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Status of Tracking and Vertexing

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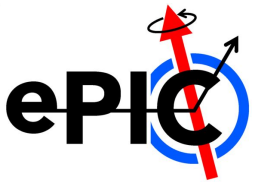
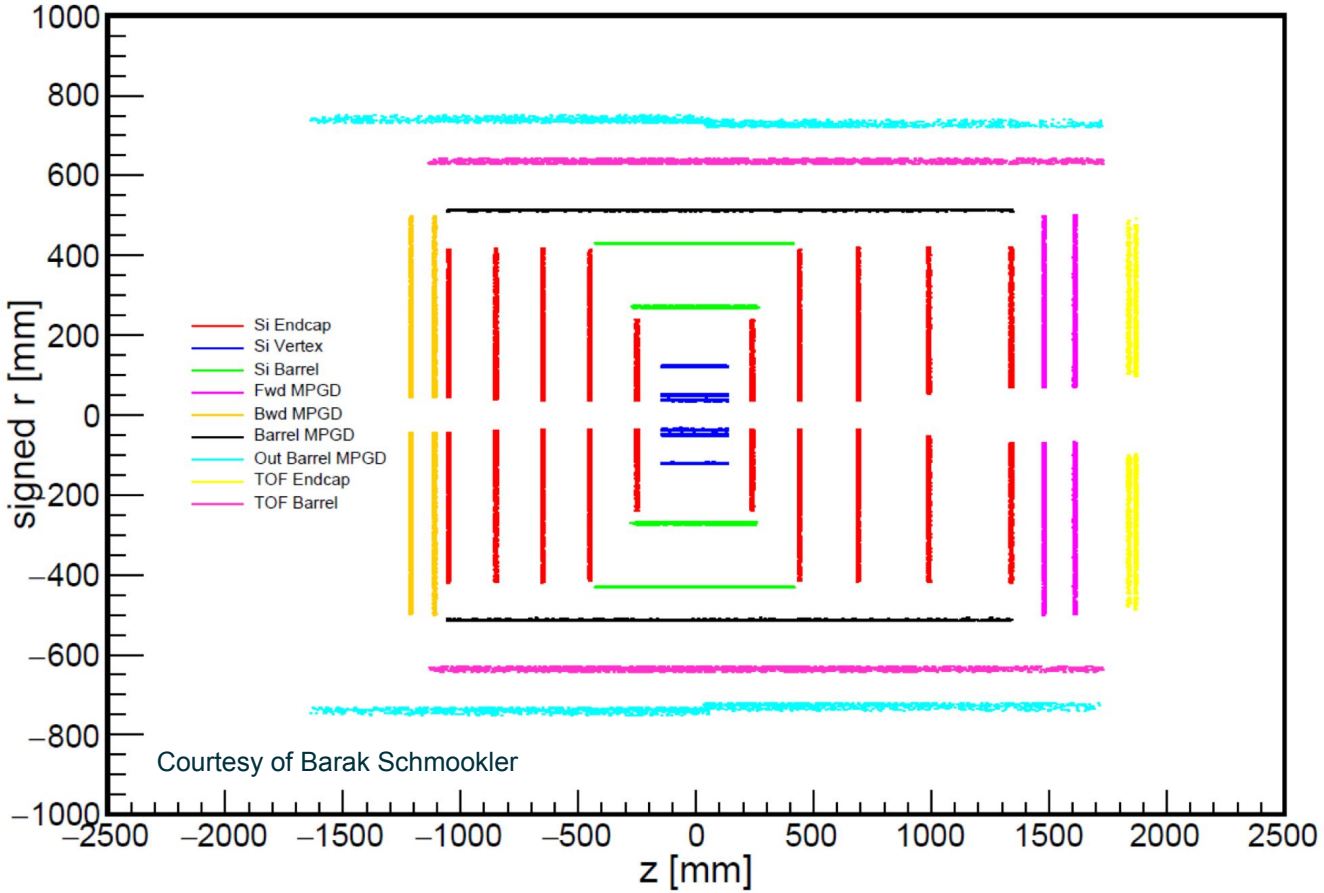


Geant-level tracker hits



Courtesy of Barak Schmookler

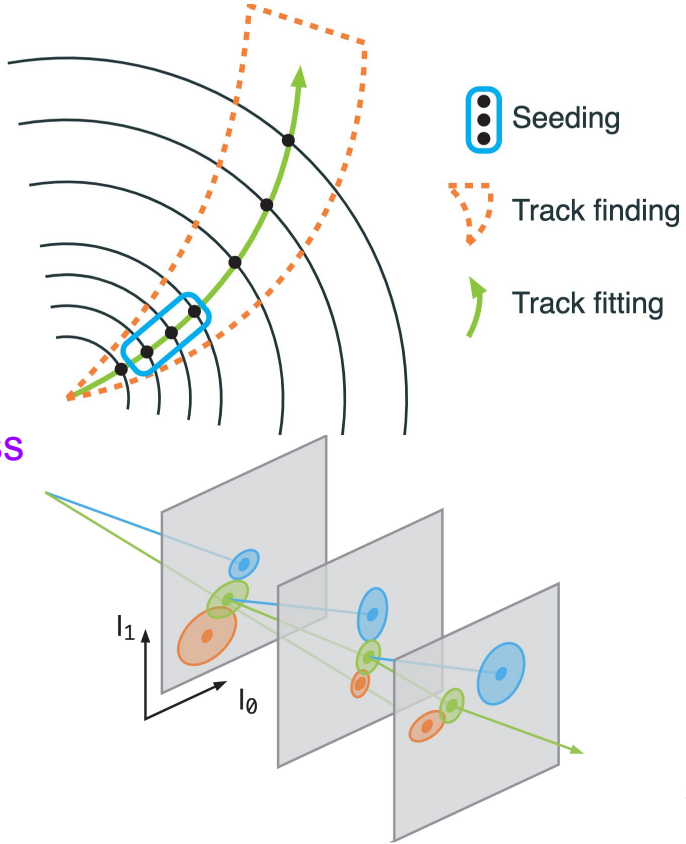
Track Reconstruction Framework

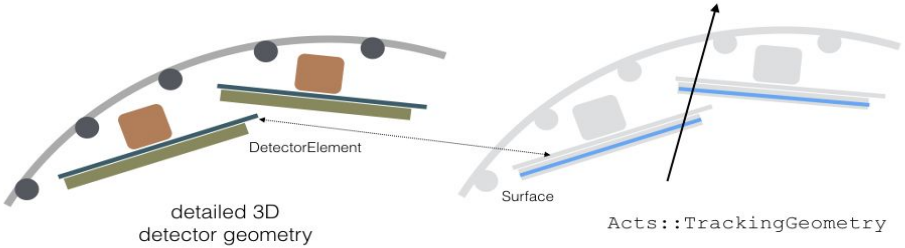
- Reconstruction Framework (**EICrecon** http://eicrecon.epic-eic.org/)
  - Hits digitization
  - Track finding/fitting:

arXiv:1910.03128

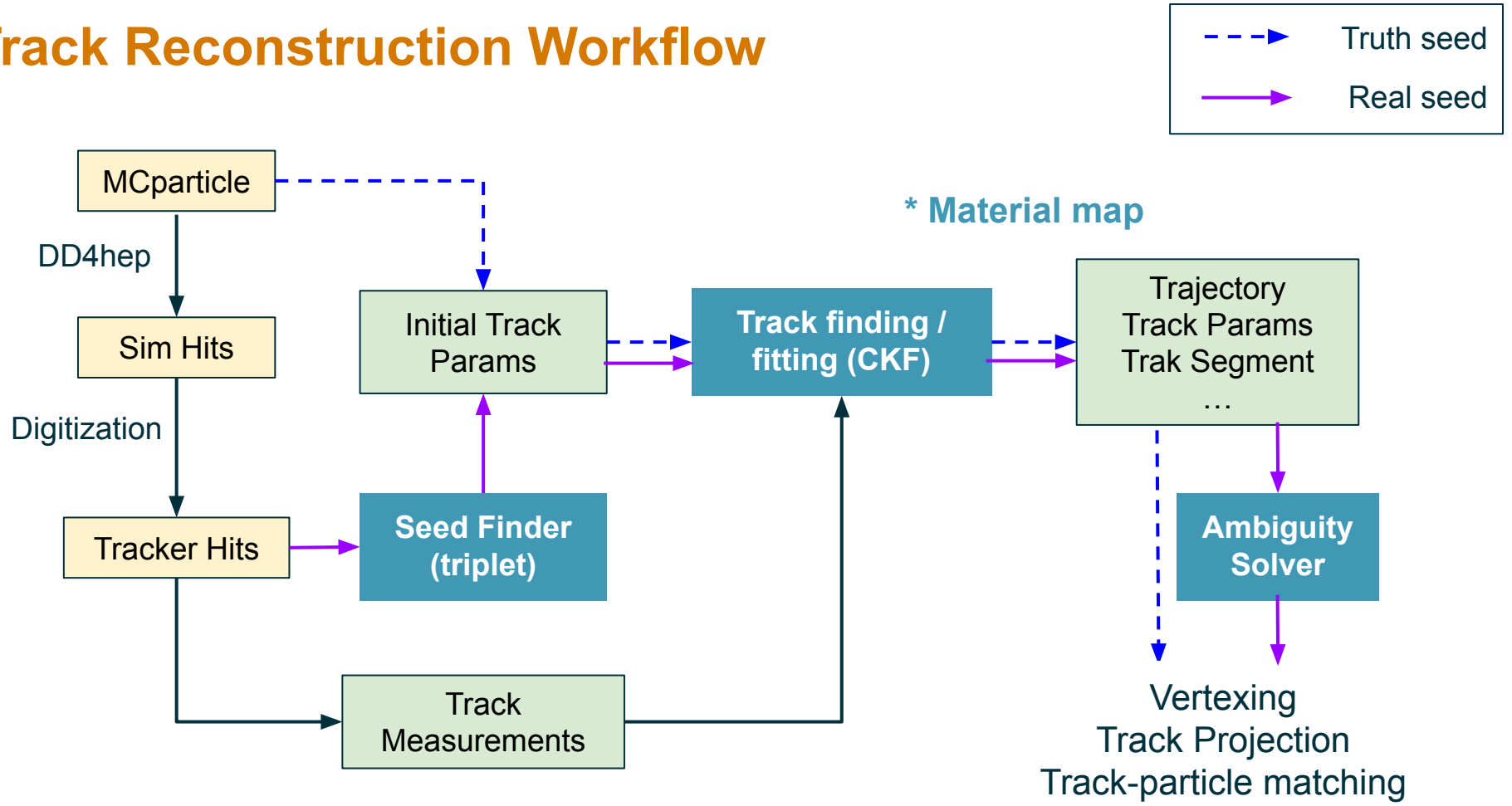
A Common Tracking Software

- **Combinatorial Kalman Filter (CKF)**
  - Combined track finding and fitting
  - Realistic seeder to provide initial guess





Track Reconstruction Workflow



Track Reconstruction Workflow

EICrecon/src/global/tracking/tracking.cc

Truth seed

```
app->Add(new JOmniFactoryGeneratorT<CKFTracking_factory>(
    "CentralCKFTrajectories",
    {
        "InitTrackParams",
        "CentralTrackerMeasurements"
    },
    {
        "CentralCKFTrajectories",
        "CentralCKFTrackParameters",
        "CentralCKFActsTrajectories",
        "CentralCKFActsTracks",
    },
    app
));

app->Add(new JOmniFactoryGeneratorT<IterativeVertexFinder_factory>(
       "CentralTrackVertices",
       {"CentralCKFActsTrajectories"},
       {"CentralTrackVertices"},
       {},
       app
       ));
```

Real seed

```
app->Add(new JOmniFactoryGeneratorT<CKFTracking_factory>(
    "CentralCKFSeededTrajectories",
    {
        "CentralTrackSeedingResults",
        "CentralTrackerMeasurements"
    },
    {
        "CentralCKFSeededTrajectories",
        "CentralCKFSeededTrackParameters",
        "CentralCKFSeededActsTrajectories",
        "CentralCKFSeededActsTracks",
    },
    app
));
```

- Most downstream algorithm still uses tracking output with truth seeding to avoid duplicated tracks and other potential uncertainties.

Track Propagation and Material Effects

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

$$C = \begin{bmatrix} \sigma^2(l_0) & \mathrm{cov}(l_0, l_1) & \mathrm{cov}(l_0, \phi) & \mathrm{cov}(l_0, \theta) & \mathrm{cov}(l_0, q/p) \\ . & \sigma^2(l_1) & \mathrm{cov}(l_1, \phi) & \mathrm{cov}(l_1, \theta) & \mathrm{cov}(l_1, q/p) \\ . & . & \sigma^2(\phi) & \mathrm{cov}(\phi, \theta) & \mathrm{cov}(\phi, q/p) \\ . & . & . & \sigma^2(\theta) & \mathrm{cov}(\theta, q/p) \\ . & . & . & . & \sigma^2(q/p) \end{bmatrix}$$

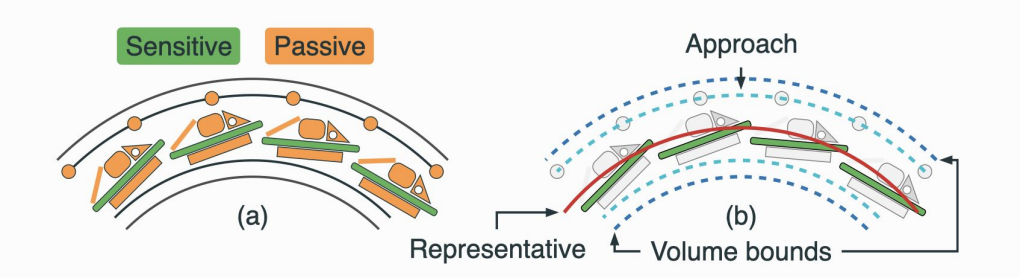
Material effects:

- Deflection and offset → averaged to 0, increased uncertainties
- Energy loss → reduced trajectory energy
- Hadronic process → disintegration etc.

Initial to final step propagation: evolve covariance in time

$$C^f = J \cdot C^i \cdot J^T,$$

$$J = \begin{bmatrix} \frac{\partial l_0^f}{\partial l_0^i} & \cdots & \frac{\partial l_0^f}{\partial (q/p)^i} \\ \vdots & \ddots & \vdots \\ \frac{\partial (q/p)^f}{\partial l_0^i} & \cdots & \frac{\partial (q/p)^f}{\partial (q/p)^i} \end{bmatrix},$$



❖ Workforce needed to update material map for track projection

Courtesy of B. Schmookler
https://indico.bnl.gov/event/22147/

Track Finding/Fitting Quality Check

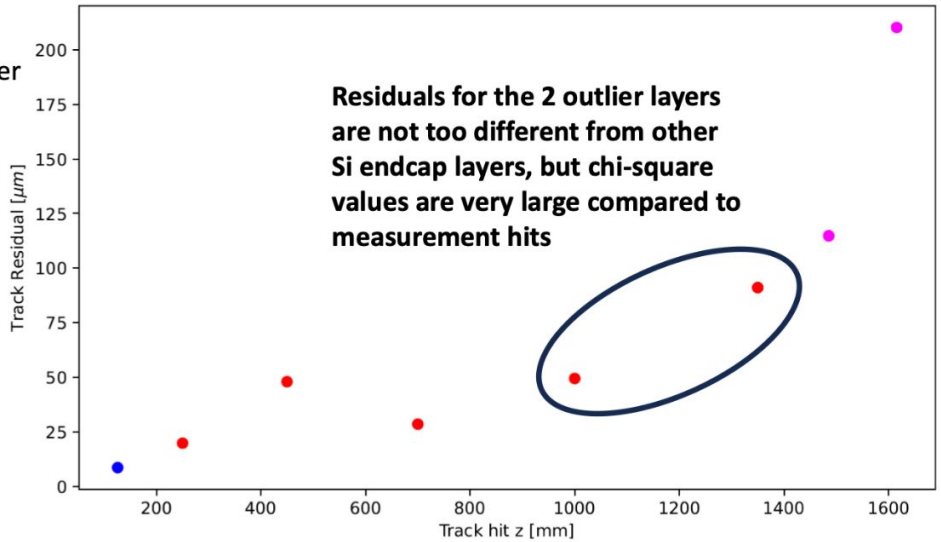
Track residuals for truth-seeded tracking in event #1

For truth-seeded tracking, we save the track states (x,y,z) at the various tracking layers. So, we can calculate residuals.

Vertex layer residual: $\sqrt{r\Delta\varphi^2 + \Delta z^2}$

Si endcap and **Fwd MPGD** residuals: $\sqrt{\Delta x^2 + \Delta y^2}$

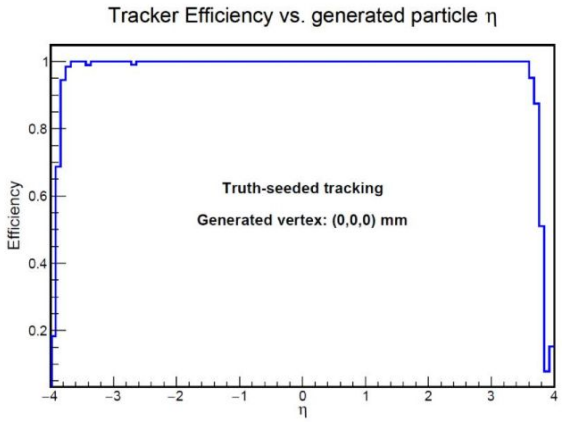
Measurement chi-square per-layer	**Outlier** chi-square per layer
1.8605283	53.284168
0.5367326	26.377220
0.5832352	
0.7475767	
0.0013756	
6.546e-06	

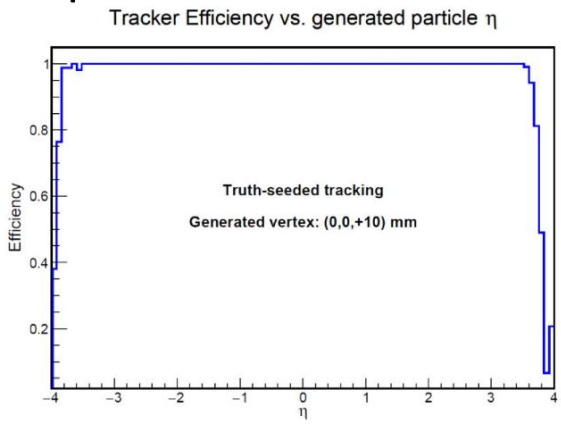


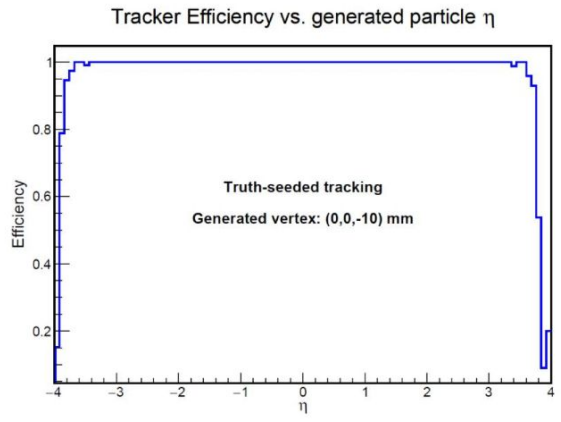
Tracking Efficiency

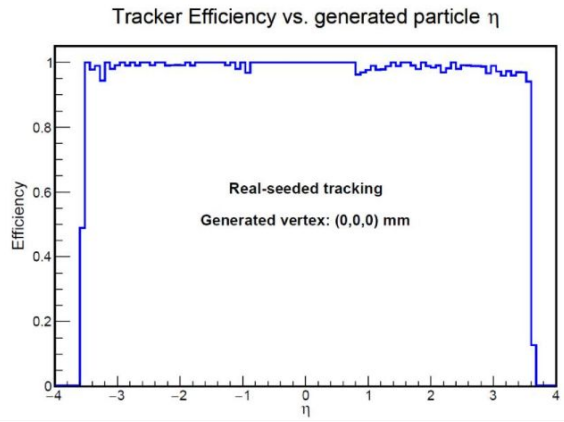
Courtesy of B. Schmookler and J. Gupta
https://indico.bnl.gov/event/21238/contributions/83543/attachments/51067/87297/tracking_111623.pdf

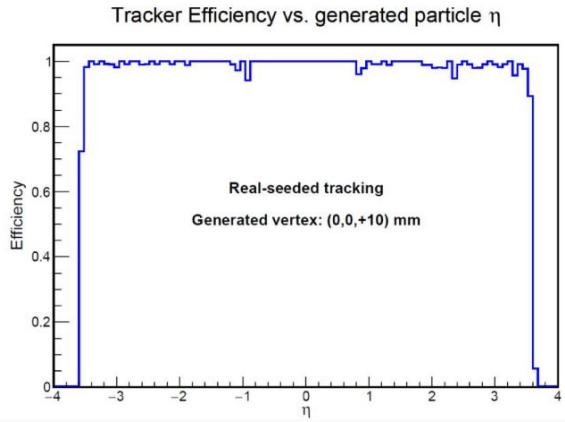
Single-particle reconstruction

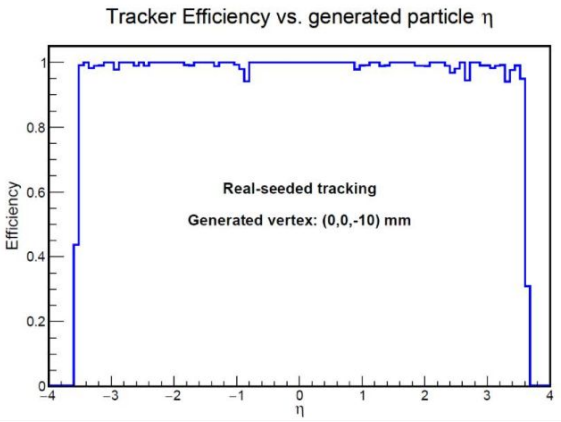




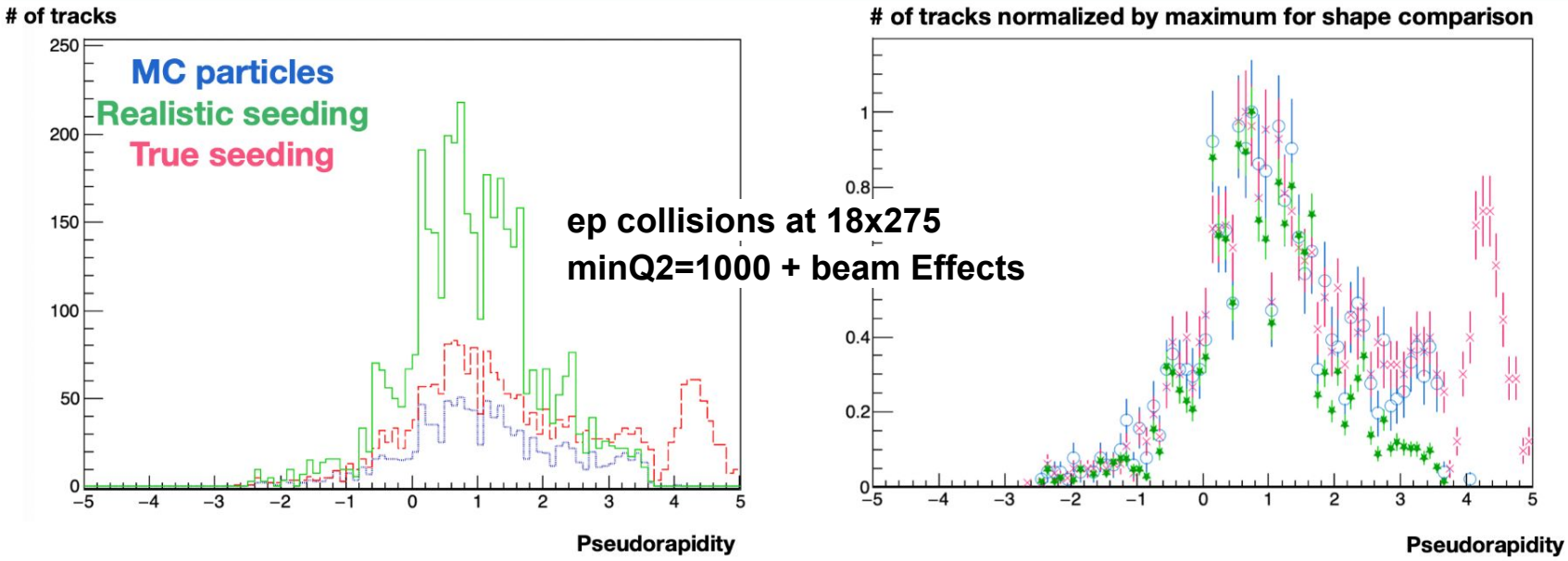








Remove Duplicates



- MC particles: stable particles generating at 3 hits on silicon trackers
- Much larger entries w.r.t. MC particles in realistic seeding: duplicate seeds visible as expected
- Larger entries in true seeding w.r.t. MC particles in true seeding, with seeds in B0 acceptance

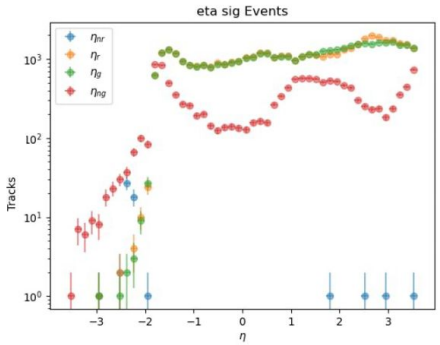
https://indico.bnl.gov/event/20473/contributions/85366/

First Look of DIS + Background Events

Courtesy of B. Sterwerf

https://indico.bnl.gov/event/20473/contributions/85365/

Sig eta



Breakdown By Particle Type

We see that the majority of not reconstructed MC particles are pions except in low eta regime where there is a strong electron peak

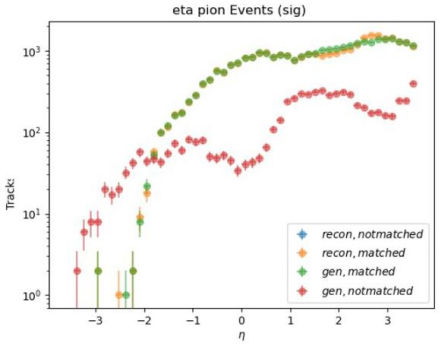
Blue=Reconstructed Particles that do not get matched

Yellow=Reconstructed Particles that get matched

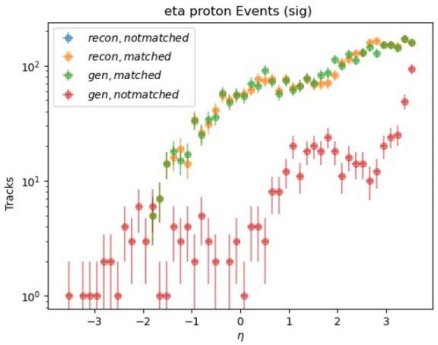
Green=MC Particles that get Reconstructed

- Red=MC Particles that do not get Reconstructed

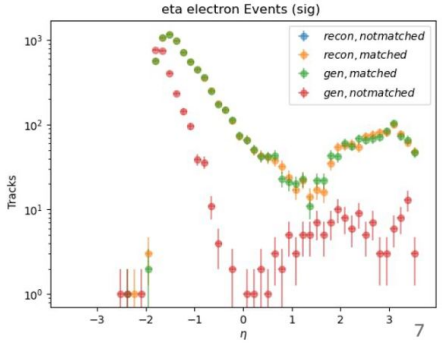
Sig eta events Pions



Sig eta events Protons



Sig eta events Electrons



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Plans for TDR (part 1)

- Reconstruction algorithm (to make real seed the default):
  - Check seeding and track finding at hit level
  - Check track optimization/error propagation:
    - Test initial cov matrix (Barak Schmookler, Jeet Gupta)
    - Check geometry segmentation and material map (need workforce)
    - Understand residual and χ^2 (Beatrice Liang-Gilman)
  - Remove duplicated tracks, match tracks to particles (Minjung Kim, Benjamen Sterwarf)
- Tracking performance study:
  - DIS+background (Minjung, Benjamen)
  - Prepare benchmark plots (need workforce)
  - Check the impact of BIC on tracking (need workforce)

* integration of far-forward detectors etc

Vertexing for Yellow Report

Detector Performance Matrix

η	Nomenclature		Tracking			
			Min p_T	Resolution	Allowed X/X_0	Si-Vertex
-3.5 — -3.0		Backwards Detectors	100 MeV π 135 MeV K	σ_p/p ~ 0.1%×p+2.0%	~5% or less	
-3.0 — -2.5						σ_{xy}~30μm/p_T+ 40μm
-2.5 — -2.0				σ_p/p ~ 0.05%×p+1.0%		σ_{xy}~30μm/p_T+ 20μm
-2.0 — -1.5						
-1.5 — -1.0						
-1.0 — -0.5		Barrel		σ_p/p ~ 0.05%×p+0.5%		σ_{xyz} ~ 20 μm, $d_0(z) \sim d_0(r\varphi)$ ~ 20/p_T GeV μm + 5 μm
-0.5 — 0.0	Central Detector					
0.0 — 0.5						
0.5 — 1.0						
1.0 — 1.5		Forward Detectors		σ_p/p ~ 0.05%×p+1.0%		σ_{xy}~30μm/p_T+ 20μm
1.5 — 2.0						
2.0 — 2.5						
2.5 — 3.0				σ_p/p ~ 0.1%×p+2.0%		σ_{xy}~30μm/p_T+ 40μm
3.0 — 3.5						σ_{xy}~30μm/p_T+ 60μm

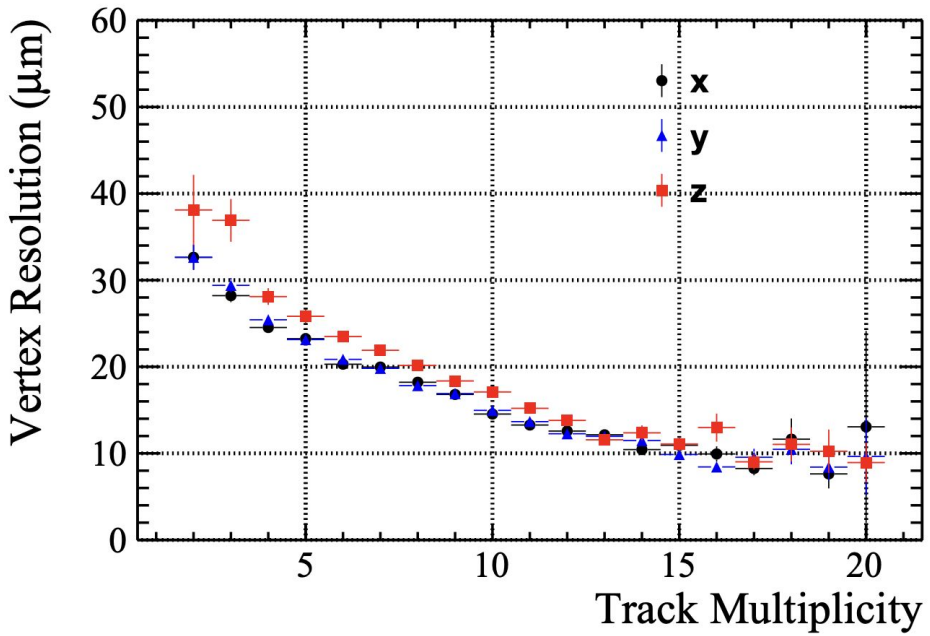
Yellow Report

Fast simulation:

DCA point smearing according to YR DCA resolution

Simple average of DCA position of primary tracks

- no error or covariance



M. Kelsey et. al., PRD 104 (2021) 054002

Vertexing Algorithm in EICrecon

- Acts::IterativeVertexFinder implemented in EICrecon
- Trajectories used as input to Acts
- Fitted vertices filled into edm4eic::Vertex objects, stored in PODIO output
    - Collection: “CentralTrackVertices”

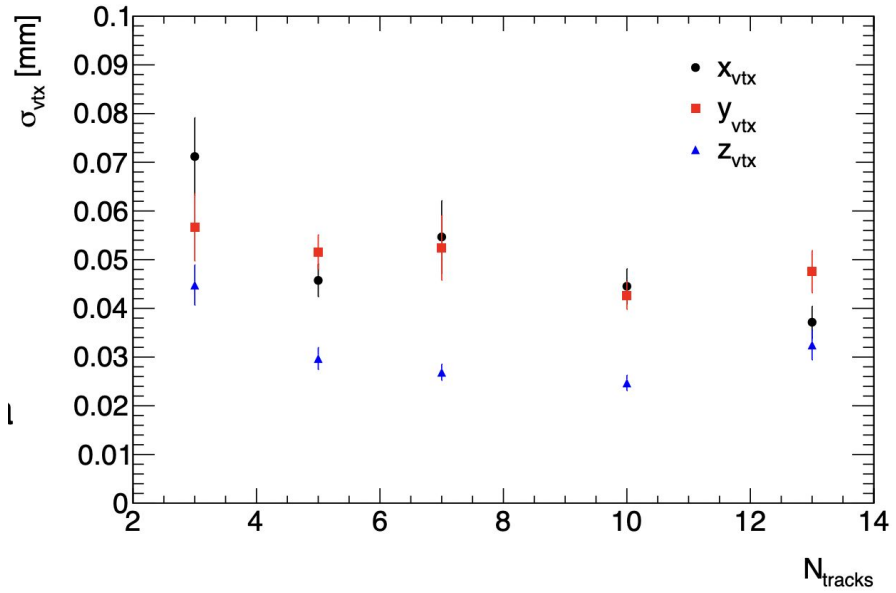
edm4eic::Vertex struct missing key fields
- to-be-updated (see discussion later)

```
std::vector<const Acts::BoundTrackParameters*> inputTrackPointers;

for (const auto& trajectory : trajectories) {
  auto tips = trajectory->tips();
  if (tips.empty()) {
    continue;
  }
  /// CKF can provide multiple track trajectories for a single input seed
  for (auto& tip : tips) {
    inputTrackPointers.push_back(&(trajectory->trackParameters(tip)));
  }
}

std::vector<Acts::Vertex<Acts::BoundTrackParameters>> vertices;
auto result = finder.find(inputTrackPointers, finderOpts, state);
if (result.ok()) {
  vertices = std::move(result.value());
}

for (const auto& vtx : vertices) {
  edm4eic::Cov3f cov(vtx.covariance()(0, 0), vtx.covariance()(1, 1), vtx.covariance()(2, 2),
                     vtx.covariance()(0, 1), vtx.covariance()(0, 2), vtx.covariance()(1, 2));

  edm4eic::Vertex* eicvertex = new edm4eic::Vertex{
      1,                              // boolean flag if vertex is primary vertex of event
      (float)vtx.fitQuality().first,  // chi2
      (float)vtx.fitQuality().second, // ndf
      {(float)vtx.position().x(), (float)vtx.position().y(),
       (float)vtx.position().z()}, // vtxposition
      cov,                           // covariance
      1,                             // algorithmtype
      (float)vtx.time(),             // time
  };
```

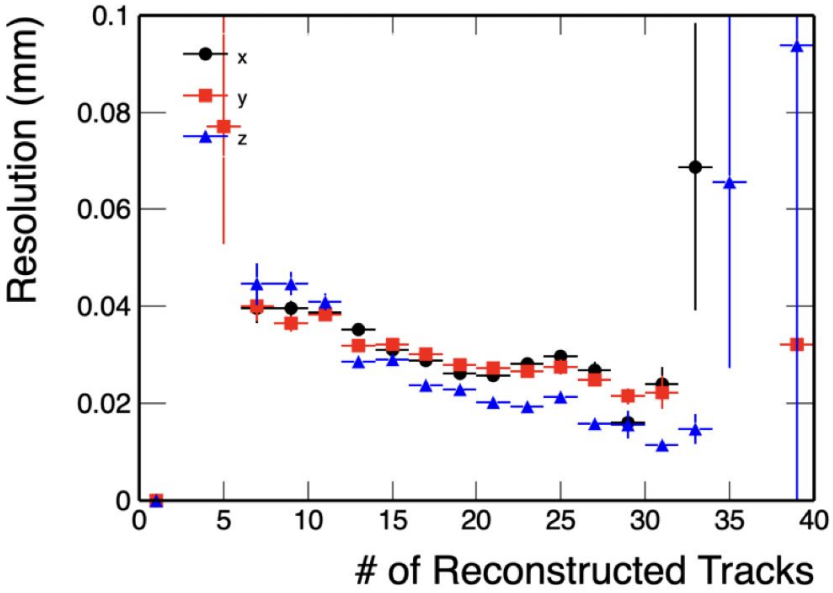
Details in Joe Osborn’s presentation on May 18 at ePIC Track Reconstruction Meeting
https://indico.bnl.gov/event/19358/contributions/76588/attachments/47593/80693/vertexing.pdf

Performance Test - events starting from (0,0)

A-few-track simu - vertex (0,0,20)



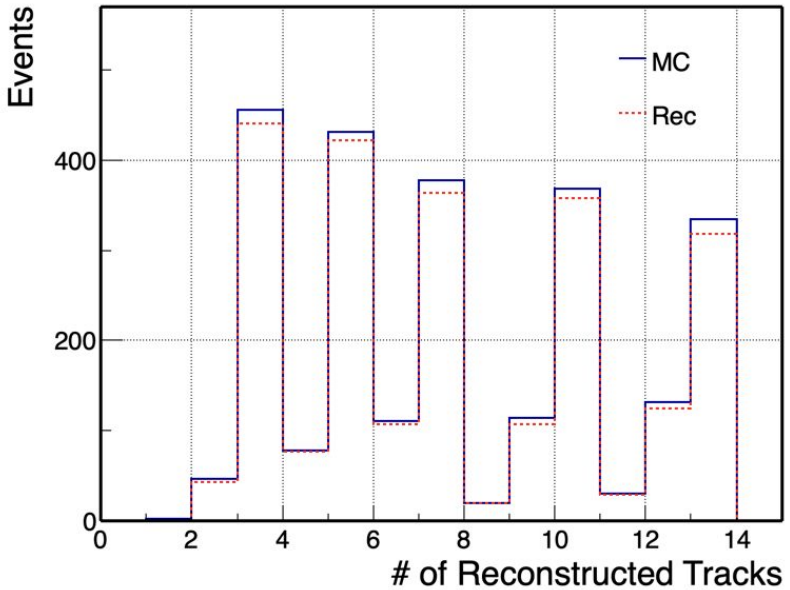
DIS (HF) simu - vertex (0,0,0)



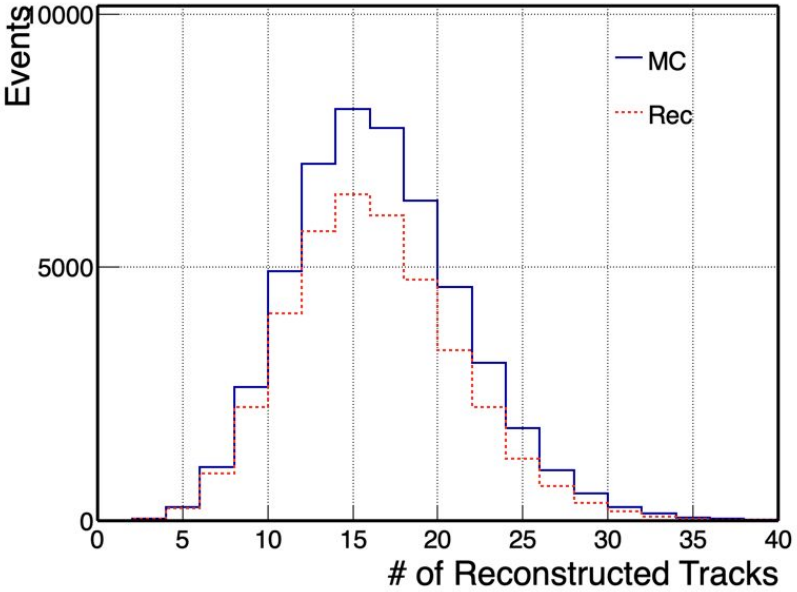
Vertexing resolution shows decent performance for events starting from (0,0)
- may be fine-tuned for optimization for different process, kinematics etc.)

Performance Test - events starting from (0,0)

A-few-track simu - vertex (0,0,20)



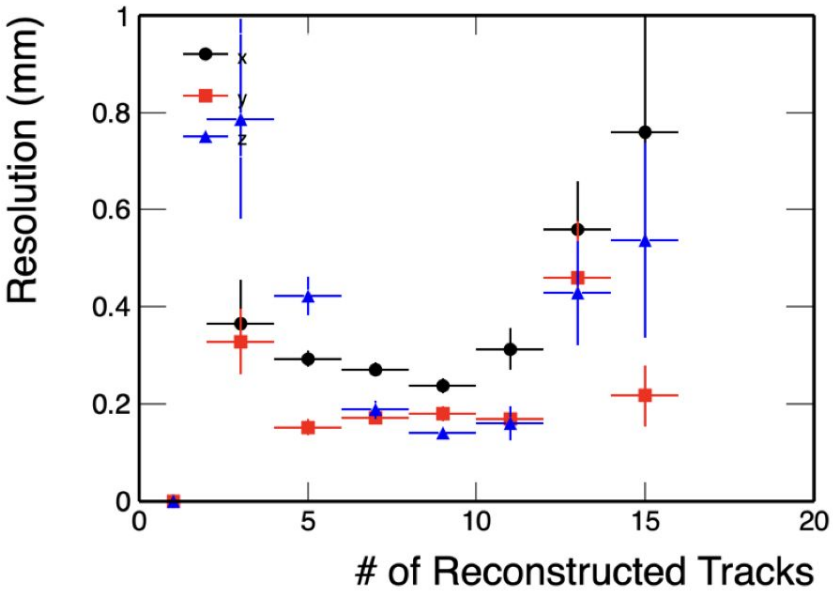
DIS (HF) simu - vertex (0,0,0)



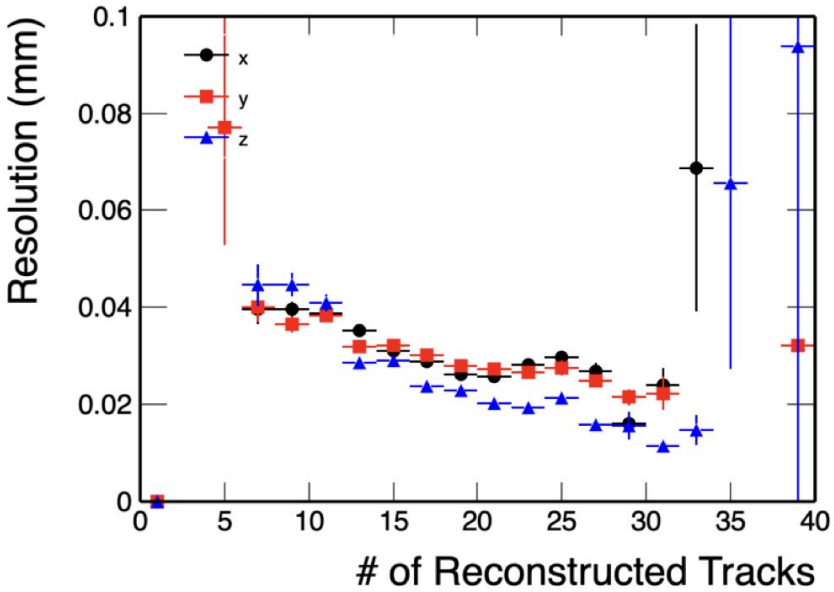
Vertexing efficiency seems to be OK, may need improvements for DIS events

Performance Test - events starting away from (0,0)

DIS S3 data - smeared vertex, X-ing angle

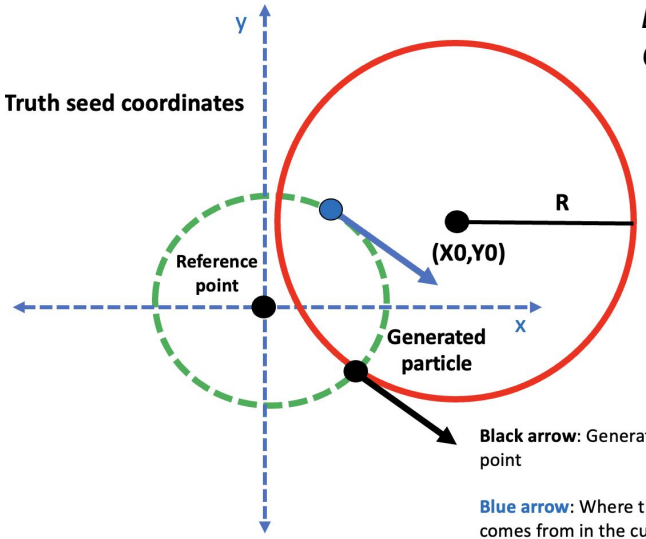


DIS (HF) simu - vertex (0,0,0)



Vertexing resolution for DIS S3 events (smeared vertex) degraded by a factor of 5-10

Tracking Issue with Off-Axis Tracks

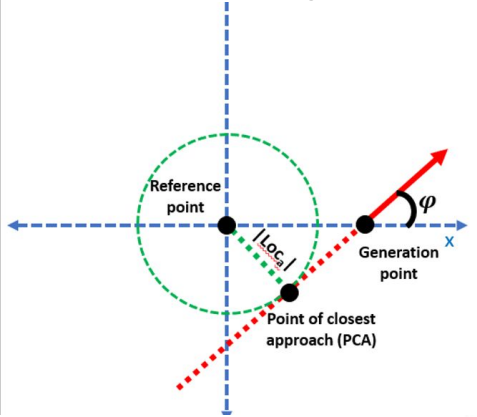


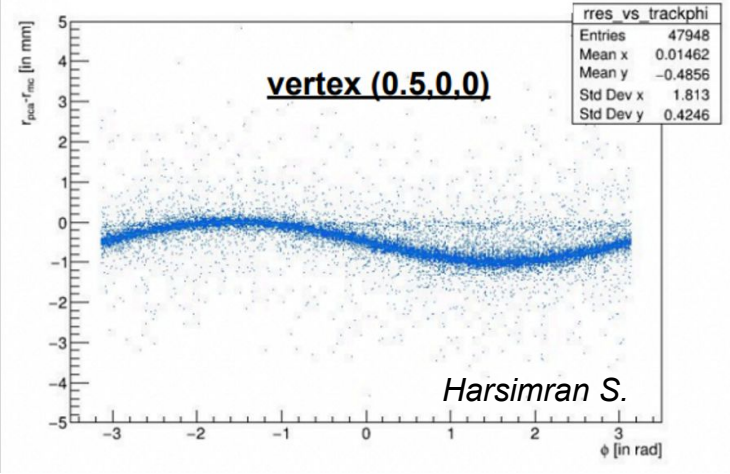
Barak S. ,
Coll. Mtg 1/9

Black arrow: Generated particle at its creation point

Blue arrow: Where the CKF will think the particle comes from in the current truth seeding implementation.

A fix being tested now





Truth-seeding:

- issue of coordinates conversion (fix being tested now)

Realistic-seeding:

- Fix to globalToLocal seed conversion. EICRecon PR #1185
- Fix to seed charge calculation. EICRecon PRs #1213, #1214
- Removal of duplicate seeds

Vertex Objects in edm4eic

Current edm4eic::Vertex definition - updated recently to include a few missing information

- Need to update the corresponding filling method

Simulated Vertex: - no structure so far, using the same/similar structure? - to be discussed

- Generator level vertices (HepMC data)
- GEANT Vertices

```
edm4eic::Vertex:
  Description: "EIC vertex"
  Author: "J. Osborn"
  Members:
    - int32_t             type          // Type flag, to identify what type of vertex it is (e.g. primary,
    - float               chi2          // Chi-squared of the vertex fit
    - int                 ndf           // NDF of the vertex fit
    - edm4hep::Vector4f   position      // position [mm] + time t0 [ns] of the vertex. Time is 4th compone
    ## this is named "covMatrix" in EDM4hep, renamed for consistency with the rest of edm4eic
    - edm4eic::Cov4f      positionError // Covariance matrix of the position+time. Time is 4th component,
  OneToManyRelations:
    - edm4eic::ReconstructedParticle associatedParticles // particles associated to this vertex.
```

Status and Plans for TDR (part 2)

Vertexing performance for DIS events from (0,0) looks reasonable

Fix or understand tracking and vertexing performance for off-axis tracks/events

Continue evaluation of vertexing performance for a few key physics processes

Refine vertex struct objects (Rc and Mc) and their filling methods in EICrecon

Longer term:

- Vertexing algorithm optimization
- Secondary vertex performance evaluation