Validation of track refitting on testsamples

ILD software and analysis meeting

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HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

Universität Hamburg
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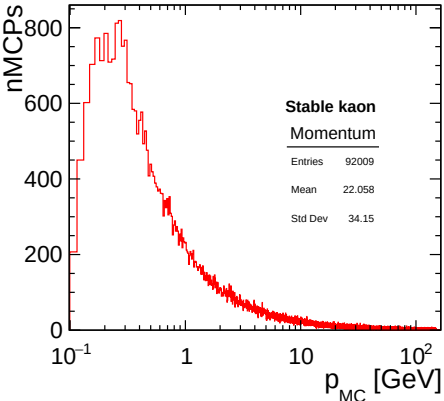
Motivation

- So far, tracks are fitted using Pandora PFA with pion mass
- Potential improvement of track re-fitting with true mass:
  - better momentum reconstruction for low momentum particles
  - correct consideration of mass of charged PFOs when calcualting E from $\vec{p}$
  - improved vertexing $\Rightarrow$ improved flavourtag
- Single particle samples: (ILCSoft v02-00-02)
  single K^+ and p^+: 10k samples per p per θ
  p=1,3,5,10,15,25,50 & 100 GeV
  θ=15^o, 25^o,..., 85^o
  - comparison based on track parameters (d_0, z_0 and p_T) resolution and bias
- New production samples:
  new software version: ILCSoft v02-01 ; MarlinTrkTracksKaon & MarlinTrkTracksProton
  single K^+ and p^+: each 100k samples (distributed p and θ)
  - validation: E/p distributions, d_0, z_0 and p_T resolution/bias

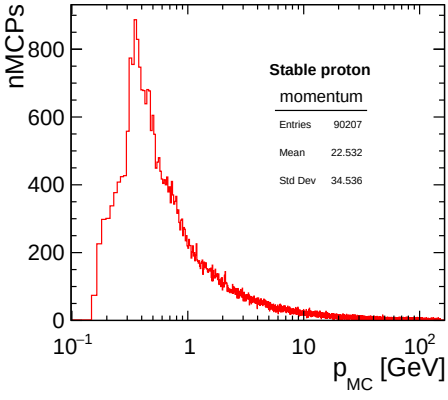
Momentum spectrum of Kaons/protons

new production samples, generator level

- Momentum dist. of Kaons



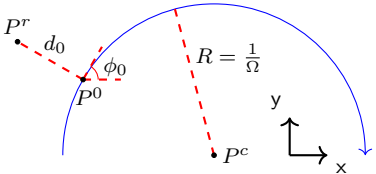
- Momentum dist. of Protons

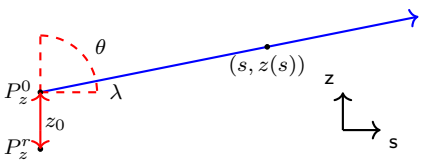


- most of particles in low momentum region
- in low momentum region: higher impact of mass in Energy calculation from momentum ($E = \sqrt{m^2 + p^2}$)

Track parameters definition in linear colliders

- For vertexing and flavour tagging, track parameters are important:
  - d_0 and z_0 for finding $2^{nd}/3^{rd}$ vertices
  - Ω, ϕ_0 and $\tan\lambda$ for momentum reconstruction
    (at P^0: $|p_T| = \frac{eB}{\Omega}$, $p_x = |p_T|\cos\phi_0$, $p_y = |p_T|\sin\phi_0$, $p_z = |p_T|\tan\lambda$)
    $\Rightarrow$ Energy of charged particles ($E = \sqrt{m^2 + |\vec{p}|^2}$)





- So far: tracks are fitted using pion mass (default in PandoraPFA)
- Now: Refitting tracks with true mass of charged particle

Pull distribution

d_0 **pull**

tracks refitted with:

proton mass

and

pion mass

charge separation:

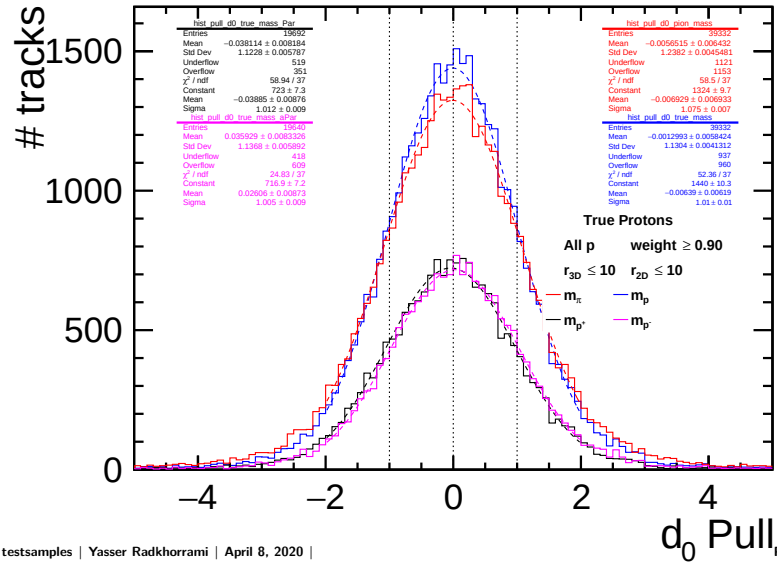
positive charges (p^+)

negative charges (p^-)

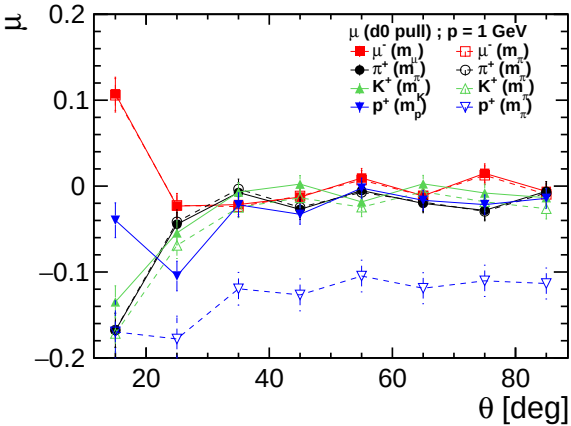
pull = $\frac{residual}{uncertainty}$

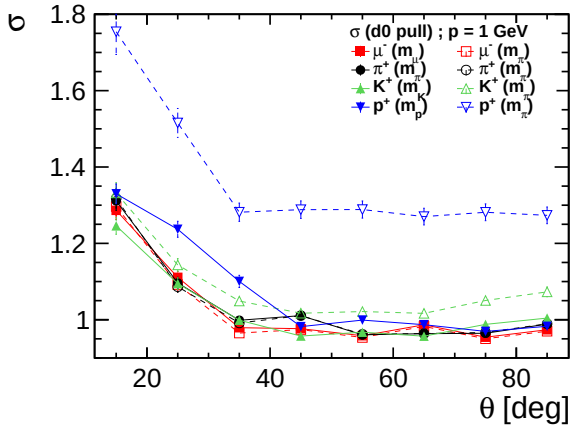
residual = $reco - true$

uncertainty: CovMatrix elements



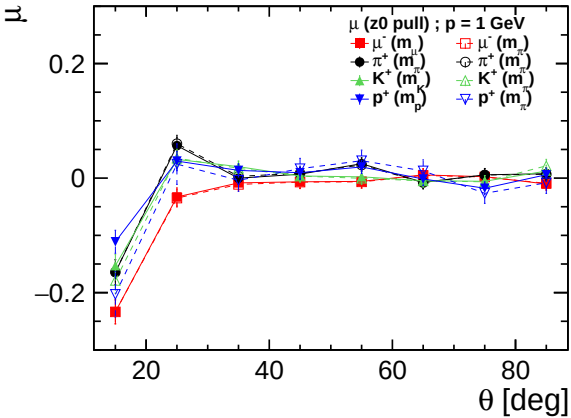
angular dependency of d_0 pull

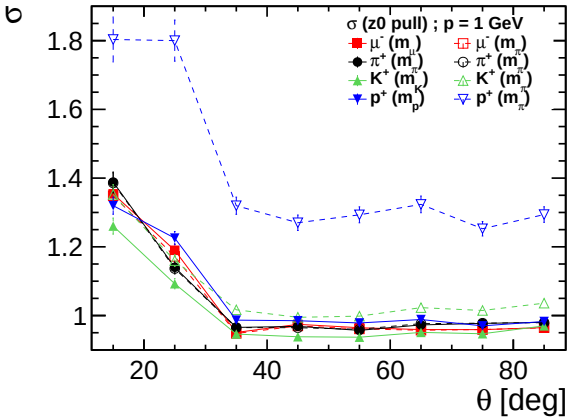




- refitting with true mass ⇒ improved impact parameter resolution for $m > m_\pi$ (Kaons & protons)
- better vertex finding performance (is expected)

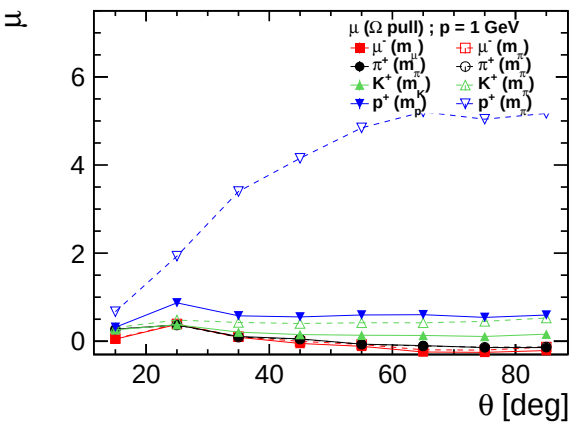
angular dependency of z_0 pull

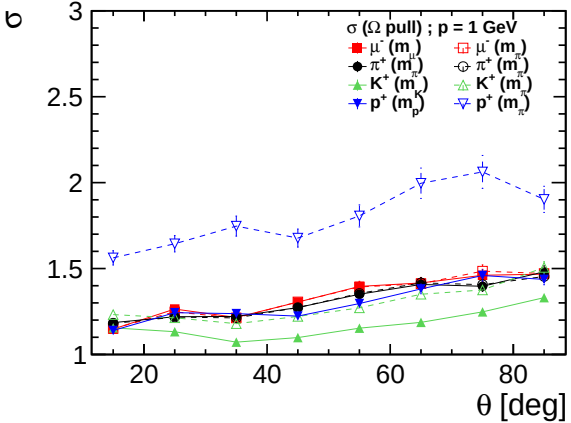




- refitting with true mass ⇒ improved impact parameter resolution for $m > m_\pi$ (Kaons & protons)
- better vertex finding performance (is expected)

angular dependency of Ω pull





- refitting with true mass $\Rightarrow$ improved momentum reconstruction for p and K (expected)
- higher importance to refit low momentum tracks with true mass in barrel!

