Study of Jet-like Particle-yield modification at 2.76 TeV in Pb-Pb collisions with ALICE

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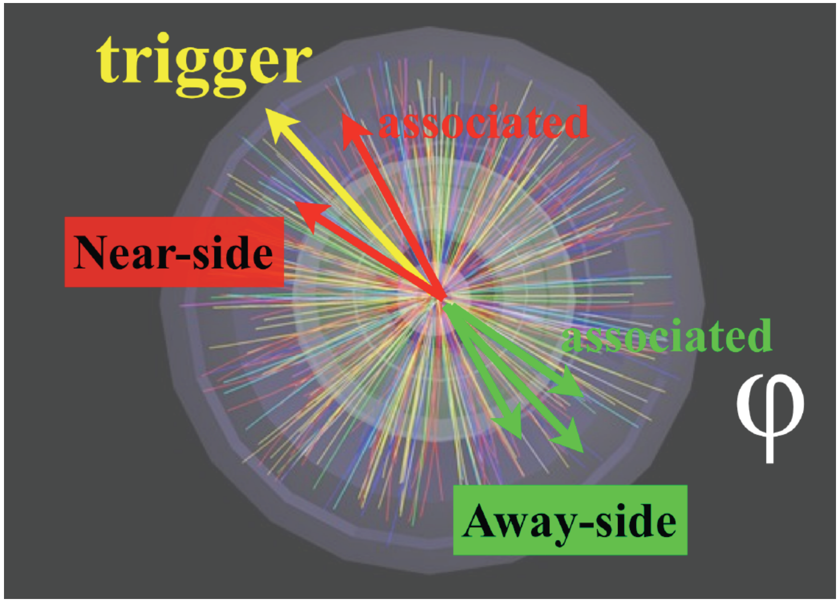
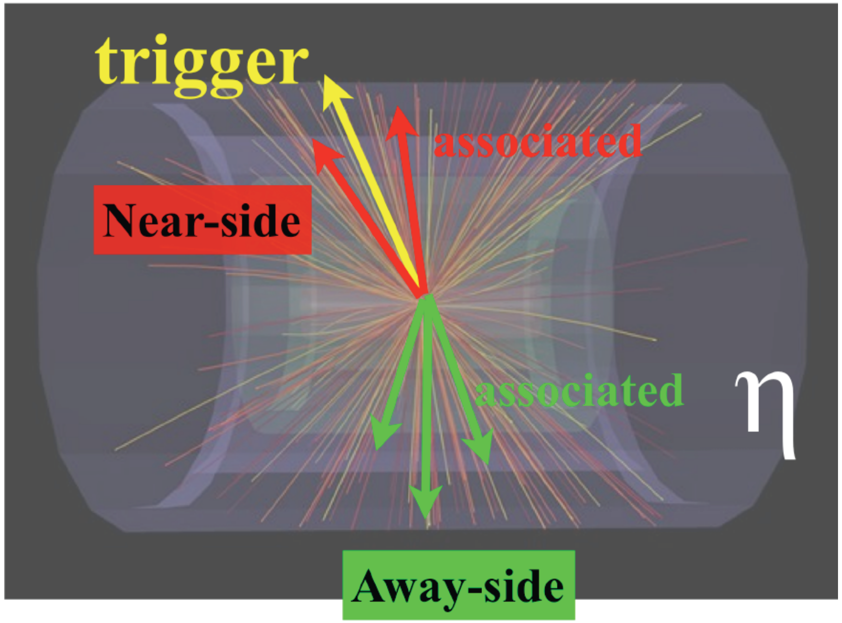
Overview

- Introduction
  - Correlation, Jets, Flow and I_{AA}
  - Recent results in two-particle correlation analysis
- Analysis Strategy
  - ALICE detectors
  - Work-flow of two particle correlation analysis
  - Precise background subtractions from $dN/d\Delta\varphi$
- Results
  - Peak shape of jet-like particles
  - Modification of yields of associated hadrons in jets
  - Model study
- Summary and Plan

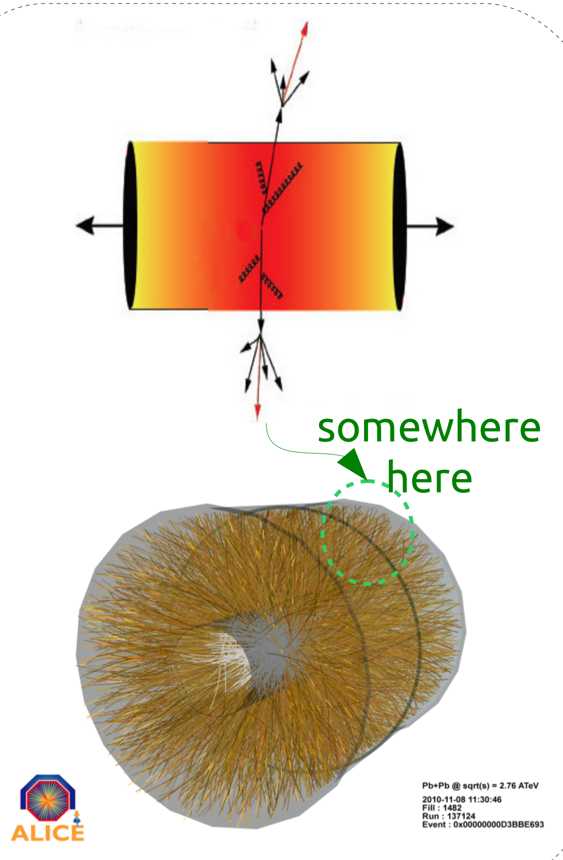
Two-particle Correlations

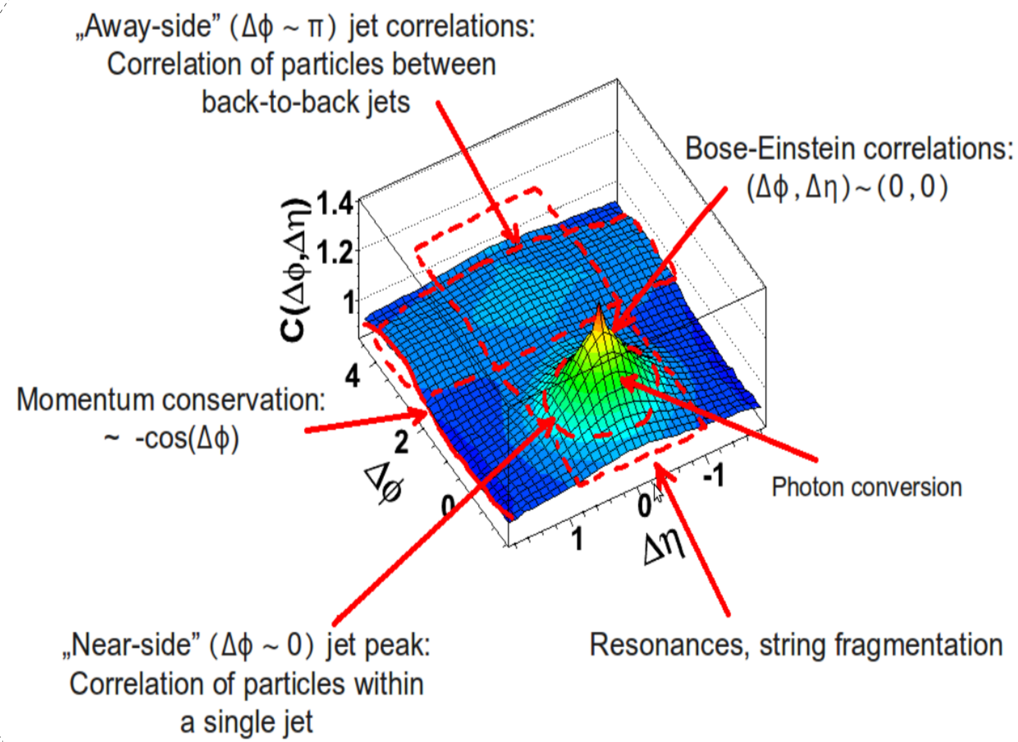




- Study the underlying mechanism and dynamics of particle production
  - Hard component : jets, in-medium modification
  - Soft component : collectivity, flow, initial state effects

