Quark-like and gluon-like contributions using jet charge in pp and PbPb collisions with the CMS detector

Olga Evdokimov (UIC) for the CMS Collaboration
Jet quenching in QGP

Jet Tomography for QGP medium:
What happens if partons traverse a hot, dense colored medium?

In QGP:
- Jets are quenched...
  - Strong suppression in $R_{AA}$
  - Changes in the dijet $p_T$ balance $A_J$
  - ...

Open questions remain:
- Detailed nature of jet-medium

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In QGP:

- **Jets are quenched…**
  - Strong suppression in $R_{AA}$
  - Changes in the dijet $p_T$ balance $A_J$
  - …

- **…and show significant energy reshuffling in PbPb vs pp**
  - Softening of jet fragmentation
  - Modifications of jet shapes
  - …

Open questions remain:

- Detailed nature of jet-medium interactions
- Flavor/color-charge dependence of parton-medium coupling
  - …

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What are the theory expectations?

In the weak coupling limit, the expected energy loss scales with corresponding color factor:

\[
\frac{dE_{\text{quark}}}{dx} / \frac{dE_{\text{gluon}}}{dx} = \frac{C_F}{C_A} = \frac{4}{9}
\]

Weak coupling models larger predict higher energy loss for gluons than quarks in QGP.
What are the theory expectations?

- In the strong coupling the Casimir scaling is expected to break down

\[ \frac{dE_{\text{quark}}}{dx} / \frac{dE_{\text{gluon}}}{dx} = \left( \frac{C_F}{C_A} \right)^{1/3} \]

- Strong coupling models expect smaller differences in energy loss for quarks and gluons
What are the theory expectations?

- Quark jet fractions with different values of $r = C_A/C_F$:
  - PYQUEN: energy loss predictions for different values of $C_A/C_F$
  - Distinct trends for central/peripheral PbPb calculations
What are the experimental indications?

- Several experimental measurements could be interpreted as favoring higher energy loss for gluons.
- Others may indicate otherwise.
Quark-rich samples for color-charge studies

Inclusive jets vs. $\gamma$-jets: quark-rich samples to tests for color-charge effects

Changes of momentum flow OR change in q/g fractions?

Similar jet shape modification in central PbPb data: energy shift towards larger radii

Quarks vs. gluons:

- Changes of momentum flow OR change in q/g fractions?
- Similar jet shape modification in central PbPb data: energy shift towards larger radii

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<table>
<thead>
<tr>
<th>CMS</th>
<th>Cent. 0 - 10%</th>
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<tbody>
<tr>
<td>$p_T^\gamma &gt; 60$ GeV/c</td>
<td></td>
</tr>
<tr>
<td>anti-$k_T$ jet $R = 0.3$</td>
<td></td>
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<tr>
<td>$p_T^{\text{jet}} &gt; 30$ GeV/c</td>
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<tr>
<td>$\Delta \phi_{j_y} &gt; 7\pi/8$</td>
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$|s_{NN}| = 5.02$ TeV

pp 27.4 pb$^{-1}$, PbPb 404 $\mu$b$^{-1}$
Jet charge observable

- **Jet Charge:**
  \[ Q^\kappa = \frac{1}{(p_T^{jet})^\kappa} \sum q_i (p_T^i)^\kappa \]
  transverse momentum-weighted sum of the electric charges of jet constituents

- \( \kappa \): controls the sensitivity of \( Q^\kappa \) to low and high \( p_T \) tracks

- Average jet charge for different flavored jets show little dependence on jet \( p_T \) →

- Can be used to study color-charge effects of jet quenching
Jet charge – Analysis strategy

Jet Charge:

\[ Q^\kappa = \frac{1}{(p_T^{jet})^\kappa} \sum q_i (p_T^i)^\kappa \]

- Kinematic selections:
  - Jets: PF, anti-\( k_T \), \( R = 0.4 \), \( p_T > 120 \text{ GeV} \), \( |\eta| < 1.6 \)
  - Tracks: \( p_T > 1, 2, 4, 5 \text{ GeV} \), \( |\eta| < 2.0 \)
  - \( \kappa = 0.3, 0.5, 0.7 \)

- Jet-track correlations are used for statistical extraction of jet-charge signal within \( R < 0.4 \) cone
- Incorporate *data-driven methods* for acceptance and underlying event corrections
- Measurements are *fully unfolded* for detector and background fluctuation effects
- Unfolded data are fit with Pythia MC templates to extract the quark- and gluon- like jet fractions
Jet charge – Analysis details

Prior Matrices for Background Unfolding

CMS Simulation Preliminary

Unfolding for background fluctuation effects:
- MC samples: PYTHIA6 (tune Z2); PYTHIA6* embedded into HYDJET

