Acts in ePIC

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On behalf of the ePIC Tracking & Vertexing working group

Acts Workshop 2026

Electron-Ion Collider

Outline

- Overview of the ePIC detector
- Acts in ePIC
- Updates since last year
  - Detector geometry and digitization
  - Tracking & vertexing performance
  - Tracking in the presence of beam backgrounds
  - New tracking tools

Overview of the ePIC detector

ePIC Central Detector Design

Magnet

- New 1.7 T SC solenoid, 2.8 m bore diameter

Tracking

- Si Vertex Tracker MAPS wafer-level stitched sensors (ALICE ITS3)
- Si Tracker MAPS barrel and disks
- Gaseous tracker: MPGDs (μRWELL, MMG) cylindrical and planar

PID

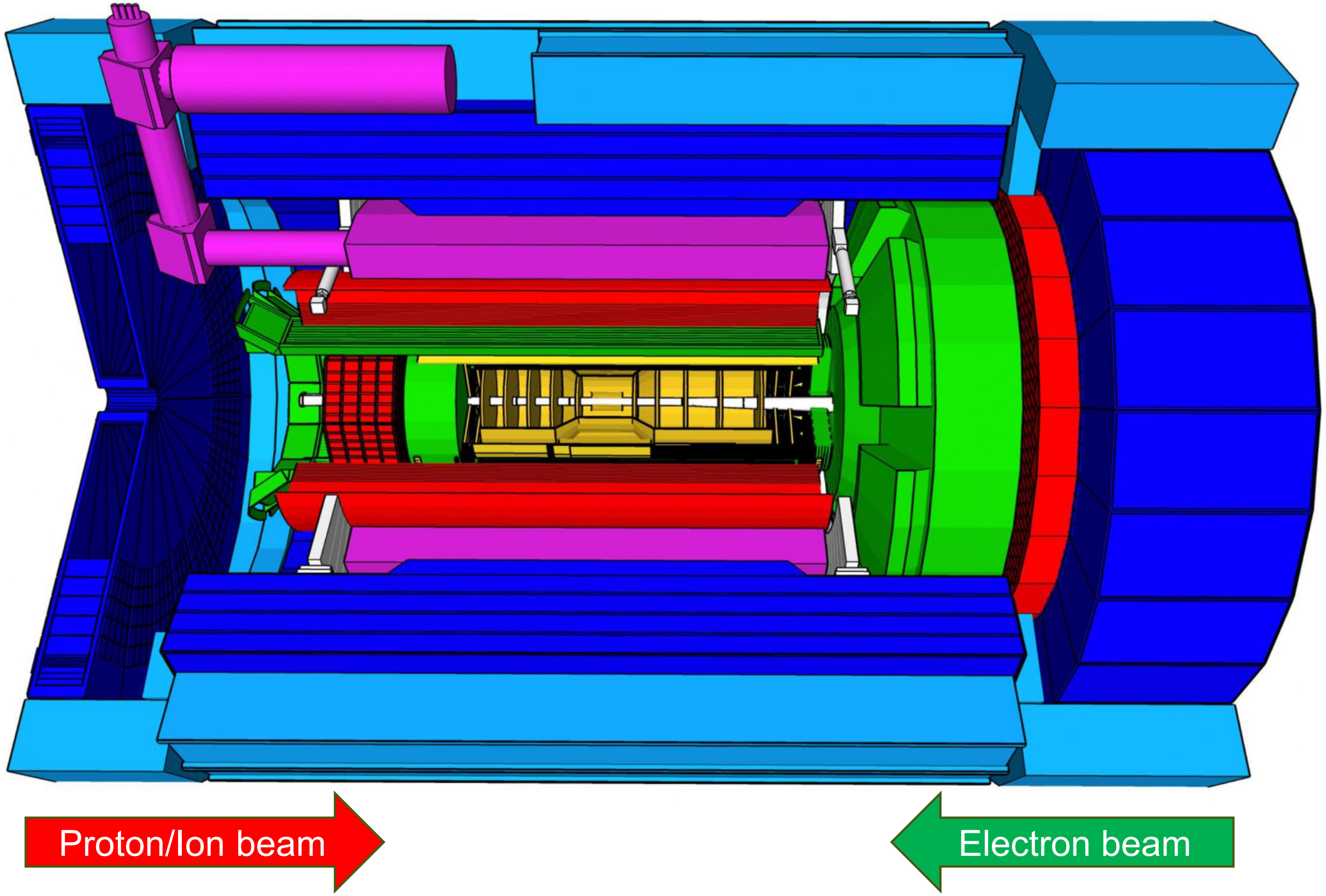
- high performance DIRC (hpDIRC)
- dual RICH (aerogel + gas) (forward)
- proximity focussing RICH (backward)
- ToF using AC-LGAD (barrel+forward)

EM Calorimetry

- imaging EMCal (barrel)
- W-powder/SciFi (forward)
- $PbWO_4$ crystals (backward)

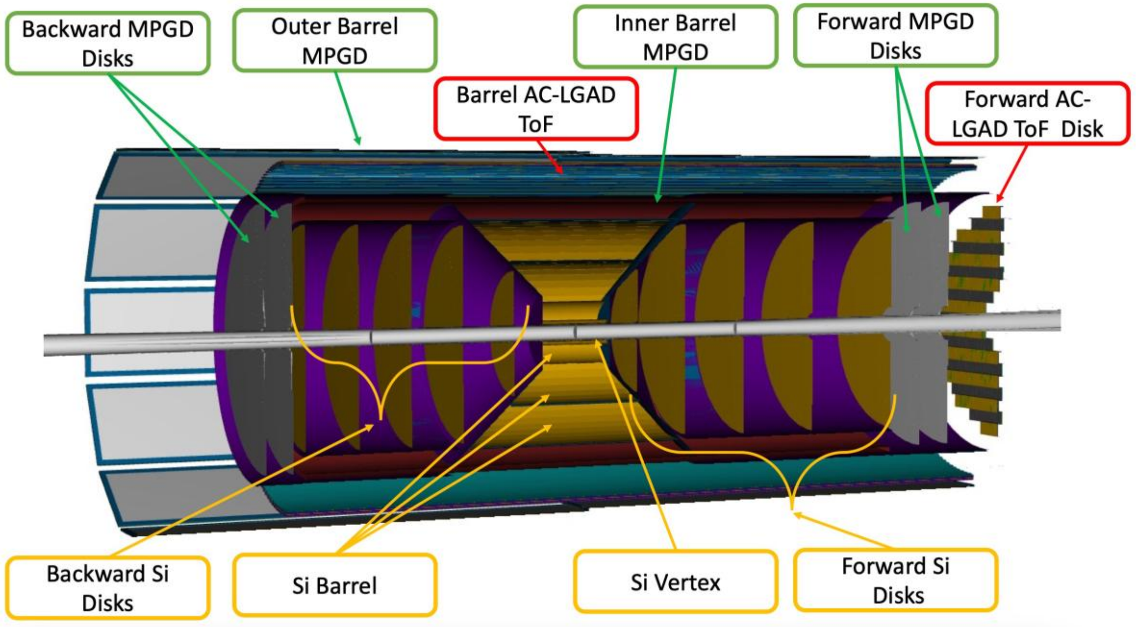
Hadron calorimetry

- FeSc (barrel, re-used from sPHENIX)
- Steel/Scint – W/Scint (backward/forward)



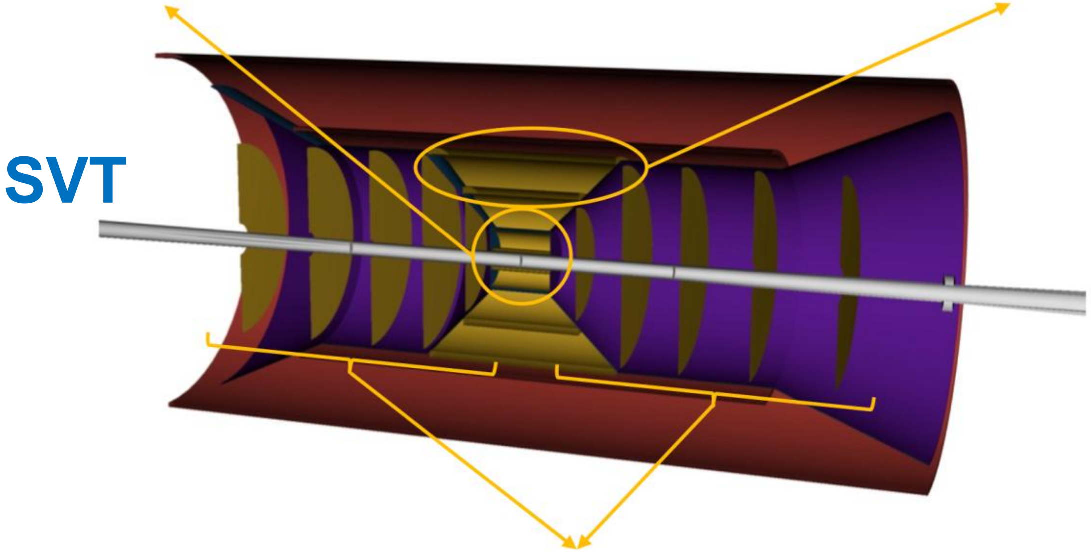
Central Tracker

Full tracking system: Silicon Vertex Tracker (SVT) + MPGDs + AC-LGAD TOF detectors



Inner Barrel (IB)
- Two curved silicon vertex layers
- One curved dual-purpose layer
- 0.05% X/X0 per layer

Outer Barrel (OB)
- One stave-based sagitta layer
- One stave-based outer layer
- 0.25/0.55% X/X0 per layer



Electron/Hadron Endcaps (EE, HE)
- Five disks on either side of the Interaction Region
- 0.25% X/X0 per layer

65 nm MAPS technology (ALICE ITS3)
O(20x20 μm^2) pixel size
Total active area of 8.5 m^2

MPGDs and AC-LGADs provide
- additional hit points for track reconstruction (<150 μm, 30 μm)
- fast timing hits for background rejection (10-20 ns, 30 ps)

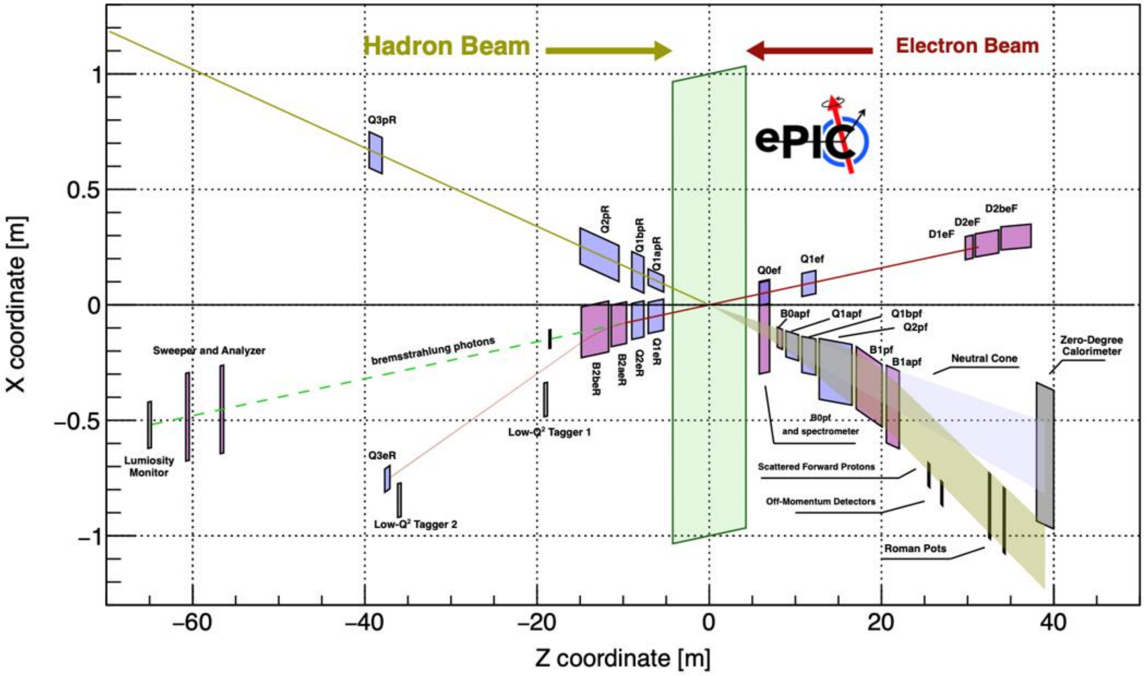
Unique features of ePIC

- The full detector design is integrated over the entire 90m long EIC interaction region.

- The central (tracking) detector has an asymmetric design, due to the larger hadron beam energy relative to the electron beam energy.
- The beams have a large (25 mRad) crossing angle, which leads to an asymmetry in the horizontal direction.
- The ePIC detector will use a streaming readout mode (time slices). The time component for tracking and vertexing will be important.

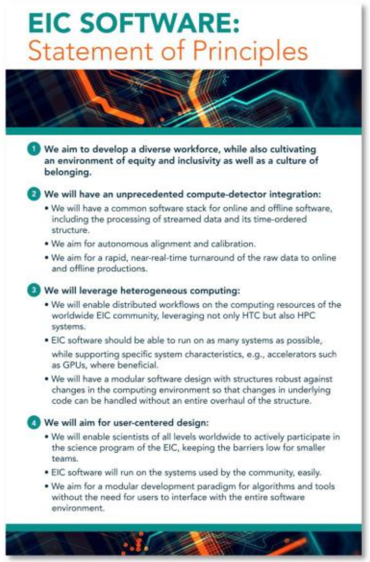
- We will have an e-p collision every 200-bunch crossings at the highest luminosity. The event activity for e-p collisions is also low.
  - Beam background rates are significantly larger than the e-p rate.
  - ePIC events will be background and noise dominated

Interaction region (IR) design



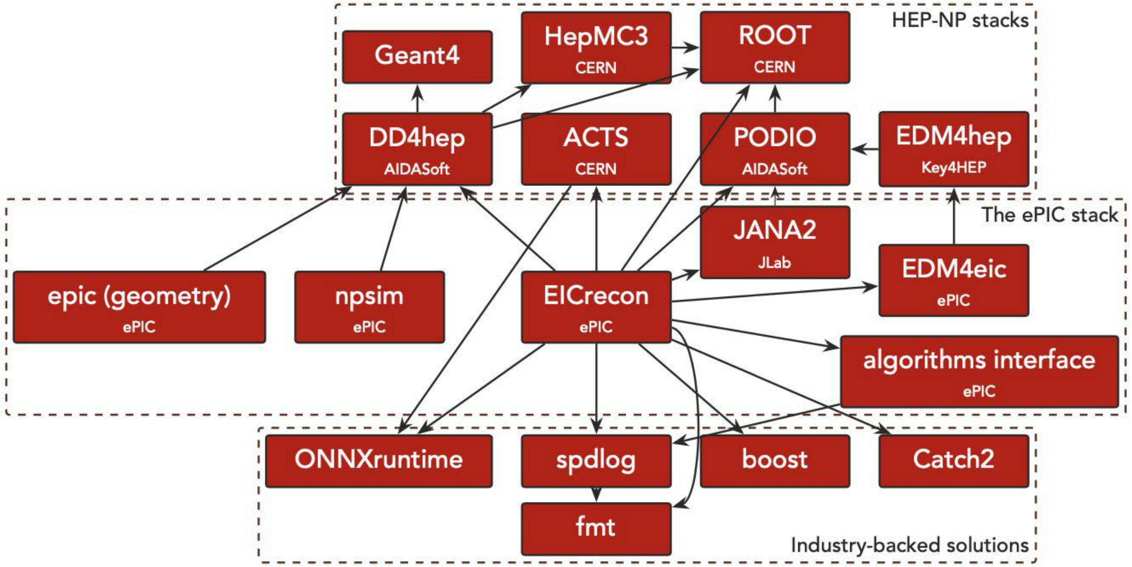
Acts in ePIC

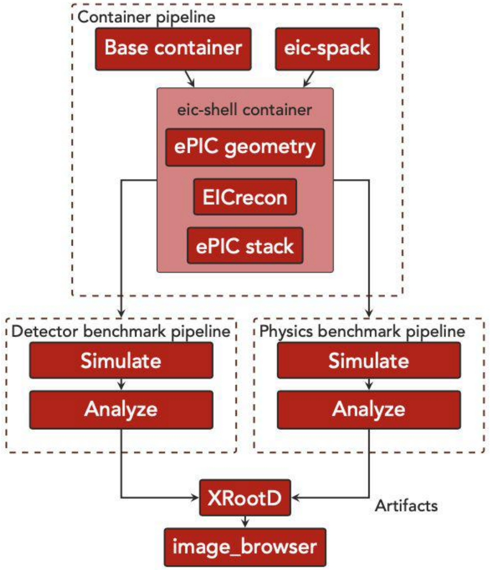
ePIC software stack

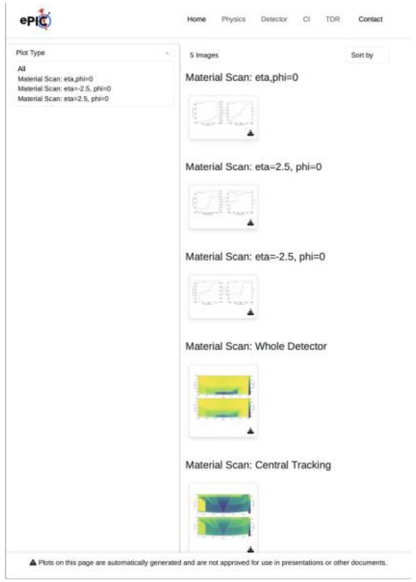


EIC SOFTWARE:
Statement of Principles

1. We aim to develop a diverse workforce, while also cultivating an environment of equity and inclusivity as well as a culture of belonging.
2. We will have an unprecedented compute-detector integration:
   - We will have a common software stack for online and offline software, including the processing of streamed data and its time-ordered structure.
   - We aim for autonomous alignment and calibration.
   - We aim for a rapid, near-real-time turnaround of the raw data to online and offline productions.
3. We will leverage heterogeneous computing:
   - We will enable distributed workflows on the computing resources of the worldwide EIC community, leveraging not only HTC but also HPC systems.
   - EIC software should be able to run on as many systems as possible, while supporting specific system characteristics, e.g., accelerators such as GPUs, where beneficial.
   - We will have a modular software design with structures robust against changes in the computing environment so that changes in underlying code can be handled without an entire overhaul of the structure.
4. We will aim for user-centered design:
   - We will enable scientists of all levels worldwide to actively participate in the science program of the EIC, keeping the barriers low for smaller teams.
   - EIC software will run on the systems used by the community, easily.
   - We aim for a modular development paradigm for algorithms and tools without the need for users to interface with the entire software environment.



