Qibo: an open-source hybrid quantum operating system

Full-stack middleware for self-hosted and cloud-based quantum devices

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[†] https://qibo.science

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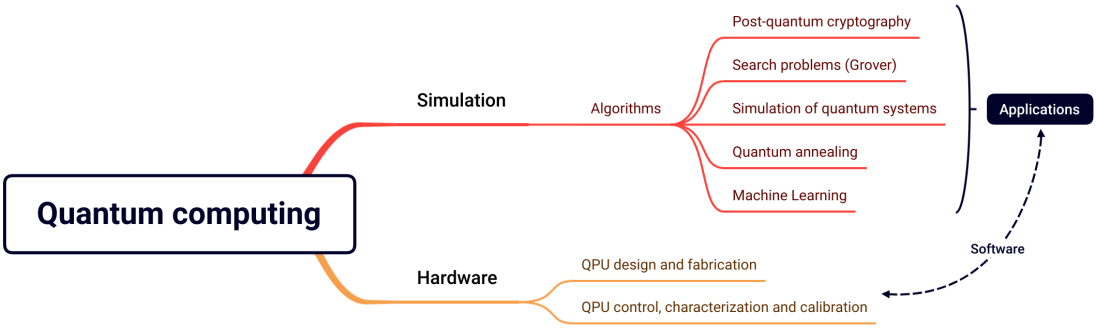
References:
Qibocal: arXiv:2410.00101
Qibolab: Quantum 8 (2024) 1247. doi:10.22331/q-2024-02-12-1247.
Qibojit: Quantum 6 (2022) 814. doi:10.22331/q-2022-09-22-814.
Qibo: Quantum Science and Technology 7 (1) (2021) 015018. doi: 10.1088/2058-9565/ac39f5.

Software and Quantum Computing



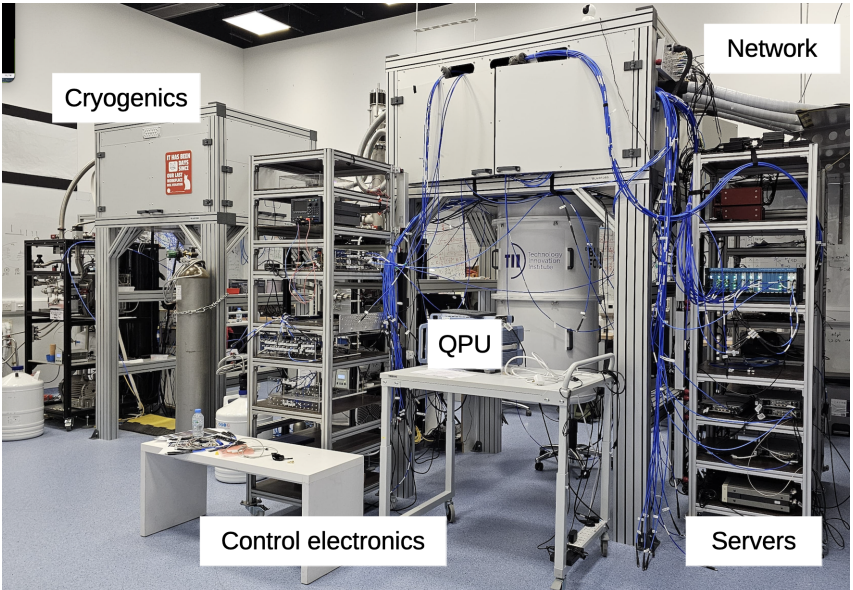
Simulation

- required to develop algorithms
- complete introspection
- require noise modeling

