Jet-like Near-side Peak Shapes in Pb-Pb Collisions at $\sqrt{s_{NN}}$=2.76 TeV with ALICE

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on behalf of the ALICE Collaboration

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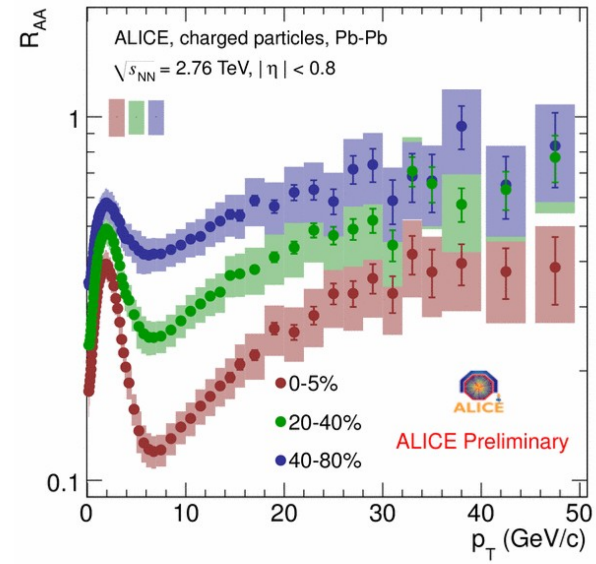
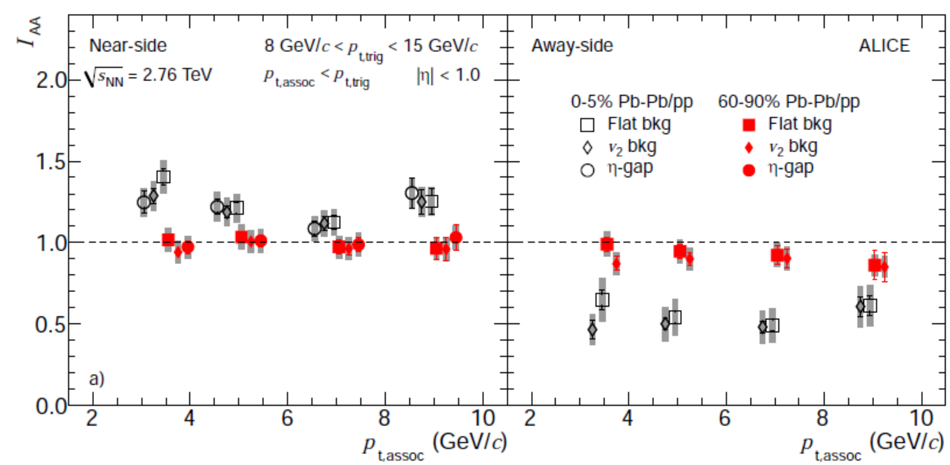
Outline

- Motivation
- Analysis Details
- Results and
  Comparison to Monte Carlo Simulations
- Conclusions

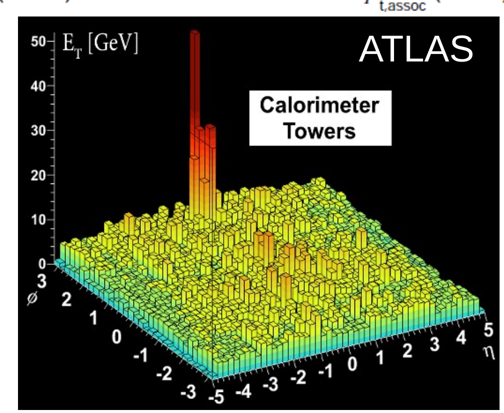
Motivation (I)



- In central Pb-Pb collisions at the LHC ($\sqrt{s_{NN}}$=2.76 TeV) evidence for strong medium induced partonic energy loss found in several observables:
  - Inclusive hadron $R_{AA}(p_T)$
  - Away-side conditional yield I_{AA}
  - Jet $R_{AA}(E_T)$
  - jet-jet and γ-jet energy imbalance
  - …



- Analysis of high-E_T jets (ATLAS, CMS) shows
  - Remnant jet looks like unquenched jet (unmodified fragmentation)
  - Radiated energy: low-p_T particles at large distance to jet axis.



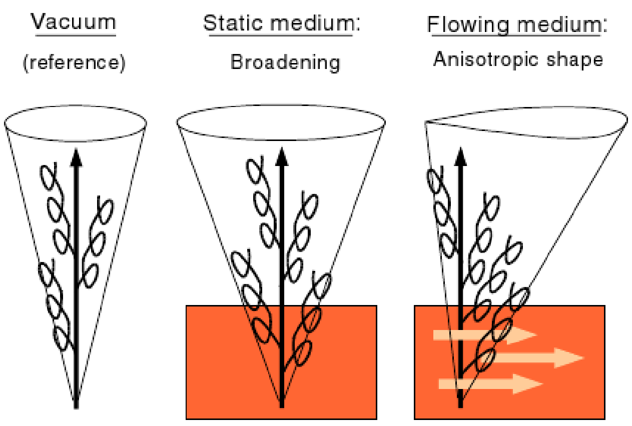
Motivation (II)

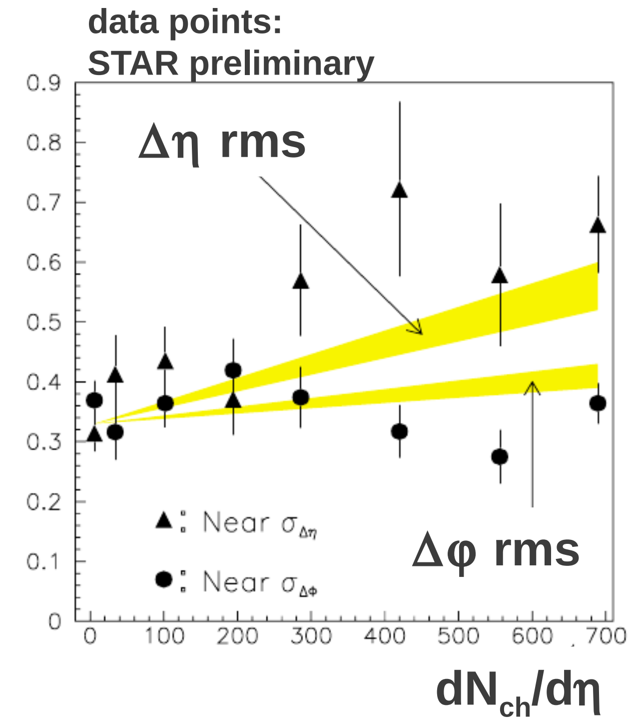
- N. Armesto, C. Salgado, U. Wiedemann: *Measuring the Collective Flow with Jets*

  [PRL 93,242301 (2004)]

  – Broadening in a static medium

  – Longitudinal flow results in deformation of the conical jet shape
  → Different $\Delta\varphi$ and $\Delta\eta$ widths (eccentric jets)





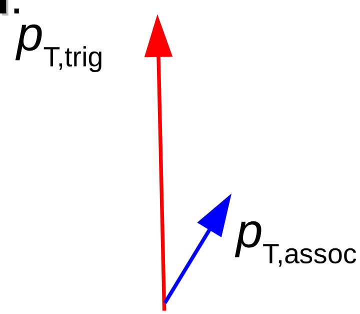
PRL 93,242301 (2004)

- Interest to study modifications of the jet shape
  - Increase of width (radiation)
  - Increase of eccentricity (longitudinal flow)
- In particular at low parton p_T
  where quenching effects are strongest.

Di-Hadron Correlations

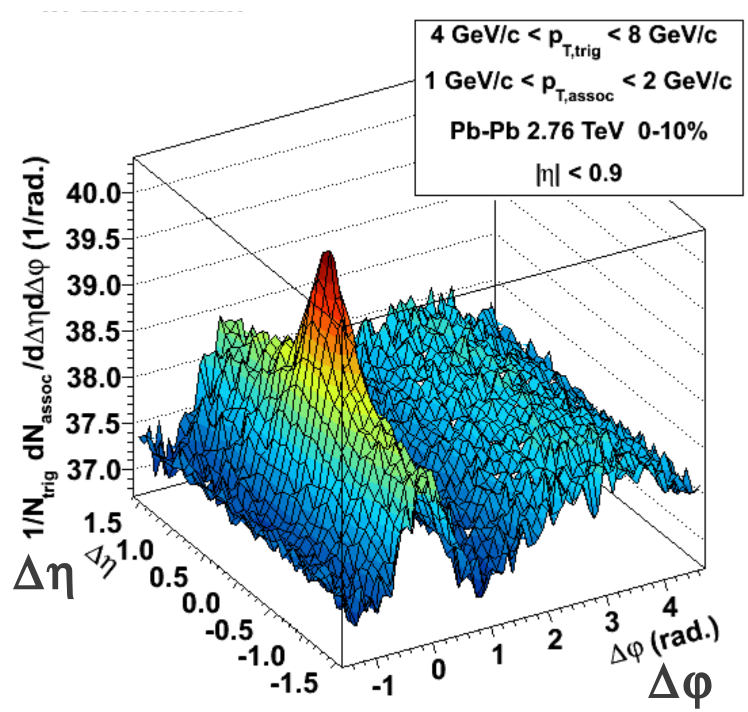
- Study jet properties in heavy ion collisions in a transverse momentum range where event-by-event jet reconstruction over the fluctuations of the underlying event is not possible.
- Analyze angular correlations in azimuth $\Delta\varphi$ and pseudo-rapidity $\Delta\eta$ differences between a trigger particle (**trig**) and all associated (**assoc**) particles satisfying specific cuts on $p_{T,trig}$ and $p_{T,assoc}$ are studied and quantified by the **per trigger associated particle yield**:

$$\frac{1}{N_{trig}}\frac{d^2 N_{assoc}}{d\Delta\varphi d\Delta\eta}$$



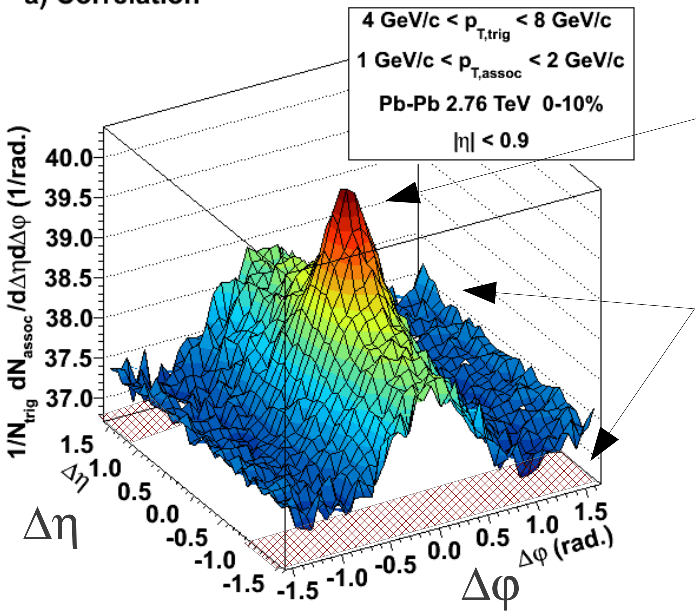
Nears-side peak ($\Delta\varphi=\Delta\eta=0$) and away-side ridge ($\Delta\varphi=\pi$) are reminiscent of LO back-to-back parton production (jets).

