Towards an open source quantum operating system

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Introduction to Quantum Computers

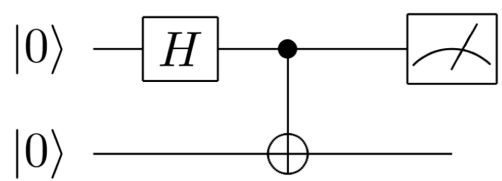
- In a quantum computer bits are replaced by **qubits**
- The state of the qubit is a superposition of two quantum states

$$|\psi\rangle = \alpha\,|0\rangle + \beta\,|1\rangle$$

- We can act on qubits with unitary operators represented as **gates** (i.e., Hadamard gate)

$$H = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}, \qquad CX = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

- When we apply a series of either unitary or measurement gates to a styem of qubits, initialized to a known state we obtain a quantum **circuit** ,i.e., Grover, variational quantum circuits.



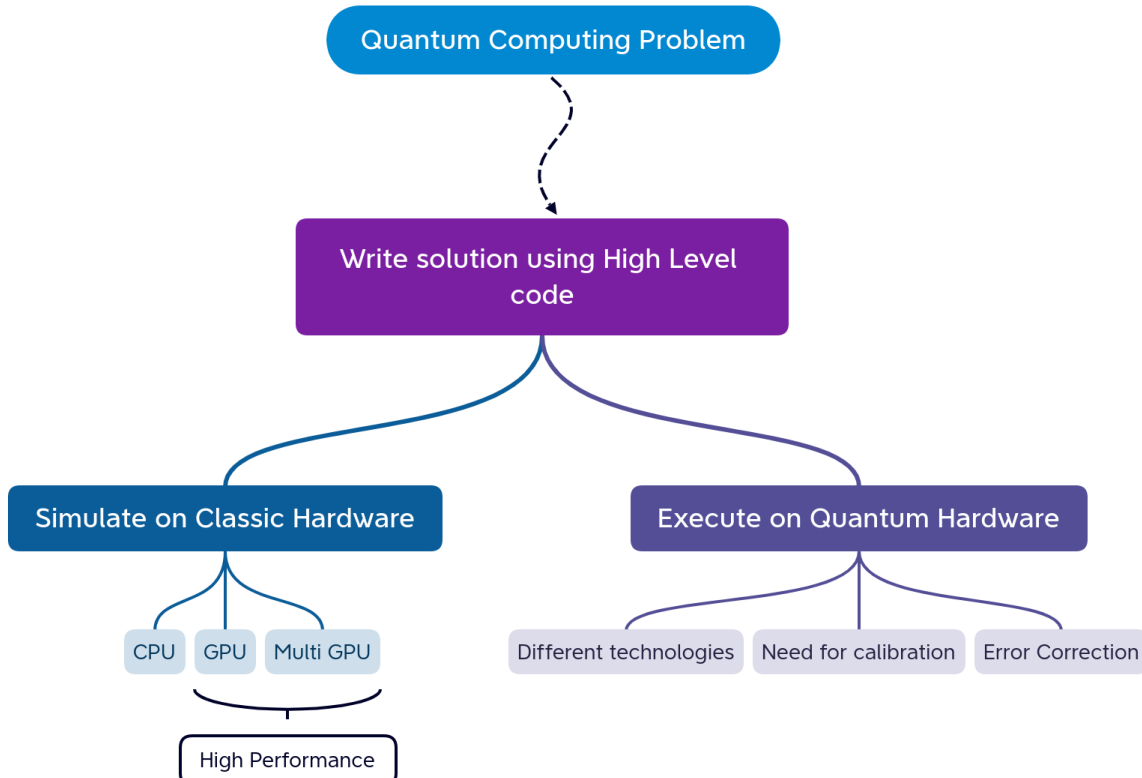
Why QC ?

Exploit QC sub-routines to speed-up classical algorithms (e.g. using Grover).

Physical advantages when dealing with combinatorial optimization (quantum annealing).