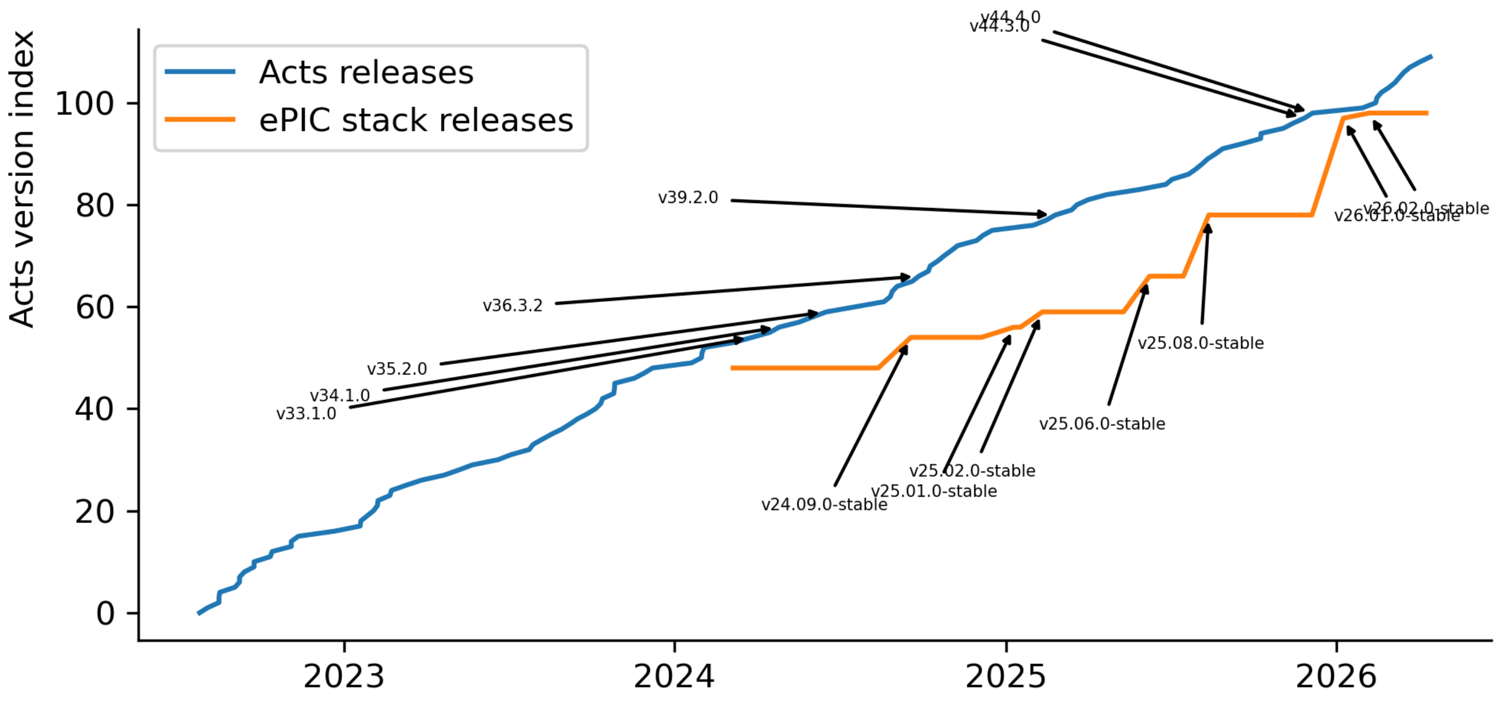




- EIC software is founded on a declared principles statement
- Intentional reliance on external dependencies for collaboration with HEP/NP communities
- Container-based deployment enables monthly simulation campaigns providing full physics event simulation and reconstruction
- Suite of validation benchmarks (detector and physics) ran for each change

Acts version upgrades in ePIC & Acts usage

We work to track Acts versions



Extensive use of ActsExamples::

Track containers and parameters

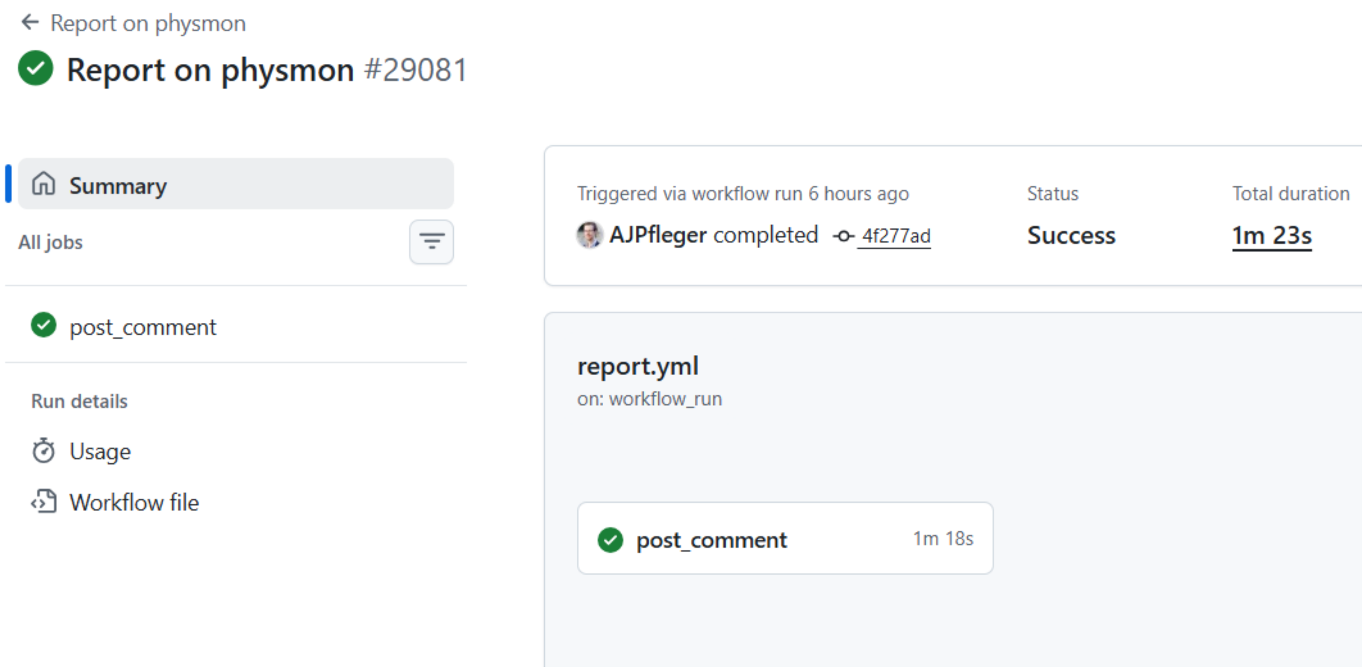
- ActsExamples::TrackContainer - wraps track state and container data
- ActsExamples::TrackParameters - initial track parameters for CKF algorithm
- ActsExamples::TrackContainer::TrackProxy - individual track proxies

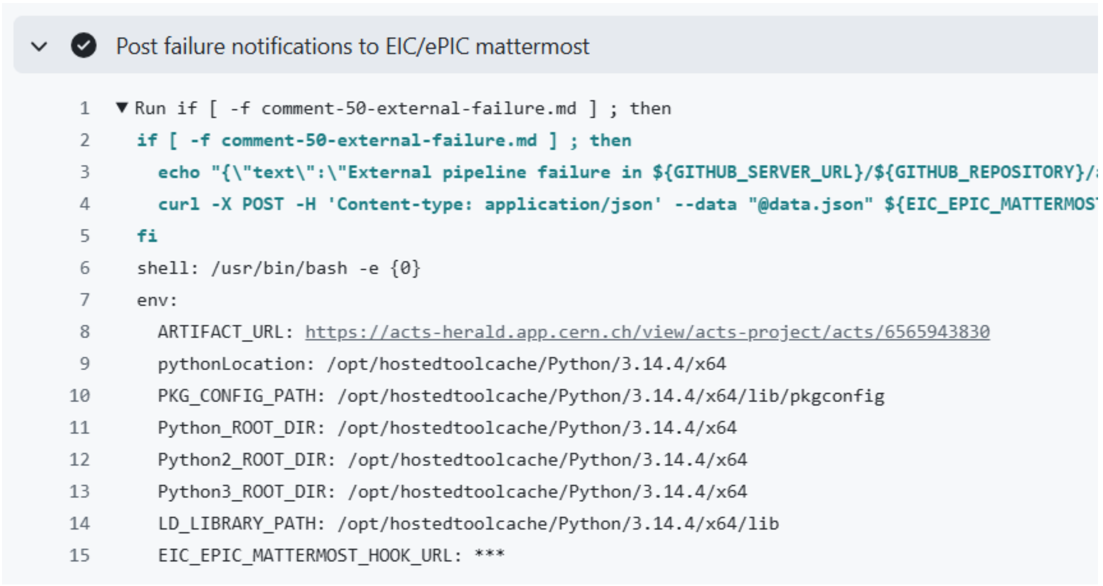
Other examples

- ActsExamples::ConstTrackContainer -wrappers for merging tracks and projections
- ActsExamples::SpacePointContainer - for seeding (getting replaced by SpacePointContainerAdapter)
- ActsExamples::MeasurementCalibratorAdapter – for measurement handling

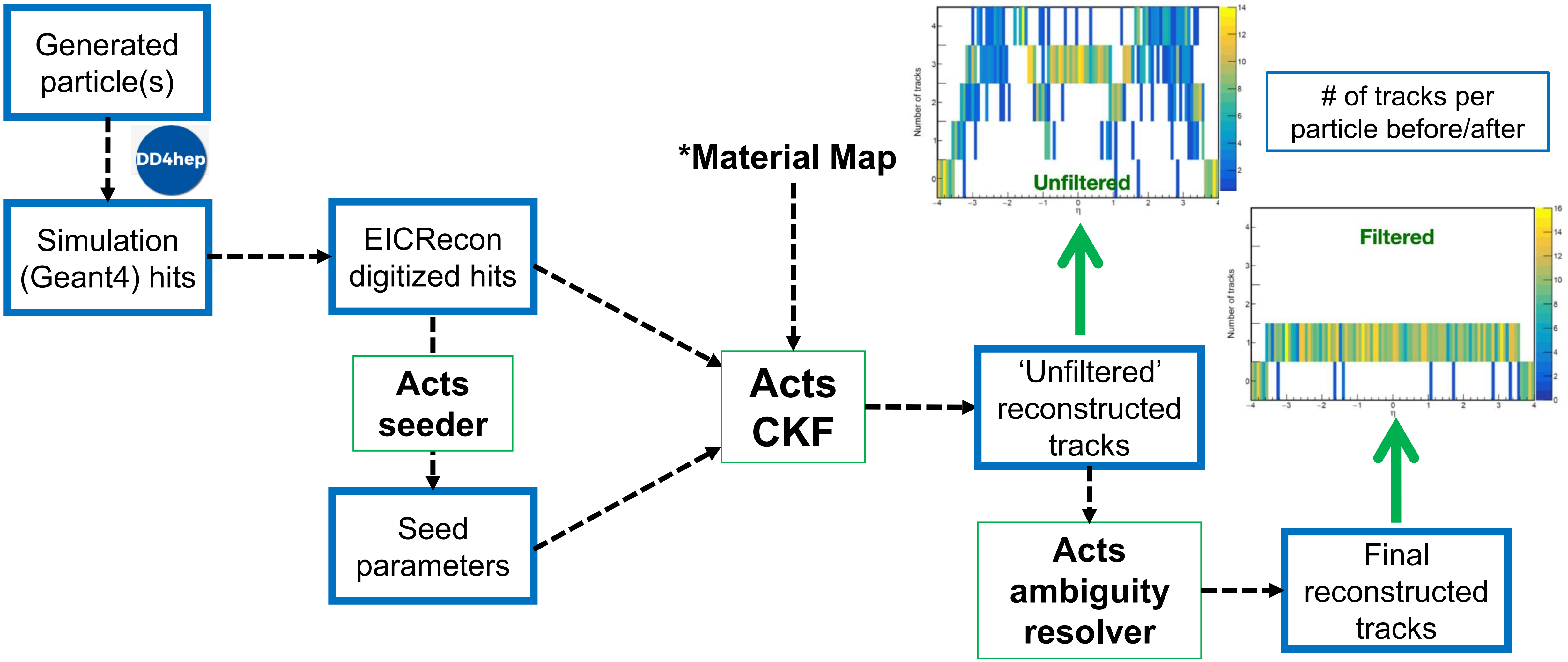
Acts pipeline notifications

We setup a CI system to monitor and warn about regressions to the ePIC stack

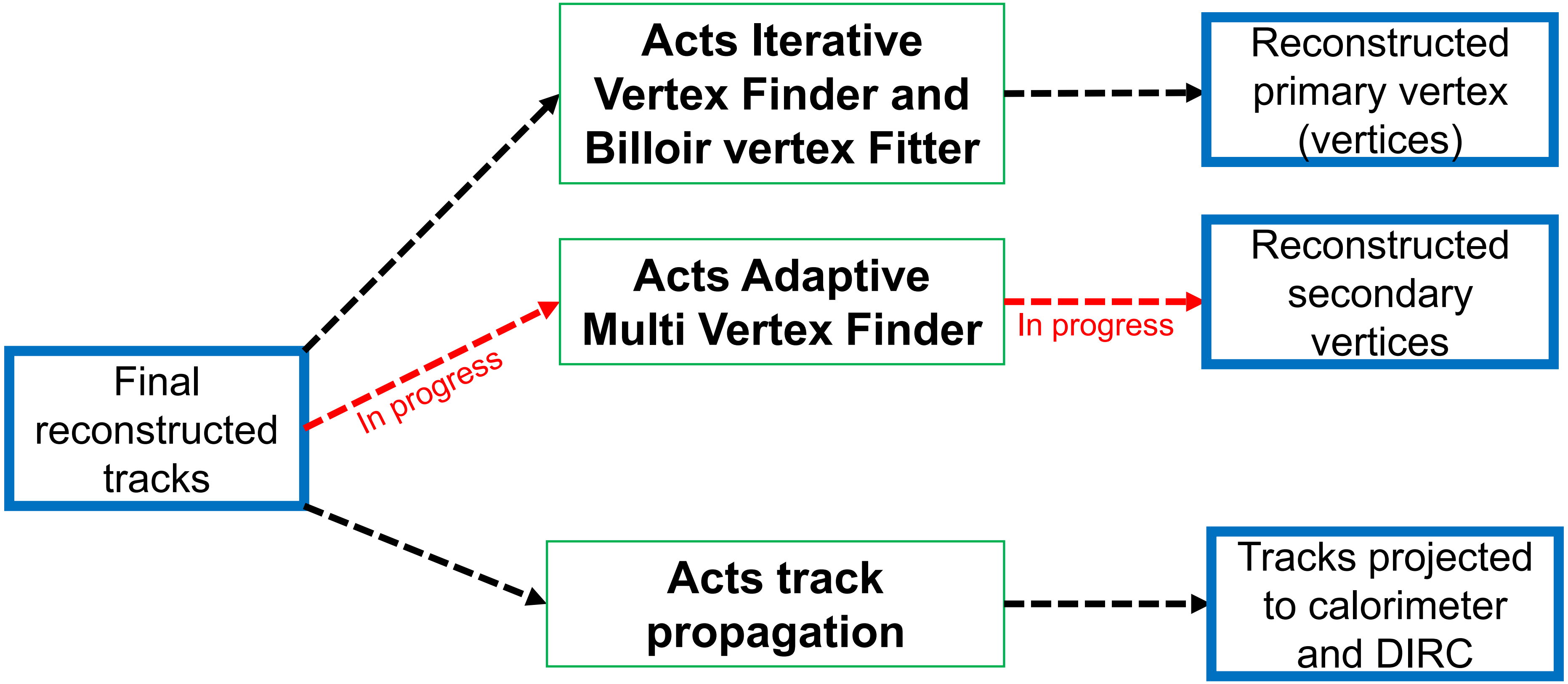




Tracking workflow



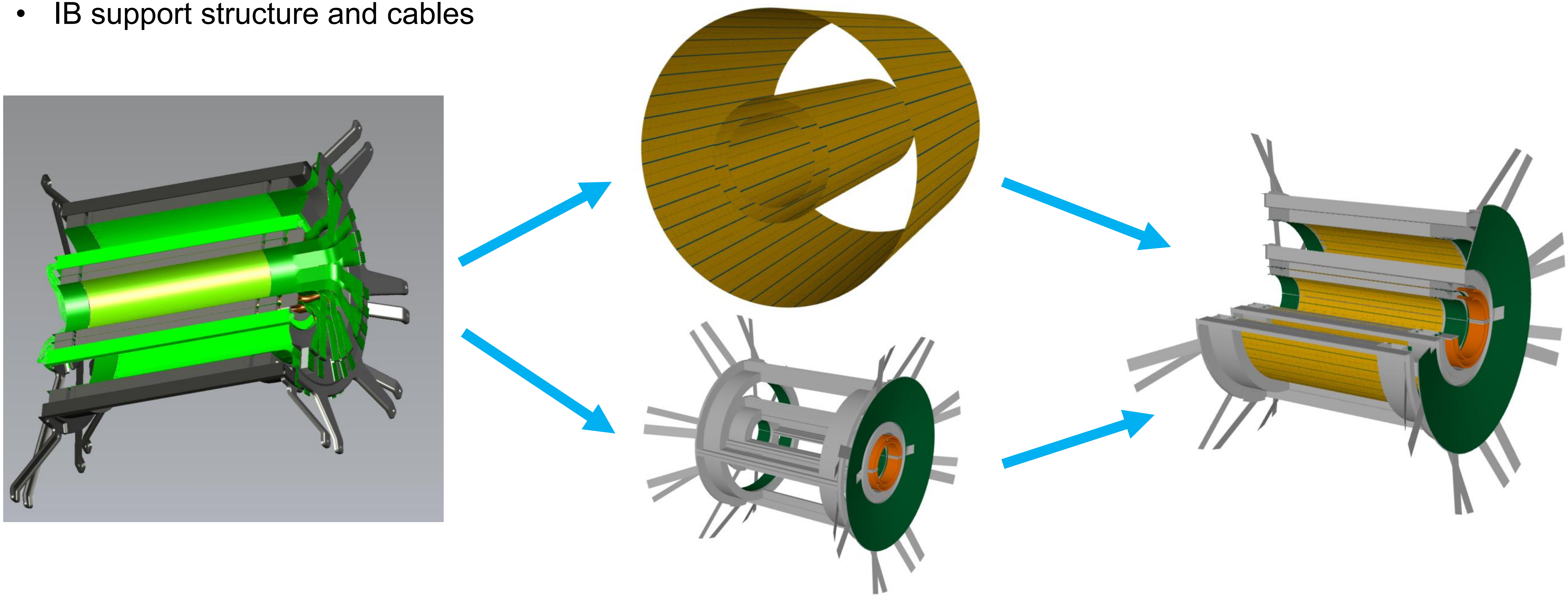
Vertexing and track projections workflow



