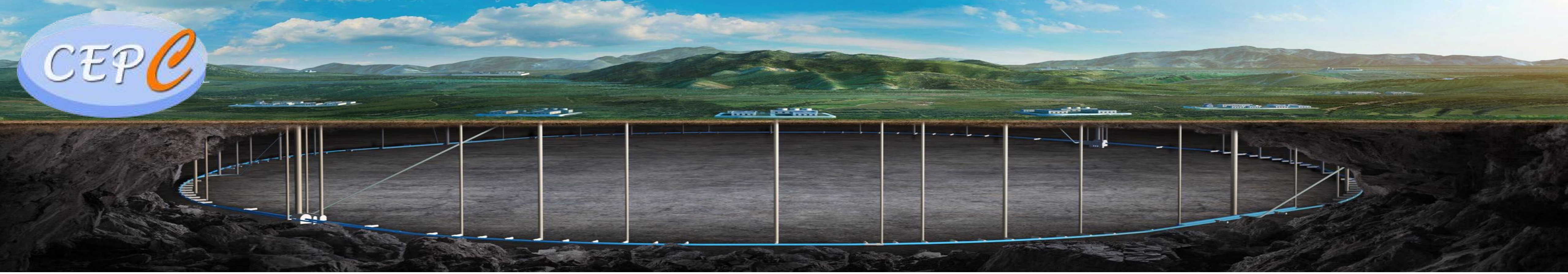
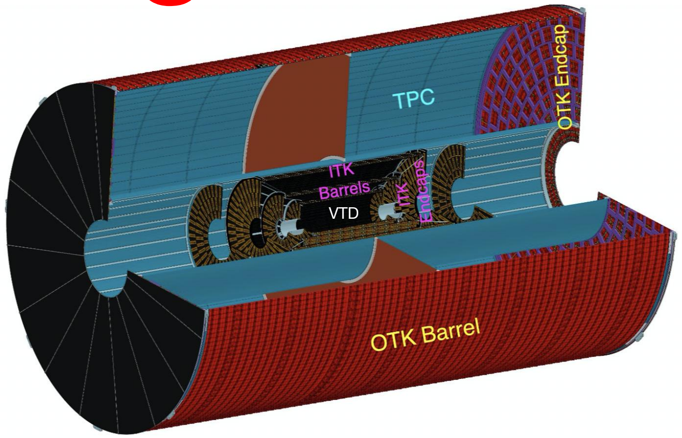


Tracking Performance



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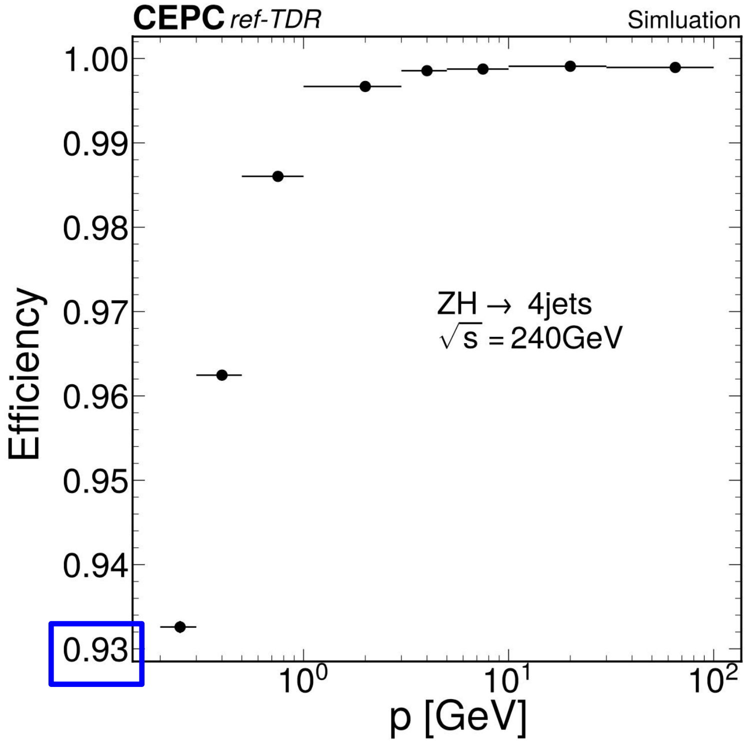
April 21st, 2025, CEPC Day

Content

- Tracking efficiency
- Tracking resolution
- Performance in physics studies
- To do
- Summary

Tracking efficiencies



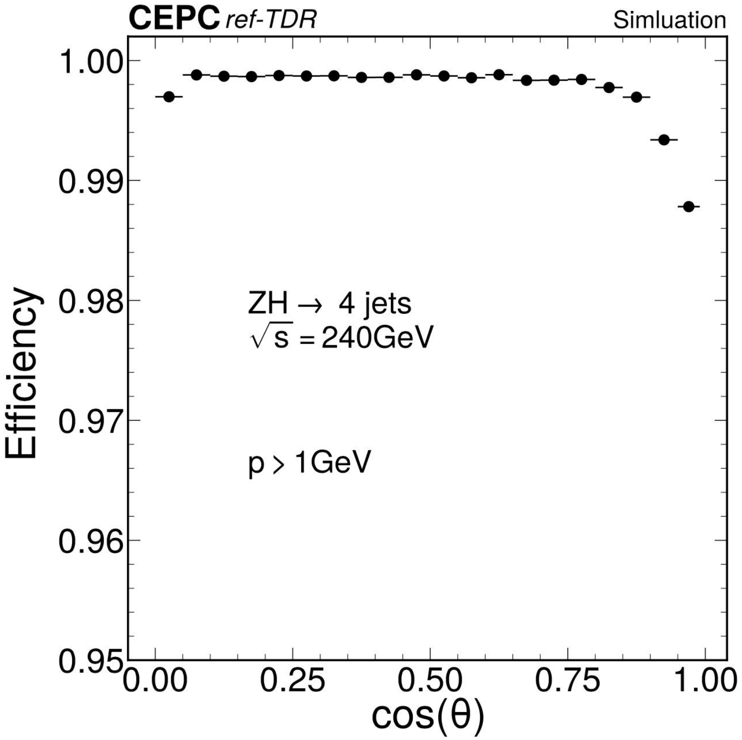


Figure 15.1: Track efficiency for ZH → 4 jets at 240 GeV plotted against (left) momentum and (right) cos(θ).

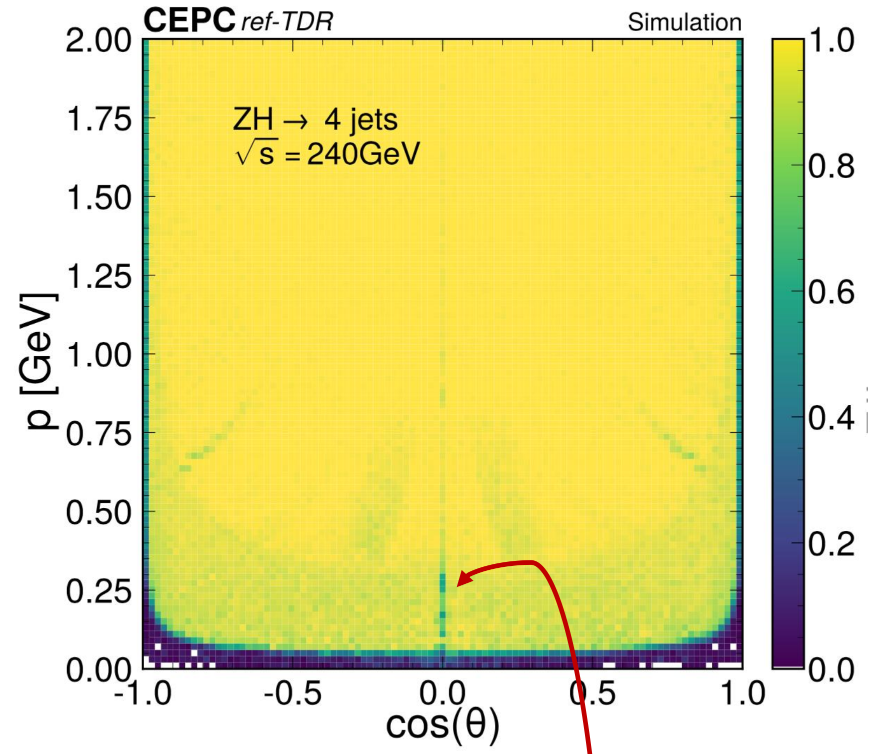
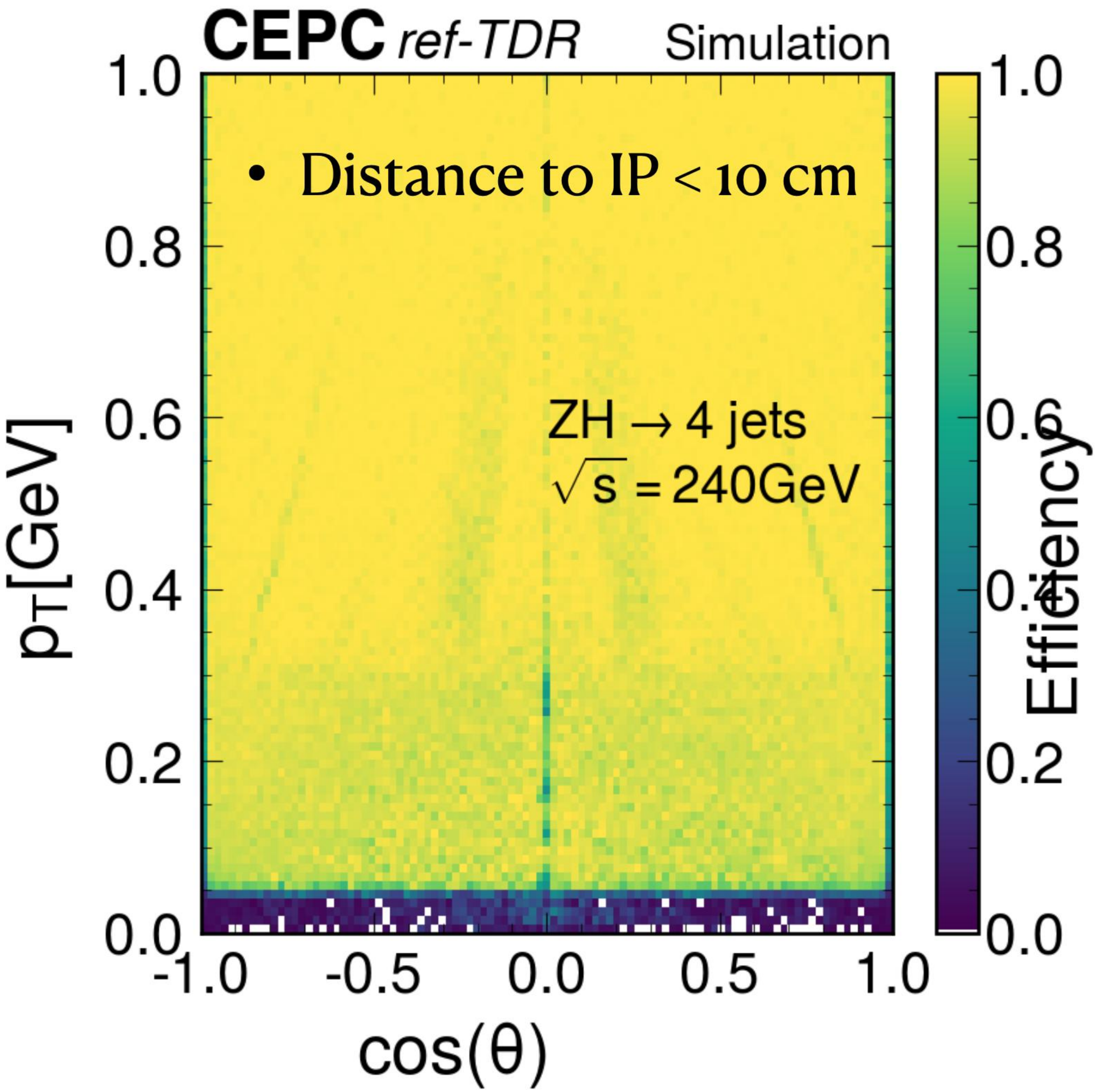
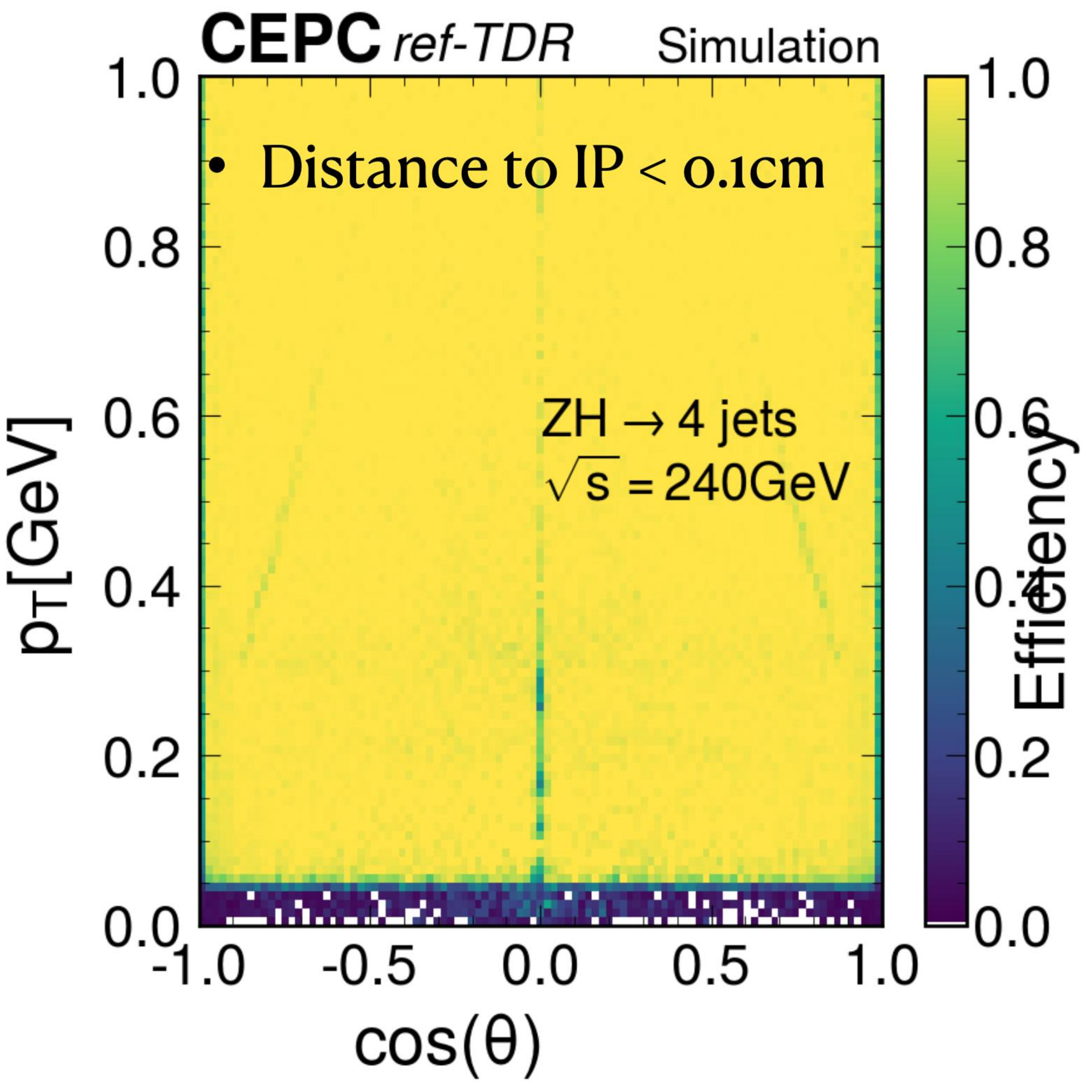


Figure 15.2

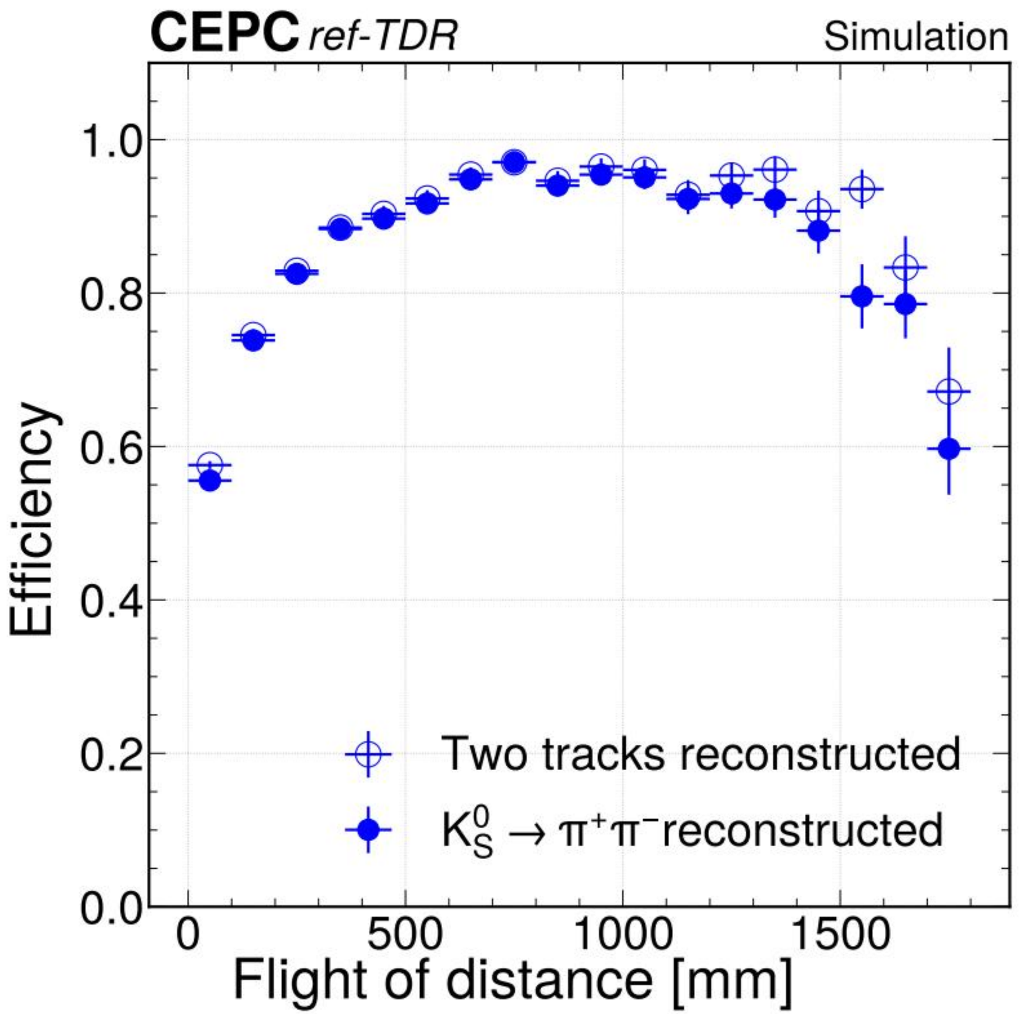
- For the combined tracking system, reconstruction efficiency is on average 99.7% for tracks with p > 1 GeV
- The membrane cathode spanned between two rings in the center of the TPC and the gap in silicon tracker cause some inefficiency

Some inefficiencies due to Off-IP tracks



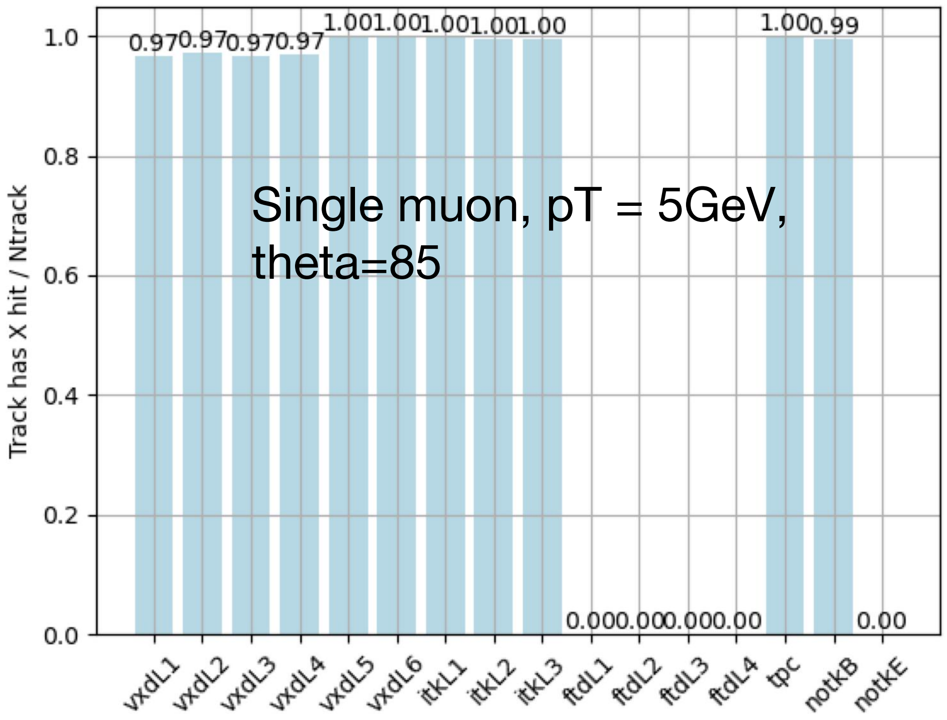


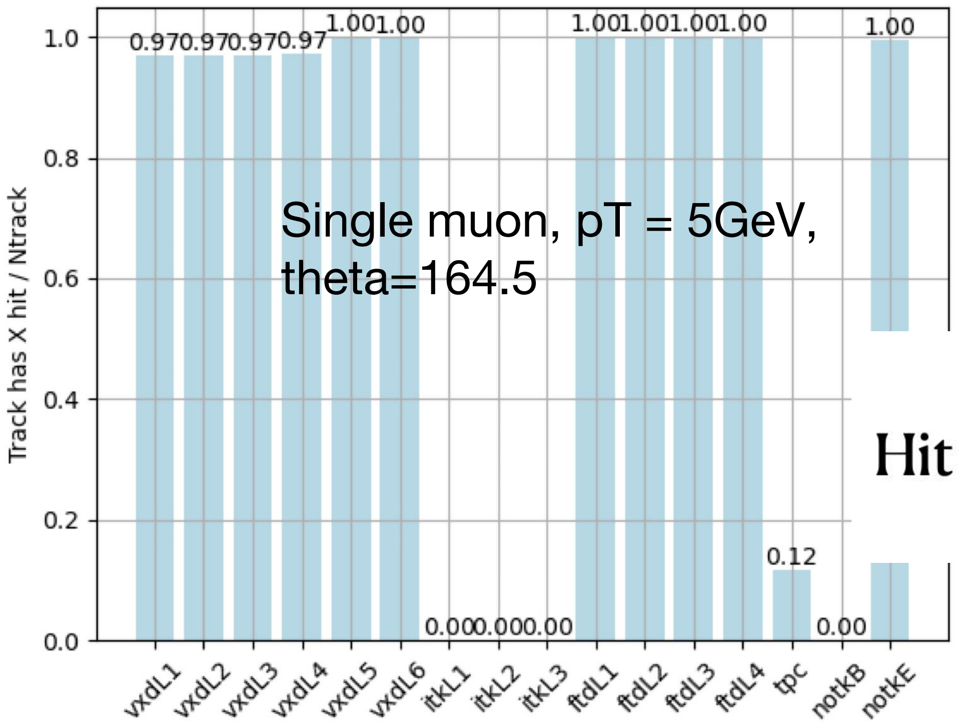
Some inefficiencies due to Off-IP tracks



