Revealing the medium-recoil effect with high $p_T Z$ boson tagged underlying event distribution in PbPb collisions at CMS

Pin-Chun Chou (CMS collaboration) Massachusetts Institute of Technology

Quark Matter, Houston

September 5, 2023





Parton energy-loss in heavy-ion collisions

• Partons interact with Quark Gluon Plasma (QGP) and lose energy.





Jet-induced recoil effects in heavy-ion collisions

- When energetic partons pass through the QGP, recoil effects can be generated.
 - the energy deposited could give rise to a Mach cone accompanied by a diffusion wake.

Depletes soft hadrons in the opposite direction.

Enhances soft hadrons

2023/9/5

in the jet direction.



Jing Wang's LHC seminar

medium

Jet-induced recoil effects in heavy-ion collisions

- When energetic partons pass through the QGP, recoil effects can be generated.
 - the energy deposited could give rise to a Mach cone accompanied by a diffusion wake.

Depletes soft hadrons in the opposite direction.

<u>Jing Wang's LHC seminar</u> Characterizing the medium response can provide information of QGP properties. e.g. transport coefficients and equation of state

medium

han



Enhances soft hadrons

in the jet direction.



γ-jet to probe parton interactions



Study parton-medium interactions using isolated γ **to constrain the initial "unquenched" parton kinematics**







Photon-Tagged Jets to probe parton interactions

PRL 121 242301 (2018)





CMS

Z-jet measurements for stronger constraints on recoil effects



Z is not sensitive to strong interaction, and "cleaner" than photons No Z from fragmentation/radiation/decay.

Additional phenomena (e.g. multiple parton interaction) might give rise to a uniform enhancement azimuthally.



Observables

• Angular correlation: $\Delta \phi_{\text{trk},Z} = |\phi^{\text{trk}} - \phi^Z|$

• **Z-tagged FF:**
$$\xi_{\mathrm{T}}^{\mathrm{trk},\mathrm{Z}} = \ln \frac{-|\overrightarrow{p}_{\mathrm{T}}^{\mathrm{Z}}|^{2}}{\overrightarrow{p}_{\mathrm{T}}^{\mathrm{trk}} \cdot \overrightarrow{p}_{\mathrm{T}}^{\mathrm{Z}}}$$





Reconstruction and Selection



- $60 < M_Z < 120 \text{ GeV}$, $p_T^Z > 30 \text{ GeV}$
- p_T^{trk} > 1 GeV, $|\eta^{trk}|$ < 2.4

Very clean channels !



Background subtraction



Tracks from PbPb underlying events (UE)

- Subtract via event mixing.
- Estimate using Minimum-Biased (MB) events matched with forward energy $E^{HF,MB} = E^{HF} - E^{HF,Z}$
- $E^{HF,Z}$ estimated from Z events in pp data.





$\xi_{trk,Z}$ in PbPb collisions at 5.02 TeV





$\Delta \phi_{trk,Z}$ correlations in PbPb collisions at 5.02 TeV





Theory comparison: $\xi_{trk,Z}$



Models with wake (CoLBT and Hybrid with wake) better describe the data.





Theory comparison: $\Delta \phi_{trk,Z}$





Models with wake (CoLBT and Hybrid with wake) better describe the data.

PRL 128 (2022) 122301



Constraining MPI modeling in pp collisions

- Medium modification of partons from the initial multiple parton interaction (MPI) might give rise to a uniform soft hadron enhancement in $\Delta \phi$.
- We need to constrain these effects to observe the diffusion wake.
- Z events → more central pp collisions → more MPI.
- MPI has been studied with underlying events using Z events in pp data.



JHEP 07 (2018) 032



Prospects for new measurement: $\Delta \eta$

PRL 130, 052301 (2023)

- A valley structure due to the diffusion-wake effect is predicted in the $\Delta\eta_{jet,trk}$ with low track p_T region.
- $\Delta\eta_{jet,trk}$ or $\Delta\eta_{Z,trk}$ may help us extract the diffusion wake effect and the MPI ridge.

(b)

Pb+Pb

0-10%

PbPb

 $p_{T} = 0.2 \text{ GeV/c}$

5

 Δn

• Looking forward to Run3 data for more statistics.

♦ 12.0 10.0 8.0 6.0 6.0

4.0 2.0

DØ

0.0



CoLBT-hydro results on γ-triggered jet-hadron correlation

2023/9/5



pp

 $p_{T} = 0.2 \text{ GeV/c}$

(a)

p4p

n

 Δn

5

d∆nd∆ø

Ø

Dø

-2

12.0

10.0

8.0

2.0

0.0

Summary

- Parton-medium studies using photon-hadron and ٠ more recently with the Z-hadron correlations.
- **Evidence for medium-response due to interaction of** ٠ high-p_T parton based on model comparison.

0-10%

-5

- Strong constraints to model description. ٠
- Looking forward to other variables such as $\Delta\eta_{jet,trk}$ or $\Delta \eta_{z,trk}$ and more data in Run_P β_{+Pb}







Backup slides











Results: $\xi_{trk,Z}$

PRL 128 (2022) 122301







Results: p_T^{trk}



CoLBT

Consistent with data both for low- p_T and high- p_T .

Hybrid with wake

Captures enhancement at low- $p_T \sim 1$ GeV. Undershoots at intermediate- $p_T \sim 3-5$ GeV.

PRL 128 (2022) 122301



Jet shapes of isolated photon-tagged jets in PbPb



γ + jet:
Measure parton-medium
interactions directly via jet
radial density profile (i.e.
jet shapes).

Parton shower: Increases energy fraction at large angles.

How if we continue jet shape to much larger r?



Theory models

SCET_G

Includes Glabuer gluons into softcollinear effective theory.

Based on PRD 93 074030 (2016), PRD 101 076020 (2020)

CoLBT

Feeds quenched jet energy into hydrodynamics evolution.

Based on PLB 810 (2020) 135783

Hybrid

Combines weak (via pQCD) and strong (via gauge/gravity) coupling regimes.

With wake:

include a medium response. i.e. recoil as the parton passes through

Without wake: do not include a medium response.

Based on JHEP 1410 (2014) 019



Prospects for $\Delta \eta_{trk,Z}$ measurement (extra plots) PRL 130, 052301 (2023)



CoLBT-hydro results on γ -triggered jet-hadron correlation in (a) $\Delta\eta$ and in (b) $\Delta\phi$



(a) Diffusion wake valley and (b) MPI ridge in γ -triggered jet-hadron correlation

