PHENIX results on reconstructed jets in $p+p$ and heavy ion collisions

Arbin Timilsina (Iowa State University)
for the PHENIX Collaboration

September 29, 2015
Jets at RHIC

- Can measure jet modification at lower energies - allows exploration of $\sqrt{s_{NN}}$ dependence of energy loss
- Versatility of RHIC provides ability to study jet modification in different collision geometries, system sizes, and energy densities

Moving beyond single particles:
Jet measurements in heavy ion collisions -> quantify the energy loss of hard-scattered partons

Phys. Rev. Lett. 101, 232301
The PHENIX Detector

PHENIX central arms: $|\eta| < 0.35, \Delta\phi = \pi$

- Charged particle tracks are reconstructed using the Drift Chamber (DC), the Pad Chamber (PC), and the collision point.

- Neutral clusters are measured in the Electromagnetic Calorimeter (EMCal). EMCal (PbSc & PbGl) measures $\pi^0$, $\gamma$, and some hadrons (with lower efficiency).
Jets in PHENIX

• 2012 $\sqrt{s_{NN}} = 200$ GeV $p+p$ and Cu+Au

• Jets reconstructed using the anti-$k_t$ algorithm with $R = 0.2$
  • track $p_T > 500$ MeV/c
  • clusters energy $> 500$ MeV

• Jet-level cuts
  • number of constituents $\geq 3$
  • $0.2 < \text{charged fraction} < 0.7$
  • jet axis from edge: $|\eta| > 0.05$, $\Delta \phi > 0.12$

Note: No single hard particle requirement in a jet

• Centrality-dependent response matrices generated by embedding PYTHIA $p+p$ jets into real Cu+Au events
Jets in PHENIX: Jet Energy Scale

- For each $p_{T,\text{True}}$ bin, $p_{T,\text{Reco}}/p_{T,\text{True}}$ distribution is examined

- Due to missing neutral hadronic energy and tracking inefficiency, on average, PHENIX gets $\approx 70\%$ of the true jet energy

- For 0-20%, the UE increases the $p_{T,\text{Reco}}$ up to 3.2% (1.7%) at 15 GeV/c (26 GeV/c) relative to that in $p+p$ events
The width of $p_{T,\text{Reco}}/p_{T,\text{True}}$ distribution is $\approx 16$-$24\%$

In PHENIX, the resolution is not driven by EMCal & DC resolution but by jet-by-jet fluctuations

For 0-20%, the UE increases the $p_{T,\text{Reco}}$ resolution up to 2.7% (1.3%) at 15 GeV/c (26 GeV/c) relative to that in $p+p$ events
Jets in PHENIX

Similar jet reconstruction method proven to work in $p+p$ and $d+Au$!!!

arXiv:1509.04657 [nucl-ex]

For $d+Au$ jet results, please see
- talk by Ali Hanks (Sept. 29 at 11:50)
- poster #0421 by D. Perepelitsa
Jets in PHENIX

Similar jet reconstruction method proven to work in \( p+p \) and \( d+Au \)!!!

arXiv:1509.04657 [nucl-ex]

For \( d+Au \) jet results, please see
• talk by Ali Hanks (Sept. 29 at 11:50)
• poster #0421 by D. Perepelitsa

Cu+Au comes with challenges
• Stronger underlying event contribution
  -> choice of smaller cone size
• Fake jet contribution
  -> fake jet subtraction
Data driven method of estimating and statistically subtracting fake jet contribution

- For events in which jet is not reconstructed, position (\(\eta, \phi\)) of tracks and position (\(\eta, \phi\)) of clusters are randomly shuffled
- Jet reconstruction performed in these shuffled tracks and clusters
  -> returns estimated fake jet
Fake jet

Data driven method of estimating and statistically subtracting fake jet contribution

- For events in which jet is not reconstructed, position ($\eta, \phi$) of tracks and position ($\eta, \phi$) of clusters are randomly shuffled
- Jet reconstruction performed in these shuffled tracks and clusters
  -> returns estimated fake jet
- Estimated fake jet yield is statistically subtracted from the raw jet yield
  -> returns estimated signal jet
• Fake jet contribution is both $p_T$ and centrality dependent; the contribution being largest for central collisions and at low $p_T$
  • for 0-20%, purity is 70% (93%) at 15 GeV/c (23 GeV/c)
**Fake jet HIJING simulation study**

- **Matched jet**: Reco jet which is within $\Delta R < 0.2$ of true jet
- **Fake jet**: Reco jet which is not matched