- $K_s^0 \to \pi^+\pi^-$ efficiency as a function of flight-of-distance
  - Compared to the CDR, the expected eff. is ~ 75%, but 70% for now.
  - Sensitive to Off-IP tracking efficiecny

An issue about the tracker hits efficiency

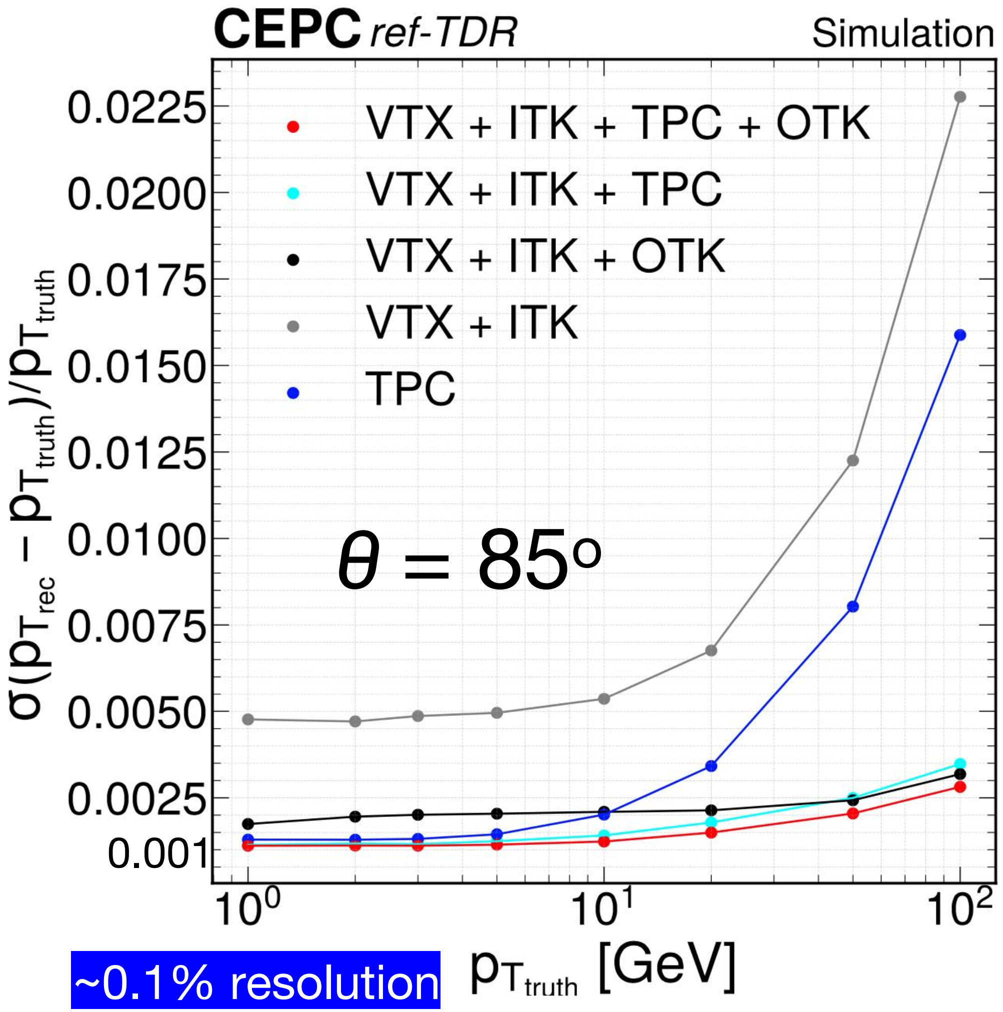




$$\text{Hit Eff} = \frac{N_{trk} \text{ has X hit}}{N_{trk}}$$

- The efficiencies for ITK layers are close to 100%
- The problem is due to the missing gaps in ITK, and has been solved by MR246
- Performance to be re-evaluated

Tracking momentum resolution



~0.1% resolution

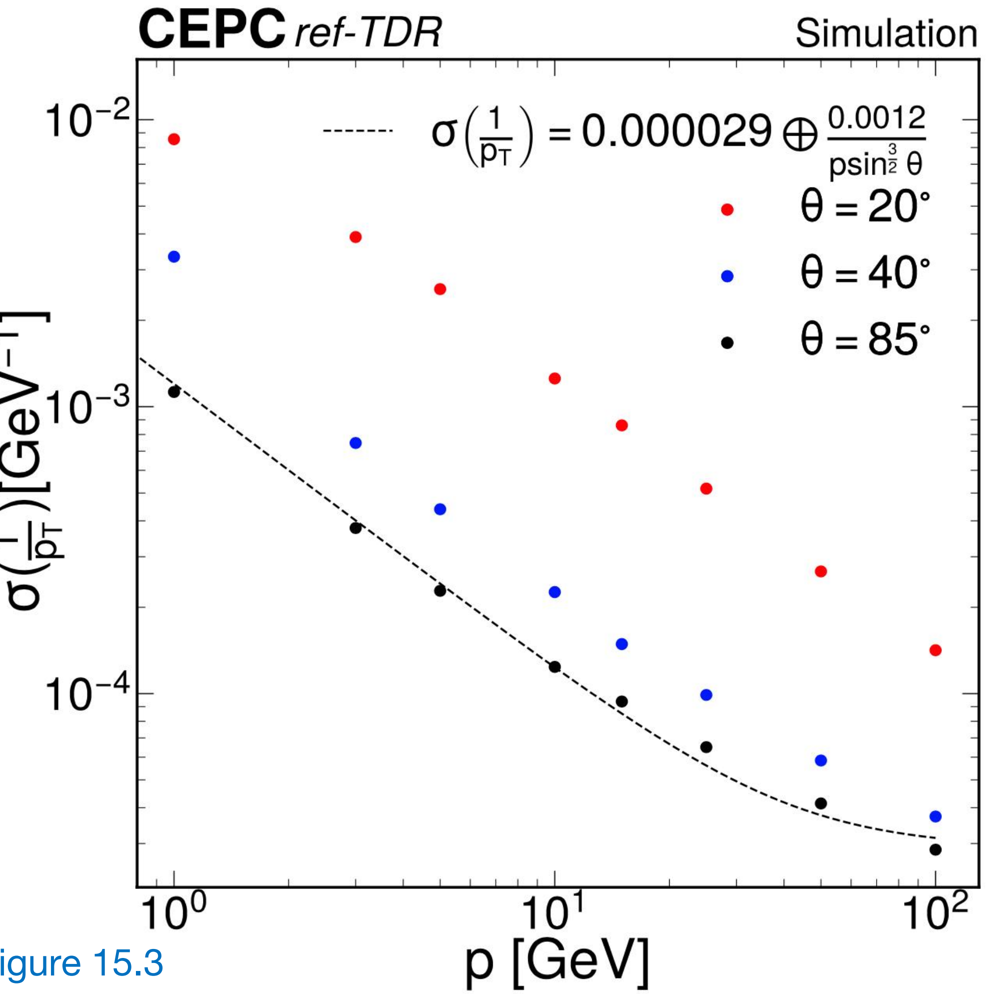
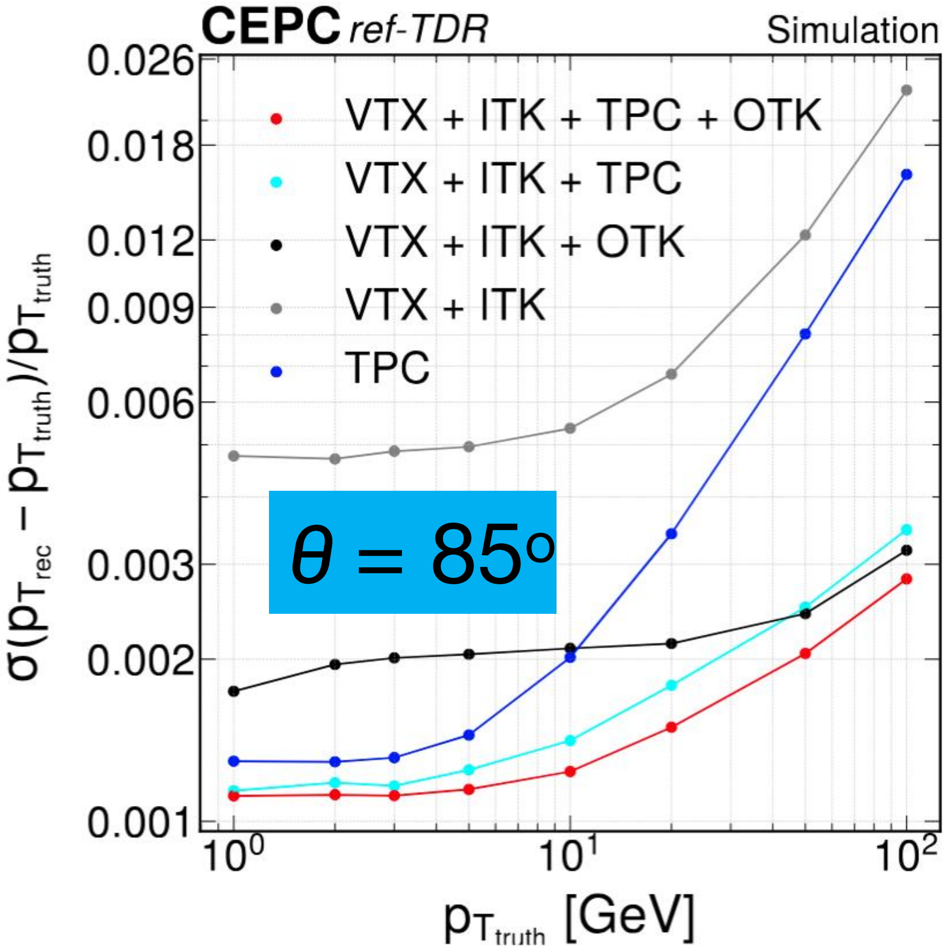


