Mitigation of readout noise on the IBM 5-qubit Quantum Computers

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WIGNER

MŰEGYETEM 1782

HUNQUTECH

Nemzeti Kutatási, Fejlesztési és Innovációs Hivatal
AZ INNOVÁCIÓ LENDÜLETE
AZ NKFI ALAPBÓL MEGVALÓSULÓ PROJEKT

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Ákos Budai, Filip Maciejewski, Michal Oszmaniec, András Pályi

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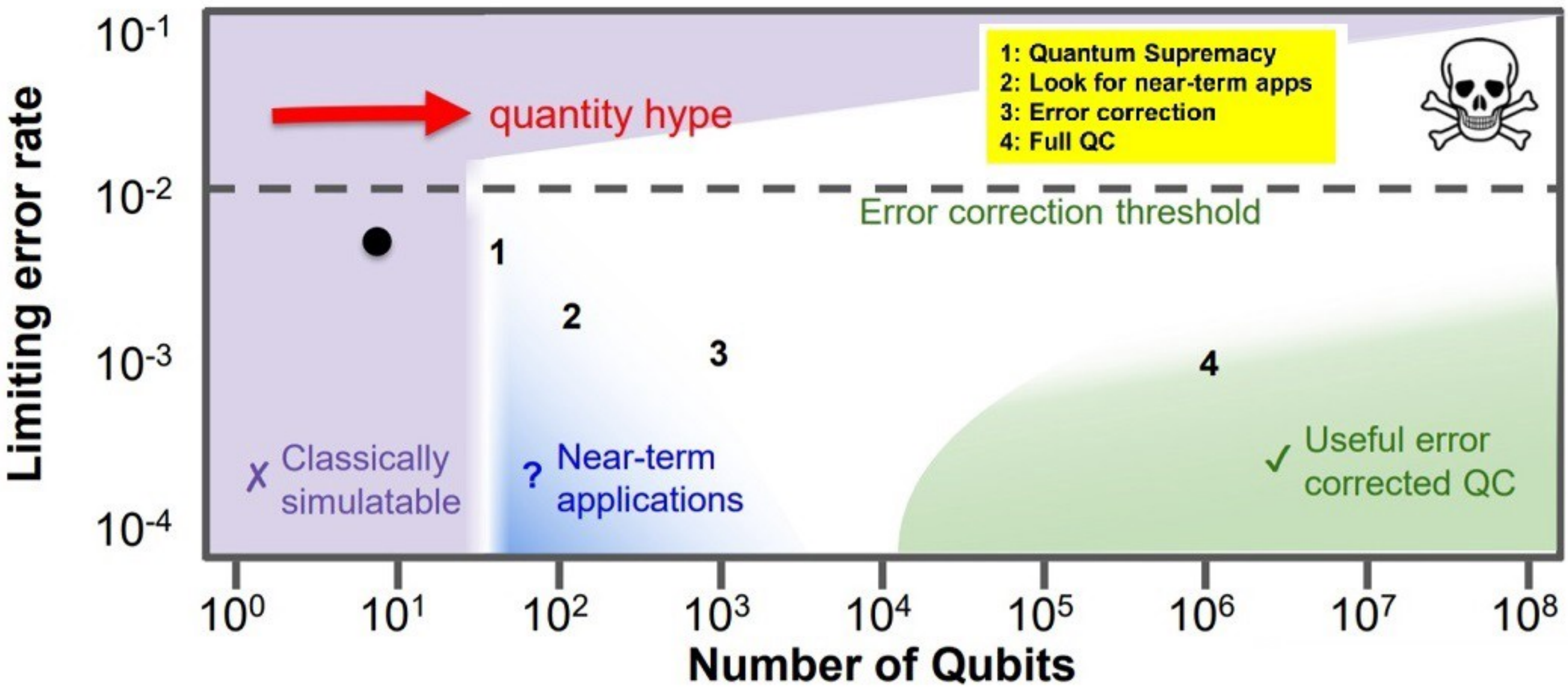
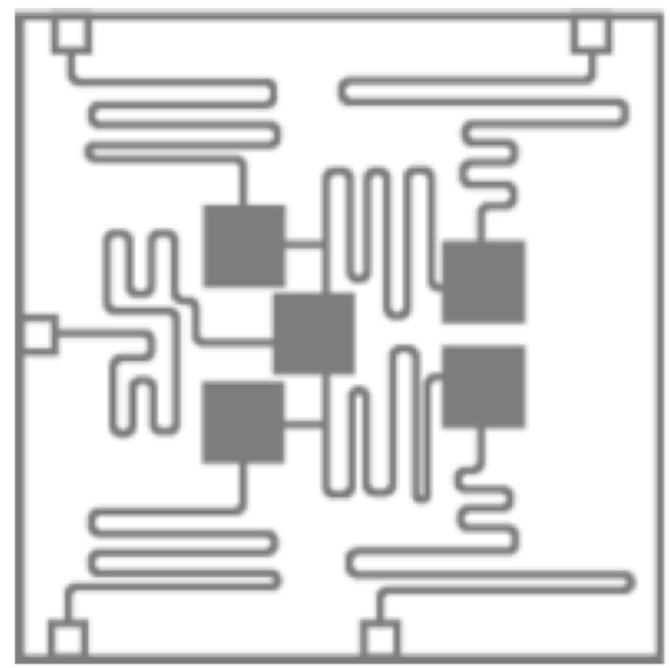
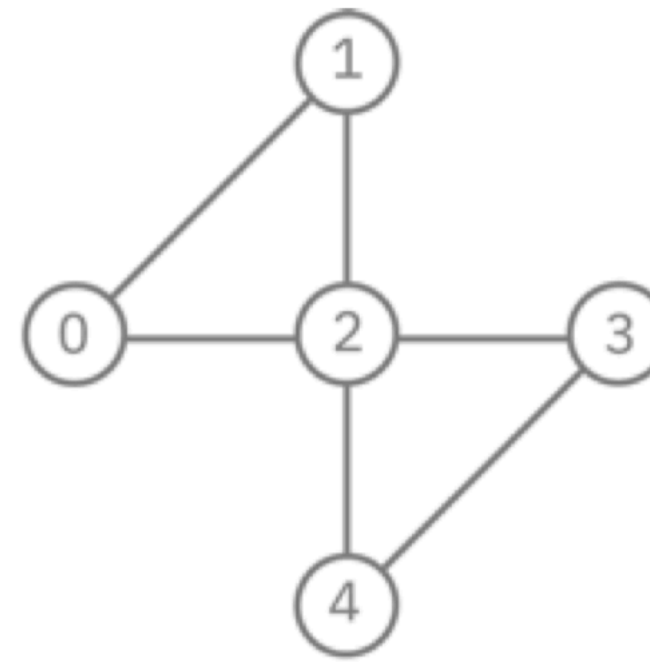
Noisy Intermediate-Scale Quantum (NISQ) Era



