# Jet fragmentation study with particle correlations from the ALICE experiment at the LHC

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for the ALICE Collaboration

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# Introduction

Particle correlation measurements are good tools to

- Study the jet properties in pp
- **Probe jet medium interactions in Heavy Ion collisions(Di-hadron Tomography)**

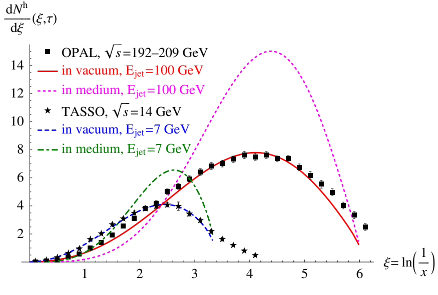


Figure : $\xi = \ln[1/z]$, N. Borghini, U.A Wiedemann arXiv:hep-ph/0506218.
Modification of the Fragmentation Function in Heavy Ion collisions

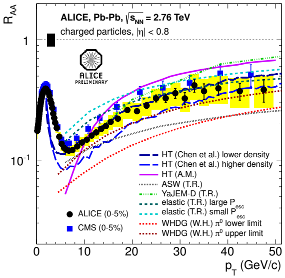


Figure : Strong single particle suppression

$$R_{AA}(p_T) = \frac{(1/N_{evt}^{AA})\, d^2N_{\mathrm{ch}}^{AA}/d\eta dp_T}{\langle N_{\mathrm{coll}}\rangle\, (1/N_{evt}^{pp})\, d^2N_{\mathrm{ch}}^{pp}/d\eta dp_T}$$

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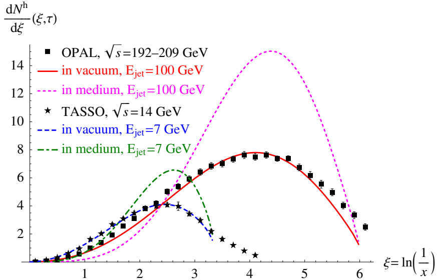


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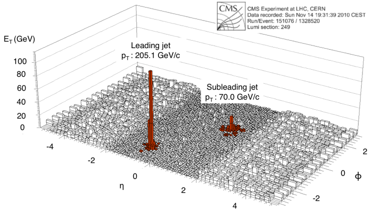


Figure : CMS, Phys. Rev. C 84, 024906 (2011)
Strong Dijet Energy Asymmetry

$$A_J = \frac{p_{T,1} - p_{T,2}}{p_{T,1} + p_{T,2}}$$

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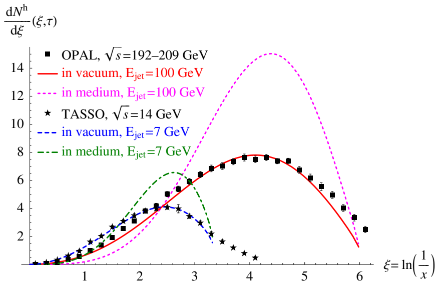


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Analysis of high-$E_T$ jets (ATLAS, CMS)

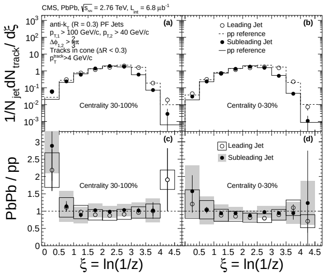


Figure : CMS(JHEP 10 (2012) 087) No indication of modification of the fragmentation function, $p_T^{track} > 4$ GeV$/c$ track cut.

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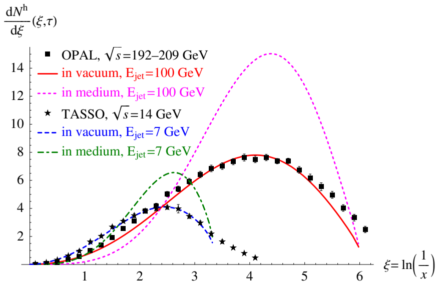


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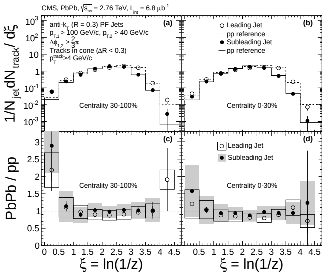


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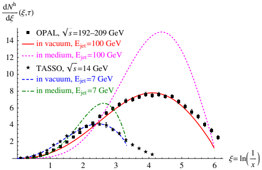


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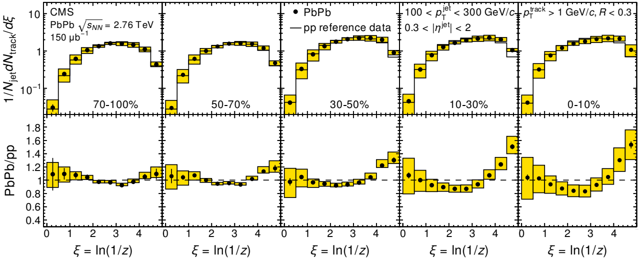


Figure : CMS(PRC 90 (2014) 024908) Indication of modification of the fragmentation function, $p_{\mathrm{T,h}} > 1$ GeV/$c$ , $p_{\mathrm{T,h}} = 1$ GeV/$c$ $\rightarrow$ $\xi \approx 4.5$ for 100 GeV jet

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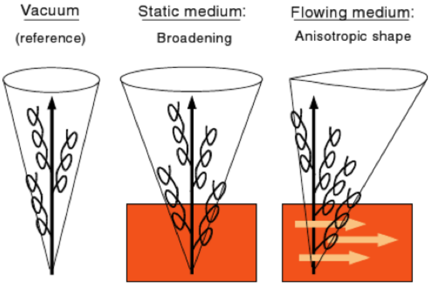


Figure : Broadening in a static medium.Longitudinal flow results in deformation of the conical jet shape

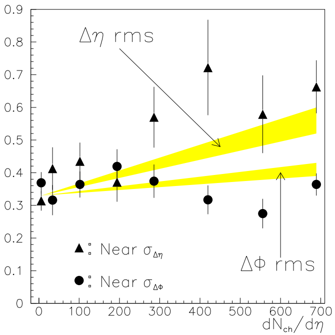


Figure : Néstor Armesto, Carlos A. Salgado and Urs Achim Wiedemann, PhysRevLett.93.242301 $(4 < p_{T,trigg} < 6 \otimes 0.15 < p_{T,assoc} < 4\ \mathrm{GeV}/c)$

# Introduction

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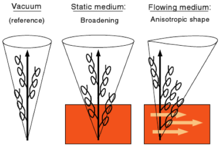
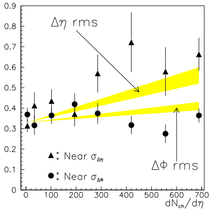
## Objectives

- Study modification of the jet shape and associated yields
  - Increase of width (radiation)
  - Increase of eccentricity (longitudinal flow)
- Study dependence on $p_{\mathrm{T}}$
  - jet quenching effects expected to be strongest a low $p_{\mathrm{T}}$
  - need to measure down to lowest possible $p_{\mathrm{T}}$
  - ALICE is capable of measuring low $p_{\mathrm{T}}$ particles and their PID

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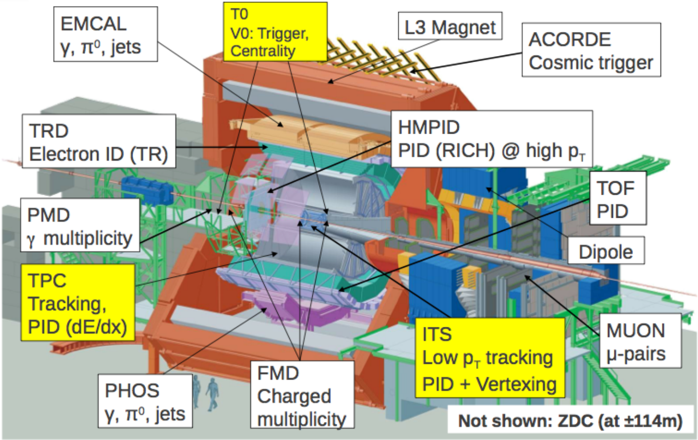
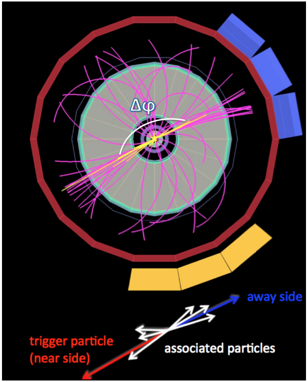
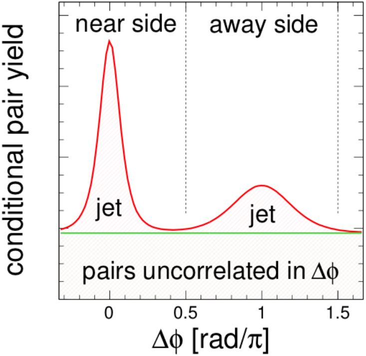
# ALICE Detectors




- Centrality determination by V0( $N_{ch}$ with scintillators in $2.8 < \eta < 5.1$ and $-3.7 < \eta < -1.7$)
- Tracking - TPC tracks constrained to the primary vertex and full azimuthal acceptance ( $|\eta| < 0.9$)

# Jet Properties from two particle correlation function




$$\frac{1}{N_{trigg}} \frac{d^2 N_{assoc}}{d\Delta\phi d\Delta\eta} \tag{1}$$

- $\Delta\phi = \phi_{trigg} - \phi_{assoc}$ ( $\Delta\eta = \eta_{trigg} - \eta_{assoc}$) in a given $p_{T,trigg}$ and $p_{T,assoc}$ bins
- Normalized by the number of trigger particles in a given $p_{T,trigg}$ bin
- Near-side($\Delta\phi, \Delta\eta = 0$) and Away side($\Delta\phi = \pi$) peaks are reminiscent of back-to-back parton production (Jets)

# Analysis Details

- Event sample
  - 15M Pb-Pb events at $\sqrt{s}$= 2.76 TeV in 2010 LHC run
  - 55M pp events at $\sqrt{s}$= 2.76 TeV in 2010 LHC run
- Track selection benefits from uniform $\phi$ acceptance of TPC
  - $|\Delta\eta| < 0.9$
- Event mixing corrects for two-track acceptance in bins of centrality and vertex position
- Per-trigger yields corrected for tracking efficiency and contamination

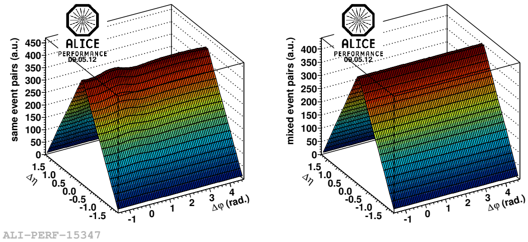
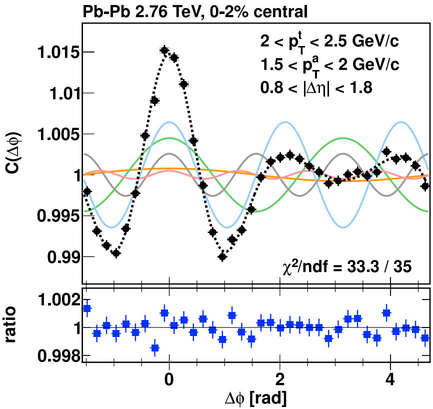



Figure : Left: Same Events, Right: Mixed Events

# Backgrounds in Correlation function in Heavy Ion collisions

- At low $p_{\mathrm{T}}$, correlations are dominated by collective effects (v2, v3, ...)
- This background at low $p_{\mathrm{T}}$ is well constrained by large $\eta$ gap correlation method (Phys.Lett. B708 (2012) 249-264)




(a) Correlation function $|\Delta\eta| > 0.8$

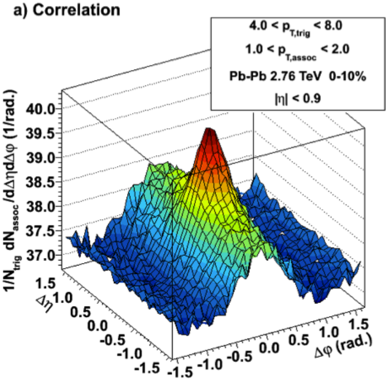
$$\frac{dN}{d\phi} \propto 1 + \Sigma 2 v_n cos\ n(\phi - \psi_n), single \qquad (2)$$

$$\frac{dN}{d\Delta\phi} \propto 1 + \Sigma 2 v_n^{trig} v_n^{assoc} cos(n\Delta\phi), pairs \qquad (3)$$

- Consistent results with event plane method(ALICE,arXiv:1205.5761)

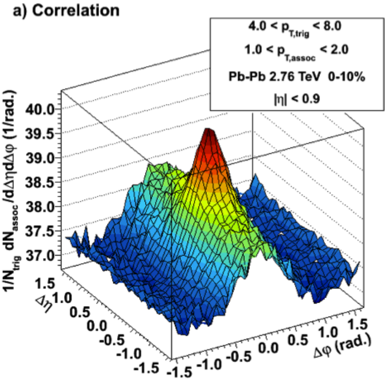
# Near-Side Peak Shapes

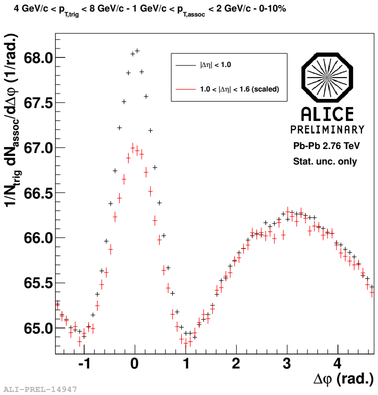
- Can we see modification of the near-side peak ?



# Near-Side Peak Shapes

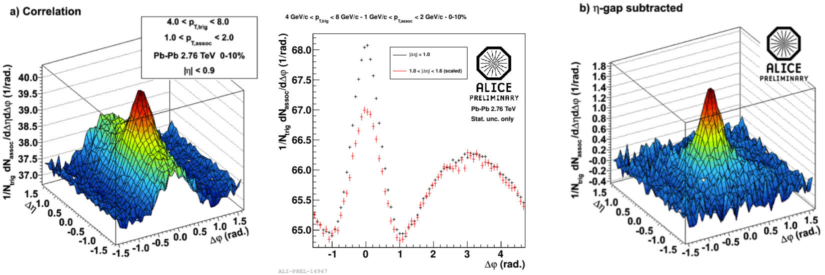
- Can we see modification of the near-side peak ?
- Estimate $\Delta\eta$-independent effects (e.g. flow) by studying the long-range correlation region ($|\Delta\eta| > 1$)



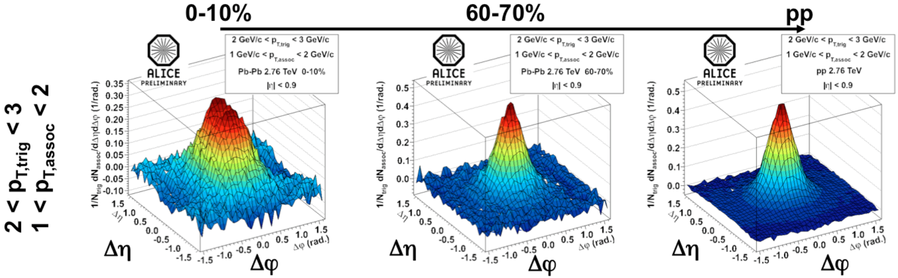



# Near-Side Peak Shapes

- Can we see modification of the near-side peak ?
- Estimate $\Delta\eta$-independent effects (e.g. flow) by studying the long-range correlation region ($|\Delta\eta| > 1$)
- Remove from short-range region ($|\Delta\eta| < 1$)