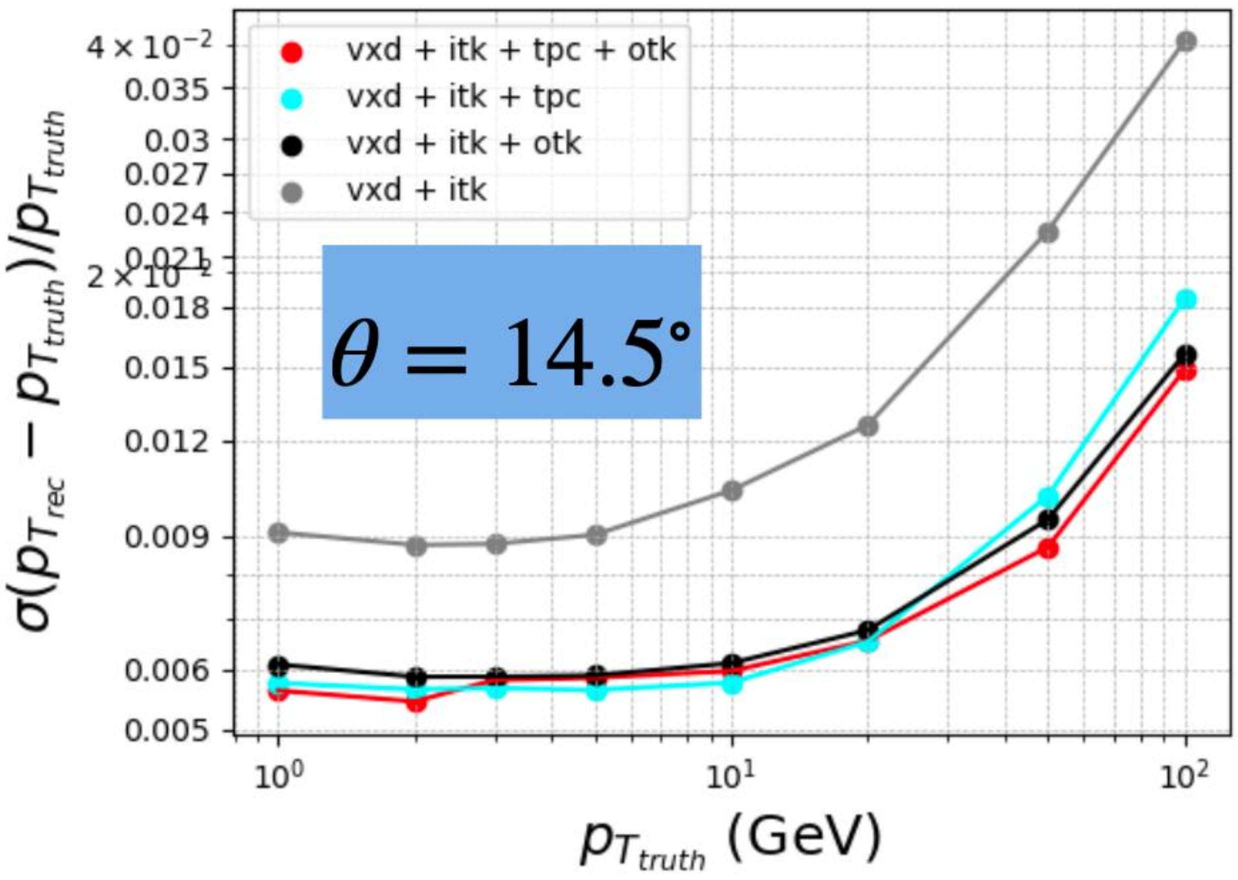
Figure 15.3

cos(20°) ~ 0.94
cos(40°) ~ 0.77
cos(85°) ~ 0.87

- TPC helps improve the resolution significantly at low momentum region
- Both TPC and OTK are able to help improve the resolution at high momentum region

Tracking momentum resolution





- In the very forward region, the TPC has no effects and is removed from the right plot.

Impact parameter resolution

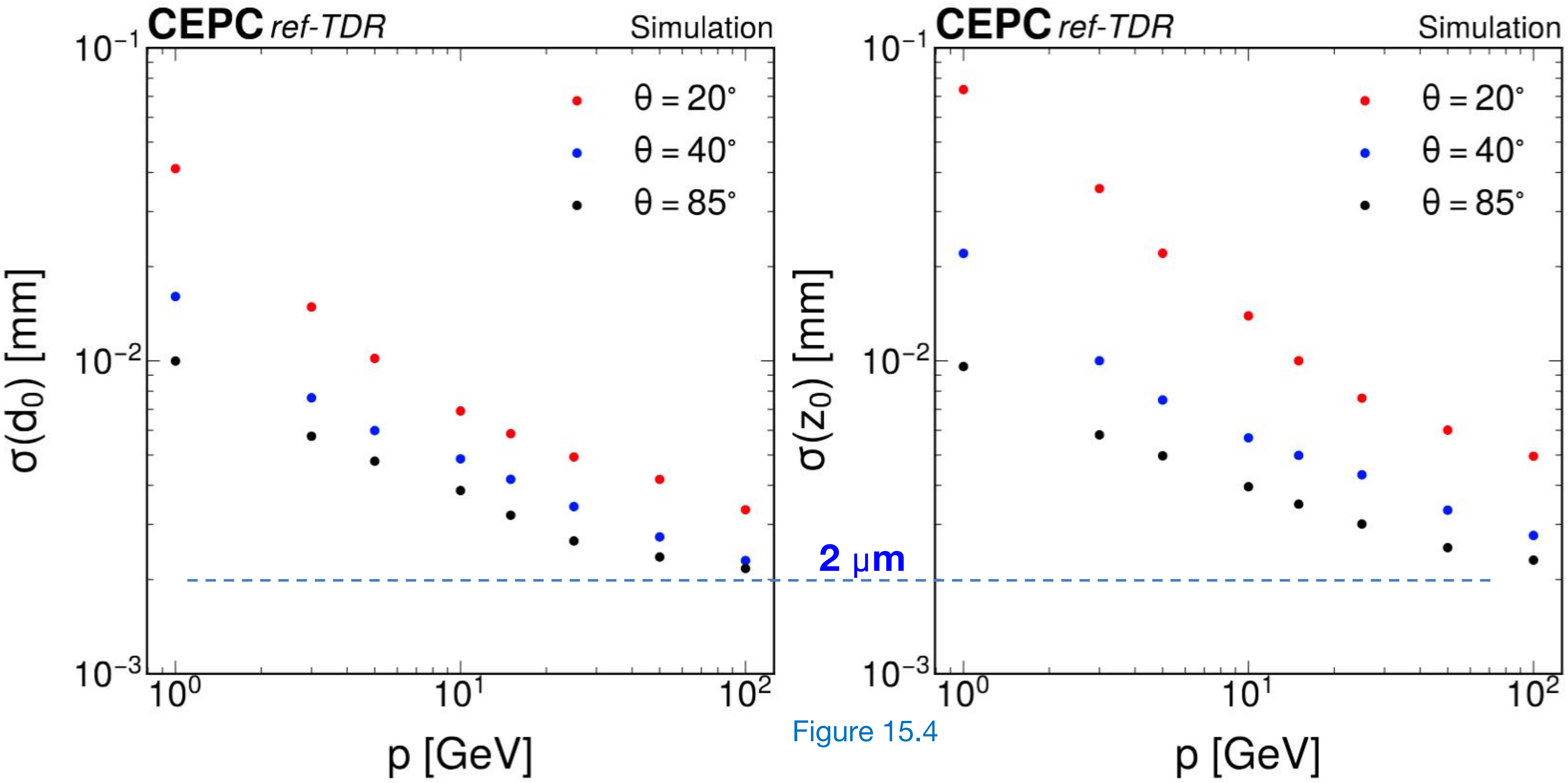
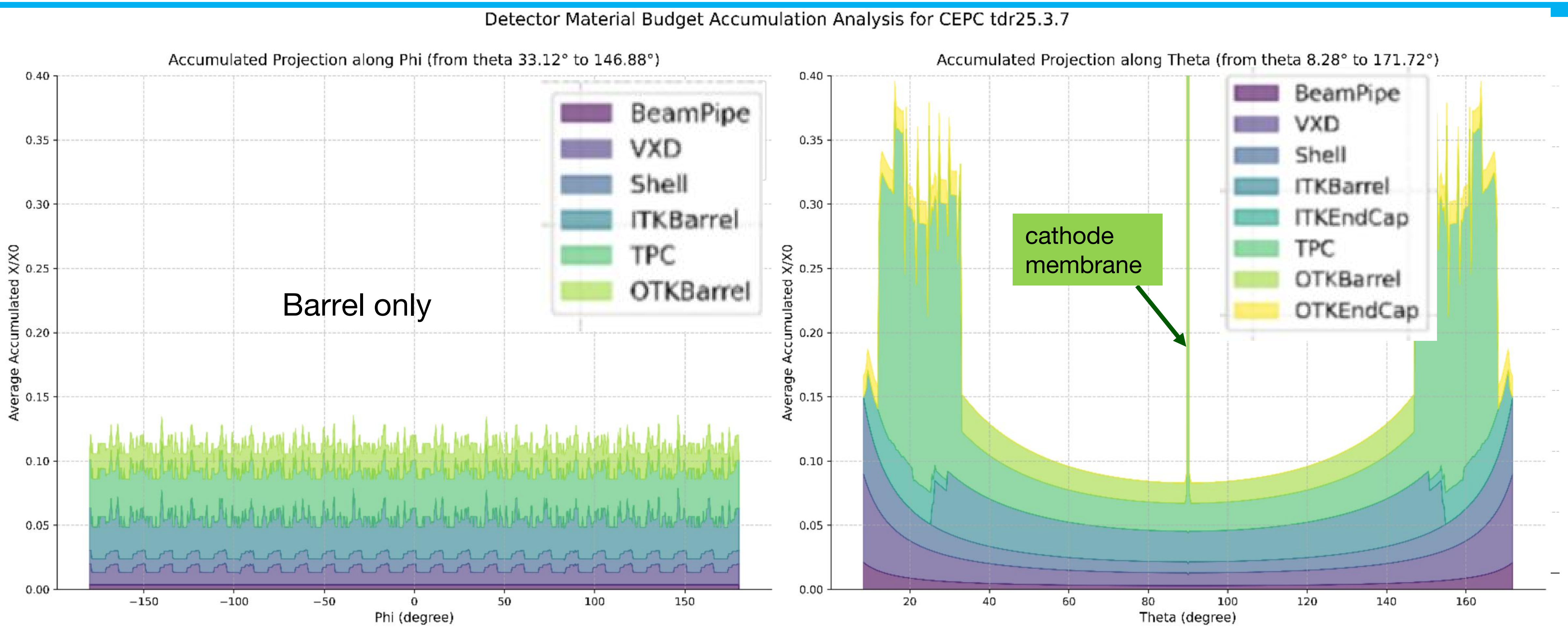


Figure 15.4

- Both d_0 and Z_0 resolutions are excellent, reaching 2-3 μm for the whole barrel region for p > 50 GeV