Detector Geometry and Digitization

SVT IB in simulation

- Curved RSU sensor with inactive areas
- IB support structure and cables



STP file of the design → simplified 2D CAD drawings → dd4hep geo description

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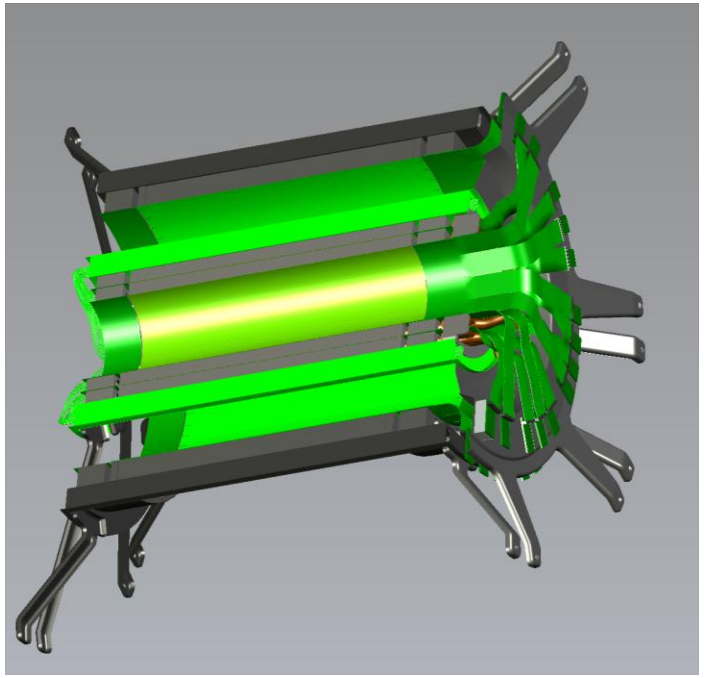

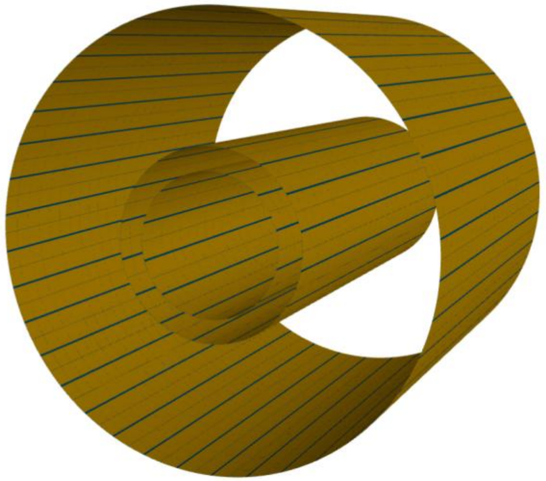

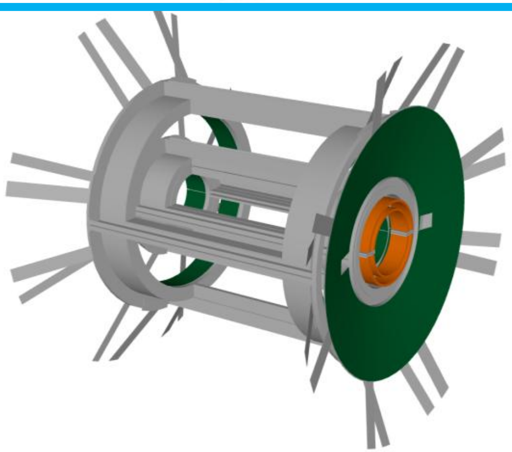

2x2 sections, 3 tiles/section

Curved RSU in simulation

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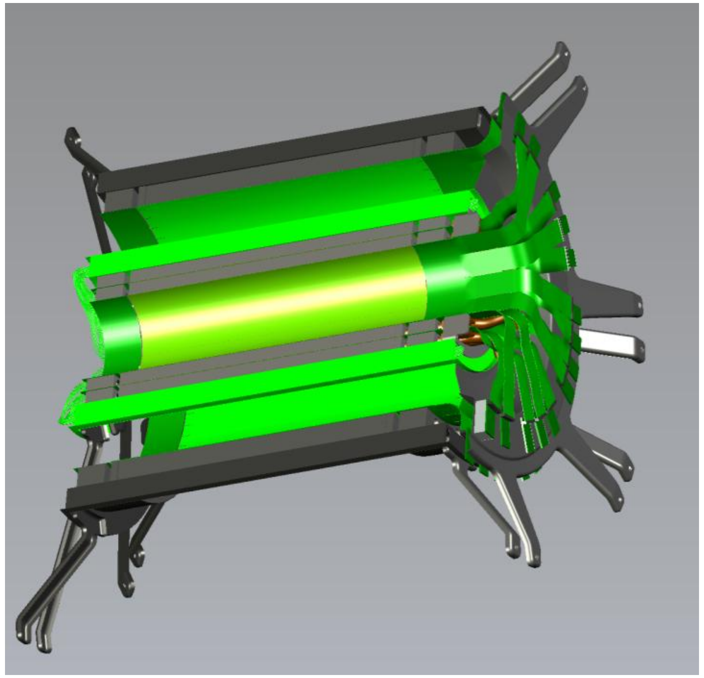
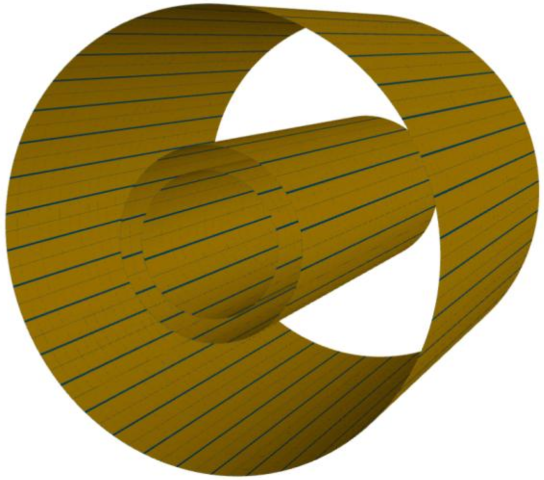
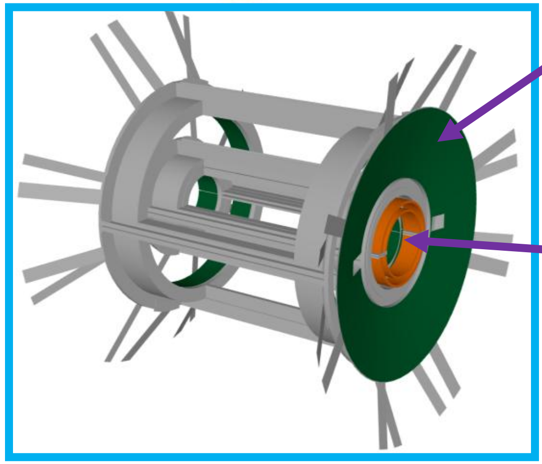
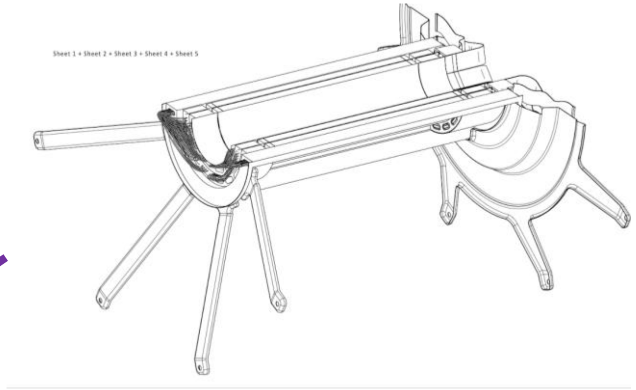


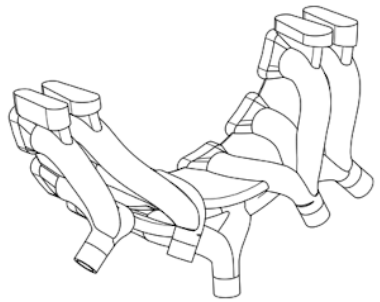




Distribute cables along the cone



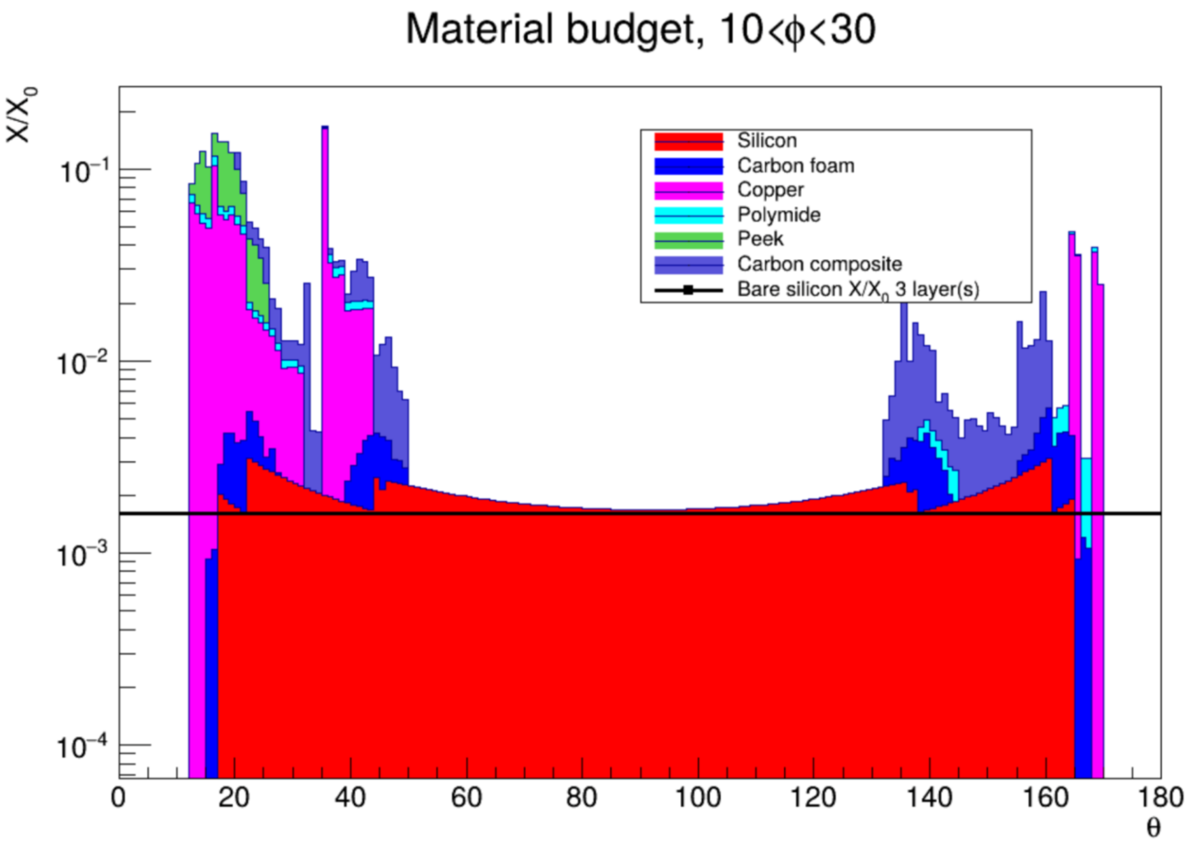
Approx. air tube connector as a ring



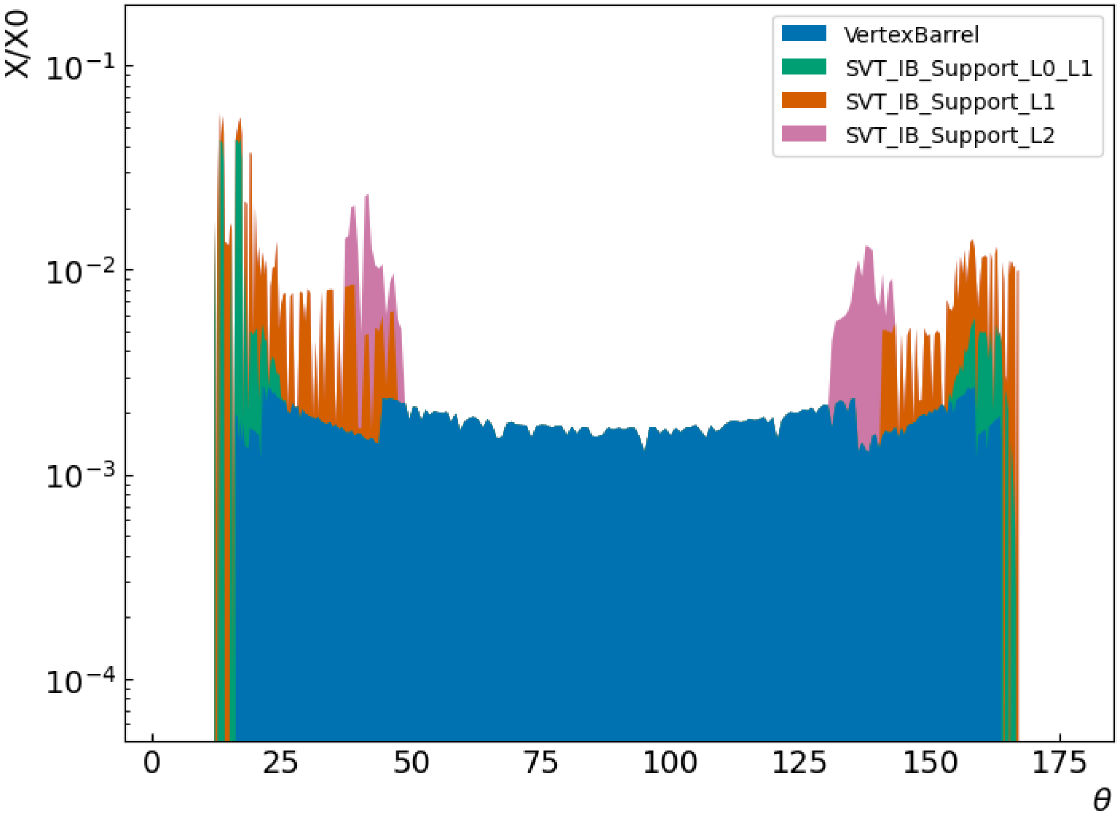
STP file of the design → simplified 2D CAD drawings → dd4hep geo description