At low p_T correlations at large $\Delta\eta$ and away-side dominated by collective effects (v_2, v_3, ...)

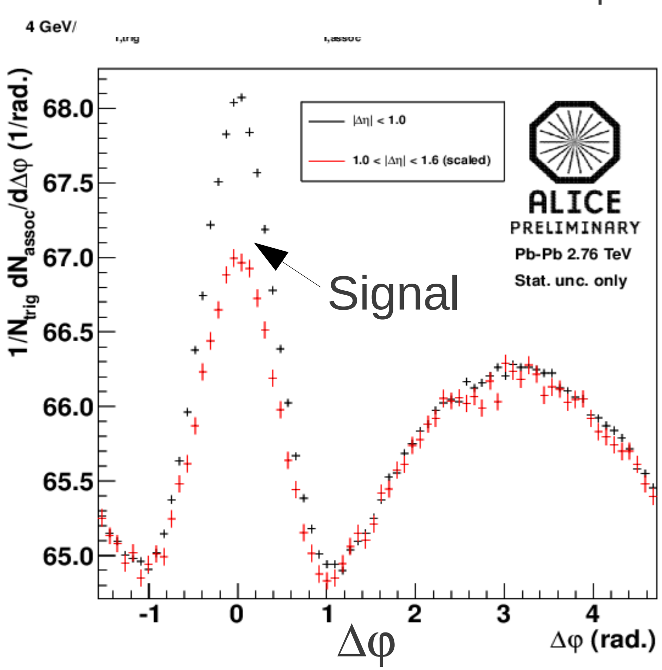


Subtraction of Δη–independent Correlations

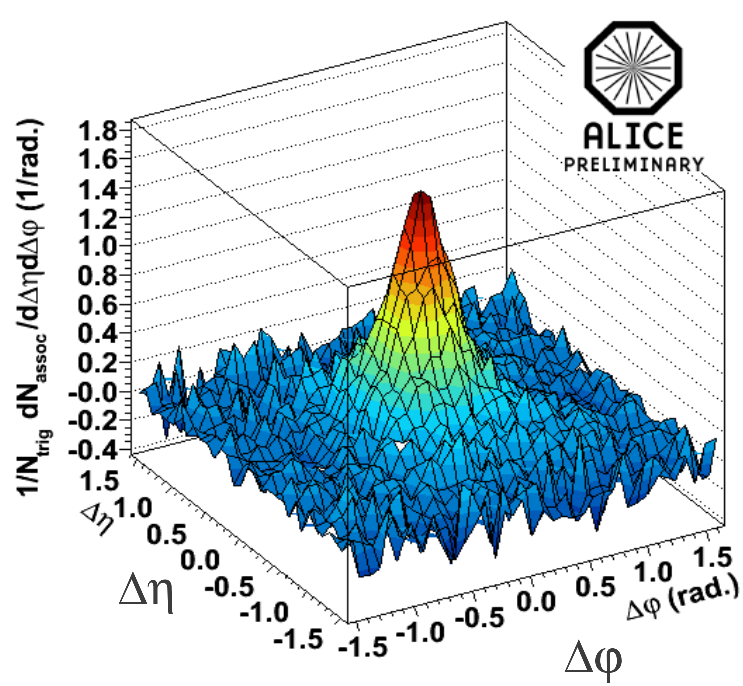
a) Correlation



- Nearside peak centered at (Δφ= 0, Δη = 0)
- Δη independent (long range) correlations (mainly flow near-side + flow+jet away-side) plus uncorrelated background.
- Signal Extraction: Subtract side bands 1 < Δη < 1.6
- Study near-side peak (away side peak is removed by this procedure)



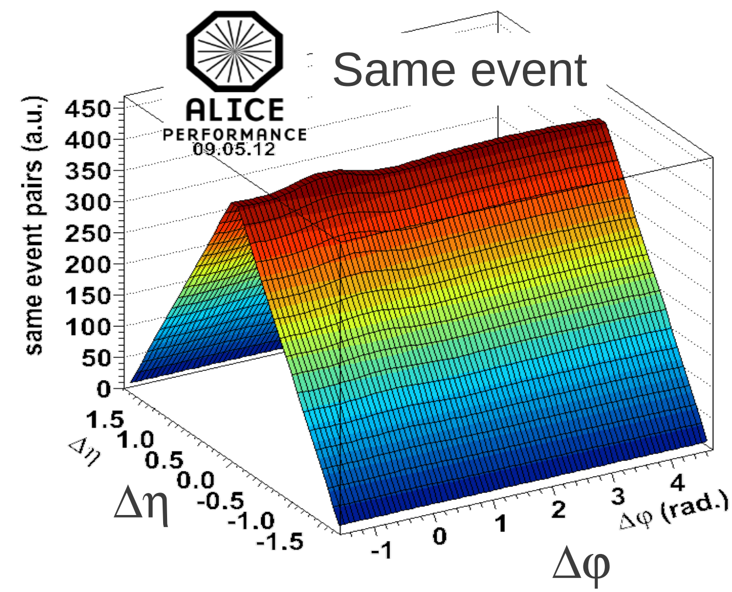
b) η-gap subtracted

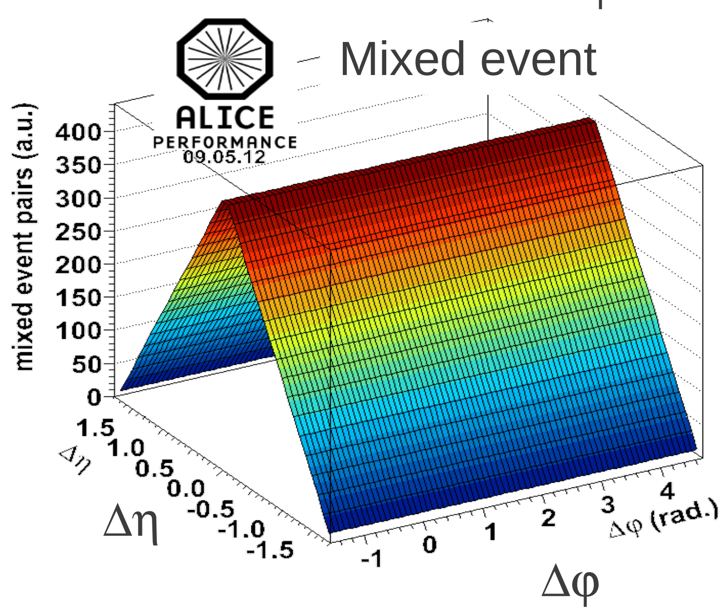


Event and Track Selection

- Data Sets
  - Pb-Pb at $\sqrt{s_{NN}}$=2.76 TeV
    - 15 M events from 2010 data taking period in 0-90% centrality class
  - pp reference at $\sqrt{s}$ = 2.76 TeV
    - 55 M events from 2011 low energy run
- Centrality selection
  - Using VZERO (N_{ch} with scintillators in $2.8 < \eta < 5.1$ and $-3.7 < \eta < -1.7$)
- Tracking
  - TPC tracks constrained to the primary vertex
    - optimal azimuth (φ) acceptance = uniformity for angular correlations
    - Minimize two-track cluster merging effects in the TPC
      - Cut in closest approach inside the TPC
    - $|\eta| < 0.9$
    -
- Two step correction procedure
  - 2-track acceptance correction using mixed events $\Rightarrow$ Corrected shape
  - Single particle efficiency and contamination correction $\Rightarrow$ Corrected per trigger particle yields

Two-Track Acceptance Correction





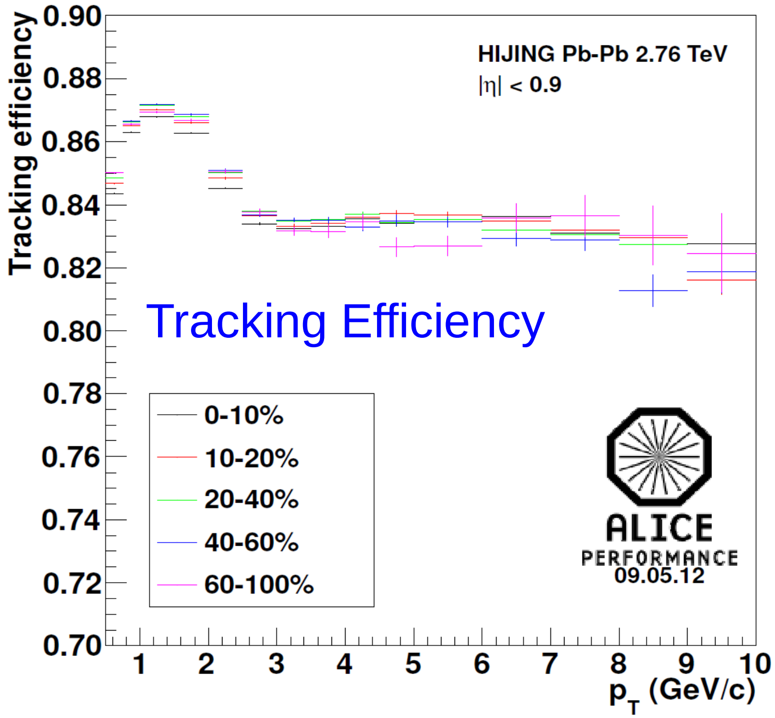
- Event Mixing performed in bins of
  - Long. vertex position (z, Δz = 2 cm)
  - Centrality: 1% steps from 0-5%; then 5-10% followed by 10% steps.
  - For each z-bin calculate the ratio:

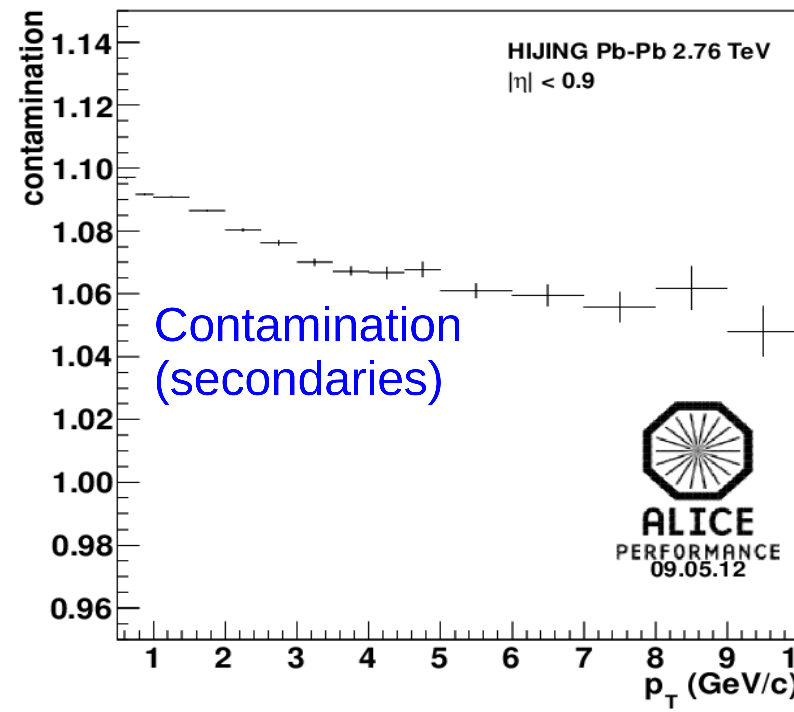
$$\frac{d^2 N^{raw}}{d\Delta\varphi\, d\Delta\eta}(\Delta\varphi,\Delta\eta,z)=\frac{1}{N_{trig}(z)}\frac{N^{same}_{pair}(\Delta\varphi,\Delta\eta,z)}{N^{mixed}_{pair}(\Delta\varphi,\Delta\eta,z)}\beta$$

  - β chosen such that correction interpolated to $\Delta\varphi=\Delta\eta=0$ is 1.
  - Calculate weighted average of ratios

$$\frac{d^2 N^{raw}}{d\Delta\varphi\, d\Delta\eta}(\Delta\varphi,\Delta\eta)=\frac{1}{\sum_z N_{trig}(z)}\sum_z N_{trig}(z)\frac{d^2 N^{raw}}{d\Delta\varphi\, d\Delta\eta}(\Delta\varphi,\Delta\eta,z)$$

Single Particle Corrections





$$N_{pair}^{corrected}(\Delta\eta,\Delta\varphi,p_{T,trig},p_{T,assoc},C)=N_{pair}^{raw}(\Delta\eta,\Delta\varphi,p_{T,trig},p_{T,assoc},C)\cdot C_{trckeff}(p_{T,assoc},C)\cdot C_{trckeff}(p_{T,trig},C)$$
$$C_{cont}(p_{T,assoc})\cdot C_{cont}(p_{T,trig})C_{correlatedcont}(p_{T,assoc},p_{T,trig},\Delta\eta,\Delta\varphi)$$

$$N_{trig}^{corrected}(p_{T,trig},C)=N_{trig}^{raw}(p_{T,trig},C)\cdot C_{trckeff}(p_{T,trig})\cdot C_{cont}(p_{T,trig})$$

Results

Shape Evolution

(side-band subtracted, fully corrected yields)

- **Wider peak in central collisions**
- **Peripheral and pp similar**
- **Strong p_T dependence**

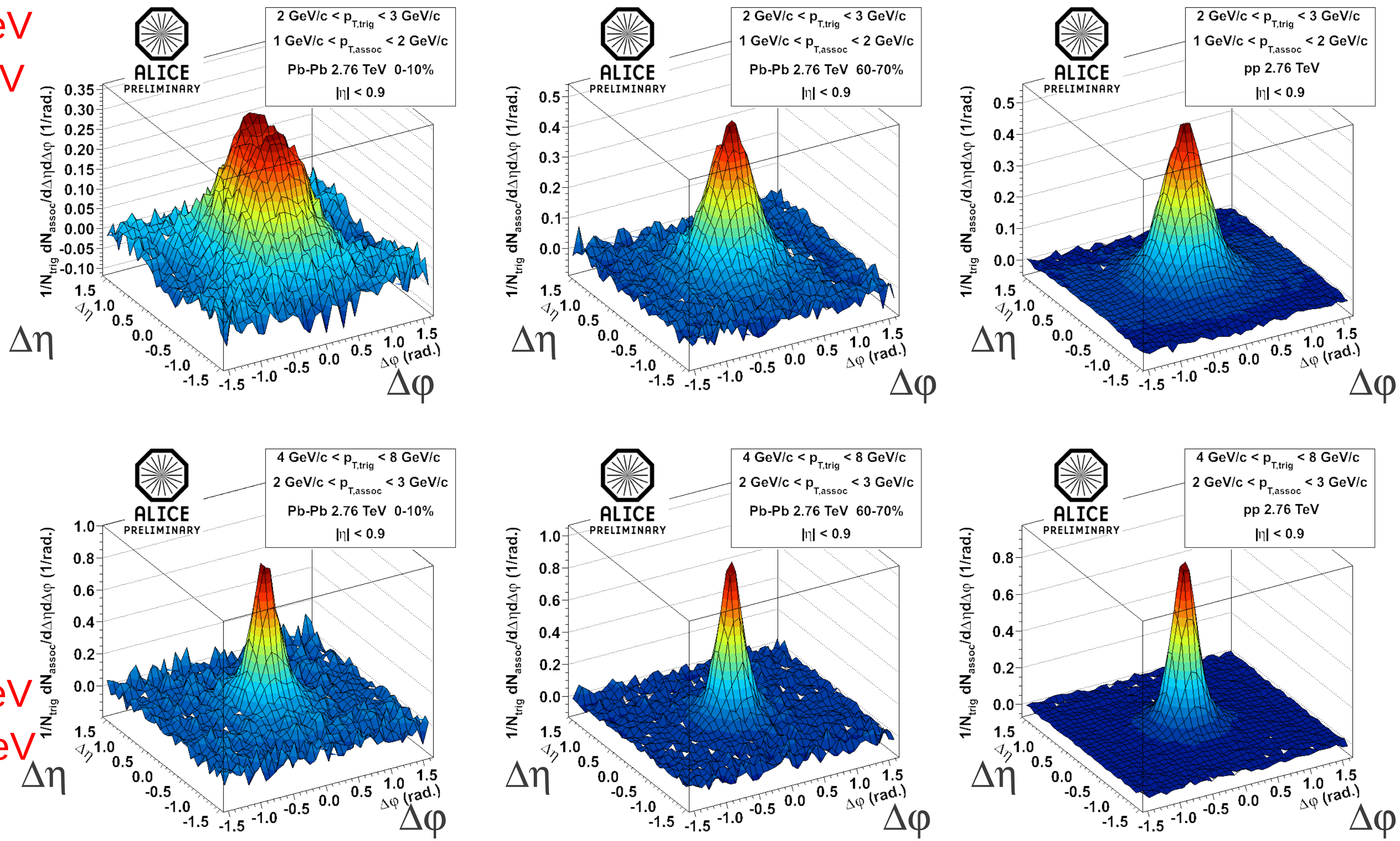
Aim: Characterize the peak

0-10% 60-70% pp

$2 < p_{T,trig} < 3$ GeV
$1 < p_{T,assoc} < 2$ GeV

p_T

$4 < p_{T,trig} < 8$ GeV
$2 < p_{T,assoc} < 3$ GeV

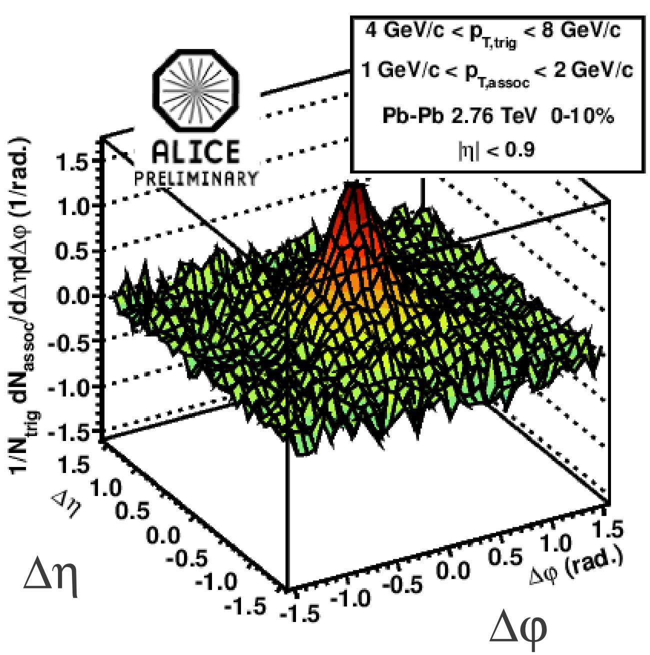


Characterization of the near-side peak

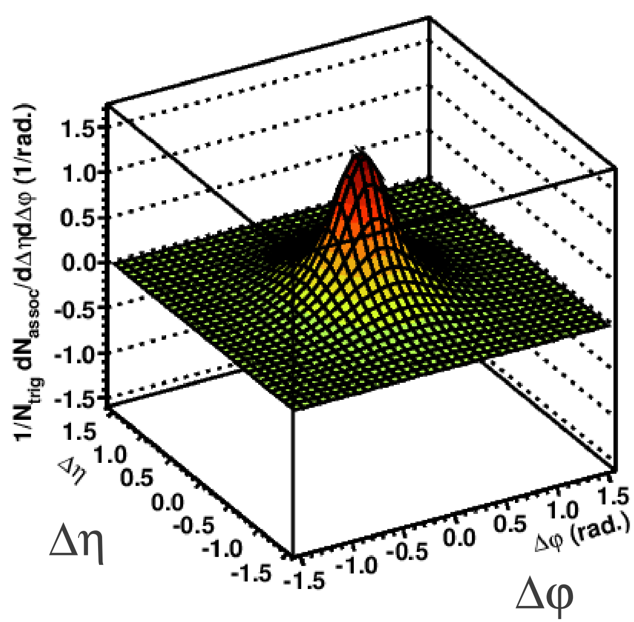
- Quantify peak shape using *rms* ($\sigma_{\Delta\varphi}$, $\sigma_{\Delta\eta}$) and Excess Kurtosis ($K_{\Delta\varphi}$, $K_{\Delta\eta}$)= $\mu_4 / \mu_2^2 - 3$ (μ_n n^{th} moment) “peakedness” (Laplace: K=3, Gaussian: 0, semi-circle: -1, uniform -1.2)
- *rms* from projections or fits
- Near-side peak fitted with 2 x 2D Gaussians

$$F_1(\Delta\varphi,\Delta\eta)=N\left[\alpha\, Gauss(0,0,\sigma^1_{\Delta\varphi},\sigma^1_{\Delta\eta};\Delta\varphi,\Delta\eta)+(1-\alpha)\, Gauss(0,0,\sigma^2_{\Delta\varphi},\sigma^2_{\Delta\eta};\Delta\varphi,\Delta\eta)\right]$$

