Energy flow in gamma-jets and dijet events in heavy-ion collisions

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In collaboration with
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Outline

• Introduction

• Jet propagation within a Linearized Boltzmann Transport (LBT) model

• Gamma-jets and Dijet in heavy-ion collisions

• Summary and Outlook
The jet shape and transverse momentum imbalance in Dijet events

- High PT photons are unmodified by the medium
- No “surface bias” in triggered events which dijet events suffer

Gamma-jet: The golden channel


arXiv:1609.02466 CMS

Phys. Rev. C 84, 024906 CMS
Jet-induced medium partons in LBT Model

\[ p_1 \cdot \partial f_1(p_1) = - \int dp_2 dp_3 dp_4 (f_1 f_2 - f_3 f_4) |M_{12 \rightarrow 34}|^2 \times (2\pi)^4 \delta^4(P_1 + P_2 - P_3 - P_4) + \text{radiation} \]

\[ dp_i \equiv \frac{d^3 p_i}{2E_i (2\pi)^3} \]

\[ f_i = \frac{1}{(e_i^{p.u/T} \pm 1)} (i = 2, 4), f_i = (2\pi)^3 \delta^3(p - \vec{p}_i) \delta^3(x - \vec{x}_i) (i = 1, 3) \]

Linearized Boltzmann jet transport

Elastic collision + Induced gluon radiation.

Follow the propagation of recoiled parton

Include recoiled parton in jet reconstruction
Global energy momentum conservation

\[ \frac{dN_g}{dxdk^2dt} = \frac{2C_A \alpha_s P(x) \hat{q}}{\pi k_{\perp}^4} \sin^2 \frac{t - t_i}{2\tau_f} \]

\[ \tau_f = 2E_x(1 - x) / k_{\perp}^2 \quad P(N_g, \langle N_g \rangle) = \frac{\langle N_g \rangle^{N_g} e^{-\langle N_g \rangle}}{N_g!} \]

Energy distribution of the radiated gluon

Total energy momentum Conservation in $2 \rightarrow n$

\[ \alpha_s = 0.3 \]

E$_0$=20 GeV  
T=0.4 GeV

analytic  
MC sampling  
radiation 2 $\rightarrow$ 3  
radiation 2 $\rightarrow$ n
Jet induced medium excitation

Propagation of a single initial jet parton in a uniform medium

Energy distribution in space

Energy distribution at different Time

Initial jet parton: gluon
$E = 100 \text{ GeV}$
$T = 0.4 \text{ GeV}$
$\alpha_s = 0.3$

Initial jet parton: gluon
$E = 100 \text{ GeV}$
$T = 0.4 \text{ GeV}$
$\alpha_s = 0.3$
Recoiled effect in the reconstructed jets

The contribution of the recoiled parton in the reconstructed jets


• Location of gamma-jet is decided according probability of binary collision.

Recoiled effect in the reconstructed jets

HL Li, FM Liu, GL Ma, XN Wang, Y Zhu
Phys.Rev.Lett. 106, 012301
Xin-Nian Wang, Yan Zhu
Phys.Rev.Lett. 111, 062301
Yayun He, Tan Luo, Xin-Nian Wang, Yan Zhu
Asymmetry distribution of gamma-jets in heavy-ion collisions

- fix the parameter $\alpha_s$ via the comparison with the $\gamma$-jet asymmetry

40GeV < $P_{T\gamma}$ < 50GeV

50GeV < $P_{T\gamma}$ < 60GeV

60GeV < $P_{T\gamma}$ < 80GeV

$P_{T\gamma}$ > 80GeV

$|\eta_\gamma| < 1.44$

$P_{Tjet} > 30$GeV

$|\eta_{jet}| < 1.6$

$\alpha_s = 0.19$
Azimuthal distribution of gamma-jets in heavy-ion collisions

- Dominance of the initial state radiation in angular correlation
  L Chen, GY Qin, SY Wei, BW Xiao, HZ Zhang
  arXiv:1607.01932
  A. H. Mueller, B Wu, BW Xiao, F Yuan
  arXiv:1604.04250

- Multiple jets in gamma-jets events

![Graph showing the distribution of gamma-jets](image)
Azimuthal distribution of gamma-jets in heavy-ion collisions

5.02 TeV

$|\eta_\gamma| < 1.44, P_{T\text{jet}} > 30 \text{GeV}, |\eta_{\text{jet}}| < 1.6$

$40 \text{GeV} < P_{T\gamma} < 50 \text{GeV}$

$50 \text{GeV} < P_{T\gamma} < 60 \text{GeV}$

$60 \text{GeV} < P_{T\gamma} < 80 \text{GeV}$

$80 \text{GeV} < P_{T\gamma} < 100 \text{GeV}$

$P_{T\gamma} > 100 \text{GeV}$

30-100%

0-30%
Asymmetry distribution of gamma-jets in heavy-ion collisions

40 GeV < $P_T\gamma$ < 50 GeV

50 GeV < $P_T\gamma$ < 60 GeV

60 GeV < $P_T\gamma$ < 80 GeV

80 GeV < $P_T\gamma$ < 100 GeV

$P_T\gamma$ > 100 GeV

0-30%

30-100%

5.02 TeV

$X_{J\gamma}$

$R_{J\gamma}$

$< X_{J\gamma} >$

$< R_{J\gamma} >$
• Shift of the peak of the pt distribution

• Path length dependence of the energy loss

$\Delta \phi_{J\gamma} > \frac{7}{8} \pi$

$5.02\text{TeV}$

$0-30\%$

$pT$ distribution of gamma-jets in heavy-ion collisions

$P_{T\gamma} > 80\text{GeV}$

$2.76\text{TeV}$

$50\text{GeV} < P_{T\gamma} < 60\text{GeV}$

$60\text{GeV} < P_{T\gamma} < 80\text{GeV}$

$80\text{GeV} < P_{T\gamma} < 100\text{GeV}$

$P_{T\gamma} > 100\text{GeV}$

$0-30\%$

$30-100\%$
Energy flow in gamma-jets events

\[ P_{||} = \sum_i P_{i\text{parton}} \ast \cos \theta_{i\text{parton-leadingjet}} \]

\[ \phi = |\phi_{\text{parton}} - \phi_{\text{leadingjet}}| \]

• Energy flow to the opposite direction of the jet

\[ P_{T\gamma} > 100 GeV, |\eta_{\gamma}| < 1.44 \]

\[ P_{T\text{jet}} > 30 GeV, |\eta_{\text{jet}}| < 1.6 \]
Energy flow in gamma-jets events

\[ P_\parallel = \sum_i p_{i(\text{parton})} \ast \cos \theta_{i(\text{parton-leadingjet})} \]

\[ \phi = |\phi_{\text{parton}} - \phi_{\text{leadingjet}}| \]

- Energy flow to the opposite direction of the jet

\[ P_{T_\gamma} > 100 \text{GeV}, |\eta_\gamma| < 1.44 \]

\[ P_{T_{\text{jet}}} > 30 \text{GeV}, |\eta_{\text{jet}}| < 1.6 \]
Energy flow in dijet events

\[ P_{||} = \sum_i P_{i(\text{parton})} \cdot \cos \theta_{i(\text{parton-leadingjet})} \]

\[ \phi = |\phi_{\text{parton}} - \phi_{\text{leadingjet}}| \]

**Leading jet**

**Subleading jet**

\( |\phi_{\text{parton}} - \phi_{\text{leadingjet}}| \)

\[ \frac{dN}{d\phi} \]

\[ |\phi_{\text{parton}} - \phi_{\text{leadingjet}}| \]

\[ P_{T_{\text{leadingjet}}} > 120 \text{GeV} \]

\[ P_{T_{\text{subleadingjet}}} > 50 \text{GeV} \]

\[ |\eta_{\text{jet}}| < 2.0 \]

\[ \Delta\phi > 2/3\pi \]

\[ |\eta_{\text{jet}}| < 1.6 \]

\[ \Delta\phi > 5/6\pi \]
Jet shape of leading jet in heavy-ion collisions

Olga Evdokimov (CMS)

Leading jet
subleading jet

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Jet shape of leading jet in heavy-ion collisions

Leading jet
subleading jet

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Jet shape of leading jet in heavy-ion collisions

Leading jet
subleading jet

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2.76 TeV

PP

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2.76 TeV
PP

```

2.76 TeV

PbPb 0-30%

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2.76 TeV
PbPb 0-30%

```

P_{Leadingjet} > 120 GeV
P_{Subleadingjet} > 50 GeV
|\eta_{jet}| < 1.6
\Delta_{\phi} > 5 / 6 \pi

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P_{Leadingjet} > 120 GeV
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Jet shape of leading jet in heavy-ion collisions

Leading jet
subleading jet

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Jet shape of leading jet in heavy-ion collisions

Leading jet
subleading jet

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Jet shape of subleading jet in heavy-ion collisions

- $P_{T_{\text{leading jet}}} > 120\, \text{GeV}$
- $P_{T_{\text{subleading jet}}} > 50\, \text{GeV}$
- $|\eta_{\text{jet}}| < 1.6$
- $\Delta \phi > 5/6\pi$

Graphs showing the density of associated particles as a function of $\Delta r$ for different $p_{T}^{\text{assoc}}$ ranges in $pp$ and $PbPb$ collisions at 2.76 TeV. The left graph is for $pp$ collisions, and the right graph is for $PbPb$ collisions at 0-30% centrality.
Jet shape of gamma-jets in heavy-ion collisions

$P_T > 100 GeV, |\eta_\gamma| < 1.44$

$P_{Tjet} > 30 GeV, |\eta_{jet}| < 1.6$

**2.76TeV**

Preliminary results:

<table>
<thead>
<tr>
<th>$p_T^{assoc}$ (GeV/c)</th>
<th>0.5</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>$p_T^{assoc} &gt; 8$</th>
<th>Total $p_T^{assoc} &gt; 0.5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 &lt; $p_T^{assoc}$</td>
<td>10^3</td>
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<td>2 &lt; $p_T^{assoc}$</td>
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<td>10^-7</td>
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<td>3 &lt; $p_T^{assoc}$</td>
<td>10^-2</td>
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<td>10^-7</td>
<td>10^-8</td>
</tr>
<tr>
<td>4 &lt; $p_T^{assoc}$</td>
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<td>10^-4</td>
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<td>10^-6</td>
<td>10^-7</td>
<td>10^-8</td>
<td>10^-9</td>
</tr>
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**2.76TeV PbPb 0-30%**

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</table>
**pT imbalance of dijet in heavy-ion collisions**

\[ p_T^{ll} = p_{T_{particle}} \times \cos(\phi_{particle} - \phi_{dijet}) \]

**2.76TeV**

**PP**

**2.76TeV**

**PbPb 0-30%**

- \( p_{T_{leading jet}} > 120 \text{GeV} \)
- \( p_{T_{subleading jet}} > 50 \text{GeV} \)
- \( |\eta_{jet}| < 1.6 \)
- \( \Delta \phi > 5/6\pi \)

Christopher McGinn (CMS)
Summary

• We present a computation of gamma-jets and Dijet in QGP within the Linear Boltzmann Transport model in which both the elastic and inelastic process are included.

Outlook

• Hadron jet and Heavy quark jet (with the recombination model developed by Texas A&M group)

Beyond LBT model (modified medium background)

CoLBT-Hydro model
(A coupled LBT Hydro (3+1D) Model)

Wei Chen’s talk in the last session

Shanshan’s talk in the morning

Yasuki’s talk tomorrow
Thanks

\[(\tau, x, y, \eta)\]

\[\varepsilon, T, f_{QGP}, u\]

LBT

• Location of gamma-jet is decided according probability of binary collision.

• Small difference between parton-jet and hadron-jet.
**Nontrivial path length dependence on parton energy loss**

**Propagation of a single initial jet parton in a uniform medium**

- $E = 100 \text{ GeV}$
- $T = 0.4 \text{ GeV}$
- $\alpha_s = 0.3$

**Leading parton energy loss**

**Leading jet energy loss**

- Leading jet only

- Initial jet parton: gluon
  - $E_0 = 100 \text{ GeV}$
  - $T = 0.4 \text{ GeV}$
  - $R = 0.3$
  - Elastic + radiation
  - Elastic only

- Initial jet parton: quark
  - $E_0 = 100 \text{ GeV}$
  - $T = 0.4 \text{ GeV}$
  - $R = 0.3$
  - Elastic + radiation
  - Elastic only