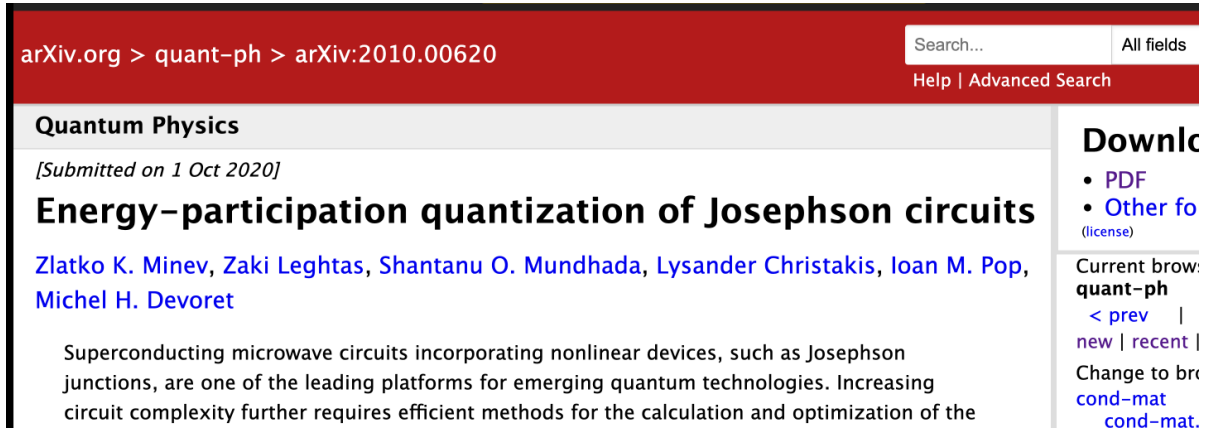
pyEPR
Working Group Meeting #1

Welcome to pyEPR 🍻! (see arXiv:2010.00620)

Open Source ❤ 🕶 awesome | star 68 | fork 70 | Install with conda | pypi package 0.8

Automated Python module for the design and quantization of Josephson quantum circuits

‼ ‼ pyEPR Working group meeting -- Planning for the future of pyEPR



https://github.com/zlatko-minev/pyEPR

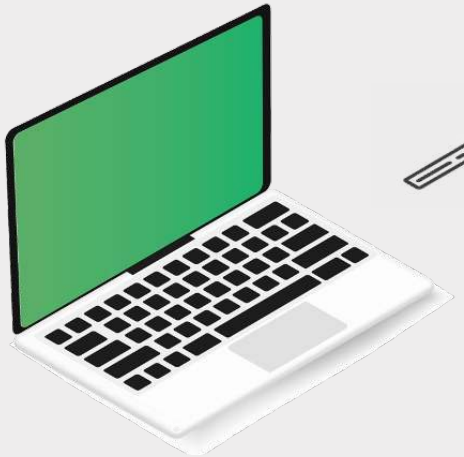
Led by Zlatko Minev
2020-10-23

Tentative agenda:

- What is pyEPR & why?
- Current state & some next desires
- Roadmap & how to get involved
- *Unitary Fund*: Short presentation & funding opportunities and potential grants to support open source work with pyEPR
- News & community announcements

