Qiskit Runtime Primitive 소개

Inho Choi
Qiskit Advocate

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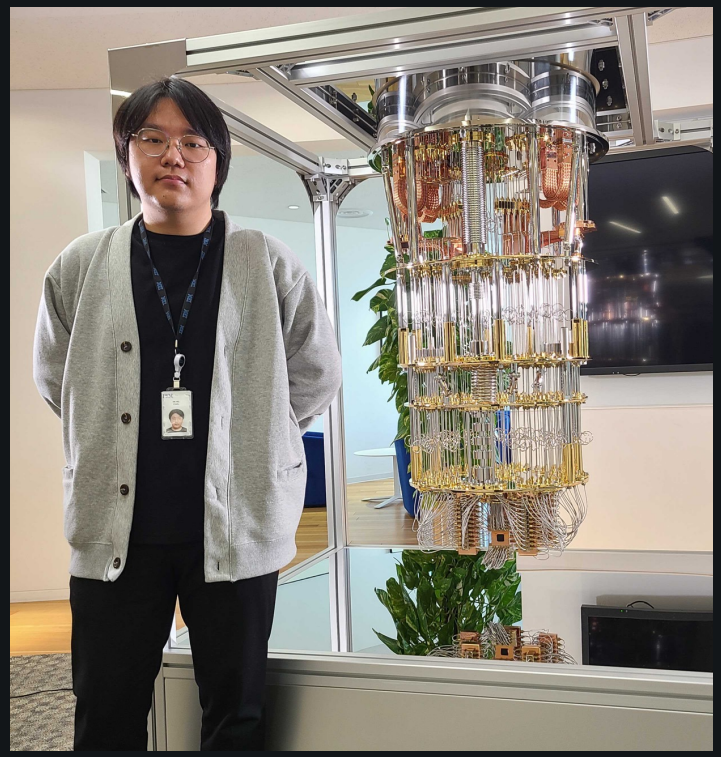
Qiskit



최인호

- Majoring Physics, Electronic Engineering and Computer Scinece in HKUST
- Qiskit Advocate
- Interested in Quantum Hardware

- Qiskit Slack @Inho Choi

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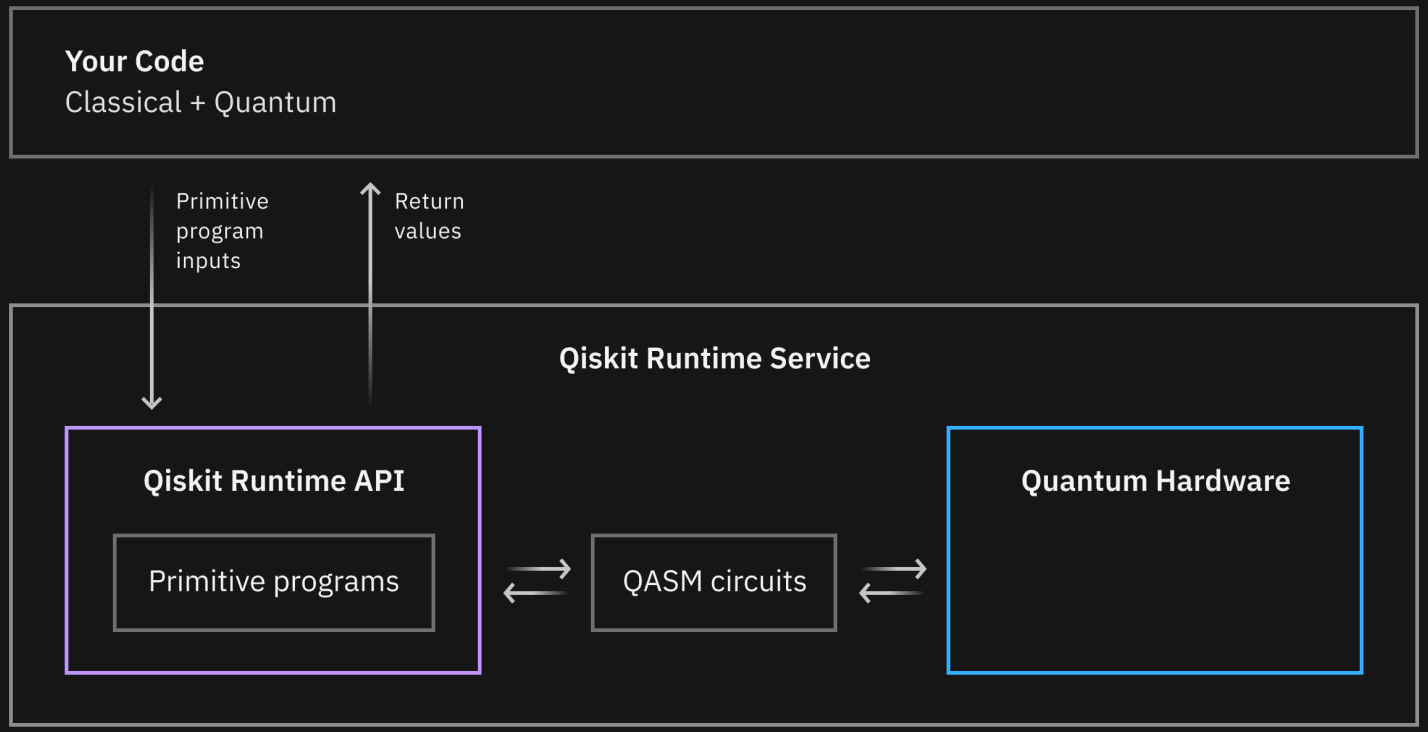
Qiskit Runtime

