Measurement of inclusive, boson-tagged, and heavy-flavor-tagged jet energy loss in PbPb collisions at $\sqrt{s_{NN}}=5$ TeV with CMS detector

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Introduction

- Jet tomography is an established experimental tool for relativistic Heavy Ion studies to answer what happens if partons traverse a high energy density colored medium?
- Jet, di-jet and boson-tagged jets allow to study:
  - Jet-medium interactions
  - Flavor dependence of parton-medium coupling
  - In-medium fragmentation/ hadronization
Jet Quenching

Jet $R_{AA}$:
Strong suppression
No appreciable $p_T$ dependence

Di-jet $A_J$:
Centrality-dependent increase in the fraction of dijets with substantial energy imbalance

$b$-jet suppression:
Similar level of suppression for high $p_T$ jets ($p_T > 80$ GeV)

What about flavor dependence?

Better understand jet energy loss: compare jets from different partons.
Understanding the flavor effects

Constrains on the energy loss scenarios could be added by comparing energy redistribution patterns for inclusive jets, $\gamma + \text{jet}$ and $Z$-boson + jet

Inclusive jets
- All initial states involved
- A mix of gluon and quark jets

$\gamma + \text{jet}$
- Good control of initial parton energy
- Larger fraction of quark jets tagged

$Z + \text{jet}$
- Great control of initial parton energy + no contamination.

See Kaya Tatar, Tuesday, 2 Oct

$\sqrt{s_{NN}} = 5.10$ TeV
$R = 0.5, 0.3 < |\eta| < 2$
$p_T > 100$ GeV
centrality $0-10\%$

arXiv:1711.09905
Jet quenching with boson+jets

- Boson energy provides a measure of initial parton energy unbiased by the jet quenching effects.

- Significant jet imbalance observed $Z$+jet and $\gamma$+jet.

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Jet quenching with b-tagged jets

- A building block to the parton mass hierarchy in the jet energy loss.
- The source of b-jets: quarks jets from primary production (FCR+FEX) and the jets splitting from a gluon jets.

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Jet quenching with b-tagged jets

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- b dijet asymmetry is similar to the inclusive jet case.
Where does the energy go?

- To better understand the details of jet energy loss, detailed studies of energy distribution of jet constituents
The jet fragmentation pattern is modified:

- correlated yield in the soft particle yield enhanced;
- the high $p_T$ particle yield depleted.

**Inclusive jet particle yield**
Jet energy is redistributed towards softer fragments and large radii
D⁰ meson yield profile in jets

- A hint of the low p_T D⁰ enhancement at large angle.
- Provide constraints on the heavy-flavor energy loss.

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See Michael Peter, Tuesday, 2 Oct
inclusive jets vs. $\gamma +$jets

- Jet shape results for $\gamma +$jets show similar pattern with inclusive jet shapes:
  - Central PbPb – energy redistributed towards larger radii

inclusive jets (5.02 TeV)

- $p_T > 120$ GeV, $|\eta_{jet}| < 1.6$
- $0.7 < p_T^{tk} < 300$ GeV

$\gamma$-jets

- CMS Preliminary
- Cent. 0 - 10%
- $p_T^{\gamma} > 60$ GeV/c
- anti-$k_T$ jet $R = 0.3$
- $p_T^{jet} > 30$ GeV/c
- $\Delta \phi_{j\gamma} > \frac{7\pi}{8}$

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Summary

- Common general trend: redistribution of energy from small angles (jet core) to the larger radii.
- Comparative analysis of the **inclusive jets** and **boson-tagged jets** help to understand the difference in quark vs. gluon energy loss mechanism.
- New constraints on flavor-dependent aspects of energy loss and medium response.

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Back up
isolated photon + jets

Jets

Jet Reconstruction
- Anti-$k_t$ calorimeter jets, $R = 0.4$
- PbPb: pile-up UE subtraction
- pp: no UE subtraction for jet energy determination

Inclusive Jet Selection
- $p_T > 120$ GeV
- $|\eta| < 1.6$
- May include multiple jets from one event

Tracks

Track Reconstruction:
- PbPb: heavy ion reconstruction, $p_T > 0.4$ GeV
- pp: pp reconstruction, $p_T > 0.2$ GeV
- Corrected for efficiency etc. as a function of $\eta$, $\phi$, $p_T$, and centrality

Track Selection:
- $0.7 < p_T < 300$ GeV
- $|\eta| < 2.4$
isolated photon + jets

- Finite jet and track acceptances result in trapezoidal geometry
- Correct for this pair acceptance effect with a mixed-event correction:
  - Jets from sample
  - Tracks from a minimum-bias event matched on centrality and $v_z$

CMS Preliminary PbPb 404 $\mu$b$^{-1}$ (5.02 TeV) anti-$k_T$ calorimeter jets, $R=0.4$, $p_T > 120$ GeV, $|\eta_{jet}| < 1.6$ 1 < $p_T^{trk}$ < 2 GeV
isolated photon + jets

- Project background (measured on $1.5 < |\Delta \eta| < 2.5$) into $\Delta \varphi$
- Propagate this background distribution in 2D
- Subtract from background from signal to yield isolated jet peak

Signal + Background

CMS Preliminary
PbPb 404 $\mu$b$^{-1}$ (5.02 TeV)
anti-$k_T$ calorimeter jets, $R=0.4$, $p_T > 120$ GeV, $|\eta_{\text{jet}}| < 1.6$

Signal Only

1 < $p_T^{\text{trk}}$ < 2 GeV

“Sideband” region $1.5 < |\Delta \eta| < 2.5$

- Finally: apply two MC-based corrections for jet reconstruction biases
Dijet shapes in 2.76 TeV

A$_J$ inclusive
pp 5.3 pb$^{-1}$ (2.76 TeV)

Leading jet shape
PbPb 166 μb$^{-1}$ (2.76 TeV)

anti-k$_T$ R = 0.3, |η$_{jet}$| < 1.6
p$_{T,1}$ > 120 GeV, p$_{T,2}$ > 50 GeV, Δφ$_{1,2}$ > 5π/6

PLB: Inclusive jets, pT > 120 GeV

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Inclusive jet shapes

pp jet shapes are significantly broader and softer at 5.02 TeV
- 2.76 TeV Leading Jets: 64.0% Quark Jets, 33.4% Gluon Jets
- 5.02 TeV Inclusive Jets: 47.4% Quark Jets, 47.6% Gluon Jets

In modification measurements:
- PbPb – pp differences are similar at 5.02 and 2.76 TeV
- Difference in jet shape ratio can be accounted for by differences in pp reference jet shape

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