Map problems into Hilbert's spaces loads to high expressivity (Quantum machine learning).

How can we start using Quantum Computing?



QIBO ECOSYSTEM

Open-source full stack API for quantum simulation, hardware control and calibration

arXiv:2009.01845

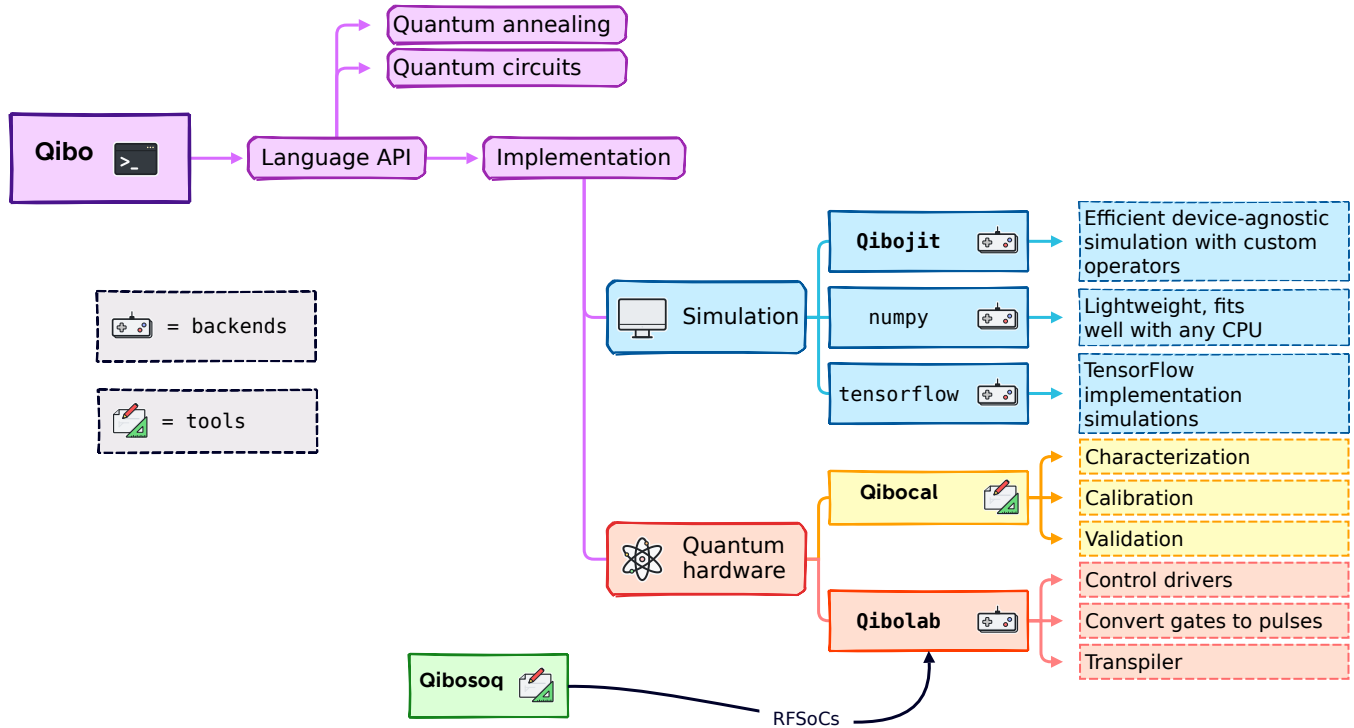
qibo.science

Goals

Fast device-agnostic simulation of quantum circuits.

Platform-agnostic reliable characterization and calibration of quantum devices.

Translate gates into pulses.


