Pi0-hadron Correlations in Small and Large Systems with PHENIX

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Jet modification in QGP

- High momentum partons lose energy when they transverse the QGP medium -> jet is modified:
  - broadening
  - energy loss
Two particle correlations

• Two particles correlations from same jet: near side ($\Delta\phi \sim 0$)
• Two particles correlations from each dijet: away side ($\Delta\phi \sim \pi$)
PHENIX detector

- Two central arms: cover $\phi \sim \pi$ and $|\eta| < 0.35$
- Electromagnetic calorimeter (EMCal): measure photon, $\pi_0 \rightarrow \gamma + \gamma$
- Drift Chamber (DC) and Pad Chamber (PC): charge particle tracking
- Beam-Bream counters (BBC) and Zero-Degree Calorimeters (ZDC) measures collision centrality
Hard scattering kinematics

\[ \hat{p}_T^{\text{trig}} \]

\[ |k_T^1 + k_T^2| \]

\[ \hat{p}_T^{\text{assoc}} \]

\[ \Delta \phi \]

\[ p_{\text{out}} = |p_T^{\text{assoc}}| \sin \Delta \phi \]

\[ x_E = -\frac{p_T^{\text{trig}} \cdot p_T^{\text{assoc}}}{|p_T^{\text{trig}}|^2} = -\frac{|p_T^{\text{assoc}}|}{|p_T^{\text{trig}}|} \cos \Delta \phi. \]

- Longitudinal momentum fraction of the associated hadron with respect to the trigger hadron (proxy for the momentum fraction \( z \))
- Momentum component of the associated hadron perpendicular to the trigger hadron
• $P_{out}$ allows to separate non-perturbative (Gaussian) and perturbative process (not Gaussian tail)
• Tails deviate from Gaussian:hard radiation
• Gaussian width increases with $P_T$ trigger
P_{out} for away side jet as a function of $X_E$

- Gaussian width increases with $X_E$
• No significant center of mass energy dependance

• Gaussian width increases with $P_T$ trigger and $X_E$

p+A
• Near side: $|\Delta \phi| < \pi/2$
• Away side: $2\pi/3 < \Delta \phi < 4\pi/3$
• Tails deviate from Gaussian: hard radiation
• Intra jet correlation, pi0 and hadron fragment from the same hard parton -> narrower than the away side
Broadening in $p+\text{A}$

Near side shows no $P_{\text{out}}$ broadening -> intrajet radiation effects are small

Away side shows $P_{\text{out}}$ broadening only in $p+\text{Au}$
• Pout broadening shows Ncoll dependance -> suggests a path length dependance
• Possible effects that may contribute:
  ◆ v2 and v3 systematically ruled out as contributor (1%)
  ◆ multiple scattering of partons inside a nuclear medium (“Croning effect region”)
  ◆ Additional K_T (initial transverse momentum) for parton in the nucleus respect to p+p
  ◆ Path length dependance -> hard scattered partonic energy loss

Broadening in p+A (away side)
Correlation in Au+Au

\[ \frac{1}{N} \frac{dN_{\pi^0}}{d\Delta \phi} \]

**5.0-7.0 \times 1.0-2.0 GeV/c**

- Au+Au (2010 & 2011)
- 200 GeV 20-40%
- \( \pi^0 \)-hadron
- \( v_2, v_3, v_4 \) subtracted
- \( \pm 8.8\% \) Scale Uncertainty

New results with better handle on \( v_2, v_3, v_4 \) background wrt our earlier PRL 104 252301 (2010)

• Flow background due to initial condition of collision

\[
BG \text{ flow} = b_0 \left[ 1 + 2 \sum v_n^{\pi^0} v_n^H \cos(n \cdot \Delta \phi) \right]
\]
Correlation in Au+Au

- Au+Au away side broadening in low associate $p_T$ region
- Au+Au results converge to p+p results in high trigger $p_T$ bins
- No significant centrality dependence within uncertainty
Summary

**p+p**
- Multi-Differential analysis with hard scales that are sensitive to small transverse momentum
- Non-perturbative momentum width increases with the hard scale
  -> suggest QCD factorization breaking effects due to QCD’s non-Abelian nature (have been seen also in DY processes)

**p+A**
- Away-side Pout broadening in p+Au with respect to p+p (not in p+Al!)
- Away-side Pout broadening increases with Ncoll
  -> Potentially provide information about cold nuclear matter effect: energy loss, PDFs, multiple scattering, additional KT, etc.

**Au+Au**
- Away side angular broadening in low associate pT
- The differences with respect to p+p tends to disappear when the trigger pT increases