Tutorial: parametric superconducting qubit design with Qiskit-metal

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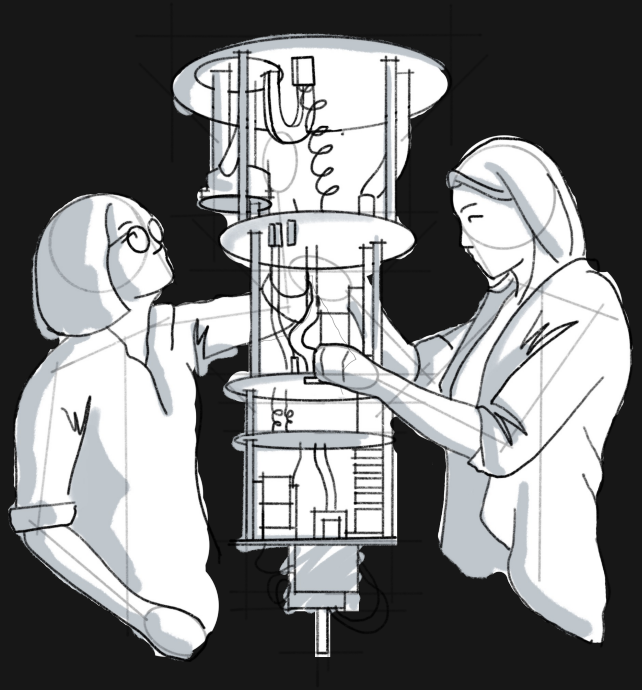

Qiskit

Qiskit

Getting started with Qiskit-metal

1. Installation

Installation

I strongly recommend you to install Qiskit-metal in independent conda environment.

It's because Qiskit-metal is highly sensitive to its dependency.

For detailed explanations, refer https://qiskit.org/documentation/metal/installation.html

```
git clone https://github.com/Qiskit/qiskit-metal.git
cd qiskit-metal

conda env create -n <env_name> environment.yml
conda activate <env_name>
python -m pip install --no-deps -e .

conda install ipykernel
ipython kernel install --user --name=<name_for_kernel>
```

Your environment name.

e.g. qiskit-metal

Your jupyter kernel name.

e.g. qiskit-metal

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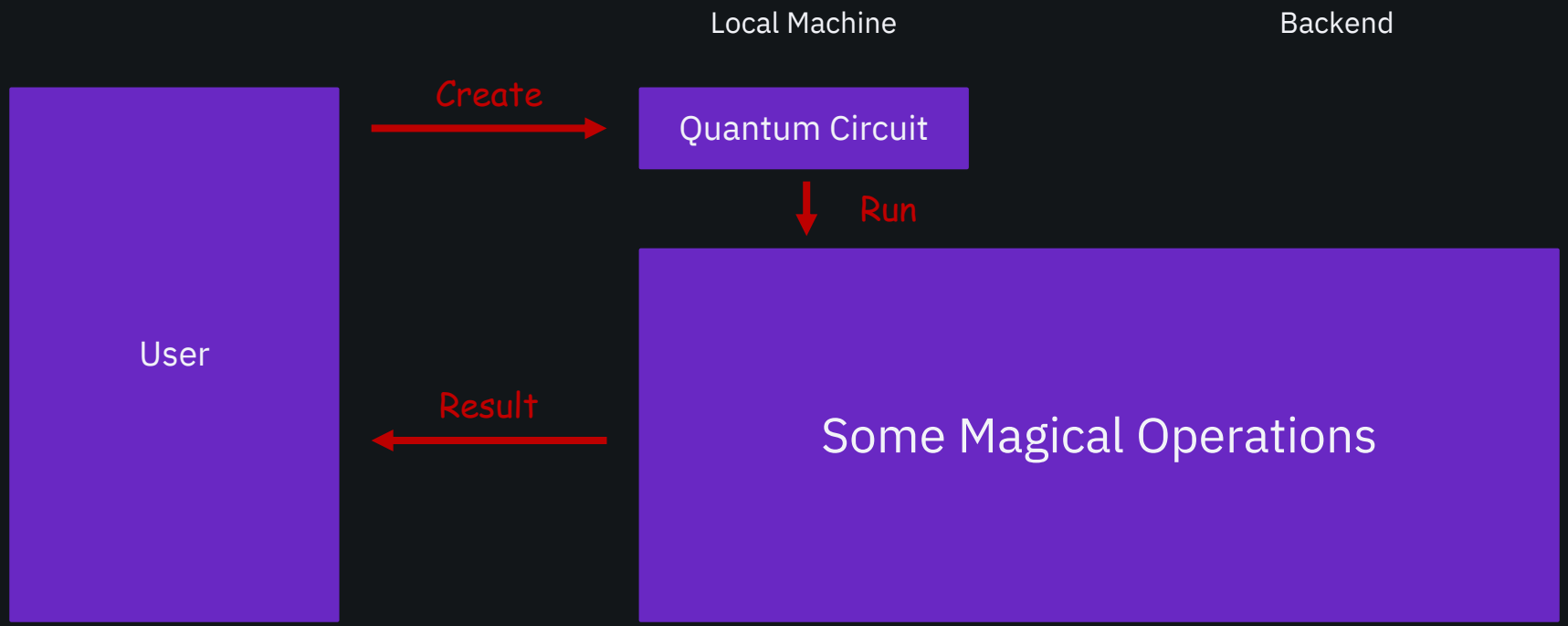
While installation...

