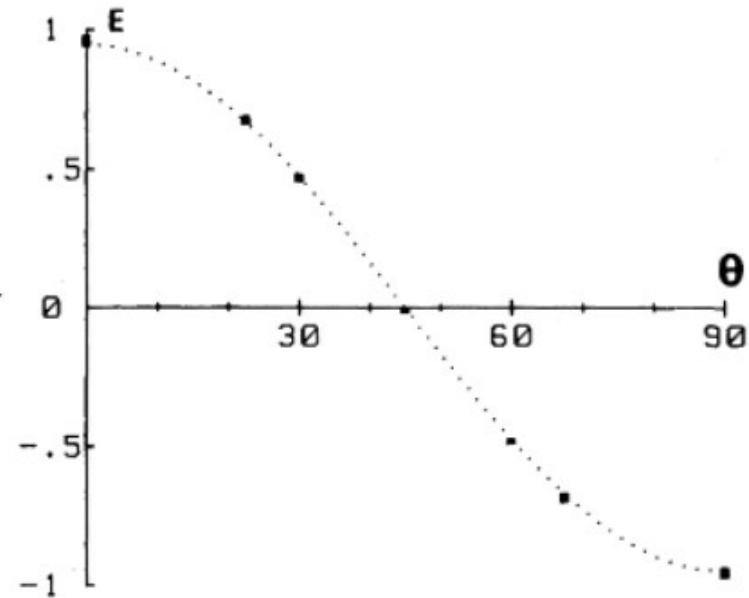
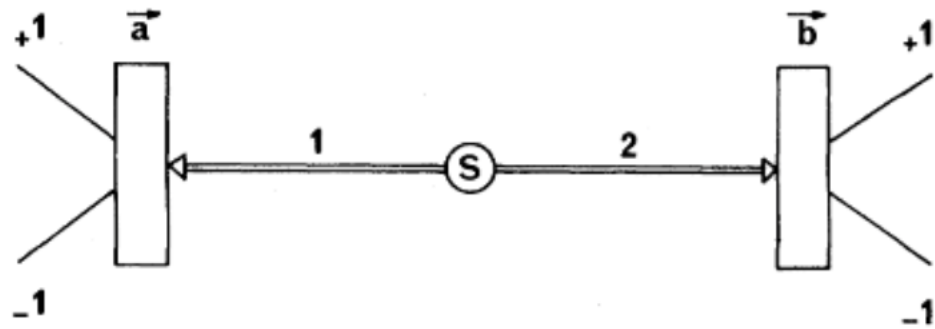


Quantum K-Means Algorithm for Signal Processing of $H \rightarrow ZZ^* \rightarrow 4L$ as Proof of Quantum Entanglement

Daniel Nik Qenani

Dr. Keith Baker (Yale), Dr. Kamal Benslama (LUM)

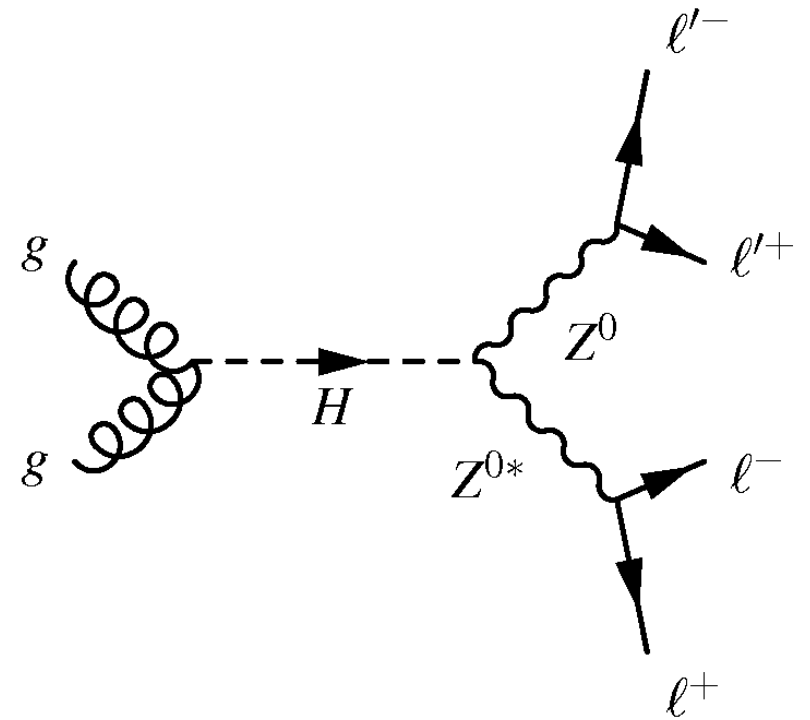
Allen Aspect Quantum Entanglement Experiment



