

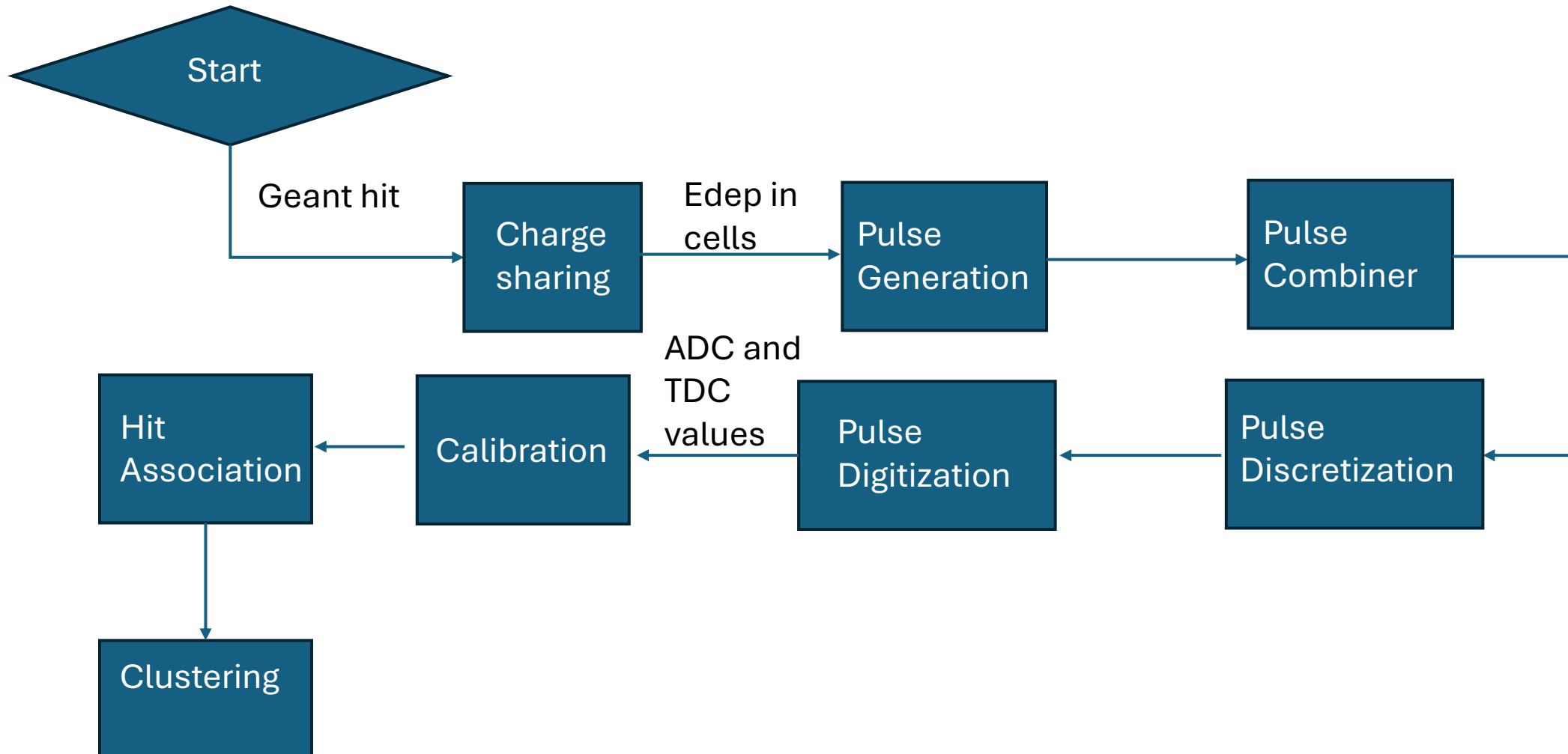
BTOF clusters performance review

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7/21/2025

Introduction: Clustering workflow

Digitization work-flow



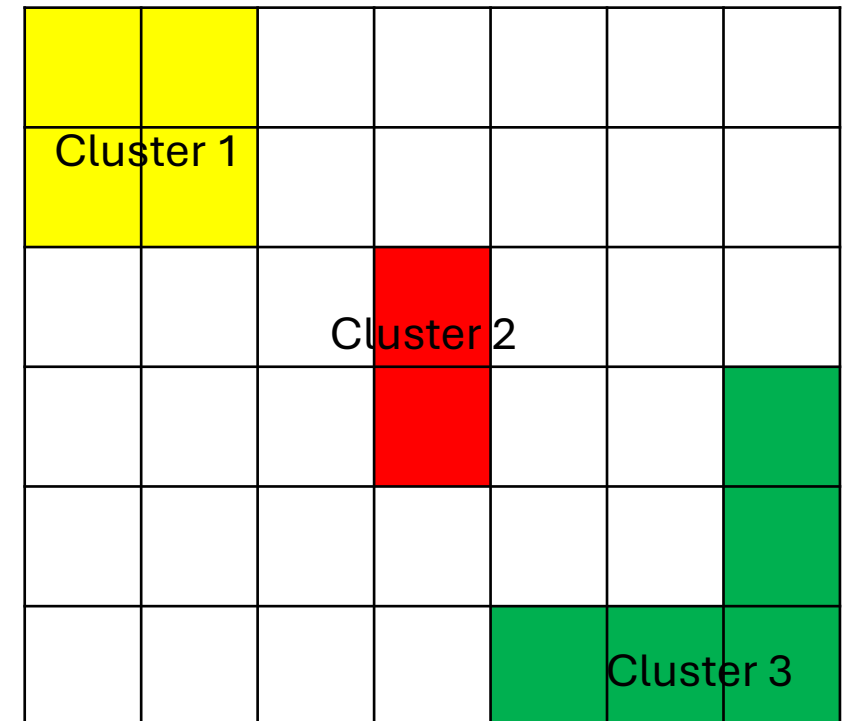
Simulation and Digitization parameters

- N.O. ADC channel = 256.
- N.O. TDC channel (within 25ns EICROC cycle) = 1024.
- Max Edep (i.e. Edep when ADC = 255) = $3e-4$ GeV.
- ADC threshold for TDC = 5% Edep = $0.05 * 3e-4 = 1.5e-5$ GeV)
- Charge sharing fix from <https://github.com/eic/ElCrecon/pull/1945> applied.
- Epic Geometry: main branch of epic on July 10th 2025.
- ElCrecon: pr/use-LGAD-clustering on July 10th 2025.
- **No noise in the pulses.**
- **Simulated 1000 uniformly distributed pi+ from the particle gun.**

Calibration and clustering

- Calibration of TDC to time is just a linear transformation.
 - Same for ADC.
 - **No time walk correction.**
- Clustering is just weighted average of neighbors.
 - Group connected neighbors together.
 - Hits are neighbors if $\Delta t < 1\text{ns}$.
 - Weighted by Edep.
 - Time of a cluster = time of the earliest hit.
 - **No Edge correction.**

Time axis not shown



Hit association

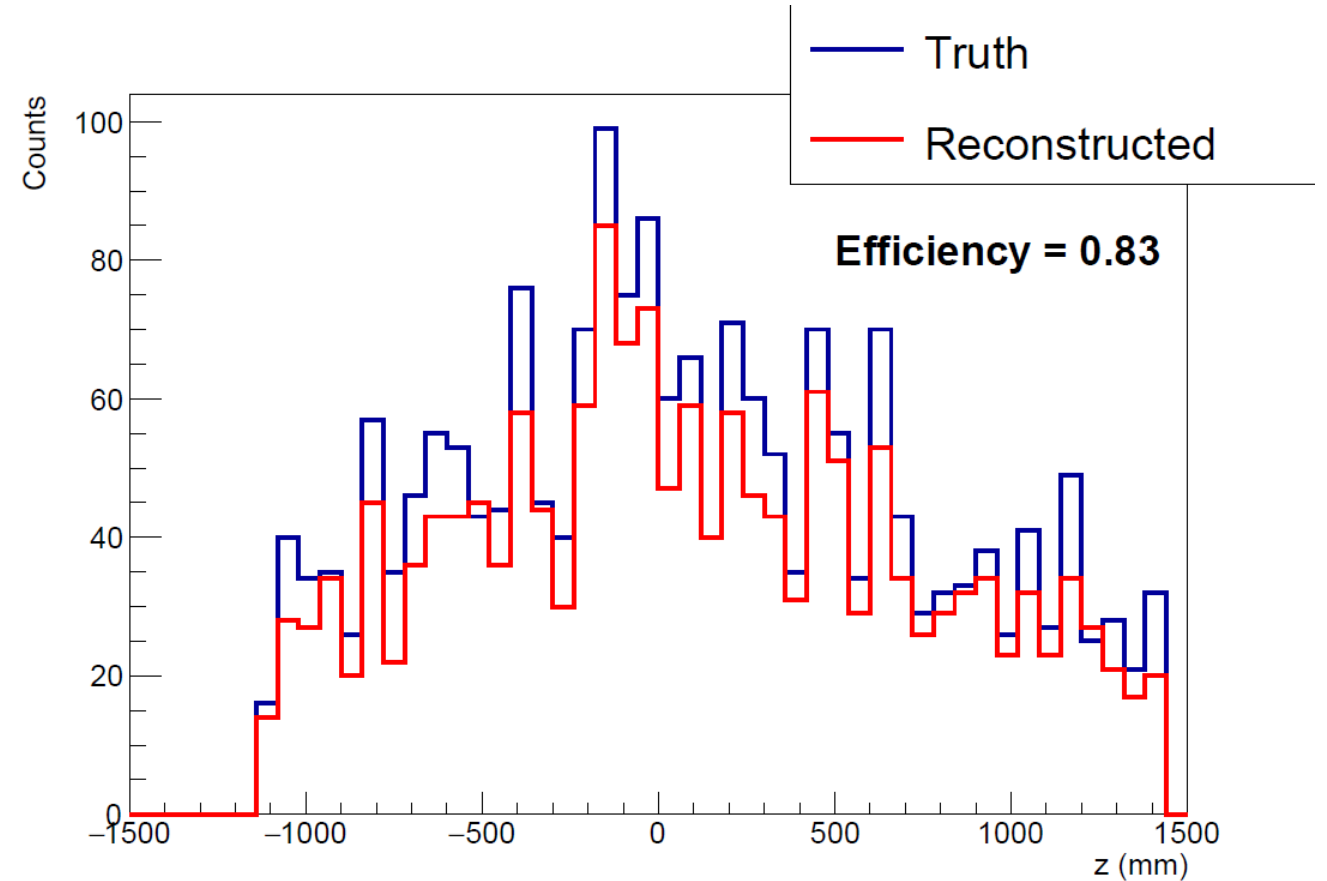
- Associate reconstructed hit with true hits if:
 1. They come from the same sensor.
 2. Time difference between the two hits < 1 ns.
 3. If there are multiple hits within 1 ns, choose the one with the smallest Delta t.

