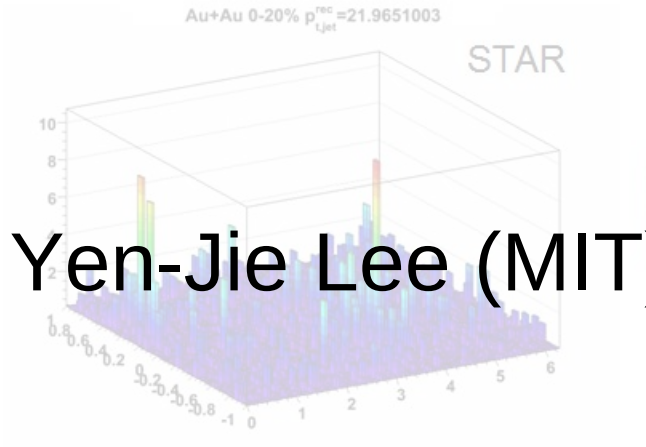
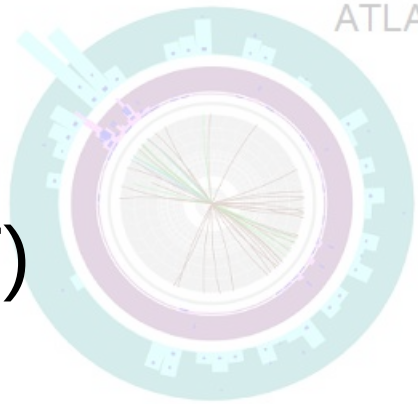
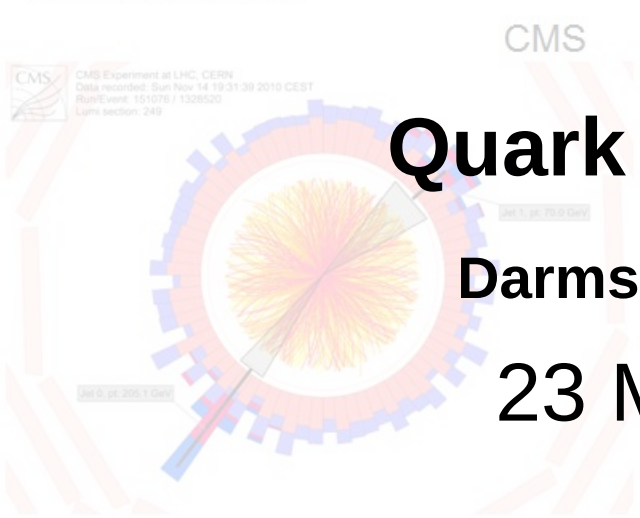
Experimental results on jets in ultra-relativistic nuclear collisions





Yen-Jie Lee (MIT)



Quark Matter 2014

Darmstadt, Germany

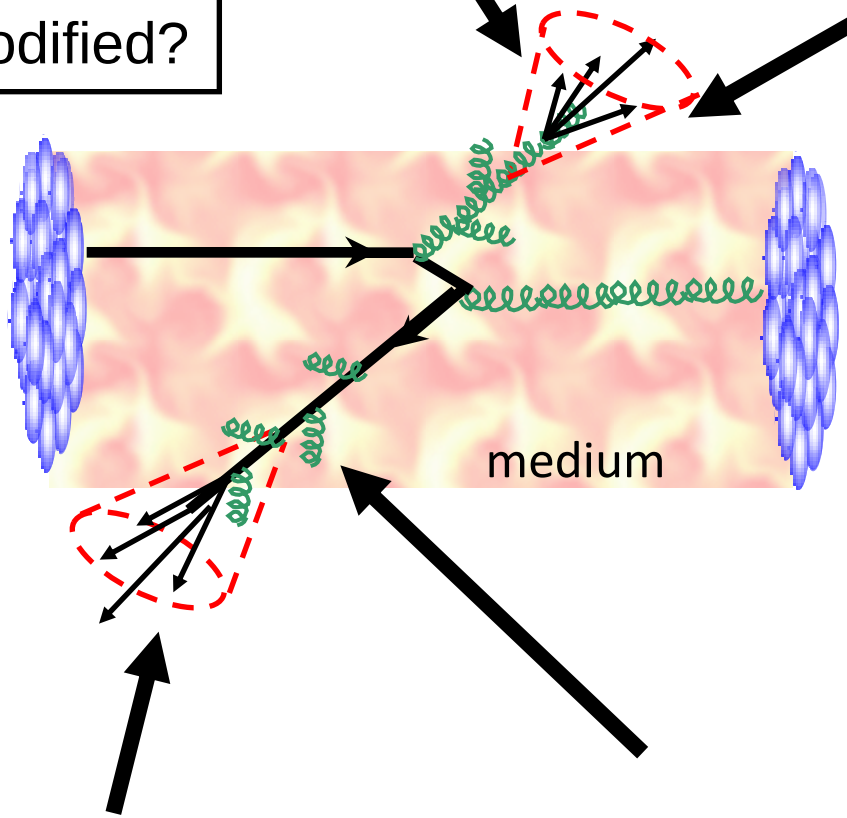
23 May, 2014

Questions to be answered

2. Can we recover the lost energy by jet reconstruction?

3. Flavor dependence of jet quenching?

1. Is the initial state modified?

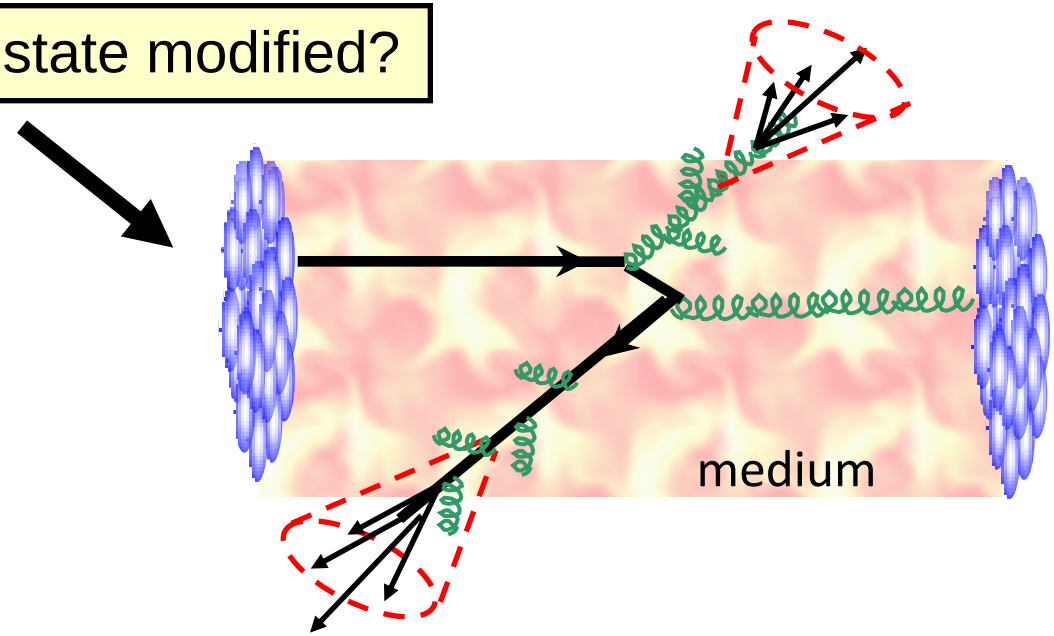


4. Is the jet structure modified?

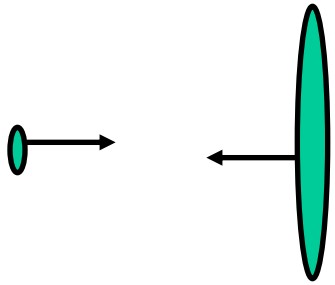
5. Where does the lost energy go?

Questions to be answered

1. Is the initial state modified?

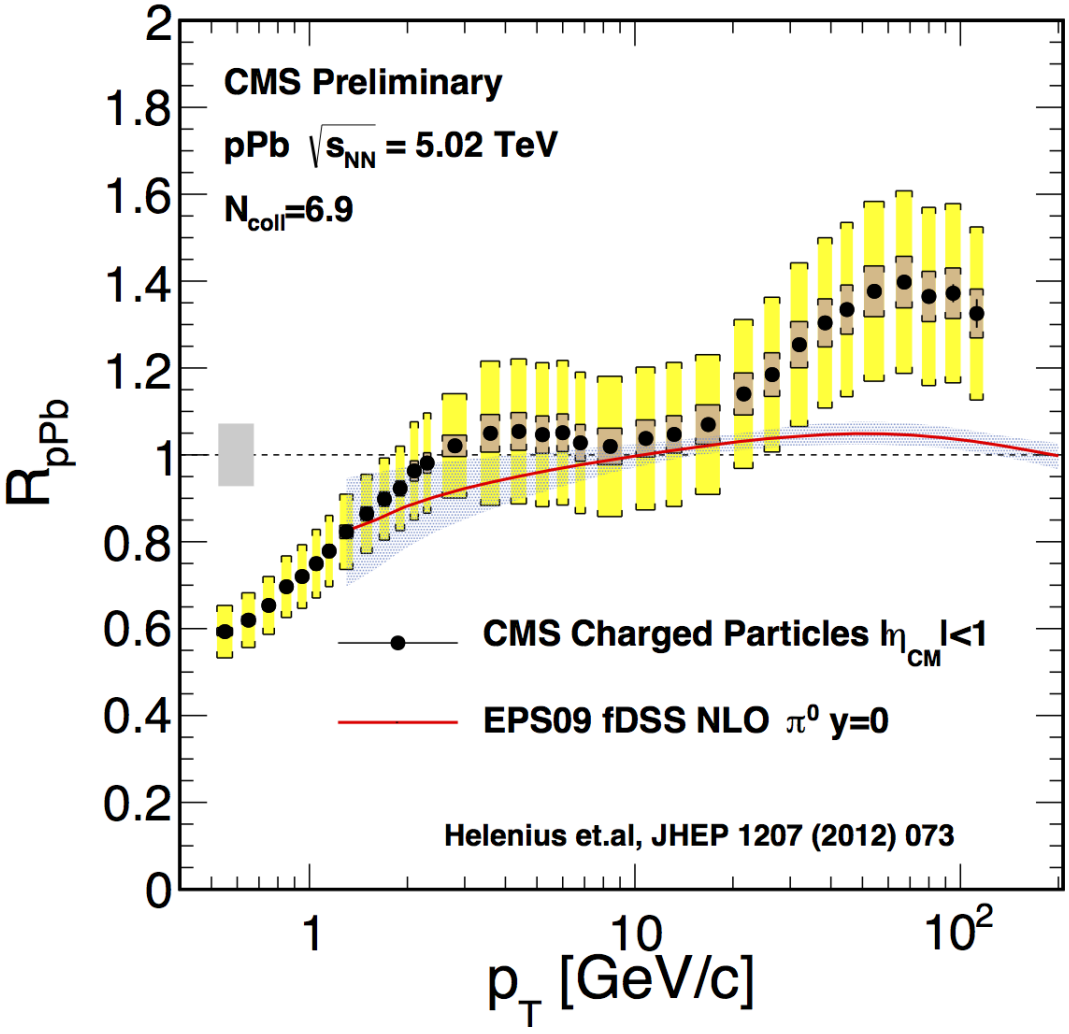


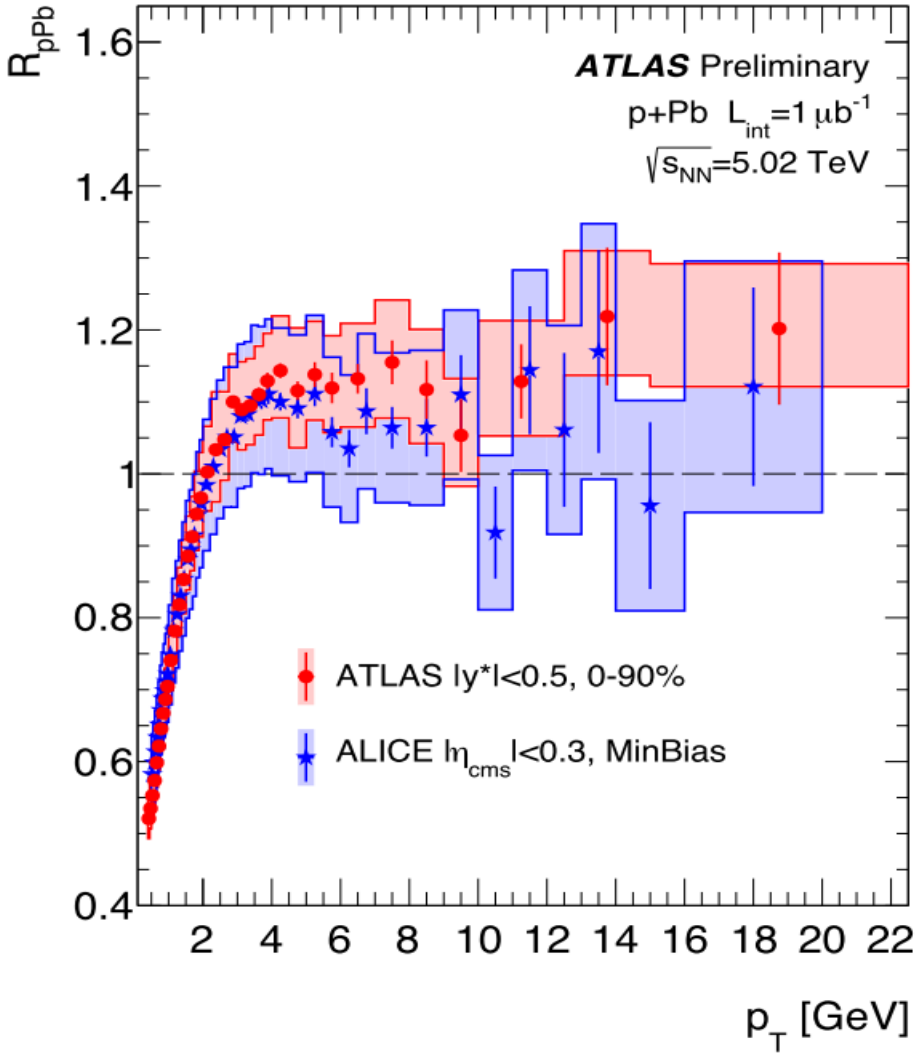
→ p(d)A collisions



Charged particle R_{pPb} (HP2013)

Starting from charged particle spectra

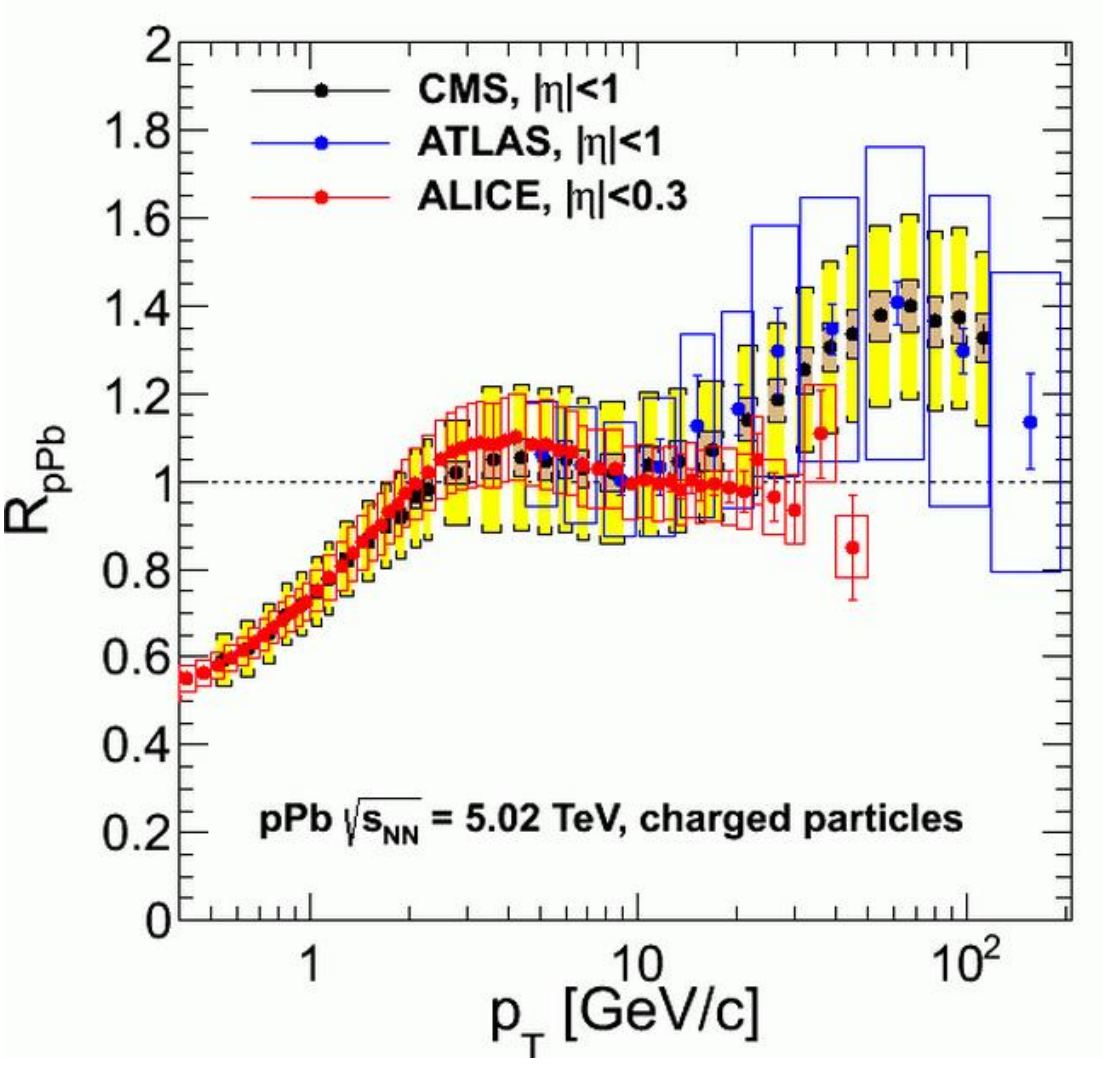




CMS charged particle R_{pPb} can not be described by nPDF (EPS09)

Charged particle R_{pPb} (QM2014)

Charged particle R_{pPb}



Excellent agreement between ATLAS and CMS.

Discrepancy between ALICE and (ATLAS+CMS)

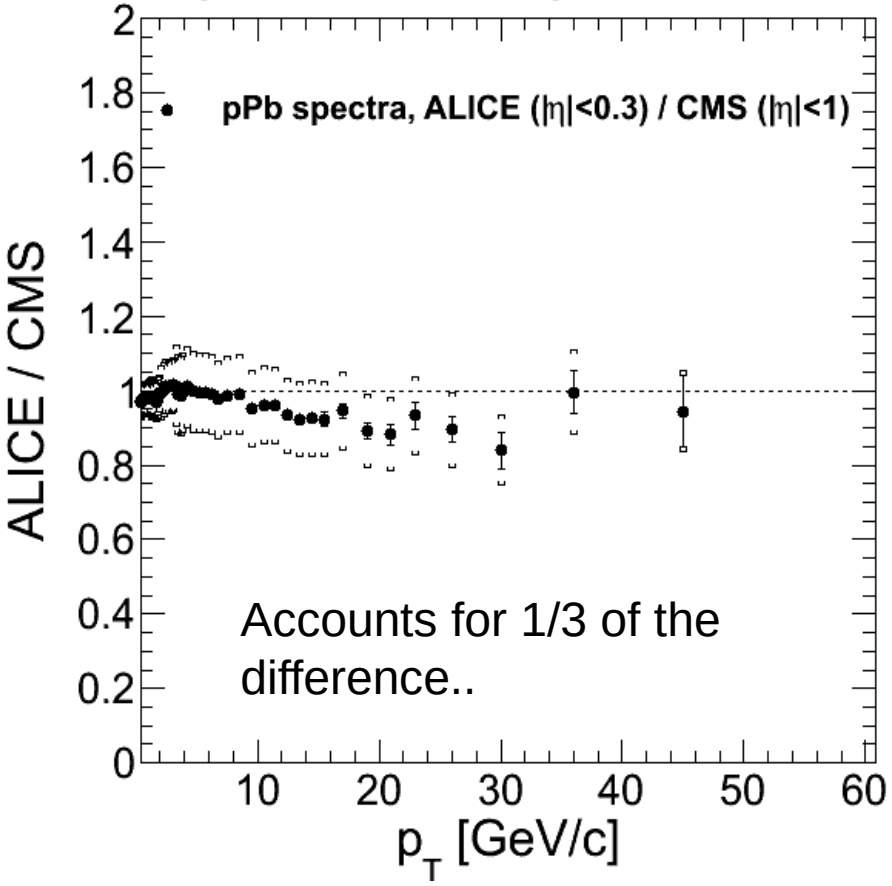
Eric Applet (CMS 5/20)

Petr Balek (ATLAS 5/20)

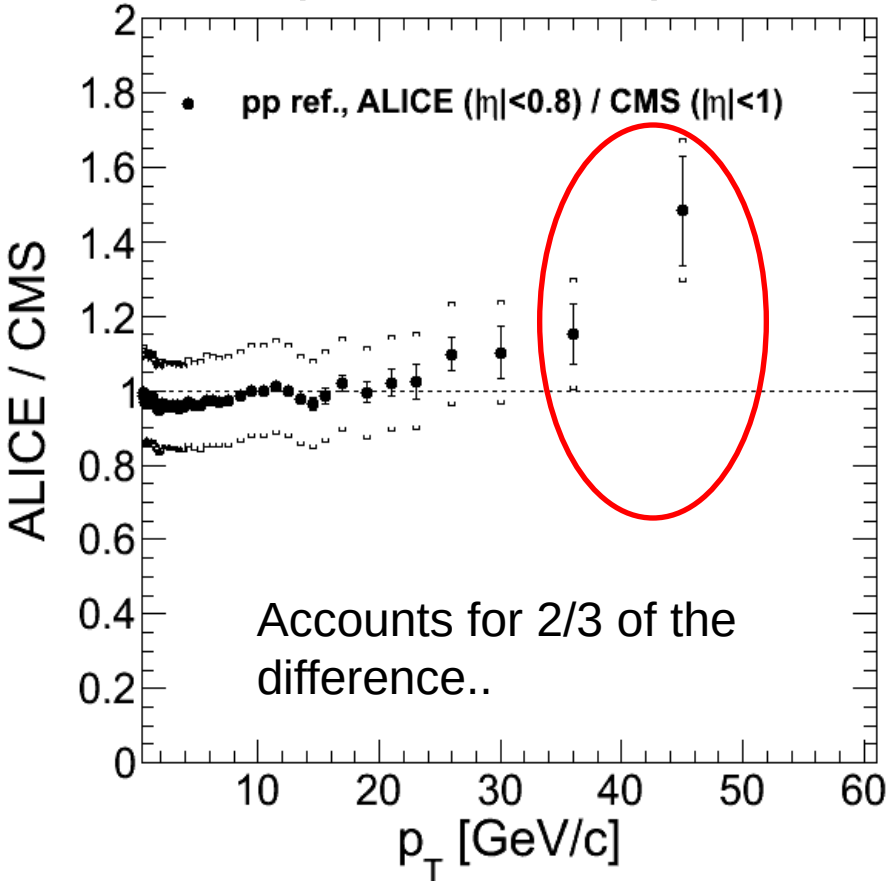
Jan Fiete Grosse-Oetringhaus (ALICE 5/22)

What causes the difference between ALICE and CMS?

pPb charged particle spectra ratio (ALICE/CMS)



pp reference spectra ratio (ALICE/CMS)

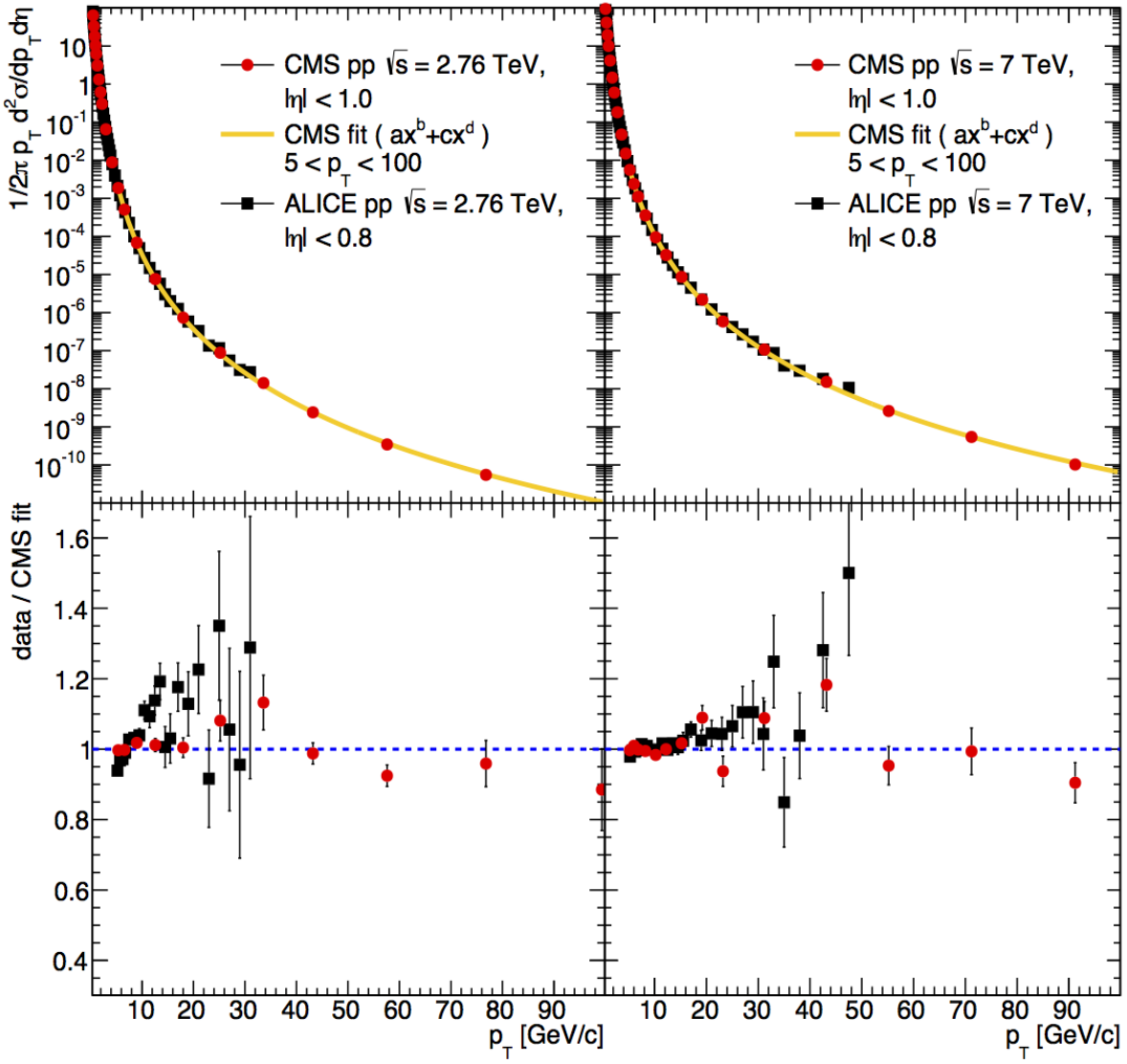


Discrepancy mainly comes from pp reference

Comparison to ALICE Charged Particles

Comparison pp Data from CMS and ALICE

- **7 TeV and 2.76 TeV datasets compared**
- **Larger statistical uncertainty on high-p_T ALICE data**

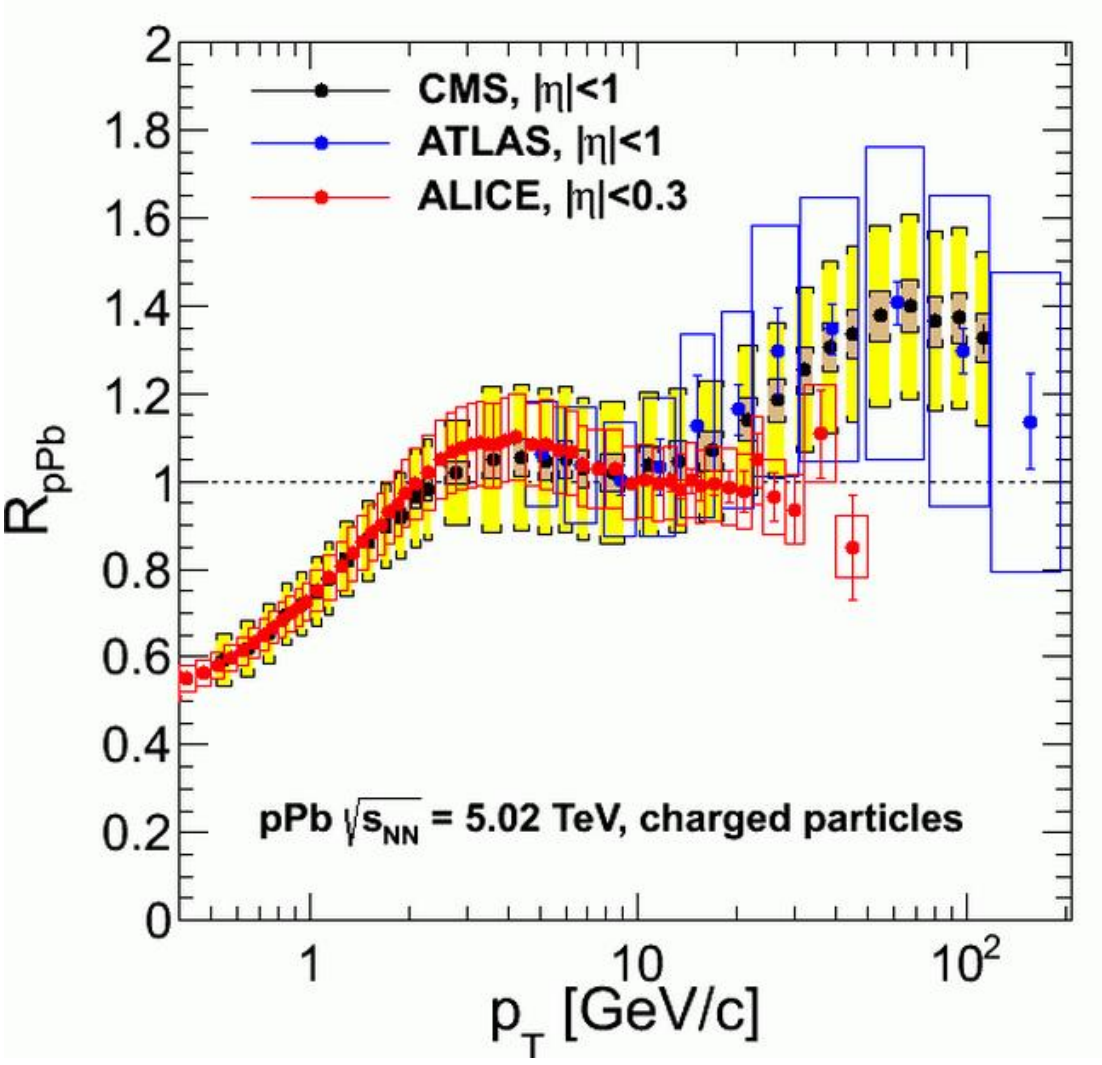


ALICE: EPJC 73 (2013) 2662
CMS: HIN-12-017

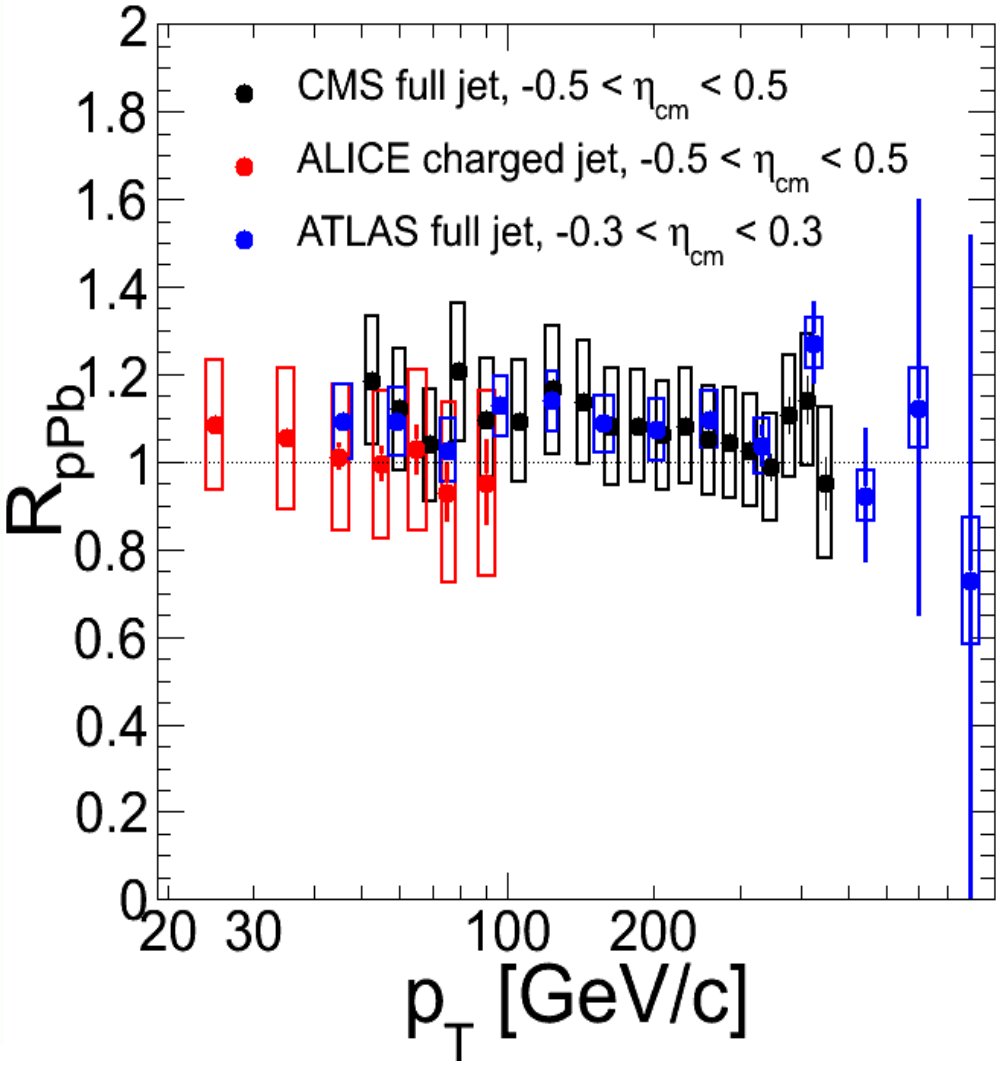
Urgently need 5.02 TeV pp reference data!

Charged particle and jet R_{pPb} (QM2014)

Charged particle R_{pPb}



(Charged) Jet R_{pPb}



Need to check jet fragmentation function

Dijet pseudorapidity distribution in pPb collisions

CMS pPb 35 nb^{-1}

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

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

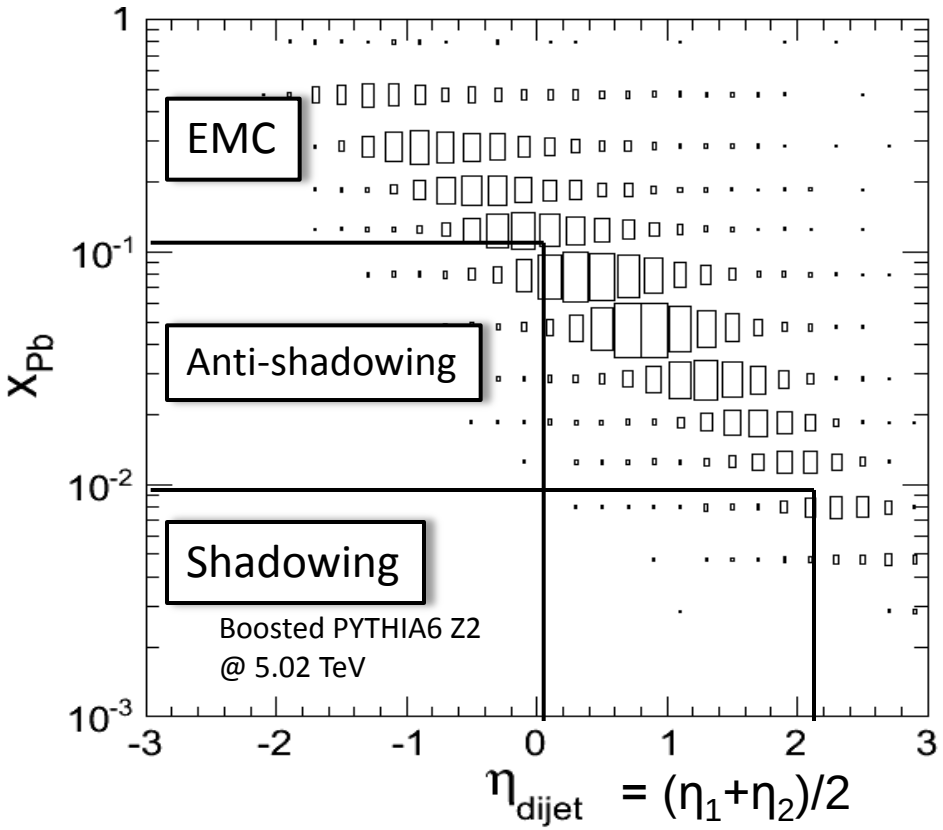
$p_{T,2}$ > 30 GeV/c

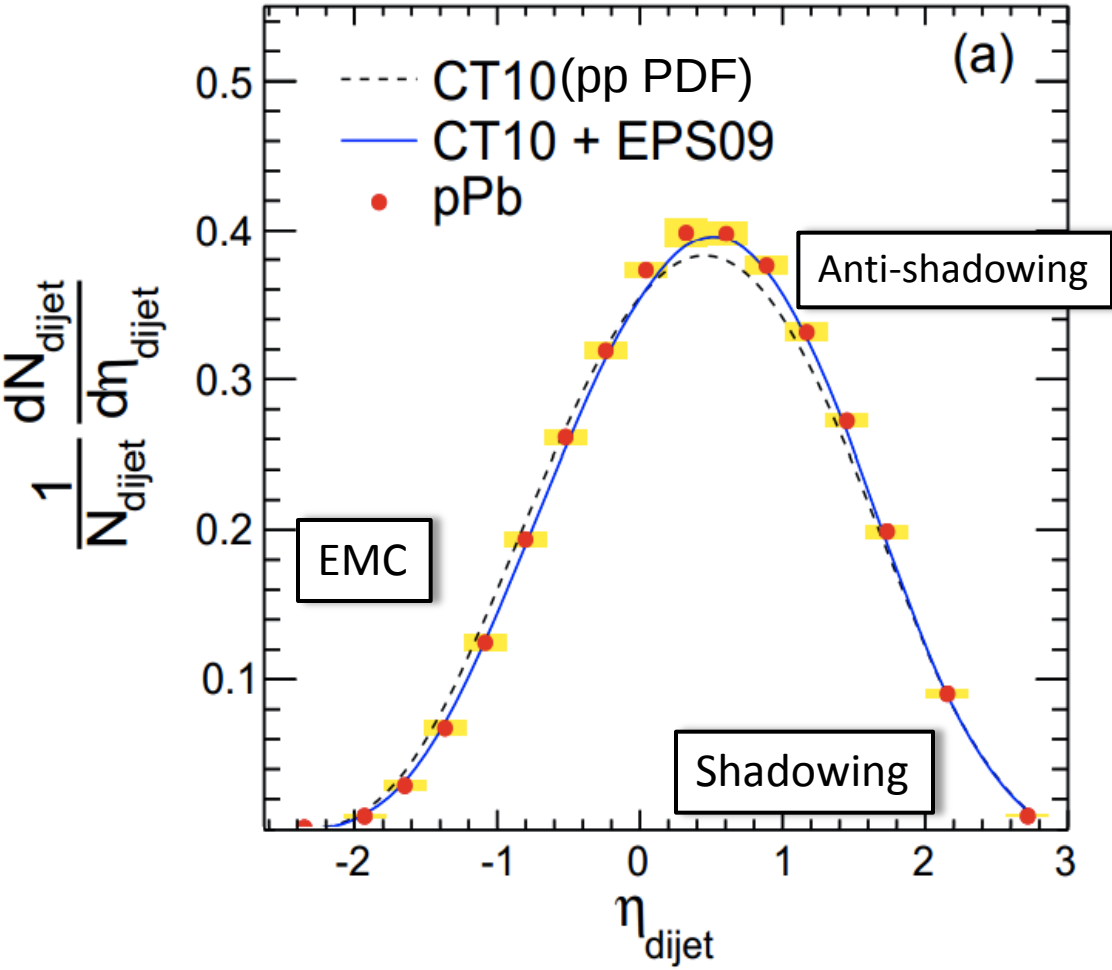
$\Delta\phi_{1,2} > 2\pi/3$

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

Jet quenching from dijet analysis in pPb:
dijet asymmetry <2%
No sizable deviation from unity found in jet R_{pPb}
→ Jets for nPDF studies

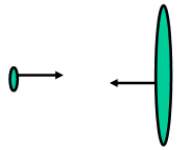
R. Alexander Barbieri (CMS 5/21)

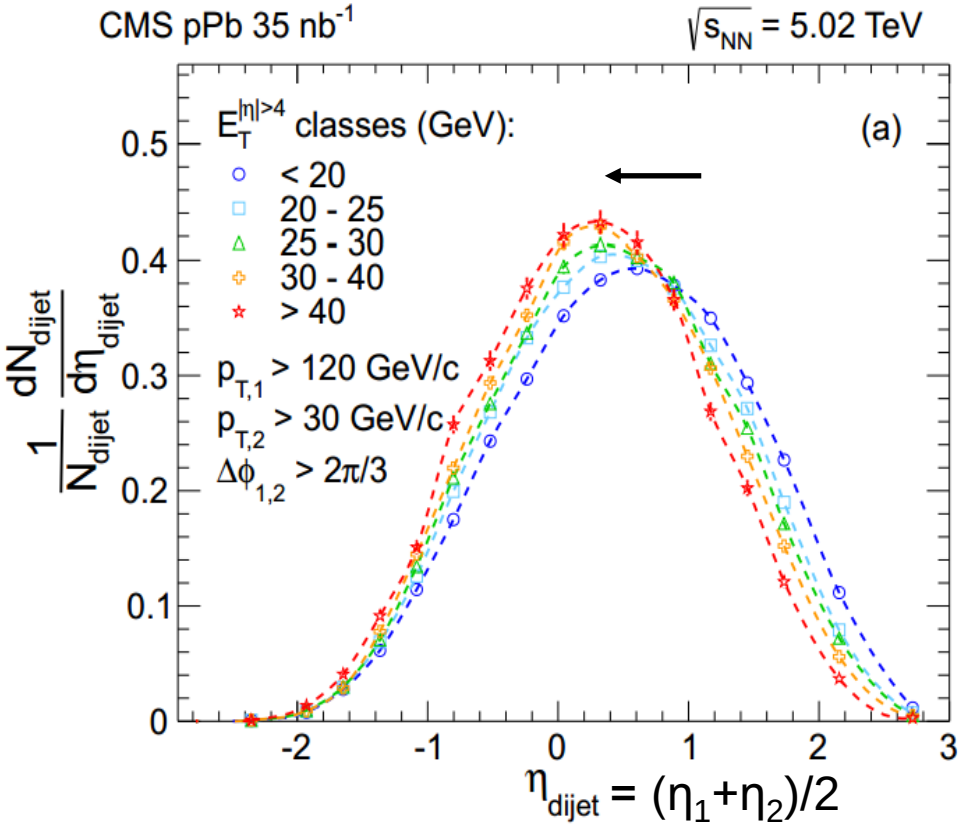




Dijet η and Jet R_{CP}

R. Alexander Barbieri
(CMS 5/21)

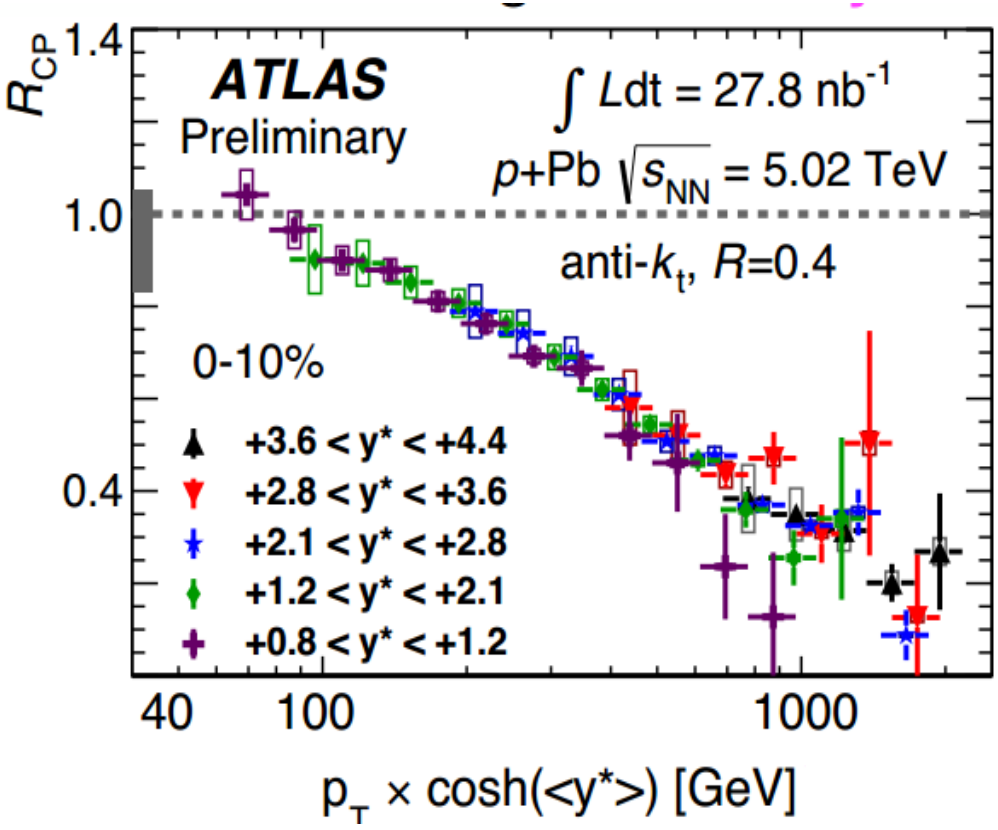




Large modification vs. event activity
Can not be explained by centrality dependent nPDF