- Bell's Inequality / Violation of Bell's Inequality
- Aspect Experiment

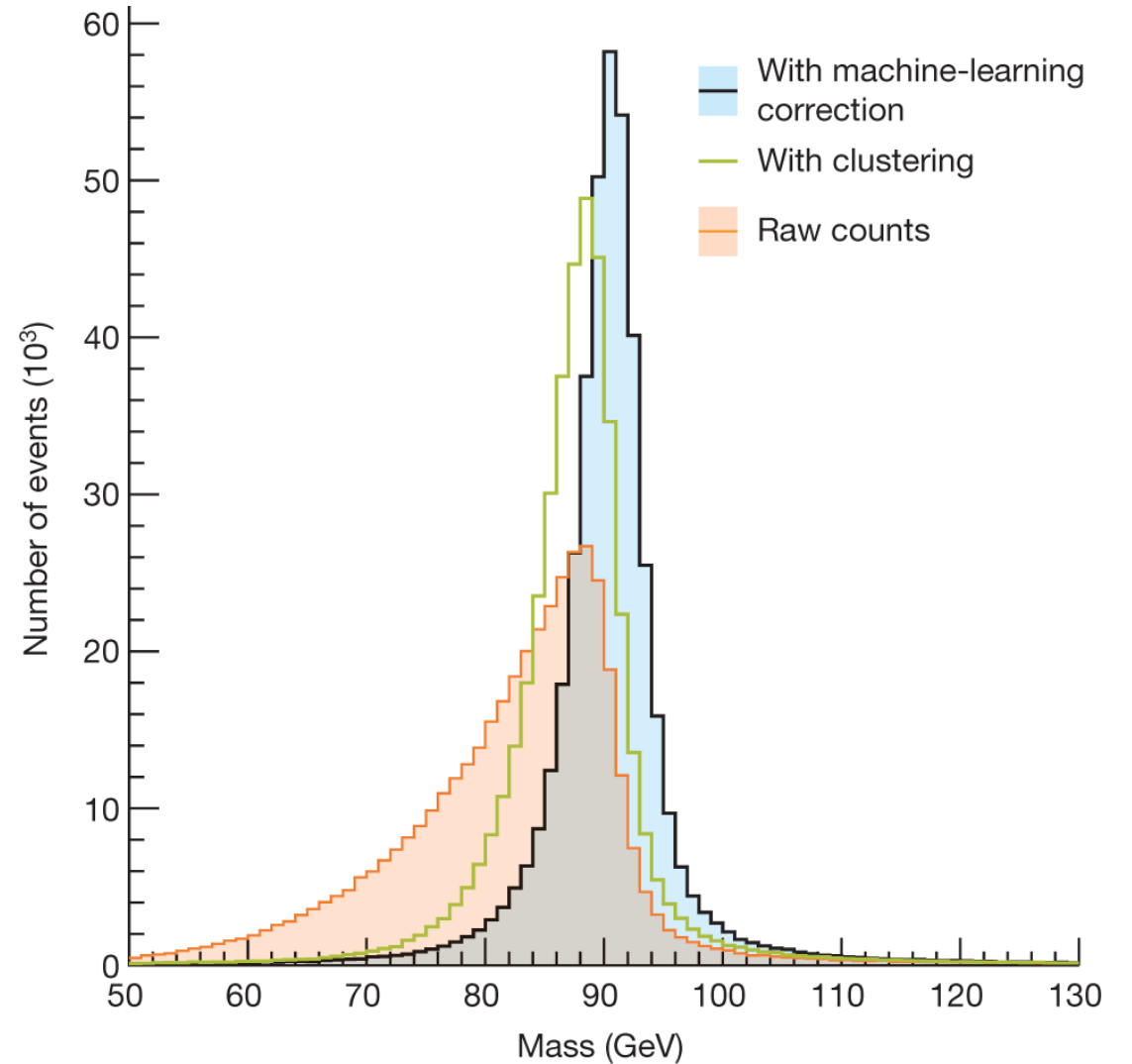
A Reinvention of Allen Aspect's Quantum Entanglement Experiment