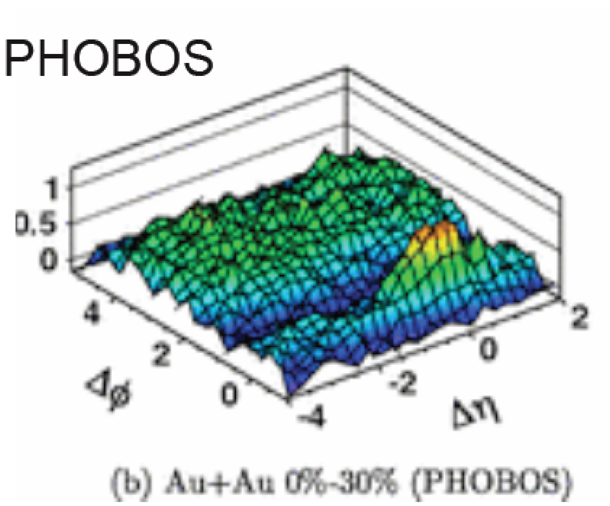
Jets and Correlation Analysis

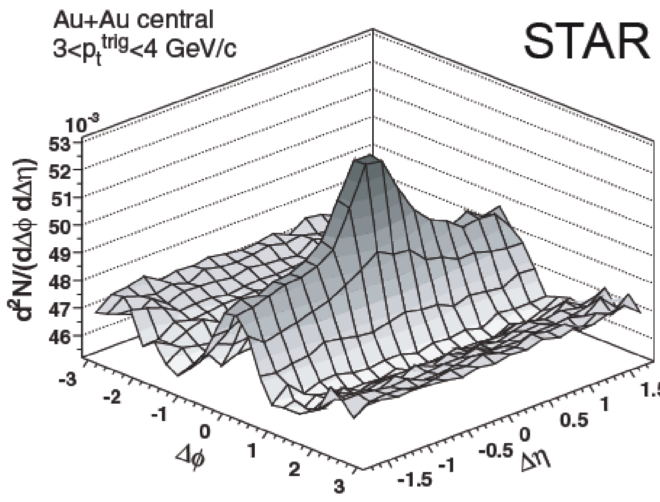


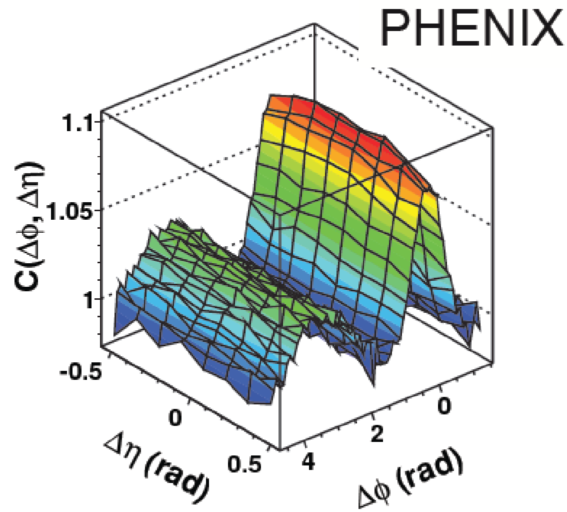


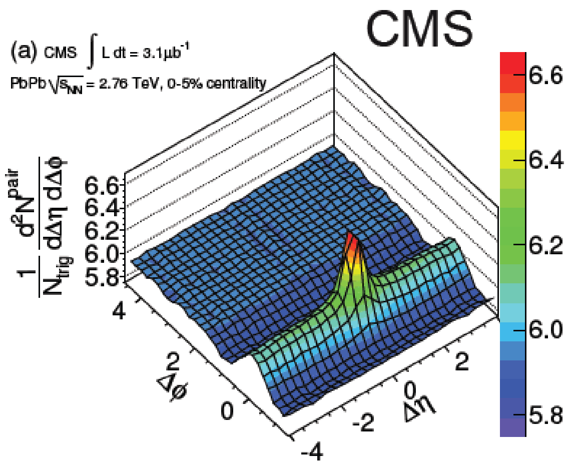
- Jets induced from hard scattering could be observed but they are hidden
- Two-particle azimuthal correlations is the powerful tool to explore QGP
  - sensitive to parton fragmentation, energy loss in the QGP
  - give a chance to study jets without full reconstruction of jets

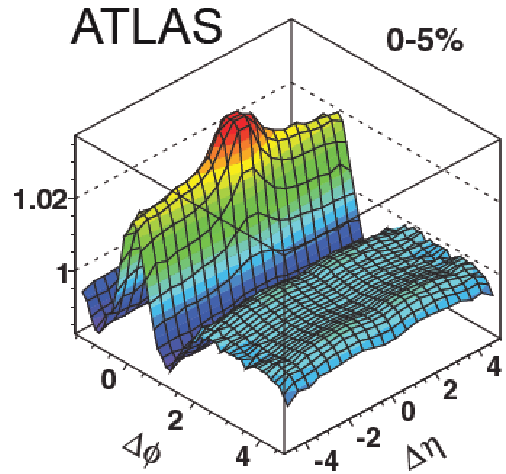
Two-particle correlations in Experiments

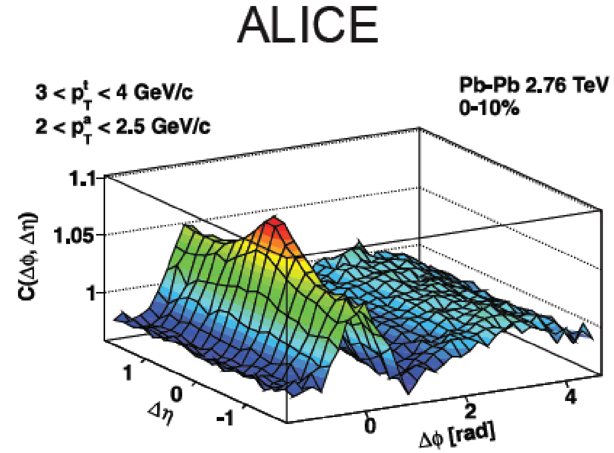




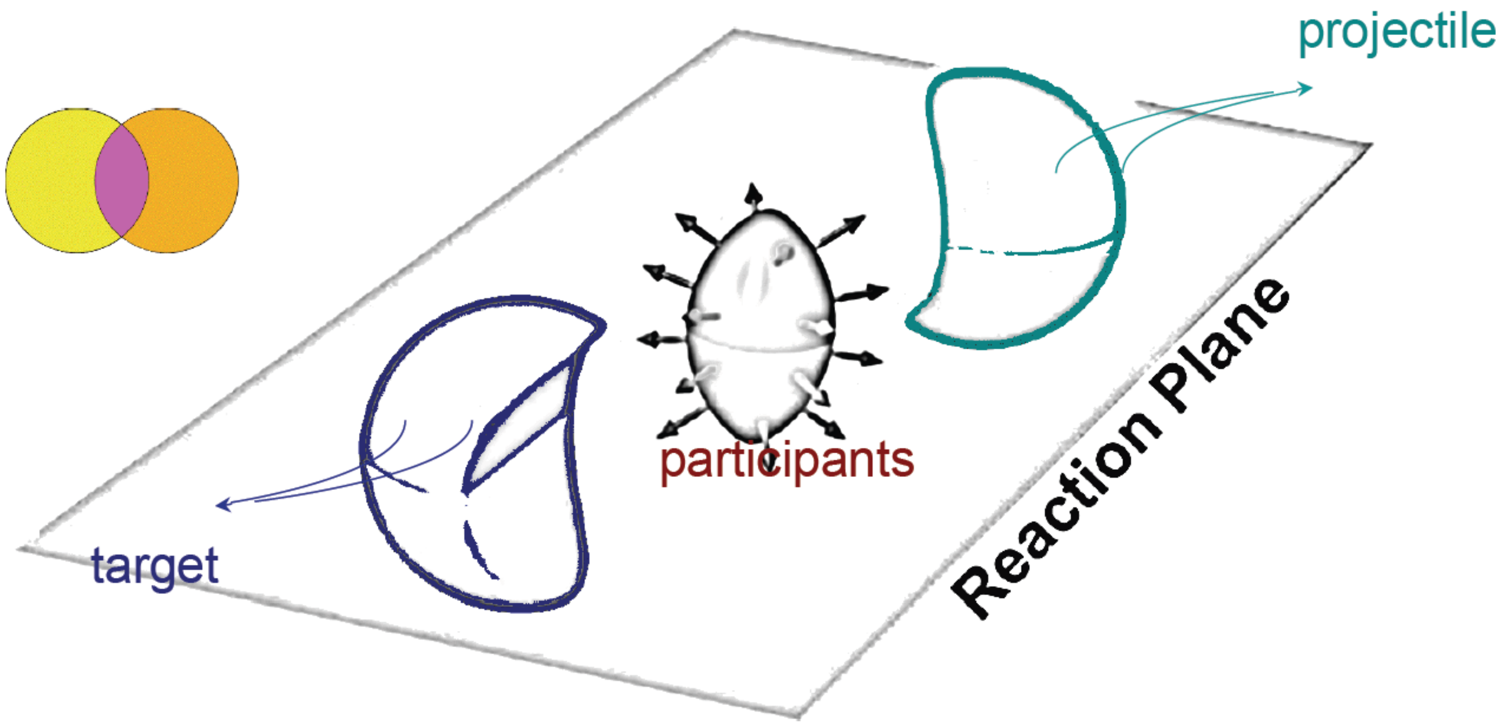






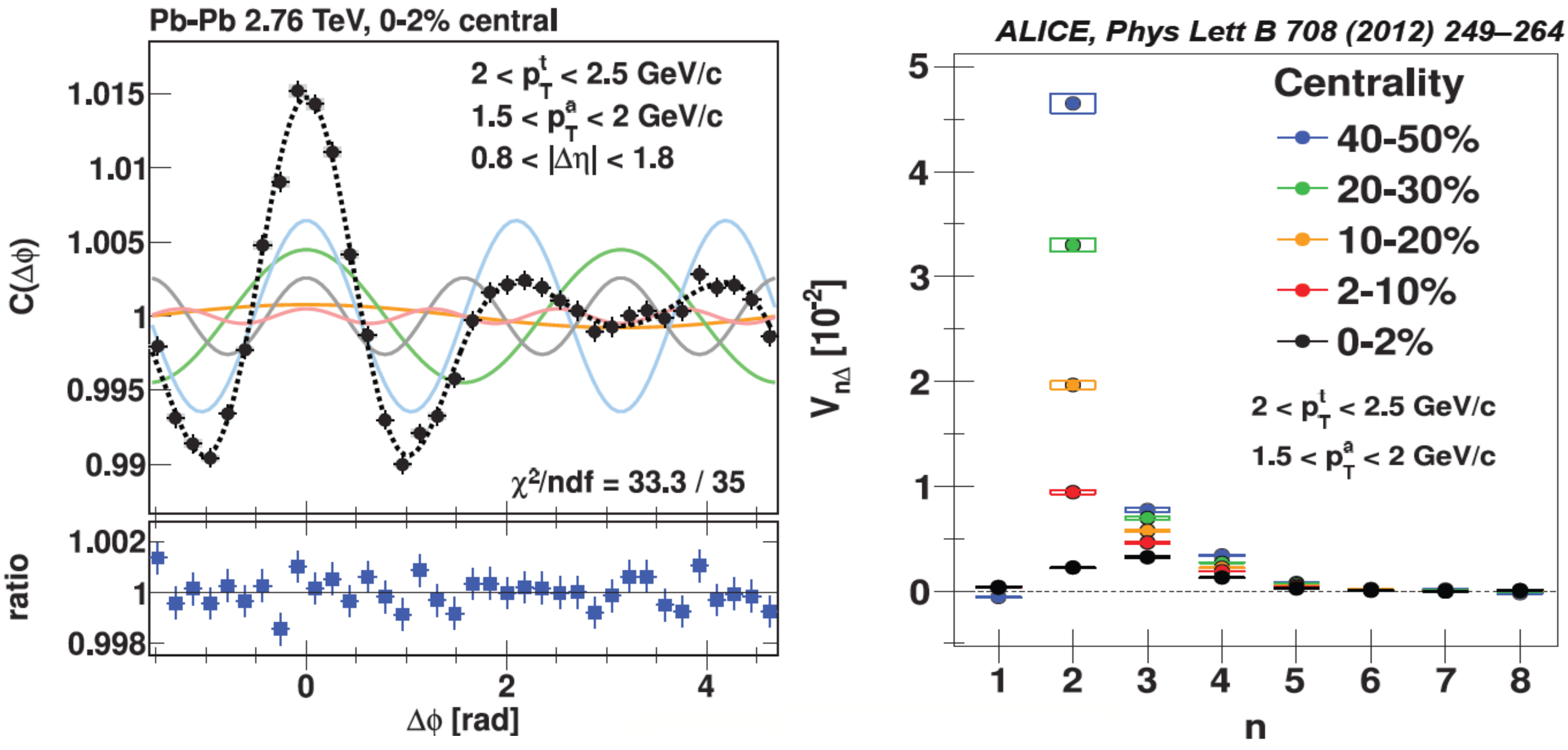


Heavy Ion collisions and Flow



- Anisotropic flow v_n is defined via Fourier decomposition of azimuthal (φ) distribution of produced particles relative to the reaction plane Ψ_{RP}
- Elliptic flow (n=2) is the largest component in mid-central collision

