Fast Shower Simulation for Future Detectors

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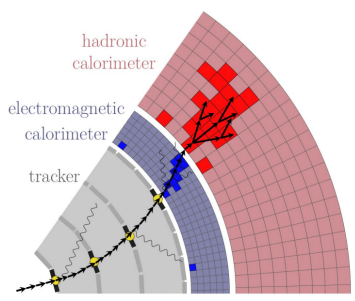
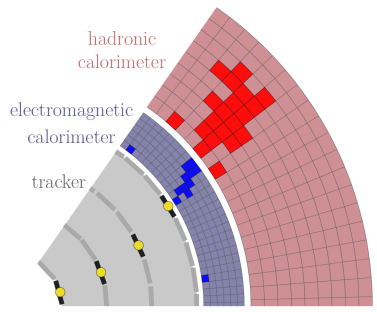
Full and Fast Simulation:



Full Simulation (e.g., Geant4):

- detailed and step-by-step modeling based on physics processes (scattering, bremsstrahlung, ionization, in-flight decay...)
- accurate but computationally expensive



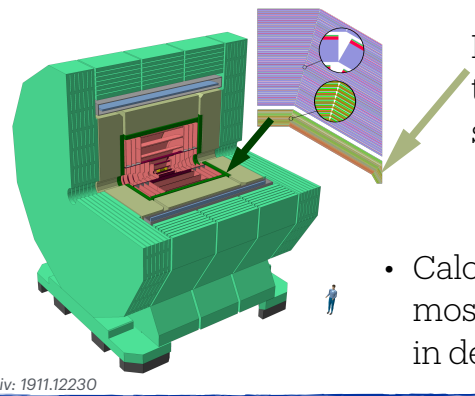
Fast Simulation:

- use generative Machine Learning (ML) models to create all hits at the detector in a single step.
- speed up simulation
- reduce the computing resources and increase sustainability

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

Electromagnetic Calorimeter at CLD:

one of the proposed detector designs for the future e+e- circular collider (FCCee)



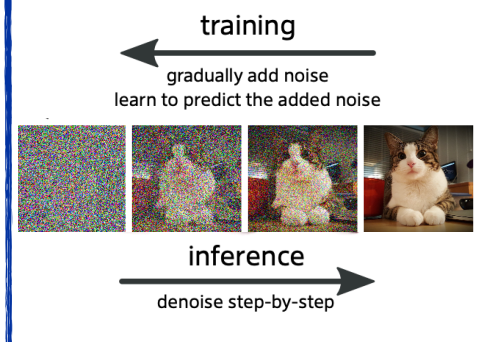
ECAL: Dodecagon (12-gon), tungsten absorber + silicon sensors, 40 layers

- Calorimeter simulation is the most computationally expensive in detector simulations.

arXiv: 1911.12230

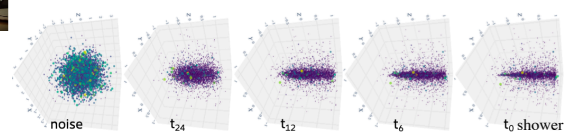
Diffusion Model:

- generate data by iterative denoising from a random initial state
- high-fidelity simulation with significant speed-up



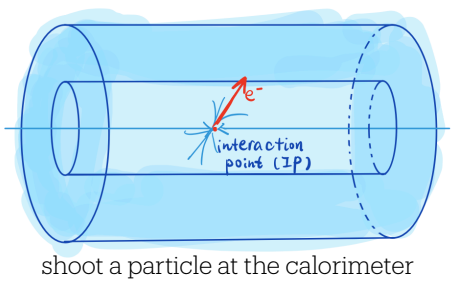
fast calorimeter shower simulation:

- training sample from the Geant4 full simulation dataset

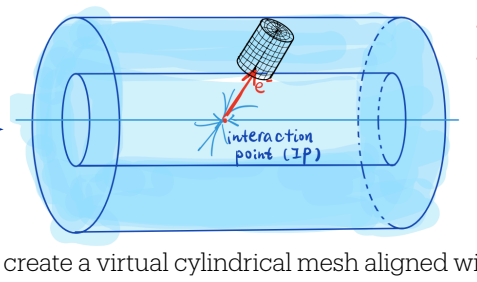


arXiv:2305.04847v2

Fast Shower Simulation Pipeline:



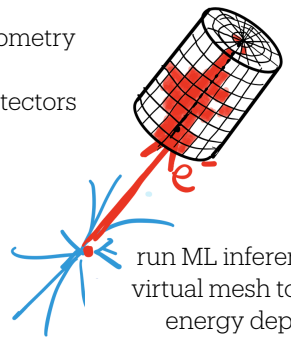
shoot a particle at the calorimeter



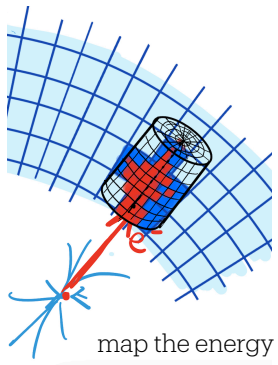
create a virtual cylindrical mesh aligned with the particle

why virtual mesh?

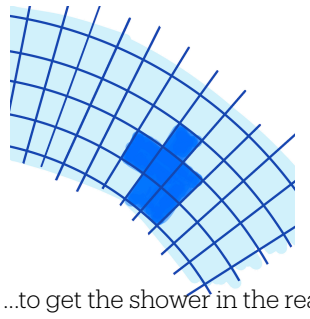
- independent to readout geometry
- generalized model
- quick adaptation to new detectors



run ML inference in the virtual mesh to generate energy deposition



map the energy deposition from the virtual mesh to calorimeter cells...



...to get the shower in the realistic calorimeter geometry

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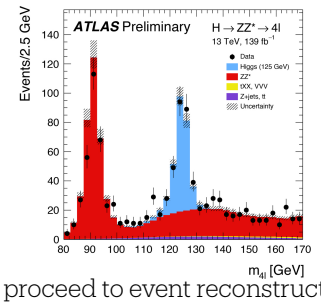
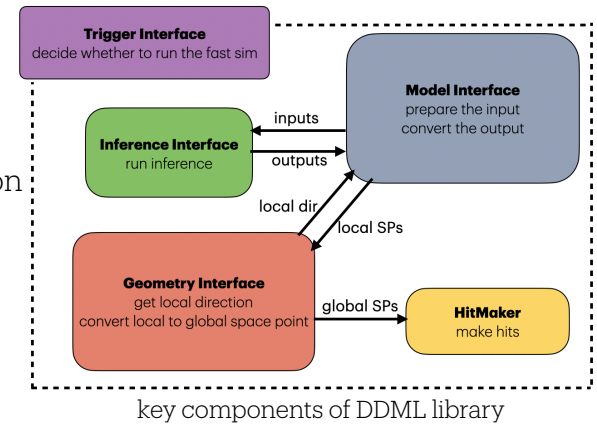


proceed to event reconstruction and physics analysis!

From Virtual Mesh to Realistic Detector Cells:

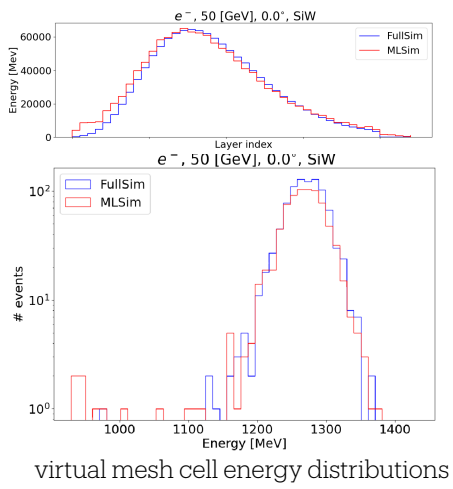
Deploy ML models (PyTorch) into the HEP software ecosystems (C++)

- Integrate fast sim inference into the DD4HEP framework via the DDML library. (work in progress)
- This allows the performance validation in realistic detector geometry and in high-level physics observables.
- DDML is generically designed for various ML models and detector geometries.

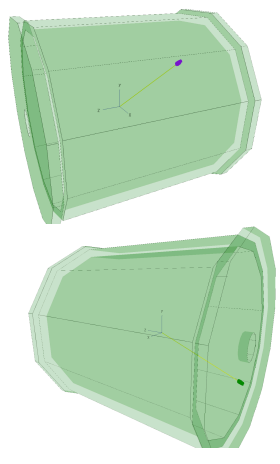


key components of DDML library

Current Result:



virtual mesh cell energy distributions

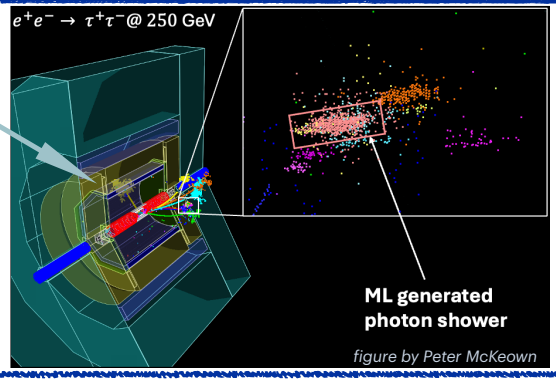


generated fast sim showers in CLD ECAL

Outlook:

- from single showers -> to full physics events -> to physics analysis
- the ultimate goal is to maintain physics performance after reconstruction for simulating full physics events (many showers per event)

simulate real events like this!



learn more about fast shower simulation: