Jets in Heavy Ion Collisions Measured by ATLAS

Helena Santos, LIP-Lisbon

On Behalf of the ATLAS Collaboration

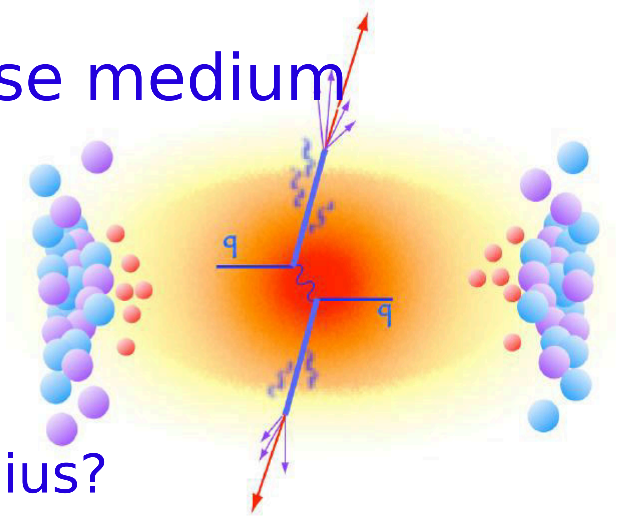
Excited QCD 2013

Bjelasnica Mountain, February 3-9th

Jets in Heavy Ion Collisions

Unknowns:

How do parton showers in hot and dense medium differ from those in vacuum?



How much is the jet yield suppressed?

How does the suppression depend on jet radius?

Is the fragmentation function modified?

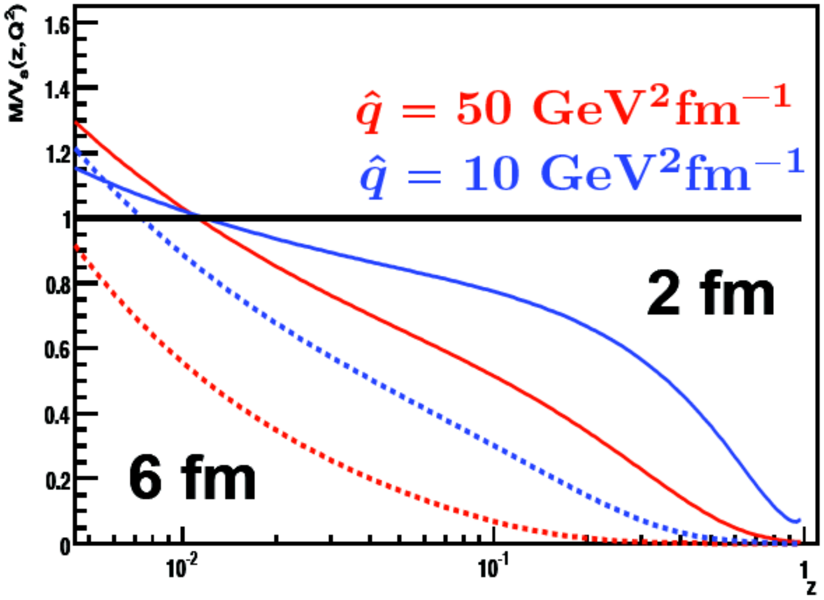
Is the partons angular distribution broadened?

What is the physics responsible for this modification?

Jets in Heavy Ion Collisions

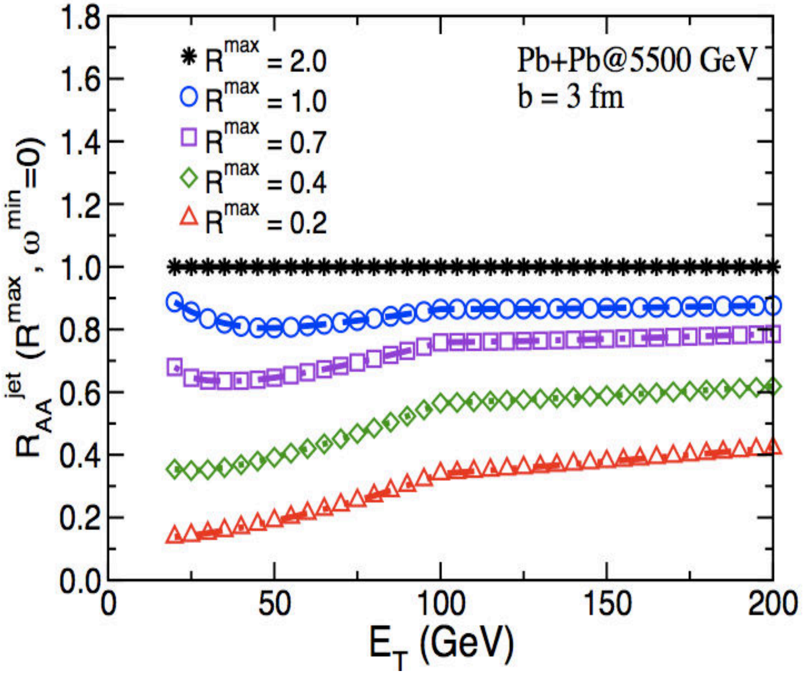
Expectations:

Medium interactions induce additional radiations modifying usual fragmentation in vacuum.



N. Armesto, L. Cunqueiro, C. A. Salgado, and W.-C. Xiang, *Medium-evolved fragmentation functions*, JHEP **0802** (2008) 048, arXiv:0710.3073 [hep-ph].

Medium-induced radiation may cause energy deposition outside jet cone

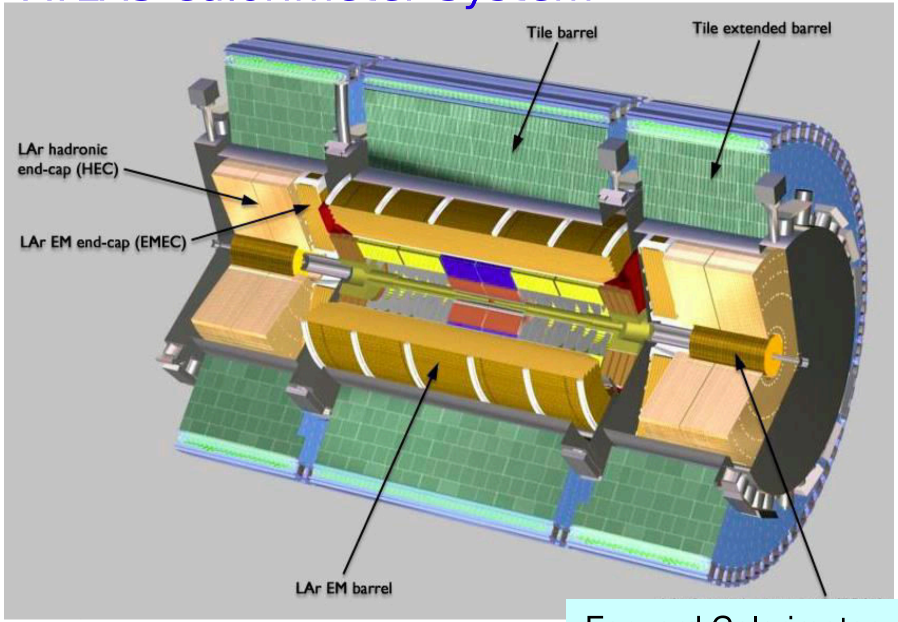


I. Vitev, S. Wicks, and B.-W. Zhang, *A theory of jet shapes and cross sections: from hadrons to nuclei*, JHEP **11** (2008) 093, arXiv:0810.2807 [hep-ph].

Predictions of radiative energy loss suggest that energy can be recovered by expanding jet cone

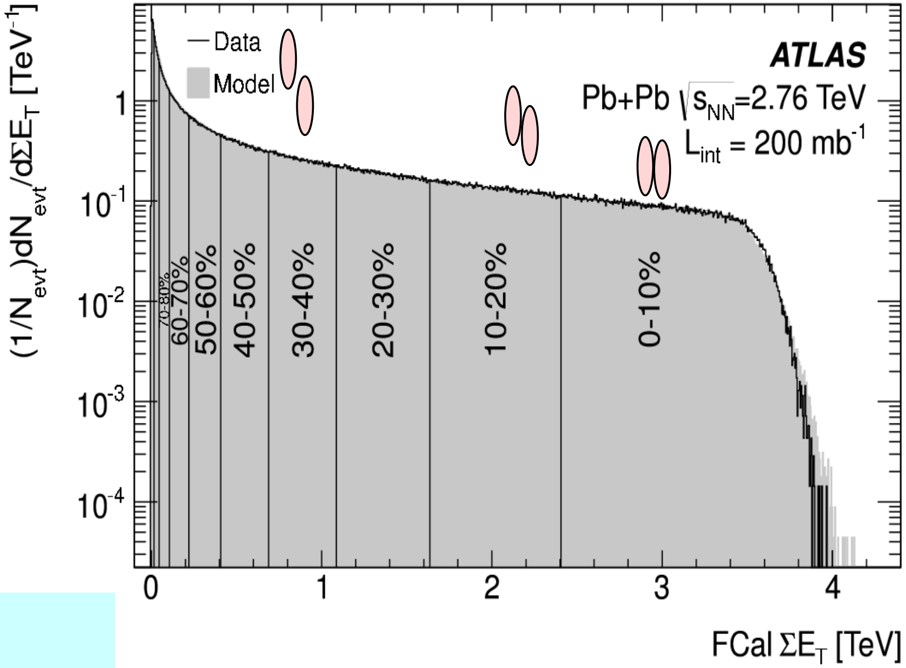
Collision's Centrality

ATLAS Calorimeter System



Forward Calorimeter
3.1<|η|<4.9,(one arm)

ET in Forward Calorimeter (FCal)



- Transverse energy in FCal compared to Glauber MC model $\otimes$ p+p data
- Sampling fraction f = 98 ± 2%, after all trigger and selection cuts
- Data are divided in 10% centrality intervals

Jets Reconstruction

Jets are reconstructed using anti-k_T algorithm with four choices of R parameter (R=0.2, 0.3, 0.4 and 0.5)

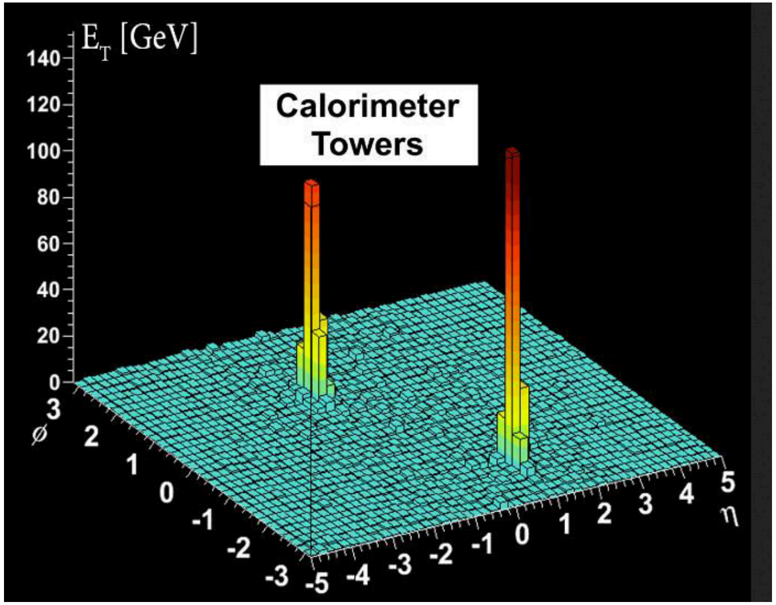
Inputs are 0.1x0.1 (ΔηxΔϕ) calorimeter towers (piled cells)

