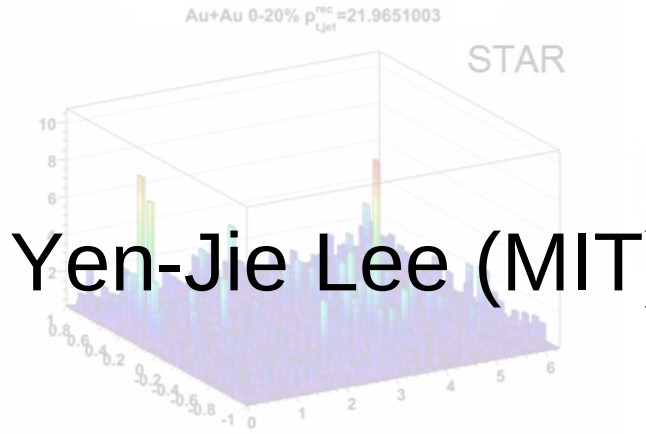
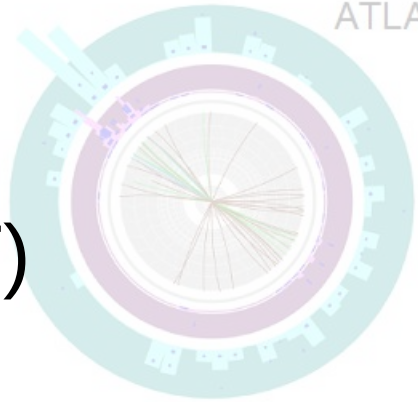
Recent jet results in heavy ion collisions





Yen-Jie Lee (MIT)

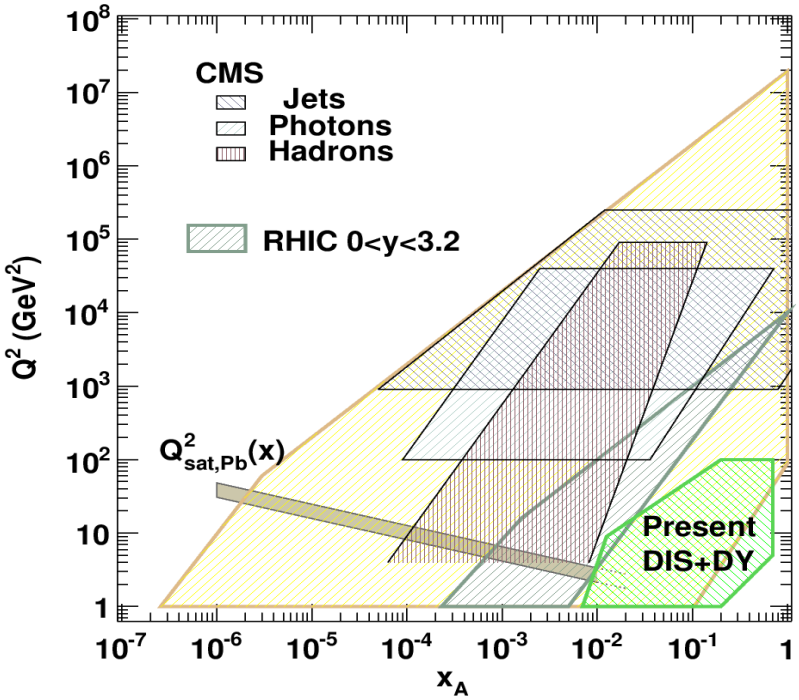
LHC Working Group on Forward Physics and Diffraction

Kansas City, USA

6 September, 2014

Jet production in heavy ion collisions

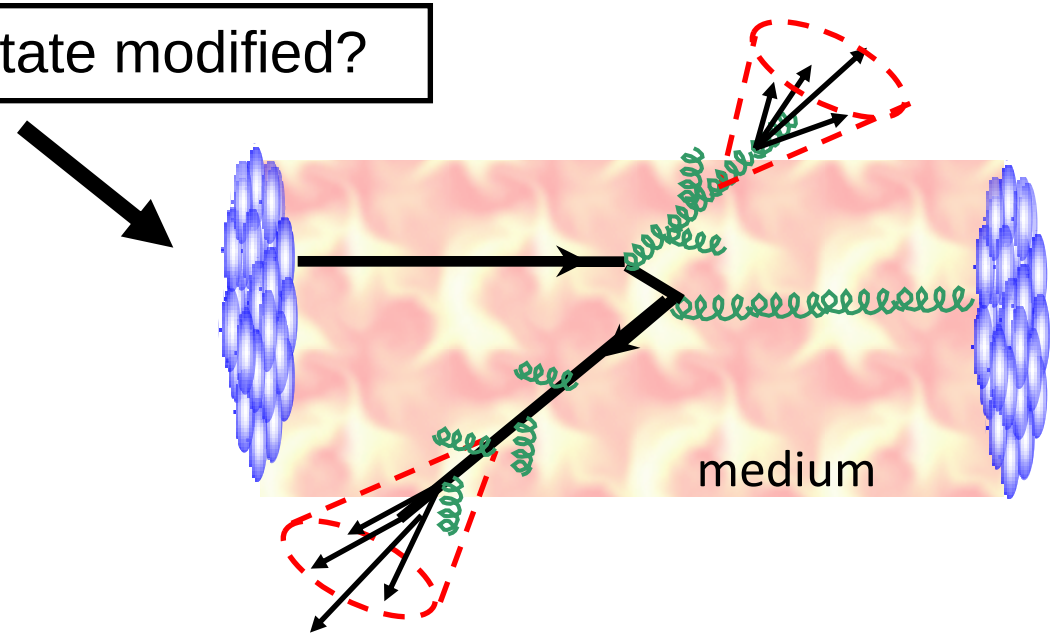
- Theoretically calculable, infra-red/collinear safe
- Give access to initial state parton distribution
- Allow the use of a well defined object (by algorithm) to study “the final parton energy” and how the energy is distributed with respect to the direction of the out-going parton
- Allow us to select quenched jets (jets from partons which lost a lot of energy when passing through the medium)



http://www.digitalpicturezone.com/digital-pictures/30-colorful-examples-of-high-speed-bullet-photography/

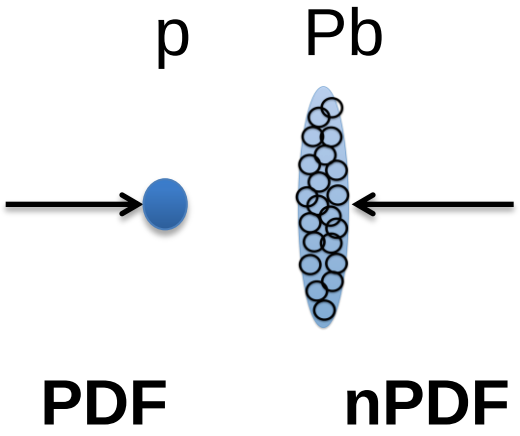
Jet as a versatile probe in heavy ion collisions

Is the initial state modified?



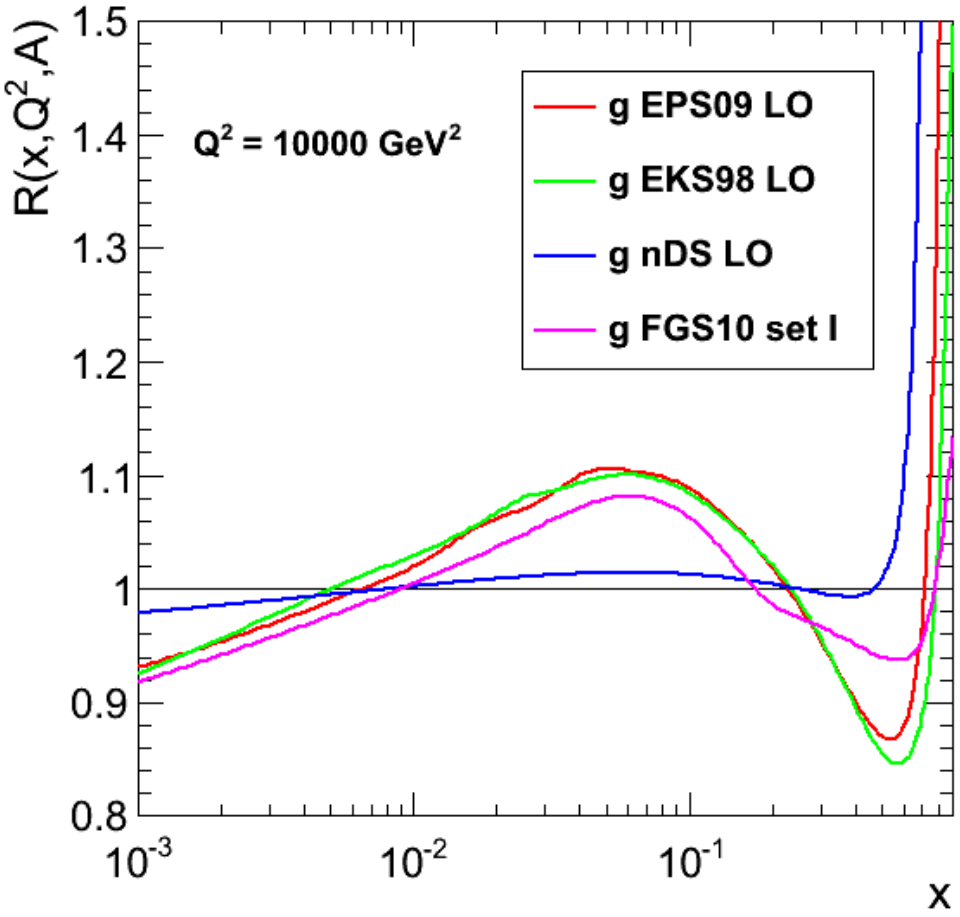
→ pA collisions

Nuclear Parton Distribution Function



$$R = \frac{nPDF}{PDF}$$

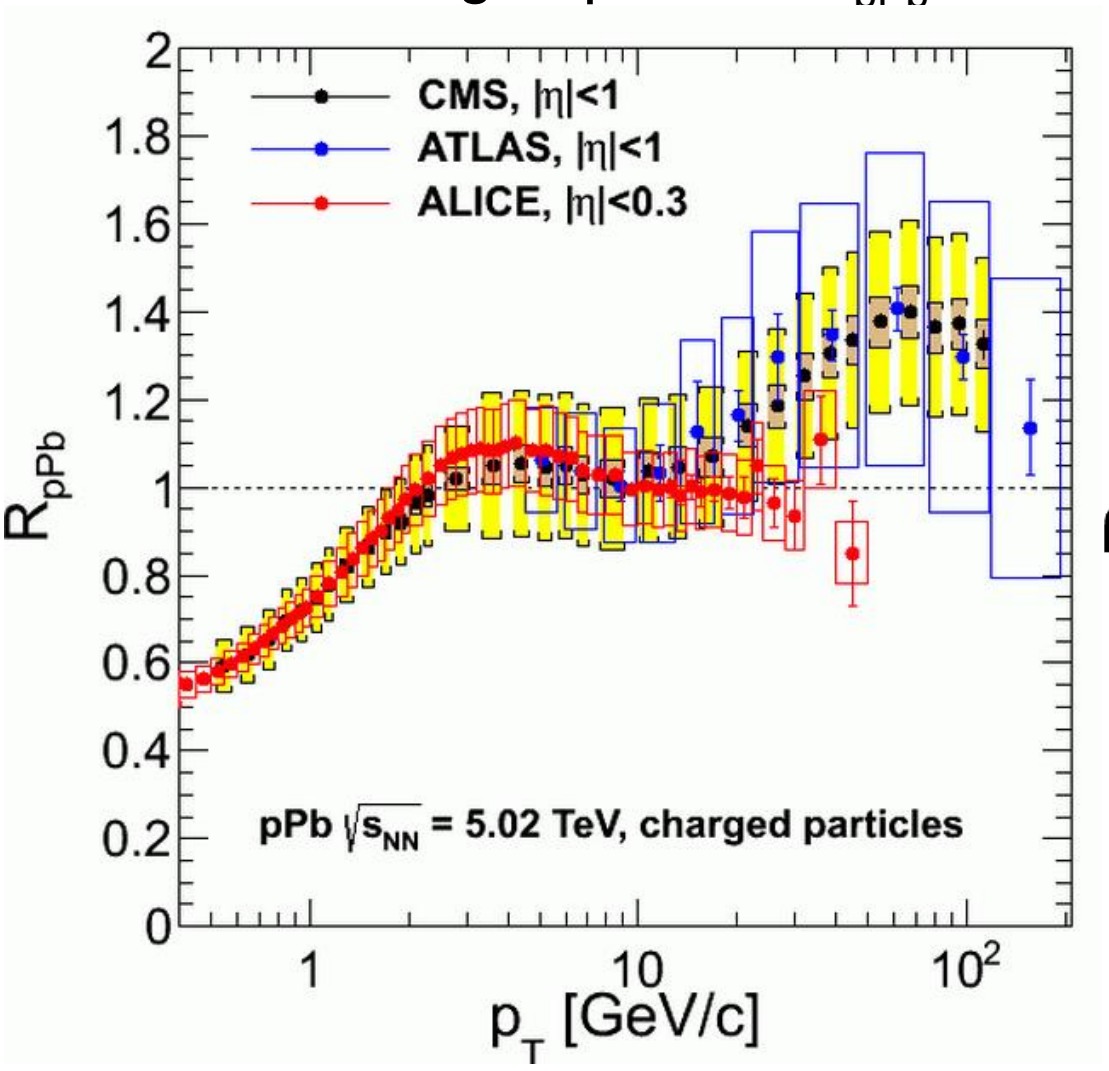
Gluon nPDF/PDF comparison between EPS09, EKS98, nDS and FGS10



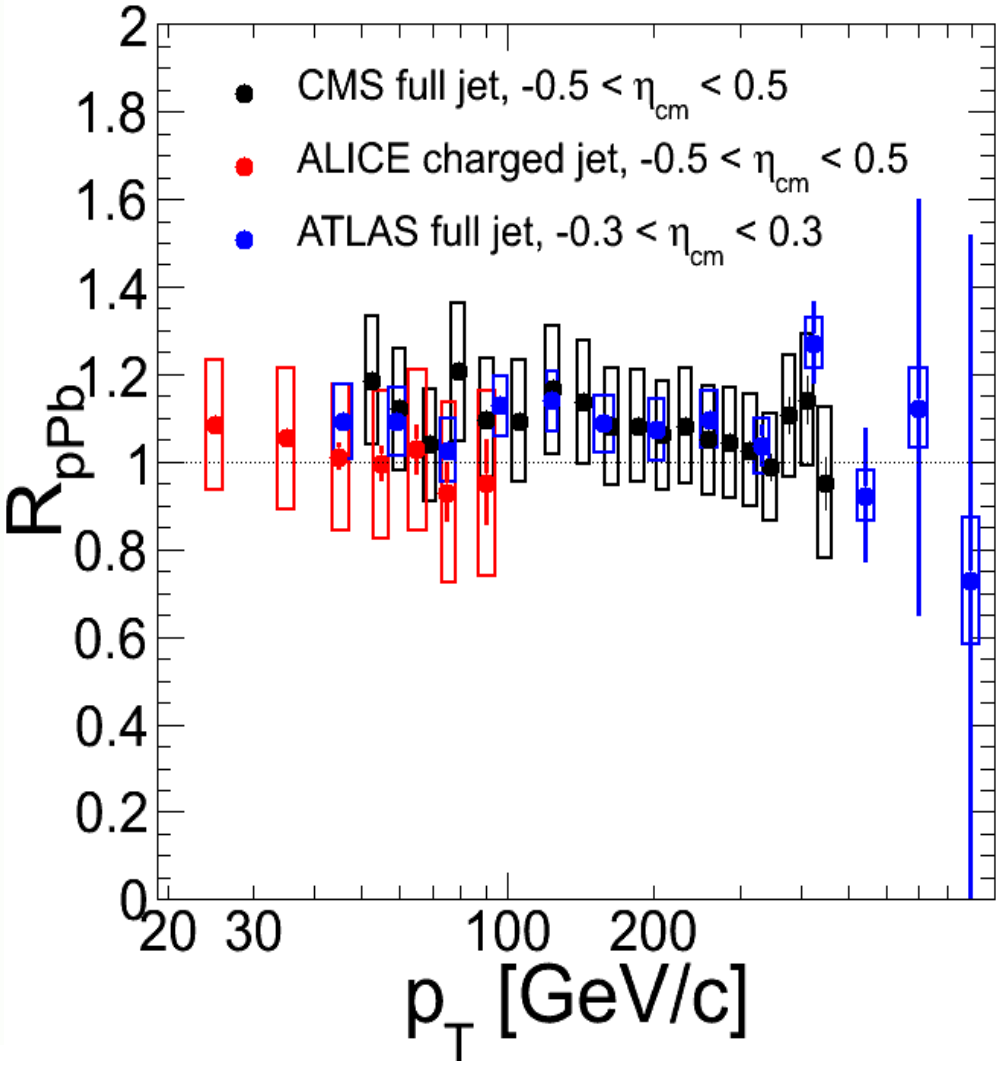
François Arleo and Jean-Philippe Guillet http://lapth.cnrs.fr/npdfgenerator/

Charged particle and jet R_{pPb} (QM2014)

Charged particle R_{pPb}



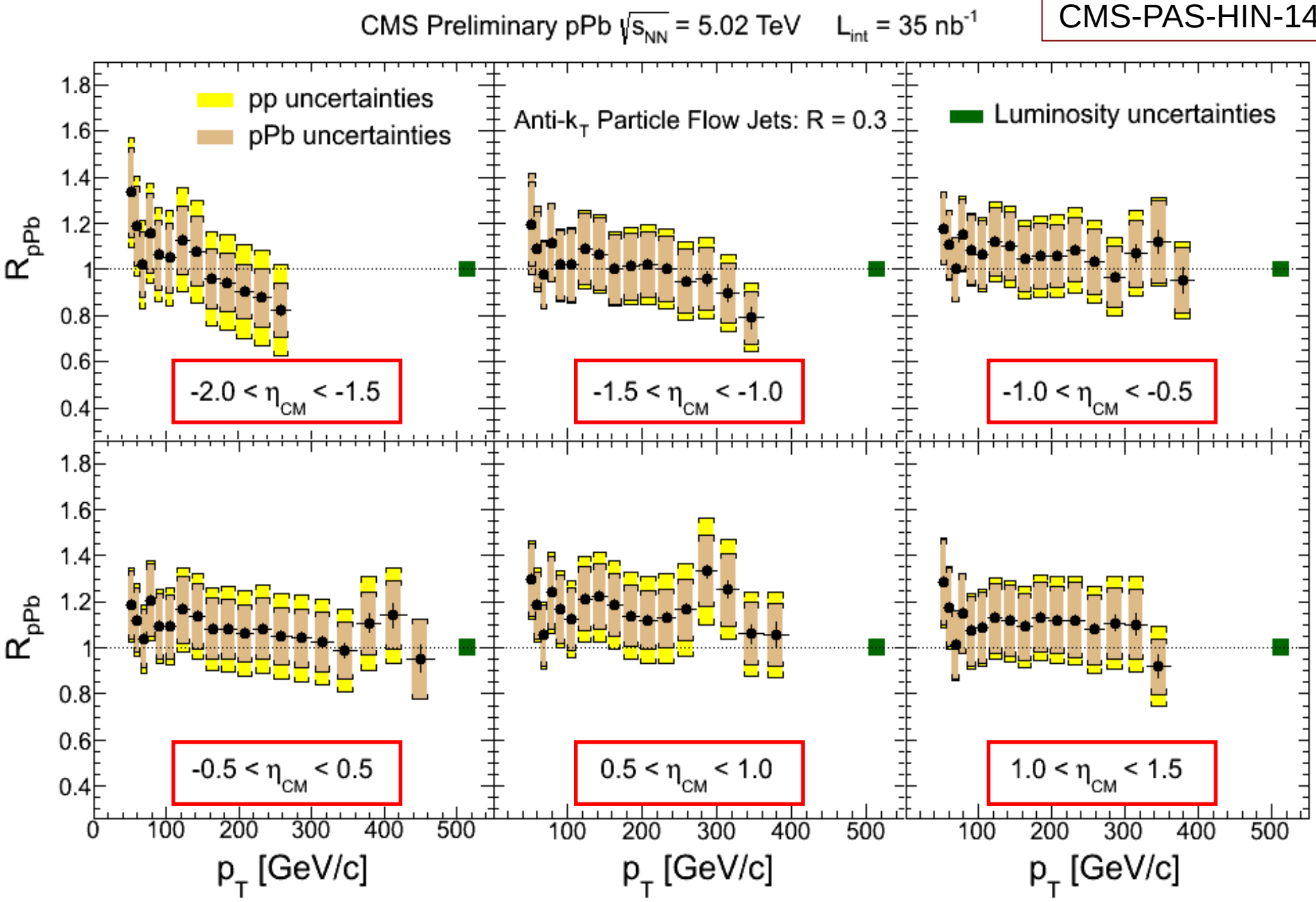
(Charged) Jet R_{pPb}



(Need to check jet fragmentation function)