*Fake jet estimation procedure gives comparable result!*

Fake jet contribution analyzed alternately by re-running the analysis with cluster and track selections of $> 2$ GeV
Jet yields

- Spectra unfolded using SVD method (cross-checked using iterative Bayesian method)
  - detector effects
  - centrality dependent underlying event fluctuations
Jet suppression: $R_{AA}$ vs. $p_T$

At high $p_T$, consistent with 1 within the uncertainties
Jet suppression: $R_{AA}$ vs. $p_T$

- Suppression shows centrality dependence
Jet suppression: $R_{AA}$ vs. $p_T$

- Suppression shows centrality dependence
- No $p_T$ dependence
Jet suppression: $R_{AA}$ vs. $p_T$

- For central collisions, jets are suppressed by approximately a factor of two
Jet suppression: $R_{CP}$ vs. $p_T$

$R_{CP}$ probes relative central vs. peripheral (60-90%) jet production

Relatively reduced systematics
Jet suppression: \( R_{AA} \) vs. \( N_{\text{part}} \)

\( R_{AA} \) shows strong centrality dependence and no \( p_T \) dependence
Jet suppression: comparison

- ATLAS result is $R=0.2 \ R_{CP}$ for $38 < p_T < 44$ GeV
- Both results asymptote towards the same value
Jet suppression: theory teaser

• Calculation done for R=0.2 but for Au+Au and different centrality classes
• Is suppression stronger than expected within this model?
Conclusion

• The ratios of jet spectra from different centrality selections of Cu+Au collisions show a strong modification of jet production at all $p_T$
  • Jets are found to be suppressed by approximately a factor of two in central Cu+Au collisions as compared to $p+p$ collisions
  • Suppression shows no $p_T$ dependence

• Work progressing towards finalizing the results and heading towards publication
Backup
Evaluation of systematic uncertainty

- Variation is made in unfolding procedure. The default data is unfolded with modification in unfolding procedure.
  - Shape of input spectrum: The input spectrum is obtained by modifying the power of the truth spectrum by $\pm 0.5$.
  - Unfolding is performed with Bayes method (default is SVD method).

- Variation is made in simulation. The default data is unfolded with modified response matrix.
  - Energy scale
    - EMCal energy scale: The energy of EMCal clusters is varied by $\pm 3\%$
    - DC $p_T$ scale: The $p_T$ of tracks is varied by $p_T$ dependent way: 2% for $p_T < 10$ GeV/c and increased linearly such that it is 4% at 30 GeV/c.

- Same variation is made in both data and simulation. The modified data is unfolded with modified response matrix.
  - Jet-level cuts:
    - Default: $nc \geq 3$ && $cf > 0.2$ && $cf < 0.7$. Variation: $nc \geq 5$ && $cf > 0.2$ && $cf < 0.6$
  - Acceptance
    - Fiducial cut: The reconstructed jets are required to lie within tighter phase space.
    - East/West arm: East arm yield is unfolded with response matrix for east arm and west arm yield is unfolded with response matrix for west arm.
  - Fake jet
    - Default: Cluster energy $> 0.5$ GeV, track $p_T > 0.5$ GeV/c. Variation: Cluster energy $> 2.0$ GeV, track $p_T > 2.0$ GeV/c.
Fake jet simulation

- **Matched jet**: Reco jet which is within $\Delta R < 0.2$ of true jet
- **Fake jet**: Reco jet which is not matched
Jets in PHENIX: Jet Energy Scale

- For each $p_{T,\text{True}}$ bin, $p_{T,\text{Reco}}/p_{T,\text{True}}$ distribution is examined

- Due to missing neutral hadronic energy and tracking inefficiency, on average, PHENIX gets $\approx70\%$ of the true jet energy

- For 0-20%, the UE increases the $p_{T,\text{Reco}}$ up to 3.2% (1.7%) at 15 GeV/c (26 GeV/c) relative to that in $p+p$ events
Jets in PHENIX: Jet Energy Resolution

- The width of $p_{T,\text{Reco}}/p_{T,\text{True}}$ distribution is $\approx 16\text{-}24\%$

- In PHENIX, the resolution is not driven by EMCal & DC resolution but by jet-by-jet fluctuations

- For 0-20%, the UE increases the $p_{T,\text{Reco}}$ resolution up to 2.7% (1.3%) at 15 GeV/c (26 GeV/c) relative to that in $p+p$ events
Central d+Au shows suppression consistent with modest CNM E-loss, but enhancement in peripheral d+Au challenging to understand within these models.