Material Budget

Not in TDR

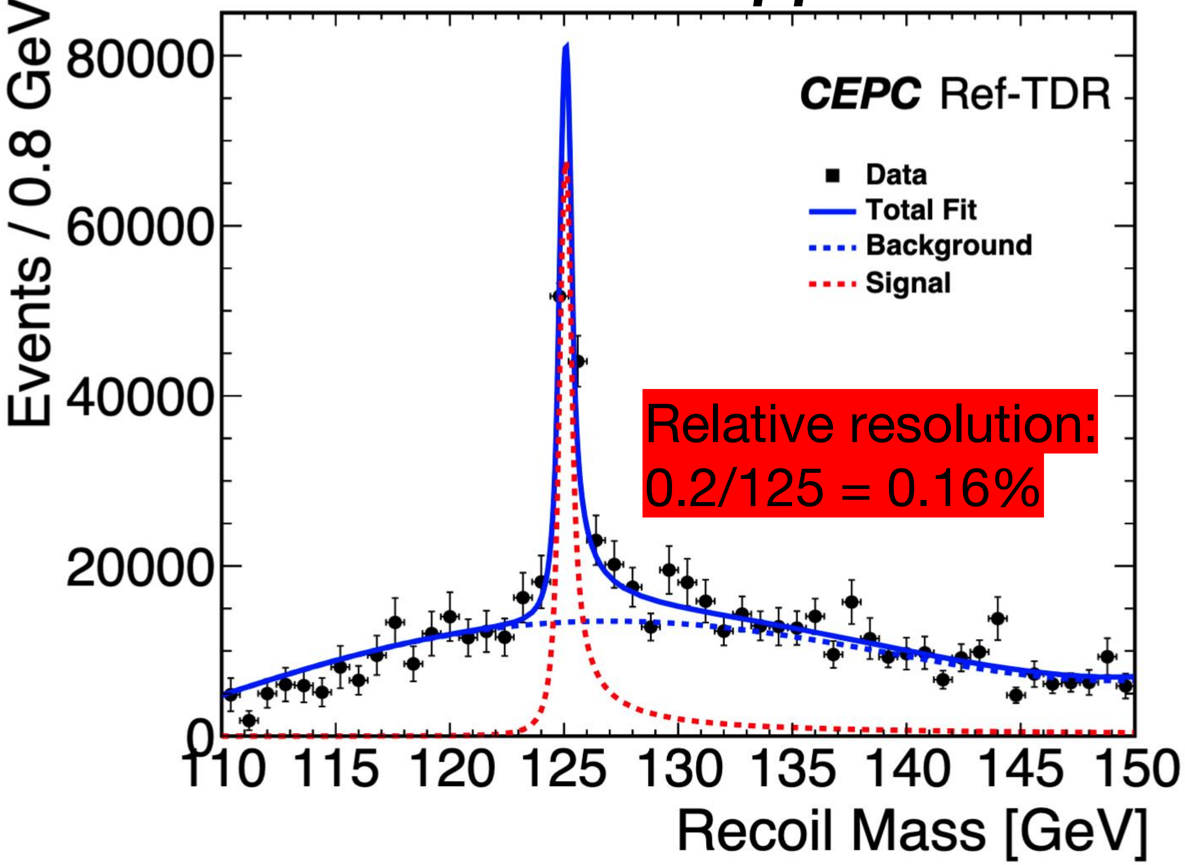


- Supporting material (carbon fiber) for beampipe in the current SW much more than expected
  - 2.5 mm thickness (1.8% X_0) instead of the actual design 1.5 mm
  - **Expect further improvement on tracking resolution** (material budget reduced by 0.7% X_0)

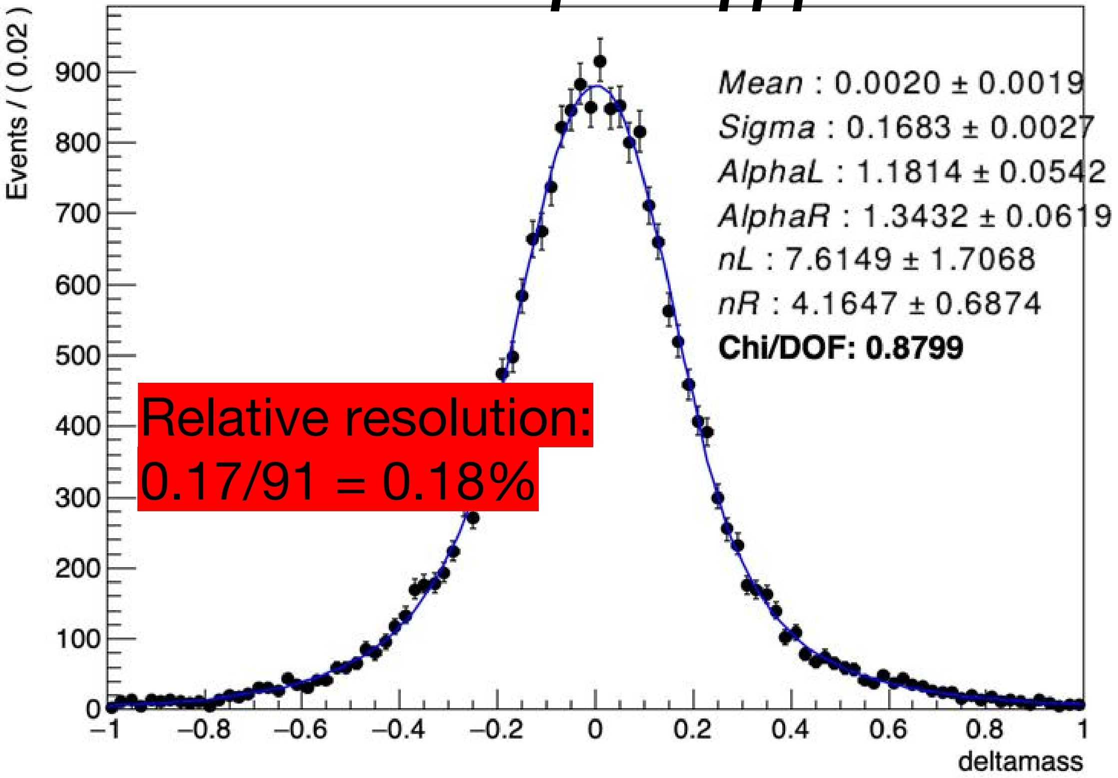
Momentum resolutions in physics studies

m_H through recoil mass in μμ channel

$ee \to ZH \to \mu\mu X$



$ee \to \gamma Z \to \gamma\mu\mu$



Fitted by Chebyshev polynomial & DoubleSidedCB

Stat unc. = 2.5 MeV (no beam energy spread)

Spectra of $\Delta m = m_{rec} - m_{gen}$

Fitted DoubleSidedCB

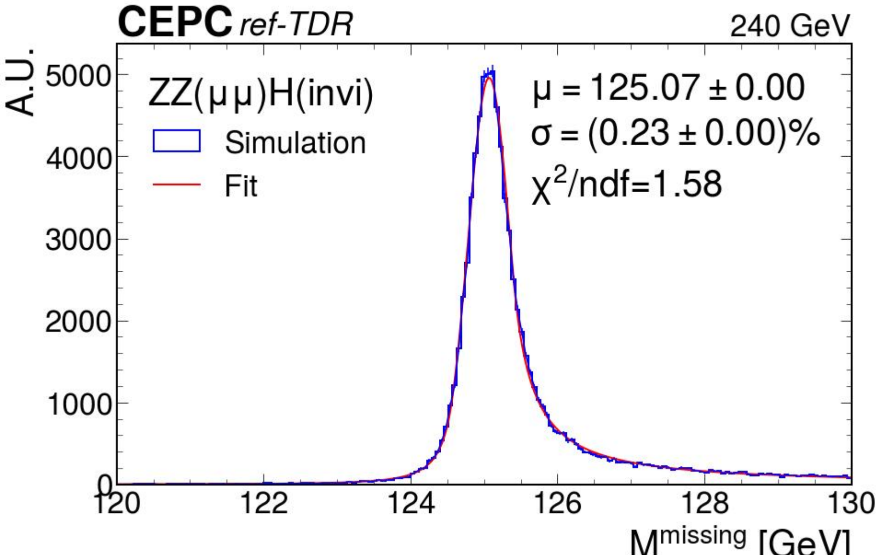
Serves for systematic error studies

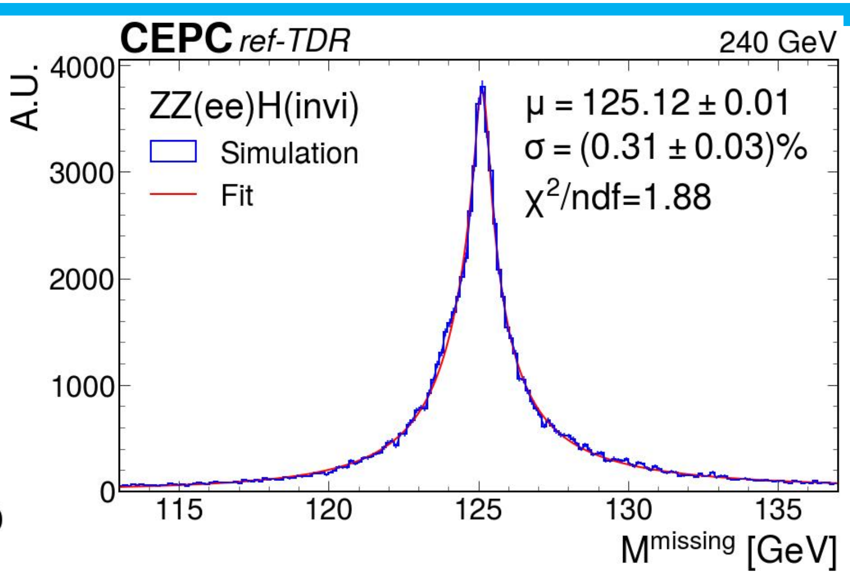
More plots

Higgs invisible decay:

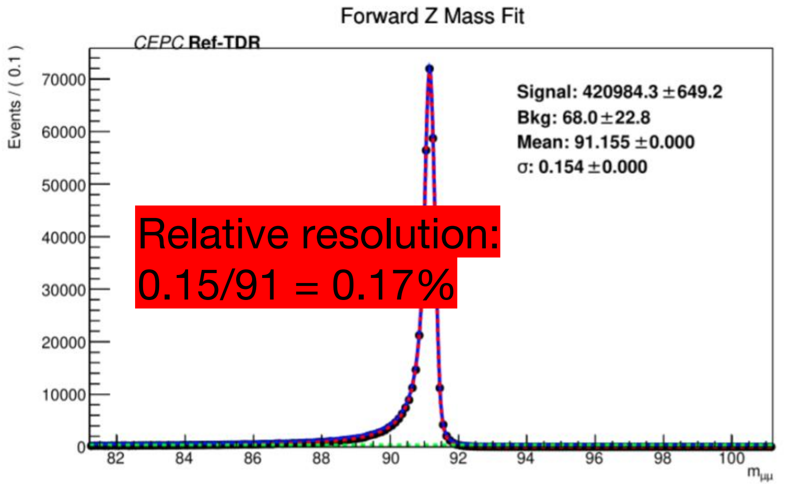
$$M^{missing} = \sqrt{(P_{init.} - P_{vis.})^2}$$