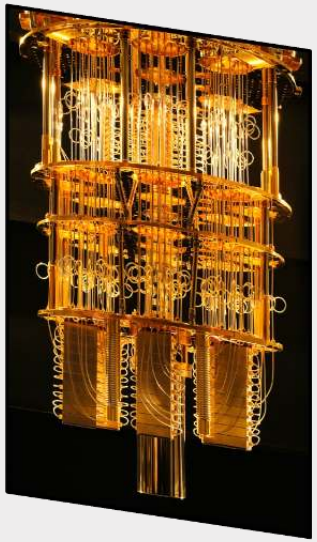
Quantum in lab

Superconducting qubits

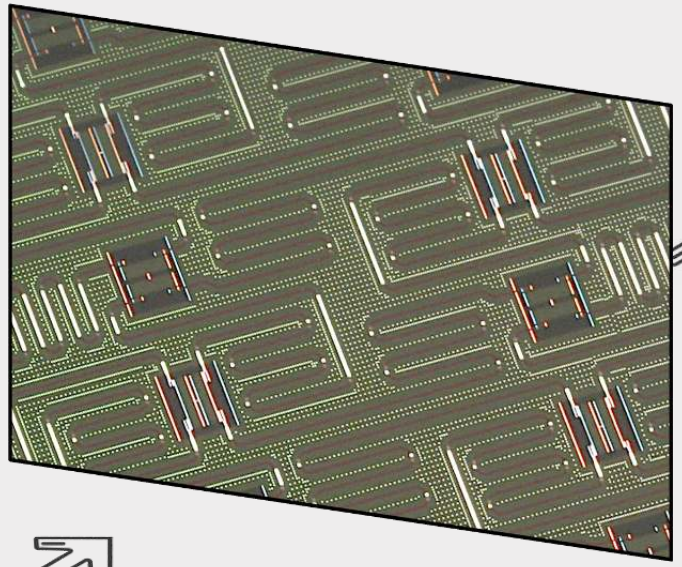


Quantum community

Lab



Cryogenic environment

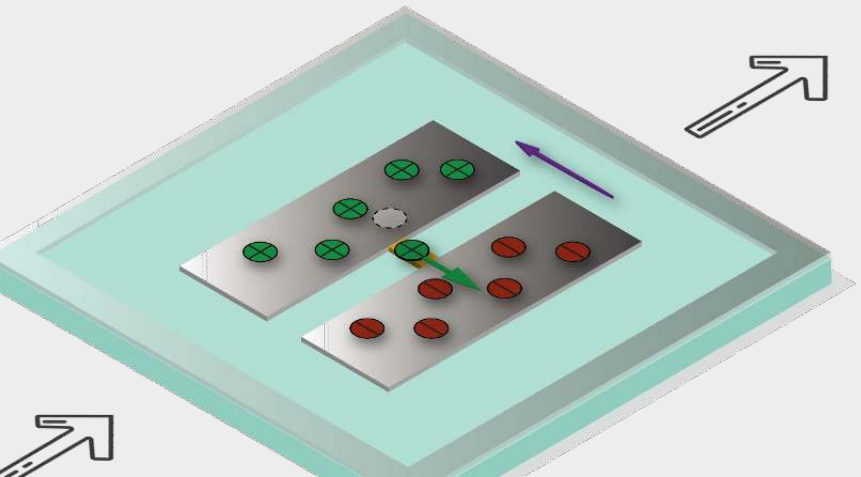


Quantum-device chip

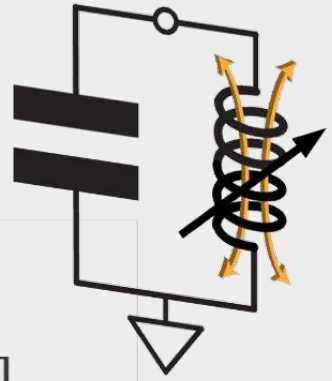
Laptop image: rawpixel.com; Photos: IBM

Quantum Device Design

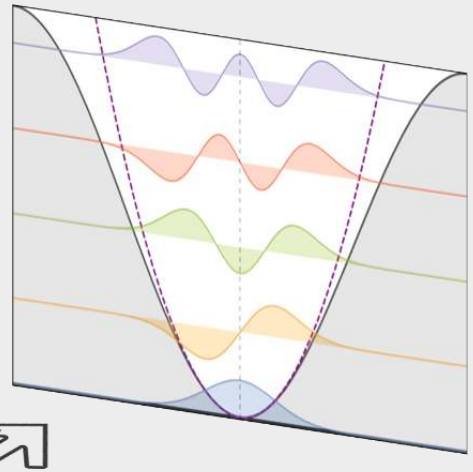
Superconducting circuits



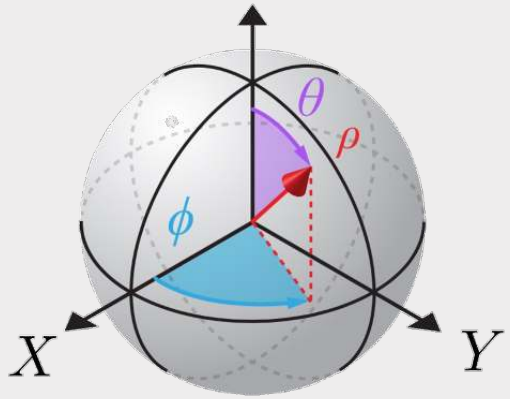
Physical layout



Electromagnetic analysis



Quantum Hamiltonian analysis



Qubit Hilbert space

A unified framework to handle all these questions.

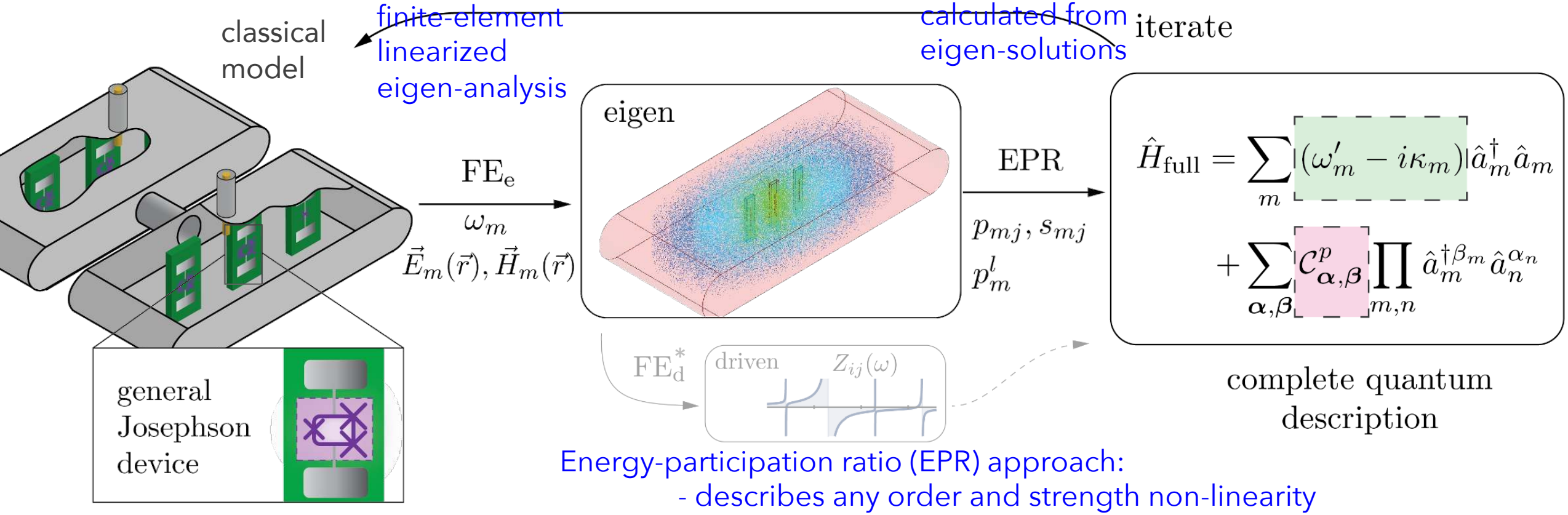
The solution reduces to asking:

Where is the energy?

What *fraction of the energy* of the mode is stored in the non-linear/dissipative element?

$$0 \leq p, p^l \leq 1$$

Overview of energy approach



Energy-participation ratio (EPR) approach:

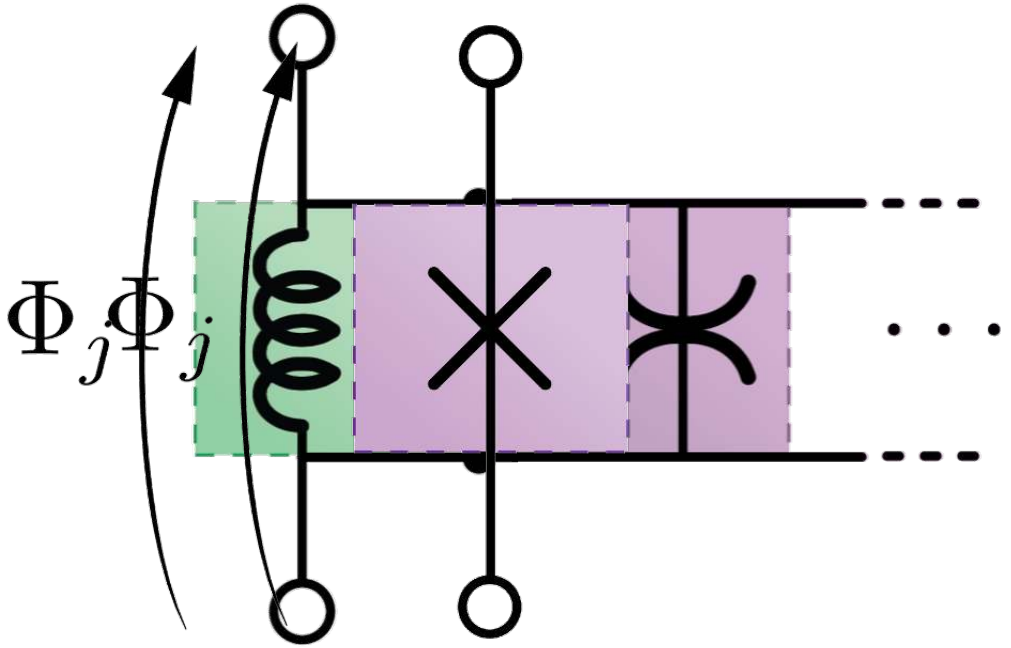
- describes any order and strength non-linearity
- describes arbitrary (composite) non-linear inductive devices
- first-principle derivation
- zero approximations (aside from truncation of modes)
- fully automated in python (github.com/zlatko-minev)

Practical limits: Fock and mode basis truncation due to computing power

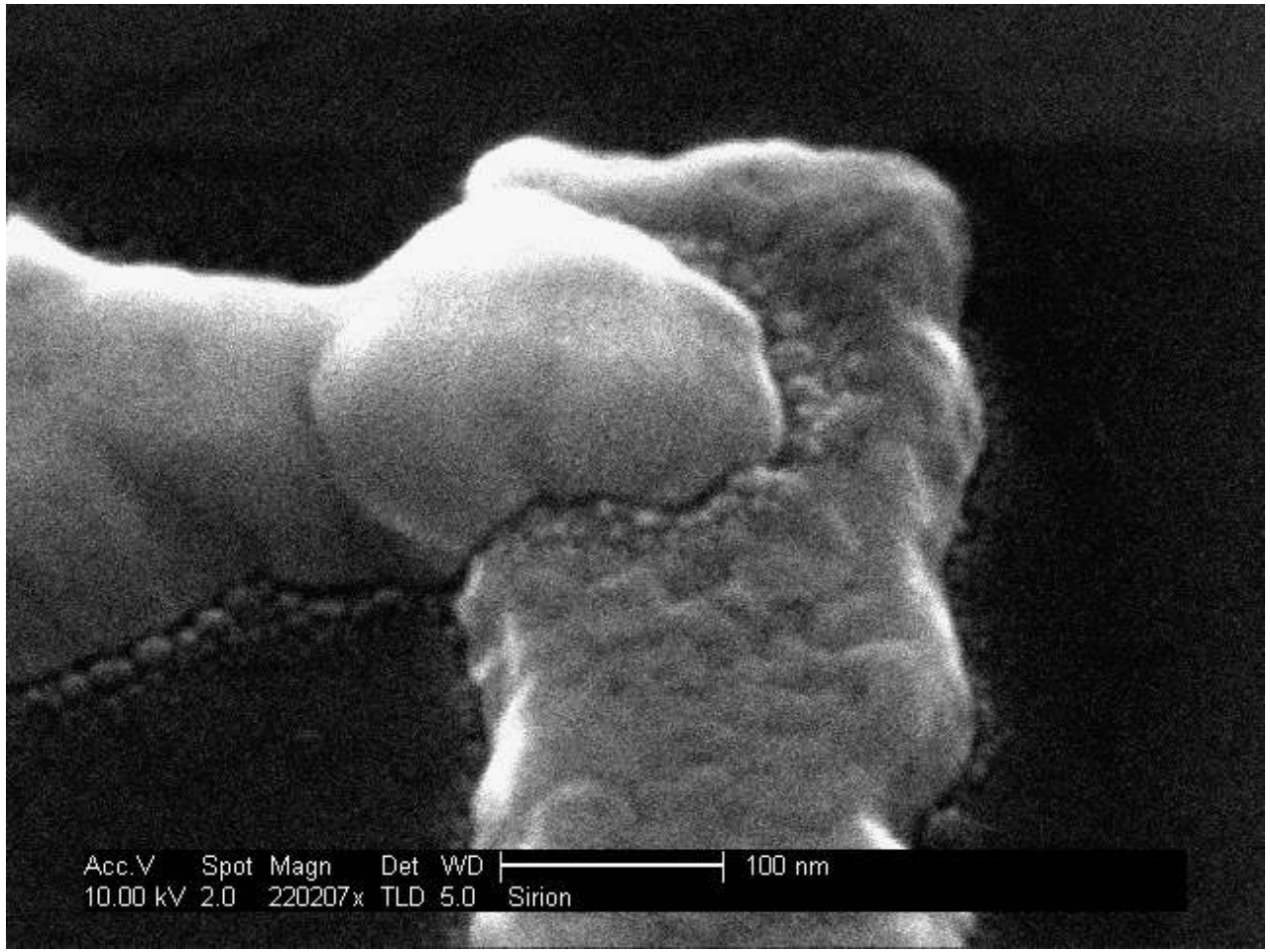
* Nigg, Paik, *et al.*, PRL (2012), Bourassa *et al.* (2012), Solgun *et al.* (2014, 2015, 2017), …

Minev *et al.*, arXiv:2010.00620 (2020)

Non-linear element: Josephson tunnel junction



$$\mathcal{E}_j(\Phi_j) = \mathcal{E}_j^{\mathrm{lin}}(\Phi_j) + \mathcal{E}_j^{\mathrm{nl}}(\Phi_j)$$