# Shape Evolution



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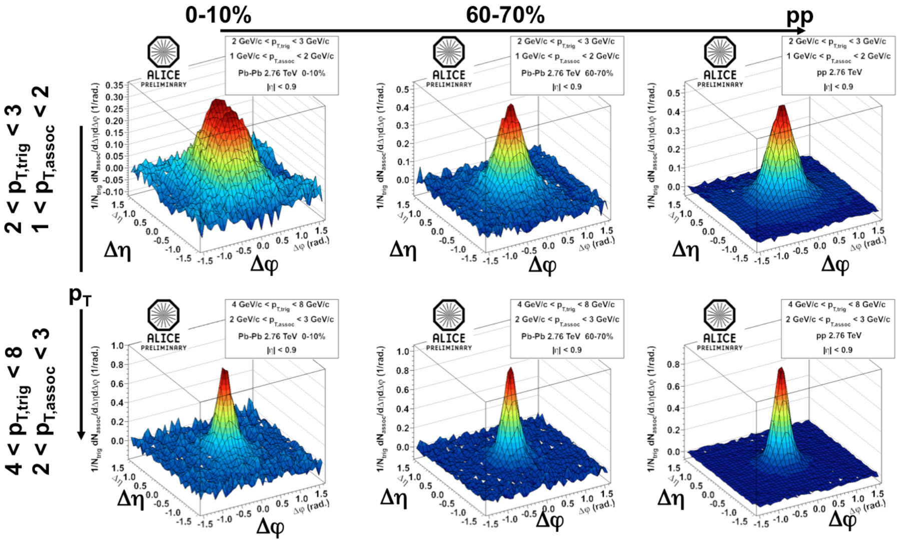


# Jet Shape Characterization

- Near-side peak fitted with 2×2D Gaussians
- 2 shape parameters: $\sigma_{\Delta\eta}, \sigma_{\Delta\phi}$

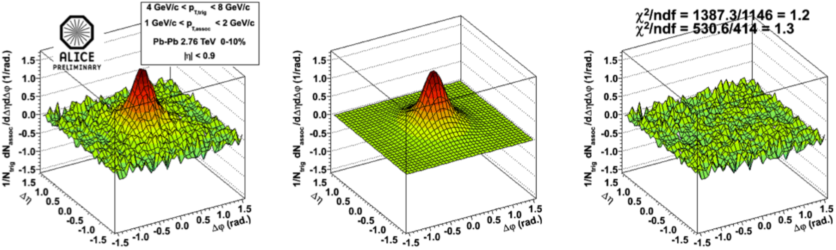
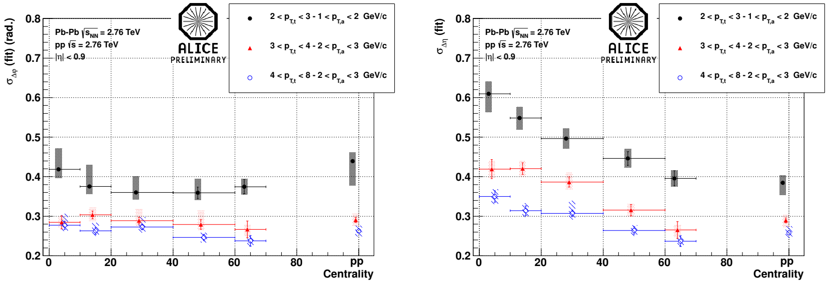



Figure : Left:Data Middle:Fit Right:Residual

# Near Side Peak, $\sigma(fit)$




(a) $\sigma_{\Delta\phi}$ (b) $\sigma_{\Delta\eta}$

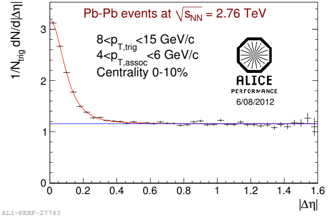
Figure : Near side peak width

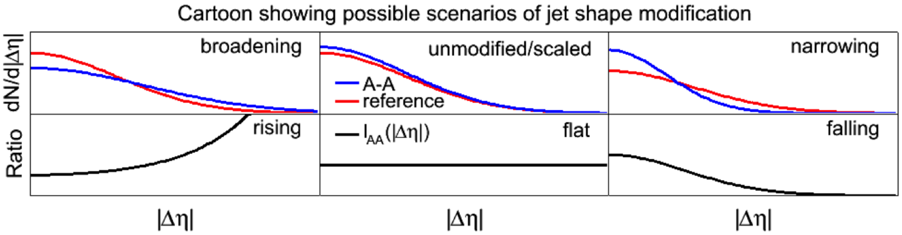
- No significant centrality dependence of $\sigma_{\Delta\phi}$
  - Dependence on $p_{T,assoc}$ governed by $j_T \approx p_{T,assoc} \times \sigma_{\Delta\phi}$
- Significant increase of $\sigma_{\Delta\eta}$ towards central events
  - For the lowest $p_{\mathrm{T}}$ bin, eccentricity ( $(\sigma_{\Delta\eta} - \sigma_{\Delta\phi})/\ (\sigma_{\Delta\eta} + \sigma_{\Delta\phi})$) increases from 0 to 0.2
- Smooth continuation from peripheral to pp

# $I_{AA}(|\Delta\eta|)$ and jet shape modification

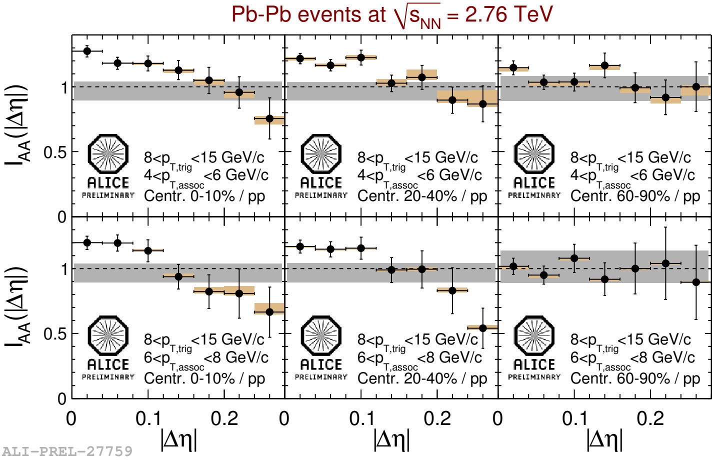
- Analyze $dN/d|\Delta\eta|$ (positive and corresp. negative bins are combined)
- Background estimated by a fit (Kaplan plus constant( parameters A,b,n,k)
  $f(\Delta\eta) = A(1 + b\Delta\eta^2)^{-n} + k$

$$I_{\mathrm{AA}}\left(|\Delta\eta|\right) = \frac{1/N_{\mathrm{trig}}^{\mathrm{Pb\text{-}Pb}} \times dN^{\mathrm{Pb\text{-}Pb}}/d|\Delta\eta|\Big|_{p_{\mathrm{T,trig}};\, p_{\mathrm{T,assoc}}}}{1/N_{\mathrm{trig}}^{\mathrm{pp}} \times dN^{\mathrm{pp}}/d|\Delta\eta|\Big|_{p_{\mathrm{T,trig}};\, p_{\mathrm{T,assoc}}}}$$



