Jet Production in p-Pb Collisions

Megan Connors
for the ALICE Collaboration
June 3, 2014
Jets in Heavy Ion Collisions

internal probe
created early in collision
Jets in Heavy Ion Collisions

Jet finding - jet finders

Cacciari, Salam, Soyez, arXiv:0802.1189

MC: proton-proton - single event

Cacciari et al arXiv:0802.1189

internal probe
created early in collision

Cacciari et al arXiv:0802.1189

Megan Connors (Yale) --- Jet Production in p-Pb
Jets in Heavy Ion Collisions

Jet suppression observed in Pb-Pb
- Energy loss in QGP

R_{AA} = \frac{dN_{jet}^{AA}}{dp_T} \frac{N_{colli}^{pp}}{N_{evt}^{AA}}

Cacciari et al arXiv:0802.1189

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Jets in Heavy Ion Collisions

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What are the Cold Nuclear Matter (CNM) effects from initial state?
- If no CNM effect expect $R_{pPb} = 1$
- Constraints on nPDF
Searching for CNM effects in p-Pb jets

- **Spectra:**
  - Quantify initial state effect to jet quenching observation

- **Fragmentation:**
  - Ratio of spectra for different $R$
  - $j_T$

- **Composition:**
  - $\Lambda/K^0_s$ Ratio in jet
Jets at ALICE

EMCal is a Pb-scintillator sampling calorimeter:
- $|\eta| < 0.7$,
- $1.4 < \varphi < \pi$

-corrected for energy deposited by charged tracks

Tracking:
- $|\eta| < 0.9$, $0 < \varphi < 2\pi$

TPC: gas drift detector
ITS: silicon detector

Charged particles
$p_T > 150$ MeV/$c$

Neutral particles
$E_T > 300$ MeV
Tracking:
\[ |\eta| < 0.9, \ 0 < \varphi < 2\pi \]
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Charged particles \[ p_T > 150 \text{ MeV}/c \]

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Megan Connors (Yale) --- Jet Production in p-Pb
Corrections: Background Subtraction

- Estimate **background density**, $\rho$, on an event by event basis
- Clusterize event into jets using the $k_T$ jet finder on tracks
- Calculate $\rho^{ch}$ using the occupancy median method\(^2\)
  - exclude $k_T$ jets overlapping with signal jets

$$\rho^{ch} = \text{median} \left\{ \frac{p_{T,i}}{A_i} \right\} \cdot C$$

$$C = \frac{\sum A_{\text{physical-jets}}}{\sum A_{k_T\text{jets}}}$$

2. based on S. Chatrchyan et. al. (CMS)
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- scale $\rho^{ch}$ by $S_{EMC}$ to account for the neutral energy

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$$\rho^{ch+em} = S_{EMC} \cdot \rho^{ch}$$

$$S_{EMC} = \frac{\sum E_T^{\text{cluster}} + \sum p_T^{\text{track}}}{\sum p_T^{\text{track}}}$$

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\[
\rho^{\text{ch}} = \text{median} \left\{ \frac{p_{T,i}}{A_i} \right\} \bullet C
\]

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C = \frac{\sum A_{\text{physical-jets}}}{\sum A_{k_T \text{jets}}}
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\[
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\]

\( \rho^{\text{ch}} \sim 3\% \) & \( S_{\text{EMC}} \sim 1\% \)
 Corrections: Unfolding

Raw Spectra (UE Subtracted)

ALICE Preliminary
p-Pb $\sqrt{s_{NN}} = 5.02$ TeV Min Bias
anti-$k_t$ $R = 0.4$ Uncorrected

- $P_{\text{ch+em}}$ signal removal
- $P_{\text{chem}}$ occupancy median approach
- $\rho = 0$

Detector Level

Energy Scale (5%)

Unfolding

Detector Response Matrix from PYTHIA + ALICE Simulation

Particle Level

EMCal is a Pb-scintillator tower covers:

Typical tracking efficiencies of

\[ \rho_{\text{det}} = 0.4 \text{ jet} \]

The jet spectrum shown in Fig. 4 is in

\[ \rho_{\text{det}} = 0.4 \text{ jet} \]

The Detector Response & Unfolding

Table 1:

\begin{tabular}{ |l|c|c| } 
\hline
\textbf{Component} & \textbf{Correction} & \textbf{Uncertainty} \\
\hline
\hline
Underlying Event & 4\% & \textbf{Systematic} \\
\hline
Charged Hadron & 5\% & \textbf{Systematic} \\
\hline
\end{tabular}
Where approach, the occupancy median approach [2], is which particle came from which process. One jet are from the initial hard scattering. Some of these the underlying event and its region-to-region fluctuations, and unfolding systematics will be explored in p-Pb collisions are valuable because they include the initial state effects of nucleus-nucleus collisions without also including the final state effects. Therefore, proton-nucleus measured jet spectrum. We can quantify the systematic uncertainties.

