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Study of jet quenching using dijets in PbPb Collisions with CMS

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Abstract

Jets are an important tool to probe the hot, dense medium that is produced in ultra-relativistic heavy ion collisions. The large collision energy at the LHC provides copious production of dijets with energies that can be cleanly identified above the heavy ion background. The multipurpose Compact Muon Solenoid (CMS) detector is well designed to measure these hard scattering processes with its high resolution calorimeters and high precision silicon tracker. Jet quenching is observed by a significant imbalance of dijet transverse momentum in PbPb collisions at $= 2.76$ TeV. The fraction of unbalanced dijets is found to increase strongly with increasing collision centrality. The dijet imbalance persists to the highest jet momenta studied. The redistribution of the quenched jet energy is studied using the transverse momentum balance of charged tracks projected onto the direction of the leading jet. In contrast to pp collisions, a large fraction of the momentum balance for asymmetric jets is found to be carried by low momentum particles at large angular distance to the jet axis.

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Study of jet quenching using dijets in PbPb Collisions with CMS

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Abstract. Jets are an important tool to probe the hot, dense medium that is produced in ultra-relativistic heavy ion collisions. The large collision energy at the LHC provides copious production of dijets with energies that can be cleanly identified above the heavy ion background. The multipurpose Compact Muon Solenoid (CMS) detector is well designed to measure these hard scattering processes with its high resolution calorimeters and high precision silicon tracker. Jet quenching is observed by a significant imbalance of dijet transverse momentum in PbPb collisions at $\sqrt{s_{_{NN}}} = 2.76$ TeV. The fraction of unbalanced dijets is found to increase strongly with increasing collision centrality. The dijet imbalance persists to the highest jet momenta studied. The redistribution of the quenched jet energy is studied using the transverse momentum balance of charged tracks projected onto the direction of the leading jet. In contrast to pp collisions, a large fraction of the momentum balance for asymmetric jets is found to be carried by low momentum particles at large angular distance to the jet axis.

The analysis presented here is based on data collected in 2010 from PbPb collisions at $\sqrt{s_{_{NN}}} = 2.76$ TeV with the CMS detector [1]. Jets are reconstructed from calorimeter energies using an iterative cone algorithm and a cone radius of 0.5. The soft underlying event is subtracted with the iterative pileup subtraction algorithm [2]. The jet energy is corrected for calorimeter response based on PYTHIA simulations and pp data [3]. Simulations of QCD dijets in PYTHIA are embedded into both HYDJET simulations and into minimum bias PbPb data. The jet reconstruction performance, efficiency, fake rate, and energy resolution are studied [4]. The fluctuations of the soft background is studied in both simulation and minimum bias PbPb data. The jet performance and background effects are included in the systematic uncertainty. Dijet events are selected with leading jet $p_{\mathrm{T},1} > 120\ GeV/c$, subleading jet $p_{\mathrm{T},2} > 50\ GeV/c$, and angular difference of $\Delta\phi_{12} > 2/3\pi$. Both jets are required to be within $|\eta| < 2$.

Dijet pair momentum balance can be quantified with the asymmetry ratio, A_J:

$$A_J = \frac{p_{\mathrm{T},1} - p_{\mathrm{T},2}}{p_{\mathrm{T},1} + p_{\mathrm{T},2}}\ , \tag{1}$$

where the subscript 1 always refers to the leading jet, so that A_J is positive by construction. The use of A_J removes uncertainties due to possible constant shifts of the jet energy scale. It is important to note that the dijet p_{T} selections impose a

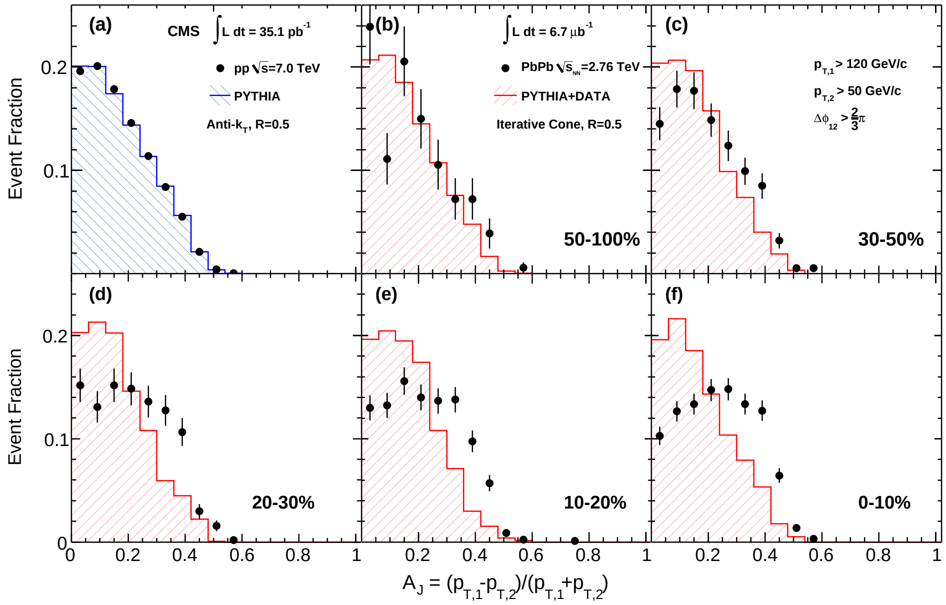

Figure 1. Dijet asymmetry ratio, A_J, for leading jets of $p_{\mathrm{T},1} > 120\ GeV/c$, subleading jets of $p_{\mathrm{T},2} > 50\ GeV/c$, and $\Delta\phi_{12} > 2\pi/3$ for (a) 7 TeV pp collisions and 2.76 TeV PbPb collisions in several centrality bins: (b) 50–100%, (c) 30–50%, (d) 20–30%, (e) 10–20% and (f) 0–10%. Data are shown as black points, while the histograms show (a) PYTHIA events and (b)-(f) PYTHIA events embedded into PbPb data. The error bars show the statistical uncertainities.

threshold on A_J, and that dijets in which the subleading jet is below the 50 GeV/c threshold are not included in the A_J calculation.

In Figure 1 (a), the dijet momentum asymmetry, A_J for pp data at $\sqrt{s} = 7$ TeV is compared to PYTHIA using jets reconstructed with the anti-k_T algorithm [5]. Most of the large A_J events in pp (and PYTHIA) are found to be from the presence of a third jet. Figures 1 (b)-(f) shows the centrality dependence of A_J in PbPb collisions in comparison to PYTHIA+DATA. The data shows an increased fraction of imbalanced dijets with increasing centrality. The jets reconstructed from PYTHIA embedded into minimum bias data (thus including a realistic soft background) do not show this increase. This momentum imbalance is also confirmed when studying high-p_T tracks associated with leading and subleading jets [4].

To quantify the dijet momentum balance and include the contribution of events without an identified subleading jet, the fraction of balanced jets is shown in Figure 2. The balanced fraction, $R_B(A_J < 0.15)$ is defined as the fraction of selected dijet events which are balanced in momentum to all other events in which only a leading jet of $p_{\mathrm{T},1} > 120\ GeV/c$ is found. This takes into account apparent mono-jet events. The value of 0.15 corresponds to the median of the PYTHIA dijet A_J distribution for selected dijets. The data show a rapid decrease in the fraction of balanced jets with collision centrality. This suggests that the passage of hard-scattered partons through the environment created in the PbPb collisions has a significant impact on the number

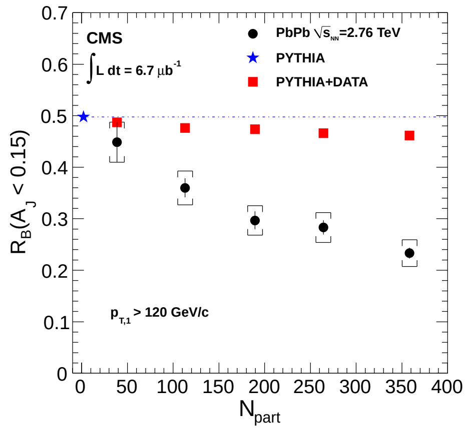

Figure 2. Fraction of all events with a leading jet with $p_{\mathrm{T},1} > 120$ GeV/c for which a subleading jet with $A_J < 0.15$ and $\Delta\phi_{12} > 2\pi/3$ is found, as a function of the number of participants (N_{part}). The result for reconstructed PYTHIA dijet events (blue filled star) is plotted at $N_{\mathrm{part}} = 2$. The red squares are for reconstruction of PYTHIA+DATA events and the filled circles are for the PbPb data, with statistical (vertical bars) and systematic (brackets) uncertainties.

of momentum balanced dijets.

Complementary to the calorimeter jet momentum studies is that of jet-track correlations. The "missing momentum" is studied using all the charged particle tracks available with of $p_{\mathrm{T}} > 0.5$ GeV/c. This is done with the projection of missing p_{T} of reconstructed charged tracks onto the leading jet axis ($\phi_{\mathrm{Leading\ Jet}}$). For each event, this projection is calculated as:

$$\not{p}_{\mathrm{T}}^{\parallel} = \sum_{\mathrm{i}} -p_{\mathrm{T}}^{\mathrm{i}} \cos\left(\phi_{\mathrm{i}} - \phi_{\mathrm{Leading\ Jet}}\right), \quad (2)$$

where the sum is over all tracks with $p_{\mathrm{T}} > 0.5$ GeV/c and $|\eta| < 2.4$. The results are then averaged over events to obtain $\langle \not{p}_{\mathrm{T}}^{\parallel} \rangle$. No background subtraction is needed, and the leading and subleading jets are required to have $|\eta| < 1.6$. The $\not{p}_{\mathrm{T}}^{\parallel}$ variable is constructed so that tracks in the direction of the subleading jet give postitive values. For all the tracks of $p_{\mathrm{T}} > 0.5$ GeV/c, the momentum balance is recovered, there is no significant missing momentum, even for increased dijet asymmetry, A_J [4].

To look for the balance of momentum with respect to a jet cone of size $\Delta R = 0.8$, $\langle \not{p}_{\mathrm{T}}^{\parallel} \rangle$ is studied separately for tracks inside cones around the leading jet axis, and for tracks outside those cones. For central events, the results are shown in Figure 3 for simulations (top row), and data (bottom row). As the underlying PbPb event in both data and simulation is not ϕ-symmetric on an event-by-event basis, the back-to-back requirement is tightened to $\Delta\phi_{12} > 5\pi/6$ for this study. Events are classified by dijet asymmetry, with the highest A_J corresponding to the most asymmetric events. For asymmetric events, in both data and simulation, the tracks in-cone show a momentum excess towards the leading jet (negative values), of mainly high p_{T} tracks.

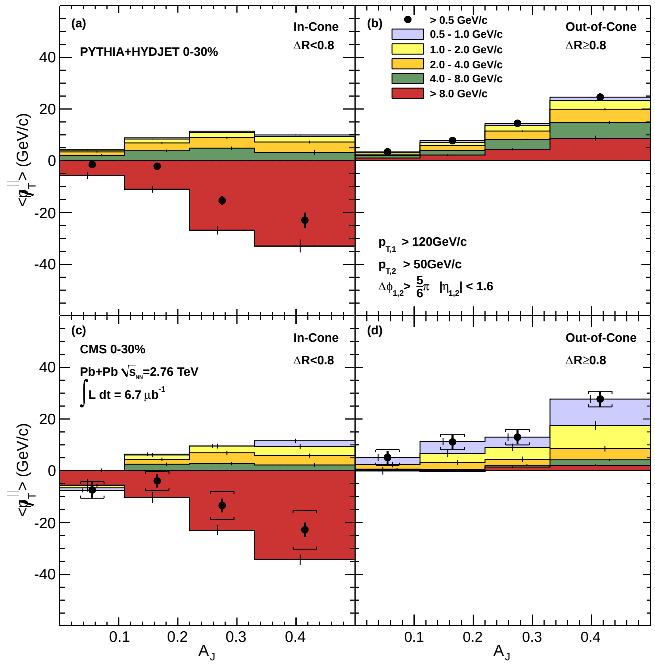

Figure 3. Average missing transverse momentum, $\langle \not{p}_{\mathrm{T}}^{\parallel} \rangle$, for tracks with $p_{\mathrm{T}} > 0.5\ GeV/c$, projected onto the leading jet axis (solid circles). The $\langle \not{p}_{\mathrm{T}}^{\parallel} \rangle$ values are shown as a function of dijet asymmetry A_J for 0–30% centrality, inside ($\Delta R < 0.8$) one of the leading or subleading jet cones (a,c) and outside ($\Delta R > 0.8$) the leading and subleading jet cones (b,d). Vertical bars represent the statistical uncertainty, and for the solid circles brackets represent the systematic uncertainty.

In PYTHIA+HYDJET, the out-of-cone tracks show an excess in the direction of the subleading jet (positive values) with more than 50% of the balance carried by tracks with $p_{\mathrm{T}} > 4\ GeV/c$. This corresponds to a third jet which is found in PYTHIA to be 90% of the rare asymmetric events. In contrast, the PbPb data show an excess of low p_{T} tracks (below $2\ GeV/c$) outside of the 0.8 cone in the hemisphere of the subleading jet for events that have a significant dijet momentum asymmetry.

References

[1] CMS Collaboration, The CMS experiment at the CERN LHC, *JINST* **3** (2008) S08004.

[2] O. Kodolova, I. Vardanian, A. Nikitenko et al., The performance of the jet identification and reconstruction in heavy ions collisions with CMS detector, *Eur. Phys. J.* **C50** (2007) 117.

[3] CMS Collaboration, Determination of the Jet Energy Scale in CMS with pp Collisions at $\sqrt{s} = 7$ TeV, *CMS-PAS-JME-10-010* (2010).

[4] CMS Collaboration, Observation and studies of jet quenching in PbPb collisions at nucleon-nucleon center-of-mass energy = 2.76 TeV, `arXiv:1102.1957`.

[5] M. Cacciari, G. P. Salam, and G. Soyez, The anti-k_t jet clustering algorithm, *JHEP* **04** (2008) 063, `arXiv:0802.1189`.