First look at electron tracking performance





A_{FB} of $ee \rightarrow Z/\gamma^* \rightarrow \mu\mu$: dimuon invariant mass



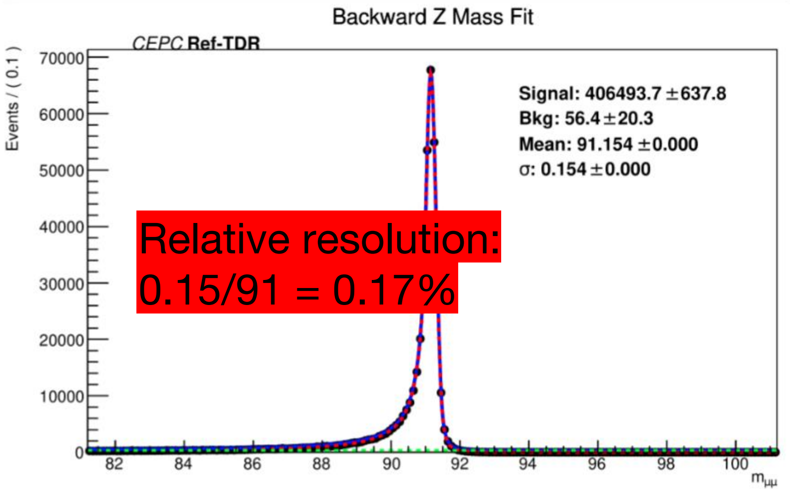
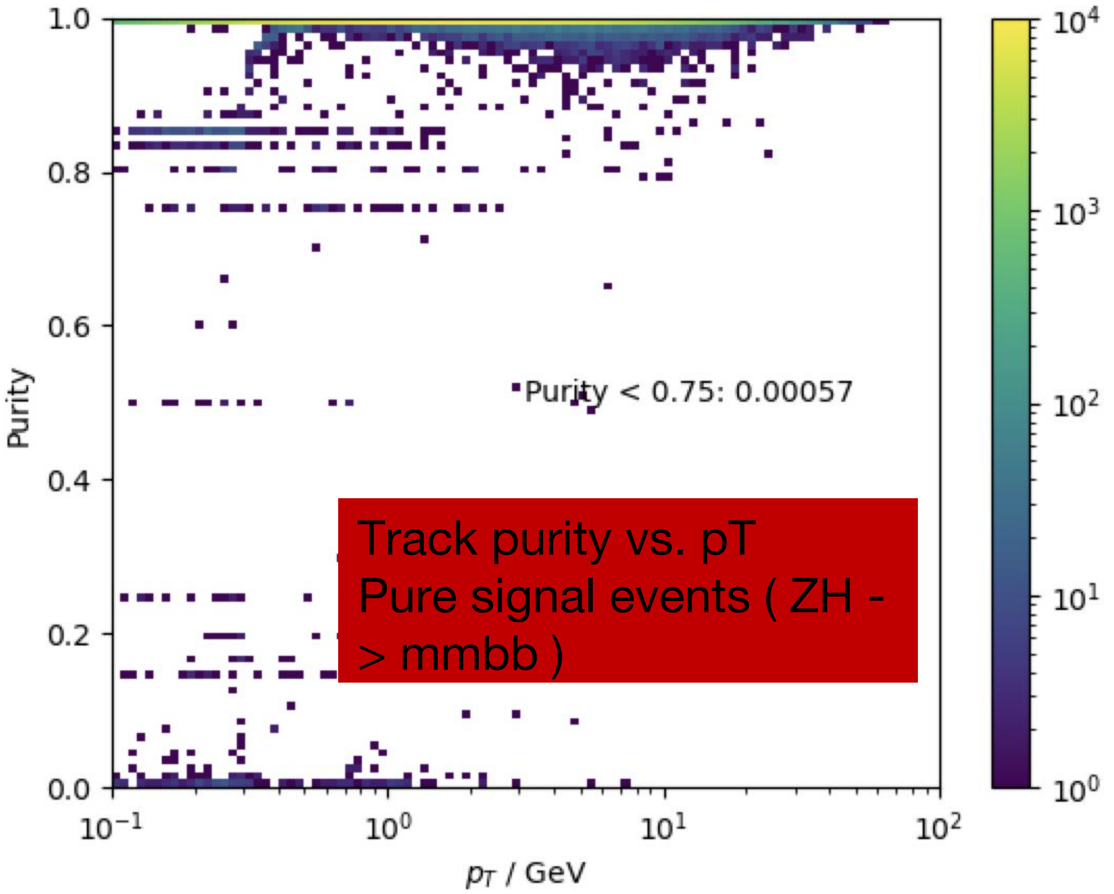


Figure 1.30: The fits on the $m_{\mu^+\mu^-}$ mass spectrum in the forward and backward regions, the $Z \rightarrow \mu^+\mu^-$ process is modeled by a double-sided crystal ball (DSCB) function, and the $\gamma* \rightarrow \mu^+\mu^-$ process is modeled by a uniform function.

To do

Beam background mixing

- Thanks to recent contributions to CEPCSW, beam background mixing is becoming available
- Track purity
  - Weight: Number of hits shared between a track and an MC particle
  - Purity: Max-weight / N-trackhits
- Fake rate
  - Apply a cut on track purity results in track fake rate
- All performance need to be re-evaluated with beam-brackground
- Electronic noise will be also studied at this stage



Track-based tracker alignment

- Definition of misalignment scenario
  - Estimating the misalignments of individual detector components is a challenging task
  - Experience from other experiments
- Simulation of misalignment
  - A plugin is needed between the simulation and tracking software to apply misalignments
- Track-based alignment algorithm
  - Common algorithms such as chi2 minimization (for global), Kalman filter (for local), or external software can be used
  - The aim is to reduce the residuals to the level of sensor's intrinsic resolution

	Δx (μm)	Δy (μm)	Δz (μm)	R_z (μrad)	LAS available
Pixel Barrel	10	10	10	10	no
Pixel Endcap	5	5	5	5	no
Strip Inner Barrel	100	100	500	90	yes
Strip Outer Barrel	70	70	500	60	yes
Strip Inner Disk	400	400	400	100	no
Strip Endcap	60	60	500	45	yes

- CMS misalignment scenario used for the "first data taking"
- Assume the mechanical, laser-baed calibration and initial track-based alignment for pixel have been done
- Typically, 100 um for XYZ coordinates

Recommendations: Detector Performance – 7

7. Explain how calibration for each sub-detector will be achieved through physics processes, and document specific calibration methods in the Ref-TDR.

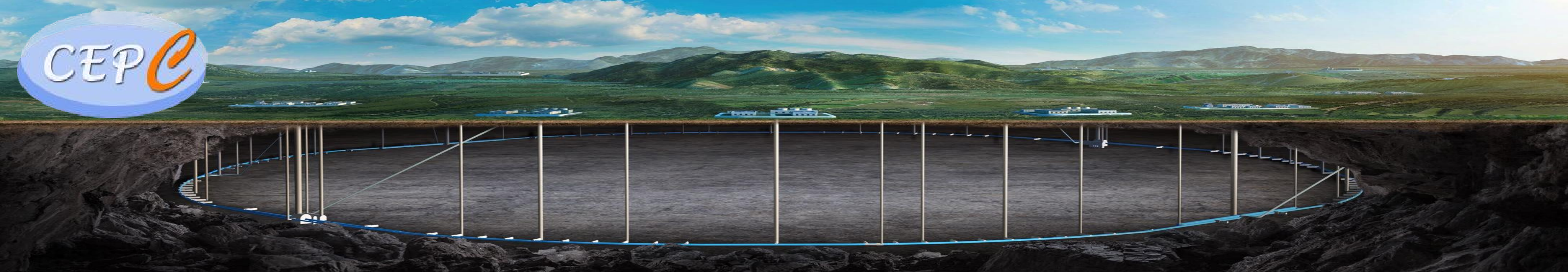
A: Section 15.4.3, methods and considerations documented for VXD, Tracker, ECAL, HCAL, Muon detector

- Vertex Detector
  - Use $Z \to \mu\mu$ events for track-based alignment by minimizing residuals
    - Iteratively adjust module positions and angles to achieve ~5–10 μm precision
  - $K^0_s \to \pi^+\pi^-$ decays validate impact parameter (d_0) resolution (target: 20–50 μm)
  - $\gamma \to e^+e^-$ conversions measure Charge Collection Efficiency (CCE) and degradation
  - Pixel gain equalized using MIPs (Landau-Gauss fits, variation < 5%)
  - Layer time differences aligned to ~33 ps for 1 cm spacing; global sync < 0.5 ns
  - Monitor thermal effects (e.g., ΔT = 1 ˚ C may cause ~1 μm shifts); apply time-dependent corrections

- Tracker (ITK, OTK, TPC)
  - Use cosmic rays & beam halo for initial alignment; refine with $Z \to \mu\mu$ (residuals ~10 μm / 200 μm)
  - Z and J/ψ to μμ decays calibrate momentum scale per module via invariant mass fits
  - TOF via $Z \to \tau\tau \to \mu\mu\nu\nu$; TPC drift velocity calibrated with UV laser tracks
  - Kalman Filter iteratively updates hit-level states until convergence
  - Real-time corrections for temperature and radiation via $\Delta p/p = k \cdot D + \alpha \cdot \Delta T$

Summary

- Tracking p_T resolution ~ 0.1% achieved for majority
- Work towards TDR publication, with help from SW team
  - Evaluate the impact of the noise
  - Evaluate the impact of beam-induced background through proper event mixing
  - Evaluate the impact of mis-alignment
    - scenario 1: mis-alignment precision from CMS experience ?
    - scenario 2: 10 times better alignment precision w.r.t. CMS ?
  - Photon conversions can be included as a test for tracking and material probe
- Work beyond TDR
  - GSF fitting of electron, tracking performance with exotic configurations (e.g. LLP)
  - ....



Thank you for your attention!

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Backup slides

Geometry

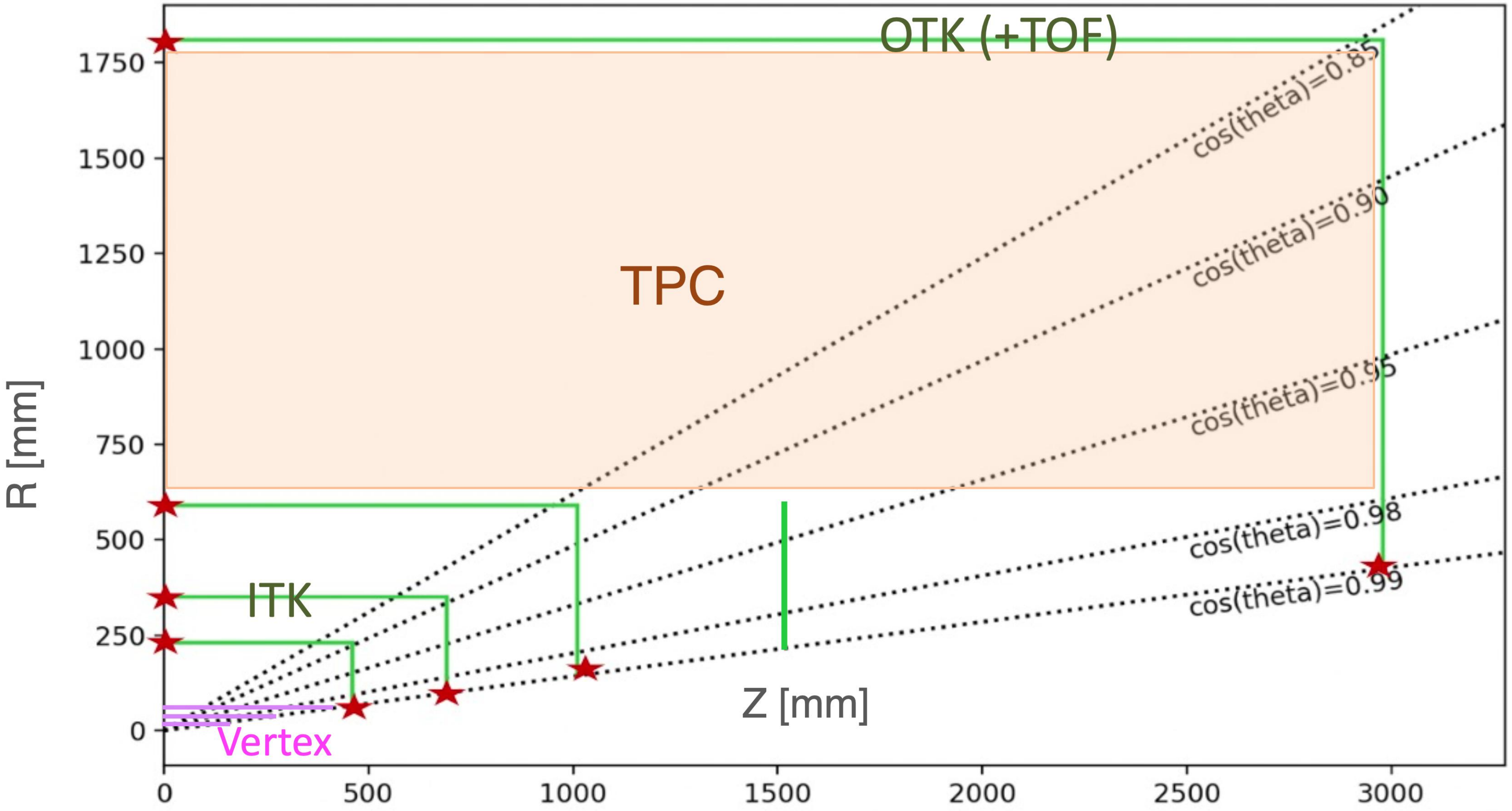
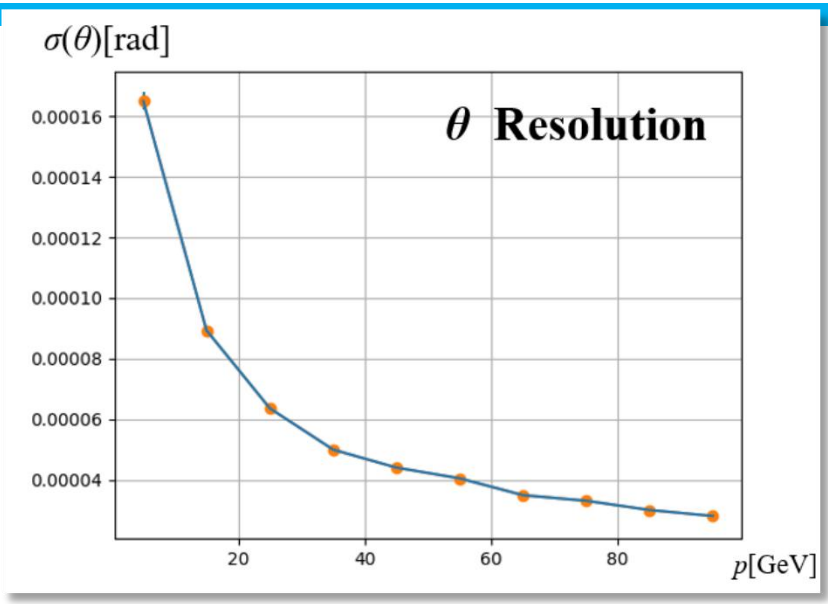
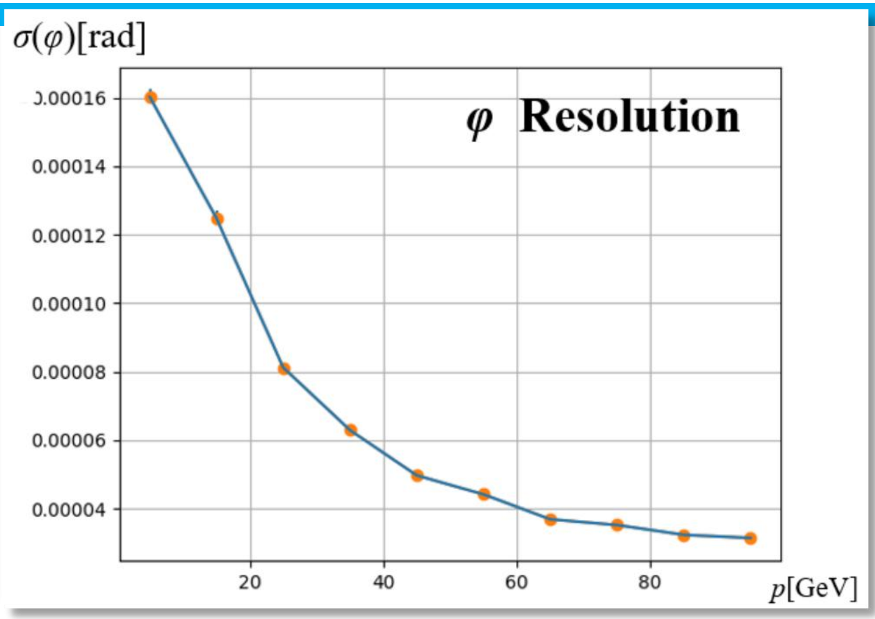


