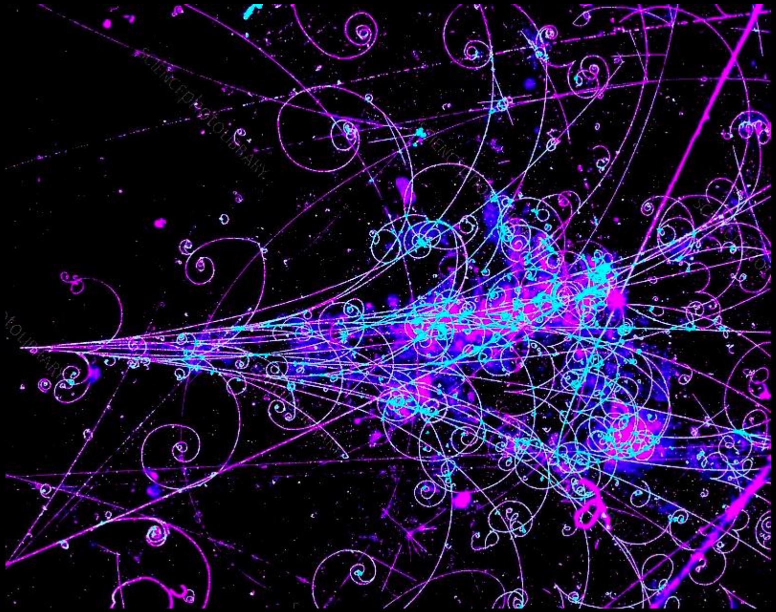


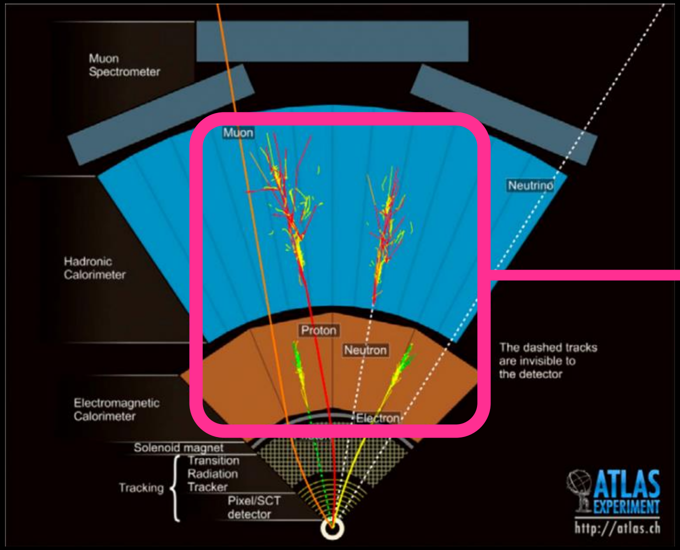
Towards Calorimeter Data Generation with Quantum Variational Autoencoders