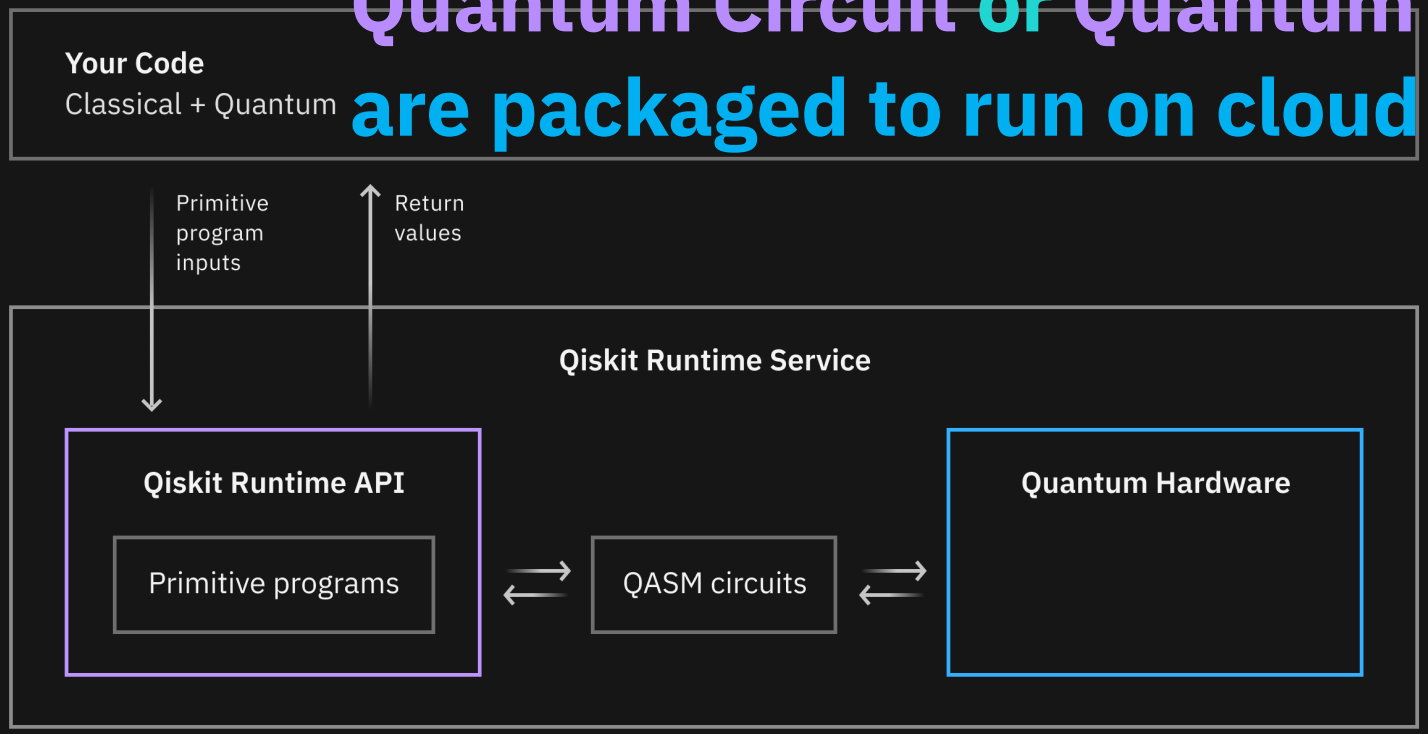
Qiskit



Qiskit Runtime

Qiskit

Quantum Circuit or Quantum Routines are packaged to run on cloud



Qiskit Runtime

Qiskit

- Remove lengthy communication trips back-and-forth to user's computers.
- Program executed in Qiskit Runtime -> More efficient
- Spend Less time waiting in queues -> Run **more** circuits in a day

Qiskit

Save Latency

Reduce overhead for iterative loops

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Qiskit

Efficiency

Save Latency

Reduce overhead for iterative loops

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Qiskit Runtime

Qiskit

Efficiency **Consistency**

Save Latency

Reduce overhead for iterative loops

Qiskit Runtime

Qiskit

Efficiency **Consistency** **Customizability**

Save Latency

Reduce overhead for iterative loops

Qiskit Runtime

Qiskit

Efficiency **Consistency** **Customizability**

Save Latency

Reduce overhead for iterative loops

Error Mitigation and Suppression

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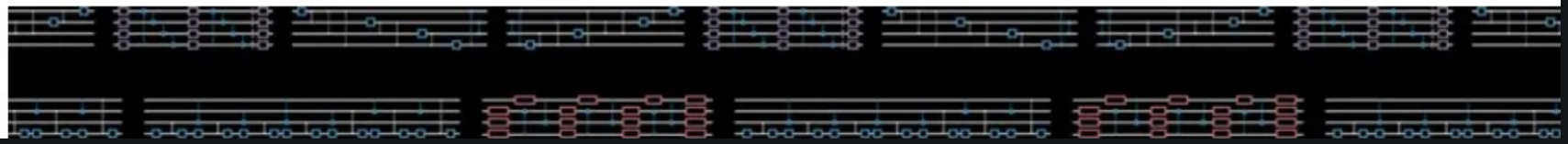
120X Speedup

Qiskit

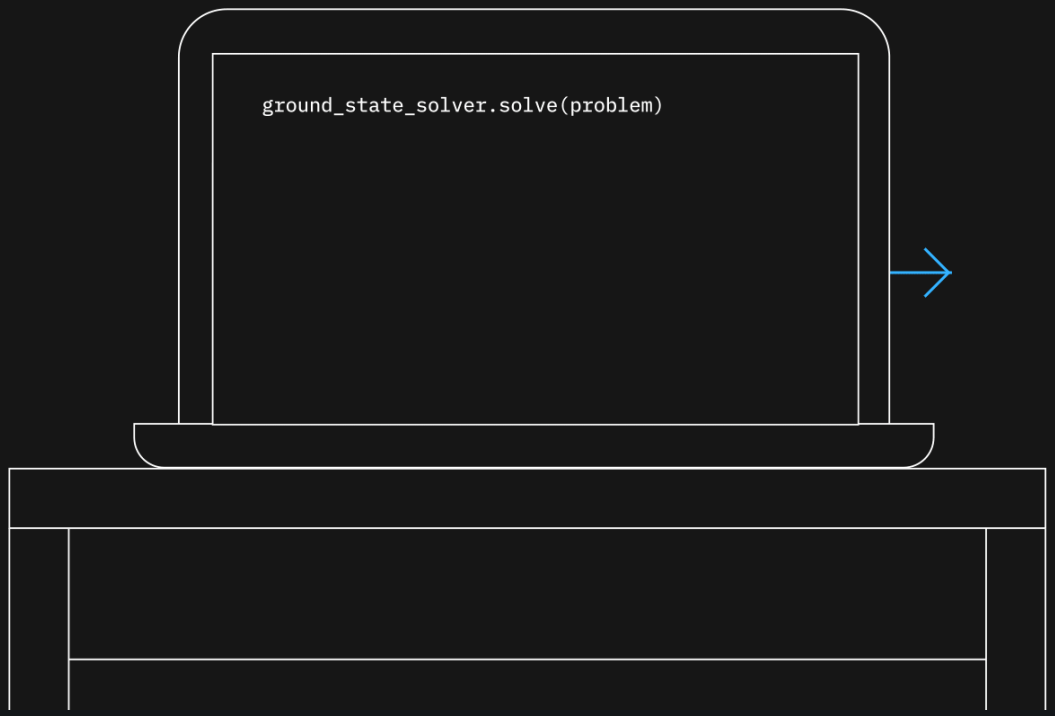
IBM Quantum delivers 120x speedup of quantum workloads with Qiskit Runtime

We're pleased to announce that the team demonstrated a 120x speedup in simulating molecules thanks to a host of improvements, including the ability to run quantum programs entirely on the cloud with Qiskit Runtime.



IBM Runtime workflow

Qiskit



Introduction to Primitives

Qiskit

Basic Element

that serve as a building block for more complex elements

Primitives with Quantum?