Performance with no charge sharing.

Sanity check.

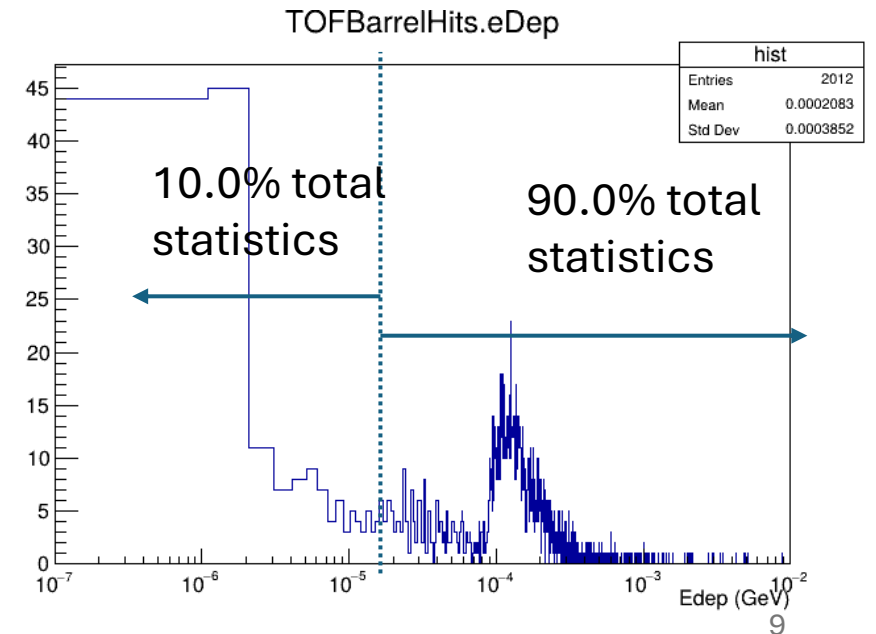
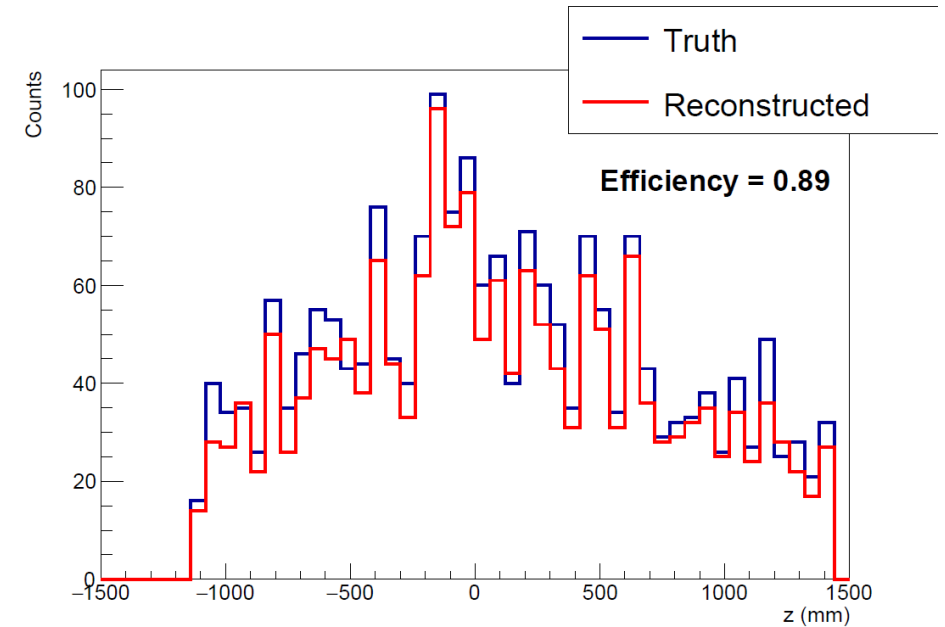
Efficiency without bug fix in <https://github.com/eic/ElCrecon/pull/1945> applied

83% efficiency is a bit low.



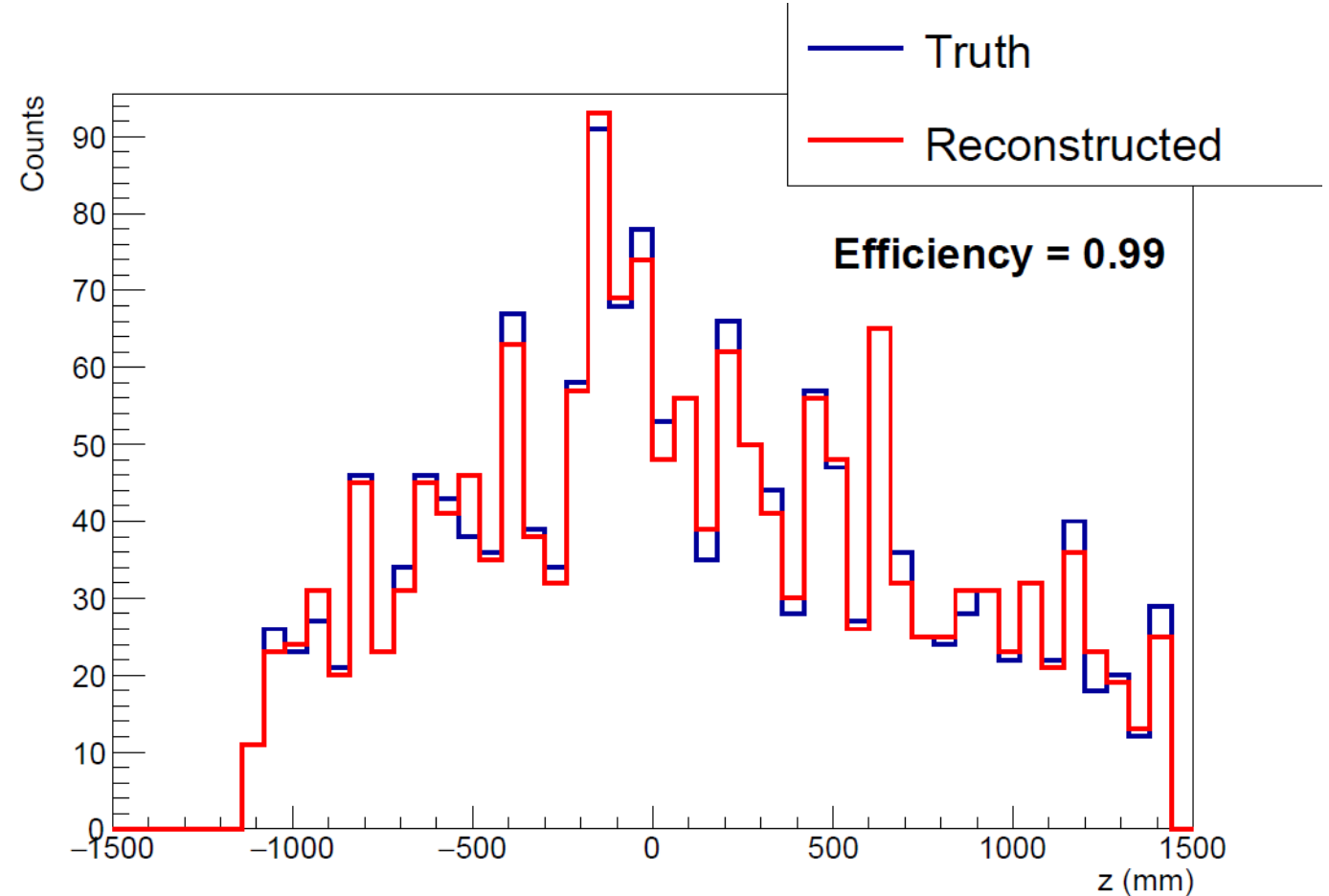
Efficiency with bug fix

- 83% -> 89% Efficiency seems low, but remember:
 - ADC threshold = $1.5e-5$ GeV !!!
- We lost 10% efficiency due to that alone.

