Studies of medium induced modification of jets using photon-tagged jets with the CMS detector

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After heavy ions collide, Quark Gluon Plasma (QGP) is formed.

Jet quenching: hard scattered partons lose energy by interaction with QGP.

Photons do not interact strongly with QGP: can tag initial $p_T$ of the recoil partons.
Photon selections:
- Selected online by L1+HLT triggers.
- $25 < E_T^\gamma < 200 \text{ GeV}$ and $|\eta| < 1.44$
- Reject if too close (difference in $\eta$ or $\phi < 0.03$) to $e^\pm$ candidate track with $p_T^e > 10 \text{ GeV}/c$.

Isolation selections:
- $E_{\text{HCal}}/E_{\text{ECal}} < 0.1$.
- Shower shape $\sigma_{\eta\eta} < 0.01$.
- Isolation variable $I = \sum_{\Delta R \leq 0.4} E < 1 \text{ GeV}$.

Efficiency corrections:
photon reconstruction, selection, trigger.

$$N_{\text{corrected}}^\gamma = \frac{N_{\text{raw}}^\gamma P}{\epsilon}. $$

Results unfolded to correct for detector resolution.
Analysis Procedure (cont.) and Photon $R_{AA}$ Results

Purity subtraction:
- Dominant background: neutral meson decays, mostly with larger width $\sigma_{\eta\eta} = \sqrt{\left(\sum_{i=5}^{5\times5} w_i (\eta_i - \eta_{5\times5})^2\right) / \left(\sum_{i=5}^{5\times5} w_i\right)}$, $w_i = \max(0, 4.7 + \ln \frac{E_i}{E_{5\times5}})$
- Use template fit method to estimate purity and subtract decay photon bkg.

Photon $R_{AA}$ Results:
- $R_{AA} = \frac{1}{\langle T_{AA} \rangle} \frac{1}{N_{MB}} \frac{d^2 N_{\gamma PbPb} / dE_T^\gamma d\eta}{d^2 \sigma_{pp}^\gamma / dE_T^\gamma d\eta}$
- Photon production in PbPb collisions and in $pp$ collisions are consistent: do not interact significantly with QGP.
- Isolated photons can be used to tag initial transverse momentum of the associated parton.

![Purity Template Fit](image)

![Isolated Photon $R_{AA}$](image)

JHEP 07 (2020) 116
Analysis Procedure for Photon-Jet Analyses

Observables:

- Momentum balance: \( x_{\text{jet}, \gamma} = \frac{p_T^{\text{jet}}}{p_T^\gamma} \).
- Fragmentation function: \( \xi_{\text{jet}} = \ln \frac{|\vec{p}^{\text{jet}}|^2}{\vec{p}^{\text{trk}} \cdot \vec{p}^{\text{jet}}} \).
- Jet shape: \( \rho(r) = \frac{1}{\delta r} \frac{\sum_{\text{jets}} \sum_{r_a < r < r_b} p_T^{\text{trk}} / p_T^{\text{jet}}}{\sum_{\text{jets}} \sum_{0 < r < r_f} p_T^{\text{trk}} / p_T^{\text{jet}}} \).

Analysis procedure:

- \( p_T^\gamma > 40 \text{ GeV} \) and \( |\eta| < 1.44 \).
- Momentum Imbalance: Select \( p_T^{\text{jet}} > 30 \text{ GeV} \) and \( \Delta \phi_{j\gamma} > 7\pi/8 \).
- Cluster anti-\( k_T \) \( R = 0.3 \) jets.
- Subtract underlying events for PbPb collisions.
- Photon isolation variable \( I = \sum_{\Delta R \leq 0.4} E < 1 \text{ GeV} \).
- Reject the photon candidate if too close to \( e^\pm \) candidate track with \( p_T^{e} > 10 \text{ GeV}/c \).
- Purity subtraction to remove decay photons.
- Subtract combinatorial jet background with mixed event background subtraction using MB events.

Results

- Mean and yield for $x_{j\gamma}$ shift to lower values in PbPb: overall jet energy loss.
- Central PbPb events show:
  - Depletion of high $p_T$ particles: evidence of jet quenching.
  - Excess of low $p_T$ particles: Medium response? Higher $p_T$ particles losing energy?
- Small relative modification of jet core and enhancement of particles away from jet axis: evidence of broadening.
- Theoretical models agree with data well.
- Future plan: other photon-jet observables such as $\Delta\phi_{j\gamma}$ and jet-axis decorrelation $\delta_{jj}$.
- See slides by Molly Taylor on April 6th for more details.

Summary

- Isolated photon production in PbPb events is not modified by the QGP.
- Isolated photons can serve as reliable tags for the hard scattering.
- Photon-jet results show hints of where energy loss is occurring.
- Azimuthal correlation does not yet show broadening at large $\Delta f$ which could indicate medium modification.
- Momentum imbalance shows overall jet energy loss.
- Fragmentation function shows enhancement of low $t$ constituents possibly from depletion of high $t$ constituents + medium.
- Jet shape shows evidence of broadening, with relative enhancement of particles away from the jet axis.
- Looking further at $Z/\gamma$-hadron correlations to learn about medium response.
- Working on new photon-jet observable – the jet axis decorrelation $\delta_{jj}$.
- A measure of the angular difference between the Winner-Take-All (WTA) and Energy-Scheme (ES) jet axes.
- Insensitive to initial state radiation which smears the photon-jet azimuthal correlation.
- Sensitive to in-medium momentum broadening of jet.
- Excited to follow up with Run 3 data!