Discovering New Physics with Quantum Computers

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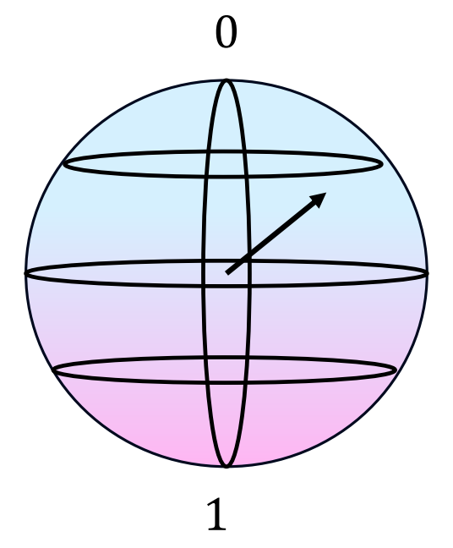
1. What is Quantum Computing?

- A new form of computing exploiting quantum mechanics.
- Certain problems can be ***solved exponentially faster*** than classical machines.

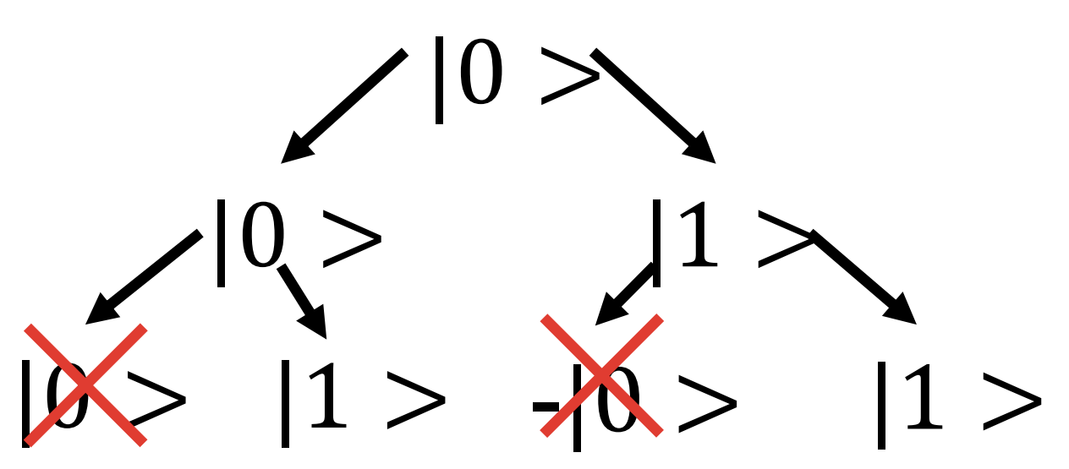
Key Properties:

Superposition

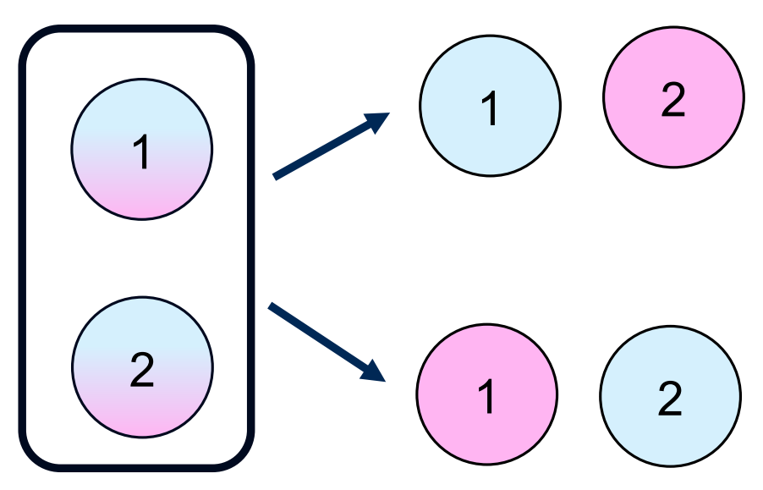


$|\psi> = \alpha|0> + \beta|1>$

Interference



Entanglement



2. Potential Applications

Simulations:

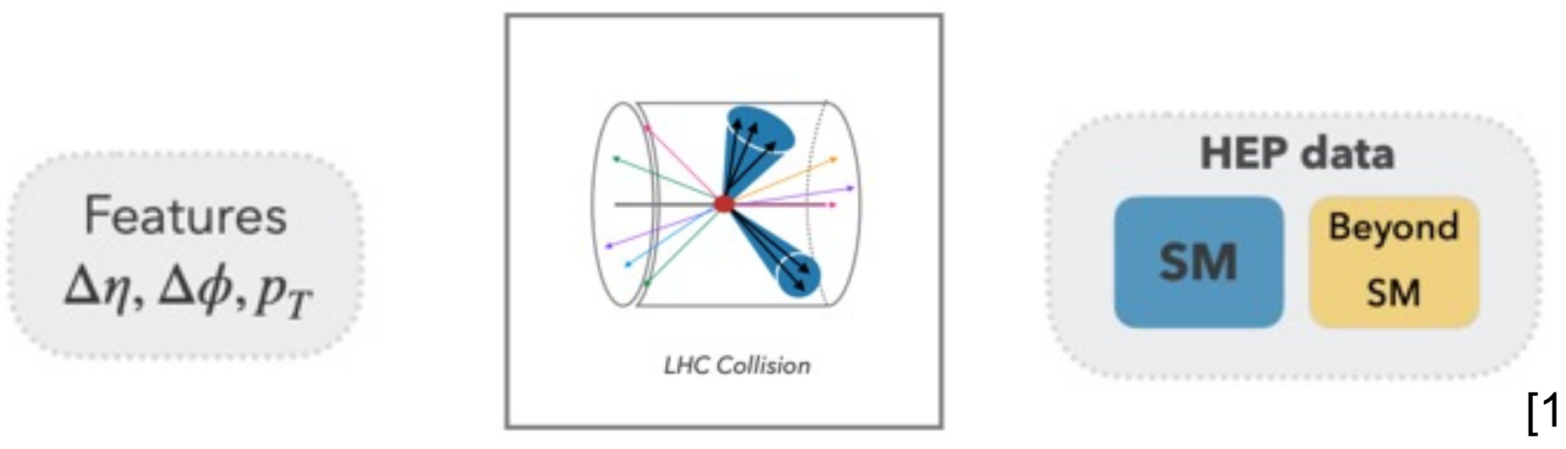
- New battery technology.
- Improved drug design.
- Particle physics simulations.

Machine learning:

- Faster training on certain tasks.
- Better prediction capabilities.
- Learning with fewer samples.

3. Our Project

- Since the Higgs boson what's next?
- Can we find ***new physics*** we have never observed?
- We use Model agnostic searches.
- Extract anomalous events using kinematic data from collisions.



[1]

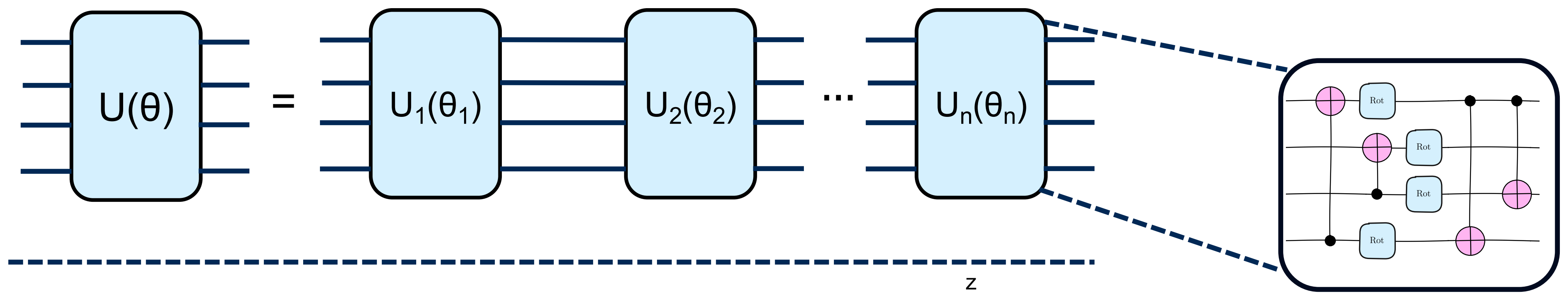
4. Variational Quantum Algorithms (VQA)

General form of cost function: $\theta^* = argmin_\theta\, C(\theta)$

$$C(\theta) = \sum_k f(Tr[O_k U(\theta)\rho_k U^\dagger(\theta)])$$

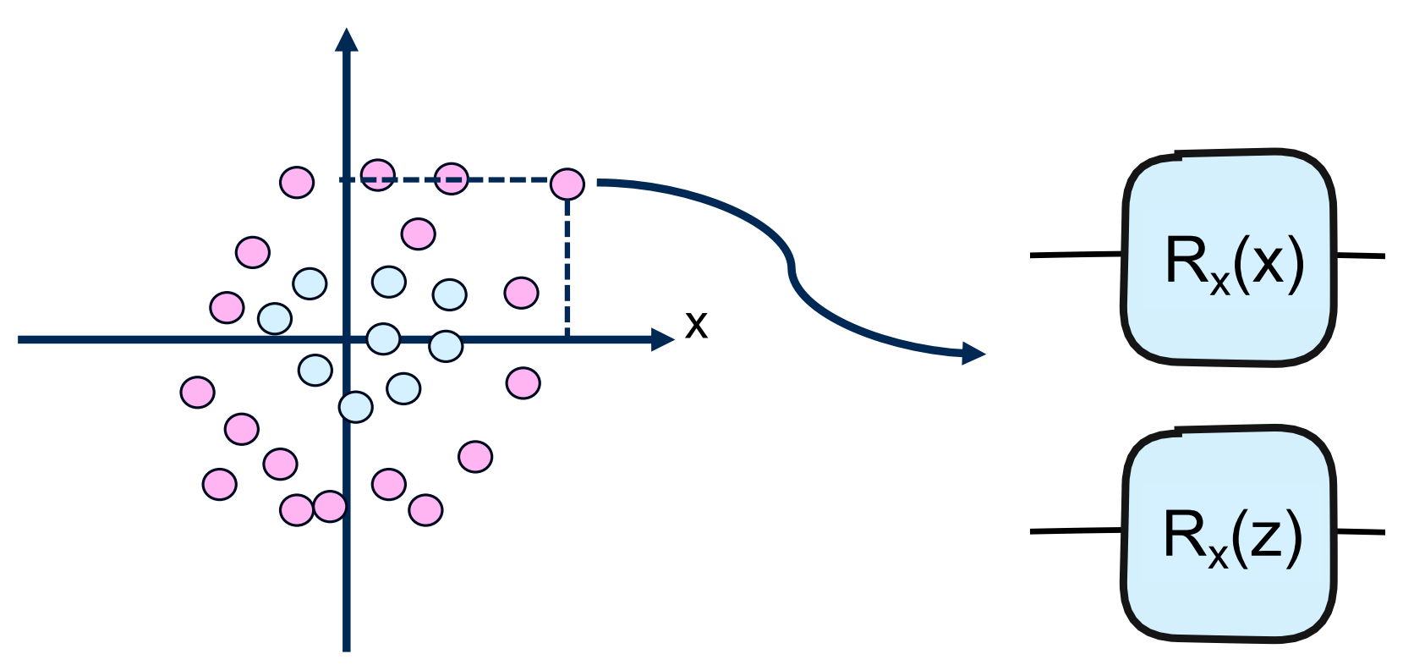
Ansatz:

- Structure determines the ***inductive biases***, parameters θ are trained to minimize cost.
- A series of rotation and entangling gates, the structure can be general or problem specific.

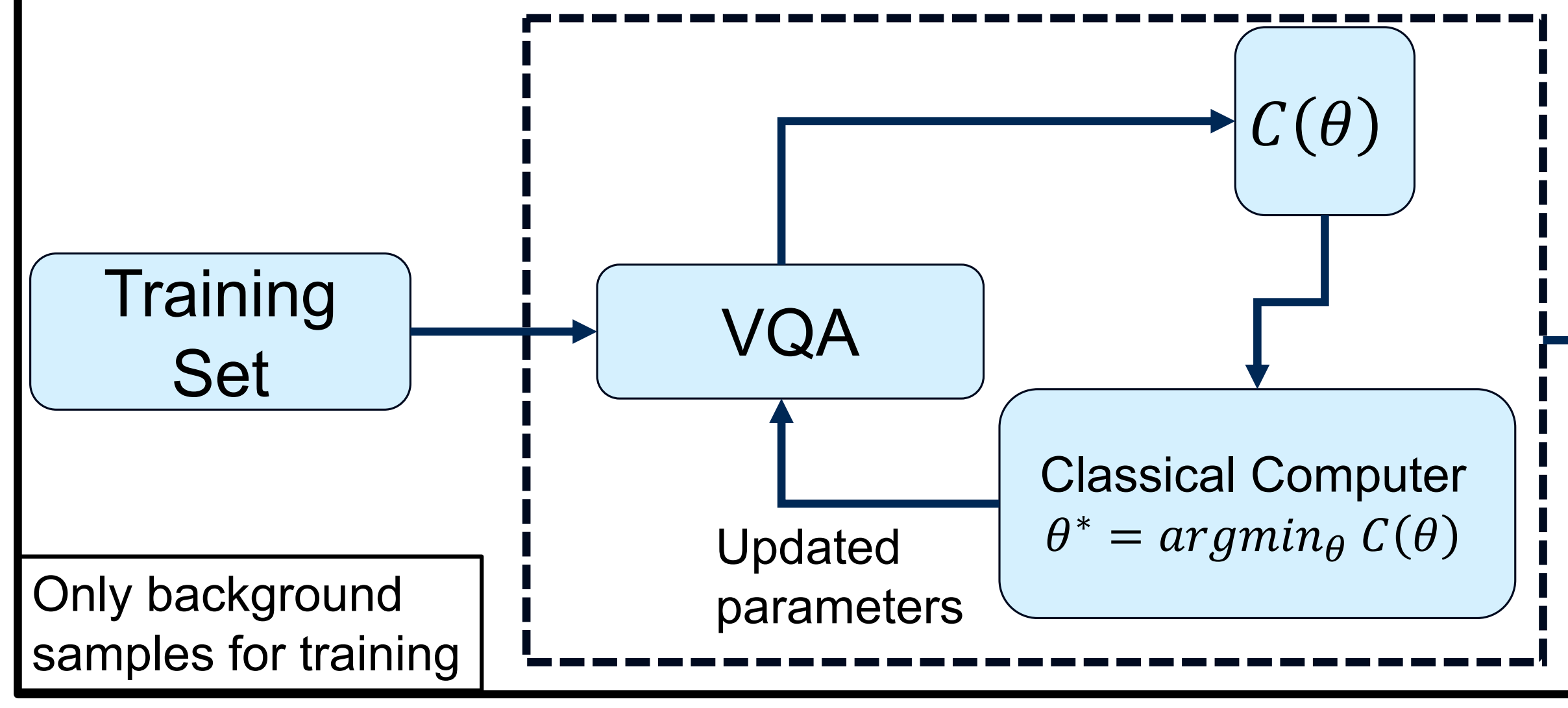


