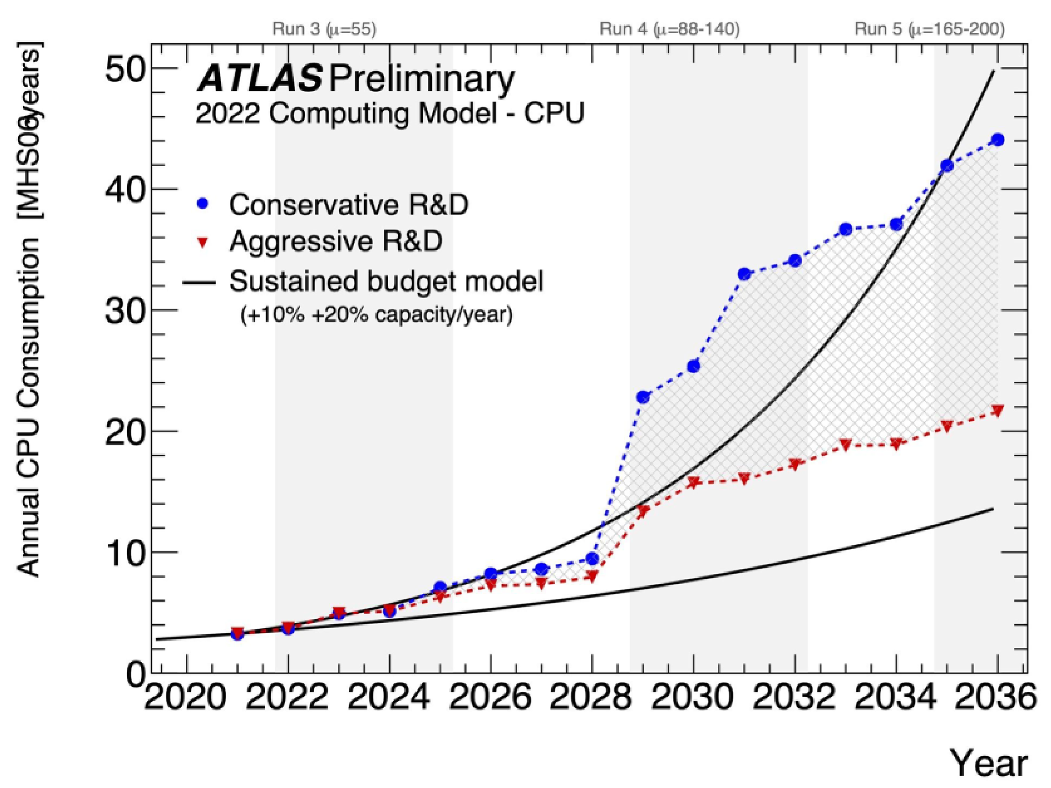
Simulating High Energy Particle Calorimeter Interactions Using 4-Partite Quantum-Assisted Variational Autoencoders

