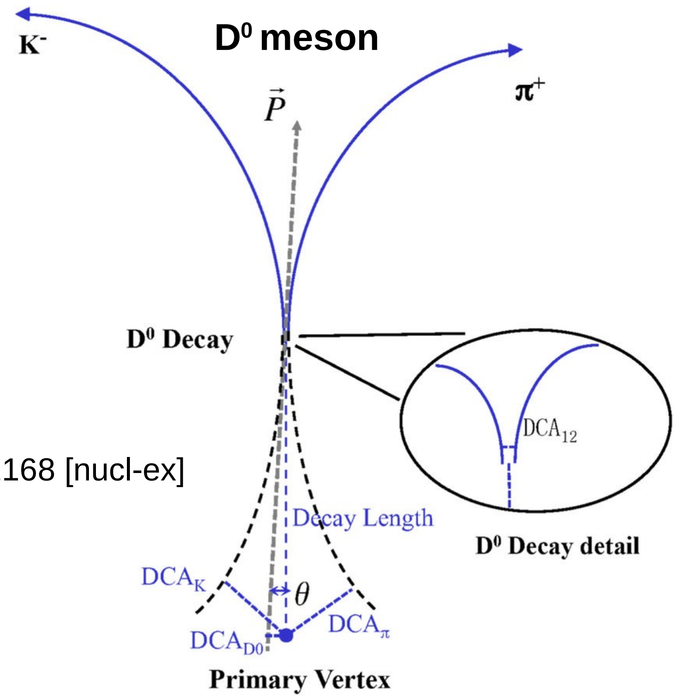
Updates on D^0 Reconstruction and Tracking Performance

Shyam Kumar*, Annalisa Mastroserio, Domenico Elia
INFN Bari, Italy

Secondary Vertex Reconstruction

Secondary vertex: allows access to more topological variables, e.g., decay length (dl), pointing angle (cosθ), DCA_{D0} or $DCA_{\Lambda c}$ etc.



arXiv:1911.12168 [nucl-ex]

Topological Variables

$$\vec{dl} = \vec{SV} - \vec{PV}$$

$$\cos\theta = \frac{\vec{dl} \cdot \vec{p}_{D0}}{|\vec{dl}||\vec{p}_{D0}|}$$

$$DCA_{D0} = |\vec{dl}| \sin\theta$$

Secondary Vertex Reconstruction:

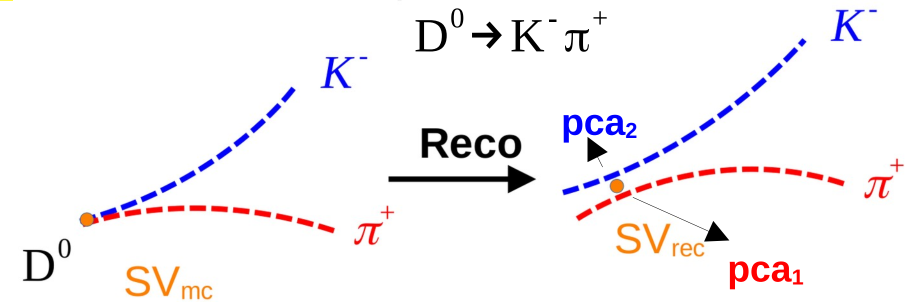
- **Helix Swimming (Ignores track errors)**
- **Chi2 minimization (considers track errors): Shyam**
- AdaptiveMultiVertexFinder (considers track errors): In development: Bishoy
- KFParticle (considers track errors): In development: Xin and others

} Based on Kalman filter

$$\vec{SV} = \frac{(\vec{pca}_1 + \vec{pca}_1)}{2} \qquad SV_x = \frac{(pca_{1x} + pca_{1x})}{2}$$

$$\sigma^2_{SV_x} = \frac{(\sigma^2_{pca_{1x}} + \sigma^2_{pca_{2x}} + 2\,\mathrm{cov}(pca_{1x}, pca_{2x}))}{4}$$

$D^0 \rightarrow K^- \pi^+$



Fit Range: Mean+/- 2*StdDev

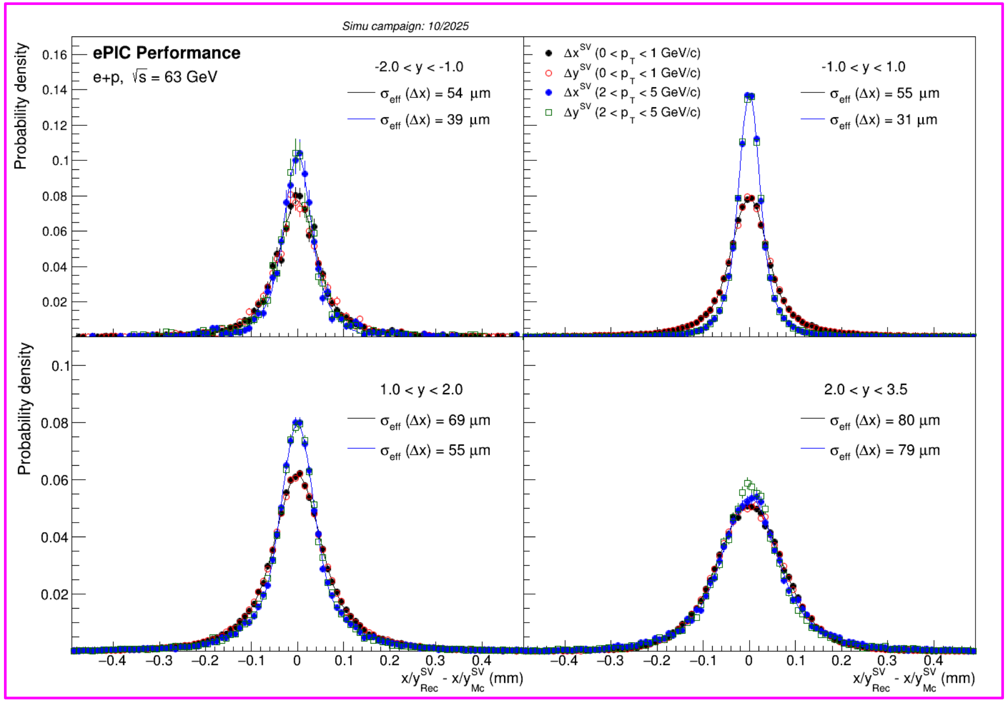
Chi-square minimization

Two Gaussian (A_{core}, σ_{core}, A_{tail}, σ_{tail})

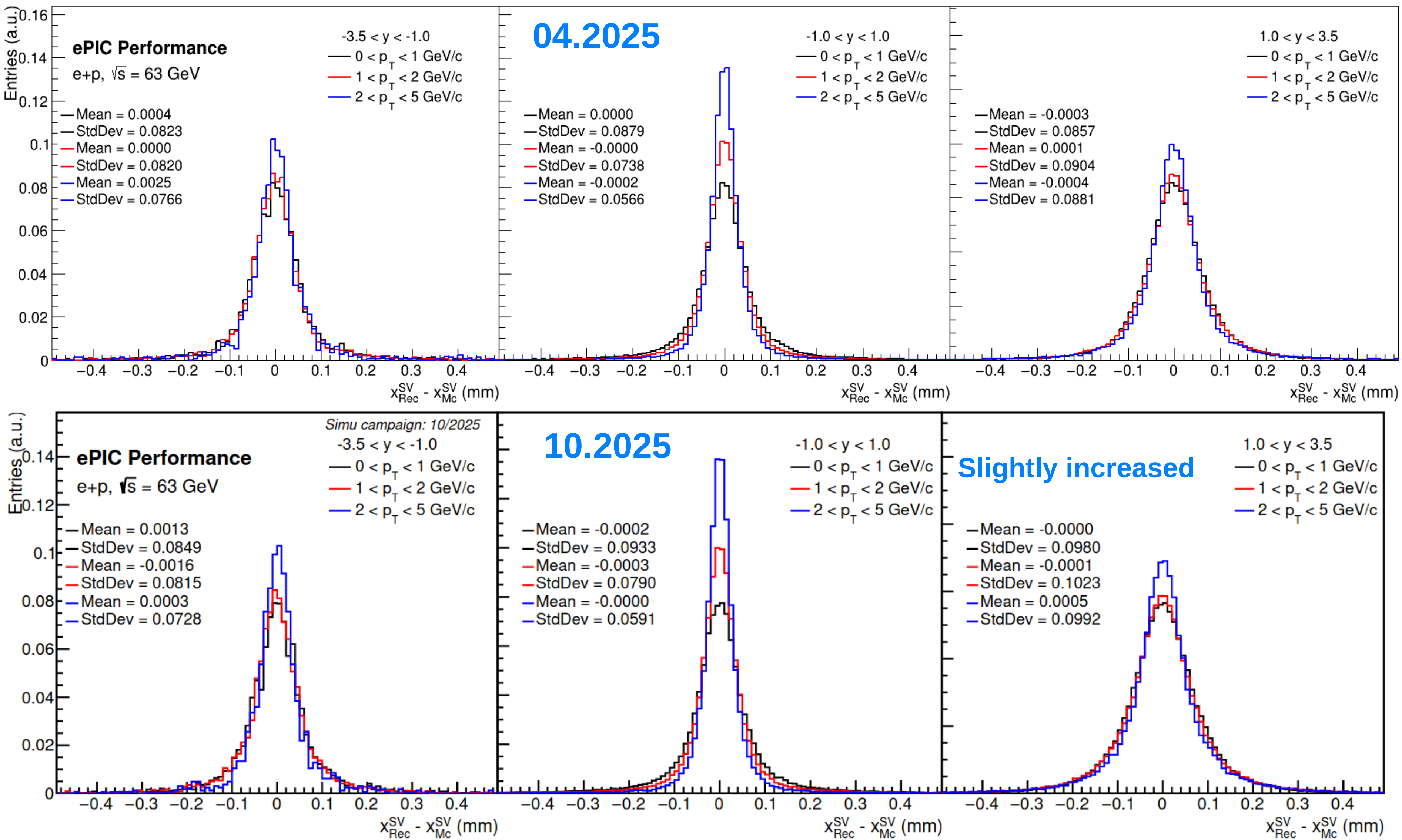
$$\sigma_{eff} = \sqrt{\frac{A_{core}}{(A_{core} + A_{tail})}\sigma^2_{core} + \frac{A_{tail}}{(A_{core} + A_{tail})}\sigma^2_{tail}}$$

σ_{eff} decreases as we go at high p_T

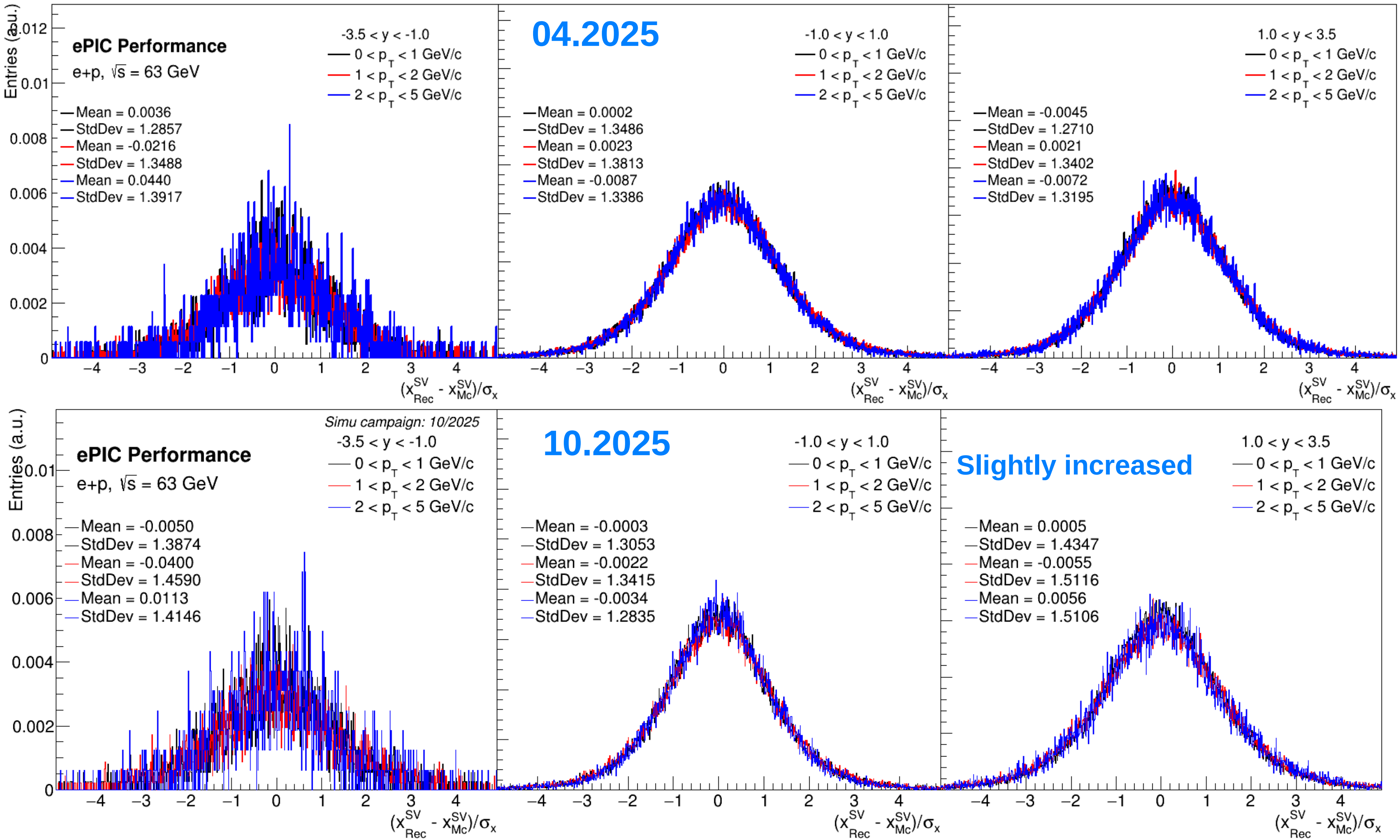
10.2025 preTDR



Secondary Vertex Resolution

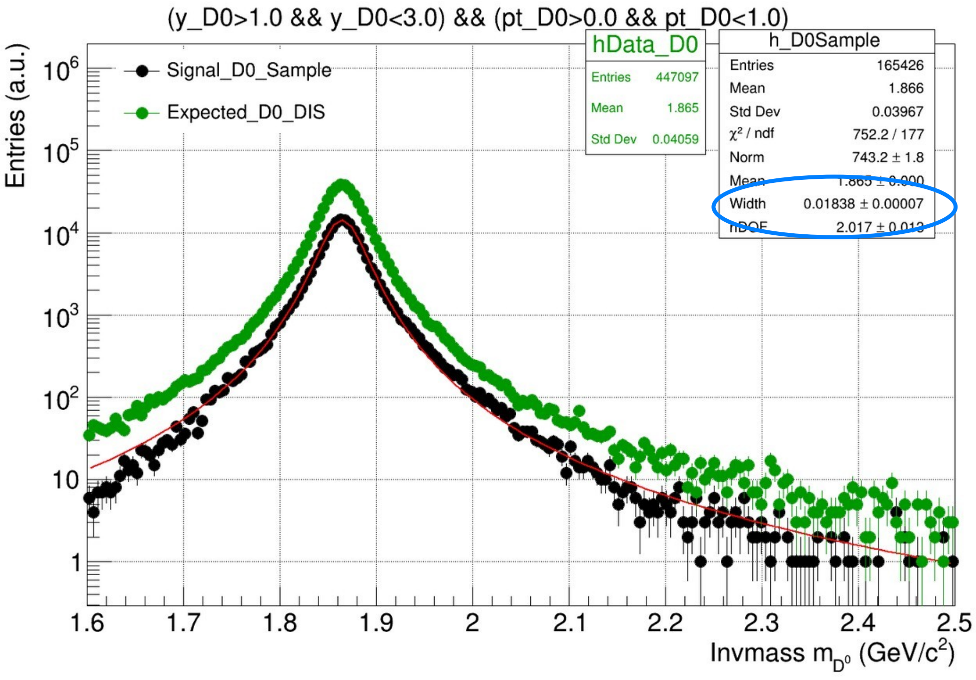


Secondary Vertex Resolution

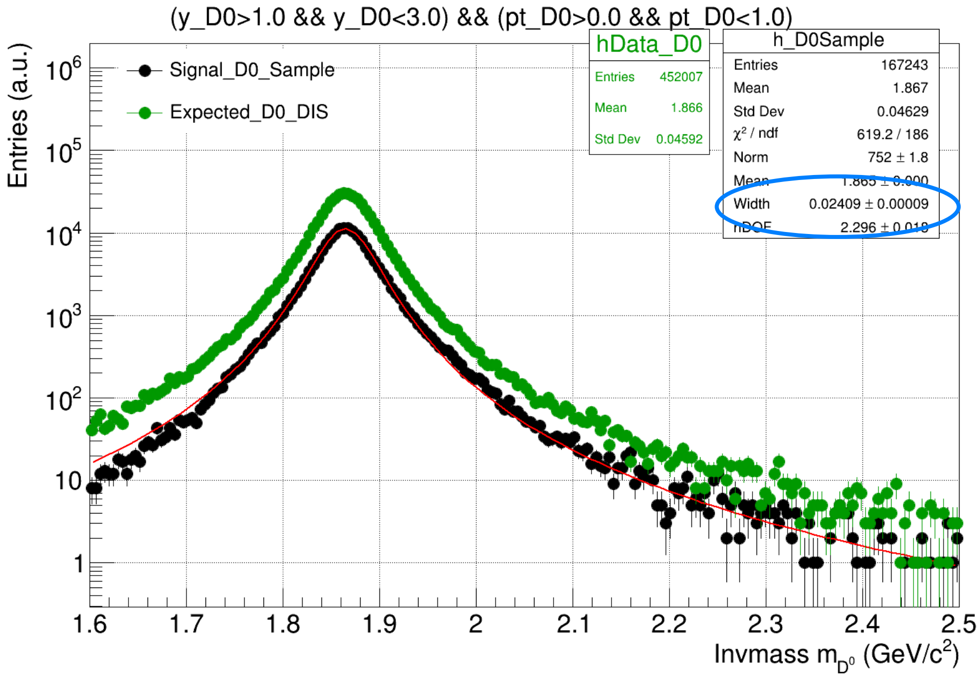


ep,10 x 100, Q^2>1 GeV^2

25.04.0

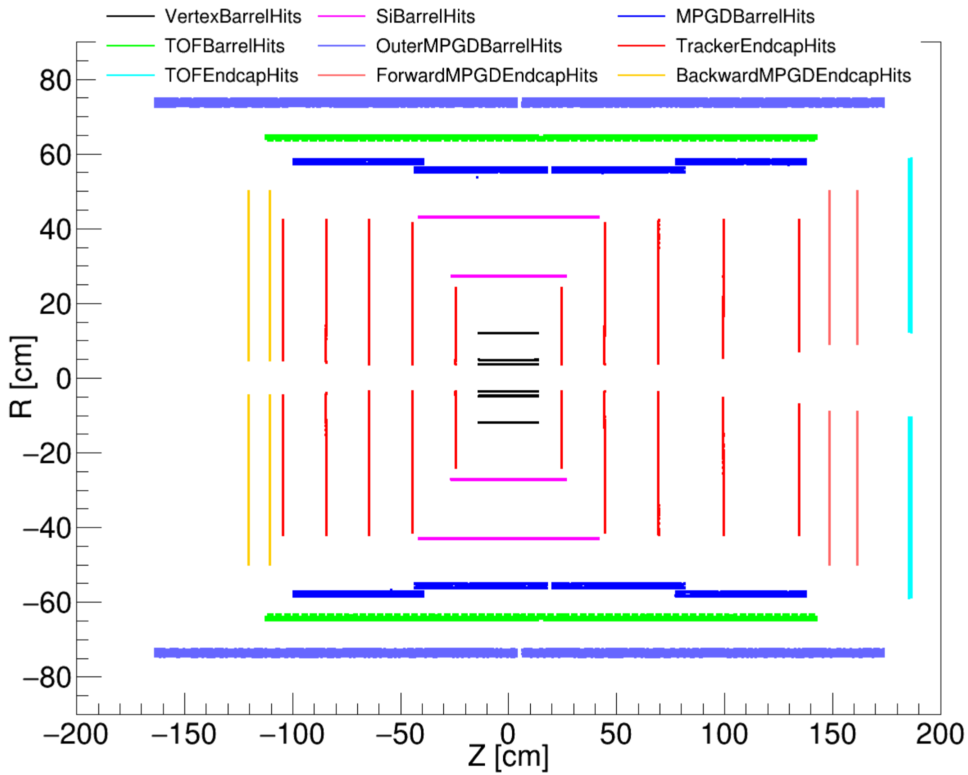


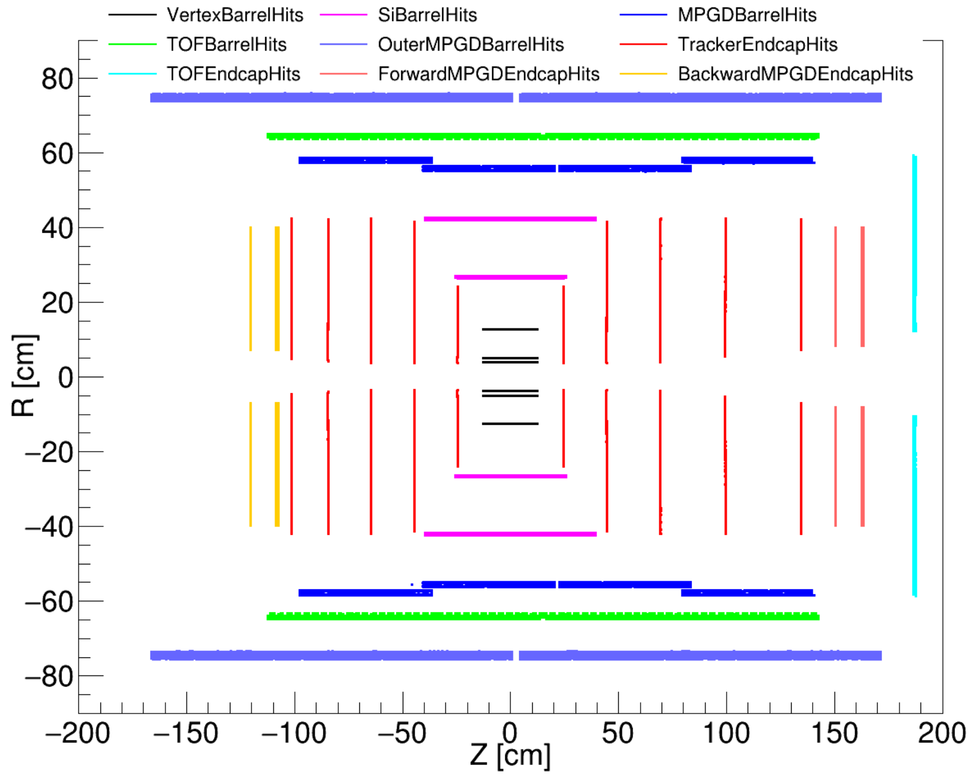
25.10.3



Black markers are from **D^0 Sample** (**Green sampled to 10 fb^{-1}**)