$\text{Probability density per bin (0.1)}$

- **Correct for**:
  - Detector Effects ~10% syst unc
  - Background Fluctuations ~3% syst unc

$\delta p_T = \sum_{RC} p_T - \rho \pi R^2$

- SVD unfolding
  - unfolding systematic: ~12%
Corrections: Unfolding

Raw Spectra (UE Subtracted)

Detector Effects ~10% syst unc

Background Fluctuations ~3% syst unc

ALICE Preliminary

p-Pb \( \sqrt{s_{NN}} = 5.02 \text{ TeV} \) Min Bias

anti-\( k_T \) \( R = 0.4 \) Uncorrected

\( \rho^{\text{ch+em}} \) anti-\( k_T \) signal removal

\( \rho^{\text{ch+em}} \) occupancy median approach

(Default)

\( \rho = 0 \)

\( \rho \leq 0.3 \)

\( \eta_{\text{jet}} \) < 0.3

p-Pb \( \sqrt{s_{NN}} = 5.02 \text{ TeV} \)

\( R = 0.4 \)

SVD unfolding

\( \delta p_T = \sum_{RC} p_T - \rho \pi R \)

- SVD unfolding

uncorrelated and contribute about 5% to the total probability of possible exclusion.

ALICE Simulation

PYTHIA-Perugia2011

pp \( \sqrt{s} = 5.02 \text{ TeV} \)

anti-\( k_T \) \( R = 0.4 \)

PYTHIA \( \rightarrow \) GEANT3

\( \delta p_T = \sum_{RC} p_T - \rho \pi R \)

production in p-Pb collisions.
\[
R_{pPb} = \frac{\frac{dN_{jet}^{pPb}}{dp_T}}{\frac{\langle N_{coll} \rangle dN_{jet}^{pp}}{dp_T}} \frac{N_{pp}}{N_{evt}^{pPb}}
\]

- 5.02 TeV pp data reference not available
- Use MC reference (PYTHIA, POWHEG)
- Large uncertainty on the MC reference
- Scale p-Pb spectrum by number of binary collisions, \(N_{coll}\)
- Data/MC consistent with no CNM effects
R=0.2 Jet Spectrum

- Data/MC consistent with no CNM effects
- Jet suppression observed in Pb-Pb due to hot medium
Jet Structure

- p-Pb ratio consistent with pp collisions at 2.76 TeV
- No modification of the jet sub-structure observed

Data is best described by PYTHIA with angular ordering

- ALICE Preliminary
- $|\eta_{\text{jet}}| < 0.5$
- $R=0.2$
- $R=0.4$

- Charged hadrons
- $j_T$ jet axis

- $p$-$\text{Pb}$ $\sqrt{s_{NN}} = 5.02$ TeV
- $\text{pp} \sqrt{s} = 2.76$ TeV

- ALICE Preliminary

- $N'$ = 0 (normalized to bin at $\ln(j_T)$)
- $20 < p_{T,\text{ch+em}} < 30$ GeV/c
- $0.3 < p_{T,\text{assoc}} < 100$ GeV/c
- $80 < p_{T,\text{ch+em}} < 100$ GeV/c
- $0.3 < p_{T,\text{assoc}} < 100$ GeV/c

- $j_T$ charged tracks
- Systematic uncertainty
- PYTHIA 6.4 CDF A tune
- PYTHIA 6.4 CDF A, no AO

- Megan Connors (Yale)
- ALI-PREL-75744
Charged Jets

- Similar observations from charged jet results
- Obtain pp reference for $R_{pPb}$ at 5.02 TeV by scaling 7 TeV pp spectrum using PYTHIA
- Cross-section ratio consistent with 7 TeV pp
Jet Composition Study Motivation

- $\Lambda/K^0_s$ enhancement observed in p-Pb
  - similar behavior seen in Pb-Pb
- Is the composition in the jet changing?
  - Or the underlying event?

\begin{align*}
\text{\small Physics Motivation} & \\
\text{talk: L. Milano, Tue. May 20th, 14:40, QM2014} & \\
\end{align*}
Measuring $\Lambda/K^0_s$ in Jets

- Tag the hard scattering with charged jet
- Reconstruct $\Lambda$ and $K_s^0$
  - within the jet region
  - within UE region
- Subtract UE from jet
\[ \Lambda/K^0_s \] Multiplicity Dependence

- No multiplicity dependence to \( \Lambda/K^0_s \) ratio in jets
- No CNM observe in \( \Lambda/K^0_s \) composition of jets

**High Multiplicity**

**Low Multiplicity**

\[ p_{\text{T,jet}} > 10 \text{ GeV/c}, \text{ anti-} k_T \]

\[ |\eta_{\text{jet}}| < 0.75 \cdot R \]

\[ |\eta_{V^0}| < 0.75 \]
Ratio Compared to PYTHIA

- Ratio within the jet lower than inclusive ratio
- Ratio within the jet consistent with PYTHIA
- Increased inclusive ratio due to UE

\[ p_{T,jet}^{ch} > 10 \text{ GeV/c} \]

\[ p_{T,jet}^{ch} > 20 \text{ GeV/c} \]
Conclusions

• Data/MC for full jets and $R_{pPb}$ for charged jets consistent with no Cold Nuclear Matter (CNM) effects
  - Jet suppression in Pb-Pb is not initial state effect
• Jet fragmentation appears similar to pp
• No enhanced $\Lambda/K^0_s$ ratio in p-Pb jets
  - jet particle composition also appears unmodified in p-Pb
  - Enhanced $\Lambda/K^0_s$ ratio in p-Pb inclusive measurement due to the UE
• All p-Pb jet observables thus far:
  - p-Pb jets similar to pp/PYTHIA jets
  - No significant Cold Nuclear Matter effects found
Corrections: Background Fluctuations

- Background density fluctuations within the event
- Characterized by $\delta p_T$ distribution from Random Cones

- RHS tail due to jet overlap
- Signal exclusion varied as a systematic uncertainty ($\sim 3\%$ on final spectrum)

**Graph:**
- ALICE Preliminary
- $p$-$p$ $\sqrt{s_{NN}} = 5.02$ TeV Min Bias
- Random Cones $R = 0.4$
- $p = 0$ (Leading signal exclusion)
  - $\sigma = 1.31$ GeV/$c$
- $p = 1$ (No signal exclusion)
  - $\sigma = 1.68$ GeV/$c$
- $p = 1/N_{coll}$ (Partial signal exclusion)
  - $\sigma = 1.38$ GeV/$c$
  - (Default)
• Build a Response matrix
• GEANT3 simulation of ALICE detector
• PYTHIA events at 5.02 TeV
• Geometrically match detector level jets to particle level jets

Detector effects contribute: ~10% to systematic uncertainty
Charged particle $R_{pPb}$

- CMS, $|\eta|<1$
- ATLAS, $|\eta|<1$
- ALICE, $|\eta|<0.3$

$(Charged)$ Jet $R_{pPb}$

- CMS full jet, $-0.5 < \eta_{cm} < 0.5$
- ALICE charged jet, $-0.5 < \eta_{cm} < 0.5$
- ATLAS full jet, $-0.3 < \eta_{cm} < 0.3$

$pPb \sqrt{s_{NN}} = 5.02$ TeV, charged particles
Dijets in p-Pb

- intrinsic $k_T$ + initial & final state radiation + CNM effects
- Measure transverse component of $k_T$ vector

\[ k_T = \rho_{T,\text{ch jet}}^{\text{trigger}} \sin(\Delta \varphi_{\text{dijet}}) \]

- dijets selected: $|\Delta \varphi - \pi| < \pi/3$
- $k_T$ via dijets in p-Pb
- $k_T$ - Intrinsic $k_T$ + initial and final state radiation + cold nuclear matter (CNM) effects
- Radiation: soft (Gaussian) + hard from NLO (power law)
- CNM: scattering of parton in nucleus

\[ \Delta \varphi_{\text{dijet}} \]

\[ \text{transverse component of } k_T \text{ vector} \]

\[ |k_T| \text{ (GeV/c)} \]

\[ 0 10 20 30 40 50 60 70 \text{ (GeV/c)} \]

\[ \text{p-Pb } \sqrt{s}=5.02 \text{ TeV } 0-20\% (V0A) \]

\[ 20<p_{T,\text{ch jet}}^{\text{trigger}}<40 \text{ GeV/c} \]

\[ 1 \text{ N}_{\text{ch dijet}}^{-1} \text{ dN}_{\text{ch dijet}} \text{ d}|k_T| \]

\[ |k_T| \text{ (GeV/c)} \]

\[ 0 10 20 30 40 50 60 70 \text{ (GeV/c)} \]

\[ 10^{-3} 10^{-2} 10^{-1} \]

\[ \text{Statistical} \]

\[ \text{Systematic} \]

\[ \text{ALICE-PREL-60627} \]
**k_T Width**

- Calculated as variance of k_T distributions
- Increases with trigger jet p_T
- Compatible with PYTHIA
- No multiplicity dependence observed
- No CNM effects observed

### Graphs

#### Left Graph

- **p-Pb √s=5.02 TeV 0-20% (V0A)**
- **Anti-k_T R=0.4; |Δφ_{ch dijet} - π| < π/3**
- **20< p_{assoc}^{T, ch jet} < p_{trigger}^{T, ch jet} GeV/c**
- **ALICE p-Pb**
- **PYTHIA8 pp**

#### Right Graph

- **p-Pb √s=5.02 TeV**
- **Anti-k_T R=0.4; |Δφ_{ch dijet} - π| < π/3**
- **60< p_{trigger}^{T, ch jet} <80 GeV/c**
- **20< p_{assoc}^{T, ch jet} < p_{trigger}^{T, ch jet} GeV/c**
- **p_T^{lead track} > 5 GeV/c**
- **V0A event class (%)**
Dijet Multiplicity Dependence

- No modification observed in high multiplicity events
- $k_T$ width shows no multiplicity dependence