Observation of the $\gamma\gamma \rightarrow \tau\tau$ process in Pb+Pb collisions and constraints on the $\tau$-lepton anomalous magnetic moment with the ATLAS detector

The ATLAS Collaboration

This Letter reports the observation of $\tau$-lepton pair production in ultraperipheral lead–lead collisions, $\text{Pb}+\text{Pb} \rightarrow \text{Pb}(\gamma\gamma \rightarrow \tau\tau)\text{Pb}$, and constraints on the $\tau$-lepton anomalous magnetic moment, $a_\tau$. The dataset corresponds to an integrated luminosity of 1.44 nb$^{-1}$ of LHC Pb+Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV recorded by the ATLAS experiment in 2018. Selected events contain one muon from a $\tau$-lepton decay, an electron or charged-particle track(s) from the other $\tau$-lepton decay, little additional central-detector activity, and no forward neutrons. The $\gamma\gamma \rightarrow \tau\tau$ process is observed in Pb+Pb collisions with a significance exceeding 5 standard deviations, and a signal strength of $\mu_{\tau\tau} = 1.03^{+0.06}_{-0.05}$ assuming the Standard Model value for $a_\tau$. To measure $a_\tau$, a template fit to the muon transverse-momentum distribution from $\tau$-lepton candidates is performed, using a dimuon ($\gamma\gamma \rightarrow \mu\mu$) control sample to constrain systematic uncertainties. The observed 95% confidence-level interval for $a_\tau$ is $-0.057 < a_\tau < 0.024$.
Measurements of the anomalous magnetic moment, \( a_\ell = \frac{1}{2}(g_\ell - 2) \), of charged leptons \( \ell \) (electrons, muons, and \( \tau \)-leptons) are cornerstone tests of the Standard Model (SM) with unique sensitivity to beyond-the-SM (BSM) phenomena. The leading contribution to \( a_\ell \) in the SM is the one-loop Schwinger term \( a_{\text{SM}} \approx 0.00116 \) [1, 2], where \( a_{\text{SM}} \) is the electromagnetic (EM) fine-structure constant. For the electron (muon), \( a_\ell \) (\( a_\mu \)) is tested to parts per \( 10^{10} \) [3–8] (\( 10^7 \) [9–11]) precision. Measurements of \( a_\mu \) report tensions with the SM expectation [12–16], which may suggest BSM dynamics. Specific BSM scenarios such as supersymmetry [17] predict enhancements that scale quadratically with lepton mass \( m_\ell \), i.e. \( \delta a_\ell \propto m_\ell^2 \), resulting in a \( (m_\tau/m_\mu)^2 \approx 280 \) times larger effect for \( \tau \)-leptons. However, the short \( \tau \)-lepton lifetime precludes precise spin-precession measurements of \( a_\tau \) to test the SM prediction of \( a_\tau^{\text{SM}} = 0.001 177 21 \) (5) [18] and potential BSM contributions.

Photon-induced events arise from interactions between the EM fields surrounding the beam particles at colliders. Observing photon-induced \( \tau \)-lepton pairs \( (\gamma\gamma \rightarrow \tau\tau) \) predicted to occur at the Large Hadron Collider (LHC) [19–26] would open the way to hadron-collider probes of \( a_\tau \). Currently, the most precise single-experiment measurement is \( a_\tau = -0.018 \) (17) by the DELPHI Collaboration [27, 28] using \( \gamma\gamma \rightarrow \tau\tau \) events at the Large Electron Positron (LEP) collider. The OPAL [29] and L3 [30] Collaborations also set constraints using radiative \( \tau \)-lepton decays [31]. At the LHC, photon-induced dilepton production has only been measured in the dielectron (ee) and dimuon (\( \mu\mu \)) channels, using proton–proton (\( pp \)) [32–37] and lead–lead (\( \text{Pb+Pb} \)) collisions [38–43]. The \( \tau\tau \) channel is challenging due to hadronic backgrounds and neutrinos in \( \tau \)-lepton decays diluting visible final-state kinematics. This renders triggering and reconstruction more difficult, especially in high-luminosity \( pp \) collisions. Strategies to overcome these experimental obstacles using heavy-ion collisions were proposed in Refs. [44–46].

This Letter presents the observation of the \( \text{Pb+Pb} \rightarrow \text{Pb}(\gamma\gamma \rightarrow \tau\tau)\text{Pb} \) process and measurement of \( a_\tau \) using 1.44 nb\(^{-1}\) of \( \sqrt{s_{\text{NN}}} = 5.02 \) TeV \( \text{Pb+Pb} \) data recorded by ATLAS in 2018. The EM fields accompanying the ions coherently create photons that interact to produce \( \tau \)-lepton pairs. The cross-section is enhanced by \( Z^4 \) relative to \( pp \) collisions, where \( Z \) is the atomic number (\( Z = 82 \) for lead). The ions can remain intact, enabling selection of low-multiplicity events with one muon originating from one of the \( \tau \)-leptons, while the other \( \tau \)-lepton decay is reconstructed as either an electron or one or three charged-particle tracks with low transverse momentum.

The ATLAS experiment [47–49] is a multipurpose particle detector with cylindrical geometry [50], comprising an inner detector (ID) tracker, EM and hadronic calorimeters, and a muon spectrometer (MS). The zero-degree calorimeters (ZDC) [51] are located at \( z = \pm 140 \) m from the interaction point, and detect neutral particles such as neutrons emitted from interacting nuclei. A two-level trigger system [52, 53] was used to select events containing one muon with \( p_T > 4 \) GeV, and at most 50 GeV (3 GeV) of transverse energy deposited in the whole (forward \( 3.2 < |\eta| < 4.9 \)) calorimeter [54]. An extensive software suite [55] is used in the reconstruction and analysis of real and simulated data, in detector operations, and in the trigger and data acquisition systems. Standard data-quality requirements are imposed [56]. The average number of hadronic interactions per bunch crossing was 0.003.

Samples of simulated \( \gamma\gamma \rightarrow \tau\tau \) signal events were produced at leading order in QED using the STARLIGHT 2.0 [57] Monte Carlo (MC) generator, interfaced with Tauola [58, 59] for \( \tau \)-lepton decays. Final-state radiation (FSR) from the \( \tau \)-leptons and charged decay products of \( \tau \)-leptons was simulated using Pythia 8.245 [60] and Photos++ 3.61 [61], respectively. One of the dominant background sources is the \( \gamma\gamma \rightarrow \mu\mu \) process, and its contribution is estimated with the aid of MC samples generated using STARLIGHT; Pythia 8 was used to model EM FSR from the muons. The photon-flux distribution in simulated \( \gamma\gamma \rightarrow \tau\tau \) and \( \gamma\gamma \rightarrow \mu\mu \) events was reweighted to that of Superchic 3.05 [62], differentially in
dilepton invariant mass and dilepton rapidity. In the Starlight and Superchic simulations, no restriction on the Coulomb breakup of either nucleus was imposed. Dijet samples from photon-induced diquark production, $\gamma\gamma \rightarrow q\bar{q}$, were generated using Pythia 8. Nondiffractive photonuclear events ($\gamma A \rightarrow X$) were simulated with Starlight interfaced with Dpmjet-III [63]. All MC samples were passed through a detailed detector simulation based on Geant4 [64, 65].

Charged-particle tracks reconstructed in the ID must satisfy $p_T > 100$ MeV, $|\eta| < 2.5$, transverse impact parameter $|d_0| < 1.5$ mm, and the “Loose Primary” track selection criterion [66–68]. Electrons must satisfy $p_T > 4$ GeV, $|\eta| < 2.47$ (excluding the calorimeter transition region, i.e. $|\eta| \notin [1.37, 1.52]$), $|d_0| < 0.5$ mm, and “Loose” [69] likelihood-based identification criteria. Muons must satisfy $p_T > 4$ GeV, $|\eta| < 2.4$, $|d_0| < 0.3$ mm, and “LowPt” [70] identification criteria. Small corrections, derived using tag-and-probe methods similar to those in Refs. [40, 71, 72], are applied to simulated reconstruction and trigger efficiencies of electrons and muons. Clusters of topologically connected calorimeter cells called topoclusters [73] must satisfy $|\eta| < 4.9$, $p_T > 0.1$ GeV ($p_T > 1$ GeV) for $2.5 < |\eta| < 4.9$ ($|\eta| < 2.5$), and the cell significance criteria for measured energies outlined in Ref. [74]. Topoclusters from calorimeter regions with an abnormal noise distribution are removed using a data-driven procedure based on analyzing $\eta$–$\phi$ distributions of topocluster activity for each calorimeter layer. Reconstructed photons must satisfy $E_T > 1.5$ GeV, $|\eta| < 2.37 \notin [1.37, 1.52]$, and dedicated identification criteria defined in Ref. [72].

Selected events must contain exactly one muon, which targets a muonic decay of one of the $\tau$-leptons while reducing backgrounds from $\gamma \gamma \rightarrow \mu\mu$ and $\gamma \gamma \rightarrow q\bar{q}$. Three signal regions (SR) then categorize events by the decay signature of the other $\tau$-lepton. The $\mu\epsilon$-SR category additionally requires one electron, and no additional tracks separated from the muon (electron) by $\Delta R_{\mu(e),\text{trk}} > 0.1$, which targets fully leptonic decays of both $\tau$-leptons. The different-flavor ($\mu\epsilon$) requirement suppresses same-flavor backgrounds dominated by $\gamma \gamma \rightarrow \mu\mu/ee$. The $\mu 1T$-SR ($\mu 3T$-SR) category requires exactly one track (three tracks) separated from the muon by $\Delta R_{\mu,\text{trk}} > 0.1$, which targets $\tau$-lepton decays to one or three charged hadrons. The one-track requirement also captures leptonic $\tau$-lepton decays that fail electron or muon reconstruction. The electric charges of the muon, electron, and tracks must sum to zero.

For both $\mu 1T$-SR and $\mu 3T$-SR, events must contain no additional muons satisfying looser criteria and no electrons to reject $\gamma \gamma \rightarrow \mu\mu/ee$ backgrounds. The looser requirements on muons comprise matched tracks in the ID and MS satisfying $p_T > 2$ GeV and $|\eta| < 2.5$. To suppress hadronic backgrounds such as photonuclear processes, there must be no topoclusters separated from the muon (track or three-track system [75]) by $\Delta R_{\text{clust},\mu} > 0.3$ ($\Delta R_{\text{clust},\text{trk(s)}} > 1.0$); this requirement is referred to as the topocluster veto. To further reduce photonuclear backgrounds, the acoplanarity between the muon and the track (three-track system) must satisfy $A_{\phi,\text{trk(s)}}^\mu = 1 - |\Delta \phi_{\mu,\text{trk(s)}}|/\pi < 0.4 (0.2)$. The signal has a narrower $A_{\phi,\text{trk(s)}}^\mu$ distribution in $\mu 3T$-SR than $\mu 1T$-SR, motivating the tighter requirement.

For $\mu 1T$-SR, the $p_T$ of the muon–track pair must satisfy $p_T^{\mu,\text{trk}} > 1$ GeV to reject $p_T$-balanced backgrounds, such as $\gamma\gamma \rightarrow \mu\mu$. To further reduce the $\gamma\gamma \rightarrow \mu\mu$ background, the $p_T$ of the muon, track, and photon (topocluster) system must fulfill $p_T^{\mu,\text{trk},\gamma_{\text{clust}}} > 1$ GeV for events containing a photon (topocluster) within $\Delta R_{\gamma_{\text{clust}},\text{trk}} = 1$ of the track. If there are multiple nearby photons (topoclusters), the highest-$p_T$ photon (topocluster) is used. The topoclusters considered here must have $p_T > 2$ GeV and not be track-matched; these criteria avoid track-induced topoclusters from, e.g., charged-pion energy deposits. Topoclusters within $\Delta R_{\text{clust},\text{trk}} = 0.1$ of a track with $p_T > 0.7$ GeV extrapolated to the calorimeter are considered track-matched. Low-multiplicity events in minimum-bias data are used to correct for the bending due to the magnetic field, such that the $\Delta R_{\text{clust},\text{trk}}$ distribution of topoclusters associated with a track peaks at
The dominant sources of background after event selection are radiative dimuon (\(\gamma\gamma \rightarrow \mu\mu\gamma\)) and photonuclear events with low central-detector activity.

