Status of Fast simulation tool

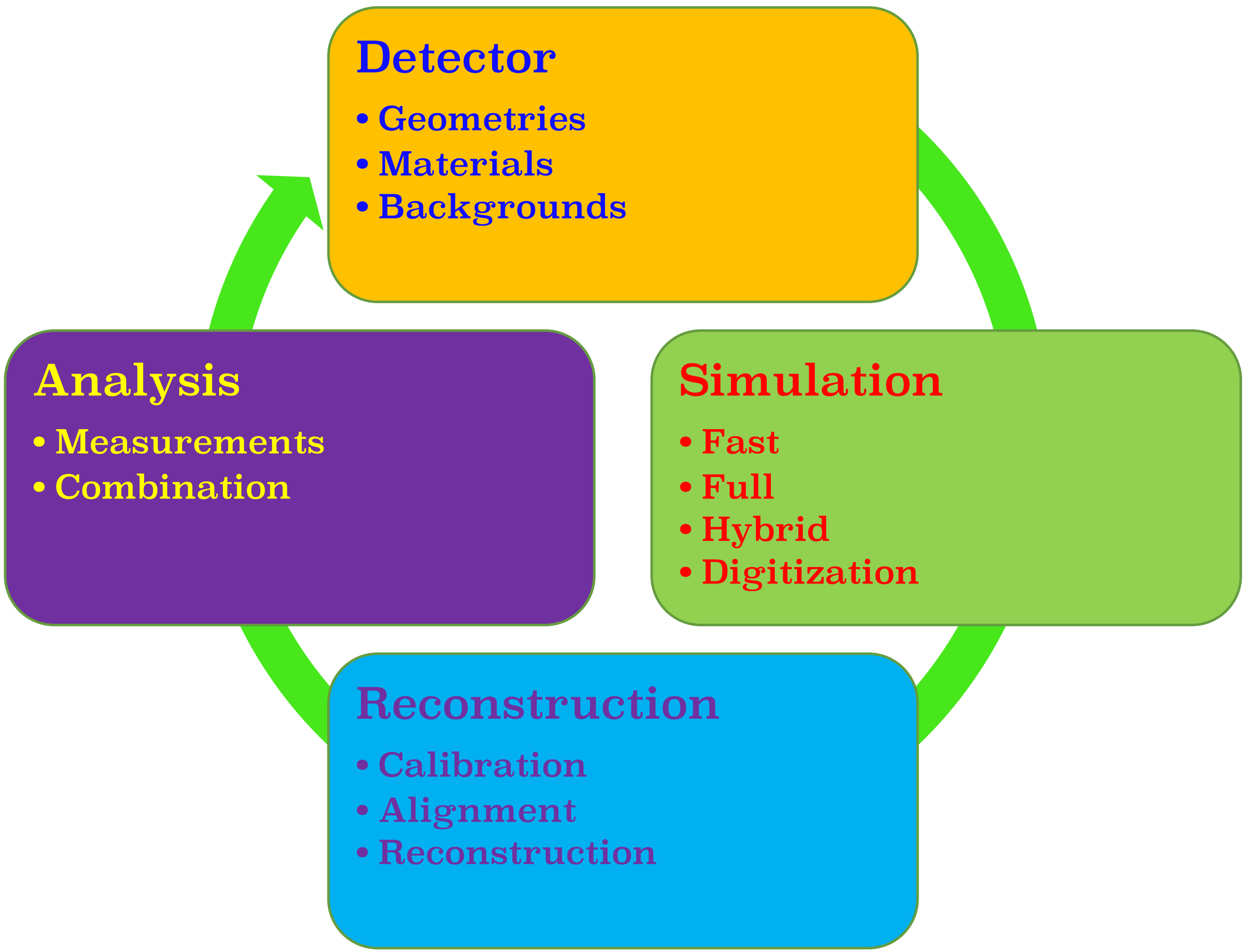
W.X. Fang, Y.B. Han, G. Li, and T. Lin

CEPC detector plenary
April 15, 2020

Motivation

- **At R&D stage, a fast/hybrid simulation tool required to optimize not only the various detector designs but software tools**
  - **Under unified EDM & framework**
  - **Easy to test various geometries and to switch between fast/full for specific sub-detectors**
  - **Fast iteration of simulation/Alignment/calibration/reconstruction/analysis**

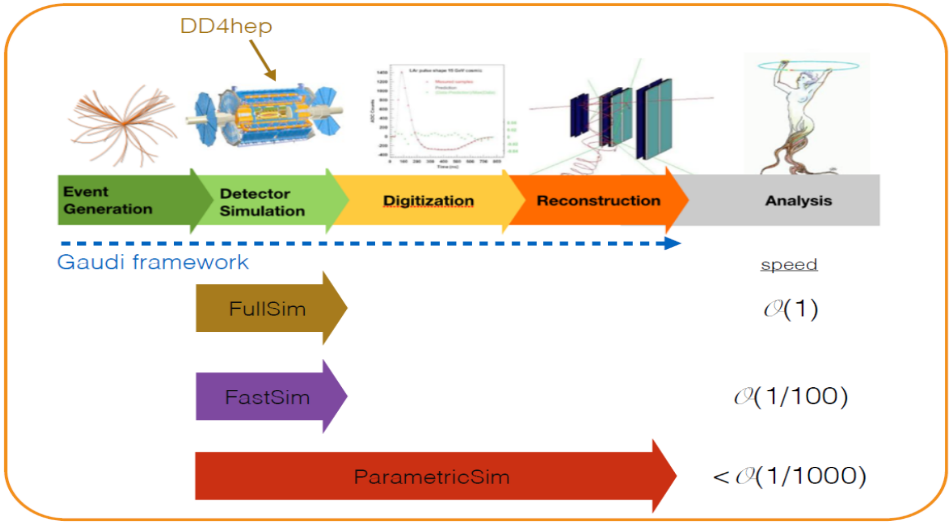
Motivation

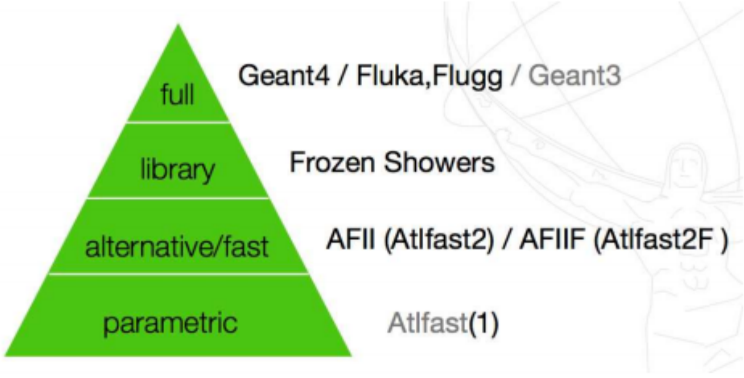

Detector
• Geometries
• Materials
• Backgrounds
Simulation
• Fast
• Full
• Hybrid
• Digitization
Reconstruction
• Calibration
• Alignment
• Reconstruction
Analysis
• Measurements
• Combination

Fast Simulation

- Three types of simulation
  - Full simulation (Geant4) $\mathcal{O}(1)$
  - Fast simulation $\mathcal{O}(1/100)$
  - Parametric simulation $\mathcal{O}(1/1000)$
- Roadmap (1): a coherent simulation framework
  - Allow mixing of full / fast simulations
  - When a particle enters a certain detector region, user-defined simulation tool could be used.
- Roadmap (2): Fast simulation tool development
  - Tracker: hit level fast simulation
  - Calorimeter: frozen showers, GAN

Data flow

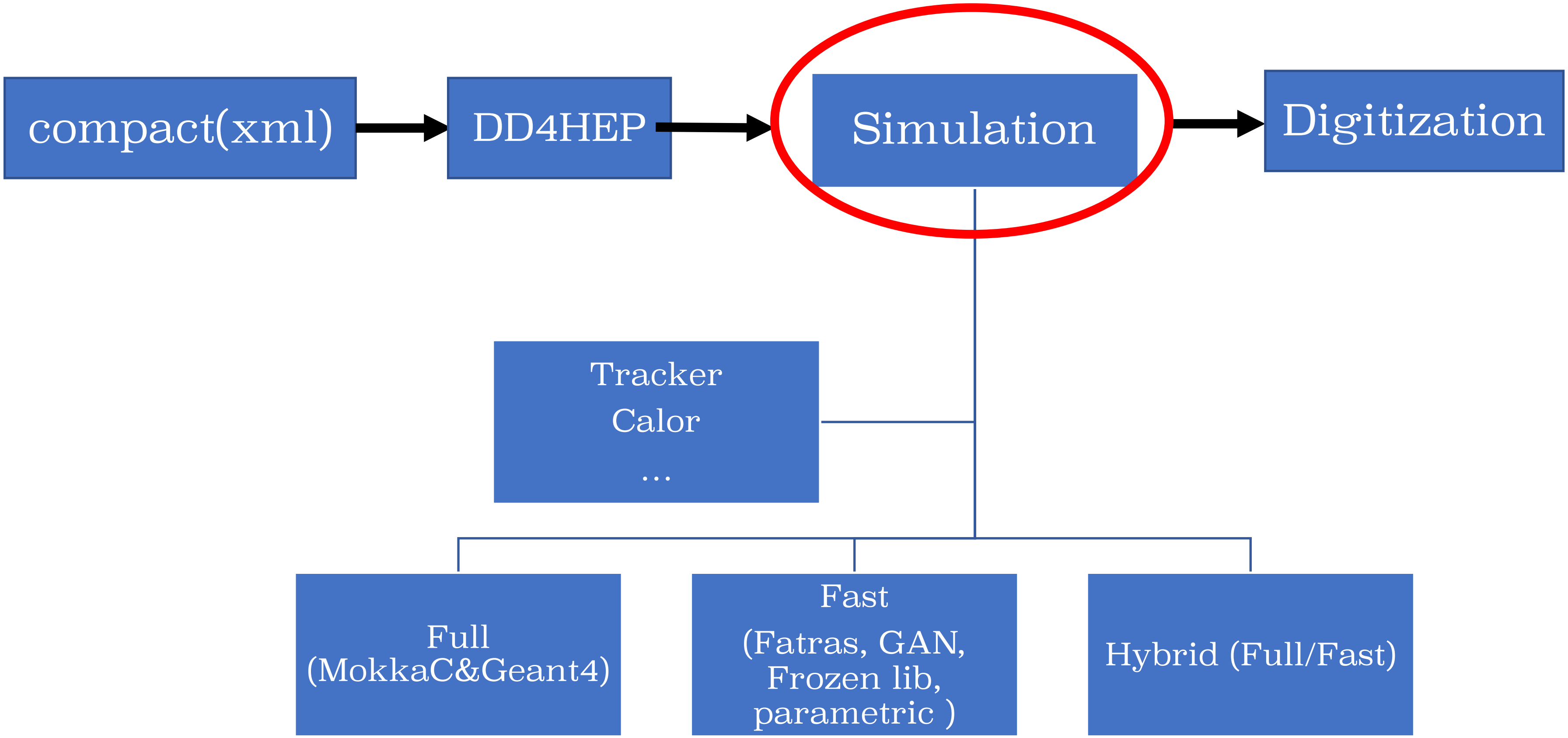




ATLAS ISF (Integrated Simulation Framework)

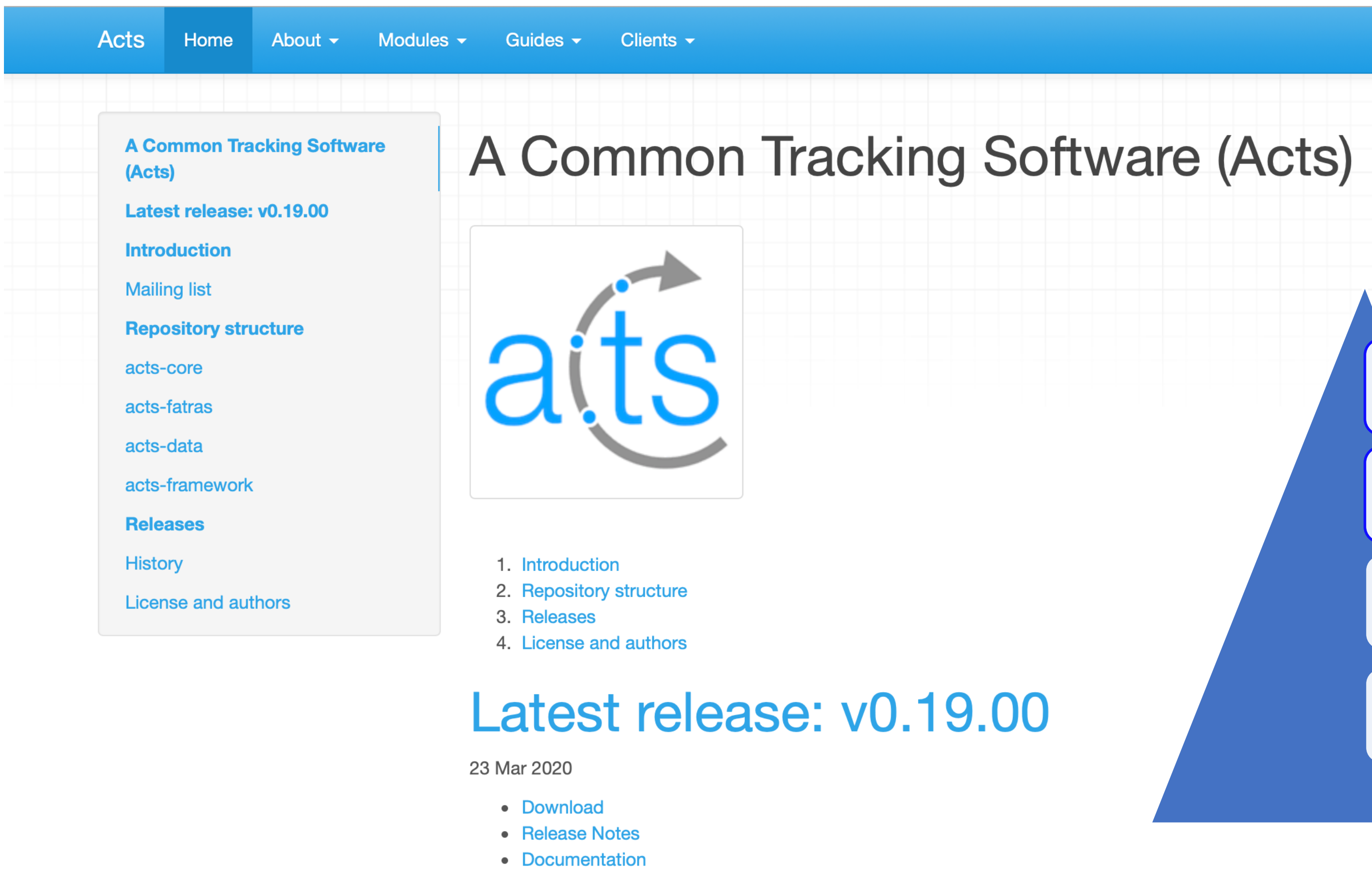
Status

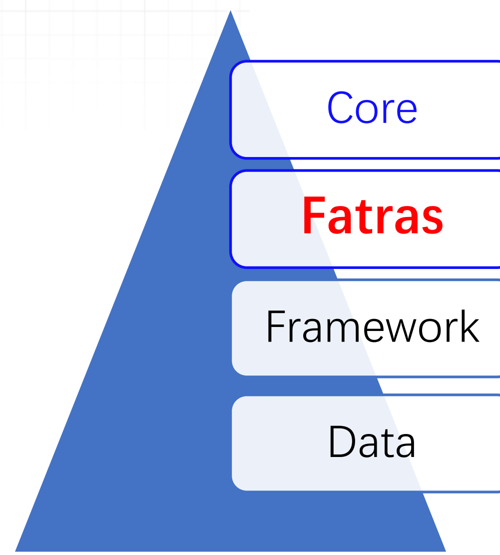
- ✓ Full covariance necessary for tracking and vertexing
- ✓ Shower fluctuation (hadron) for PFA …



ACTS: A Common Tracking Software

- Aims to provide a tracking toolkit for the future tracking community





Fatras uses

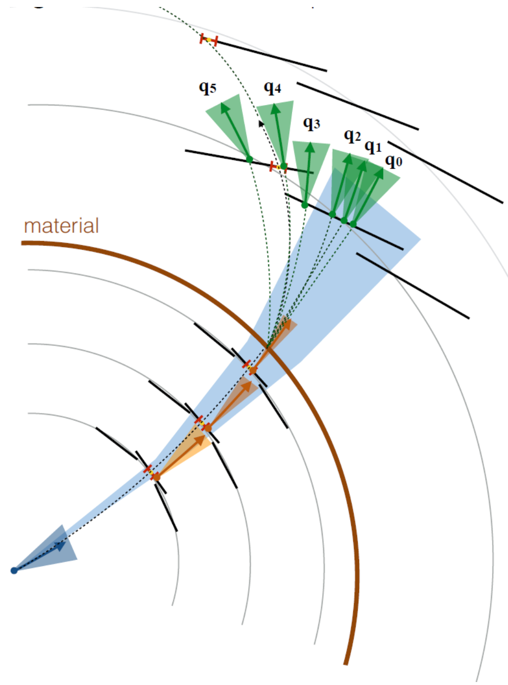
Acts::Propagator and

Acts::TrackingGeometry

to simulate particle trajectories through the tracking detector.

Customizable

- ✓ Multiple scattering is done by gaussian (mixture) approximations
- ✓ Ionization loss is calculated using the Bethe-Bloch formalism
- ✓ Radiation loss follows Bethe-Heitler formalism
- ✓ Limited nuclear interaction processes are parameterized from Geant4



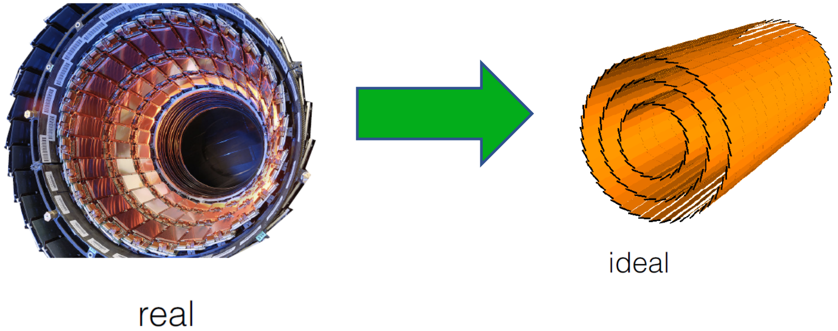
From YuBo

Tracking Geometry

- Tracking Geometry =

  Simplified geometry + approximated material

  - full detailed detection module
  - Simplified material description

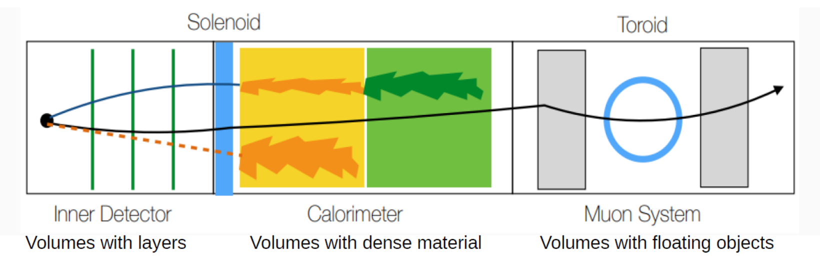


- ACTS : DD4HEP and TGeo

➡ G4, fast simulation and reconstruction

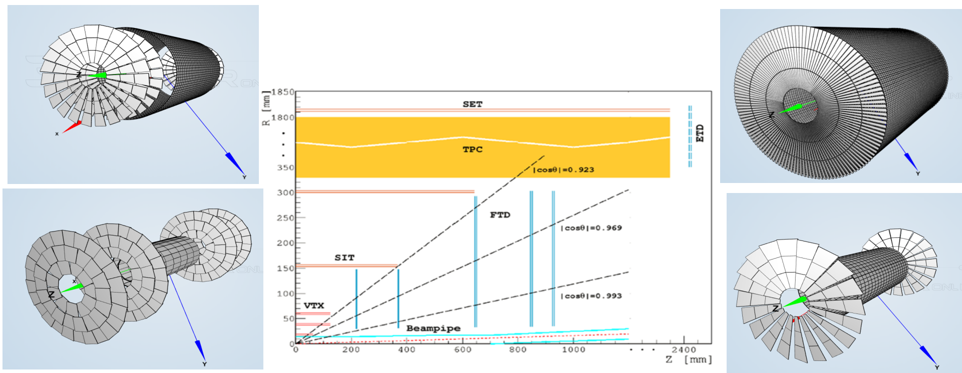
  ✓ Silicon tracker + Calorimeter

  ☐ Other type of detector (wire chamber/TPC are taking consideration)

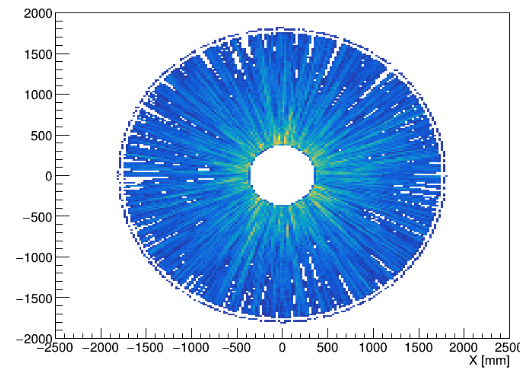


Geometry and Material mapping

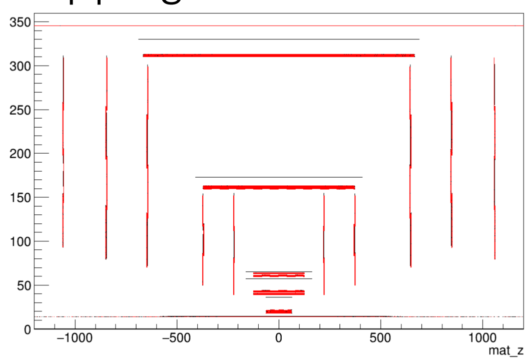
- Silicon trackers are built with ACTS typical building method
- TPC Surface-based concept of surface : 220 cylindrical surface

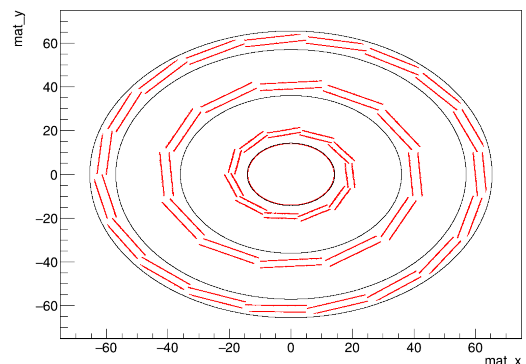


Fast simulation of TPC hit



- Material recording(geant4 plugin) and material mapping have been validated:
  - Plugin for Geant4: Recording the detailed full material
  - Mapping the material recorded onto the chosen binned surface



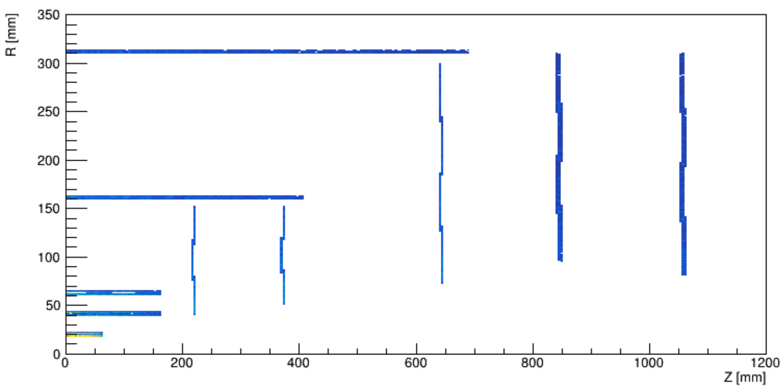


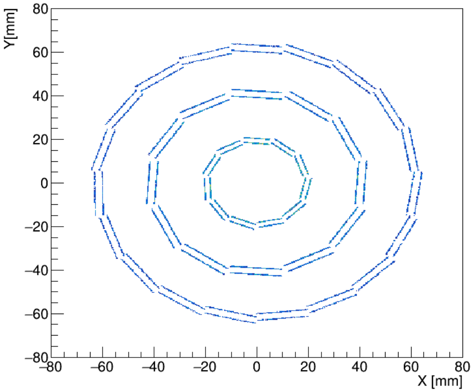
G4 mapping to surface

From YuBo

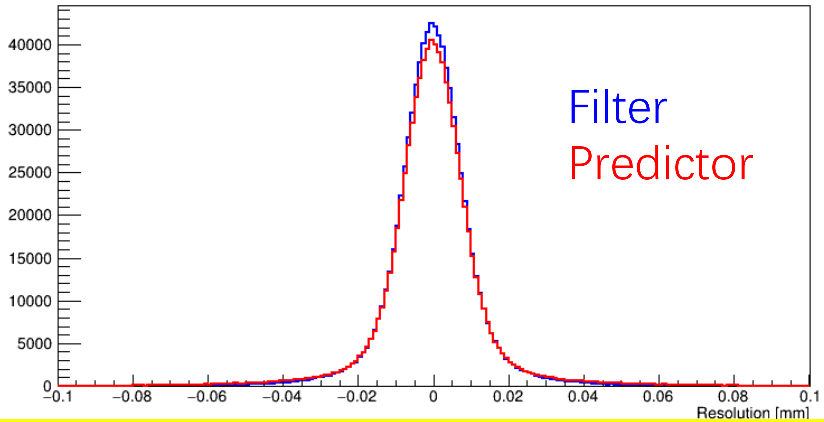
FATRAS and Kalman Filtering

- Tracking Geometry debugged with the propagation tool
- Validation of Kalman filter in progress





Propagation (sensitive) output

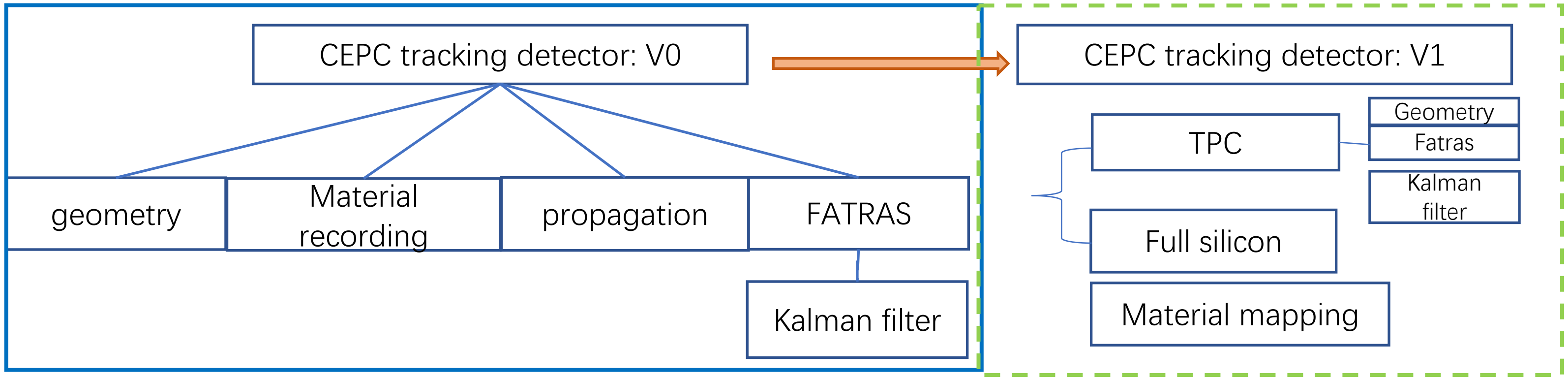


Shuiting and Gang going to take over the fast simulation part

From YuBo

CEPC-ACTS Integration Status

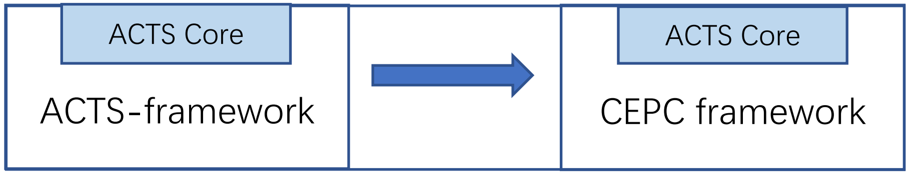
✓ V0 of CEPC baseline detector(without TPC) is implemented



◆ V1 of CEPC detector are ready with the geometry

- Silicon detectors implemented with typical ACTS tools
- TPC implemented with 220 cylinder layers currently
- Material mapping is in being validated

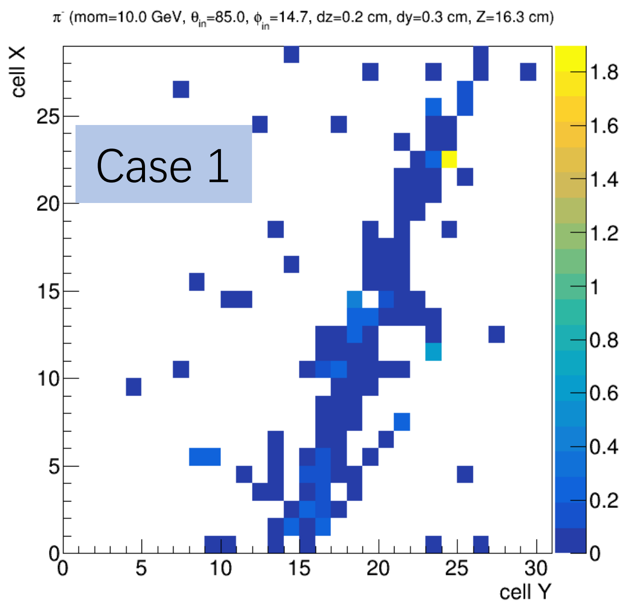
☐ Temporarily using acts-framework
planning to migrate ACTS into Gaudi for CEPC

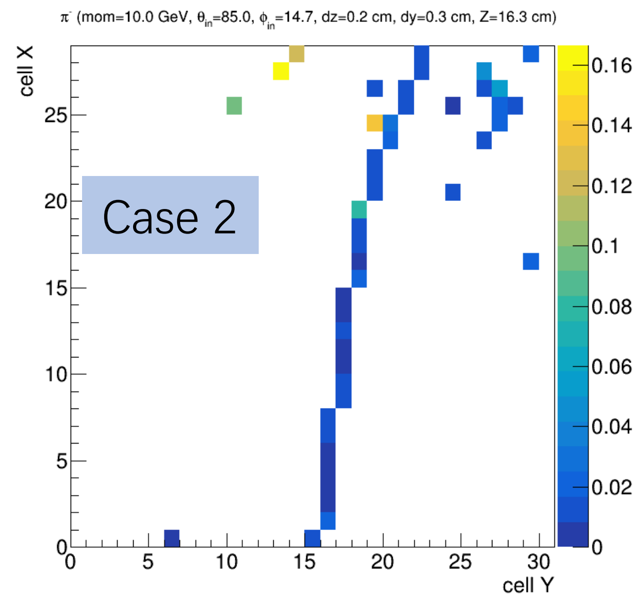


Xingtao promised to integrate ACTS to new framework

Fast calorimeter simulation-GAN

- Generative Adversarial Networks (GAN)
- Trying to add HCAL and simulating the shower of pion in ECAL together with HCAL.
- Due to the complex processes of pion shower, it is more difficult to mimic the pion shower than electron (or γ). For example, two cases of pion showers in ECAL are showed below.



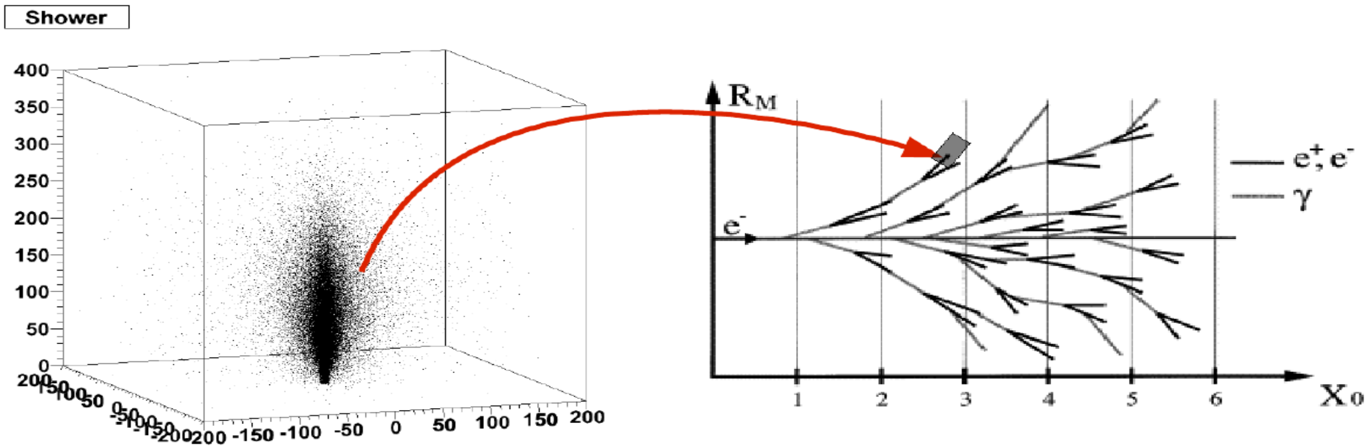


Model training …

From Wenxing

Fast calorimeter simulation

- Frozen shower (FS) method for calorimeter fast simulation.
- During the FS simulation the low-energy particle are substituted with pre-generated shower from the library.
- The purpose of the FS library is to store the shower and the condition, with which this shower was generated.
- When required, the library should return the shower with the generation conditions as close to the required, as possible
- FS in steps:
  - Library creation: need to be performed only ones. Library is created with respect of the shower properties.
  - Fast simulation: Showers from the library is used instead of filly simulated showers.



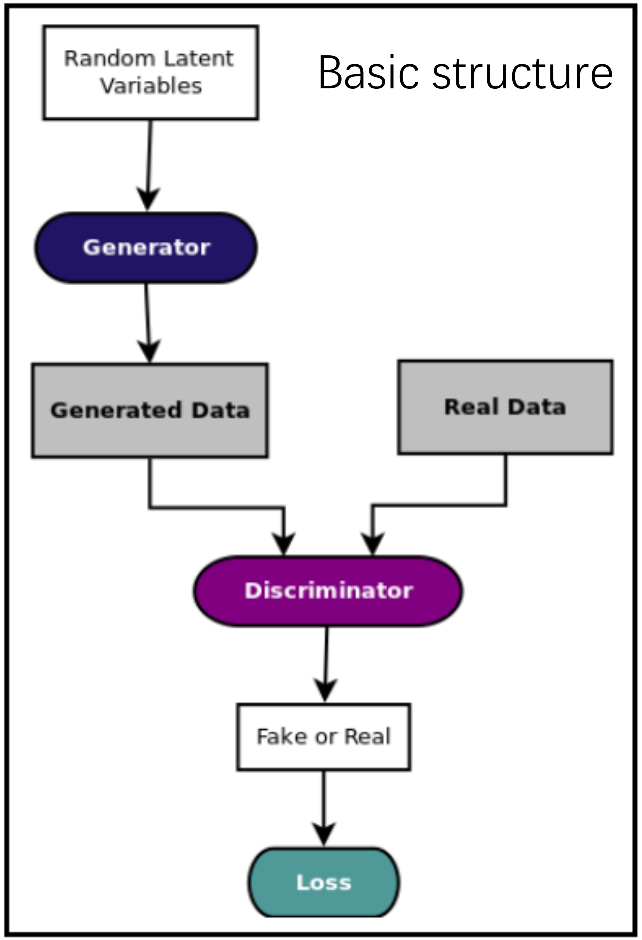
- Status: making electron ECAL barrel shower library.

Future plan

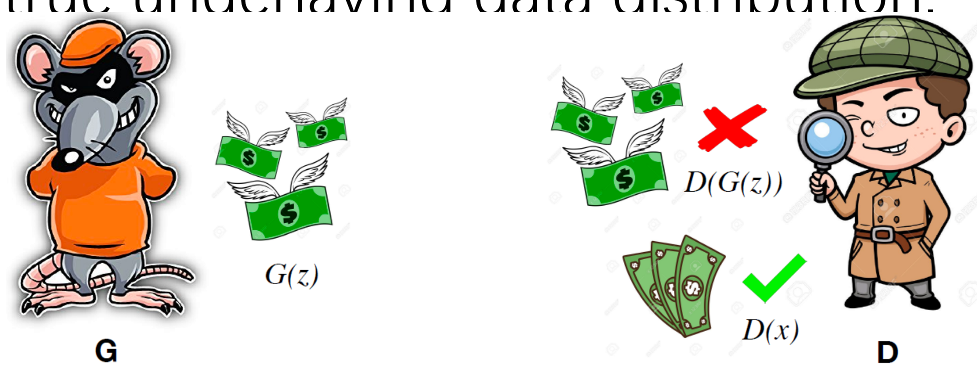
- ACTS
  - to be integrated as external library
  - Geometry implemented, being validated
  - Tracking/vertex tool for alternative reconstruction method
    - Need tracking finding …
- Calo
  - GAN
  - FSlib
- Unify interfaces to geometry and EDM

backup

Generative Adversarial Networks (GAN)



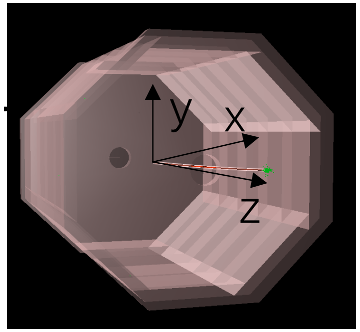
- Discriminator tries to discriminate the real data and generated data.
- Generator tries to produce generated data which can confuse the discriminator.
- In the end, the discriminator can not discriminate the real or generated data. And the generator learns the true underlaying data distribution.



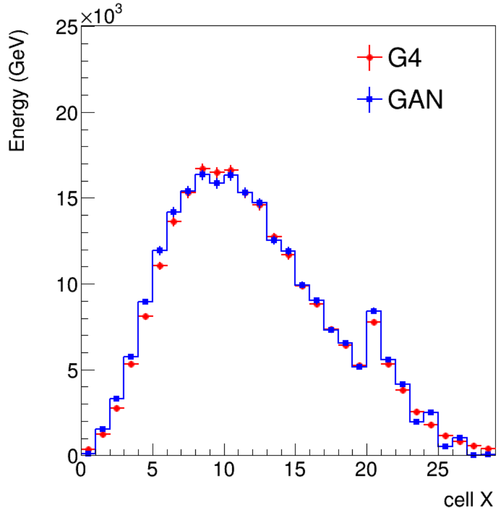
vanilla loss formulation $\min_G \max_D V(D,G) = E_{x\sim p_{data}(x)}[logD(x)] + E_{z\sim p_z(z)}[log(1-D(G(z)))]$

Here, x is real data, G(z) is fake data

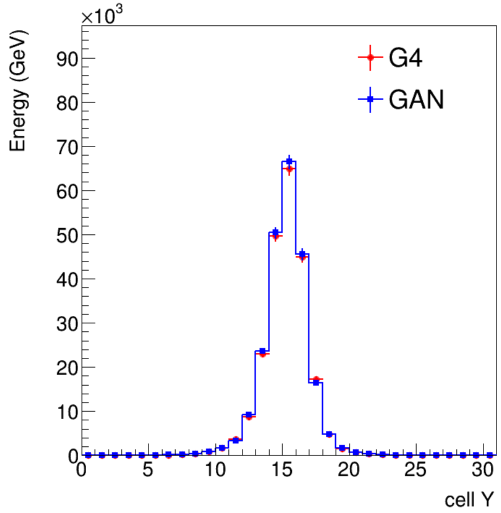
Simulation of Calorimeter with GAN



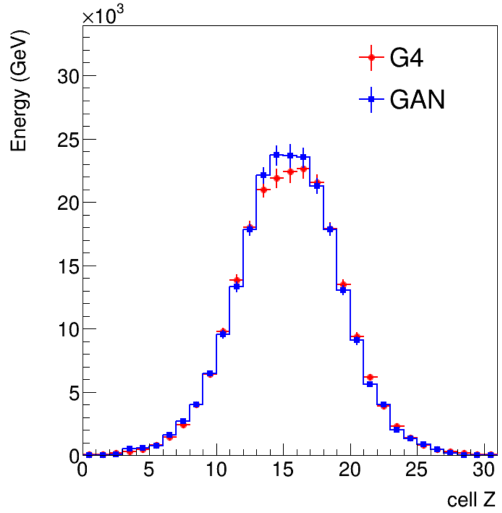
- ❑ Geant4 simulation:
  - ➢ Pro: very precise
  - ➢ Con: requires large computing resources
- ❑ Calorimeter simulation is one of bottlenecks.
- ❑ The Generative Adversarial Networks (GAN) could be used for calorimeter fast simulation.
- ❖ Training data:
  - ○ Single photon gun sample.
  - ○ Energy in [1, 100] GeV uniformly.
  - ○ θ in [50, 140] degree uniformly.
  - ○ ϕ in [-15, +15] degree uniformly.
  - ➢ Hit energy in 31×31×29 calorimeter cells are considered.



Energy deposited in X(layer) direction



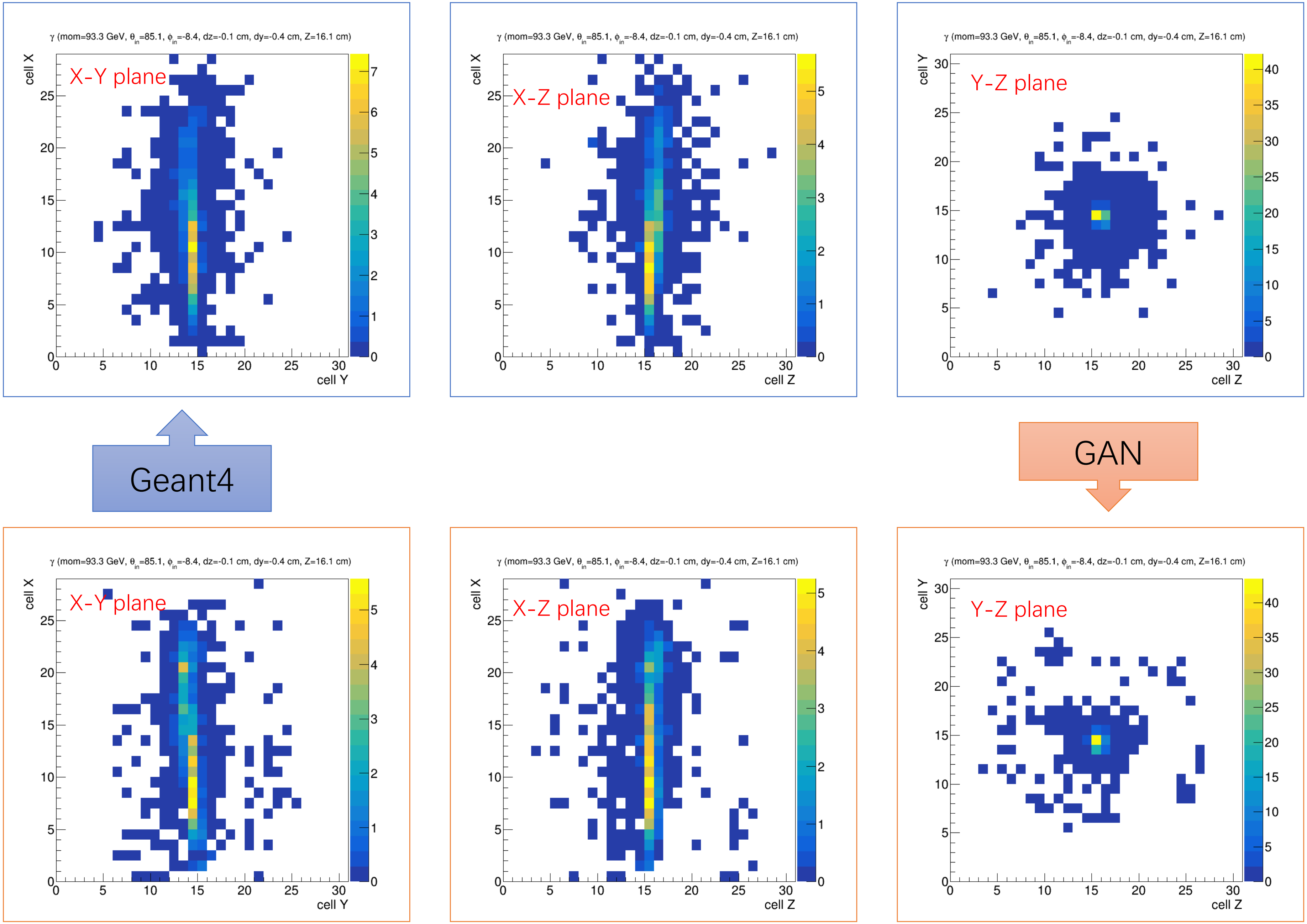
Energy deposited in Y direction



Energy deposited in Z direction

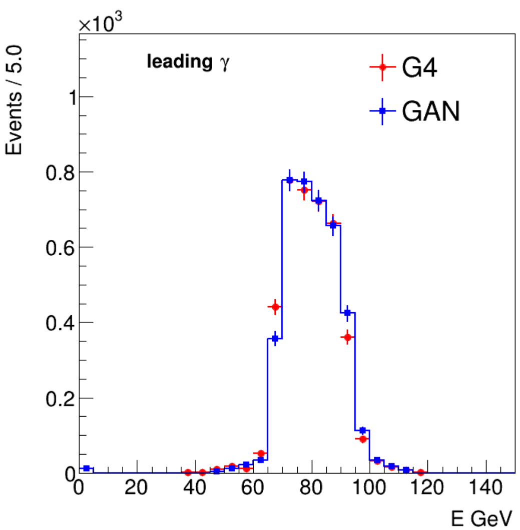
Event display

$\gamma\ (\mathrm{Mom} = 93.3\ \mathrm{GeV}, \theta_{in} = 85.1^{\circ}, \phi_{in} = -8.4^{\circ},$
$\Delta Z^{Pos} = -0.1\ \mathrm{cm}, \Delta Y^{Pos} = -0.4\ \mathrm{cm}, Z = 16.1\ \mathrm{cm})$

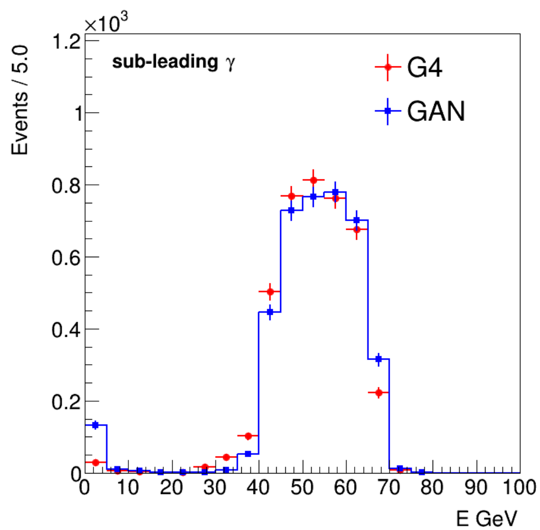


Simulation of Calorimeter with GAN

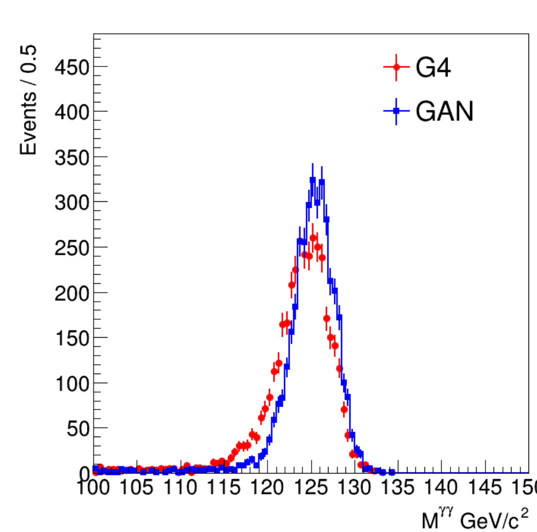
- Apply GAN and do event reconstruction using mc samples.
  - $e^+e^- \rightarrow Z(\nu\nu)H(\gamma\gamma)$ mc samples are used.
  - Comparing the properties of reconstructed gamma.



Leading γ E_{rec}



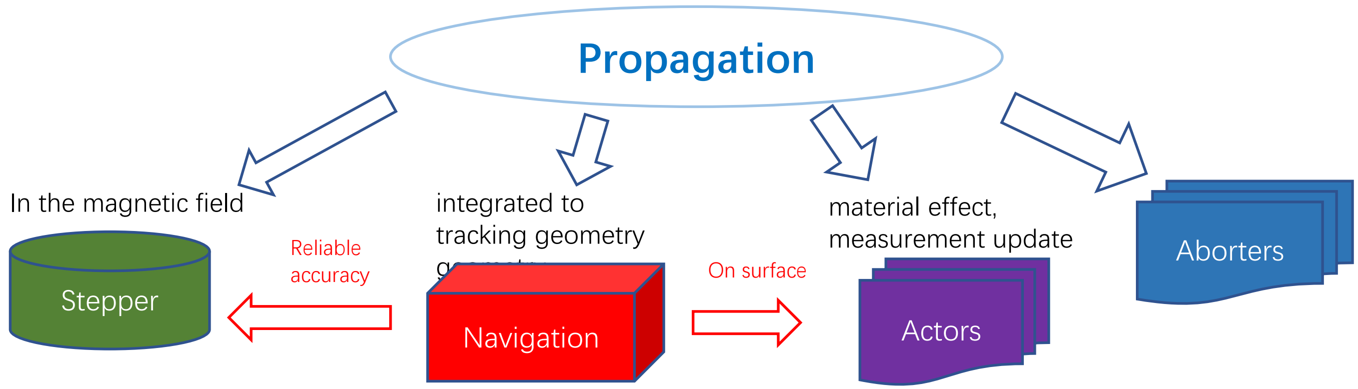
Sub−leading γ E_{rec}



$M_{\gamma\gamma}$

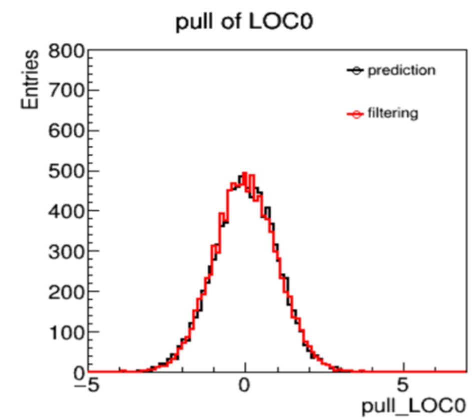
- Looks fine, has room for improvement.

Propagation and Kalman Filter



Kalman Filter in ACTS

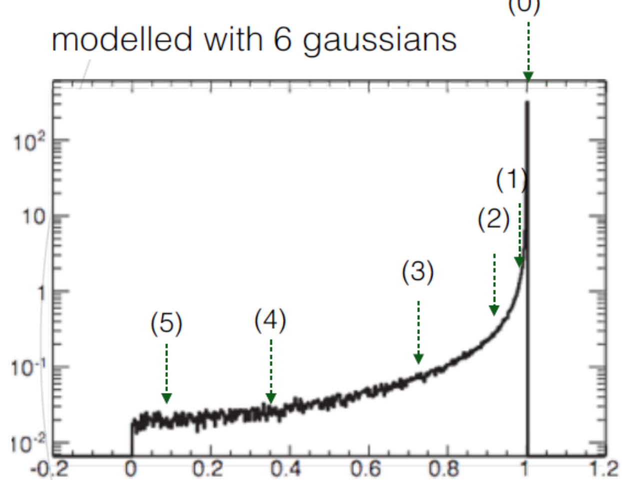
- Implemented as an Actor
- Update direction, uncertainties after filtering step
- Aims to minimize heap allocation
- Study of numerical performance (From Xiaocong Ai)

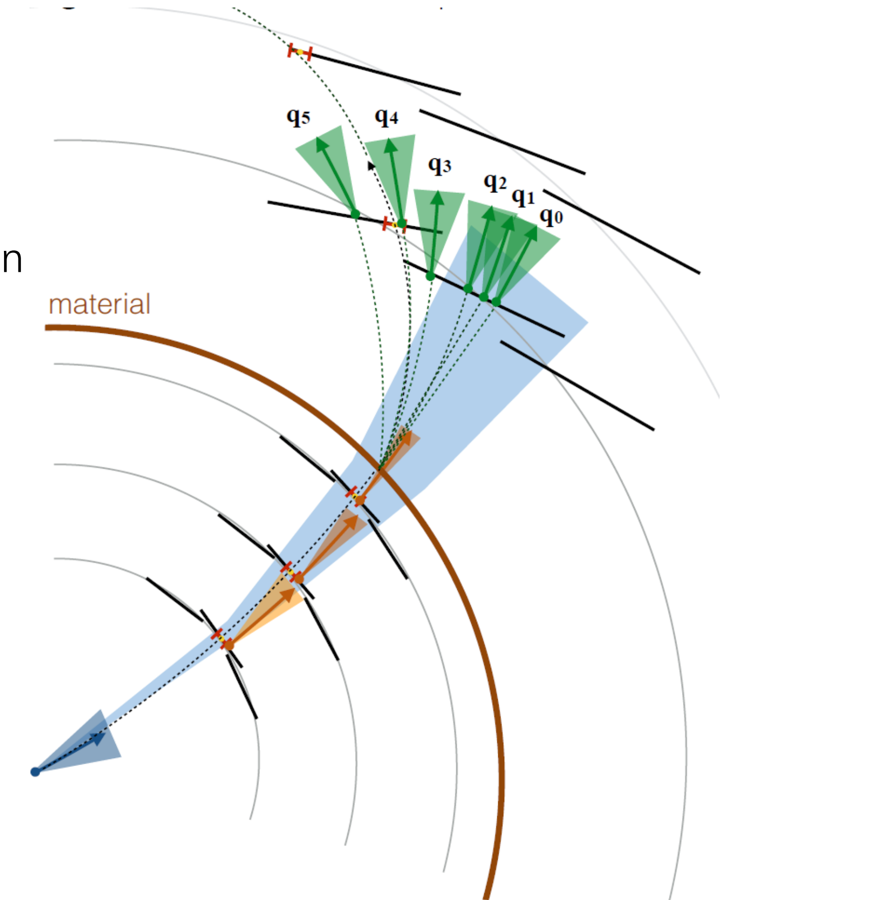


◆ These tools serve for the track reconstruction chain/support (convenient mechanism of validation for geometry building)

Gaussian Sum Filter

- Electron reconstruction are well handled with Gaussian Sum Filter, which is a parallel sets of Kalman Filter
- The bremsstrahlung energy loss distribution can be approximated as a weighted sum of gaussian components
- Each component behaves like a Kalman component, **propagate** individually
- Components should be merged to avoid the exponentially increasing





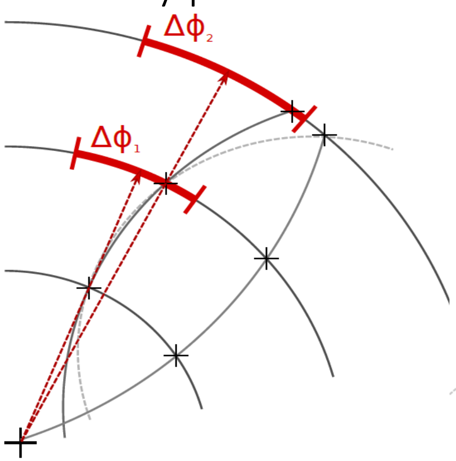
One component splits into 6 components

The (mean/cov/weight) of each component taken from ATLAS at the first step

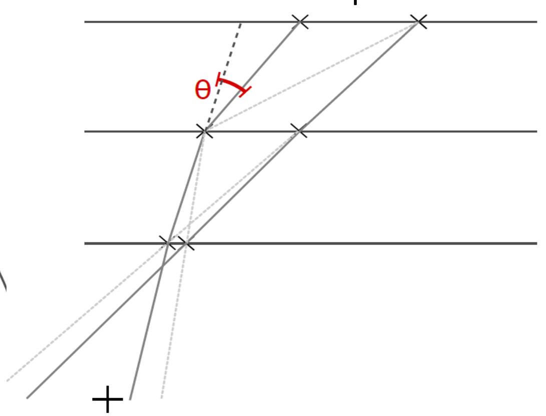
Seeding and Track Finding

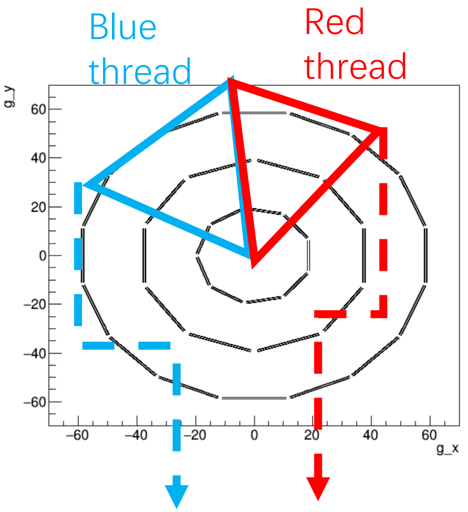
- A combinatorial seed finder – select 3-hit seeds
- Multi thread seed finder in different regions intra event is allowed

x-y plane

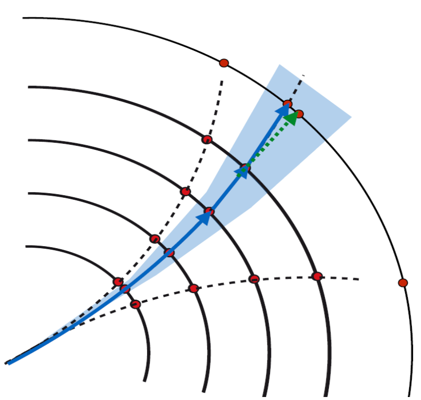


r-z plane





- CKF as the basic track finding method is under developing



Combinatorial Kalman Filter