Jet suppression and the flavor dependence of partonic energy loss with ATLAS

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for the ATLAS collaboration

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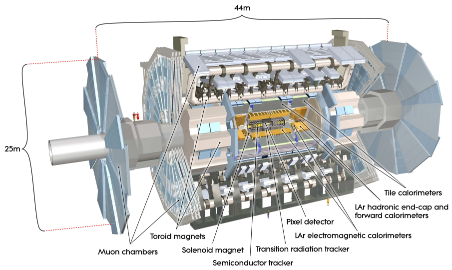
Overview

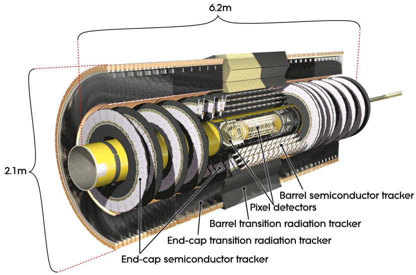
- ATLAS presented several measurements showing strong modification of jet/track properties in HI collisions since the beginning of LHC run 1
- Studies of asymmetric dijet events, suppressed production of jets and charged tracks in Pb+Pb collisions, measurement of jet fragmentation modification published
- All of these measurements provided fruitful information on the partonic energy loss and its path length dependence

Flavor dependence

- The next step is to understand the flavor dependence of the energy loss
- The difference in quenching between quarks and gluons is not accessible in a straightforward way
- Relative number of quarks and gluons changes with pseudorapidity $\rightarrow$ it's worth to study η dependence of the energy loss

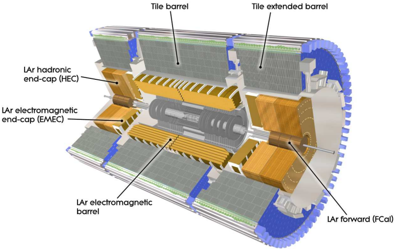
ATLAS experiment

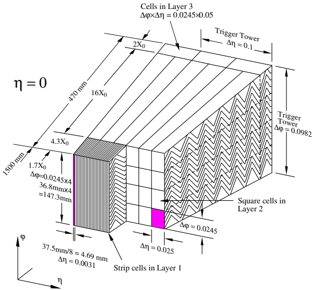




- ATLAS is multi-purpose detector well capable of measuring heavy-ion collisions
- Excellent tracking performance within $|\eta| < 2.5$. Combination of silicon pixel and strip detectors and transition radiation tracker.
- Powerful calorimeter system with fine segmentation with η coverage up to $|\eta| < 4.9$

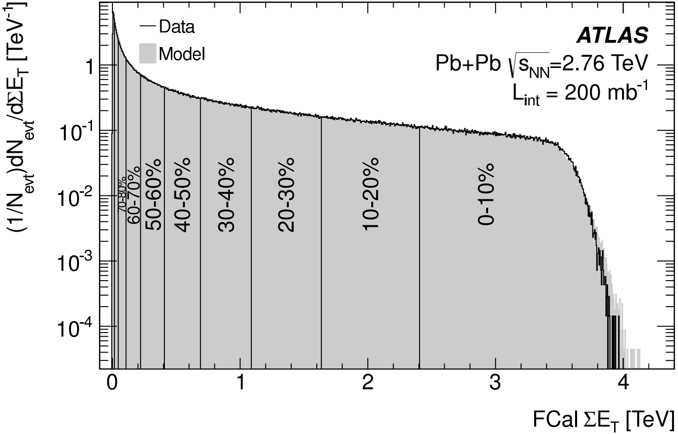
More about calorimetry





- Calorimetry system is composed of electromagnetic, hadronic and liquid-argon (LAr) forward calorimeters
- High granularity LAr electromagnetic calorimeter covers range of $|\eta| < 3.2$ and is composed of barrel and end-cap modules
- EM calorimeter is backed by hadronic calorimeter
- Allows for precise measurement of photons, electrons and jets
- Forward calorimeters are located in the range $3.1 < |\eta| < 4.9$, used for centrality bin selection

Centrality in Pb+Pb collisions



- In ATLAS, centrality is determined by the sum of E_{T} deposited in the FCAL calorimeter $(3.1 < |\eta| < 4.9)$
- Events divided into successive percentiles of the $\sum E_{\mathrm{T}}^{\mathrm{FCal}}$

Charged particle R_{AA}

- Variable that expresses the size of the suppression/enhancement is the so called R_{AA} defined as

$$R_{\mathrm{AA}} = \frac{\frac{1}{N_{\mathrm{evt}}} \frac{\mathrm{d}^2 N_{\mathrm{Pb+Pb}}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}\Big|_{\mathrm{centr}}}{\langle T_{\mathrm{AA}} \rangle \frac{\mathrm{d}^2 \sigma_{pp}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}}$$

- Data samples: 2010 and 2011 Pb+Pb, 2011 and 2013 *pp* runs used
- Spectra were corrected for fake tracks, track reconstruction efficiency and momentum resolution (1D Bayesian unfolding)
- Spectra measured up to p_{T}=150 GeV

Charged particle spectra

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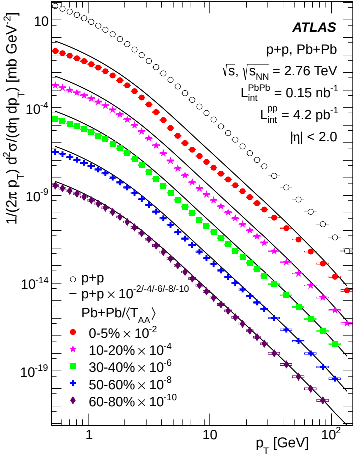
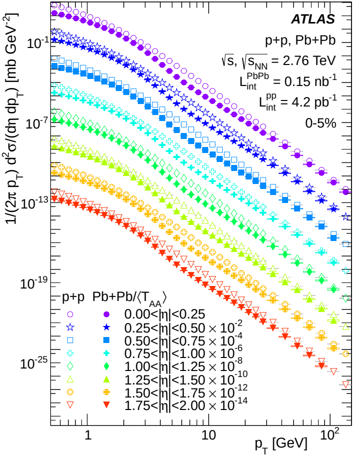
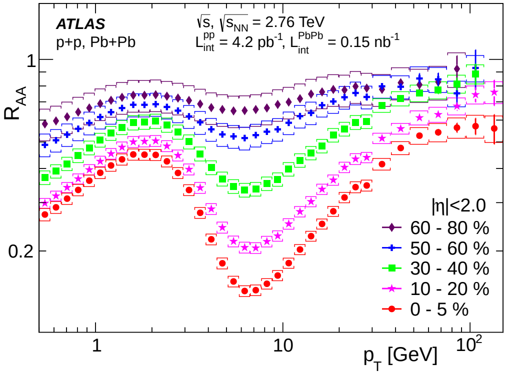
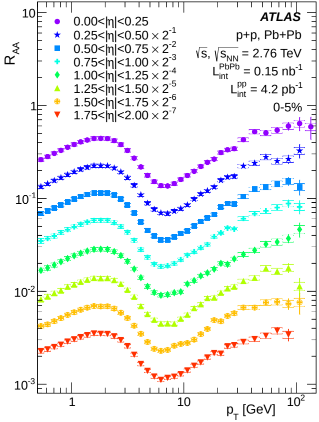




- Charged particle spectra from *pp* and HI (scaled by $1/\langle T_{\mathrm{AA}}\rangle$) binned in centrality (left) and pseudorapidity (right)



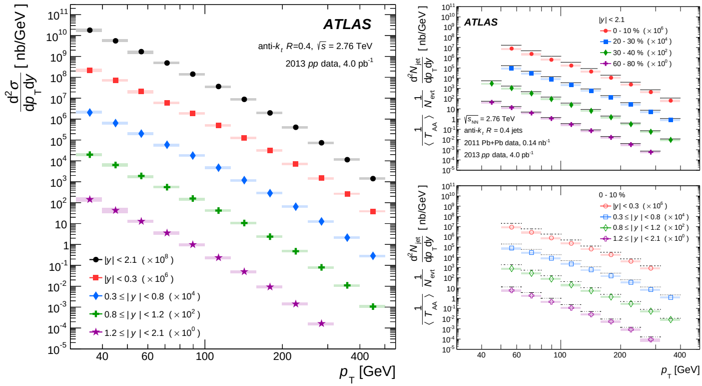


- Very strong suppression at intermediate p_{T}, saturation at $p_{\mathrm{T}} \approx 60$ GeV
- No signs of η dependence

Jet R_{AA}

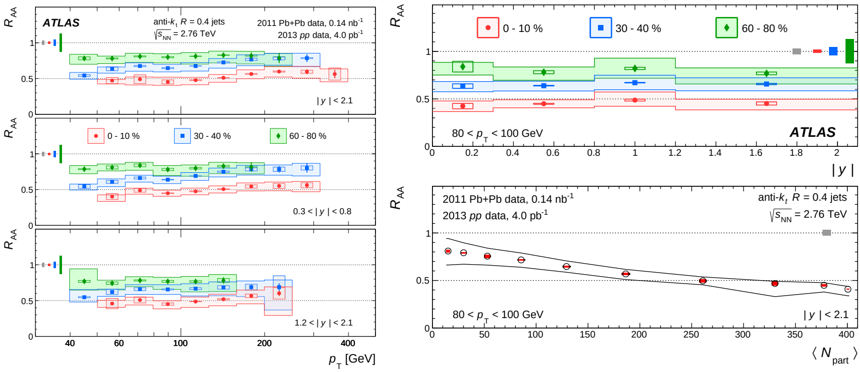
- Complementary measurement for charged track R_{AA}
- We measured R_{AA} for anti-k_t jets using 2011 Pb+Pb and 2013 *pp* run, MB and jet triggered samples were combined to get continuous jet spectra $32 < p_{\mathrm{T}} < 500$ GeV
- Unfolding based on SVD method was used to account for detector effects

Jet spectra



- Differential cross sections for the different rapidity ranges
- Differential per-event jet yield in Pb+Pb collisions divided by $1/\langle T_{\rm AA} \rangle$ with *pp* jet cross sections
- Normalized Pb+Pb yields in central collisions significantly below the *pp* reference

Jet R_{AA}



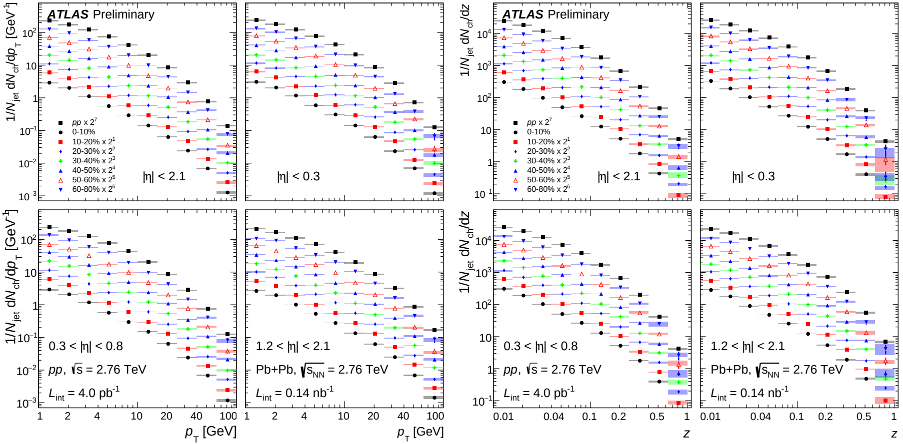
- R_{AA} plots clearly show suppression down to ≈ 0.5 for most central collisions
- Weak dependence of R_{AA} on the p_{T}
- No significant dependence on the y observed

Fragmentation functions

- Jet Fragmentation Functions (FF) $D(p_{\mathrm{T}})$ and $D(z)$ are defined as

$$D(p_{\mathrm{T}}) = \frac{1}{N_{\mathrm{jet}}}\frac{\mathrm{d}N_{\mathrm{ch}}}{\mathrm{d}p_{\mathrm{T}}^{\mathrm{ch}}} \qquad D(z) = \frac{1}{N_{\mathrm{jet}}}\frac{\mathrm{d}N_{\mathrm{ch}}}{\mathrm{d}z} \quad z = \frac{p_{\mathrm{T}}.p_{\mathrm{T}}^{\mathrm{jet}}}{|p_{\mathrm{T}}^{\mathrm{jet}}|^2}$$

- New FF measurement of $R = 0.4$ jets measured differentially in 4 η and 4 $p_{\mathrm{T}}^{\mathrm{jet}}$ bins
- Jet substructure measured using charged tracks starting at $p_{\mathrm{T}} = 1$ GeV
- Using *pp* as a reference
- FF are background subtracted, efficiency corrected and fully unfolded with 2-D Bayesian unfolding



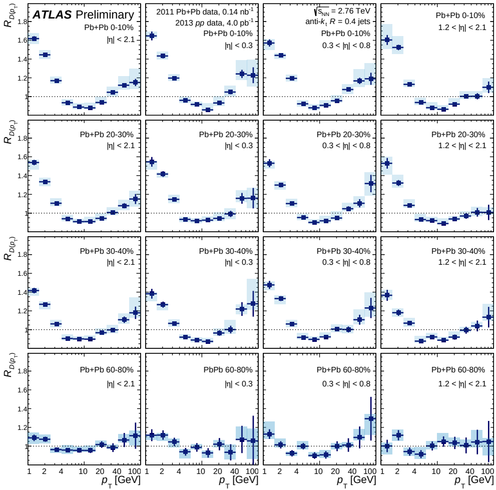
- FF for pp and 6 centrality bins in 4 η regions
- Inclusive in $p_{\mathrm{T}}^{\mathrm{jet}}$

inclusive midrapidity → forward

central

↓

peripheral



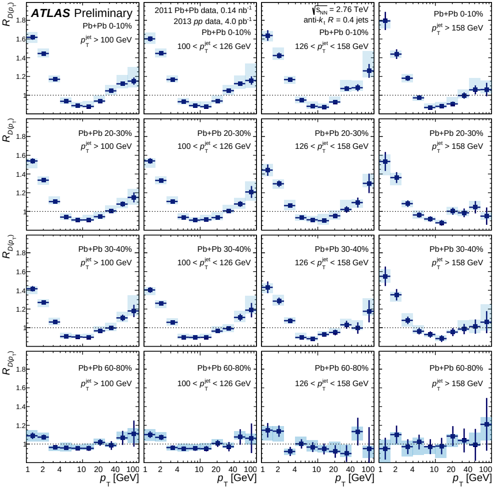
- $R_{D(p_{\mathrm{T}})}$ for 4 centralities in 4 η bins
- Hint of η dependence at large p_{T} observed

inclusive | low $p_{\mathrm{T}}^{\mathrm{jet}}$ | $\rightarrow$ | high $p_{\mathrm{T}}^{\mathrm{jet}}$

central

$\downarrow$

peripheral



- $R_{D(p_{\mathrm{T}})}$ for 4 centralities in 4 $p_{\mathrm{T}}^{\mathrm{jet}}$ bins
- No clear dependence on $p_{\mathrm{T}}^{\mathrm{jet}}$ except change of trends at highest p_{T}

FF - extra/missing particles

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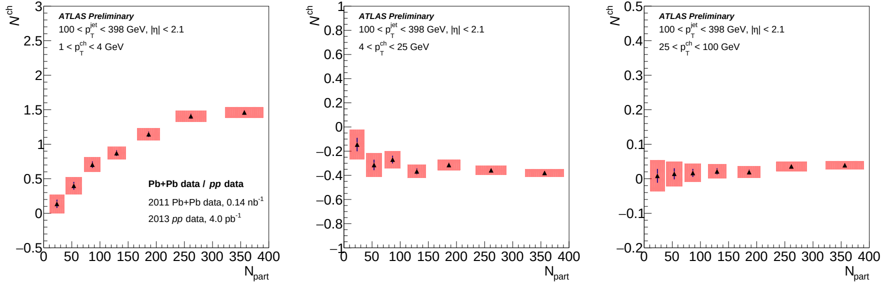
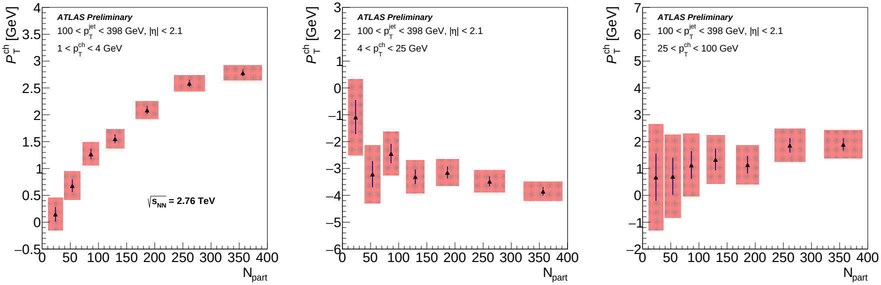


- To quantify the size of enhancement/suppresion, we calculated

$$N^{\mathrm{ch}} \equiv \int_{p_{\mathrm{T,min}}}^{p_{\mathrm{T,max}}} \left(D(p_{\mathrm{T}})|_{\mathrm{cent}} - D(p_{\mathrm{T}})|_{\mathrm{pp}} \right) \mathrm{d}p_{\mathrm{T}} \qquad (1)$$

- N_{part} dependence shown for three characteristic p_{T} regions
- Tells how many extra/missing particles is in p_{T} range

FF - extra/missing momentum



- To quantify the p_{T} flow, we calculated

$$P_{\mathrm{T}}^{\mathrm{ch}} \equiv \int_{p_{\mathrm{T,min}}}^{p_{\mathrm{T,max}}} \left(D(p_{\mathrm{T}})|_{\mathrm{cent}} - D(p_{\mathrm{T}})|_{\mathrm{pp}} \right) p_{\mathrm{T}} \, \mathrm{d}p_{\mathrm{T}}. \quad (2)$$

- Tells how much p_{T} is carried by extra/missing particles in given p_{T} range

Summary

- ATLAS measurement of charged particle R_{AA} shows modification
  - strongly dependent on centrality
  - strongly dependent on the track p_{T}
  - no sign of η dependence observed
- Jet R_{AA} exhibits similar features but weaker dependence on jet p_{T}
- Fragmentation functions show
  - Enhancement at low and high p_{T}, suppression at intermediate track p_{T}
  - no significant dependence on jet p_{T}
  - no significant evolution with η except the largest track p_{T}

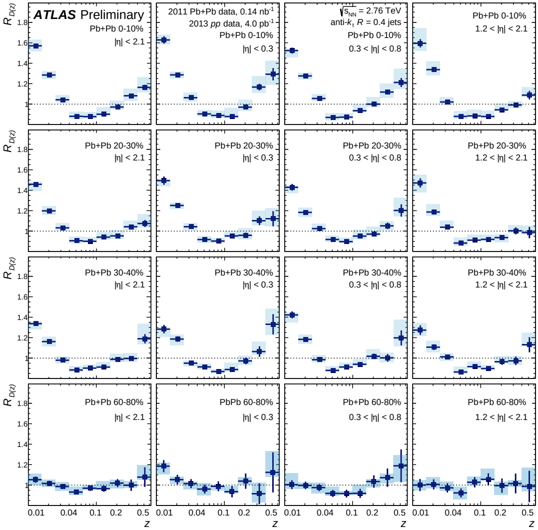
Backup

N^{ch} and $P_{\mathrm{T}}^{\mathrm{ch}}$ for $1.0 < p_{\mathrm{T}} < 100.0$ GeV

Centrality	0 – 10%	10 – 20%	20 – 30%	30 – 40%
$P_{\mathrm{T}}^{\mathrm{ch}}$ [GeV]	0.8 ± 0.7	0.9 ± 0.9	0.1 ± 1.0	-0.4 ± 1.2
N^{ch}	1.1 ± 0.1	1.0 ± 0.1	0.8 ± 0.1	0.5 ± 0.1

Centrality	40 – 50%	50 – 60%	60 – 80%
$P_{\mathrm{T}}^{\mathrm{ch}}$ [GeV]	-0.1 ± 1.6	-1.8 ± 2.1	-0.3 ± 2.7
N^{ch}	0.4 ± 0.1	0.1 ± 0.2	0.0 ± 0.2

FF $D(z)$ ratios (1)



FF $D(z)$ ratios (2)