Qiskit

- Higher level core primitive terms with categorization
- Enable to build a program more accessibility
- Do not need low machine code level

Install Qiskit Runtime

Qiskit

Getting started ¶

Install Qiskit packages ¶

Install these packages. They let you create circuits and work with primitive programs via Qiskit Runtime.

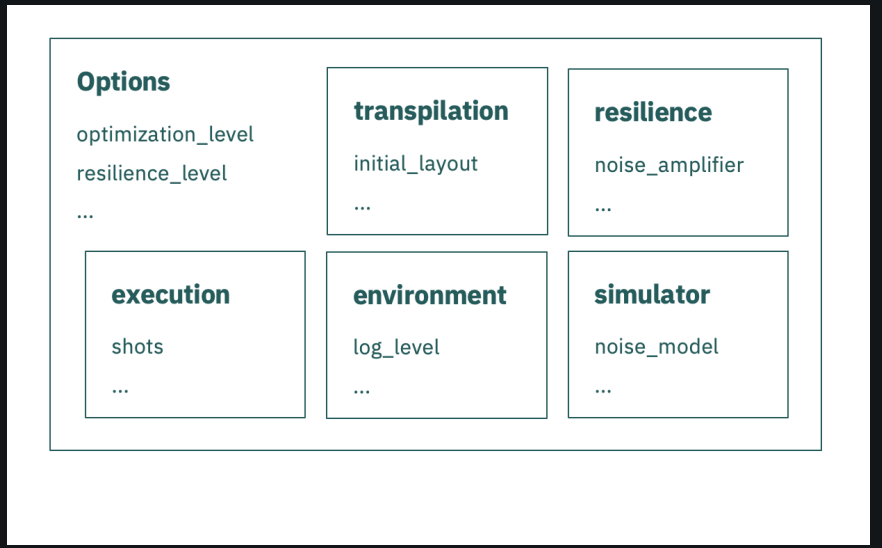
```
pip install qiskit
pip install qiskit-ibm-runtime
```

Qiskit Runtime Primitive keywords

Qiskit

- **Session**
  - Open and Close session to use the primitives on cloud
  - Define a job as collection of iterative calls to the quantum computer

- **Options**
  - Configure the current session and parameter
  - Control execution environment



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Qiskit Runtime Primitive

Qiskit

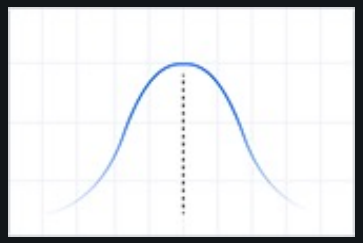
Sampler

Estimator

Qiskit Runtime Sampler

Qiskit

- Generates an error-mitigated readout of quasi-probabilities
  - **Input**: User Circuit

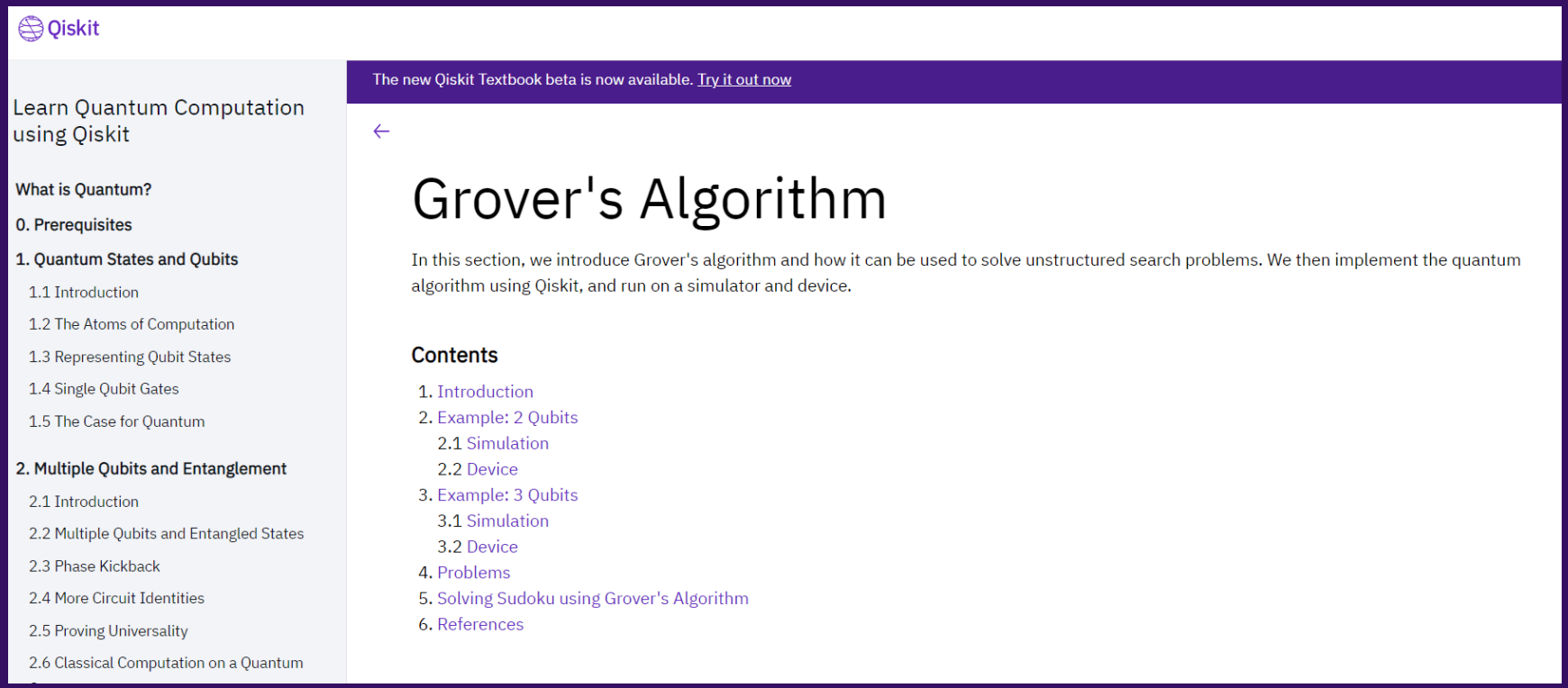


- **Better** evaluate shot result
  - Error mitigation
  - More efficient evaluation of the possibility of multiple relevant data points
    - **Where**: the context of destructive interference

https://qiskit.org/documentation/partners/qiskit_ibm_runtime/tutorials/how-to-getting-started-with-sampler.html

Grover Algorithm Demonstration

Qiskit



Qiskit Runtime Estimator

Qiskit

- Efficiently calculate and interpret expectation values of quantum operators required for many algorithms
- Allow selectively group between circuits and observables for execution
  - Efficient evaluation of expectation values and variances for given parameter input.