Dennis Perepelitsa
(ATLAS 5/20)

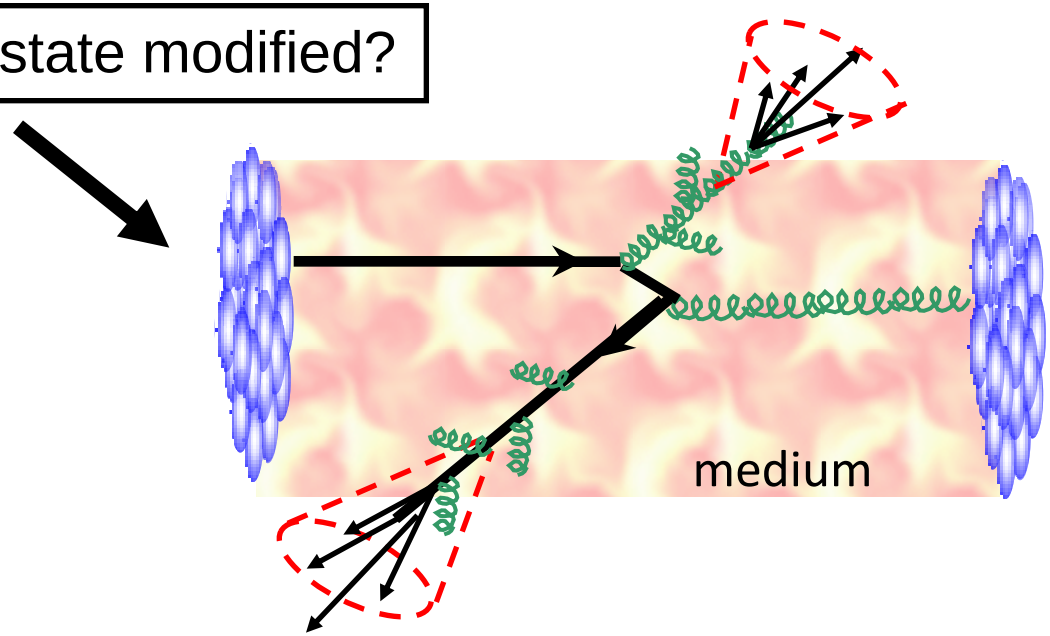
y* > 0 (proton going data)



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

Questions to be answered

1. Is the initial state modified?



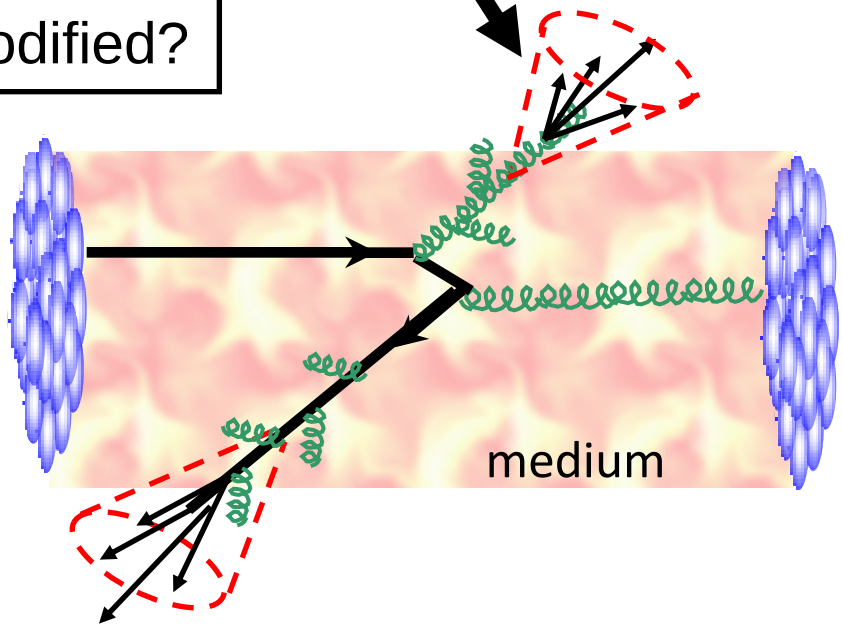
Jet production in inclusive pPb collisions can be described by nPDF

Studies in bins of event activity: interesting effects such as energy conservation, fluctuating proton size come into play

Questions to be answered

2. Can we recover the lost energy by jet reconstruction?

1. Is the initial state modified?

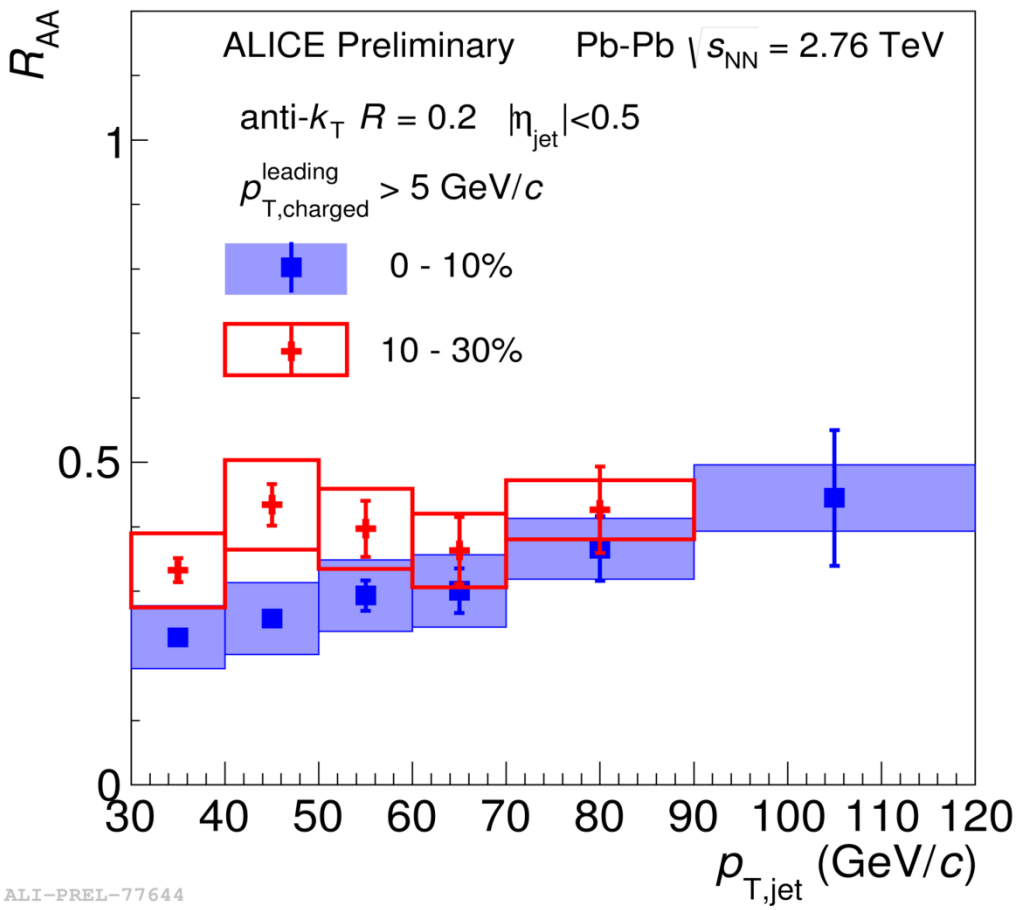


→ AA collisions

Jet R_{AA} at LHC

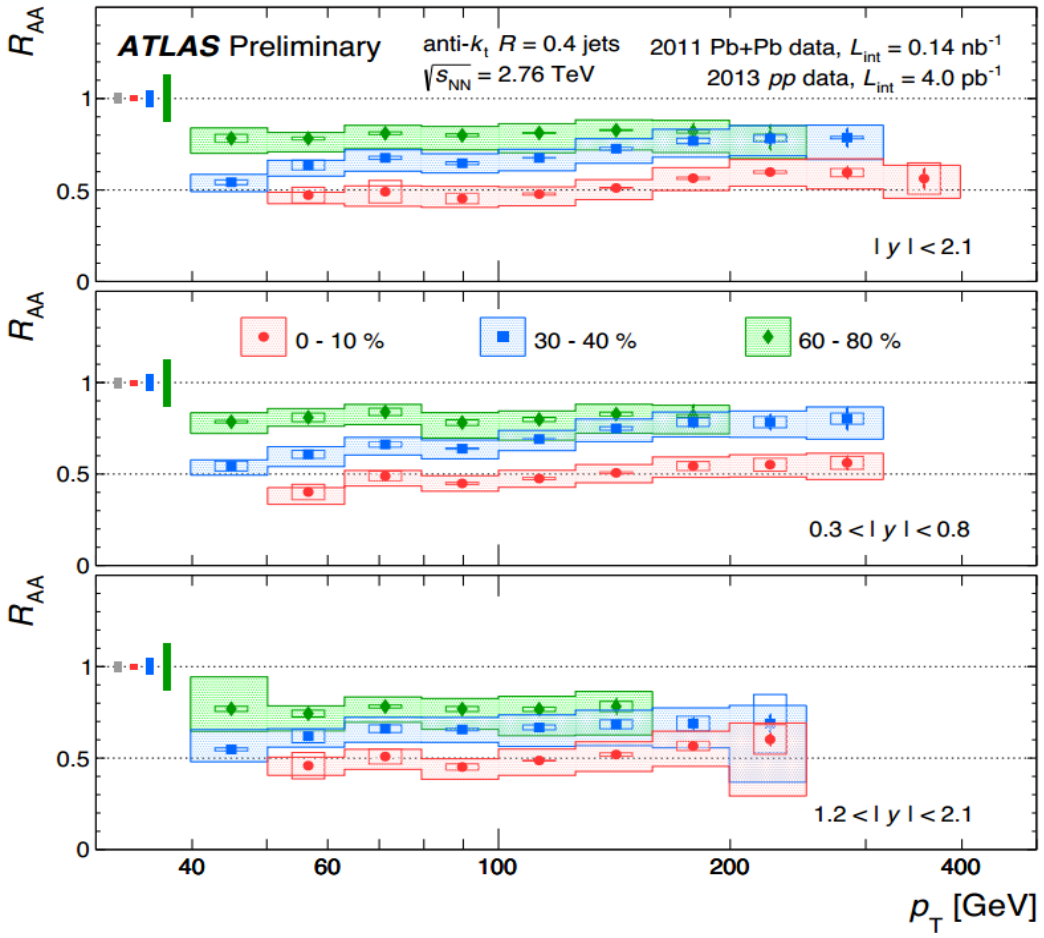
Aaron Angerami (ATLAS 5/20)

ALICE new result 10-30%



Salvatore Aiola (ALICE 5/20)

ATLAS new results on jet R_{AA}

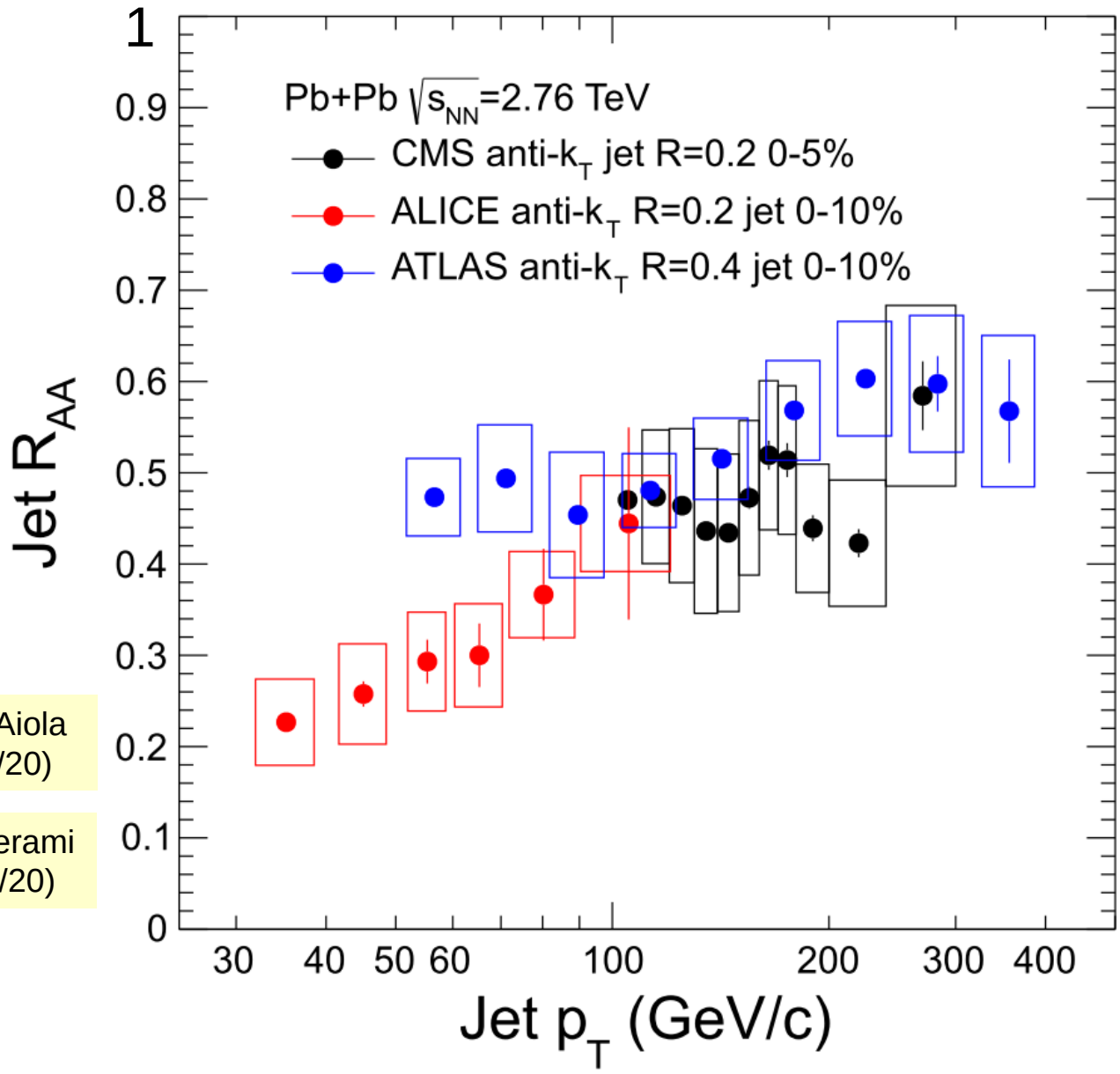


R_{AA} v.s p_T (as well as y)

Weak dependence on jet rapidity

Quark/gluon fraction (as well as the slope of the jet p_T spectra) changes v.s. y

Jet R_{AA} in PbPb collisions at LHC

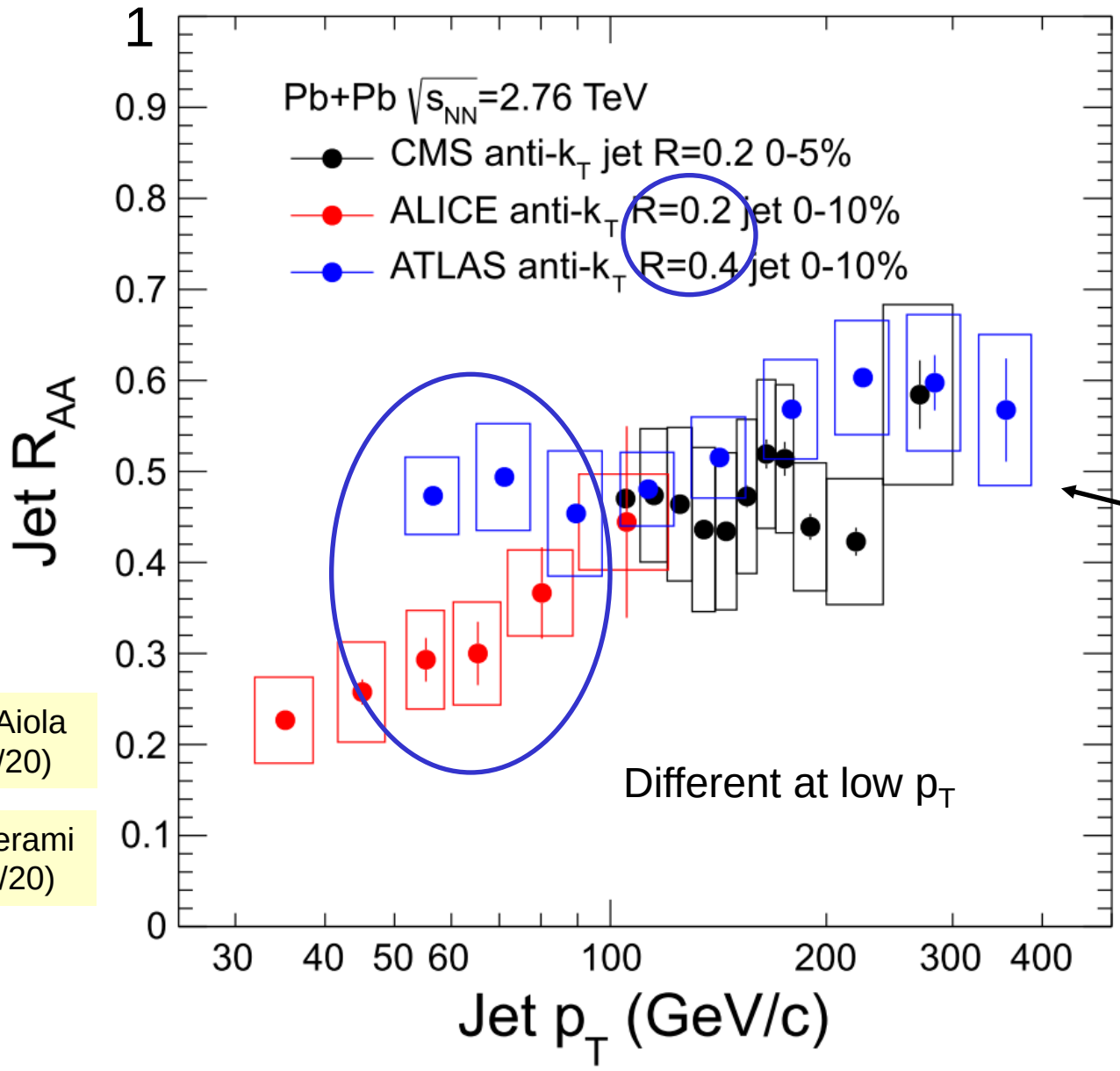


Salvatore Aiola (ALICE 5/20)

Aaron Angerami (ATLAS 5/20)

