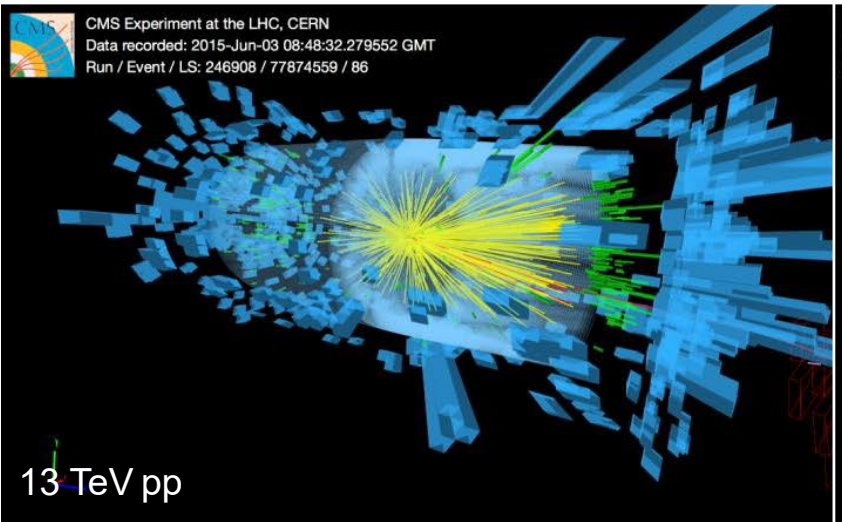
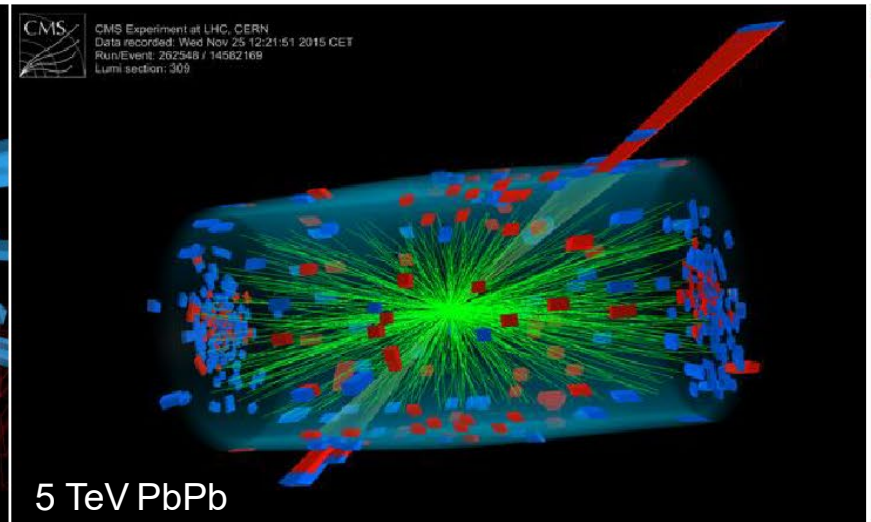
Quark-like and gluon-like contributions using jet charge in pp and PbPb collisions with the CMS detector

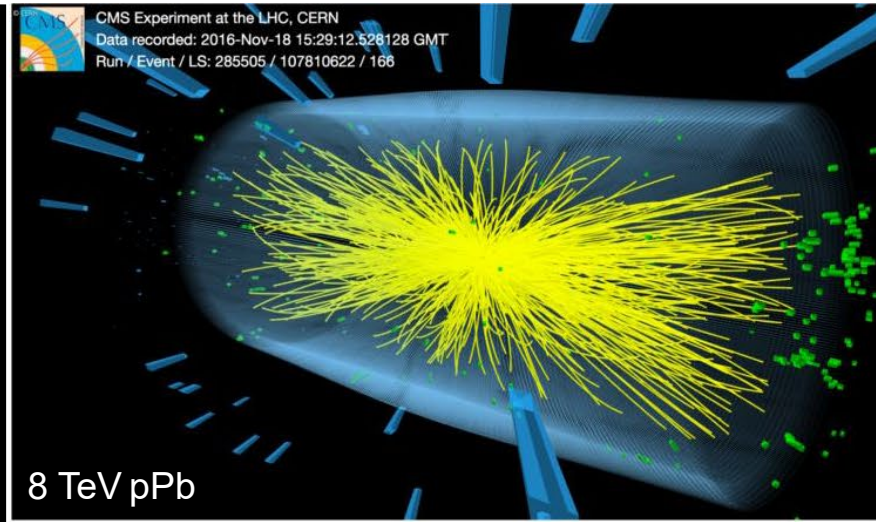
Olga Evdokimov (UIC) for the CMS Collaboration



13 TeV pp



5 TeV PbPb



8 TeV pPb

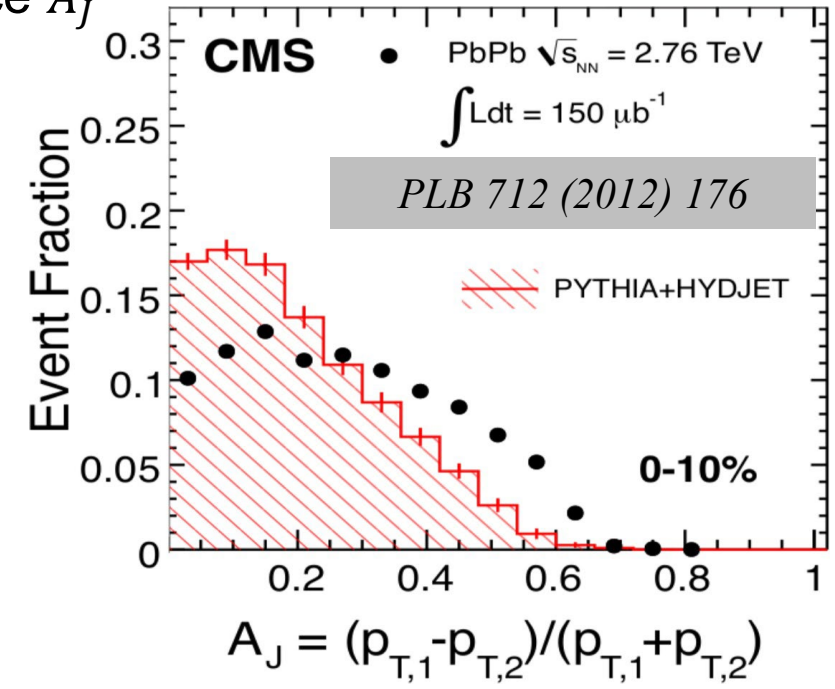
Jet quenching in QGP

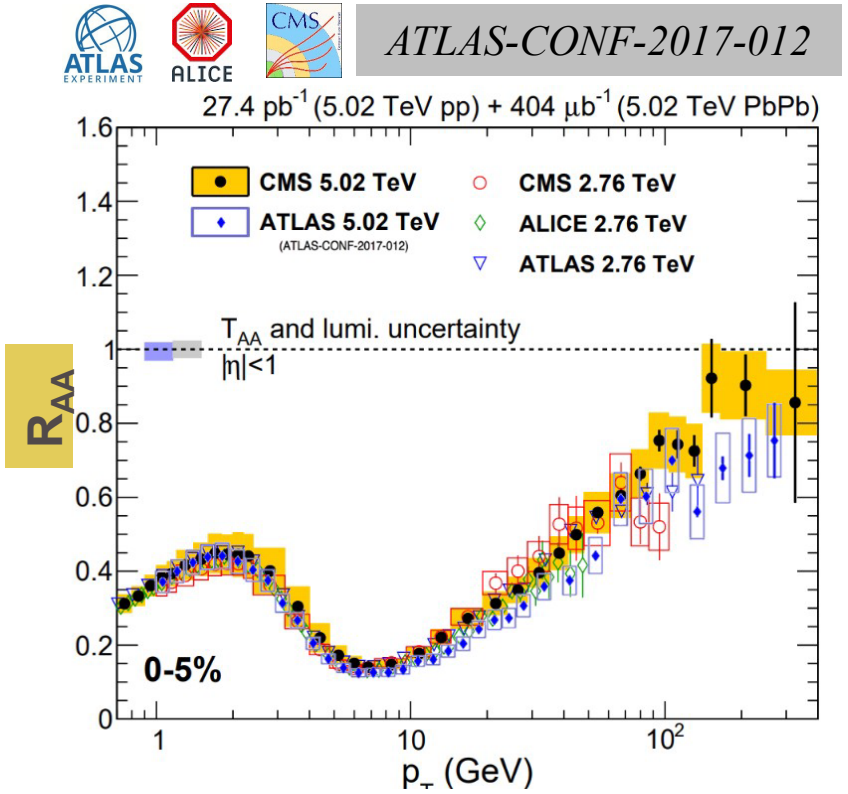
Jet Tomography for QGP medium:

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
  - ….





