Generative Models for Particle Shower Simulation

E. Buhmann, S. Diefenbacher, E. Eren, F. Gaede, D. Hundhausen, G. Kasieczka, W. Korcari, A. Korol, K. Krüger, P. McKeown and L. Rustige

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

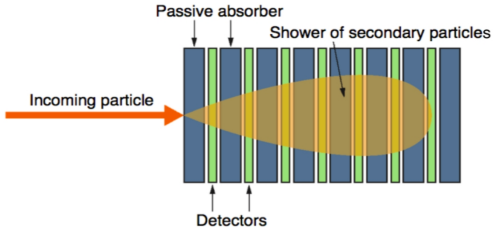
CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

HELMHOLTZ SPITZENFORSCHUNG FÜR GROSSE HERAUSFORDERUNGEN

DESY.

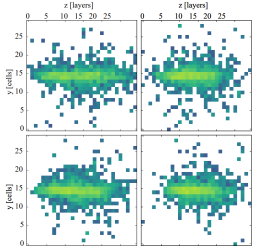
Introduction

- Precise simulations of interactions between particles and complex detectors via GEANT4 are a prerequisite for doing modern particle physics
- However, these simulations are computationally **costly**
  - Dominated by *calorimeter* simulations
  - Becoming more complex due to highly granular calorimeters
    - Potential bottleneck for future experiments
- Use generative machine learning to produce **fast** surrogate models

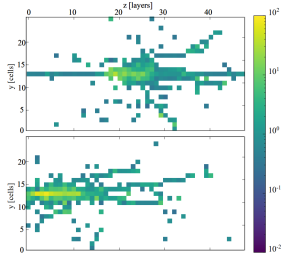


Training Data

- Consider for the first time more challenging hadron showers in a highly granular hadronic calorimeter
- Why are hadronic showers more challenging ?
  - Governed by hadronic **and** EM interactions
  - Complex structure
  - Large event-to-event fluctuations



Cell Layout: 30 x 30 x 30 (Photon showers)



Cell Layout: 48 x 25 x 25 (Charged pion showers)

Generative Models

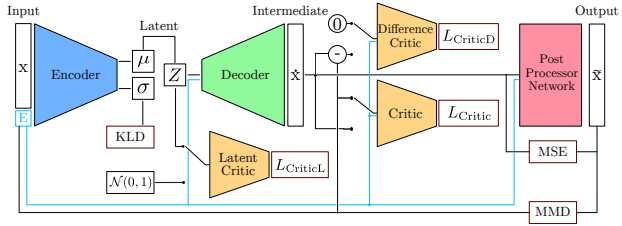
We train and evaluate Generative Adversarial Network (GAN) optimizing a Wasserstein loss (WGAN) and Bounded-Information Bottleneck Autoencoders (BIB-AE)

Wasserstein GAN

- Alternative to classical GAN training [1]:
  - Helps improve the stability of the training
  - Use Wasserstein-1 distance as a loss with gradient penalty

BIB-AE and Post-Processor

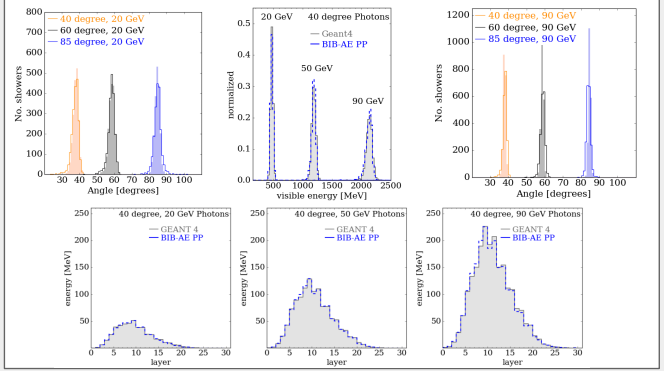
- Unifies features of GANs and Autoencoders [2]



$$L_{\text{BIB-AE}} = \text{KLD} + L_{\text{CriticL}} + L_{\text{Critic}} + L_{\text{CriticD}} \qquad L_{\text{Post}} = \text{MMD} + \text{MSE}$$

Results on Photon Showers

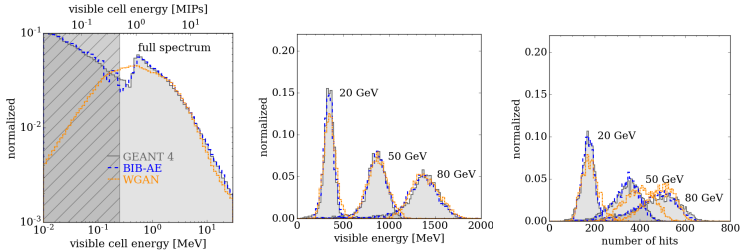
- Need to compare differential distributions of physics quantities between ground truth (GEANT4) and BIB-AE with incident angle conditioning (**new!**)



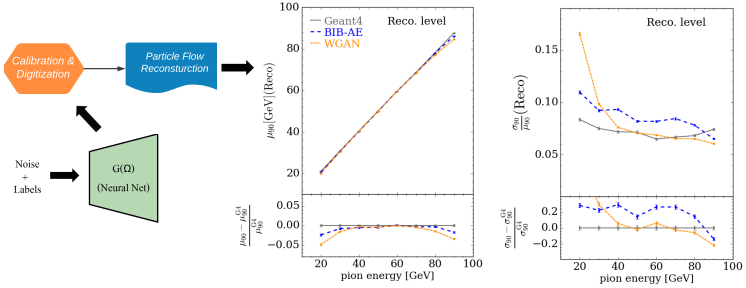
Results on Pion Showers

- Differential distributions of physics quantities
- First to achieve this level of precision in a highly granular hadron calorimeter [3]

Generator Level



Reconstruction Level



Computational Performance

Major goal to speed-up the sampling process: observe speed-ups of up to four orders of magnitude on GPU

Hardware	Simulator	Time / Shower [ms]	Speed-up
CPU	GEANT4	2684 ± 125	$\times 1$
	WGAN	47.923 ± 0.089	$\times 56$
	BIB-AE	350.82 ± 0.57	$\times 8$
GPU	WGAN	0.264 ± 0.002	$\times 10167$
	BIB-AE	2.051 ± 0.005	$\times 1309$

References

[1] arXiv:1701.07875
[2] arXiv:1912.00830
[3] arXiv:2112.09709

engin.eren@desy.de

GitHub