Angular correlations of jets in lead-lead collisions at 2.76 TeV using the ATLAS detector

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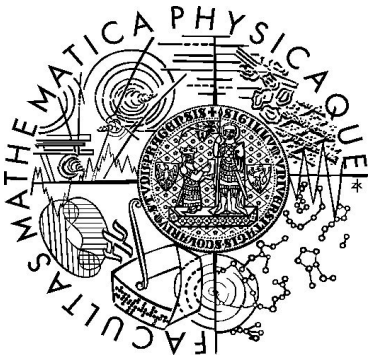
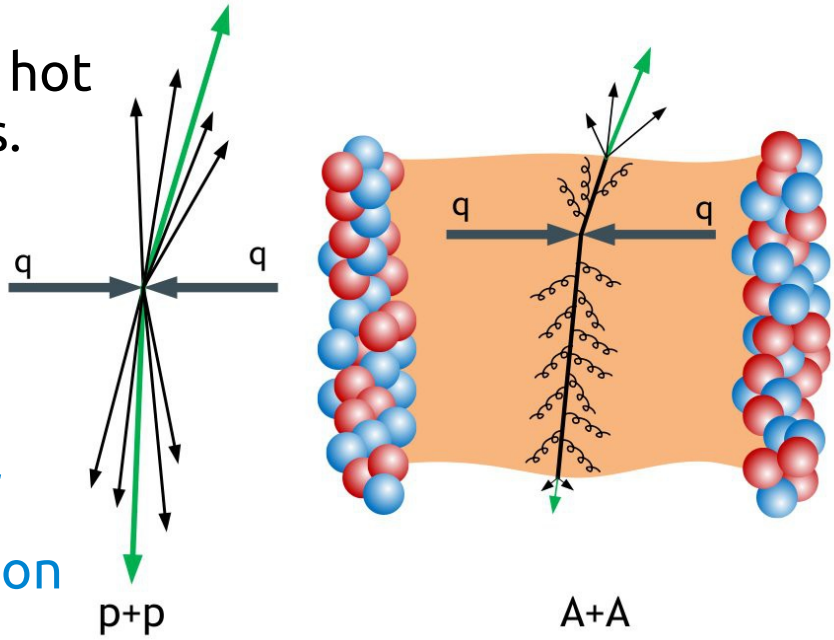


IPNP
Charles University

Quark Matter 2014, May 21, 2014

Jets in Heavy Ion Collisions

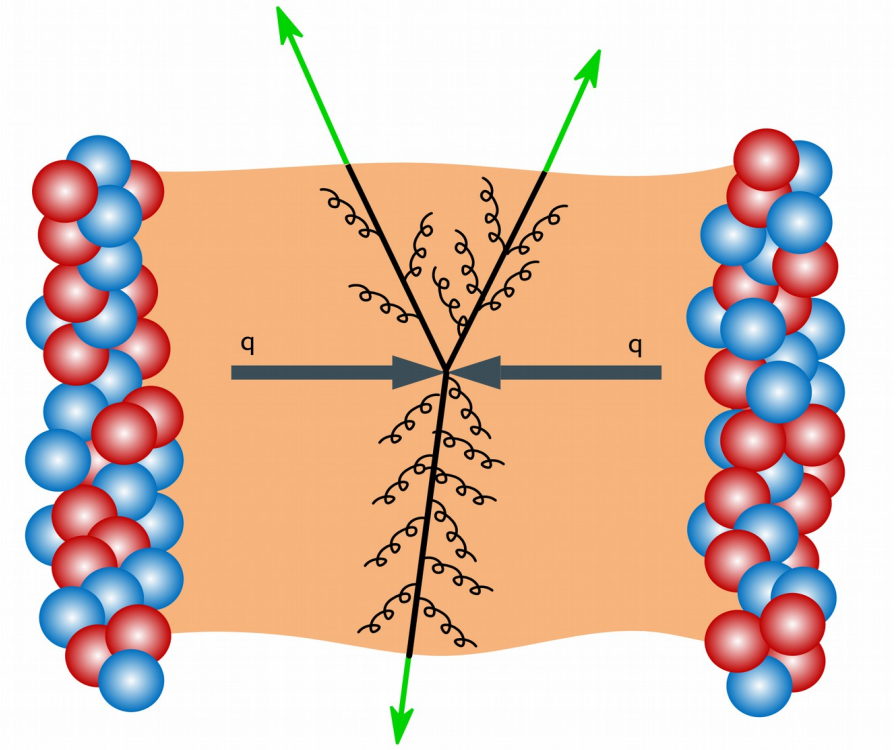
- Jets provide a powerful tool to probe the hot and dense medium created in HI collisions.
- RHIC's measurements of single high p_T particles: the first evidence for jet quenching.
- A significant modification of di-jet and photon-jet p_T-balance and suppression of inclusive jet spectra with increasing collision centrality is observed at the LHC.



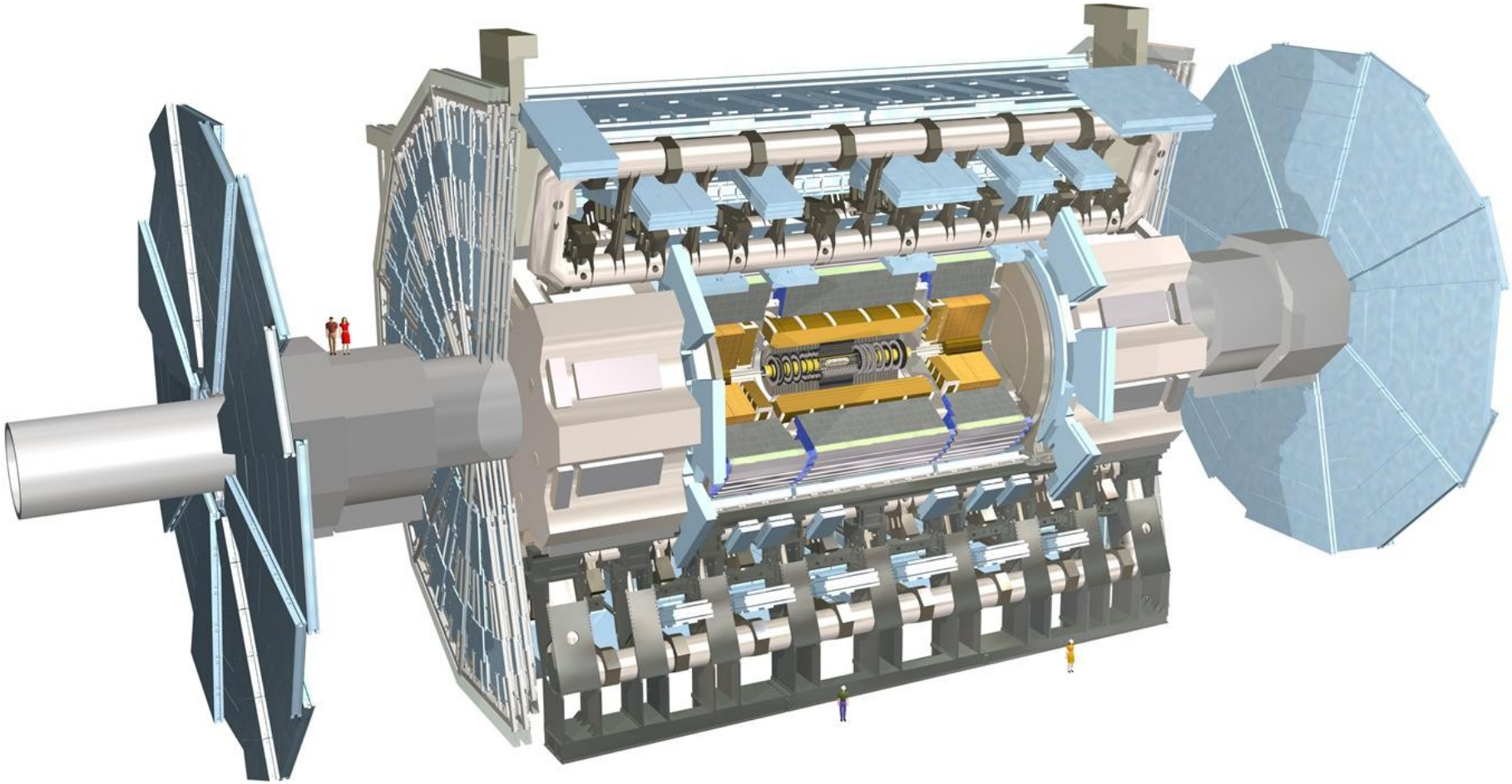
  - The single jet measurements are sensitive to the average energy loss.
  - The dijet measurements probe differences in the quenching between the two parton showers.