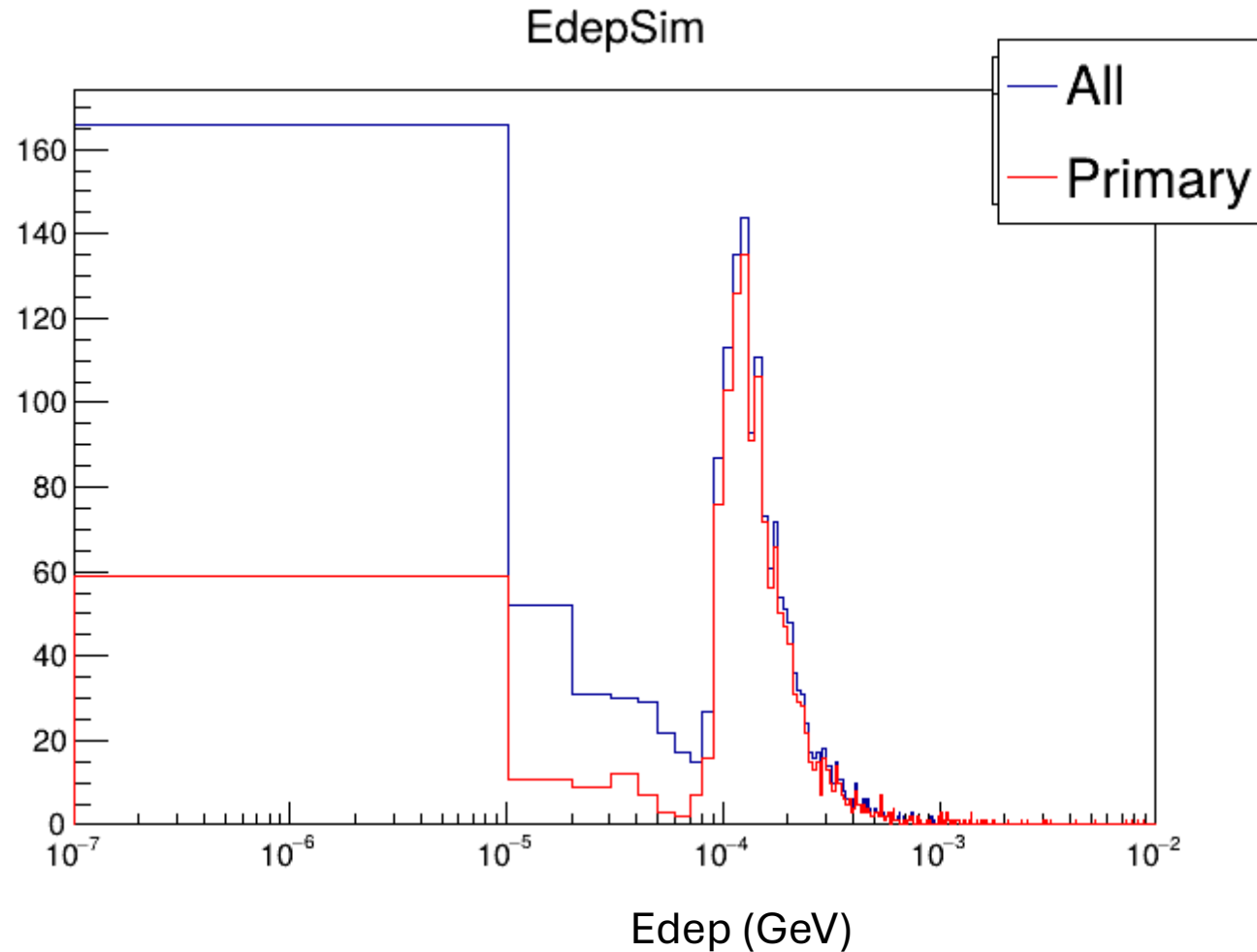


Efficiency with $E_{\text{dep}} > 5e-5$ GeV

- Efficiency = 99%

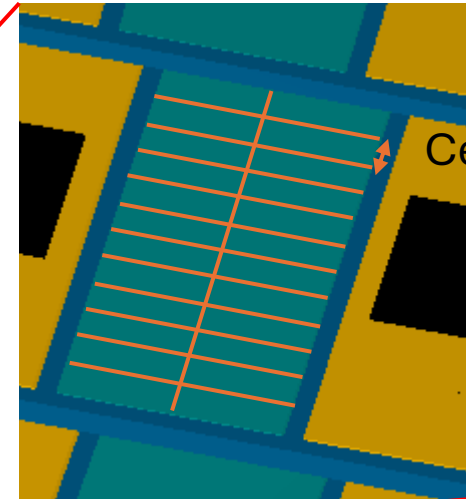
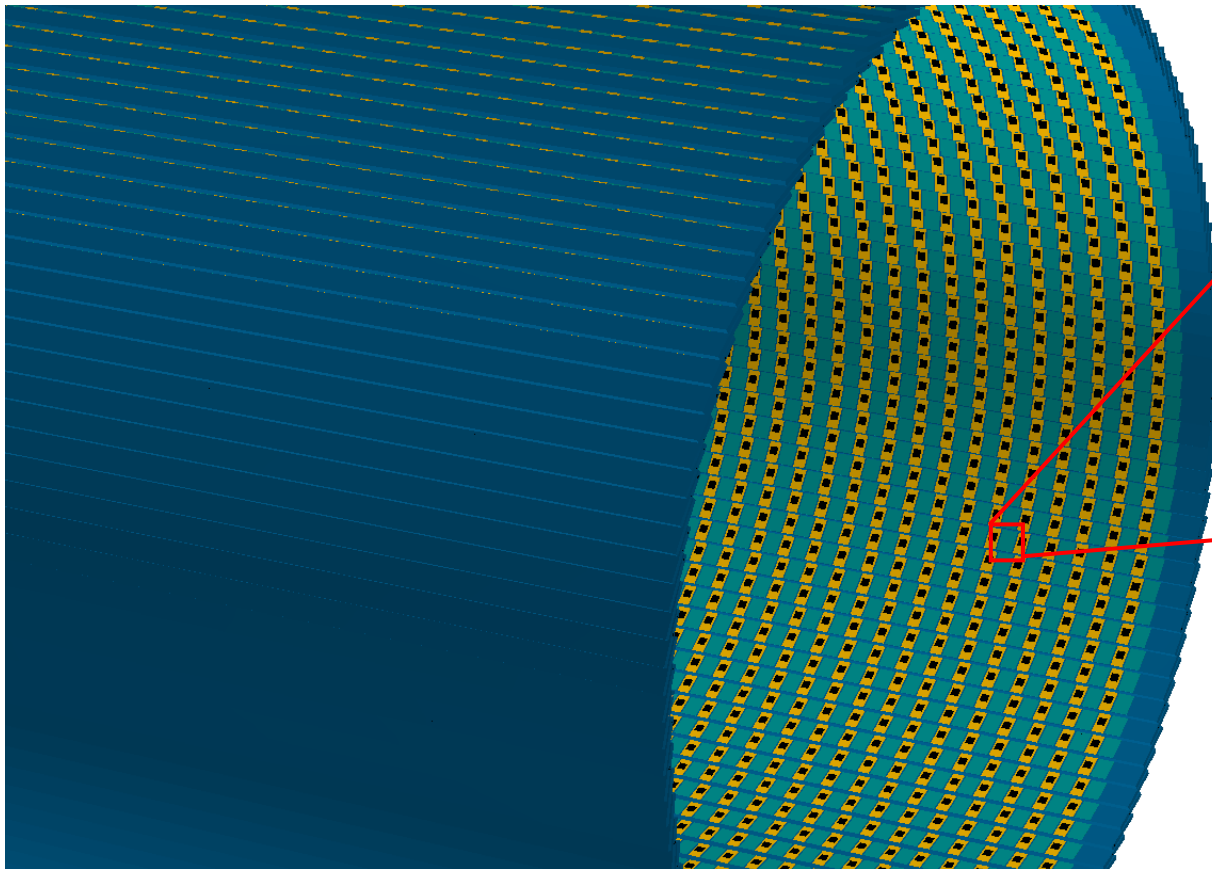


7.7% of Primary hits have $E_{\text{dep}} < 5 \times 10^{-5}$ GeV.