Establish a rising trend from low to high jet p_T

Jet R_{AA} in PbPb collisions at LHC



~ Agreement between CMS and ATLAS at high jet p_T

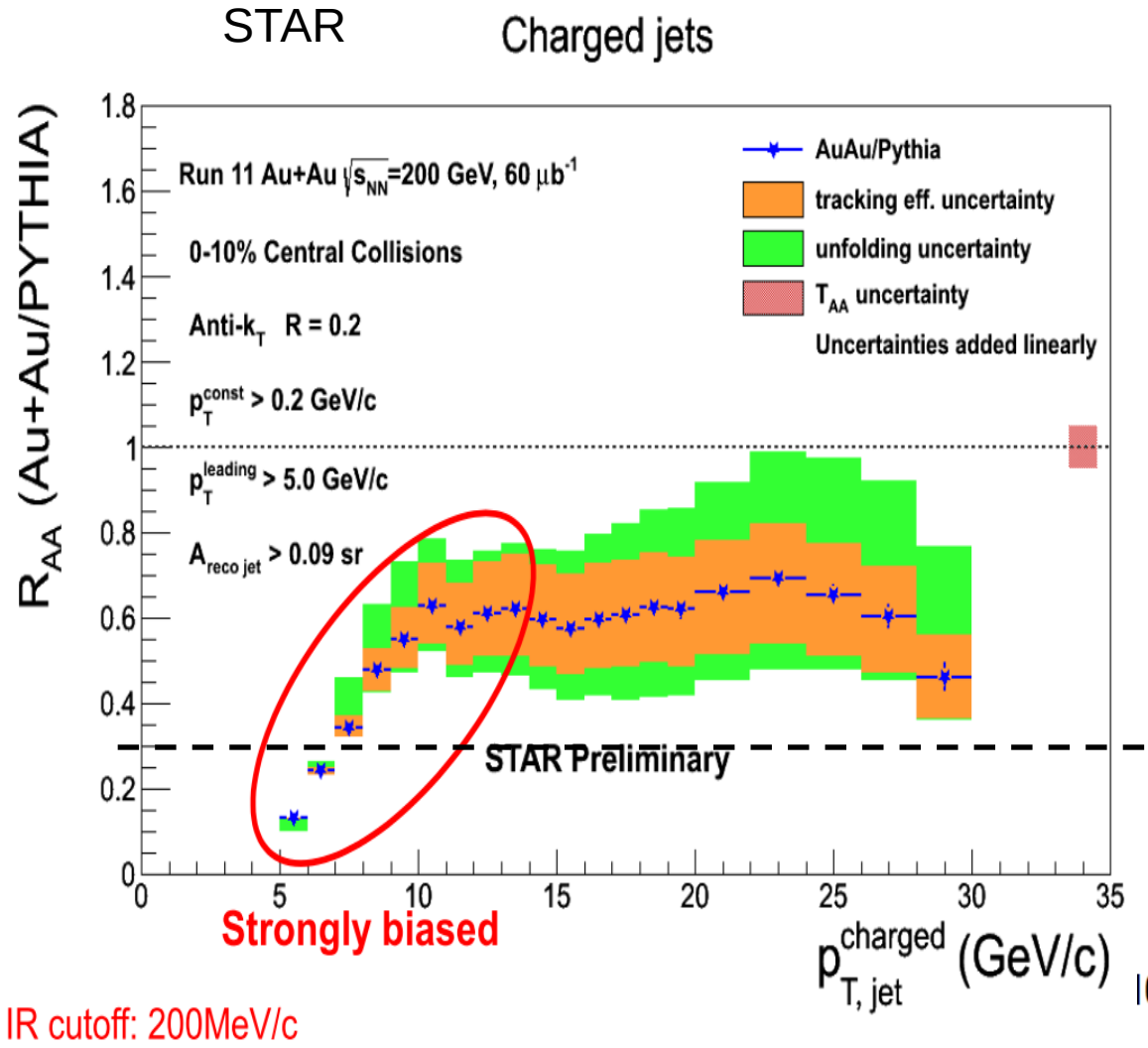
Agree with charged particle R_{AA} at high p_T

Salvatore Aiola (ALICE 5/20)

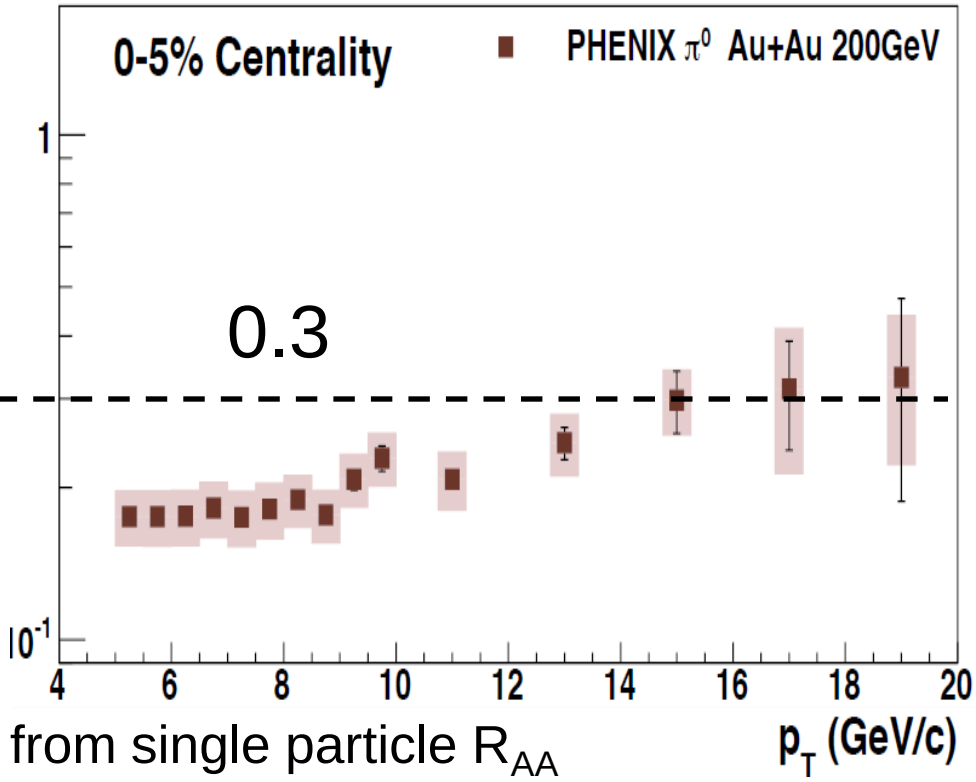
Aaron Angerami (ATLAS 5/20)

It would be nice to have low p_T CMS data / ATLAS R_{AA} with R=0.2 / ALICE high p_T data

Charged Jet R_{AA} v.s π^0 R_{AA} at RHIC



IR cutoff: 200MeV/c



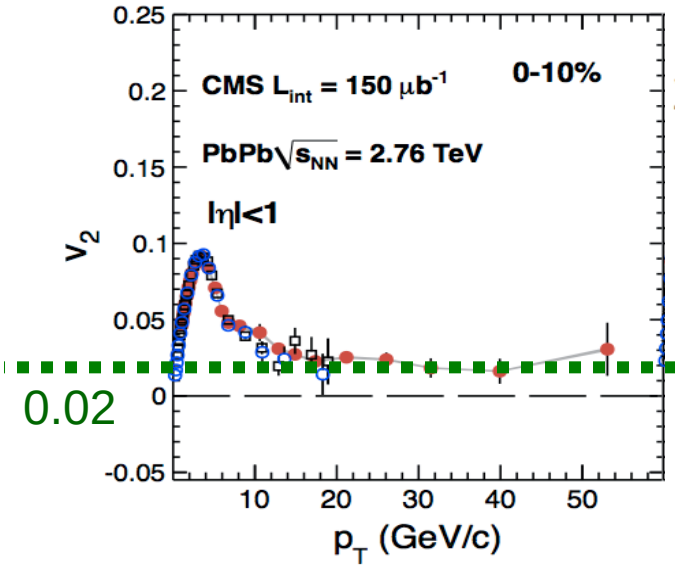
Charged jet R_{AA} results: different from single particle R_{AA}

Indication of modification of jet fragmentation function?

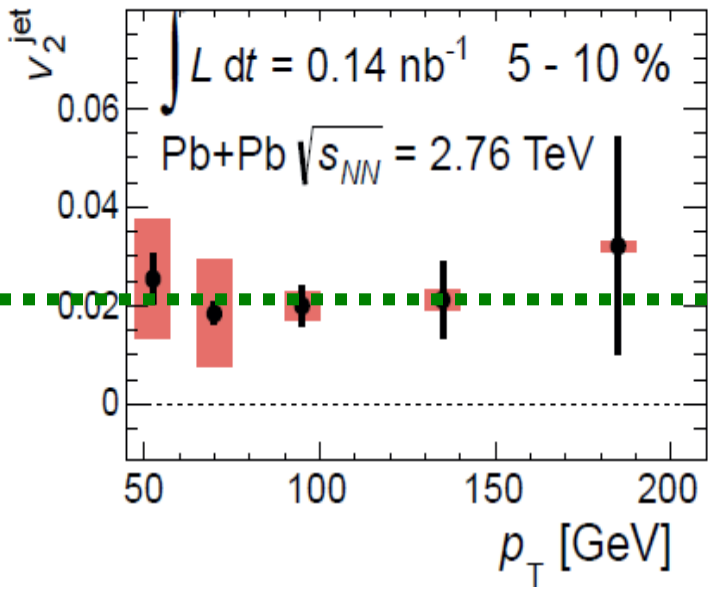
Due to the steeply falling p_T spectra?

Jet and high p_T track v_2 at the LHC

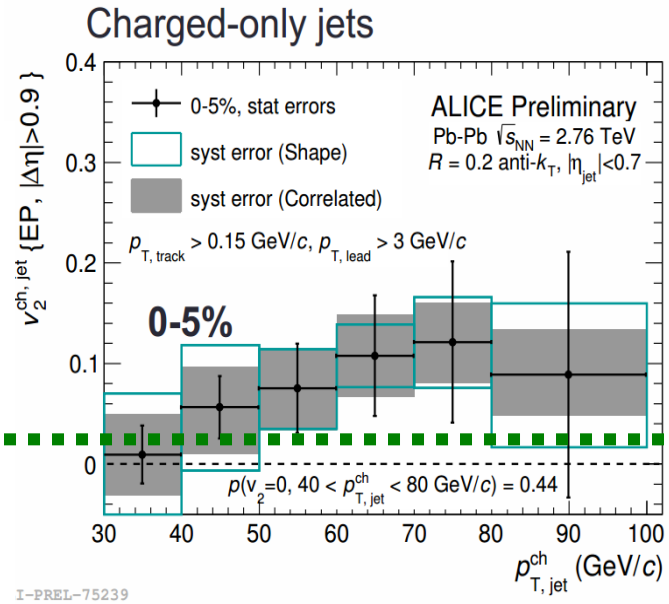
CMS 0-10%
High p_T Track v_2



ATLAS 5-10%
Jet v_2



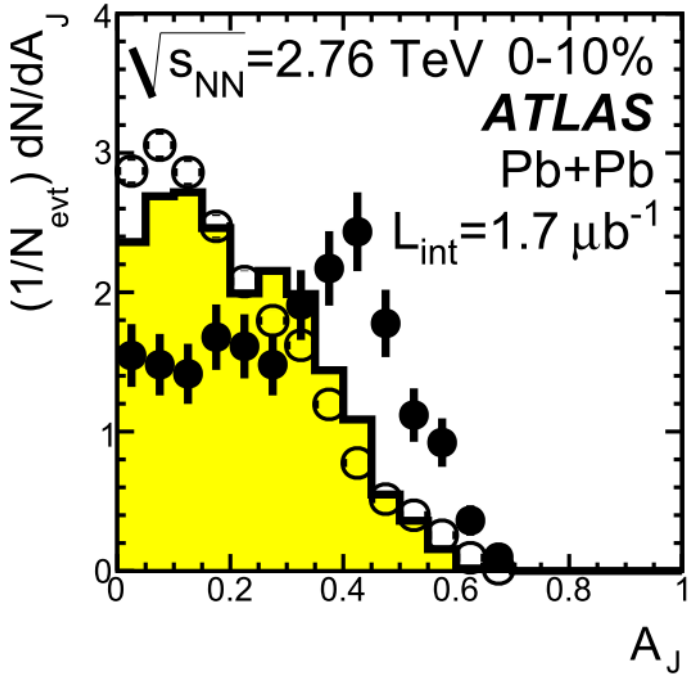
ALICE 0-5%
Charged Jet v_2

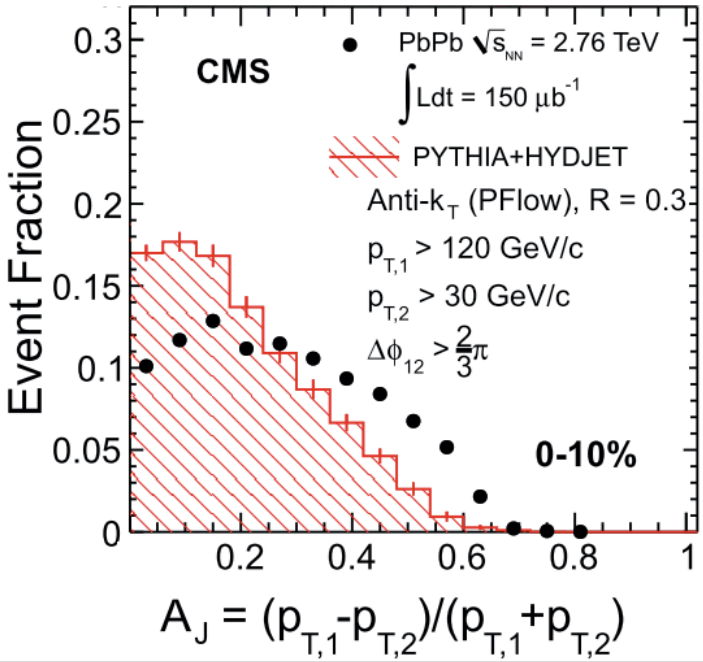


Salvatore Aiola
(ALICE 5/20)

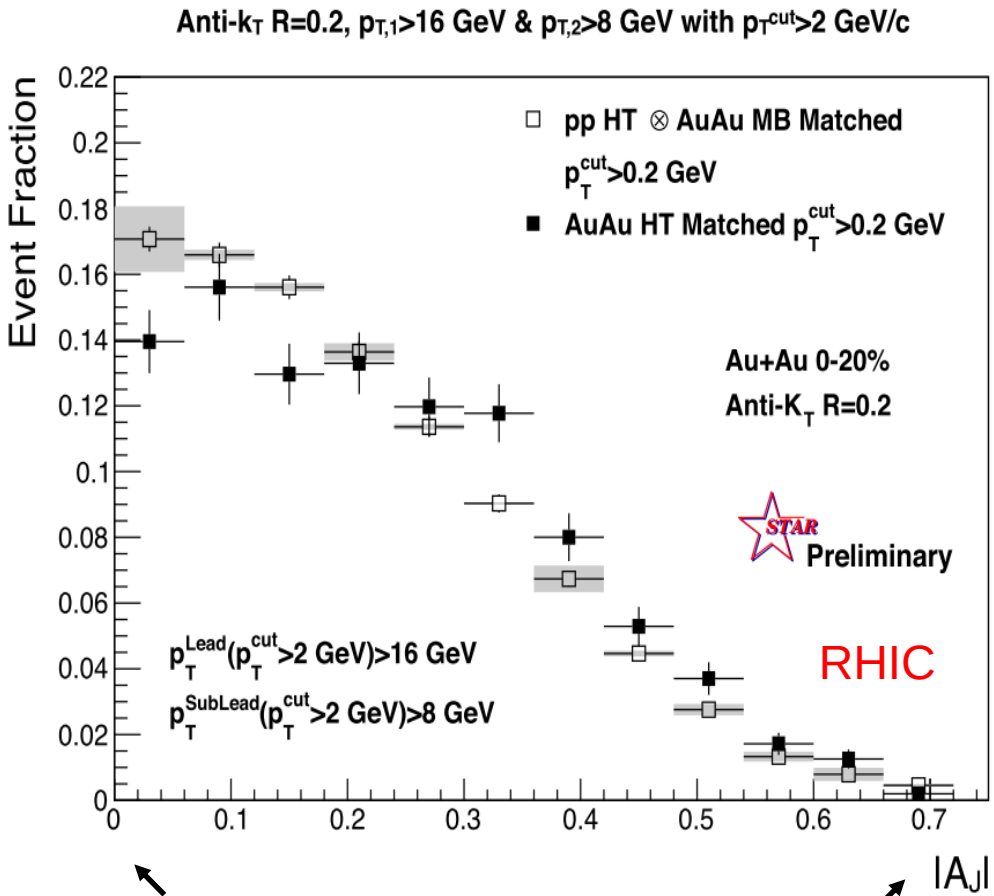
- Jet and high p_T track v_2 : non-zero up to very high p_T
- Larger v_2 is reported by ALICE

Dijet asymmetry A_J in RHIC and LHC



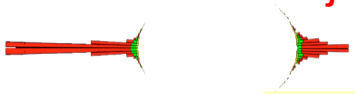


$$A_J = (p_{T,1}-p_{T,2})/(p_{T,1}+p_{T,2})$$



Balanced dijet

Imbalanced dijet

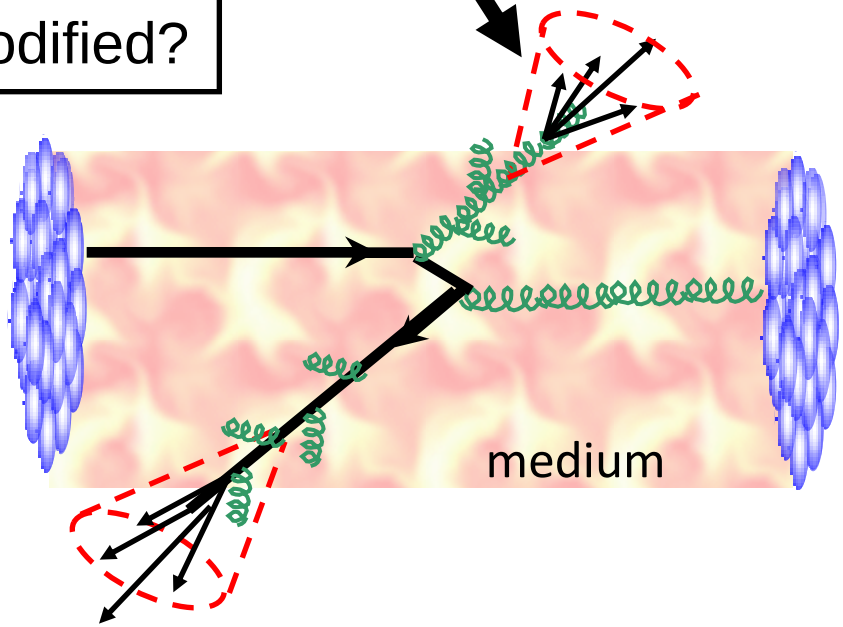


Joern Putschke (STAR 5/21)

Questions to be answered

2. Can we recover the lost energy by jet reconstruction?

1. Is the initial state modified?



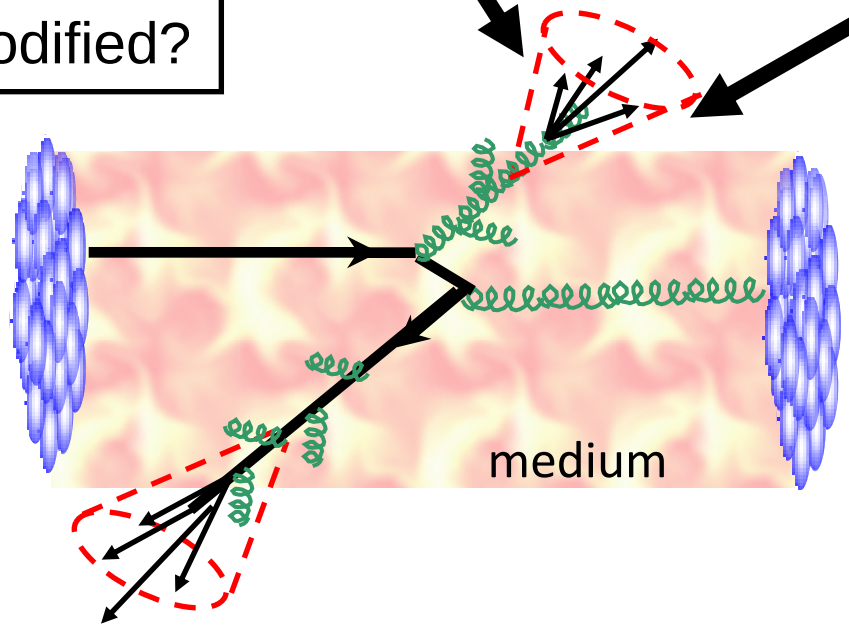
Anti-k_T R=0.2 (RHIC) and R=0.2-0.5 (LHC) doesn't collect all the lost energy

Questions to be answered

2. Can we recover the lost energy by jet reconstruction?

3. Flavor Dependence of Jet Quenching?

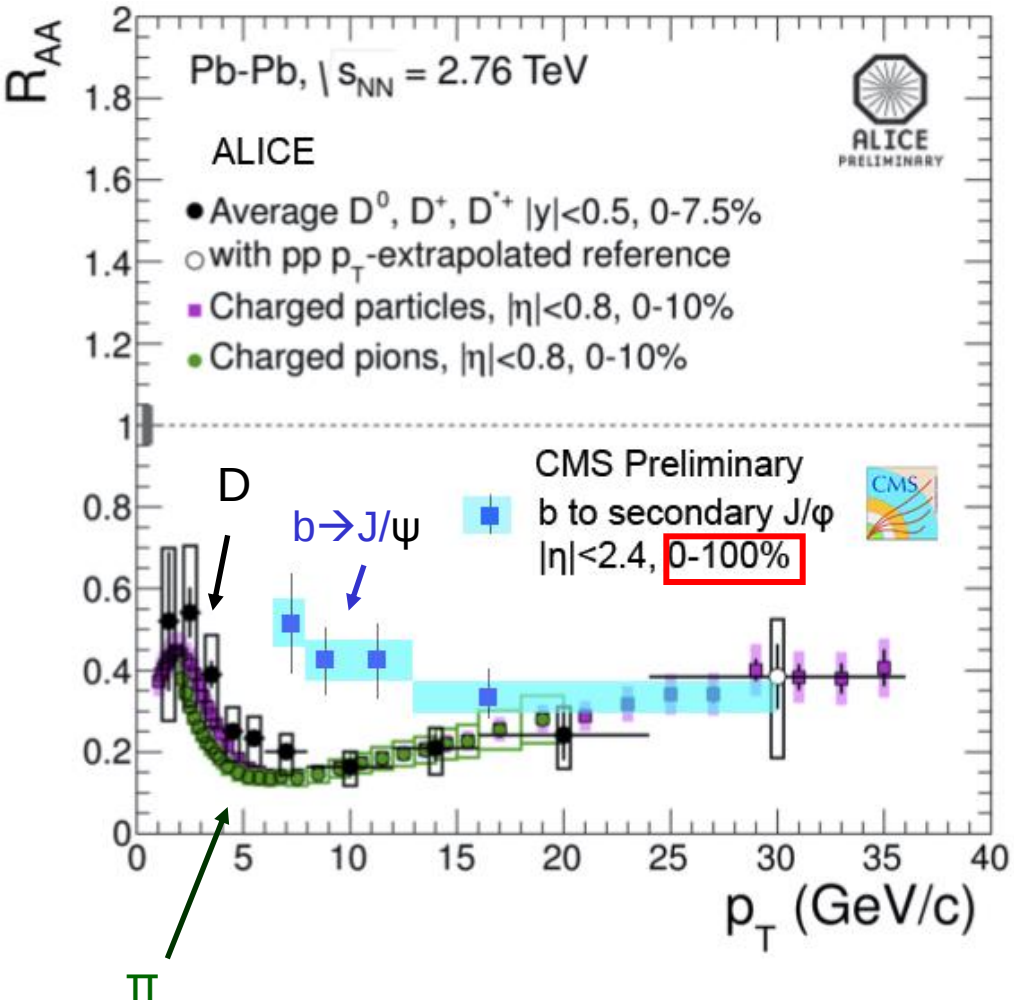
1. Is the initial state modified?



