Simulation of electromagnetic showers in calorimeters with generative adversarial networks

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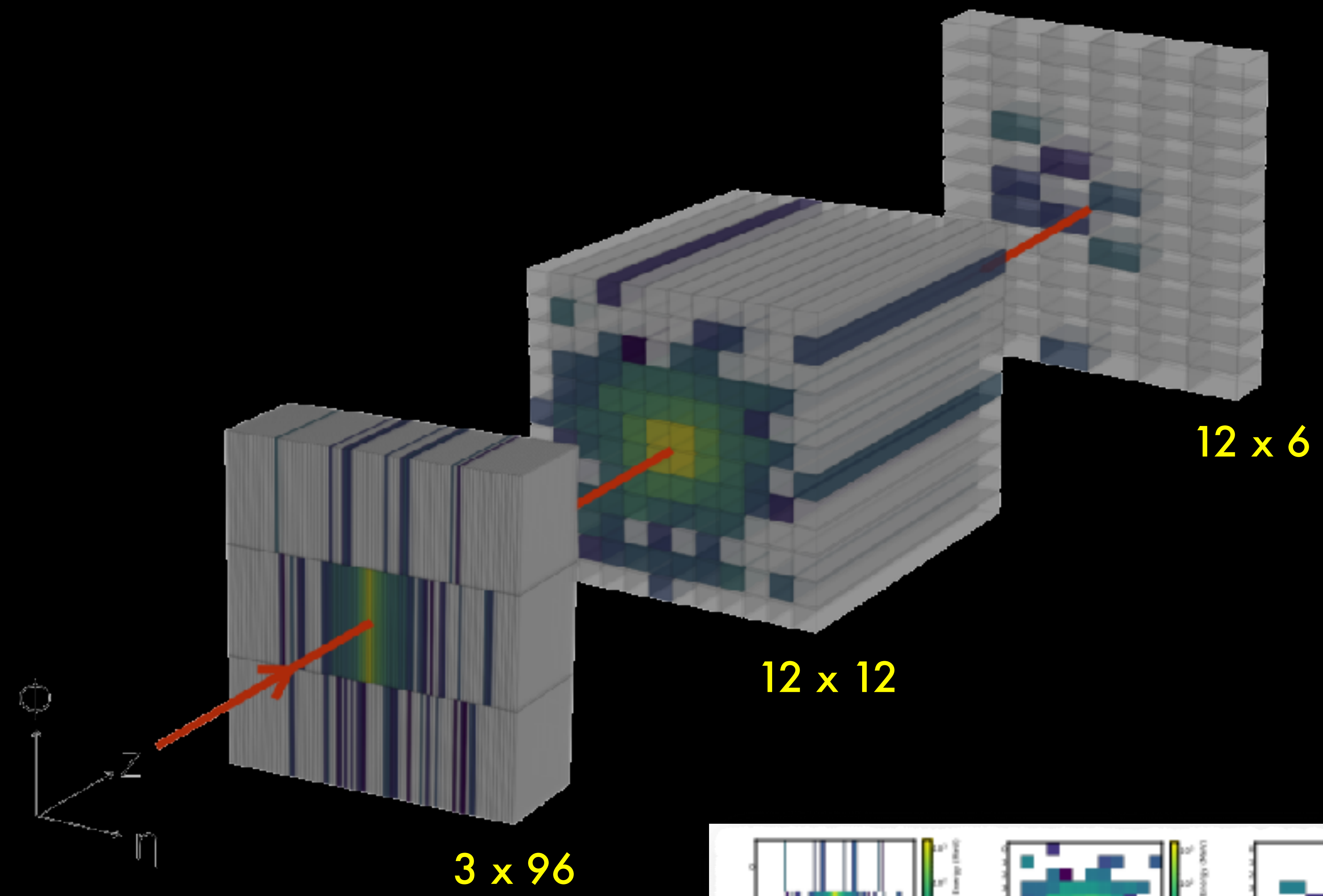
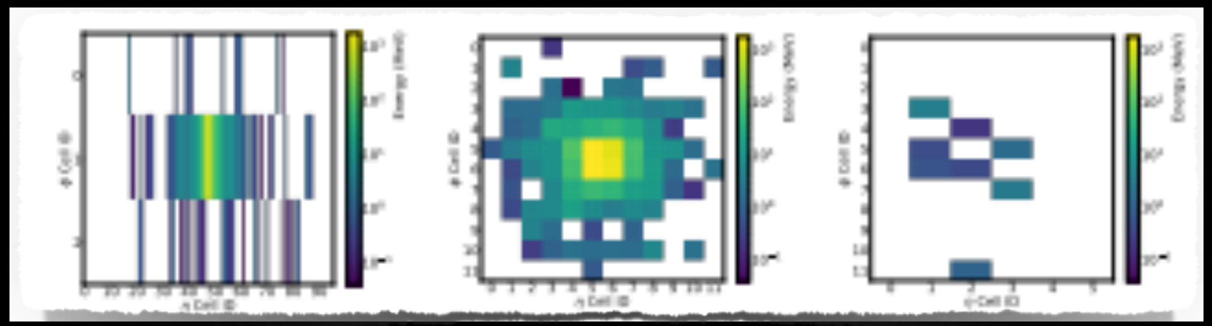
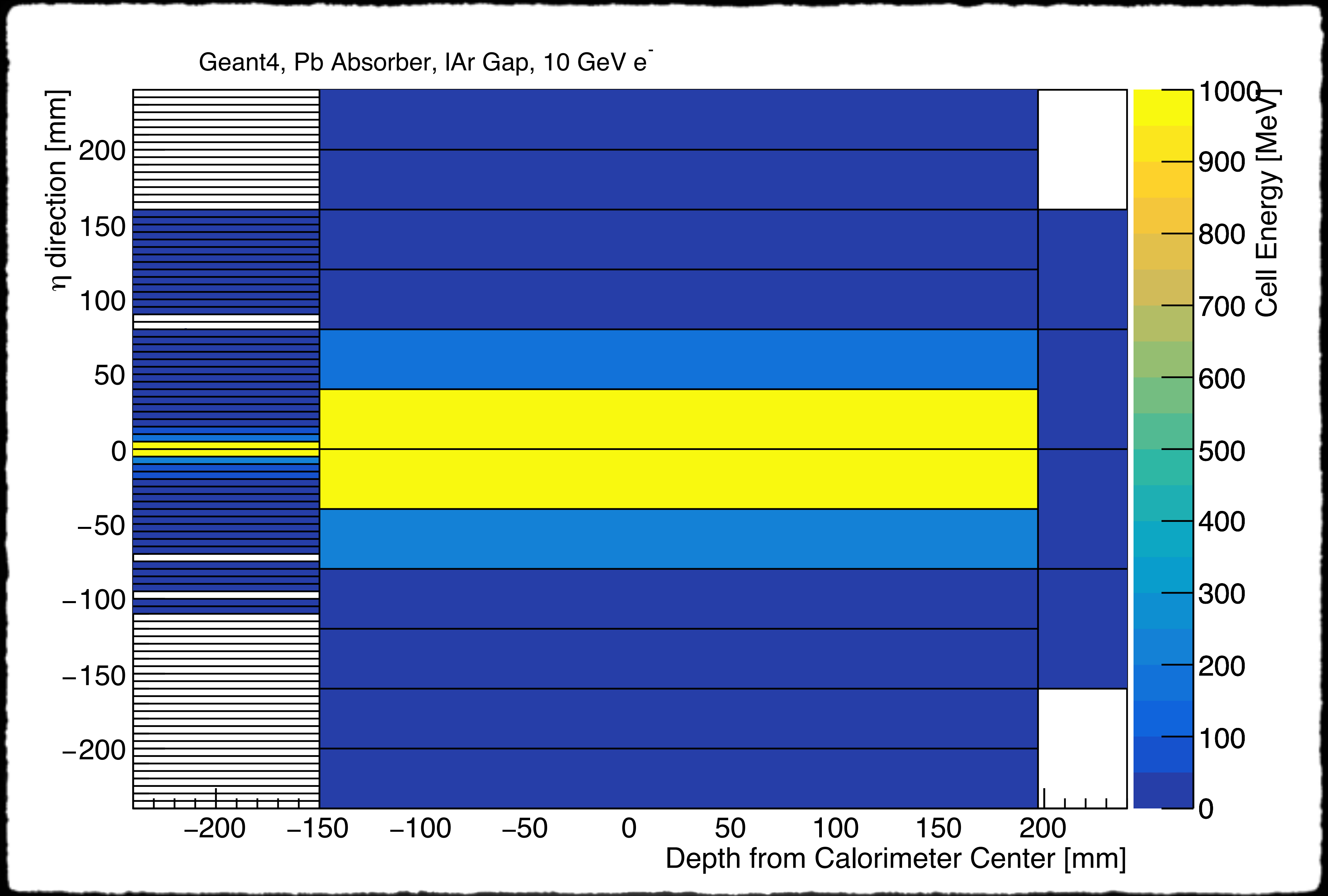
M. Paganini, L. de Oliveira, B. Nachman
Phys. Rev. D 97, 014021 (2018)
arXiv:1712.10321v1 [hep-ex]

