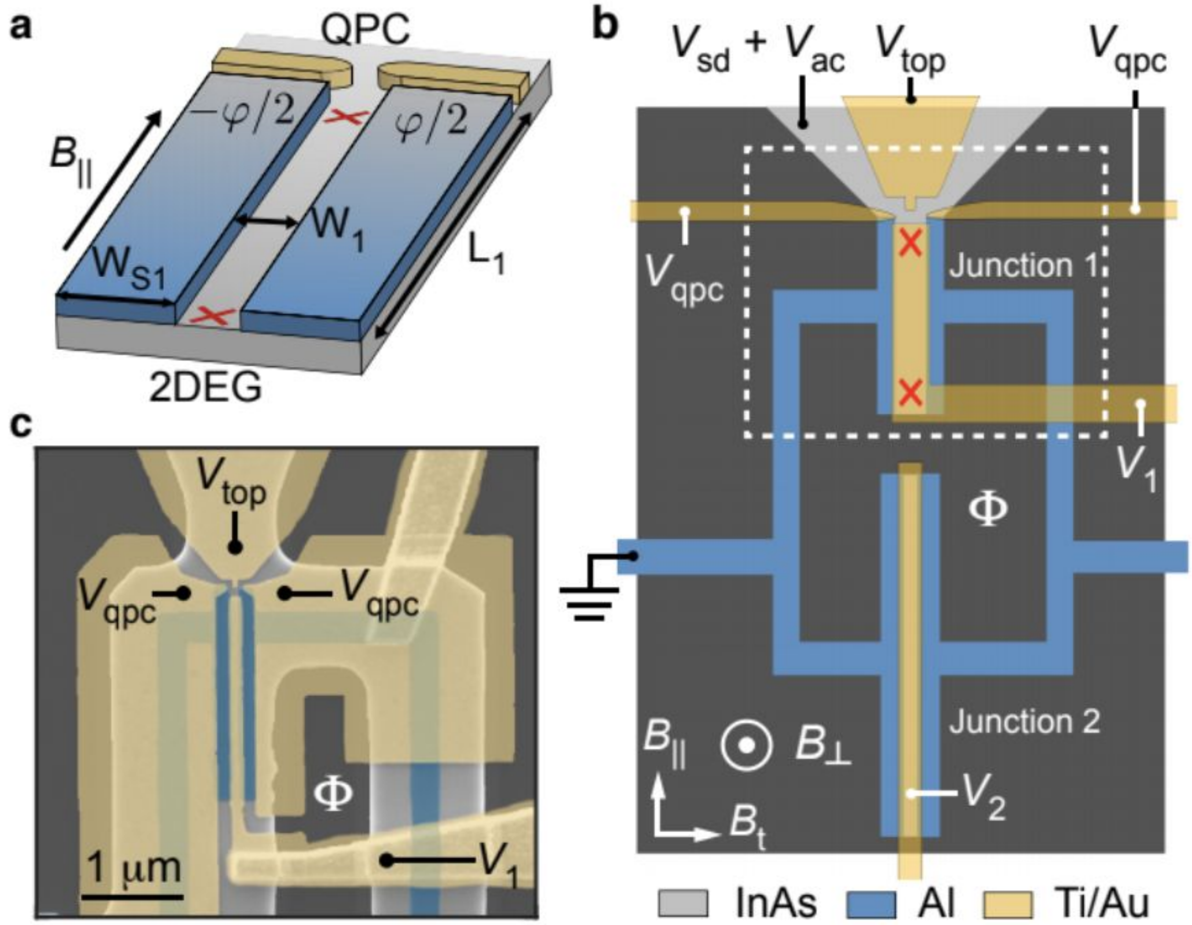
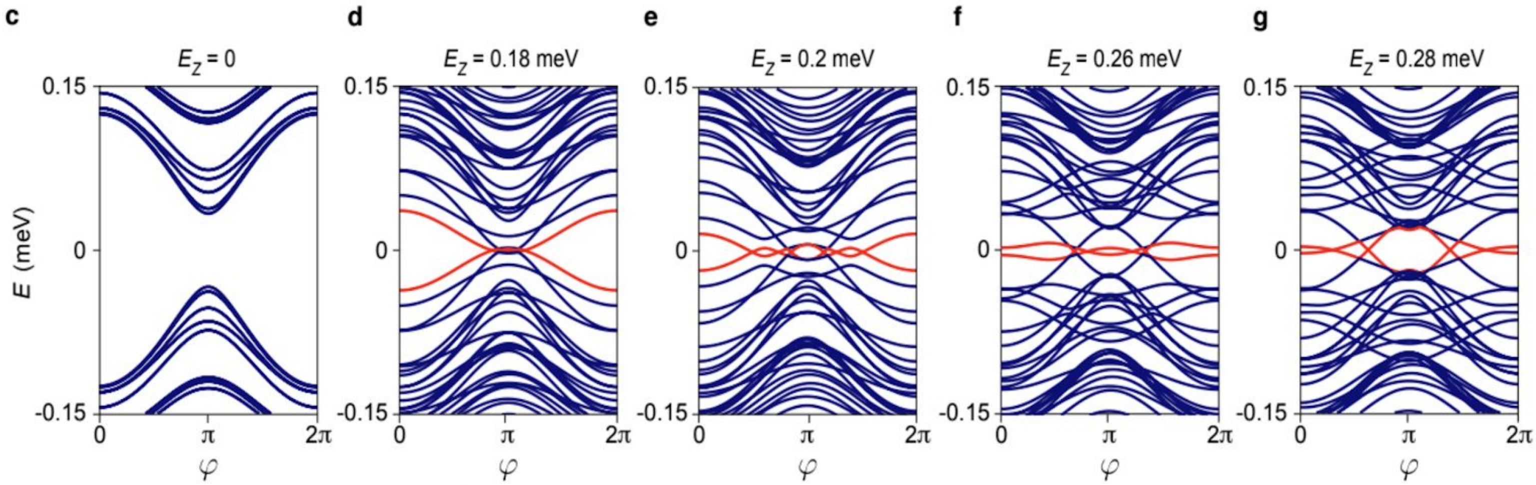
Evidence of topological superconductivity in planar Josephson junctions

Antonio Fornieri,[1,*] Alexander M. Whiticar,[1,*] F. Setiawan,[2] Elías Portolés Marín,[1] Asbjørn C. C. Drachmann,[1] Anna Keselman,[3] Sergei Gronin,[4,5] Candice Thomas,[4,5] Tian Wang,[4,5] Ray Kallaher,[5,6] Geoffrey C. Gardner,[5,6] Erez Berg,[2,7] Michael J. Manfra,[4,5,8,9] Ady Stern,[7] Charles M. Marcus,[1,†] and Fabrizio Nichele[1,‡]





EXTENDED DATA FIG. 1. **Calculated topological phase diagrams and energy spectra.** **a**, Topological phase diagram as a function of the Zeeman energy E_Z and the 2DEG chemical potential μ for phase bias $\varphi = 0, \pi$, calculated from the tight-binding Hamiltonian for JJ1 with infinite length (see Methods). The curves indicate the critical value of E_Z above which the system is tuned into the topological phase. **b**, Topological phase diagram as a function of E_Z and φ for different values of μ, as indicated by the horizontal ticks in panel **a**. The diagrams were calculated for a junction with width $W_1 = 80$ nm, superconducting lead width $W_{S1} = 160$ nm, induced gap $\Delta = 150$ μeV and Rashba spin-orbit coupling constant $\alpha = 100$ meV Å. The length of the junction L_1 was assumed to be infinite in order to obtain a well-defined topological invariant, as described in the Methods. **c-g**, Calculated energy spectra as a function of φ for different values of the Zeeman energy. The spectra were obtained for the same