Probing jet medium interaction via dijet and photon-jet $p_T$ imbalances

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Introduction

Jet Quenching and Jet Energy Loss

\[ R_{AA} = \frac{\text{cross section in AA}}{\text{cross section in pp}} \]

ATLAS
\[ p+p, \text{Pb}+\text{Pb} \]
\[ \sqrt{s}, \sqrt{s_{NN}} = 2.76 \text{ TeV} \]
\[ \frac{L}{p_{T}} = 4.2 \text{ pb}^{-1}, \frac{L}{p_{T}} = 0.15 \text{ nb}^{-1} \]

ATLAS, JHEP 1509 (2015)

Inclusive Hadron

Parton/Jet Energy Loss

Inclusive Jet

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Introduction

Jet Quenching and Jet Energy Loss

\[
R_{AA} = \frac{\text{cross section in } AA}{\text{cross section in } pp}
\]

ATLAS, 1805.05635

ATLAS, 2015 Pb+Pb data, 0.49 nb^{-1}

2015 pp data, 25 pb^{-1}

0-10%, |y| < 2.1

\[q/T^3(\text{DIS})\]

\[q/T^3(\text{DIS})\]

Inclusive Hadron

Parton/Jet Energy Loss

Inclusive Jet
Introduction

Beyond single inclusive hadron/jet

![Graphs showing distributions of dihadron and hadron-jet events in various experiments.]

Introduction

Why is it interesting?


\[ A_J \equiv \frac{pT_1 - pT_2}{pT_1 + pT_2} \]

Dijet Asymmetry

- Intuitive picture on the jet energy loss.
- Sensitive to geometry, qhat, energy loss formalism…
Introduction

**First Thing:** baseline in *pp* collisions

- From Event Generators to a solid QCD calculation.
- Unfolding

Recent measurements of dijet *p_T* correlations [12] and inclusive jet fragmentation functions at large longitudinal momentum fraction [22] in Pb+Pb collisions used unfolding procedures to correct for bin-migration effects and return the distributions to the particle level, i.e. free from detector effects. In these cases, fully correcting the data revealed non-trivial features in the distributions which would not otherwise be evident.

- Establish a baseline that can describe the fully corrected data without any free parameters.
Our approach  Establish baselines without free parameters

Perturbative Expansion

Correlations:
- $2 \rightarrow 2$: 0th order
- $2 \rightarrow 3$: leading order
- $2 \rightarrow 4$: next-to-leading order

Normalization
Our approach
Establish baselines without free parameters

Perturbative Expansion

- energy conservation
- $4\pi$ coverage (no missing jet)
- leading and sub-leading jets

For $n$-jet final state

$$(n - 1)p_{T2} \geq p_{T1}$$

$$x_J^{2 \rightarrow n} \equiv \frac{p_{T2}}{p_{T1}} \geq \frac{1}{n - 1}$$

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Our approach Establish baselines without free parameters

Perturbative Expansion

\[ \frac{1}{N} \frac{dN}{dx_J} \]

- LO (2 \rightarrow 3)
- NLO (2 \rightarrow 4)

perturbative expansion fails

\[ \text{10} \]

\[ \text{10}^2 \]

\[ \text{10}^3 \]

Sudakov double log

\[ \frac{\alpha_s}{q_T^2} \ln \frac{p_T^2}{q_T^2} \]

\[ \Delta \phi \]

back-to-back configuration
Our approach Establish baselines without free parameters

Resummation Improved pQCD approach

\[ \sigma_0 \sum_{i=0}^{\infty} \left( (\alpha_s \log)^i + \alpha_s^i C_i \right) \]

no large logs \( \phi_m \)
large logs

<table>
<thead>
<tr>
<th>perturbative expansion</th>
<th>Sudakov resummation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma_0 \sum_{i=0}^{n} \left( (\alpha_s \log)^i + \alpha_s^i C_i \right) )</td>
<td>( \sigma_0 \sum_{i=0}^{n} \left( (\alpha_s \log)^i \right) + \sigma_0 \sum_{n+1}^{\infty} \left( (\alpha_s \log)^i \right) )</td>
</tr>
</tbody>
</table>

\[ \left. \frac{1}{\sigma} \frac{d\sigma}{dx_J} \right|_{\text{Improved}} = \left. \frac{1}{\sigma_{\text{NLO}}} \frac{d\sigma_{\text{NLO}}}{dx_J} \right|_{\Delta\phi<\phi_m} + \left. \frac{1}{\sigma_{\text{Sudakov}}} \frac{d\sigma_{\text{Sudakov}}}{dx_J} \right|_{\pi>\Delta\phi>\phi_m} \]

- ✔ NLO pQCD provides very precious result at small \( X_J \) region.
- ✔ Sudakov resummation resums the alternating sign series of large logarithms.
- ✔ There is no free parameter in this calculation.
Our approach
Establish baselines without free parameters

Resummation Improved pQCD approach

To compare with the uncorrected data.

\[
\frac{d\sigma_{\text{smeared}}}{dp_{\perp J}} = \int \frac{dE}{\sqrt{2\pi}\Delta} e^{-(E-E')^2/2\Delta^2} \frac{d\sigma}{dp'_{\perp J}} \bigg|_{p'_{\perp J}=p_{\perp J}+E}
\]

\( d\sigma_{\text{smeared}} \)

\( dp_{\perp J} \)

\( \frac{d\sigma}{dp'_{\perp J}} \)

\( p'_{\perp J}=p_{\perp J}+E \)
Our approach: Establish baselines without free parameters

Resummation Improved pQCD approach

Our result

ATLAS $5.02$ TeV, $25$ pb$^{-1}$ $p_T^\gamma = 63.1$-$79.6$ GeV

photon-jet, Sudakov + LO(2→3)

ATLAS $5.02$ TeV, $25$ pb$^{-1}$ $p_T^\gamma = 100$-$158$ GeV

dijet, Sudakov + NLO(2→3&2→4)
\( p_T \) imbalance in AA collisions & jet energy loss

**BDMPS formalism**

\[
e \epsilon D(\epsilon) = \sqrt{\frac{\alpha^2 \omega_c}{2\epsilon}} \exp\left(-\frac{\pi \alpha^2 \omega_c}{2\epsilon}\right)
\]

\[\omega_c \equiv \int dL \hat{q}L \quad \alpha \equiv \frac{2\alpha_s C_R}{\pi}\]

☑ Probability for a jet to lose energy (\( \epsilon \)).

**Results:**

☑ Assuming all the jets are gluon jets.
☑ Typical energy loss is 20 ~ 30 GeV.
☑ \( \hat{q}_0 \) is 2 ~ 6 GeV^2 / fm at \( T_0 = 481\) MeV.
☑ Agrees with the original BDMPS estimate \( \hat{q} \sim 0.3-0.8 \) GeV^2 / fm at \( T = 250 \) MeV.  

\[
\frac{d\sigma}{dp_{T1}dp_{T2}} = \int d\epsilon_1 d\epsilon_2 D(\epsilon_1)D(\epsilon_2) \frac{d\sigma}{dp_{T1}dp_{T2}} \bigg|_{p_{T1}=p'_{T1}+\epsilon_1; \ p_{T2}=p'_{T2}+\epsilon_2}
\]

\[\text{hep-ph/9608322}\]
$p_T$ imbalance in AA collisions & jet energy loss

BDMPS formalism

$$\epsilon D(\epsilon) = \sqrt{\frac{\alpha^2 \omega_c}{2\epsilon}} \exp \left( -\frac{\pi \alpha^2 \omega_c}{2\epsilon} \right)$$

$$\omega_c \equiv \int dL \hat{q}L \quad \alpha \equiv \frac{2\alpha_s C_R}{\pi}$$

✓ Probability for a jet to lose energy ($\epsilon$).

Results:

✓ $\hat{q}_0$ is $2 \sim 8$ GeV$^2$/fm at $T_0 = 509$ MeV.
We established a framework to calculate the $p_T$ imbalances. Sudakov resummation + perturbative expansion.

We extracted $\hat{q}_0$ using BDMPS energy loss approach.

$\hat{q}_0$ is $2 \sim 6 \text{ GeV}^2 / \text{fm}$ at $T_0 = 481\text{MeV}$. (dijet)

$\hat{q}_0$ is $2 \sim 8 \text{ GeV}^2 / \text{fm}$ at $T_0 = 509\text{MeV}$. (photon-jet)

Thank you very much for your attention!
The End