Photon-jet Ridge @p+A

Amir Rezaeian
UTFSM, Valparaiso

3rd International Conference on the Initial Stages in High-Energy Nuclear Collisions
Lisbon, May 25, 2016
Motivation:
See talk by Alex Kovner

- Does the ridge phenomenon in p+p(A) collisions mainly come from initial-state or final-state effects?
- Is the "ridge" universal phenomenon, for all different two-particle productions in p+p(A) collisions? di-photon, photon-jet, etc.


**Di-photon Ridge:** Kovner, Rezaeian, PRD92, arXiv:1508.02412.
**Back-of-the-envelope measurements: Initial-state v. final-state!**

Increase v. flatness of $<p_T>(N_{ch})$

$$<p_T>(N_{ch}) : K_T - Factorization, \text{ and } Q_{s,\text{min}}^2 \to Q_{s,\text{min}}^2 \times N_{ch}/\langle N_{ch} \rangle$$

Different system sizes:

$$S_{eff}(N_{cri}) = Const.$$

Two competing effects: saturation scale and effective interactions area.

A event with the same multiplicity in pp, pA and AA does not necessarily correspond to the same system.
Geometric scaling in p+Pb@LHC

CMS, p+p 7 TeV
CMS, p+Pb 5.02 TeV

\[ N_{\text{tracks}}^{p+p} \propto S_p Q_{s,\min}^2(x) \quad \text{and} \quad N_{\text{tracks}}^{p+Pb} \propto S_A Q_{s,\min}^2(x) \]

\[ N_{\text{tracks}}^{p+p} \approx K \frac{S_p}{S_A} N_{\text{tracks}}^{p+Pb} \]


Can final-state type approaches like hydrodynamic explain this scaling phenomenon?
Photons can be produced at different stages of collisions (prompt, thermal, decay). Here I only discuss prompt photon coming from hard collisions in small-x region.

In AA collisions all hadrons are strongly quenched except prompt photon → prompt photon can be a good probe of initial-state effects.
Two-particle production

- Soft gluons are scattered out of the projectile wave function by directly scattering on a saturated target.
  **Photons do not scatter themselves, but rather decohere from the scattered quarks.**
- Virtual photons do not directly interact with the gluons inside target.
- Final-state effects are absent in the photon production, no initial-final state interference, and no hadronization.
Two-particle production in $p + A$ collisions from the CGC

**Dihadron**

Weizsacker–Williams (WW) gluon distribution (quadrupole) counts the number of gluons \textbf{(never measured)}

**Photon–hadron**

Color dipole gluon distribution (dipole) appears in $F_2, F_L$ structure functions \textbf{(measured)}

**Diphoton**

Dihadron v. photon–hadron v. diphoton production in the CGC

- In contrast to dihadron production, photon–hadron and diphoton cross section depend only on the dipole amplitude \textbf{(not WW gluon distribution)}. 
Prompt Photon+Jet production in p+A collisions at LO:

\[ \sigma = \alpha_{em} F(x_q, \mu^2) \otimes \mathcal{H}^\gamma \otimes N_F(x_g, p_T) \]


Prompt Diphoton+Jet production in p+A collisions at LO:

\[ \sigma = \alpha_{em}^2 F(x_q, \mu^2) \otimes \mathcal{H}^{\gamma\gamma} \otimes N_F(x_g, p_T) \]

Prompt Photon+Jet production in p+A collisions at LO from the CGC:

**Theory:**

**Phenomenology:**
**Condition 1:** If \( p_T^{\text{total}} = |q_T + k_T| \approx 0 \), then \( \sigma^{p+A\rightarrow\gamma(k)+\text{jet}(q)+X} \approx 0 \).

This condition can be satisfied for away-side correlations: \( \Delta \phi = \pi \) for \( q_T \sim k_T \).

**Condition 2:** If \( p_T^{\text{total}} = |q_T + k_T| \approx Q_s \), then \( \sigma^{p+A\rightarrow\gamma(k)+\text{jet}(q)+X} \rightarrow \text{Maximum} \).