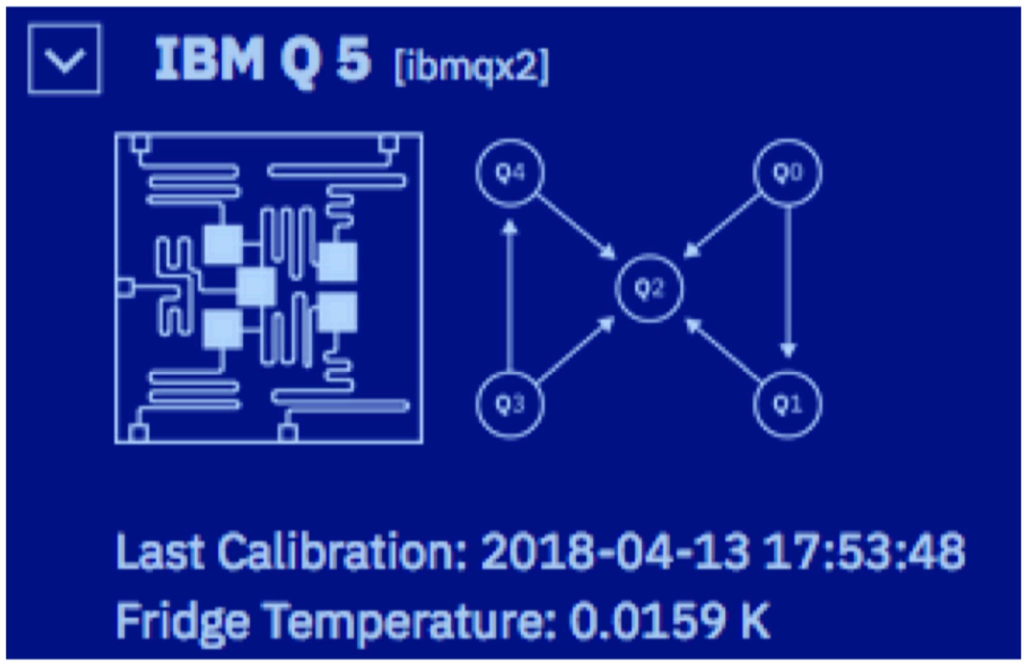
Online Accessible Programable Quantum Computers

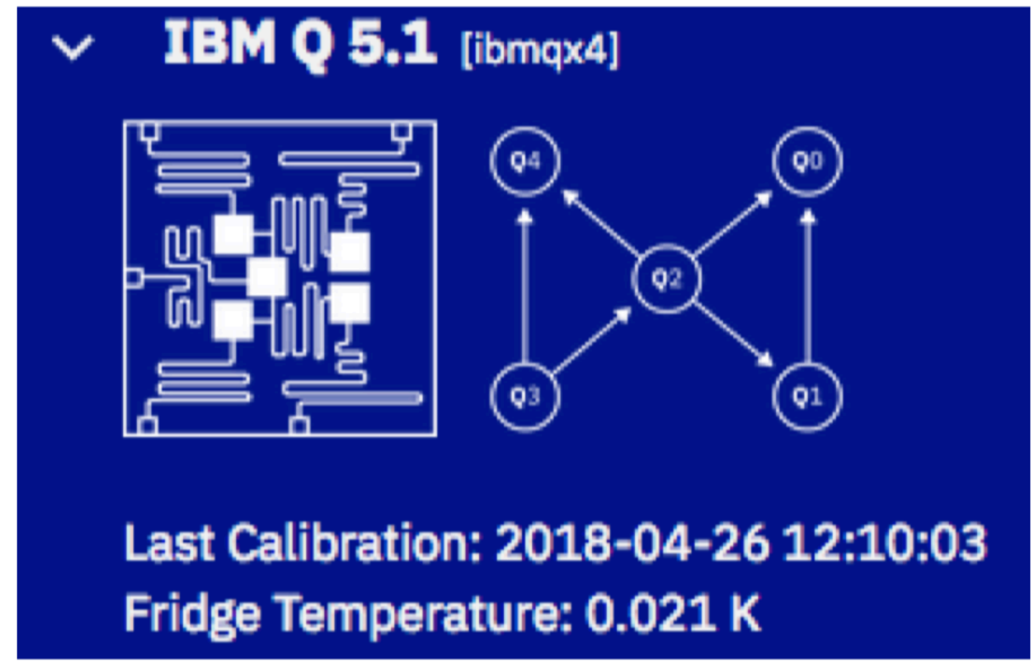


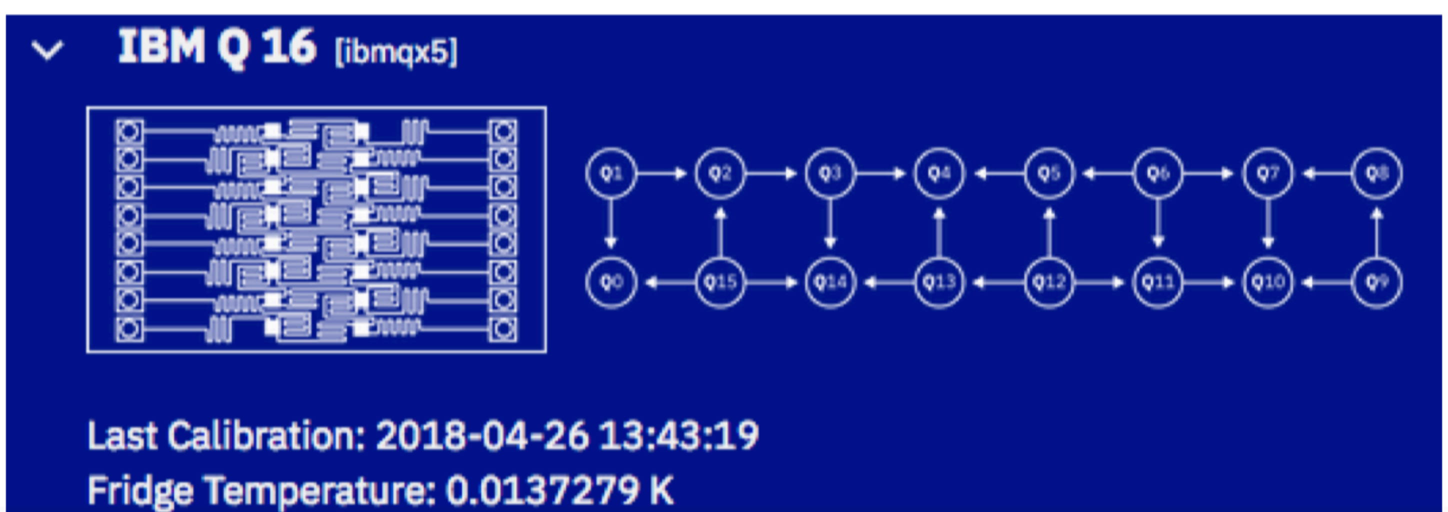


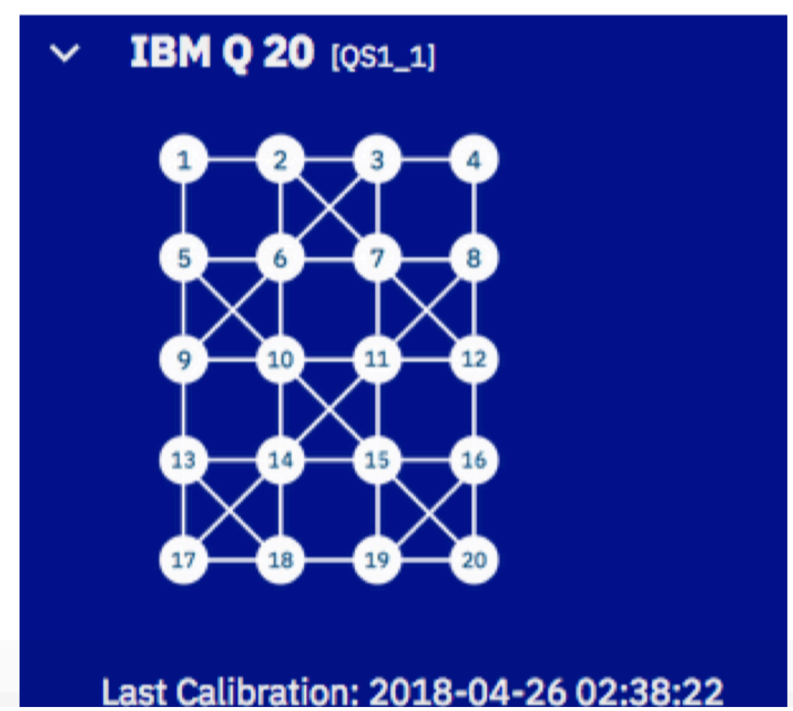
IBM Quantum Experience

3 out of these 4 machines are available for anyone

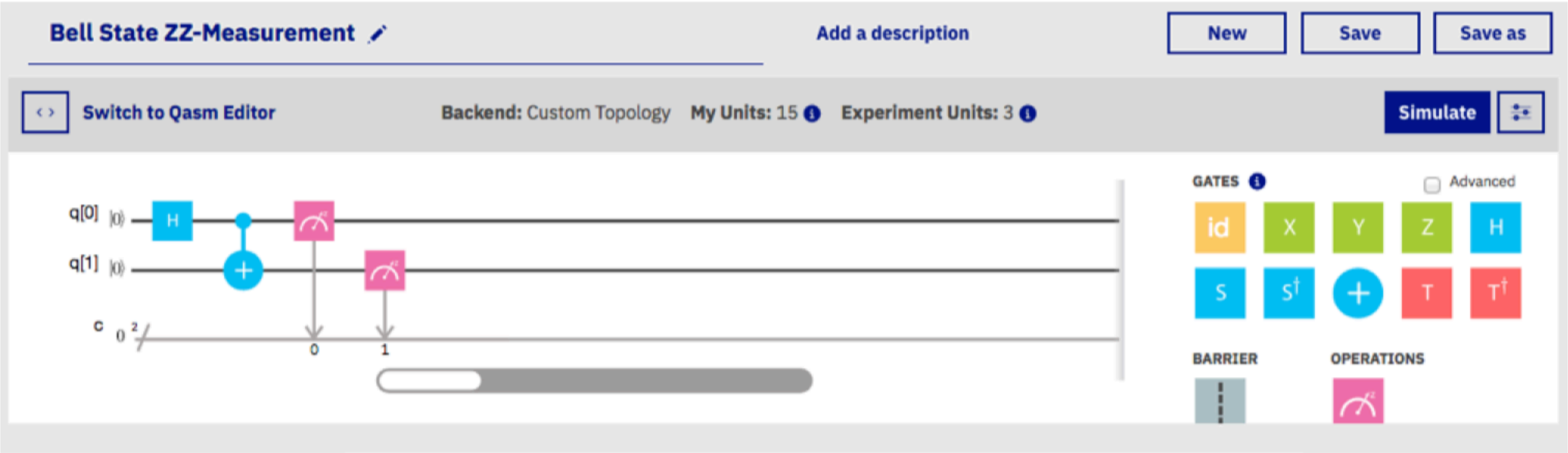








There is a handy python environment for quantum programming




```python
from qiskit import QuantumProgram
qp = QuantumProgram()
qr = qp.create_quantum_register('qr', 2)
cr = qp.create_classical_register('cr', 2)
qc = qp.create_circuit('Bell', [qr], [cr])
qc.h(qr[0])
qc.cx(qr[0], qr[1])
qc.measure(qr[0], cr[0])
qc.measure(qr[1], cr[1])
result = qp.execute('Bell')
print(result.get_counts('Bell'))
```

The IBM Quantum Devices are already used in University Courses

Quantum Information Processing

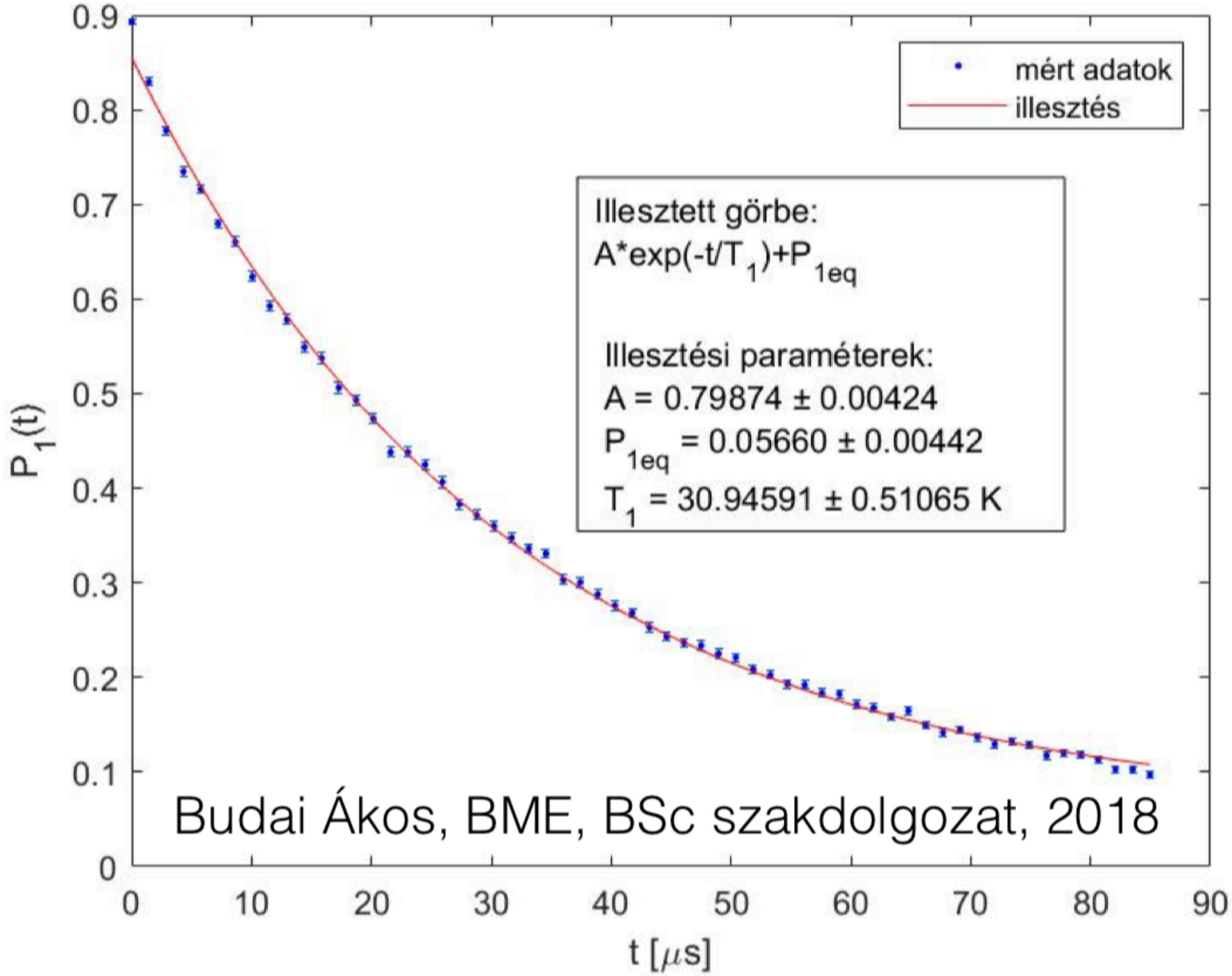
Course Information, 2019 Spring

- **Lecturers:** András Pályi, Zoltán Zimborás
- **Responsible lecturer:** András Pályi
- **Language:** English
- **Location:** F3212
- **Time:** Wednesdays, 12:15-13:45

Details

- One goal is to provide an introduction to basic concepts of quantum information theory and computing. Another goal is to provide hands-on experience in programming an actual quantum computer. That is, the basic concepts, gadgets, algorithms, etc., should be implemented and run by the students themselves during the course and as homework. We will use the quantum computers of the IBM Quantum Experience project, which are available via the cloud for anyone.

As all NISQ devices, the IBM machines are quite noisy



4. ábra. A Q1 qubit relaxációs idő (T_1) mérése.

