Simulation Study of Σ^0 Reconstruction in Bi+Bi at $\sqrt{s_{NN}}$ = 9.2 GeV

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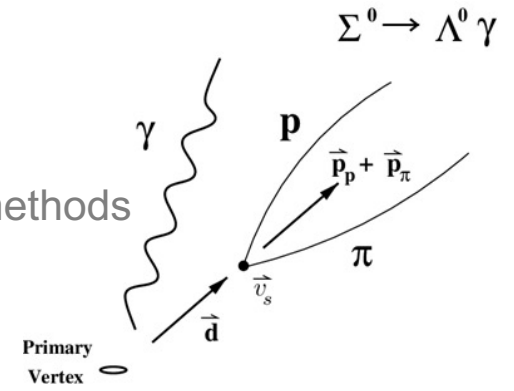
Introduction

Σ^0 is an important particle in heavy-ion collisions, reconstruction by the decay channel with $\mathbf{B.R.} \approx 100\%$:

$$\Sigma^0 \rightarrow \gamma\Lambda$$

- ✓ probe strangeness and hyperon production at NICA energies
- ✓ study low-energy photon reconstruction via $\Sigma^0 \rightarrow \gamma\Lambda$ using the PCM and ECal methods
- ✓ provide a basis for Σ^0 measurements with future MPD data analysis



Physics Letters B 479 (2000)

Analysis Workflow

Λ reconstruction (p + π⁻) → **Photon reconstruction** (PCM / ECal) → **Σ^0 candidates** (γ + Λ) → **Background estimation** (MIX / ROT) → **Signal extraction** (fits / pT yield)

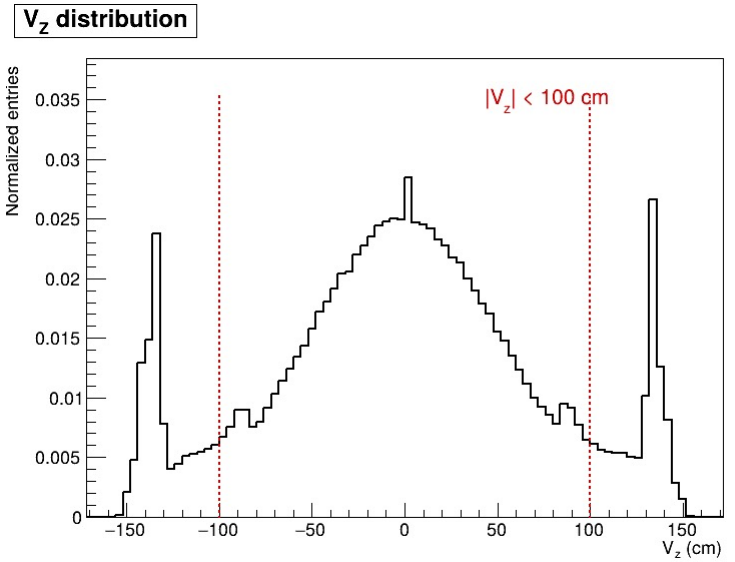
Event Selection

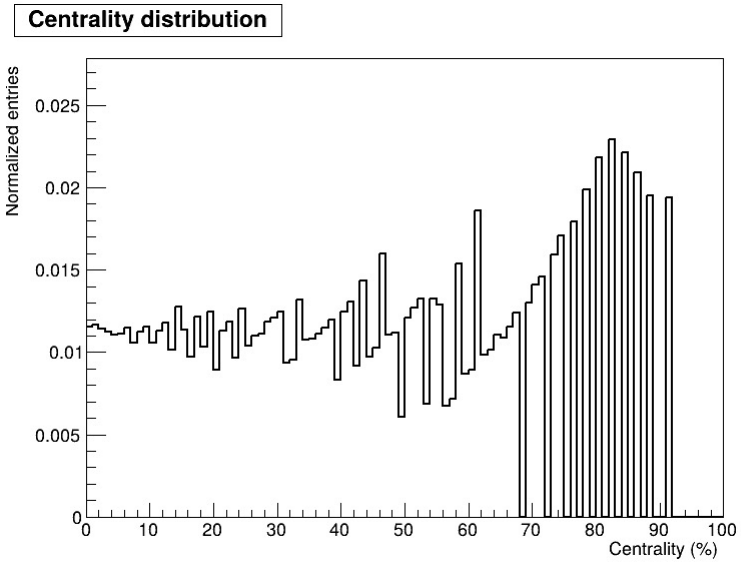
Dataset:

- Collision system: BiBi@9.2 GeV
- Event generator: UrQMD
- Production: 105M events (req25+req34+req38)

Event cut:

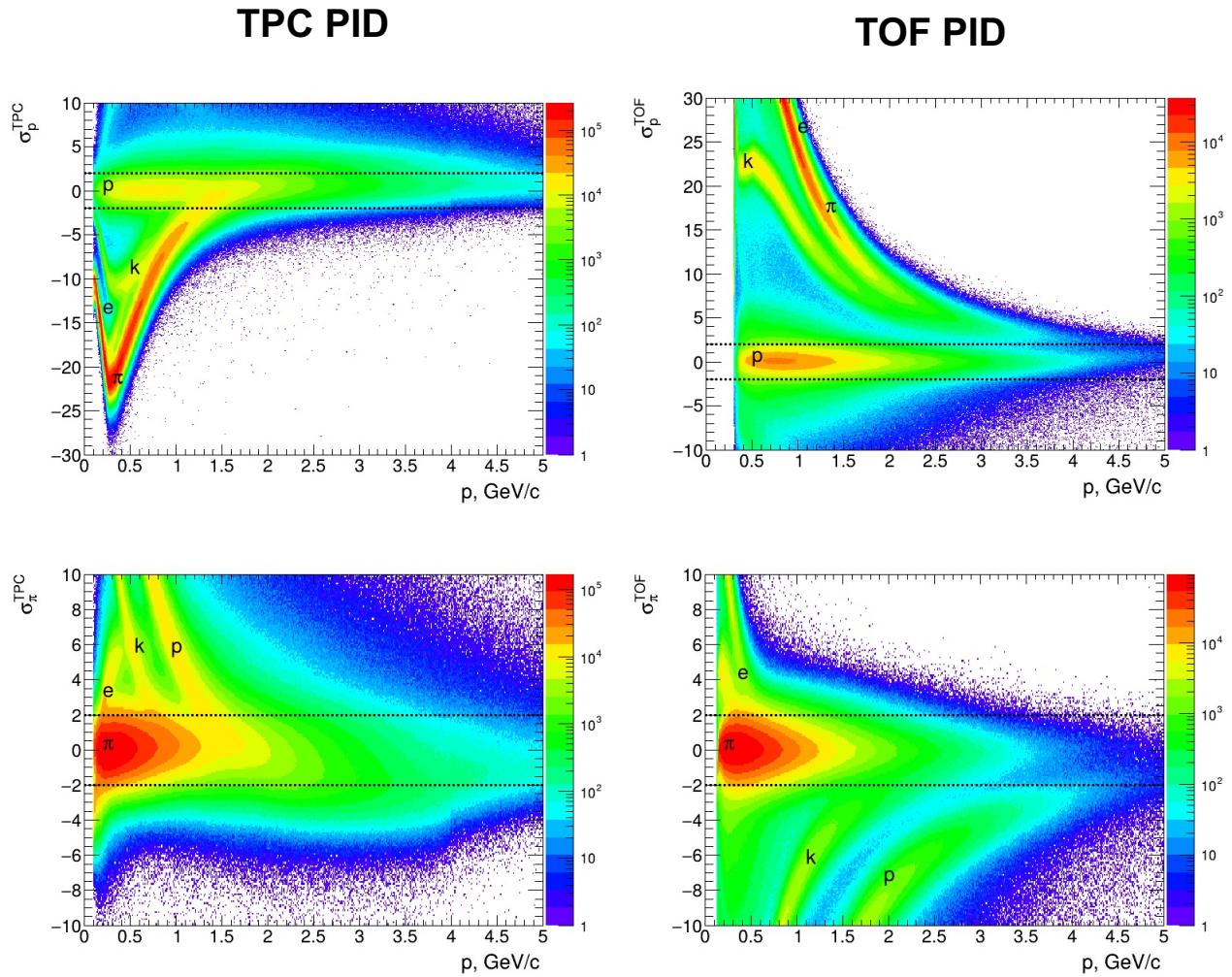
- Primary vertex of event reconstructed and | V_z | < 100 cm
- Centrality: 0-100%





Λ Reconstruction: Daughter Track PID

$\Lambda \rightarrow p + \pi^-$ (B.R. ≈ 64.1%)



Track quality:

- $N_{hits}^{TPC} > 20$
- $p_T > 0.1\ GeV/c$

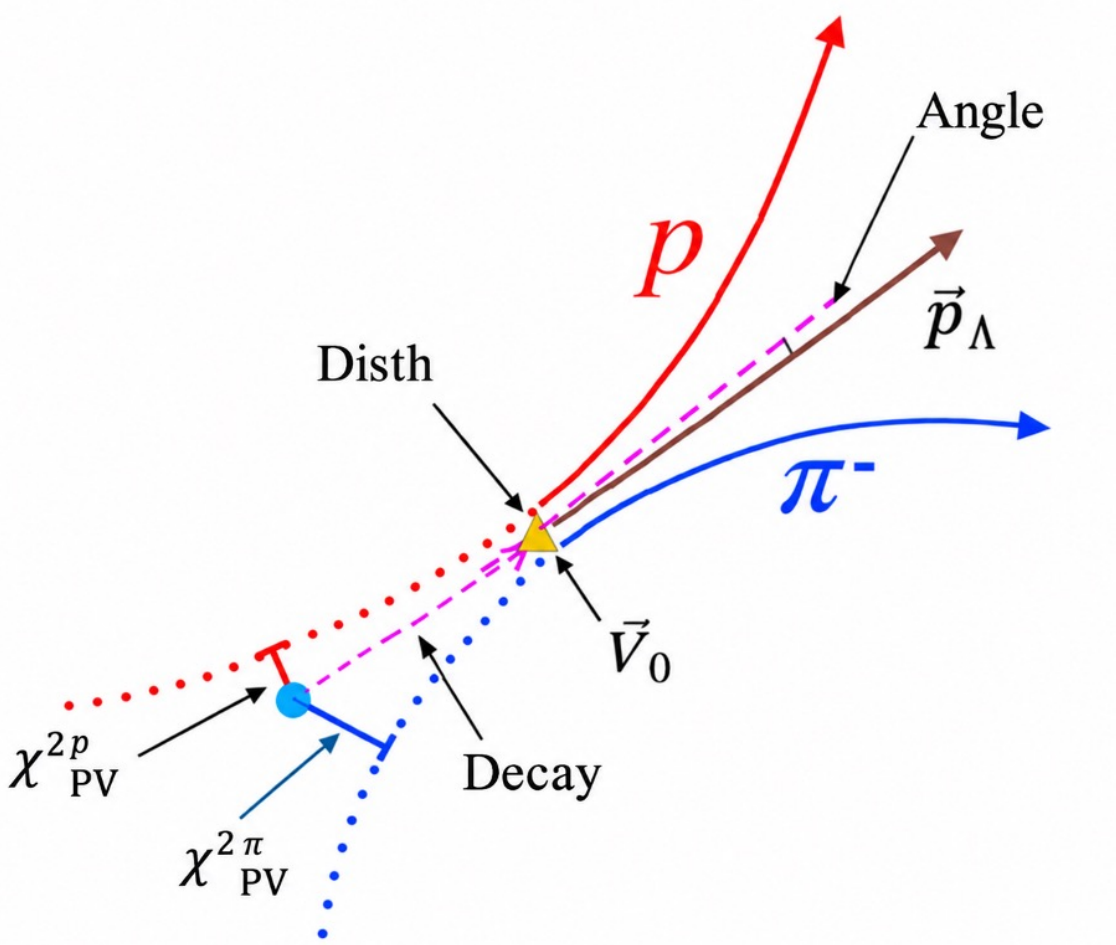
Particle identification:

- $|\ \sigma_{TPC}^{p/\pi^-}\ | < 2.0$
- If TOF matched: $|\ \sigma_{TOF}^{p/\pi^-}\ | < 2.0$
- TOF matched:
  $\sigma_{\phi^{TPC-TOF}} < 3.0$
  $\sigma_{Z^{TPC-TOF}} < 2.0$

TPC provides the baseline PID
TOF information is added only for matched tracks

Λ Reconstruction: V^0 Candidate Selection

$\Lambda \to p + \pi^-$ (B.R. ≈ 64.1%)



$\Lambda \to p\pi^-$ decay topology

Selection variables for $p\pi^-$ pairs:

- $\chi^2_{\mathrm{V^0}} < 6.0$

  the fit quality of the reconstructed secondary vertex (SV)
- $\mathrm{Disth} < 1.25\ \mathrm{cm}$

  the DCA between the p and π^- tracks
- $\mathrm{Angle} < 0.1\ \mathrm{rad}$

  the angle between $\vec{p}_\Lambda$ and $\vec{r}_\Lambda$
- $\mathrm{Decay} > 4.0\ \mathrm{cm}$

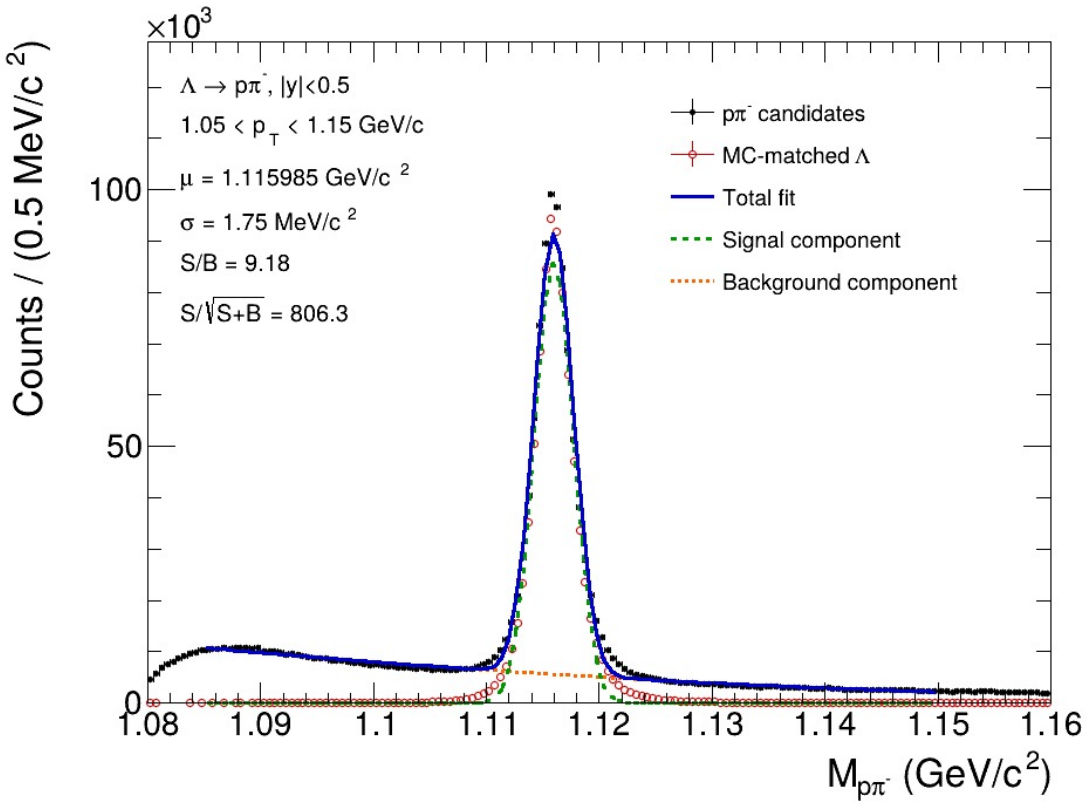
  the distance from primary vertex (PV) to SV
- $\chi^2_{p\ \mathrm{to\ PV}} > 7.0$

  the fit quality of p with respect to the PV
- $\chi^2_{\pi^-\ \mathrm{to\ PV}} > 3.0$

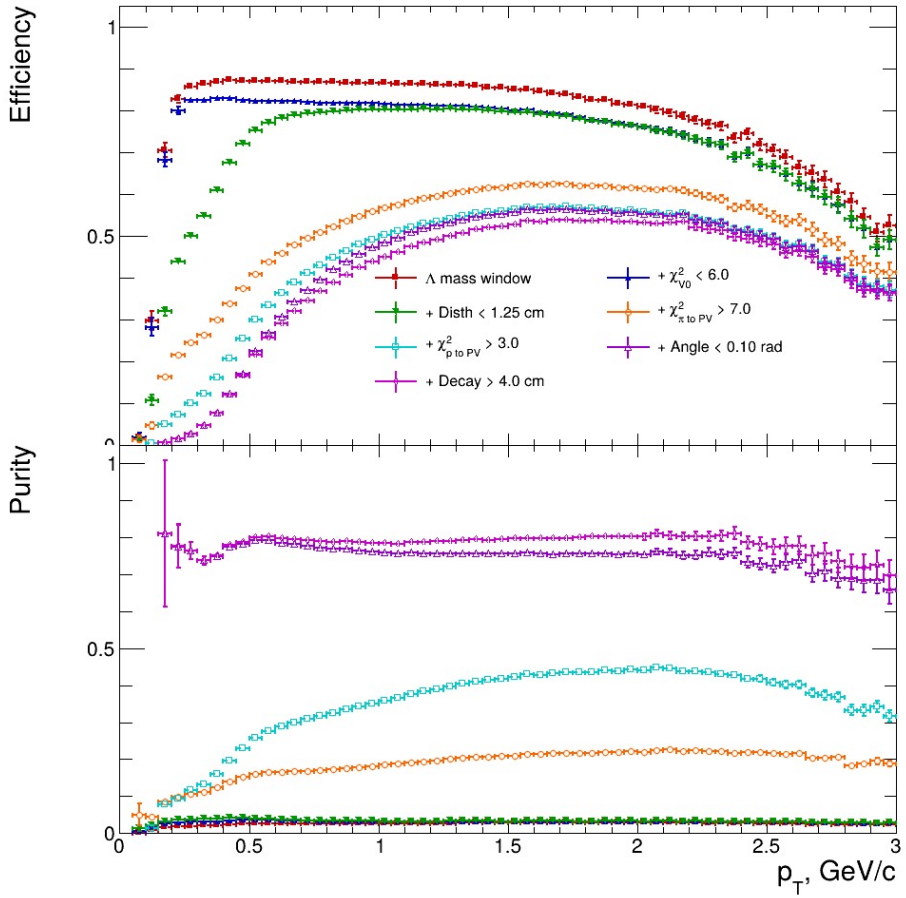
  the fit quality of π^- with respect to the PV

Λ Reconstruction: Performance

Invariant mass reconstruction



Selection performance

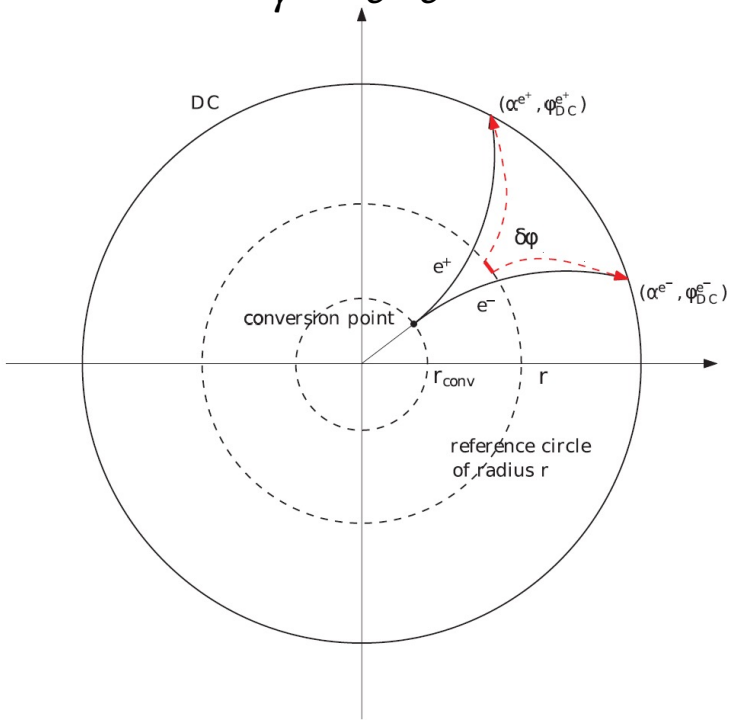


Λ candidates are selected within $1.111 < M_{p\pi^-} < 1.121$ GeV/c²

Photon Reconstruction

Photons Conversion Method (PCM)

$\gamma \rightarrow e^+e^-$

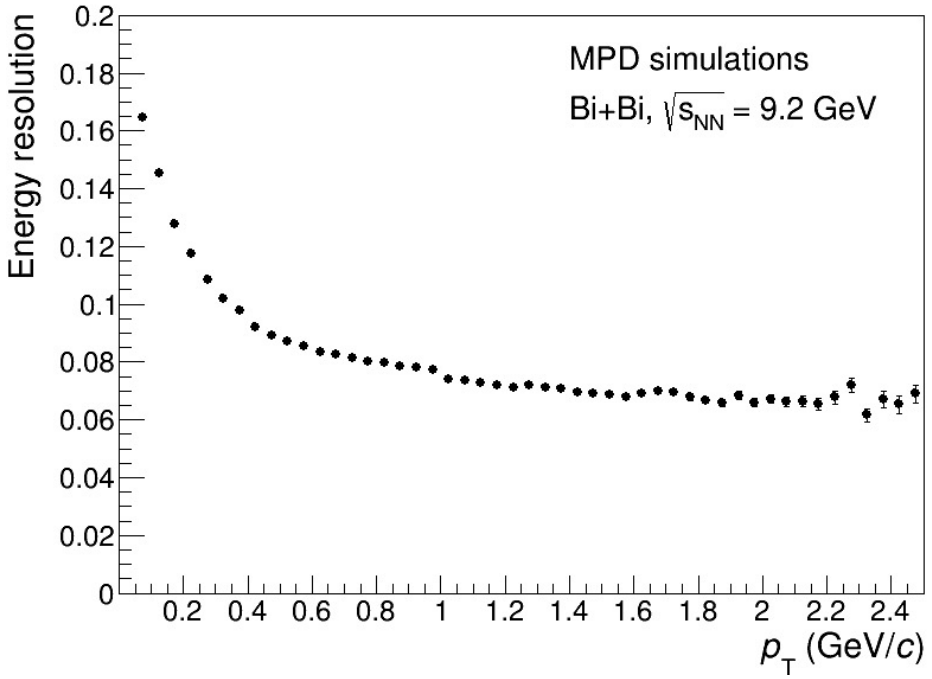


arXiv:1907.08893

- Measured in the TPC as e^+e^- conversion pairs
- Good low-energy photon reconstruction
- Efficiency limited by conversion probability