- $H \rightarrow ZZ^* \rightarrow 4L$
- New way to violate Bell's Inequality



Signal Processing of Experimental Data

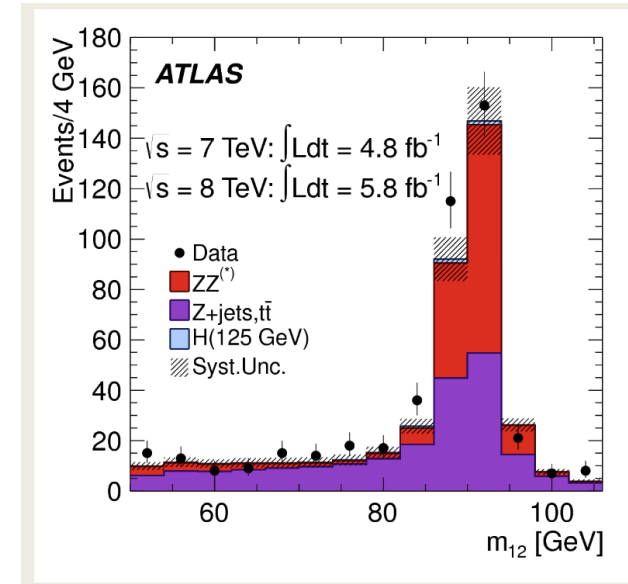
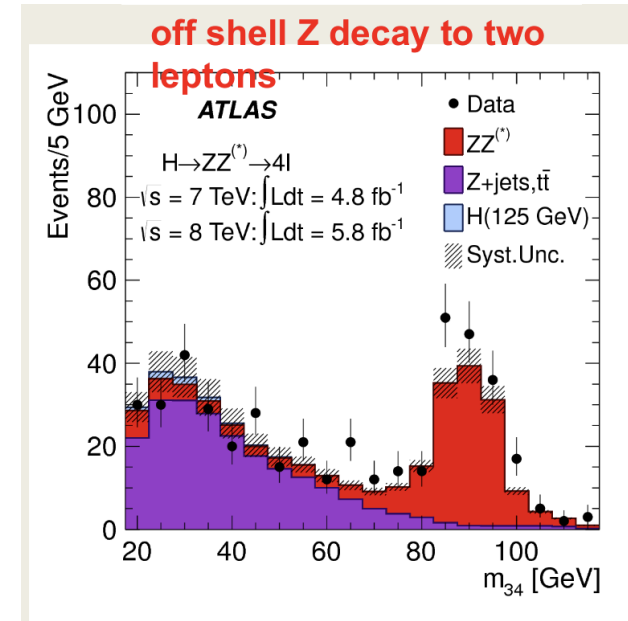
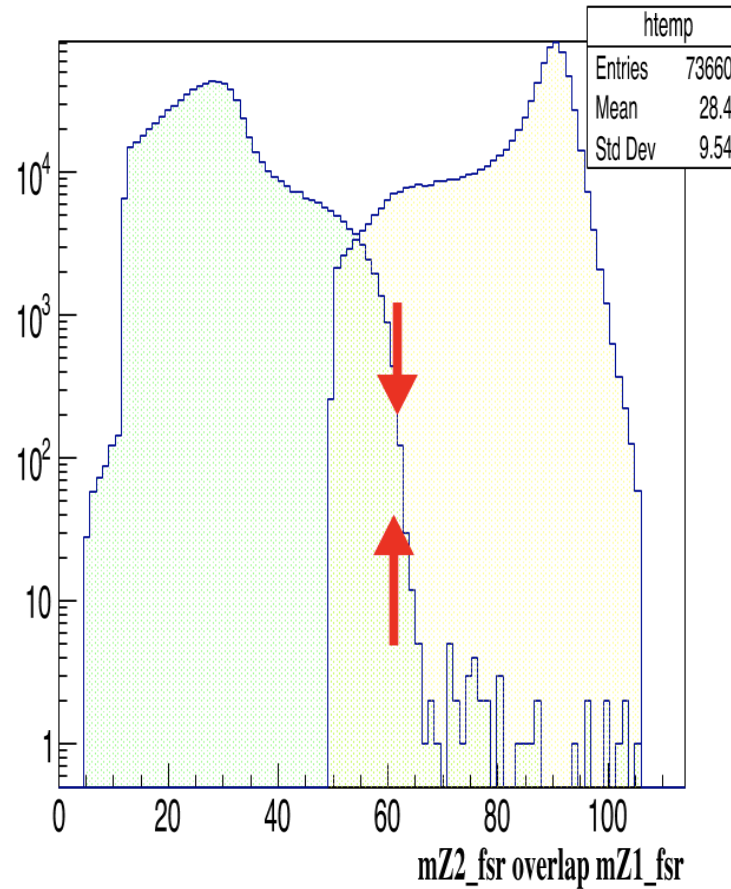
- Signal vs Background (Higgs Decay vs Jets)
- Current Signal Processing Techniques
- Machine Learning and Other New Techniques



Sources of Data

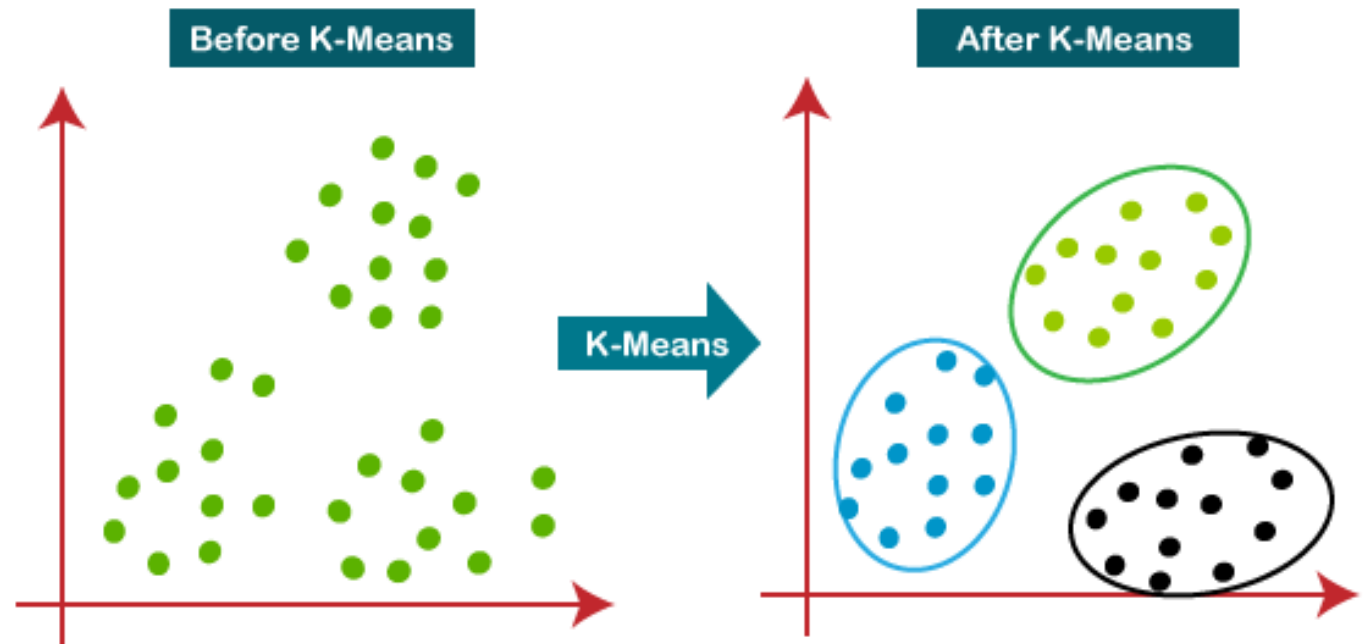
- Monte-Carlo Simulation
- Proton-Proton Collision Data