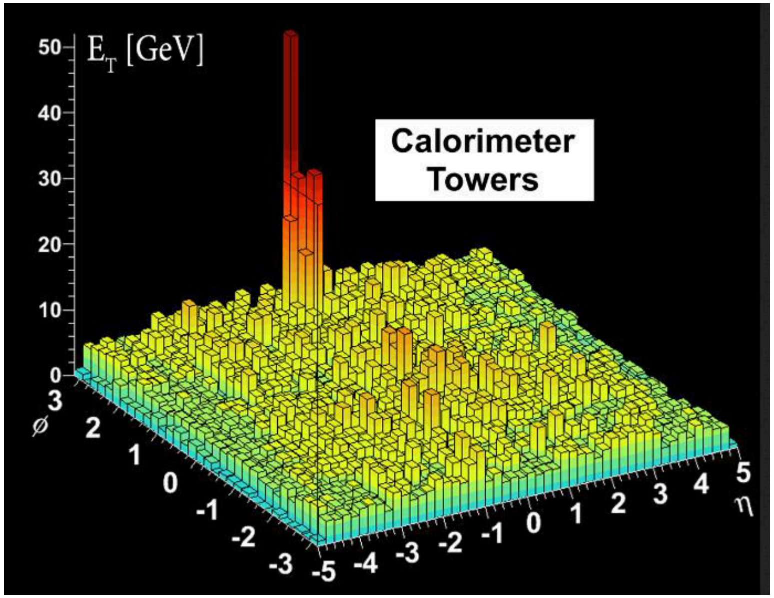
Average background estimated event-by-event per calorimeter sampling layer and per 0.1 η strip

$$E_{T,subt}^{cell} = E_T^{cell} - \rho x A^{cell}$$

Background modulated by elliptic flow before subtraction

Define jet seeds and exclude them from cell's energy density (ρ) and elliptic flow estimates



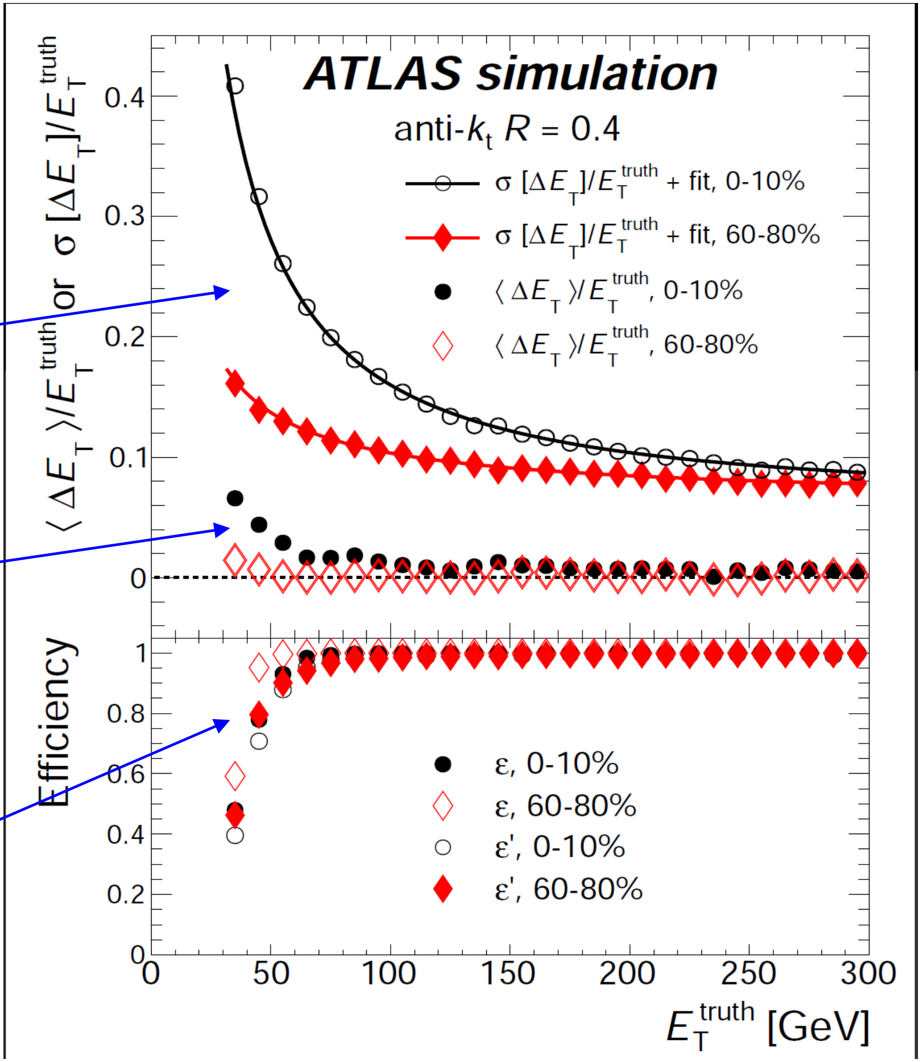


Jets Reconstruction Performance

Jet energy resolution
- Low ET: dominated by underlying event fluctuations
- High ET: limited by intrinsic detector resolution

Jet energy scale evaluated from the mean fractional energy shift

Efficiencies for finding jets before and after removing jets from the underlying event



Di-jet Asymmetry

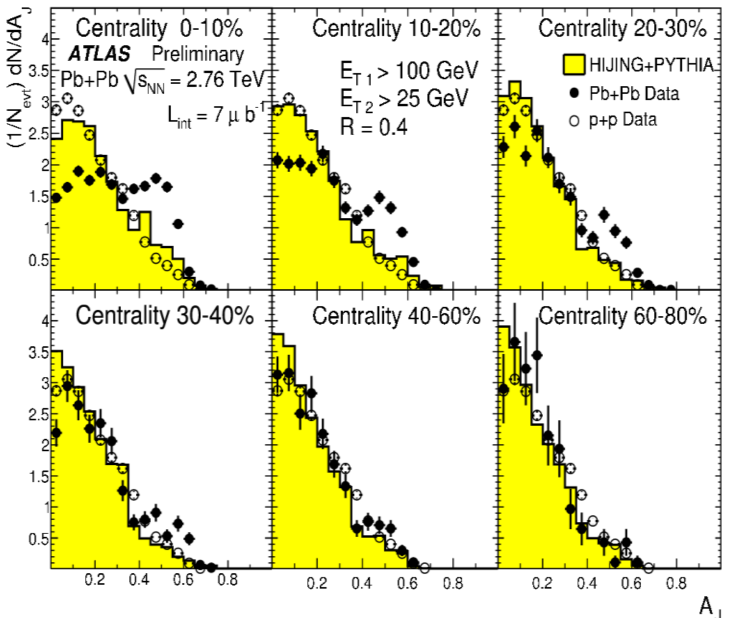
Enhancement of asymmetric di-jets, relatively to p+p and PYTHIA+HIJING → first indication of jet suppression