1. About Qiskit-metal: a short overview

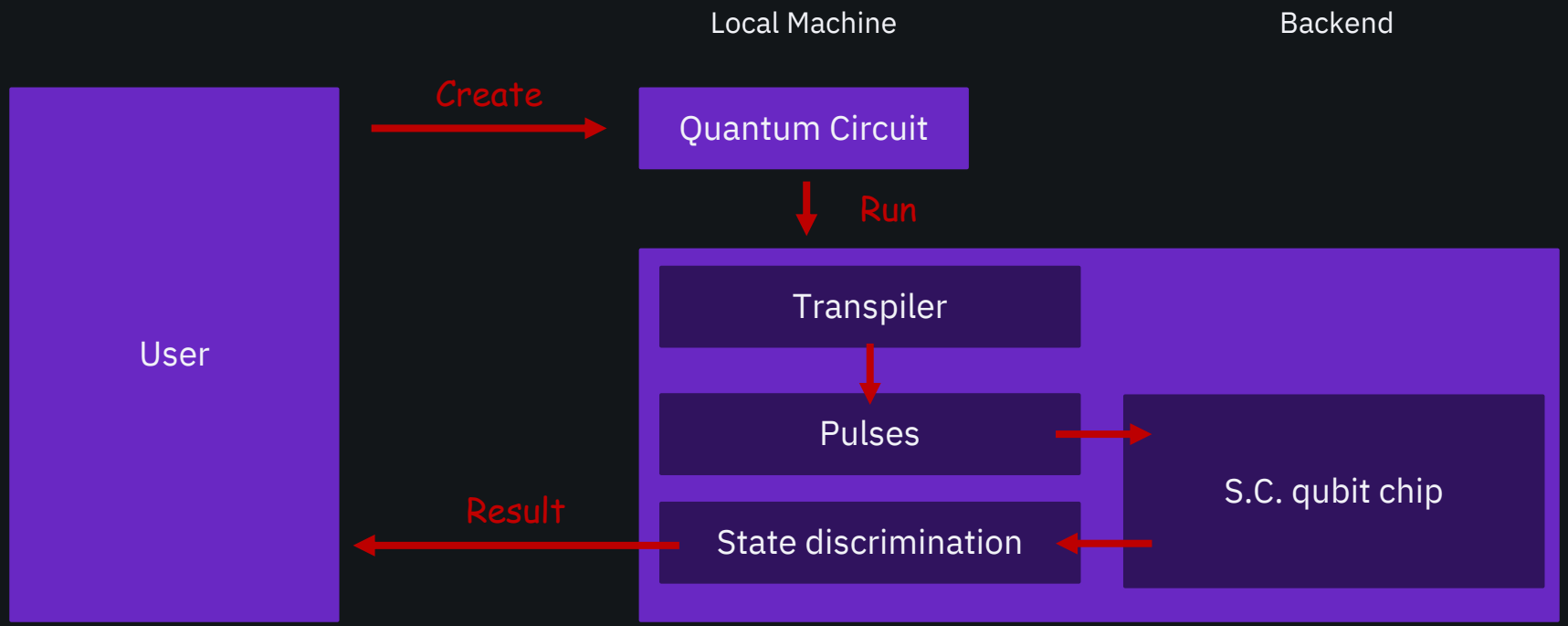
Full stack quantum computer

Qiskit



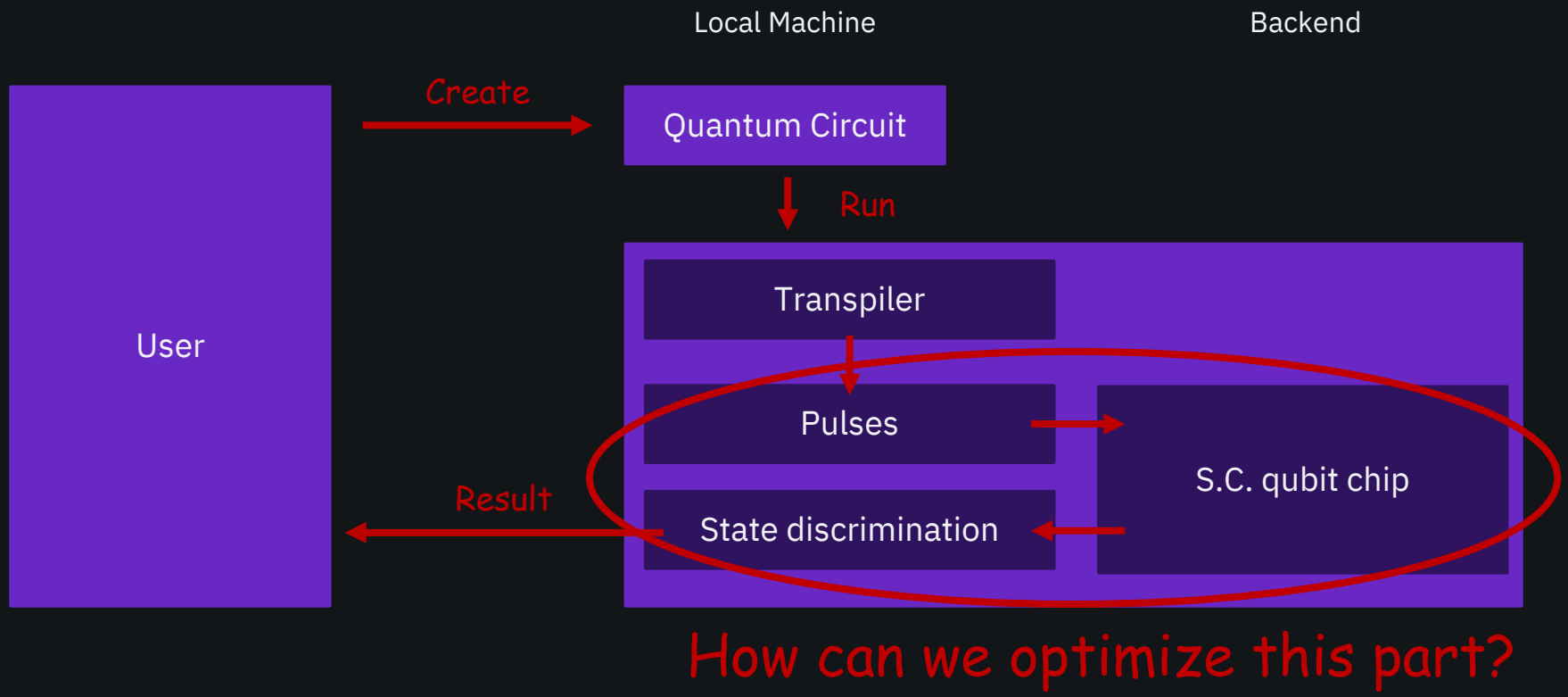
Full stack quantum computer

Qiskit



Full stack quantum computer

Qiskit



Parametric design and optimization of SC qubit chip

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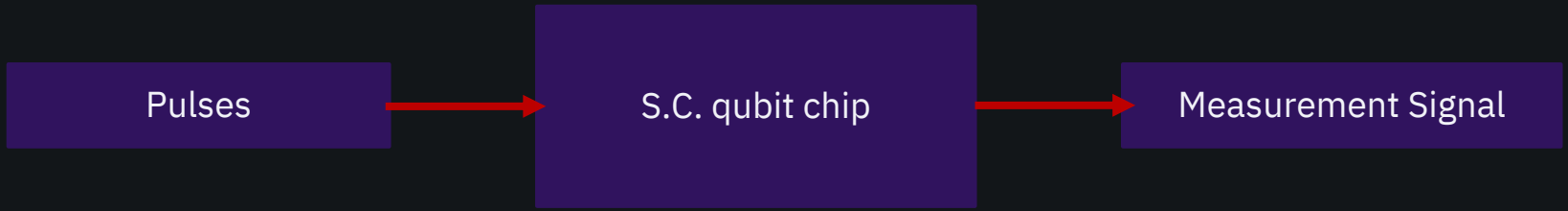
To optimize SC qubit chip,

1. We have to parametrize geometry of the SC qubits chip.
2. We have to simulate how the circuit response to the pulse signal.