Flavor Dependence of Jet Quenching

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

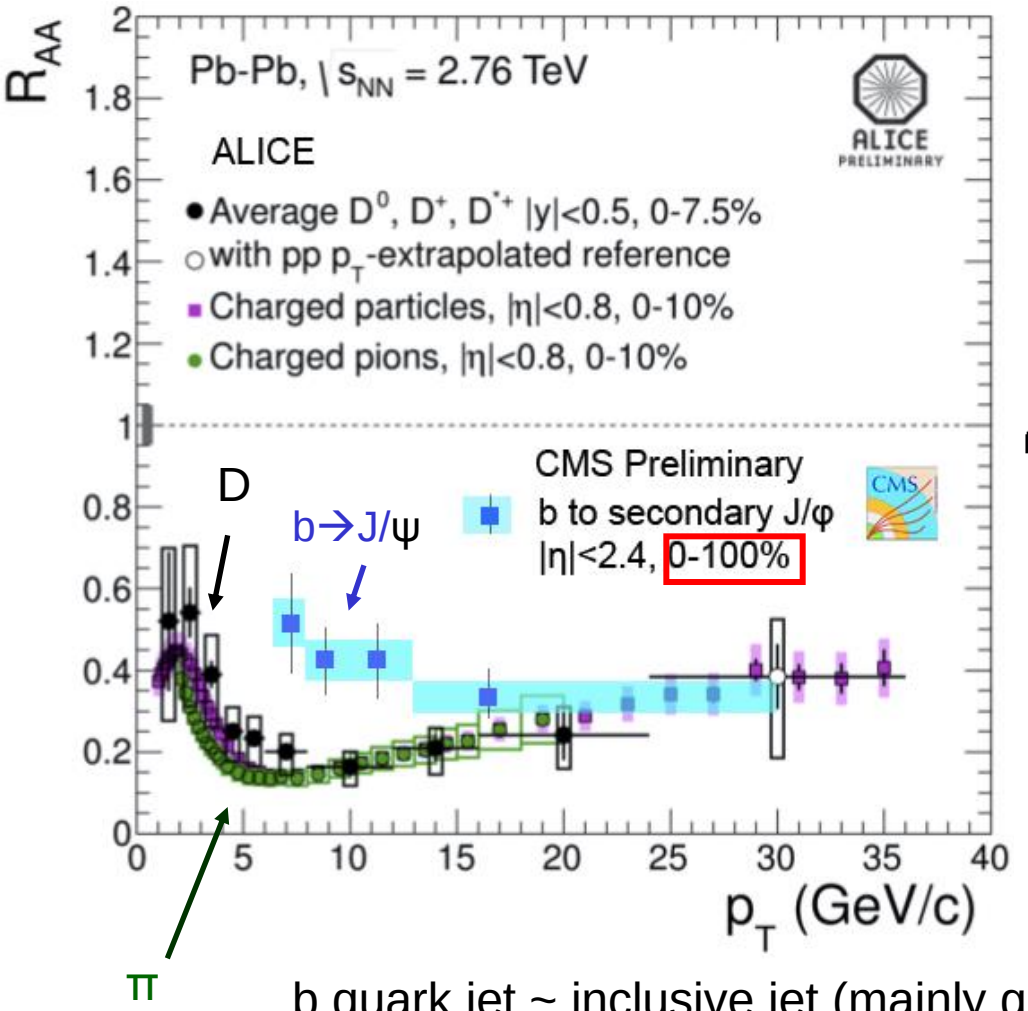
(However, spectra slope are different)



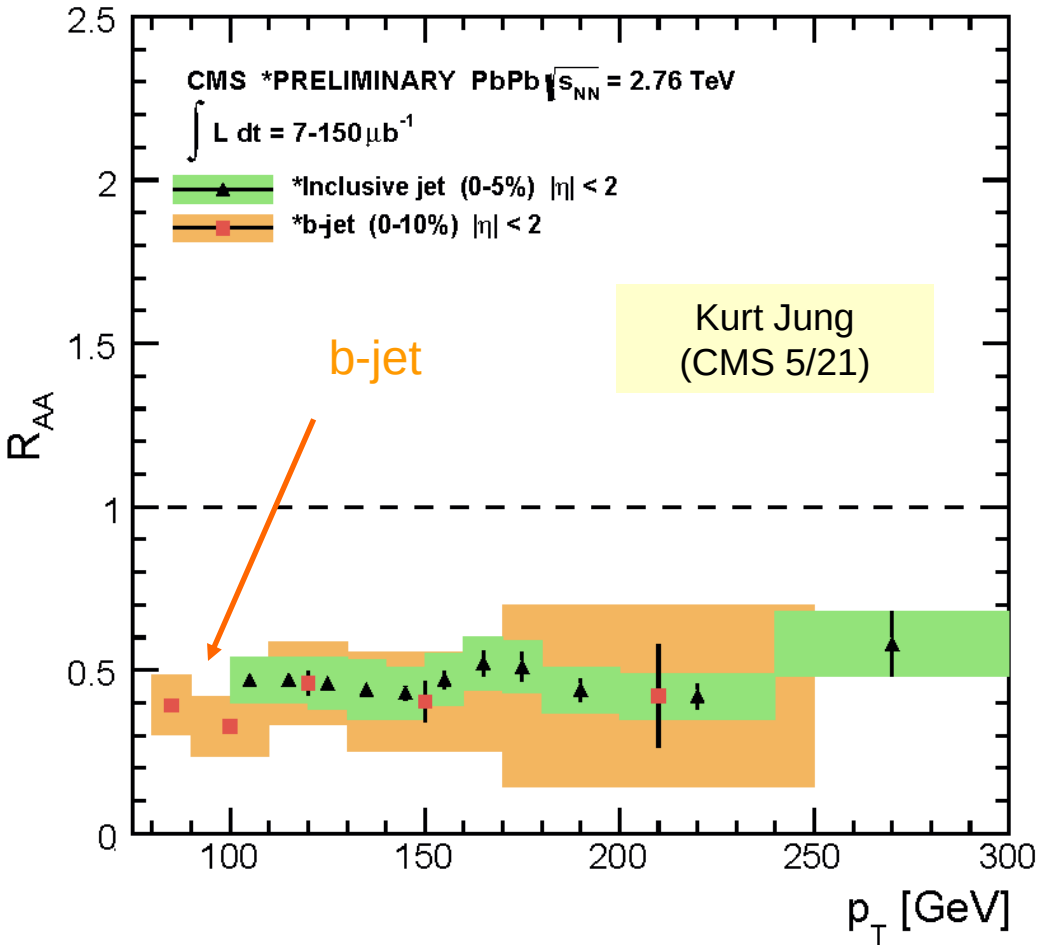
Flavor Dependence of Jet Quenching

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

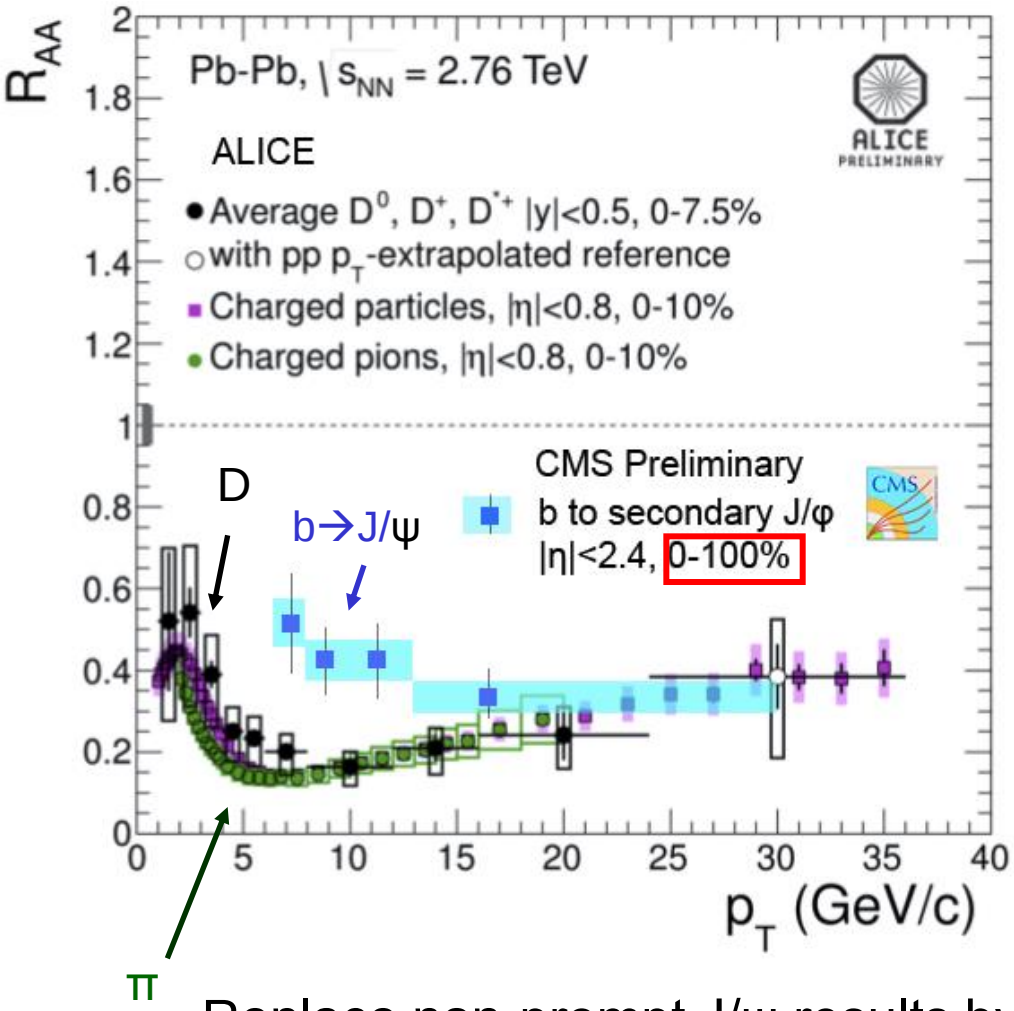


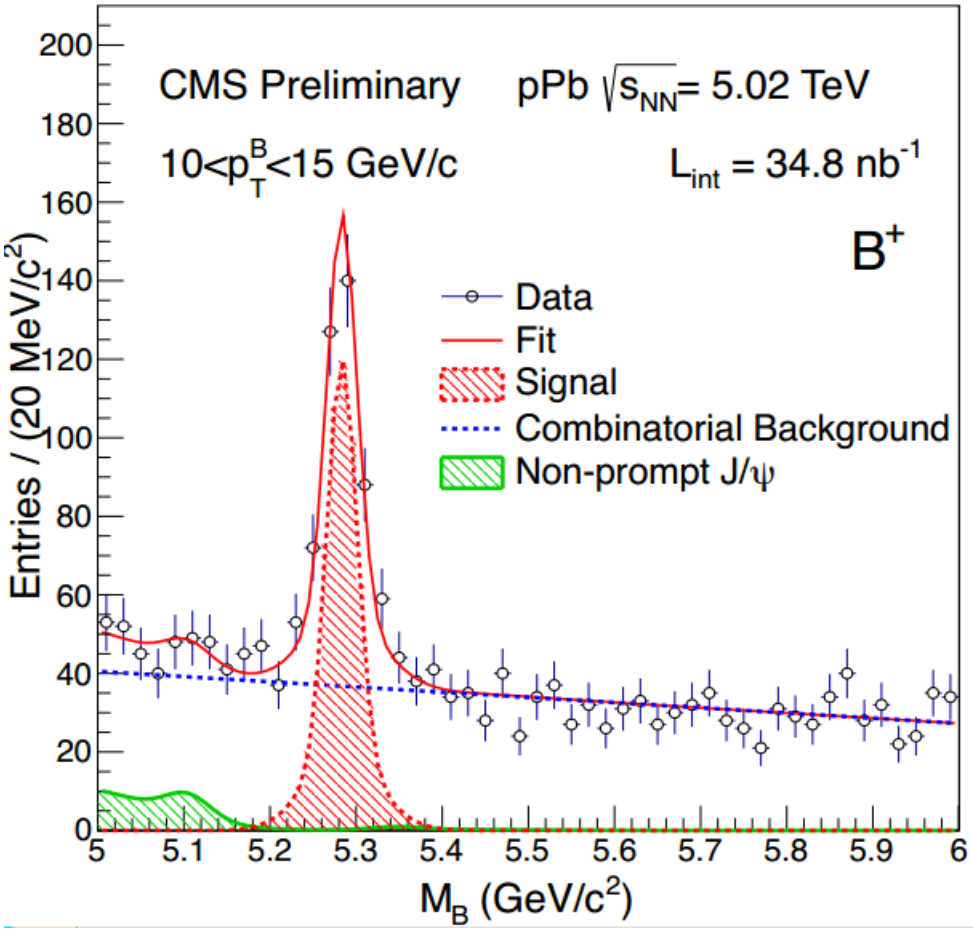
b quark jet ~ inclusive jet (mainly gluon jets), contribution from gluon splitting?

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)





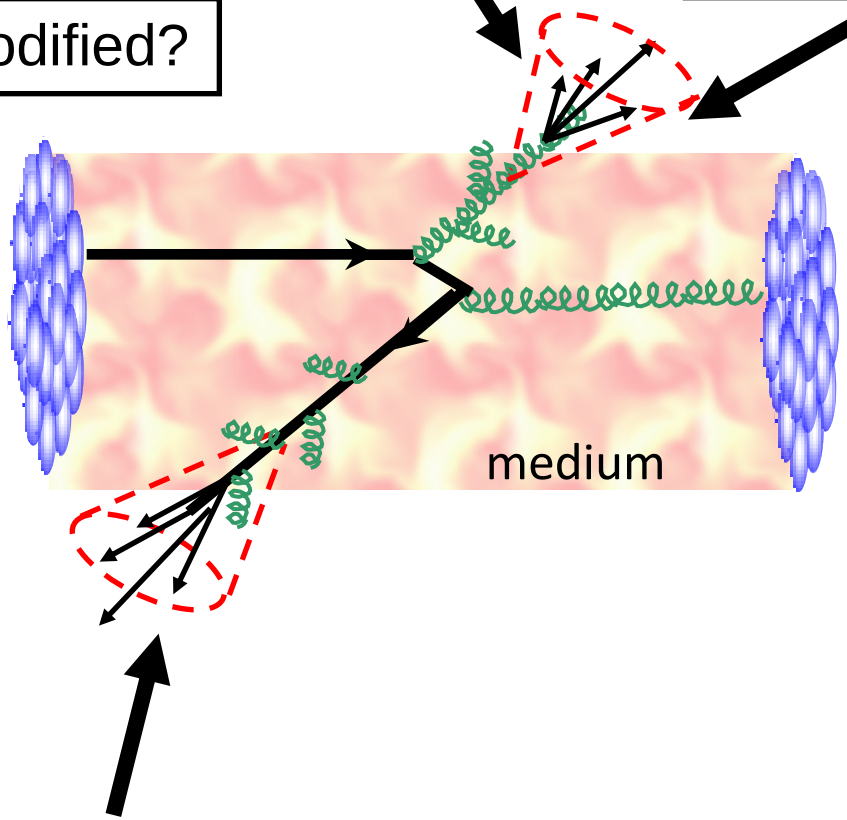
Replace non-prompt J/ψ results by exclusive B meson to fix the x axis scale

Questions to be answered

2. Can we recover the lost energy by jet reconstruction?

3. Flavor Dependence of Jet Quenching?

1. Is the initial state modified?



4. Is the jet structure modified?

Jet Fragmentation at LHC

Using **Jet Energy** as a reference

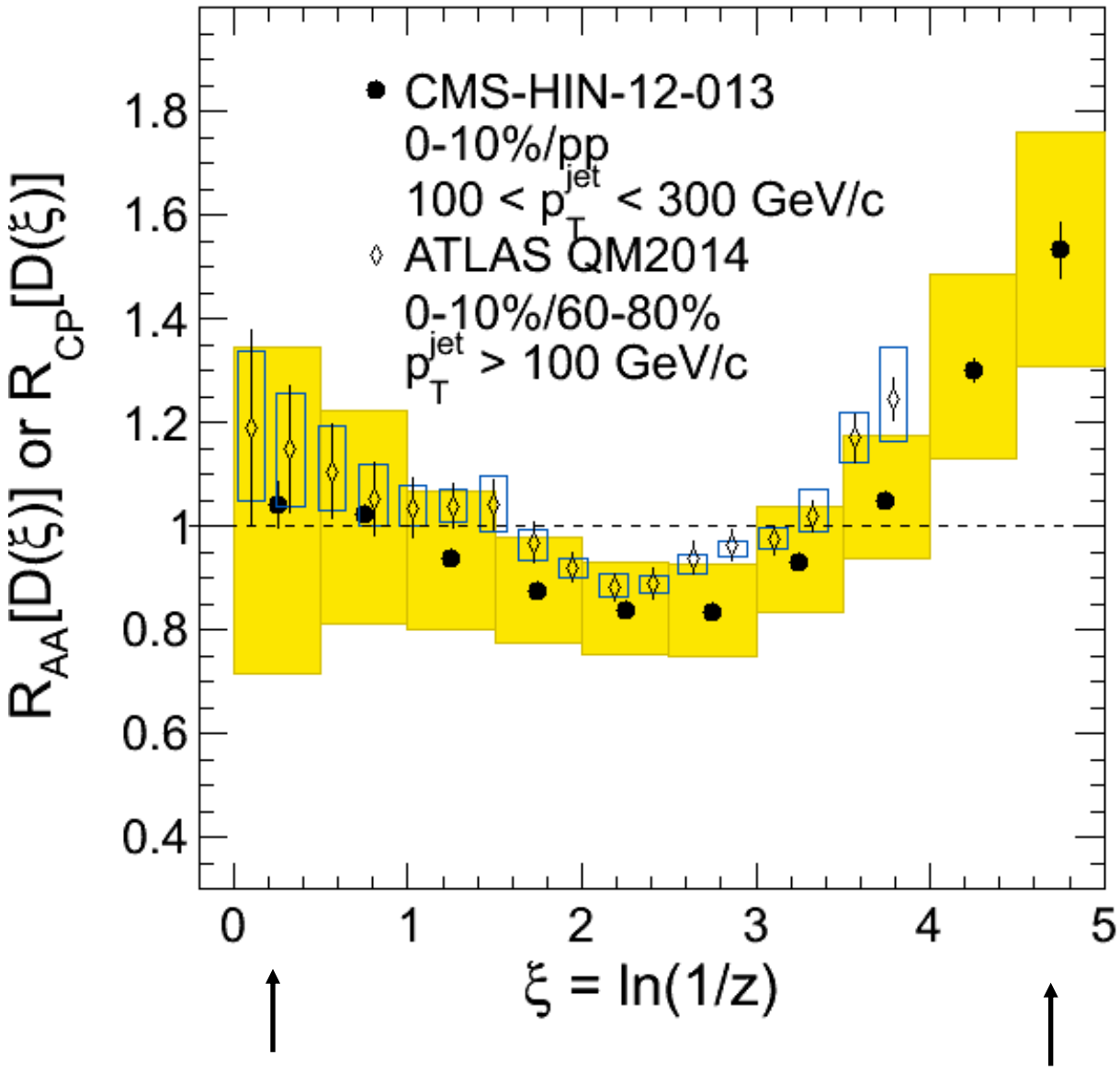
CMS FF R_{AA} compared to ATLAS FF R_{CP}

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

Qualitative consistent results between CMS and ATLAS

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

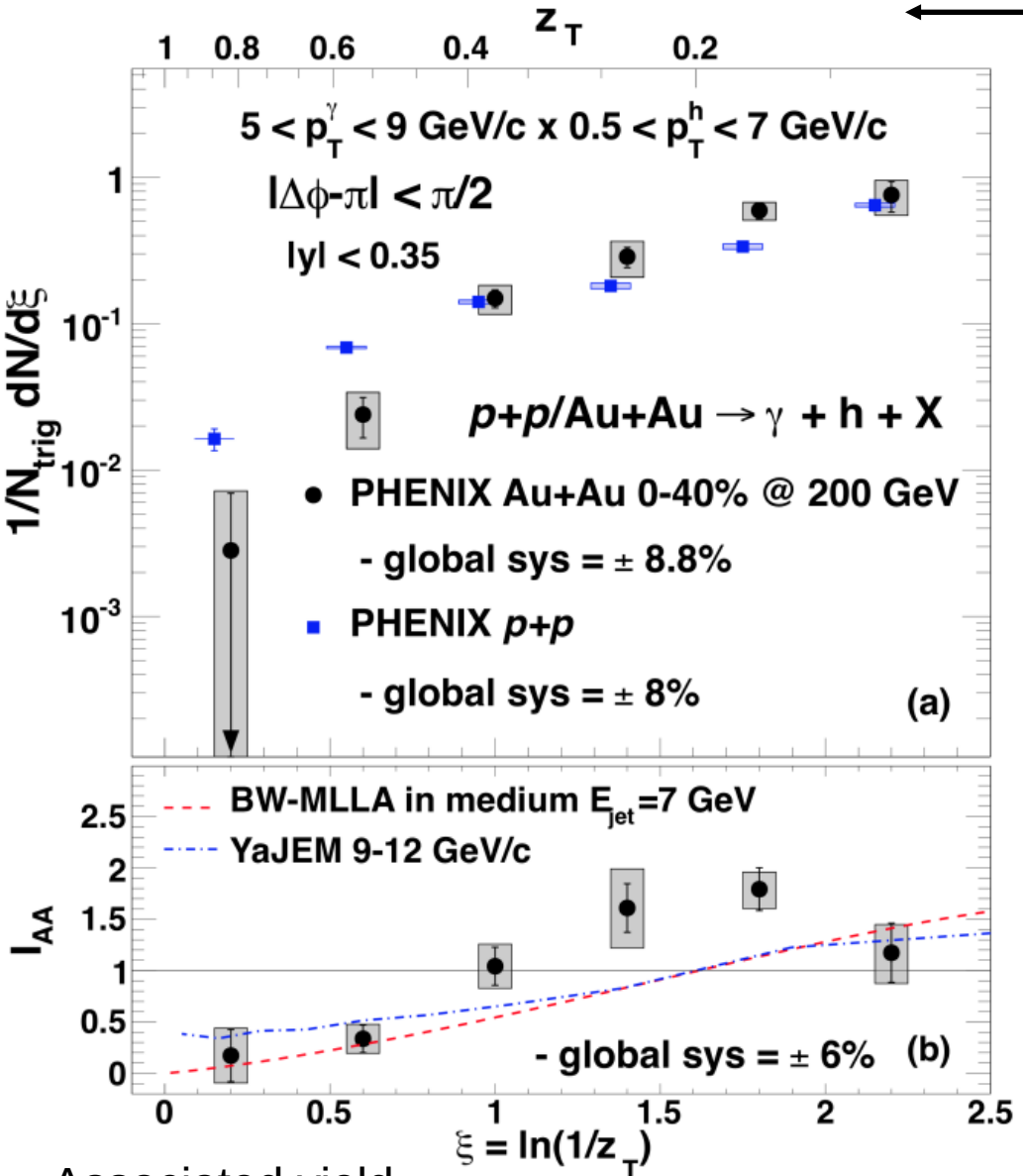
Martin Spousta (ATLAS 5/20)



