

Efficient Fault-Tolerant Quantum Computing via Fine-Grained Logic Gates on Qudit Codes

PROJECT SUMMARY

Quantum computing holds the potential to transform many fields of research and industry by solving a range of problems significantly faster than the best classical devices. Yet achieving this promise hinges critically on our ability to protect fragile quantum information against noise and errors. Quantum error correction aims to achieve this by redundantly encoding quantum information into collective degrees of freedom, forming logical qubits, to achieve fault-tolerance. Yet, quantum error correction comes with large overheads and only allows for a restricted, discrete set of gate operations that can be applied while maintaining protection against errors. Typically, such gate sets consist of all Clifford gates and a single non-Clifford T gate. While such gate sets can arbitrarily approximate any target unitary gate, the resulting circuits can often require a large number of logical operations. As a result, the overheads of current approaches to quantum error correction are excessive, which severely limits their applicability to real-world quantum computing use-cases and hardware.

The EQUALITIES project aims to address this challenge by developing novel resource-efficient quantum error correction codes that support extended logical gate sets featuring fine-grained, i.e. small-angle fault-tolerant non-Clifford gate operations as well as native operation on logical qudits, rather than qubits only.

Both of these approaches have the potential to greatly improve the efficiency of quantum error correction by reducing the circuit complexity at the logical level, which in turn reduces the requirements on the logical error rates required for algorithmic applications. Fine-grained non-Clifford gates directly address the challenge of reducing the overhead of approximating arbitrary unitaries by a small discrete gate set, while native error-corrected qudit support alleviates the challenge of having to transpile native qudit applications into inefficient qubit-based circuits. The combination of these two research developments will lay the groundwork of a new framework of resource-efficient fault-tolerant quantum computing and will boost the practical realisation of versatile fault-tolerant quantum processors.

OUR CONSORTIUM



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Funding organisations

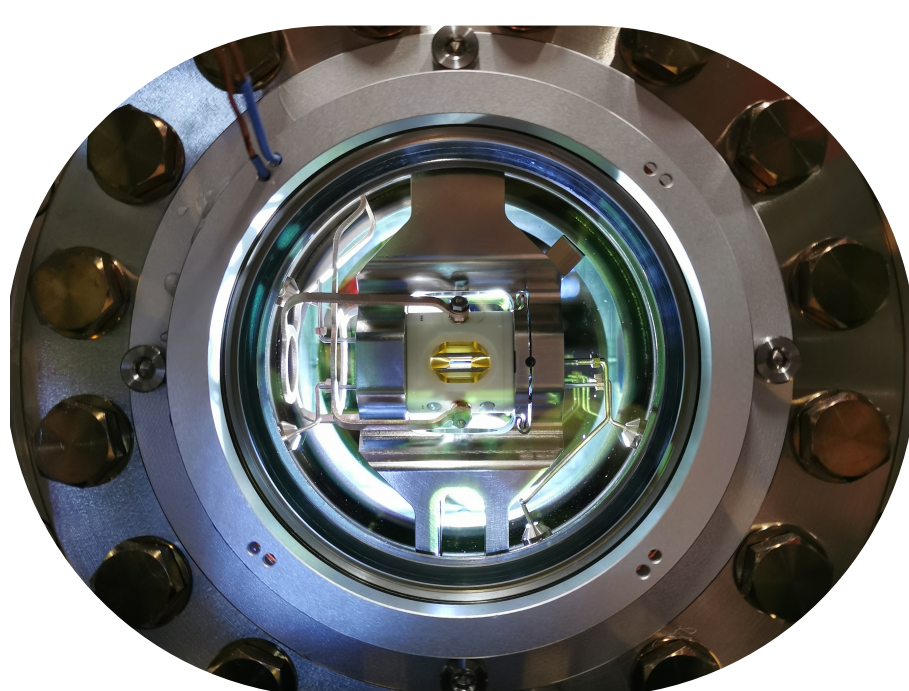
- ✦ **Austria:** FWF
- ✦ **Germany:** DFG
- ✦ **Spain:** AEI
- ✦ **Finland:** AKA
- ✦ **Poland:** NCN