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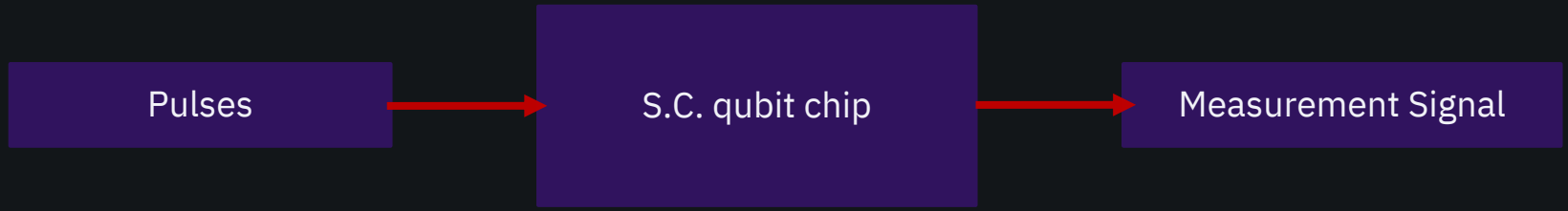
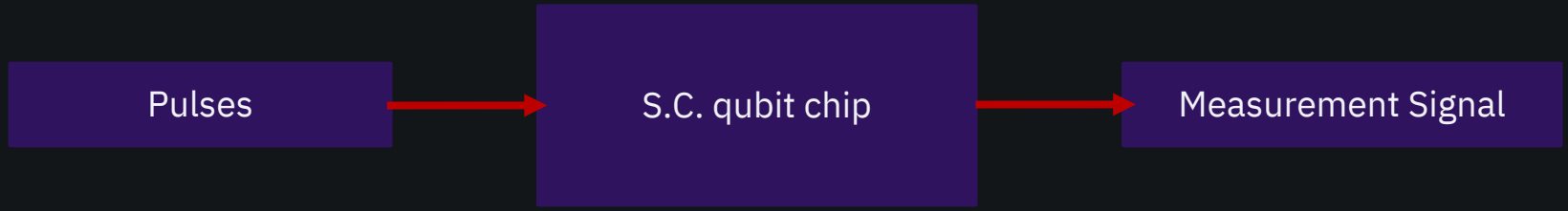


How?

Parametric design and optimization of SC qubit chip

Qiskit



How?

1. Parametric design of the SC qubits chip.
2. Electromagnetic Simulation on Chip components. (e.g. maxwell capacitance matrix)
3. Quantize the circuit (lumped / quasi-lumped[1] / impedance-based BBQ[2] / EPR analysis[3])
4. Evaluate Hamiltonian of the chip
5. Solve time dependent Schrodinger equation with noise model.

