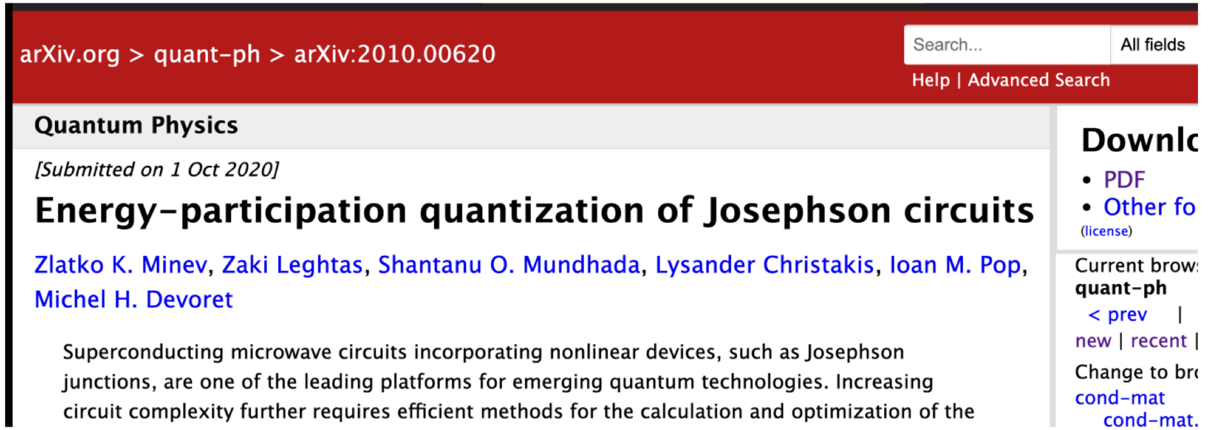
pyEPR
Working Group Meeting #1

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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Quantum Physics

[Submitted on 1 Oct 2020]

Energy-participation quantization of Josephson circuits

Zlatko K. Minev, Zaki Leghtas, Shantanu O. Mundhada, Lysander Christakis, Ioan M. Pop, Michel H. Devoret

Superconducting microwave circuits incorporating nonlinear devices, such as Josephson junctions, are one of the leading platforms for emerging quantum technologies. Increasing circuit complexity further requires efficient methods for the calculation and optimization of the

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

Led by Zlatko Minev
2020-10-23

@zlatko_minev zlatko-minev.com

Tentative agenda:

- What is pyEPR & why?

- Current state & some next desires

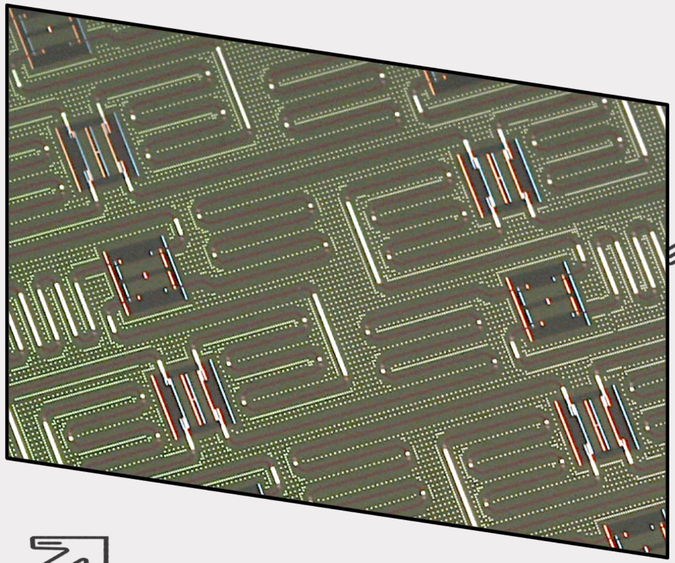
- Roadmap & how to get involved

- *Unitary Fund*: Short presentation & funding opportunities and potential grants to support open source work with pyEPR

