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Resolving medium properties using high-p_{T} jets with jet and in-jet correlations in PbPb collisions at 5.02 TeV with the CMS detector

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Abstract. Even though the quark-gluon plasma produced in high-energy heavy ion collisions has been studied in detail for years, there are still properties that are not known to a good precision. One example of such property is the medium resolution length, which is related to the smallest angle of emission where the medium can still resolve the daughter particles as individual particles. This can be probed for example through the energy-energy correlator. The medium resolution length has implications for parton energy loss, since two particles will emit energy more vigorously compared to one. Also other details of the parton energy loss, like the path-length dependency, could use precision measurements to provide better discriminating power between available theoretical models. Jets are a good observable to experimentally tackle these questions. In this talk, we present recent, high-precision CMS jet measurements in lead-lead collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV aimed to explore the properties of the quark-gluon plasma.

1 Introduction

In these proceedings, we present two analyses studying path-length dependent parton energy loss and energy loss fluctuations within the quark-gluon plasma using jet-hadron correlations in dijet events. These analyses take advantage of the large lead-lead (PbPb) dataset at center-of-mass energy per nucleon pair $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV with integrated luminosity of $1.69\,\mathrm{nb}^{-1}$ recorded in 2018 by the CMS detector [1] together with a proton-proton (pp) dataset with integrated luminosity of $320\,\mathrm{pb}^{-1}$ recorded in 2017. The first analysis builds upon previous CMS measurements of momenta carried by charged hadrons as a function of radial distance from the jet axis ("jet shape") [2, 3]. In a dijet system, these momentum profiles are measured separately with respect to leading and subleading jets as a function of the dijet momentum balance $x_j = \frac{p_{\mathrm{T}}^{\mathrm{sub}}}{p_{\mathrm{T}}^{\mathrm{lead}}}$ [4]. Categorizing the distributions with x_j provides a handle in studying path-length dependent energy loss and energy loss fluctuations.

In the second analysis we look at the long range jet-hadron correlations in a dijet system and extract the azimuthal anisotropies of the jets via Fourier expansion coefficients v_n^{dijet} [5]. When the initial collision region of the heavy ions has an almond-like shape, the jets are expected to lose less energy in the in-plane direction compared to the out-of-plane direction. This results in a measurable jet v_2^{dijet} signal. The higher order v_n^{dijet} coefficients reflect medium density or initial state geometry fluctuations. The results presented in these proceedings introduce a new method for the jet azimuthal anisotropy measurements [6, 7].

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2 Jet-hadron correlations

All the charged particles in events containing a high-p_{T} dijet are paired with leading and subleading jet axes and the relative pseudorapidity $\Delta\eta$ and relative azimuth $\Delta\varphi$ values from these pairs are collected. To account for limited detector acceptance in η, a mixed event method is applied, where the jets and charged particles from different events are paired. Dividing the same-event distribution with a mixed-event distribution normalized to one in the region where no particles are lost to acceptance effects gives the acceptance corrected distribution. This is then further normalized by the number of jets.

Jet-like correlations are confined to small angles on the near side ($\Delta\varphi < \pi/2$) of the distributions, while on the away side ($\Delta\varphi > \pi/2$) the jet peak is elongated in $\Delta\eta$. On the near side, we can measure the long-range $\Delta\varphi$ distribution LR($\Delta\varphi$) free from jet contributions by requiring $1.5 < |\Delta\eta| < 2.5$. In a statistical distribution, leading and subleading jet peaks are separated by $\Delta\varphi = \pi$. Thus we can write $\mathrm{LR}(\Delta\varphi_{\mathrm{leading}}) = \mathrm{LR}(\pi - \Delta\varphi_{\mathrm{subleading}})$. It follows that we can construct LR($\Delta\varphi$) in the whole 2π range by replacing the away side of the leading jet distribution with the near side of the subleading jet distribution. For an illustration of this method, see Fig. 1 in Ref. [5]. Subtracting the long-range correlation distribution from the acceptance corrected one gives the distribution for jet-like correlations.

3 Jet shapes for leading and subleading jets

We define jet shapes from the jet-like correlation distribution using the equation

$$\rho(\Delta r) = \frac{1}{\delta r}\frac{1}{N_{\mathrm{jets}}}\frac{\Sigma_{\mathrm{jets}}\Sigma_{\mathrm{tracks}\in(\Delta r_a,\,\Delta r_b)}p_{\mathrm{T}}^{\mathrm{ch}}}{\Sigma_{\mathrm{jets}}\Sigma_{\mathrm{tracks}\in\Delta r<1}\;p_{\mathrm{T}}^{\mathrm{ch}}}\,, \tag{1}$$

where Δr_a and Δr_b define the annular edges of Δr, and $\delta r = \Delta r_b - \Delta r_a$. This is done differentially as a function of charged particle transverse momentum $p_{\mathrm{T}}^{\mathrm{ch}}$, centrality, and dijet momentum balance x_j.

The jet shape distributions are presented in Fig. 1 and PbPb to pp ratios in Fig. 2. The leading jets show the greatest modifications with respect to pp reference in balanced events, while the subleading jets are the most modified in unbalanced events. These observations are consistent with interpretations that unbalanced events are more prone to bias caused by dijets created near the surface of the quark-gluon plasma compared to balanced events, and that the unbalance is caused by energy loss fluctuations.

Outside of the jet cone radius $R = 0.4$ the PbPb to pp ratio gets closer to one for subleading jets in unbalanced events. This is due to the fact that to create an unbalanced event in pp case, there is likely to be a third jet to balance momentum. Indeed, there is an enhancement of high $p_{\mathrm{T}}^{\mathrm{ch}}$ particles around $\Delta r = 0.5$ for the unbalanced pp case on the right hand side of Fig. 1.

4 Azimuthal anisotropy of dijet events

The long-range correlation distribution is fitted with a Fourier fit up to the fourth order

$$f_{\mathrm{Fourier}}(\Delta\varphi) = A\left(1 + \sum_{n=1}^{4} 2V_{n\Delta}\cos(n\Delta\varphi)\right)\,, \tag{2}$$

where A is an overall normalization factor and $V_{n\Delta}$ is the Fourier coefficient of order n. Since we are fitting a jet-hadron distribution, the obtained $V_{n\Delta}$ components are a mixture of dijet and hadron v_n. Assuming no remaining nonflow contributions, $V_{n\Delta}^{\mathrm{jet-hadron}}$ factorizes [8] as

$$V_{n\Delta}^{\mathrm{jet-hadron}} = v_n^{\mathrm{dijet}}\,v_n^{\mathrm{hadron}}\,, \tag{3}$$

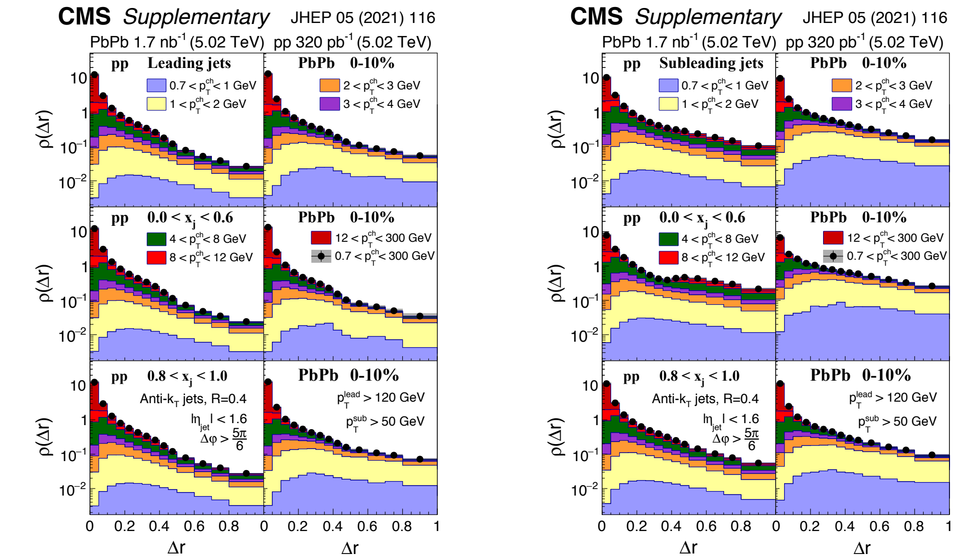

Figure 1. Jet shape distributions from pp and 0-10 % central PbPb collisions for different x_j selections for leading (left) and subleading (right) jets [4].

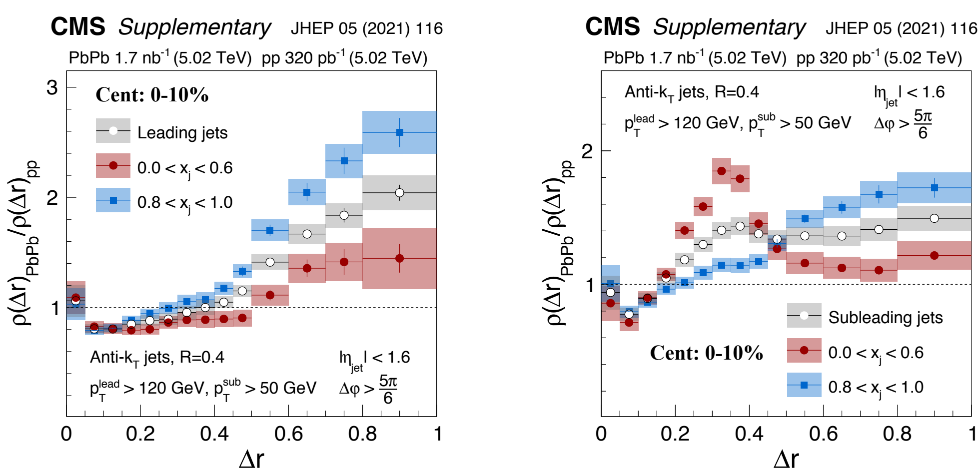

Figure 2. Ratios of PbPb to pp jet shapes for different x_j selections for leading (left) and subleading (right) jets. [4].

from which v_n^{dijet} is solved for. The v_n^{hadron} coefficient is factorized from dihadron correlations requiring the same p_{T}^{ch} bin for the trigger and associated hadrons. The away-side jet peak is explicitly removed from the jet-hadron correlation distribution as described in Section 2. Since there is no jet information for dihadrons, we need to restrict the analysis to $p_{\text{T}}^{\text{ch}} < 3\,\text{GeV}$ to keep the impact of the away-side jet contribution to v_n^{hadron} small.

The v_n^{dijet} results as a function of centrality factorized from the hadron p_{T} region of $0.7 < p_{\text{T}}^{\text{ch}} < 3\,\text{GeV}$ are presented in Fig 3. For v_2^{dijet} we see a rising trend towards more peripheral events up to 30–50% centrality bin. As the collision region becomes more almond-like for these more peripheral collisions, the in-plane versus the out-of-plane path-length difference gets more pronounced, causing this trend. The results are also compatible with previously measured multiparticle cumulant v_2 results at $p_T > 20$ GeV and $|\eta| < 1$ [9], and qualitatively in agreement with previous ALICE [7] and ATLAS [6] jet v_2 measurements. Both v_3^{dijet} and v_4^{dijet} are compatible with zero, meaning that we do not observe a measurable impact from medium density or initial state geometry fluctuations. In contrast, ATLAS has reported a positive jet v_3 [6]. However, direct comparison of the results should be avoided due to different analysis parameters and kinematic regions.

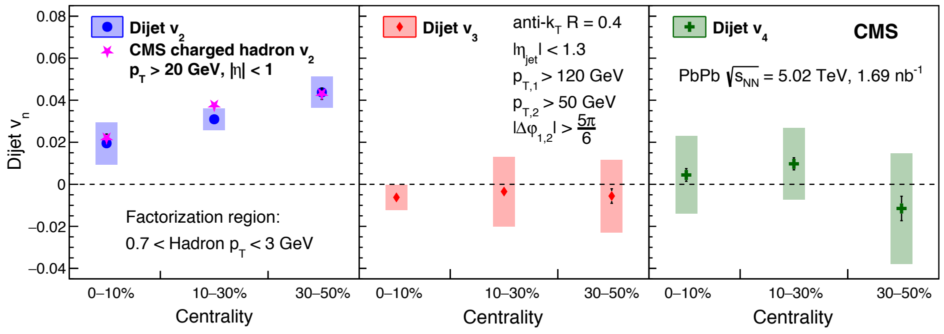

Figure 3. Dijet v_n as a function of centrality factorized from the region $0.7 < p_T^{\text{ch}} < 3$ GeV [5].

5 Summary

The CMS Collaboration has used the jet-hadron correlation method to study the path-length dependent parton energy loss in dijet events. We observe the greatest widening for the jet shapes for leading jets in lead-lead collisions with respect to proton-proton collisions in events where the dijet momentum is balanced. For subleading jets, the modifications are the greatest in events with significant dijet momentum imbalance. These observations are consistent with interpretations that unbalanced events are more susceptible to surface bias compared to balanced events, and that they are caused by energy loss fluctuations. We have further measured the Fourier expansion coefficients v_n for dijets, and observe positive and centrality dependent v_2^{dijet}. This can be interpreted as a result of the in-plane versus the out-of-plane path-length difference getting larger for more peripheral events, leading to larger difference in energy loss between these two directions. The higher order coefficients are consistent with zero.

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