Validation of GANs for High Energy Physics Simulations

AAAI-MLPS 2021 Spring Symposium

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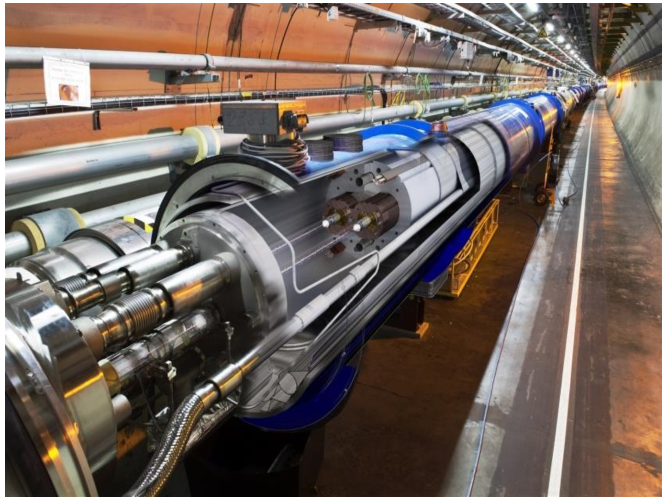
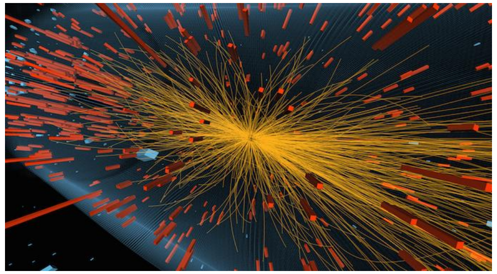
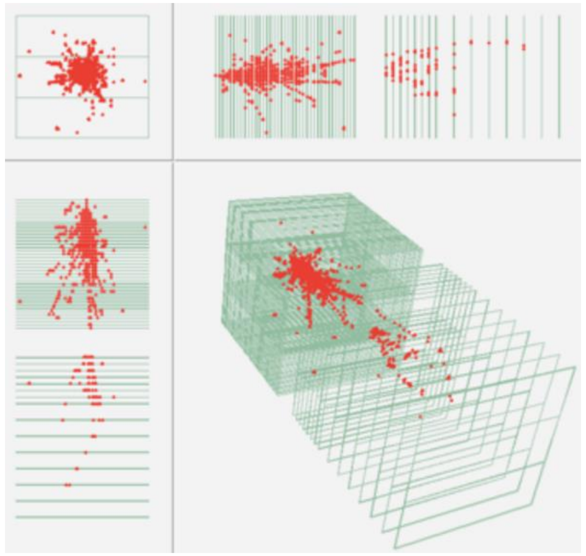
23.03.2021

Calorimeter Detectors



- Particle physics studies the fundamental properties and interactions of (novel) elementary particles.
- Particles are colliding with highest energy to produce know and novel particles.
- Calorimeter detectors measure the energy of particles produced in the collisions.
- The entering particle produces a cascade of shower particles which are absorbed and detected.



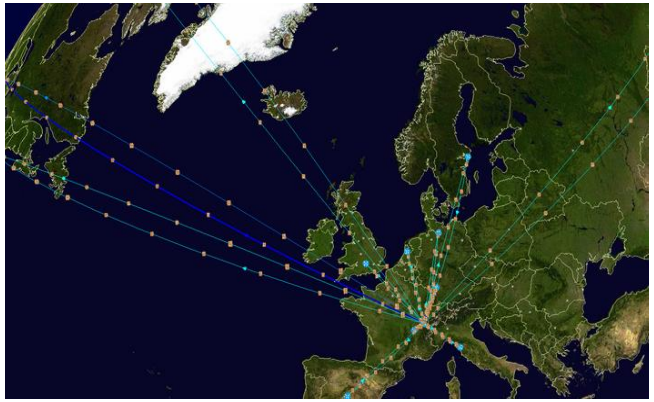


Calorimeter Simulations

- Calorimeter simulations are based on Geant4
- Geant4 use about 50% of the resources of the worldwide LHC grid
- LHC high luminosity phase requires 100 times more simulated data*