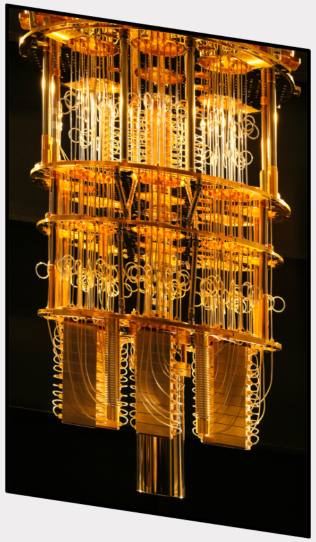
- News & community announcements

Quantum in lab

Superconducting qubits



Quantum-device chip



Cryogenic environment

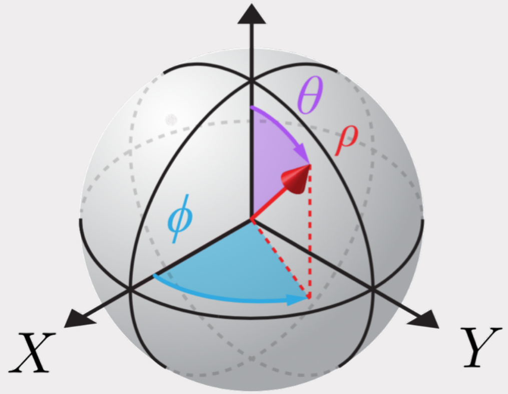
Lab

Quantum community

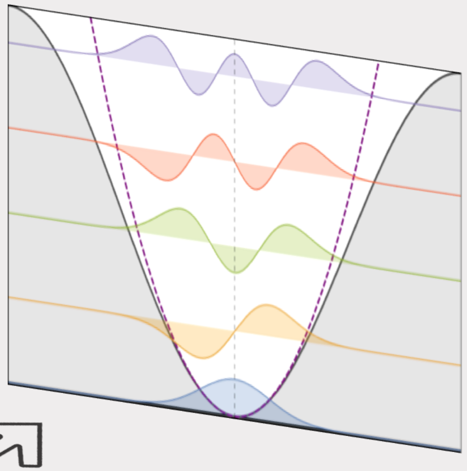
Laptop image: rawpixel.com; Photos: IBM

Quantum Device Design

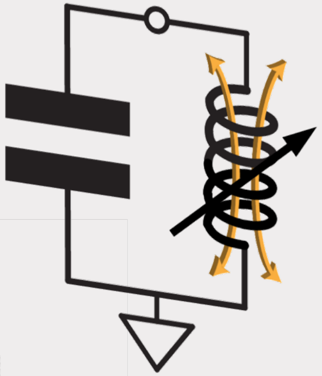
Superconducting circuits



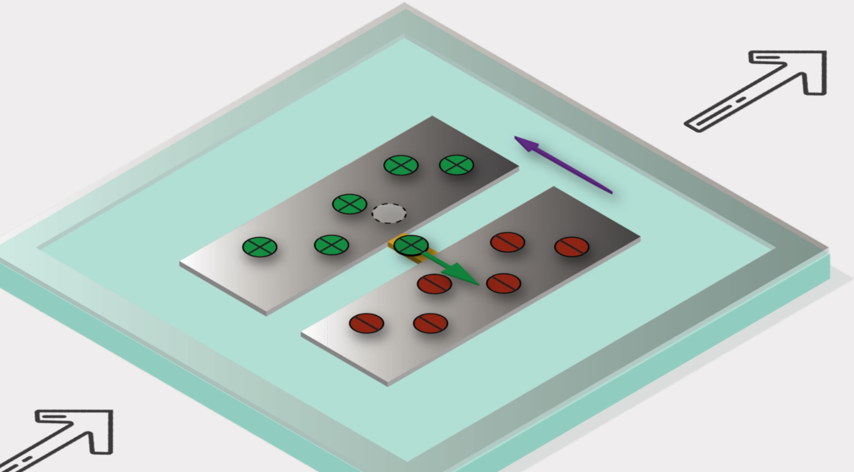
Qubit Hilbert space



Quantum Hamiltonian analysis



Electromagnetic analysis



Physical layout

A unified framework to handle all these questions.

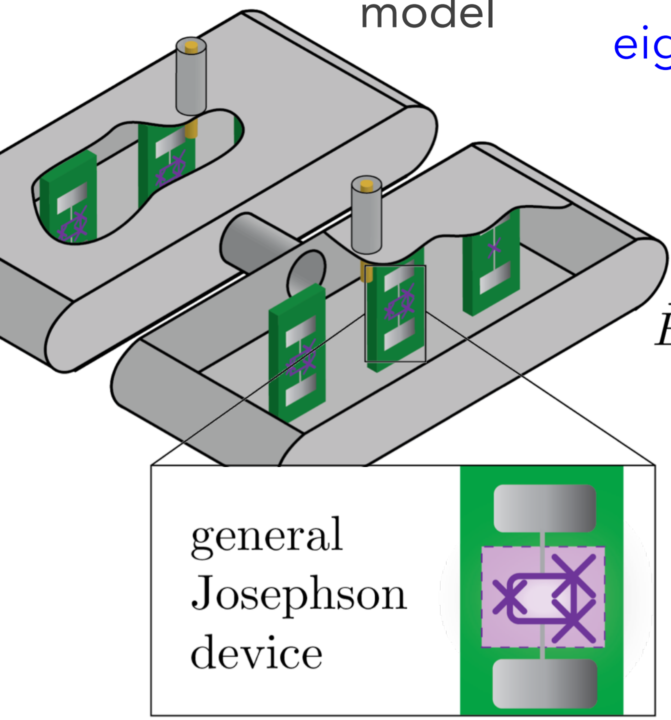
The solution reduces to asking:

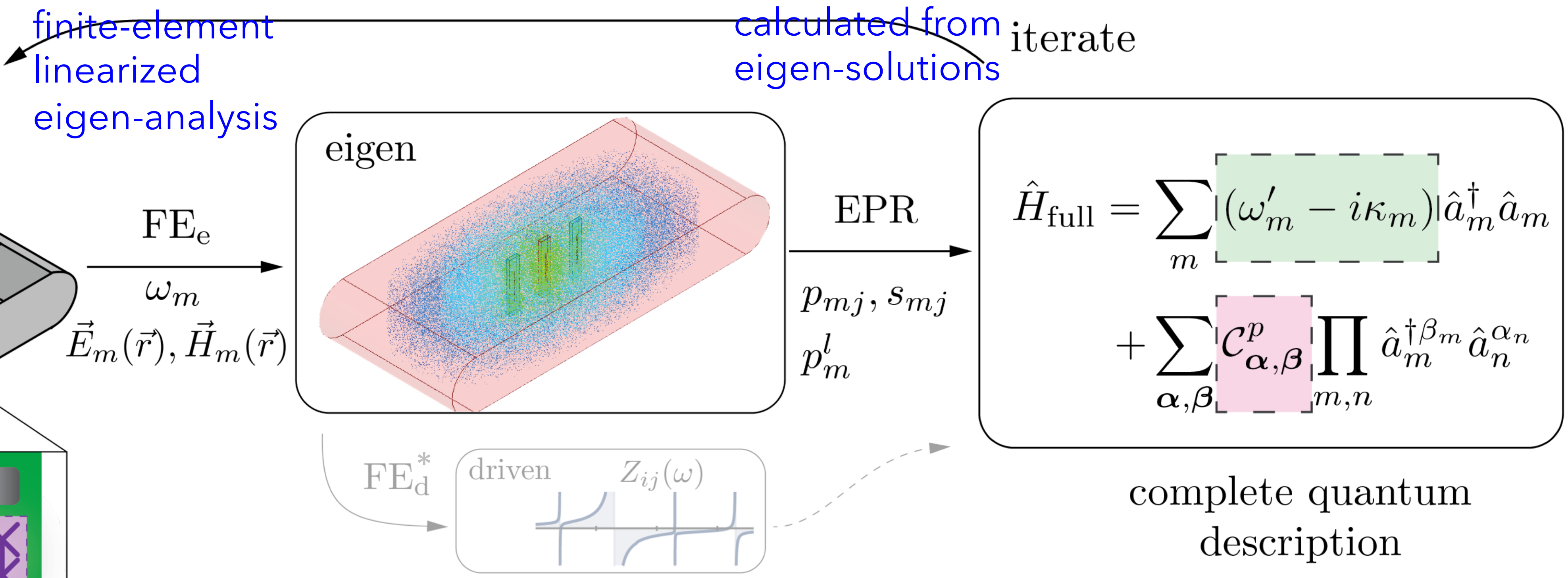
Where is the energy?