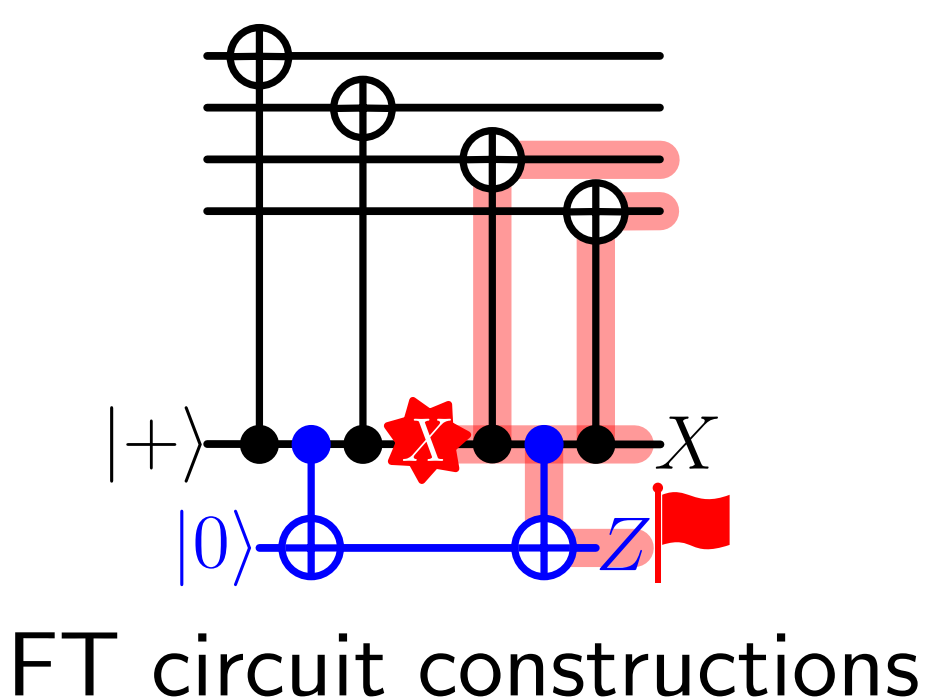
PROJECT STRUCTURE AND GOALS

Experimental Demonstrations