Jets in Heavy Ion Collisions

- The purpose of this analysis is to study properties of final state with neighbouring jets.
- It may help to disentangle the contributions of path length and fluctuations to the quenching.
- It may provide more detailed insight on the modification of the parton shower in the quark gluon plasma.



The ATLAS Detector



Jet Reconstruction at ATLAS

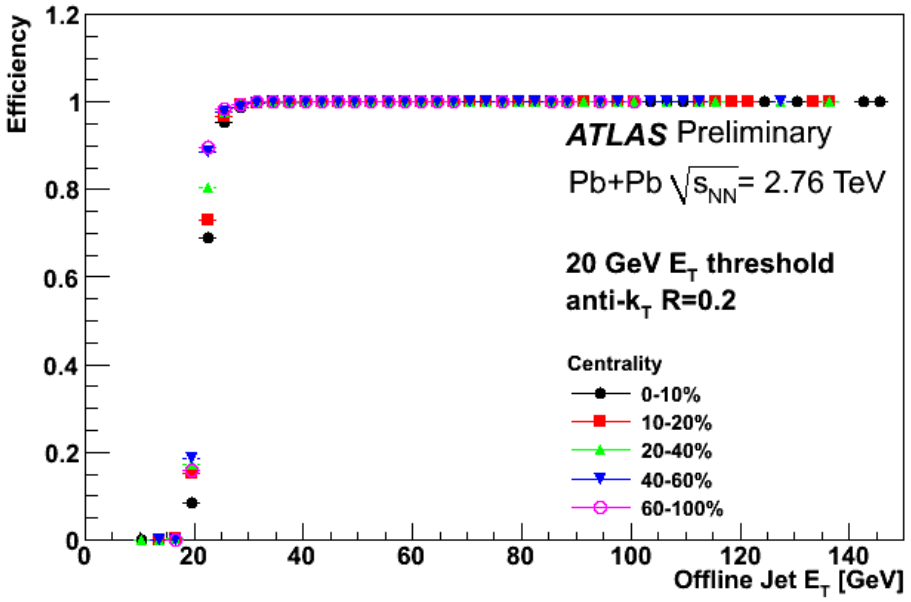
- Reconstruction algorithm: anti-k_t with R=0.2, 0.3 and 0.4.
- Input: calorimeter towers 0.1 x 0.1 ($\Delta\eta$ x $\Delta\varphi$).
- Event-by-event background subtraction:

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

- Jets corrected for flow contribution.
- Anti-k_t reconstruction prior to the background subtraction.
- Underlying event estimated for each longitudinal layer and η slice separately.
- Jet candidates are excluded with requirement $D = E_{T\,tower}^{max} / \langle E_{T\,tower} \rangle > 4$ to avoid bias of the UE determination .
- Additional iteration step to remove residual effect of the jets on the background estimation.

Data and MC

- Two data samples were used:
- Pb+Pb data recorded in 2011 using jet triggers with integrated luminosity of 0.14 nb^{-1}.
- Pb+Pb data recorded in 2011 using Minimum Bias (MB) with integrated luminosity of 7 μb^{-1}.
- Jet trigger algorithm required a $R = 0.2$ jet with $E_T > 20$ GeV.
- All events were required to satisfy MB events selection: good timing and vertex.
- Data are compared to MC, where MC Pythia di-jet events were embedded into real MB Pb+Pb events.



Neighbouring jet production

- Measured variable is defined as

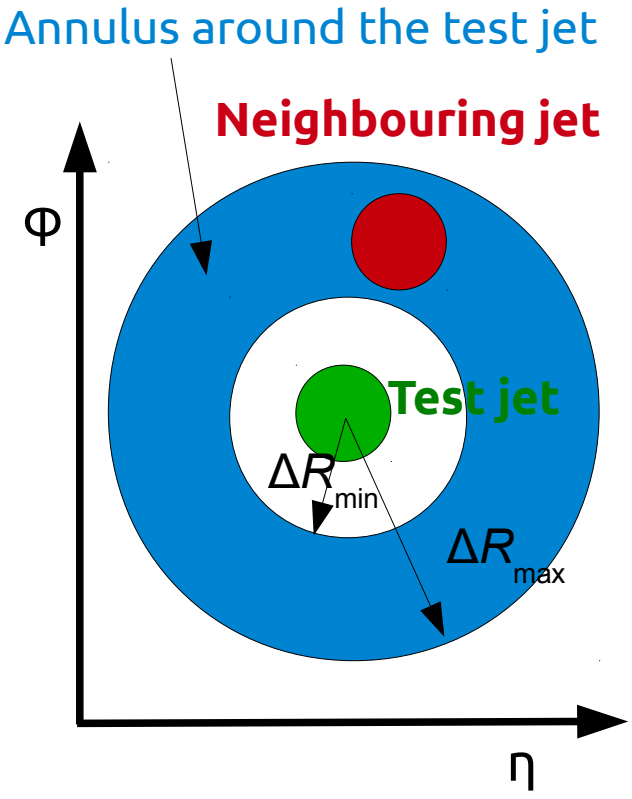
$$R_{\Delta R} = \frac{1}{\mathrm{d}N_{\mathrm{jet}}^{\mathrm{test}}/\mathrm{d}E_{\mathrm{T}}^{\mathrm{test}}} \sum_{i=1}^{N_{\mathrm{jet}}^{\mathrm{test}}} \frac{\mathrm{d}N_{\mathrm{jet},i}^{\mathrm{nbr}}}{\mathrm{d}E_{\mathrm{T}}^{\mathrm{test}}}(E_{\mathrm{T}}^{\mathrm{test}}, E_{\mathrm{T,min}}^{\mathrm{nbr}}, \Delta R)$$

➡ The rate of the neighbouring jets that accompany a test jet with given $E_{\mathrm{T}}^{\mathrm{test}}$.

- Two different binning logics are used:
  - Minimum $E_{\mathrm{T,min}}^{\mathrm{nbr}}$
  - Minimum $E_{\mathrm{T,min}}^{\mathrm{test}}$

➡ $$\frac{\mathrm{d}R_{\Delta R}}{\mathrm{d}E_{\mathrm{T}}^{\mathrm{nbr}}} = \frac{\Delta R_{\Delta R}}{\Delta E_{\mathrm{T}}^{\mathrm{nbr}}}(E_{\mathrm{T}}^{\mathrm{test}}, E_{\mathrm{T}}^{\mathrm{nbr}}, \Delta R)$$

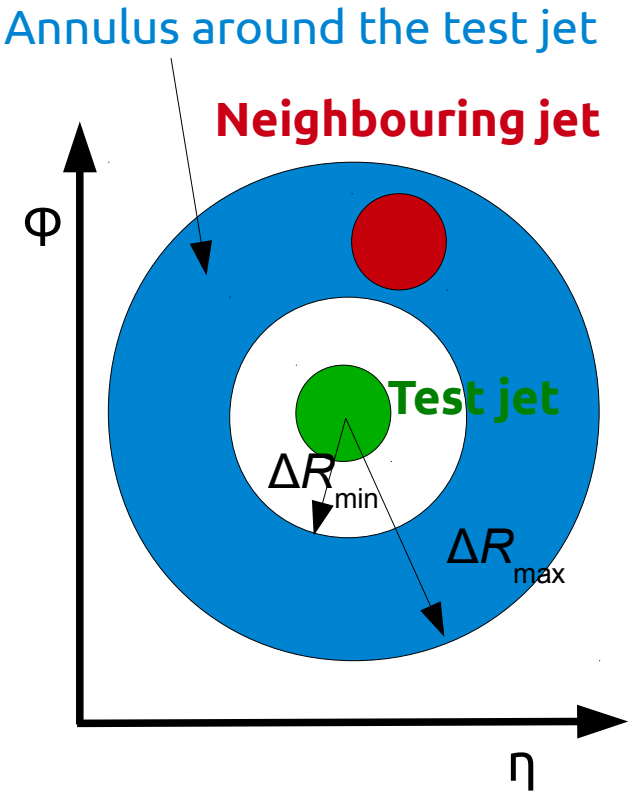
- The centrality dependence is studied by evaluation central to peripheral ratios $\rho_{R\Delta R}$.