Phi resolution expectation

$$\Delta\phi = \phi_{true} - \phi_{reco}$$



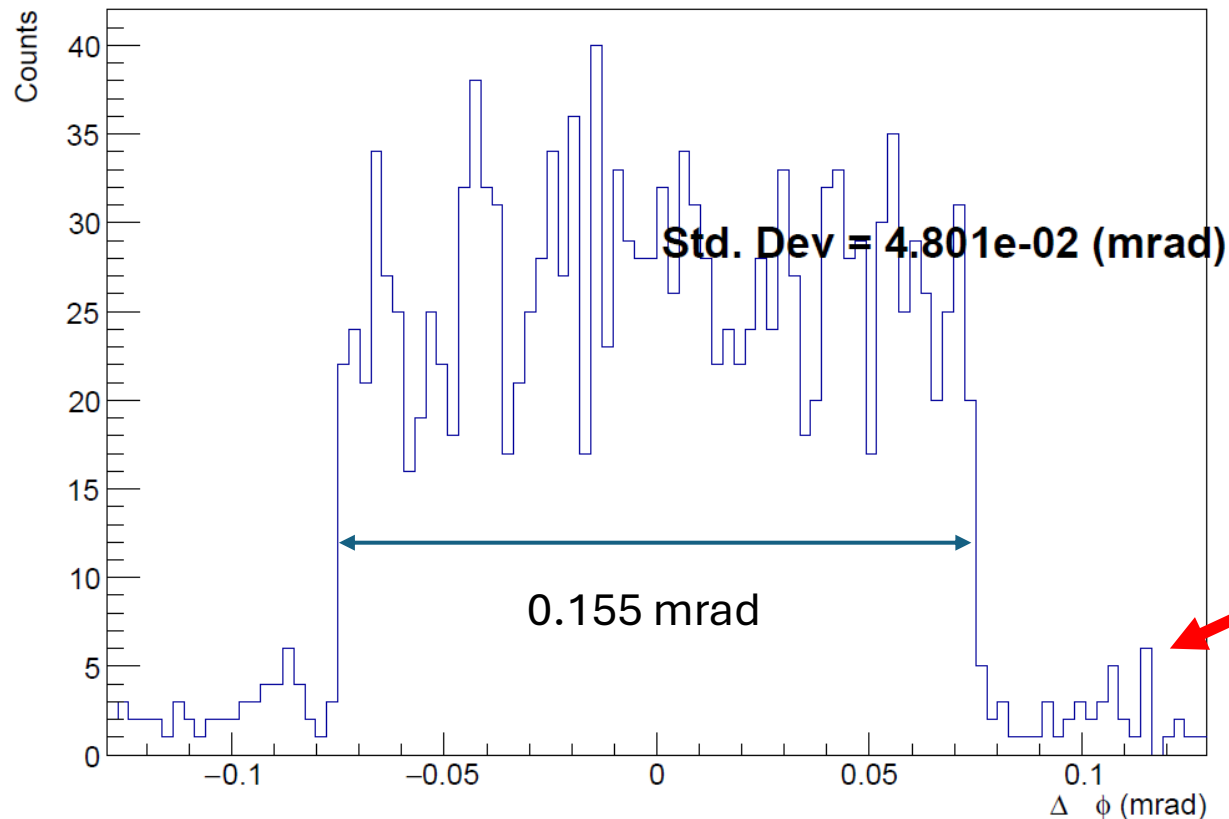
Cell pitch = 0.1 mm

- BTOF barrel radius = 64.4 cm
- Expected ϕ range = 0.1 mm/64.4 cm = 0.155 mrad
- **Expected res. = 0.155/sqrt(12) = 0.045 mrad**

Phi resolution

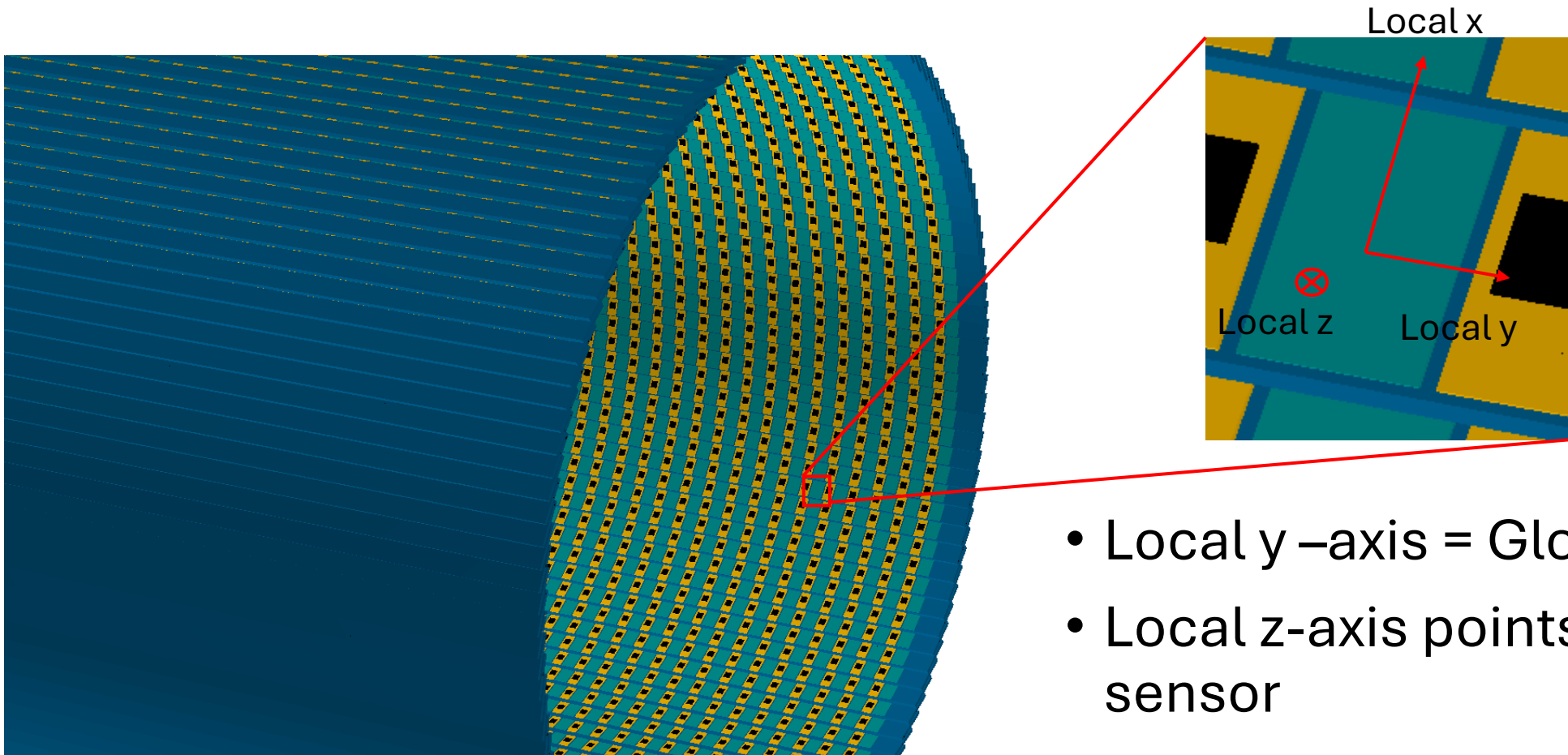
$$\Delta\phi = \phi_{true} - \phi_{reco}$$

- Expected ϕ range = 0.155 mrad
- Expected ϕ resolution = **0.045 mrad**



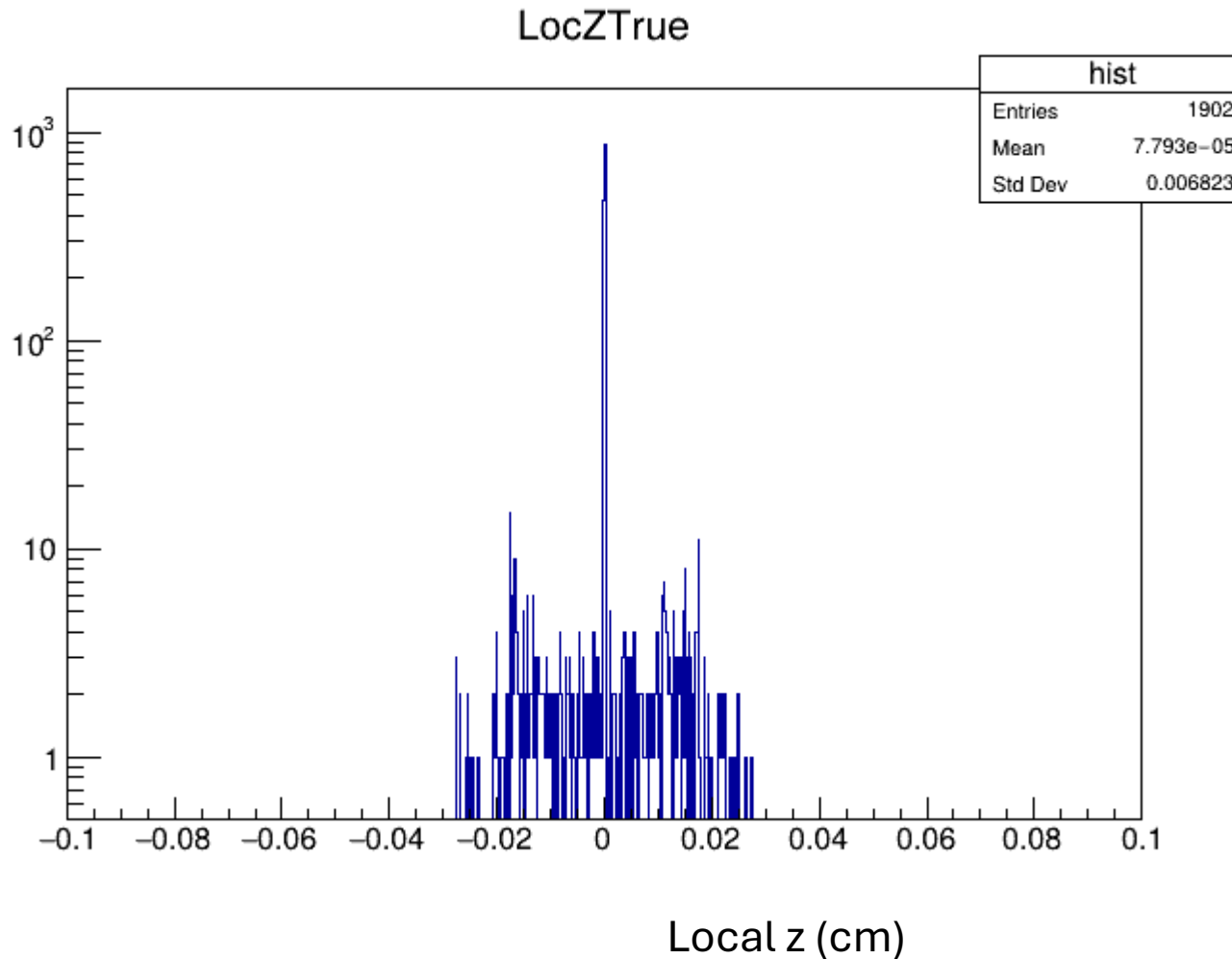
What are these tails?