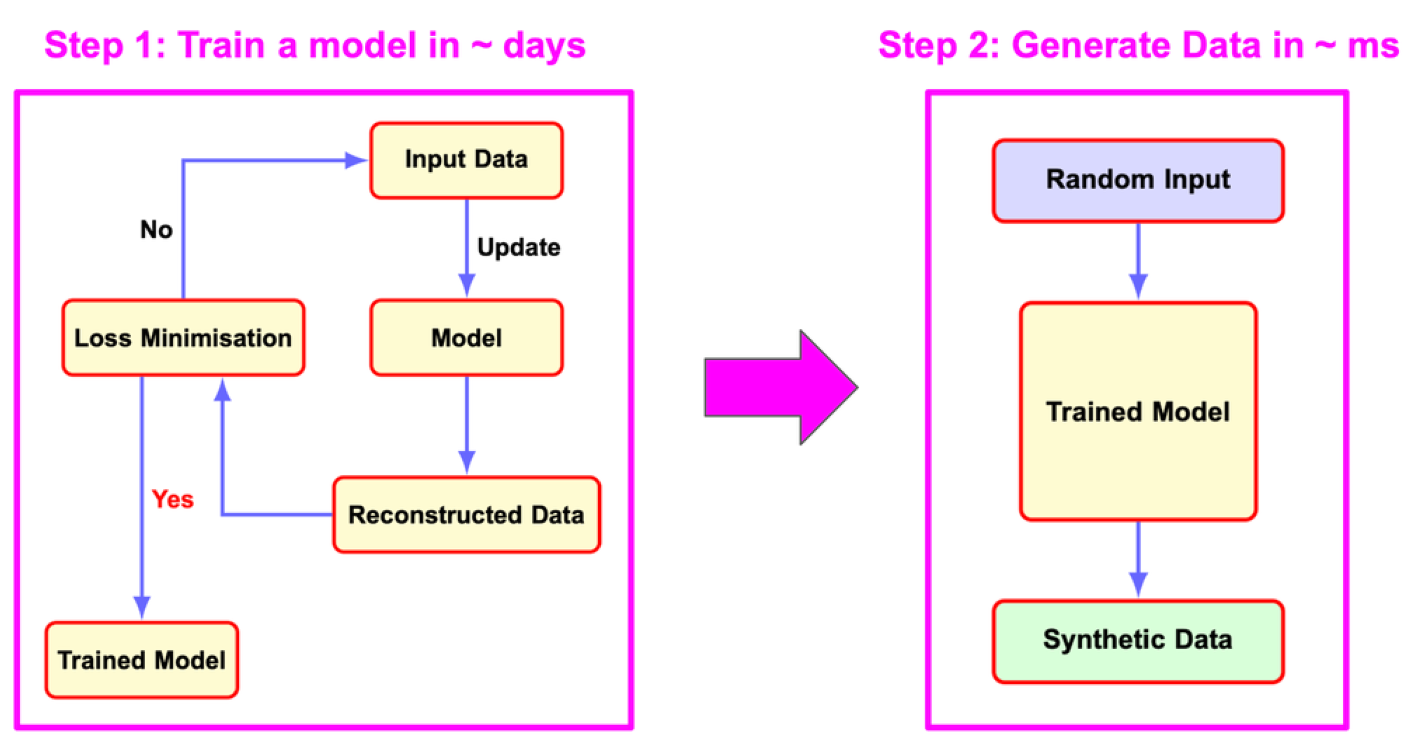
Hao Jia, (To be added)

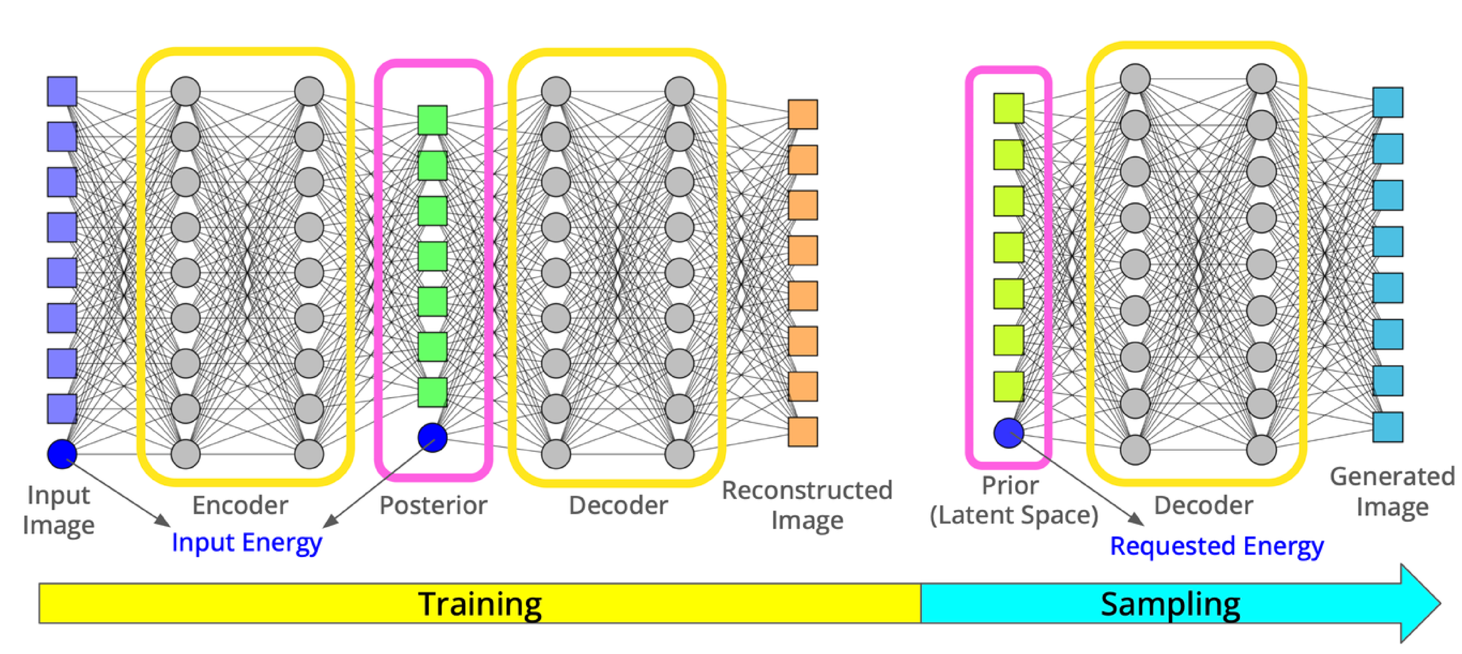
Motivation

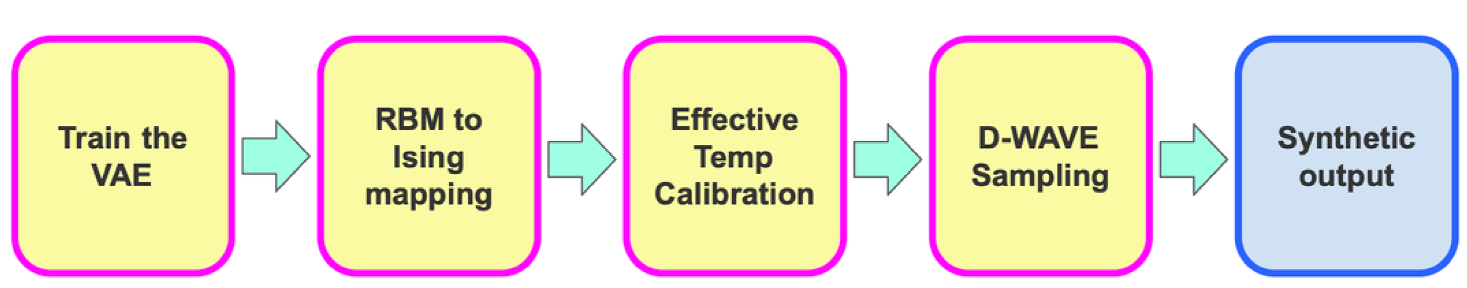


- Current techniques for Calorimeter shower simulation are computationally expensive
- Development of faster, computationally cheaper detector simulation techniques required for HL-LHC

Methodology







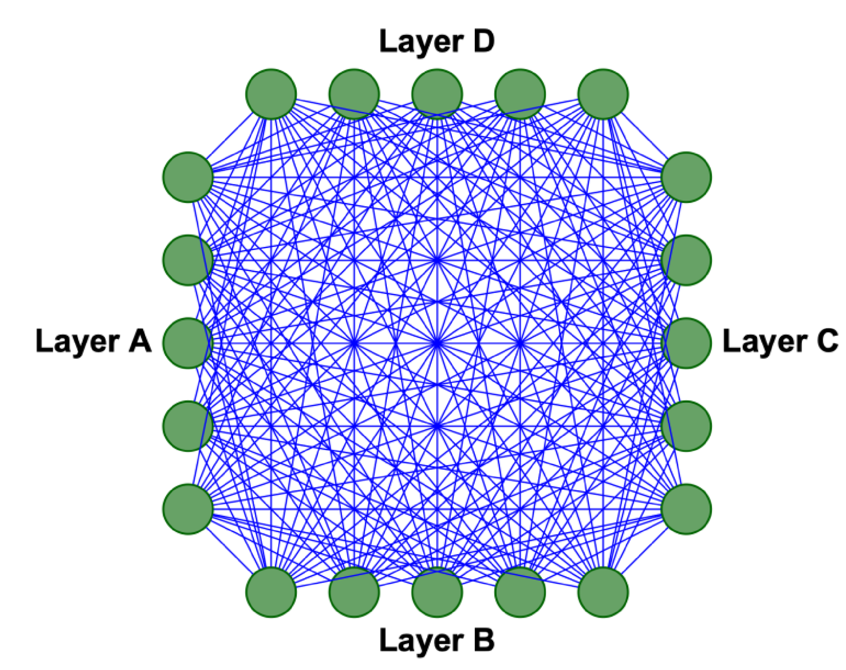
CONCLUSION

- We have shown that it is possible to utilize the Quantum Processing Unit for generating Restricted Boltzmann Machine samples, which facilitate the generation of particle showers.
- Quantum Processing Unit sampling offers the potential to go significantly faster than traditional Monte Carlo methods, maintaining high-quality shower image generation.

[1] https://docs.dwavesys.com/docs/latest/c_gs_2.html

Principle

Four Partite Restricted Machine



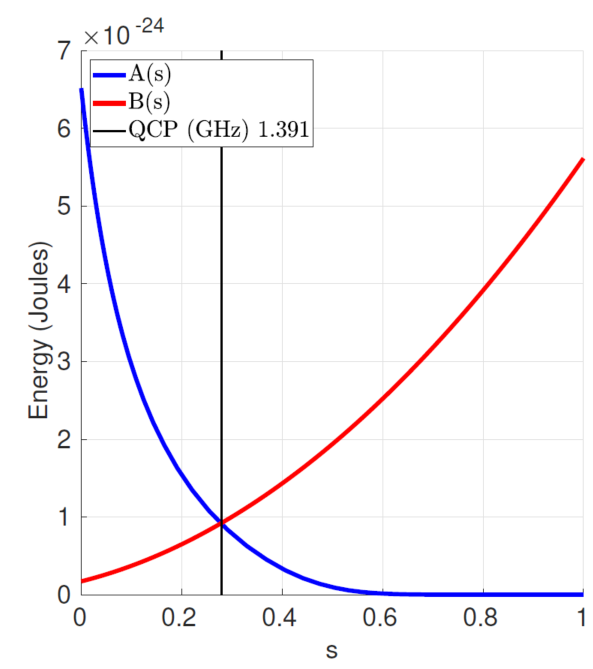
A four-partite Restricted Boltzmann Machine (RBM), featuring a four-layer architecture with binary-valued nodes(0 or 1) across each layer. These nodes, representing 'on' or 'off' states of dataset features, are interconnected across layers, but not within the same layer. Each node includes a bias, and connections are defined by weights, enhancing the model's ability to learn data patterns.
As an energy based model, the RBM energy is defined by:

$$E(x) = -\sum_{\substack{\rho,\sigma\in\{a,b,c,d\}\\ \rho\neq\sigma}} \sum_{i,j} w_{ij}^{\rho\sigma} x_i^\rho x_j^\sigma - \sum_{\rho\in\{a,b,c,d\}} \sum_i b_i^\rho x_i^\rho$$

with the possibility distribution for a specific state:

$$P(x) = \frac{1}{Z} e^{-E(x)}, \quad \text{where } Z = \sum_x e^{-E(x)}$$

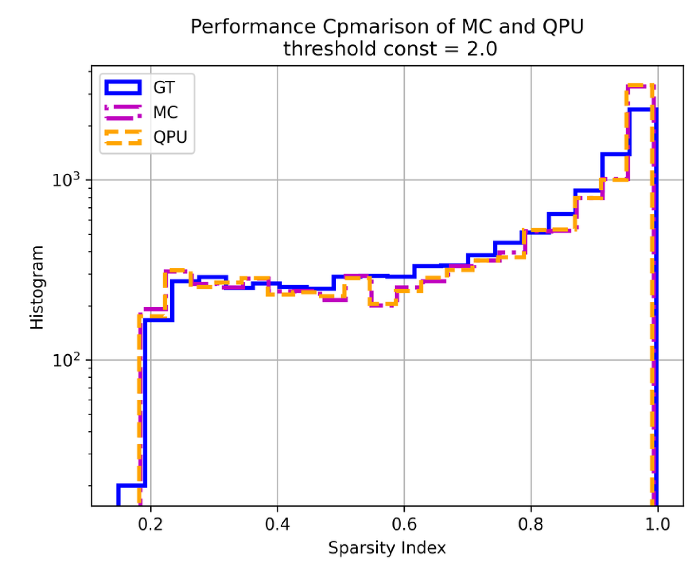
Quantum Annealing

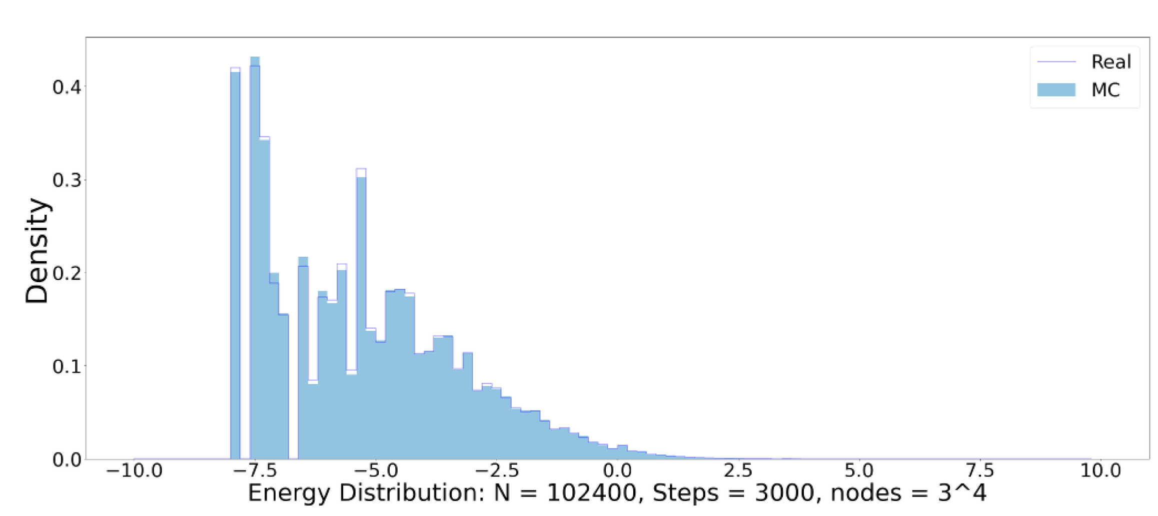


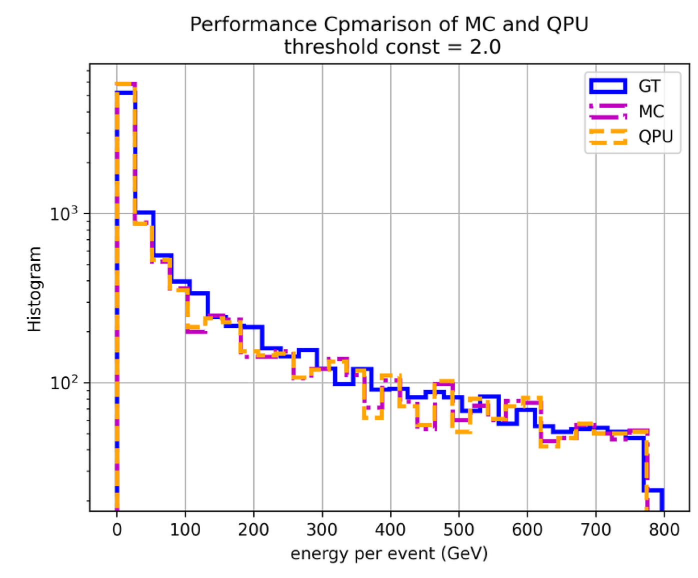
Initially, qubits exist in a superposition of -1 and 1 without entanglement. Through quantum annealing, couplers and biases entangle the qubits, creating a complex entangled state representing multiple potential solutions. As annealing concludes, qubits settle into a classical state, embodying the problem's lowest energy configuration. Here is the Hamiltonian during quantum annealing process:

$$\mathcal{H}(s) = A(s)\sum_l \sigma_l^x + B(s)\left[\sum_l \sigma_l^z h_l + \sum_{l<m} J_{lm}\sigma_l^z\sigma_m^z\right]$$

Results







Type	Monte Carlo	QPU Annealing	Total QPU Access
Time per sample	>500 µs	20µs	176µs