# $I_{AA}(|\Delta\eta|)$ at high $p_{\mathrm{T}}$ ($8 < p_{\mathrm{T,trig}} < 15$ GeV/$c$)

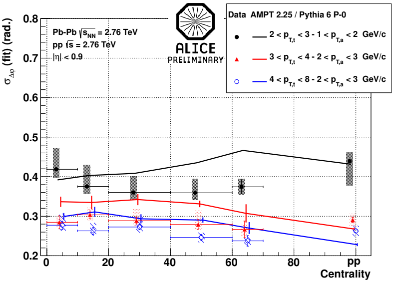



- $I_{AA}$ shows a possible onset of jet shape modification in $\Delta\eta$ (Narrowing).

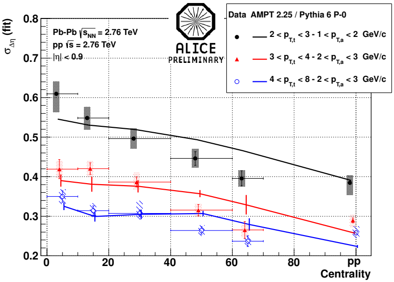
# Summary

1. Low momentum regions, the centrality and $p_T$ evolution of near-side peak shapes
   - fitted with $2\times$2D Gaussians
     - No significant centrality dependence of $\sigma_{\Delta\phi}$
     - Significant increase of $\sigma_{\Delta\eta}$ towards central events. (Broadening)
2. $I_{AA}(|\Delta\eta|)$ at high $p_{\mathrm{T}}$ ($8 < p_{\mathrm{T,trig}} < 15$ GeV/$c$)
   - a possible onset of jet shape modification in $\Delta\eta$ (Narrowing)
3. Perspectives
   - These observations are intriguing and a combination of these studies seems promising
     - PID-dependent shape,
     - going down to lower $p_{\mathrm{Ta}}$ with higher momentum trigger particles
     - Away side correlation is under construction.
     - Comparisons with various quenching models

# Backup Slides




(a) $\sigma_{\Delta\phi}$

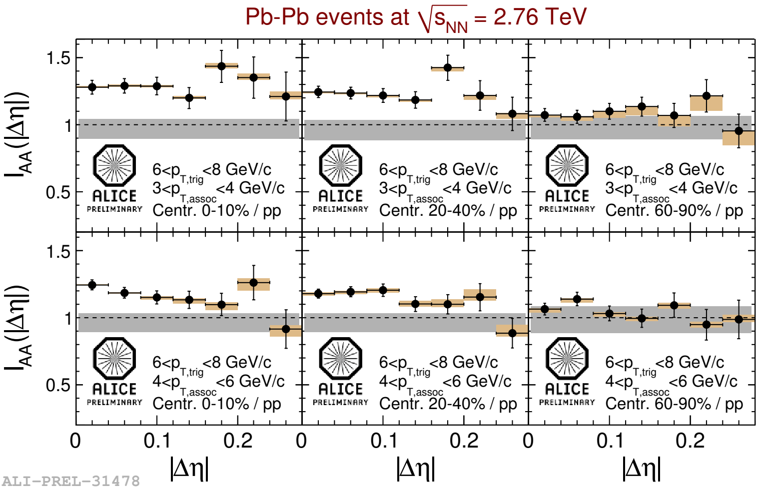



(b) $\sigma_{\Delta\eta}$

Figure : Comparison to AMPT model

- AMPT (A MultiPhase Transport Code, Jun Xu, Che Ming Ko,PhysRevC.83.034904)
  - Initial conditions simulated using HIJING
  - Parton scattering, Hadronization : String melting + Coalescence and Hadron scattering
- Lines are from AMPT 2.25 (Pb-Pb) and Pythia6 (Perugia0) (pp)
- AMPT describes the main features of the near-side shape evolution observed in data

# $I_{AA}(|\Delta\eta|)$ at intermediate $p_T$ ($6 < p_{TT,trigg} < 8$ GeV/$c$)




(a)