For \(\mu 3\)T-SR, the three-track system mass must fulfill \(m_{3\text{trk}} < 1.7\) GeV, assuming each track has the charged-pion mass of 140 MeV. This requirement retains three-prong hadronic \(\tau\)-lepton decays and suppresses background from exclusive \(\rho^0\) mesons (\(\gamma A \rightarrow \rho^0 \rightarrow \pi\pi\)) produced simultaneously with \(\gamma\gamma \rightarrow \mu\mu\) events. In this background process, neither muon is correlated with the \(\pi\pi\) system and \(m_{\pi\pi\mu}\) typically exceeds 1.7 GeV for a muon with \(p_T\) of several GeV.

To constrain the \(\gamma\gamma \rightarrow \mu\mu\) background, a control region (CR) of dimuon events called \(2\mu\)-CR is defined. It requires exactly two muons with invariant mass above 11 GeV to suppress quarkonia (\(Y(nS) \rightarrow \mu\mu\)) backgrounds and no additional tracks separated from the muons by \(\Delta R_{\mu,\text{trk}} > 0.1\).

Events must additionally not have ZDC energies satisfying \(E_{ZDC} > 1\) TeV on each side, mainly to suppress photonuclear backgrounds where ion dissociation typically occurs. This class of events with no forward neutrons detected (0n0n) corresponds to the absence of Coulomb breakup of either nucleus. Such breakup typically proceeds through the giant dipole resonance and induces the emission of one or more neutrons [40]. This requirement also fully suppresses lepton-pair production in which the initial photon emission results in the dissociation of one or both nuclei [40]. The SRs and \(2\mu\)-CR are all statistically independent. Since the extra forward neutron emissions are not simulated, the \(\gamma\gamma \rightarrow \mu\mu\) MC samples are corrected using data-driven probabilities for the 0n0n event topology, which are found to be between 0.4 and 0.7. These are extracted from \(2\mu\)-CR without the \(E_{ZDC}\) requirement, differentially in dilepton invariant mass and dilepton rapidity.

The dominant sources of background after event selection are radiative dimuon (\(\gamma\gamma \rightarrow \mu\mu\gamma\)) and photonuclear events with low central-detector activity.

The \(\gamma\gamma \rightarrow \mu\mu\gamma\) background is estimated with the aid of MC samples. This process enters \(\mu 1\)T-SR when FSR photons substantially modify the dimuon kinematics so as to mimic the signal kinematics, and enters \(\mu 3\)T-SR and \(\mu e\)-SR primarily when photons convert to \(e^+e^-\) in detector material. To improve the modeling of high-\(p_T\) (\(p_T^\gamma \gtrsim p_T^\mu\)) photon emissions for \(t\)- and \(u\)-channel \(\gamma\gamma \rightarrow \mu\mu\) processes, an additional \(\gamma\gamma \rightarrow \mu\mu\gamma\) MC sample generated using MadGraph5_AMC@NLO [76] with the photon flux reweighted to SuperChic is used instead of Starlight+Pythia 8 if a leading photon has \(p_T^\gamma > 2\) GeV. Comparing the \(\gamma\gamma \rightarrow \mu\mu(\gamma)\) simulated events with data in \(2\mu\)-CR shows reasonable data-to-MC agreement in differential distributions, and normalization to within 5%. The simulated \(\gamma\gamma \rightarrow \mu\mu(\gamma)\) event yield in \(2\mu\)-CR is 15% lower than data if Starlight photon-flux calculations are used due to known limitations of Starlight [40, 77]. Before the fit to data, this method estimates 70, 6.5, and 2.8 \(\gamma\gamma \rightarrow \mu\mu(\gamma)\) events enter \(\mu 1\)T-SR, \(\mu 3\)T-SR, and \(\mu e\)-SR, respectively.