CaloGAN simulation

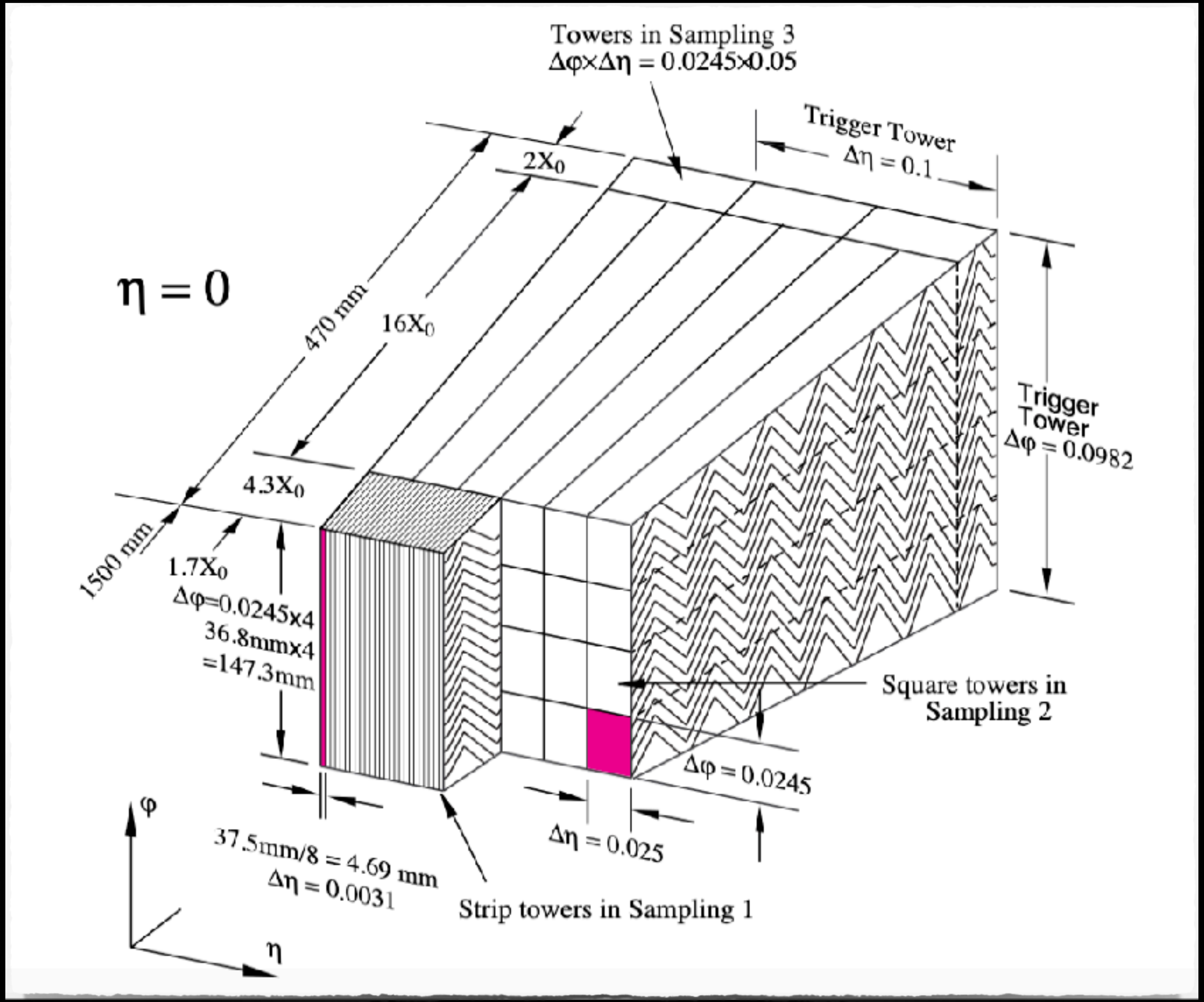
- This study is based on the CaloGAN package for LAr of the ATLAS ECAL;
- The strategy slices the sensitive detector into sections to be used as layers for a generative adversarial network (GAN) to be trained.