MC16



K-Means

- Unsupervised Machine Learning Algorithm
- Classical Version



Reduced Quantum K-Means Algorithm

Using PCA for
dimensionality
reduction

Encoding qubits
using cosine
distances

Storing within
distance matrix

Quantum K-Means (Full Algorithm)

Data Encoding

Distance Calculation

Closest Cluster
Assignment

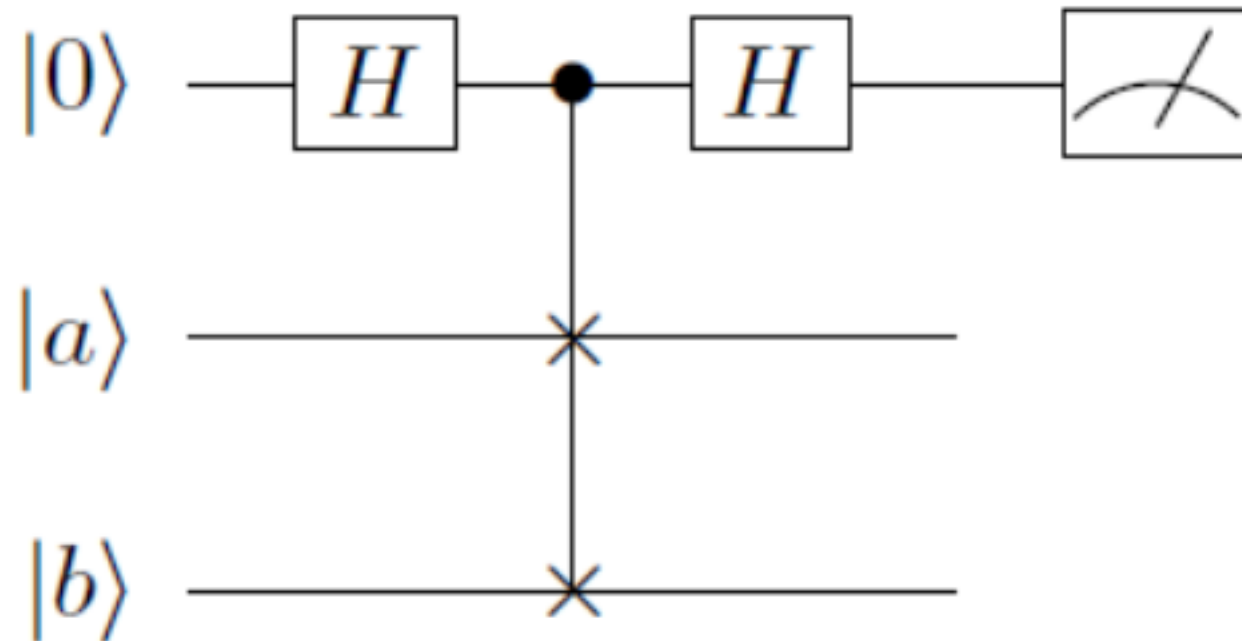
Data Encoding

- Amplitude Encoding
- PennyLane
- Power of using High Dimensionality

$$|a\rangle = \frac{1}{|a|} \sum_{i=1}^d a_i |i\rangle$$

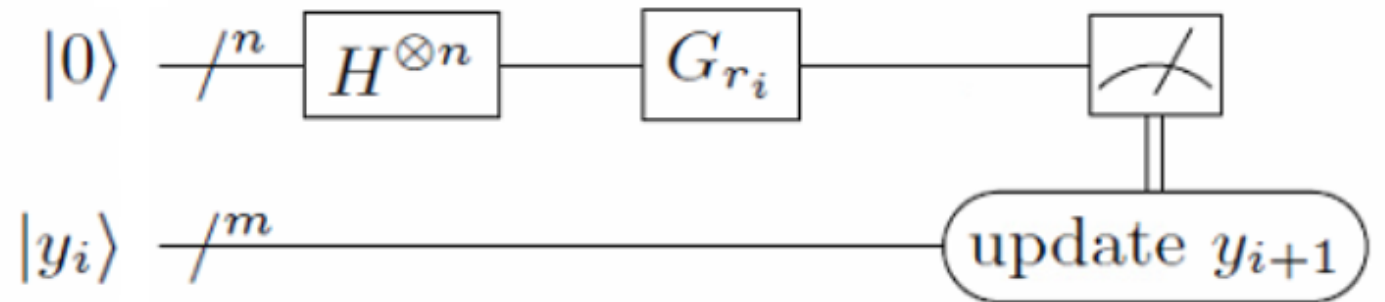
Distance Calculation

SWAPTEST



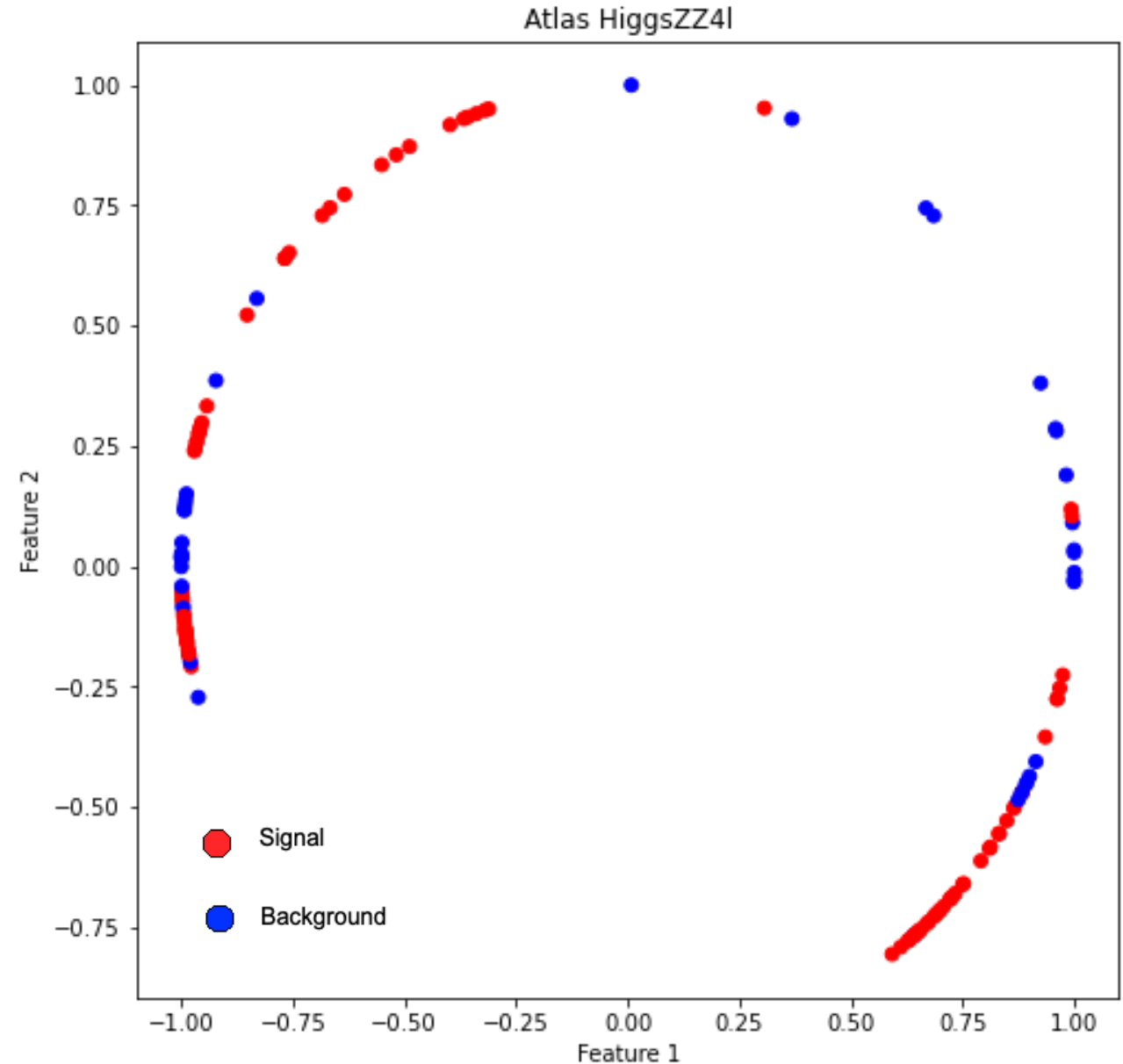
Closest Cluster Assignment

- Quantum Minimization Algorithm
 - Randomly choose a threshold index
 - Mark all the values less than the value at the threshold
 - Perform Grover Search algorithm
 - If result is less than threshold replace threshold index
- Power of the QKM lies in QMA
- Runs $O(\sqrt{N})$