Quantum annealing
Quantum circuits
Qibo
Language API
Implementation
= backends
= tools
Simulation
Qibojit
numpy
tensorflow
Efficient device-agnostic simulation with custom operators
Lightweight, fits well with any CPU
TensorFlow implementation simulations
Quantum hardware
Qibocal
Qibolab
Characterization
Calibration
Validation
Control drivers
Convert gates to pulses
Transpiler
Qibosoq
RFSoCs

QIBOLAB

open-source software library for quantum hardware control

arXiv:2308.06313

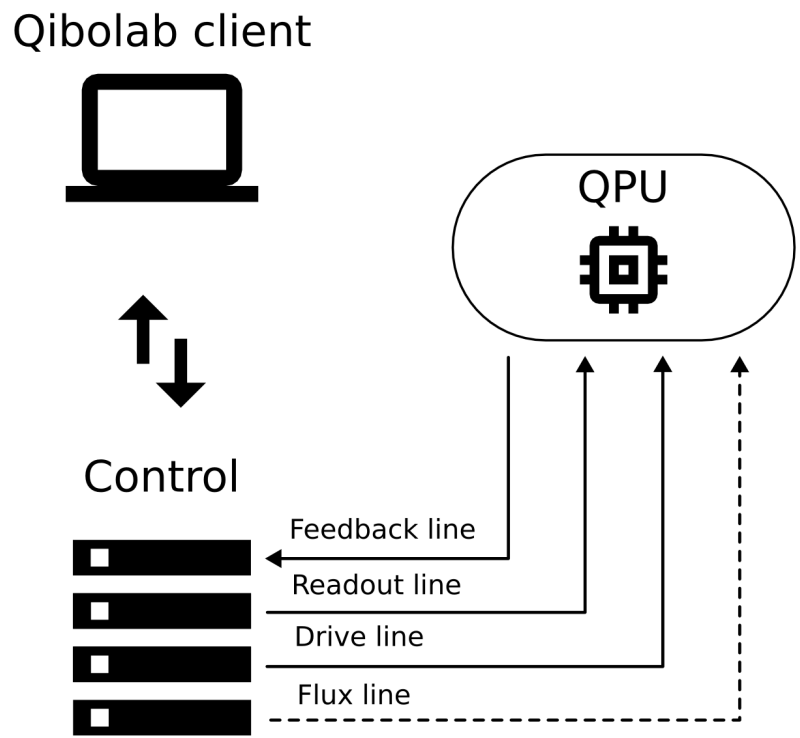
qiboteam/qibolab

Quantum lab


Input-Output lines
Cryostat
Cryostat
Control
Electronics
Oscilloscope

How does a quantum lab work?

- The host computer running Qibolab communicates with the different electronics used to control a QPU.
- The readout and feedback channels measure the qubits,
- the drive channel applies gates,
- the flux channels for tuning their frequency.



QIBOCAL

A reporting tool for calibration using Qibo

arXiv:2303.10397

qiboteam/qibocal

Motivation

Let’s suppose the following:

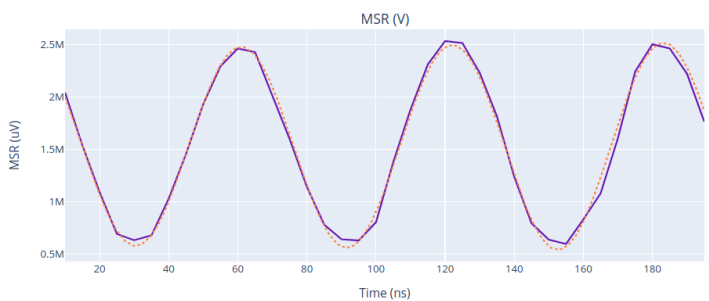
We have a QPU (self-hosted).

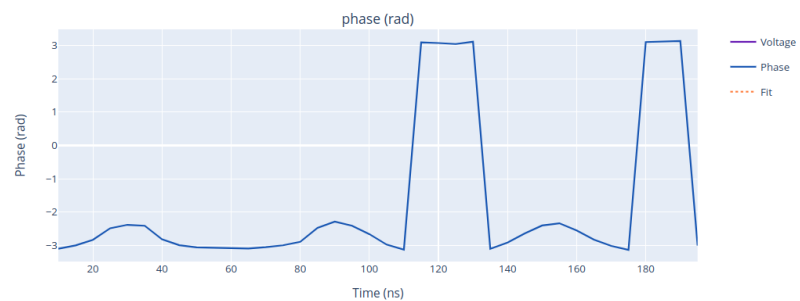
We have control over what we send to the QPU.