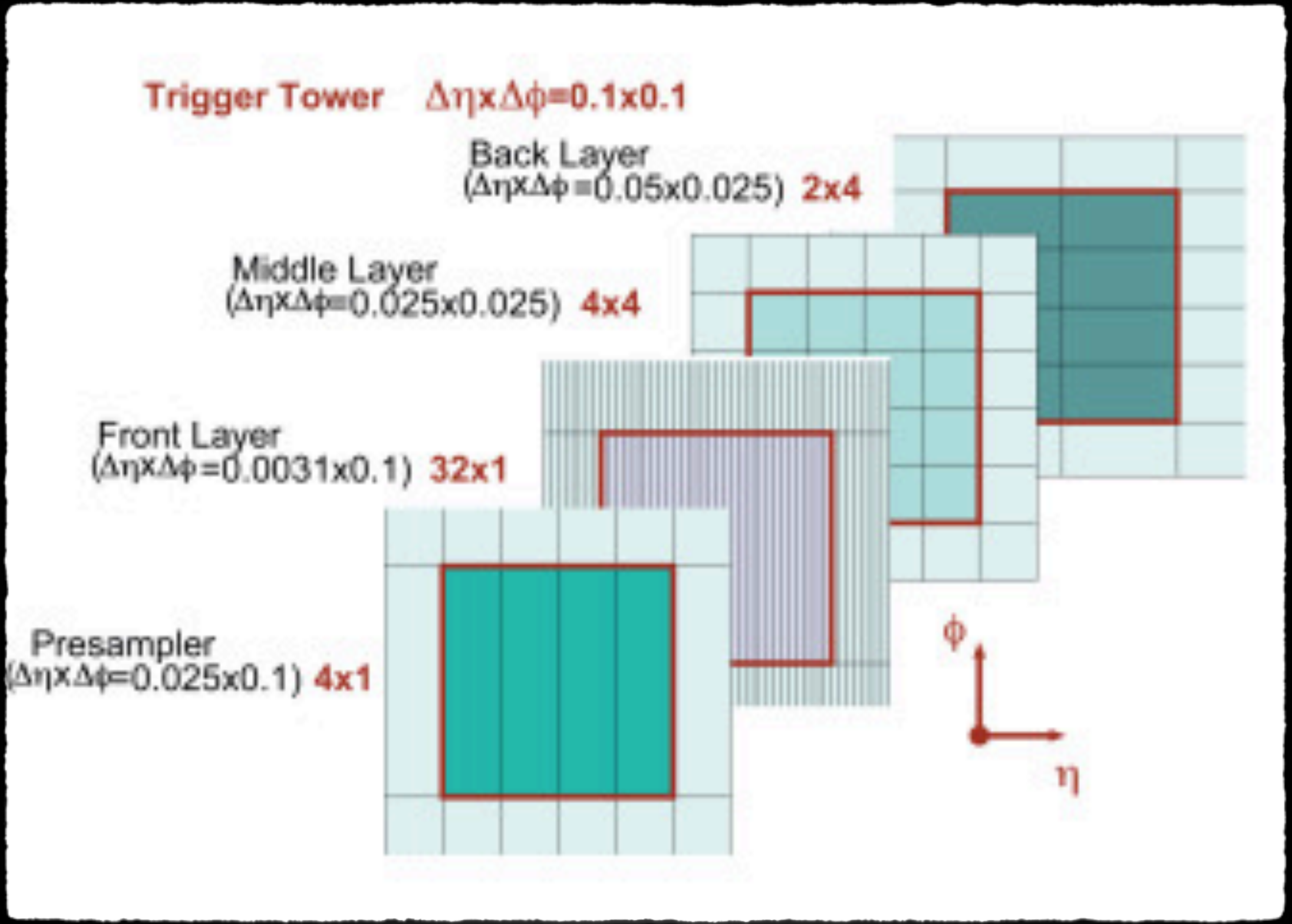




ATLAS ECAL



before Phase I Upgrade



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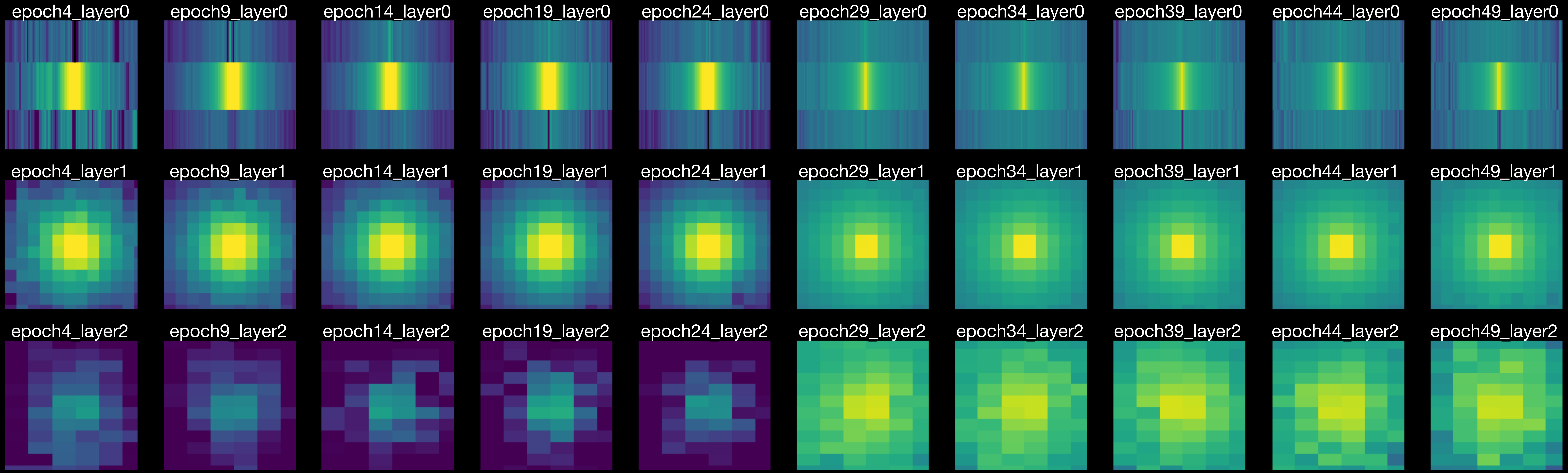
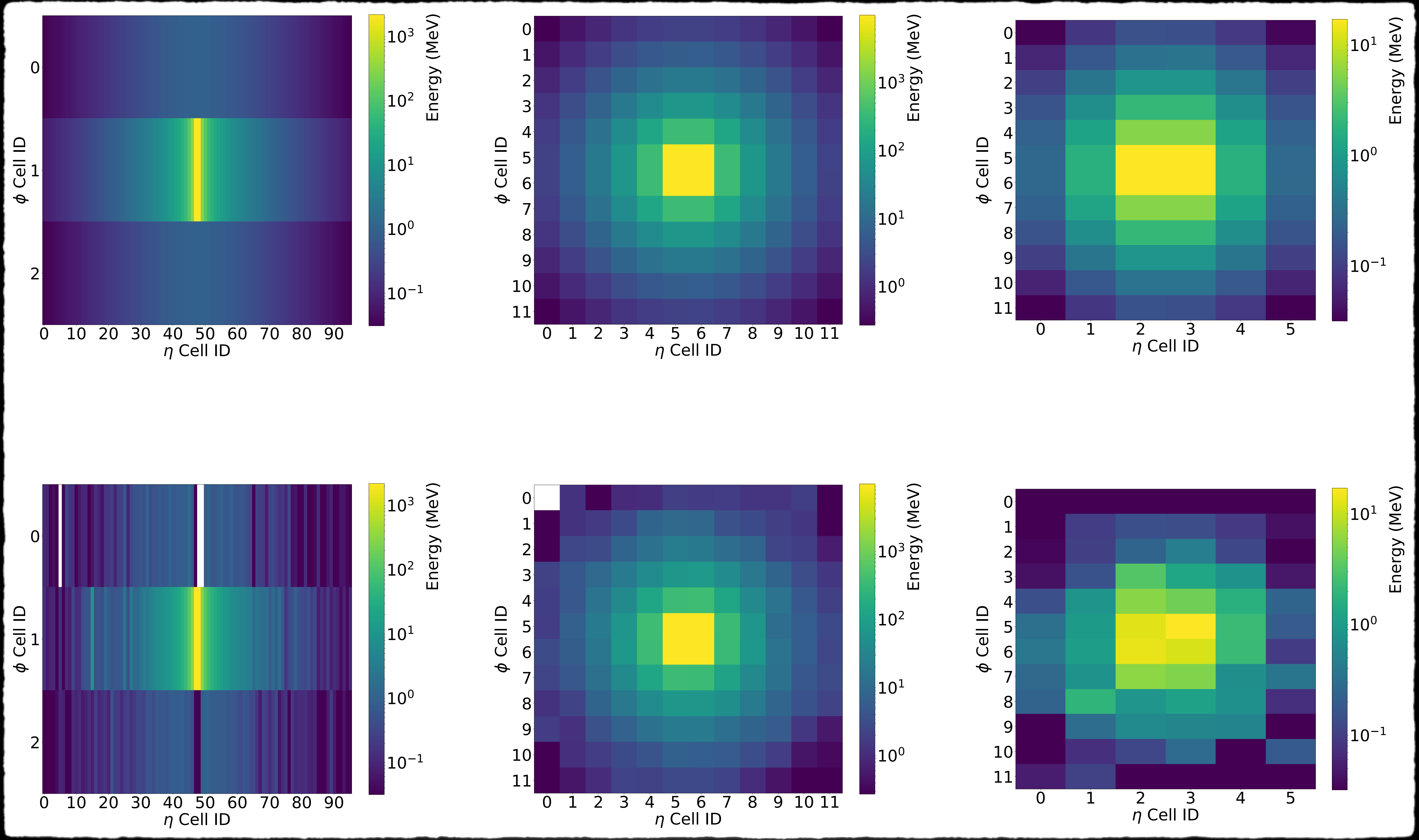
GAN training

