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Study of Z+jet correlations in PbPb and pp collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV

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Abstract

The production of Z+jet pairs is measured for the first time in pp and central PbPb collisions at a nucleon-nucleon center of mass energy of 5.02 TeV per nucleon pair, using data samples collected by the CMS experiment at the LHC. The Z+jet azimuthal angle difference and p_T imbalance are analysed for events containing a Z boson with transverse momentum $p_{\mathrm{T}}^{\mathrm{Z}} > 60$ GeV$/c$ and an associated jet with $p_{\mathrm{T}}^{\mathrm{Jet}} > 30$ GeV$/c$. A moderate shift in the $p_{\mathrm{T}}^{\mathrm{Jet}}/p_{\mathrm{T}}^{\mathrm{Z}}$ ratio is seen in central PbPb collisions with respect to the ratio found using pp data.

Keywords: jet quenching, boson-jet correlation, heavy ion

1. Introduction

The quark-gluon plasma (QGP) [1, 2] created in ultrarelativistic collisions of heavy nuclei is supposed to have a small size and short lifetime. One can study the medium by looking at the dynamics of elementary particles through it. The particles of interest are high energy quarks and gluons which are detected as jets in the final state. Among the probes used for QGP study [3, 4, 5, 6, 7, 8], dijet provides a large cross section, but has the disadvantage that both partons of the probe suffer energy loss so that a relative energy loss can be extracted [9, 10]. On the other hand, photon+jet and Z+jet events can be used to perform an absolute energy loss study [11, 12]. Photon+jet probe has a relatively larger cross section than Z+jet, however photon signal is contaminated with background processes which complicates the experimental selection of photon candidates. Z+jet probe has the advantage that there is no background process which challanges the boson selection.

The analysis presented here focuses on the characterization of the jet energy loss using Z+jet pairs and uses the data sets collected by the CMS experiment at the CERN LHC in 2015. A detailed description of the CMS detector can be found in Ref. [13]. The PbPb and pp data taken at nucleon-nucleon center of mass energy of 5.02 TeV correspond to an integrated luminosity of 404 μb^{-1} and 25.8 pb^{-1}, respectively. Correlations of the Z boson, reconstructed in the dimuon and dielectron decay channels, and jet are studied via the the azimuthal angle difference $\Delta\phi_{JZ} = |\phi^{\mathrm{Jet}} - \phi^{\mathrm{Z}}|$, the transverse momentum ratio $x_{JZ} = p_{\mathrm{T}}^{\mathrm{Jet}}/p_{\mathrm{T}}^{\mathrm{Z}}$, its mean value as a function of p_{T}^{Z} and the average number of jet partners per Z boson, R_{JZ}.

2. Analysis

Specific lepton filters are exploited for online event selection, then an offline cleaning is performed to reject noncollision events such as beam-gas interactions.

For the analysis of PbPb collisions, the "centrality" (i.e., the degree of the overlap of the two colliding nuclei) is determined by the sum of the total energy deposited in both HF calorimeters. The distribution of this total energy was used to divide the event sample into centrality bins. The most central 30% of the events (i.e., smallest impact parameter) is denoted as 0–30%. Details about the centrality determination can be found in Ref. [9].

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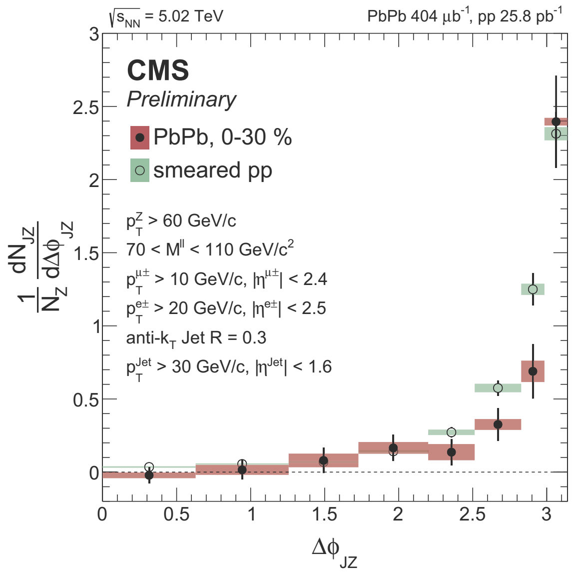

Figure 1: Azimuthal angle difference $\Delta\phi_{JZ}$ between the Z boson and the jet. The distribution is normalized by the number of Z boson events. Transverse momentum thresholds are $p_T^Z > 60$ GeV/c for Z bosons and $p_T^{\text{Jet}} > 30$ GeV/c for jets.

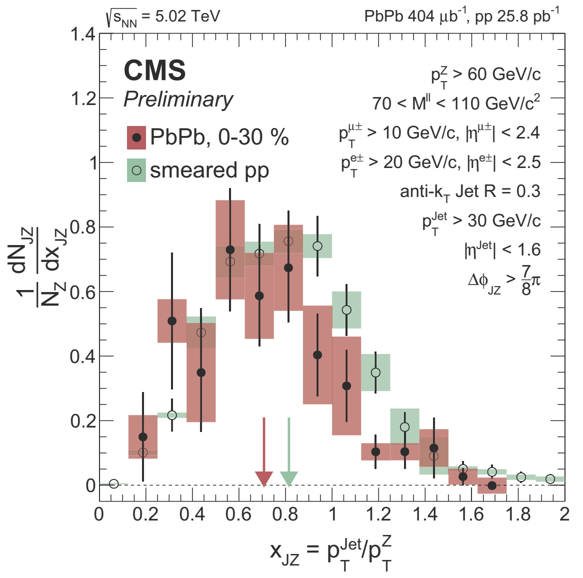

Figure 2: Transverse momentum ratio x_{JZ} between the Z boson and the jet, with the azimuthal angle separation $\Delta\phi_{JZ} > 7\pi/8$. The distribution is normalized by the number of Z boson events. Transverse momentum thresholds are $p_T^Z > 60$ GeV/c for Z bosons and $p_T^{\text{Jet}} > 30$ GeV/c for jets. The mean of the x_{JZ} distributions in PbPb and pp data are indicated with red and green arrows, respectively.

For simulation of Z+jet events, the PYTHIA 8 [14] event generator is used to generate events with a Z boson having a minimum p_T of 30 GeV/cand $|y| < 2.5$. For the simulation of PbPb collisions, the PYTHIA 8 events are embedded into HYDJET [15] samples.

Information from muon stations and the tracker is combined to identify muons. Then muons are required to have a transverse momentum of at least 10 GeV/c and to avoid detector edge effects, a kinematic range of $|\eta^{\mu}| < 2.4$ is selected. Electrons are identified as superclusters of energy deposition in the ECAL that are matched to tracks reconstructed in the tracker. The electrons are required to fulfill kinematic selections $p_T >$ 20 GeV/c and $|\eta| < 2.5$.

Jet reconstruction is performed with the anti-k_T jet algorithm that is encoded in the FastJet framework [16]. A distance parameter of $R = 0.3$ is used to minimize the effects of fluctuations in the underlying event (UE) which is formed in heavy ion collisions. In PbPb collisions, the heavy ion background is subtracted with an event-by-event approach [17, 18]. In pp collisions, no subtraction is applied. For energy corrections, the standard jet energy calibration procedure of CMS [19] is followed. The jet energy resolution is quantified using the Gaussian standard deviation σ of the $p_T^{\text{reco}}/p_T^{\text{gen}}$ ratio, where p_T^{reco} is the UE-subtracted, detector-level jet p_T and p_T^{gen} is the generator-level jet p_T without any contributions from the UE in PbPb. The jet energy resolution can be parametrized as a function of p_T^{gen} using the expression $\sigma\left(p_T^{\text{gen}}\right) = C \oplus \frac{S}{\sqrt{p_T^{\text{gen}}}} \oplus \frac{N}{p_T^{\text{gen}}}$, where $\oplus$ stands for the sum in quadrature and the quantities C, S, and N are parameters determined from simulation.

The Z boson candidates are defined as opposite-charge electron or muon pairs, with a reconstructed invariant mass in the interval 70–110 GeV/c^2 and $p_T >$ 40 GeV/c. For $\Delta\phi_{JZ}$ and x_{JZ} observables, a minimum p_T of 60 GeV/c is chosen for the the Z candidate so that it allows some dynamic range with the recoiling jet. Jets are required to satisfy kinematic selections $p_T^{\text{Jet}} >$ 30 GeV/c and $|\eta^{\text{Jet}}| < 1.6$. To eliminate the contribution of leptons from Z boson decays, jets that are reconstructed within a distance of $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.4$ from a lepton are rejected. After these selections, each Z boson candidate is paired with all jets in the same event. Finally, a minimum azimuthal angle between the jet and the Z boson, $\Delta\phi_{JZ} > 7\pi/8$, is required for the energy loss study, in order to suppress fake jets arising from the heavy ion background.

For jets, the background contribution comes from fake jets that are reconstructed from regional energy

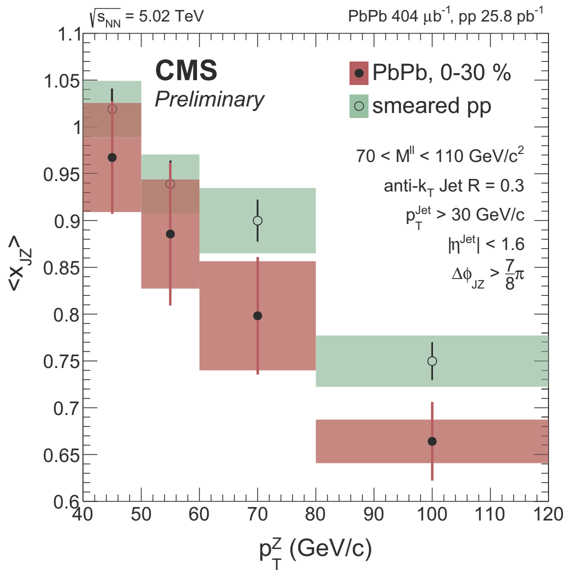

Figure 3: The mean value of the x_{JZ} distribution as a function of the Z boson transverse momentum.

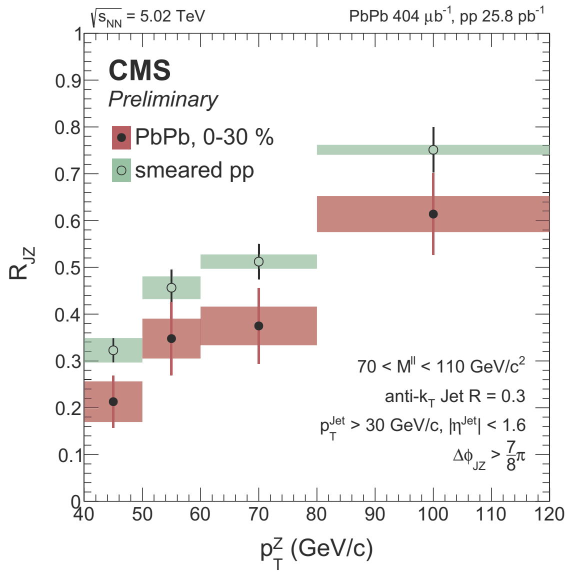

Figure 4: The R_{JZ} average number of jet partners per Z boson.

fluctuations in the high multiplicity heavy ion UE, or from multiple interactions. Background jets are not correlated to the Z boson and, therefore, are expected to appear uniformly in ϕ. The background jet contribution is estimated using a mixed-event method. The mixed-event jet background is constructed by correlating the Z boson from the candidate Z+jet event with jets reconstructed in a suitably chosen set of minimum bias events. The background spectrum is subtracted from the raw spectrum to obtain the background-subtracted spectrum.