Single particle (pi-) simulation



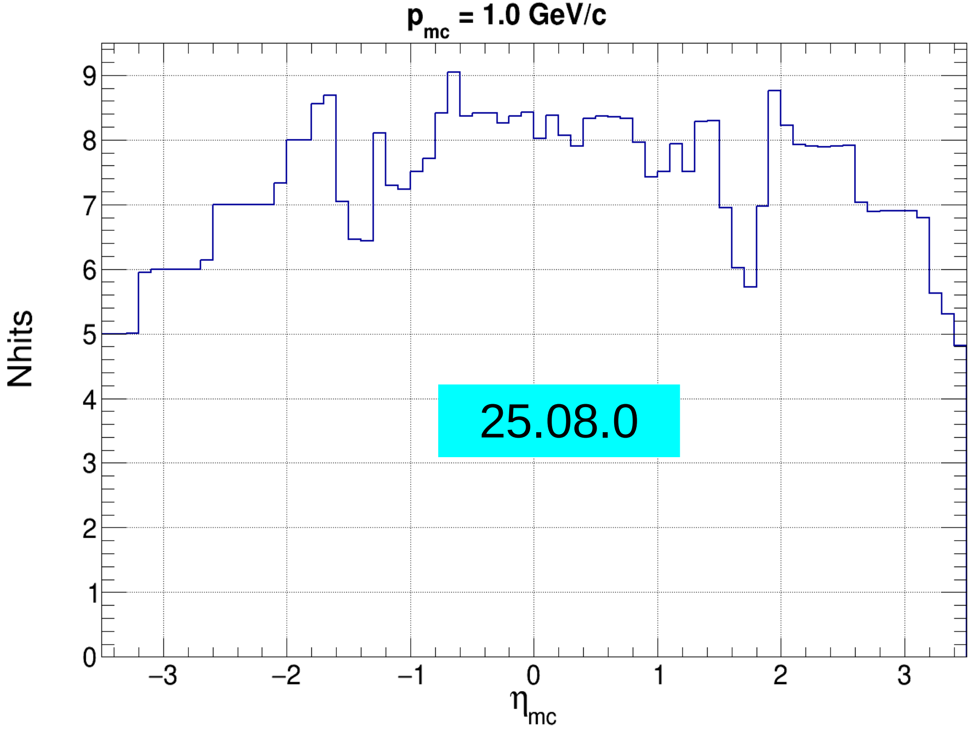


Forward/backward MPGDs have been modified, including changes in their thickness

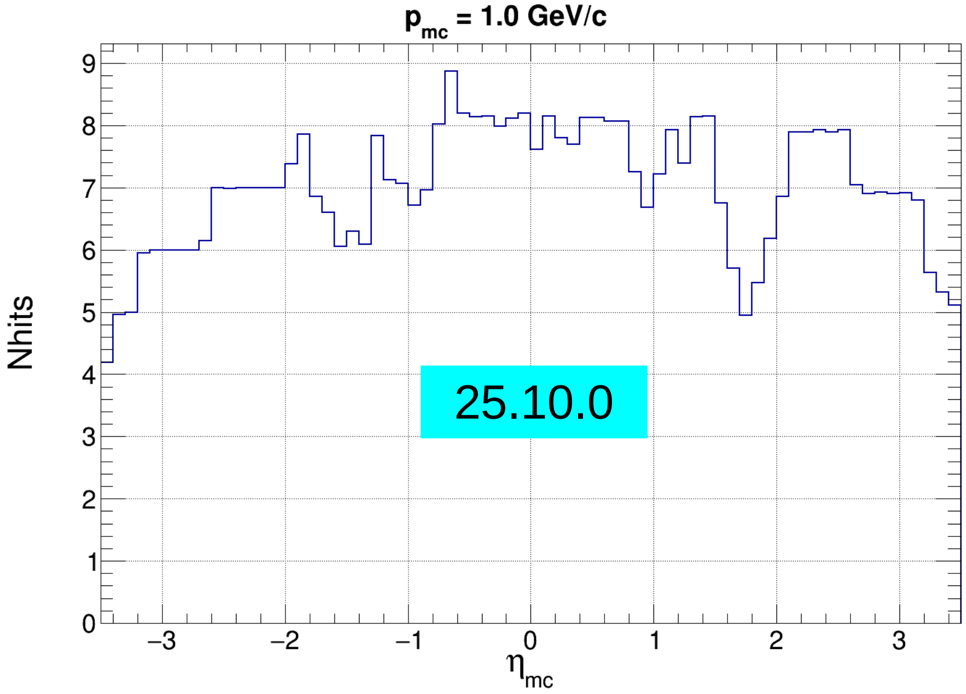
The thickness of SVT outer barrel (OB) layers has also increased

Single particle (pi-) simulation

Nhits at MC Level (no digitization)



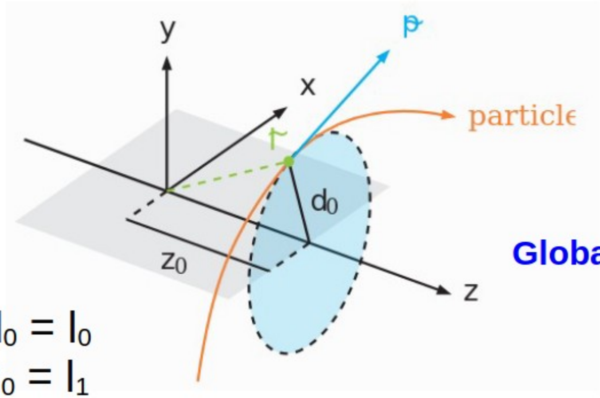
Nhits at MC Level (no digitization)



Track Parameters in ACTS

https://indico.bnl.gov/event/28544/contributions/109057/attachments/62799/108633/ePIC_Tracking_Meeting_30June2025_ShyamKumar.pdf

Track Parameters $(l_0, l_1, \phi, \theta, q/p, time)$ If tracking algorithm is working fine Pull must be consistent with unity



$d_0 = l_0$
$z_0 = l_1$

At Point of closest approach

$$(l_0, l_1, \phi, \theta, q/p)$$

Global (Lab frame) ↓

$$(x, y, z, p_x, p_y, p_z, q)$$

$$x = -l_0 \sin\phi, \quad y = l_0 \cos\phi, \quad z = l_1$$

$$p_x = p\cos\phi\sin\theta, \quad p_y = p\sin\phi\sin\theta, \quad p_z = p\cos\theta$$

$$charge = sign(q/p)$$

Plan to add it to the benchmarks

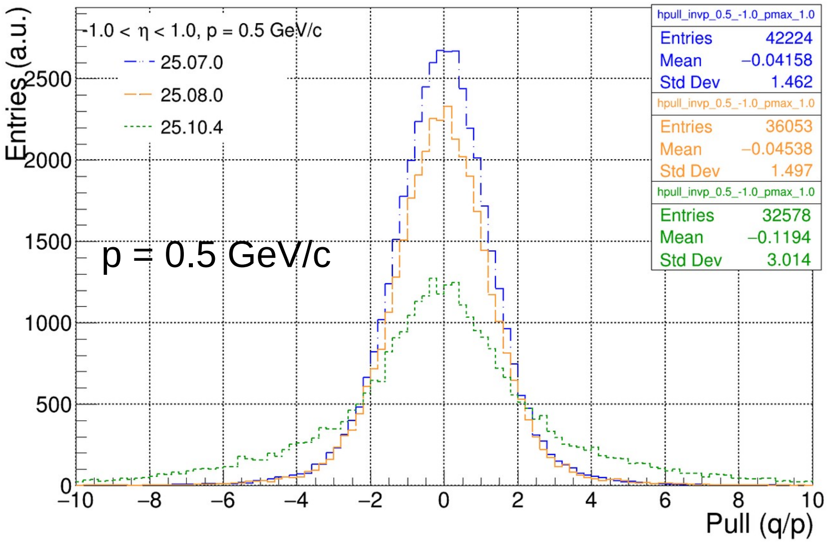
$$\text{Pull } l_0 = \frac{(l_{0\,rec} - l_{0\,gen})}{\sigma_{l0}} \qquad \text{Pull } \phi = \frac{(\phi_{rec} - \phi_{gen})}{\sigma_\phi} \qquad \text{Pull } q/p = \frac{(q/p_{rec} - q/p_{gen})}{\sigma_{q/p}}$$

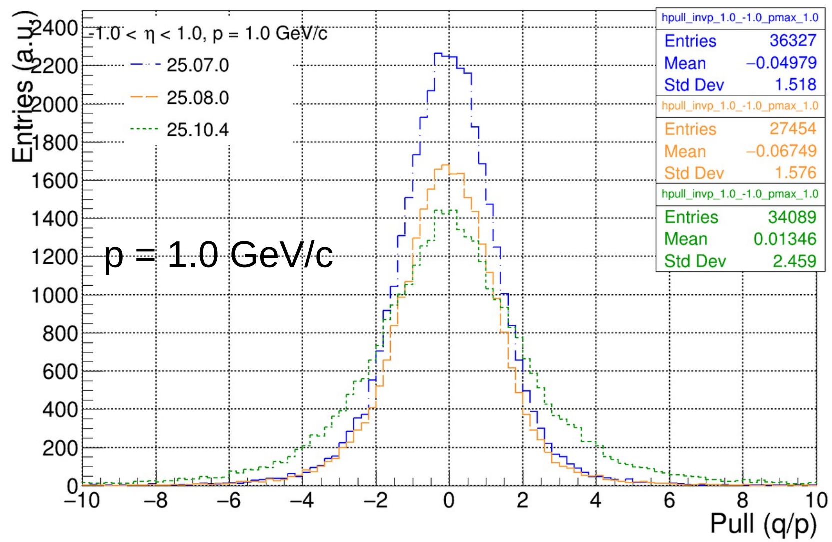
$$\text{Pull } l_1 = \frac{(l_{1\,rec} - l_{1\,gen})}{\sigma_{l1}} \qquad \text{Pull } \theta = \frac{(\theta_{rec} - \theta_{gen})}{\sigma_\theta} \qquad \text{Pull } p = \frac{(p_{rec} - p_{gen})}{\sigma_p}$$

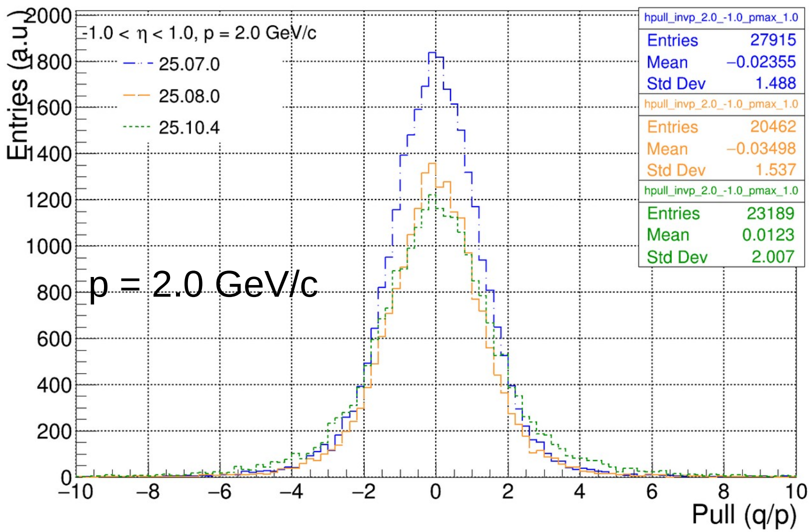
TTreeReaderArray<std::array<float, 21>> rcTrkCov(myReader, “CentralCKFTrackParameters.covariance.covariance[21]"); // **Reading covariance this way works but gives an error message (otherwise change it to vector in data type)**

Pull distributions (q/p)

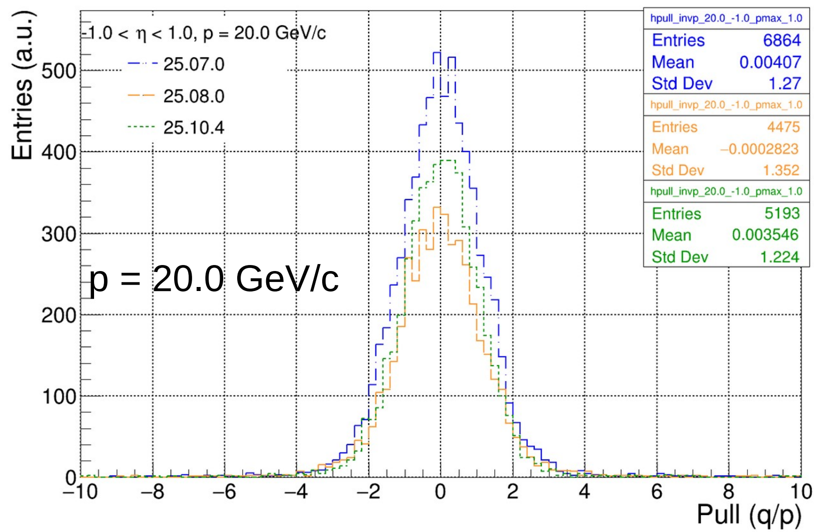
-1< η <1





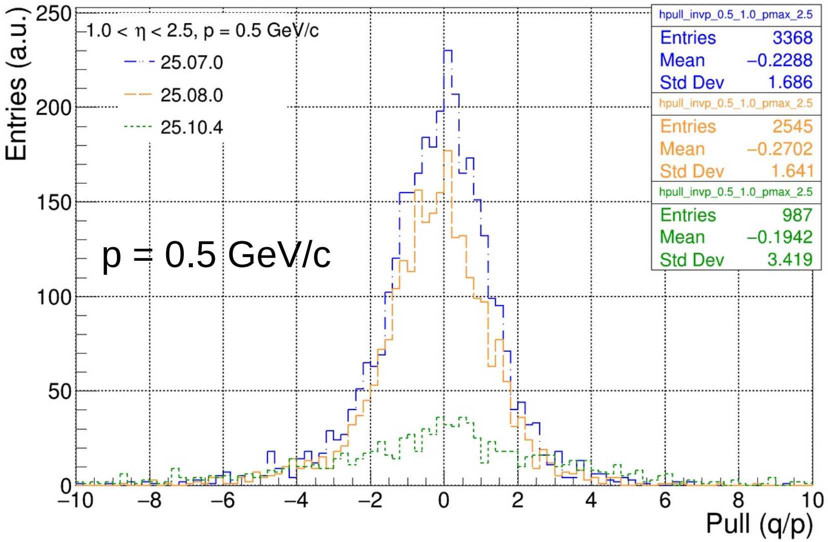


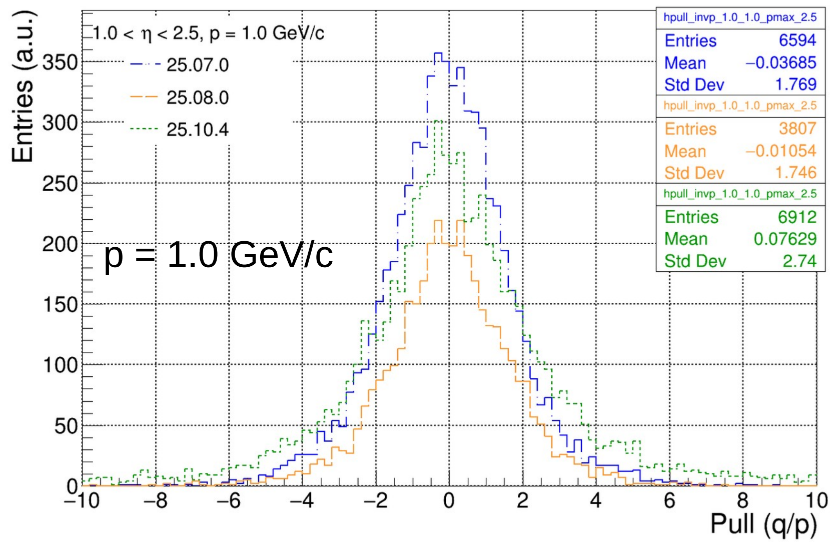
Tracking benchmarks

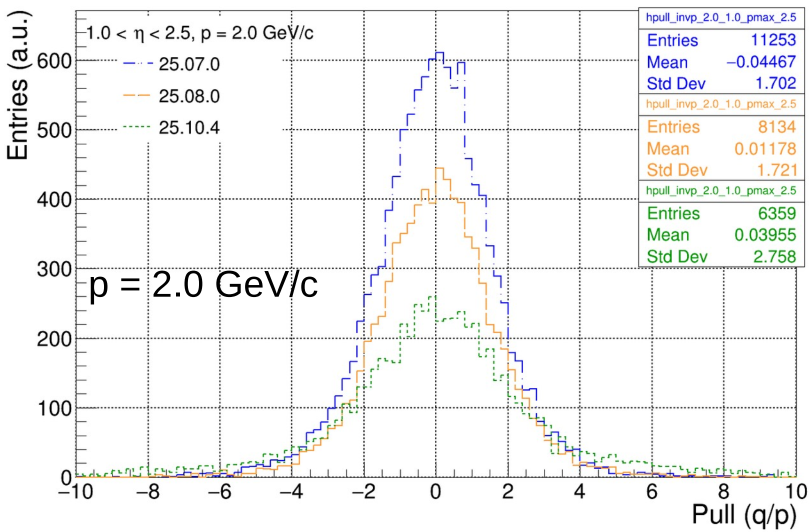


Pull distributions (q/p)

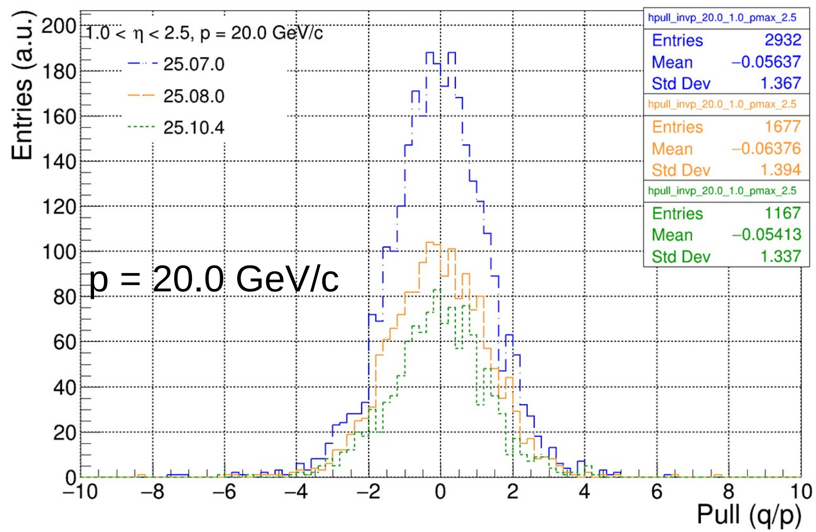
1.0< η <2.5



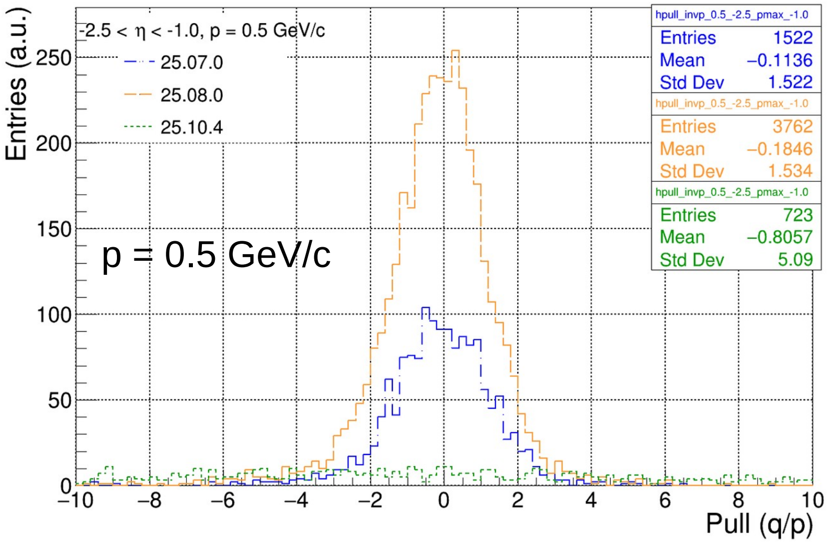




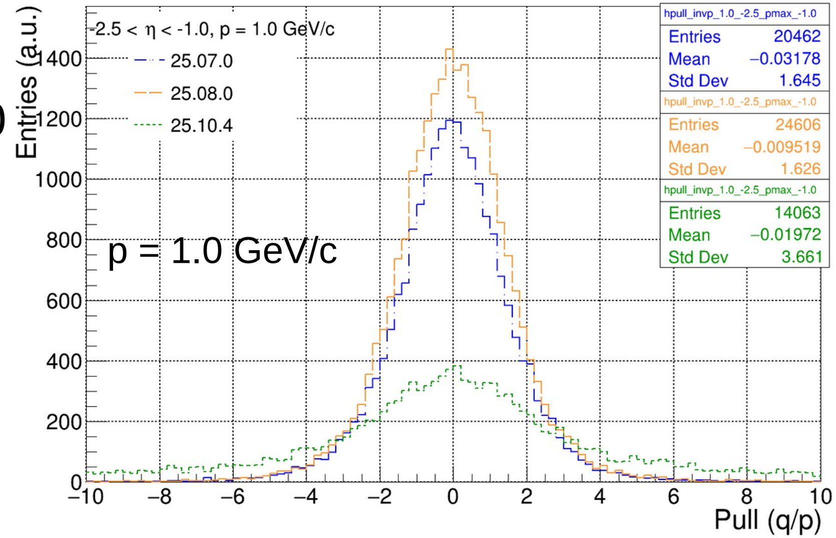
Tracking benchmarks

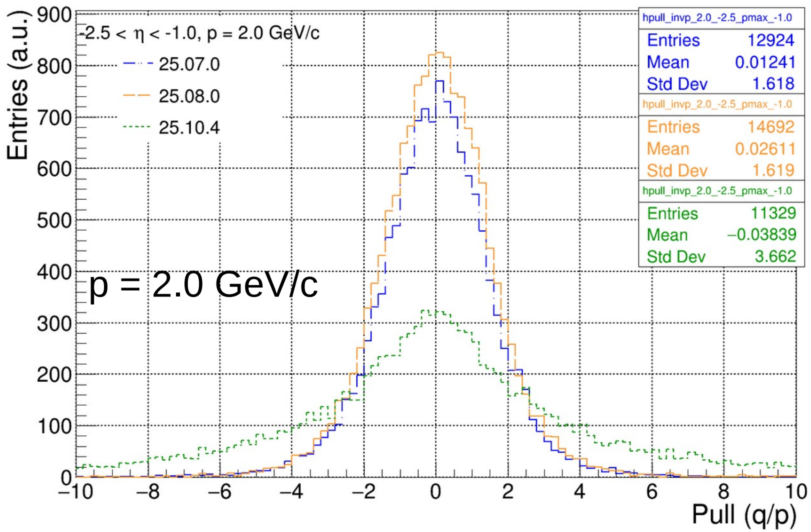


Pull distributions (q/p)

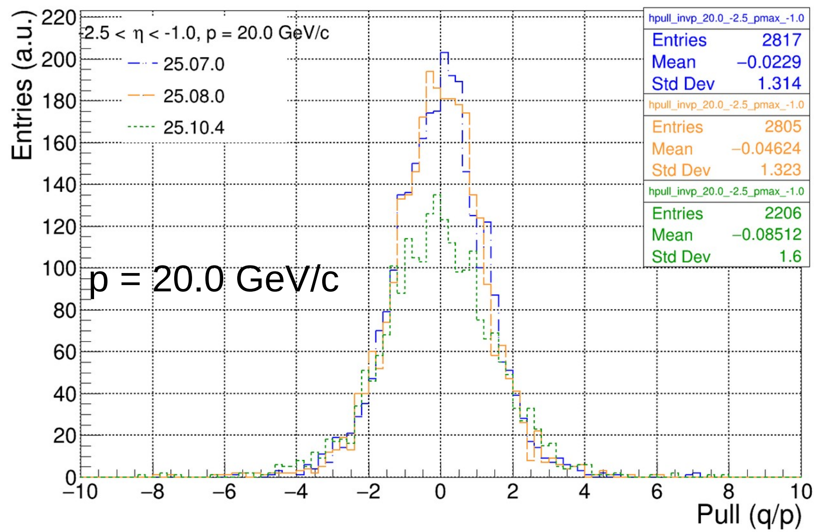


-2.5< η <-1.0





Tracking benchmarks



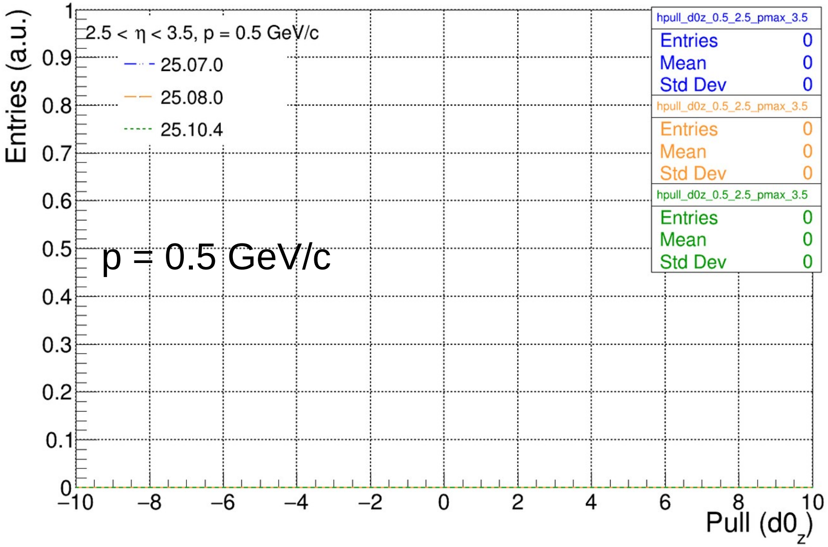
Summary

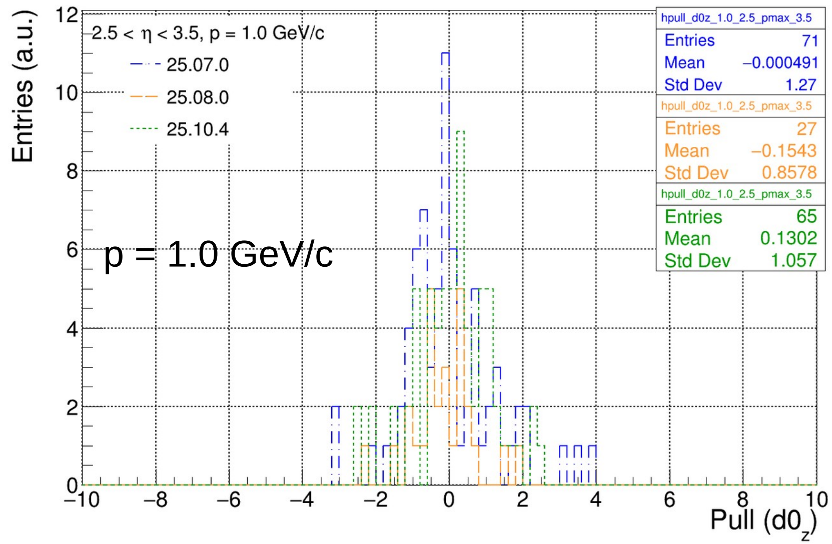
- There were many changes in the detector geometry during the October campaign.
- A small degradation was observed in the secondary-vertex resolution, which is expected since it depends on the DCA_{xy} resolution.
- The pulls for momentum are significantly degraded, indicating a mismatch between the material map and the updated geometry.
- Future Steps:
  - I have already added the momentum pulls to the benchmark tests, which must be checked at every commit.
  - The momentum pulls must remain consistent and close to ~1.
  - Before starting each campaign, produce a single-particle simulation and validate the pulls and related performance metrics.
  - It would be useful to present a comparison of these performances across consecutive campaigns.

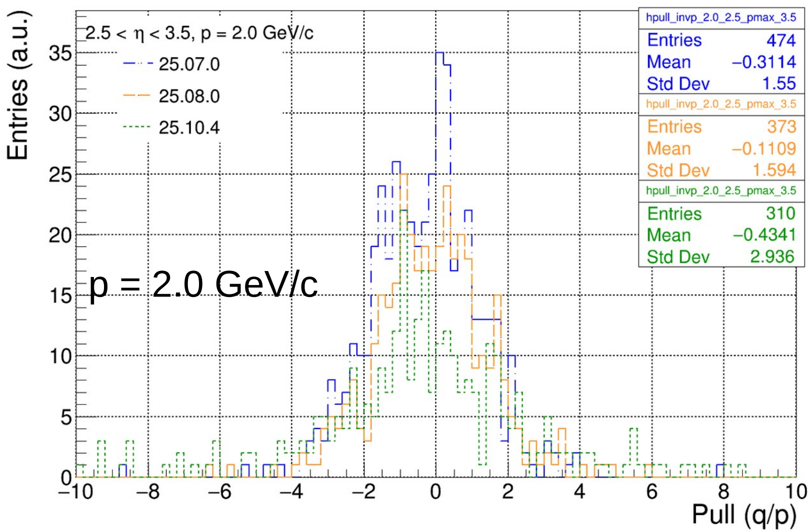
Thank you for your attention!

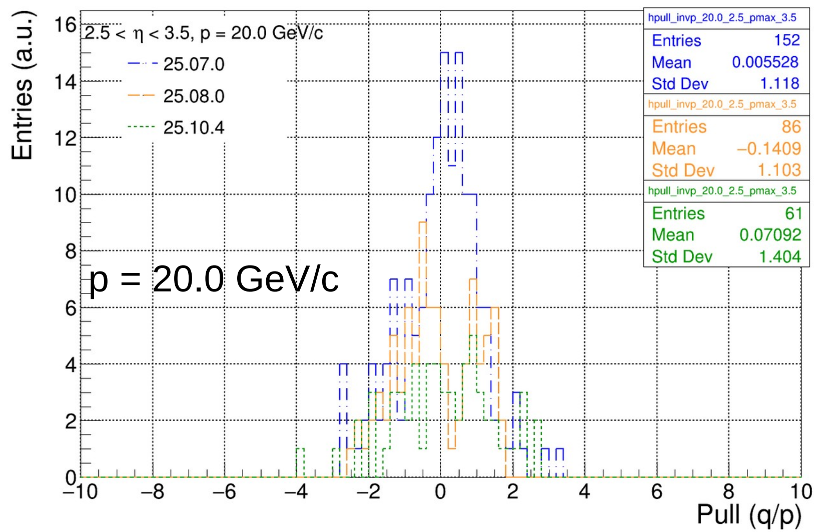
Pull distributions (q/p)

2.5 < η <3.5



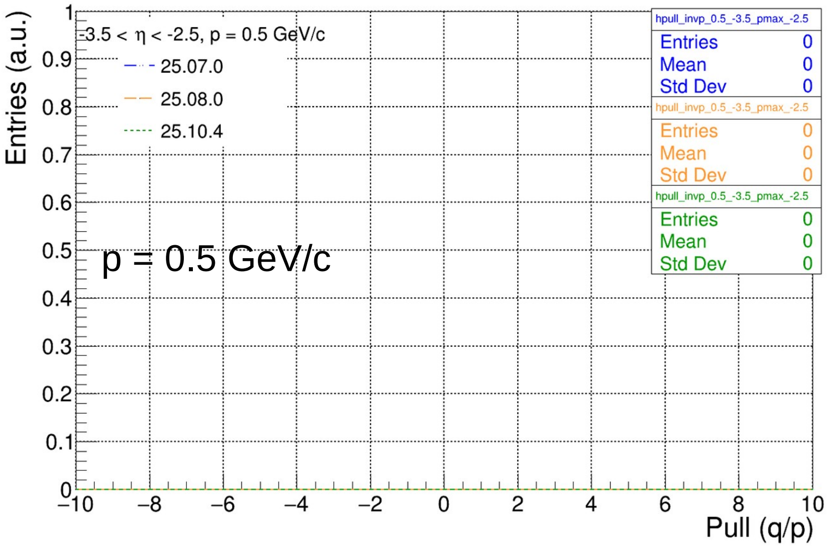


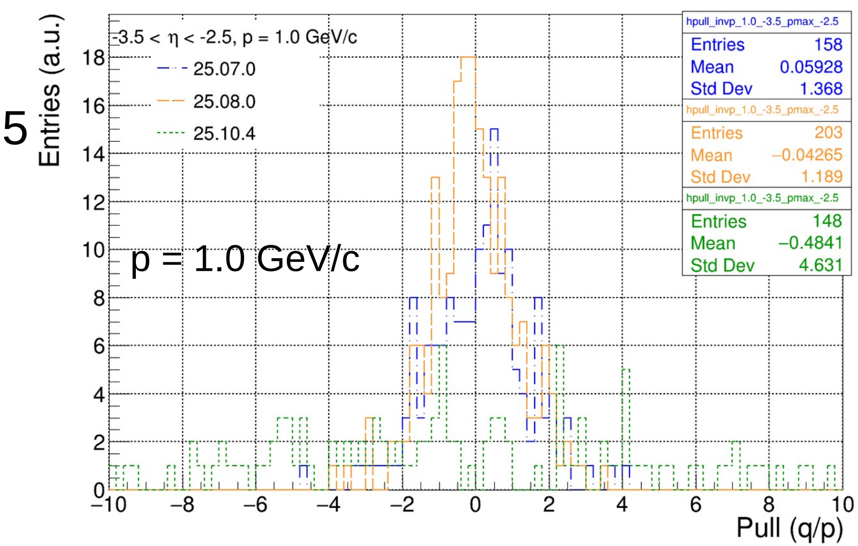


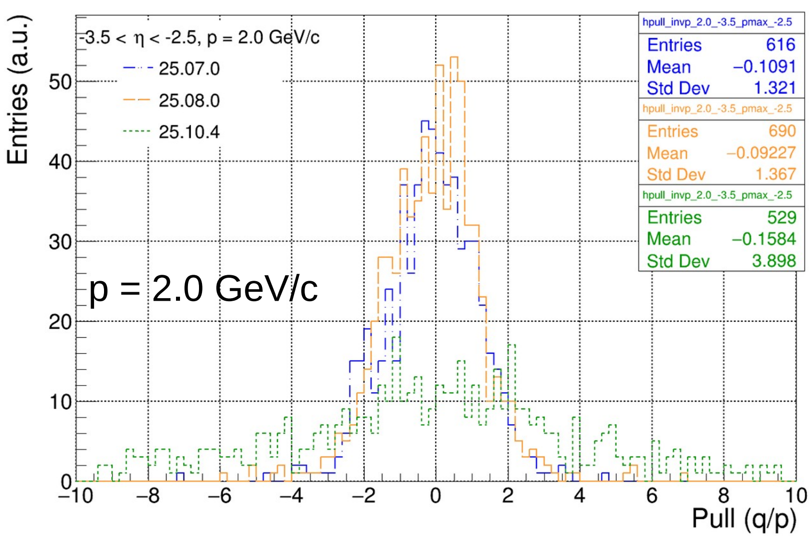


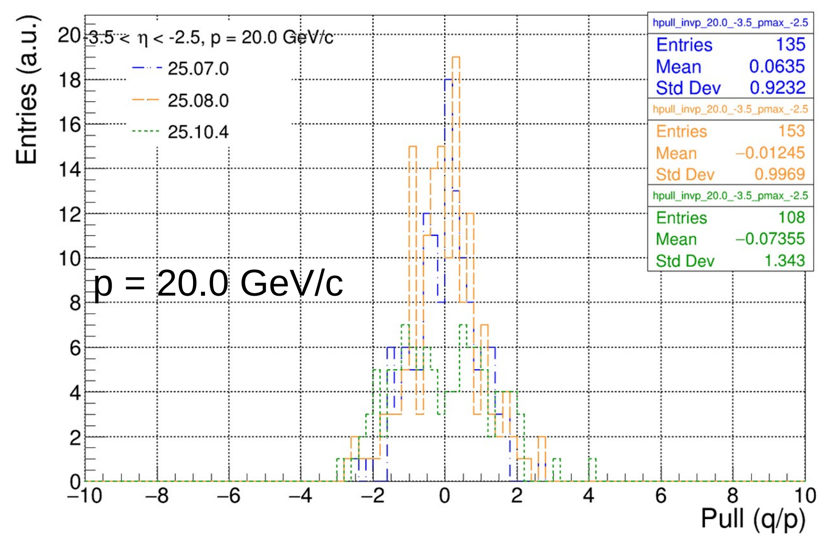
Pull distributions (q/p)

$-3.5 < \eta < -2.5$



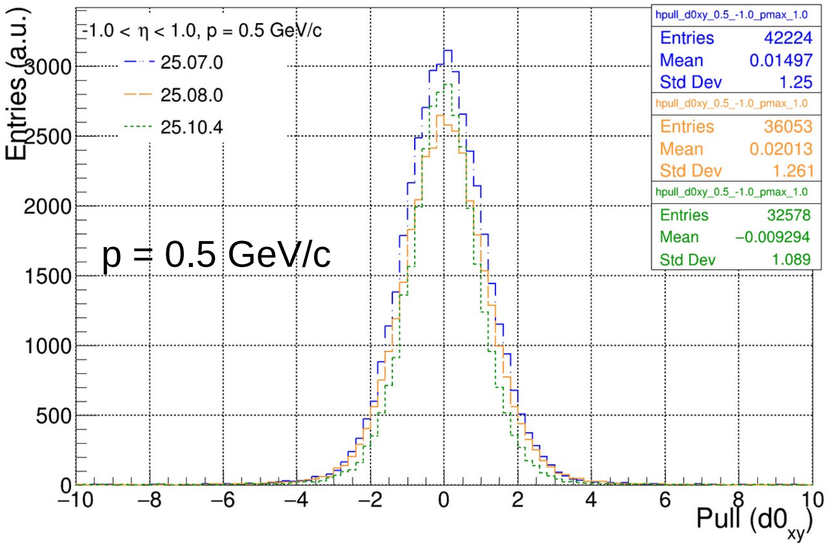


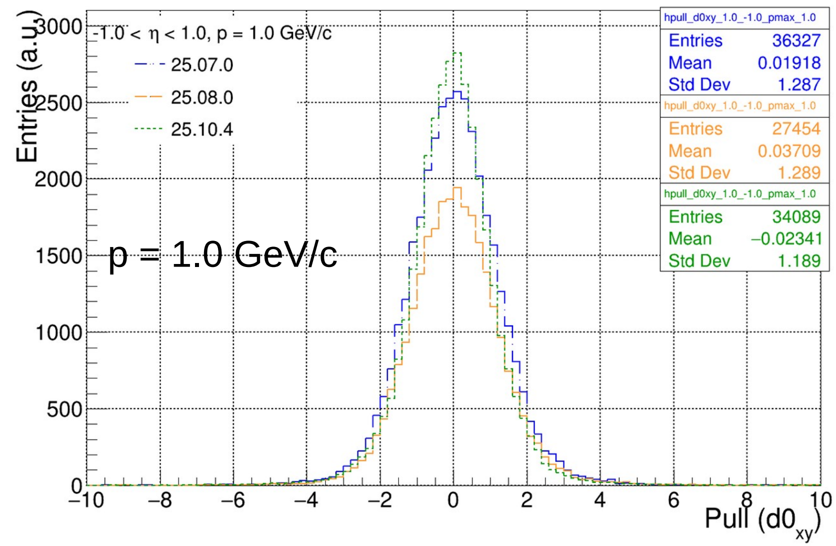


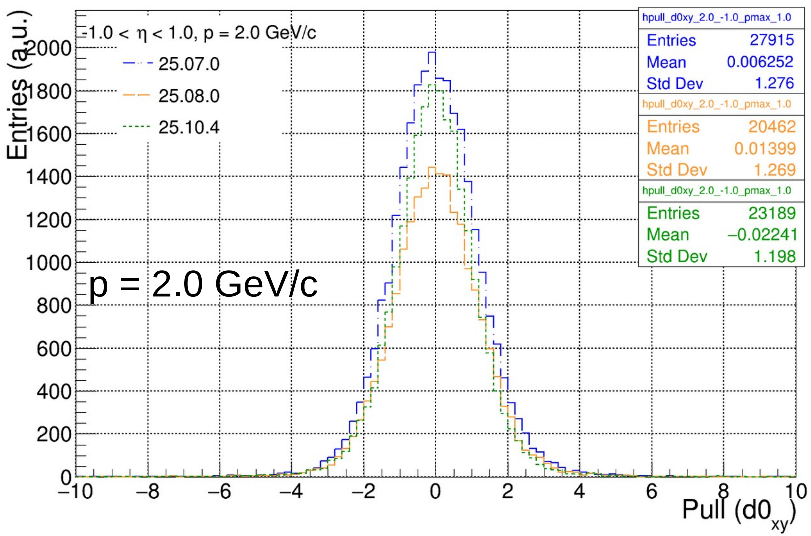


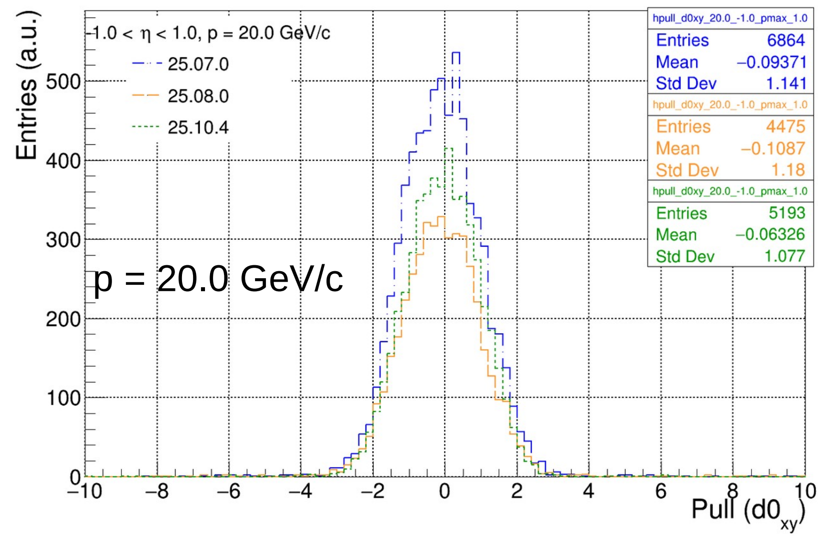
Pull distributions (d_{0xy})

-1< η <1



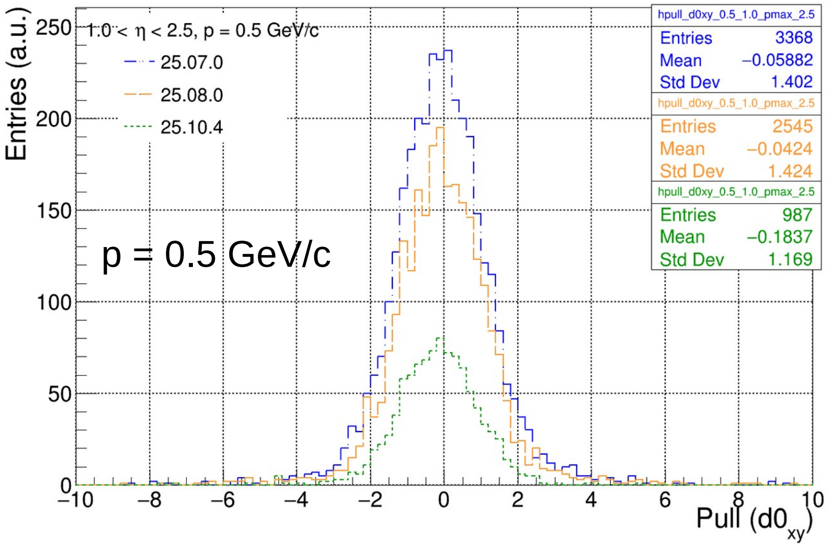


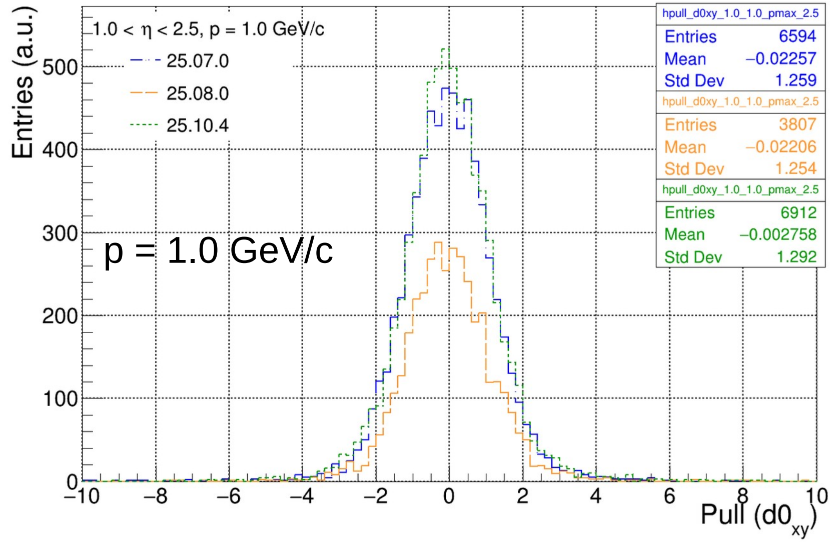


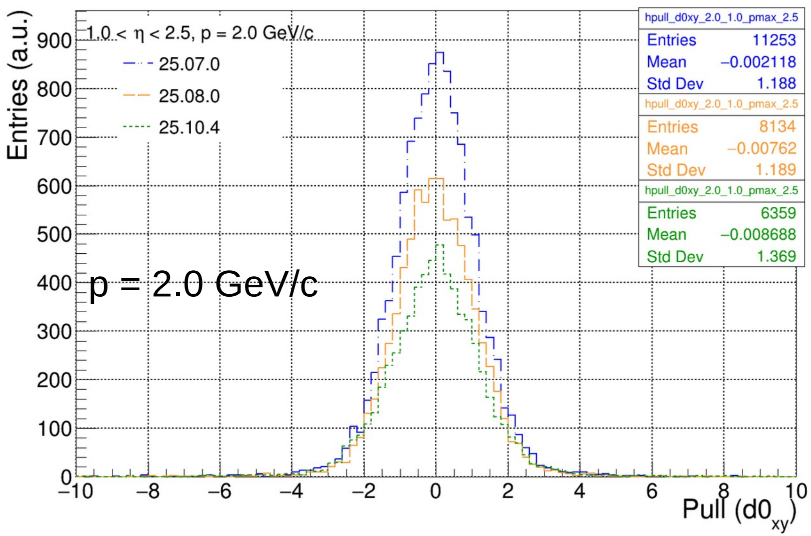


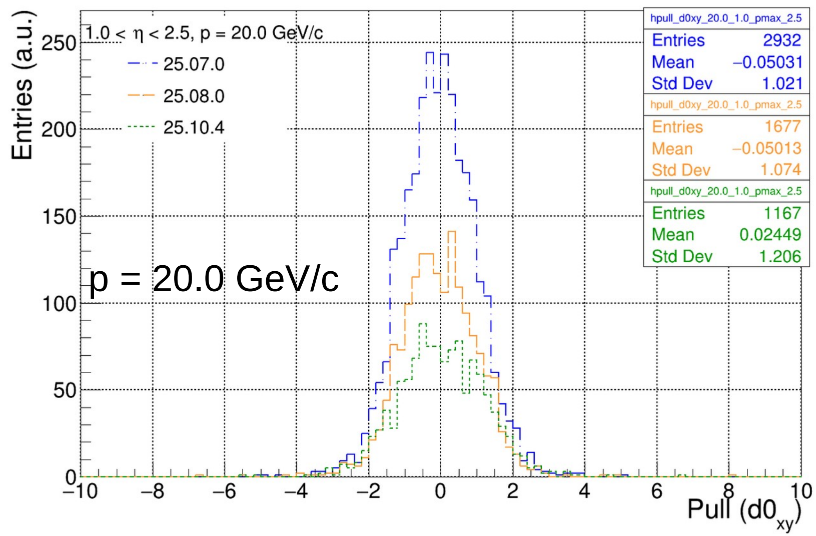
Pull distributions (d_{0xy})

1.0< η <2.5



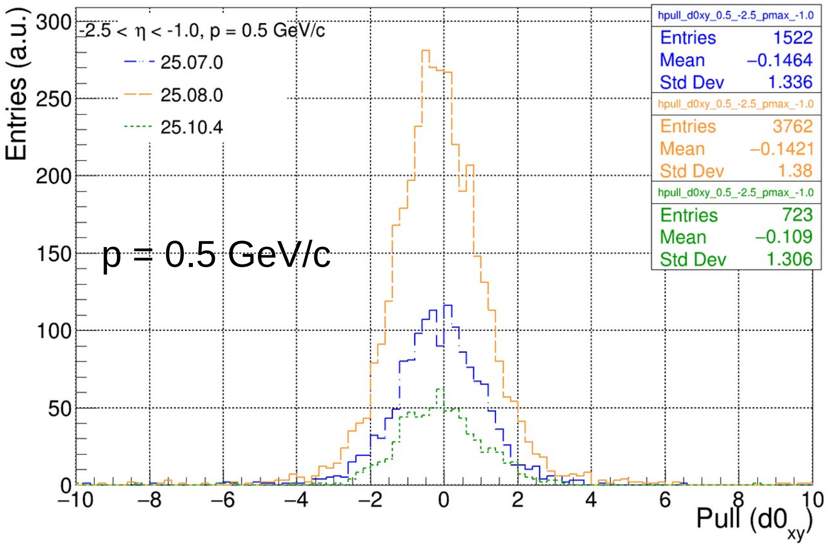


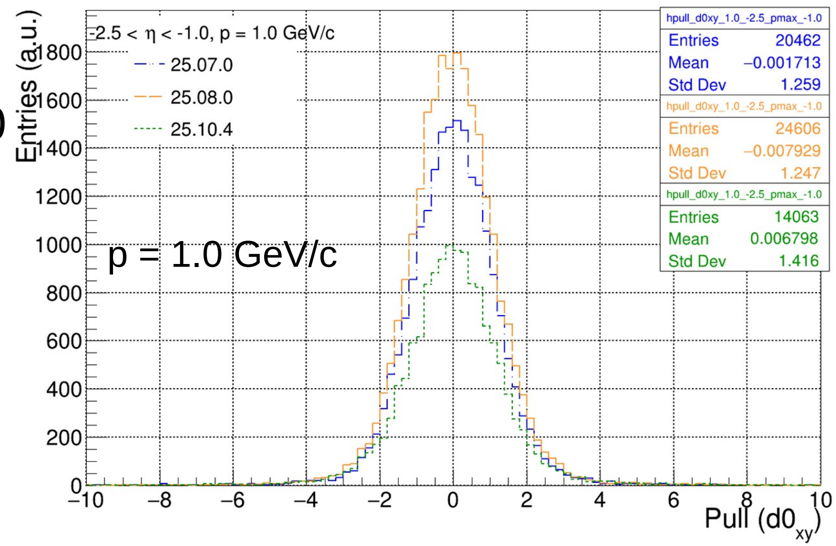


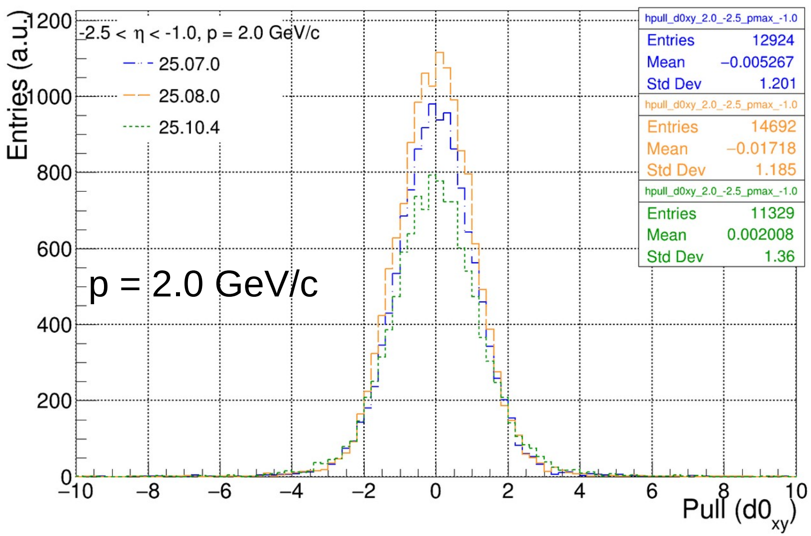


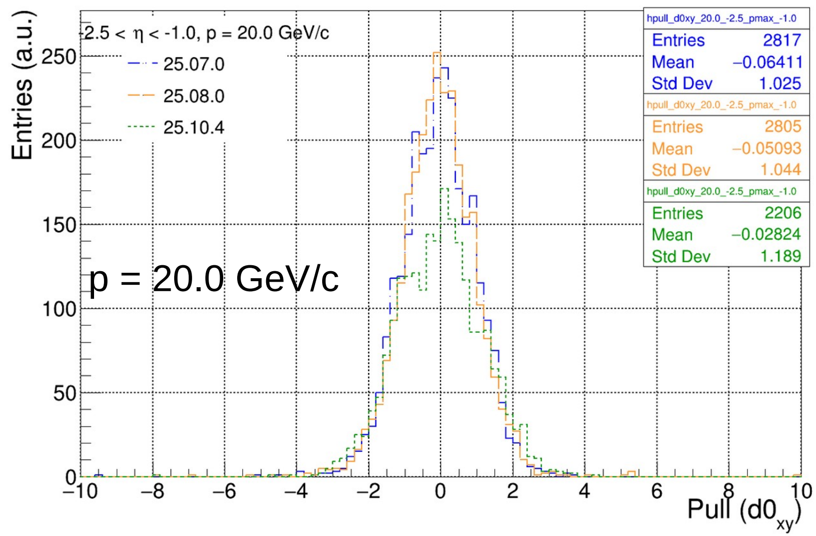
Pull distributions (d_{0xy})

-2.5< η <-1.0



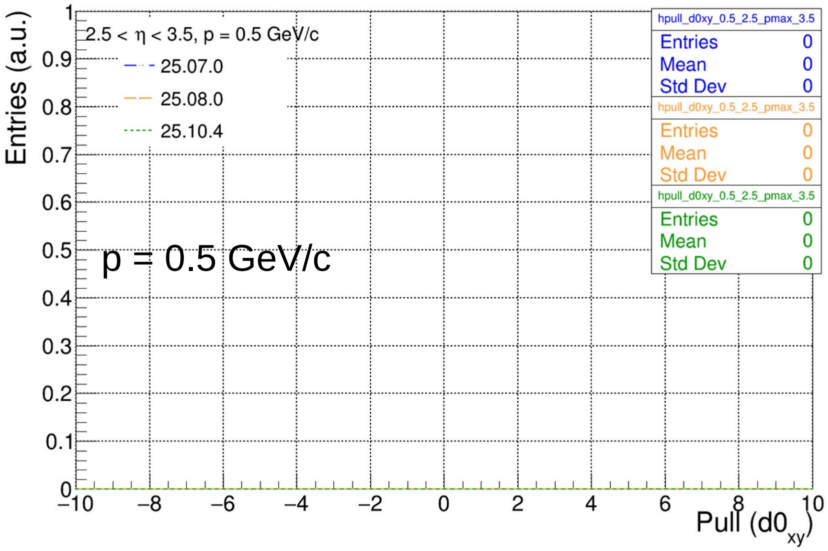


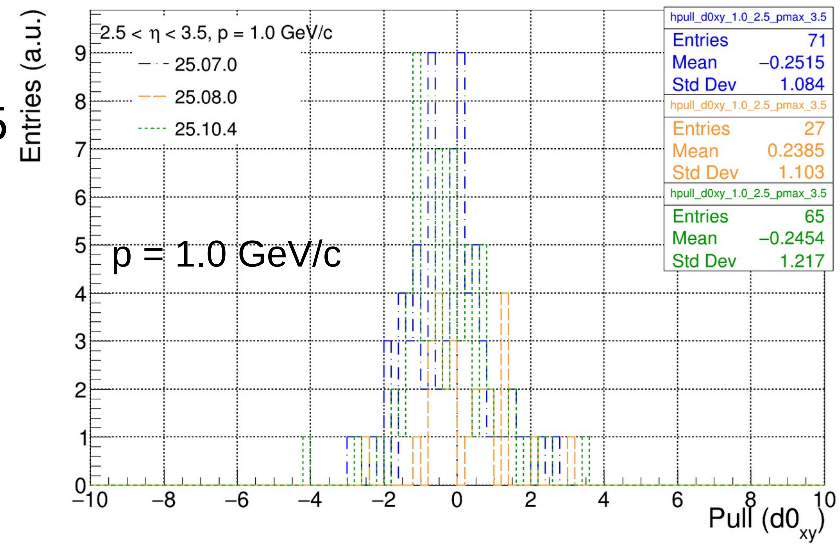


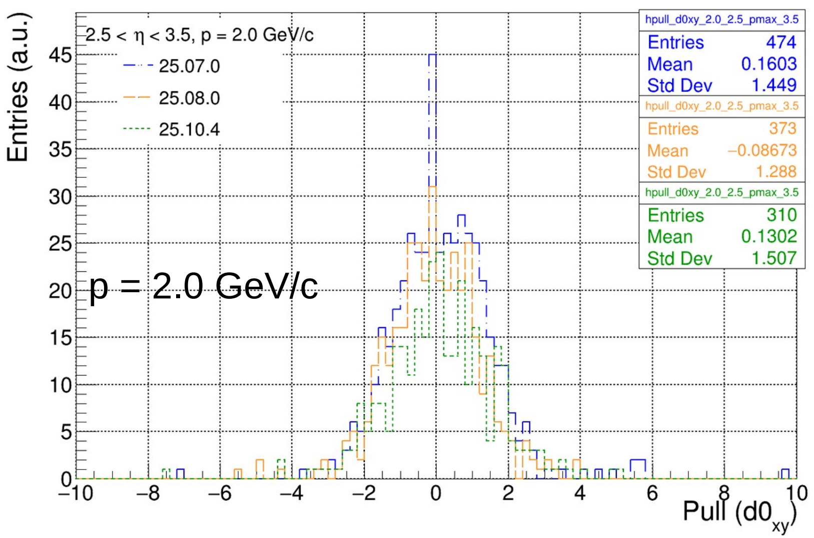


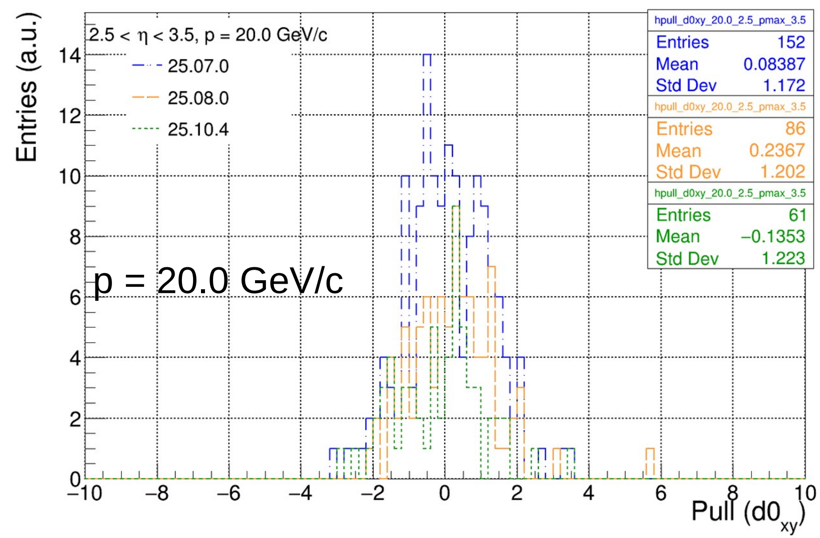
Pull distributions (d_{0xy})

$2.5 < \eta < 3.5$



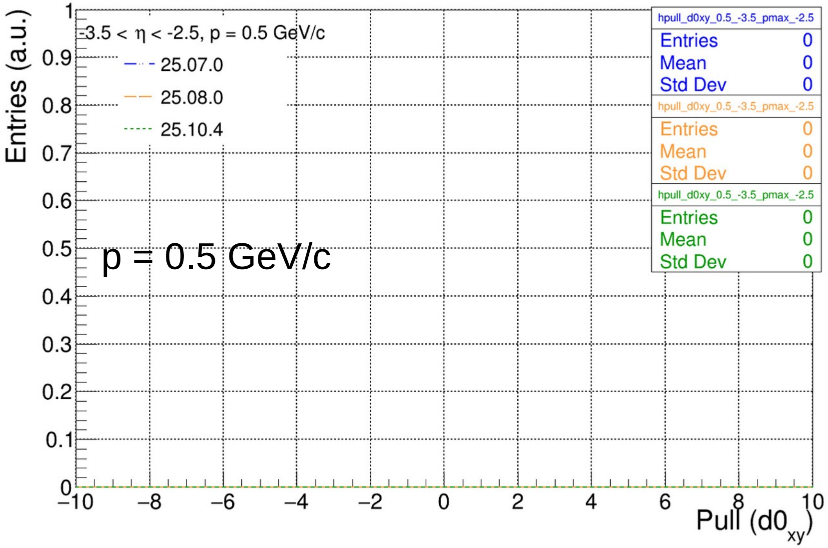


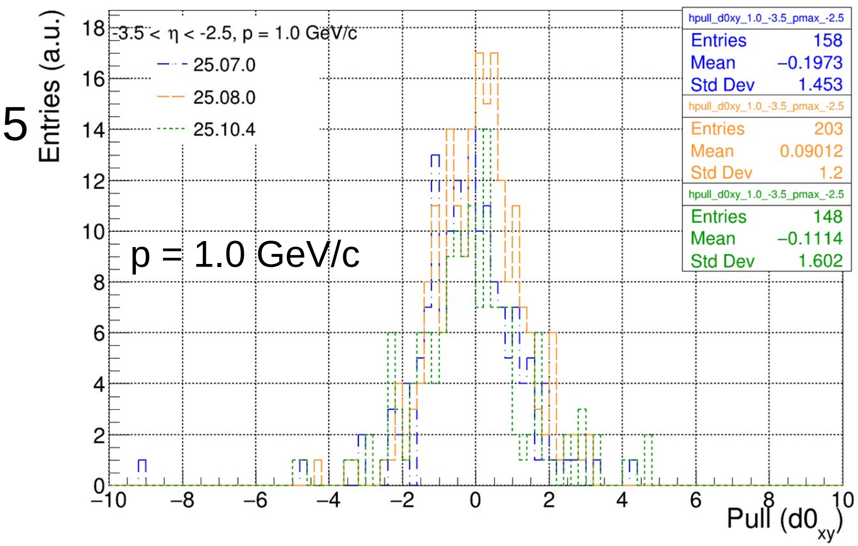


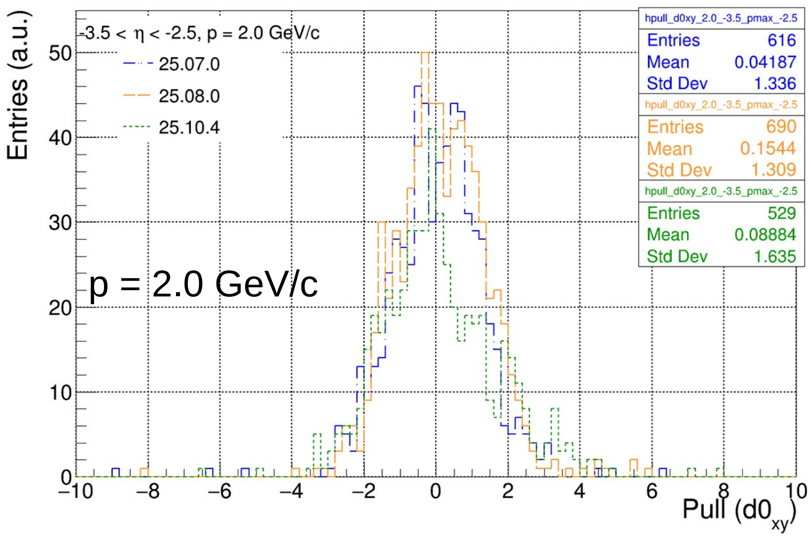


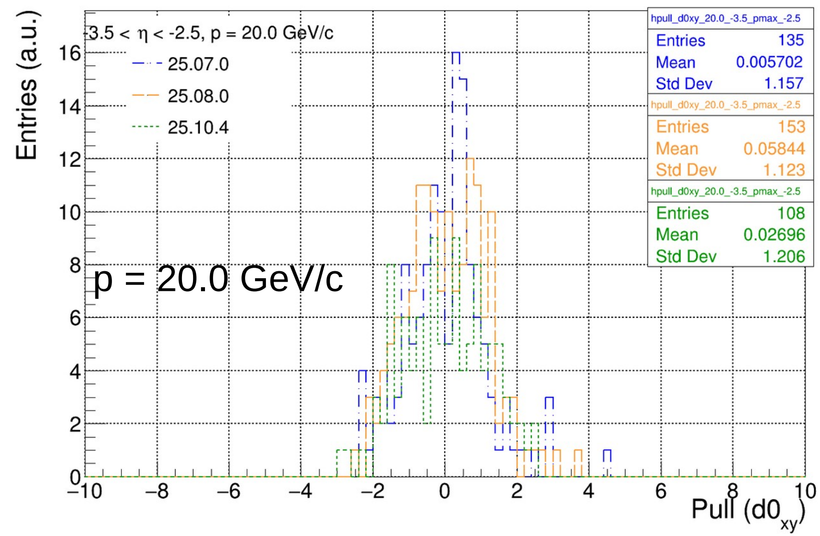
Pull distributions (d_{0xy})

-3.5 < η <-2.5



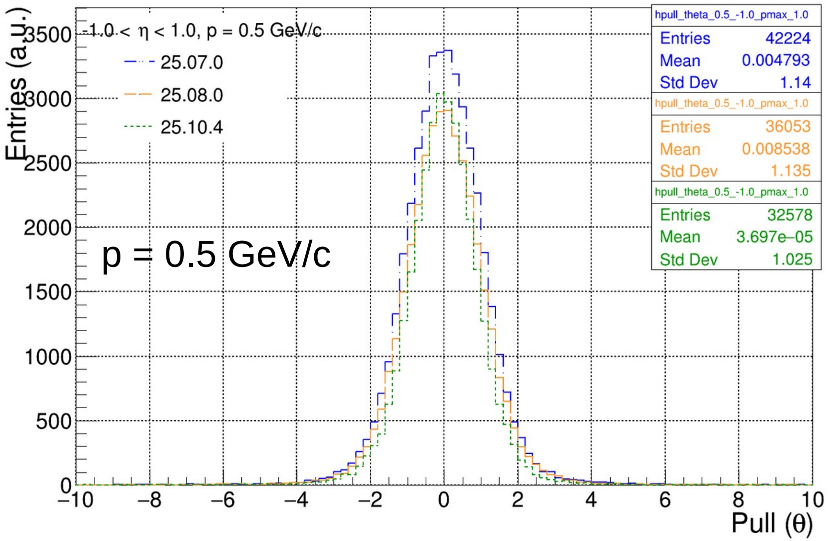


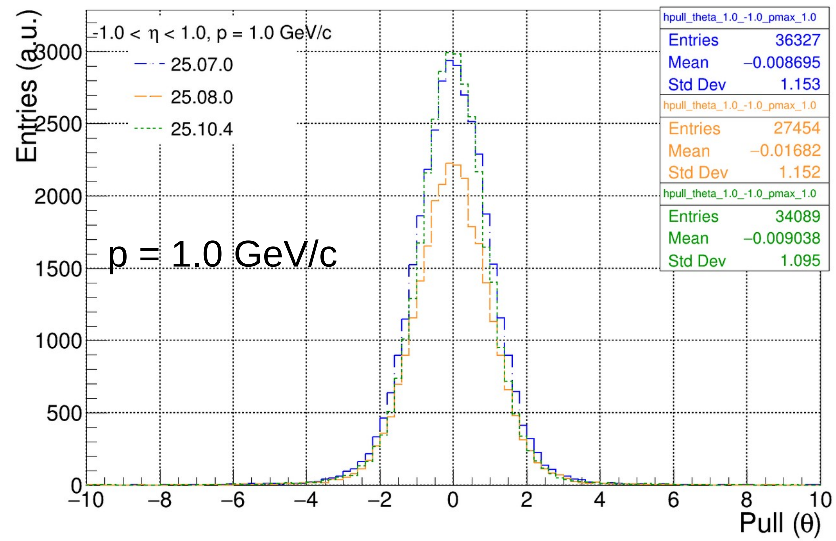


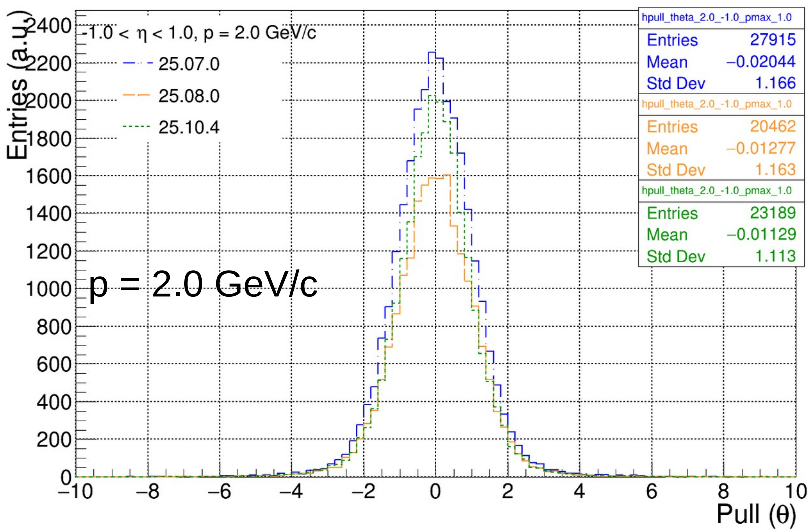


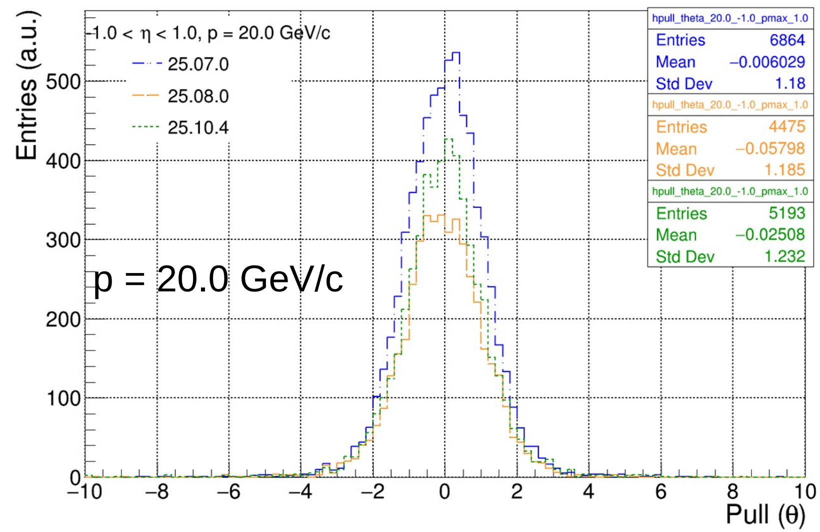
Pull distributions (θ)