→ **Develop a new approach which occupies less resources**

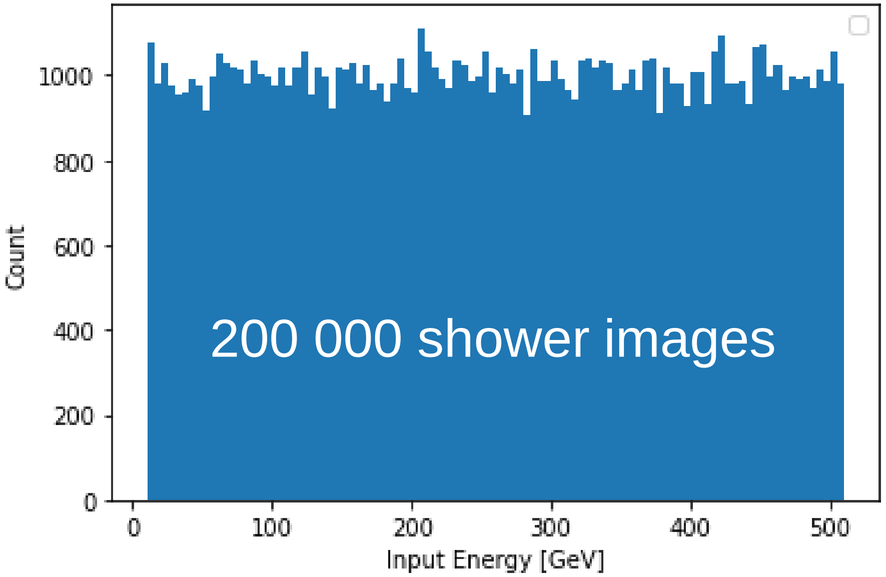
→ **Employ deep learning**

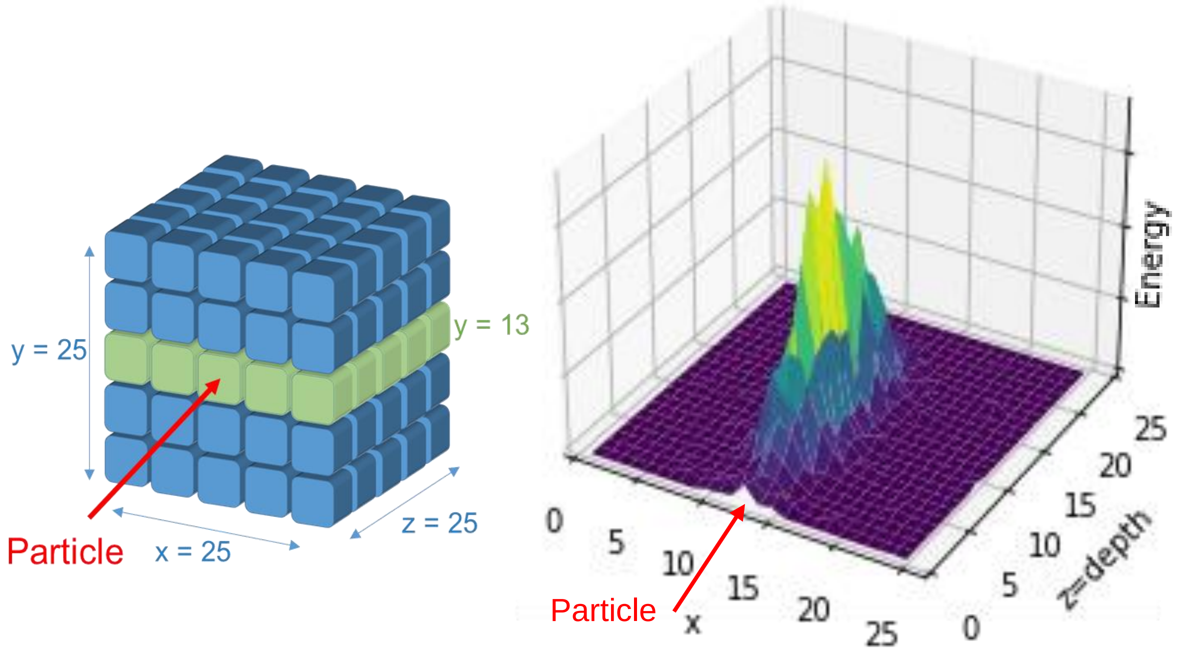


*A Roadmap for HEP Software and Computing R&D for the 2020s https://doi.org/10.1007/s41781-018-0018-8

3D Training Data

- Interpretation of the calorimeter outputs as images
- 3D shower image granularity: 25x25x25
- Energies between 2-500 GeV





Generative Adversarial Networks

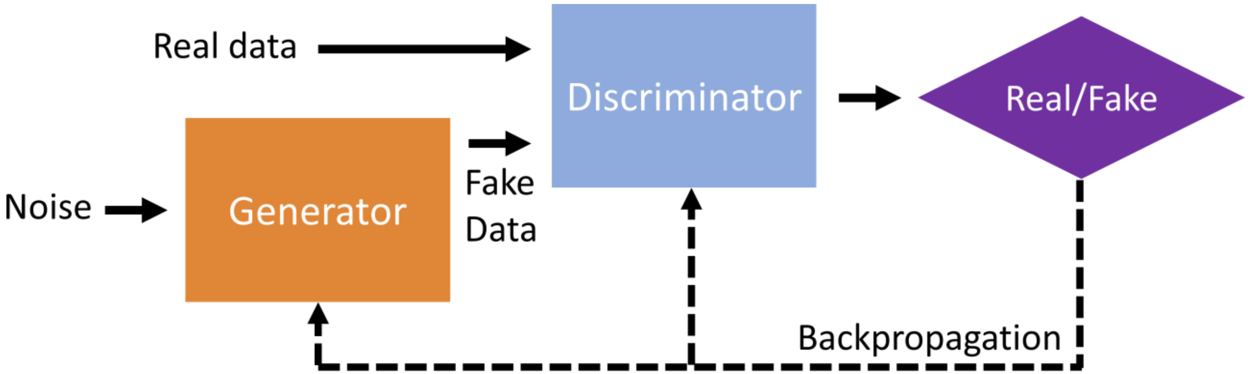
3DGAN

- Train two networks (Generator & Discriminator) in a minmax game

- GANs reach a good level of accuracy*

➢ We want to further decrease the computational resources

- Only the generator network is used to generate shower images

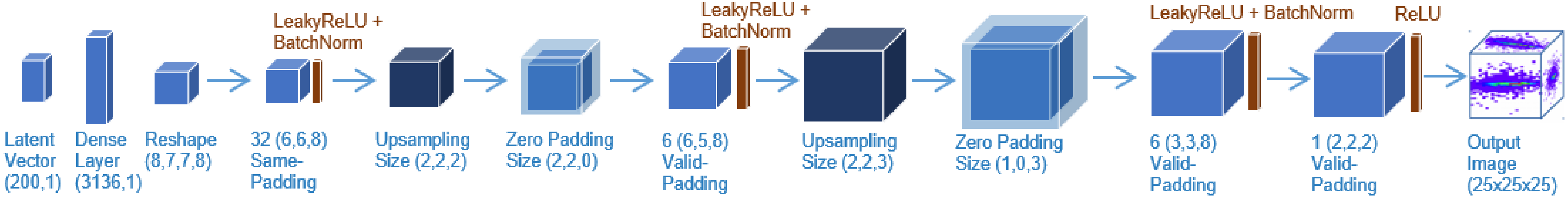


*G. R. Khattak, et al., ICMLA 2019 Particle Detector Simulation using Generative Adversarial Networks with Domain Related Constraints