Neighbouring jet production

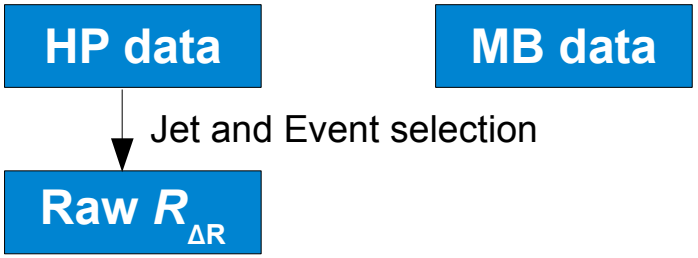
Analysis bins:

- 3 jet sizes: R=0.2, 0.3 and 0.4 jets
- 5 bins in the test jet transverse energy (E_t^{test})
- 4 bins in the neighbouring jet transverse energy (E_T^{nbr}).
- Four centrality bins: 0 - 10% - 20% - 40% - 80%
- The size of the annulus: $\Delta R_{min} < \Delta R < 1.6$, where
  - ΔR_{min} = 0.8 (R=0.4 jet)
  - ΔR_{min} = 0.6 (R=0.3 jets)
  - ΔR_{min} = 0.5 (R=0.2 jets)



Analysis flow

- Standard HI event selection criteria
- "fake" jets (from UE fluctuations) were identified and rejected by requirement of matching calorimeter jet to a track jet or electro-magnetic cluster with $E_T > 7$ GeV.
- Measurement is restricted to $|\eta| < 2.8$.
- The annulus size restricts the position of test jets to $|\eta| < 1.2$.
- Jet E_T was corrected to reduce the effect of the jet up-feeding due to JER.



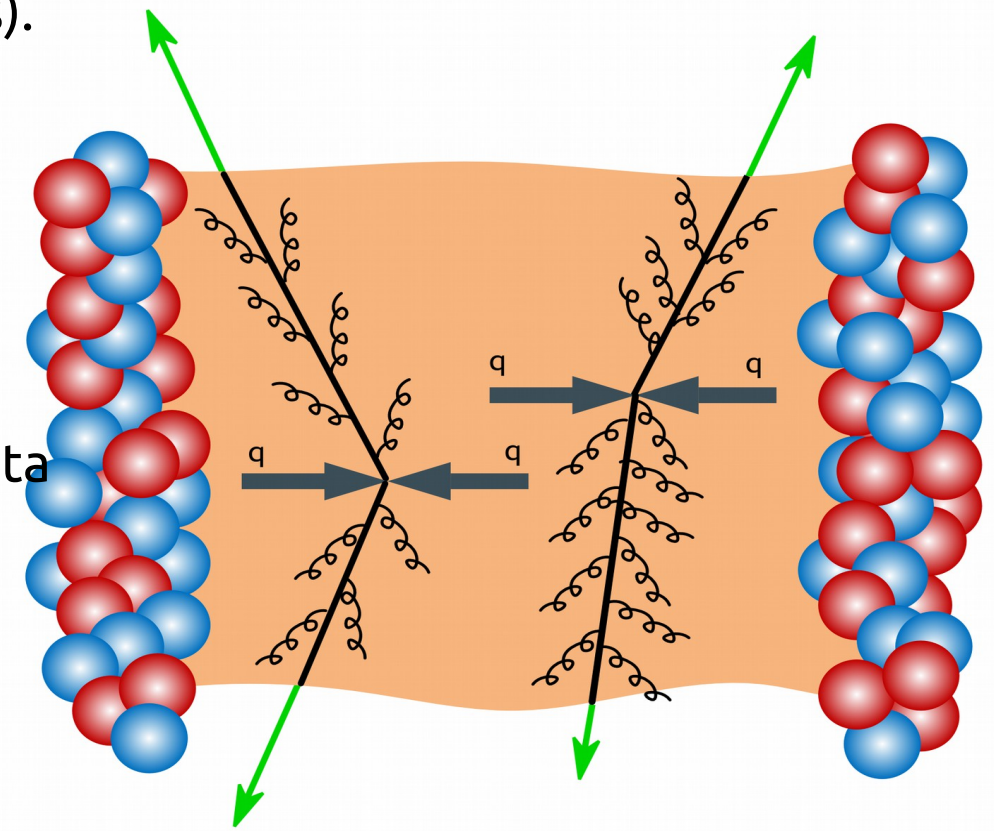
Analysis flow

- Two independent hard scatterings may result in an additional contribution to the yield of neighbouring jets. (Significant cross-section in Pb+Pb collisions).

➡ a subtraction of such combinatoric contribution is needed:

$$R_{\Delta R} = R_{\Delta R}^{raw} - R_{\Delta R}^{combi}$$

- We benefit from Pythia to overlay here. data



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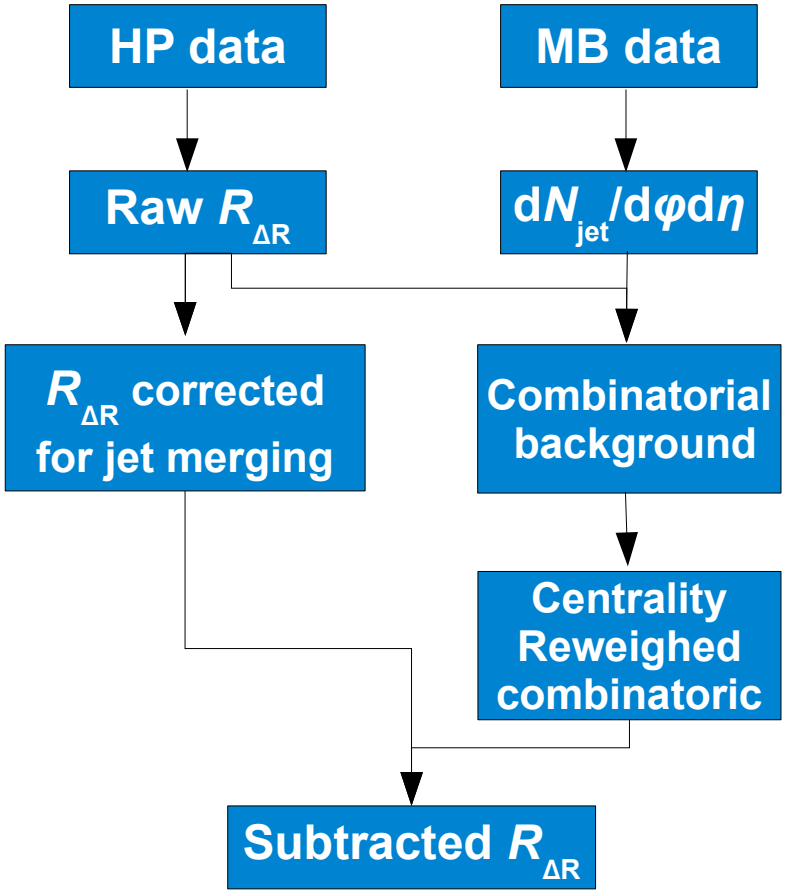
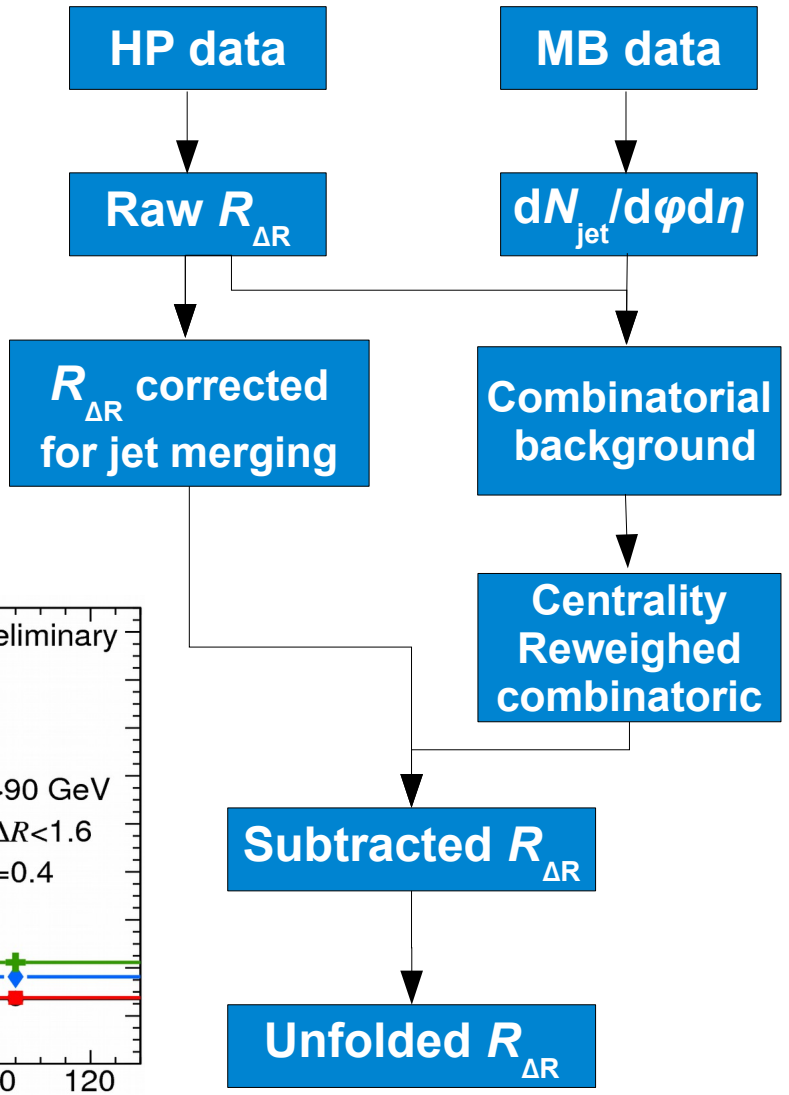
- Minimum Bias events are used to estimate yield of combinatoric neighbouring jets in the annulus.

  (Correction for the effect when two neighbouring jets overlap is applied.)

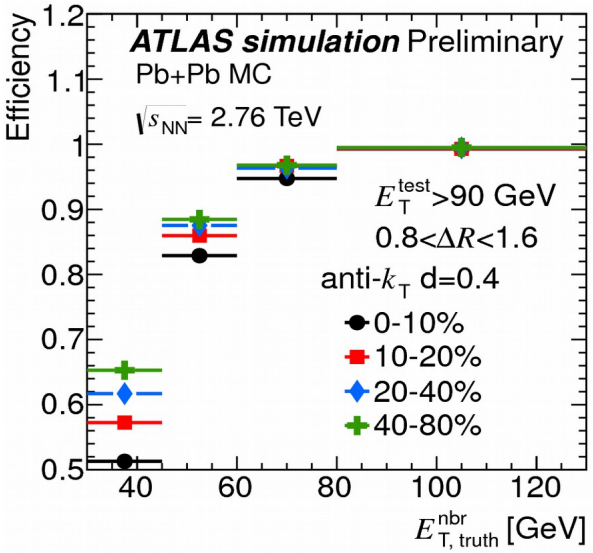


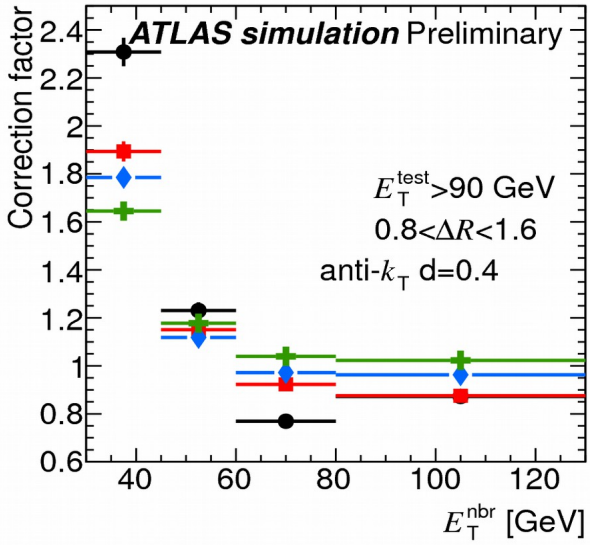
Analysis flow

- Bin-by-bin unfolding is used to correct for bin migration due to the finite JER.
- It also corrects for efficiency and for the migration inside and outside the annulus.



Efficiency and bin-by-bin correction factors



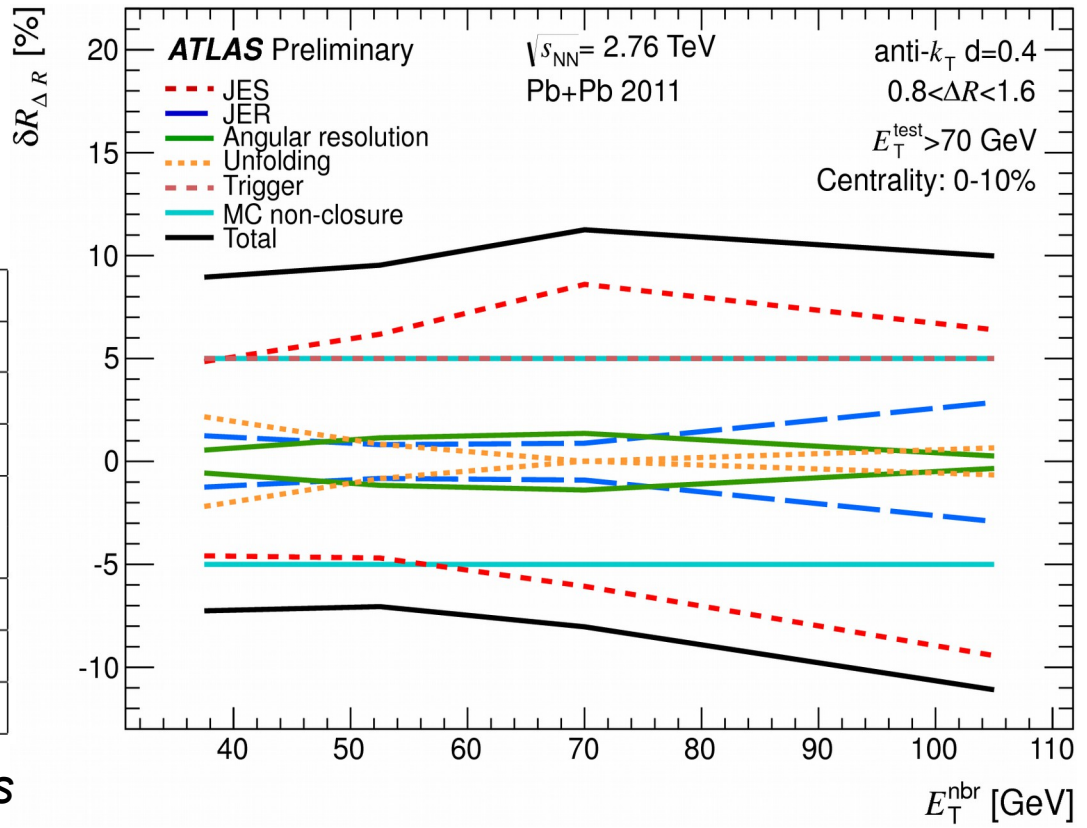


Systematic Uncertainties

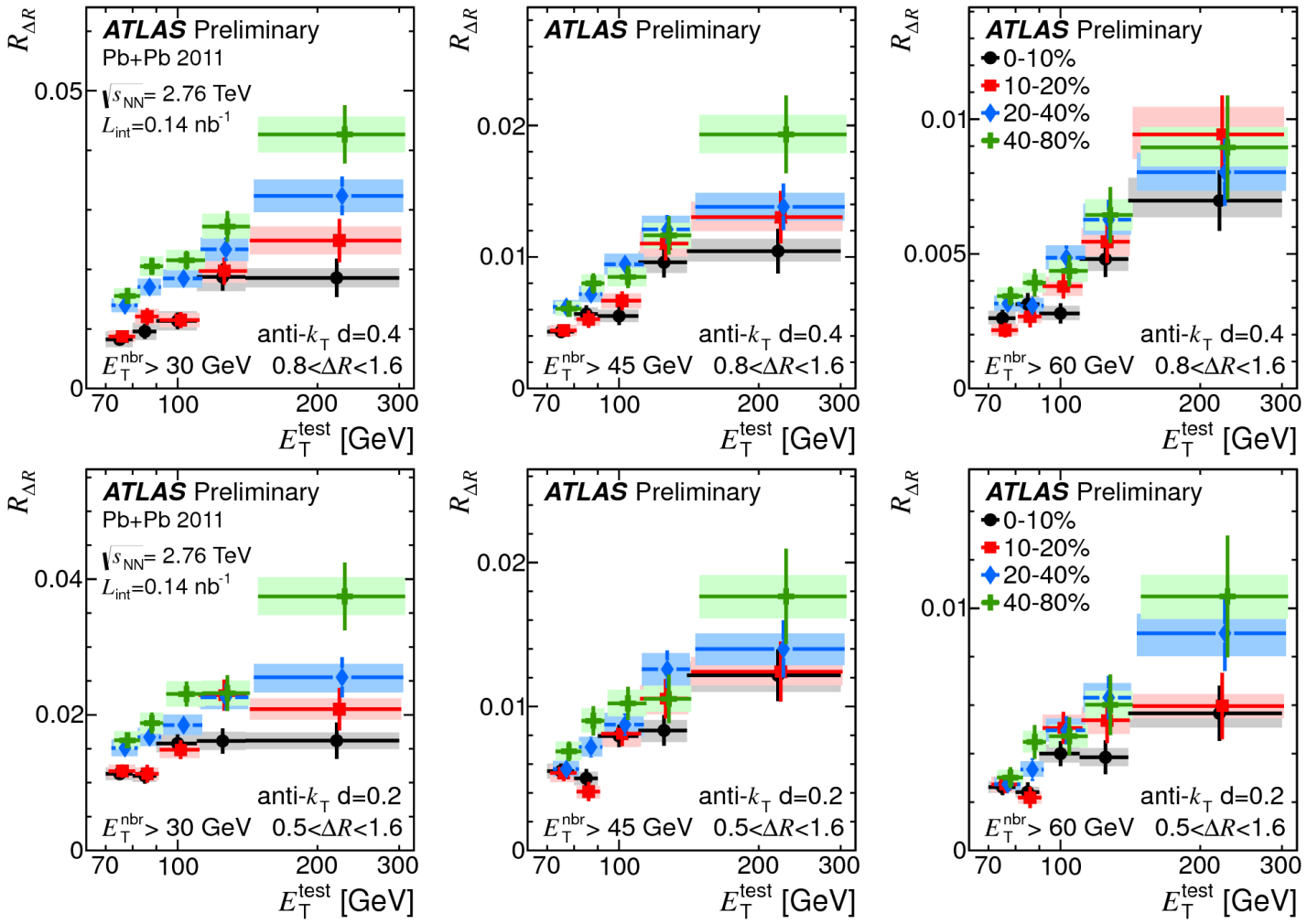
- The measurement is dominated by the statistical uncertainty.
- Systematic uncertainties due to:
  - Jet Energy Scale
  - Jet Energy Resolution
  - Jet Angular Resolution
  - Unfolding
  - Trigger
  - MC non-closure

	$\delta R_{\Delta R}$		$\delta \rho_{R_{\Delta R}}$
	0–10%	40–80%	0–10%
JES	12%	6%	5 %
JER	4%	2%	2%
Angular resolution	2%	0.5%	2%
Unfolding	6%	2%	5%
MC	5%	5%	5%
Trigger	5%	–	5%

Maximal systematic uncertainties

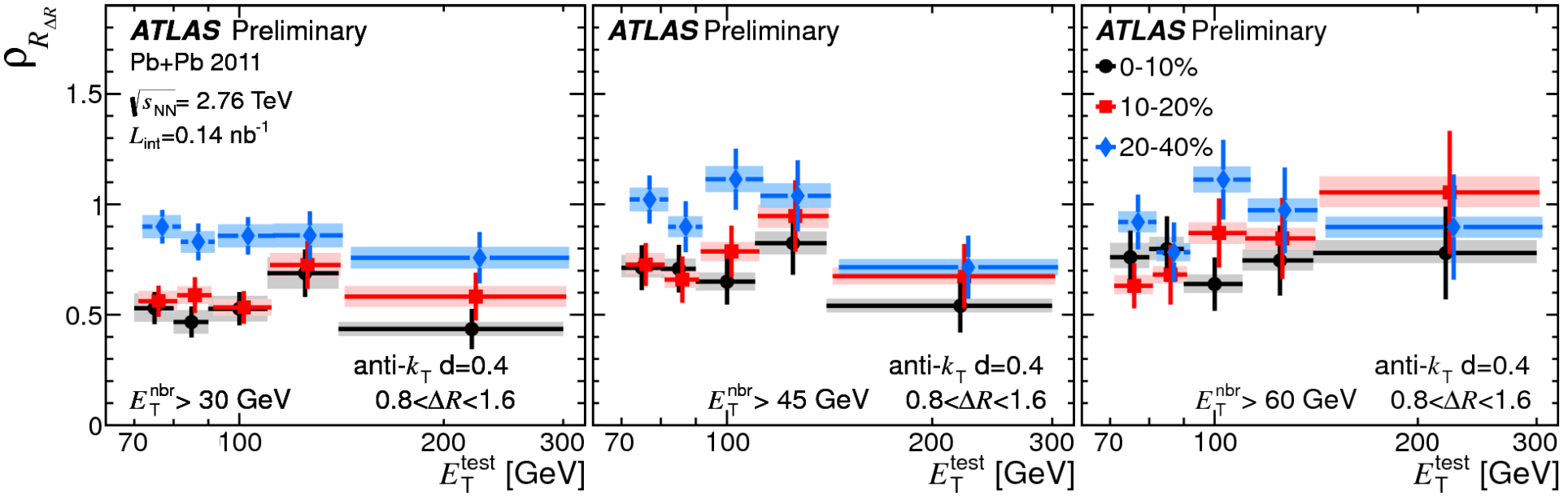


$R_{\Delta R}$: test jet E_T dependence



- The distribution exhibits a monotonic increase with increasing E_T^{test}.
- This is consistent in shape with the previous measurement by D0 (arXiv:1207.4957).
- Suppression from peripheral to central collisions is observed.

Central to peripheral ratios, $\rho_{R_{\Delta R}}$

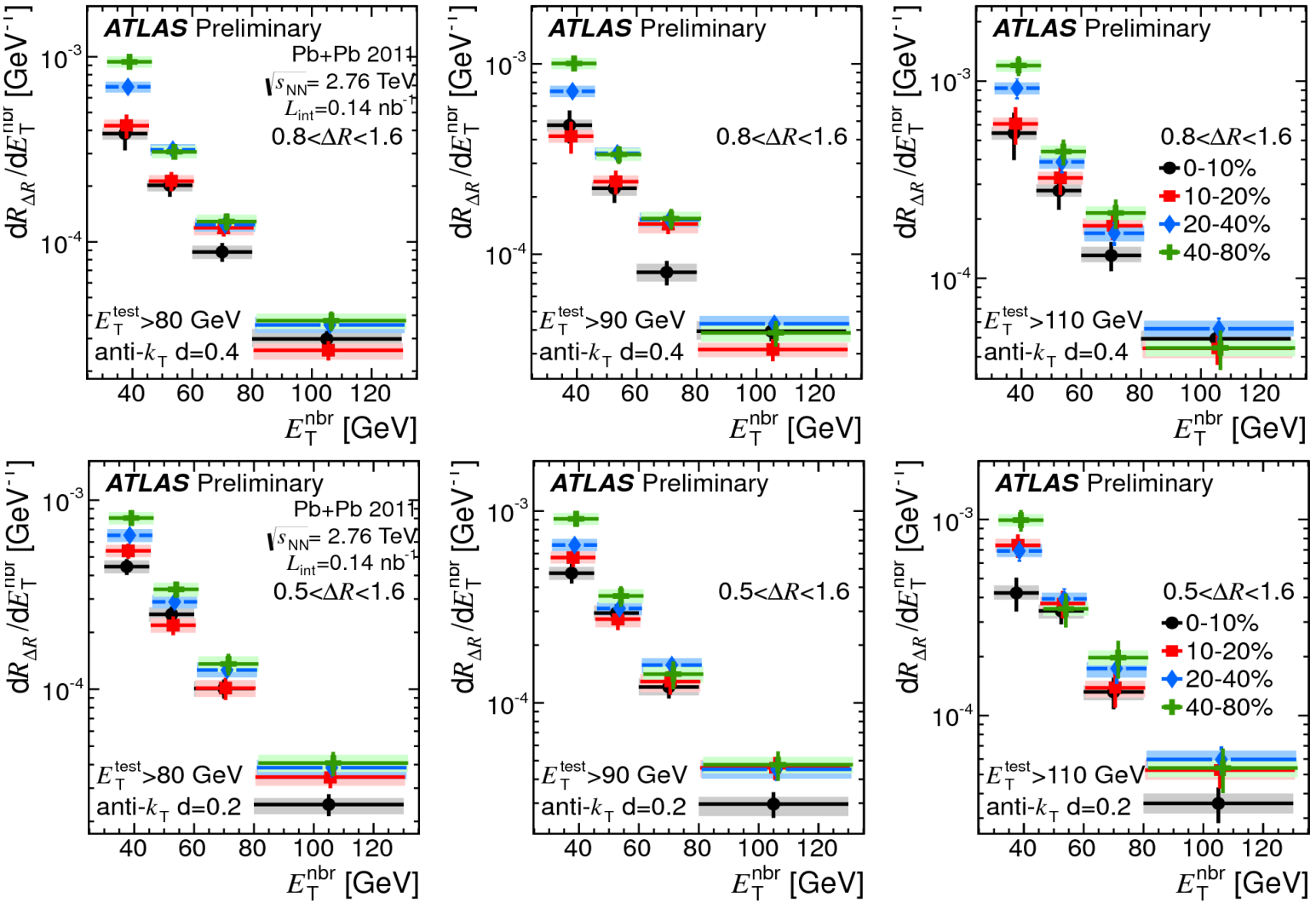


- The central to peripheral ratio does not exhibit any strong dependence on the test jet E_T.
- The suppression factor in the most central collisions is at the level of 0.5-0.7 for all three thresholds on E_T^{nbr} .
- The suppression becomes less pronounced with decreasing centrality.
- This is qualitatively consistent with the observation of the centrality dependent suppression of inclusive jet yields.

Yields of neighbouring jets

R = 0.4

R = 0.2



- The similar trends of the suppression can be seen.
- But less pronounced than for the ratio evaluated as a function of test jet E_T.

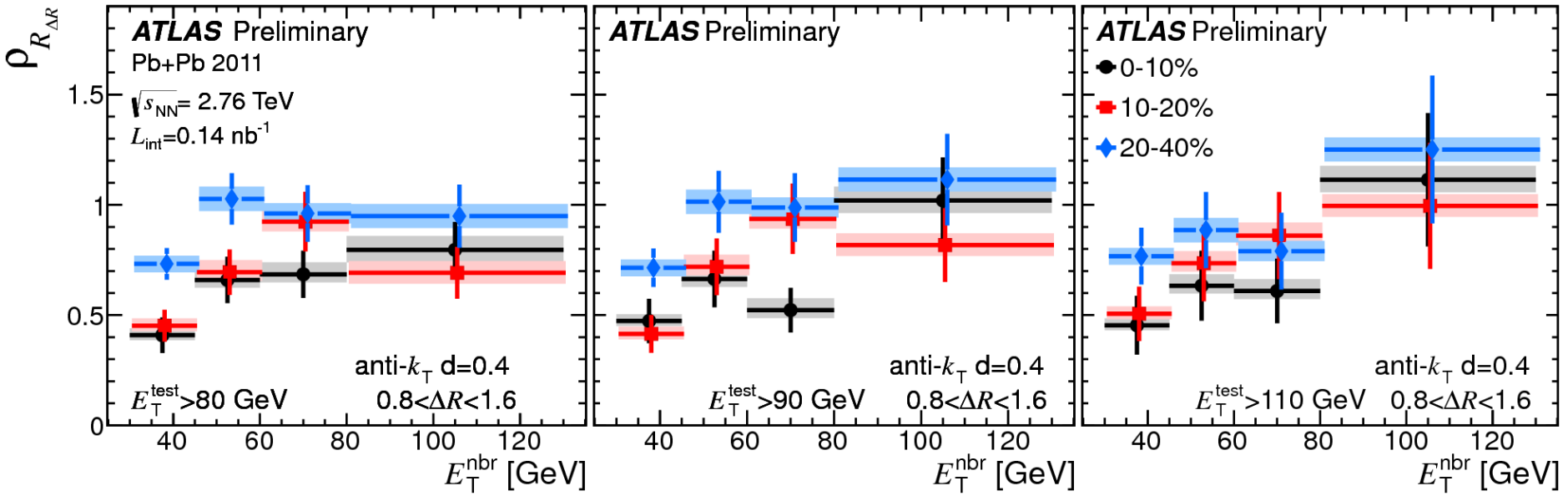
Shape of the neighbouring jet yield

- Yields of neighbouring jets were fitted by a power-law fit.
- The spectral index was extracted and summarized as a function of the centrality for different jet collections.

	0-10%	10-20%	20-40%	40-80%
$R = 0.4$	2.66 ± 0.23	2.72 ± 0.22	2.93 ± 0.15	3.29 ± 0.21
$R = 0.3$	2.75 ± 0.21	2.45 ± 0.20	2.95 ± 0.16	3.23 ± 0.19
$R = 0.2$	2.76 ± 0.19	2.58 ± 0.19	2.67 ± 0.17	3.00 ± 0.20

- Indication of a change in the E_T^{nbr} spectral shape from peripheral to central collisions.
- The significance is limited due to limited statistics of available data sample.

Central to peripheral ratios $\rho_{R_{\Delta R}}$



- The central to peripheral ratio evaluated as a function of E_T^{nbr} suggests a decrease of suppression with increasing E_T^{nbr}.
- Such a decrease of suppression may in fact be expected:
  - Two partons have similar energy and similar in-medium path-length.
  - In the configuration of $E_T^{nbr} \sim E_T^{test}$ the per test jet normalization effectively removes the impact of the suppression.

Conclusions

- We have studied the production of neighbouring jets in HI collisions.
- Centrality dependence is observed in data:

➡ $R_{\Delta R}$ is the lowest for central collisions.

➡ Significant suppression from peripheral to central collisions when test jet E_T is different from the neighbouring jet E_T.

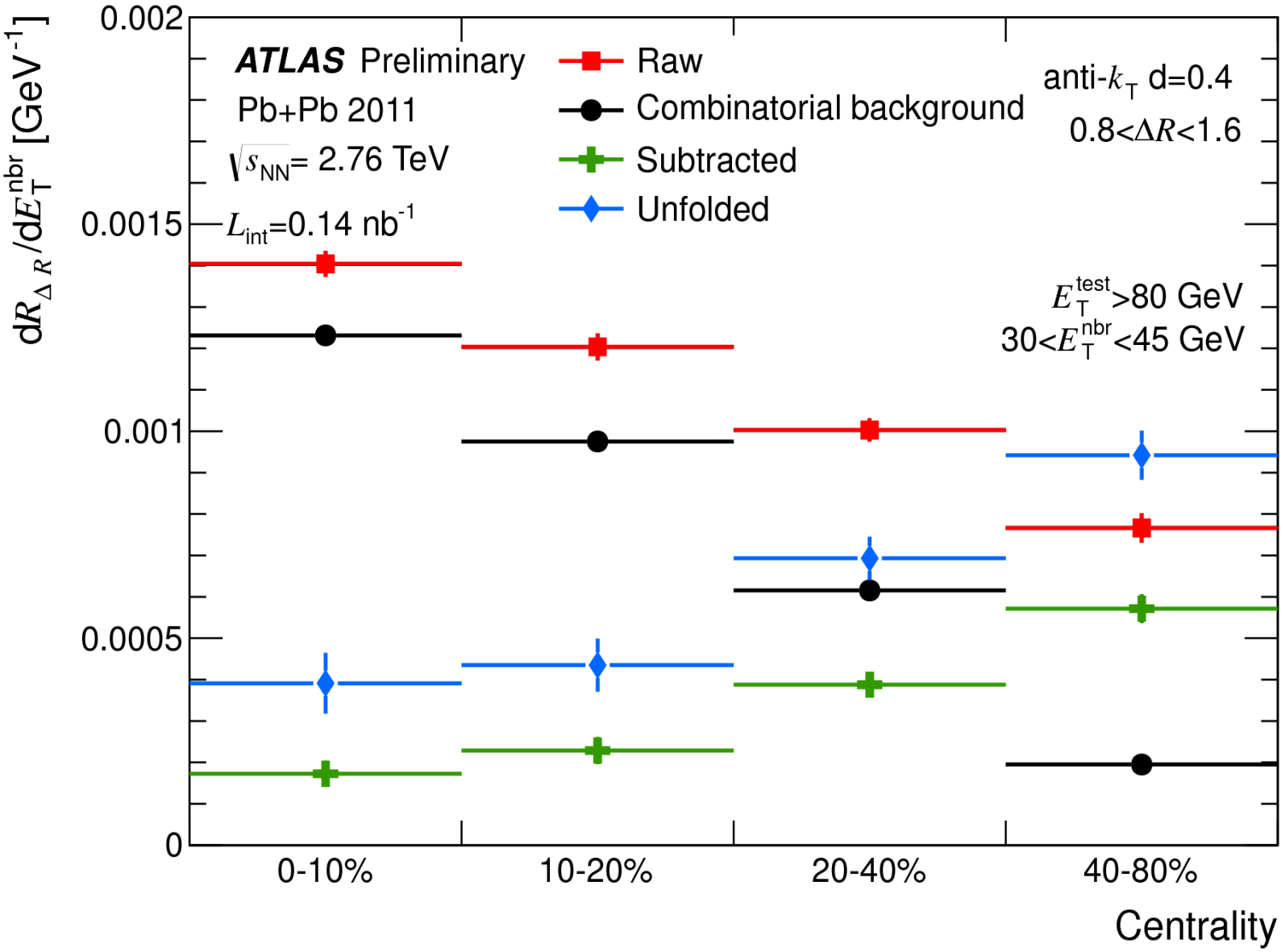
➡ The central to peripheral ratio evaluated as a function of E_T^{nbr} suggests a decrease of suppression with increasing E_T^{nbr}.

➡ Indication of a change in the E_T^{nbr} spectral shape from peripheral to central collisions.

➡ The suppression does not exhibit any strong dependence on the test jet E_t^{test}. (qualitatively consistent with the measurement of the inclusive jet suppression)

Backup

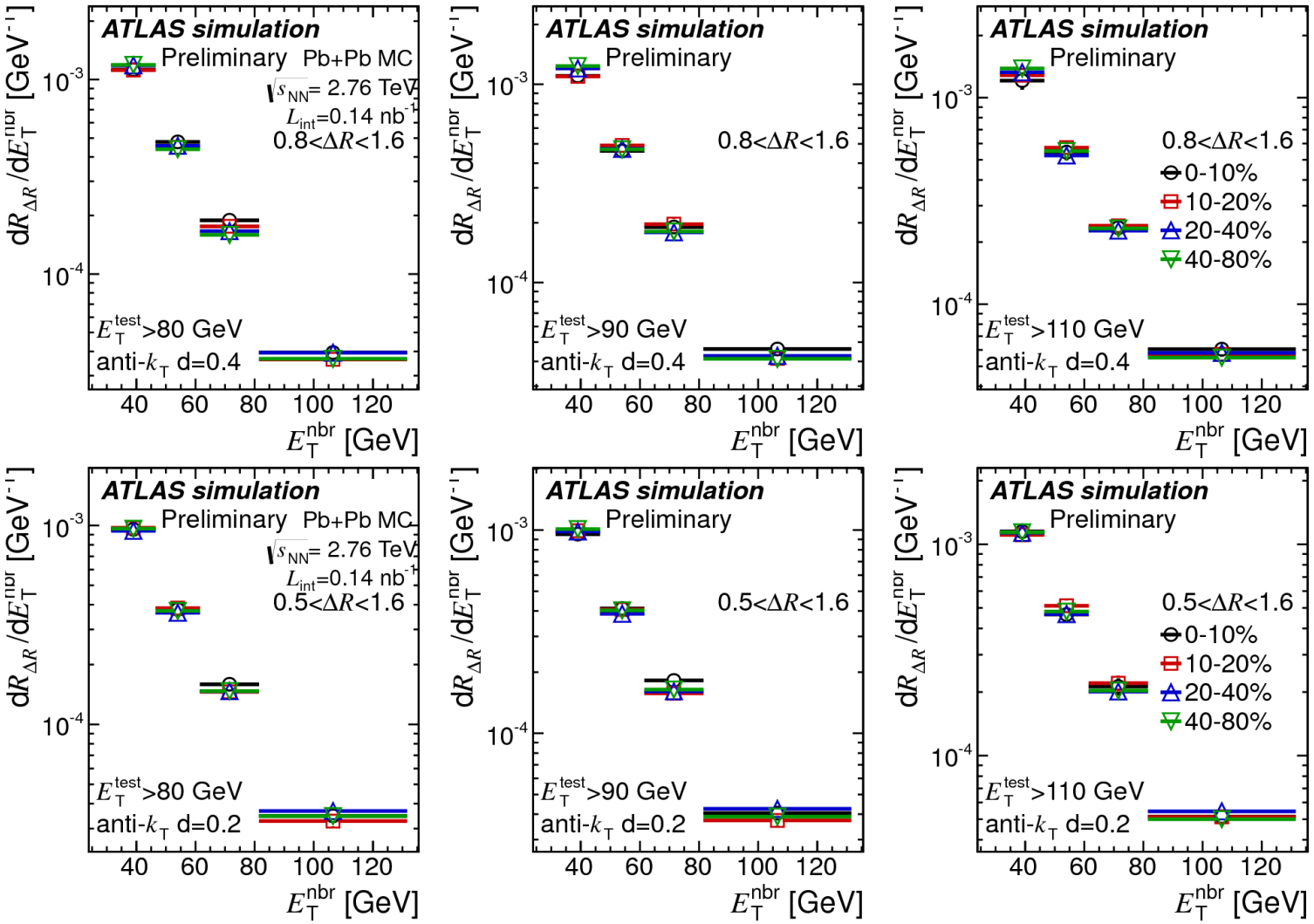
Impact of various corrections



Yields of neighbouring R=0.4 jets in the MC

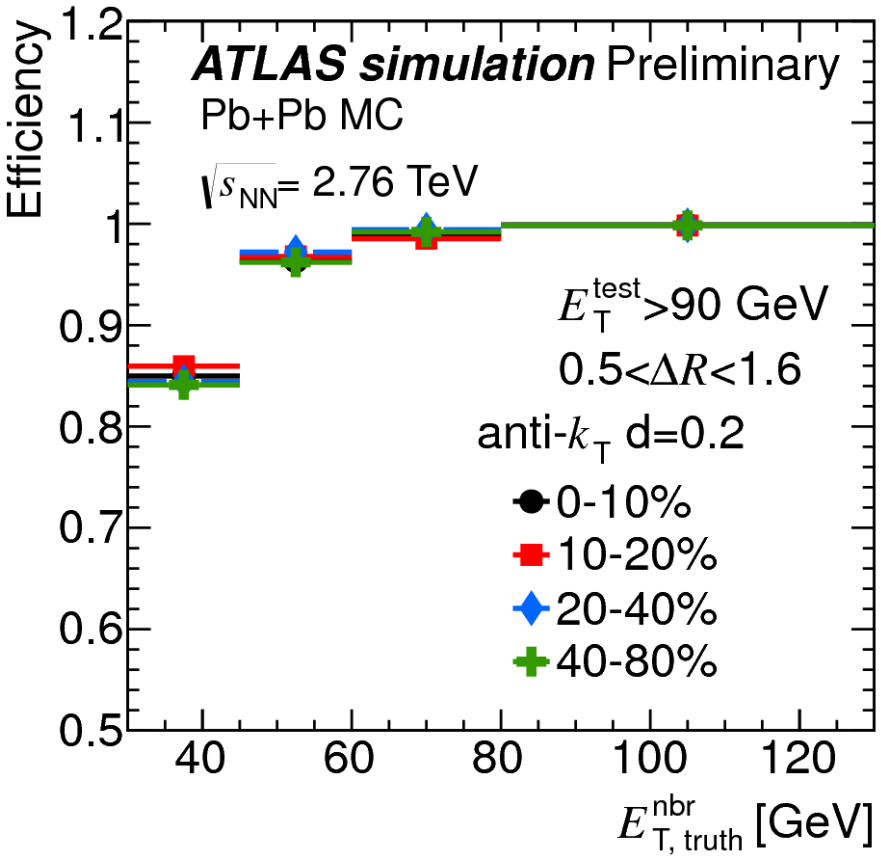
R = 0.4

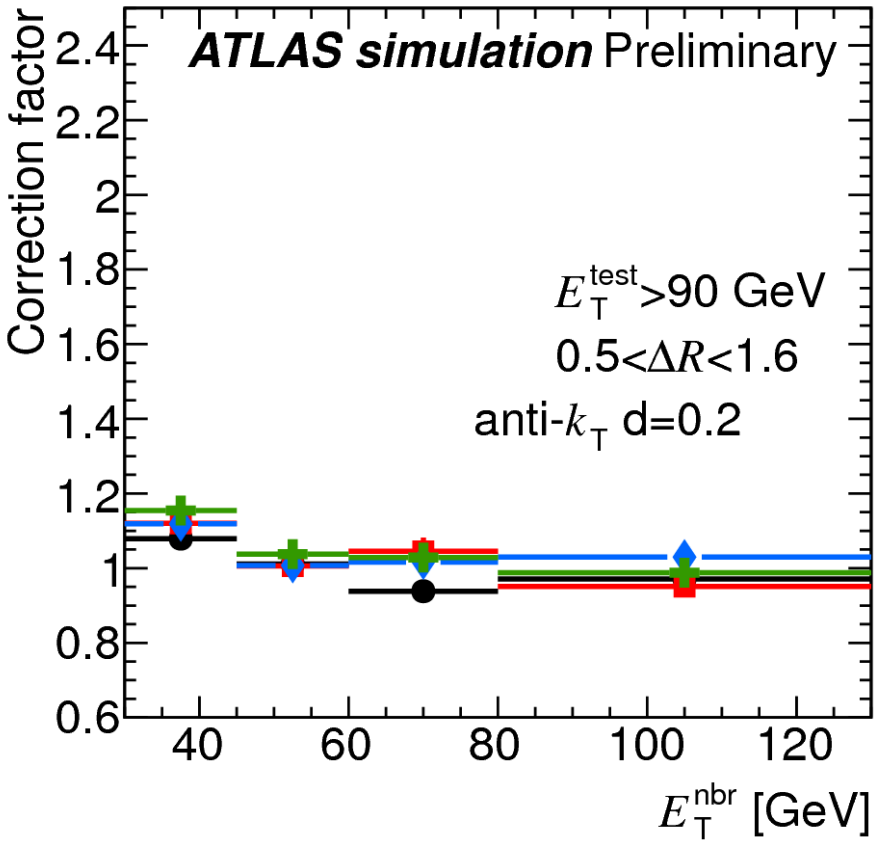
R = 0.2



- Very good agreement in different centrality bins.

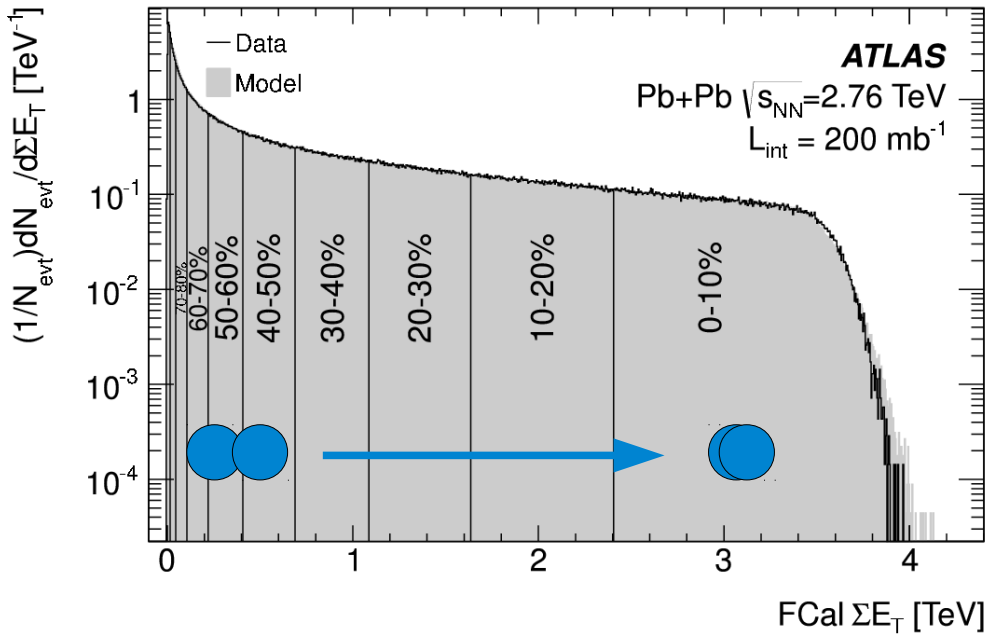
Performance of the Jet Reconstruction

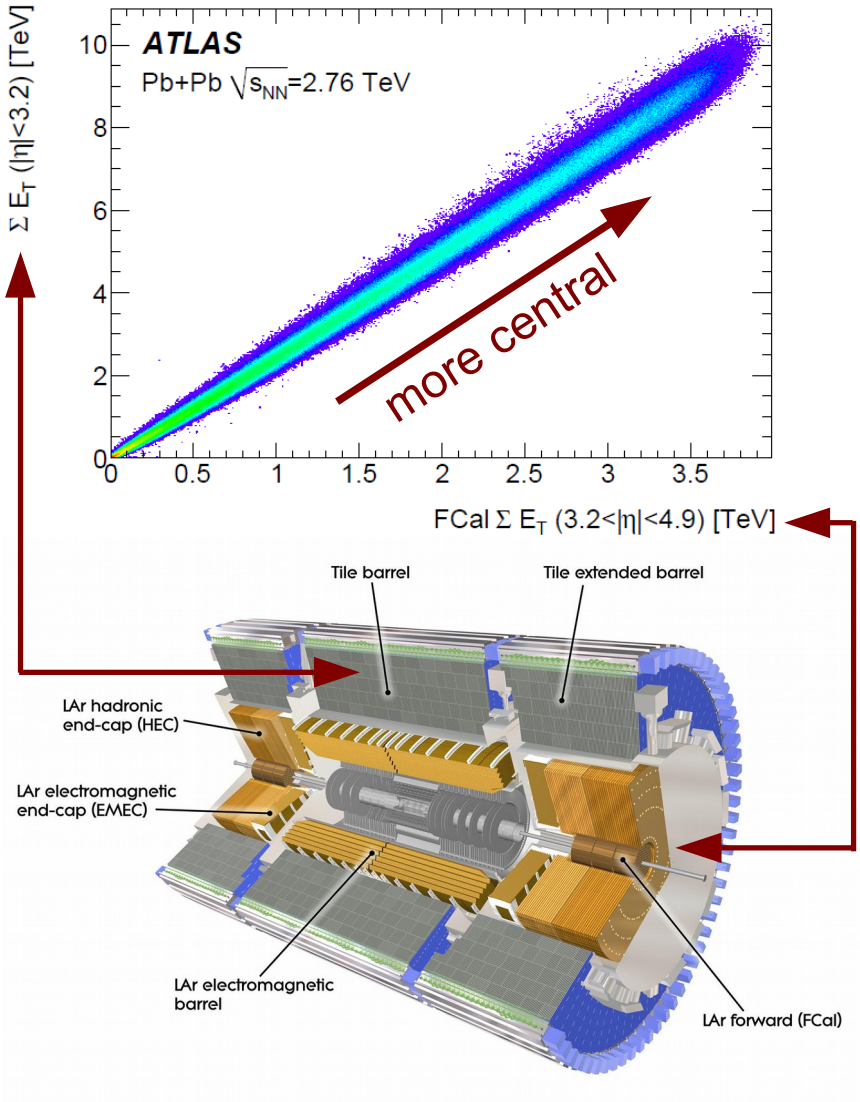




Centrality

- 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} determined with the default Glauber analysis





ATLAS calorimeter

Performance of the Jet Reconstruction

- Performance is evaluated using pp hard scattering events from Pythia overlying on top of MB Pb+PB events.