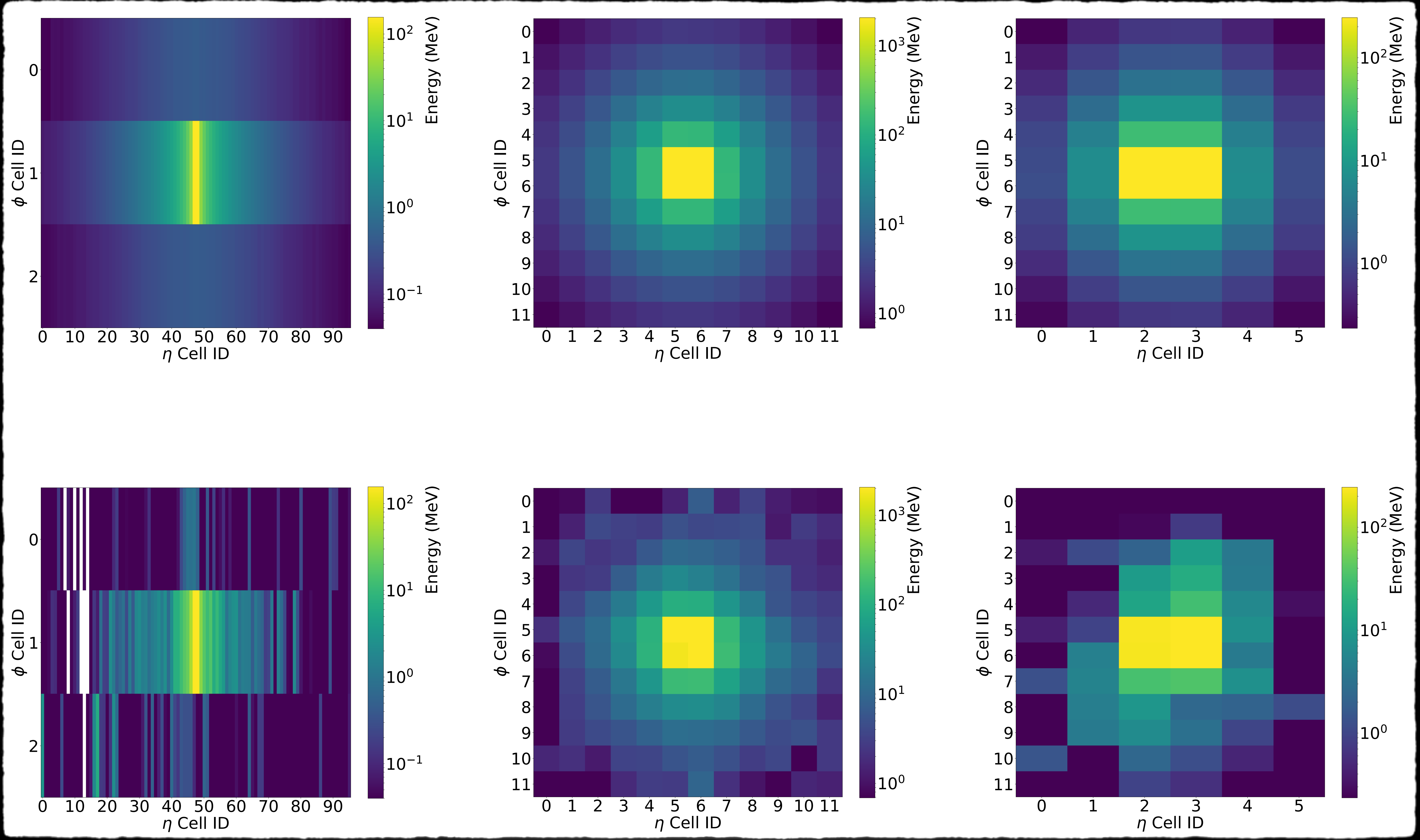
- Positrons, photons, and pions are used as incident particles for training;
- Sampling over the 3 layers to train the energy deposition in different granularities;
- GPU training ~3x faster than usual CPU.



