Charged Jet Structure in 2.76 TeV Pb-Pb Collisions at ALICE

Leticia Cunqueiro on behalf of the ALICE collaboration
Charged Jet structure in 2.76 TeV Pb-Pb Collisions at ALICE

Goal: precise measurement of jet structure and modifications due to quenching ➔ minimize fragmentation bias on jet population

Observable: hadron-triggered semi-inclusive recoil jet distribution

Hadron trigger: highest particle $p_T$ in event
Count number of reconstructed jets in recoil azimuth
- $|\phi_{\text{recoil jet}} - \phi_{\text{trig h}}| < \pi - 0.6$  
- $|\eta_{\text{recoil jet}}| < 0.5$
- Normalize to number of triggers

pp recoil jet yield : PYTHIA

1/N_{\text{trig}} dN/dp_T^{\text{ch}} (GeV/c)^{-1}

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Data Analysis

Pb-Pb dataset
- 2010 run, $\sqrt{s}=2.76$ TeV
- 0-20% most central collisions: 3M events

pp reference: PYTHIA6 (Perugia 2010 tune)

Charged particle jets
- jet constituents: all charged tracks, $|\eta_{\text{track}}|<0.9$
  - minimal cuts: $p_T>0.15$ GeV/c, good tracking efficiency (>75%)
- jets: anti-$k_T$ R=0.2 and R=0.4, $|\eta_{\text{jet}}|<0.5$
  - correct event-wise for background: $p_{T,\text{jet}}=p_{T,\text{reco}}-\rho A$

Hadron trigger: choose $p_T$ large enough to be “rare” per central
Pb-Pb $\rightarrow$ high probability that hard recoil jet comes from same hard
interaction

Corrections for heavy ion background:
- suppression of combinatorial jet contribution without imposing
  fragmentation bias  (G. de Barros et al., arXiv:1208.1518)
- unfolding of fluctuations in jet energy
Hadron+Jet in Heavy-Ion Collisions

- Semi-inclusive measurement: biases are ONLY due to trigger hadron
- Geometric bias in model calculations
  distribution of vertices that generate the trigger

  1. Hadron trigger: strong “surface bias”
     maximizes recoil path length
     (T. Renk, private com.)

  2. Full jet trigger: no geom. bias
     (T. Renk, Phys. Rev. C85 064908)

Centrality and reaction plane biases:
- finite, but only weak trigger \( p_T \) dependence for high \( p_T^{\text{trig}} \)
Conjecture: combinatorial background distribution is independent of trigger $p_T$

Caveats: reaction plane and centrality biases

$p_T$ dependence is minimized for high $p_T$ triggers

$p_{T,\text{jet}} < 20 \text{ GeV/c}$: uncorrelated with trigger $p_T$
- consistent with dominance by combinatorial jet contribution

$p_{T,\text{jet}} > 20 \text{ GeV/c}$: correlated with trigger $p_T$
- consistent with dominance by hard jets from the same hard scattering
Removal of Combinatorial Component

1. Combinatorial background distribution is independent of trigger $p_T$
   
   Opportunity: removal of combinatorial jets via DIFFERENCE of triggered distributions: $\Delta_{\text{recoil}}$

2. Difference distribution $\Delta_{\text{recoil}}$ contains only correlated hard jet component

3. Still smeared in energy by the underlying event $\rightarrow$ correct by unfolding

Reference spectrum (15-20) scaled by $\sim 0.96$ to account for conservation of jet density.
The Response Matrix: Background & Detector Effects

1. Background response: using random cones \((ALICE, JHEP 03 (2012) 053)\)
\[ \sigma = 9.74 \text{ GeV} \text{ for } 0\text{-}20\% \text{ central and } p_T^{\text{const}} > 0.15 \text{ GeV}/c \]

2. Detector response: dominated by tracking efficiency based on PYTHIA fragmentation

3. Combined matrix \( A_{ij} = \text{Det}_{ik} \text{ Bkg}_{kj} \)

Detector and background effects go in opposite directions
Spectrum is almost exponential
Reduced combined effect
Unfolding of Background Fluctuations

Two systematically different techniques:
1) Bayesian unfolding \( (G.D'Agostini, NIM A362 (1995)487) \)
2) \( \chi^2 \) minimization of refolded and measured

The two methods give consistent results. Maximum difference of \(~20\%) included in the systematics as part of the shape uncertainty.
Recoil jet distributions $\Delta_{\text{recoil}}$

Correlated uncertainty:
1. flow bias on background induced by hadron trigger
   (Inclusive Charged Jet Spectrum Measurement - Poster M.Verweij)
2. variation of tracking efficiency
3. reference distribution scaling factor

Shape uncertainty:
1. $p_T^{\text{min}}$ cut variations, feed in/out
2. regularization: $\beta$ variations/difference to Bayesian result
Ratio of Recoil Jet Yield $\Delta I_{AA}$

We want to measure: $\Delta I_{AA} = \left\langle \frac{Y_{AA}^{20-50} - Y_{AA}^{15-20}}{Y_{pp}^{20-50} - Y_{pp}^{15-20}} \right\rangle$

$Y = \frac{1}{N_{trig}} \frac{dN_{jet}}{dp_{T,jet}}$

Finite event statistics $\rightarrow$ need to average $\Delta I_{AA}$ over broad $p_T^{trig}$ bins

Under mild assumptions, the average of the ratios~the ratio of the averages
  - Avoids large non-statistical fluctuations in calculation of average

\[
\langle \Delta I_{AA} \rangle \approx \frac{\langle Y_{AA}^{20-50} \rangle - \langle Y_{AA}^{15-20} \rangle}{\langle Y_{pp}^{20-50} \rangle_{AAw} - \langle Y_{pp}^{15-20} \rangle_{AAw}}
\]

Where:

\[
\langle Y_{AA}^{20-50} \rangle = \frac{1}{N_{trig}^{AA}} \int_{p_T^{trig} = 20}^{50} dp_T^{trig} \frac{dN_{jet}^{AA}}{dp_T^{trig} dp_T^{jet}}
\]

\[
\langle Y_{pp}^{20-50} \rangle_{AAw} = \frac{1}{N_{pp}} \int_{p_T^{trig} = 20}^{50} dp_T^{trig} \left[ f_w(p_T^{trig}) \frac{dN_{jet}^{pp}}{dp_T^{trig} dp_T^{jet}} \right]
\]

\[
f_w(p_{T,\text{trig}}) = \frac{1}{\langle R_{AA} \rangle} R_{AA}
\]

i.e. the pp distribution is weighted by the shape of the AA $p_T^{trig}$ spectrum
Ratio of Recoil Jet Yield $\Delta I_{AA}^{\text{PYTHIA}}$

Recoil jet yield $\Delta I_{AA}^{\text{PYTHIA}} \approx 0.75$, approx. constant with jet $p_T$

Constituents: $p_{T}^{\text{const}} > 0.15$ GeV/c

no fragmentation bias imposed on recoil jet population

pp reference: PYTHIA (Perugia 2010)
Recoil/Inclusive :: Hadrons/Jets

Di-hadrons:
\( p_T^{\text{trig}} > 8 \text{ GeV} \), \( I_{AA}(h) \approx 0.6 \)
\( R_{AA}(h) \approx 0.3 \)

Hadron+jet:
\( p_T^{\text{trig}} > 20 \text{ GeV} \), \( I_{AA}(\text{jet}) \approx 0.8 \)
\( R_{AA}(\text{jet}) \approx 0.3 \)

Why are hadron-triggered correlations less suppressed?

Phys. Rev. Lett. 108 092301 (2012)
Recoil Jet $\Delta I_{AA}^{\text{PYTHIA}}$: R dependence

Similar $\Delta I_{AA}^{\text{PYTHIA}}$ for $R=0.2$ and $R=0.4$

→ little, if any, energy redistribution within $R=0.4$ relative to PYTHIA reference
Recoil Jet $\Delta l_{AA}^{PYTHIA}$: Cut On Constituent $p_T$

$p_T^{const} > 0.15$ GeV

$p_T^{const} > 2$ GeV

No indication of large variation of fragmentation pattern compared to PYTHIA
ΔI_{AA}^{PYTHIA} vs Models: JEWEL

JEWEL: Zapp et al., Eur.Phys.J.C69 (2009) 617

JEWEL correctly describes inclusive jet $R_{AA}$
Predicts $ΔI_{AA} \sim 0.4$, below measured
$\Delta I_{AA}^{\text{PYTHIA}}$ vs models: YAJEM

YAJEM: T. Renk, Phys. Rev. C78 (2008) 034908

YAJEM describes the asymmetry $A_i$ and predicts an $I_{AA} \sim 0.75$, in reasonable agreement with data.
Summary

We have reported the first measurement of the semi-inclusive yield of jet recoiling from a high $p_T$ hadron trigger

- Measured recoil jet population has minimal fragmentation bias

Recoil jets are significantly less suppressed than inclusive jet

- Qualitatively similar behaviour for single particle inclusive vs recoil ($R_{AA}$ vs $I_{AA}$)

No indication of large modification of the fragmentation with respect to PYTHIA:

- $\Delta I_{AA}$: small, if any, dependence on jet radius $R$
- $\Delta I_{AA}$: small, if any, dependence on minimum constituent $p_T$

$\Delta I_{AA}$: new constraint to models

- Understand physics of energy loss of recoiling jet
- Understand geometry biases, time dependence of energy loss…