Hardware

- limited (in many senses)
- requires calibration
- final validation

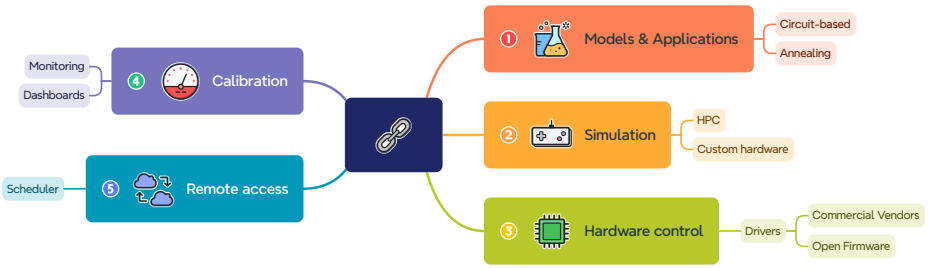
The real-world...



Software challenges

Requirements for self-hosted quantum hardware:

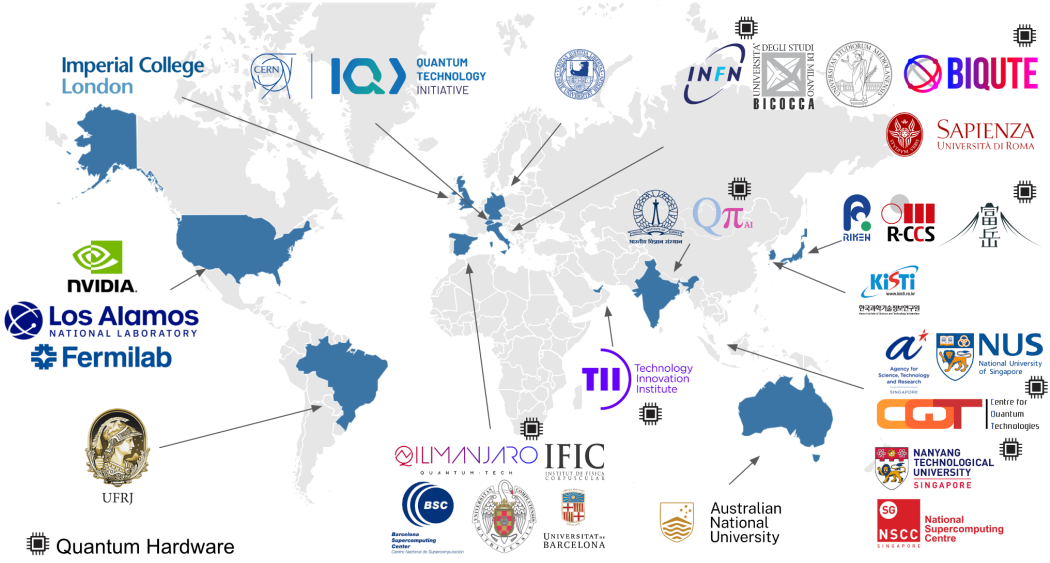
- Access to **interdisciplinary set of software tools** for:



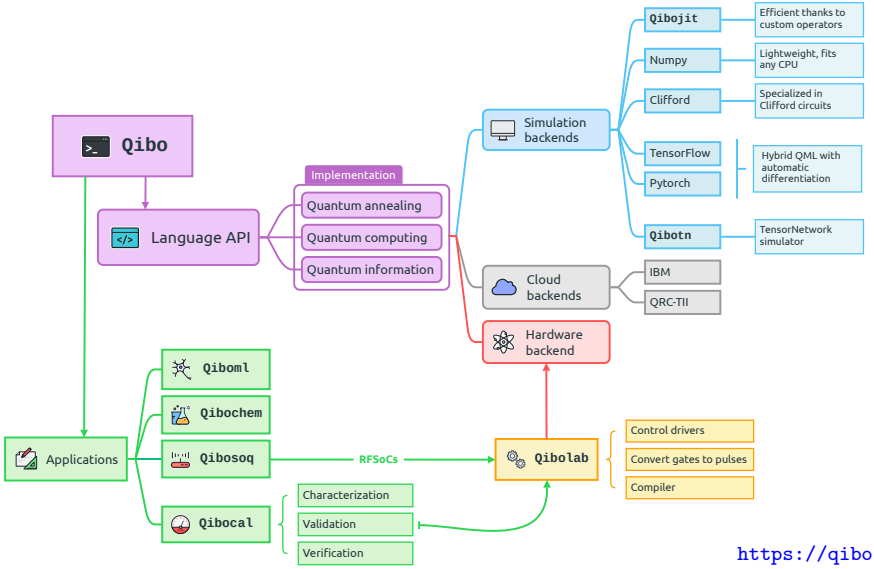
- **Open-source software** tools supported by benchmarks and publications.

Towards the “Linux of Quantum Computers”

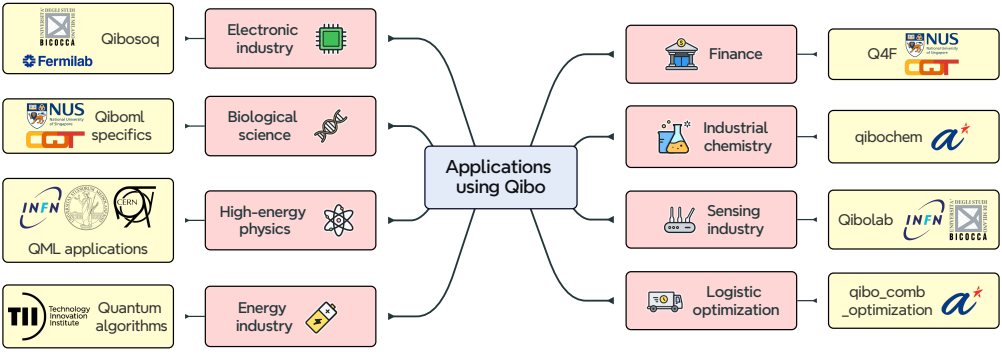
Qibo Collaborators (January 2025): +50 code contributors



Qibo's macrostructure (v0.2.15)



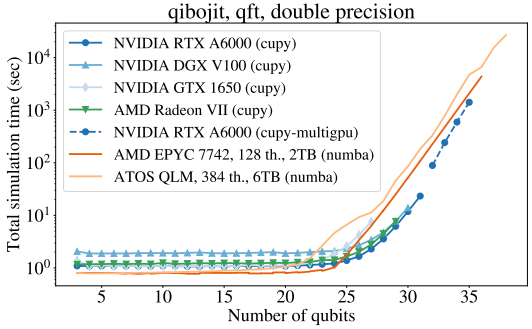
On-going quantum applications using Qibo



Quantum Classical Simulation

Classical quantum simulation benchmarks

arXiv:2203.08826



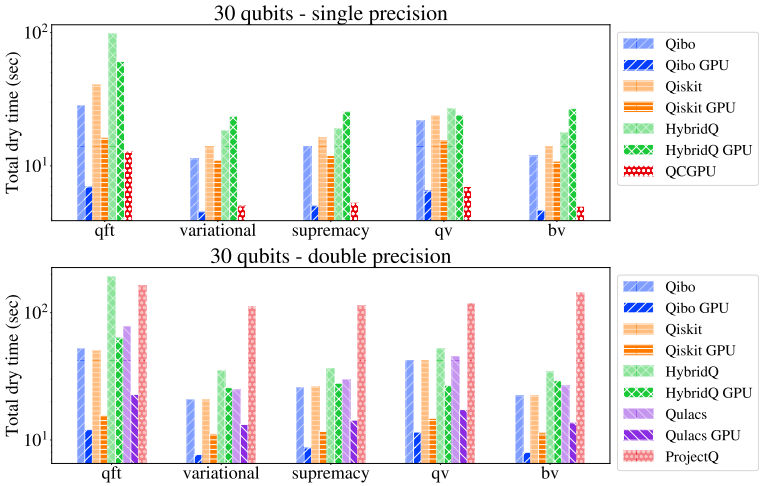
Major features:

- Exact state-vector simulation.
- Just-in-time compilation.
- Supports CPU, GPU and multi-GPU.
- NVIDIA and AMD GPUs support.
- Reduced memory footprint.
- Optional cuQuantum integration.

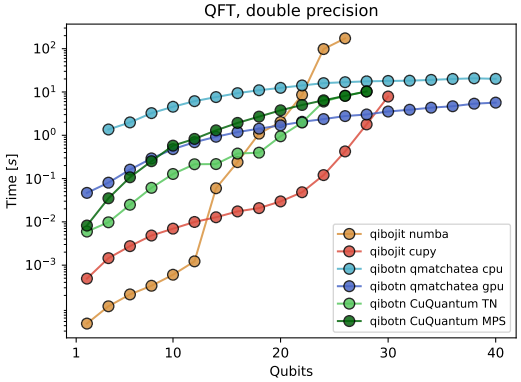
Qibo vs other libraries

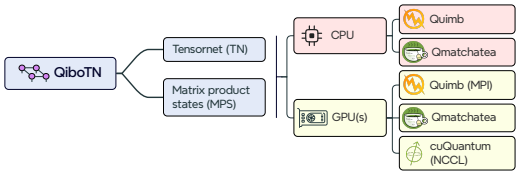
arXiv:2203.08826

Benchmark library: `https://github.com/qiboteam/qibojit-benchmarks`



Scaling qubits simulation with QiboTN





Major features:

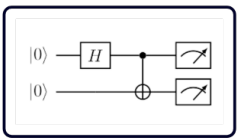
- Tensor Network and MPS simulation.
- Probability, shots, state reconstruction.
- Supports CPU and GPU.
- MPI multi-node support.
- Better memory footprint scaling.
- Optional cuQuantum integration.

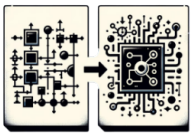
Quantum Hardware Control and Calibration

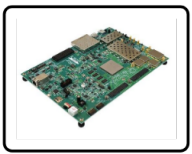
How to control qubits?

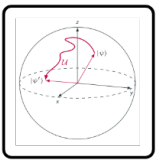
arXiv:2308.06313

Circuit definition → Circuit transpilation → Hardware deployment → Experiment execution







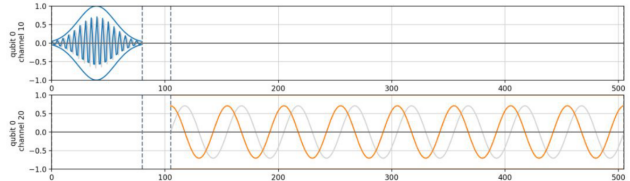


Given a general single-qubit gate it is possible to decompose it in R_X and R_Z gates:

$$U_3(\theta, \phi, \lambda) = R_Z(\phi) R_X\left(-\frac{\pi}{2}\right) R_Z(\theta) R_X\left(\frac{\pi}{2}\right) R_Z(\lambda)$$

From the level of pulses:

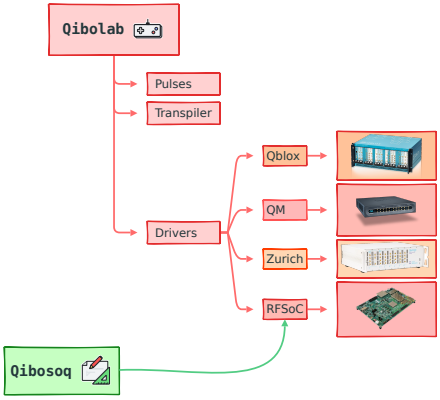
- an R_X is a Gaussian pulse calibrated by Rabi experiment,
- an R_Z is a change in the virtual phase of the pulses,
- an M_Z is a rectangular pulse calibrated by readout optimization routines.



How an RX and measurement gate is performed at the pulses level on a qubit.

