Towards the realization of topological qubits: how to detect topological order

The realization of scalable quantum computers in condensed matter platforms remains a central goal in modern physics. One of the main challenges in this goal is decoherence, which arises from the unavoidable interaction between a quantum system and its environment. Although significant progress has been made in developing quantum error correction to mitigate decoherence, these approaches typically require a lot of additional physical qubits, posing a major obstacle to scalability.

In this Colloquium, I will share my recent research toward realizing topological qubits, which promise intrinsic resilience to decoherence. These qubits operate through the braiding of non-Abelian anyons---exotic quasiparticles predicted to emerge in fractional quantum Hall systems. However, their existence has not yet been conclusively demonstrated. As an essential first step, we propose a transport experiment to detect topological order, a quantum order characterized by properties such as the presence of anyons and long-range entanglement. Since topological order represents all the fundamental features necessary for topological quantum computation, its detection would make a crucial advance toward realizing topological qubits. We will also discuss recent experimental progress in probing and identifying topological order.