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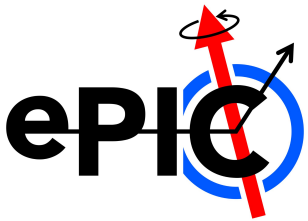
U.S. DEPARTMENT OF ENERGY
Office of Science

Tracking Simulation Status and Plan

Shujie Li

ePIC SVT working meeting @ Stony Brook, NY

July 11, 2025

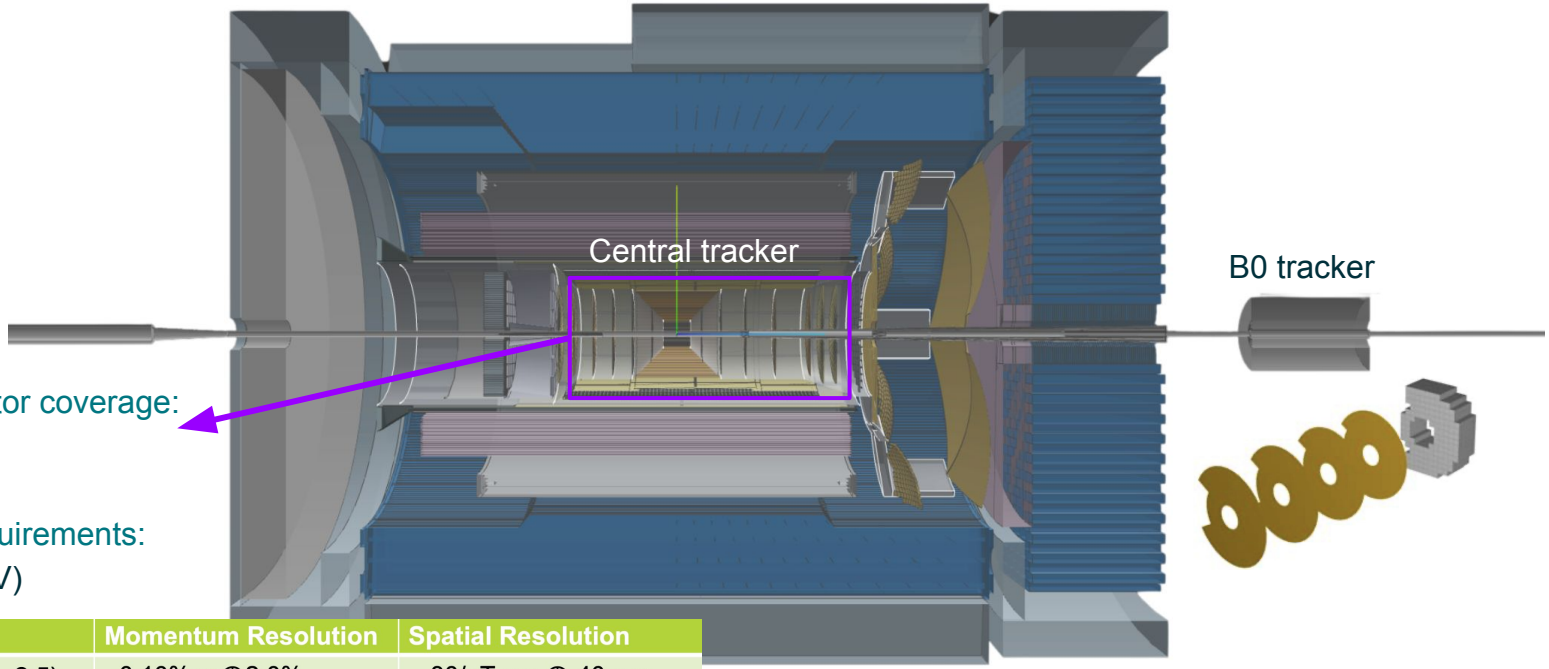


Outlines

- **Tracker in Simulation**
  - Geometry and materials
- **Tracking performance**
  - workflow
  - single particle events
  - DIS+Background

➢ ePIC joint tracking, track and vertex reconstruction meeting every Thursday
➢ EICUG meeting - tracking workfest on July 16

ePIC Tracking System



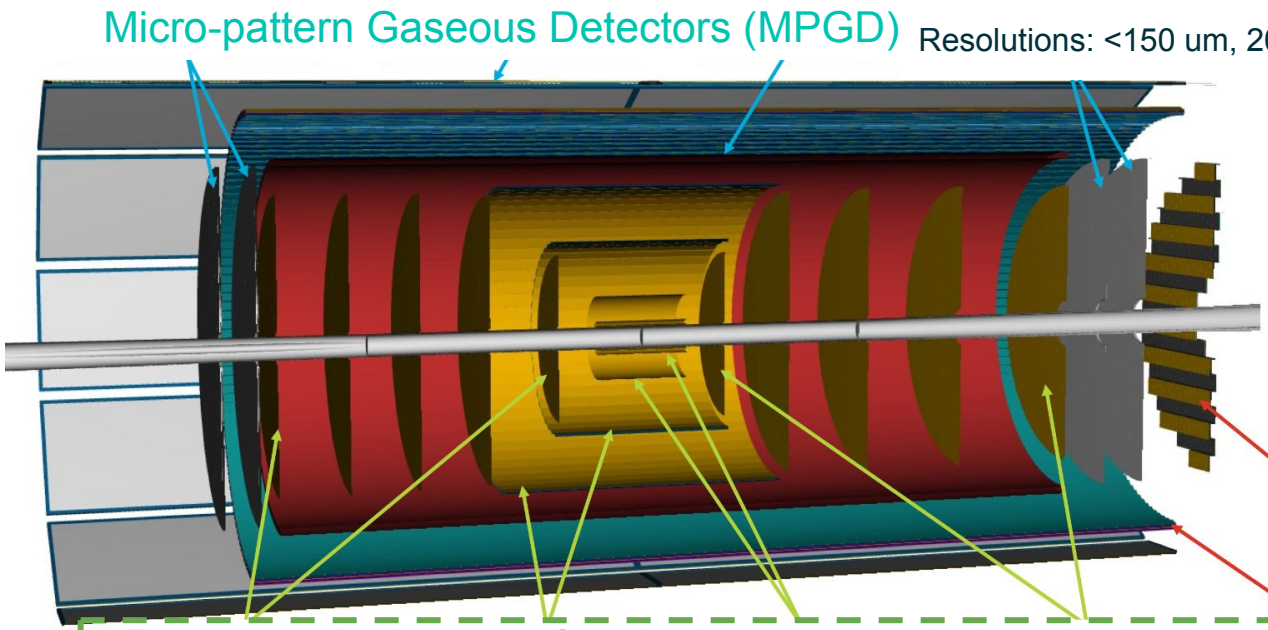
*Central detector coverage:
$-4 < \eta < 4$

Resolution requirements:
(for pT<15 GeV)

	Momentum Resolution	Spatial Resolution
Backward (-3.5 to -2.5)	~0.10%×p⊕2.0%	~ 30/pT μm ⊕ 40 μm
Backward (-2.5 to -1.0)	~ 0.05%×p⊕1.0%	~ 30/pT μm ⊕ 20 μm
Barrel (-1.0 to 1.0)	~0.05%×p⊕0.5%	~ 20/pT μm ⊕ 5 μm
Forward (1.0 to 2.5)	~0.05%×p⊕1.0%	~ 30/pT μm ⊕ 20 μm
Forward (2.5 to 3.5)	~0.10%×p⊕2.0%	~ 30/pT μm ⊕ 40 μm

Central Tracker

See detector reports from ePIC R&D Day

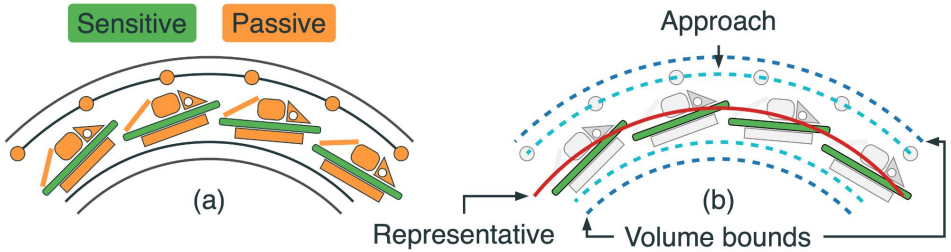


SVT Geometry in Simulation

- **DD4hep** : Geant4-based detector description and particle propagation through materials and magnetic field.
  - **Sensitive detector:**
    - 2d segmentation of 20x20um to account for pixel size
    - generate detector hits:
      - position, cell ID, time, energy deposit
  - **Other structures and materials**:
    - Multiple scattering, Secondary particles, …
  - **Geometry Implementation:**
    - Use TGeo shape (box, trapezoid, cylinder, …) to describe detector element → assemble elements to layers → assign position, materials etc
    - Have to pass BOTH Geant4 and ACTS overlap check
    - More geometry details/shapes → slower simulation

SVT Geometry in Simulation

- In-house developed **EICrecon** framework for digitization, track and particle reconstruction, and analysis
  - Use **ACTS** for tracking:
    - Navigate track propagation through onion-like (endcap-barrel-endcap) tracking hierarchy.
    - Detector **volumes** are reduced to representing **surfaces** to speed up track reconstruction.

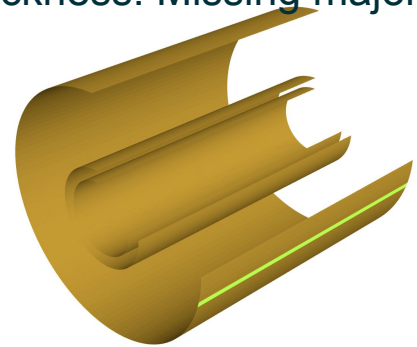


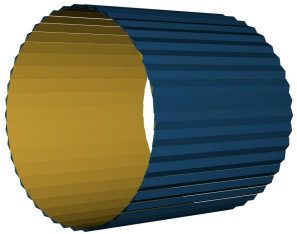
    - Materials are projected to selected surfaces, e.g. at the entrance and exit boundaries of sensitive surfaces ← this information is provided with a pre-generated **material map**, will NOT consider any dd4hep materials otherwise.

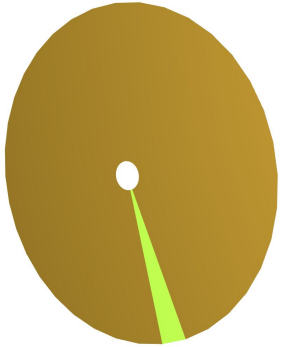
SVT Geometry in ePIC 25.06

Current Status:

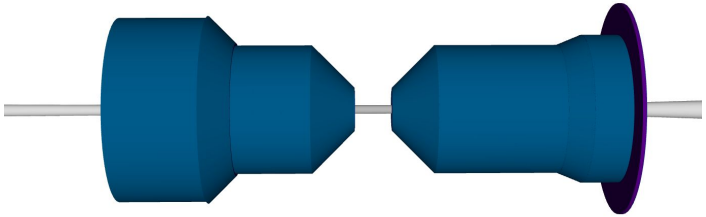
- Simple layers of silicon, carbon, aluminum to represent the rough shape and thickness. Missing major mechanic structures.







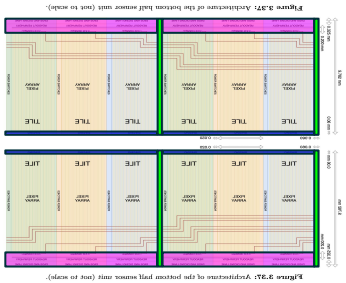
- Cone + tube to account for services and supports (see details)



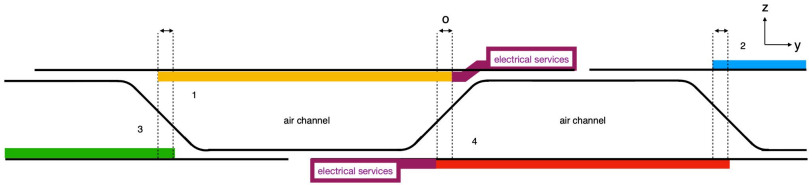
SVT Geometry Update Plan

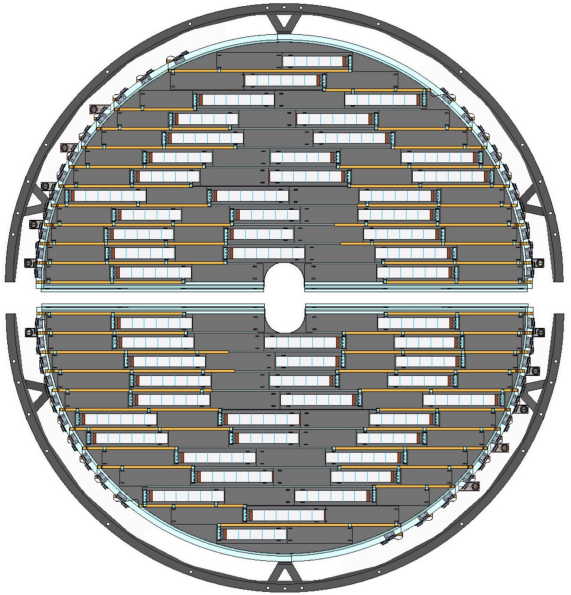
Disks (LBL):

Approximated RSU geometry →
LAS → disk pavement



Corrugated core





SVT Geometry Update Plan

OB (UK)

Ongoing effort:

- CAD drawing → GDML → DD4hep

```
module name="L4Module12" vis="TrackerLayerVis">
 <!--bundle-->
 <module_component name="ActivePixelArray_480_ASCII.gdml"
                   matching_name="Active"
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                   sensitive="true"
                   thickness="0.09996 * mm"
                   vis="TrackerLayerVis"
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                   matching_name="Biasing"
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```
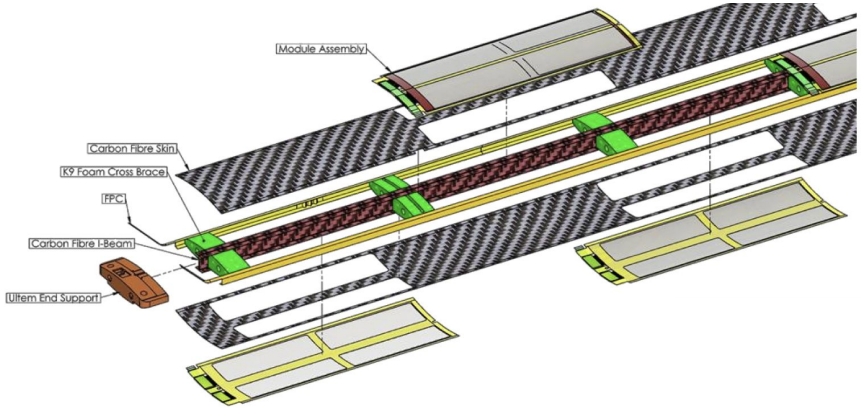
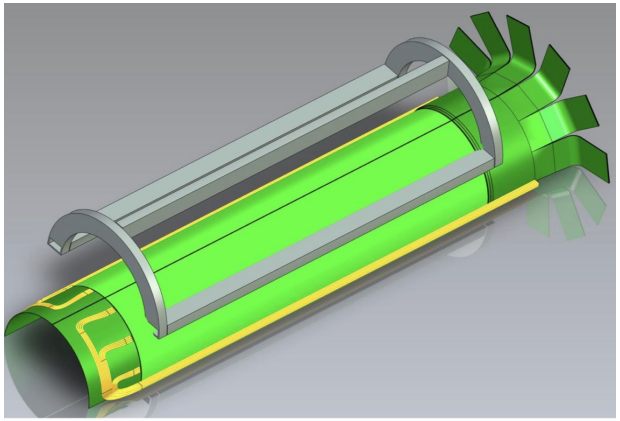



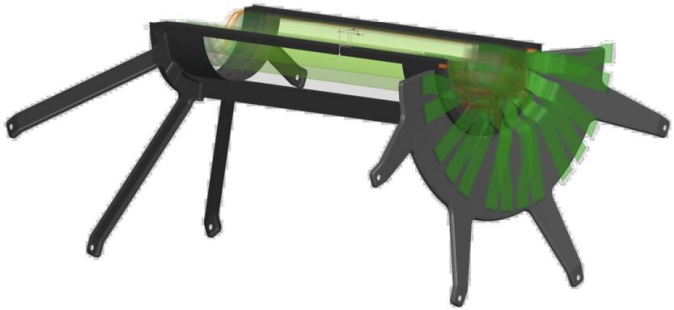
Status:

- Worked with the tracking software, with tracking resolution comparable to the default (simplified) geometry
- Runs very slow in simulation
- Still need to resolve material thickness mismatch.
- Code available

SVT Geometry Update Plan

IB (Italy)

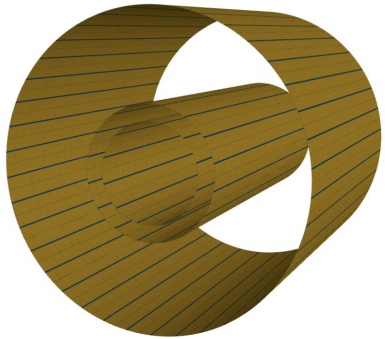




Ongoing effort:

1. Stp file→ GDML → Geant4 test
   To do:
   - resolve overlaps
   - Implement dd4hep plugin and ACTS interface

2. Simplified curved ITS3:
   - No info on mechanics, need manual simplification/translation
   - The acceptance gap at eta=0.9 needs to be compensated by disk in integration.



SVT Geometry Update Plan

Thoughts on the drawing to simulation approach:

- Accurate material and geometry description, but
  - Very expensive to run with DD4hep
  - ACTS only takes tracking surface with mapped materials
- Non-trivial efforts to
  - Resolve overlaps and mesh/facets
  - Import parts from gdml to dd4hep and place volumes.

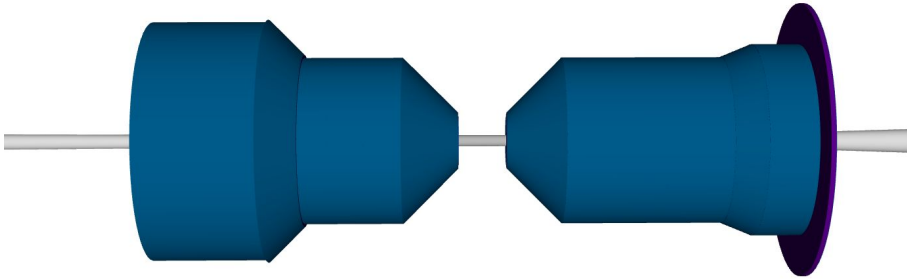
My suggestion:

- Update the geometry, but only the simplified version
- Need reliable human-interpreter to make reasonable approximation of shapes and materials
