Introducing Qibo

Quantum simulation, control and calibration

Stefano Carrazza, on behalf of the Qibo team

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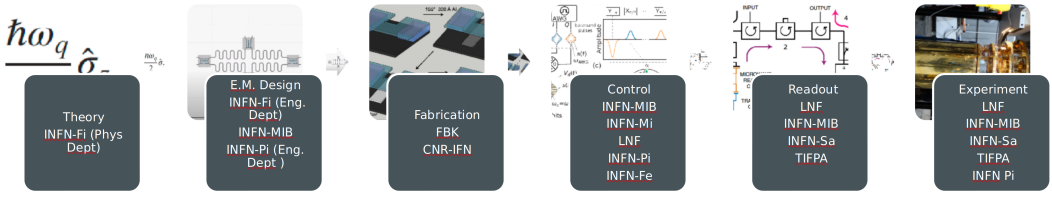
Quantum Computing @ INFN, Bologna

Introduction

Qub-IT project - CSN V

Qub-IT: Realization of an itinerant single-photon counter that surpasses present devices in terms of efficiency and low dark-count rates by exploiting repeated QND measurements of a single photon and entanglement in multiple qubits.

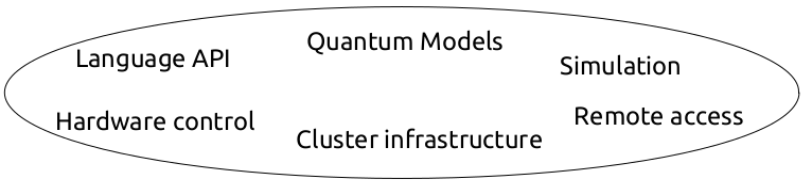


- Design and simulation of a SC qubit coupled to resonators.
- Fabrication of circuits with SC qubit.
- Single-shot measurement of SC qubit with quantum amplifier.
- Software for simulation, control and calibration of SC qubit.
- Quantum sensing experiment with entangled qubits.

Quantum software challenges

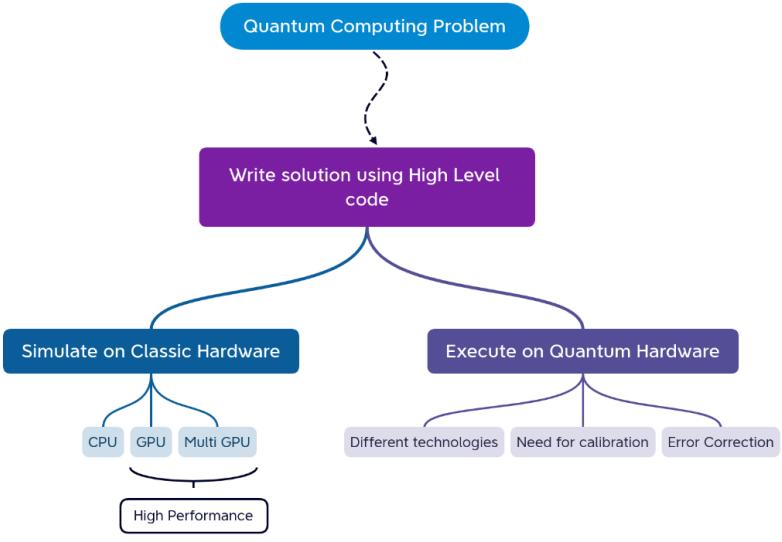
Researcher's needs (lab and theory):

1. Access to **interdisciplinary set of software tools** for:



2. **Open-source software** linked to benchmarks and publications.
3. Collaborative development and **definition of standards**.

Quantum software challenges



Cloud vs self-hosted

Cloud-based vs **self-hosted** devices and simulators:

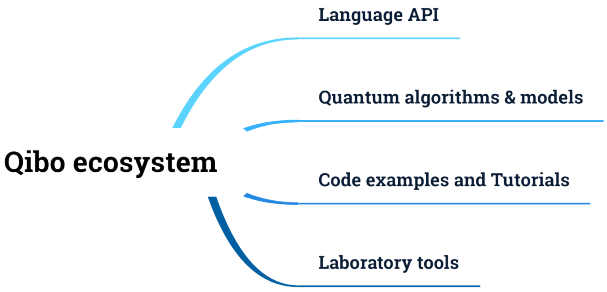
Industry (cloud-based)