We know how to convert quantum circuits to pulses.

Can I **trust** my results? **NO!**

Characterization and **calibration** are an essential step to properly operate emerging quantum devices.





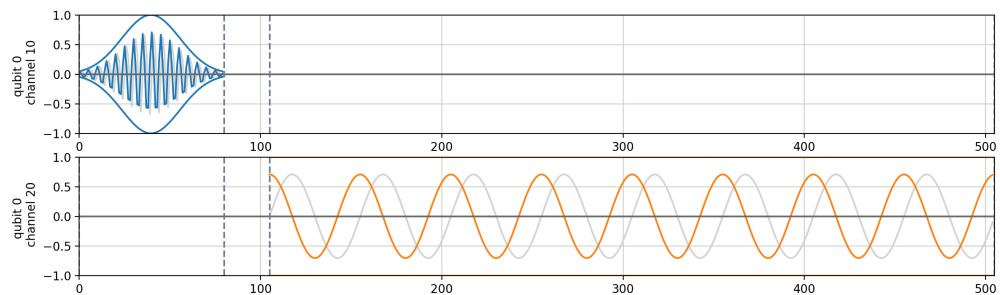
From gates to pulses

Given a general single qubit gate it is possible to decompose it in **RX** and **RZ** gates

$$U3(\theta, \phi, \lambda) = RZ(\phi)RX(-\pi/2)RZ(\theta)RX(\pi/2)RZ(\lambda)$$

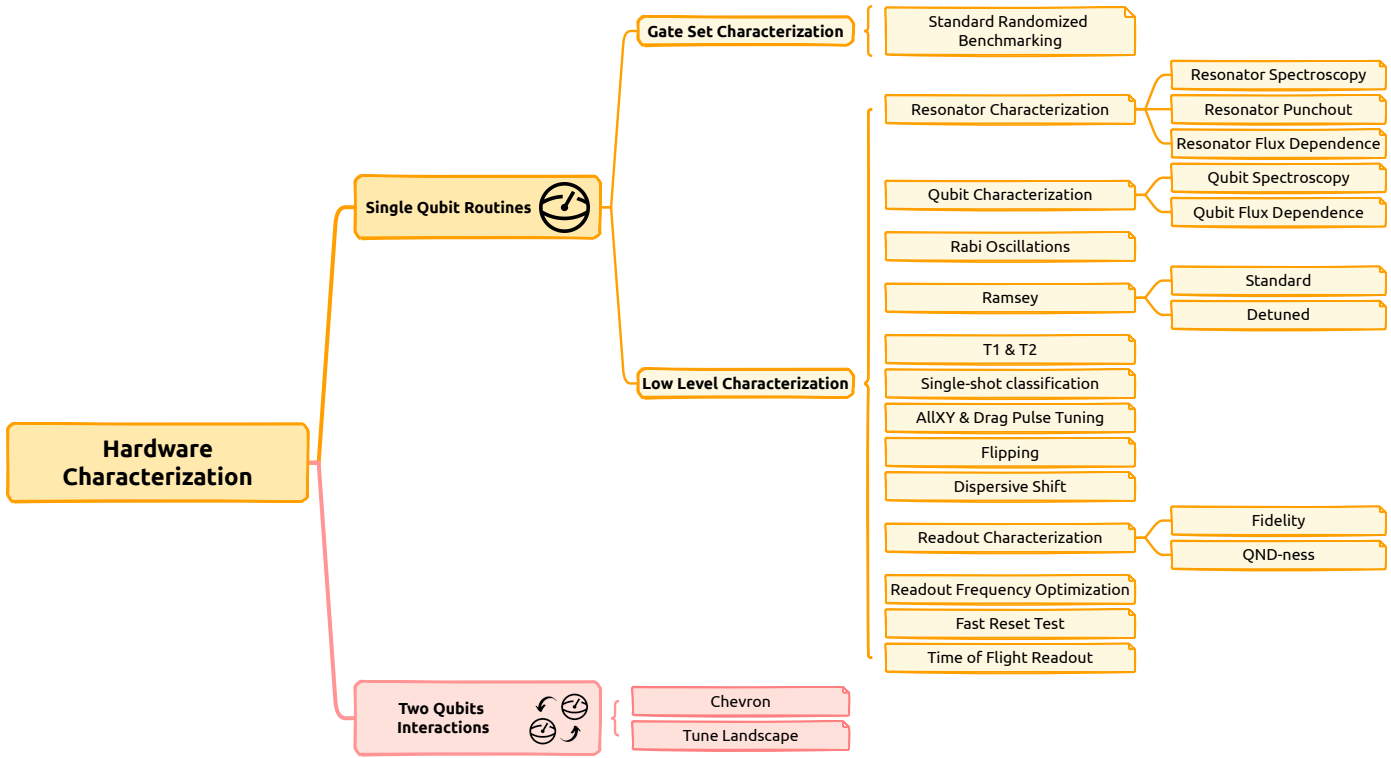
From the level of pulses:

- An **RX** is a Gaussian pulse calibrated by Rabi experiment
- An **RZ** is a change in the virtual phase of the pulses.
- An **MZ** is a rectangular pulse calibrated by readout optimization routines

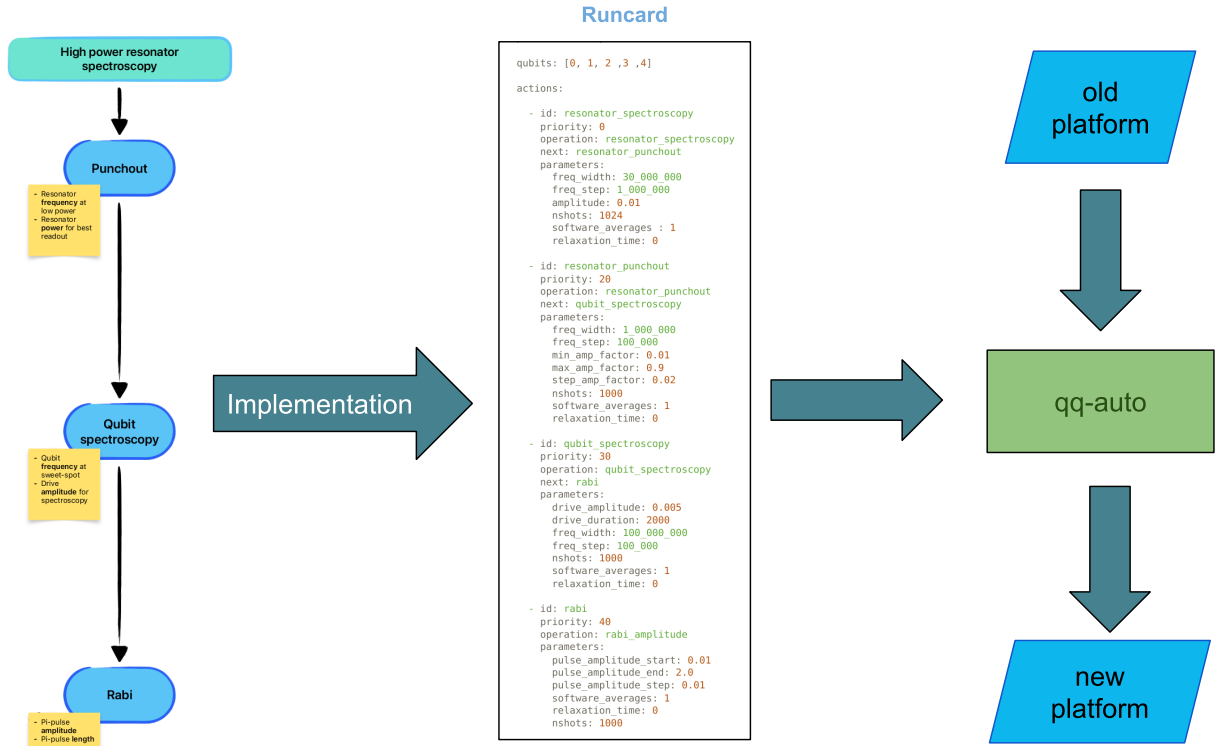


How an RX and measurement gate is performed at the pulses level on a qubit.

Qubits Characterization



How to perform an experiment



Report

Qibocal Reports

- Home
  - Timestamp
  - Summary
- Actions
  - Ramsey - 0

Ramsey Experiment

Export to pdf

Platform: tii_rfsoc4x2