- Only use gdml when we have a single big piece of materials that is not sensitive

SVT Geometry Update Plan

Support tube/cone and services

Current:

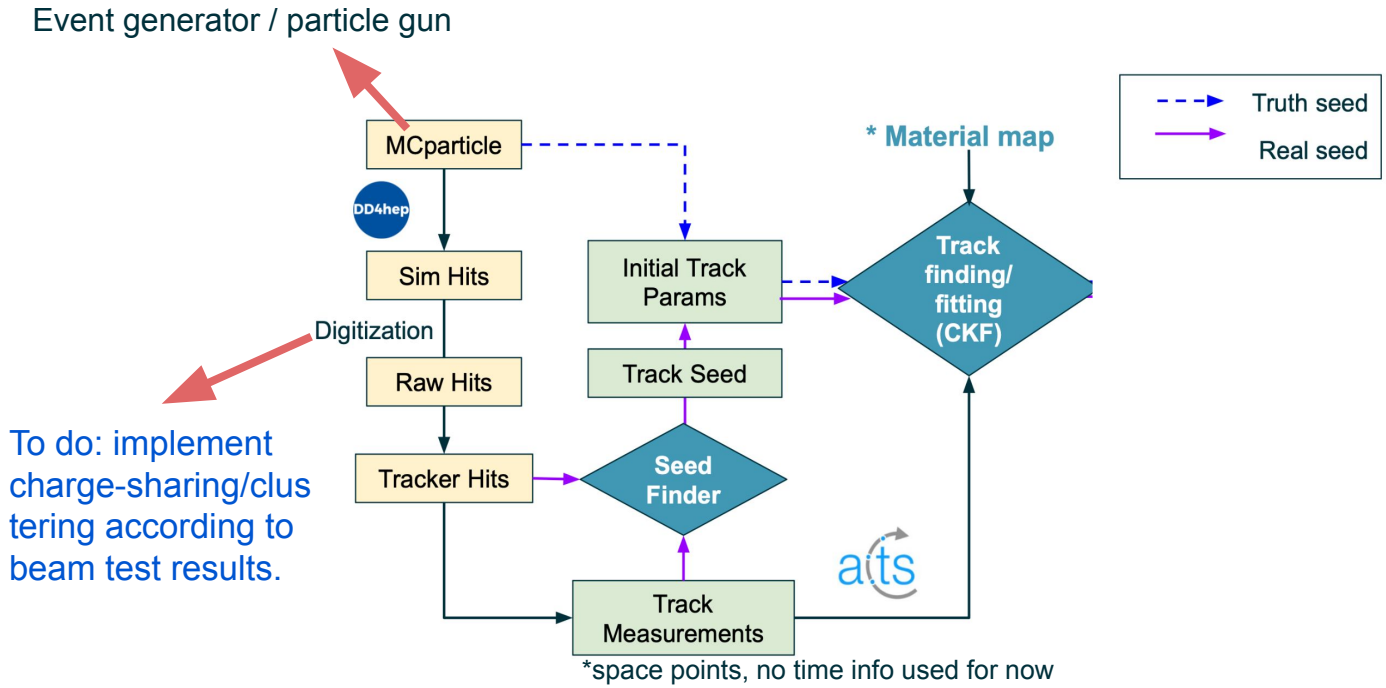


Plan:

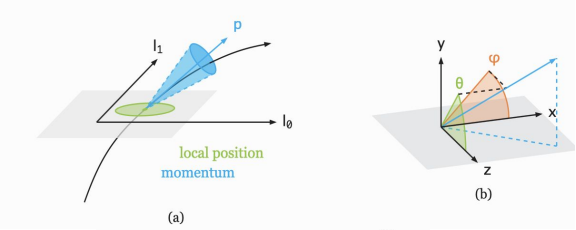
Continue using uniform layers of materials to account for the thickness. Update shape and values once new estimates become available.

Discussion?

Tracking workflow



Tracking workflow



$$\vec{x} = (l_0, l_1, \phi, \theta, q/p, t)^T$$

Event generator / particle gun

MCparticle

DD4hep

Sim Hits

Digitization

Raw Hits

Tracker Hits

ElCrecon

Initial Track Params

Track Seed

Seed Finder

Track Measurements

* Material map

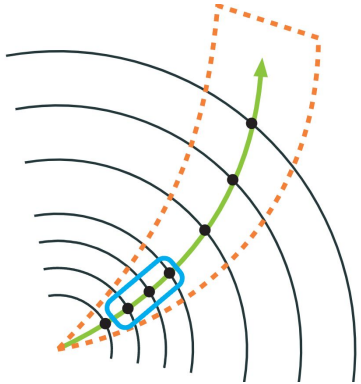
Track finding/ fitting (CKF)

acts

*space points, no time info used for now

Truth seed

Real seed

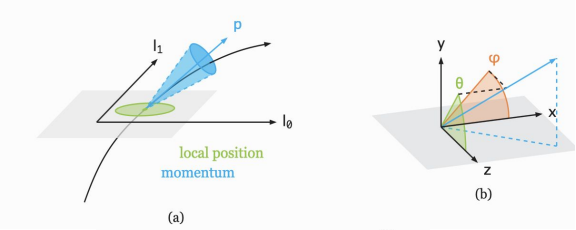


Seeding

Track finding

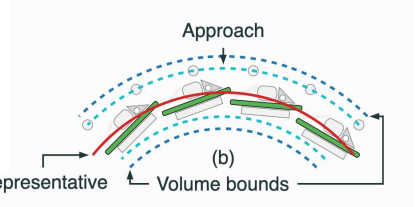
Track fitting

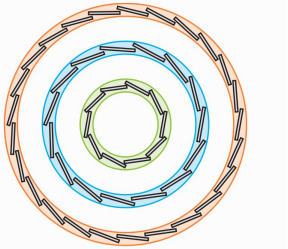
Tracking workflow

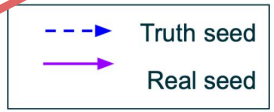


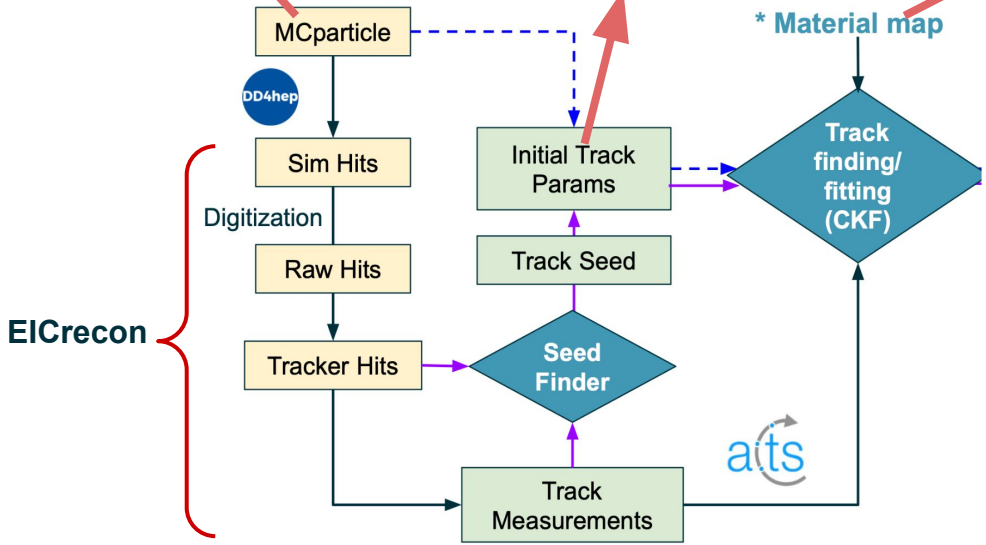
$$\vec{x} = (l_0, l_1, \phi, \theta, q/p, t)^T$$

Event generator / particle gun





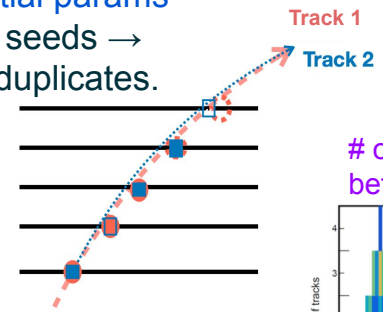




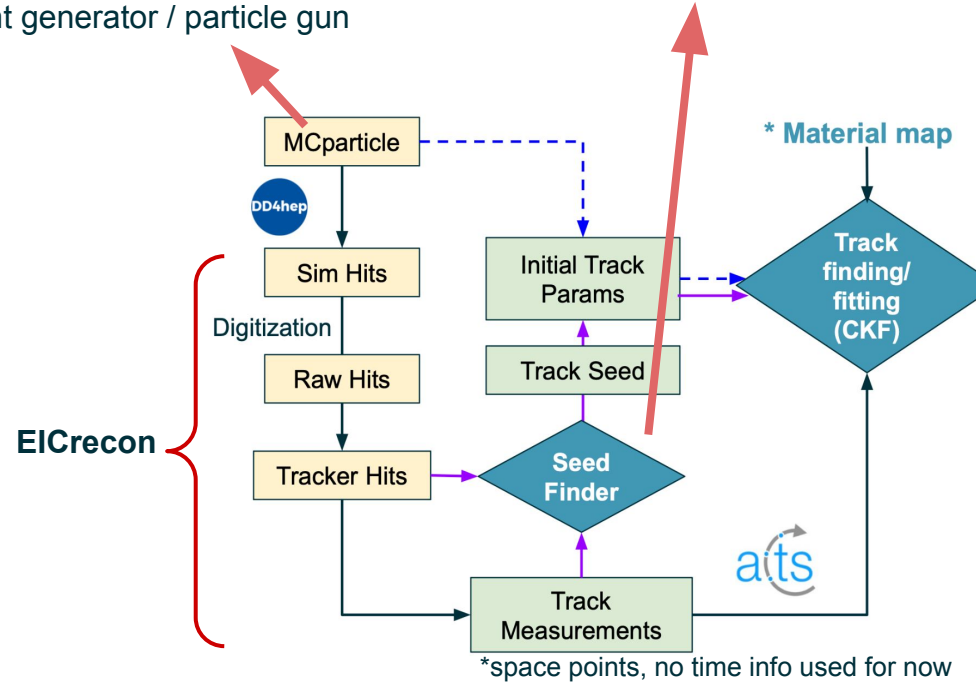
*space points, no time info used for now

Tracking workflow

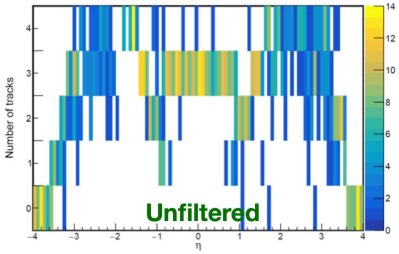
3 qualified hits → 1 track seed → 1 set of initial params
Hits from one particle can construct multiple seeds → multiple identified tracks → need to resolve duplicates.

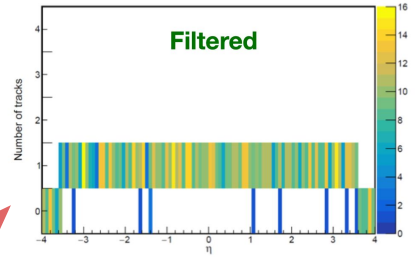


Event generator / particle gun



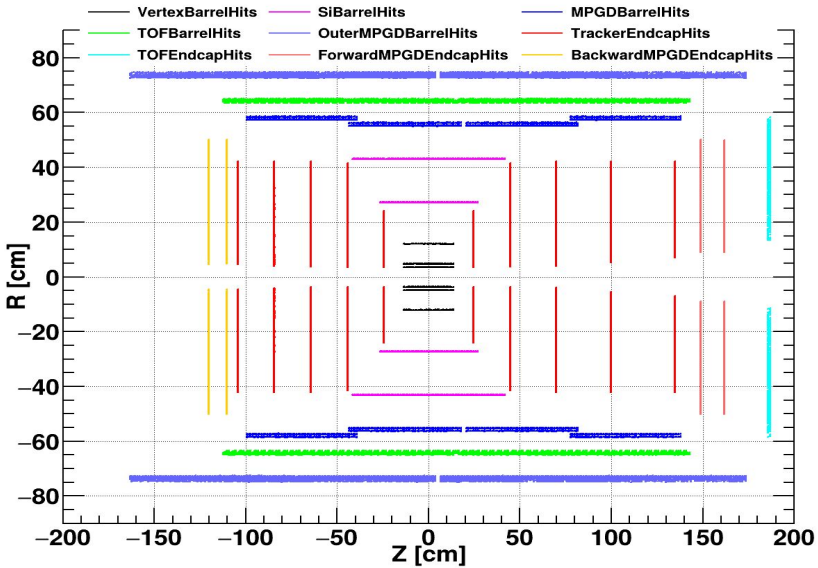
# of tracks per particle before/after

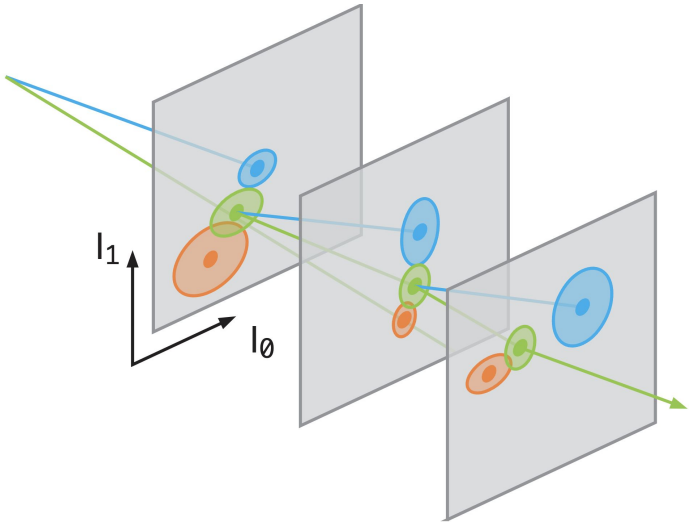




Tracking workflow

- **Core tracking algorithm: Combinatorial Kalman Filter (CKF):**
  - Initial guess from an orthogonal seed finder which forms triplet with hits from five SVT layers.
  - Combined track finding and fitting
  - Demonstrated to handle high multiplicity tracking. Works well with 5+ hits.
    - Expect to have **5-8 hits per particle** with the current tracker design.
    - Hits which deviate from projected track will be rejected by chi2 (residual weighted by resolution and material effects) cut.

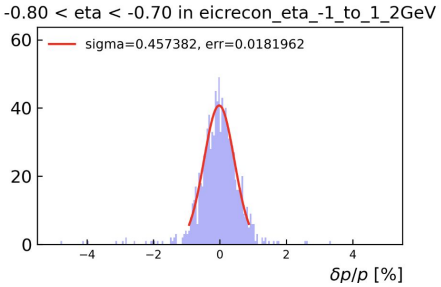


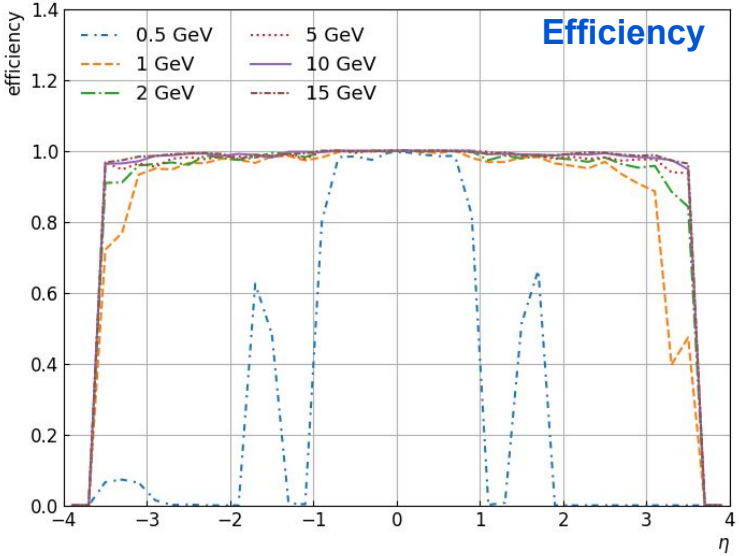


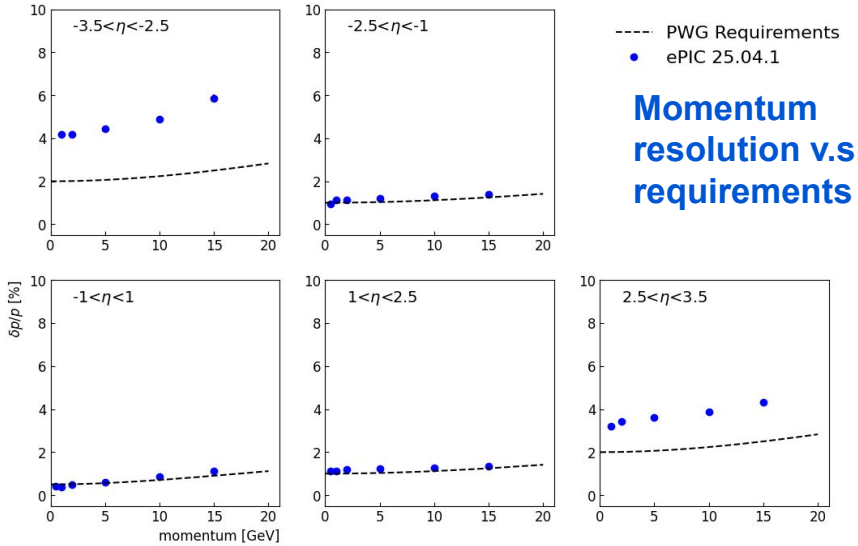
Single Particle Tracking Performance

- **Source events:**
  - Uniformly distributed single pion+ event at fixed momentum
- **Observables:**
  - **Efficiency**: fraction of qualified generated tracks that are reconstructed
  - **Purity**: for a given reconstructed track, the fraction of used hits from the same initial particle.
  - **Resolutions**: dp/p, theta, phi, DCAr

dp/p Resolution fit
(recon - initial)/initial,







Momentum resolution v.s. requirements

Tracking Layer Impact Study

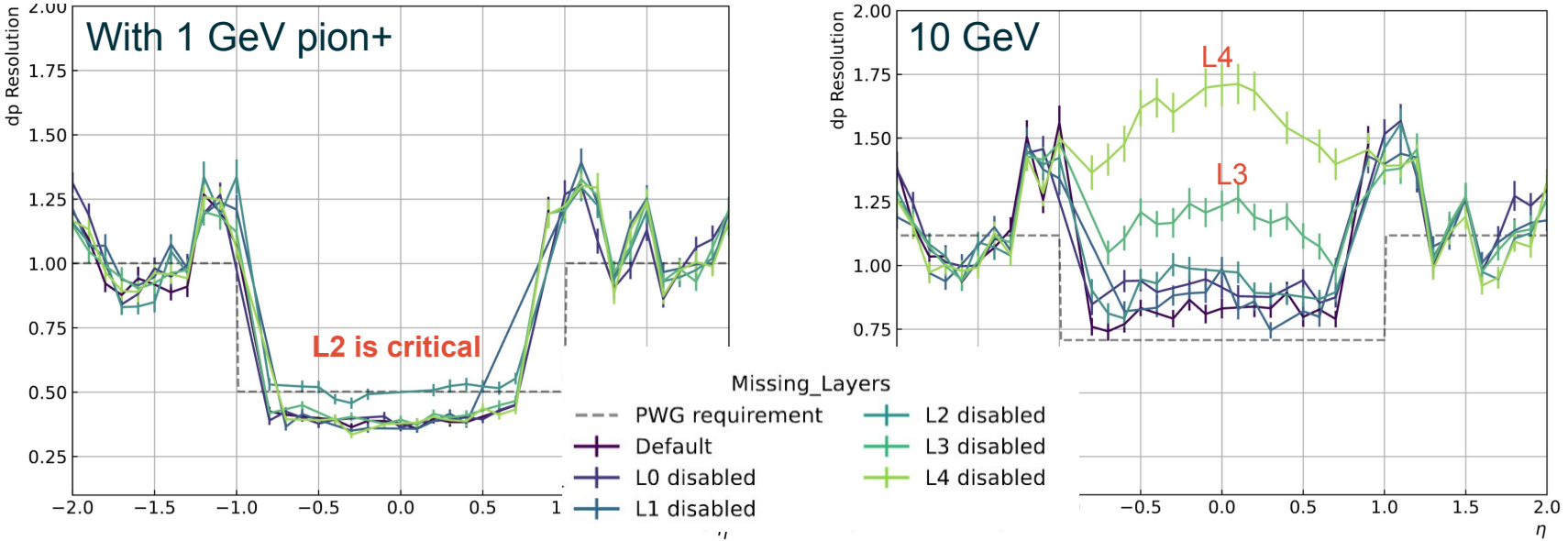
Concern:

What if a particle doesn't leave hit on a specific SVT layer for any reason?

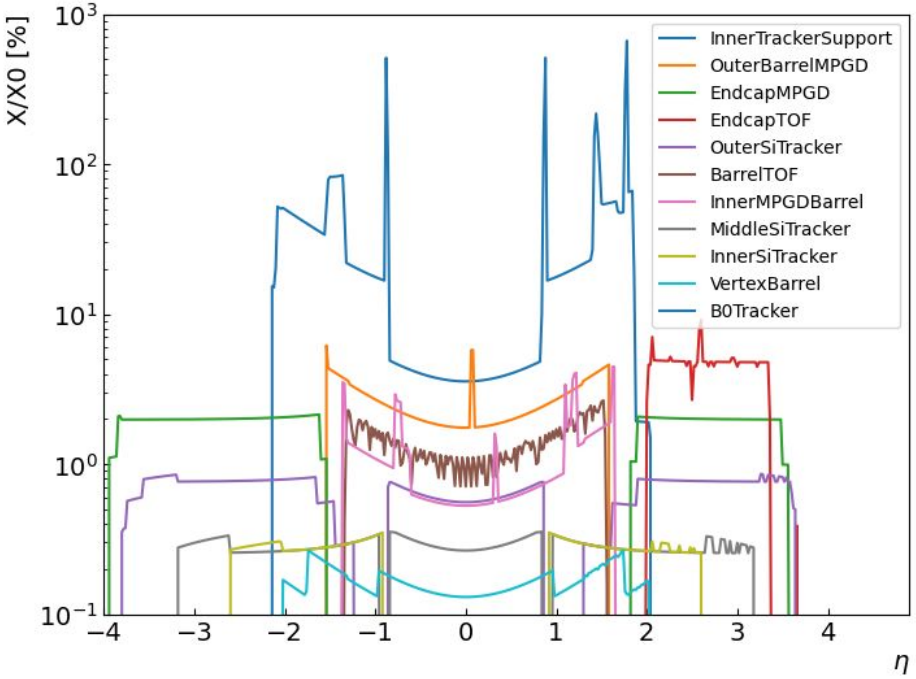
Simulation setting:

Disable the layer in track reconstruction while keep it in DD4hep simulation.

dp/p (%) with disabled **Barrel layer** (cover -0.9 < eta < 0.9):



Tracking Layer Material Thickness Study



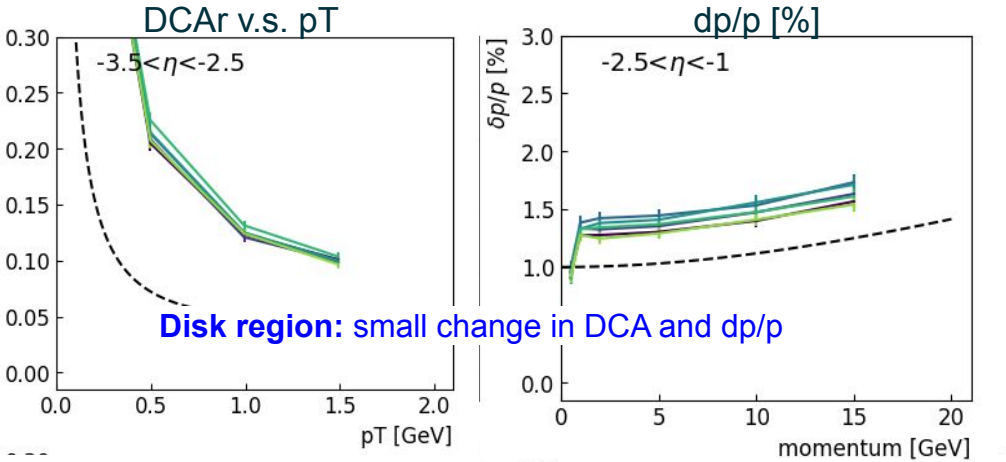
The nominal SVT thickness per layer:

- Si Vertex barrel: 0.05%
- Si Outer Barrel: 0.25 - 0.55%
- Si disk: 0.24%

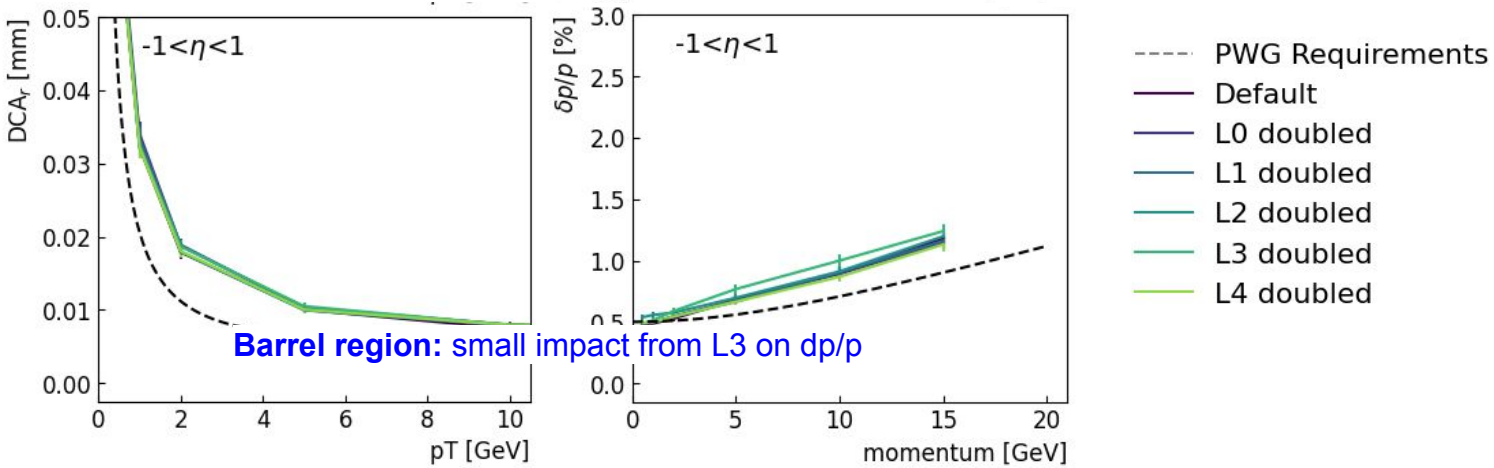
More materials from service, support structure etc will induce more rescattering

In single particle simulation, double the thickness of each layer to check the impact on reconstructed resolution

Tracking Layer Material Thickness Study



Disk region: small change in DCA and dp/p



Barrel region: small impact from L3 on dp/p

Tracking Study with Realistic Environment

Concern:

Noise on pixel can confuse tracking algorithms:

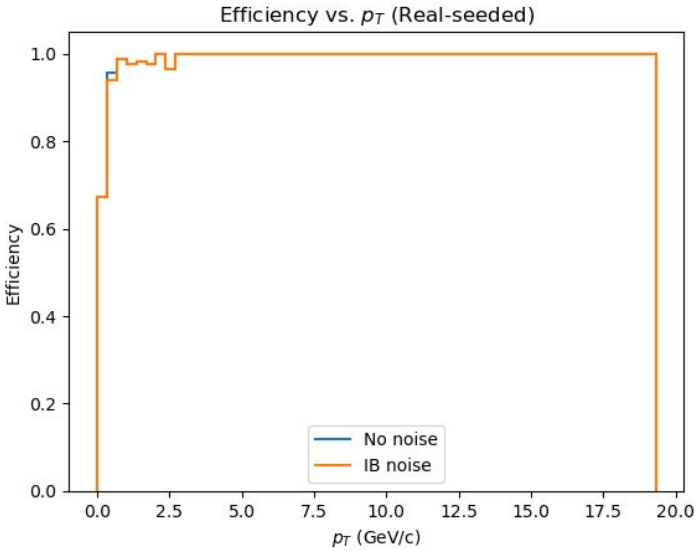
Simulation setting:

Randomly generate fake hit in digitization

- **Preliminary study on IB** (Mito Funatsu, UCB)
  - Negligible impact on efficiency

Sampled fake-hit rate: FHR < 5 x 10^{-7} per event per pixel.
Fake hits/event/collection: FHR x total pixels

	Inner Barrel	Outer Barrel	Endcaps
Total pixels	8.65E+08	7.83E+09	1.18E+10
Fake hits/event	4.33E+02	3.92E+03	5.91E+03



- **Planned study:**
  - Noise hits on disks and OB
  - Noise + background + missing layer study

Tracking Study with Realistic Environment

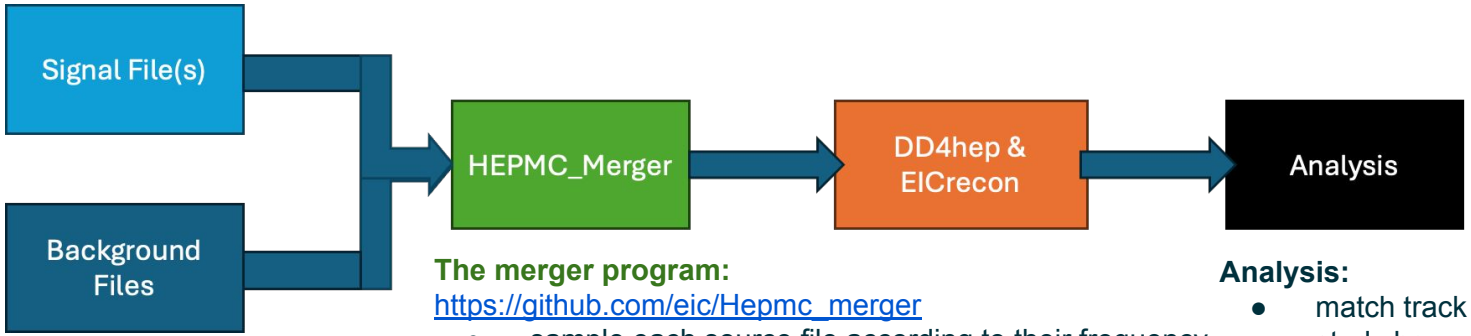
Concern:

How well can our device and tracking algorithm perform with **beam background**

Simulation setting:

Performance study with signal+background merged event

- New Hepmc merger and background samples described here (simulation campaign) and here (configurations on p14) , See also discussion at the ePIC TIC meeting
- Reconstructed events from merged sample will be available in next simulation campaign



The merger program:

https://github.com/eic/Hepmc_merger

- sample each source file according to their frequency within a fixed-length (2us) time window
- label each source particle with custom generator code

Analysis:

- match track to particles
- study how well we can reconstruct signal particles

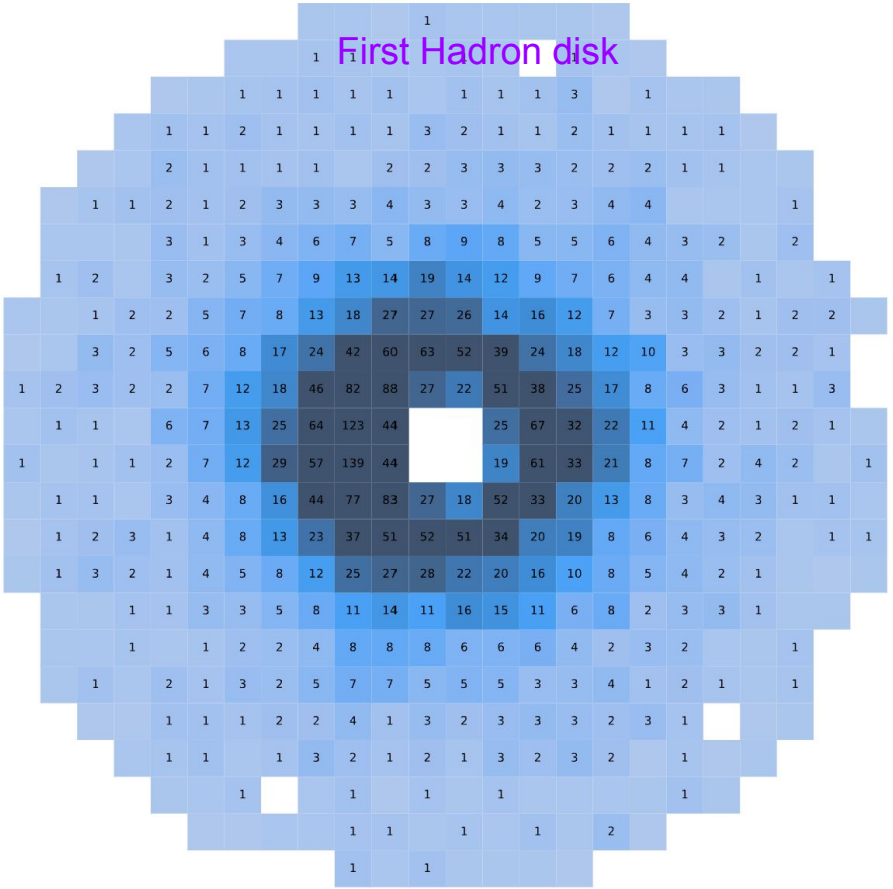
One event = one collision → **merged** → one 2us time slice contains (in this presentation):

- One 18x275 NC DIS events **(This is NOT the highest lumi configuration)**
- Beam background at calculated freq. (SR, electron Bremsstrahlung, Coulomb, Touschek, proton beam gas)

Beam Background Impact at Hit Level

Hits from charged beam particles:
plot digitized hits (edep > 0.54 keV) for each SVT surface
→ check number of hits per 2cm x 2cm square (size of RSU)

→ show result in **ms** (500 x 2us slices)



Hits distribution on disks

- x v.s. y, one square = one RSU
- First Hadron disk : max=135 hits / ms
- All disk hits:
  - distributions are similar: high density near the beampipe
  - Max hits=195/ms on H-disk 3

Beam Background Impact at Hit Level

Hits from charged beam particles:
plot digitized hits (edep > 0.54 keV) for each SVT surface
→ check number of hits per 2cm x 2cm square (size of RSU)

→ show result in **ms** (500 x 2us slices)

L0

39	68	42	39	48	44	54	44	53	45	49	43	44	25
23	43	41	34	39	38	35	56	56	55	59	57	66	50
29	34	35	38	40	55	51	32	36	42	43	33	46	30
24	29	37	44	35	40	49	45	43	40	45	62	43	33
23	34	40	47	55	40	40	43	38	36	46	43	49	40
28	43	55	49	57	58	63	51	56	62	52	56	49	39
50	52	46	53	44	51	45	36	59	59	81	40	47	46
24	33	37	32	42	37	47	45	38	34	28	26	32	32
25	24	25	29	29	40	43	44	48	40	38	35	37	36
27	33	32	41	34	35	33	33	40	42	46	62	50	40
21	34	44	49	48	47	43	48	56	38	52	45	52	40
24	27	31	38	49	42	47	32	38	38	51	33	33	35

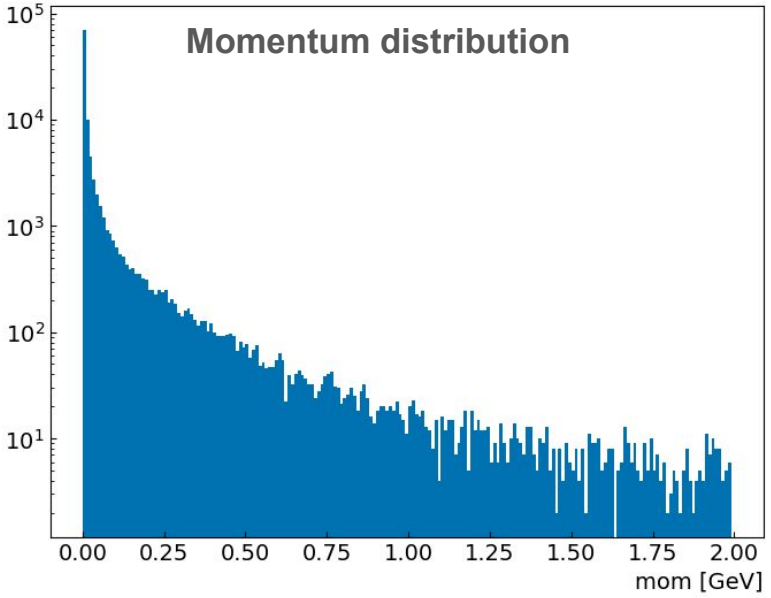
Hits distribution on Barrels:

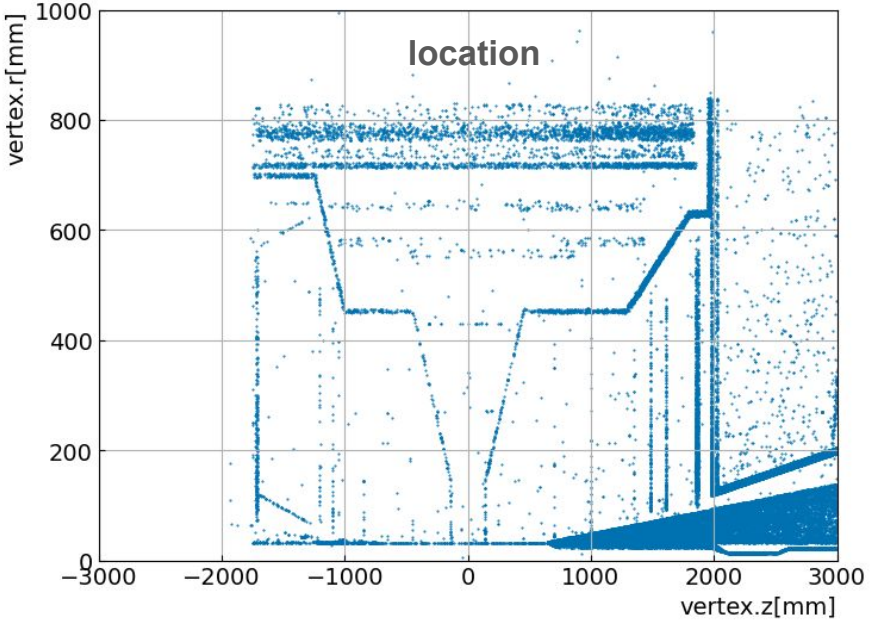
- Rphi v.s. Z, one square = one RSU
- L0 : max=63 hits / ms
- All barrels:
  - L0 and L1 get similar hit density
  - Number reduced quickly to <10 on L2 and further

Beam Background Impact at Hit Level

Secondary particles generated in DD4hep:

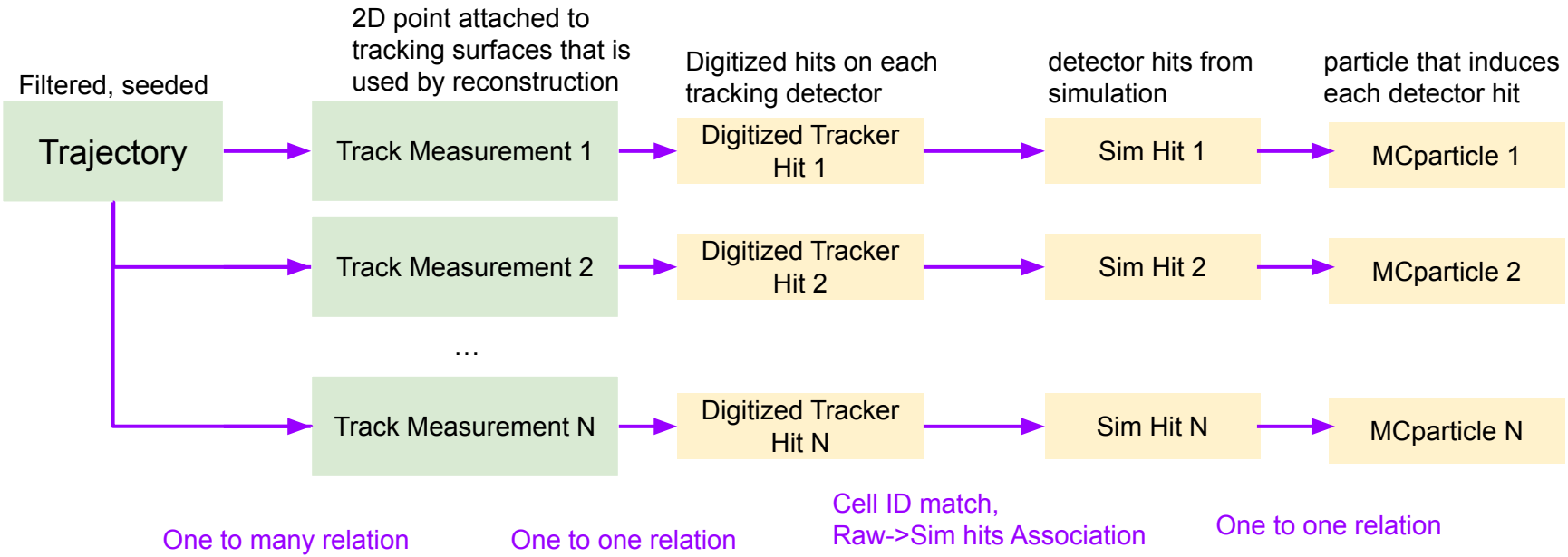
- generatorStatus==0 created by Geant4
- Widely distributed across detectors
- not likely to generate tracks due to low energy (0/1000 events), mostly stop at the immediate surface and leave a hit
- ~700 particles → hits per 2us





Beam Background Impact at Track Level

- **Match trajectory to simulated particles**

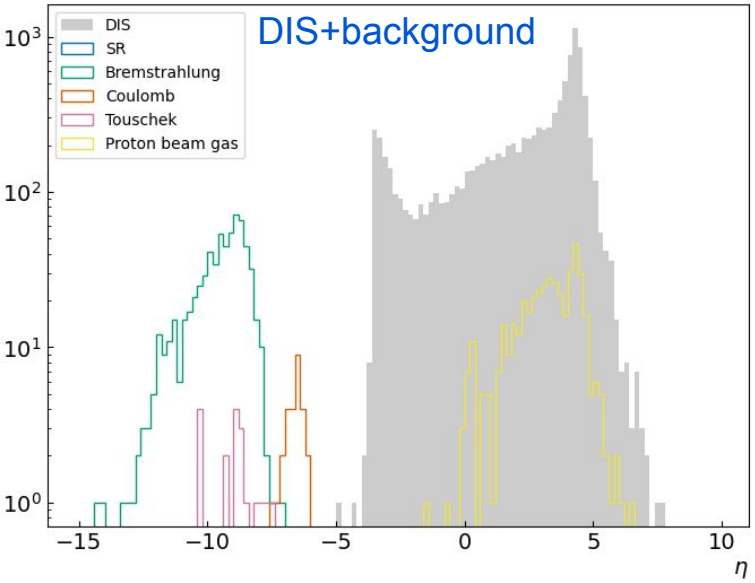


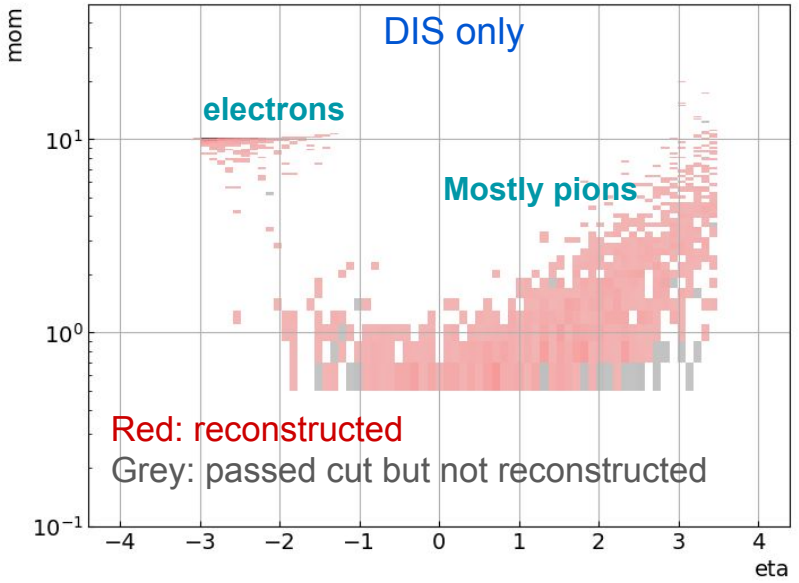
Efficiency: fraction of primary particles that are associated with tracks.
Purity: for a given track, fraction of hits from one particle.

Event sample inspection

- **Basic particle selection:**
  - Primary (un)decayed particle:
    - generatorStatus==xxx1 or xxx2
    - Charged
  - Momentum > 0.5 GeV
  - -4<eta<4
  - Vertex.r<1mm, abs(Vertex.z)<100mm
  - Particle endpoint outside of a barrel with
    - -850<z<1000mm (4th endcap disk)
    - r<270mm (L3 barrel)

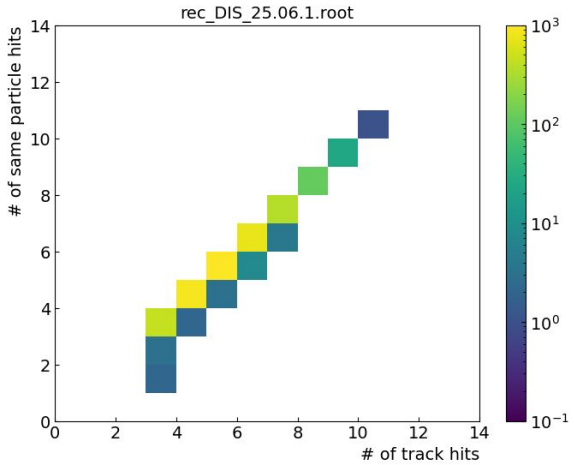
    So that it has high chance to go through 4 layers

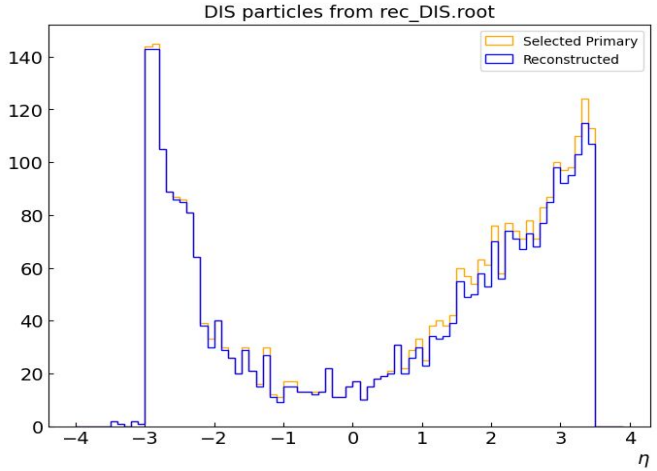


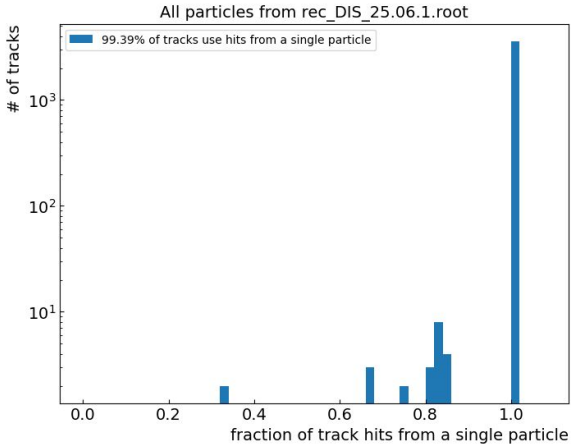


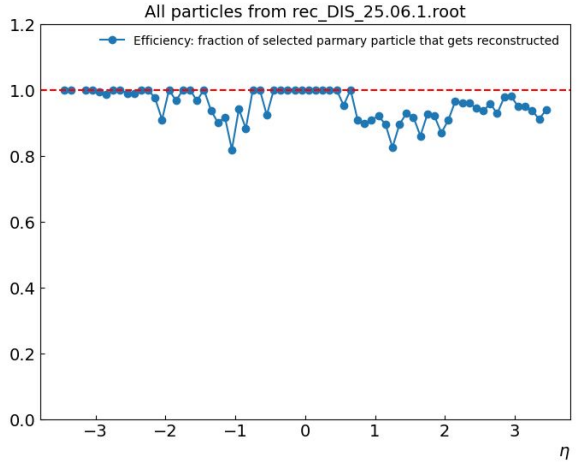
Purity and Efficiency: DIS only sample

18x275



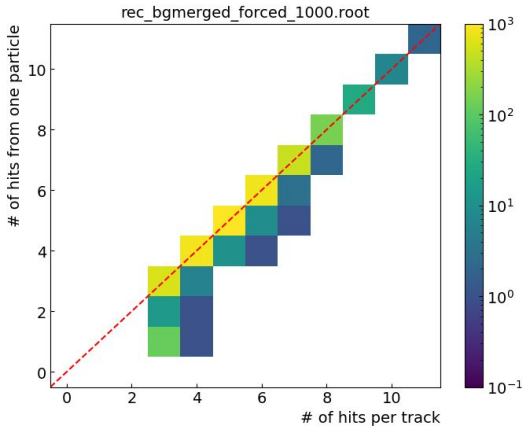


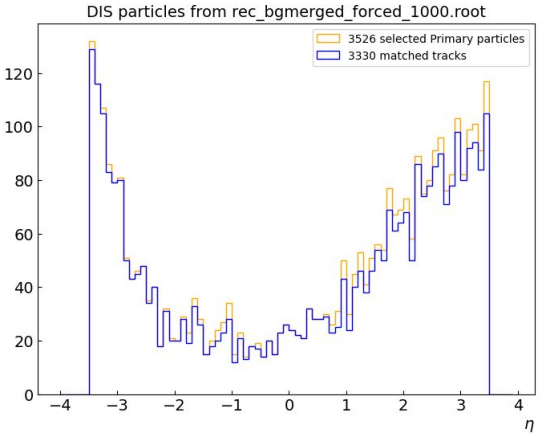


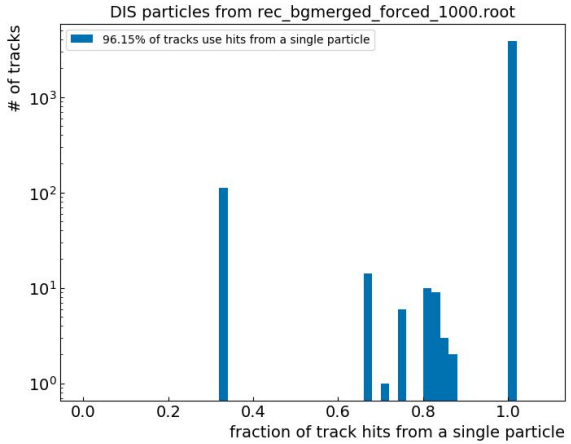


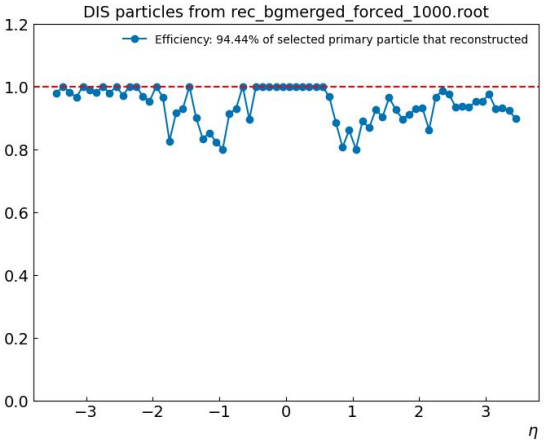
Purity and Efficiency: DIS (forced) + background sample

18x275









Simulation Work Plan

Short term:

- Update tracking geometry
  - Need expert help to translate the geometry design to simple TGeo shapes
- Background+noise study
  - + layer impact study
  - + TOF / MPGD impact study
- Tracking algorithm optimization

Long term:

- Charge sharing and clustering?
- alignment

Thanks!