Reconstructed Jet Measurements in p+p, d+Au and Cu+Au collisions using PHENIX

Milap Patel
Nuclear Modification at PHENIX

- Nuclear modification provides insight into the behavior the QGP medium
  - RHIC can measure in different collision geometries, system sizes, and energy densities
- Have measurements for single particles
  - Jet measurements -> quantify the energy loss of hard-scattered partons

\[ R_{AB} = \frac{\left( \frac{1}{N_{\text{evt}}} \frac{dN}{dp_T} \right)_{\text{AB}}}{T_{\text{AB}} \frac{d\sigma}{dp_T}} \]
Jets at PHENIX

- A Jet is a QCD observable which is a collimated cone of hadrons produced by hadronization of a quark or gluon
  - Jet reconstruction is a procedure to combine the fragments of original parton, i.e. undoing the fragmentation process
- The anti-$k_T$ algorithm is used, which iteratively clusters jets by:
  \[
  d_{ij} = \min \left( \frac{1}{k_{T,i}^2}, \frac{1}{k_{T,j}^2} \right) \frac{\Delta \phi_{ij}^2 + \Delta \eta_{ij}^2}{R^2}
  \]
  Where $d_{ij}$ is the anti-$k_T$ distance between pair of particles $i$ and $j$. $R$ is the chosen radius parameter chosen.
  \[
  R = \sqrt{(\Delta \eta)^2 + (\Delta \phi)^2}
  \]
- By placing $k_T$ in the denominator, it ensures that soft particles will cluster with the hard particles
PHENIX Detector

- Located at Brookhaven National Lab on the RHIC ring
- Two central arms (East and West) and Muon arms (north and south)
- Pseudorapidity range of $|\eta| < 0.35$ and azimuthal ($\phi$) $90^\circ$
- Magnets in central arm and muon arms
- Central arm detectors:
  - DC and PC to track charged particles
  - EMCal to measure energy from electromagnetic showers
Measuring Jets in PHENIX d+Au $\sqrt{s} = 200$ GeV

- Jet production sensitive to cold nuclear matter effects
- Jets reconstructed using anti-$k_T$ $R = 0.3$
  - Track $p_T > 0.4$ GeV
  - Cluster $E > 0.4$ GeV
  - Jet particle multiplicity $\geq 3$
  - Jet axis to edge: $\Delta\eta > 0.05$, $\Delta\phi > \pi/64$
  - Charged fraction $< 0.75$
    - $CF = \frac{\sum \vec{p}_T}{\text{Charged Particles}}$
    - Eliminate fake high $p_T$ tracks from conversions
Measuring Jets in PHENIX d+Au $\sqrt{s} = 200$ GeV

- Detector effects corrected for using SVD unfolding procedure
- PYTHIA embedded in d+Au data to correct for underlying event
- Many systematics are common to p+p and d+Au and will cancel in $R_{dA}$ and $R_{CP}$
Jet Modification in d+Au

Data points consistent with nPDF calculations

Favors CNM E-loss calculations with small momentum transfer

\[ 0.175 < \xi < 0.7 \text{ GeV} \]

\[ \xi = p_T \text{ transfer per scattering} \]

Phys. Rev. Lett. 116, 122301


+Phys. Rev. C 92, 054911
Centrality Dependent Jet Modification in d+Au

- Central d+Au (0-20%) shows suppression
- Consistent with modest CNM E-loss
- Peripheral events consistent with unity with large overall normalization uncertainty

Phys. Rev. Lett. 116, 122301
Relation to Other Systems

- See similar trend at LHC pPb
  - $x_T = 2p_T / \sqrt{s}$
Jets in PHENIX Cu+Au $\sqrt{s} = 200$ GeV

