

# Highlight of 2nd Workshop of Quantum Computing and High Energy Physics

Yu Zhang

Qujing Normal University, Yunnan

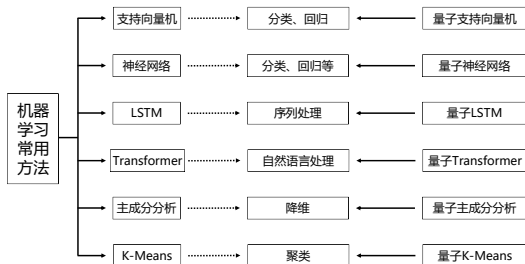
April 6, 2023

Link :<https://indico.ihep.ac.cn/event/19239/>

- Platform
  - Origin Quantum Company
  - Quafu by BAQIS
  - Simulator platform from IHEP
- High Energy Physics
  - Experiment QSVM QCNN QGAN QGNN, QTransformer
  - Theory : Lattice QCD, Simulation of gauge theory
- Other
  - Nuclear Physics, Condensed Matter Physics

- The company has already developed a Quantum Machine Learning framework — VQNet. It supports quantum simulator and quantum hardware.
- The framework already includes many machine learning methods.
- Usefull links : [cloud of OriginQ](#)

## 量子机器学习常用方法分类

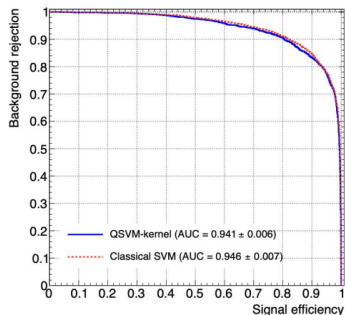
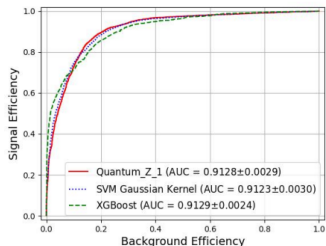


- Link : [quafu cloud](#)
- The new 136 qubit machine is already online!
- User can submit task asynchronously.



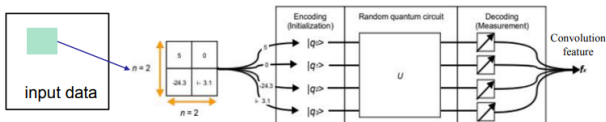
- IHEP simulator is based on the existing GPU and AFS system. It can support the simulator with 38 qubits.
- The platform supports online composer, jupyter and batch system.
- Document : <https://qc.ihep.ac.cn/docs/zh/>
- Website : <https://quantum.ihep.ac.cn>

- Employ quantum kernel to classify signal and background events.
- Currently the performance of QSVM is similar to the classical machine learning algorithm
- Left is BES PID, right is CEPC  $ZH \rightarrow qq\gamma\gamma$

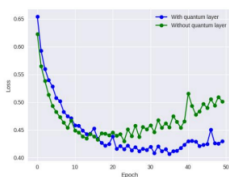
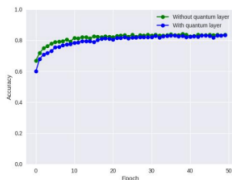


- Utilize the trainable quantum convolution kernel to extract the feature in an image.
- It is used in object identification in STCF DTOF.

❖ 利用可训练的“量子卷积核”提取图像特征，输入经典CNN



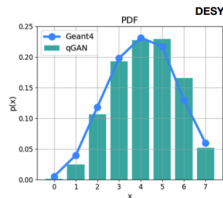
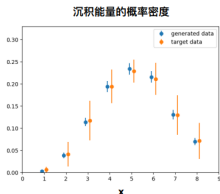
❖ 初步结果



\* 该项工作细节和初步结果将于CHEP2023口头报告

16

- Calorimeter simulation is the most time consuming part of HEP computing especially in future high granularity calorimeter.
- GAN(Generative Adversarial Network) is already used for fast simulation in ATLAS Collaboration.
- QGAN may further improve the accuracy and speed.
- Compared with DESY group, IHEP group already reduces the training time.