Research labs and HPC (self-hosted)

Introducing Qibo

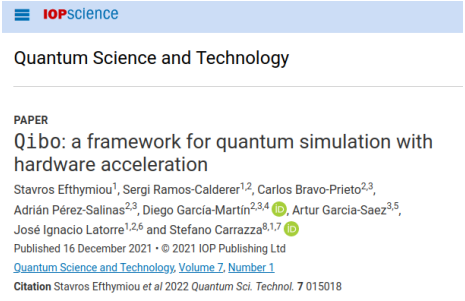
Introducing Qibo

Qibo is an open-source full stack **API** for quantum simulation and hardware control.
It is platform **agnostic** and supports **multiple backends**.



https://github.com/qiboteam/qibo

Introducing Qibo



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PAPER

Qibo: a framework for quantum simulation with hardware acceleration

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https://arxiv.org/abs/2009.01845

Quantum

the open journal for quantum science

Quantum simulation with just-in-time compilation

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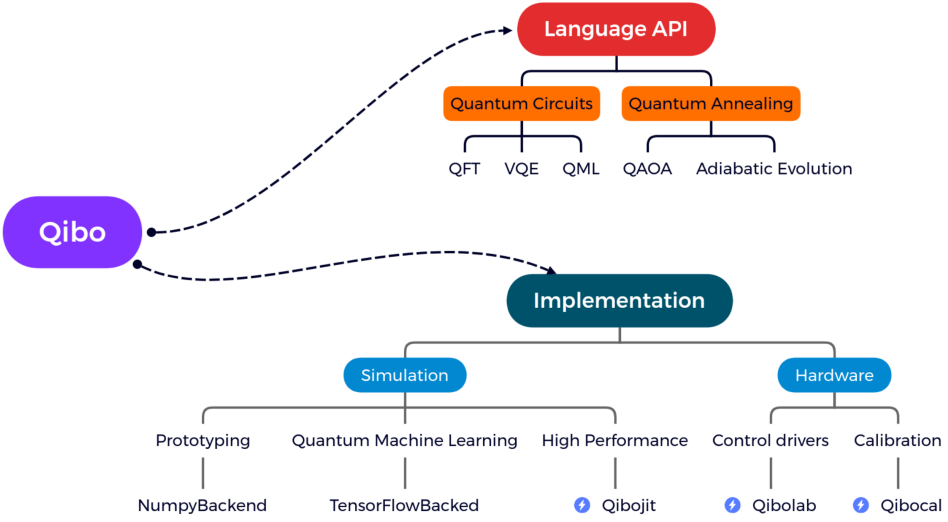
https://arxiv.org/abs/2203.08826

Laboratory	Country	Technology	Qubits
INFN	Italy	Superconducting	1
TII	United Arab Emirates	Superconducting	1, 2, 5, 20
Qilimanjaro	Spain	Superconducting	1 and 2
CQT	Singapore	SC and trapped ion	up to 10

Backends in Qibo



Qibo simulation benchmarks

Introducing Qibojit

State vector simulation solves:

$$\psi'(\sigma_1, \ldots, \sigma_n) = \sum_{\boldsymbol{\tau}'} G(\boldsymbol{\tau}, \boldsymbol{\tau}')\psi(\sigma_1, \ldots, \boldsymbol{\tau}', \ldots, \sigma_n)$$

number of operations scales exponentially with the number of qubits. **Qibo** uses just-in-time technology:

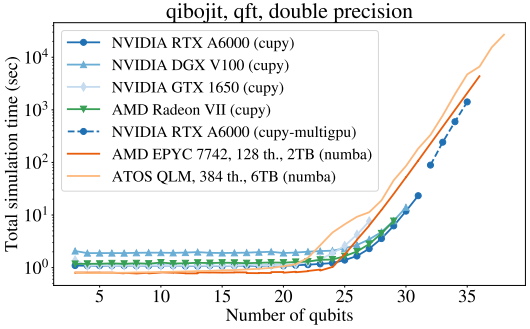
- CPU: Numpy tensor, custom operations with Numba.
- GPU(s): CuPy tensors, custom operations using:
  - CuPy JIT raw kernels
  - NVIDIA cuQuantum API

```python
from numba import njit, prange

@njit(parallel=True, cache=True)
def apply_gate_kernel(state, gate, target):
    """Operator that applies an arbitrary one-qubit gate.

    Args:
        state (np.ndarray): State vector of size (2 ** nqubits,).
        gate (np.ndarray): Gate matrix of size (2, 2).
        target (int): Index of the target qubit.
    """
    k = 1 << target
    # for one target qubit: loop over half states
    nstates = len(states) // 2
    for g in prange(nstates):
        # generate index with fast binary operations
        i1 = ((g >> m) << (m + 1)) + (g & (k - 1))
        i2 = i1 + k
        state[i1], state[i2] = (gate[0, 0] * state[i1] + \
                                gate[0, 1] * state[i2],
                                gate[1, 0] * state[i1] + \
                                gate[1, 1] * state[i2])
    return state
```

Qibojit features

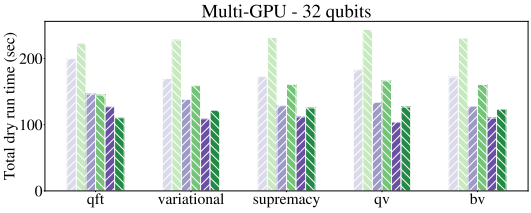
In-place updates, specialized operators for single and two qubit gates (exploit sparsity).

Qibojit



Qibojit

- Supports CPU, GPU and multi-GPU.
- NVIDIA and AMD GPUs.
- Reduced memory footprint.



Benchmark library: `https://github.com/qiboteam/qibojit-benchmarks` [arXiv:2203.08826]

Qibo vs other libraries

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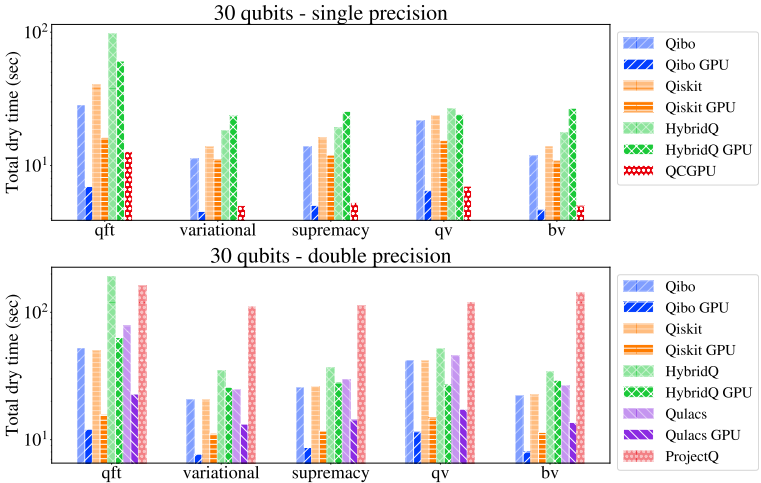
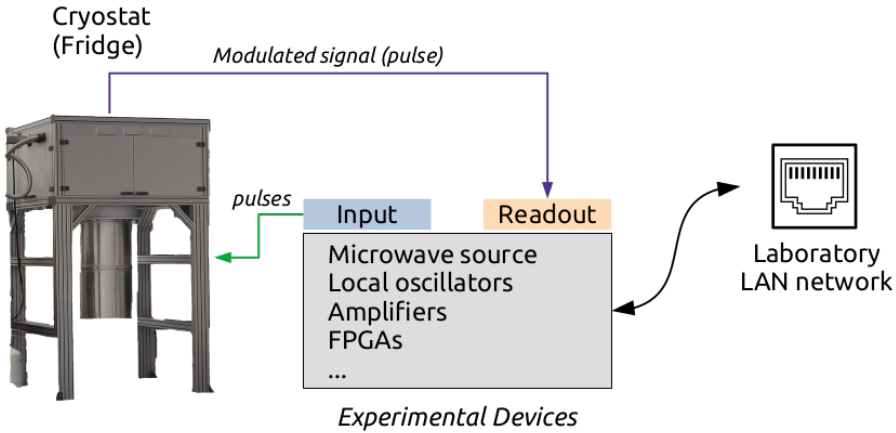
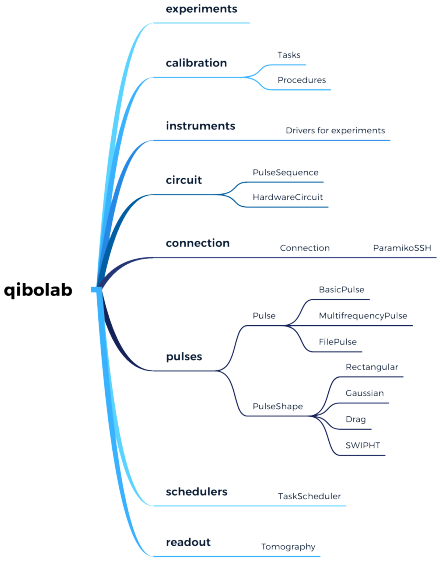


