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The first measurement of energy-energy correlator of jets in PbPb collisions at CMS

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Abstract. Energy-energy correlators can isolate physics of different angular scales, which has attracted a lot of interest recently to study it in heavy ion environments. Any modification from proton-proton reference can reveal hints about the inner workings of the quark-gluon plasma. In this presentation, we will present the first measurement of the energy-energy correlator of jets in heavy ion collisions using lead-lead data at 5.02 TeV collected by CMS. We observe significant modifications over the pp reference and discuss the implications of these observations.

1 Introduction

The two-point energy correlator is defined as a weighted distribution of angular separation Δr of all possible particle pairs within a jet cone, where the weights are the product of the transverse momenta (p_{T}) of the two particles in a pair. One of the most useful properties of the energy-energy correlator is that different time scales of the jet evolution are imprinted in different angular scales of the correlator. Parton showers in quantum chromodynamics are angular ordered, meaning that gluon emissions to angles larger than the opening angle of the parent partons are strongly suppressed. It follows that in the energy-energy correlator, large angles correspond to early times in the jet evolution, while small angles correspond to late times.

Energy correlators are particularly good observables for measuring phenomena that depend on angle. In heavy ion collisions, energy-energy correlators are predicted to be sensitive to color coherence effects [1], where only the gluons emitted above some critical angle can independently emit more gluons. They are also predicted to be sensitive to the “jet wake” effect [2], where a high-p_{T} parton traversing the plasma drags medium particles with it. While the relative contribution of these two mechanisms of energy loss in the quark-gluon plasma has yet to be experimentally established, energy correlators promise to be important new observables for their study.

2 Analysis methods

To construct the energy-energy correlators for this analysis, we first find high-p_{T} jets using the anti-k_{T} algorithm with $R = 0.4$. In heavy ion collisions, the underlying event background

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is subtracted from the jets using constituent subtraction algorithm. We then find the winner-take-all axis within each jet and place a cone of $R = 0.4$ around this axis. Energy-energy correlators are constructed from all unique particle pairs within this cone as

$$\mathrm{EEC}(\Delta r) = \frac{1}{W_{\mathrm{pairs}}} \frac{1}{\delta r} \sum_{\mathrm{jets} \in [p_{\mathrm{T},1}, p_{\mathrm{T},2}]} \sum_{\mathrm{pairs} \in [\Delta r_a, \Delta r_b]} \left(p_{\mathrm{T},i}\, p_{\mathrm{T},j} \right)^n , \tag{1}$$

where i, j refer to the particles inside the cone, $\Delta r = \sqrt{(\eta_i - \eta_j)^2 + (\varphi_i - \varphi_j)^2}$, Δr_a and Δr_b are the bin boundaries, $\delta r = \Delta r_b - \Delta r_a$ is the bin width, $p_{\mathrm{T},1}$ and $p_{\mathrm{T},2}$ are the $p_{\mathrm{T,jet}}$ borders, and exponent n controls the sensitivity to soft particles. The distributions are normalized to the weighted number of pairs W_{pairs}, meaning that they integrate to unity. Thus, when comparing correlators from different systems, we only look at differences in shapes.

To subtract the background coming from underlying event particles uncorrelated to the jet signal, we apply a mixed cone method. In this method the background is estimated by finding two minimum bias (MB) events with similar global event characteristics as the jet event, and pairing particles between different cones. The background subtracted distribution is obtained as

$$\mathrm{EEC}(\Delta r)_{\mathrm{subtracted}} = \mathrm{Jet\&Jet} - \mathrm{Jet\&MB1} - \mathrm{MB1\&MB1} + \mathrm{MB1\&MB2}\ . \tag{2}$$

Here the signal+background pairs are subtracted from the jet cone by the Jet&MB1 term and background+background pairs by the MB1&MB1 term. The background+background pairs oversubtracted by the Jet&MB1 term are added back to the jet cone in the MB1&MB2 term.

Furthermore, everything is corrected to particle level using efficiency corrections for tracks and iterative D'Agostini unfolding for jet p_{T}.

3 Results

The main goal of this analysis is to study the medium modifications of the energy-energy correlators. For this purpose, we compare the energy-energy correlator distributions from 0–10% central PbPb collisions to those from pp collisions with $p_{\mathrm{T}}^{\mathrm{ch}} > 1\,\mathrm{GeV}$, $120 < p_{\mathrm{T,jet}} < 140\,\mathrm{GeV}$, and $n = 1$ kinematic selection in Fig. 1. On the left side plot, we directly compare the distributions. First, we observe that the peak position in the PbPb correlator has moved to smaller Δr value compared to the pp case. This is a sign of jet energy loss. Since many jets in PbPb collisions have lost some amount of energy, the initial parton p_{T} for these is higher than the final measured jet p_{T}. In pp collisions, there is no jet energy loss, so initial parton p_{T} and final jet p_{T} values are much closer. The position of the peak depends on the virtuality of the initial parton. Higher parton p_{T} corresponds to higher virtuality, which causes the shift in the peak position. Furthermore, the amount of jet energy loss is proportional to the magnitude of the observed peak position shift.

Another observation we make from the comparison of the distributions is that the shape of the PbPb distribution with respect to the pp one changes at large Δr values. The slope at large Δr is much steeper for pp compared to PbPb collisions. To quantify this difference, we look at PbPb to pp ratio of the energy-energy correlator distributions on right side plot of Fig. 1. We can see that the shift of the peak position appears as an enhancement in the ratio at low Δr. Then, somewhere around $\Delta r \approx 0.1$, the trend in ratio starts to change and we see an enhancement again at large Δr.

To better understand the nature of the large Δr enhancement, we compare the results to CoLBT model [2], to a perturbative calculation by Holguin and collaborators [4], to the hybrid strong/weak coupling model [5], and to the JEWEL simulation [6] in Fig. 2. Concentrating on the large angle enhancement, this is produced dominantly by different medium

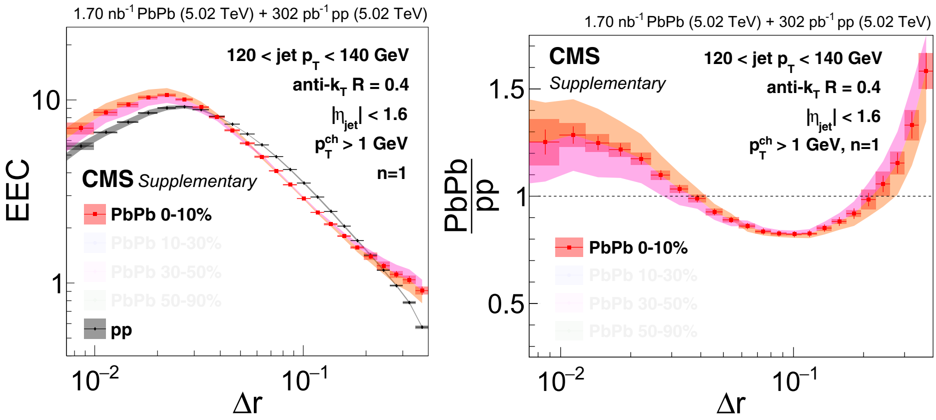

Figure 1. Left: Comparison of energy-energy correlator distributions with $p_T^{ch} > 1$ GeV, $120 < p_{T,jet} < 140$ GeV, and $n = 1$ between pp collisions and 0–10% central PbPb collisions. Right: Ratio of energy-energy correlator distribution on PbPb to pp collisions with the same kinematic selections. Statistical uncertainties are shown as vertical bars, while uncorrelated systematic uncertainties are presented as shaded boxes and correlated systematic uncertainties as shaded bands. Data is taken from Ref. [3].

response implementations in CoLBT, hybrid, and JEWEL and by color coherence contributions in the perturbative calculation. We see that qualitatively, each model can produce similar shape compared to data, with the perturbative calculation and JEWEL simulation best predicting the onset angle of enhancement. In JEWEL and hybrid model the same qualitative shape as in data is only obtained if the medium response effects are accounted for. These observations combined tell us that the large Δr enhancement is most likely caused by an interplay of several different effects.

Briefly mentioning about the small Δr region, setting q-parameter to $q = 1$ simulates jet energy loss effects in CoLBT, while $q = 0.5$ essentially corresponds to no energy loss. We see that the trend in data is captured only if the energy loss is simulated in this model.

4 Conclusions

We have measured the energy-energy correlators for the first time from heavy-ion collisions. We observe interesting modifications with respect to the proton-proton reference. Because of jet energy loss, the peak position of the energy-energy correlator distribution is shifted towards smaller angles. In addition to this, we observe jet substructure modification at large angles, where the distribution in lead-lead collisions is enhanced compared to the one in proton-proton collisions. To interpret this enhancement, the results are compared to models implementing the color coherence effect, and to models implementing medium response effects. Both classes of models predict same general structure, but cannot fully describe the observed modifications. This hints that both kinds of effects play an important role in heavy ion collisions.

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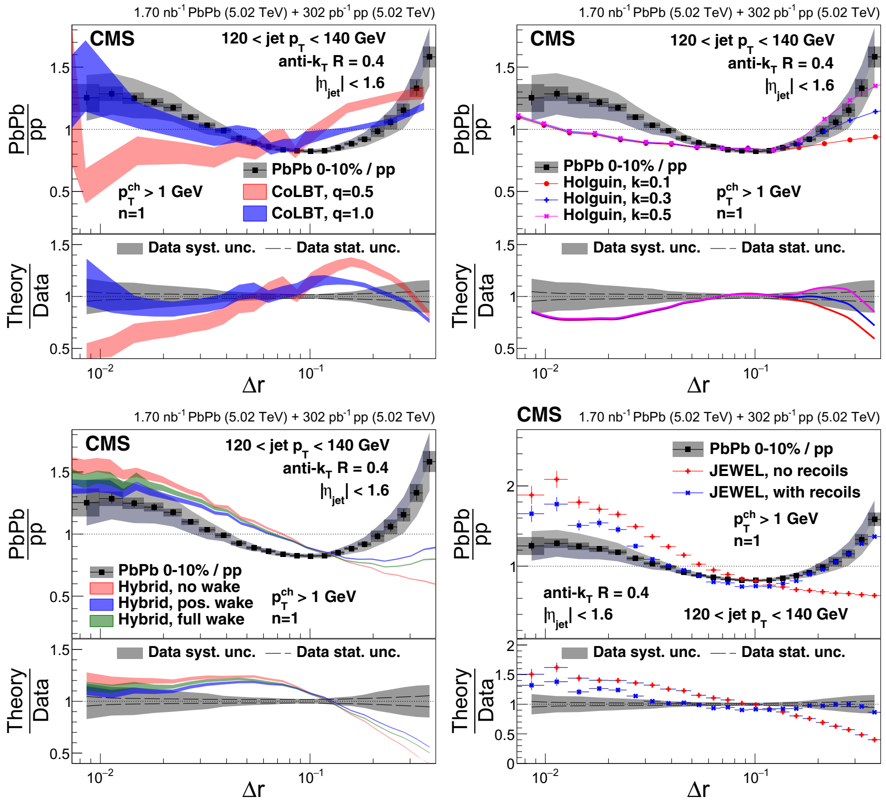

Figure 2. Top left: Comparison of 0–10% PbPb to pp energy-energy correlator ratio with $p_{\mathrm{T}}^{\mathrm{ch}} > 1\,\mathrm{GeV}$, $120 < p_{\mathrm{T,jet}} < 140\,\mathrm{GeV}$ and $n = 1$ kinematic selections from data to a prediction from CoLBT model (top left), a perturbative calculation by Holguin and collaborators (top right), a prediction from a hybrid strong/weak coupling model (bottom left), and a prediction from the JEWEL simulation (bottom right). All plots are taken from Ref. [3].

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