Fast Shower Simulation for Future Detectors

Cinyu Zhu | 12.07.2024

About Myself

Cinyu from Hangzhou, China

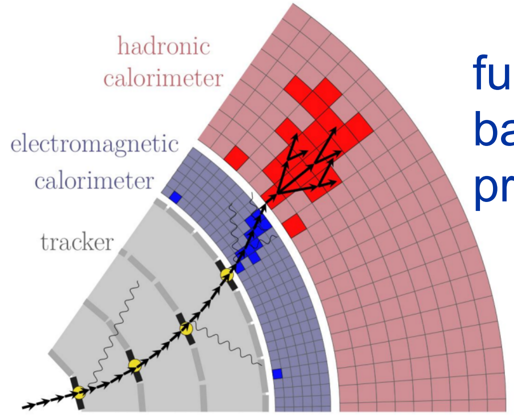
2019 - 2024 Zhejiang University, Bachelor in Physics
Thesis: Prospect of measuring the top quark mass via jet substructure

2023 DESY Zeuthen Summer Student
Determination of top-Yukawa coupling from ttbar dileptonic channel with ATLAS experiment

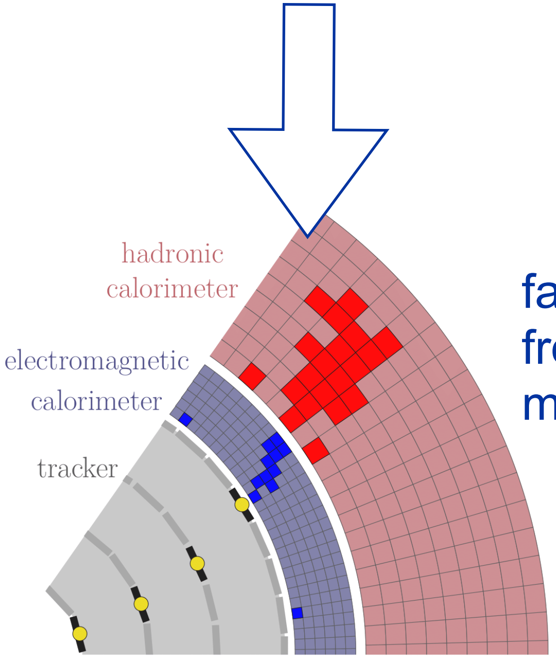
2024 -> ? : Johns Hopkins University:
DAMIC-M experiment (Dark Matter In CCDs)

fun facts:
flutist & piccoloist. once appeared in a commercial movie (as a background orchestra)
hobbies: swimming, spending the rest of my time on Switch/Steam

Motivation



full simulation
based on the physics
processes



fast simulation
from generative ML
models

Traditional detector simulation based on actual physics process is computationally expensive, especially at the calorimeter

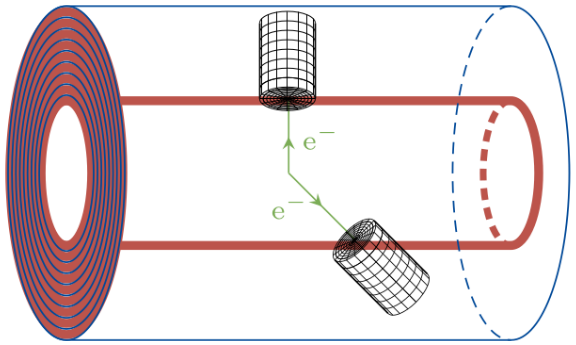
-> Use generative ML models

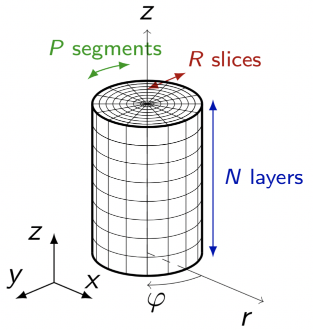
However, designing and training models for each experiment requires dedicated ML expertise and expensive computational resources

Goal: Develop a generalizable ML model with a generic energy scoring mesh, to make FastSim easily available for different detectors without access to ML expertise.

credit: https://g4fastsim.web.cern.ch/

Detector FastSimulation





credit: https://g4fastsim.web.cern.ch/

1. construct a virtual mesh (a container/virtual scoring of energy) that aligns with the direction of the incident particle and is agnostic of the real detector geometry

2. In this virtual mesh, train and validate the ML models that generate the energy deposition of each virtual cell

by computer science experts

3. integrate ML model inference into the production simulation framework (e.g. KEY4HEP)

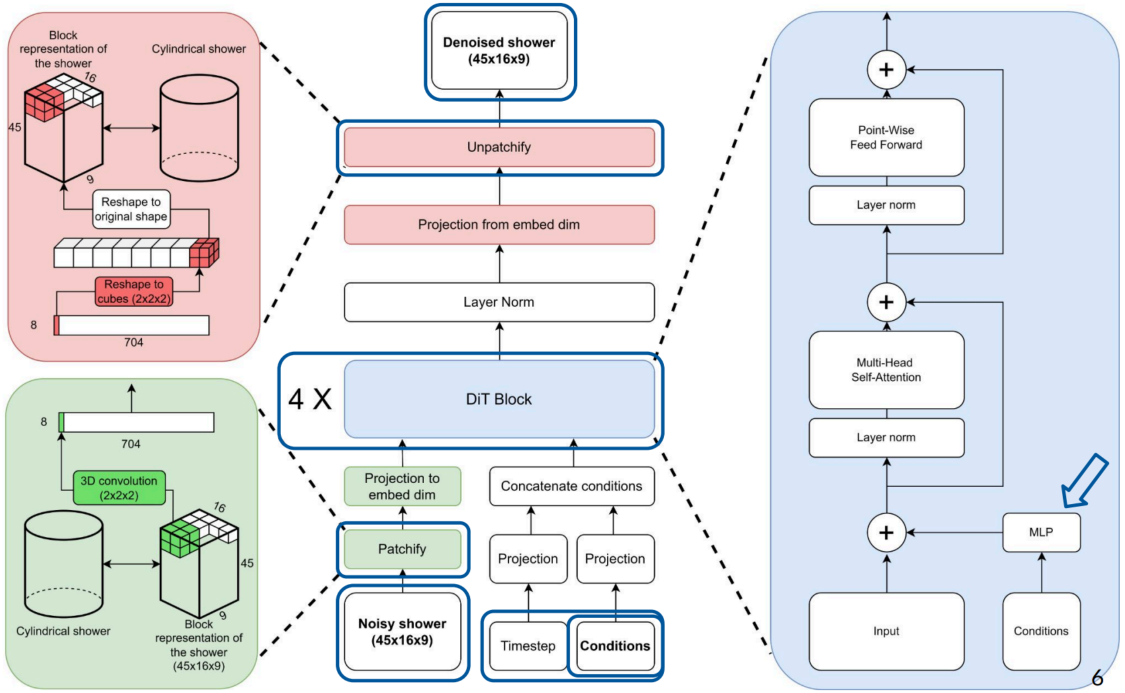
4. In key4hep, generate events with ML models, map the energy from the virtual mesh to the realistic detector cells (by DDML library)

5. validate the result in realistic detector geometry with detector performance observable

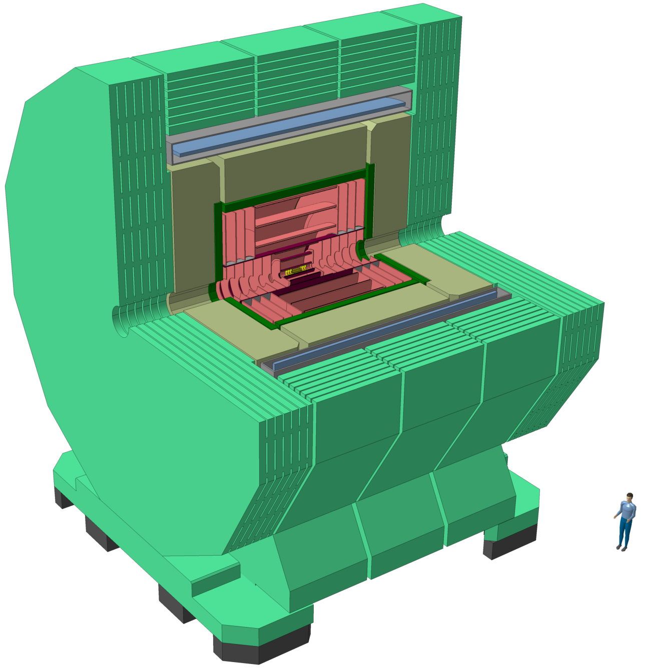
5. reconstruct the primary particle, validate the result by comparing physics observables

CaloDiT Model and FCCeeCLD

CaloDiT: diffusion transformer architecture

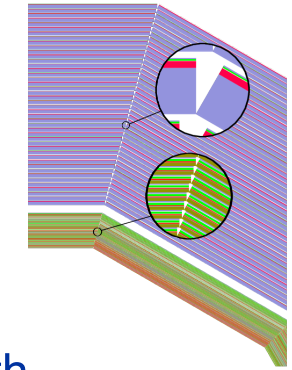


arxiv: 2212.09748



CLD ECAL:

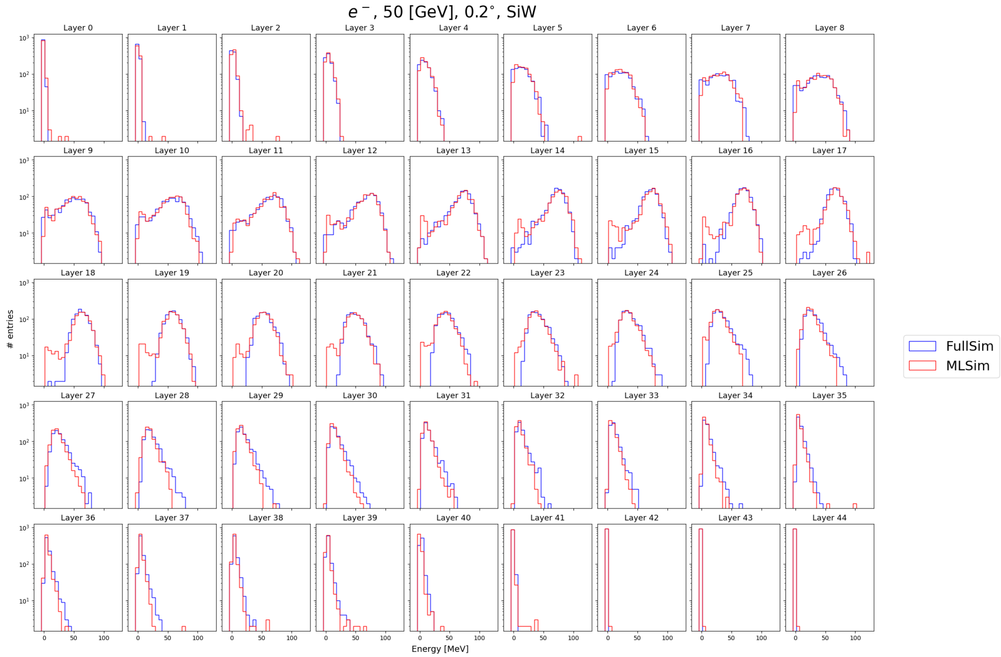
40 layers, 1.9 mm tungsten absorber
0.5 mm thick silicon sensors with 5×5 mm2 granularity



arxiv: 1911.12230

Current Progress

- set up the environments, cloned repositories.
- successfully run the full and fast simulation (BIB-AE model)
- start the training Calo-DiT for FCCeeCLD ECAL
- start working on converting the Calo-DiT model to torch script, so later it could run in the C++ environment of DD4HEP for

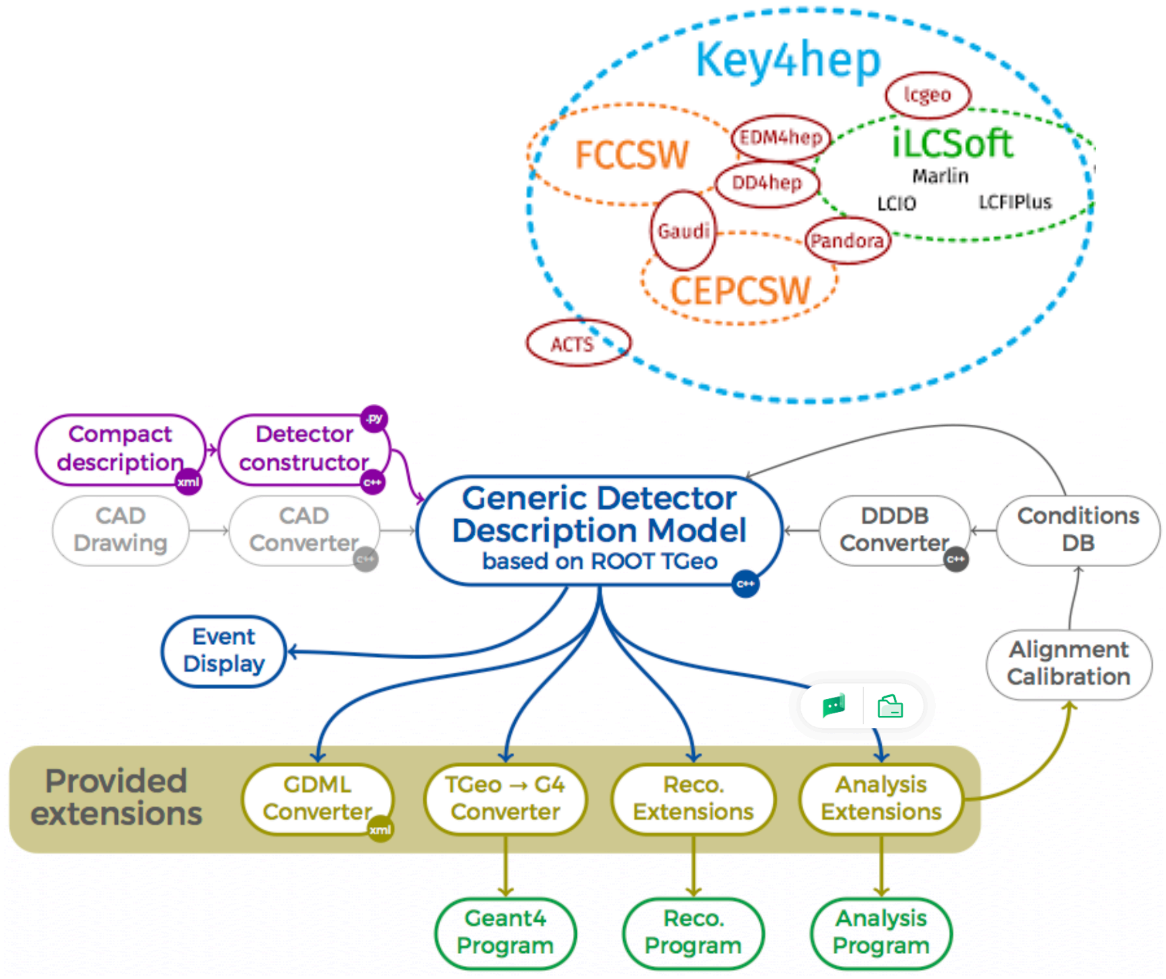


energy deposition distribution after 156 training epochs

Next:

- in DD4HEP, use the converted model to generate simulated showers, and map them into the CLD Geometry
- in the CLD detector geometry: validating the result
- reconstruct and validate the energy of incoming particles

Key4HEP, DD4HEP, DDML



The components of the DD4hep detector geometry toolkit.

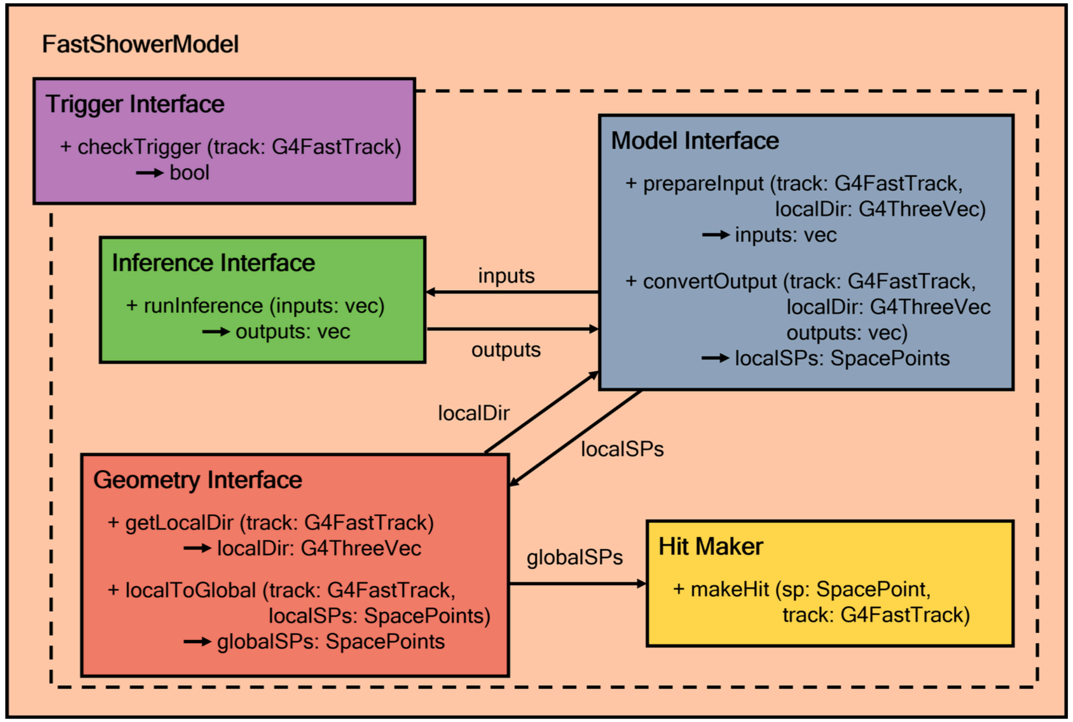


Figure 9.1: Class diagram for the core components of the *DDFastShowerML* library. For the purposes of illustration, slight simplifications have been made with respect to the actual implementation, which includes some memory optimisations such as re-using existing allocations from previous events.

Credit: Peter McKeown

Detector Description Toolkit
https://dd4hep.web.cern.ch/dd4hep/page/about/

can be used for all kinds of
various designs