π^0 - hadron correlations and π^0 v_2 in pp and PbPb collisions at 2.76 TeV in ALICE

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The work is done by PhD student Xinye Peng (and collaborators)

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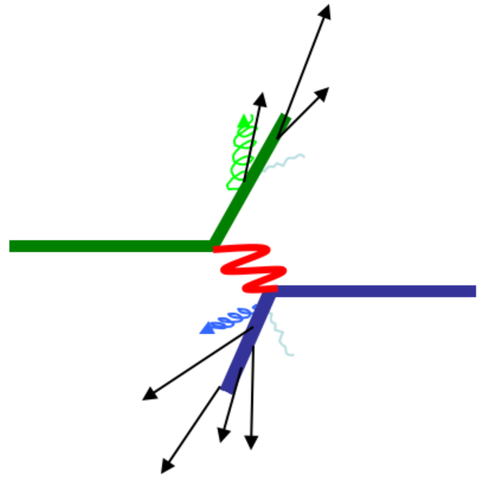
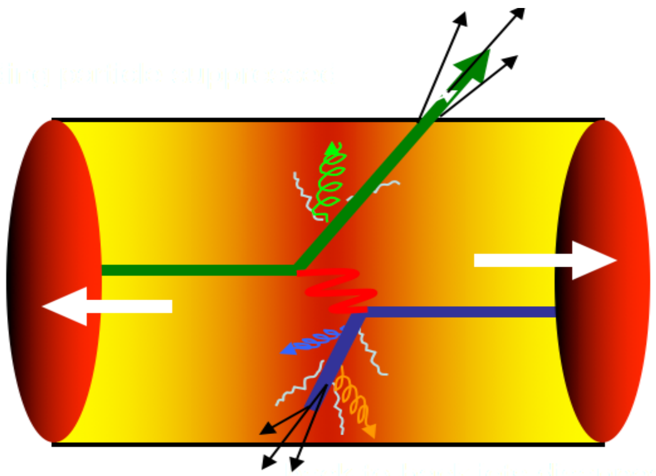
π^0 - h correlations

- Study away-side parton energy loss and jet modification via high p_T-hadron correlations.
- An important step to study direct photon-hadron correlations.
- Two main steps:

1. Azimuthal correlations: $C = \frac{1}{N_{trig}} \frac{dN^{pair}}{d\Delta\varphi}$, $J = C - B(flat\ or\ v_n\ background)$
2. Modification of the yield in the correlations: $Y = \frac{1}{N_{trig}} \int J d\Delta\varphi$, $I_{AA} = \frac{Y_{Pb-Pb}}{Y_{pp}}$ or $I_{CP} = \frac{Y^{central}_{Pb-Pb}}{Y^{peripheral}_{Pb-Pb}}$



Hard Scattering in pp

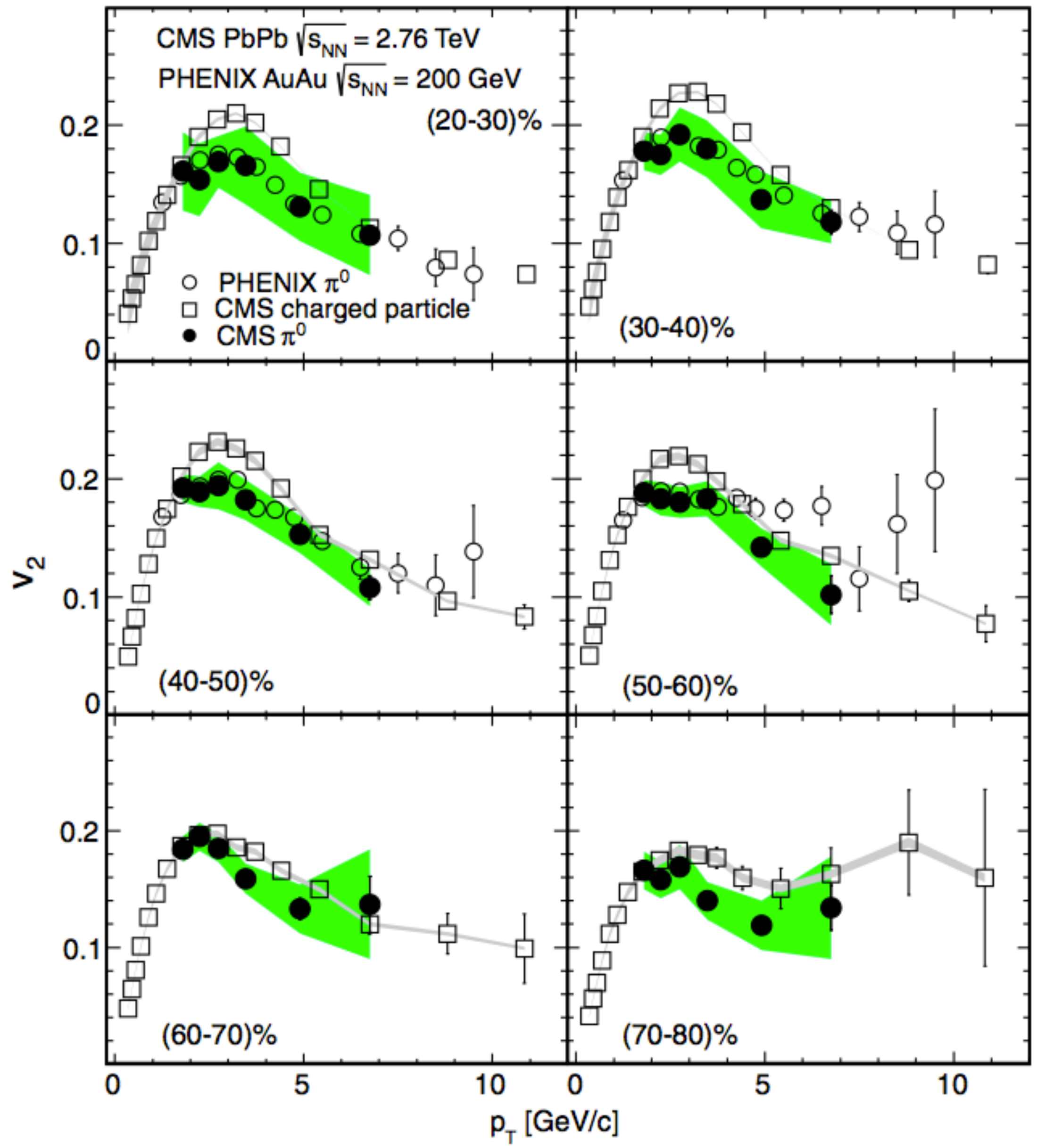


Parton Energy Loss in Pb–Pb

Two particles are selected in given p_T region. One is named "trigger particle", another one is called "associated particle". Generally, $p_T^{assoc} < p_T^{trig}$.

π^0 v_2

The investigation of neutral and charged pions is of significance since they are considered to carry direct information from the early stage of collisions.



- Low p_T: collective hydrodynamic expansion of the medium
  initial-state spatial info
- Mid p_T: difference between baryons and mesons
  production mechanism
- High p_T: suppression of hadron yields
  path-length dependence of energy loss

PHENIX Collaboration, PRL 105, 142301 (2010)
CMS Collaboration, PRL 110, 042301 (2013)

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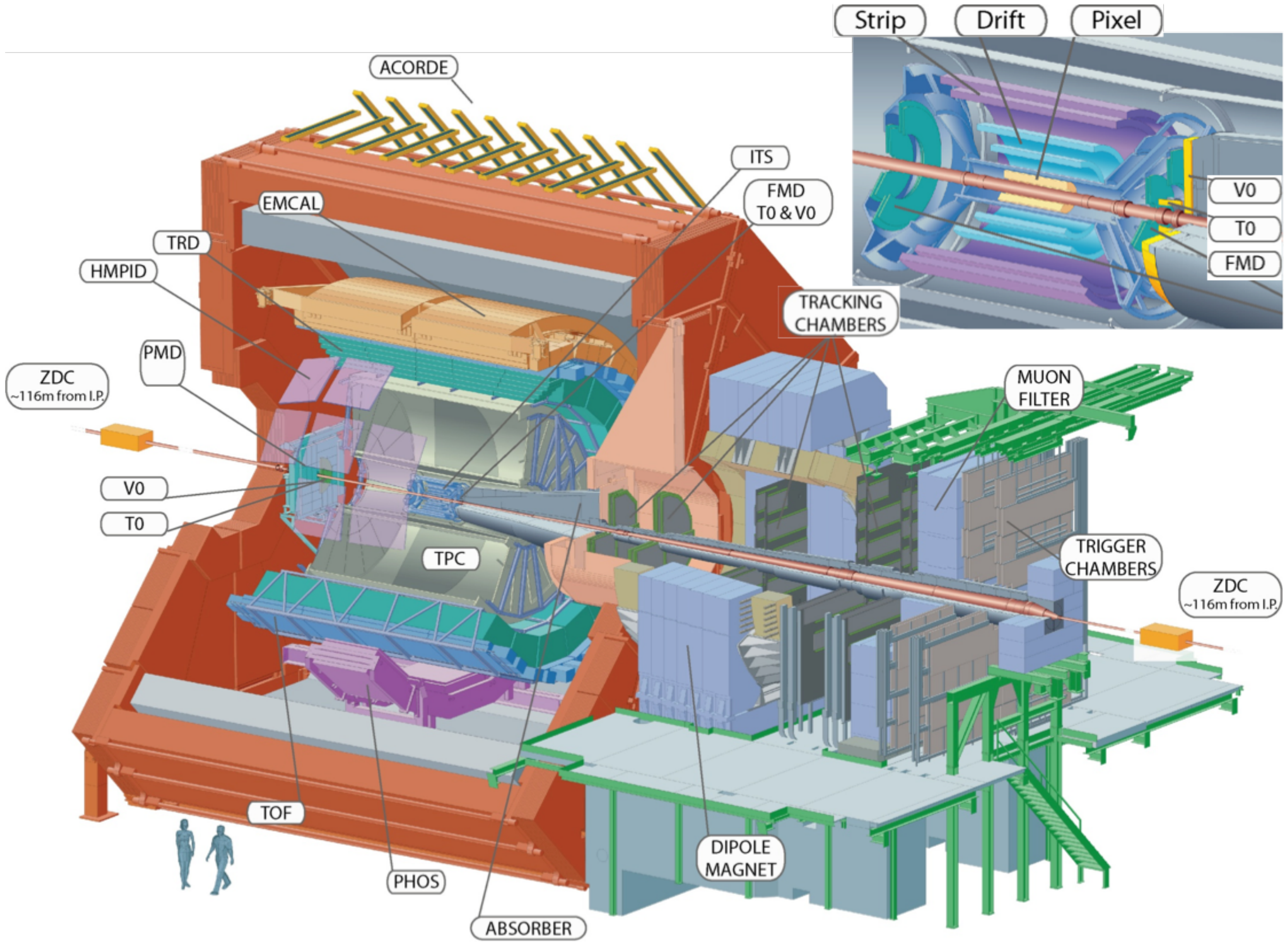


- ITS (Inner Tracking System)

six cylindrical layers of silicon detectors, $|\eta| < 0.9$
  - localize the primary and secondary vertices.
  - track and identify particles down to $p_T \sim 100$ MeV/c

- TPC (Time Projection Chamber)

a cylindrical gas detector, $|\eta| < 0.9$
  - charged particle momentum $(0.15 < p_T < 100$ GeV/$c)$
  - particle identification (dE/dx resolution better than 10%)

- EMCal (Electro Magnetic Calorimeter)

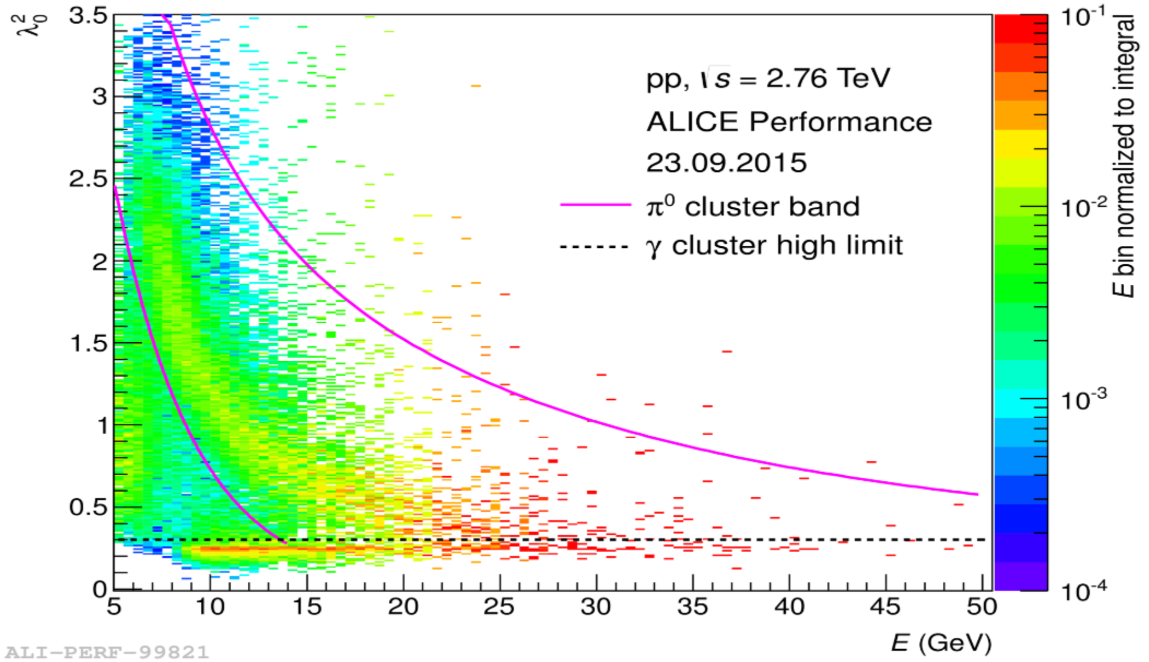
a lead-scintillator sampling calorimeter,

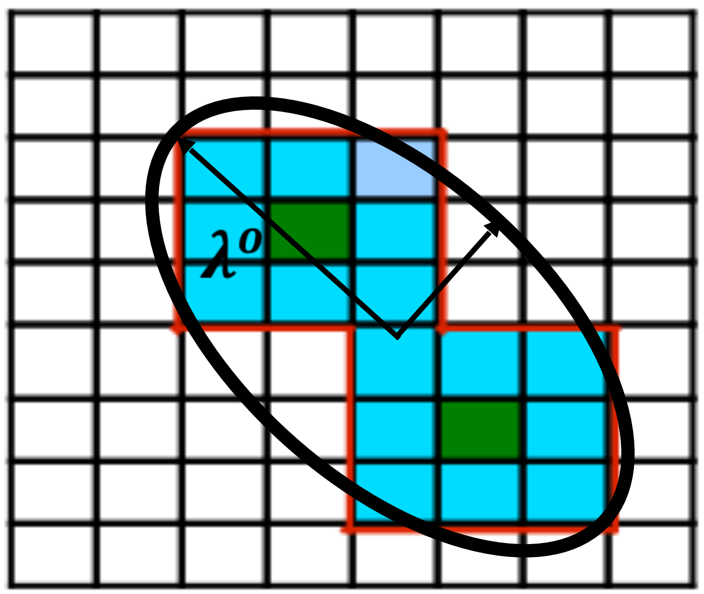
$|\eta| < 0.7$, $\frac{\sigma_E^2}{E^2} = A^2 + \frac{B^2}{E} + \frac{C^2}{E^2}$ with A = (1.65±0.04)%, B = (8.0±0.2)%, C = (7.4±0.2)%
  - high-p_T neutral mesons, photons and electrons
  - high energy jets

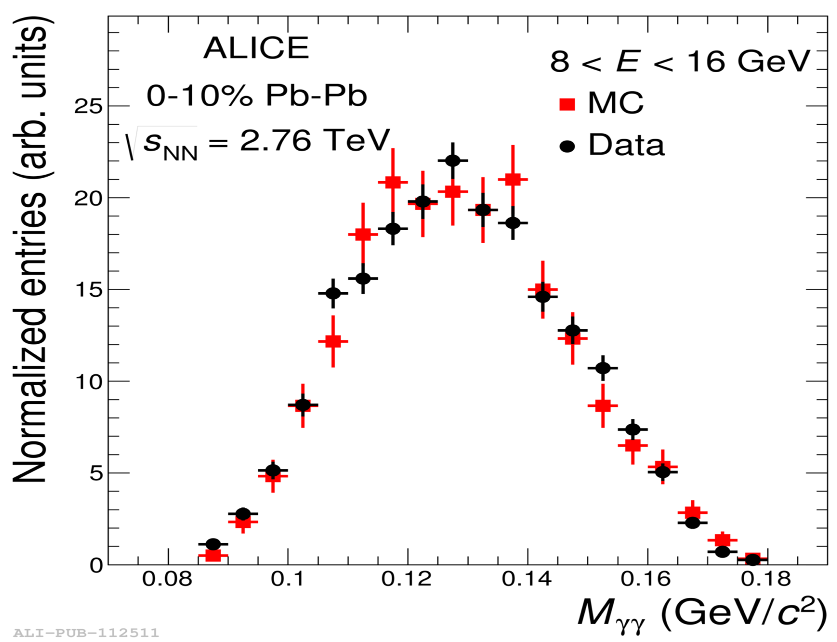
data taken in year 2011;

pp and Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

π^0 selection



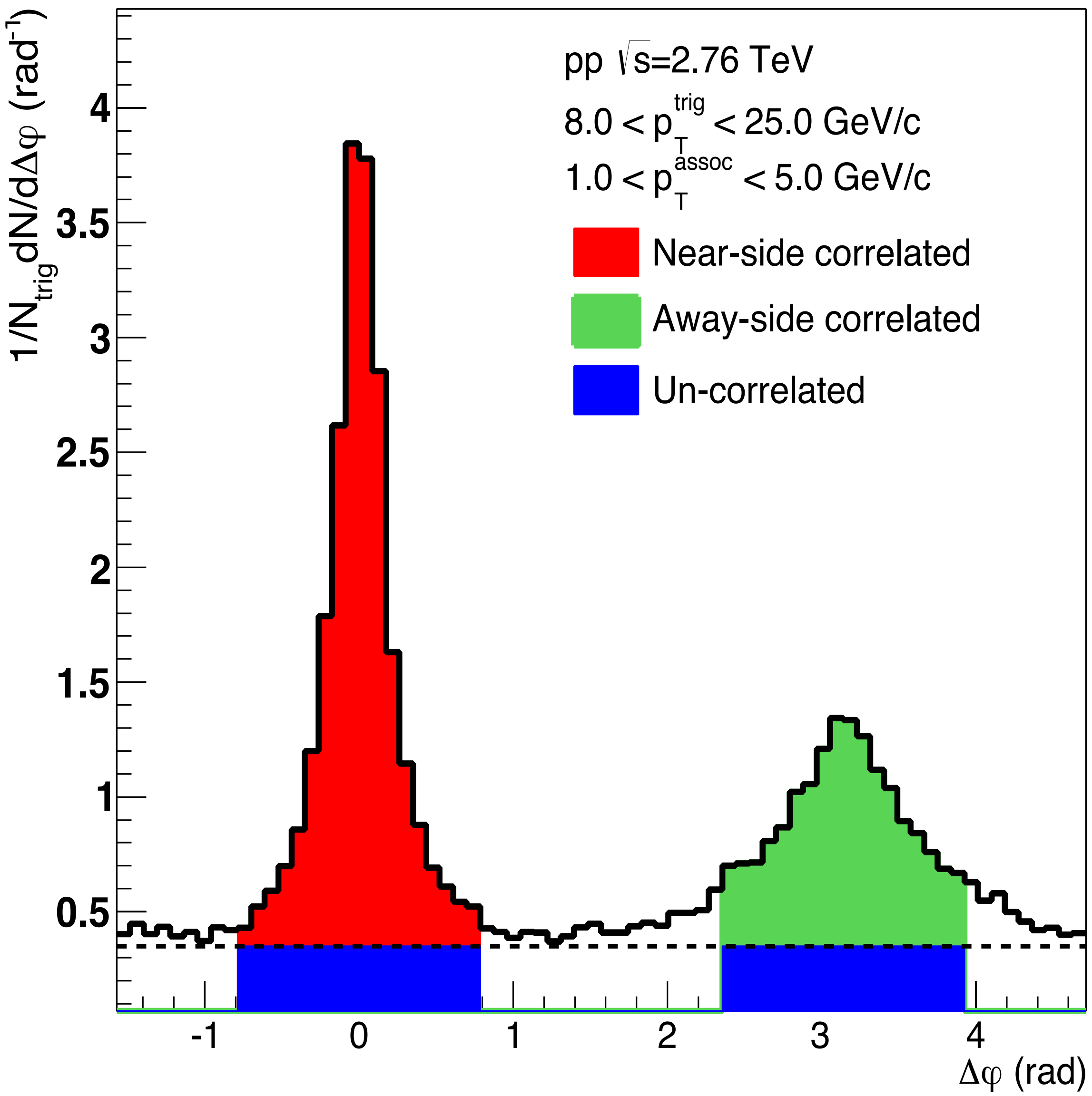




π^0 decay photons start to merge for $E > 6$ GeV

- Select clusters with elongated λ_0^2 shower shape
- A cluster is split in 2 sub-clusters, the seed are the 2 highest energy cells or local maxima. Select cells around
- Select those with invariant mass within 3 sigma of the π^0 mass

Yield and background

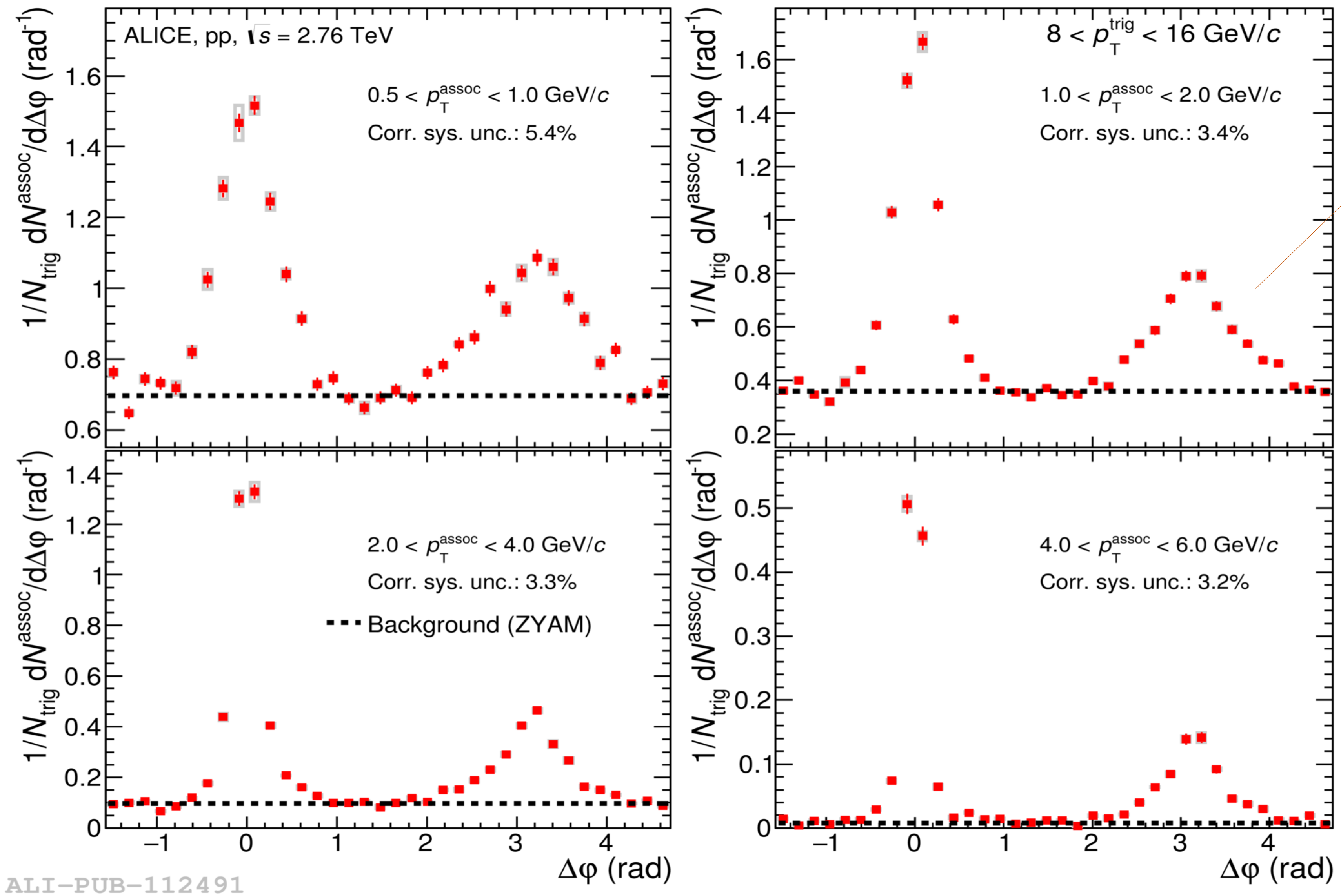


red, green: Correlated
blue: Un-correlated

- Per-trigger yield in two region
  - ✓ Near side $|\Delta\varphi| < 0.7$ rad
  - ✓ Away side $|\Delta\varphi - \pi| < 1.1$ rad
- Subtract the background with ZYAM
  - ✓ Flat background (pp)
  - ✓ v_n(up to v_5) background (Pb–Pb)

$$J(\Delta\varphi) = C(\Delta\varphi) - b_0(1 + 2\sum_{n=2}^{5}\langle v_n^{trig}\rangle\ \langle v_n^{assoc}\rangle\ cos(n\Delta\varphi))$$

Azimuthal distribution in pp



di-jet behavior

Trigger p_T region:

$8 < p_T^{trig} < 16$ GeV/c

Associate p_T region:

$0.5 < p_T^{assoc} < 1.0$ GeV/c

$1.0 < p_T^{assoc} < 2.0$ GeV/c

$2.0 < p_T^{assoc} < 4.0$ GeV/c

$4.0 < p_T^{assoc} < 6.0$ GeV/c

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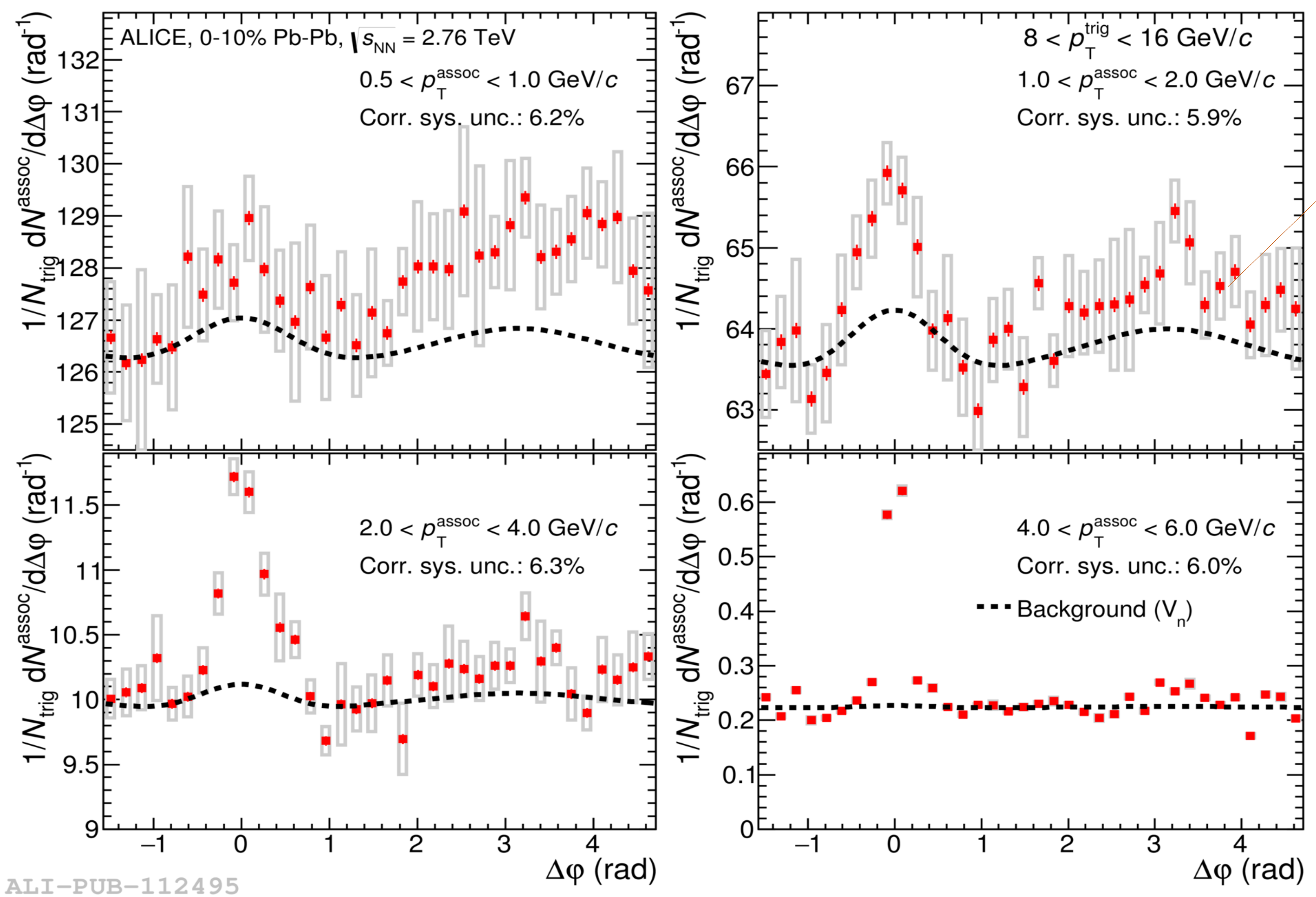
Azimuthal distribution in PbPb



Low p_T away side broadens

Near side yield is higher than away side yield at high p_T, but lower than away side yield at low p_T

0–10% most central Pb–Pb collisions

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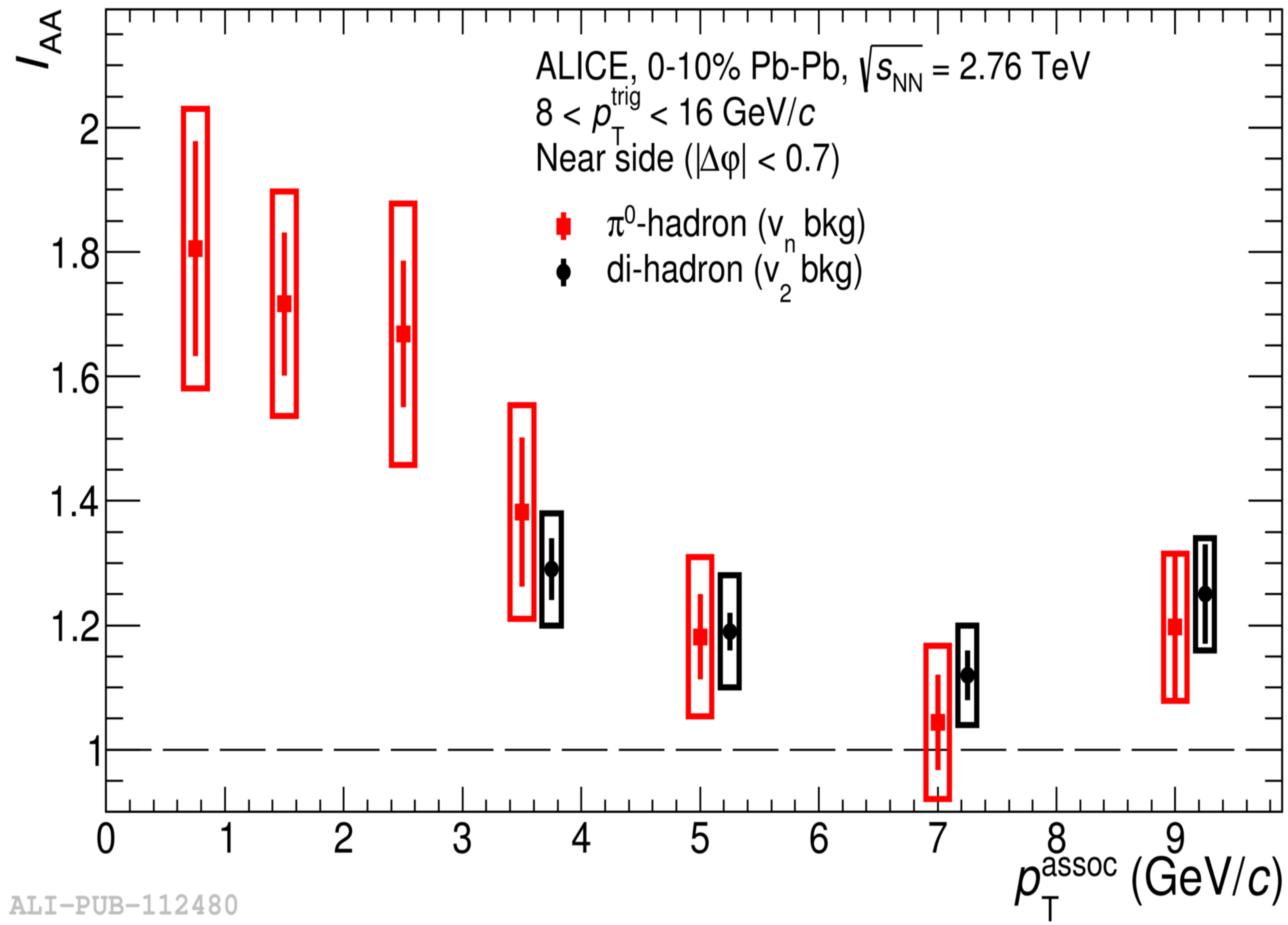
Near side I_{AA}



- Near-side enhancement at high p_T ($I_{AA} \sim 1.2$), $I_{AA} \sim$ 1.2 to 1.8 at low p_T
  - ✓ Change of the fragmentation function?
  - ✓ Change of the quark vs gluon jet ratio?
  - ✓ Bias on the parton p_T spectrum?

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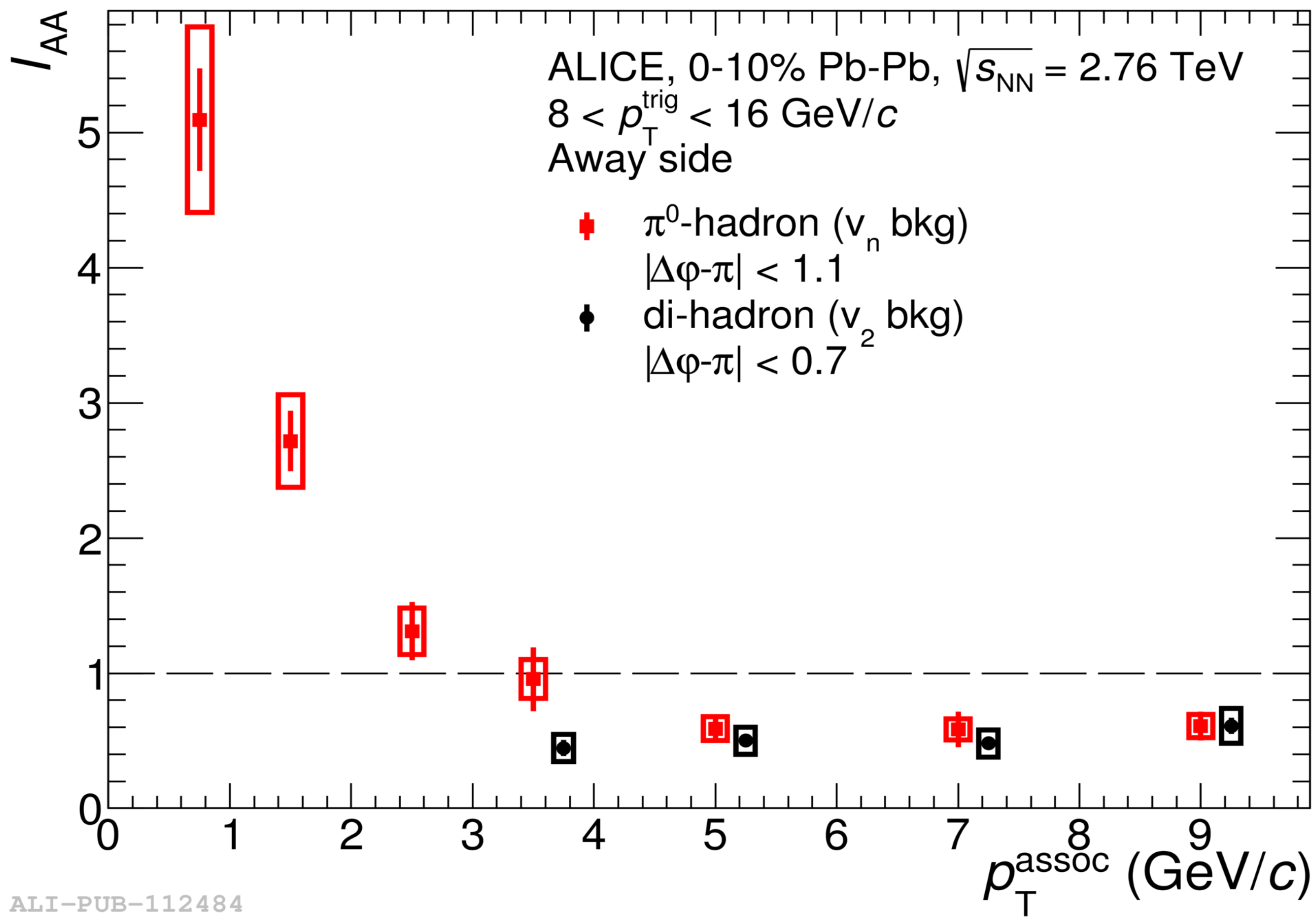
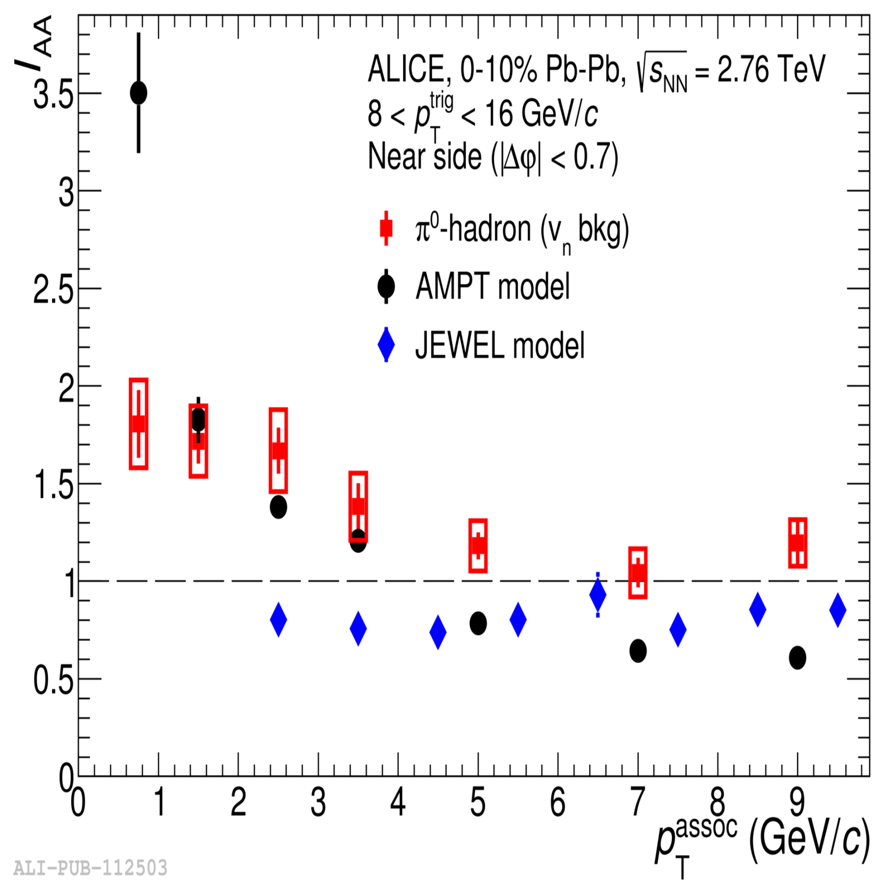
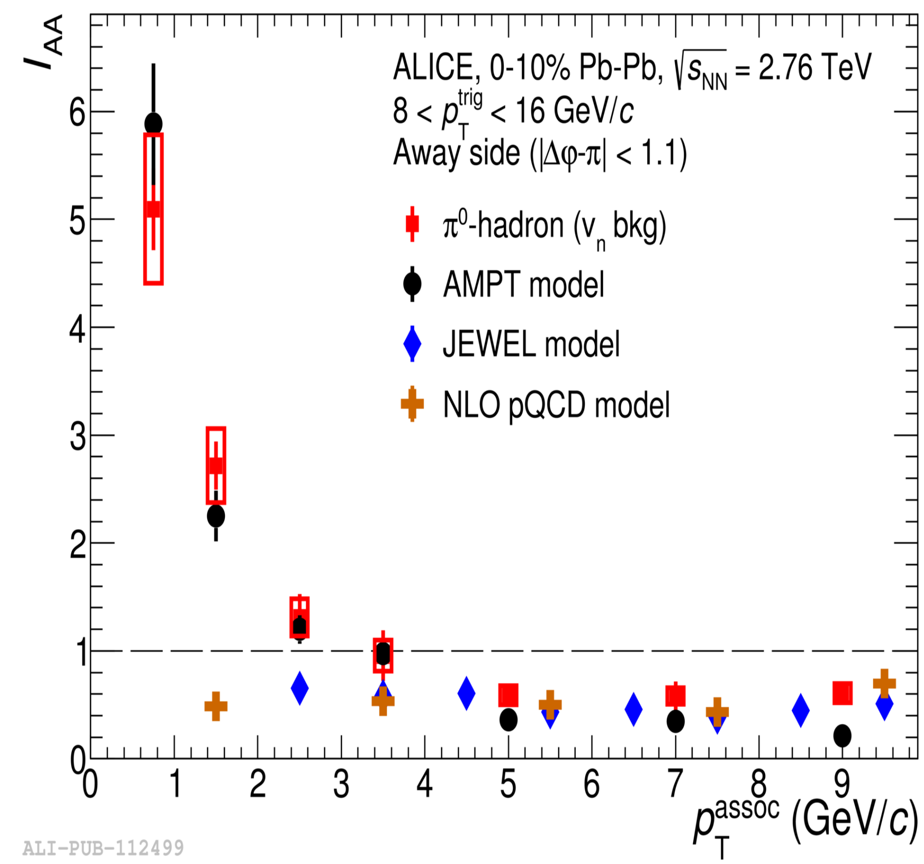
Away side I_{AA}



- Away-side suppressed at high p_T ($I_{AA} \approx 0.6$)
  - ✓ Energy loss in medium
- Enhancement up to $I_{AA} \sim 5$ at low p_T
  - ✓ k_T broadening?
  - ✓ medium-excitation?
  - ✓ fragments from radiated gluons?

I_{AA} compared with models





Near-side

Only AMPT can qualitatively describe the enhancement at low p_T

Away-side

All can qualitatively describe the suppression at high p_T

Only AMPT can describe the enhancement at low p_T

Summary 1

- Azimuthal angle difference $\Delta\varphi$ at midrapidity in pp and central Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV have been measured.
- The per-trigger yield modification factor, I_{AA}, has been measured for the near and away side in 0–10% most central Pb–Pb collisions .
  - ✓ Extend the results to low p_{T}, both near and away side show enhancement.
  - ✓ Measured I_{AA} comparison to models, away side suppression reproduced by JEWEL, NLO and AMPT but enhancement on near and away side only qualitatively reproduced by AMPT.

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Jet-like correlations with neutral pion triggers in pp and central Pb–Pb collisions at 2.76 TeV

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ALICE Collaboration *

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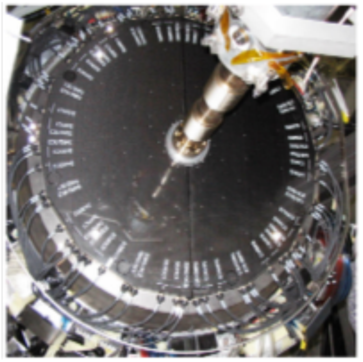
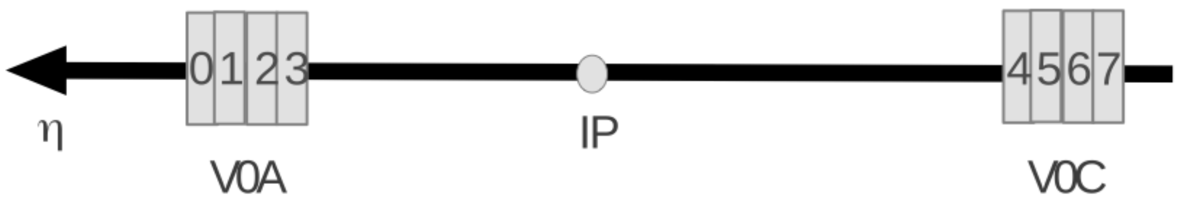
Analysis strategy

v_2 is measured in event plane method. The Forward VZERO system is used to reconstruct the event plane. The large η gap between EMCal and VZERO is able to ensure the quality of flow measurement by reducing the non-flow contribution. EP resolutions are studied in 3-sub-event method.

- The ALICE VZERO system, consists of two scintillator arrays at forward asymmetric positions, VZERO-A ($2.8 < \eta < 5.1$) and VZERO-C ($-3.7 < \eta < -1.7$). The VZERO system is used as a trigger source, and also plays an important role in monitoring beam conditions and measuring luminosity, multiplicity, centrality and **event plane direction**.

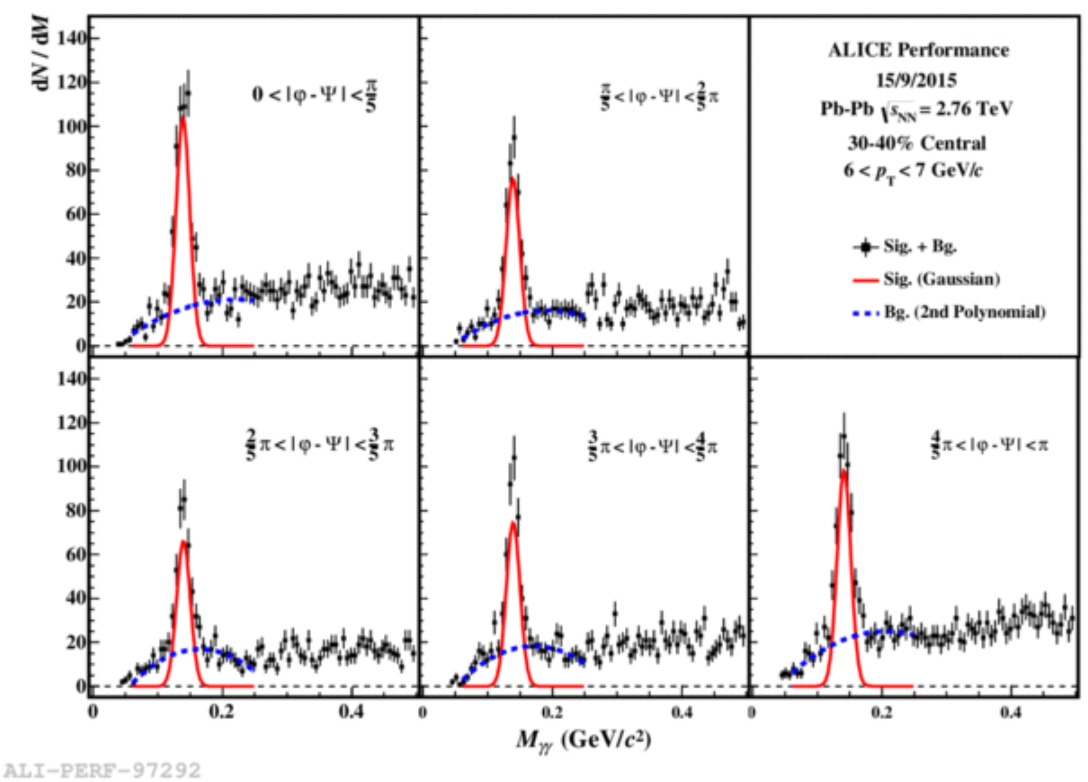


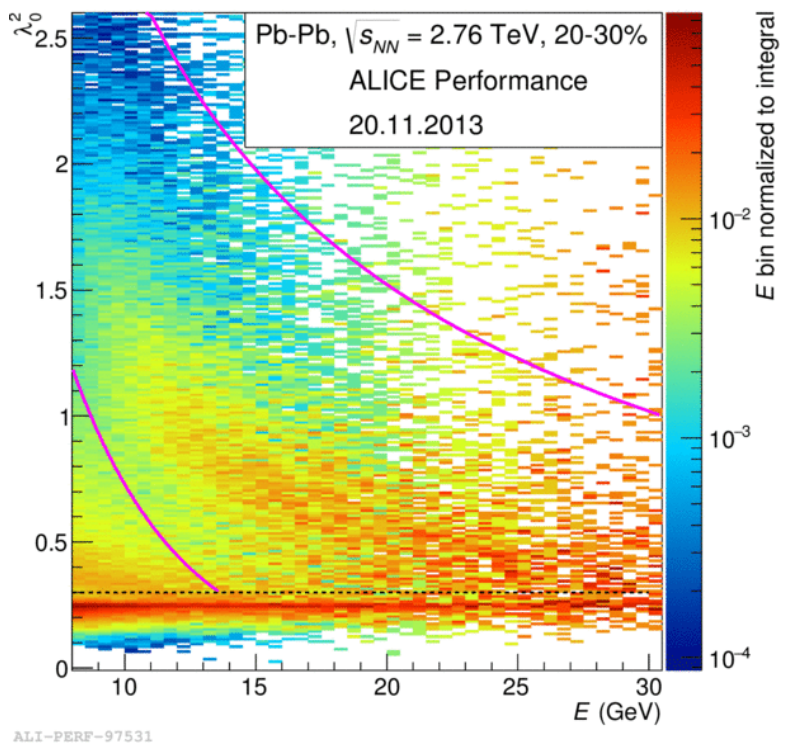


$$\text{Resolution V0A} = \sqrt{\frac{<\cos[2(\psi^{V0A}-\psi^{ring4})]><\cos[n(\psi^{V0A}-\psi^{ring7})]>}{<\cos[2(\psi^{ring4}-\psi^{ring7})]>}}$$

$$\text{Resolution V0C} = \sqrt{\frac{<\cos[2(\psi^{V0C}-\psi^{ring0})]><\cos[n(\psi^{V0C}-\psi^{ring3})]>}{<\cos[2(\psi^{ring0}-\psi^{ring3})]>}}$$

π^0 selection





- V2 clusterization with Eseed/Ecell = 300/150 MeV
- Ncell>1, Eclust>1 GeV, M02<0.5
- Gaussian+poly2 fit, within 3σ

- V1 clusterization with Eseed/Ecell = 300/150 MeV
- Ncell>2, M02>0.3, shower shape cut according to NLM (1 or 2)

Cases of with or without slipt method, NLM=1,2 or 1+2 are studied.

v_2 extraction

After obtaining the information of π^0 yield in different azimuthal angle intervals, one can use function

$$Yield(\Delta\phi) = A(1 + 2v_2 cos2\Delta\phi) \quad (1)$$

Center value

to fit the $\Delta\phi$ depencence of π^0 yield and then extract the v_2 parameter. Here $\Delta\phi$ denotes the difference between the azimuthal angle of the emitted π^0 and the event plane angle. In this analysis, this method is chosen to measure the center value of v_2 . In addition, another two formulas (with sine term and with v4 term) are also used to fit. Sine term is used to check the event plane performance, while v2 extracted from the equation with v4 term is used to estimate the systematic uncertainty.

$$Yield(\Delta\phi) = A(1 + 2v_2 cos2\Delta\phi + 2v_2^{sin} sin2\Delta\phi) \quad (2)$$

EP performance check

$$Yield(\Delta\phi) = A(1 + 2v_2 cos2\Delta\phi + 2v_4 cos4\Delta\phi) \quad (3)$$

Systematic check of v_2 extraction

For those mid-p_T π^0 (identified by reconstructing invariant mass of two photons), there is an alternative way to measure v_2, which studies the correlation between the invariant mass of the photon pairs and their corresponding cos$2\Delta\phi$. Such correlation can be fitted by

$$v_2^{tot}(m_{\gamma\gamma}) = v_2^{sig}\frac{N_{sig}}{N_{tot}}(m_{\gamma\gamma}) + v_2^{bg}\frac{N_{bg}}{N_{tot}}(m_{\gamma\gamma}), \quad (4)$$

Systematic check of v_2 extraction

where v_2^{sig} is the flow information. In this analysis, this method is also used to estimate the systematic uncertainty of π^0 v_2 in mid-p_T range.

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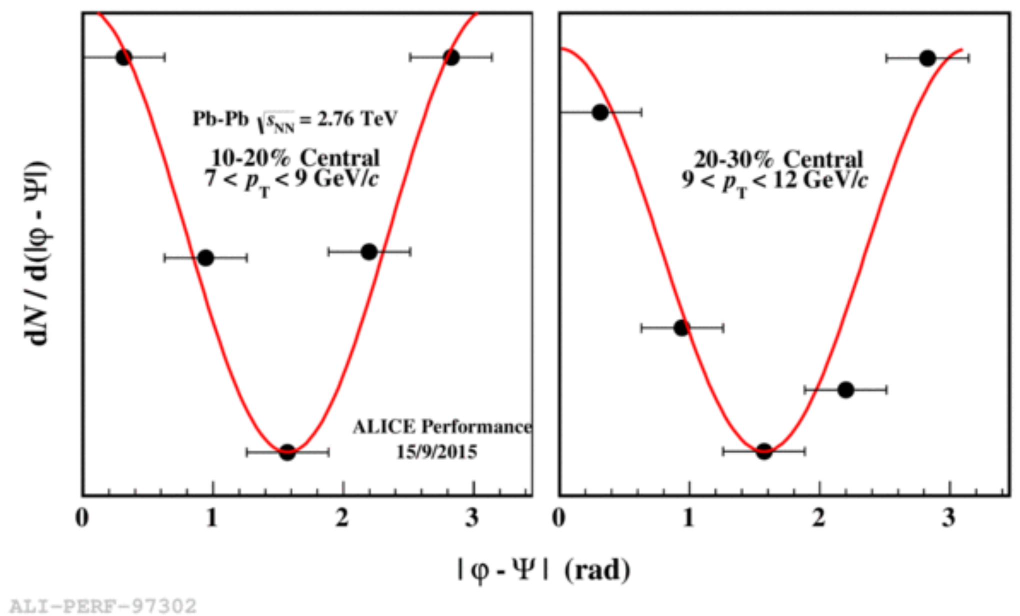
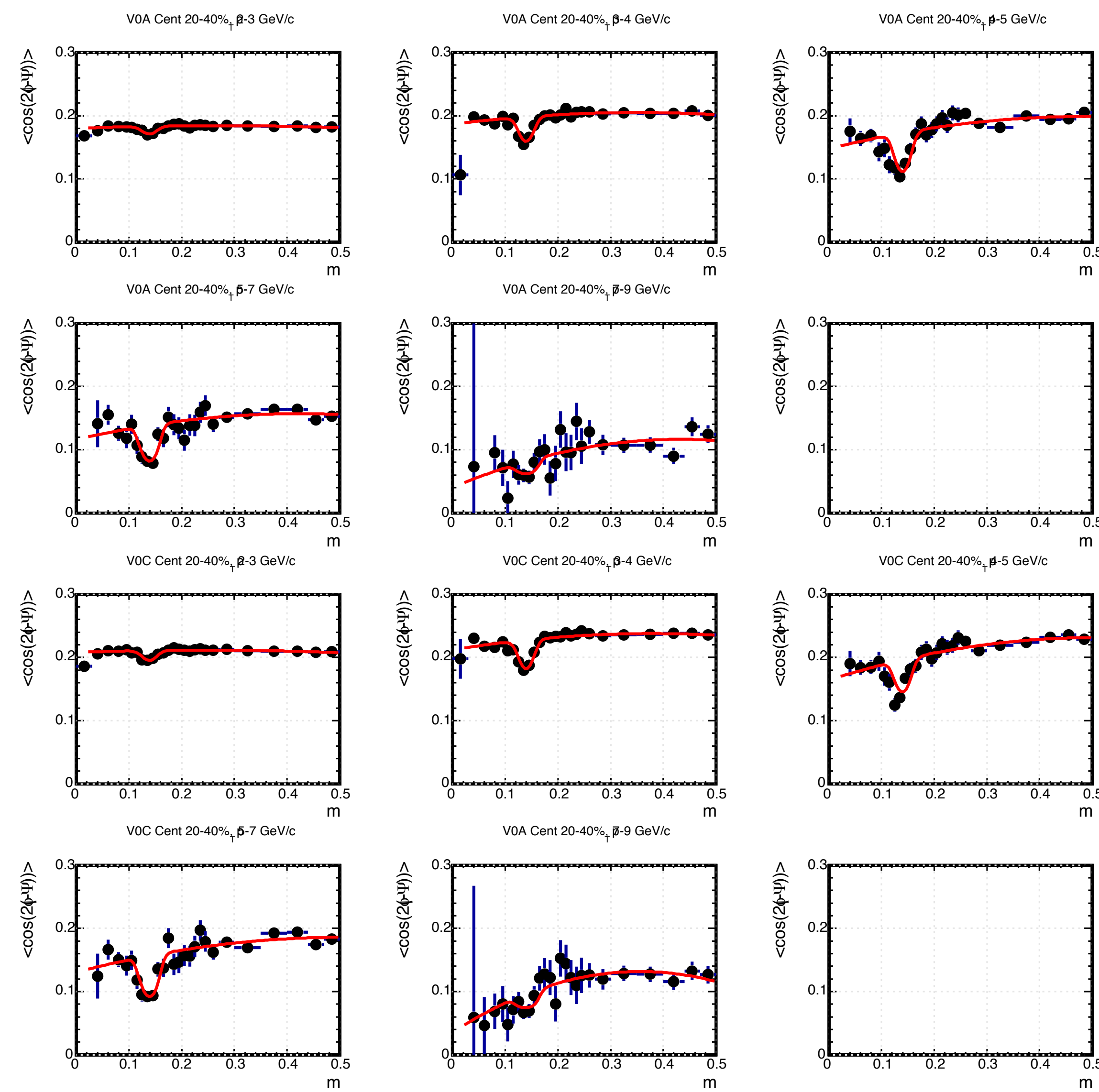
v_2 extraction

Fit $\cos 2\Delta\phi$ vs $m^{\gamma\gamma}$

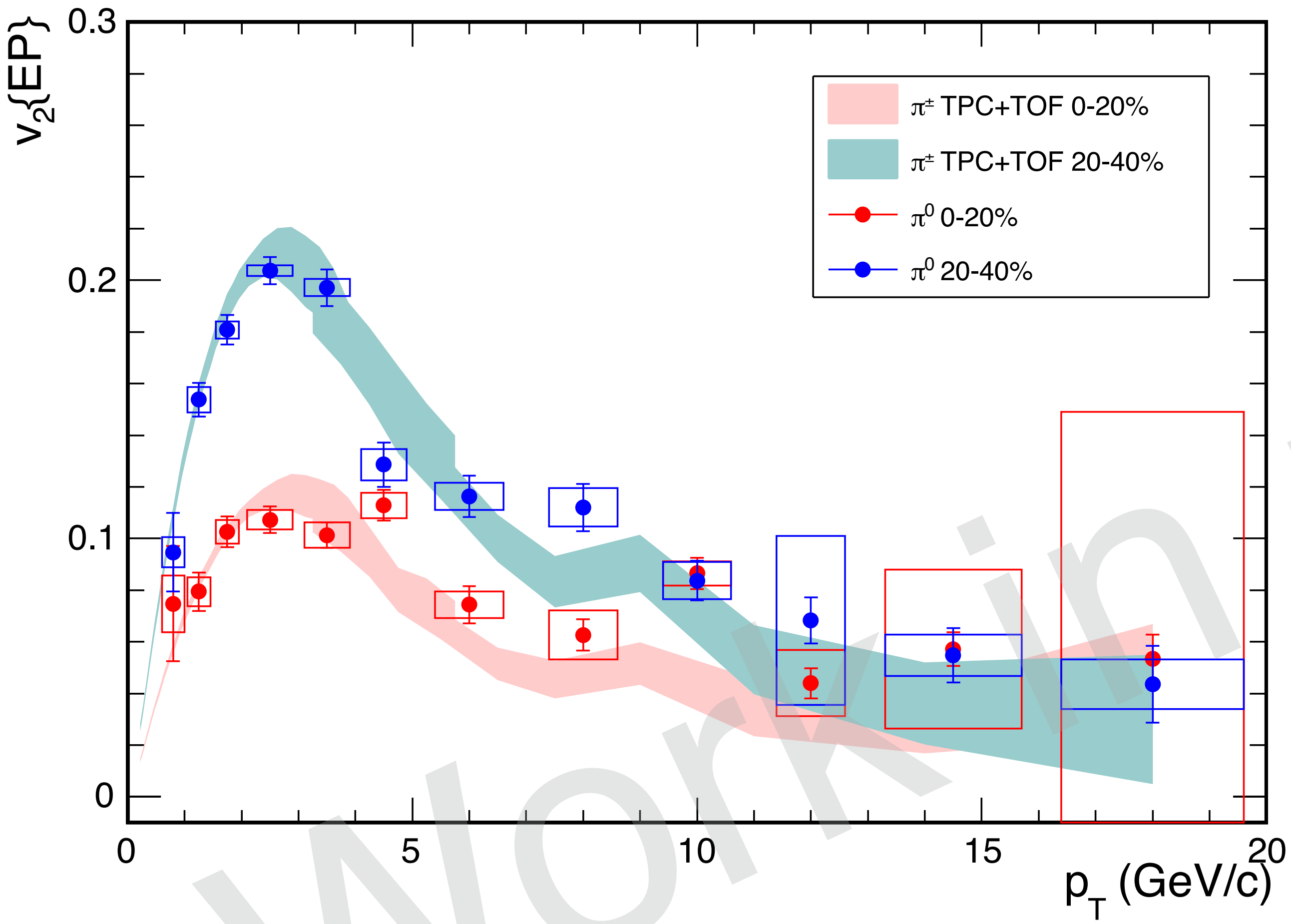
Fit $dN/d\Delta\phi$

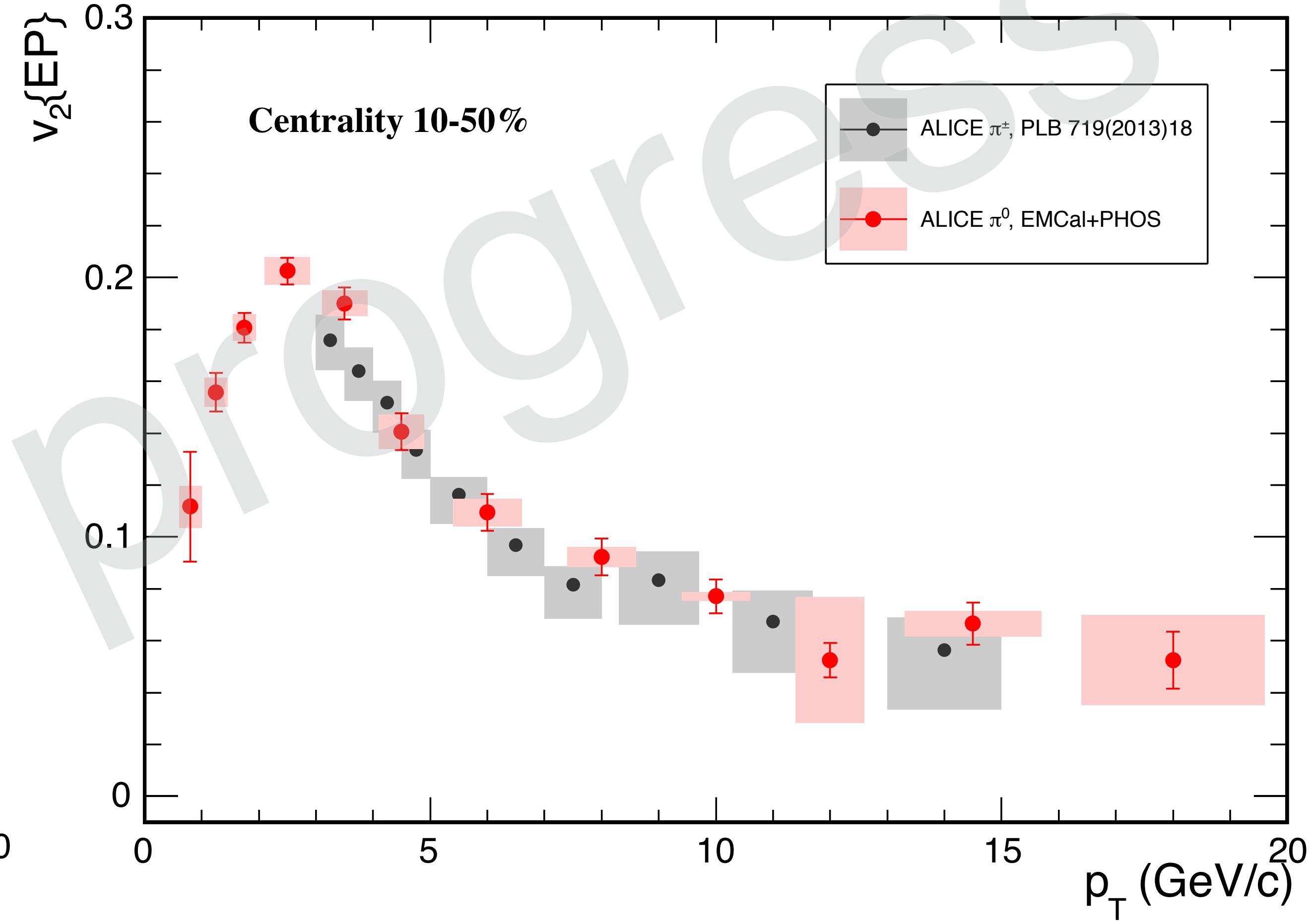




Azimutal anisotropy are clearly observed at full p_T range

Combined (EMCal+PHOS+PCM) π^0 v_2 results





v_2 of π^0 are consistent with that of charged π within systematic uncertainty

Charged pion results:
Nuclear Physics A 904–905 (2013) 483c–486c

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Summary 2

- π^0 v_2 at ALICE in wide p_T coverage (up to 20 GeV/c) are presented, in both narrow (5-10%, 10-20%…) and wide (0-20%, 20-40%) centrality intervals

- The results are consistent with charged π results within the uncertainties

Is it possible that v_2 between charged and neutral mesons ($\pi^{0/+-}$, $K^{0/+-}$…) can be different?

- v_2 difference between particles and anti-particles have been found at RHIC-STAR, in particular, at BES low energies
- STAR claims that no difference of v_2 between $K_s^{0/+-}$ within the uncertainties

- Same constituent quarks -> same quark flow
- Different charge -> different interactions
- [low p_T] Chiral Magnetic Effect could give rise to the difference?