Old Conv3D Generator Network

- Until now: Representing 3D images → Using 3D convolutional layers

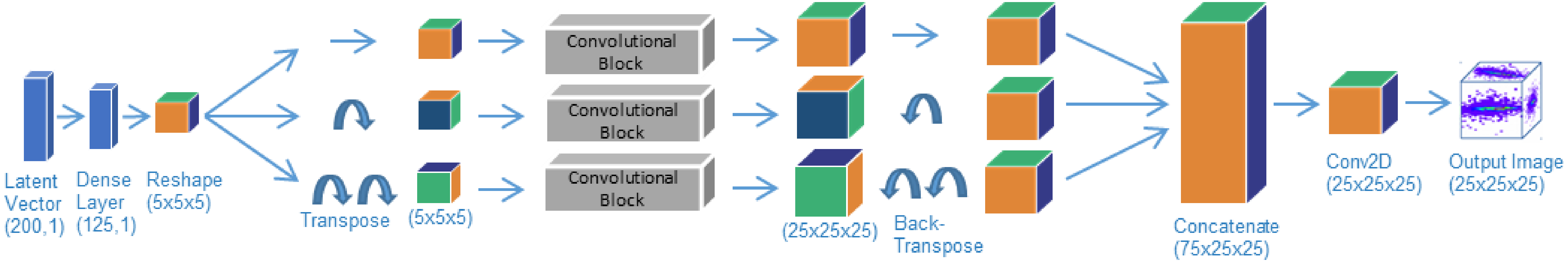
Paper: Three dimensional Generative Adversarial Networks for fast simulation, Carminati et al., 2018



- Conv3D layers are computational demanding

  → Creating neural network consisting only of Conv2D layers

New Conv2D Generator Network



- Solving a 3D problem with 2D layers
- **1.3x speed up vs Conv3D → 8 000x speed up vs Monte Carlo**
- Increasing the number of parameters → more powerful network → higher accuracy

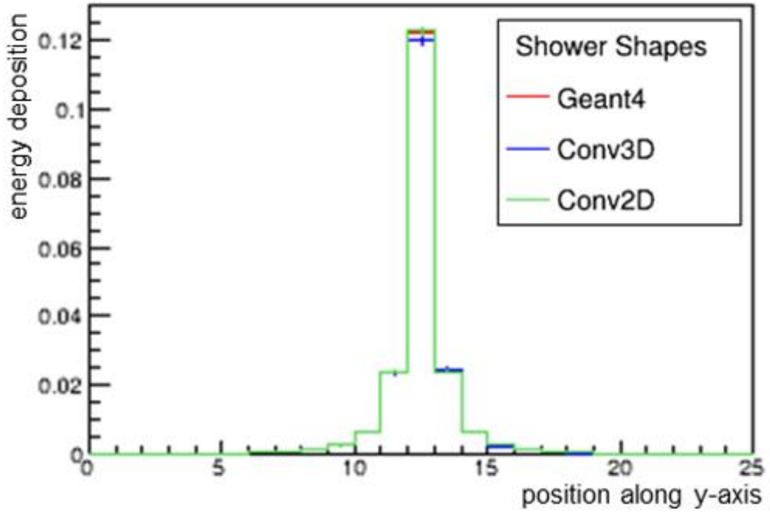
Physics Evaluation 1

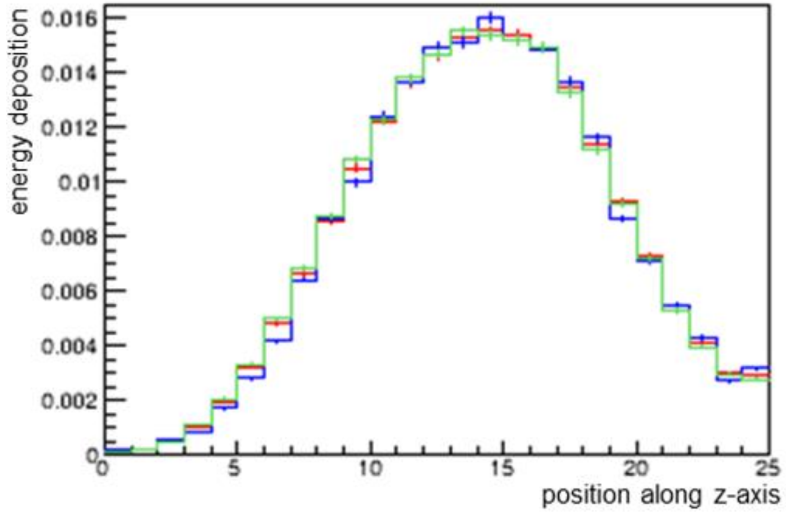
Shower Shapes

- Mean Squared Error (MSE) between GAN and validation data:

Model	MSE (Lower is better)
Conv3D	0.065
Conv2D	**0.044**

- Conv2D model performs better



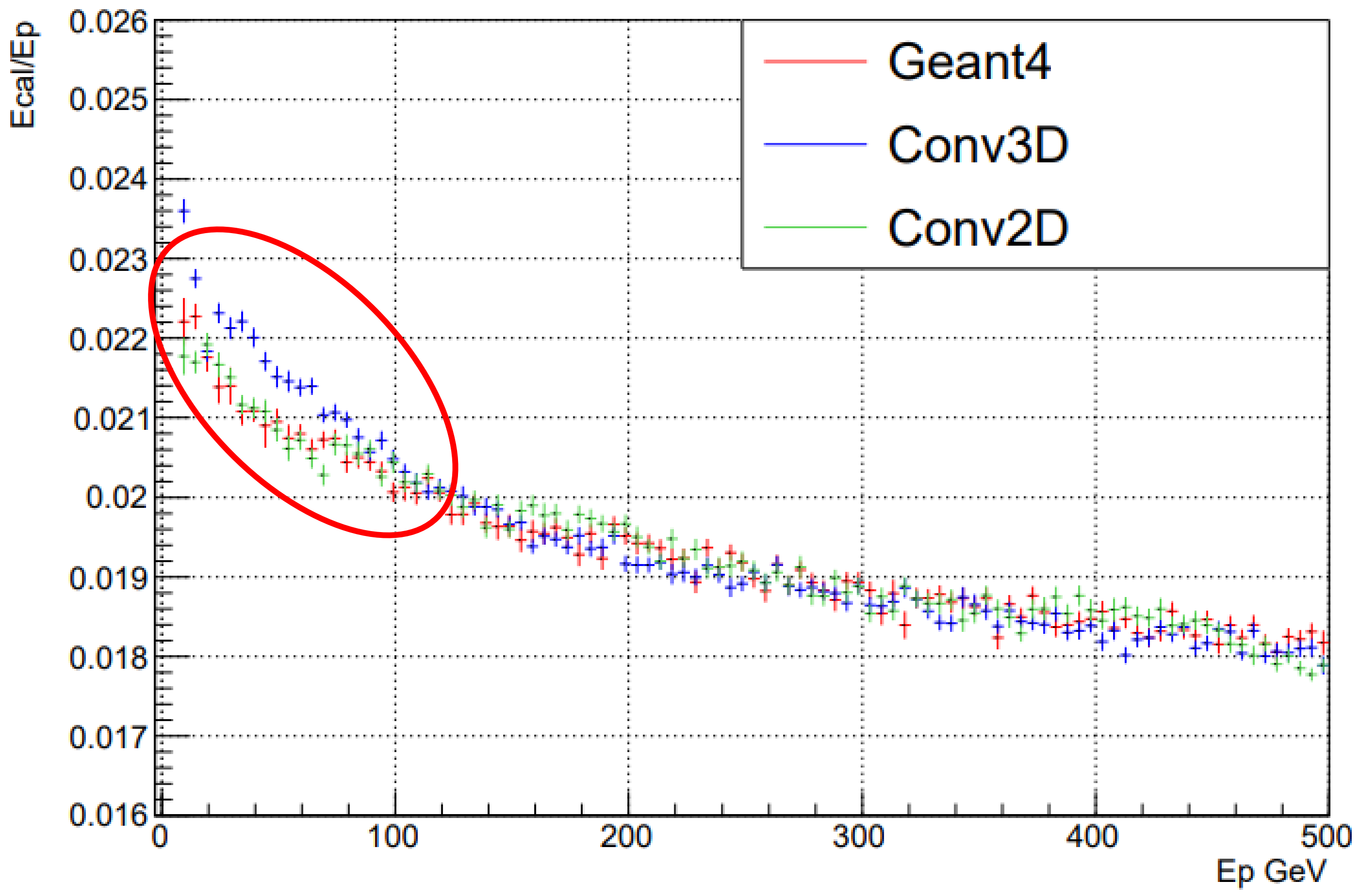


Physics Evaluation 2

Sampling Fraction

- Ratio between the total measured energy ECAL and the initial particle energy E_p

- Conv2D performs better for energies below 100 GeV



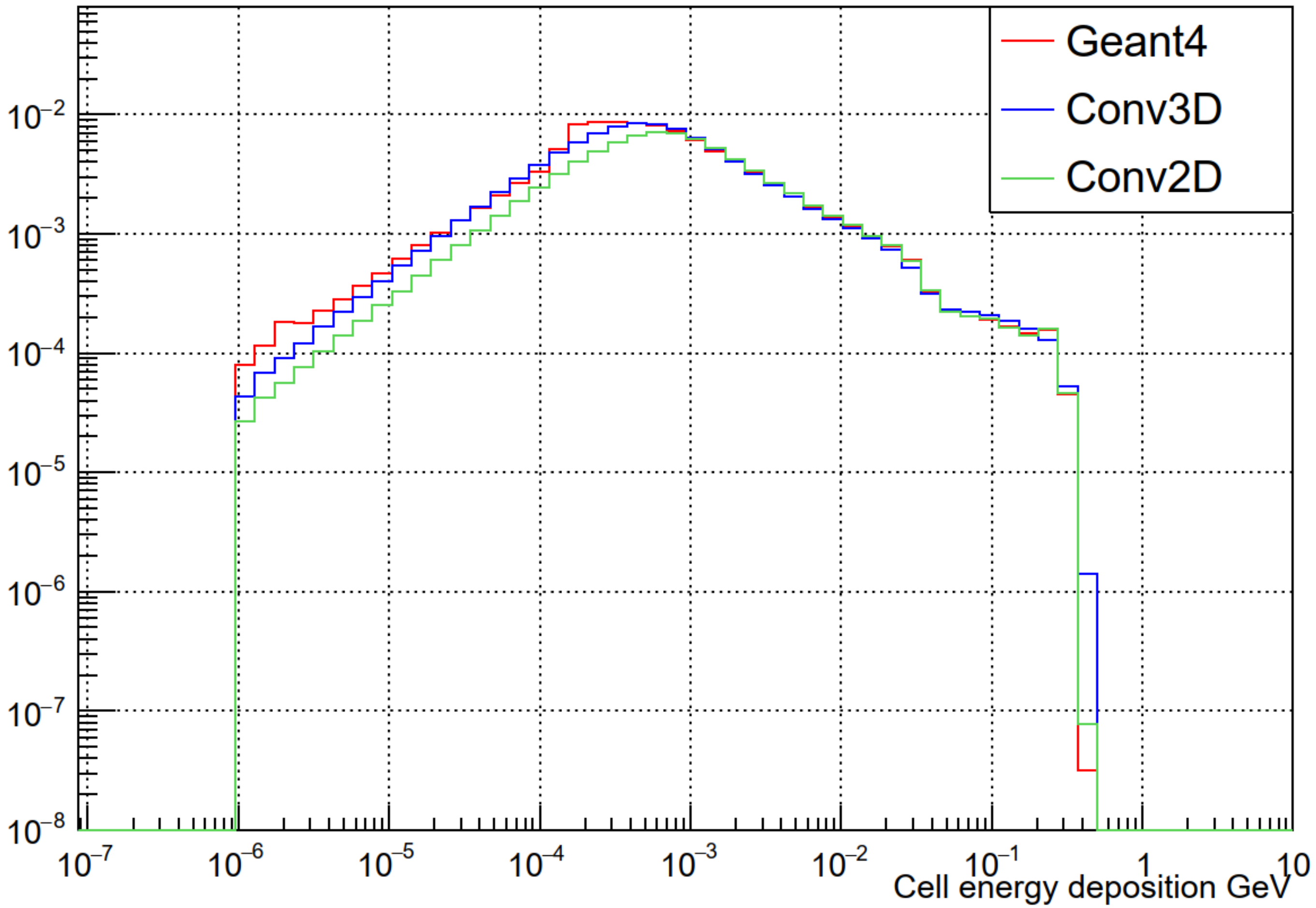
Physics Evaluation 3

Histogram of Single Cell Energy Deposition

- Conv2D model performs slightly worse for lower energy cells

→ Further investigations

- Minimal energy threshold at 10^{-6} GeV because of detector resolution



Physics Evaluation 4

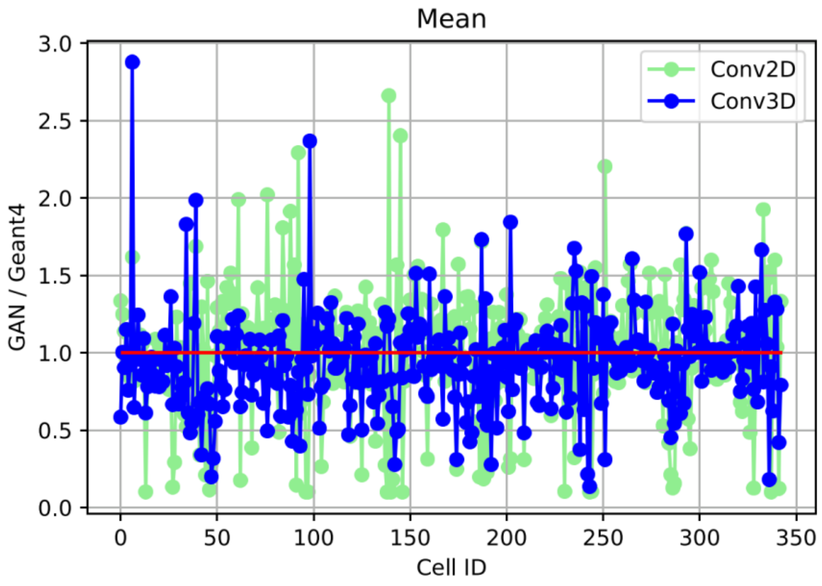
Single Pixel Comparison

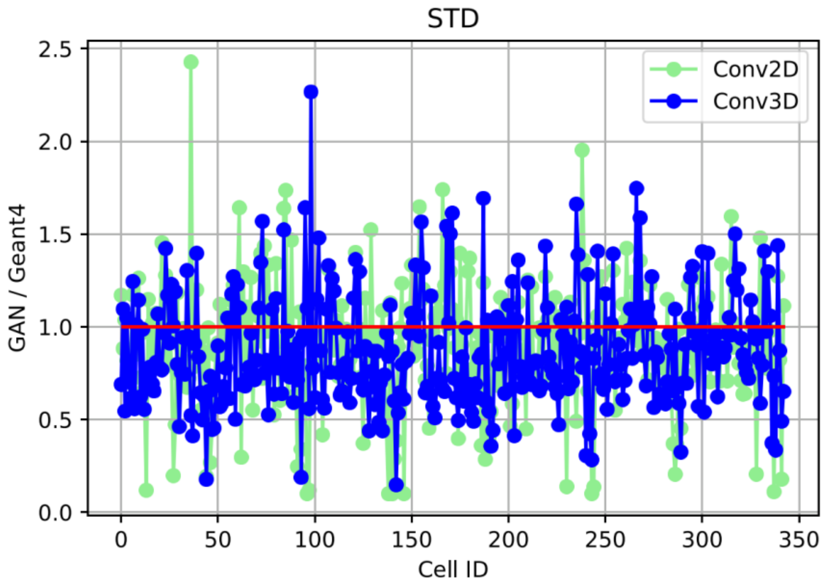
We compare the single cell energy distribution for the pixels with larger energy depositions

