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Observation of the $\gamma\gamma \to \tau^+\tau^-$ production in ultraperipheral PbPb collisions with the CMS experiment

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Abstract. We report the observation of the photon-induced $\gamma\gamma \to \tau^+\tau^-$ production based on a data sample of $404\,\mu\mathrm{b}^{-1}$ collected by the CMS experiment at a per nucleon center-of-mass energy of 5.02 TeV. The cross section is measured in a fiducial phase space region via the decay process involving one muon and three charged hadrons, and is found to be $\boldsymbol{\sigma}(\gamma\gamma \to \tau^+\tau^-) = \mathbf{4.8 \pm 0.6}$ (stat) $\mathbf{\pm 0.5}$ (syst) μb, in agreement with leading-order quantum electrodynamics predictions. The $\boldsymbol{\sigma}(\gamma\gamma \to \tau^+\tau^-)$ measurement is used to determine the anomalous magnetic moment of the τ lepton $\boldsymbol{a}_\tau$, which is currently poorly constrained.

1 Introduction

Ultraperipheral collisions (UPC) of heavy ions provide an extremely clean environment to probe the τ lepton anomalous magnetic moment a_τ at the LHC, hence offering ample room for searching for physics beyond the standard model. Here, we present [1] the observation of the photoproduction of pairs of τ leptons in lead-lead (PbPb) collisions PbPb $(\gamma\gamma) \to$ $\mathrm{Pb}^{(*)}$+$\mathrm{Pb}^{(*)}\,\tau^+\tau^-$ (hereafter referred to as $\gamma\gamma \to \tau^+\tau^-$) by analyzing a data sample collected by the CMS experiment [2] at a per nucleon center-of-mass energy of $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV in 2015, and corresponding to an integrated luminosity of $404\,\mu\mathrm{b}^{-1}$. The τ leptons are reconstructed in a decay process involving in the final state one muon and three particles ("prongs") assume to be charged π mesons, and the cross section $\sigma(\gamma\gamma \to \tau^+\tau^-)$ is measured in a fiducial phase space region defined by the muon and pion transverse momenta (p_{T}) and their pseudorapidities (η). The ATLAS Collaboration has also reported a measurement of $\gamma\gamma \to \tau^+\tau^-$ using a larger PbPb data sample with an integrated luminosity of $1.44\,\mathrm{nb}^{-1}$ [3].

2 Event selection, signal and background estimation

The exchange of photons in UPC does not primarily disassociate the lead ions but scatters them at small angles close to the beam direction, such that the final state is uniquely characterized by low track multiplicity. We thus filter events from UPC by requiring in real time ("online") a single muon with no p_{T} threshold requirement and minimum event activity above the noise threshold in the forward hadron (HF) calorimeter ($3.0 < |\eta| < 5.2$). A further event selection is applied offline for the "τ_μ" and "$\tau_{3\mathrm{prong}}$" candidates, which at the same time defines the $\sigma(\gamma\gamma \to \tau^+\tau^-)$ fiducial phase space region as summarized in Table 1.

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A dedicated $\gamma\gamma \to \tau^+\tau^-$ [4] Monte Carlo (MC) sample is generated with MadGraph5_amc@nlo (v2.6.5) [5], decayed and hadronized with pythia8 (v2.1.2) [6], and simulated by Geant4 [7] to study the detector effects. The background contamination is estimated in a data-driven way using uncorrelated phase space regions defined based on the track multiplicity and the HF activity. In all cases, good agreement is observed between the measured distributions and the sum of the signal simulation and background estimation, e.g., as shown in Fig. 1 (left) for the invariant mass of the $\tau_{3\text{prong}}$ candidate.

Table 1. Summary of the kinematic event selection, which also defines the fiducial phase space region for the $\sigma(\gamma\gamma \to \tau^+\tau^-)$ measurement [1]. Additional quality criteria are applied for the τ_μ candidate and all selected tracks.

τ_μ selection	$p_T > 3.5$ GeV for $\lvert\eta\rvert < 1.2$ $p_T > 2.5$ GeV for $1.2 < \lvert\eta\rvert < 2.4$
Track selection	$p_T > 0.5$ GeV for the leading-p_T $p_T > 0.3$ GeV for the (sub-)subleading-p_T $\lvert\eta\rvert < 2.5$
$\tau_{3\text{prong}}$ selection	$p_T^{\text{vis}} > 2$ GeV and $m_\tau^{\text{vis}} < 1.5$ GeV

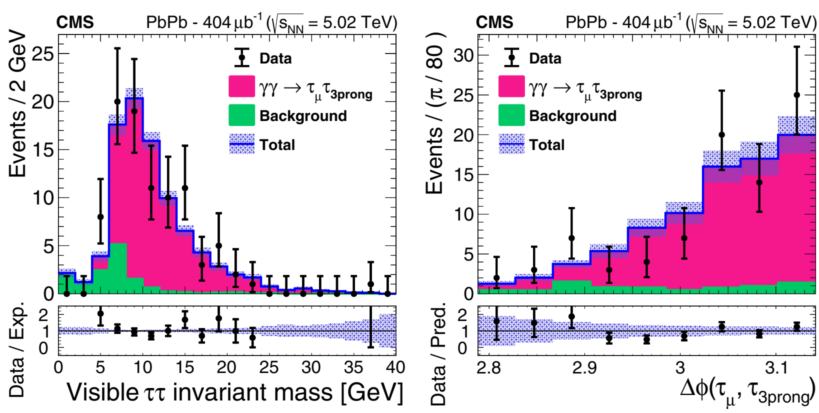

Figure 1. Left: Invariant mass of the three pions forming the $\tau_{3\text{prong}}$ candidate [1]. Right: Difference in azimuthal opening angle between the τ_μ and $\tau_{3\text{prong}}$ candidates [1]. The lower panels show the ratios of data to the signal-plus-background prefit expectation (left) or postfit prediction (right).

3 Results

A binned maximum likelihood method is used for the signal extraction. The difference in opening azimuthal angle between the τ_μ and $\tau_{3\text{prong}}$ leptons, $\Delta\phi(\tau_\mu, \tau_{3\text{prong}})$, is used as the final discriminant. The sum in quadrature of systematic uncertainties, which may affect the normalization and the shape of the $\Delta\phi(\tau_\mu, \tau_{3\text{prong}})$ distribution, is found to be 9.7%, with the statistical component contributing with an almost equal amount. To compare the compatibility of the data with the background-only and signal plus background hypotheses, where the signal is allowed to be scaled by some factor r, we construct a test statistic based on the profile likelihood ratio. The best fit value of the signal strength is $r = 0.99^{+0.16}_{-0.14}$, with the number of signal events of $N_{\mathrm{sig}} = 77 \pm 12$. The post-fit $\Delta\phi(\tau_{\mu}, \tau_{3\mathrm{prong}})$ distribution is shown in Fig. 1 (right).

The cross section is found to be $\sigma(\gamma\gamma \to \tau^{+}\tau^{-}) = 4.8 \pm 0.6\,(\mathrm{stat}) \pm 0.5\,(\mathrm{syst})\,\mu\mathrm{b}$, and it is measured in the fiducial phase space region, following the kinematic requirements listed in Table 1. The result, summarized in Fig. 2 (left), is compared to leading-order quantum electrodynamics (QED) predictions [4, 8]. Further assuming the correction factor of Ref. [4] to extrapolate the fiducial cross section measurement to the full phase space region, we then use the dependence of the total $\sigma(\gamma\gamma \to \tau^{+}\tau^{-})$ as a function of a_{τ} to extract the model-dependent value of $a_{\tau} = 0.001^{+0.055}_{-0.089}$. The comparison of the world best a_{τ} constraints [9] to the ones extracted from this analysis and its expected performance [10] in the High-Luminosity LHC program is given in Fig. 2 (right).

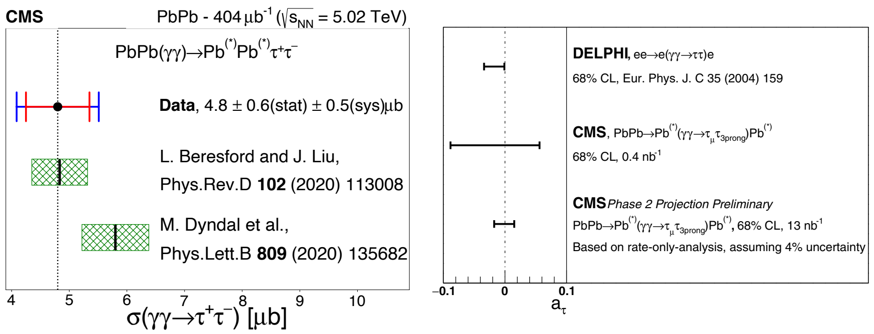

Figure 2. Left: The cross section, $\sigma(\gamma\gamma \to \tau^{+}\tau^{-})$, measured in a fiducial phase space region at $\sqrt{s_{_{\mathrm{NN}}}} = 5.02\,\mathrm{TeV}$ [1], and compared to theoretical predictions at leading-order accuracy in QED [4, 8]. Right: Comparison between the world best a_{τ} constraints [9] and the ones extracted from this analysis [1] and its performance [10] using the integrated PbPb luminosity expected from the High-Luminosity LHC program.

4 Summary

In summary, an observation of the τ lepton pair production in ultraperipheral nucleus-nucleus collisions is reported. Events with one muon and three particles identified as charged pions in the final state are reconstructed from a lead-lead data sample collected by the CMS experiment at $\sqrt{s_{_{\mathrm{NN}}}} = 5.02\,\mathrm{TeV}$ in 2015, and corresponding to an integrated luminosity of $404\,\mu\mathrm{b}^{-1}$. This measurement introduces a novel experimental strategy using heavy ion data recorded by the LHC in order to measure the τ lepton magnetic moment a_{τ}. This approach can be used to extract constraints on a_{τ} that surpass the current best from previous lepton-lepton colliders.

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