Fast and Accurate Electromagnetic and Hadronic Showers from Generative Models

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Introduction

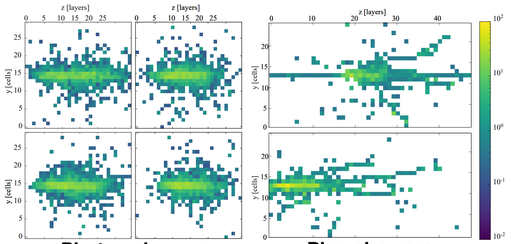
Particle colliders probe interactions of fundamental particles
- Need Monte Carlo (MC) simulation to compare to experiment
- Amount of simulated data should match recorded data

Full simulation very time consuming
- Will become bottleneck in the future
- Faster, more time efficient simulation methods required
- Turn to generative Machine Learning methods
- Train on classical simulation, evaluate orders of magnitude faster

Training Dataset

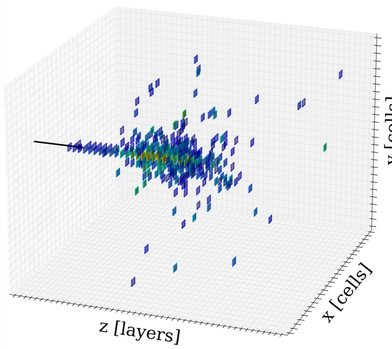
Particles interact with detector material
- Deposit energy
- Split into further particles

➡ Particle avalanche
➡ Shower



Photon showers 30x30x30 **Pion showers 25x25x48**

Calorimeters based on proposed International Large Detector (**ILD**) for International Linear Collider (**ILC**)
Photons: Homogenous shaped showers in EM calorimeter
Pions: Hadronic calorimeter showers with diverse shape profiles

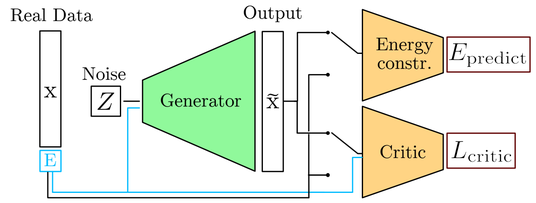


BIB-AE generated Pion shower

Training sets simulated by **Geant 4**
- 1M Photon showers
- 500k Pions showers
- Constant impact points
- Constant impact angle
- Particle energy [10, 100] GeV
- Projected onto regular grid
  - 30x30x30 for Photons
  - 25x25x48 for Pions
- Examples available on Zenodo:

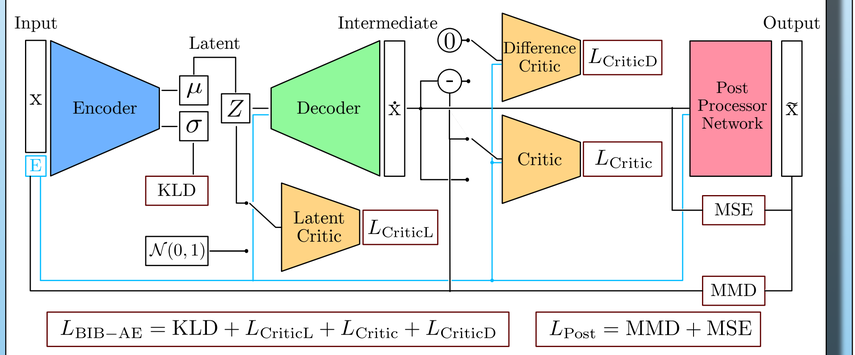
Photons: **Pions:**

Generative Models



Wasserstein Generative Adversarial Network
- Use Wasserstein-1 distance as a loss
- Second network to constrain energy

Bounded Information Bottleneck AutoEncoder
- It unifies features of GANs and AutoEncoders [1]
- Additional Post-Processor network [2] trained in second step
- Buffer VAE-like [3] latent sampling via multi-dimensional Kernel Density Estimation (KDE) [4]



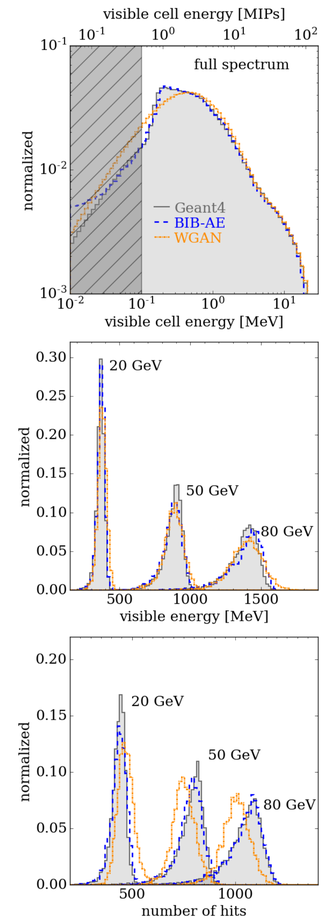
Computational Speed-up

Hardware	Simulator	Photons		Pions	
		Time/shower[ms]	Speed-up	Time/shower[ms]	Speed-up
CPU	Geant4	4082±170	×1	2684±125	×1
	WGAN	61.44±0.03	**×66**	47.923±0.089	**×56**
	BIB-AE	95.98±0.08	**×43**	350.824±0.574	**x8**
GPU NVIDIA V100	WGAN	3.93±0.03	**×1039**	0.264±0.002	**x10167**
	BIB-AE	1.60±0.03	**×2551**	2.051±0.005	**×1309**

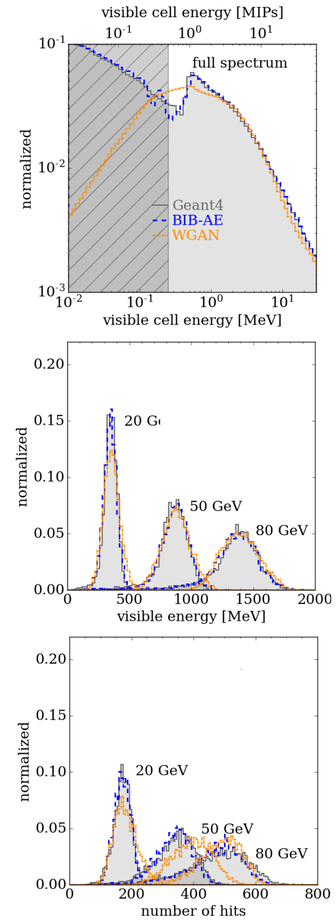
Results

- Generative Models need to reproduce overall properties of data
- Compare physical observables to validation set, for example:
  - Visible cell-energy spectrum
  - Visible energy as function of particle energy
  - Number of hits as function of particle energy

Photons



Pions



References

[1]: 1912.00830 [3]: 1901.00875
[2]: 2005.05334 [4]: 2102.12491

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