Qiskit Runtime Estimator

Qiskit

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“No Measurements”

Parameterized circuits

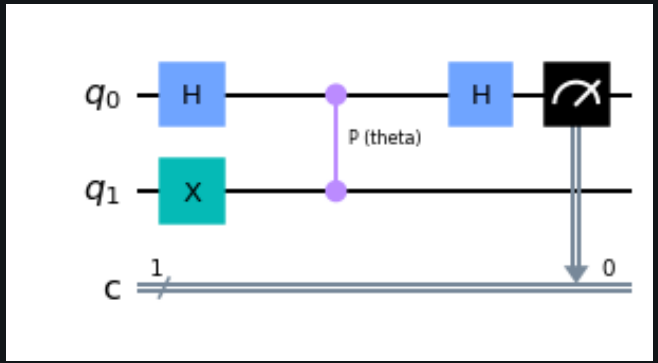
Qiskit

Primitive allows simplification of binding multiple parameters in parameterized circuits.

Parameterized circuits

Qiskit

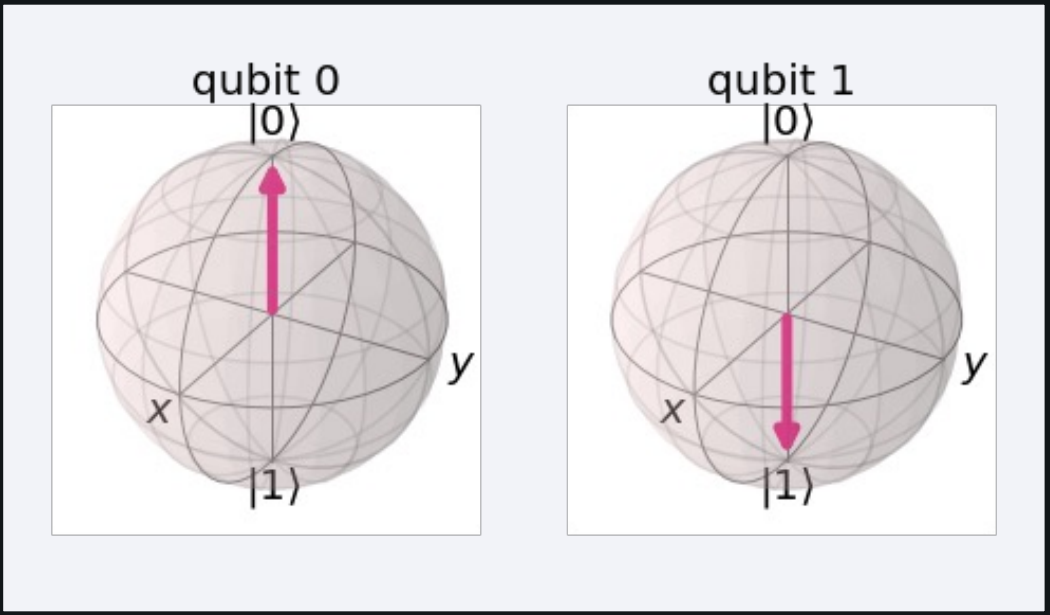
Primitive allows simplification of binding multiple parameters in parameterized circuits.



0 to 2π: divided over 50 evenly spaced points

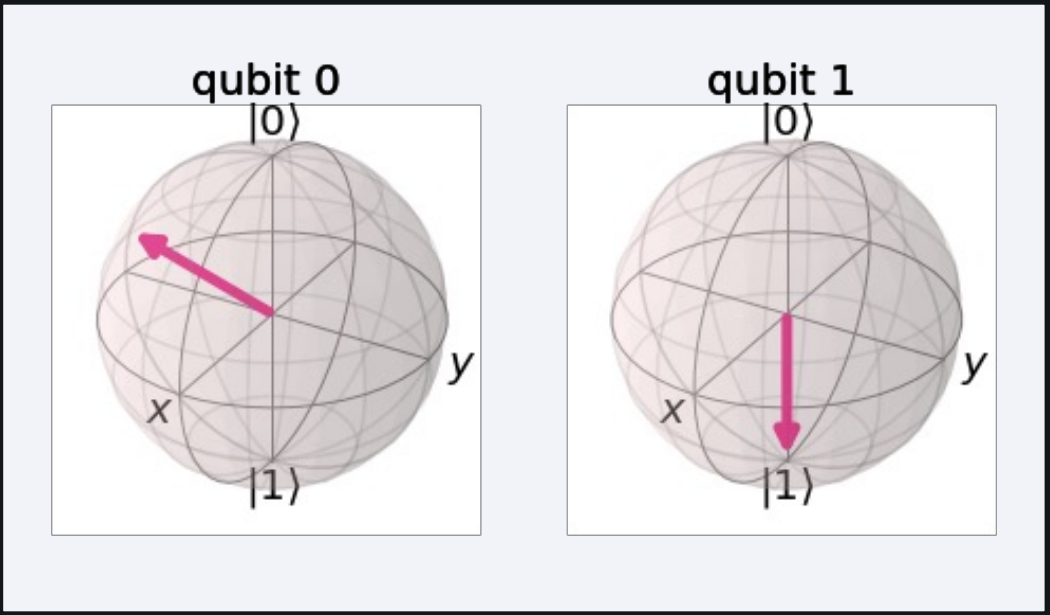
Parameterized circuits

Qiskit



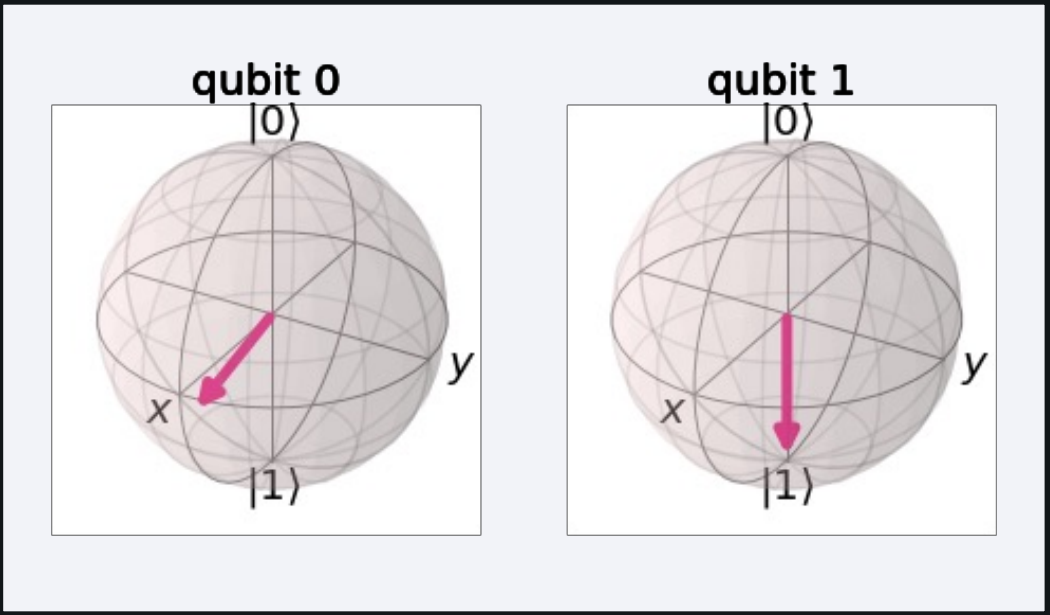
Parameterized circuits

Qiskit



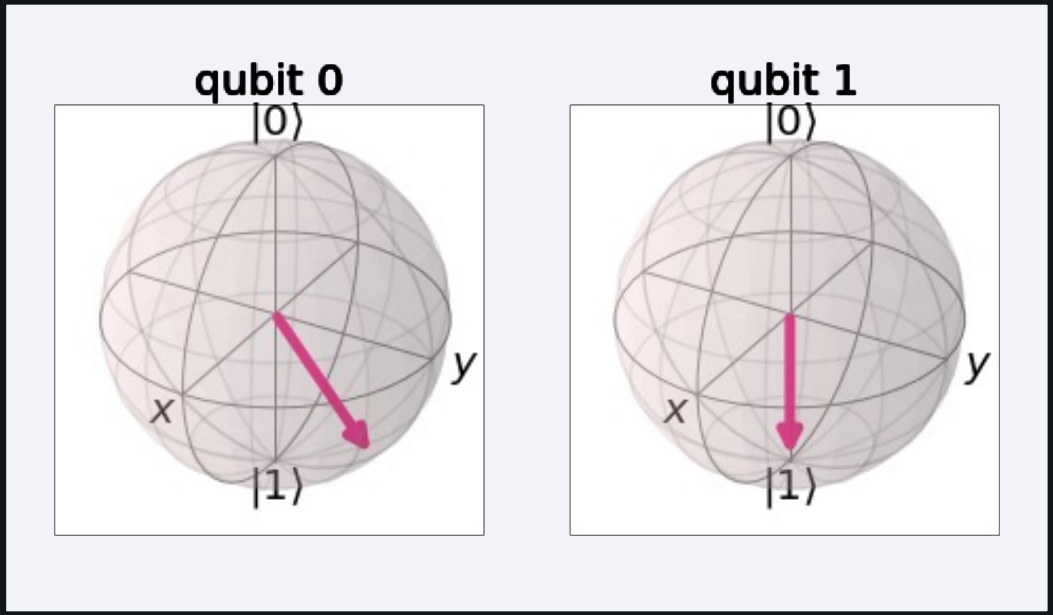
Parameterized circuits

Qiskit



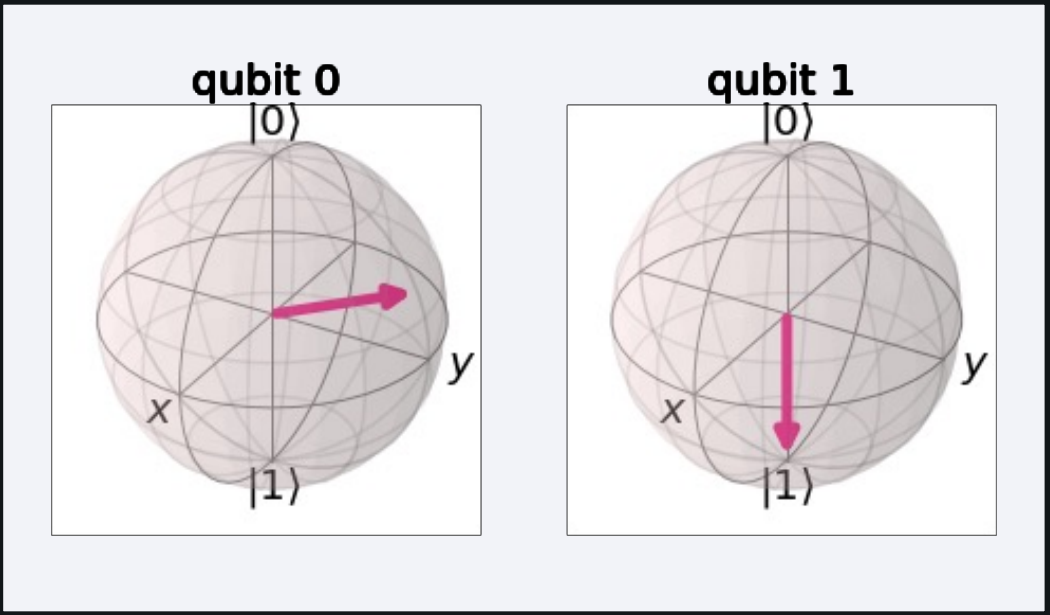
Parameterized circuits

Qiskit

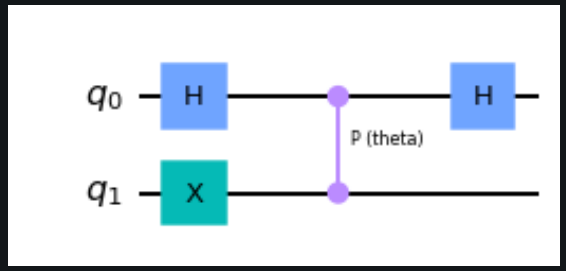


Parameterized circuits

Qiskit



Parametrized Circuit



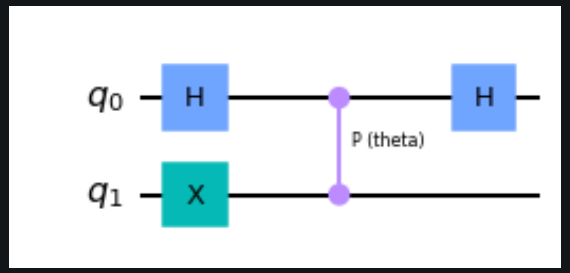
Parametrized Circuit

Qiskit

Calculate expectation value

$$\langle ZZ \rangle = \langle \psi | ZZ | \psi \rangle = \langle \psi | (|0\rangle\langle 0| - |1\rangle\langle 1|) \otimes (|0\rangle\langle 0| - |1\rangle\langle 1|) | \psi \rangle = |\langle 00|\psi\rangle|^2 - |\langle 01|\psi\rangle|^2 - |\langle 10|\psi\rangle|^2 + |\langle 11|\psi\rangle|^2$$

```
ZZ = SparsePauliOp.from_list([("ZZ", 1)])
```