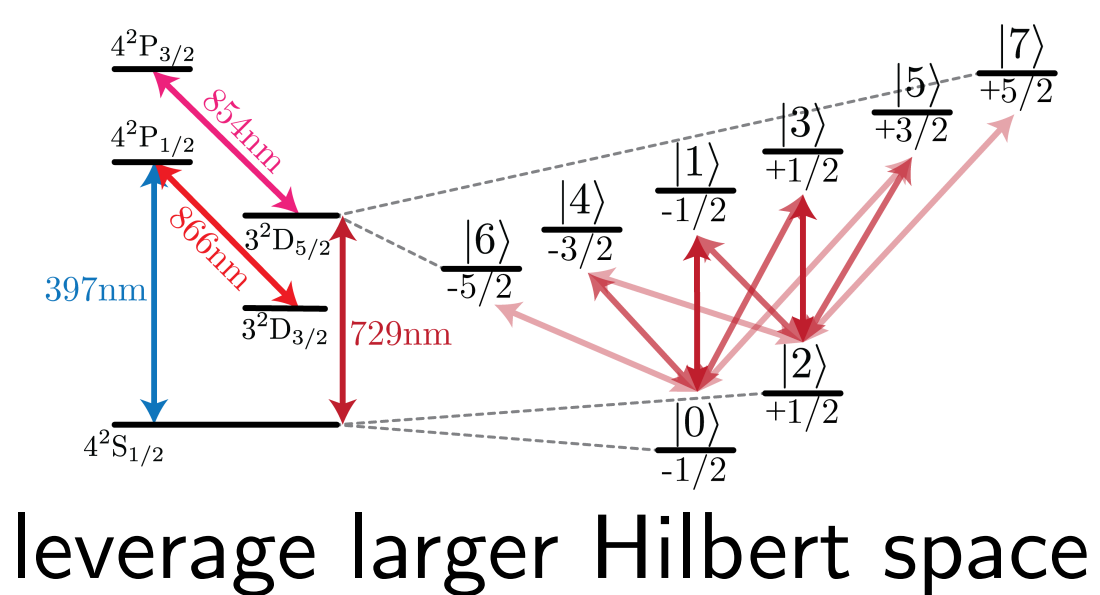
Qubit vs. Qudit Codes



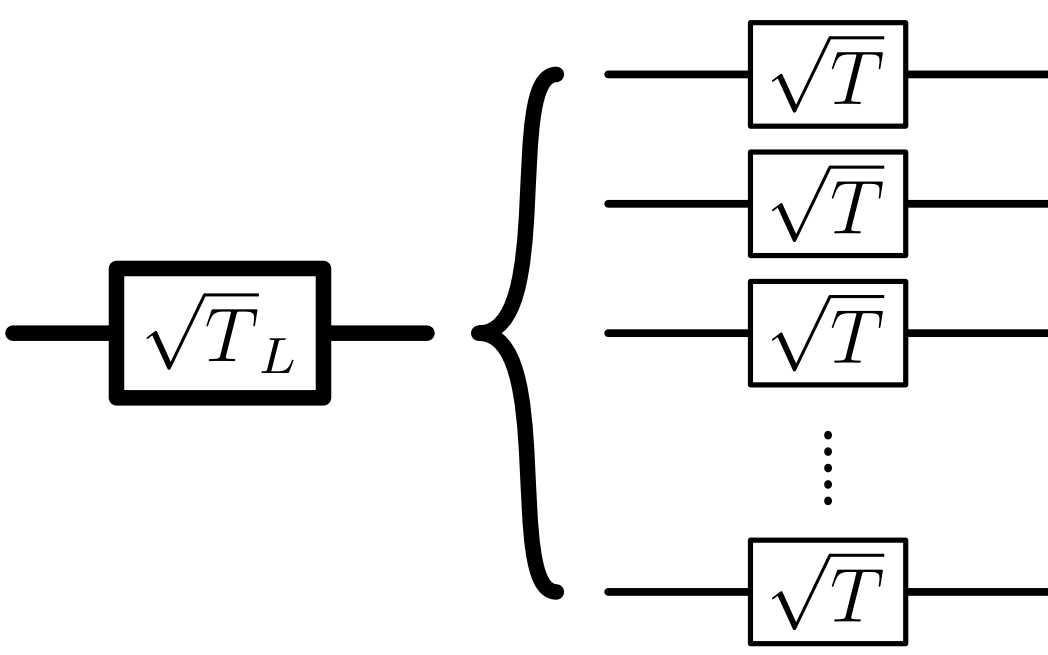
Theory to Experiment



