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

Nihar Ranjan Sahoo
(for the STAR collaboration)
Texas A&M University, USA
Outline

Two measurements

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

2. 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

High jet $p_T$ suppression

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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
  \[ p_{T,\text{jet}}^{\text{reco, ch}} = p_{T,\text{jet}}^{\text{raw, ch}} - \rho A_{\text{jet}} \]
  \( R \): Jet resolution parameter (jet radius), \( A_{\text{jet}} \): Active jet area and \( \rho \): ave. momentum density ($k_T$- algo.)
\[ \rho \equiv \text{median} \left\{ \frac{p_{T,\text{jet}}^{\text{ch}}}{A_{\text{jet}}} \right\} \]

- $\pi^0/\gamma$ discrimination in heavy-ion experiment
  - STAR barrel electromagnetic calorimeter (BEMC) and shower maximum detector (BSMD)
  - Transverse shower profile (TSP) method

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?

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π^0+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, π^0+jet and h^±+jet show agreement within uncertainties

What about comparison between π^0+jet and γ+jet?

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\( \pi^0 + \text{jet} \) vs. \( \gamma + \text{jet} \)

Raw Jet \( p_T \) without background and detector effect correction

\[ p+p \]

- PYTHIA predicts larger jet yield for \( \pi^0 \) trigger than \( \gamma_{\text{dir}} \)
- In \( p+p \), reasonable agreement with standalone PYTHIA considering purity of \( \gamma_{\text{dir}} \)

\[ \text{Purity of } \gamma_{\text{dir}} : \]
- \( p+p \sim 40\% \)
- \( \text{Au+Au (0-10\%) } \sim 70\% \)

**PYTHIA expectation**

(for different purity of \( \gamma_{\text{dir}} \))

\[ \text{[At particle level]} \]

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To extract medium effect for $\pi^0 + \text{jet}$ vs. $\gamma + \text{jet}$, need full corrections, detailed study and large statistics.
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 $\gamma/\pi^0 > ~2$) and hence expect > 5K $\gamma$ triggers.

...Stay tuned

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

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

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How is the recovered energy distributed?

Trigger jet+hadron correlation

Di-jet Definition:

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

$p+p$ HT

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

Au+Au HT 0-20% central

$(\text{After mixed event correction})$

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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.
Recoil jet+hadron correlations

Δη projection

Recoil Jet Yield Δη

Δφ projection

Recoil Jet Yield Δφ

• 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 $\rightarrow$ data available!
Summary

• Neutral trigger semi-inclusive recoil jets
  • Within systematic uncertainty, agreement between $\pi^0 + \text{jet}$ and $\text{h}^\pm + \text{jet}$ for $R=0.3$
  • working to extract medium effect on $\gamma + \text{jet}$ vs. $\pi^0 + \text{jet}$
    • 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
STAR detector system and $\pi^0/\gamma_{\text{dir}}$ discrimination

- BEMC to identify EM clusters and trigger 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 “$\pi^0_{\text{rich}}$”)
- A sample with enhanced fraction of $\gamma_{\text{dir}}$ (called “$\gamma_{\text{rich}}$”)
- Purity of $\gamma_{\text{dir}} \sim 40\%$ and $\sim 70\%$ 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

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Background subtraction and correction

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

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

STAR Preliminary

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Di-Jet Hadron Correlation Background Subtraction

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

$\Delta\eta$: no flow
correlation fit with
gaussian+constant
$\rightarrow$ Constant subtracted from signal
Di-jet hadron correlations in $\Delta\eta$

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

1. $1.0 < p_T^{\text{track}} < 2.0$ (projection range $|\Delta\phi|<0.71$

2. Trigger jet + hadron

3. Recoil jet + hadron

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

1. $3.0 < p_T^{\text{track}} < 4.0$ (projection range $|\Delta\phi|<0.71$

2. Trigger jet + hadron

3. Recoil jet + hadron

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

**Trigger jet + hadron**

**Recoil jet + hadron**