$$A_J = \frac{E_{T1} - E_{T2}}{E_{T1} + E_{T2}}$$

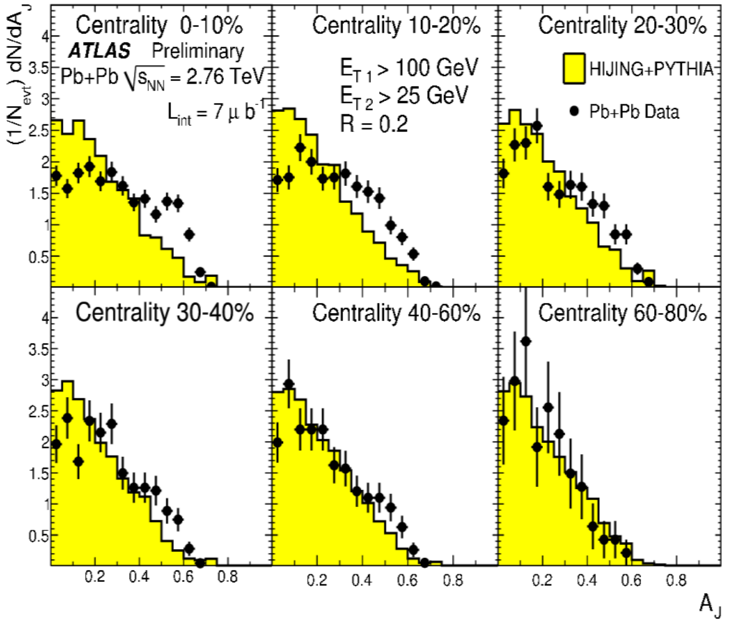
$$E_{T1} > 100\, GeV$$

$$E_{T2} > 25\, GeV$$

$$|\eta| < 2.8$$



R=0.4



R=0.2

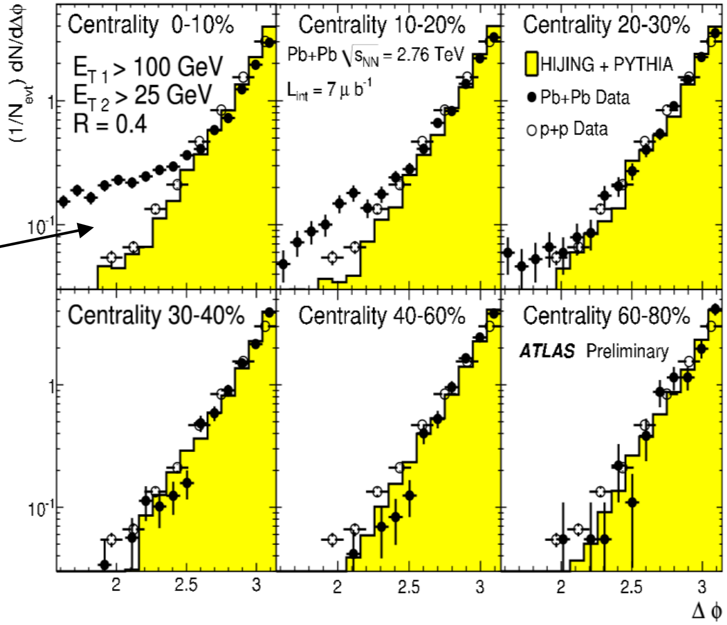
Flatter distribution for R=0.2 jets

PRL 105 (2010) 252303; ATLAS-CONF-2011-075

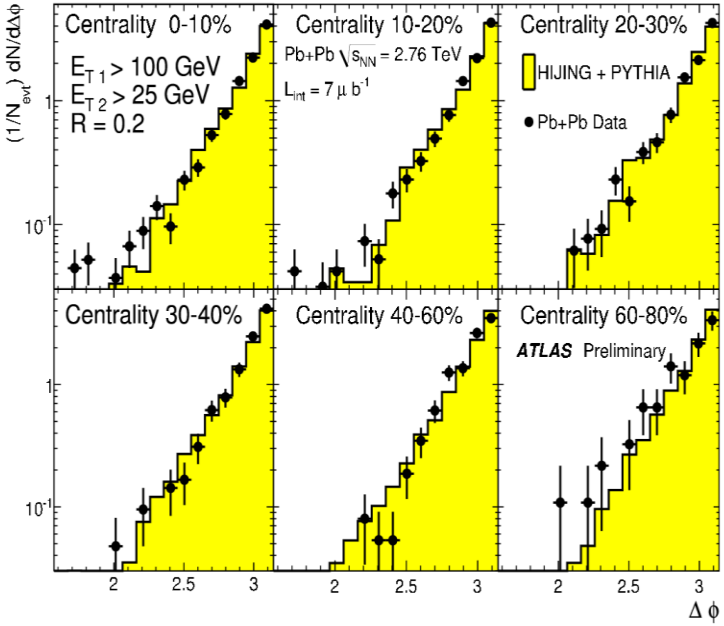
Di-jet Azimuthal Correlation

$\Delta\varphi=\pi$ acoplanarity remains, while A_J is changing

Consistent with combinatoric contribution to R=0.4 di-jet $\Delta\varphi$ distribution
– 2nd jet “missing” and uncorrelated jet used



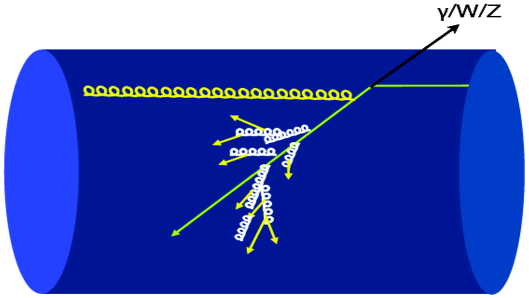
R=0.4



R=0.2

- But, combinatoric contribution much smaller for R=0.2
– Yet, equally strong asymmetry modification

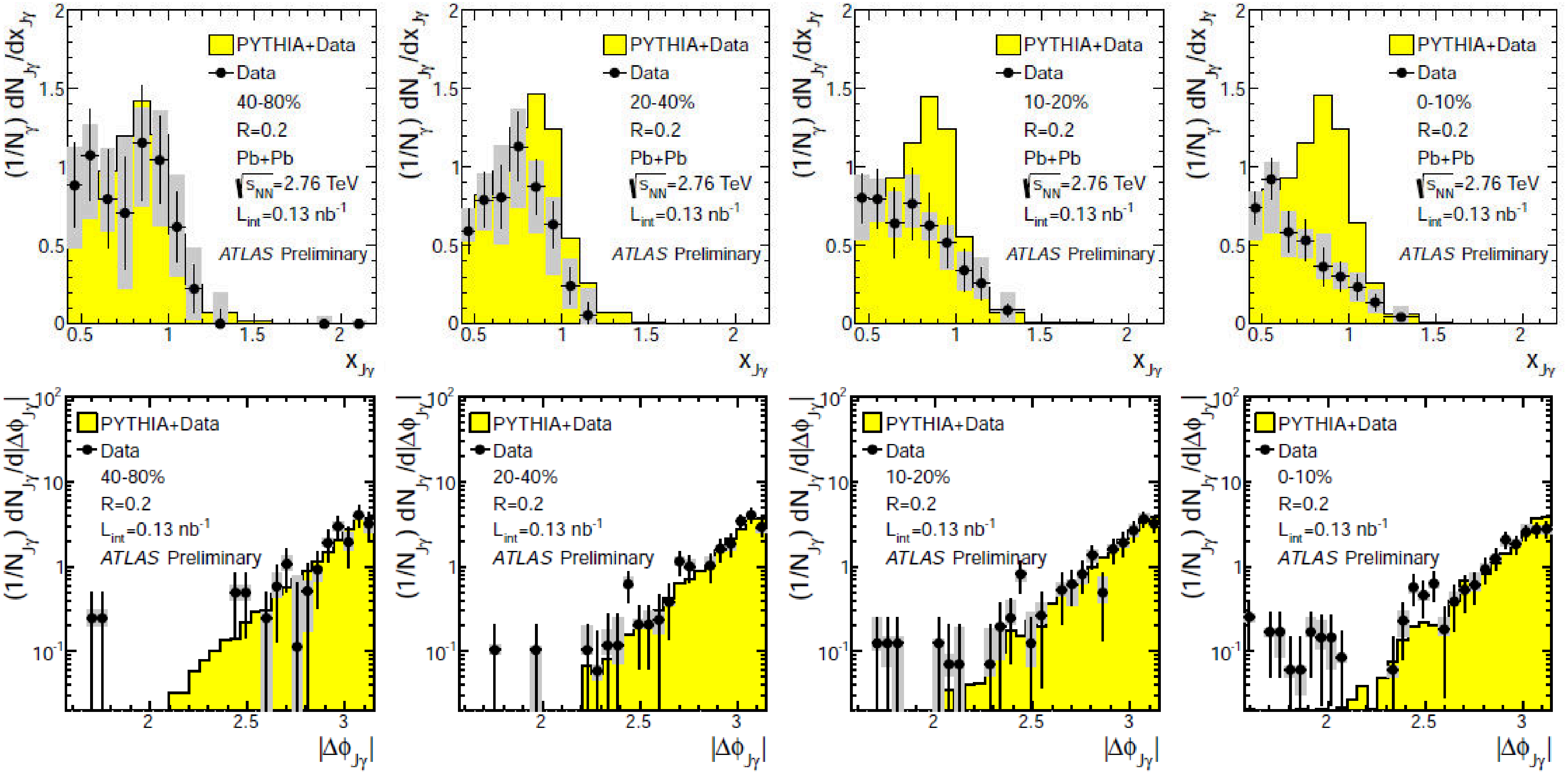
Probing Jet Energy Loss with Photons



ATLAS-CONF-2012-121

Electroweak bosons are unaffected by the medium, allowing calibrate scale of the hard process and directly probe jet energy loss

$$x_{J\gamma} = p_T^{jet} / p_T^{\gamma}$$



Beyond Asymmetry

Di-jet asymmetry and unbalanced photon-jet transverse momentum are direct probes of parton energy loss but cannot account for the details. A deeper insight is needed:

– How are the inclusive jet yields suppressed?

– How does the suppression depend on jet energy and collisions centrality?

– Does the suppression depend on the size of the jet?

– Is the structure of jets modified? How do the spectra of particles inside jets differ in central collisions?

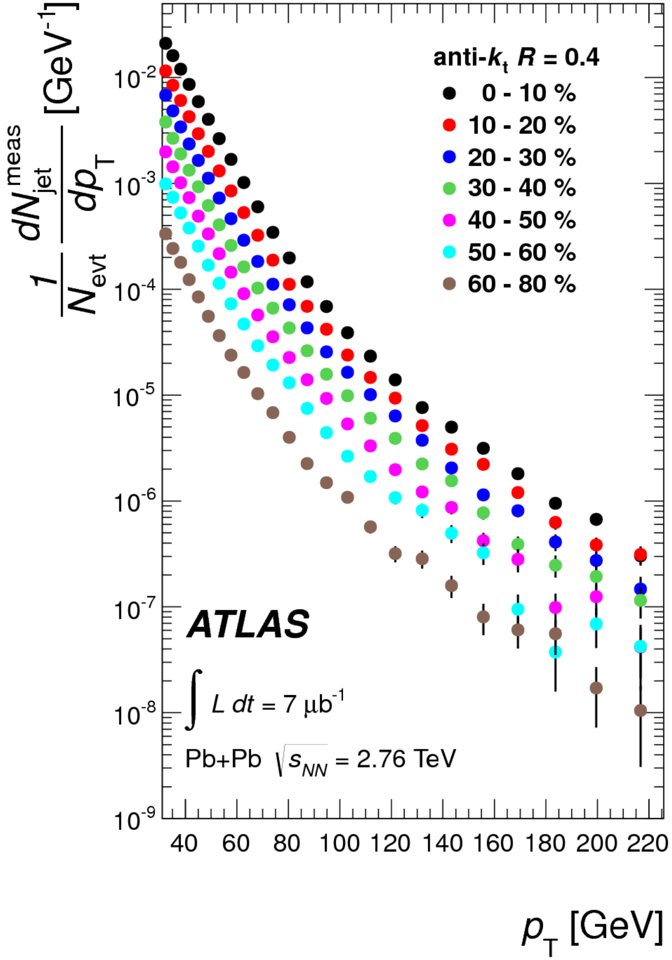
And more (not covered in this talk)
- Does the suppression depend on the path-length of a parton traversing the medium?

- Does the suppression depend on the flavor of initial parton?

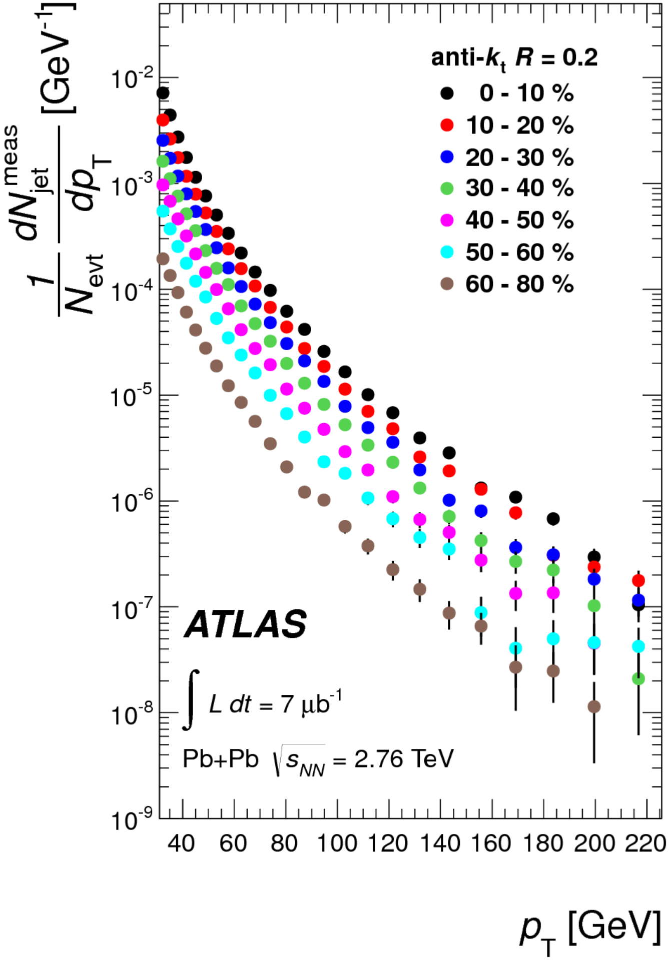
More...?

