Physics Validation of Conv2D Networks for HEP Simulations

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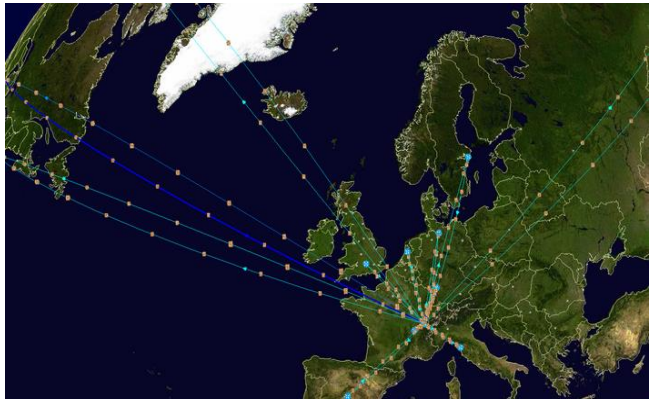
Calorimeter Simulations

- Calorimeter detectors measure the energy of particles
- Calorimeter simulations are based on Geant4
- Simulations 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

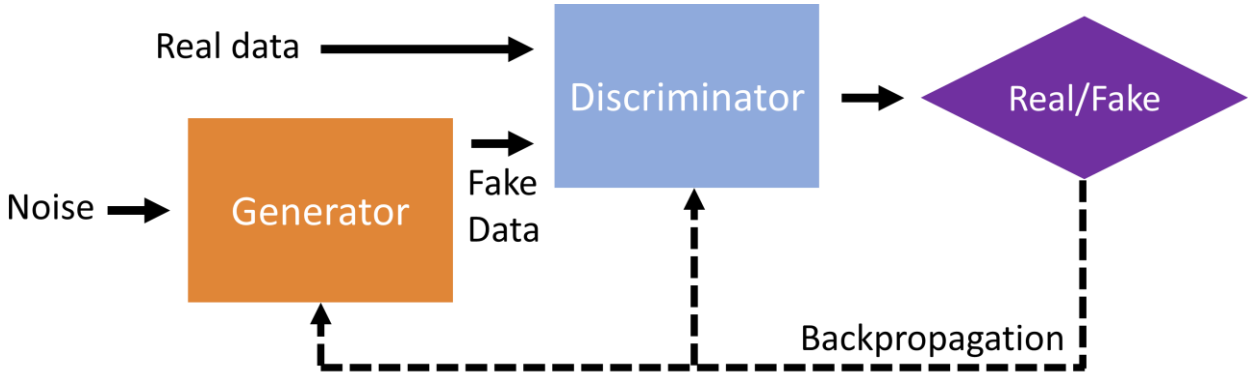


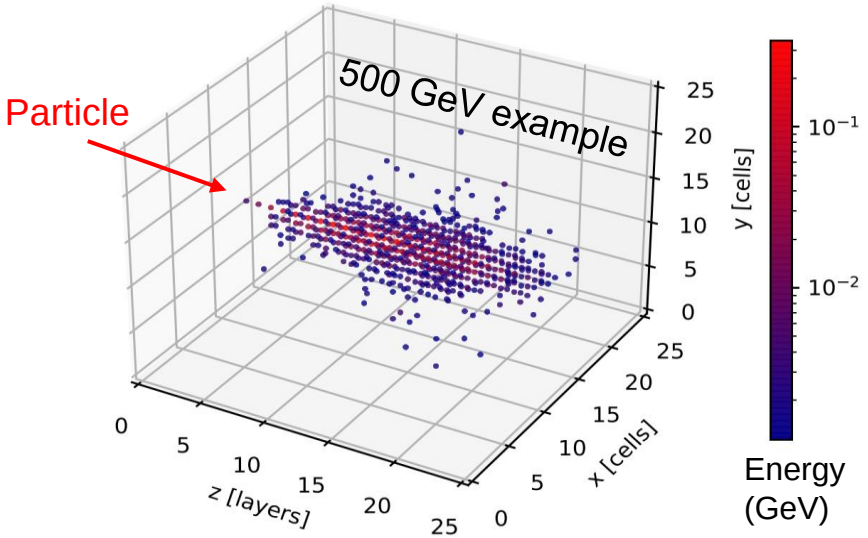
*A Roadmap for HEP Software and Computing R&D for the 2020s https://doi.org/10.1007/s41781-018-0018-8

