Search for jet quenching in high-multiplicity pp collisions using inclusive and semi-inclusive jet production in ALICE

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QGP in small collision systems?

QGP-like signatures in high-multiplicity pp and pA:
- Collective phenomena (ridge, $v_2$)
- Strangeness enhancement

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CMS, JHEP 09 (2010) 091
Jet quenching in small collision systems?

But at the same time jet quenching signal is below current sensitivity

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Jet quenching observables

- Yield suppression relative to min. bias pp → energy transport out-of-cone
  - Measurement of inclusive suppression ($R_{AA}$) requires Glauber scaling → ill defined in high-multiplicity pp collisions
- Jet substructure modification
- Jet deflection → dijet acoplanarity

D. A. Appel, PRD 33, 717 (1986)
J.P. Blaizot and L. McLerran, PRD 34, 2739 (1986)

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Event activity selection in pp at $\sqrt{s} = 13$ TeV

- **Trigger:**
  - Minimum bias (MB) $L_{\text{int}} \approx 32$ nb$^{-1}$
  - High multiplicity (HM) $L_{\text{int}} \approx 10$ pb$^{-1}$

- **Event activity (EA) selection:**
  - $V0M = V0A + V0C$
  - HM is 0.1% of MB cross section
  - $5 < V0M / \langle V0M \rangle < 9$
  - $\langle V0M \rangle = \text{mean of } V0M \text{ in MB}$

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Charged-particle jets in MB and event activity biased pp collisions at $\sqrt{s} = 13$ TeV

How does the imposed event activity selection bias the spectrum shape?

- Tracks
  \[ |\eta_{\text{track}}| < 0.9 \]
  \[ 0 < \varphi_{\text{track}} < 2\pi \]
  \[ p_{T,\text{track}} > 150 \text{ MeV/c} \]

- Charged-particle jets
  Anti-$k_T$ algorithm
  \[ |\eta_{\text{jet}}| < 0.9 - R \]
  \[ R = 0.2 \text{ – } 0.7 \]

- \[ p_{T,\text{ch jet}} = p_{T,\text{ch jet}}^{\text{raw}} - \rho A_{\text{jet}} \]

How does the imposed event activity selection bias the spectrum shape?

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Event activity (EA) bias affects the shape mostly for $p_{T,ch jet} < 20 \text{ GeV}/c$

- Bias on high-EA causes increase of jet yield per event
  - May arise from increase in average number of hard scatterings per event

New

arXiv:2202.01548
Self-normalized jet yield versus self-normalized multiplicity

- Jets with $p_{T,jet}^{ch} > 9$ GeV/$c$ follow non-linear trend similar to J/ψ in midrapidity
  
  John Dello Stritto, talk on 7 Apr at 4 pm
  Parallel Session T14: Hadron prod. and col. dyn. I

- Electrons from W decay follow linear trend
  
  Shingo Sakai, talk on 7 Apr at 5 pm
  Parallel Session T13: Electroweak probes II

- Overshoot of the trend by PYTHIA at high charged-particle multiplicities

**New**

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Search for jet quenching in HM pp 13 TeV in ALICE  
QM 2022  
arXiv:2202.01548
Ratios of jet $p_T$ spectra with different $R$

MB ratio of $p_T$-differential cross section spectra:
- independent of $\sqrt{s}$

EA-selected ratio of spectra:
- small $R$: independent of EA
- large $R$: hint of EA dependence
Impact of high-EA bias on jet longitudinal fragmentation

Poster by Debjani Banerjee
Poster Session 1 T05_1 on 6 Apr

HM event selection \rightarrow \text{softer jet fragmentation}

This is consistent with larger portion of jets coming from NLO processes

HM event activity selection:

\[ 5 < \frac{V_0}{\langle V_0 \rangle} < 9 \]

0.1% of MB cross section

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Hadron-jet acoplanarity

Jets recoiling from high-$p_{\mathrm{T}}$ trigger hadron (TT)

Data-driven statistical approach to remove recoil-jet yield uncorrelated to TT

\[ \Delta_{\text{recoil}} (\Delta \varphi) = \frac{1}{N_{\text{trig}}} \frac{dN_{\text{jet}}}{d\Delta \varphi} \bigg|_{\text{TT}(20,30) & p_{T,jet}^{\text{ch}}} - c_{\text{ref}} \cdot \frac{1}{N_{\text{trig}}} \frac{dN_{\text{jet}}}{d\Delta \varphi} \bigg|_{\text{TT}(6,7) & p_{T,jet}^{\text{ch}}} \]

\[ \text{TT}\{X,Y\} \text{ means } X < p_{T,\text{trig}} < Y \text{ GeV/c} \]
Distributions of hadron-jet acoplanarity

- HM acoplanarity distributions relative to MB
  - suppressed back-to-back correlation
  - broader

The effect is stronger for low $p_T$ jets

HM event activity selection:
- 5 < V0M / $\langle V0M \rangle$ < 9
- 0.1% of MB cross section

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Comparison of hadron-jet acoplanarity with PYTHIA

Quantitative comparison to PYTHIA 8 Monash shows similar suppression pattern.

The effect is not due to jet quenching.

Use PYTHIA to explore the origin of the effect.
PYTHIA : recoil jet $\eta_{\text{jet}}$ versus $p_{T,\text{jet}}$

HM events:
- significant bias in distribution of high-$p_T$ recoil jets
- enhancement in forward trigger detector acceptance
- V0A and V0C have asymmetric coverage
Summary

• Event activity bias on inclusive jet production
  - affects largely the yield of high $p_T$ jets
  - has weak impact on the shape of jet $p_T$ spectrum

• Semi-inclusive jet production
  - broadening and suppression of back-to-back hadron-jet correlation in HM pp relative to MB
  - quantitatively reproduced by PYTHIA

• HM event selection
  - biases towards multi-jet final states
  - masks potential jet quenching signatures

• Significant issue for all HM analyses in small collision systems
Backup
Hadron-jet observables and $T_{AA}$

Calculable at NLO pQCD

\[
\frac{1}{N_{\text{trig}}^{AA}} \left. \frac{d^2 N_{\text{jet}}^{AA}}{dp_{T,\text{jet}}^{ch} \, d\eta_{\text{jet}}} \right|_{p_{T,\text{trig}} \in \text{TT}} = \left( \frac{1}{\sigma^{AA \rightarrow h+X}} \cdot \frac{d^2 \sigma^{AA \rightarrow h+jet+X}}{dp_{T,\text{jet}}^{ch} \, d\eta_{\text{jet}}} \right) \left|_{p_{T,h} \in \text{TT}} \right.
\]

measured

from theory

In case of no nuclear effects

\[
\frac{1}{N_{\text{trig}}^{AA}} \left. \frac{d^2 N_{\text{jet}}^{AA}}{dp_{T,\text{jet}}^{ch} \, d\eta_{\text{jet}}} \right|_{p_{T,\text{trig}} \in \text{TT}} = \left( \frac{1}{\sigma^{pp \rightarrow h+X}} \cdot \frac{d^2 \sigma^{pp \rightarrow h+jet+X}}{dp_{T,\text{jet}}^{ch} \, d\eta_{\text{jet}}} \right) \left|_{p_{T,h} \in \text{TT}} \right. \times \frac{T_{AA}}{T_{AA}}
\]

- This coincidence observable is self-normalized, no requirement of $T_{AA}$ scaling
- No requirement to assume correlation between Event Activity and collision geometry
Jet quenching measurements with hadron-jet correlations

- Jets recoiling from high-$p_T$ trigger track (TT)
- Data-driven statistical approach to remove recoil-jet yield uncorrelated to TT (including MPI)
- Does not impose fragmentation bias on the recoil jet

\[
\Delta_{\text{recoil}}(p_{T,\text{ch,jet}}^{\text{ch}}) = \frac{1}{N_{\text{trig}}} \left. \frac{dN_{\text{jet}}}{dp_{T,\text{ch,jet}}^{\text{ch}}} \right|_{TT\{20,30\}} - c_{\text{ref}} \cdot \left. \frac{1}{N_{\text{trig}}} \frac{dN_{\text{jet}}}{dp_{T,\text{ch,jet}}^{\text{ch}}} \right|_{TT\{6,7\}}
\]

Coincidence observable is self-normalized, no requirement of $T_{AA}$ scaling:

\[
\left. \frac{1}{N_{\text{trig}}} \frac{dN_{\text{jet}}}{dp_{T,\text{ch,jet}}^{\text{ch}}} \right|_{TT} = \left. \left( \frac{1}{\sigma_{pp\rightarrow h+X}} \cdot \frac{d\sigma_{pp\rightarrow h+jet+X}}{dp_{T,\text{jet}}^{\text{ch}}} \right) \right|_{TT} \times \frac{T_{AA}^{TT}}{T_{AA}}
\]

TT\{X,Y\} means X < $p_{T,\text{trig}}$ < Y GeV/c

ALICE, JHEP 09 (2015) 170

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PYTHIA simulations

- Charged particles $|\eta| < 6$
  fully covering V0C and V0A
- Events containing TT{20,30} or TT{6,7} in $|\eta|<0.9$
- Anti-$k_T$ charged particle $R=0.4$ jets in
  1) ALICE central barrel $|\eta_{jet}| < 0.5$
  2) broad $\eta$ range $|\eta_{jet}| < 5.6$

V0M defined by the number of charged, final state particles in V0A & V0C
PYTHIA: Number of recoil jets versus event activity in ALICE acceptance

Distrib. of the number of recoil jets above $p_T$ threshold:

- HM trigger suppresses events with 1 hard recoil jet in the ALICE central barrel
- HM trigger enhances multi-jet events in small systems

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