Tracking refitting: bias improvement

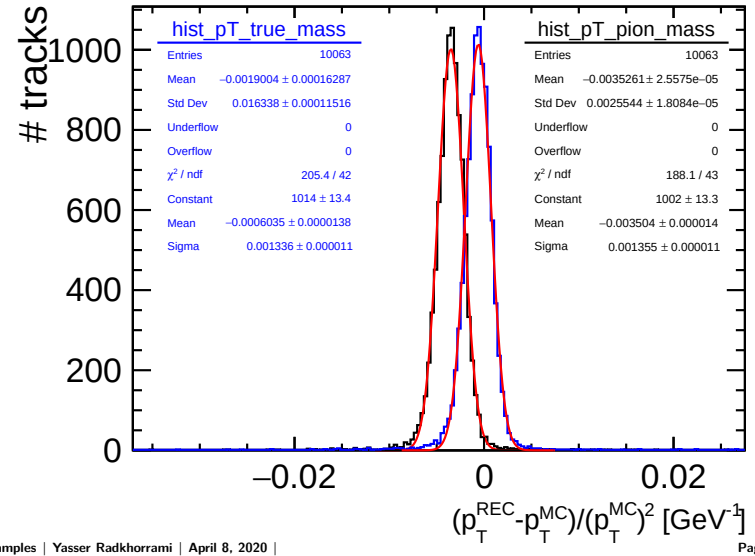
single protons: $p = 1$ **GeV** , $\theta = 85^o$

- Track refitting with true mass (barrel):

  same resolution

  drastically reduced bias

  More accurate p with refitted tracks



Tracking refitting: bias improvement (cntd)

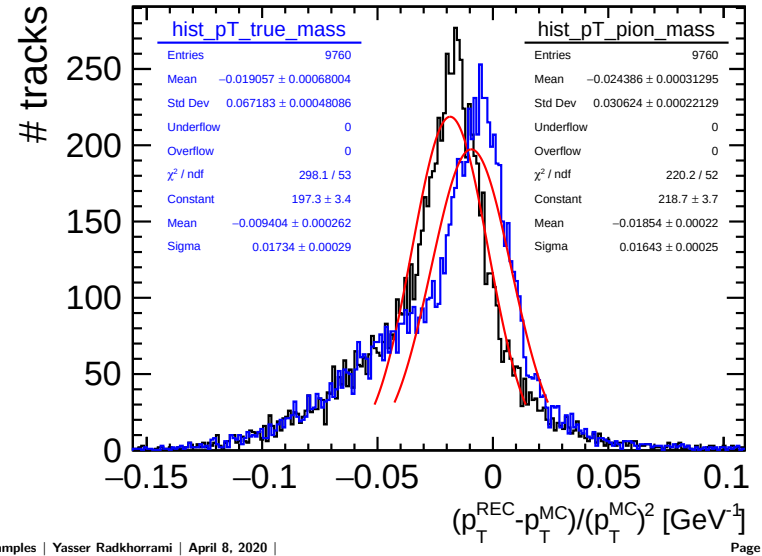
single protons: $p = 1$ **GeV** , $\theta = 25^o$

- Track refitting with true mass(forward):

  same resolution

  drastically reduced bias

  larger error compared with barrel



Tracking refitting: bias improvement (cntd)

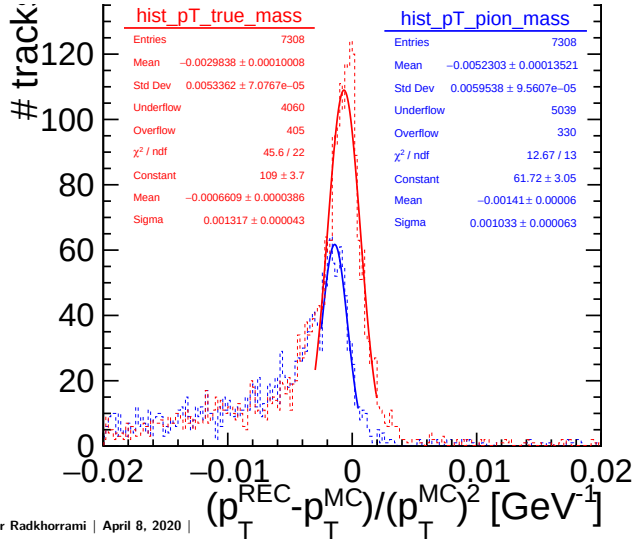
new production samples: 0.1 $\leq p \leq =$ 1.5 GeV , $\theta \geq 80^o$

- Track refitting with true mass (protons): (mid. detector)

