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U.S. DEPARTMENT OF ENERGY
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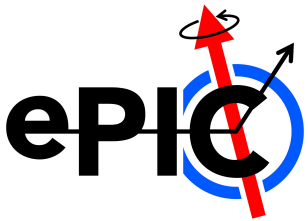
Tracking Performance with Background

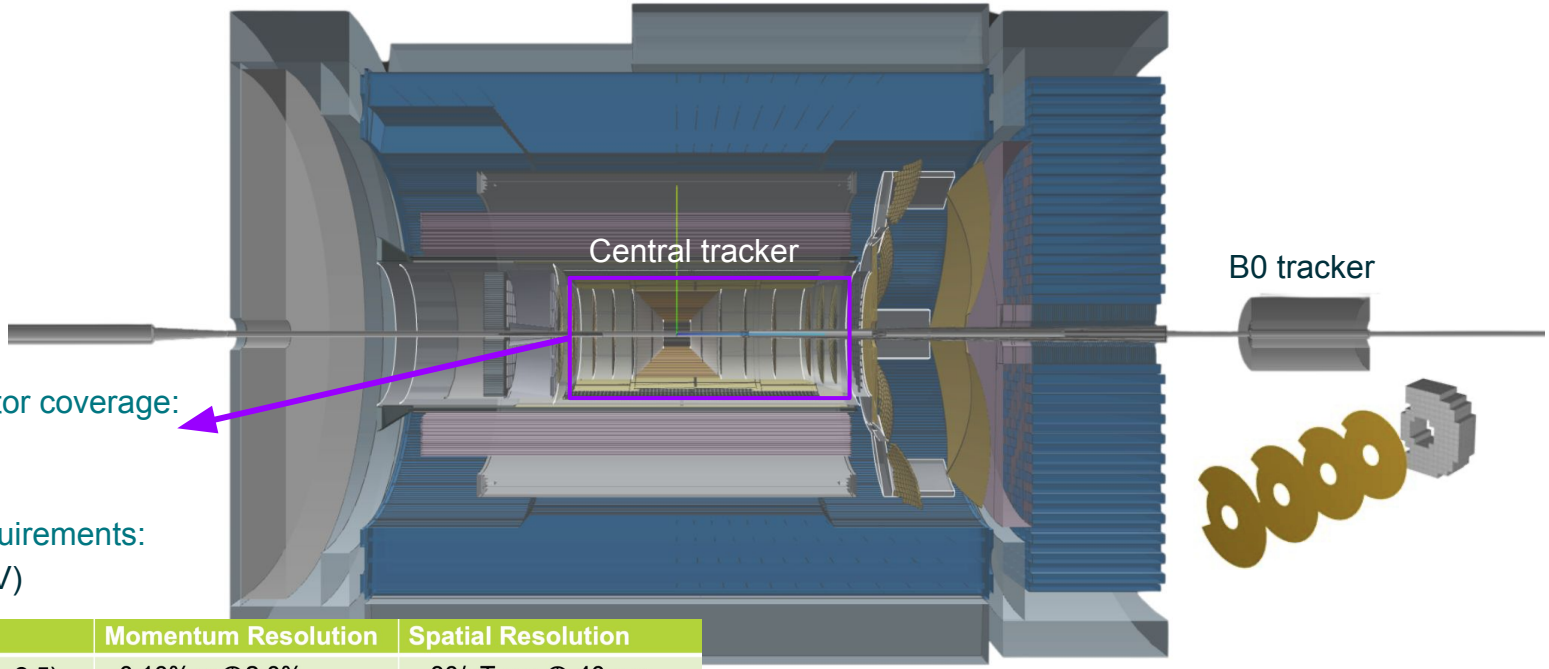
Shujie Li

ePIC Tracking WG @ EICUG 2025

Newport News, VA, July 16, 2025



ePIC Tracking System



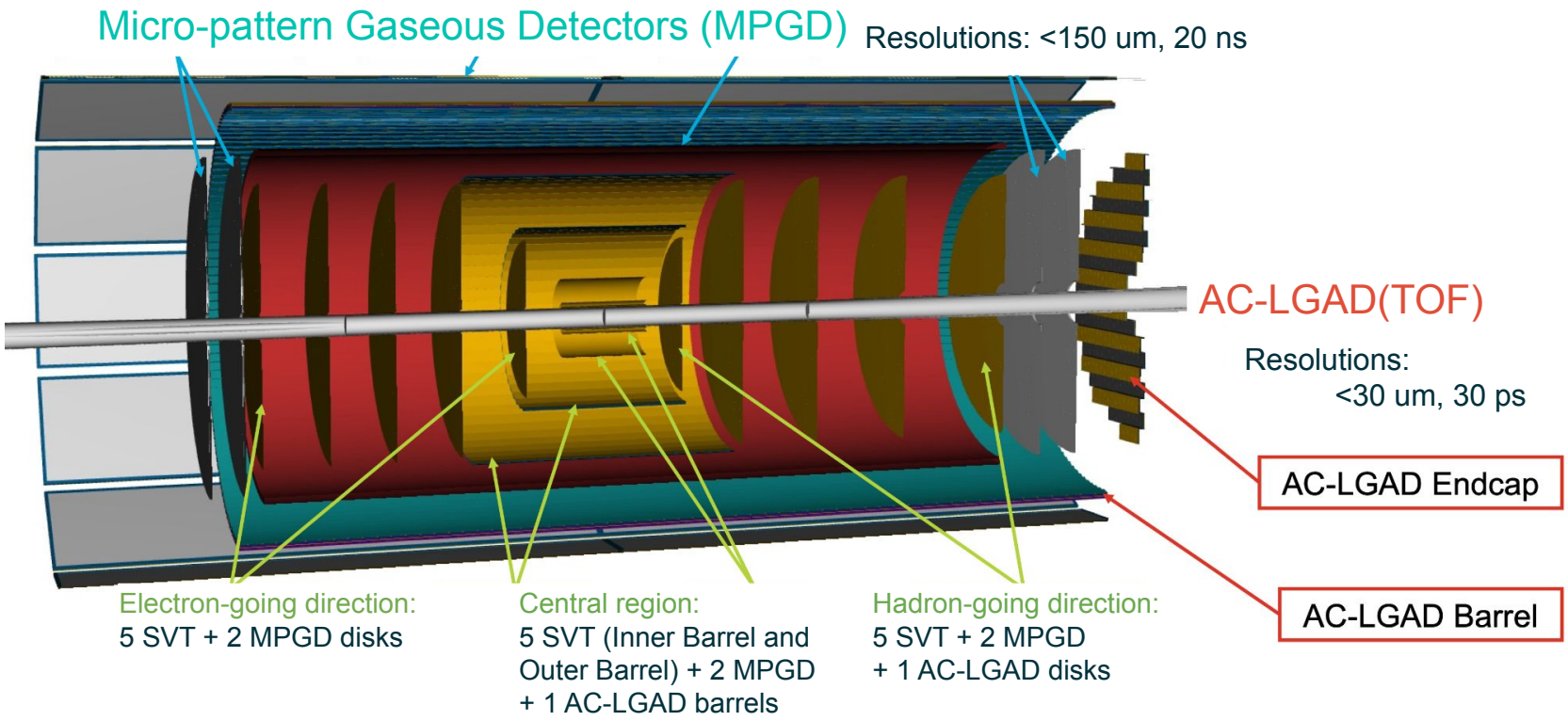
*Central detector coverage:
$-4 < \eta < 4$

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



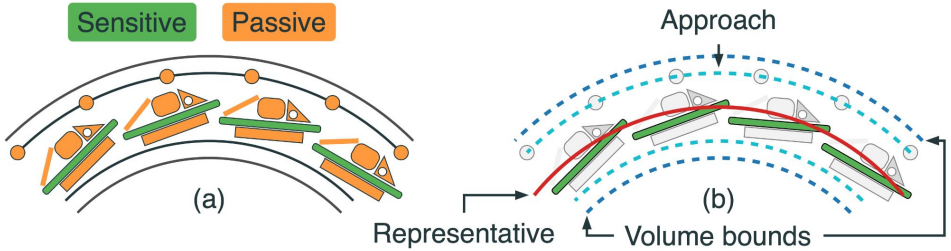
SVT Geometry in Simulation

- **DD4hep** : Geant4-based detector description and particle propagation through materials and magnetic field.
  - **Sensitive detector:**
    - Segmentations (2d or 3d grids) to reflect for spatial resolution through digitization.
    - 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

Check detector design details from the DAC meeting. And implementation in simulation from SVT, TOF, and MPGD working groups.
Near term priority: major geometry updates on SVT (IB and EIC-LAS), MPGD and TOF (strip), and integation of support / service structures.