Abhishek Abhishek, Eric Drechsler, Wojtek Fedorko

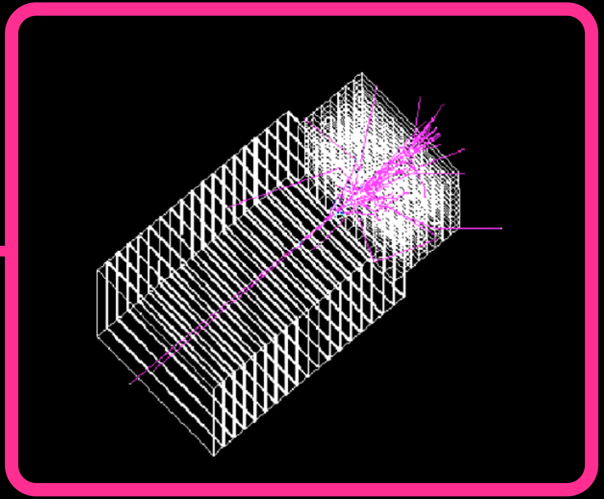
TRIUMF Science Week, 16. August 2021

SFU
ATLAS EXPERIMENT
TRIUMF

HL-LHC Computing Bottleneck: Calorimeter Shower Simulation

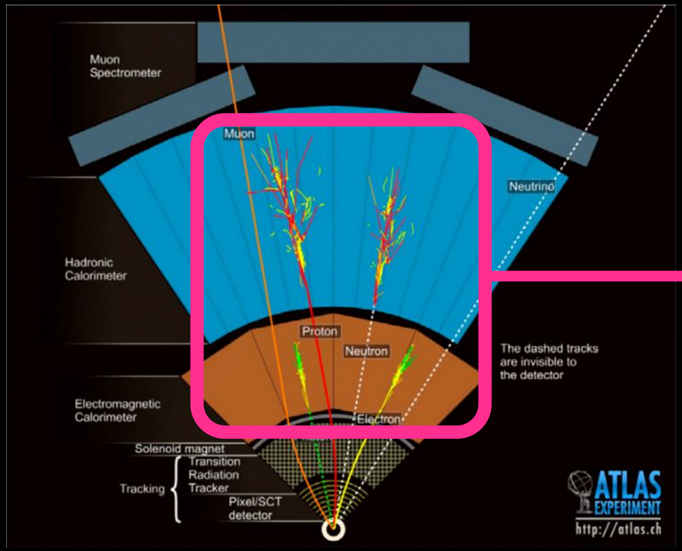


Cross-section ATLAS Detector

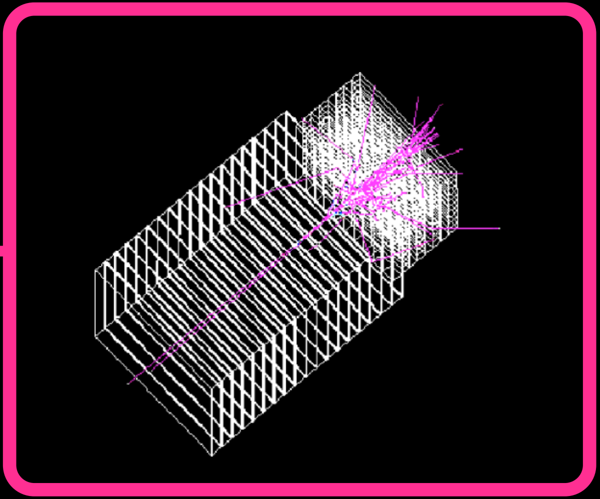


Representation of single
GEANT4 simulated EM shower

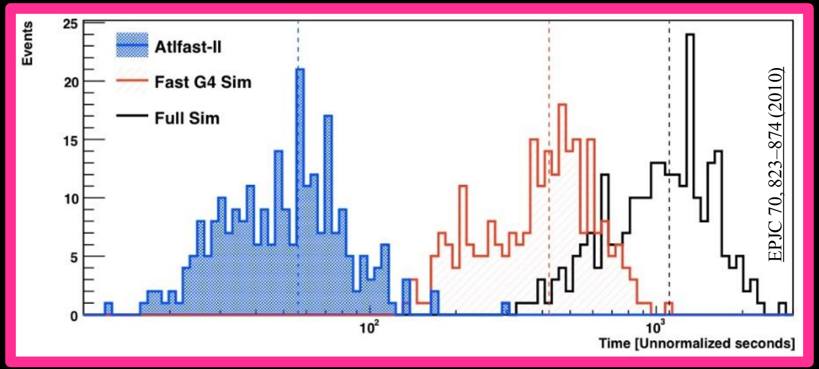
HL-LHC Computing Bottleneck: Calorimeter Shower Simulation



