Jet quenching studies with new jet substructure and suppression measurements in ATLAS

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• Jets lose energy in the quark-gluon plasma (QGP) and this probes the properties of the QGP.

• Does this energy loss depend on the jet substructure?
  • Can we see the color coherence/de-coherence effects?

\[ \text{Measure } R_{AA} \text{ vs “splitting”} \]
Analysis technique (1)

- Reconstruct large-radius jets by re-clustering underlying-event subtracted $R = 0.2$ jets.

\[
\begin{align*}
\text{Anti-}\kappa & \quad R = 0.2 \text{ jets} \\
p_T & > 35 \text{ GeV} \\
\Rightarrow & \quad \text{Re-clustered} \\
\text{Anti-}\kappa & \quad R = 1.0 \\
\Rightarrow & \quad R = 1.0 \text{ large-radius jets} \\
\text{with } R & = 0.2 \text{ sub-jets}
\end{align*}
\]

\begin{itemize}
  \item "Conventional" $R=1.0$ jet
  \item Re-clustered $R=1.0$ jet
\end{itemize}

ATLAS Preliminary
Pb+Pb 1.72 nb$^{-1}$, pp 257 pb$^{-1}$
$\sqrt{s_{NN}} = 5.02$ TeV
$|y| < 2.0$, $200 < p_T < 251$ GeV
Recoulered $R = 1.0$ jets
• Reconstruct large-radius jets by re-clustering underlying-event subtracted $R = 0.2$ jets.

At the last $k_t$ clustering step (2->1) (hardest splitting in the jet), define the splitting scale:

$$\sqrt{d_{12}} = \min(p_{T1}, p_{T2}) \cdot \Delta R_{12}, \quad \Delta R_{12} = \sqrt{\Delta \phi^2_{12} + \Delta y^2_{12}}$$

• 2D (1D) Bayesian unfolding in jet $p_T$ and $\sqrt{d_{12}}$ (in jet $p_T$ only).
Analysis technique (2)

- Reconstruct $R = 0.4$ jets by re-clustering underlying-event subtracted track-calorimeter clusters (TCCs).

TCCs for "particles" $p_T > 4$ GeV

Anti-$k_t$ $R = 0.4$

$R = 0.4$ jets (with TCC constituents)

Calorimeter: energy
Track: angular information
• Reconstruct $R = 0.4$ jets by re-clustering underlying-event subtracted track-calorimeter clusters (TCCs).

  TCCs for "particles" $p_T > 4$ GeV  \[ \text{Anti-}k_t \ R = 0.4 \text{ Cluster} \]

  $R = 0.4$ jets (with TCC constituents)

  C/A alg. re-cluster + Soft-drop grooming ($z_{cut} = 0.2$, $\beta = 0$)

  unfold

• Soft-drop (with C/A) identifies the hardest splitting and its opening angle:

  \[
  (\text{groomed}) \ r_g = \Delta R_{12} = \sqrt{\Delta \phi_{12}^2 + \Delta y_{12}^2}
  \]

• 2D (1D) Bayesian unfolding in jet $p_T$ and $r_g$ (in jet $p_T$ only).
Analysis technique (summary)

• Technique 1:
  • \( R = 1.0 \) jet (\( R = 0.2 \) jet based) (w/ \( \sqrt{d_{12}} \))

- **Anti-\( k_t \) \( R = 0.2 \) jets \( p_T > 35 \) GeV**
  - Cluster

- **Anti-\( k_t \) \( R = 1.0 \)**
  - **\( R = 1.0 \) large-radius jets** (with \( R = 0.2 \) sub-jets)
  - **\( k_t \) alg. re-cluster**

- **unfold**
  - \( p_T / \sqrt{d_{12}} \)

• Technique 2:
  • \( R = 0.4 \) soft-drop jet (TCC based) (w/ groomed \( r_g \))

- **TCCs for “particles” \( p_T > 4 \) GeV**
  - Cluster

- **Anti-\( k_t \) \( R = 0.4 \)**
  - **\( R = 0.4 \) jets** (with TCC constituents)
  - **C/A alg. re-cluster + Soft-drop grooming** (\( z_{cut} = 0.2, \beta = 0 \))

- **unfold**
  - \( p_T / r_g \)

• Data: 2018 Pb+Pb (1.72 nb\(^{-1}\)) + 2017 pp (257 pb\(^{-1}\)), both at 5.02 TeV.
Result: inclusive $R_{AA}$

$R = 0.2$ jet based

$R = 1.0$ jet

**Technique 1**

<table>
<thead>
<tr>
<th>$p_T$ [GeV]</th>
<th>$R_{AA}$ vs jet $p_T$</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>0.5</td>
</tr>
<tr>
<td>300</td>
<td>0.6</td>
</tr>
<tr>
<td>400</td>
<td>0.7</td>
</tr>
<tr>
<td>500</td>
<td>0.8</td>
</tr>
</tbody>
</table>

**Yields and $R_{AA}$ vs $\sqrt{d_{12}}$**

- $R_{AA}$ drops significantly from single sub-jet (SSJ) to non-zero $\sqrt{d_{12}}$ (more complex substructure).

- Again jets with a single sub-jet are less suppressed.

- Jets with a single sub-jet show similar trends as inclusive measurement but smaller suppression.

- Again jets with a single sub-jet are less suppressed.

- $R_{AA}$ decreases as $\langle N_{part} \rangle$ increases (more central collisions).
• $r_g = 0$: single TCC (or groomed down to single TCC).
• $R_{AA}$ does not depend strongly on $p_T$ for a given $r_g$.
• Stronger suppression in more central collisions.

• $R_{AA}$ decreases monotonically and significantly with increasing $r_g$.
• Higher decrease rate at low $r_g$.
Summary

• These two analyses directly probe the ability of the medium to resolve the partonic fragments in the jet.

\[ R = 0.2 \text{ jet based} \]
\[ R = 1.0 \text{ jet (Technique 1)} \]

\[ R = 0.4 \text{ soft-drop jet (Technique 2)} \]

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• Jets with one single sub-jet (narrower opening angle) are significantly less suppressed compared to jets with multiple sub-jets (wider opening angle).