Electromagnetic Calorimeter (ECal)

$\gamma \rightarrow$ EM shower $\rightarrow$ cluster



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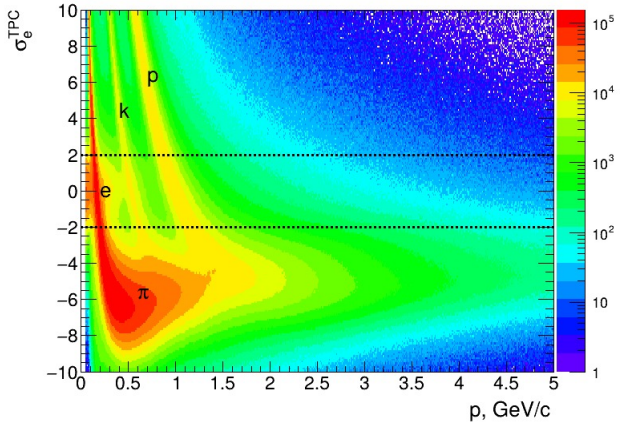
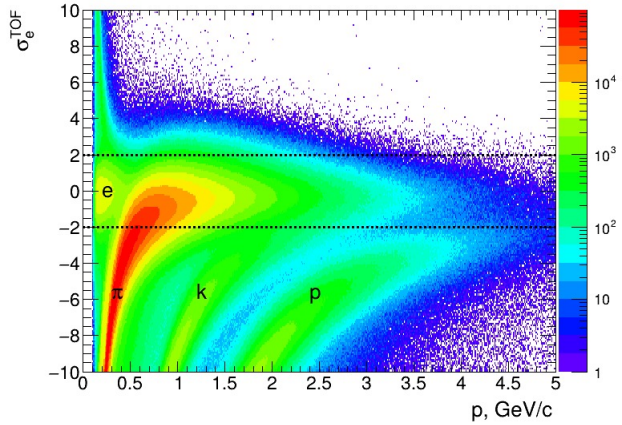
- Direct photon-energy measurement
- Larger photon acceptance
- Limited energy resolution at low energy

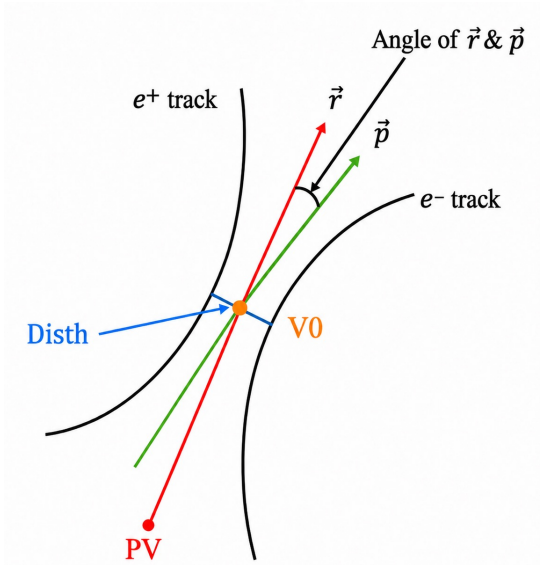
Photon Conversion Method

TPC PID



TOF PID





$\gamma \rightarrow e^+e^-$ conversion topology

Track quality:

- $N_{hits}^{TPC} > 10$
- $p_T > 0.03\ GeV/c$

Particle identification:

- $|\ \sigma_{TPC}^{e^\pm}| < 2.0$
- If TOF matched: $|\ \sigma_{TOF}^{e^\pm}| < 2.0$
- TOF matched:

$$\sigma_{\phi^{TPC-TOF}} < 3.0$$

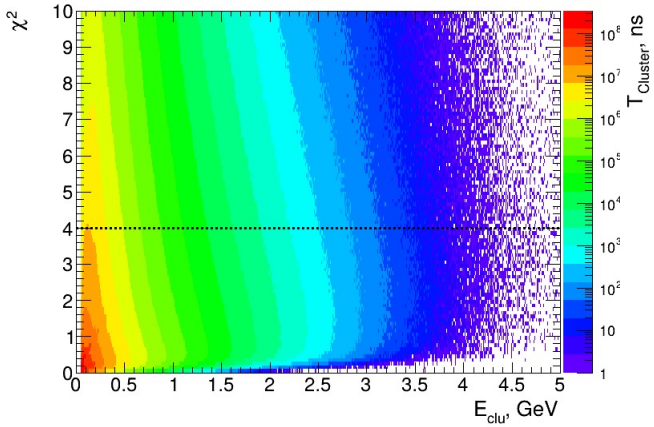
$$\sigma_{Z^{TPC-TOF}} < 2.0$$

p_T-dependent selections:

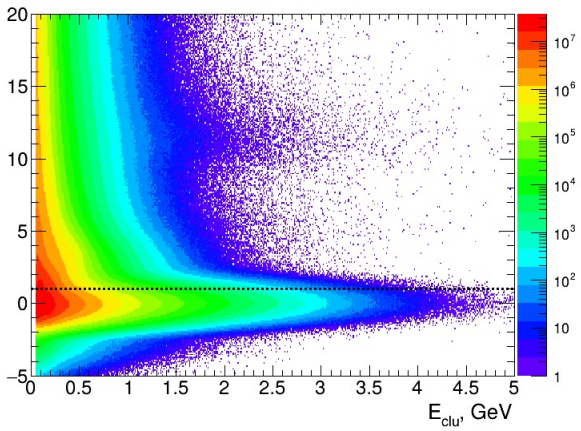
- 90% Angle
- 95% Disth
- 99% $\chi^2_{V^0}$
- 90% Mass
  invariant mass of the photon candidate
- 95% PhiV
  angle between the pair-plane normal and the magnetic-field direction

ECal Method

χ^2



$T_{cluster}$



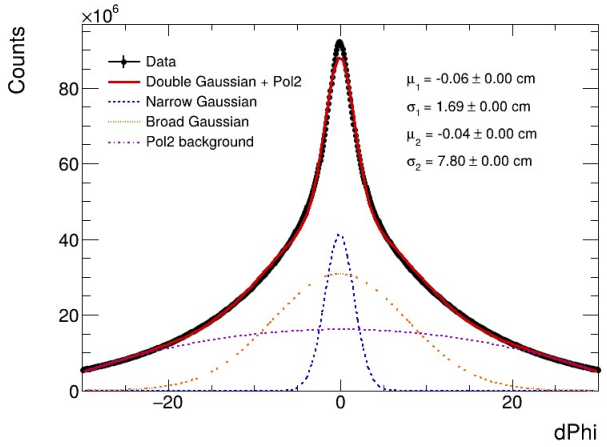
Cluster quality:

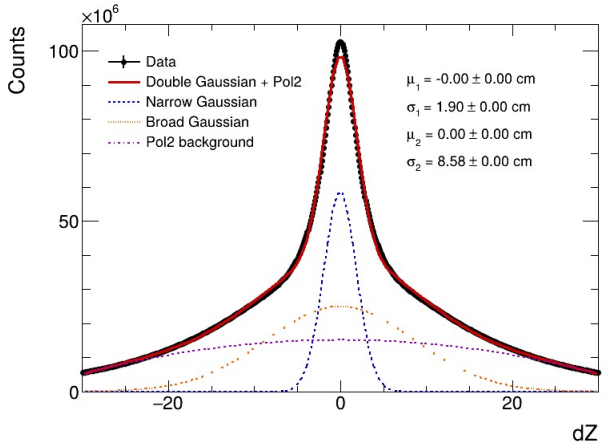
- $\mathrm{N}_{\mathrm{cell}}^{\mathrm{Ecal}} > 2$
- $E_{cluster} > 0.05$ GeV

Photon identification:

- $\chi^2 < 4$
- $T_{cluster} < 1\ ns$
- 4σ Charge Particle Veto (CPV)

Charge Particle Veto





Charge particle match:

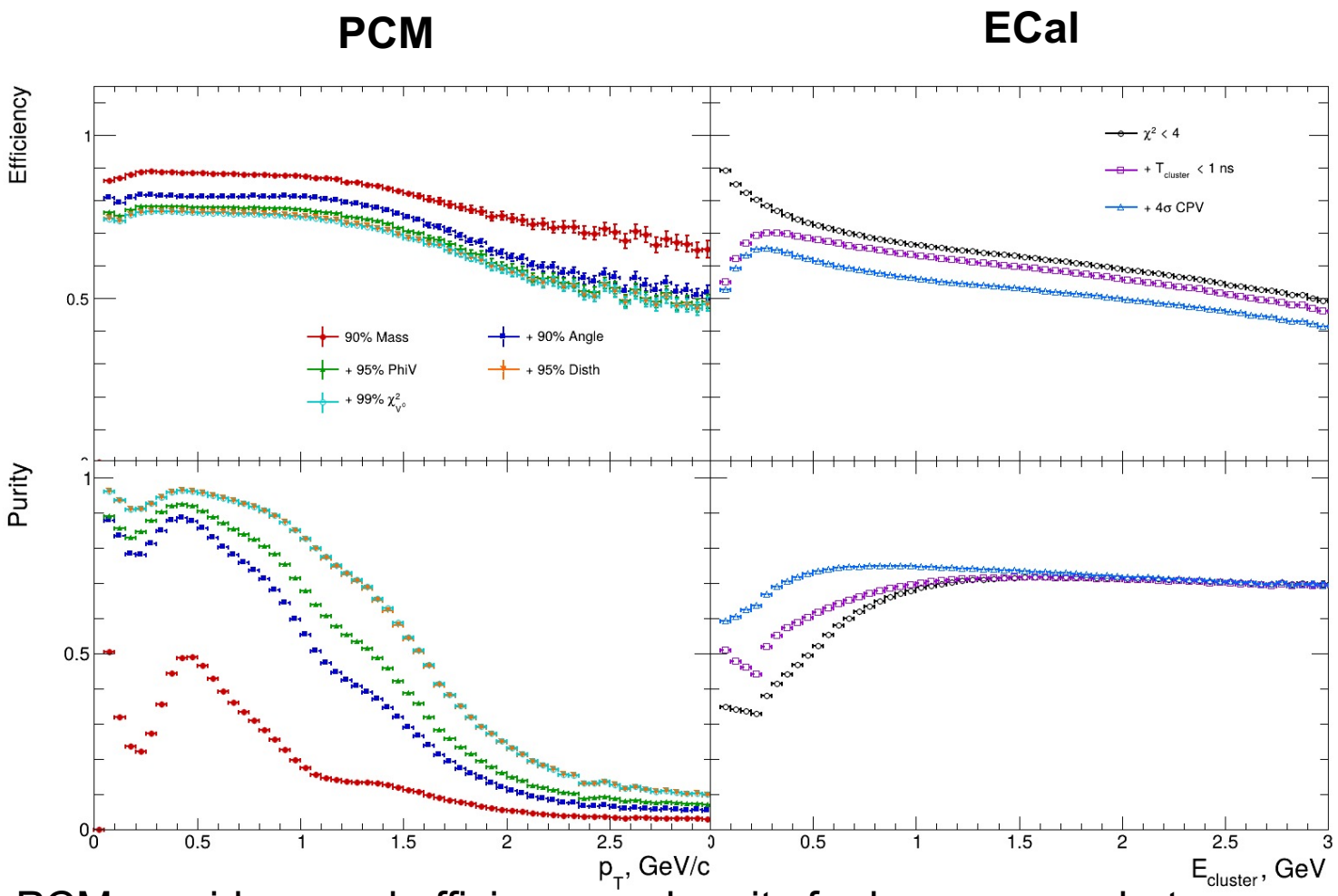
$$\sigma_{match}^2 = \left(\frac{\Delta\phi}{\sigma_{\Delta\phi}}\right)^2 + \left(\frac{\Delta Z}{\sigma_{\Delta Z}}\right)^2$$

$$\sigma_{\Delta\phi} = \sigma_1^{dPhi}$$

$$\sigma_{\Delta Z} = \sigma_1^{dZ}$$

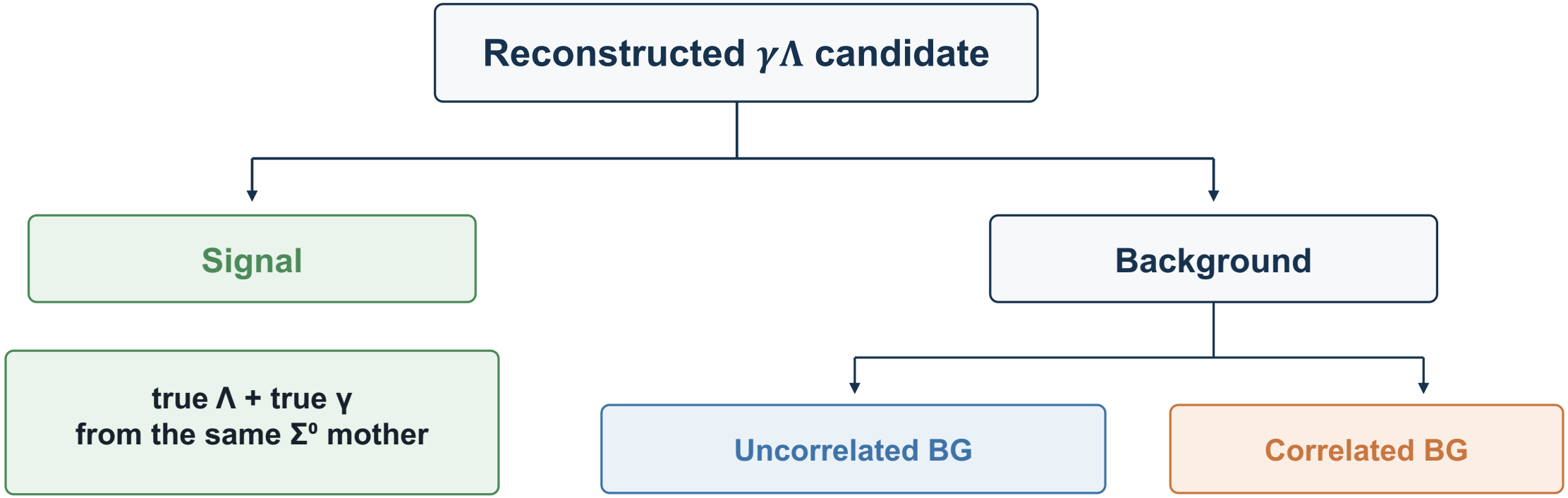
- Narrow: matched charged tracks and clusters
- Intermediate: broader matching tails
- Pol2: photon or other neutral clusters

PCM and ECal: Selection Performance



- PCM provides good efficiency and purity for low-energy photons
- Low-energy ECal photon purity is limited, mainly by pion contamination
- 4σ CPV improves purity with a small efficiency loss

Σ^0 Candidates



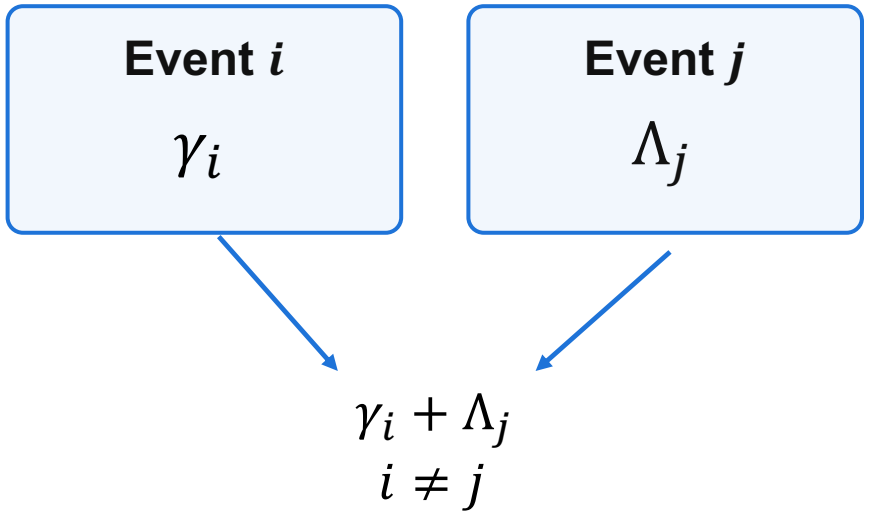
Estimation by mix event method or rotation method

$\Xi^0 \to \Lambda\pi^0$, $\Xi^- \to \Lambda\pi^-$, $\Sigma(1385)^0 \to \Lambda\pi^0$ $\Sigma(1385)^\pm \to \Lambda\pi^\pm$ …

Background Estimation

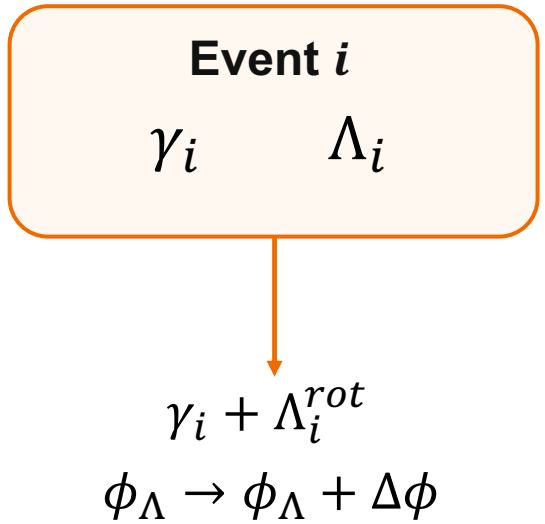
Phys. Rev. Lett. 128, 202301

Mix Event



different but similar events

Rotation



rotate Λ in the same event

Mix Event

Event pool: 10 Vz bins × 10 Centrality bins × 1 EP bin

Mix depth = 10

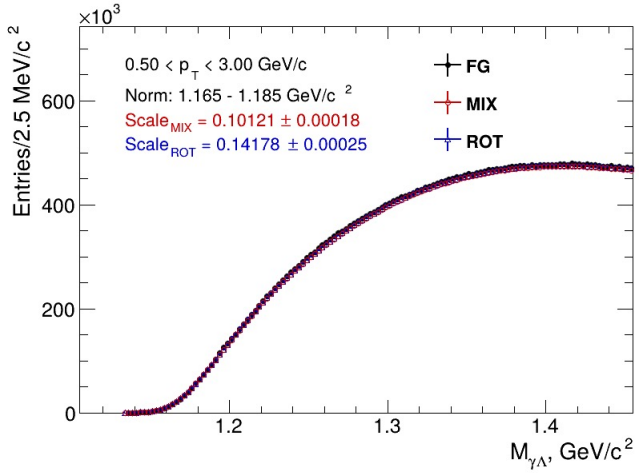
Rotation

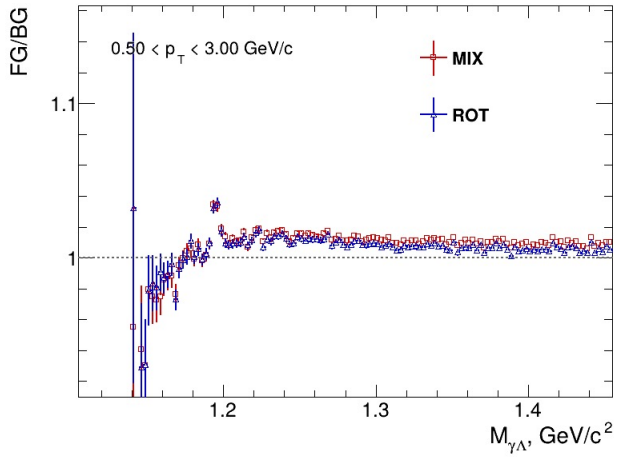
$\Delta\phi = 90° - 270°, \quad step = 30°$

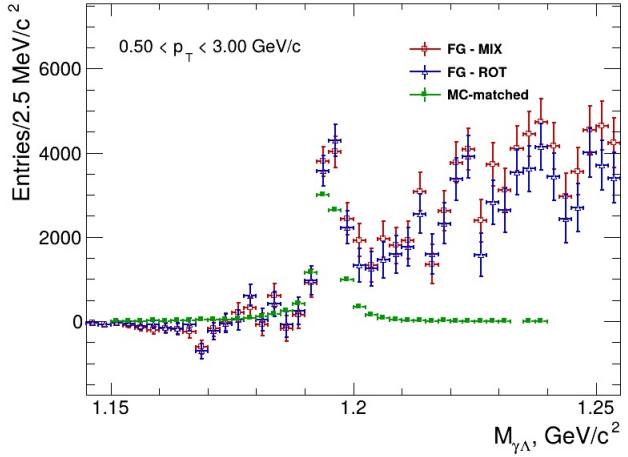
Mix Event and Rotation Method

Mass distribution | **FG/BG ratio** | **After subtraction**

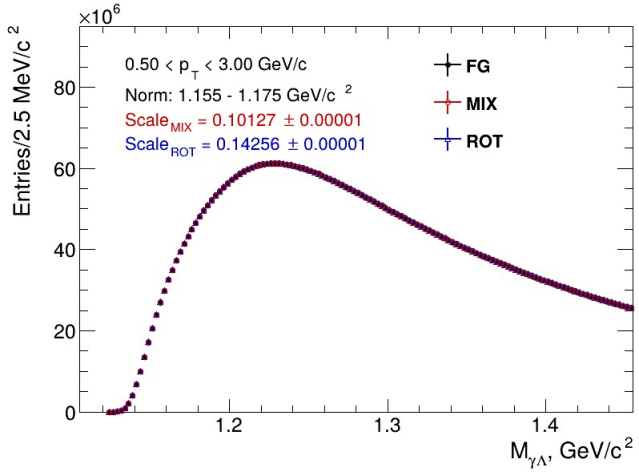
$\Lambda + \gamma(\mathrm{PCM})$

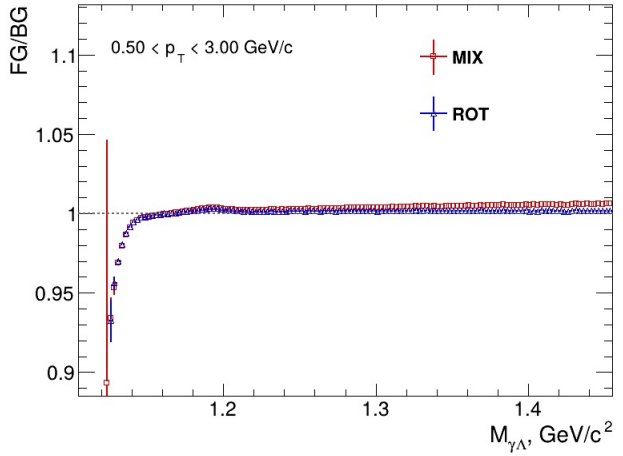


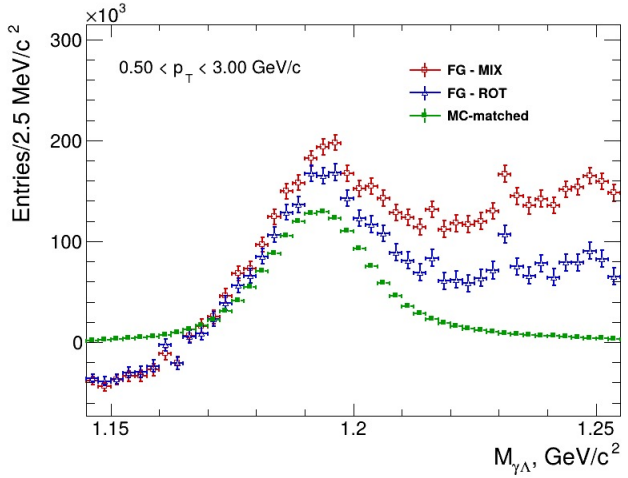




$\Lambda + \gamma(\mathrm{ECal})$





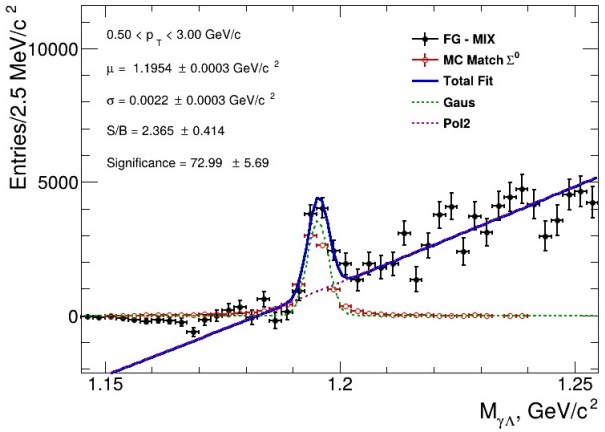


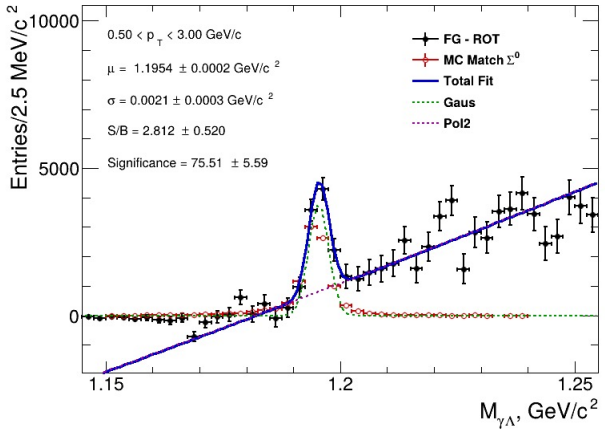
- MIX and ROT give similar background shapes, with ROT closer to FG, especially for ECal
- After subtraction, a sizable correlated background remains, dominated by π^0-decay photons

Signal Extraction

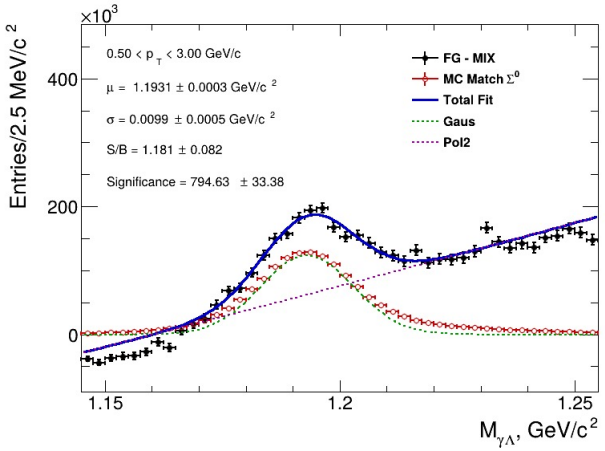
Mix Event | **Rotation**

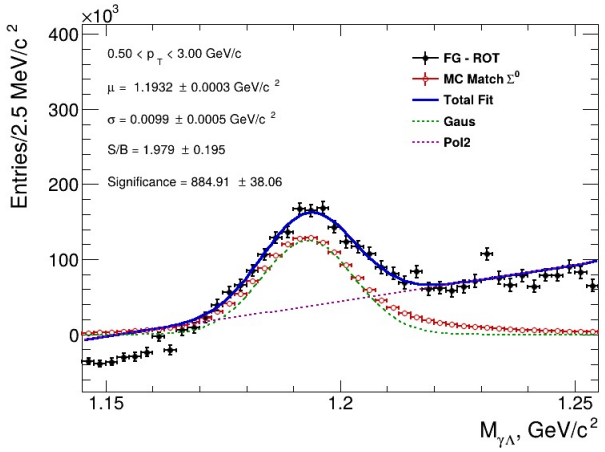
$\boldsymbol{\Lambda + \gamma(\mathrm{PCM})}$





$\boldsymbol{\Lambda + \gamma(\mathrm{ECal})}$





$$S = \int_{\mu-2\sigma}^{\mu+2\sigma} G(m)dm$$

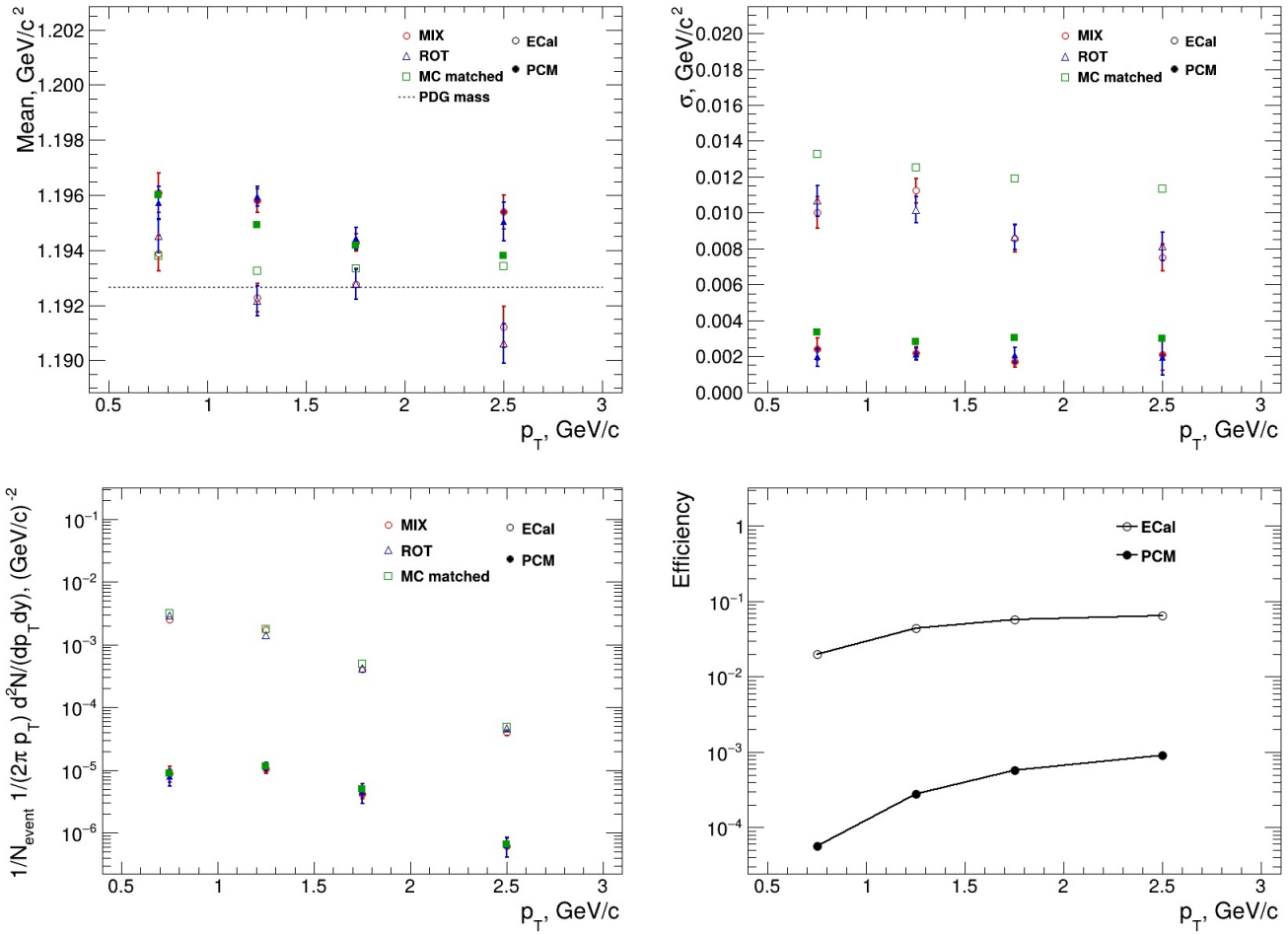
$$B = \int_{\mu-2\sigma}^{\mu+2\sigma} P(m)dm$$

$$\text{Significance: } Z = \frac{S}{\sqrt{S+B}}$$

- $G(m)$: Gaussian signal
- $P(m)$: 2nd-order polynomial background

- PCM has higher S/B, while ECal has higher significance
- MIX and ROT give consistent peak positions and widths

Reconstruction Performance



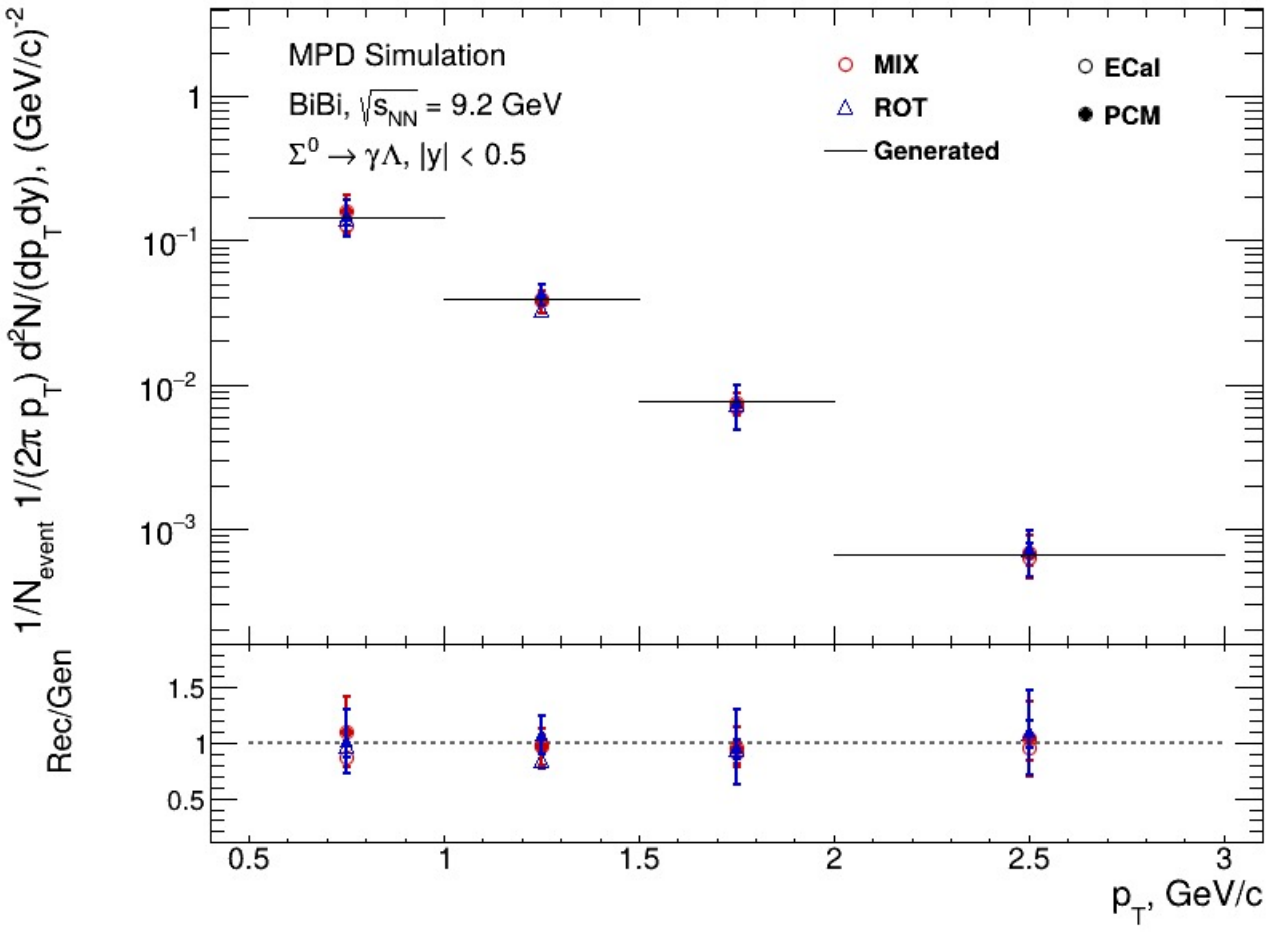
$$Y_{Raw} = \frac{1}{N_{event}} \cdot \frac{N_{sig}}{2\pi p_T dp_T dy}$$

$$N_{sig} = S = \int_{\mu-2\sigma}^{\mu+2\sigma} G(m)dm$$

$$\text{Efficiency: } \epsilon = \frac{N_{True}}{N_{Gen}}$$

- MIX and ROT give consistent peak parameters
- PCM shows a narrower reconstructed peak than ECal
- ECal has much higher reconstruction efficiency than PCM

Corrected Σ^0 Yield



$$Y_{Corr} = \frac{1}{N_{event}} \cdot \frac{N_{sig}}{2\pi p_T dp_T dy} \cdot \frac{1}{\epsilon}$$

- MIX and ROT give similar corrected yields
- Both PCM and ECal agree with the generated spectrum within statistical uncertainties

Summary

- Σ^0 reconstructed with both PCM and ECal has been studied
- MIX and ROT were used to estimate the uncorrelated background, with ROT giving a flatter FG/BG ratio
- After subtracting the uncorrelated background, a sizable correlated background remains, with a significant contribution from π^0- decay photons
- Corrected PCM and ECal yields are consistent within statistical uncertainties

Next:

- ☐ Apply the same analysis strategy to the MPD fixed-target configuration

Summary

- Σ^0 reconstructed with both PCM and ECal has been studied
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Thanks!

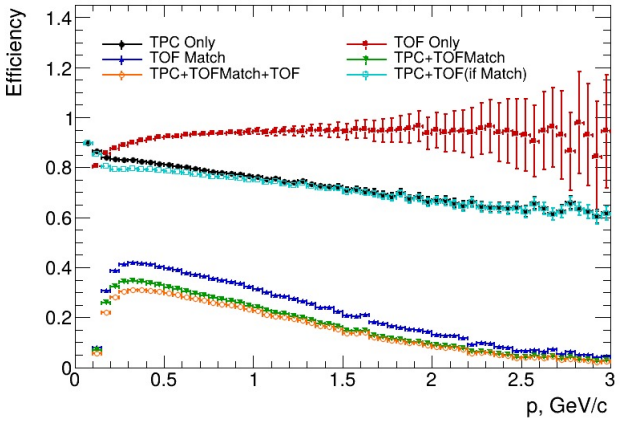
Backup

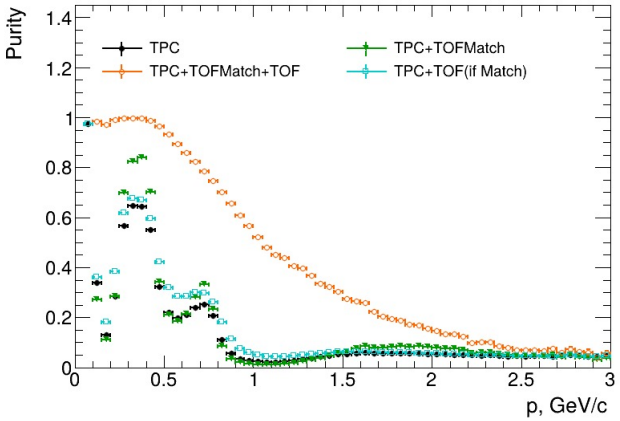
Efficiency and Purity of PID

Efficiency

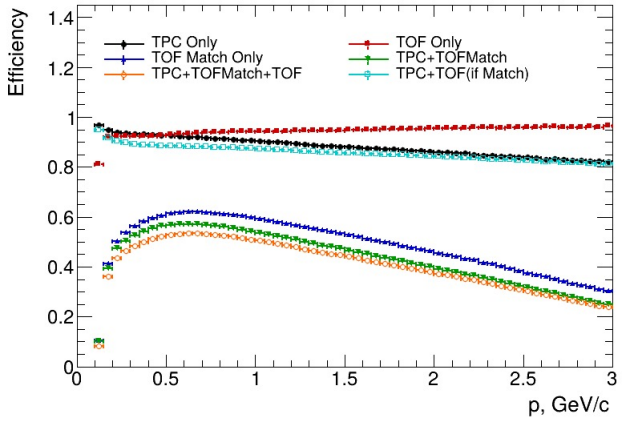
Purity

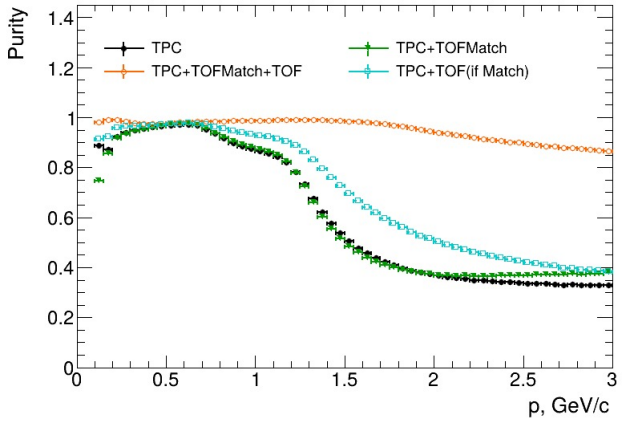
e



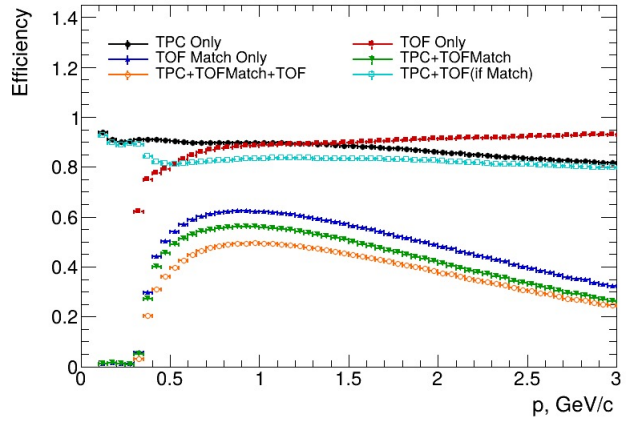


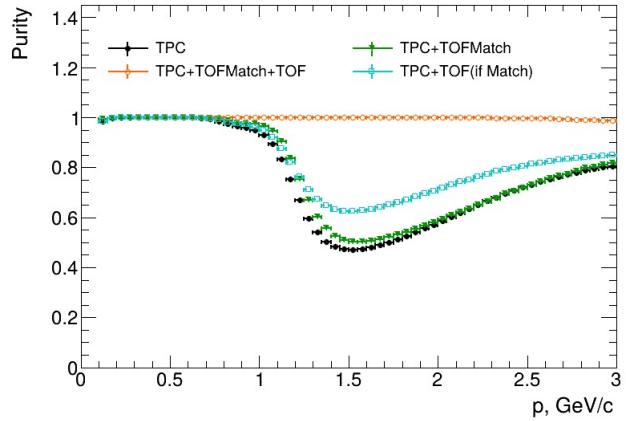
π





p





Photon Reconstruction Efficiency

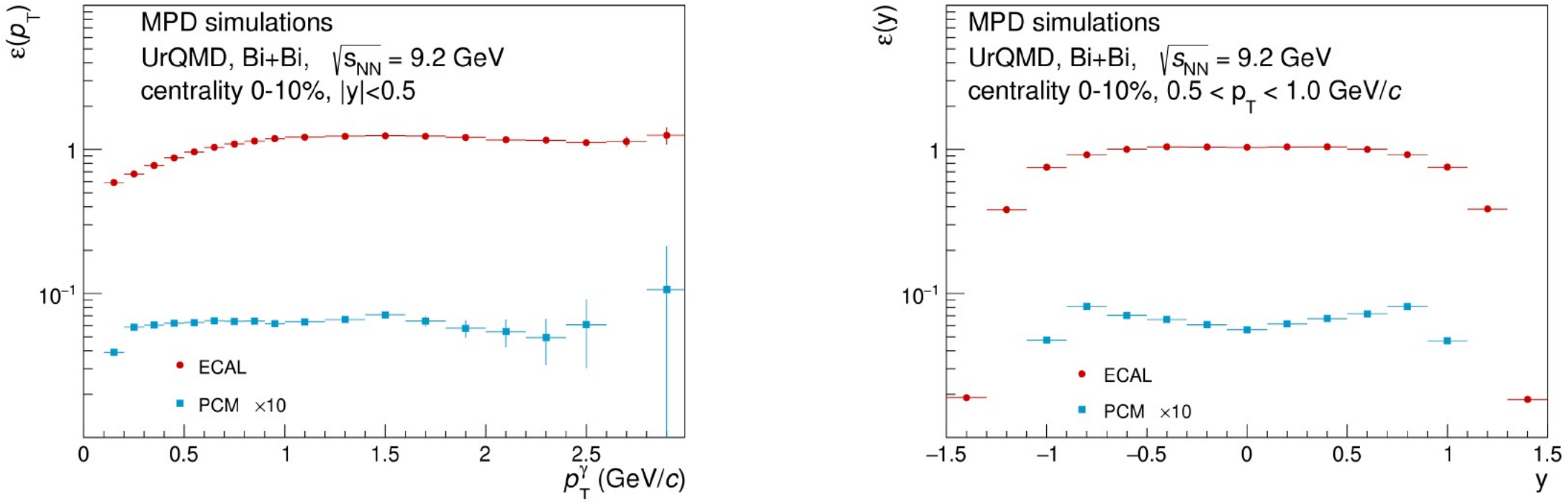


FIGURE 42. Left: inclusive photon reconstruction efficiency in the ECAL and PCM method as a function of photon p_T^γ. Right: inclusive photon reconstruction efficiency in the ECAL and PCM method as a function of rapidity.

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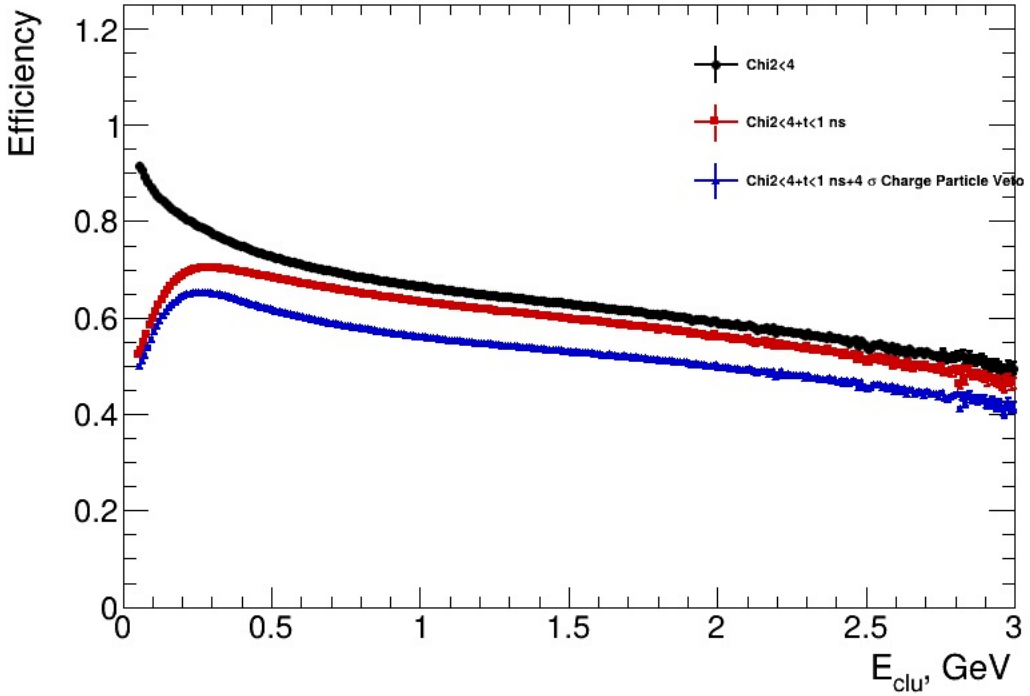
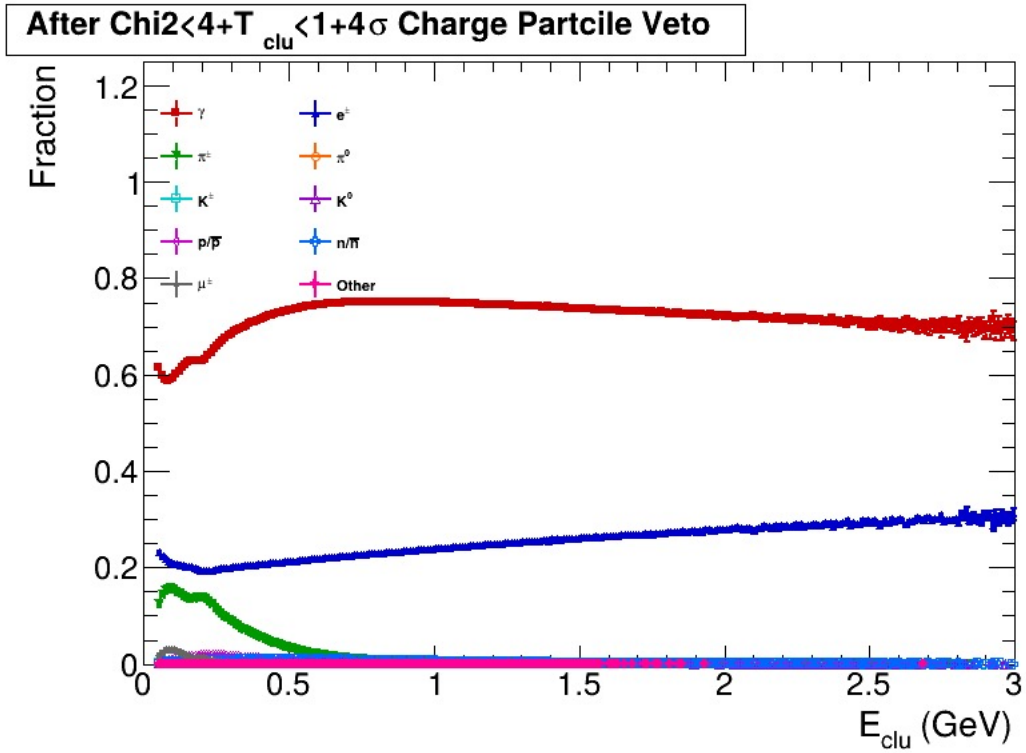
ECal Selection



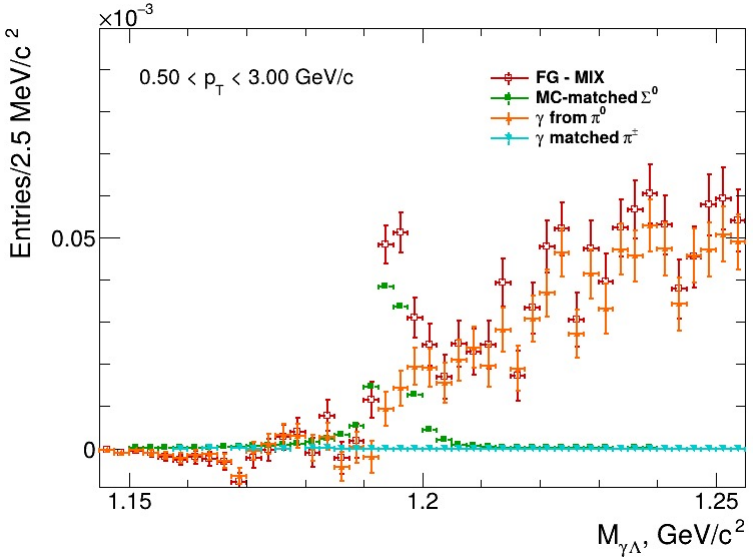


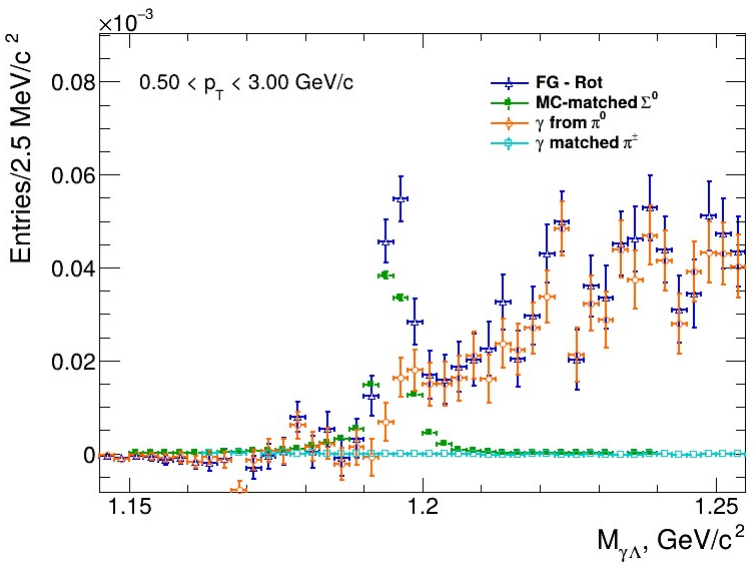
- pion contamination remains at low energy

Background

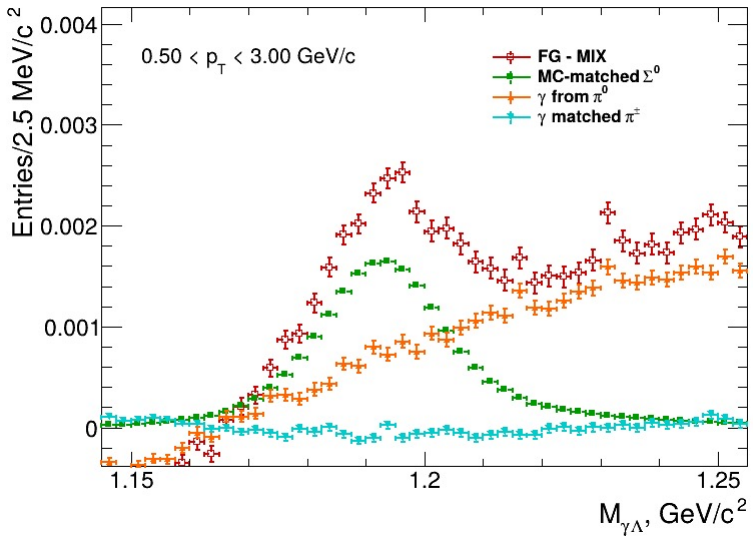
Mix Event | **Rotation**

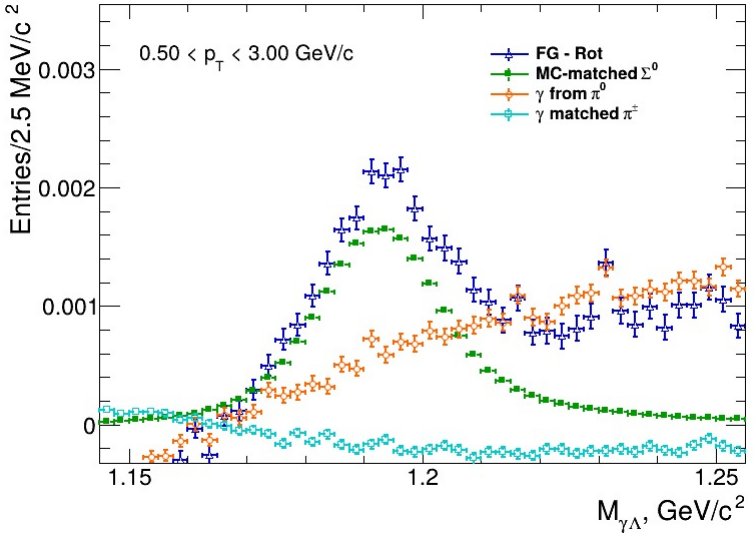
$\Lambda + \gamma(\mathbf{PCM})$





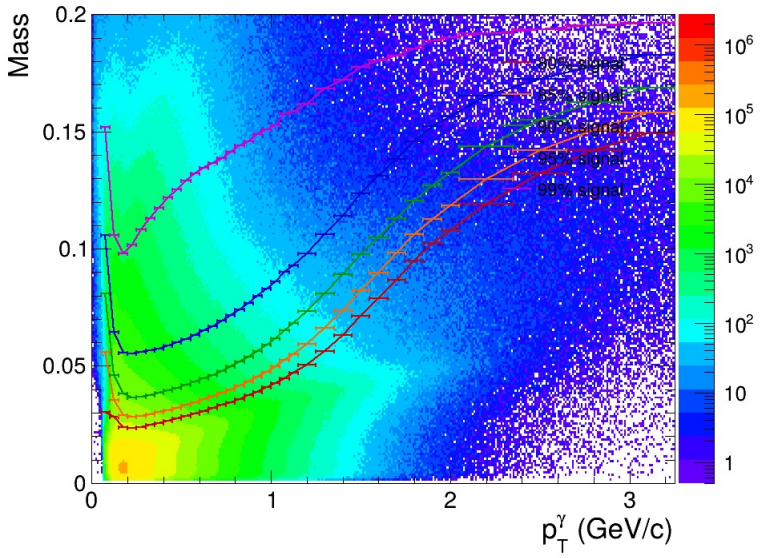
$\Lambda + \gamma(\mathbf{ECal})$

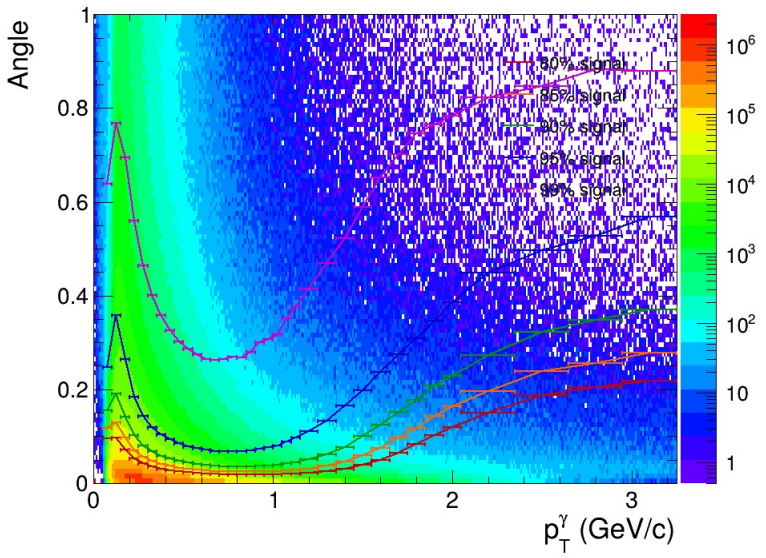


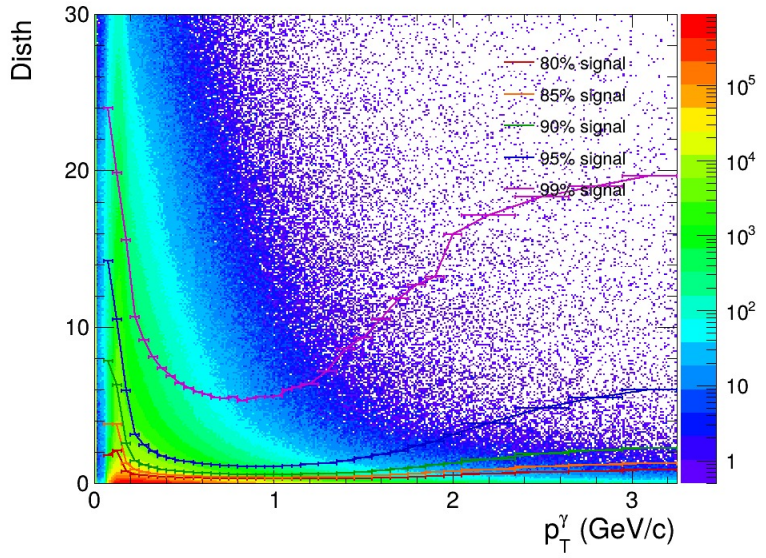


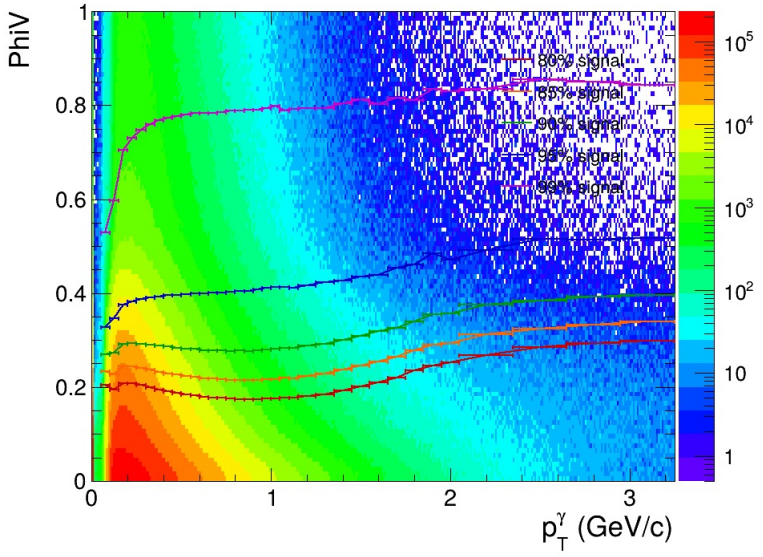
- π^0-decay photons are major background component

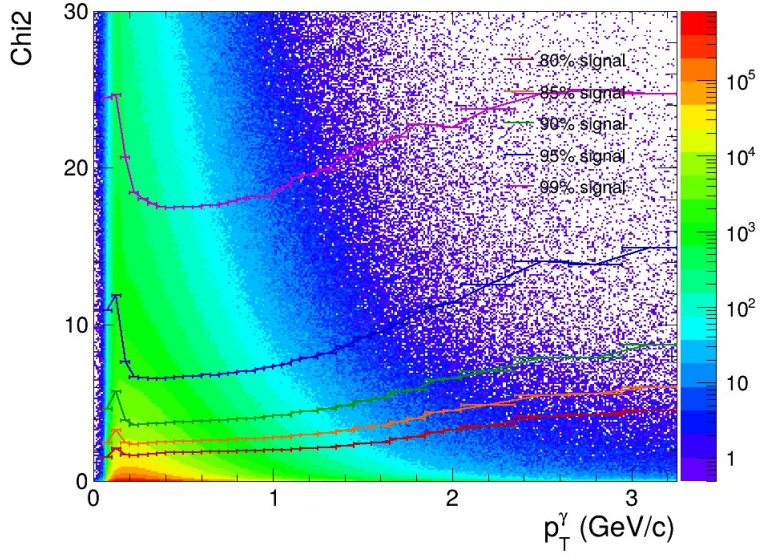
p_T-Dependent Selections





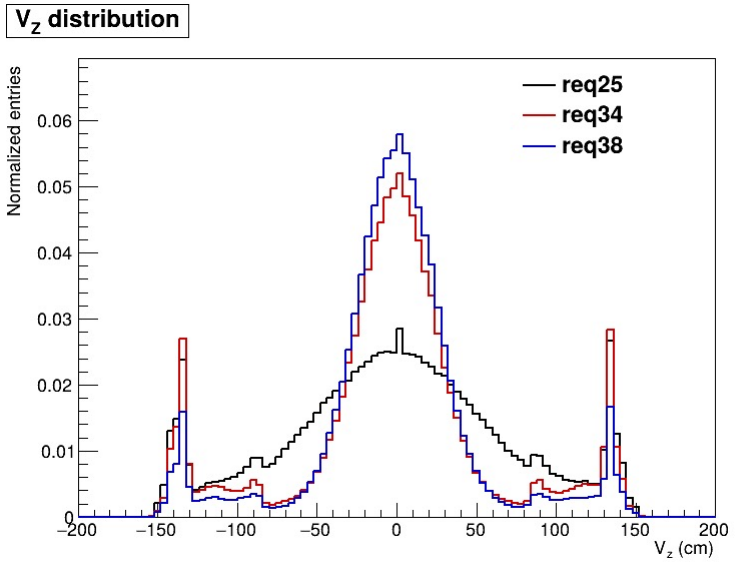


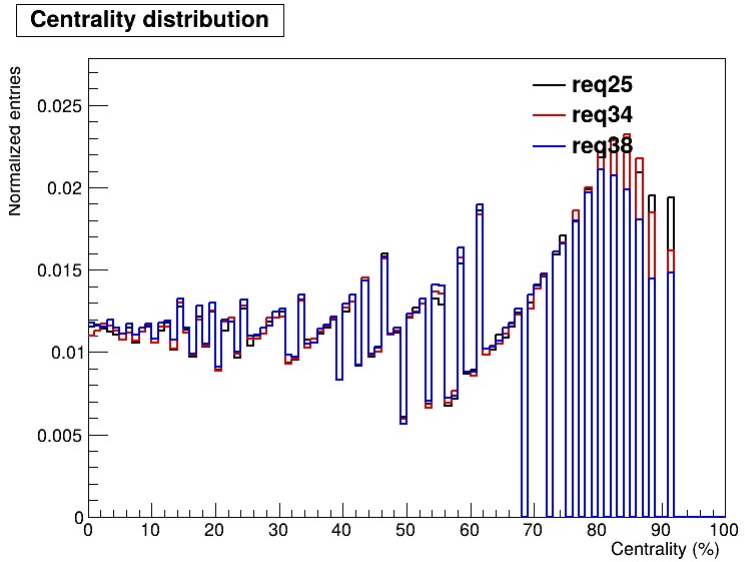


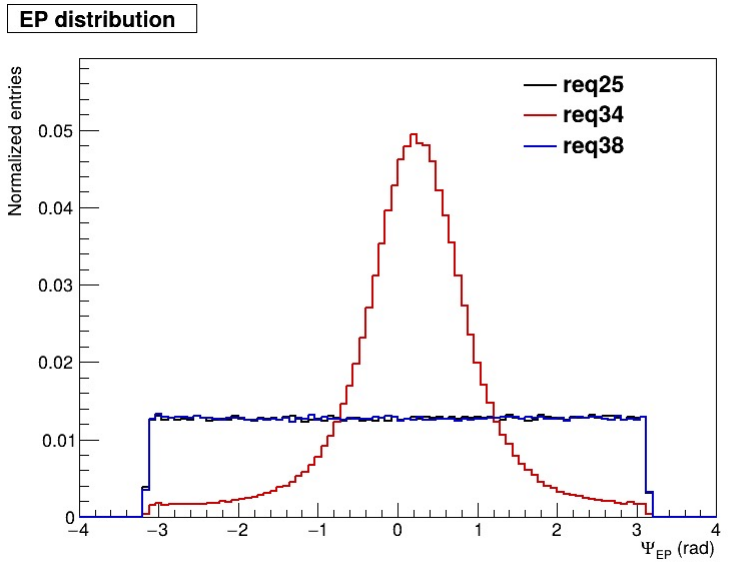


- Thresholds set to keep 80–99% of MC-matched γ candidates
- Point-to-point parameterization at low p_T
- Linear extrapolation at high p_T

Vz, Centrality and EP distribution







- Current mix event pool: 10 Vz × 10 centrality × 1 EP bins, mixDepth = 10
- Both histograms are normalized to unit integral
- The Vz distribution of req25 differs from req34/req38, which may affect the mixed-event background estimate