Sensor local coordinates and global coordinates



- Local y -axis = Global z-axis.
- Local z-axis points into the sensor
- Expectation: Local $z = 0$

Local z distribution

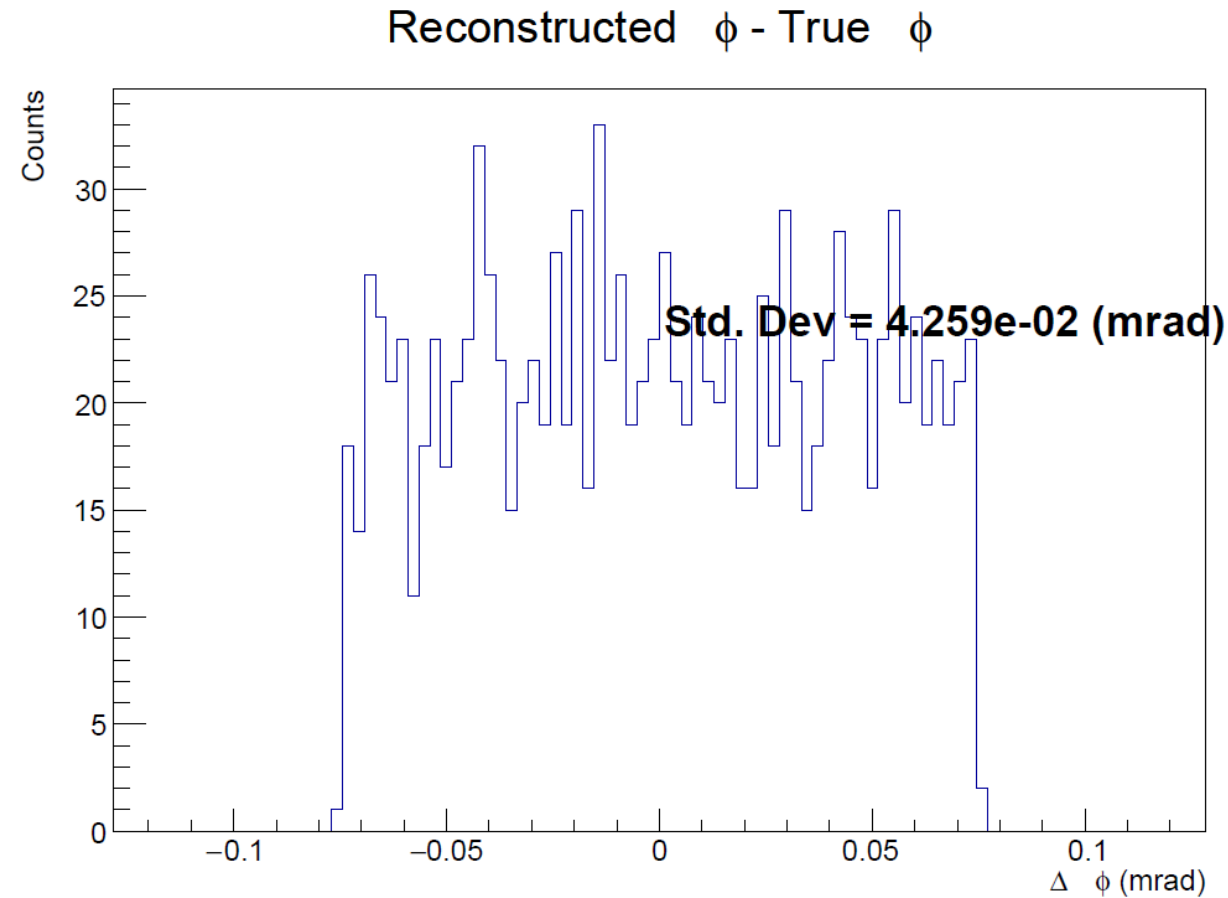


Not all hits lies on the surface of the sensor.

When hit point has large angle of incidence, the extrapolated points deviates from its hit point on surface by more than one cel width.

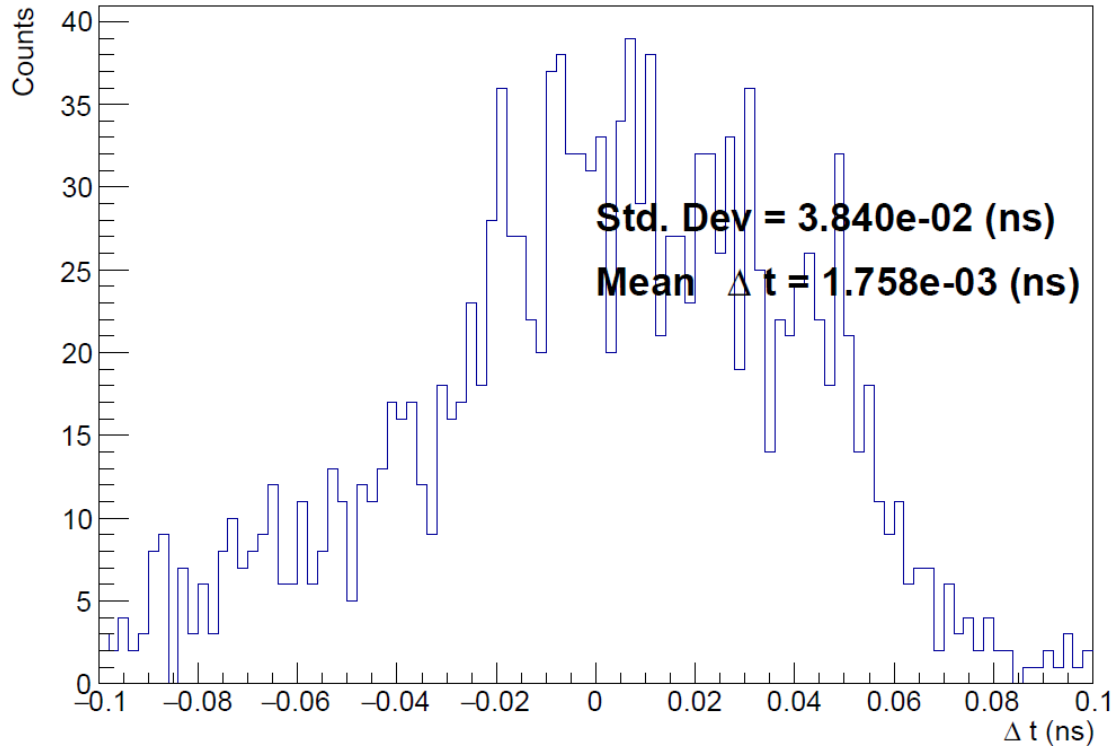
Phi resolution

AFTER $|local - z| < 1e-4$ cm



Time resolution

Reconstructed time - True time



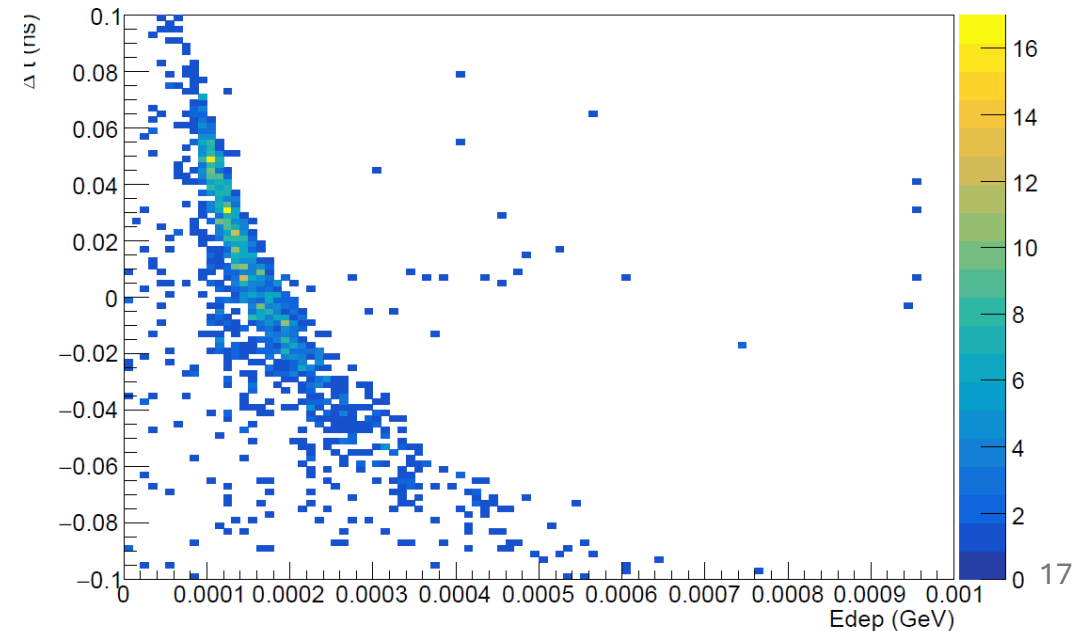
Reco time = slope*TDC + intercept

Uncertainty in time = time range in a TDC bin /sqrt(12).