Run date: 2023-05-07
Start time (UTC): 05:20:51
End time (UTC): 05:21:19

Summary

In the table below we show the libraries and respective versions used in Ramsey Experiment.

Library	Version
numpy	1.23.5
qibo	0.1.13
qibocal	0.0.2
qibolab	0.0.3

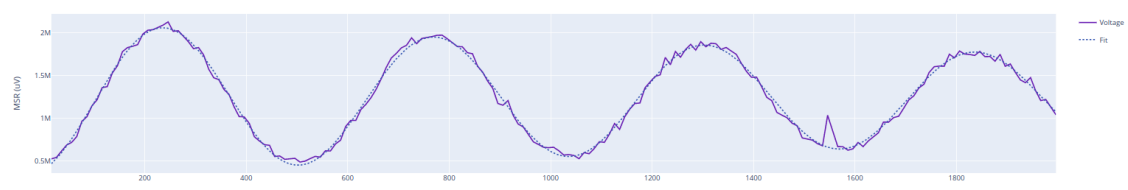
Actions

Please find below data generated by actions:

Ramsey - 0

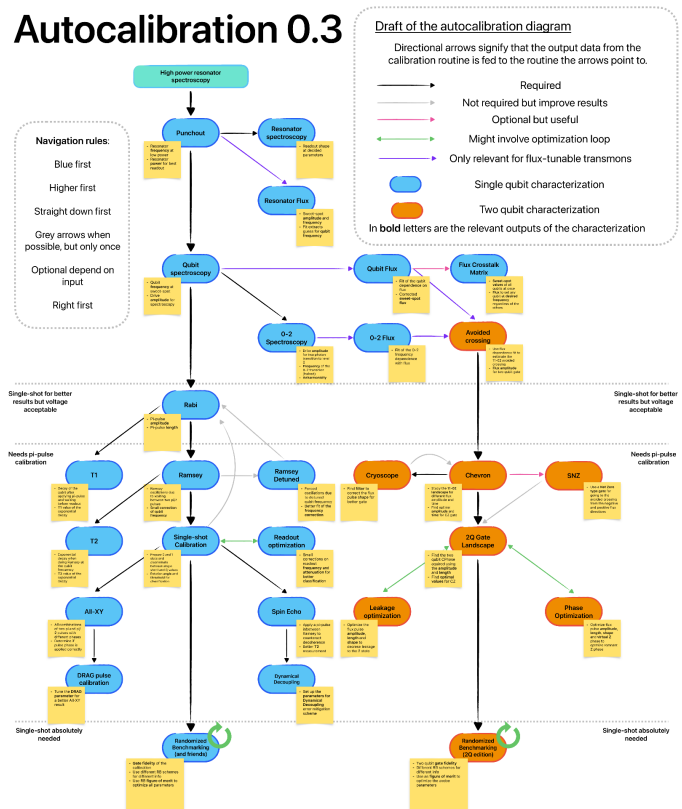
- Qubit 0

qubit	Fitting Parameter	Value
0	delta_frequency	-625,626.0 Hz
0	drive_frequency	5542303347.0 Hz