Harmonic decomposition



- Double hump structure can be naturally explained by accounting for higher harmonics

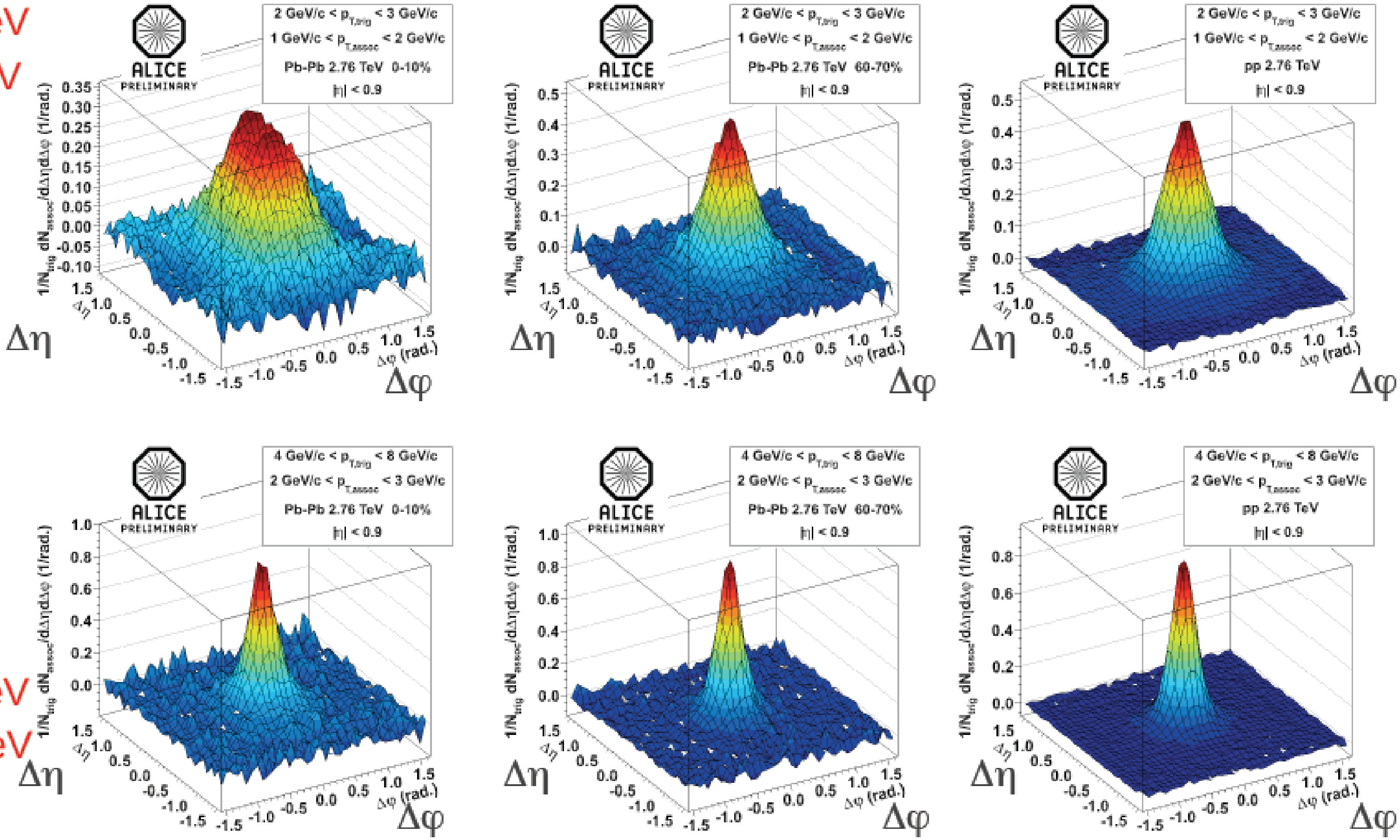
Jet-like Near-side Peaks in the Hot Medium

0-10% 60-70% pp

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

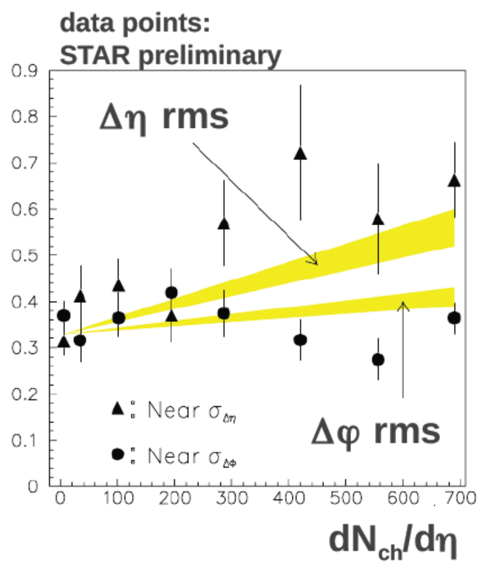
p_T

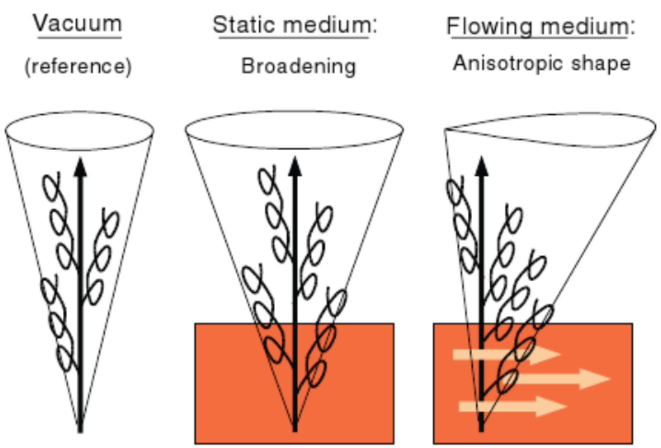
$4 < p_{T,trig} < 8$ GeV
$2 < p_{T,assoc} < 3$ GeV

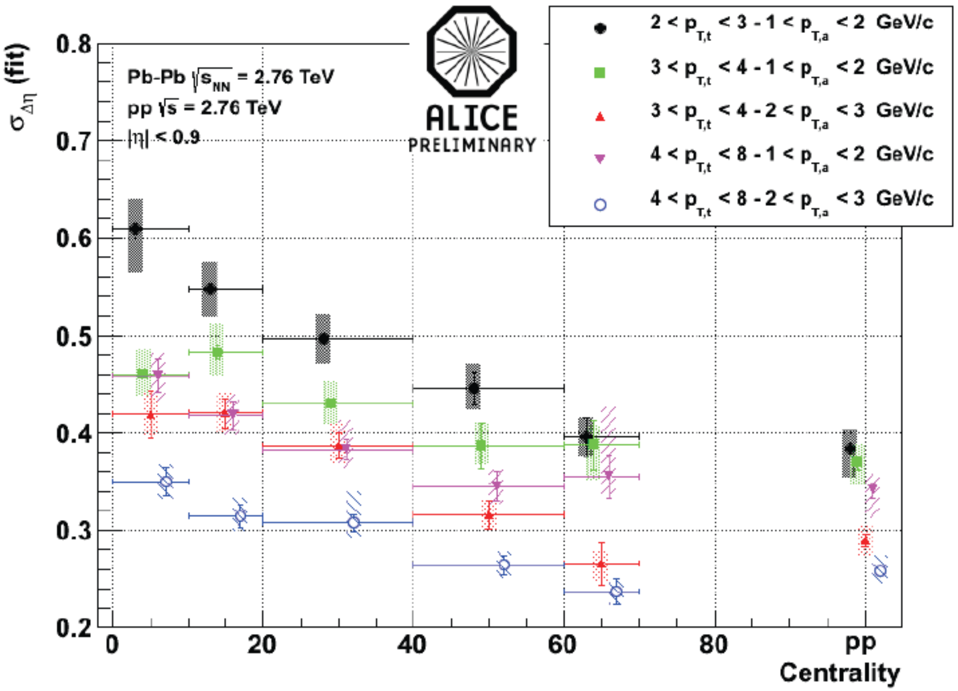


The Shape of the near-side peaks

Armesto, Salgado, Wiedemann, Phys. Rev. Lett. 93, 242301

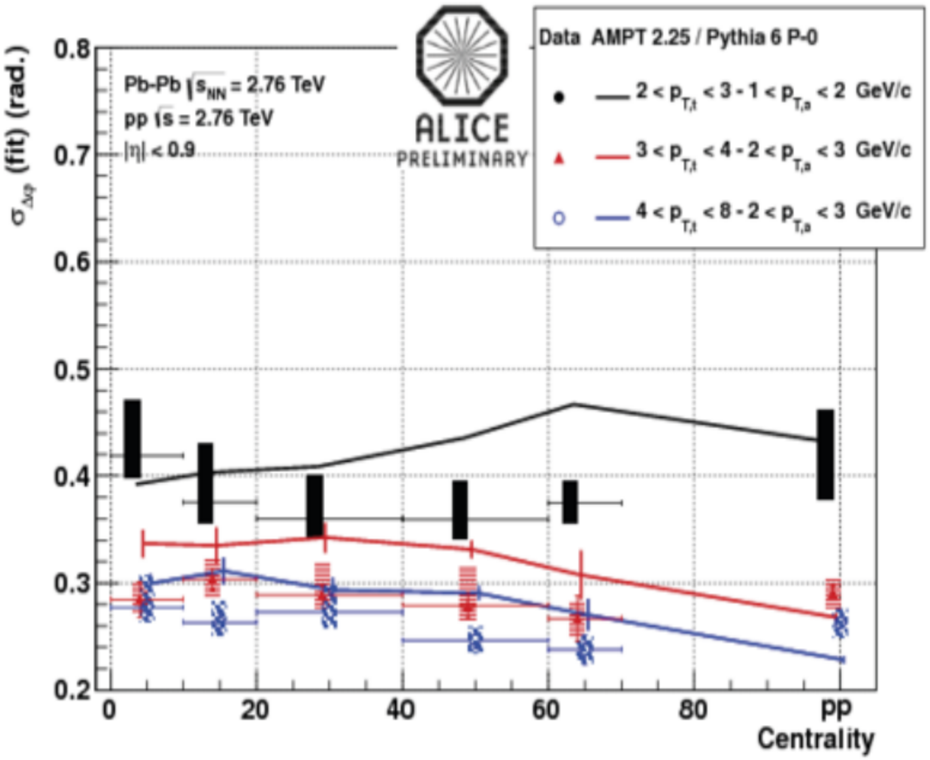


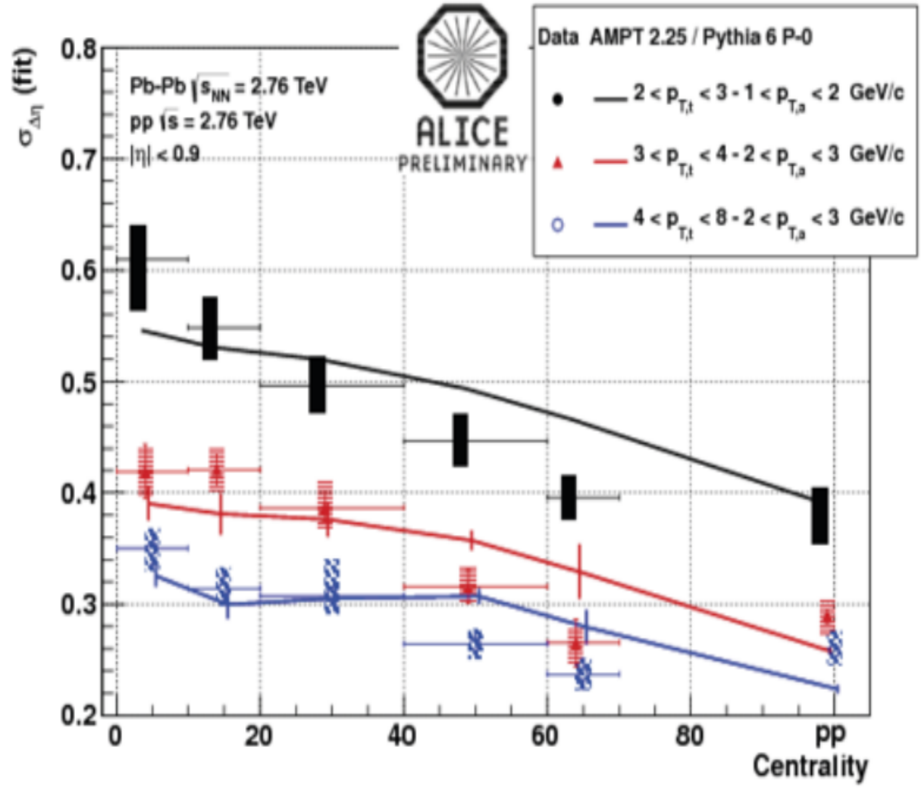




- Near-side peak shapes
  - Broadening with centrality
  - Static or flowing medium effect?

The Shape of the near-side peaks





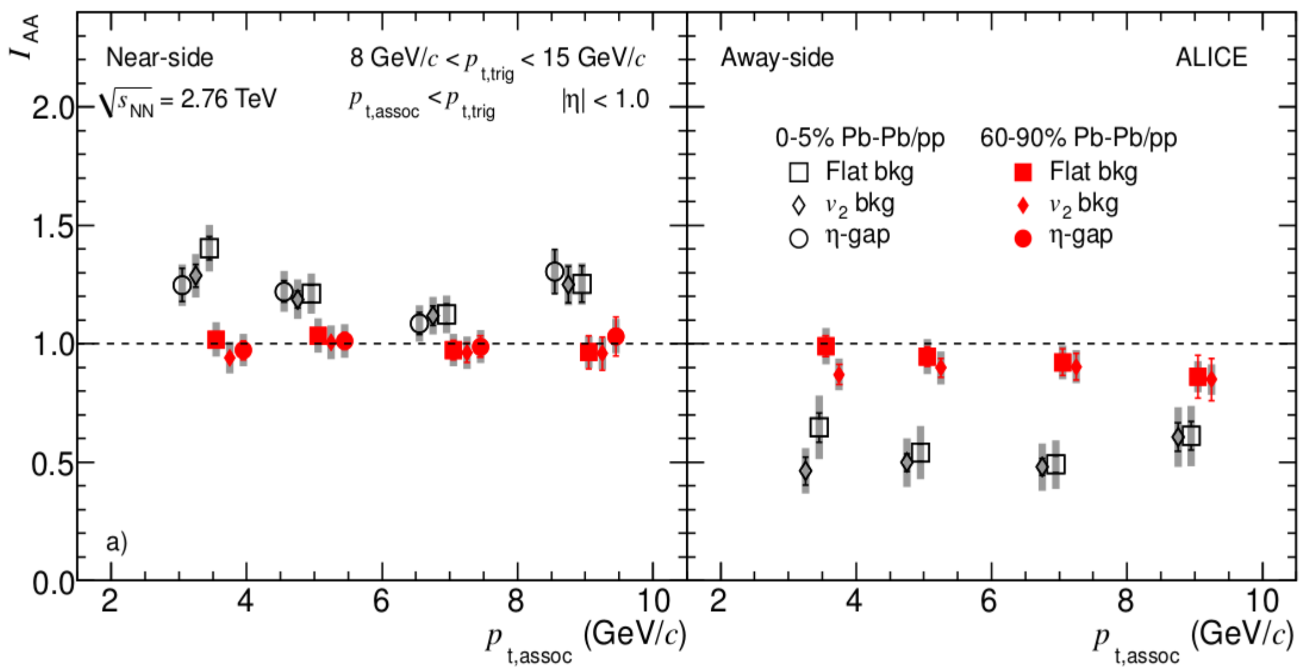
"Hadron Correlations Measured with ALICE", Jan Fiete Grosse-Oetringhaus (Nuclear Physics A 910-911 (2013) 58-64)

- The rms in $\Delta\eta$ increases significantly towards central collisions

  The rms in $\Delta\varphi$ is rather independent of centrality

- The interplay of longitudinal flow with a fragmenting high p_T parton can lead to such an asymmetric peak shape

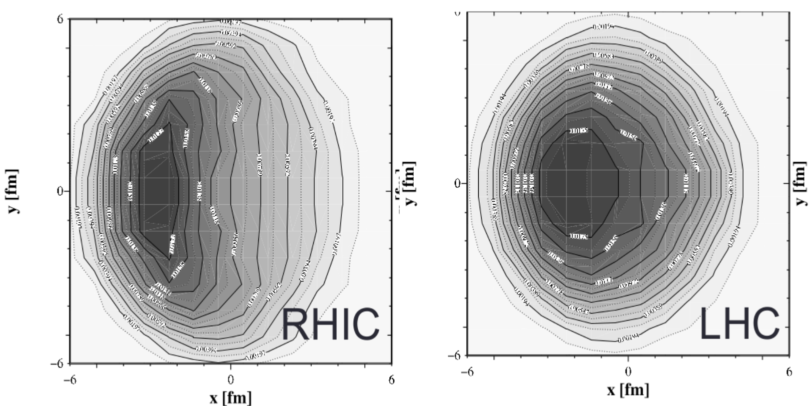
Modification of associated hadrons yield : I_{AA} *vs.* $p_{T,assoc}$



ALICE, PRL 108, 092301 (2012)

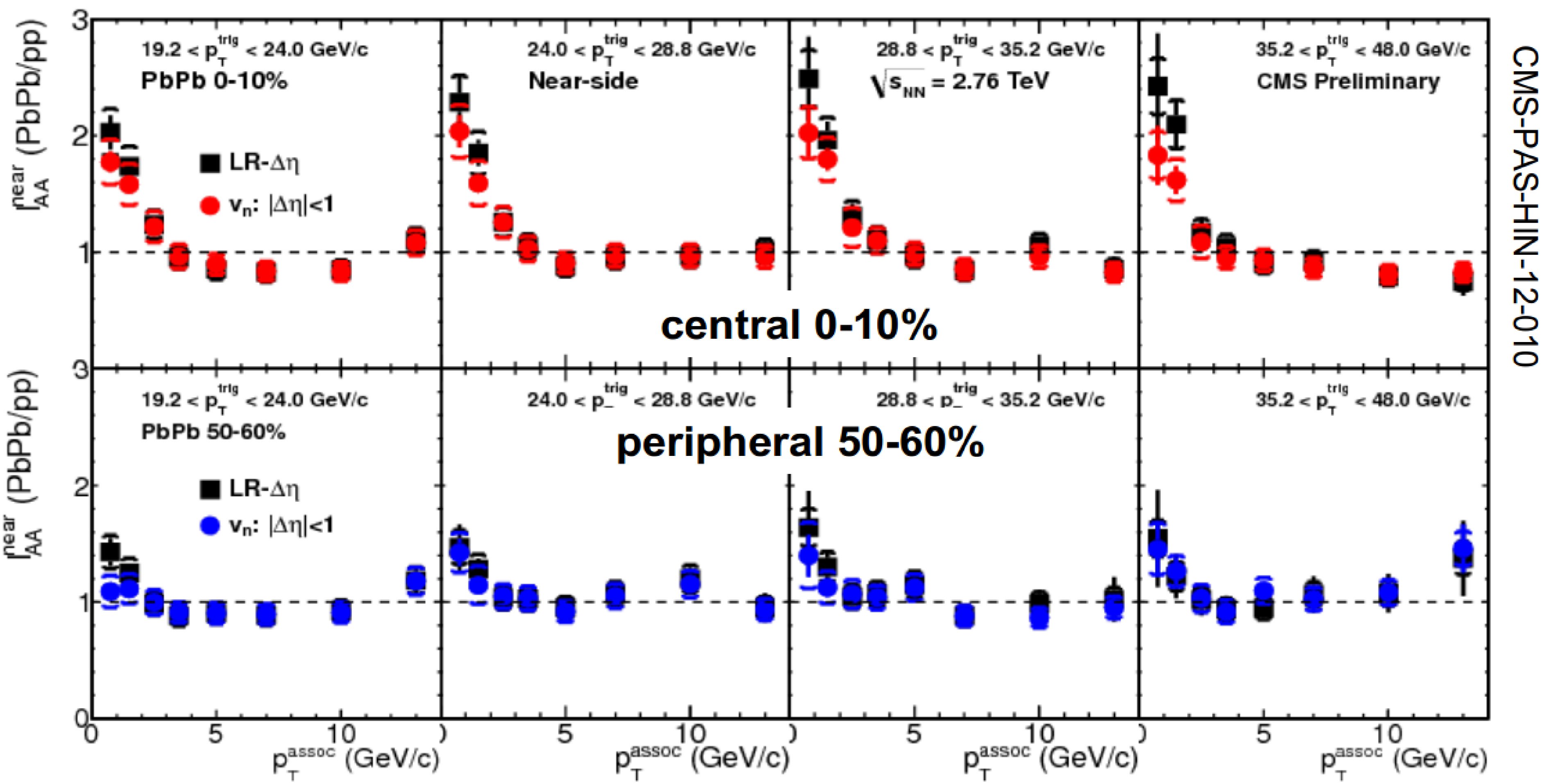
- In central collisions (0~5%),
  - Away-side suppressed (I_{AA} ~ 0.6)
  : due to the strong in-medium energy loss
  - Near-side enhancement (I_{AA} ~ 1.2)
  : the near-side parton might be also subject to medium effects

h-h Surface Bias



T. Renk, 1212.0646 [hep-ph]

I_{AA} vs. p_T from CMS



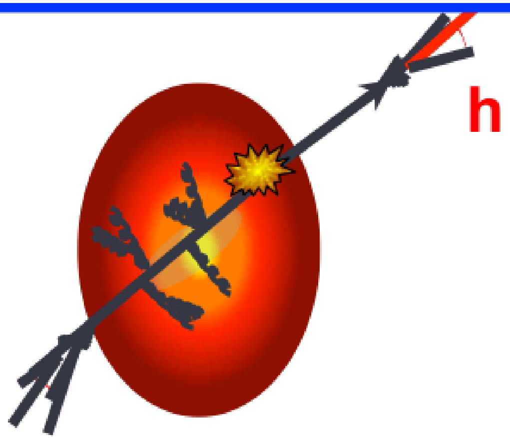
ALICE

Analysis Strategy

"How can we practically study jets with correlations in heavy-ion collisions?"

- ALICE detectors
- Work-flow of two-particle correlation analysis
- Precise background subtractions from dN/d$\Delta\varphi$
- Event-plane angle

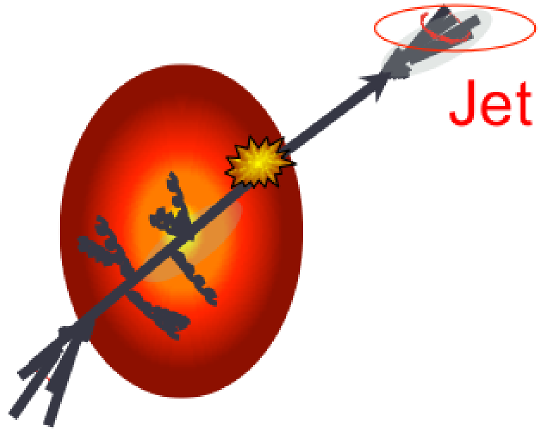
Studying energy loss with Correlations



Hadron-hadron

-Surface bias the trigger
-Potential nearside modifications
-Mix of tangential jets & maximized modification
-Broad parton energy distribution

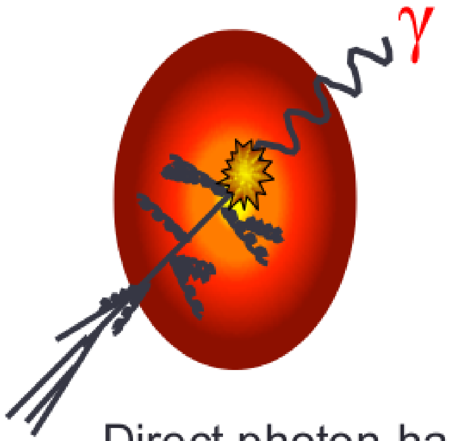
ALICE PRL 108 092301



Jet-hadron

-less surface bias
-nearside pp like by construction
-Several parameters to vary pathlength
-better constrains initial parton energy

STAR PRL 112 122301



Direct photon-hadron

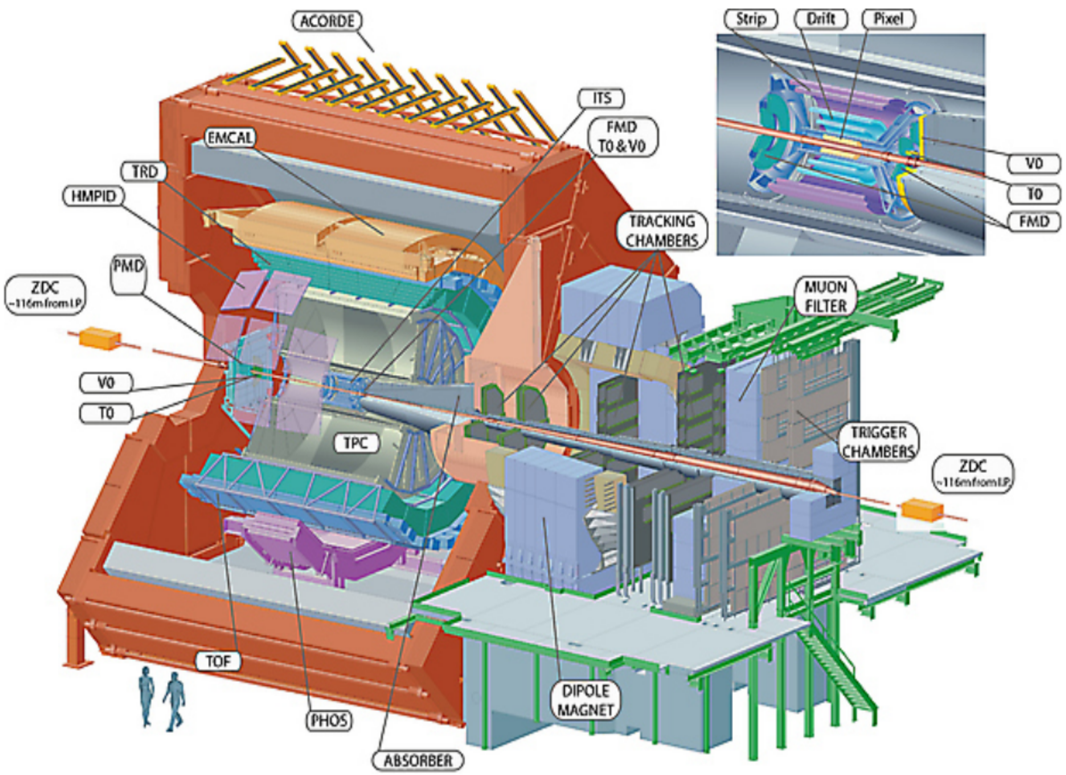
-No surface bias
-No nearside

-quark jets on awayside

-photon p_T approximates initial parton p_T

PHENIX PRL 111, 032301

Experimental setup: ALICE detectors



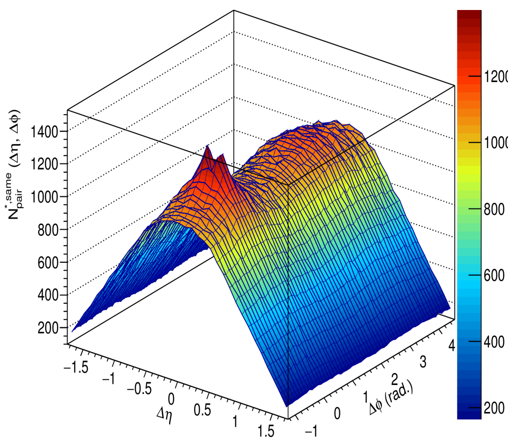
- ITS (Inner Tracking System)
  - six cylindrical layers of silicon detectors
  - Coverage : |η| < 0.9, 2π on φ
  - specialized to reconstruct vertex positions
  - good tracking performance and particle identification down to $p_T \sim 100\ MeV/c$

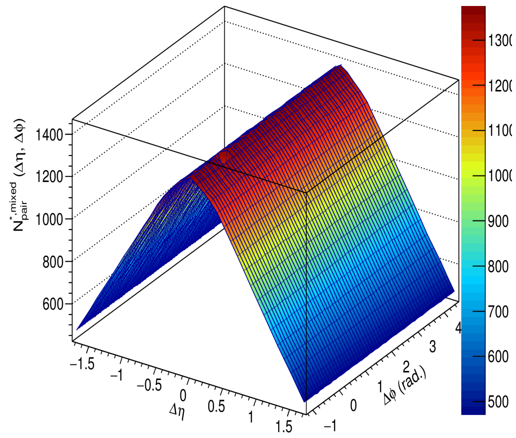
- TPC (Time Projection Chamber)
  - a cylindrical gas detector
  - coverage : |η| < 0.9, 2π on φ
  - wide momentum coverage to measure ($0.15 < p_T < 50\ GeV/c$)
  - PID with high resolution of dE/dx

- VZERO
  - Scintillator located in forward rapidity
  - Centrality determination and Trigger

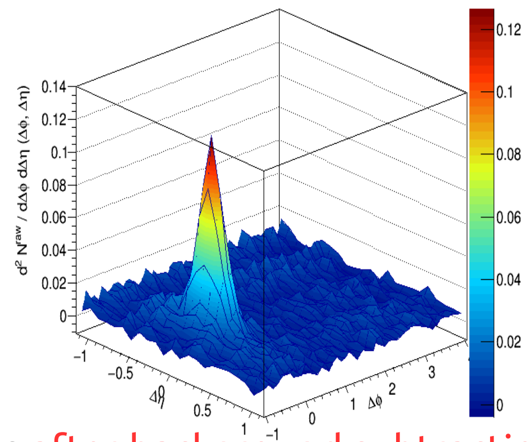
Work-Flow of two-particle correlation analysis

(1) N_{same} & N_{mixed} & N_{trig}

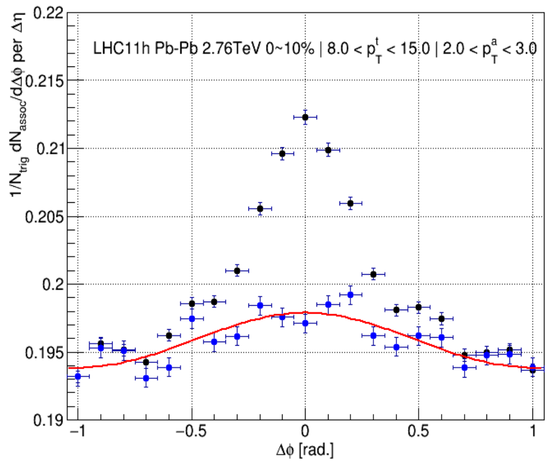




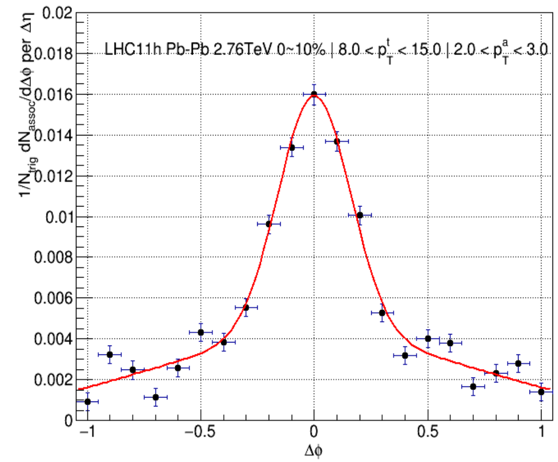
(2) per-trigger Yields



(3) dN/d$\Delta\varphi$ by projection



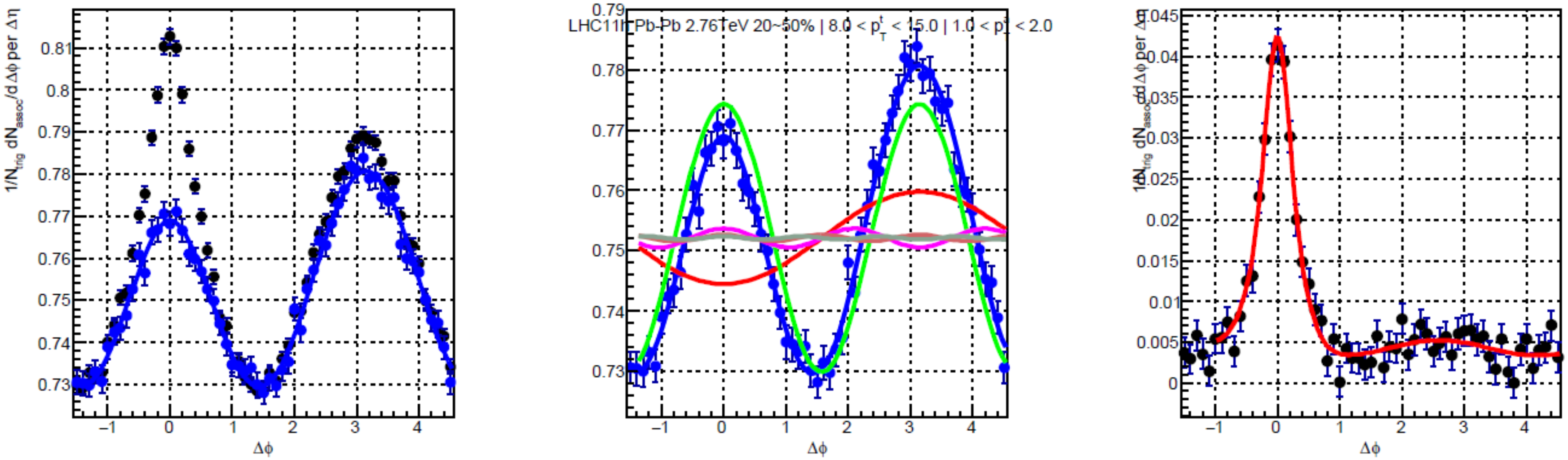
(4) Jet-like peaks after background subtraction



- Pb-Pb : 2.76 TeV taken in 2011, 8.60 M events
- p-p : 2.76 TeV taken in 2011 (~25.4 M events, without SDD)

dN/d$\Delta\varphi$ of Pb-Pb : subtraction of harmonics

ALICE



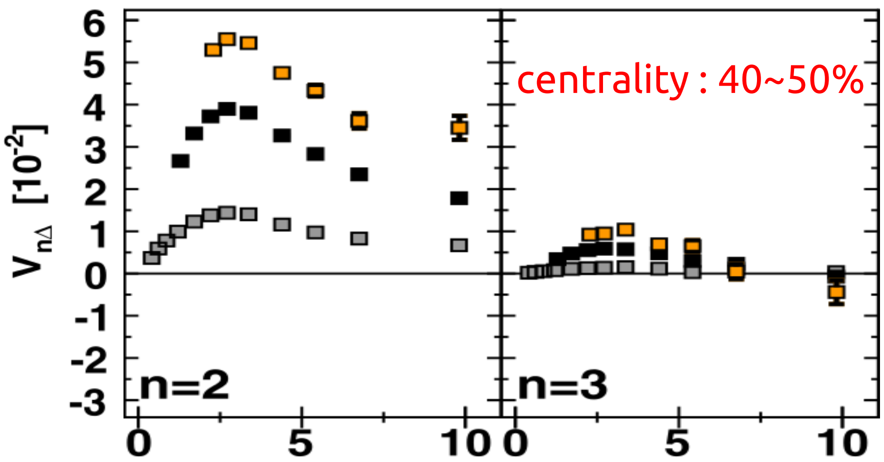
$$\frac{dN^{pairs}}{d\Delta\varphi} \propto 1+\sum_{n=1}^{\infty} 2V_{n\Delta}(p_T^t, p_T^a)\cos(n\Delta\varphi)$$

$$\sim a_0+2a_1\cos(\Delta\varphi)+2a_2\cos(2\Delta\varphi)+2a_3\cos(3\Delta\varphi)$$

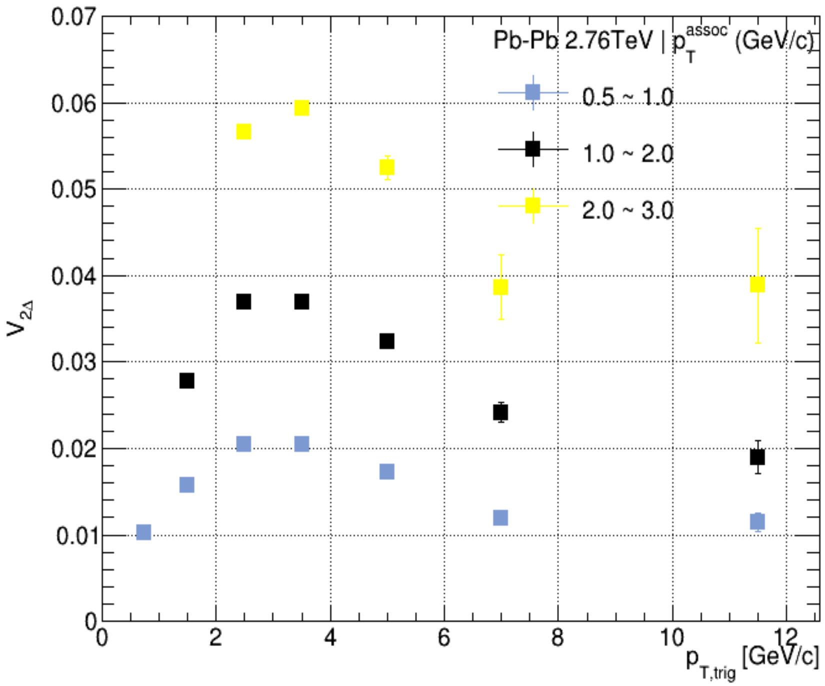
$$V_{n\Delta}^{h-i}=\frac{a_n^{h-i}}{a_0^{h-i}},\quad v_n^h\{2PC\}=\sqrt{V_{n\Delta}^{h-h}},\quad v_n^i\{2PC\}=\frac{V_{n\Delta}^{h-i}}{\sqrt{V_{n\Delta}^{h-h}}}$$ (ref. Phys.Lett. B708 (2012) 249-264)

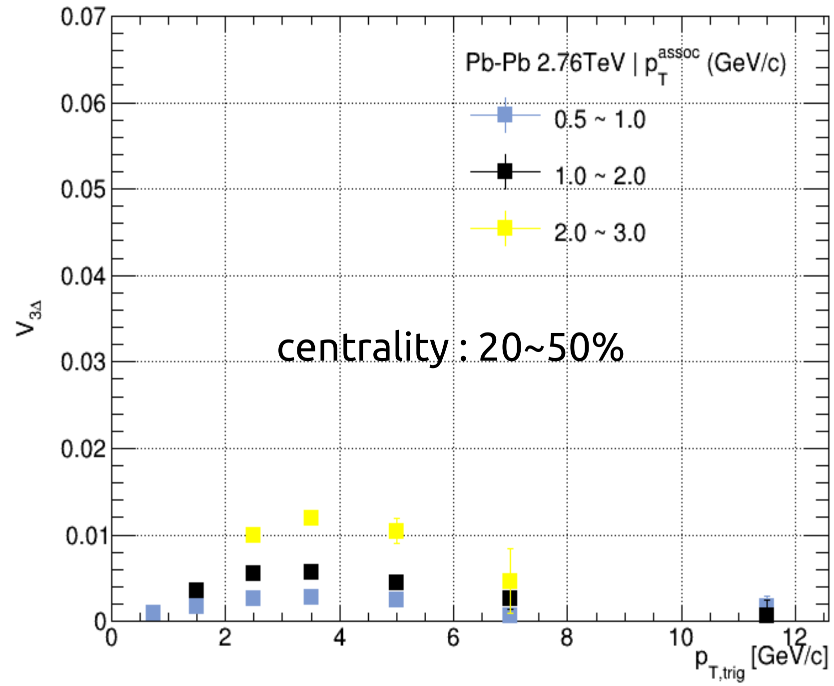
1. Fourier decomposition of (dN/d$\Delta\varphi$)$_{|\Delta\eta|\text{-gap}}$: up to 5th order
2. Subtract the harmonics from (dN/d$\Delta\varphi$)$_{|\Delta\eta|<1.6}$ based on the fits
3. Integrate over $\Delta\varphi$ to calculate the yields per trigger particle