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:

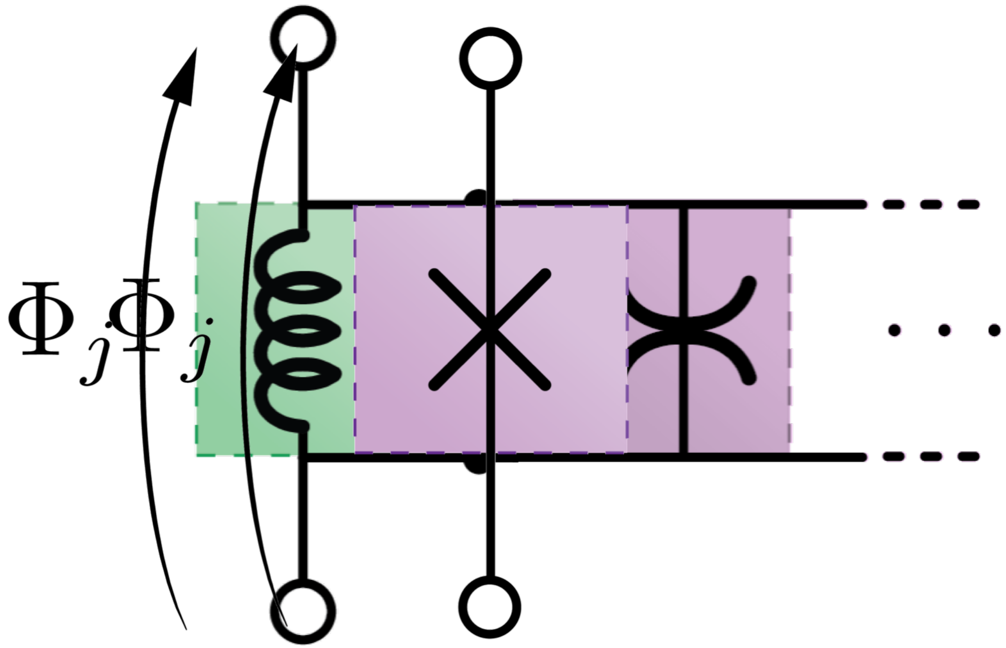
- describes any order and strength non-linearity
- describes arbitrary (composite) non-linear inductive devices
- first-principle derivation
- <u>zero</u> approximations (aside from truncation of modes)
- fully automated in python (github.com/zlatko-minev)

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

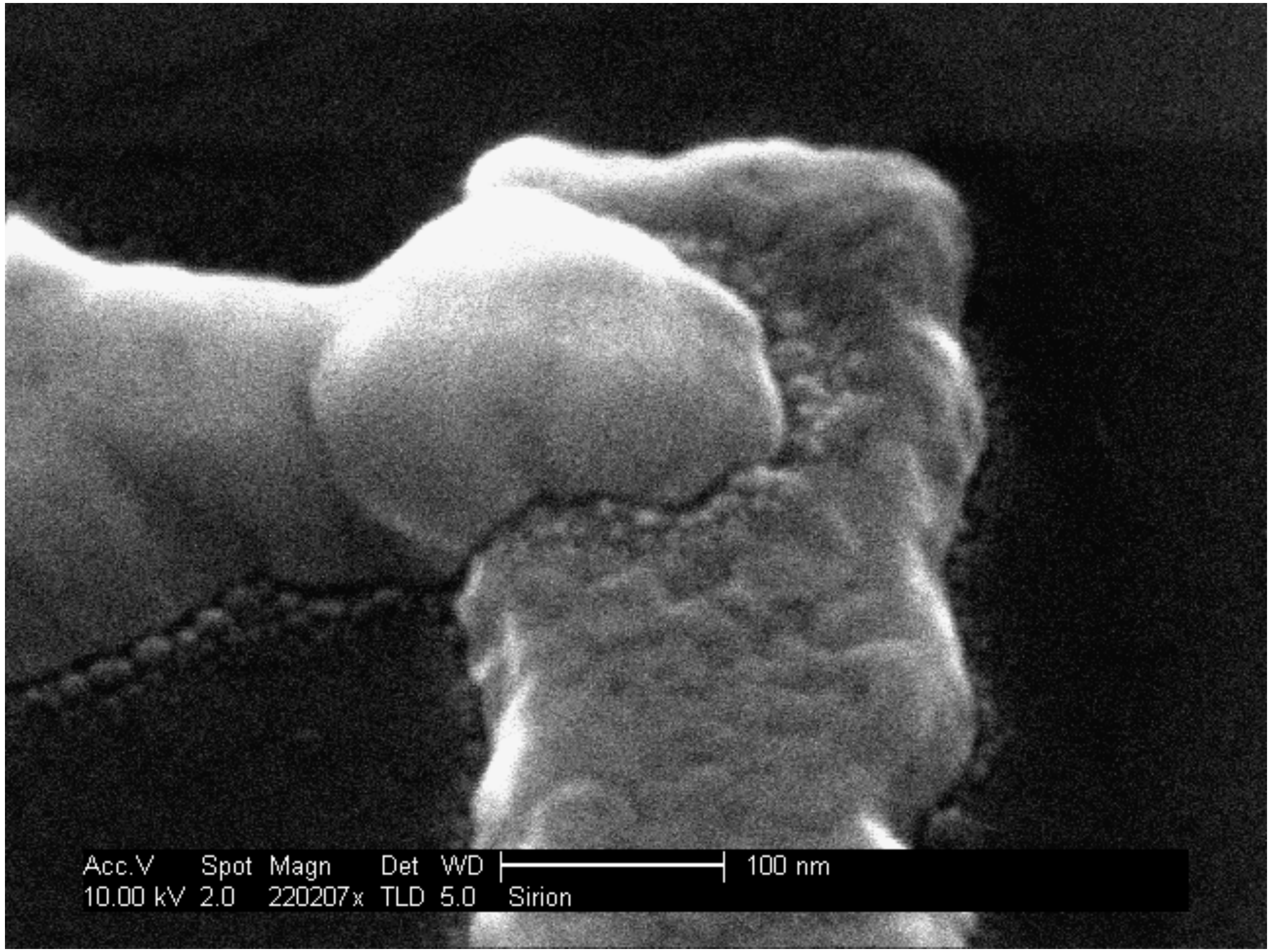
* Nigg, Paik, *et al.*, PRL (2012),
Bourassa *et al.* (2012),
Solgun *et al.* (2014, 2015, 2017), …

