Fault-Tolerant Quantum Error Correction and Computing: From Concepts to Experiments

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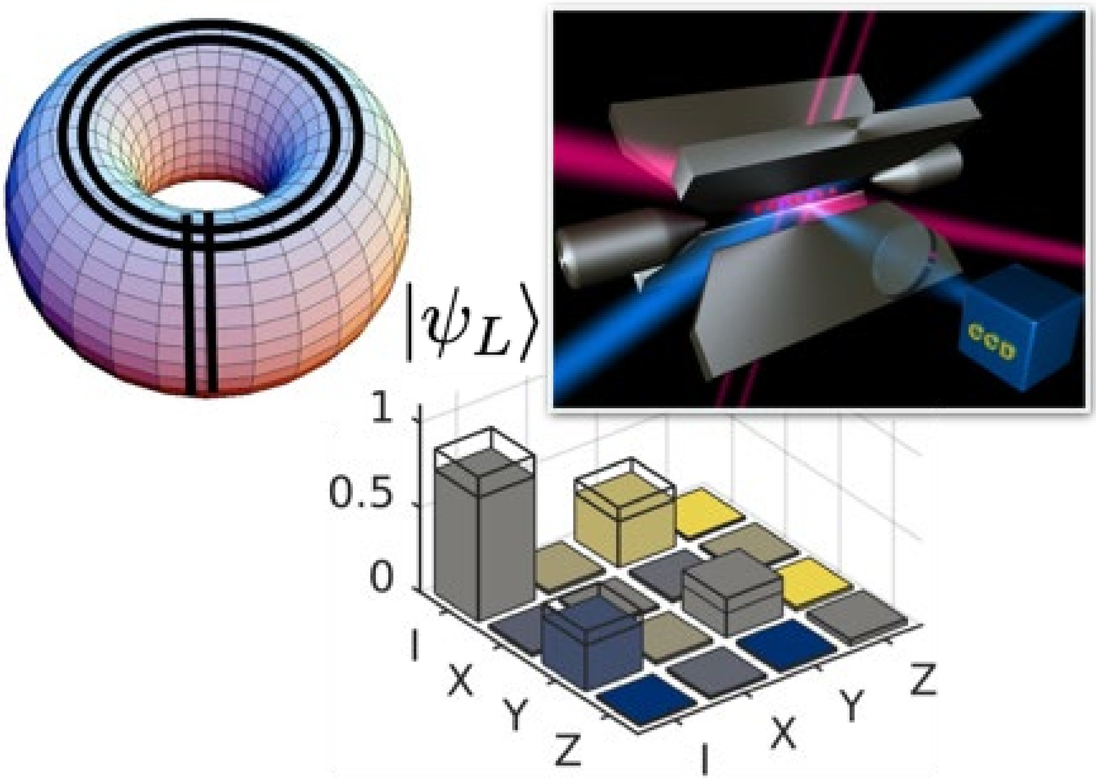
Abstract

To date, the construction of scalable fault-tolerant quantum computers remains a fundamental scientific and technological challenge, due to the influence of unavoidable noise. In my talk, I will first introduce basic concepts of topological quantum error correction codes. These allow one to protect quantum information during storage and processing by redundant encoding of information in logical qubits formed of multiple physical qubits. When manipulating logical quantum states, it is imperative that errors caused by imperfect operations do not spread uncontrollably through the quantum register, requiring so-called fault-tolerant quantum circuit designs. I will discuss recent theory work, perspectives and recent collaborative experimental breakthroughs towards fault-tolerant quantum error correction on various physical quantum computing platforms. This includes the first realisation of repeated, fast and high-performance quantum error-correction cycles on a surface code with 17 superconducting qubits [1]. In complementary efforts with trapped ions, fault-tolerant stabilizer measurements [2] and the first demonstration of a universal and fault-tolerant logical gate set was achieved [3]. Furthermore, I will highlight alternative explorative approaches towards robust quantum processors, based e.g. on quantum machine-learning based concepts such as recently proposed quantum autoencoders for quantum error correction [4].

[1] S. Krinner *et al.*, Realizing repeated quantum error correction in a distance-three surface code, Nature 605, 669 (2022)
[2] J. Hilder *et al.*, Fault-tolerant parity readout on a shuttling-based trapped-ion quantum computer, Physical Review X 12, 011032 (2022)
[3] L. Postler *et al.,* Demonstration of fault-tolerant universal quantum gate operations, Nature 605, 675 (2022)
[4] D. Locher *et al.*, Quantum error correction with quantum autoencoders, arXiv:2202.00555 (2022)



$|\psi_L\rangle$
1
0.5
0
I
X
Y
Z
I
X
Y
Z