Shower shapes: photons

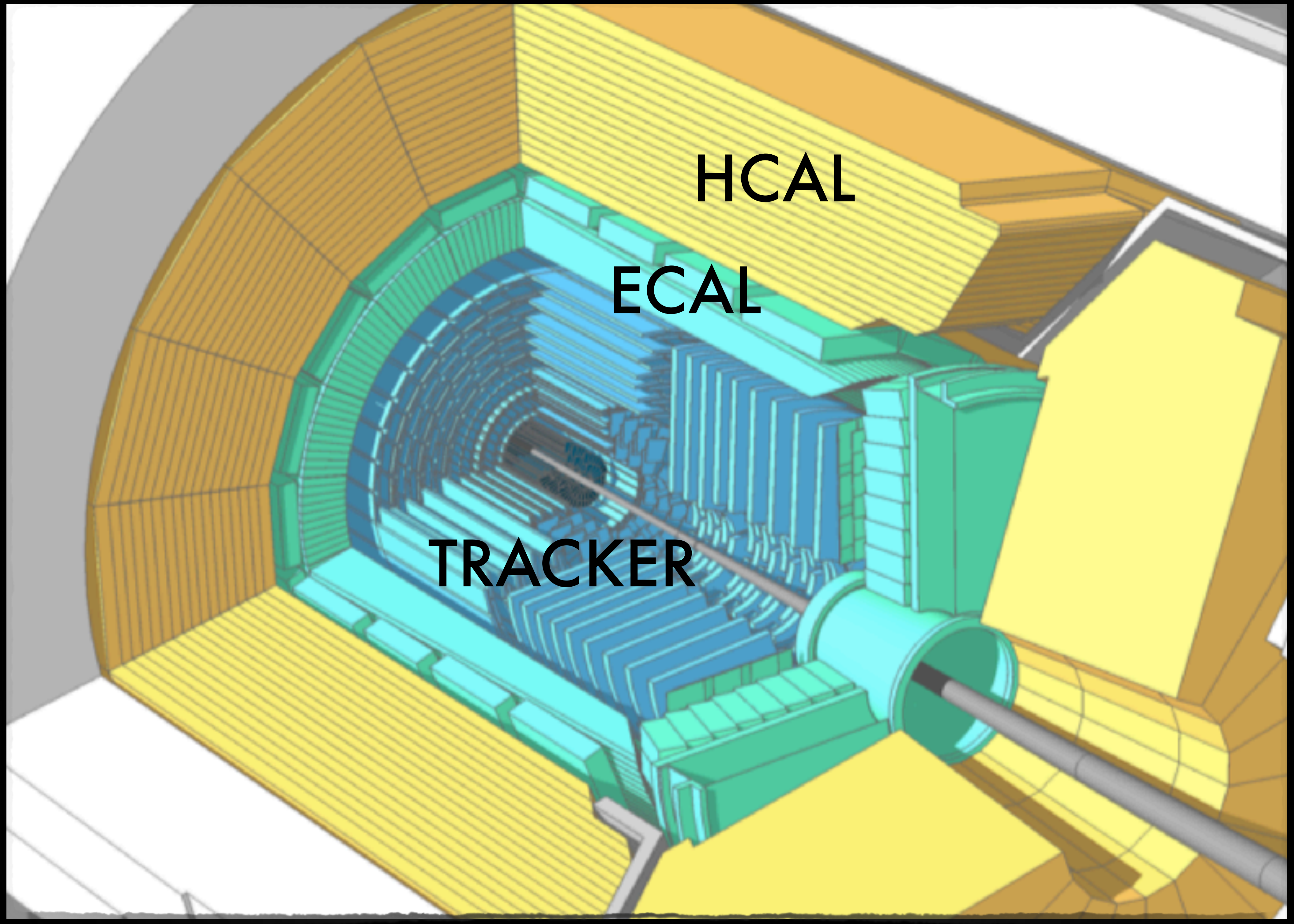


Shower shapes: charged pions

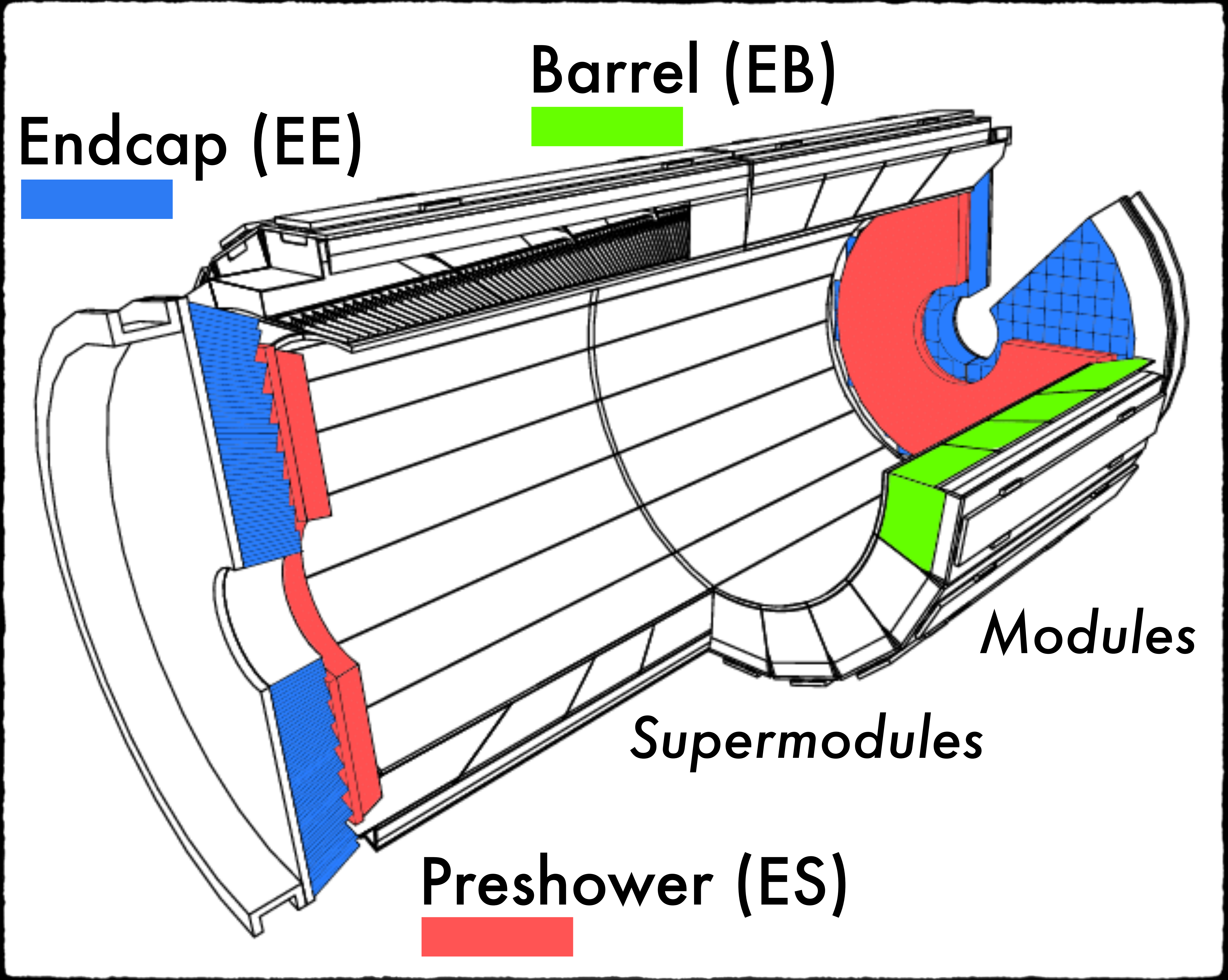


CMS detector

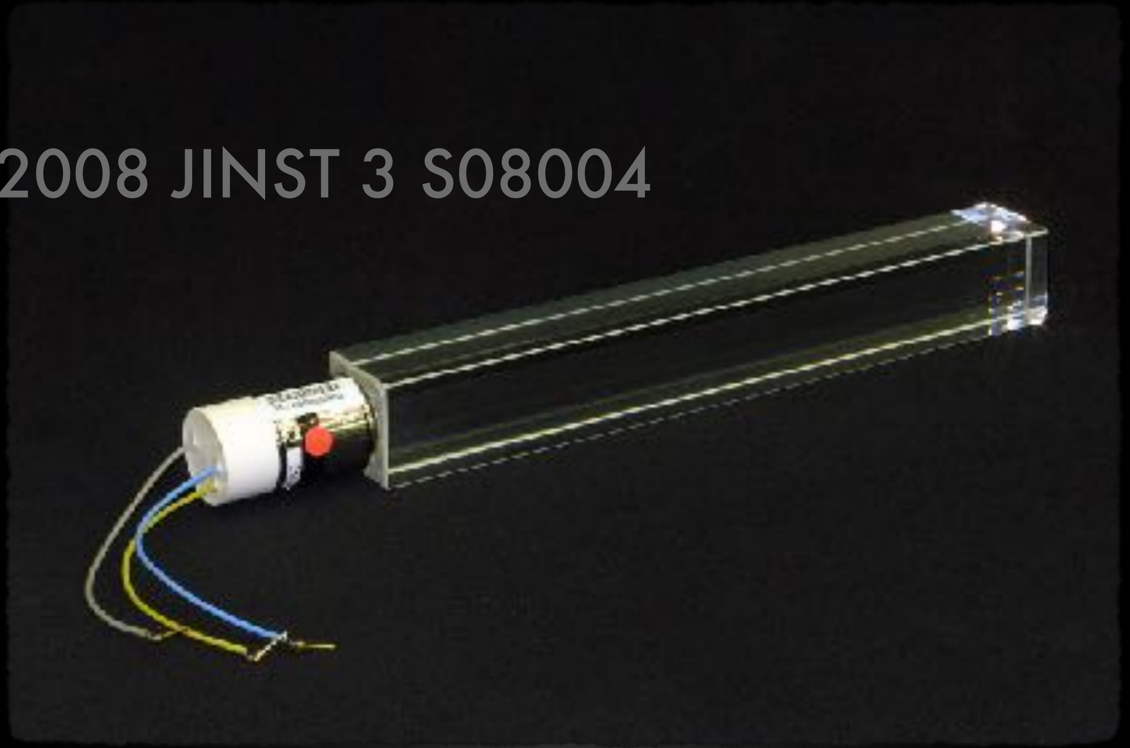
- Along the Pixel tracker and the Hadronic Calorimeter, the CMS detector has an Electromagnetic Calorimeter with scintillator crystals.
- Layout: barrel and encaps with 75k+ crystals covering the interaction point.