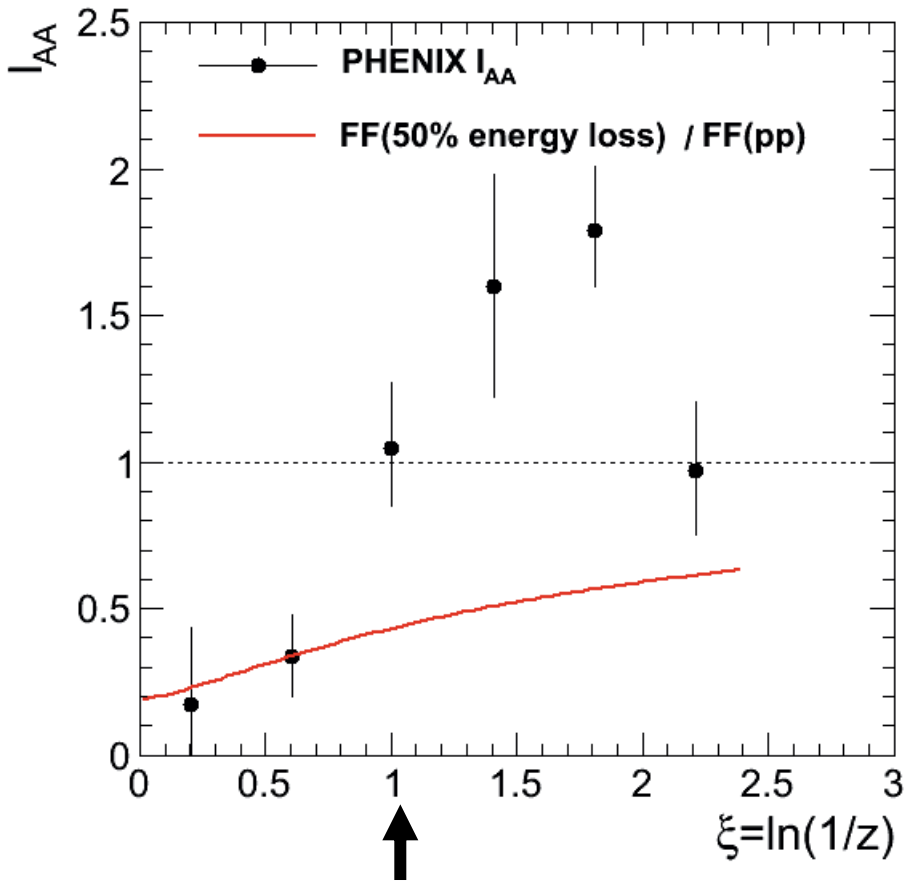
Photon-hadron correlation

Using **Photon Energy** as a reference

The FF shape can not be explained by simple shift of pp fragmentation function



Associated yield

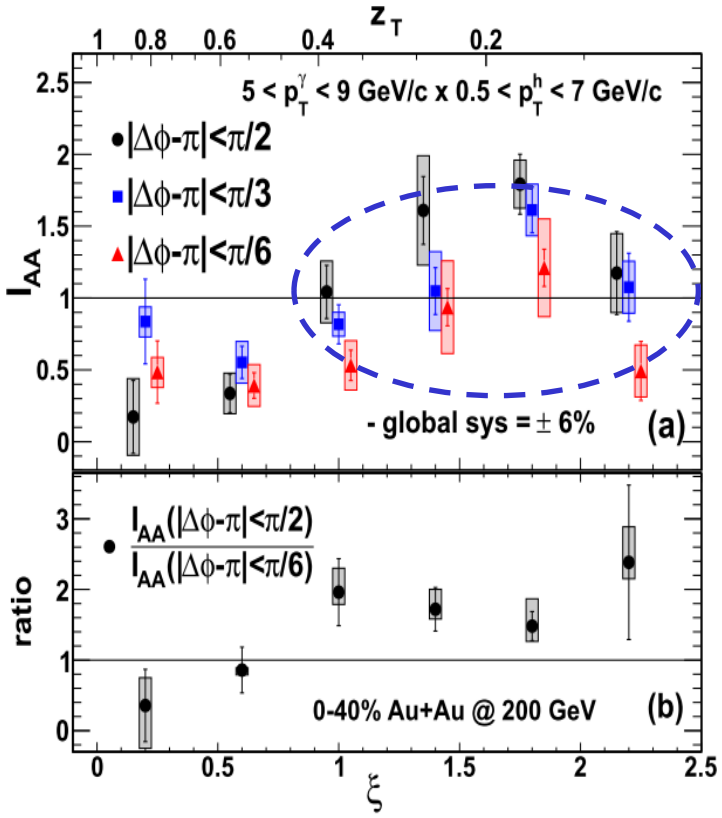


Track p_T ~2 GeV

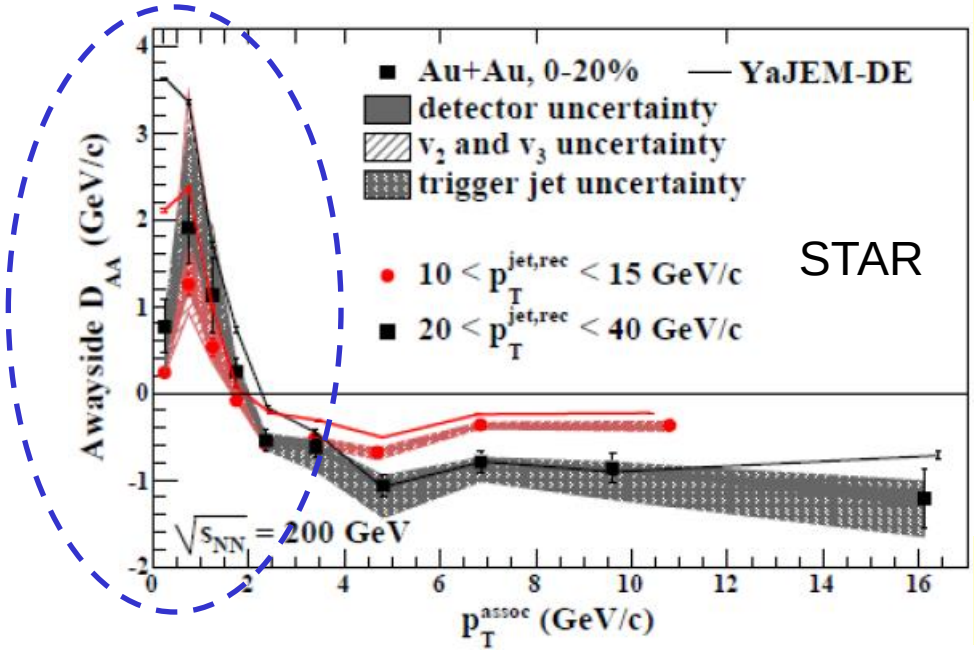
Enhancement of low p_T particles

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

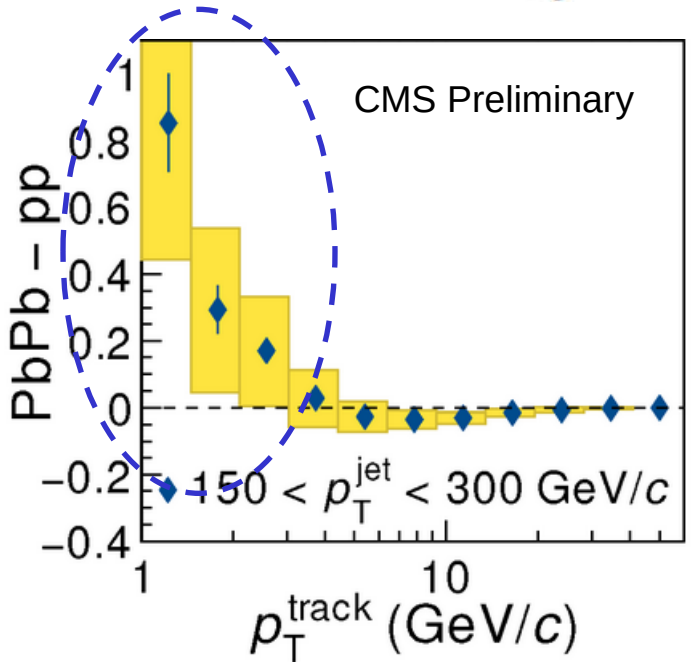
PHENIX

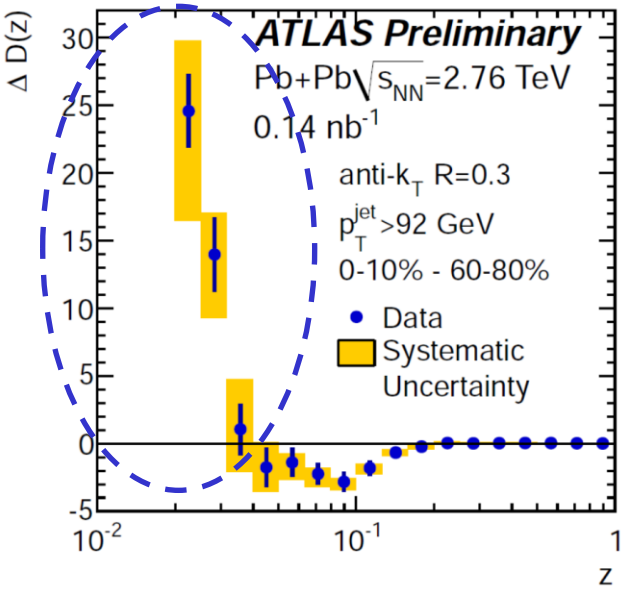


Joern Putschke (STAR 5/21)



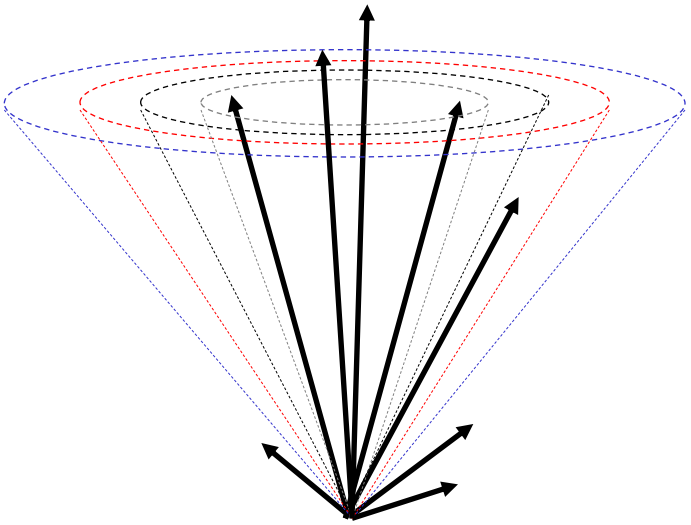
Martin Spousta (ATLAS 5/20)



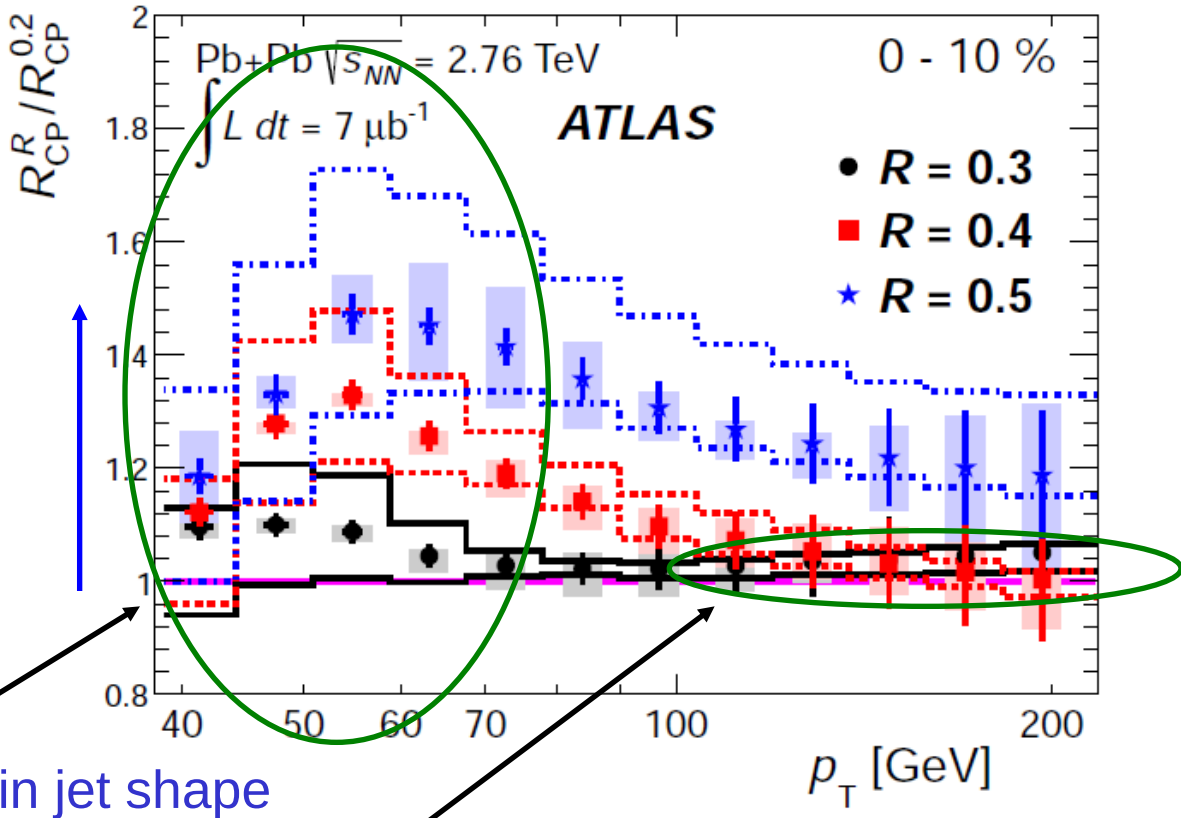


Do we collect the radiated energy with large cone size?

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



Ratio of R_{CP} with different cone sizes



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

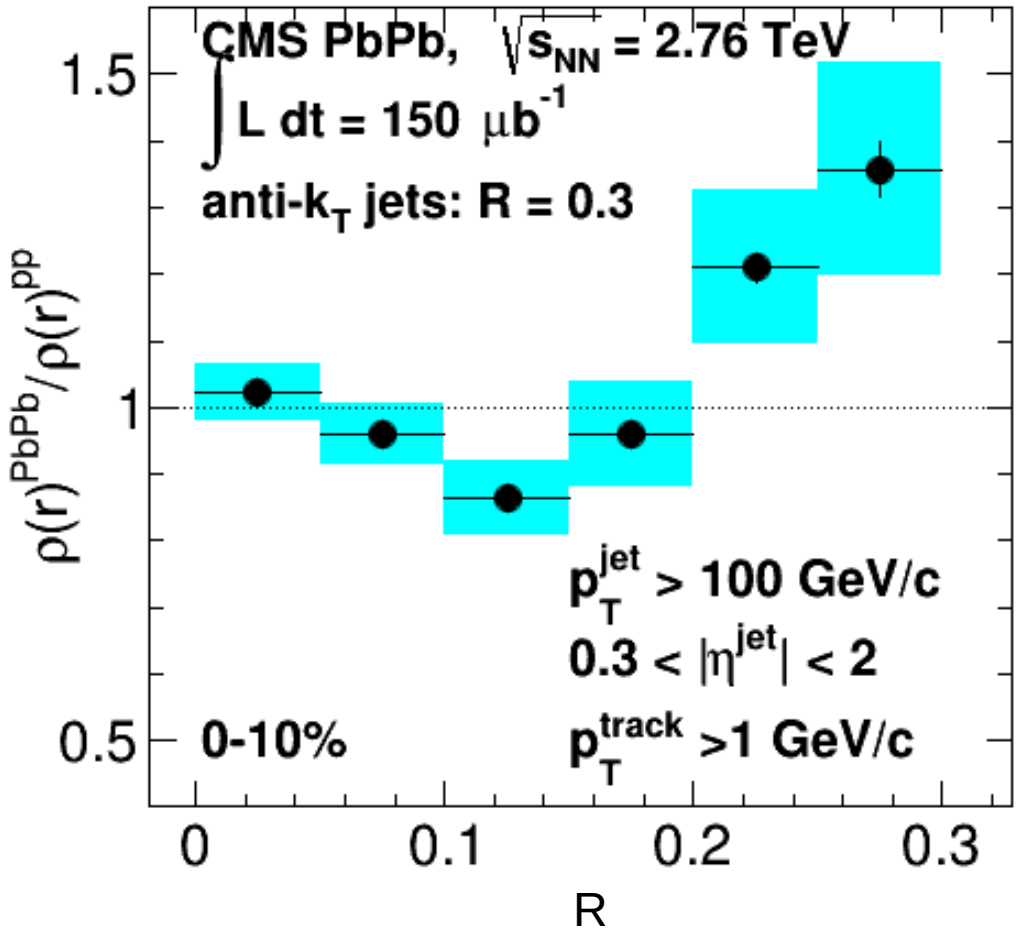
→ recovery of lost energy, change in jet shape with respect to the pp reference

ATLAS Jet $R_{CP}^{(R=0.3)} / R_{CP}^{(R=0.2)} \sim 1.0 \pm 0.2$

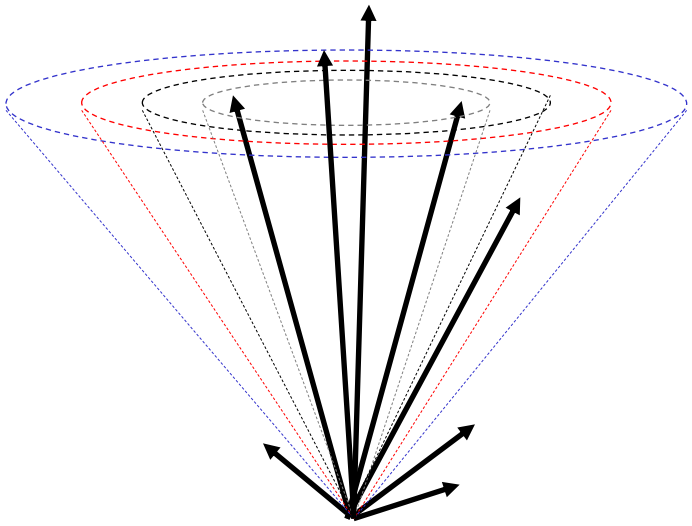
Allows to recover up to 0-4% more jet energy when moving from R=0.2 → R=0.3 in PbPb collisions than pp reference

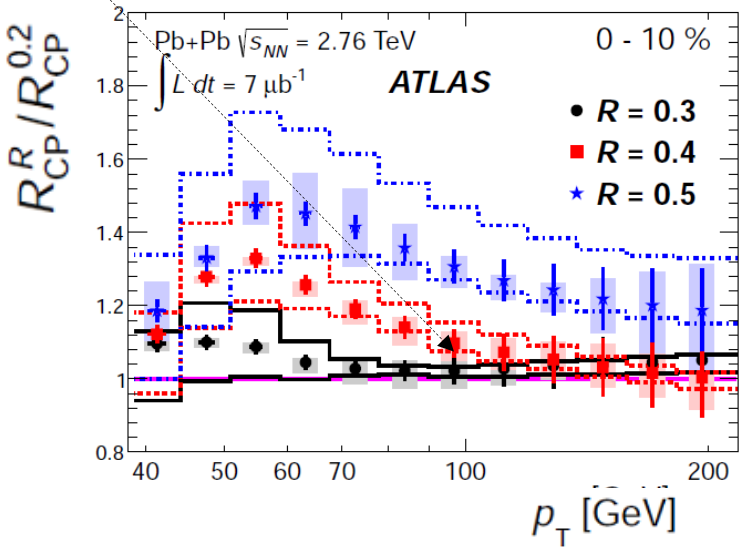
Jet shape v.s. R_{AA} ratio

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)

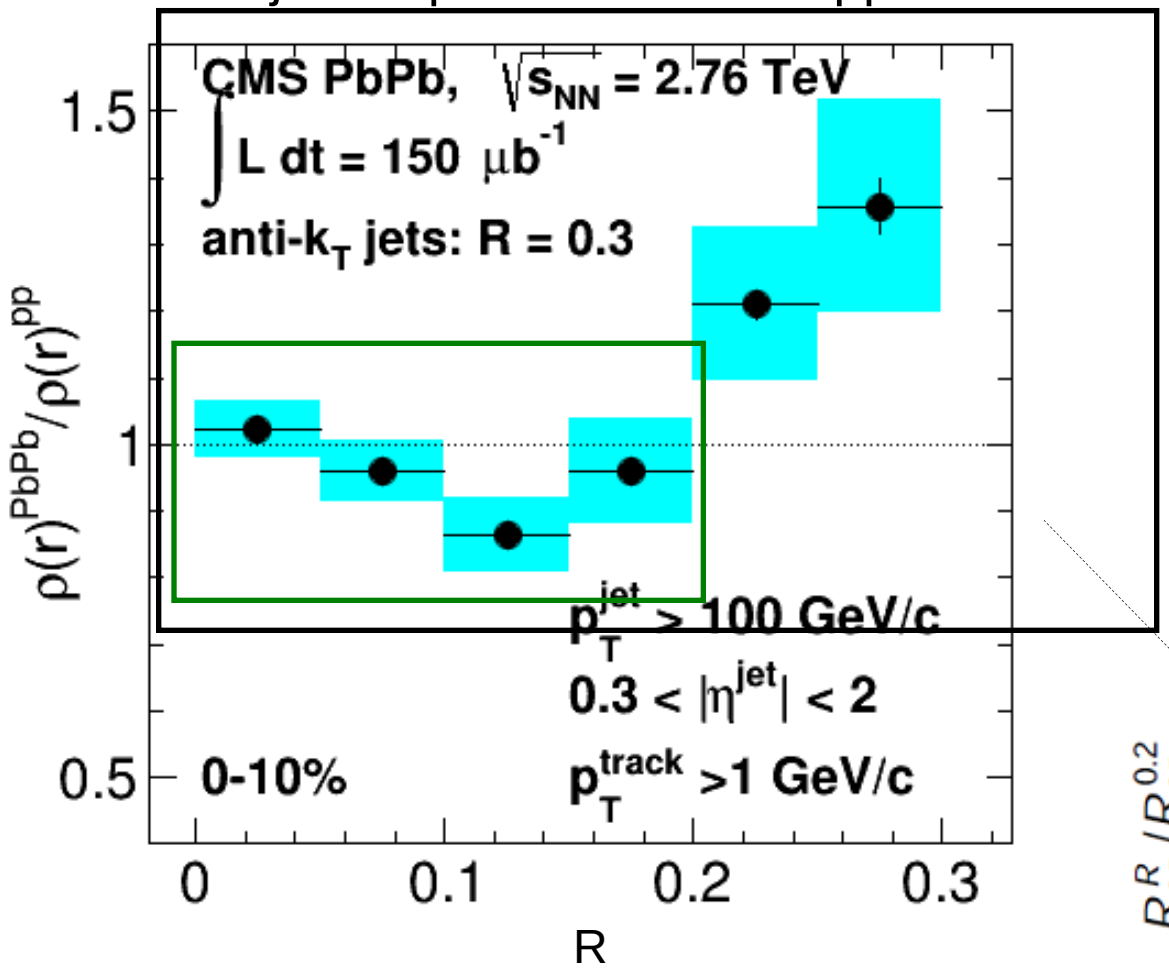




ATLAS Jet R_{CP} (R=0.3) / R_{AA} (R=0.2) ~ 1.0 ±0.2
Allows to recover up to 0-4% more jet energy than pp reference

Jet shape v.s. R_{AA} ratio

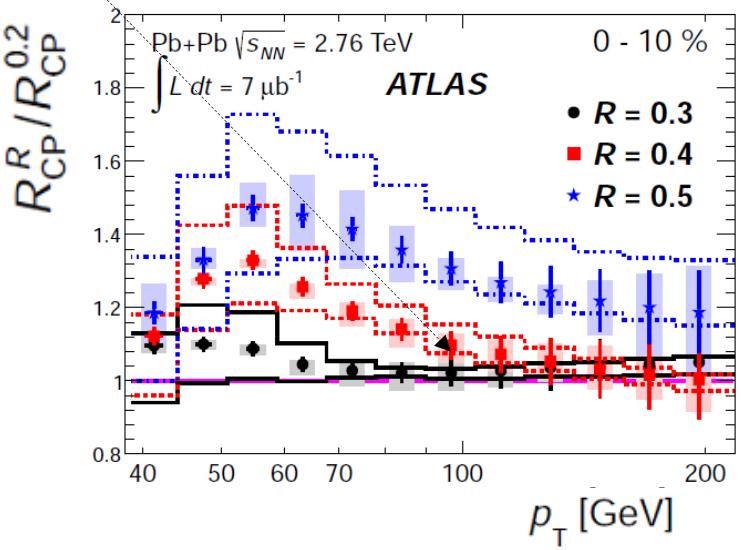
Ratio of jet shapes in PbPb and pp collisions



Changing the R from 0.2 to 0.3→ recover more radiated energy

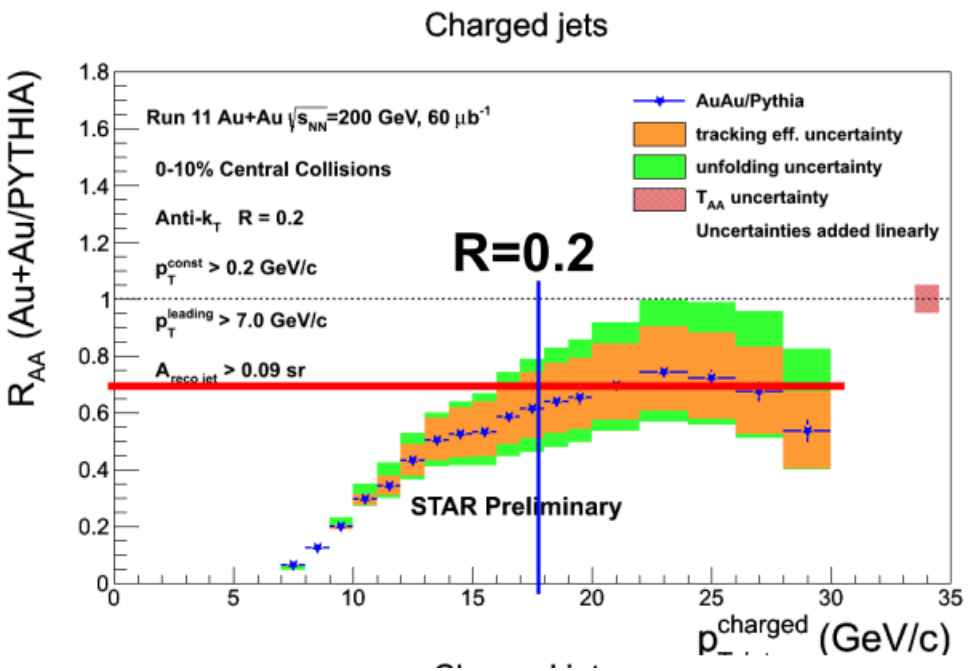
CMS observed this change in R recover ~1% more energy in PbPb than pp

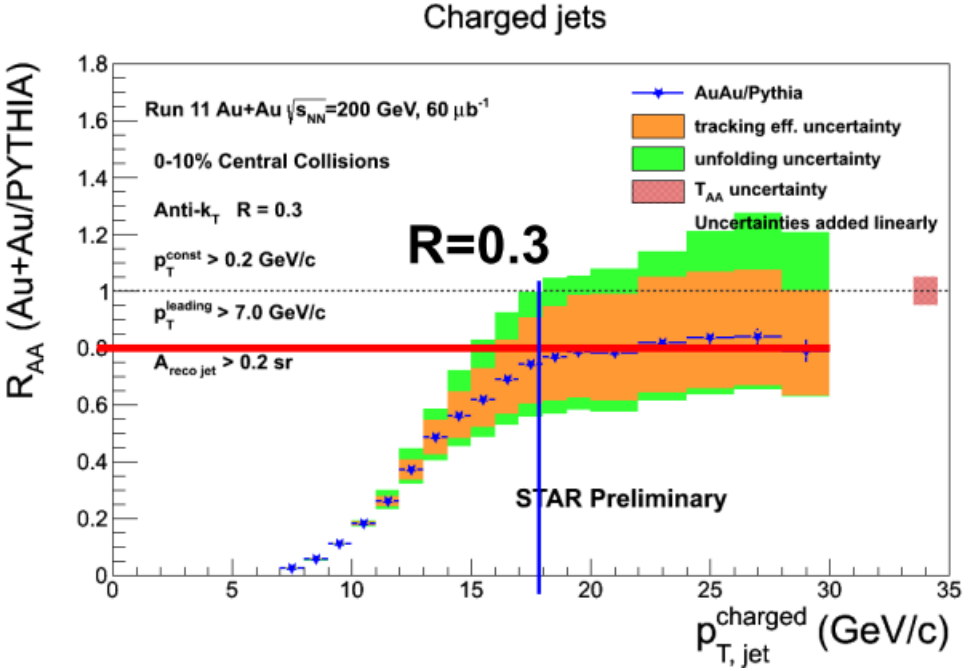
CMS and ATLAS results are compatible

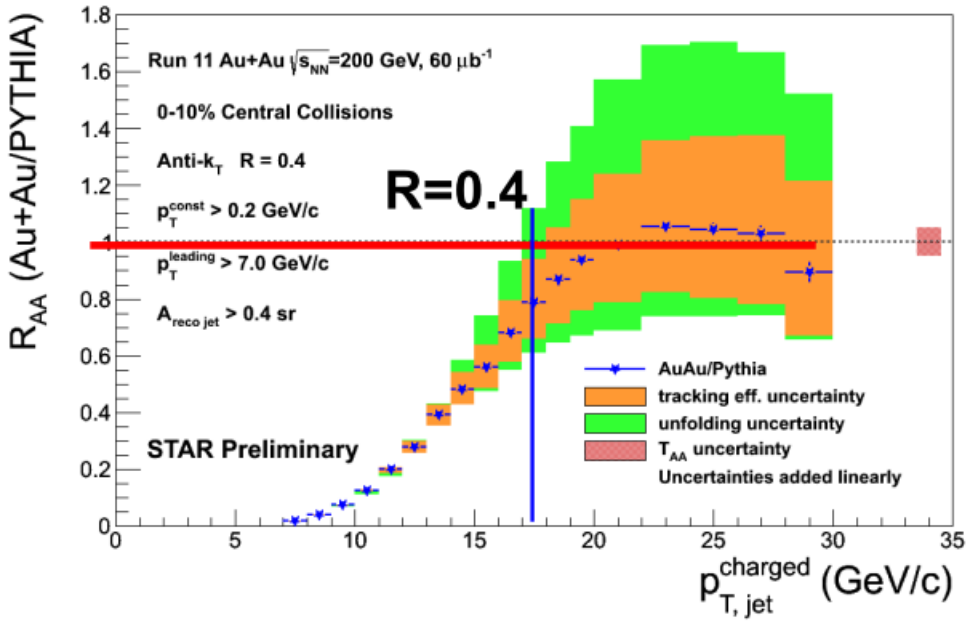


ATLAS Jet R_{CP} (R=0.3) / R_{AA} (R=0.2) ~ 1.0 ±0.2
Allows to recover up to 4% more jet energy than pp reference

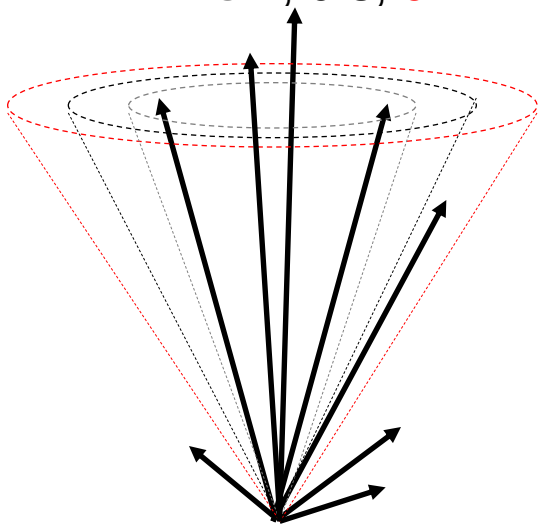
STAR R_{AA} v.s. R







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

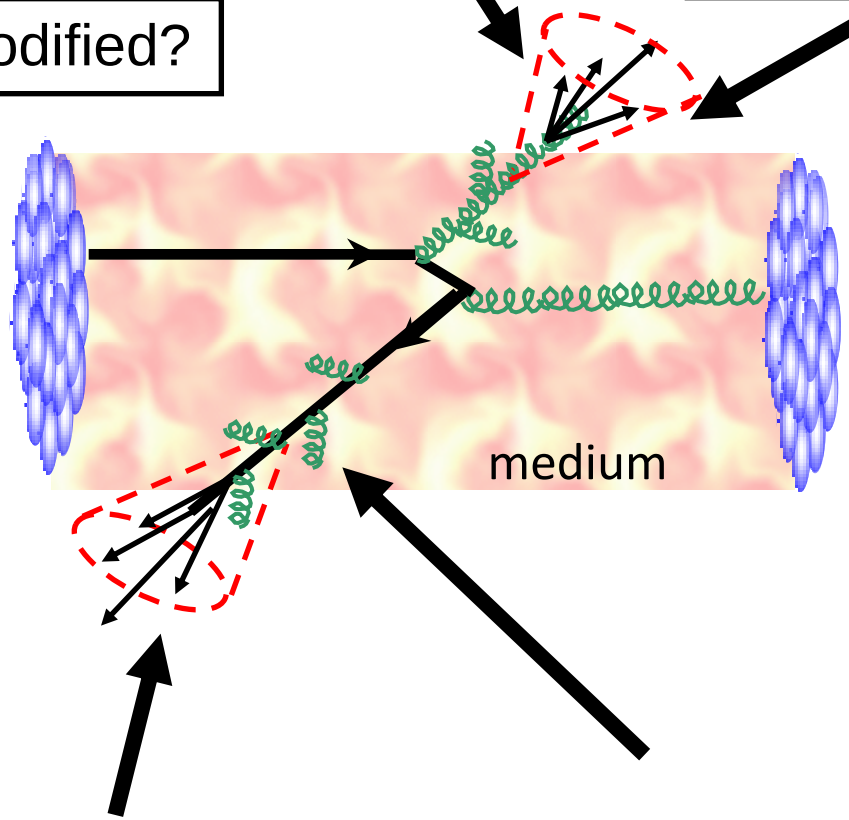


Questions to be answered

2. Can we recover the lost energy by jet reconstruction?

3. Flavor Dependence of Jet Quenching?

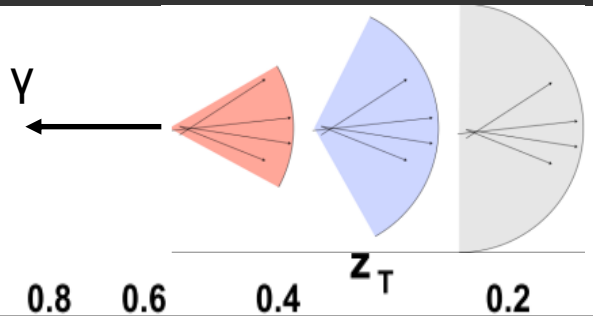
1. Is the initial state modified?

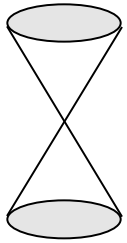


4. Is the jet structure modified?

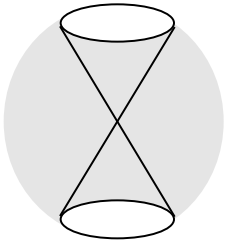
5. Where does the lost energy go?

Lost energy at RHIC and LHC

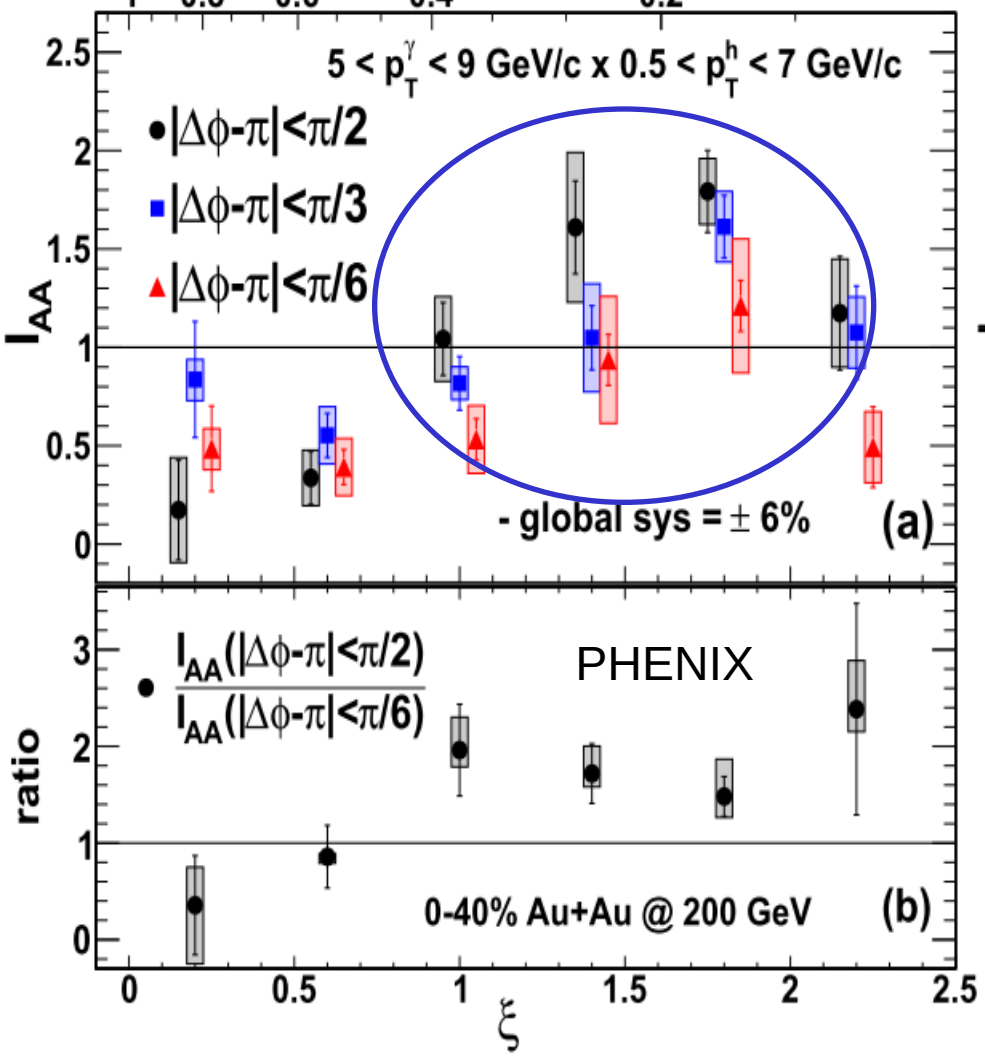


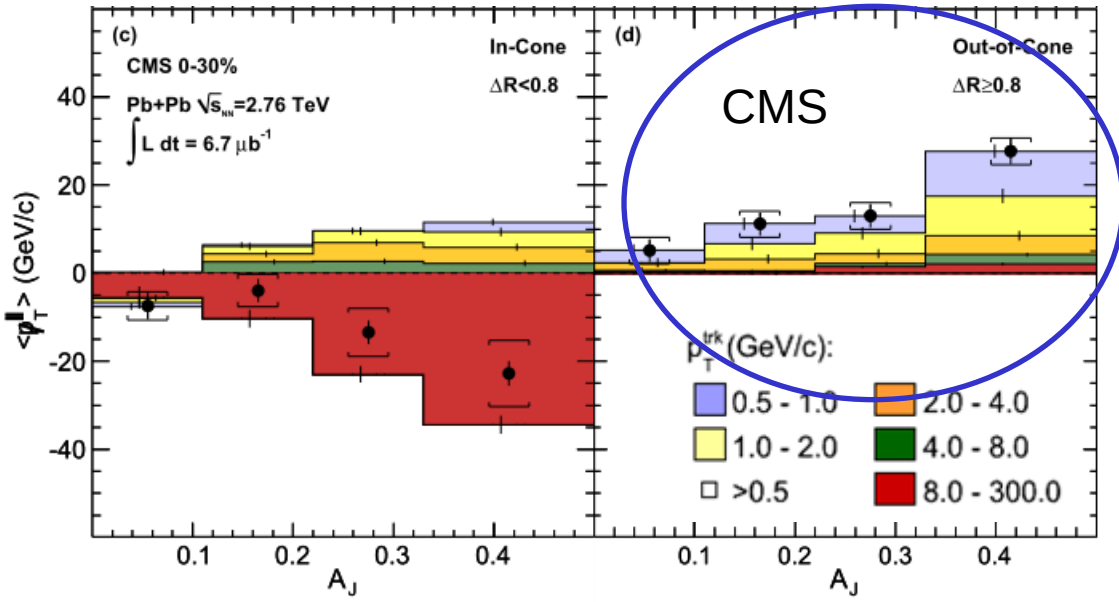


Tracks in the jet cone $\Delta R<0.8$



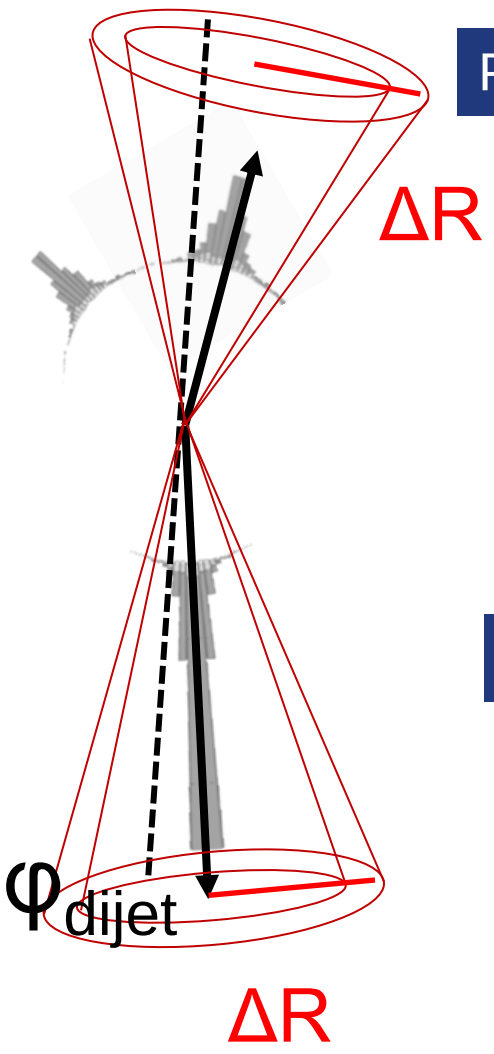
Tracks out of the jet cone $\Delta R>0.8$



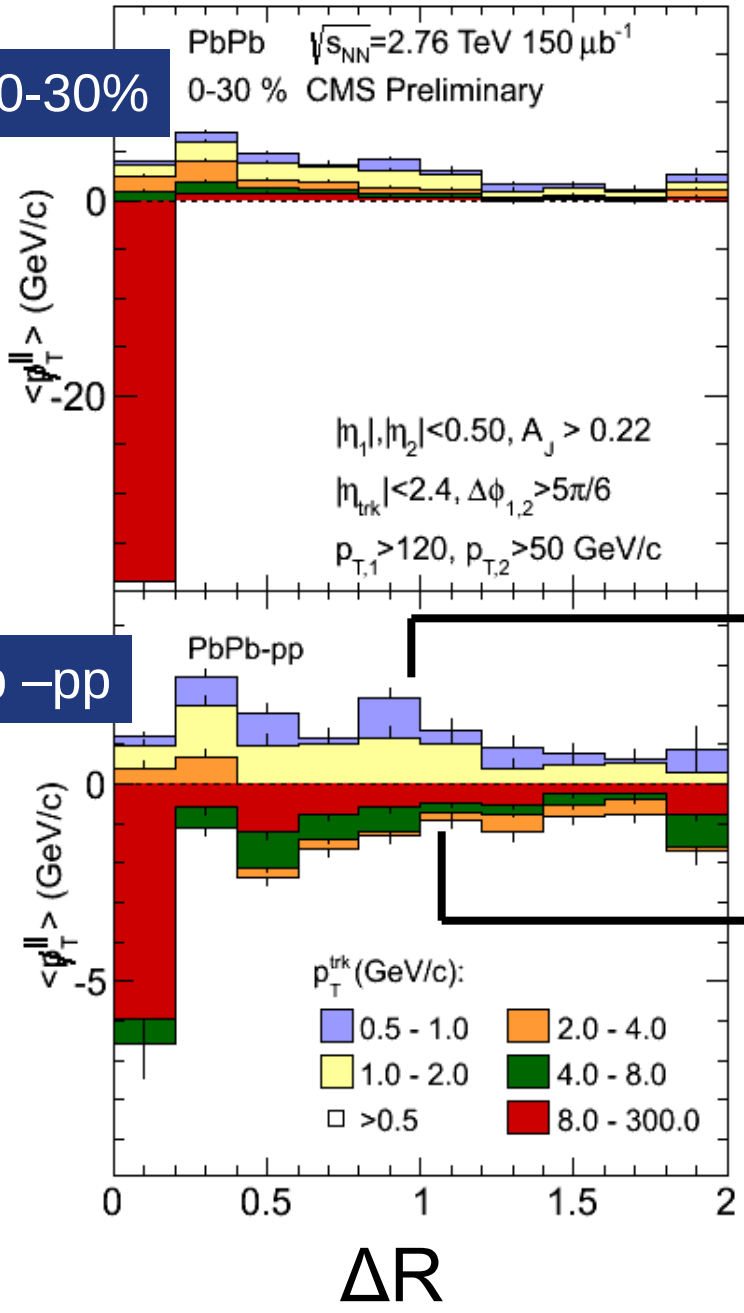


Lost energy: found in large Δφ(ΔR) with respect to the away-side jet, converted to low p_T particles.

