XQi

Quantum computers based on NV centers in diamond

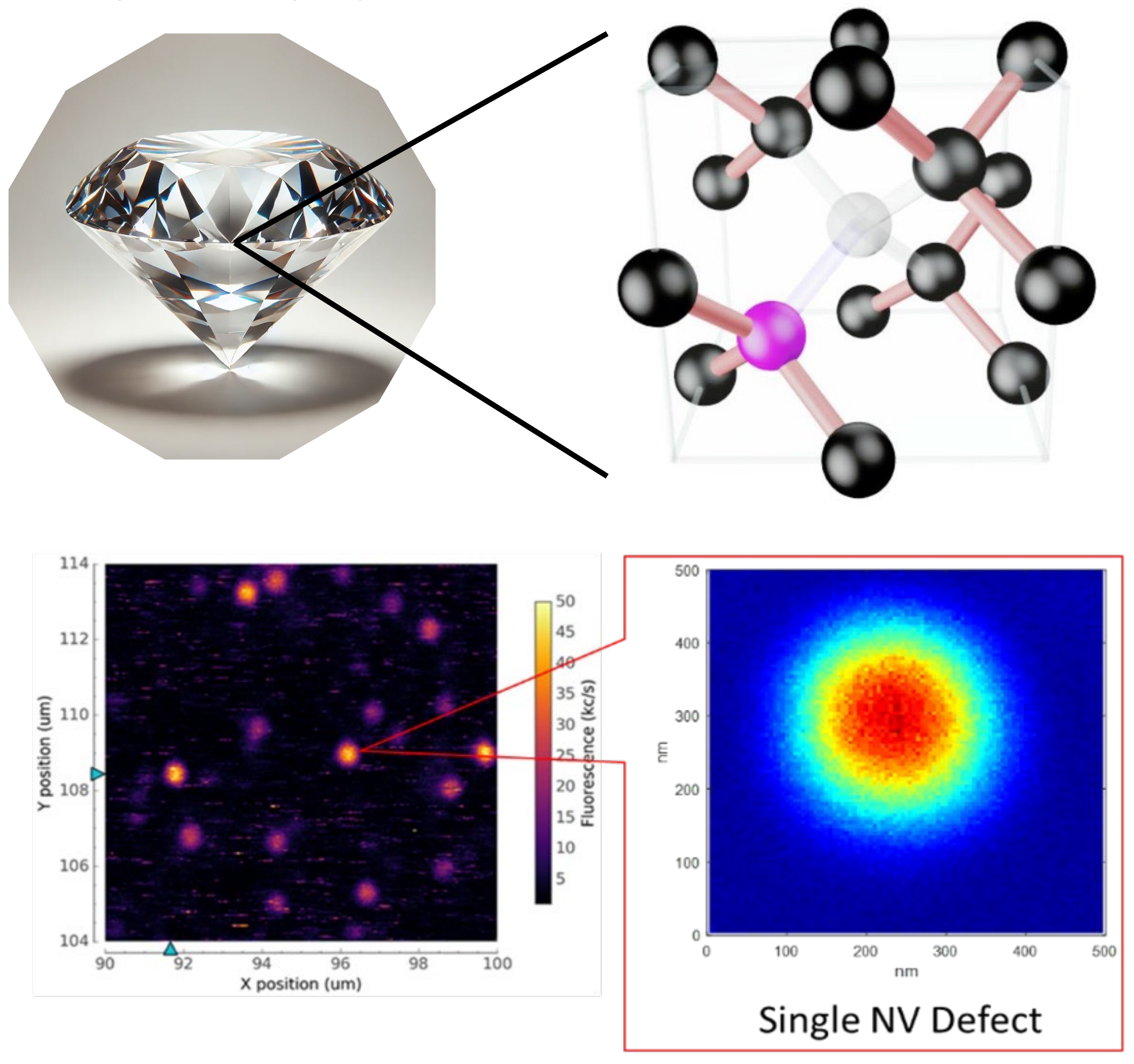
We are developing a fully functional, robust and scalable diamond spin-based quantum computer with more than 32 qubits for use in office and home environments.

- NV-Centers
- Quantum Computer

Motivation

Today, most quantum computers are accessed remotely through the cloud due to significant infrastructure requirements for their operation. In contrast, our quantum processor systems function at room temperature, are powered by a standard power outlet, and are robust enough to be used in office and home environments. Our goal is to provide high-quality quantum information processing systems for both businesses and industry partners. These systems serve as tools for innovation, enabling them to easily integrate quantum advantages into their products. This approach democratizes access to quantum computing.

We utilize Nitrogen-Vacancy (NV) centers in diamonds for our quantum processors. These NV defects exhibit unique quantum properties: they are atom-sized, embedded in robust diamond material, fully functional and controllable at room temperature, and integrated into extremely small diamond chips. They require no special cooling, operating with minimal power consumption and space requirements. In an industry landscape dominated by large, power-hungry quantum processing units, diamond qubits represent a turning point. They pave the way for the democratization of quantum computing, allowing quantum computers to move from lab settings to everyday use.



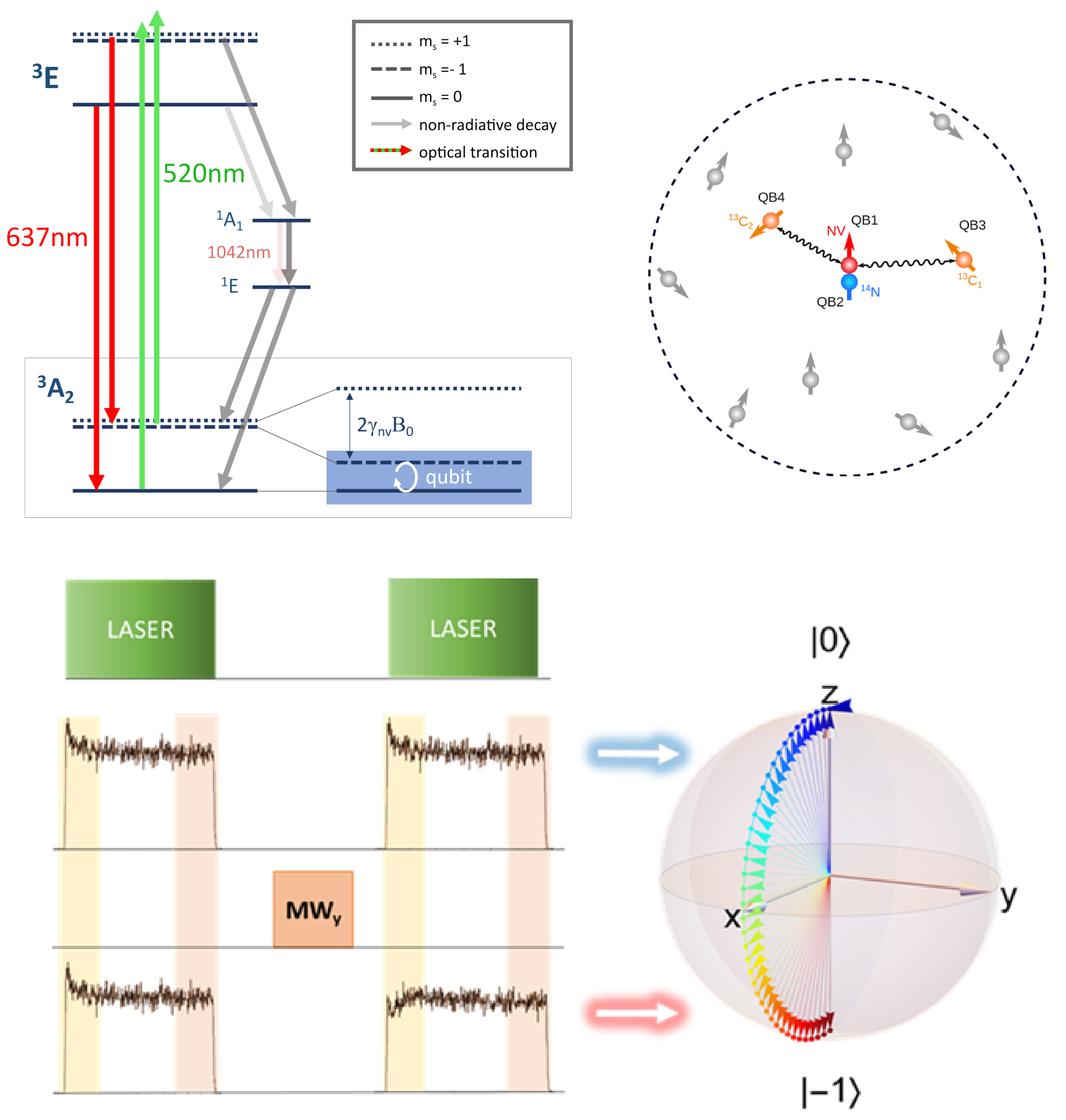
Nitrogen vacancy center inside diamond used as a platform for quantum computing.

XQ mobile quantum processors

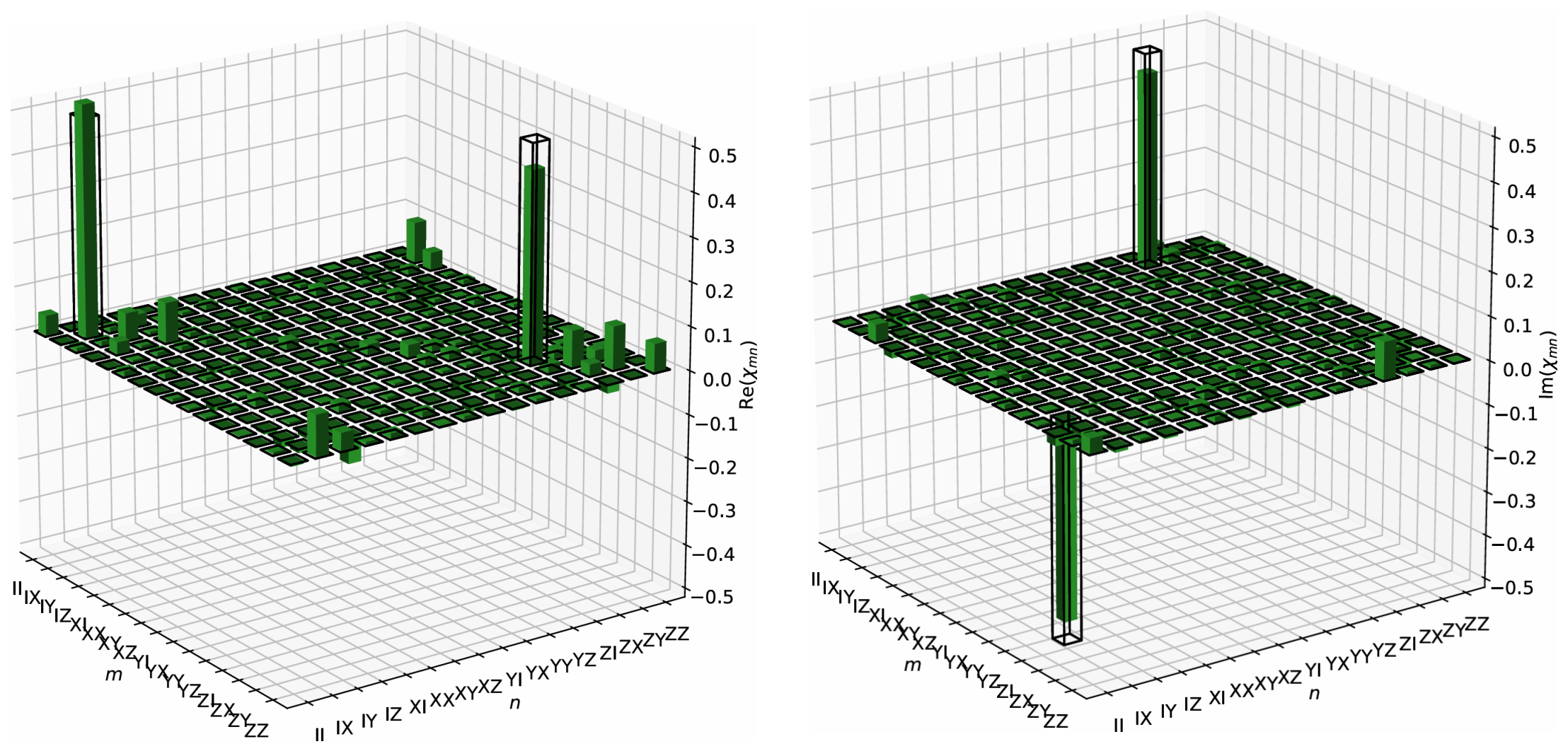
The XQ mobile quantum processors utilize a star topology in which qubits are centrally connected and controlled via a central spin node. This configuration allows each qubit to interact through a shared point, facilitating communication across the network of qubits. In this setup, specific operational techniques are applied to distinct types of spins:

- **Electron Spin of the NV Center:** The electron spin within the Nitrogen-Vacancy (NV) center acts as the central "satellite" spin and is directly addressed through microwave excitation. This spin serves as the primary mediator within the star topology, enabling communication and coordination across qubits.
- **Intrinsic Nitrogen Spin:** The NV center's nitrogen nucleus spin is separately controlled via radiofrequency (RF) fields. This ability to address the nitrogen spin independently provides an additional degree of freedom in quantum operations, crucial for creating more complex quantum states and maintaining coherence within the system.
- **Coupled Carbon-13 Spins**: Surrounding Carbon-13 (^{13}C) spins, which naturally occur in diamond, require indirect manipulation via the electron spin. The electron spin's interaction with ^{13}C allows for quantum state transfer and more complex entanglement operations. This indirect addressing is pivotal for expanding the qubit register and allows additional spins to be coherently integrated within the NV-based system.

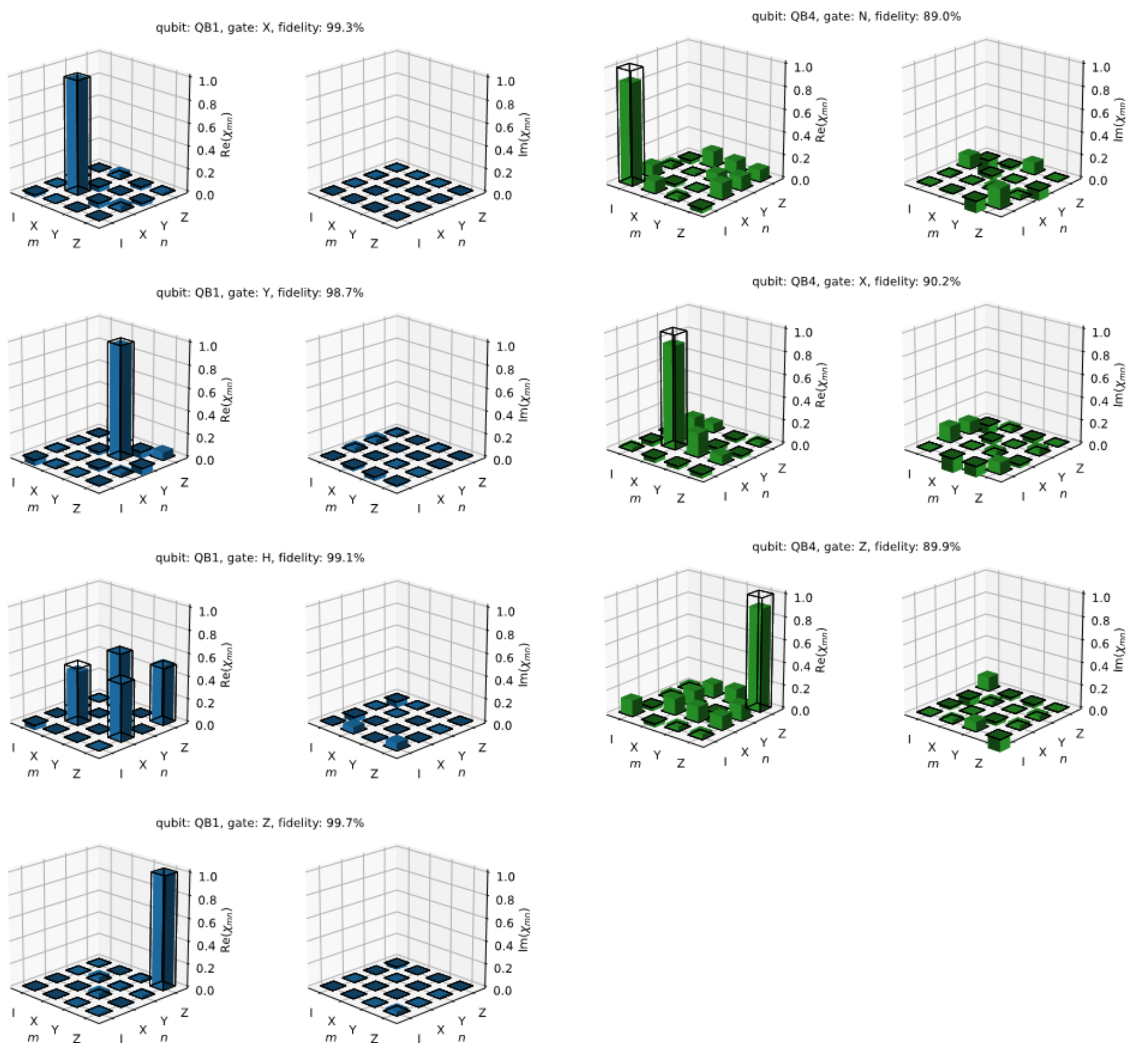
For scaling the qubit architecture, multiple NV centers positioned closely enough for effective dipole-dipole coupling are required. This proximity allows direct qubit-qubit interaction through magnetic dipolar fields, paving the way for larger and interconnected qubit networks. However, achieving such precise configurations poses significant technical challenges, particularly in the fabrication of diamond chips with reliably spaced NV centers and consistent quality. Advanced nanofabrication techniques are critical to producing these diamond substrates with the required structural and quantum coherence properties.



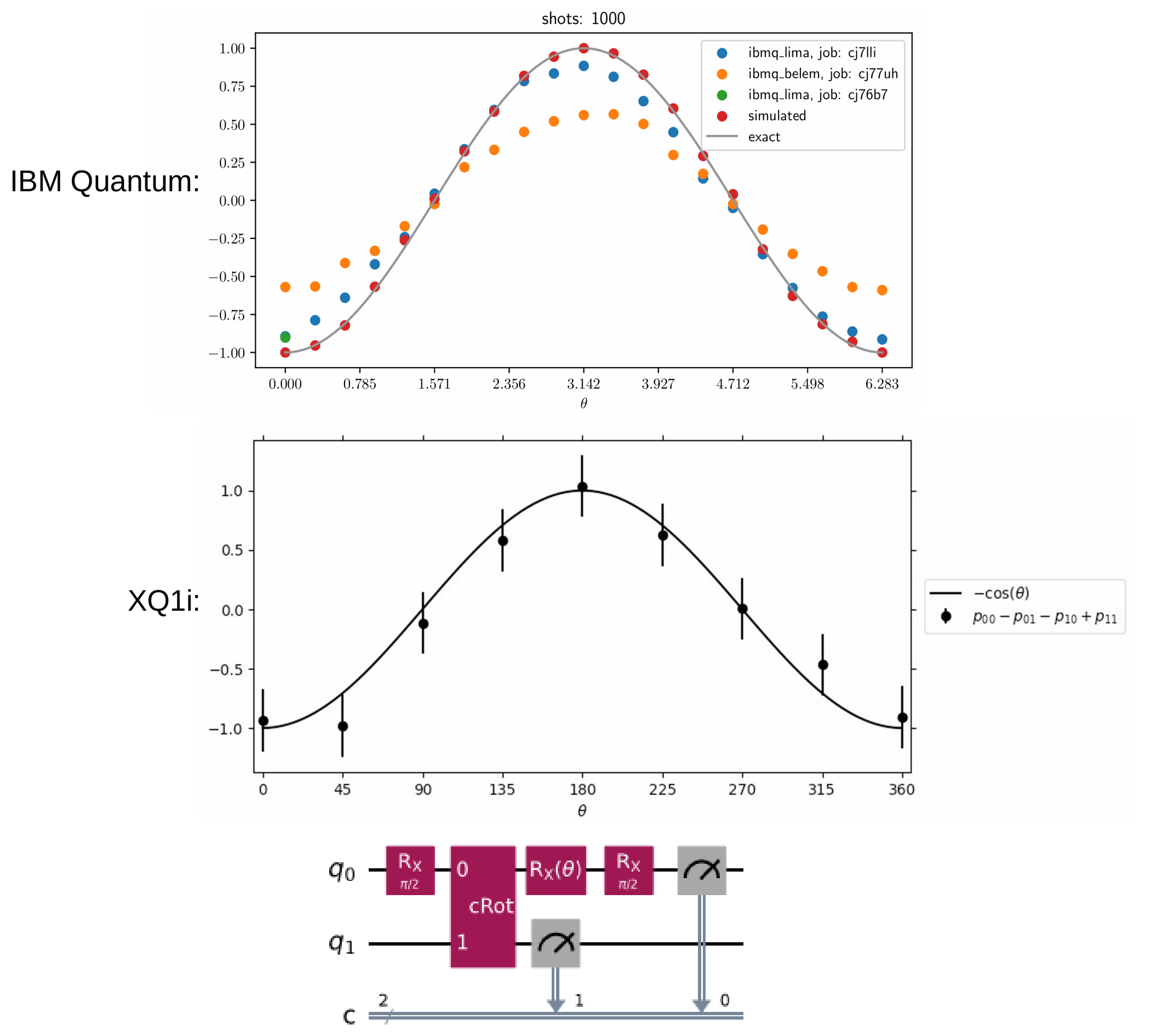
Control scheme of the qubits and schematic of the qubit topology of XQ1*i*, containing four spin qubits: NV electron spin (QB1; red), nitrogen nuclear spin (QB2; blue), and two ^{13}C nuclear spins (QB3,QB4; orange). Additional weakly coupled ^{13}C nuclear spins in the vicinity of the NV-center are shown in grey, but do not form part of the XQ1*i* qubit register.



QPT of a CeROT gate on qubit pair 1-3 with a gate fidelity of 89,8%



QPT of single qubit gates measured for QB1 (electron spin) and QB4 (^{13}C spin). For QB4 the fidelity of the NOOP already shows, that initialization and readout is a major bottleneck.



Comparison of a two-qubit gate on XQ1*i* and different IBM quantum processors

Challenge

The first major achievement was transitioning quantum computers from the lab to practical applications. This was accomplished by significantly reducing the complexity of laboratory systems, resulting in a compact and robust mobile system. However, the real challenge lies ahead: enhancing the performance of these systems. This is the central focus of Project XQ*i*. Our aim is to develop scalable, high-capacity quantum systems based on compact, mobile NV-center quantum computers, while maintaining simplicity and practicality to make them suitable for the mass market.

More information about the project on our website

A project of

XEEDQ

Contact

Florian Frank
florian@xeedq.com
info@xeedq.com

DLR | QCi

Get in touch.
We enable quantum!

Supported by:

Federal Ministry
for Economic Affairs
and Climate Action

on the basis of a decision
by the German Bundestag