Generative Adversarial Networks

3DGAN

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





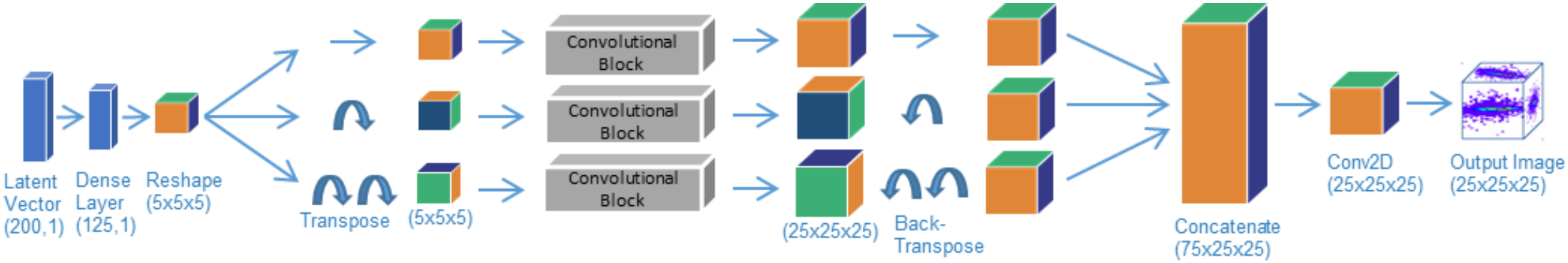
- 200 000 3D shower images with granularity 25x25x25
- Energies between 2-500 GeV

New Conv2D Generator Architecture

- Conv3D layers are computational demanding
- Conv3D layers are not yet supported in less than 32bit precision

  → Creating neural network consisting only of Conv2D layers

  → 3 new Conv2D architectures: only best shown in the presentation



→ Solve 3D image problems with only 2D convolutional layers

Computational Evaluation

Model	Number of Parameters	Inference Time [s]	Speed up vs Geant4 *	GPU Utilization
Conv3D	752 000	7	6 200x	78.75%
(Best) Conv2D	2 055 000	4.9 (1.29x faster)	8 000x	21.75%

- New Conv2D model has more than double as much parameters as the previous Conv3D model
- Inference of Conv2D model is faster
- GPU utilization of Conv2D model lower → potential for further speed up
- → **8 000x speed up** vs Geant4 simulation

*Geant4 simulation time from a previous measurement in 2018: Book title: “High Performance Computing”, Springer, Chapter: “Distributed Training of Generative Adversarial Networks for Fast Detector Simulation”