The two dominant sources of systematic uncertainties for this analysis are the jet energy scale and the jet energy resolution. The systematic uncertainties in Z boson reconstruction are dominantly from dielectron channel, while the ones from dimuon channel are negligible. The contributions from all sources are added in quadrature, bin by bin.

3. Results

Here a subset of the results from Ref. [20] is presented. The final results are shown for the pp and the 0–30% most central PbPb collisions, after all the analysis steps. The pp data shown is smeared to simulate the worse of resolution due to the heavy ion UE. The back-to-back alignment of the Z boson and the recoiling jet is studied by looking at the azimuthal angle difference distribution $\Delta\phi_{JZ}$. Fig. 1 shows the $\Delta\phi_{JZ}$ distribution of Z+jet pairs that pass the relevant analysis selections. The shape of the $\Delta\phi_{JZ}$ correlation peak in PbPb (after background subtraction) is similar to the one in pp for small $\Delta\phi_{JZ}$ and is slightly narrower for large $\Delta\phi_{JZ}$. To measure the Z+jet momentum imbalance, the transverse momentum ratio x_{JZ} is used. Fig. 2 shows the x_{JZ} distribution for central PbPb collisions, in comparison to pp collisions. The Z+jet pairs where the jet has transverse momentum lower than 30 GeV/c are not included in the x_{JZ} calculation. This selection for the partner jet imposes a $p_T^{\rm Jet}$ -dependent limit on the magnitude of x_{JZ}. As the p_T^Z rises and moves away from the $p_T^{\rm Jet}$ cut-off, the kinematic phase space for lower x_{JZ} opens up resulting in a natural shift to lower mean x_{JZ} at higher p_T^Z.

The mean value of the x_{JZ} distribution, denoted as $\langle x_{JZ}\rangle$, is studied in Z boson p_T bins and shown in Fig. 3. The x_{JZ} distributions shown so far were for $p_T^Z > 60$ GeV/c. The 4 bins of p_T^Z are: 40–50, 50–60, 60–80, and > 80 GeV/c.

The average number of associated back-to-back jet partners per Z boson is denoted as R_{JZ}. This number is expected to increase as a function of p_T^Z due to the p_T threshold on the jets limiting the available phase space. In addition, it is expected that a jet with higher $p_T^{\rm Jet}$ is more likely to survive quenching in PbPb collisions. Fig. 4 shows how R_{JZ} depends on p_T^Z. The R_{JZ} values are systematically smaller in PbPb than in pp.

4. Conclusions

This is the first study of Z+jet correlations in PbPb collisions, made with the CMS experiment. The collisions of PbPb and pp at 5.02 TeV center-of-mass energy, corresponding to an integrated luminosity of 404 μb^{-1} and 25.8 pb^{-1}, respectively, were collected during the 2015 data taking period. The Z+jet correlations were studied using the azimuthal angle difference $\Delta\phi_{JZ}$, the transverse momentum ratio x_{JZ} and the probability to find a back-to-back jet partner R_{JZ}. The Z boson and jet were required to have transverse momentum greater than 60 GeV/c and 30 GeV/c, respectively. The transverse momentum ratio x_{JZ} for the 0–30% centrality PbPb collisions is shifted to lower values with respect to pp collisions. The study of the average value of the transverse momentum ratio in Z boson p_T bins shows that $\langle x_{JZ} \rangle$ is systematically smaller for PbPb collisions than in pp for all p_T bins. These observations are in agreement with expected jet quenching effects. For all Z boson p_T bins, R_{JZ} in PbPb collisions is lower than in pp collisions, which suggests that in PbPb collisions a larger fraction of partons associated with the Z boson lost energy and fell below the 30 GeV/c jet p_T threshold.

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