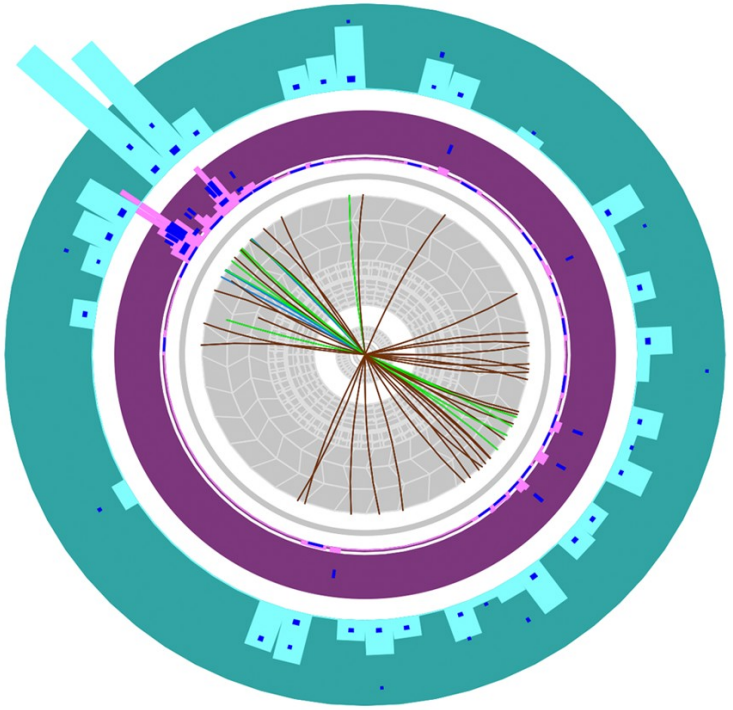
ATLAS results on Heavy Ion Physics



Martin Rybář

for the ATLAS collaboration

25th Rencontres de Blois:
Particle Physics and Cosmology, May 29, 2013

Motivation

- Study of the QCD phase diagram.
- Understanding the bulk properties of the strongly interacting hot medium - Quark-Gluon Plasma (QGP):
  - Bulk yields
  - Study of fluctuations
  - Flow measurement
- How do partons loose energy in QGP?

→ Better understanding of QCD in the limit of high densities and temperatures.

- How does the medium modify the parton showers?
  - High momentum charged particles yields.
  - Measurement of jet yields and jet properties.
  - Electroweak probes and their correlations with jets.

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  } Yesterday plenary presentation by Silvia Masciocchi
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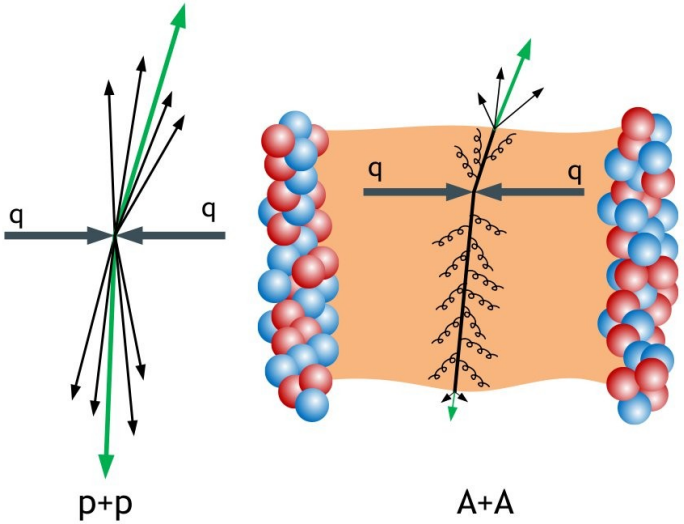


Hard probes:

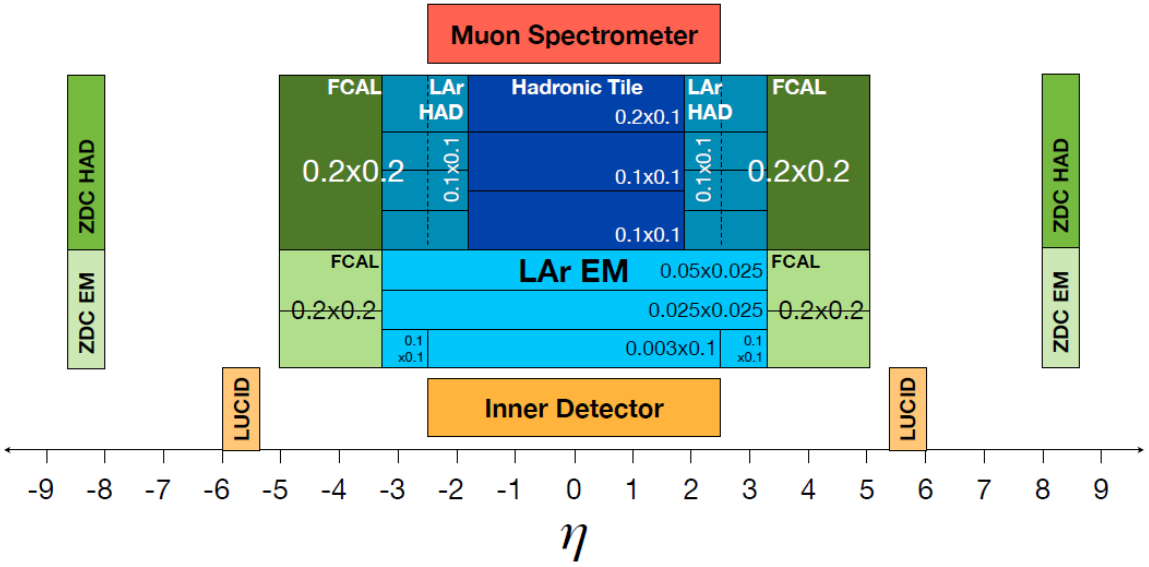
- How do partons loose energy in QGP?

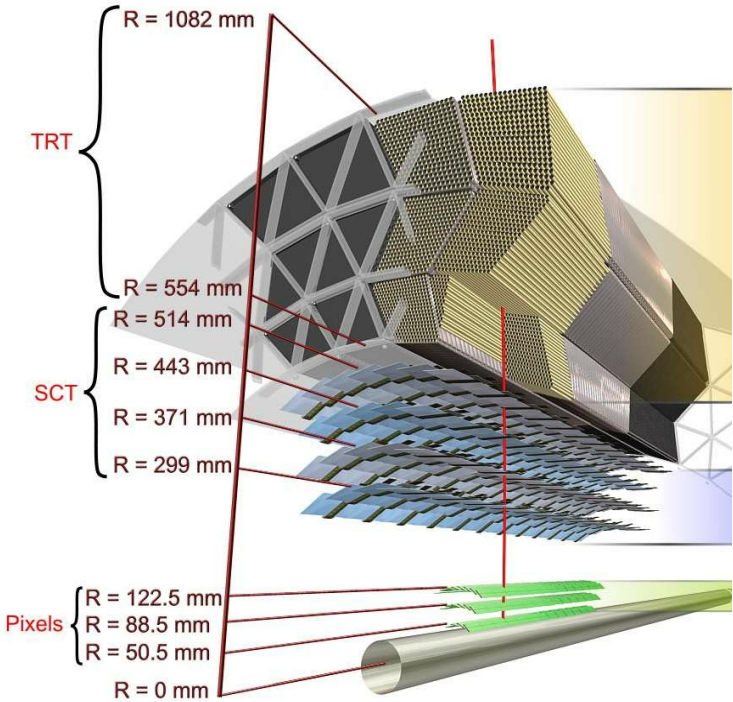
→ Better understanding of QCD in the limit of high densities and temperatures.

- How does the medium modify the parton showers?
  - High momentum charged particles yields.
  - Measurement of jet yields and jet properties.
  - Electroweak probes and their correlations with jets.

The ATLAS Detector

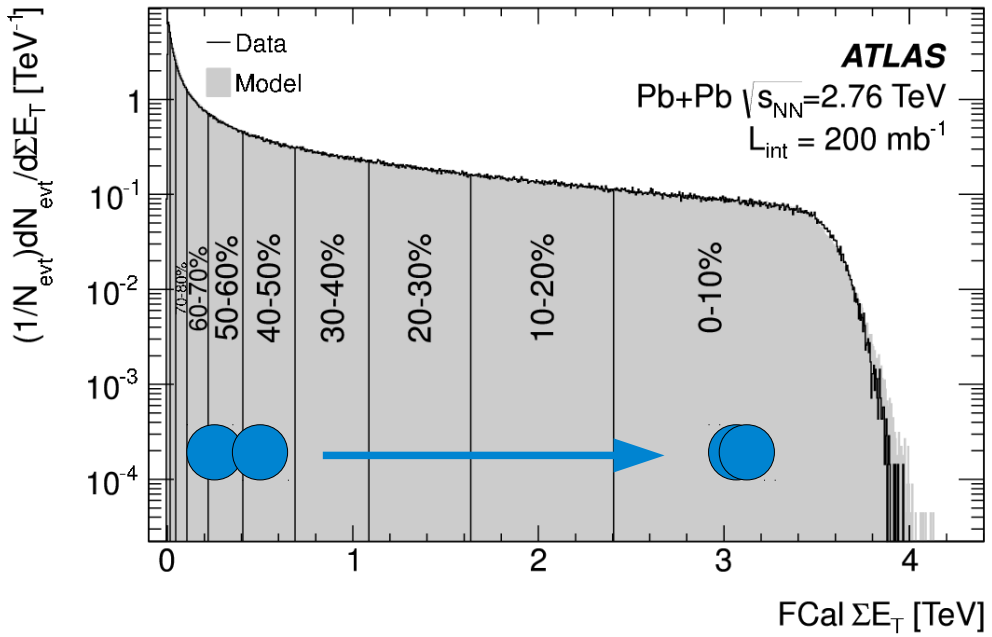
- ATLAS is a general-purpose p-p experiment, but it was proven to be well suited also for heavy ion physics!
- Large pseudorapidity coverage and full azimuthal acceptance.
- Fine granularity and longitudinal segmentation.
- Precise inner detector in a 2T solenoid field.
- Extensive system of muon chambers placed inside a 1T toroid field.