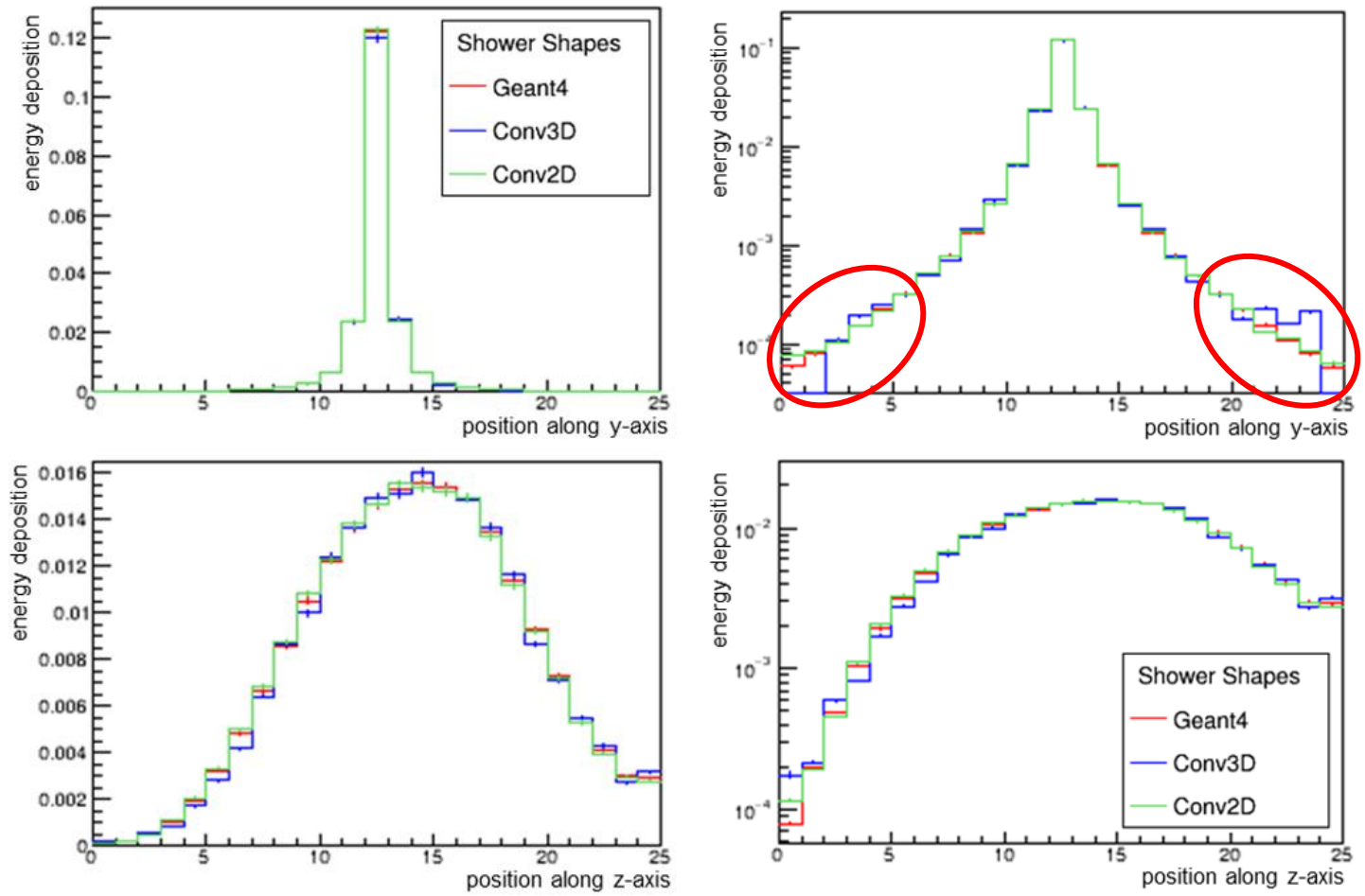
Physics Evaluation 1

Shower Shapes

- Cell wise the Mean Squared Error (MSE) between GAN and validation data along the three canonical axes:

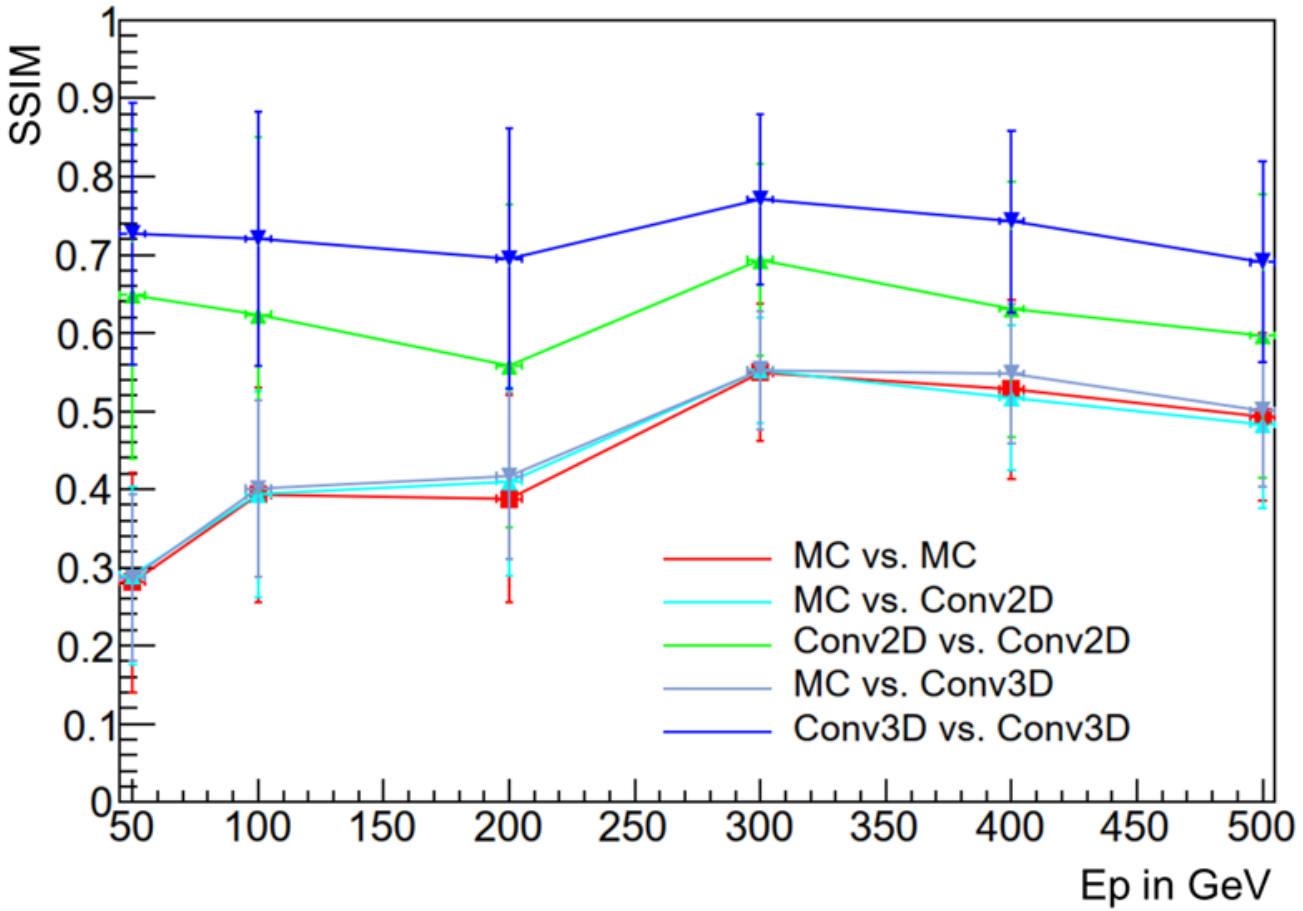
Model	MSE (Lower is better)
Conv3D	0.065
Conv2D	**0.027**

- Projection of the shower along the different axes
  - Conv2D performs better along the tails