  same resolution

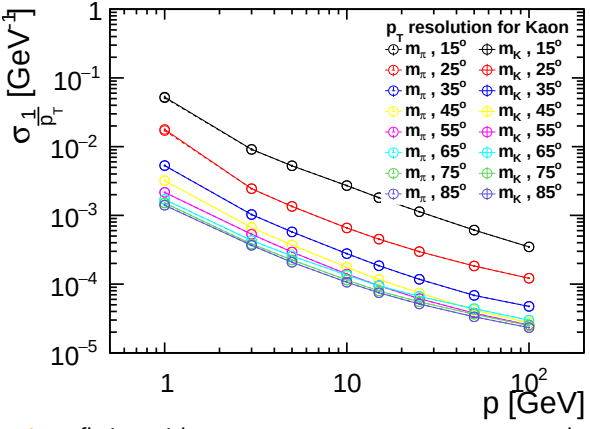
  reduced bias

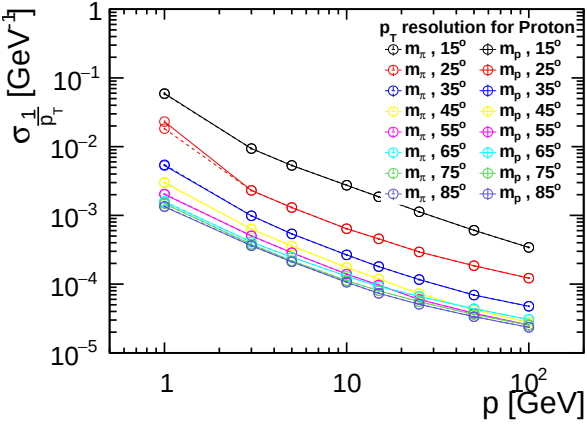
  larger error compared with fixed p/θ



Momentum resolution, $\sigma_{\frac{1}{p_T}}$

$\sigma_{\frac{1}{p_T}}$: $(\frac{p_T^{REC} - p_T^{MC}}{(p_T^{MC})^2})$ width

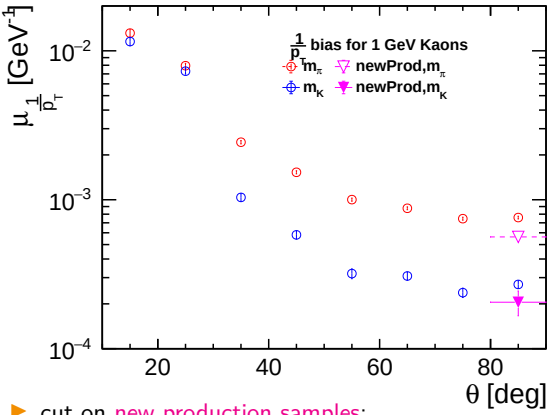


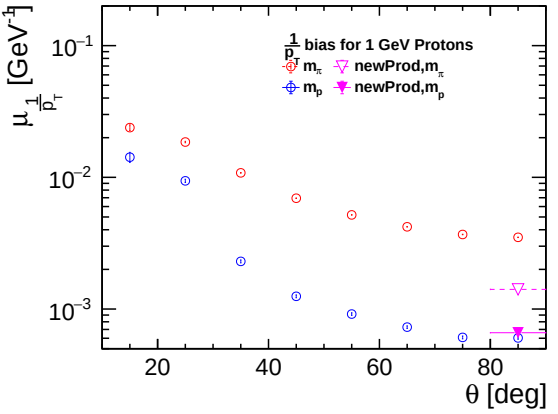


- refitting with true mass ⇒ same momentum resolution

Transverse momentum bias, $\mu_{\frac{1}{p_T}}$

single Kaon/proton: $p = 1$ GeV , $\theta = 15, 25, ..., 85^o$

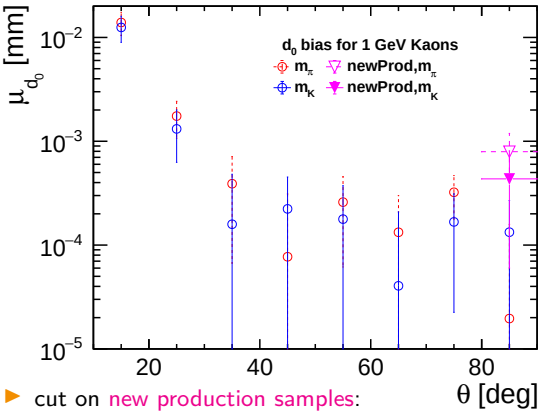


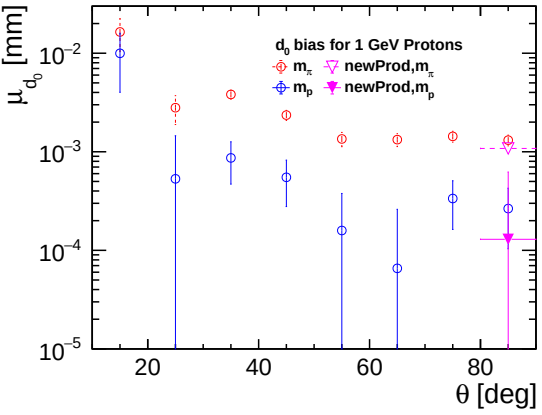


- cut on new production samples:
  - Kaons: $0.1 \leq p \leq 1.5$ GeV , $\theta \geq 80^o$
  - Protons: $0.1 \leq p \leq 1.5$ GeV , $\theta \geq 80^o$
- reduced p_T bias $\Rightarrow$ more accurate p/E Reco.

Impact parameter bias, μ_{d_0}

single Kaon/proton: $p = 1$ GeV , $\theta = 15, 25, ..., 85^o$



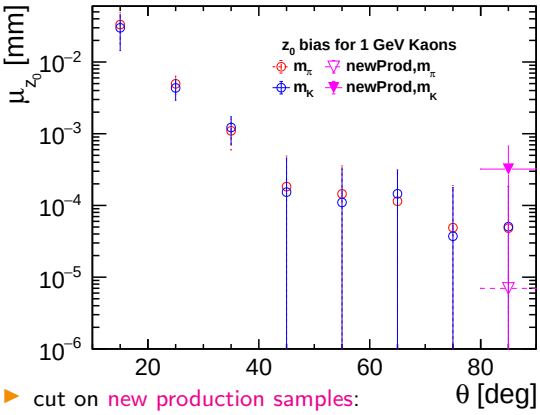


- cut on new production samples:
  - Kaons: $0.1 \leq p \leq 1.5$ GeV , $\theta \geq 80^o$
  - Protons: $0.1 \leq p \leq 1.5$ GeV , $\theta \geq 80^o$

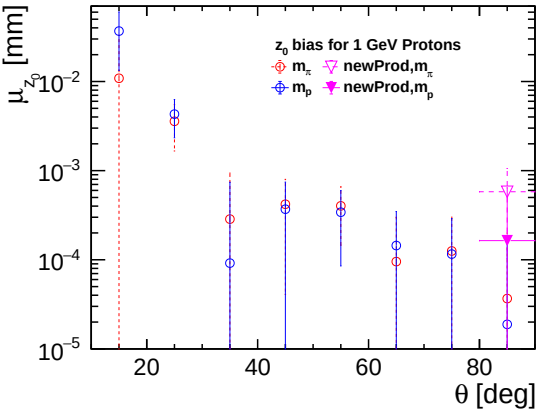
- reduced d_0 bias $\Rightarrow$ more accurate vertexing

Impact parameter bias, μ_{z_0}

single Kaons/protons: $p = 1$ GeV , $\theta = 15, 25, ..., 85^o$



- cut on new production samples:
  - Kaons: $0.1 \leq p \leq 1.5$ GeV , $\theta \geq 80^o$
  - Protons: $0.1 \leq p \leq 1.5$ GeV , $\theta \geq 80^o$

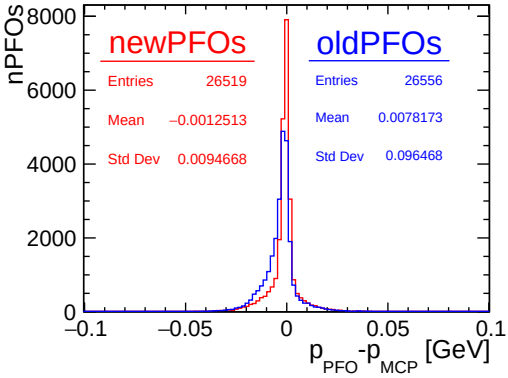


- refitting with true mass ⇒ reduced z_0 bias

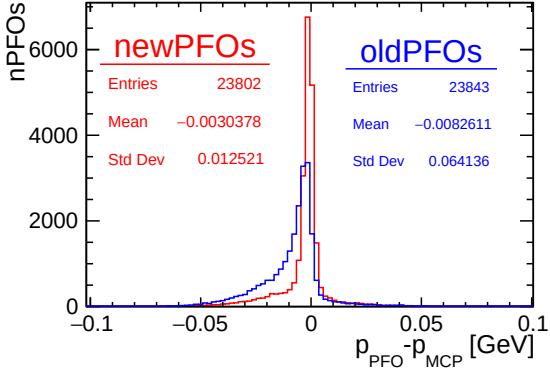
Momentum reconstruction in new production samples

using refitted trackes with true mass

Kaon ($p \leq 2$ GeV)



Proton ($p \leq 2$ GeV)

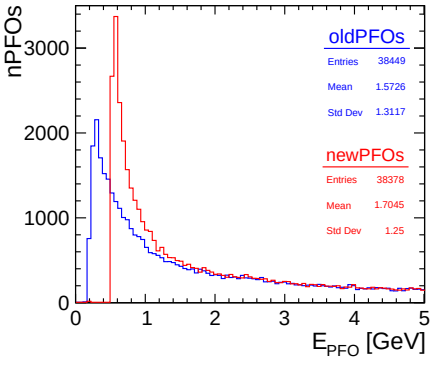


- Improved momentum reconstruction with refitted tracks:
  - oldPFO: reconstructed particle with original track(s) (MarlinTrkTracks)
  - newPFO: reconstructed particle with refitted track(s) (MarlinTrkTracksKaon/Proton)

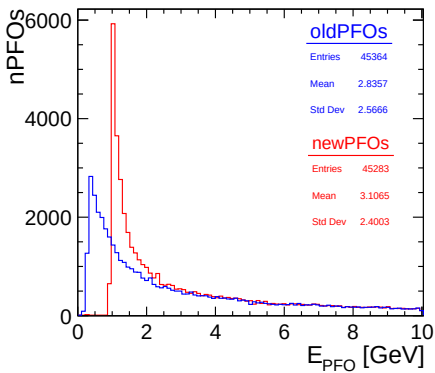
Energy reconstruction in new production samples

using refitted trackes with true mass

Kaon ($p \leq 2$ GeV)



Proton ($p \leq 2$ GeV)



- Improved Energy reconstruction: **improved momentum + taking correct mass of particle**:
  - oldPFO: reconstructed particle with original track(s) (MarlinTrkTracks), $m_{PFO} = m_{\pi}$
  - newPFO: reconstructed particle with refitted track(s) (MarlinTrkTracksKaon/Proton), $m_{PFO} = m_K/m_p$

Conclusion

- Low momentum charged particles are required to be refitted
  $\Rightarrow$ more correct estimate of the track parameters
  $\Rightarrow$ more correct estimate of the momentum and the impact parameters
- New production samples (standard reconstruction):
  - refit all tracks with proton mass $\rightarrow$ MarlinTrkTracksProton ✓
  - refit all tracks with Kaon mass $\rightarrow$ MarlinTrkTracksKaon ✓
- Drastic improvements:
  - reduced $\frac{1}{p_T}$ bias by a factor of 2 - 3
  - reduced $d_0 z_0$ bias by a factor of 2 - 10
- Further expected improvements:
  - improved vertexing flavour tagging

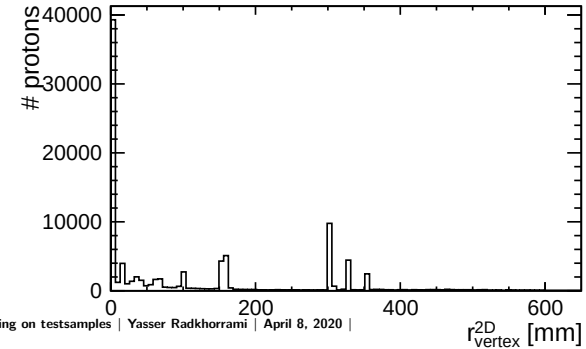
BACKUP

Vertex of charged particles (e and p)

$e^+e^- \to b\bar{b}$, $\sqrt{s} = 40 \oplus 91 \oplus 200 \oplus 350 \oplus 500$ **GeV**

Protons vertex in $x - y$ plane ($r^{2D} = \sqrt{x^2 + y^2}$).