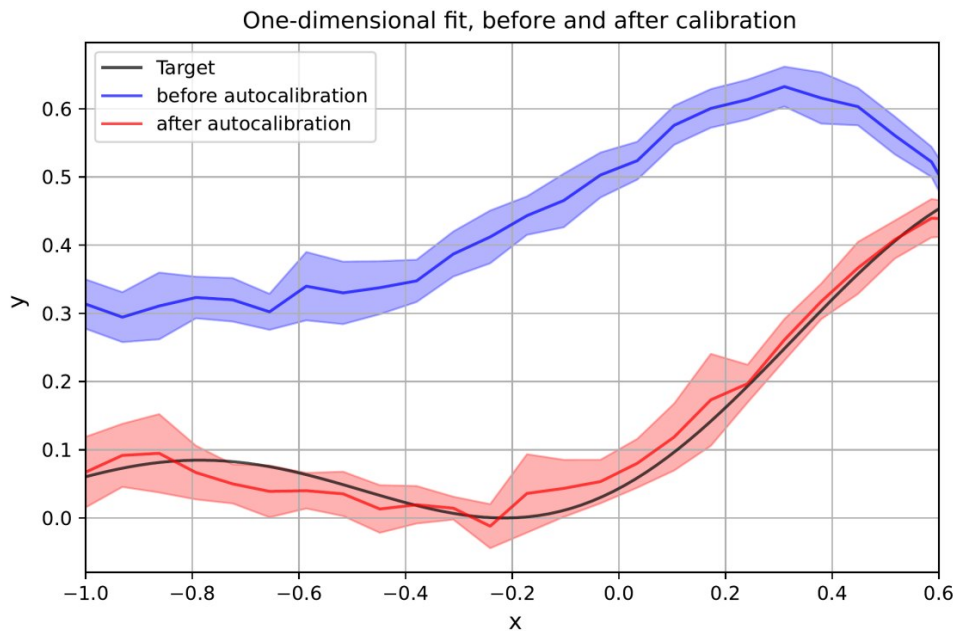


Towards automation

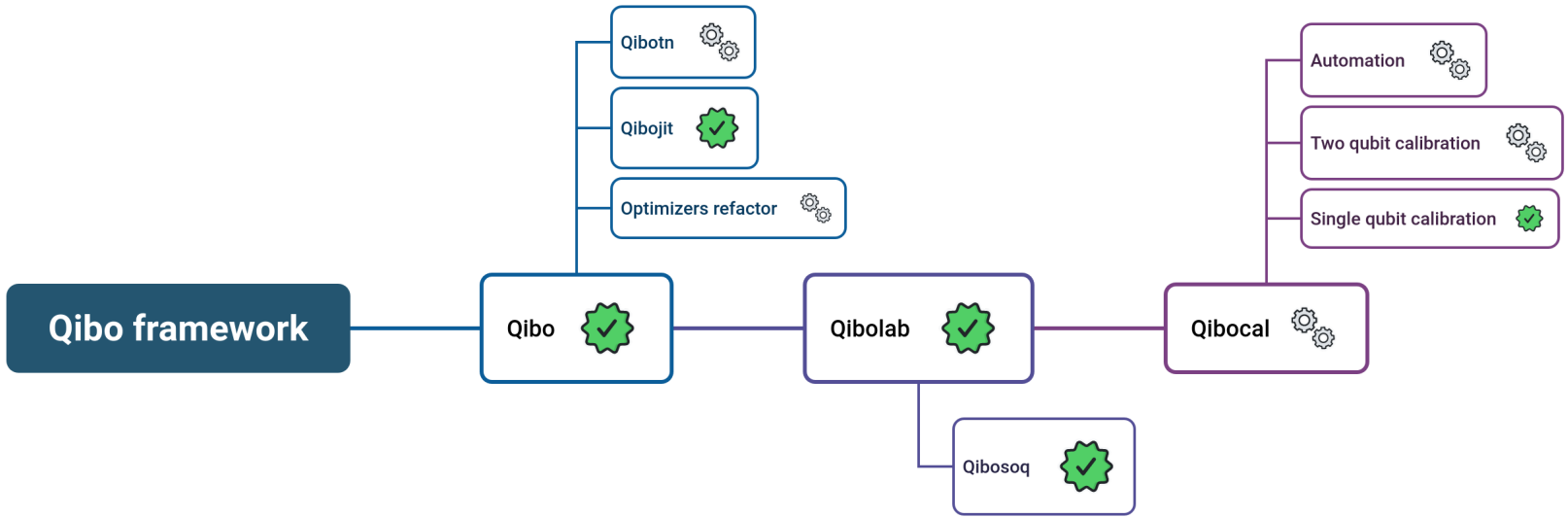
- Specify a direct acyclic graph with various experiments
- Parameters computed are fed from one routine to the next
- Full quantum chip recalibration



Qibo + Qibolab + Qibocal



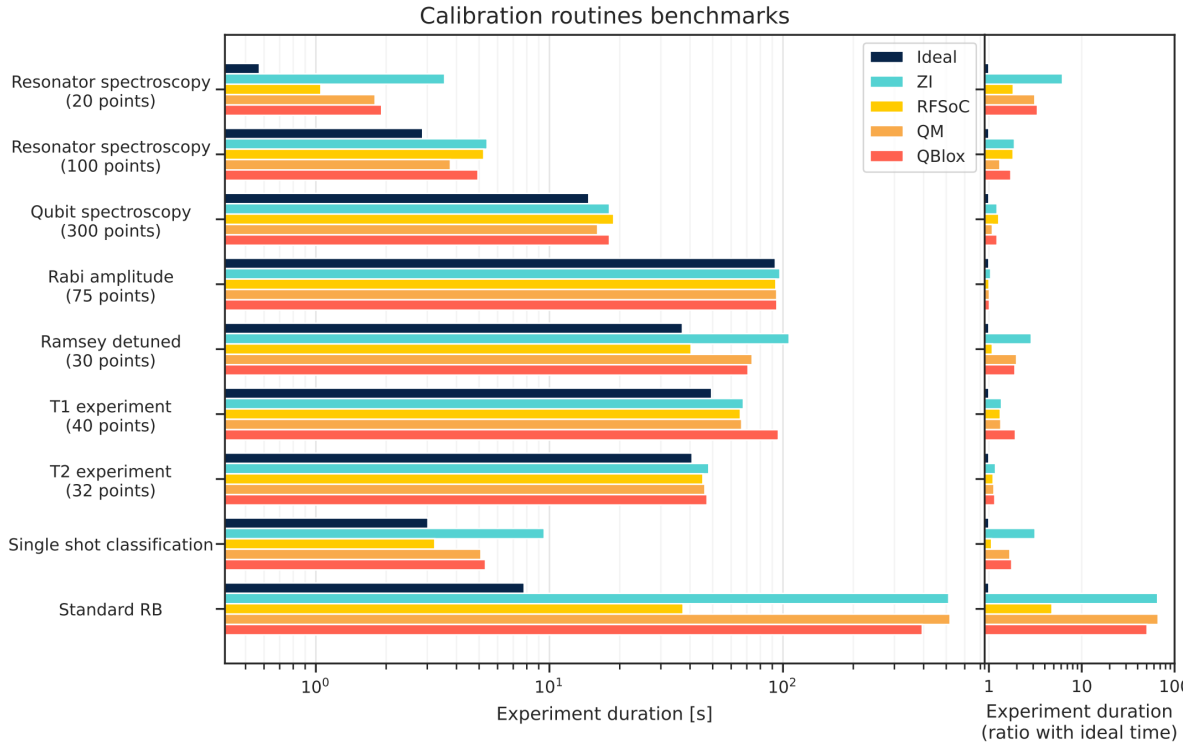
Where are we now?



Thanks for listening!

Backup slides

QIBOLAB + QIBOCAL



Main features