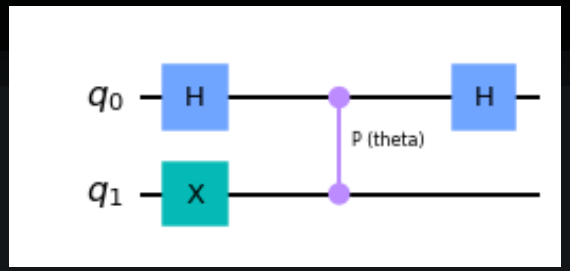
Parametrized Circuit

Qiskit

Run using Estimator

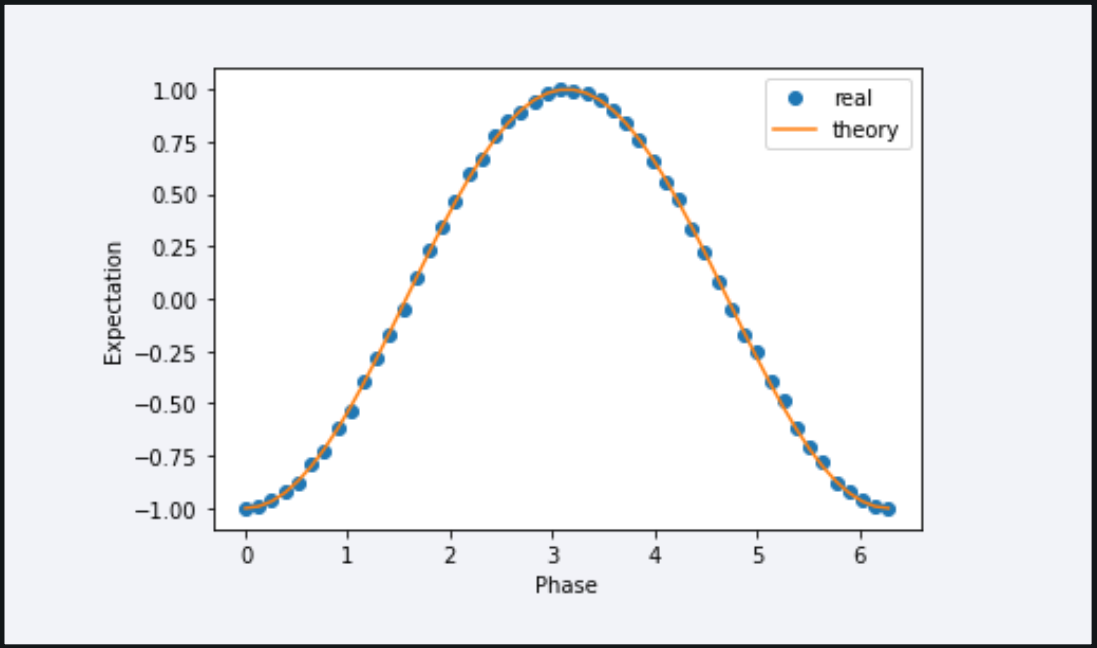
```
options = Options(simulator={"seed_simulator": 42}, resilience_level=0)

with Session(service=service, backend=backend):
    estimator = Estimator(options=options)
    job = estimator.run(circuits=[qc_no_meas]*len(phases), parameter_values=individual_phases,
observables=[ZZ]*len(phases))
```



Parametrized Circuit

Qiskit



Error Suppression

Qiskit

- The most basic level of error handling
- Use knowledge about the undesirable effects to introduce customization
  - **Anticipate** and **avoid** the potential impacts of these effects

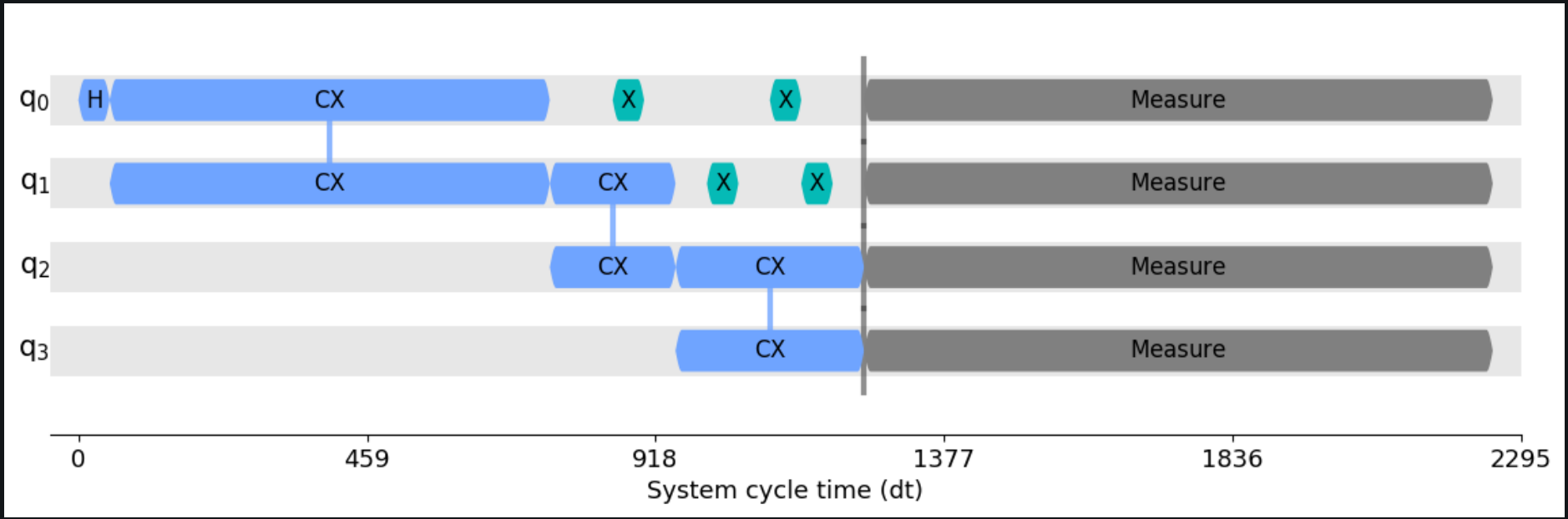
Dynamical Decoupling

- This feature is enabled by default on Qiskit Runtime
- Used to increase the lifetime of quantum information

Dynamical Decoupling

Qiskit

- Effectively disconnect the environment using decoupling methods
  - Prevent idle state of qubit – leakage of information to surrounding due to decoherence.



Error Mitigation

Qiskit

- **Reduce** the error effects with a much smaller overhead
  - Instead of completely eliminating using a huge amount of resourecs
- Error correction is not practically feasible in the current NISQ
  - Number of qubits
  - Controlled error rates
  - Extra circuit depth and measurements

Error Mitigation with Sampler

Qiskit

- Matrix-free Measurement Mitigation (M3)

https://qiskit.org/documentation/partners/mthree/

M3

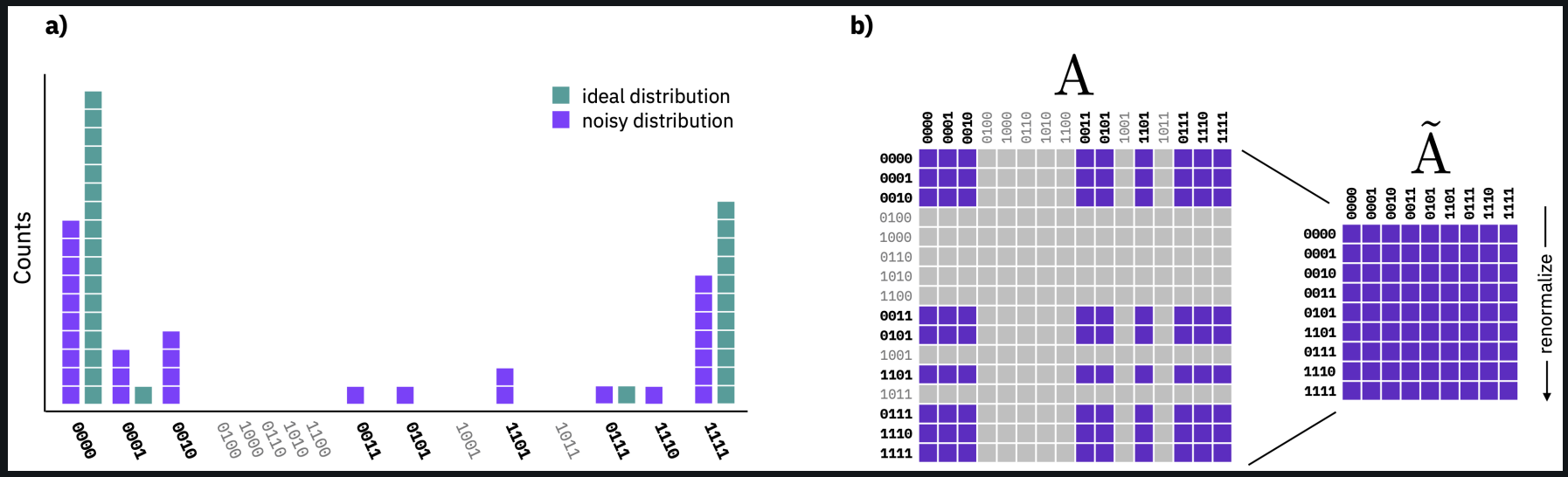
Qiskit

- This feature is enabled by setting `resilience_level=1` in `Options` with Sampler
- Scalable quantum measurement error mitigation
  - Need not explicitly form the assignment matrix or its inverse.

M3

Qiskit

- M3 works in a reduced subspace defined by the noisy input bitstrings that are to be corrected.
- Resulting linear system of equations is nominally much easier to solve.
  - Much smaller number of unique bitstrings than full multi-qubit Hilbert space



M3

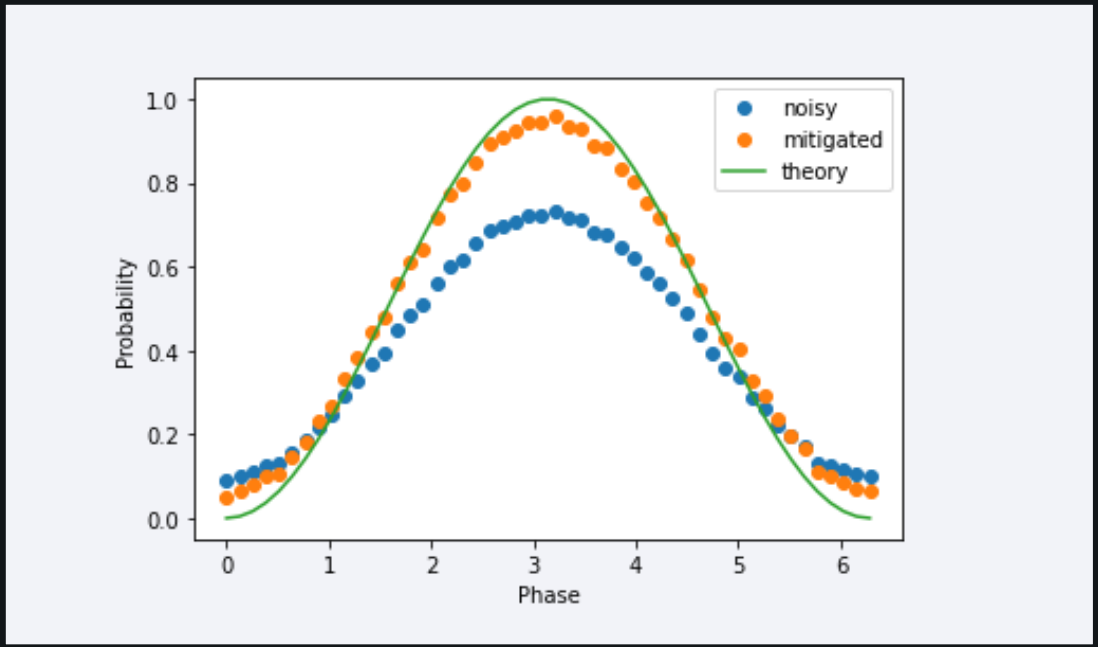
Qiskit

```python
# Import FakeBackend
fake_backend = FakeManila()
noise_model = NoiseModel.from_backend(fake_backend)

# Set options to include noise_model and resilience_level
options_with_em = Options(
    simulator={
        "noise_model": noise_model,
        "seed_simulator": 42,
    },
    resilience_level=1
)
```

M3

Qiskit


noisy
mitigated
theory
Probability
Phase
0.0
0.2
0.4
0.6
0.8
1.0
0
1
2
3
4
5
6

Error Mitigation with Estimator

Qiskit

- Twirled Readout Error eXtinction (T-Rex)
- Zero Noise Extrapolation (Digital ZNE)
- Probabilistic error cancellation (PEC)

•T-REx: arXiv:2012.09738
•ZNE: arXiv:1612.02058
•PEC: arXiv:1612.02058

T-Rex

Qiskit

- This feature is enabled by setting `resilience_level=1` in `Options` with Estimator (Default)
- Implementation which involves "twirling" of gates
- View noise as a set of **extra probabilistic gates** on top of our perfect circuit implementation
  - Conjugate this noisy gate set with a gate randomly chosen from a set of gates
- Inserts pairs of Pauli gates (I, X, Y, Z) **before** and **after** entangling gates such that the overall unitary is the same
- Turning **coherent errors** into **stochastic errors**
  - **Stochastic errors can be eliminated by sufficient averaging**