SVT Geometry in Simulation

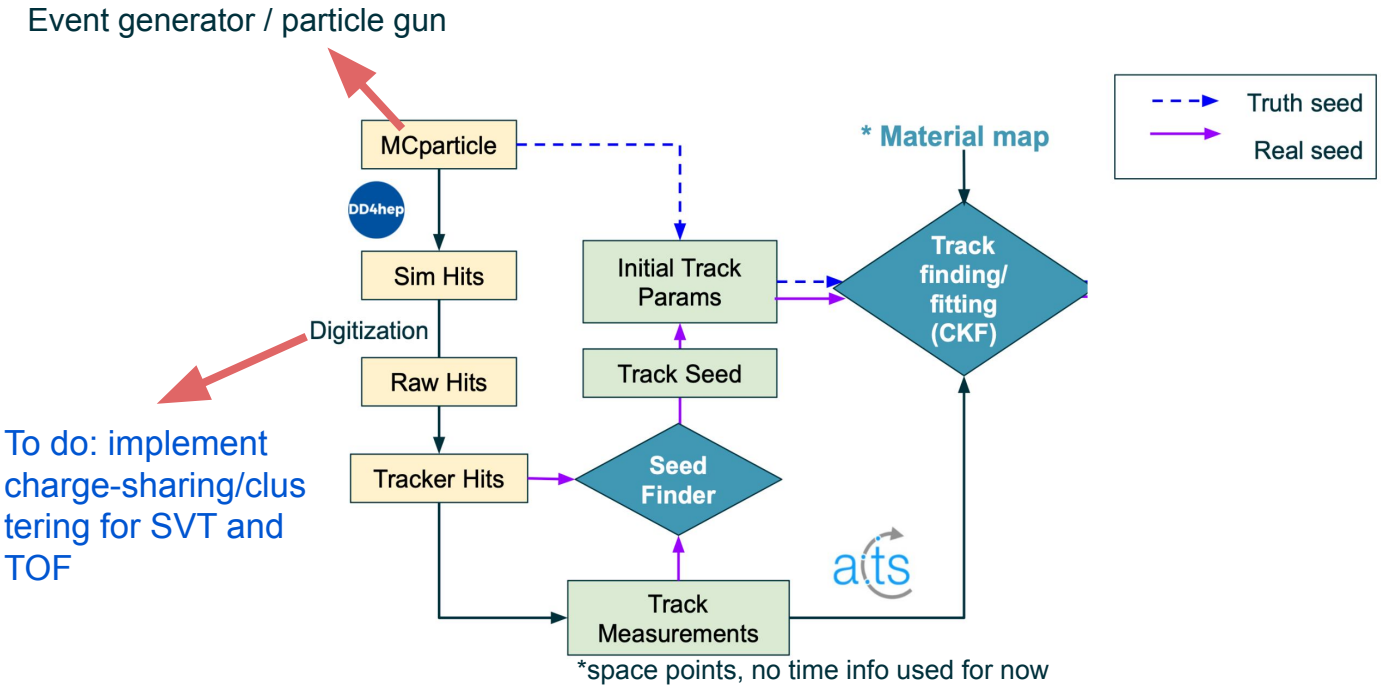
- In-house developed **EICrecon** framework for digitization, track and particle reconstruction, and analysis
  - Use **ACTS** for tracking:
    - Navigate track propagation through onion-like (endcap-barrel-endcap) tracking hierarchy.
    - Detector **volumes** are reduced to representing **surfaces**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



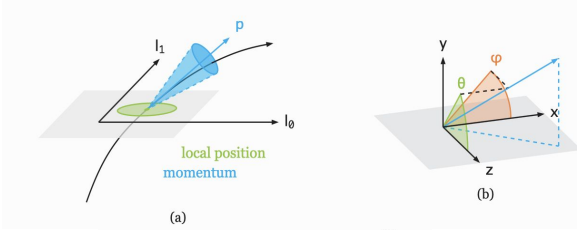
    - Materials are projected to selected surfaces, e.g. at the entrance and exit boundaries of sensitive surfaces ← this information is provided with a pre-generated **material map**, will NOT consider any dd4hep materials otherwise.

WARNING: material map needs to be updated whenever ANY structure within the tracking volume is modified