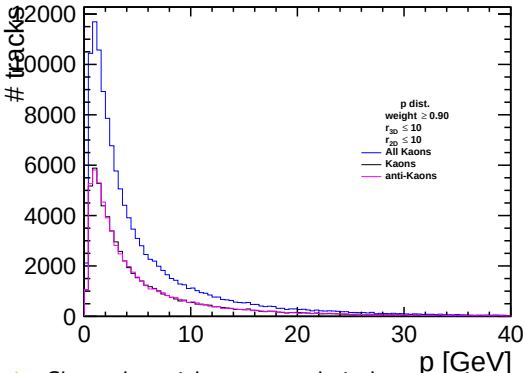
- VXT: $r_{in} = 16\ mm$, $r_{out} = 60\ mm$, $z_{max} = 125\ mm$
- SIT: $r_{in} = 153\ mm$, $r_{out} = 303\ mm$, $z_{max} = 644\ mm$
- TPC: $r_{in} = 329\ mm$, $r_{out} = 1770\ mm$, $z_{max} = 2350\ mm$
- SET: $r_{in} = 1773\ mm$, $r_{out} = 1776\ mm$, $z_{max} = 2300\ mm$
- Protons vertex



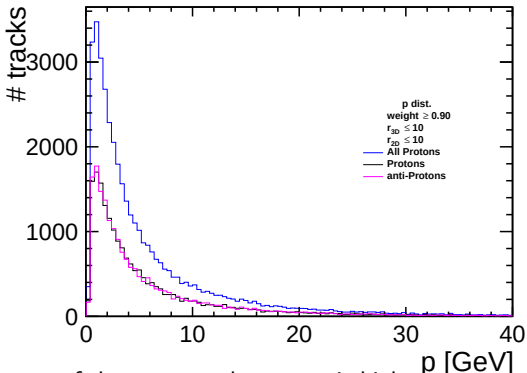
Momentum spectrum of charged particles (generator level)

$e^+e^- \to b\bar{b}$, $\sqrt{s} = 40 \oplus 91 \oplus 200 \oplus 350 \oplus 500$ **GeV, 10k events per energy point**

- Momentum dist. of Kaons



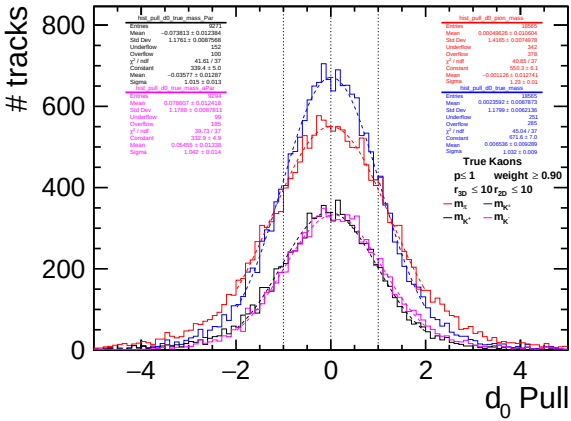
- Momentum dist. of Protons

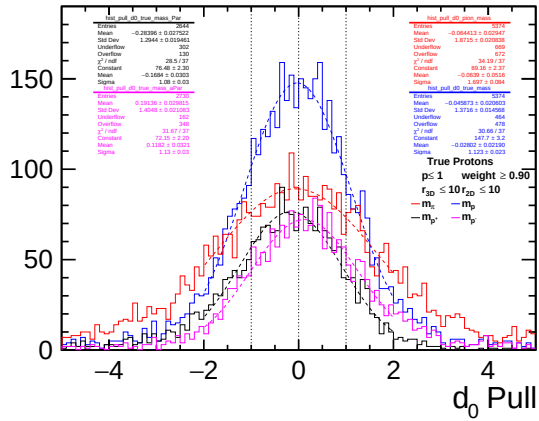


- Charged particles are mostly in low p region, where impact of the mass on the energy is high ($E = \sqrt{m^2 + p^2}$)

  $\Rightarrow$ Focus on low momentum region

d_0 pull


hist_pull_d0_true_mass_Par
Entries 9271
Mean −0.073813 ± 0.012394
Std Dev 1.1761 ± 0.0087568
Underflow 152
Overflow 100
χ² / ndf 41.61 / 37
Constant 339.4 ± 5.0
Mean −0.03577 ± 0.01287
Sigma 1.015 ± 0.013
hist_pull_d0_true_mass_aPar
Entries 9294
Mean 0.078007 ± 0.012418
Std Dev 1.1788 ± 0.0087811
Underflow 99
Overflow 185
χ² / ndf 39.73 / 37
Constant 332.9 ± 4.9
Mean 0.05455 ± 0.01139
Sigma 1.042 ± 0.014
hist_pull_d0_pton_mass
Entries 18565
Mean 0.00046626 ± 0.010004
Std Dev 1.4165 ± 0.0074978
Underflow 342
Overflow 378
χ² / ndf 40.85 / 37
Constant 550.3 ± 6.1
Mean −0.001126 ± 0.010741
Sigma 1.23 ± 0.01
hist_pull_d0_true_mass
Entries 18565
Mean 0.0023592 ± 0.0067873
Std Dev 1.1799 ± 0.0062136
Underflow 251
Overflow 285
χ² / ndf 45.04 / 37
Constant 671.6 ± 7.0
Mean 0.006536 ± 0.006289
Sigma 1.032 ± 0.009
True Kaons
p≤ 1 weight ≥ 0.90
r3D ≤ 10 r2D ≤ 10
mc mb
mK- mK+
tracks
d0 Pull


hist_pull_d0_true_mass_Par
Entries 2644
Mean −0.282396 ± 0.027522
Std Dev 1.2944 ± 0.019461
Underflow 302
Overflow 130
χ² / ndf 28.5 / 37
Constant 76.48 ± 2.30
Mean −0.1894 ± 0.0303
Sigma 1.08 ± 0.03
hist_pull_d0_true_mass_aPar
Entries 2730
Mean 0.19136 ± 0.029815
Std Dev 1.4048 ± 0.021083
Underflow 162
Overflow 348
χ² / ndf 31.67 / 37
Constant 72.15 ± 2.20
Mean 0.1182 ± 0.0321
Sigma 1.13 ± 0.03
hist_pull_d0_ptop_mass
Entries 5374
Mean −0.064413 ± 0.02947
Std Dev 1.8715 ± 0.020838
Underflow 669
Overflow 672
χ² / ndf 34.19 / 37
Constant 89.16 ± 2.37
Mean −0.0639 ± 0.0516
Sigma 1.697 ± 0.084
hist_pull_d0_true_mass
Entries 5374
Mean −0.045873 ± 0.026003
Std Dev 1.3716 ± 0.014568
Underflow 464
Overflow 478
χ² / ndf 30.66 / 37
Constant 147.7 ± 3.2
Mean −0.02802 ± 0.02190
Sigma 1.323 ± 0.023
True Protons
p≤ 1 weight ≥ 0.90
r3D ≤ 10 r2D ≤ 10
mc mb
mp- mp+
tracks
d0 Pull

d_0-pull interpretation

- mean and width:

  d_0 of protons and Kaons are better found with true mass.

  μ's don't need to refit with true mass ($m_\mu \approx m_\pi$).

  d_0 of electrons with m_π are still a bit better than true mass m_e

- bias:

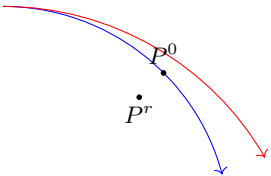
  (I). Positive charged particles: $(d_0 = P^0 - P^r)$

  $q > 0 \Rightarrow \Omega > 0$; d_0 pull biased to left $\Rightarrow d_0^{rec} - d_0^{MC} < 0$

a. P^r inside the arc:

sgn(d_0)=sgn(Ω) $\Rightarrow d_0 > 0$

$d_0^{rec} < d_0^{MC} \Rightarrow |d_0^{rec}| < |d_0^{MC}|$



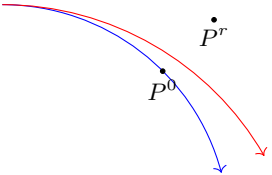
Blue: REC

Red: MC

b. P^r outside the arc:

sgn(d_0)=-sgn(Ω) $\Rightarrow d_0 < 0$

$d_0^{rec} < d_0^{MC} \Rightarrow |d_0^{rec}| > |d_0^{MC}|$



d_0-pull interpretation

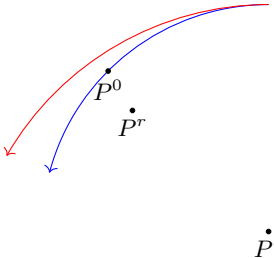
(II). Negative charged particles: ($d_0 = P^0 - P^r$)

$q < 0 \Rightarrow \Omega < 0$; d_0 pull biased to right $\Rightarrow d_0^{rec} - d_0^{MC} > 0$

a. P^r inside the arc:

sgn(d_0)=sgn(Ω) $\Rightarrow d_0 < 0$

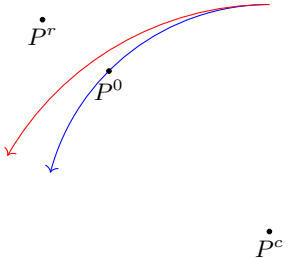
$d_0^{rec} > d_0^{MC} \Rightarrow |d_0^{rec}| < |d_0^{MC}|$



b. P^r outside the arc:

sgn(d_0)=-sgn(Ω) $\Rightarrow d_0 > 0$

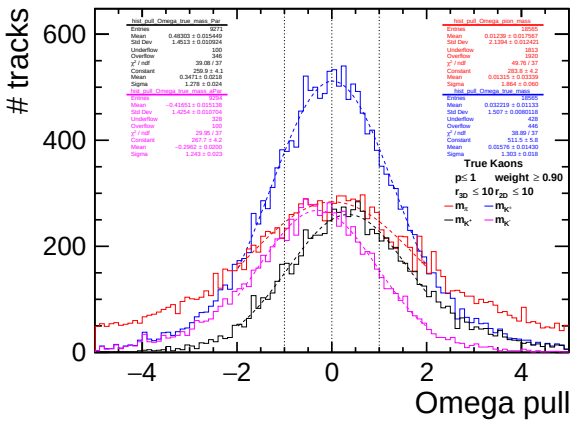
$d_0^{rec} > d_0^{MC} \Rightarrow |d_0^{rec}| > |d_0^{MC}|$

