

Study of jet quenching using di-jet and photon-jet events in $PbPb$ collisions at 2.76 TeV with CMS

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Abstract. The first measurement of the transverse momentum imbalance of isolated-photon-jet pairs and the modification of fragmentation function of the inclusive jets in relativistic heavy ion collisions are reported. The analysis uses data from $PbPb$ collisions at a center-of-mass energy of 2.76 TeV per nucleon pair and corresponding to an integrated luminosity of $150 \mu\text{b}^{-1}$ recorded by the CMS experiment at the LHC in 2011. For events containing an isolated photon with transverse momentum $p_T > 60$ GeV/c and an associated jet with $p_T > 30$ GeV/c, the photon-jet p_T imbalance is studied as a function of collision centrality and compared to pp data and PYTHIA calculations at the same center-of-mass energy. Using the p_T of the isolated photon as an estimate of the energy of the associated parton at production, this measurement allows an unbiased characterization of the in-medium parton energy loss. In addition, further study on the modification of jet fragmentation function was studied using inclusive jets with $p_T > 100$ GeV/c. Both show the gradual centrality dependence of jet energy loss and fragmentation function modification.

1. Introduction

These proceedings can be divided into two subjects. The first half shows the study of the jet energy loss using isolated-photon-jet pairs from $PbPb$ data taken by CMS detector [1]. The result was compared to pp reference dataset with $\int \mathcal{L} dt = 230 \text{ nb}^{-1}$ at $\sqrt{s} = 2.76$ TeV which was obtained in 2011. The properties of isolated-photon-jet pairs are studied via the azimuthal angular correlation in $\Delta\phi_{J\gamma} = |\phi - \phi^\gamma|$ and the transverse momentum ratio given by $x_{J\gamma} = p_T^{Jet}/p_T^\gamma$. Photons with transverse momentum of $p_T^\gamma > 60$ GeV/c are selected in a pseudorapidity range of $\eta^\gamma < 1.44$, using isolation criteria. These photons are then correlated with jets having $p_T > 30$ GeV/c and $\eta < 1.6$ [2].

In the second half, the measurement of fragmentation function for inclusive jets above 100 GeV/c is discussed [3]. The fragmentation properties of jets connect the perturbatively calculable production of high- p_T quarks and gluons with the hadronized final state particles. The study of jet production via final state particles relies on hadronization models to determine e.g. the non-perturbative hadronization corrections of the production cross section, and also the experimental jet energy scale. It also provides an important experimental check on the validity of the assumed jet fragmentation.

2. Photon-jet correlations

2.1. Azimuthal angle correlations

Possible medium effects on the back-to-back alignment of the photon and recoiling jet can be studied using the distribution of the number of photon-jet pairs, $N_{J\gamma}$, as a function of the relative azimuthal angle, $\Delta\phi_{J\gamma}$, normalized by the total number of pairs, $(N_{J\gamma})^{-1}dN_{J\gamma}/d\Delta\phi_{J\gamma}$. The $PbPb$ data are compared to PYTHIA + HYDJET simulation and pp data. For both $PbPb$ data and MC distributions, the jet is found to be well aligned opposite to the photon direction, with a clear peak at $\Delta\phi_{J\gamma} = \pi$. The shape of the $\Delta\phi_{J\gamma}$ correlation peak is similar in $PbPb$ data and MC. An excess in the tail of the 0–10% centrality bin was found. However, further investigation showed that it was not inconsistent with PYTHIA + HYDJET within the given statistics.

To study the centrality evolution of the shape, the distributions are fitted to a normalized exponential function:

$$\frac{1}{N_{J\gamma}} \frac{dN_{J\gamma}}{d\Delta\phi_{J\gamma}} = \frac{e^{(\Delta\phi-\pi)/\sigma}}{(1 - e^{-\pi/\sigma}) \sigma}. \quad (1)$$

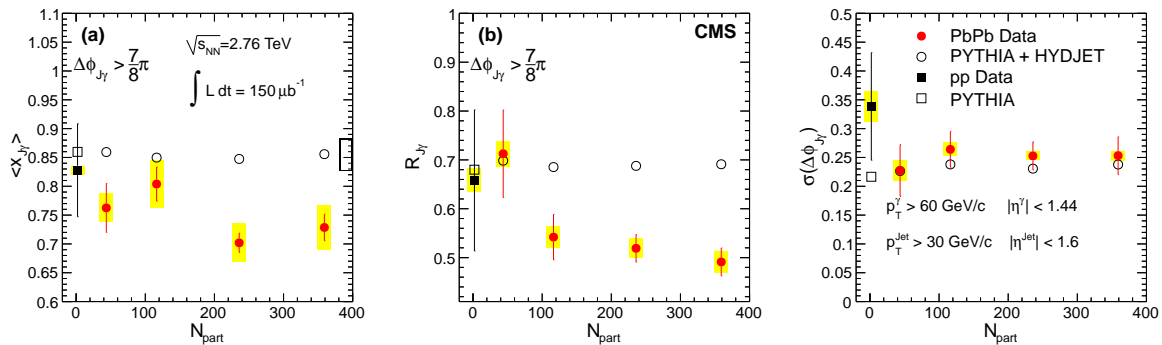


Figure 1. (Left) Average ratio of jet transverse momentum to photon transverse momentum as a function of N_{part} . The empty box at the far right indicates the correlated systematic uncertainty. (Middle) Average fraction of isolated photons with an associated jet above 30 GeV/c as a function of N_{part} . In both panels, the yellow boxes indicate point-to-point systematic uncertainties and the error bars denote the statistical uncertainty. (Right) Azimuthal angle correlation is consistent with MC for all centrality bins.

The resulting $\sigma(\Delta\phi_{J\gamma})$ values in $PbPb$ do not show a significant centrality dependence within the present statistical and systematic uncertainties. For central $PbPb$ collisions, $\sigma(\Delta\phi_{J\gamma})$ is similar to the PYTHIA reference based on the Z2 tune, and comparison with other PYTHIA tunes shows a theoretical uncertainty that is larger than the difference between the data and MC. Comparing the PYTHIA tune Z2 with tune D6T [4, 5] shows an 8% difference in $\sigma(\Delta\phi_{J\gamma})$, which is expected because these two tunes differ in their parton shower ordering resulting in a different $\Delta\phi$ correlation. The result that $\sigma(\Delta\phi_{J\gamma})$ is not found to be significantly modified by the medium is consistent with the earlier observation of an unmodified $\Delta\phi$ correlation in dijet events [6].

2.2. Photon-jet momentum imbalance

The momentum asymmetry ratio $x_{J\gamma} = p_T^{Jet}/p_T^{\gamma}$ is used to quantify the photon-jet momentum imbalance. In addition to the jet and photon selections used in the $\Delta\phi_{J\gamma}$ study, we further impose a strict $\Delta\phi_{J\gamma} > \frac{7}{8}\pi$ cut to suppress contributions from background jets. Note that photon-jet pairs for which the associated jet falls below the 30 GeV/c threshold are not included in the $x_{J\gamma}$ calculation. This limits the bulk of the $x_{J\gamma}$ distribution to $x_{J\gamma} \gtrsim 0.5$. The $\langle x_{J\gamma} \rangle$

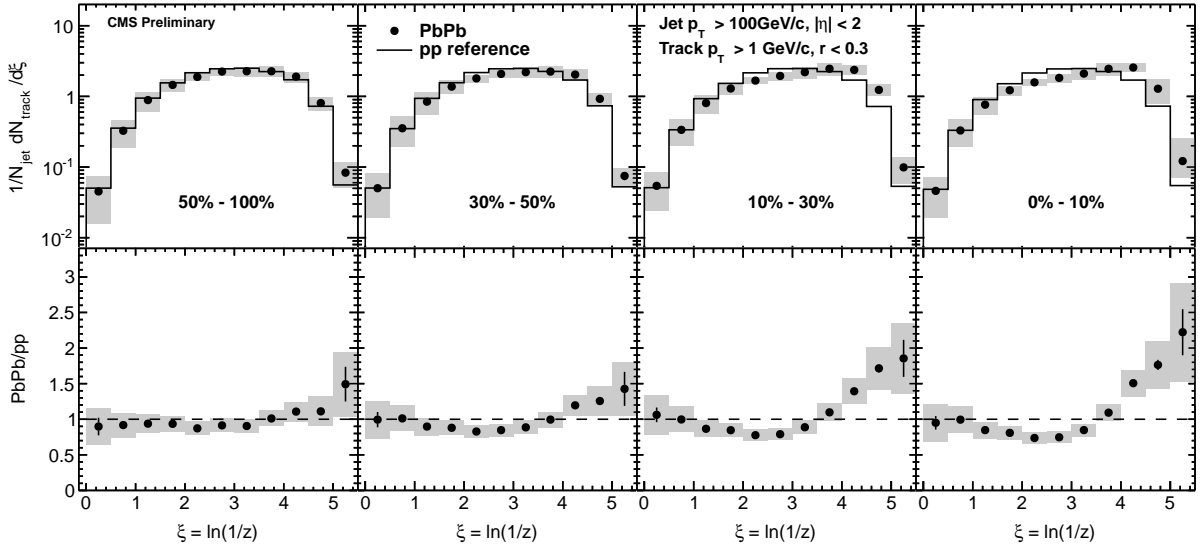


Figure 2. Top row shows fragmentation function in $PbPb$ in bins of increasing centrality overlaid with pp reference data. The reference was made from the fragmentation function in pp collision with the same jet selection, but reweighted by the $PbPb$ jet spectra and then smeared by the momentum resolution. The $PbPb$ data is shown in the top row in four increasing centrality bins from left to right. The bottom row shows the ratio of each $PbPb$ fragmentation function to its pp reference.

obtained from PYTHIA tunes Z2 and D6T agree to better than 1%. Overlaid in the peripheral bin is the $\langle x_{J\gamma} \rangle$ for 2.76 TeV pp data, showing consistency to the MC reference. However the poor statistics of the pp data does not allow a significant comparison. Further studies using the 7 TeV high statistics pp data showed a good agreement in $\langle x_{J\gamma} \rangle$ between data and PYTHIA justifying the use of PYTHIA + HYDJET as an un-modified reference.

While the photon-jet momentum ratio in the PYTHIA + HYDJET simulation shows almost no change in the peak location and only a modest broadening, even in the most central $PbPb$ events, the $PbPb$ collision data exhibit a change in shape, shifting the distribution towards lower $x_{J\gamma}$ as a function of centrality. It is important to note that, as discussed above, the limitation of $x_{J\gamma} \gtrsim 0.5$ limits the degree to which this distribution can shift.

It is important to keep in mind that the average energy loss of the selected photon-jet pairs does not constitute the full picture. There are genuine photon-jet events which do not contribute to the $\langle x_{J\gamma} \rangle$ distribution because the associated jet falls below the $p_T^{Jet} > 30$ GeV/c threshold.

As shown in Figure 1, the value of $R_{J\gamma}$ is found to decrease, from $R_{J\gamma} = 0.685 \pm 0.008(stat.) - 0.698 \pm 0.006(stat.)$ for the PYTHIA + HYDJET reference, as well as pp and peripheral $PbPb$ data, to the significantly lower $R_{J\gamma} = 0.49 \pm 0.03(stat.) \pm 0.02(syst.) - 0.54 \pm 0.05(stat.) \pm 0.02(syst.)$ for the three $PbPb$ bins above 50% centrality.

3. Modification of Jet Fragmentation

Jet fragmentation functions are measured by correlating reconstructed charged-particle tracks falling within the jet cones, with the axis of the respective jet [7]. As done in previous measurements at hadron colliders [8], the fragmentation function is presented as a function of the variable

$$\xi = \ln \frac{1}{z} ; \quad z = \frac{p_{\parallel}^{track}}{p^{jet}}, \quad (2)$$

where p_{\parallel}^{track} is the momentum component of the track along the jet axis, and p^{jet} is the magnitude of the jet momentum. The tracks in a cone of $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} < 0.3$ around the jet axis are selected for analysis. The fragmentation functions, defined as $1/N_{jet}$, are normalized to the total number jets (N_{jet}).

In order to quantify the medium-related effects, the results are compared to the references based on pp data. For constructing a proper reference distribution, the pp jet momenta are smeared and reweighted to match the $PbPb$ jet distributions for a given analysis selection. As for the jet shape analysis, the background of tracks not correlated with the jet in $PbPb$ collisions is estimated using the η -reflection method.

Figure 2 shows the comparison of fragmentation function between the pp reference and $PbPb$. The significant modification of the fragmentation function was found in central events and it grows with the collision centrality. In the 50-100% bin, the ratio of $PbPb / pp$ is flat at unity which means no modification. However, an excess in high ξ is observed for more central events. In the most central 0-10% collisions and for the lowest charged particle momenta studied, the $PbPb / pp$ fragmentation function ratio rises about a factor of 2. This implies that for central collisions the spectrum of particles in a jet has an enhanced contribution of soft particles compared to one from pp collisions.

4. Summary

The first study of isolated-photon-jet correlations and modification of the inclusive jet fragmentation function in $PbPb$ collisions at $\sqrt{s_{NN}} = 2.76$ TeV has been performed as a function of collision centrality using a dataset corresponding to an integrated luminosity of $150 \mu\text{b}^{-1}$. Isolated photons with $p_{\text{T}}^{\gamma} > 60$ GeV/c were correlated with jets with $p_{\text{T}}^{jet} > 30$ GeV/c to determine the width of the angular correlation function, $\sigma(\Delta\phi_{J\gamma})$, the jet/photon transverse momentum ratio, $x_{J\gamma} = p_{\text{T}}^{jet}/p_{\text{T}}^{\gamma}$, and the fraction of photons with an associated jet, $R_{J\gamma}$. Also, in order to study the jet fragmentation function to high ξ region with high statistics, high p_{T} jets were selected instead of isolated-photon-jet events.

In summary, no angular broadening of recoiled jets was observed beyond that seen in the pp data and MC reference at all centralities. Due to the hot and dense medium created in central $PbPb$ collisions, there was significant energy loss of jets and remarkable modification of fragmentation function was found.

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