Fast Calorimeter Simulation with Generative Models

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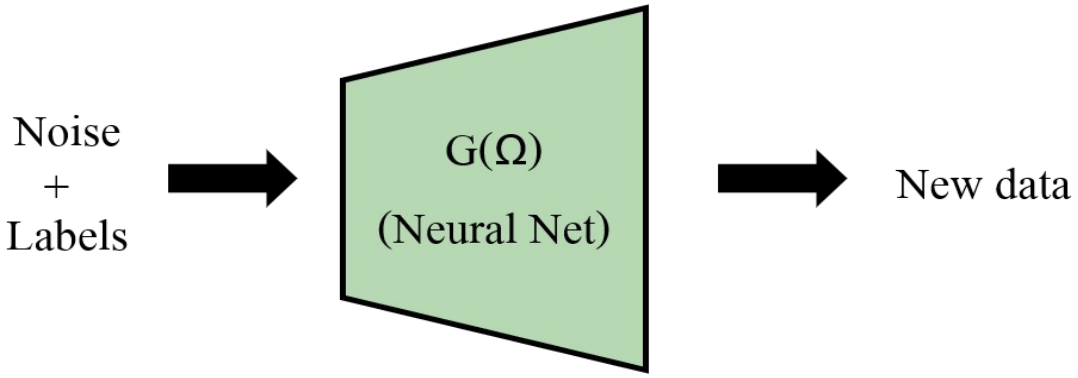
ACCLAIM Meeting

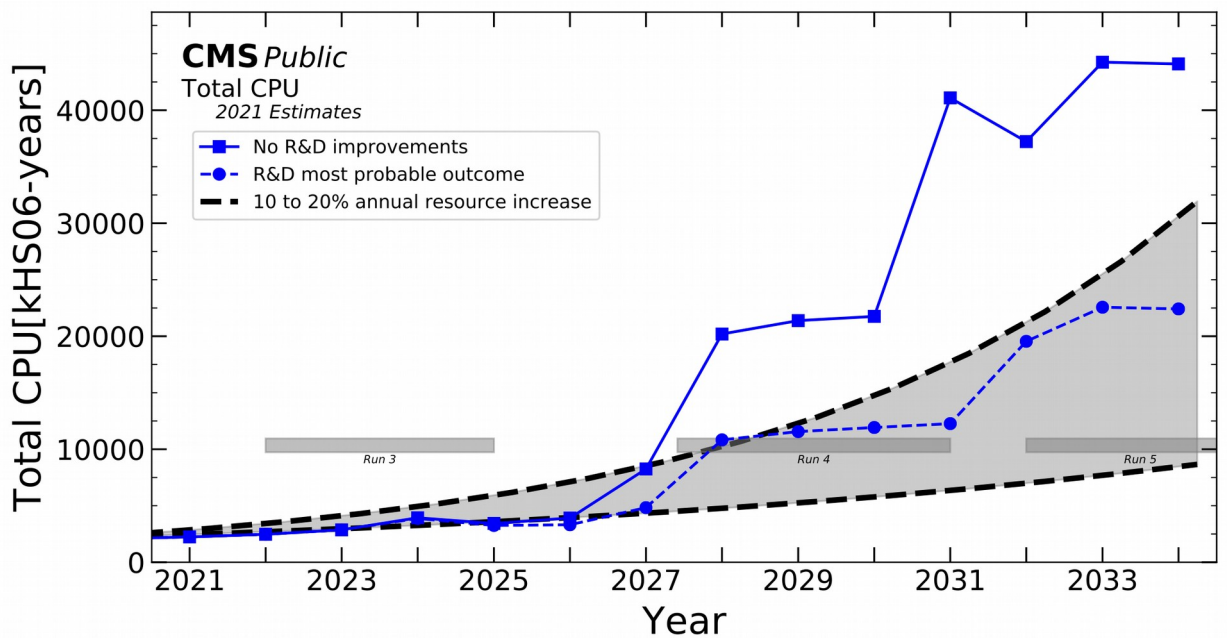
HELMHOLTZ

DESY.

Reducing the Strain on HEP Computing Resources

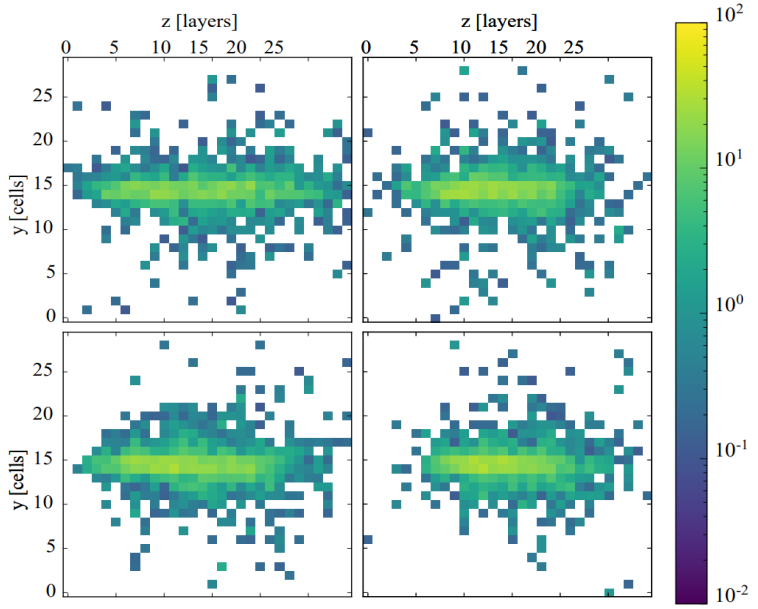
- **MC simulation (Geant4)** is computationally **expensive**
  - Calorimeters most intensive part of detector simulation
- **Generative models** potentially offer orders of magnitude speed up
- Work conducted in **DESY-FH** together with **UHH** through **QU** excellence cluster