1. arXiv:2103.10344
2. arXiv:2010.00620
3. arXiv:1403.7341

Parametric design and optimization of SC qubit chip

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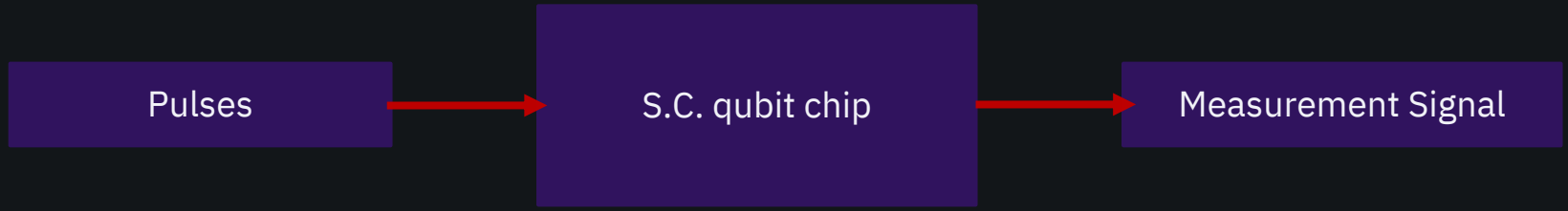

We will focus on this part today!

1. Parametric design of the SC qubits chip.
2. Electromagnetic Simulation on Chip components. (e.g. maxwell capacitance matrix)