parameters used in panels **a** and **b**, except for $L_1 = 1.6$ μm. The chemical potential μ was set to 79.1 meV (corresponding to the blue curve in panel **b**). For the chosen parameters, the system undergoes a topological transition at $E_Z = 0.153$ meV for $\varphi = \pi$ and at $E_Z = 0.195$ meV for $\varphi = 0$. The lowest energy subgap states are shown in red and indicate two Majorana zero modes at the edges of the junction in the topological regime. As a function of E_Z these states first reach zero energy at $\varphi = \pi$ and progressively extend in phase. At high values of E_Z the Majorana modes oscillate around zero energy due to the finite size of our system which causes the Majorana wave functions to hybridize. This is particularly evident at $\varphi = \pi$, where the induced gap is minimized and the coherence length is maximized. **h, i**, Probability density $|\Psi|^2$ of the Majorana wavefunction calculated as a function of the spatial directions x and y in JJ1 for $E_Z = 0.26$ meV and $\varphi = 0$, π. x is the coordinate in the width direction including the superconducting leads ($W_1 + 2W_{S1} = 0.4$ μm, with $x = 0$ indicating the center of the junction), while y is the coordinate along the length of the junction. The Majorana wavefunctions are localized in the y direction at the edges of the junction when the lowest energy states in the spectrum are close to zero energy. In the x direction the Majorana modes are delocalized below the superconducting leads, due to our geometry having $W_{S1} \ll \xi_S$.