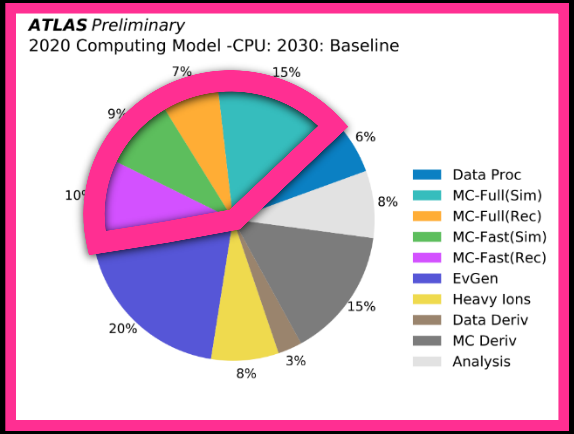
Cross-section ATLAS Detector



Representation of single GEANT4 simulated EM shower

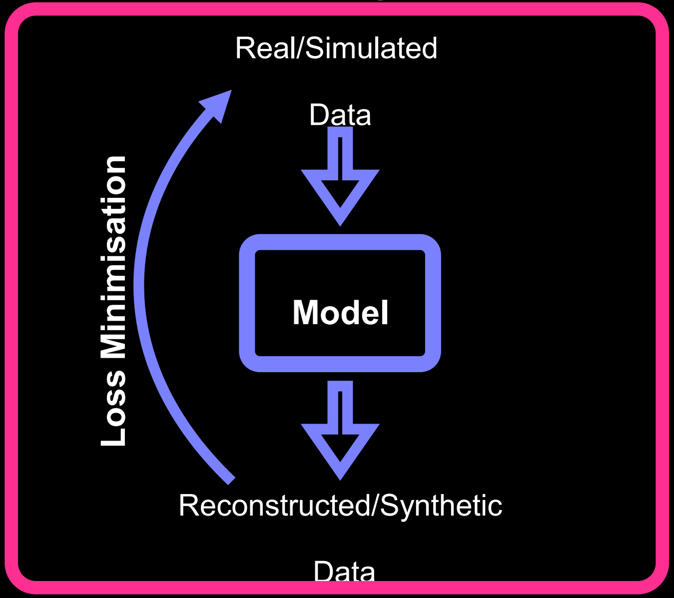


CPU time for simulating 250 ttbar events



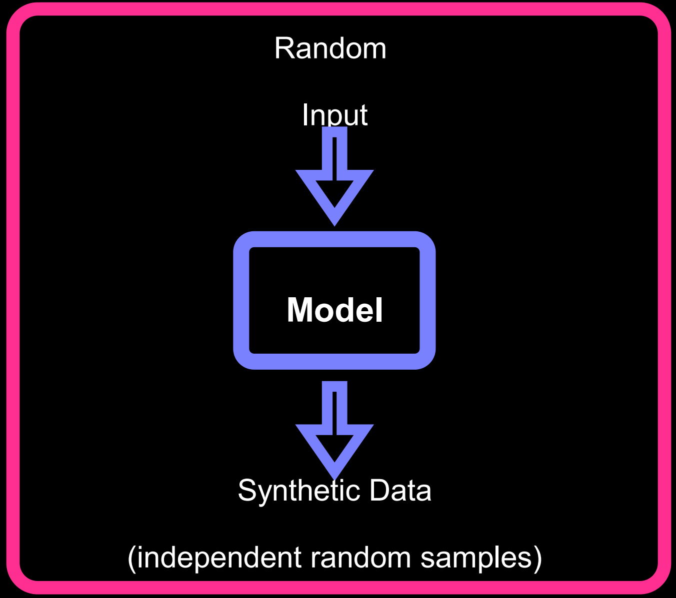
Generative Models for Synthetic Shower Generation