Diffractive photonuclear backgrounds with low particle activity are estimated using fully data-driven methods. Dedicated CRs are introduced, called \(\mu 2\)T-CR (\(\mu 4\)T-CR), which apply the same selection as \(\mu 1\)T-SR (\(\mu 3\)T-SR), but require an additional track satisfying \(p_T < 0.5\) GeV. Furthermore, the \(E_{ZDC} < 1\) TeV requirement is removed on either side to enrich the sample with events from photonuclear processes. To suppress the \(\gamma\gamma \rightarrow \tau\tau\) signal contamination in \(\mu 2\)T-CR, the two-track system mass must fulfill \(m_{2\text{trk}} > 1\) GeV; if \(m_{2\text{trk}} < 1\) GeV, the acoplanarity of the muon and highest-\(p_T\) track is required to exceed 0.2. The event yields in CRs are extrapolated to SRs by loosening the veto on topoclusters not matched to the muon or tracks from \(n_{\text{TC}}^{\text{unmatch}} = 0\) to \(n_{\text{TC}}^{\text{unmatch}} < 8\), both in CRs and SRs. The \(\mu 2\)T-CR (\(\mu 4\)T-CR) templates for \(n_{\text{TC}}^{\text{unmatch}}\) distributions are normalized to the event yield in \(\mu 1\)T-SR (\(\mu 3\)T-SR) in the region \(4 \leq n_{\text{TC}}^{\text{unmatch}} \leq 8\). In this region, the signal and dimuon background contributions are found to be
negligible, and events exhibit properties that suggest nonexclusive diffractive production, such as a small
or no rapidity gap [78]. As the additional track in $\mu 2T$-CR and $\mu 4T$-CR is soft ($p_T < 0.5$ GeV), its possible
correlation with topocluster activity is very small. This method estimates that 13 (2.8) photonuclear
events enter $\mu 1T$-SR ($\mu 3T$-SR); photonuclear events are expected to be negligible in $\mu e$-SR.

Other sources of background are predicted to be negligible in the SRs. Nondiffractive photonuclear
interactions are estimated using the Starlight+Dpmjet-III sample and are found to be negligible in all
three SRs. The PYTHIA 8 simulation of $\gamma\gamma \rightarrow q\bar{q}$ estimates dijet backgrounds contribute less than 0.3
events in both $\mu 1T$-SR and $\mu 3T$-SR. Similarly, the contribution from resolved $\gamma\gamma$ interactions, as estimated
with PYTHIA 8 [79], is found to be negligible. Exclusive $p^0$-meson production with simultaneous $\gamma\gamma \rightarrow \mu\mu$
production in $\mu 3T$-SR is studied using a data-driven method. Template distributions for this process are
built from events with two muons and two additional charged-particle tracks. The acoplanarities of both
the muon pair and the track pair must be below 0.05. All events in these templates are found to have
$m_{3\text{trk}} > 1.7$ GeV, so this background is expected to be negligible in $\mu 3T$-SR.

Systematic uncertainties affecting the measurement arise from the reconstruction of leptons, photons,
charged-particle tracks and topoclusters, the signal and background modeling, and integrated luminosity.

Uncertainties in the muon momentum scale and resolution follow those in Ref. [80]. The analysis
includes uncertainties in the data-to-MC correction factors applied to simulated samples for the muon
trigger and reconstruction efficiencies. Uncertainties in the reconstruction, identification, and energy
calibration of electrons and photons are evaluated in accord with Ref. [72]. The uncertainty in the
inclusive track reconstruction efficiency is dominated by the uncertainty in the amount of ID material [67].
This uncertainty is applied in the simulation by randomly removing tracks with a $p_T$- and $\eta$-dependent
probability corresponding to the material uncertainty. Uncertainties in the topocluster reconstruction
efficiency and energy calibration are estimated using $\gamma\gamma \rightarrow e\bar{e}$ events where one of the electrons emits a
hard bremsstrahlung photon due to its interaction with detector material [72].

