PROCEEDINGS OF SCIENCE

Studies of quark-like and gluon-like contributions to jets using jet charge measurements in pp and PbPb collisions with the CMS experiment

Dhanush Anil Hangal on behalf of the CMS Collaboration[a,*]

[a] *University of Illinois at Chicago, 845 W Taylor St, Chicago, IL 60607, USA*

E-mail: dhanush.anil.hangal@cern.ch

The momentum-weighted sum of the electric charges of particles inside a jet, known as jet charge, is sensitive to the electric charge of the hard-scattered parton initiating the jet. Jet charge distributions are presented for PbPb and pp collisions recorded by the CMS detector at $\sqrt{s_{NN}} = 5.02$ TeV at the LHC. The measurements are unfolded for detector and background effects, and are presented differentially in p_T and additionally as a function of the overlap of the colliding Pb nuclei. A template-fitting method is presented to estimate the quark- and gluon-like jet fractions in an inclusive jet sample using jet charge templates from Monte Carlo simulations. The jet charge template-fitting results for quark- and gluon-like jet fractions in pp and PbPb collisions test the color charge dependence of jet energy loss due to interactions with the quark-gluon plasma.

HardProbes2020
1-6 June 2020
Austin, Texas

*Speaker

PoS(HardProbes2020)170

1. Introduction

A deconfined state of quarks and gluons, referred to as the quark-gluon plasma (QGP), is predicted to be formed at extremely high temperature and density conditions achieved in heavy-ion collisions [1]. Parton scatterings with large momentum transfer occur very early in these collisions and their fragmentation results in high transverse momentum (p_T) jets which can be used as tomographic probes to study the QGP. The hard-scattered partons interact strongly with the QGP and lose energy in a phenomenon known as "jet quenching", which has been studied extensively via measurements at the CERN LHC [2]. The details of the high-p_T parton energy loss mechanisms in the QGP, along with their color-charge dependence, are still not fully understood [3].

Theoretical models operating in the limit of weak coupling consistently predict a significantly larger energy loss for gluons compared to quarks traversing the QGP due to their larger color charge [4]. Recent studies have attempted to interpret heavy-ion jet measurements based on a modification in the fractions of quark- and gluon-initiated jets in PbPb collisions compared to the pp baseline arising from the color charge dependence of jet quenching [5]. However, studies incorporating strong coupling effects show a much smaller difference in the magnitude of energy loss for quarks and gluons while interacting with the deconfined QCD medium [6]. Recent results from JEWEL and Hybrid, heavy-ion Monte Carlo (MC) generators simulating quenching effects, also indicate a more similar energy loss for quark- and gluon-initiated jets in heavy-ion collisions compared to the vacuum reference [7].

Jet charge, defined as the momentum-weighted sum of the electric charges of particles inside the jet, is expected to be sensitive to the electric charge of the initiating parton [8]. Measurements of jet charge, presented here for pp and PbPb collisions, provide valuable input to the color-charge dependence of the jet quenching mechanisms in QGP and help distinguish between the various energy loss scenarios. The results presented here use pp and PbPb collision data collected with the CMS detector [9]. Measurements are unfolded for detector and background effects, and the results are presented in bins of the minimum p_T threshold of the jet constituents used in the measurement, and also as a function of the degree of overlap between the colliding heavy nuclei (collision centrality).

2. Analysis and Results

These measurements use pp and PbPb collision data collected with the CMS detector at $\sqrt{s_{NN}} = 5.02$ TeV corresponding to integrated luminosities of 27.4 pb^{-1} and 404 μb^{-1}, respectively. A jet trigger requiring at least one reconstructed jet with $p_T > 100$ GeV is used to select collision events. PYTHIA event generator (version 6.424 [11], tune Z2), referred to as PYTHIA6, is used to produce MC simulation samples of hard-scattered pp and PbPb collision events. For PbPb measurements, the PYTHIA6 hard-scattering signal events are embedded into simulated minimum-bias PbPb collision events produced with HYDJET (version 1.383) [12], referred to as PYTHIA6+HYDJET. Reconstruction of jets is performed using the anti-kT algorithm [13] with a distance parameter R = 0.4, and a noise/pedestal subtraction method [14] is implemented in PbPb collisions to subtract the underlying event contribution to the measured jet energy. The measurements use reconstructed jets with $p_T > 120$ GeV within pseudorapidity $|\eta| < 1.5$, and charged tracks that lie within the jet cone having $p_T > 1$ GeV.

Jet charge is defined as:

$$Q^{\kappa} = \frac{1}{p^{\kappa}_{\mathrm{T,jet}}} \sum_{i \in \mathrm{jet}} q_i p^{\kappa}_{\mathrm{T},i} \, , \tag{1}$$

where $p_{\mathrm{T,jet}}$ represents the transverse momentum of the jet, and q_i and $p_{\mathrm{T,i}}$ refer to the electric charge (in terms of the proton charge e) and transverse momentum of the i–th constituent in the jet cone, respectively. The sensitivity of jet charge to the transverse momentum of the jet constituents is controlled using the κ parameter. Higher values of κ increases the sensitivity of the measured jet charge to high p_T particles inside the jet cone and vice versa. Theoretical calculations for pp collisions have indicated that a κ value of ~ 0.5 is the most sensitive to the electric charge of the parton initiating the jet [15]. Results are presented for different minimum track p_T thresholds for particles used in the jet charge measurements (1, 2, 4 and 5 GeV), and also for various κ values (0.3, 0.5 and 0.7).

Jet charge measurements performed using reconstructed jets and charged tracks are affected by detector resolution and inefficiencies, and additionally by background in heavy-ion collisions. The detector-level jet charge measurements are therefore unfolded to the particle-level using a D'Agostini iterative method [16], as implemented in the RooUnfold software package [17]. The background unfolding procedure and corresponding MC bias is analyzed using a data-driven method by measuring jet charge using jets in a jet-triggered event and charged tracks within the jet cone from a separate minimum-bias event. The minimum-bias event is chosen to have a similar primary vertex and event centrality as the signal jet-triggered event. The contribution of the underlying-event to the jet charge measurements calculated using the data-driven technique is observed to be within 1% agreement with the background contribution simulated using HYDJET.

A template-fitting method, using jet charge distributions of different flavor jets in PYTHIA6 as templates, is implemented to study the quark/gluon dependence of jet energy loss in the QGP. The MC jet charge templates for up quark-, down quark- and gluon-initiated jets are used to fit the unfolded data jet charge measurements to extract the respective jet flavor fractions in pp and PbPb collisions. Up quark-, down quark- and gluon-initiated jet charge distributions are used as the nominal templates as they constitute the dominant fraction of the inclusive jet sample in the p_T range considered in this analysis. The fractions of up and down antiquark jets are varied along with the up and down quark jets, respectively. The fraction of jets initiated by the "other flavors", i.e., charm, strange, and bottom (anti)quarks, is estimated from MC and kept fixed in the nominal fitting procedure. The resulting bias is analyzed by varying the "other flavor" jets by their total fractions and repeating the fitting; any deviation from the nominal fitting results are assigned as a systematic uncertainty. Corrections are also applied to account for jets with no reconstructed tracks within the jet cone and for calorimeter response biases.

The unfolded jet charge measurements, normalized by the total number of jets in the sample $\mathrm{N_{jets}}$, are shown in the upper panel of Fig. 1 for a sample selection of κ and a minimum track p_T. The results are shown with solid black points and the extracted fraction of quark and gluon-initiated jets are displayed as stacked histograms. The lower panel of the figure shows the ratio of the data over the results from the template fits, and no significant deviation from unity is observed. The