- 343 pixels
- Energy 250±2 GeV
- 1580 shower images

Model	Mean	STD
Conv3D	0.93	0.86
Conv2D	1.00	0.90

→ Conv2D model performs better





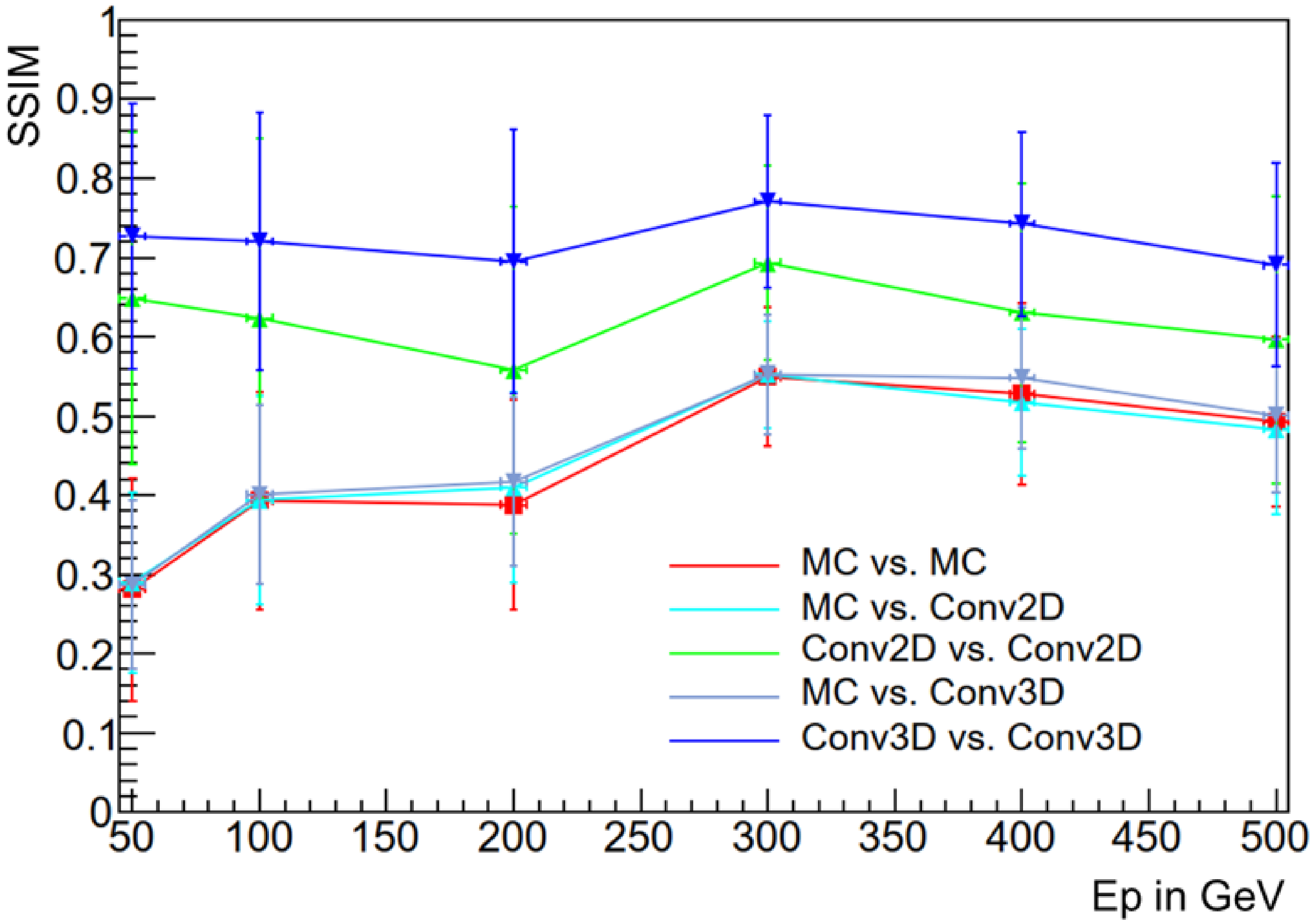
Physics Evaluation 5

SSIM

Structural Similarity Index

- Known problem of GANs: Mode collapse
- SSIM estimates the perceptual difference between similar images

→ Conv2D performes better



Summary

- **1.3x** speed up due to transition from Conv3D to Conv2D
- **8 000x** speed up of Conv2D vs Monte Carlo

- Both GAN models show high physics accuracy

→ Overall, the Conv2D model better

QUESTIONS?

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