MSc project proposal: Time-resolved transport in QAH edge states towards the single electron limit

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What is our goal? In condensed matter physics, one typically studies collective phenomena involving vast numbers of particles. But imagine how exciting it would be to zoom in and study how a single electron behaves. In conventional metals, this is impossible to detect. However, certain exotic materials provide a unique platform for observing single-electron behavior. One such material is the quantum anomalous Hall (QAH) insulator—a quasi-2D material with an insulating bulk and 1D metallic edge states. The transport along the edges is chiral and topologically protected, which results in exceptionally long mean free paths. In these confined 1D channels, electron interactions can become exceptionally strong, leading to collective modes that challenge the traditional picture of electrons propagating independently. We want to explore how these interactions give rise to new physics beyond what we observe in 2D or 3D systems.

And how do we realize this? Three key ingredients make this possible. The first is extremely low temperatures: we conduct our measurements in a dilution refrigerator and reach base temperatures as low as 10 mK (see Fig.1a). The second ingredient is the sample geometry itself, which allows us to control the edge states electrically. As shown in Fig.1b, our sample consists of the QAH insulator with electrical contacts designed to inject or detect electrons.

A third crucial component is a high-frequency setup to push the limits and reach single-electron transport. This setup enables us to send picosecond-long pulses to the sample, to generate single-electron wavepackets and detect them after propagation along the edge (see Fig.1c). Optimizing this setup is at the heart of this project, and while detecting single-electron transport is a challenging task, our state-of-the-art equipment gives us confidence in mastering this process!

Are you interested in joining us? Just contact us: qelec@ph2.uni-koeln.de

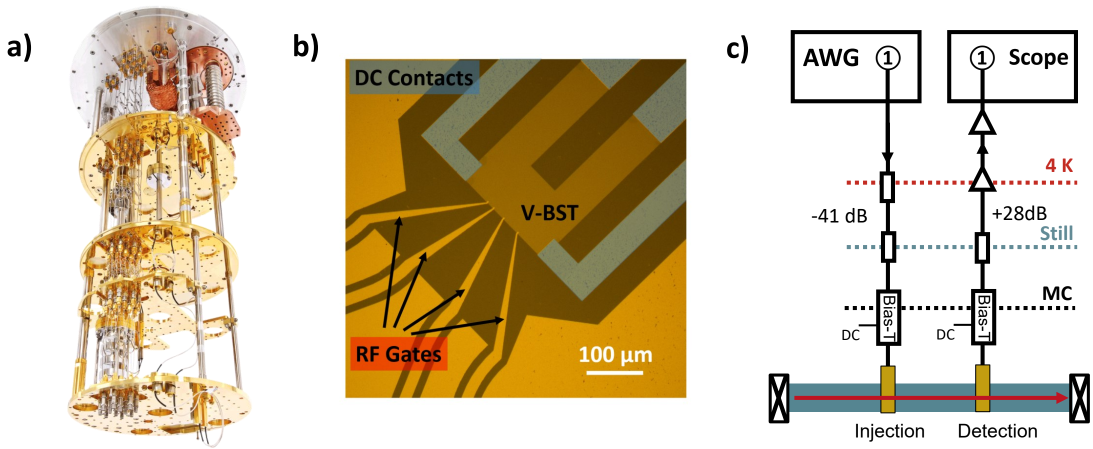

Figure 1: **Measurement setup** a) Bluefors dilution refrigerator, which is used to cool the sample down to 10mK. b) Microscope image of a sample: The QAH insulator is contacted via ohmic contacts (blue) and narrow finger gates (red). c) Electronic setup: The signal is generated using an ultrafast arbitrary waveform generator (AWG) and attenuated before reaching the injection gate. The detected signal is afterward amplified in the cryostat and at room temperature before it is digitized using a state-of-the-art oscilloscope