Quantum hardware control

Software control challenges



Introducing qibolab



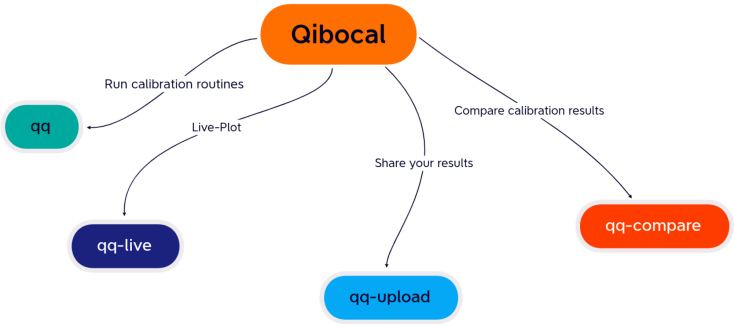
Qibolab key features:

- Create **custom experimental drivers** for lab setup.
- Platform **agnostic** layout.
- Deploy **Qibo models** on quantum hardware easily

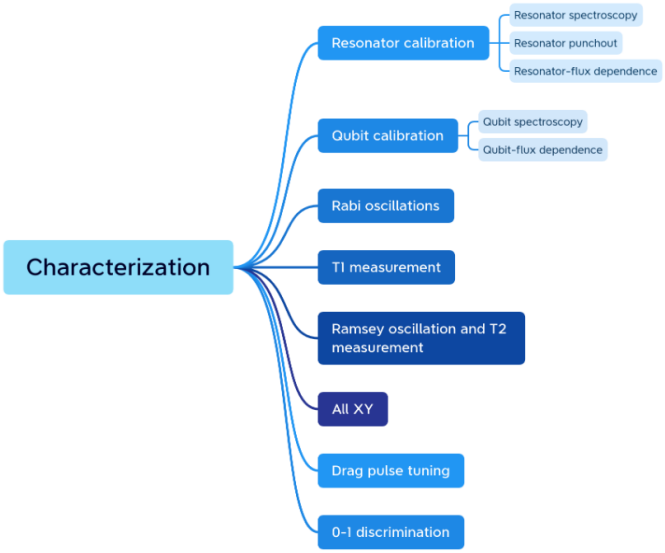
Quantum calibration software

Introducing Qibocal

We are developing **Qibocal** for qubit calibration through Qibolab as the main driver:

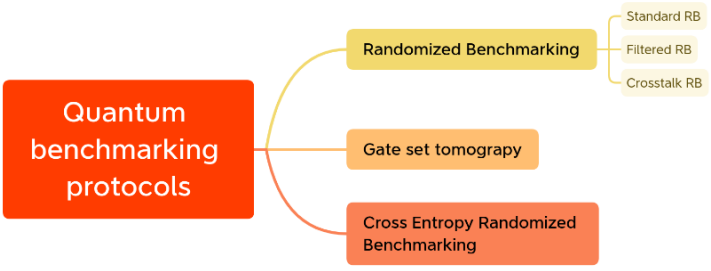


Single Qubit characterization



Quantum benchmarking protocols

Quantum hardware we need to compute the gates error behavior. In the current state-of-the-art this is computed using Quantum benchmarking protocols.

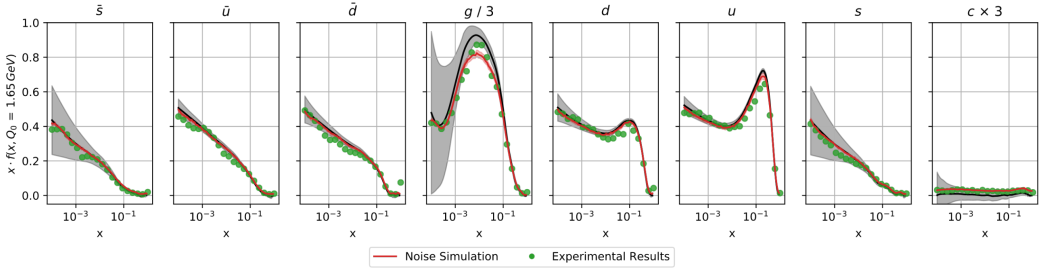


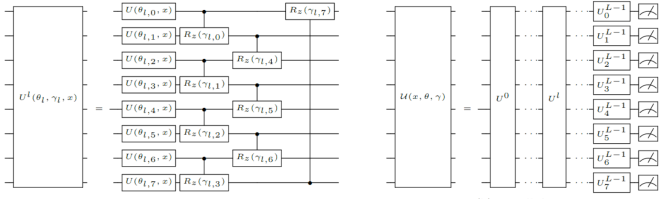
In Qibocal we are currently developing a suite for the execution of the latest QBP available.

Applications in HEP

Determination of parton distribution functions using QML

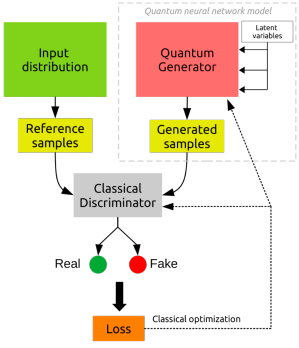
A. Salinas et al, **Determining the proton content with a quantum computer**, PRD, 2011.13934.

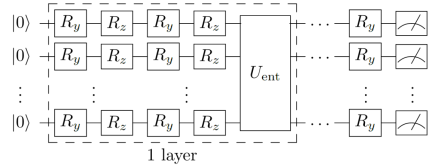


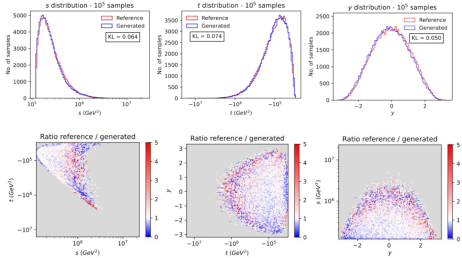


MC event generation using Style-qGAN

C. Bravo-Prieto et al, **Style-based quantum generative adversarial networks for Monte Carlo events**, Quantum, 2110.06933.

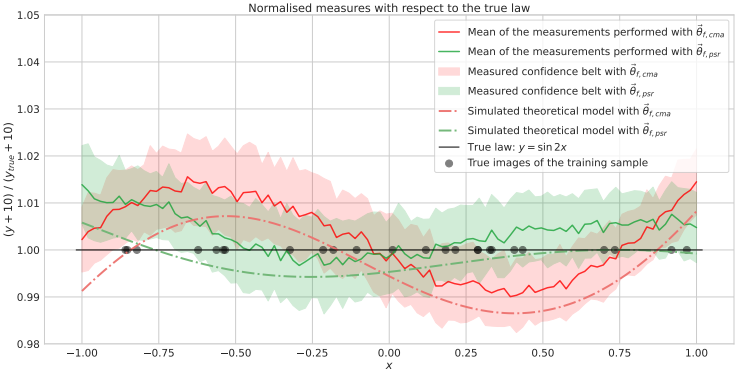






Gradient descent on a QPU

M. Robbiati et al, **A quantum analytical Adam descent through parameter shift rule using Qibo**, ICHEP 2022 proceedings, 2210.10787.



Outlook

Outlook

Qibo accommodates different tasks:

- High performance quantum simulation: qibojit
- Hardware control: qibolab
- Hardware calibration: qibocal

Unique features in Qibo:

1. All modules are open source.
2. Modular layout design with possibility of adding
   - new backends for simulation
   - new platforms for hardware control
3. Community driven effort

`https://github.com/qiboteam/qibo`

`https://qibo.readthedocs.io`