Mitigation of the readout noise

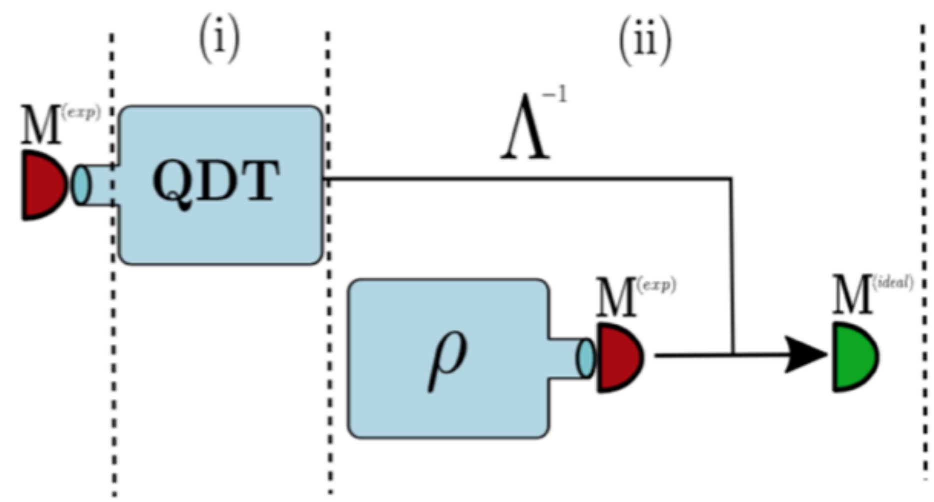


FIG. 1: Pictorial representation of a correction procedure.

Mitigation of readout noise by classical post-processing based on Quantum Detector Tomography

Filip B. Maciejewski,[1,*] Zoltán Zimborás,[2,3,†] and Michał Oszmaniec[4,‡]

We propose a simple scheme to reduce readout errors in experiments on quantum systems with finite number of measurement outcomes. Our method relies on performing classical post-processing which is preceded by Quantum Detector Tomography, i.e., the reconstruction of a Positive-Operator Valued Measure (POVM) describing the given quantum measurement device. If the reconstructed POVM differs from the ideal one only by an invertible classical noise, it is possible to correct the outcome statistics of other experiments performed on the same device. We provide empirical arguments that a classical noise might be the dominant form of measurement noise in contemporary quantum devices consisting of transmon qubits. We also analyze the influence of both finite-size statistics and non-classical errors on the performance of our correction scheme. Finally, we provide a characterization of readout noise occurring in IBM quantum devices and test our mitigation scheme on these. We observe a large improvement of results for a number of tasks including Quantum State Tomography (QST), Quantum Process Tomography (QPT), implementation of non-projective measurements, implementation of a certain probability distributions and implementation of certain quantum algorithm's - Grover's search and the Bernstein-Vazirani algorithm.

Results: great improvements

no.	Standard	Corr ($1q \otimes 1q$)	Corr ($2q$)
1	0.681 ± 0.003	0.925 ± 0.004	0.904 ± 0.004
2	0.784 ± 0.003	0.906 ± 0.004	0.923 ± 0.004
3	0.701 ± 0.003	0.921 ± 0.004	0.898 ± 0.004

(a) Qubits $q_1 q_0$

no.	Standard	Corr ($1q \otimes 1q$)	Corr ($2q$)
1	0.625 ± 0.005	0.743 ± 0.006	0.835 ± 0.005
2	0.764 ± 0.005	0.846 ± 0.006	0.870 ± 0.007
3	0.662 ± 0.002	0.777 ± 0.002	0.825 ± 0.002

(b) Qubits $q_2 q_1$

TABLE VIII: Fidelities of states reconstructed in two-qubit QST experiments on *ibmqx4*. Confidence interval is 1σ.

Results: great improvements

Algorithm	Standard	Corr ($1q \otimes 1q$)	Corr ($2q$)
Grover's	0.578 ± 0.004	0.704 ± 0.005	0.793 ± 0.006
BV	0.553 ± 0.006	0.610 ± 0.007	$0610. \pm 0.007$

TABLE XII: Correct guesses for the three-qubit Grover's and BV algorithms implemented on *ibmqx4*. Confidence interval is 1σ.

Quantum Resource Estimation Workshop in Arizona

08:20	**Welcome** *Alexandru Paler*
08:30	*Joseph Fitzsimons*
09:00	**Verifiable Hybrid Secret Sharing: Reducing Quantum Resources** *Victoria Lipinska, Glaucia Murta and Stephanie Wehner*
09:30	**Fault-tolerant quantum error correction on NISQ devices: flag and bridge qubits** *Lingling Lao and Carmen G. Almudever*
10:00	**Minimizing State Preparations for VQE** *Pranav Gokhale and Fred Chong*
10:30	**Coffee Break**
11:00	*Craig Gidney*
11:30	**Fault tolerant resource estimation of quantum random-access memories** *Olivia Di Matteo, Vlad Gheorghiu and Michele Mosca*

Quantum Resource Estimation Workshop in Arizona

14:00	*Daniel Litinski*
14:30	**Reducing the cost of implementing AES as a quantum~circuit** *Brandon Langenberg, Hai Pham and Rainer Steinwandt*
16:30	*Christian Gogolin*
17:00	**Determining the capacity of any quantum computer to perform a useful computation** *Joel Wallman and Joseph Emerson*
17:30	**Mitigation of readout noise by classical post-processing based on Quantum Detector Tomography** *Filip Maciejewski, Michal Oszmaniec and Zoltan Zimboras*
18:00	*Brad Lackey*
18:30	**Closing** *Daniel Herr*

QDrive Budapest workshop

QDrive Budapest

July 3-5, 2019, Eötvös Loránd University

Eötvös Loránd University, Faculty of Science, 1117 Budapest, Pázmány Péter sétány 1/A

Introduction to Quantum Programming

- What is a quantum computer, what can it do, how does it work?
- How can I write my own programs and run them on **IBM's quantum computer**?

If you wonder about these questions, have had some experience with linear algebra, a touch of quantum physics, and basic familiarity with python, this 3-day free workshop at Eötvös Loránd University by **QLatvia** could be for you! We encourage students with a basic knowledge of quantum mechanics to apply, from all levels (BSc, MSc, PhD). Applications from senior researchers and outside of academia are also welcome.

The workshop is part of **QDrive**, with classes given in English by Latvian quantum programmers, and is hosted by the Eötvös Loránd University Budapest, with local support from the Budapest University of Technology and Economics and the Wigner Research Centre for Physics of the Hungarian Academy of Sciences.

"Quantum programming workshop travelling to your city - reaching 400 participants, by driving 20.000 km through 20 countries in 100 days."

The workshops cover **40 *Jupyter notebooks***, with 2-5 tasks each. Participants should have **Anaconda** and **Qiskit** installed on their own computers, and test their own system, using 12 notebooks which will be shared with them before the workshop (reviewing the basics of Python, vectors, matrices, and basic operations). Bring your own laptops to the workshop, or use the desktop computers we provide.

Apply fast - number of participants limited to 24

Please apply to the workshop **until June 7** by filling out the **online application form**. There is no registration fee for this event - the workshop is free - but the number of participants is limited to 24.

Project Team

Leader: Abuzer Yakaryilmaz

QDrivers:

Maksims Dimitrijevs and Abuzer Yakaryilmaz

Contributors:

Agnieszka Wolska, Matīss Apinis, Mārtiņš Kālis

Local organizers:

Zoltán Zimborás (Wigner RCP), János Asbóth (Wigner RCP), László Oroszlány (Eötvös Univ), András Pályi (BUTE), Gábor Vattay (Eötvös Univ)

Application deadline

June 7, 2019

The workshop is free, but the number of participants is limited to 24

Contact:

zimboras.zoltan@wigner.mta.hu