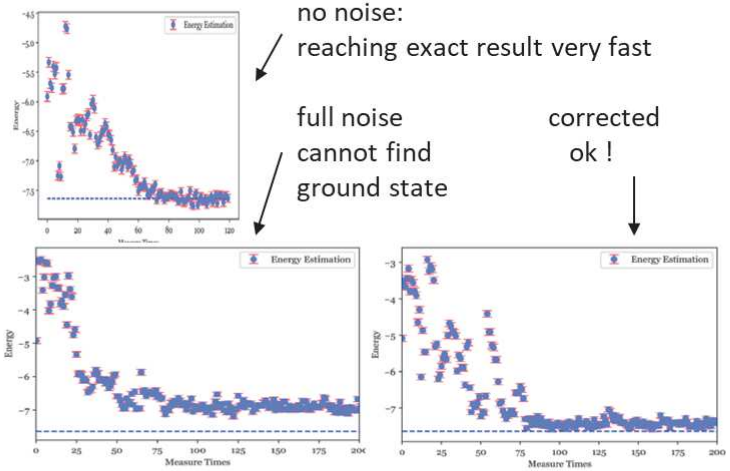
Methods for reliable Quantum Computing Calculations

Increase the Reliability for Quantum Computing Calculations

$$H = \sum_{i=1}^{N} \beta \left[\sigma_x(i)\sigma_x(i+1) + \sigma_y(i)\sigma_y(i+1) + \sigma_z(i)\sigma_z(i+1)\right] + J\sigma_z(i)$$

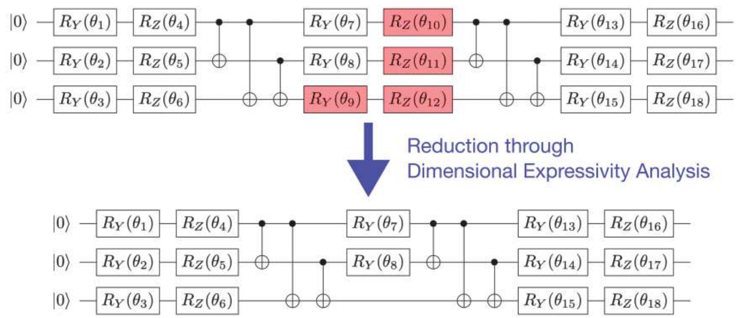
➢ Example for Error Mitigation in VQS

- Model in Condensed Matter Physics:
  1-Dimensional Heisenberg model
  very sensitive to QC noise
  cured by own developed error mitigation methods



➢ Optimize Dimensional Expressivity of a Quantum Gate Circuit

- Gate Operations are noisy
- Develop methods for Dimensional Expressivity Analysis
- **Generate as many/complicated states as possible with fewest number of gates**

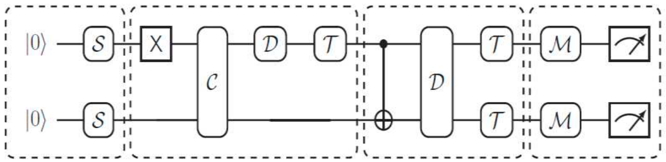


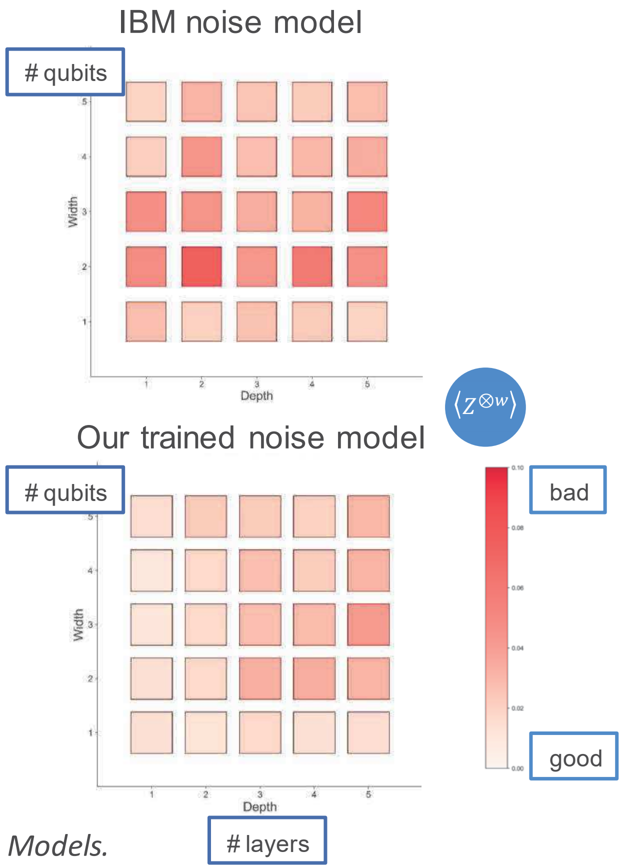
Software engineering for Noise Model Benchmarks