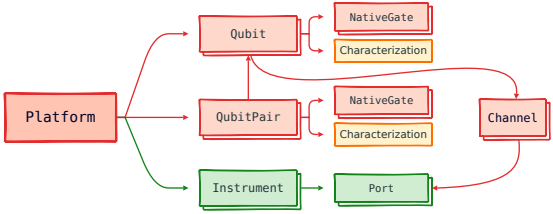
How to control qubits? Qibolab

arXiv:2308.06313



Major features:

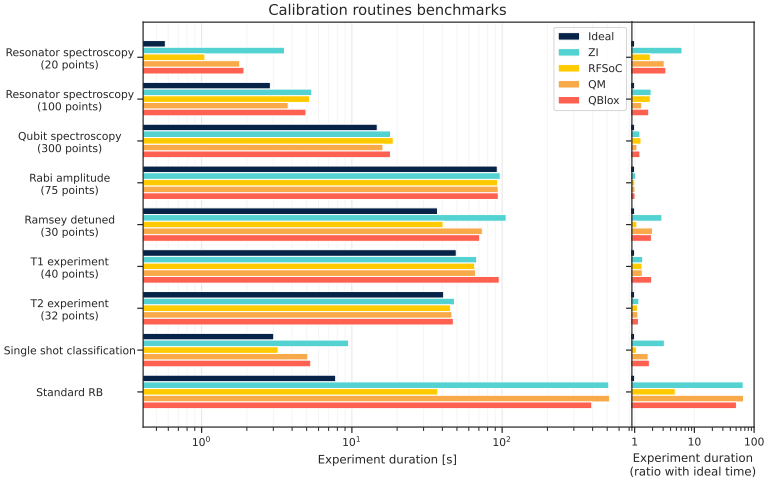
- Pulse and pulse sequence API.
- Extensible API to drivers of control instruments.
- Hardware sweeps for faster execution of calibration routines.
- Transpilers from arbitrary circuits to pulses.
- Integration with QuTiP for platform emulation.



Benchmarking instruments performance

arXiv:2308.06313

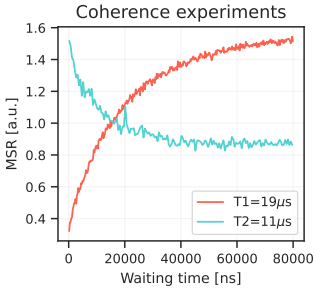
We compare the ideal pulse sequence execution performance to instruments execution duration.

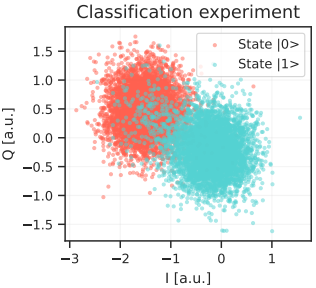


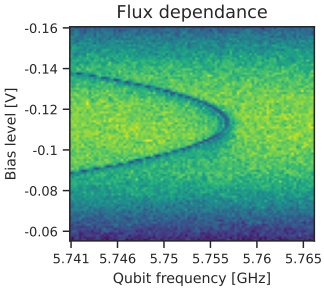
Zurich Instruments (ZI), Quantum Machines (QM), QBlox and RFSoC FPGA (Qibosoq+QICK).