This condition can be satisfied for near-side correlations: \( \Delta \phi = 0 \) for \( q_T \sim k_T \sim Q_s/2 \).
Increasing $Q_s$

\[ r_2(p_T^{\text{trig}}, \eta^\gamma, p_T^{\text{asc}}, \eta^{\text{jet}}, \Delta \phi) = \frac{2\pi Q^2}{dN_{p+A\rightarrow \gamma(k)+\text{jet}(q)+X} d^2k_T d\eta^\gamma d^2q_T d\eta^{\text{jet}}}{dN_{p+A\rightarrow \gamma(k)+X} d^2k_T d\eta^\gamma} \mid_{k_T=p_T^{\text{trig}}, q_T=p_T^{\text{asc}}} \]
Correlations via Coincidence probability

Coincidence probability (Photon triggered): \[ CP(\Delta \phi) = \frac{N_{\text{photon-jet}}(\Delta \phi)}{N_{\text{photon}}} \]

\[ CP(p_{T}^{\text{trig(photon)}}, \eta^{\gamma}, p_{T}^{\text{asc(jet)}}, \eta^{\text{jet}}, \Delta \phi) = \frac{2\pi \int_{p_{T}^{\text{trig}}} k_{T} k_{T} \int_{\eta^{\gamma}} d\eta^{\gamma} \frac{d\sigma_{p+A \rightarrow \gamma(k)+\text{jet}(q)+X}}{d^{2}b_{T} d^{2}k_{T} d\eta^{\gamma} d^{2}q_{T} d\eta^{\text{jet}}}}{\int_{p_{T}^{\text{trig}}} d^{2}k_{T} \frac{d\sigma_{p+A \rightarrow \gamma(k)+X}}{d^{2}b_{T} d^{2}k_{T} d\eta^{\gamma}}} - C_{ZYAM} \]

\[ CP[\gamma (\text{trigger}) + \text{Jet (associated)}] > CP[ \gamma (\text{associated}) + \text{Jet (trigger)}] \]

ZYAM subtraction: is not the same way as defined by ATLAS Coll. But this will not change the over-all physics here.

See talk by Brian Cole
For $P_T^\text{Total} < Q_s$ or $P_T^\text{Total} > Q_s$, away from the condition 2, the near-side correlations diminishes.
Density (multiplicity) dependence of the Ridge

At events with $N_{\text{part}}^{\text{Pb}}>10$, near-side photon-jet correlations are maximum and does not change with multiplicity further.

At the same events, the di-hadron Ridge shows up (Dusling, Venugopalan, 2013).

\[ Q_0^2(\text{lead}) = N_{\text{part}}^{Pb} Q_0^2(\text{proton}) \]

# of “wounded” nucleons in lead nucleus

$N_{\text{part}}^{Pb} \approx 5$ : minimum bias collisions
The near-side and away-side photon-jet correlations practically do not change within $\Delta \eta^{\gamma-jet} \approx 2-4$ in high-multiplicity events.

Although, $x_g$ changes from $10^{-3}$ to $10^{-6}$, there is little energy dependence for the photon-jet ridge at high multiplicity events.
 Photon-jet v. two-hadron correlations

◆ The cross-section of photon-jet production and the correlations are **NOT** symmetric with respect to the replacement of:

\[ \eta^\gamma \leftrightarrow \eta^{jet}, \quad q_T \leftrightarrow k_T \]

\[ K_T \]

\[ q_T \]
Photon-hadron correlations

For $\eta^\gamma - \eta^h \ll 0 : \langle p_{T}^{total} = |k_T + q_T^h/z_h| \rangle \rightarrow \text{Min},$ because $\langle z_h \rangle \rightarrow \text{Max}$

For $\eta^\gamma - \eta^h \gg 0 : \langle p_{T}^{total} = |k_T + q_T^h/z_h| \rangle \rightarrow \text{const},$ because $\langle z_h \rangle \rightarrow \text{const}$
Photon-hadron near-side correlations

For photon-hadron production a ridge-like structure only exist for:

$$\eta^h > \eta^\gamma$$
Conclusion

- A ridge-type structure exists for pairs of prompt photon and jet production in high-multiplicity p+A collisions at both RHIC and the LHC.

The photon-jet collimation at near-side strongly depends on saturation dynamics and is maximum at:

- $P_T^{total} \sim Q_s \rightarrow p_T^{jet,\gamma} \approx 1 - 3$ GeV
- $N_{part}^{Pb} > 5$
- $\eta^{\gamma-jet} \approx 2 - 5$

These ridge-like features are strikingly similar to the observed ridge effect for di-hadron correlations at RHIC and the LHC.

In the Glasma approach of Dusling-Venugopalan: both projectile and target are in the saturation regime. Here only target is in the saturation regime!.

- Hadronization of jet has non-trivial effects on the photon-jet correlations.
- Photon-hadron correlations: the near-side collimation exists for $\eta^{\gamma} < \eta^{h}$. 