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

Non-linear element: Josephson tunnel junction



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

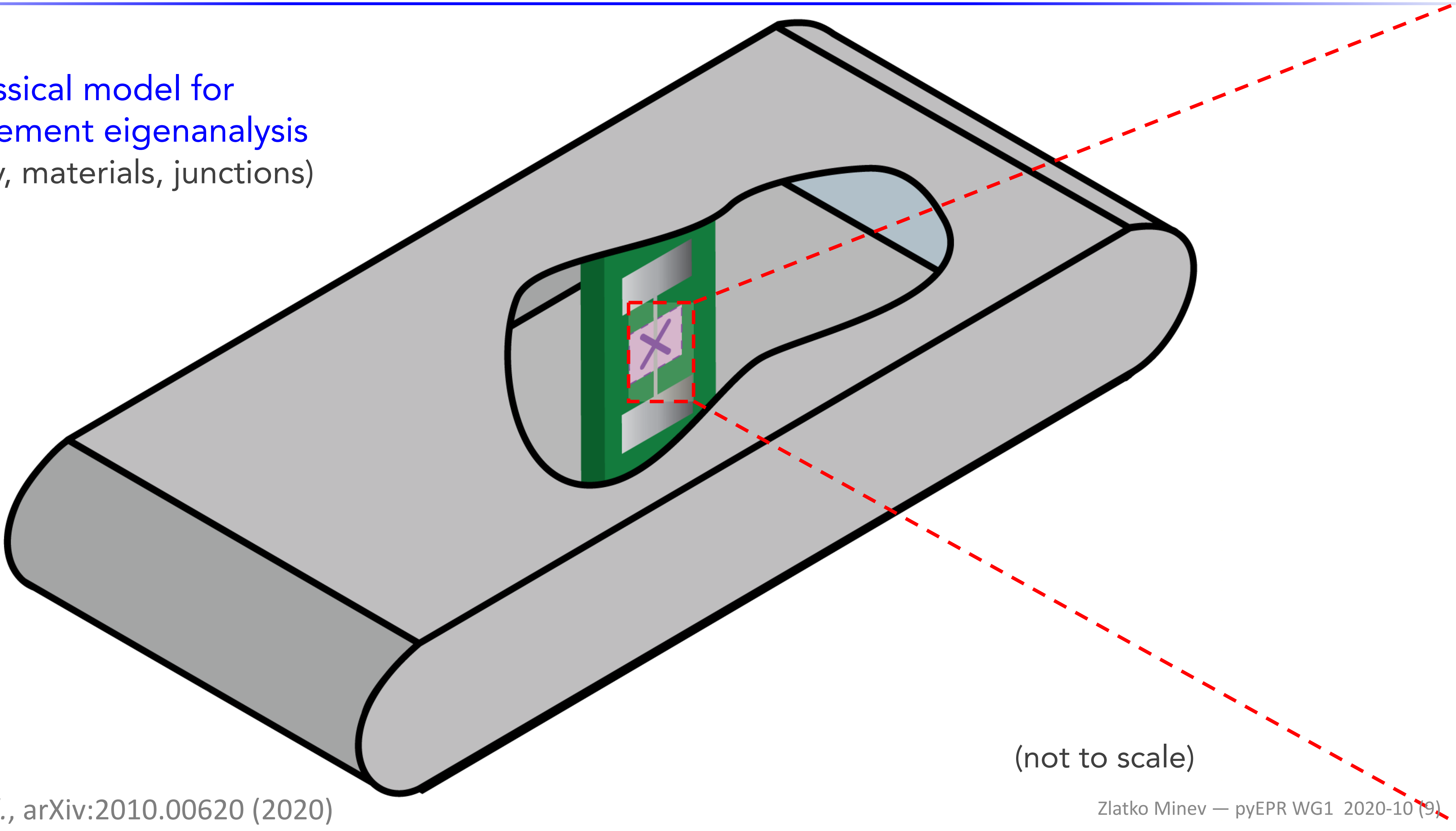


SEM image: L. Frunzio

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

Transmon qubit coupled to cavity