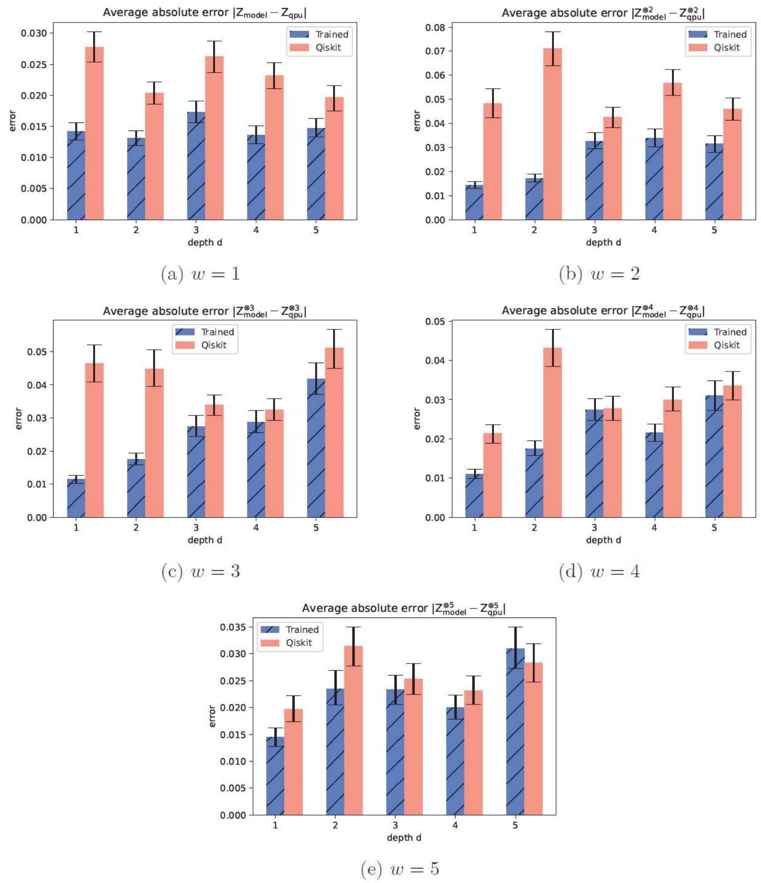
Increase the Reliability for Quantum Computing Calculations

- **Software Engineering Models for Error Mitigation**
  - Systematic approach to train error models with Machine Learning and perform benchmarks for quantum computing applications

symbol	error	parameters	number of parameters
$\mathcal{S}$	state preparation	$p_{\mathrm{sp}}(q)$	N
$\mathcal{D}$	depolarization	$\lambda_g(q)$	$4N-1$
$\mathcal{C}$	crosstalk	$\phi_g(q)$	$2N$
$\mathcal{T}$	thermal relaxation	$T_{1,2}(q)$	$2N$
$\mathcal{M}$	measurement	$p_{0\to1}(q)$, $p_{1\to0}(q)$	$2N$
total			$11N-1$





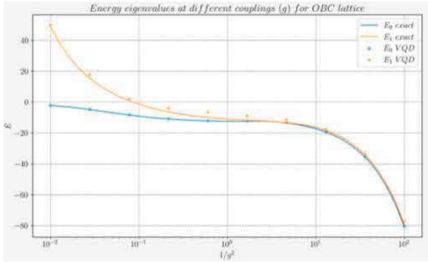


Weber, T. et al.
Volumetric Benchmarking of Quantum Computing Noise Models.
Submitted to IOP Quantum Science and Technology.

Quantum Computing: From Theory towards Applications

From QED in 2+1 dimensions to Flight Gate Assignments

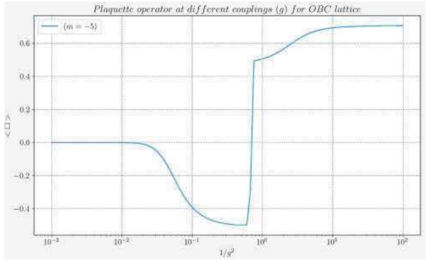
- Variational Quantum Simulations (VQS) for QED