CMS Collaboration, Offline and Computing Public Results (2021), https://twiki.cern.ch/twiki/bin/view/CMSPublic/CMSOfflineComputingResults

From Photons to Pions



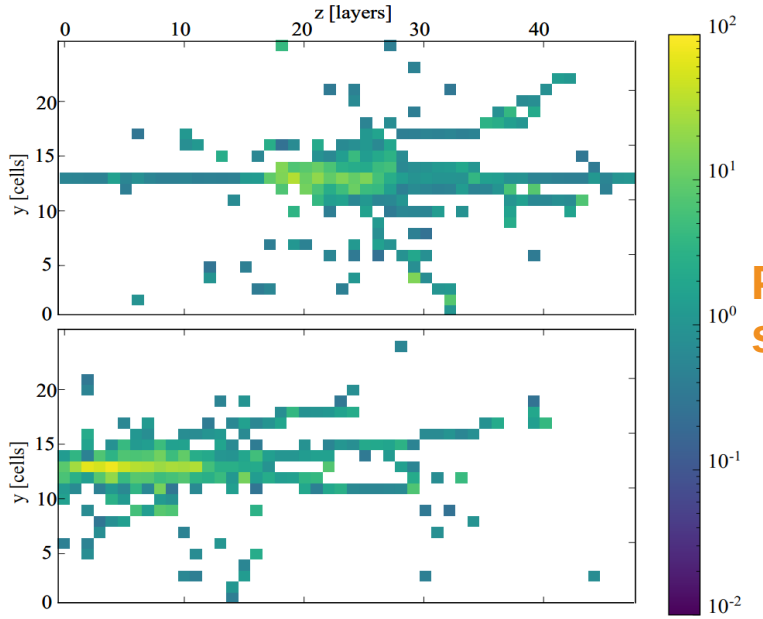
Photon showers

- Predominantly governed by **EM interactions**
- **Compact** structure

→ **Relatively easy to generalise**

Energy	Angles θ, ϕ	ECAL +HCAL	Reco
✓	+	N/A	+

Buhmann et. al: **Getting High: High Fidelity Simulation of High Granularity Calorimeters with High Speed**, CSBS 5, 13 (2021)



Pion showers

- Hadronic and EM interactions
- **Complex** structure
- Large event-to-event **fluctuations**

→ **Hard to learn**

Buhmann et. al., **Hadrons, Better, Faster, Stronger**, MLST 3 025014, (2022)

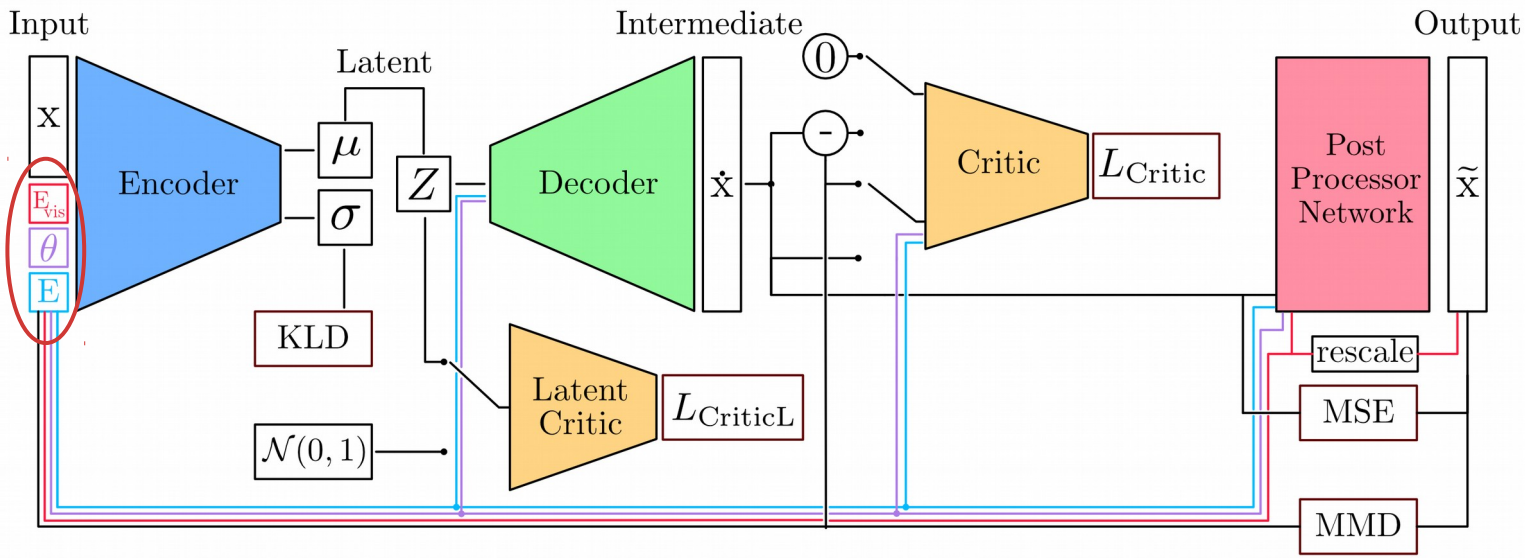
✓	X	X	−

✓ = Achieved X = Yet to be done

\+ = Addressed here − = Partially addressed

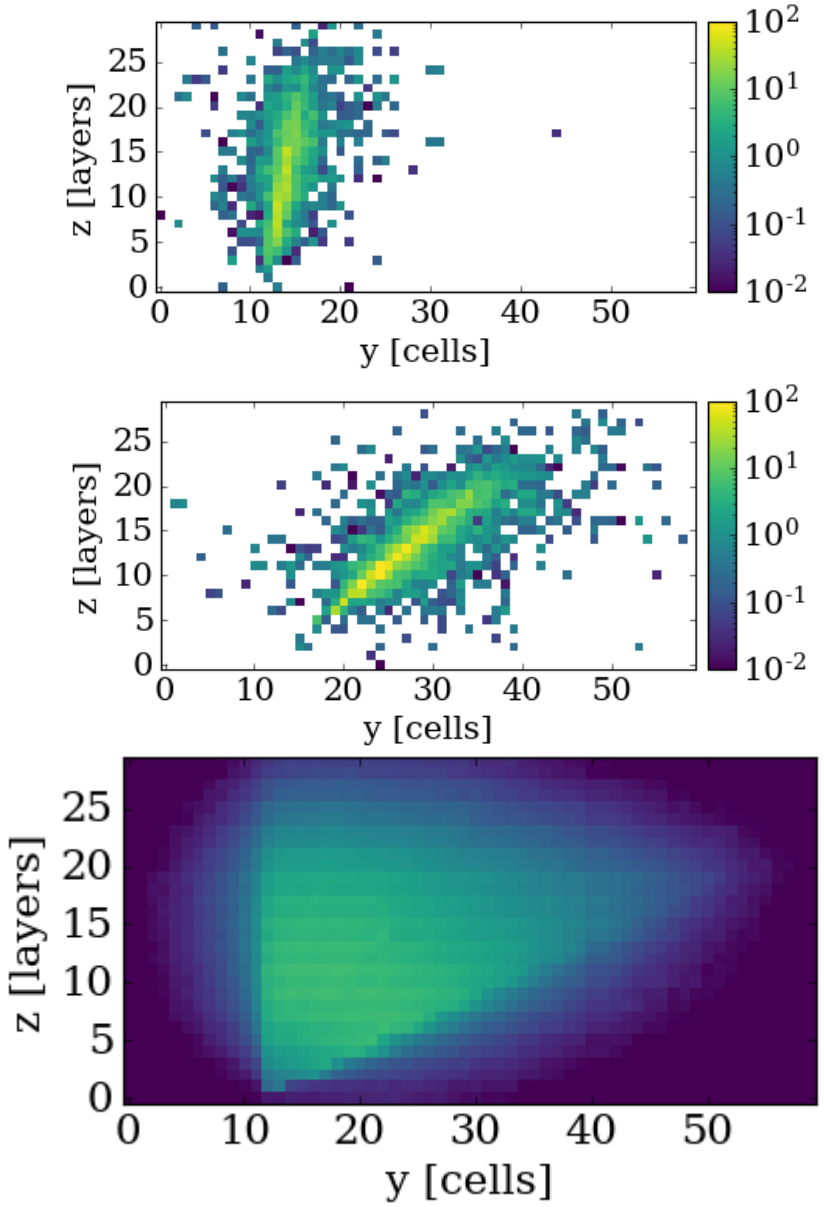
Project 1: Angular and Energy conditioning

- 500,000 photons with **fixed incident point**
- Vary **energy**: 10-100 GeV
- Vary polar **angle** in one direction: 90°-30°
- Project to **regular grid**
- Adapt **BIB-AE** model previously developed



$$L_{\text{BIB-AE}} = \text{KLD} + L_{\text{CriticL}} + L_{\text{Critic}}$$

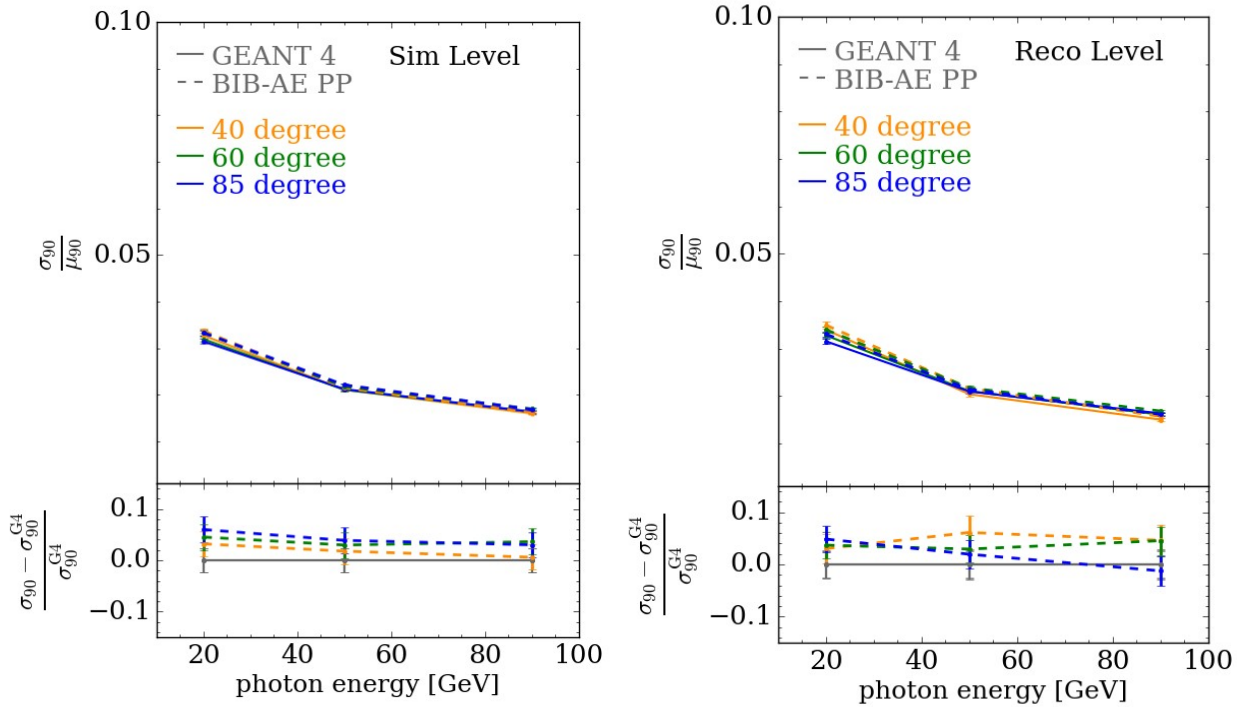
$$L_{\text{Post}} = \text{MMD} + \text{MSE}$$

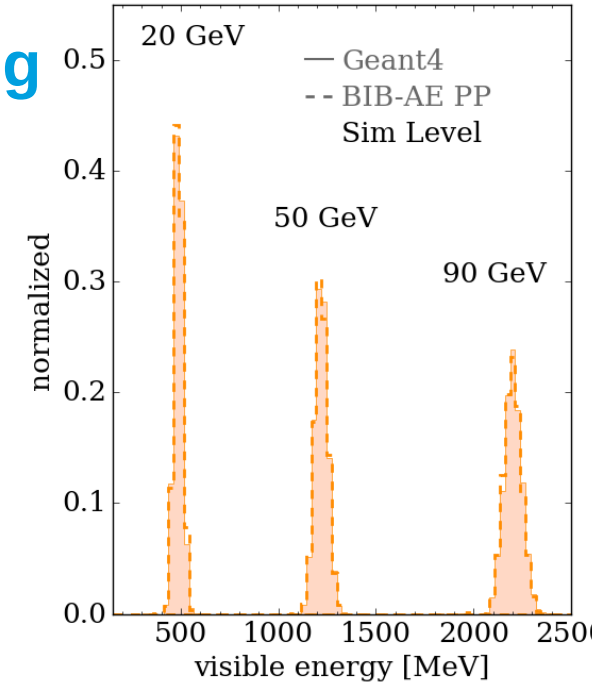


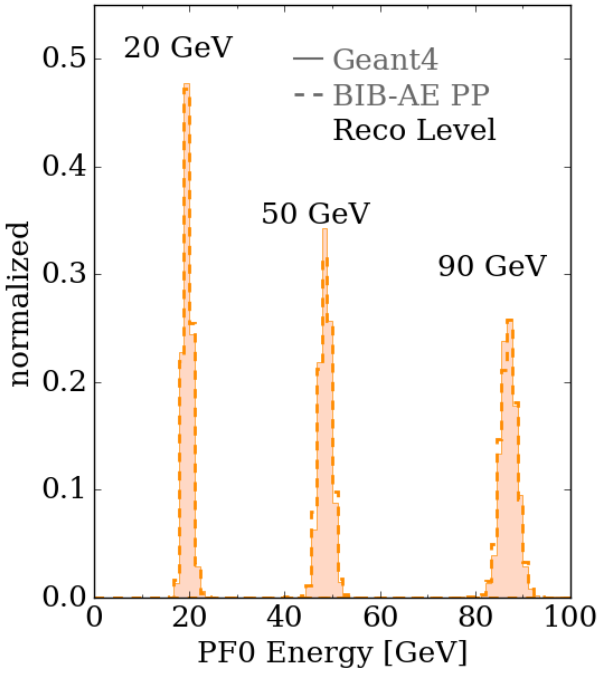
Project 1: Angular and Energy conditioning

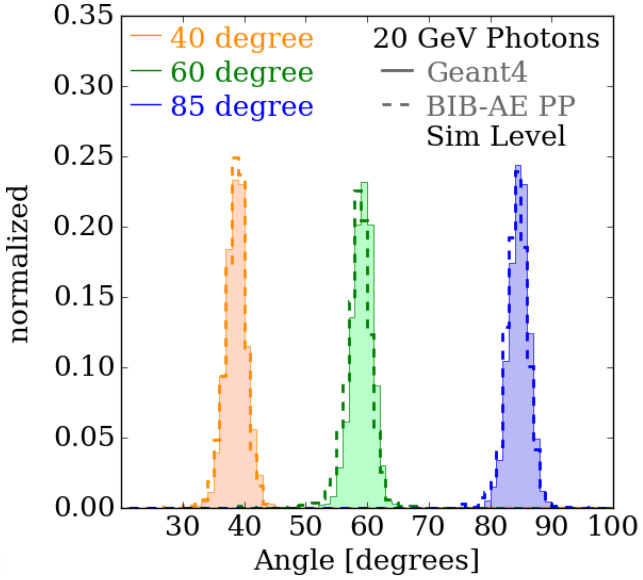
Simulation vs Reconstruction

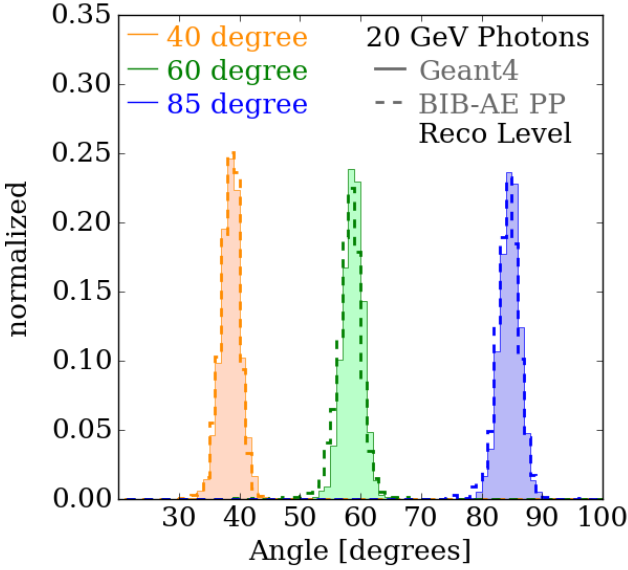
- **Normalising Flow** to generate BIB-AE latent space + Esum for given shower
- Study performance of model in reproducing **shower observables**
- Also perform detailed per-observable study after **Reco**







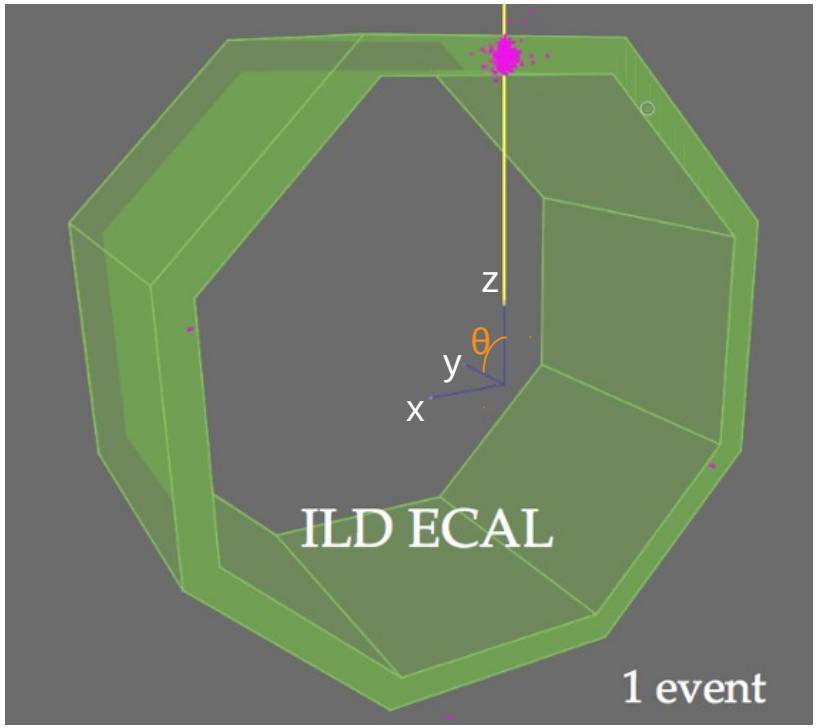


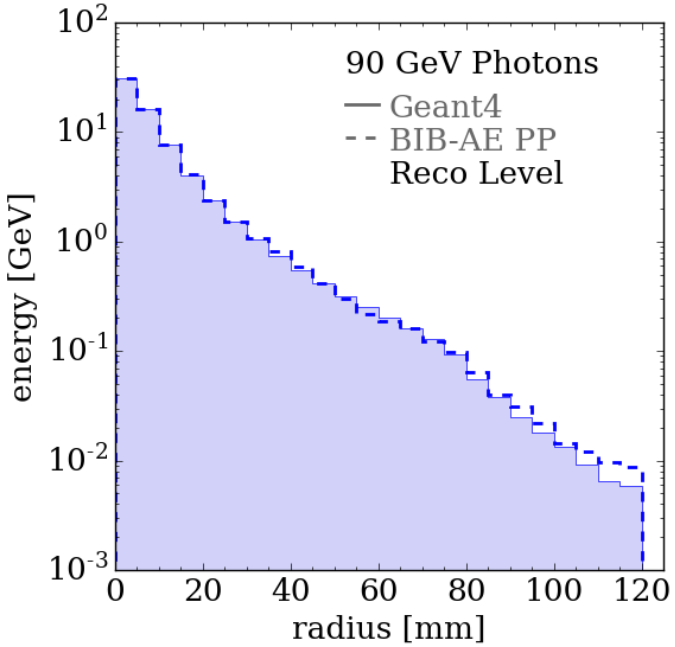


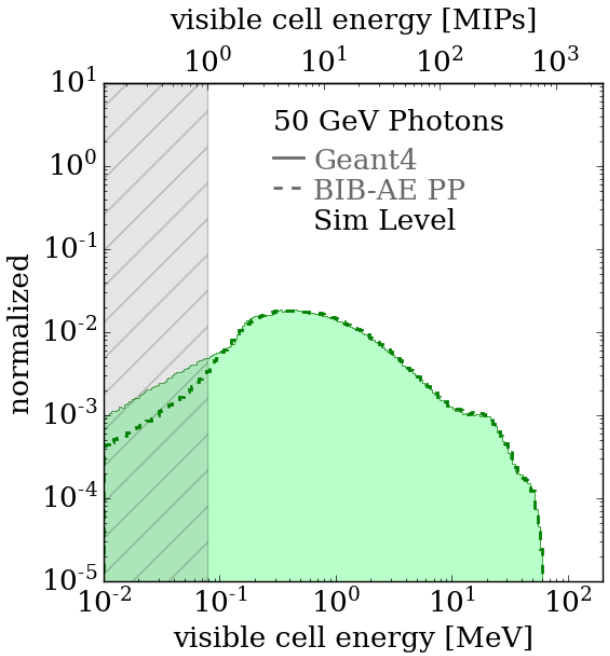
Project 1: Angular and Energy conditioning

Latest progress

- **Publication** in preparation
- Next step: **arbitrary** incidence **positions**
  - Major challenge of models trained using regular grids
  - Exploring potential algorithms for back-projection at arbitrary positions



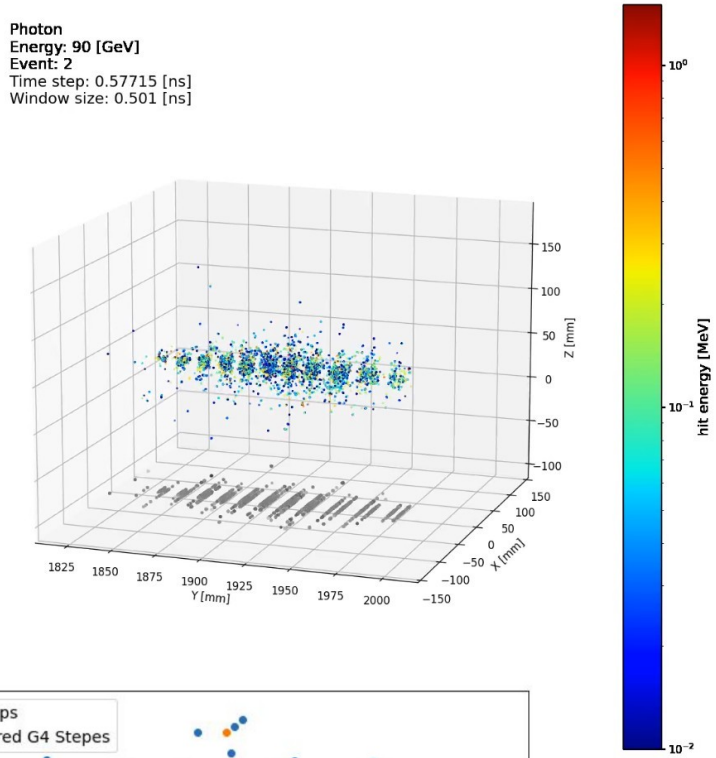


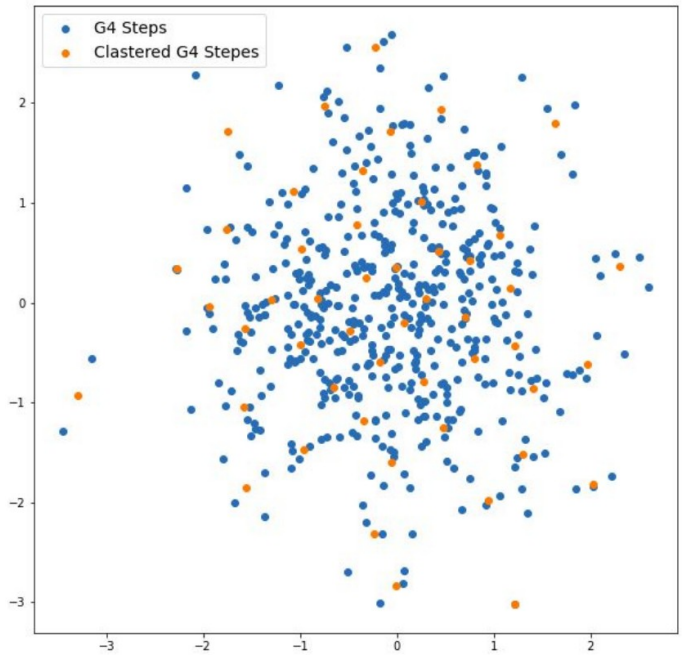


Project 2: Point clouds and diffusion models

Point Cloud

- Potential solution to the geometry problems caused by very irregular geometries
- Point clouds for photons at the level of **Geant4 steps**
  - Lower-level information than 1 cell
- **Problem**: too many points (~40k) per-shower ⟶ **slow**
- **Solution**: Clustering procedure- reduce number of points by ~x10
  - Full shower has ~4k points



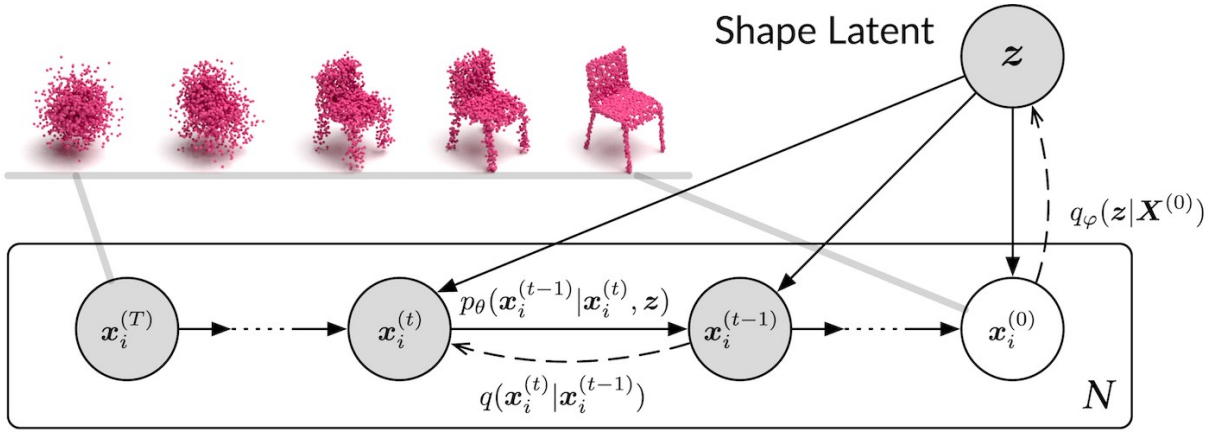


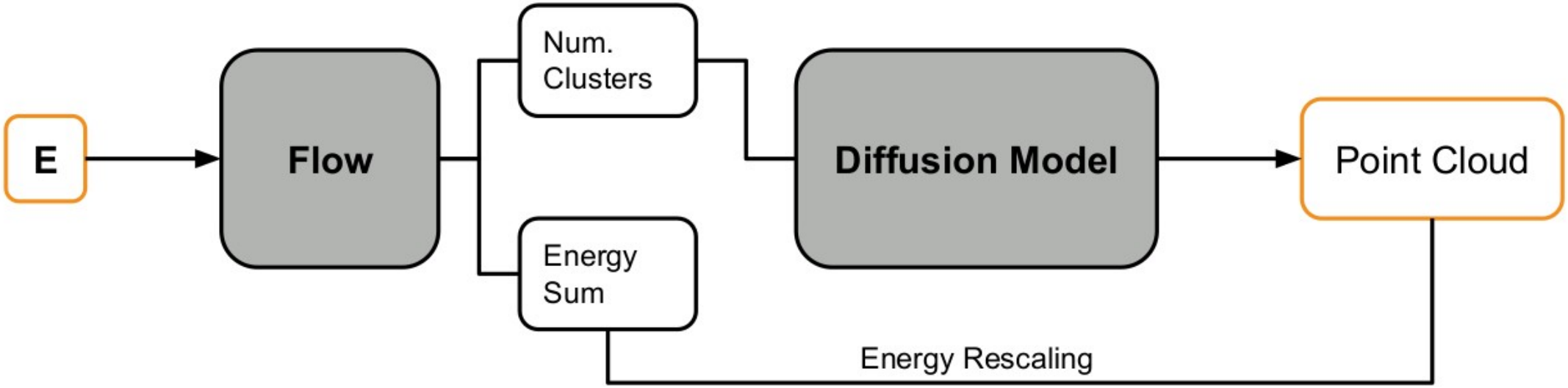
Project 2: Point clouds and diffusion models

Diffusion model

- **Diffusion** Probabilistic **Model**
  - Inspired by non-equilibrium thermodynamics
- Use **Normalising Flow** to generate number of points and ESum

Original Diffusion model:
https://arxiv.org/abs/2103.01458

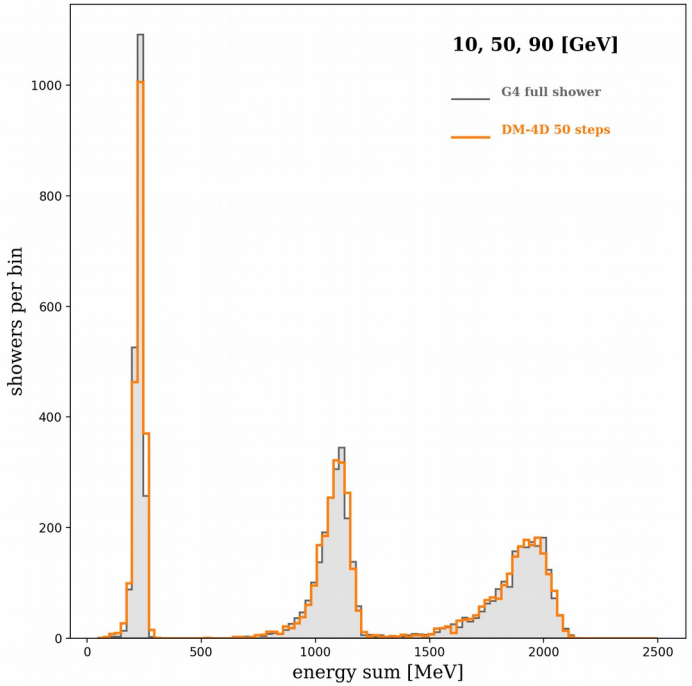


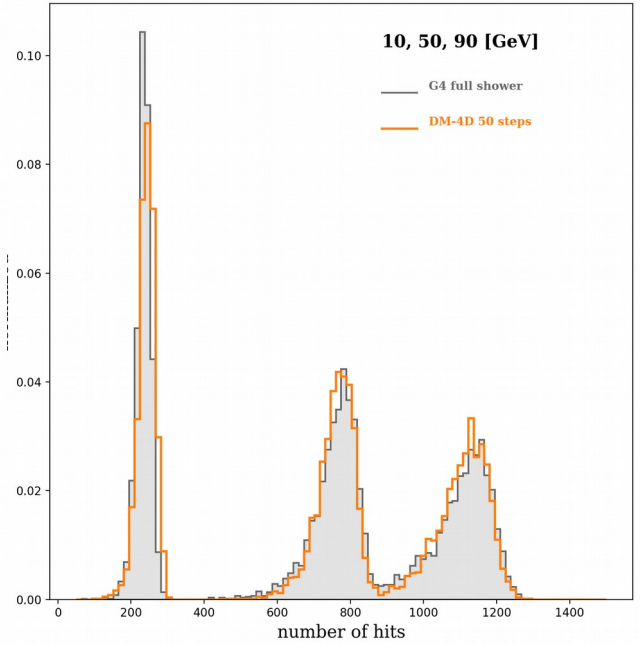


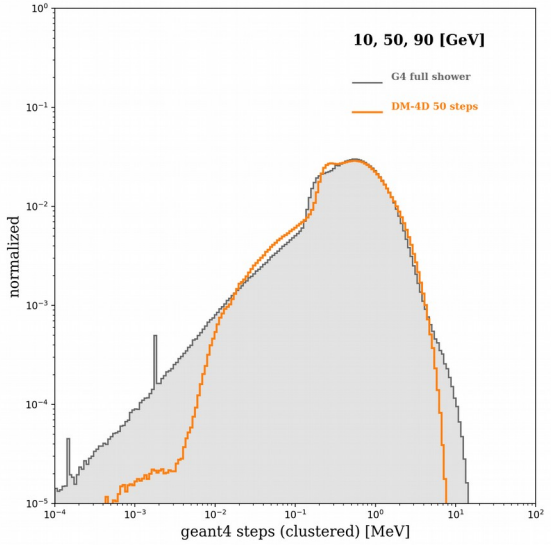
Project 2: Point clouds and diffusion models

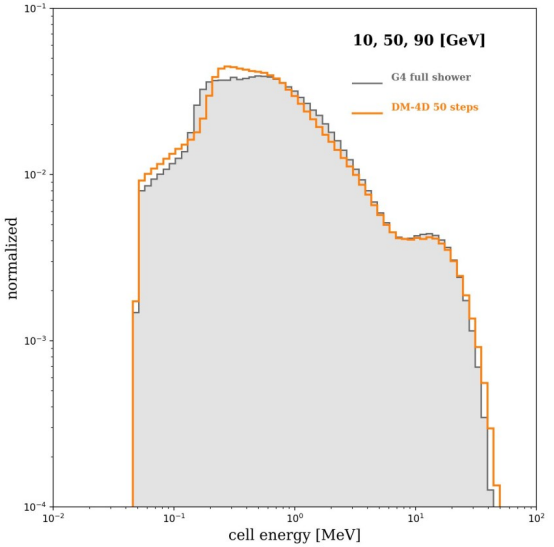
Latest Progress

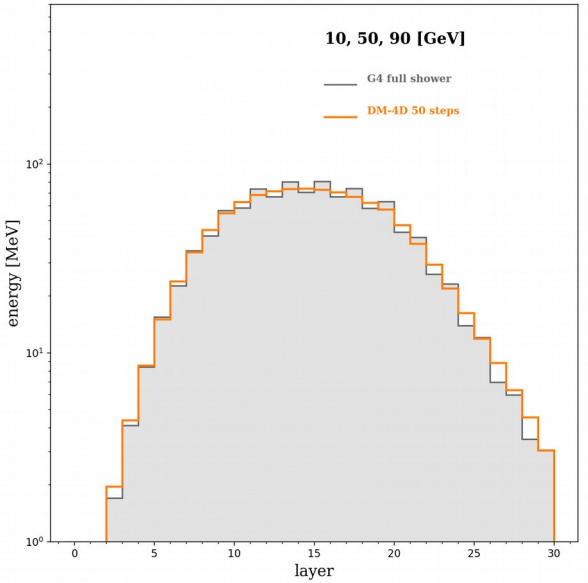
- **First** successful application of a **point-cloud** based generative model to **calorimeter simulation**
- **Publication** in preparation

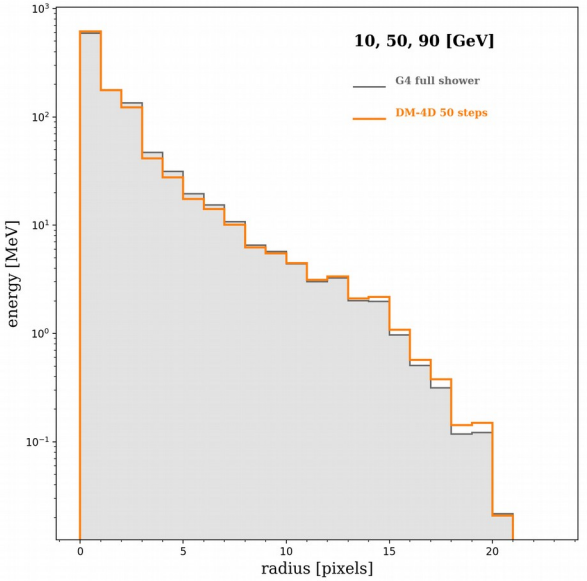












Summary

- DESY-FH continues to develop **generative ML models for fast calorimeter simulation**
- Demonstrated capability to generalise models by **conditioning** on **multiple parameters** while **maintaining performance after reconstruction**
- Developed the **first** performant **generative model** for **calorimeter point cloud** simulation
- **Publications** being prepared for both projects