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

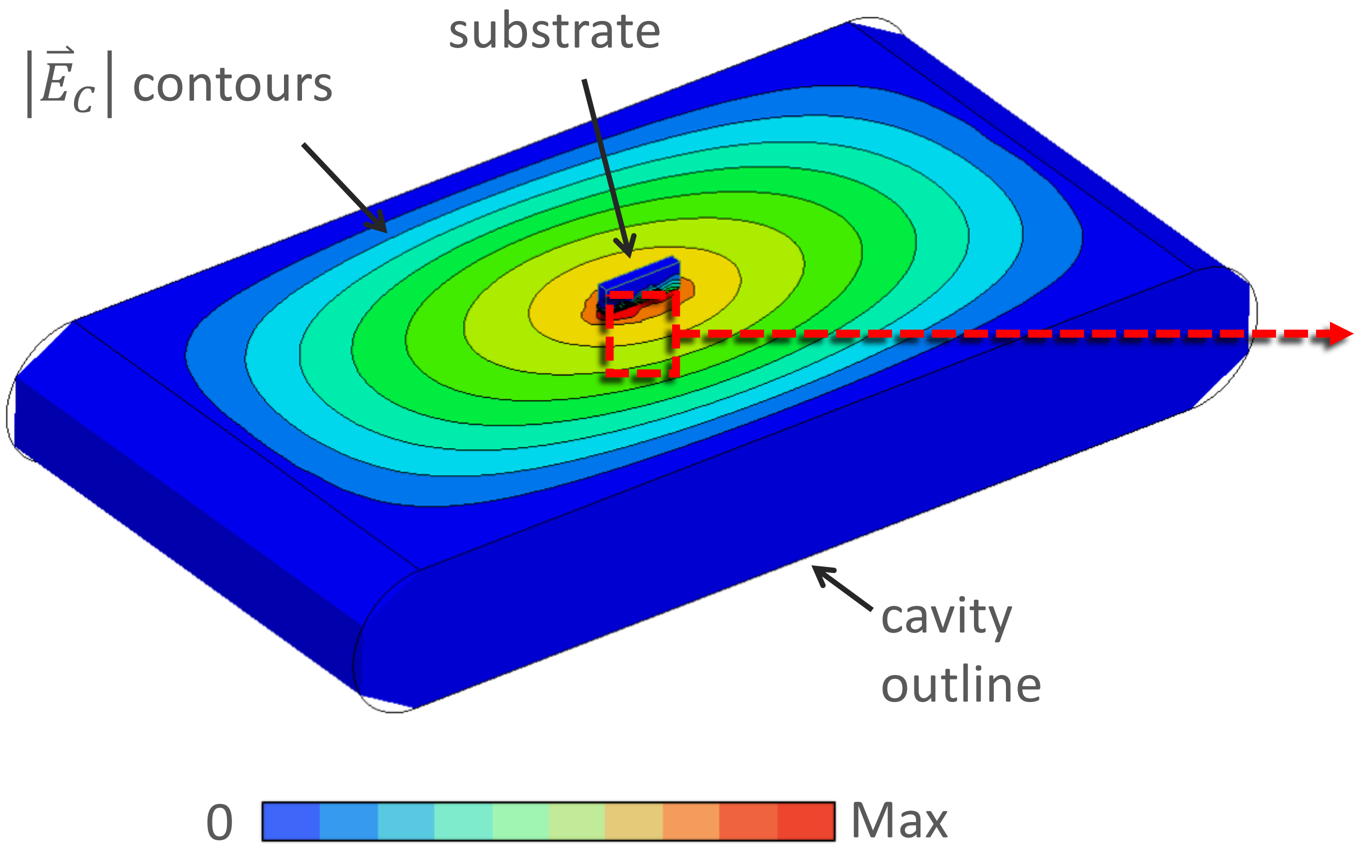


(not to scale)

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

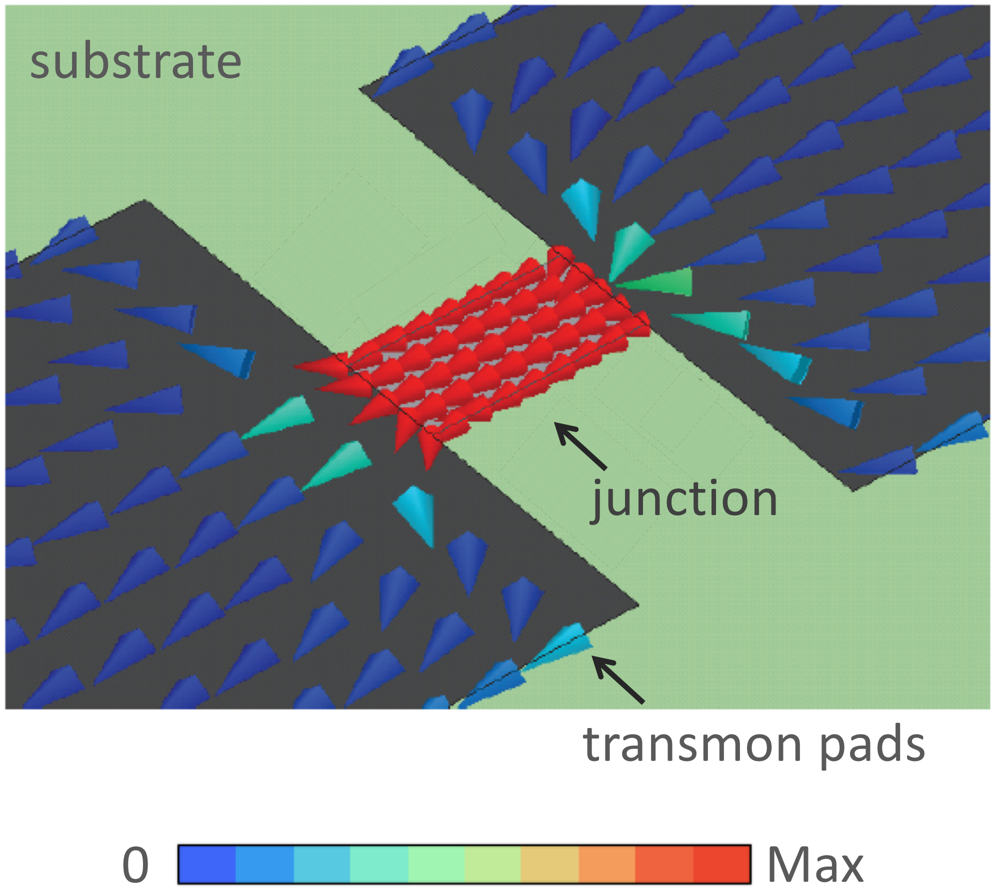
$\mathcal{H}_{\text{lin}}$ eigen modes

Cavity mode (7.0 GHz)



E-field magnitude

Qubit mode (linearized, 5 GHz)



Current-density magnitude

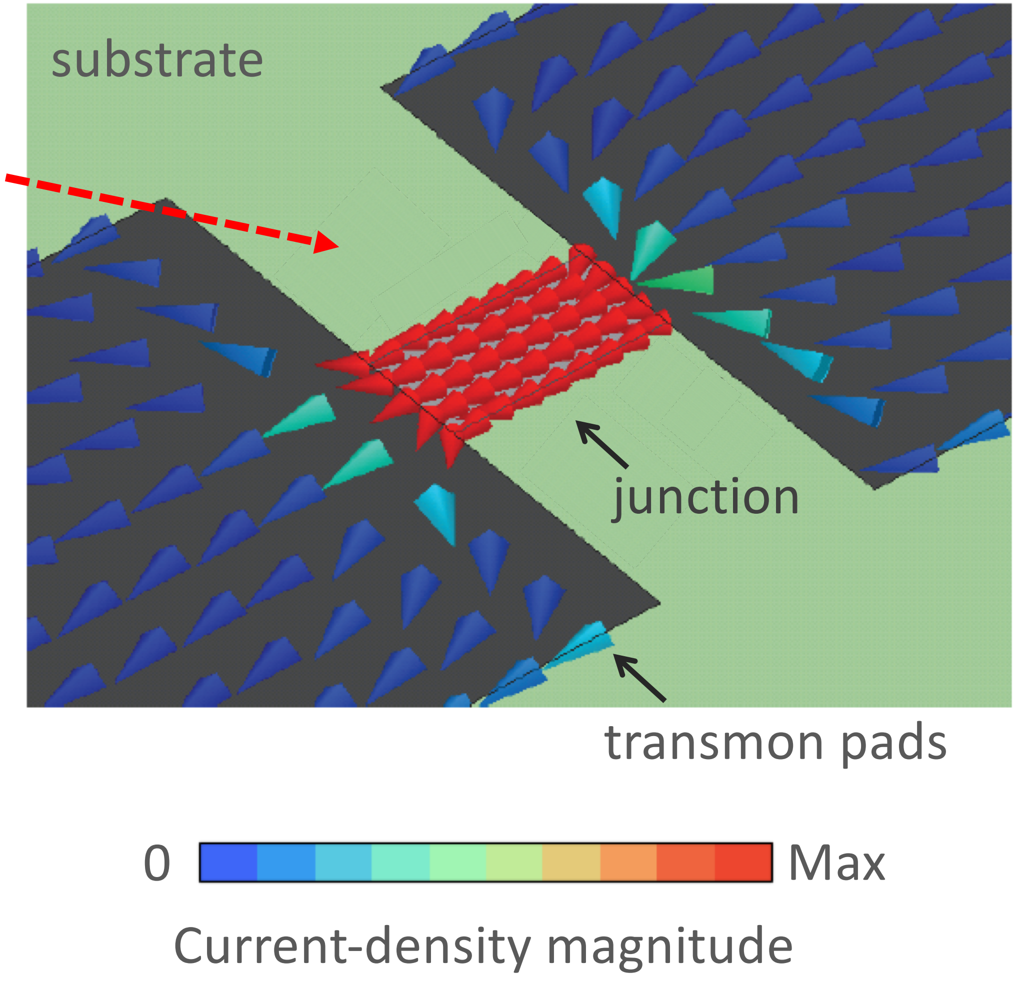
* Minev *et al.*, arXiv:2010.00620 (2020) Impedances: Nigg *et al.*, PRL (2012); Bourassa *et al.* (2012); Solgun *et al.* (2014, 2015, 201

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)

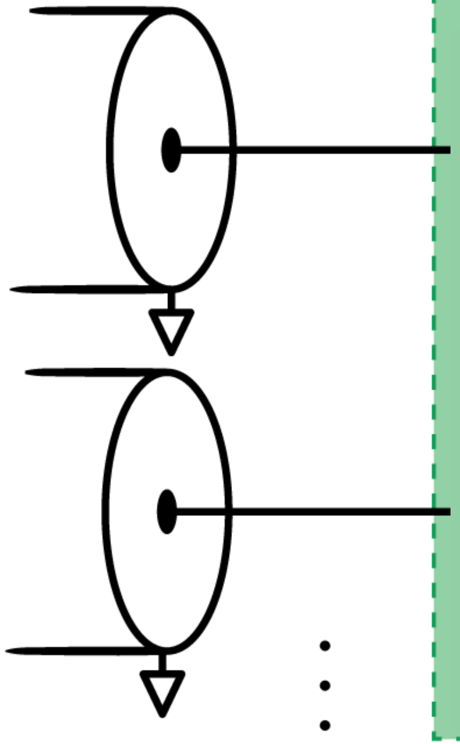


Minev *et al.*, arXiv:2010.00620 (2020)