Step 1: Training the Model



~ hours

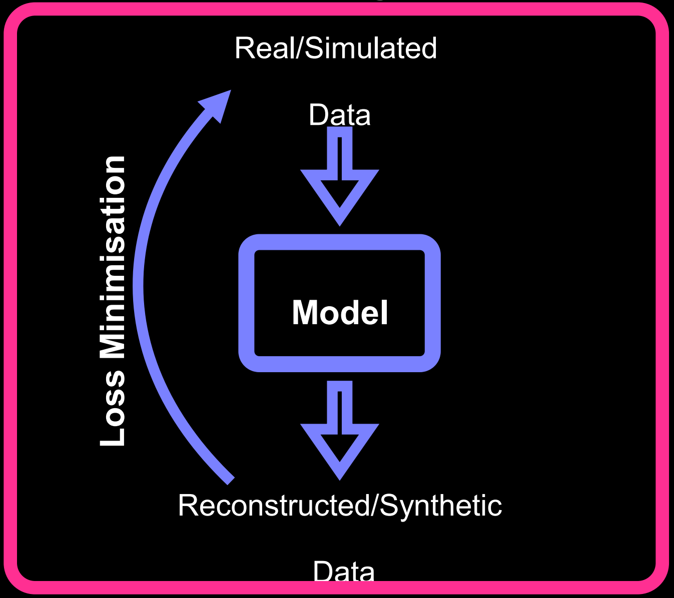
Step 2: Generating Synthetic Data



~ milliseconds

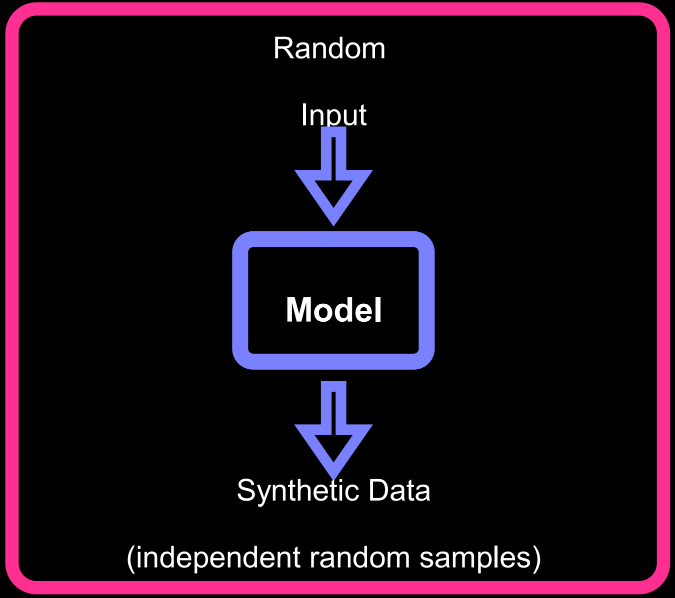
Generative Models for Synthetic Shower Generation

Step 1: Training the Model



~ hours

Step 2: Generating Synthetic Data

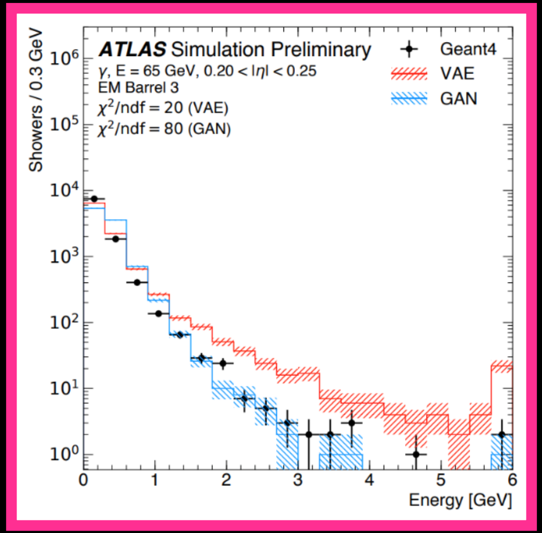


~ milliseconds

Example: Variational Autoencoder trained with modified loss

$$\mathcal{L}(x, x'; \theta, \phi) = w_{\text{reco}} \mathbb{E}_{\zeta \sim q_\phi(\zeta|x)}[\log p_\theta(x|\zeta)] - w_{\text{KL}} D_{\text{KL}}[q_\phi(\zeta|x) || p_\theta(\zeta)]$$
$$- w_{E_{tot}} \left| \sum_i x_i - \sum_i x'_i \right| - \sum_l w_l \left| \frac{1}{E_{tot}} \sum_j^{N_l} x_j - \frac{1}{E'_{tot}} \sum_j^{N_l} x'_j \right|$$

Total Energy **Energy per layer**

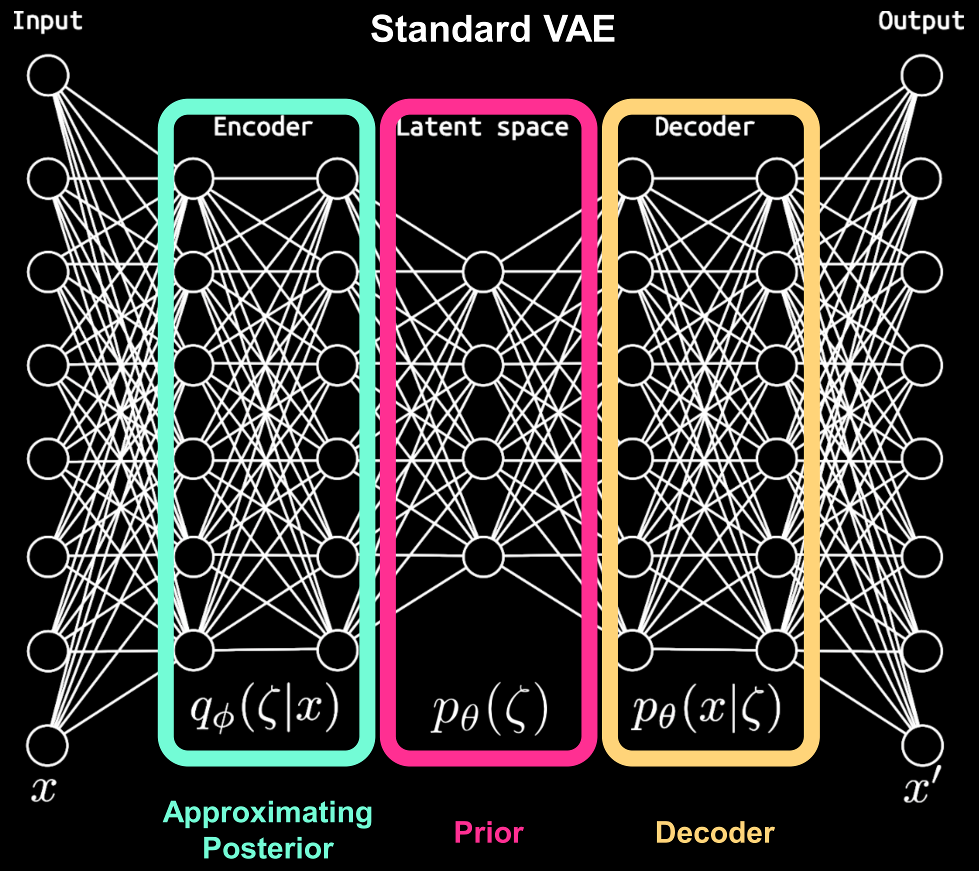


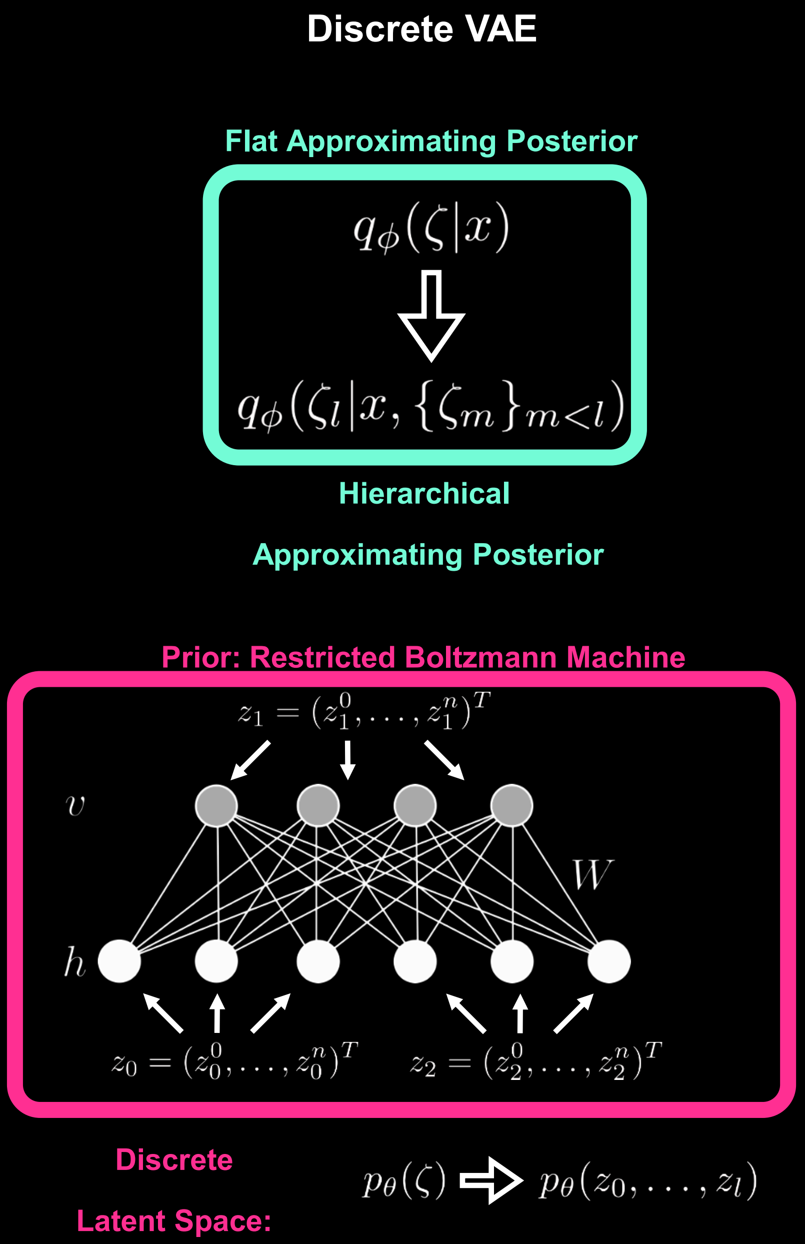
ATL-SOFT-PUB-2018-001

A. Abhishek, Eric Drechsler, Wojtek Fedorko, *Calorimeter Shower Generation with QVAE*, 16. August 2021

Discrete Variational Autoencoders

arxiv:1609.02200

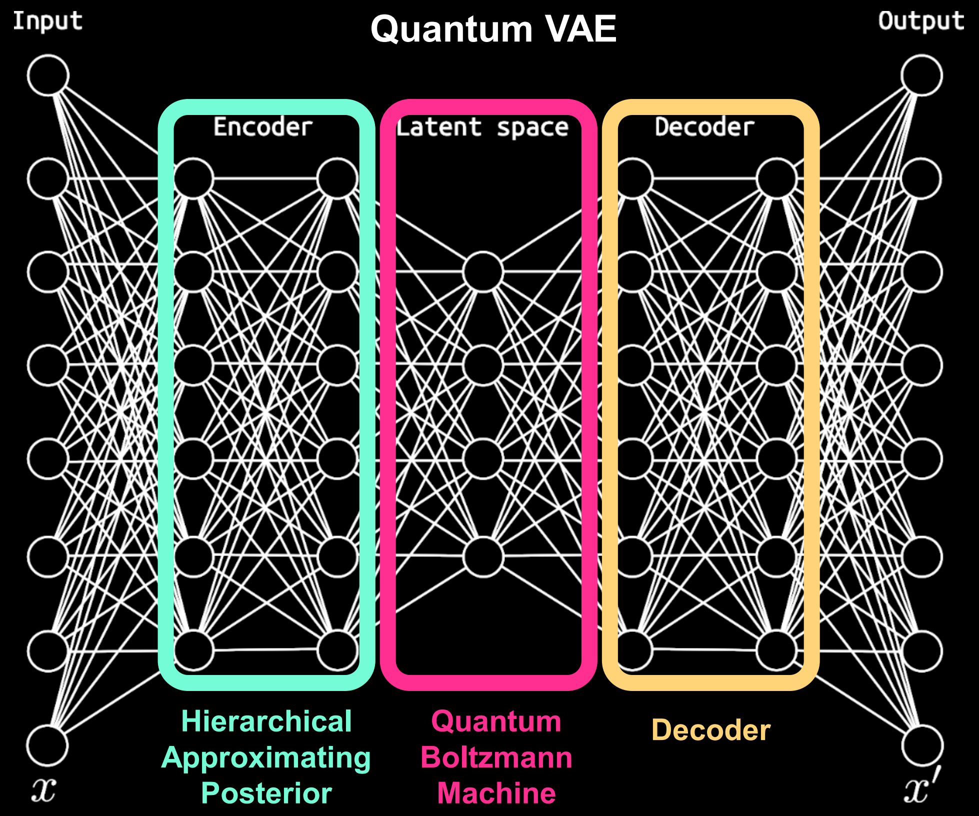




Quantum Variational Autoencoders

arxiv:1802.05779

Quantum VAE



Hierarchical Approximating Posterior

Quantum Boltzmann Machine

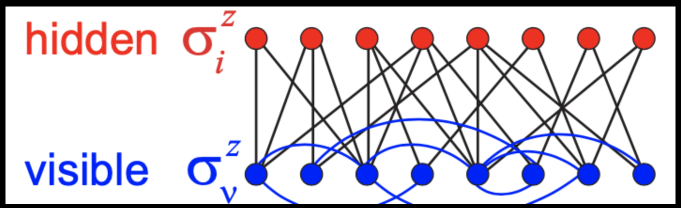
Decoder

$$q_\phi(\zeta_l | x, \{\zeta_m\}_{m<l})$$

$$p_\theta(z) = \frac{1}{Z_\theta} \mathrm{Tr}[\Lambda_z e^{-\mathcal{H}_\theta}]$$

Prior: Quantum Boltzmann Machine

qbits on DWave QPU



Restricted BM

State Probability $$p_\theta(v,h) = \frac{1}{Z_\theta} \exp[-E_\theta(v,h)]$$

State Energy $$E_\theta(v,h) = -\sum_{i=0}^{D}\sum_{j=0}^{M} W_{ij} v_i h_j - \sum_{j=0}^{D} b_i v_i - \sum_{j=0}^{M} a_j h_j$$

Quantum BM

State Probability $$p_\theta(z) = \frac{1}{Z_\theta} \mathrm{Tr}[\Lambda_z e^{-\mathcal{H}_\theta}]$$

State Energy $$\mathcal{H}_\theta = \sum_l \sigma_l^x \Gamma_l + \sum_l \sigma_l^z h_l + \sum_{l<m} W_{lm} \sigma_l^z \sigma_m^z$$

A. Abhishek, Eric Drechsler, Wojtek Fedorko, *Calorimeter Shower Generation with QVAE*, 16. August 2021