CMS ECAL layout



C. Biino, J. Phys.: Conf. Ser. 587 (2015) 012001

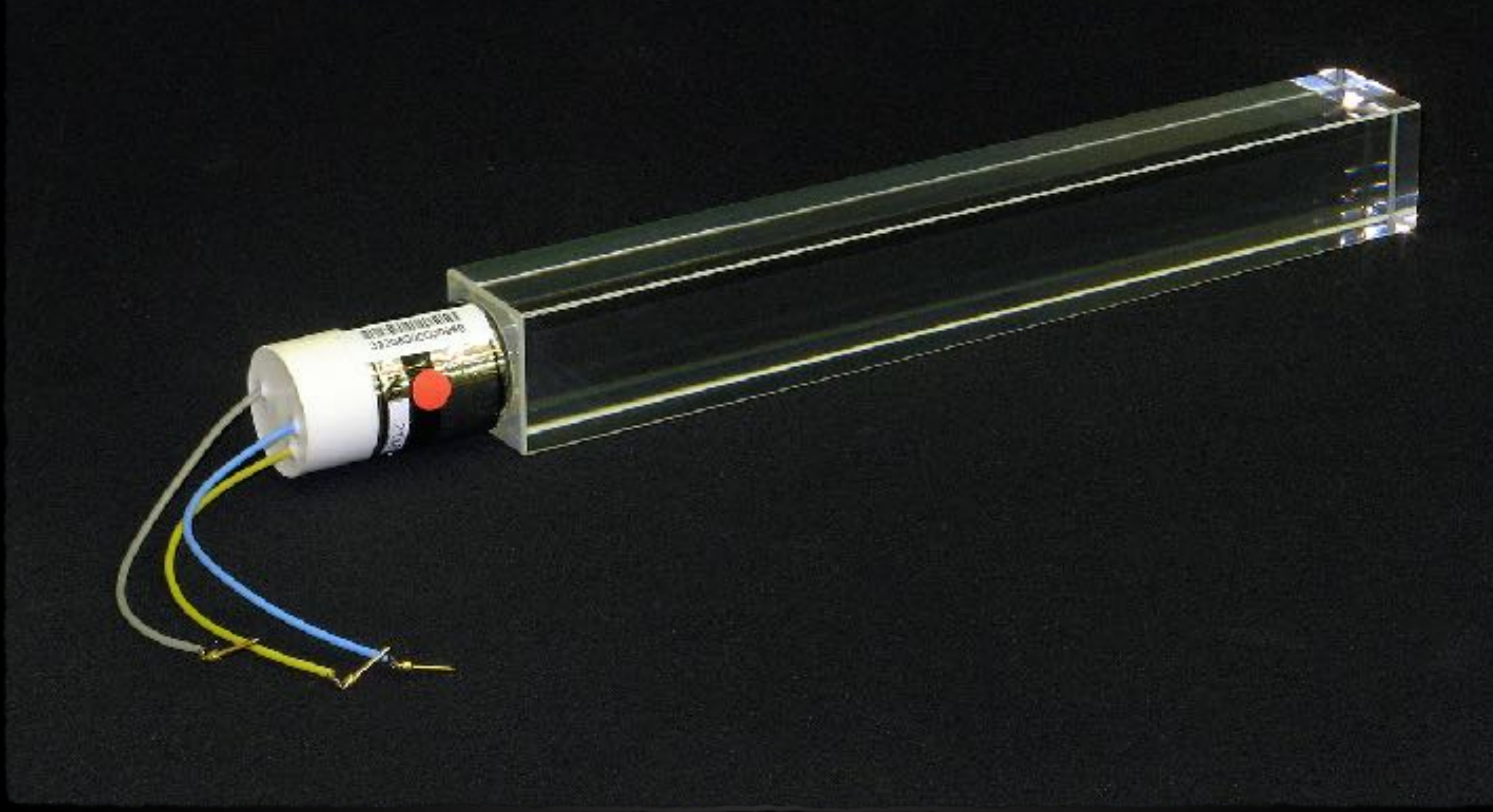


PbWO4 crystals

CERN, *Crystal assembly*, https://cds.cern.ch/record/929399

CMS ECAL in CaloGAN

- PbWO4 crystals used as sensitive detector, updating the detector length to the 25 cm of the CMS crystals.
  - Pb layer of 3 mm is used as preshower to enlarge shower area.
- The detector description follows a close design of the ECAL modules in the CMS detector:
  1. Different layer binning for better description;
  2. 10% – 70% – 20% of total length;
- Distributions investigated: Energy ratio, particle fractions per layer, max depth, etc.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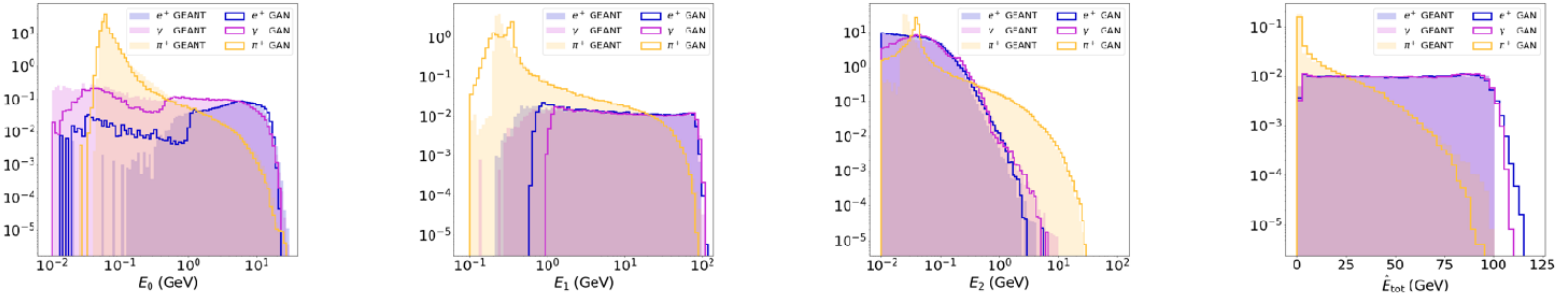
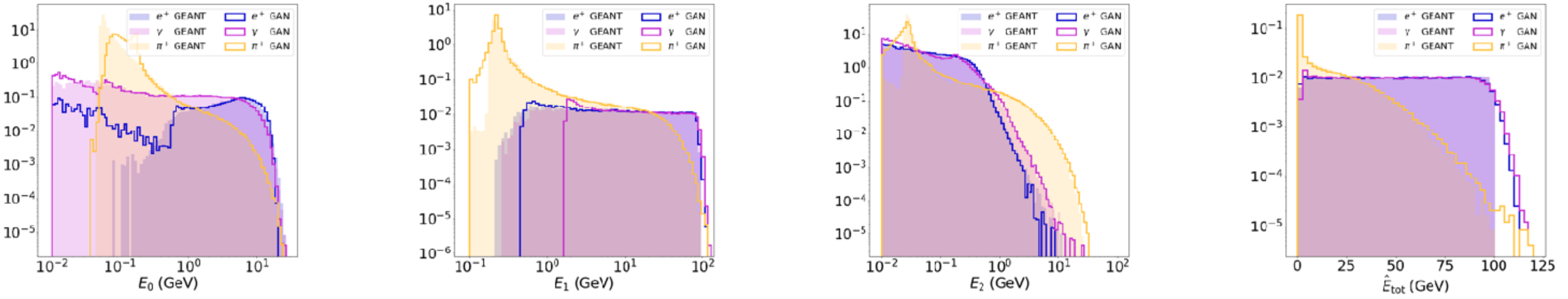
Energy distributions