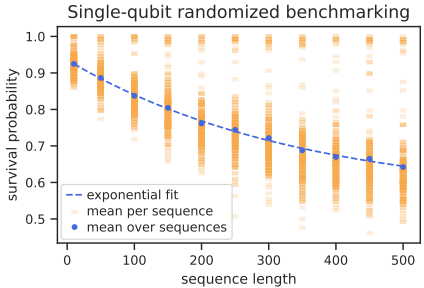
Pulse-calibration and experiments

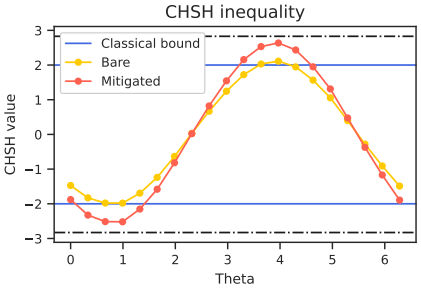
arXiv:2303.10397





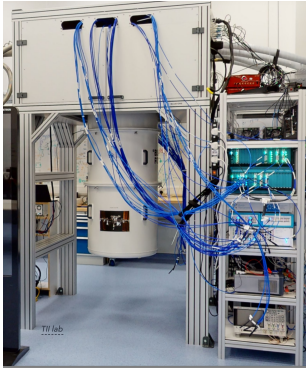


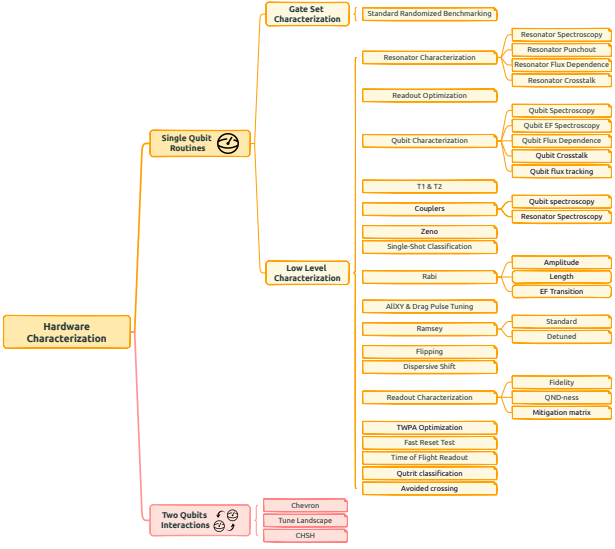


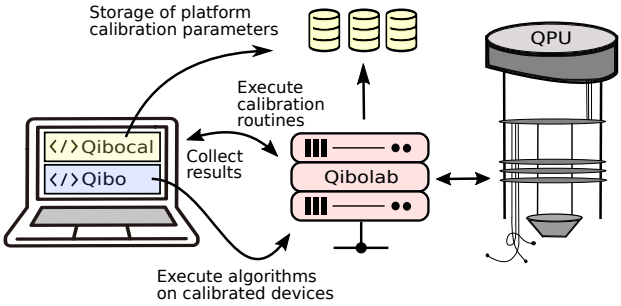


Calibration routines with Qibocal

arXiv:2410.00101







Schematic representation of Qibocal's role within the Qibo framework.

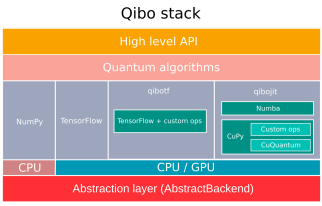
Outlook

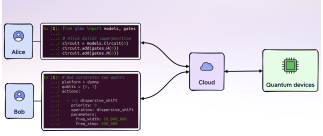
Outlook

Why **Qibo**?

1. Open-source from **control electronics drivers to quantum algorithms** (full-stack).
2. Decentralized development model and a **diversified funding strategy**.
3. New opportunities of **software integration** with research institutions.

Adoption	Integration	QCaaS
Use Qibo as it is.	Qibo as 3rd party software.	Cloud access based on Qibo.





Recent case studies using Qibo in industry and academia

- Adoption (from 2020):
  TII (UAE), **NQCH** (Singapore), **NQSTI** (Italy),
  QπAI (India): **default quantum OS** for quantum hardware.

- Integration (from 2022):
  - **FNL** (USA): Qibo as front-end of **QICK box** electronics.
  - **QIQ-B / QuEL Inc.** (Japan): **new drivers in Qibolab**.

- QCaaS (from 2024):
  Cloud access, management and hybrid HPC infrastructure to quantum hardware operated by Qibo.