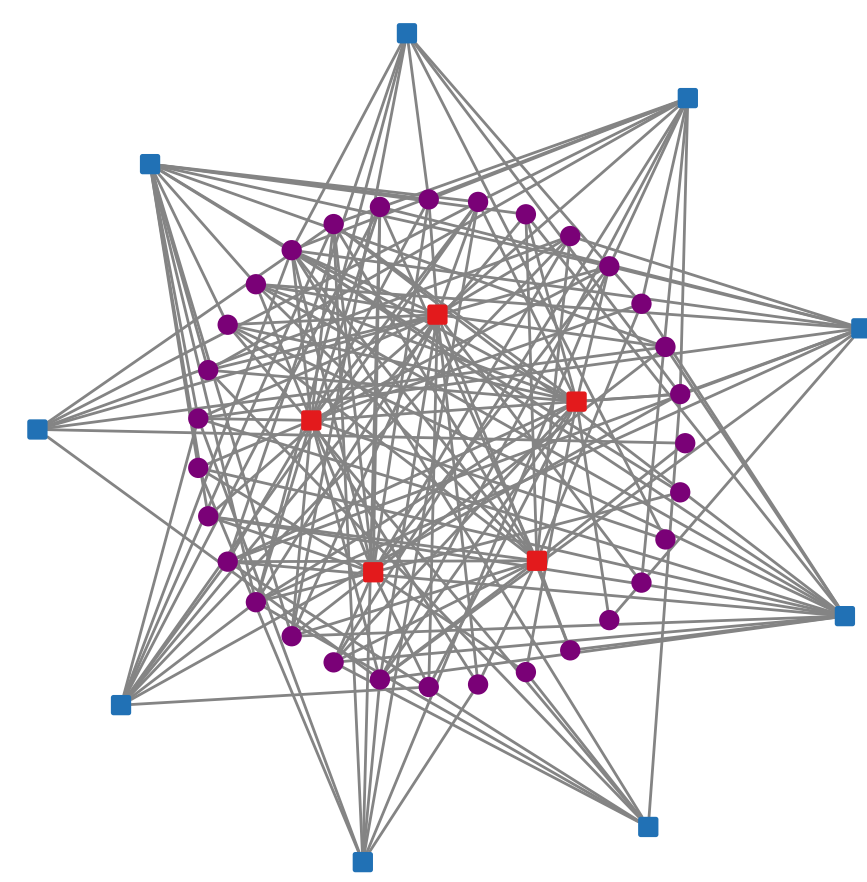
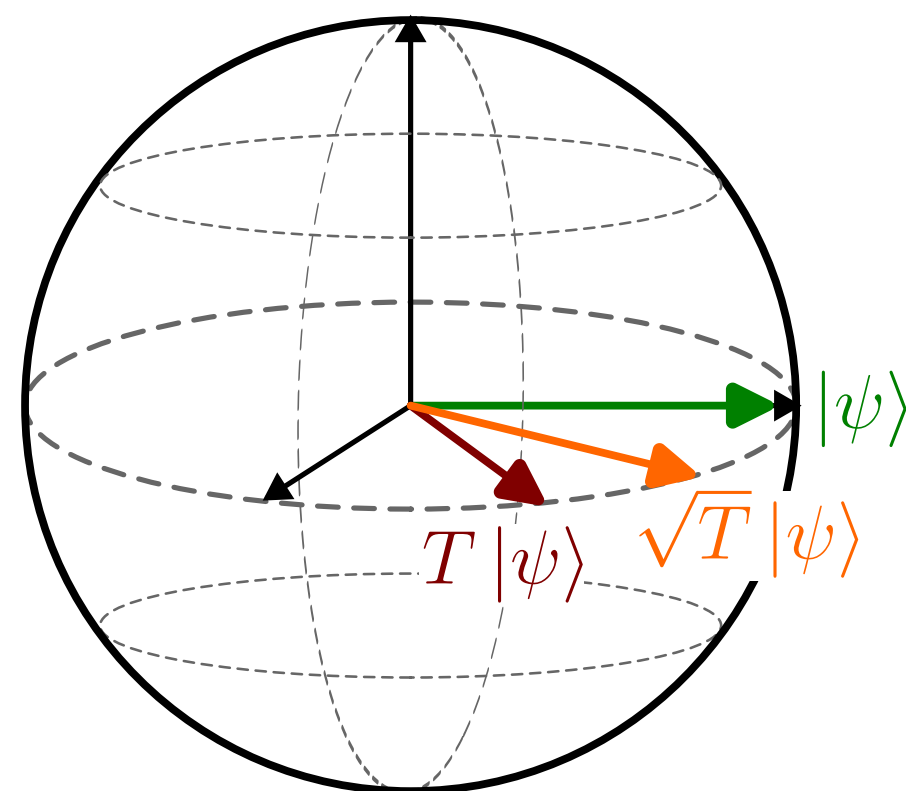
Mathematical Foundations



