The Compact Muon Solenoid Experiment
Conference Report

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

16 December 2016 (v3)

Photon-Jet Correlations in pp and PbPb collisions at 5.02 TeV with CMS

Christopher Mc Ginn for the CMS Collaboration

Abstract

Electromagnetic probes such as photons do not participate in the strong interaction, and thus provide a clean measurement of the initial state in nuclear collisions. Correlations of photons balancing with jets in PbPb collisions constitute the golden channel to study parton energy loss in strongly interacting matter, since the photon not only determines the initial transverse momentum of the balancing parton, but also preferentially selects quark jets. We will present new results from pp and PbPb collisions at 5.02 TeV collision energy, including the high statistics data collected with the CMS detector in the 2015 LHC run. The results include detailed studies of azimuthal and momentum correlations of isolated photons and associated jets, as well as jet I_{AA} , *as a function of photon p_T and collision centrality.*

Presented at *HardProbes2016 The 8th International Conference on Hard and Electromagnetic Probes of High-energy Nuclear Collisions*

Photon-Jet Correlations in pp and PbPb collisions at 5.02 TeV with CMS

Christopher McGinn

On behalf of the CMS collaboration

Abstract

Electromagnetic probes such as photons do not participate in the strong interaction, and thus provide a clean measurement of the initial state in nuclear collisions. Correlations of photons balancing with jets in PbPb collisions constitute the golden channel to study parton energy loss in strongly interacting matter, since the photon not only determines the initial transverse momentum of the balancing parton, but also preferentially selects quark jets. We will present new results from pp and PbPb collisions at 5.02 TeV collision energy, including the high statistics data collected with the CMS detector in the 2015 LHC run. The results include detailed studies of azimuthal and momentum correlations of isolated photons and associated jets, as well as jet I_{AA} , as a function of photon p_T and collision centrality.

Keywords:

1. Introduction

In heavy ion collisions at ultrarelativistic energies, quarks and gluons can exist freely as part of a hot, dense medium [1]. To study this medium, referred to as the Quark-Gluon Plasma, or QGP, energetic partons are a useful tool. These probes are produced before medium formation, and therefore modifications relative to vacuum can be interpreted as resulting from interaction with the medium as the parton travels through it. One potential signature of the medium is parton energy loss [2, 3, 4, 5, 6, 7]. Observed imbalance in dijet transverse momentum relative to pp reference and Monte Carlo at the LHC is interpreted as resulting from parton energy loss [8, 9].

To quantify absolute parton energy loss, an unquenched probe is needed to tag initial parton momentum prior to traversing the medium. In the dijet case, both leading and subleading object are quenched and this is not easily disentangled. However, in photon + jet channel, the photon is colorless and therefore unmodified when traversing the medium. By studying photon + jet momentum imbalance in the medium and comparing to reference vacuum, absolute energy loss of partons

can be quantified.

In this analysis, photon + jet events in PbPb and pp collisions are used to quantify absolute parton energy loss in the medium, by studying the azimuthal angle between photon and correlated jets, the ratio of jet transverse momentum with photon transverse momentum for pairs back-to-back in azimuth, and the average number of jets correlated to a photon.

2. CMS Detector

Data analyzed was recorded using the CMS detector at the LHC. The coordinate system referred to throughout is pseudorapidity η , where $\eta = -\ln[\tan(\theta/2)]$ and θ is the polar angle relative to the counterclockwise beam direction, and ϕ , the azimuthal angle covering symmetric 2π around the beam. The most relevant subdetector systems employed in this analysis are the electromagnetic calorimeter (ECAL) and the hadronic calorimeter (HCAL). Photon candidates used in this analysis are reconstructed using the energy deposited in the barrel region of the PbWO₄ crystal ECAL, which covers $|\eta| < 1.479$. The brass/scintillator HCAL barrel region covers $|\eta| < 1.74$. The calorimeters are located

Figure 1: Azimuthal correlation of photons and jets in each p_T^γ bin is plotted, going left to right in panels p_T^γ is binned as 40-50, 50-60, 60-80, 80-100, and > 100 GeV, while top is plotted for central, 0-30% PbPb and bottom peripheral, 30-100% PbPb data. The PbPb data are compared to smeared pp data. Statistical uncertainties are represented by vertical lines, while systematic uncertainties are represented by shaded boxes. For more please refer to CMS Physics Analysis Summary, Ref. [10].

within the 3.8 T magnetic field of the super-conducting solenoid. For a more detailed overview of the CMS detector, including other subdetector systems used in this analysis but omitted here, refer to Ref. [10] and Ref. [11].

3. Photon Reconstruction

Photons are reconstructed with the CMS detector from energy depositions in the ECAL. In this analysis, photon reconstruction is restricted to the barrel, $|\eta| < 1.44$. Algorithm used in reconstruction of photons in pp sample is detailed in Ref. [12]. The algorithm used to reconstruct photons in PbPb sample is detailed in Ref. [13]. A cut on ratio of HCAL and ECAL energy, $\text{HCAL/ECAL} < .1$ within a cone surrounding the photon in $\eta - \phi$ of 0.15 excludes some background. Further background from neutral mesons can be excluded with cuts on shower shape. Photons are also required to be isolated, requiring a measure of local background-subtracted activity to be less than 1 GeV. Further details on photon selection and reconstruction can be found in Ref. [10].

4. Jet Reconstruction

In this analysis, jets are reconstructed using the “particle-flow” algorithm as detailed in Refs. [14, 15].

Particle-flow constituents are created by combining information from all subdetector systems. Produced particle flow constituents are clustered using anti- k_T jet algorithm as provided in FASTJET [16, 17]. The jet radius parameter of $R = 0.3$ is chosen to reduce the impact of fluctuations from underlying event (UE).

The UE background is subtracted from jets in PbPb collisions using the iterative algorithm as implemented in Ref. [8]. No such background subtraction is employed in pp collisions. Further details on jet selection and reconstruction can be found in Ref. [10].

5. Event Selection

This analysis is performed with 5.02 TeV PbPb and reference pp data collected at the LHC with the CMS detector at the end of 2015. A total integrated luminosity of $404 \mu\text{b}^{-1}$ of PbPb collisions was collected, while 25.8 pb^{-1} of pp collisions was collected. The analysis includes all photon+jet pairs satisfying kinematic selection. The photon is cut at $p_T > 40$ GeV and $|\eta| < 1.44$. Corresponding correlated jets are cut at $p_T > 30$ GeV, $|\eta| < 1.6$. Since all jets in any given event are correlated with leading photon, a mixed event background subtraction is employed to remove contributions from jets that come from UE. Photon + jets are required to be back-to-back in azimuthal plane with a cut of $\Delta\phi_{J\gamma} > \frac{7}{8}\pi$ in Fig. 2-4.

Figure 2: Distribution of $x_{J\gamma} = p_T^{\text{jet}}/p_T^\gamma$ in each p_T^γ bin is plotted, going left to right in panels p_T^γ is binned as 40-50, 50-60, 60-80, 80-100, and > 100 GeV, while top is plotted for central, 0-30% PbPb and bottom peripheral, 30-100% PbPb data. The PbPb data are compared to smeared pp data. Statistical uncertainties are represented by vertical lines, while systematic uncertainties are represented by shaded boxes. For more please refer to CMS Physics Analysis Summary, Ref. [10].

6. Results

Figure 1. shows distributions of $\Delta\phi_{J\gamma}$, defined as the difference in azimuth between the photon and correlated jet pairs. The top set of panels corresponds to a central binning of 0-30% centrality. The bottom set of panels corresponds to peripheral binning of 30-100% centrality. Moving from left-most to right-most panels, the photon transverse momentum is binned 40-50, 50-60, 60-80, 80-100, and > 100 GeV. The pp reference with jet energy resolution smeared to match corresponding resolution per PbPb centrality is overlaid. $\Delta\phi_{J\gamma}$ is of particular interest as an indication of in-medium deflection of partons, which is as of yet unobserved in dijet collisions. Comparing the PbPb and smeared pp results in the top set of panels, there is no evidence of $\Delta\phi_{J\gamma}$ modification.