Uncertainties in the photonuclear background evaluation are estimated by repeating the procedure with
alternative requirements for CRs. These resemble the $\mu 1T$-SR ($\mu 3T$-SR) selection except that the track
(three-track system) has the same electric charge as the muon candidate. The difference between the
photonuclear background contribution evaluated with alternative and nominal CRs defines the uncertainties,
affecting both the normalization and differential distributions. Uncertainties in modeling the photon flux
are estimated by using the Starlight MC samples without reweighting to Superchic. This affects the
normalization and differential distributions of the signal and $\gamma\gamma \rightarrow \mu\mu$ background. Uncertainties in
modeling $\tau$-lepton decays are estimated using PYTHIA 8 [81] as an alternative MC simulation to Tauola.
The effect of $\tau$-lepton spin correlations in Tauola is implemented using helicity amplitudes from the
$\gamma' \rightarrow \tau\tau$ process. This modeling is therefore cross-checked by comparing signal events simulated using
two versions of PYTHIA 8: v8.245 uses helicity amplitudes from the $\gamma' \rightarrow \tau\tau$ process, whereas v8.305
uses the $\gamma\gamma \rightarrow \tau\tau$ elementary process. The difference between the two implementations is found to be
negligible, and no further systematic uncertainty is assigned.

The uncertainty in the integrated luminosity is 1.9%, obtained with the LUCID-2 detector [82] using
methods similar to Ref. [83] for the primary luminosity measurements.

After applying the event selection, a total of 532, 85, and 39 data events are observed, compared with
$84 \pm 19, 9 \pm 3$, and $2.8 \pm 0.7$ expected background events in $\mu 1T$-SR, $\mu 3T$-SR, and $\mu e$-SR, respectively.
The background-only hypothesis is rejected with significance exceeding 5$\sigma$, establishing the observation
of the $\gamma\gamma \rightarrow \tau\tau$ process at ATLAS. The signal significance is highest in $\mu 1T$-SR, while $\mu e$-SR has the
The pre-fit signal-plus-background hypothesis predicts 543 ± 111, 93 ± 20, and 35 ± 8 events in $\mu_1T$-SR, $\mu_3T$-SR, and $\mu_e$-SR, respectively, which is compatible with the observed data. The signal strength $\mu_{\tau\tau}$, defined as the ratio of the observed signal yield to the SM expectation assuming the SM value for $a_\tau$, is measured using a profile-likelihood fit \[84, 85\] to be $\mu_{\tau\tau} = 1.03^{+0.06}_{-0.05}$ (tot) = 1.03$^{+0.05}_{-0.05}$ (stat) $^{+0.03}_{-0.03}$ (syst). The fit uses the $p_\tau^\mu$ distribution in the three SRs and 2$\mu$-CR with $\mu_{\tau\tau}$ being the only parameter of interest.

Approximately 80 nuisance parameters representing the systematic uncertainties are included in the fit. Many systematic uncertainties are correlated between the SRs and 2$\mu$-CR, so their impact on the measurement precision is minimized since they are constrained by 2$\mu$-CR. The dominant pre-fit contribution is the photon-flux uncertainty, which mainly affects the signal yield (by approximately 20%), with a significantly smaller impact on the signal shape found upon decorrelation from the normalization component. After the fit, the photon-flux uncertainty becomes subdominant and luminosity uncertainty becomes negligible relative to other sources. The leading contributions to the total systematic uncertainty are the estimation of the muon trigger efficiency, $\tau$-lepton decay modeling, and track reconstruction efficiency.

To measure $a_\tau$, an alternative fit is performed where $a_\tau$ is the only free parameter using the $p_\tau^\mu$ distribution in the three SRs and 2$\mu$-CR; $p_\tau^\mu$ is chosen because of its high sensitivity to $a_\tau$ \[46\]. Simulated signal samples with various $a_\tau$ values are employed. In the nominal sample, $a_\tau$ is set to its SM value. Signal templates for alternative $a_\tau$ hypotheses are obtained by reweighting the nominal sample in three dimensions, differentially in $\tau\tau$ invariant mass, $\tau\tau$ rapidity, and rapidity difference between the two $\tau$-leptons, according to calculations from Ref. \[46\]. These calculations parameterize the $\tau\gamma$ coupling by $F_1(q^2)\gamma^\mu + F_2(q^2)\frac{1}{\sqrt{m}}\sigma^\mu\nu q_\nu$, where $q_\nu$ is the photon four-momentum, $\sigma^\mu\nu = i[\gamma^\mu, \gamma^\nu]/2$ the spin tensor, and the form factors satisfy $F_1(q^2 \to 0) = 1$ and $F_2(q^2 \to 0) = a_\tau$. A similar parameterization was used in previous LEP measurements \[27, 29, 30\], which exploits the near-zero virtuality of initial-state photons. A total of 14 templates for different $a_\tau$ values are created to model the dependence of the $p_\tau^\mu$ distribution on $a_\tau$ in the three SRs.