Results - Missing p_T vs. ΔR



PbPb 0-30%



PbPb –pp

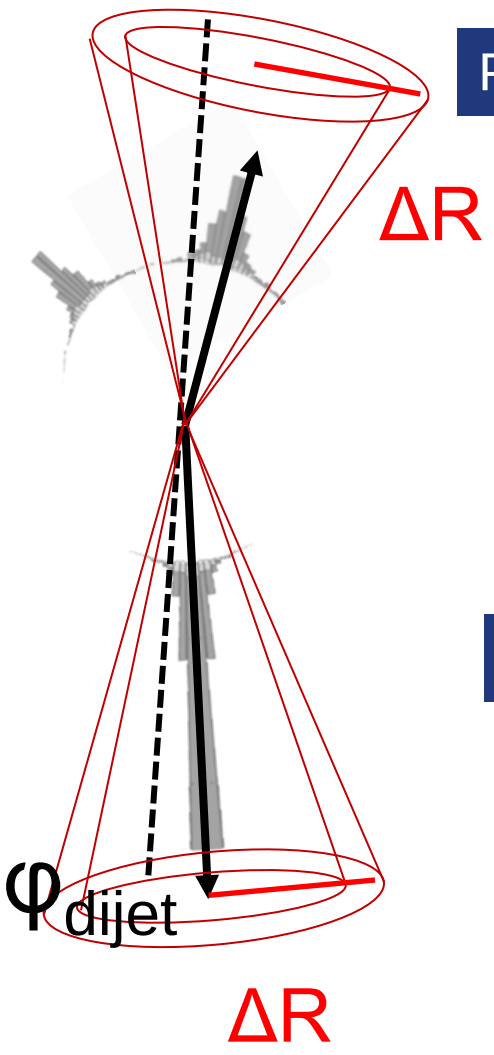
$A_J > 0.22$

Enhancement of low p_T particles in PbPb

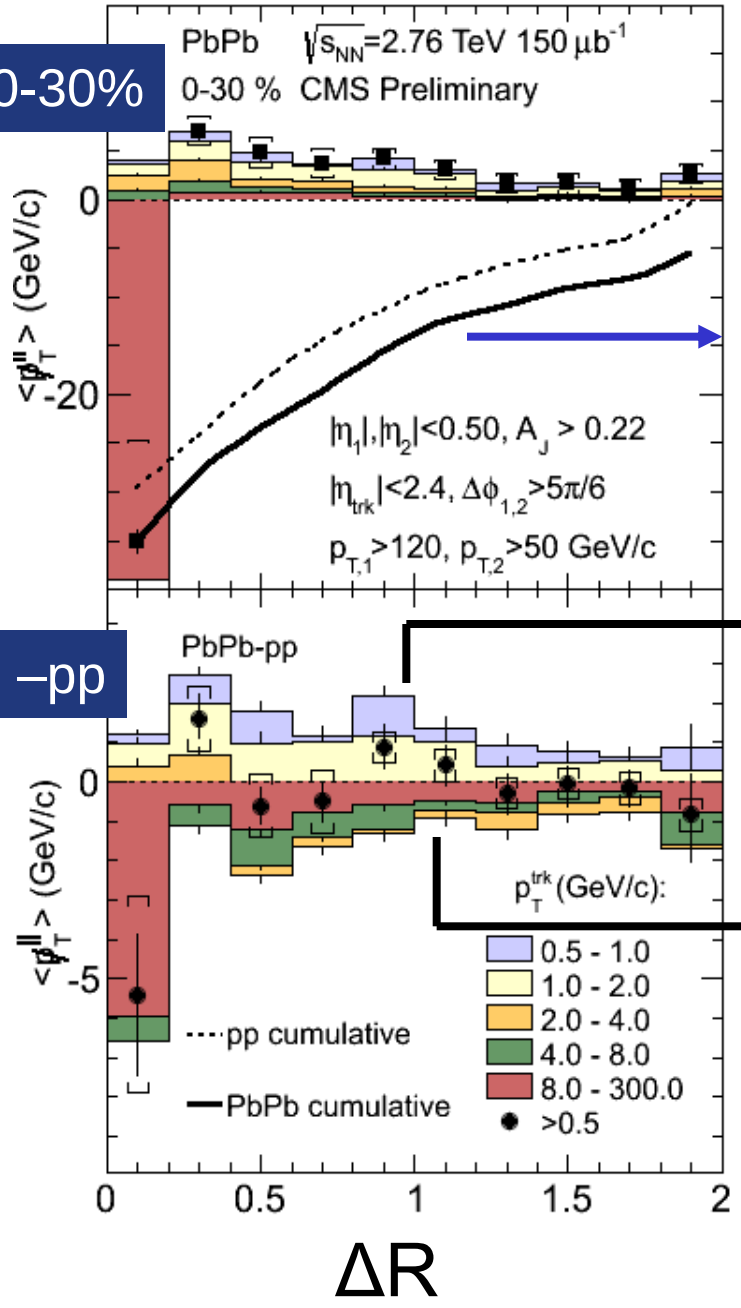
Out of cone radiation is carried by a third jet in pp

Doga Gulhan (CMS 5/20)

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

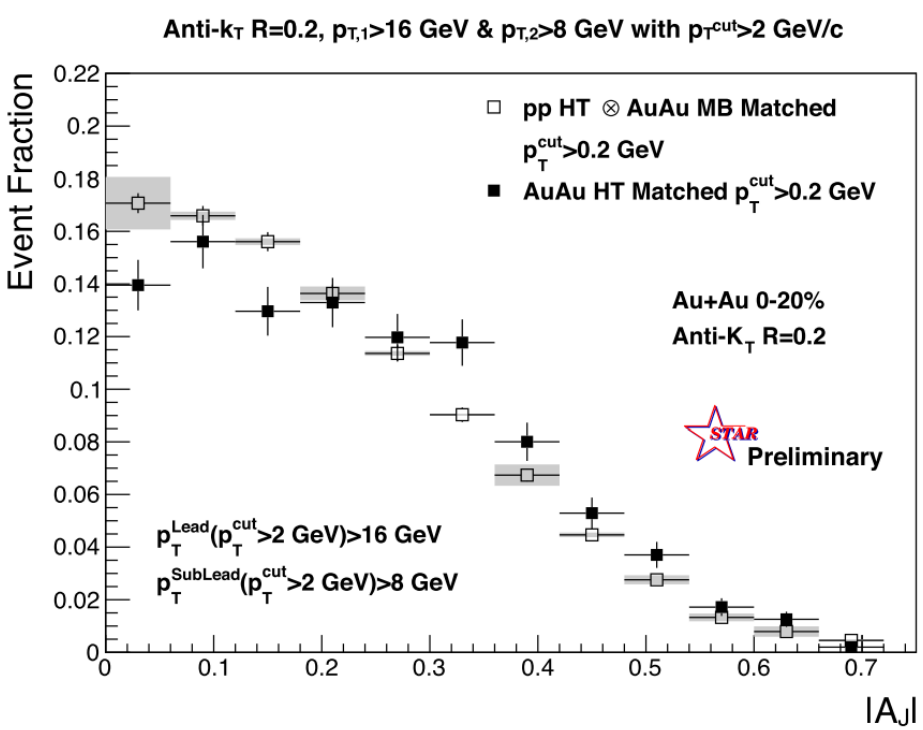
Enhancement of low p_T particles in PbPb

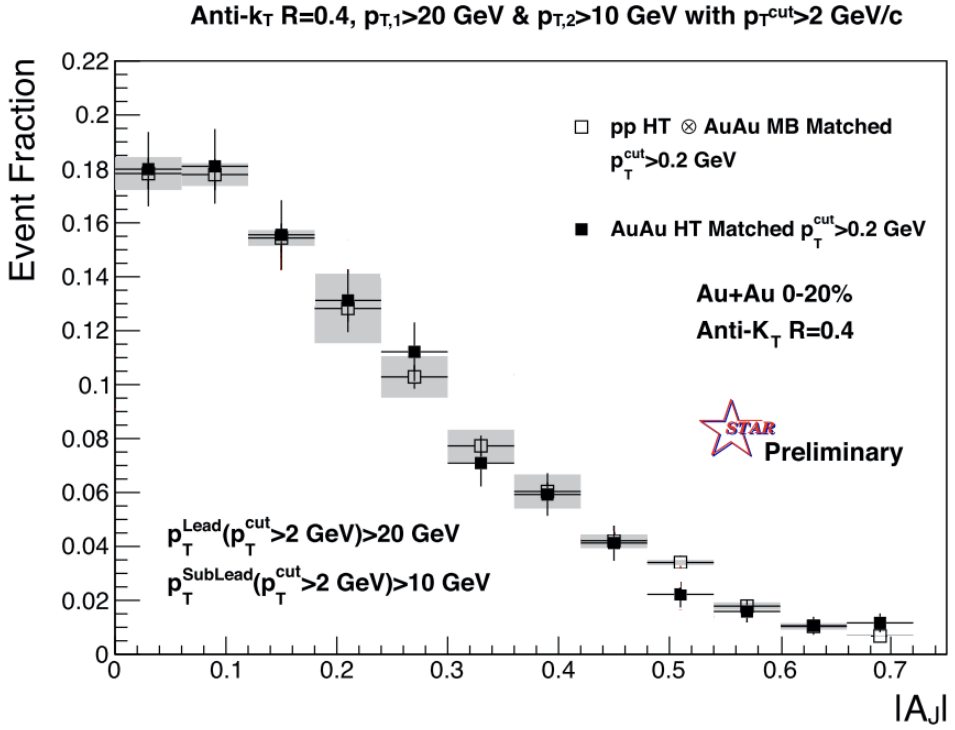
Out of cone radiation is carried by a third jet in pp

Doga Gulhan (CMS 5/20)

Lost energy at RHIC

R=0.2 cone ⟶ R=0.4 cone





Dijet transverse momentum balance is recovered with anti-k_T R=0.4 jet reconstruction

Selection on the hard fragmenting jet may bias the production vertex of the jets toward the surface of the medium

→ interesting to see what we get when implementing similar bias at the LHC

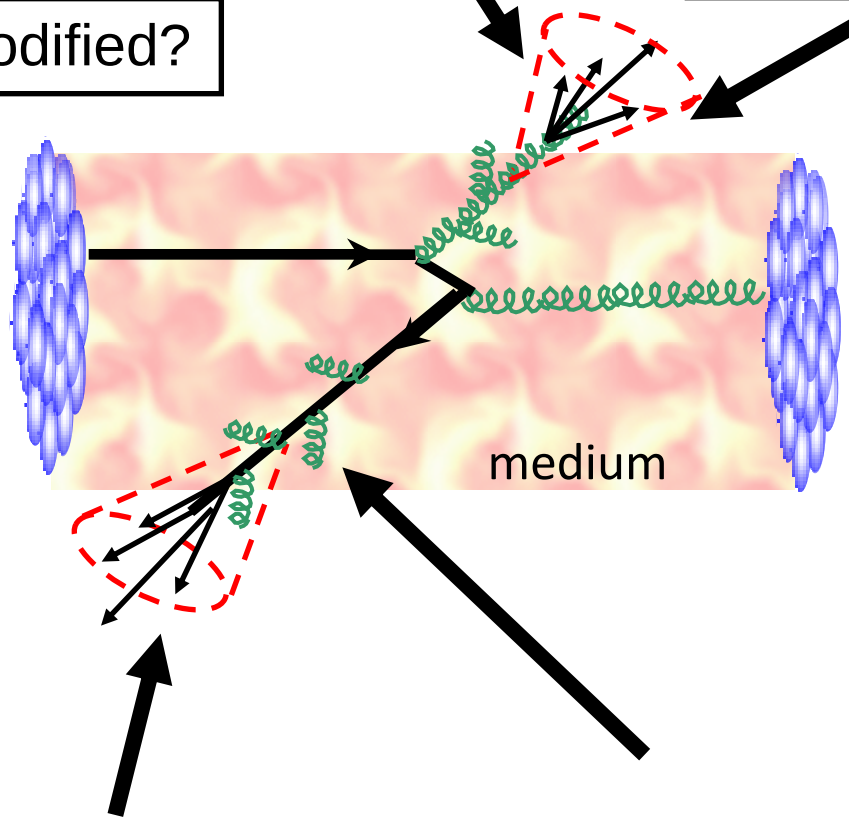
sPHENIX upgrades to look at fully reconstructed jets at RHIC

Questions to be answered

2. Can we recover the lost energy by jet reconstruction?

3. Flavor Dependence of Jet Quenching?

1. Is the initial state modified?

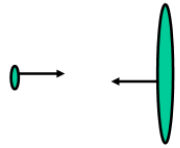


4. Is the jet structure modified?

5. Where does the lost energy go?

Summary and outlook (1/2)

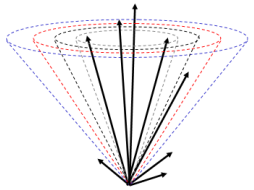
1. Is the initial state modified?



Inclusive pPb collisions: can be described by nPDF

In bins of event activity: interesting effects such as energy conservation (G. Milhano, N. Armesto), fluctuating proton size (M. Strikman) come into play

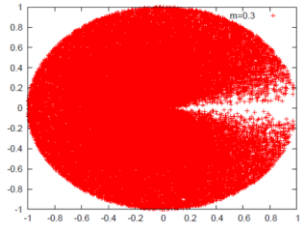
2. Can we recover the lost energy by jet reconstruction?



Lost energy is recovered slowly, R=0.2-0.5 doesn't recover all the lost energy

Different behavior observed (in STAR) if biased jet fragmentation selection is used

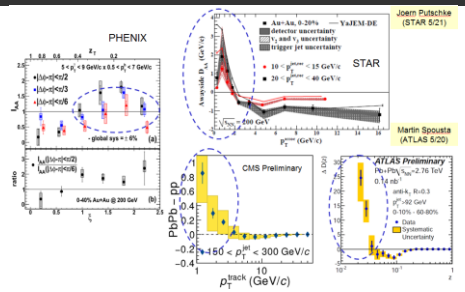
3. Flavor Dependence of Jet Quenching?



Hint of parton flavor dependence of energy loss at low p_T, disappearance at high p_T
To be followed up by high statistics fully reconstructed D meson, B meson, b-jet angular correlation, and identified jets

Summary and outlook (2/2)

4. Is the jet structure modified?



Excess of low p_T particles inside the jet cone.

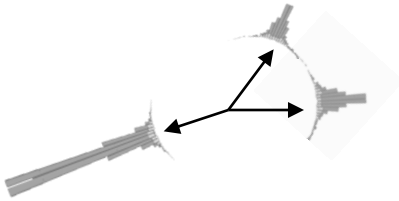
Modified jet FF and/or jet shapes can be explained by different classes of models

Which part of it is coming from the changing q/g fraction?

How does parton energy loss depend on the fragmentation pattern?

Can we learn more using sub-jet reconstruction?

Fluctuation of jet fragmentation modification?



5. Where are the lost energy?

The lost energy is carried by low p_T particles far away from the jet cone

Distribution of lost energy: Initial configuration (2/3/multi-jet) + medium effects

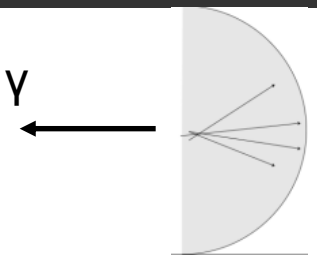
Can we kill the effect by biasing the jet fragmentation?

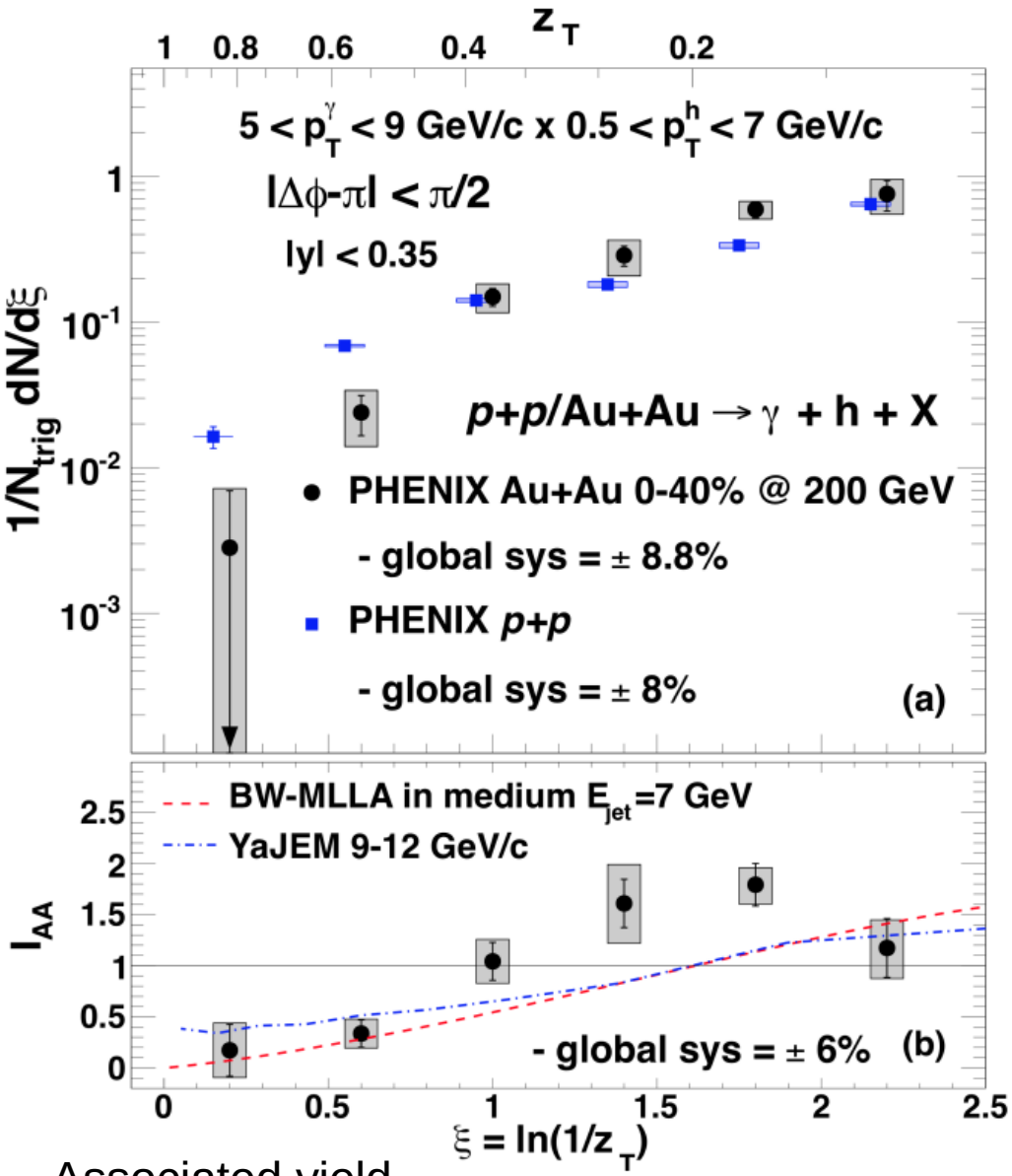
What are the alternative way to select quenched jets?

Backup slides

Photon-hadron correlation

Using **Photon Energy** as a reference





Associated yield