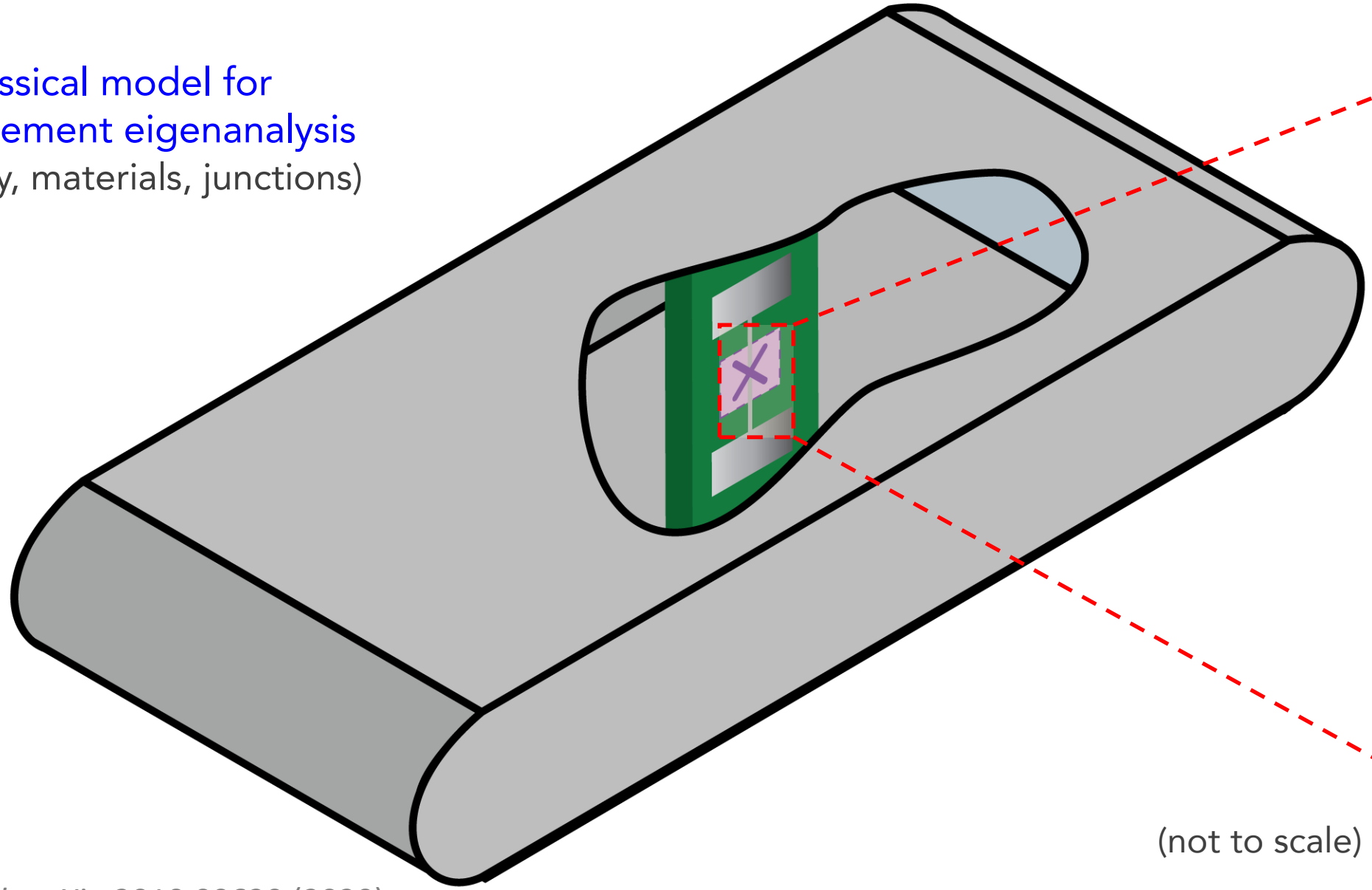


SEM image: L. Frunzio

* Minev *et al.*, arXiv:2010.00620 (2020)

Transmon qubit coupled to cavity

Classical model for
finite-element eigenanalysis
(geometry, materials, junctions)

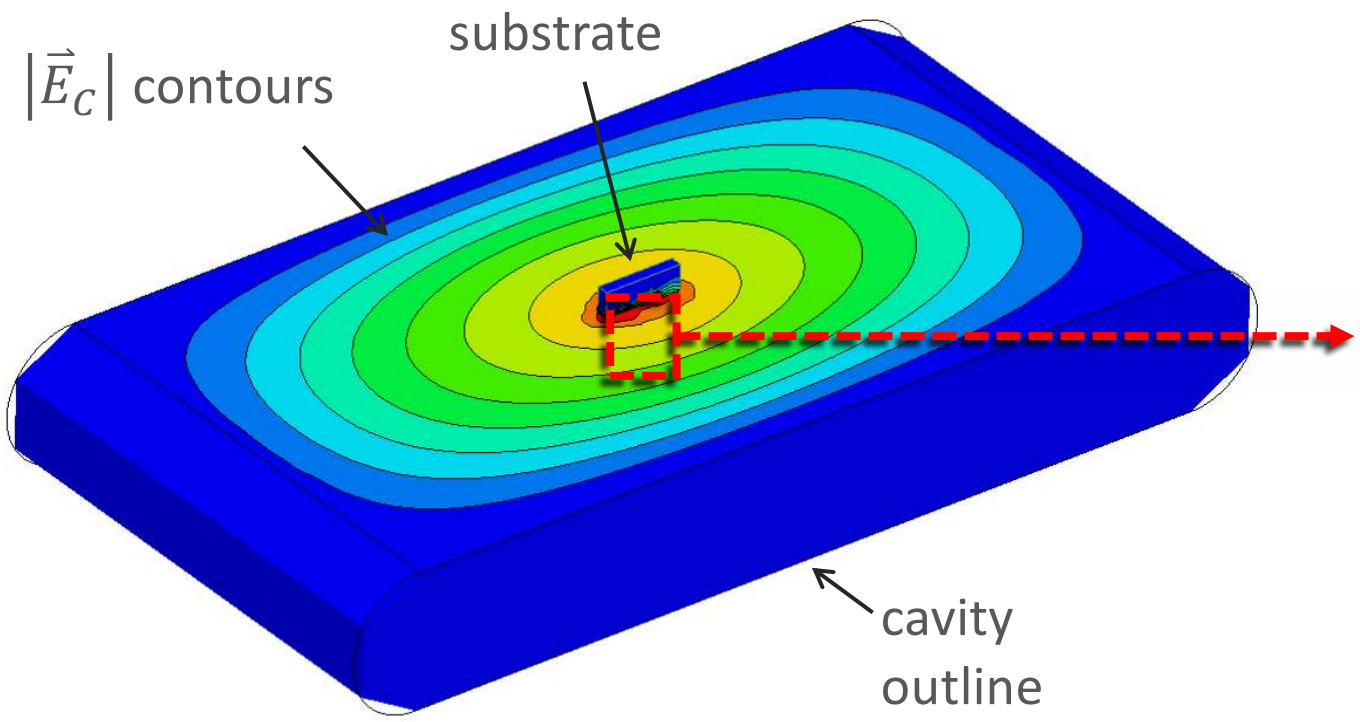


(not to scale)