-1< η <1



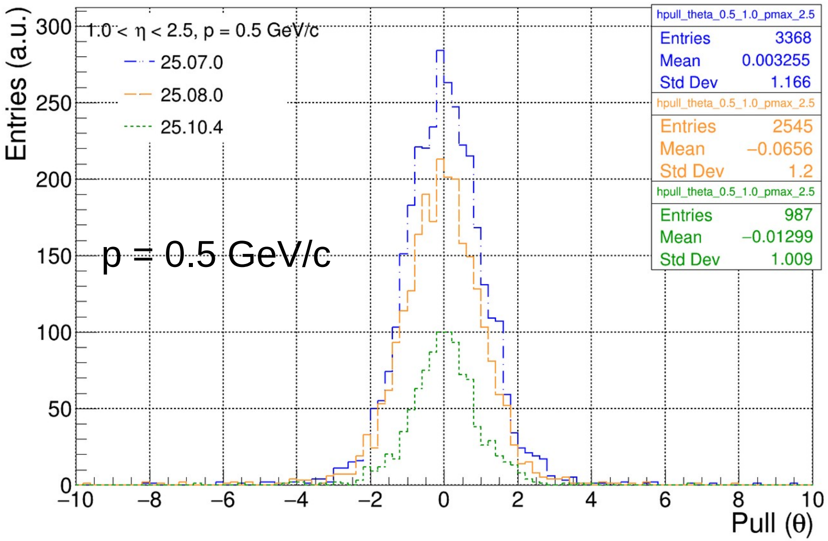


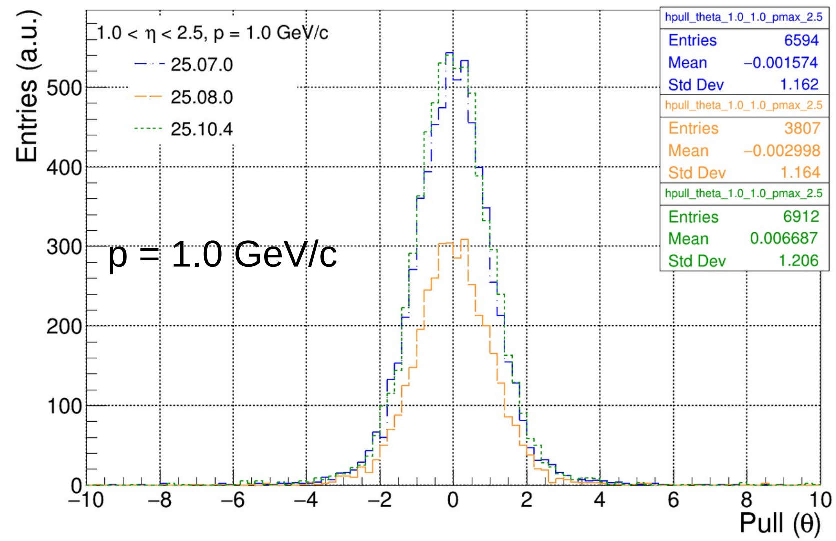


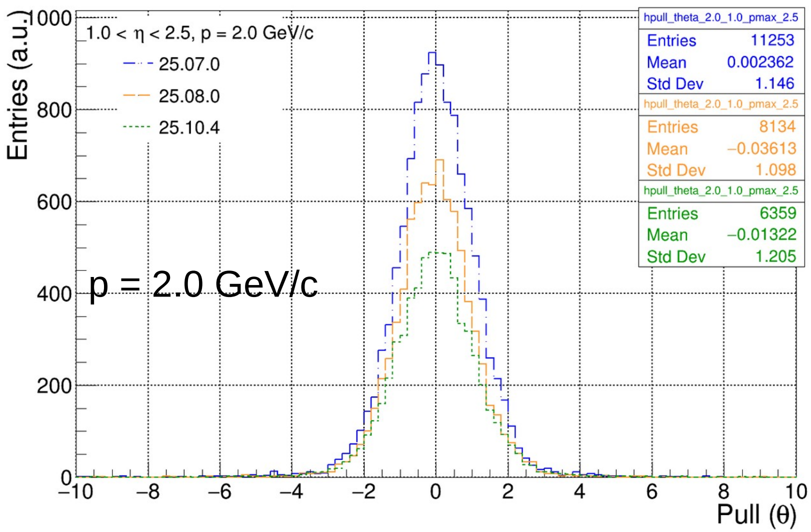


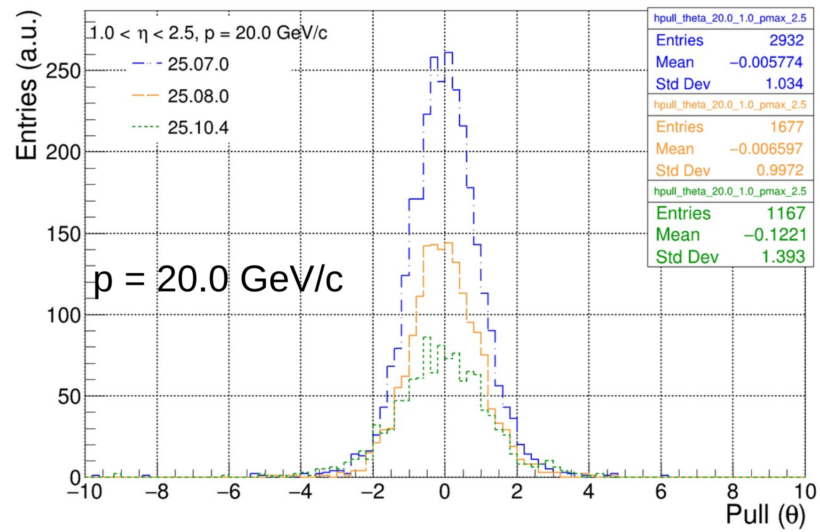
Pull distributions (θ)

1.0< η <2.5



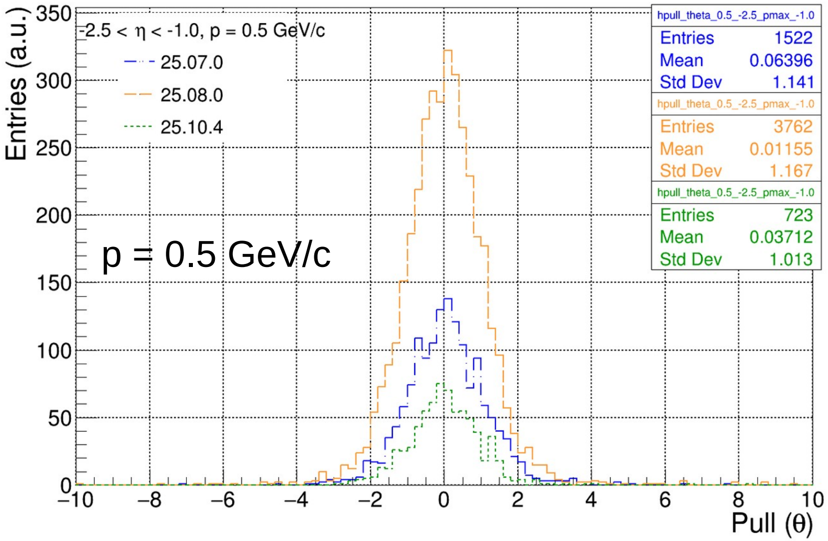


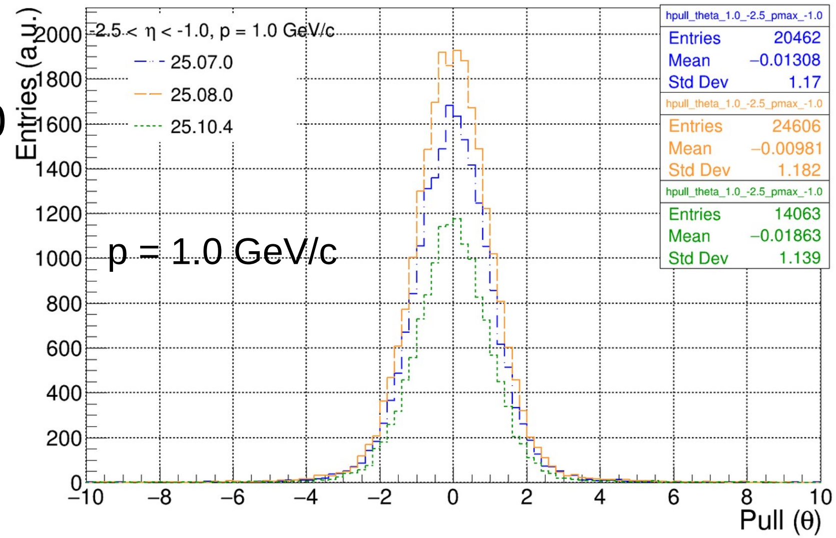


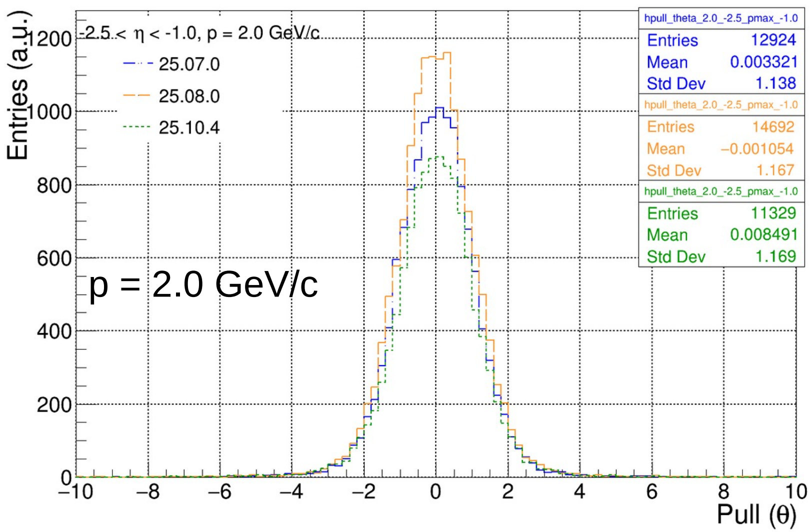


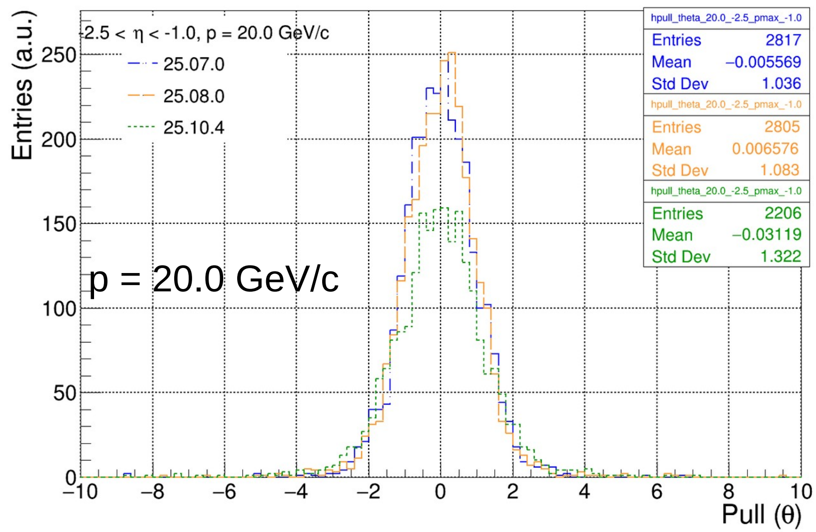
Pull distributions (θ)

-2.5< η <-1.0

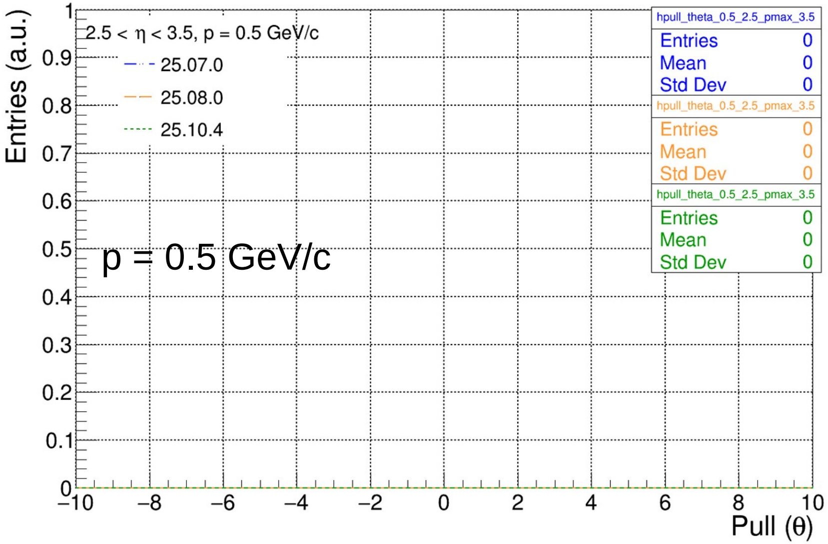




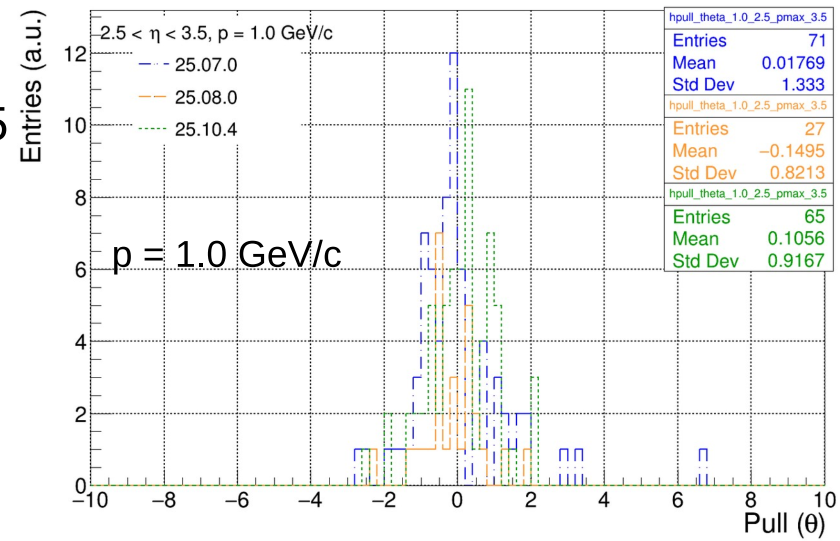


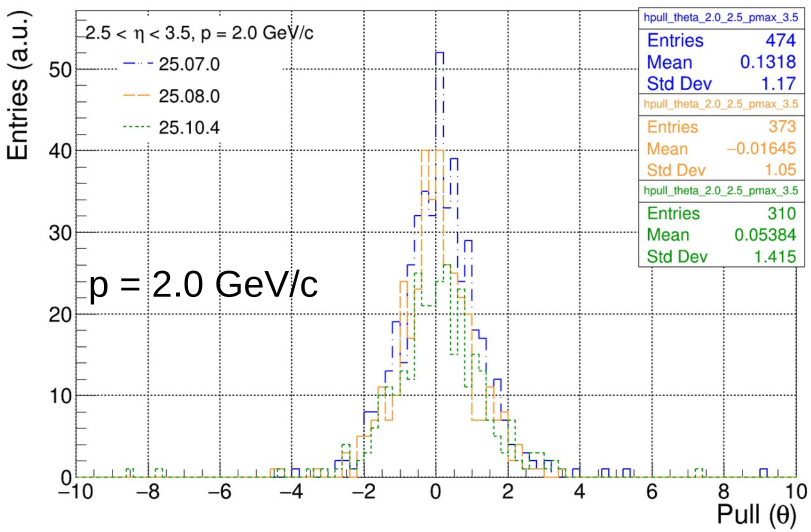


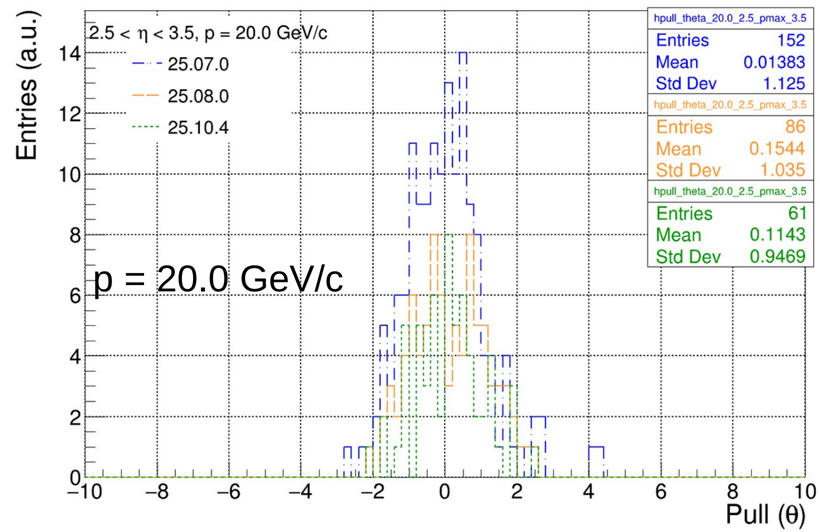
Pull distributions (θ)



$2.5 < \eta < 3.5$

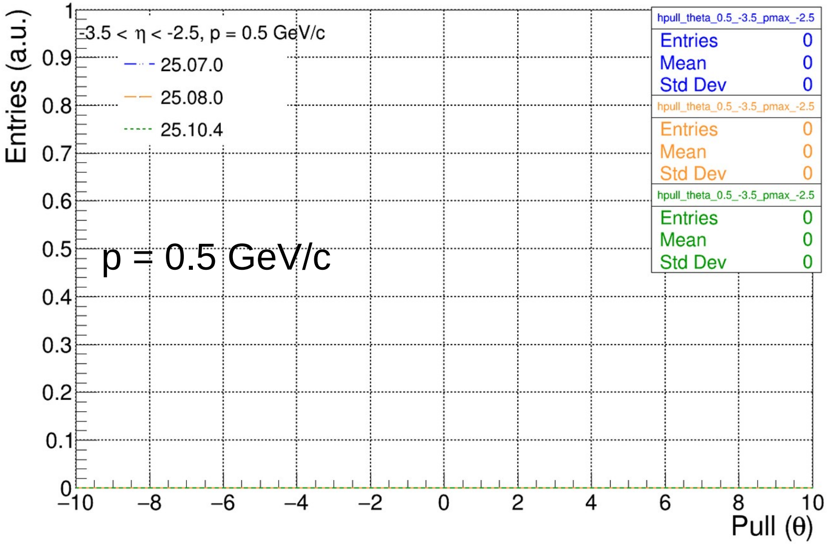


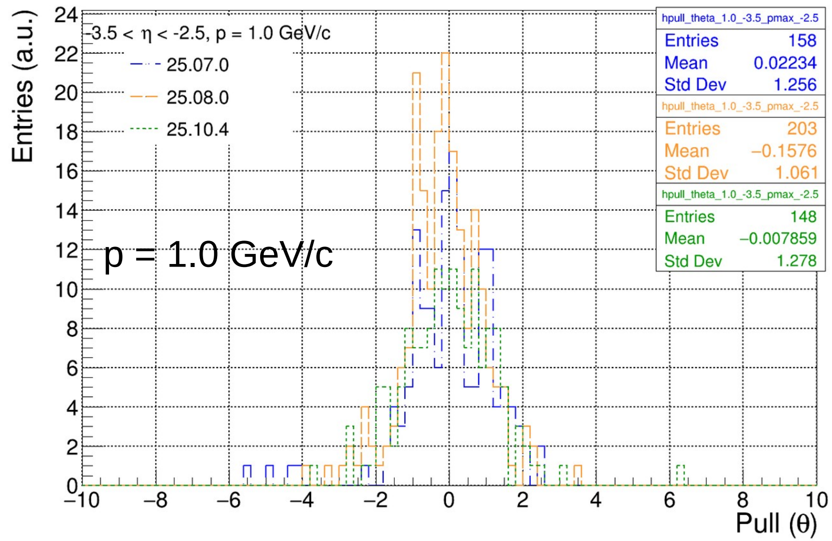


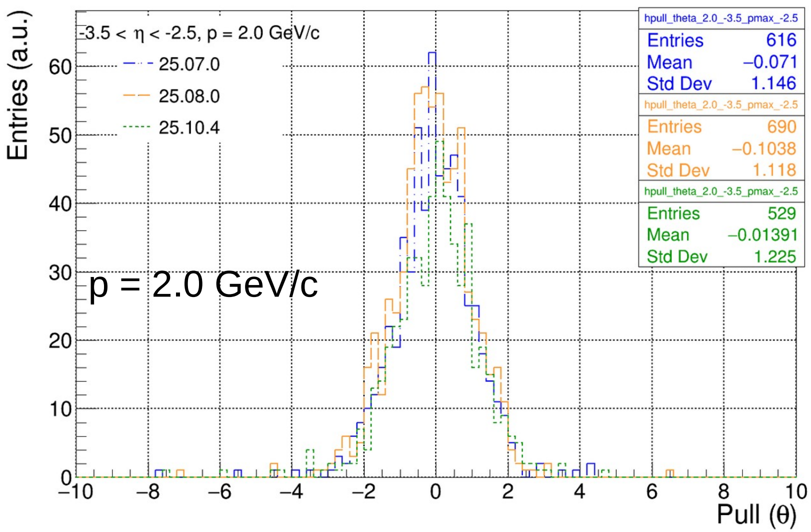


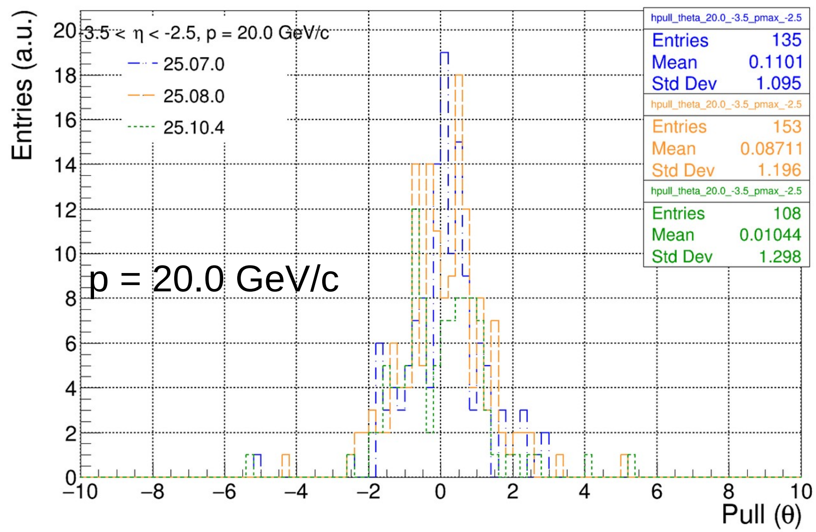
Pull distributions (θ)

$-3.5 < \eta < -2.5$



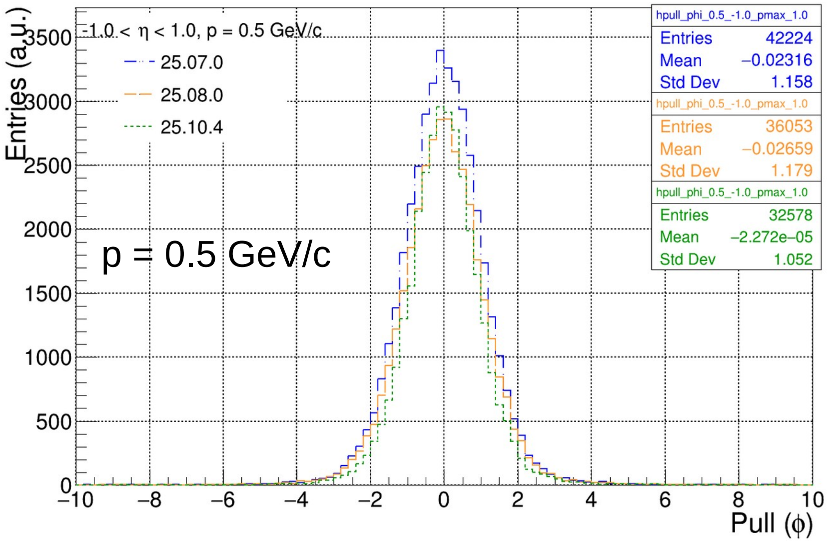


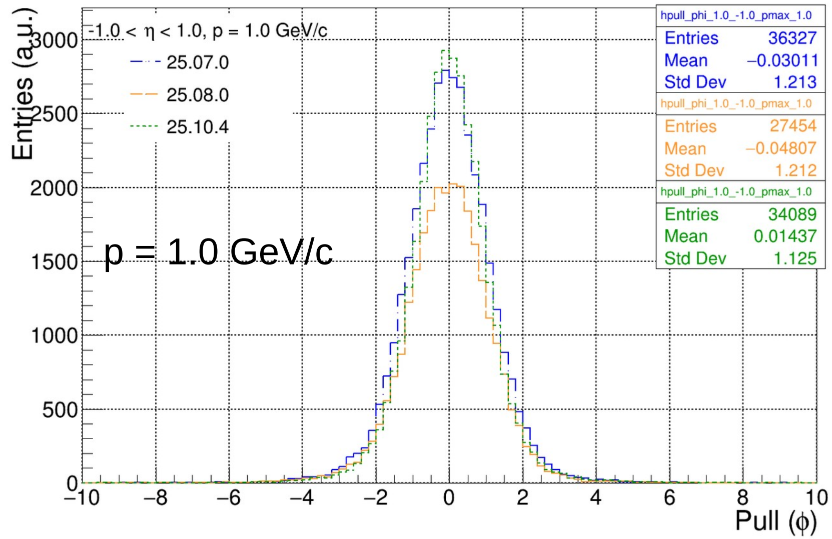


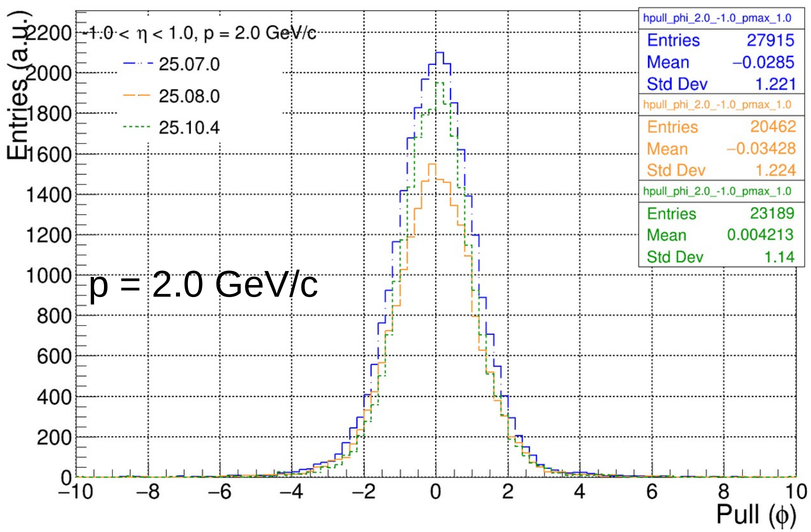


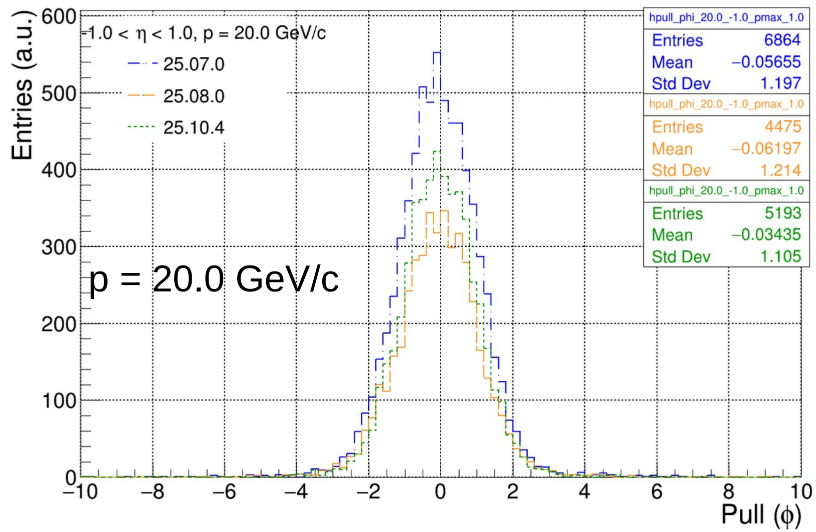
Pull distributions (Φ)