colab

ATLAS LAr ECAL with 48 cm



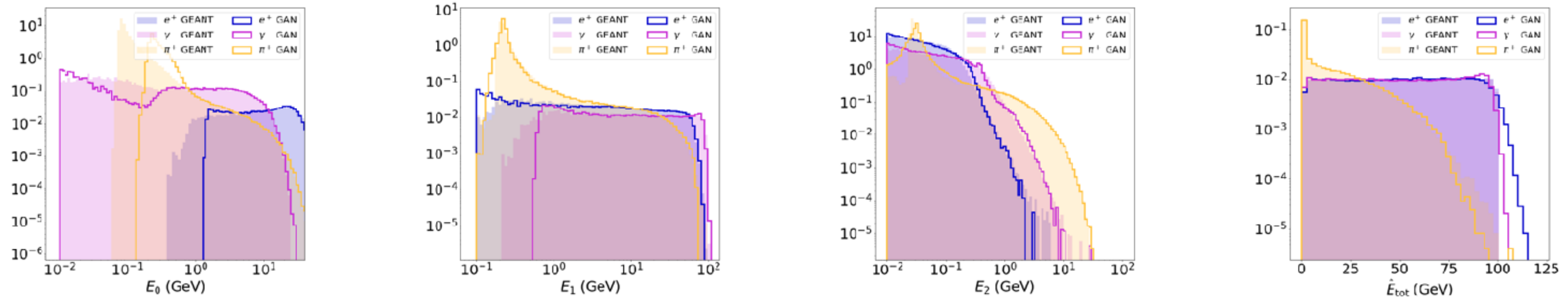
CMS PbWO4 ECAL with 25 cm



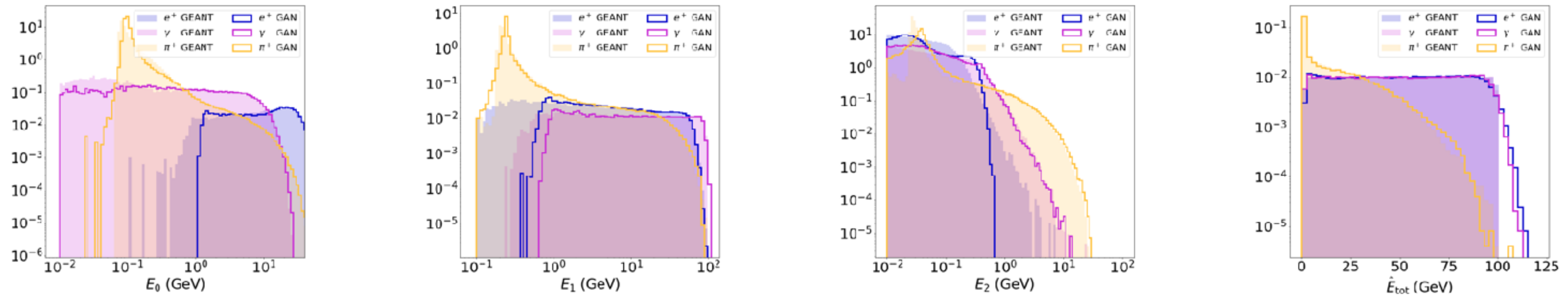
Google Colab: GPU K80 ~8h training
CERN LXBATCH: GPU Tesla T4 ~5h training

Adding the preshower

CMS PbWO4 ECAL with 25 cm + preshower with 20 x 20 crystals in setup #1



CMS PbWO4 ECAL with 25 cm + preshower with 20 x 20 crystals in setup #2



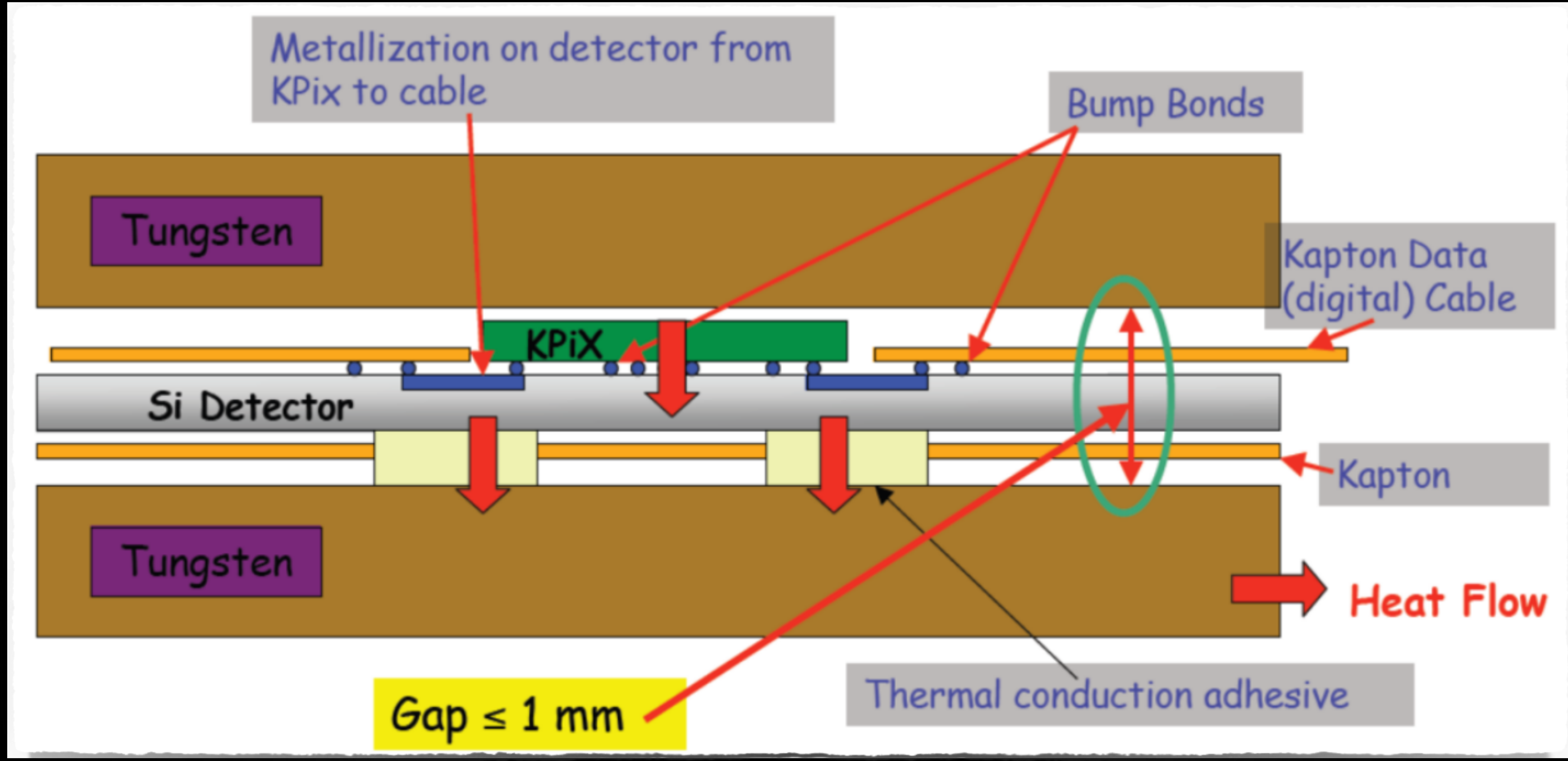
Google Colab: GPU K80 ~8h training
CERN LXBATCH: GPU Tesla T4 ~5h training

Overview of ILC plans for ECAL

- Two proposal for detectors:
  - SiD: compact detector with Silicon tracker and 5 Tesla.
  - ILD: large detector with good energy and momentum resolution.
- For both detectors, plans are set based on Particle Flow Algorithm (PFA) aiming improved jet energy resolution (better <3%).
  - Tracker inside the magnet for measuring the track position and momentum precisely.
- Molière radius has to be small to minimize lateral shower size.
- Granularity is achieved by using scintillator strips (5 mm x 45 mm) with Tungsten as absorber material (X_0 = 3.5 mm, Molière radius R_M = 9 mm, interaction length 99 mm).

