Jet Measurements with Neutral and Di-jet Triggers in Central Au+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV with STAR

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Outline

Two measurements

1. Neutral trigger jets: \(\gamma + \text{jet} \) and \(\pi^0 + \text{jet} \)

1. Di-jet energy imbalance in heavy-ion collisions at the STAR experiment
Motivation for $\gamma$+jet

• Good tomographic probe

Direct photon:

• Transverse energy approximates that of initial recoil parton $p_T$
• Not surface biased

Challenging $\gamma$+jet measurement

$\gamma$+hadron correlation [PLB 760 (2016) 689]

Investigating $\gamma$+jet events by combining these two analyses

Indication of less suppression of soft particles

Semi-inclusive $h^{\pm}$+jet

(h$^{\pm}$+jet: arXiv:1702.01108)

High jet $p_T$ suppression

0.3
Semi-inclusive recoil jets

- A new mixed event (ME) method to correct the uncorrelated background jets in HIC
- Large signal to background at high jet $p_T^{\text{reco}}$
- Charged jet reconstruction (using FastJet3.0.6)
  - $k_T$ algo. for bkgd. Subtraction and anti-$k_T$ algo. for jet reconstruction
  \[ p_{T,jet}^{\text{reco, ch}} = p_{T,jet}^{\text{raw, ch}} - \rho A_{jet} \]
  \( R \): Jet resolution parameter (jet radius), \( A_{jet} \): Active jet area and \( \rho \): ave. momentum density ($k_T$- algo.)
  \[ \rho \equiv \text{median} \left( \left\{ \frac{p_{T,jet}^{\text{jet}}}{A_{jet}} \right\} \right) \]

- $\pi^0/\gamma$ discrimination in heavy-ion experiment
  - STAR barrel electromagnetic calorimeter (BEMC) and shower maximum detector (BSMD)
  - Transverse shower profile (TSP) method
    \[ \Delta \phi \in \left[ \frac{3\pi}{4}, \frac{5\pi}{4} \right] \]

Now move to $\pi^0$+jet in Au+Au collisions

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Background subtraction and correction

\[ \pi^0 + \text{jet} : 9 < p_T^{\text{trig}} < 30 \text{ GeV/c} \]

- Event-by-event average background energy density correction done
- Signal dominates with respect to background at high jet \( p_T^{\text{reco}} \) and combinatorial jets at small jet \( p_T^{\text{reco}} \)
- Uncorrelated background jet contribution corrected by mixed events subtraction

Does our \( \pi^0 + \text{jet} \) agree with \( h^\pm + \text{jet} \) measurements in HIC?
π⁰+jet vs. h±+jet

- Applying correction due to detector and background fluctuations effects
  - Singular value decomposition (SVD) method for unfolding
- Taking into account systematic effects, π⁰+jet and h±+jet show agreement within uncertainties

(h±+jet: arXiv:1702.01108)

What about comparison between π⁰+jet and γ+jet?
**π^0 + jet vs. γ+jet**

Raw Jet $p_T$ without background and detector effect correction

$p+p$

- **Purity of $γ_{dir}$**: $p+p \sim 40\%$
- **Au+Au (0-10%)**: $\sim 70\%$

**PYTHIA expectation**

(for different purity of $γ_{dir}$)

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- **PYTHIA predicts larger jet yield for $π^0$ trigger than $γ_{dir}$**
- **In $p+p$, reasonable agreement with standalone PYTHIA considering purity of $γ_{dir}$**
To extract medium effect for $\pi^0$ +jet vs. $\gamma$+jet, need full corrections, detailed study and large statistics.

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Future measurements of $\pi^0$+jet vs. $\gamma$+jet

Au+Au collisions in the STAR experiment

- For $p_T > 9$ GeV/c
  - Run11: $\gamma$+jet ~30K trigger ($p_T > 9$ GeV/c) events with tight PID cuts
  - Combining year 2014+ year 2016, we have 8 times year 2011 statistics on the tape.
- For $p_T > 25$ GeV/c
  - we don’t need tight PID (Ratio $\gamma/\pi^0 > \sim 2$) and hence expect > 5K $\gamma$ triggers.

Int. Luminosity sampled by BEMC trigger
Year 2011: 2.8 nb$^{-1}$
Year 2014+ year 2016: ~25 nb$^{-1}$ on tape (~10 times more statistics)
- ~25 nb$^{-1}$ corresponds to 175 billion MB events

...Stay tuned
Di-jet hadron correlations

AuAu

pp
Di-Jet imbalance in transverse momentum

Jet resolution parameter $R=0.4$

- Di-jets with "hard cores" (constituents above $p_T > 2$ GeV/c only) show significantly more imbalance in central Au+Au than in embedded p+p
- Balance is restored for $R=0.4$ (but not $R=0.2$!) when including jet constituents $p_T < 0.2$ GeV/c

Jet resolution parameter $R=0.2$

- Indication of energy loss of di-jet interacting with the medium and lost energy reappears as soft particles

$p_T$ imbalance for back-to-back di-jet pairs

$$A_J = \frac{p_{T,\text{Lead}} - p_{T,\text{SubLead}}}{p_{T,\text{Lead}} + p_{T,\text{SubLead}}}$$

Submitted in PRL

arXiv:1609.03878

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How is the recovered energy distributed?

Trigger jet+hadron correlation

\[ \Delta \eta = \eta_{\text{jet}} - \eta_{\text{track}} \]
\[ \Delta \phi = \phi_{\text{jet}} - \phi_{\text{track}} \]

**Di-jet Definition:**
- Trigger jet containing a BEMC tower with energy \( E > 6 \text{ GeV} \) (HT)
- \( p_T^{\text{cut}} \geq 2.0 \text{ GeV/c} \)
- \( p_T^{\text{Trigger}} > 20 \text{ GeV/c} \)
- \( p_T^{\text{Recoil}} > 10 \text{ GeV/c} \)
- anti-\( k_T \) R=0.4

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Trigger jet + hadron yield shows no significant difference at all $p_T^{assoc}$

Indication of surface bias of trigger jets in Au+Au collisions

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Recoil jet+hadron correlations

Δη projection

Δφ projection

- Recoil: hints of excess low p_T yield, not significant within uncertainties
- Integrated A_J could dilute the recoil jet suppression
- Further differential measurements needed → data available!
Summary

• Neutral trigger semi-inclusive recoil jets
  • Within systematic uncertainty, agreement between $\pi^0$ +jet and $h^\pm$ +jet for R=0.3
  • working to extract medium effect on $\gamma$+jet vs. $\pi^0$ +jet
    • Larger statistics from year 2014+2016 data

• Dijet hadron correlation
  • Soft particles ($p_T < 2.0$ GeV/c) redistributed in $\Delta\eta$-$\Delta\phi$ in a recoil jet whereas trigger jet shows no significant modification due to surface bias in Au+Au collisions
  • Further differential measurements needed to understand redistribution of lost energy due to $A_J$ imbalance

Two posters (Ph.D students):
Derek Anderson (poster#173  $\pi^0$ - jet vs. $\gamma$-jet in p+p)
and Nick Elsey (poster#571  Dijet)
Back up
Solenoidal Tracker at RHIC (STAR)

- BEMC to identify EM clusters and trigged on high energy tower
- Time Projection Chamber (TPC) to identify charged hadron tracks
- Au+Au (year 2011) and pp (year 2009) 200 GeV

- TSP cuts are tuned to get
  - a nearly pure sample of \( \pi^0 \) (called “\( \pi^0 \) rich“)
  - a sample with enhanced fraction of \( \gamma_{\text{dir}} \) (called `\( \gamma \) rich ‘)
  - Purity of \( \gamma_{\text{dir}} \) ~40% and ~70% for p+p and Au+Au central (0-10%) collisions, respectively

\[ TSP = \frac{E_{\text{cluster}}}{\sum_i e_i r_i^{1.5}} \]

- \( E_{\text{cluster}} \): Cluster energy, \( e_i \): BSMD strip energy, \( r_i \): distance of the strip from the center of the cluster

Full azimuth and wide \( |\eta| < 1.0 \), both for BEMC and TPC

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Background subtraction and correction

Levy, $T_{\text{true}} = 0.60$ GeV, $n=8.5$, TSD, $k_{\text{reg}} = 3$, norm = 1

Au+Au, 0%-10%
Trigger-$\pi_0^{\text{trig}}$
$9.0 < p_{T,\text{trig}} < 30.0$ GeV/c
$R=0.3$, anti-$k_T$

STAR Preliminary

$\frac{1}{N_{\text{trig}}} \frac{dN_{\text{jets}}}{dp_{T,\text{jet}}^{\text{ch}}} (\text{GeV/c})^{-1}$

Uncorr. data
unfolded
backfolded
MC prior

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Di-Jet Hadron Correlation Background Subtraction

$\Delta\phi$: possible flow
→ Side band subtraction method

$\Delta\eta$: no flow
→ correlation fit with gaussian+constant
→ Constant subtracted from signal

![Graph showing correlation distribution vs. $\Delta\phi$](image)
Di-jet hadron correlations in $\Delta \eta$

**1.0 < $p_T^{\text{track}}$ < 2.0 GeV/c**

- **Trigger jet + hadron**
- **Recoil jet + hadron**

**3.0 < $p_T^{\text{track}}$ < 4.0 GeV/c**

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Di-jet hadron correlations in $\Delta \phi$

**Trigger jet + hadron**

1.0 < $p_T^{\text{track}}$ < 2.0 GeV/c

3.0 < $p_T^{\text{track}}$ < 4.0 GeV/c

**Recoil jet + hadron**

1.0 < $p_T^{\text{track}}$ < 2.0 GeV/c

3.0 < $p_T^{\text{track}}$ < 4.0 GeV/c

STAR Preliminary