Study of resonances flow and production in Pb-Pb collision at 5.36 TeV

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Outline

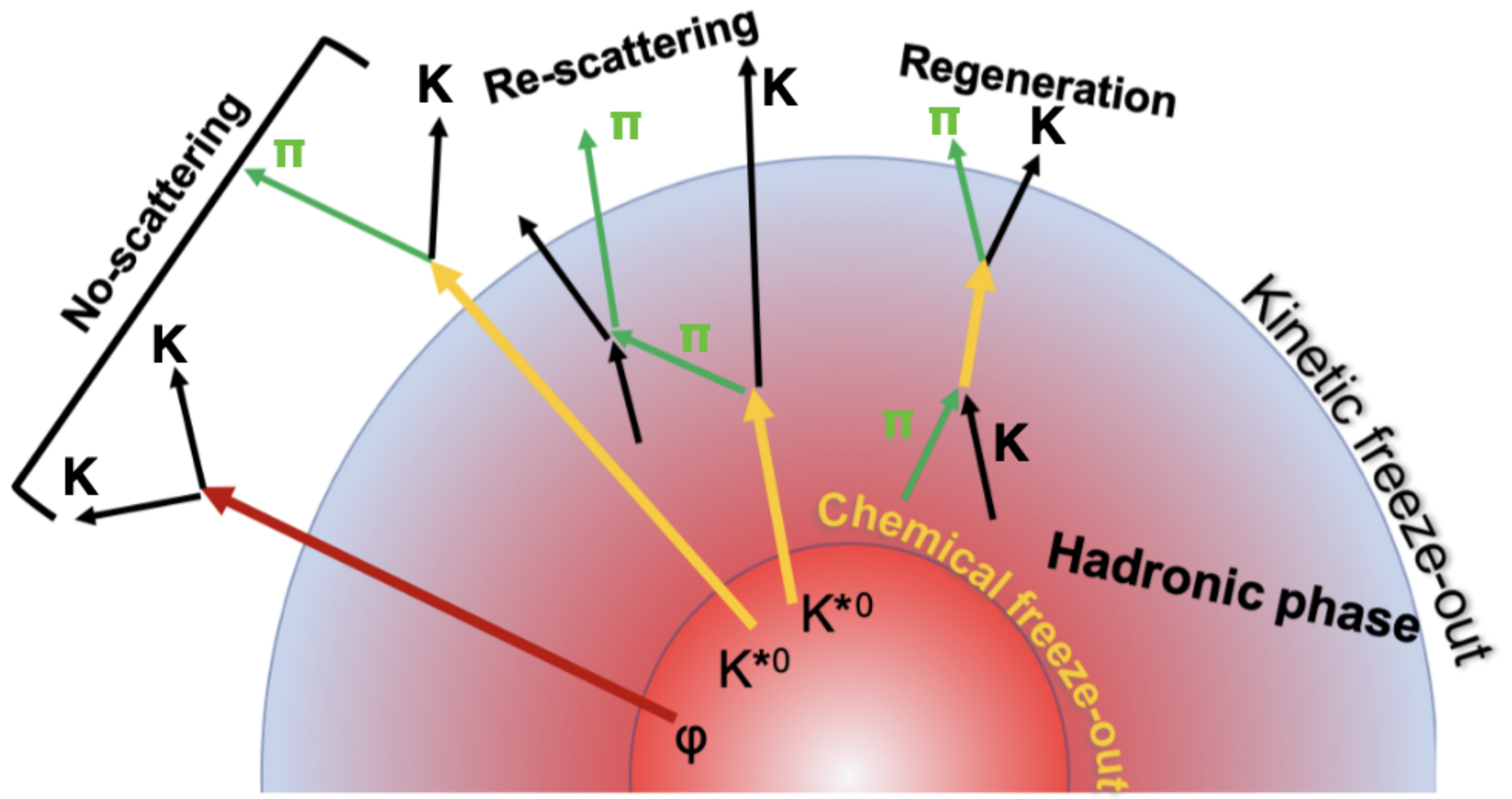
- Part 1: ϕ Resonance production
- Motivation
- Analysis Details
- Results
- Summary and outlook

- Part 2: Elliptic flow of K^{*0}
- Motivation
- Analysis Details
- Results
- Summary and outlook

Part 1
Measurement of $\phi(1020)$ in Pb-Pb collisions at 5.36 TeV

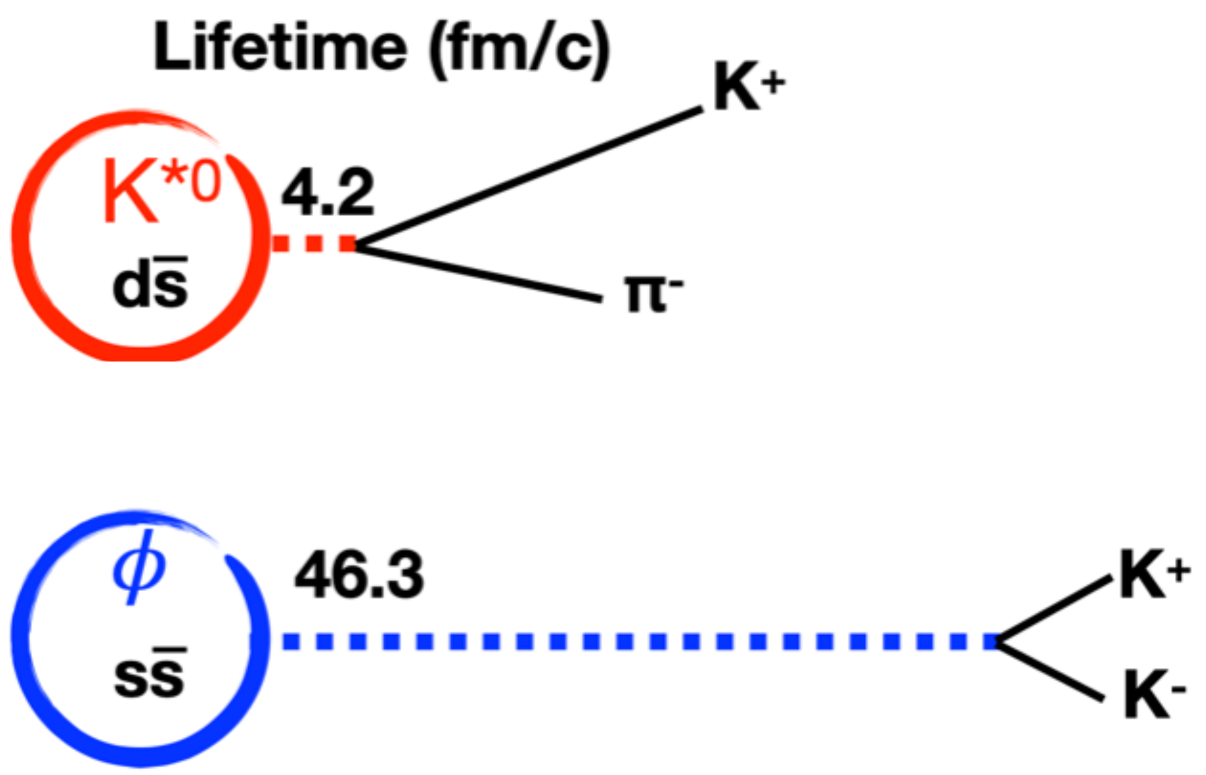
Motivation

- Resonances are short-lived particles that decay via the strong interaction
- Sensitive to probe hadronic phase via regeneration and re-scattering effects

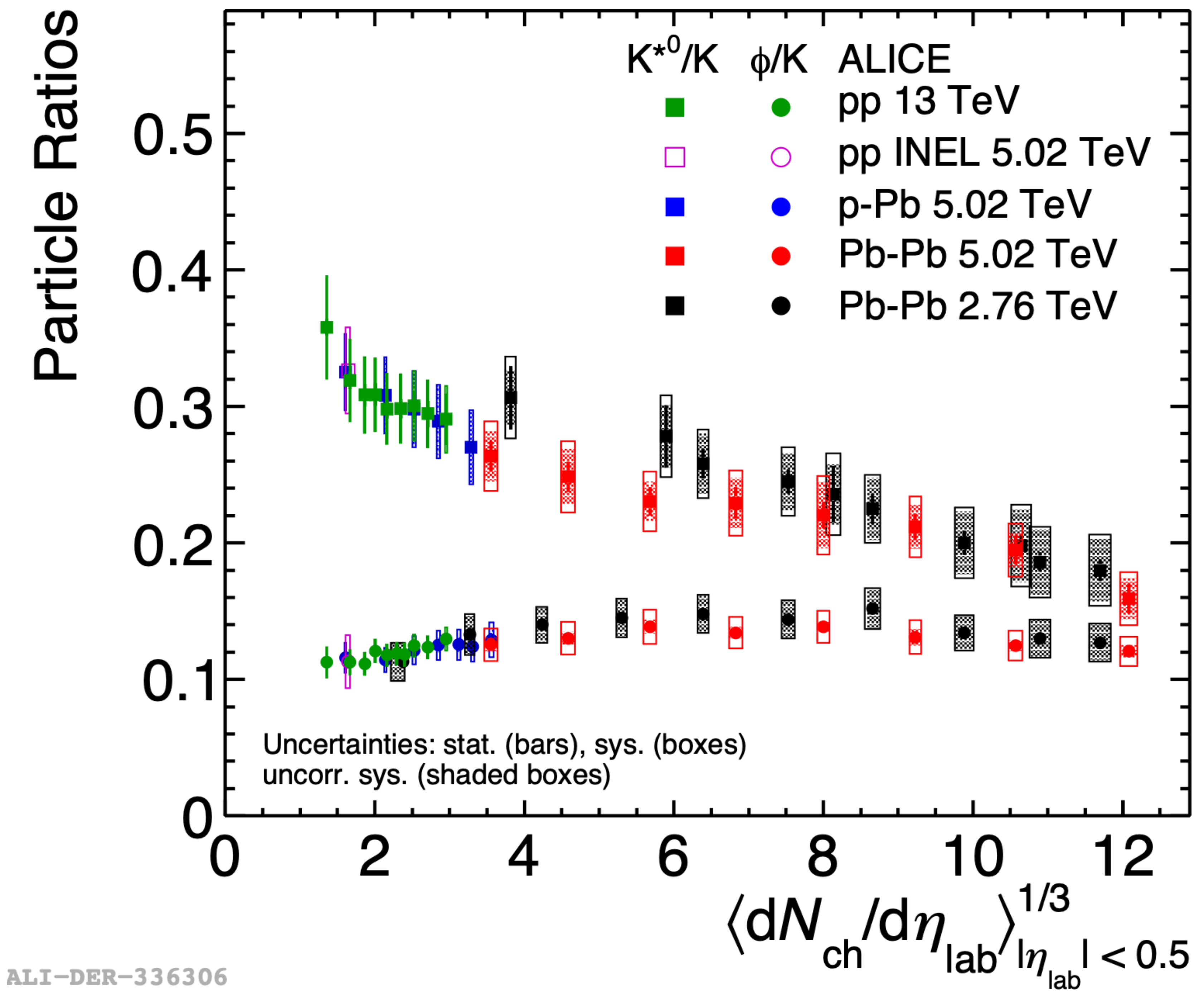


Properties of ϕ Resonance

- Mass : $1019.461 \pm 0.020\ MeV/c^2$
- Width : $4.26 \pm 0.04\ MeV/c^2$
- Lifetime : $\sim 46.3\ fm/c$
- Major decay mode : K^+K^- (48.9 ± 0.5) %
- Quark content : $s\bar{s}$
- Spin : 1



Phys. Lett. B 802, 135225, (2020)   Phys. Rev. C 106 (2002) 034907



Observations :

- ϕ/K - No suppression -> No observed rescattering of ϕ
- K^{*0}/K - Suppression -> Observed rescattering of K^{*0}

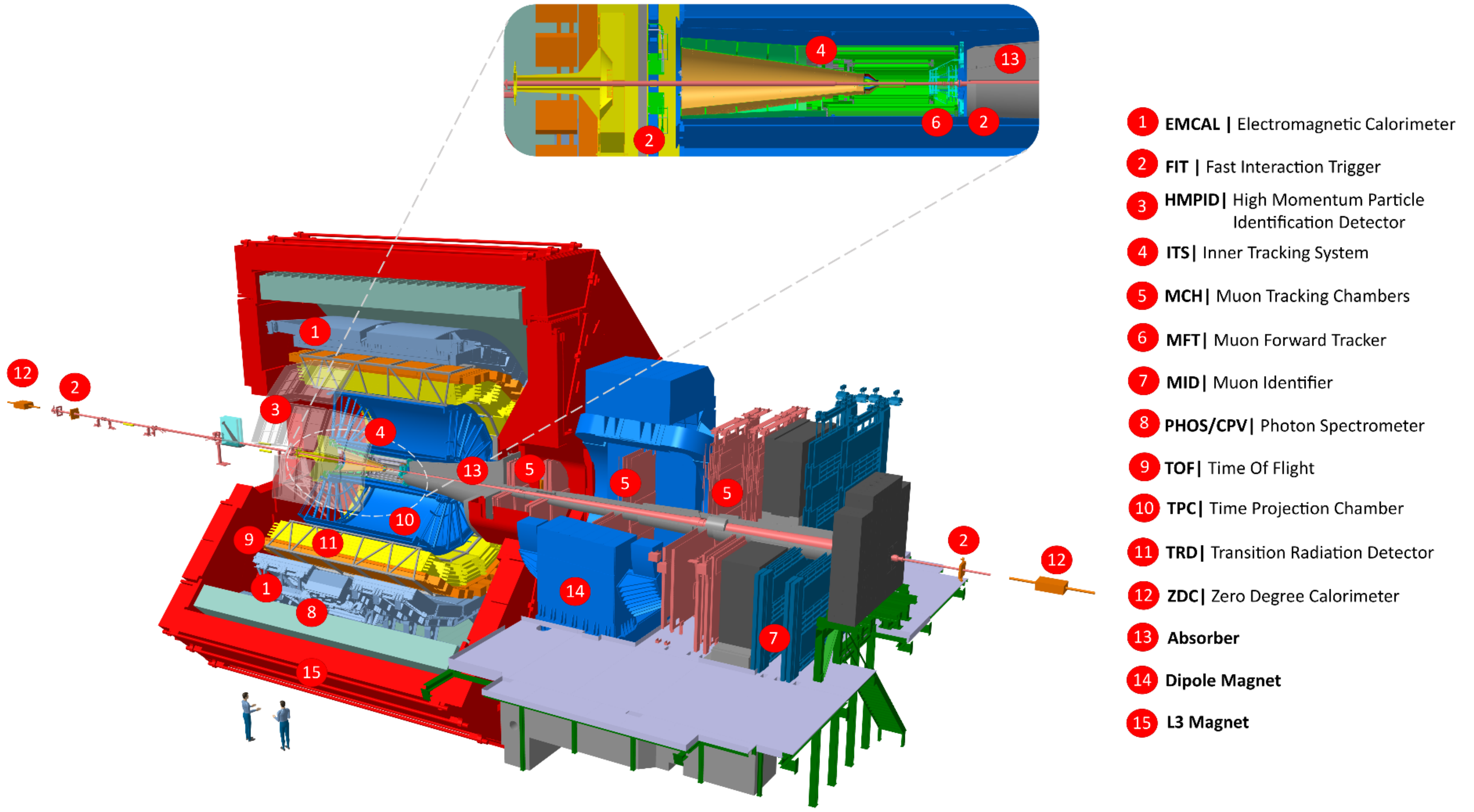
Goal :

- To calculate particle ratio using Run 3 data with higher energy and statistics
- Extend particle ratio measurements to higher $< dN_{ch}/d\eta_{lab} >^{1/3}_{|\eta_{lab}|<0.5}$ values

Analysis Details

- Collision system : Pb-Pb 5.36 TeV
- Dataset : LHC23zzh_pass3 (501 million)
- MC production : PYTHIA8 HI
- Period : LHC24d2b (4.2 million)
- p_T bins (GeV/c) : 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, 1.8, 2.0, 2.2, 2.4, 2.6, 2.8, 3.0, 3.5, 4.0, 4.5, 5.0, 6.0, 7.0, 8.0, 10.0
- Centrality : 0-80%
- Combinatorial background : Mixed event background
- Mixed event background condition : Number of mixed event = 5 (based on Vz and centrality)
- Normalisation range(GeV/c^2) : 1.055 -1.075

Detectors (used in this analysis) : ITS, TPC, TOF, FIT



- ITS : Tracking and vertexing
- TPC : Tracking, Particle identification and Momentum measurement
- TOF : Particle identification
- FIT : Centrality/multiplicity estimation

Event & Track selection

Event selection cuts

$|V_z| < 10$ cm

sel8

Track selection cuts

$p_T > 0.15$ GeV/c

$|\eta| < 0.8$

$|dca_{xy}|$ <0.1 cm

$|dca_z|$ <0.1 cm

$|n\sigma_{TPC}|$ <3

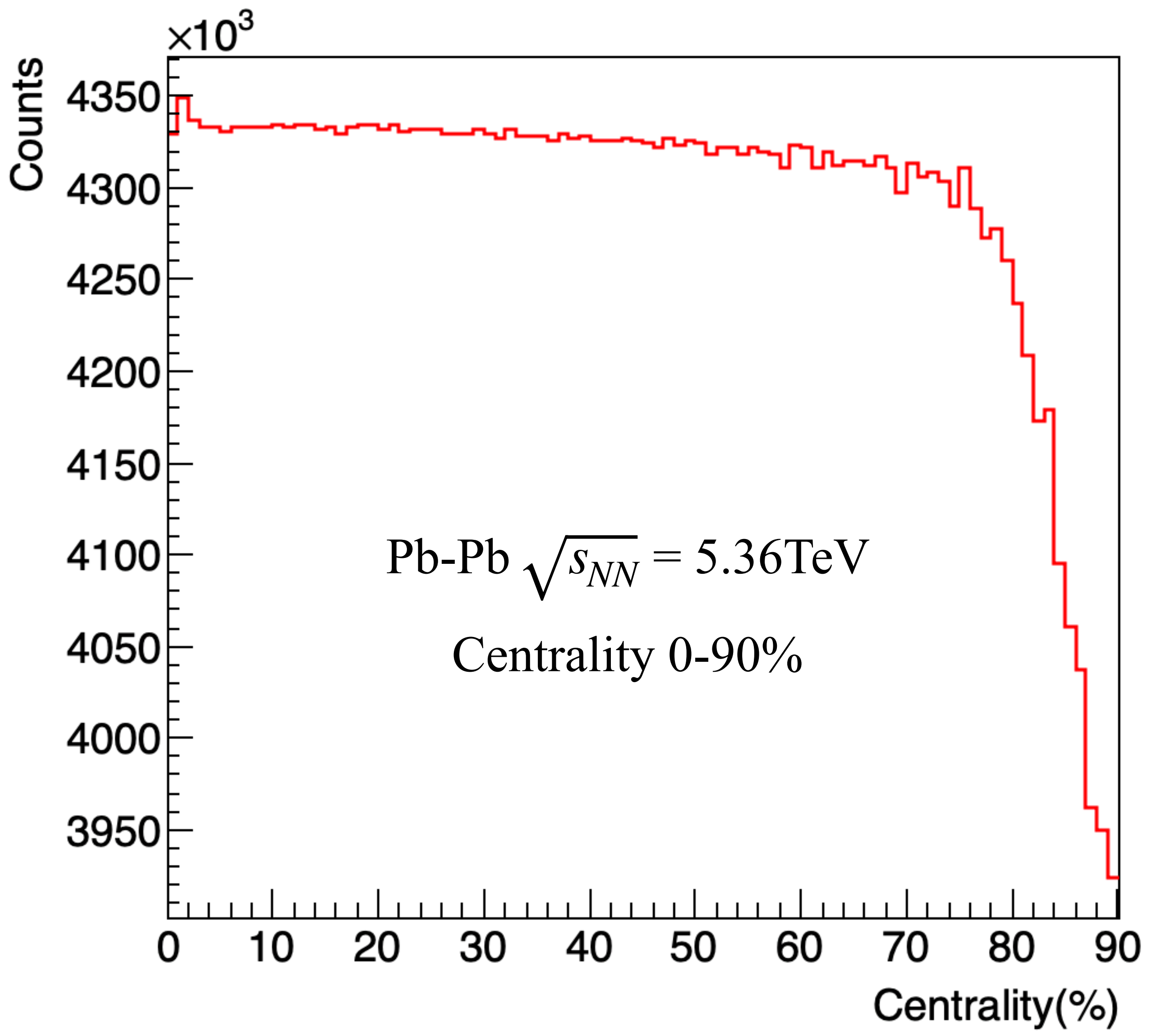
$|\sqrt{n\sigma_{\mathrm{TPC}}^2 + n\sigma_{\mathrm{TOF}}^2}| < 3$

GlobalTrack()

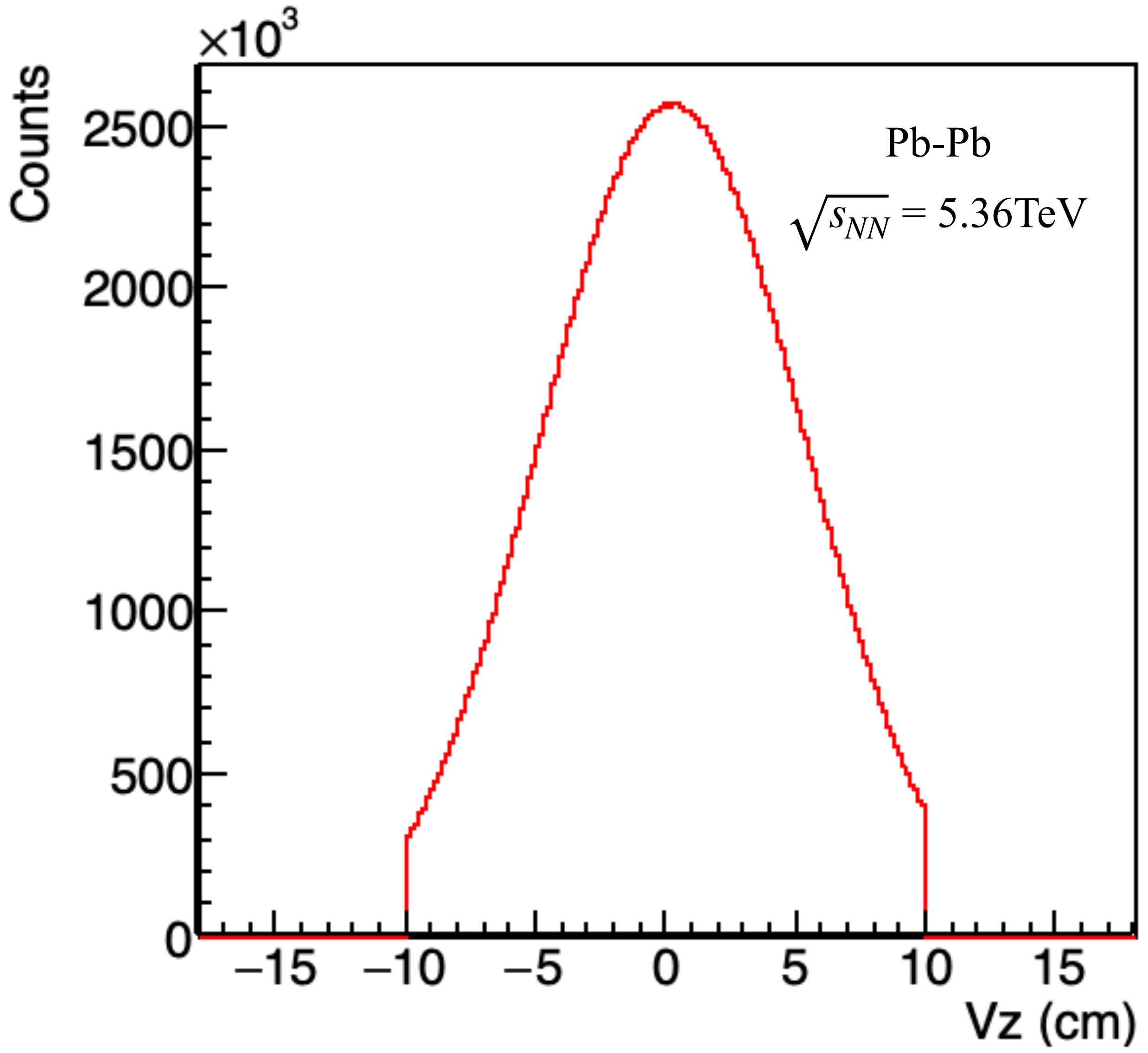
PVContributor()

Dip angle > 0.04

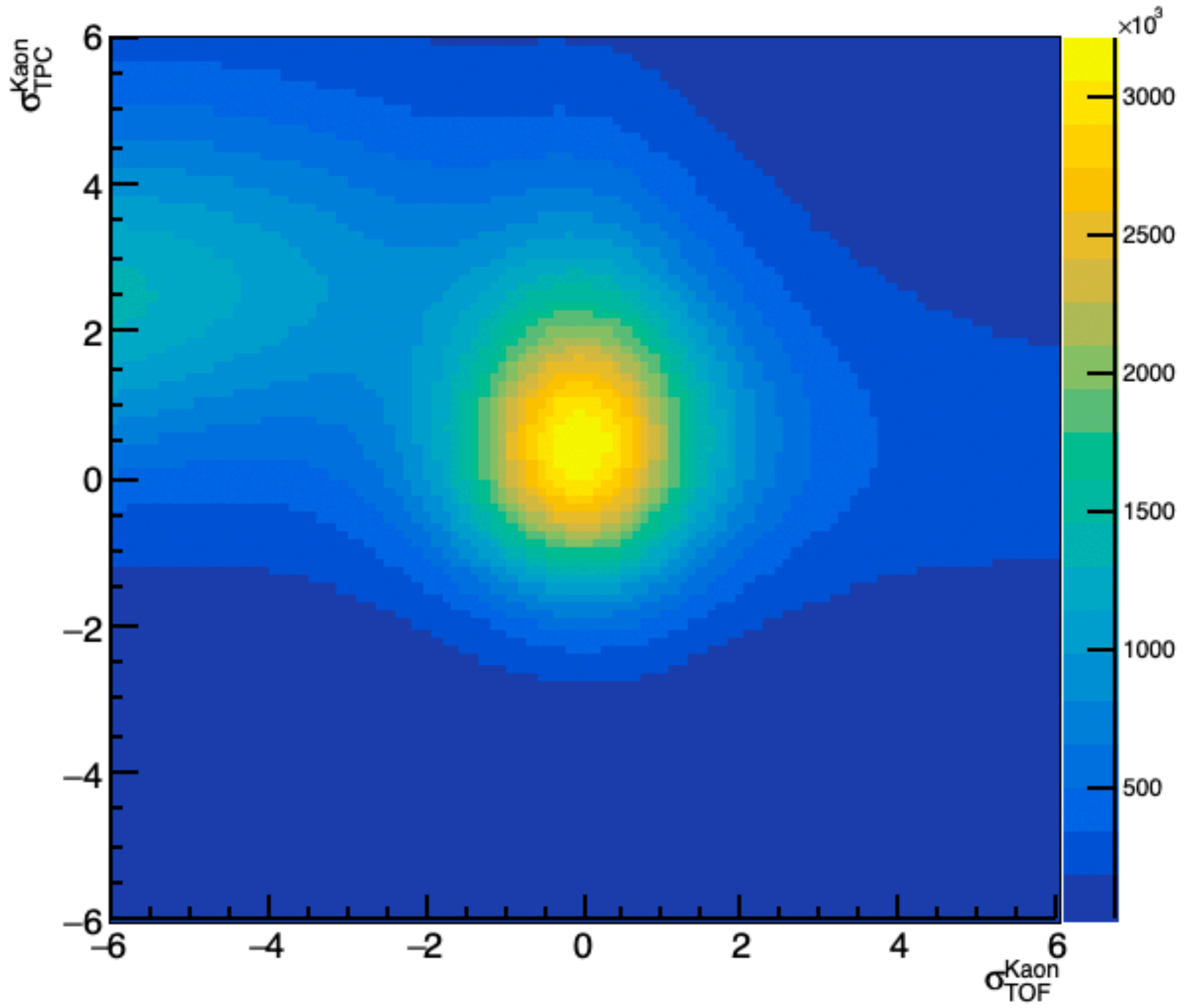
Centrality distribution



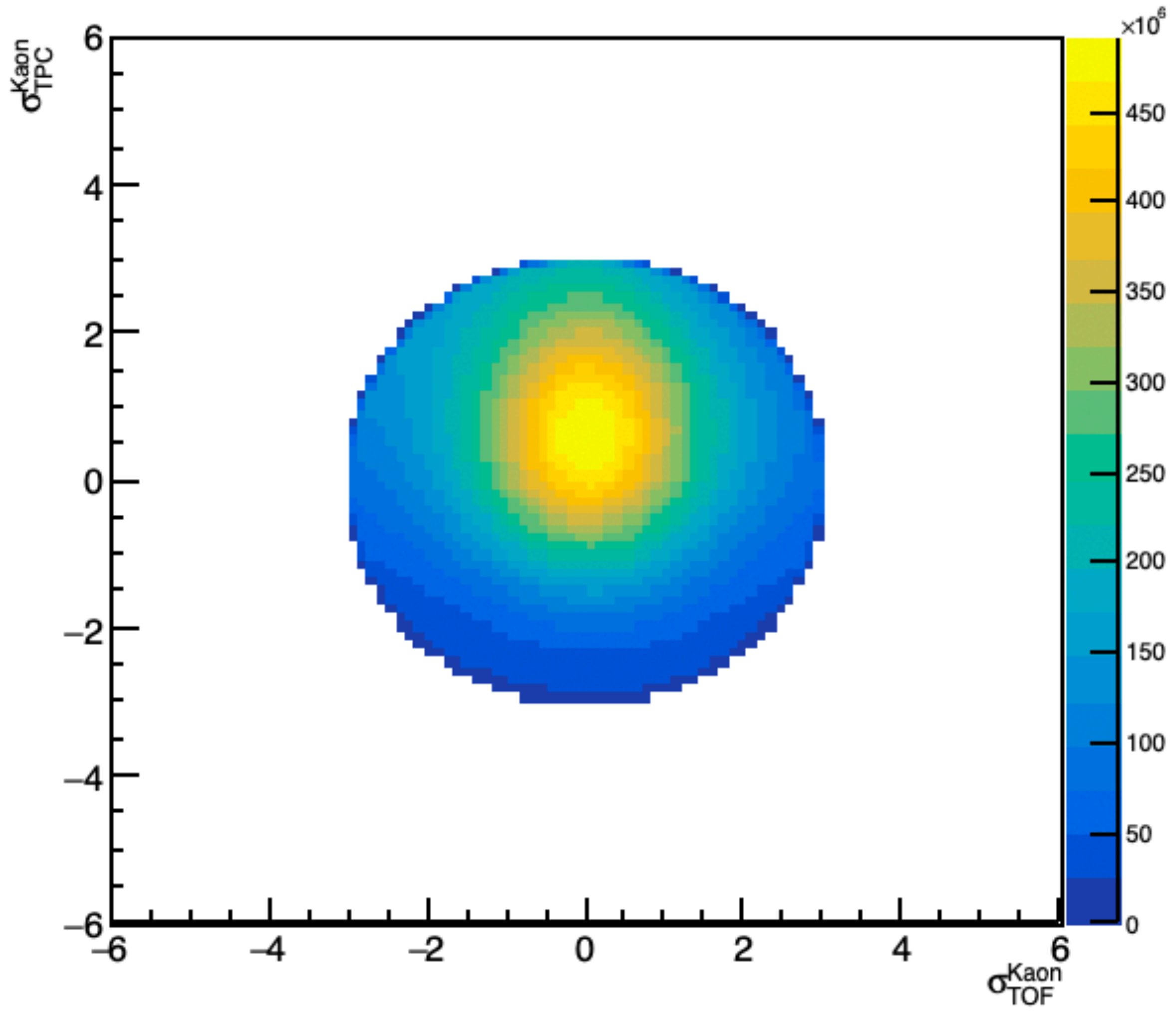
Vertex z distribution



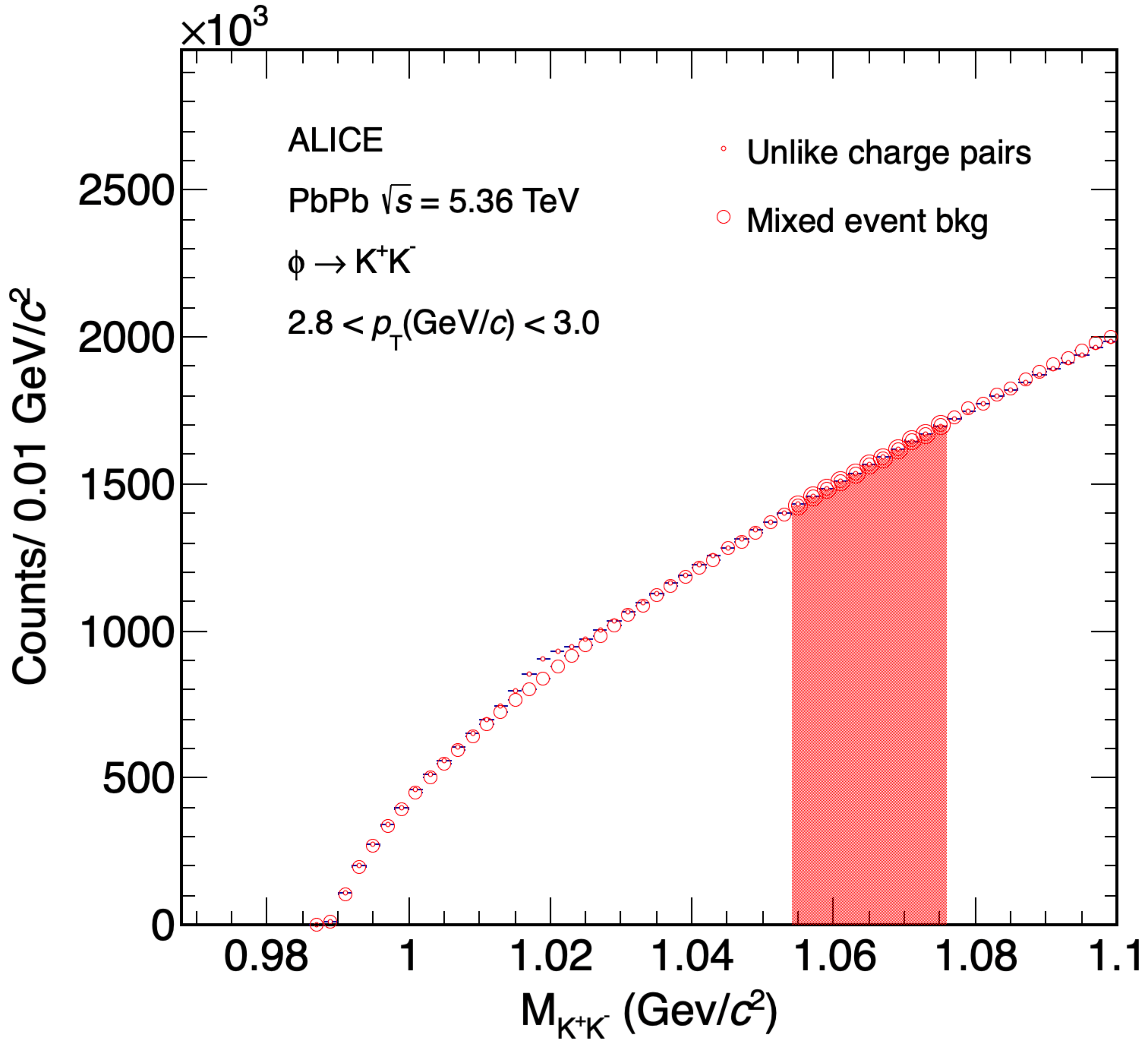
Before PID selection



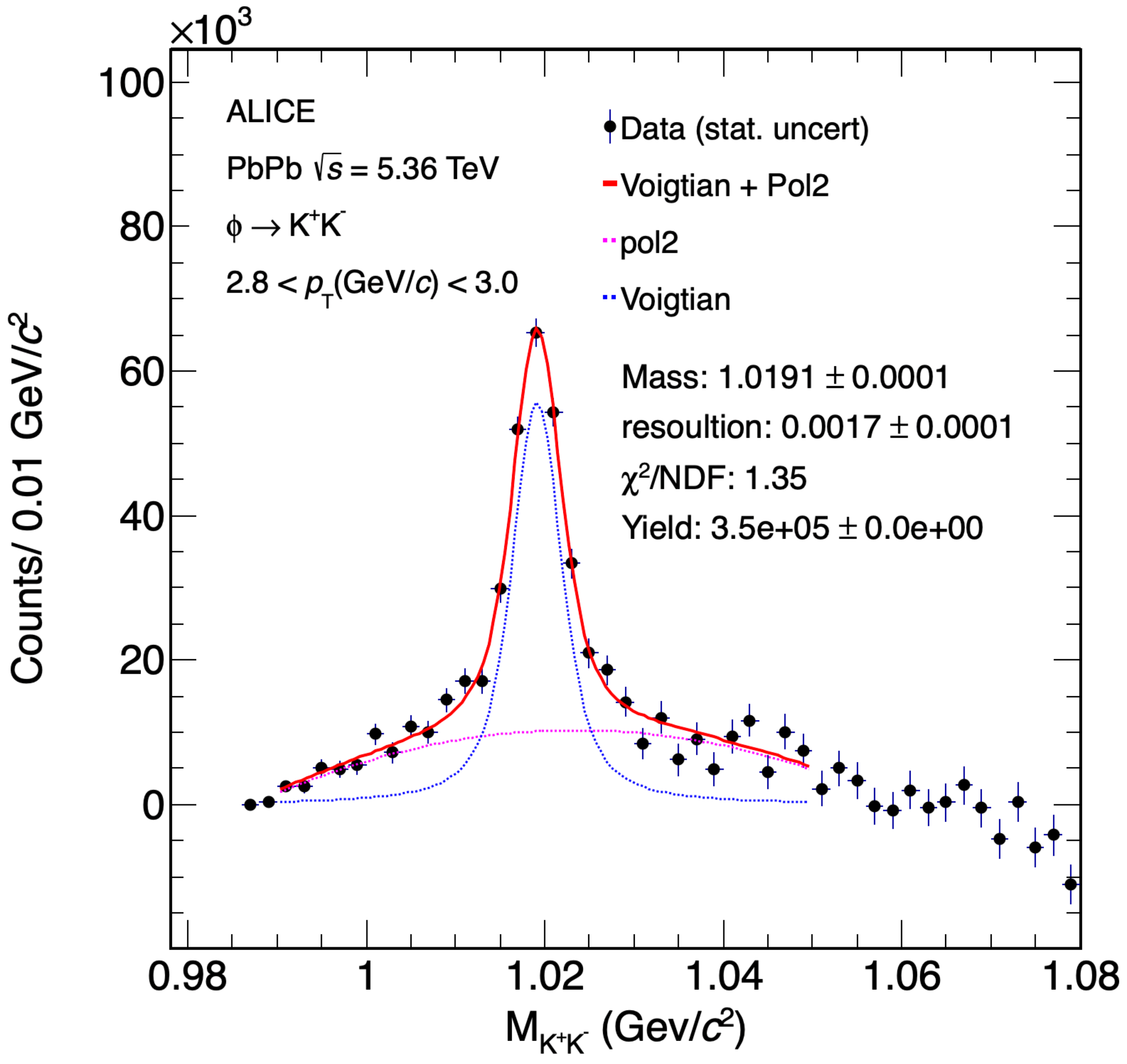
After PID selection



Signal extraction



Invariant mass distribution before combinatorial background subtraction



Invariant mass distribution after combinatorial background subtraction

- **Fitting function** : Voigtian(signal)+ Pol2(residual background)

$$f\left(m_{KK}\right) = \frac{Y\Gamma}{2\pi^{3/2}\sigma} \int_{-\infty}^{\infty} \exp\left(\frac{\left(m_{KK} - m'\right)^2}{2\sigma^2}\right) \frac{dM_{KK}}{\left(M_{KK} - M_0\right)^2 + \frac{\sigma^2}{4}} + F_{BG}$$

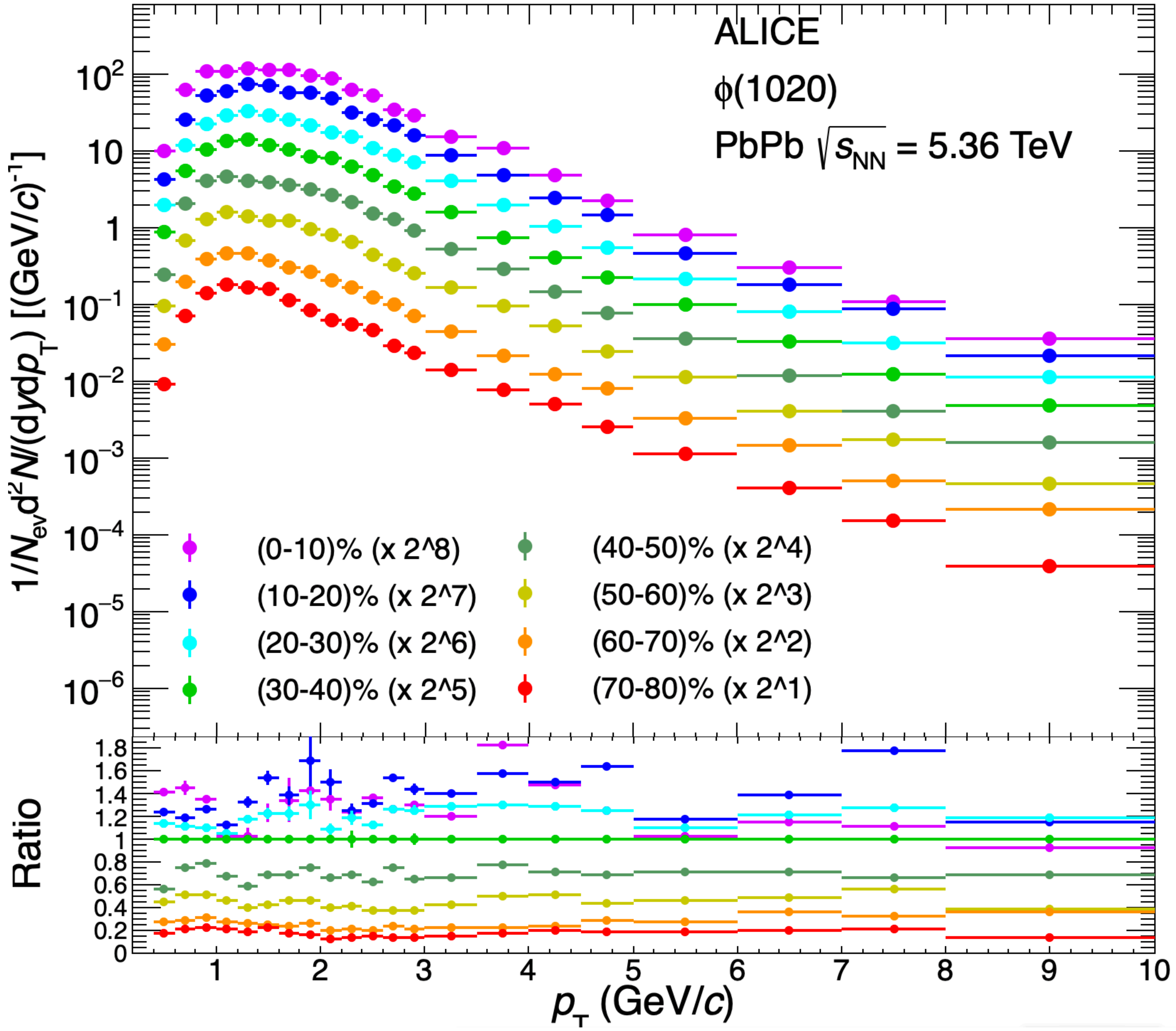
$$F_{BG} = AM^2_{K^+K^-} + BM_{K^+K^-} + C$$

- M_0 and Γ are the mass and width of ϕ
- M_{KK} is the K^+K^-invariant mass
- σ represents the mass resolution

- **Free parameters** : Mass, Yield, Resolution
- **Fixed parameter** : lorentzian width is fixed to it's PDG value 0.0042 GeV/c^2

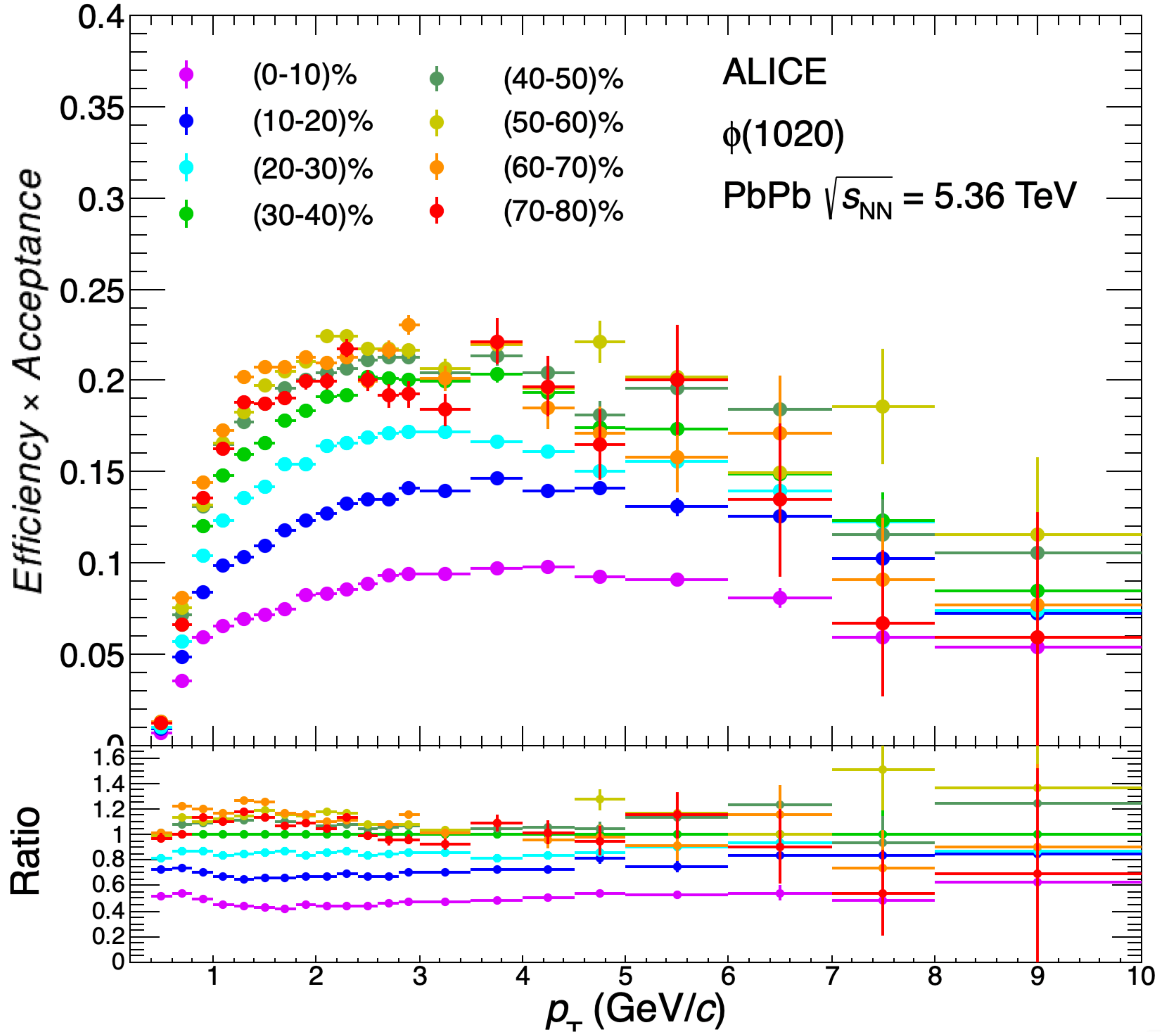
Raw spectra and Efficiency

Raw p_T spectra



Ratio : Raw spectra(centrality)/Raw spectra(30-40)%

Efficiency × Acceptance

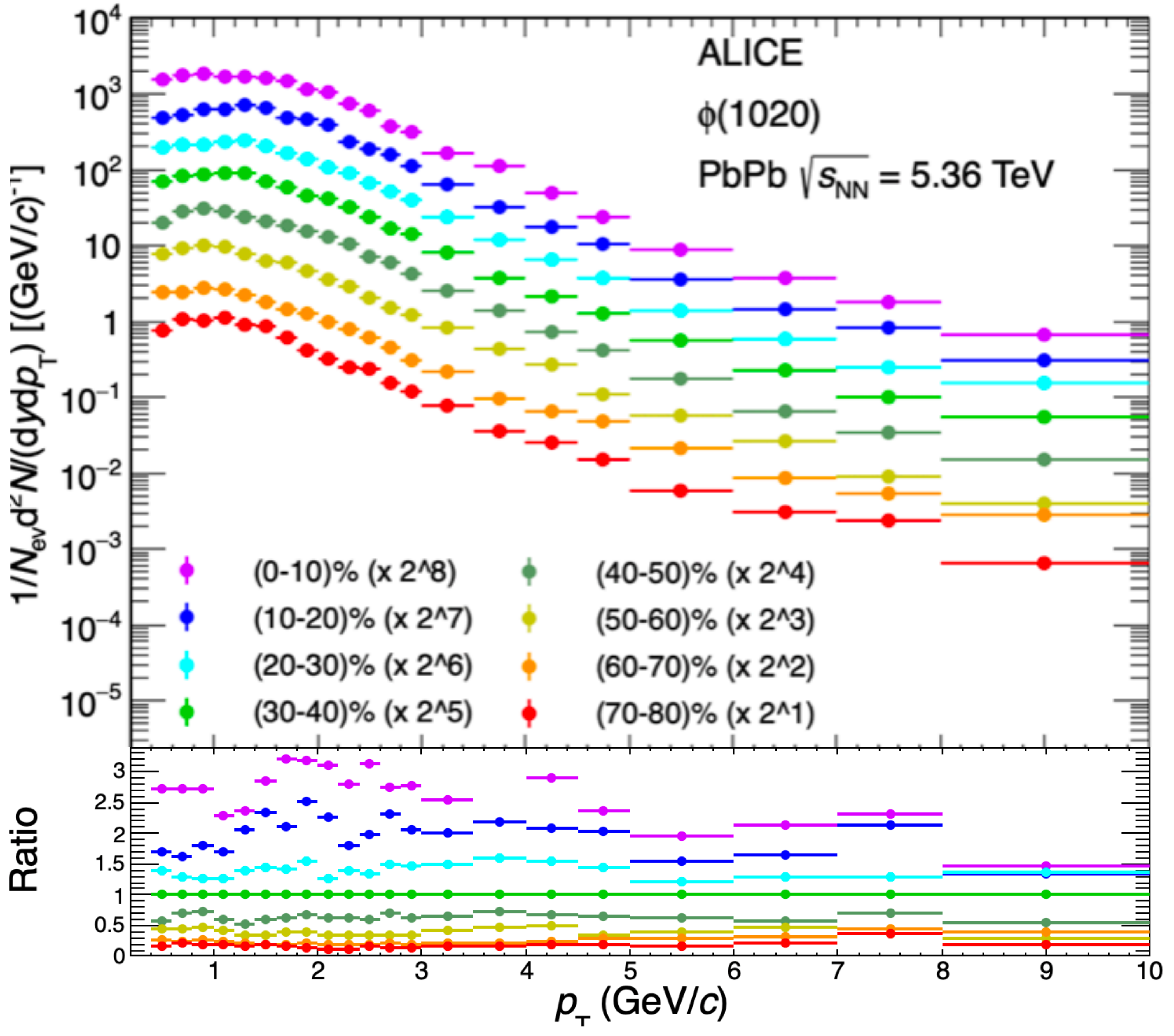


Ratio : Efficiency × Acceptance(centrality)/
Efficiency × Acceptance(30-40)%

Centrality dependence of raw p_T spectra and efficiency x acceptance is observed

Corrected Spectra

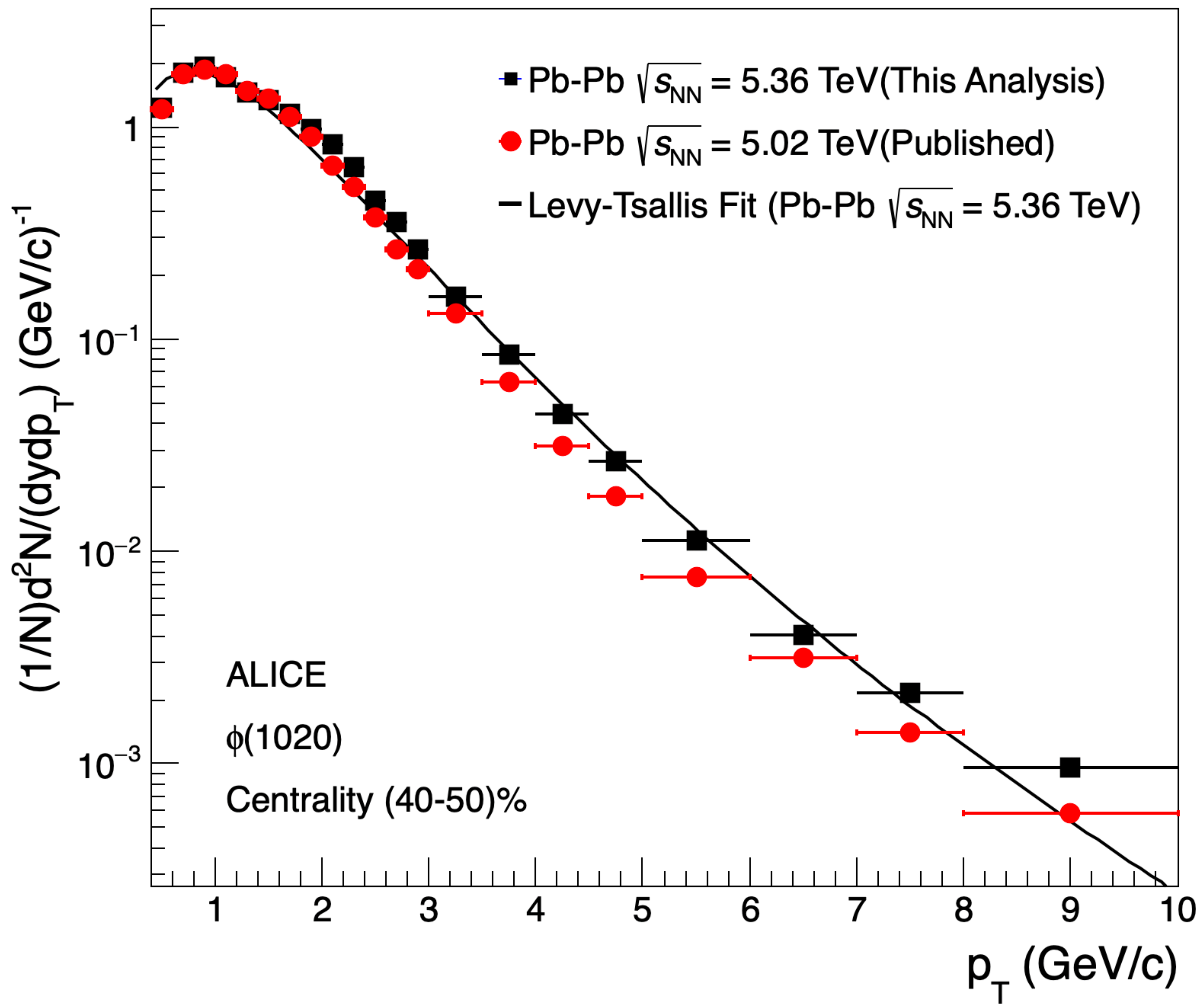
Corrected p_T spectra

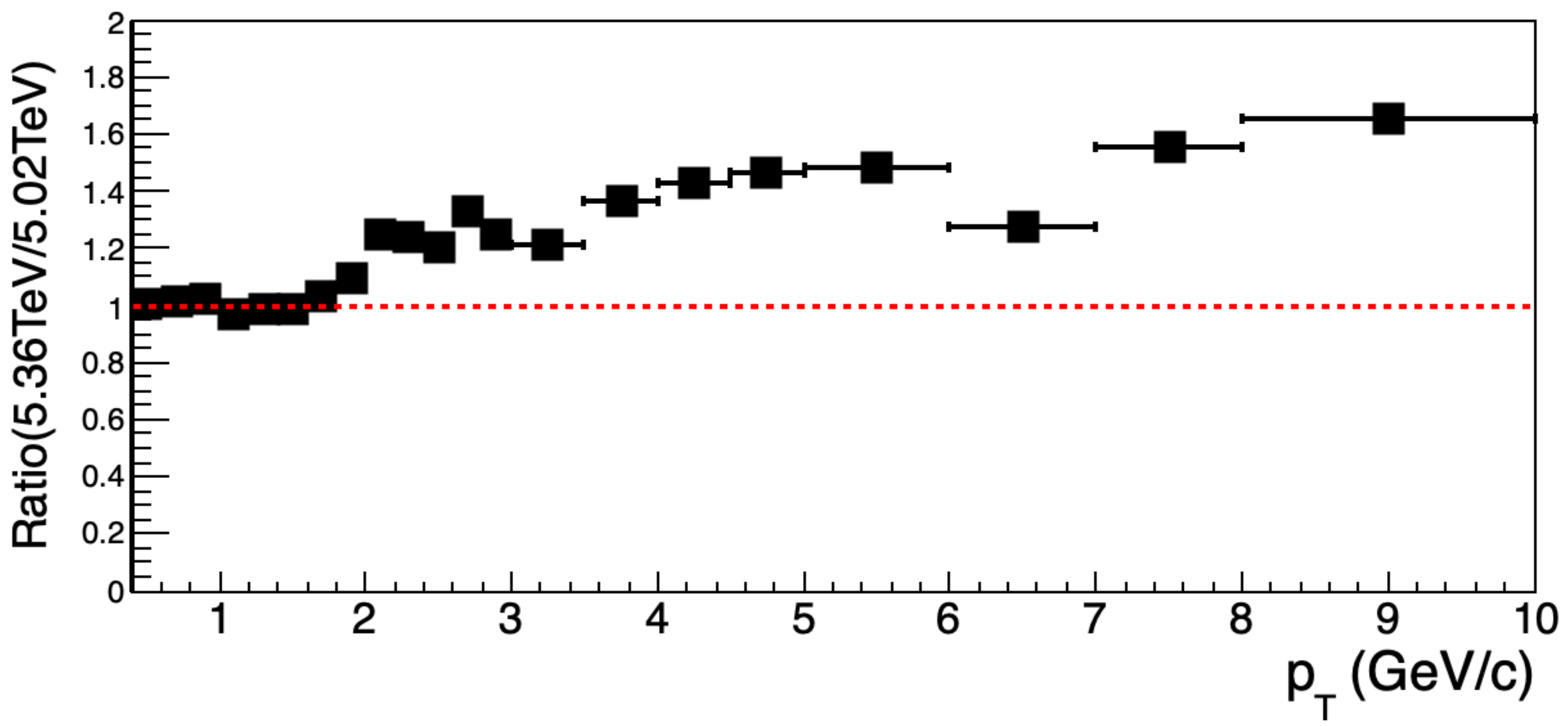


Ratio : Corrected spectra(centrality)/Corrected spectra(30-40)%

Centrality dependence of corrected p_T spectra is observed

Phys. Rev. C 106, 034907, (2022)





Comparison of transverse momentum spectra of ϕ in 40-50% centrality in Pb-Pb collision at $\sqrt{s_{NN}}$ = 5.36 TeV and $\sqrt{s_{NN}}$ = 5.02 TeV

Summary (part 1)

- ϕ meson signal is presented for Pb-Pb collisions at $\sqrt{s_{NN}}$= 5.36 TeV from p_T range 0.4 to 10 GeV/c for eight different centrality classes.
- Corrected p_T spectra of ϕ meson is obtained from 0.4-10 GeV/c for various centrality classes and compared with the published Run 2 results.

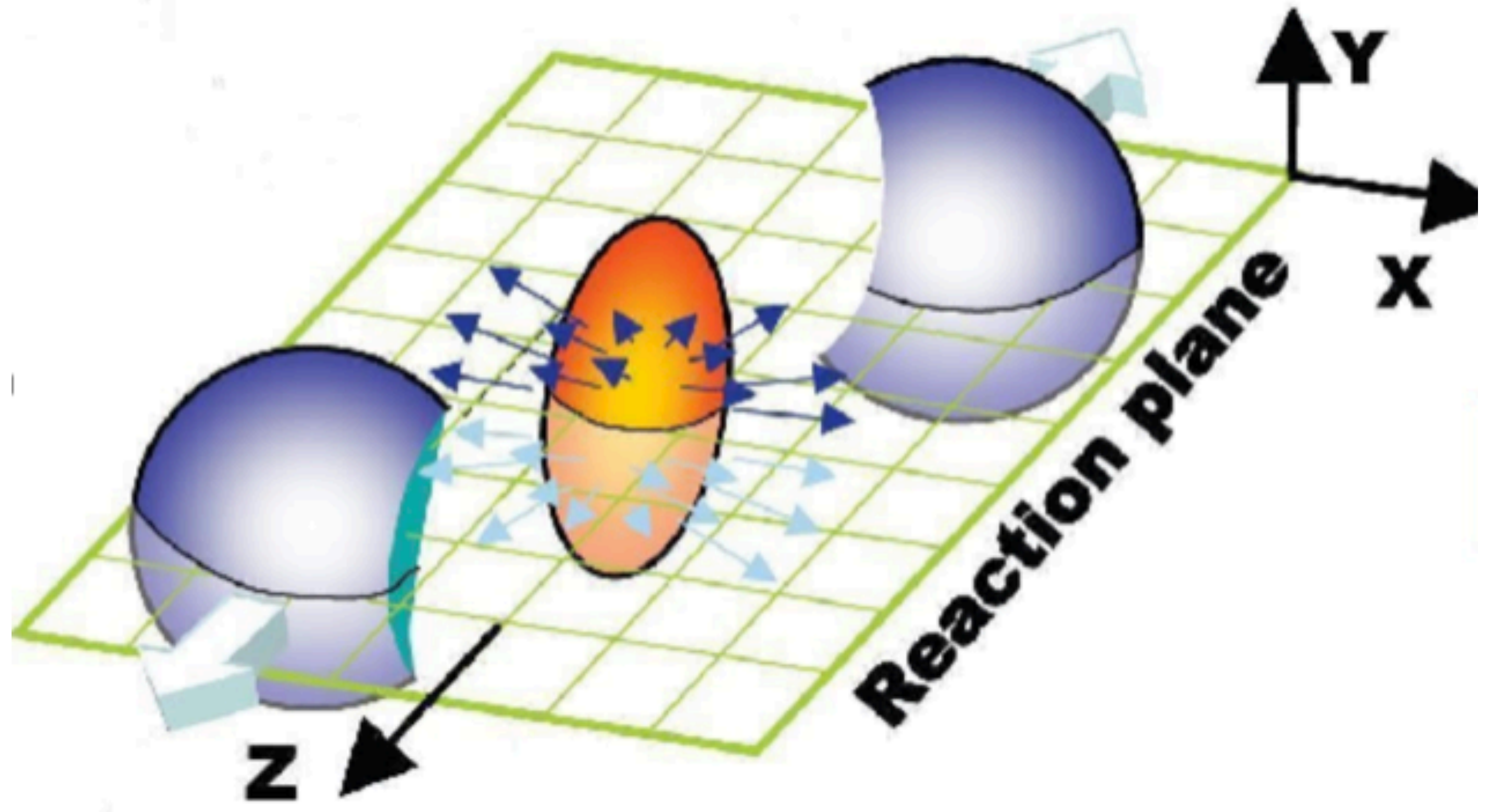
Outlook

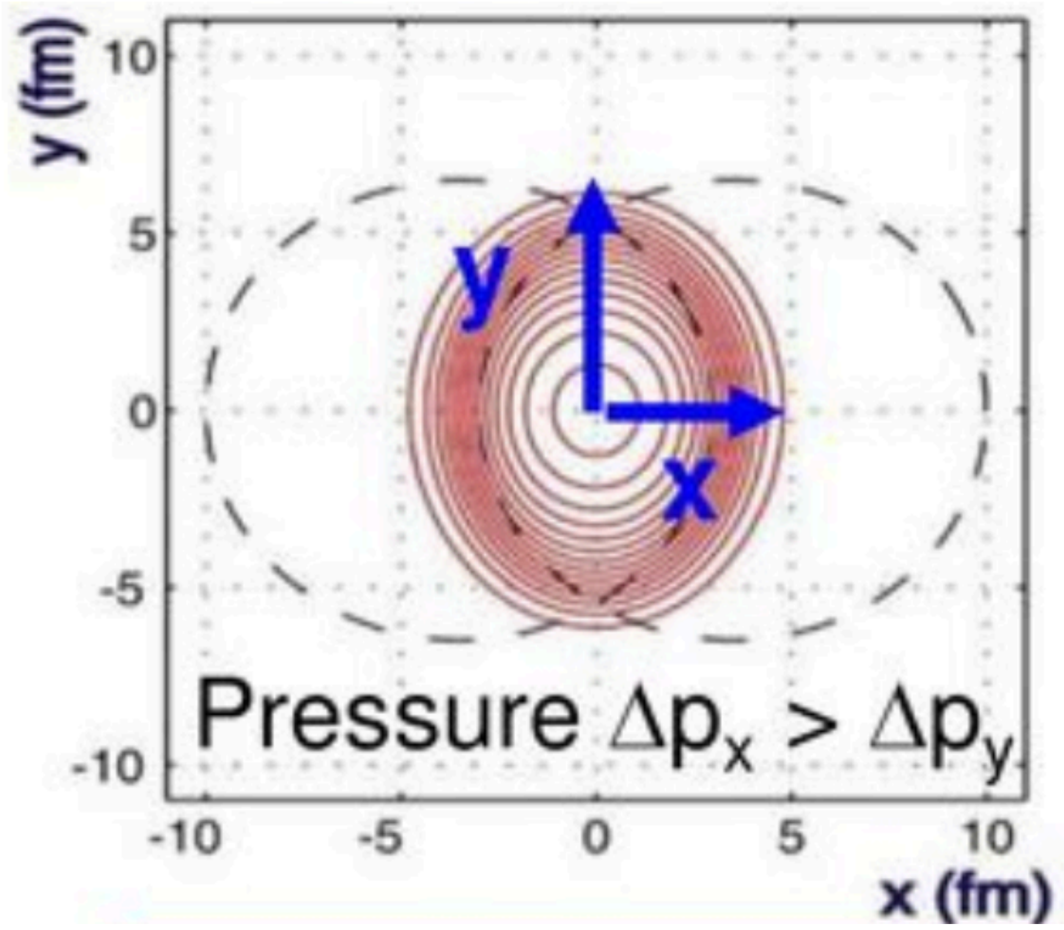
- dN/dy and $< p_T >$ will be calculated and compared with Run2 published results.
- Systematic studies will be performed.
- Particle ratio will be calculated with higher statistical significance.
- Analysis note to be prepared with pass 4(waiting for MC production)

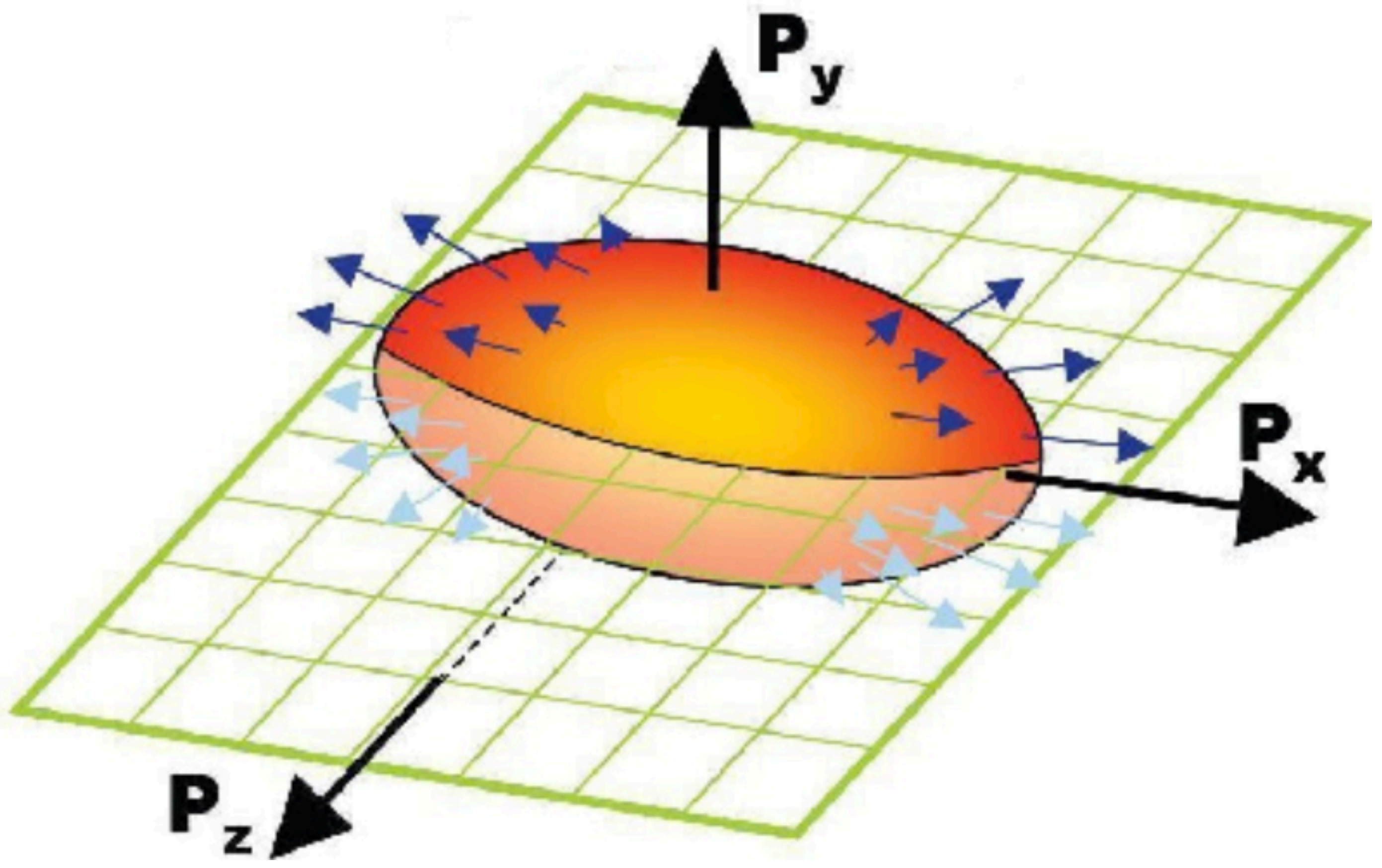
Part 2
Measurement of K^{*0} elliptic flow in Pb-Pb collisions at 5.36 TeV

Elliptic flow

Phys. Rev. D. **46,** 229 (1992)







Spatial deformation → Azimuthal pressure gradients → Anisotropic flow

Fourier expansion of azimuthal angle distribution with respect to reaction plane

$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left(1 + \sum_{n=1}^{\infty} 2v_n \cos\left[n\left(\phi - \Psi_r\right)\right]\right)$$

ϕ is azimuthal angle and ψ_r reaction plane angle

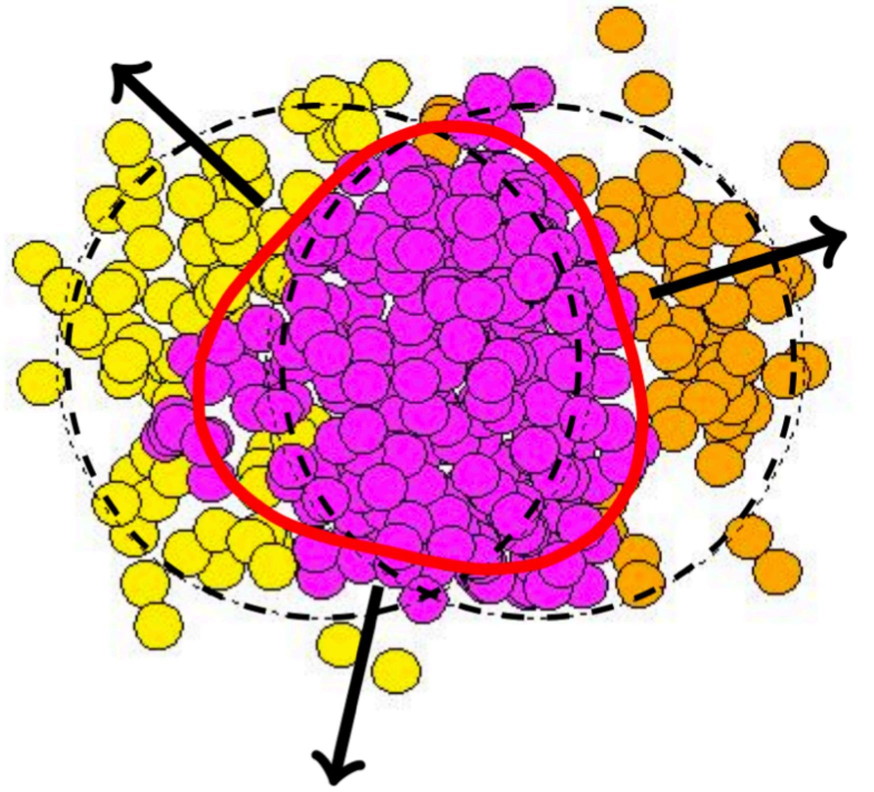
Fourier coefficients :

$v_n = < < cos[n(\phi - \psi_r)] > >$

2^{nd} fourier coefficient v_2 : elliptic flow

3^{rd} fourier coefficient v_3 : triangular flow

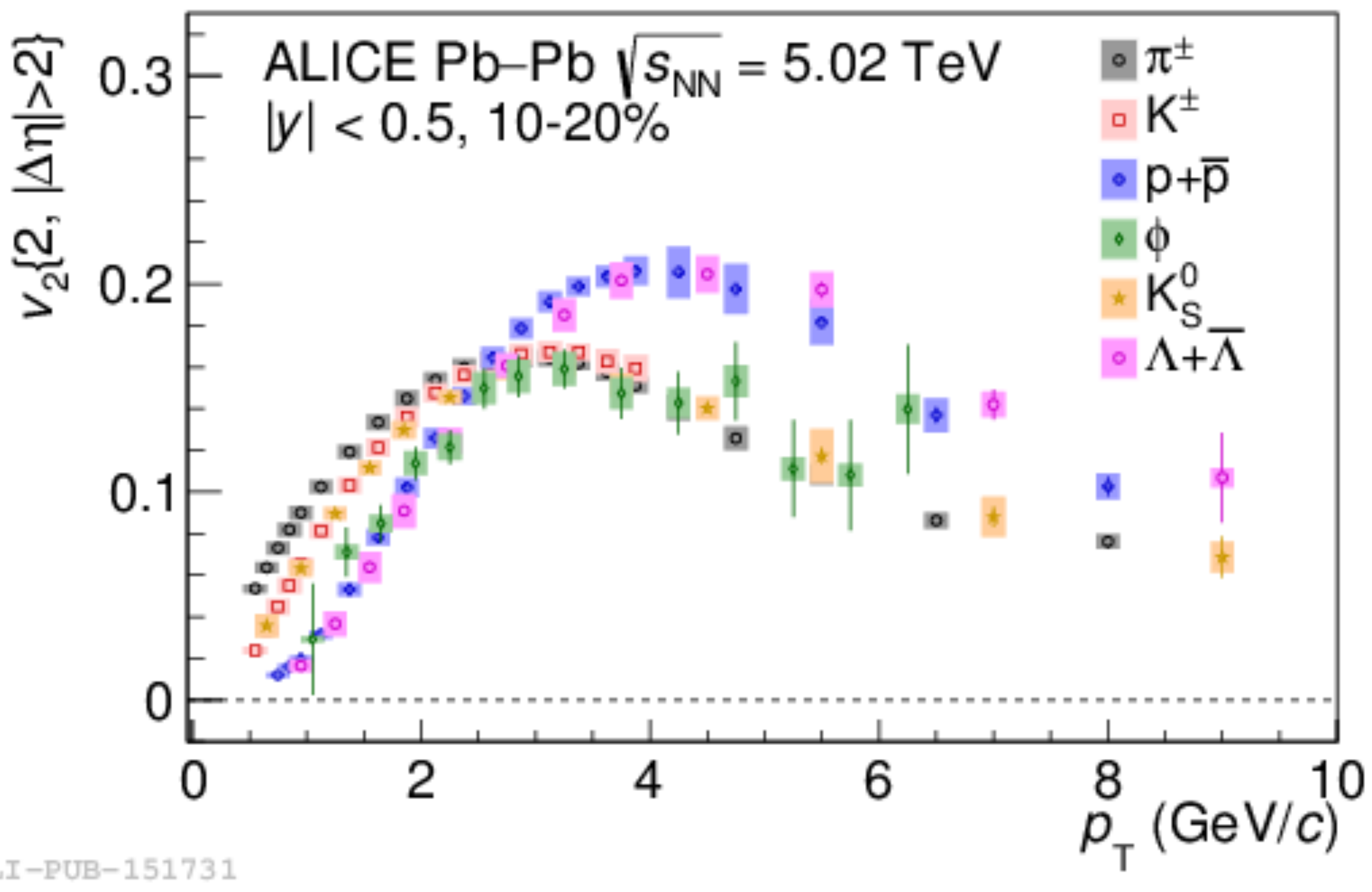
4^{th} fourier coefficient v_4 : quadrangular flow



Phys. Rev. C58, 1671-1678 (1998)

Motivation

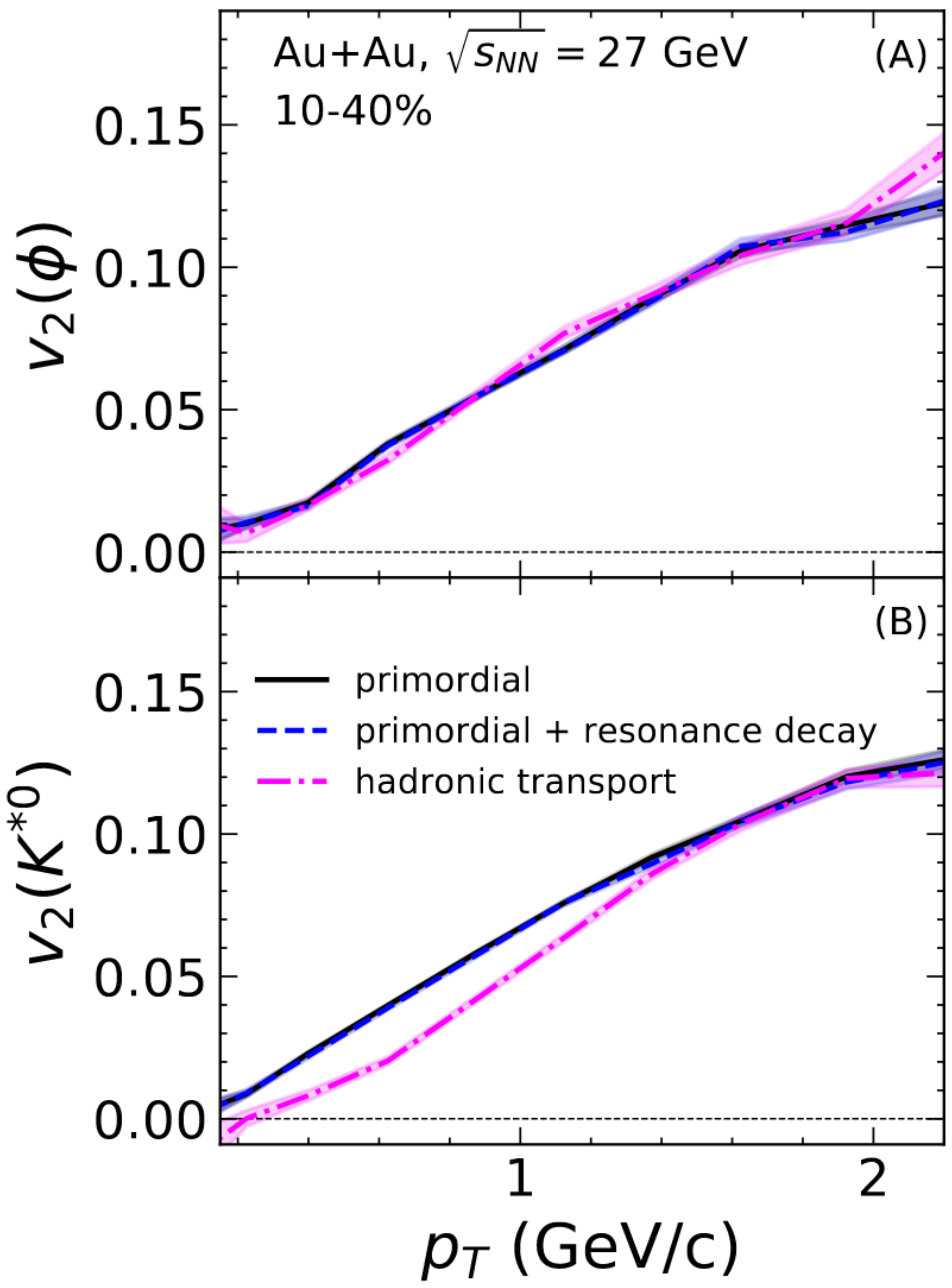
JHEP09 (2018) 006



★ Mass ordering at lower p_T

★ Baryon meson crossing at intermediate p_T

https://arxiv.org/abs/2312.06359



Goal :

- To investigate the effect of final state re-scattering on the elliptic flow of K^{*0}
- Run 3 allows precise measurements of resonances flow with higher energy and statistics

Measurement of elliptic flow

1. Elliptic flow(v_2) = $<<cos(2(\phi - \psi_{RP}))>>$
   - ψ_{RP} is reaction plane
   - 2^{nd} order coefficient of fourier expansion of particle azimuthal distribution relative to reaction plane

2. Event plane $\psi_n = \frac{1}{n}\tan^{-1}\left(\frac{\sum_i w_i \sin(n\phi_i)}{\sum_i w_i \cos(n\phi_i)}\right)$
   - ψ_n is n^{th} order event plane
   - estimation of reaction plane from particle azimuthal anisotropy

3. $v_2' = <<cos(2(\phi - \psi_2))>>$
   - 2^{nd} order event plane
   - particle distribution relative to event plane

4. $v_2 = \frac{v_2'}{\sqrt{\frac{\left\langle \cos\left(n\left(\Psi_n^A - \Psi_n^B\right)\right)\right\rangle \left\langle \cos\left(n\left(\Psi_n^A - \Psi_n^C\right)\right)\right\rangle}{\left\langle \cos\left(n\left(\Psi_n^B - \Psi_n^C\right)\right)\right\rangle}}}$
   - correct for event plane resolution

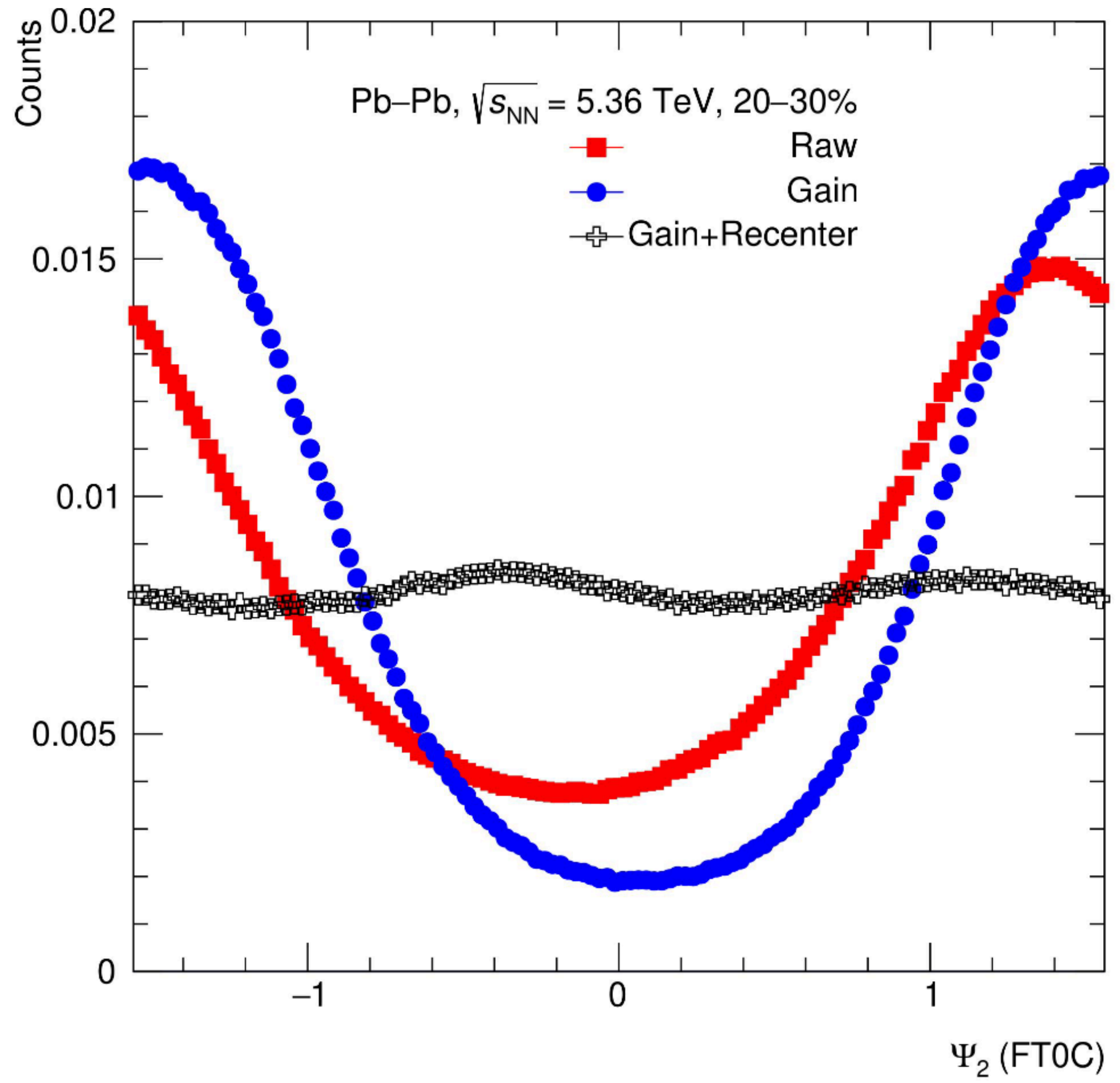
A = FT0C , -3.3 < η < -2.1

B = TPC , -0.8 < η < -0.1

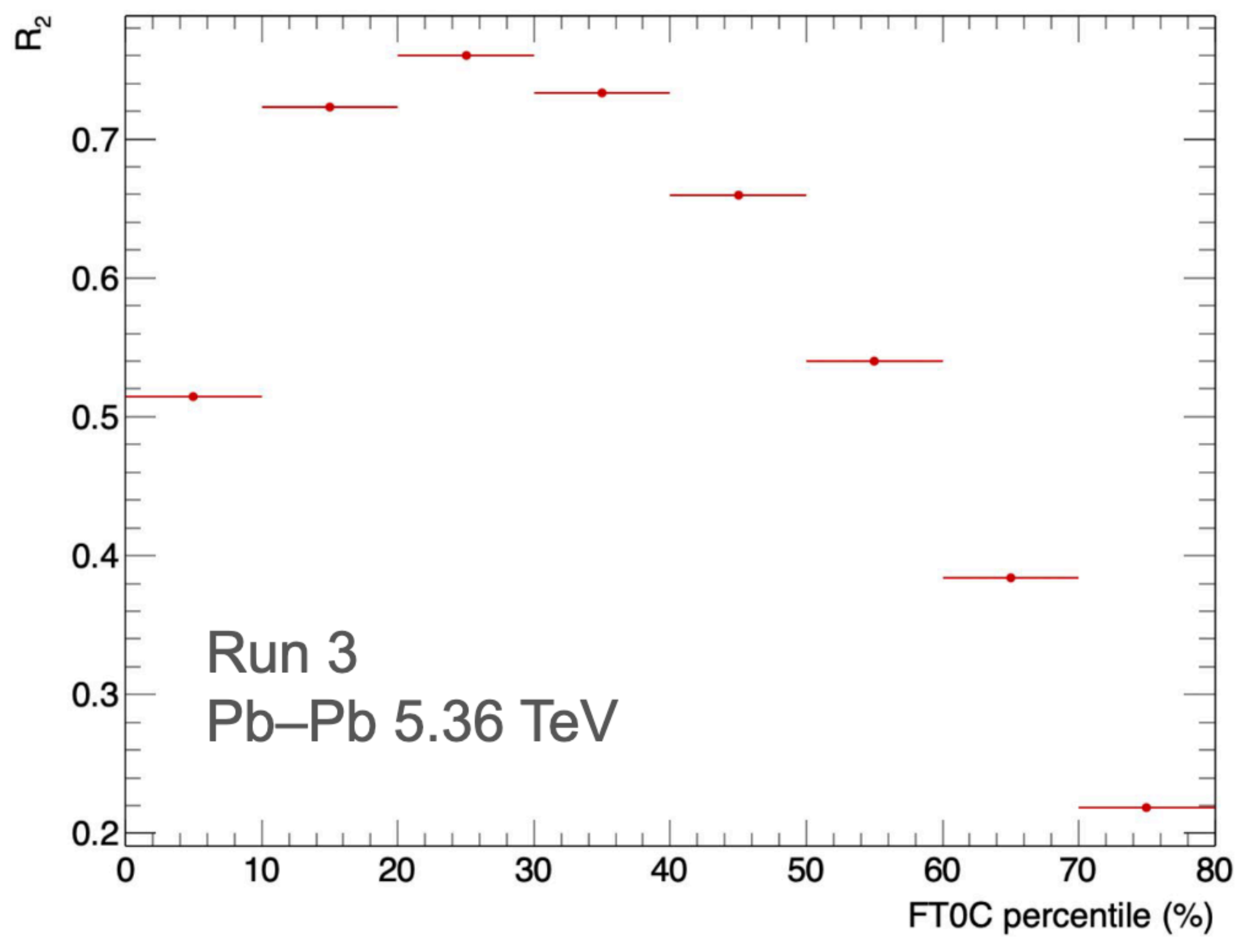
C = TPC , 0.1 < η < 0.8

JHEP09 (2018) 006

Event plane angle distribution



Event plane resolution



Analysis details

Collision system	Pb-Pb
Energy	5.36 TeV
Data set	LHC23zzh_pass3
Total no. of events	528 million
Flow coefficient method	Event plane method
Centrality(%)	20-60
p_T bins (GeV/c)	1.5-6.5
Combinatorial background	Mixed event
Normalisation range	1.1-1.3
Fitting function	Breit Wigner(signal) pol2(Res. background) pol2(v2 background)

Event selection cuts

$|V_z| < 10$ cm

sel8

Track selection cuts

$p_T > 0.2$ GeV/c

$|\eta| < 0.8$

$|dca_{xy}| < 0.1$ cm

$|dca_z| < 0.1$ cm

TPC cluster > 70

GlobalTrack()

PVContributor()

$|n\sigma_{TPC}| < 3$

$|\sqrt{\sigma_{TPC}^2 + \sigma_{TOF}^2}| < 3$

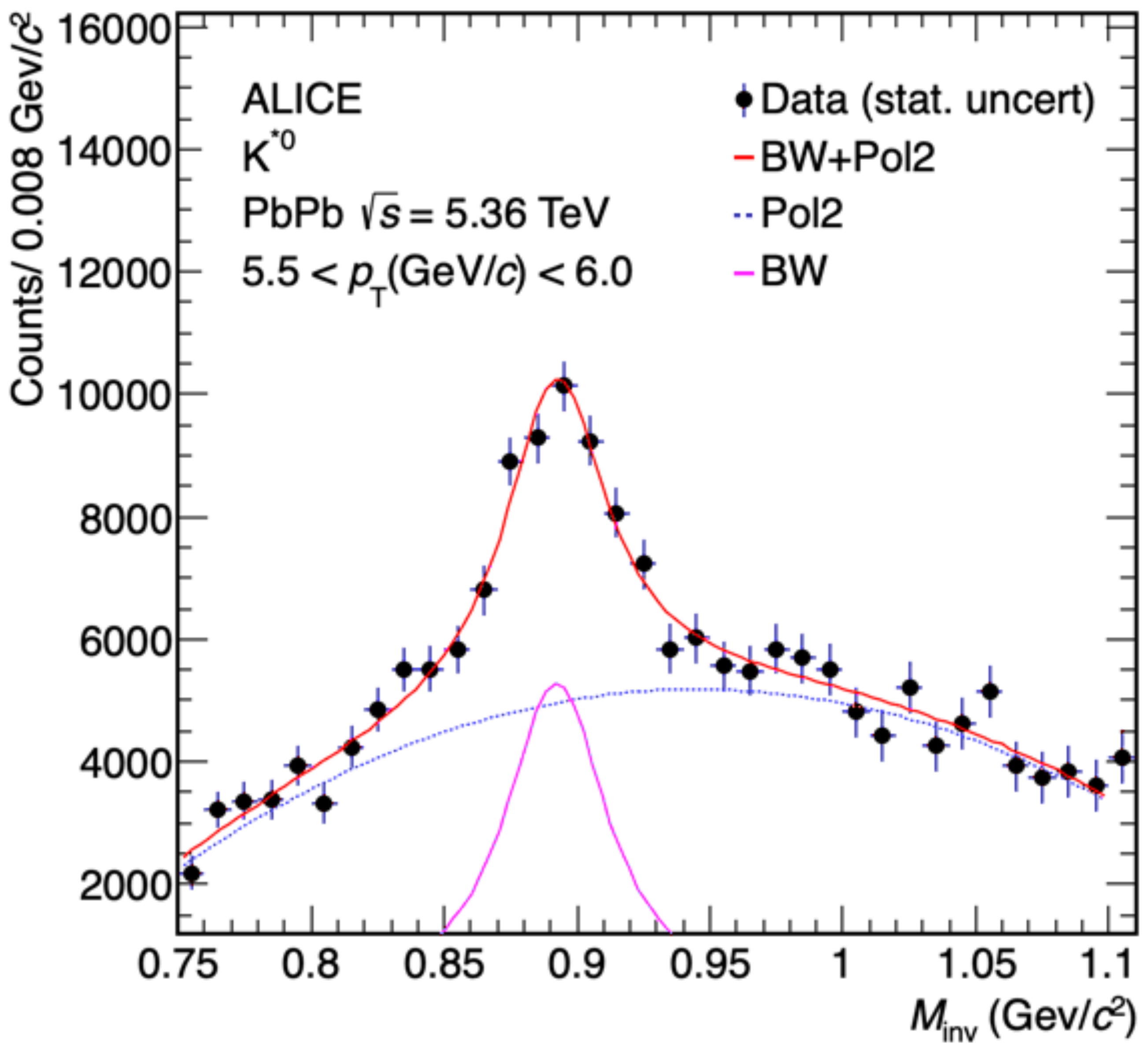
Analysis Method and Results

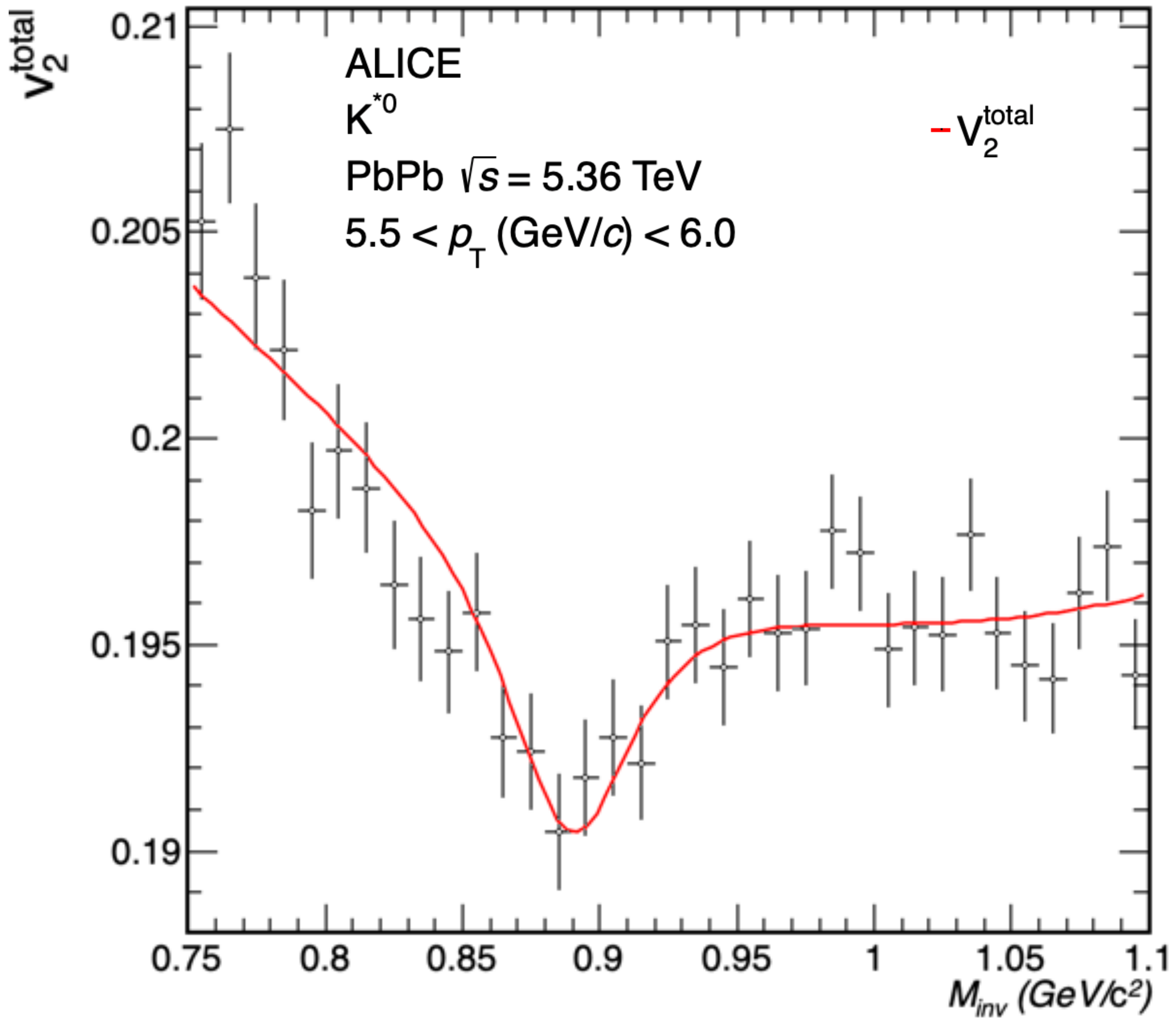
- Invariant mass fit method is used to calculate v_2

$$v_2^{Sig+Bg}\left(m_{inv}\right) = A\left(m_{inv}\right) v_2^{Sig} + \left[1 - A\left(m_{inv}\right)\right] v_2^{Bg}$$

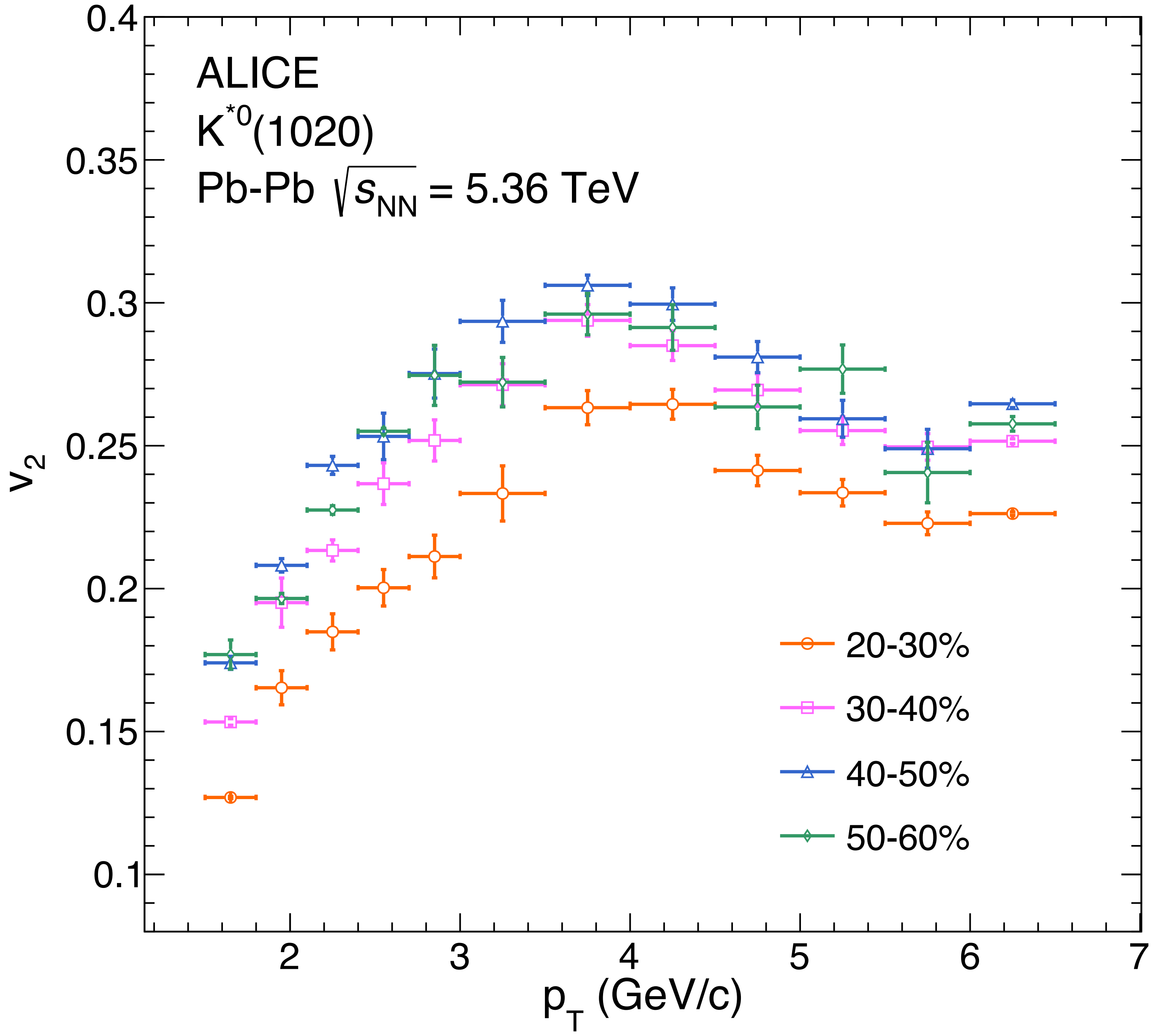
$$\text{Here, } A\left(m_{inv}\right) = N^{Sig}\left(m_{inv}\right) / N^{Sig+Bg}\left(m_{inv}\right)$$

$$N^{Sig+Bg}\left(m_{inv}\right) = N^{Sig}\left(m_{inv}\right) + N^{Bg}\left(m_{inv}\right)$$

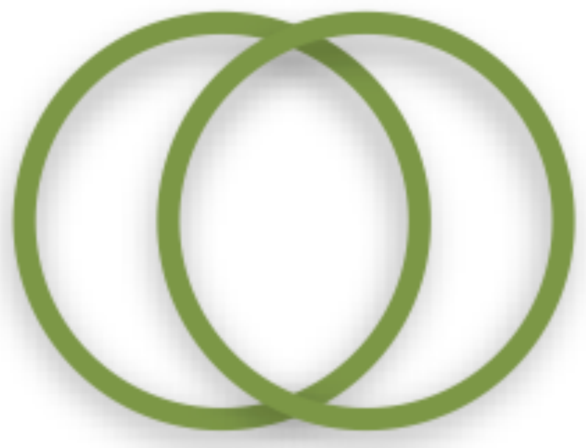




Elliptic flow v_2 of K^{*0} as a function of p_T



20-30%



40-50%

Phys. Rev. C 70, 064905 (2004)

Summary (part 2)

- K^{*0} meson is presented for in Pb-Pb collisions at $\sqrt{s_{NN}}$= 5.36 TeV from p_T range 1.5 to 6.5 GeV/c for different centrality classes.
- v_2^{sig} of K^{*0} is obtained for four different centrality intervals.

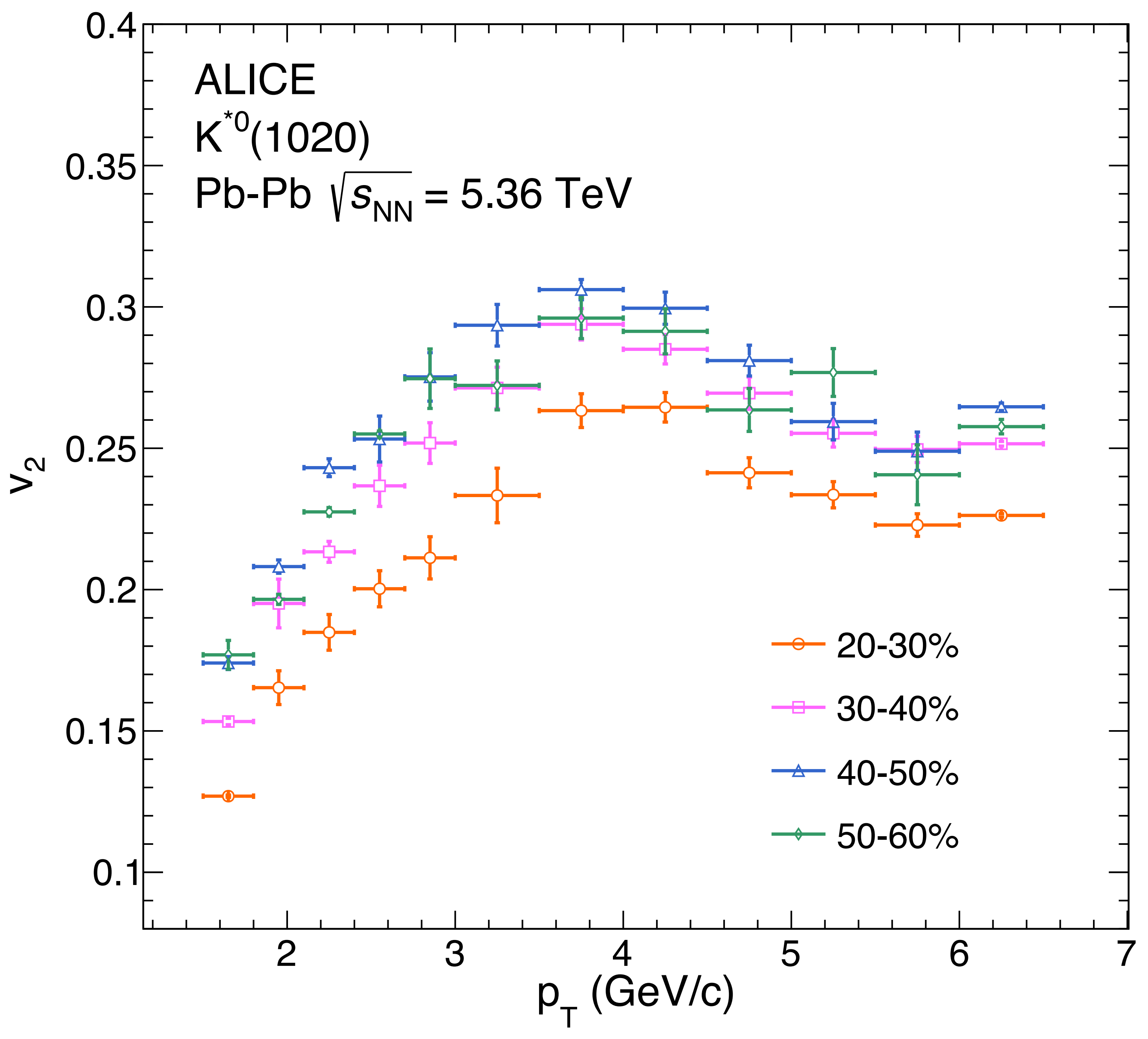
Outlook

- Analysis will be perform with higher statistics data and more finer centrality interval.
- v_2 of K^{*0} will be compared with v_2 of ϕ to investigate re-scattering effect.
- Systematic studies will be performed.

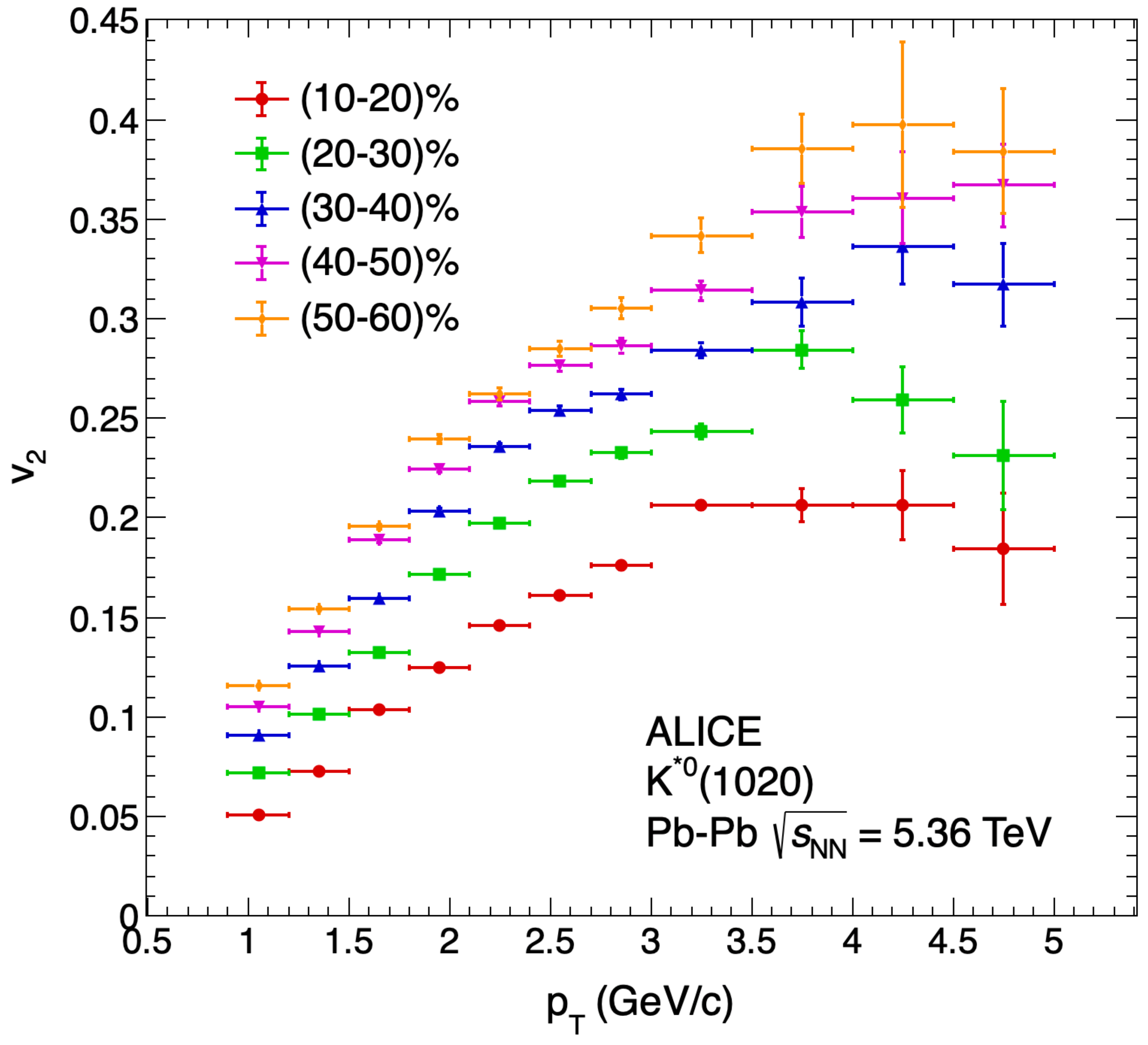
Thank You

Back up slides

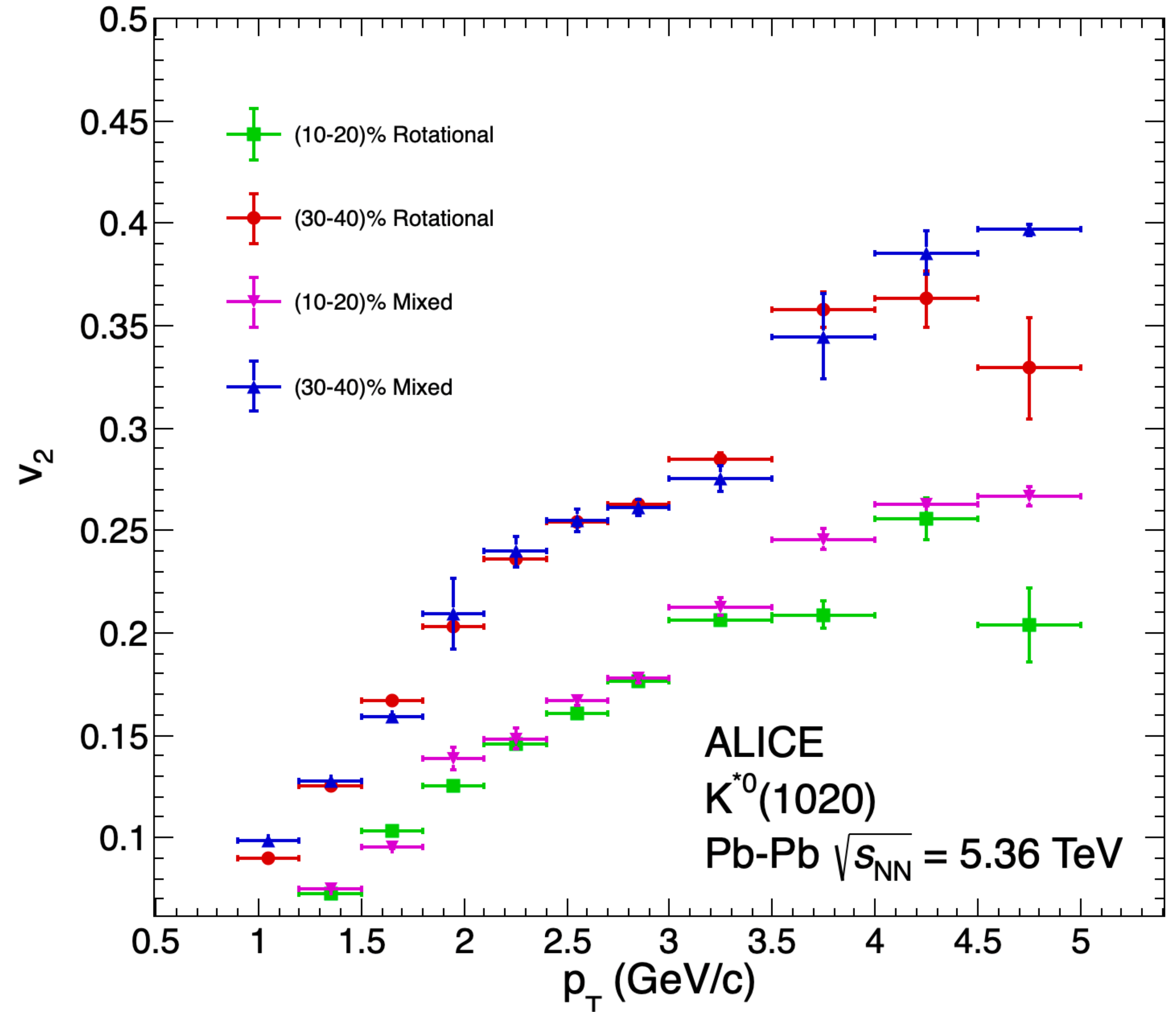
Rotational background



Mixed event background

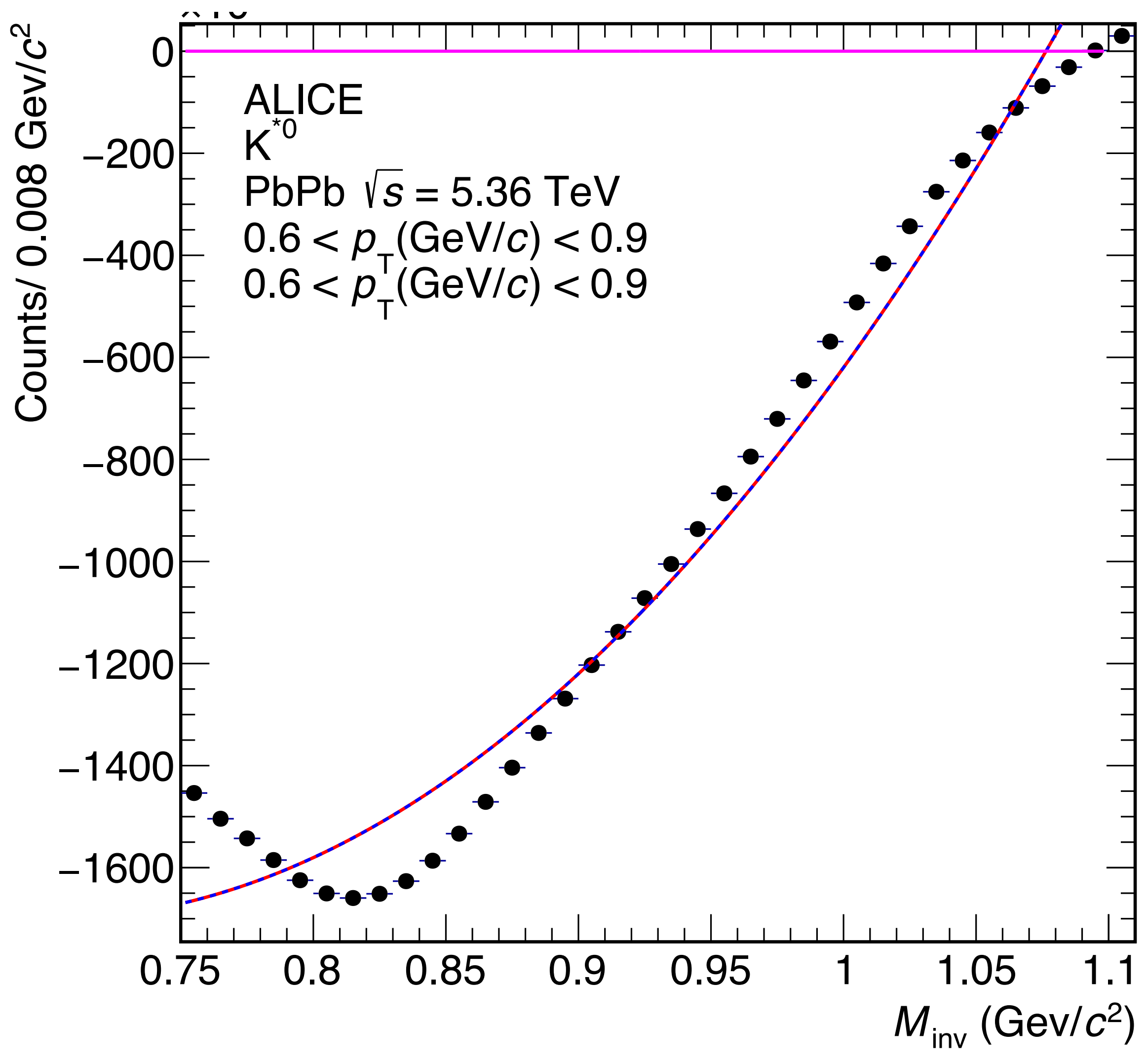


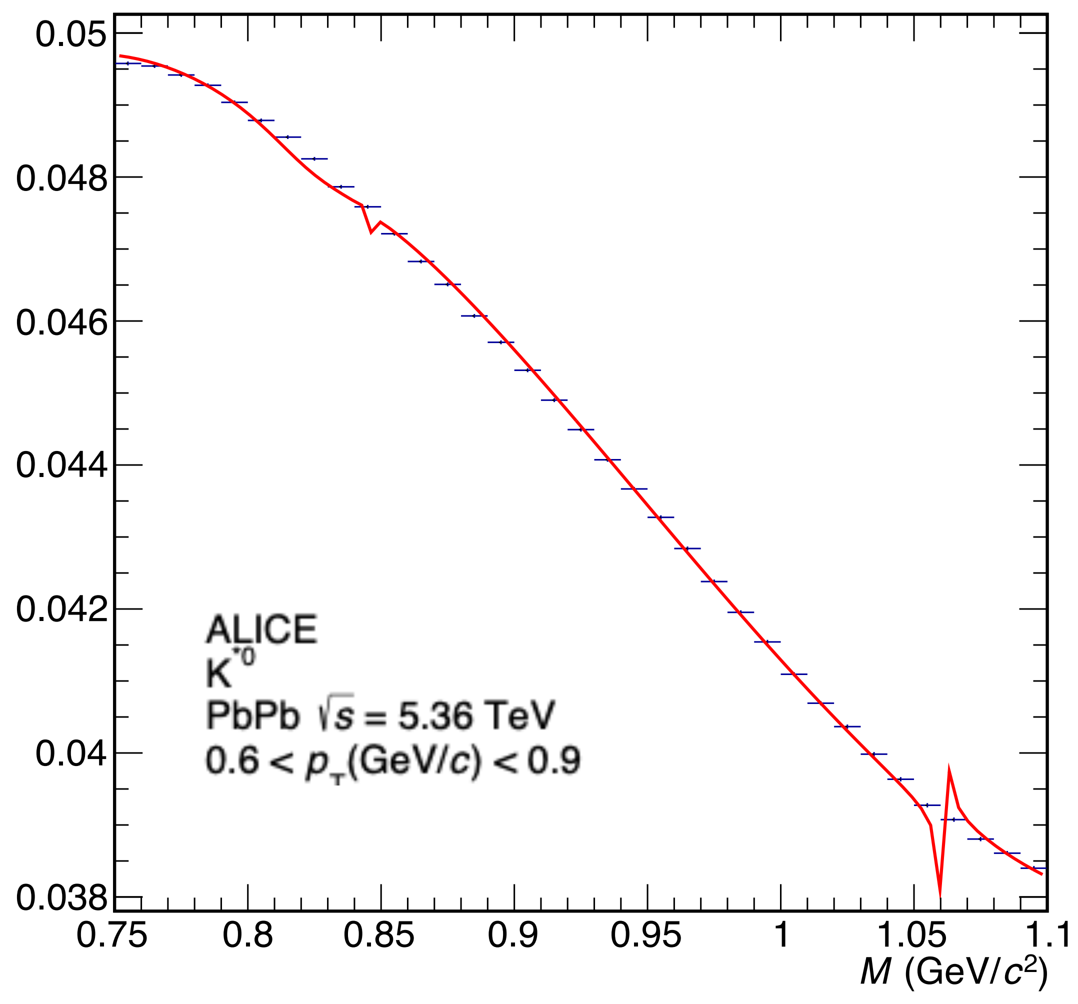
Rotational background



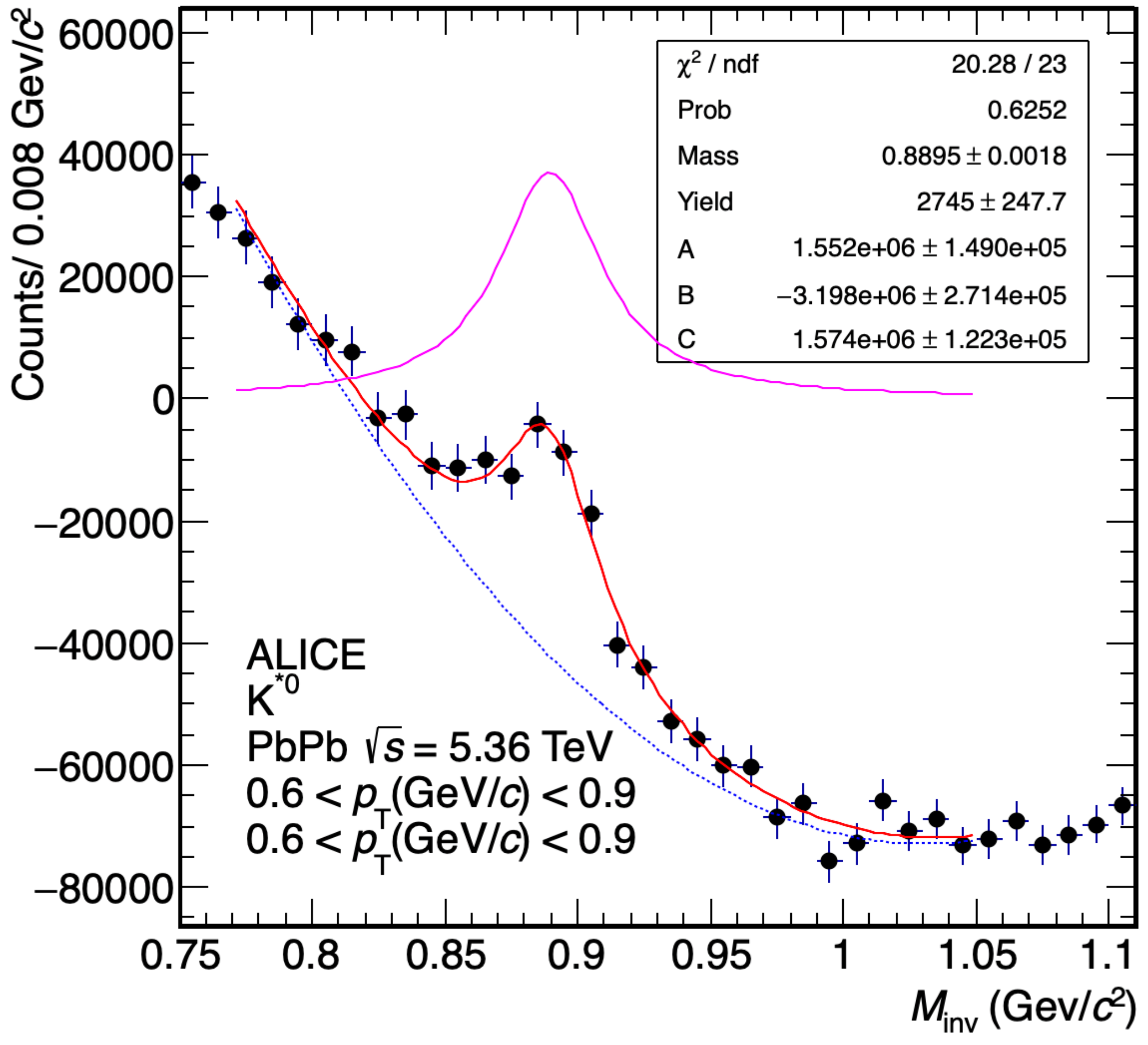
Comparison of mixed and rotational background

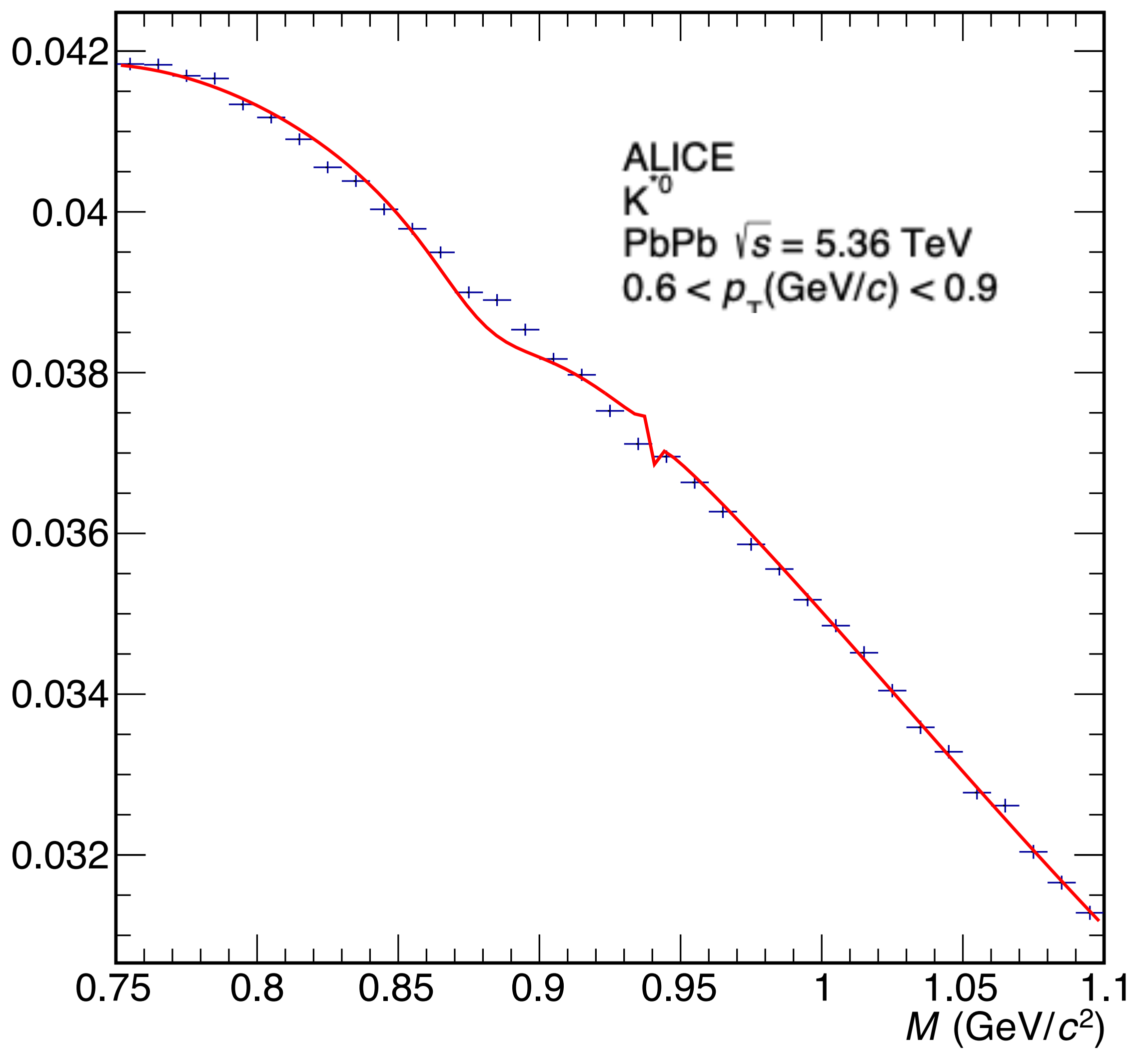
Mixed background





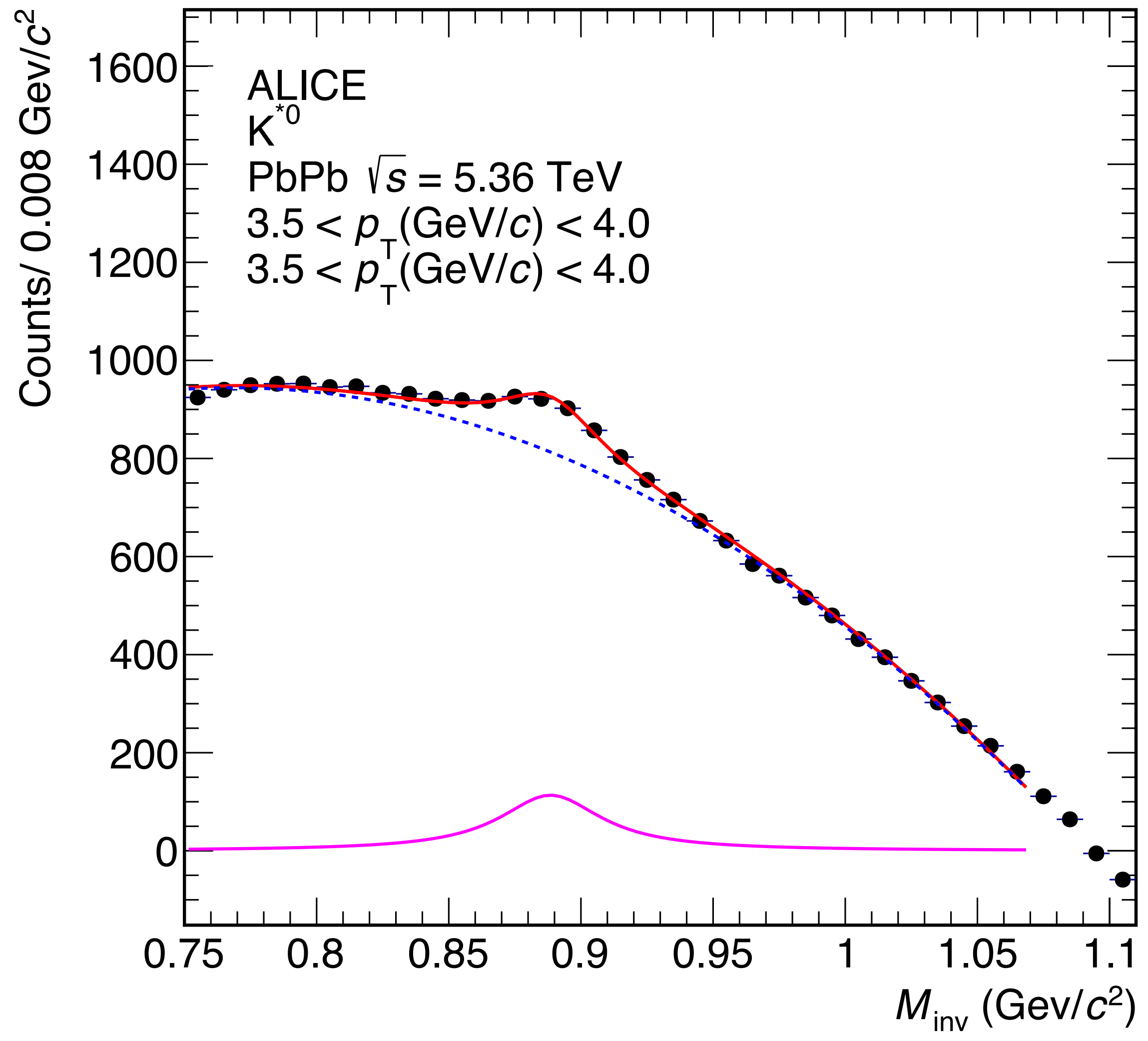
Rotational background

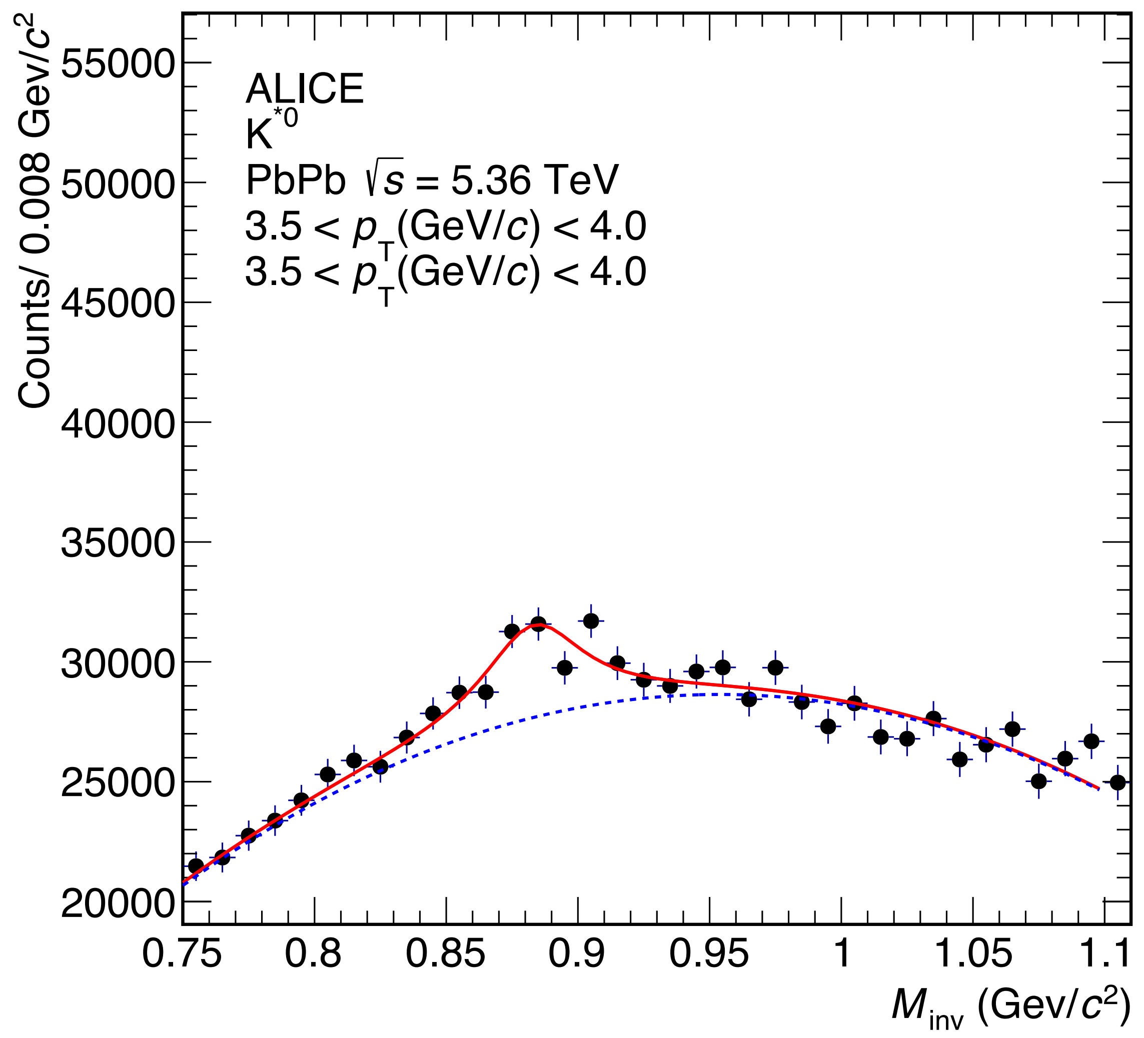


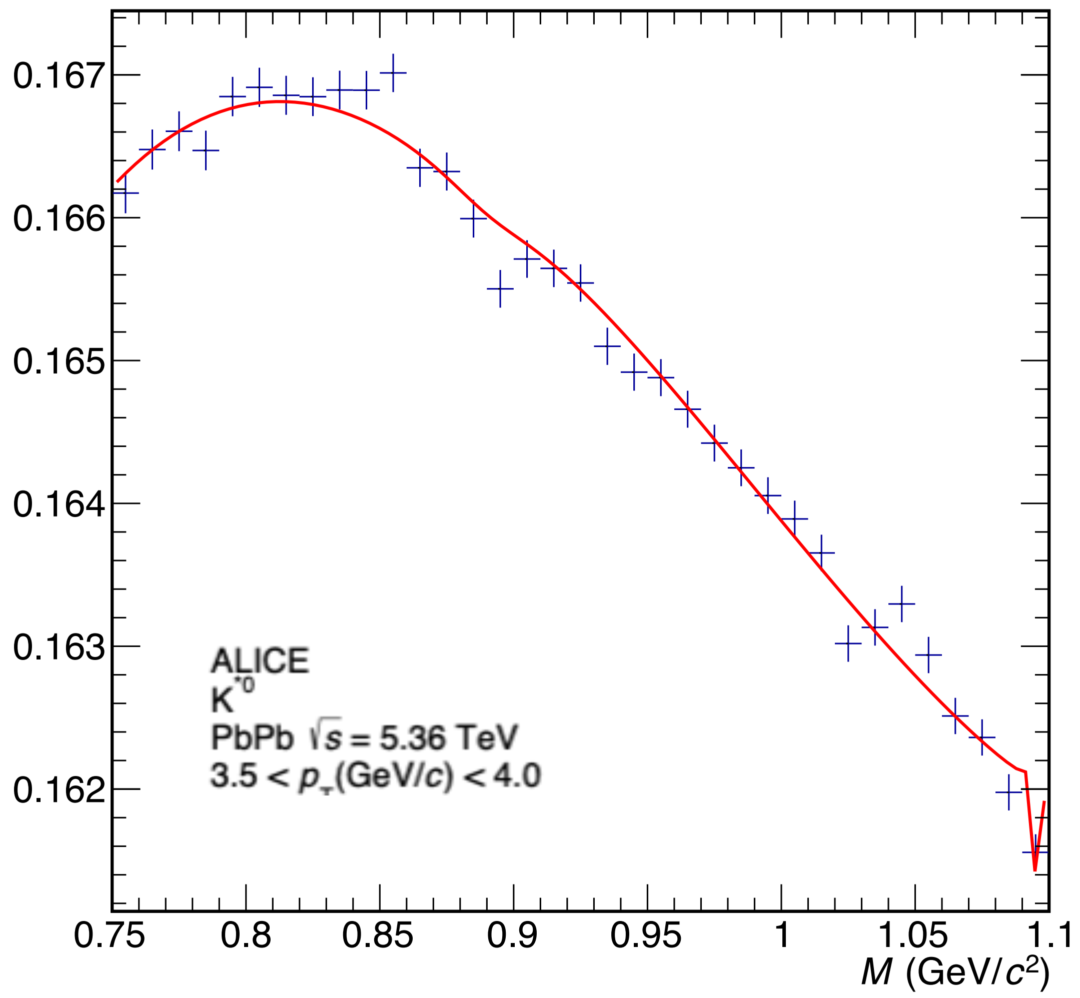


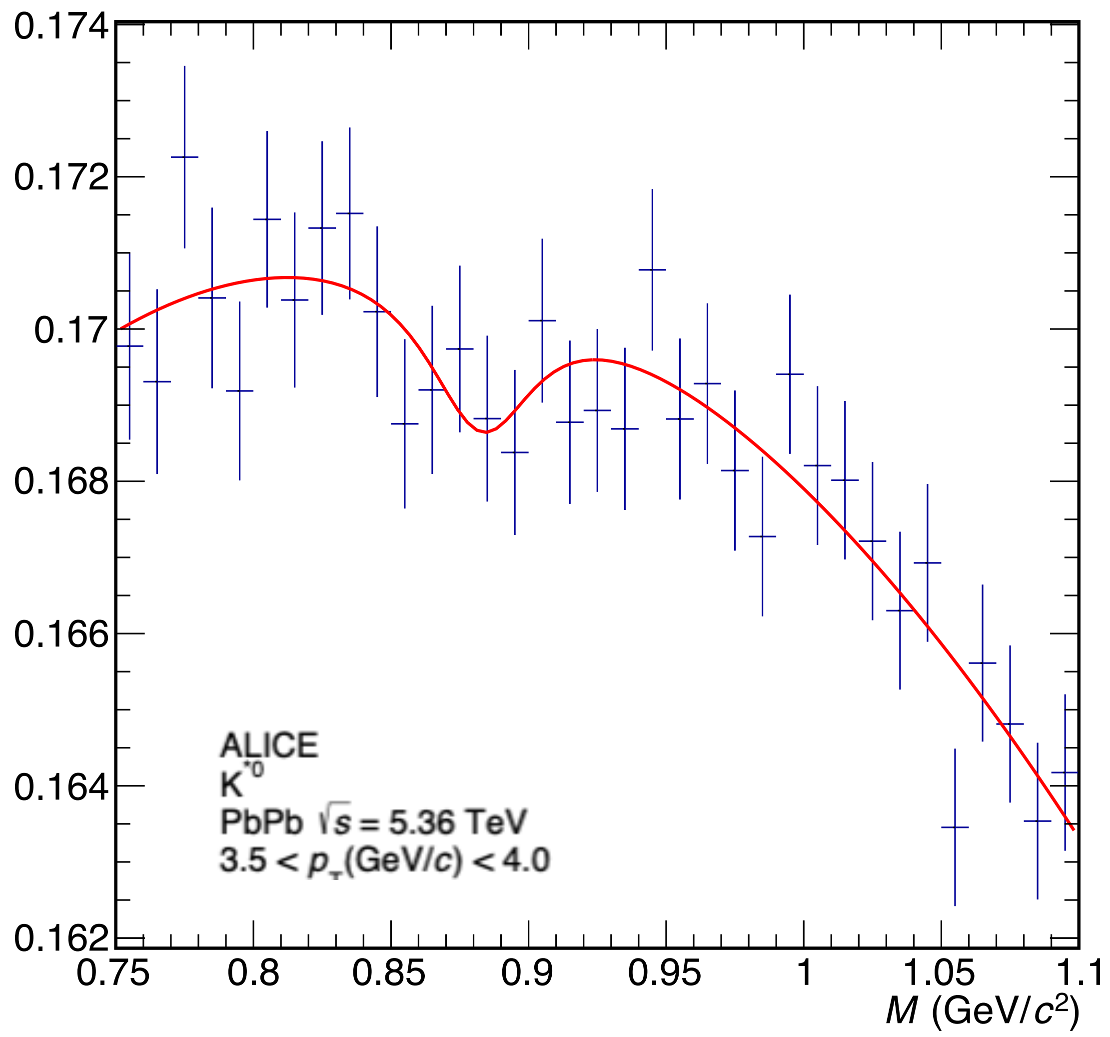
Mixed background

Rotational background

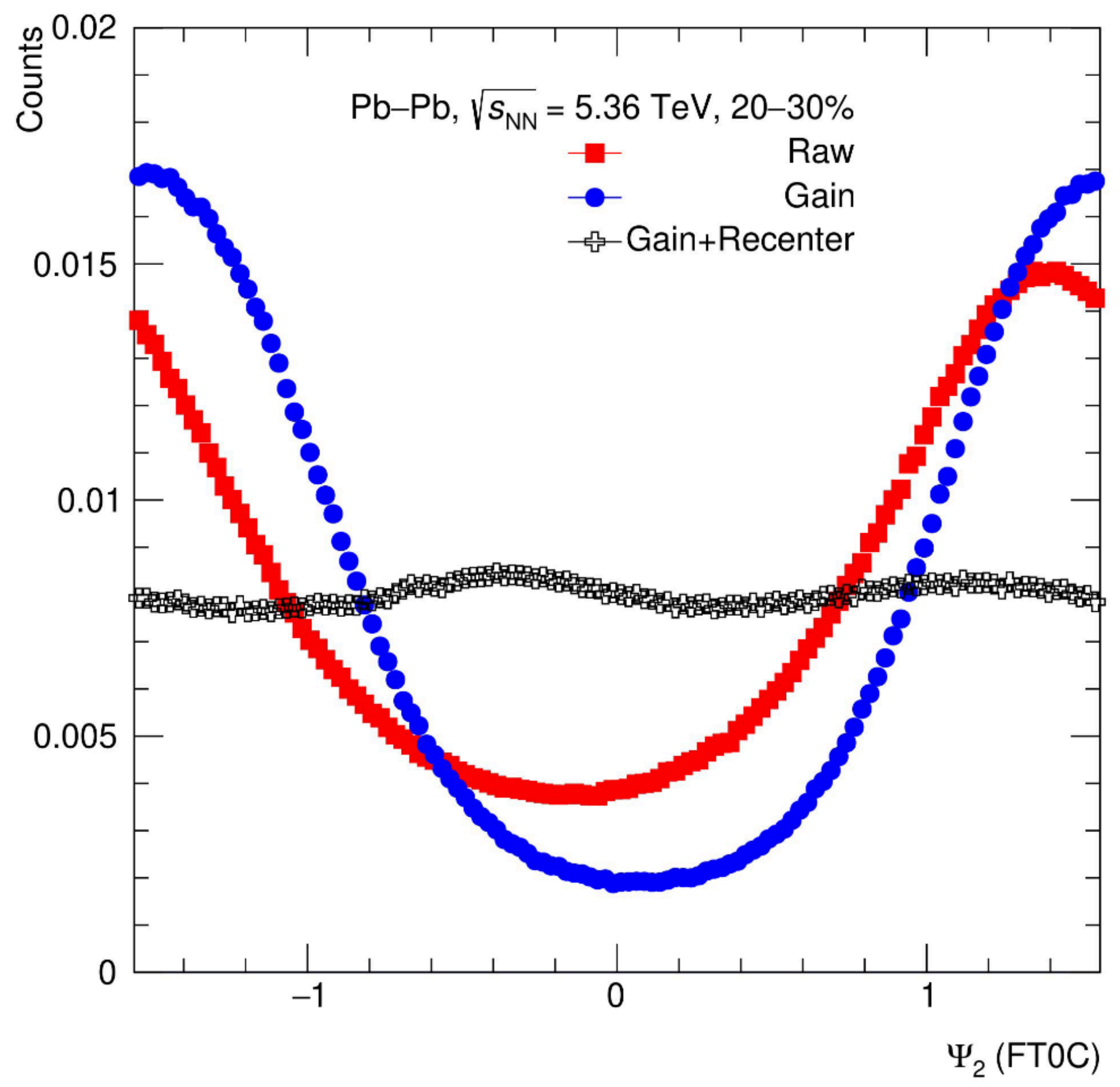








Reconstruction of the Event Plane

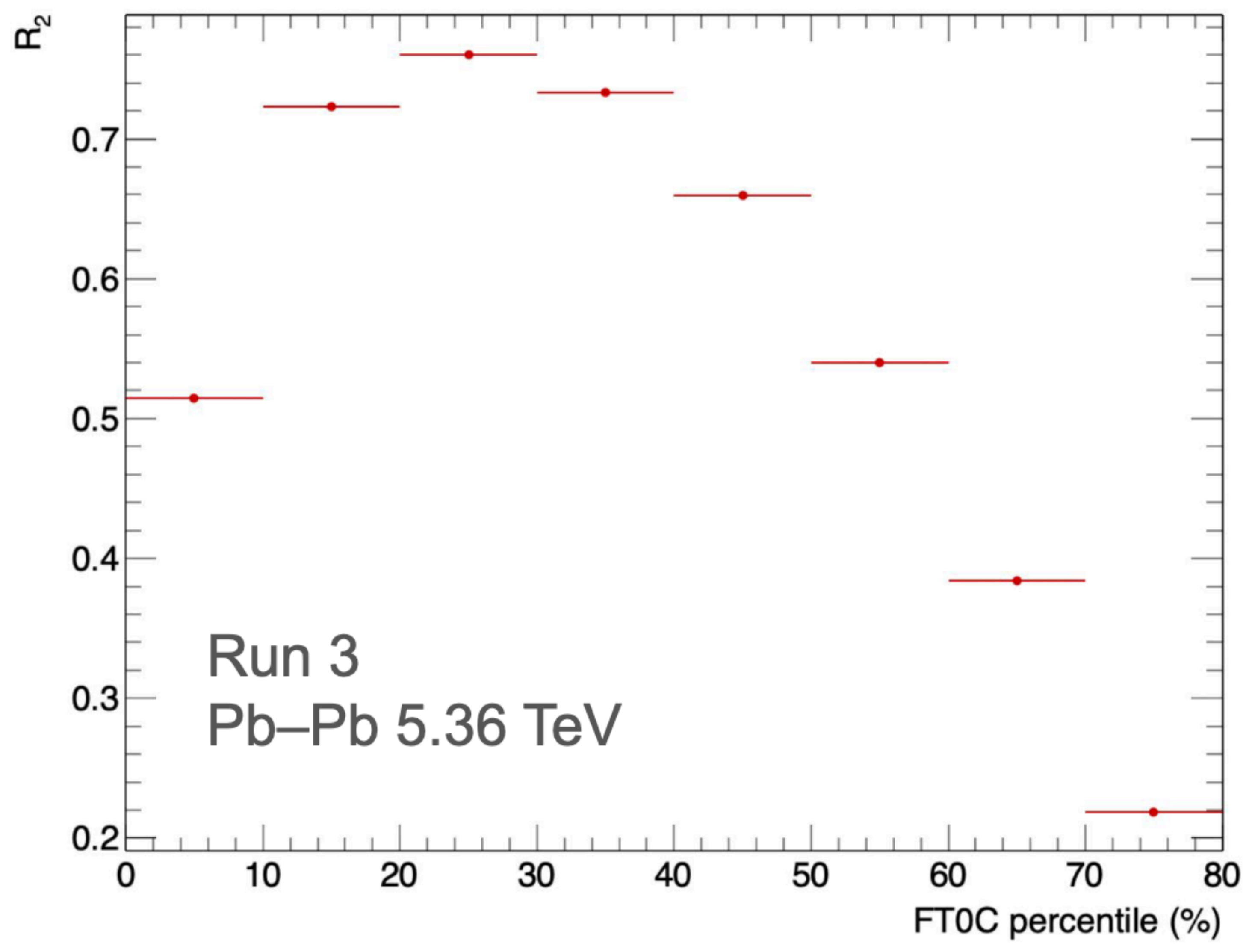


$$\psi_2 = \frac{1}{2}\tan^{-1}\left(\frac{Q_y}{Q_x}\right)$$

Q: event plane vector

$$Q_x = \sum_i w_i \cos(2\phi_i), \quad Q_y = \sum_i w_i \sin(2\phi_i)$$

- w_i : amplitude of the i^{th} cannel of FIT detector
- ϕ_i : position of the i^{th} cannel of FIT detector



$$\mathcal{R}_n = \langle \cos(n(\Psi_n^A - \psi_n)) \rangle \approx \sqrt{\frac{\langle \cos(n(\Psi_n^A - \Psi_n^B)) \rangle \langle \cos(n(\Psi_n^A - \Psi_n^C)) \rangle}{\langle \cos(n(\Psi_n^B - \Psi_n^C)) \rangle}}$$

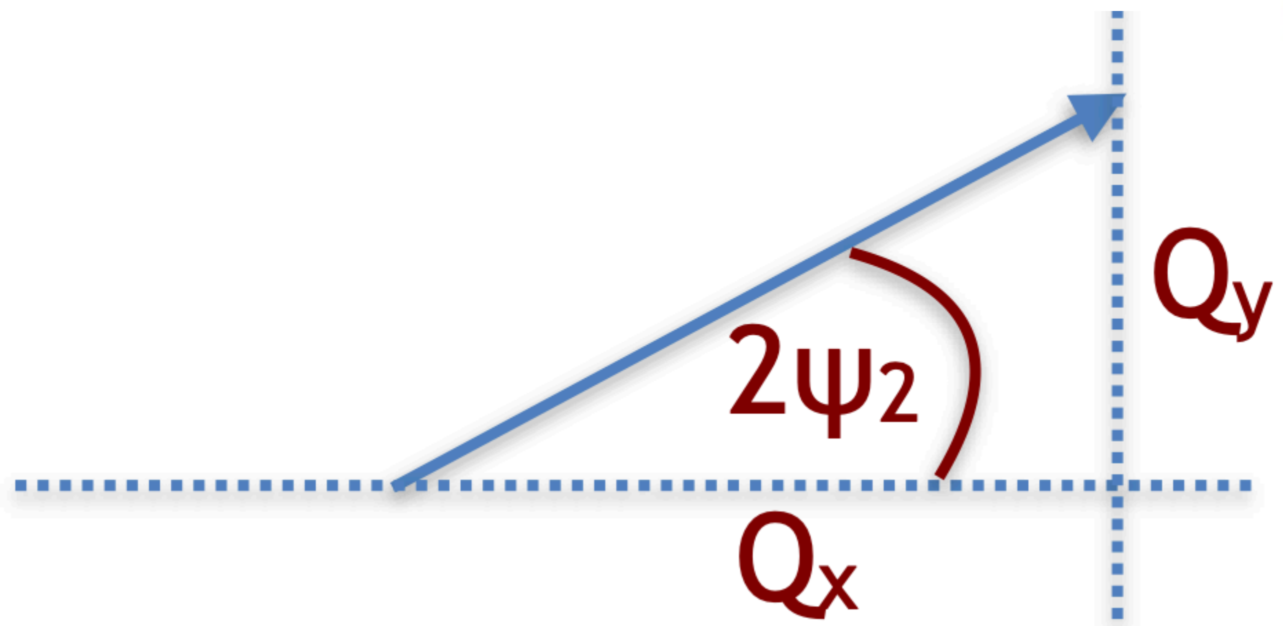
- **Gain correction :**

$w_i / < w >$ for each channel and run by run

- **Recenter :**

$Q'_x = (Q_x - < Q_x >)/\delta_{Qx}$ for each channel and run by run

$Q'_y = (Q_y - < Q_y >)/\delta_{Qy}$ for each channel and run by run



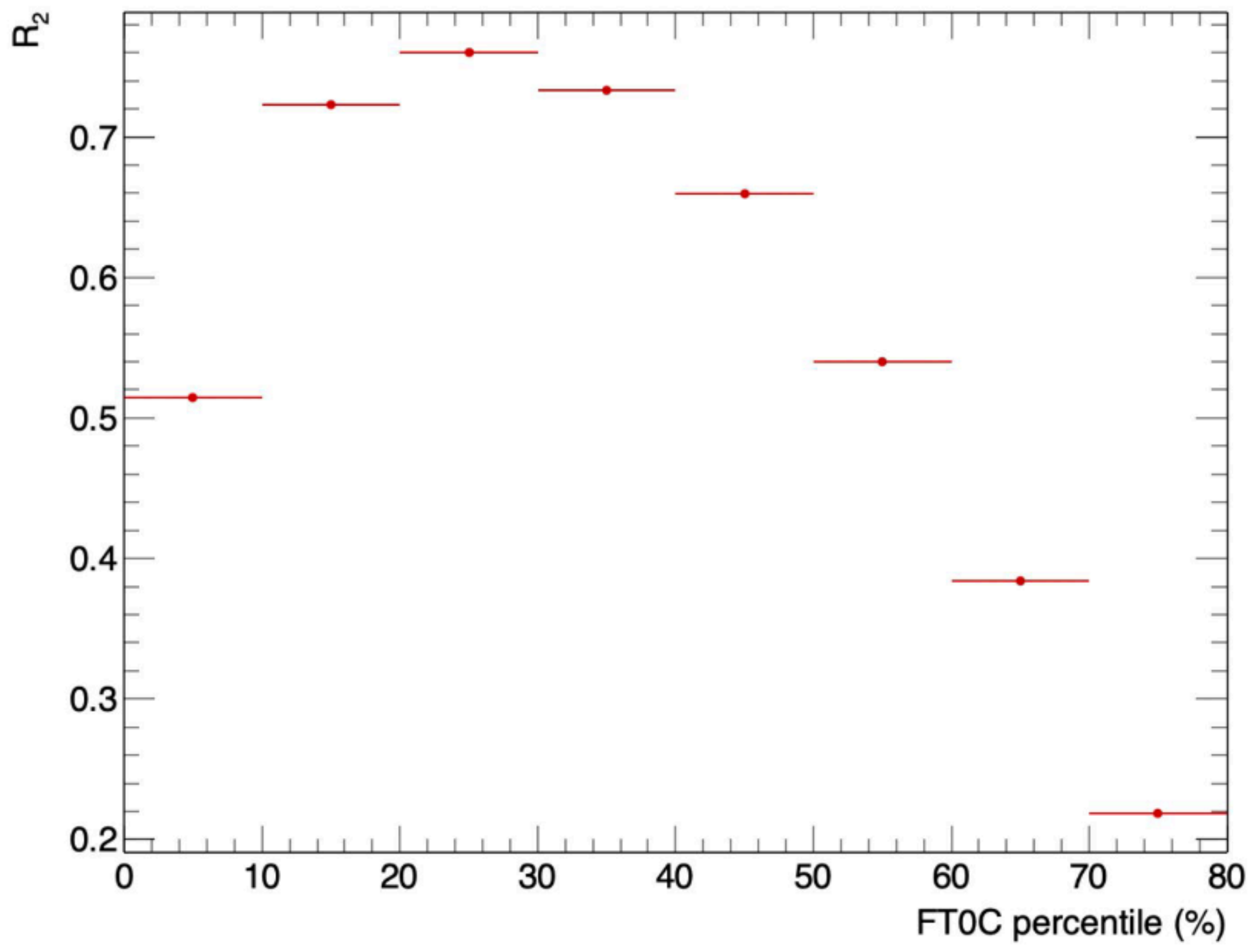
A = FT0C
B = TPC -0.8 < eta < -0.1
C = TPC 0.1 < eta < 0.8

https://indico.cern.ch/event/1395460/

Event plane resolution

- Finite number of particle in an event leads to limited resolution in measured event plane angle.
- Observed v_n is divided by resolution to get v_n w.r.t event plane.

$$v_n = v_n^{obs}/R_n$$



$$\mathcal{R}_n = \langle \cos(n(\Psi_n^A - \psi_n)) \rangle \approx \sqrt{\frac{\langle \cos(n(\Psi_n^A - \Psi_n^B)) \rangle \langle \cos(n(\Psi_n^A - \Psi_n^C)) \rangle}{\langle \cos(n(\Psi_n^B - \Psi_n^C)) \rangle}}$$

A = FT0C
B = TPC -0.8 < eta < -0.1
C = TPC 0.1 < eta < 0.8

https://indico.cern.ch/event/1395460/

Formula

$$Dip - angle = \cos^{-1}\left[\frac{p_{T1}p_{T2} + p_{z1}p_{z2}}{p_1 p_2}\right]$$

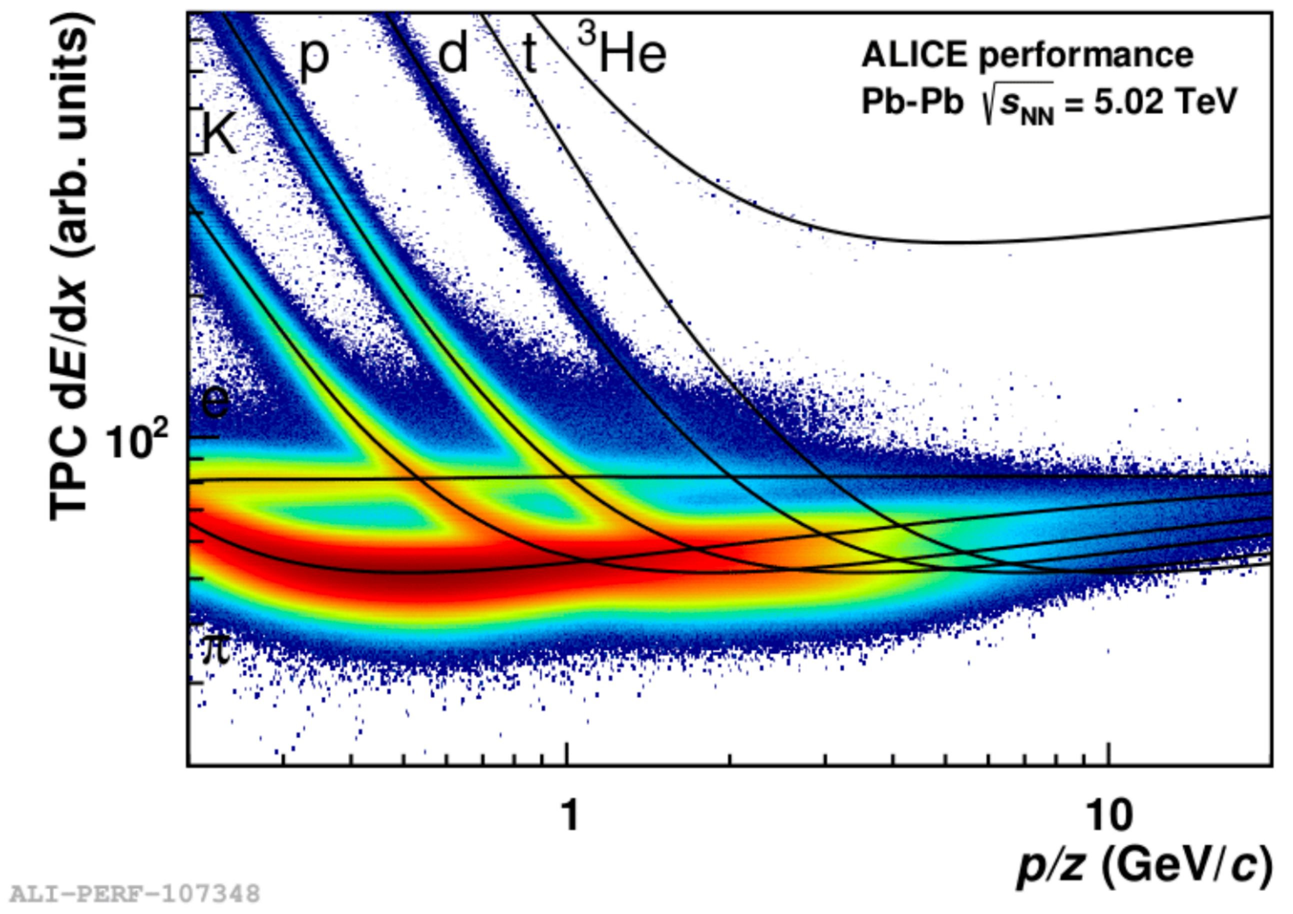
$$m = p/\gamma\beta$$

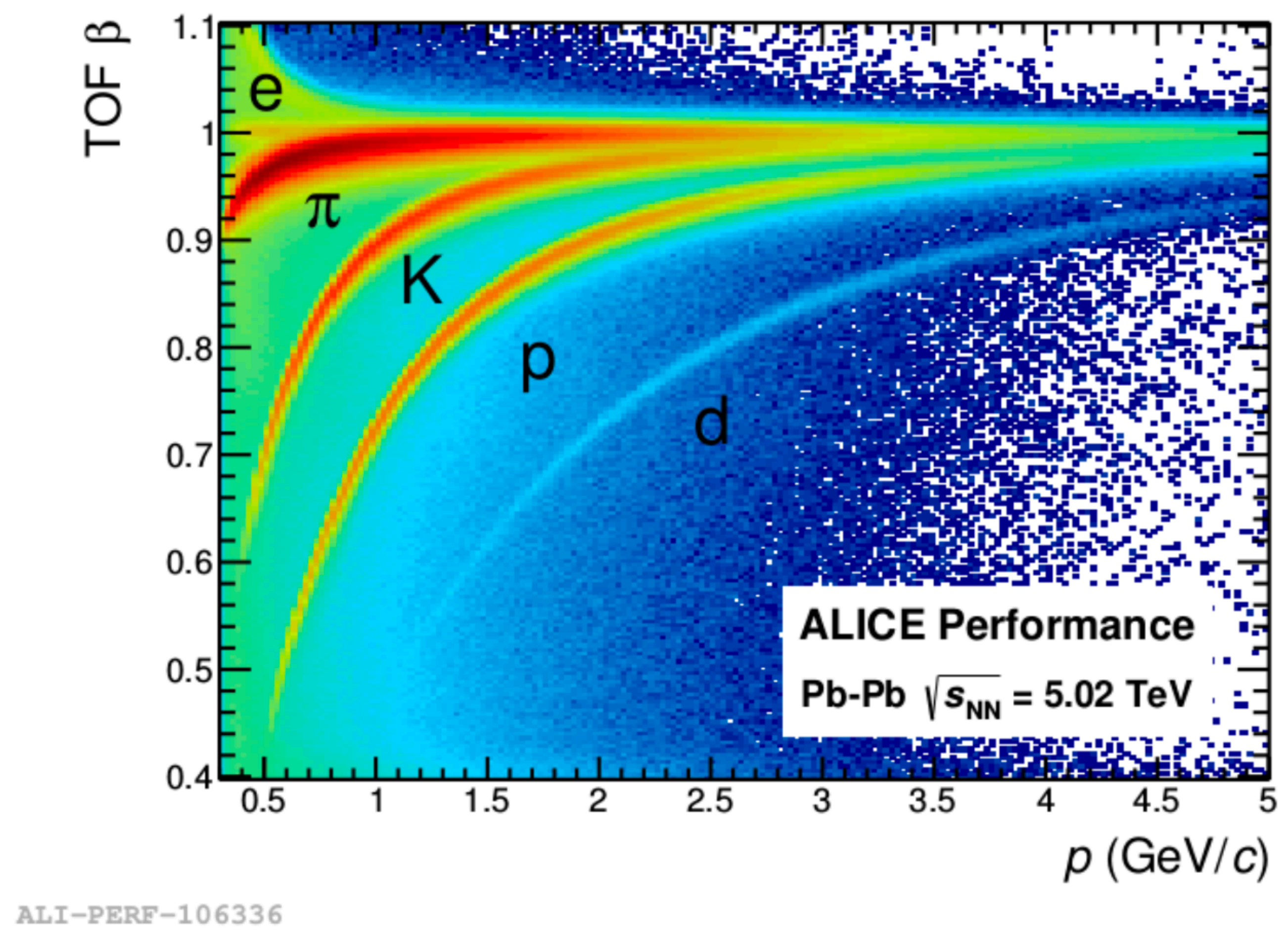
$$n\sigma_{\mathrm{TOF}} = \frac{t_{\mathrm{measured}} - t_{\mathrm{expected}}}{\sigma_{\mathrm{TOF}}}$$

$$n\sigma_{\mathrm{TPC}} = \frac{\mathrm{dE/dx}_{\mathrm{measured}} - \mathrm{dE/dx}_{\mathrm{expected}}}{\sigma_{\mathrm{TPC}}}$$

$$m = p/\sqrt{t^2/l^2 - 1}$$

$\langle\tau\rangle = L/\beta = L(1 + m^2/p^2)^{1/2}$





Formula

$$\frac{1}{N_{evt}}\frac{d^2N}{dy\,dp_T} = p_T\frac{dN}{dy}\frac{(n-1)(n-2)}{nT[nT+m(n-2)]}\left(1+\frac{\sqrt{m^2+p_T^2}-m}{nT}\right)^{-n}$$

dN/dy is defined as:
$\frac{dN}{dy} = I_{hist}+I_{extrapolated}$, where $I_{hist} = \sum 2\pi p_T f(p_T,y)dp_T$ in the measured range and $I_{extrapolated}$ $= \int 2\pi f(p_T,y)p_T dp_T$ in the extrapolated region.
Similarly, the mean transverse momentum ($\langle p_T\rangle$) is defined as:
$\langle p_T\rangle = (\sum 2\pi p_T^2 f(p_T,y)dp_T + \int 2\pi p_T^2 f(p_T,y)dp_T)/(I_{hist}+I_{extrapolated})$, where $f(p_T,y)$ is the invariant yield.

Normalized corrected spectra

$$\frac{1}{N_{evt}}\frac{d^2N_{\mathrm{corrected}}}{dp_{\mathrm{T}}dy} = \frac{N_{\mathrm{raw}}}{N_{\mathrm{evt}}\times BR\times dp_{\mathrm{T}}\times dy\times \epsilon_{\mathrm{rec}}}$$

$N_{corrected}$: corrected yield

N_{raw} : raw yield

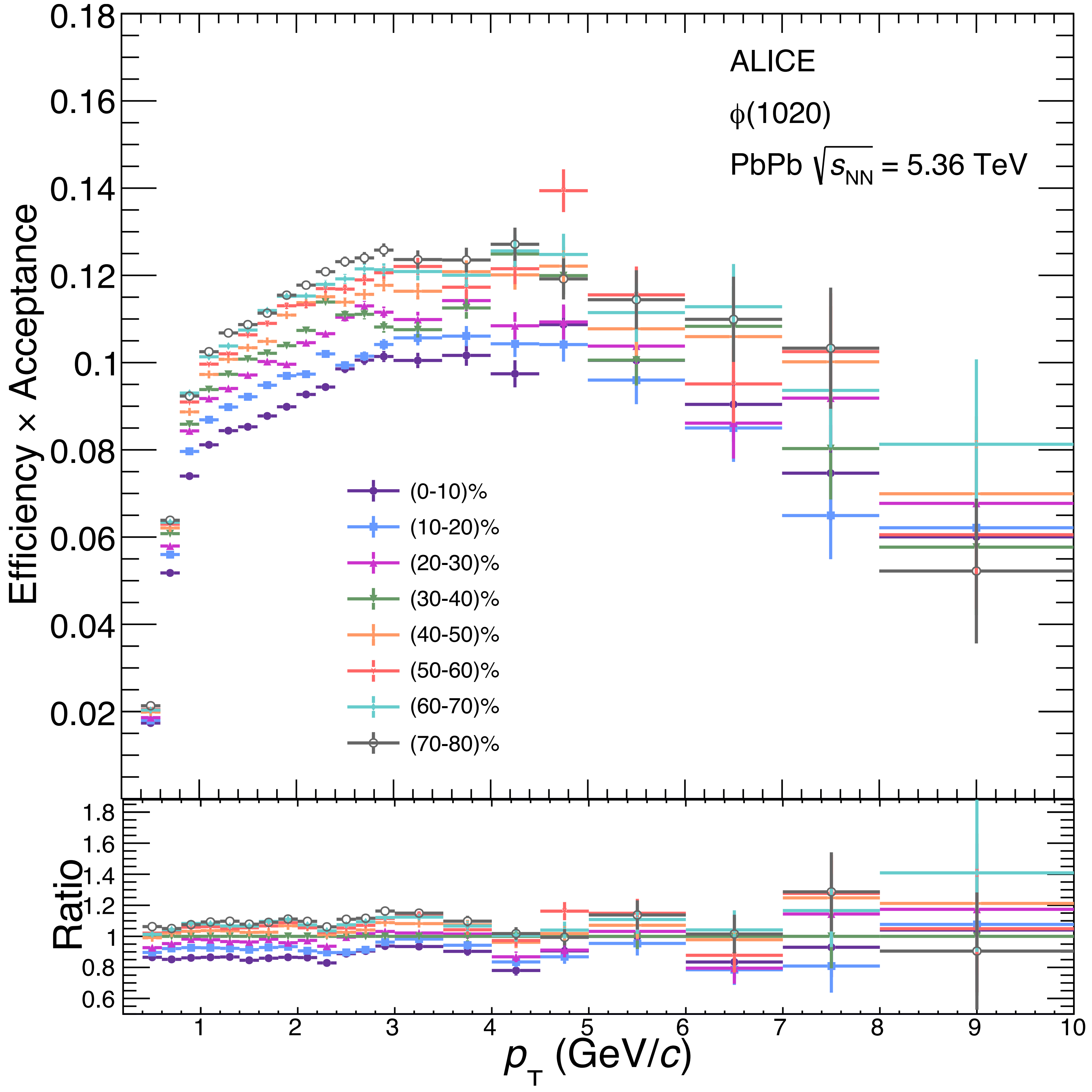
N_{evt} : number of events

BR : branching ratio

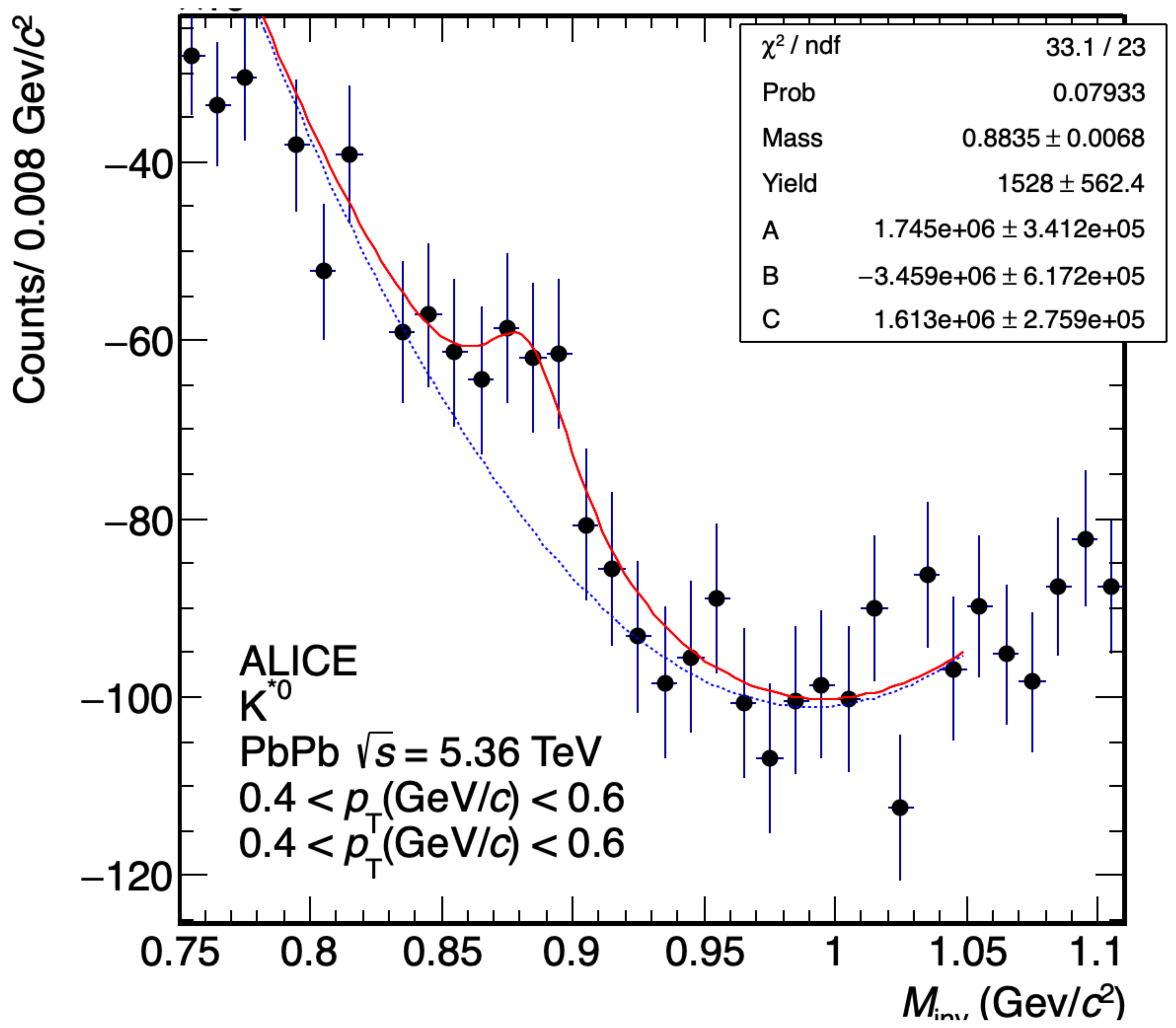
p_T : transverse momentum

y : rapidity

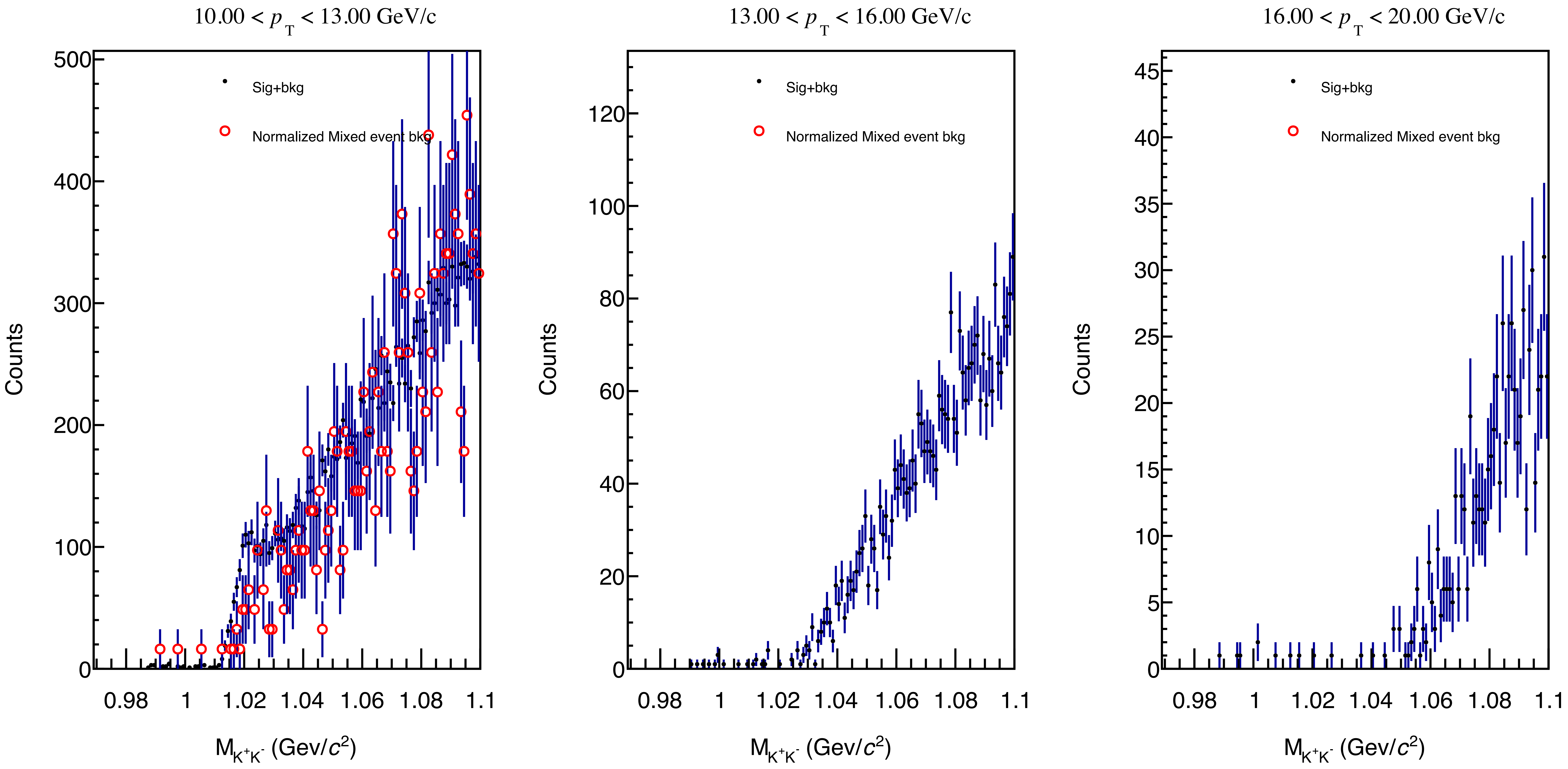
ϵ_{rec} : efficiency × acceptance



Ratio : Efficiency × Acceptance(centrality)/
Efficiency × Acceptance(20-30)%



For higher p_T



For higher p_T