3. Quantize the circuit (lumped / quasi-lumped[1] / impedance-based BBQ[2] / EPR analysis[3])
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While installation...

2. Basic design elements

Basic design elements in Qiskit-metal

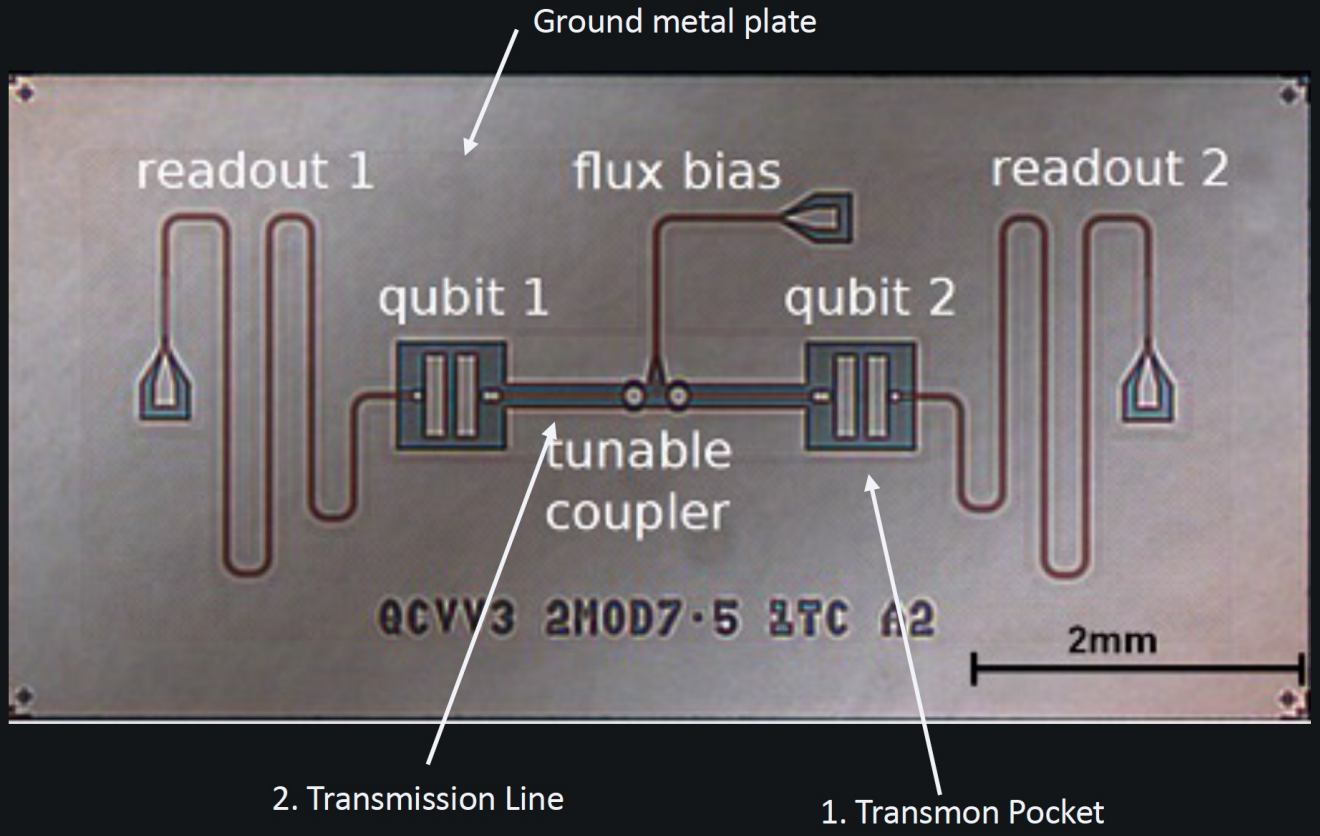
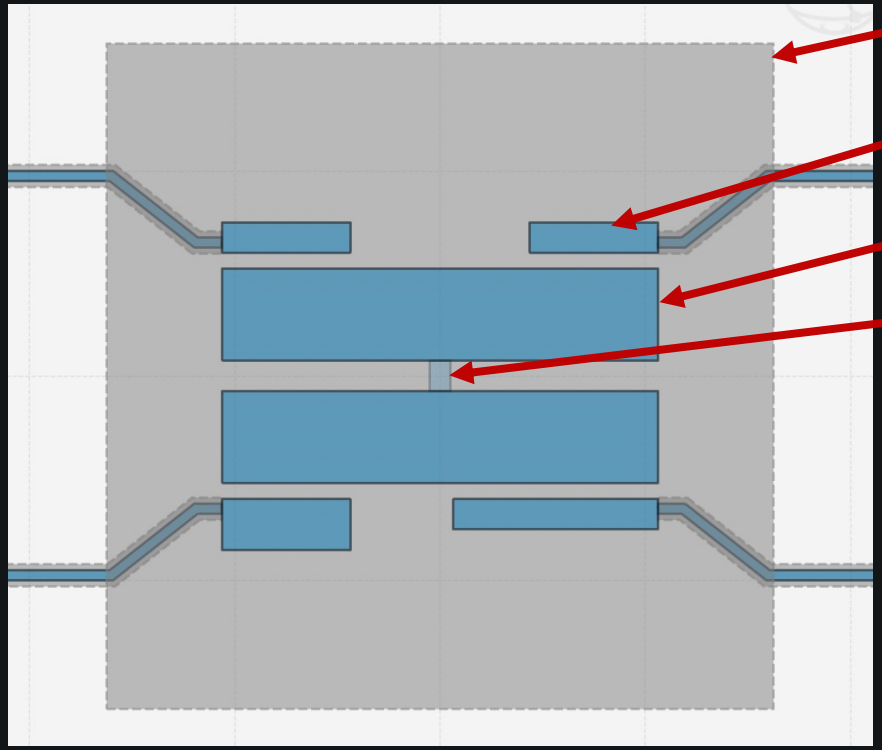


Image: IBM Zurich (https://www.zurich.ibm.com/st/quantum/)

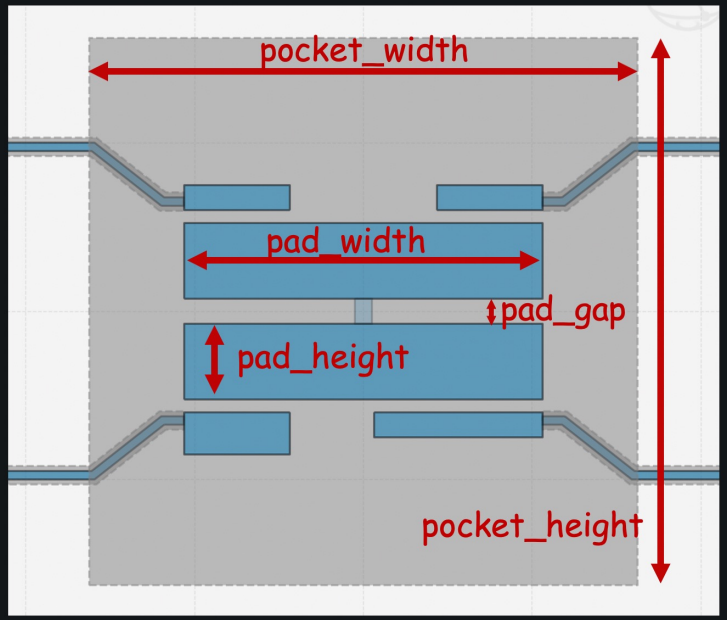
Basic design elements in Qiskit-metal
1. Transmon Pocket



E_J/E_C is one of the critical factors in the superconducting qubit.

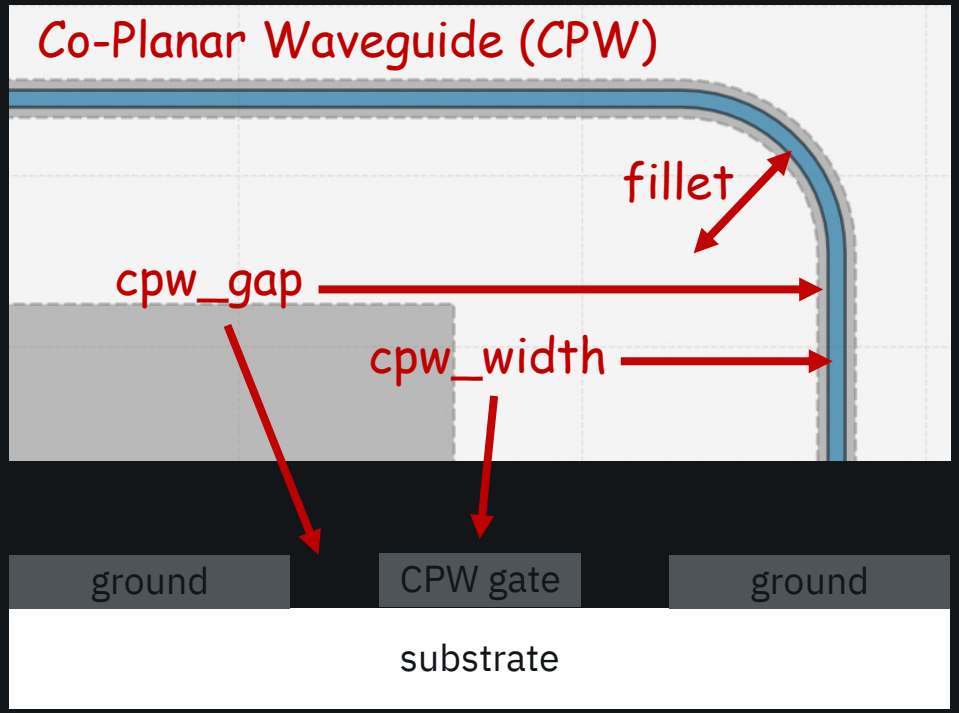
To control E_C, we can modify the geometry of the conductor. (With larger pads, we can get large capacitance, which means small capacitance energy).

Basic design elements in Qiskit-metal
1. Transmon Pocket



Since name of parameters in each components are intuitive, you could easily familiarize with them.

Basic design elements in Qiskit-metal
2. Co-planar waveguide



Co-planar waveguides (CPW) are capacitively connected to the qubit or other CPW.

The resonant frequency of the CPW is important to prevent crosstalk.

We can modulate the resonant frequency of CPW by changing its geometry (length, width, and gap)