SVT IB material scan

STP file → GDML

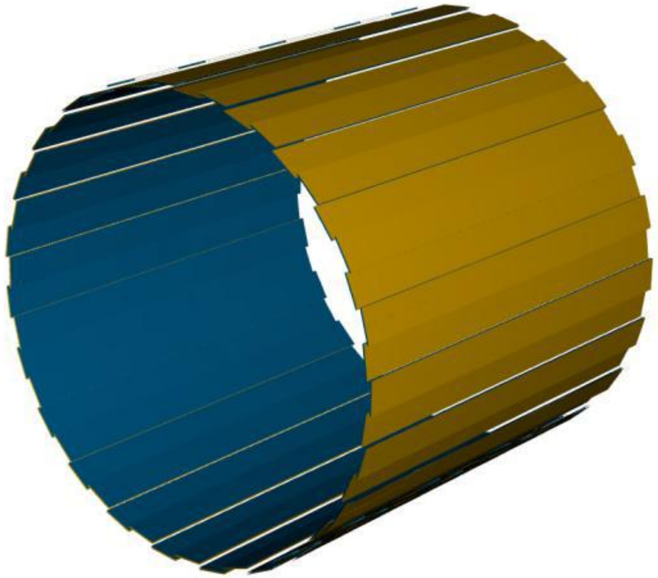


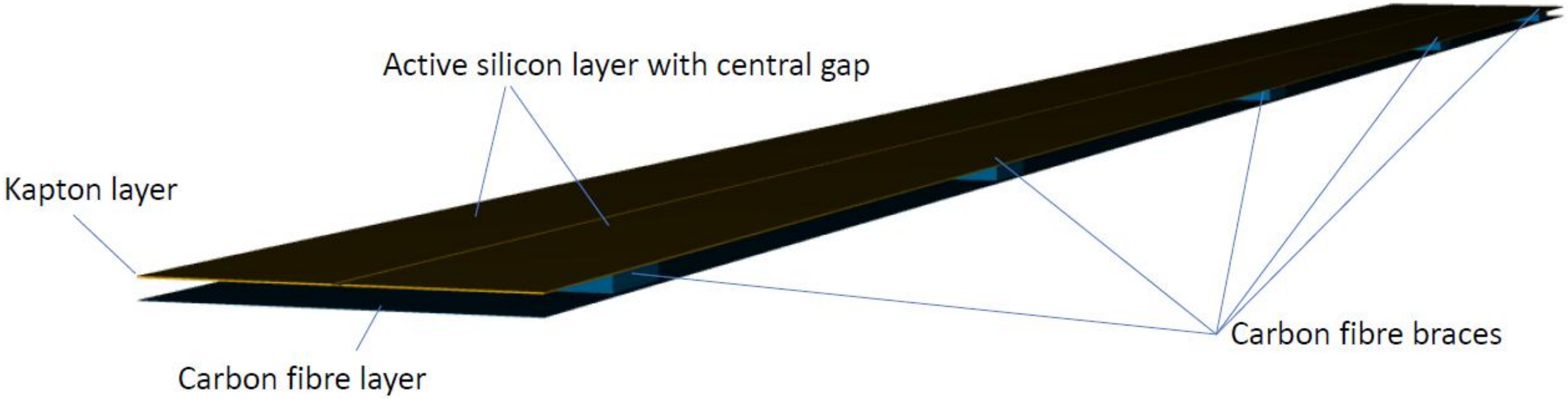
Simulation geometry

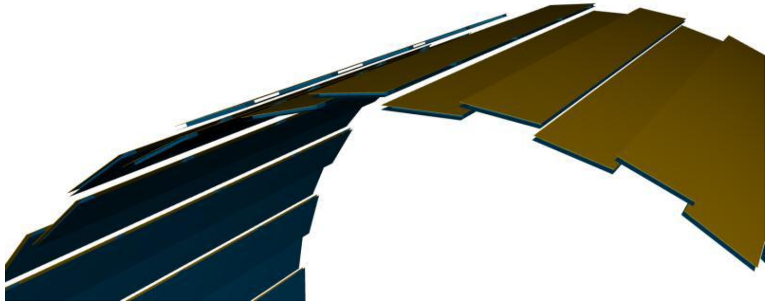


SVT OB in simulation

- Carbon fiber braces to reproduce peaks on material thickness scan
- Gap in active silicon to reproduce dead area
- Castellated stave arrangement (alternate staves at +6mm radius)

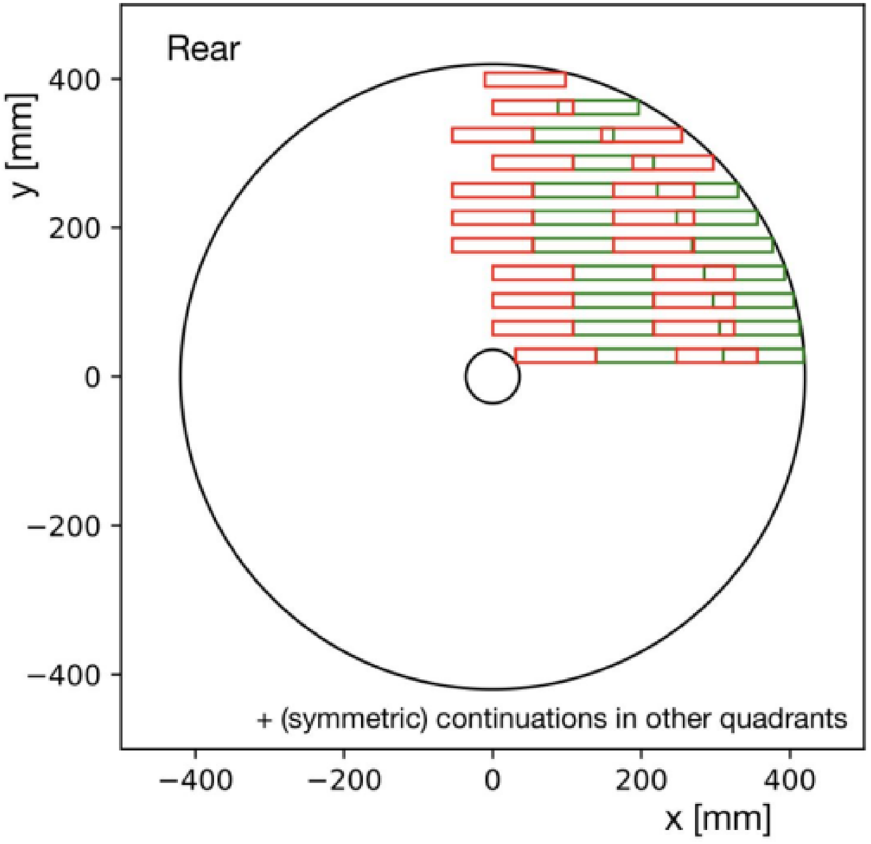




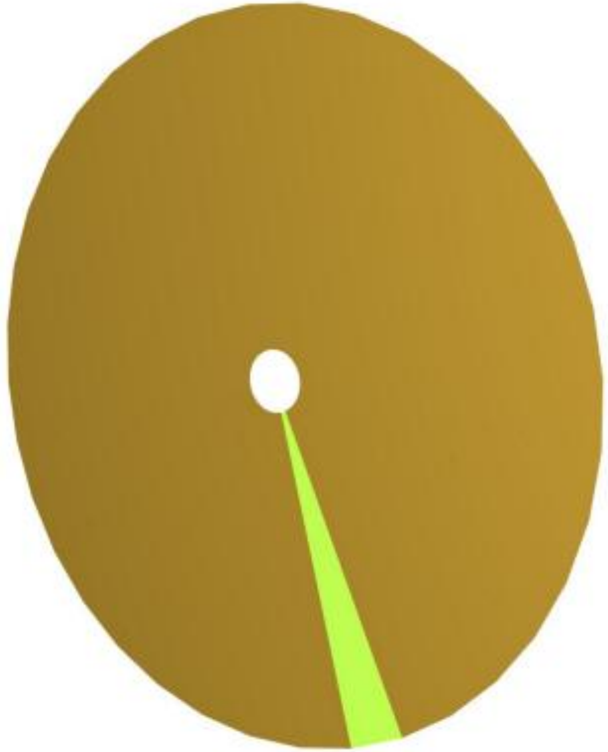


SVT EC Disks in simulation

Design: Disks are assembled with staves

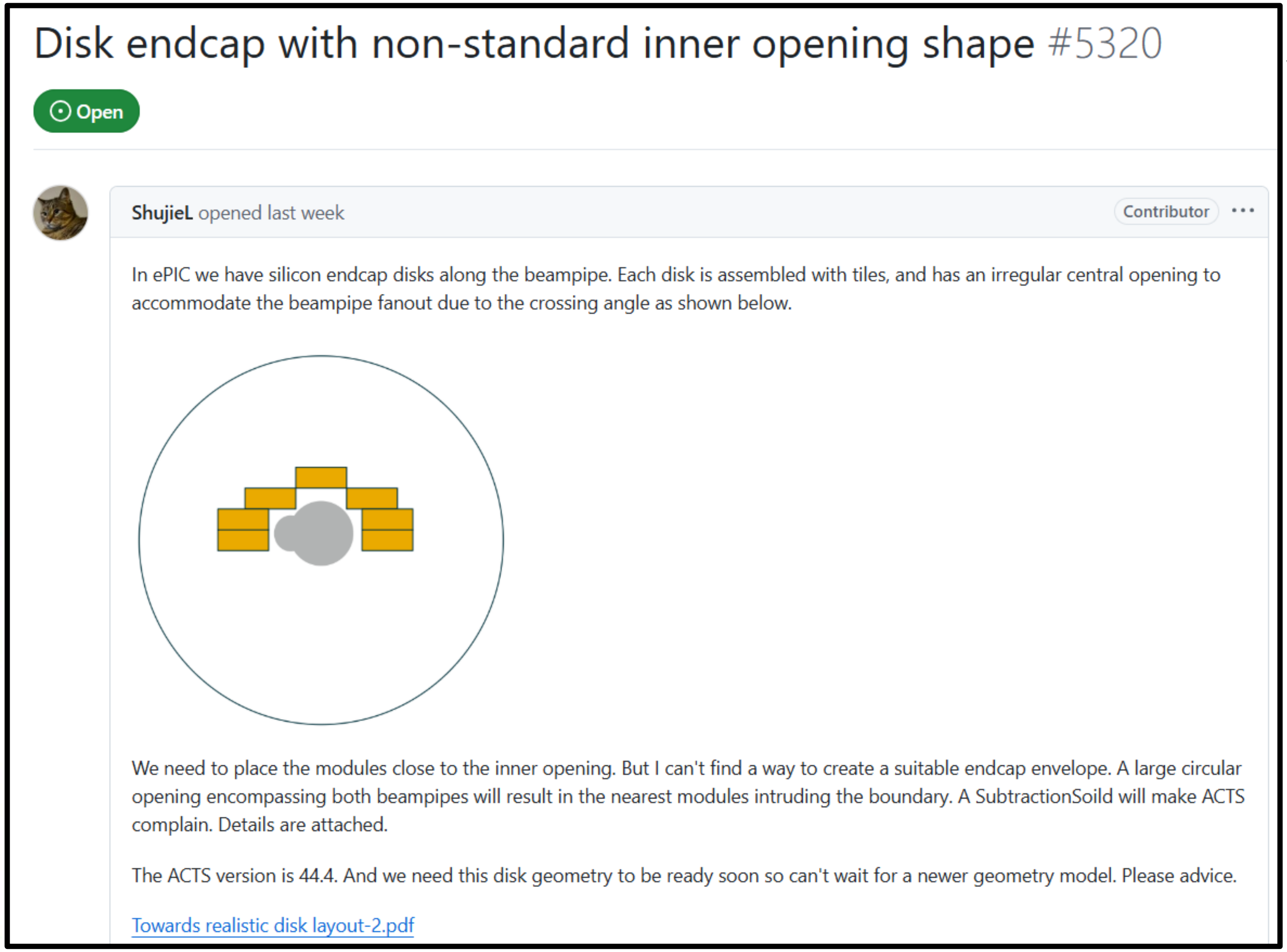


Simulation: Disks from 36 trapezoid slices



Ongoing effort: implementation of off-centered hole and staves to reflect true acceptance.

SVT EC Disks in simulation



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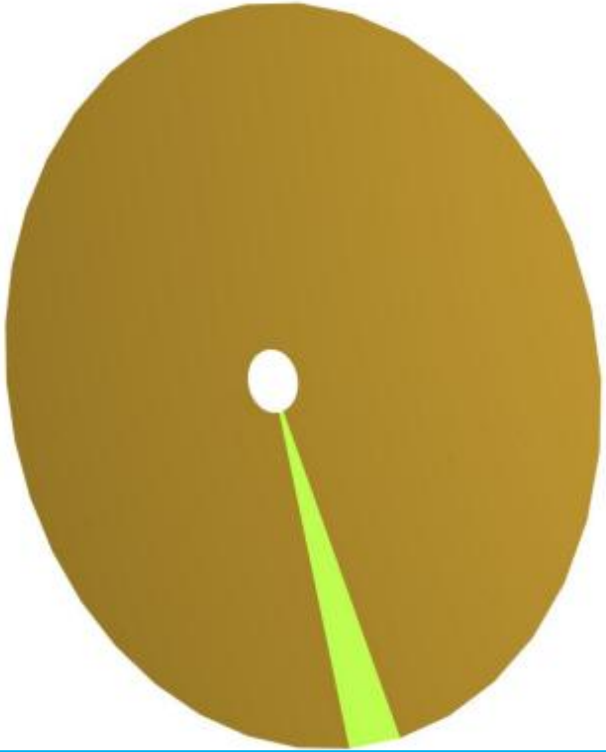

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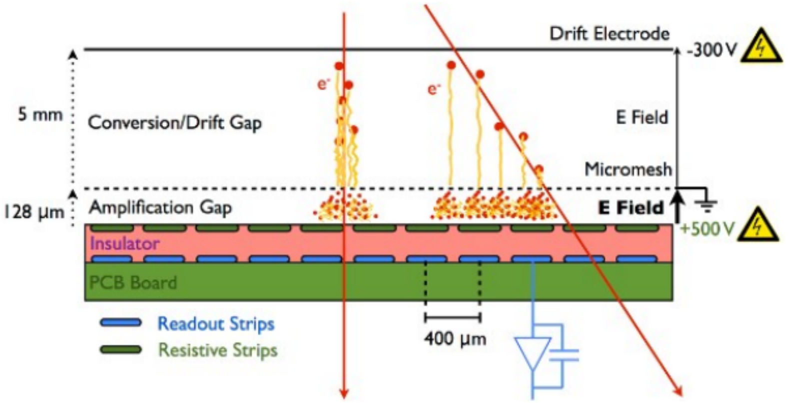
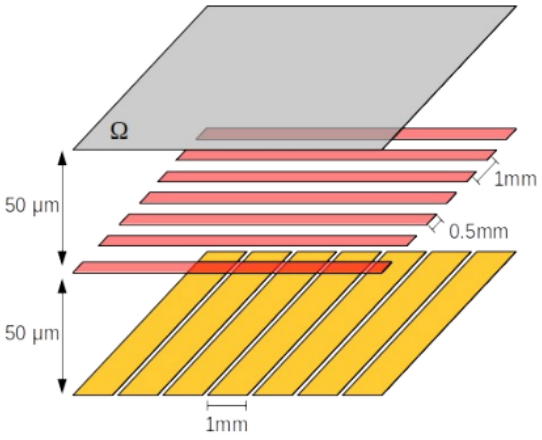
MPGD Digitization – 2D strip readout

Barrel: CyMBaL, µRWELL-BOT. EndCaps: µRWELL-ECT's.



Class12 Micromegas: 1D-strip Readout



Charge Sharing ⇒ 2D-strip Readout

- **One Ionization** × **Amplification** $\xrightarrow[\text{Sharing}]{\text{Charge}}$ **Two proto** Hits, along strips $\boldsymbol{u = p, n}$
- Charge Spreading (*enhanced by resistive layer* Ω): **proto** Hit → **cluster** of Hits.

Strips ***per se***, no big problem: they are **stretched pixels**. . .

. . . *i.e.* **2D objects**, w/ **bad precision** (= $\mathcal{O}$(size)) **along one of the D's**.

Problem is **2D**Strip, because **One and only one Sensitive Surface** ***per*** **volume** in `DD4hep`.

From ePIC Mattermost discussion:

Ways to create 2d strip:

1. Divide the geometry in multiple layer volume In dd4hep: this will change the energy deposit pattern which is a major concern.
2. Follow the ACTS example to split the sensitive surface to two (preferable method for now).
3. [...] write a custom DD4hep sensitive detector action that is associated with the gas volume, and creates sim hits on one (or more) surfaces from the Geant4 hit inside the gas volume. see DDG4/plugins/Geant4SDActions.cpp

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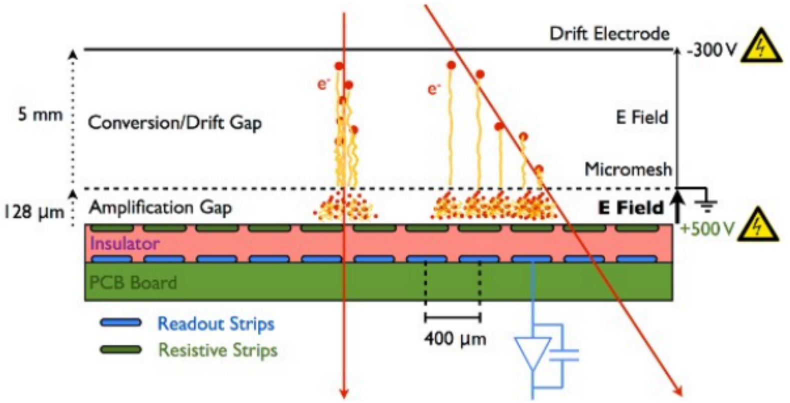

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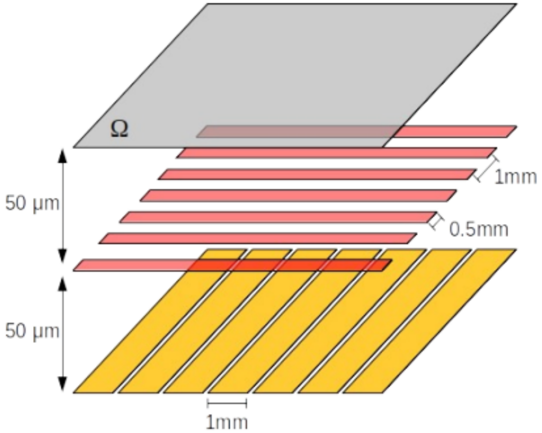

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. . . *i.e.* **2D objects**, w/ **bad precision** (= $\mathcal{O}$(size)) **along one**

Problem is **2D**Strip, because **One and only one Sensitive Surfac**

We have implemented this option so far

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Tracking & vertexing performance