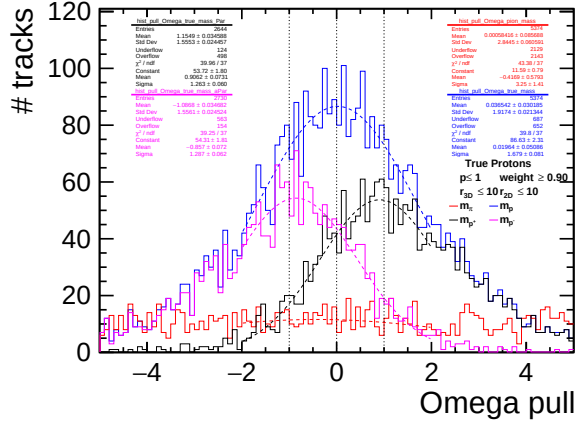


Blue: REC

Red: MC

Ω pull


hist_pull_Omega_true_mass_Par
Entries 9271
Mean 0.48303 ± 0.015449
Std Dev 1.4513 ± 0.010924
Underflow 100
Overflow 346
χ² / ndf 39.08 / 37
Constant 259.9 ± 4.1
Mean 0.3471 ± 0.0218
Sigma 1.278 ± 0.024
hist_pull_Omega_true_mass_aPar
Entries 9239
Mean -0.41651 ± 0.015138
Std Dev 1.4254 ± 0.010704
Underflow 328
Overflow 109
χ² / ndf 29.85 / 37
Constant 287.7 ± 4.2
Mean -0.2962 ± 0.0200
Sigma 1.243 ± 0.023
hist_pull_Omega_pion_mass
Entries 18565
Mean 0.01230 ± 0.017567
Std Dev 2.1394 ± 0.012421
Underflow 1813
Overflow 1620
χ² / ndf 49.76 / 37
Constant 283.8 ± 4.2
Mean 0.01315 ± 0.01339
Sigma 1.864 ± 0.060
hist_pull_Omega_true_mass
Entries 18565
Mean 0.032219 ± 0.01133
Std Dev 1.507 ± 0.008018
Underflow 428
Overflow 446
χ² / ndf 38.89 / 37
Constant 511.5 ± 5.8
Mean 0.01576 ± 0.01430
Sigma 1.303 ± 0.018
True Kaons
p≤ 1 weight ≥ 0.90
r3D ≤ 10 r2D ≤ 10
mΞ
mΩ-
mK-
mK
tracks
Omega pull


hist_pull_Omega_true_mass_Par
Entries 2644
Mean 1.1549 ± 0.034588
Std Dev 1.5553 ± 0.024457
Underflow 124
Overflow 498
χ² / ndf 39.96 / 37
Constant 53.72 ± 1.80
Mean 0.9062 ± 0.0731
Sigma 1.263 ± 0.060
hist_pull_Omega_true_mass_aPar
Entries 2730
Mean -1.0868 ± 0.034682
Std Dev 1.5581 ± 0.024524
Underflow 583
Overflow 154
χ² / ndf 39.25 / 37
Constant 54.31 ± 1.81
Mean -0.857 ± 0.072
Sigma 1.297 ± 0.062
hist_pull_Omega_pion_mass
Entries 5374
Mean 0.00058416 ± 0.0485688
Std Dev 2.8445 ± 0.060591
Underflow 2129
Overflow 2143
χ² / ndf 43.38 / 37
Constant 11.59 ± 0.79
Mean -0.4169 ± 0.5793
Sigma 3.25 ± 1.41
hist_pull_Omega_true_mass
Entries 5374
Mean 0.036542 ± 0.030185
Std Dev 1.9174 ± 0.021344
Underflow 687
Overflow 652
χ² / ndf 39.8 / 37
Constant 86.63 ± 2.31
Mean 0.01964 ± 0.05086
Sigma 1.679 ± 0.081
True Protons
p≤ 1 weight ≥ 0.90
r3D ≤ 10 r2D ≤ 10
mΞ
mΩ-
mp
mp-
tracks
Omega pull

Ω-pull interpretation

- mean and width:

  track refitting improves momentum calculation for K and $p(m_p, m_K > m_\pi)$.

  p_μ is not affected by refitting ($m_\mu \approx m_\pi$).

  electrons are special case; tracks fitted with m_π are still better.

- bias:

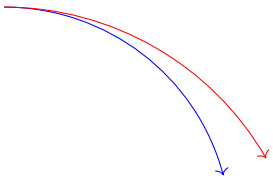
(I). Positive charged particles:

$q > 0 \Rightarrow \Omega(= \frac{1}{r}) > 0$

$\mu_{\Omega pull} > 0 \Rightarrow \Omega^{rec} - \Omega^{MC} > 0$

$\Omega^{rec} > \Omega^{MC} \Rightarrow |\Omega^{rec}| > |\Omega^{MC}|$

$\Rightarrow p^{rec} < p^{MC}$



Blue: REC

Red: MC

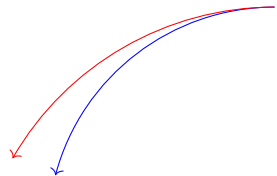
(II). Negative charged particles:

$q < 0 \Rightarrow \Omega(= \frac{1}{r}) < 0$

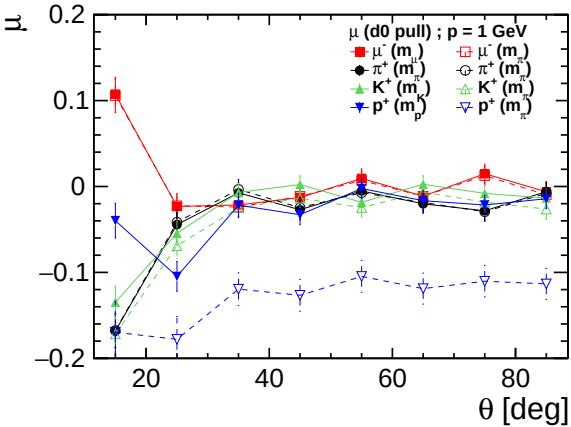
$\mu_{\Omega pull} < 0 \Rightarrow \Omega^{rec} - \Omega^{MC} < 0$

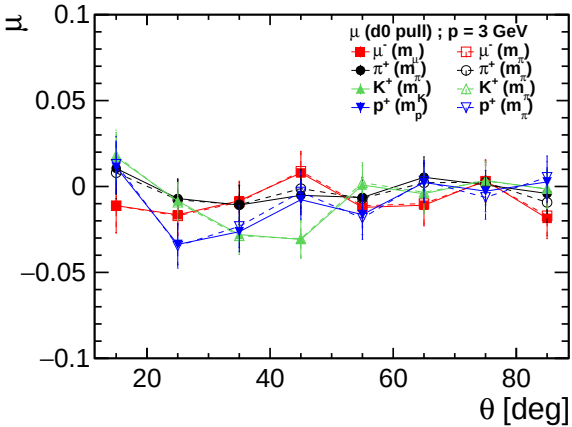
$\Omega^{rec} < \Omega^{MC} \Rightarrow |\Omega^{rec}| > |\Omega^{MC}|$

$\Rightarrow p^{rec} < p^{MC}$



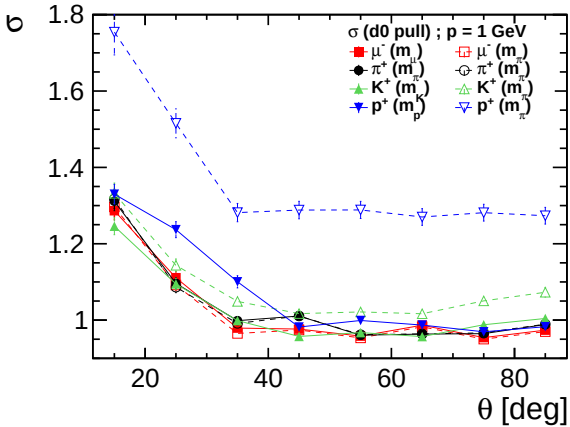
angular dependency of d_0 pull

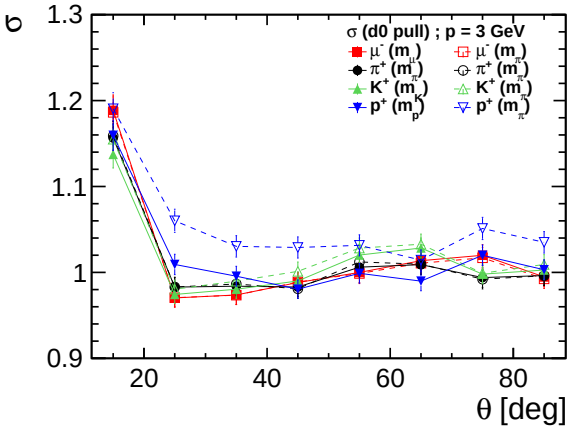




- refitting with true mass improves impact factor resolution $m > m_\pi$
- using true mass, d_0 reconstruction is improved in (especially in forward region).