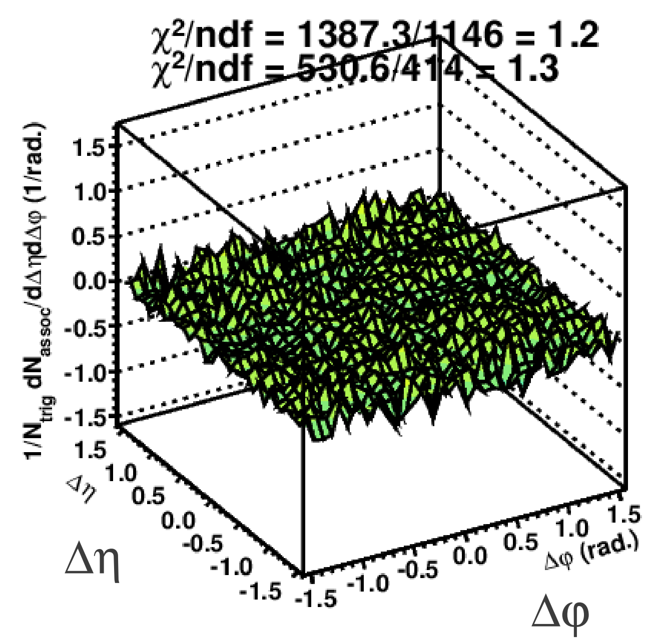
Data



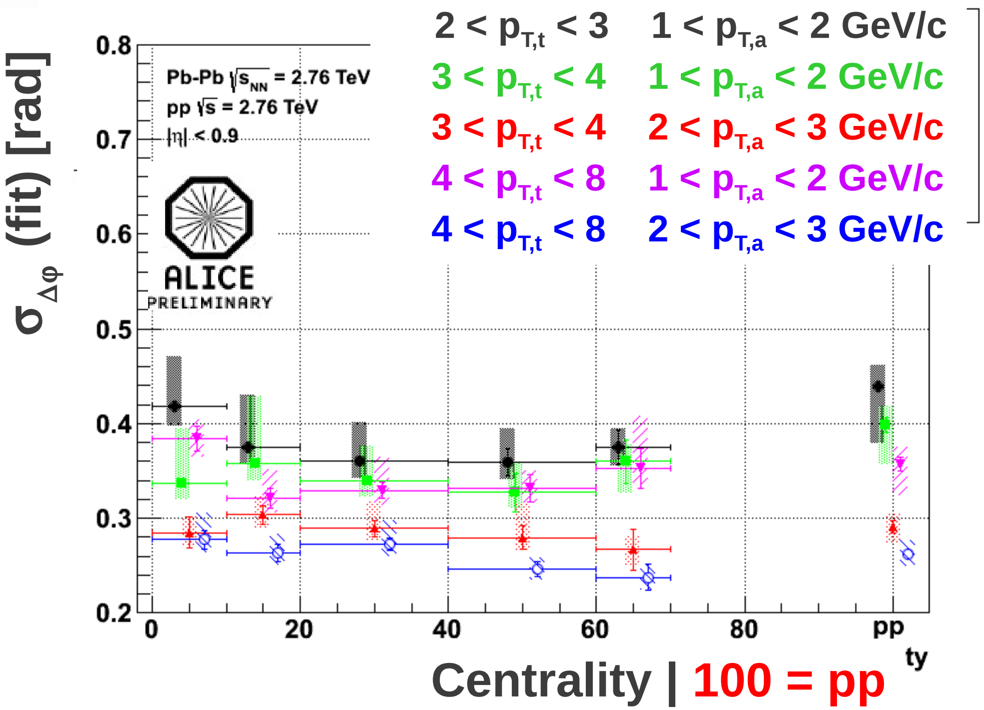
Fit

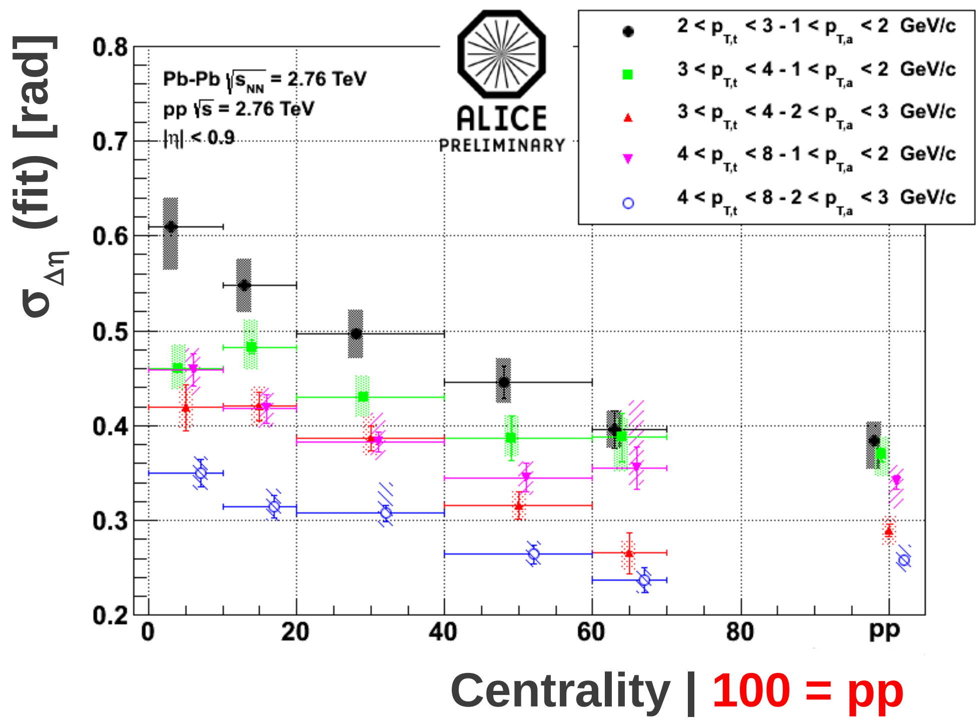


Residuals



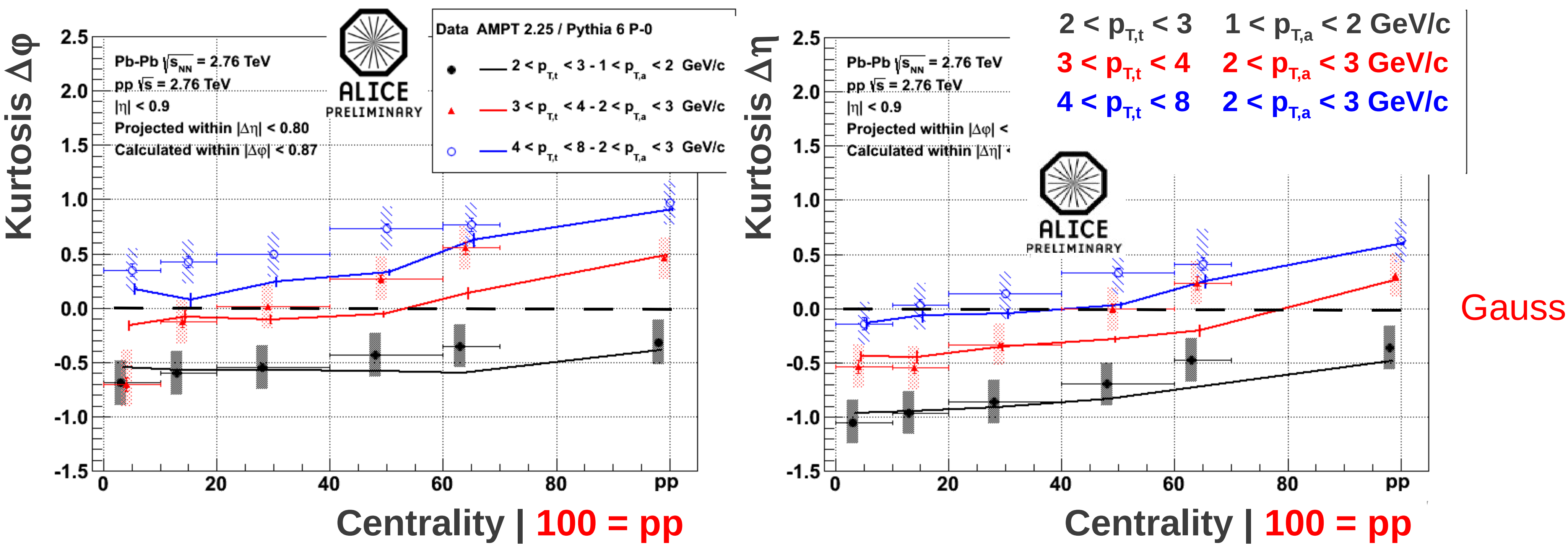
$\sigma_{\Delta\phi}, \sigma_{\Delta\eta}$ from Fit





- No centrality dependence of σ_ϕ
  - $p_{T,assoc}$ dependence governed by $j_T \sim p_{T,assoc}\,\sigma_\phi = \text{const.}$
  - Same for σ_η in peripheral collisions
- Significant increase of σ_η towards central events
  - For the lowest p_T bin, eccentricity $(\sigma_\eta - \sigma_\phi) / (\sigma_\eta + \sigma_\phi)$ increases from 0 to 0.2
- Smooth continuation from peripheral to pp