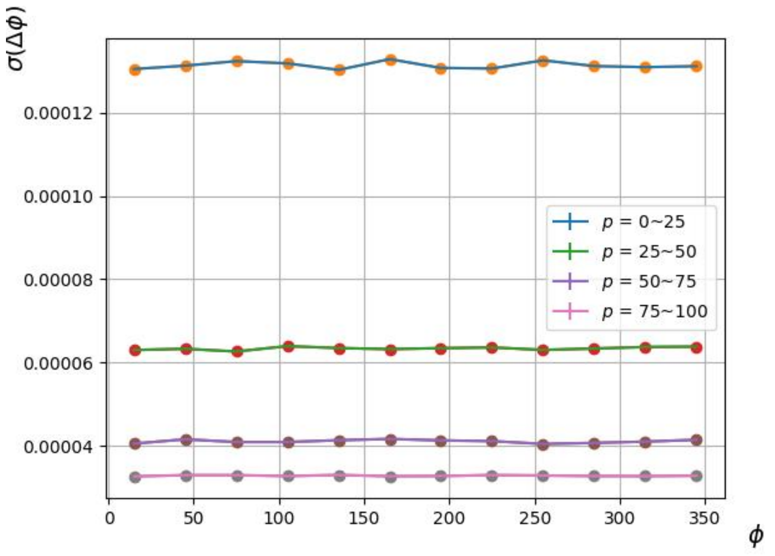
Figure 5.2: The layout of the CEPC tracker system.

TPC radius 0.6m - 1.8m, length 5.8m
Angle for the **transition btw barrel and endcap**:
θ ~ 31.8 degree cos(θ) ~ 0.85

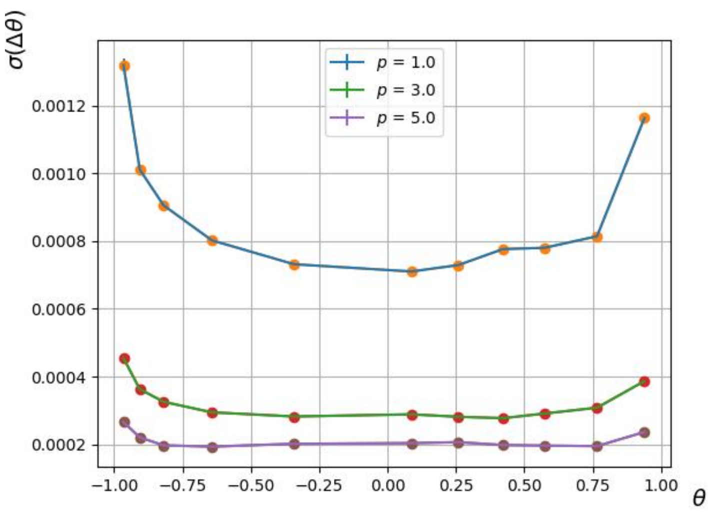
Tracking angular resolution

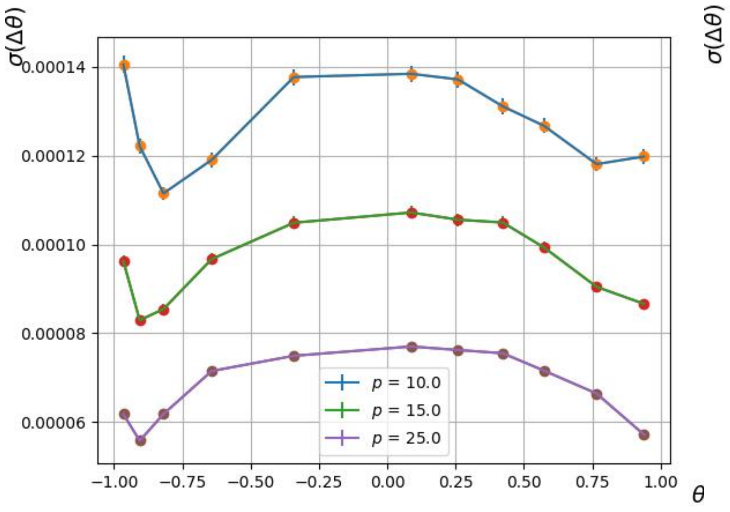


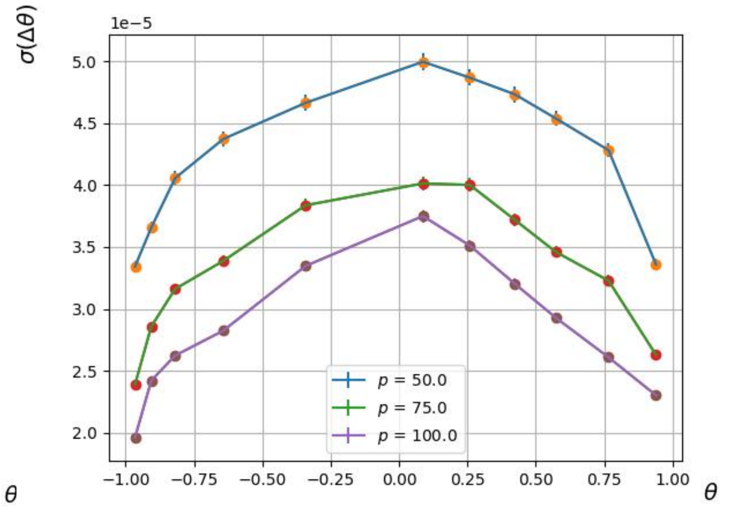




$$
\begin{aligned}
\Delta\theta|_{res.} &= \frac{\sigma_z \sin^2\theta}{L_0}\sqrt{\frac{12N}{(N+1)(N+2)}} \\
&\approx \frac{2\,\sigma_z \sin^2\theta}{L_0}\sqrt{\frac{3}{N+3}} \\
\Delta\theta|_{m.s.} &= \frac{\sin\theta}{\beta\, p_T}\, f\left(\frac{d}{X_0 \sin\theta}\right) \\
&\approx \frac{0.0136\,\mathrm{GeV/c}\,\sin\theta}{\beta\, p_T}\sqrt{\frac{d}{X_0 \sin\theta}}
\end{aligned}
$$

