CaloClouds 3: Ultra-Fast Geometry-Independent Highly-Granular Calorimeter Simulation

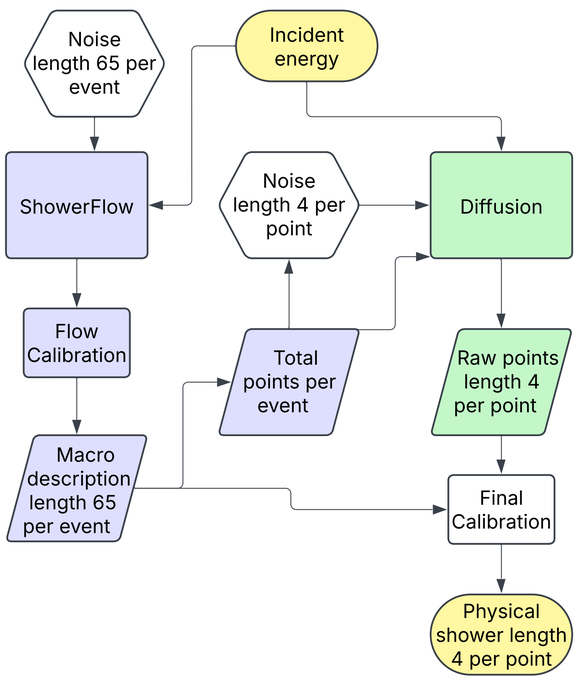
Thorsten Buss, Henry Day-Hall*, Frank Gaede, Gregor Kasieczka,
Katja Krüger, Anatolii Korol, Peter McKeown, Lorenzo Valente
*henry.day-hall@desy.de

Premise

Calorimeters are the most time consuming part of detector simulation. Future high granularity calorimeters make this worse. Fast simulation tools prevent simulation statistical uncertainties from dominating measurements.

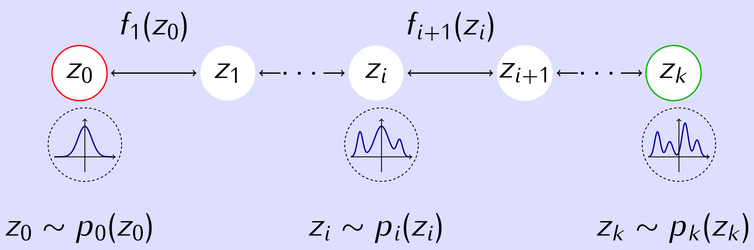
CaloClouds 2

Previous iteration of fast photon shower model for high granularity calorimeter.
Incident particle conditioning is **only energy**.



ShowerFlow provides extensive macro description of each event. **Large flow model**, with 70 transforms total. Diffusion generates indervidual energy deposits as an iid distiribution. **Diffusion model is large**, and conditioned on total particles and incident particle energy. **Training data is location specific**, with detector artefacts.

Normalising Flows



Invertible sequence of transforms from Gaussian to complex distribution.

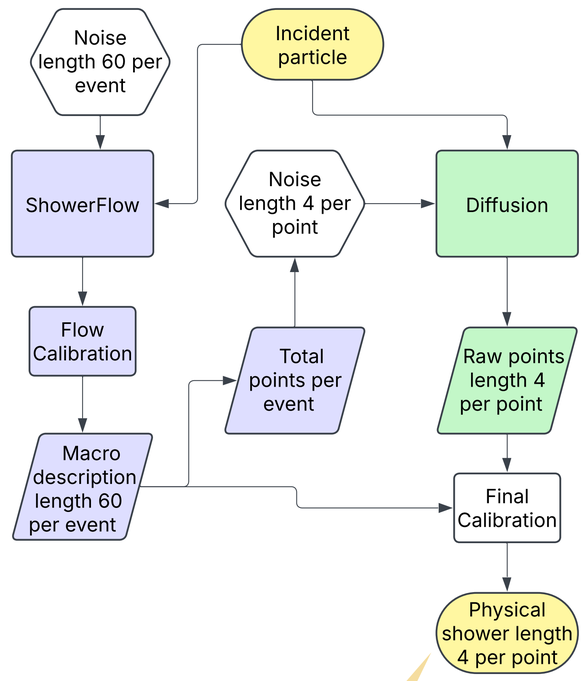
Diffusion model

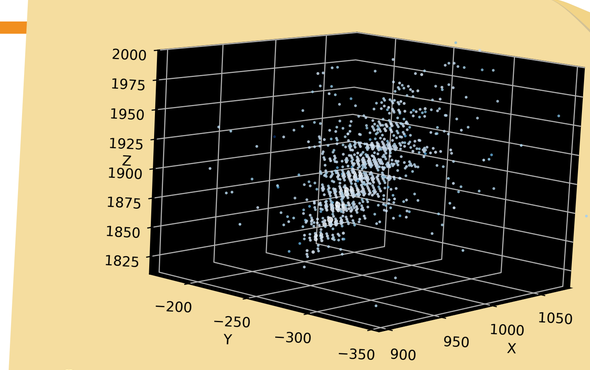
Train model to incrementally remove entropy from distribution.

CaloClouds 3

Latest iteration of fast photon shower model for high granularity calorimeter.
Incident particle conditioning is **both direction and energy**. Training data is position independent. So the model can simulate any regular location in the calorimeter.

ShowerFlow provides only profile along the shower axis. Systematically minimised flow model for faster inference. **Diffusion model is reduced**, and conditioned only on incident particle.





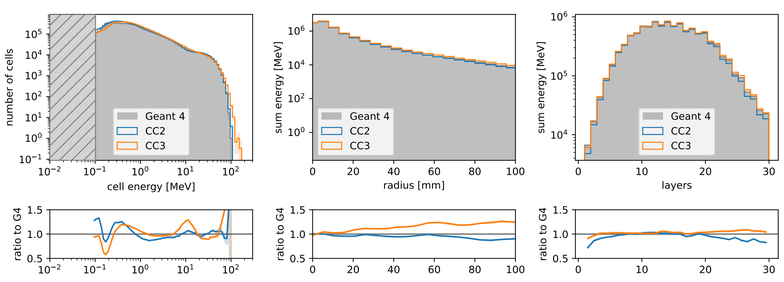
Sample from CaloClouds 3 for photon with $E = 40$ GeV.

CaloClouds 2 → CaloClouds 3 Upgrade Summary

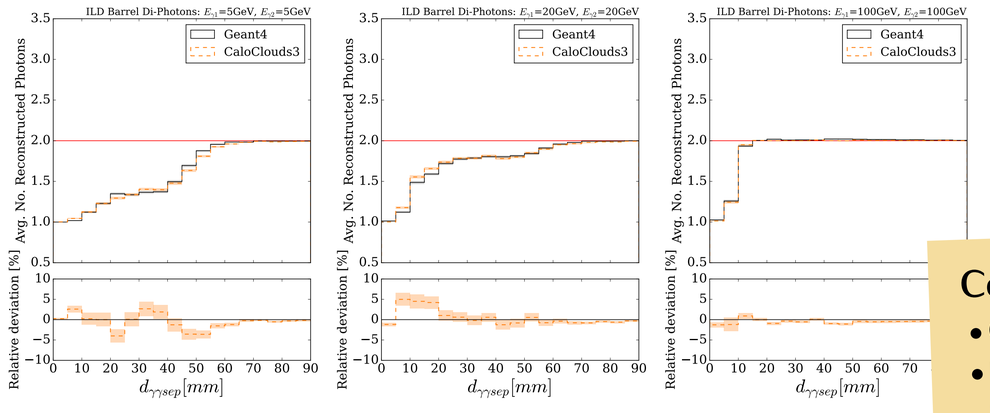
- Model composition simplified and systematically optimised for faster inference.
- Trained on position independent data.
- Conditioning includes photon direction.

Physics performance

Kinematic performance of CaloClouds 3 is on par with CaloClouds 2.

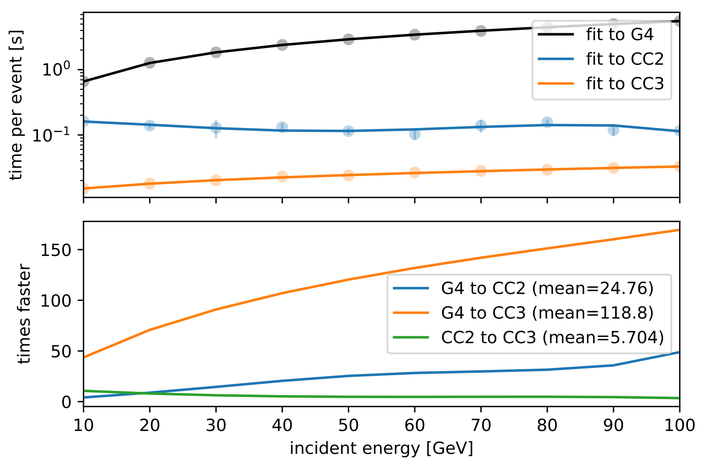


As CaloClouds 3 can be conditioned on photon direction, it can be used in arbitrary reconstruction tasks. It's **behaviour replicates Geant4** within errors.



Inference speed

CaloClouds 3 is ≈ 6 times faster than CaloClouds 2 and **two orders of magnitude faster** than Geant4.



Conclusions

- CaloClouds 3 replicates Geant4 in studied reconstruction tasks, while being ≈ 100 times faster.
- Point cloud approach is optimal for high granularity calorimeters; no time is wasted simulating empty space.
- With domain specific optimisations, normalising flows and diffusion models offer fast and accurate inference.

Deutsches Elektronen-Synchrotron DESY
Ein Forschungszentrum der Helmholtz-Gemeinschaft