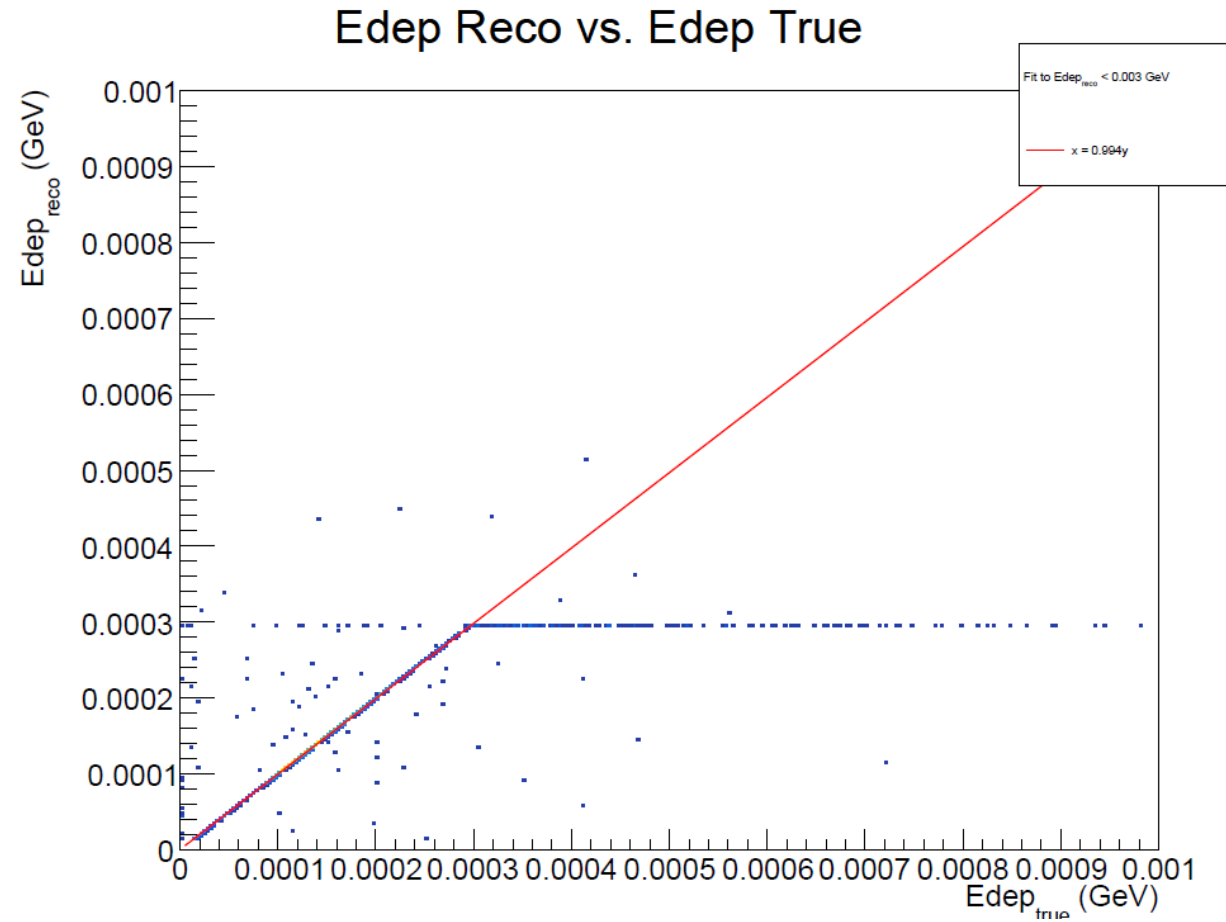
Expected resolution =
 $0.024414/\text{sqrt}(12) = 7.05\text{e-}3 \text{ ns}$

Simulated resolution = $3.8\text{e-}2 \text{ ns}$

Reconstructed time - True time vs. True Edep



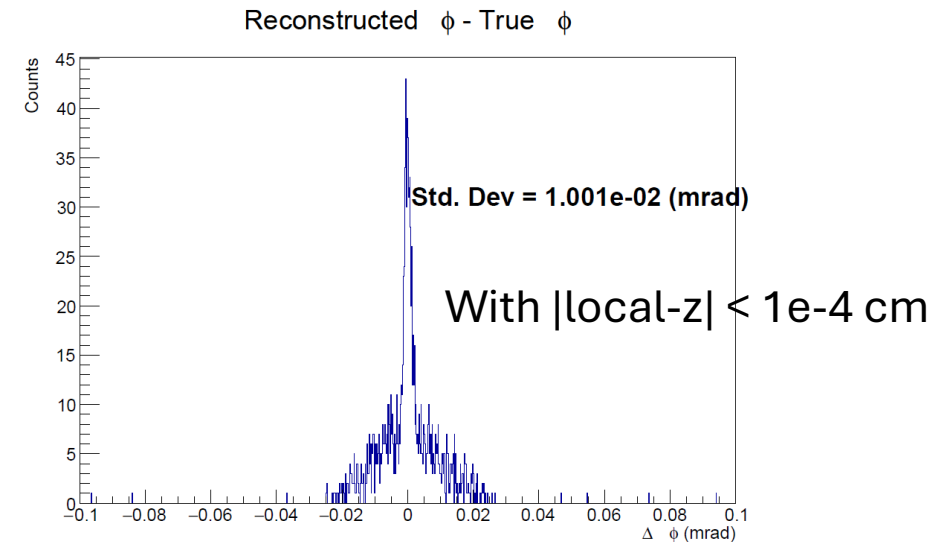
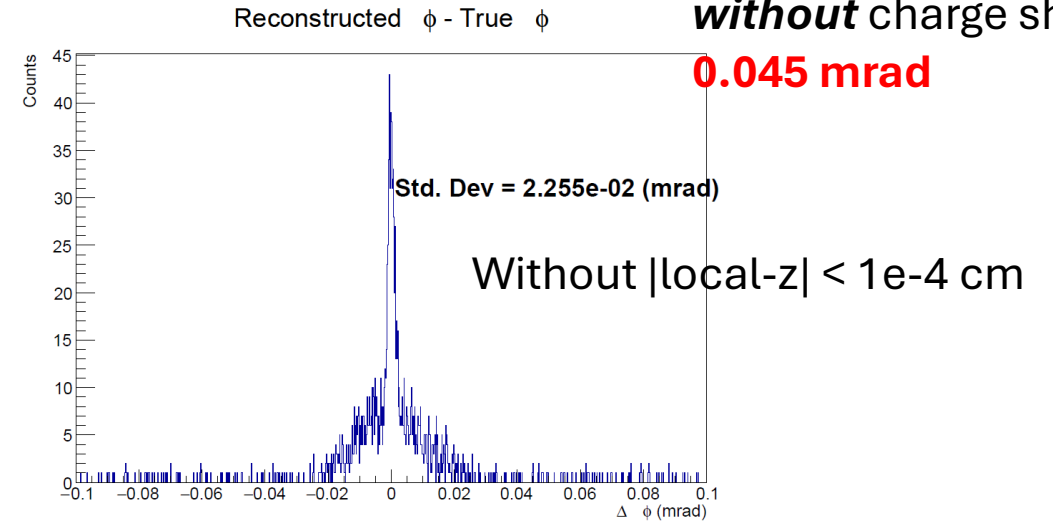
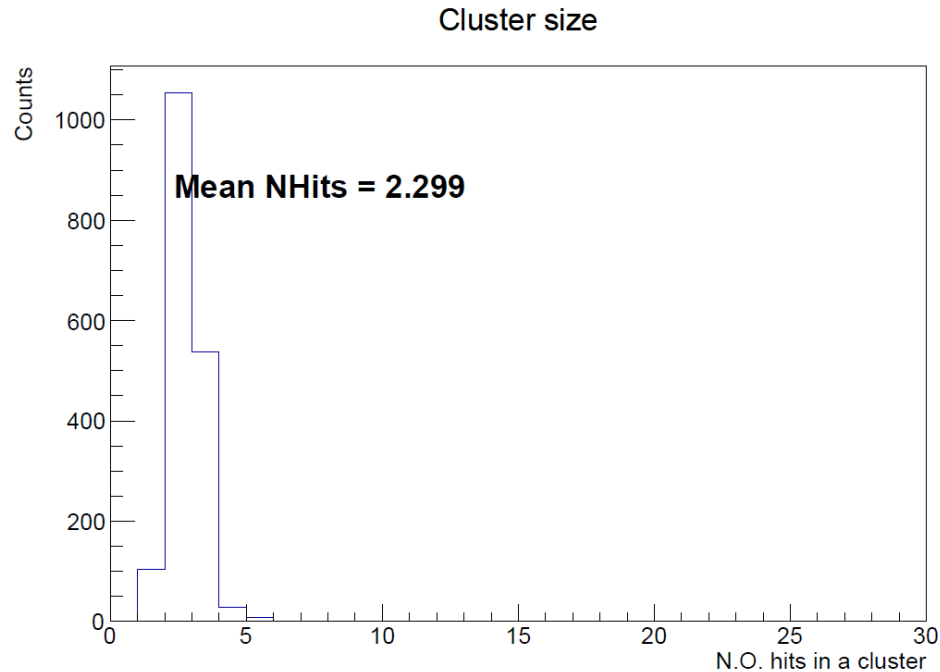
Edep