Decomposition of a general circuit

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

κ_m^l



$$\hat{H}_{\mathrm{lin}}$$

$$\sum_{m=1}^{M} \hbar\omega_m \hat{a}_m^\dagger \hat{a}_m$$

$$\hat{H}_{\mathrm{nl}}$$

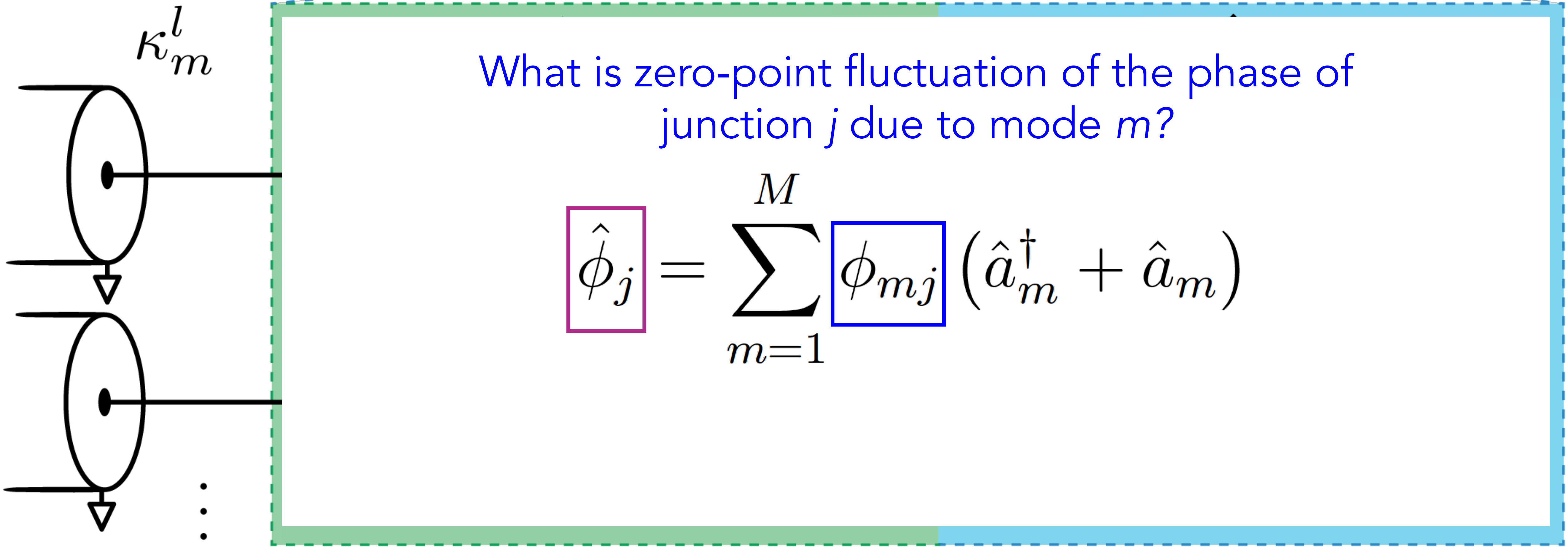
$$\hat{H}_{\mathrm{nl}}(\hat{\phi}_j)$$

second quantization in eigen basis of linearized circuit

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

Decomposition of a general circuit

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



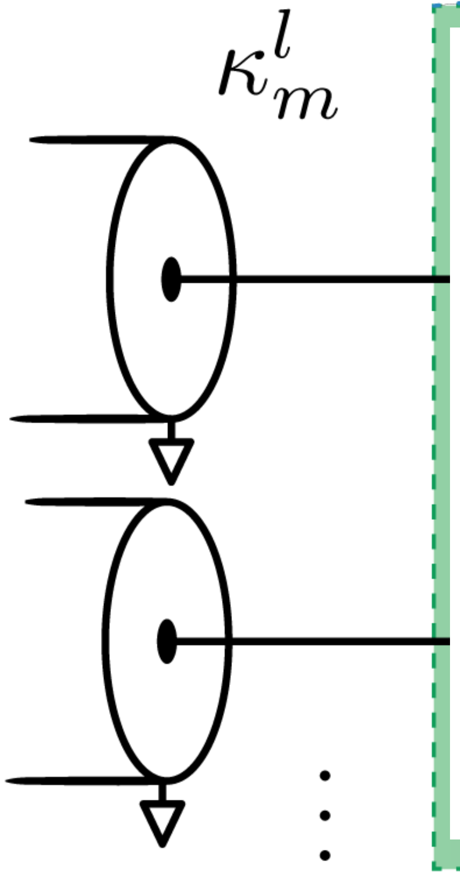
What is zero-point fluctuation of the phase of junction *j* due to mode *m*?