* Minev *et al.*, arXiv:2010.00620 (2020)

$\mathcal{H}_{\text{lin}}$ eigen modes

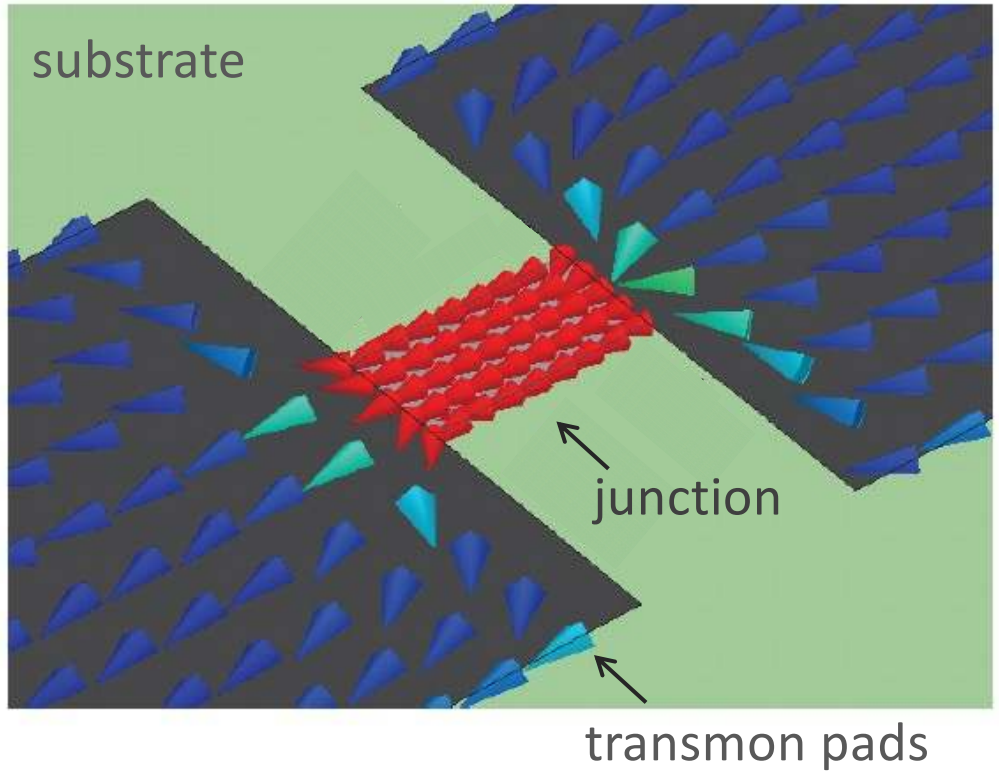
Cavity mode (7.0 GHz)



0 Max

E-field magnitude

Qubit mode (linearized, 5 GHz)



0 Max

Current-density magnitude

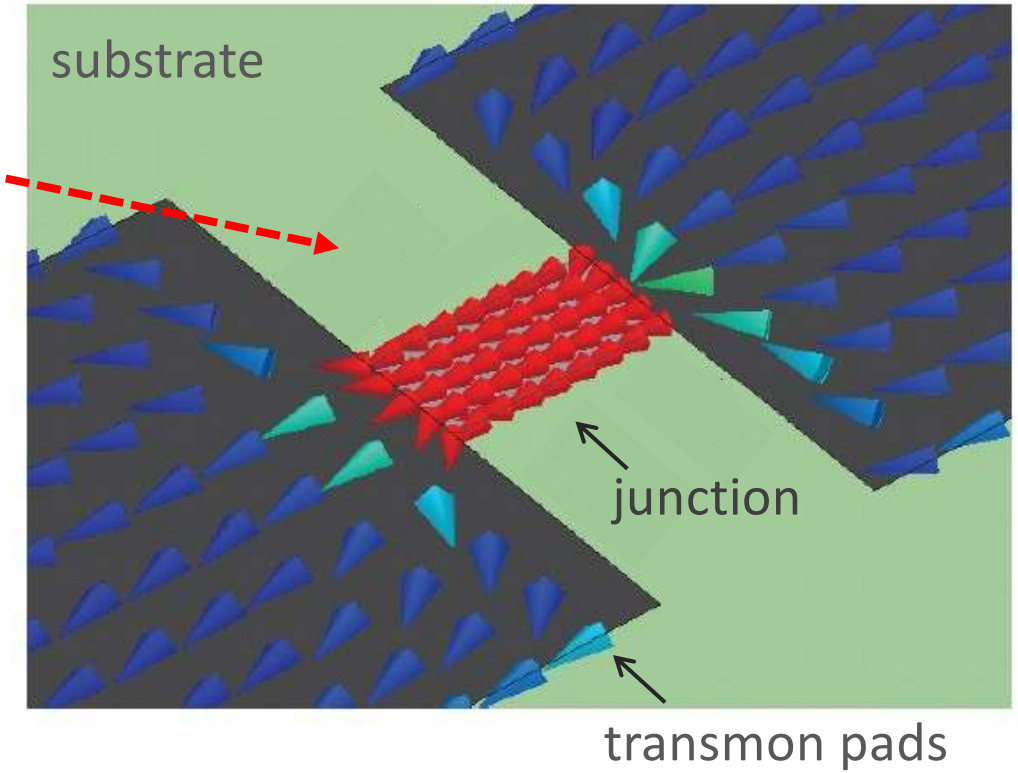
* Minev *et al.*, arXiv:2010.00620 (2020) Impedances: Nigg *et al.*, PRL (2012); Bourassa *et al.* (2012); Solgun *et al.* (2014, 2015, 201

Energy participation of the junction

$$p_m = \frac{\frac{1}{2} L_j I_{mj}^2}{\mathcal{E}_{ind,m}}$$

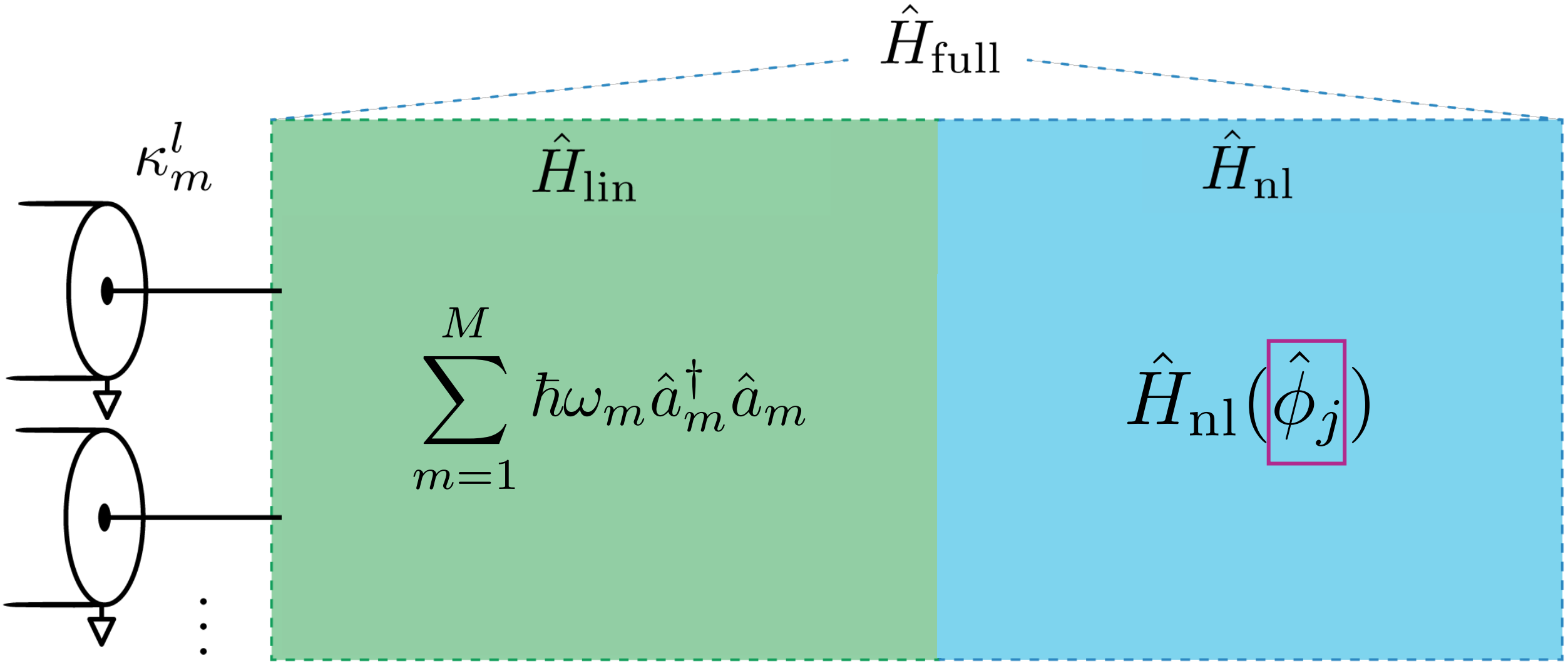
$$p_m = \frac{\text{Energy stored in junction}}{\text{Inductive energy stored in mode } m}$$

Qubit mode (linearized, 5 GHz)



Minev *et al.*, arXiv:2010.00620 (2020)

Decomposition of a general circuit

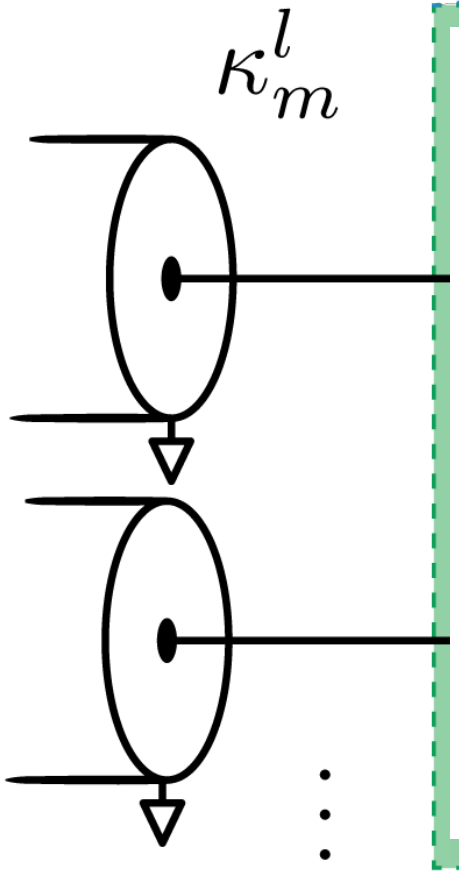


Minev *et al.*, arXiv:2010.00620 (2020)

second quantization in eigen basis of linearized circuit

Decomposition of a general circuit

$\hat{H}_{\text{full}}$



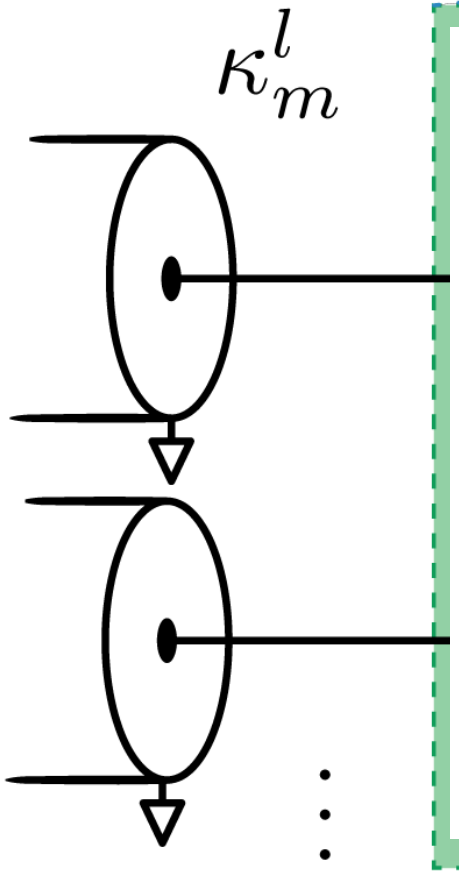
What is zero-point fluctuation of the phase of junction *j* due to mode *m*?

