High p_T correlations in ALICE

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Outline

- Motivation
- ALICE detector
- Di-hadron correlations
  - Study near-side (NS) and away-side (AS) peaks, and compare Pb-Pb to pp
- h+jet coincidence measurement
  - New method to subtract the background jets

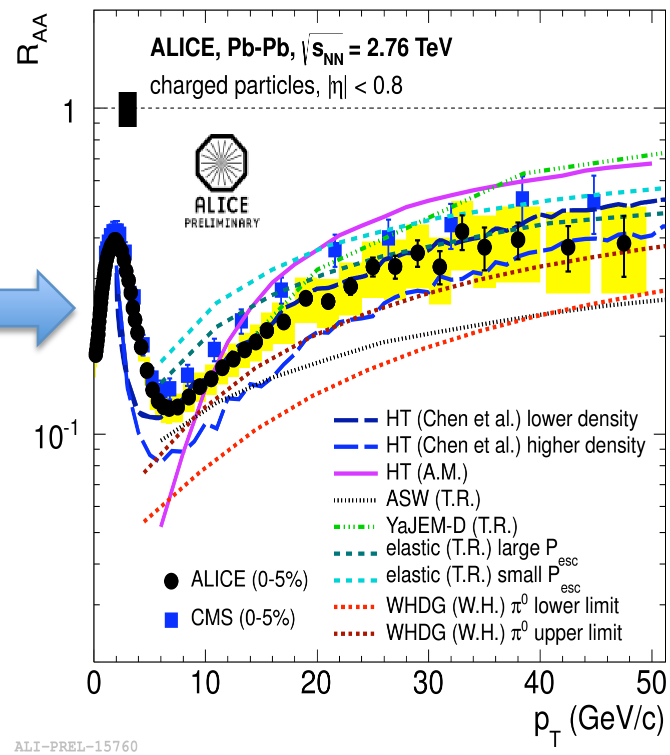
Correlation vs inclusive measurements

- Hard scattered partons generated in the early stage lose energy when travel through the medium ("jet quenching").

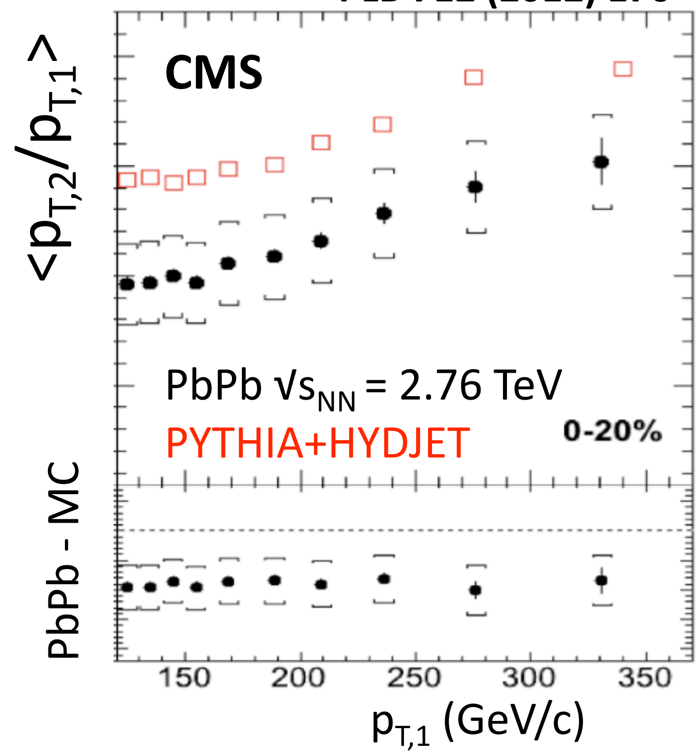
Energy loss is observed at the LHC:

ALICE jet R_{AA}
C. Loizides
Monday, Oct. 22

arXiv: 1208.2711v1

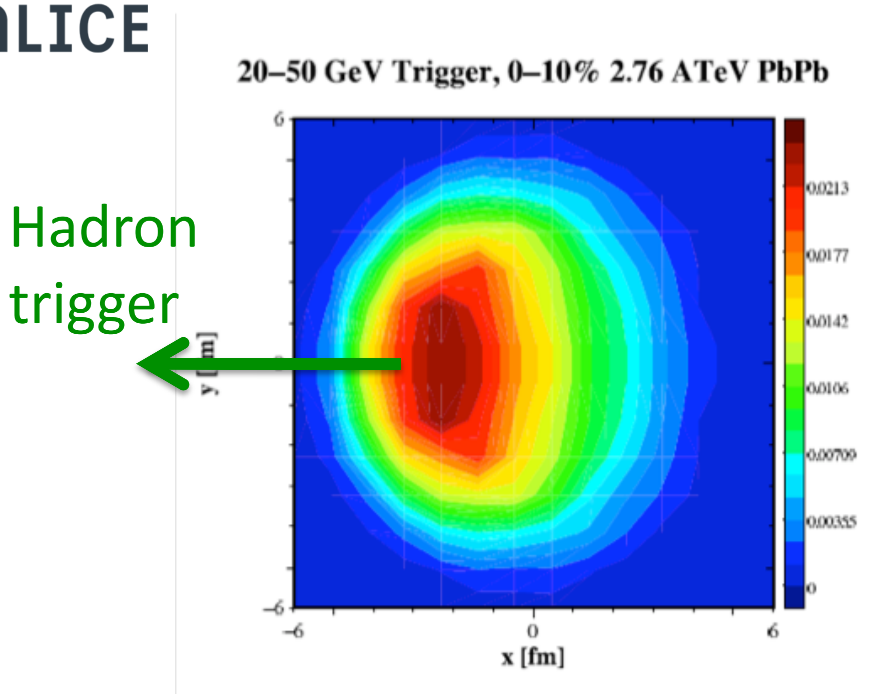


PLB 712 (2012) 176

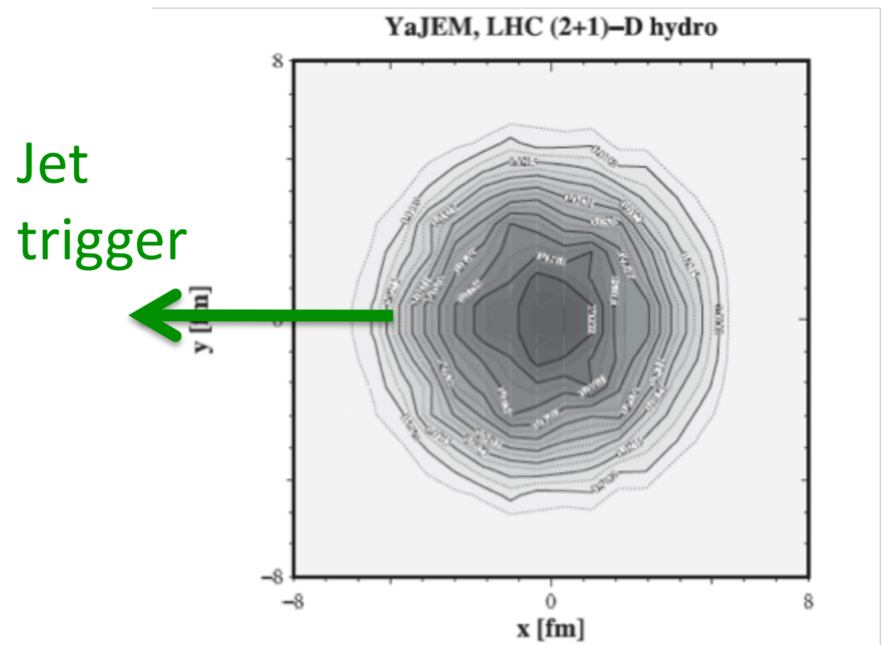


- Correlation studies can help to further quantify the modification of jet fragmentation in medium

Hadron trigger bias



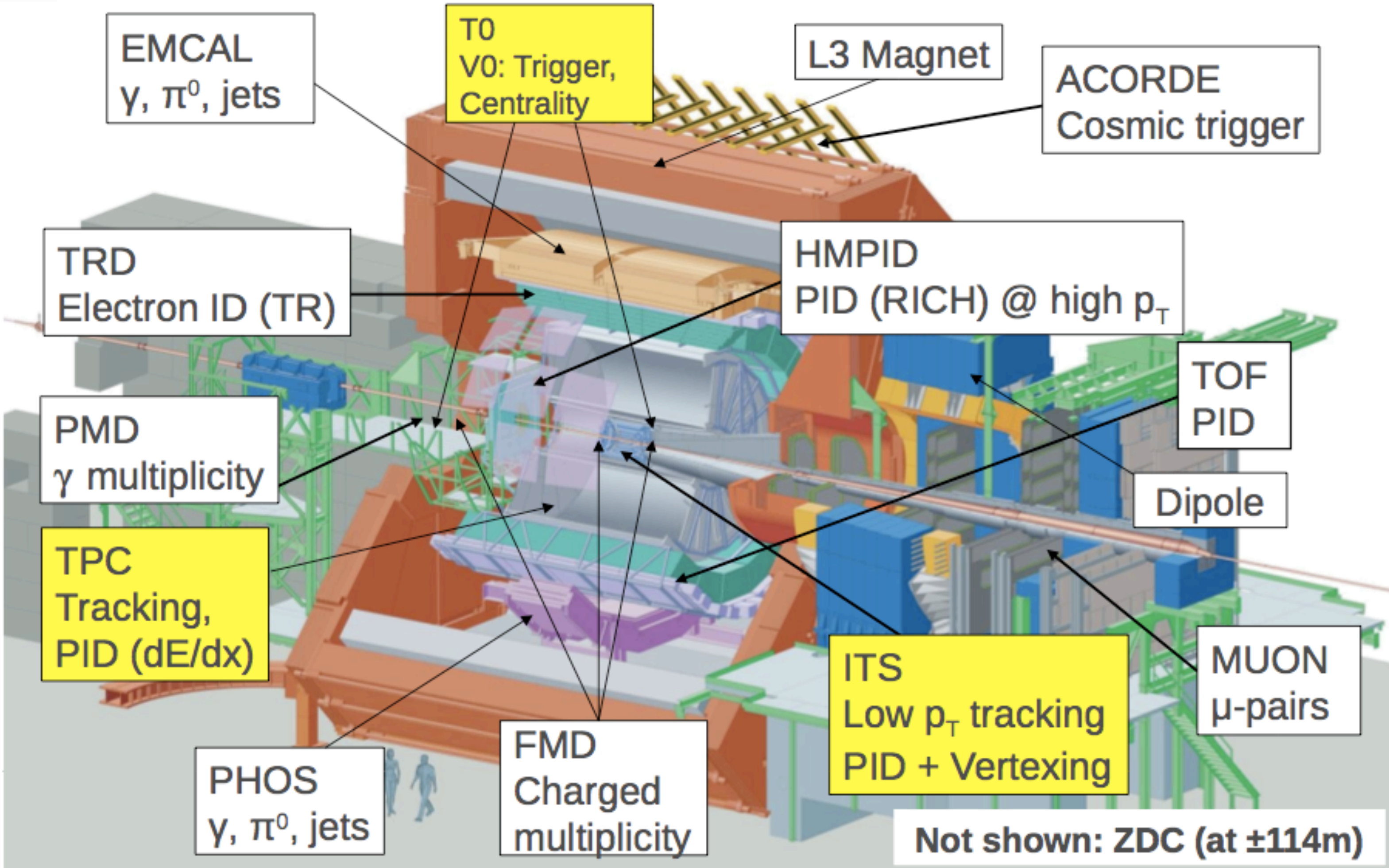
T.Renk, private com.



(T.Renk, Phys.Rev .C85 064908)

- Hadron trigger -> strong surface bias -> maximize the recoil path length
- Jet trigger -> smeared and averaged by the background fluctuations -> less surface bias

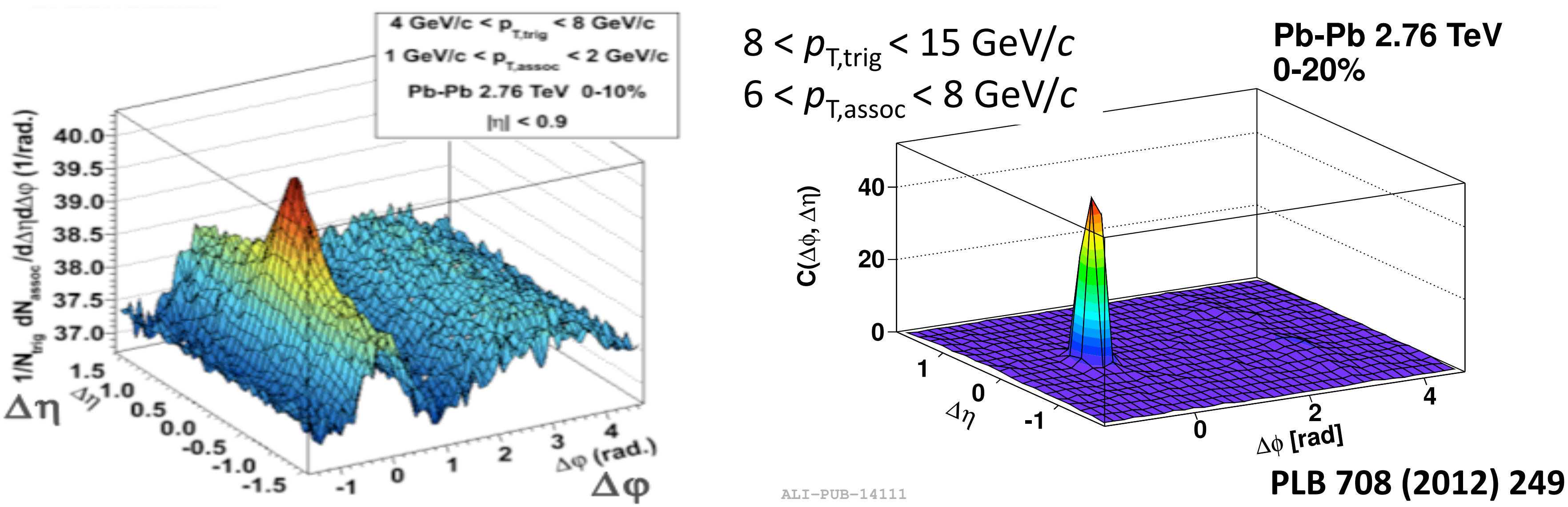
ALICE detector



Di-hadron correlations

Correlation functions

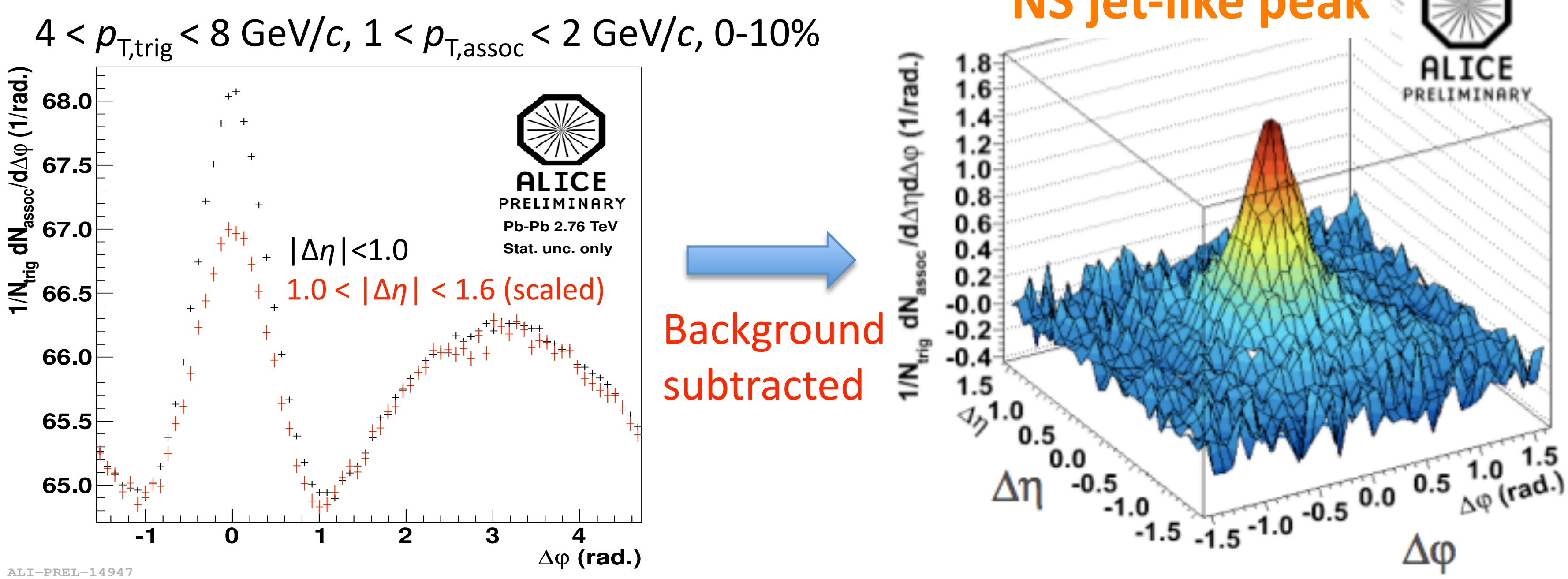
- Angular correlations in $\Delta\varphi$ (azimuth) and $\Delta\eta$ (pseudo-rapidity) between a trigger particle and all the associated particles.
  - Cut on $p_{T,trig}$ and $p_{T,assoc}$



- Correlations can be quantified via per trigger associated particle yield or the width of the peaks

Correlation at low p_T

- Tracks: $|\eta|<0.9$
- Signal extraction: η-gap subtraction $1<|\Delta\eta|<1.6$
  - $\Delta\eta$ independent (long range) correlations
  - Flow + uncorrelated background
- Jet-like NS peak ($\Delta\varphi = 0$, $\Delta\eta = 0$)



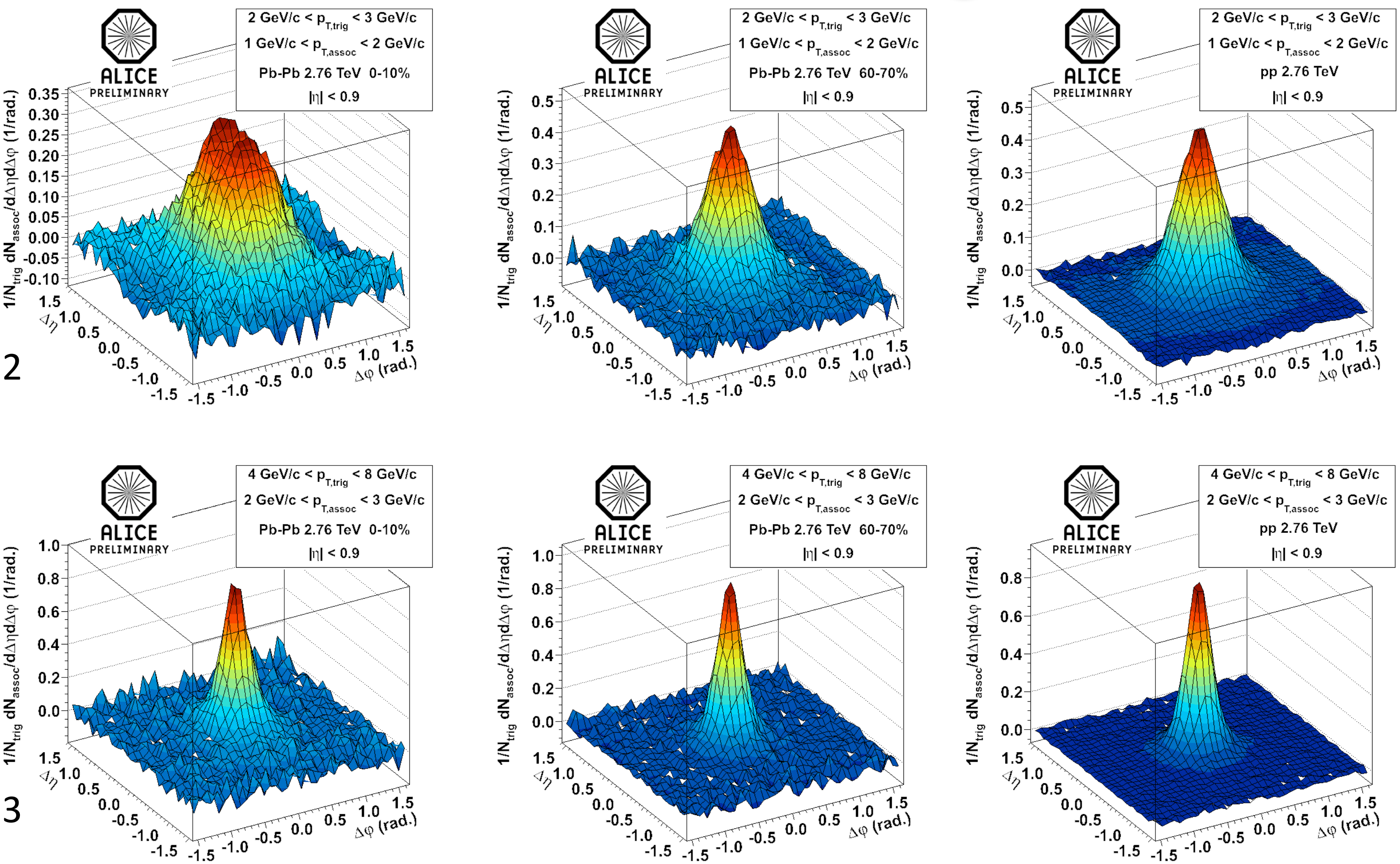
Shape evolution

0-10% Pb-Pb PbPb 60-70% Pb-Pb PbPb pp

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

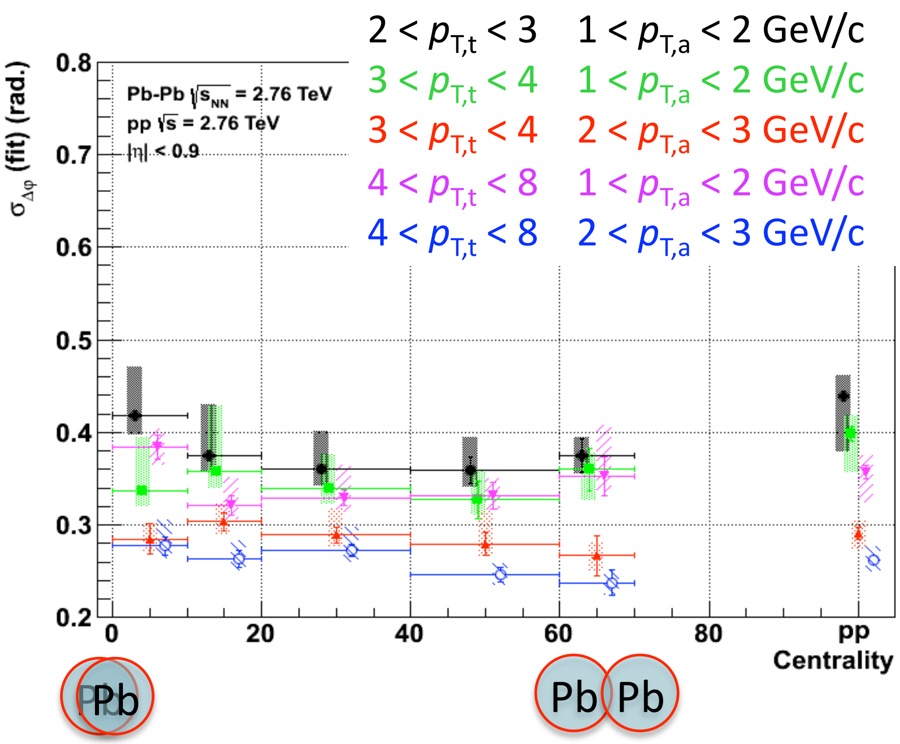
p_T

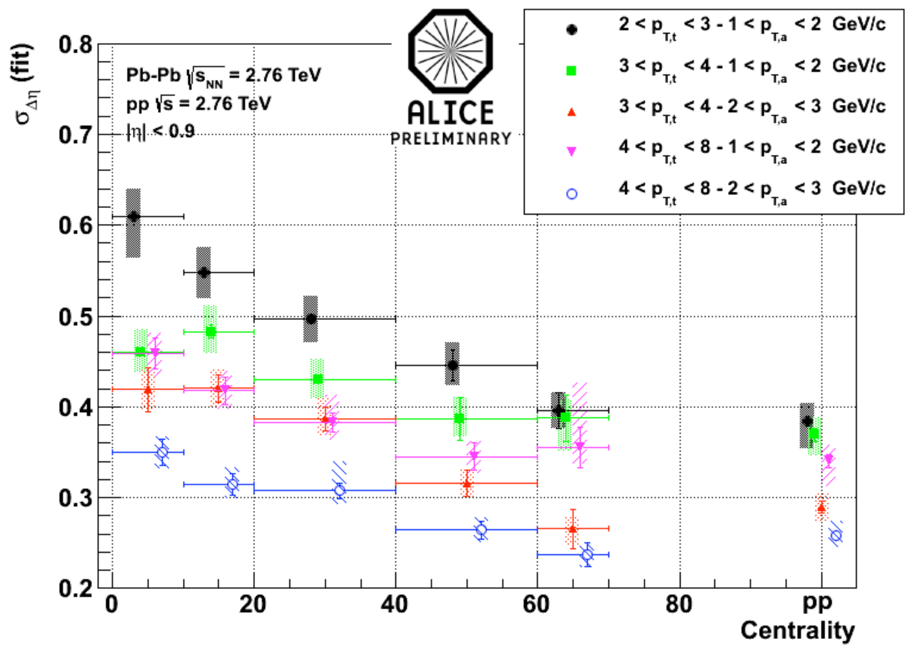
$4 < p_{T,trig} < 8$
$2 < p_{T,assoc} < 3$



Quantify the NS peak with width

- Fit the correlation with a sum of two 2D Gaussians





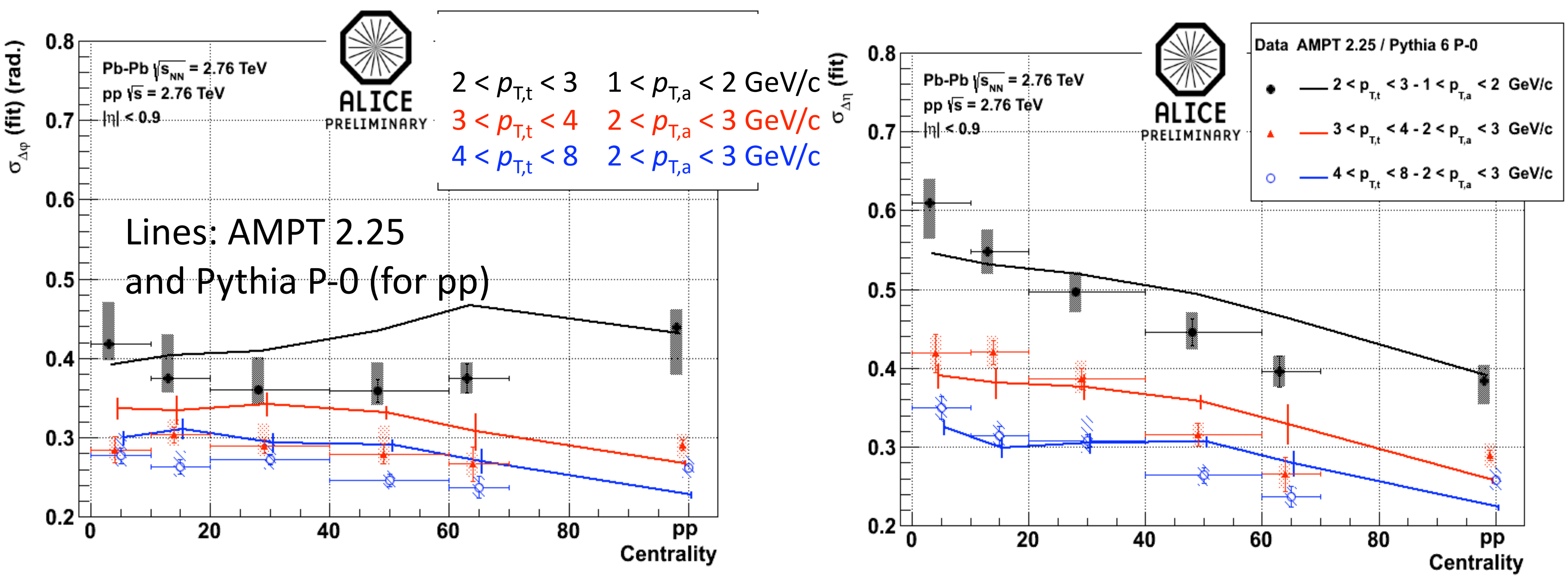
- $\sigma_{\Delta\varphi}$: weak dependence on centrality
- $\sigma_{\Delta\eta}$: increase towards central collisions

Broadening in η direction -> longitudinal flow?

Predicted in PRL 93,242301 (2004)

AMPT Comparison

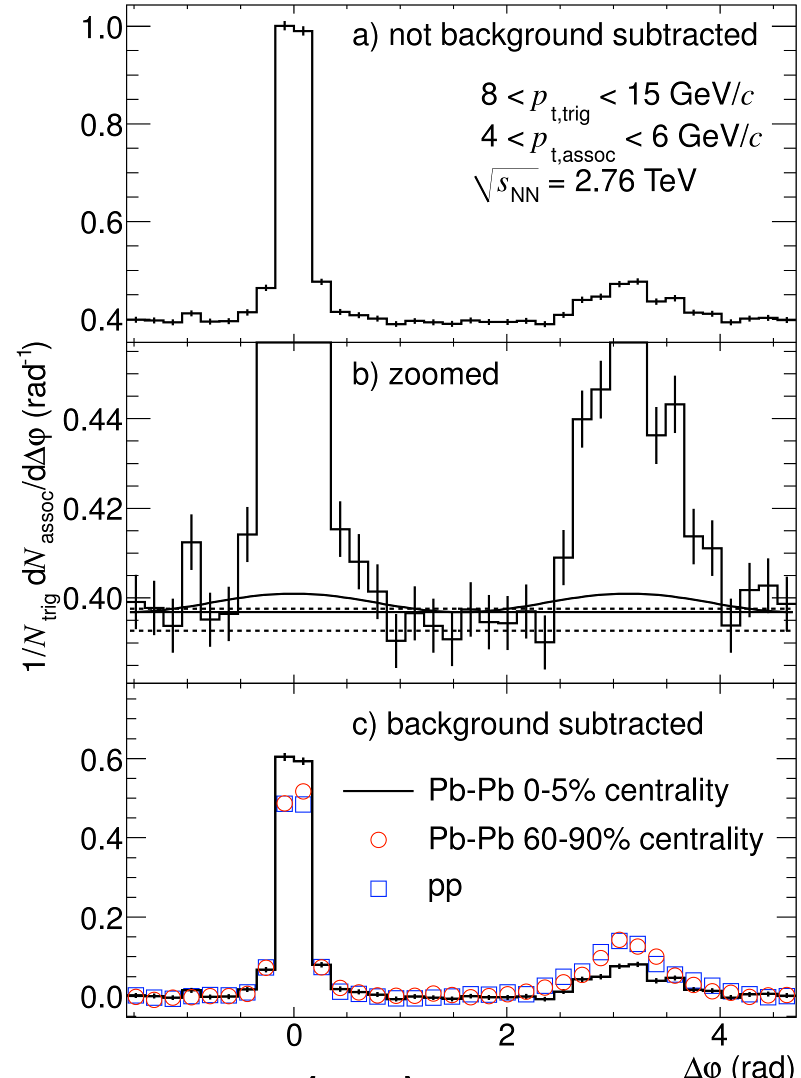
- AMPT (A MultiPhase Transport Code) describes collective effects (e.g. v_2, v_3, v_4) at the LHC
  - Here version with string melting (2.25) is shown



- Agree with data for the near-side peak width
  - Interplay of jet and flow in AMPT via parton and hadron scattering

Correlation at high p_T: $8 < p_T^{trig} < 15$ GeV/c

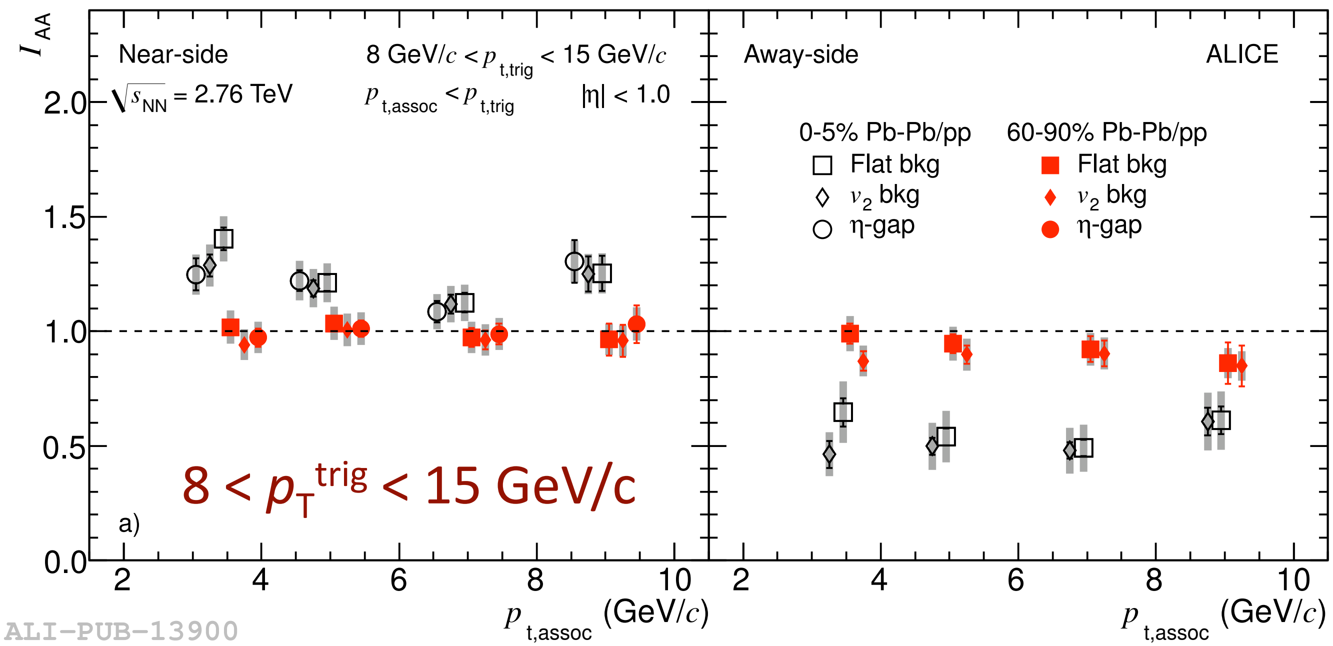
- High p_T tracks are used to enhance the signal to background ratio -> reliable extraction of signal
- Tracks: $|\eta|<1.0$
- Correlation in azimuth: $\Delta\varphi$
- Background subtraction:
  - ZYAM: fit a constant value in the region $|\Delta\varphi-\pi/2|<0.4$
  - ZYAM + v2 background
  - η-gap method: all the flow components are subtracted



PRL 108, 092302 (2012)

Ratio of hadron yield in Pb-Pb to pp

Near side (NS) **Away side (AS)** **PRL 108, 092302 (2012)**



$$I_{AA} = Y_{Pb-Pb} / Y_{pp}$$

$$Y = \int \frac{1}{N_{trig}} \frac{dN_{assoc}}{d\Delta\varphi} d\Delta\varphi$$

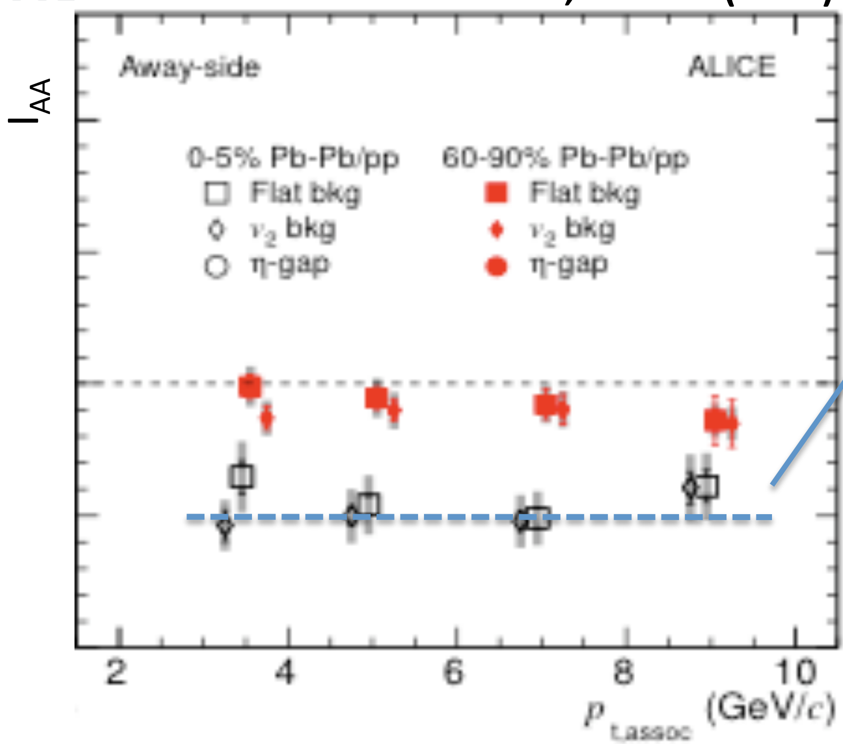
NS: $\Delta\varphi$ in ± 0.7
AS: $\Delta\varphi$ in π ± 0.7

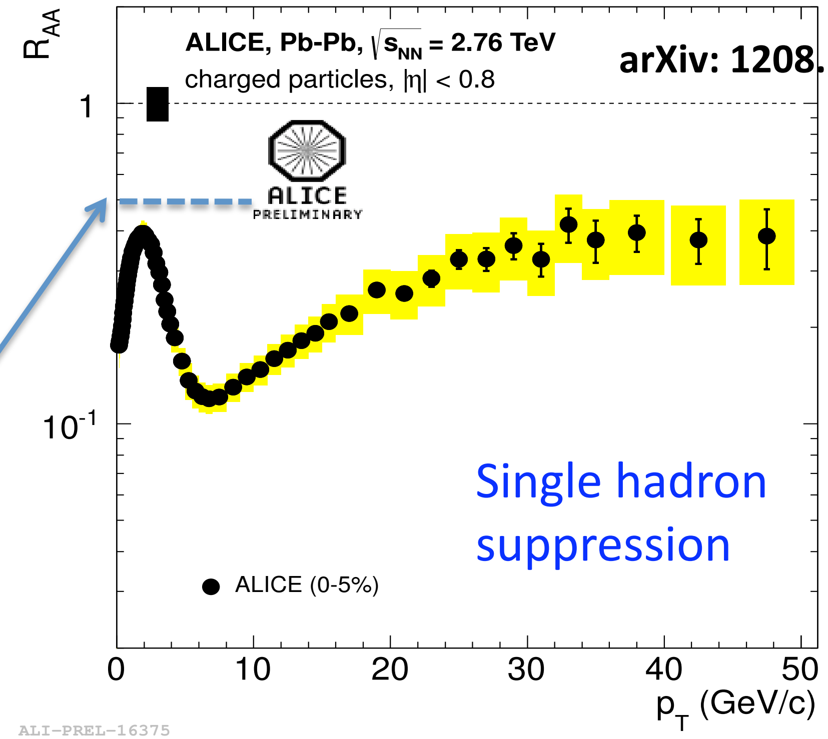
- **Enhancement of NS yield**
  - Softening of fragmentation function in medium
  - Harder parton distribution in central collisions
  - Relative abundance of gluon vs quark jets
- STAR at RHIC: I_{AA} is consistent with 1 **(PRL 97, 162301)**

- **Suppression of AS yield**
  - Weak dependence on $p_{T,assoc}$
  - Less suppressed than PHENIX π^0-h measurement at RHIC **(PRL 104, 252301)**

Compare to R_{AA}: $I_{AA} > R_{AA}$

PRL 108, 092302 (2012)





arXiv: 1208.2711v1

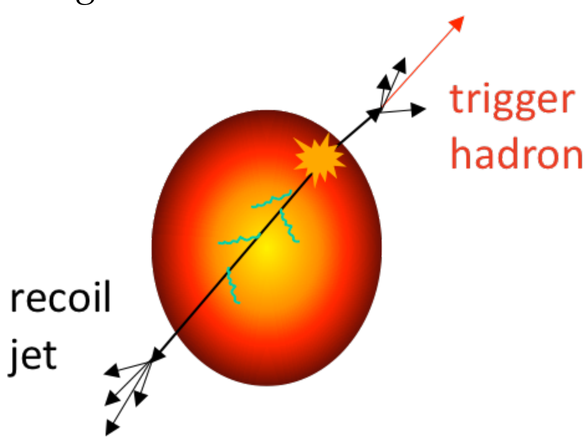
- The away-side hadrons are expected to experience larger in-medium path
- Away-side spectrum is less steeply falling
- **Important for models to get both R_{AA} and I_{AA} right.**

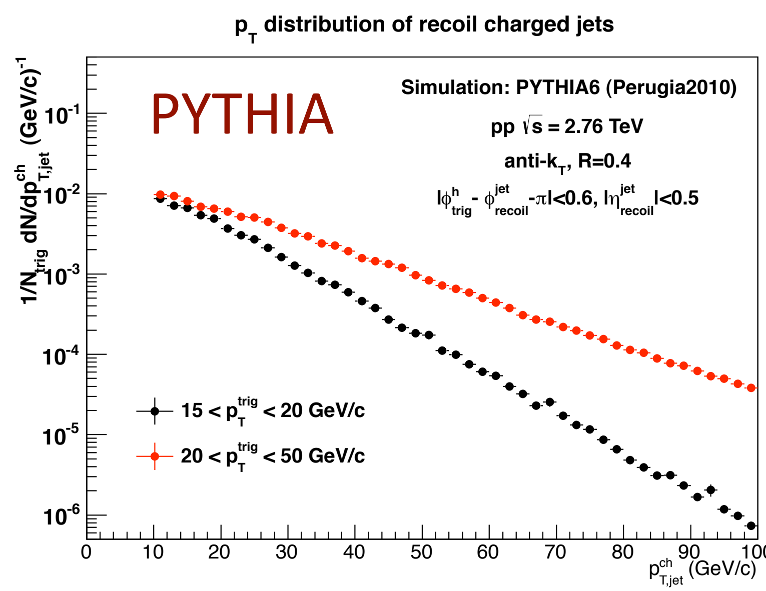
h+jet coincidence measurement

h+jet coincidence measurement

- Goal: precise measurements of jet structure -> minimal fragmentation bias
- Observable: hadron-triggered semi-inclusive recoil jet distribution
  - Trigger hadron: leading charged particle in the event
  - Recoil jet: count the jet rate in the away side per trigger hadron

$$|\varphi_{trig}^{h} - \varphi_{recoil}^{jet}| < \pi - 0.6$$





Analysis setup

- Hadron trigger: *p_T large enough to be "rare" per central Pb-Pb event (0-20%) -> high probability that the hard recoil jet is from the same hard scattering*
- Track p_T > 0.15 GeV/c
- Charged jets: anti-k_T with R=0.2 and 0.4, $|\eta_{jet}|<0.5$
  - Correct event-wise for background: $p_{T,jet} = p_T^{reco} - \rho \times A$
- pp reference: PYTHIA6 (Perugia-2010)

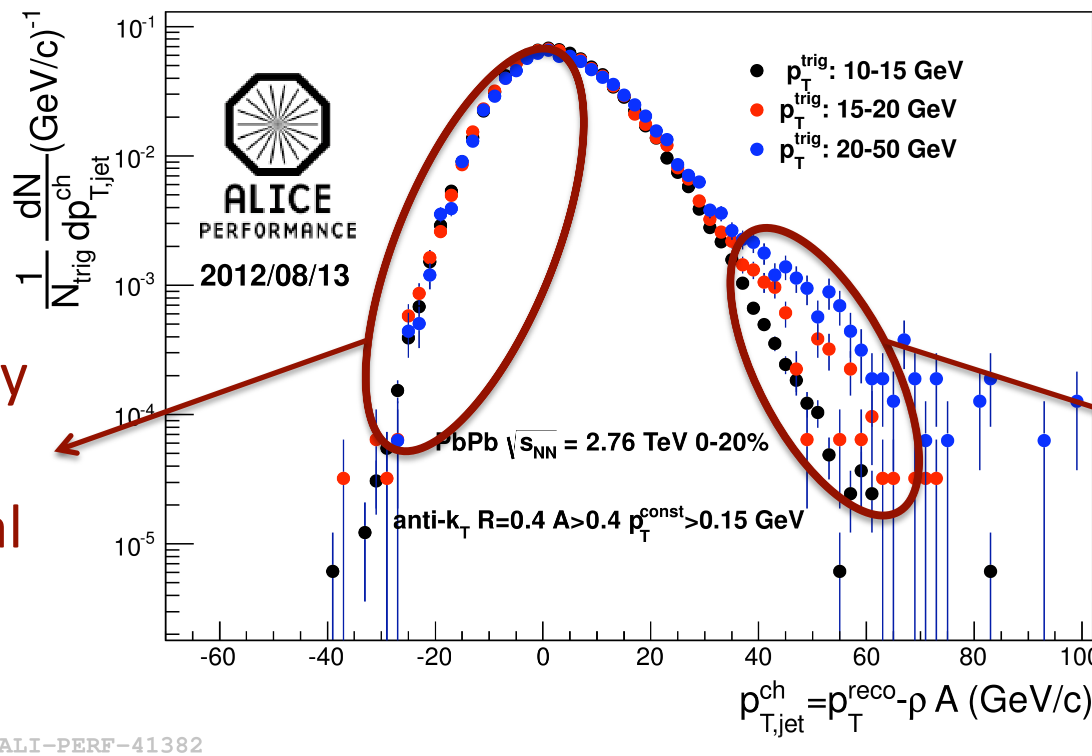
Combinatorial jet distribution

- **Conjecture: combinatorial jet distribution is independent of trigger p_T**

arXiv:1208.1518

  - Caveats: reaction plane and centrality biases are minimized for high p_T triggers

Dominated by uncorrelated combinatorial jets

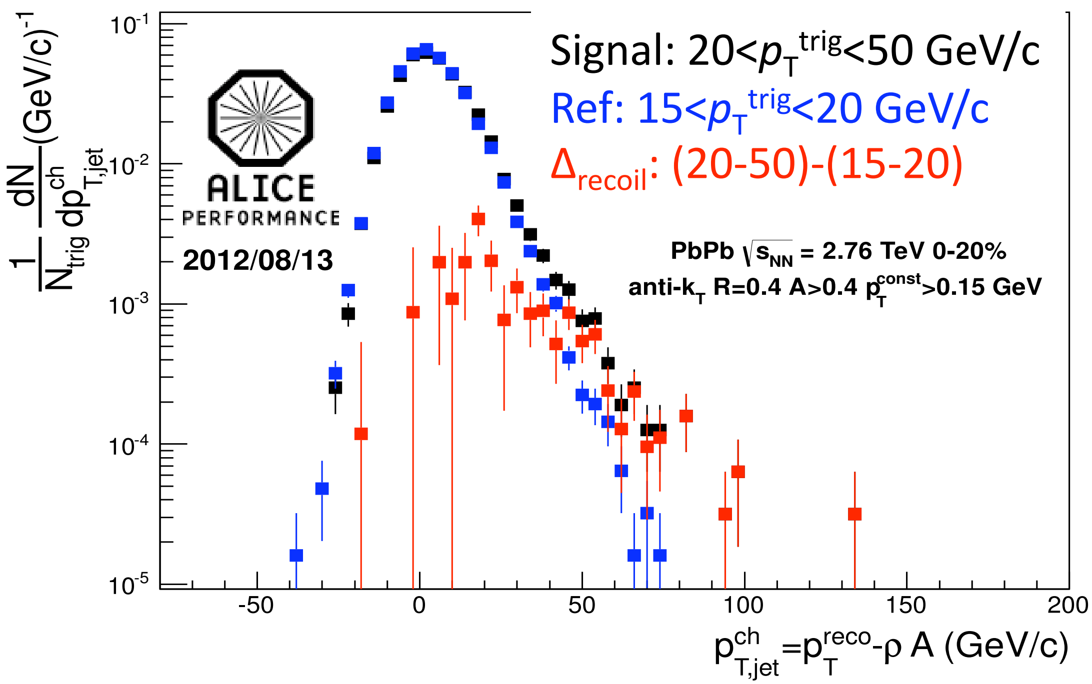


Dominated by true hard jets

- Remove the combinatorial jets via **DIFFERENCE** of triggered distributions: Δ_{recoil}

Remove combinatorial jets

$$\Delta_{recoil}(p_{T,jet}^{ch}) = \frac{1}{N_{trig}} \frac{dN(p_{T,jet}^{ch}; p_T^{\min}, p_T^{\max})}{dp_{T,jet}^{ch}} - \frac{1}{N_{trig,ref}} \frac{dN(p_{T,jet}^{ch}; p_{T,ref}^{\min}, p_{T,ref}^{\max})}{dp_{T,jet}^{ch}}$$

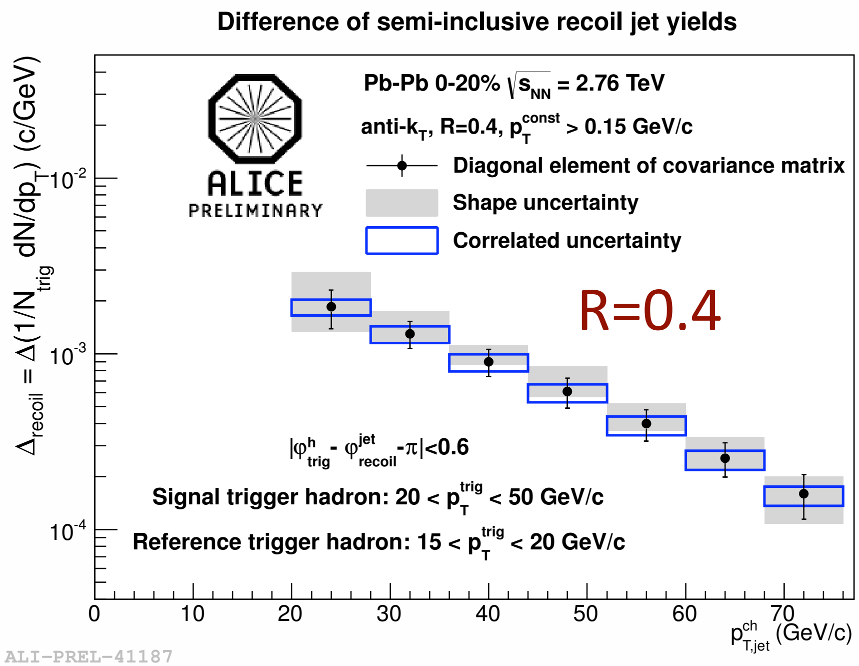


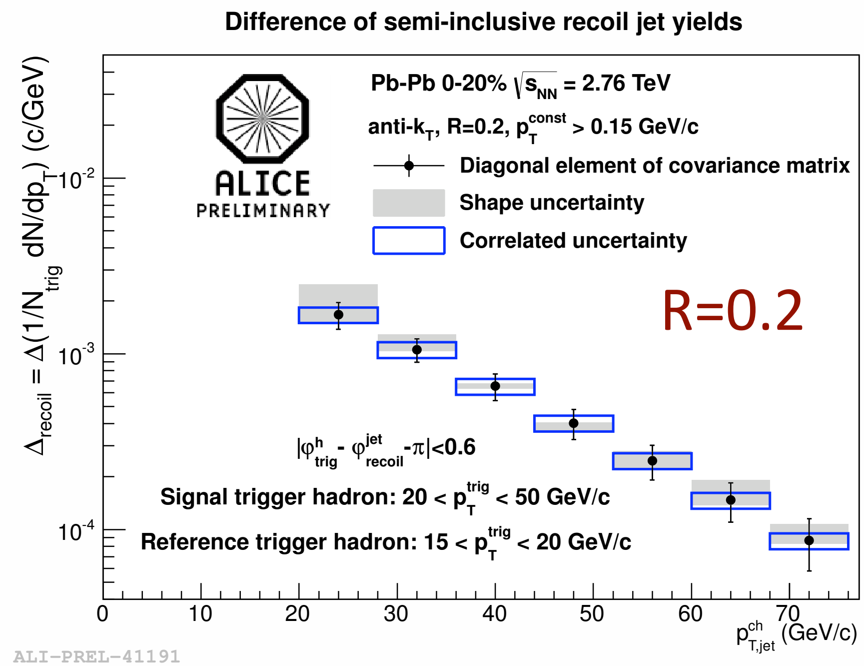
- Δ_{recoil} contains only correlated hard jet component

Reference spectrum (15-20) scaled by ~0.96 to account for conservation of jet density.

- Resulting Δ_{recoil} is smeared by the background fluctuation +detector effects-> unfolding

Unfolded recoil jet distributions Δ_{recoil}





- Correlated uncertainty
  - Flow bias on background
  - Tracking efficiency
  - Reference distribution scaling factor
- Shape uncertainty
  - Minimum p_T min cut on measured spectrum
  - Regularization: β variations
  - Difference to Bayesian result

Ratio of recoil jet yield: ΔI_{AA}

- Observable: the recoil jet yield (Δ_{recoil}) in Pb-Pb compared to pp

$$\Delta I_{AA} = \left\langle \frac{Y_{AA}^{20-50} - Y_{AA}^{15-20}}{Y_{pp}^{20-50} - Y_{pp}^{15-20}} \right\rangle \qquad Y = \frac{1}{N_{trig}} \frac{dN_{jet}^{assoc}}{dp_{T,jet}}$$

Finite statistics -> average over broad p_T^{trig} bins -> reference is reweighted using trigger hadron spectrum in Pb-Pb to minimize the influence of large p_T^{trig} bin

$$\langle \Delta I_{AA} \rangle \approx \frac{\langle Y_{AA}^{20-50} \rangle - \langle Y_{AA}^{15-20} \rangle}{\langle Y_{pp}^{20-50} \rangle_{AAW} - \langle Y_{pp}^{15-20} \rangle_{AAW}}$$

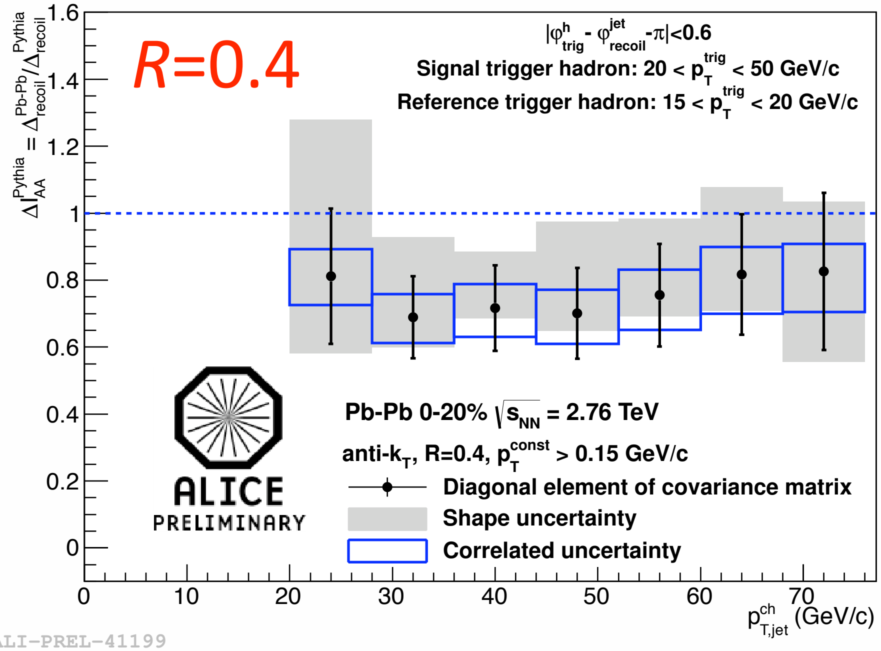
$$\langle Y_{AA}^{20-50} \rangle = \frac{1}{N_{AA,trig}^{20-50}} \int_{20}^{50} dp_T^{trig} \frac{dN_{AA}^{jet}}{dp_T^{trig} dp_T^{jet}}$$

$$\langle Y_{pp}^{20-50} \rangle_{AAW} = \frac{1}{N_{pp,trig}^{20-50}} \int_{20}^{50} dp_T^{trig} \frac{dN_{pp}^{jet}}{dp_T^{trig} dp_T^{jet}} \times f_w(p_T^{trig})$$

Reweighting pp ↓

$$f_w(p_T^{trig}) = \frac{1}{\langle R_{AA} \rangle} R_{AA}$$

Recoil Jet ΔI_{AA}^{PYTHIA}



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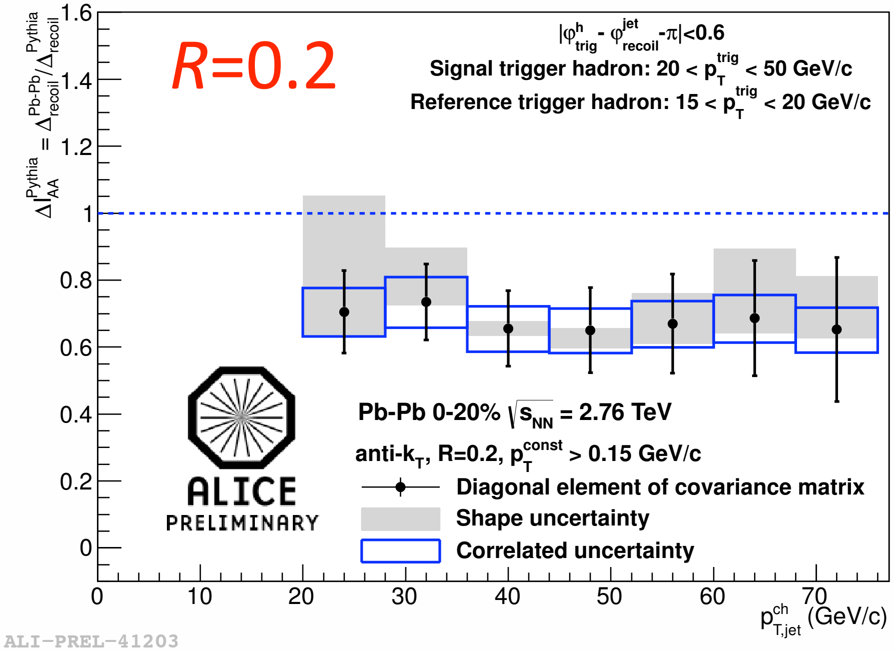
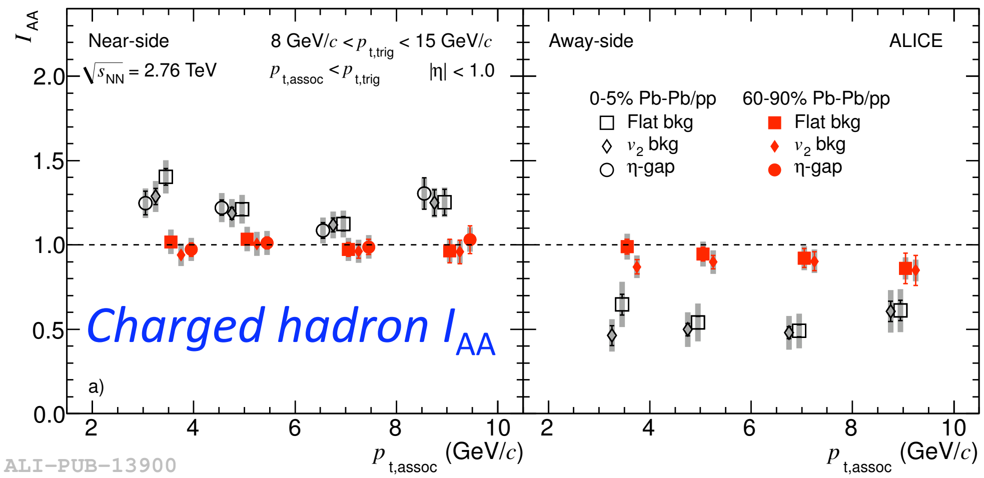
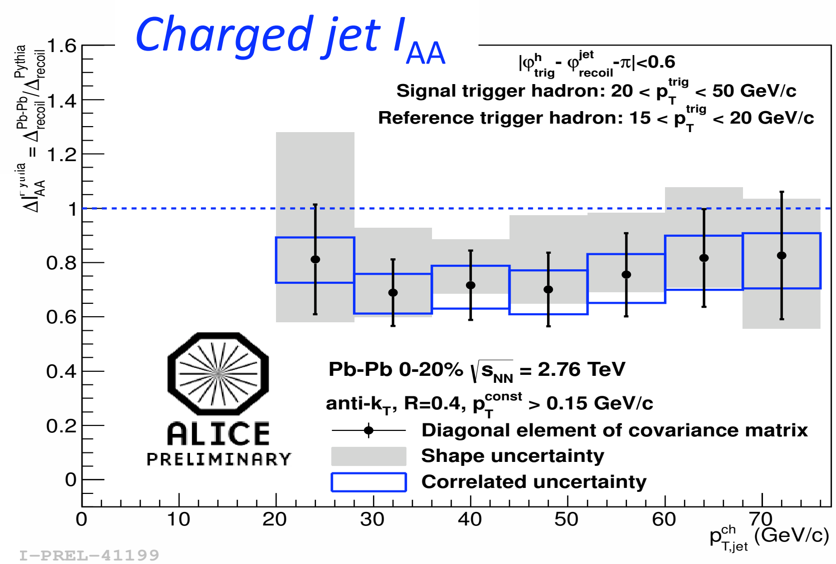


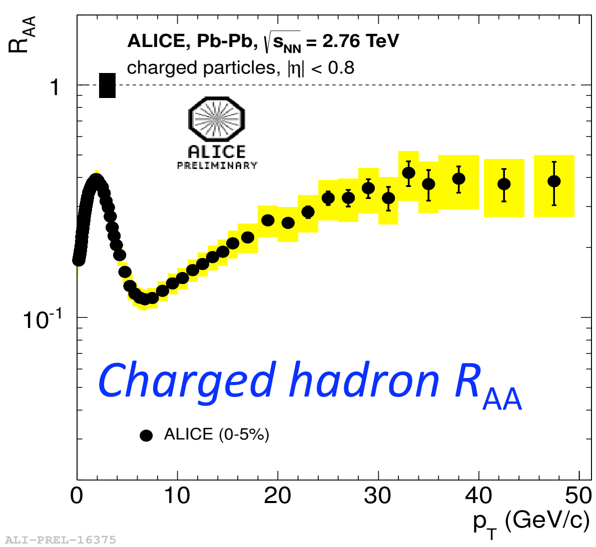
ALI-PREL-41203

- *R*=0.4: recoil jet yield ΔI_{AA}^{PYTHIA} ≈0.75, approx. constant with jet p_T
- *R*=0.2: similar ΔI_{AA}^{PYTHIA} as *R*=0.4
- Systematic uncertainties are too large to make more conclusive statements about out-of-cone radiation

I_{AA} vs R_{AA}







Di-hadron:

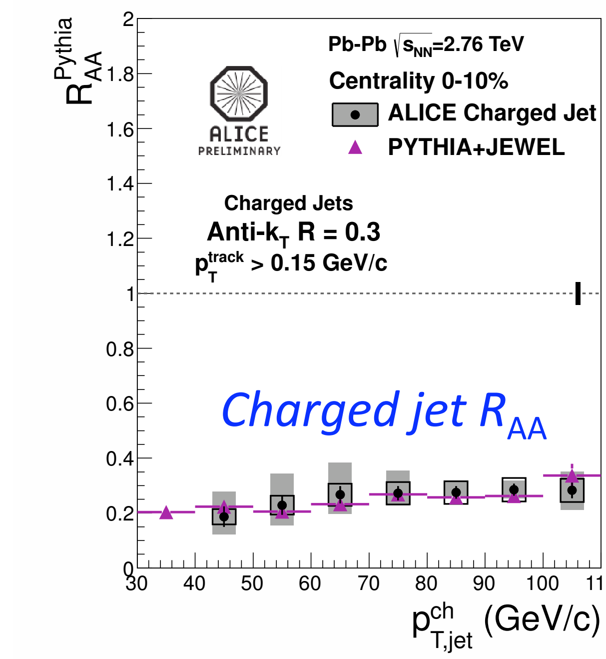
$p_T^{trig} > 8$ GeV/c, $I_{AA}(h) \approx 0.6$

$R_{AA}(h) \approx 0.3$

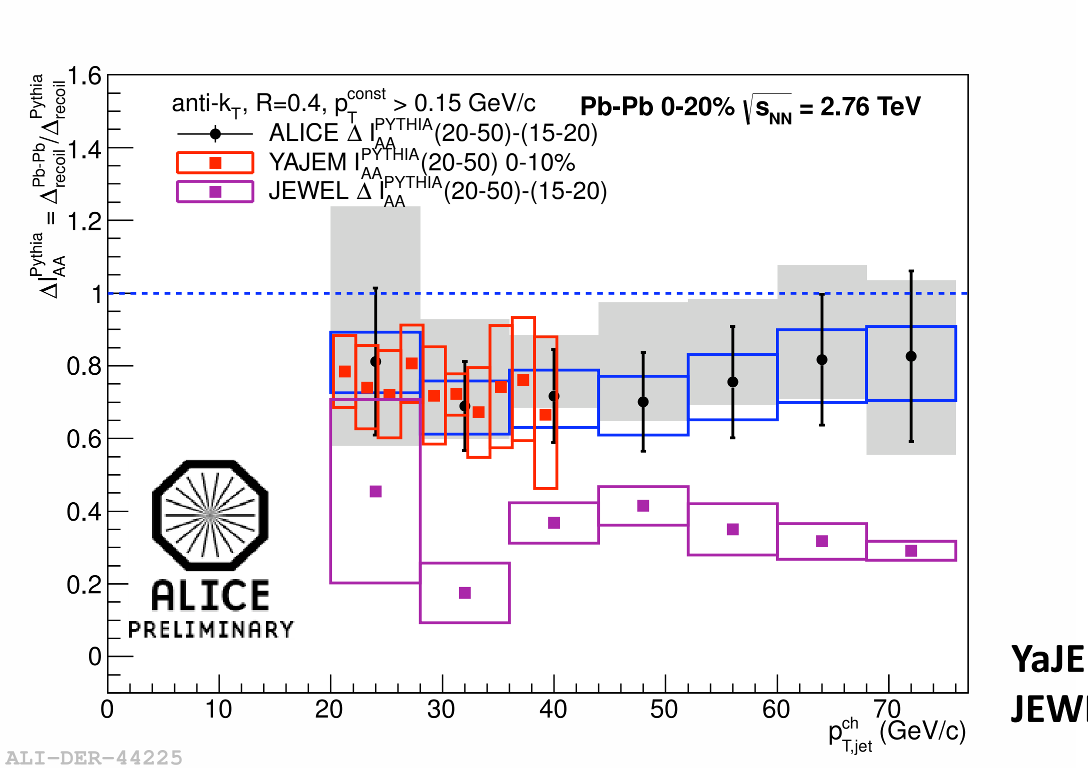
h+jet:

$p_T^{trig} > 20$ GeV/c, $I_{AA}(jet) \approx 0.75$

$R_{AA}(jet) \approx 0.3$



Compare to models



YaJEM: PRC 78 (2008) 034908
JEWEL: EPJ C60 (2009) 617

- Left: JEWEL describes the ALICE charged jet R_{AA} right, but undershoots the I_{AA}
- Right: YaJEM describes asymmetry A_j, and predicts an I_{AA} in agreement with data.
- **New constraint on models** (energy loss, geometry, path length dependendence, etc)

Summary

- Di-hadron correlations:
  - Low $p_{T:}$ $p_T^{trig} < 8$, $p_T^{assoc} < 3$ GeV/c
    - In central Pb-Pb events, significant broadening of near-side peak in $\Delta\eta$, but not in $\Delta\varphi$: interplay between longitudinal flow and jet shape?
  - High p_T: $8 < p_T^{trig} < 15$ GeV/c (dominated by jet signal)
    - Constraint for models: enhancement in near-side yield, but suppression at away-side.
- h+jet coincidence measurement: new method to suppress background contribution
    - Minimal fragmentation bias; infrared and collinear safe
    - Consistent results for different radii (0.2, 0.4) within large uncertainty
    - Next: evolution of recoil jet spectrum by changing trigger p_T range
- **It is important for models to describe both R_{AA} and I_{AA} for both single hadrons and jets.**

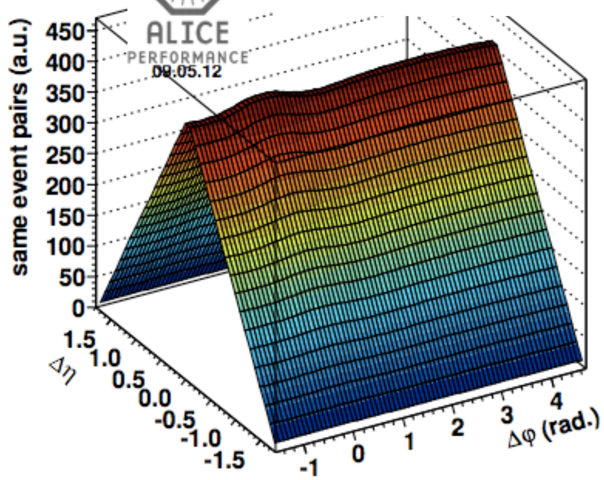
Backup

Event and Track Selection

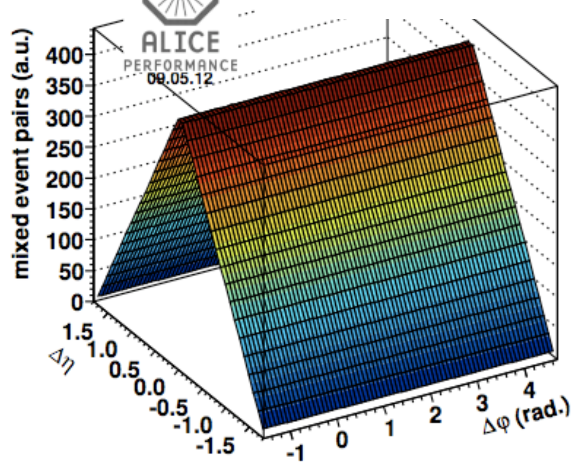
- Data sets
  - Pb-Pb at $\sqrt{s_{NN}}$=2.76 TeV: 15M events from 2010 data taking period in 0-90% centrality class
  - pp reference: 55M events from 2011 low energy run
- Centrality selection: VZERO ($2.8 < \eta < 5.1$ and $-3.7 < \eta < -1.7$)
- Tracking
  - TPC tracks constrained to the primary vertex
    - Optimal azimuth (φ) acceptance = uniformity for angular correlations
    - Minimize two-track cluster merging effects in the TPC
- Two step correction procedure
  - 2-track acceptance correction using mixed events => shape
  - Single particle efficiency and contamination correction => yield

Two-track acceptance correction

Same event



Mixed event



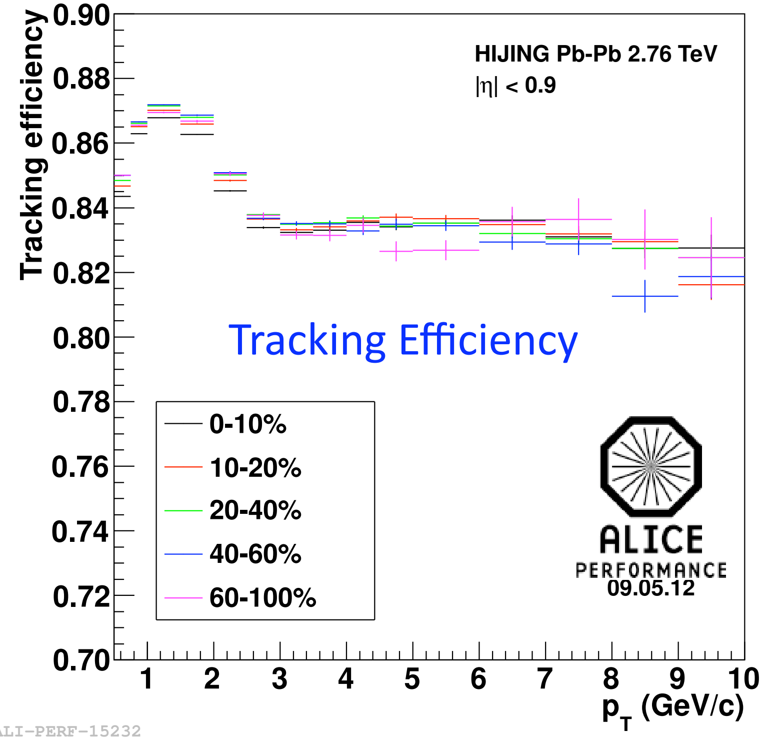
- Event Mixing: performed in bins of
  - Long. vertex position (z, Δz = 2 cm)
  - Centrality: 1% steps from 0-5%; then 5- 10% followed by 10% steps.
  - For each z-bin calculate the ratio:

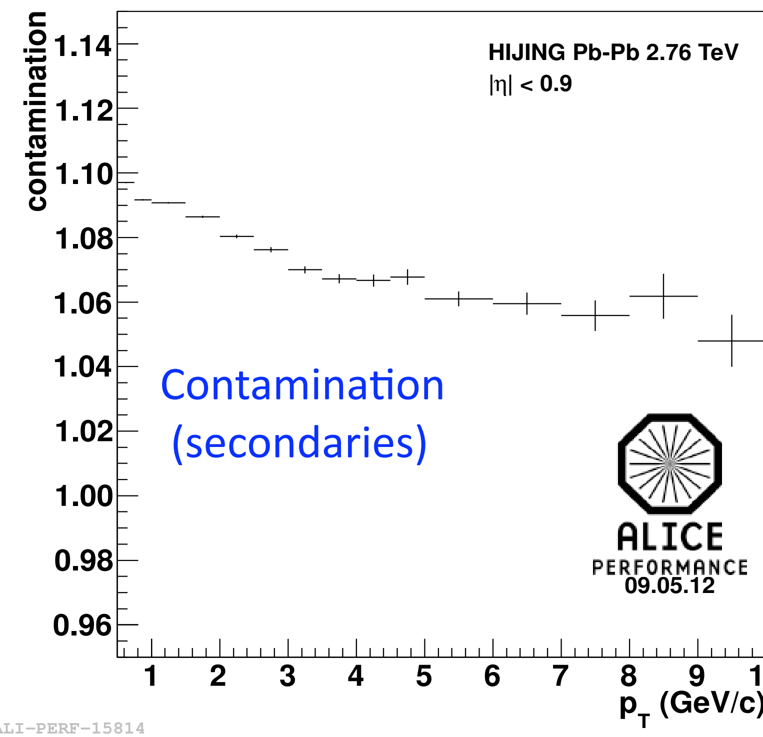
$$\frac{d^2N^{raw}}{d\Delta\varphi d\Delta\eta}(\Delta\varphi,\Delta\eta,z)=\frac{1}{N_{trig}(z)}\frac{N^{same}_{pair}(\Delta\varphi,\Delta\eta,z)}{N^{same}_{pair}(\Delta\varphi,\Delta\eta,z)}\beta$$

  - β chosen such that correction interpolated to Δφ=Δη=0 is 1.
  - Calculate weighted average of ratios

$$\frac{dN^{raw}}{d\Delta\varphi d\Delta\eta}(\Delta\varphi,\Delta\eta)=\frac{\sum_z N_{trig}(z)\frac{d^2N^{raw}}{d\Delta\varphi d\Delta\eta}(\Delta\varphi,\Delta\eta,z)}{\sum_z N_{trig}(z)}$$

Single particle corrections





$$N_{pair}^{corrected}(\Delta\eta,\Delta\varphi,p_{T,trig},p_{t,assoc},C)=N_{pair}^{raw}(\Delta\eta,\Delta\varphi,p_{T,trig},p_{T,assoc},C)\times C_{trkeff}(p_{T,assoc},C)$$
$$\times C_{trkeff}(p_{T,trig},C)\times C_{cont}(p_{T,assoc})\times C_{correlatedcont}(\Delta\eta,\Delta\varphi,p_{T,trig},p_{t,assoc})$$

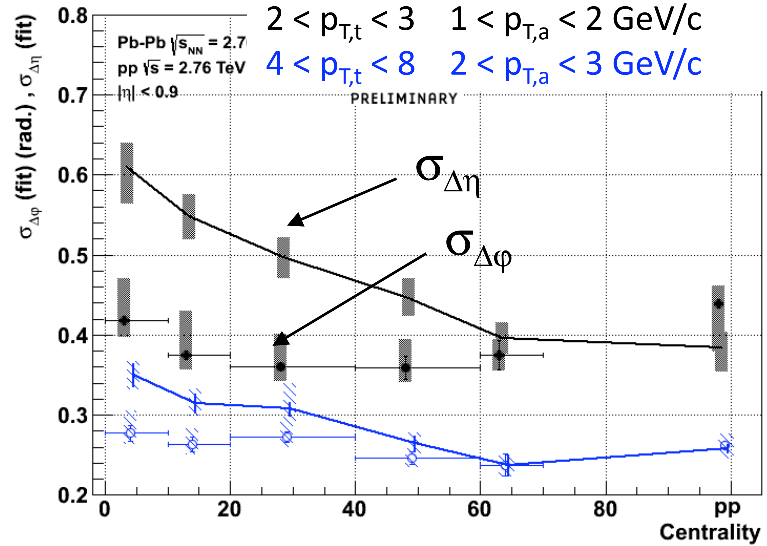
$$N_{trig}^{corrected}(p_{T,trig},C)=N_{trig}^{raw}(p_{T,trig},C)\times C_{trkeff}(p_{T,trig})\times C_{cont}(p_{T,trig})$$

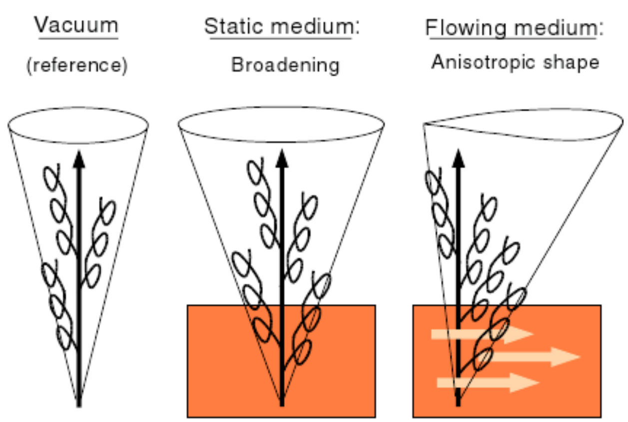
Systematic Uncertainties

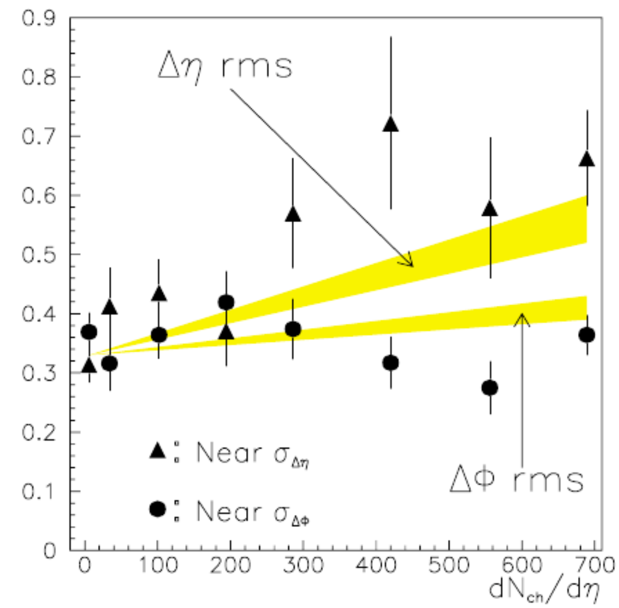
- Sources
  - η range of flow subtraction
  - Track selection
  - Vertex range
  - Influence of resonances and conversions
  - Two-track effect
  - Wing (increase at large Δη) correction
  - Two different fit procedures

Peak deformation

- Significant increase of $\sigma_{\Delta\eta}$ towards central events
  - $\sigma_{\Delta\eta} > \sigma_{\Delta\varphi}$ (eccentricity ~ 0.2)
- Armesto, Salgado, Wiedemann suggested that longitudinal flow can deform the conical jet shape (PRL 93,242301 (2004))







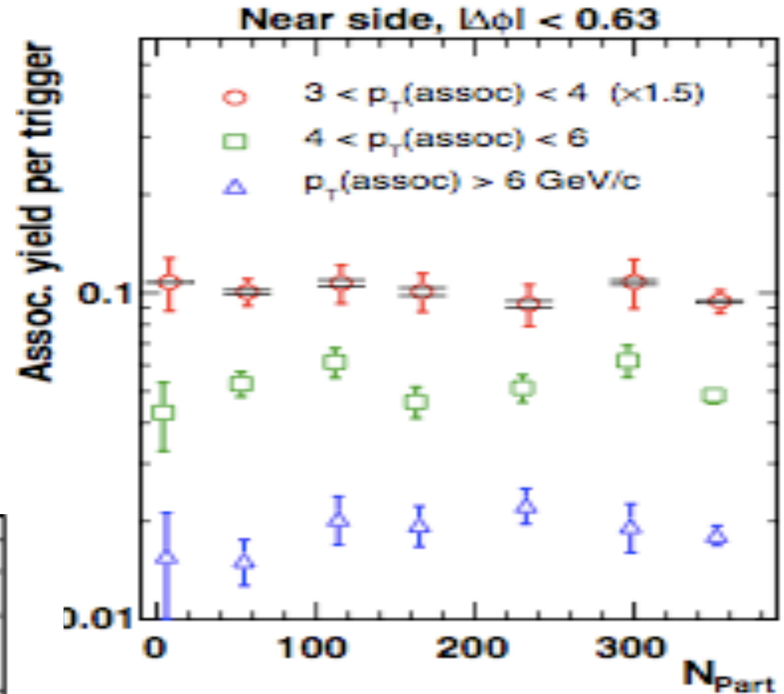
PRL 93,242301 (2004)

- Interplay of flow with the jet?

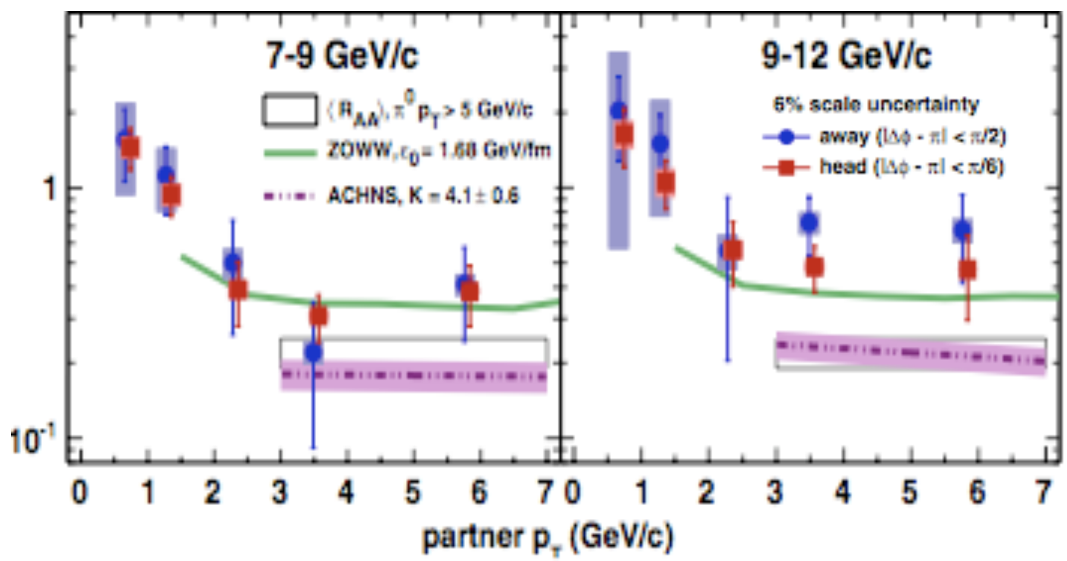
Compare to RHIC: $\sqrt{s_{NN}}$ = 200 GeV

- STAR: NS I_{AA} is consistent with 1
- Very different kinematics: 8 < p_T^{trig} < 15 GeV/c is almost the highest hadron trigger accessible at RHIC

STAR Near-side



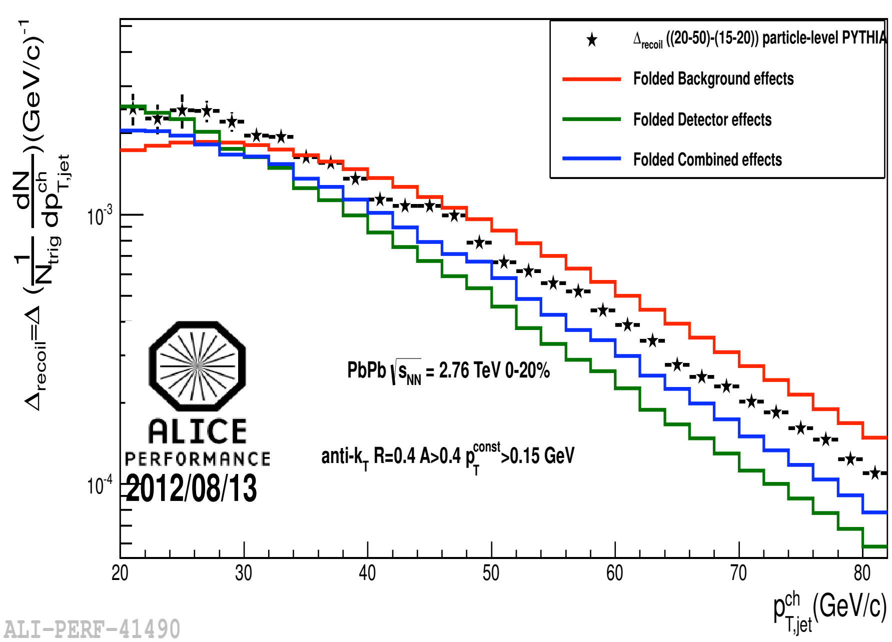
PHENIX Away-side: 0-20%



- PHENIX: π^0-h measurement
- More suppressed
- Increase of I_{AA} below 2 GeV/c

The Response Matrix: background fluctuation & detector effects

- Background response: using random cones (ALICE, JHEP 03 (2012) 053)
  - **σ=9.74 GeV for 0-20% central and p_T^{const}>0.15 GeV/c**
- Detector response: dominated by tracking efficiency
  - Based on PYTHIA fragmentation
- Combined matrix: $R = R_{det} R_{bkg}$

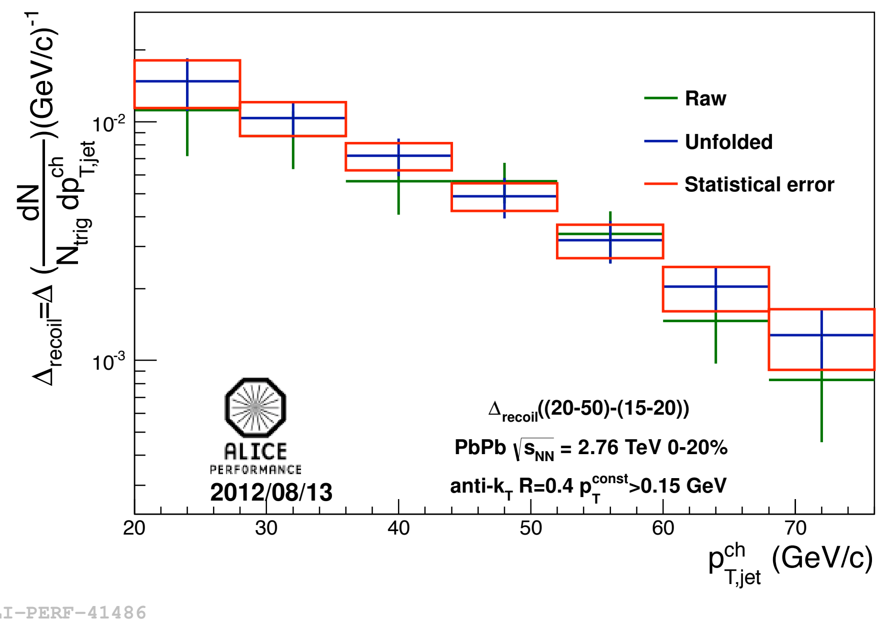


- Detector and background effects go in opposite directions
- Spectrum is almost exponential
- Reduced combined effect

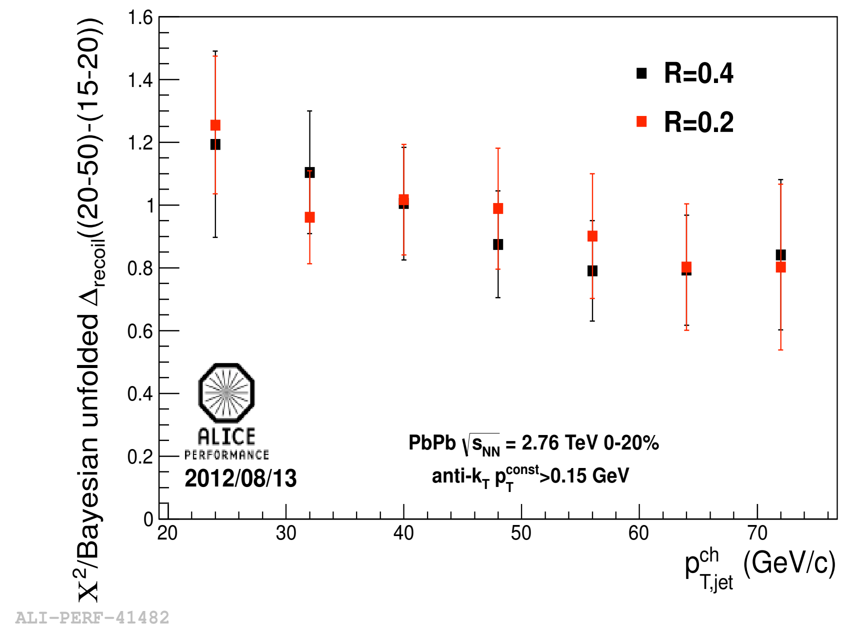
Unfolding stability

- Two systematically different techniques
  - Bayesian unfolding (**G.D'Agostini , NIM A362 (1995)487**)
  - χ^2 minimization of refolded and measured

Δ_{recoil} : χ^2 unfolded

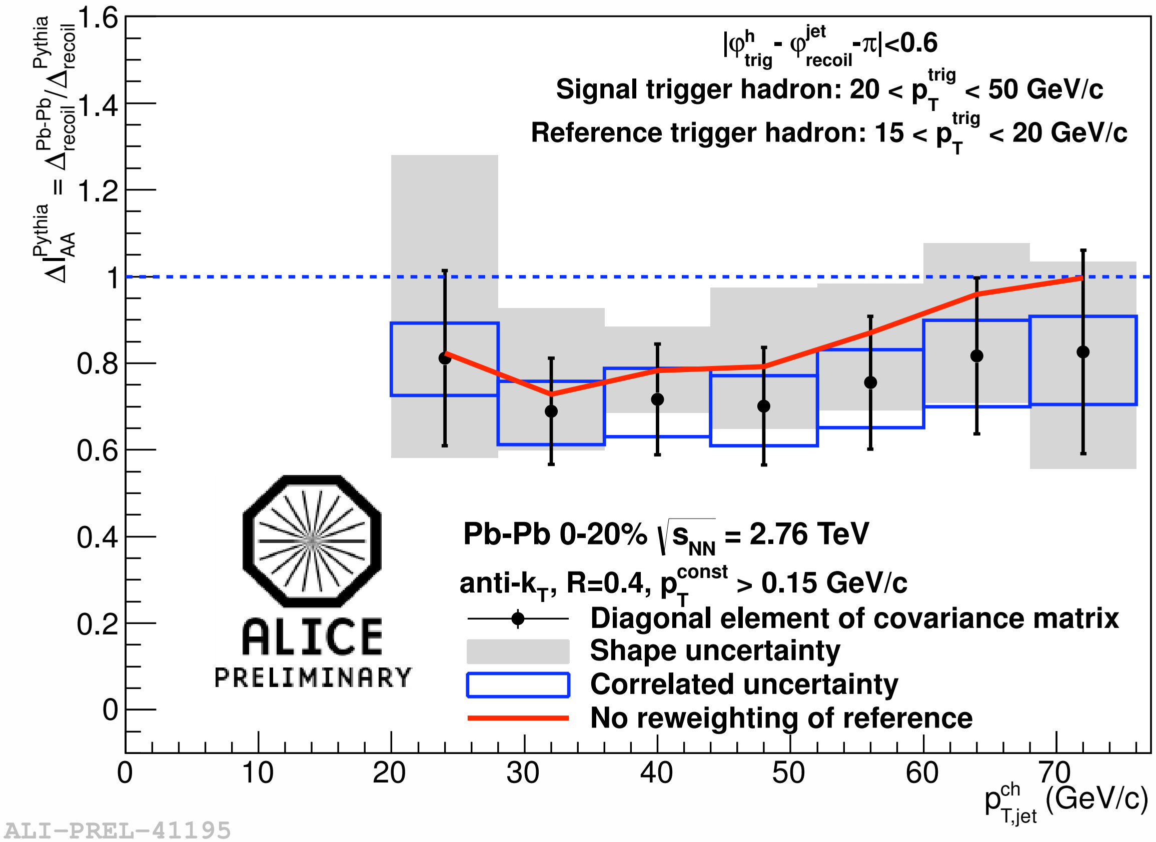


unfolded Δ_{recoil}: χ^2 / Bayesian



Recoil Jet ΔI_{AA}^{PYTHIA}

pp reference: PYTHIA (Perugia 2010)

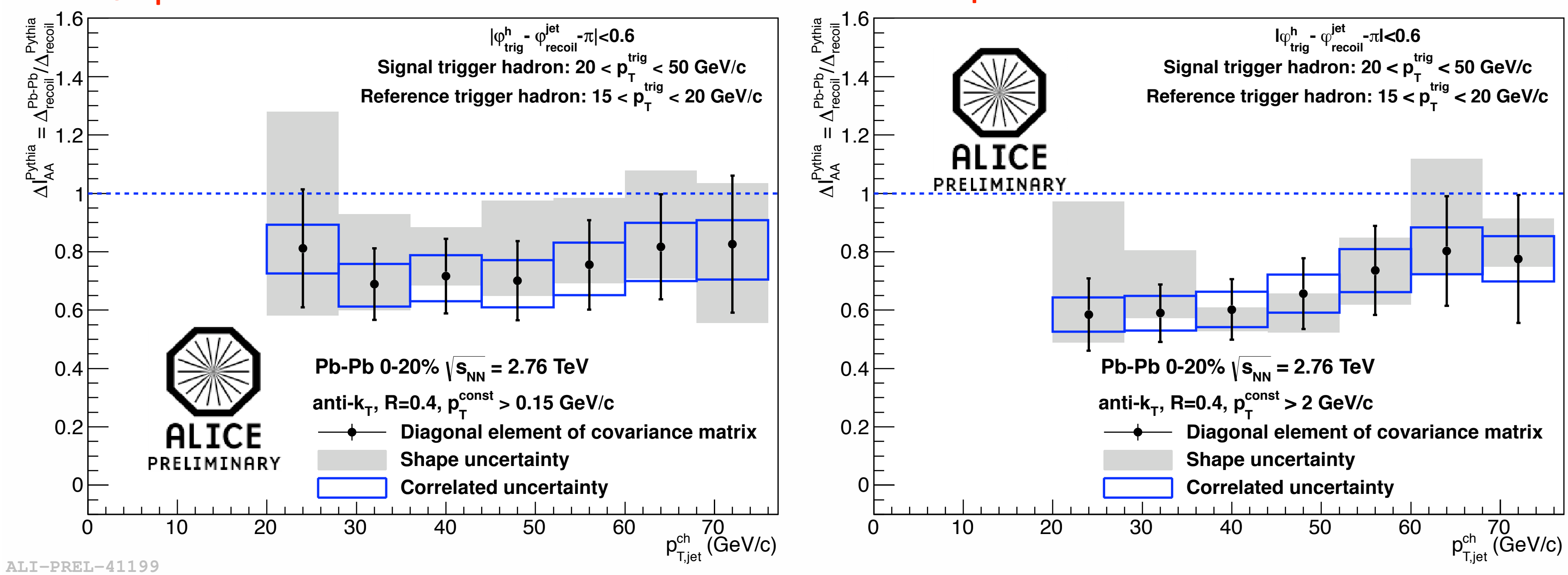


- R=0.4
- Constituents: p_T^{const} > 0.15 GeV/c
- No fragmentation bias imposed on recoil jet population

Recoil Jet ΔI_{AA}^{PYTHIA}: cut on constituent p_T

$p_T > 0.15$ GeV/c

$p_T > 2$ GeV/c



- No indication of large variation of fragmentation pattern compared to PYTHIA