T-Rex

Qiskit

```
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fake_backend = FakeManila()
noise_model = NoiseModel.from_backend(fake_backend)

# Set options to include noise_model and resilience_level
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        "seed_simulator": 42,
    },
    resilience_level=1
)
```
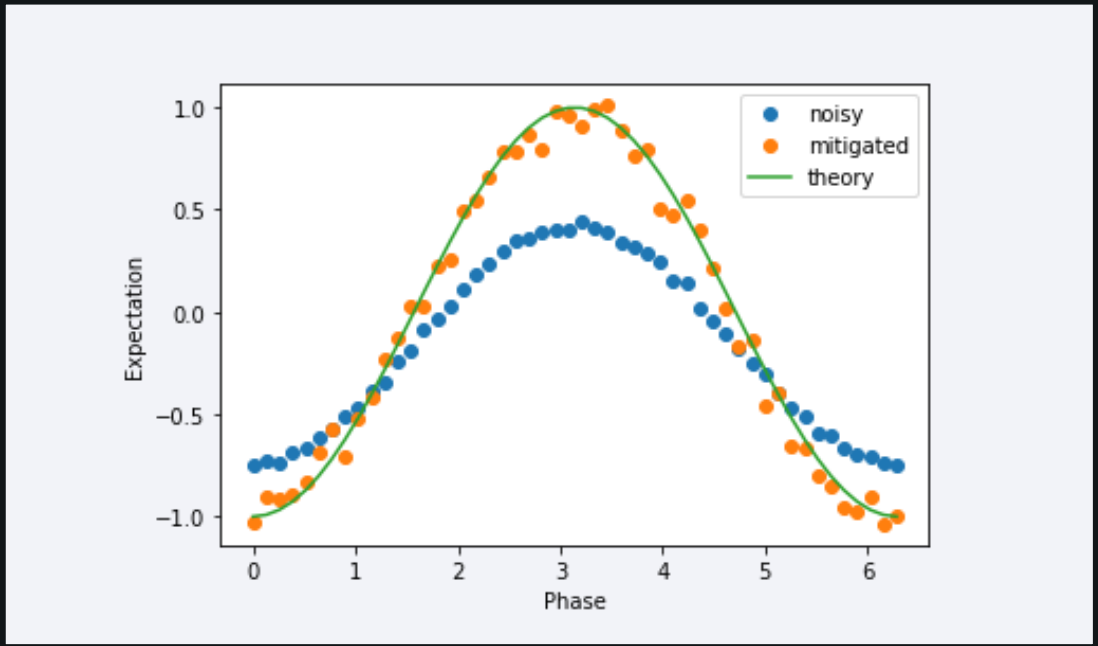
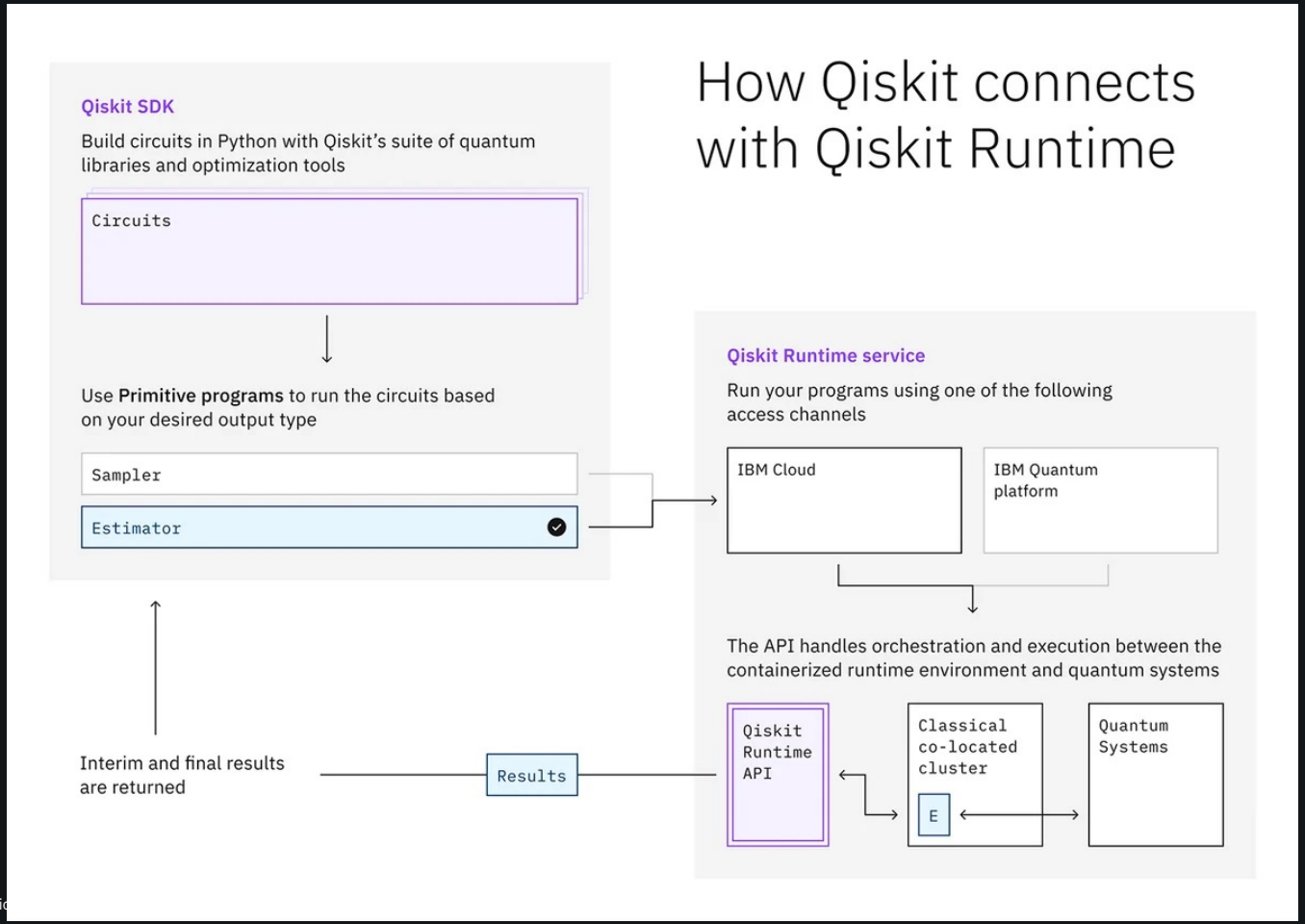

T-Rex

Qiskit


noisy
mitigated
theory
Expectation
Phase
1.0
0.5
0.0
−0.5
−1.0
0
1
2
3
4
5
6

Digital ZNE

Qiskit

- This feature is enabled by setting `resilience_level=2` in `Options` with Estimator
- Mitigating errors in noisy quantum computers without the need for additional quantum resources.
- A quantum program is altered to run at different effect levels of processor noise
- The result of the computation is extrapolated to an estimated value at a noiseless level.
- Digital way means not using physical pulse.
- Still an active research question around which method is the best to use

How Qiskit connects to Qiskit Runtime