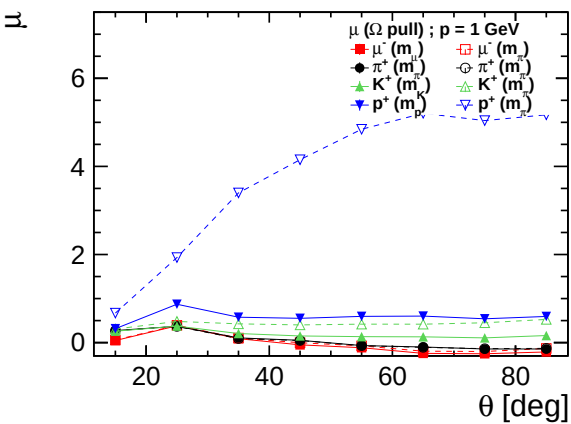
angular dependency of d_0 pull

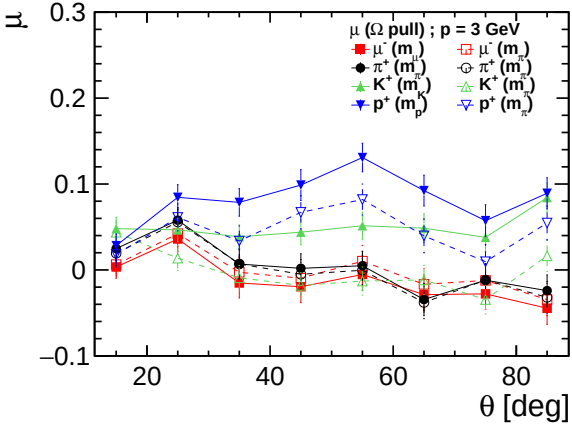




- refitting with true mass improves impact factor resolution $m > m_\pi$
- using true mass, d_0 reconstruction is improved in (especially in forward region).

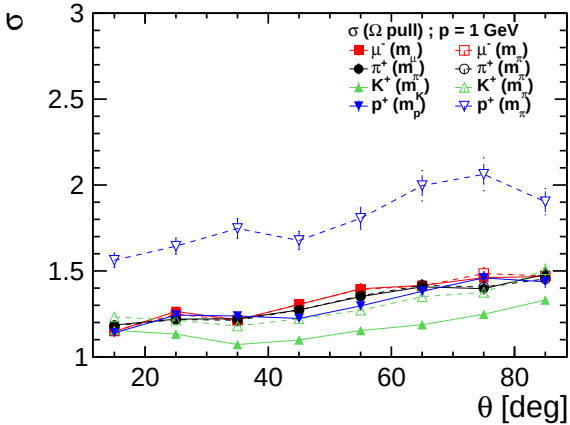
angular dependency of Ω pull

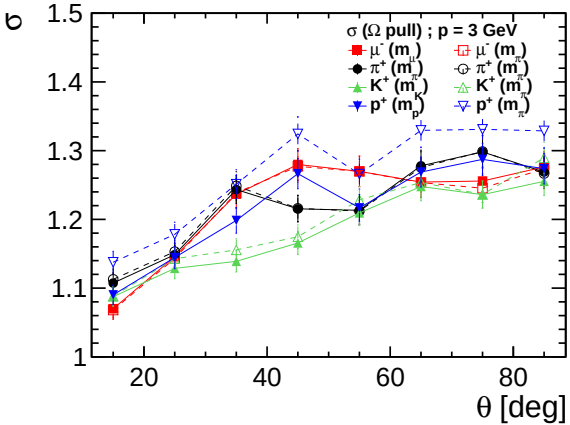




- refitting with true mass improves momentum reconstruction for $m > m_\pi$
- barrel has higher importance to refit low momentum tracks with true mass!

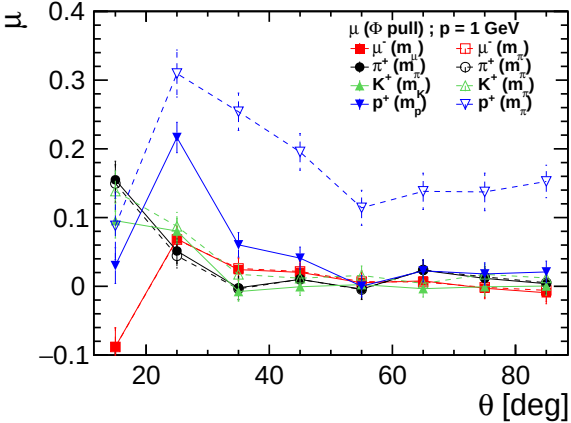
angular dependency of Ω pull

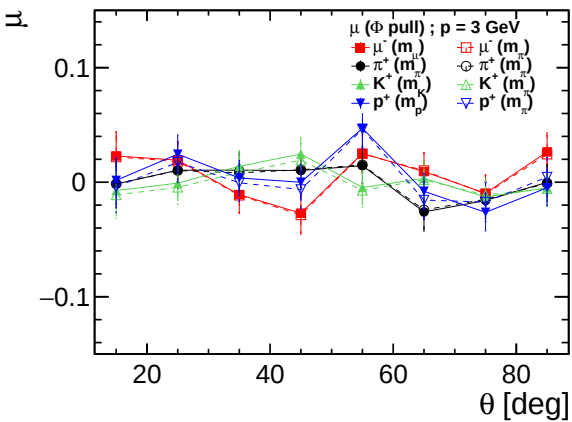




- refitting with true mass improves momentum reconstruction for $m > m_\pi$
- barrel has higher importance to refit low momentum tracks with true mass!

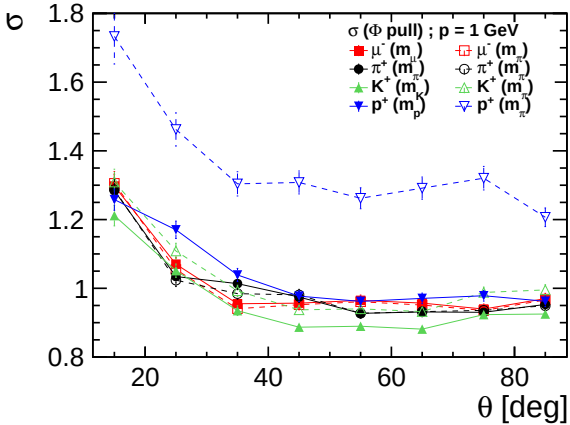
angular dependency of Φ pull

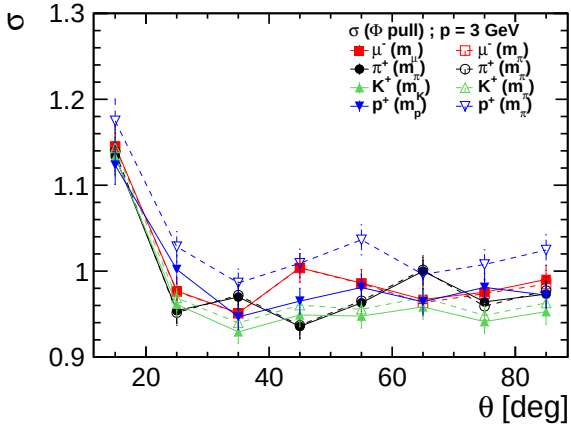




- refitting with true mass hes better results for heavy particles especially in low momentums ($m > m_\pi$)

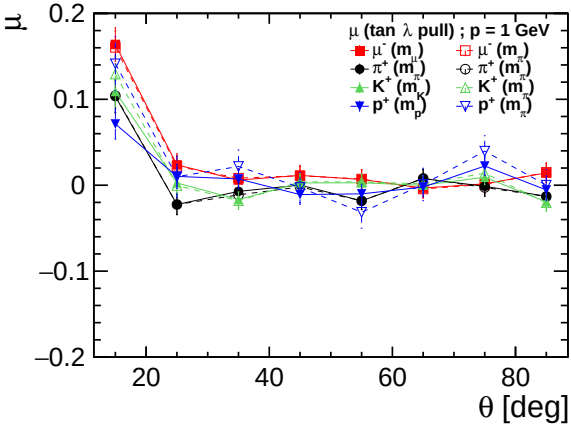
angular dependency of Φ pull

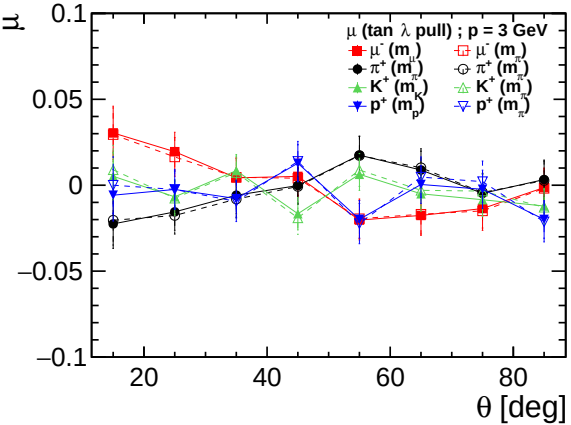




- refitting with true mass hes better results for heavy particles especially in low momentums ($m > m_\pi$)