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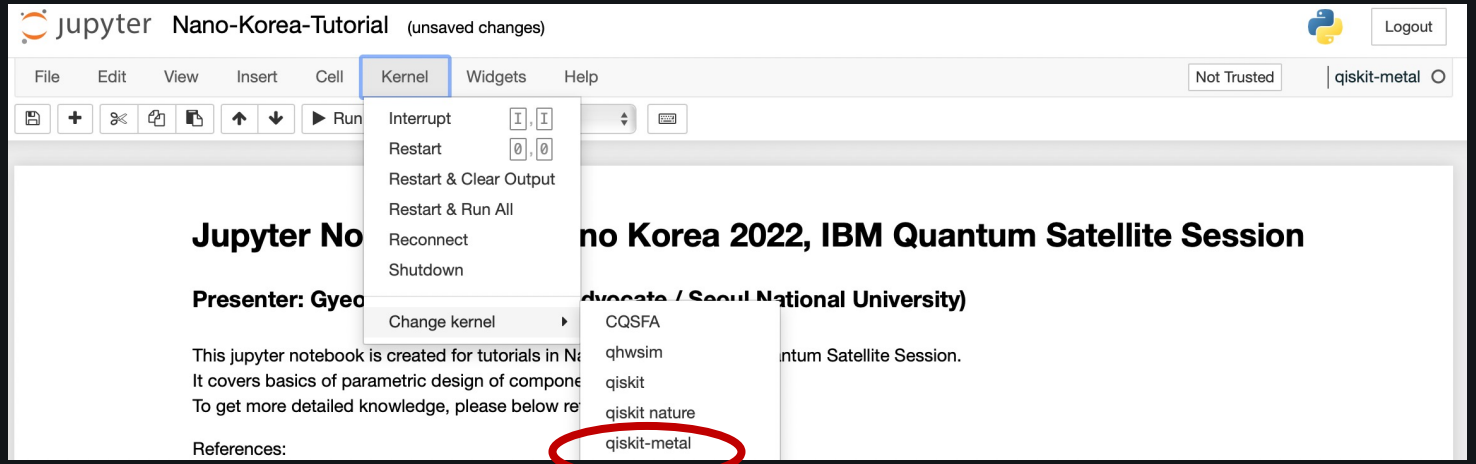
Getting started with Qiskit-metal

2. Running qiskit-metal with Jupyter Notebook

Running Jupyter notebook

```
jupyter notebook
```



Select your kernel with qiskit-metal

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3. Demonstration

Qiskit-metal needs people from various background!

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Many things to be implemented:

In the near future we aim to (see near-term roadmap image): **Legend:**

✓ Completed ☆ Desired ☆☆☆ Highly desired

Add & enhance quantization analysis & ease of use

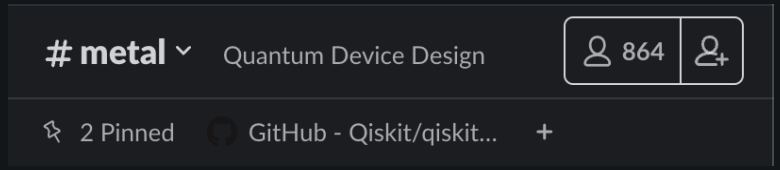
- ✓ New lumped analysis code
- More general couplers
- ☆☆☆ WebApp

☆☆ Impedance quantization

- Add fitting of Z curves & extraction of ZPF

- ☆☆☆ pyEPR General potential - e.g. fluxonium

Active discussion on slack channel!



Now it's your turn!!

https://qiskit.org/documentation/metal/workflow.html#qiskit-metal-workflow

Recommended Materials (Introductory)

Qiskit

1. Qiskit-metal official tutorials: https://qiskit.org/documentation/metal/tut/index.html
2. Video lectures from **Zlatko Minev**:
    1. https://www.youtube.com/watch?v=jjdYHZ0qxcY
    2. https://www.youtube.com/watch?v=ggfQa6jBV3Y
3. Introductory video series() about physics of transmon qubit from **Gyeonghun Kim** (in Korean):
    1. **https://youtu.be/Nss_3gYFcAY**

Recommended Materials (Papers)

Qiskit

1. Reviews on Superconducting Circuit Qubits
    1. M. H. Devoret, el al., Superconducting qubits: A short review (2004)
    2. Thomas E. Roth, et al., An Introduction to the Transmon Qubit for Electromagnetic Engineers (2021)
2. Circuit Quantization
    1. LOM analysis: Zlatko K. Minev, et al., Circuit quantum electrodynamics (cQED) with modular quasi-lumped models (2021)
    2. EPR analysis: Zlatko K. Minev, et al., Energy-participation quantization of Josephson circuits (2020)
    3. Blackbox Quantization: Firat Solgun, et al., Blackbox quantization of superconducting circuits using exact impedance synthesis (2014)
    4. Comparison: Benzheng Yuan, et al., Comparison of Lumped Oscillator Model and Energy Participation Ratio Methods in Designing Two-Dimensional Superconducting Quantum Chips (2022)

Acknowledgement

Qiskit Metal Team

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Qiskit Korea Community

Especially, **Soyoung Shin (Sophy)**, who organized Qiskit-metal challenges and study in Korea, and

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