Figure 2. shows distributions of $x_{J\gamma}$, defined as the ratio of jet transverse momentum with photon transverse momentum for all photon+jet pairs back-to-back in the azimuthal plane. The panel layout is identical to that of Fig. 1. The pp reference with jet energy resolution smeared to match corresponding resolution per PbPb centrality is overlaid. In all central panels there is modification of $x_{J\gamma}$ relative to the smeared pp reference. At low p_T^γ , this manifests primarily in a suppression. Point-by-point, the reduction in PbPb data compared to pp is clear. As the p_T^γ increases, the distribution shifts to a lower mean, and shape is modified as there is more kinematic space for quenching to act on the correlated jets.

Figure 3: Average ratio of jet p_T with photon p_T , $\langle x_{J\gamma} \rangle$, as a function of p_T^γ . Each point in p_T^γ is the mean of the distribution shown in Fig. 2. Left corresponds to central 0-30% and right corresponds to peripheral 30-100% in PbPb data. The pp results are smeared by the relative jet energy resolution in each centrality bin and overlaid with the PbPb points for comparison. Statistical uncertainties are represented by vertical lines, while systematic uncertainties are represented by shaded boxes. For more please refer to CMS Physics Analysis Summary, Ref. [10].

Figures 3 and 4 quantify the distribution of $x_{J\gamma}$ in terms of $\langle x_{J\gamma} \rangle$ and $R_{J\gamma}$, or the average number of jets correlated with a photon candidate after selections and mixed-event background subtraction. Each of these quantities is plotted as a function of photon transverse momentum, in a binning identical to the left-to-right panels of 2. In Figure 3, the $\langle x_{J\gamma} \rangle$ is consistently lower in the central PbPb result when compared to the corresponding smeared pp reference. This mean difference

between pp and PbPb data increases with photon p_T , as the corresponding jet has greater dynamic range when moving away from the minimum 30 GeV jet p_T cut.

In Figure 4 the average number of jets correlated increases as p_T^γ increases. It increases for both PbPb case and smeared pp case, as is to be expected when moving away from the lower bound jet p_T cut of 30 GeV. However, there is an overall extra offset in central PbPb result from both the peripheral case and the smeared pp reference, indicating that jets are missing. This is interpreted as quenching acting on correlated jets, pushing them below the 30 GeV p_T cut more in central PbPb data.

Figure 4: Average number of associated jets per photon ($R_{J\gamma}$) as a function of p_T^γ . Each point in p_T^γ quantifies the observed overall suppression panel-by-panel in Fig. 2. Left corresponds to central 0-30% and right corresponds to peripheral 30-100% in PbPb data. The pp results are smeared by the relative jet energy resolution in each centrality bin and overlaid with the PbPb points for comparison. Statistical uncertainties are represented by vertical lines, while systematic uncertainties are represented by shaded boxes. For more please refer to CMS Physics Analysis Summary, Ref. [10].

7. Conclusions

Correlations of photon+jets in PbPb collisions are the key to understanding jet energy loss in the hot and dense medium produced in ultrarelativistic heavy ion collisions. Studies of isolated-photons correlated with jets using the CMS detector in PbPb and pp data show that in central (0-30%) PbPb collisions there is no evidence of deflection in the azimuthal plane. For back-to-back photon-jet pairs, the average number of jets correlated with a photon is reduced for all photon p_T relative to smeared pp reference. $\langle x_{J\gamma} \rangle$ is also found to be reduced for central PbPb collisions relative to smeared pp reference, while the $x_{J\gamma}$ distribution itself shows some modification of shape.