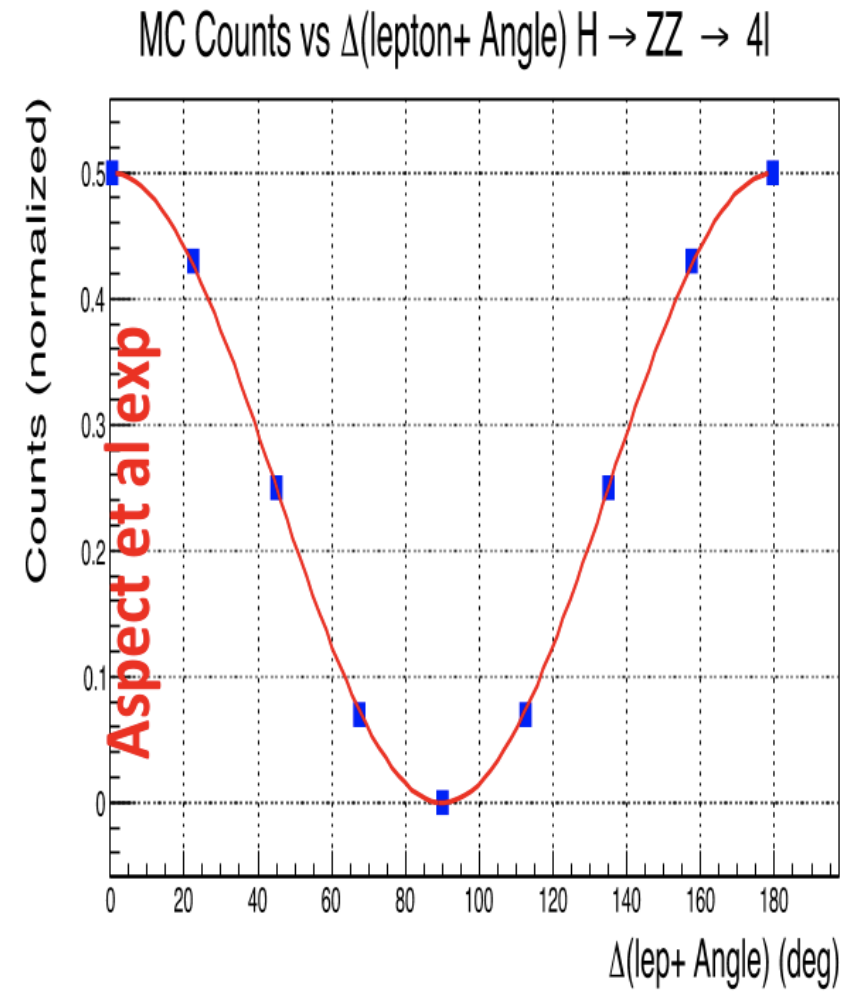


Preliminary Results

- Features: Mass and ETA Distribution
- Data is normalized by the way the quantum states are programmed



More Preliminary Results



Future of Quantum Algorithms in HEP

- Signal Processing
- Going Beyond the Standard Model (Dark Matter, Dark Energy, etc.)

Acknowledgments

- I would like to thank my advisor Dr. Keith Baker and collaborator Dr. Kamal Benslama for all their help throughout