$$\hat{\phi}_j = \sum_{m=1}^{M} \phi_{mj} \left(\hat{a}_m^\dagger + \hat{a}_m \right)$$

Minev *et al.*, arXiv:2010.00620 (2020)

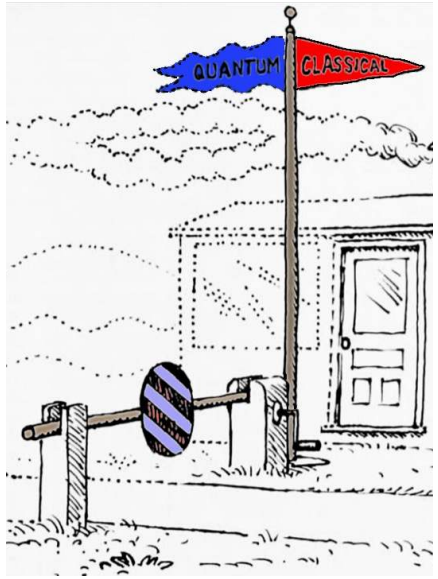
Decomposition of a general circuit

$\hat{H}_{\text{full}}$



What fraction of the energy of mode *m* is stored in junction *j*?

$$\frac{1}{\hbar}\phi_{mj}^2 = p_{mj}\frac{\omega_m}{2E_j}$$

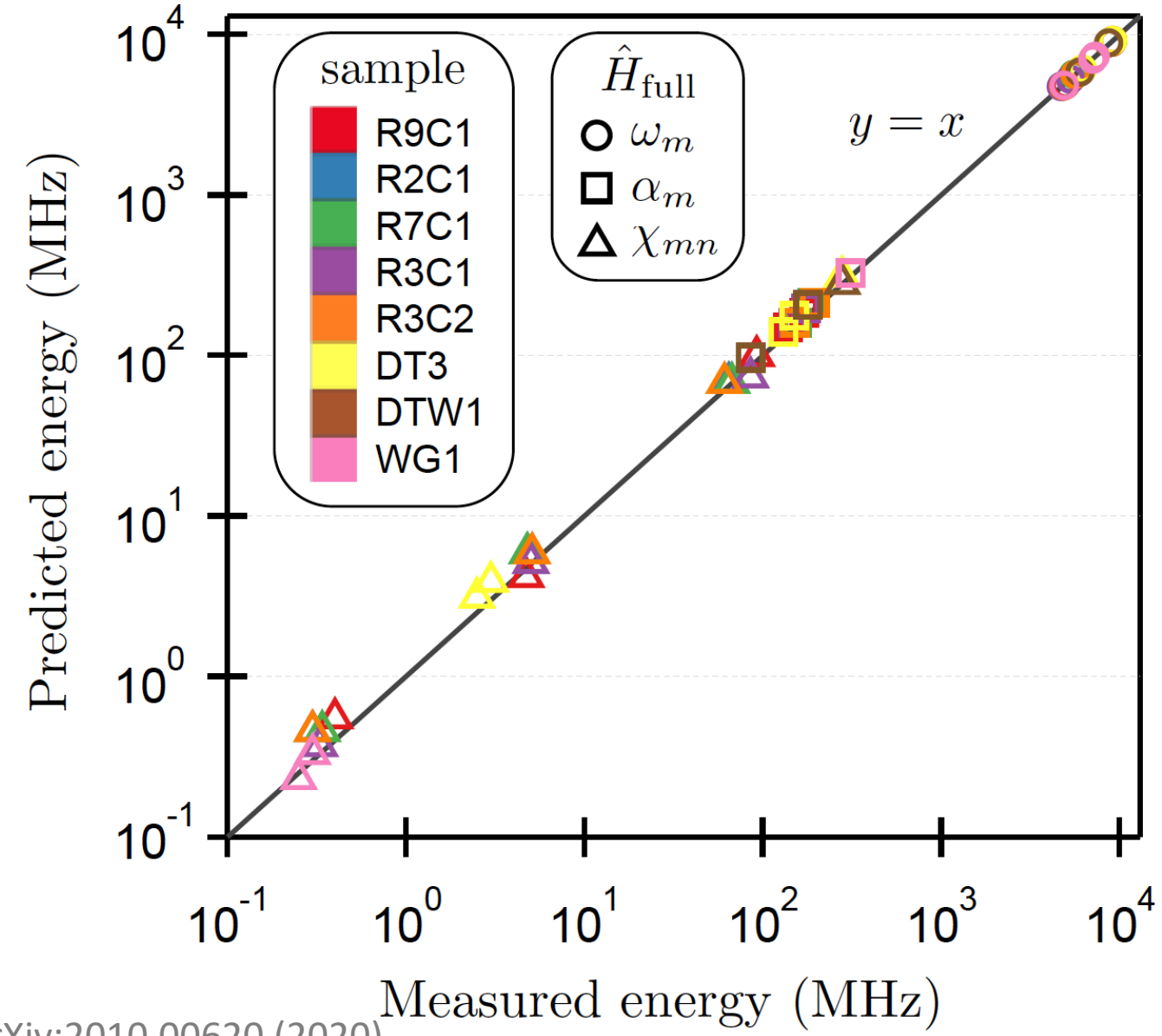


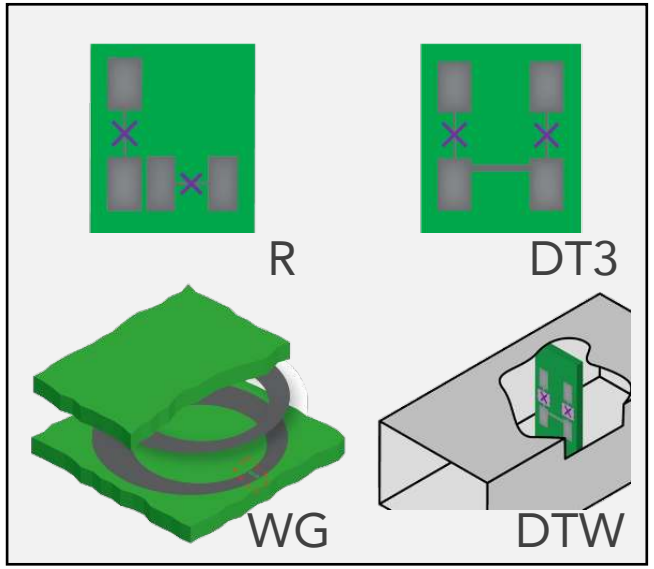
for $j>1$, root requires sign bit $s_{mj} = \pm 1$

Minev *et al.*, arXiv:2010.00620 (2020)

Drawing: Zurek, Physics Today (1991)

Theory vs. experiment: agreement over 5 orders of magnitude





R: Minev *et al.* (2018)
WG: Minev *et al.* (2013, 2016)
DT3, DTW: Minev *et al.* (2020)

Minev *et al.*, arXiv:2010.00620 (2020)

What do people want to see?