Possible approaches with CaloGAN

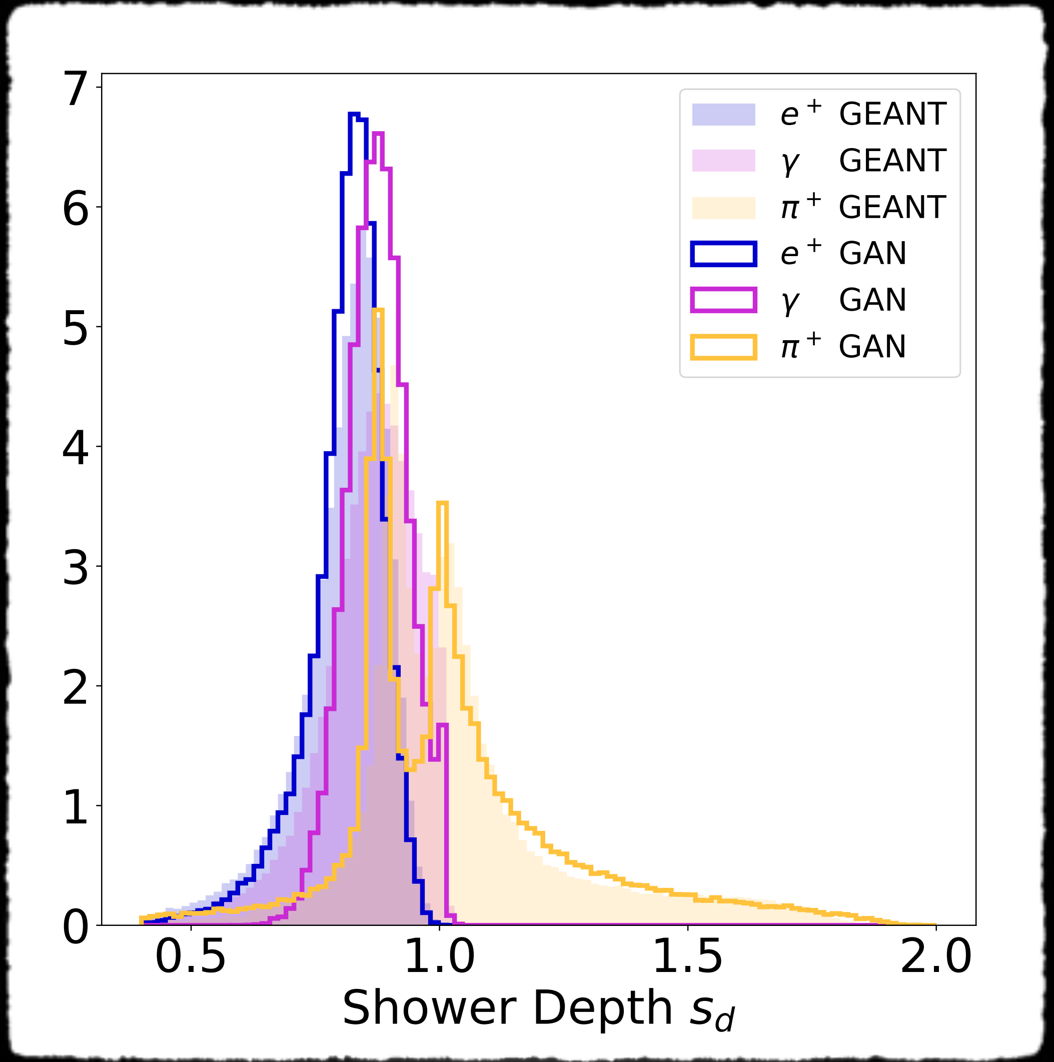
- As done in the transition from ATLAS to CMS, the Geant4 geometry can be customized for the detector under study.
  - Optimization of binning and #layers may be needed.
  - Silicon-tungsten SiD ECAL plans to have several layer of tungsten and readout electronics.

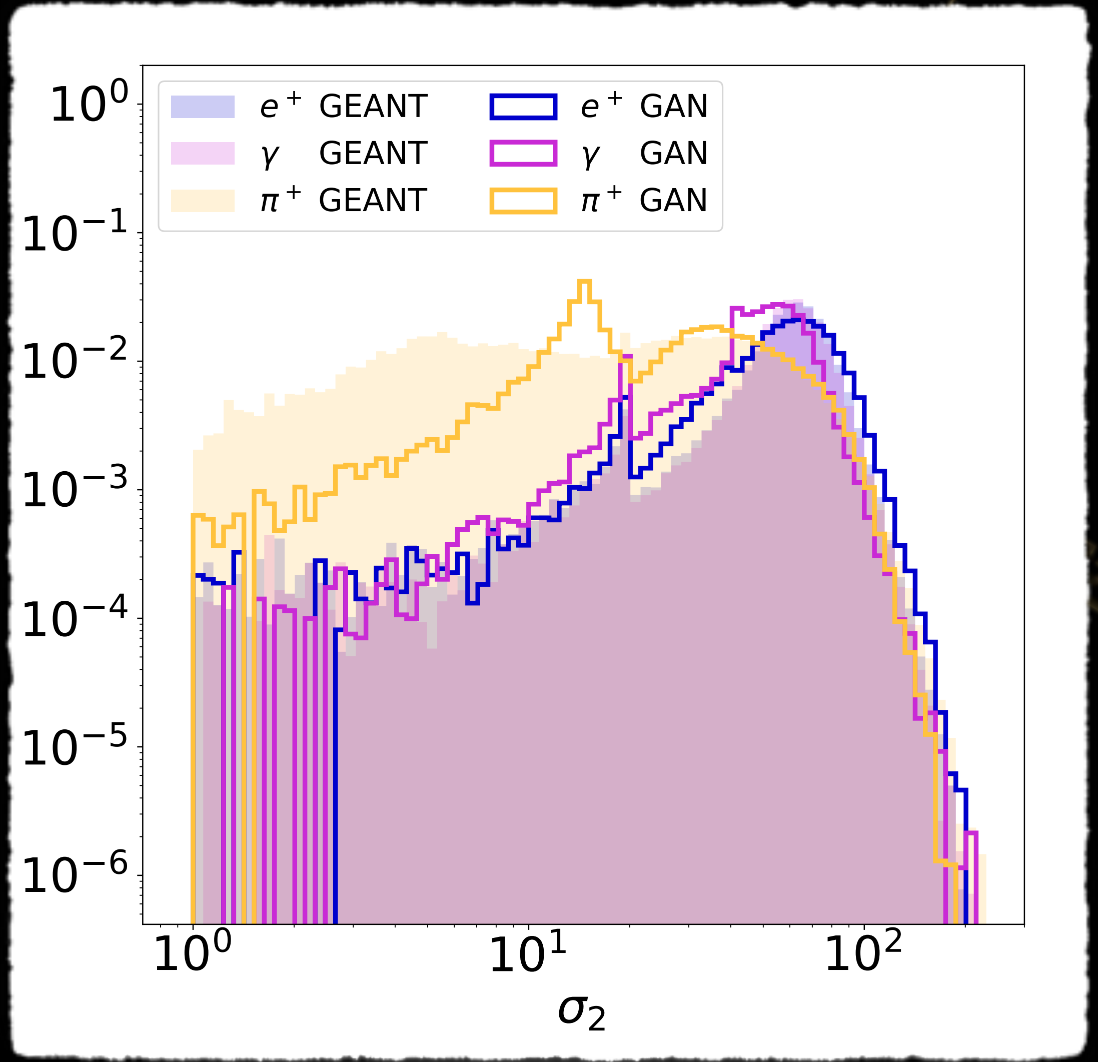


ILC Detector R&D Report
doi:10.5281/zenodo.3749461

Constraints

- Proper material description is fundamental to reproduce the physics behind the detection.
- Beyond the usual shower observables, reproduce the needed Molière radius is a key observable.





Closing remarks

- ML applications is a fast growing research field with great potential for high-efficient computing;
- ML fast simulation more cost-effective recources (GPUs) for large scale computing.
- CaloGAN performs well for a small detector set and needs more developments for a full scale detector simulation.
- Flexibility to train the GAN based on Geant4 simulations, which are available for ILC detectors and can be retrained in future geometries.
- Current funding from:

CNPq CAPES FAPERGS UFRGS UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL