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# Measurement of isolated photon production in pp and PbPb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV with CMS

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**Abstract**

Isolated photon production is measured in pp and PbPb collisions at nucleon-nucleon centre-of-mass energies of 2.76 TeV in the pseudorapidity range $|\eta| < 1.44$ and transverse energies $E_{\mathrm{T}}$ between 20 and 80 GeV with the CMS detector at the LHC. The measured $E_{\mathrm{T}}$ spectra are found to be in good agreement with next-to-leading-order perturbative QCD predictions. The ratio of PbPb to pp isolated photon $E_{\mathrm{T}}$-differential yields, scaled by the number of incoherent nucleon-nucleon collisions, is consistent with unity for all PbPb reaction centralities.

*Keywords:* Nuclear modification factor, photon, CMS, LHC

Prompt photons with high transverse energy ($E_{\mathrm{T}}$) in hadronic collisions are produced directly from the hard scattering of two partons. Measured photon production cross sections provide a direct test of perturbative quantum chromodynamics (pQCD) [1], and constrain the proton [2] and nuclear [3] parton distribution functions (PDFs). In the case of nuclear collisions, jets are significantly suppressed [4, 5] but direct photons are unaffected by the strongly interacting medium produced in the reaction. The comparison of photon production cross sections in pp and PbPb collisions allows one to estimate possible modifications of the nuclear parton densities with respect to nucleon PDFs. However, the measurement is complicated by the presence of a large background from the electromagnetic decays of neutral mesons. Backgrounds from these decays and the fragmentation photons are typically suppressed by imposing isolation requirements on the reconstructed photon candidates. The isolated photon measurements presented here are based on samples collected in pp and PbPb collisions at 2.76TeV with the Compact Muon Solenoid (CMS) detector [6]. The total data sample corresponds to an integrated luminosity of 231/nb and $6.8\,\mu\mathrm{b}^{-1}$ for pp and PbPb, respectively.

In order to study the photon selection efficiency and electron rejection in PbPb collisions, $\gamma$+jet, dijet, and $W \to e\nu$ events are simulated using the PYTHIA generator (version 6.422, tune D6T) [7], modified to take into account the isospin of the colliding nuclei [8]. These simulated PYTHIA events, propagated through the CMS detector using the GEANT4 package [9] to simulate the detector response, are embedded in actual minimum-bias (MB) PbPb events in order to study the effect of the underlying event (UE). These mixed samples (denoted "PYTHIA+DATA") are used for signal shape studies, and for energy and efficiency corrections. At the generator level, an isolation cone of radius $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} < 0.4$ around the photon candidate direction is defined. A photon is considered to be isolated if the sum of the $E_{\mathrm{T}}$ of all the other final state particles produced from the same hard scattering inside the isolation cone is smaller than 5 GeV.

The photon reconstruction algorithm and isolation requirements in pp and PbPb collisions are detailed in Ref. [10] and [11]. The selected photon candidates are required to be within $|\eta^{\gamma}| < 1.44$, to not match with any electron candidates, and to have $E_{\mathrm{T}}^{\gamma} > 20$ GeV. A first rejection of neutral mesons mimicking a high-$E_T$ photon candidate is done using the $H/E$ ratio defined as the ratio of hadronic energy to electromagnetic energy inside a cone of $\Delta R =$



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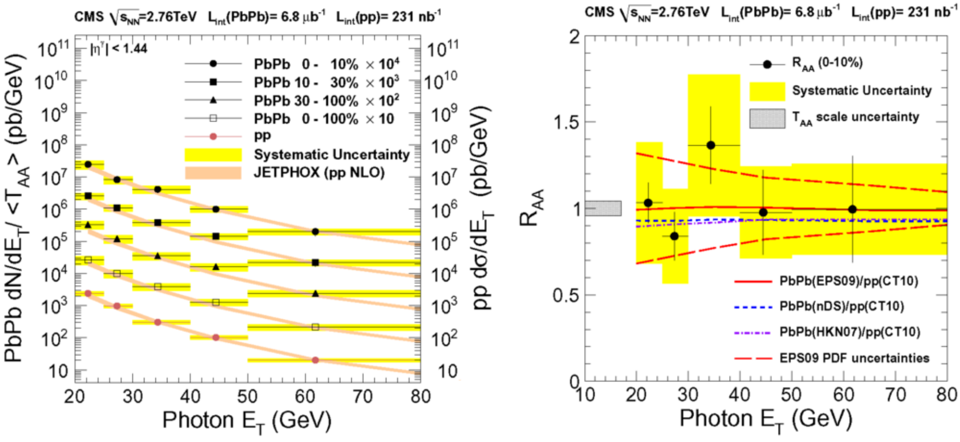


Figure 1: (Left) Isolated photon spectra measured as a function of $E_T^{\gamma}$ for 0–10%, 10–30%, 30–100%, 0–100% PbPb collisions (scaled by $T_{AA}$) and pp collisions at 2.76TeV. The horizontal bars indicate the bin width. The total systematic uncertainty is shown as a yellow box at each $E_T$ bin. The results are compared to the NLO JETPHOX calculation shown as a pink band. The vertical error bars indicate the statistical uncertainty and the horizontal bars reflect the bin width. (Right) Nuclear modification factor $R_{AA}$ as a function of the photon $E_T$ measured in the 0–10% most central PbPb collisions at 2.76 TeV.

0.15 [12]. Photon candidates with $H/E < 0.2$ are selected for this analysis. To measure the isolation of a given photon candidate in a PbPb event, the detector activity in a cone of radius $\Delta R = 0.4$ with respect to the centroid of the cluster is used. The average value of the energy deposited per unit area in the $\eta - \phi$ phase space is estimated within a rectangular region $2\Delta R$-wide and centered on $\eta^{\gamma}$ in the $\eta$-direction and $2\pi$ wide in the $\phi$-direction, excluding the isolation cone. The UE-subtracted isolation calculated from calorimeter and tracks with $p_T > 2$ GeV/$c$ is required to be smaller than 5 GeV. The remaining decay photon backgrounds are estimated using a two-component fit of the shape of the electromagnetic shower in the calorimeter and separated from the signal on a statistical basis. The isolated prompt photon yield is estimated with a binned maximum likelihood fit to the transverse shower shape distribution with the expected signal (PYTHIA+DATA) and data-driven background components for each $E_T^{\gamma}$ interval [11]. The remaining electron contribution estimated from data is subtracted to extract the raw signal yields ($N_{raw}^{\gamma}$). A bin-by-bin correction for the energy smearing ($U$) is also applied to the raw signal yields to obtain the final number of isolated photons. The $E_T$-differential photon yield per event is defined as $\frac{dN_{PbPb}^{\gamma}}{dE_T^{\gamma}} = \frac{N_{raw}^{\gamma}}{U \times \epsilon \times f_{cent} \times N_{MB} \times \Delta E_T^{\gamma}}$, where $N_{MB}$ is the number of sampled MB PbPb events, $f_{cent}$ is the fraction of events in each centrality bin, and $\epsilon$ is the efficiency of the photon identification.

The total systematic uncertainties are 22–30% for PbPb and 14–16% for pp collisions which are dominated by the uncertainty on the background modeling. In order to compare the isolated photon cross sections in PbPb and pp collisions, a scaling factor, the nuclear overlap function $T_{AA}$, is needed to provide proper normalization. This factor can be interpreted as the NN-equivalent integrated luminosity at any given PbPb centrality. Figure 1 shows the pp cross sections and the PbPb $T_{AA}$-scaled yields compared to the JETPHOX predictions obtained with the CT10 PDF. The pp and PbPb data are consistent with the NLO calculation at all transverse energies. The photon nuclear modification factor $R_{AA} = dN_{PbPb}^{\gamma}/dE_T^{\gamma}/(T_{AA} \times d\sigma_{pp}^{\gamma}/dE_T)$, is computed from the measured PbPb scaled yield and the pp differential cross section. Figure 1 displays $R_{AA}$ as a function of the isolated photon $E_T$ for the 0–10% most central PbPb collisions. The ratio is compatible with unity within the experimental uncertainties for all $E_T$ values.

In summary, the isolated photon spectra at $|\eta^{\gamma}| < 1.44$ have been measured in pp and PbPb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV. The measured spectra are well reproduced by NLO pQCD calculations with recent PDFs for the proton and nucleus. It is consistent with the expectation that nuclear parton densities are not significantly modified compared to the proton PDF in the explored kinematic range, dominated by high-$p_T$ photons produced in parton-parton scatterings in the large-$Q^2$ and moderate parton fractional momentum $x$ region of the nuclear PDFs [14]. The measurement presented here establishes isolated photon production as a valuable perturbative probe of the initial state in heavy-ion collisions and provides a baseline for the study of in-medium parton energy loss in $\gamma$+jet events.

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