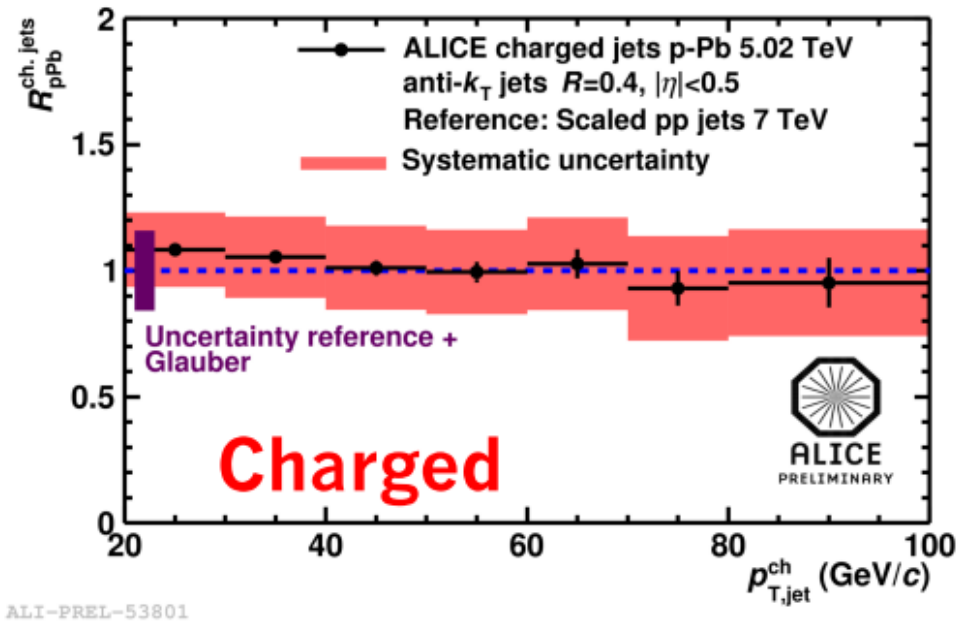
Nuclear Modification Factor R_{pPb} (Jets)

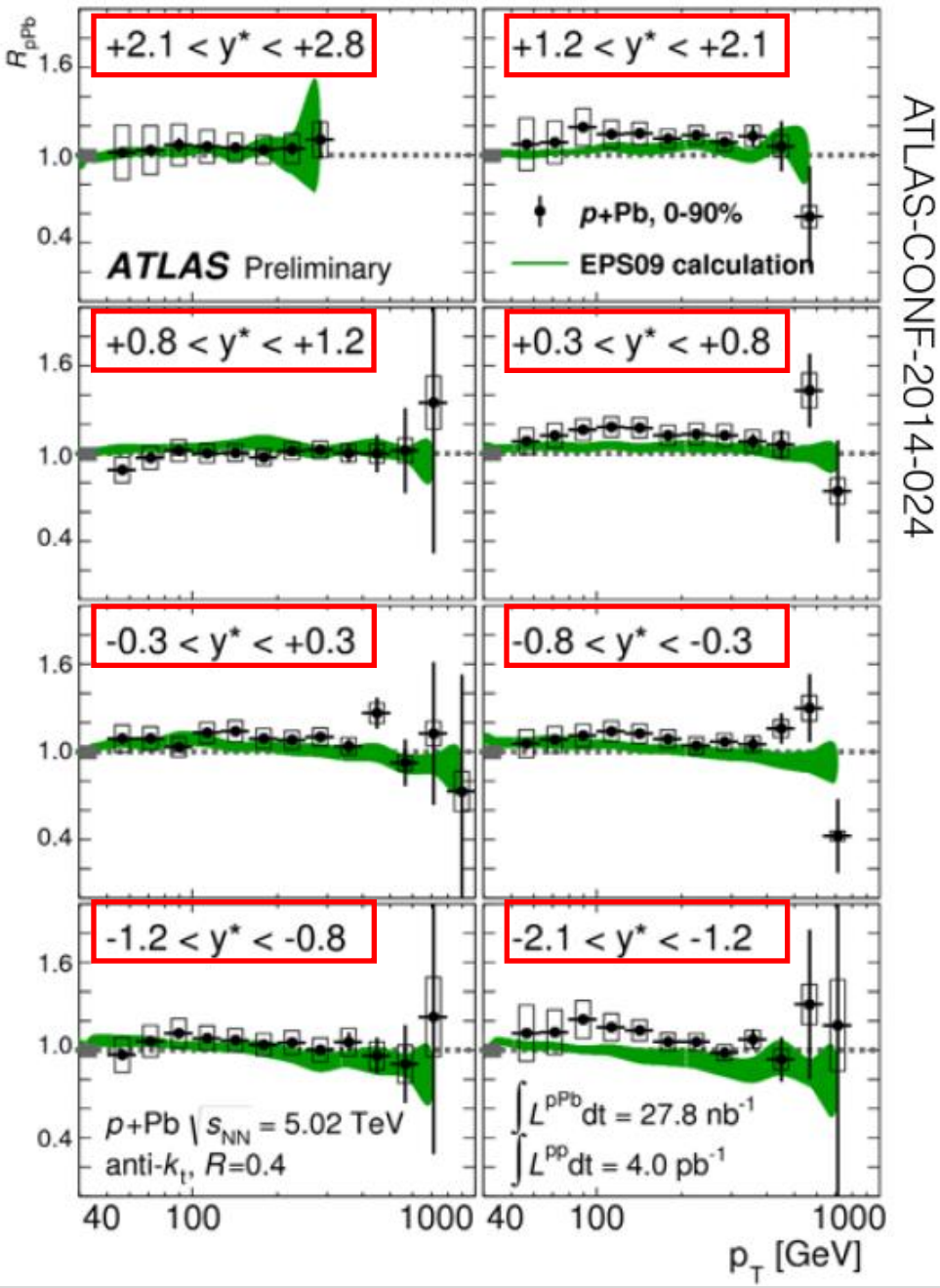
CMS-PAS-HIN-14-001



Nuclear Modification Factor R_{pPb} (Jets)

|η|<0.5 Charged Jet





- Jet R_{pPb} has been measured in |y|< ~3 region
- No sizable modification
- **Would be interesting to extend to even more forward region**

Dijet pseudorapidity distribution in pPb collisions

CMS pPb 35 nb^{-1}

$\sqrt{s_{NN}}$ = 5.02 TeV

$p_{T,1}$ > 120 GeV/c

$p_{T,2}$ > 30 GeV/c

$\Delta\phi_{1,2} > 2\pi/3$

All $E_T^{|\eta|>4}$

Jet quenching from dijet analysis in pPb: dijet asymmetry <2%

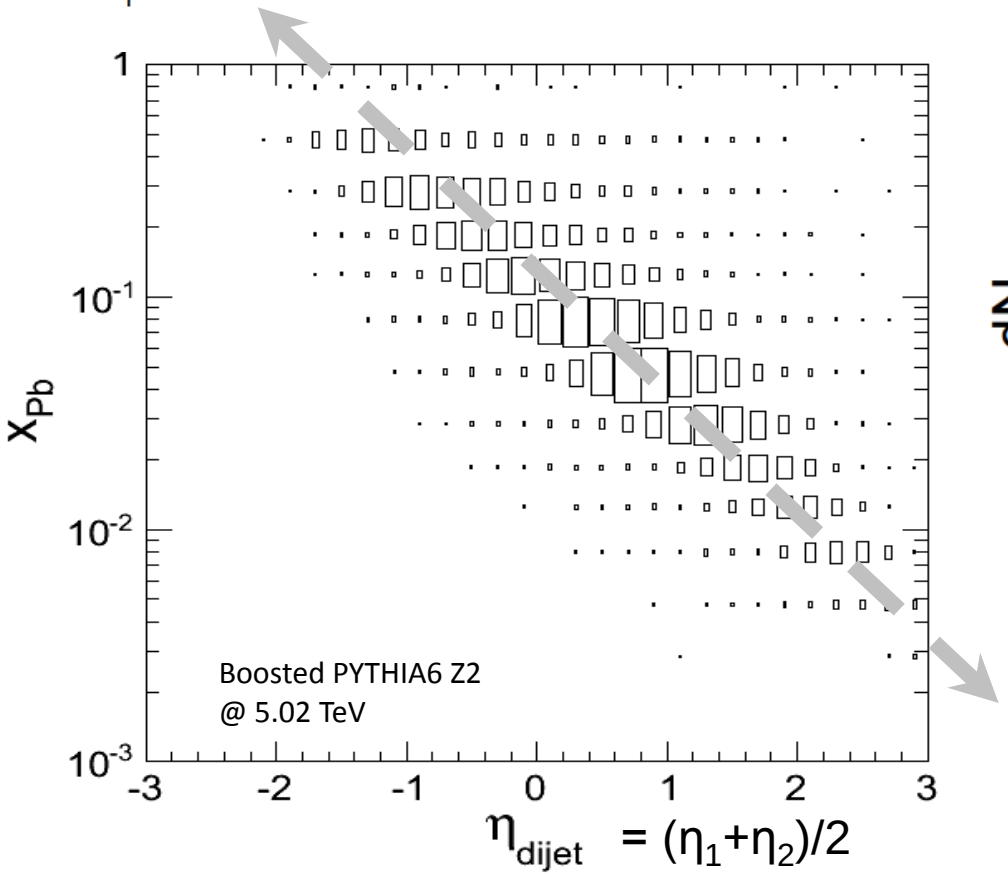
ArXiv 1401.4433

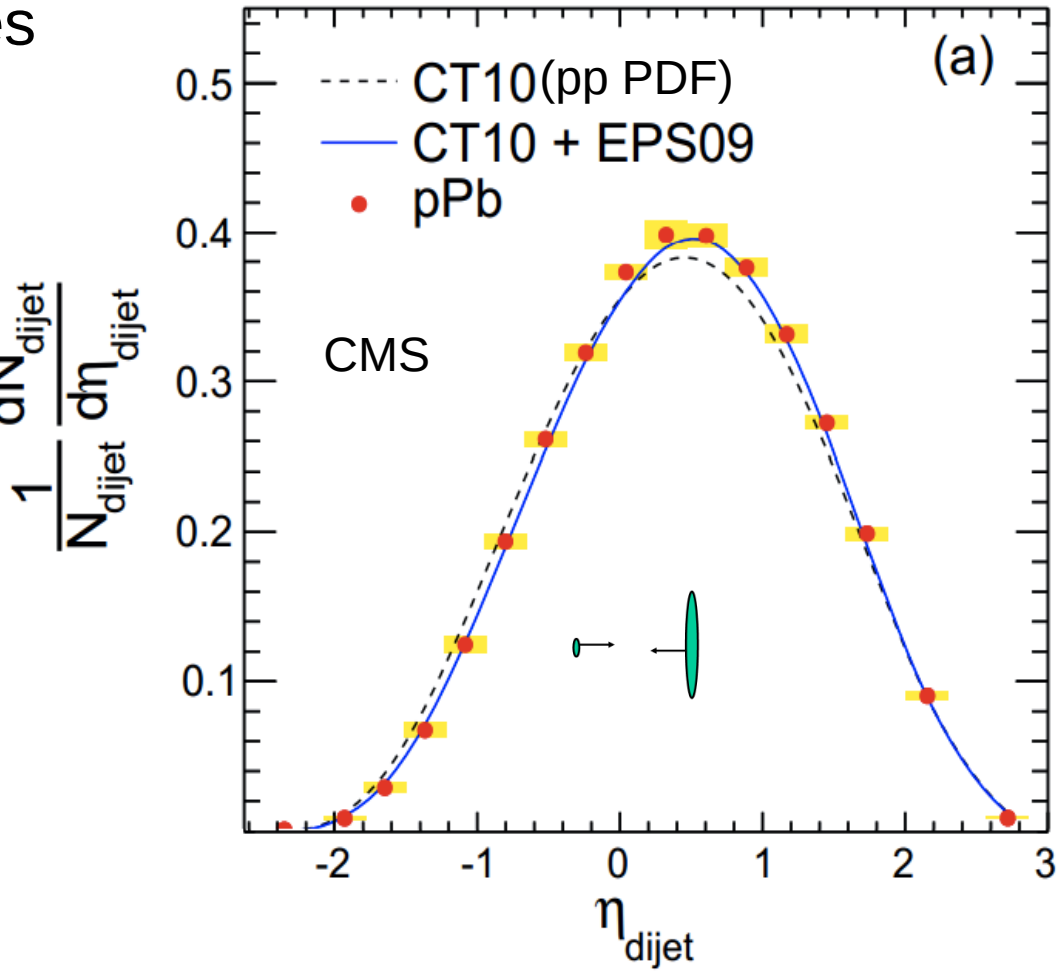
EPJC74 (2014) 2951

No significant jet quenching seen in γ-jet analysis in pPb

No sizable deviation from unity found in jet R_{pPb}

→ Jets for nPDF studies





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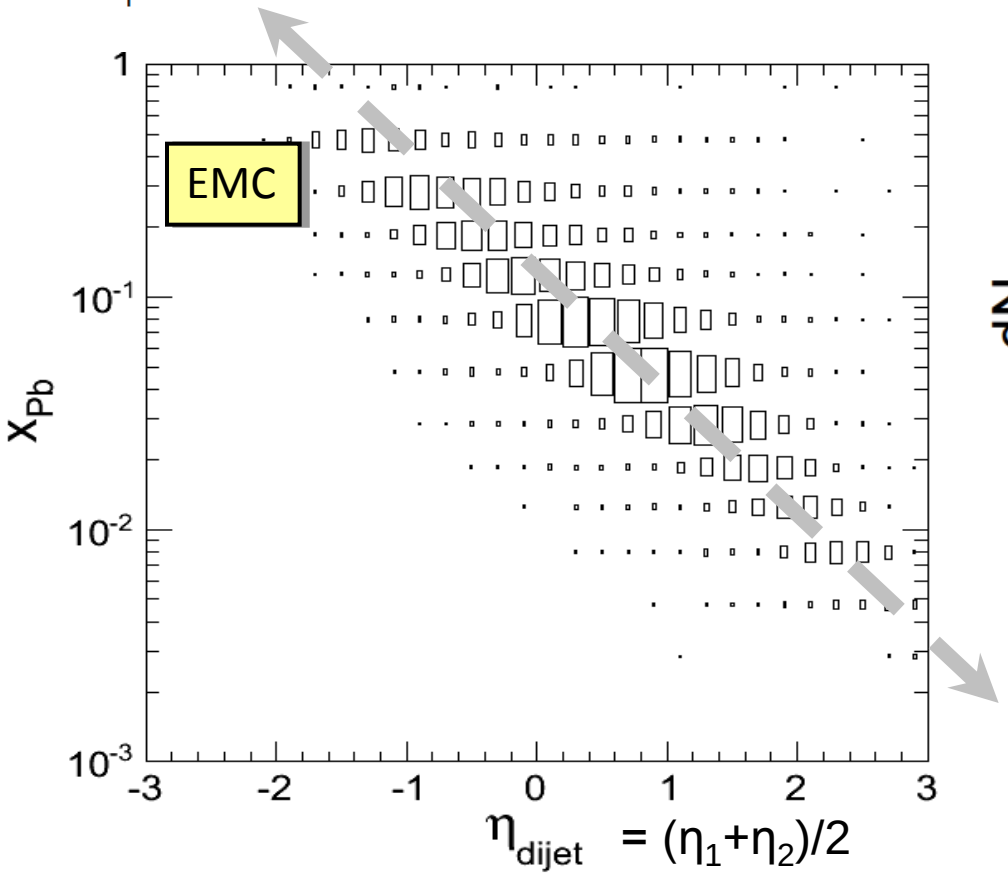

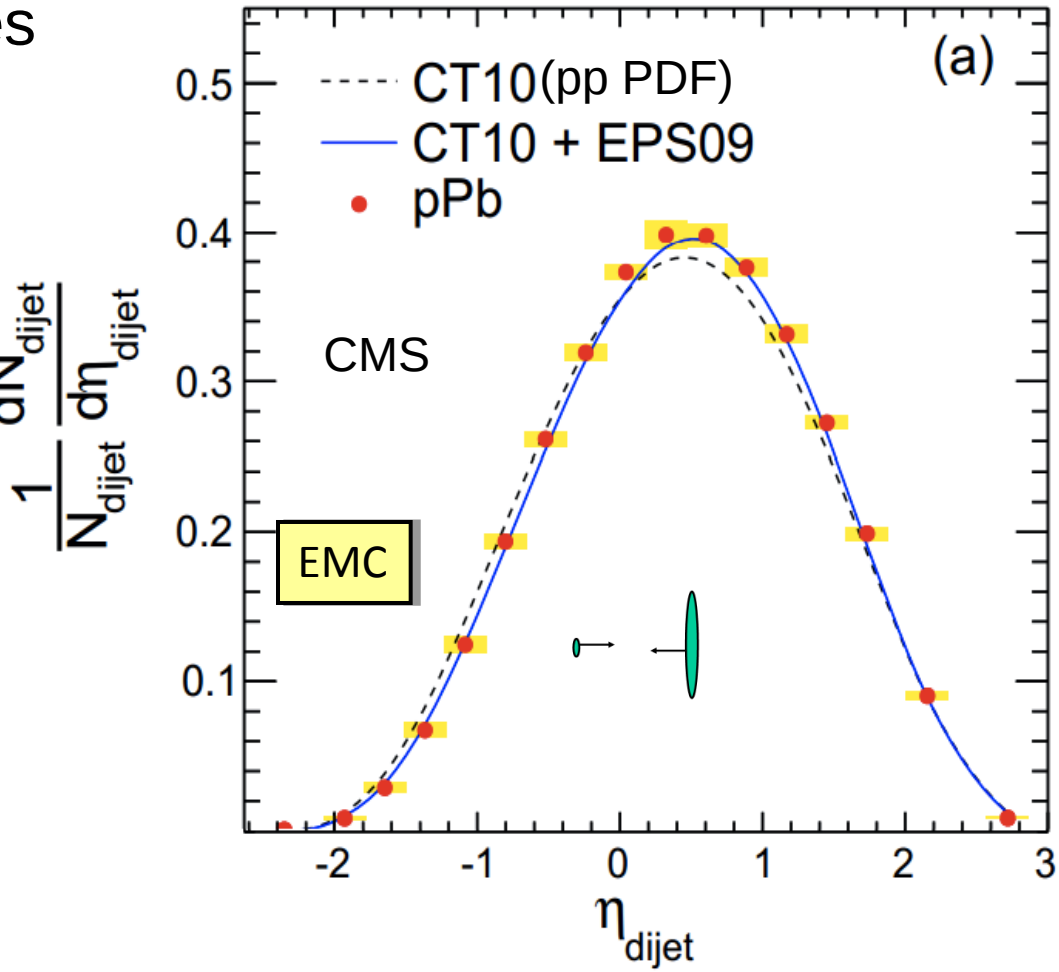

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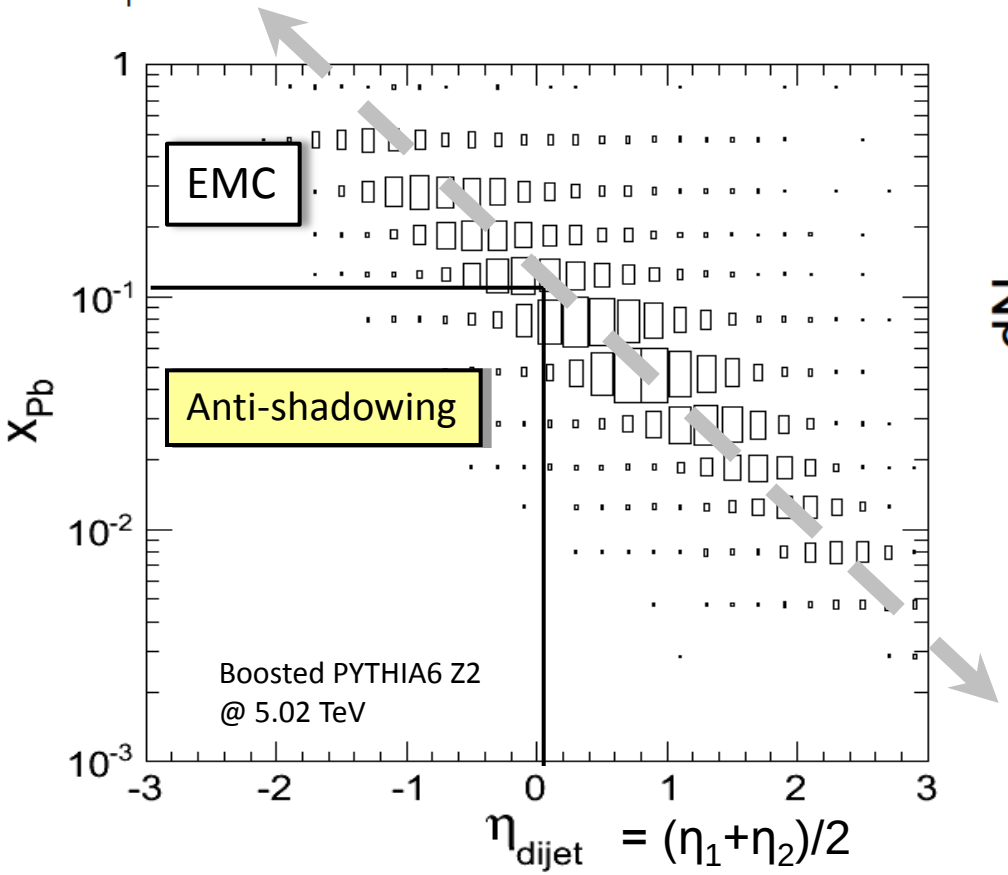