PoS(HardProbes2020)170

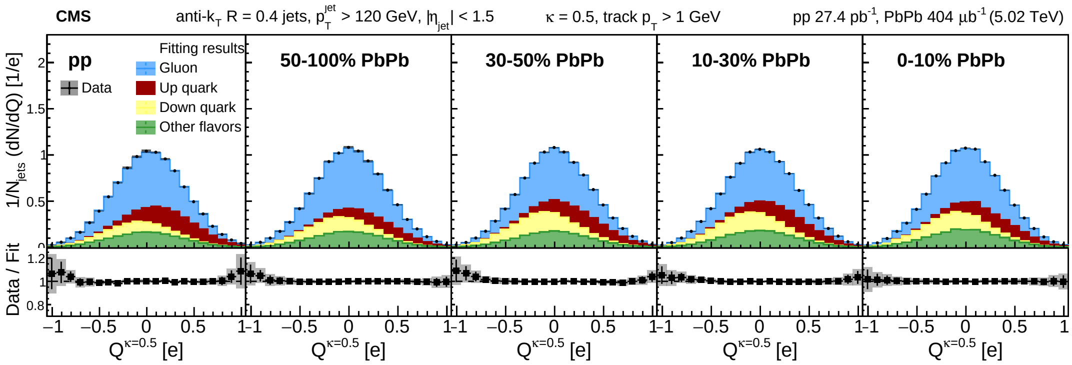

Figure 1: (Upper) Jet charge measurements shown for inclusive jets, with $\kappa = 0.5$ and a minimum track p_T of 1 GeV, in data along with the extracted fractions of different flavor jets. The systematic and statistical uncertainties in the distributions are shown by the shaded regions and vertical bars, respectively. (Lower) Ratio of the jet charge measurements to the template fits [10].

widths (standard deviations) of the unfolded jet charge measurements are shown in Fig. 2 for pp and PbPb collisions. No significant modification is observed in the jet charge width in different event centrality bins in PbPb collisions, and it is also very well described by PYTHIA6 without accounting for any quenching effects. Theoretical predictions from weak coupling models predict a reduced gluon jet fraction in central PbPb collisions leading to an increase in the measured jet charge width, which is not observed in the results shown here.

The extracted fractions of quark- and gluon-like jets from the template-fitting in pp and PbPb collisions are shown in Figs. 3 and 4, as a function of the minimum track p_T threshold and κ, respectively. No significant modification is observed in the relative fractions of the quark- and gluon-like jets in central PbPb collisions compared to peripheral PbPb and pp collisions.

The first measurements of jet charge in heavy-ion collisions are presented using PbPb collision data collected with the CMS detector. The PbPb results are compared to measurements from pp collisions at the same collision energy. The widths of the unfolded jet charge distributions are presented for pp and PbPb collisions and are observed to be very well described by PYTHIA6. The quark- and gluon-like jet fractions are extracted from pp and PbPb data using a MC based

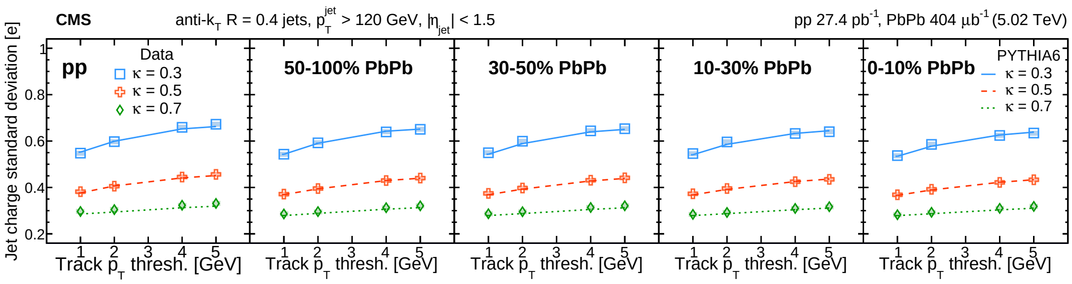

Figure 2: Standard deviations of jet charge distributions for different κ and track p_T threshold values for pp and PbPb collisions compared to PYTHIA6 predictions. The systematic and statistical uncertainties in the standard deviation measurements are shown by the shaded regions and vertical bars, respectively [10].

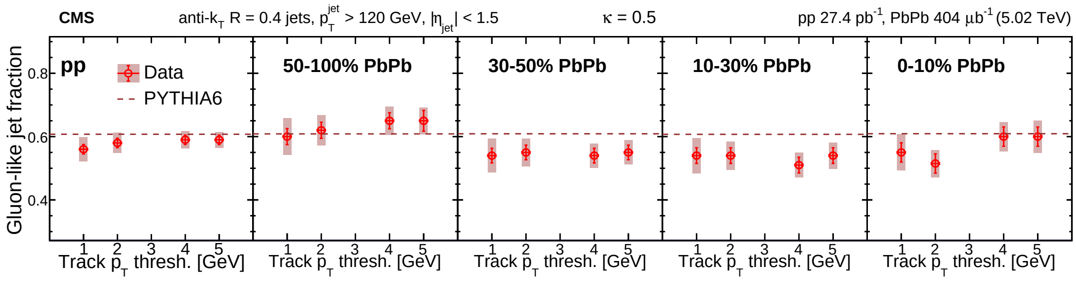

Figure 3: Fit results for gluon-like jet fractions in pp and PbPb data for $\kappa = 0.5$ and for different track p_T values. The systematic and statistical uncertainties are shown by the shaded regions and vertical bars, respectively. The PYTHIA6 prediction for the gluon-initiated jet fraction is shown with dashed red lines [10].

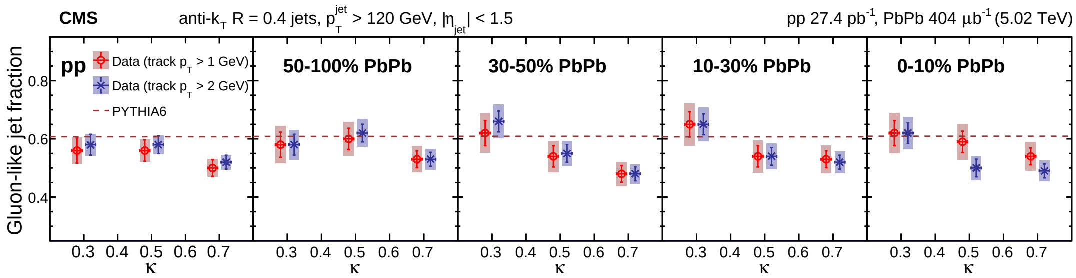

Figure 4: Fit results for gluon-like jet fractions similar to Fig. 3, but for different κ values [10].

template-fitting method. In the studied p_T range, no significant modification is observed in the quark- and gluon-like fractions in all studied centrality bins in PbPb collisions and also compared to pp measurements.

References

[1] Nucl. Phys. A **590**, 367C-382C (1995) doi:10.1016/0375-9474(95)00248-Y.
[2] Phys. Rev. C **84**, 024906 (2011) doi:10.1103/PhysRevC.84.024906.
[3] Int. J. Mod. Phys. E **24**, 1530014 (2015) doi:10.1142/S0218301315300143.
[4] Phys. Rev. C **94**, no.1, 014909 (2016) doi:10.1103/PhysRevC.94.014909
[5] Eur. Phys. J. C **76**, 50 (2016) doi:10.1140/epjc/s10052-016-3896-0
[6] JHEP **10**, 019 (2014) doi:10.1007/JHEP09(2015)175
[7] Eur. Phys. J. C **80**, no.6, 586 (2020) doi:10.1140/epjc/s10052-020-8133-1
[8] Nucl. Phys. B, **136**, 1, doi:10.1016/0550-3213(78)90015-9
[9] JINST **3** (2008) S08004, doi:10.1088/1748- 0221/3/08/S08004.
[10] JHEP **07**, 115 (2020) doi:10.1007/JHEP07(2020)115
[11] JHEP **05**, 026 (2006) doi:10.1088/1126-6708/2006/05/026
[12] Eur. Phys. J. C **45**, 211-217 (2006) doi:10.1140/epjc/s2005-02426-3
[13] JHEP **04**, 063 (2008) doi:10.1088/1126-6708/2008/04/063
[14] Eur. Phys. J. C **50**, 117-123 (2007). doi:10.1140/epjc/s10052- 007- 0223- 9.
[15] Phys. Rev. D **86**, 094030 (2012) doi:10.1103/PhysRevD.86.094030
[16] Nucl. Instrum. Meth. A **362** (1995) 487 doi:10.1016/0168-9002(95)00274-X
[17] CERN-2011-006.313 doi:10.5170/CERN-2011-006.313