Excess Kurtosis

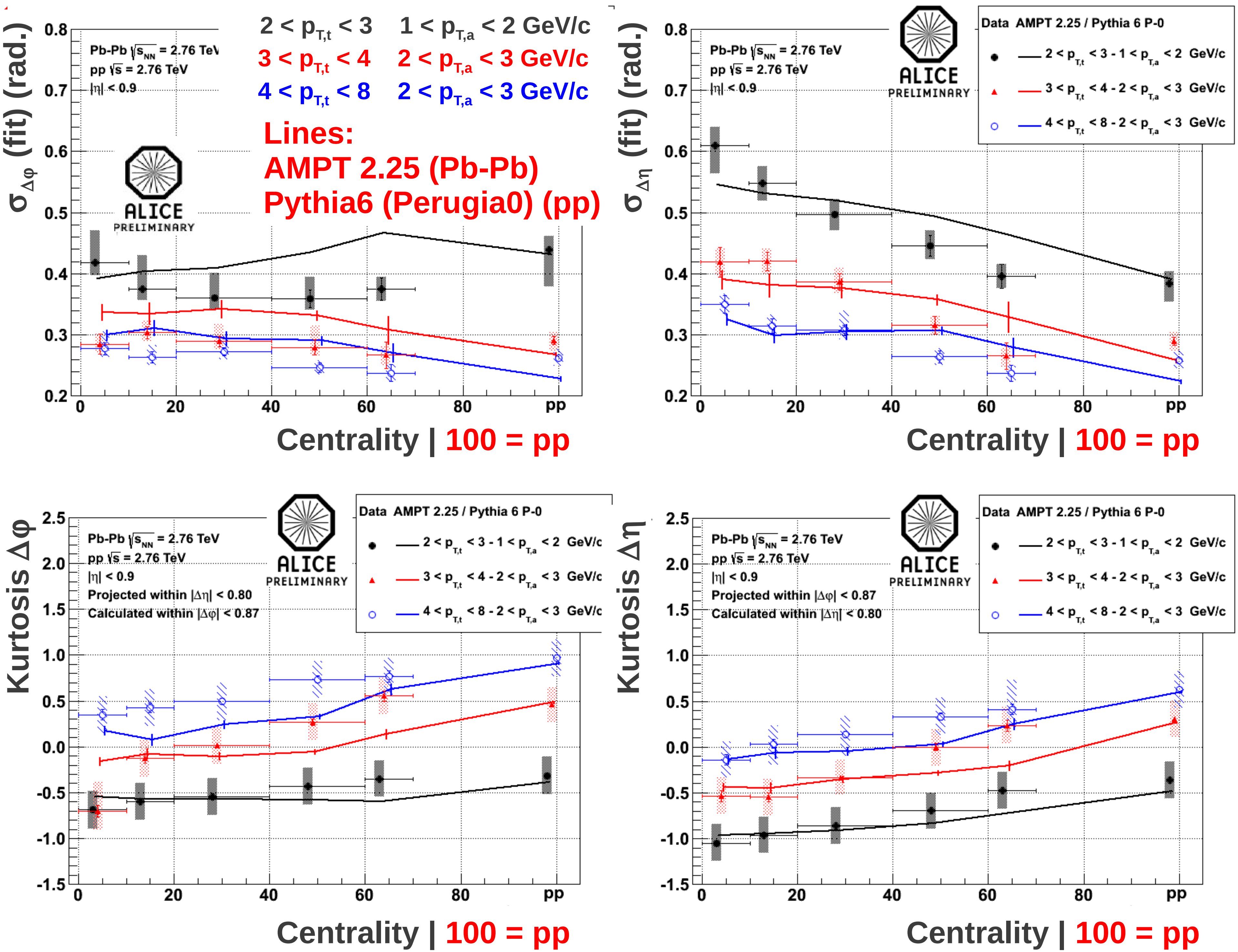


- Obtained from projections within |Δφ|, |Δη| < 0.8
- Clear p_T dependence
  - Kurtosis increases with p_T
- Centrality dependence
  - Kurtosis decreases going from pp to peripheral, to central events

Comparison with AMPT MC

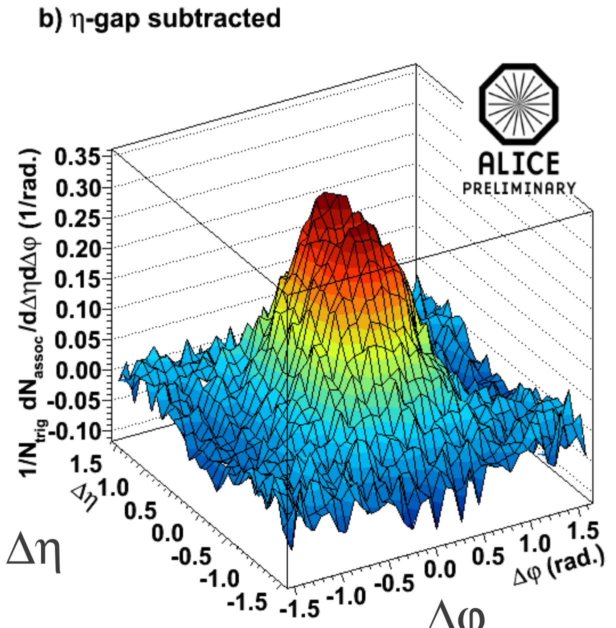
- AMPT (**A** **M**ulti**P**hase **T**ransport Code)
  - Initial conditions simulated using HIJING
  - Parton scattering
  - Hadronization: Lund model + coalescence
  - Hadron scattering
- AMPT describes the main features of the near-side shape evolution observed in data

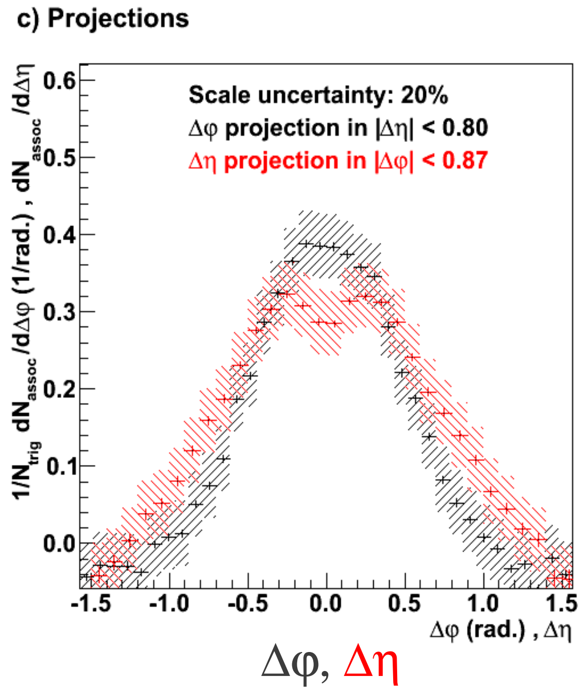
PHYSICAL REVIEW C 72, 064901 (2005)



2 < p_T,t < 3   1 < p_T,a < 2 GeV/c
3 < p_T,t < 4   2 < p_T,a < 3 GeV/c
4 < p_T,t < 8   2 < p_T,a < 3 GeV/c
Lines:
AMPT 2.25 (Pb-Pb)
Pythia6 (Perugia0) (pp)
σ_Δφ (fit) (rad.)
σ_Δη (fit) (rad.)
Kurtosis Δφ
Kurtosis Δη
Pb-Pb √s_NN = 2.76 TeV
pp √s = 2.76 TeV
|η| < 0.9
Projected within |Δη| < 0.80
Calculated within |Δφ| < 0.87
Projected within |Δφ| < 0.87
Calculated within |Δη| < 0.80
ALICE PRELIMINARY
Data AMPT 2.25 / Pythia 6 P-0
2 < p_T,t < 3 - 1 < p_T,a < 2 GeV/c
3 < p_T,t < 4 - 2 < p_T,a < 3 GeV/c
4 < p_T,t < 8 - 2 < p_T,a < 3 GeV/c
Centrality | 100 = pp

A closer look to the lowest ($p_{T,trig}$,$p_{T,assoc}$) bin

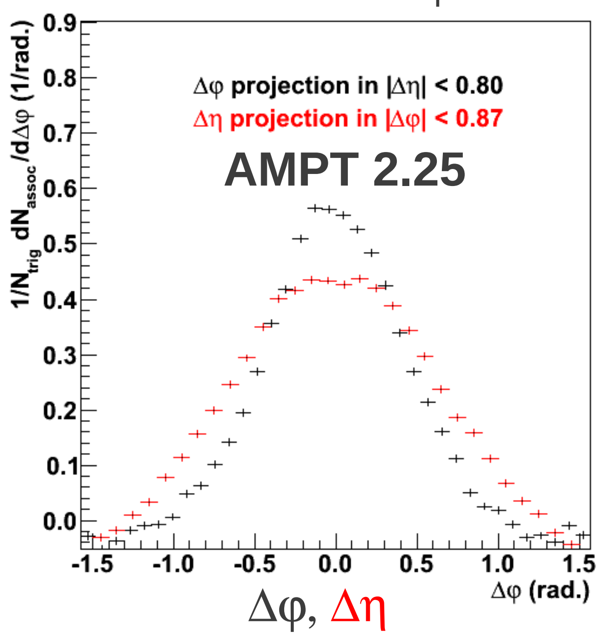




2 < $p_{T,trig}$ < 3 GeV

1 < $p_{T,assoc}$ < 2 GeV

Centrality 0-10%

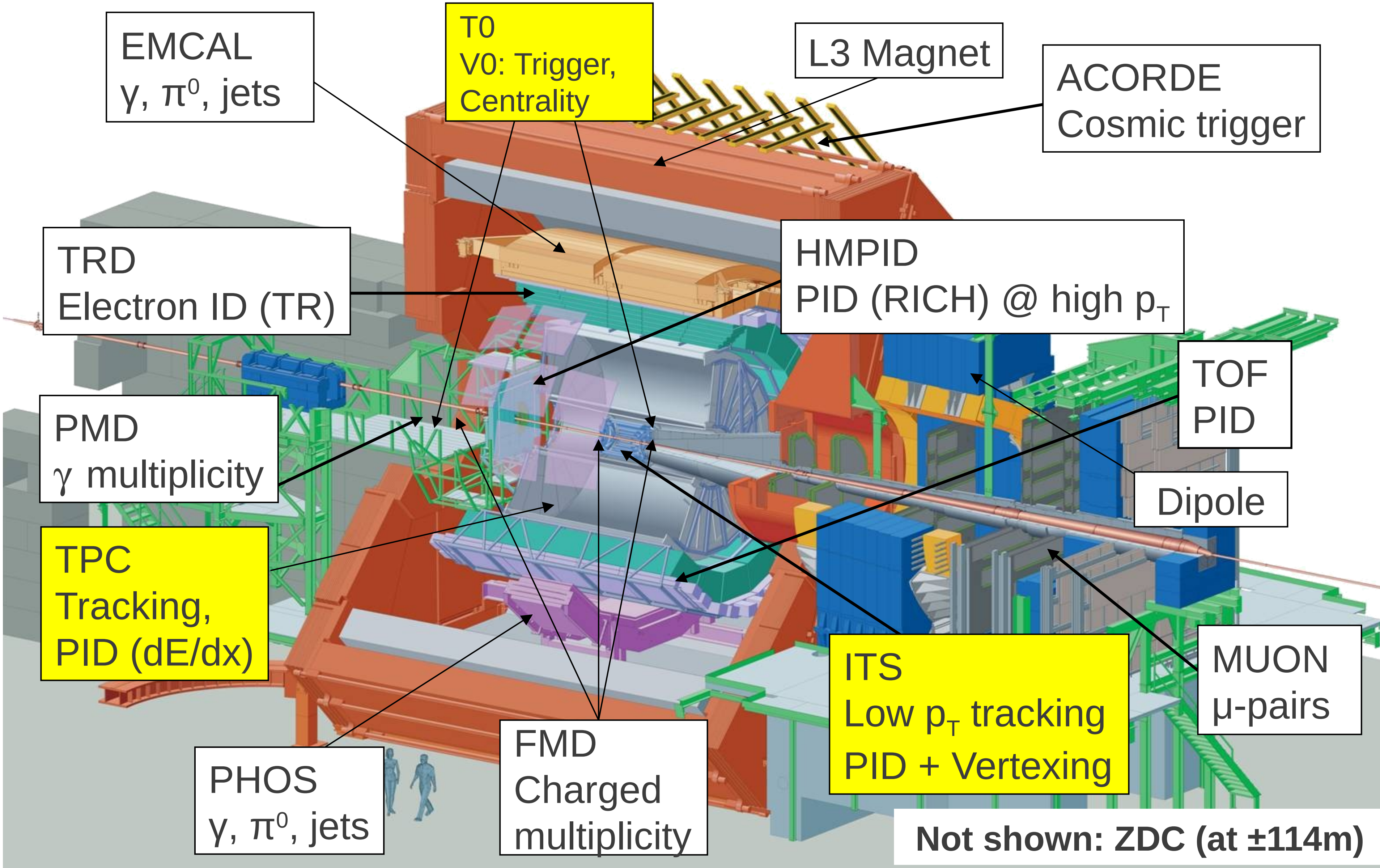


"Flattening" of the $\Delta\eta$ distribution seen in data and AMPT

Conclusions

- ALICE has studies the centrality and p_T evolution of near-side peak shapes in Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV
- The shapes have been quantified by their *rms* and Kurtosis in the $\Delta\phi$ and $\Delta\eta$ directions.
  - We observe (within errors) no centrality dependence of σ_ϕ
  - Significant increase of σ_η towards central events
    - Eccentricity reaches 0.2 for the lowest p_T bin studied
    - Interaction of jets with longitudinal flow ?
  - Kurtosis ("peakedness") monotonically decreases with increasing centrality of the collisions.

ALICE



EMCAL
γ, π0, jets
T0
V0: Trigger,
Centrality
L3 Magnet
ACORDE
Cosmic trigger
TRD
Electron ID (TR)
HMPID
PID (RICH) @ high pT
TOF
PID
PMD
γ multiplicity
Dipole
TPC
Tracking,
PID (dE/dx)
ITS
Low pT tracking
PID + Vertexing
MUON
μ-pairs
PHOS
γ, π0, jets
FMD
Charged
multiplicity
Not shown: ZDC (at ±114m)

Systematic Uncertainties

- Sources
  - η range of flow subtraction
  - Track selection
  - Vertex range
  - Influence of resonances and conversions
  - Two-track effect
  - Wing (increase at large Δη) correction
  - Two different fit procedures

treated with on average

added directly

shown as 2^{nd} result

- All sources have been evaluated
  - For the parameters: σ_η/σ_ϕ (fit), σ_η/σ_ϕ, K_η/K_ϕ
  - For the correlation functions

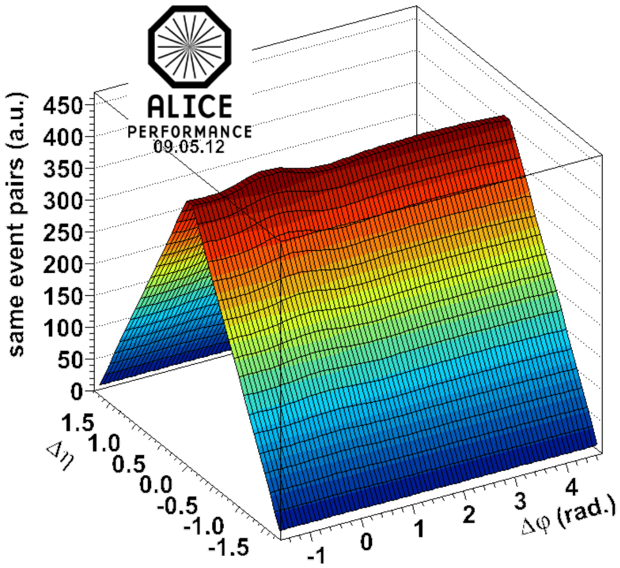
Two-Track Efficiency

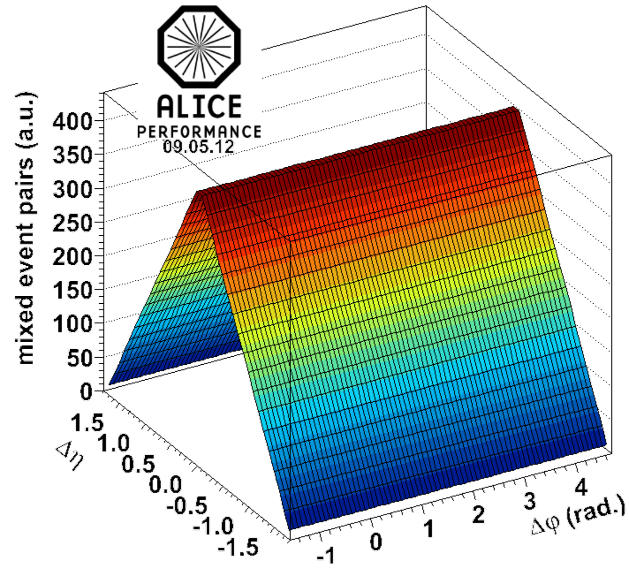
$$\Delta\phi^* = \Delta\phi + \arcsin\frac{z_1 e B_z r}{2p_{\mathrm{T},1}} - \arcsin\frac{z_2 e B_z r}{2p_{\mathrm{T},2}}$$

- z charge, e elementary charge, Bz magnetic field, r Radius in the TPC
- DCA of the track pair in the TPC corrected for magnetic field bending
- Minimum evaluated in the TPC volume (0.8 < r < 2.5m)
- Cut on $|\Delta\varphi^*_{min}| < 0.02$ && $|\Delta\eta| < 0.02$
  - Values doubled for systematic uncertainty
- Applied consistently to same and mixed event

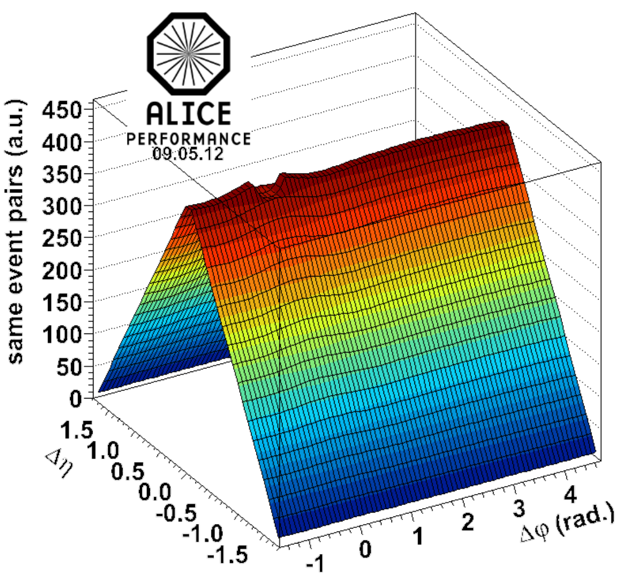
Two-Track Efficiency (2)

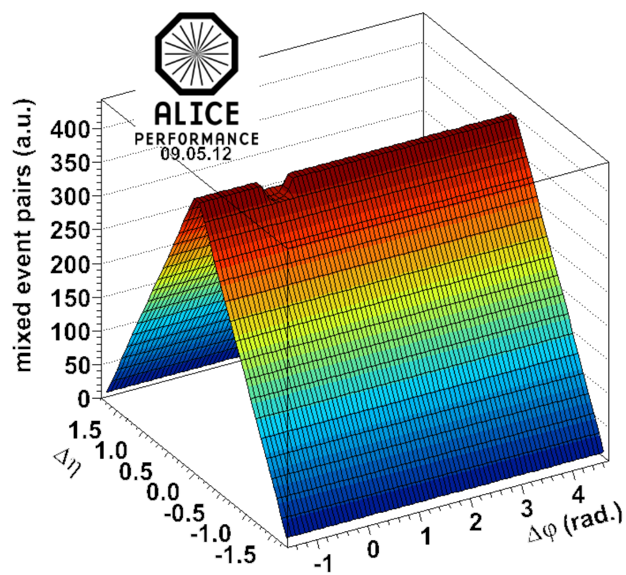
No cut

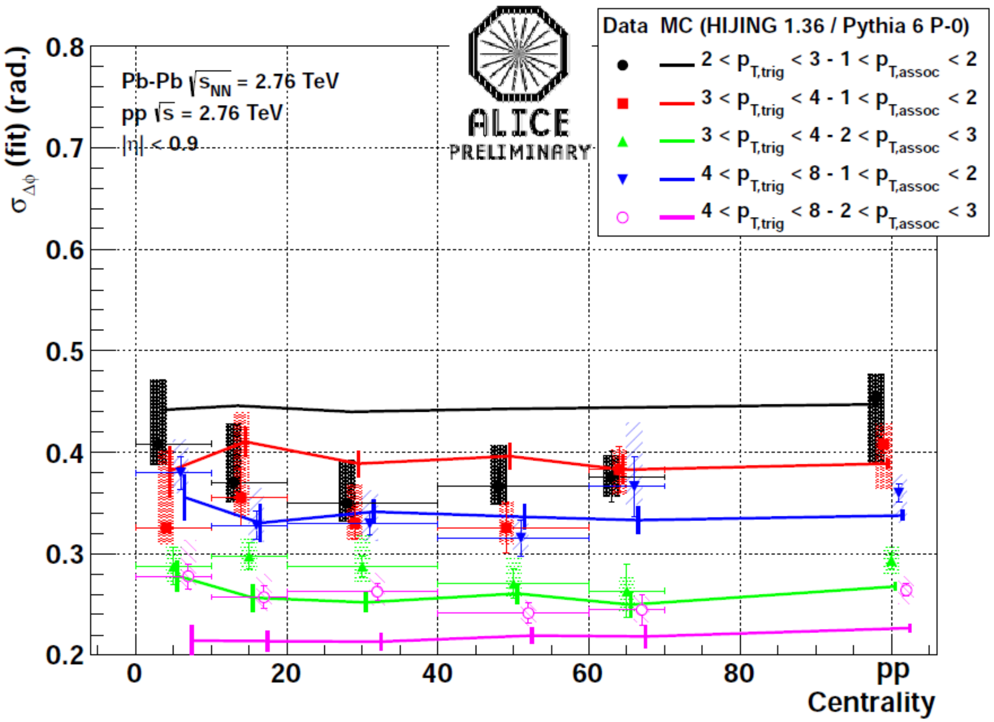




Cut







$\sigma_{\Delta\phi}$ (fit) (rad.)
Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
pp $\sqrt{s}$ = 2.76 TeV
$|\eta| < 0.9$
ALICE PRELIMINARY
Data MC (HIJING 1.36 / Pythia 6 P-0)
$2 < p_{T,trig} < 3 - 1 < p_{T,assoc} < 2$
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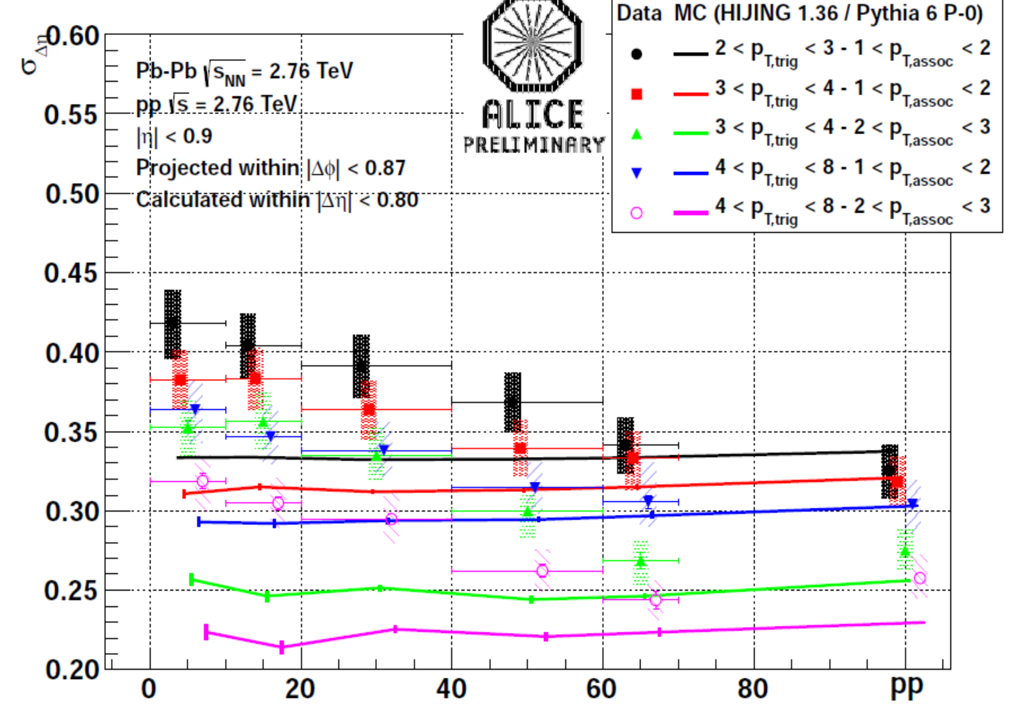
Centrality
pp



$\sigma_{\Delta\eta}$
Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
pp $\sqrt{s}$ = 2.76 TeV
$|\eta| < 0.9$
Projected within $|\Delta\phi| < 0.87$
Calculated within $|\Delta\eta| < 0.80$
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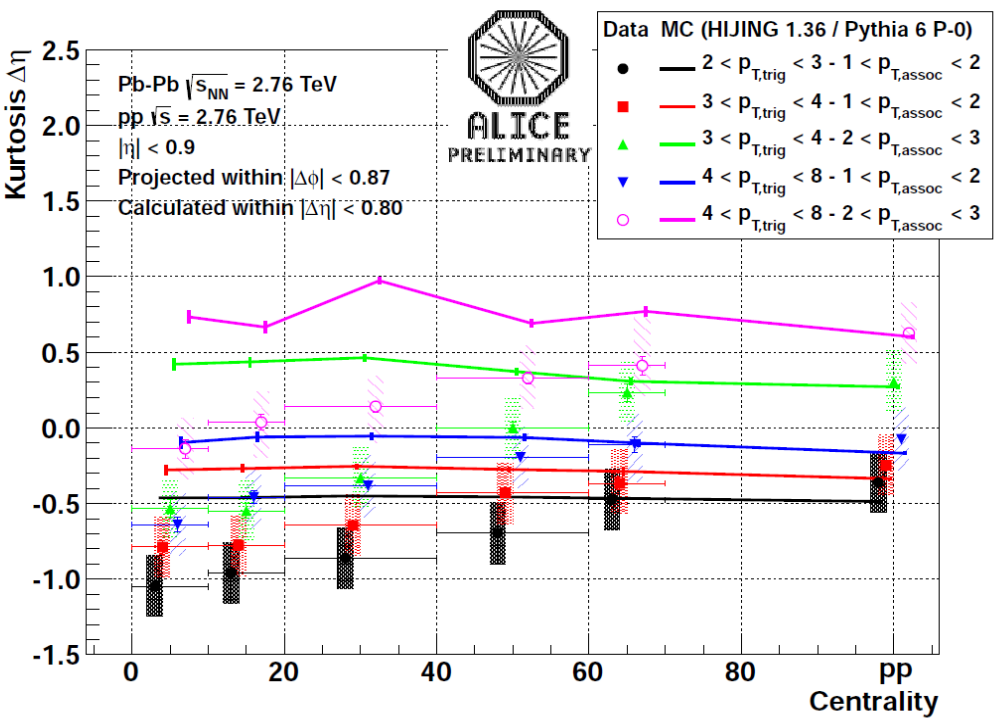
pp



Kurtosis $\Delta\eta$
Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
pp $\sqrt{s}$ = 2.76 TeV
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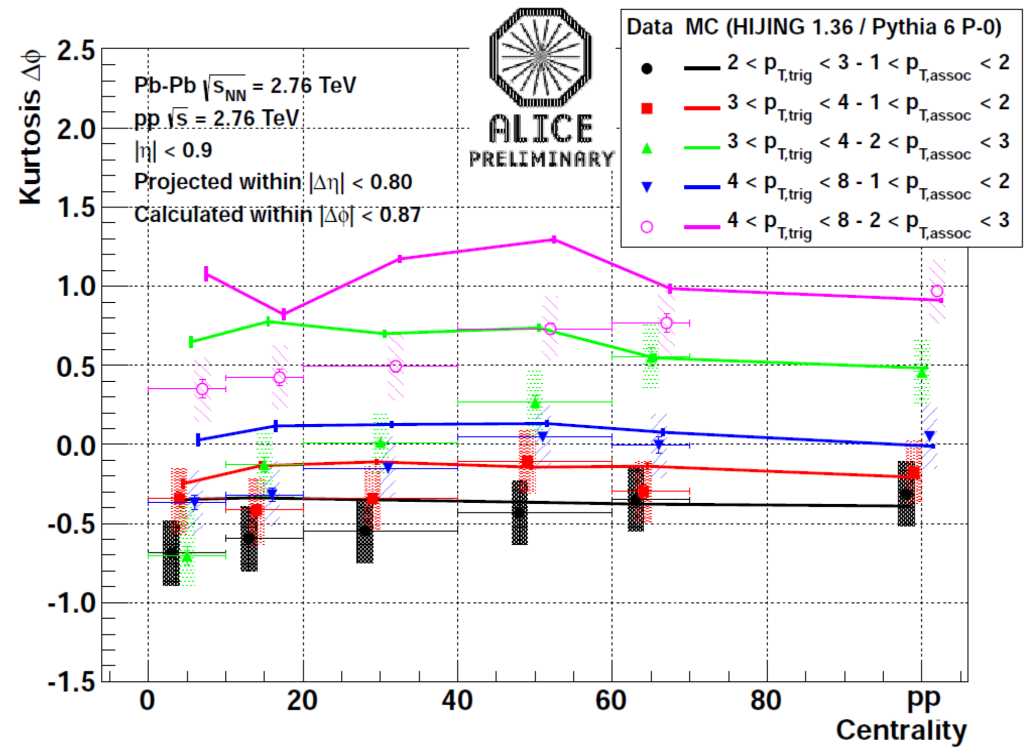
Centrality
pp



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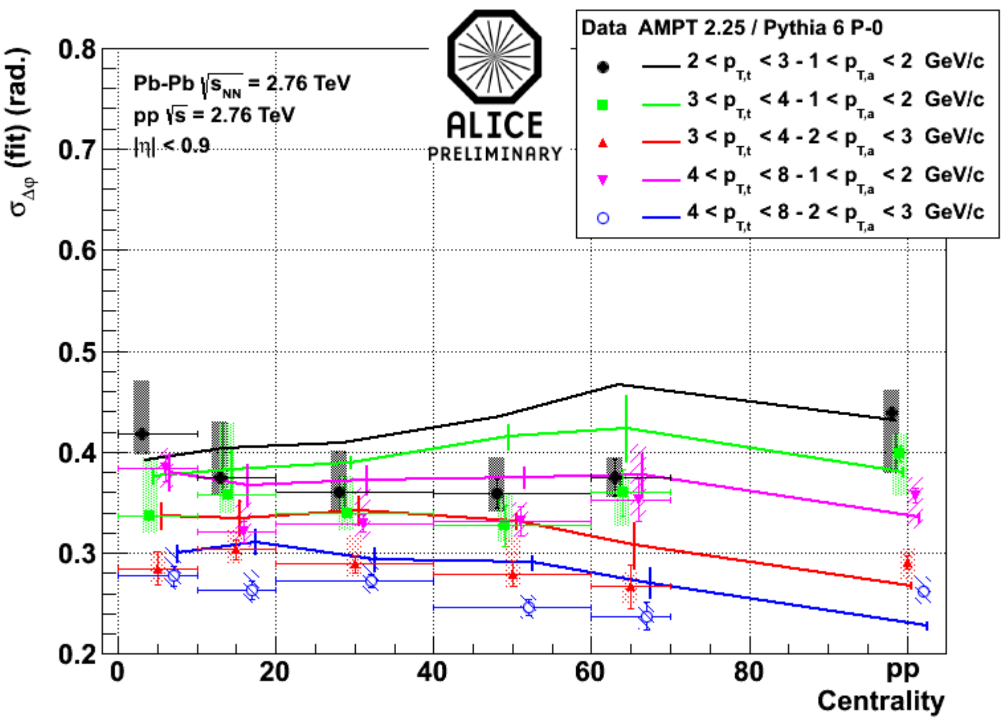
Centrality
pp



ALICE
PRELIMINARY
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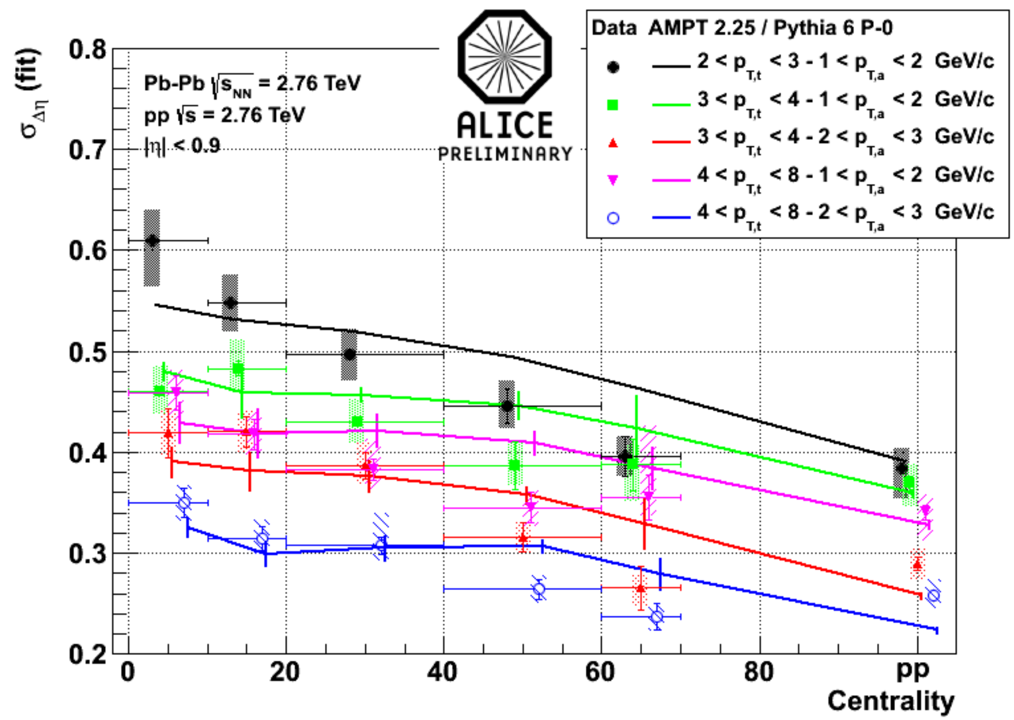
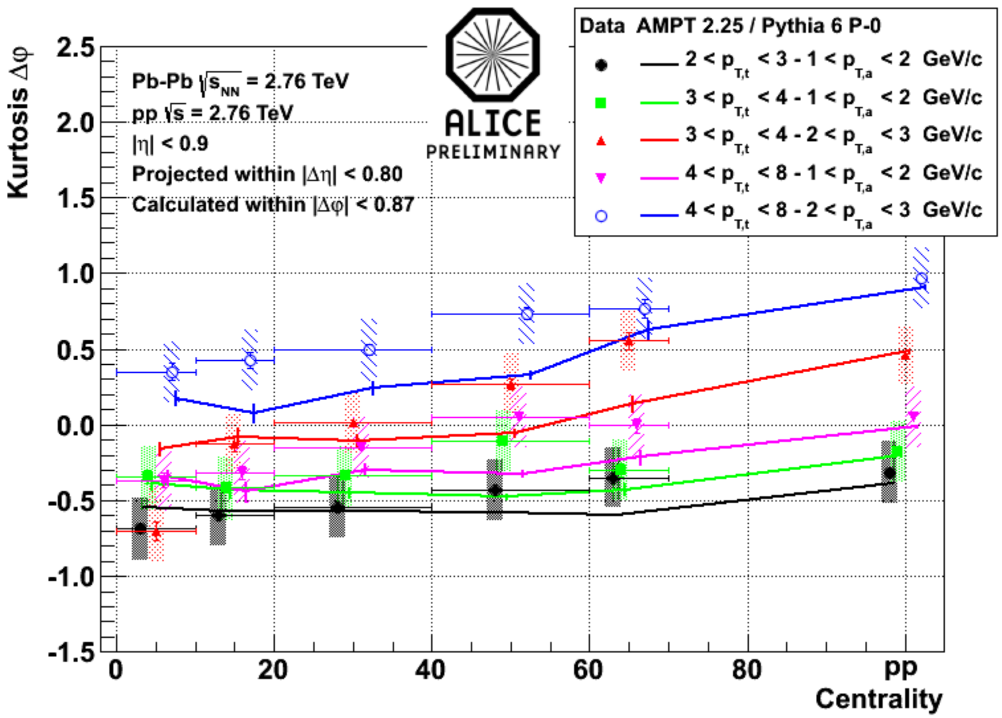
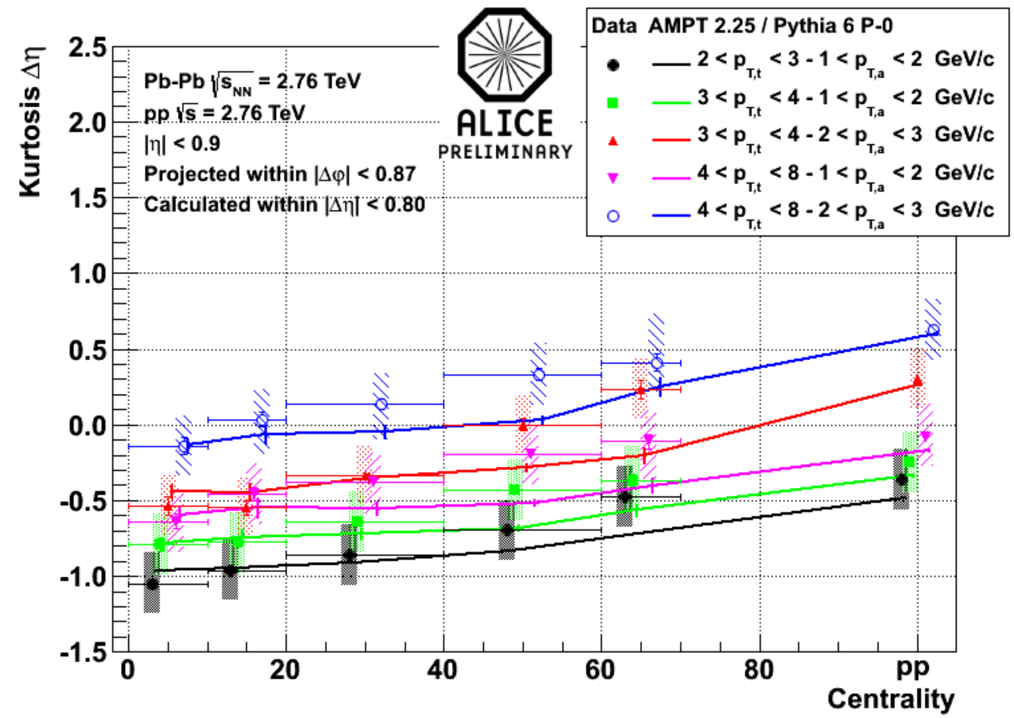
4 < p_T,t < 8 - 1 < p_T,a < 2 GeV/c
4 < p_T,t < 8 - 2 < p_T,a < 3 GeV/c
Pb-Pb √s_NN = 2.76 TeV
pp √s = 2.76 TeV
|η| < 0.9
σ_Δφ (fit) (rad.)
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
20
40
60
80
pp
Centrality



ALICE
PRELIMINARY
Data AMPT 2.25 / Pythia 6 P-0
2 < p_T,t < 3 - 1 < p_T,a < 2 GeV/c
3 < p_T,t < 4 - 1 < p_T,a < 2 GeV/c
3 < p_T,t < 4 - 2 < p_T,a < 3 GeV/c
4 < p_T,t < 8 - 1 < p_T,a < 2 GeV/c
4 < p_T,t < 8 - 2 < p_T,a < 3 GeV/c
Pb-Pb √s_NN = 2.76 TeV
pp √s = 2.76 TeV
|η| < 0.9
σ_Δη (fit)
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
20
40
60
80
pp
Centrality


Kurtosis Δφ
Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
pp $\sqrt{s}$ = 2.76 TeV
|η| < 0.9
Projected within |Δη| < 0.80
Calculated within |Δφ| < 0.87
ALICE
PRELIMINARY
Data AMPT 2.25 / Pythia 6 P-0
$2 < p_{T,t} < 3 - 1 < p_{T,a} < 2$ GeV/c
$3 < p_{T,t} < 4 - 1 < p_{T,a} < 2$ GeV/c
$3 < p_{T,t} < 4 - 2 < p_{T,a} < 3$ GeV/c
$4 < p_{T,t} < 8 - 1 < p_{T,a} < 2$ GeV/c
$4 < p_{T,t} < 8 - 2 < p_{T,a} < 3$ GeV/c
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
0
20
40
60
80
pp
Centrality


Kurtosis Δη
Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
pp $\sqrt{s}$ = 2.76 TeV
|η| < 0.9
Projected within |Δφ| < 0.87
Calculated within |Δη| < 0.80
ALICE
PRELIMINARY
Data AMPT 2.25 / Pythia 6 P-0
$2 < p_{T,t} < 3 - 1 < p_{T,a} < 2$ GeV/c
$3 < p_{T,t} < 4 - 1 < p_{T,a} < 2$ GeV/c
$3 < p_{T,t} < 4 - 2 < p_{T,a} < 3$ GeV/c
$4 < p_{T,t} < 8 - 1 < p_{T,a} < 2$ GeV/c
$4 < p_{T,t} < 8 - 2 < p_{T,a} < 3$ GeV/c
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
0
20
40
60
80
pp
Centrality