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

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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 $\eta$ → it’s worth to study $\eta$ dependence of the energy loss.
• 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 $\eta$ coverage up to $|\eta| < 4.9$
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
In ATLAS, centrality determined by the sum of $E_T$ deposited in the FCAL calorimeter ($3.1 < |\eta| < 4.9$).

- Events divided into successive percentiles of the $\sum E_T^{FCal}$.
Variable that expresses the size of the suppression/enhancement is the so called $R_{AA}$ defined as

$$R_{AA} = \frac{\frac{1}{N_{\text{evt}}} \frac{d^2 N_{\text{Pb+Pb}}}{dp_T dy} |_{\text{centr}}}{\langle T_{AA} \rangle \frac{d^2 \sigma_{pp}}{dp_T dy}}$$

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

- Very strong suppression at intermediate $p_T$, saturation at $p_T \approx 60$ GeV
- No signs of $\eta$ dependence
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 $32 < p_T < 500$ GeV

Unfolding based on SVD method was used to account for detector effects
Differential cross sections for the different rapidity ranges
Differential per-event jet yield in Pb+Pb collisions divided by $1/\langle T_{AA}\rangle$ with $pp$ jet cross sections
Normalized Pb+Pb yields in central collisions significantly below the $pp$ reference
Jet $R_{AA}$ plots clearly show suppression down to $\approx 0.5$ for most central collisions.

- Weak dependence of $R_{AA}$ on the $p_T$
- No significant dependence on the $y$ observed
Jet Fragmentation Functions (FF) $D(p_T)$ and $D(z)$ are defined as

\[
D(p_T) = \frac{1}{N_{\text{jet}}} \frac{dN_{\text{ch}}}{dp_T^{\text{ch}}} \\
D(z) = \frac{1}{N_{\text{jet}}} \frac{dN_{\text{ch}}}{dz} \\
z = \frac{p_T}{p_T^{\text{jet}}} \cos \Delta R
\]

New FF measurement of $R = 0.4$ jets measured differentially in 4 $\eta$ and 4 $p_T^{\text{jet}}$ bins.

Jet substructure measured using charged tracks starting at $p_T = 1$ GeV.

Using $pp$ as a reference.

FF are background subtracted, efficiency corrected and fully unfolded with 2-D Bayesian unfolding.
**$D_{p_T}$ and $D(z)$ distributions**

- FF for $pp$ and 6 centrality bins in 4 $\eta$ regions
- Inclusive in $p_T^{\text{jet}}$

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ATLAS Preliminary

$|\eta| < 0.8$

$p\bar{p}$, $\sqrt{s} = 2.76$ TeV

$L_{\text{int}} = 4.0$ pb$^{-1}$

$|\eta| < 2.1$

$|\eta| < 0.3$

ATLAS Preliminary

$|\eta| < 0.3$

$|\eta| < 2.1$

$|\eta| < 0.8$

$|\eta| < 2.1$

$|\eta| < 0.3$

Preliminary

ATLAS

$|\eta| < 0.8$

$|\eta| < 2.1$

$|\eta| < 0.3$

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$\sqrt{s}_{\text{NN}} = 2.76$ TeV

$L_{\text{int}} = 0.14$ nb$^{-1}$

$0.3 < |\eta| < 0.8$

$1.2 < |\eta| < 2.1$

$0.01 < z < 1.0$

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$D(p_T)$ Ratios (1)

- $R_{D(p_T)}$ for 4 centralities in 4 $\eta$ bins
- Hint of $\eta$ dependence at large $p_T^{ch}$ observed
\(D(p_T)\) Ratios (2)

- \(R_D(p_T)\) for 4 centralities in 4 \(p_T^{\text{jet}}\) bins
- No clear dependence on \(p_T^{\text{jet}}\) except change of trends at highest \(p_T\)
To quantify the size of enhancement/suppression, we calculated

$$N_{\text{ch}} \equiv \int_{p_T,\text{min}}^{p_T,\text{max}} \left( D(p_T)|_{\text{cent}} - D(p_T)|_{pp} \right) \, dp_T$$  \hspace{1cm} (1)

- $N_{\text{part}}$ dependence shown for three characteristic $p_T$ regions
- Tells how many extra/missing particles is in $p_T$ range
To quantify the $p_T$ flow, we calculated

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

- Tells how much $p_T$ is carried by extra/missing particles in given $p_T$ range
Conclusions

- Charged particle $R_{AA}$ measurement shows modification
  - strong dependence on centrality
  - strong dependence on the track $p_T$
  - no sign of $\eta$ dependence observed

- Jet $R_{AA}$ exhibits similar features but weaker dependence on jet $p_T$

- Fragmentation functions show
  - Enhancement at low and high $p_T^{trk}$, suppression at intermediate track $p_T$
  - no significant dependence on jet $p_T$
  - no significant evolution with $\eta$ except the largest track $p_T$
Backup
FF $D(z)$ ratios (1)
FF \( D(z) \) ratios (2)

\[ \frac{R}{D(z)} = \text{ATLAS Preliminary} \]

\[ \text{Pb+Pb 0-10\%} \]
\[ \rho_T > 100 \text{ GeV} \]
\[ \text{2011 Pb+Pb data, 0.14 nb}^{-1} \]
\[ \text{2013 pp data, 4.0 pb}^{-1} \]
\[ \text{Pb+Pb 0-10\%} \]
\[ 100 < \rho_T < 126 \text{ GeV} \]
\[ \text{Pb+Pb 0-10\%} \]
\[ 126 < \rho_T < 158 \text{ GeV} \]

\[ \text{Pb+Pb 20-30\%} \]
\[ \rho_T > 100 \text{ GeV} \]
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\[ \text{Pb+Pb 30-40\%} \]
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\[ \text{Pb+Pb 30-40\%} \]
\[ 126 < \rho_T < 158 \text{ GeV} \]

\[ \text{Pb+Pb 60-80\%} \]
\[ \rho_T > 100 \text{ GeV} \]
\[ \text{Pb+Pb 60-80\%} \]
\[ 100 < \rho_T < 126 \text{ GeV} \]
\[ \text{Pb+Pb 60-80\%} \]
\[ 126 < \rho_T < 158 \text{ GeV} \]