Jet p_T Spectra

R=0.4



R=0.2



Not corrected for detector effects

Steep falling spectra independently on collisions centrality, but how does the ratio between a given centrality interval and the most peripheral one?

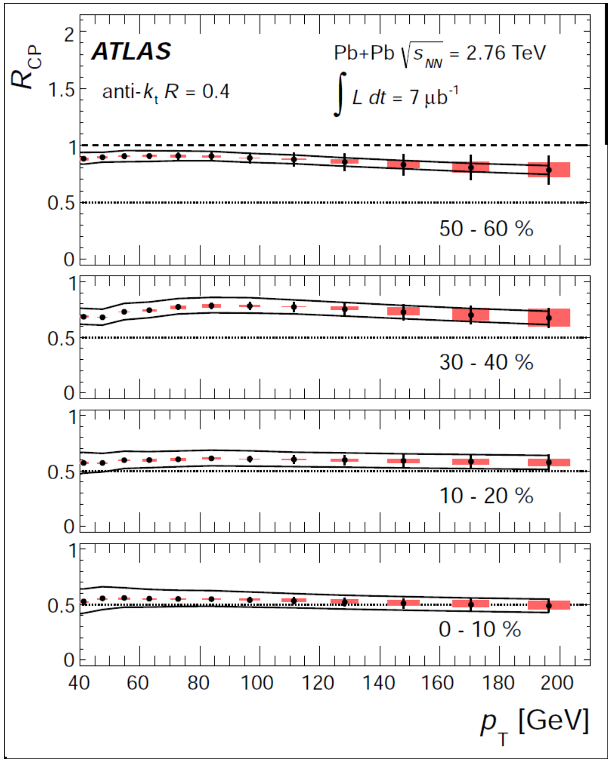
R_{cp} versus p_T and Centrality

Reference is the jet yield in the 60-80% centrality interval

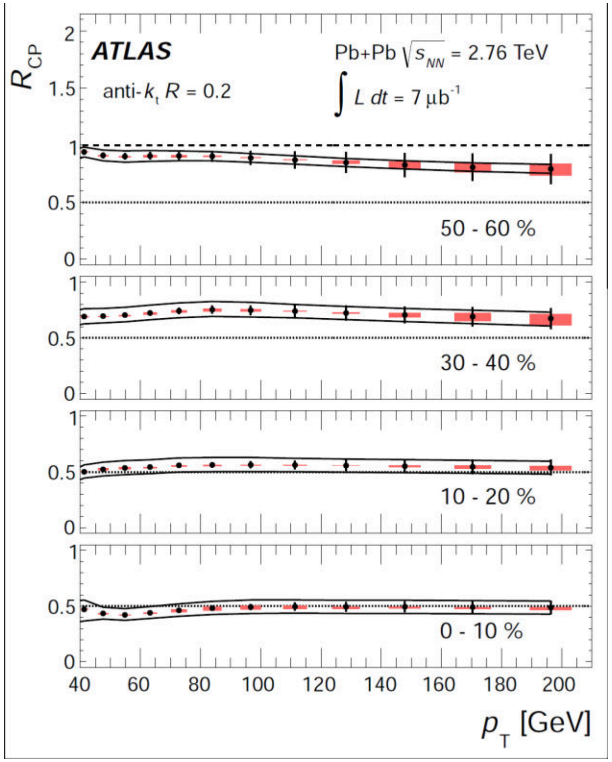
[hep-exarXiv:1208.1967]

Corrected for detector effects

R=0.4



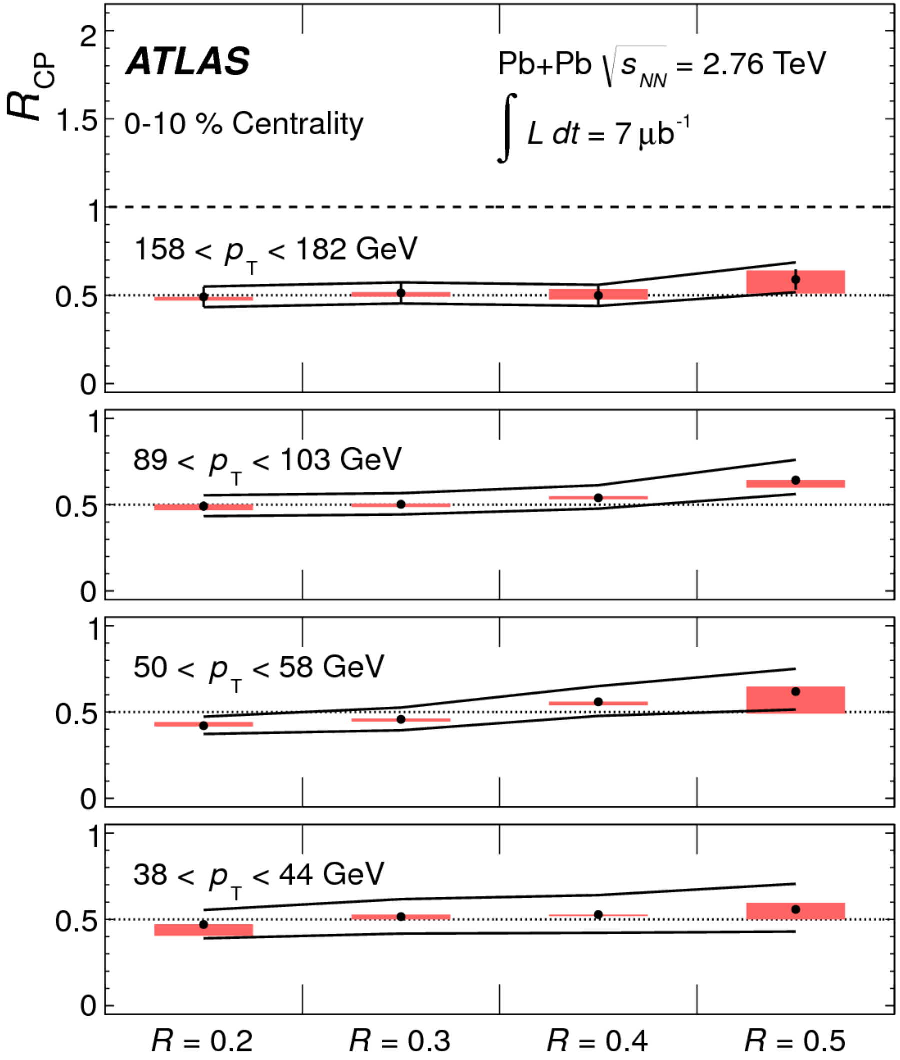
R=0.2

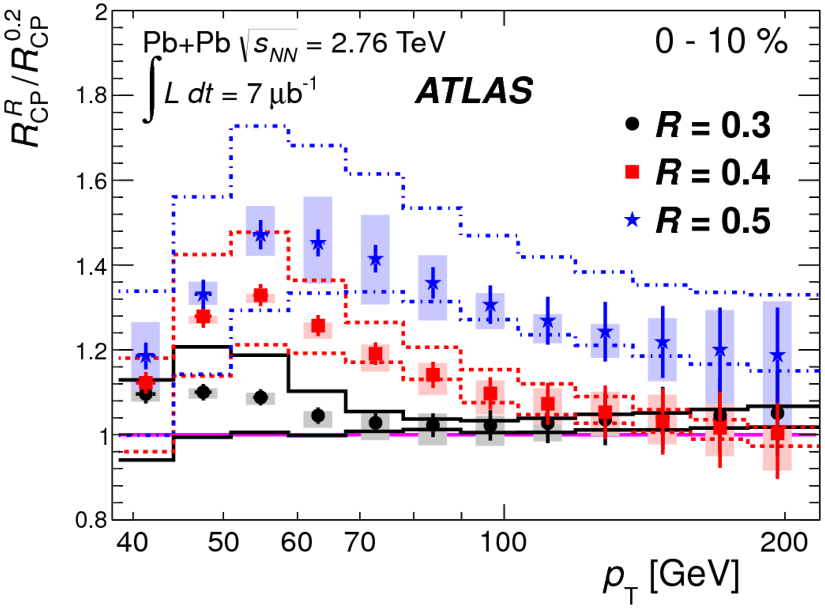


- Increasing jet suppression with centrality, up to a factor of 2 in the most central collisions, well beyond statistical and systematic errors
- Weak dependence on jet p_T