-1< η <1

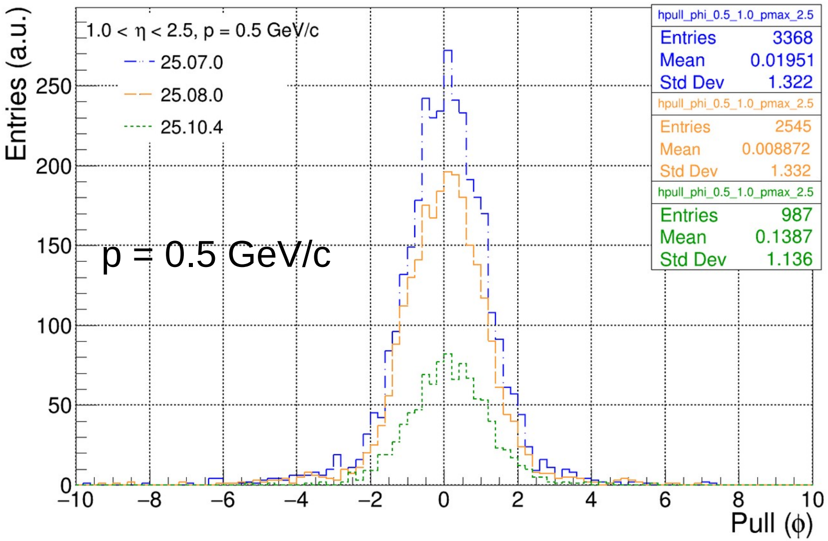




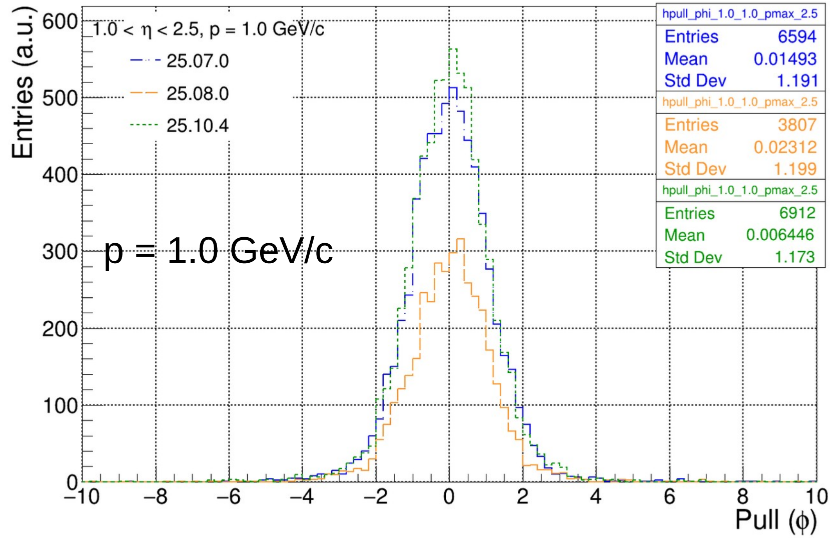


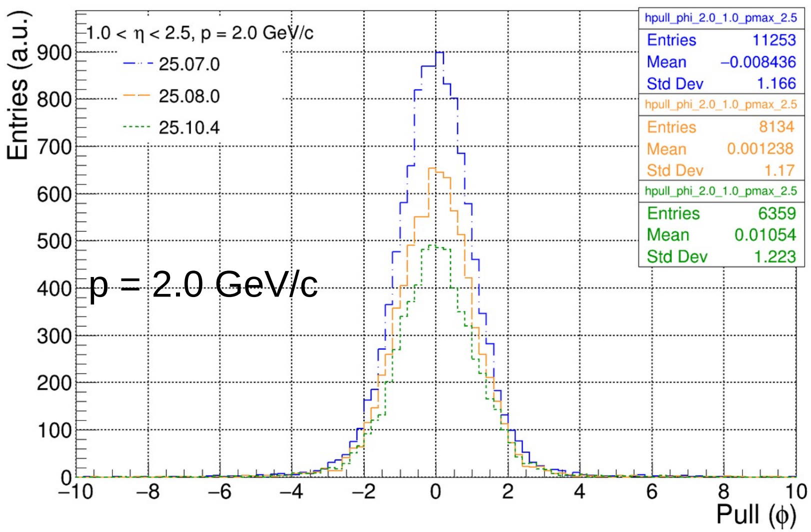


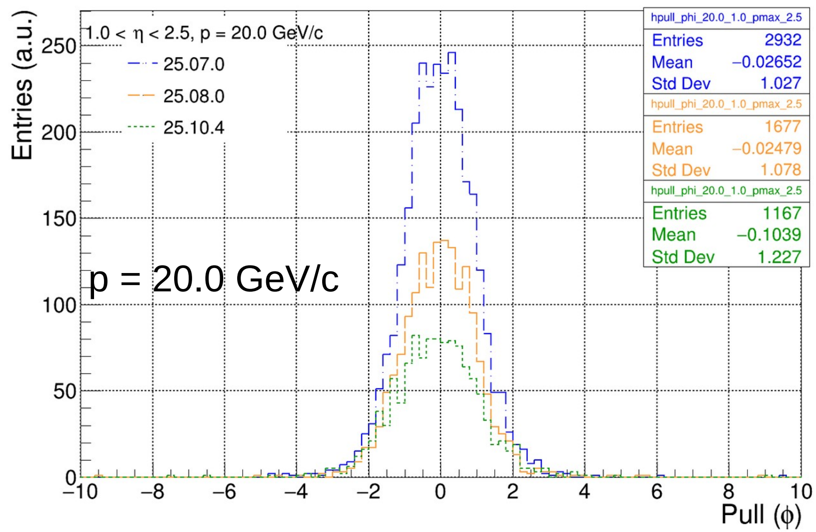
Pull distributions (Φ)



1.0< η <2.5

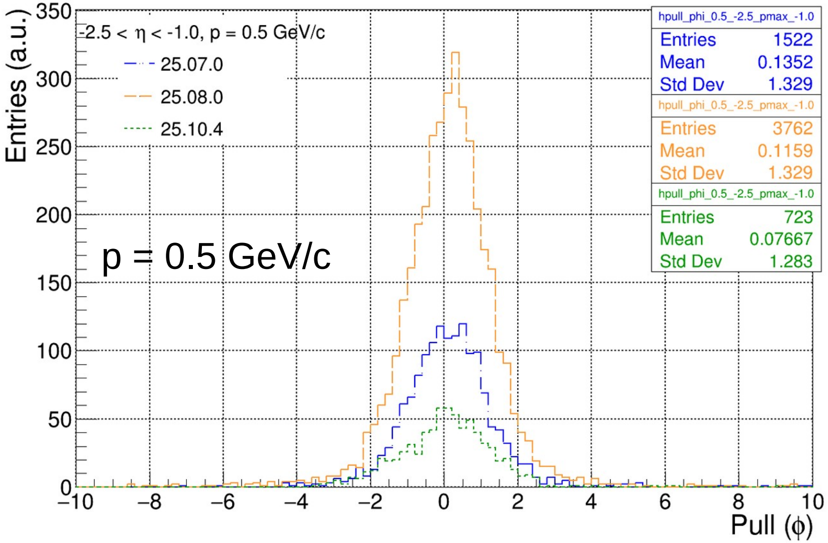


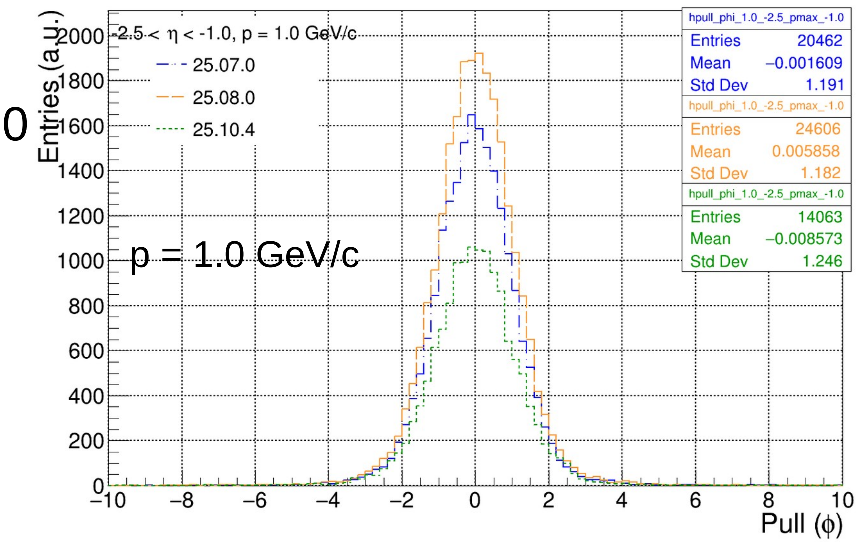


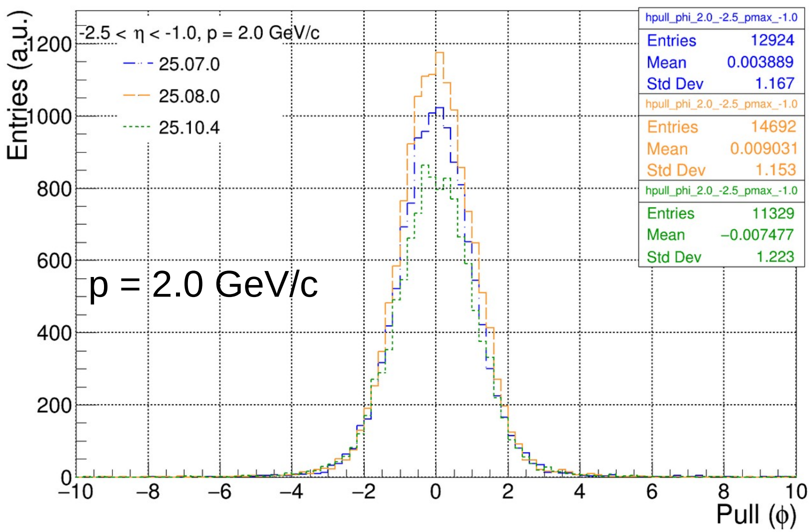


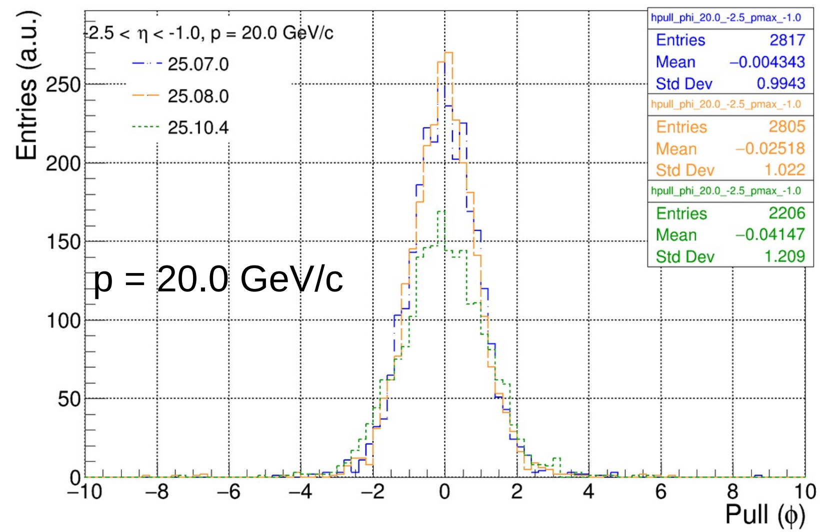
Pull distributions (Φ)

-2.5< η <-1.0



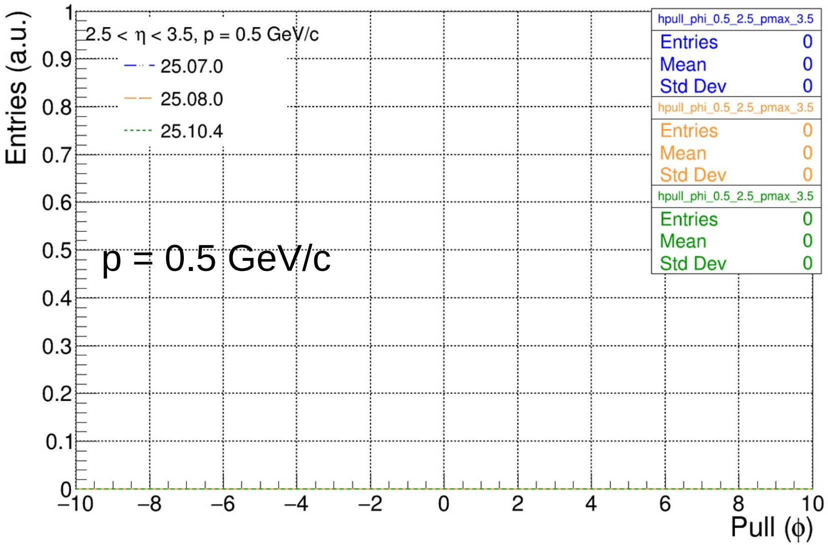


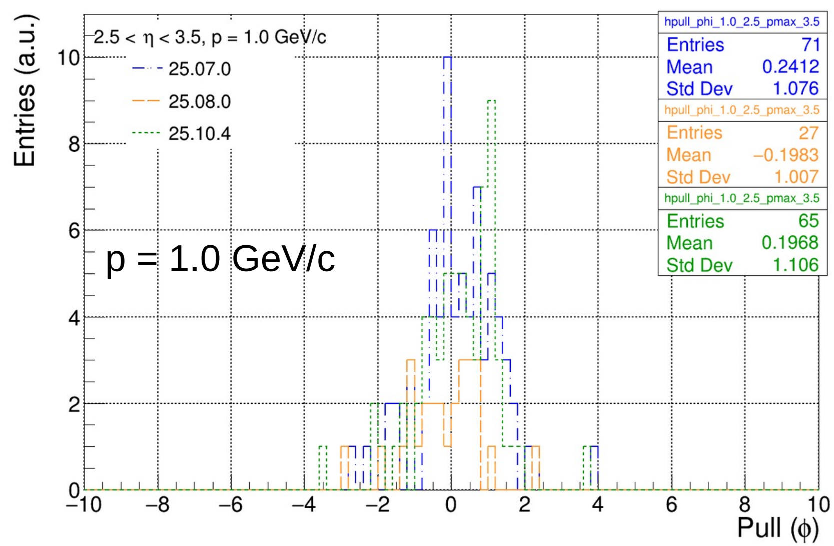


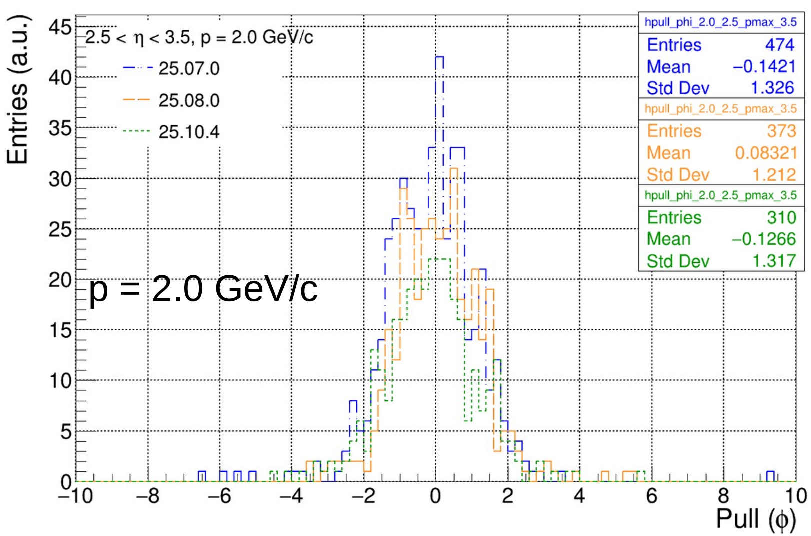


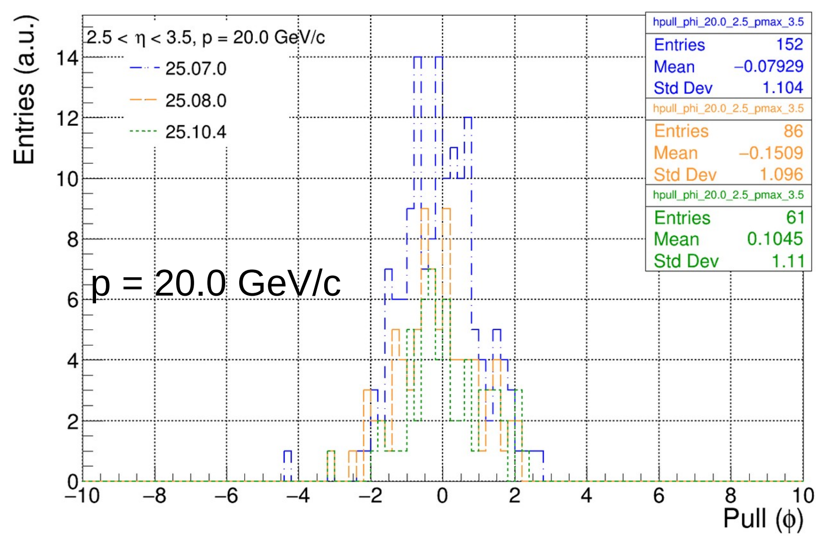
Pull distributions (Φ)

$2.5 < \eta < 3.5$

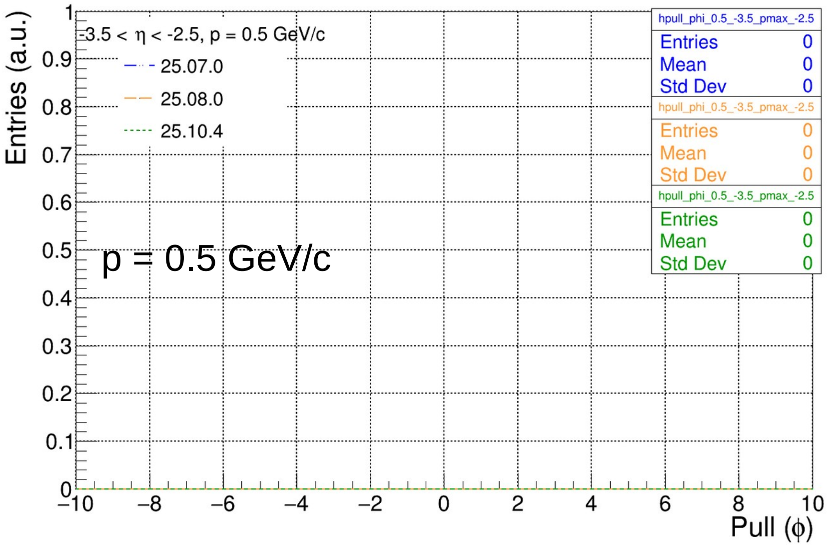




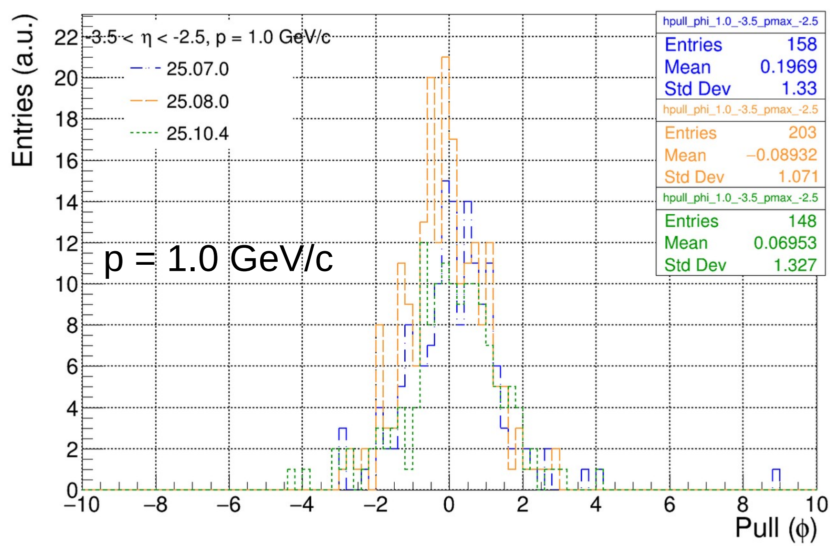


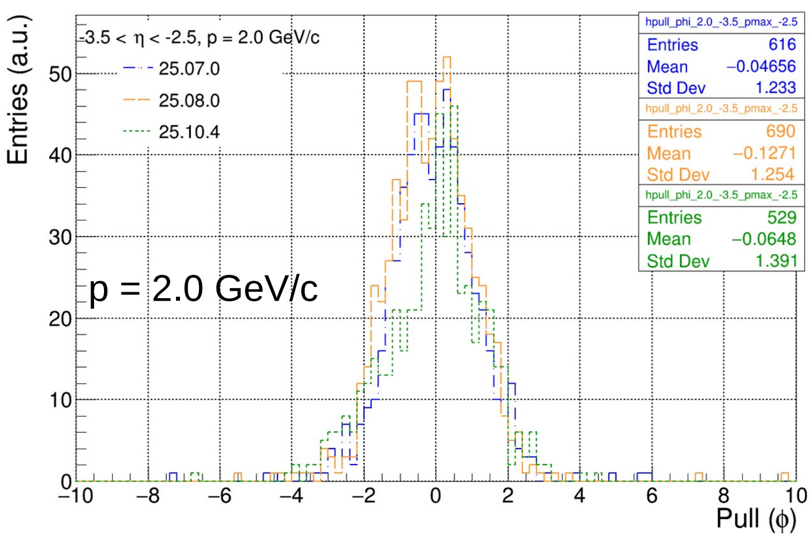


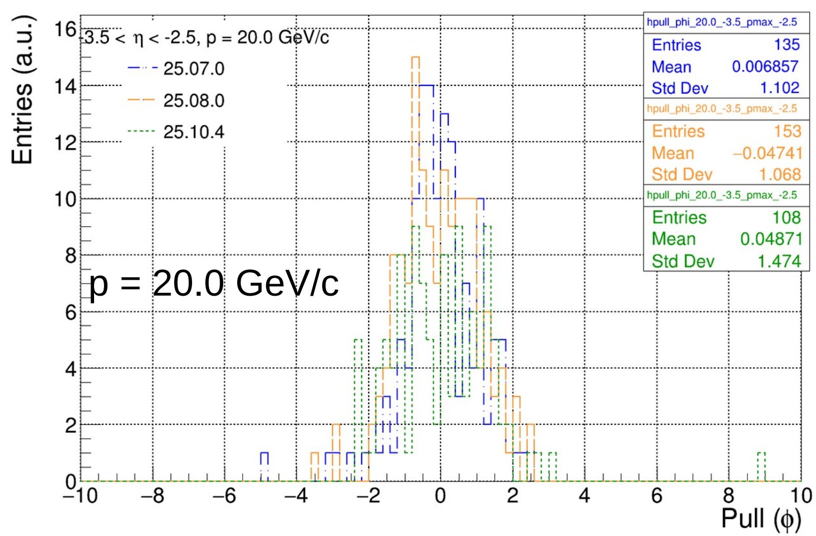
Pull distributions (Φ)



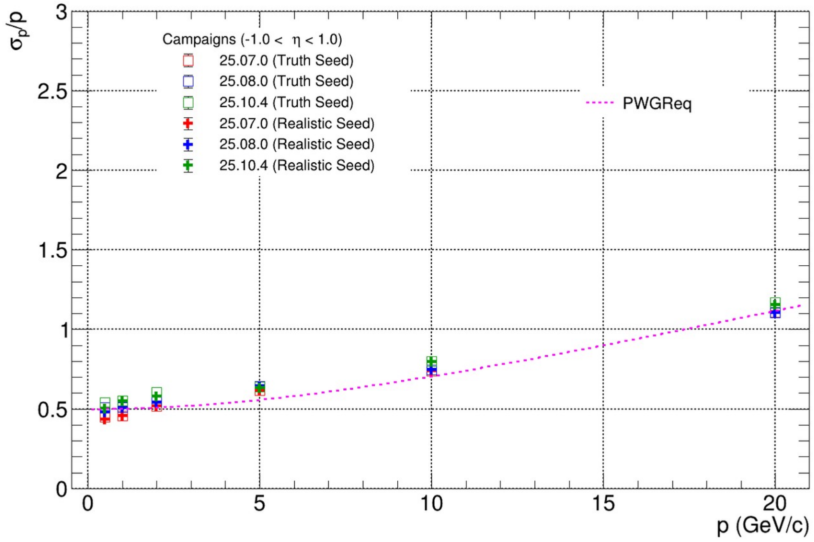
-3.5 < η <-2.5

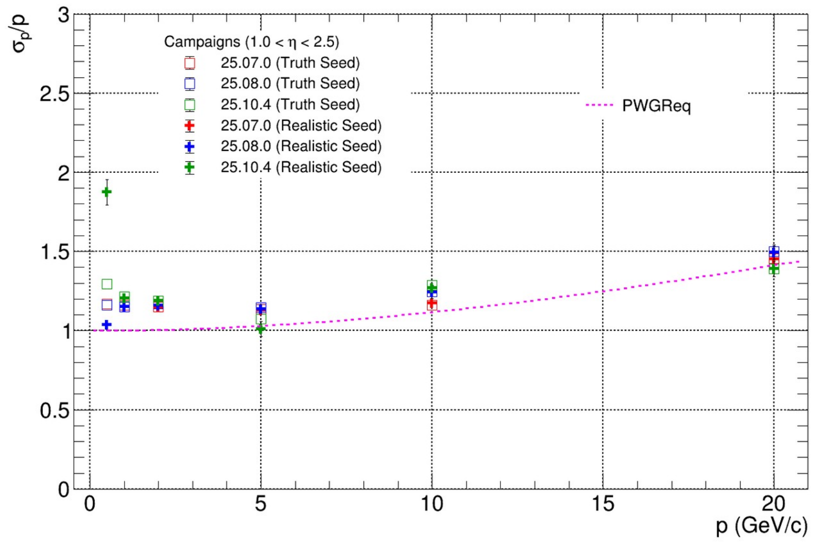


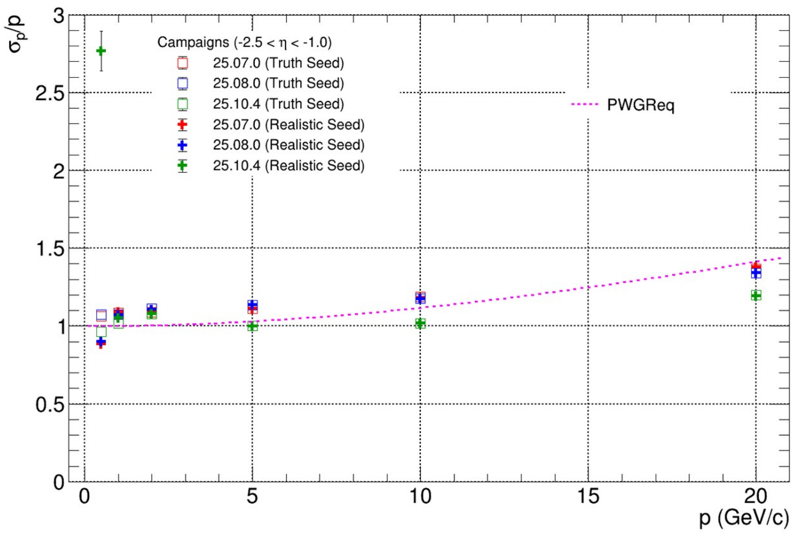




Tracking Performances



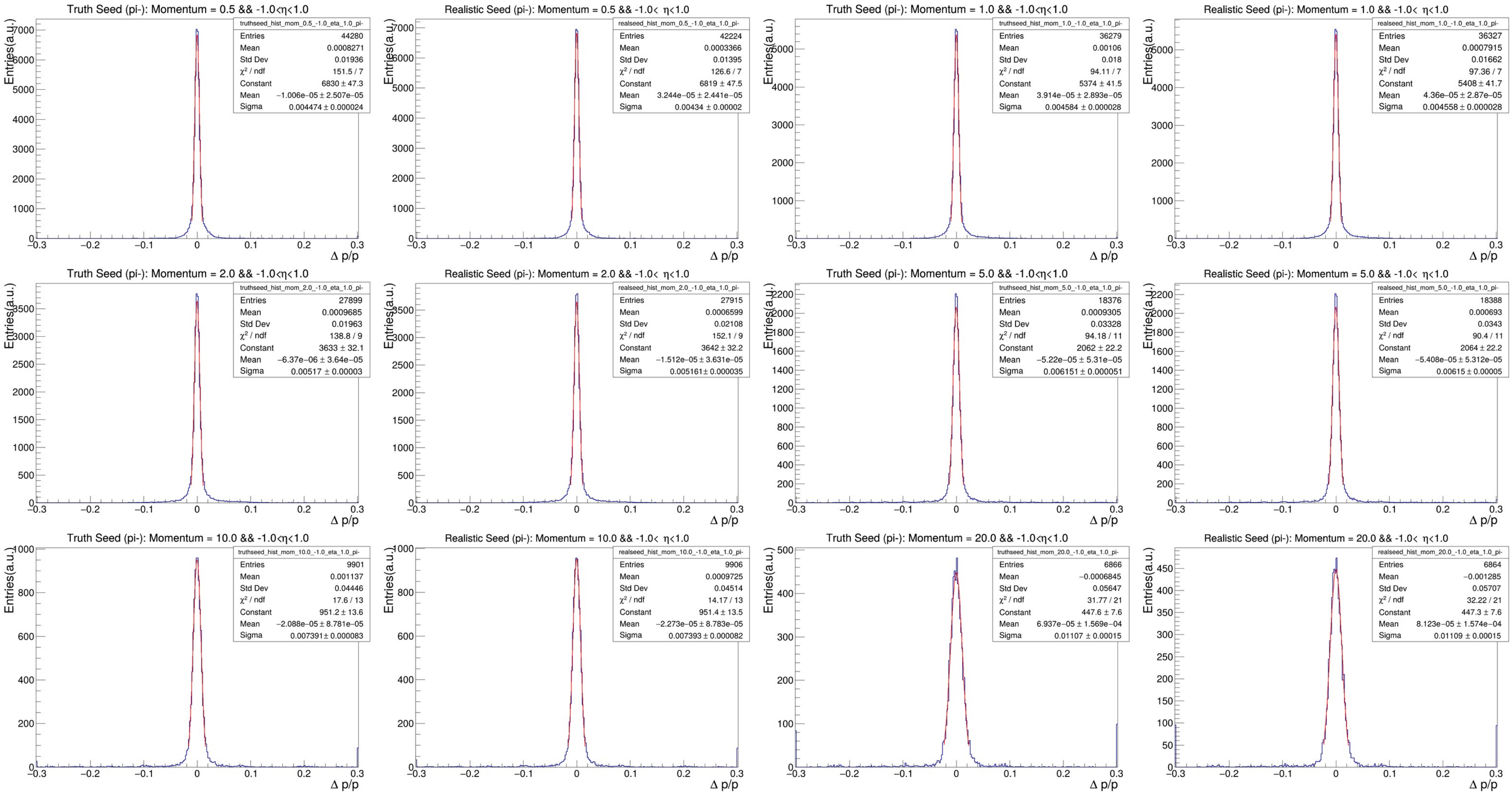




Tracking performance based on Gaussian fit in (2 sigma) region

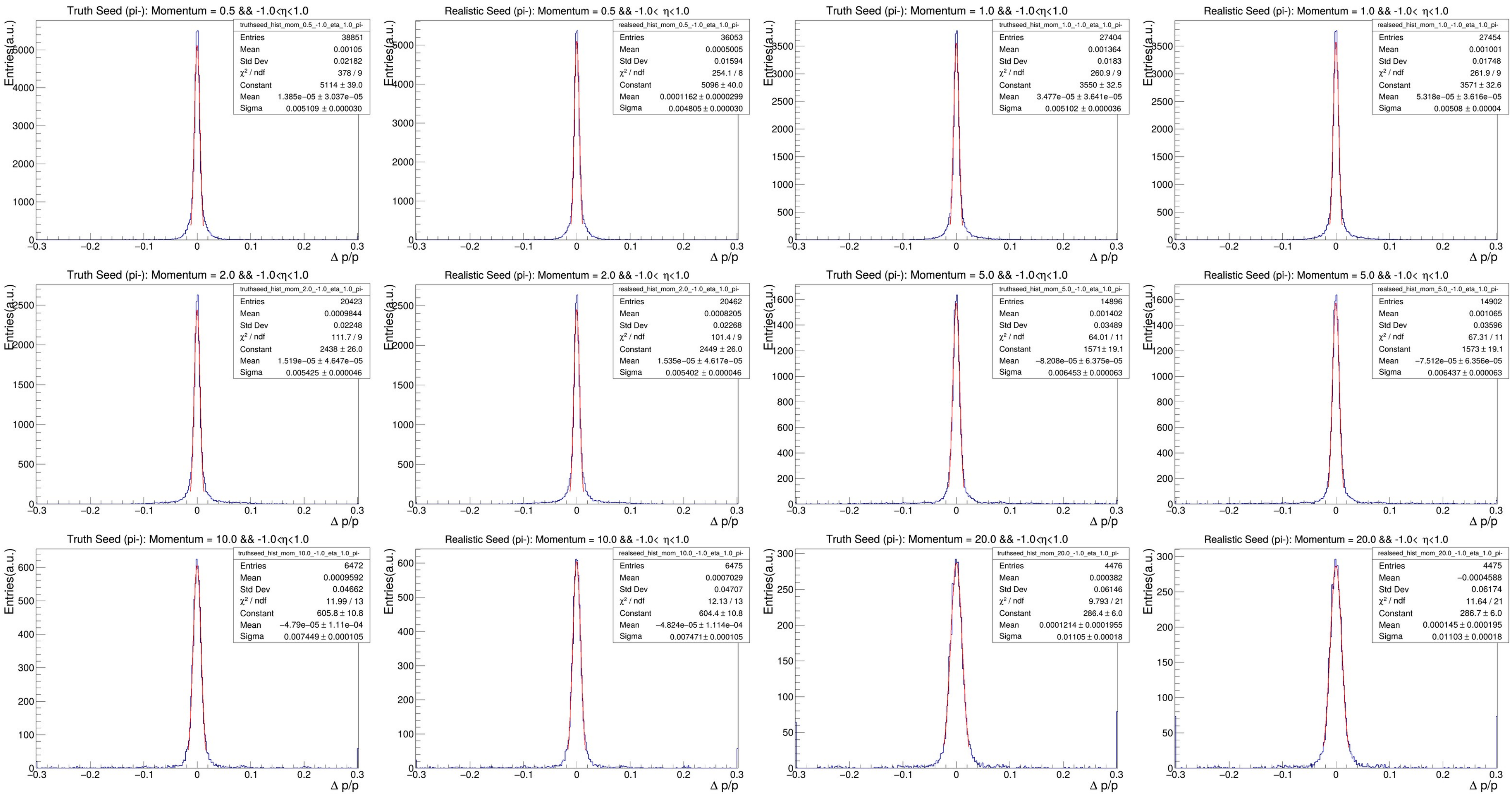
Momentum debug plots (25.07.0)

-1.0 < η < 1.0



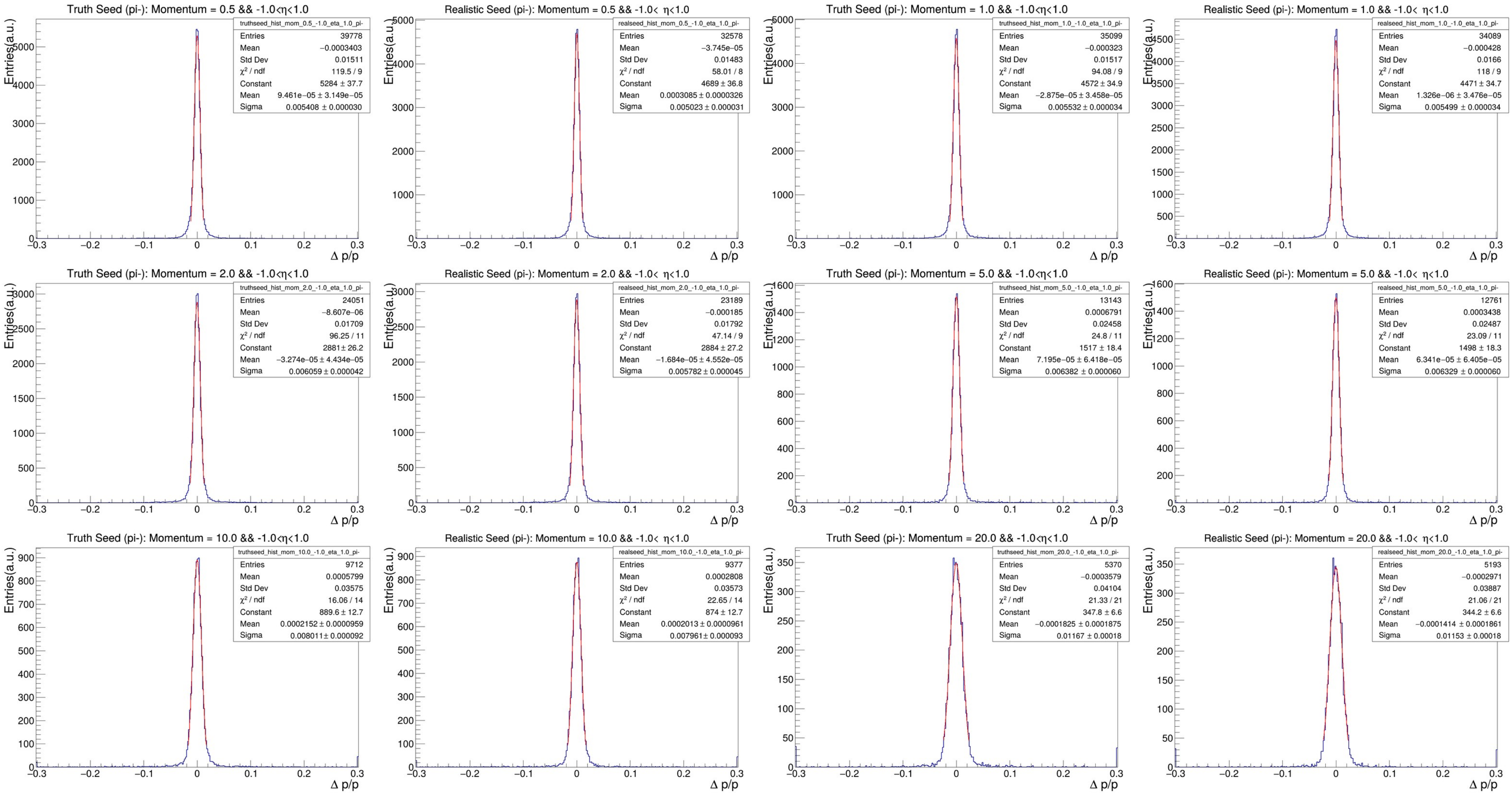
Momentum debug plots (25.08.0)

-1.0 < η < 1.0



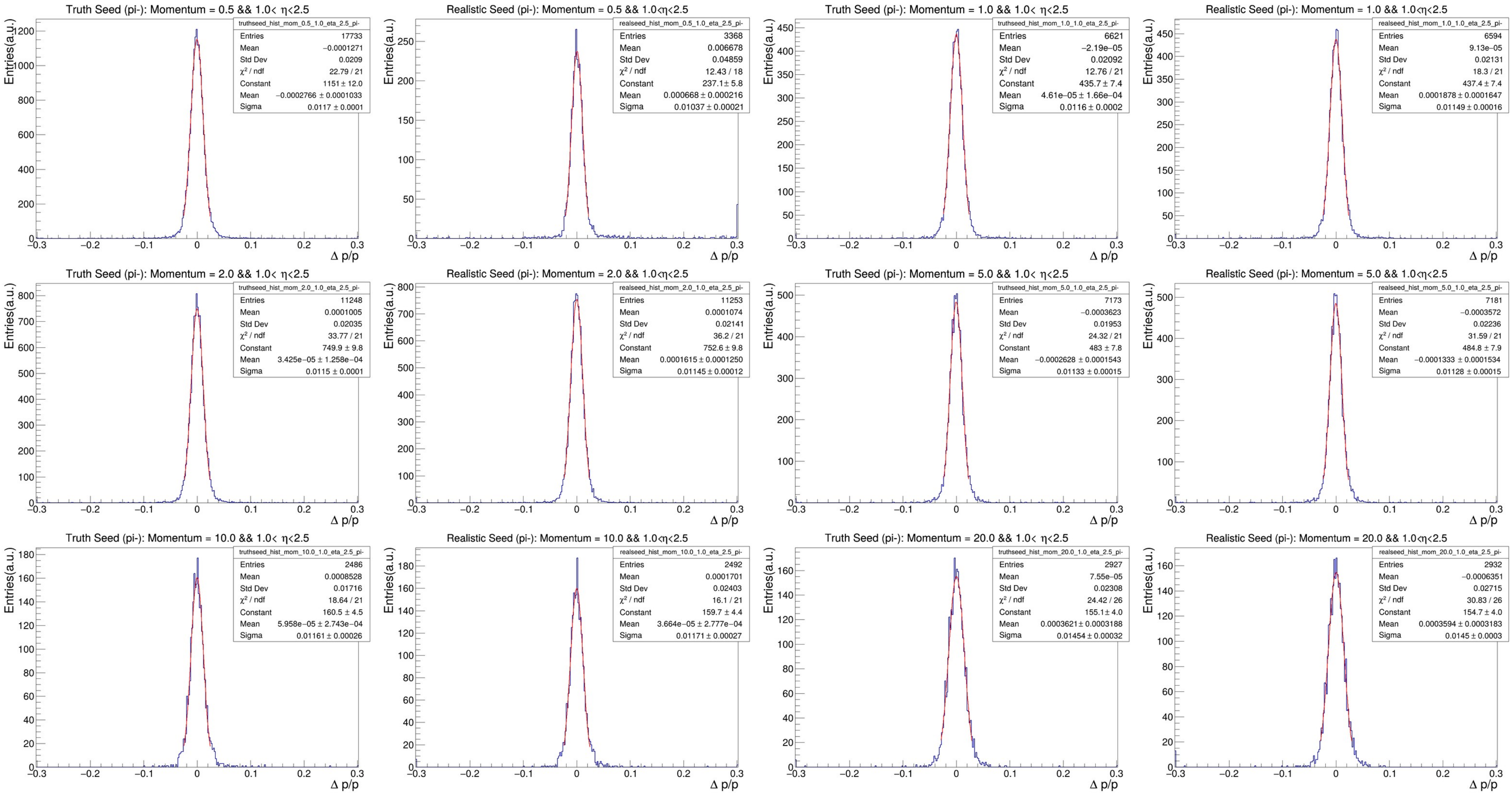
Momentum debug plots (25.10.4)

-1.0 < η < 1.0



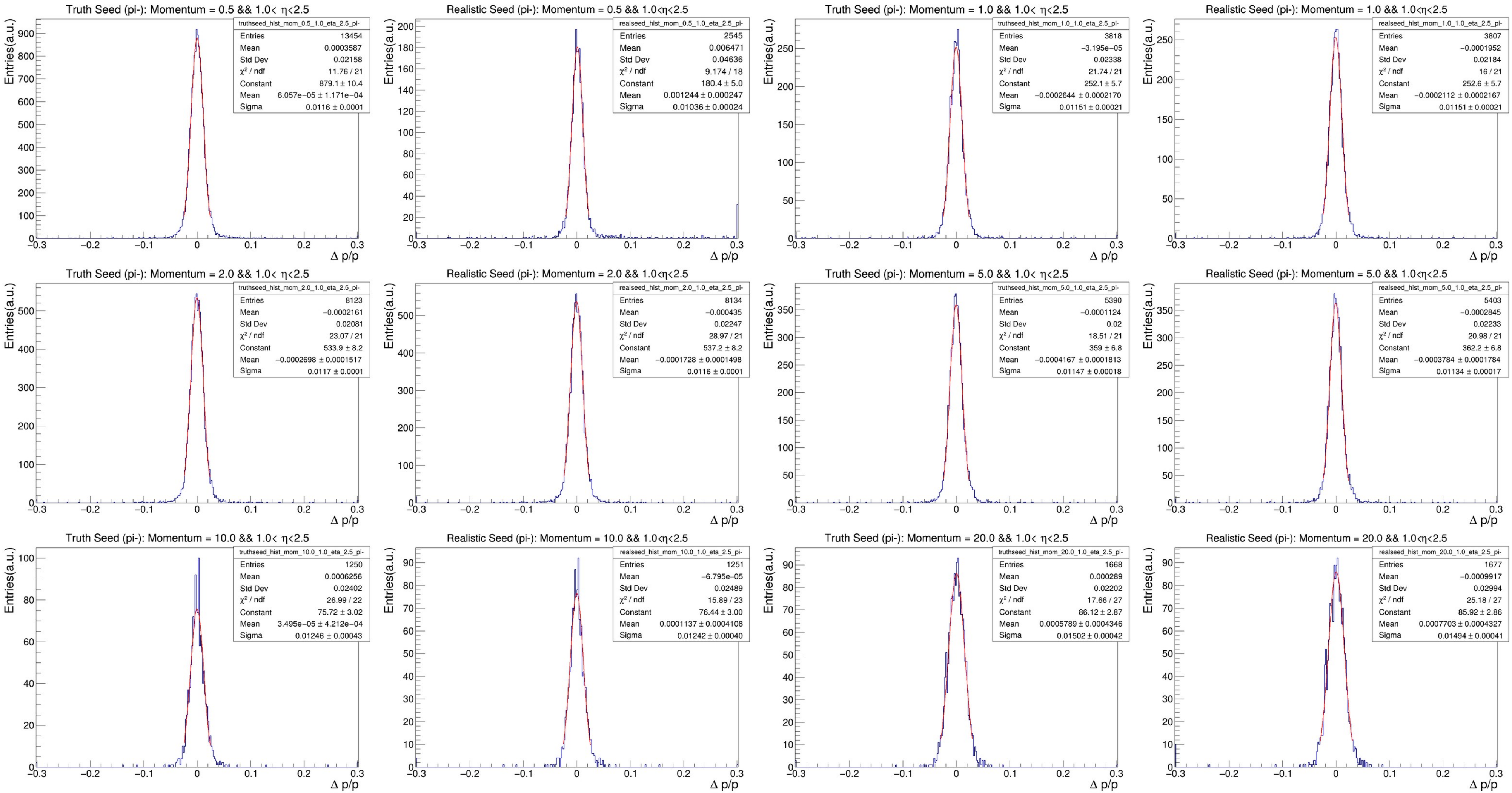
Momentum debug plots (25.07.0)

1.0 < η < 2.5



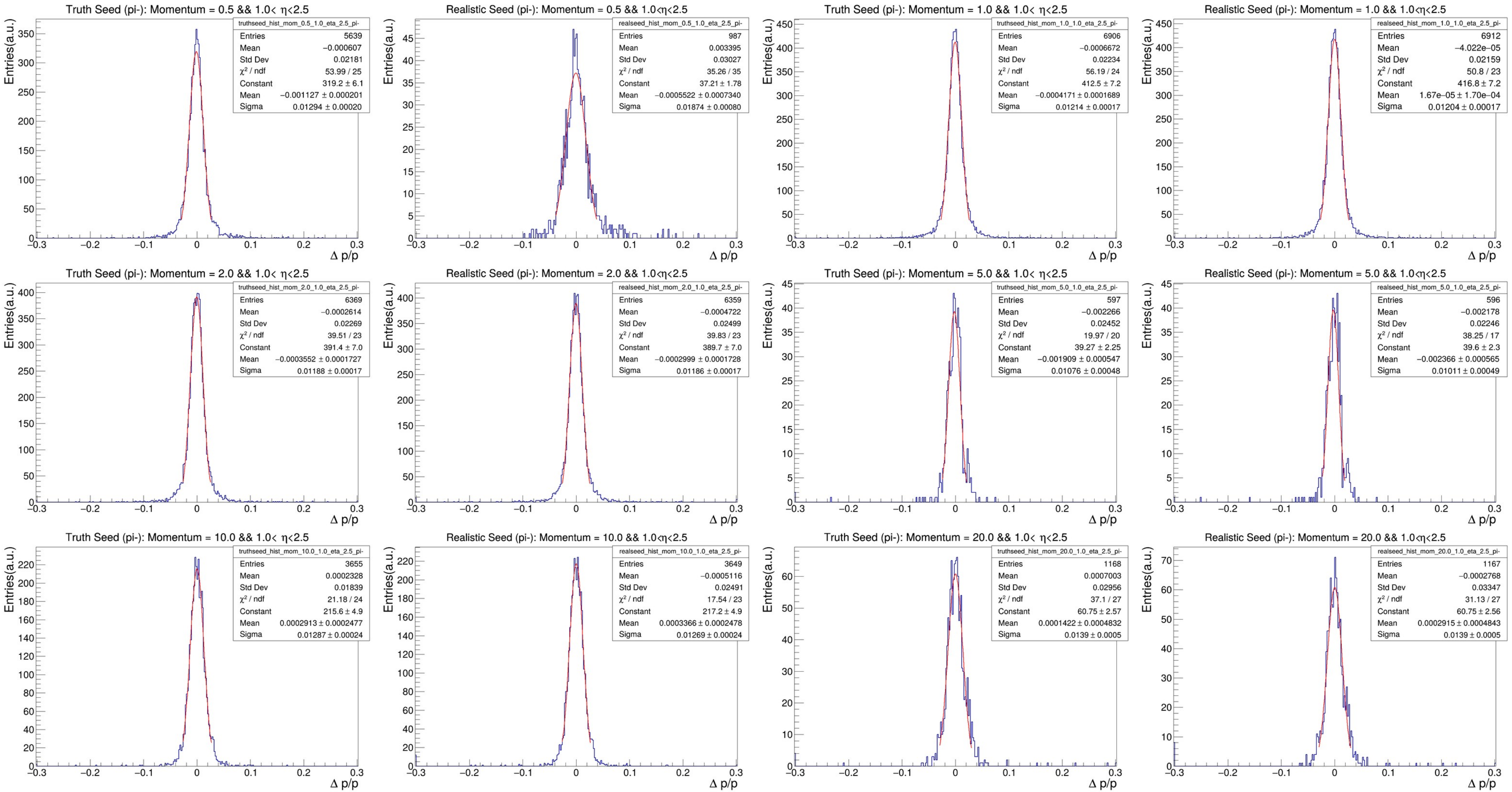
Momentum debug plots (25.08.0)

1.0 < η < 2.5



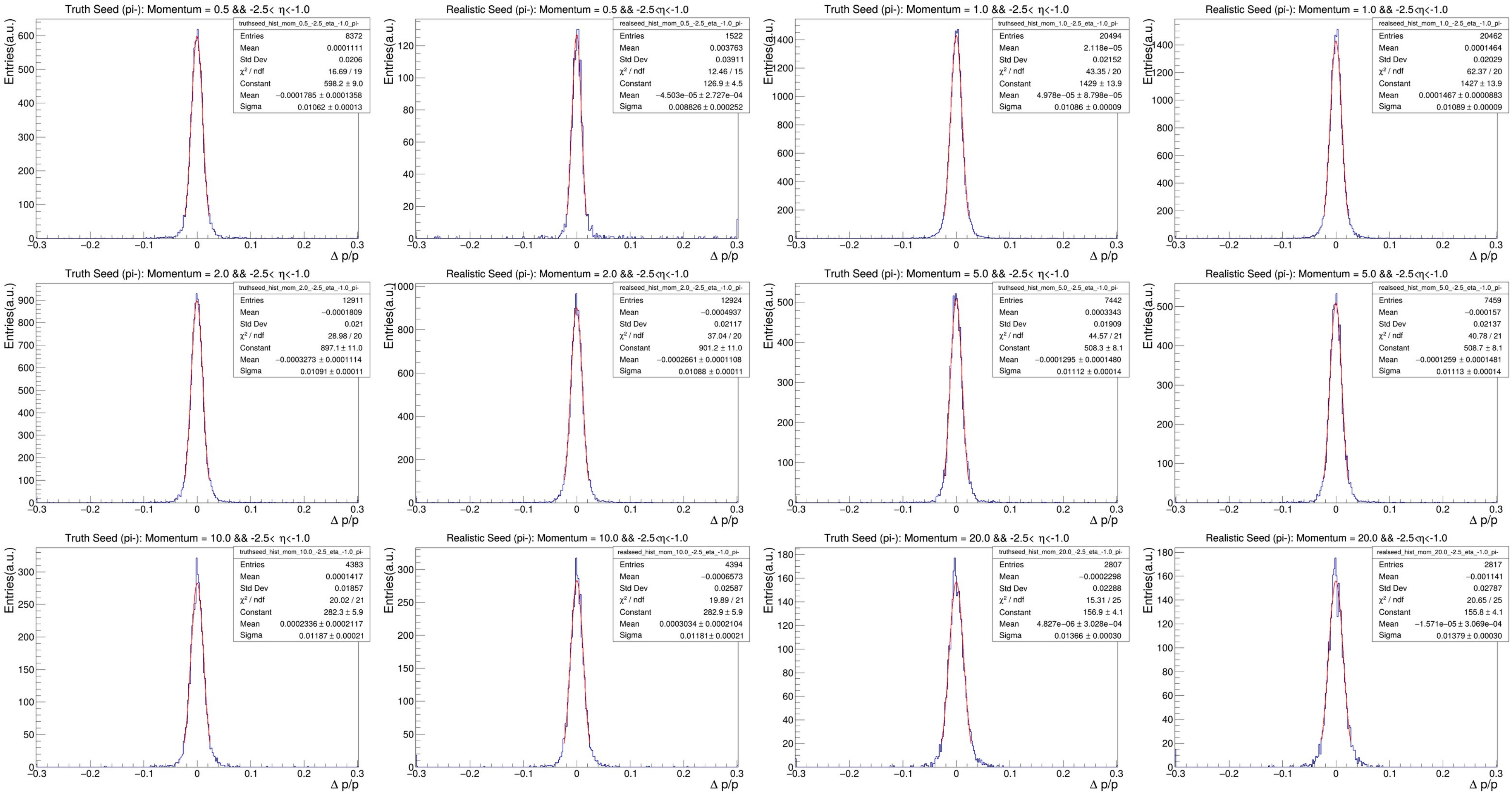
Momentum debug plots (25.10.4)

1.0 < η < 2.5



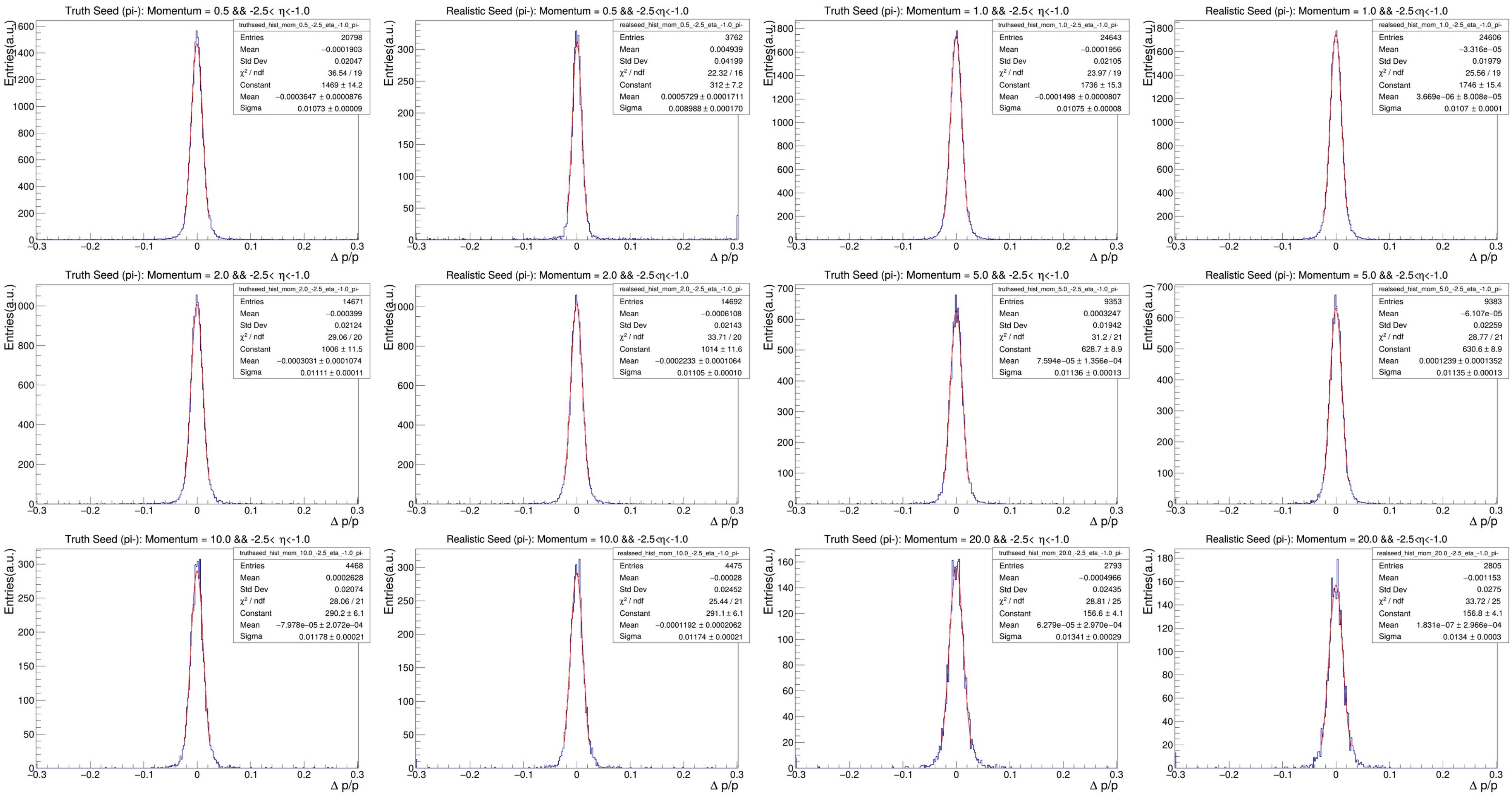
Momentum debug plots (25.07.0)

-2.5 < η < -1.0

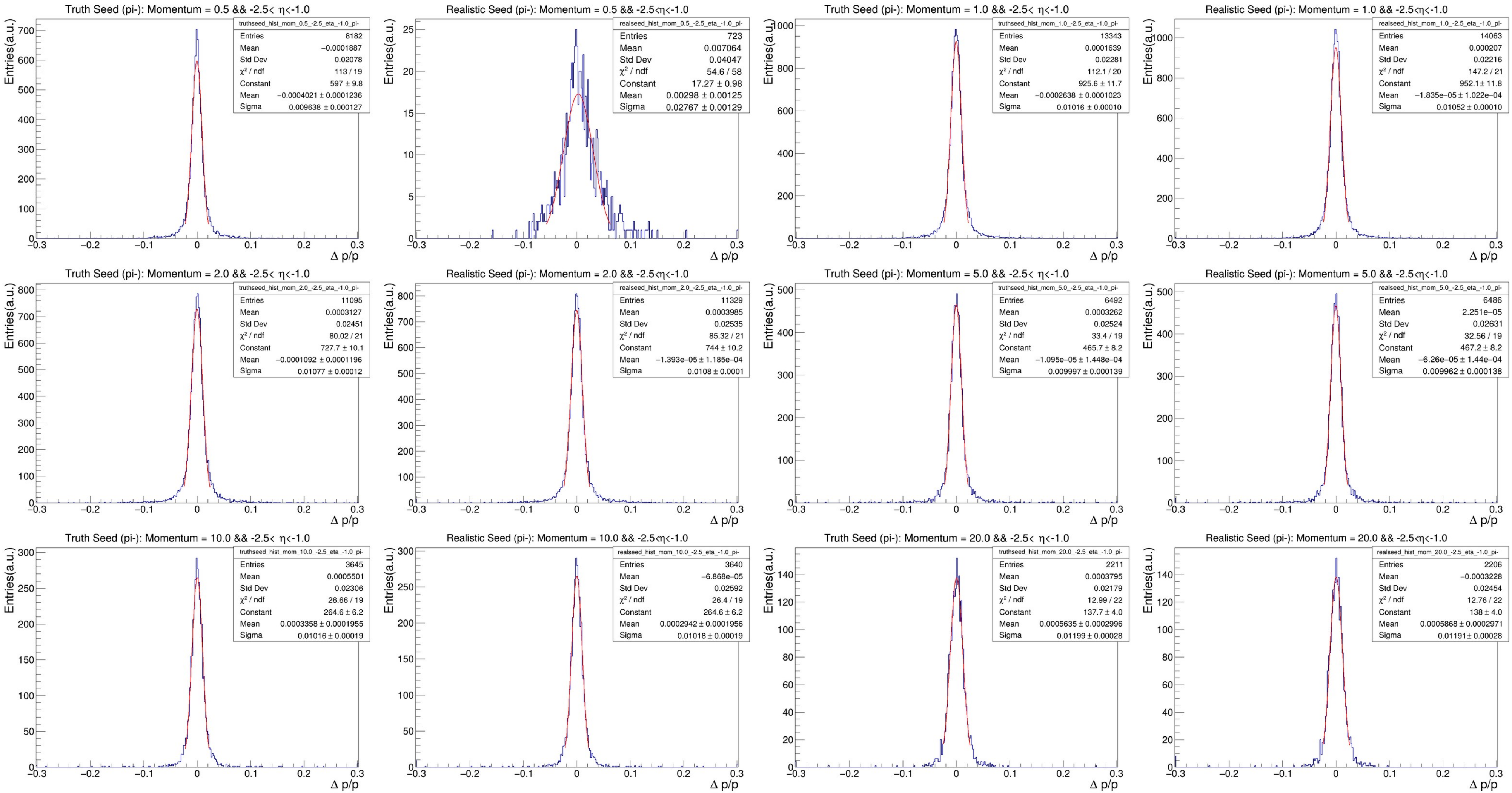


Momentum debug plots (25.08.0)

-2.5 < η < -1.0



-2.5 < η < -1.0


Truth Seed (pi-): Momentum = 0.5 && -2.5< η<-1.0
truthseed_hist_mom_0.5_-2.5_eta_-1.0_pi-
Entries 8182
Mean −0.0001887
Std Dev 0.02078
χ² / ndf 113 / 19
Constant 597 ± 9.8
Mean −0.0004021 ± 0.0001236
Sigma 0.009638 ± 0.000127
Realistic Seed (pi-): Momentum = 0.5 && -2.5<η<-1.0
realseed_hist_mom_0.5_-2.5_eta_-1.0_pi-
Entries 723
Mean 0.007064
Std Dev 0.04047
χ² / ndf 54.6 / 58
Constant 17.27 ± 0.98
Mean 0.00298 ± 0.00125
Sigma 0.02767 ± 0.00129
Truth Seed (pi-): Momentum = 1.0 && -2.5< η<-1.0
truthseed_hist_mom_1.0_-2.5_eta_-1.0_pi-
Entries 13343
Mean 0.0001639
Std Dev 0.02281
χ² / ndf 112.1 / 20
Constant 925.6 ± 11.7
Mean −0.0002638 ± 0.0001023
Sigma 0.01016 ± 0.00010
Realistic Seed (pi-): Momentum = 1.0 && -2.5<η<-1.0
realseed_hist_mom_1.0_-2.5_eta_-1.0_pi-
Entries 14063
Mean 0.000207
Std Dev 0.02216
χ² / ndf 147.2 / 21
Constant 952.1 ± 11.8
Mean −1.835e−05 ± 1.022e−04
Sigma 0.01052 ± 0.00010
Truth Seed (pi-): Momentum = 2.0 && -2.5< η<-1.0
truthseed_hist_mom_2.0_-2.5_eta_-1.0_pi-
Entries 11095
Mean 0.0003127
Std Dev 0.02451
χ² / ndf 80.02 / 21
Constant 727.7 ± 10.1
Mean −0.0001092 ± 0.0001196
Sigma 0.01077 ± 0.00012
Realistic Seed (pi-): Momentum = 2.0 && -2.5<η<-1.0
realseed_hist_mom_2.0_-2.5_eta_-1.0_pi-
Entries 11329
Mean 0.0003985
Std Dev 0.02535
χ² / ndf 85.32 / 21
Constant 744 ± 10.2
Mean −1.393e−05 ± 1.185e−04
Sigma 0.0108 ± 0.0001
Truth Seed (pi-): Momentum = 5.0 && -2.5< η<-1.0
truthseed_hist_mom_5.0_-2.5_eta_-1.0_pi-
Entries 6492
Mean 0.0003262
Std Dev 0.02524
χ² / ndf 33.4 / 19
Constant 465.7 ± 8.2
Mean −1.095e−05 ± 1.448e−04
Sigma 0.009997 ± 0.000139
Realistic Seed (pi-): Momentum = 5.0 && -2.5<η<-1.0
realseed_hist_mom_5.0_-2.5_eta_-1.0_pi-
Entries 6486
Mean 2.251e−05
Std Dev 0.02631
χ² / ndf 32.56 / 19
Constant 467.2 ± 8.2
Mean −6.26e−05 ± 1.44e−04
Sigma 0.009962 ± 0.000138
Truth Seed (pi-): Momentum = 10.0 && -2.5< η<-1.0
truthseed_hist_mom_10.0_-2.5_eta_-1.0_pi-
Entries 3645
Mean 0.0005501
Std Dev 0.02306
χ² / ndf 26.66 / 19
Constant 264.6 ± 6.2
Mean 0.0003358 ± 0.0001955
Sigma 0.01016 ± 0.00019
Realistic Seed (pi-): Momentum = 10.0 && -2.5<η<-1.0
realseed_hist_mom_10.0_-2.5_eta_-1.0_pi-
Entries 3640
Mean −6.868e−05
Std Dev 0.02592
χ² / ndf 26.4 / 19
Constant 264.6 ± 6.2
Mean 0.0002942 ± 0.0001956
Sigma 0.01018 ± 0.00019
Truth Seed (pi-): Momentum = 20.0 && -2.5< η<-1.0
truthseed_hist_mom_20.0_-2.5_eta_-1.0_pi-
Entries 2211
Mean 0.0003795
Std Dev 0.02179
χ² / ndf 12.99 / 22
Constant 137.7 ± 4.0
Mean 0.0005635 ± 0.0002996
Sigma 0.01199 ± 0.00028
Realistic Seed (pi-): Momentum = 20.0 && -2.5<η<-1.0
realseed_hist_mom_20.0_-2.5_eta_-1.0_pi-
Entries 2206
Mean −0.0003228
Std Dev 0.02454
χ² / ndf 12.76 / 22
Constant 138 ± 4.0
Mean 0.0005868 ± 0.0002971
Sigma 0.01191 ± 0.00028
Entries(a.u.)
Δ p/p

Covariance Matrix in ACTS

Track Parameters $(l_0, l_1, \phi, \theta, q/p, time)$

For each fitted track we get track parameters and covariance matrix

$$
\begin{array}{c|cccccc}
 & l_0 & l_1 & \phi & \theta & q/p & time \\
\hline
l_0 & \sigma^2(l_0) & \mathrm{cov}(l_0, l_1) & \mathrm{cov}(l_0, \phi) & \mathrm{cov}(l_0, \theta) & \mathrm{cov}(l_0, q/p) & \mathrm{cov}(l_0, t) \\
l_1 & . & \sigma^2(l_1) & \mathrm{cov}(l_1, \phi) & \mathrm{cov}(l_1, \theta) & \mathrm{cov}(l_1, q/p) & \mathrm{cov}(l_1, t) \\
\phi & . & . & \sigma^2(\phi) & \mathrm{cov}(\phi, \theta) & \mathrm{cov}(\phi, q/p) & \mathrm{cov}(\phi, t) \\
\theta & . & . & . & \sigma^2(\theta) & \mathrm{cov}(\theta, q/p) & \mathrm{cov}(\theta, t) \\
q/p & . & . & . & . & \sigma^2(q/p) & \mathrm{cov}(q/p, t) \\
time & . & . & . & . & . & \sigma^2(t)
\end{array}
$$

Symmetric matrix: Independent entries = n(n+1)/2 = 6*7/2 = 21

```
Processing ReadCovarianceArray_new.C...
Event 0, number of tracks: 8
  Track 0 covariance:
    cov[0] = 0.0104456
    cov[1] = 2.366e-06
    cov[2] = 0.0103324
    cov[3] = -0.000289634
    cov[4] = 7.52669e-07
    cov[5] = 8.04972e-06
    cov[6] = -8.12589e-07
    cov[7] = 0.000284166
    cov[8] = 4.50984e-08
    cov[9] = 7.82997e-06
    cov[10] = 0.000153944
    cov[11] = 7.02629e-07
    cov[12] = -4.94218e-06
    cov[13] = 5.14138e-09
    cov[14] = 0.00011838
    cov[15] = -1.41347e-06
    cov[16] = -3.20263e-06
    cov[17] = 3.89044e-08
    cov[18] = -8.82041e-08
    cov[19] = 2.242e-09
    cov[20] = 0.000333566
```

Cov[0] = cov(l0, l0)
Cov[1] = cov(l0, l1)
Cov[2] = cov(l1, l1)
Cov[3] = cov(l0, φ)
cov[4] = cov(l1, φ)
cov[5] = cov(φ, φ)
cov[6] = cov(l0, θ)
cov[7] = cov(l1, θ)
cov[8] = cov(φ, θ)
cov[9] = cov(θ, θ)
cov[10] = cov(l0, q/p)
Cov[11] = cov(l1, q/p)
Cov[12] = cov(φ, q/p)
Cov[13] = cov(θ, q/p)
Cov[14] = cov(q/p, q/p)
Cov[15] = cov(l0, time)
Cov[16] = cov(l1, time)
Cov[17] = cov(φ, time)
Cov[18] = cov(θ, time)
Cov[19] = cov(q/p, time)
Cov[20] = cov(time, time)

$\sigma_{l0} = \sqrt{(Cov[0])}$ $\quad \sigma_{l1} = \sqrt{(Cov[2])}$

$\sigma_{\phi} = \sqrt{(Cov[5])}$ $\quad \sigma_{\theta} = \sqrt{(Cov[9])}$

$\sigma_q / p = \sqrt{(Cov[14])}$