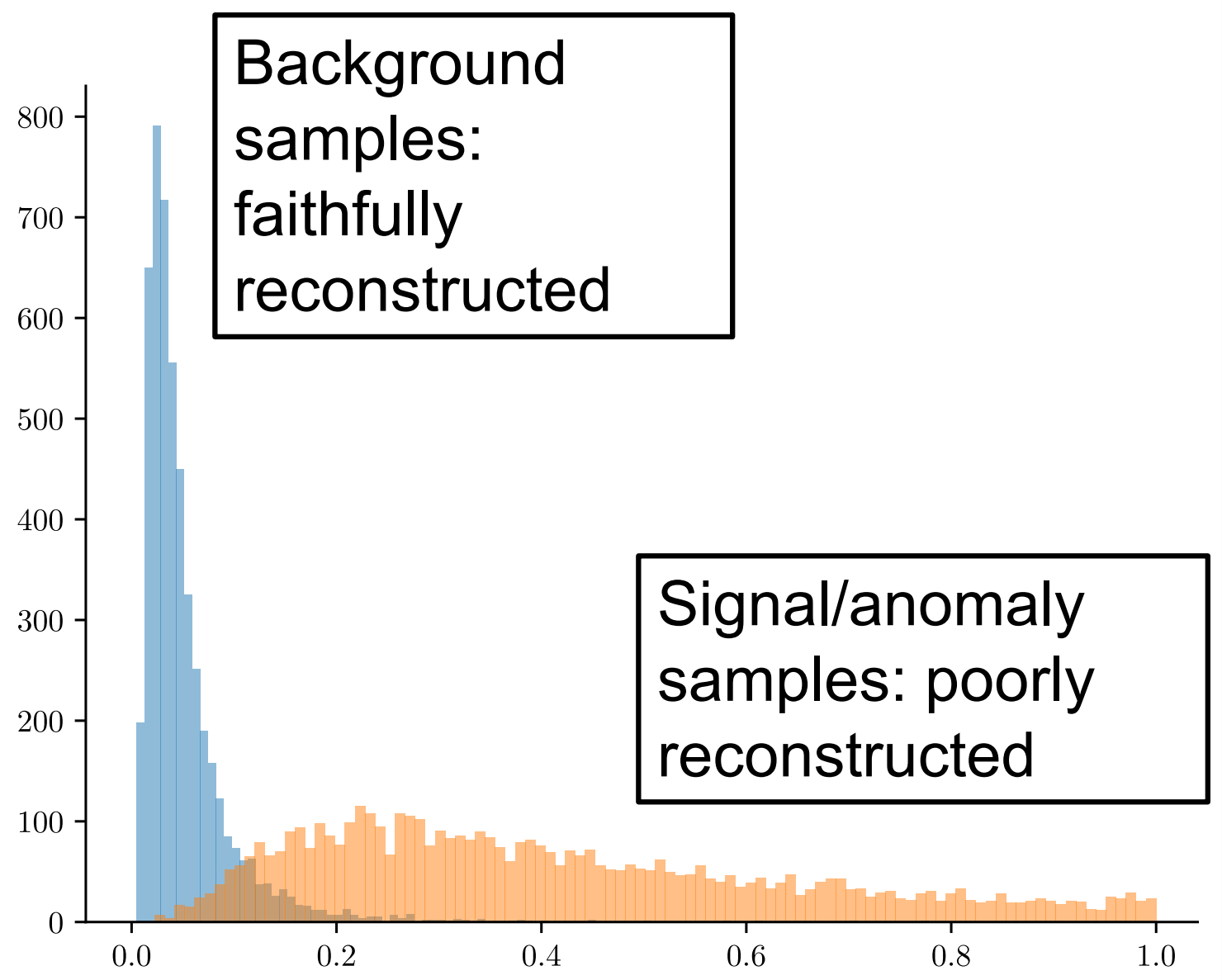
Feature map:

- Maps input vectors to a Hilbert space.
- Encoded data can be fed into an ansatz.

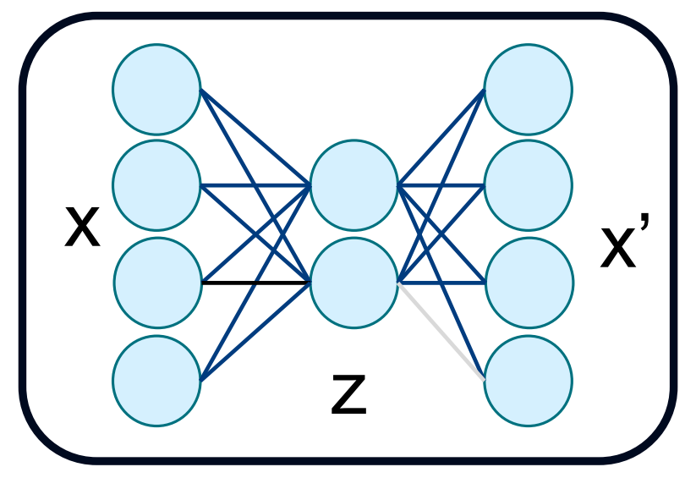


Training Loop:



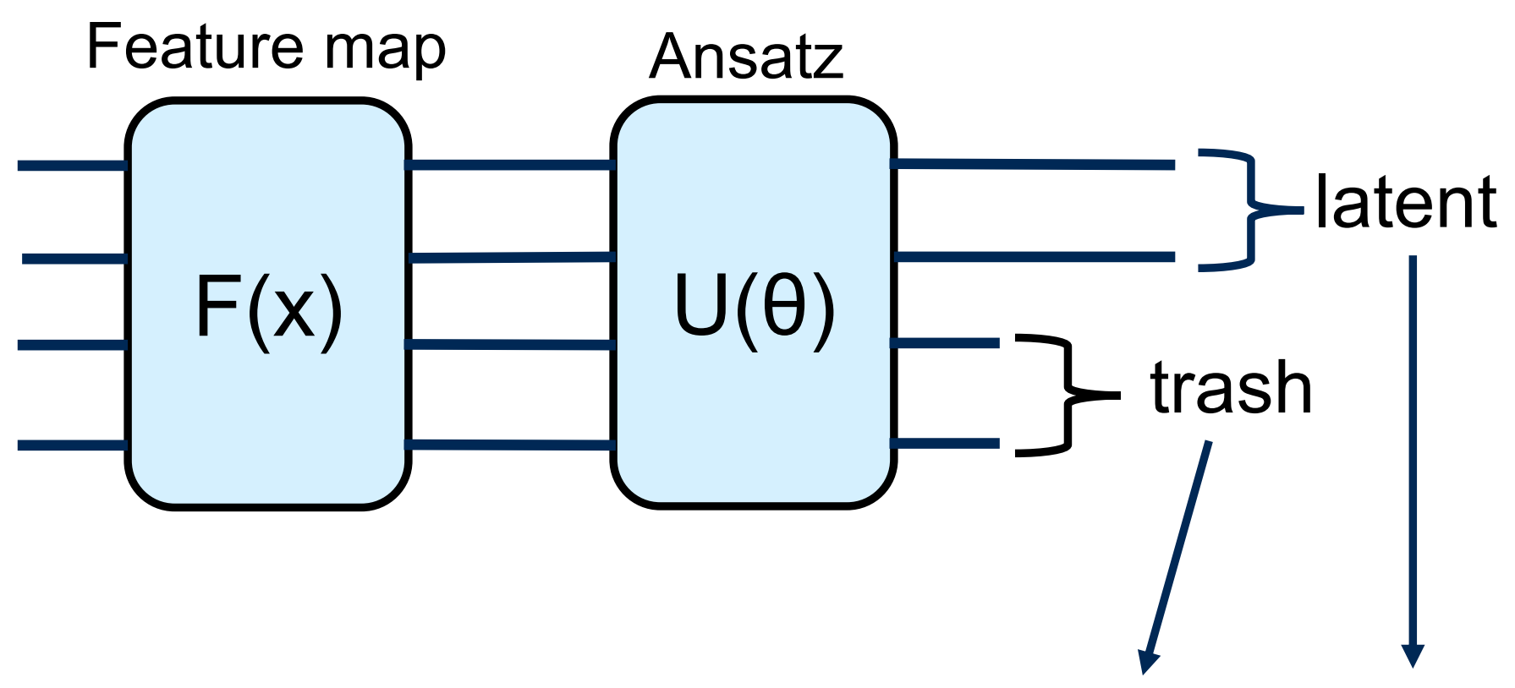


5. Classical Autoencoder (CAE)



- Input vectors x are compressed to a representation z.
- z is decoded into x'.
- x and x' are compared with a cost function to be minimized.

6. Quantum Autoencoder (QAE)

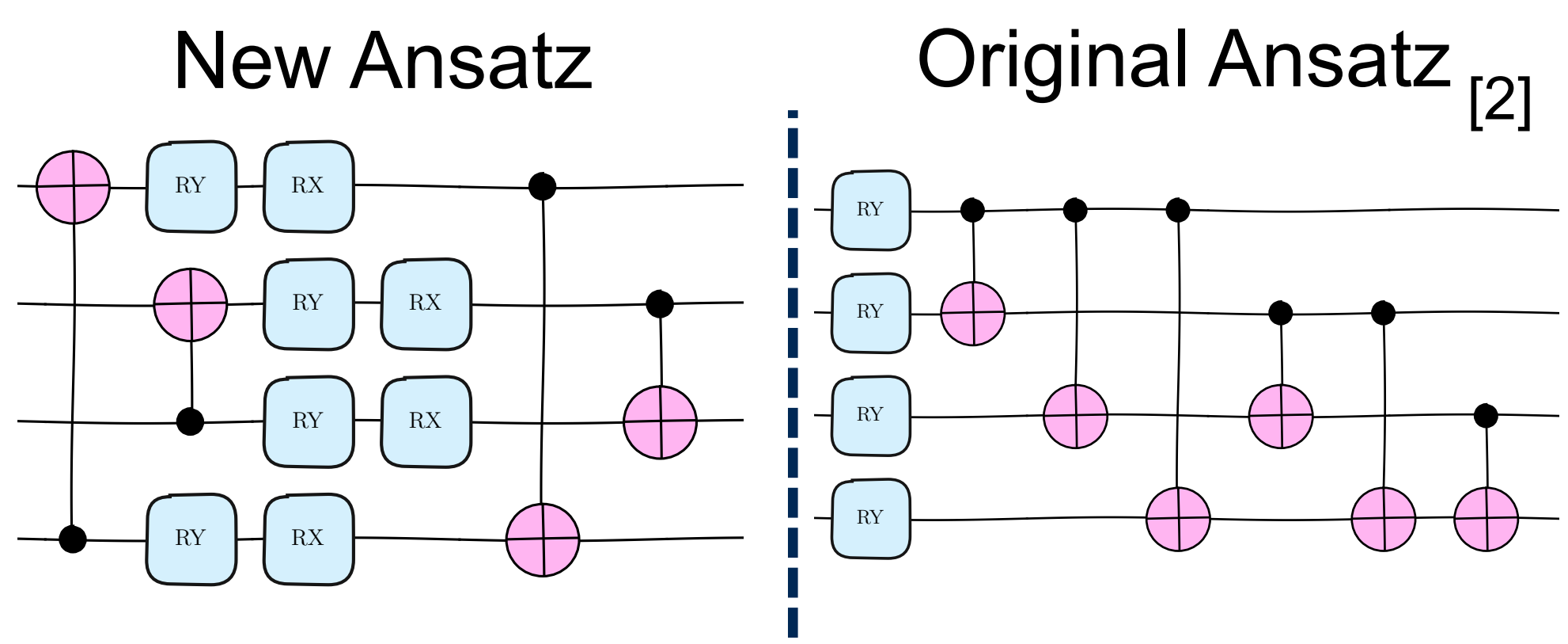


- Ideal output state: $|\psi> = |0>^n \otimes |\phi>$.
- Cost function aims to maximize the number of zero states in the trash.

7. Compared to CAE, can QAE

- Learn with fewer samples?
- Make better predictions?
- Learn with fewer parameters?

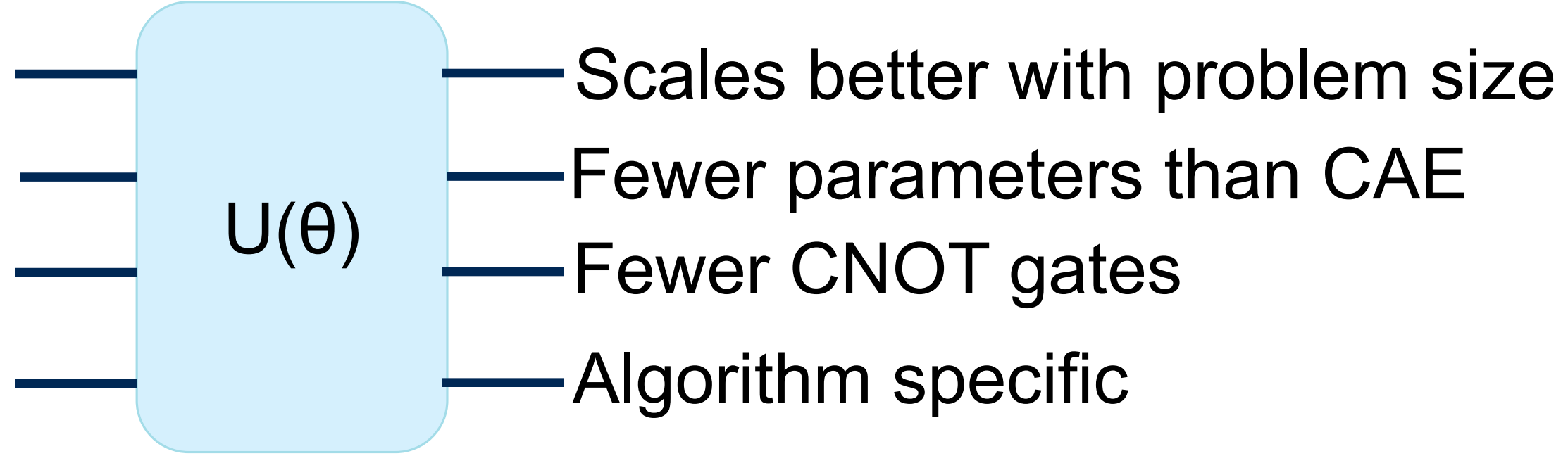
8. New Ansatz Design



9. Results

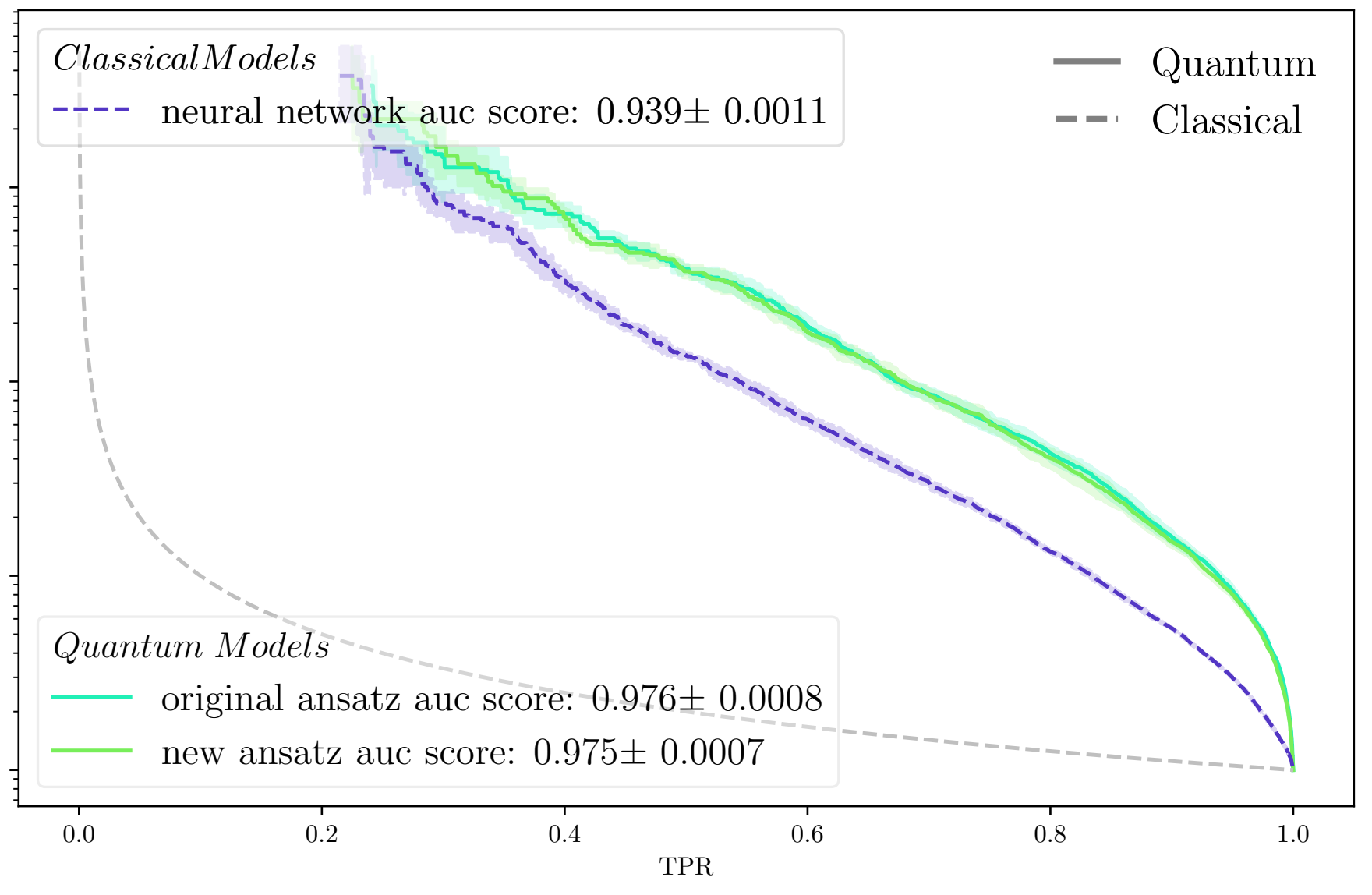
- Identifying BSM Higgs amongst QCD events.
- AUC score: measures predictive performance.

New Ansatz!

