PHOTON–TAGGED JET SUBSTRUCTURE IN PP AND PBPB COLLISIONS AT 5.02 TEV WITH CMS

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Opportunities and Challenges with Jets at LHC and beyond
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ENERGY LOSS IN DIJET EVENTS

- Jet quenching is a characteristic feature of the QGP
  - Observed through measurements of jet energy loss in dijet systems
- Caveat: both jets are modified when passing through the medium
ENERGY LOSS IN PHOTON-JET EVENTS

- Photons, being colourless, do not interact with the medium
  - Clean tag of the initial energy
  - Better handle on the quark/gluon jet ratio
- Measurements with photon-jet and Z-jet events show clear evidence for in-medium energy loss
PHOTON-TAGGED JET SUBSTRUCTURE

- Where does the quenched jet energy go?
  - Jet substructure measurements can help answer this
ENERGY LOSS MECHANISMS

- Various models exist with different approaches to modelling the energy loss

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**Perturbative QCD**
Weak coupling limit

- Collisonal energy loss
- Radiative energy loss

**Holographic calculation**
Strong coupling limit

- AdS/CFT “drag force”

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JEWEL  LBT  SCET$_G$  Hybrid
ANALYSIS TECHNIQUE

- Reconstruct photons, tracks, jets
- Correlate selected photons with all jets (back-to-back with the photon) within the event (inclusive jet measurement)
- Subtract backgrounds
  - Underlying event
  - Neutral meson decays
- Smear jet resolutions/Correct for resolution effects
  - Necessary for proper comparison
BACKGROUND SUBTRACTION (EVENT MIXING)

- Tracks from the underlying event are uncorrelated with the photon
  - Estimate contribution of underlying event by embedding the photon into minimum bias (MB) events
  - Select MB events with similar event characteristics
    - Centrality, primary vertex position, event plane angle
Contributions from background tracks (UE) and background jets (fake jets) must be subtracted.
BACKGROUND SUBTRACTION (EVENT MIXING . . . . .)

- Contributions from background tracks (UE) and background jets (fake jets) must be subtracted

\[ \text{N RAW jets} - \text{N BKG jets} \]
BACKGROUND SUBTRACTION (NEUTRAL MESON DECAY)

- Photons produced from neutral meson decays mimic direct photons
  - Generally have wider shower shapes
  - Estimated and subtracted using a template fitting method
    - Signal template from simulation
    - Background template from data

![Graph showing CMS Preliminary results with PbPb Data, Signal, and Background]

Final result: $\frac{1}{\text{purity}} \times \text{Observable from all photon candidates} - \frac{1 - \text{purity}}{\text{purity}} \times \text{Observable from sideband photons}$
OBSERVABLES (JET FRAGMENTATION FUNCTION)

• Jet fragmentation function
  \[ \xi_{\text{jet}} = \ln \frac{|p_{\text{jet}}|^2}{p_{\text{trk}} \cdot p_{\text{jet}}} \]
  - Distribution of jet momentum parallel to the jet axis
    - Sensitive to hadronisation
  - Can also be calculated with respect to photon momentum
    \[ \xi_{\gamma} = \ln \frac{-|p_{\gamma}|^2}{p_{\text{trk}} \cdot p_{\gamma}} \]
    - Momentum conservation is valid only in transverse direction
RESULTS (JET FRAGMENTATION FUNCTION)

- Enhancement of low-pT particles, depletion of high-pT particles

\[ \sqrt{s_{NN}} = 5.02 \text{ TeV} \]
\[ p_T^{\text{jet}} > 1 \text{ GeV/c}, \text{ anti-}k_T \text{ jet } R = 0.3 \]
\[ p_T^{\text{jet}} > 30 \text{ GeV/c}, |\eta| < 1.6 \]
\[ p_T^{\gamma} > 60 \text{ GeV/c}, |\eta| < 1.44, \Delta \phi_n > \frac{7\pi}{8} \]
THEORY COMPARISON (JET FRAGMENTATION FUNCTION)

- Stronger modification for $\xi_T^\gamma$ compared to $\xi_{\text{jet}}$
  - Jet energy quenched
- SCET$_G$/CoLBT-hydro describes trend in both observables
- Enhancement at large $\xi$ (low-$p_T$ particles) is underestimated in all models
OBSERVABLES (JET SHAPE)

- Distribution of jet energy in transverse direction with respect to jet axis
  - Complementary information to jet fragmentation function
    \[ \rho(r) = \frac{1}{\delta r} \sum_{\text{trk} \in [0, r_f]} \sum_{\text{jets}} \left( \frac{p_{T}^{\text{trk}}}{p_{T}^{\text{jet}}} \right) \]

\[ \text{CMS Preliminary} \]

- PbPb 4C4 $\mu$b$^{-1}$, pp 27.4 pb$^{-1}$
- $\sqrt{s_{NN}} = 5.02$ TeV
- $p_T > 60$ GeV/c, $|\eta| < 1.44$, $p_T^{\text{trk}} > 1$ GeV/c
- anti-$k_T$ jet $R = 0.3$, $p_T^{\text{jet}} > 30$ GeV/c, $|\eta| < 1.6$, $\Delta\phi > 7\pi/8$
RESULTS (JET SHAPE)

• Comparison to inclusive jet shapes
  • No depletion at intermediate $r$
    • Increased quark/gluon ratio
    • Lower jet $p_T$ threshold - jets lose more energy

• Comparison to theory models
  • SCET$_G$/LBT describes trend
SUMMARY

- Photon-tagged measurements constrain initial parton kinematics and flavour
- Photon-tagged jet fragmentation functions:
  - Depletion of high-$p_T$ particles and excess of low-$p_T$ particles within the jet
- Photon-tagged jet shapes:
  - Larger amount of jet energy found at larger radial distances from the jet axis