The Compact Muon Solenoid Experiment
Conference Report

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

18 March 2014 (v2, 31 March 2014)

Isolated photon measurements in pp and PbPb collisions with CMS

Richard Alexander Barbieri for the CMS Collaboration

Abstract

We report new measurements using isolated photons based on the high statistics 2.76 TeV pp reference data collected in 2013. The nuclear modification factors of reconstructed isolated photons, obtained by the comparison of heavy ion collisions and pp data, are presented and provide useful constraints to the nuclear parton distribution functions. For events containing an high p_T isolated photon with an associated jet, the photon+jet p_T imbalance is studied as a function of collision centrality and compared to pp data and model calculations. These measurements allow an unbiased characterization of the in-medium parton energy loss.

Presented at *HardProbes2013 6th International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions*

Isolated photon measurements in pp and PbPb collisions with CMS

Richard Alexander Barbieri for the CMS Collaboration

Massachusetts Institute of Technology

Abstract

We report new measurements using isolated photons based on the high statistics 2.76 TeV pp reference data collected in 2013. The nuclear modification factors of reconstructed isolated photons, obtained by the comparison of heavy ion collisions and pp data, are presented and provide useful constraints to the nuclear parton distribution functions. For events containing an high p_T isolated photon with an associated jet, the photon+jet p_T imbalance is studied as a function of collision centrality and compared to pp data and model calculations. These measurements allow an unbiased characterization of the in-medium parton energy loss.

Keywords: CMS, physics, heavy ion, photon, jet, gamma, gamma-jet

1. Introduction

A strongly interacting medium, called the Quark-Gluon Plasma (QGP) is thought to be formed in relativistic heavy ion collisions at RHIC and the LHC. Because of the short lifetime of the QGP, high transverse-momentum (p_T) partons created by hard scatterings within the collision are used as probes [1–6]. At the LHC, colored probes are modified by the QGP medium during traversal [7, 8], while electroweak probes like photons remain unmodified [9]. Therefore, photon+jet production in which the photon is used as a “tag” of the initial parton energy and the jet as a “tag” of the final parton energy can be used to gain information about the structure of the QGP.

Direct photon+jet production is experimentally selected by applying an isolation requirement to photons to reduce background from neutral meson decay produced in jet fragmentation. The properties of the isolated photon+jet pairs are studied as a function of the azimuthal correlation, $\Delta\phi_{J\gamma} = |\phi^{Jet} - \phi^\gamma|$, the transverse momentum ratio $x_{J\gamma} = p_T^{Jet}/p_T^\gamma$, the ratio of the jet yield in PbPb over pp, I_{AA} , and the fraction of photons with an associated jet, $R_{J\gamma}$ [10].

2. Datasets and Reconstruction

The analysis presented here on isolated photon+jet correlations is performed on $150 \mu\text{b}^{-1}$ of PbPb and 5.3 pb^{-1} pp data at $\sqrt{s_{NN}} = 2.76 \text{ TeV}$ and 30.4 nb^{-1} pPb data¹ at $\sqrt{s_{NN}} = 5.02 \text{ TeV}$ collected with the Compact Muon Solenoid (CMS) detector in 2011 and 2013 [12]. Events with a reconstructed photon with $p_T^\gamma > 40 \text{ GeV}/c$ are recorded for further analysis. The PbPb collisions are characterized in terms of the centrality of the collision [7].

Photons are reconstructed from clusters of energy in the ECAL according to the algorithm in Ref. [13] for pp and pPb collisions and Ref. [9] for PbPb collisions. Only photons found within the barrel region of the ECAL, $|\eta^\gamma| < 1.44$, and with $p_T^\gamma > 40 \text{ GeV}/c$ are used in the analysis. A dedicated tracking algorithm is used to remove ECAL clusters

¹The final measured integrated luminosity for pPb Data was 35 nb^{-1} [11]

Figure 1. Comparison of $\Delta\phi_{J\gamma}$ width, $R_{J\gamma}$ and $\langle x_{J\gamma} \rangle$ in pp and PbPb collisions. The shaded boxes represent the systematic uncertainty while the lines through the points represent the statistical uncertainty.[12]

associated to electron tracks. Candidates with a large ratio of energy deposited in the hadronic calorimeter are dropped to reduce neutral meson background [10]. An isolation requirement that the energy in a hollow cone surrounding the candidate be less than a threshold value in each of the ECAL, HCAL, and tracker is used to further reduce background. In the case of PbPb collisions the isolation energy is corrected for the presence of the underlying event [9].

The fraction of the photons which are prompt (purity) is estimated using a template-fitting method with signal coming from MC simulations and background measured in a data sideband [9].

Jets are reconstructed according to the CMS “particle flow” algorithm, using the FASTJET anti- k_T implementation and a resolution parameter of 0.3 [14–17]. In the case of PbPb collisions a background subtraction method described in Ref. [18] is also applied. Jets with $p_T^{\text{Jet}} > 30 \text{ GeV}/c$ and within $|\eta^{\text{Jet}}| < 1.6$ are used for this analysis.

3. Analysis

The highest p_T^γ photon in each event is paired to every jet which passes the cuts described in Sec. 2. For PbPb collisions only, the uncorrelated background in each observable is removed by subtracting the correlation of the photon with jets in separate minimum bias events of the same centrality. For all collisions the background from decay photon+jet correlations is removed by subtracting the photon+jet correlation from a background-enriched data sideband, normalized by the photon purity estimated as in Sec. 2. The pp reference data is smeared to match the jet reconstruction resolution in PbPb for each centrality class.

4. Results

A subset of the results of Ref. [12] are reproduced here. In Fig. 1(left), no deflection of the jets as a function of centrality is observed. In Figs. 1(middle) and 2(middle,right), a significant loss of jet partners as a function of centrality is observed, and as a function of p_T^γ this loss is constant. This is corroborated by Fig. 1(right) which shows a shift to lower $x_{J\gamma}$ as a function of centrality. Figs. 3(middle,right) show a decrease in $x_{J\gamma}$ as a function of p_T^γ in central events. In all cases the PYTHIA+HYDJET reference agrees with the smeared pp reference.

The pPb results shown in Figs. 2(left) and 3(left) are consistent with the pp reference at $\sqrt{s_{NN}} = 2.76 \text{ TeV}$, however interpreting the deviation from the PYTHIA+HYDJET reference at $\sqrt{s_{NN}} = 5.02 \text{ TeV}$ is difficult without a proper pp reference at $\sqrt{s_{NN}} = 5.02 \text{ TeV}$.

Fig. 4 shows a shift of jet partners in PbPb from high p_T^{Jet} to low p_T^{Jet} in the central case; in the first p_T^γ bin only a deficit in I_{AA} is apparent, but an excess at low p_T^{Jet} in the high p_T^γ bin indicates movement of jets to lower p_T^{Jet} .

References

- [1] D. A. Appel, Jets as a probe of quark-gluon plasmas, Phys. Rev. D33 (1986) 717. doi:10.1103/PhysRevD.33.717.

Figure 2. Fraction of photons associated to a jet ($R_{J\gamma}$) as a function of leading photon p_T^γ in (left) pPb, unsmeared pp, and PYTHIA+HIJING, (middle) smeared pp and peripheral PbPb, and (right) smeared pp and central PbPb. The shaded boxes represent the systematic uncertainty while the lines through the points represent the statistical uncertainty.[12]

Figure 3. Average jet over photon transverse momentum ratio ($\langle x_{J\gamma} \rangle$) of the recoiled jets in (left) pPb, unsmeared pp, and PYTHIA+HIJING, (middle) smeared pp and peripheral PbPb, and (right) smeared pp and central PbPb. The shaded boxes represent the systematic uncertainty while the lines through the points represent the statistical uncertainty.[12]

Figure 4. Ratio of jet yield in PbPb to smeared pp. The shaded boxes represent the systematic uncertainty while the lines through the points represent the statistical uncertainty.[12]

- [2] J. Blaizot, L. D. McLerran, Jets in Expanding Quark - Gluon Plasmas, *Phys.Rev. D* 34 (1986) 2739. doi:10.1103/PhysRevD.34.2739.
- [3] M. Gyulassy, M. Plumer, Jet Quenching in Dense Matter, *Phys.Lett. B* 243 (1990) 432–438. doi:10.1016/0370-2693(90)91409-5.
- [4] X.-N. Wang, M. Gyulassy, Gluon shadowing and jet quenching in A + A collisions at $s^{*}(1/2) = 200$ -GeV, *Phys.Rev.Lett.* 68 (1992) 1480–1483. doi:10.1103/PhysRevLett.68.1480.
- [5] 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.
- [6] 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.
- [7] 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.
- [8] 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.
- [9] 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.
- [10] S. Chatrchyan, et al., Studies of jet quenching using isolated-photon+jet correlations in PbPb and pp collisions at $\sqrt{s_{NN}} = 2.76$ TeV, *Phys.Lett. B* 718 (2013) 773–794. arXiv:1205.0206, doi:10.1016/j.physletb.2012.11.003.
- [11] Luminosity Calibration for the 2013 Proton-Lead and Proton-Proton Data Taking, Tech. Rep. CMS-PAS-LUM-13-002, CERN, Geneva (2014).
URL <http://cds.cern.ch/record/1643269>
- [12] Study of Isolated photon jet correlation in PbPb and pp collisions at 2.76TeV and pPb collisions at 5.02TeV, Tech. Rep. CMS-PAS-HIN-13-006, CERN, Geneva (2013).
URL <http://cds.cern.ch/record/1631991>
- [13] CMS Collaboration, Photon reconstruction and identification at $\sqrt{s} = 7$ TeV, CMS Physics Analysis Summary CMS-PAS-EGM-10-005 (2010).
URL <http://cdsweb.cern.ch/record/1279143>
- [14] CMS Collaboration, Particle-flow event reconstruction in CMS and performance for jets, taus, and missing et, 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 (2010).
URL <http://cdsweb.cern.ch/record/1247373>
- [16] 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.
- [17] 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.
- [18] O. Kodolova, I. Vardanian, A. Nikitenko, A. Oulianov, The performance of the jet identification and reconstruction in heavy ions collisions with CMS detector, *Eur. Phys. J. C* 50 (2007) 117. doi:10.1140/epjc/s10052-007-0223-9.