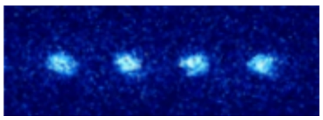
Developing a Scalable Quantum Network of Trapped Ions

PhD Project

Introduction and Motivation

Trapped ions are recognized globally as one of the most promising physical systems for realizing quantum computers and distributed quantum networks. Individual atoms can be confined for extended periods—up to several weeks—using carefully controlled electric



potentials, allowing for unprecedented quantum-level control over single particles. This degree of control is why many leading technology companies are currently investing heavily in trapped ion architectures for assembling quantum computing hardware.

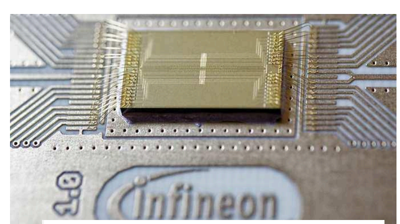
The Challenge of Scalability

A central challenge in the field is scaling the number of quantum bits (qubits). While a single ion trap is typically limited to a few tens of ions, and only recently have a few groups managed to scale this to a few hundred, significant scaling requires a fundamental shift in architecture. The necessary path forward is the development of distributed quantum computing architectures where multiple, separate ion traps operate cooperatively within a network. This networking concept - essential for building a foundational quantum internet - relies on the principle of quantum entanglement over distance. This is achieved by collecting single photons emitted by ions confined in separate traps and then entangling those photons using interferometric schemes. This process effectively establishes a quantum link, creating entanglement between the ions even when they are physically separated by significant distances.

Thesis Theme and Objectives

The theme of this PhD thesis is the design, implementation, and characterization of a new quantum network of trapped ions at the newly established INRIM site on the science campus in Sesto Fiorentino, Italy. This is a unique and highly rewarding opportunity to be at the forefront of the global quantum technology revolution. The successful candidate will play a critical role in developing a full, state-of-the-art experiment, acquiring expertise in a field that is exploding with new career paths and poised to reshape technology. The student will implement the quantum network by integrating an existing, operational ion trap (the first of its kind in Italy) with a second, custom-designed trap that will form the second node of the network.

Project Structure and Deliverables



A chip ion trap built at Infineon

Phase I: Chip-Based Trap Design and Preparation. The student will collaborate with senior researchers and an industrial partner to design a novel chip-based ion trap. This trap will be specifically engineered to maximize photon collection efficiency, a crucial factor for establishing high-fidelity quantum links. While the trap is being fabricated, the student will work on developing the basic networking functionalities on the existing ion trap platform, having the opportunity to work on a running experiment.

Phase II: Trap Commissioning and Network Realization. Upon delivery of the custom-designed trap, the student will be responsible for its integration and characterization. This includes bringing the trap into operational conditions, characterizing its performance, and utilizing it to realize a first-generation quantum network. The core deliverable will be the successful entanglement of two separate Ba+ ions confined in different traps, at a distance of up to a few hundred meters, proving the viability of this distributed architecture.

Required Background and Acquired Competencies

A strong background in Physics or Electronic Engineering is highly advantageous. However, the most critical attribute for success is passion, motivation, and a dedicated willingness to learn. While the project is technically challenging, it is designed for a PhD student, meaning that the specific competencies you already possess are secondary to your dedication. You will be fully supported to master the complex skills required.

The technical skill set the student will acquire includes:

- Computational Modeling: Programming with finite element software for simulating trap performance and electric fields.
- Laser Optics and Spectroscopy: Advanced use of lasers and optical systems for atomic spectroscopy and quantum state manipulation.
- Instrumentation and Control: Development of basic electronics and control systems for operating complex experimental setups.
- Data Science: Expertise in data acquisition, processing, and advanced analysis techniques.

The student will join a vibrant, international research group and a highly active scientific environment, characterized by frequent seminars and collaborative scientific life. This is a challenging but immensely rewarding project that offers the opportunity to be at the forefront of the global quantum revolution. *For information, contact dr. Carlo Sias: c.sias@inrim.it*