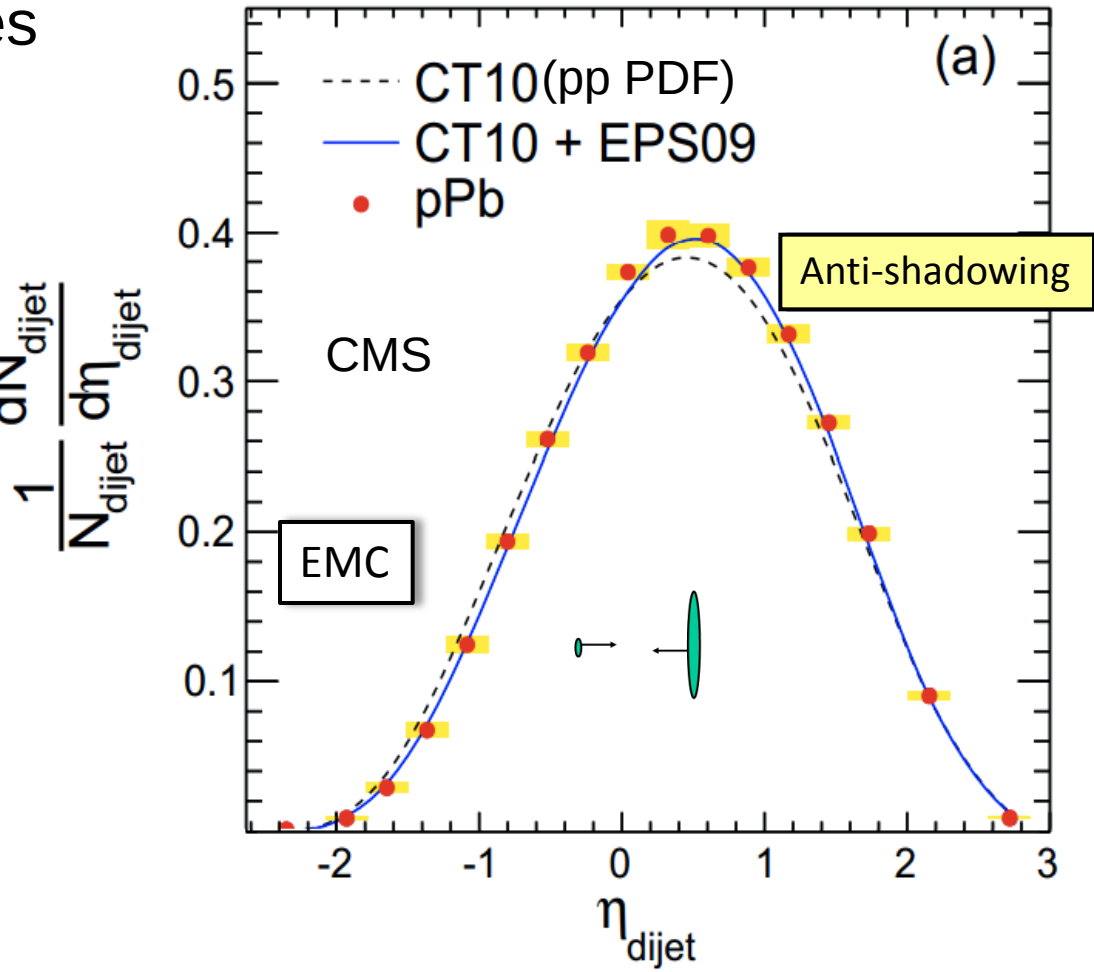

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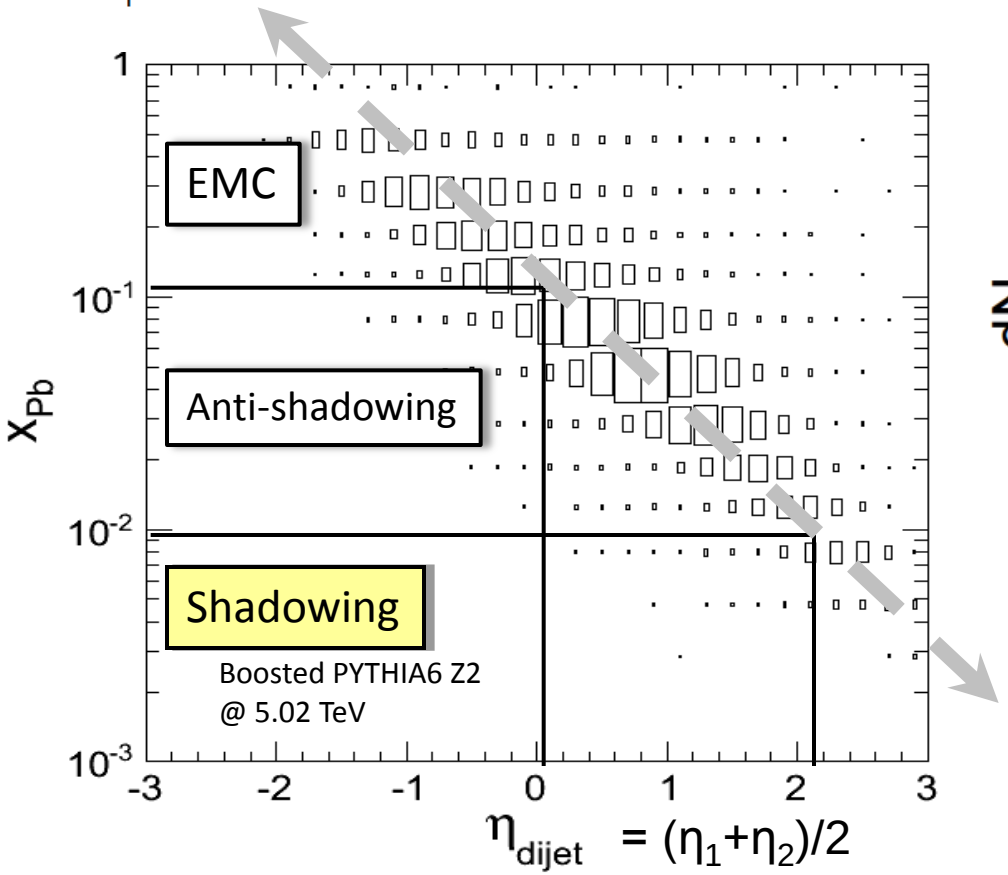
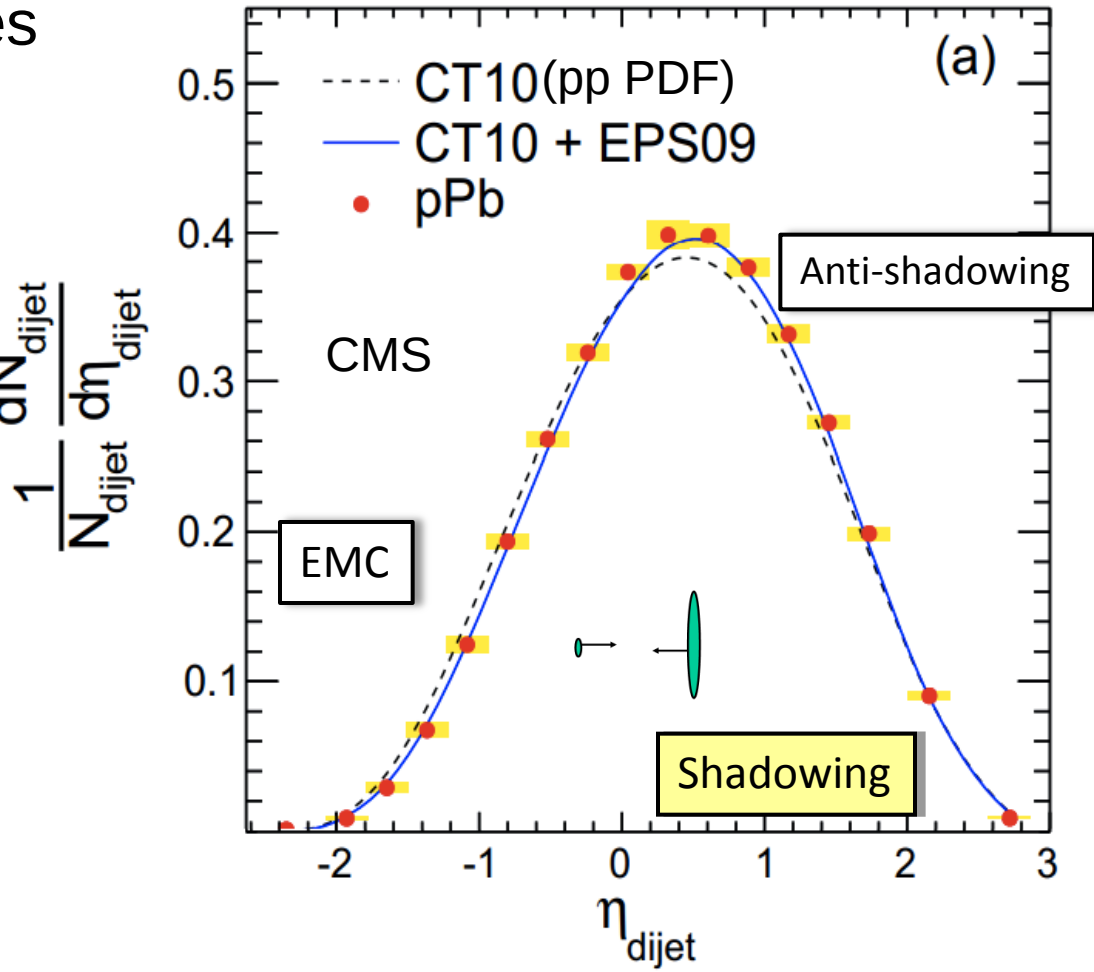
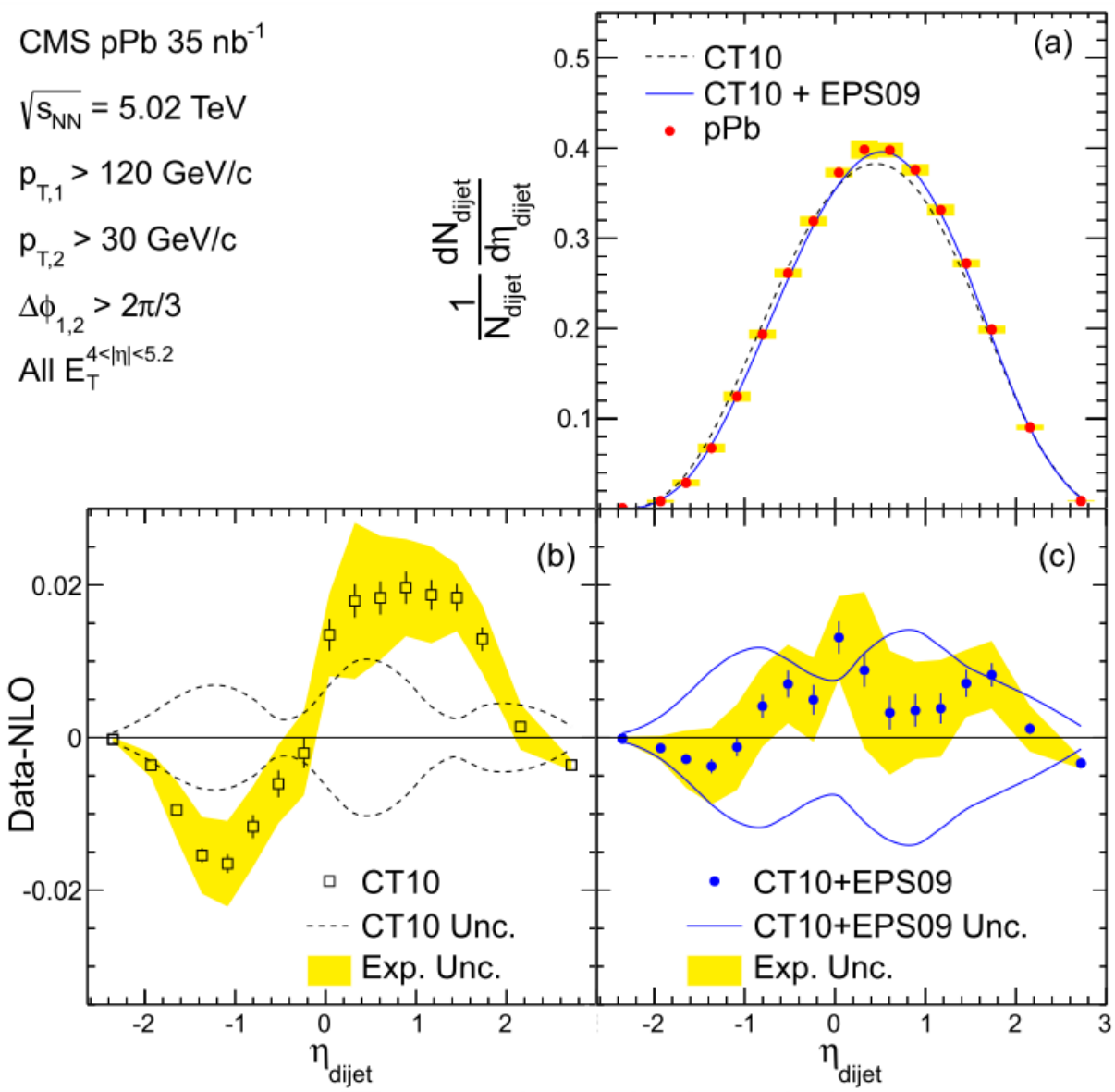


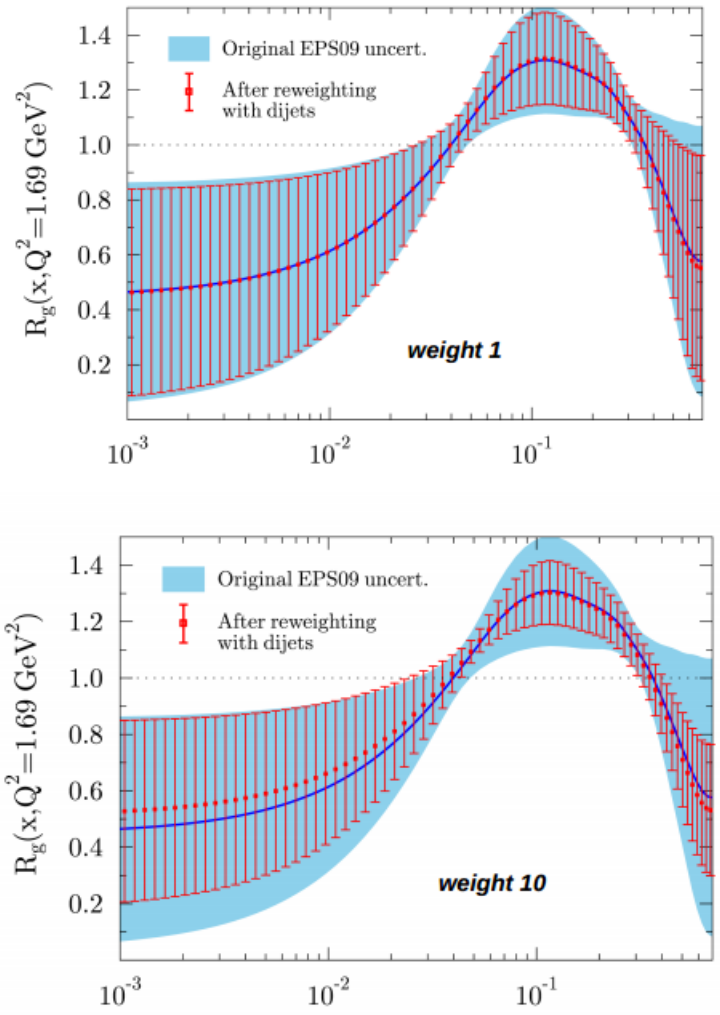


Compare to CT10 and CT10+EPS09

ArXiv 1401.4433



EPJC74 (2014) 2951



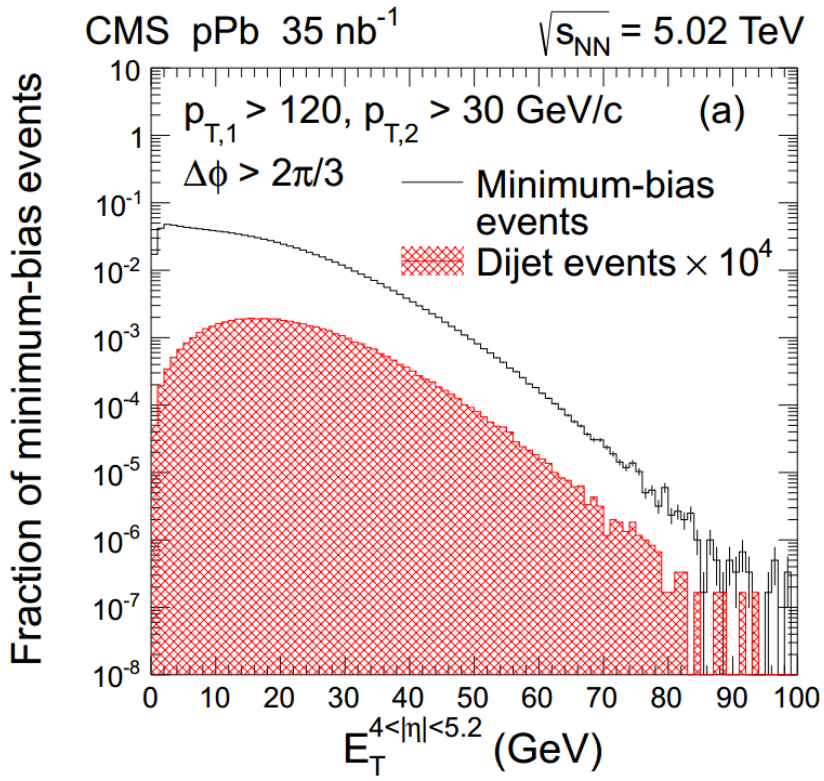
Hannu's QM14 talk

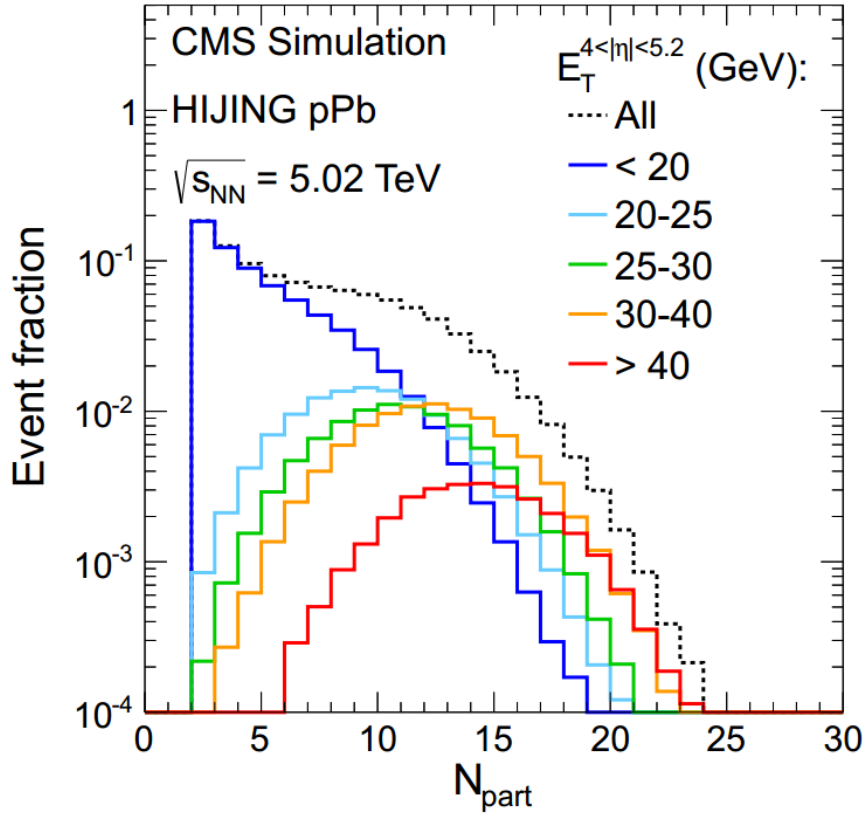
Possibility to extend the measurement to forward region