R_{cp} versus Jet Size and p_T

R_{cp} for most central collisions as a function of p_T ranges and jet cone size

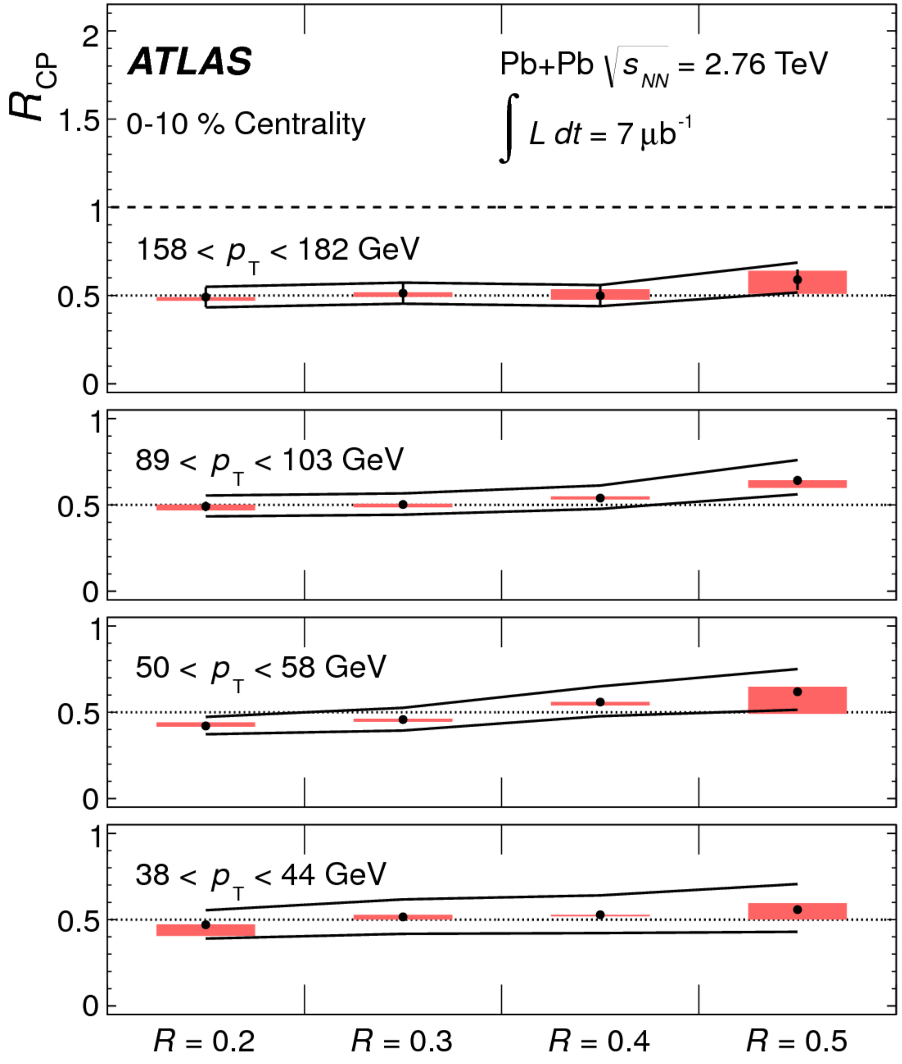


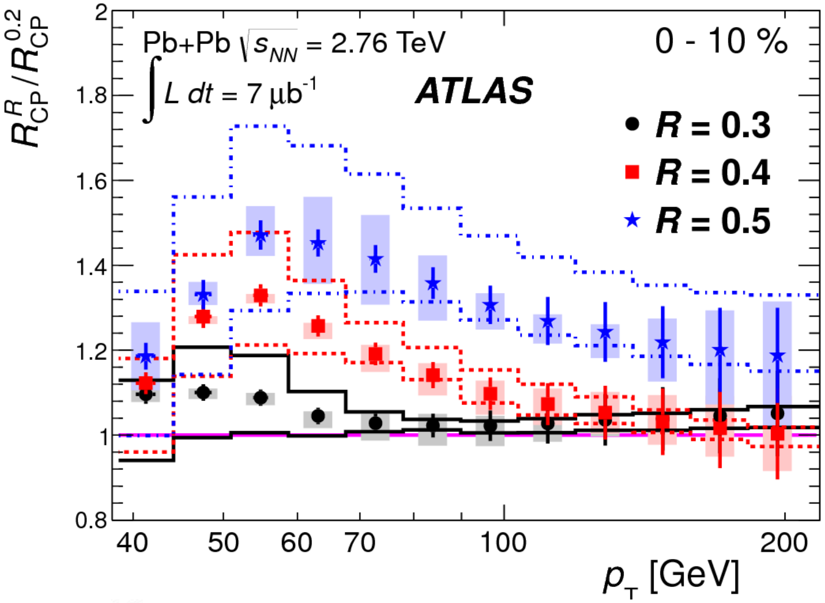


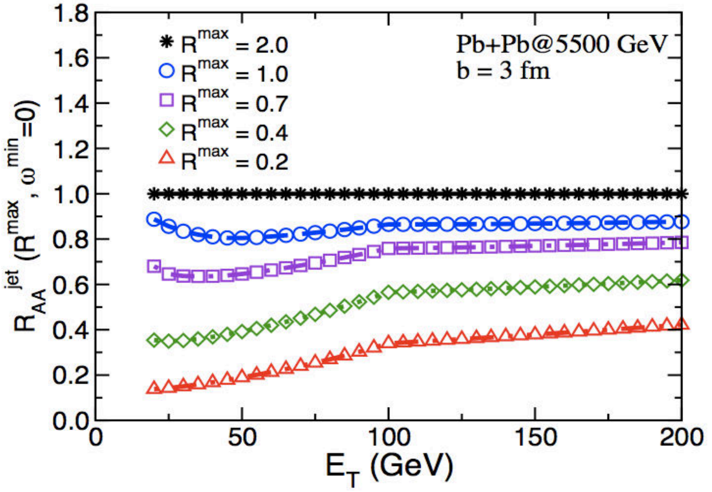
The suppression is higher for narrower jets, which is consistent with a scenario of energy recovered out of cone

R_{cp} versus Jet Size and p_T

R_{cp} for most central collisions as a function of p_T ranges and jet cone size

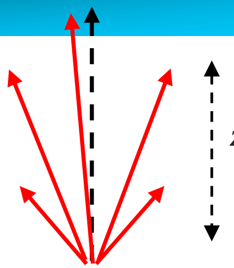




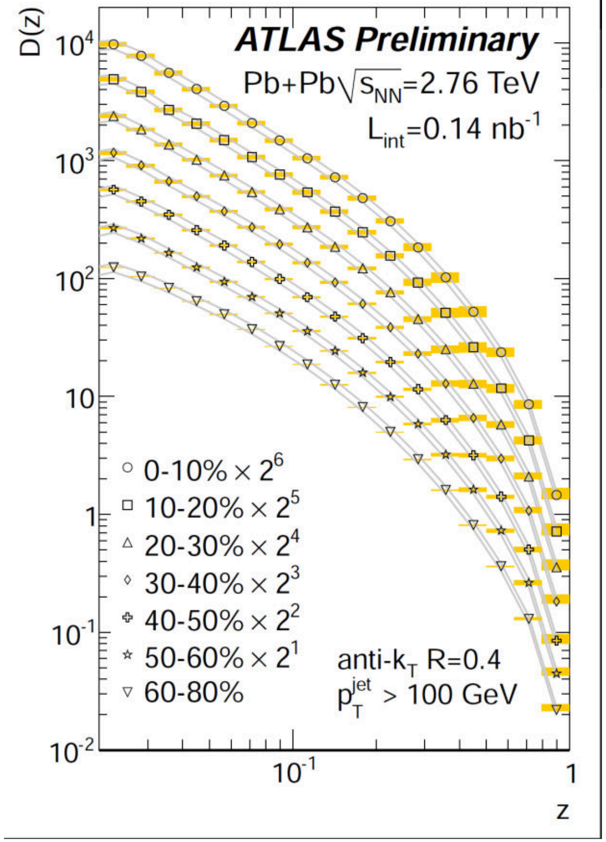


Jet Fragmentation – D(z) and D(p_T)

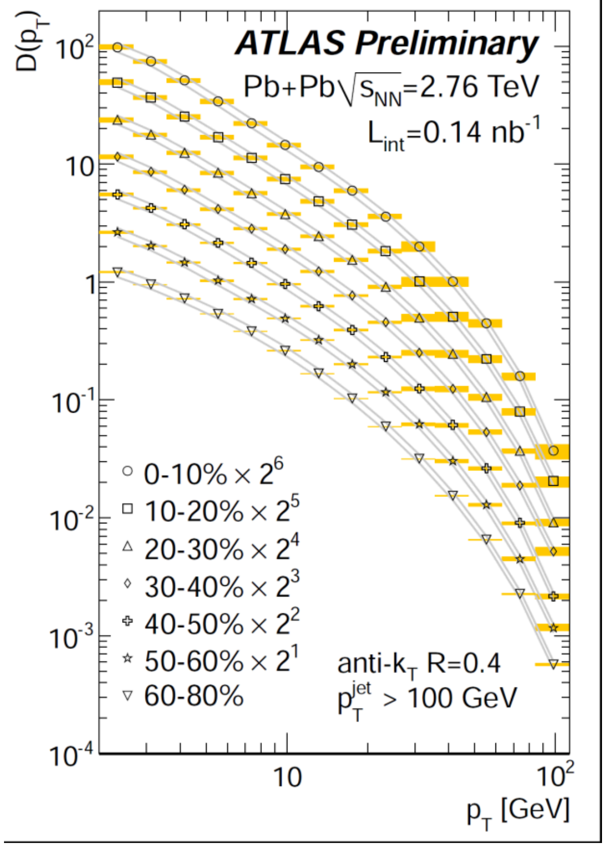
$$D\left(z\left[p_T\right]\right)=\frac{1}{N_{jet}}\frac{1}{\varepsilon}\frac{\Delta N_{ch}\left(z\left[p_T\right]\right)}{\Delta z\left[p_T\right]}$$



$$z\equiv\left(\frac{p_{T,had}}{p_{T,jet}}\right)\cos\Delta R$$



D(z) measures the p_T of the charged particles parallel to the jet axis

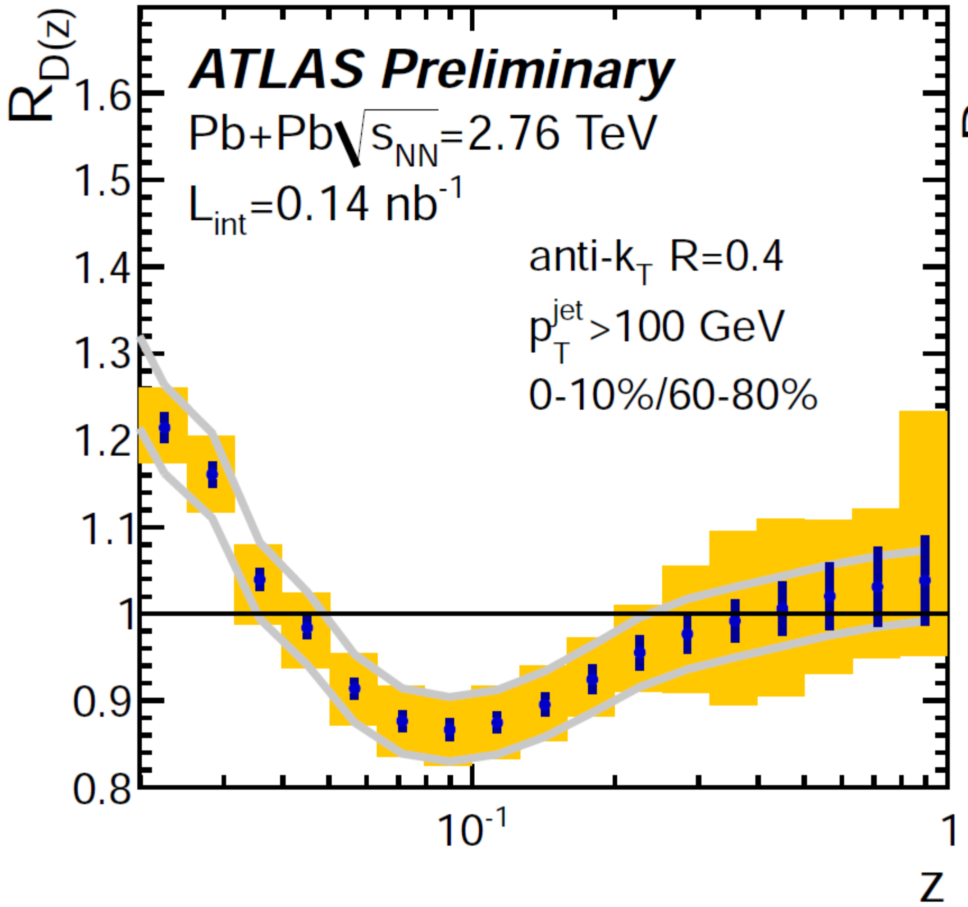


D(p_T) is the p_T spectrum of charged particles inside the jet

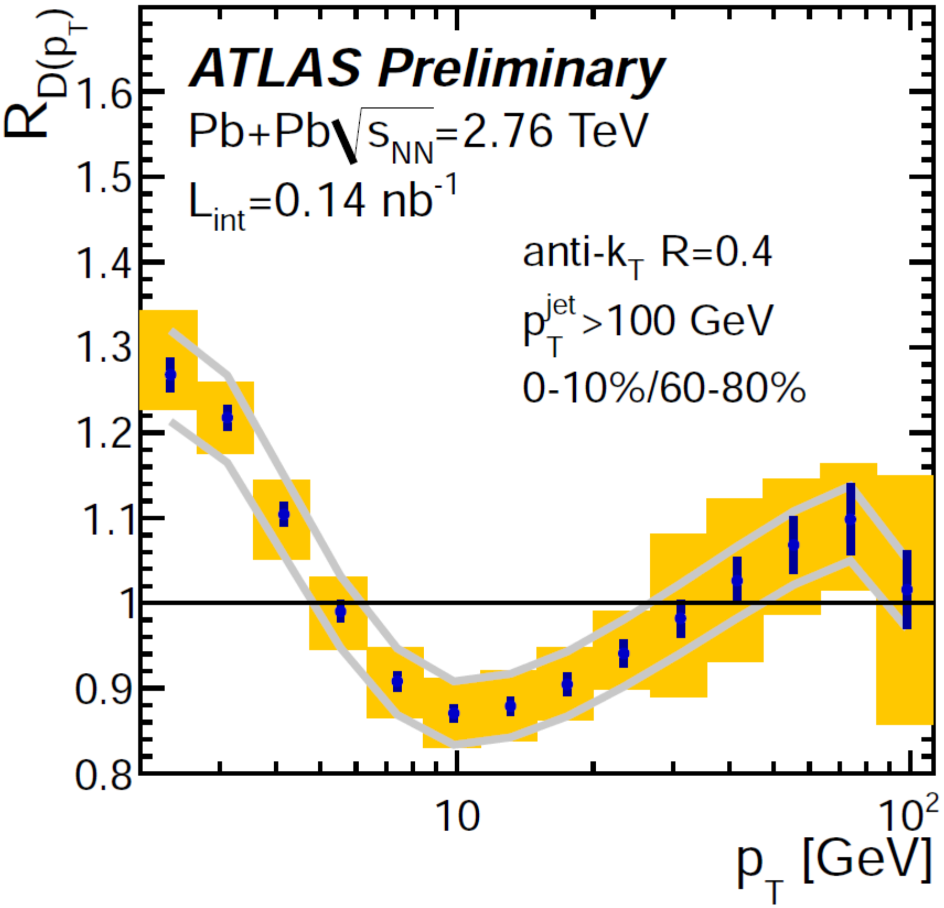
ATLAS-COM-CONF-2012-159

Jet Fragmentation – $R_{D(z)}$ and $R_{D(pT)}$

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



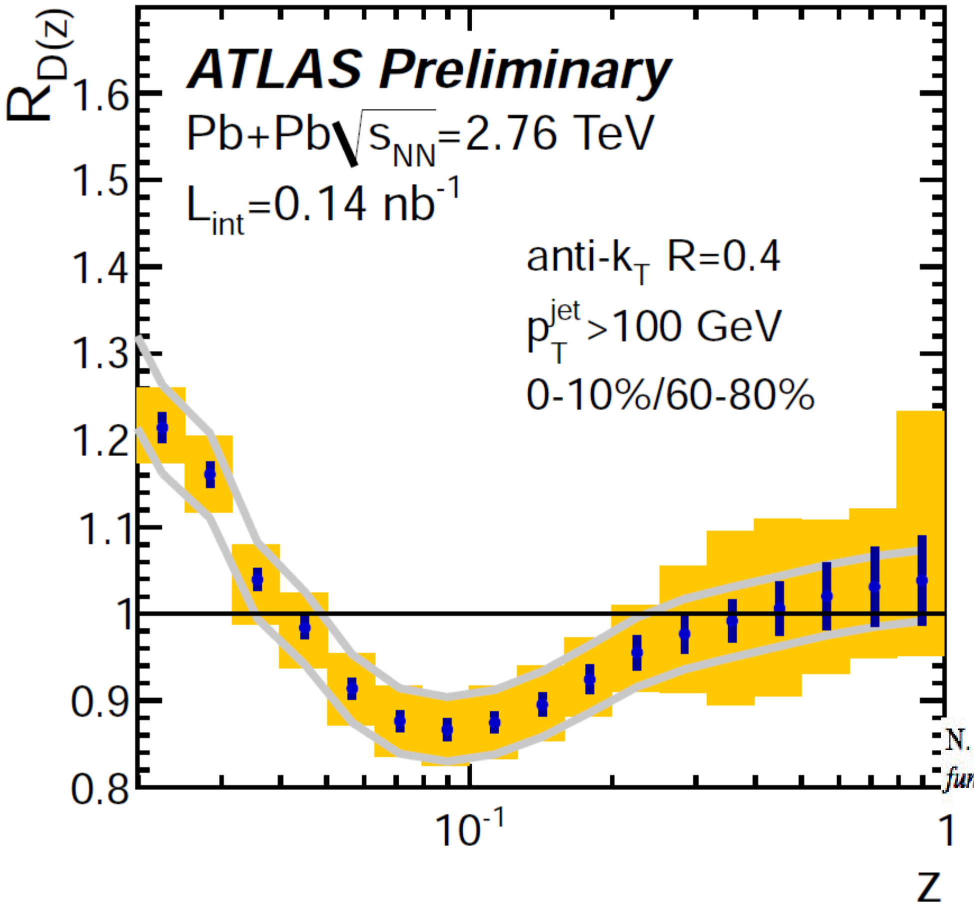
$$R_{\mathrm{D(p_T)}} = \frac{\mathrm{D}(p_T)|_{\mathrm{cent}}}{\mathrm{D}(p_T)|_{60-80\%}}$$

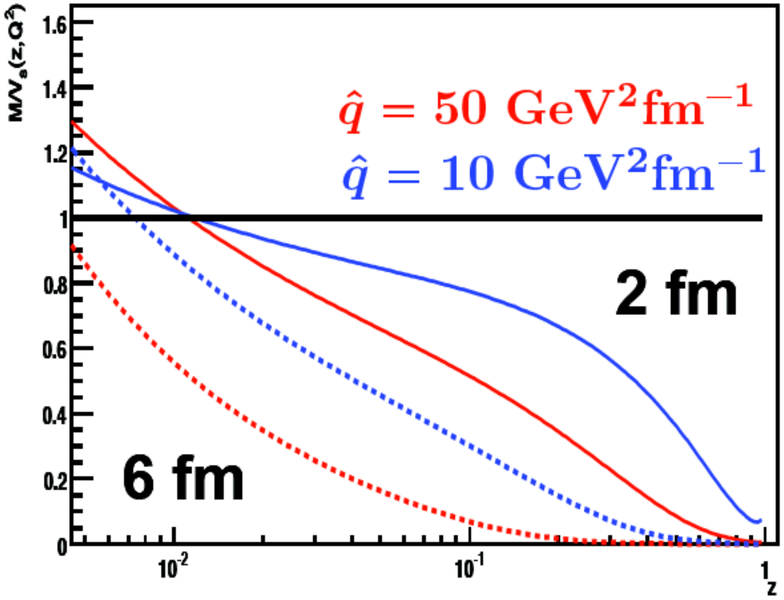


- Enhancement at low z and low p_T
- Suppression at intermediate z and p_T
- No modification at high z or high p_T

Jet Fragmentation – $R_{D(z)}$

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



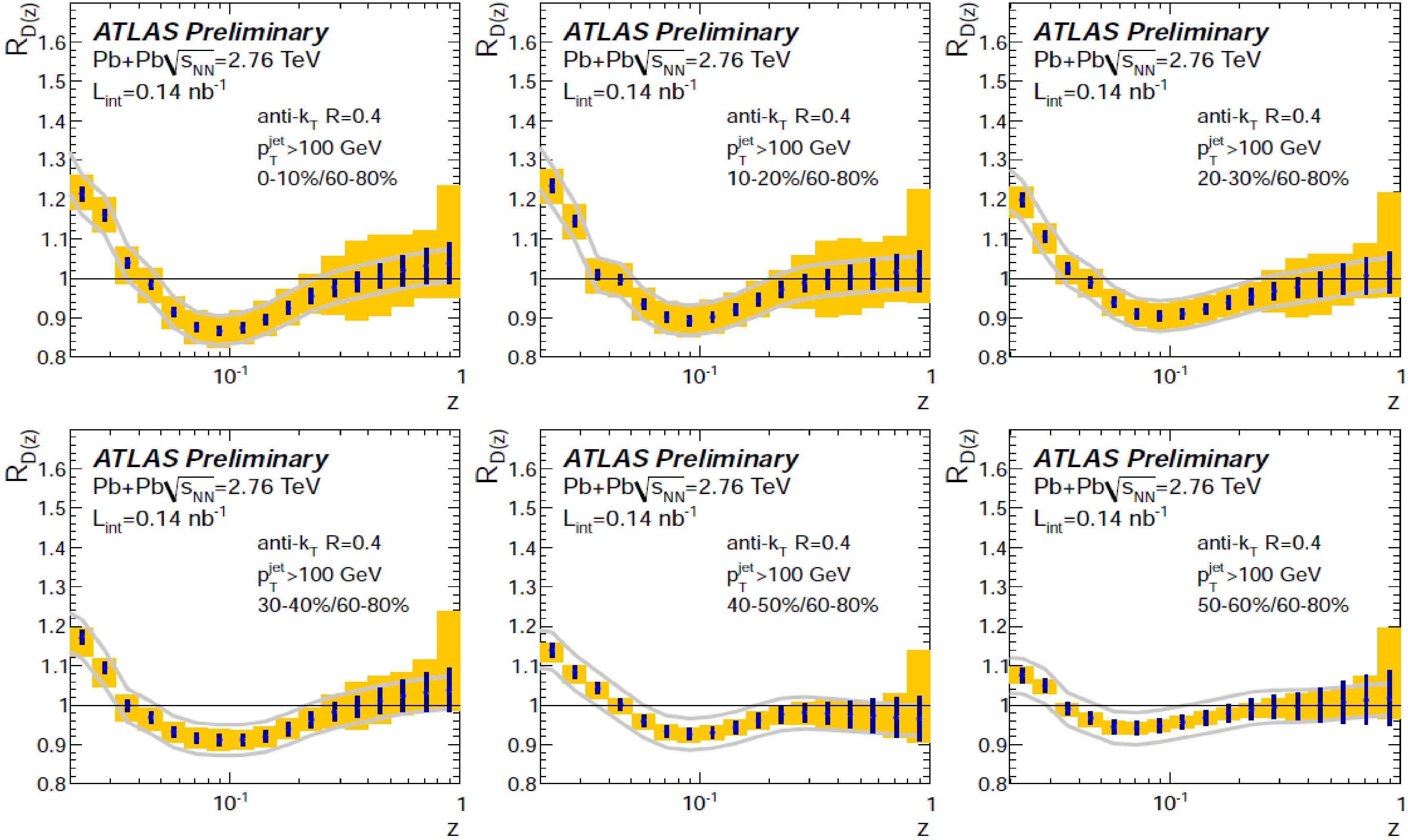


N. Armesto, L. Cunqueiro, C. A. Salgado, and W.-C. Xiang, *Medium-evolved fragmentation functions*, JHEP **0802** (2008) 048, `arXiv:0710.3073 [hep-ph]`.