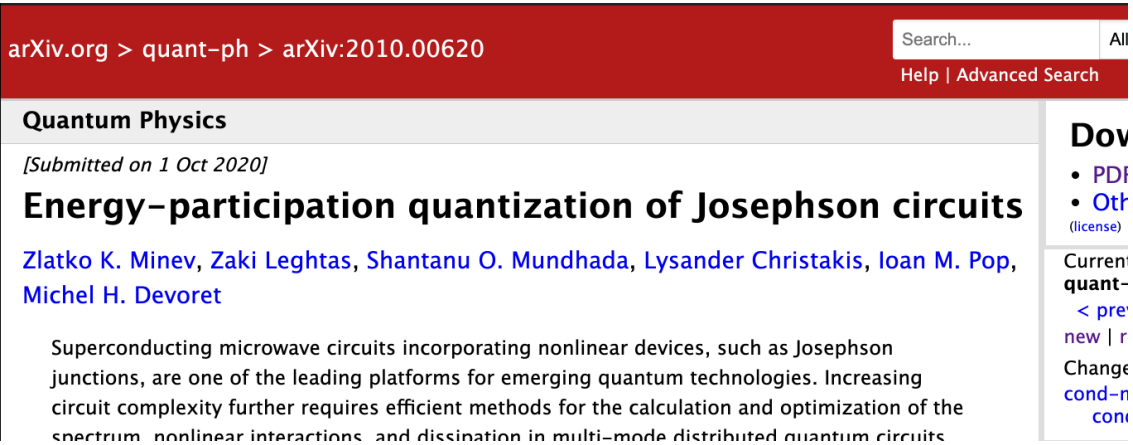
- Existing issues
- Docs
- Unit Tests
- Integration with theory packages and methods
- Tesnor network (Agustin)
- Closed-loop optimization (Raphael)

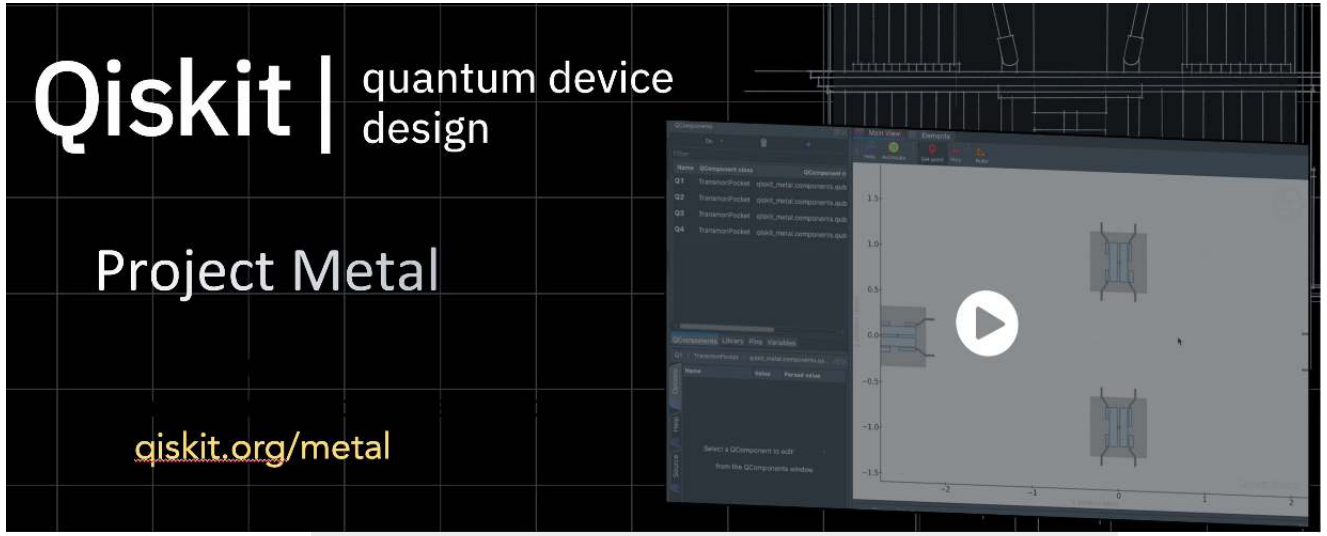
Unitary Fund

Short presentation & funding opportunities and potential grants to support open source work with pyEPR

Micro grants

News & community announcements





Other?

Jobs

Home › Quantum Software Developer (Yorktown Heights, NY) - Yorktown Heights, NY

APPLY NOW

Quantum Software Developer (Yorktown Heights, NY)

- **Country/Region:** US
- **State:** NEW YORK
- **City:** Yorktown Heights
- **Category:** Software Development & Support
- **Required Education:** Master's Degree
- **Position Type:** Professional
- **Employment Type:** Full-Time
- **Contract Type:** Regular
- **Company:** (0147) International Business Machines Corporation
- **Req ID:** 337206BR

https://careers.ibm.com/ShowJob/Id/1004173/Quantum-Software-Developer-(Yorktown-Heights,-NY)

How to be involved & stay in touch?

Validation

Ratan: How do we check output of pyEPR works

William Livingston – have example file with output of HFSS so can use to verify numerical method vs. experiment

Theory & Hamitlonian

What can we contribute on theory side?

numerical / semi-analytic diagonalization of the Hamiltonian

Handling anything other than transmons (interface with Jens' code) [Agustin DiPaolo]

Speed up transmons & incorporate new qubits (Agustin / Jose / Abhijit / Ratan)

Closed-loop optimization

E&M Side

Linux on HPC ()

Comsol (Abhijit) – parallel thing with comsol; examples on 2D; planar resonators; (Jose/Nick Materise has used)

(Other used: CST, Sonnet)

Package (to involve people)

How do you contribute (pre-solved example files; minimum things for deo) (Nick)

Adding