→ Sensitive to EMC and shadowing effects

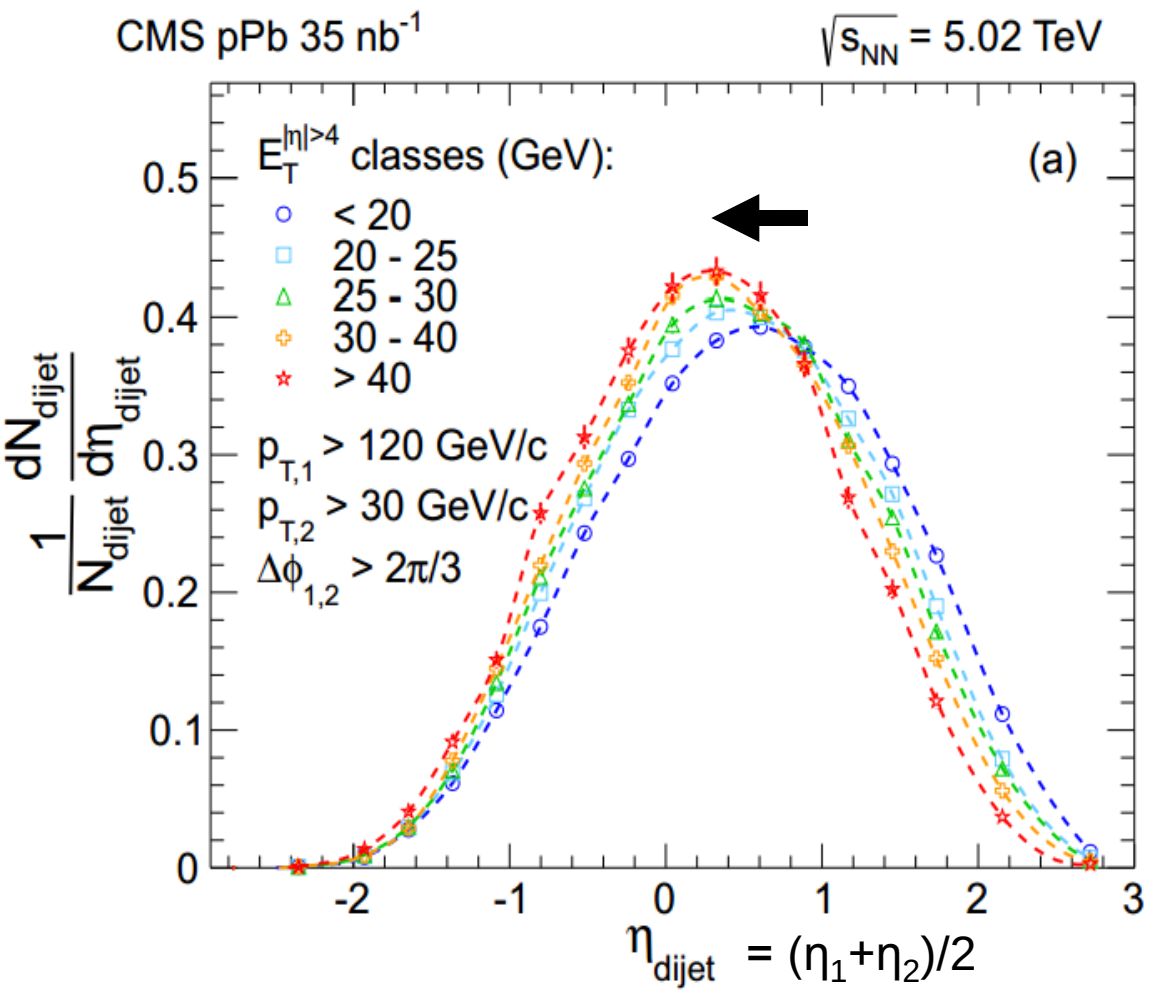
Looking at high multiplicity event

- **E_T measured in 4<|η|<5.2 by forward calorimeter ($E_T^{HF[|\eta|>4]}$)**



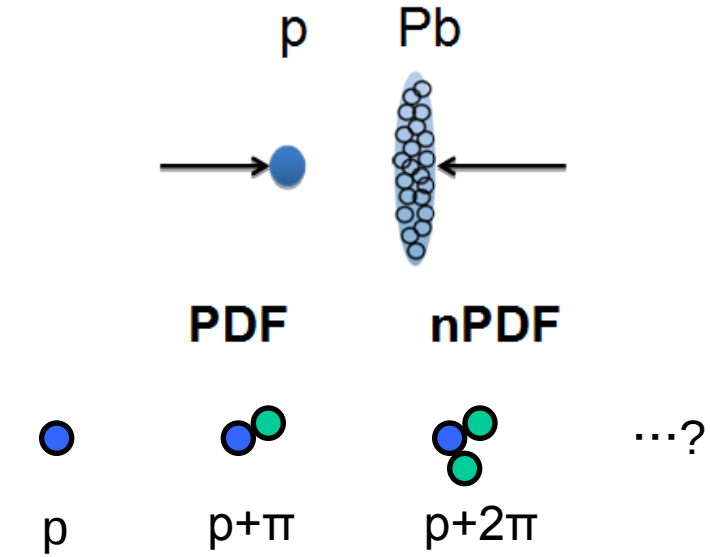


Dijet η vs. forward calorimeter energy in pPb



See Mark' s talk

EPJC74 (2014) 2951



Stringy proton from quantum fluctuations caughter by a nucleus?

PRD 89, 025019 (2014)

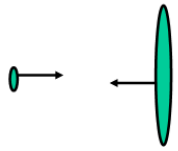
The large modification can not be explained by nPDF

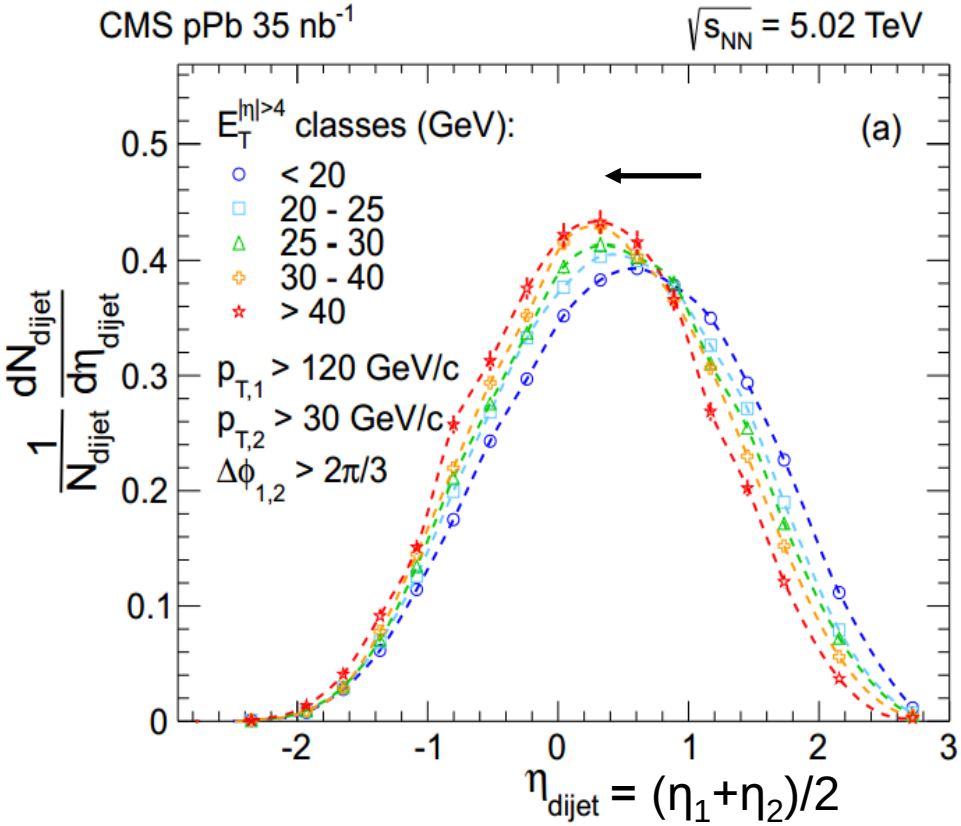
"Color fluctuation"? "Fluctuating proton size"?

"Energy-momentum conservation"?

Dijet η and Jet R_{CP}

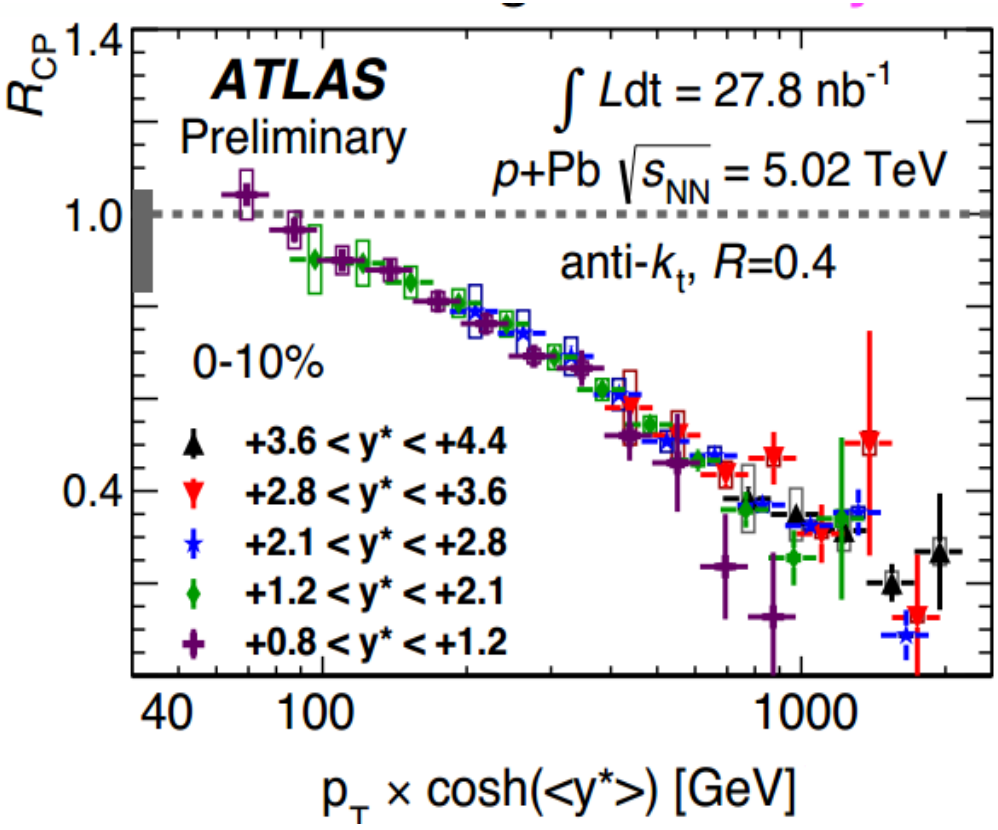
EPJC74 (2014) 2951





Large modification vs. event activity
Can not be explained by centrality dependent nPDF

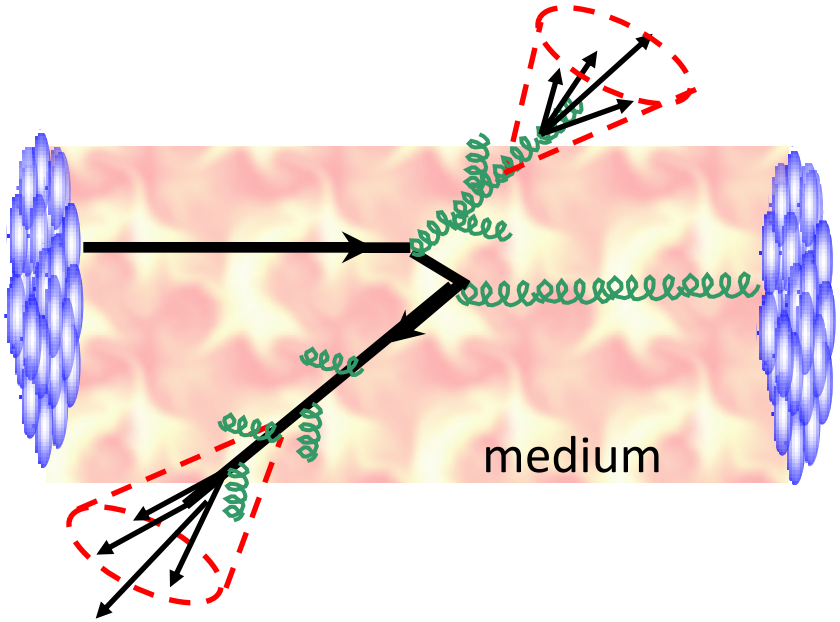
y* > 0 (proton going data)

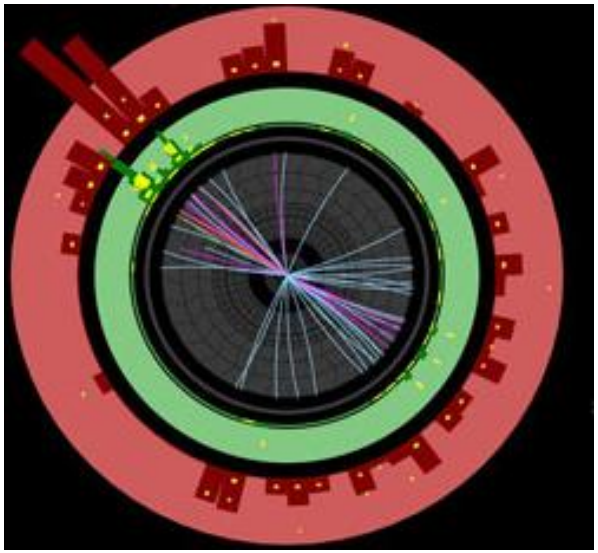


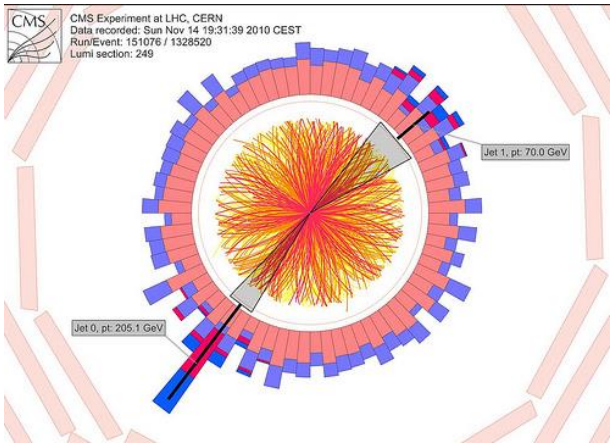
R_{CP} scaling vs. jet momentum in y*>0 data (proton going side)

Possibility to extend the measurement to forward region

Jet as a versatile probe in heavy ion collisions

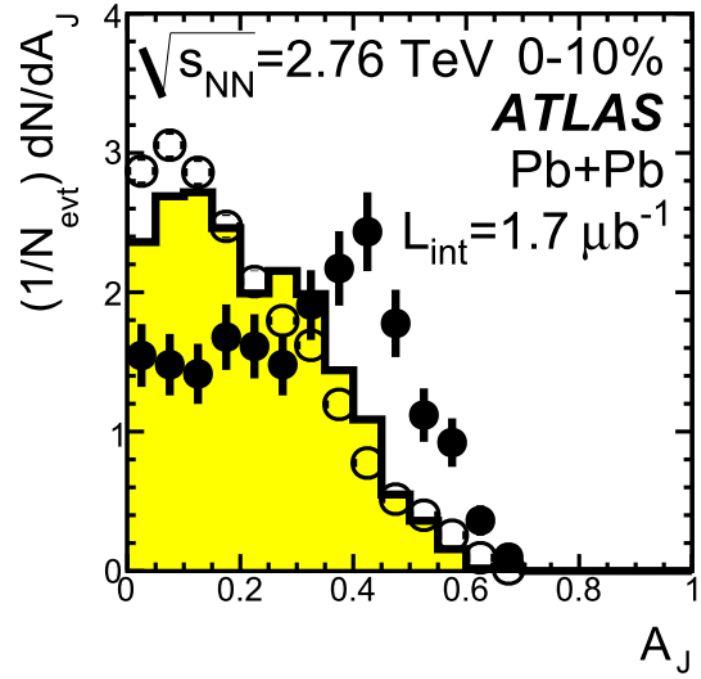


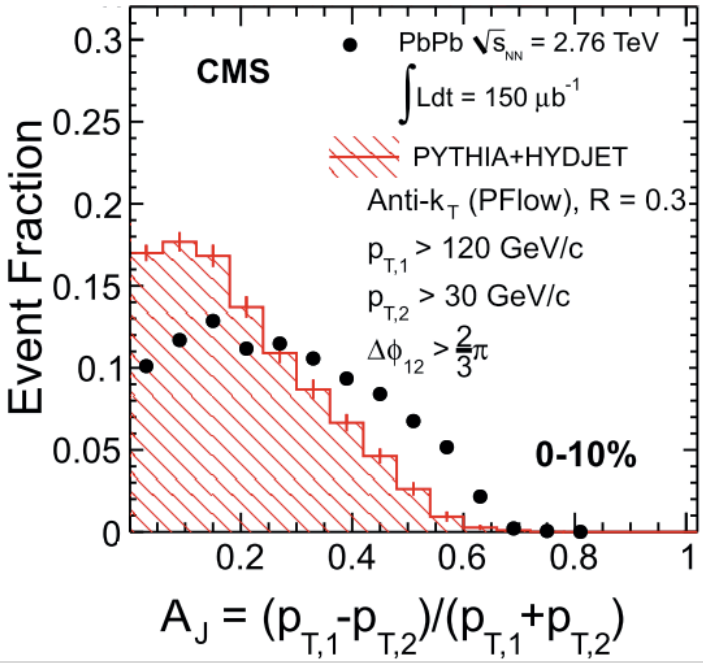




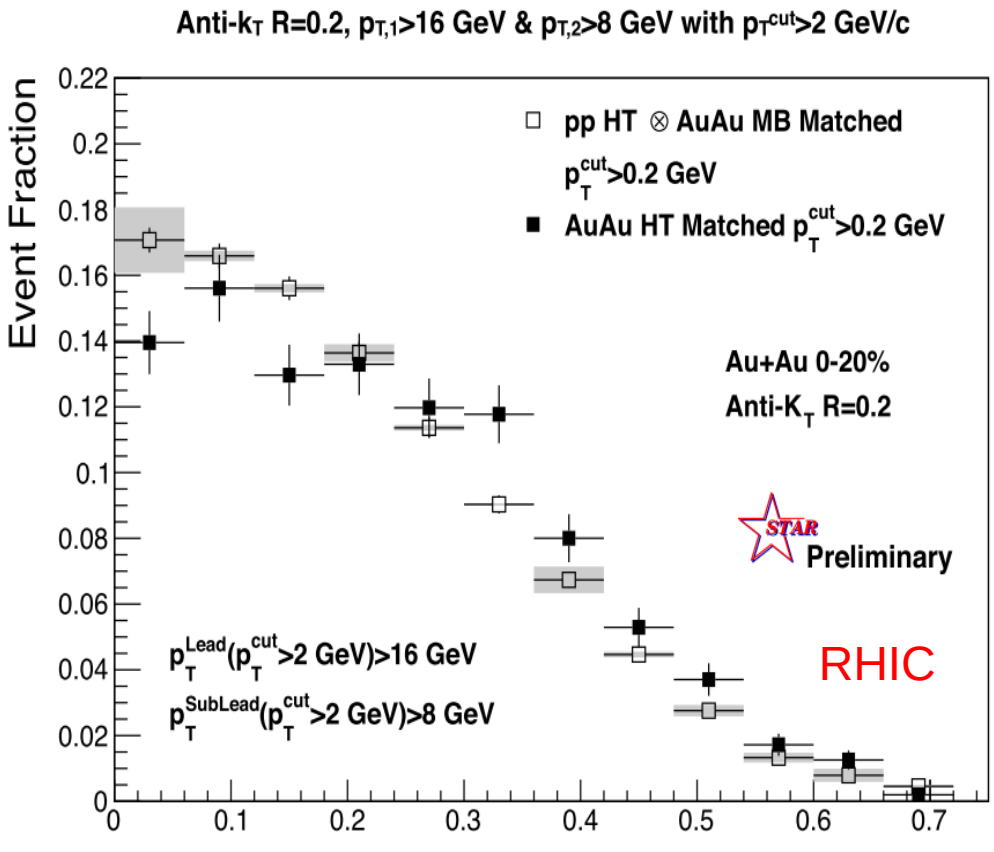
→ AA collisions

Dijet asymmetry A_J in RHIC and LHC



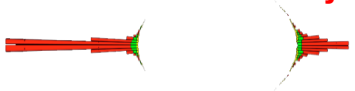


$$A_J = (p_{T,1}-p_{T,2})/(p_{T,1}+p_{T,2})$$

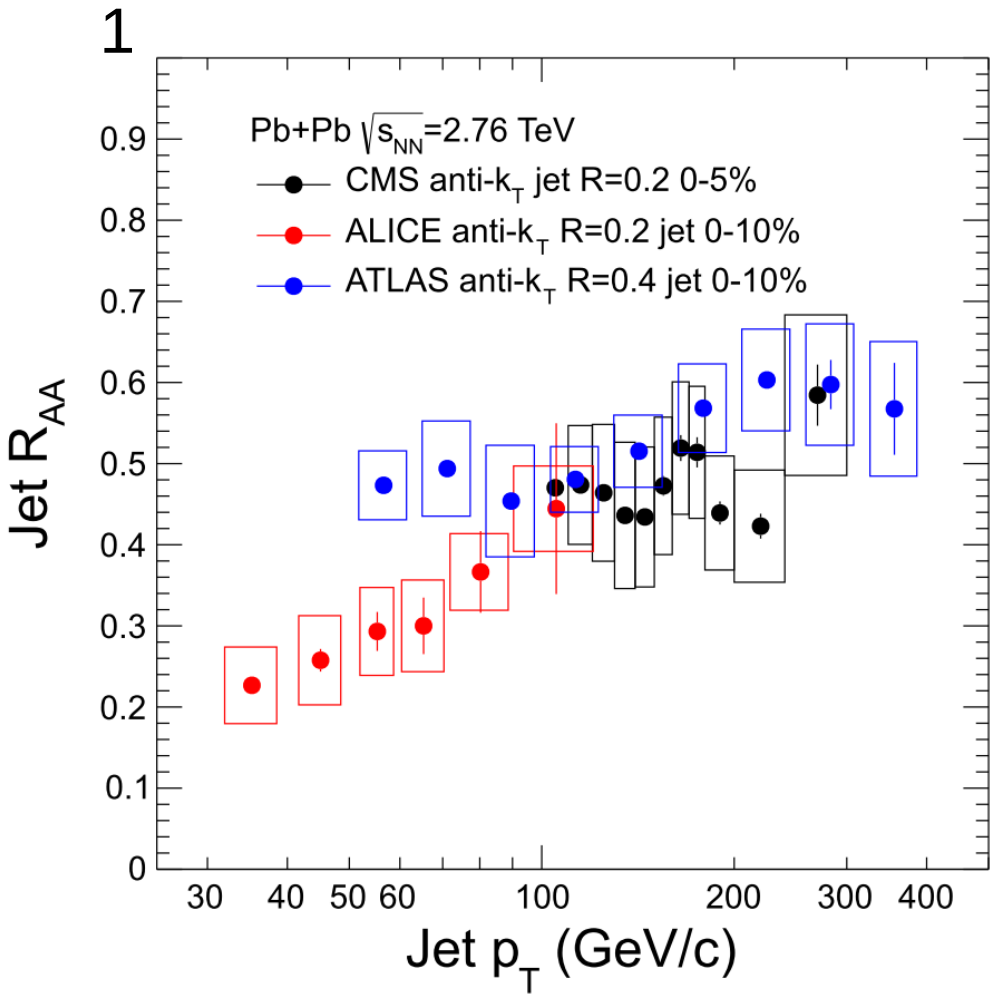


Balanced dijet

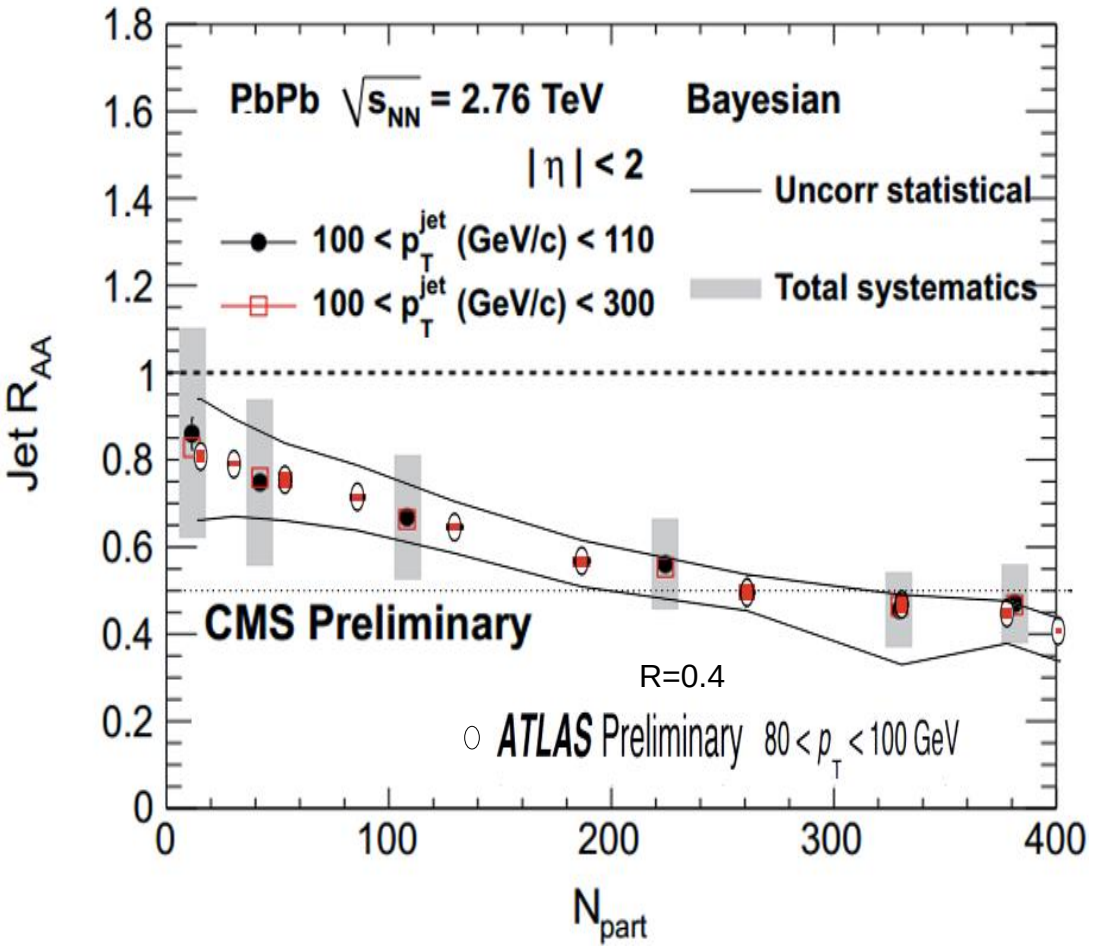
Imbalanced dijet



Jet R_{AA} in PbPb collisions at LHC

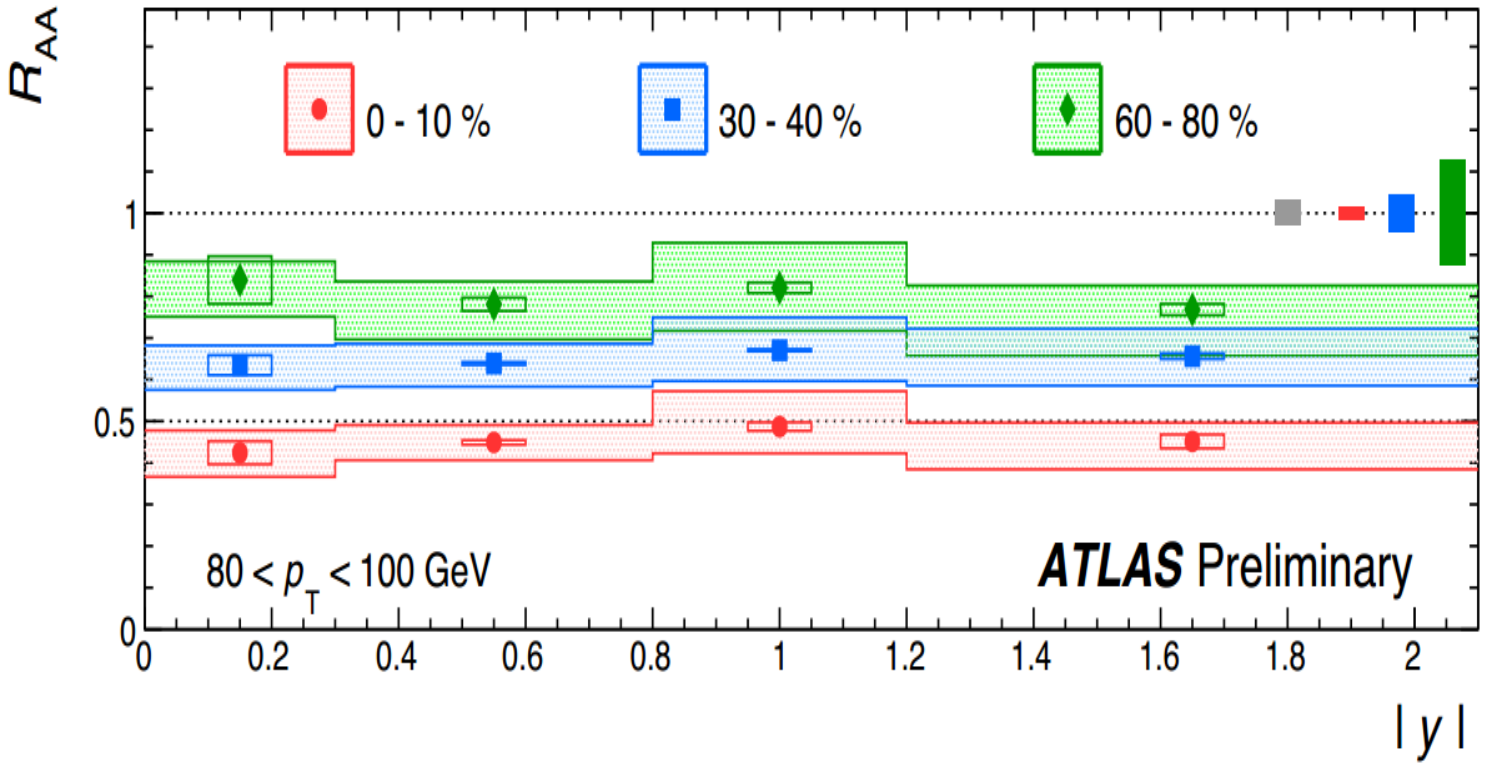


Establish a rising trend from low to high jet p_T



Decreases as a function of N_{part}

Preliminary ATLAS R_{AA} vs |y|

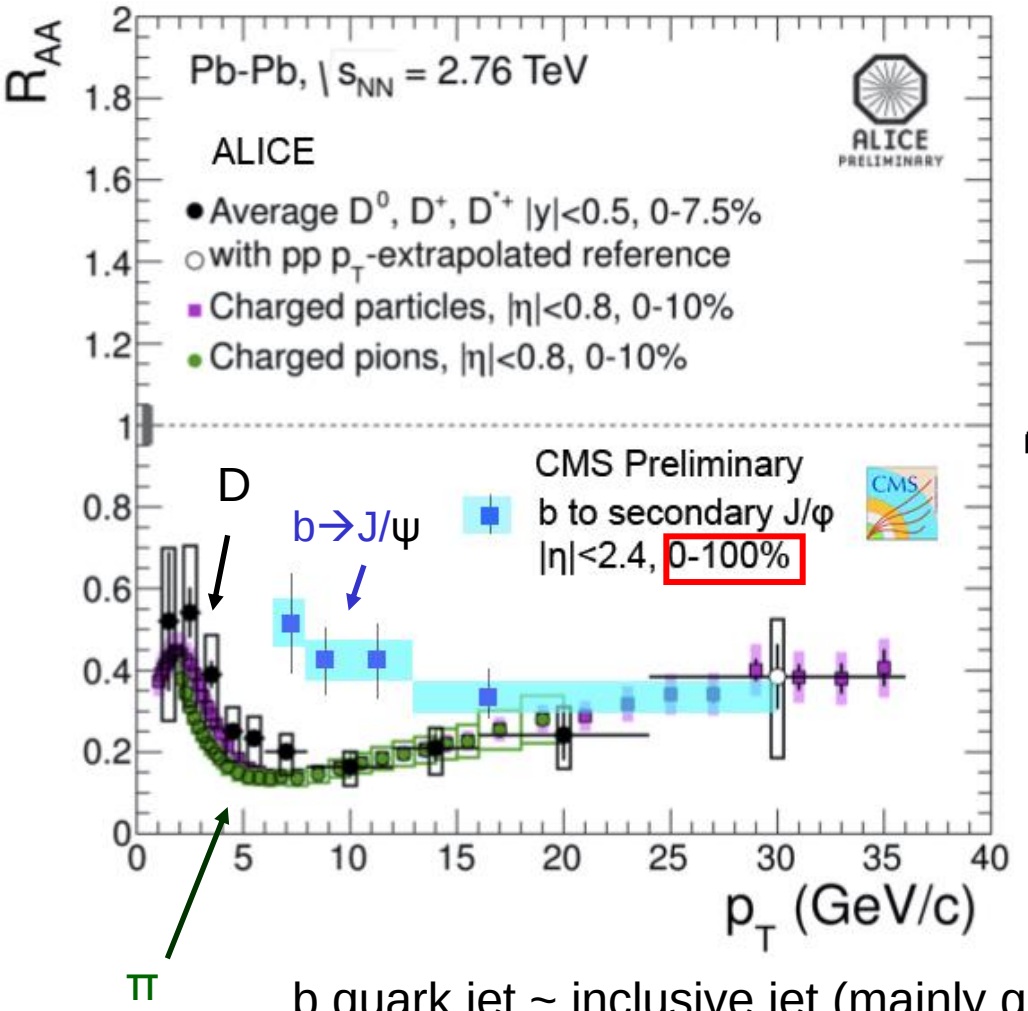


- ATLAS result: Jet R_{AA} weakly dependent on jet rapidity
- **Quark/gluon fraction** (as well as the slope of the jet pT spectra) changes vs. y
- **Would be interesting to go to even more forward region! (|y|>2.0)**

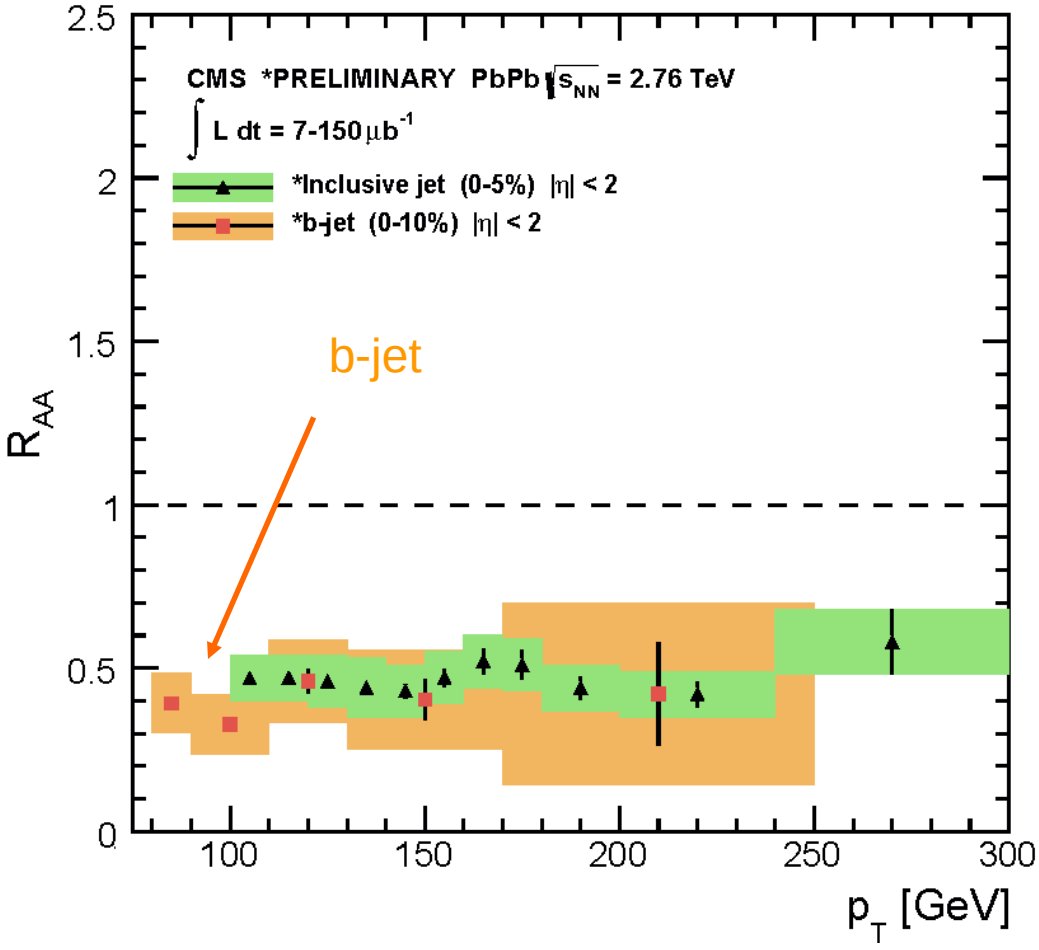
Flavor Dependence of Jet Quenching

Indication of $R_{AA}(B) > R_{AA}(D) > R_{AA}(\pi)$ at low p_T

(However, spectra slope are different)

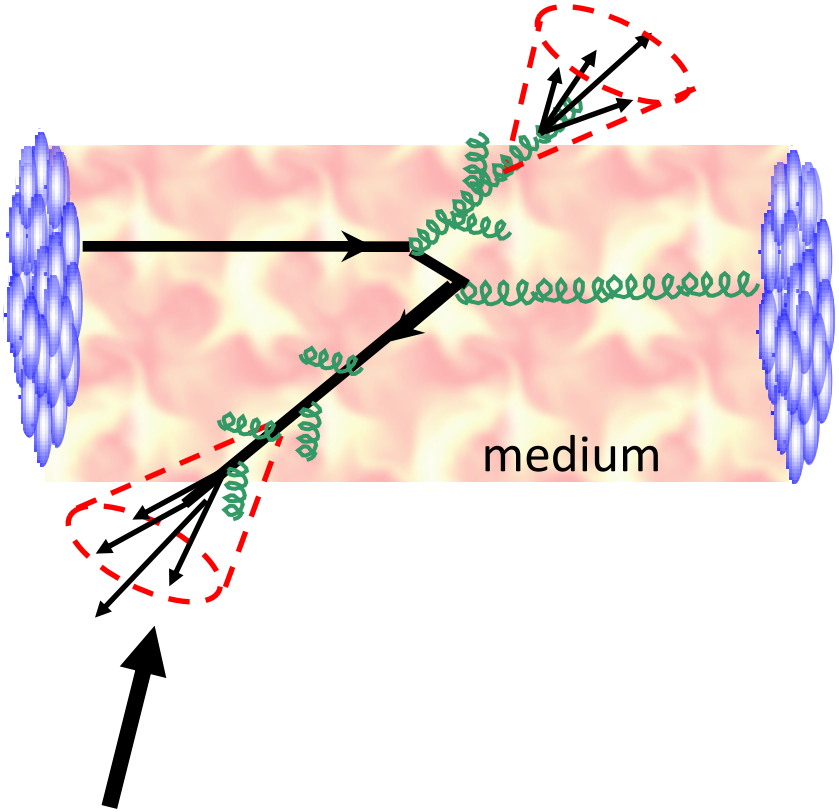


Indication of R_{AA}(b-jet) ~ R_{AA}(all jets) at high jet p_T



b quark jet ~ inclusive jet (mainly gluon jets), contribution from gluon splitting?

Jet as a versatile probe in heavy ion collisions



Is the jet structure modified?

Jet Fragmentation at LHC

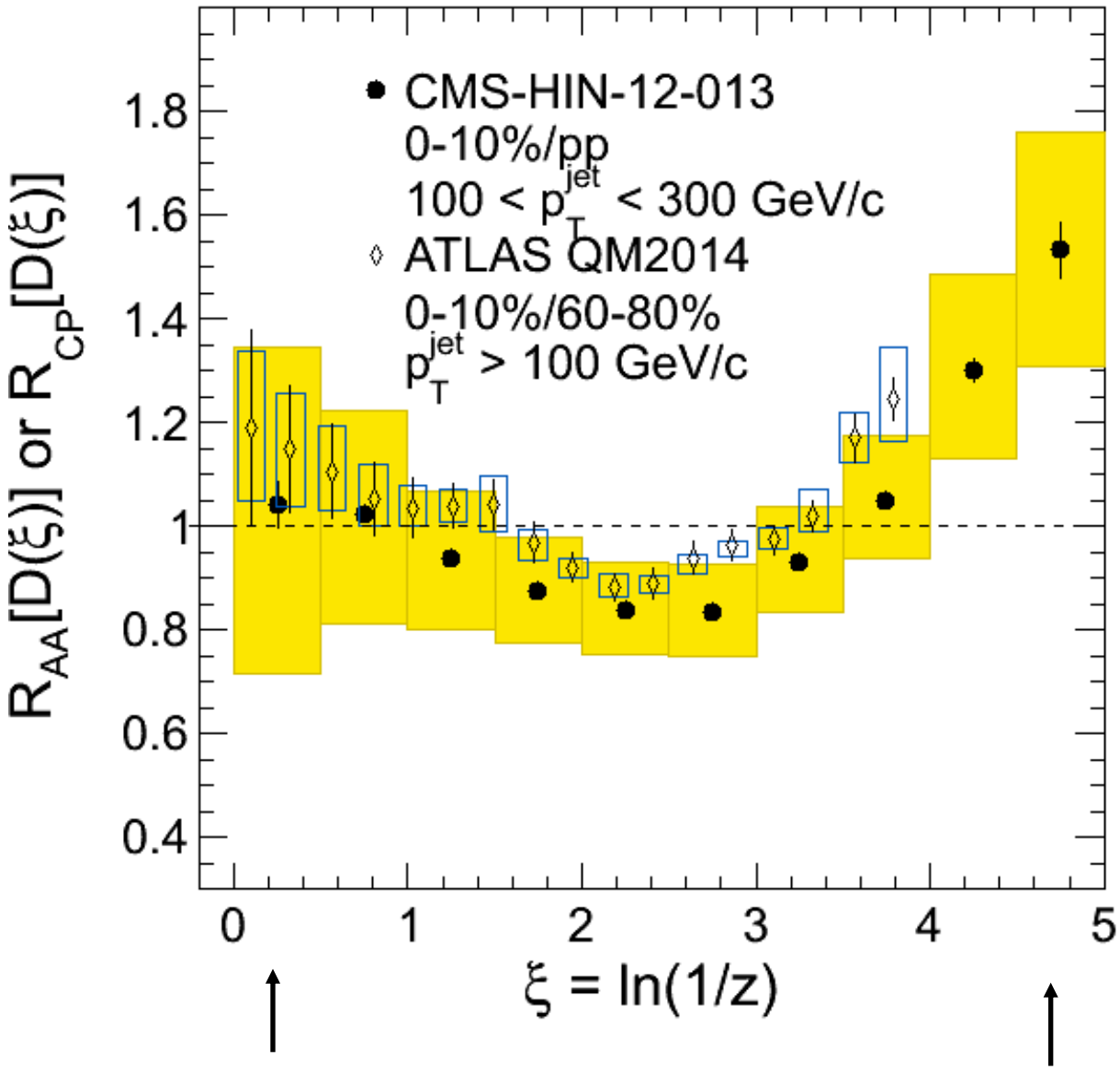
Using **Jet Energy** as a reference

CMS FF R_{AA} compared to ATLAS FF R_{CP}

$Z = p_T^{Trk} / p_T^{Jet}$

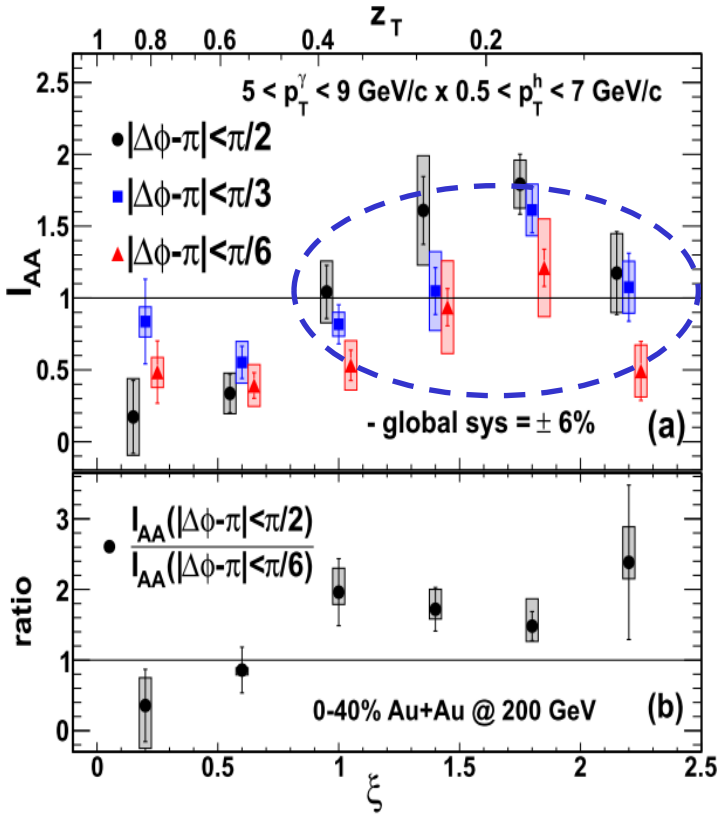
Qualitative consistent results between CMS and ATLAS

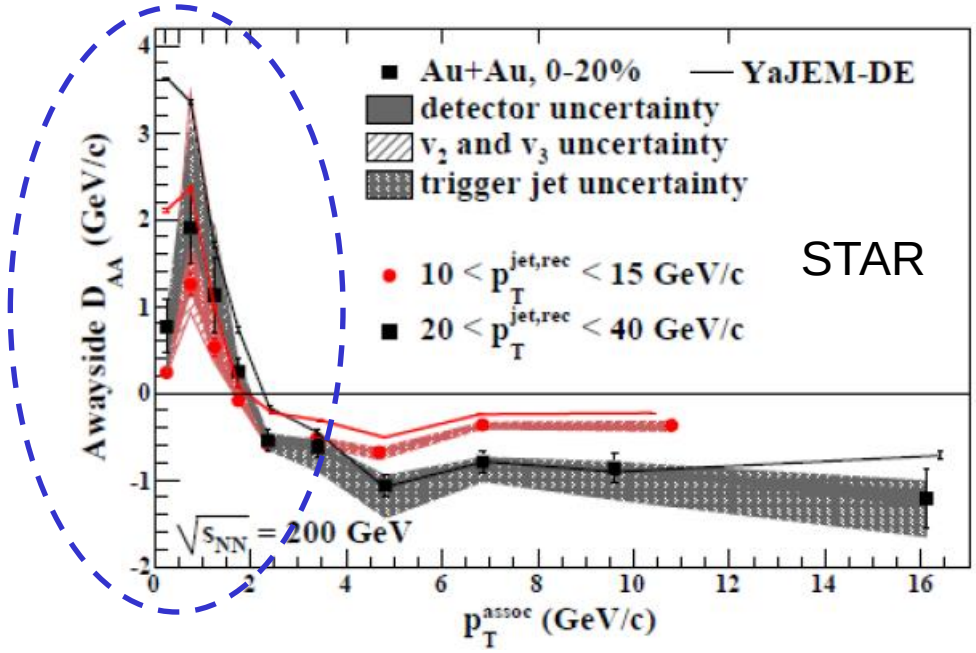
ATLAS update: indication of enhancement of low ξ (high z) particles in the jet cone



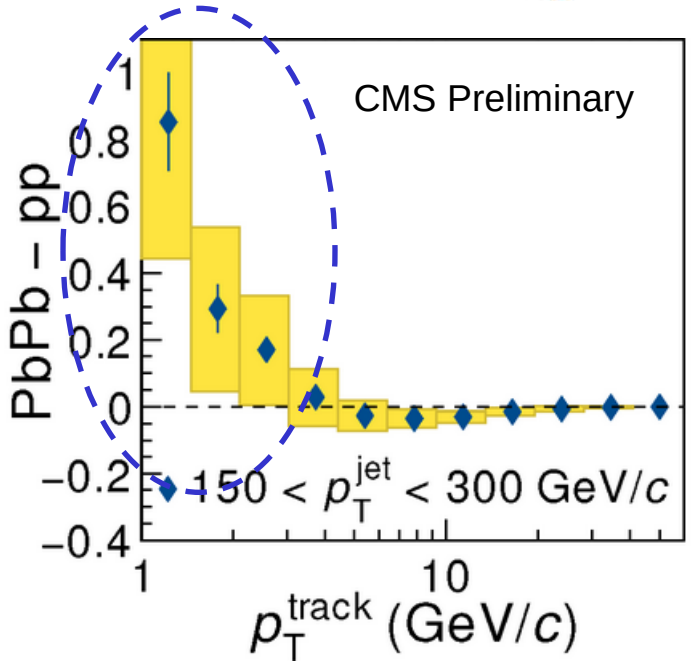
Consistent picture: excess of low p_T particle in the jet cone

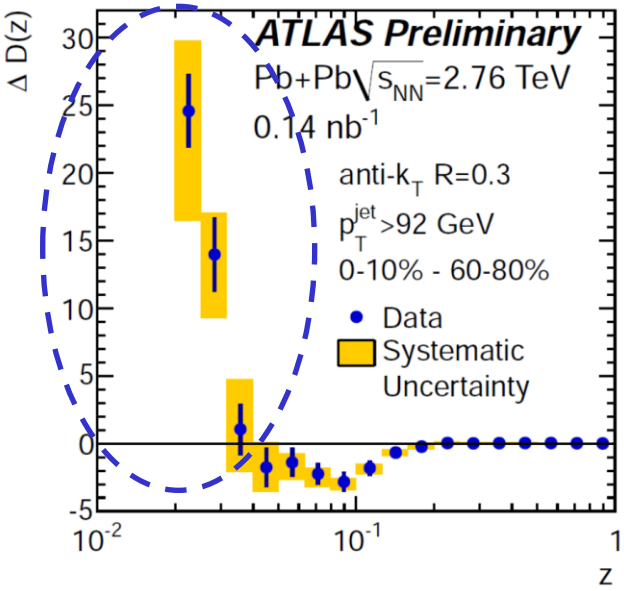
PHENIX





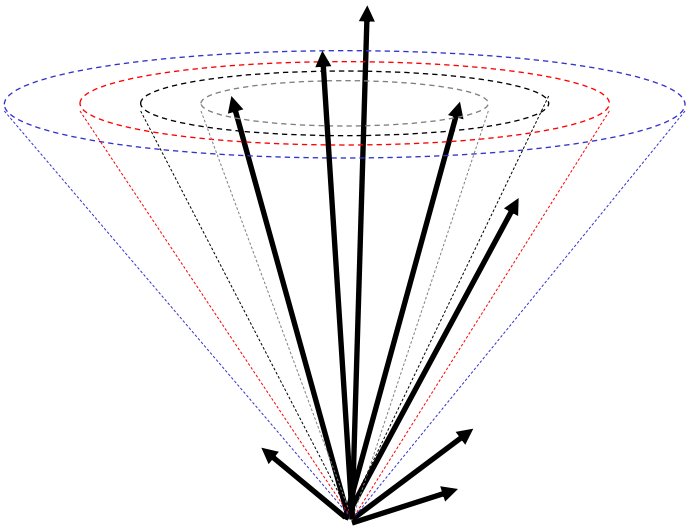
STAR



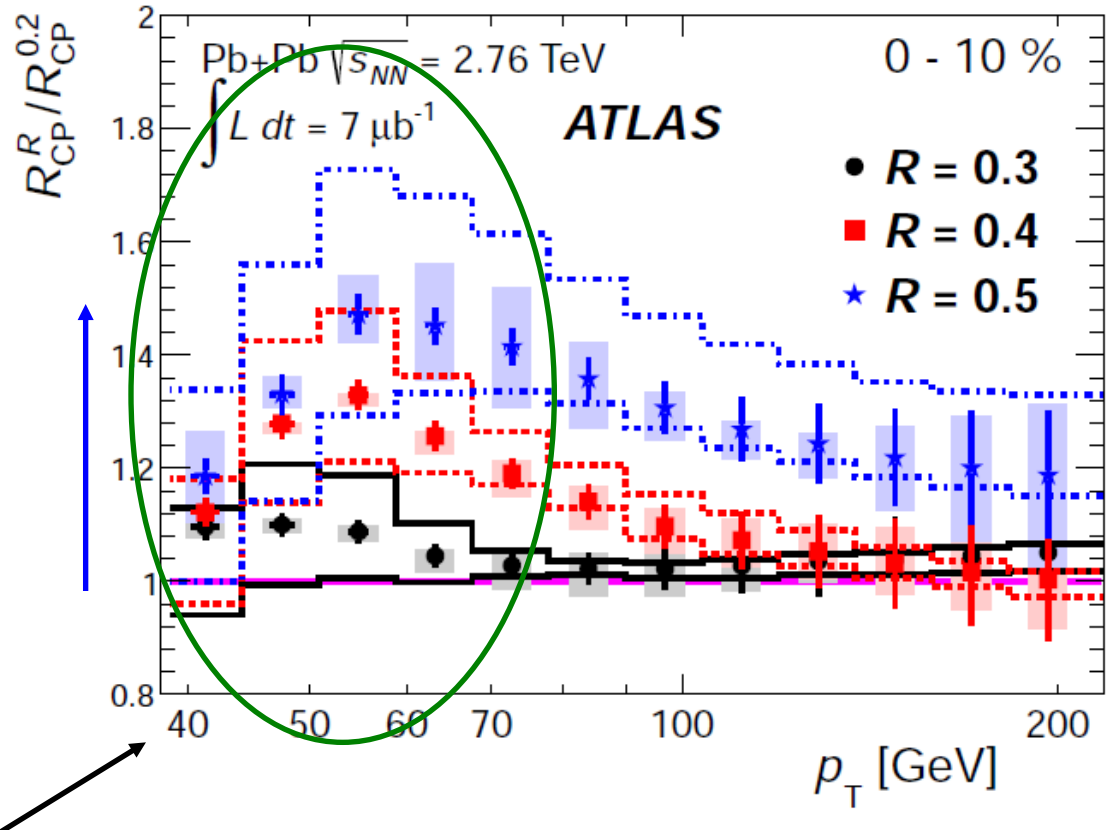


Do we collect the radiated energy with large cone size?

Anti-k_T jets with
R = 0.2, 0.3, 0.4, 0.5



Ratio of R_{CP} with different cone sizes

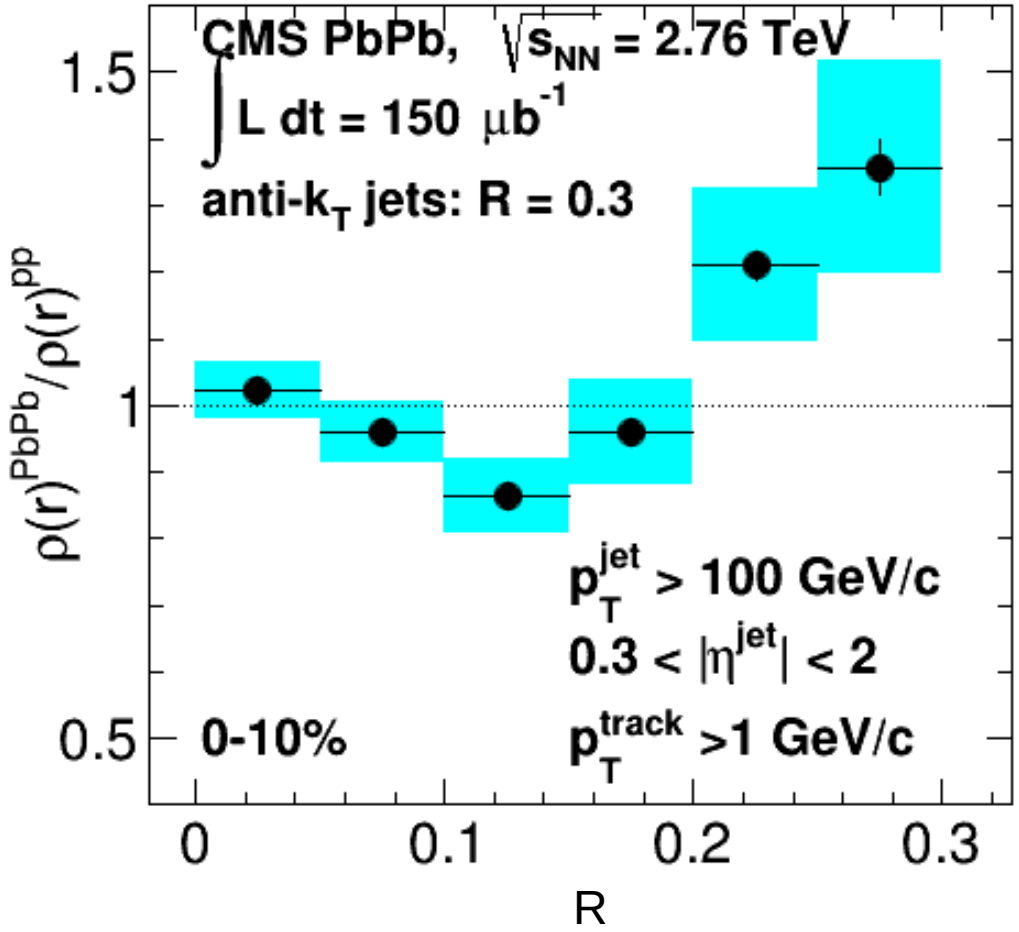


$R_{CP}^{(R=0.5)}/ R_{CP}^{(R=0.2)}>1$

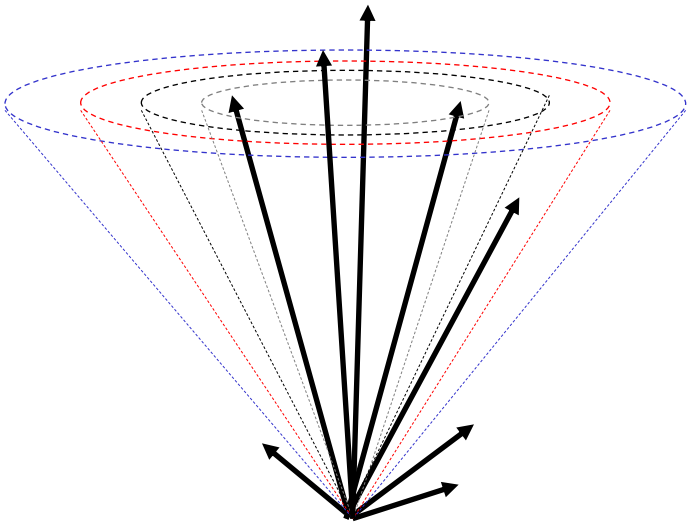
→ recovery of lost energy, change in jet shape with respect to the pp reference

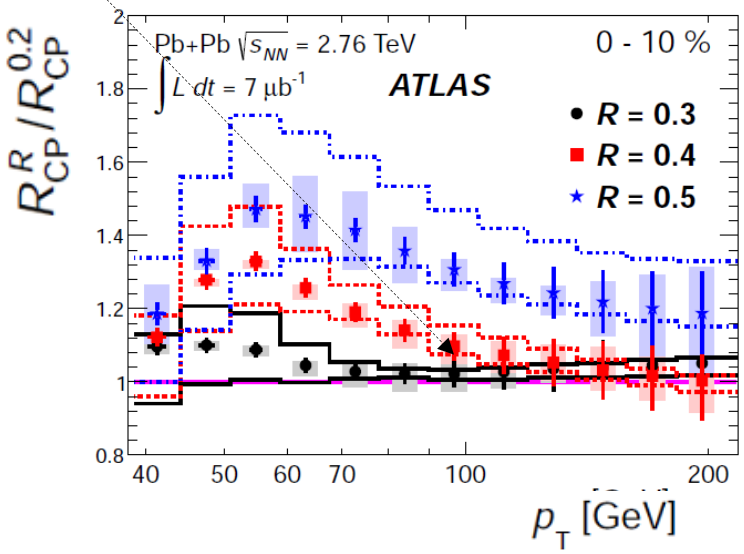
CMS Jet shape vs. ATLAS R_{CP} ratio

Ratio of jet shapes in PbPb and pp collisions



Jet shapes: how the energy is distributed as a function of R (distance between jet and track)



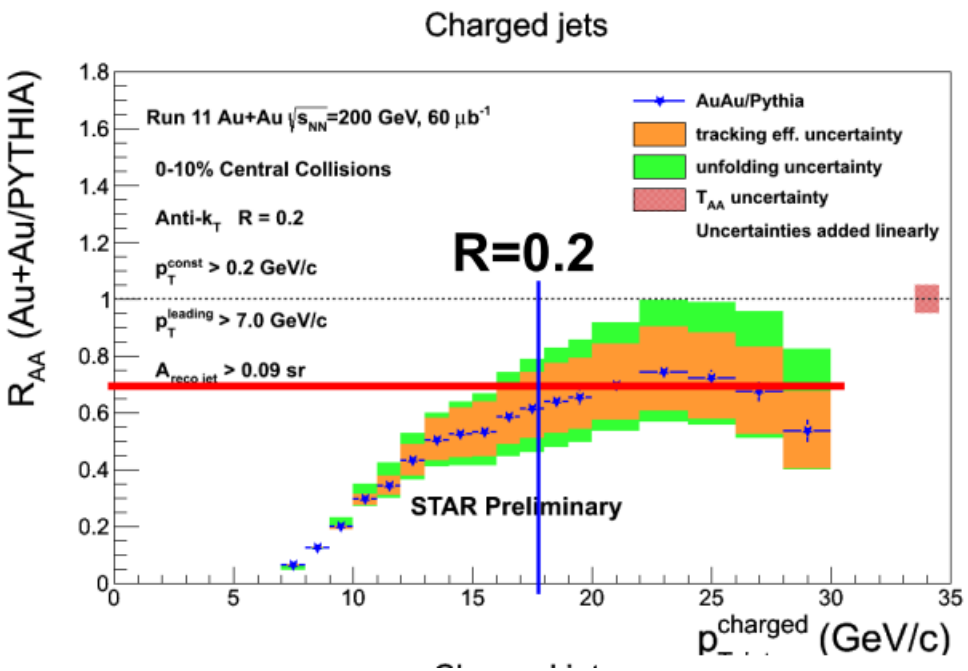


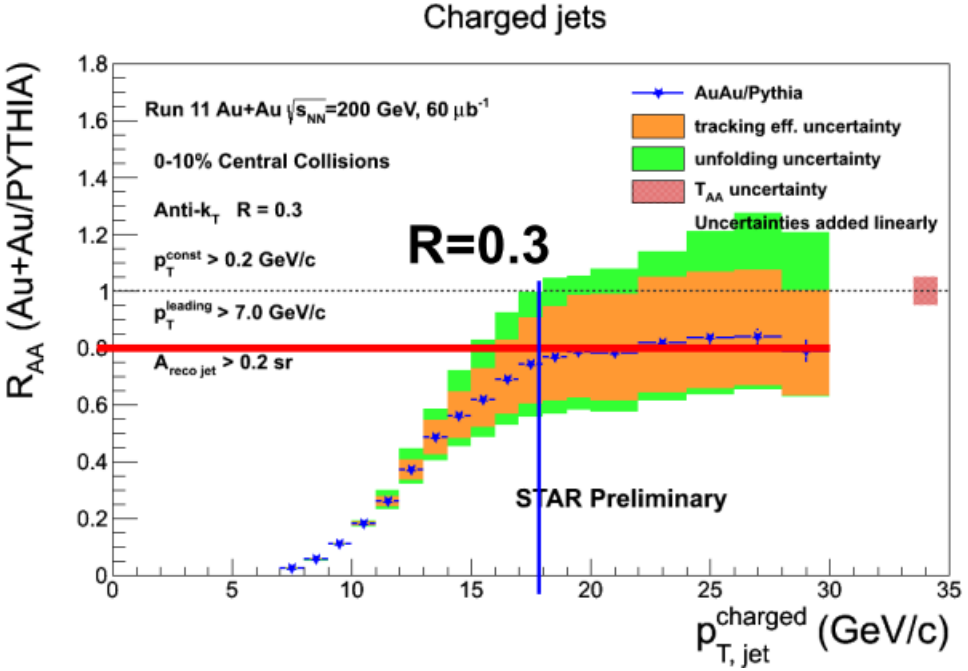
ATLAS Jet R_{CP} (R=0.3) / R_{AA} (R=0.2) ~ 1.0 ±0.2

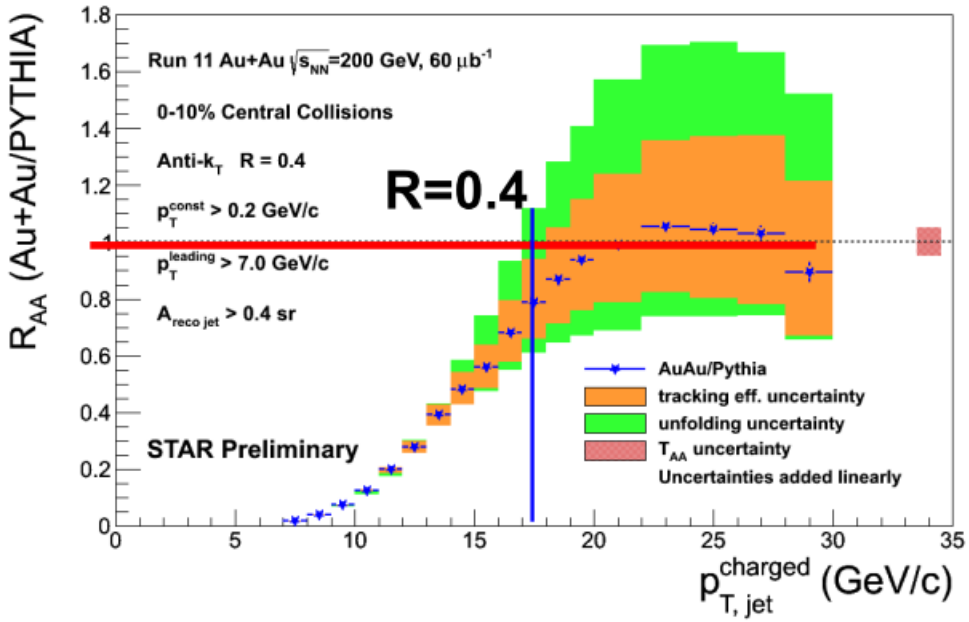
Allows to recover up to 0-4% more jet energy than pp reference

→ Would be interesting to see the R_{CP} or R_{AA} ratio studies in the forward region

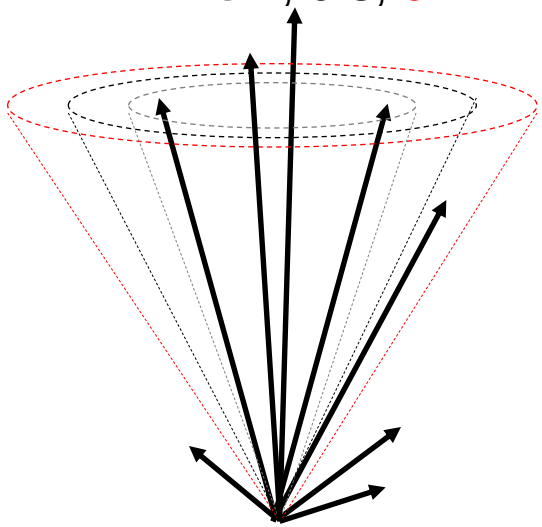
STAR Biased Charged Jet R_{AA} vs. R



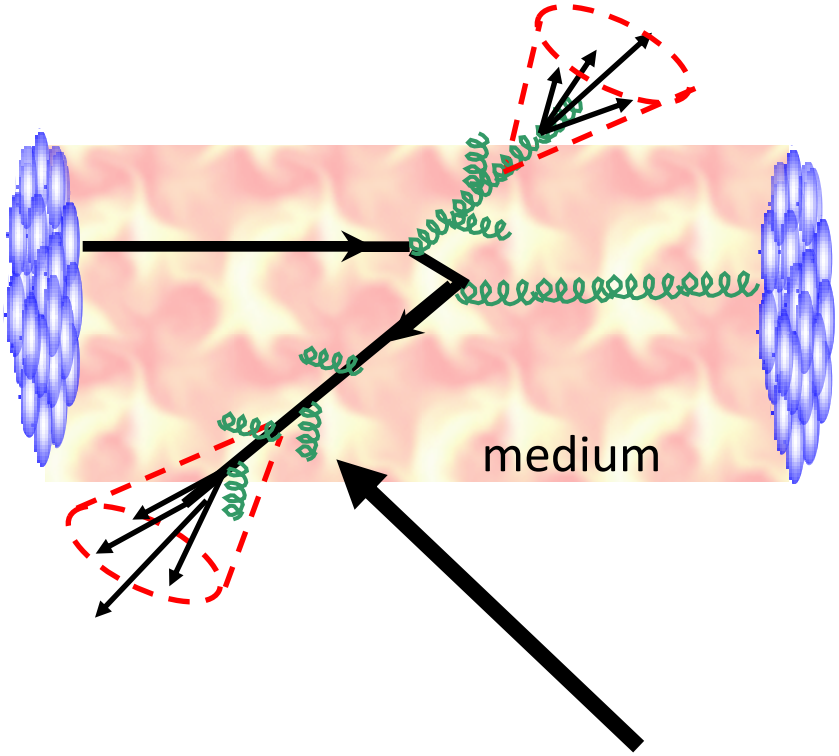




Anti-k_T jets with
R = 0.2, 0.3, 0.4

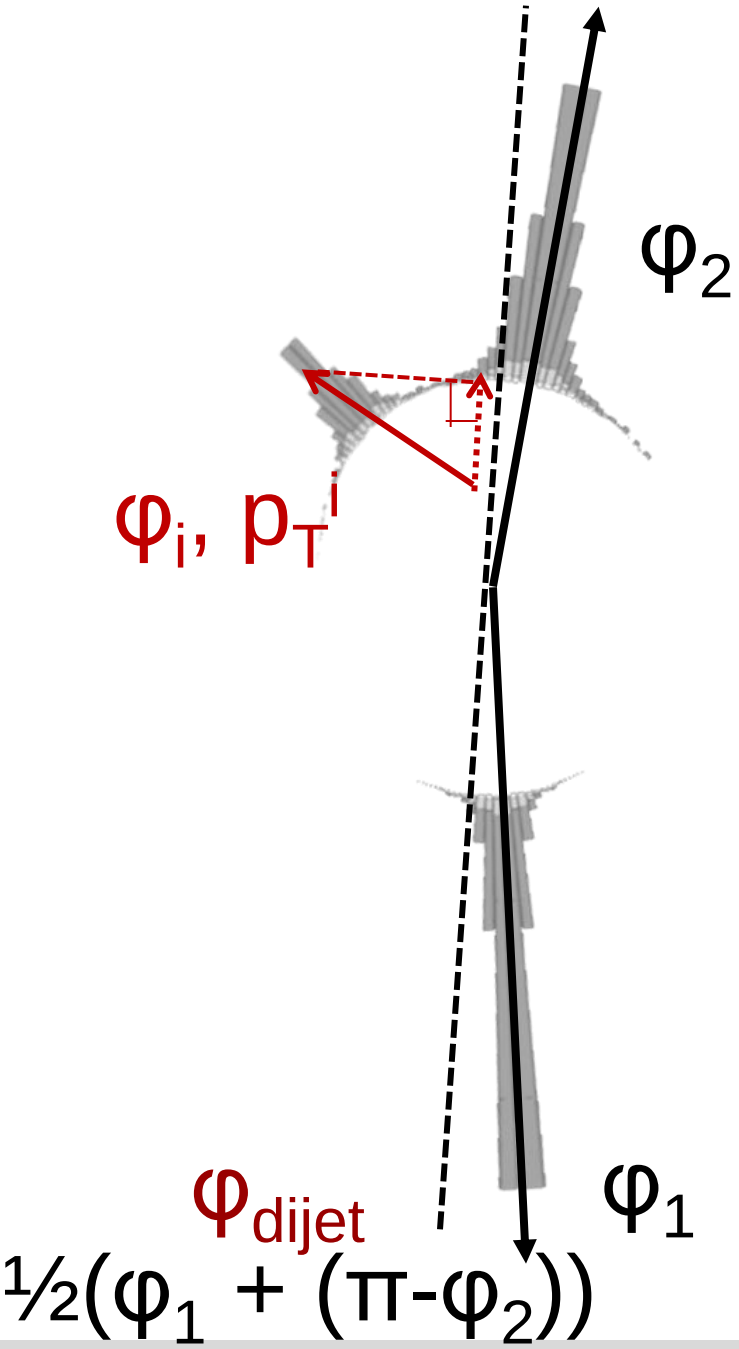


Jet as a versatile probe in heavy ion collisions



Where does the lost energy go?

2014 Missing p_T

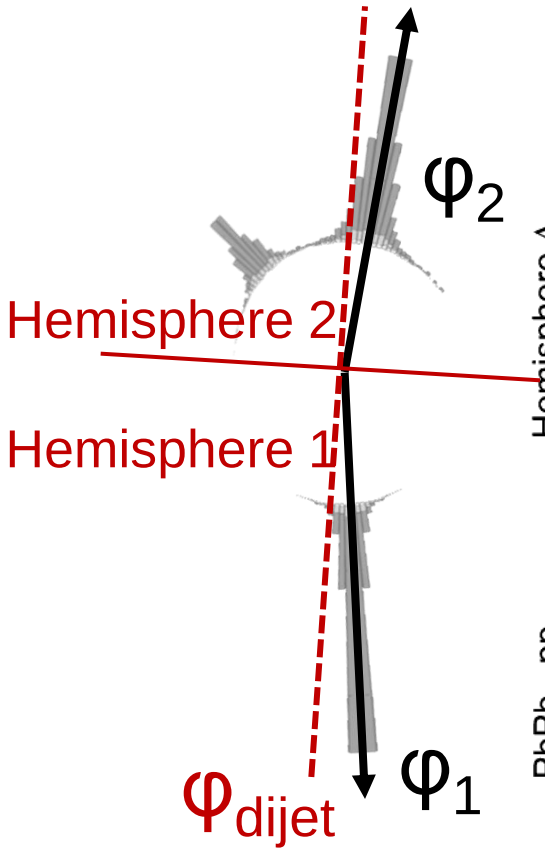


What is the multiplicity and **spectrum** of particles that balance the "extra" lost p_T?

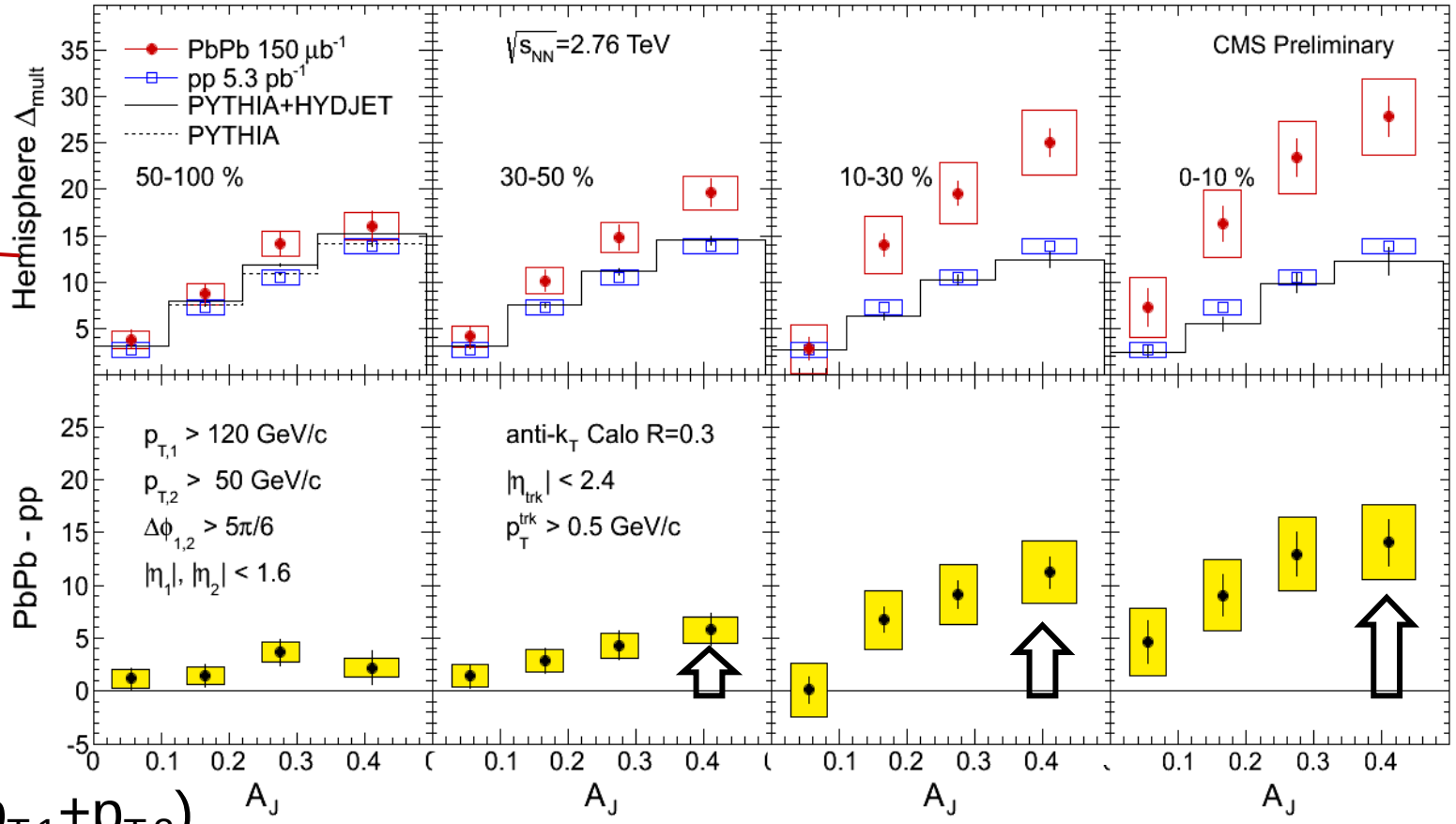
Calculate the missing p_T for charged particles in different p_T ranges

$$\not{p}_{\mathrm{T}}^{\parallel} = \sum_{\mathrm{i}} -p_{\mathrm{T}}^{\mathrm{i}} \cos\left(\phi_{\mathrm{i}} - \phi_{\mathrm{Dijet}}\right)$$

2014: Multiplicity difference vs. A_J



CMS-PAS-HIN-14-010



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

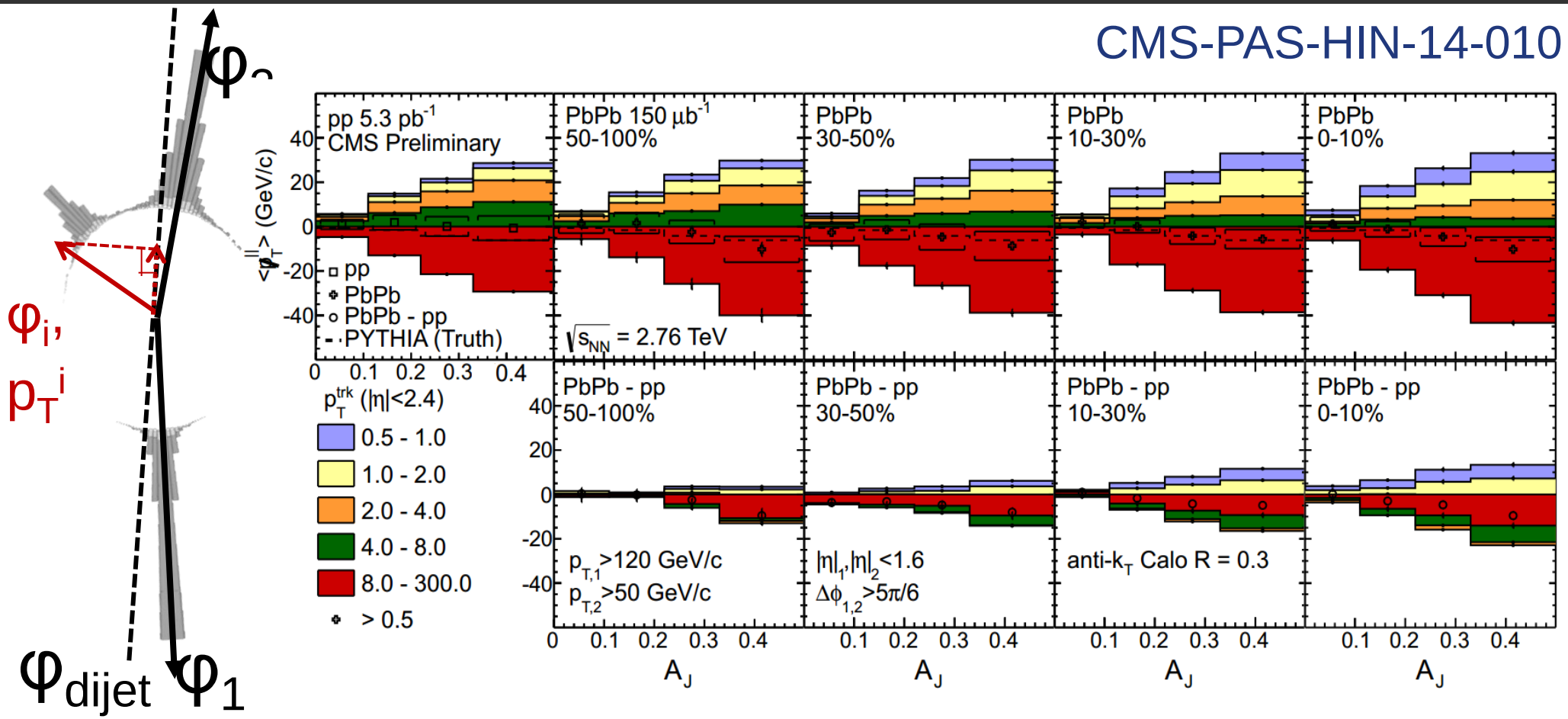
Multiplicity difference (in acceptance) increases as a function of A_J

The increase is larger in PbPb

The enhancement in PbPb compared to pp increases with centrality

Large A_J, 0-10% ⟶ 15 extra particles with $p_T > 0.5$ GeV/c

Results - Missing p_T vs. A_J



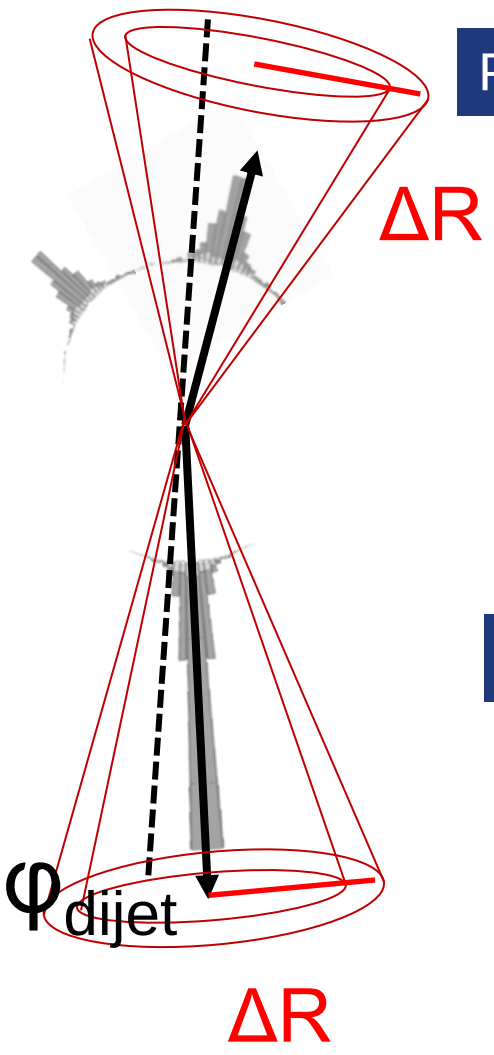
CMS-PAS-HIN-14-010

Access to high p_T particles increases as a function of A_J

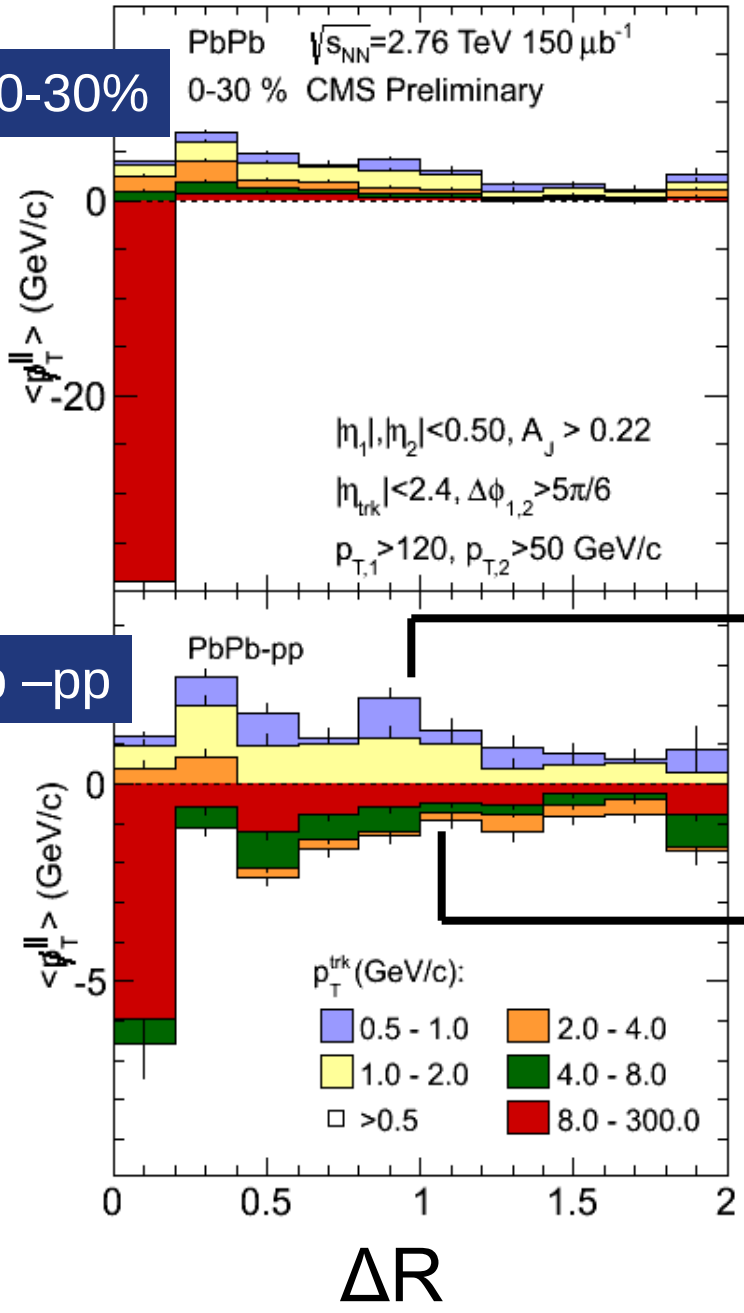
In pp ⟶ Balanced by 2-8 GeV/c particles

In PbPb ⟶ Balanced by particles with p_T < 2 GeV/c

Results - Missing p_T vs. ΔR



PbPb 0-30%



PbPb –pp

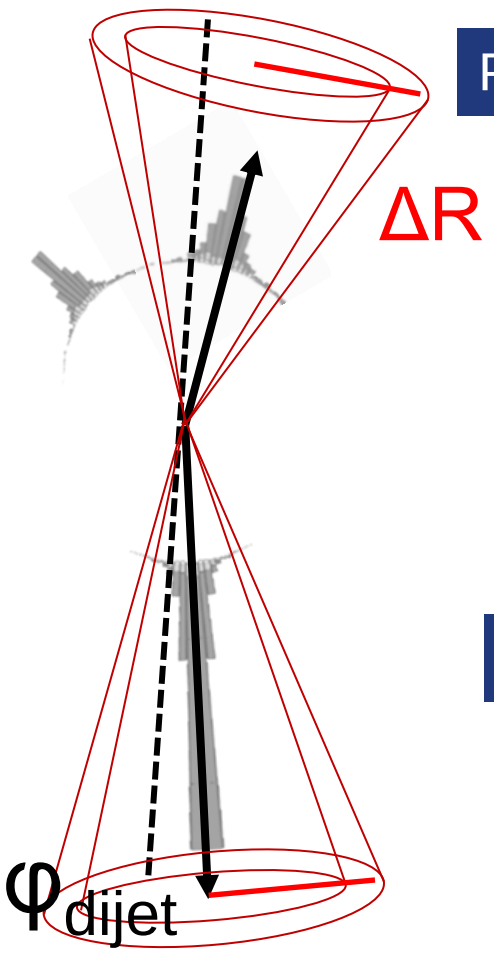
$A_J > 0.22$

Enhancement of low p_T particles in PbPb

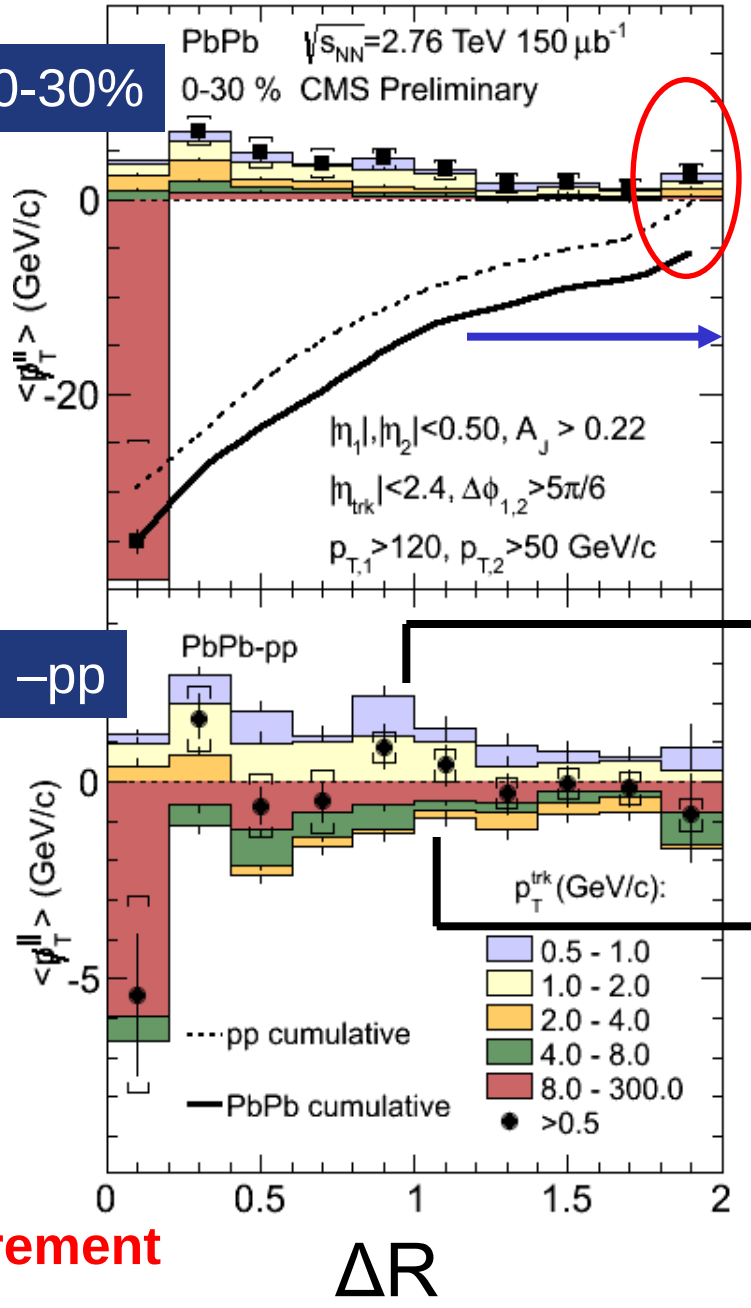
Out of cone radiation is carried by a third jet in pp

CMS-PAS-HIN-14-010

Results - Missing p_T vs. ΔR



PbPb 0-30%



PbPb –pp

$A_J > 0.22$

Similar shape of the balancing distribution in pp and PbPb

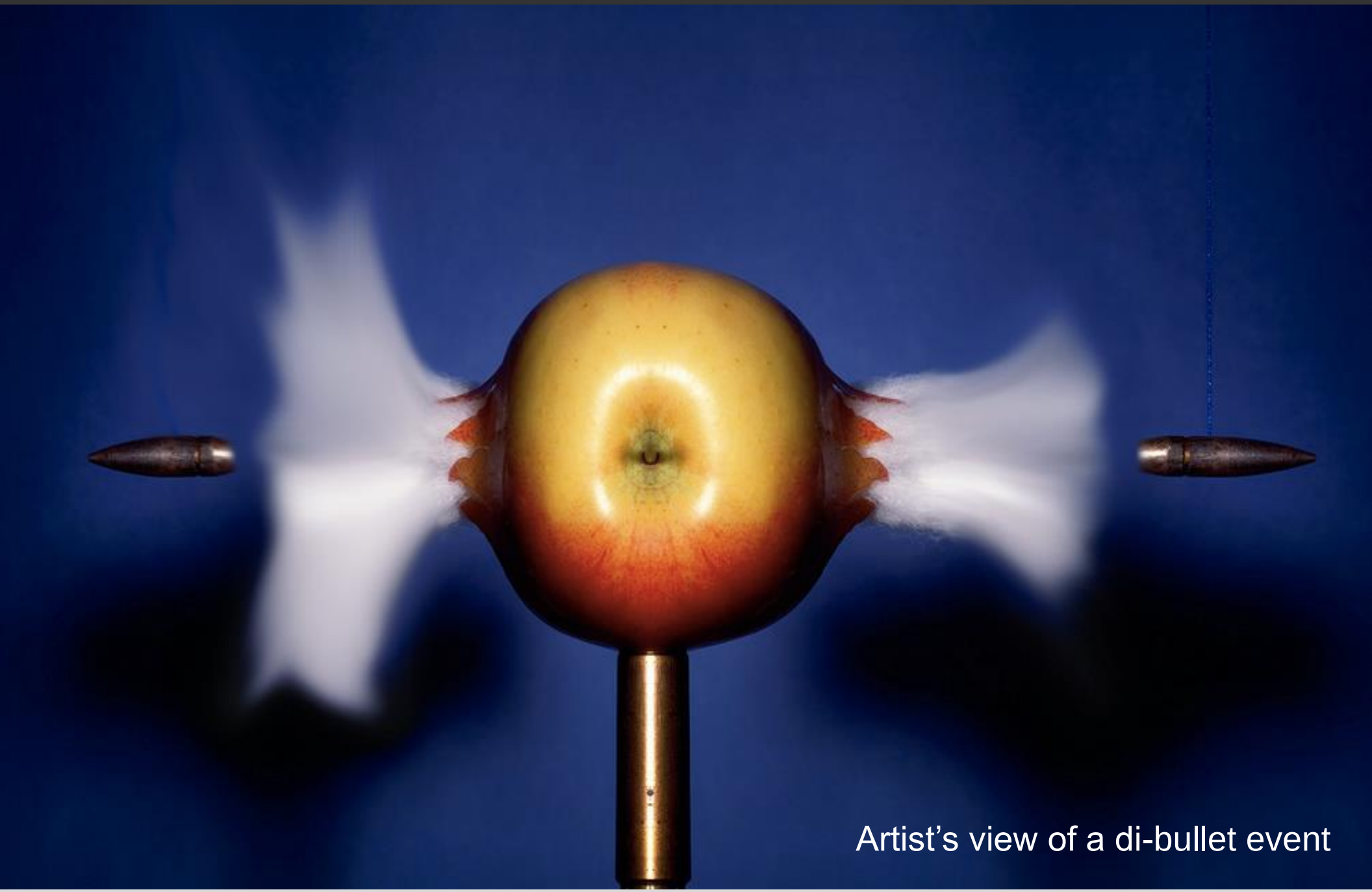
Enhancement of low p_T particles in PbPb

Out of cone radiation is carried by a third jet in pp

Extend the Eflow measurement to even larger dR?

CMS-PAS-HIN-14-010

Jet quenching in heavy ion collisions



Artist’s view of a di-bullet event

Inputs to measurements in forward region

- pA collisions:
  - Forward jet R_{pA} and dijet η: sensitive to low x (shadowing) and large x (EMC) region.
- AA collisions:
  - Flavor dependence of jet quenching:
    - Jet RAA as a function of rapidity: changing quark/gluon ratio
    - Jet R_{AA} ratio using different cone sizes for the study of jet shape modificaiton
  - Energy flow initiated by a hard scattered parton
    - Use the calorimeter to extend the energy flow measurement up to large pseudorapidity

Backup slides