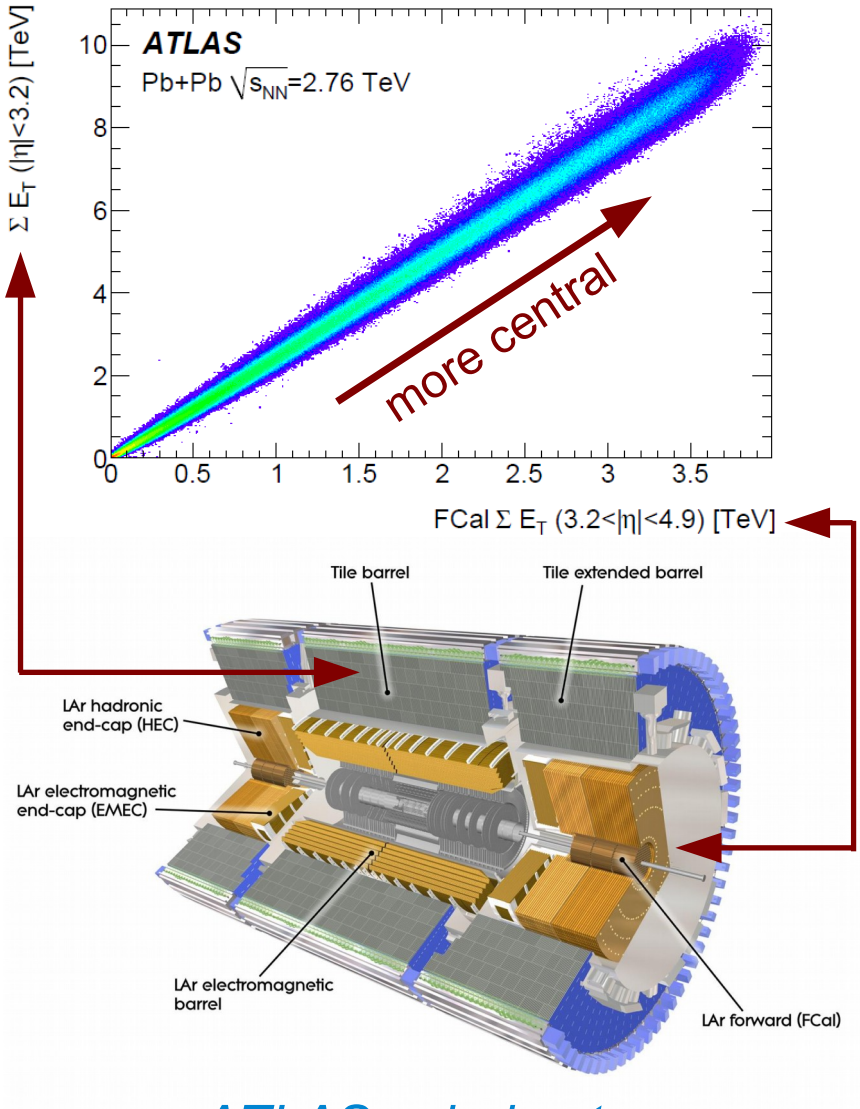




Centrality

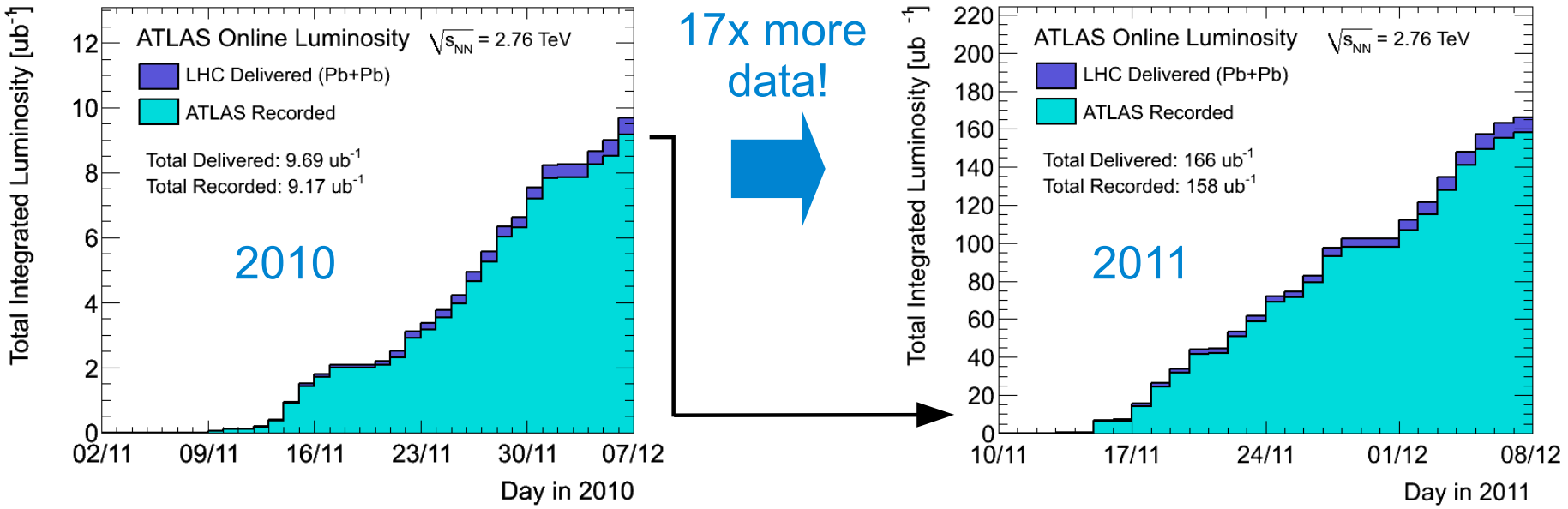
- Characterize centrality by percentile of total cross-section using total E_T.
- Measured in Forward Calorimeter ($3.2<|\eta|<4.9$).
- Centrality → number of participants N_{part} and binary collisions N_{coll}.





ATLAS calorimeter

Data Sets



Run:	2010	2011
L_{int}	8μb^{-1}	0.15nb^{-1}
Triggers	Min Bias	γ, μ, jets, Min Bias, UPC
Nevents	50M	1000M

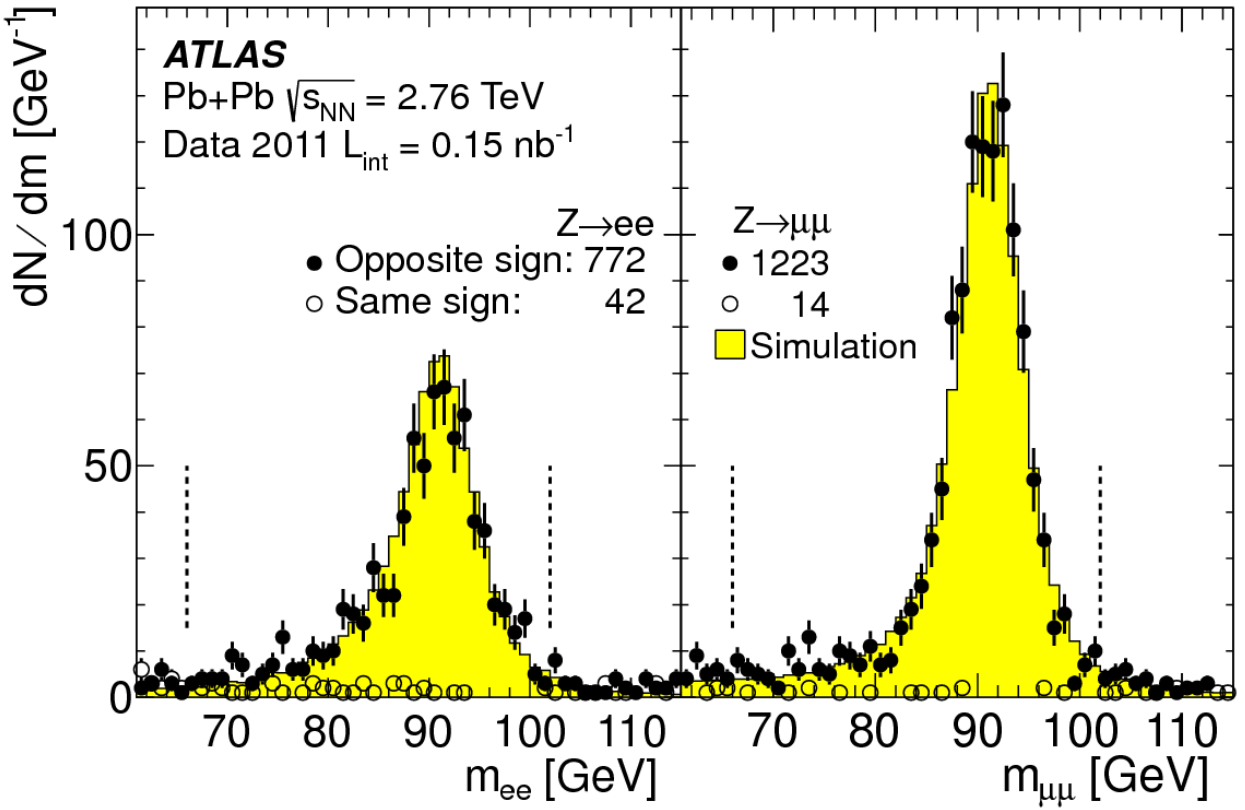
Electroweak Probes

- Z, W^{+-} and photon do not interact strongly with medium.

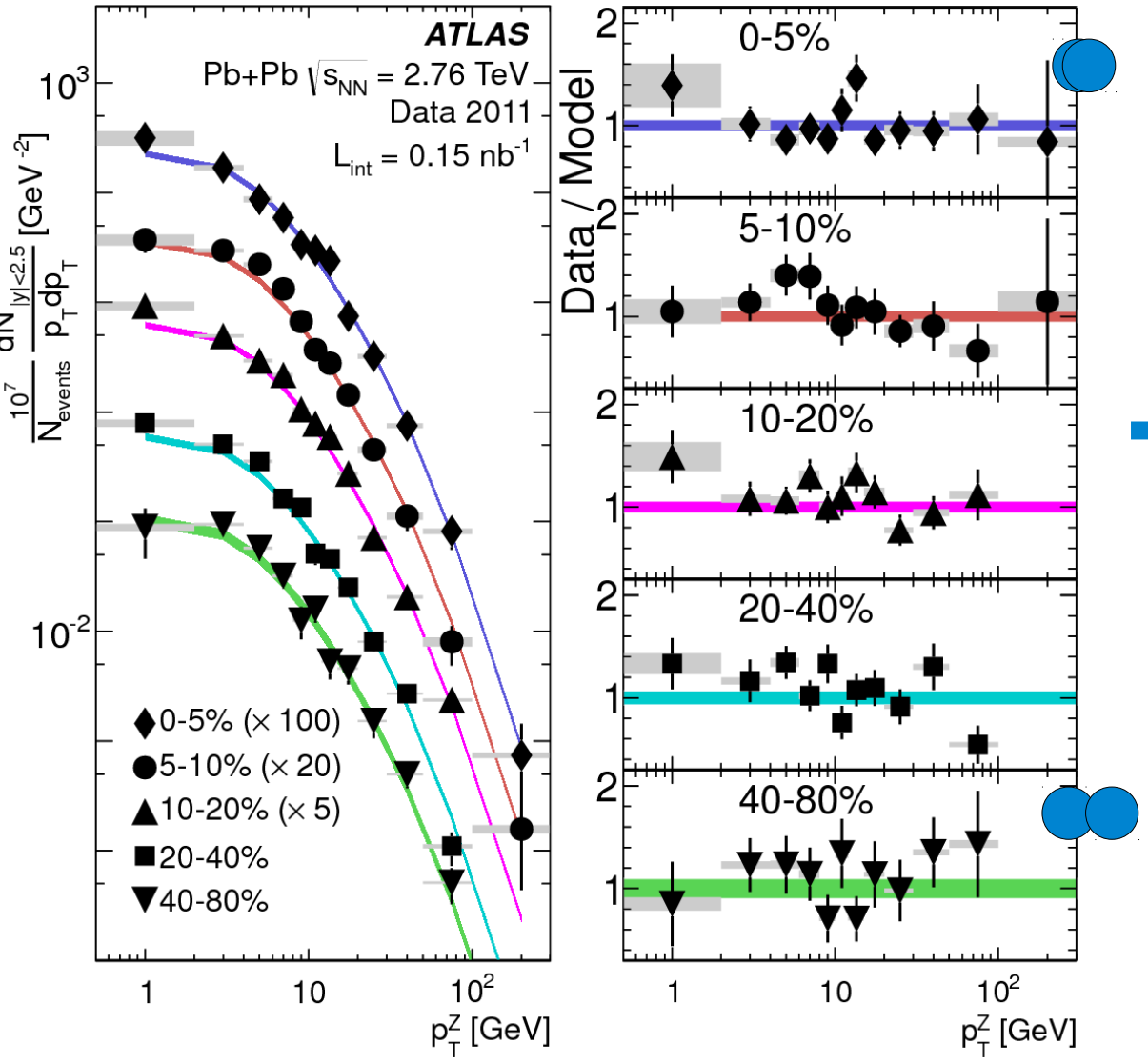
➡ They should obey scaling with number of binary collisions N_{coll}.

➡ Their production rate is a standard candle for other processes.

- Test of nuclear PDFs.



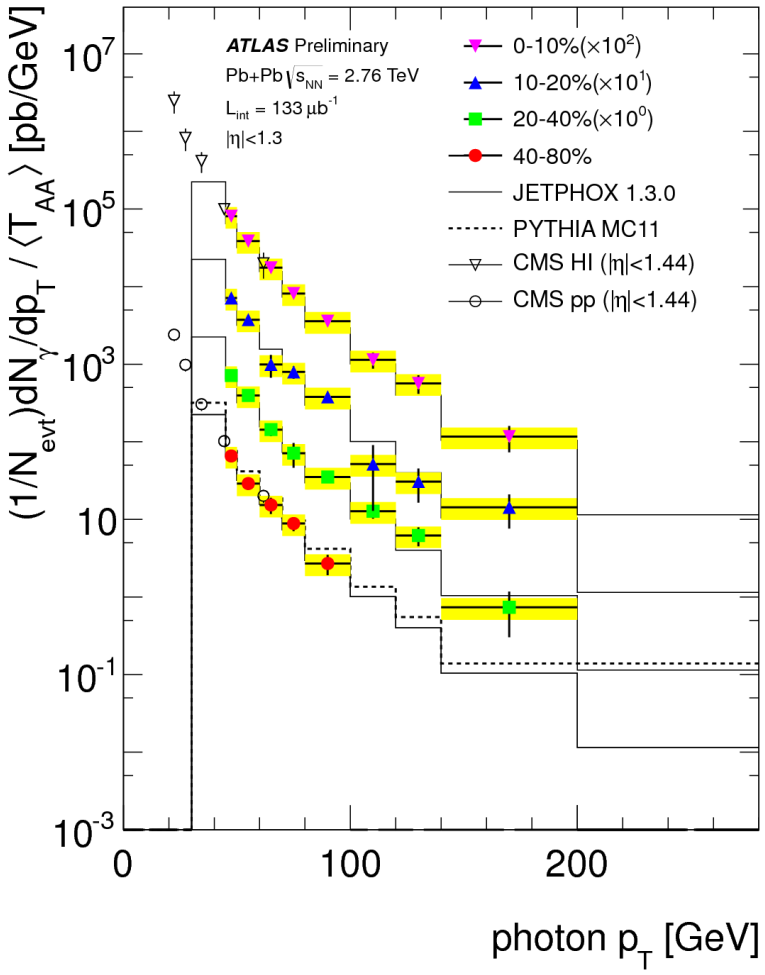
Z Boson Production

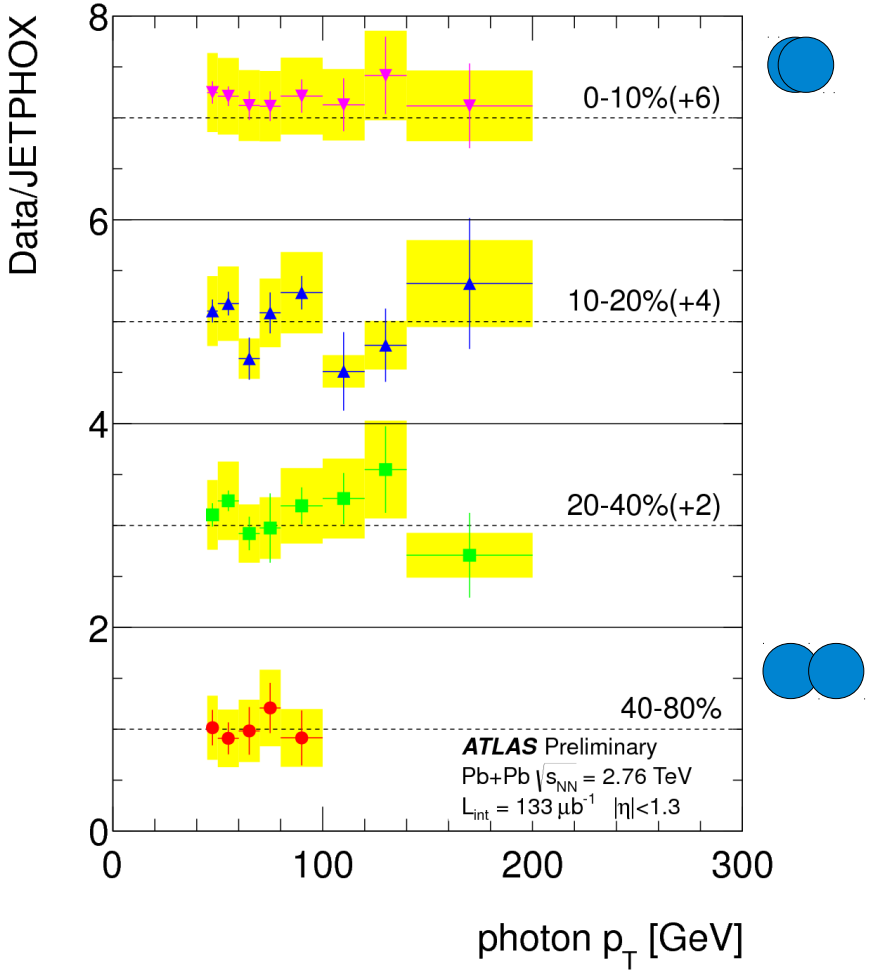


- Corrected for efficiency of the reconstruction
- Compared to the PYTHIA with NNLO cross-section simulation scaled by T_{aa}

→ Yields consistent with N_{coll} scaling

Promt Photon Production

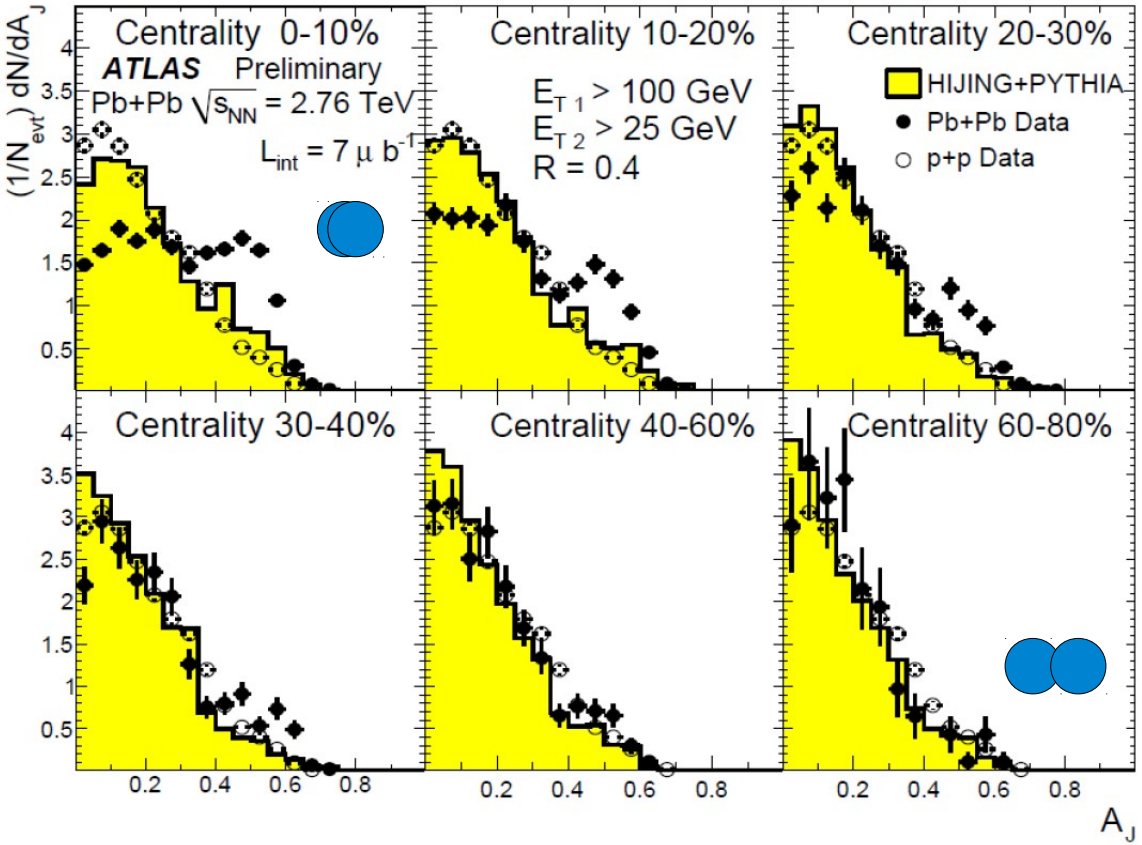




- Photons are UE subtracted.
- Compared to the JETPHOX simulation scaled by T_{aa}.
- Yields consistent with N_{coll} scaling.

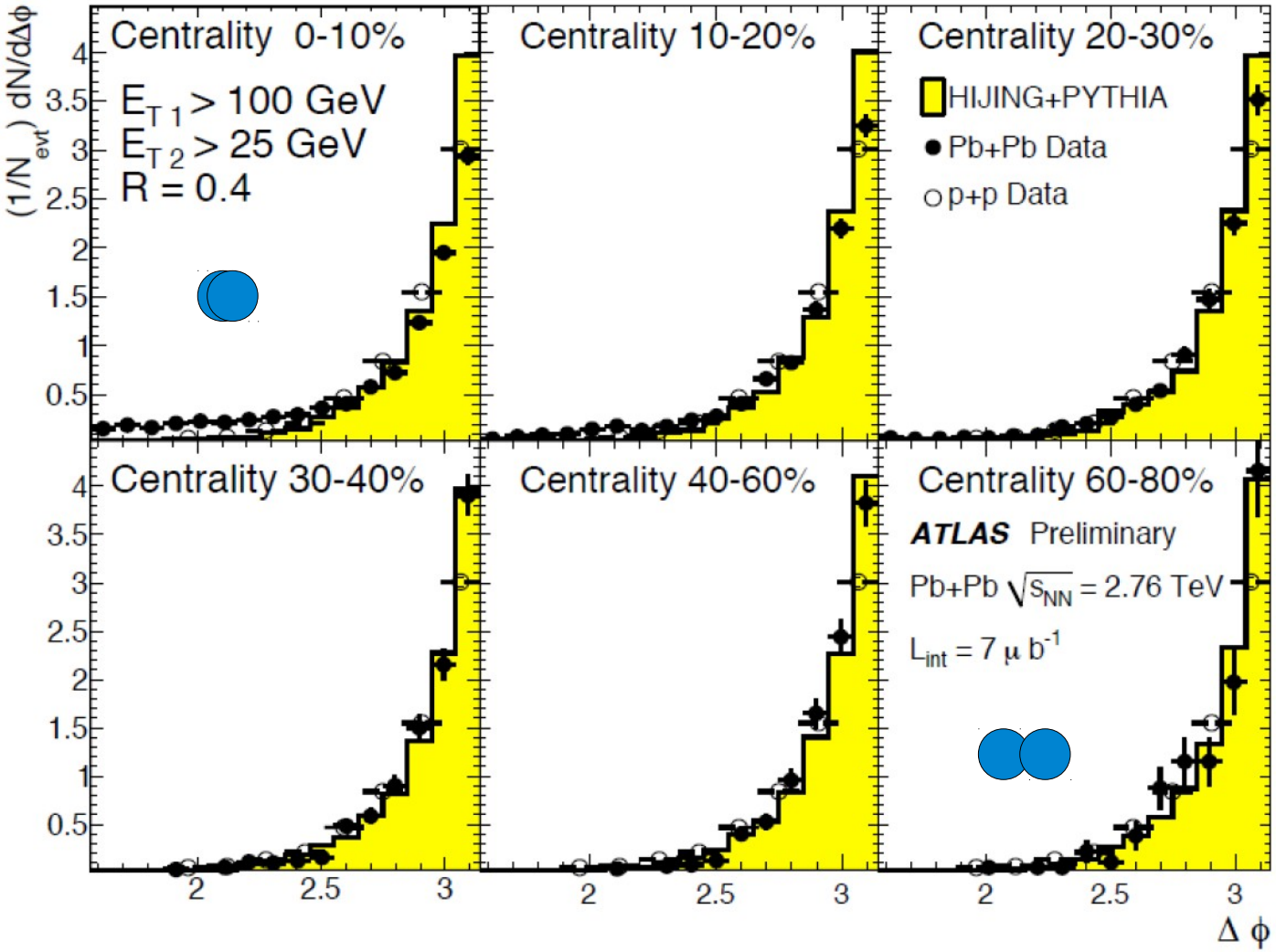
Di-jet Analysis

- Dijet imbalance quantified by asymmetry variable: $A_J \equiv \frac{E_{T1} - E_{T2}}{E_{T1} + E_{T2}}$
- Leading jet: E_{T1}>100 GeV, |η|<2.8.
- Sub-leading jet: highest E_T jet in opposite hemisphere: $\Delta\varphi_{12}>\pi/2$, E_{T2}>25 GeV, |η|<2.8



Increasing asymmetry with increasing centrality.

Di-jet Analysis: dφ Distribution

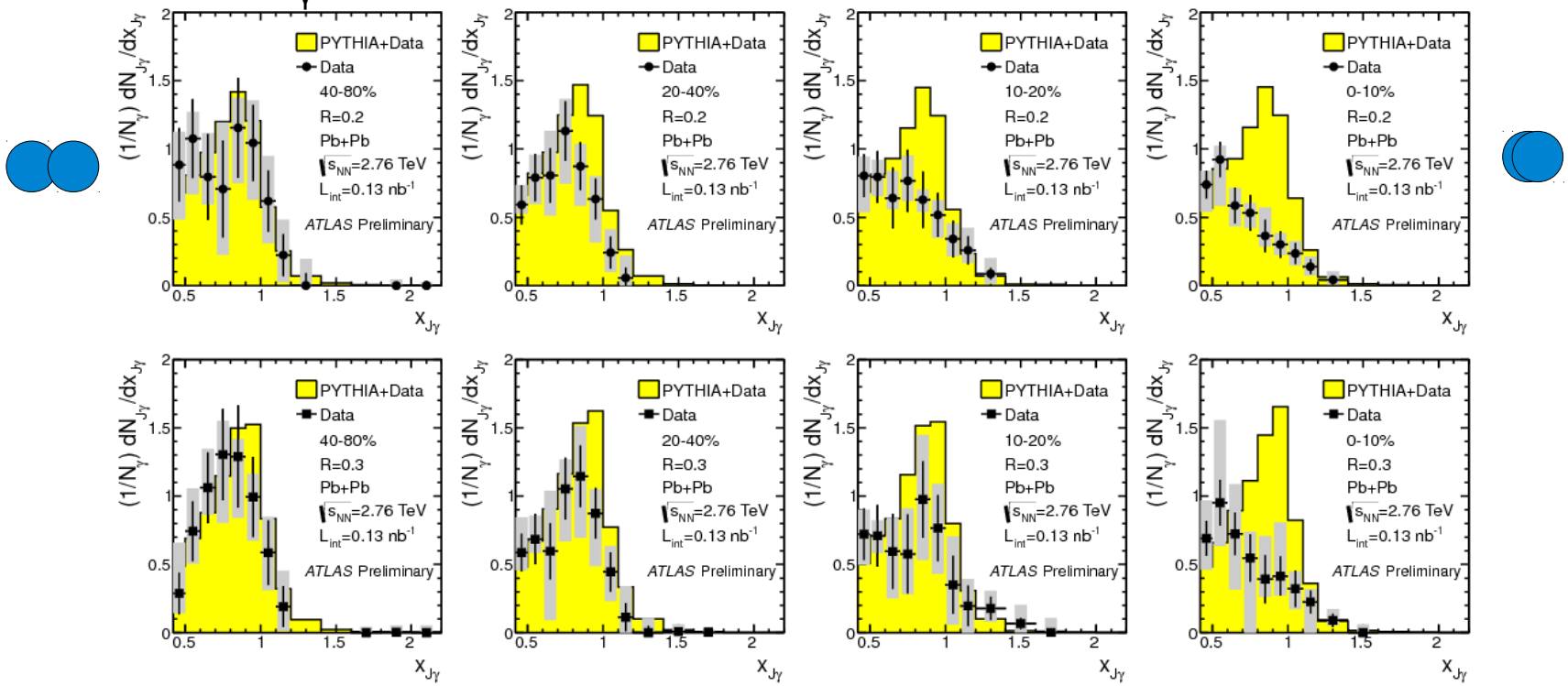


Jets remains still back-to-back even in central collisions!

Photon-jet Correlations

- Energy of a parton is calibrated by the energy of photon.
- Large cross-section, purity 75-85%
- Jet: p_T>25 GeV, |η|<2.1.
- Photon E_γ: 60-90 GeV, |η|<1.3 in opposite hemisphere: Δφ>7π/8

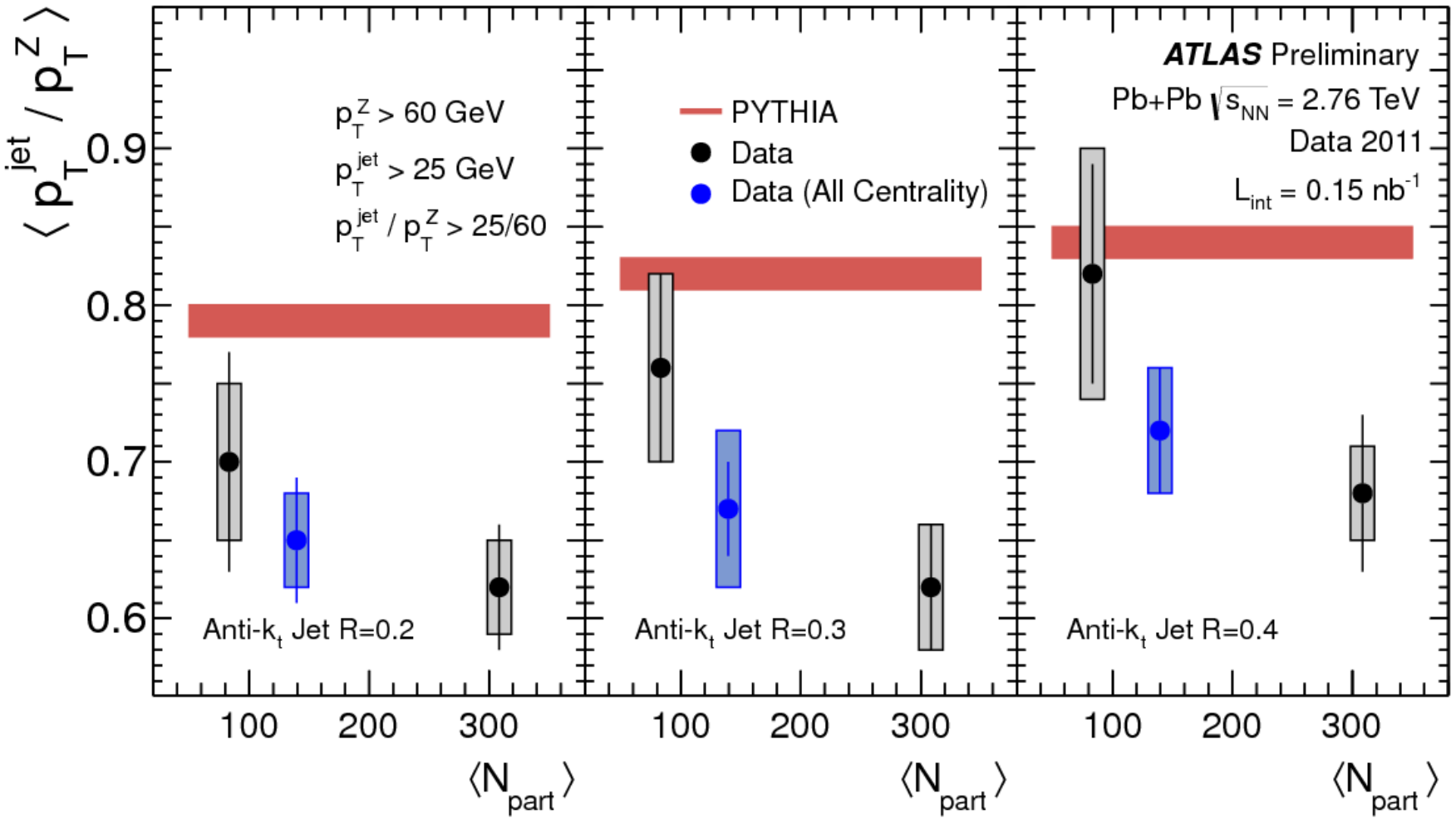
$$X_{J\gamma} \equiv \frac{p_T^{jet}}{p_T^{\gamma}}$$



- Good agreement with PYTHIA in peripheral collisions.
- Shift towards smaller $x_{J\gamma}$ and reduction of the integral in central collisions.

Z-jet Correlations

- $Z \rightarrow e^+e^-, \mu^+\mu^-$: $p_T > 60$ GeV in opposite hemisphere: $\Delta\varphi > \pi/2$



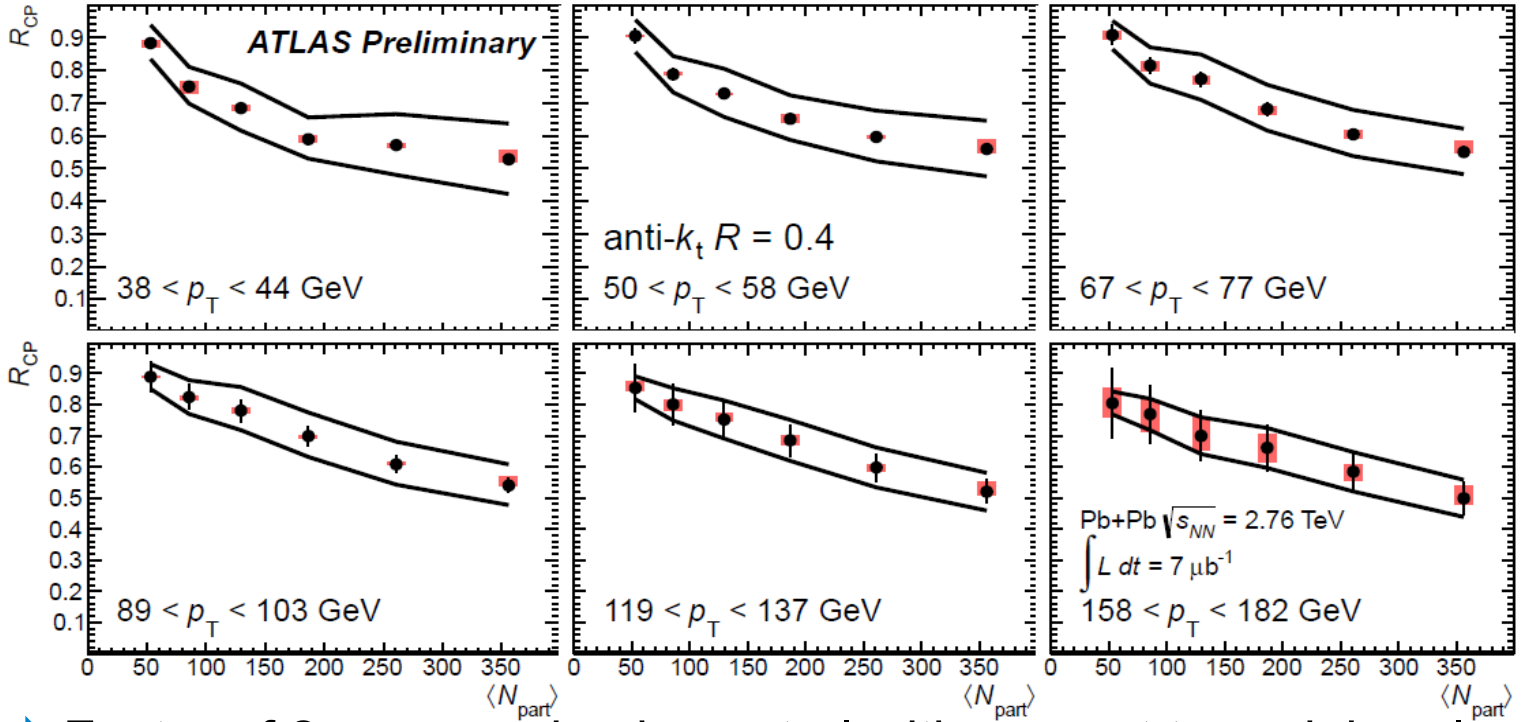
- Similar observation as in photon-jet correlation but with limited statistic.

Physics of Jet Quenching

- Measurement of inclusive jet production is another way to study QGP.
- The jet suppression is quantified by central to peripheral ratio:

$$R_{CP} = \frac{1/N_{coll}^{cent}}{1/N_{coll}^{periph}} \frac{1/N_{evnt}^{cent}\, dN/dE_T}{1/N_{evnt}^{periph}\, dN/dE_T}$$

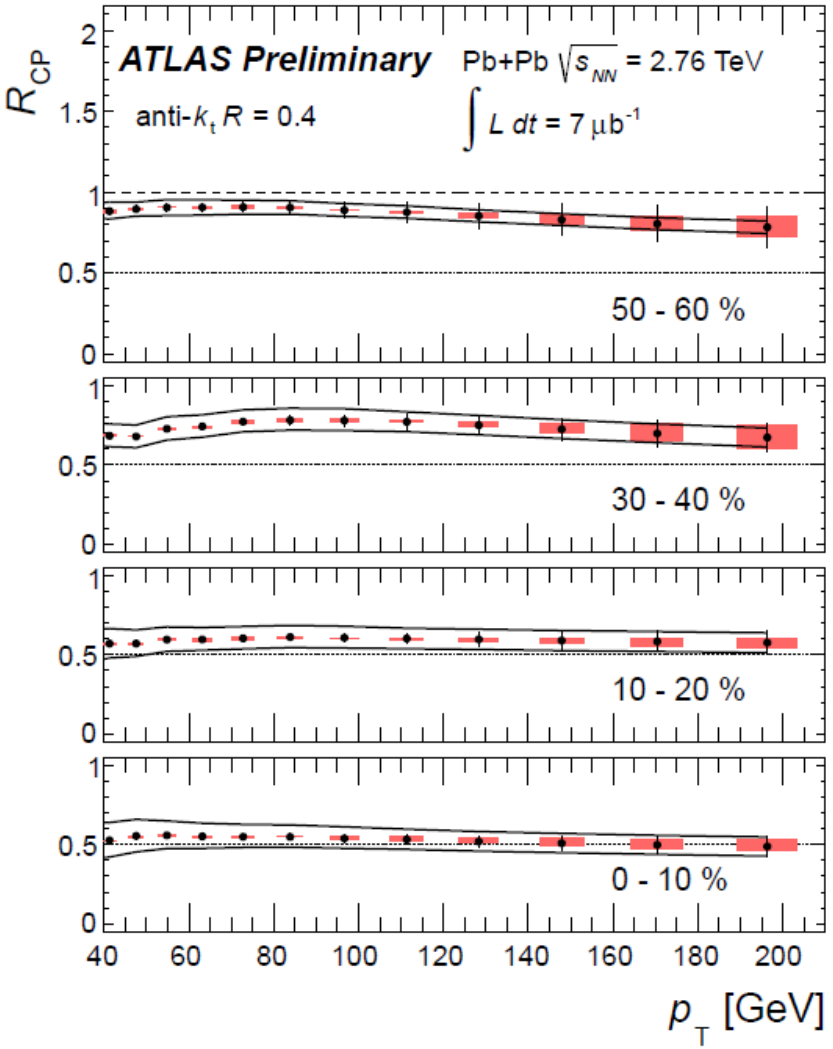
- Some predictions of radiative energy loss suggest that energy can be recovered by expanding the jet cone.

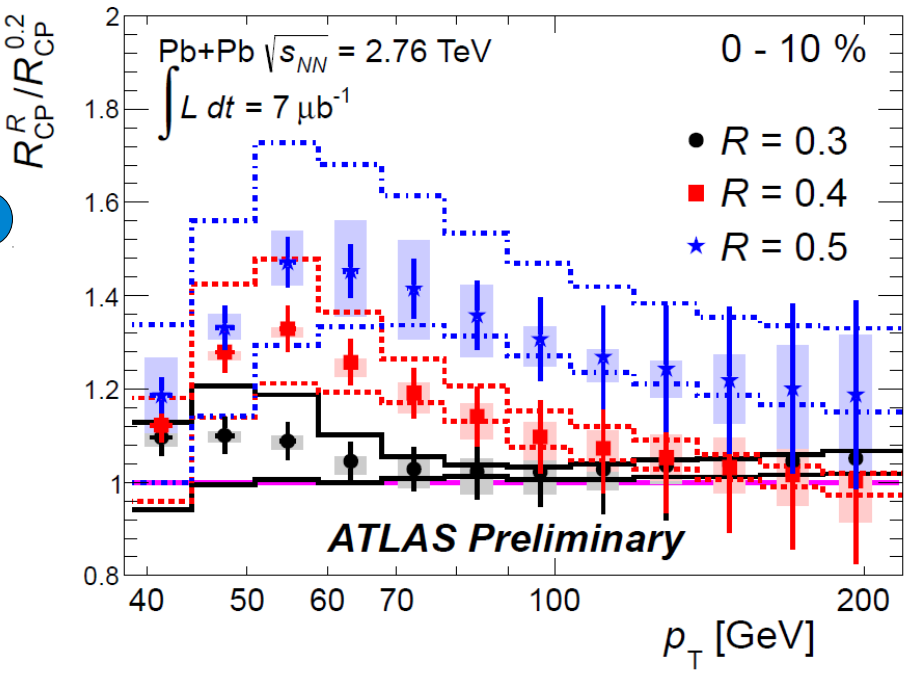


➡ Factor of 2 suppression in central with respect to peripheral collisions.

➡ The increase is linear for high p_T, quick turns on at low p_T.

Jet R_{CP} as a Function of Jet Radius and Jet p_T



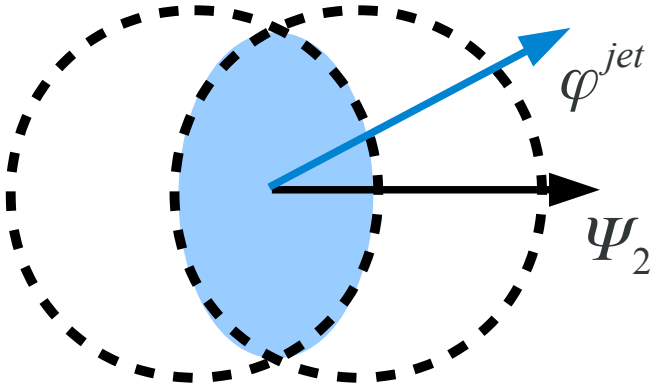


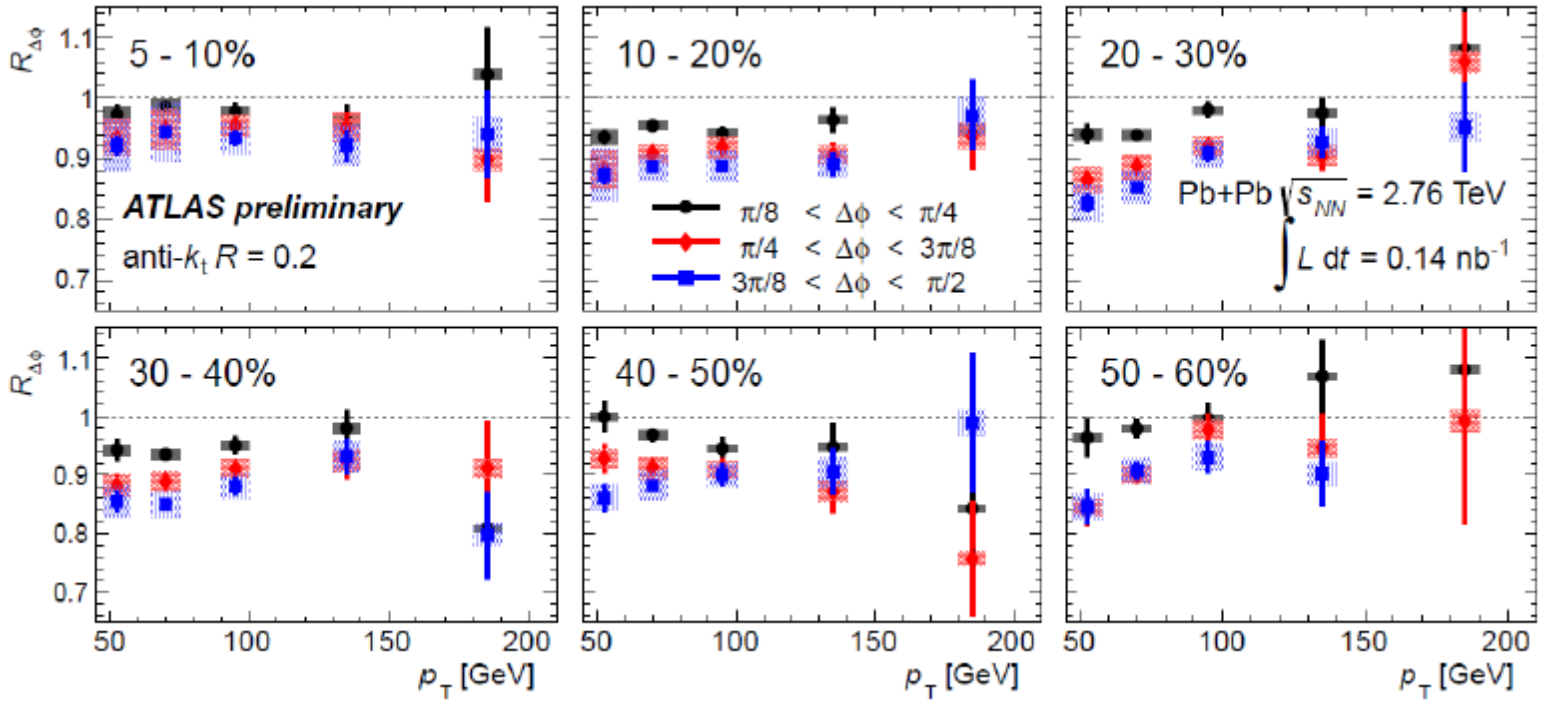
- The jet suppression factor shows small variation with the jet p_T.

- Less suppression for jets with larger R.
- The dependence is more pronounced at lower p_T.
- Qualitatively consistent with theoretical calculations.

Azimuthal dependence of jet yields

- Path length dependence of jet suppression
- Ratios of yields in different slices of $\Delta\varphi = \varphi^{jet} - \Psi_2$ with respect to $\Delta\varphi = 0 - \pi/8$





➡ ~15% reduction in plane yields with respect to out of plane yields.

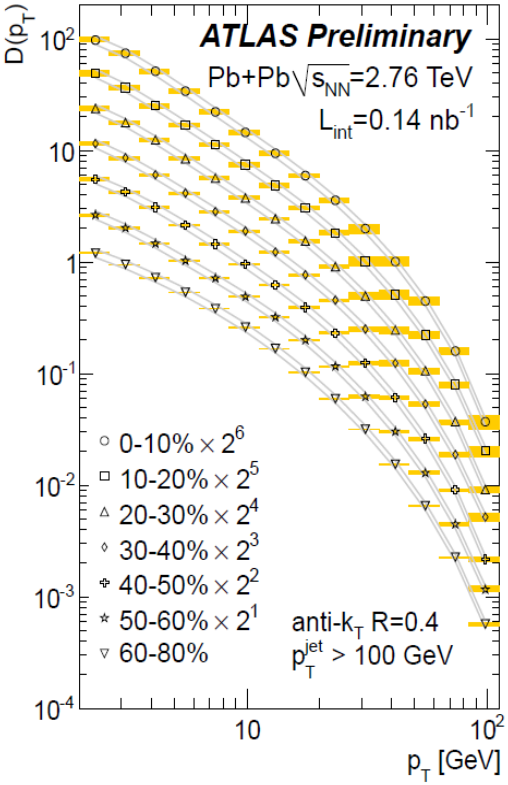
Jet Structure

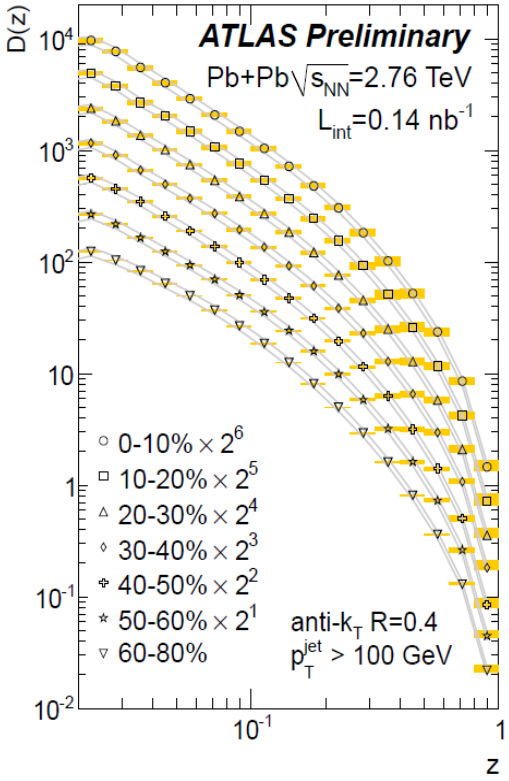
- We measured two sets of fragmentation distributions describing the jet structure:

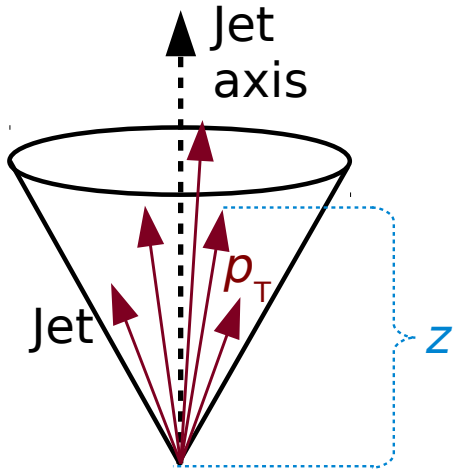
$$D(p_{\mathrm{T}}) \equiv \frac{1}{N_{\mathrm{jet}}} \frac{1}{\varepsilon} \frac{\Delta N_{\mathrm{ch}}(p_{\mathrm{T}})}{\Delta p_{\mathrm{T}}} \qquad D(z) \equiv \frac{1}{N_{\mathrm{jet}}} \frac{1}{\varepsilon} \frac{\Delta N_{\mathrm{ch}}(z)}{\Delta z} \qquad z = p_{\mathrm{T}}^{\mathrm{ch}} / p_{\mathrm{T}}^{\mathrm{jet}} \cos \Delta R$$

Spectra of charged particles in jets

Fragmentation function

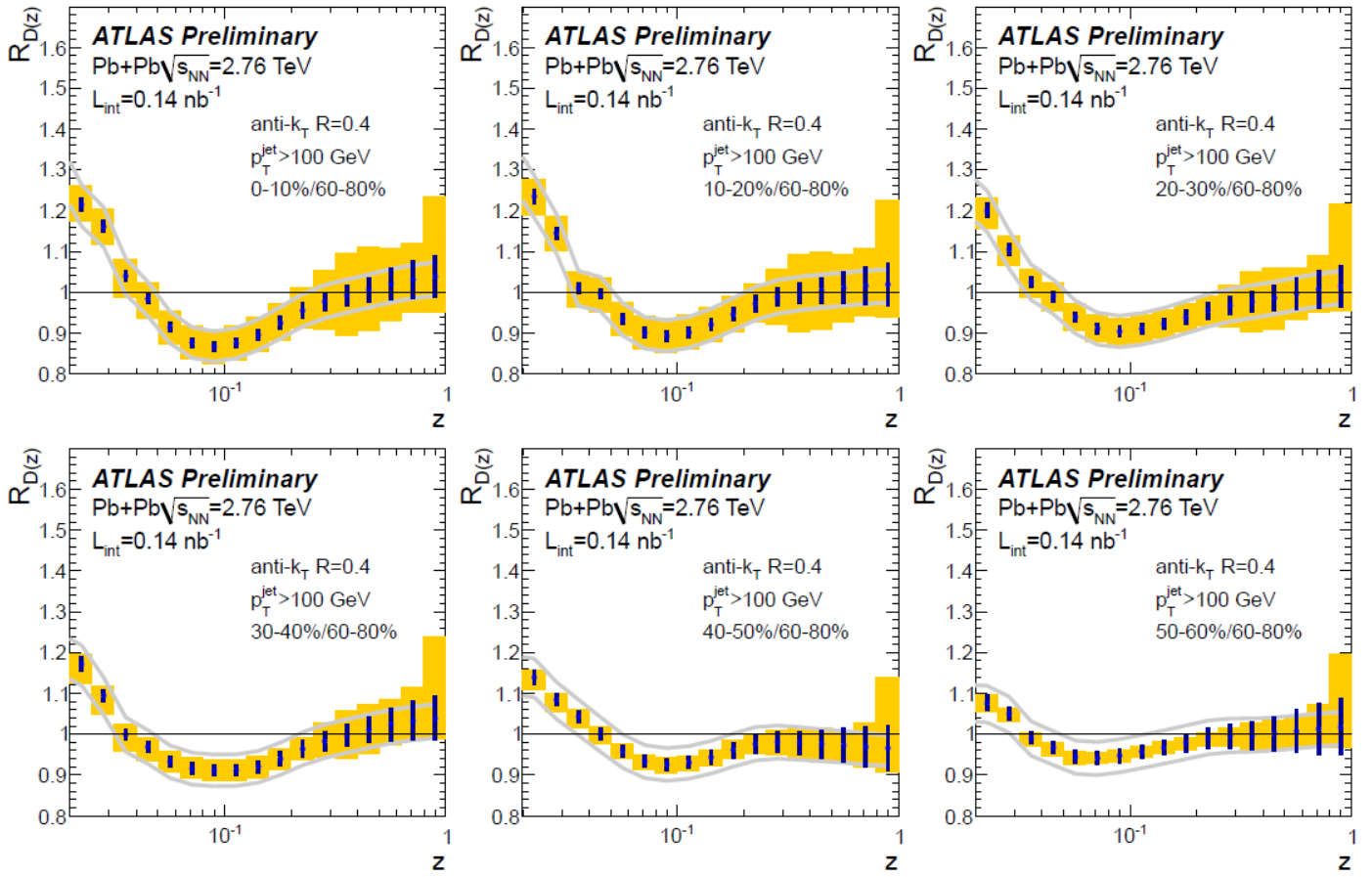






- D(z) and D(p_T) distributions have similar shape in all centrality bin.
- ➡ ratios are needed to study centrality dependence.

D(z) centrality dependence



- ~15% suppression at intermediate z (~0.1) and 25% enhancement at very low z (~0.02).
- No strong modification at large z (↔ leading parton) in central collisions with respect to peripheral ones.

Conclusions

Electroweak probes:

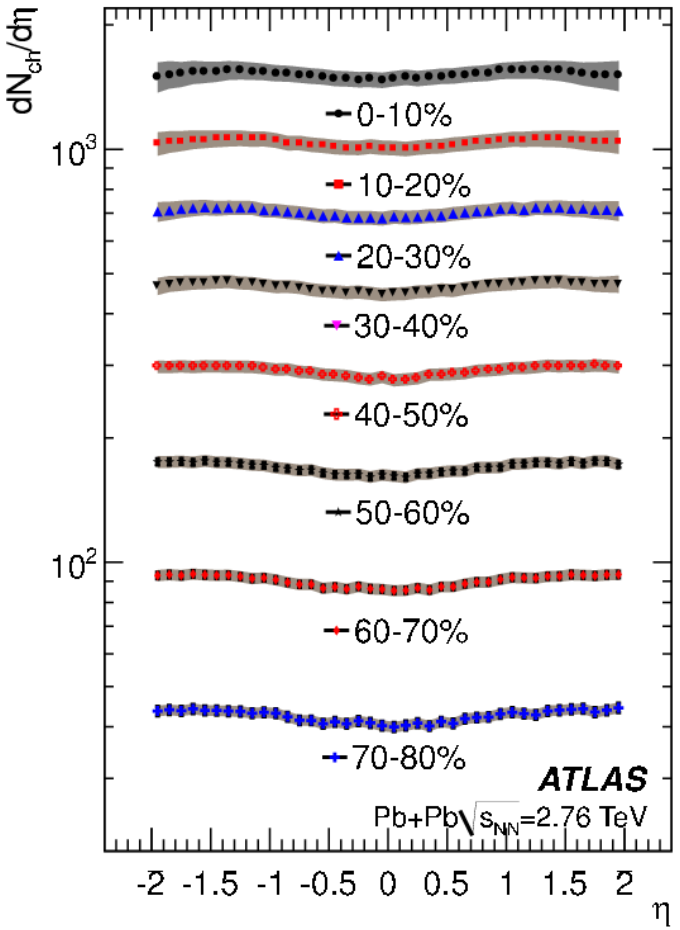
- Z and γ production consistent with N_{coll} scaling

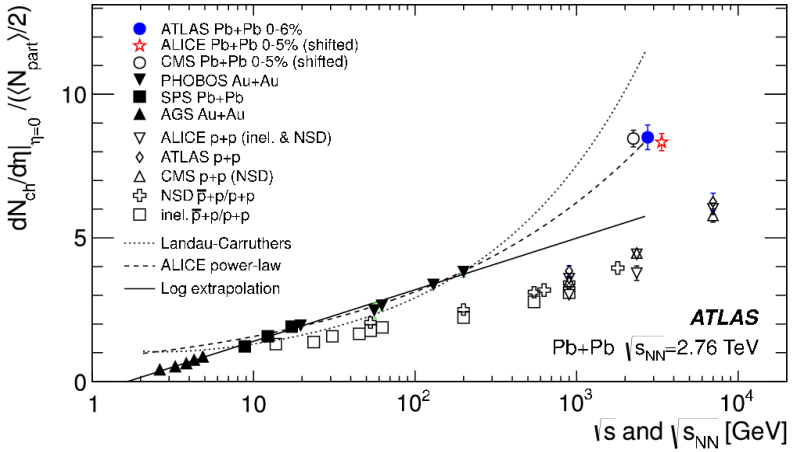
Jets:

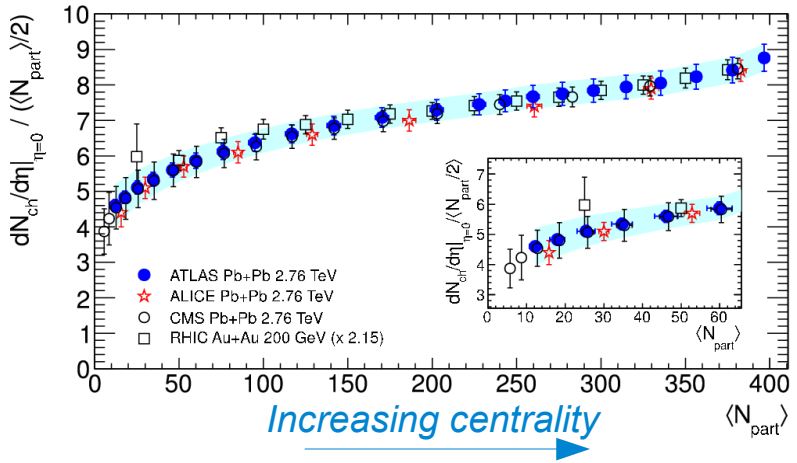
- Energy imbalance in the di-jet, Z-jet and γ-jet system is strongly increasing with increasing centrality.
- Suppression by a factor of 2 is observed in jet yield in central with respect to peripheral collisions.
- The dependence of the jet suppression is very weak on jet p_T and jet size except for low p_T region.
- Study of jet internal structure shows increasing size of modifications of fragmentation functions with increasing centrality.
- Azimuthal dependence of jet yields exhibits a clear path length dependence.
- Heavy quarks exhibits similar suppression as jets.
- Similar level of suppression observed also in high p_T spectra of charged particles.

Backup

Charged Particles Multiplicity







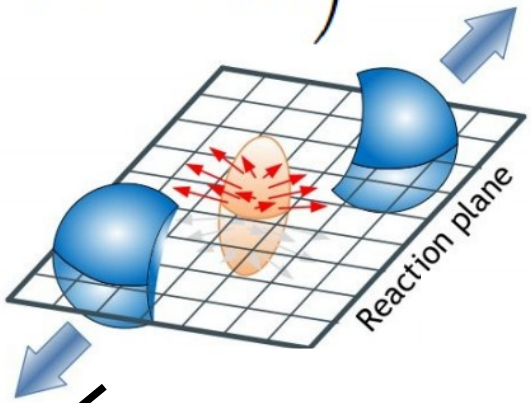
- Yield per participant pair increases by factor of two relative to RHIC with similar centrality dependence.
- Flat in pseudorapidity within |η|<2, similarly to p+p.
- Similar centrality dependence as at RHIC → robust scaling feature in HI.

Flow Measurement

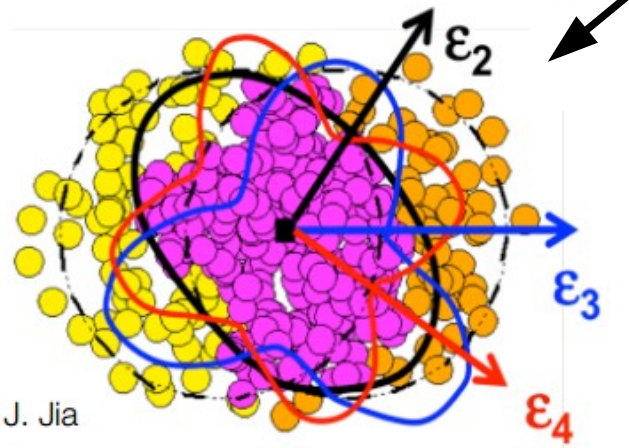
- Understanding the geometry and bulk properties of the medium.
  - Flow ↔ Particle emission asymmetry due to spatial deformations in the initial overlap region.
  - Studied via Fourier decomposition:

$$E\frac{d^3N}{dp^3} = \frac{1}{p_T}\frac{d^3N}{d\phi dp_T dy} = \frac{1}{2\pi p_T}\frac{E}{p}\frac{d^2N}{dp_T d\eta}\left(1 + 2\sum_{n=1}^{\infty} v_n \cos\left[n(\phi - \Phi_{RP})\right]\right)$$

  - RHIC: mainly measurement of the second and third Fourier coefficient.

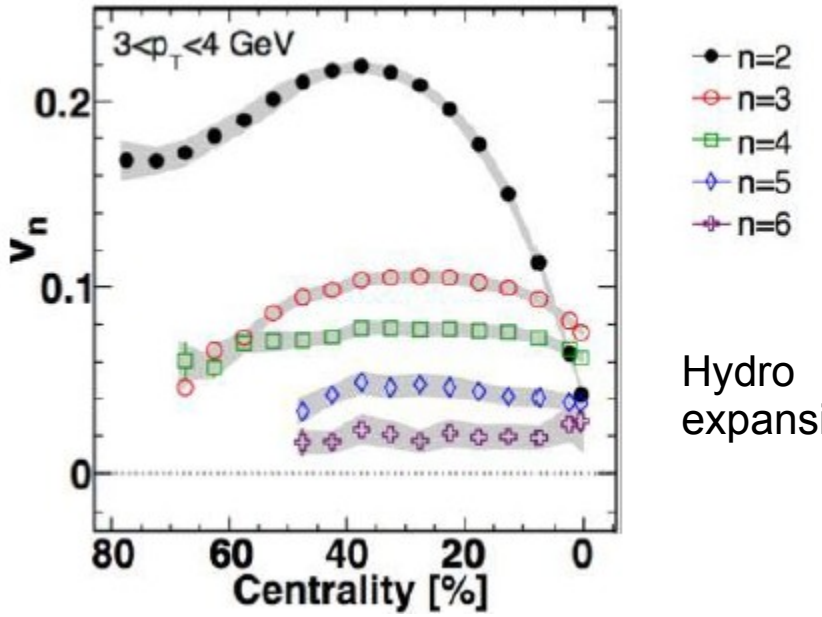


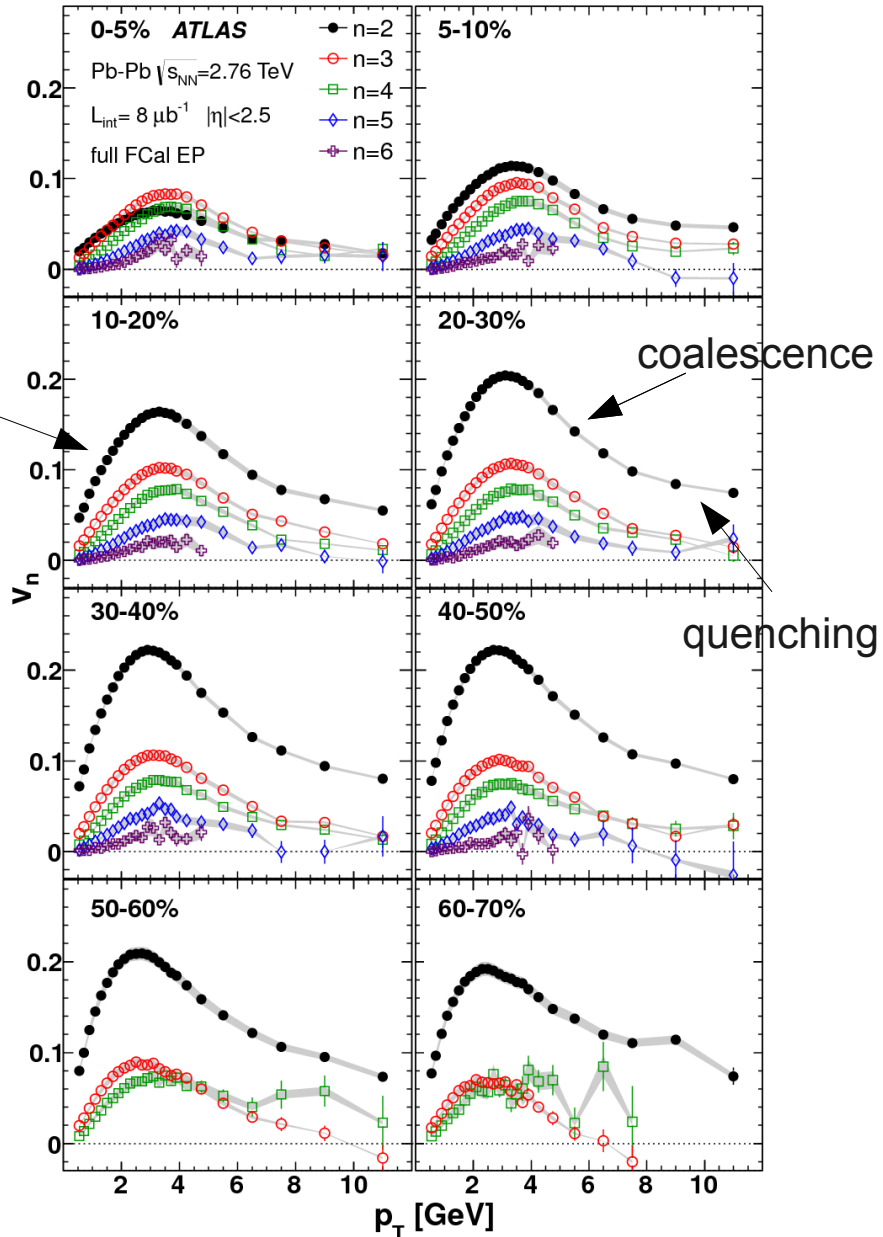
  - With the higher multiplicities and larger acceptance ATLAS study higher order components of the flow.



Fluctuations in initial state.

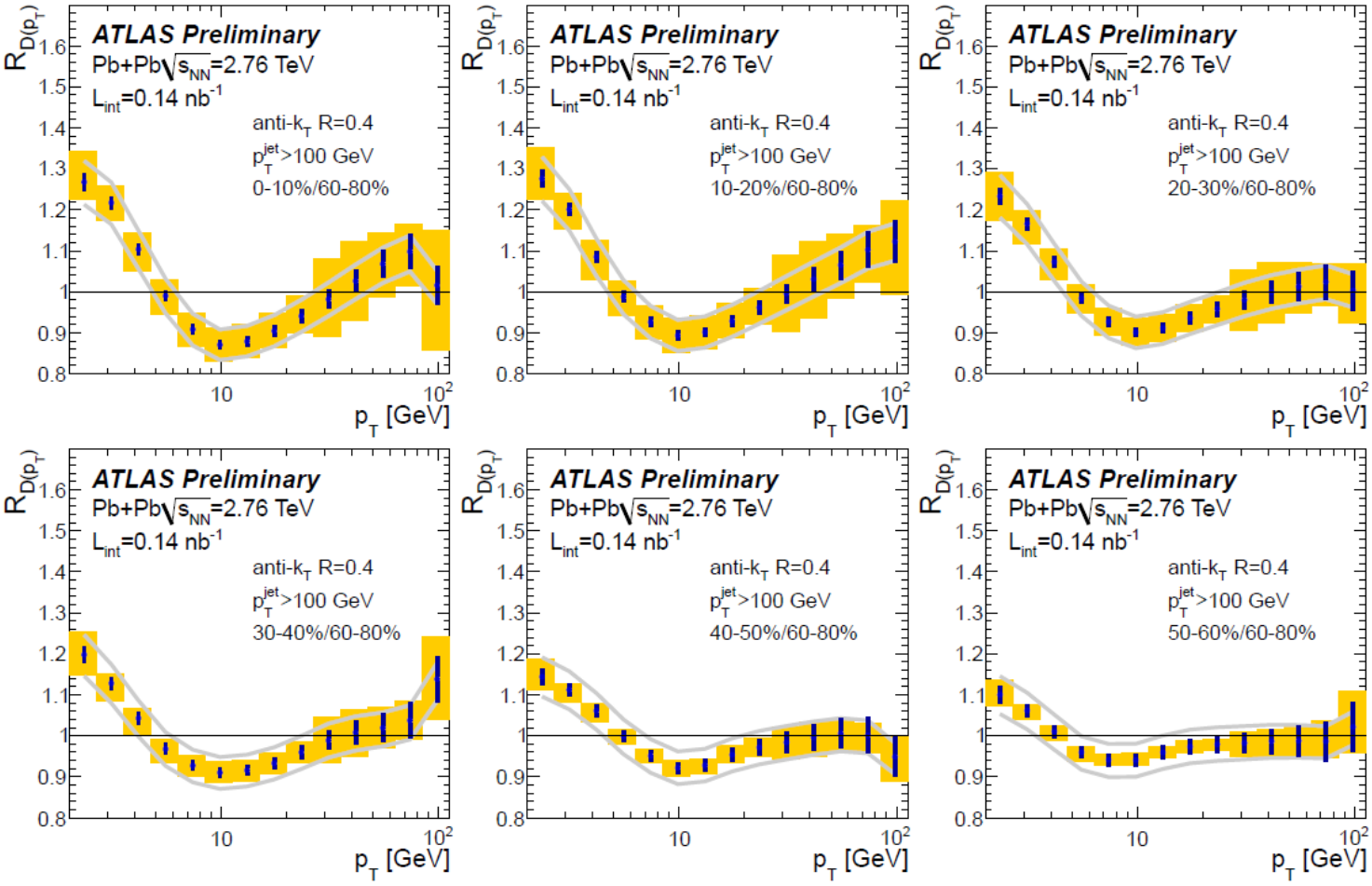
Flow measurement





- Similar p_T dependence for v_3-v_6.
- Weak centrality dependence observed for v_3-v_6.
- For the 5% most central events $v_3 > v_6$.
- No significant η dependence.
- Higher harmonics result from. fluctuations of interaction area.

D(p_T) centrality dependence



Shaded bands: uncorrelated or partially correlated systematic errors

Solid lines:

100% correlated systematic errors

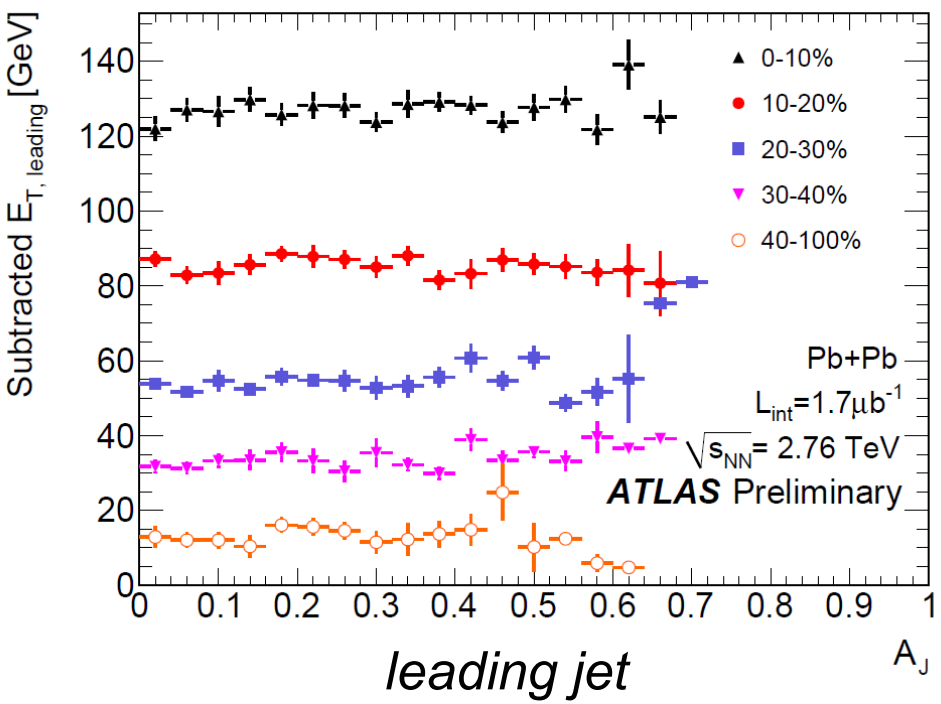
➡ Similar behaviour as for D(z) distribution.

ATLAS Detector Status

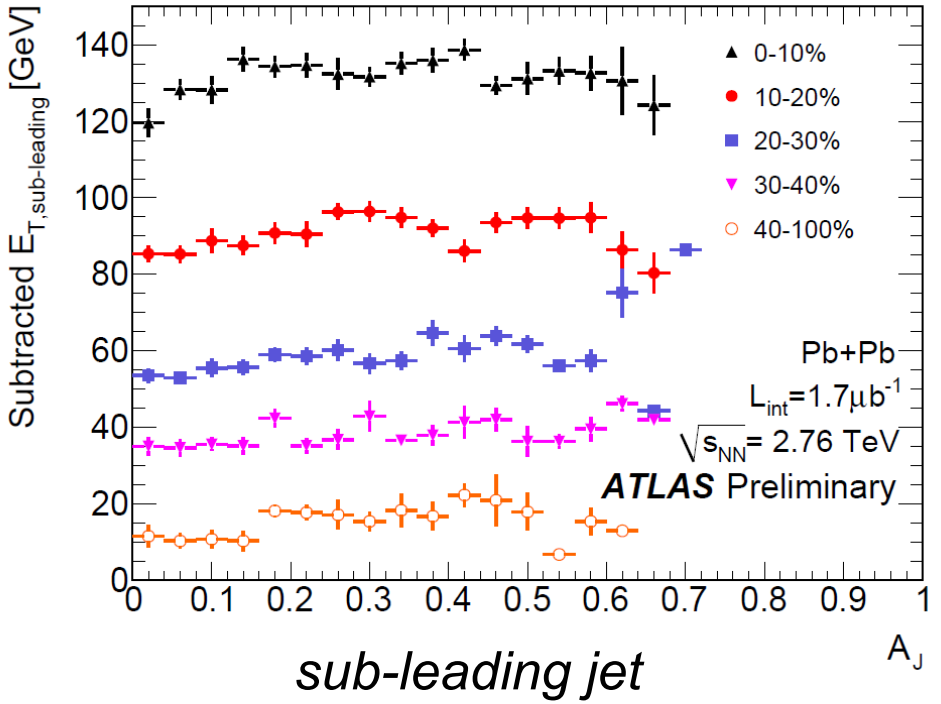
Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	95.9%
SCT Silicon Strips	6.3 M	99.3%
TRT Transition Radiation Tracker	350 k	97.5%
LAr EM Calorimeter	170 k	99.9%
Tile calorimeter	9800	99.5%
Hadronic endcap LAr calorimeter	5600	99.6%
Forward LAr calorimeter	3500	99.8%
LVL1 Calo trigger	7160	100%
LVL1 Muon RPC trigger	370 k	98.4%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	97.7%
RPC Barrel Muon Chambers	370 k	93.8%
TGC Endcap Muon Chambers	320 k	99.7%

Cross Checks: Subtraction

- Mean subtracted energy as a function of asymmetry



leading jet



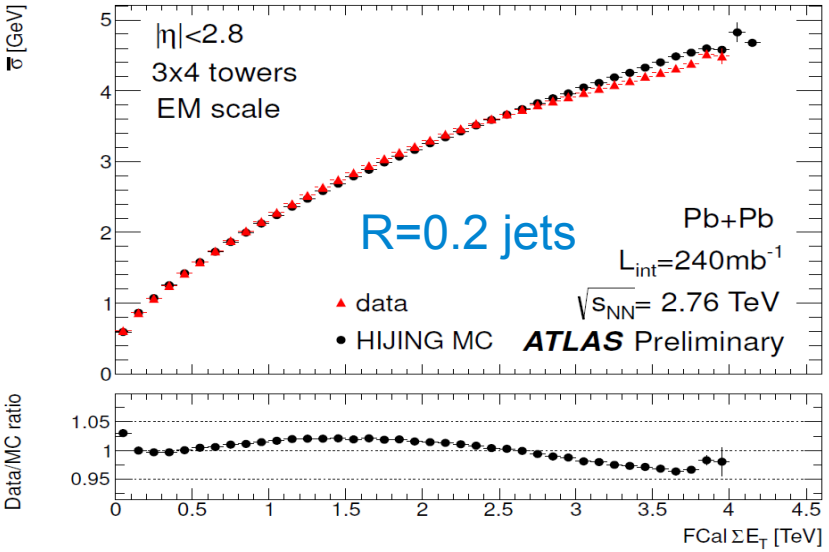
sub-leading jet

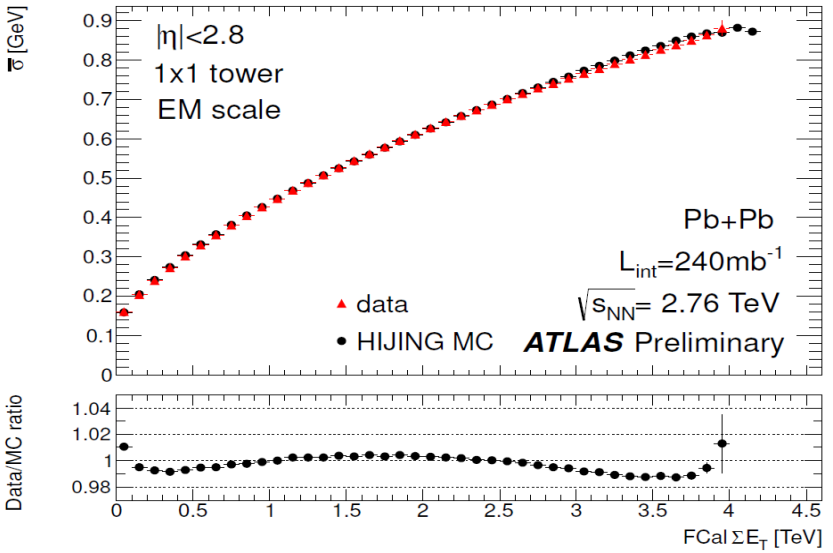
➡ no asymmetry dependence

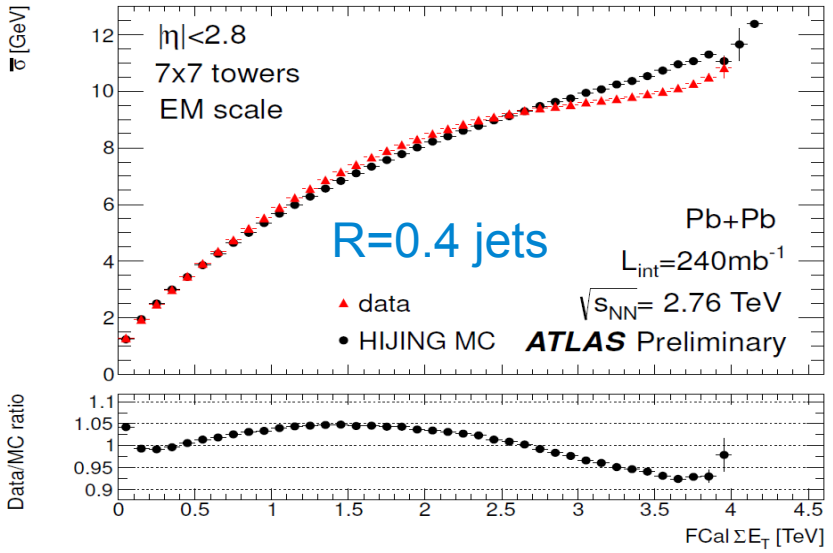
➡ amount of subtracted energy for leading and sub-leading jet is comparable

Background Fluctuations

- The fluctuations are evaluated as a standard deviation of the summed E_T in windows of towers of different size.
- 7x7 towers ~ R = 0.4 jets.
- 4x3 towers ~ R = 0.2 jets.







- Good agreement between data and MC.
- Basic data driven check of jet energy resolution.

Jet Reconstruction at ATLAS

- Reconstruction algorithm anti-k_t with R=0.2, 0.3 and 0.4.
- Input: calorimeter towers 0.1 x 0.1 ($\Delta\eta$ x $\Delta\varphi$).
- Event-by-event background subtraction:

$$E_{\mathrm{T}\,j}^{\mathrm{sub}} = E_{\mathrm{T}\,j} - A_j\ \rho_i(\eta_j)\,(1 + 2v_{2\,i}\cos\left[2\,(\phi_j - \Psi_2)\right])$$

➡ Anti-k_t reconstruction prior to a background subtraction.

➡ Underlying event estimated for each longitudinal layer and η slice separately.

- We exclude jet candidates with $D = E_{T\ tower}^{max} / \langle E_{T\ tower} \rangle > 4$ to avoid biasing subtraction from jets but no jet rejection based on *D*.
- Additional iteration step to remove residual effect of the jets on the background estimation.
- Jets corrected for flow contribution.

Transverse Energy in 7x7 tower window