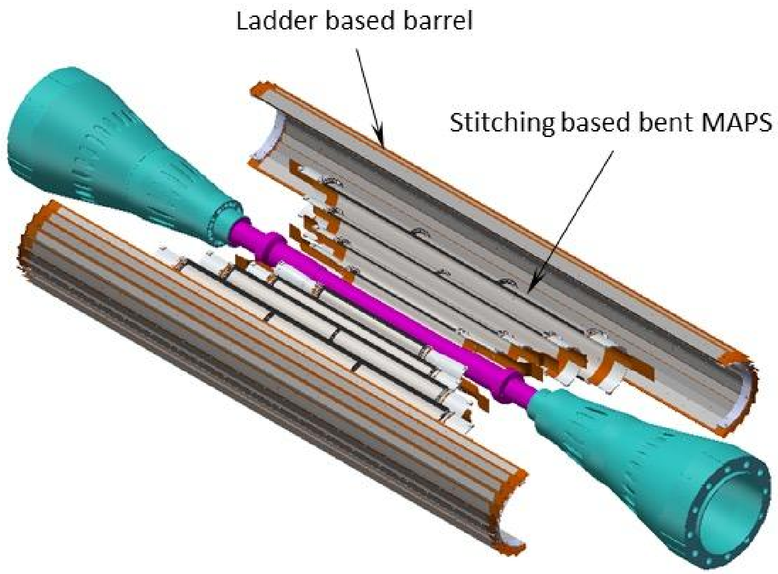




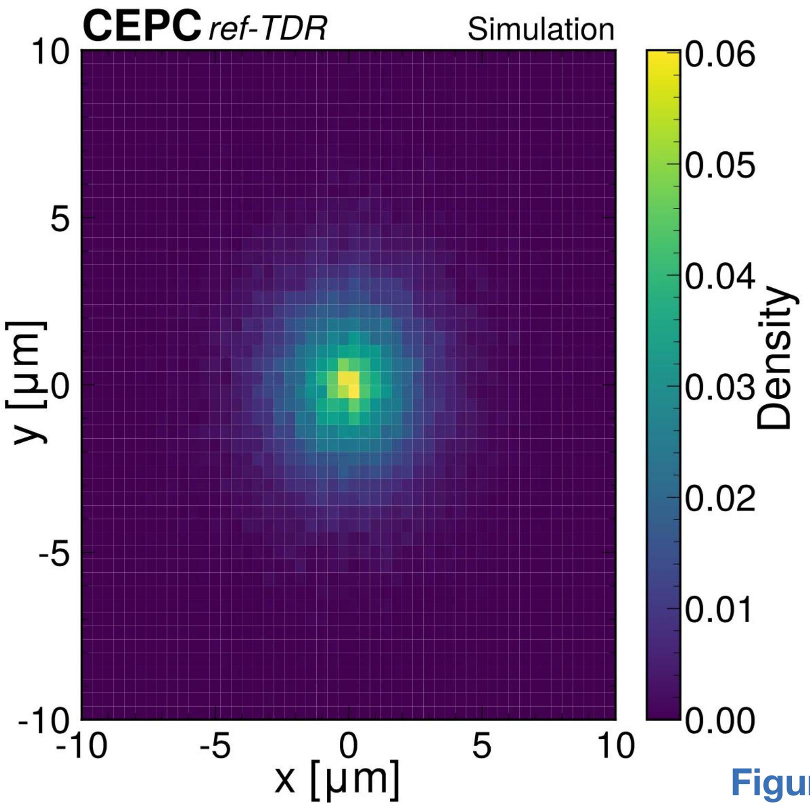


A similar algorithm following
LCFIPlus has been developed

Vertexing



Primary Vertex



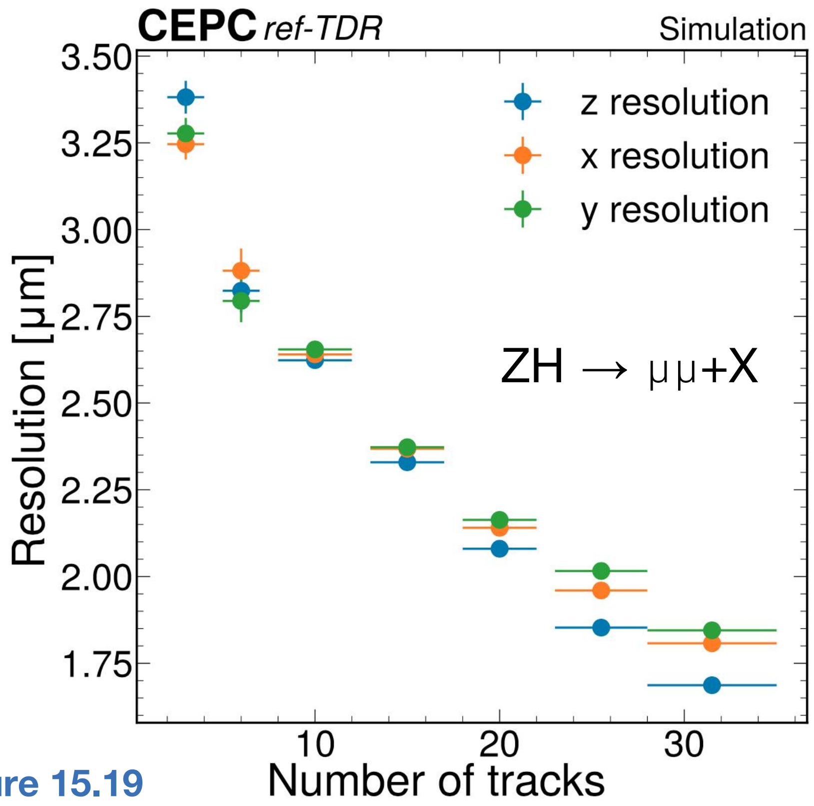
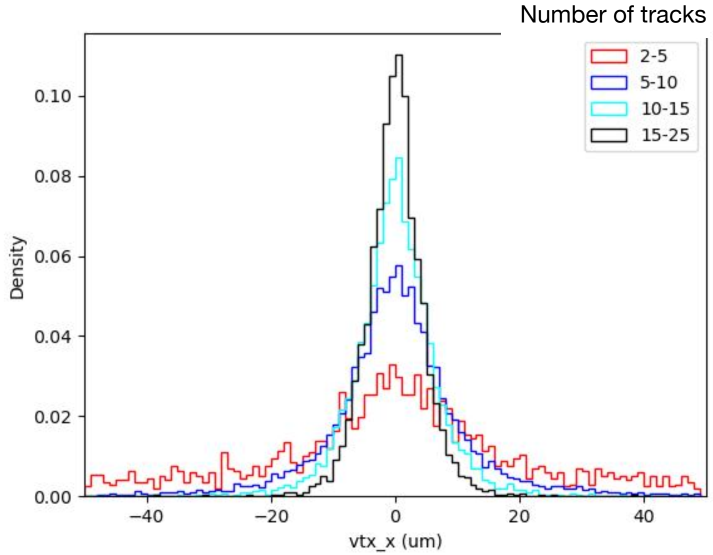
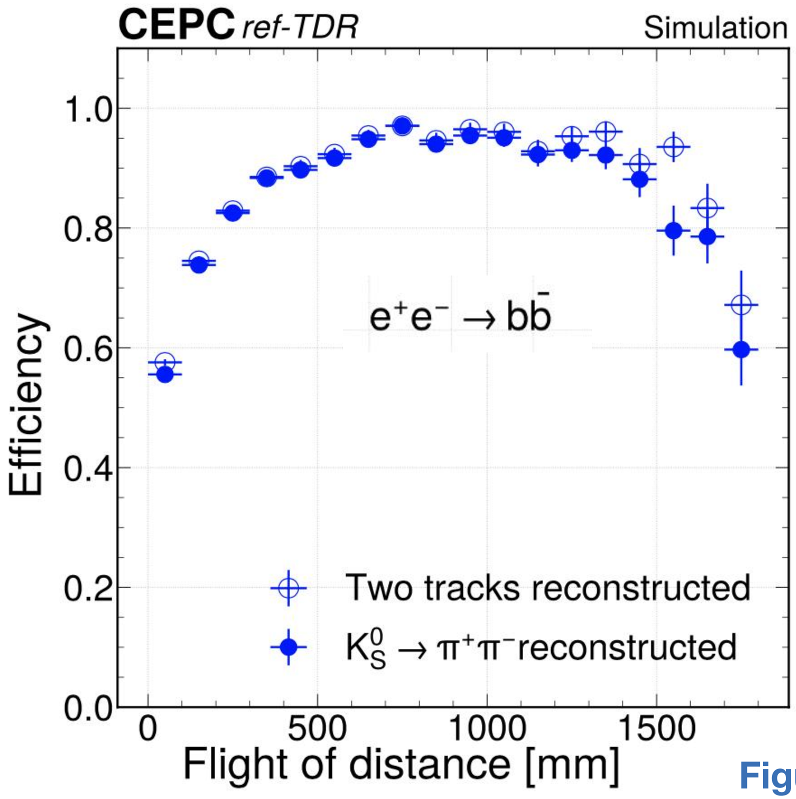


Figure 15.19



- Excellent resolution as expected, **< 3.5 μ m** for low multiplicity events, and **< 2 μ m** for high multiplicity events.

Secondary vertex



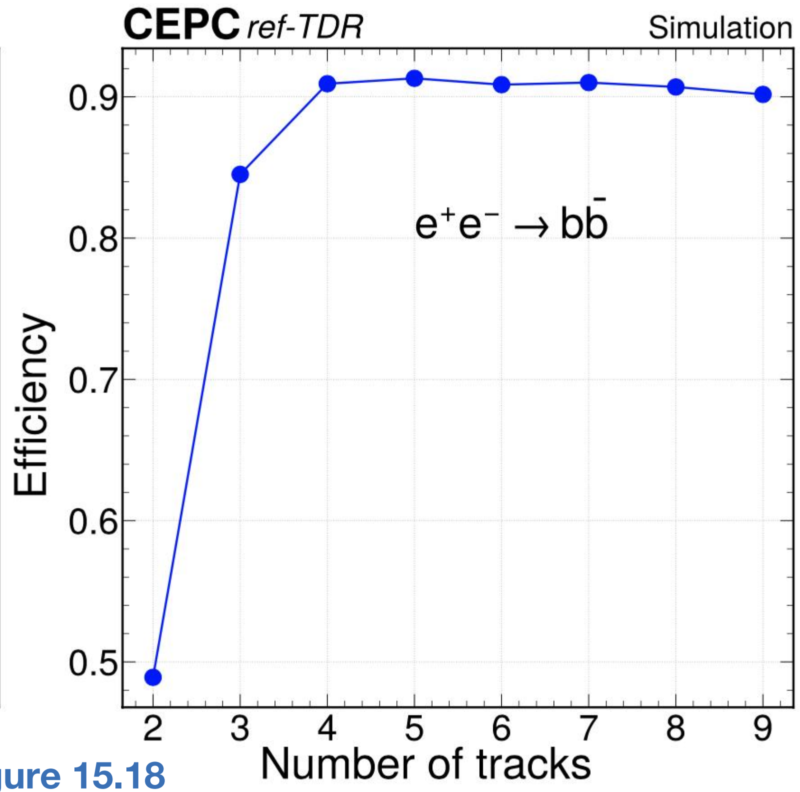


Figure 15.18

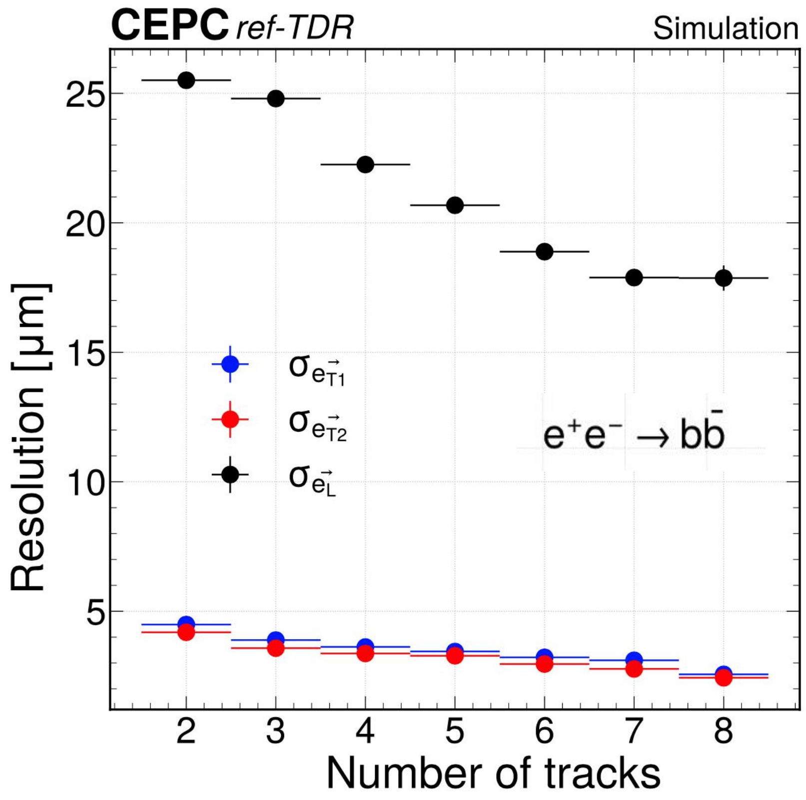


Figure 15.20: Resolution of the transverse and longitudinal components of the secondary vertices

- With ee→bb sample, the average efficiency for Ks is ~70%
- The efficiency for all true secondary vertices is ~75%
  - A true secondary vertex is considered reconstructed if a reconstructed secondary vertex is found within a distance of 200 μm
  - if a true vertex with > 2 tracks, at least two corresponding reconstructed tracks must be used to form this reconstructed vertex
- **Excellent resolution for secondary vertex**

Secondary Vertex

- Zbb sample