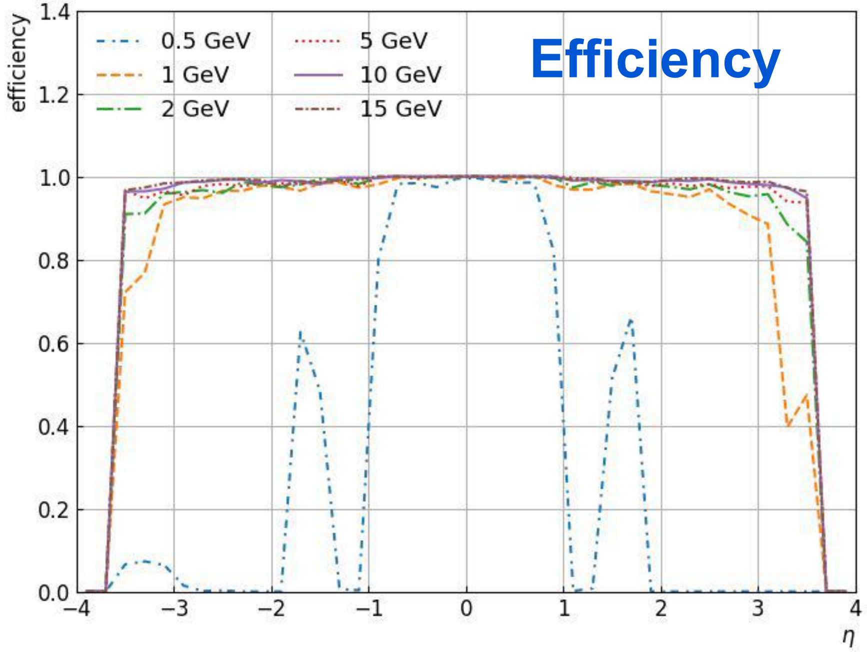
Tracking performance – single particle events

Source events

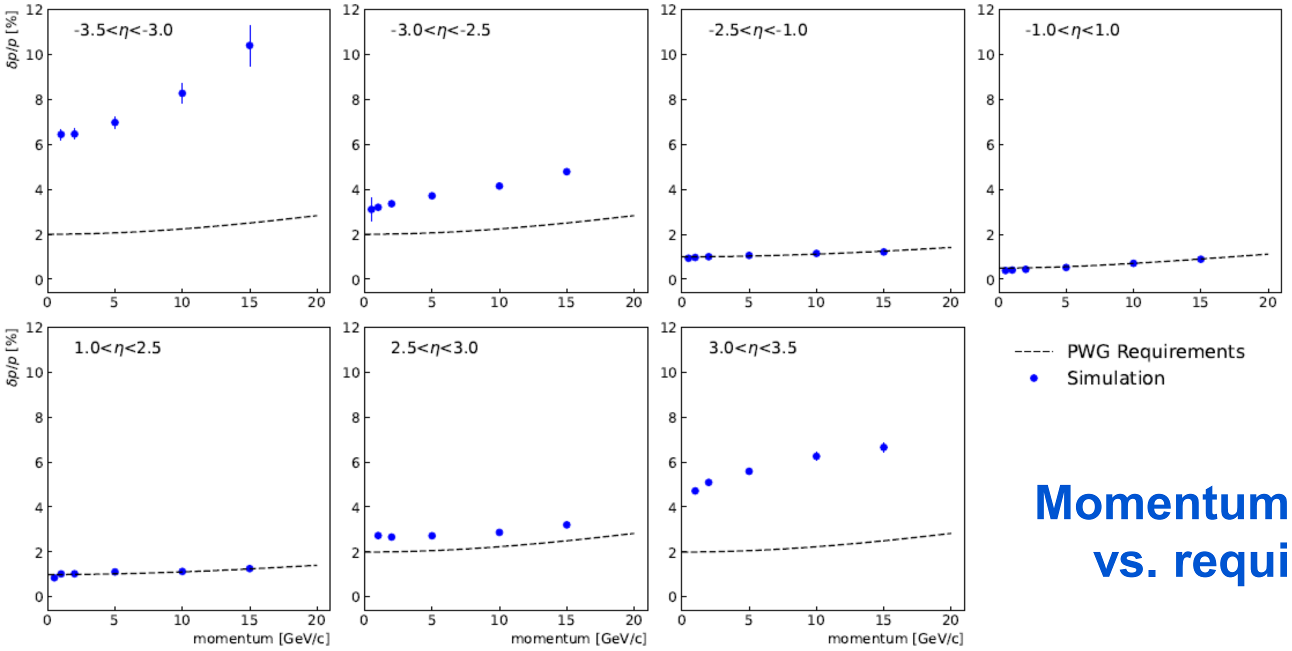
- Single charged pion events at fixed momentum uniformly distributed in angle

Observables

- **Efficiency**: fraction of generated particles with a reconstructed track
- **Resolution**: dp/p, theta, phi, DCA_r
- **Pull distributions**: reconstructed resolution compared to reconstructed covariance matrix



Efficiency



Momentum resolution vs. requirements

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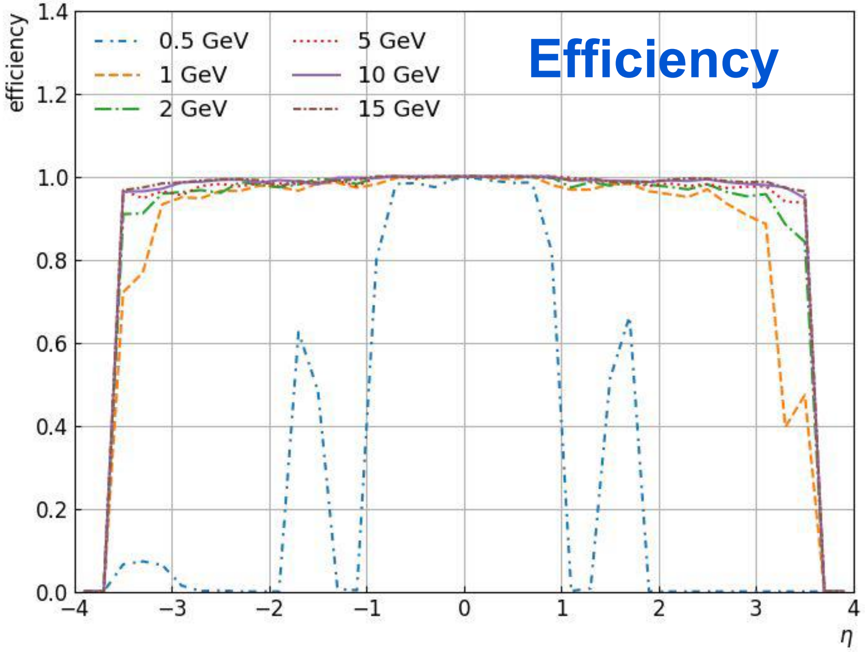

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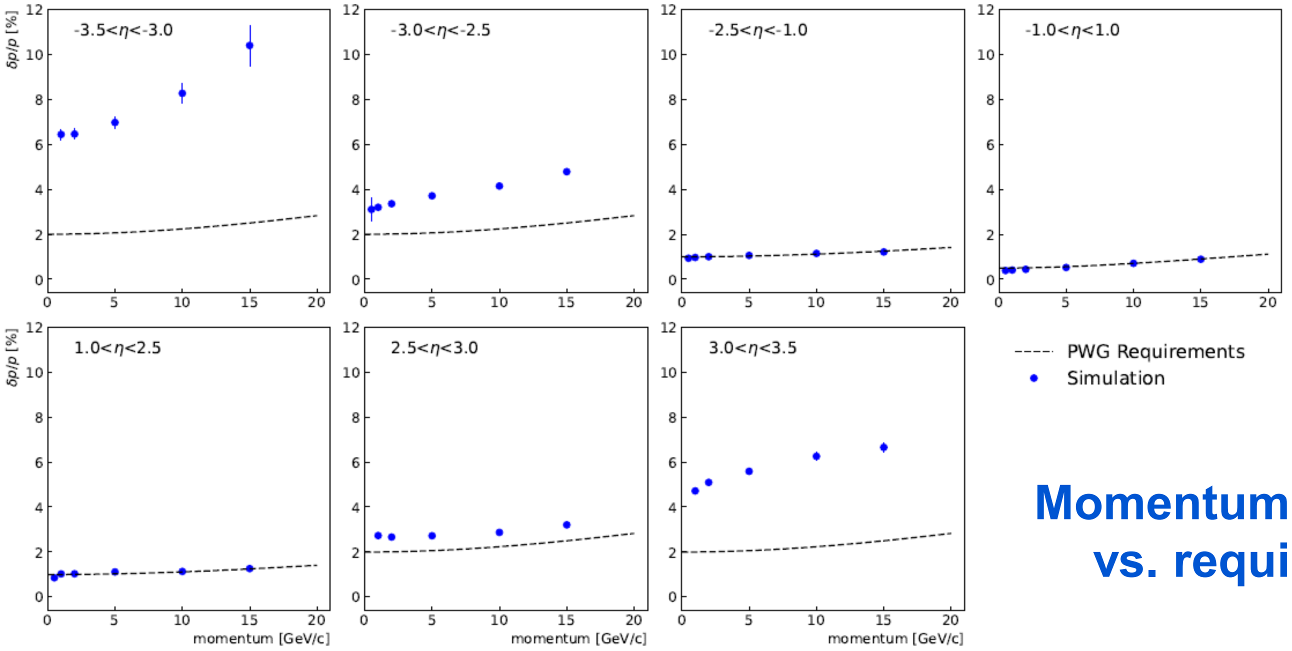


Momentum resolution vs. requirements

The momentum resolution requirements in the larger |η| bins represent a combined detector requirement on the tracking and calorimeter detectors.

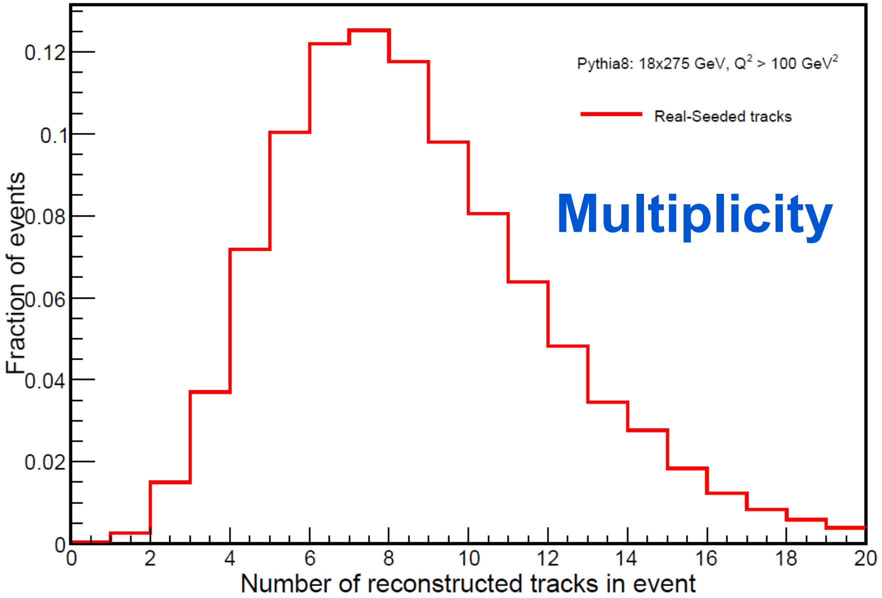
Tracking performance – DIS signal events

Source events

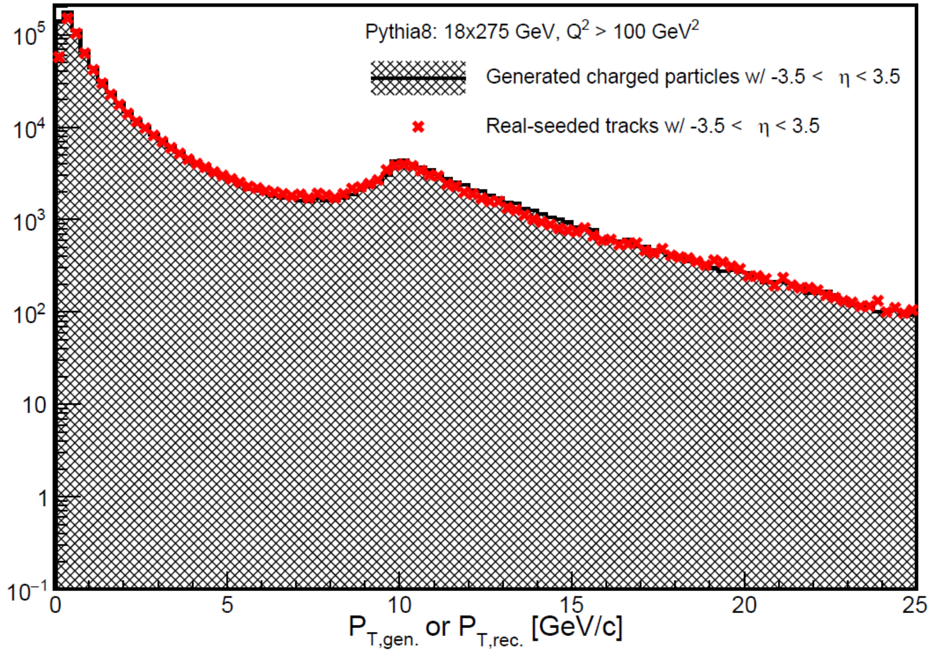
- DIS events simulated with a minimum Q^2 threshold and beam-smearing effects applied

Observables

- **Track multiplicity**: number of reconstructed tracks per event
- **Track spectra**: reconstructed eta distribution for tracks
- **Efficiency**: fraction of generated particles with a reconstructed matched track
- **Hit Purity**: fraction of hits used in a track fit associated with a given generated particle



Reconstructed P_t distribution



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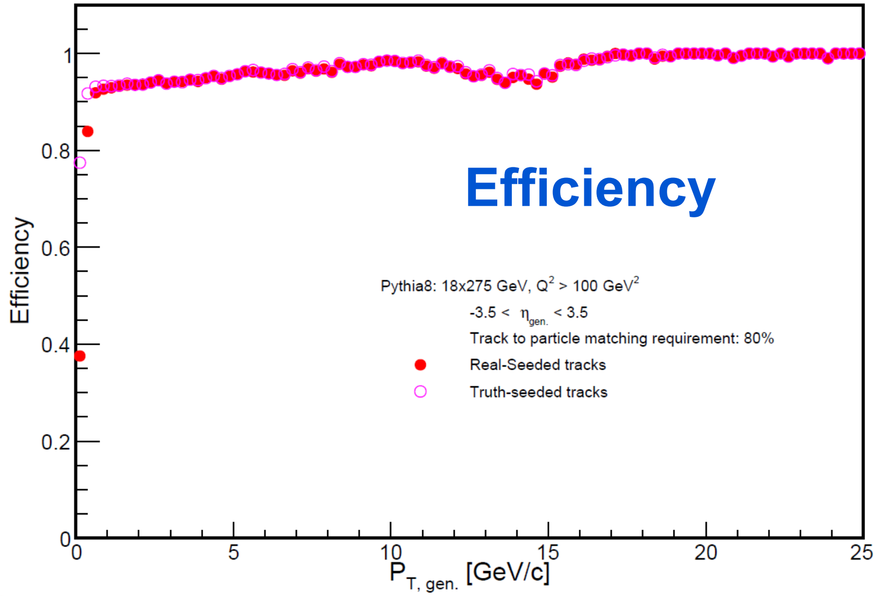
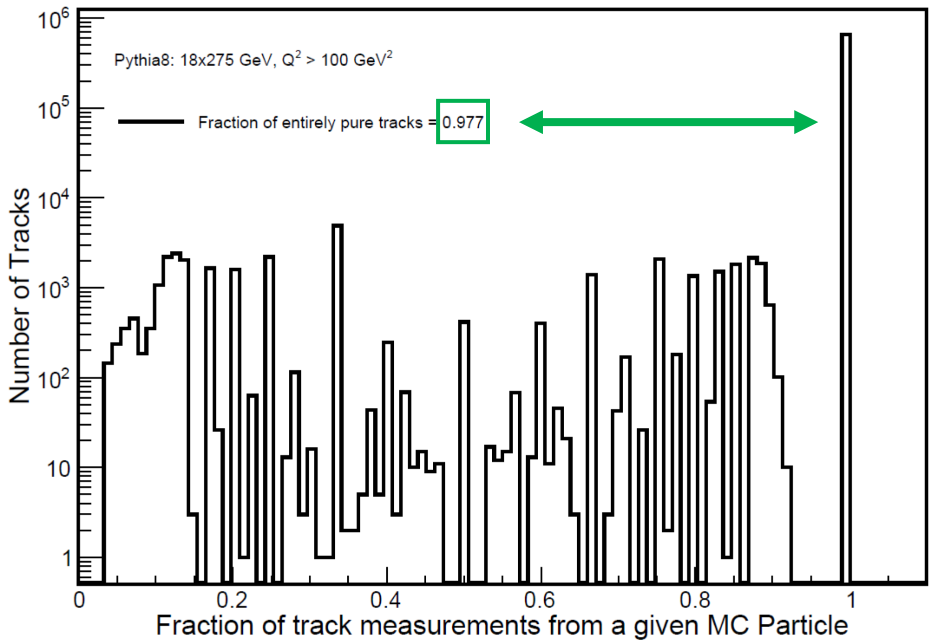
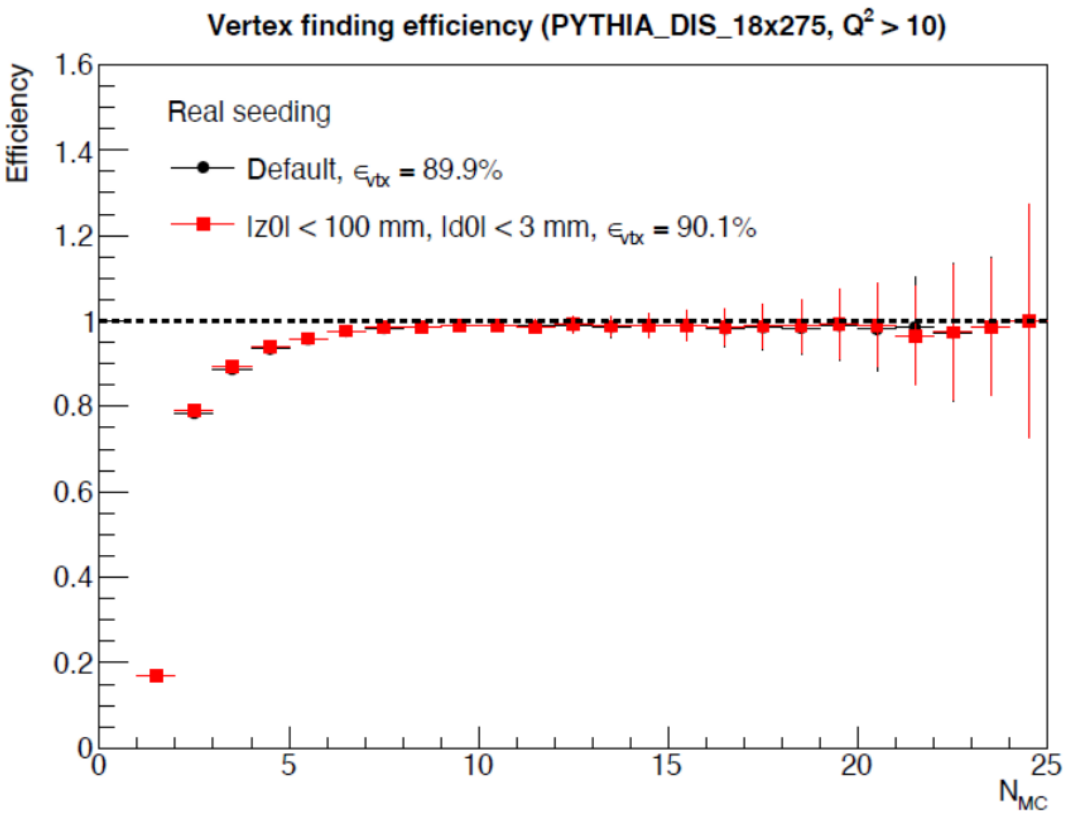
Tracks w/ 100% purity should have resolution performance as found in single-particle studies

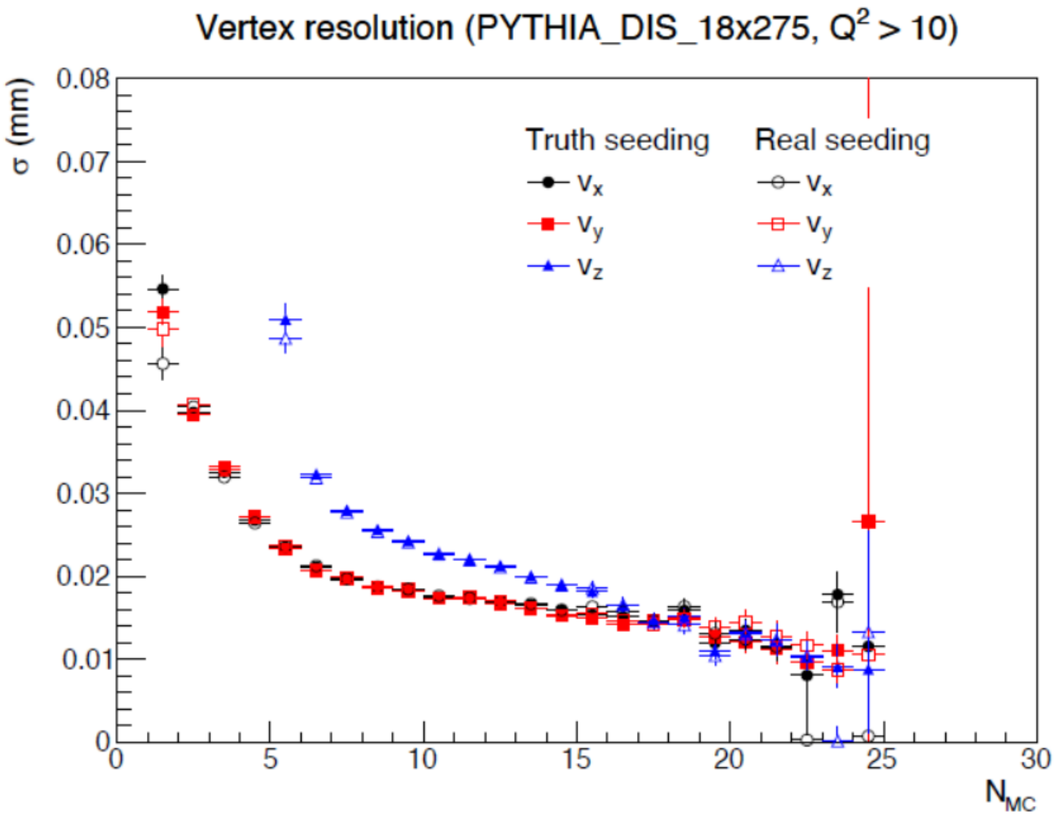


Hit Purity



Primary vertex reconstruction performance

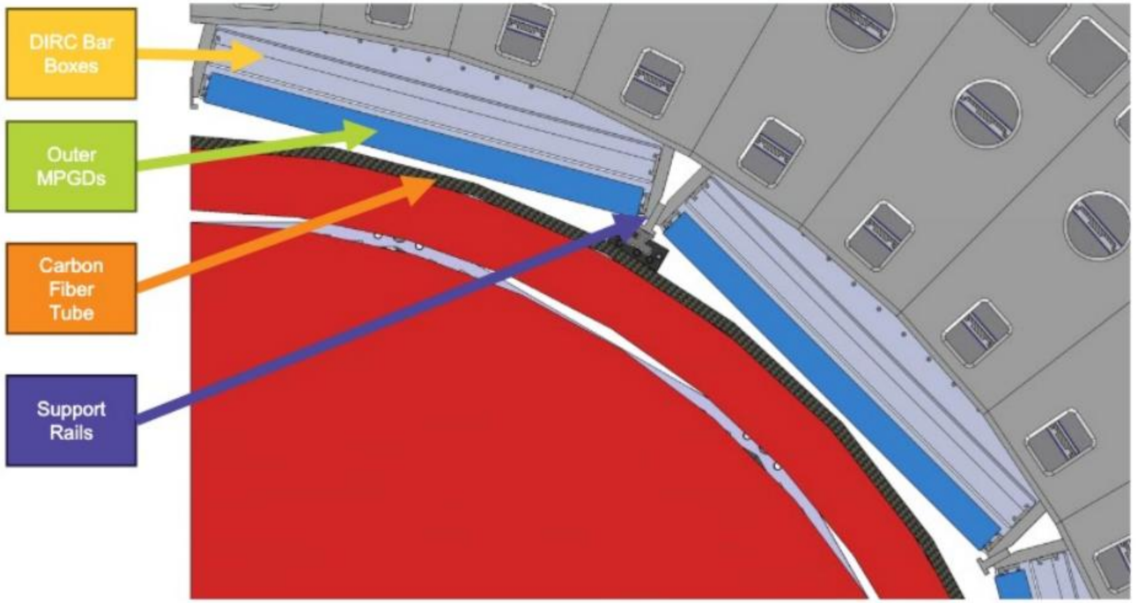




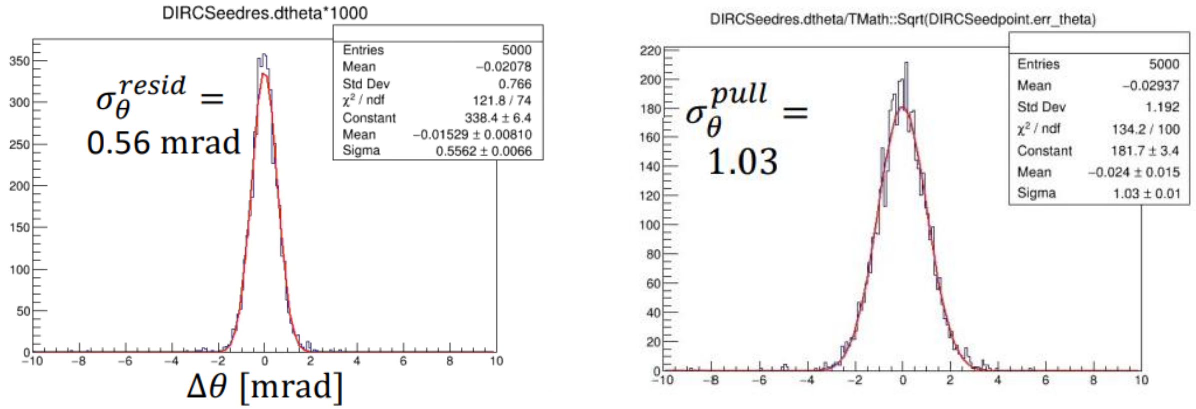
N_{MC}: number of MC charged particles originating from collision vertex within |eta| < 3.5
Efficiency: fraction of events with at least one reconstructed vertex

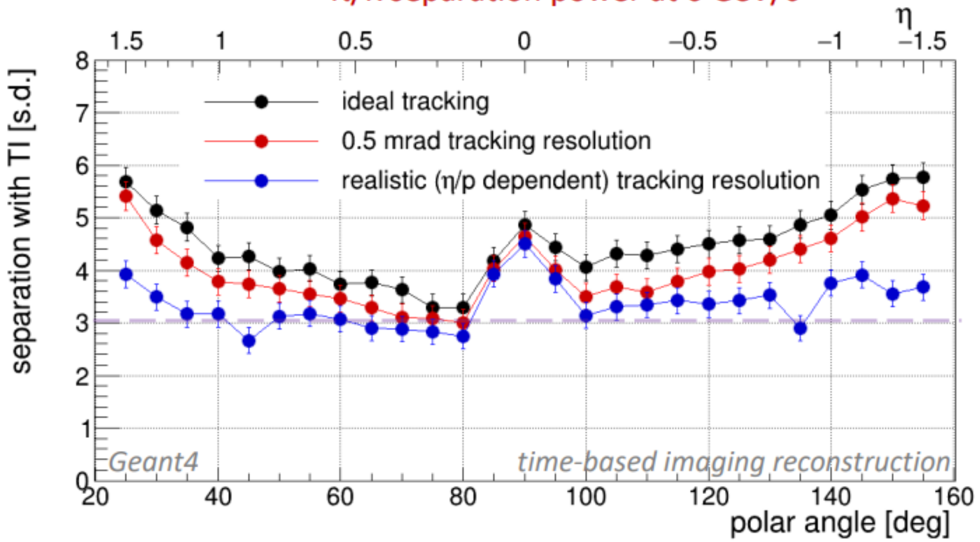
Track projections to the DIRC

- PID performance of the DIRC depends on the quality of the track projection at the DIRC surface.
- Implementation of material between the vertex and the DIRC in the simulation has been essential for an accurate determination of the track projection resolutions.



6 GeV/c pi-





Tracking in the presence of beam backgrounds

Backgrounds Rates in ePIC

Unlike hadron-hadron colliders, beam-related background cross-sections are larger than the signal cross-section

Process	5 GeV x 41 GeV	5 GeV x 100 GeV	10 GeV x 100 GeV	10 GeV x 275 GeV	18 GeV x 275 GeV
Total ep	12.5 kHz	129 kHz	184 kHz	500 kHz	83 kHz
Hadron beam gas	12. 2 kHz	22.0 kHz	31.9 kHz	32.6 kHz	22.5 kHz
Electron beam gas Bremsstrahlung	2182 kHz	2826 kHz	3177 kHz	3177 kHz	317 kHz
Electron beam gas Coulomb		117 kHz		30 kHz	0.86 kHz
Electron beam gas Touschek		1112 kHz		233 kHz	0.55 kHz
Electron SR		36608 MHz		36608 MHz	3324 MHz

Backgrounds Rates in ePIC

Unlike hadron-hadron colliders, beam-related background cross-sections are larger than the signal cross-section

Process	5 GeV x 41 GeV	5 GeV x 100 GeV	10 GeV x 100 GeV	10 GeV x 275 GeV	18 GeV x 275 GeV
Total ep	12.5 kHz	129 kHz	184 kHz	500 kHz	83 kHz
Hadron beam gas	12. 2 kHz	22.0 kHz	31.9 kHz	32.6 kHz	22.5 kHz
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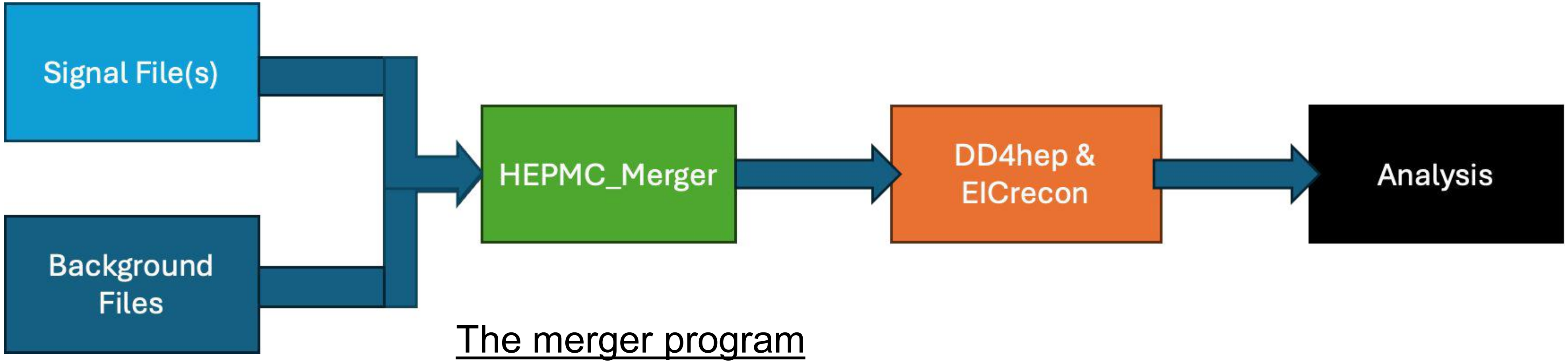
Electron SR		36608 MHz		36608 MHz	3324 MHz

This shows the rate of SR photons (5-100 keV) that exit the beampipe into the ePIC central detector region (with a 5um gold coating on the beampipe). During the 2us integration window of the SVT, we can have 60,000 such photons at the highest luminosity.

Track reconstruction with realistic beam-induced backgrounds

- **Motivation**: study how well our device and track finding and fitting perform in the presence of backgrounds
- **Simulation setting**: DIS (forced) + background merged events



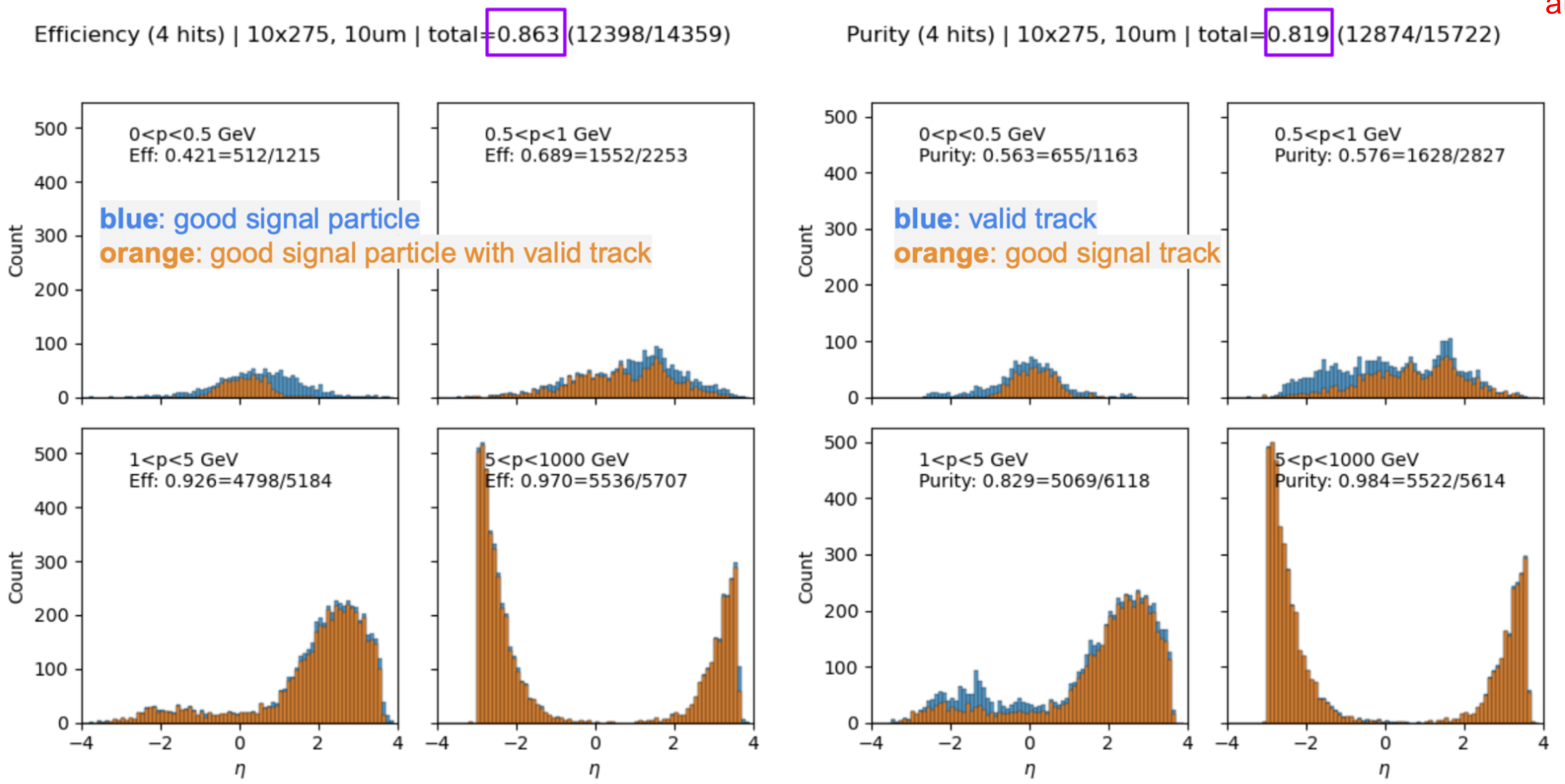
<u>The merger program</u>

- Sample each background source – SR, electron Bremsstrahlung, Coulomb, Touschek, proton beam gas – according to its frequency within a fixed-length (2us) time window
- Label each source particle with a custom generator code
- Example configuration: One 18x275 NC DIS collision with $Q^2 > 1$ GeV^2/c^2 per time slice with all backgrounds included at their respective rates

Tracking Performance with Background

10x275, 10um gold coating, at least 4 hits per track: OK efficiency, OK purity

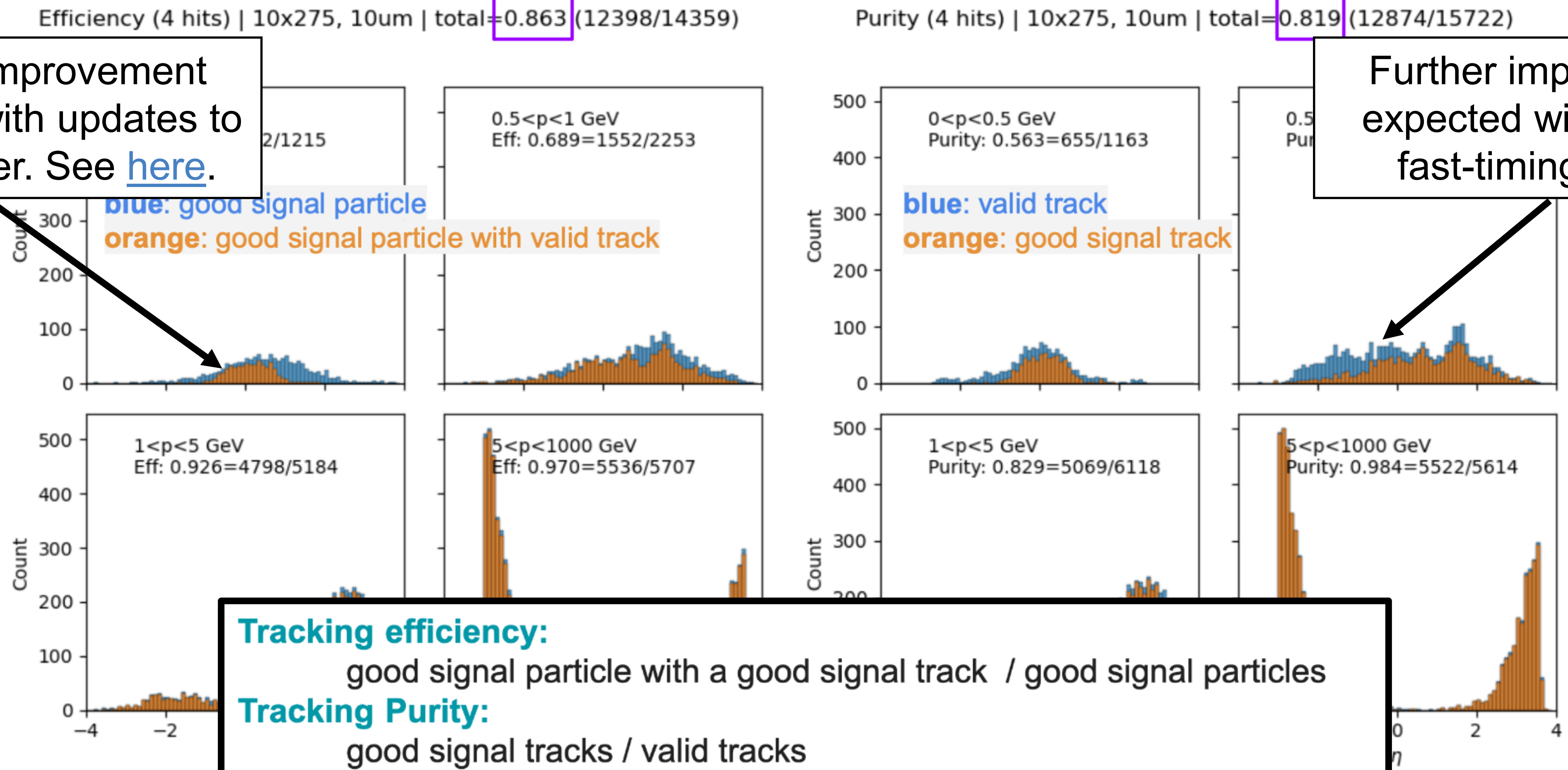
All backgrounds included.
Highest background rates at 10 GeV



Tracking Performance with Background

10x275, 10um gold coating, at least 4 hits per track: OK efficiency, OK purity

All backgrounds included. Highest background rates at 10 GeV



Further improvement expected with updates to seed finder. See here.

Further improvement expected with cuts on fast-timing layers.

Tracking efficiency:
good signal particle with a good signal track / good signal particles

Tracking Purity:
good signal tracks / valid tracks

Tracking Performance with Background

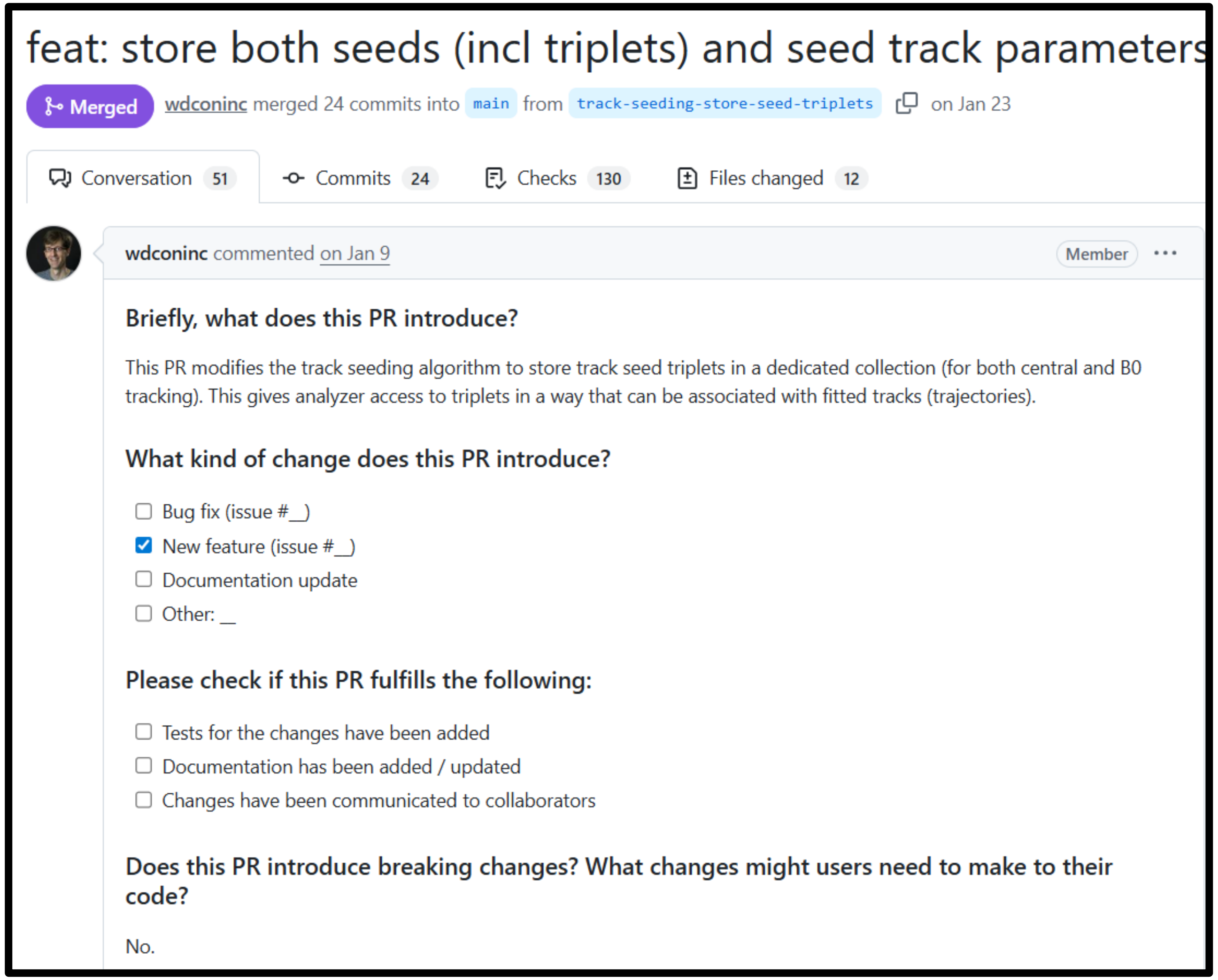
4 hits → 5 hits cut: lower efficiency, higher purity

≥ 4 hits per track		≥ 5 hits per track	
Efficiency	Purity	Efficiency	Purity
0.863	0.819	0.822	0.982

Tracking efficiency:
good signal particle with a good signal track / good signal particles
Tracking Purity:
good signal tracks / valid tracks

New Tracking Tools

Additional track seed information



feat: store both seeds (incl triplets) and seed track parameters

Merged wdconinc merged 24 commits into main from track-seeding-store-seed-triplets on Jan 23

Conversation 51 | Commits 24 | Checks 130 | Files changed 12

wdconinc commented on Jan 9 — Member

Briefly, what does this PR introduce?

This PR modifies the track seeding algorithm to store track seed triplets in a dedicated collection (for both central and B0 tracking). This gives analyzer access to triplets in a way that can be associated with fitted tracks (trajectories).

What kind of change does this PR introduce?

- [ ] Bug fix (issue #_)
- [x] New feature (issue #_)
- [ ] Documentation update
- [ ] Other: _

Please check if this PR fulfills the following:

- [ ] Tests for the changes have been added
- [ ] Documentation has been added / updated
- [ ] Changes have been communicated to collaborators

Does this PR introduce breaking changes? What changes might users need to make to their code?

No.

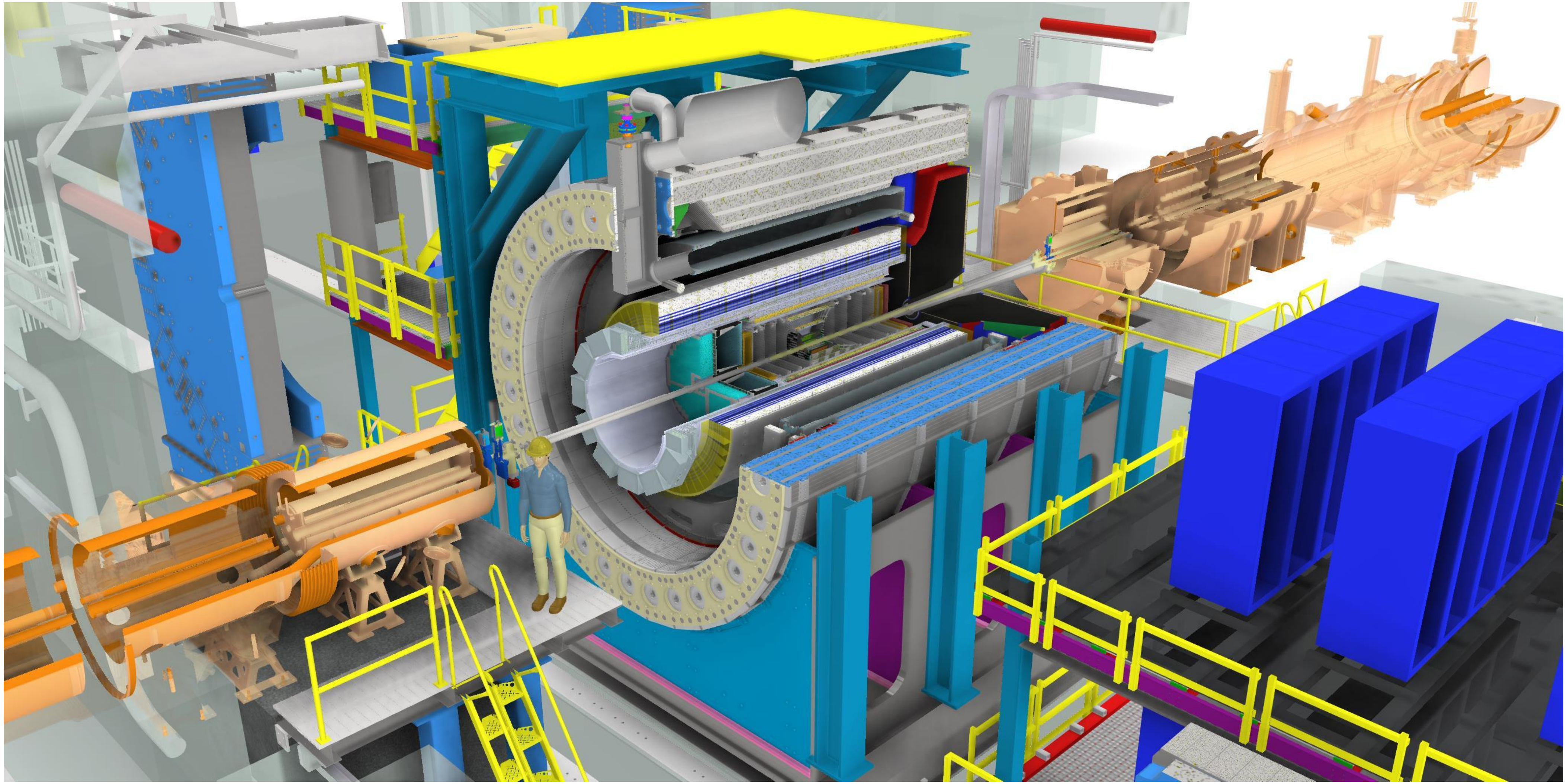
- In the presence of beam backgrounds, many ‘bad’ seeds associated with beam background hits are formed.
- These seeds are then passed to the CKF. Although most of these bad seeds get removed with our requirement on at 4 measurements per track fit, it would be good to filter some of these seeds prior to the CKF.
- We now store the set of hit points that formed a triplet as well as the seed quality. We hope to use this information to perform additional filtering at the seed level.

Next steps for ePIC tracking & vertexing

- We plan to incorporate the timing information from the fast-tracking layers into the reconstruction:
  - We can use the fast-tracking layers assign a ‘timestamp’ to each track. This will allow us to build ‘physics’ events tied to specific bunch crossings, as well as check the impact of timing information on background rejection.
  - In parallel, we will work to incorporate the timing information into the track chi-square calculation.
- Our far-forward B0 tracking detector consists of 4 planes in a telescope-like configuration. We are working to implement realistic track finding for this detector.
- We are beginning to add the infrastructure for a Millepede-II global alignment workflow for the ePIC silicon tracking detectors (here).