Tracking workflow

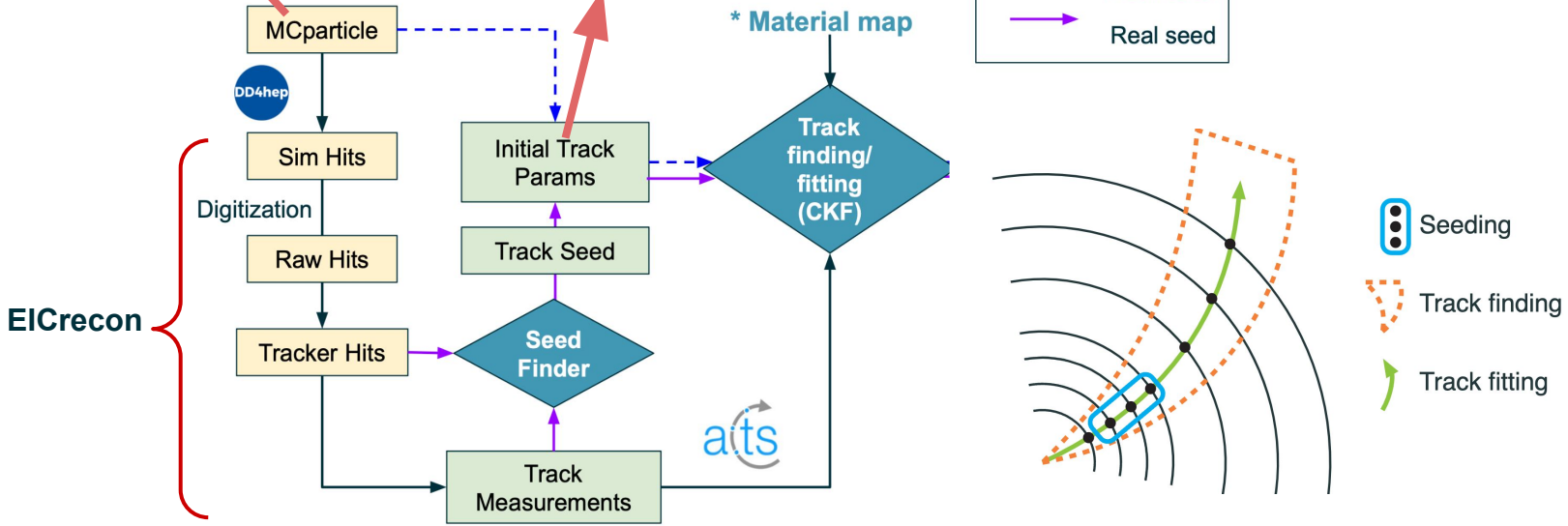


Tracking workflow



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

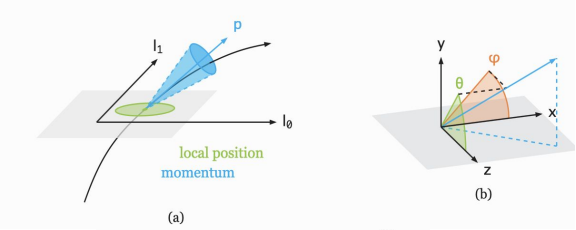
Event generator / particle gun



*space points, no time info used for now

Longer term priority: include time info from TOF and MPGD for tracking

Tracking workflow



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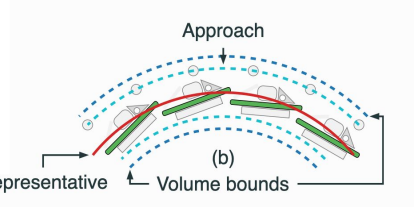
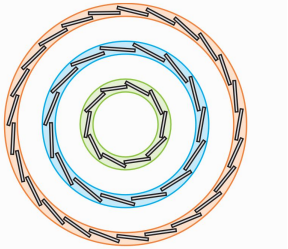
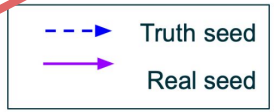
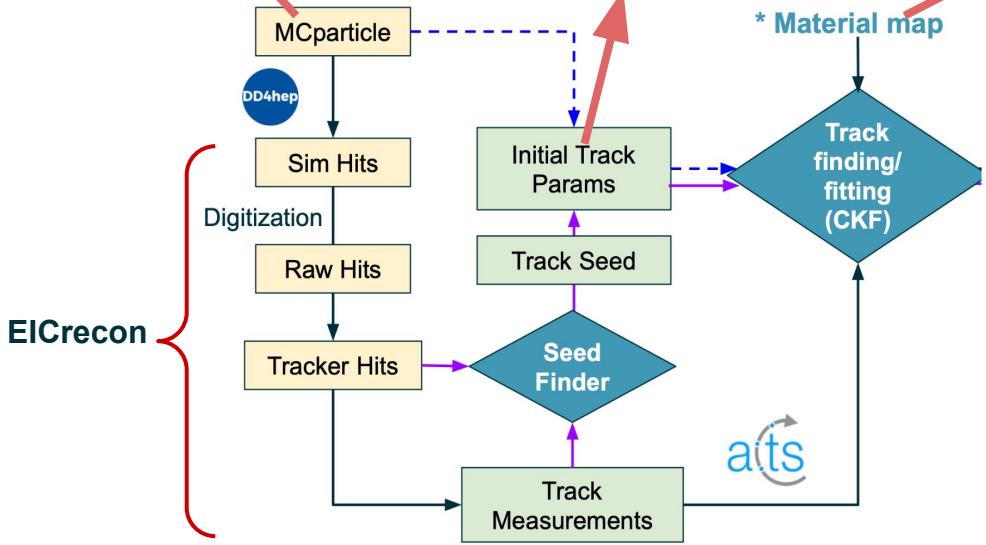




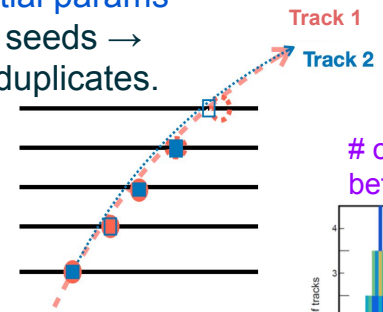




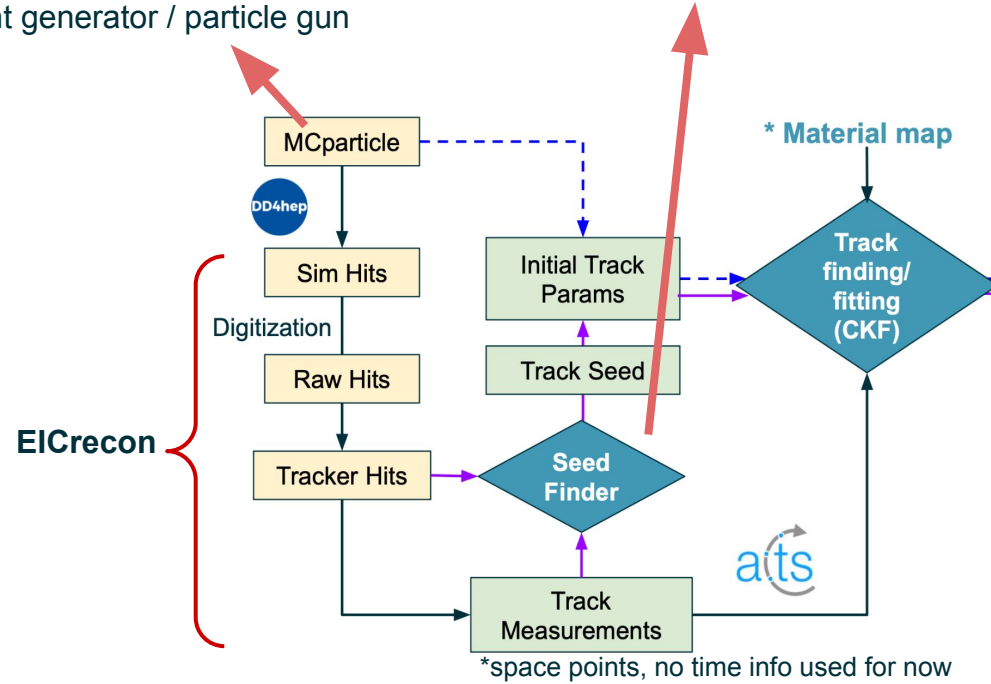
*space points, no time info used for now

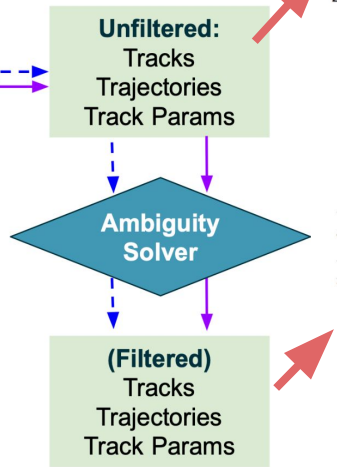
Tracking workflow

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.

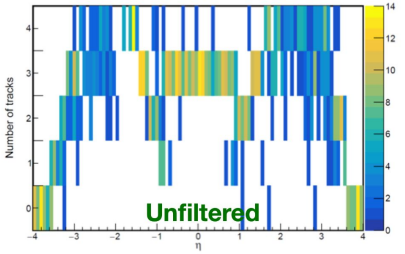


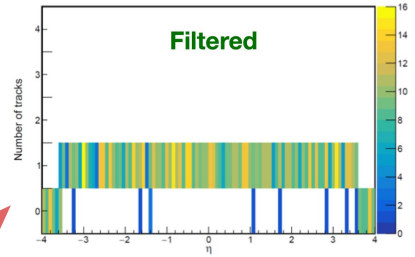
Event generator / particle gun





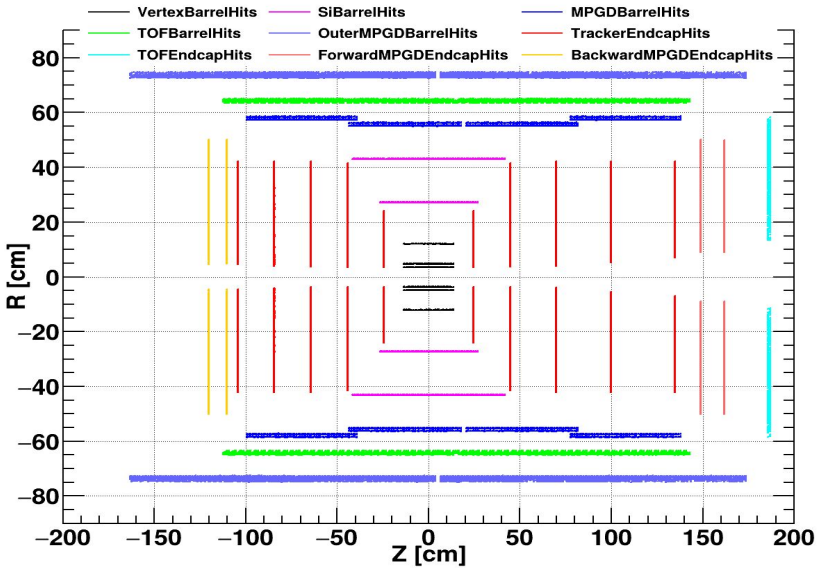
# of tracks per particle before/after

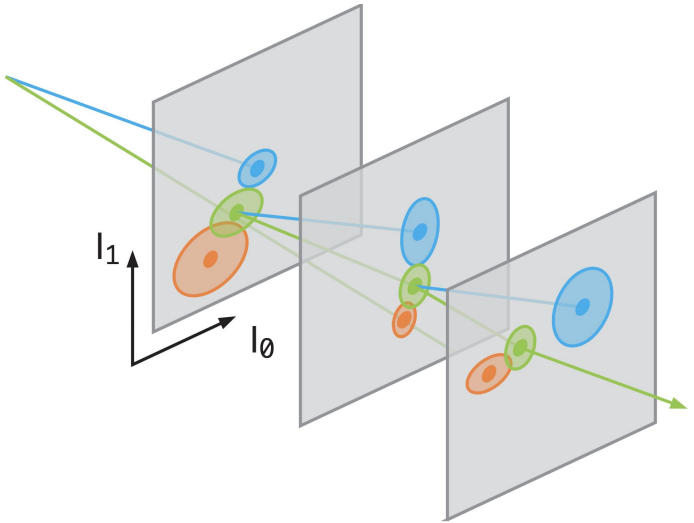




Tracking workflow

- **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.

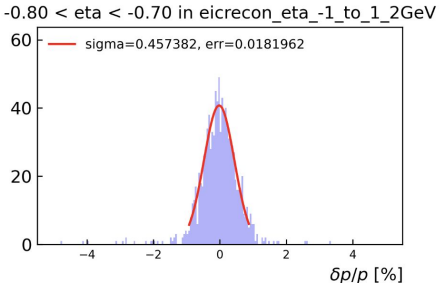


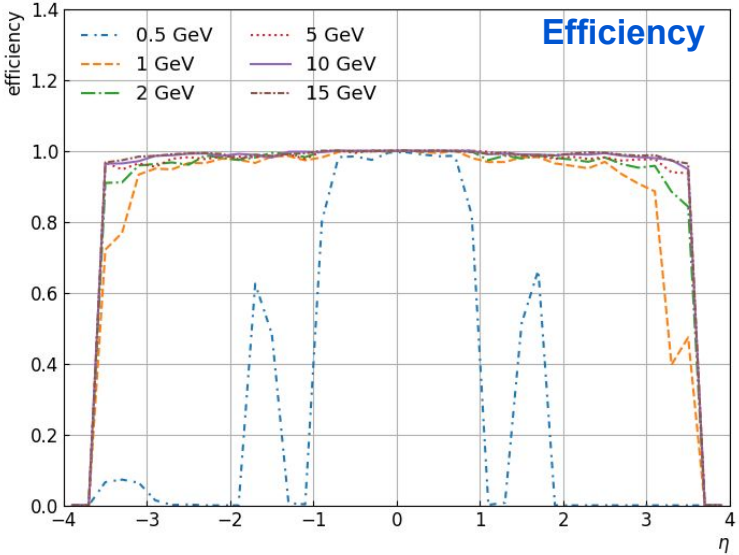


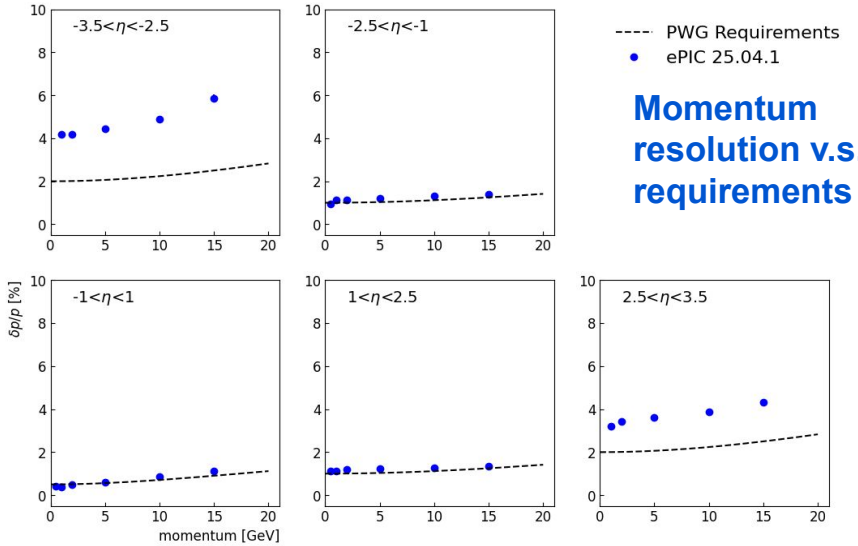
Single Particle Tracking Performance

- **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 at vertex**: dp/p, theta, phi, DCAr

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







Momentum resolution v.s. requirements

Tracking Layer Impact Study

Concern:

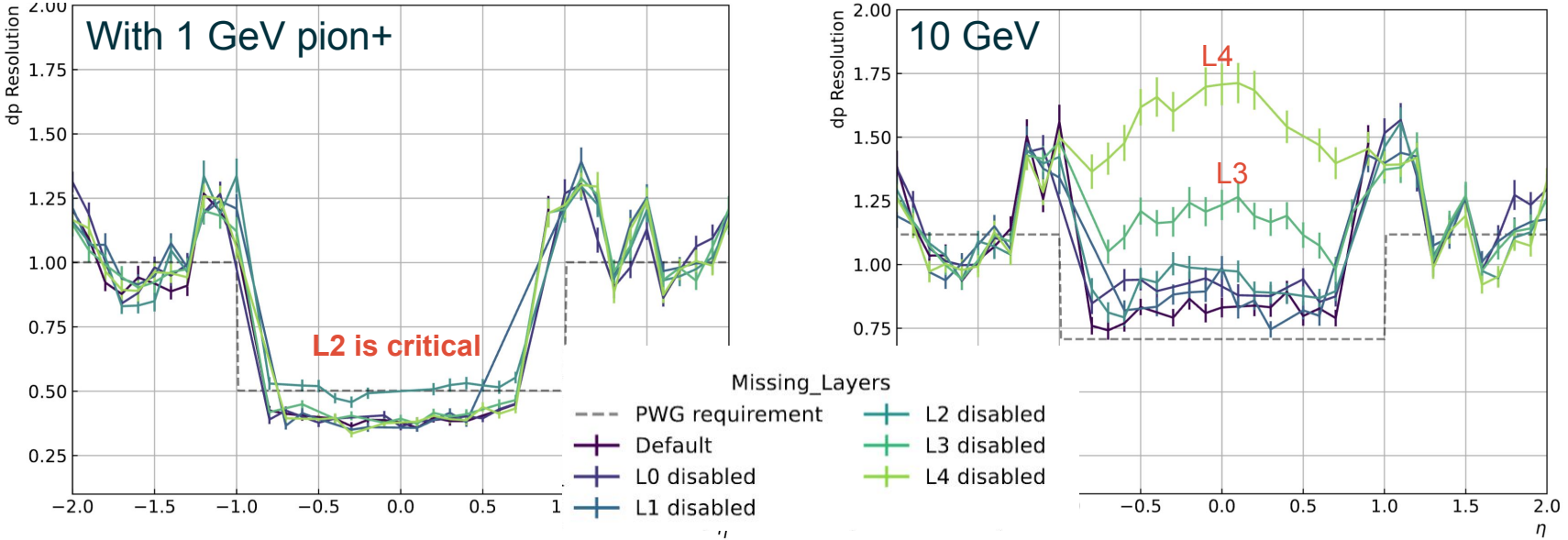
What if a particle doesn't leave hit on a specific tracking layer for any reason?

Simulation setting:

Don't use hits from that layer in track reconstruction while keep the geometry and materials in DD4hep simulation.

Example:

dp/p (%) with disabled **SVT Barrel layer** (L0 to L4 that covers -0.9 < eta < 0.9):



Tracking Study with Realistic Environment

Concern:

Noise hits can impact our tracking purity and efficiency.

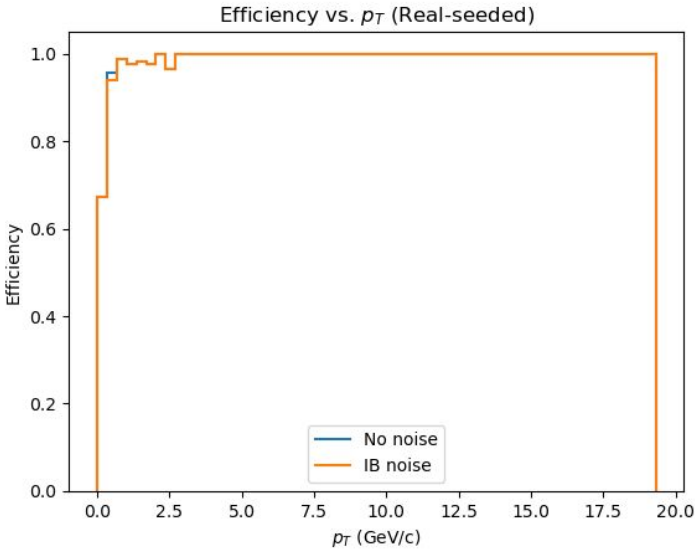
Simulation setting:

SVT: randomly generate fake hit in digitization. TOF: noise injection in charge-sharing/ clustering

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

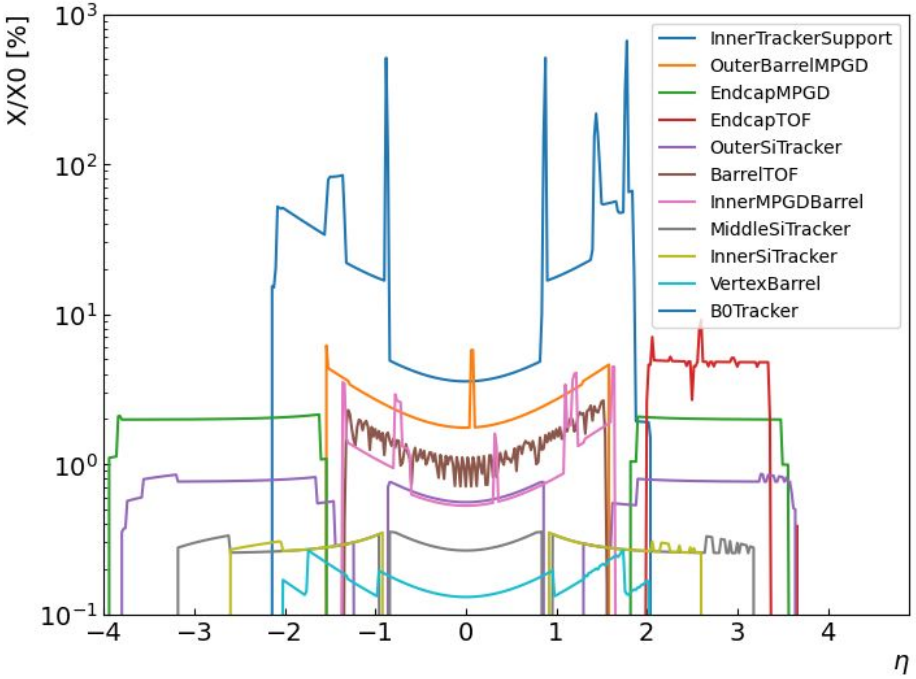
Sampled fake-hit rate: FHR < 5 x 10^{-7} per event per pixel.
Fake hits/event/collection: FHR x total pixels

	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



- **Near term priority:**
  - Noise + background + missing layer impact study for all tracking detectors

Tracking Layer Material Thickness Study



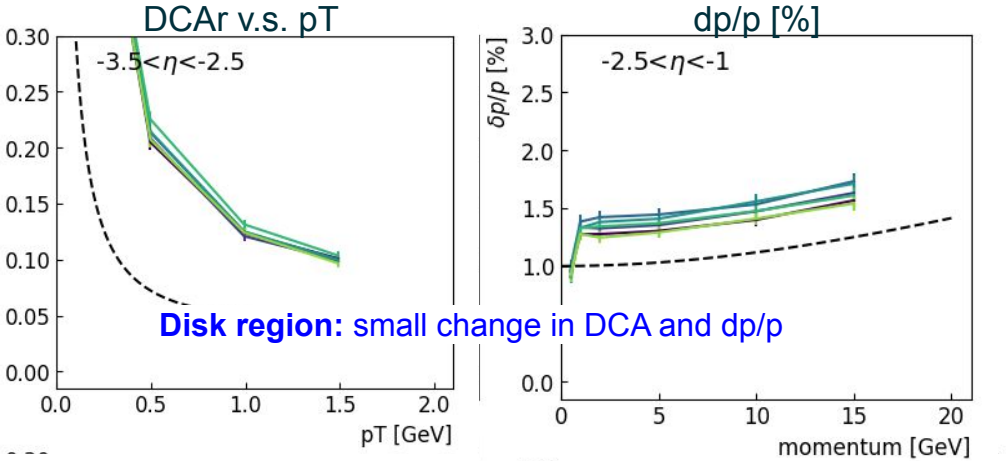
The nominal SVT thickness per layer:

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

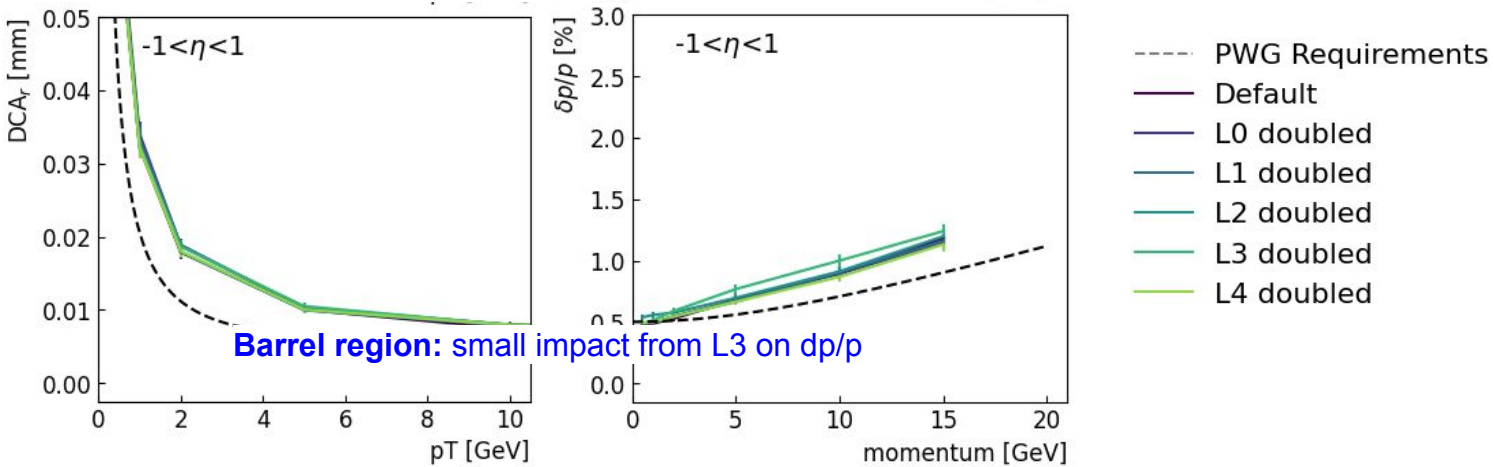
More materials from service, support structure etc will induce more rescattering

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

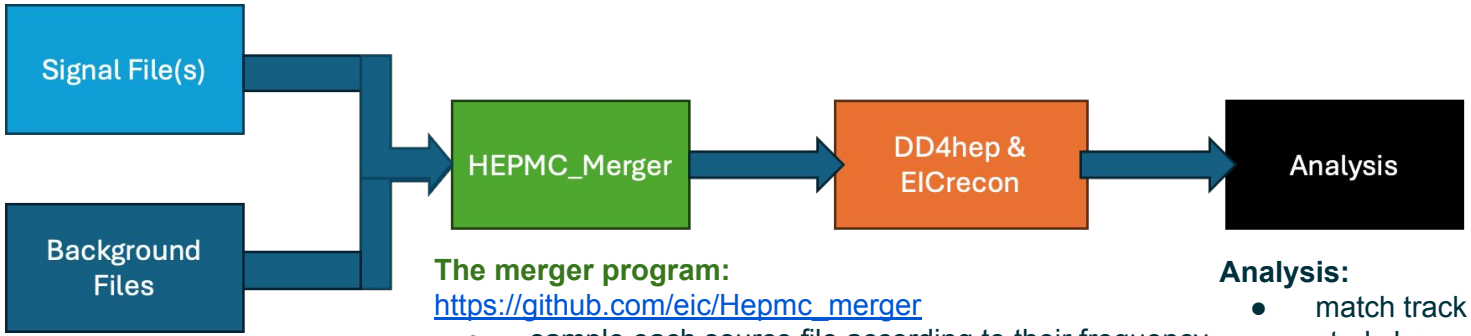
Concern:

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

Simulation setting:

Performance study with signal+background merged event

- Reconstructed events from DIS+background, and minbias+background are available in the recent 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

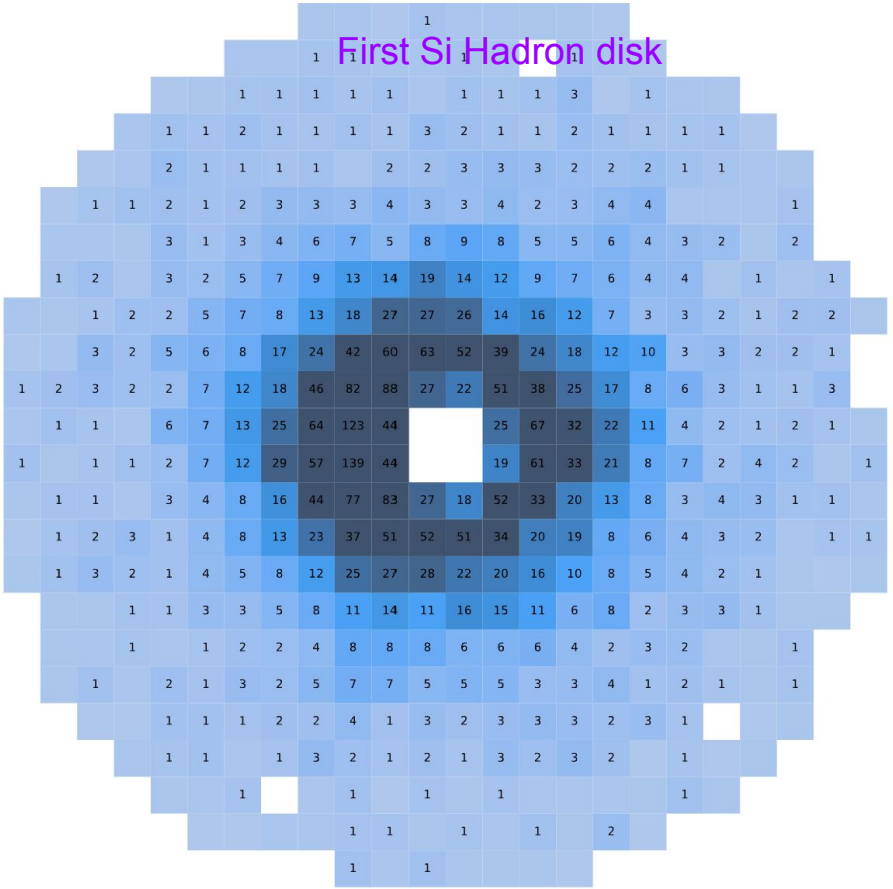
One event = one collision → **merged** → one 2us time slice contains (in this presentation):

- 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

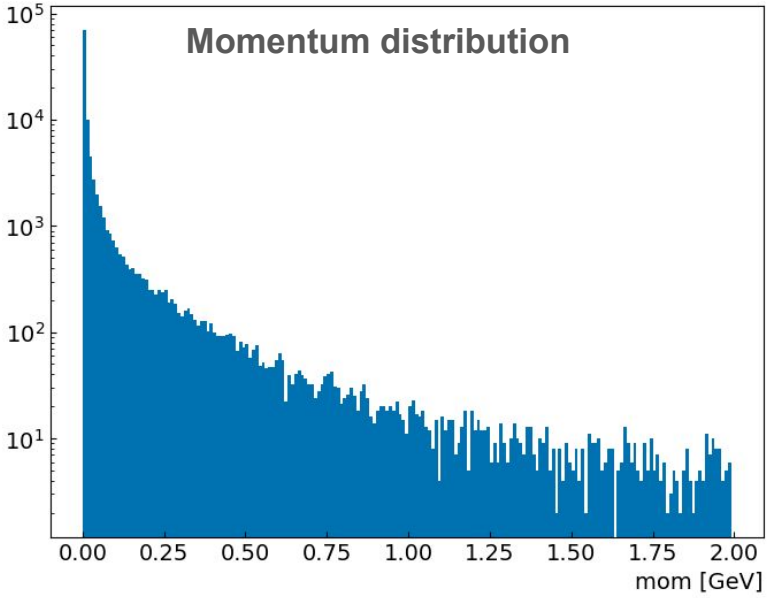
Hits distribution on Barrels:

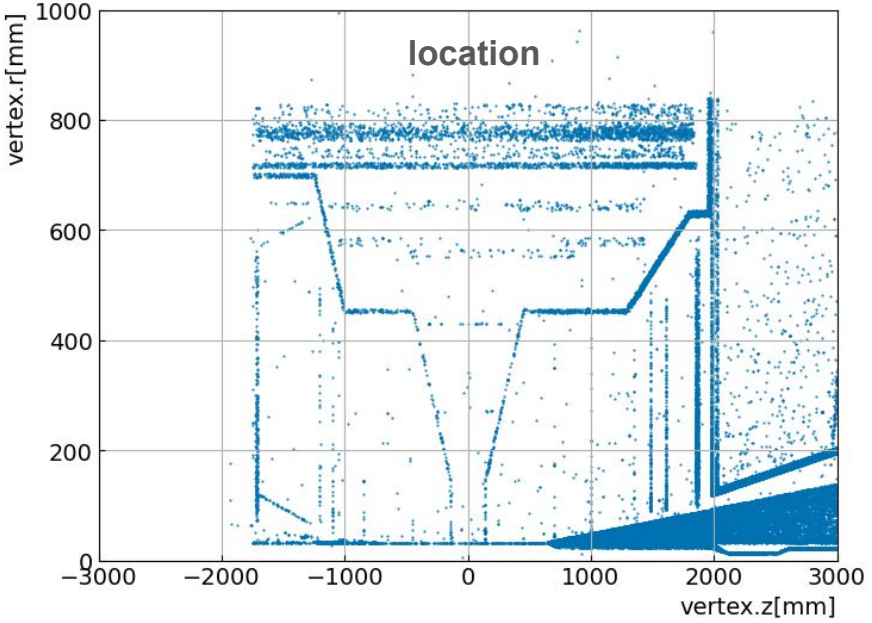
- Rphi v.s. Z, one square = one RSU
- L0 : max=63 hits / ms
- All barrels:
  - L0 and L1 get similar hit density
  - Number reduced quickly to <10 on L2 and further

Beam Background Impact at Hit Level

Secondary particles generated in DD4hep:

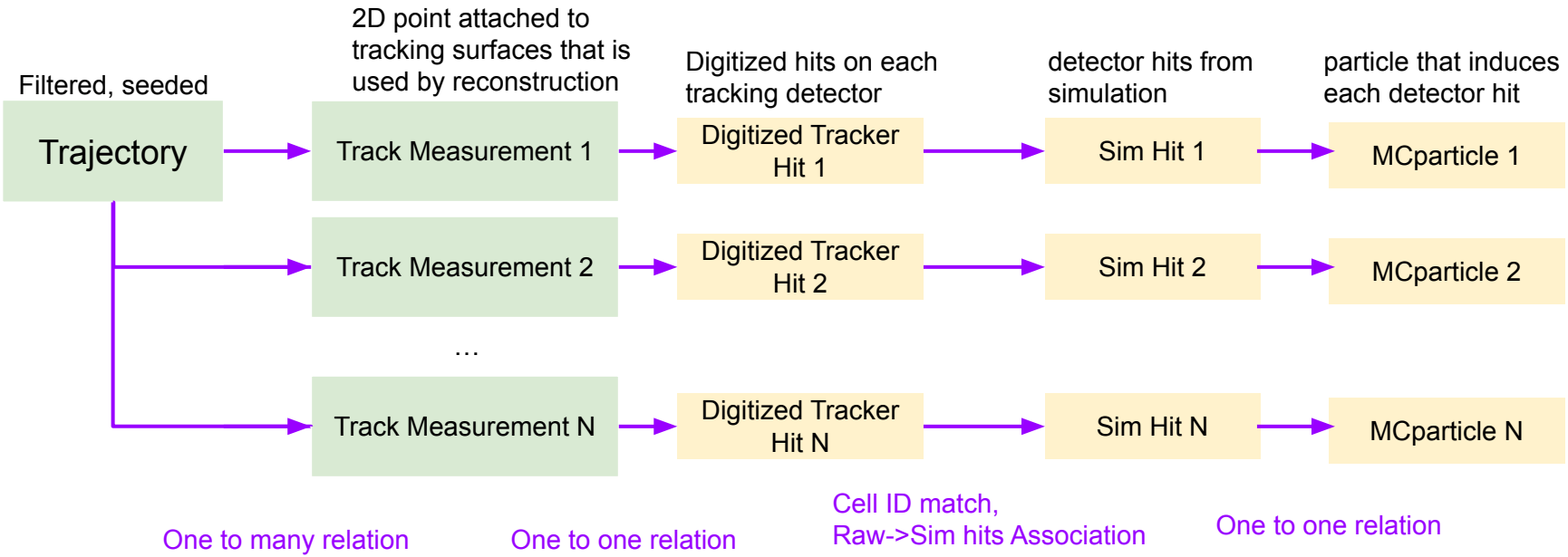
- generatorStatus==0 created by Geant4
- Widely distributed across detectors
- not likely to generate tracks due to low energy (0/1000 events), mostly stop at the immediate surface and leave a hit
- ~700 particles → hits per 2us





Beam Background Impact at Track Level

- **Match trajectory to simulated particles**

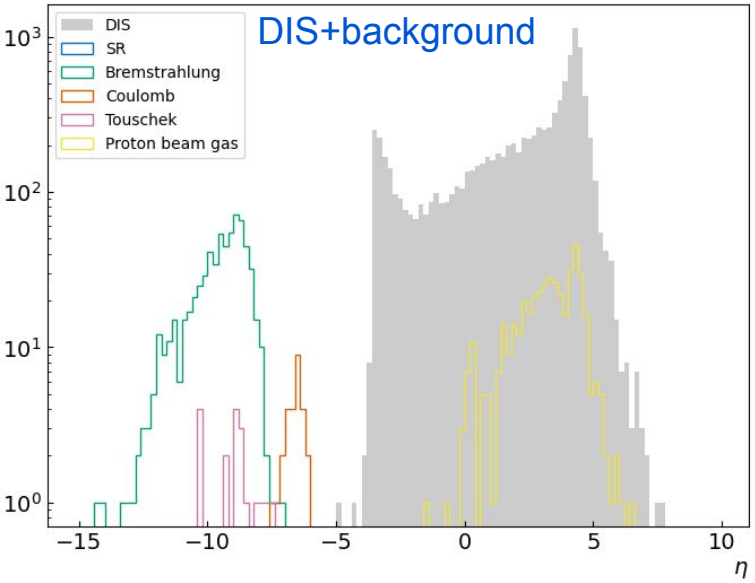


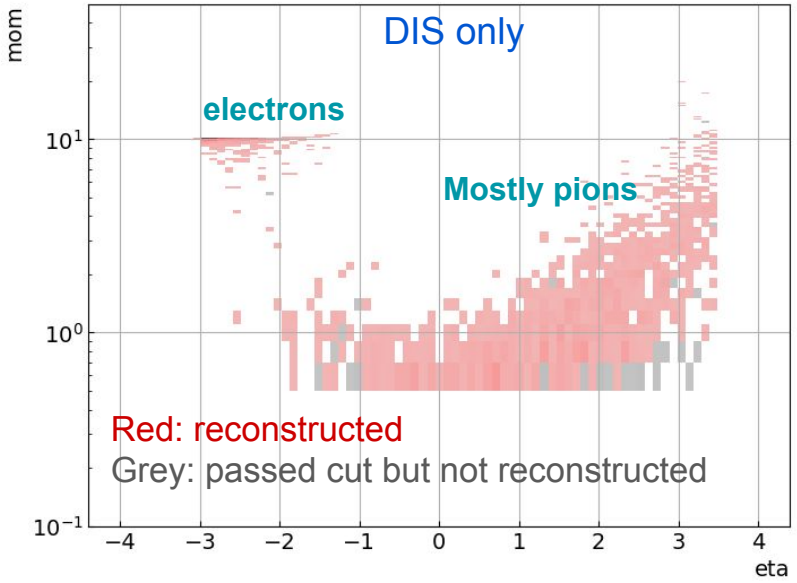
Efficiency: fraction of primary particles that are associated with tracks.
Purity: for a given track, fraction of hits from one particle.

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)

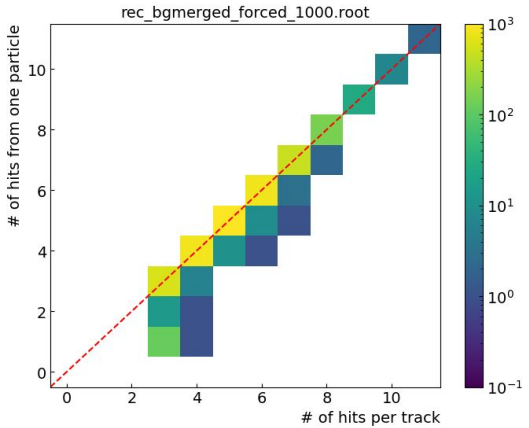
    So that it has high chance to go through 4 layers

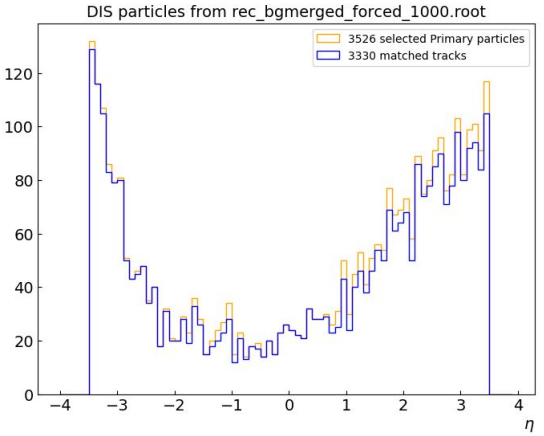


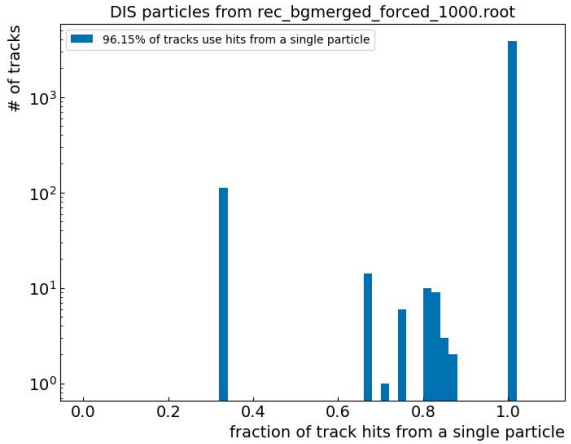


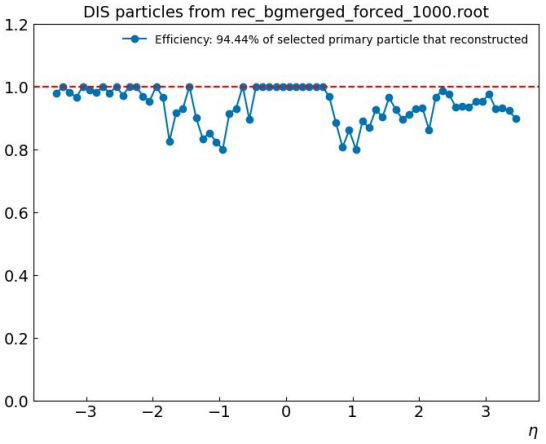
Purity and Efficiency: DIS (forced) + background sample

18x275



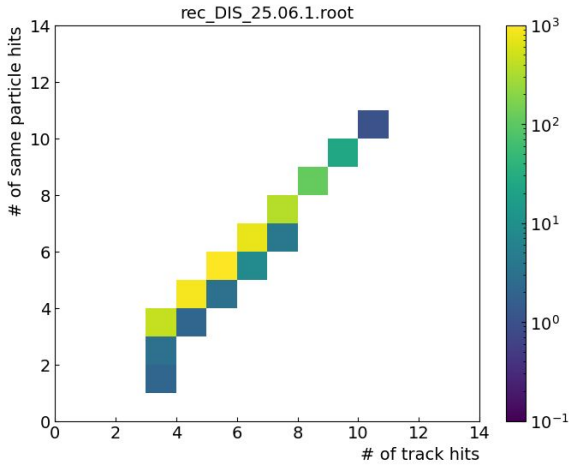


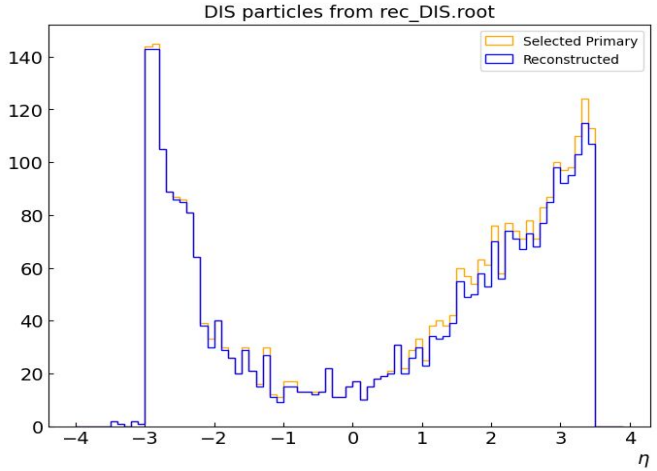


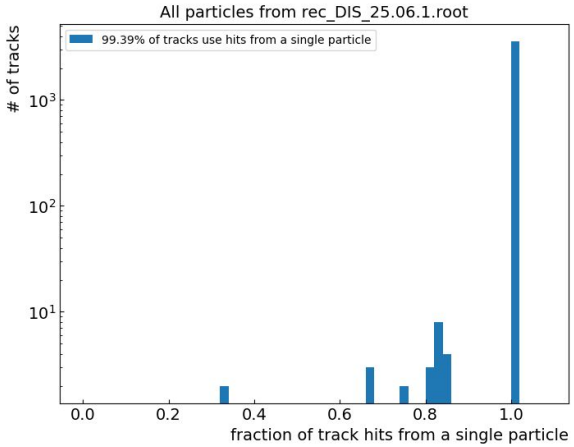


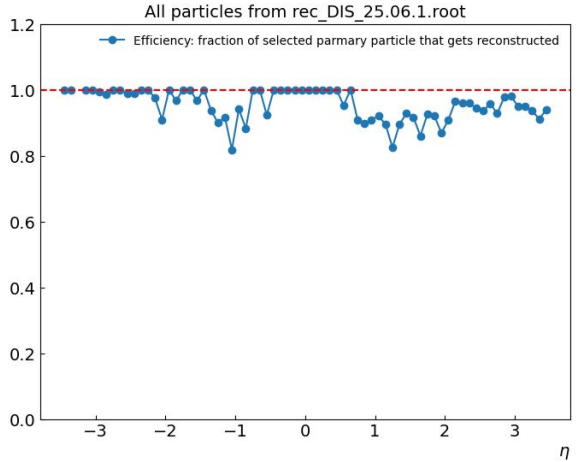
Purity and Efficiency: DIS only sample

18x275









Background study plan

- Update tracking geometry
  - Need inputs on the detector shape, as well as service/support structures.
- Tracking algorithm optimization
- Quantities to check:
  - Track resolution at vertex
  - Integrated study of angular resolution projected to PID detectors e.g. hpDIRC, see studies from DIRC, TOF and MPGD
  - Displaced vertex

⇒ Background+noise study
  - SVT + TOF / MPGD impact study
  - Include BIC

Thanks!