

Superconductivity and the quantum Hall effect are two remarkable quantum phenomena that reveal the strange and beautiful behaviors of electrons in extreme conditions. Superconductors allow electric current to flow without resistance, while in the quantum Hall effect, electrons travel only along the edges of a material in perfectly ordered, one-way channels. For decades, these effects were studied separately, but recent breakthroughs in materials and nanotechnology have opened a new frontier: combining both phenomena in the same system.

The aim of this project is to explore what happens when superconductivity meets the quantum Hall effect—specifically, how electrons behave at the interface where these two quantum worlds collide. One of the most fascinating outcomes of this combination is the creation of so-called chiral Andreev edge states. These are exotic quantum states where electrons and their mirror-like partners, called holes, move together in a fixed direction along the edge of the material, forming coherent quantum superpositions. In certain conditions, these states may even host particles that behave like Majorana fermions, which could one day be useful for building powerful quantum computers.

To investigate these ideas, the project will use advanced computer simulations and theoretical models. It will focus on several key questions: How exactly do these edge states form in special materials known as topological insulators? How do superconductors interact with "hole-like" particles in materials with unusual band structures? What happens when the superconductor itself is unconventional, with more exotic forms of electron pairing? And finally, how does this strange physics change when single electrons are sent into the system one by one, like flying quantum bits?

This research is motivated by recent experiments that have shown it is now possible to create such hybrid systems in the lab, especially using materials like graphene, gallium arsenide, or magnetically doped topological insulators. These systems open exciting possibilities not only for fundamental physics but also for future applications in quantum technologies, such as creating entangled particles or designing novel forms of quantum transport.

By answering fundamental questions about these hybrid quantum systems, the project is expected to deliver new insights into how superconductivity and topological effects combine. It will help scientists understand how to control these interactions at the microscopic level and offer theoretical guidance for designing next-generation quantum devices. Ultimately, this work contributes to the broader goal of harnessing quantum phenomena to build more advanced, reliable, and scalable technologies.