Physics Evaluation 2

SSIM



Structural Similarity Index

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

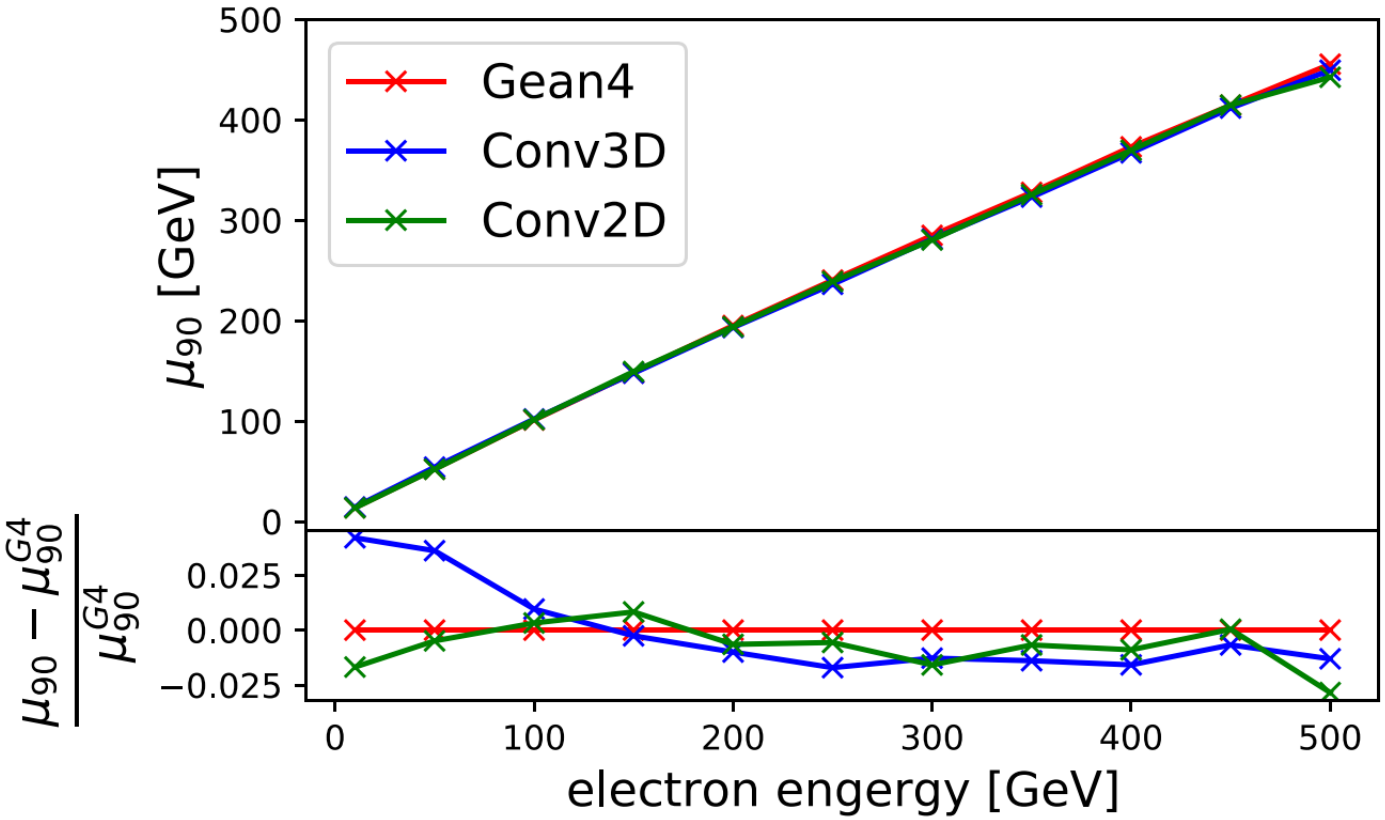
→ Conv2D performes better

Physics Evaluation 3

Deposited Mean Energy

- Deposited energy with respect to the incident electron energy
- μ_{90}: 90% core of the distributions

→ Conv2D model performs better for lower energies



Summary

- **1.29x speed up** with transition from Conv3D to Conv2D networks
  - Further potential speed up for the Conv2D model with using multiple streams

- Overall, both GAN models reached a good physics accuracy
  - The new Conv2D models reached a slightly **higher accuracy**

→ Total **8 000x speed up versus Geant4** simulation

QUESTIONS?

More Details? Read our Paper: http://arxiv.org/abs/2105.08960

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