- Challenges with Cu+Au
  - Stronger underlying event contribution
    - Choice of smaller cone size
  - Fake jet contribution
    - Fake jet subtraction
- Jets reconstructed with anti-$k_T$ using $R = 0.2$
  - Track $p_T > 0.5$ GeV
  - Cluster $E > 0.5$ GeV
  - Jet particle multiplicity $\geq 3$
  - Jet axis to edge: $\Delta\eta > 0.05$, $\Delta\varphi > 0.12$
  - $0.2 < \text{Charged fraction} < 0.7$
- Centrality-dependent response matrices generated by embedding PYTHIA p+p jets into real Cu+Au events

$$CF = \frac{\sum_{\text{Charged Particles}} \vec{p}_T}{\text{jet}_{p_T}}$$
Jet Radius Study

- $R = 0.3$ has more severe contribution from the underlying event than $R = 0.2$
- For each $p_{T,\text{True}}$ bin, the $p_{T,\text{Reco}}/p_{T,\text{True}}$ distribution is examined
- PHENIX gets ~70% of the true jet energy
  - Missing neutral hadronic energy and tracking inefficiency
- For 0-20%, the UE increases the $p_{T,\text{Reco}}$ up to 3.2% (1.7%) at 15 GeV (26 GeV) relative to p+p events
The width of $p_{T,\text{Reco}}/p_{T,\text{True}}$ distribution is $\approx 16-24\%$

For 0-20%, the UE increases the $p_{T,\text{Reco}}$ resolution up to 2.7% (1.3%) at 15 GeV (26 GeV) relative to p+p events
Data driven method of estimating and statistically subtracting fake jet contribution

- For events with no jet reconstructed, the position \((\eta, \phi)\) of tracks and position \((\eta, \phi)\) of clusters are randomly shuffled, respectively
- Jets reconstructed with these shuffled tracks and clusters are the estimated fake jet
- The estimated signal jet are the raw jet yield after subtracting the fake jets
Jets in PHENIX Cu+Au: Fake Jets

- Fake jet contribution is both $p_T$ and centrality dependent
- Largest for central collisions at low $p_T$
  - For 0-20%, purity is 70% (93%) at 15 GeV (23 GeV)
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 procedures gives comparable result!

\[
Purity = \frac{\text{Signal Jets}}{\text{Raw Jets}}
\]
Jet Yields

- Spectra unfolded using SVD method
  - Accounts for detector effects
  - Centrality dependent underlying event fluctuations
Jet Suppression

- Suppression shows centrality dependence
- No $p_T$ dependence
- Preference for smaller values of $g$ in SCET
  - Strength of interaction between parton and medium

\[
R_{AB}^{cent} = \frac{1}{N_{Evtx}^{Cent}} \frac{dN_{x}^{cent}}{dp_T} \frac{CuAu}{T_{AB}^{cent}} \frac{d\sigma}{dp_T}
\]
Jet Suppression

- 0-20% jet and $\pi^0$ show similar suppression

$$R_{AB}^{cent} = \left( \frac{1}{N_{Evtt}} \frac{dN_{\text{cent}}}{dp_T} \right)_{CuAu} \frac{T_{AB}^{cent} d\sigma}{dp_T}$$

Cu+Au, $\sqrt{s_{NN}} = 200$ GeV, anti-$k_T$, $R = 0.2$
Conclusion

- Centrality dependent jet modification in both d+Au and Cu+Au
  - d+Au $R_{CP}$ vs $p_T$ shows a decreasing trend
    - Consistent with LHC p+Pb
    - Cu+Au consistent with $\pi^0$
- PHENIX two-particle correlation:
  - Talk by Cheuk-Ping Wong (Initial State, 1 Jun 2020, 13:55, ID 298)
  - Poster by Anthony Hodges (ID 276)
  - Poster by Megan Conners (ID 297)
- Future jet studies at PHENIX:
  - Substructure – jet substructure studies in pAu, CuAu
    - Momentum fraction($z_g$), Fragmentation ($z$), charge ($j_T$), distance ($dN/dR$)
    - Spin – jet Longitudinal Double Spin Asymmetry ($A_{LL}$) in polarized pp $\sqrt{s} = 510$ GeV