- Enhancement at low z and low p_T
- Suppression at intermediate z and p_T
- No modification at high z or high p_T

Jet Fragmentation – $R_{D(z)}$

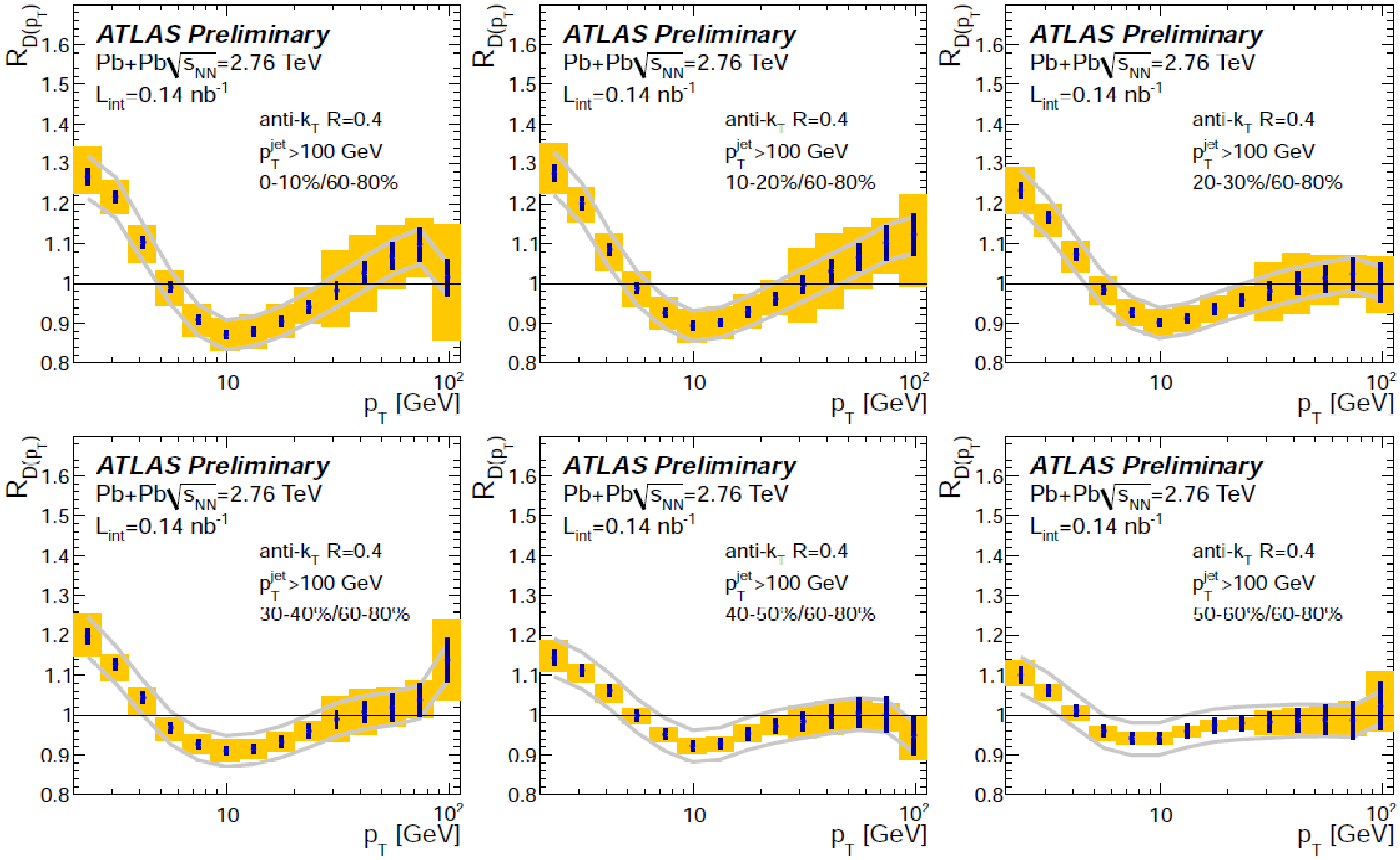
Reference is the D(z) in the 60-80% centrality interval



The jet structrure modification is higher as the centrality of the collisions increases

Jet Fragmentation – $R_{D(pT)}$

Reference is the D(z) in the 60-80% centrality interval



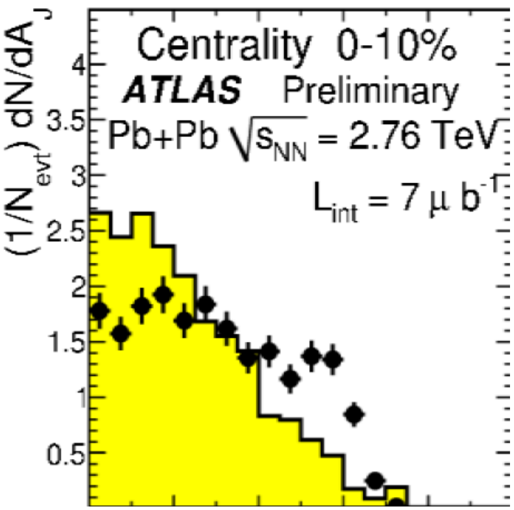
The jet structrure modification is higher as the centrality of the collisions increases

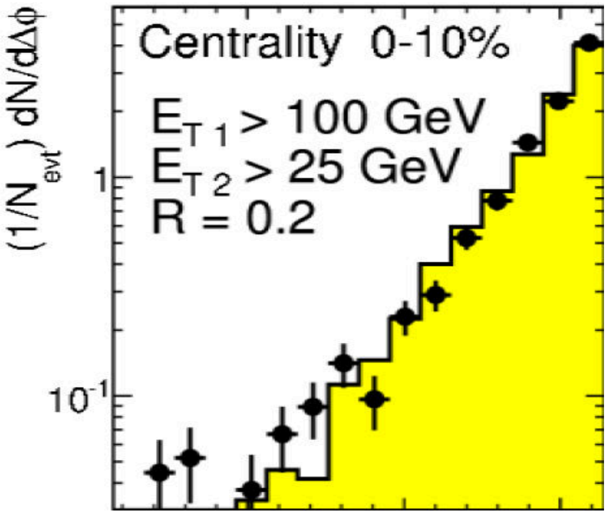
Conclusions

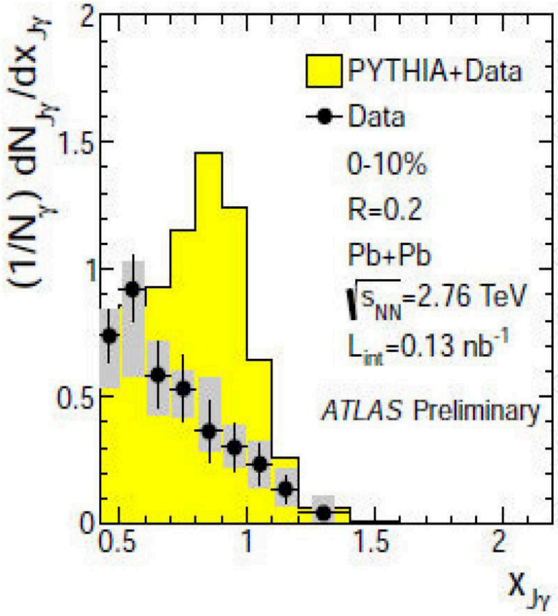
1 - Di-jet balance in peripheral collisions well compatible with p+p collisions and non-quenching based MC;
Di-jet asymmetry increases with increasing centrality.

2 - No broadening of Δφ.

3 – The same conclusions for photon-jet balance



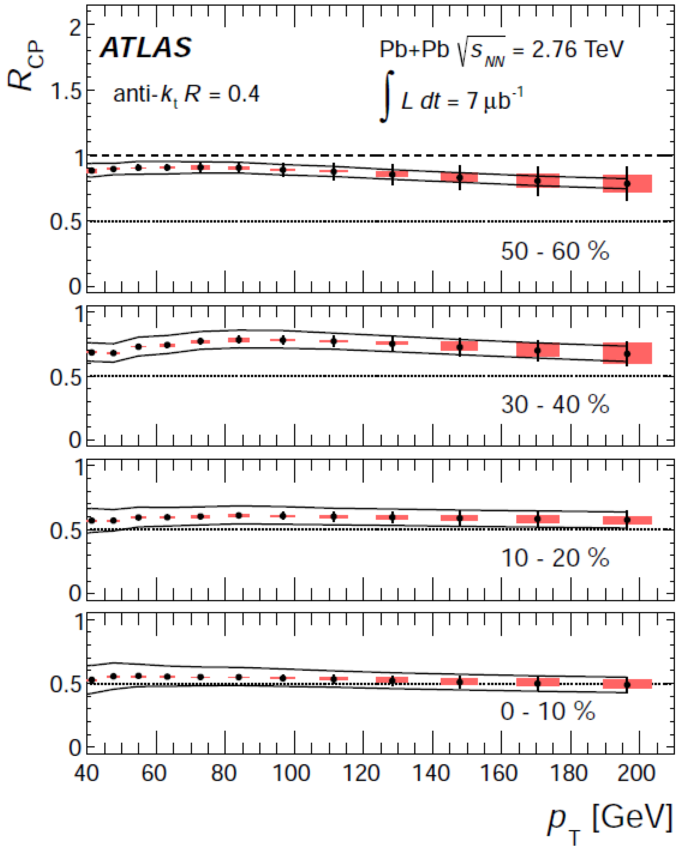


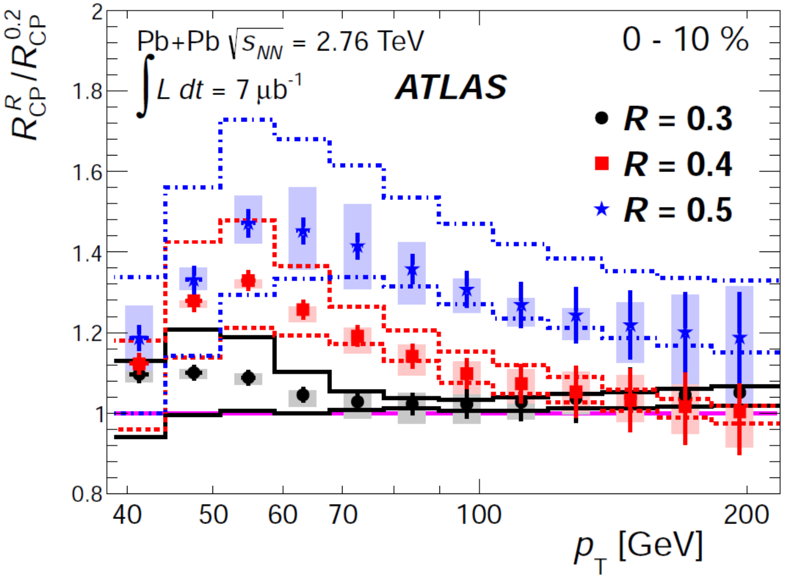


Conclusions

4 - Jet production suppressed by a factor of 2 in central collisions w.r.t. peripheral; tiny dependence with jet p_T is observed.

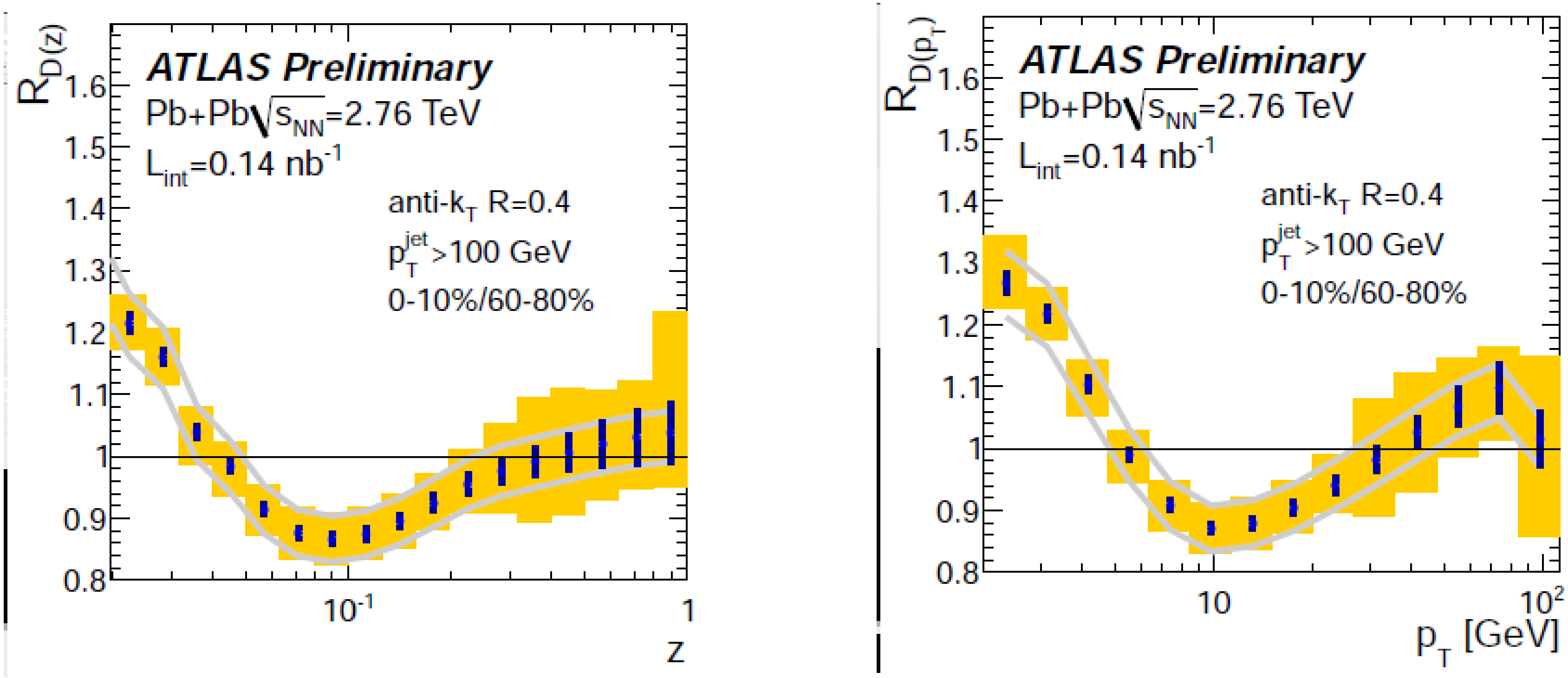
5 – The suppression is larger for narrower jets. This is consistent with radiation-dominated energy loss scenario.





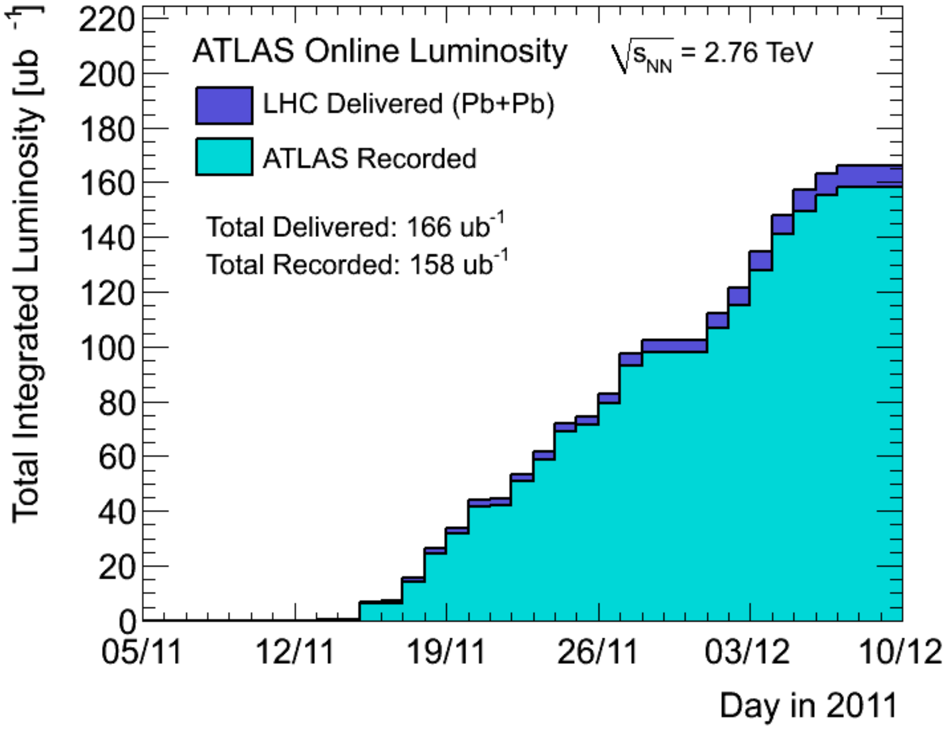
Conclusions

6 – The jet structure is modified: enhancement of particles at low z and p_T; suppression at intermediate z and p_T. The modification increases as the centrality of the collisions increases. Predictions of high suppression at high z are not confirmed.



Backup

2011 Pb+Pb Run



- sqrt(s_{NN}) = 2.76 TeV

– ATLAS recorded 158 μb^{-1} of Pb+Pb data
– Data recording efficiency > 97%

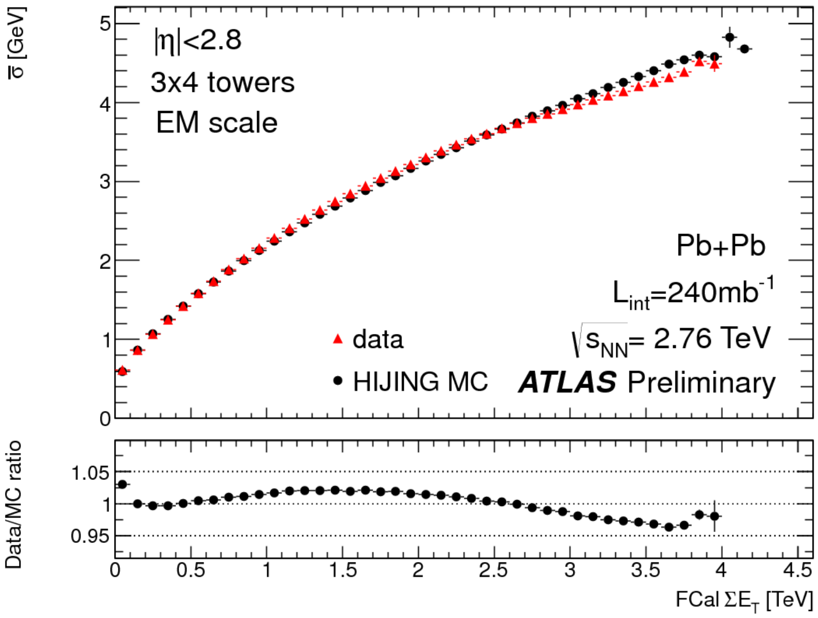
- Triggers: MB, *e*, μ, γ, jet, UPC

- 1x10^{9} events!

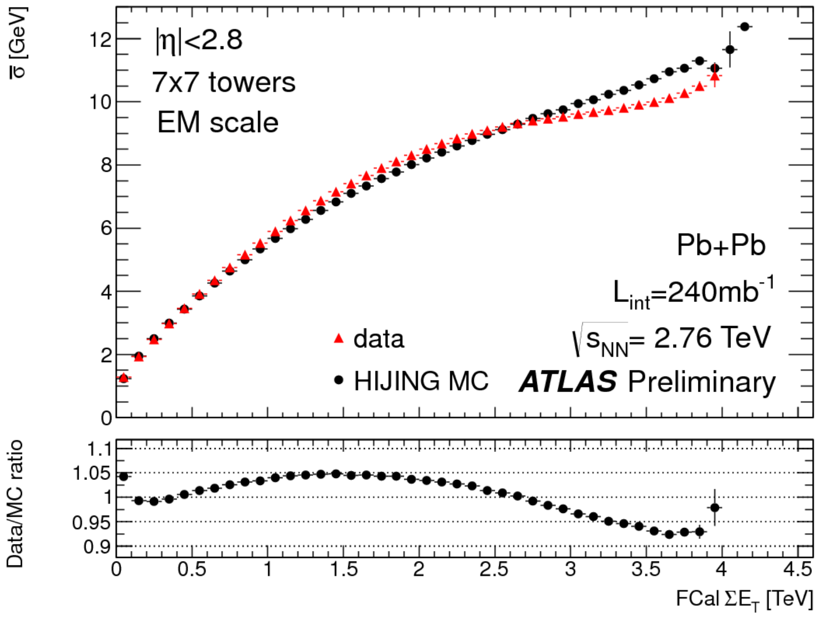
Calorimeter fluctuations

Fluctuations are measured in single towers and also in larger windows comparable to the area of jet:

4x3 towers ~ R = 0.2 jets



7x7 towers ~ R = 0.4 jets



The agreement between data and MC is better than 5% for R=0.2 jets

Fluctuations in data are at most 5% higher than in MC for R=0.4 jets

Fluctuations are higher in MC in the most central events

Detecting Particles