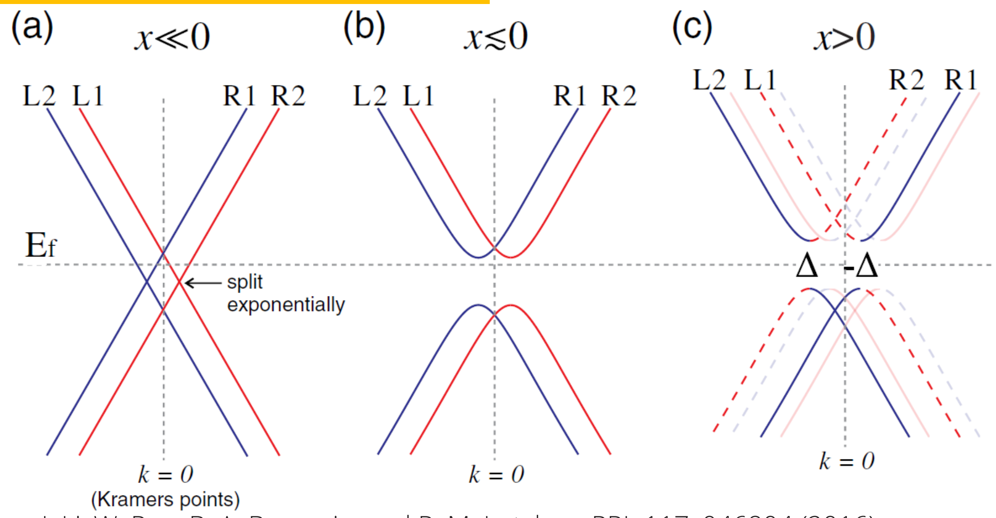


F. Schulz, K. Plekhanov, D. Loss, and J. Klinovaja. PR Res. 2, 033215 (2020)

Role of buried Dirac point in QPC setup & fate of Majorana Kramer pairs?

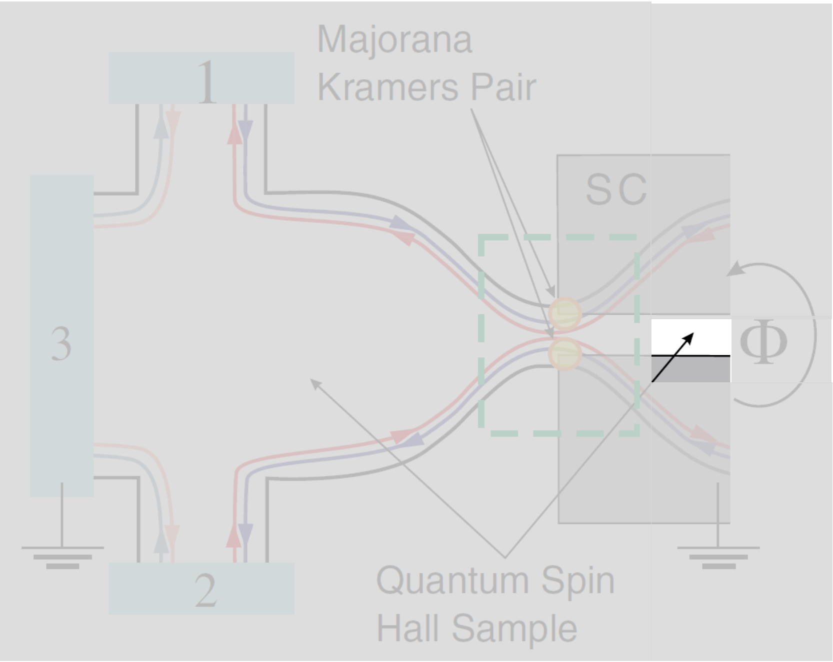
MZMs robust against buried DP

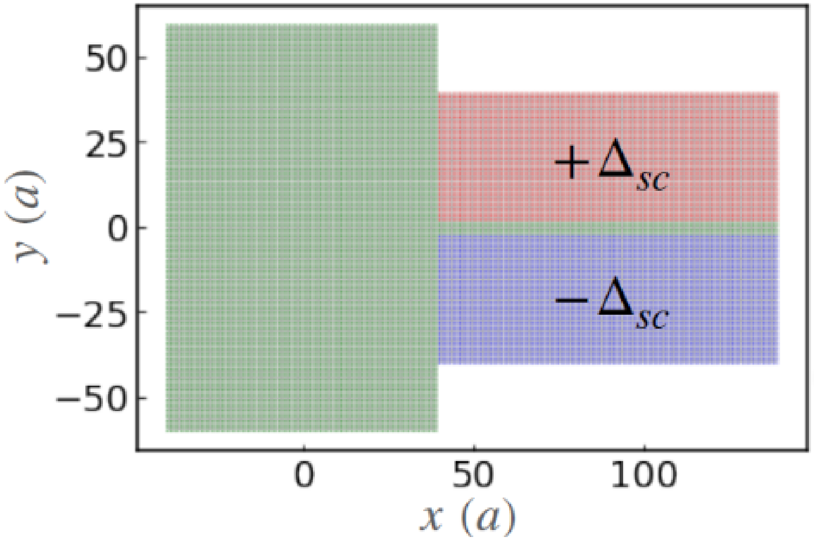




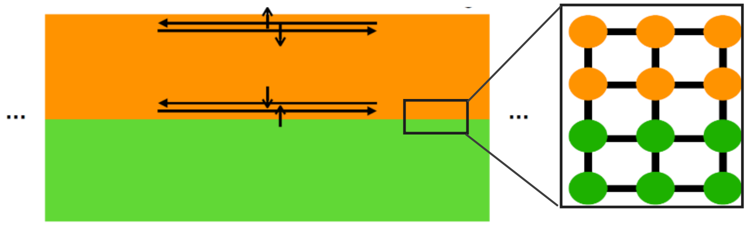
J. Li, W. Pan, B. A. Bernevig, and R. M. Lutchyn. PRL 117, 046804 (2016)

MAJORANA KRAMER PAIRS IN HETEROSTRUCTURES





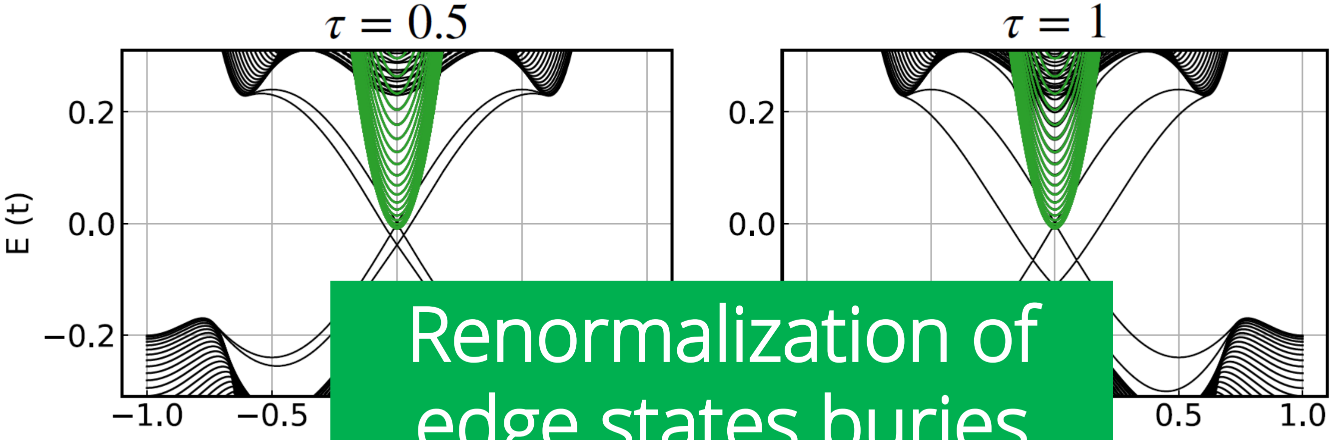
π-phase: condition for MKPs



QSHI

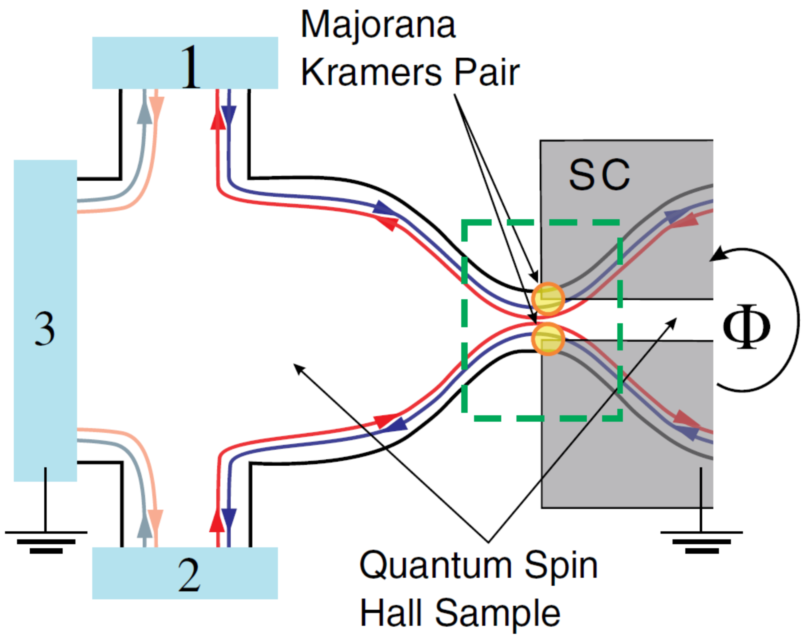
Normal metal

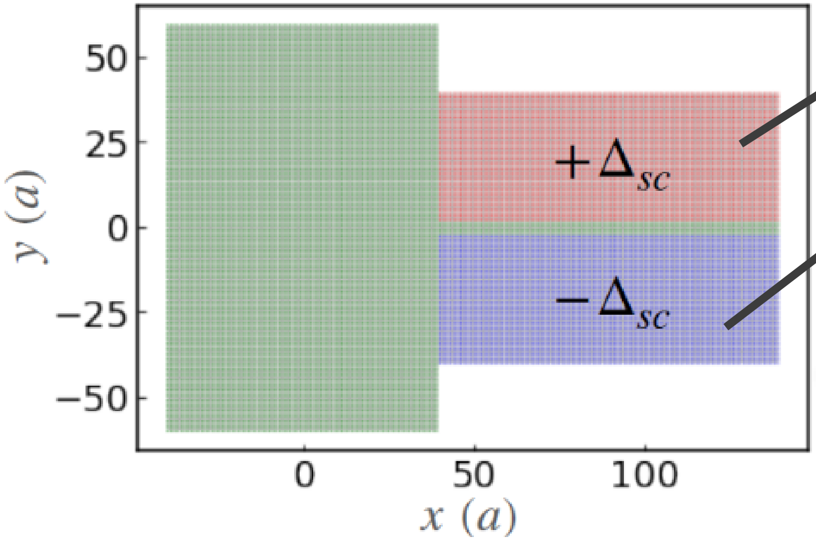
$$\hat{t}_{int} = \tau\left(\frac{\hat{t}_{BHZ} + \hat{t}_{2DEG}}{2}\right)$$



Renormalization of edge states buries Dirac point

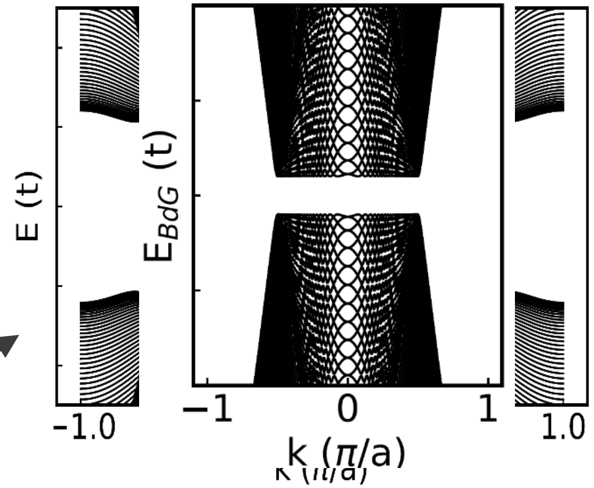
MAJORANA KRAMER PAIRS IN HETEROSTRUCTURES

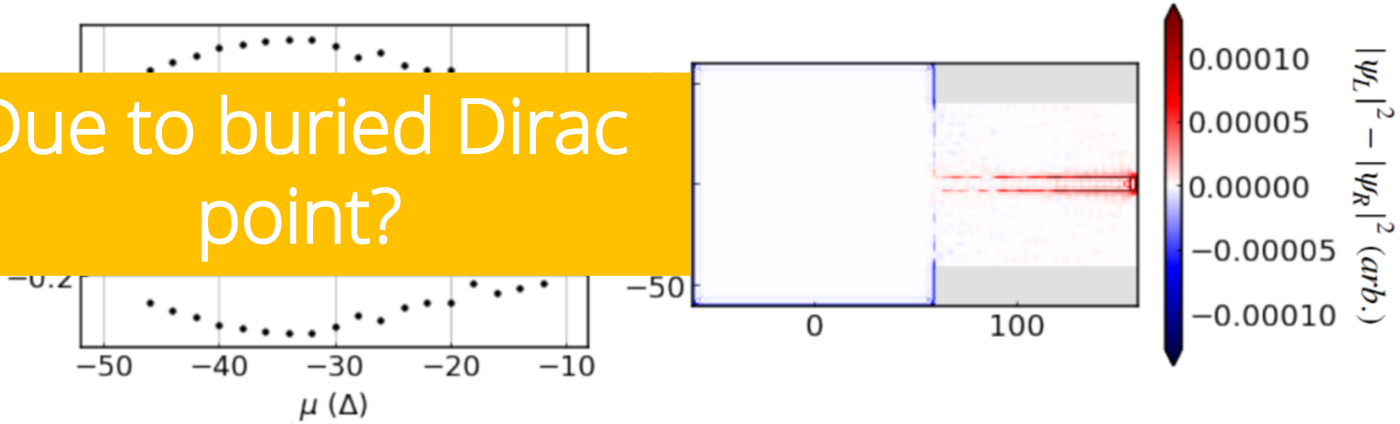




π-phase: condition for MKPs

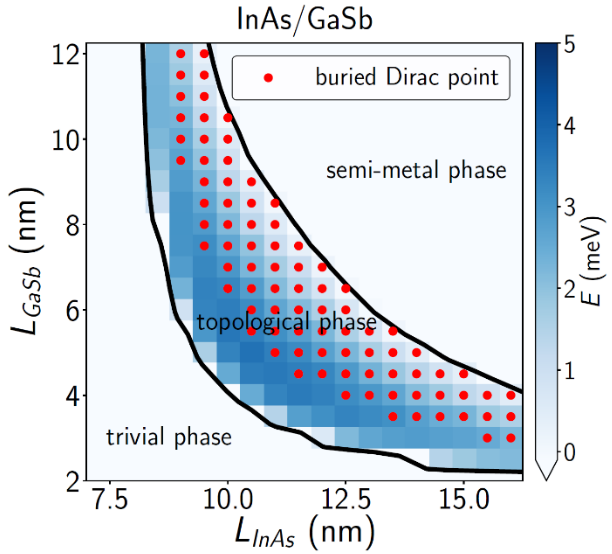
Parabolic band SC



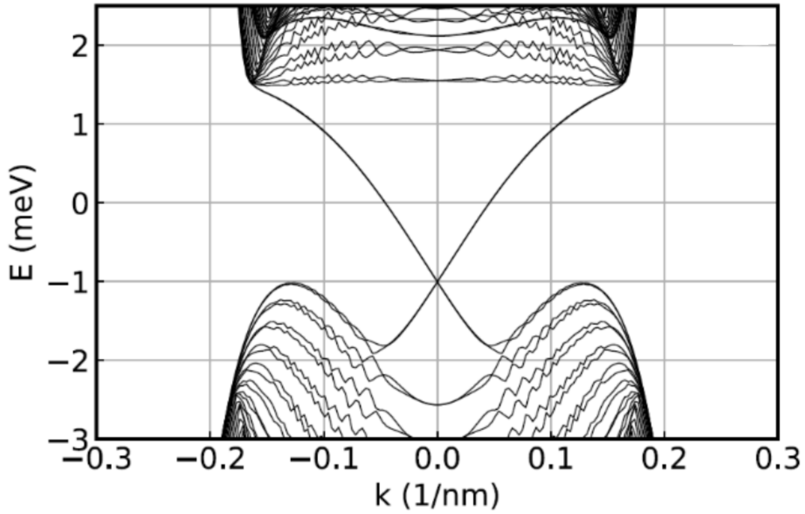


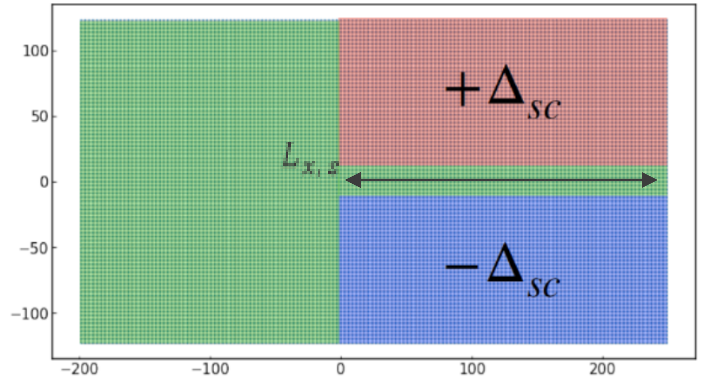
Due to buried Dirac point?

MAJORANA KRAMER PAIRS IN INAS/GASB

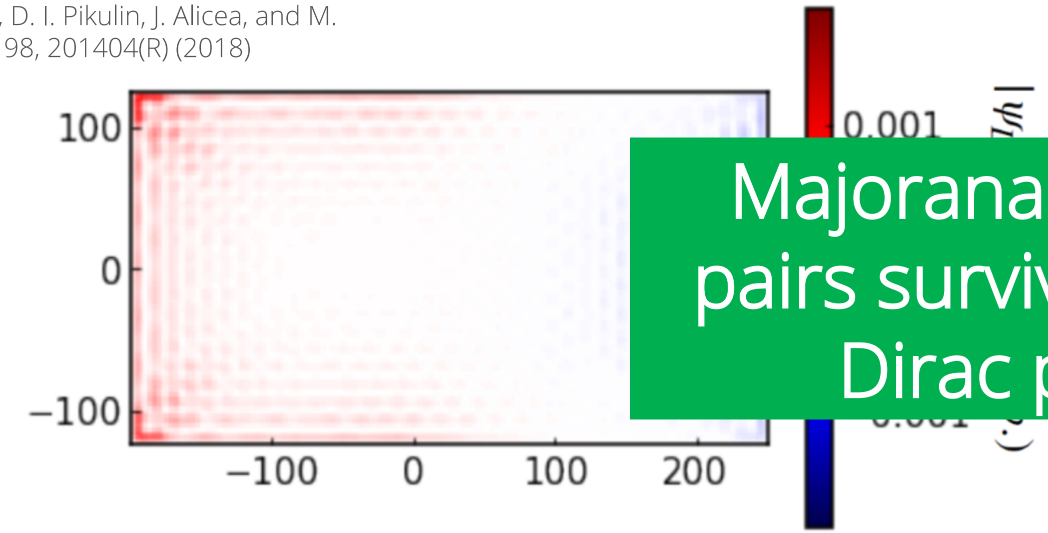


$$H = H_{BHZ} + H_3 + H_{soc}$$

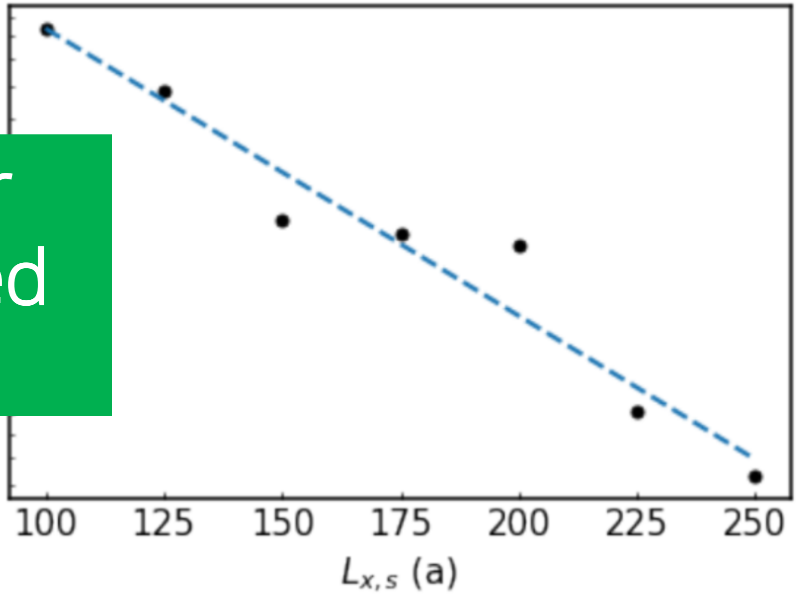




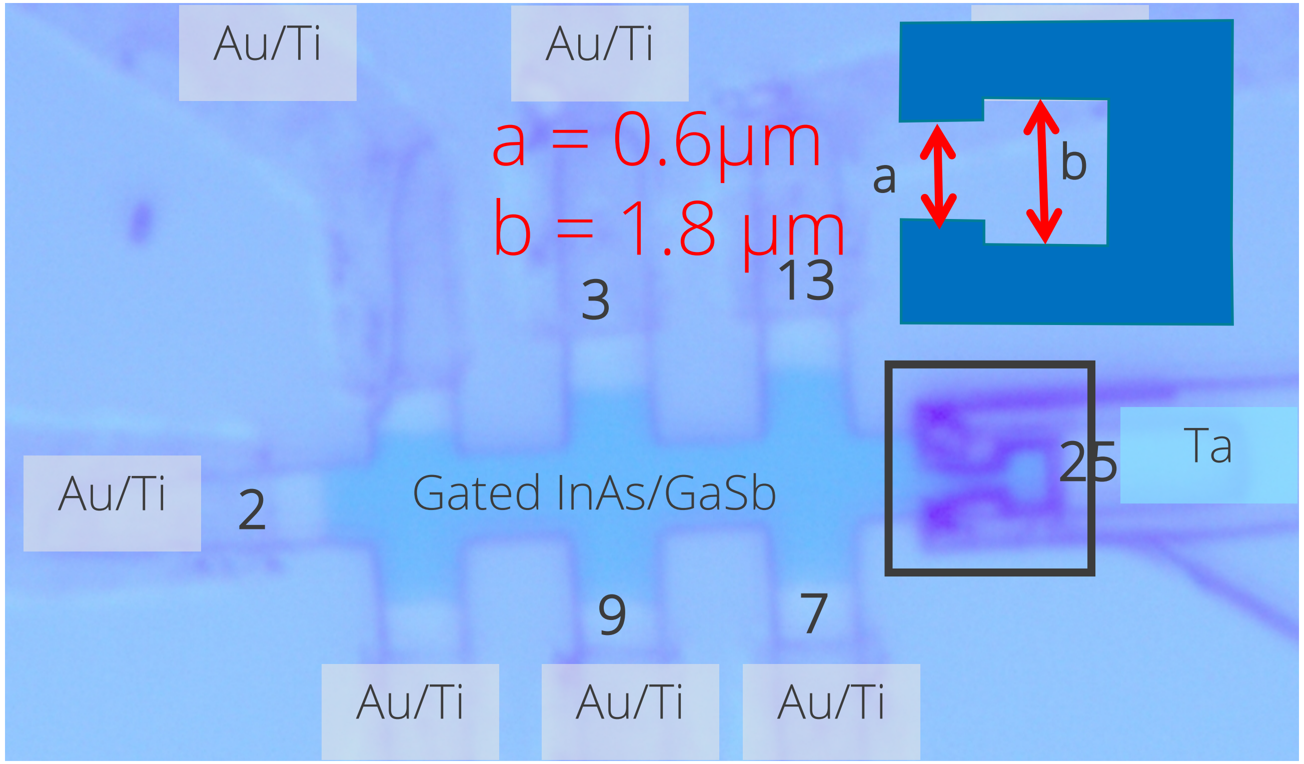
R. Skolasinski, D. I. Pikulin, J. Alicea, and M. Wimmer PRB 98, 201404(R) (2018)

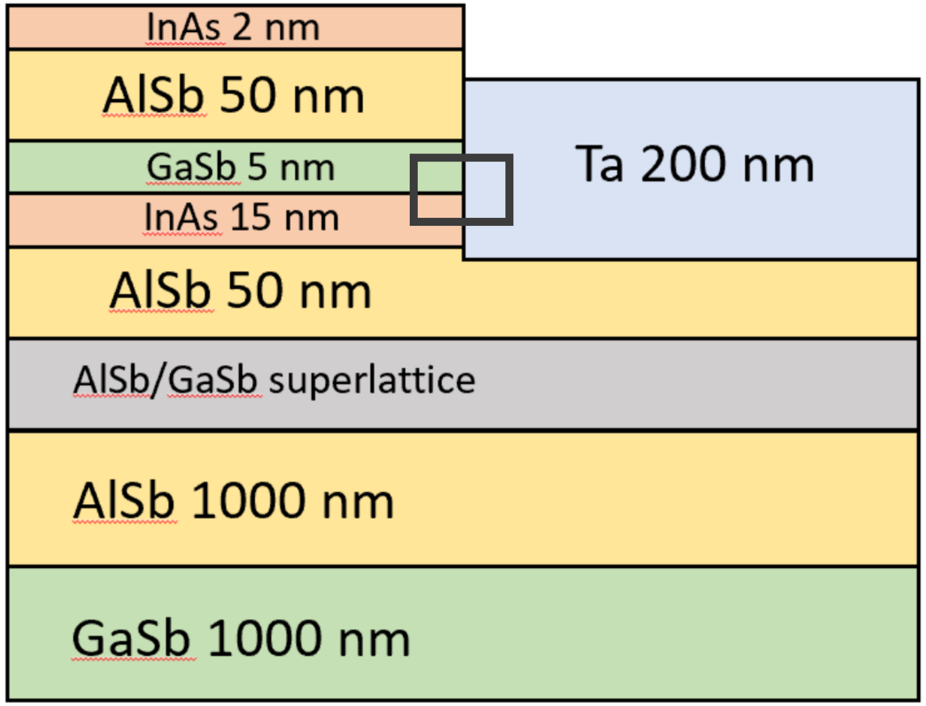


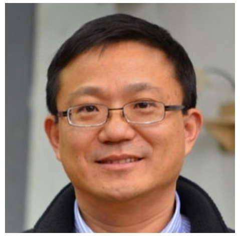
Majorana Kramer pairs survive buried Dirac point



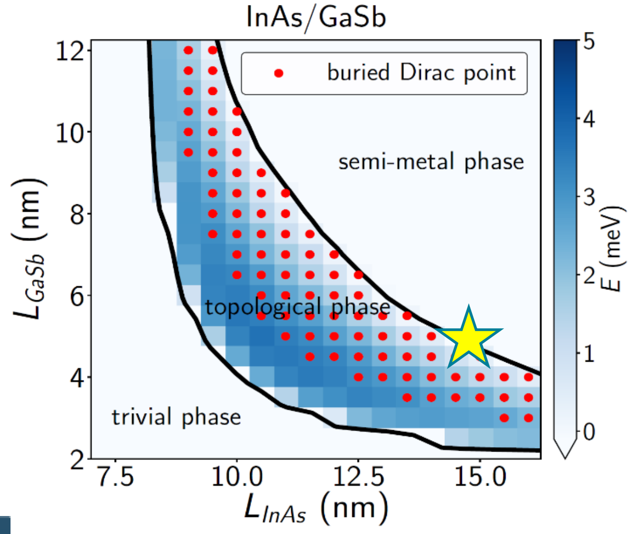
INAS/GASB DOUBLE QUANTUM WELL QPC

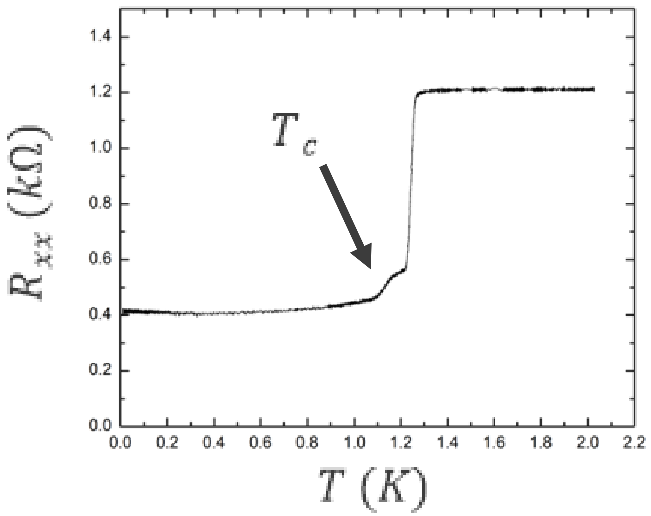


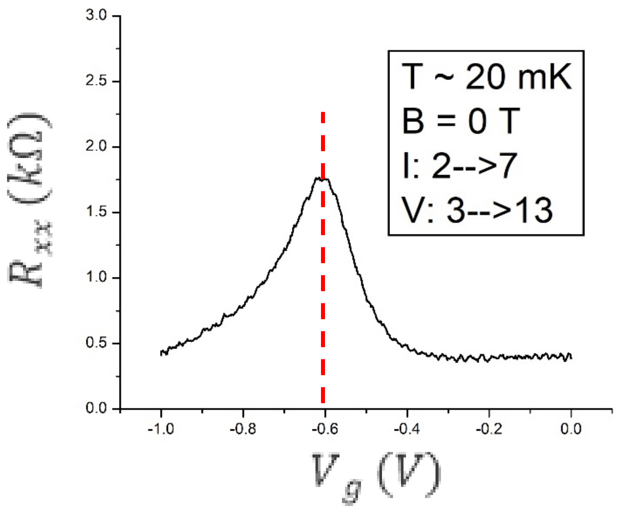




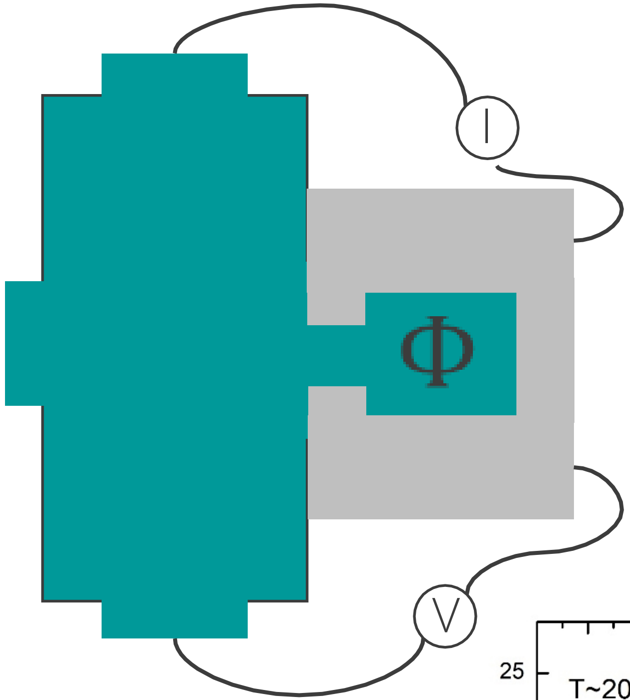
Wei Pan

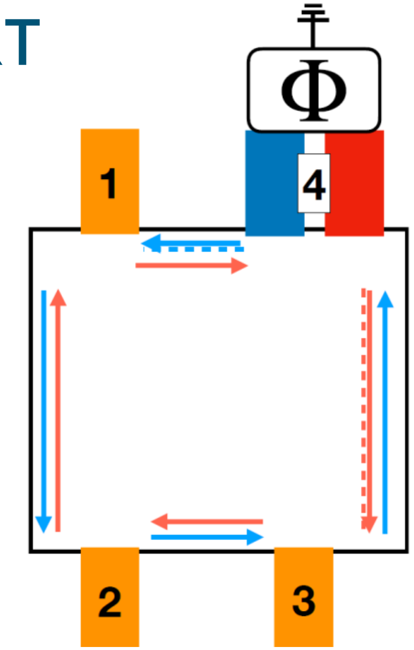






ELECTRONIC EDGE TRANSPORT

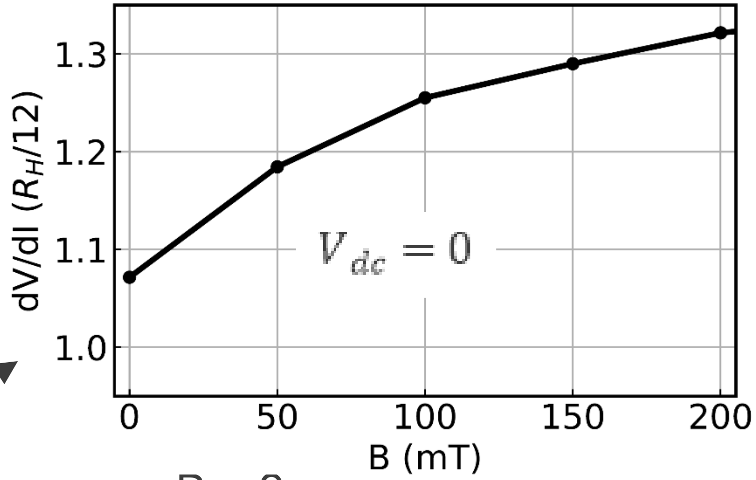




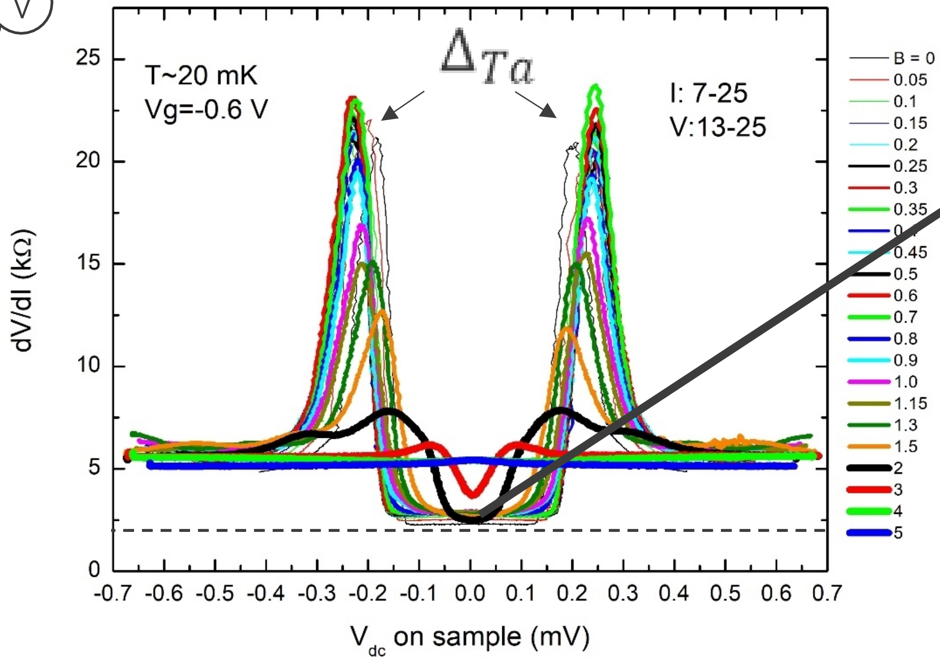
Modified Landauer-Büttiker analysis:

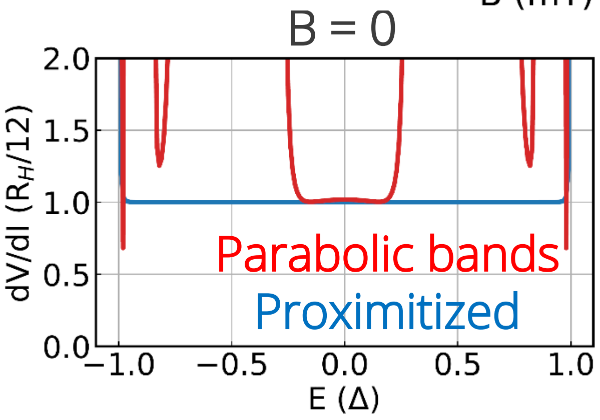
$$I : 1 \rightarrow 4$$

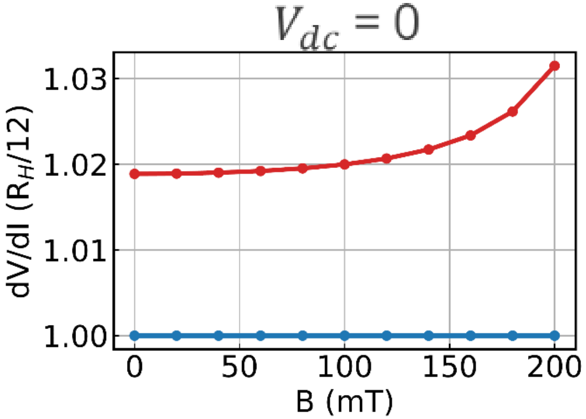
$$R_{34} = \frac{1}{12} R_H, \quad (T^{LAR} = 1)$$



Nearly perfect AR robust to B field







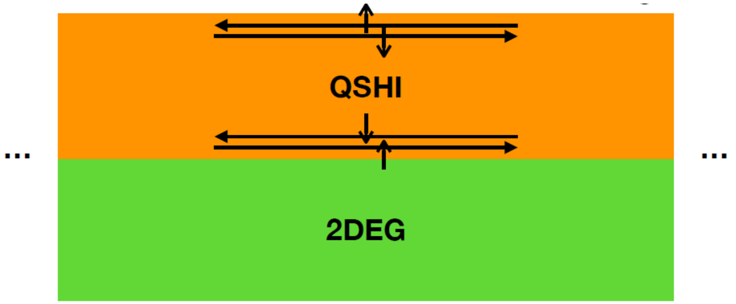
CONCLUSIONS

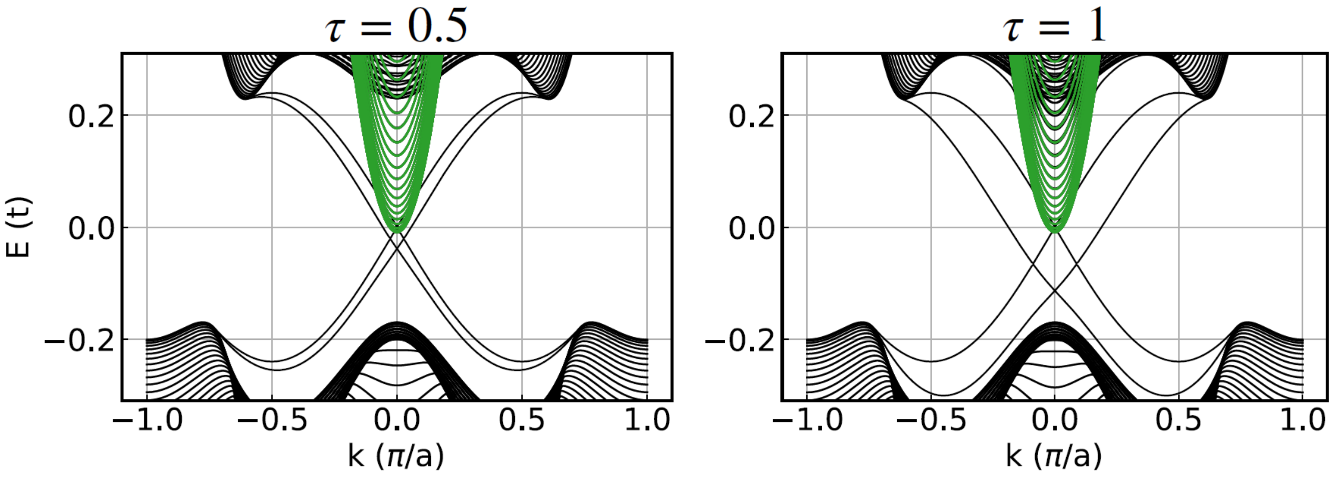
- **Buried Dirac points do not eliminate Majorana Kramer pairs** in QPC setup
- We showed **buried Dirac points** are **generic in heterostructures**
- We presented **experimental results** on high-quality **InAs/GaSb – Ta QPC device**
- Observed nearly **perfect Andreev reflection**
- Edge transport **robust at high fields**, suggesting an **intrinsic buried Dirac point** in InAs/GaSb(15 nm/5 nm) double quantum well

Thank you for your attention!
Questions?

ADDITIONAL SLIDES

MAJORANA KRAMER PAIRS IN HETEROSTRUCTURES





$$H = H_0 + H_N + H_T$$

$$H_0 = \sum_{\mathbf{k}} \psi^\dagger_{0,\mathbf{k}} \bar{\bar{h}}_0(\mathbf{k}) \psi_{0,\mathbf{k}} = \sum_{\mathbf{k}} \psi^\dagger_{0,\mathbf{k}} \left(\hbar v k_x \sigma_z - \mu_0\right) \psi_{0,\mathbf{k}}$$

$$H_N = \sum_{\mathbf{k}} \psi^\dagger_{N,\mathbf{k}} \bar{\bar{h}}_N(\mathbf{k}) \psi_{N,\mathbf{k}} = \sum_{\mathbf{k}} \psi^\dagger_{N,\mathbf{k}} \left(\frac{\hbar^2}{2m}\mathbf{k}^2 - \mu_N\right) \psi_{N,\mathbf{k}}$$

$$H_T = \sum_{\mathbf{k}} \psi_{N,\mathbf{k}} \bar{\bar{h}}_T(\mathbf{q}) \psi_{0,\mathbf{k}+\mathbf{q}} + H.c.$$

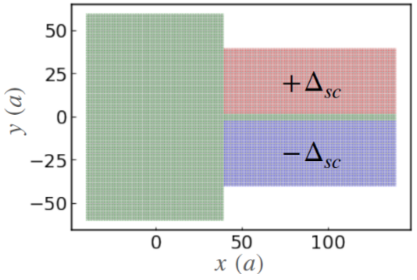
$$\bar{\bar{\Sigma}}_{int}(\omega, \mathbf{k}) = \int d\mathbf{q}\; \bar{\bar{h}}_T(-\mathbf{q}) G_N(\omega, \mathbf{k}+\mathbf{q}) \bar{\bar{h}}_T(\mathbf{q})$$

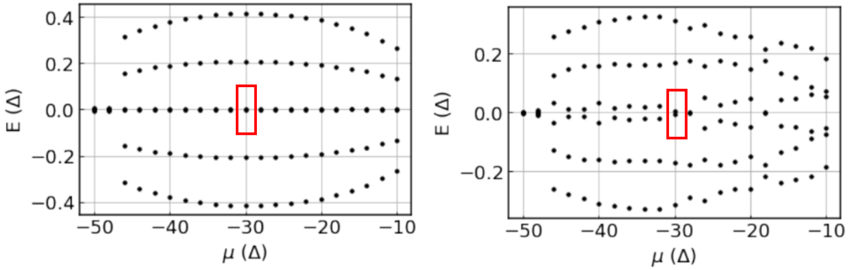
$$\boxed{\bar{\bar{h}}_{eff}(\mathbf{k}) = \left(\hbar v k_x \sigma_z - \Lambda\right) - \mu \qquad \Lambda \equiv \pi t_T^2 \rho_{F,N}}$$

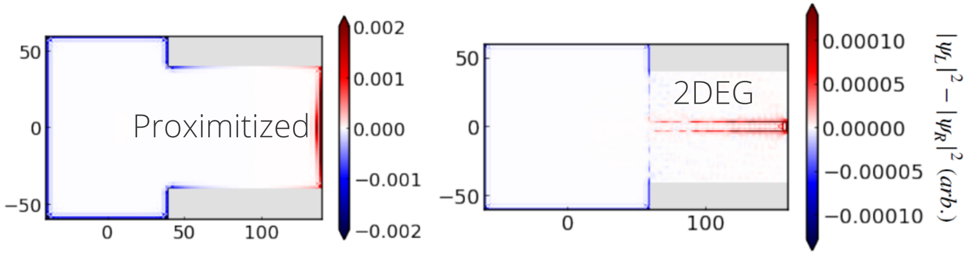
$$H_0^{(tb)} = \sum_i \Phi_i^\dagger \left(\mu_{sm}\rho_z - \mu\right)\Phi_i + \sum_{\langle ij\rangle} \Phi_i^\dagger \left[-\frac{t_1}{2}\rho_z - \frac{t_2}{2} - i\frac{\lambda}{2}\left(\delta_{y_i y_j}\rho_x\sigma_z - \delta_{x_i x_j}\rho_y\right)\right]\Phi_j + H.c.$$

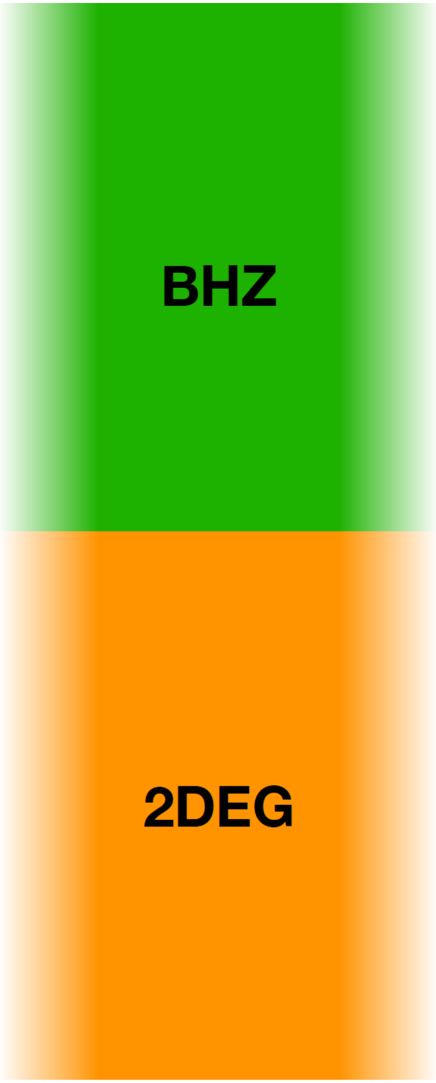
$$\Phi_i = \left(s_{\uparrow,\mathbf{r}_i}, s_{\downarrow,\mathbf{r}_i}, p_{\uparrow,\mathbf{r}_i}, p_{\downarrow,\mathbf{r}_i}\right)^T$$

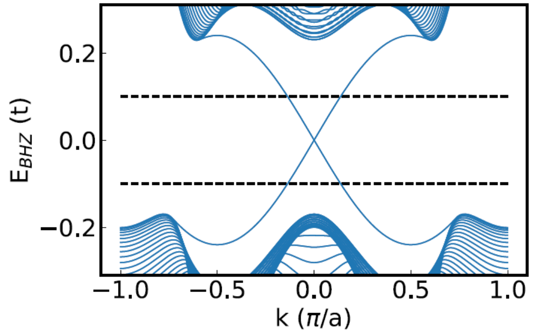
$$\begin{pmatrix} H-\mu & \Delta \\ \Delta^* & \mu - THT^{-1} \end{pmatrix} \begin{pmatrix} u \\ v \end{pmatrix} = E \begin{pmatrix} u \\ v \end{pmatrix}$$

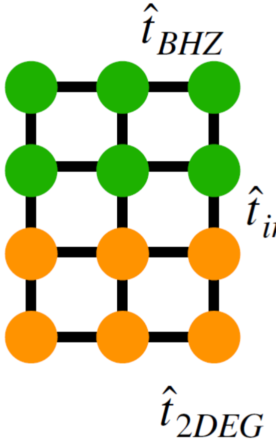




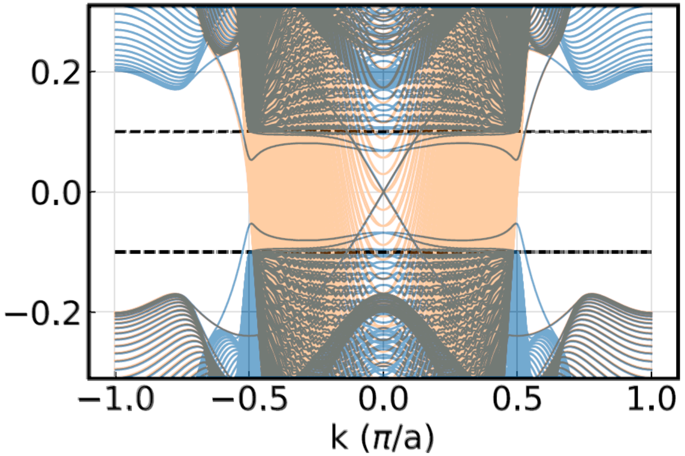


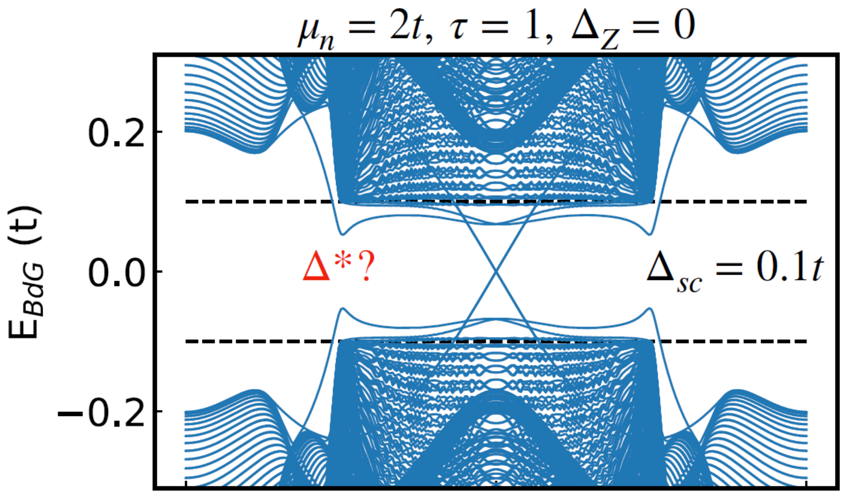


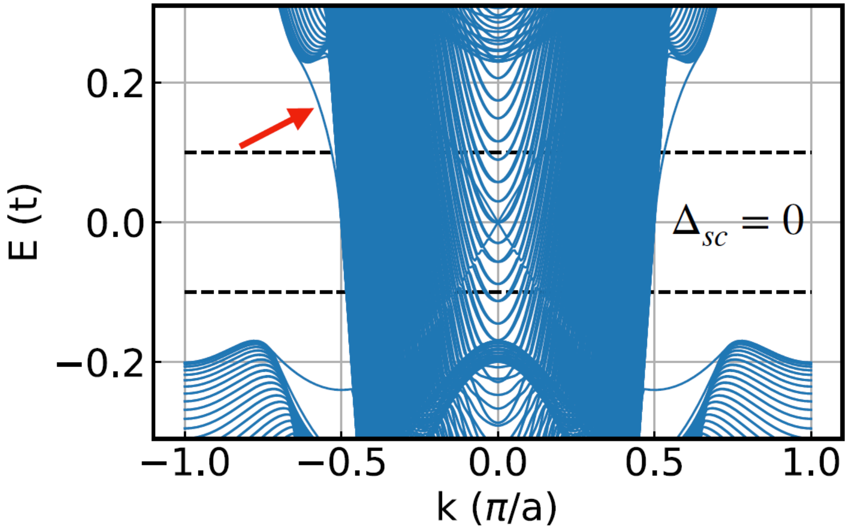




$$\hat{t}_{int} = \tau \left(\frac{\hat{t}_{BHZ} + \hat{t}_{2DEG}}{2} \right)$$

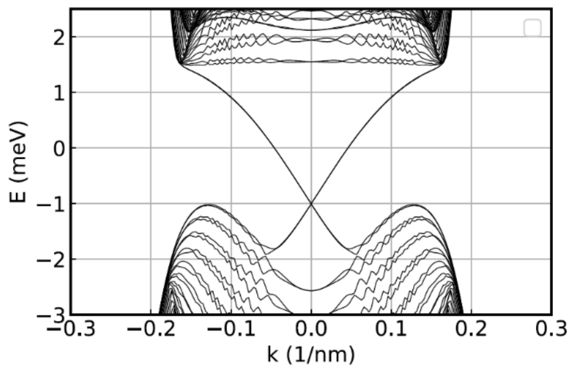


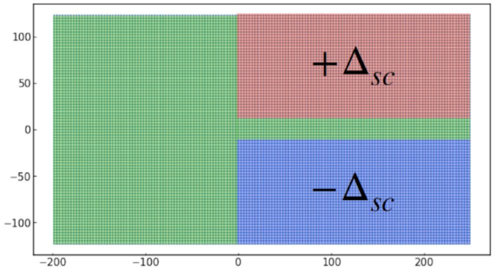


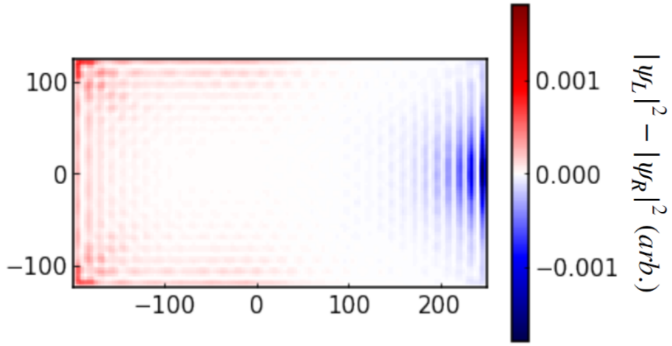


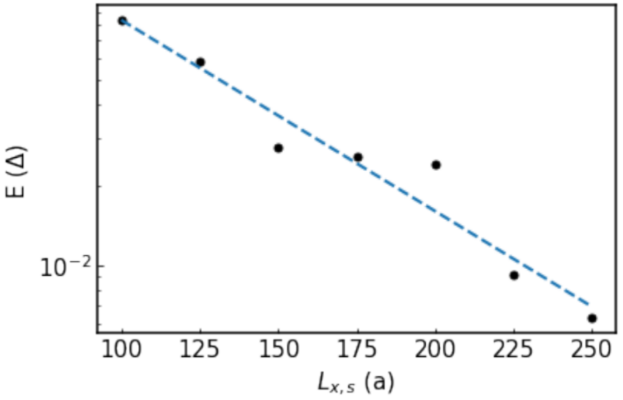
MAJORANA KRAMER PAIRS IN INAS/GASB

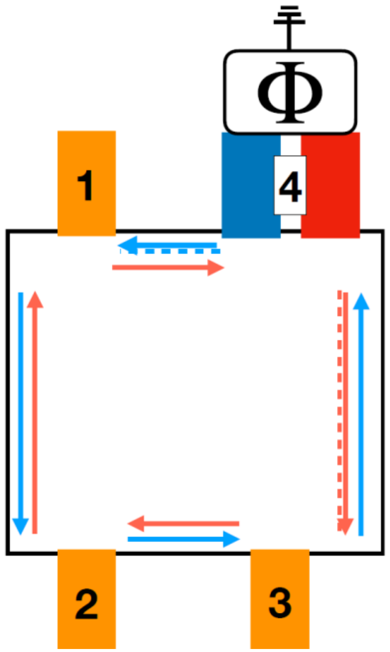
$$H = H_{BHZ} + H_3 + H_{soc}$$











$$I : 1 \rightarrow 4$$

$$R_{14} = \frac{V_1 - V_4}{I} = R_H \left(\frac{1}{4(T^{LAR} + T^{CAR})} + \frac{1}{2(3 - 2T^{CAR} - 2T^{B})} \right)$$

$$R_{24} = \frac{V_2 - V_4}{I} = R_H \left(\frac{1}{4(T^{LAR} + T^{CAR})} \right)$$

$$\boxed{R_{34} = \frac{V_3 - V_4}{I} = R_H \left(\frac{1}{4(T^{LAR} + T^{CAR})} - \frac{1}{2(3 - 2T^{CAR} - 2T^{B})} \right)}$$

$$R_{34} = \frac{1}{12} R_H, \quad (T^{LAR} = 1)$$

$$R_{34} = -\frac{1}{4} R_H, \quad (T^{CAR} = 1)$$