Particle Mass

$\Delta = E_1 - E_0$

→ physical quantity



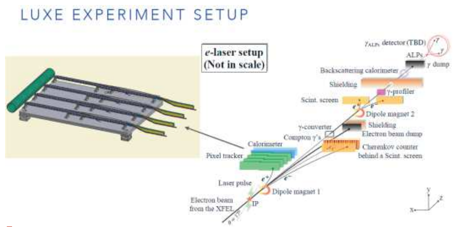
Detecting a phase transition at negative mass

→ **not possible with MC methods**

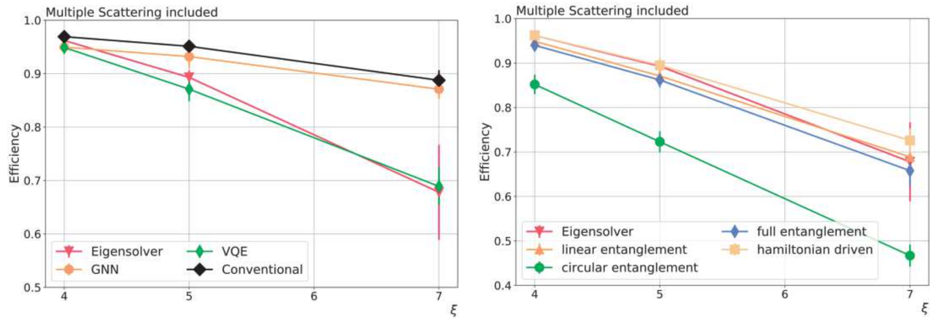
Clemente G. et al, Strategies for the Determination of the Running Coupling of (2+1)-dimensional QED with Quantum Computing, https://arxiv.org/abs/2206.12454

- Very similar methods for tracking at the LUXE Experiment

Q-GNN and VQE for particle tracking in the LUXE Experiment
(Laser Und XFEL Experiment)
study of the influence of entanglement



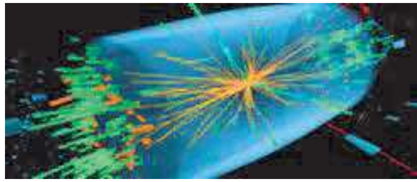
Crippa A. et al, Quantum algorithms for charged particle track reconstruction in the LUXE experiment, https://arxiv.org/abs/2304.01690

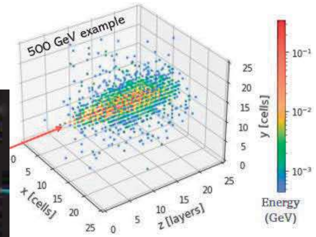


Efficiency as a function of the field intensity ξ

Methods and Quantum Machine Learning for Experiment

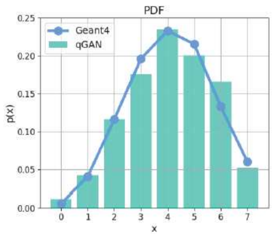
Early examples in Experimental Particle Physics

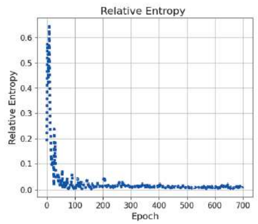




CERN openlab

- **Quantum Machine Learning proved to be robust against noise**
  - High Luminosity LHC needs vast amount of simulations with 200 pile-up events → a formidable computing challenge
- **Develop methods and machine learning applications for QC**
  - **Q-GAN simulations for detectors** (Quantum Generative Adversarial Network)

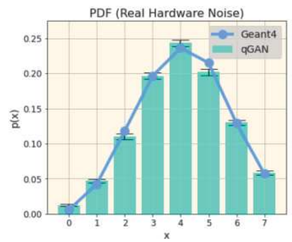


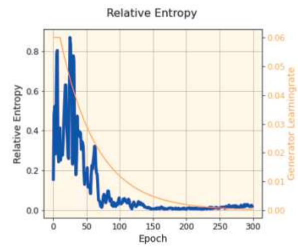


← readout noise

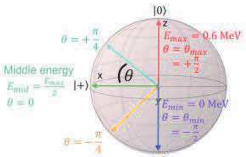
full noise

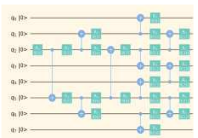
real hardware →

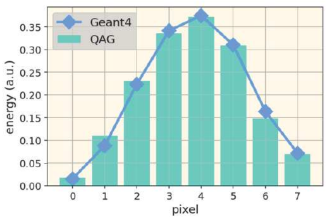


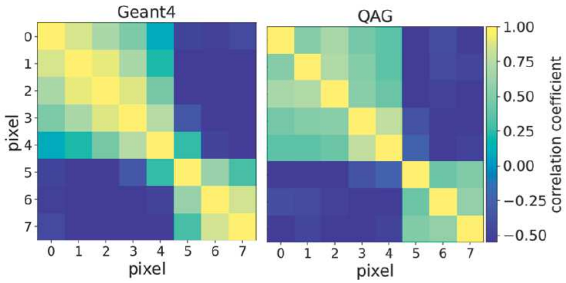


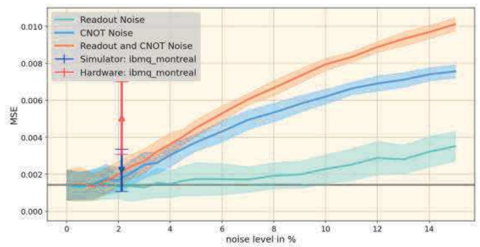
  - **Full Quantum Angle Generator → modelling correlations and robust against noise**

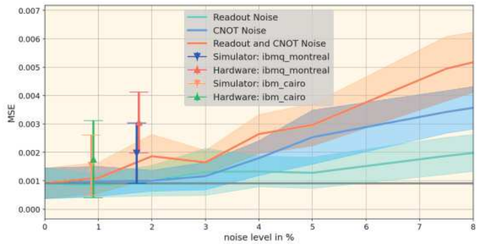












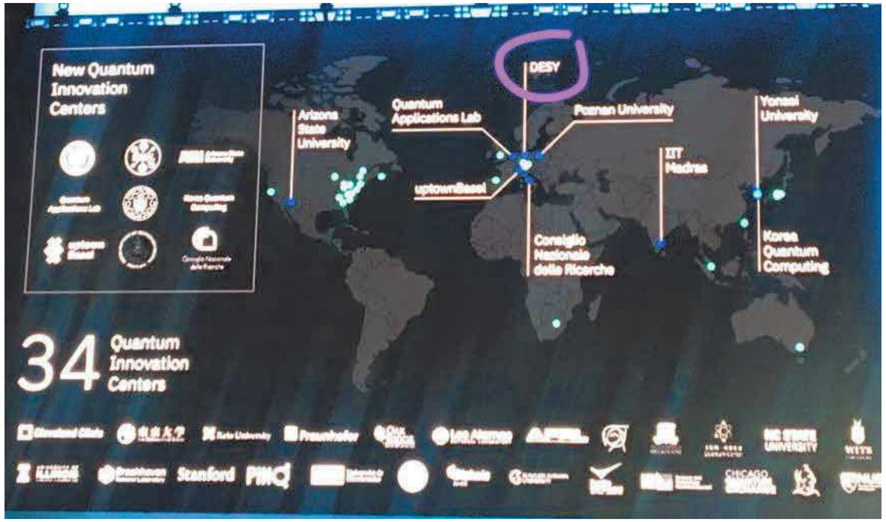
Rehm, F. et al. Precise Image Generation on Current Noisy Quantum Computing Devices. Subm. to IOP Quantum Science and Technology / PhD Thesis RWTH Aachen

DESY. QUANTUM and CQTA in Zeuthen

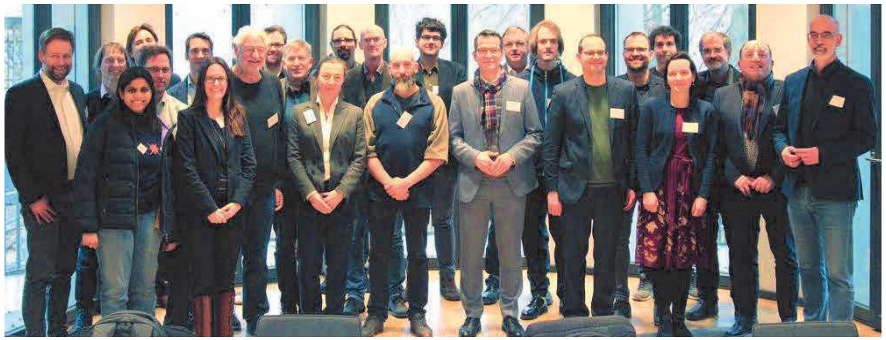
DESY. QUANTUM | Center for Quantum Technology and Applications

Special focus on Quantum Computing Applications

- **Innovation-Funding from Brandenburg:**
  15 M€ over 5 years for CQTA
  - access to quantum computer → **new IBM – Hub**
  - develop applications and use cases
  - enable quantum simulations
  - benchmark and verify emerging hardware platforms
  - provide training in quantum computing
  - make new generation "quantum ready“



Already very vibrant and intense connections to industry



Brandenburg Quantentechnology-Network meets in Zeuthen
Research-State-Secretary Dünow visits researchers