* Embedded jet sample rescaled to match up and down quark fractions in Pb

Data driven validation: $\eta$ – reflection and random-cone

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Unfolding for detector acceptance and tracking efficiency:

- MC samples: PYTHIA6 (tune Z2); PYTHIA6* embedded into HYDJET
  
  * Embedded jet sample rescaled to match up and down quark fractions in Pb

- Validation: MC-based unfolding for detector and background effects performed in a single step
First AA jet charge measurements

- Fully-unfolded jet charge results for pp and PbPb events at 5 TeV
- MC-based templates describe data for all $p_T$, centrality and $k$ bins

**CMS**

anti-$k_T$, $R = 0.4$ jets, $p_T^{jet} > 120$ GeV, $|\eta_{jet}| < 1.5$

$\kappa = 0.5$, track $p_T > 1$ GeV

pp $27.4$ pb$^{-1}$, PbPb $404$ $\mu$b$^{-1}$ (5.02 TeV)
Centrality and $p_T$ dependence:

- No significant modifications observed in the extracted gluon-like jet fractions between the different PbPb centrality bins and pp results.
Extracted gluon-like jet fractions

- Constituent threshold and weight-scheme dependence:

- No significant modifications observed in the extracted gluon-like jet fractions between the different PbPb centrality bins and pp results.
Jet charge distribution width

- Centrality and $p_T$ dependence of jet charge distribution widths:
  
  - No significant modifications observed in the measured widths between the different PbPb centrality bins and pp results
  
  - Width of the jet charge measurements well described by PYTHIA (unquenched)

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Jet charge: Model comparisons

- **PYQUEN:**
  - Collisional E-loss
  - Radiative E-loss

Both PYQUEN settings predict a decrease in the gluon jet fraction due to its larger color factor.

Corresponding increase in the jet charge width not observed in data.

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Future directions

- Dynamic jet charge: \( Q_{dyn}^i = \sum_{h \in i \text{-jet}} z_h^{k(z_h)} Q_h \)
- with a possible (simple) form of \( k(z_h) = \begin{cases} k_-, z_h < \xi_{cut} \\ k_+, z_h \geq \xi_{cut} \end{cases} \)
- Jet charge likelihood distributions are proposed as effective q/g discriminator

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**Summary and outlook**

- **Jet charge**: is an established tool for flavor-tagging in HEP. Now, first jet charge measurements from AA collisions have been published by CMS for 5TeV PbPb (and pp) data.
- **Jet charge in AA**: jet charge distributions and extracted g- and q-like jet fractions show no significant modifications between different PbPb centrality bins and pp measurements.
- **Jet charge in theory**: Quenching modeling in PYQUEN leads to increase in the width of jet charge distribution, not present in data.
- **Outlook**: New charge-dependent observables could offer higher sensitivity for color-charge effects.

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**Graphs and Diagrams**

- CMS pp 27.4 pb⁻¹ (5.02 TeV)
  - anti-kₜ, R=0.4 jets, pₜ > 120 GeV, ln₂⁻¹ < 1.5
  - κ = 0.5

- CMS PbPb 404 μb⁻¹ (5.02 TeV)
  - anti-kₜ, R=0.4 jets, pₜ > 120 GeV, ln₂⁻¹ < 1.5
  - κ = 0.5

- CMS PbPb 404 μb⁻¹ (5.02 TeV)
  - 0-10% PbPb
  - κ = 0.5

  - Jet Charge Standard Deviation [σ]
    - PYTHIA6
    - PYQUEN (Collisional)
    - PYQUEN (Radiational)
Back-up slides
Jet charge: different track $p_T$
Jet charge: different $\kappa$ scales

**CMS**

\[ \text{anti-} k_T \text{ } R = 0.4 \text{ jets, } p_T^{\text{jet}} > 120 \text{ GeV, } |\eta|_\text{jet} < 1.5 \quad \kappa = 0.3, \text{ track } p_T > 1 \text{ GeV} \quad \text{pp } 27.4 \text{ pb}^{-1}, \text{PbPb } 404 \mu \text{b}^{-1} \text{ (5.02 TeV)} \]

**Fitting results**
- Gluon
- Data
- Up quark
- Down quark
- Other flavors

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\[ \text{anti-} k_T \text{ } R = 0.4 \text{ jets, } p_T^{\text{jet}} > 120 \text{ GeV, } |\eta|_\text{jet} < 1.5 \quad \kappa = 0.7, \text{ track } p_T > 1 \text{ GeV} \quad \text{pp } 27.4 \text{ pb}^{-1}, \text{PbPb } 404 \mu \text{b}^{-1} \text{ (5.02 TeV)} \]