References

- [1] F. Karsch, The Phase transition to the quark gluon plasma: Recent results from lattice calculations, Nucl. Phys. A 590 (1995) 367C–382C. arXiv:hep-lat/9503010, doi:10.1016/0375-9474(95)00248-Y.
- [2] D. A. Appel, Jets as a probe of quark-gluon plasmas, Phys. Rev. D33 (1986) 717. doi:10.1103/PhysRevD.33.717.
- [3] J. Blaizot, L. D. McLerran, Jets in Expanding Quark - Gluon Plasmas, Phys. Rev. D 34 (1986) 2739. doi:10.1103/PhysRevD.34.2739.
- [4] M. Gyulassy, M. Plumer, Jet Quenching in Dense Matter, Phys. Lett. B 243 (1990) 432–438. doi:10.1016/0370-2693(90)91409-5.
- [5] X.-N. Wang, M. Gyulassy, Gluon shadowing and jet quenching in A + A collisions at $\sqrt{s} = 200$ A GeV, Phys. Rev. Lett. 68 (1992) 1480–1483. doi:10.1103/PhysRevLett.68.1480.
- [6] R. Baier, Y. L. Dokshitzer, A. H. Mueller, S. Peigne, D. Schiff, Radiative energy loss and p(T) broadening of high-energy partons in nuclei, Nucl. Phys. B 484 (1997) 265–282. arXiv:hep-ph/9608322, doi:10.1016/S0550-3213(96)00581-0.
- [7] B. Zakharov, Radiative energy loss of high-energy quarks in finite size nuclear matter and quark - gluon plasma, JETP Lett. 65 (1997) 615–620. arXiv:hep-ph/9704255, doi:10.1134/1.567389.
- [8] S. Chatrchyan, et al., Observation and studies of jet quenching in PbPb collisions at nucleon-nucleon center-of-mass energy = 2.76 TeV, Phys. Rev. C 84 (2011) 024906. arXiv:1102.1957, doi:10.1103/PhysRevC.84.024906.
- [9] G. Aad, et al., Observation of a Centrality-Dependent Dijet Asymmetry in Lead-Lead Collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the ATLAS Detector at the LHC, Phys. Rev. Lett. 105 (2010) 252303. arXiv:1011.6182, doi:10.1103/PhysRevLett.105.252303.
- [10] CMS Collaboration, Study of Isolated-Photon + Jet Correlations in PbPb and pp Collisions at $\sqrt{s_{NN}} = 5.02$ TeV, CMS Physics Analysis Summary CMS-PAS-HIN-16-002. URL <http://cds.cern.ch/record/2217884>
- [11] S. Chatrchyan, et al., The CMS experiment at the CERN LHC, JINST 03 (2008) S08004. doi:10.1088/1748-0221/3/08/S08004.
- [12] CMS Collaboration, Performance of photon reconstruction and identification with the CMS detector in proton-proton collisions at $\sqrt{s} = 8$ TeV, Journal of Instrumentation 10. arXiv:1502.02702, doi:10.1088/1748-0221/10/08/P08010.
- [13] S. Chatrchyan, et al., Measurement of isolated photon production in pp and PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Phys. Lett. B 710 (2012) 256–277. arXiv:1201.3093, doi:10.1016/j.physletb.2012.02.077.
- [14] CMS Collaboration, Particle-flow event reconstruction in CMS and performance for jets, taus, and E_T^{miss} , CMS Physics Analysis Summary CMS-PAS-PFT-09-001. URL <http://cdsweb.cern.ch/record/1194487>
- [15] CMS Collaboration, Commissioning of the particle-flow event reconstruction with the first LHC collisions recorded in the CMS detector, CMS Physics Analysis Summary CMS-PAS-PFT-10-001. URL <http://cdsweb.cern.ch/record/1247373>
- [16] M. Cacciari, G. P. Salam, G. Soyez, FastJet User Manual, Eur. Phys. J. C 72 (2012) 1896. arXiv:1111.6097, doi:10.1140/epjc/s10052-012-1896-2.
- [17] M. Cacciari, G. P. Salam, G. Soyez, The Anti-k(t) jet clustering algorithm, JHEP 0804 (2008) 063. arXiv:0802.1189, doi:10.1088/1126-6708/2008/04/063.