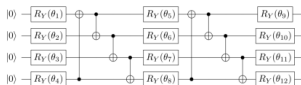
- ⊗ ~30 epoch左右, 损失函数趋于稳定 (DESY: ~100 epoch)
- ⊗ 因为体元的划分不一致, 训练数据的分布和DESY有差别
- ⊗ 量子对抗生成网络可以生成平均的能量分布 (3个量子比特 -> 8个体元)



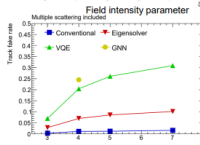
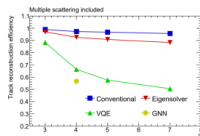
- QGNN is already applied for track reconstruction.
- This project is in collaboration with DESY.
- Quantum annealing machine is interesting.
- Some results are already available.

L.Funcke, T.Hartung, B.Heinemann, K.Jansen, A.Kropf, S.Kühn,  
F.Meloni, D.Spataro, C.Tüysüz, Y.C.Yap, <https://arxiv.org/abs/2202.06874>

## Previous Results from LUXE



- Tracking successfully ran w/ quantum & classical benchmarks
- Classical GNN performance is limited by the training dataset size
- Room for improvement for both GNN & quantum tracking (optimization ongoing)



H. Okawa

IHEP ML Innovation Group Meeti

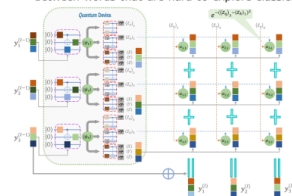
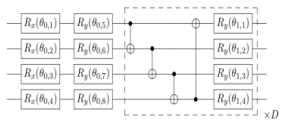
13

- Particle transformer is demonstrated to be powerful in jet tagging in CMS Collaboration.
- It is possible to build a quantum version

## Quantum Self-Attention Neural Networks

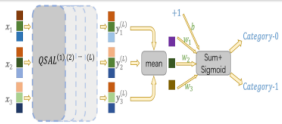
6

- The algorithm is used for text classification. It has the potential advantage of mining hidden correlations between words that are hard to explore classically.

- The algorithm consists of:
  - A quantum self-attention layer
  - A loss function and an analytical gradients
- Classical input used as a rotation angles of Ansatz
- The computed states passed to another Ansatz
- The output query and keys computed using Gaussian function to obtain quantum self-attention coefficients.
- See the [ArXiv: 2205.05625](https://arxiv.org/abs/2205.05625) paper.

- The quantum ansatz circuit on the self-attention



- A series of classical vectors input to the algorithm.
- The classification is performed classically.

## QEM 算法

### 已知:

- 2 比特门的错误率比 1 比特门大很多
- 量子计算机的底层实现, 一般只需要一种 2 比特门, 其他都可以用它构造出来
- 连着放 2 个 CX 门, 理论上会互相抵消

### 模型假设:

- 所有噪声都来自于 CX 门
- 多个 CX 门叠加, 信号以指数形式衰减
- 衰减到完全没有信号的时候, 每个状态是均等的

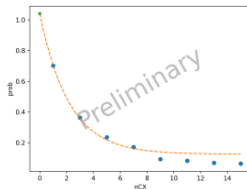
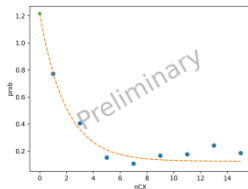
### 算法:

- 把电路中的每个 CX 门分别换成 1 个、3 个、5 个、……个 CX 门, 分别运行
- 把结果对 CX 门的个数进行拟合:

$$(A - 1/2^{n_{bit}})e^{-BN_{CX}} + 1/2^{n_{bit}}$$

- 将拟合结果外推到 CX 门个数为 0 的地方, 得到最终结果

## QEM 实机测试结果：求逆



- Shijie Wei, quantum computing package of nuclei shell model
- Zhenghang Sun, Analog Quantum Simulation Based on Superconducting Quantum Processors
- Yanwu Gu, Noise-resilient phase estimation with randomized compiling

- The workshop is full of fresh results and active discussions between quantum hardware experts, HEP experimentalist and theorist
- Many quantum machine learning algorithms have already been used in HEP and the performance is comparable with classical algorithms.
- With more qubits and better fidelity, we expect better performance of quantum algorithms and more area to use quantum algorithms.