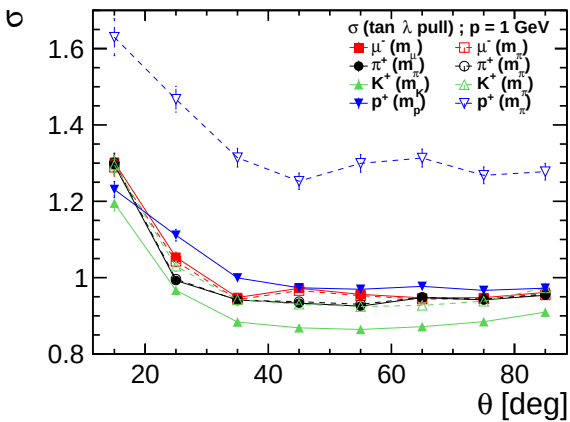
angular dependency of $tan\lambda$ pull

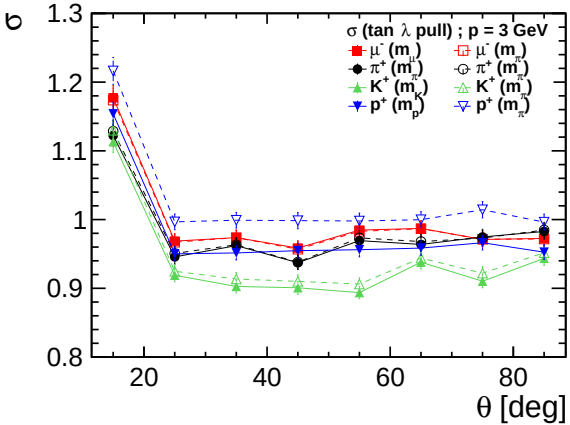




- refitting with true mass hes better results for heavy particles especially in low momentums ($m > m_\pi$)

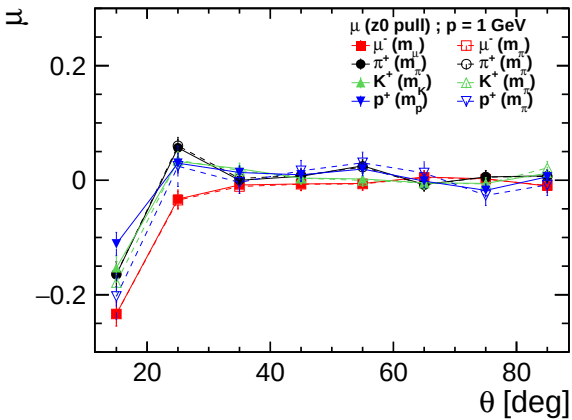
angular dependency of $tan\lambda$ pull

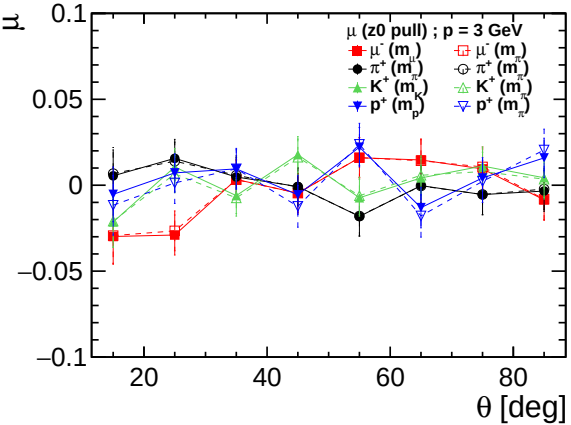




- refitting with true mass hes better results for heavy particles especially in low momentums ($m > m_\pi$)

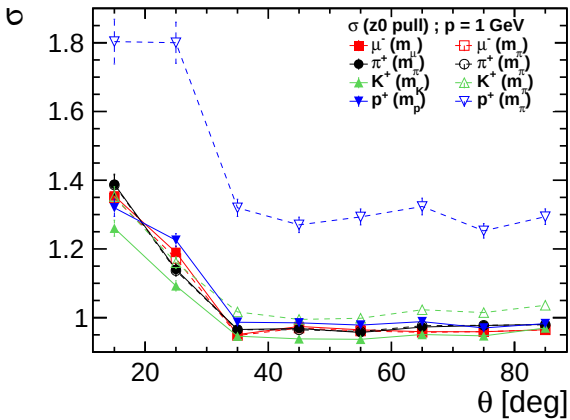
angular dependency of z_0 pull

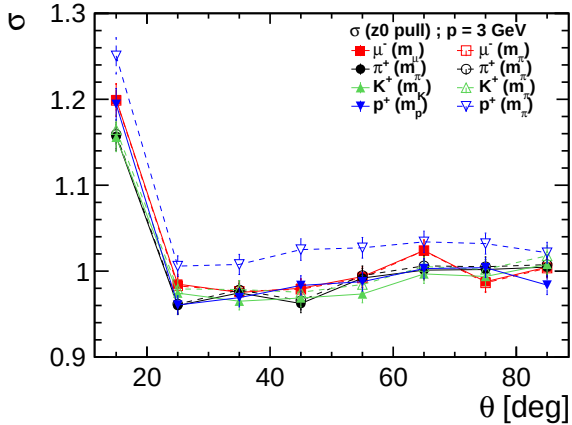




- refitting with true mass hes better results for heavy particles especially in low momentums ($m > m_\pi$)

angular dependency of z_0 pull





- refitting with true mass hes better results for heavy particles especially in low momentums ($m > m_\pi$)

Tracking refitting: bias improvement

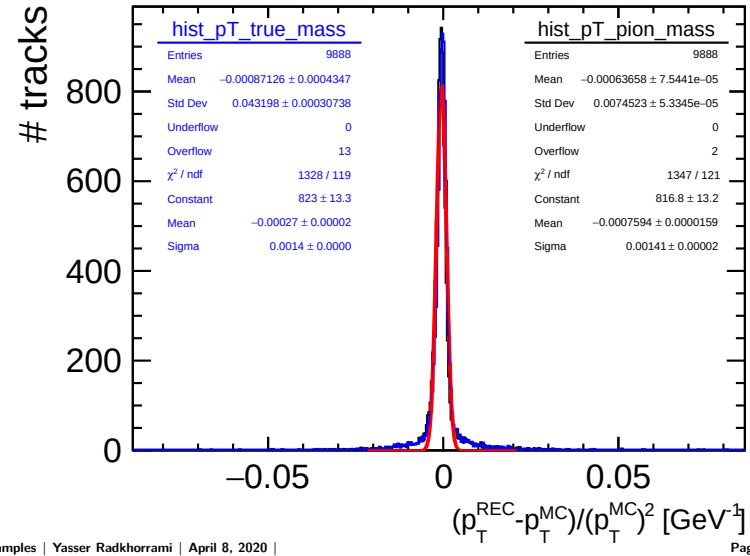
single Kaons: $p = 1$ GeV , $\theta = 85^o$

- Track refitting with true mass (barrel):

  same resolution

  drastically reduced bias

  More accurate p with refitted tracks



Tracking refitting: bias improvement (cntd)

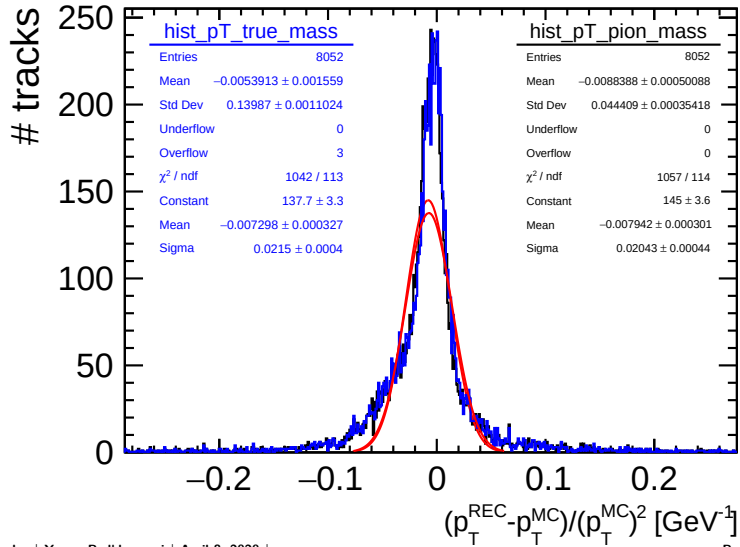
single Kaons: $p = 1$ GeV , $\theta = 25^o$

- Track refitting with true mass(forward):

  same resolution

  drastically reduced bias

  larger error compared with barrel



Tracking refitting: bias improvement (cntd)

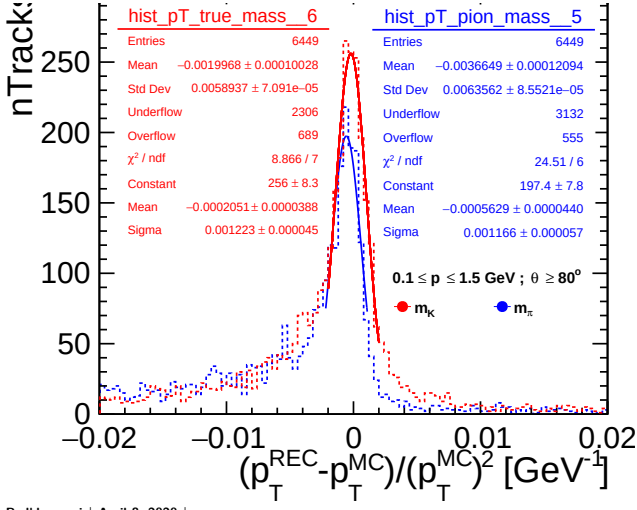
new production samples: $0.1 \leq p \leq = 1.5$ GeV , $\theta \geq 80^o$

