CaloClouds:

Fast Geometry-Independent Highly-Granular Calorimeter Simulation

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Introduction

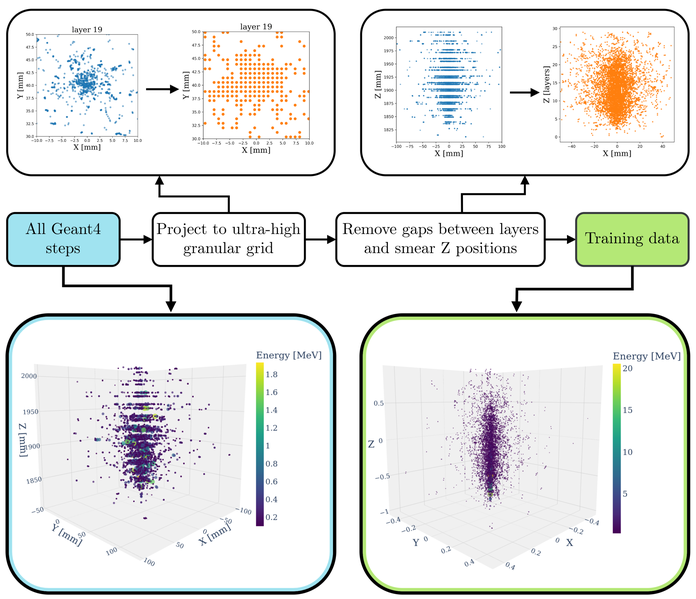
- Monte Carlo simulation vital for particle physics
- Calorimeter simulation time/resource intensive
- ➡ Fast-Sim methods desired

- Generative Machine Learning models
  - Successfully applied to calorimeters [1]
  - So far: focus on fixed grid structures [2]

- Point Cloud models
  - Generate energy deposits at arbitrary positions
  - Independent of cell geometry/translation/granularity

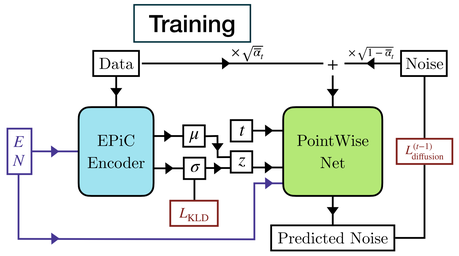
Dataset

- Photon showers in highly-granular ILD e-cal
- Start from Geant4 energy depositions
- Pre-cluster into grid 36× more granular than e-cal
- Use clusters to define point cloud
- Process to de-quantize positions of the clusters

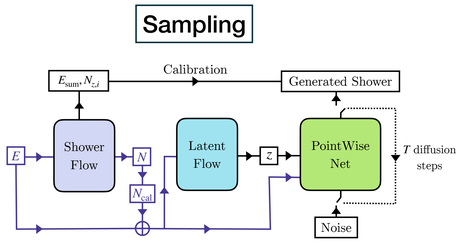


CaloClouds Model

- PointWise Net:
  - Probabilistic diffusion model [3] Maps N random points to N energy depositions



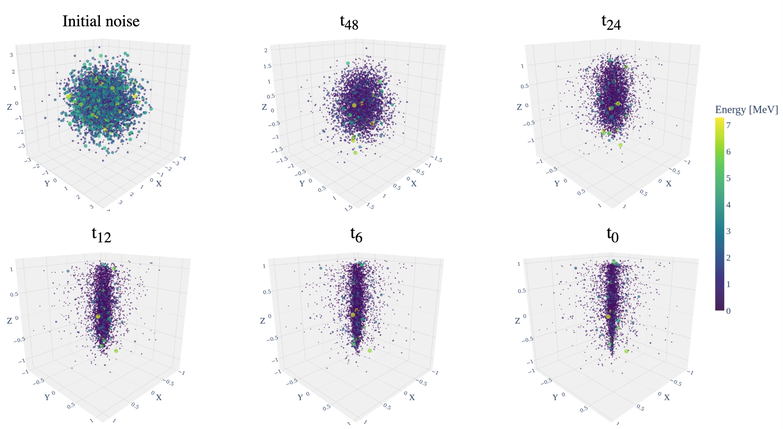
- EPiC Encoder [4]:
  - Pointwise encoder
  - Transforms real showers to latent representation



- Training:
  - EPiC Encoder builds latent vector Z from data
  - PointWise Net conditioned on latent vector Z, calibrated N, real E, and current time-step t

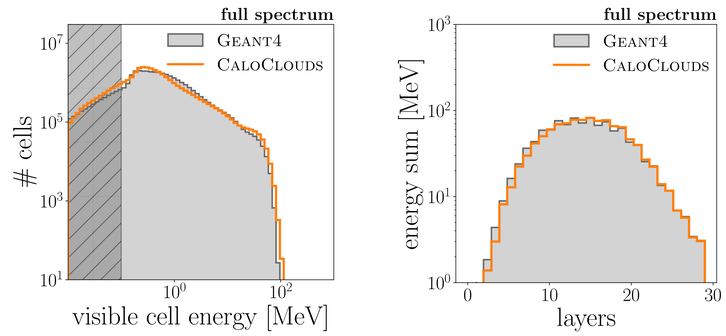
- Sampling
  - N and shower energy sampled from Shower Flow
  - Latent space sampled from Latent Flow
  - PointWise Net conditioned sampled latent and N

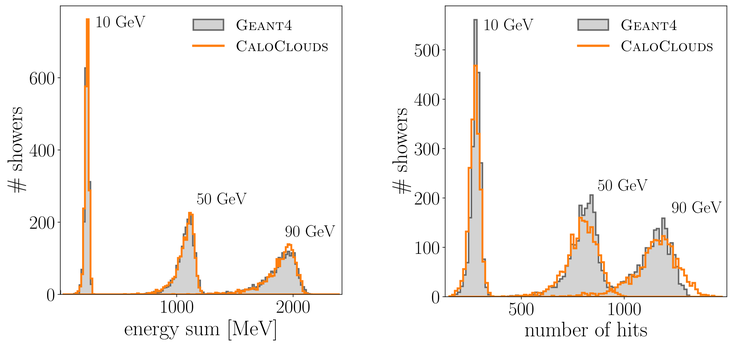
De-noising Steps of PointWise Net



Results

- Compare CaloCloud showers to Geant4 showers
- Hits projected into calorimeter cells for comparison
- High level of agreement for multiple physics variables
- Remains consistent under translation





- Similar speed to Geant4 on CPU
- Significant speedup when run on GPU
- Newer diffusion models potentially significantly faster

Hardware	Simulator	Time / Shower [ms]	Speed-up
CPU	GEANT4	4082 ± 170	×1
	CALOCLOUDS	3509 ± 220	×1.2
GPU	CALOCLOUDS	38 ± 3	×107

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[1]: arxiv.org/abs/2109.02551
[2]: arxiv.org/abs/2303.18150
[3]: arxiv.org/abs/2103.01458
[4]: arxiv.org/abs/2301.08128

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