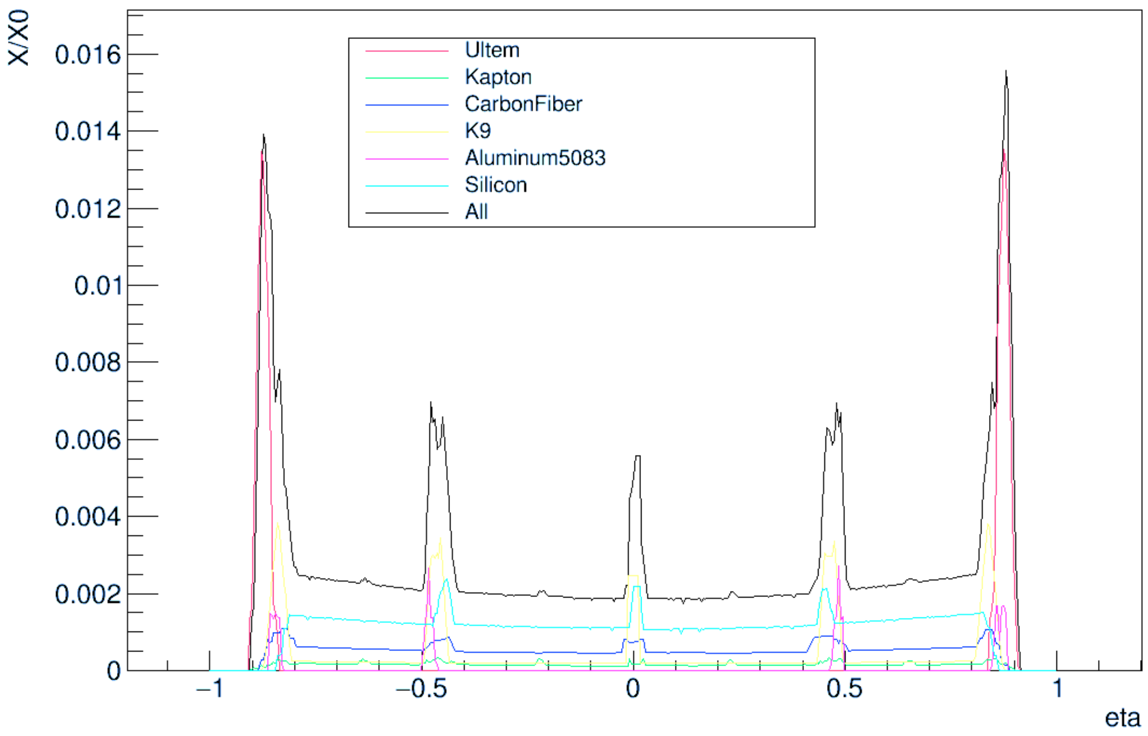
Backup Slides

ePIC Detector & Interaction Region

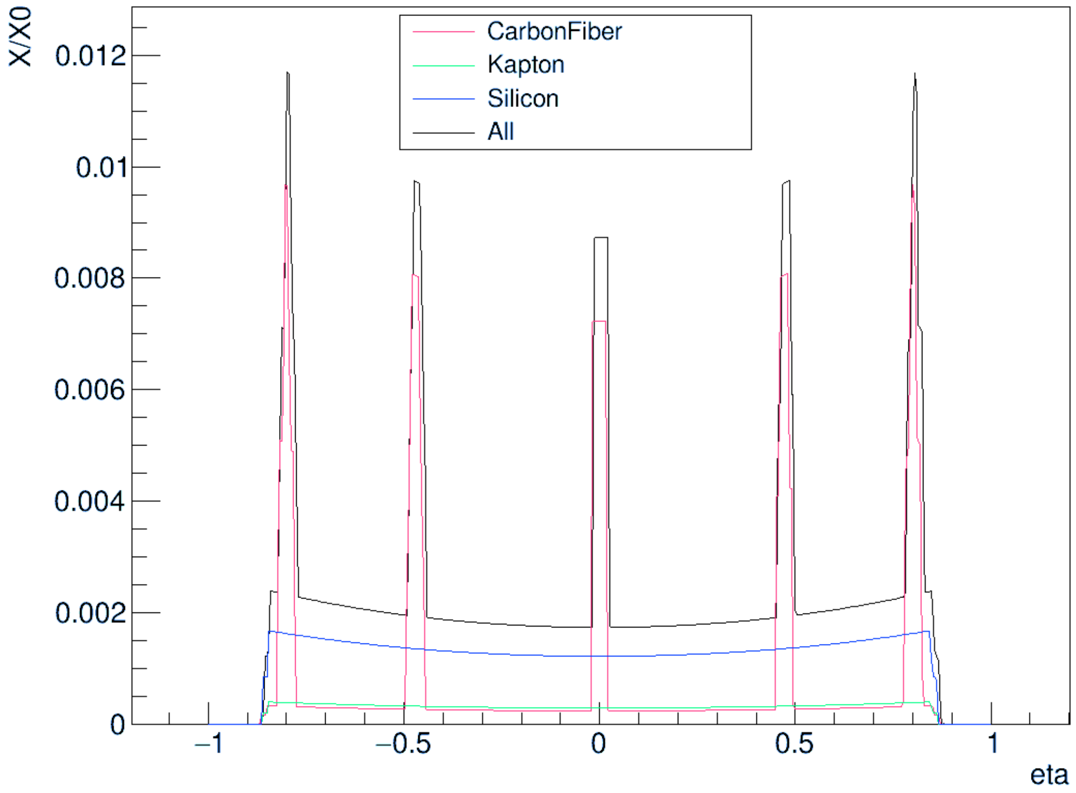


SVT OB L3 Material Scan

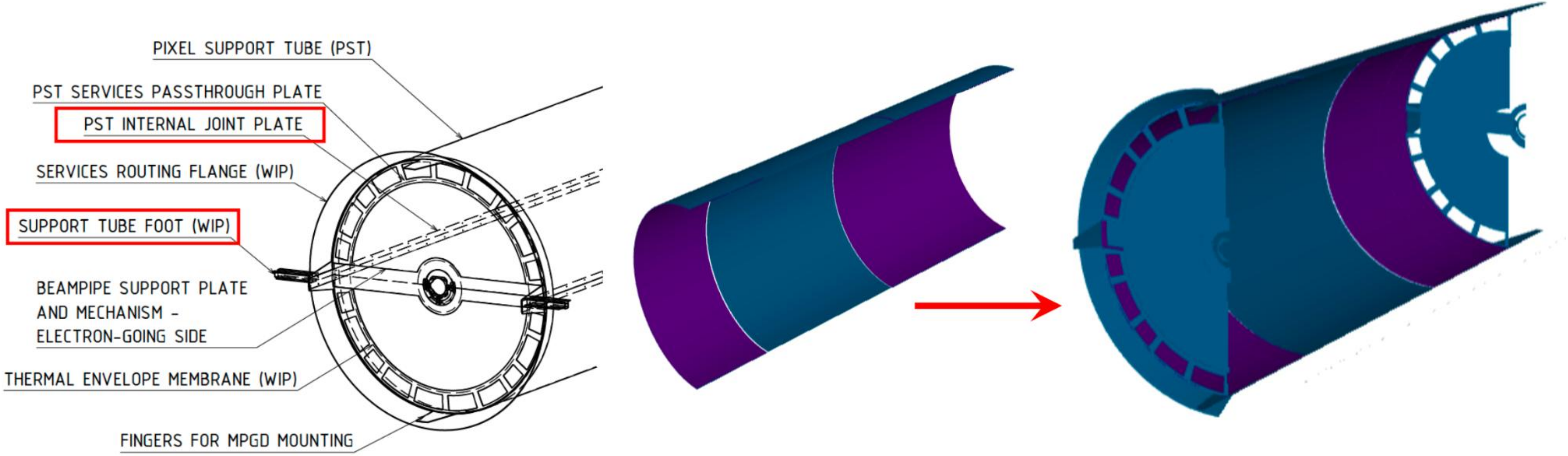
Full layer in CAD



Full layer in simulation



PST and Services



□ Yet to be implemented.

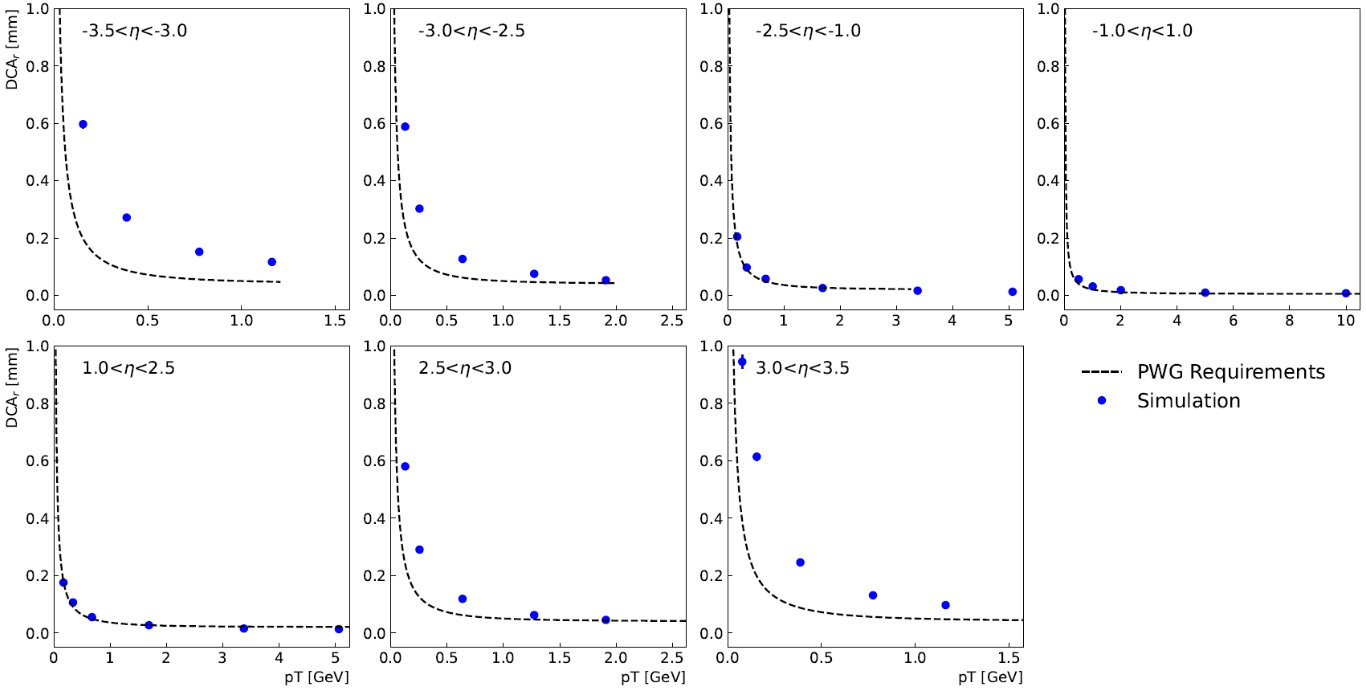
Tracking performance – single particle events

Source events

- Single charged pion events at fixed momentum uniformly distributed in angle

Observables

- **Efficiency**: fraction of generated particles with a reconstructed track
- **Resolution**: dp/p, theta, phi, DCA_r
- **Pull distributions**: reconstructed resolution compared to reconstructed covariance matrix



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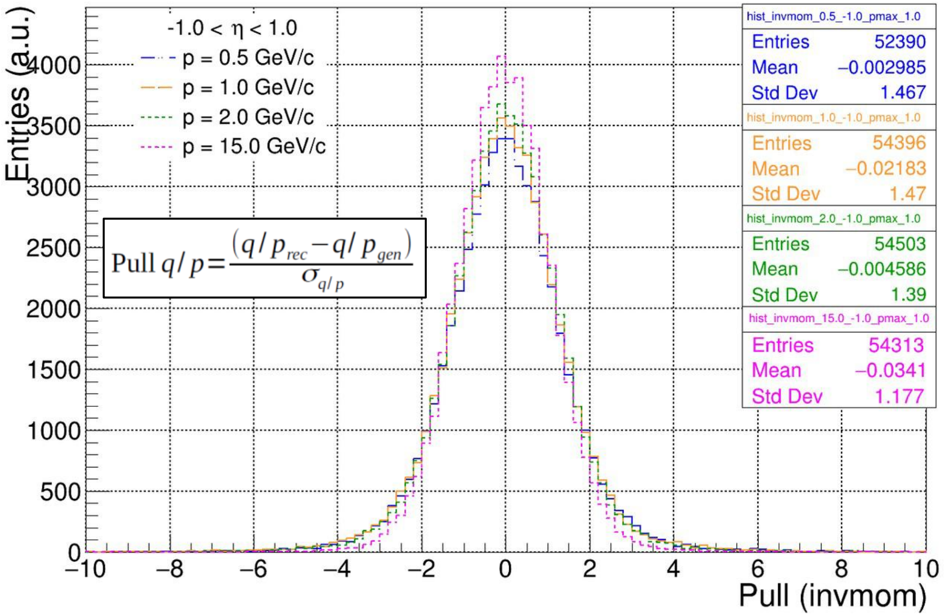
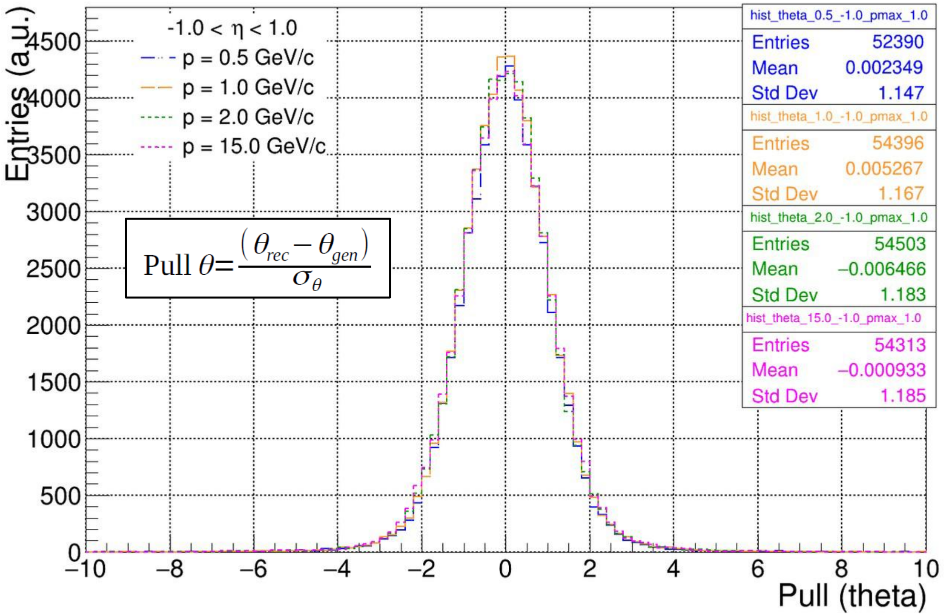
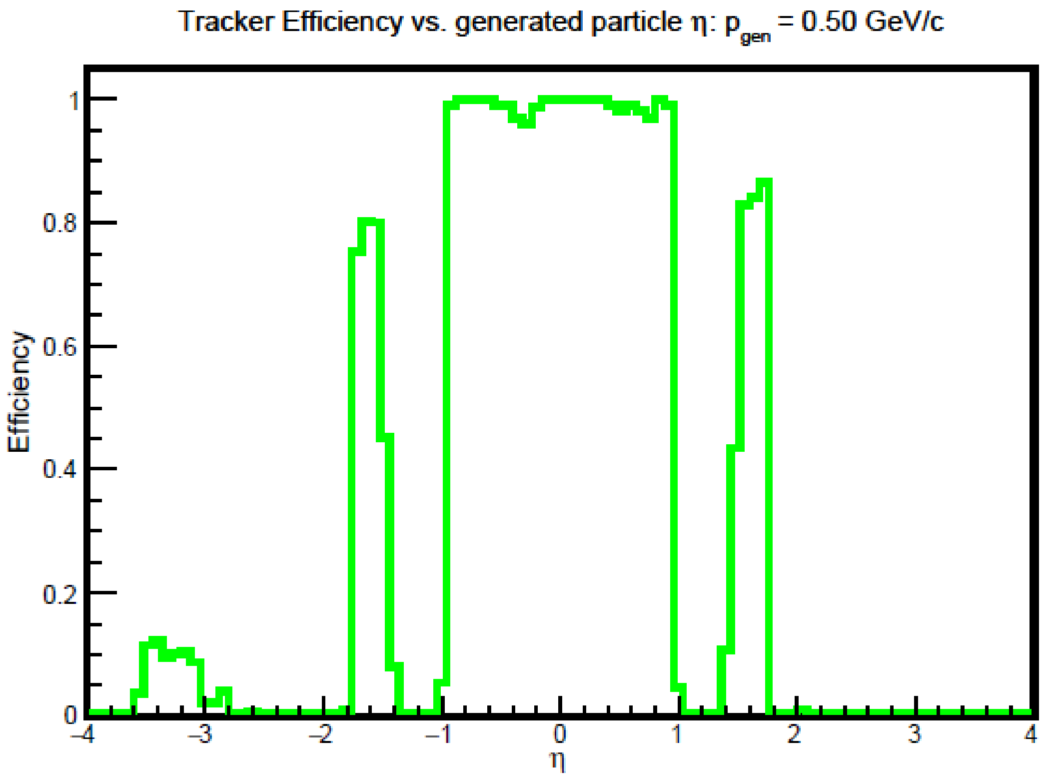


Pull distributions

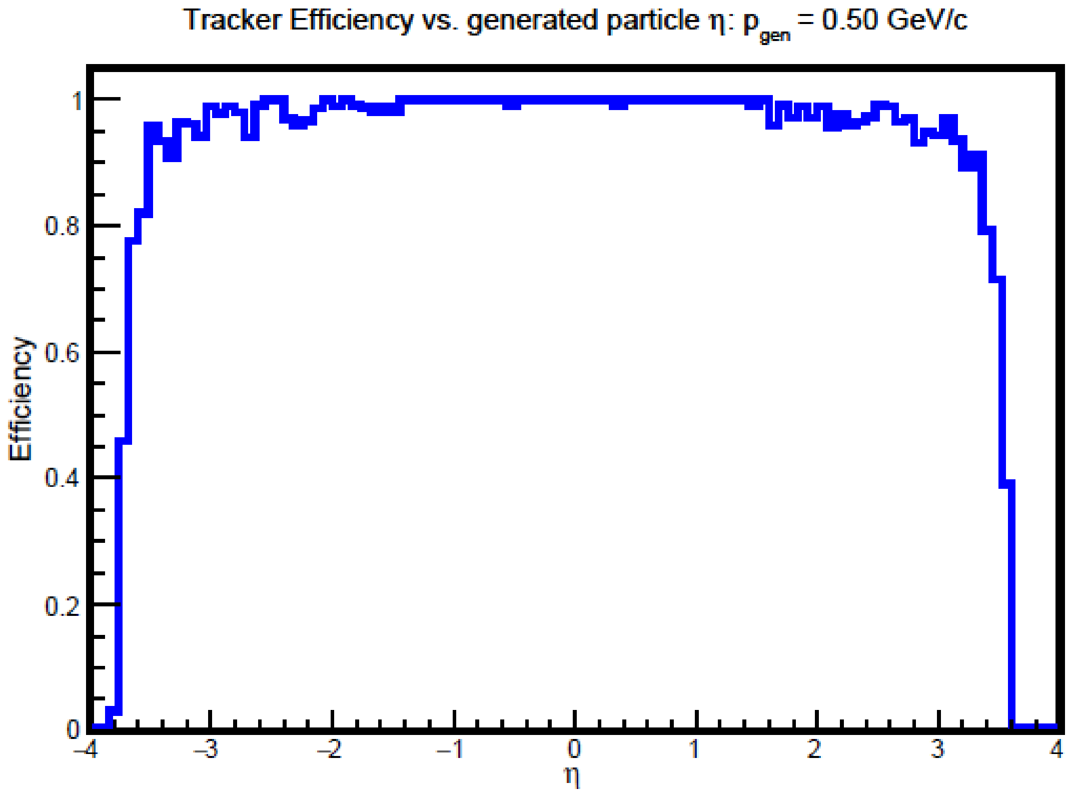


Tracking inefficiency at low momentum

Full track finding and fitting



Idealized track finding



In idealized tracking – which uses some truth-level information – we see good tracking efficiency at 0.5 GeV/c. This suggests the issue in our realistic track reconstruction is related to our track finding algorithm and/or parameters.