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

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

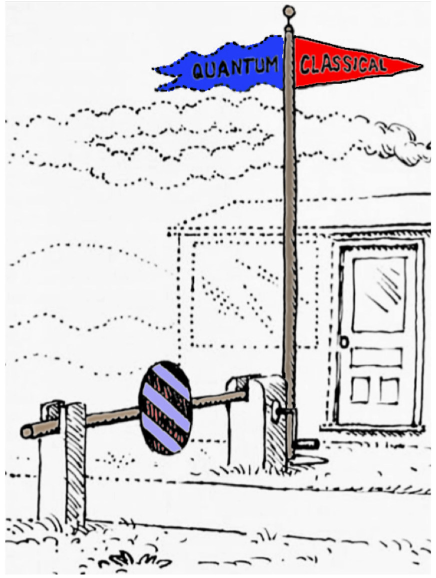
Decomposition of a general circuit

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



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

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

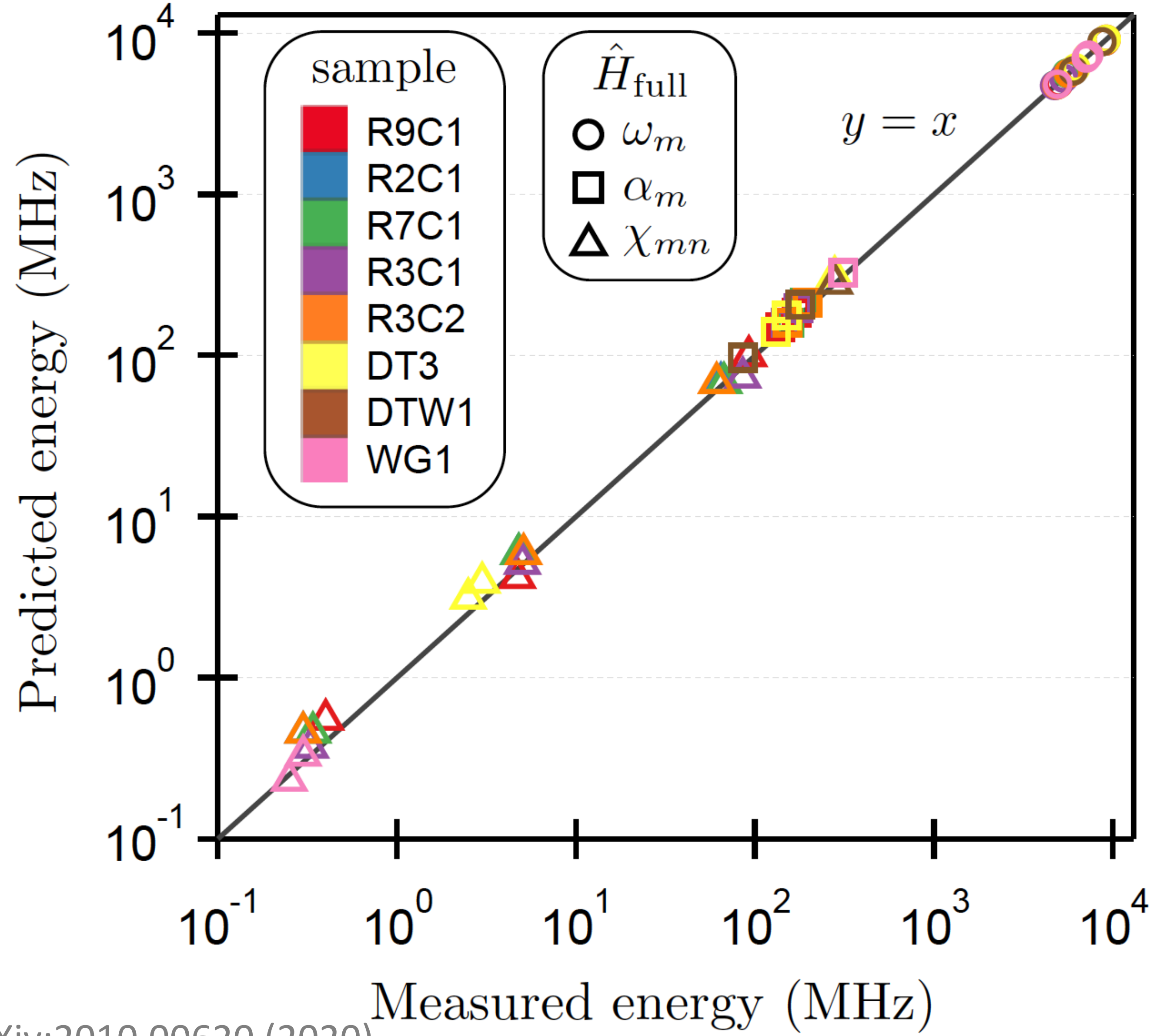


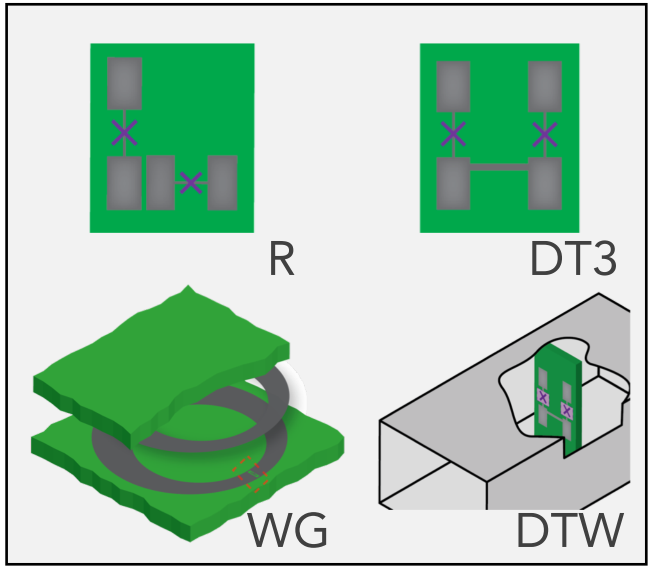
for $j>1$, root requires sign bit $s_{mj} = \pm 1$

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

arXiv.org > quant-ph > arXiv:2010.00620

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[Submitted on 1 Oct 2020]

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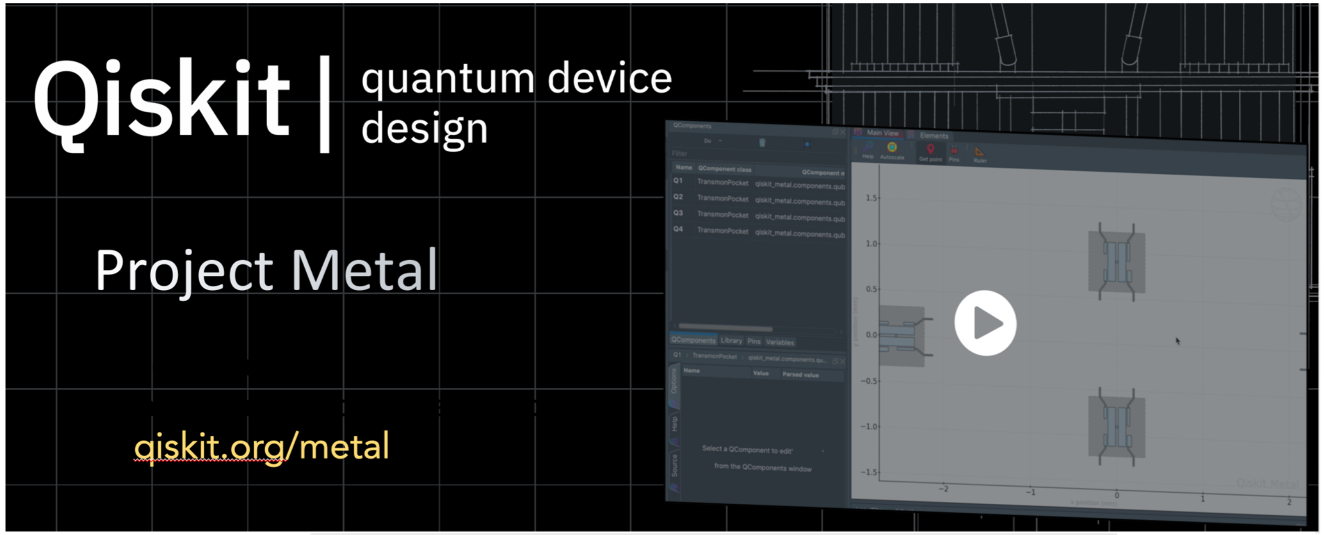

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Other?

Jobs

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