Jet quenching in QGP

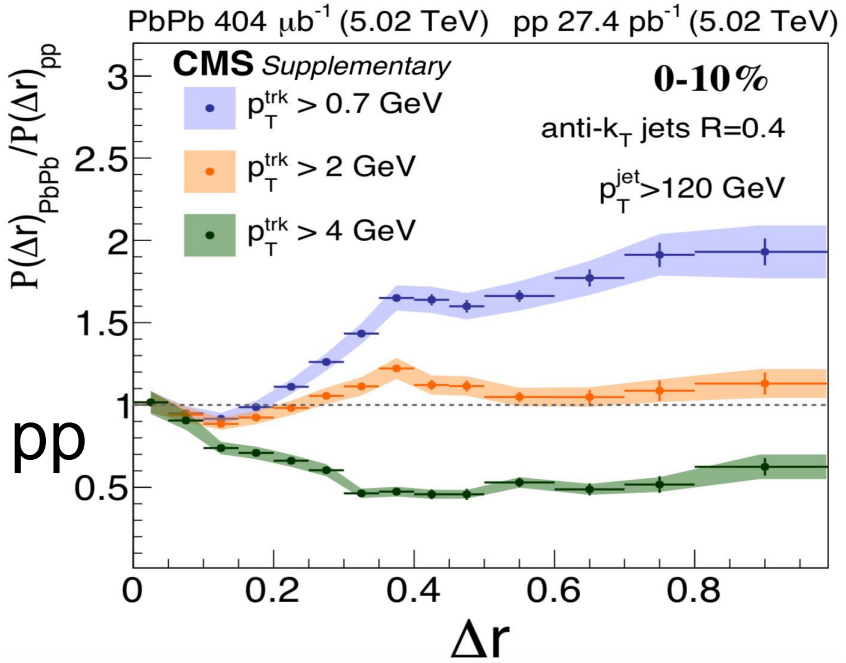
Jet Tomography for QGP medium:

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

JHEP05(2018)006, CMS HIN-16-020



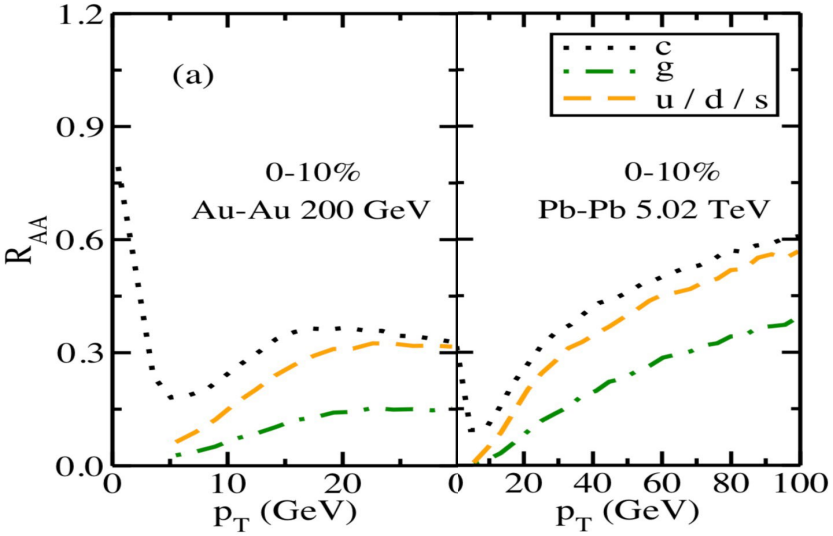
Open questions remain:

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

Energy loss for quarks vs. gluons

- What are the theory expectations?

LBT PLB 777 (2018) 255



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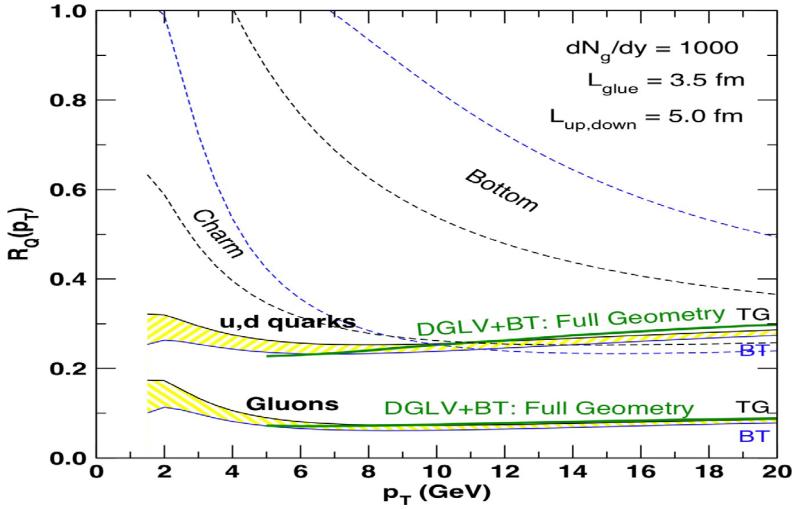

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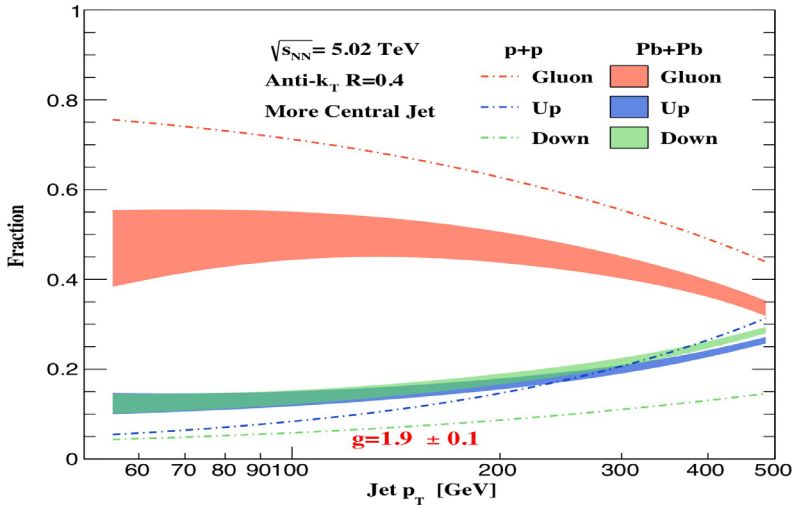


- In the weak coupling limit, the expected energy loss scales with corresponding color factor

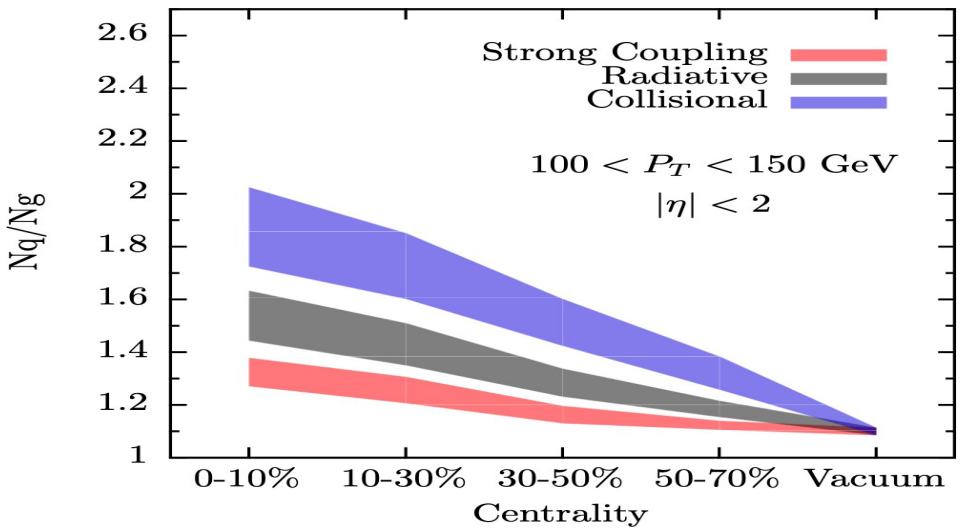
$$\frac{dE_{quark}}{dx} \Big/ \frac{dE_{gluon}}{dx} = \frac{C_F}{C_A} = \frac{4}{9}$$

- Weak coupling models larger predict higher energy loss for gluons than quarks in QGP

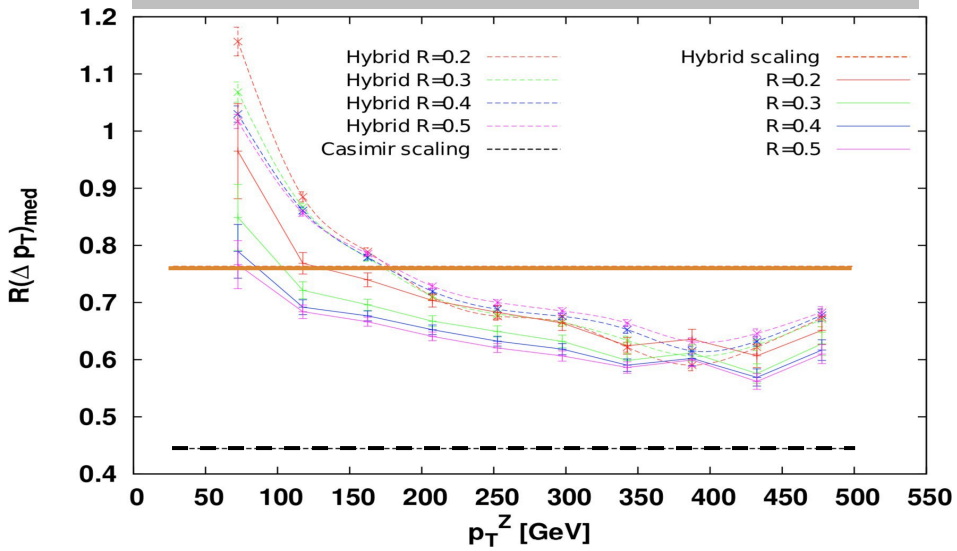
Energy loss for quarks vs. gluons

- What are the theory expectations?

Hybrid S/W *JHEP 10 (2014) 019*



JEWEL/Hybrid MC EPJC 80 (2020) 6, 586



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

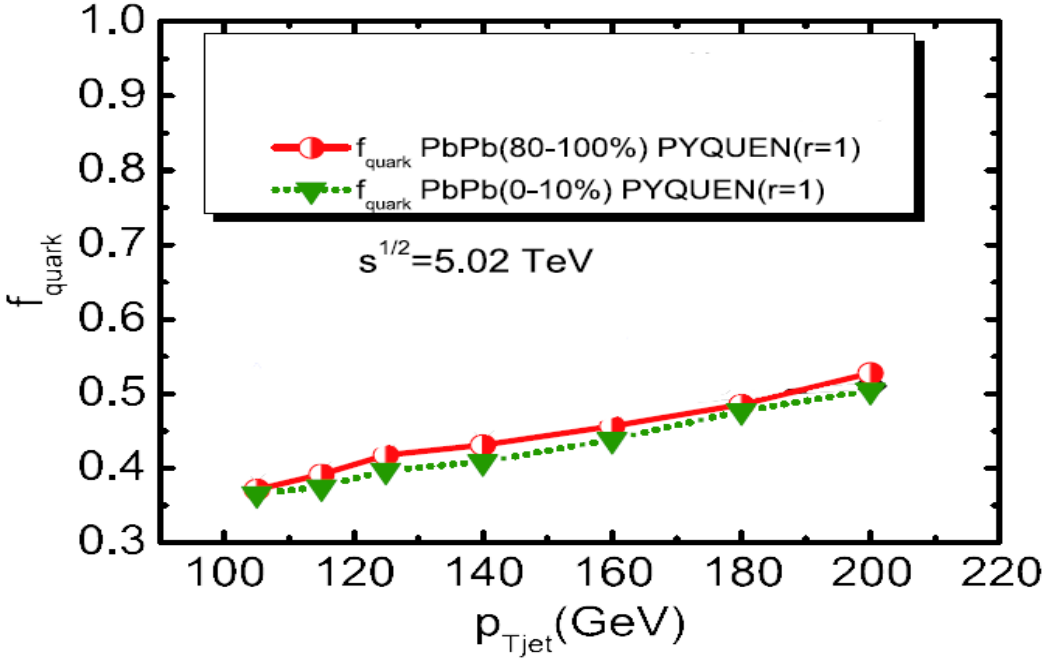
$$\frac{dE_{quark}}{dx} \Big/ \frac{dE_{gluon}}{dx} = \left(\frac{C_F}{C_A}\right)^{\frac{1}{3}}$$

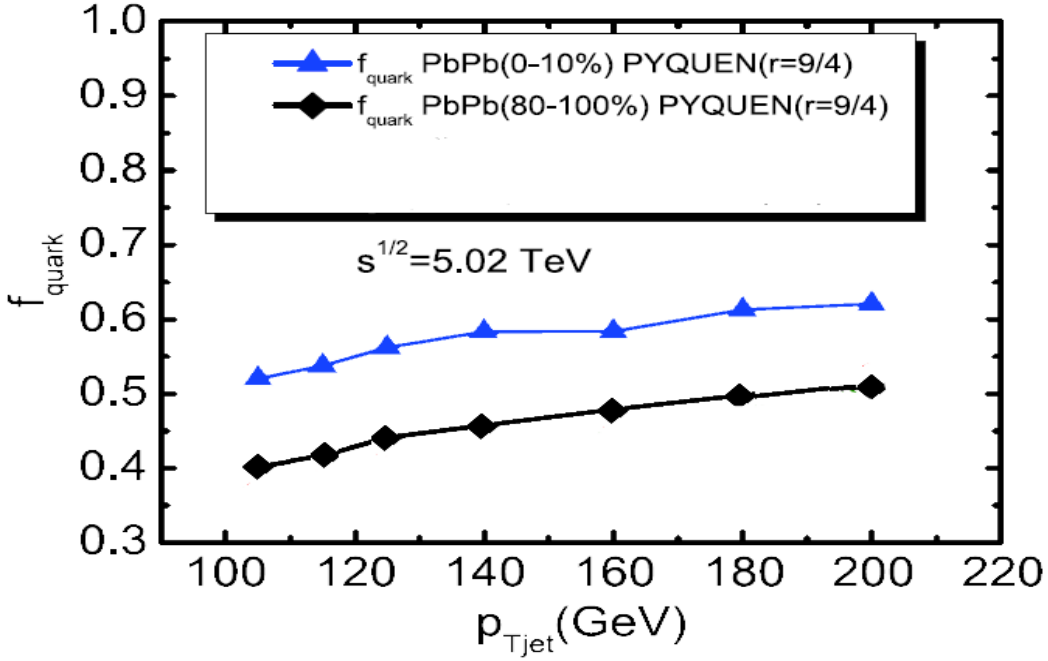
- Strong coupling models expect smaller differences In energy loss for quarks and gluons

Quenching and jet flavor composition

- What are the theory expectations?
  - Quark jet fractions with different values of $r = C_A/C_F$:

Chinese Physics C Vol. 44, (2020) 024103



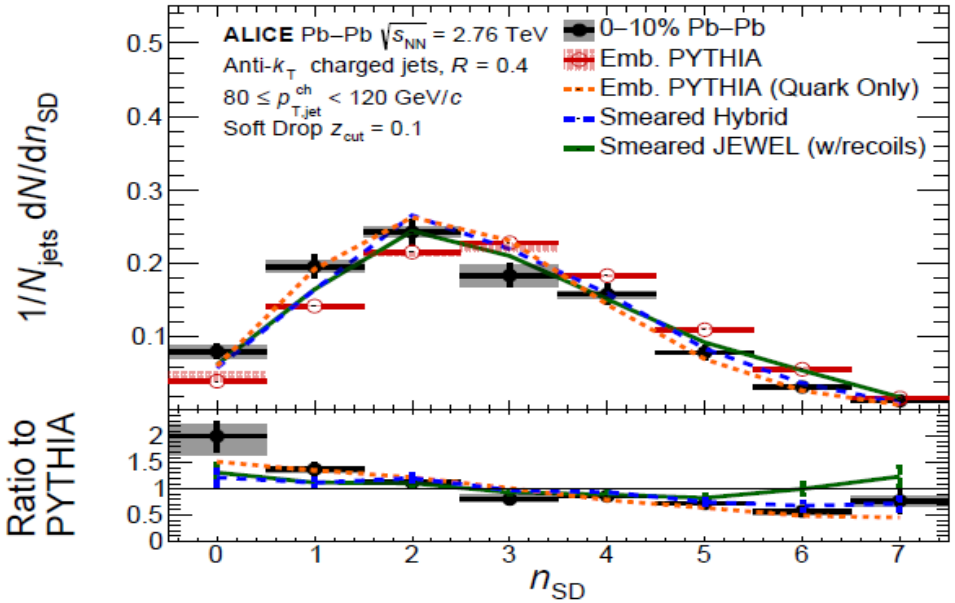


  - PYQUEN: energy loss predictions for different values of C_A/C_F
  - Distinct trends for central/peripheral PbPb calculations

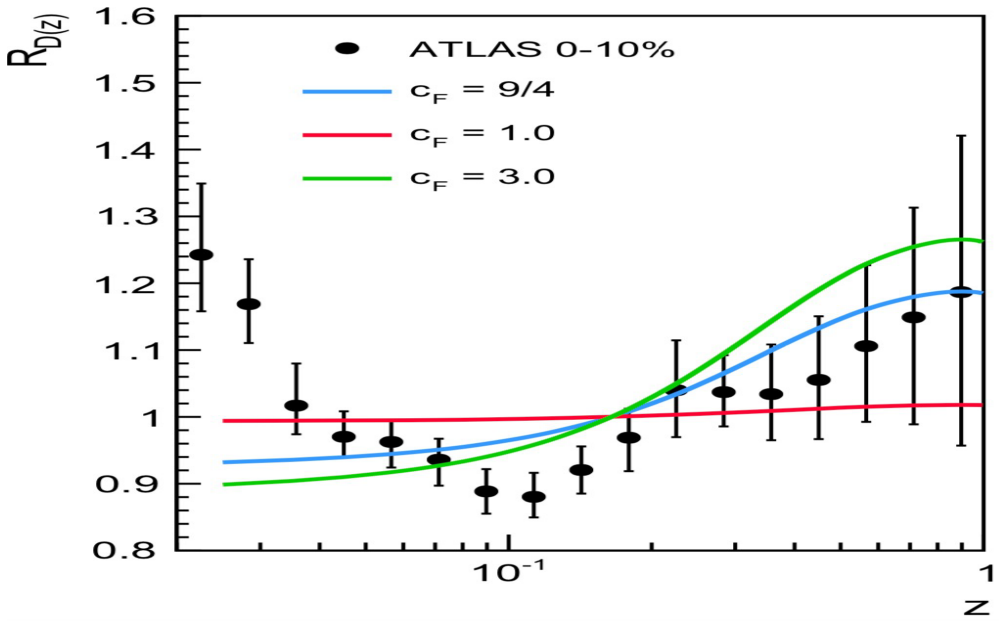
Quenching and jet flavor composition

- What are the experimental indications?

PLB 802 (2020) 135227



Eur. Phys. J. C76 (2016) 50

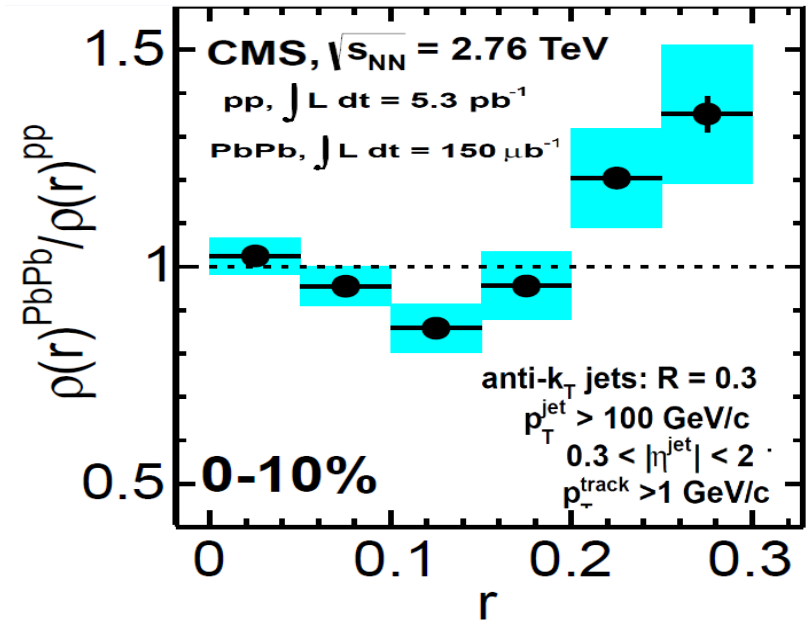


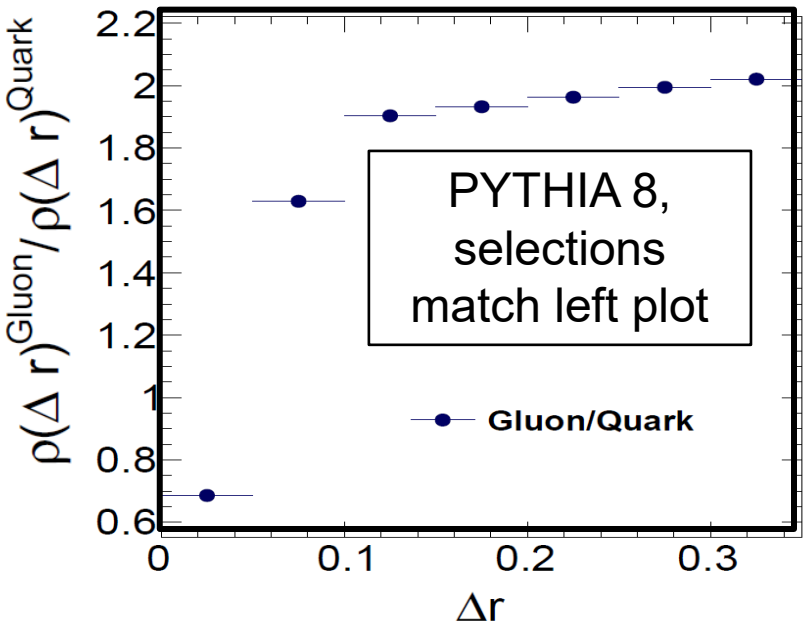
- Several experimental measurement could be interpreted as favoring higher energy loss for gluons
- Others may indicate otherwise

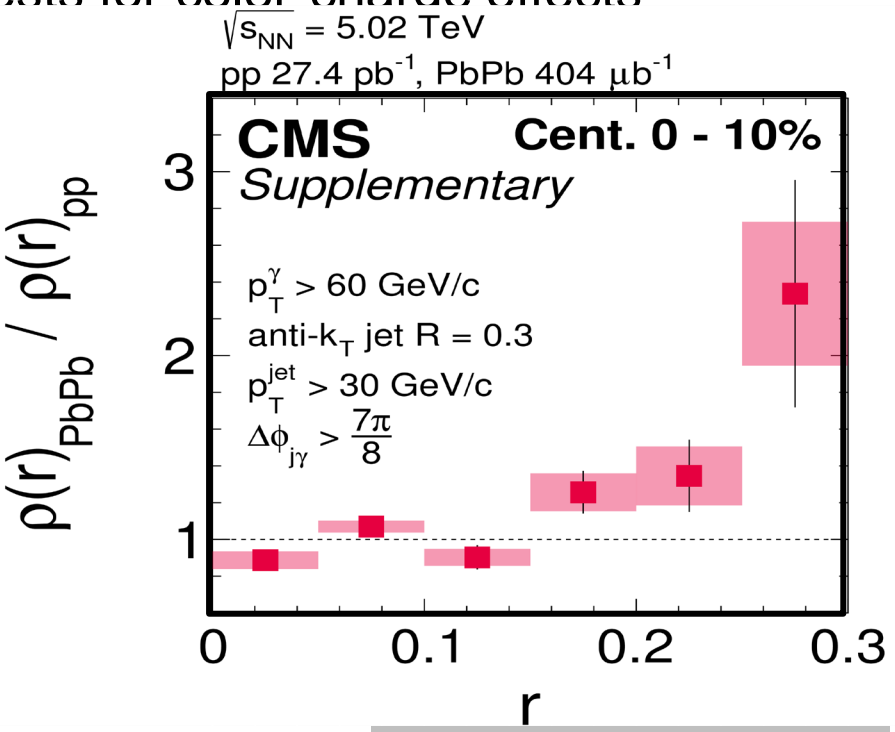
Quark-rich samples for color-charge studies

quarks vs. gluons:

- Inclusive jets vs. γ-jets: quark-rich samples to tests for color-charge effects







PLB 730 (2014) 243

PRL 122(2019)152001

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

Jet charge observable

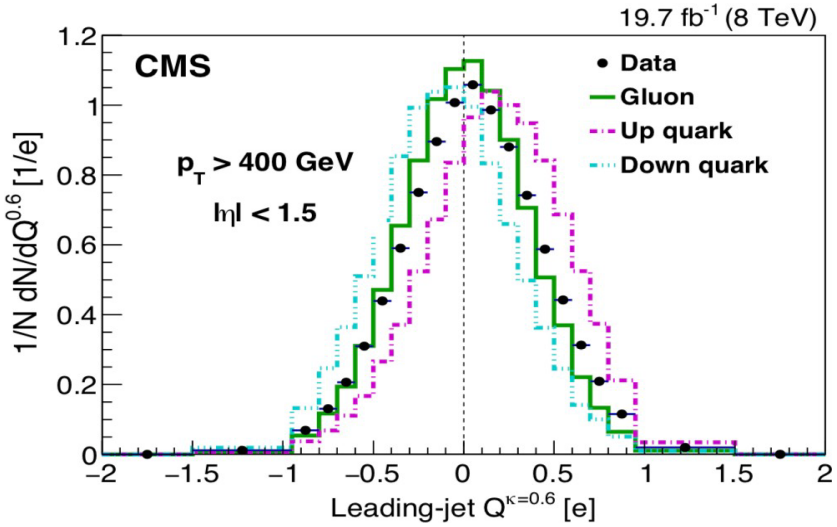
- Jet Charge:

$$Q^{\kappa} = \frac{1}{\left(p_T^{jet}\right)^{\kappa}} \sum q_i \left(p_T^i\right)^{\kappa}$$

transverse momentum-weighted sum of the electric charges of jet constituents

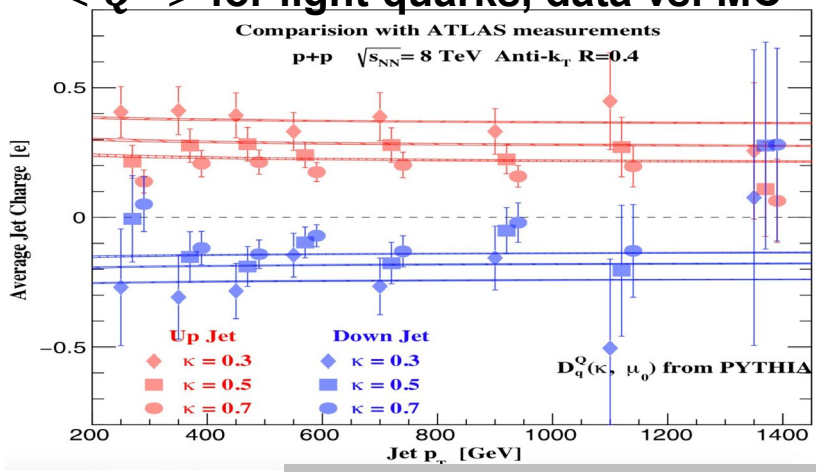
- $\boldsymbol{\kappa}$: controls the sensitivity of Q^{κ} to low and high p_T tracks

- 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



JHEP 10 (2017) 131

$< Q^k >$ for light quarks, data vs. MC



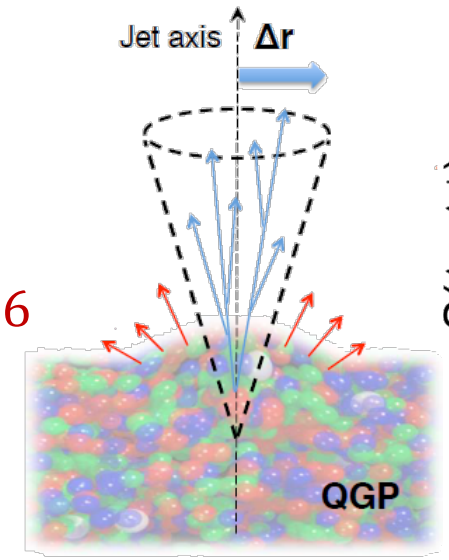
PRD 101 (2020) 076020

Jet charge – Analysis strategy

- Jet Charge:

$$Q^{\kappa} = \frac{1}{\left(p_T^{jet}\right)^{\kappa}} \sum q_i \left(p_T^i\right)^{\kappa}$$

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



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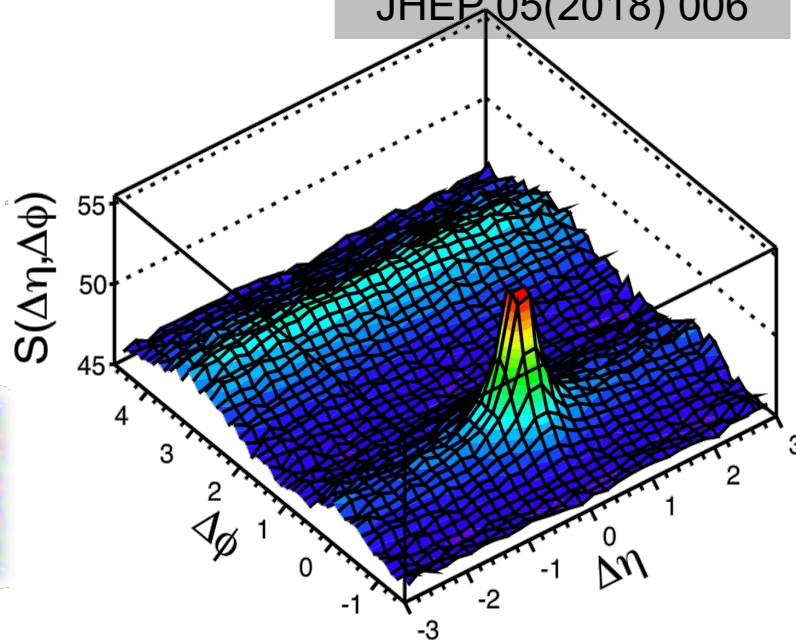
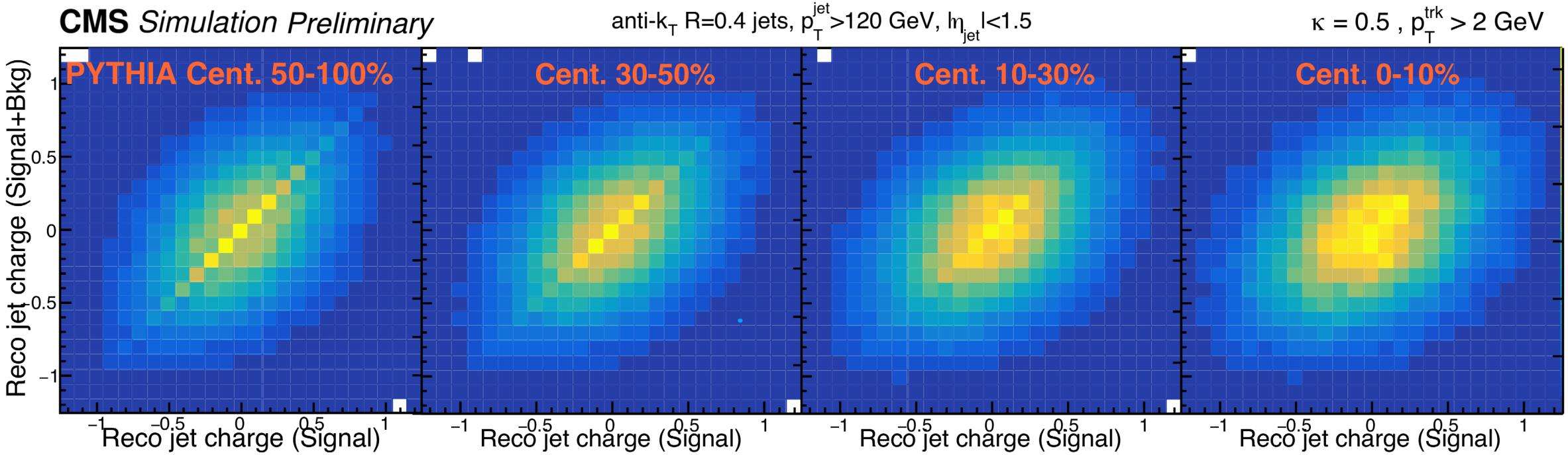


- Jet-track correlations are used for statistical extraction of jet-charge signal within $R < 0.4$ cone
- Incorporate *data-driven methods* for acceptance and underlying event corrections
- Measurements are fully unfolded for detector and background fluctuation effects
- Unfolded data are fit with Pythia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

Jet charge – Analysis details

Prior Matrices for Background Unfolding

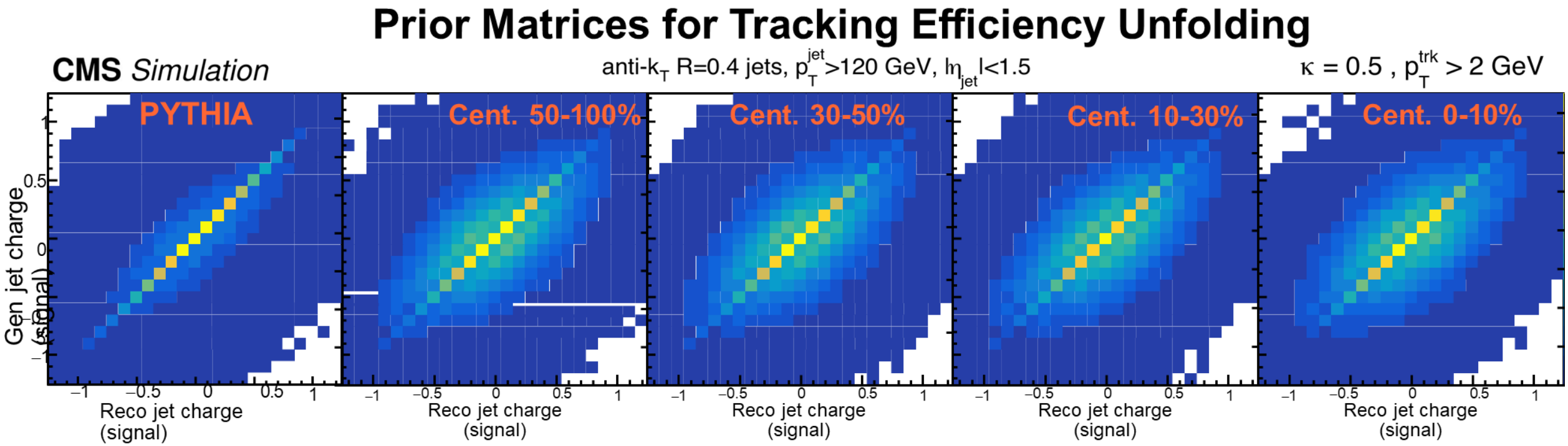


JHEP 07 (2020) 115

- 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: η –reflection and random-cone

Jet charge – Analysis details

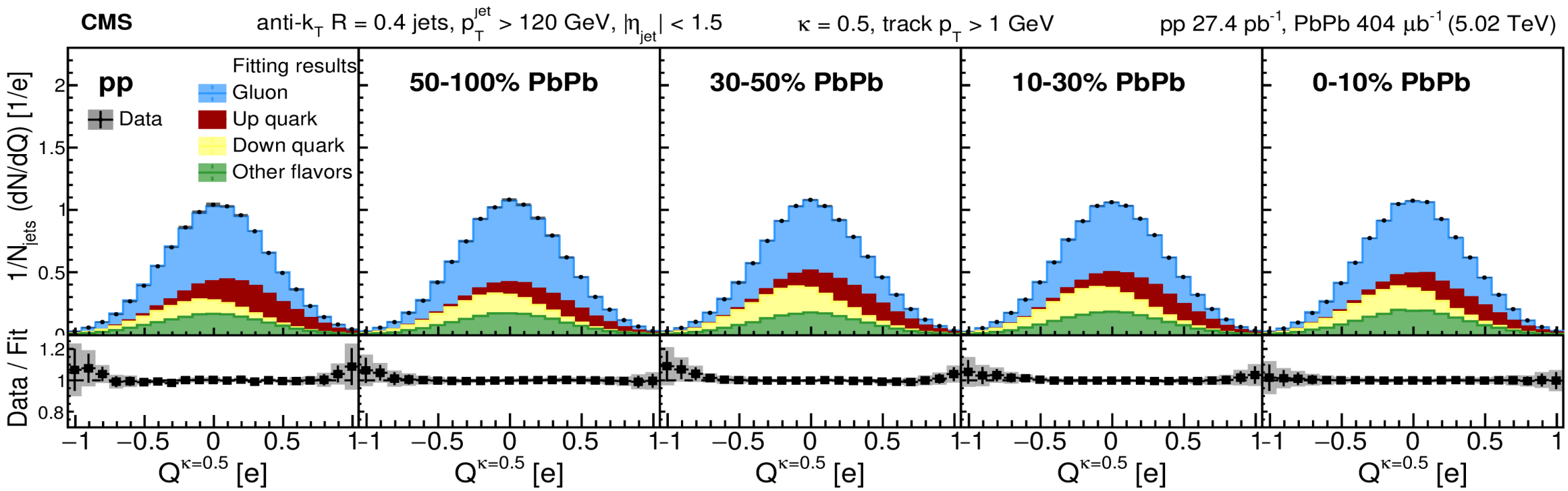


JHEP 07 (2020) 115

- 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



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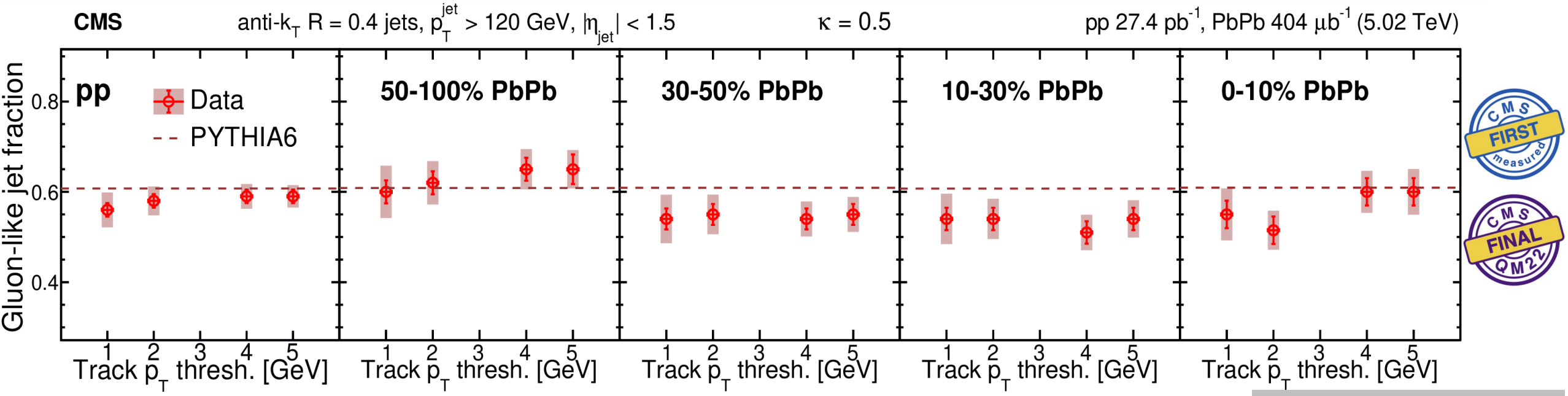
- Fully-unfolded jet charge results for pp and PbPb events at 5 TeV
- MC-based templates describe data for all p_T, centrality and k bins

Extracted gluon-like jet fractions

- Centrality and p_T dependence:

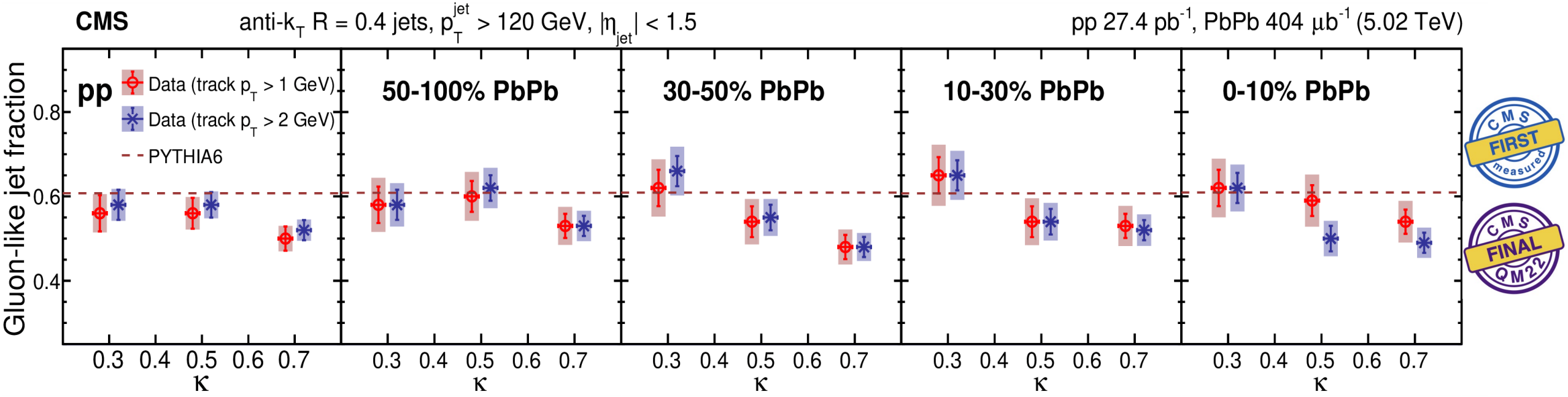


JHEP 07 (2020) 115

- 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:

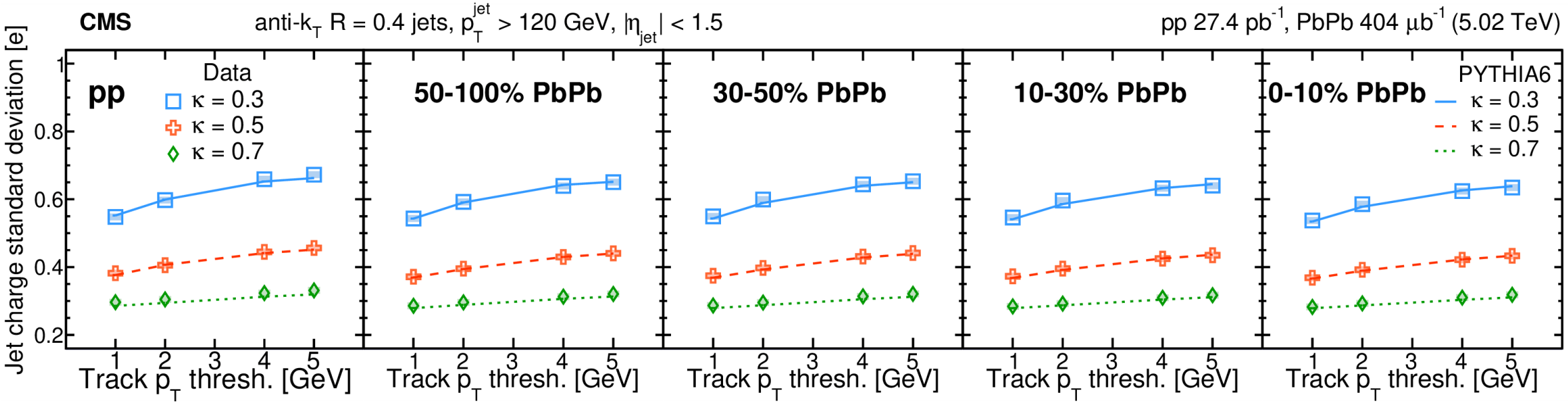


JHEP 07 (2020) 115

- 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:



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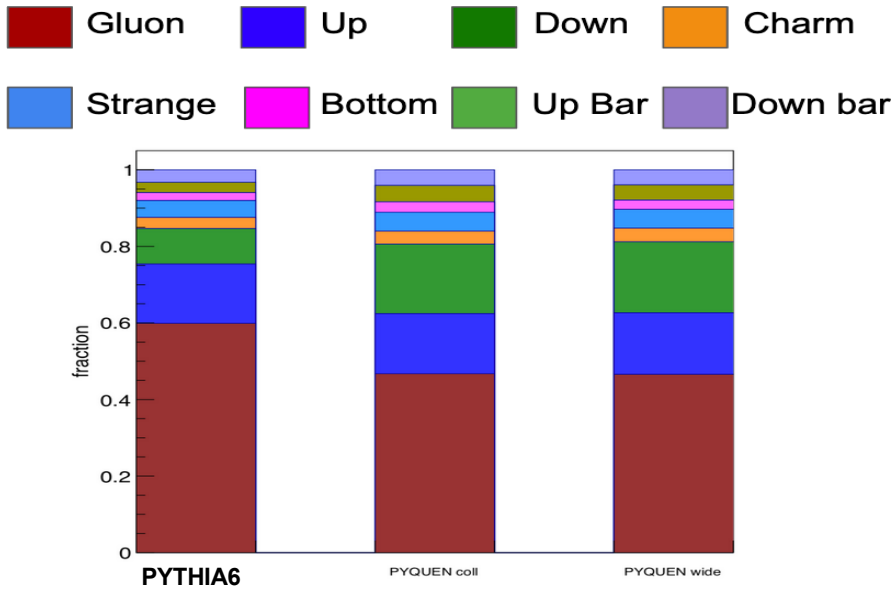
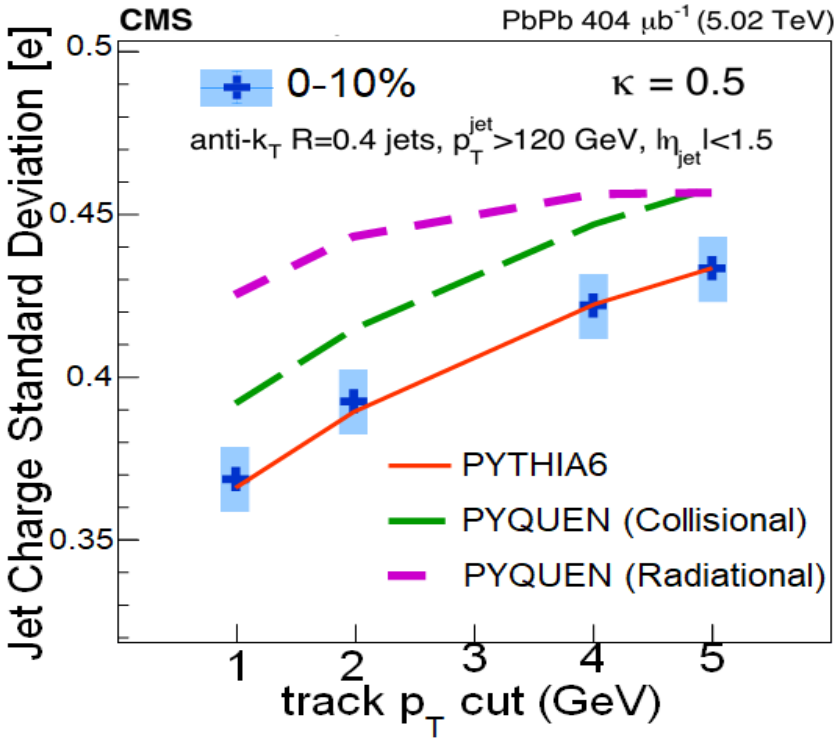
- No significant modifications observed in the measured widths between the different PbPb centrality bins and pp results
- Width of the jet charge measurements well described by PYTHIA (unquenched)

Jet charge: Model comparisons

- PYQUEN: EPJC71 (2011) 1650
  - Collisional E-loss
  - Radiative E-loss





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CMS HIN-18-018

- 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

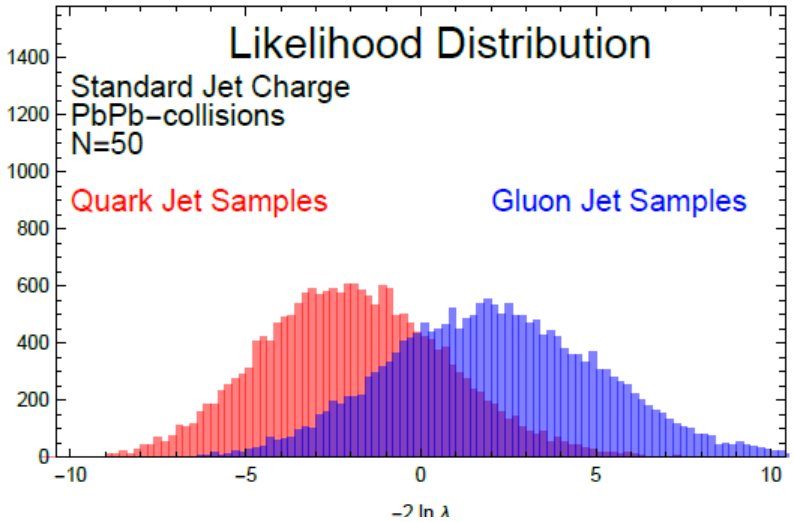
Future directions

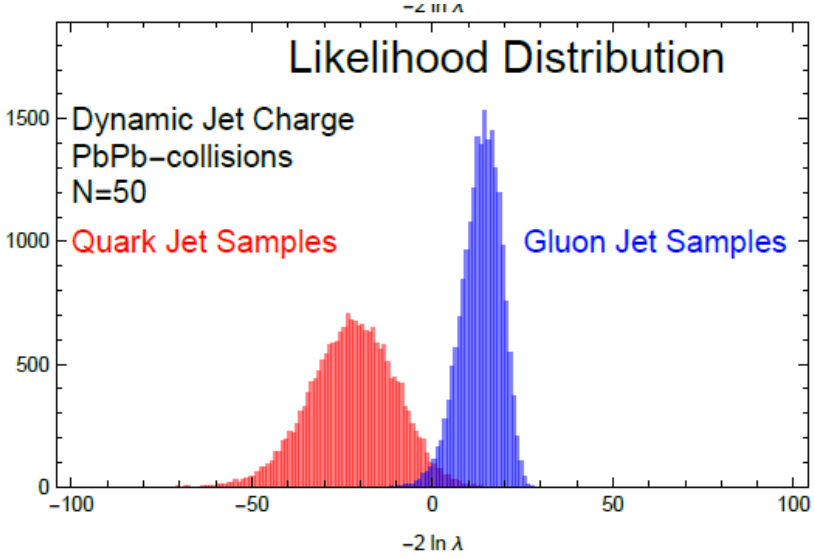
- Dynamic jet charge: $Q^i_{dyn} = \sum_{h \in i-\text{jet}} \left(z_h^{k(z_h)} Q_h \right)$

PRD 103 (2021) 074028

  - with a possible (simple) form of $k(z_h) = \begin{cases} k_<, z_h < \xi_{cut} \\ k_>, z_h \geq \xi_{cut} \end{cases}$

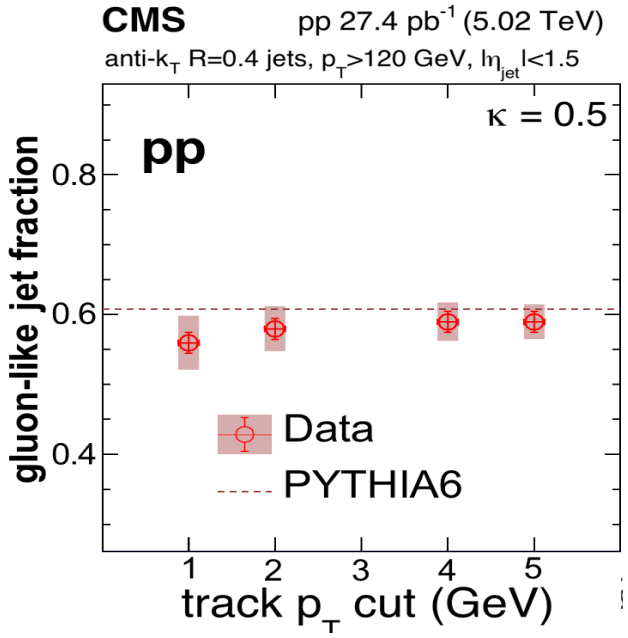
- Jet charge likelihood distributions are proposed as effective q/g discriminator

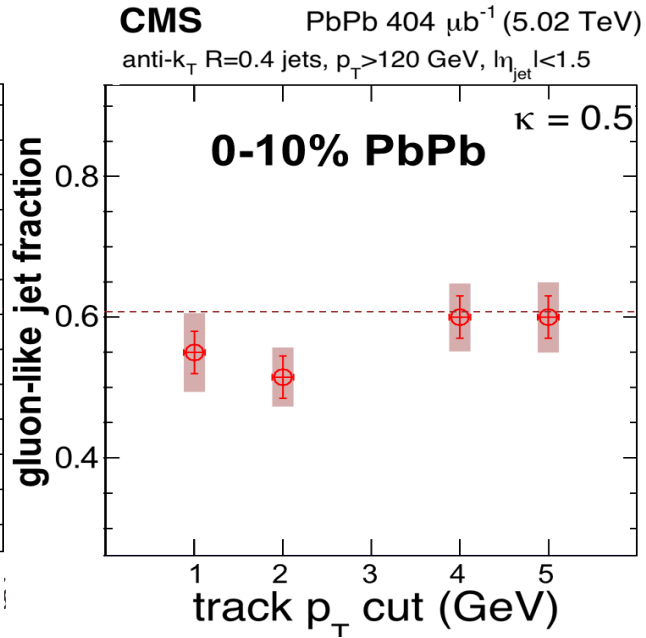


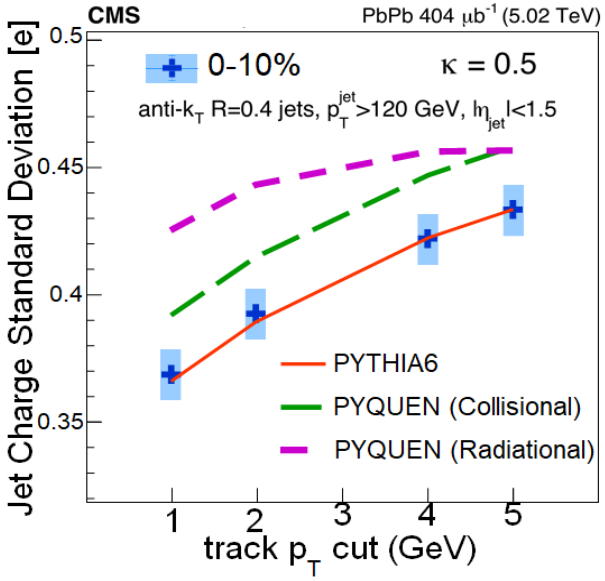


Summary and outlook

- **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

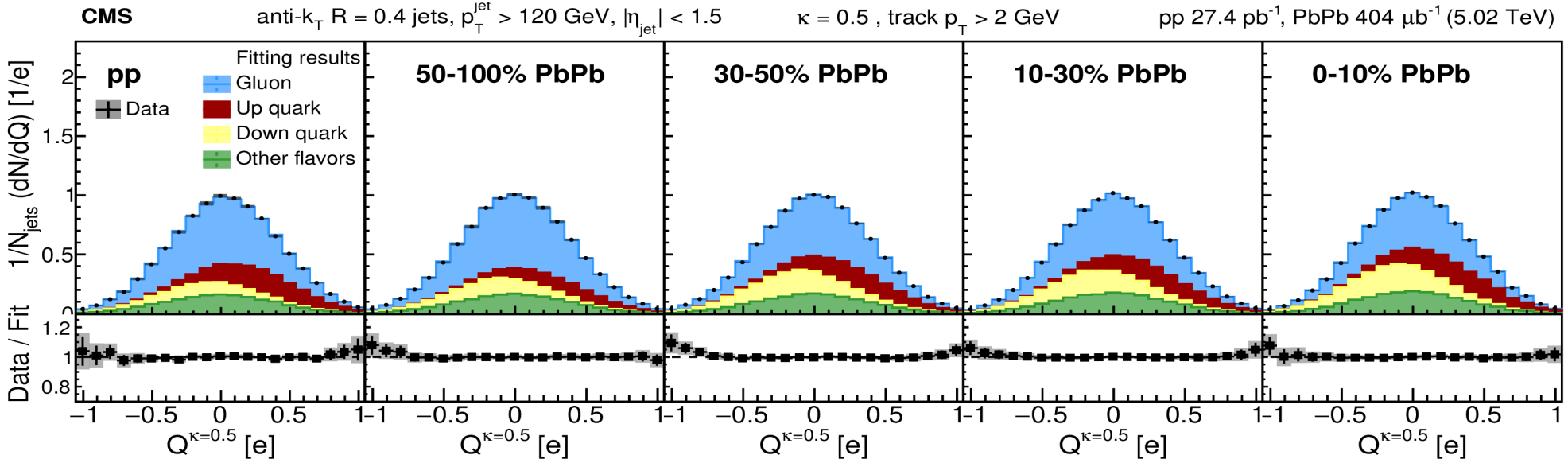


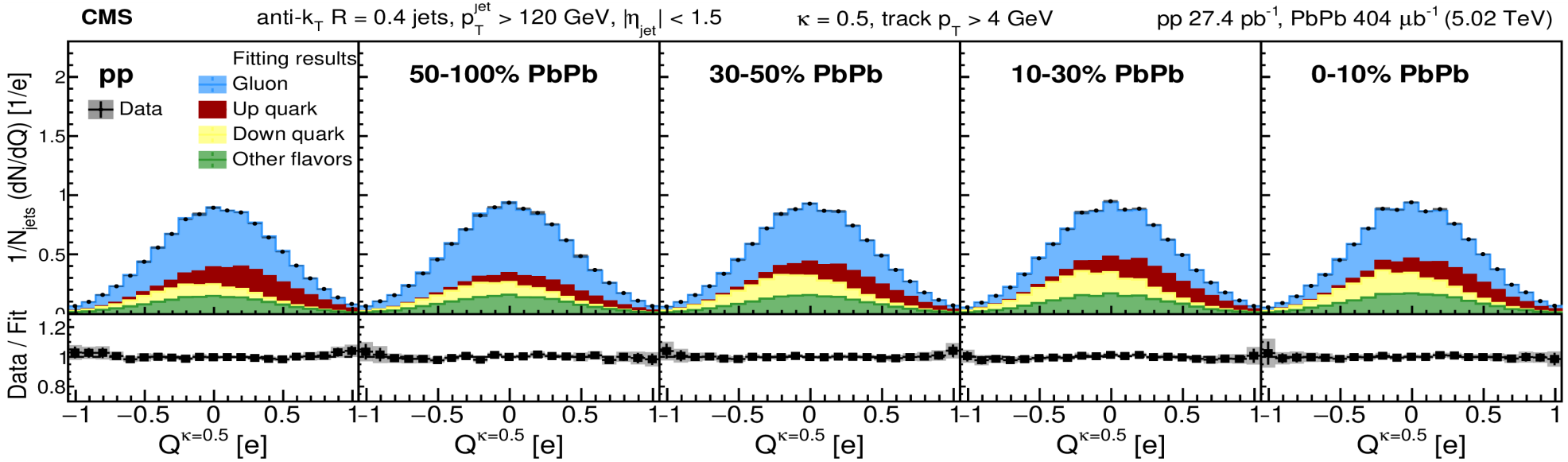




Back-up slides

Jet charge: different track p_T





Jet charge: different κ scales