Abstract

Finite-acceptance effects in pair measurements are analysis, ratio function might produce different analysis mean that pairs are not counted depending!
Jets in Heavy Ion Collisions

internal probe created early in collision
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Internal probe created early in collision

Cacciari et al JHEP 0804:063, 2008
Jets in Heavy Ion Collisions

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

Cacciari et al JHEP 0804:063, 2008

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

Jet suppression observed in Pb-Pb
- Energy loss in QGP
- What are the Cold Nuclear Matter (CNM) effects from initial state?
  - If no CNM effect expect \( R_{pPb} = 1 \)
  - Constraints on nPDF

Cacciari et al JHEP 0804:063, 2008

\[
R_{AA} = \frac{dN_{jet}^{AA}}{dp_T} \frac{N_{evt}^{pp}}{\langle N_{coll} \rangle dN_{jet}^{pp}} \frac{N_{evt}^{AA}}{N_{evt}^{AA}}
\]
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
  - talk by X. Zhang

Physics Motivation

- enhanced $\Lambda/K^0_s$ ratio
  - involving several phenomena:
    - radial flow
    - coalescence/recombination
    - jet fragmentation...

This analysis:

- separation of soft and hard processes
  - double ridge structure
  - $v_2 > 0$ and PID dependent

High multiplicity p-Pb and Pb–Pb collisions - similarities

Talk: L. Milano, Tue. May 20th, 14:40, QM2014


ALICE
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

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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*
  - 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}}}
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* 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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\]

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

- $\rho_{\text{chem}}$ signal removal
- $\rho_{\text{chem}}$ occupancy median approach
- $\rho = 0$

Probability Density per bin (0.1)

Legend:
- $\rho_{\text{chem}}$ signal removal
- $\rho_{\text{chem}}$ occupancy median approach
- $\rho = 0$

ALICE Simulation

References:

3. 1207.2392.
Corrections: Unfolding

Raw Spectra (UE Subtracted)

Detector Effects ~10% syst unc

Background Fluctuations ~3% syst unc

- SVD unfolding
  - unfolding systematic: ~12%

\[ \delta p_T = \sum_{RC} p_T - \rho \pi R^2 \]
 Corrections: Unfolding

**Raw Spectra (UE Subtracted)**

ALICE Preliminary

\( \frac{1}{N_{\text{events}}} \langle dp_{T_{\text{jet}}} dp_{A_{\text{jet}}} \rangle (\text{GeV}/c)^{2} \)

- p-Pb: \( \sqrt{s_{NN}} = 5.02 \text{ TeV Min Bias} \)
- anti-\( k_T \) \( R = 0.4 \) Uncorrected
  - \( \rho_{\text{ch+em}} \), signal removal (Default)
  - \( \rho_{\text{ch+em}} \), occupancy median approach
  - \( \rho = 0 \)

**Detector Effects \( \sim 10\% \) syst unc**

- Background Energy Density
- Background Subtraction Methods
- Detector Response Matrix

**Background Fluctuations \( \sim 3\% \) syst unc**

- Detector Effects: \( \sim 10\% \)
- Tracking Efficiency: 8%
- Detector Response: 8%
- Unfolding Systematics: 12%

- Unfolding Minimum Bias: 30 GeV/c
- Unfolding Maximum Bias: 140 GeV/c

\( L_{\text{int}} = 51 \mu b^{-1} \)

ALICE Preliminary

- anti-\( k_T \) \( R = 0.4 \) |\( \eta_{\text{jet}} \)< 0.3
- p-Pb: \( \sqrt{s_{NN}} = 5.02 \text{ TeV} \)

**SVD unfolding**

\( \delta p_{T} = \sum_{RC} p_{T} - \rho \pi R^{2} \)

- unfolding systematic: \( \sim 12\% \)

**References**


**Image 1:**

- ALICE Simulation
- PYTHIA-Perugia2011

**Image 2:**

- Particle-Level \( p_{T_{\text{jet}}} \) vs Detector-Level \( p_{T_{\text{jet}}} \) (GeV/c)
- Probability Density Matrix

**Image 3:**

- Unfolding Minimum Bias
- Unfolding Maximum Bias

**Image 4:**

- Detector Response Matrix

**Image 5:**

- Detector Effects
- Tracking Efficiency
- Detector Response
- Unfolding Systematics

