Review of recent results on jet physics in Heavy Ion from LHC

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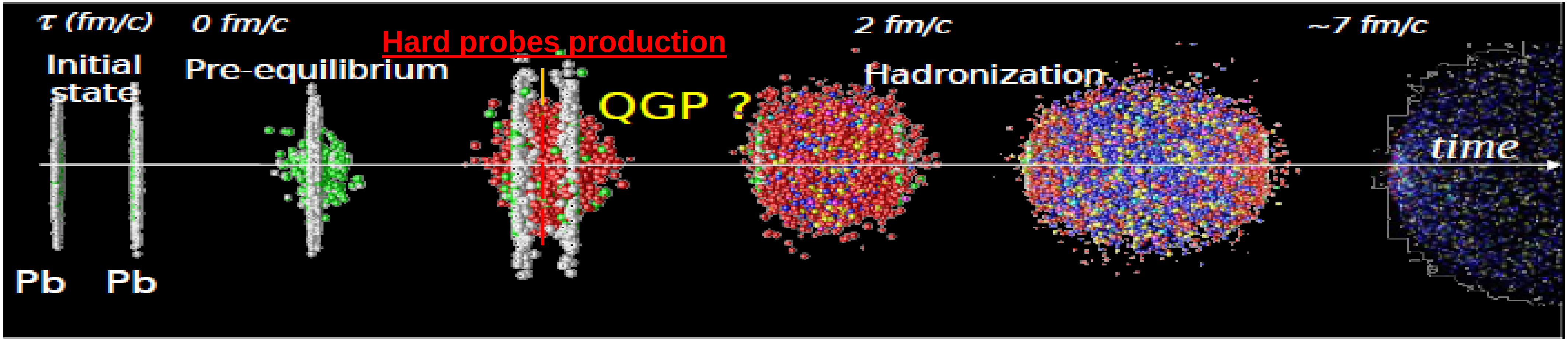
Physics motivation



Jets are produced very early and are sensitive to early stage of the collision

➔ This allows to probe and study the QGP by using jet properties

- Study jet production (ex. Cross section measurements) : test pQCD
- Study in medium energy loss
  - Path length dependence
  - Broadening of shower
  - Leading hadron vs. softening of FF
    - Probe the density of the medium

This can be studied by using various observables, in this talk we will mainly discuss: nuclear modification factors, azimuthal correlations, di-jet asymmetry and jet FF.

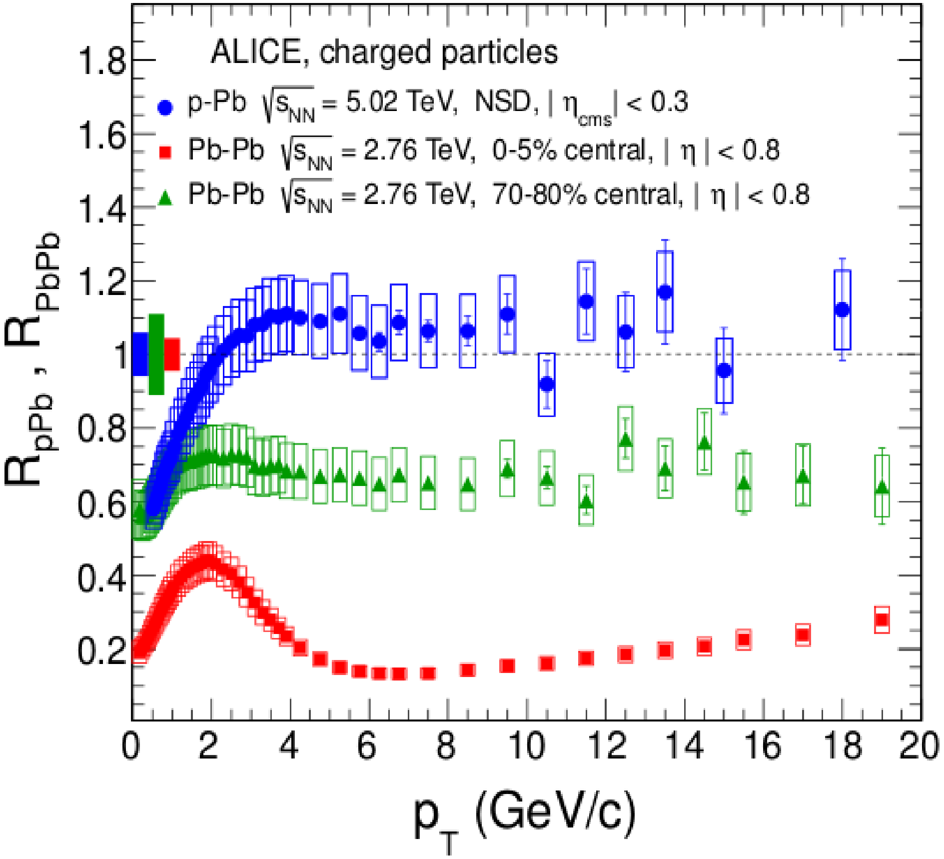
Hadron Nuclear Modification Factor

$$R_{AA} = \frac{Yield(AA)}{Yield(pp)}$$

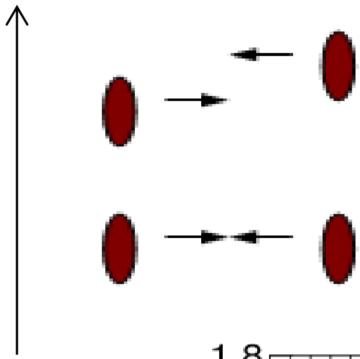
$$R_{AA}(,p_T) = \frac{1}{N_{coll}} \times \frac{dN_{AA}/dp}{dN_{pp}/dp}$$

In absence of nuclear modifications, hard processes are expected to follow N_{col} scaling ➔ $_{RAA} = 1$

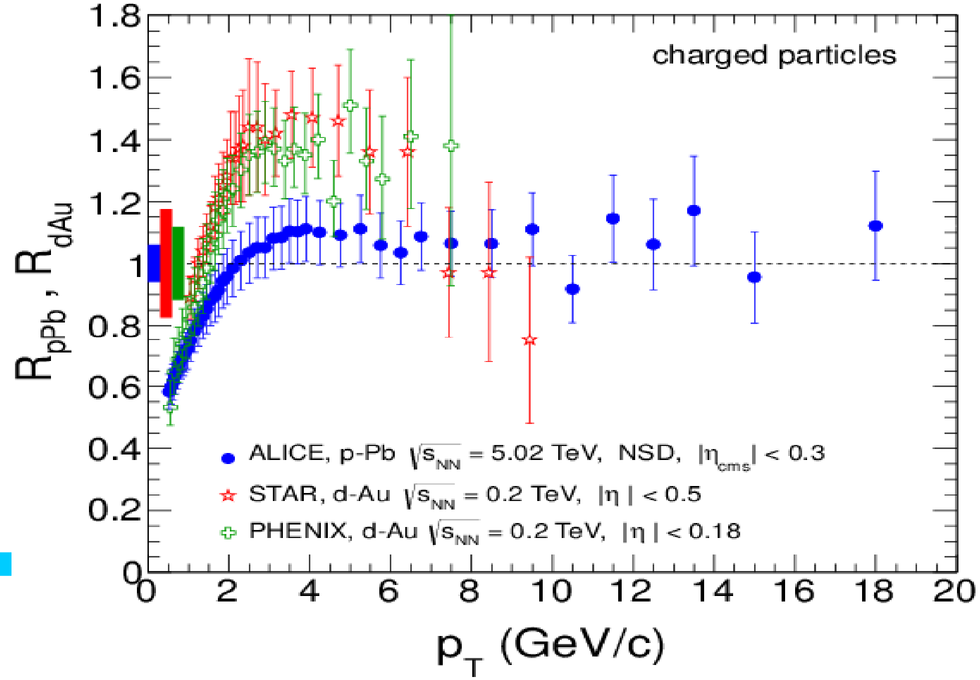
Hot vs. Cold Nuclear Matter Effects



LHC : Strong suppression in PbPb (hadron R_{AA} ~ 0.2)
ALICE: First p-Pb results (Measured on the small data sample from the September pilot run)
High-p_T charged particles follow binary scaling.
Initial state effects are small.



RHIC: R_{dAu} > 1 at high p_T => Cronin effect

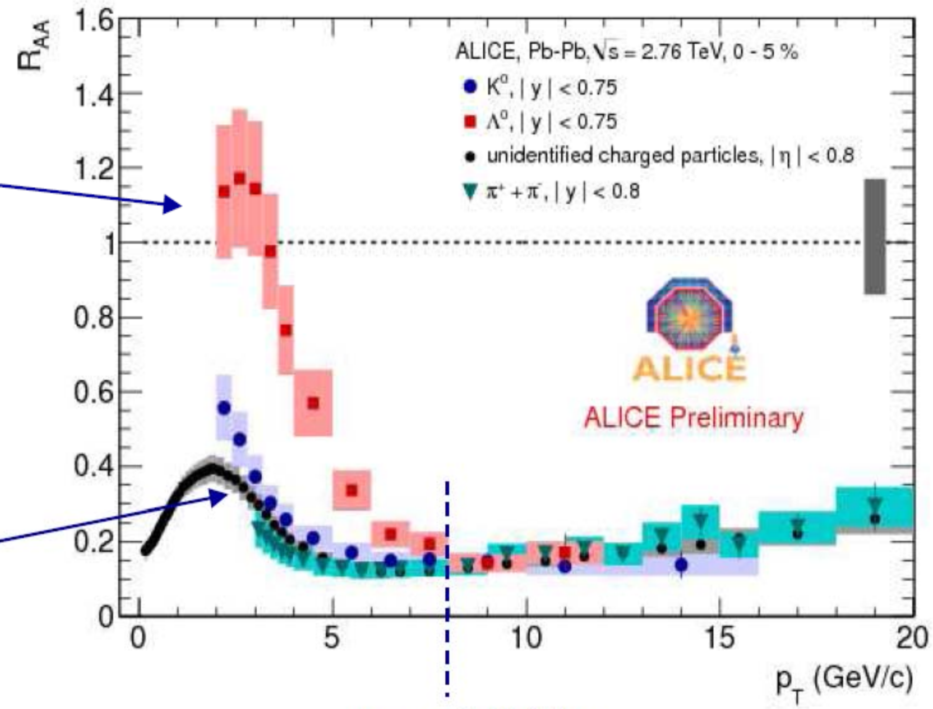


ALICE, arXiv:1210.4520

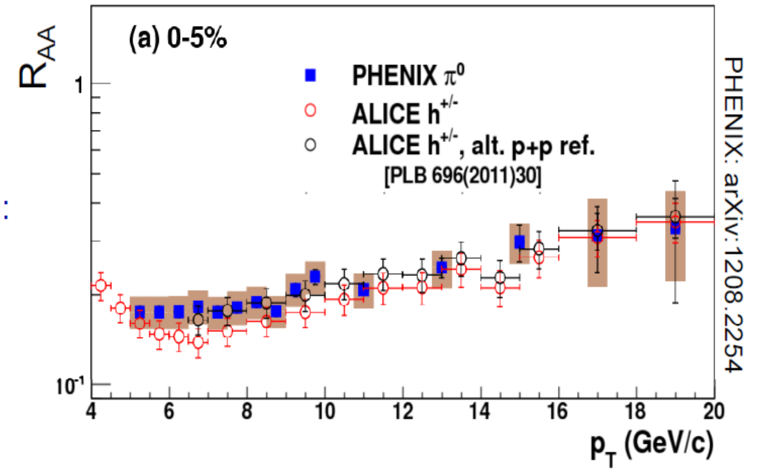
R_{AA} RHIC vs LHC

Λ: R_{AA}~1 at p_T~3 GeV/*c*
Smaller suppression,
Λ/K enhanced at low p_T

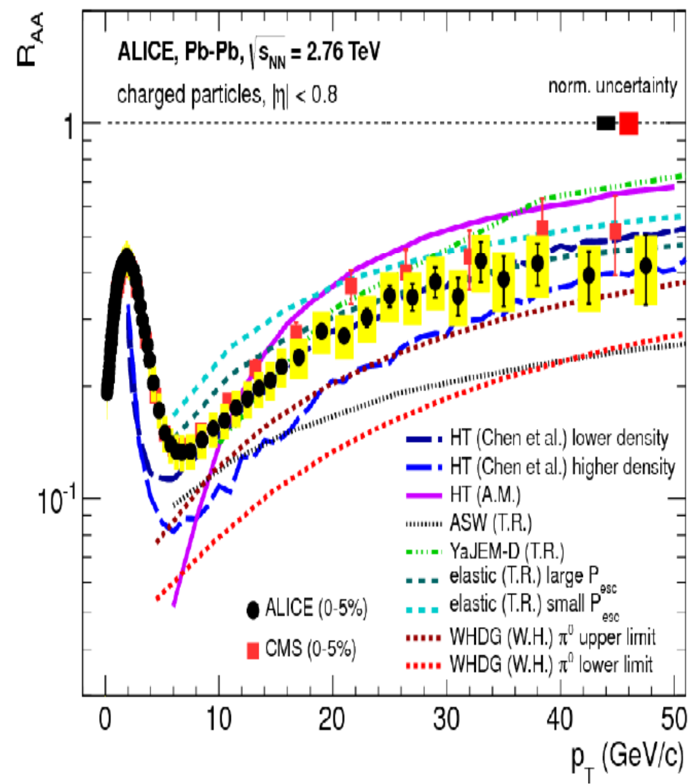
Kaon, pion R_{AA} similar



$p_T \geq$ ~8 GeV/*c*:
All hadrons similar

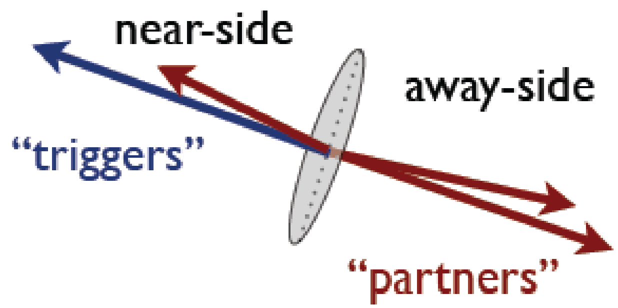


ALICE: arXiv:1208.2711
CMS: arXiv:1202.2554

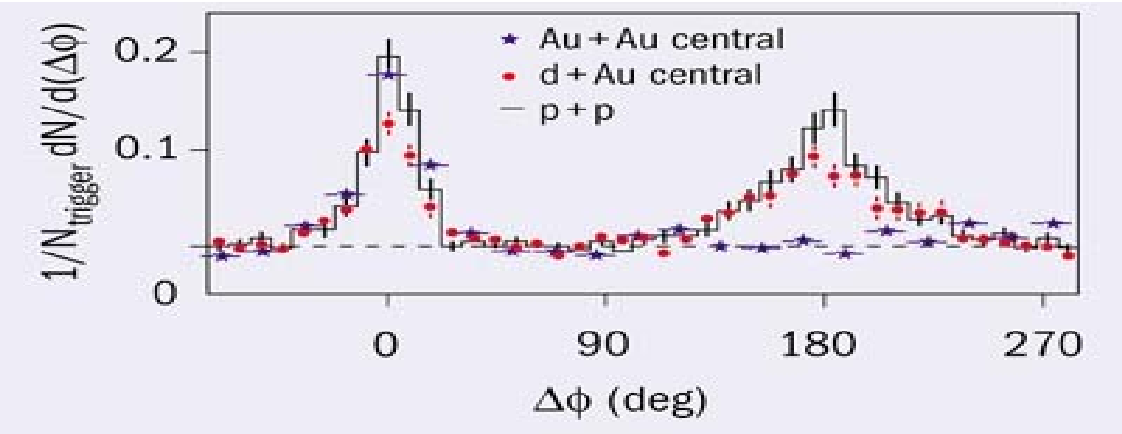


- All hadrons R_{AA} are similar at pT~8-10 GeV/c
- PHENIX run 7 : more statistics : RHIC R_{AA} now increases with p_T (as seen @ LHC)
- Extrapolation from RHIC gives too much suppression at LHC (if Eloss. calc. are calibrated at RHIC this can over predict results at LHC→ Eloss is not a simple function of color charge at fixed coupling …)

→Broad agreement between models
but no quantitative understanding of medium density yet…



Di-hadron Azimuthal Correlations

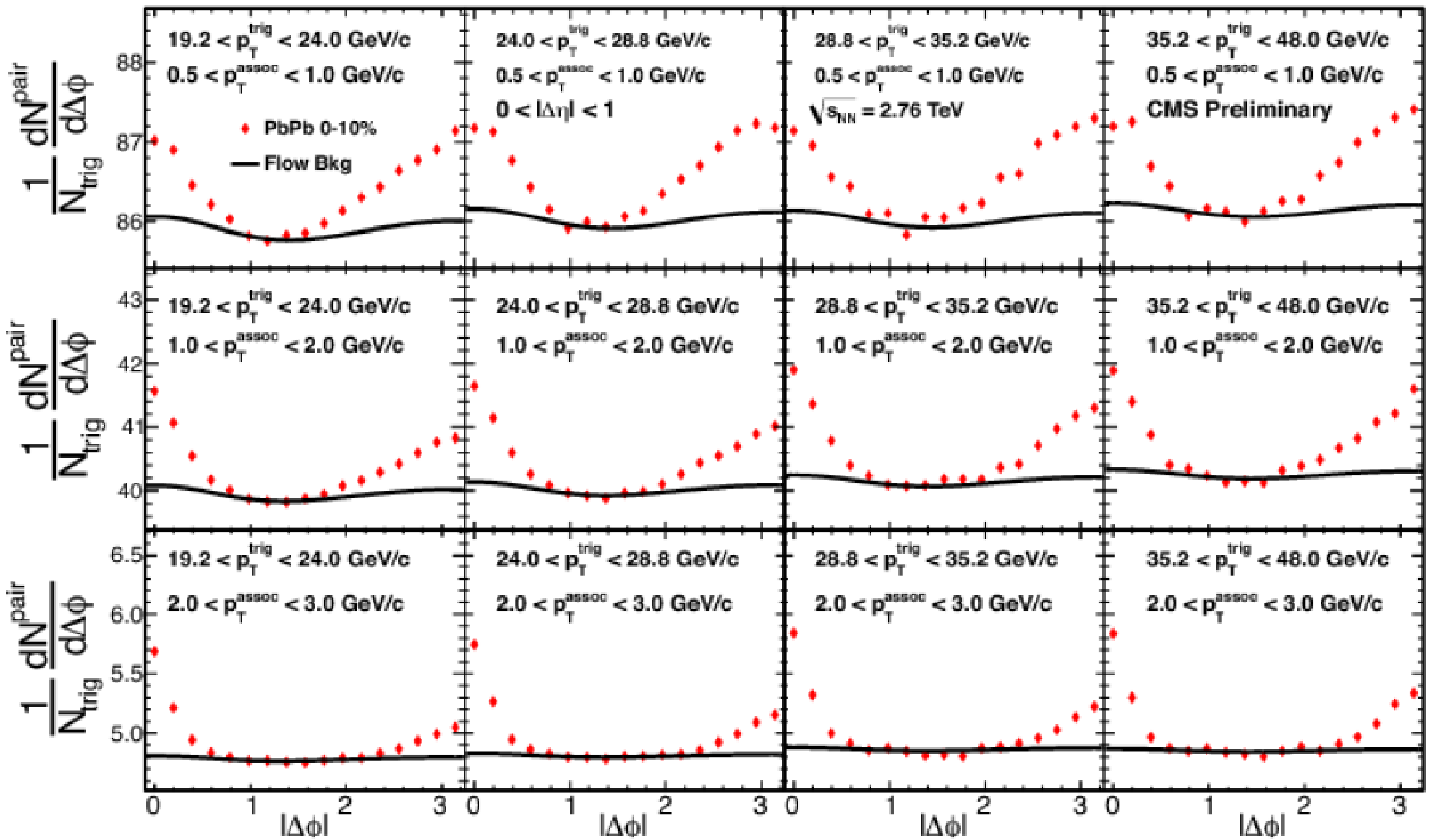


STAR Phys. Rev. Lett. 91 (2003) 072304

- No direct access to the jet energy (~20% of the jet energy)

CMS:Very high-p_T di-hadron correlations in PbPb

p_T^{trig} (GeV): 19.2 - 24.0 GeV 14.0 - 28.8 GeV 28.8-35.2 GeV 35.2-48.0 GeV

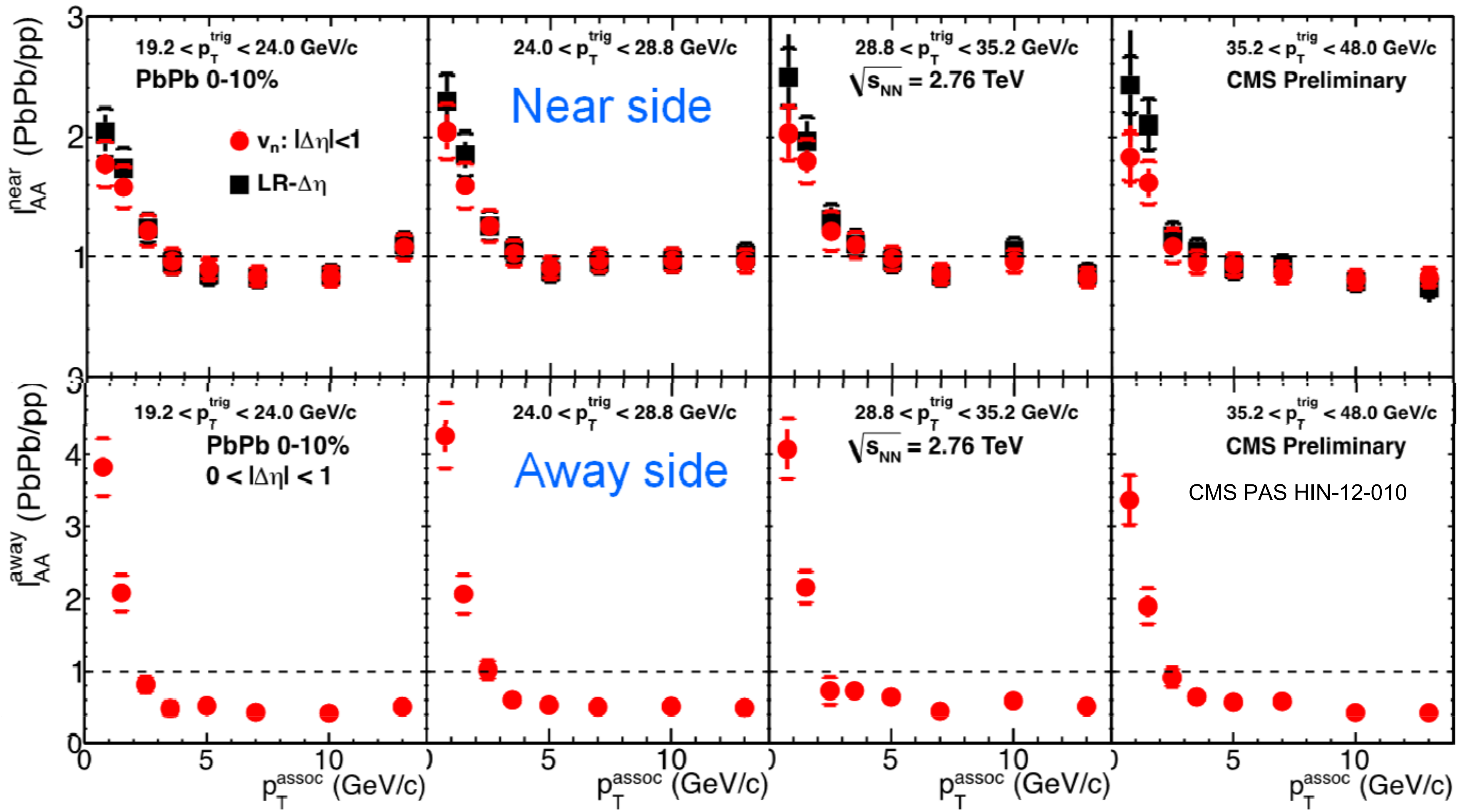


➔ $p_{T\ trig}$ > 30 GeV/c : strong signal even at low pT_{assoc} (1-3 GeV/c)

Effect of flow is important (modification of away side structure)

CMS PAS HIN-12-010

Very high-p_T di-hadron correlations in PbPb (2)



Away-side: large enhancement below ~3 GeV/c and deficit at higher p_T.

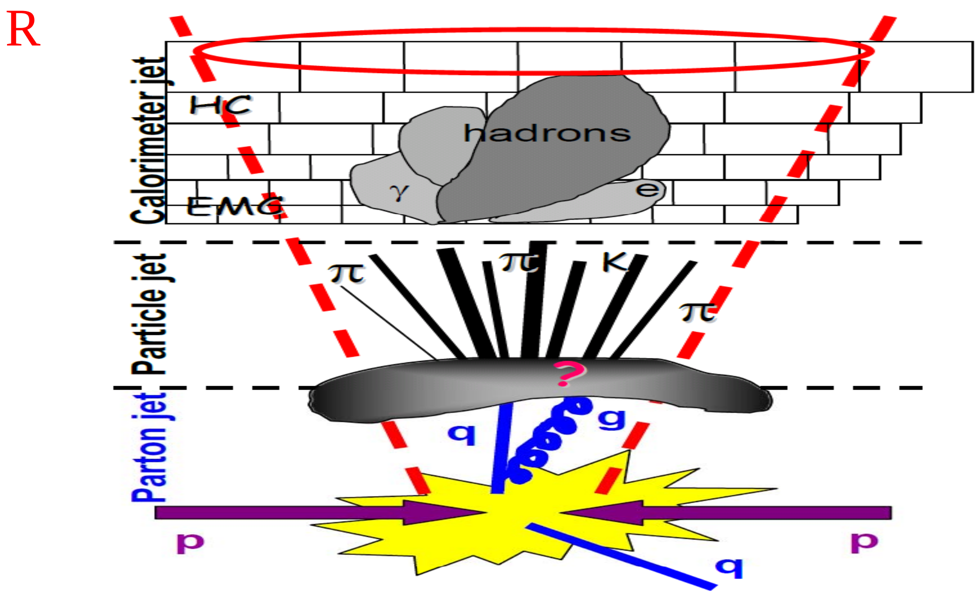
Near-side: enhancement below 3 GeV/c

All v_n harmonics subtracted! ($n \geq 2$)

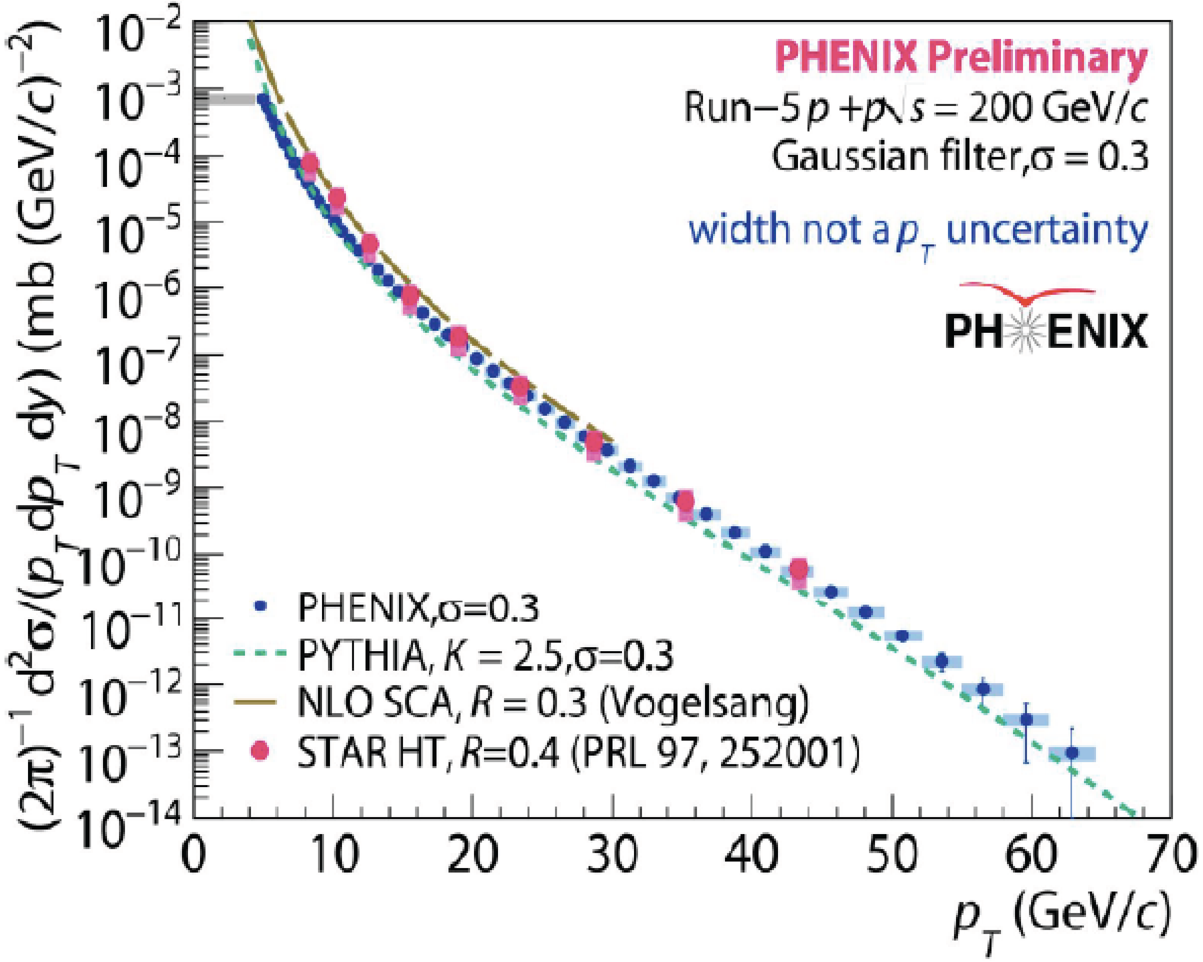
$$I_{AA}^{near} = \frac{Y_{PbPb}^{near}}{Y_{pp}^{near}}$$

$$I_{AA}^{away} = \frac{Y_{PbPb}^{away}}{Y_{pp}^{away}}$$

Full jets:
p-p cross-section



STAR & PHENIX p-p Jets



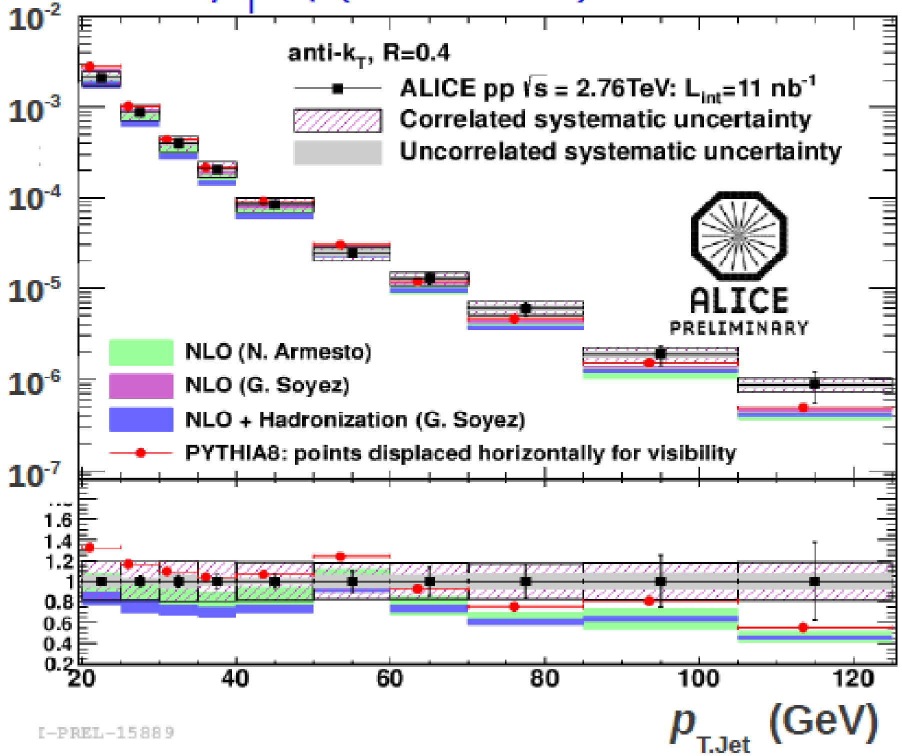
Gaussian Filter used
(seedless cone-like algorithm)

➔ p-p measurement benchmark well with NLO

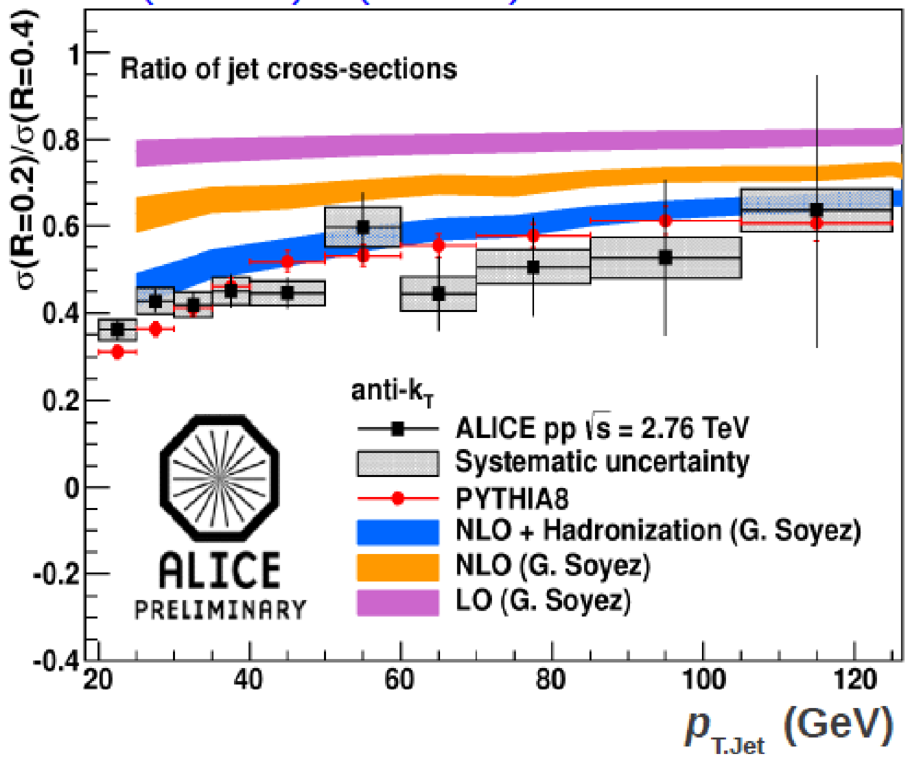
Full Jets in p-p 2.76 TeV

anti k_T : R = 0.4

$d^2\sigma/dp_Td\eta$ (mb c/GeV)



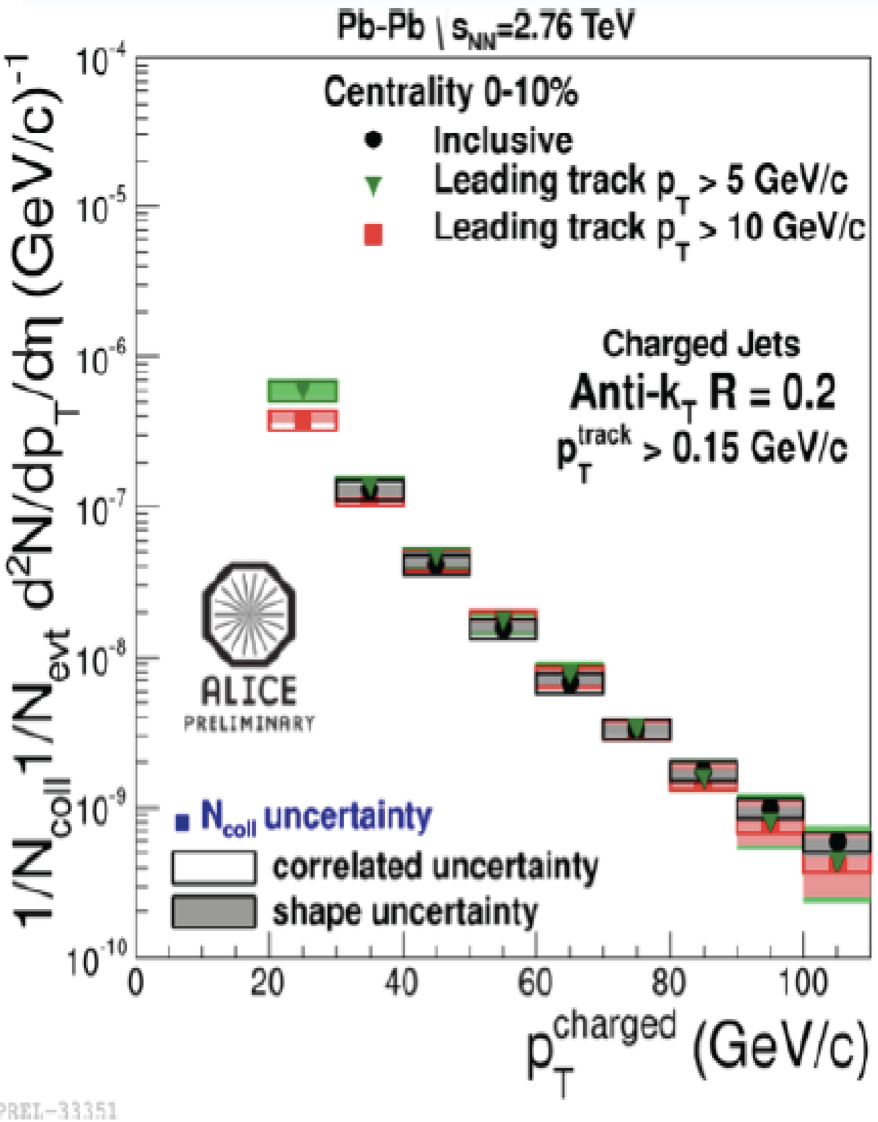
σ(R=0.2)/σ(R=0.4)

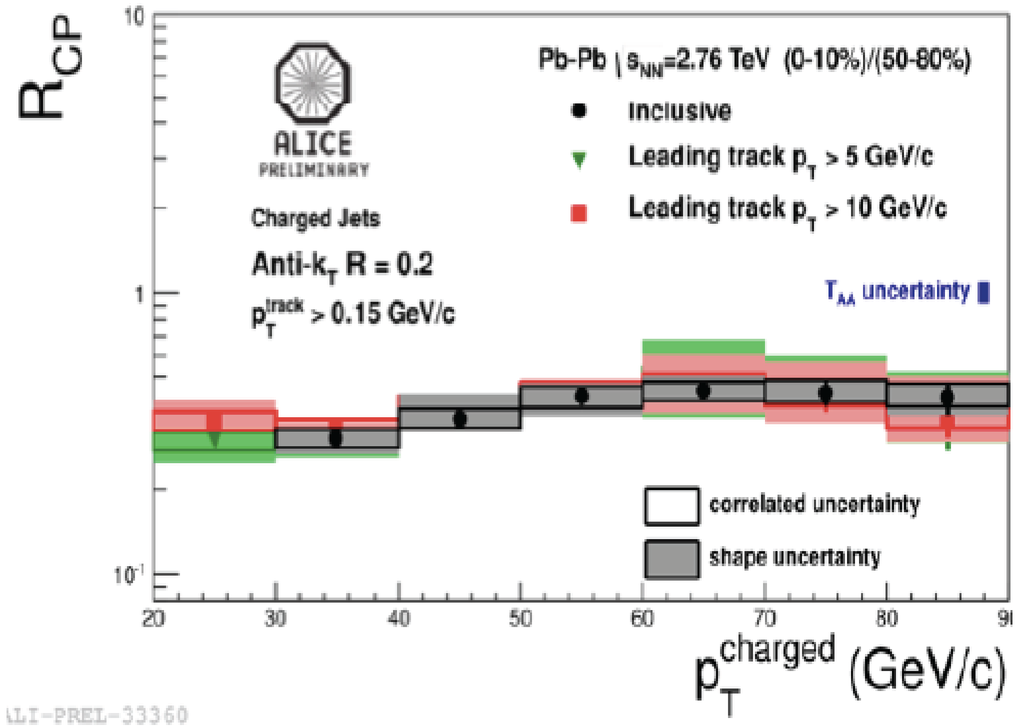


- ➔ Good agreement with NLO pQCD (+ hadronization) and Pythia8
- ➔ Increase of σ(R=0.2)/σ (R=0.4): Higher pT jets are more collimated
- ➔ Important reference for Pb-Pb analysis

Full Jets:
Nuclear modification factor

ALICE (Charged-Jet) R_{cp}





R_{cp} relative to 50-80% centrality

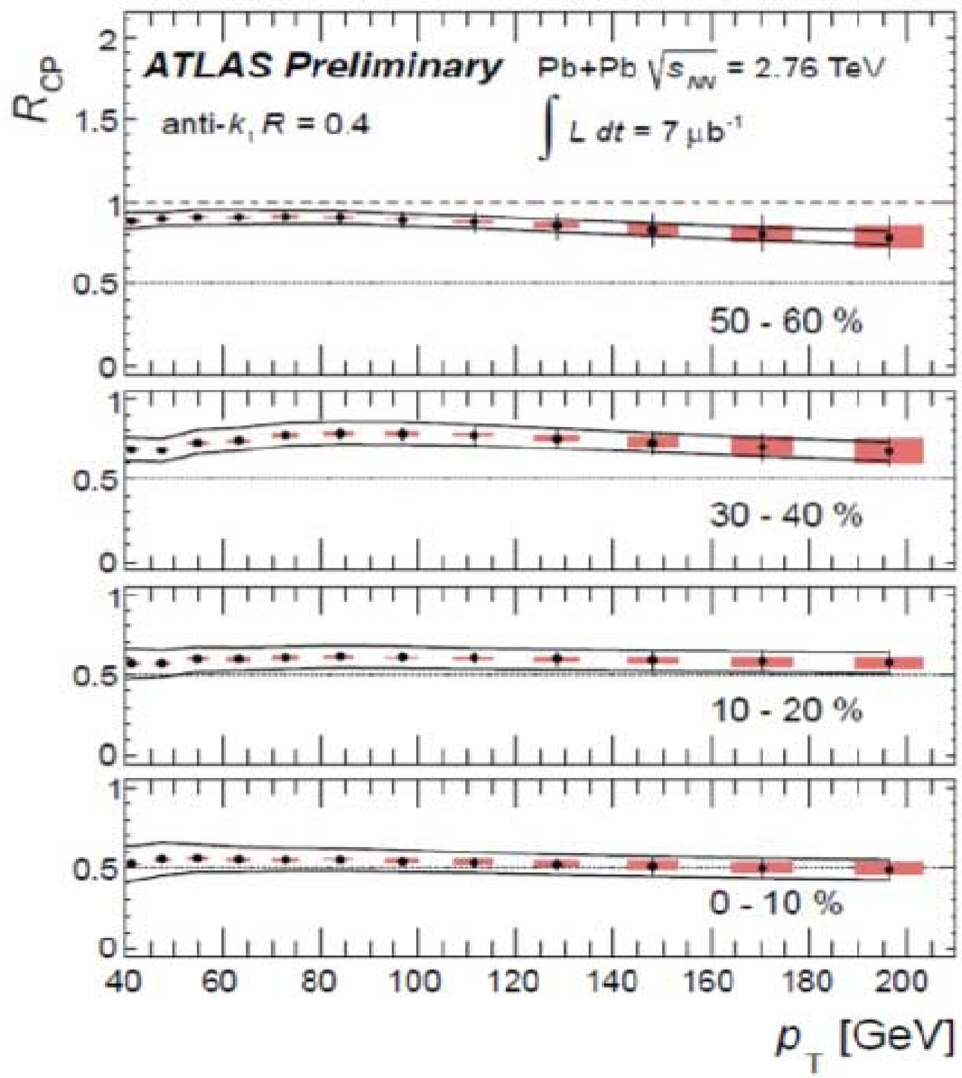
Charged track jets

Anti-KT with fastjet bkg subtraction

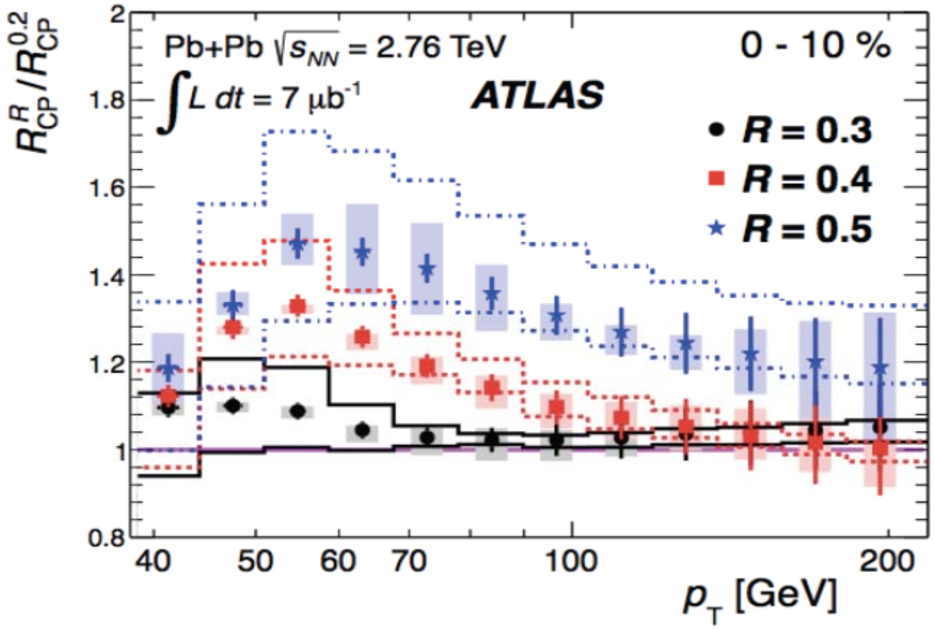
Leading track p_T cuts

(p_T>5 and p_T>10 GeV/c) to suppress fake jets (combinatorial)

Atlas R_{cp}



Anti-kT with iterative background subtraction

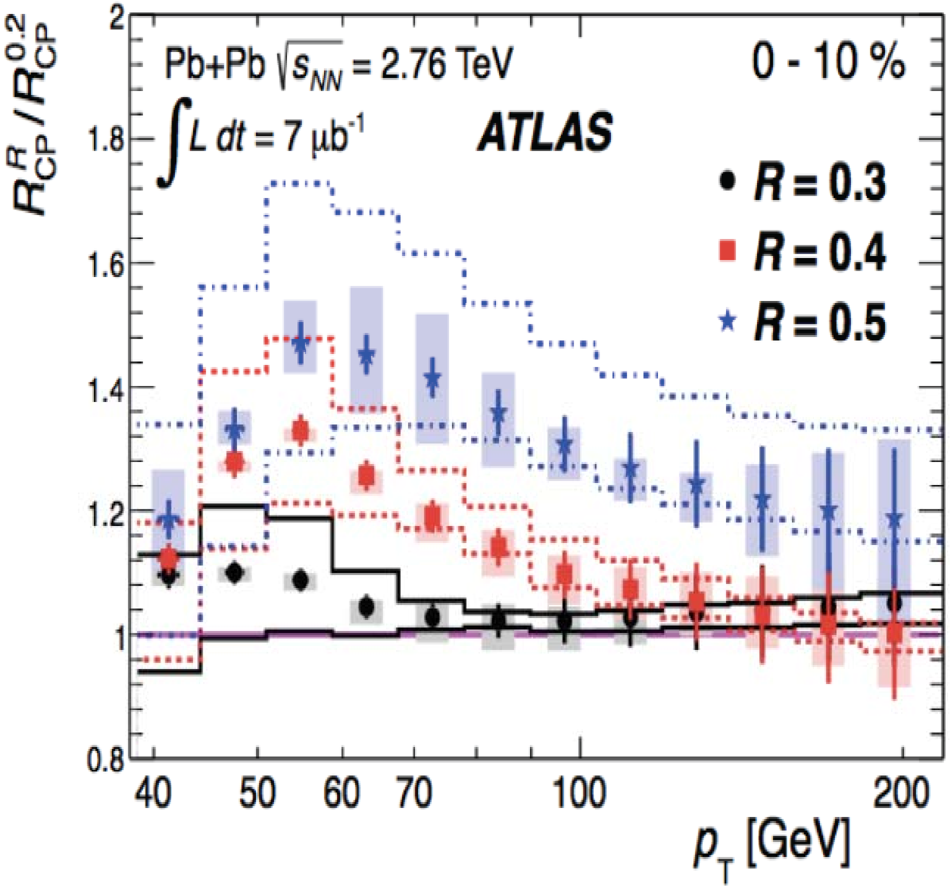


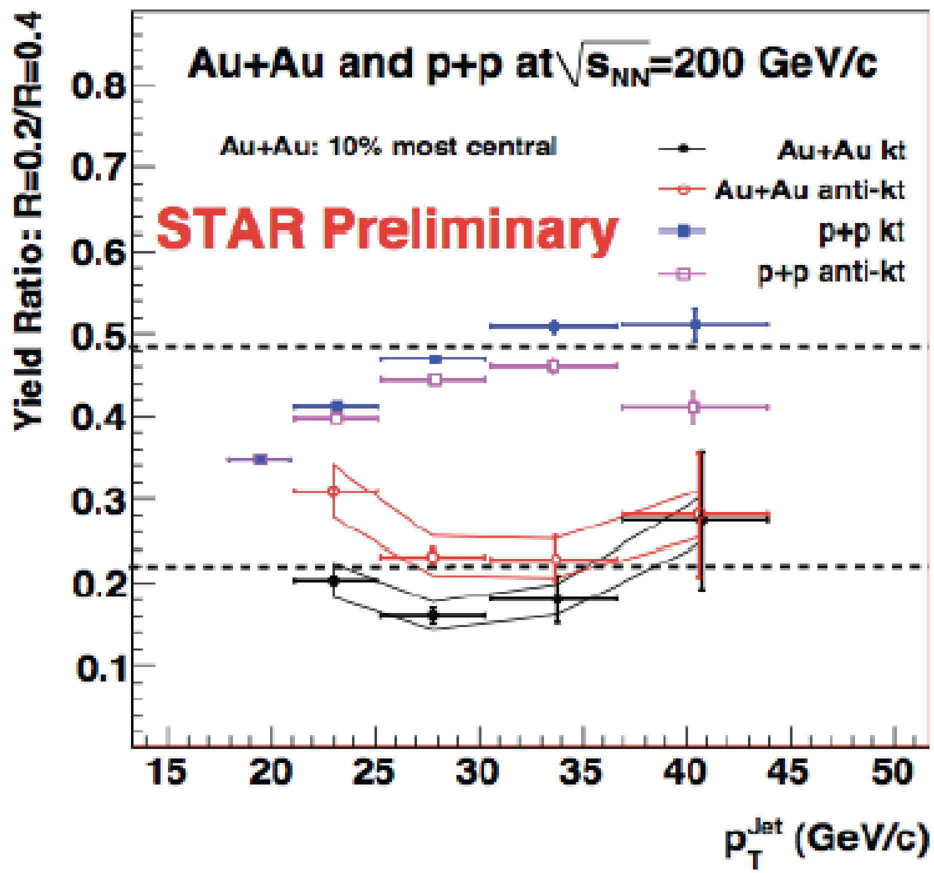
Flat at ~0.5

ATLAS: ➔ Moderate but significant R dependence (~ 0.4-0.6 for 0.2 < R < 0.6) stronger suppression for smaller jets

ATLAS, arXiv:1208.1967

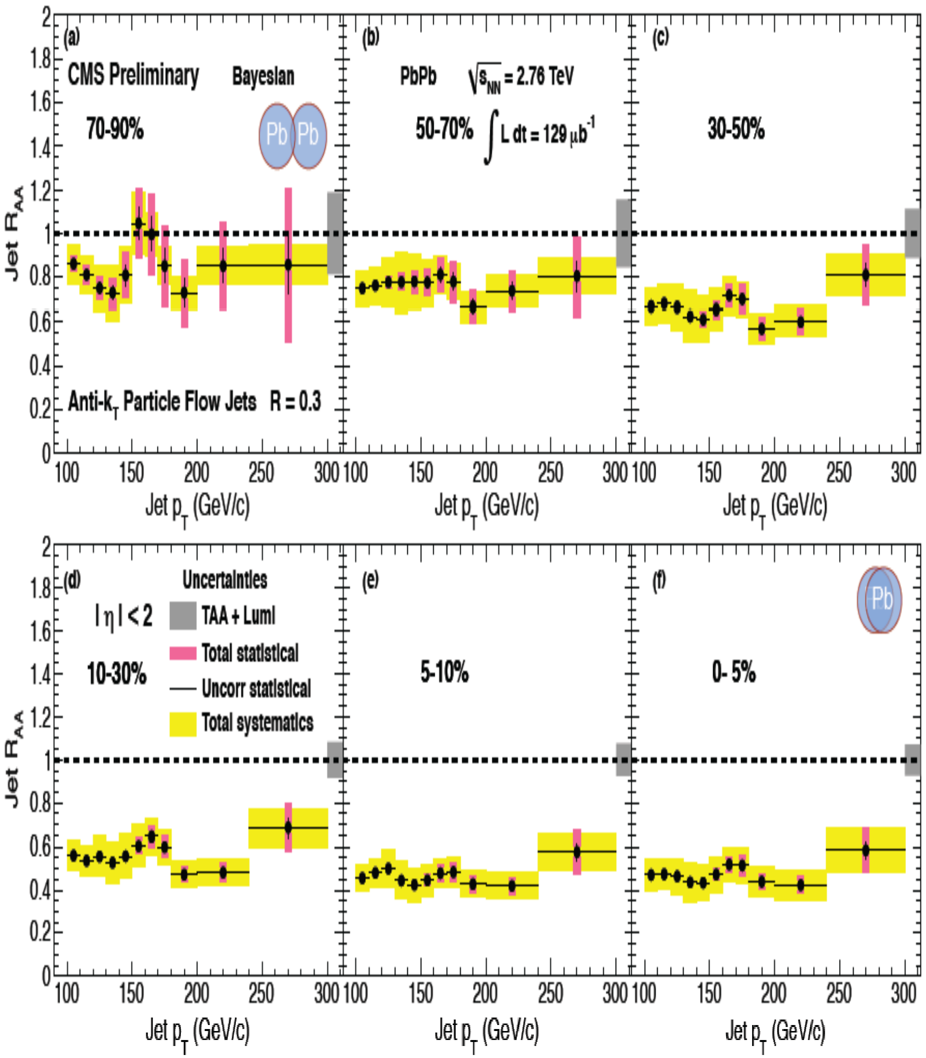
Suppression vs. radius RHIC vs LHC

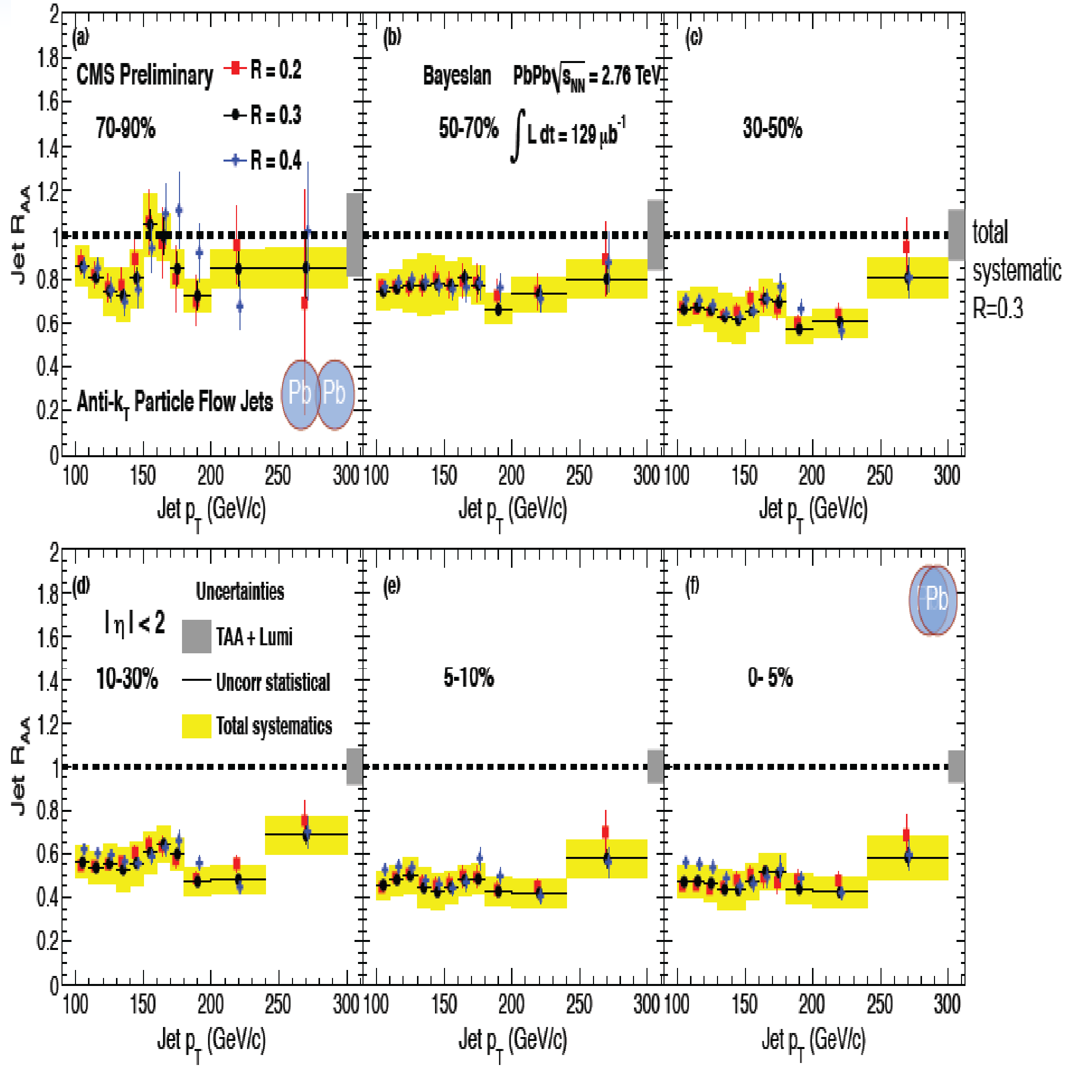




➔ Stronger dependence seen @ RHIC ?

CMS R_{AA}

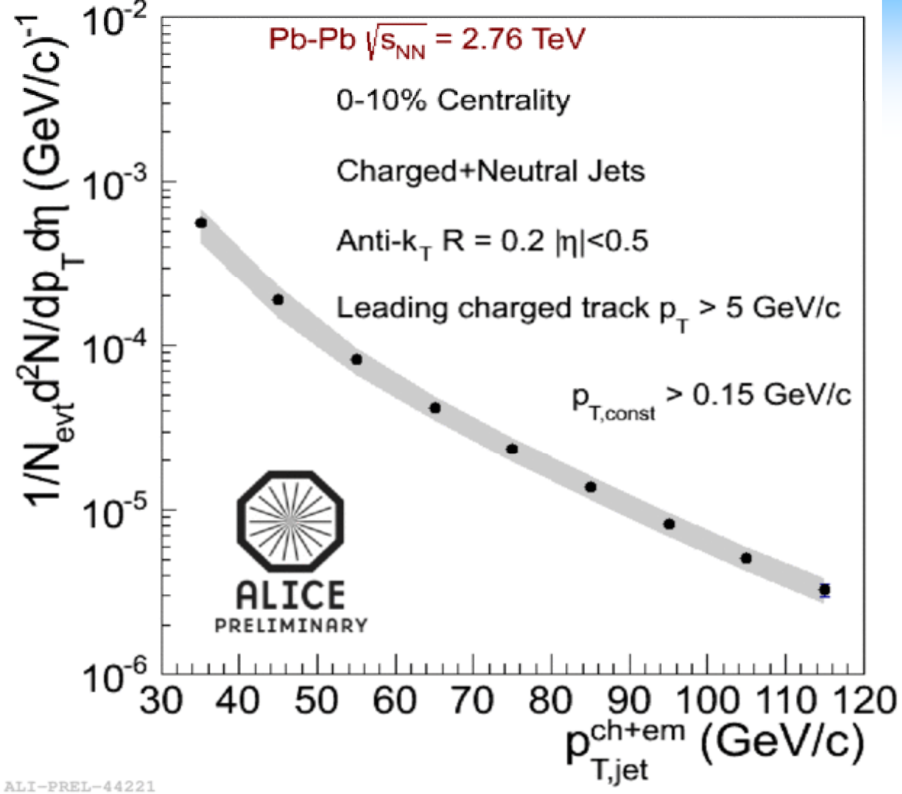




CMS : ➔ Almost no dependence on jet pT ➔No strong dependence on jet radius
jet R_{AA} and hadron R_{AA} agree

CMS PAS HIN-12-004

ALICE: Full jet R_{AA}



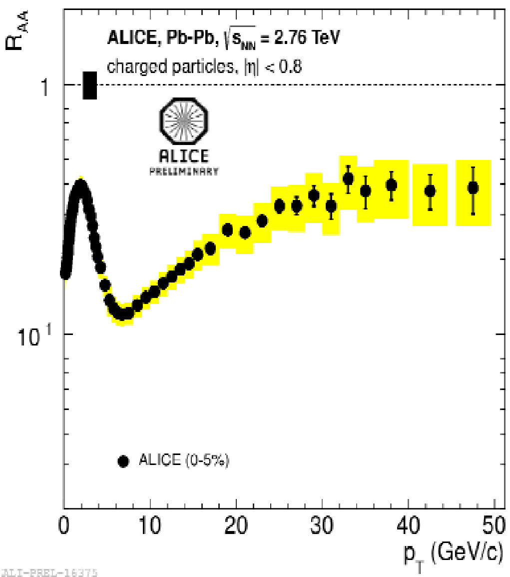
Charged + Neutral (full) jets

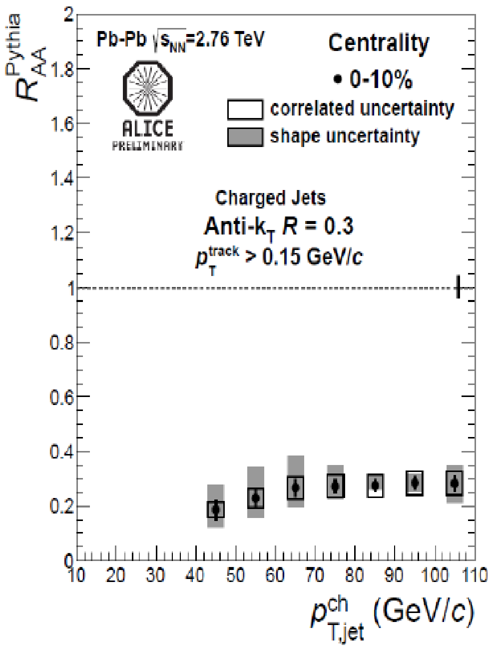
Anti-KT with fastjet bkg subtraction

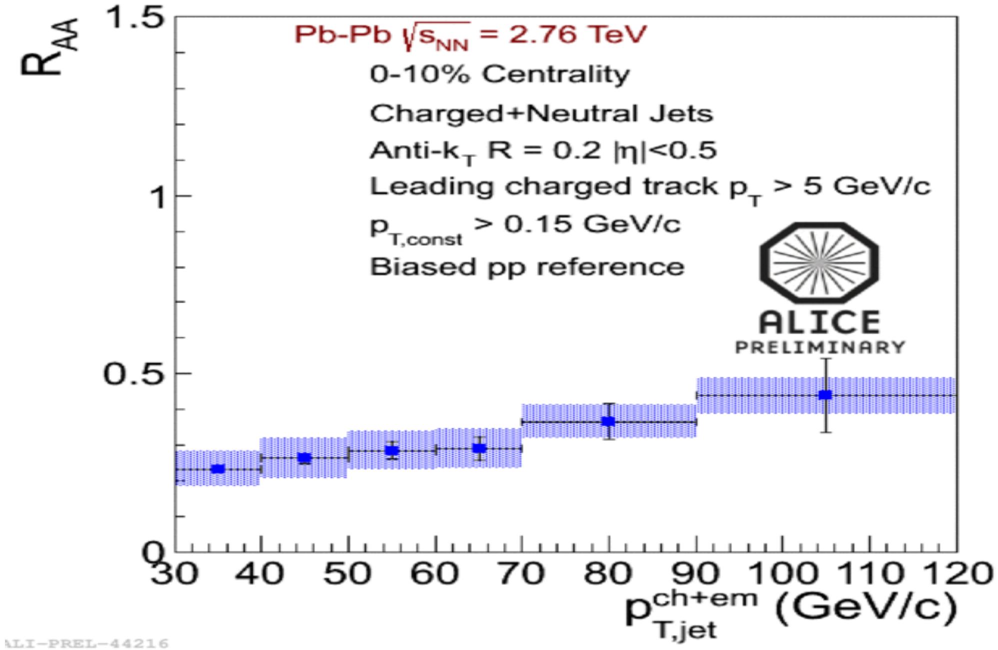
Leading track p_T cuts (pT>5 GeV/c) to suppress fake jets (combinatorial)

Jet R_{AA}: At low jet p_T suppression decreases with pT

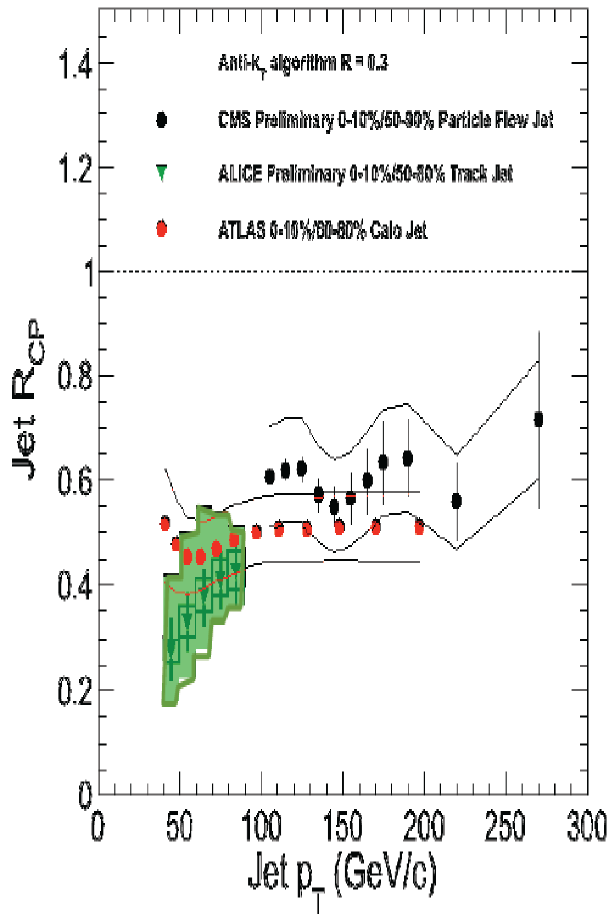
At high p_T jet R_{AA} rising ~ hadron R_{AA} ~ 0.3-0.4

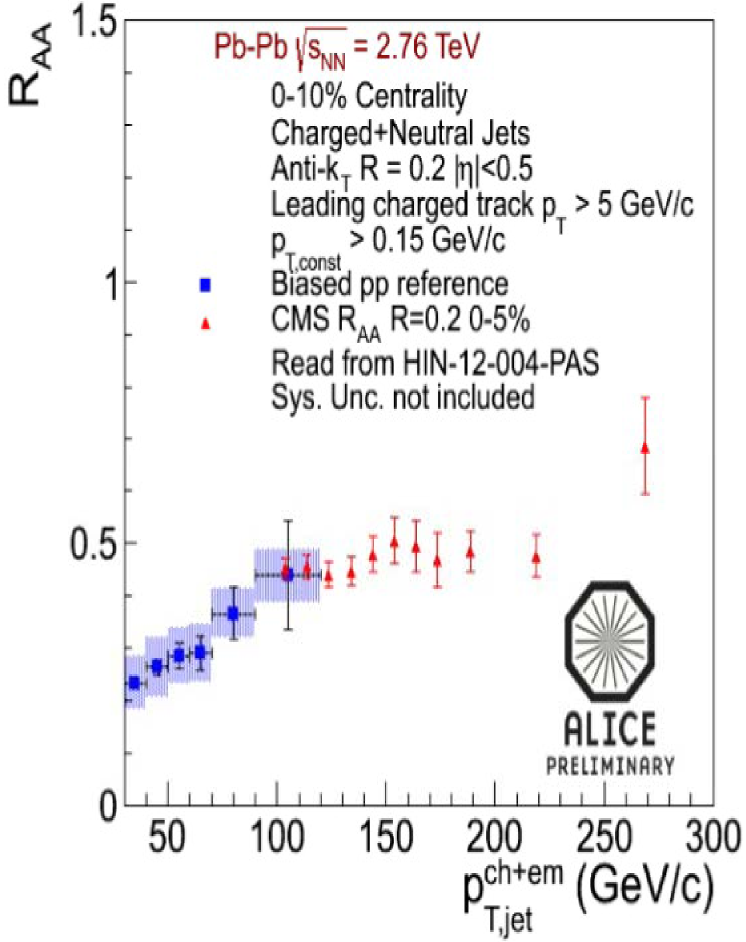


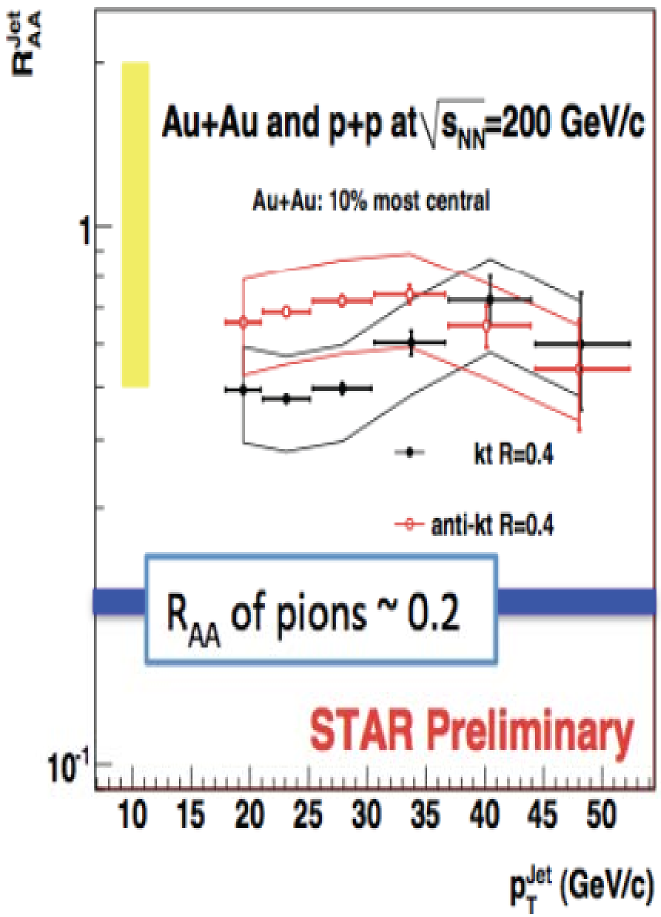




Comparison: Jet R_{cp} & R_{AA} @ LHC vs. RHIC







➔ Jet R_{cp} consistent within systematic uncertainties

Different measurements (tracks,PF, calo jets)

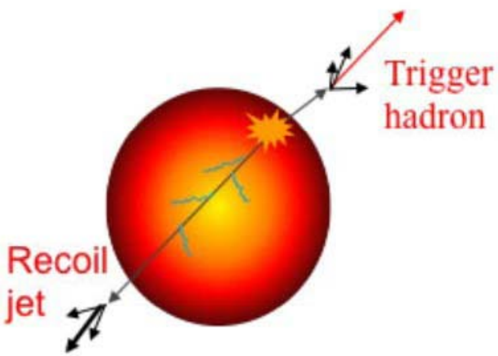
Flat (ATLAS,CMS) vs rising R_{cp} & R_{AA} (ALICE)

Important shape difference (effect of leading hadron biased jets ?)

Large uncertainty

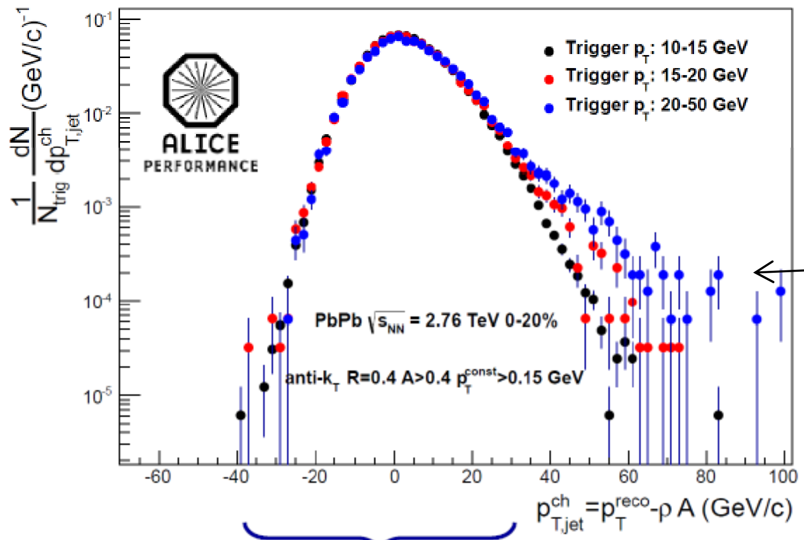
➔Large difference between jet and pion R_{AA} (unlike LHC)

Hadron-jet
Azimuthal Correlations



Surface bias effect: the parton producing the jet is biased towards higher in-medium path length
Trigger Hadron: close to the surface

ALICE: Hadron-jet correlations



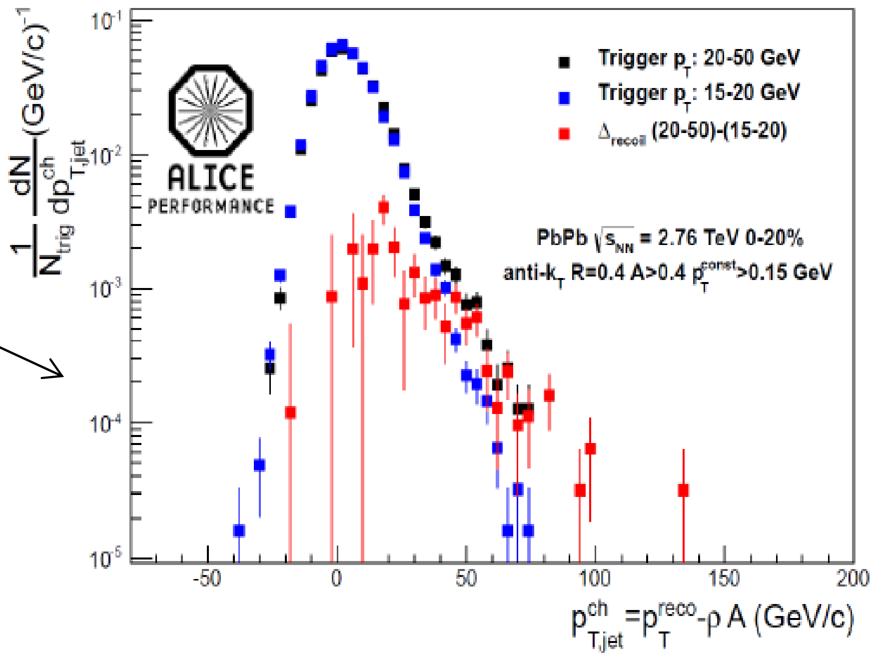
$p_{T,jet}$< 20 GeV/c:
No change with trigger p_T
Combinatorial background

$p_{T,jet}$> 20 GeV/c:
Evolves with trigger p_T
Recoil jet spectrum

Clear correlation with trigger pT
Dominated by high Q2 events

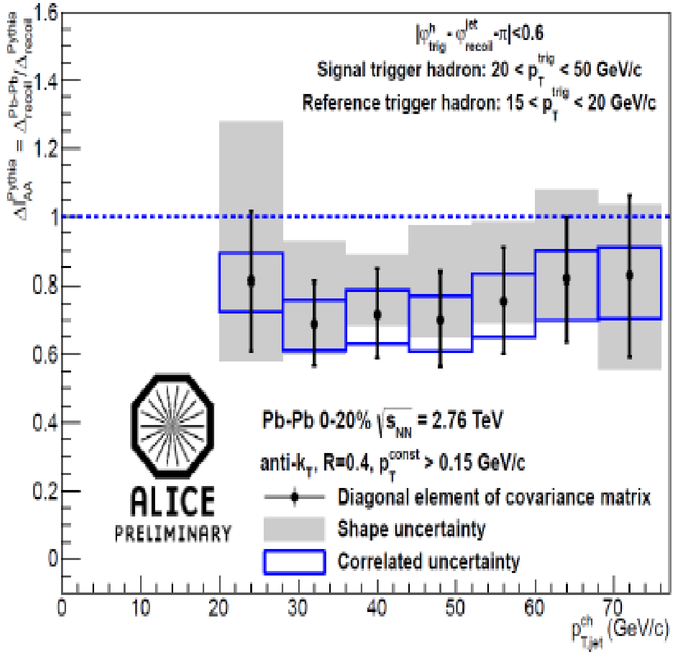
$$\Delta_{recoil}\left(p^{ch}_{T,Jet}\right) = \frac{1}{N_{trig}}\frac{dN\left(p^{ch}_{T,Jet};p^{min}_{T},p^{max}_{T}\right)}{dp^{ch}_{T,Jet}} - \frac{1}{N_{trig,ref}}\frac{dN\left(p^{ch}_{T,Jet};p^{min}_{T,ref},p^{max}_{T,ref}\right)}{dp^{ch}_{T,Jet}}$$

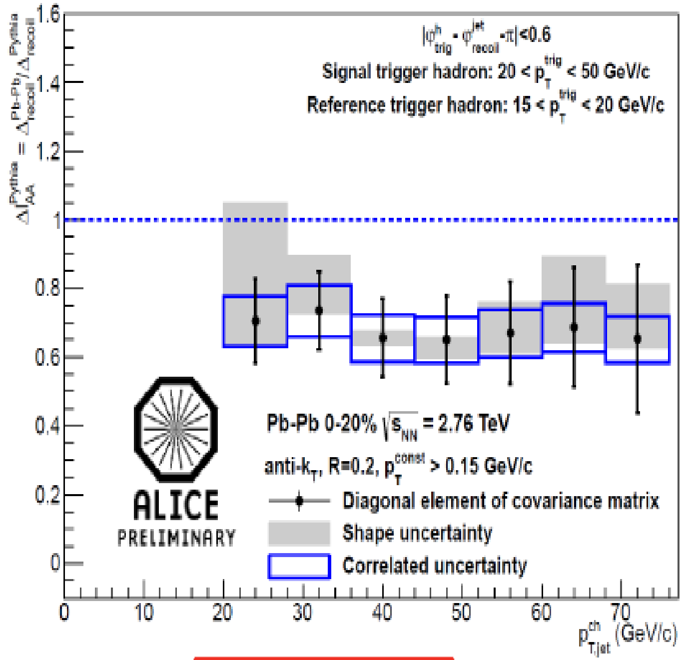
How to remove uncorrelated component ?
Study difference between recoil spectrum (signal) and a reference (15-20 GeV)

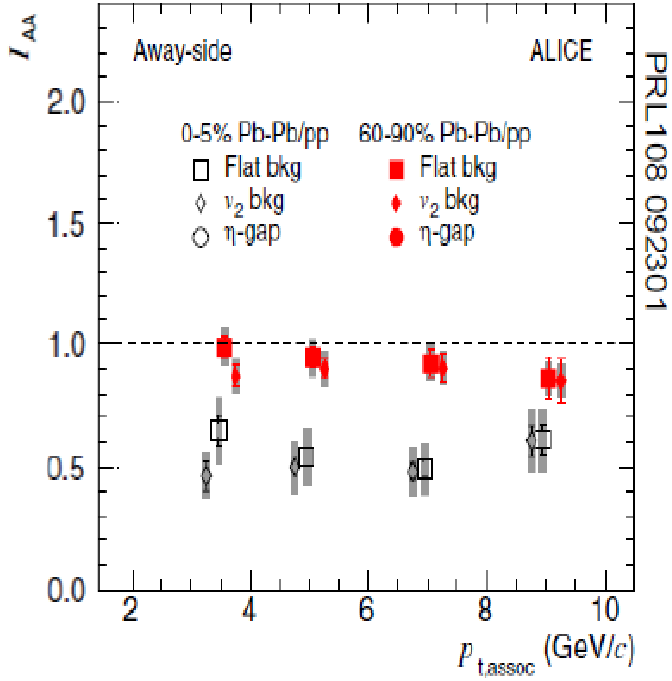


Ratio of recoil Jet Yield

Jets R=0.4 R=0.2 **Hadrons**







p-p ref PYTHIA (Perugia 2010)
R=0.4 pT track > 0.15 GeV/c

$$I_{AA}^{away} = \frac{Y_{PbPb}^{away}}{Y_{pp}^{away}}$$

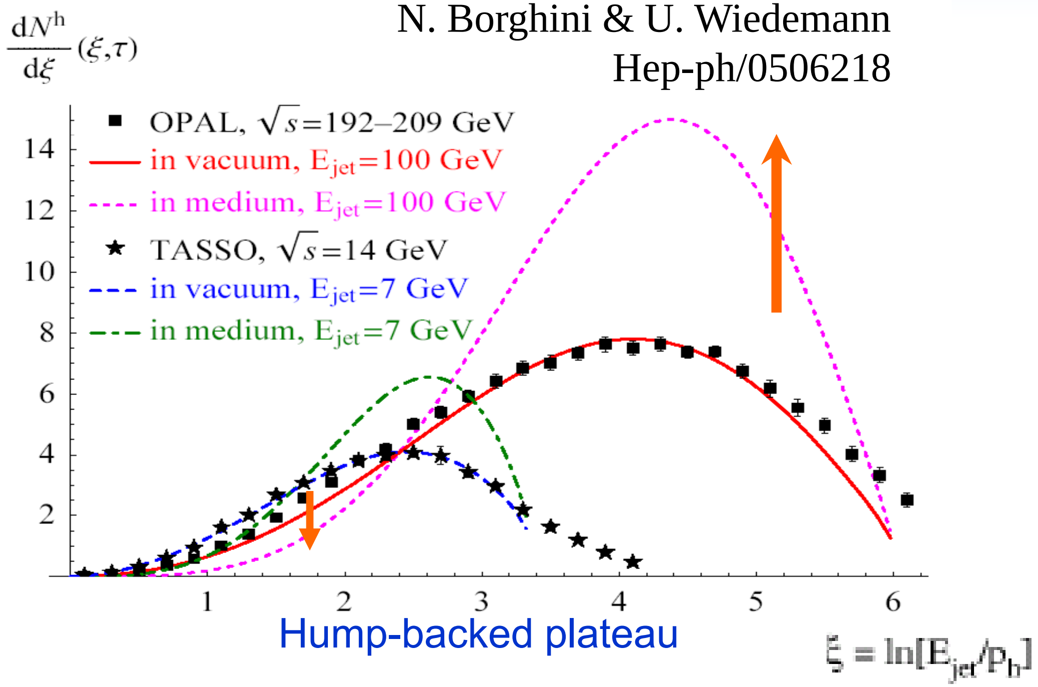
➔ Jet I_{AA} = 0.7 0.8
No visible broadening R=0.2..R=0.4

Hadron I_{AA} = 0.5-0.6
➔ Jet I_{AA} > Hadron I_{AA}
(momentum scale different)

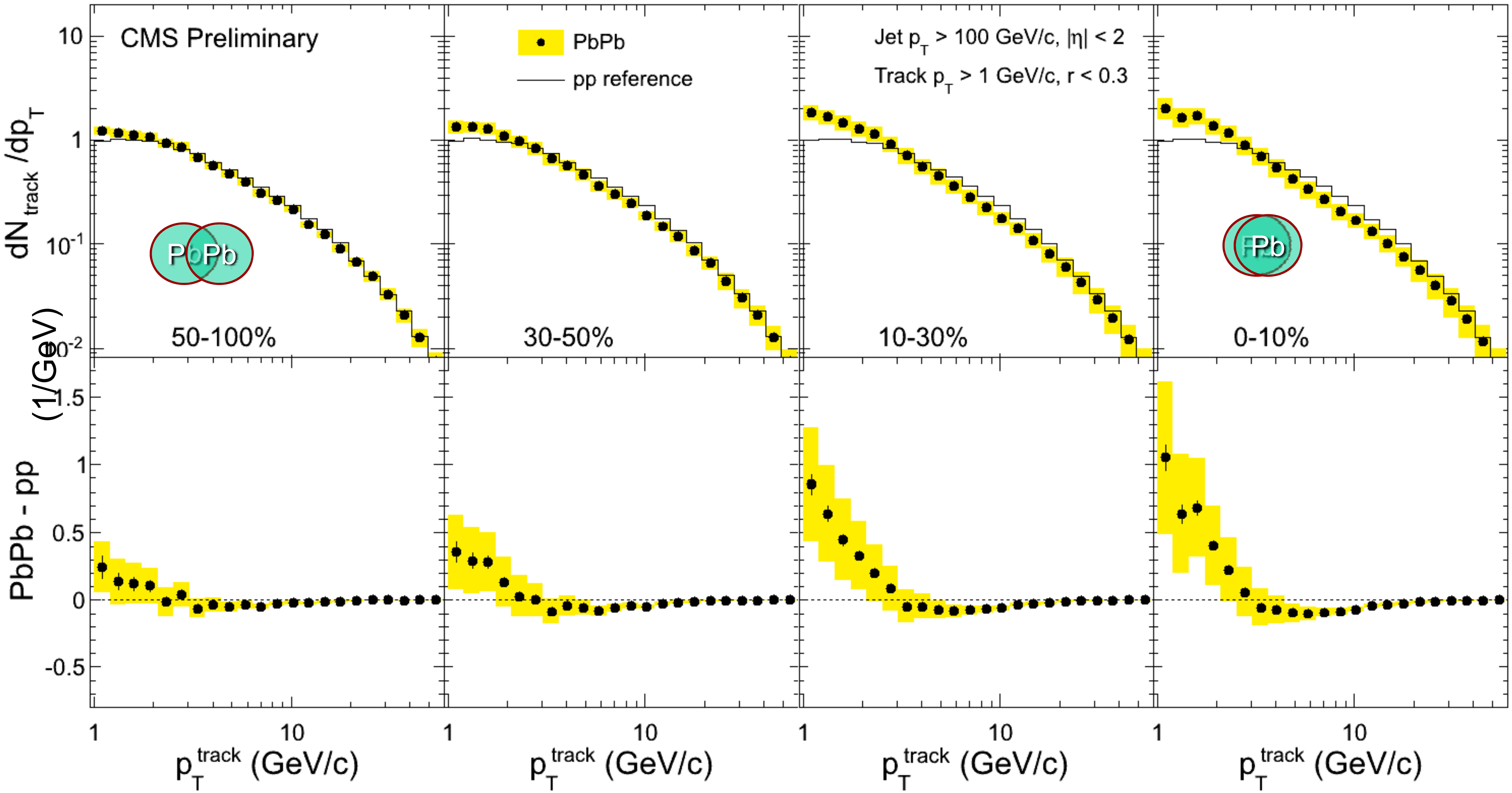
Hadron I_{AA} :
- Near side : ~ 20% yield enhancement (fragmentation after energy loss)
- Away side : suppression by a factor of 2

Fragmentation Functions

N. Borghini & U. Wiedemann
Hep-ph/0506218



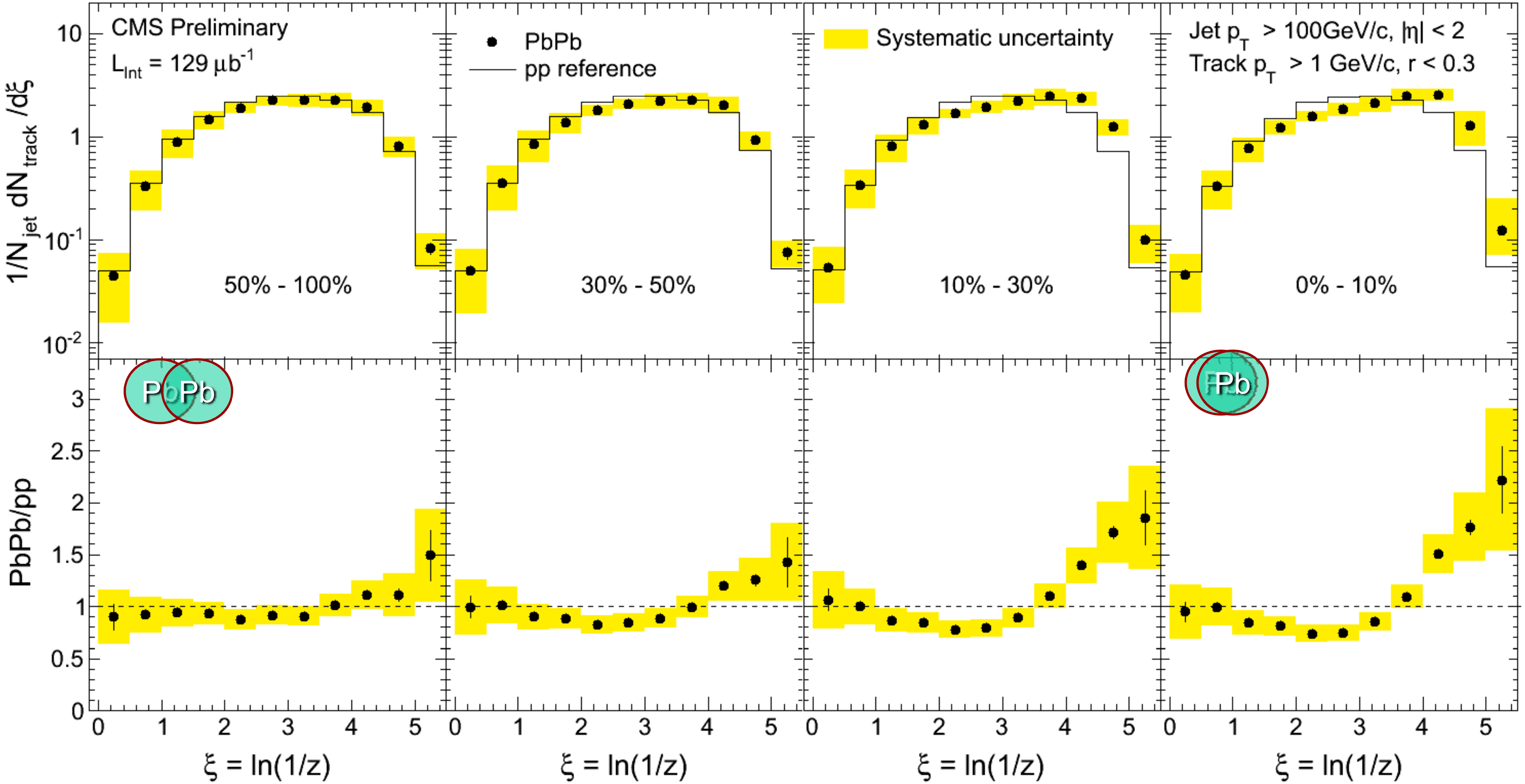
CMS: Track p_T distributions in jet cones (R=0.3)



In (central) Pb-Pb: **excess** of tracks compared to pp at low p_T (high ξ)
High p_T (low ξ): **no change** compared to jets in p-p collisions

CMS PAS HIN-12-013

CMS: Jet fragmentation functions

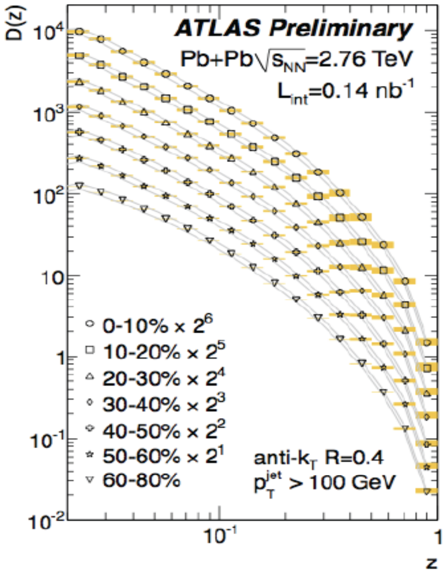


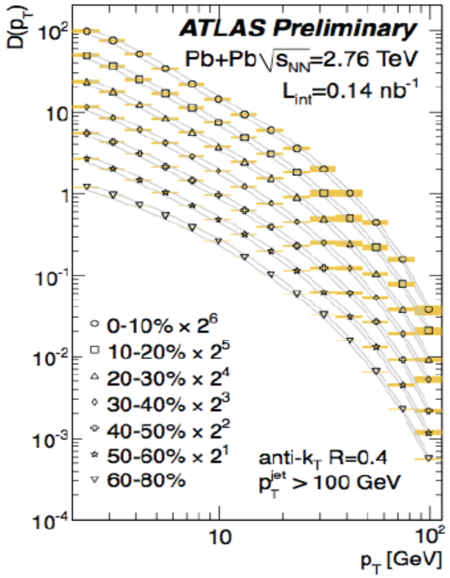
20 times more data in 2011: decreased uncertainties down to much lower track p_T (starting from 1 GeV/c) reveals an excess at high ξ compared to p-p

$z = pT_{,track}/pT_{,jet}$

CMS PAS HIN-12-013

FF ATLAS

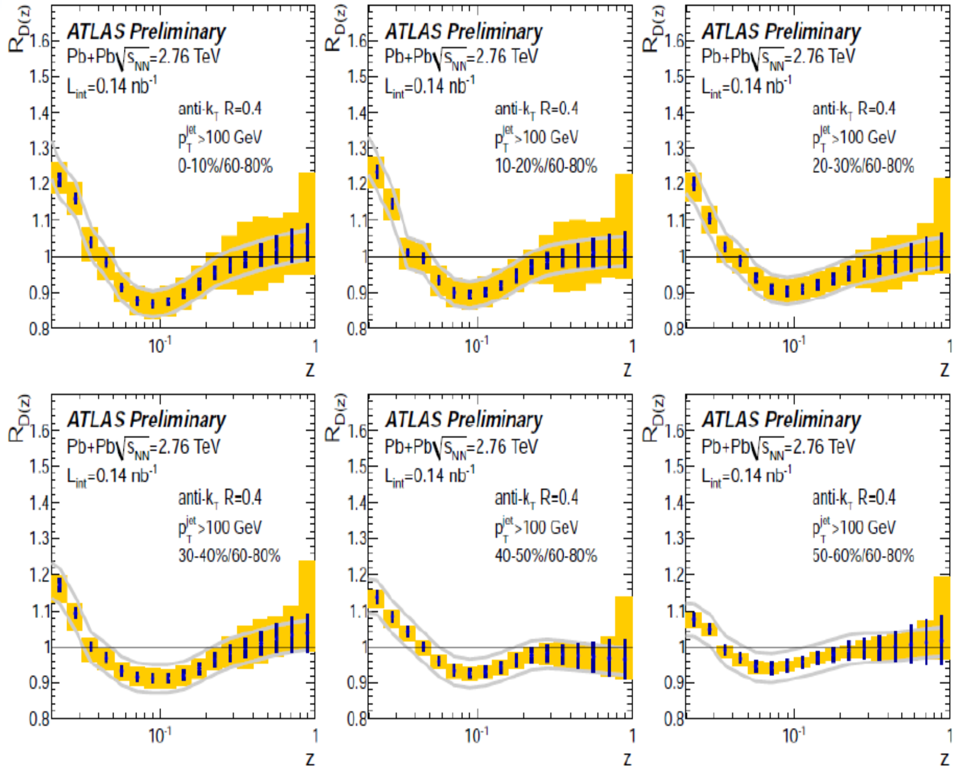


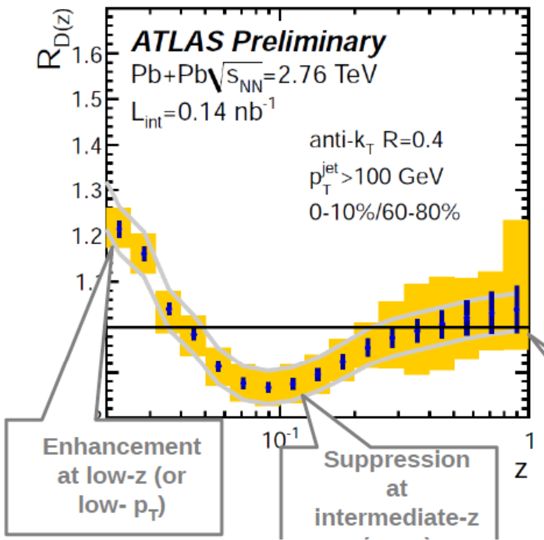


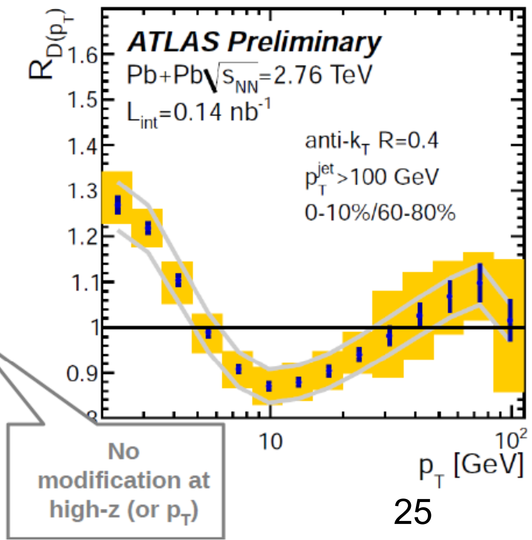
$$z = p_T^{ch}/p_T^{jet} \cos \Delta R$$

$$R_{D(z)} = \frac{D(z)|_{cent}}{D(z)|_{60-80\%}}$$

$$R_{D(p_T)} = \frac{D(p_T)|_{cent}}{D(p_T)|_{60-80\%}}$$





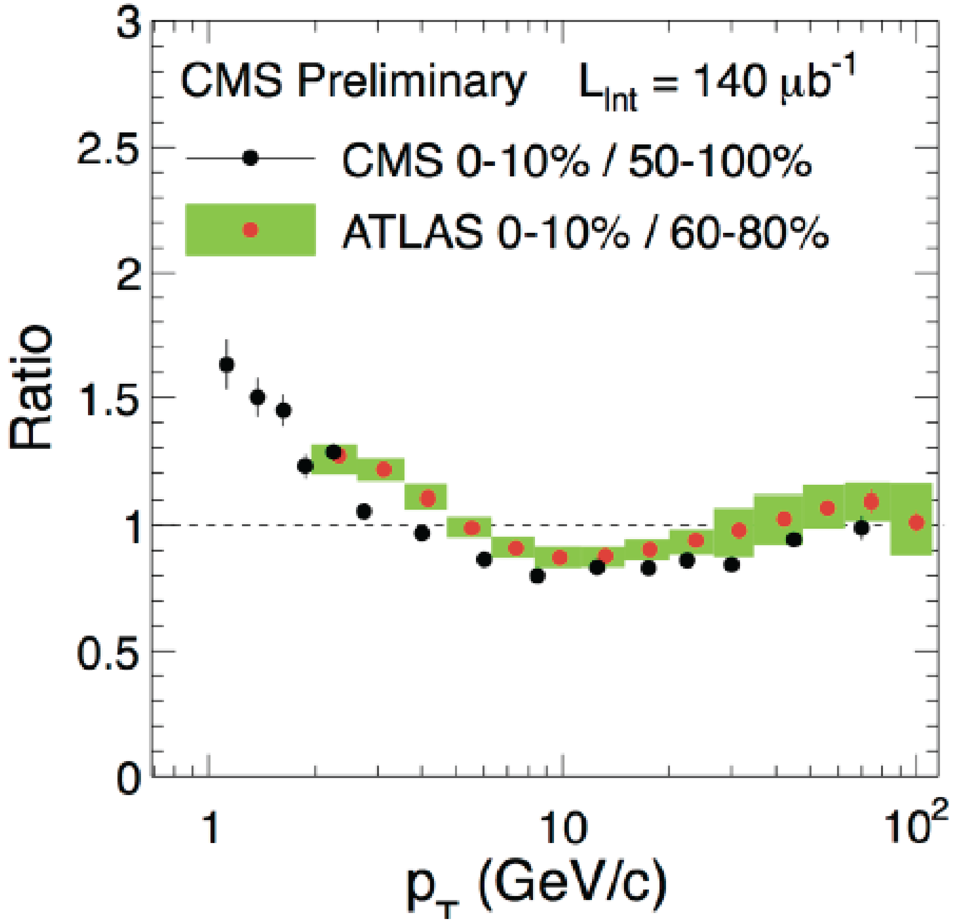


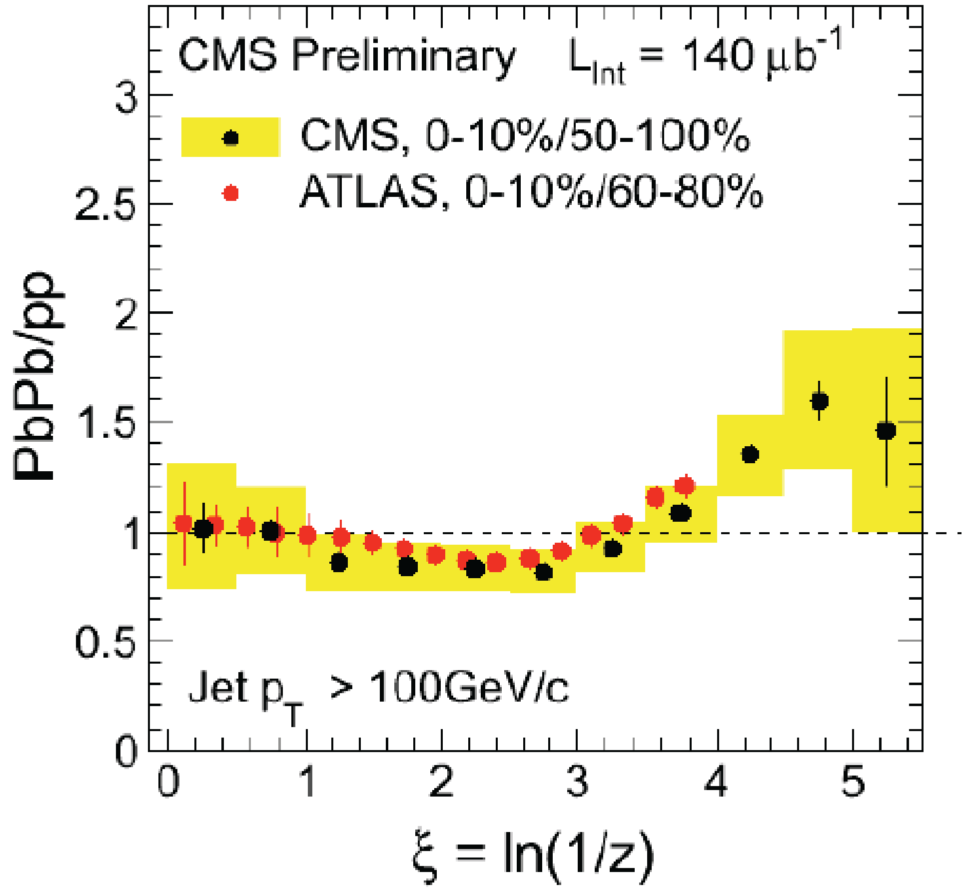
➔ Modification as function of centrality

Effect going away by decreasing centrality

ATLAS-CONF-2012-115

FF CMS vs ATLAS





Only one set of systematic uncertainties shown

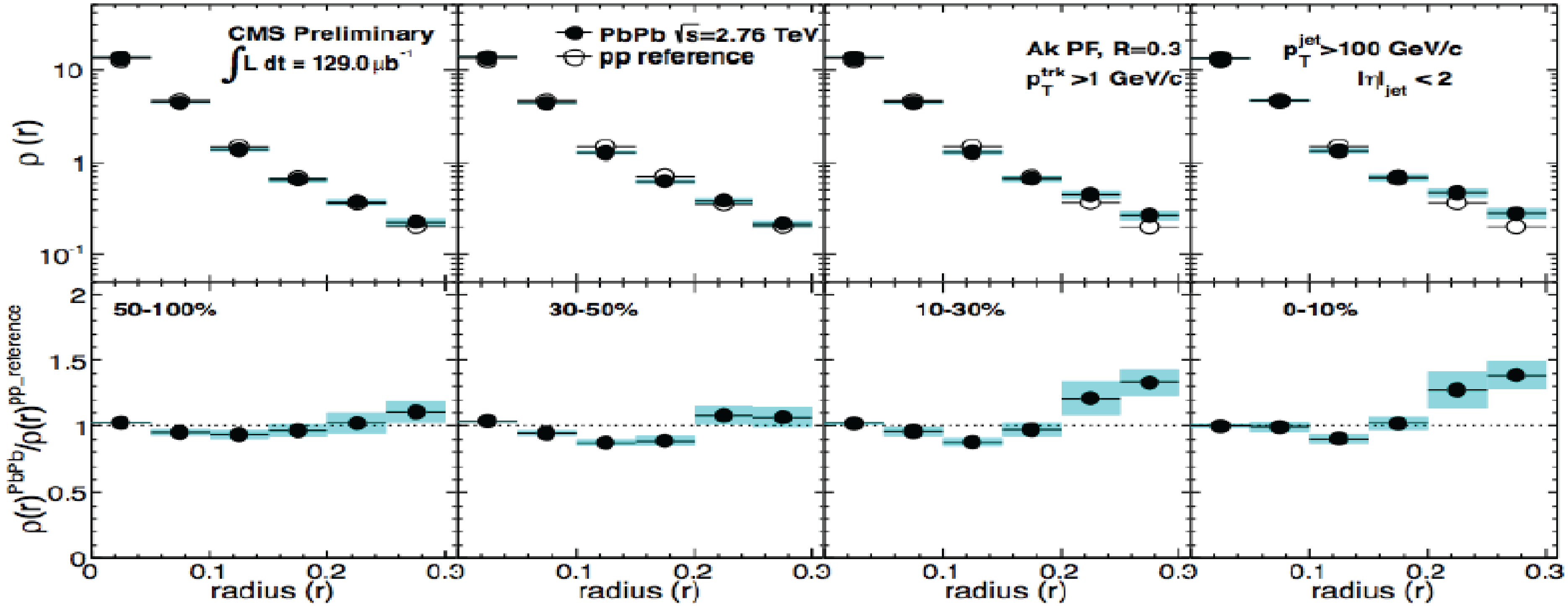
Good agreement between ATLAS and CMS

Depletion from 3-4 GeV to 40-50 GeV (2-3% of the total jet energy)

Enhancement below 3-4 GeV (~ 2% of the jet energy)

CMS: jet shapes vs. centrality

$$\rho(r) = \frac{1}{f_{ch}} \frac{1}{\delta r} \frac{1}{N_{jet}} \sum_{jets} \frac{p_T(r - \delta r/2, r + \delta r/2)}{p_T^{jet}} \qquad f_{ch} = \frac{1}{N_{jet}} \sum_{jets} \frac{p_T(0, R)}{p_T^{jet}}$$

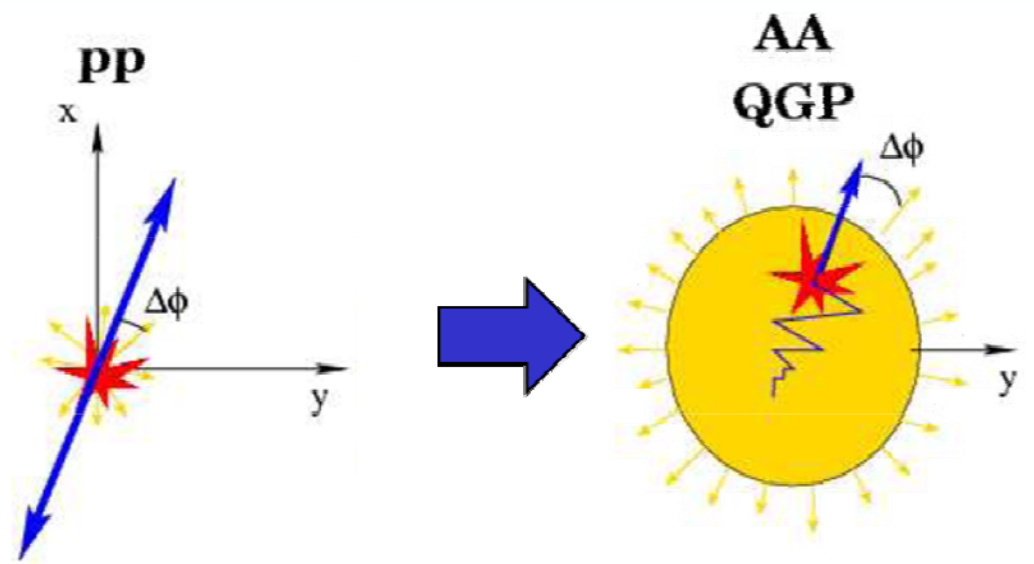


Again, depletion/enhancement pattern (correlation between fragment p_T and r)

Compared to p-p: same p_T-flow close to the jet axis
more p_T-flow at large radii
and a bit less in between.

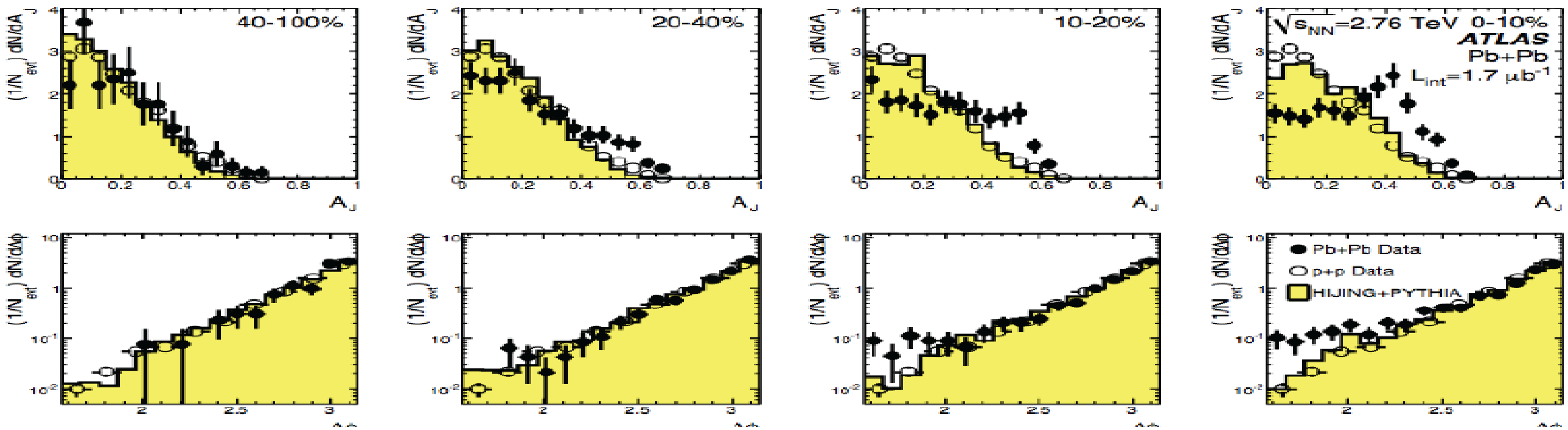
CMS PAS HIN-12-013

Di-jets Asymmetry

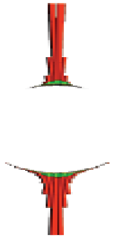


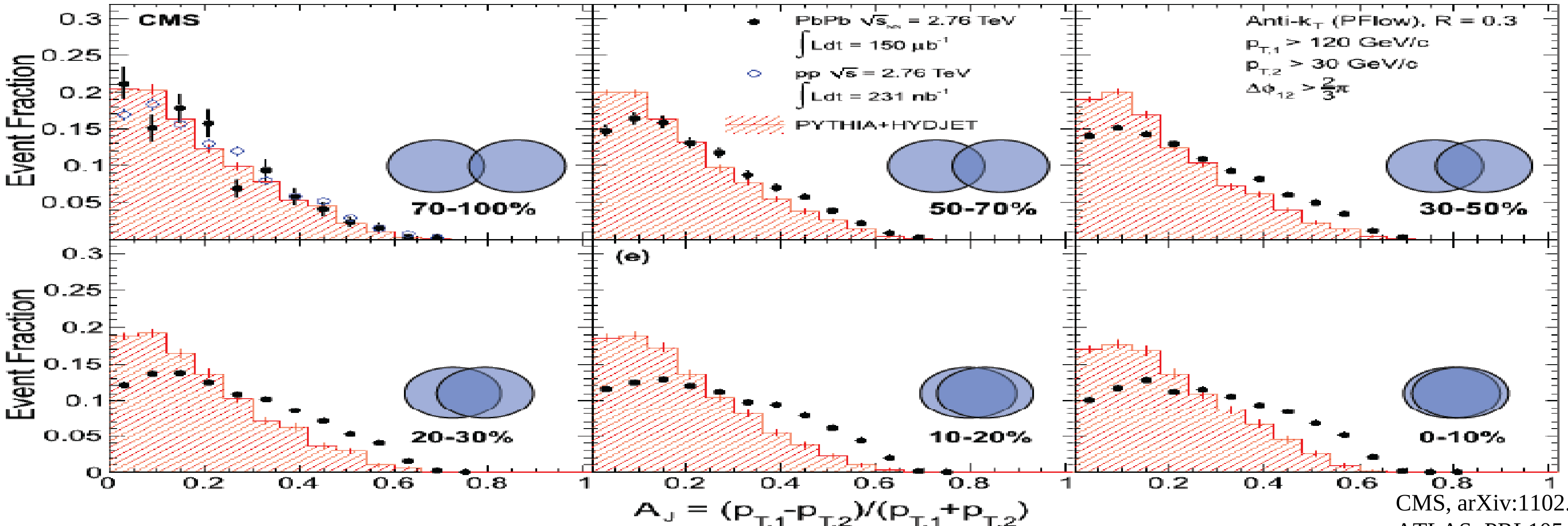
$$A = \frac{(pT_1 - pT_2)}{(pT_1 + pT_2)}$$

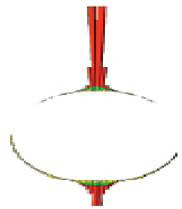
Di-jets Asymmetry ATLAS & CMS



ATLAS: For central events a strong imbalance of leading vs subleading momentum develops
Azimuthal back to back correlation remains

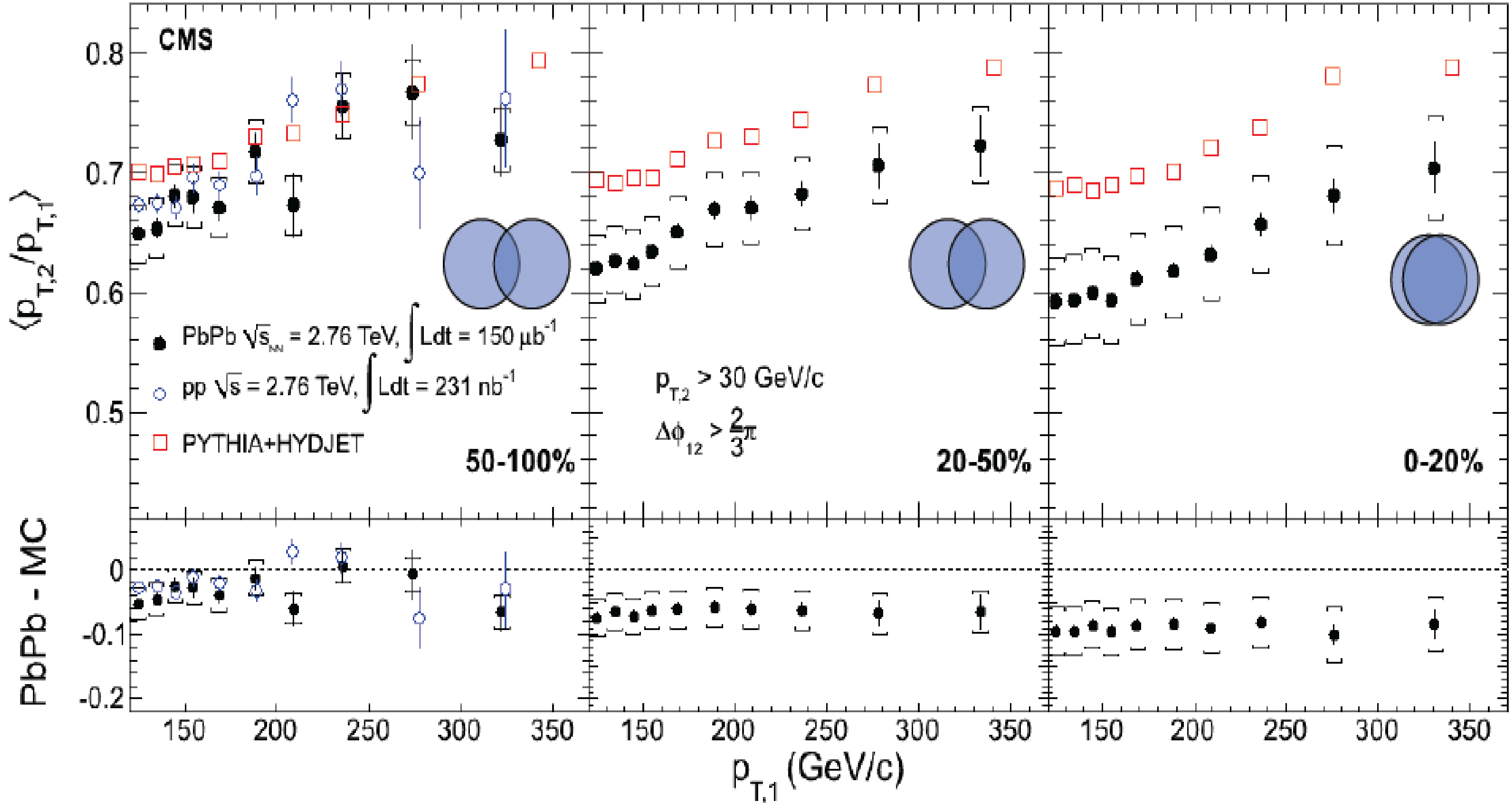






CMS, arXiv:1102.1957
ATLAS: PRL105 (2010) 252303

CMS: Di-jet balance centrality evolution from 2011 data set



How does the di-jet imbalance depend on the leading jet energy?

CMS : Di-jets in reference (p-p, PYTHIA) more balanced with increasing p_T

<pT,2/pT,1> in Pb-Pb consistent with a constant offset from reference MC (increasing with centrality but does not depend on p_T)

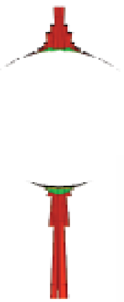
What else ?

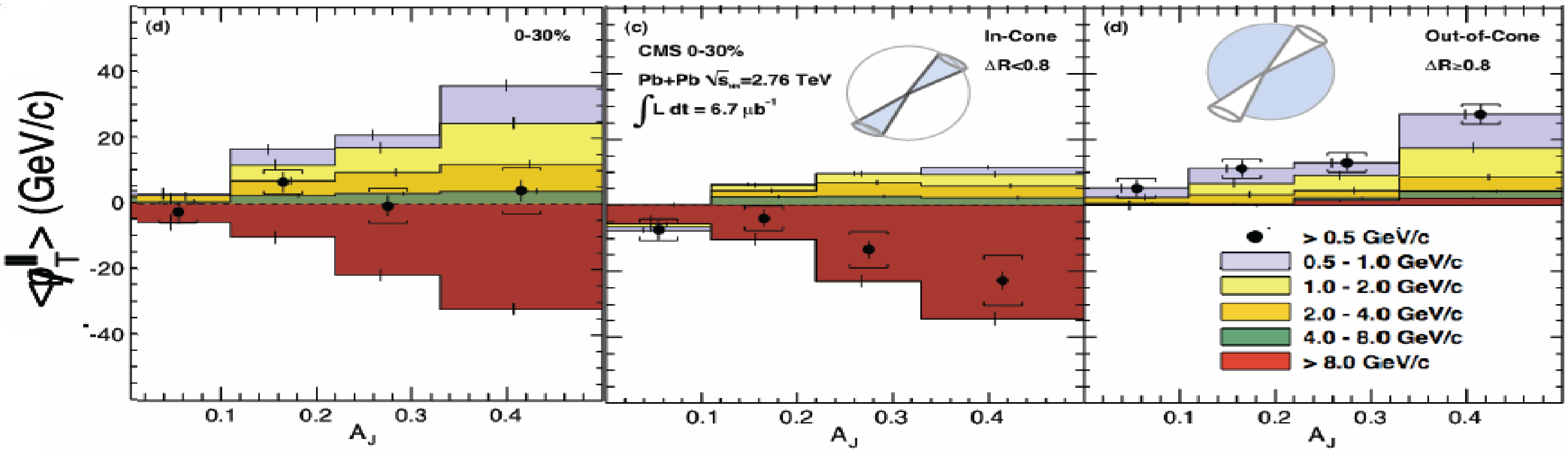
Missing energy recovered at large angle

Leading jet : more high pt tracks, sub-leading more low p_T → look outside of the cone

CMS: The momentum difference in the di-jet is balanced by low p_T particles mainly at large angles relative to the away side jet axis

STAR: Energy lost at high p_T approximately recovered at low p_T and high R

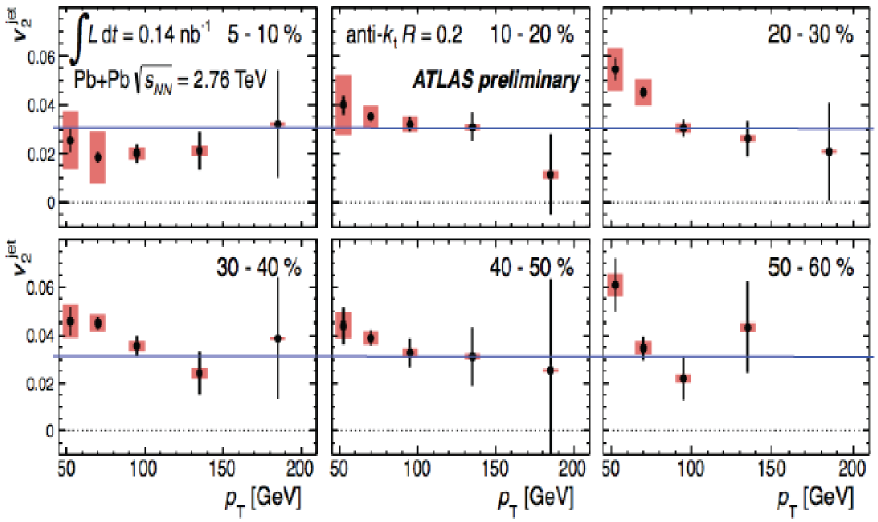


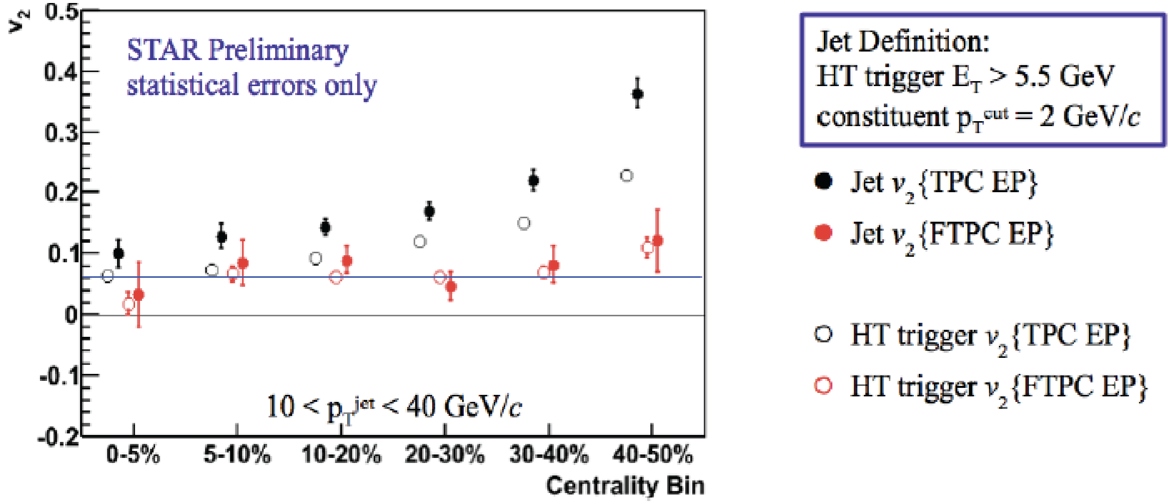


$A_J = (p_{T,1} - p_{T,2})/(p_{T,1} + p_{T,2})$

$$\not{p}_T^{\parallel} = \sum_{\text{Tracks}} -p_T^{\text{Track}} \cos\left(\phi_{\text{Track}} - \phi_{\text{Leading Jet}}\right)$$

v_2 vs Jet v_2 (ATLAS & STAR)



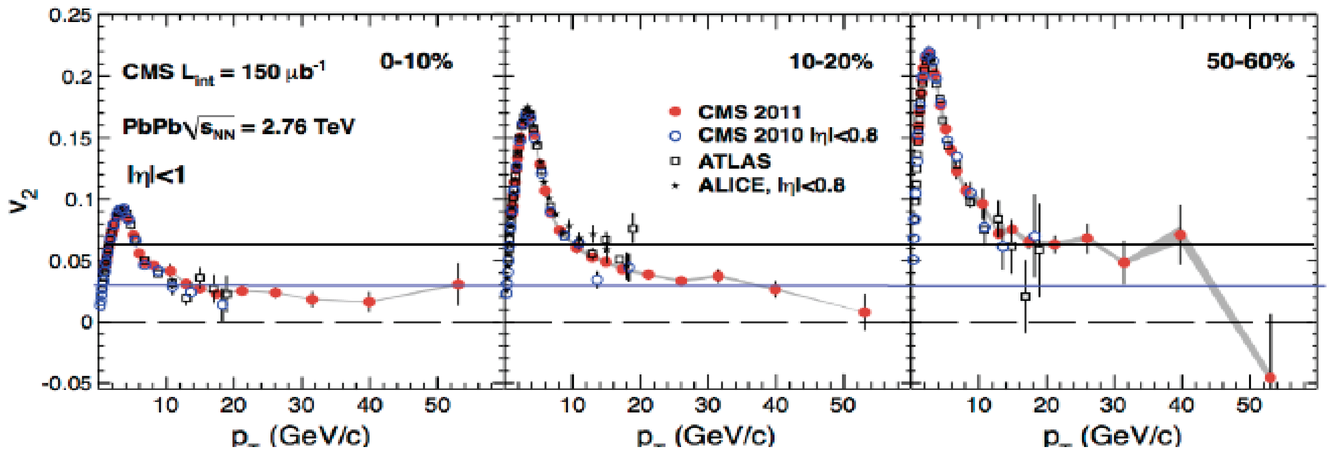


ATLAS: Jet v_2 wrt. event plane from forward calorimeters

Jets v_2 = Correlation between event plane and reco. jets

STAR: non 0 jet v_2 in mid central collisions

Path length of parton energy loss ?

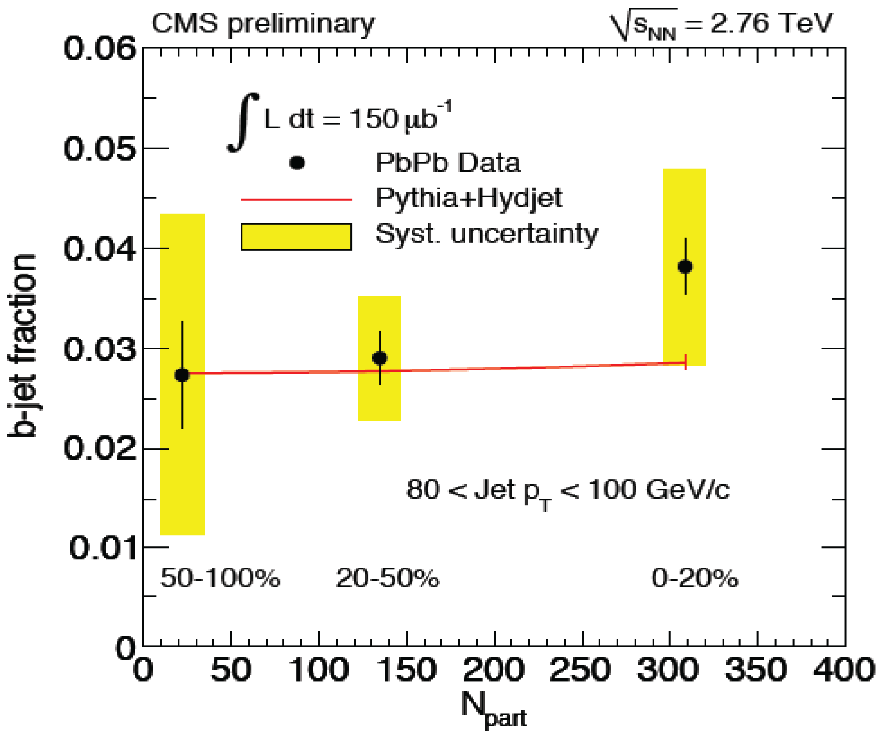


ATLAS & STAR results compared to hadron v_2 up to 50 GeV/c from CMS

ATLAS-CONF-2012-116

CMS :B jets (p-p & Pb-Pb)

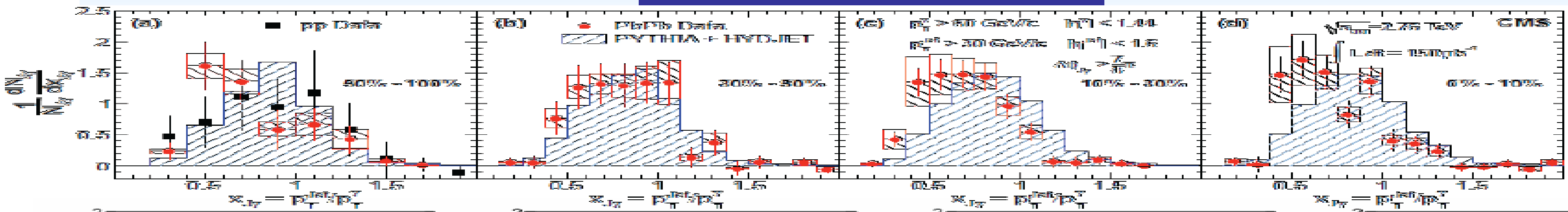
• Secondary vertex tagged using flight distance significance

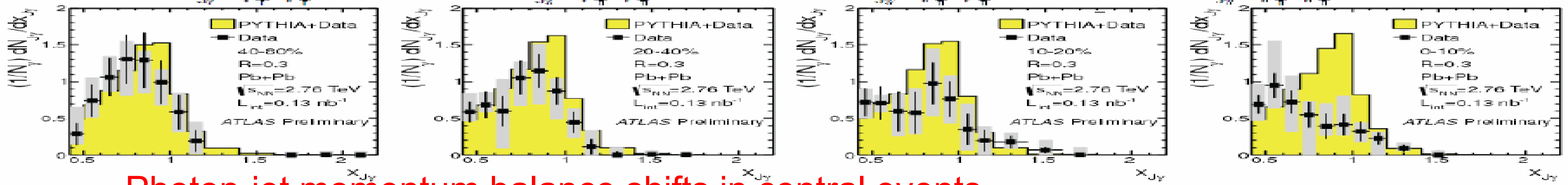


b-jet fraction: similar in p-p and Pb-Pb
(**does not show a strong centrality dependence)**
→ b-jet quenching is comparable to light-jet quenching (R_{AA}≈0.5), within present systematics

CMS-PAS-HIN-12-003

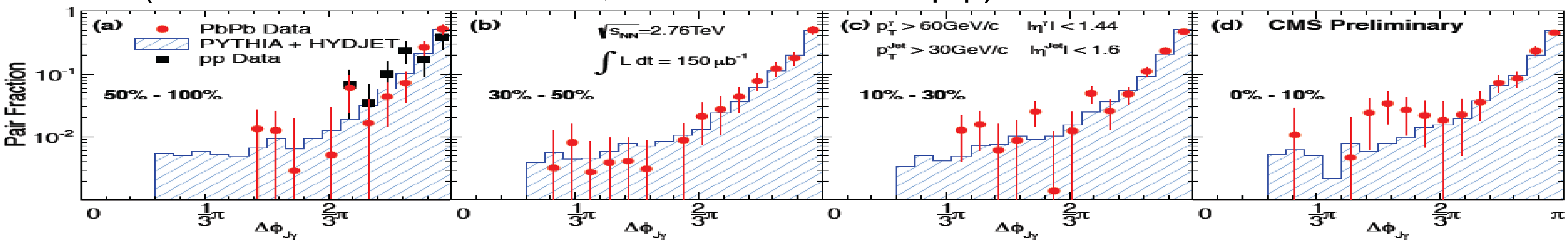
Gamma jets

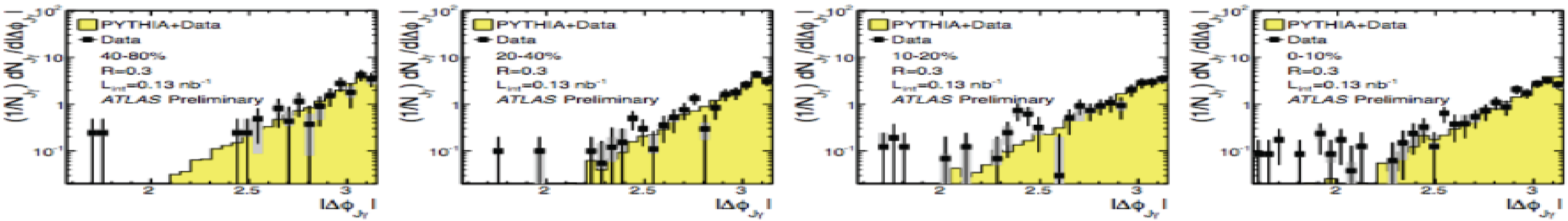




Photon-jet momentum balance shifts in central events

(relative to PYTHIA reference, calibrated in 7 GeV p-p)





No angular decorrelation observed (now with much lower jet p_T)

CMS, arXiv:1205.0206
ATLAS-CONF-2012-121

Summary

Theory / Experiments comparisons were only briefly discussed in this talk.
→Are we realy comparing the same observables ?

A lot of new results on jets from both LHC and RHIC
The next p-A run at LHC should soon provide some additional measurements

→In general good consistency between experiments