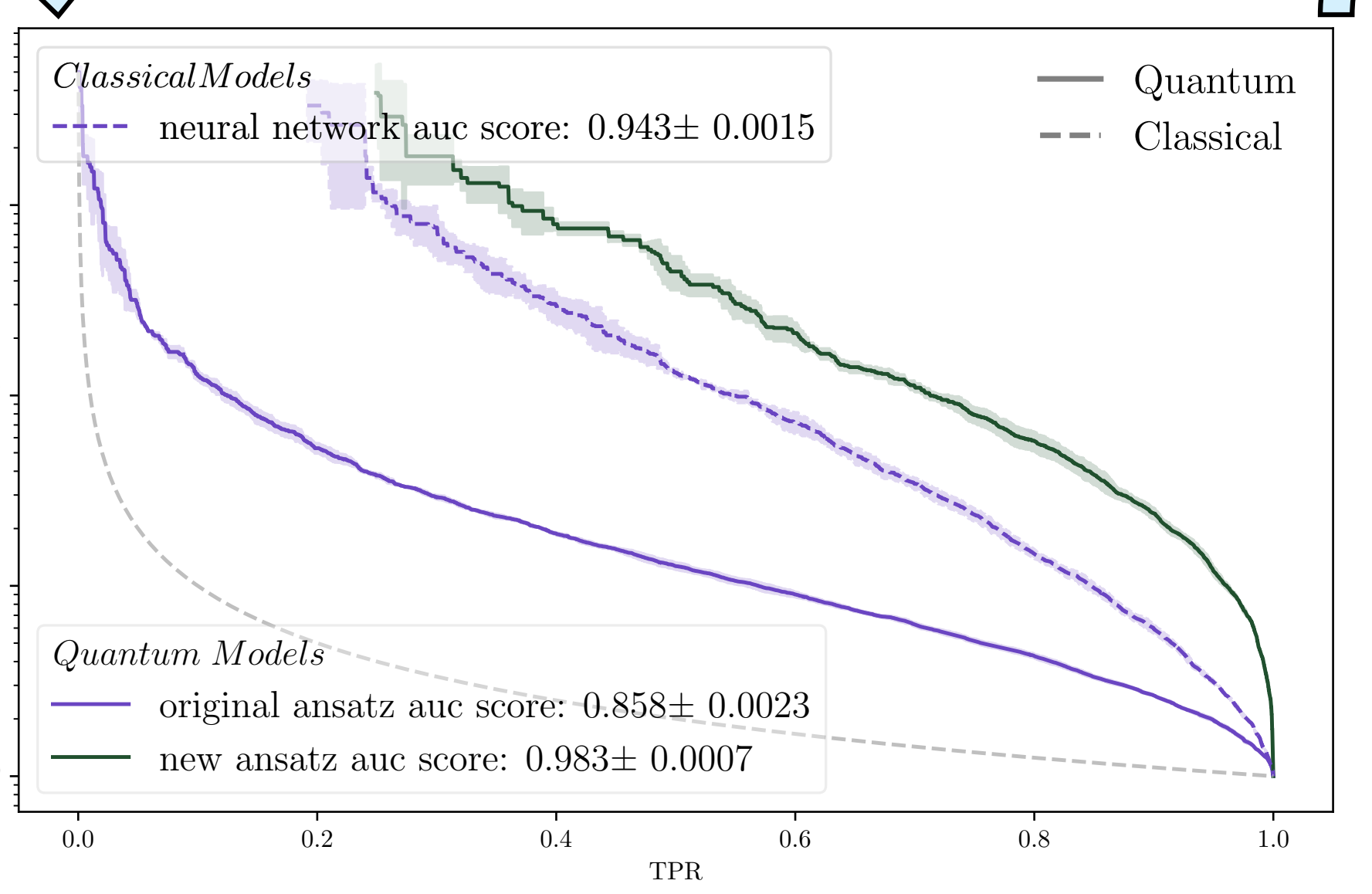


- Scales better with problem size
- Fewer parameters than CAE
- Fewer CNOT gates
- Algorithm specific

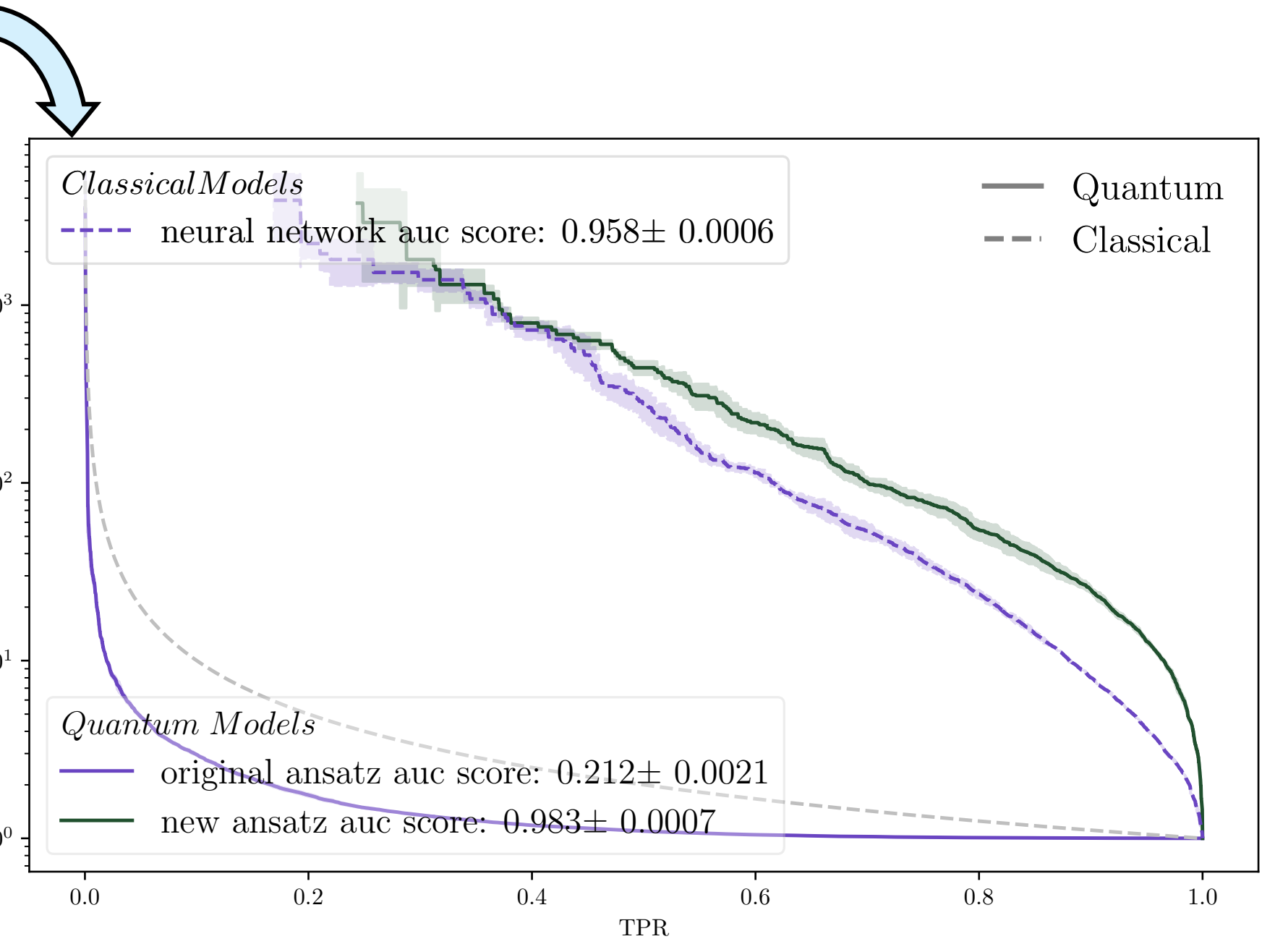
Heavy Higgs Search



Input features 4



Input features 6



Input features 8

10. Conclusions and Outlook

- Potential for ***better performance with fewer parameters*** compared to CAE.
- Further analysis needed on a variety of classical autoencoders (pruned CAEs).
- Further study into the scaling of QAE with problem size and number of parameters.

References:

[1] - Woźniak et al (2023)

[2] - Ngairangbam_et al (2022)

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