Using di-hadron correlations to investigate jet modifications in Pb-Pb collisions with **ALICE**

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On behalf of the ALICE Collaboration

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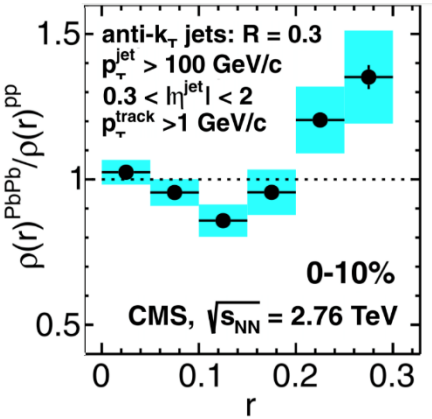
Hard Probes 2018

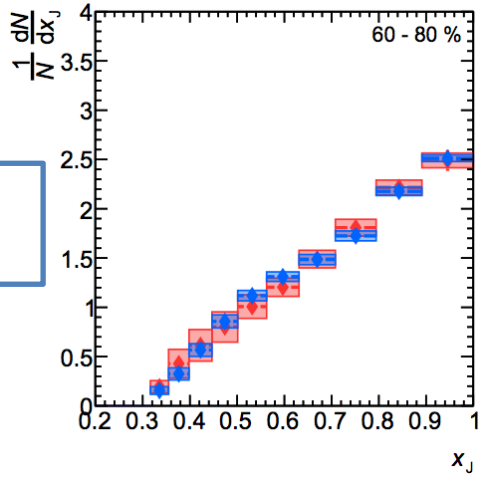
Jet suppression in heavy-ion collisions

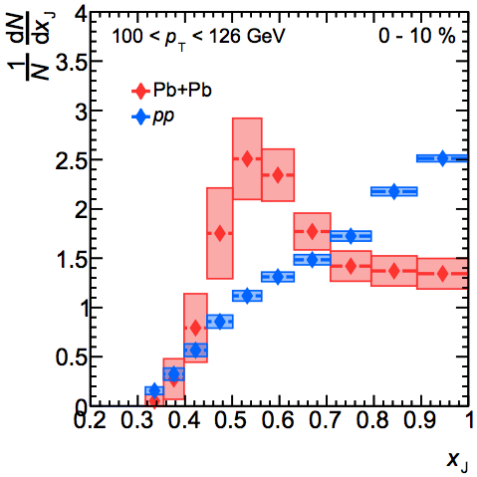
- Strong jet quenching is observed in heavy-ion collisions

- Measurements based on fully reconstructed jets
  - Jet suppression
    [ALICE PLB 746(2015), ATLAS PLB 719(2013) 220, CMS PRC 84 (2011) 024906]
  - Strong di-jet energy asymmetry
    [ATLAS ATL-PHYS-PROC-2016-240 (2016), CMS PRC 84, 024906 (2011)]
  - Centrality dependence of jet fragmentation
    [CMS PRC 90(2014) 204908]
  - Jet shape modifications
    [CMS PLB 730(2014), 243]

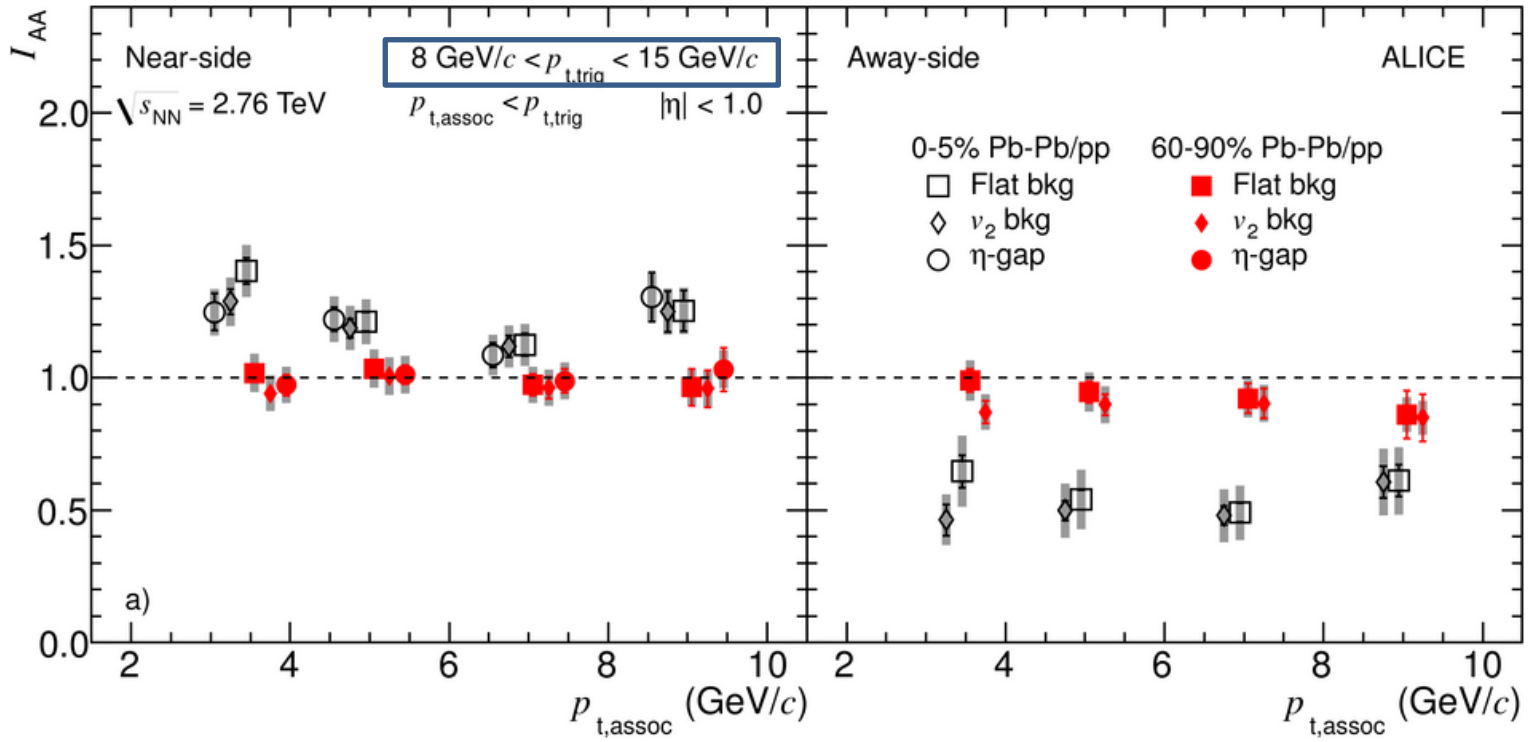


Jet properties in two particle correlation?





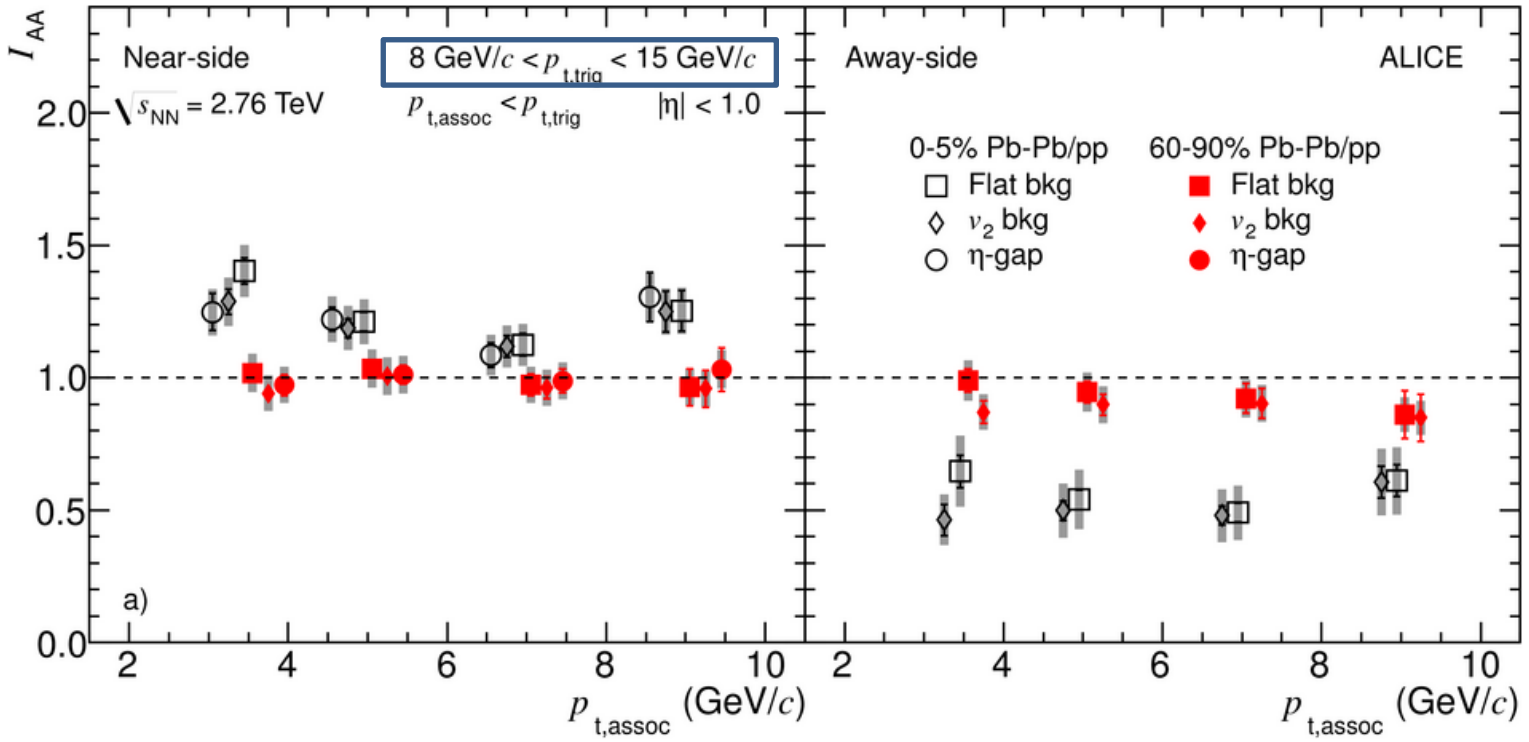
E_{loss} in two-particle correlation



- Can provide additional information on jet properties
- I_{AA} measurement in ALICE [ALICE, PRL108, 092301]
  - Modification of a fragmentation function
  - Modification of a quark/gluon jet ratio
  - Bias on the parton p_{T} distribution after energy loss due to the trigger selection

Near-side is also sensitive to the medium

E_{loss} in two-particle correlation



- Can provide additional information on jet properties
  - I_{AA} measurement in ALICE [ALICE, PRL108, 092301]
  - Near side I_{AA} at lower $p_{\mathrm{T,assoc}}$
  - Near side jet shape modification in longitudinal/azimuthal direction
  - Path-length dependence of near side I_{AA}

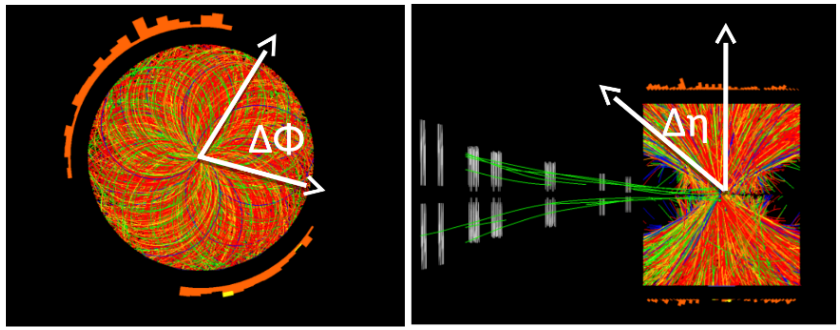
Jets in two-particle correlation

- In-direct method of studying jet properties, based on statistical basis
- Background is averaged over many events

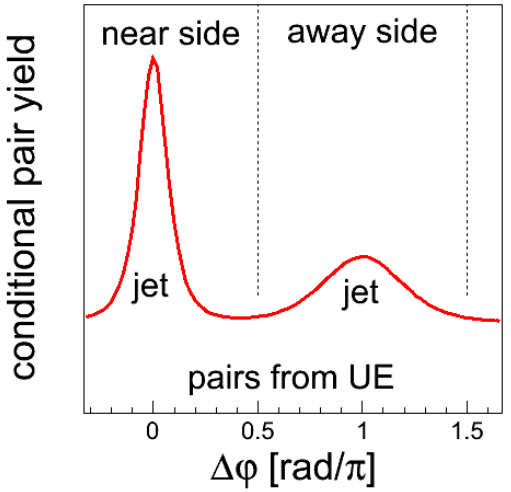
Basic quantities

$$\Delta\varphi = \varphi_{\mathrm{trig}} - \varphi_{\mathrm{assoc}}$$

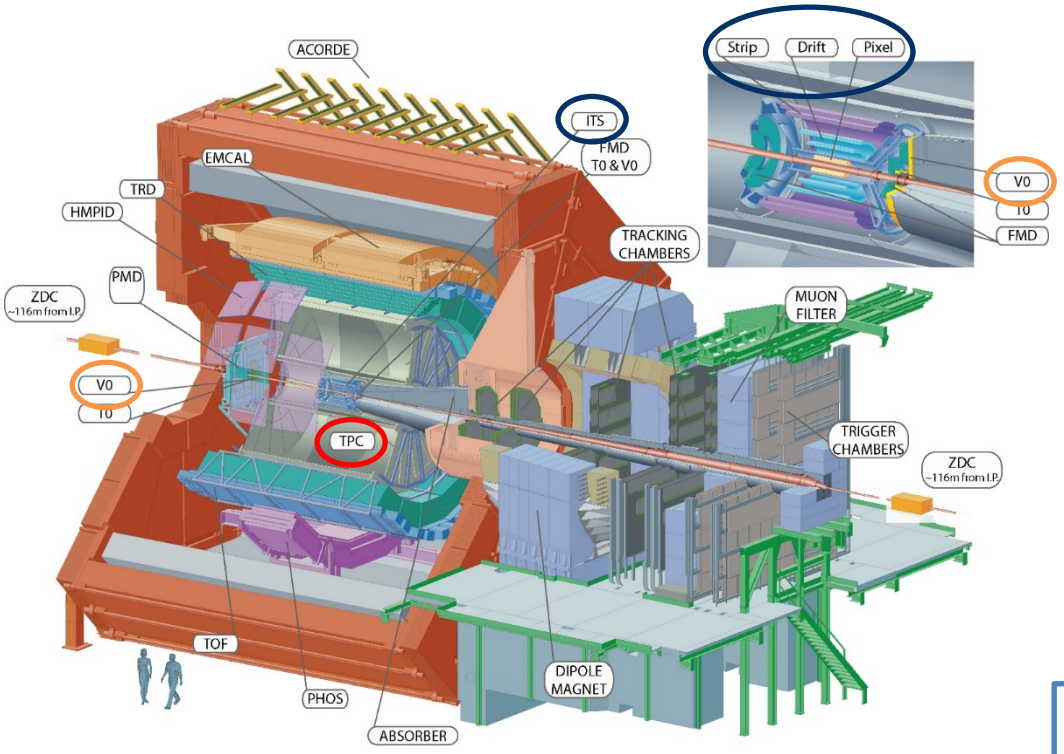
$$\Delta\eta = \eta_{\mathrm{trig}} - \eta_{\mathrm{assoc}}$$



- Near side jet : Single jet properties
  - Jet fragmentation
- Away side jet : Di-jet properties
  - Acoplanarity + momentum imbalance due to k_{T}
  - Additional medium induced modification



ALICE Detector



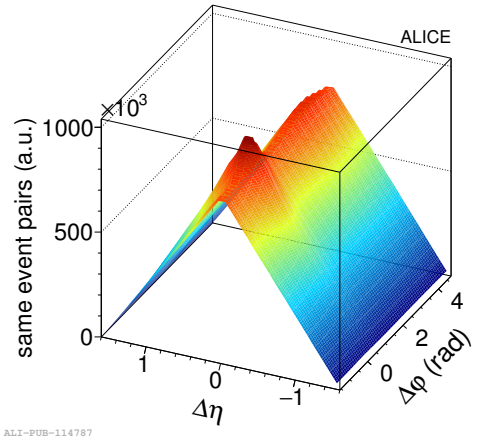
- ITS (Inner Tracking System)
  - $|\eta| < 0.8$ in analysis
  - Tracking, vertexing
- TPC (Time Projection Chamber)
  - $|\eta| < 0.8$ in analysis
  - Tracking
- V0
  - V0A $(2.8 < \eta < 5.1)$& V0C $(-3.7 < \eta < -1.7)$
  - Centrality estimator
  - Event plane estimator

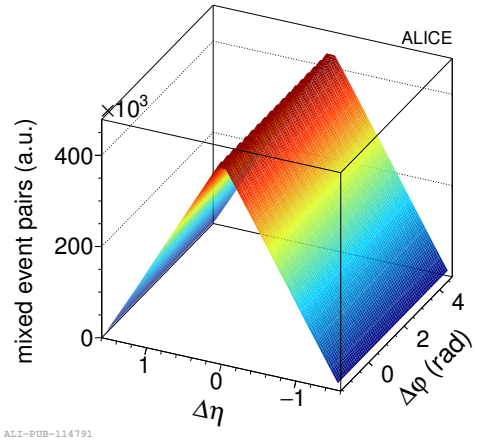
$9\mu\mathrm{b}^{-1}$ in 2010 Pb-Pb $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV
$46\mathrm{nb}^{-1}$ in 2011 pp $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV

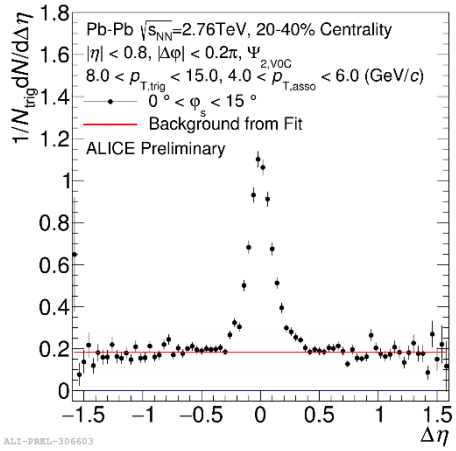
I_{AA} analysis procedure

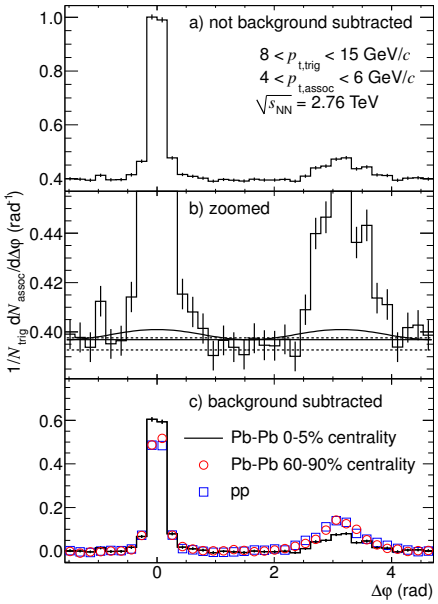
1. Construct same and mixed event distributions
2. Correct the experimental effects (i.e. tracking inefficiencies, and pair acceptance effect)
3. Background level is estimated by fit
4. Evaluate the ratio between Pb-Pb and pp

$$I_{AA} = Y^{\mathrm{Pb-Pb}} / Y^{\mathrm{pp}}$$

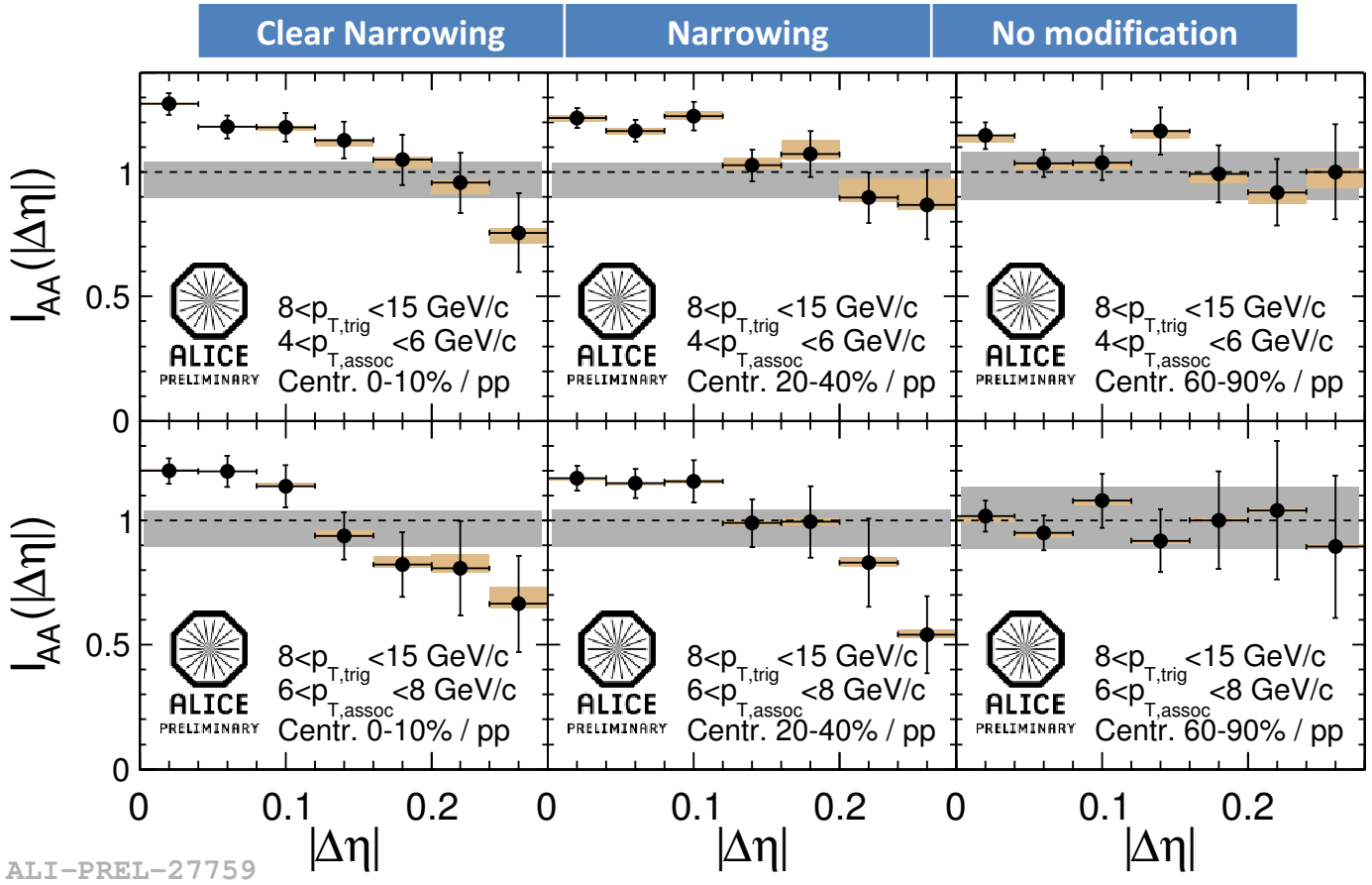








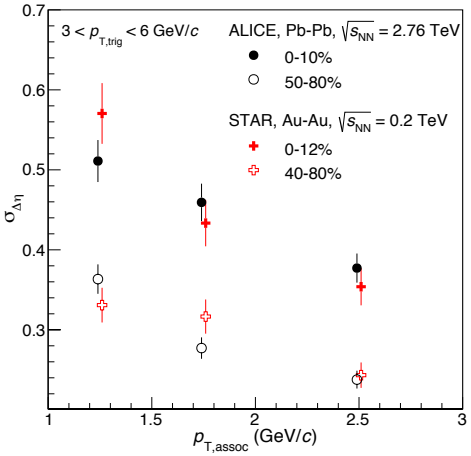
Jet shape modification and I_{AA}

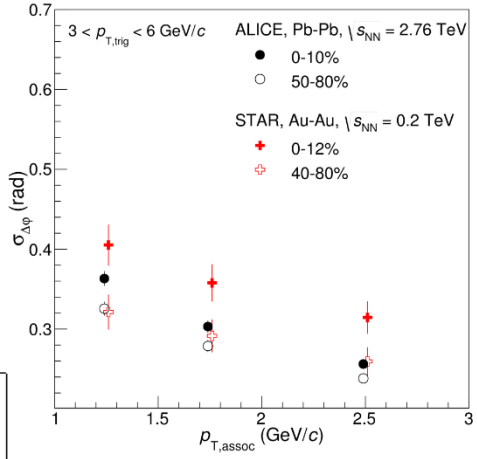


- Trend of I_{AA} shows a possible onset of jet shape modification in $\Delta\eta$ (narrowing), in most central collisions with
  $8 < p_{T,trig} < 15$ & $4 < p_{T,asso} < 8$ (GeV/c)

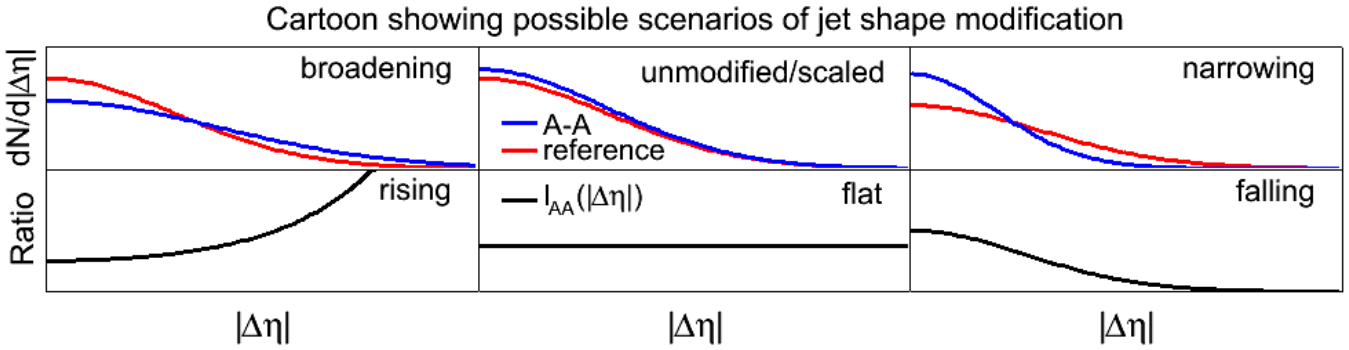
Jet shape modification and I_{AA}

- ALICE measurement on jet shape modification [ALICE PRC 96(2017) 034904]
  - Broadening observed most central collisions, with $1 < p_{\mathrm{T,trig}} < 8$, $1 < p_{\mathrm{T,asso}} < 4$ (GeV/c)
  - Different behavior that we observed in more higher $p_{\mathrm{T,trig}}$, with higher $p_{\mathrm{T,asso}}$ pairs

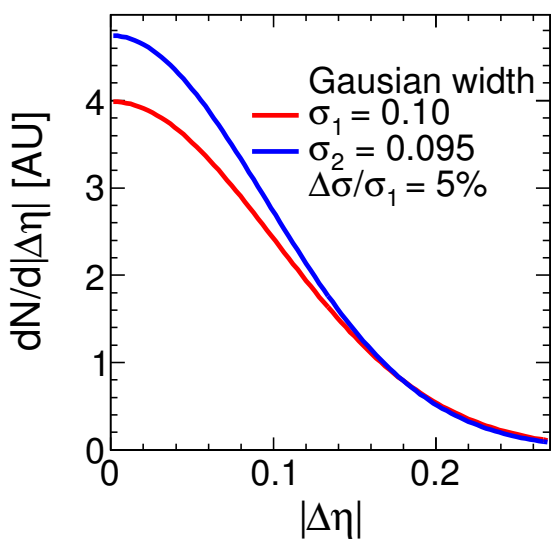


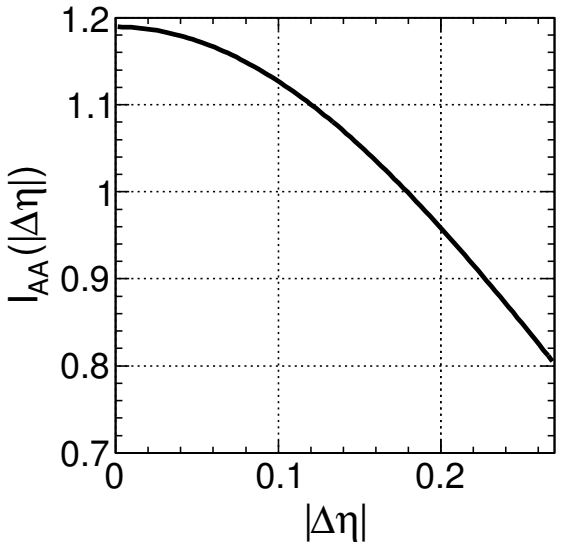


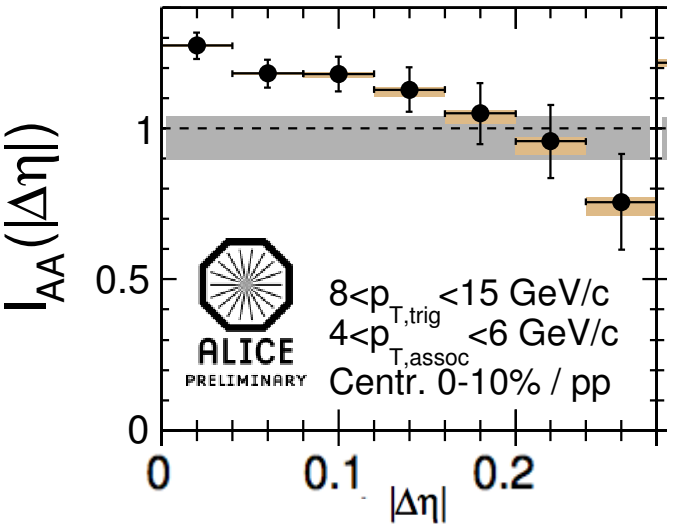
- Cartoon describes possible scenarios of modification, in terms of I_{AA}



Interpretation of shapes of I_{AA} to width

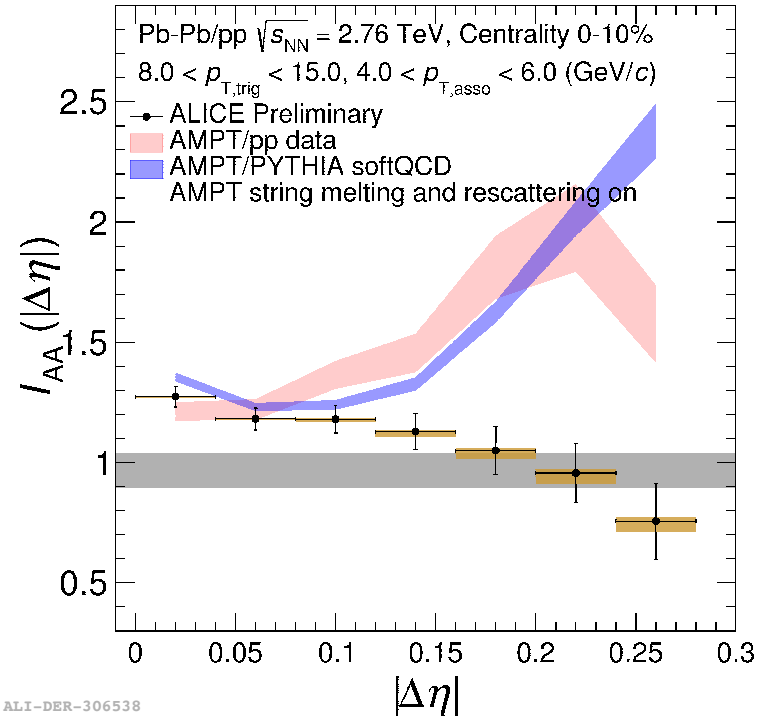


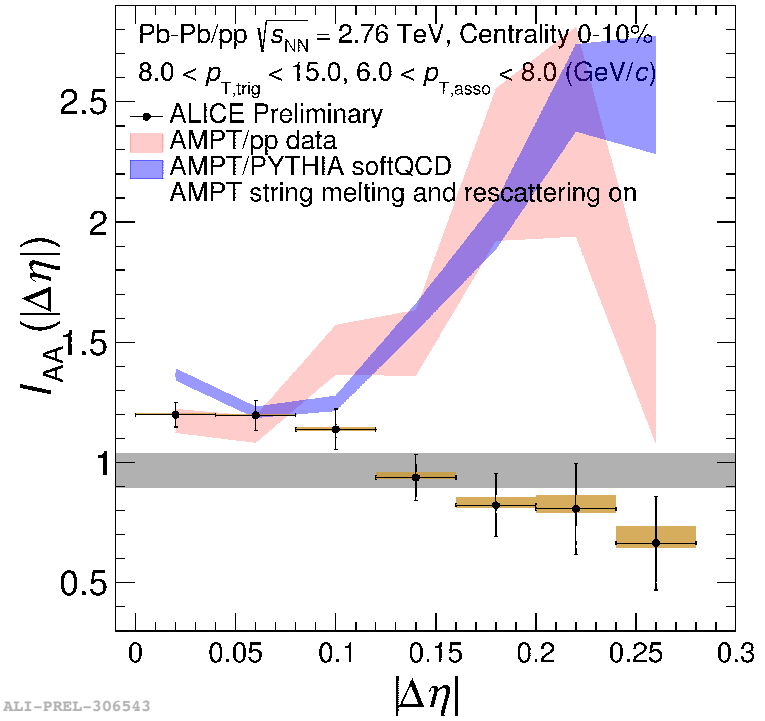




- Cartoon shows the ratio between two gaussian shapes, width differing by only 5%
- Only with few % difference in width can result in large difference in I_{AA} trend

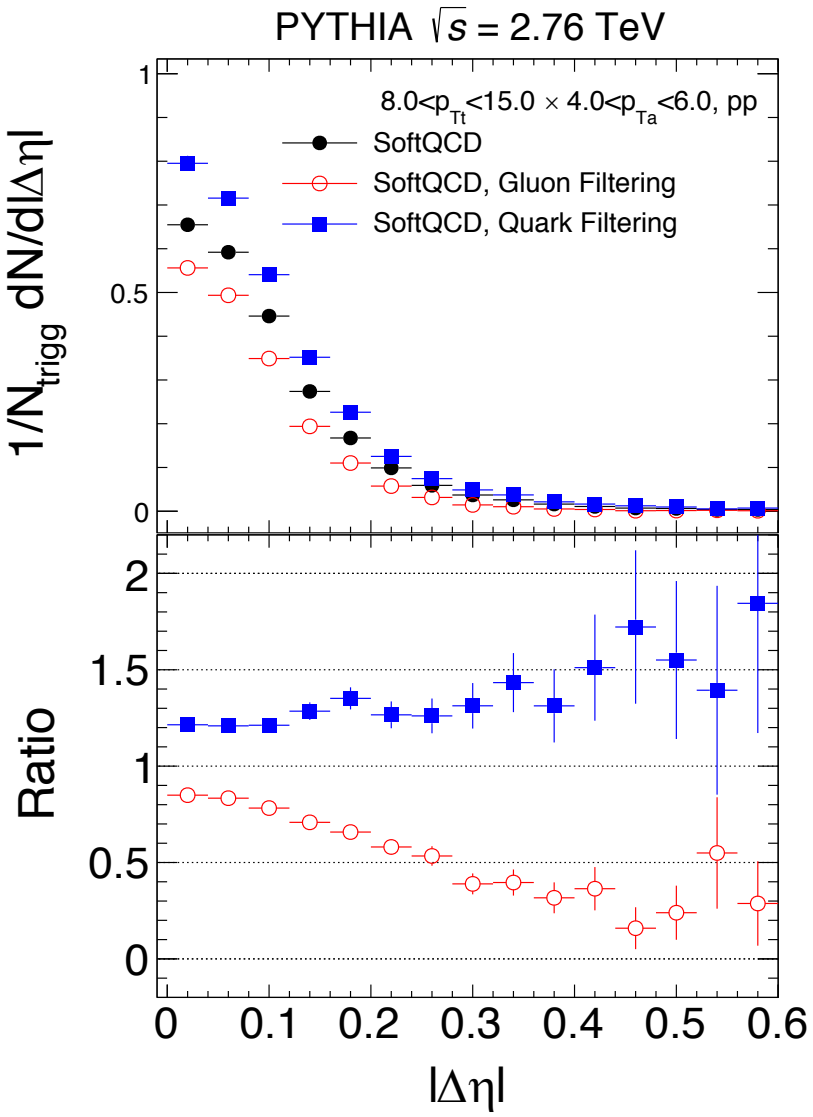
Model comparison on shapes





- Comparison with AMPT model, string melting on with hadronic rescattering
  - pp reference – Data or PYTHIA (softQCD setting)
- Very large broadening at $|\Delta\eta| > 0.1$
- I_{AA} is overestimated by AMPT

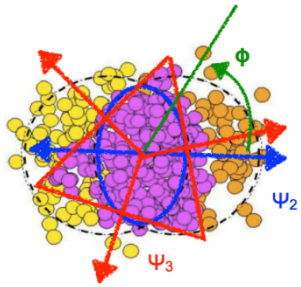
Quark/Gluon jets and shapes of jet



- Casimir scaling gives color charge dependence of jet suppression in heavy ion collisions
  - Strong gluon jet suppression can explain the narrowing
  - Tested with PYTHIA in same kinematic region
- Relative quark and gluon jet suppressions and modification of their fragmentation functions play a role
  - Gives constraints to models

Near side I_{AA} and path length dependence

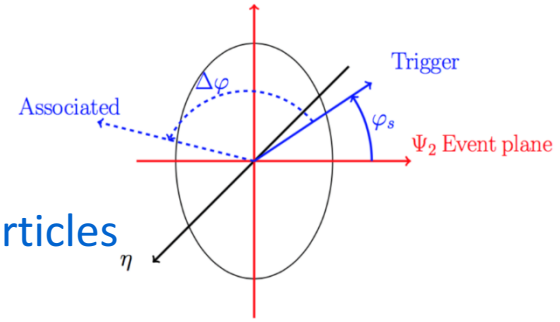
- Spatial anisotropy due to almond-like shape, and event-by-event fluctuations



- Constrain the trigger particle's direction

$$\varphi_s = \varphi_{\mathrm{trig}} - \Psi_2$$

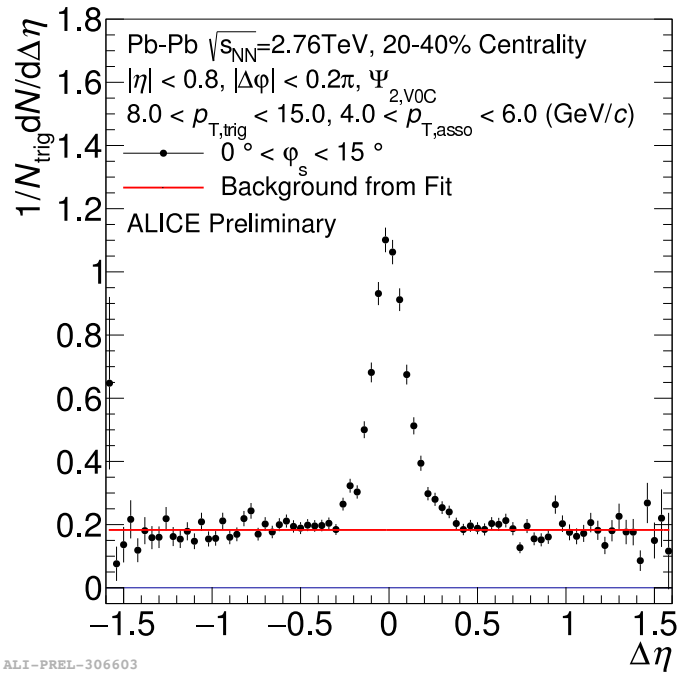
  - Amount of interaction through the medium depends on the direction
  - Can be interpreted as path length dependence of jet-like particles

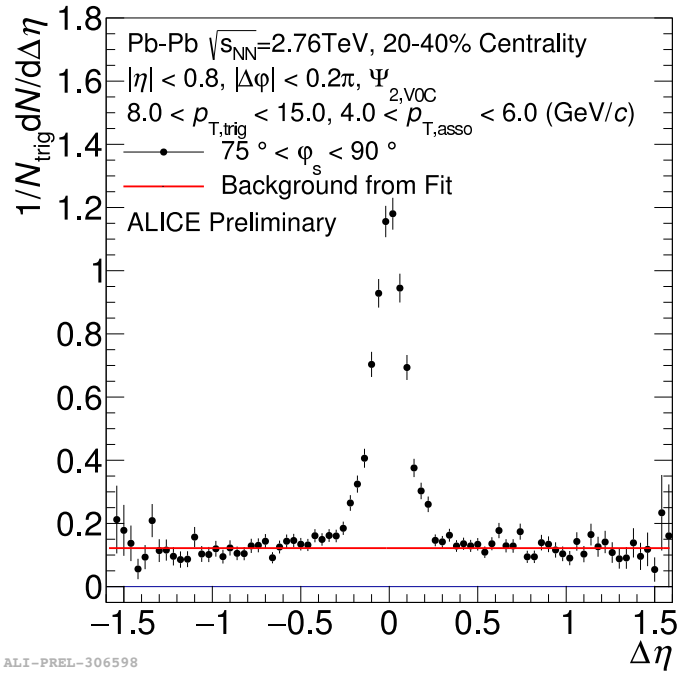


- In this analysis, to avoid flow modulation in background → study the associated particles in η direction

* Also Check [STAR, PRC 89(2014) 041901], [PHENIX, arXiv:1803.01749], [ALICE, Nucl.Phys.A 967(2017) 500], for reaction plane dependence study of jets

Correlation functions and background removal

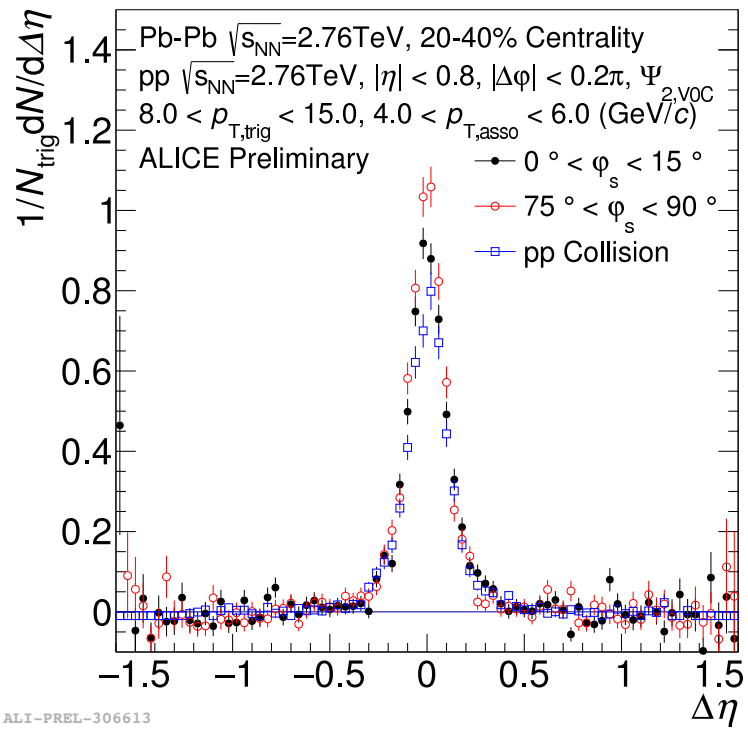


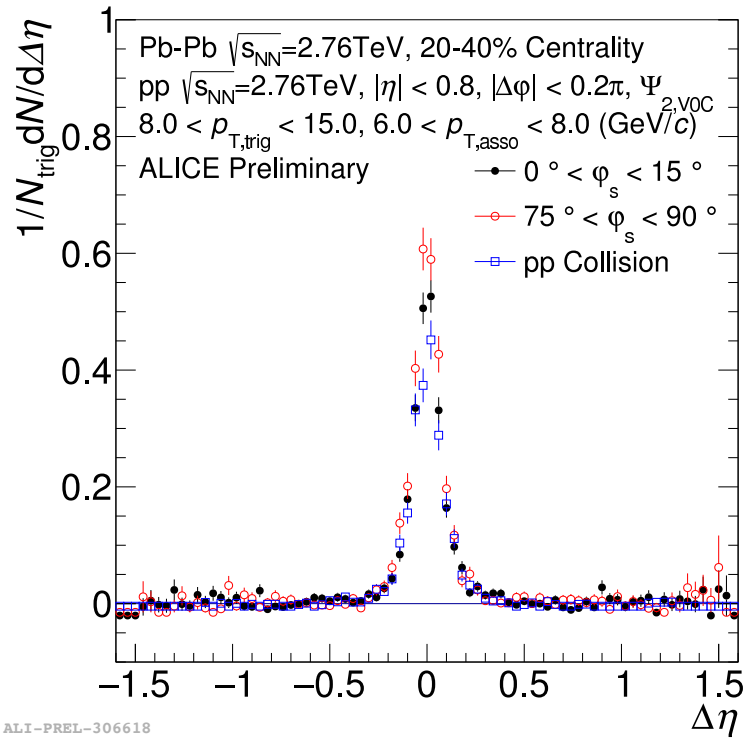


- $\Delta\eta$ projected yield gives advantage on background removal
- We estimate the background using the generalized gaussian + simple flat distribution in the peak area

$$f(\Delta\eta) = bck + \frac{\beta}{2\alpha\Gamma(1/\beta)} e^{-(|\Delta\eta|/\alpha)^{\beta}}$$

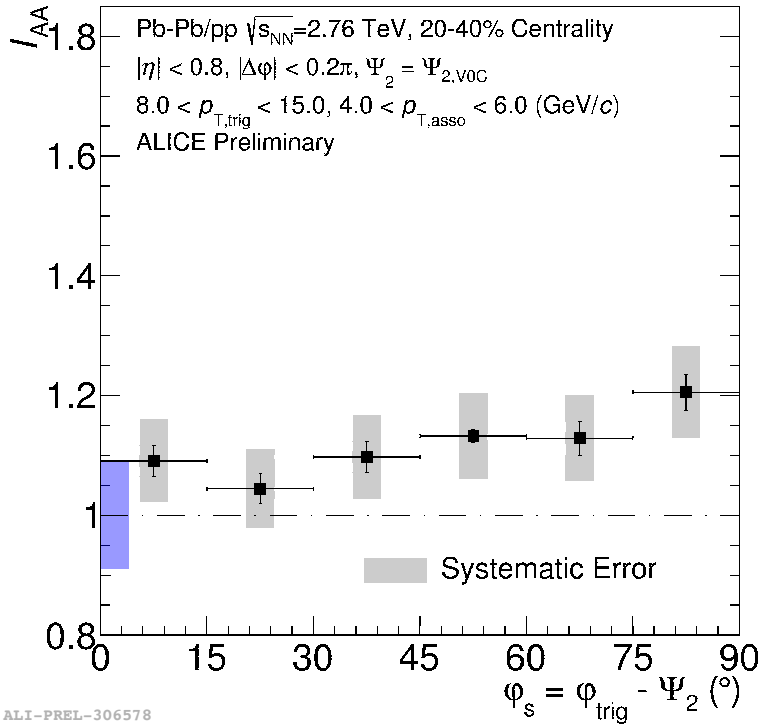
Per-trigger yield after background subtraction

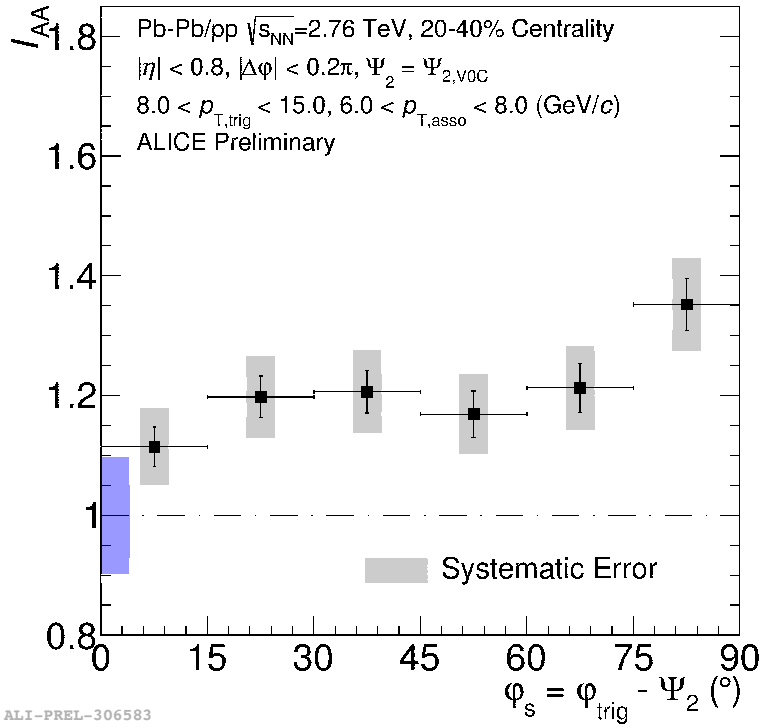




- Clear signal is observed, benefiting from flat background in $\Delta\eta$
- We integrate the signal inside the peak region, and use the integrated yield for I_{AA} calculation

Path length dependence of I_{AA}





- No significant path length dependence is observed in $4.0 < p_{\mathrm{T,asso}} < 8.0$ (GeV/c)
- Similar to lower $p_{\mathrm{T,trig}}$ and $p_{\mathrm{T,asso}}$ results in other measurements

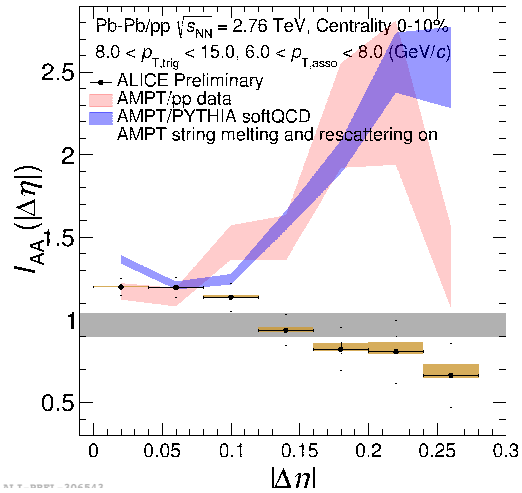
Summary & Outlook

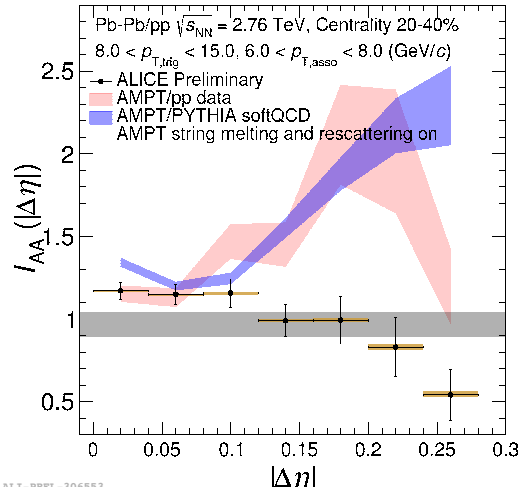
- I_{AA} shape modification
  - Possible onset of narrowing is observed
  - AMPT shows very large broadening in $|\Delta\eta| > 0.1$, contrary to the data
  - I_{AA} is also overestimated by AMPT, in $|\Delta\eta| < 0.3$

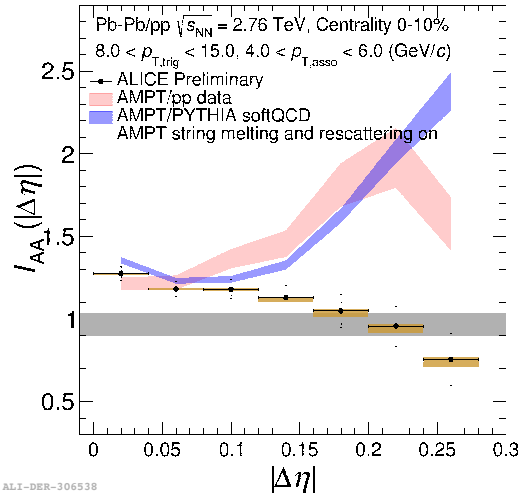
- Path length dependence of jet-like particles
  - No significant path length dependence is observed at $4.0 < p_{\mathrm{T,asso}} < 8.0$ (GeV/c)
  - Model studies are needed
  - Extending analysis to 5.02 TeV

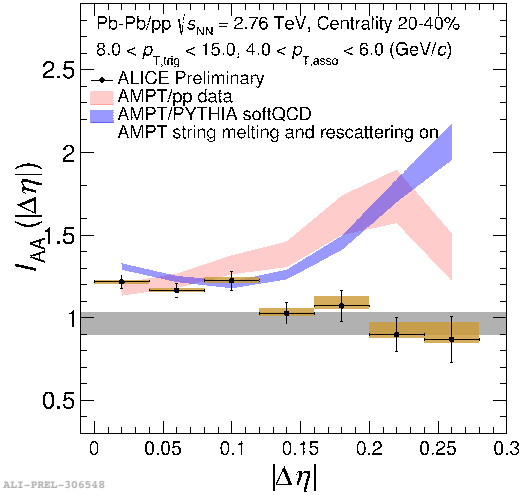
Backups

Model comparison on shapes



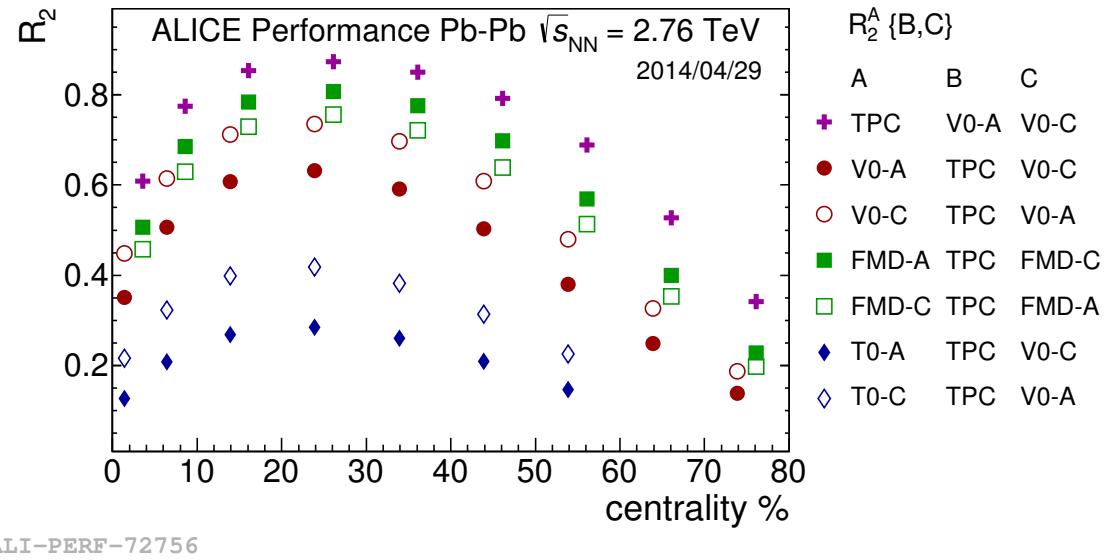


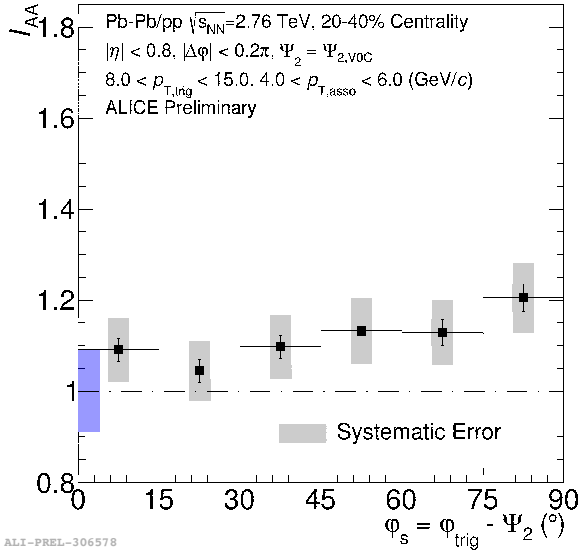




- Comparison with AMPT model, string melting on
  - pp reference – Data or PYTHIA (softQCD setting)
- Very large broadening at $|\Delta\eta| > 0.1$
- I_{AA} is overestimated by AMPT

Event plane resolution and correction



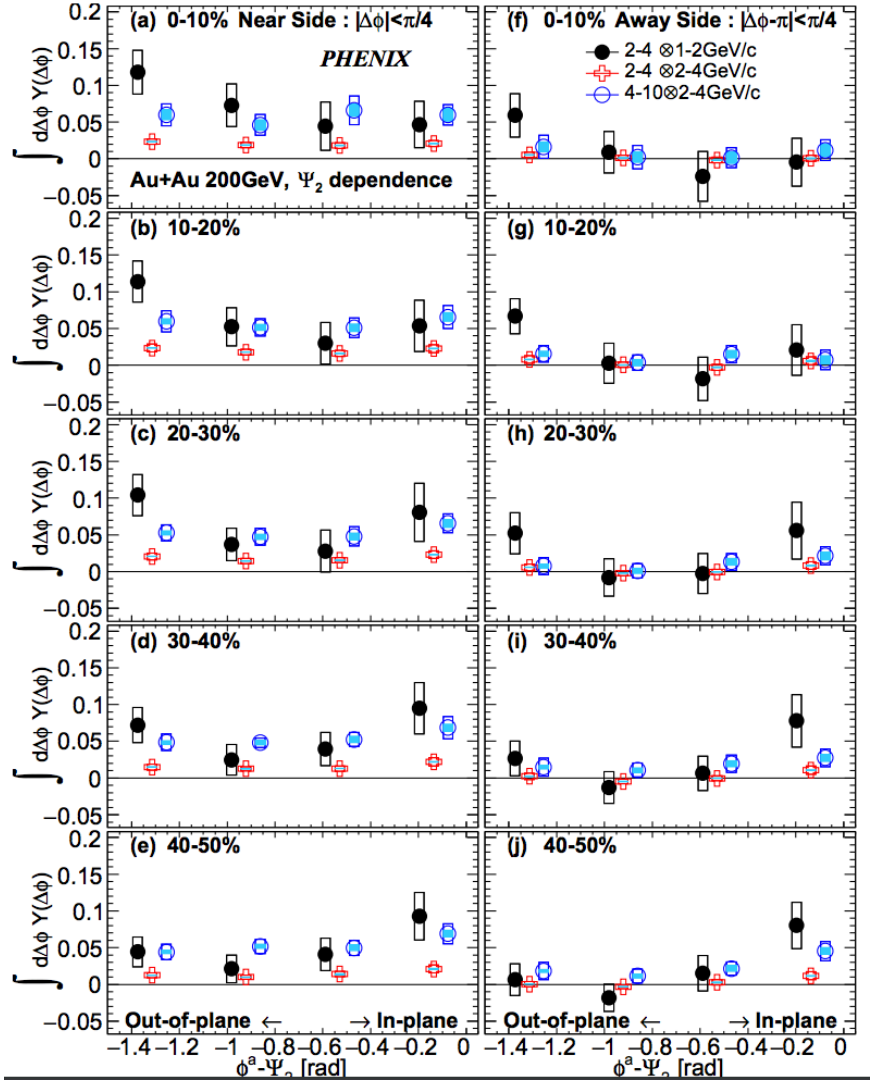


- Assumption that the coefficients determined from the fits are diluted by the event plane resolutions [PHENIX, arXiv:1803.01749]
  - The effects can be corrected in a way similar way that we correct azimuthal anisotropy v_n
- Finite resolution of event plane determination is corrected with :

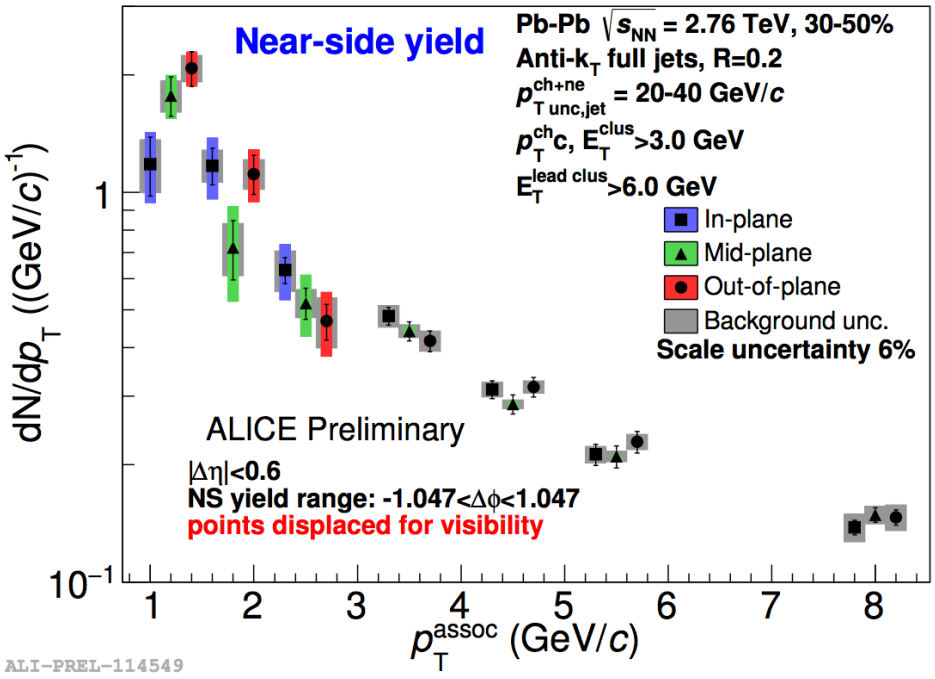
$$1 + I_{\mathrm{AA}}^{\mathrm{corrected}} = \frac{1+v_2^{\mathrm{IAA}}/R_2\cos(\varphi_s+\Delta\varphi)}{1+v_2^{\mathrm{IAA}}\cos(\varphi_s+\Delta\varphi)}\,(1 + I_{\mathrm{AA}}^{\mathrm{raw}})$$

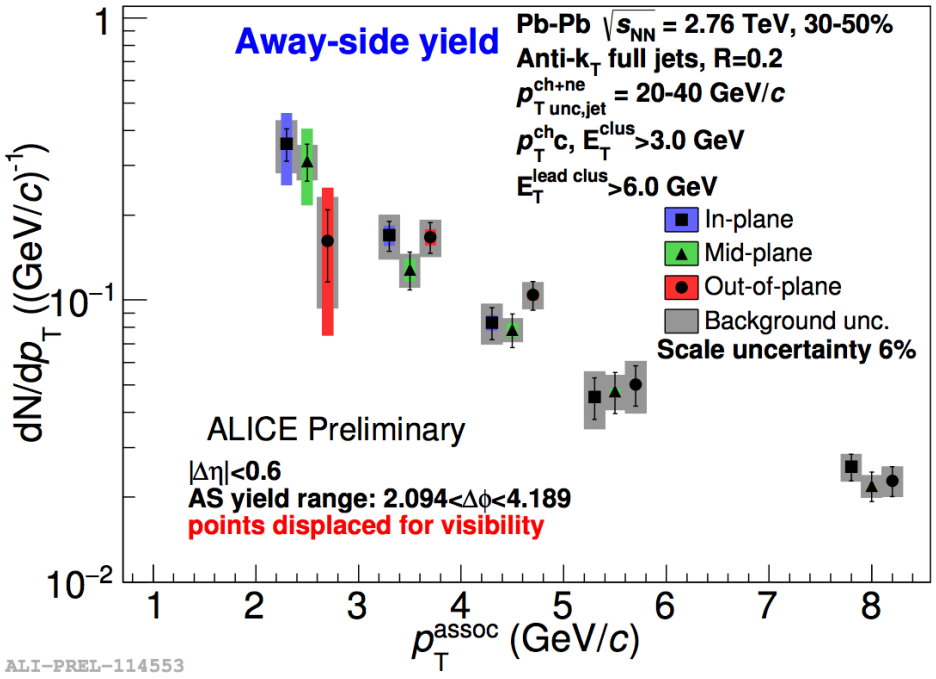
Other event plane dependence studies

- [PHENIX, arXiv:1803.01749]
- No significant 2nd order plane dependence of per-trigger yields
  - At $2 < p_{T,trig} < 10$ with $2 < p_{T,asso} < 4$ (GeV/c)
- Weak 2nd order dependence of per trigger yields
  - At $2 < p_{T,trig} < 4$ with $1 < p_{T,asso} < 2$ (GeV/c)



Other event plane dependence studies





- [ALICE, Nucl.Phys.A 967(2017) 500]
- No significant 2nd order plane dependence of yields in jet-hadron correlation