Performance with charge sharing
enabled

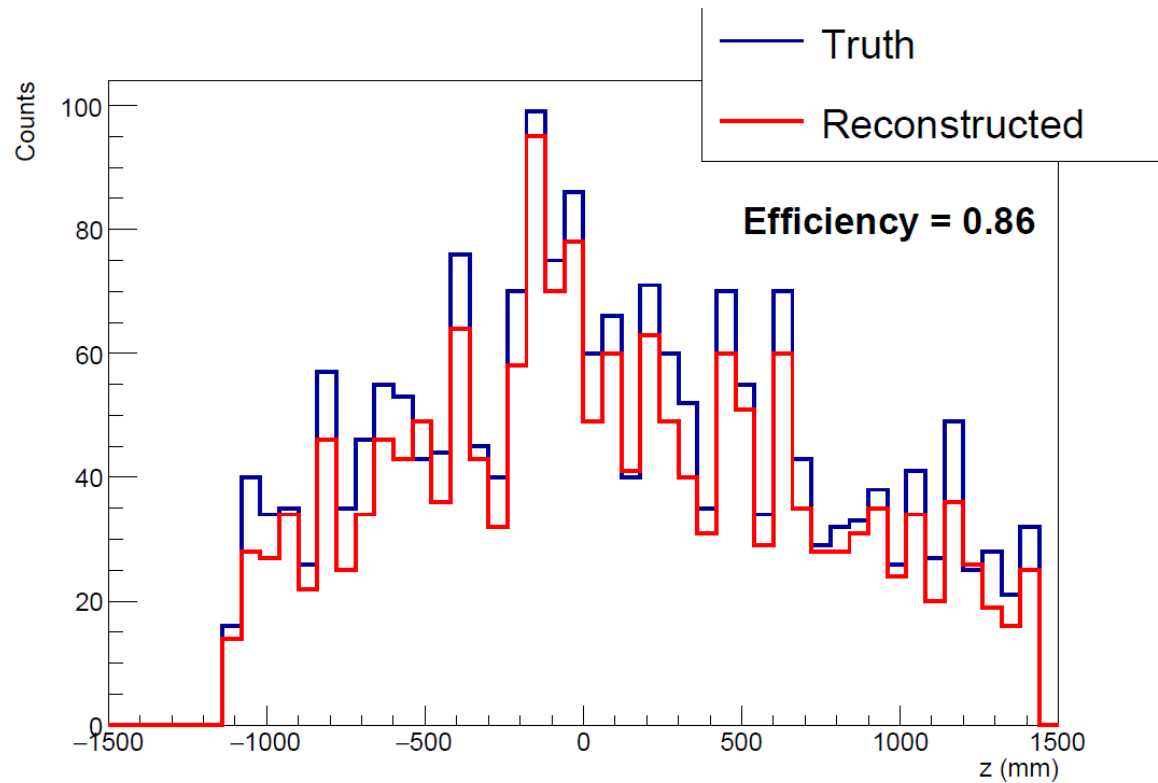
When $\sigma_x = 0.01$ cm = cell pitch

Reminder:
Expected ϕ resolution
without charge sharing =
0.045 mrad

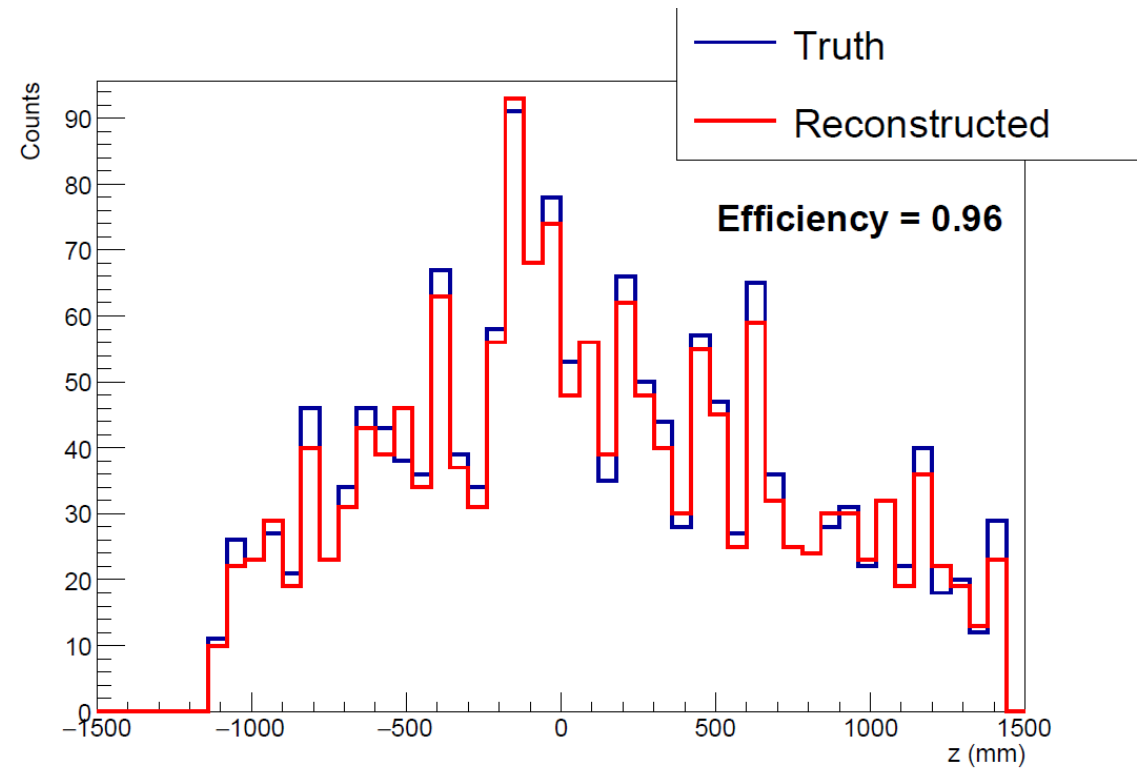


Efficiency at sigma X = 0.01 cm

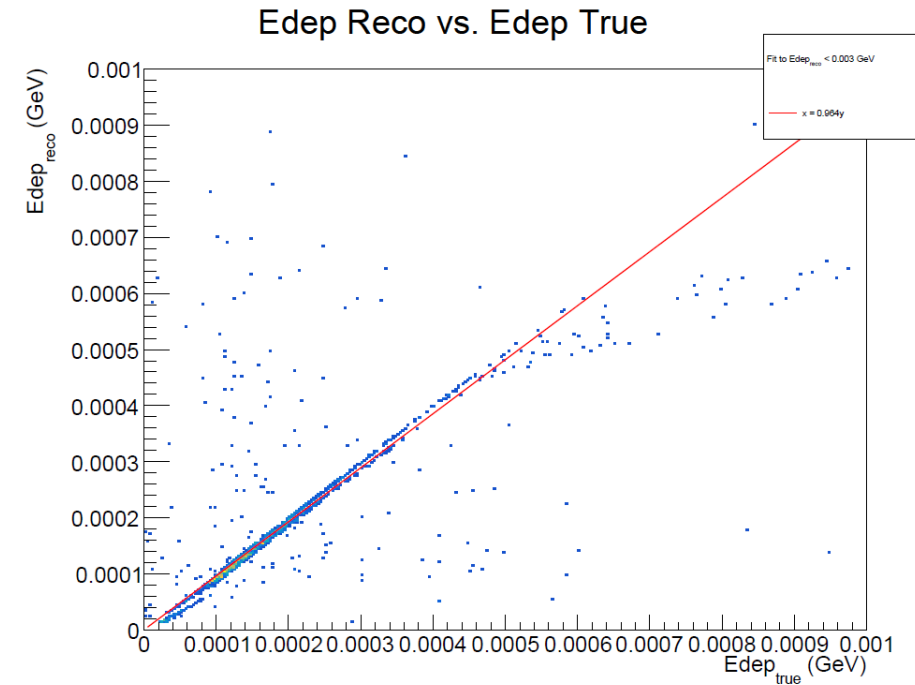
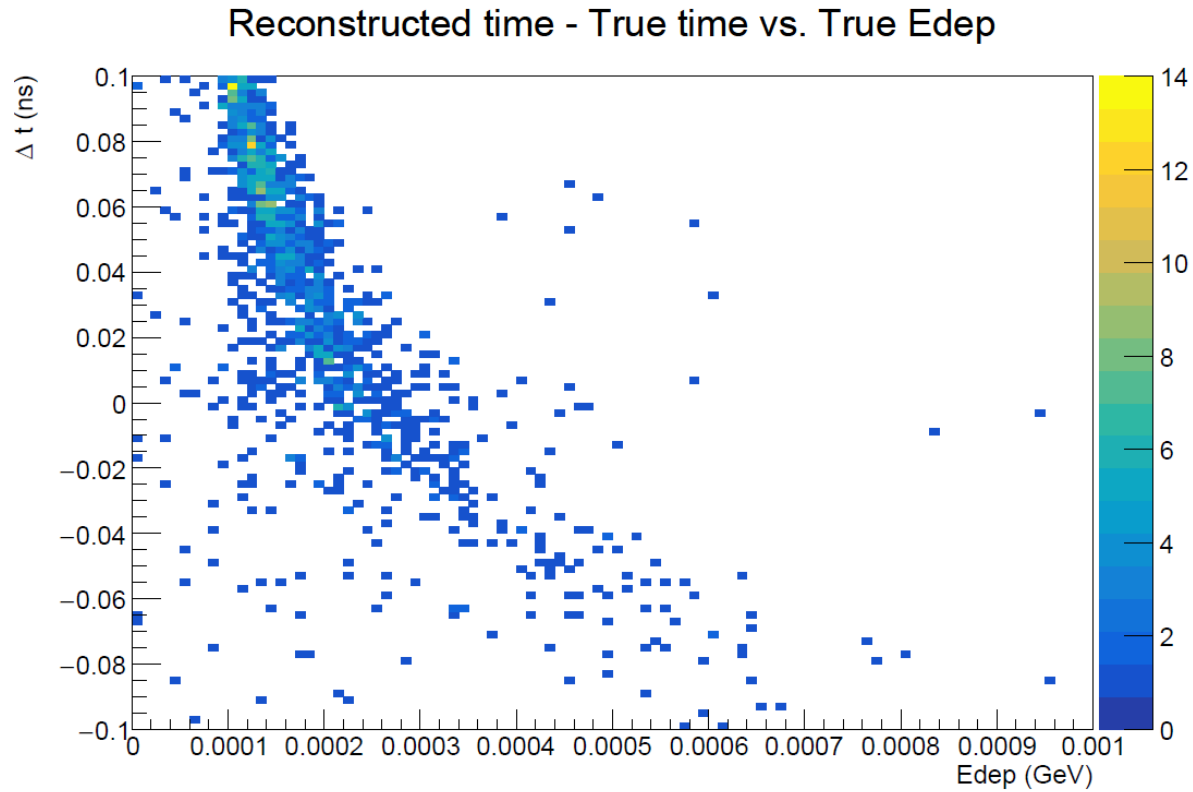
No Edep threshold