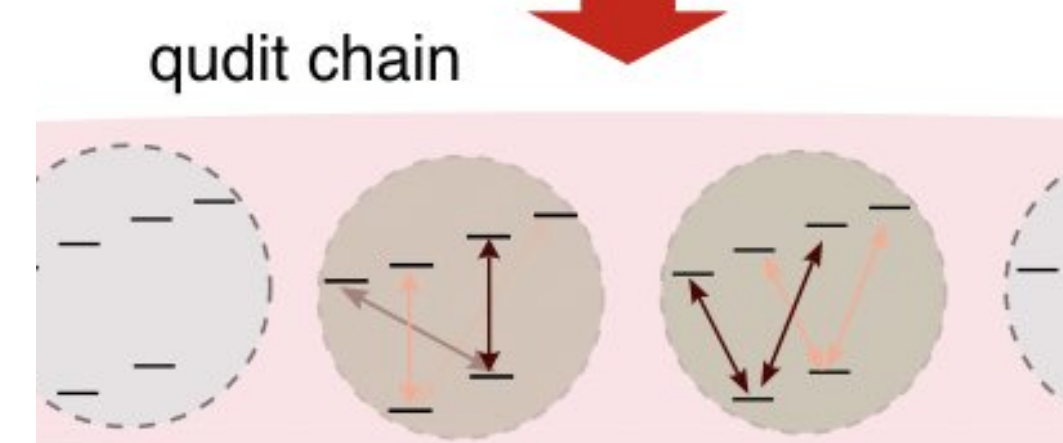
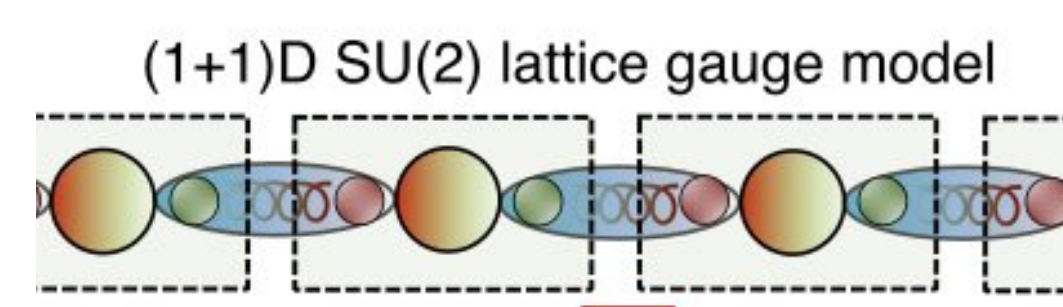
Fine-grained non-Clifford gates



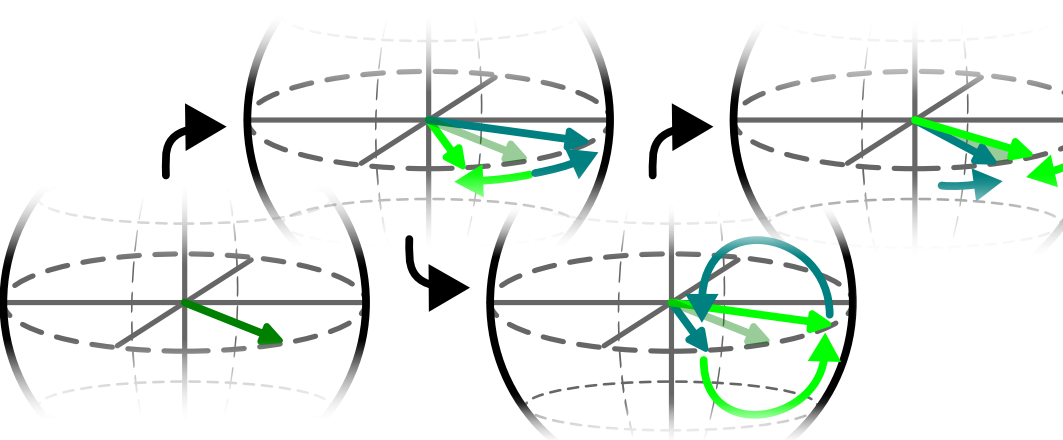
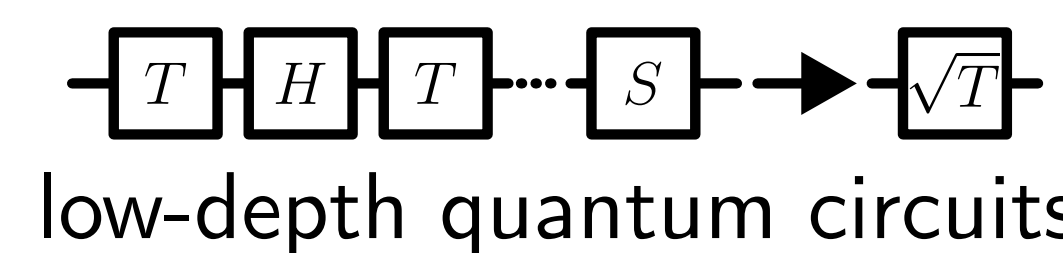
transversal and fault-tolerant gates



Towards quantum advantage



more efficient quantum algorithms



Algorithmic applications

Compilation & Verification

QEC code constructions