- Track refitting with true mass (Kaons): (mid. detector)

  same resolution

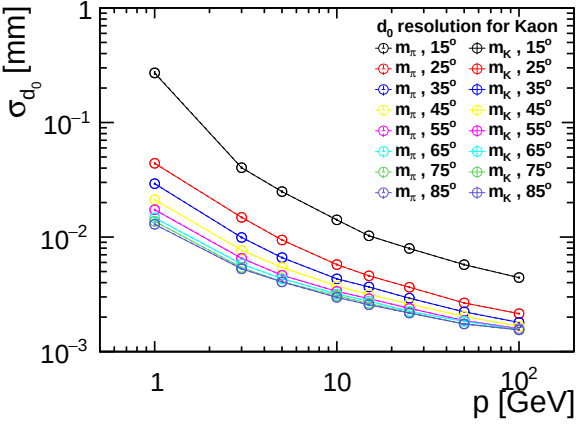
  reduced bias

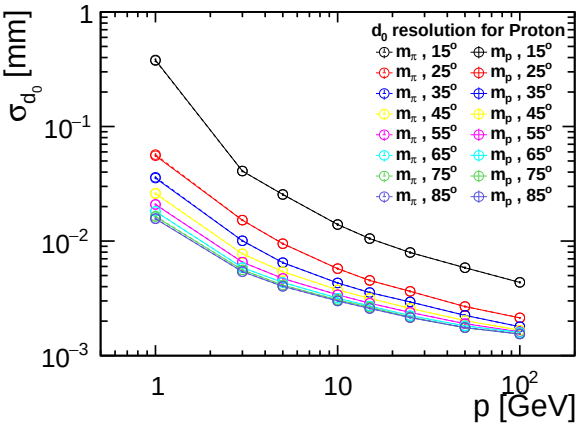
  larger error compared with fixed p/θ



Impact parameter resolution, σ_{d_0}

σ_{d_0}: $(d_0^{REC} - d_0^{MC})$ width

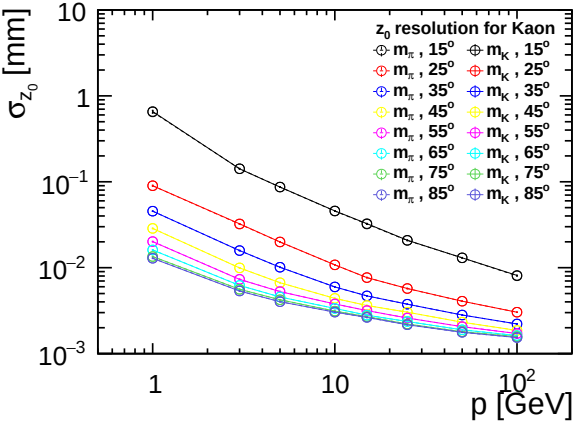


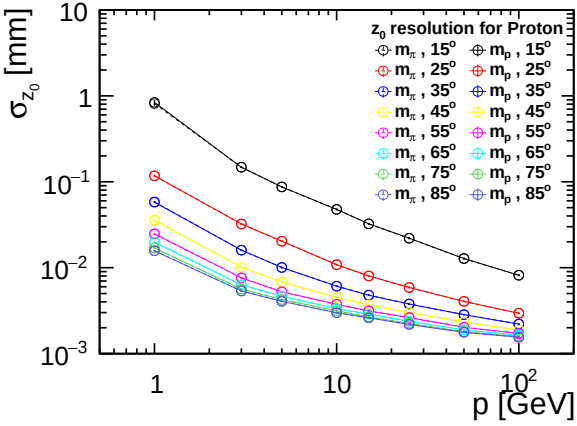


- refitting with true mass ⇒ same Impact Parameter resolution

Impact parameter resolution, σ_{z_0}

σ_{z_0}: $(z_0^{REC} - z_0^{MC})$ width

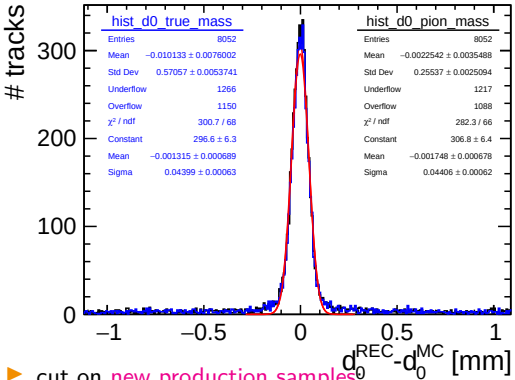




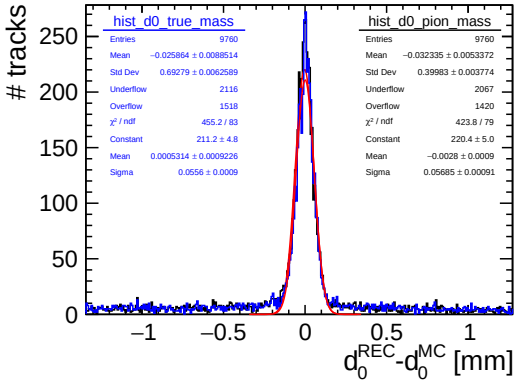
- refitting with true mass ⇒ same Impact Parameter resolution

Impact parameter bias, μ_{d_0}

single Kaons/protons: $p = 1$ GeV , $\theta = 25^o$



- cut on new production samples:
  - Kaons: $0.1 \leq p \leq 1.5$ GeV , $\theta \geq 80^o$
  - Protons: $0.1 \leq p \leq 1.5$ GeV , $\theta \geq 80^o$

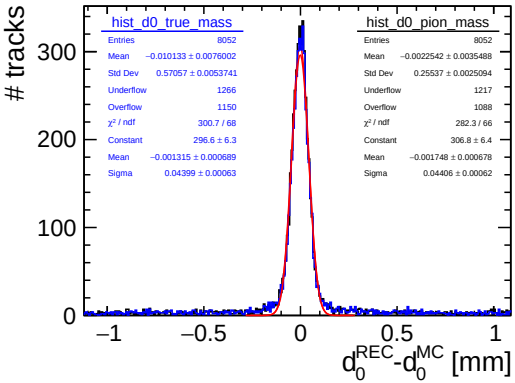


- reduced d_0 bias $\Rightarrow$ more accurate vertexing

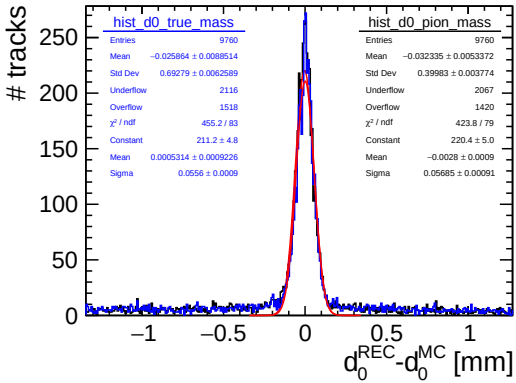
Impact parameter bias, μ_{d_0}

single Kaons/protons: $p = 1$ GeV , $\theta = 25^o$

Kaons:



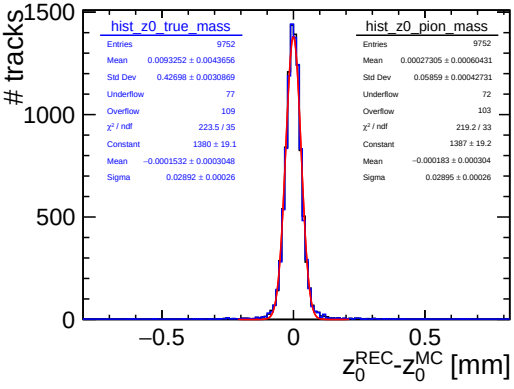
Protons:



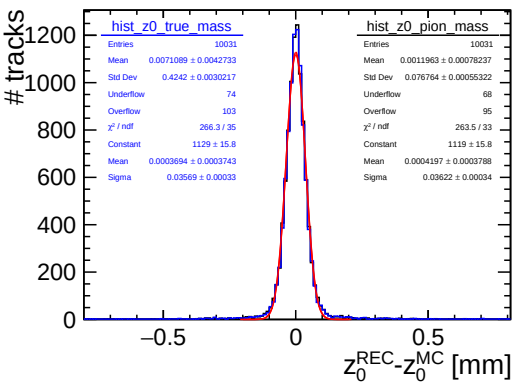
Impact parameter bias, μ_{z_0}

single Kaons/protons: $p = 1$ GeV , $\theta = 45^o$

Kaons:



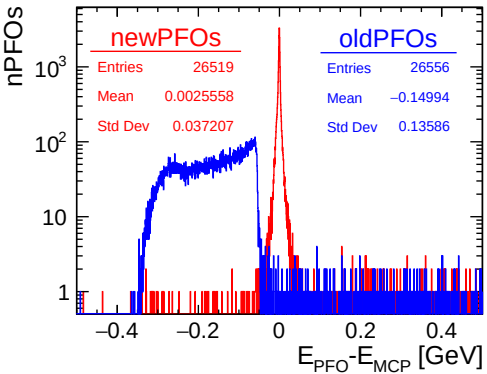
Protons:



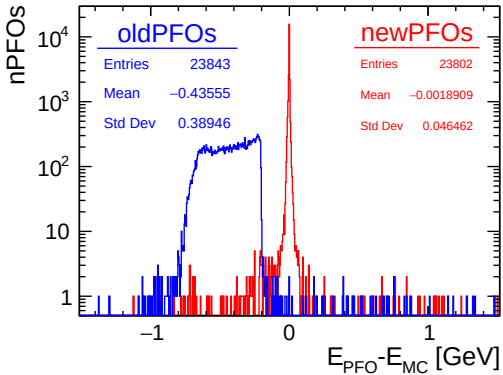
Energy residuals in new production samples

using refitted trackes with true mass

Kaon ($p \leq 2$ GeV)



Proton ($p \leq 2$ GeV)



- Improved Energy reconstruction: **improved momentum + taking correct mass of particle**: