Angular correlation results from ALICE

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MTA Wigner RCP

on behalf of the ALICE Collaboration

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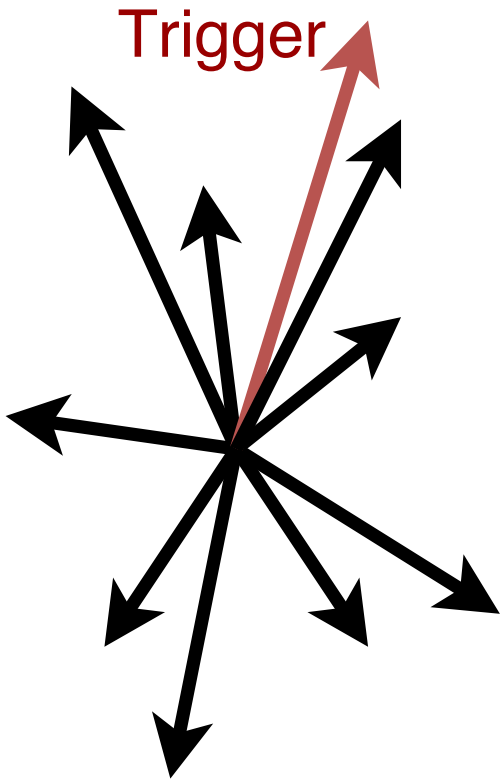
This work has been supported by the Hungarian NKFIH/OTKA K 120660 grant.

Analysis strategy

- Trigger and associated particle
- Azimuthal ($\Delta\varphi$) difference
- Pseudorapidity ($\Delta\eta$) difference



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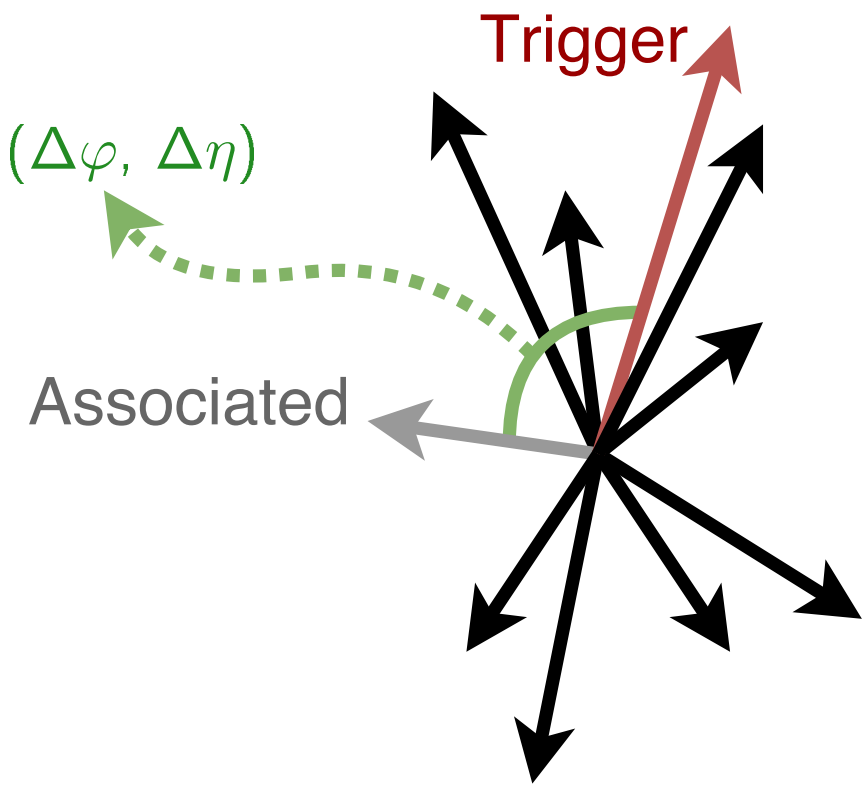
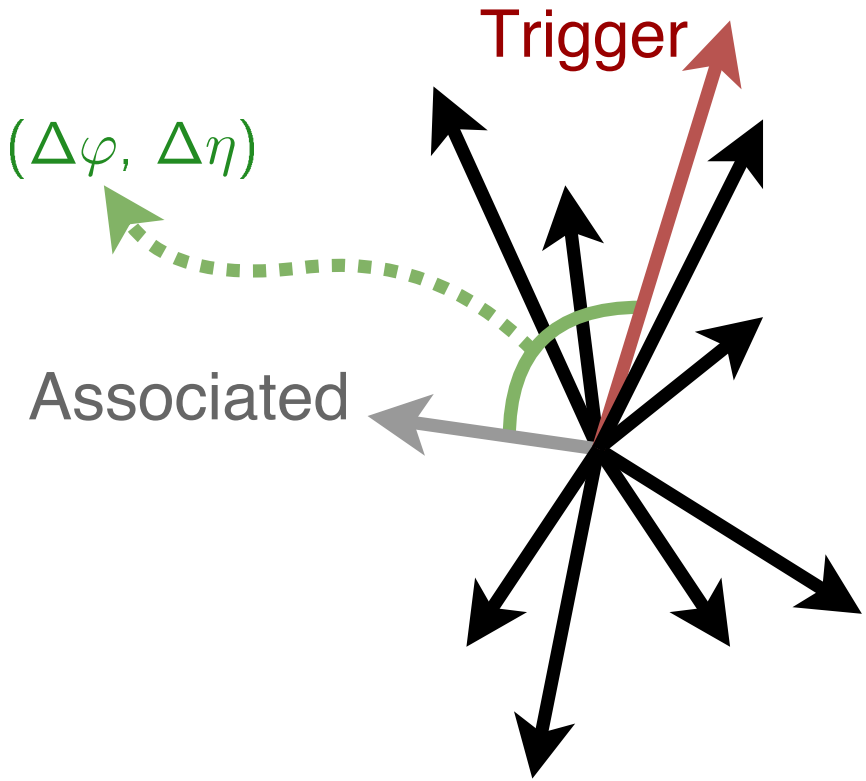


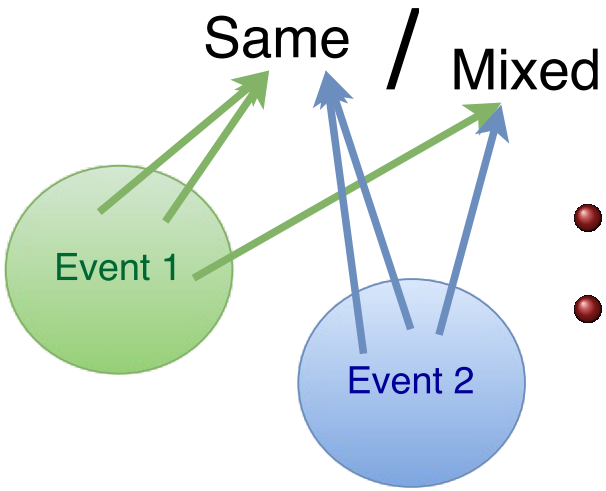
Analysis strategy

- Trigger and associated particle
- Azimuthal ($\Delta\varphi$) difference
- Pseudorapidity ($\Delta\eta$) difference
- Associated yield per trigger:

$$\frac{1}{N_{trig}}\frac{d^2N_{assoc}}{d\Delta\eta d\Delta\varphi} = \frac{S(\Delta\eta,\Delta\varphi)}{\alpha M(\Delta\eta,\Delta\varphi)}$$

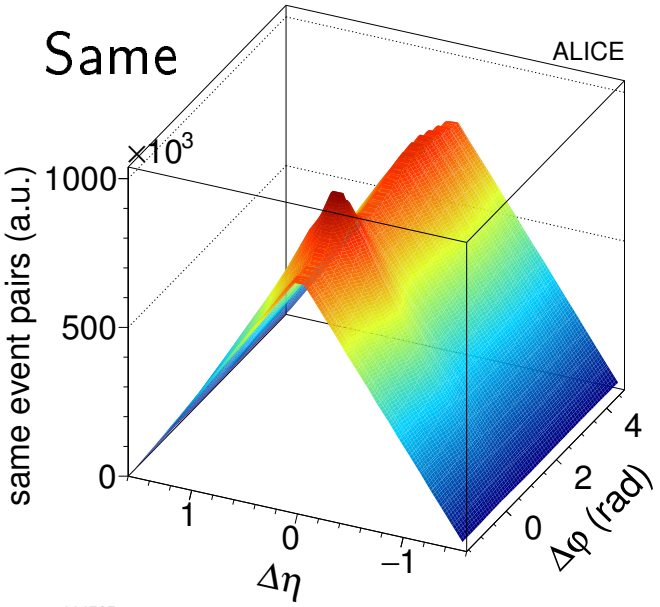
- Denominator normalized to 1 by α at $(\Delta\varphi, \Delta\eta) = (0, 0)$

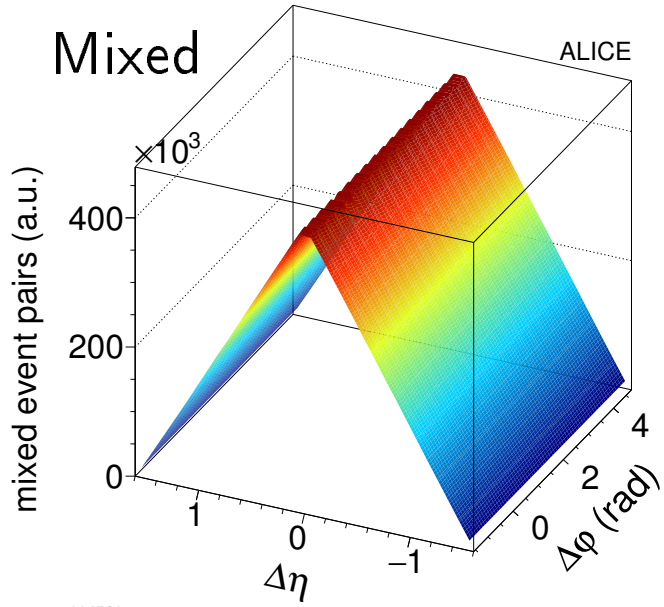




- $\Delta\varphi$–$\Delta\eta$ distribution calculated in both
- Division removes acceptance effects and inefficiencies

Example from Pb–Pb





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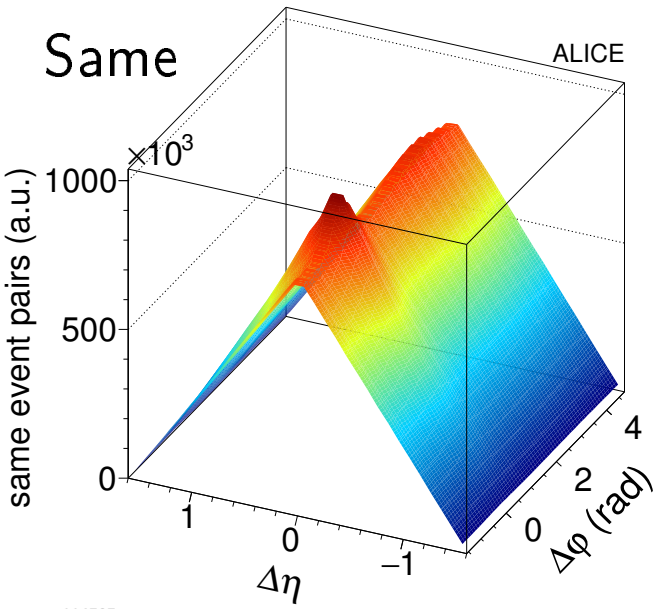
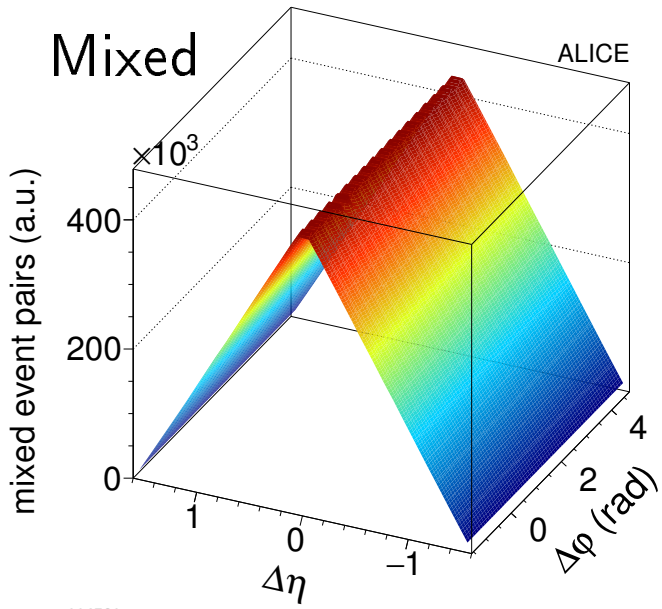


ALI-PUB-114787



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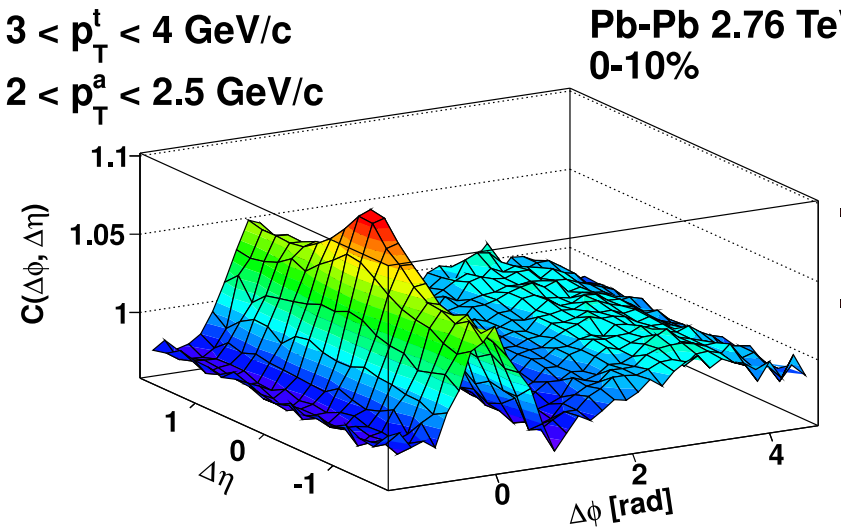

ALI-PUB-14107

- Useful for studying jets or flow
- Useful for studying hard or soft processes

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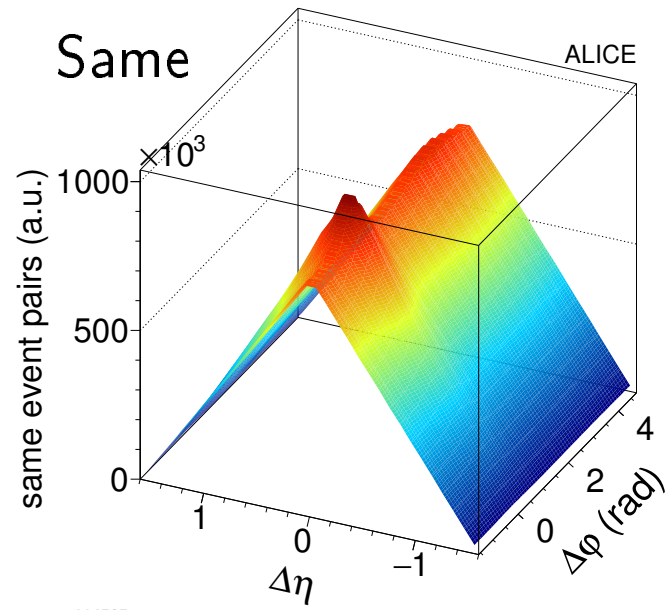

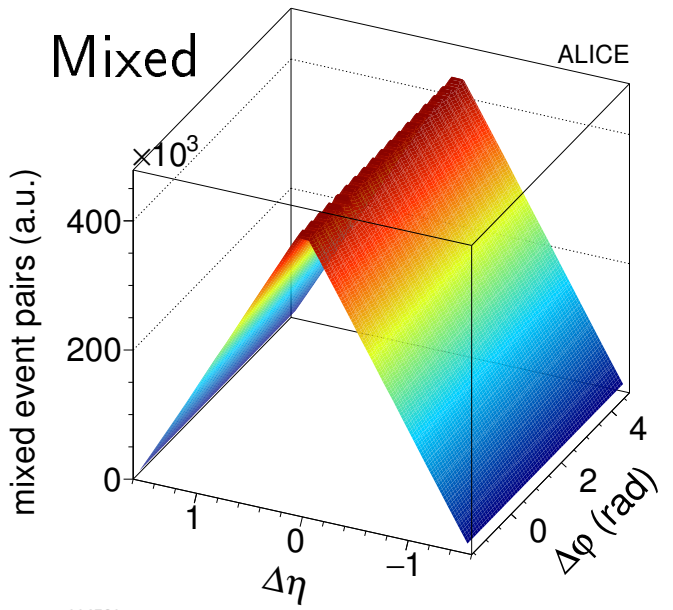

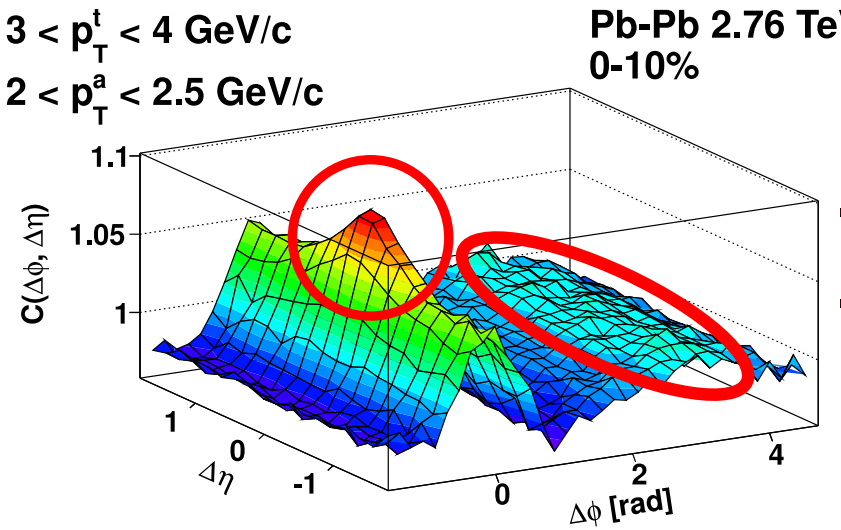

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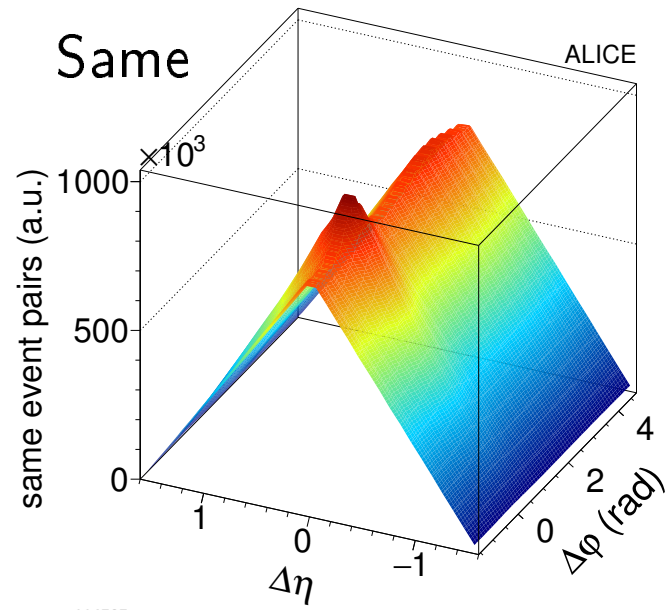

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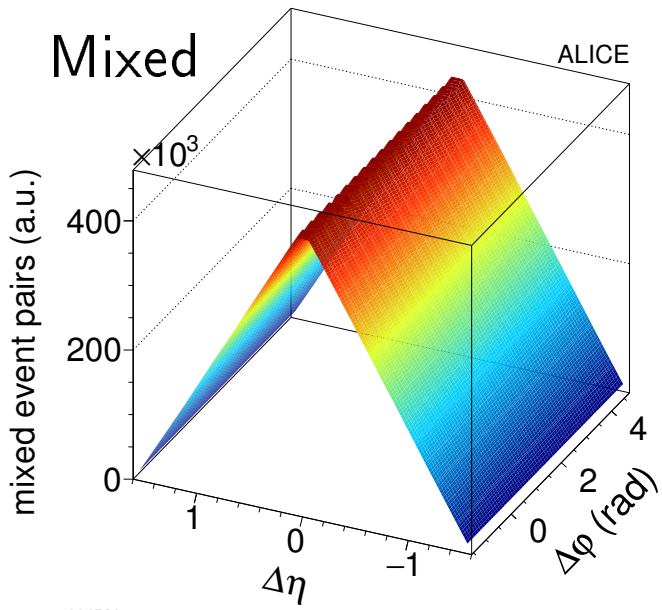

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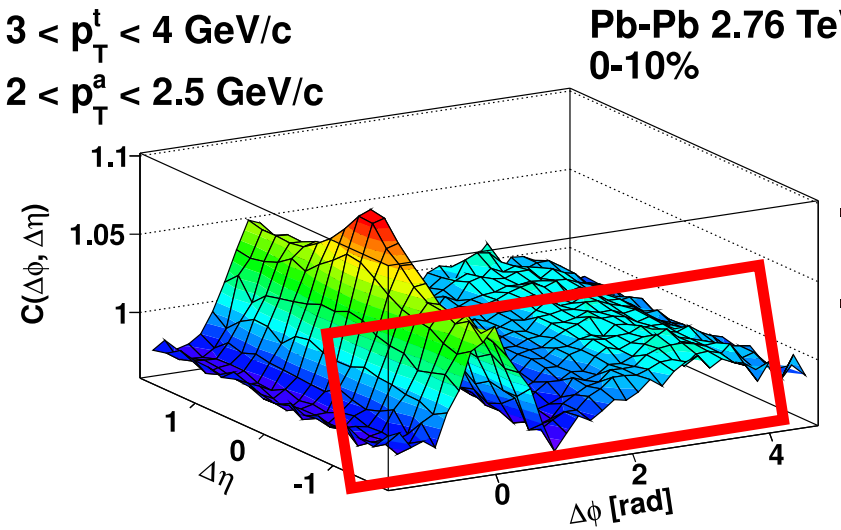

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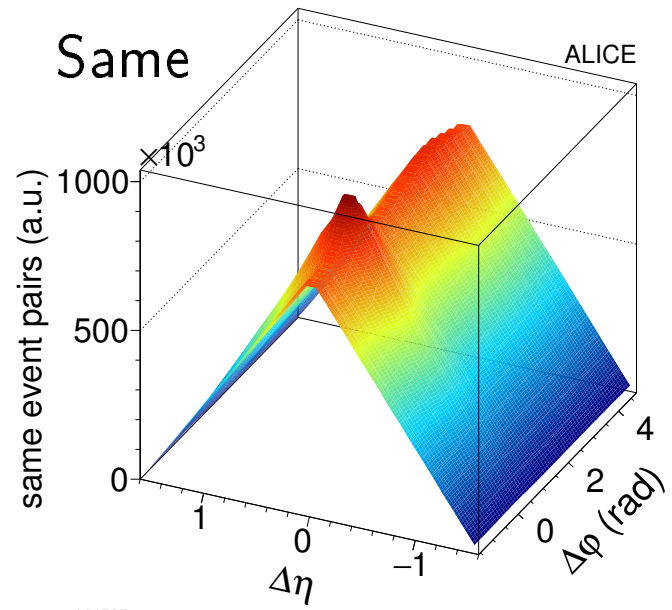

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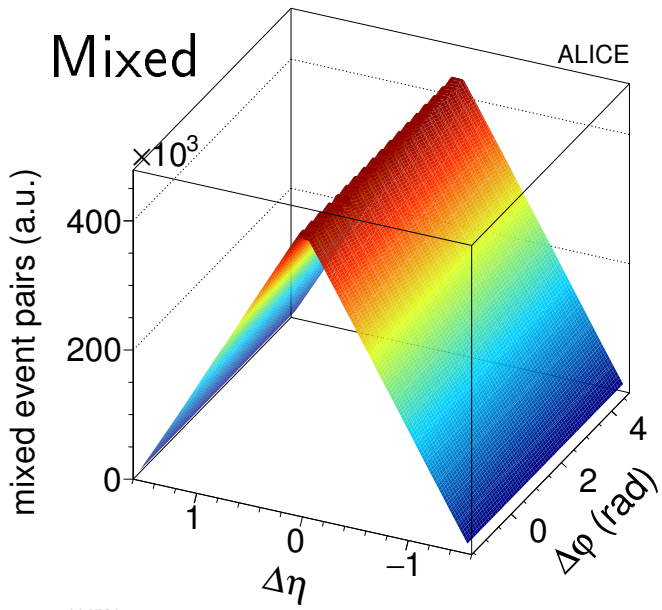

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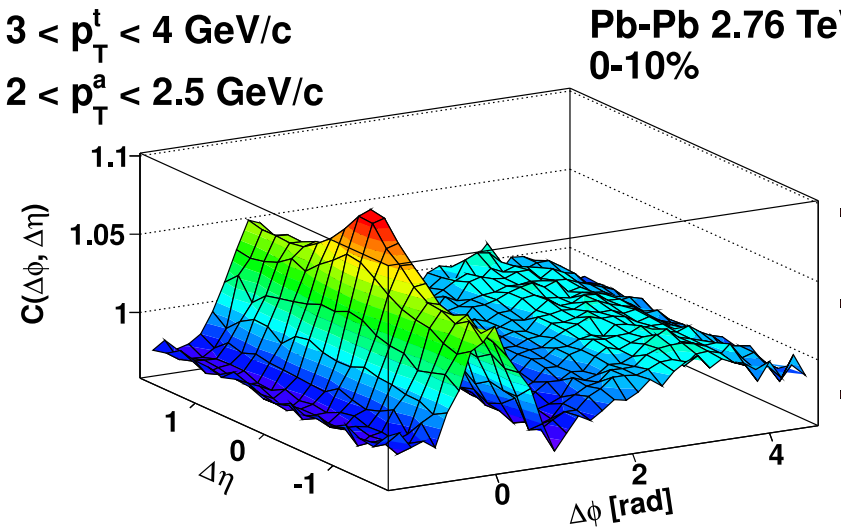
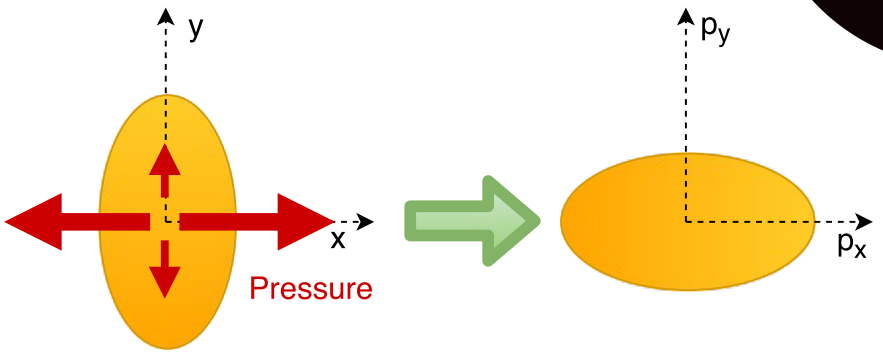


ALI-PUB-14107

- Useful for studying jets or flow
- Useful for studying hard or soft processes
- One can be the background of the other

Flow

- QGP:
  - Strongly interacting
  - Almost perfect fluid
- Initial spatial asymmetry
  $\Rightarrow$ Asymmetric particle distribution



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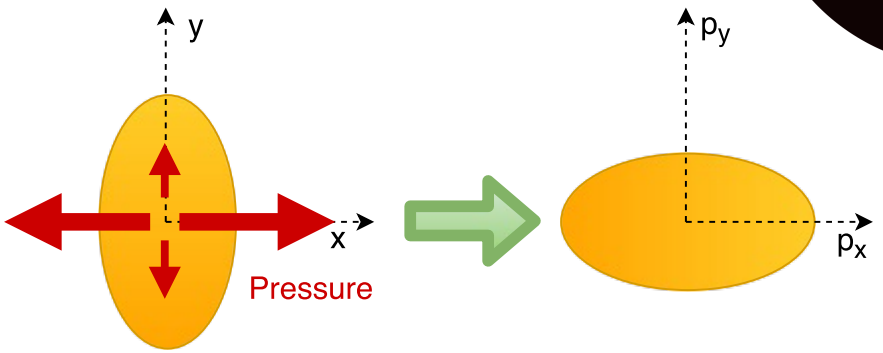
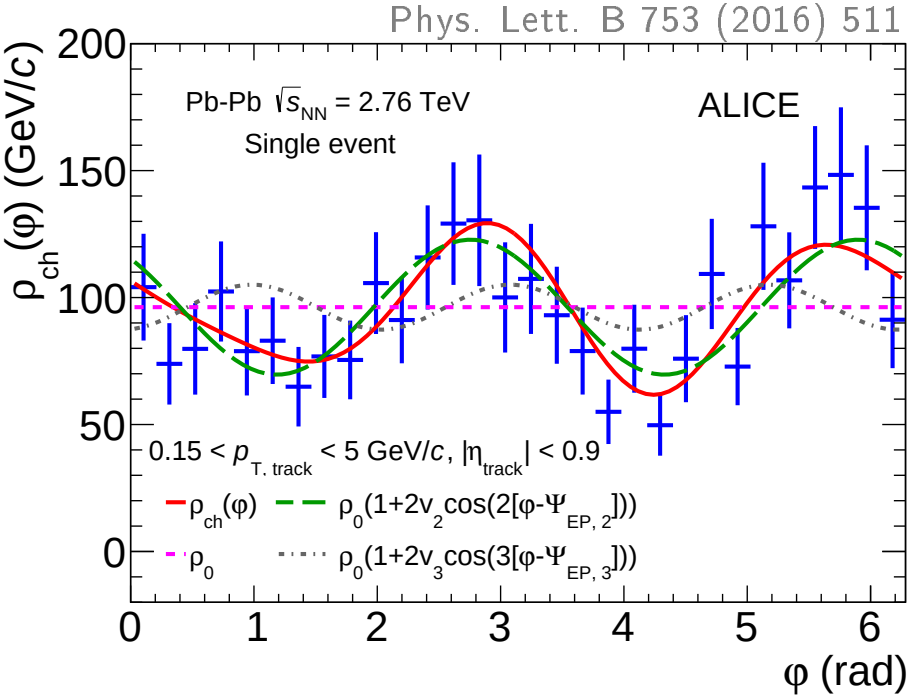
- Measured by the Fourier coefficients:
  $2\sum_{n=1}^{\infty} v_n \cos[n(\varphi - \Psi_n)]$
- Can even be visible event by event



Phys. Lett. B 753 (2016) 511



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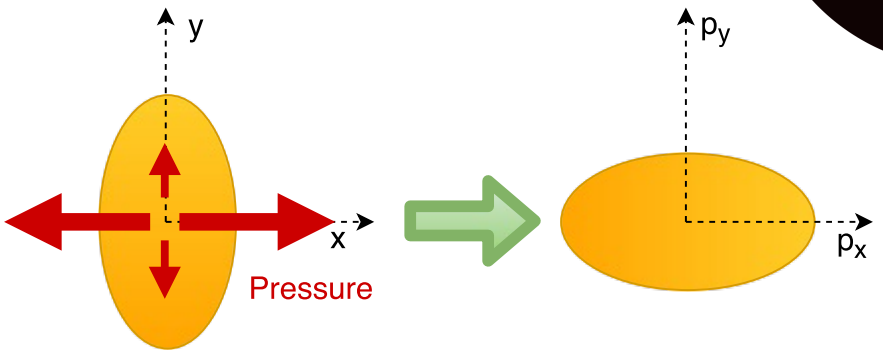
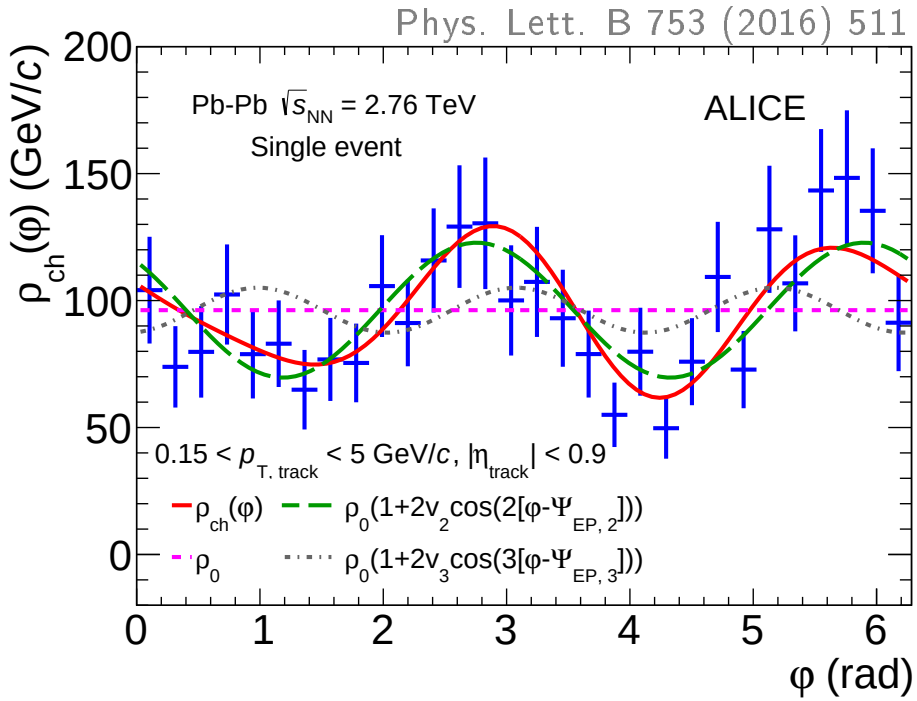


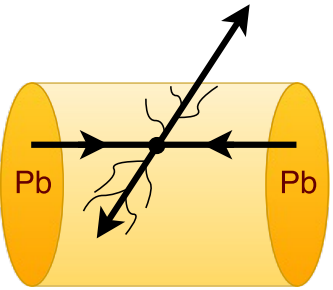


- In Pb–Pb considered as a sign of collectivity
- Do we see the same in pp or p–Pb?

What can we learn from angular correlations?

Jets

- Quarks from initial collision fragment into collinear particles $\Rightarrow$ jets
- Jets interacting with the QGP lose energy $\Rightarrow$ jet-quenching



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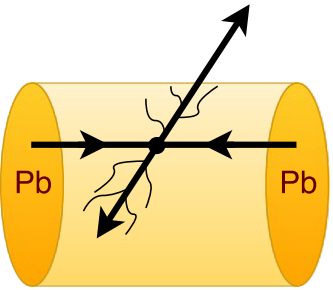
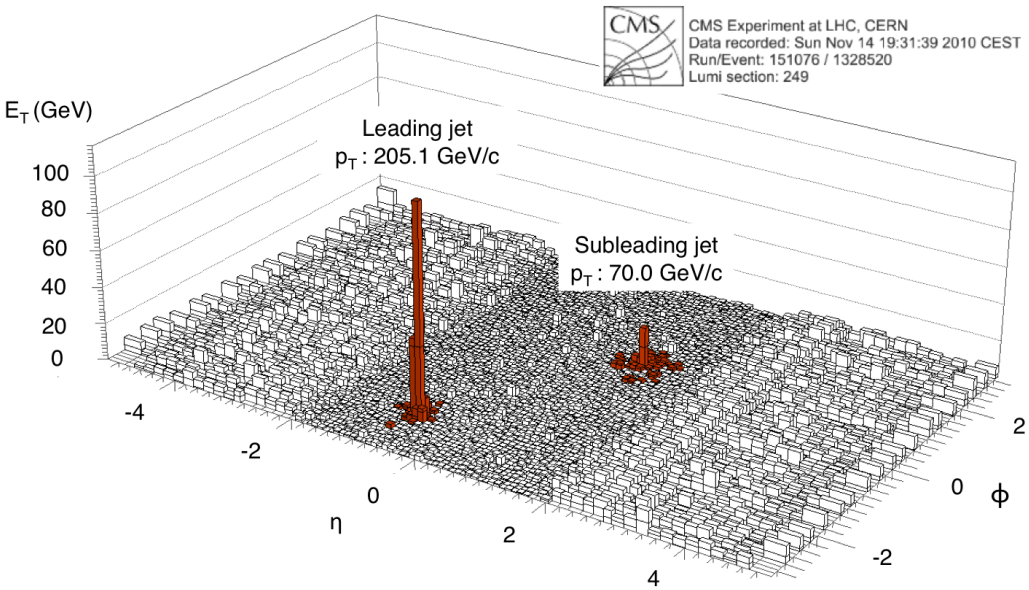
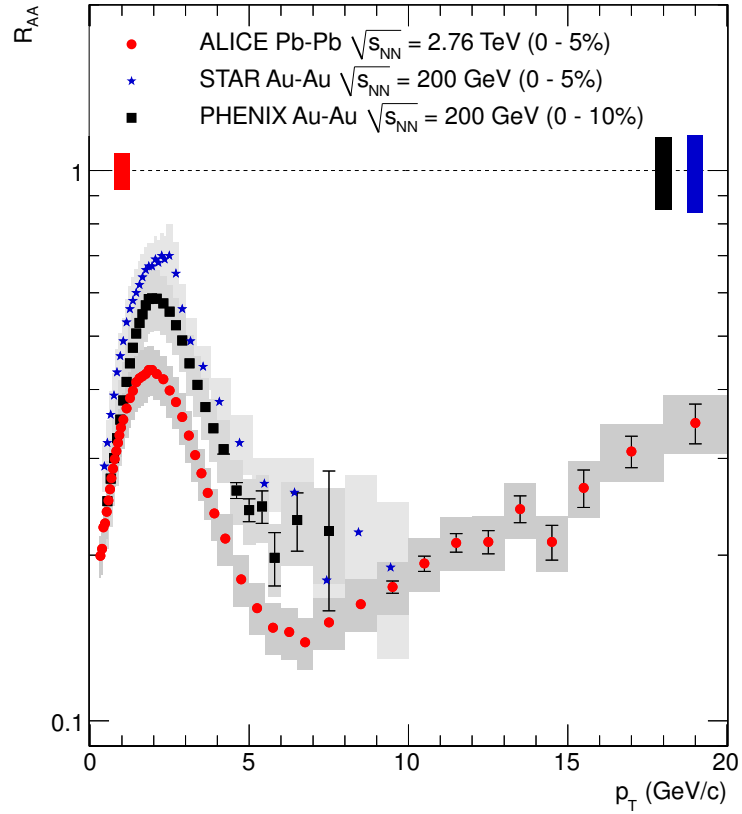
- Yield of high p_{T} particles in Pb–Pb is smaller than scaled vield from pp





Phys. Rev. C84 (2011) 024906



Phys. Lett. B 696 (2011) 30-39

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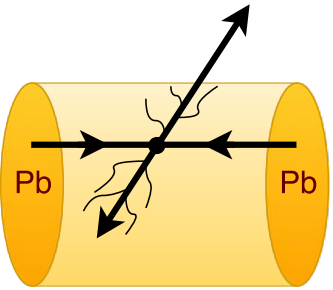

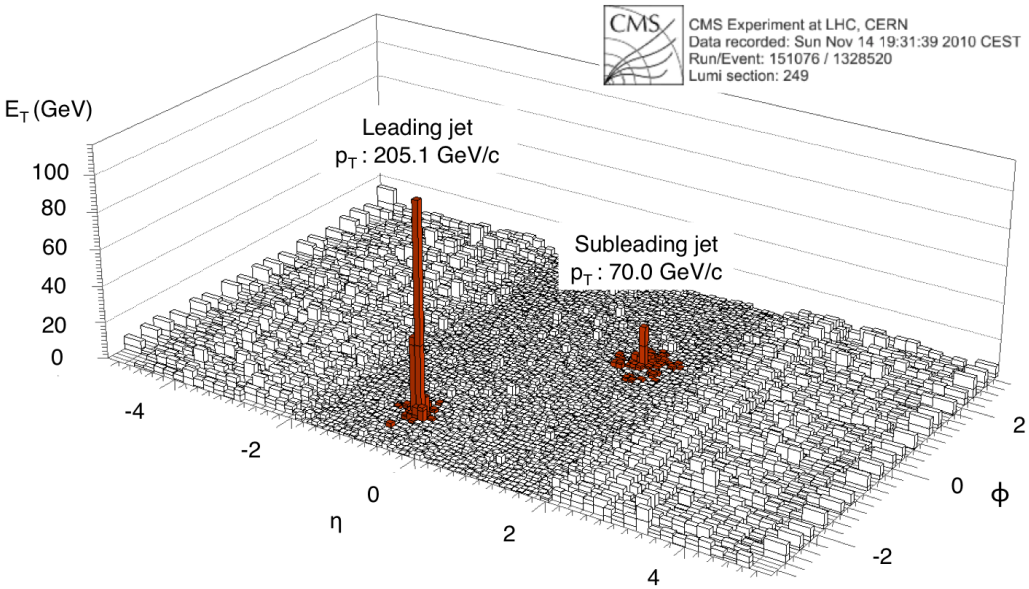

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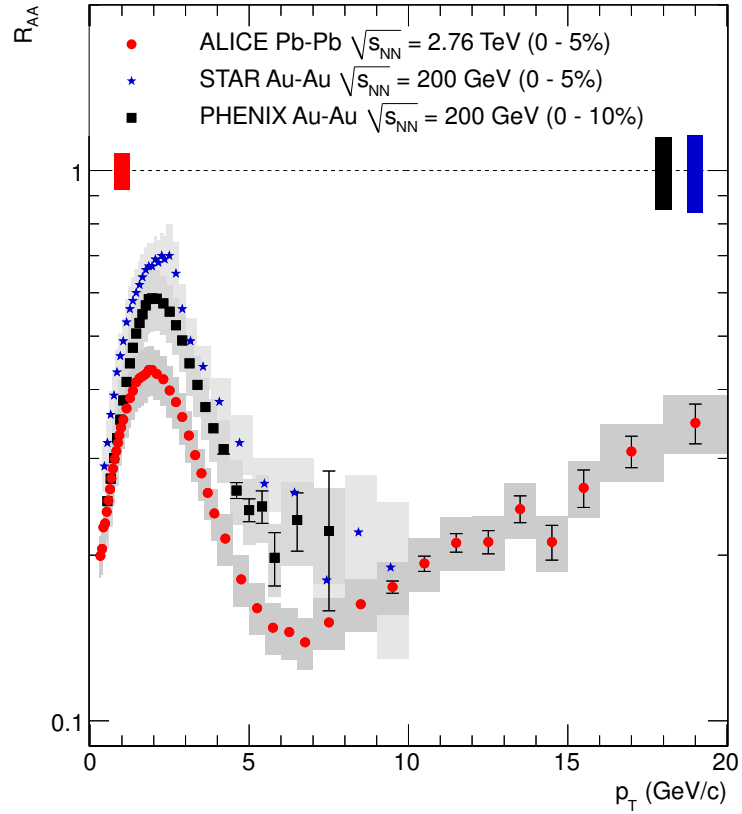

Phys. Lett. B 696 (2011) 30-39

- How is the quenched energy dissipated?

What can we learn from angular correlations?

Possible studies with angular correlations

- Low-energy processes in the jets
- Large angle scatterings
- Inner structure of the jet
- Path-length dependence
- Collectivity in small systems
- Multiplicity dependence of flow
- Species dependence of flow
- ...

How do we achieve that?

Trigger and associate selection

- (Identified) hadron – (identified) hadron
- Jet – hadron
- Hadron – jet
- More refined probes (e.g. heavy flavor electrons, photons, b-jets)

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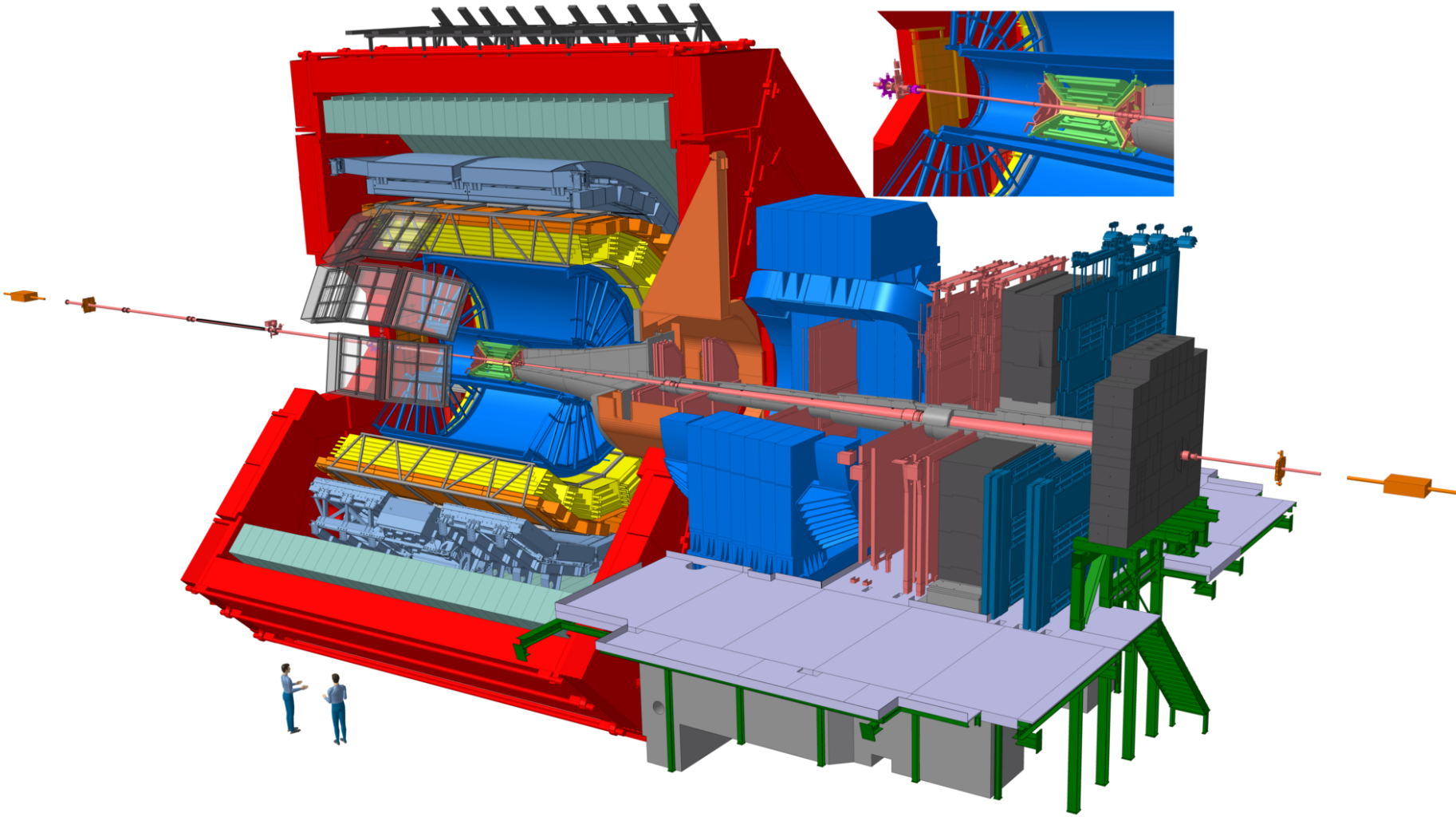
Observables

- 1D or 2D per trigger yield
- I_{AA} or I_{CP}
- Peak width
- Peak shape

As a function of

- Multiplicity or centrality
- p_{T}
- Event plane
- Energy
- Collision system

The ALICE detector



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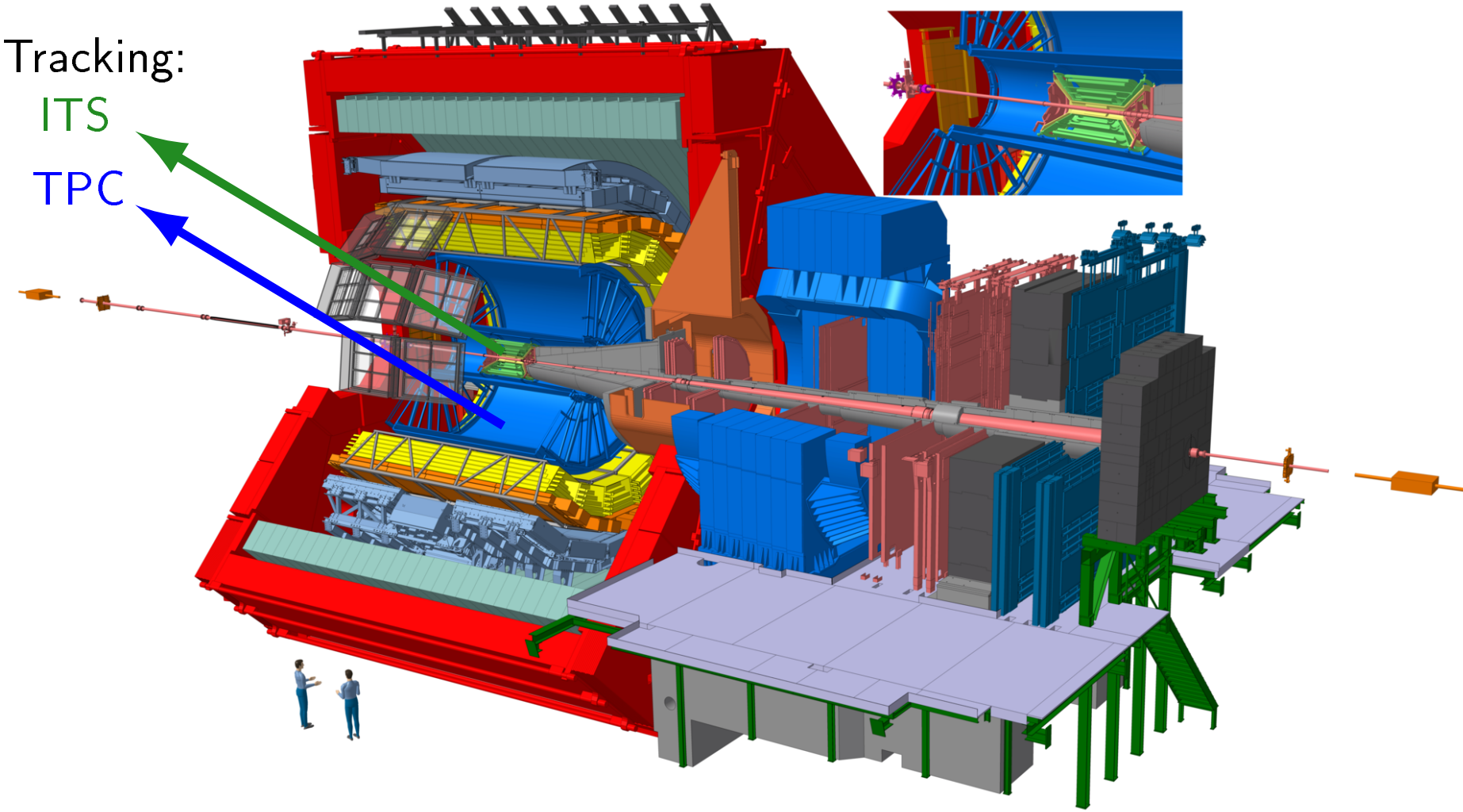

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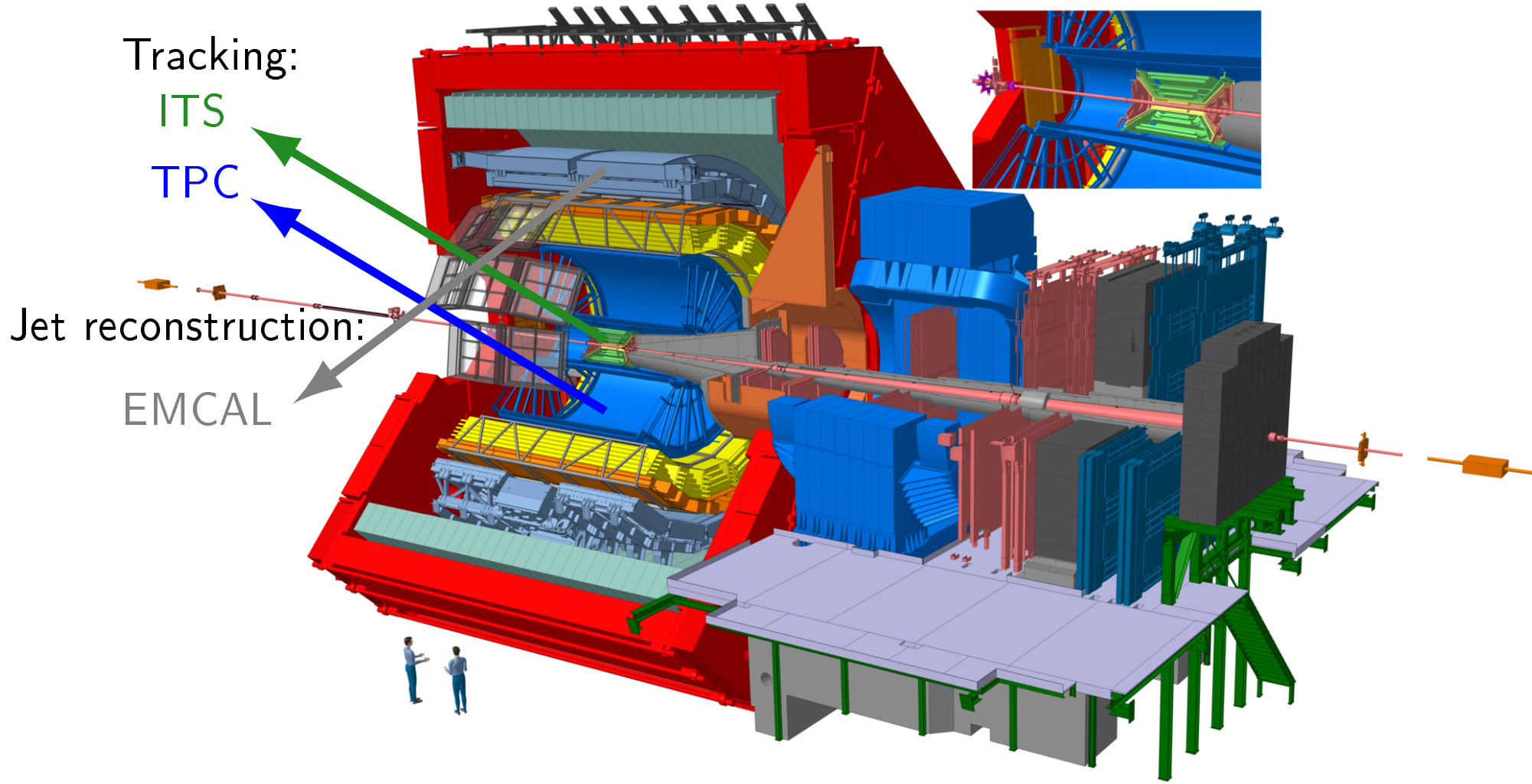

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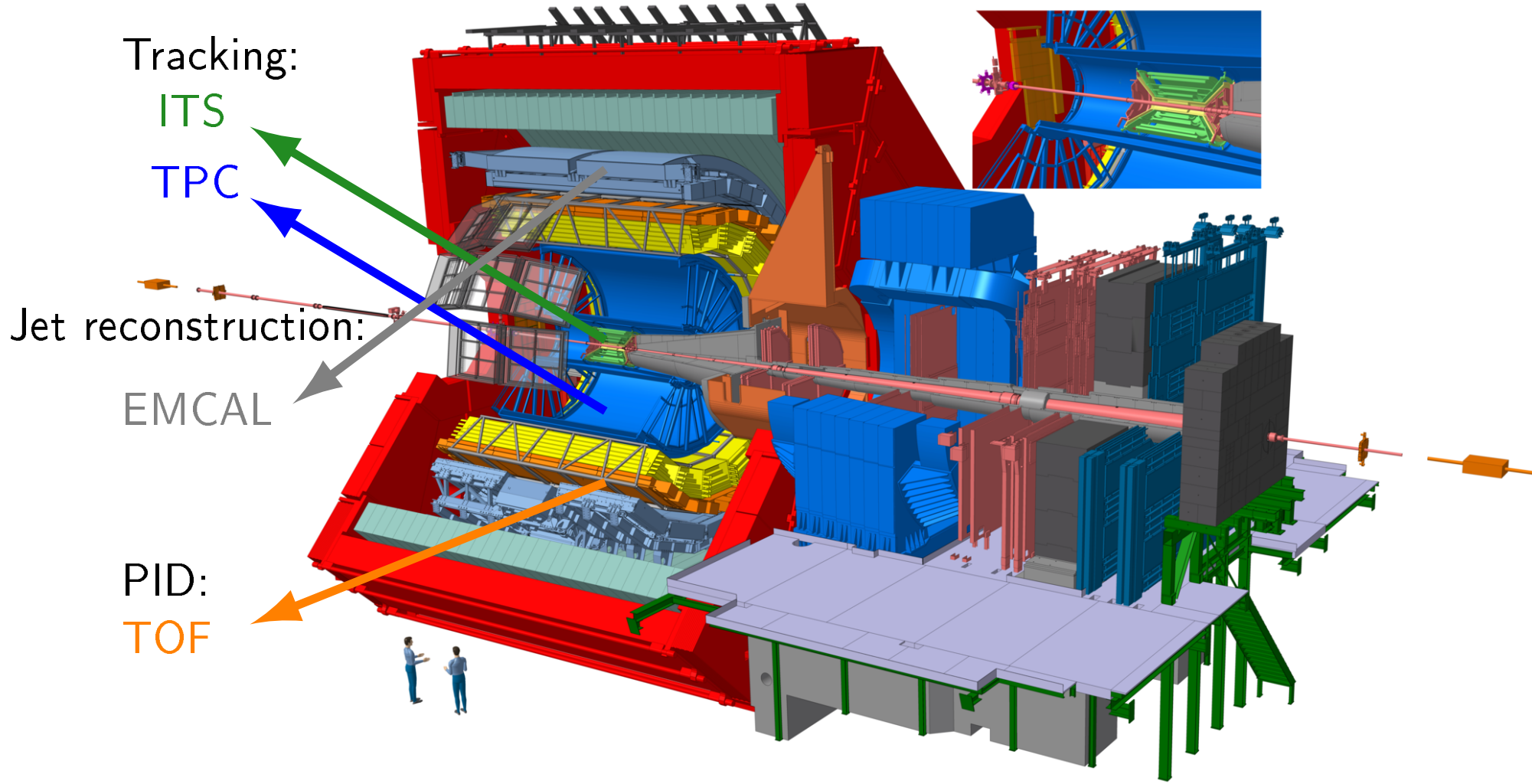

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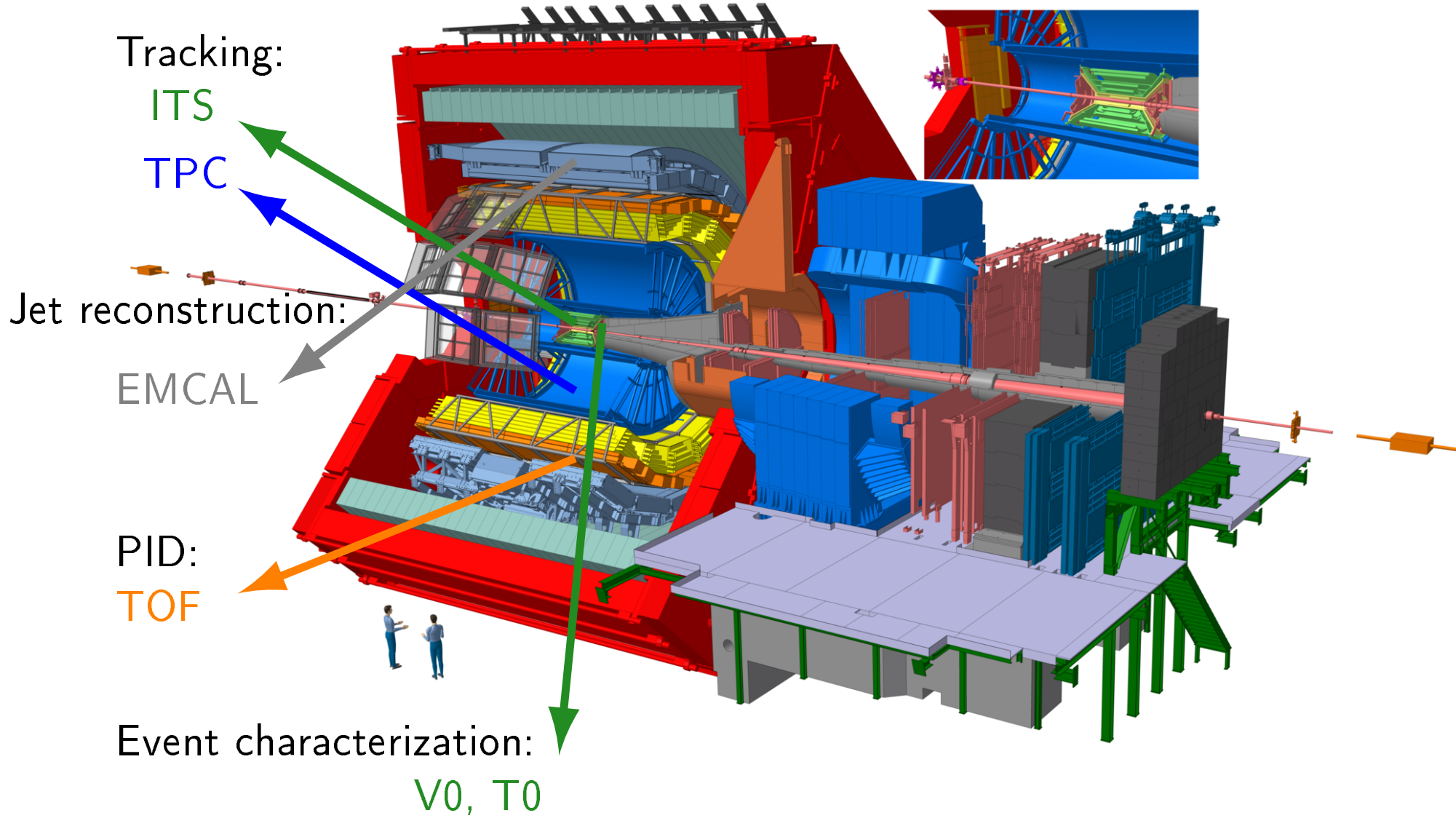
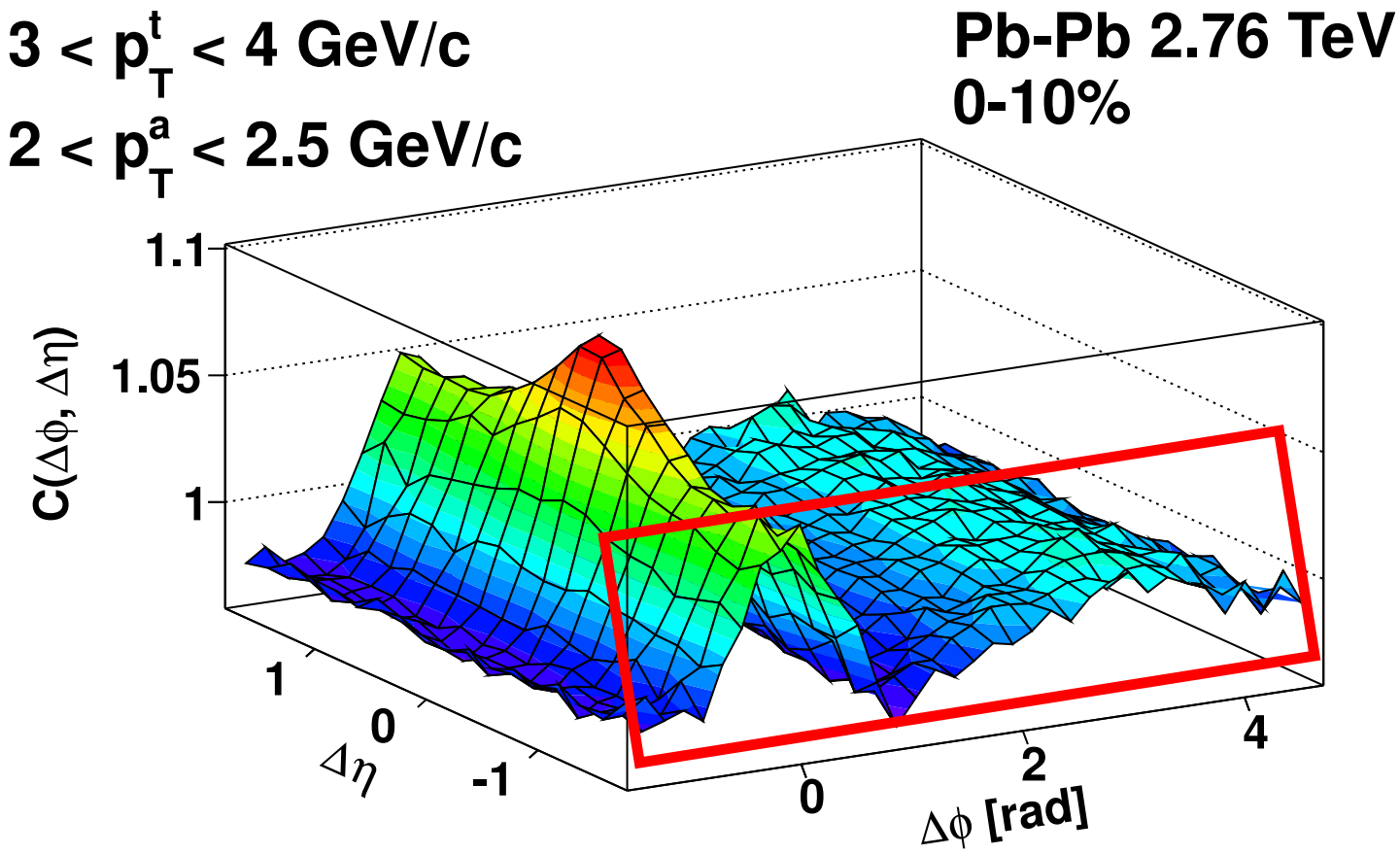


Results from flow measurements



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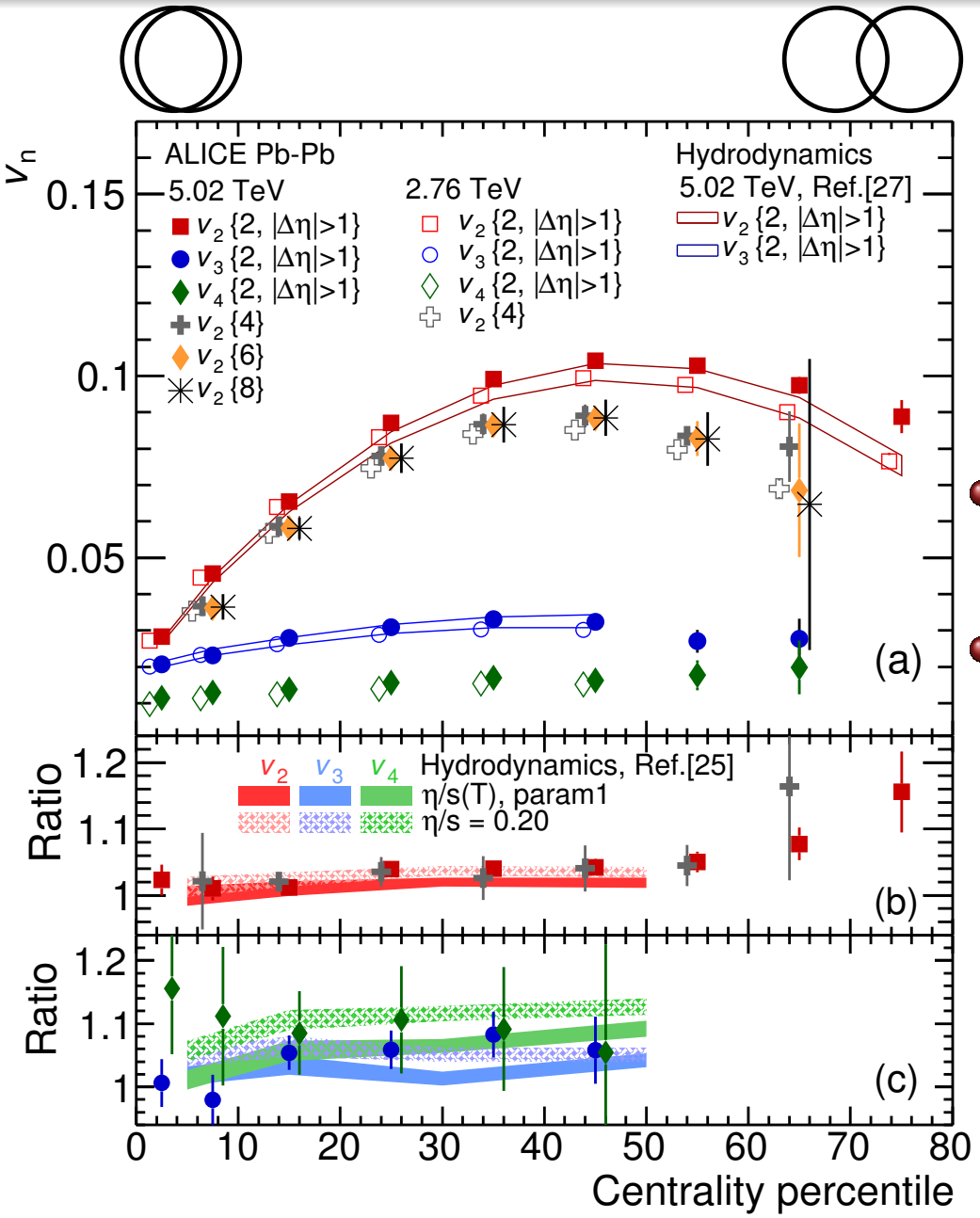
Flow measurements at ALICE



Phys. Rev. Lett. 116 (2016) 132302

- Measured by excluding short-range correlations (η gap)
- Characteristic shape vs centrality

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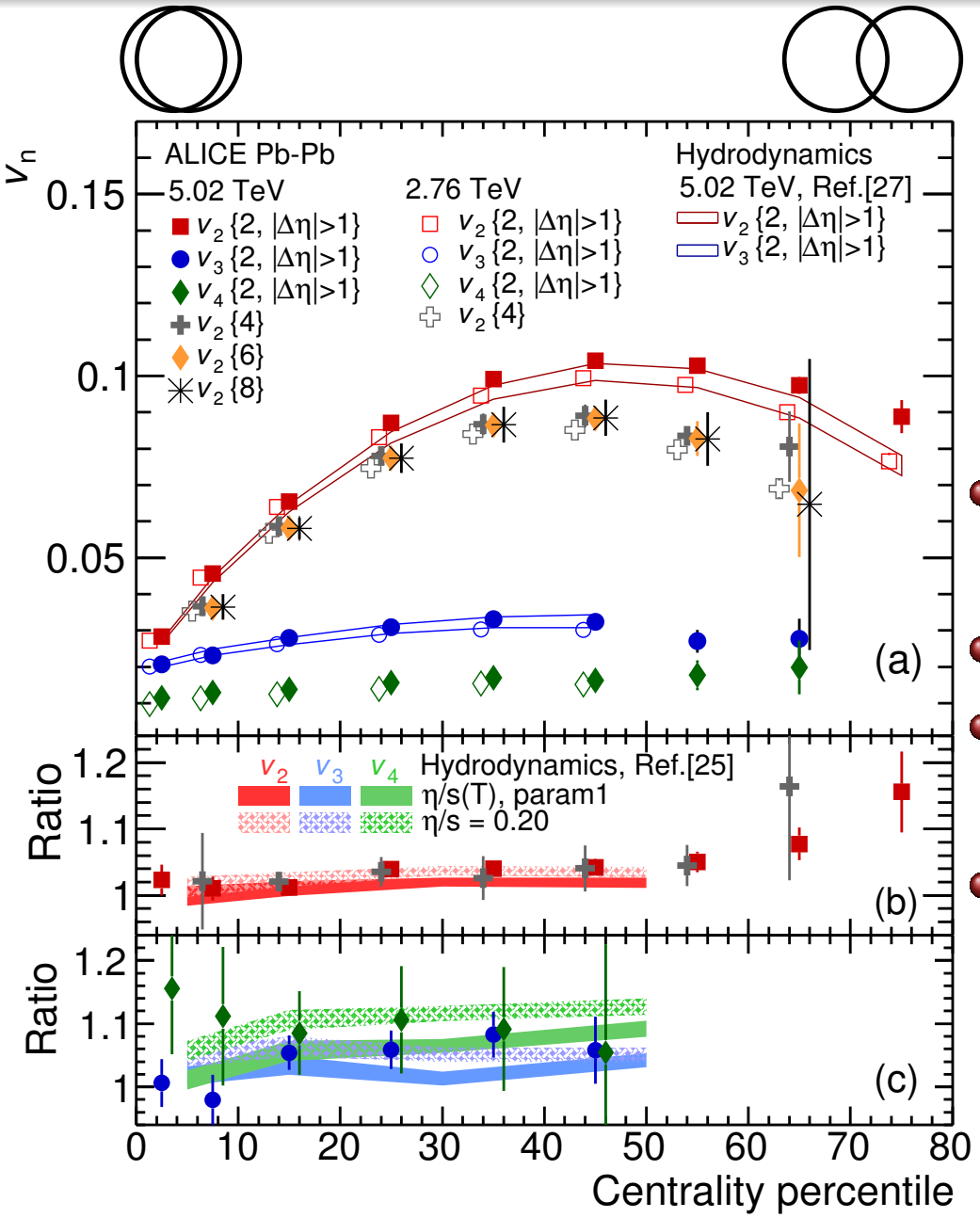
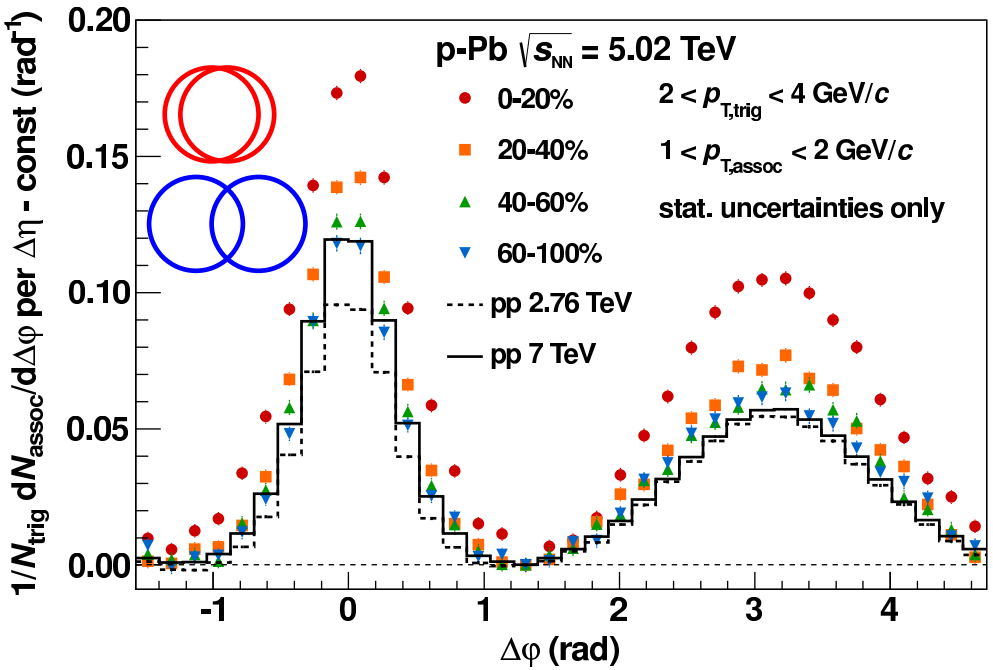


Phys. Rev. Lett. 116 (2016) 132302

- Measured by excluding short-range correlations (η gap)
- Characteristic shape vs centrality
- Values slightly higher at 5.02 TeV
  - From average p_{T} difference
- Hydro models describe data

Ridge in small system

Phys.Lett. B719 (2013) 29-41



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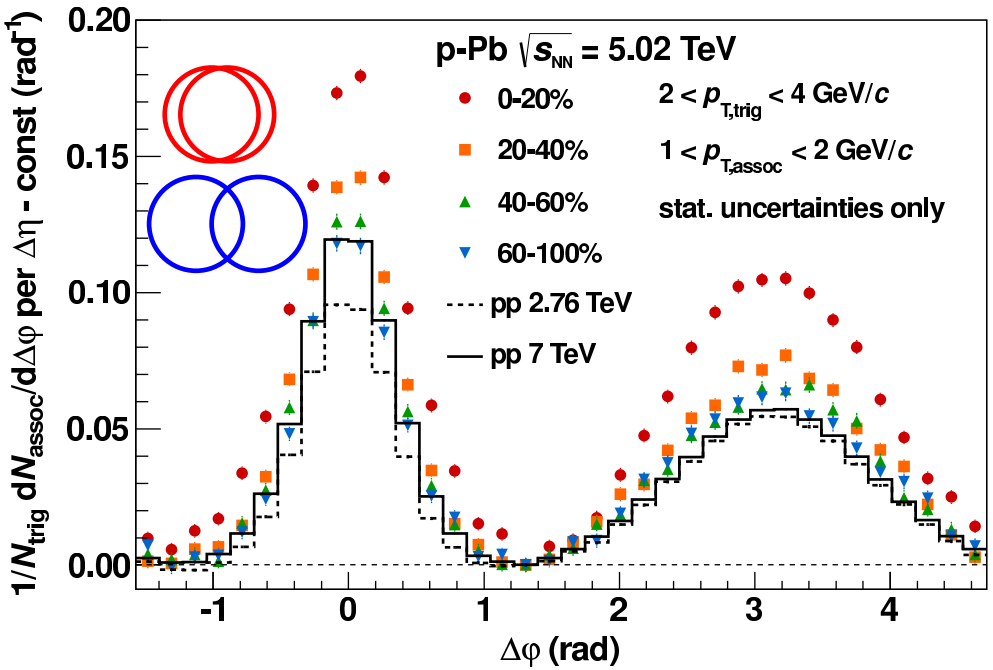
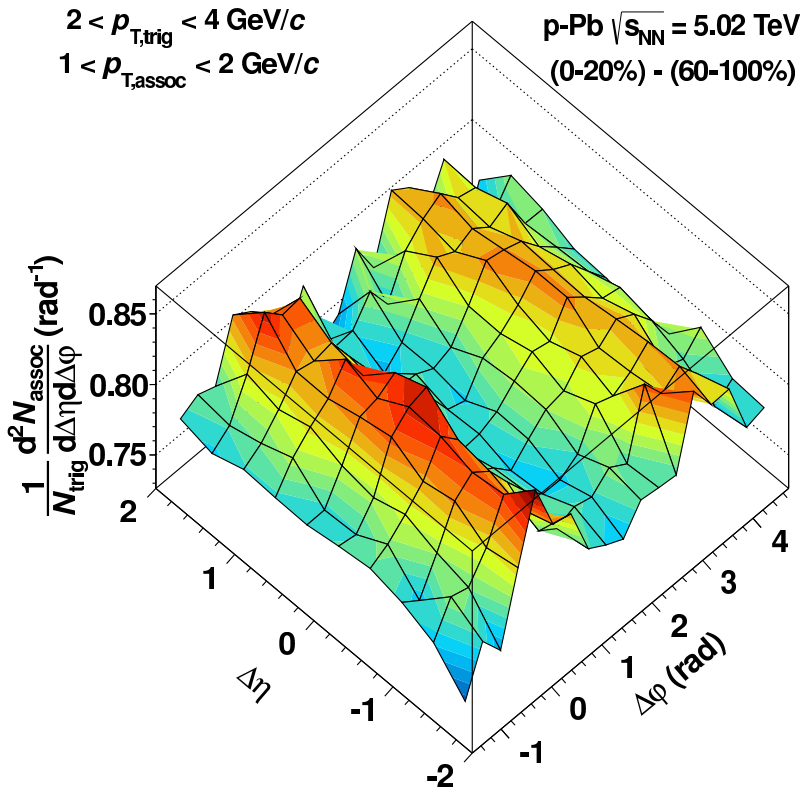
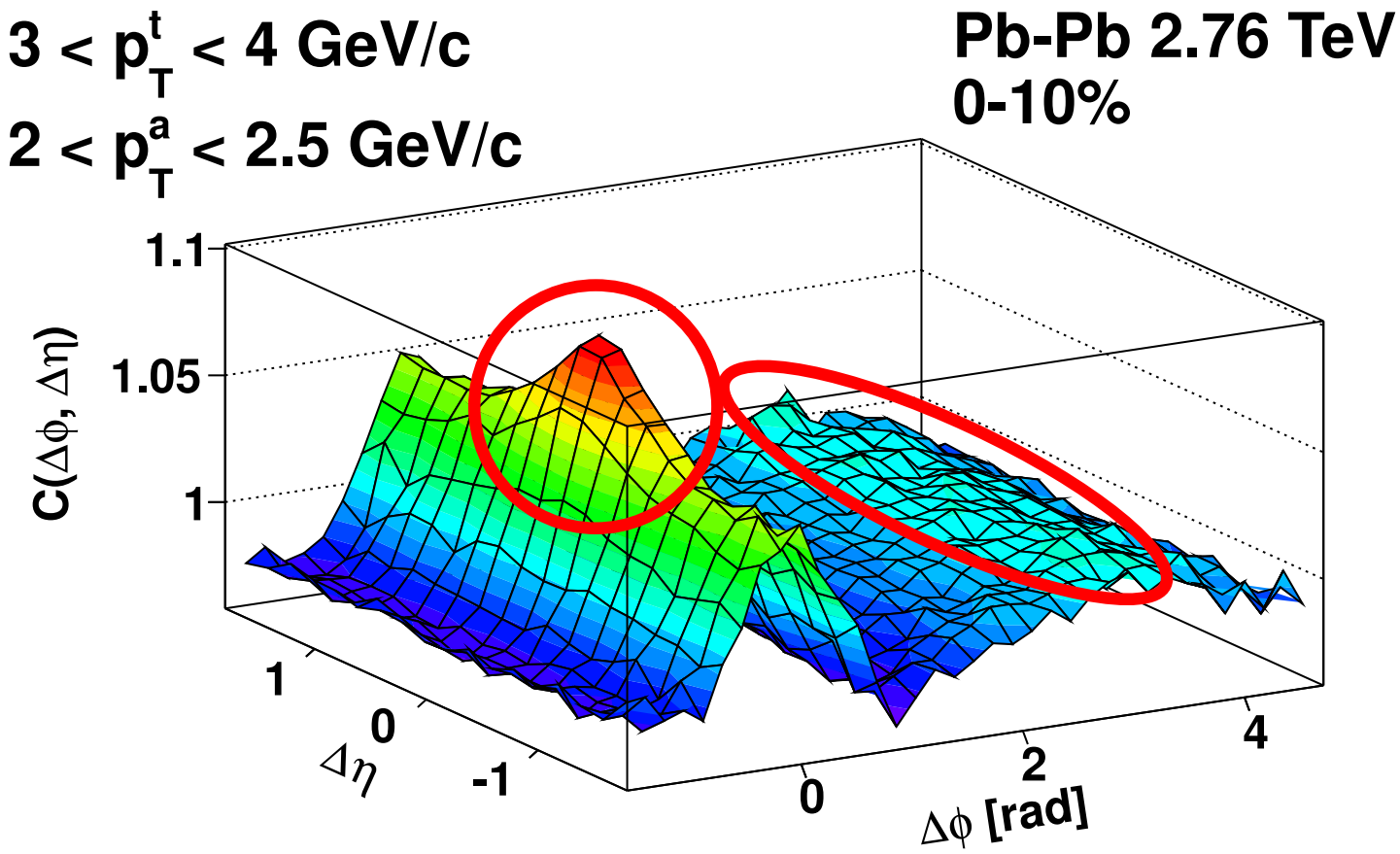




- High and low multiplicity p–Pb data look different
- (High - low) shows double ridge structure, elongated in $\Delta\eta$
- Origin?

Results from jet measurements

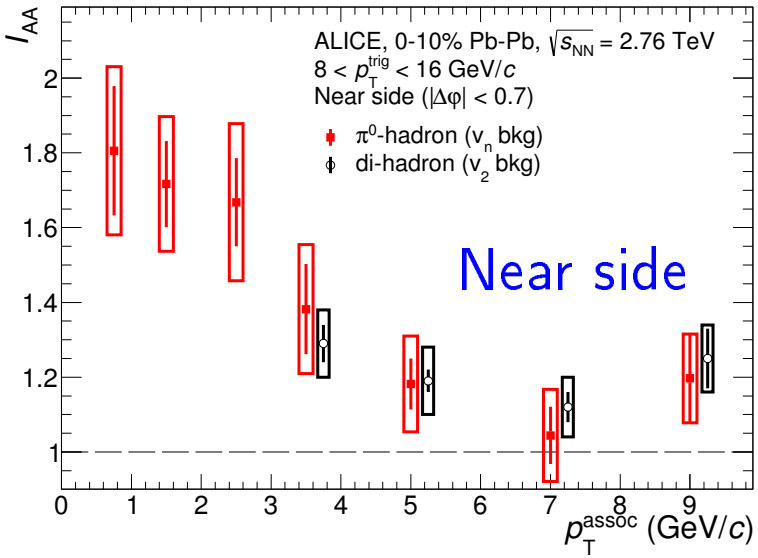


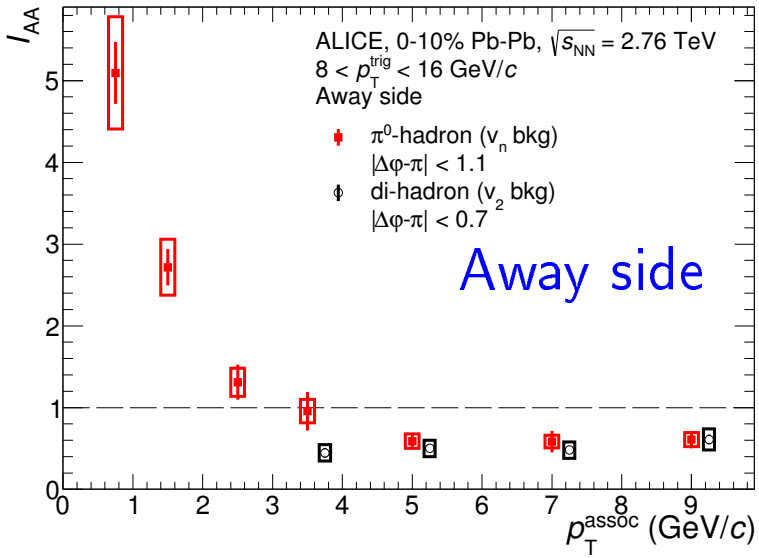
ALI-PUB-14107

Relative yield in Pb–Pb

Phys. Lett. B 763 (2016) 238-250

- Study modification of the jet yield in Pb–Pb compared to pp
- Hadron – hadron and π^0 – hadron





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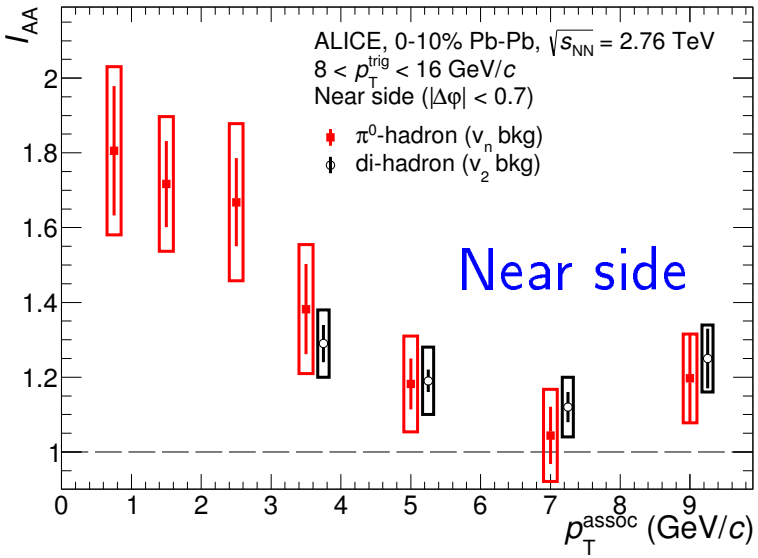
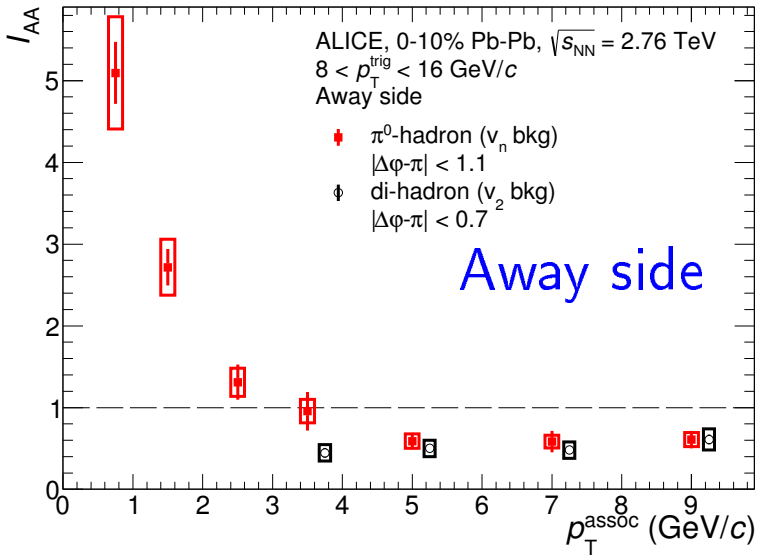


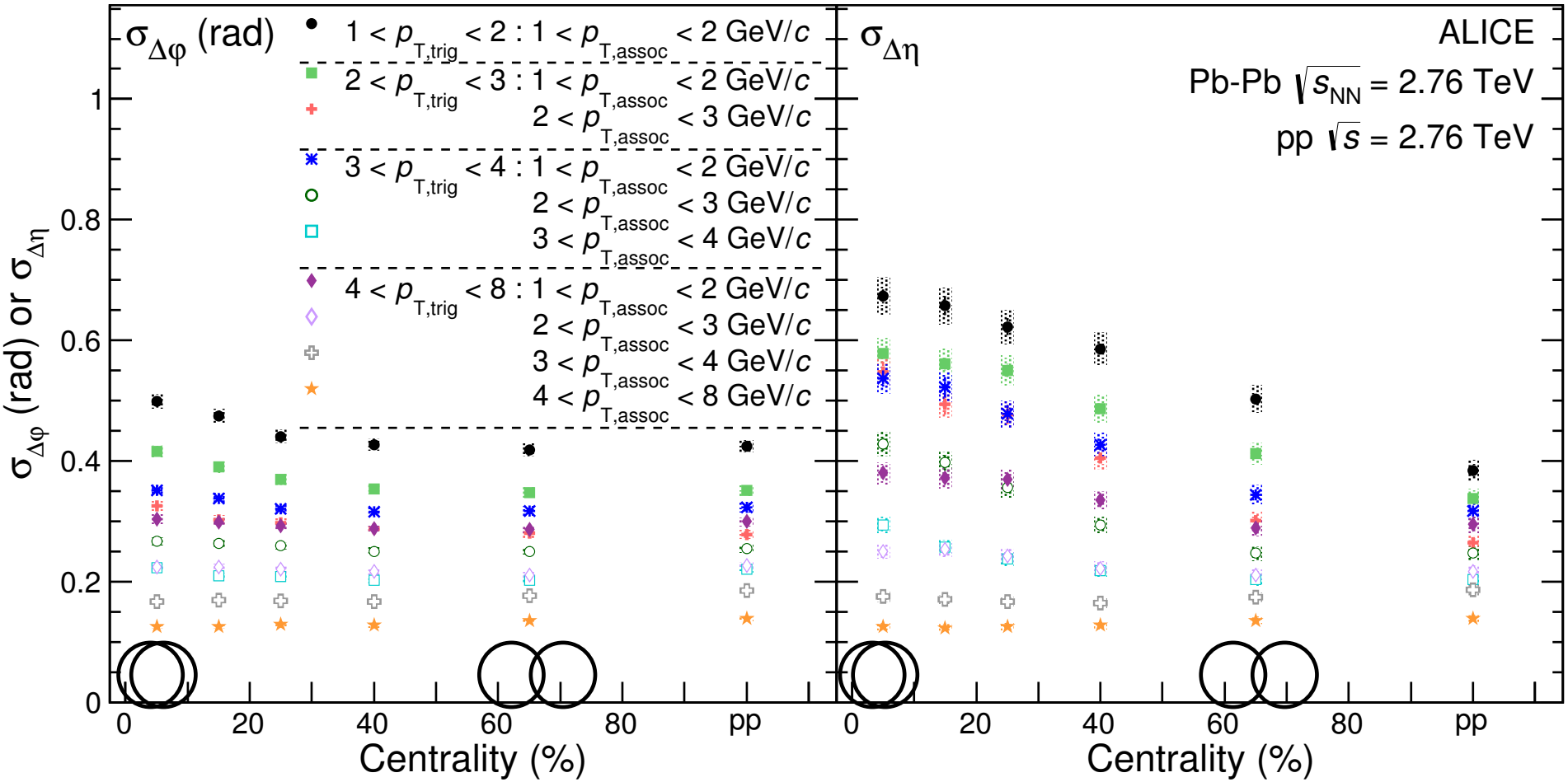


- Enhancement on near side
- Suppression on away side
- π^0 triggers agree with unidentified hadrons
- Suppression on away side above 4 GeV/c, enhancement below

Shape of the near-side peak in Pb–Pb

Phys. Rev. Lett. 119, 102301 (2017)
Phys. Rev. C 96, 034904 (2017)

- Direct characterization of the peak ⇒ fit by generalized Gaussian

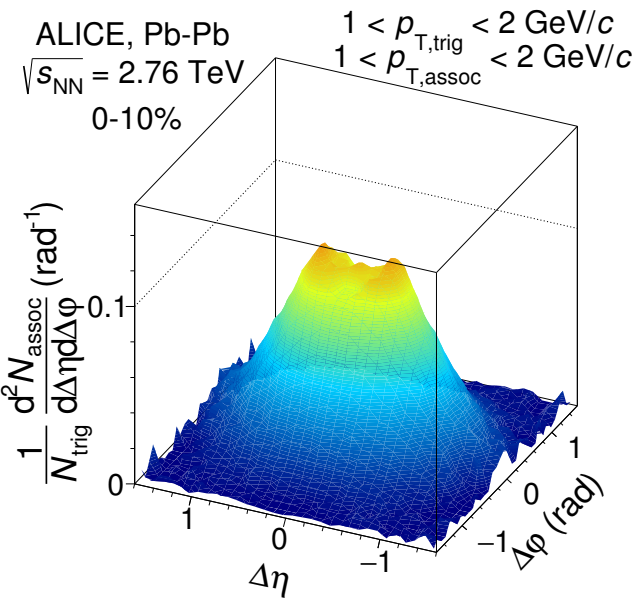


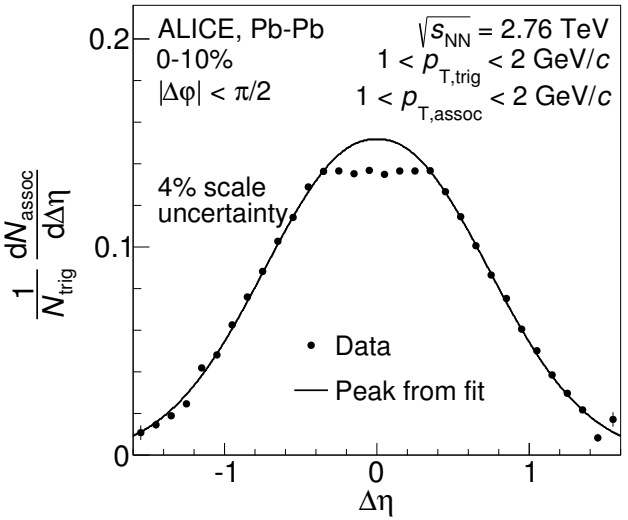
- Asymmetric broadening ($\sigma_{\Delta\varphi} < \sigma_{\Delta\eta}$) towards central collisions

Depletion

Phys. Rev. Lett. 119, 102301 (2017)
Phys. Rev. C 96, 034904 (2017)

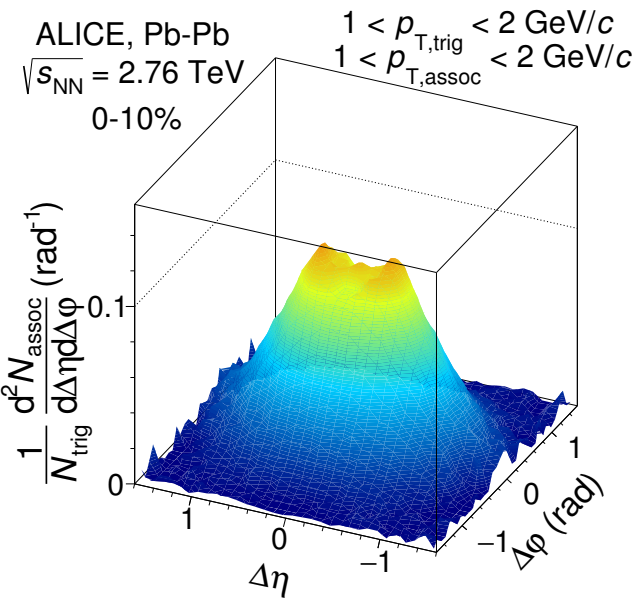
- Depletion at low p_{T} around $(\Delta\varphi, \Delta\eta) = (0, 0)$

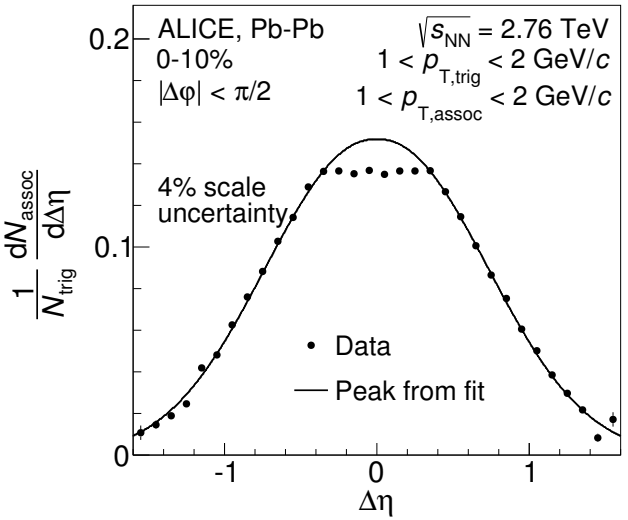




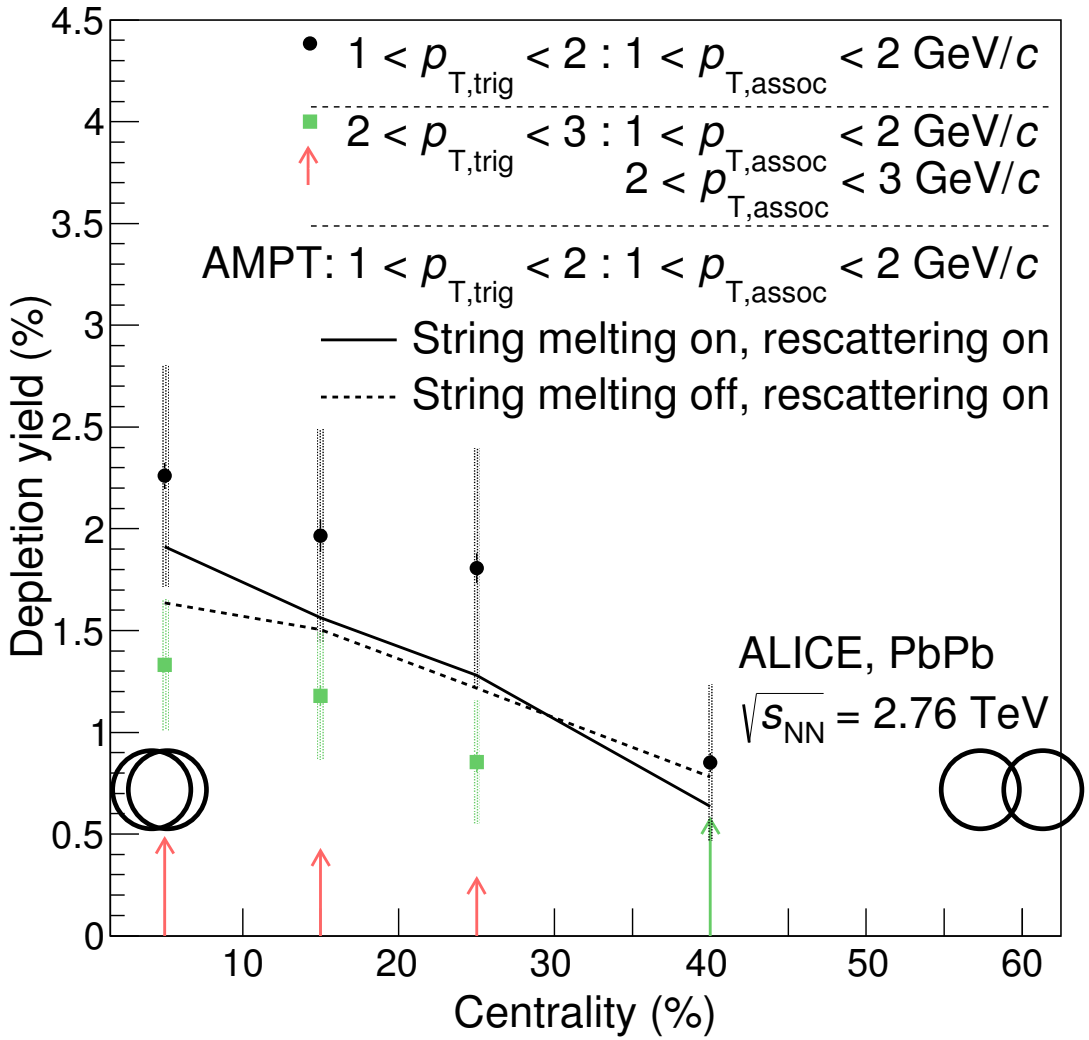
Depletion

Phys. Rev. Lett. 119, 102301 (2017)
Phys. Rev. C 96, 034904 (2017)





- Depletion at low p_{T} around $(\Delta\varphi, \Delta\eta) = (0, 0)$
- Missing yield quantified



Hadron – jet correlations

JHEP 09 (2015) 170

- Studying jets recoiling from a high p_{T} hadron
- Study yield and acoplanarity

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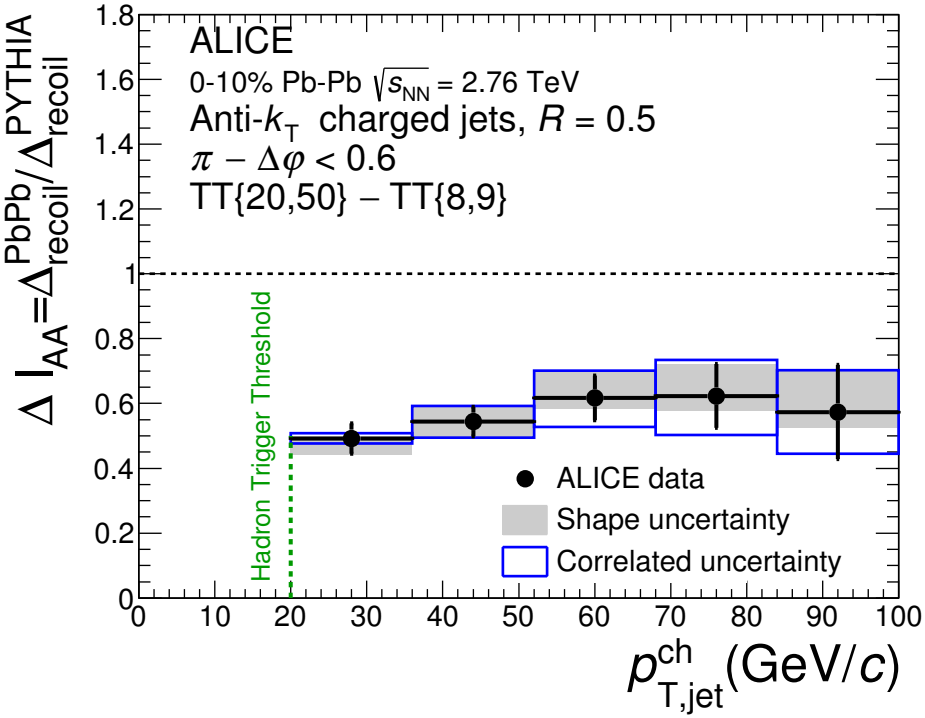

- Recoil jet yield is suppressed in Pb–Pb compared to pp

Hadron – jet correlations

JHEP 09 (2015) 170

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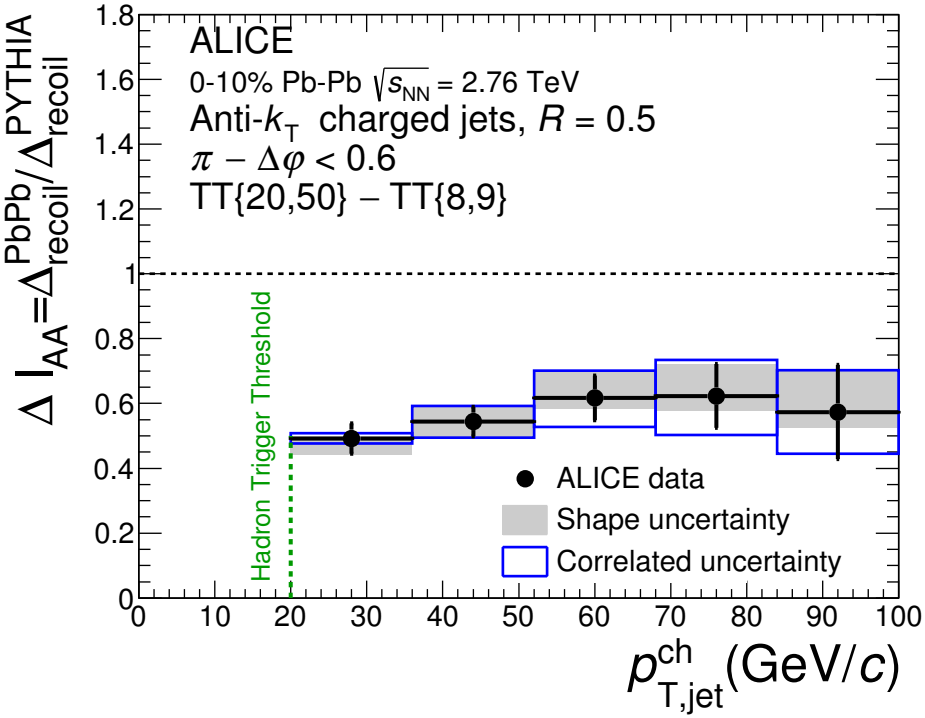
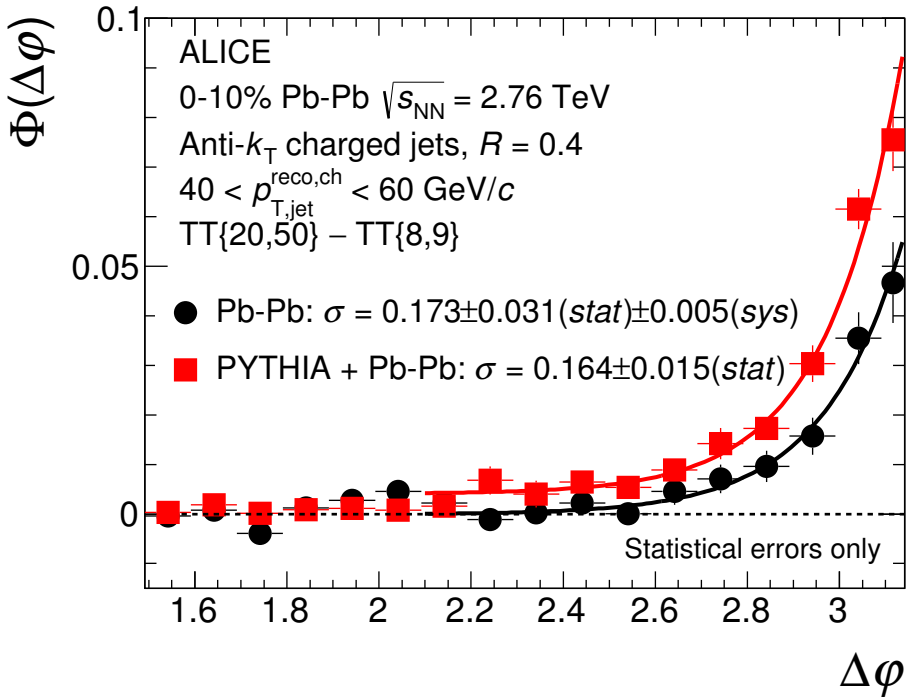
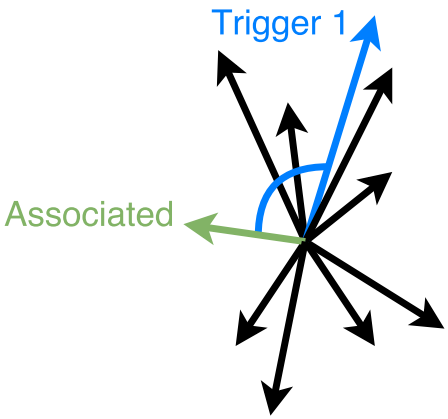




- Recoil jet yield is suppressed in Pb–Pb compared to pp
- No modification of the acoplanarity is observed

Two plus one correlations

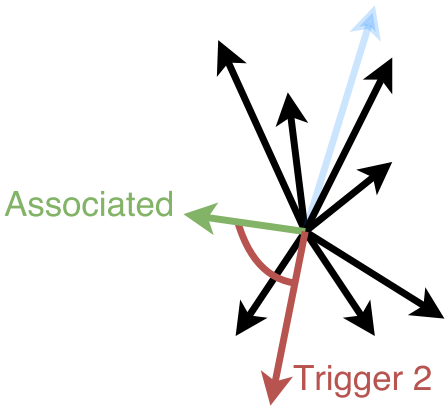
- Study path length dependence



- Trigger 1 and associates $\Rightarrow$ leading jet

Two plus one correlations

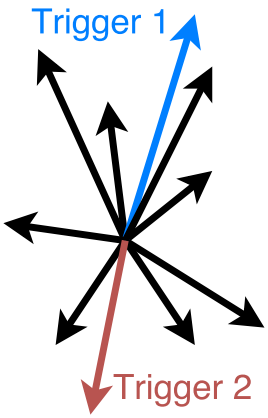
- Study path length dependence



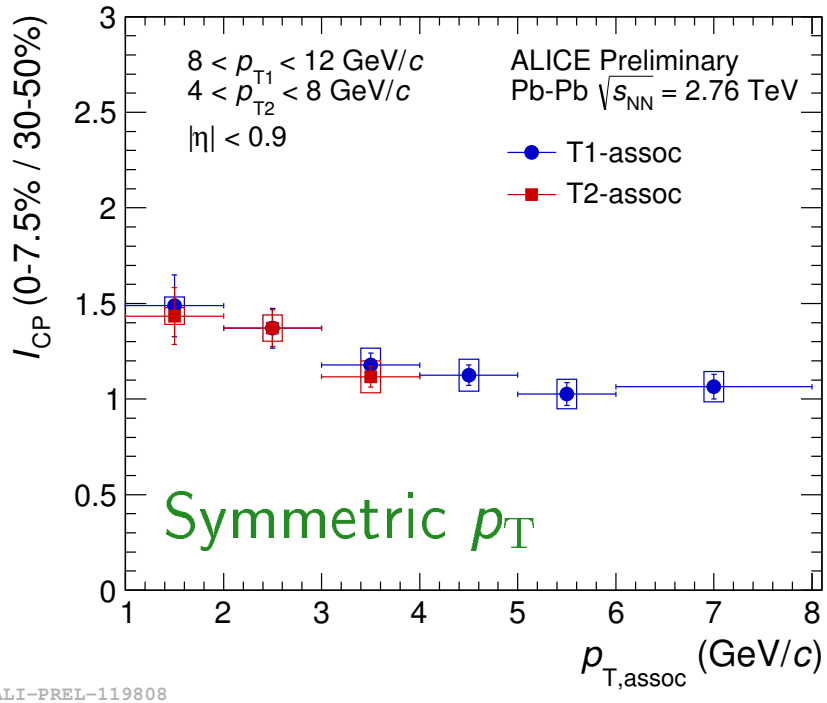
- Trigger 2 and associates $\Rightarrow$ away-side jet

Two plus one correlations

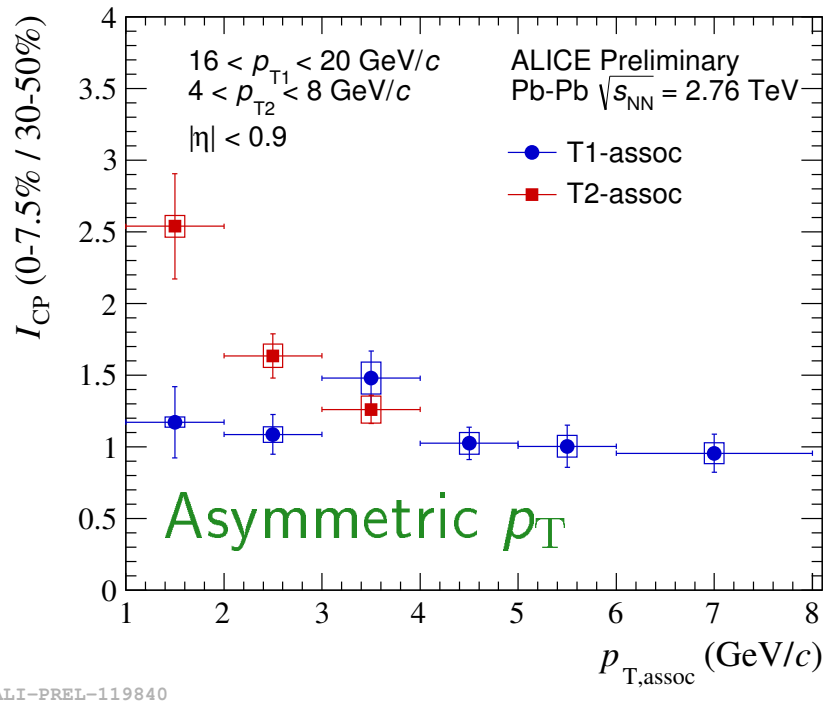
- Study path length dependence



- p_{T} of two triggers are close $\Rightarrow$ no difference
- p_{T} is asymmetric $\Rightarrow$ large modification for T2



ALI-PREL-119808



ALI-PREL-119840

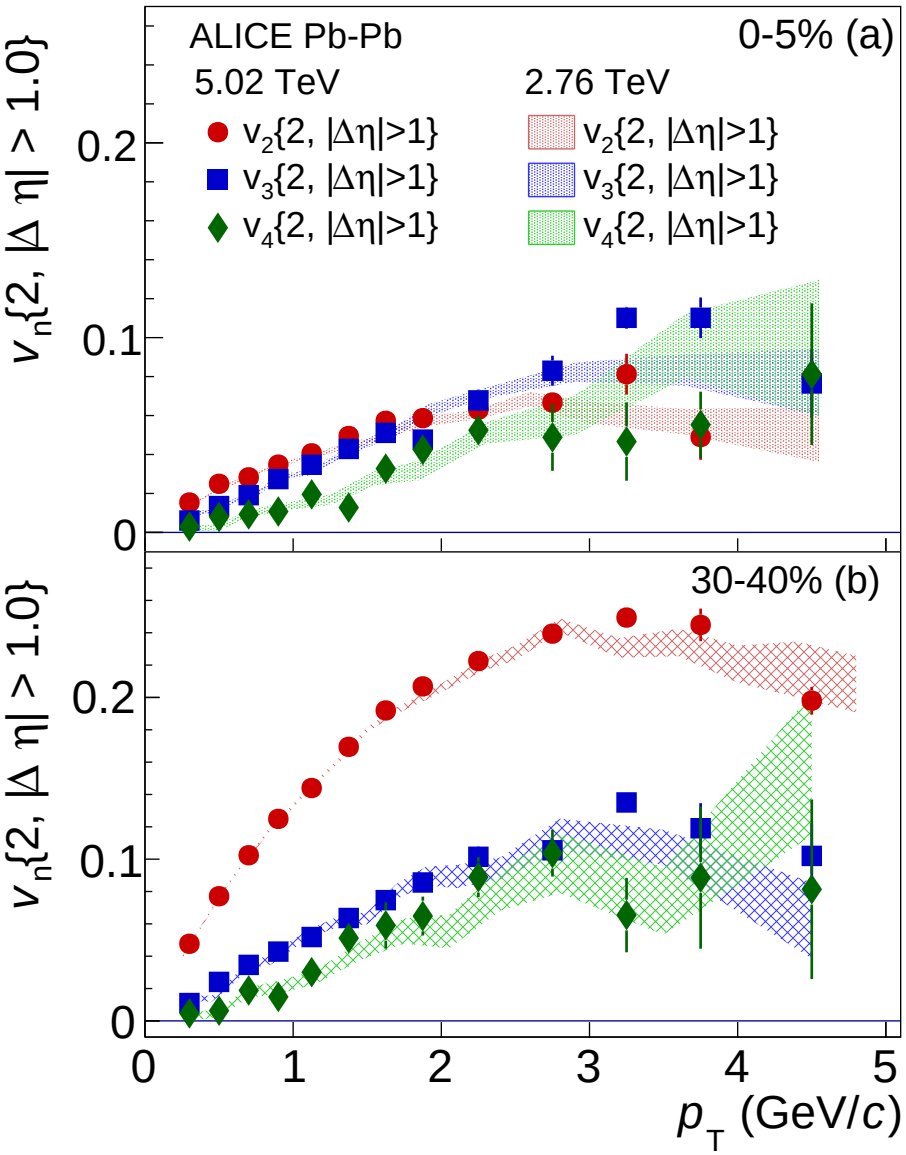
Conclusions

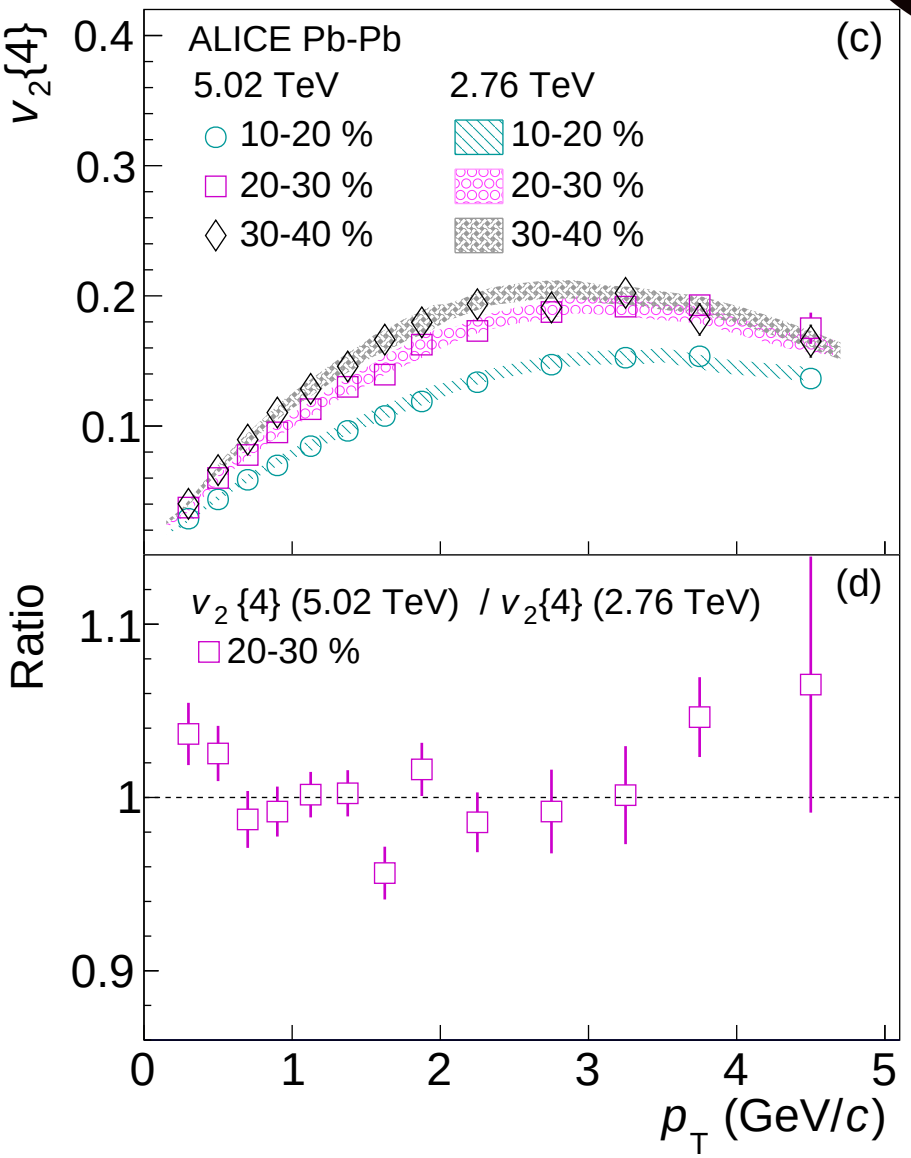
- **Angular correlations**
  - Trigger and associated object
  - Study the distribution of $\Delta\varphi$ and $\Delta\eta$
  - Can be used for soft and hard probes
- **Studying flow**
  - Flow in Pb–Pb higher in 5.02 TeV than 2.76 TeV
    $\Rightarrow$ Arising from higher average p_{T}
  - Double ridge in p–Pb
- **Studying jets**
  - Yield at low p_{T} enhanced on both near- and away-side
  - At higher p_{T} suppression on away-side
  - Peak broadened and asymmetric at low p_{T}
  - Depletion around $(\Delta\varphi, \Delta\eta) = (0, 0)$
  - Recoil jet yield is suppressed
  - Enhancement of yield if p_{T} of T1 and T2 asymmetric

Thank you for your attention!

BACKUP

Flow vs p_T





- No significant difference between 2.76 TeV and 5.02 TeV

Angular correlations vs femtoscopy

	Femtoscopy	**Angular correlations**
Physics	HBT, FSI, resonancies freeze out dynamics	Jets, flow, HBT, resonancies
What to correlate	Identified particles	Anything
Correlating in	Momentum	Angles $\Delta\varphi$ and/or $\Delta\eta$
Source function	Well defined, Levy distribution widely used	?
Correlation function	Stretched exponential or Generalized Gaussian widely used	
Limits	$0 <$ Exponent ≤ 2	Exponent positive