Comparison of extracted $V_{n\Delta}$ with published values

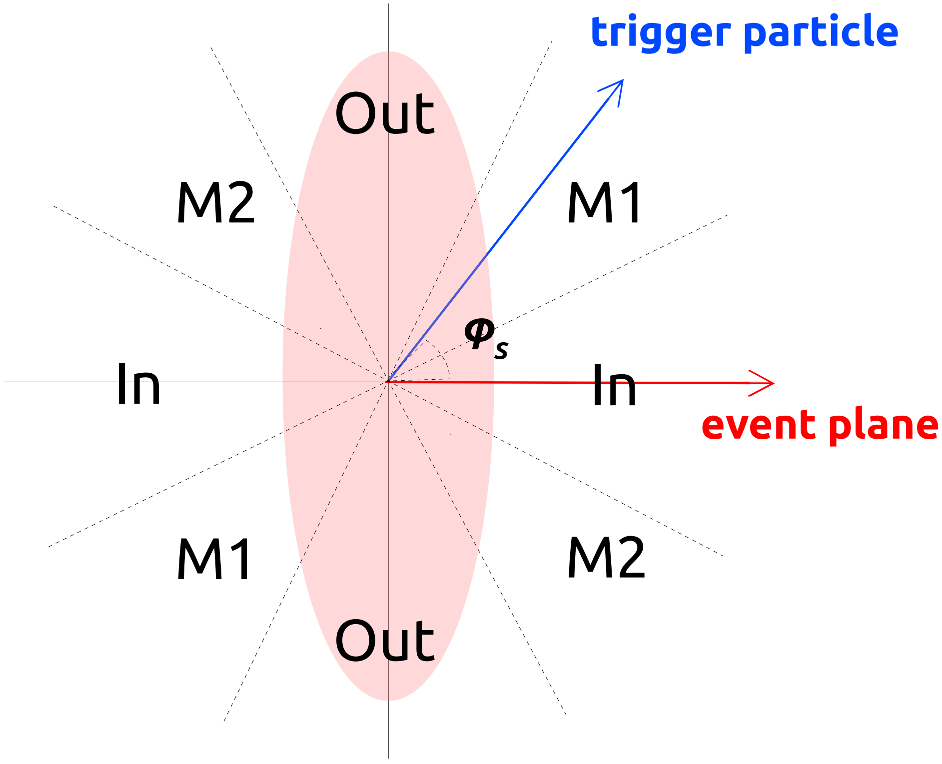


(ref. Phys.Lett. B708 (2012) 249-264)





Geometrical setup for φ_s analysis



$$Q_{n,x} = \sum W_i \cos(n\phi_i) = Q_n \cos(n\psi_n)$$

$$Q_{n,y} = \sum W_i \sin(n\phi_i) = Q_n \sin(n\psi_n)$$

$$\psi_{EP,\,n} = \tan^{-1}(Q_{n,x} / Q_{n,y}) / n$$

event plane angle
calculated by Q-vector (Scalar Product)

$$\varphi_S = |\varphi_{trigger} - \psi_{EP}|$$

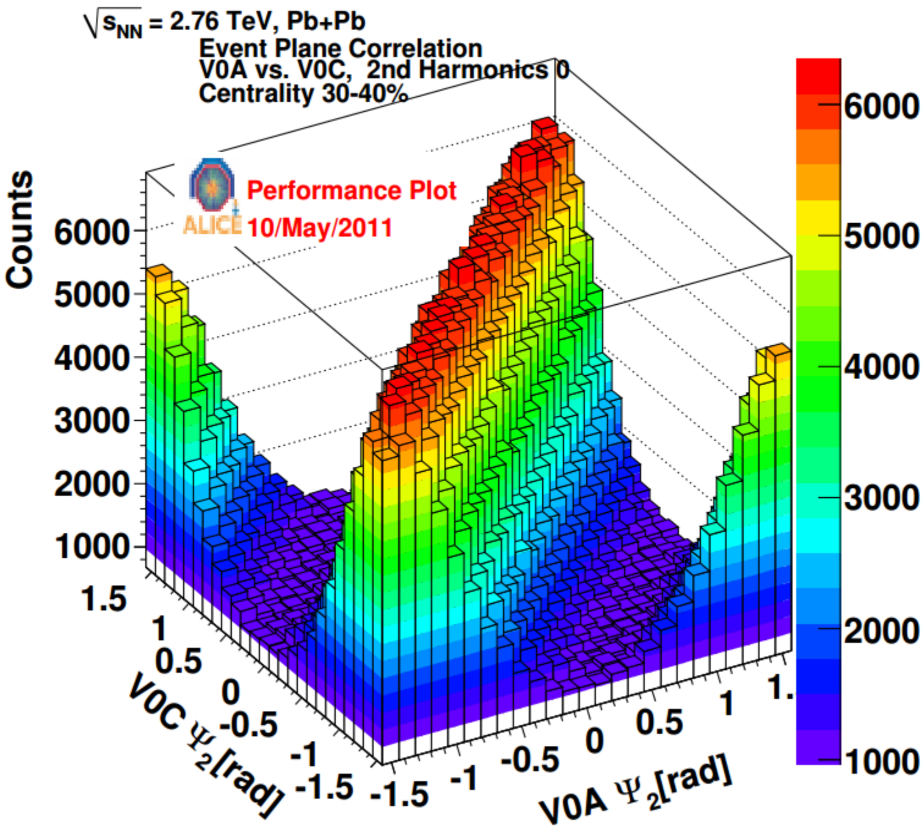
angle difference
between trigger and EP

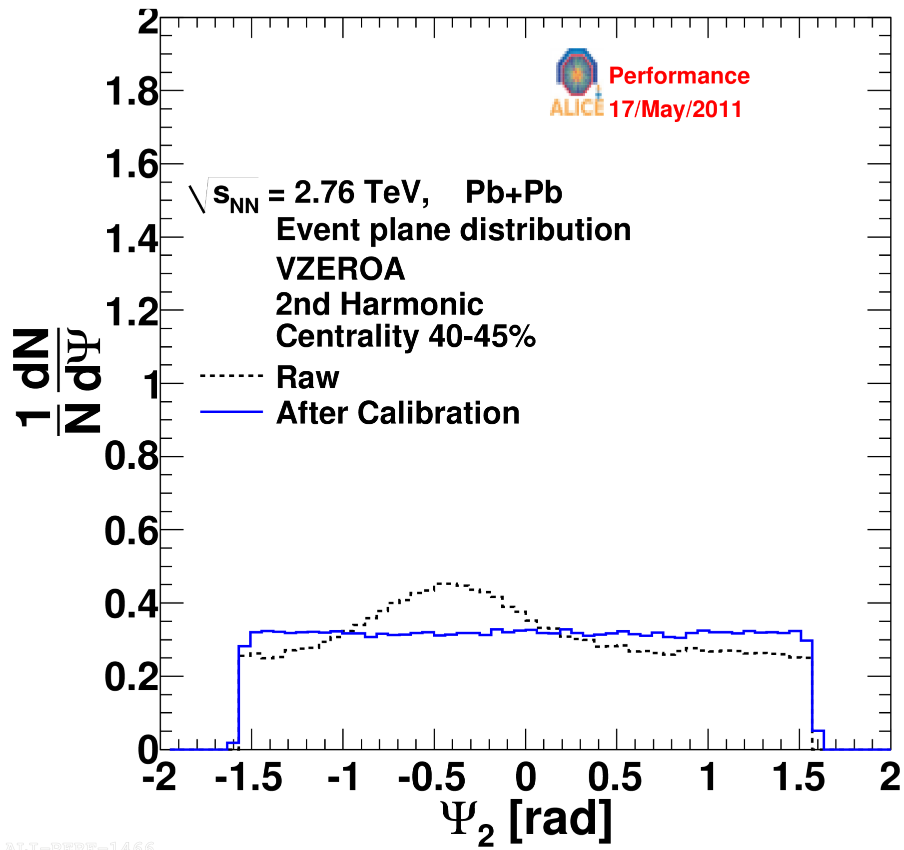
In-plane : Close to EP (in case of the 2nd harmonics, ψ_2)

Middle I / II : intermediate

Out-of-plane : perpendicular to EP

Event-plane angle at forward rapidity

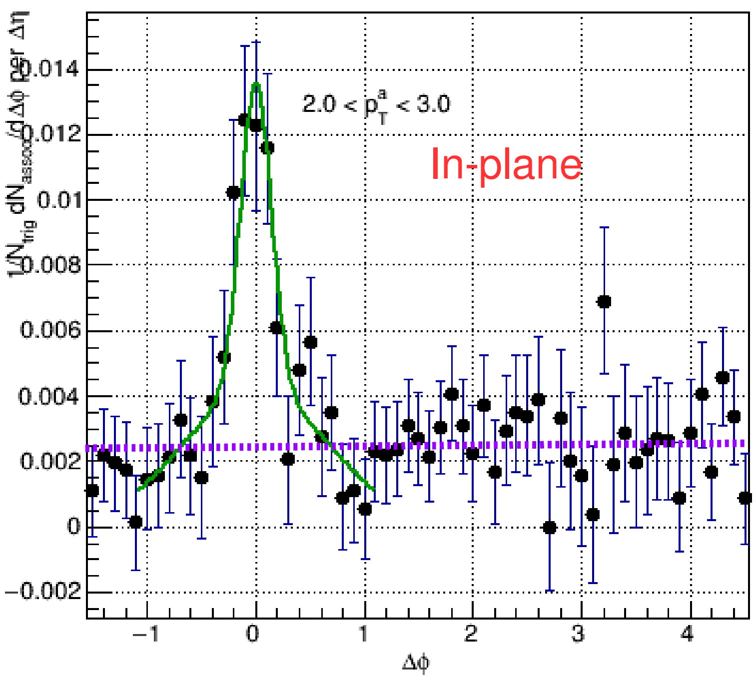


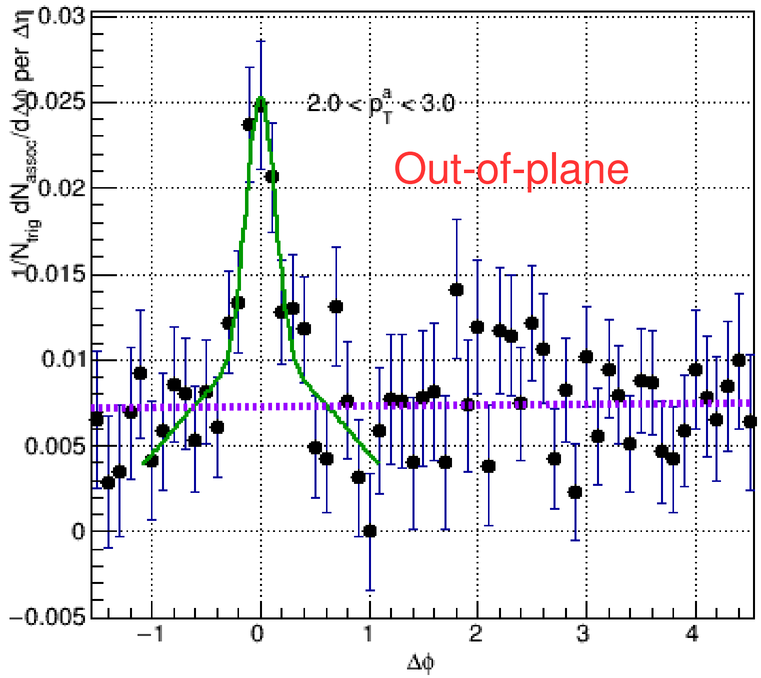


- Event-plane angle obtained from both V0A and V0C detectors at forward rapidity is used to reduce the bias from jets
- Calibration has been performed (re-centering, twist and etc.) for flat distribution

$\Delta\varphi$ of Near-side peak : Flat background subtraction

Even after large |Δη|-gap subtraction + additional subtraction based on v_2 fit on away-side, the flat background is still remaining on both in/out-of-plane.





- Azimuthal variation of trigger particles inside jet cone and EP resolution might cause the flat background
- Average background calculated in [π/2,3π/2] is subtracted

Summary

- New methods for accurate background subtractions are introduced
  - Subtractions of Residuals of flow after large $|\Delta\eta|$-gap and Flat backgrounds

- Study of Peak shapes of jets with two Gaussian functions are presented
  - composed of one narrow peak representing jet and the other showing tails
  - The width on near-side jets in Pb-Pb is broader than the width from *pp*
  - The width of narrow peak on near-side jets in Pb-Pb is similar to the *pp*

- Study of the Modification of associated particles on near-side jets are presented
  - low $p_{T,assoc}$ are included in I_{AA} results on near-side jets
  - More enhancements of yields in central collisions are observed
  - There are more enhancements of yields at Out-of-plane compared to In-plane

- Model studies are done with AMPT Monte Carlo with different settings
  - The trend of widths qualitatively agrees with data points
  - None of AMPT reproduces I_{AA} results on near-side jets

Thank you for the attention

Backup

Data sets and Cut information

- Input data

 - Pb-Pb : 2.76 TeV taken in 2011, 8.60 M events
 - p-p : 2.76 TeV taken in 2011 (~25.4 M events, without SDD)
 7 TeV taken in 2010 (~78.8 M events, LHC10b/c/d)

- Track selection

 - $p_{T,track}$ > 200 MeV/c, $|\eta_{track}| < 0.8$
 - TPC-only track cut
 (cut with clusters, reject kink daughters, $d_{xy} < 2.4$ cm, $d_z < 3.2$ cm and etc.)
 - Two-track efficiency cut applied ($|\Delta\varphi^*_{min}| < 0.02$ and $|\Delta\eta| < 0.02$)

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

- Centrality bins
 - 0~10%, 20~50%, 60~90%

- Event plane angle
 - determined by V0 ($2.8 < \eta < 5.1$ and $-3.6 < \eta < -1.7$)

Corrections

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

$\beta(z) = N^{*\text{mixed}}_{\text{pair}}(0,0,z)$

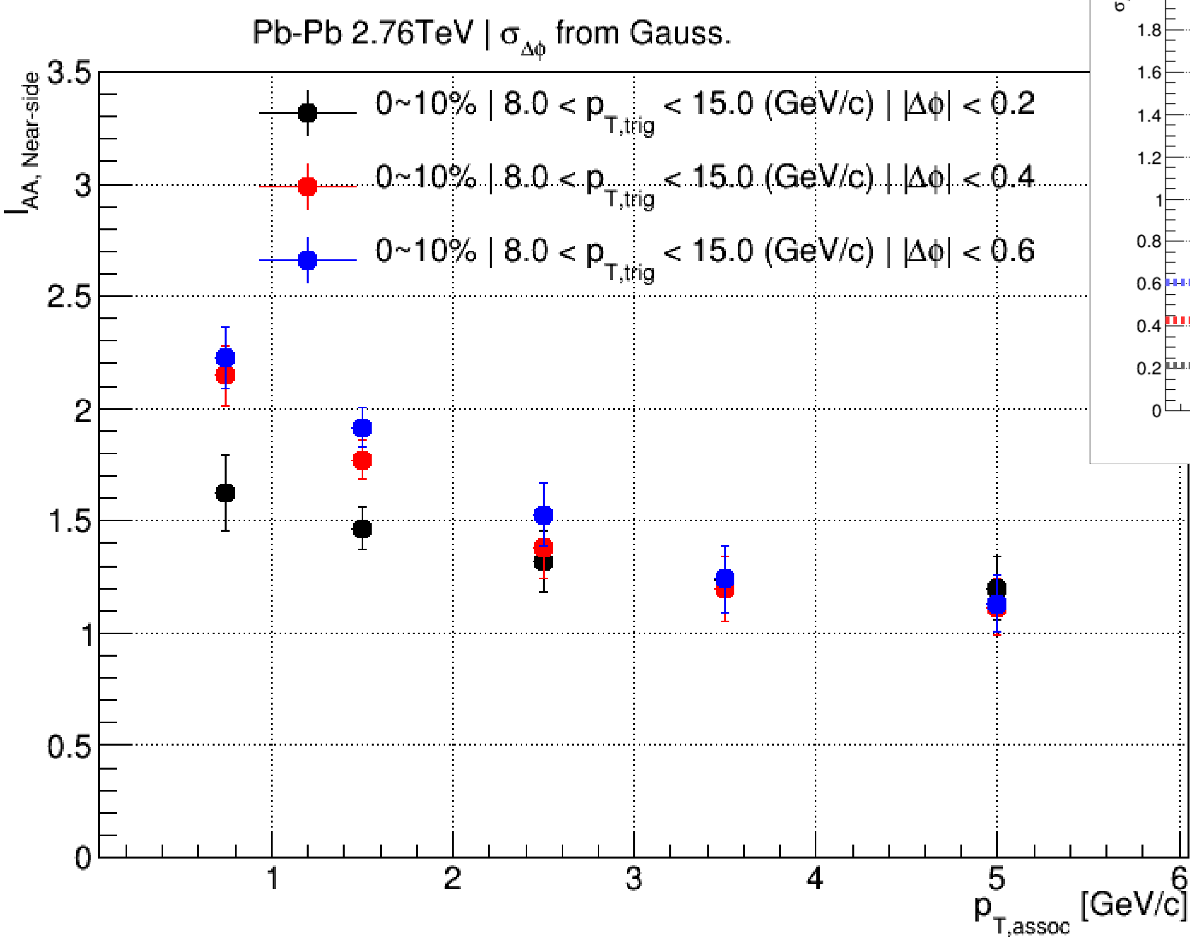
$$\frac{d^2N^{\text{raw}}}{d\Delta\varphi d\Delta\eta}(\Delta\varphi,\Delta\eta)=\frac{1}{\sum_z N^*_{\text{trig}}(z)}\sum_z N^*_{\text{trig}}(z)\cdot\frac{d^2N^{\text{raw}}}{d\Delta\varphi d\Delta\eta}(\Delta\varphi,\Delta\eta,z)$$

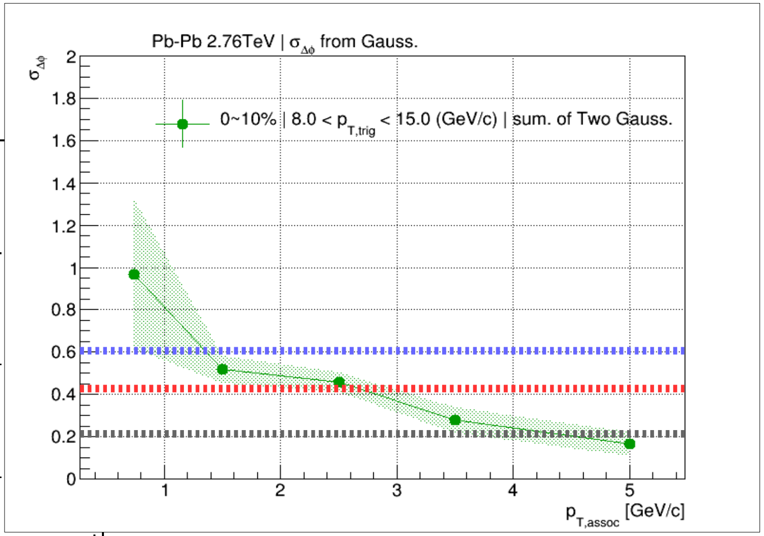
z bins are combined by calculated weight, $N^*_{\text{trig}}(z)$

$$\begin{aligned}
N^{\text{corrected}}_{\text{pair}}(\Delta\eta,\Delta\varphi,p_{T,\text{trig}},p_{T,\text{assoc}},C) &= N^{\text{raw}}_{\text{pair}}(\Delta\eta,\Delta\varphi,p_{T,\text{trig}},p_{T,\text{assoc}},C)\\
&\cdot\ C_{\text{trckeff}}(p_{T,\text{assoc}},C)\\
&\cdot\ C_{\text{trckeff}}(p_{T,\text{trig}},C)\\
&\cdot\ C_{\text{cont}}(p_{T,\text{assoc}})\\
&\cdot\ C_{\text{correlatedcont}}(p_{T,\text{assoc}},p_{T,\text{trig}},\Delta\eta,\Delta\varphi)\\
N^{\text{corrected}}_{\text{trig}}(p_{T,\text{trig}},C) &= N^{\text{raw}}_{\text{trig}}(p_{T,\text{trig}},C)\\
&\cdot\ C_{\text{trckeff}}(p_{T,\text{trig}},C)
\end{aligned}$$

(ref. Analysis Note “Jet-like Peak-shapes in Angular Correlations in Pb-Pb Collisions” https://aliceinfo.cern.ch/Notes/node/33)

I_{AA} with different $|\Delta\varphi|$ cuts





Other Experiments

ALICE (pub.) : R < 0.2

CMS (prel.) : 1.0 cut on Δφ

STAR (pub.) : R < 0.4

- There are not too much difference between 0.4 and 0.6 cuts