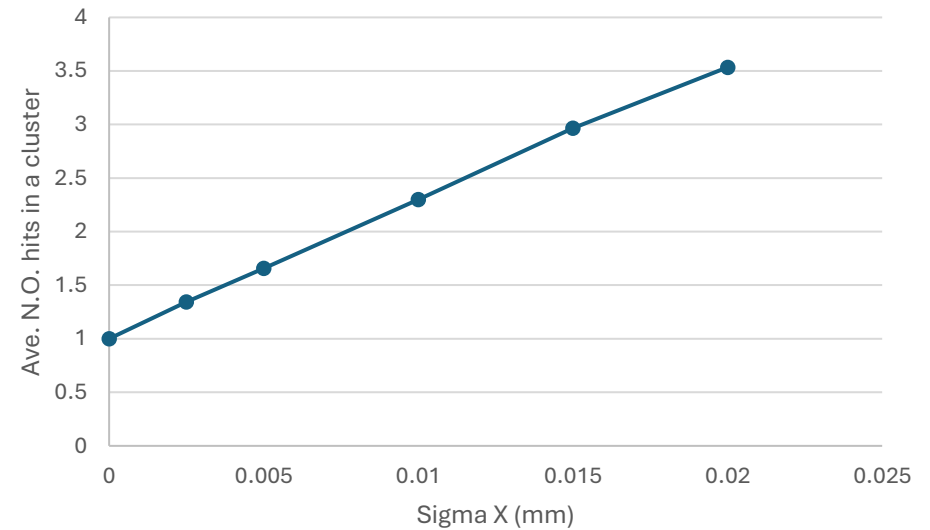
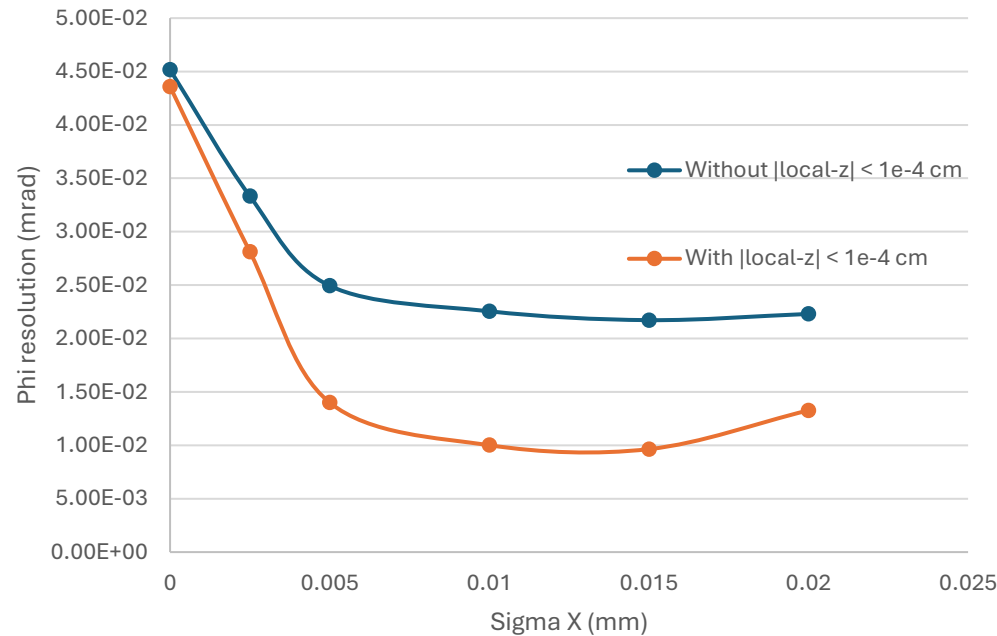
Edep threshold > 5e-5 GeV



Time and Edep with sigma X = 0.01 cm



Min Phi resolution = 9.6×10^{-3} mrad at $\sigma_X = 0.015$ cm



Reduce charge sharing spread

- Default $\sigma_x = 0.1$ cm
- <https://github.com/eic/ElCrecon/pull/1779> switch to 0.01cm.
- Speed improvement:

```
eicrecon-dis (clang++, 18x275, 0, craterlake_18x275, ASAN) #1779
succeeded 5 hours ago in 14m 34s

Run ElCrecon
1310 15:03:28.248 [info] Final report: 100 events processed at 0.9 Hz
1311 15:03:28.908 [info] Finalized JEventProcessor JEventProcessorPODIO
1312 Links:
1313 100 calls, 4.01 s ( 4.6%) edm4hep::RawTimeSeries:TOFBarrelPulses ->
edm4eic::SimPulse:TOFBarrelCombinedPulses
1314 100 calls, 4.44 s ( 5.0%) JEventProcessorPODIO ->
edm4eic::TrackSegment:CalorimeterTrackProjections
1315 100 calls, 5.76 s ( 6.5%) edm4eic::Cluster:HcalFarForwardZDCClustersWithoutShapes ->
edm4eic::ProtoCluster:HcalFarForwardZDCImagingProtoClusters
1316 100 calls, 7.99 s ( 9.1%) edm4eic::RawTrackerHit:TOFBarrelADCTDC ->
edm4hep::RawTimeSeries:TOFBarrelPulses
1317 100 calls, 8.00 s ( 9.1%) JEventProcessorPODIO -> edm4eic::RawTrackerHit:TOFBarrelADCTDC
1318 100 calls, 8.39 s ( 9.5%) JEventProcessorPODIO ->
edm4eic::ReconstructedParticle:GeneratedCentauroJets
1319 100 calls, 8.42 s ( 9.6%) JEventProcessorPODIO ->
edm4eic::ReconstructedParticle:ReconstructedCentauroJets
1320 100 calls, 9.57 s ( 10.9%)
edm4eic::MCRcoClusterParticleAssociation:HcalFarForwardZDCClusterAssociations ->
edm4eic::Cluster:HcalFarForwardZDCClustersWithoutShapes
1321 100 calls, 9.63 s ( 10.9%) JEventProcessorPODIO ->
edm4eic::MCRcoClusterParticleAssociation:HcalFarForwardZDCClusterAssociations
1322 100 calls, 21.42 s ( 24.4%) JEventProcessorPODIO ->
edm4eic::CherenkovParticleID:DRICHaerogelIrtCherenkovParticleID
```

```
eicrecon-dis (clang++, 18x275, 0, craterlake_18x275, ASAN)
succeeded 2 weeks ago in 13m 47s

Search logs main

Run ElCrecon
947 18:49:08.005 [info] Finalized JEventProcessor JEventProcessorPODIO
948 Links:
949 100 calls, 5.55 s ( 5.0%) edm4eic::Cluster:HcalFarForwardZDCClustersWithoutShapes ->
edm4eic::ProtoCluster:HcalFarForwardZDCImagingProtoClusters
950 100 calls, 6.61 s ( 5.9%) edm4eic::SimPulse:TOFBarrelCombinedPulses ->
edm4eic::SimPulse:TOFBarrelSmoothPulses
951 100 calls, 6.64 s ( 6.0%) edm4hep::RawTimeSeries:TOFBarrelPulses ->
edm4eic::SimPulse:TOFBarrelCombinedPulses
952 100 calls, 8.35 s ( 7.5%) JEventProcessorPODIO ->
edm4eic::ReconstructedParticle:ReconstructedCentauroJets
953 100 calls, 8.39 s ( 7.5%) JEventProcessorPODIO ->
edm4eic::ReconstructedParticle:GeneratedCentauroJets
954 100 calls, 8.82 s ( 7.9%)
edm4eic::MCRcoClusterParticleAssociation:HcalFarForwardZDCClusterAssociations ->
edm4eic::Cluster:HcalFarForwardZDCClustersWithoutShapes
955 100 calls, 8.88 s ( 8.0%) JEventProcessorPODIO ->
edm4eic::MCRcoClusterParticleAssociation:HcalFarForwardZDCClusterAssociations
956 100 calls, 23.59 s ( 21.2%) JEventProcessorPODIO ->
edm4eic::CherenkovParticleID:DRICHaerogelIrtCherenkovParticleID
957 100 calls, 31.68 s ( 28.4%) edm4eic::RawTrackerHit:TOFBarrelADCTDC ->
edm4hep::RawTimeSeries:TOFBarrelPulses
958 100 calls, 31.71 s ( 28.4%) JEventProcessorPODIO -> edm4eic::RawTrackerHit:TOFBarrelADCTDC
```


Conclusion

- ✓ Good efficiency.
- ✓ Good position resolution.
- ✓ Good Edep resolution.
- ✓ Time walk as expected.
- Issue to work on:
 - Time walk/edge correction.
 - Use CFD instead of ELCROC for BTOF.

Outstand pull request

- Add clustering algorithm (output NOT linked to tracking):
 - <https://github.com/eic/ElCrecon/pull/1779>
- Reduce charge sharing magnitude (Not needed if #1779 is approved):
 - <https://github.com/eic/ElCrecon/pull/1973>
- Fix Charge Sharing
 - <https://github.com/eic/ElCrecon/pull/1945>
- Use CFD for BTOF
 - <https://github.com/eic/ElCrecon/pull/1974>
- Pipe output of digitization to tracking in a future pull request.