**Image 6:**

- SVD unfolding
- Unfolding systematic: \( \sim 12\% \)
\[ R_{pPb} = \frac{dN_{jet}^{pPb} / dp_T}{\left\langle N_{coll} \right\rangle dN_{jet}^{pp} / dp_T N_{evt}^{pp}} N_{evt}^{pPb} \]

- 5.02 TeV pp data reference not available
- Use MC references
  - LO -- PYTHIA -- 2 Tunes
  - NLO -- POWHEG -- 2 PDFs
- Large uncertainty on the MC reference
- Scale p-Pb spectrum by number of binary collisions, \( N_{coll} \)
- Data/MC consistent with no CNM effects
Comparison to Model Expectations

- Theories predict an $R_{pPb}$ ranging from $\sim 0.85$ to $1.1$
- Expected CNM effects are all within current systematic uncertainties
- Need reduced uncertainties to differentiate and quantify CNM effects
  - Need 5 TeV pp baseline
• Jet suppression observed in Pb-Pb due to hot medium
Jet Structure

No modification of the jet sub-structure observed

- p-Pb ratio consistent with pp collisions at 2.76 TeV

\[ R = 0.2 \]  
\[ R = 0.4 \]
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

charged hadrons

charged tracks

systematic uncertainty

PYTHIA 6.4 CDF A tune
PYTHIA 6.4 CDF A, no AO

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 normalized to bin at ln\(|\eta_{jet}|<0.5\)
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 shape ratio compared to 7 TeV pp

Note: Systematic uncertainties highly correlated
• Ratio agrees for all multiplicity bins
• No modifications to jet substructure observed
Conclusions

• Data/MC for full jets and $R_{pPb}$ for charged jets consistent with no Cold Nuclear Matter (CNM) effects
  – Also consistent with CNM effect expectations
  – Need to reduce uncertainty
  – 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
• All p-Pb jet observables thus far:
  – p-Pb jets similar to pp/PYTHIA jets
  – No modification to fragmentation observed
  – 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 (~3% on final spectrum)
Corrections: Detector Response

- 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 $R_{\text{pPb}}$

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

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

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

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

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

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

**Graph:**
- p-Pb $\sqrt{s}=5.02$ TeV 0-20% (V0A)
- $20 < p_{\text{trigger} \, \text{ch jet}} < 40$ GeV/c
- $|\Delta \varphi - \pi| < \pi/3$

**Data Points:**
- Statistical
- Systematic

**Legend:**
- Associated jet
- Trigger jet
- $k_T$
- $\Delta \varphi_{\text{dijet}}$
\( k_T \) 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

\[ \sigma(k_T) \text{ (GeV/c)} = \text{Calculated as variance of } k_T \text{ distributions} \]

\[ \text{Increases with trigger jet } p_T \]

\[ \text{Compatible with PYTHIA} \]

\[ \text{No multiplicity dependence observed} \]

\[ \text{No CNM effects observed} \]
Dijet Multiplicity Dependence

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

"\(\Lambda/K^0_s\) ratio involving several phenomena:
- radial flow
- coalescence/recombination
- jet fragmentation…"

This analysis:
- $\Lambda/K^0_s$ ratio in jets in p–Pb
- separation of soft and hard processes
- double ridge structure
- $v_2 > 0$ and PID dependent

High multiplicity p–Pb and Pb–Pb collisions - similarities

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**References**

Measuring $\Lambda/K^0_s$ in Jets

- Tag the hard scattering with charged jet
- Reconstruct $\Lambda$ and $K^0_s$ — within the jet region — within UE region
- Subtract UE from jet

Detector acceptance

Jet region

Underlying Event:
- $R(V^0, \text{jet}) > 0.6$
- Non jet events

Jet acceptance

primary charged particles

Jet cone

Jet axis

$V^0$
• No multiplicity dependence to $\Lambda/K^0_S$ ratio in jets
• No CNM observe in $\Lambda/K^0_S$ composition of jets
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

\[ p_{T,jet}^{ch} > 10 \text{ GeV}/c \] \[ p_{T,jet}^{ch} > 20 \text{ GeV}/c \]