Figure 1 shows the $p_\tau^\mu$ distributions of the four analysis regions for the data and post-fit expectation. The fit describes the data well.

The best-fit value of $a_\tau$ is $a_\tau = -0.041$, with the corresponding 68% CL and 95% CL intervals being $(-0.050, -0.029)$ and $(-0.057, 0.024)$, respectively. The higher-than-expected observed yields lead to the highly asymmetric 95% CL interval. This arises from the nearly quadratic signal cross-section dependence on $a_\tau$, caused by the interference of the SM and BSM amplitudes \[29, 30, 46\]. The expected 95% CL interval is $-0.039 < a_\tau < 0.020$. The impact of systematic uncertainties on the final results is small relative to statistical uncertainties. Figure 2 shows the $a_\tau$ measurement alongside previous results obtained at LEP. The precision of this measurement is similar to the most precise single-experiment measurement by the DELPHI Collaboration.
Figure 1: Muon transverse momentum distributions in the (top-left) $\mu_1$T-SR, (top-right) $\mu_3$T-SR, (bottom-left) $\mu$e-SR, and (bottom-right) $2\mu$-CR categories. Black markers denote data and stacked histograms indicate the different components contributing to the regions. Post-fit distributions are shown with the signal contribution corresponding to the best-fit $\alpha_\tau$ value ($\alpha_\tau = -0.041$). For comparison, signal contributions with alternative $\alpha_\tau$ values are shown as solid red ($\alpha_\tau = -0.06$) or dashed blue ($\alpha_\tau = 0.04$) lines. The bottom panel shows the ratio of the data to post-fit predictions. Vertical bars denote uncertainties from the finite number of data events. Hatched bands represent $\pm 1\sigma$ systematic uncertainties of the prediction with the constraints from the fit applied.
Figure 2: Measurements of $a_\tau$ from fits to individual signal regions (including the dimuon control region), and from the combined fit. These are compared with existing measurements from the OPAL [29], L3 [30] and DELPHI [27] experiments at LEP. A point denotes the best-fit $a_\tau$ value for each measurement if available, while thick black (thin magenta) lines show 68% CL (95% CL) intervals. The expected interval from the ATLAS combined fit is also shown.

In summary, $\tau$-lepton pair production in ultraperipheral heavy-ion collisions, $\text{Pb}+\text{Pb} \to \text{Pb}(\gamma\gamma \to \tau\tau)\text{Pb}$, is observed by ATLAS with a significance exceeding $5\sigma$ in 1.44 nb$^{-1}$ of $\sqrt{s_{\text{NN}}} = 5.02$ TeV data at the LHC. The observed event yield is compatible with that expected from the SM prediction within uncertainties. The events are used to set constraints on the $\tau$-lepton anomalous magnetic moment, corresponding to $-0.057 < a_\tau < 0.024$ at 95% CL. The measurement precision is limited by statistical uncertainties. This result introduces the use of hadron-collider data to test electromagnetic properties of the $\tau$-lepton, and the results are competitive with existing lepton-collider constraints.

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J. Jovicic 15, X. Ju 17a, J.J. Junggeburth 36, A. Juste Rozas 13y, S. Kabana 136c, A. Kaczmarska 85, M. Kado 77a,74b, H. Kagan 118, M. Kagan 142, A. Kahn 41, A. Kahn 127, C. Kahra 49, T. Kaji 167, E. Kajomovitz 149, N. Kakati 168, C.W. Kalderon 29, A. Kamenshchikov 154, N.J. Kang 135, Y. Kano 110, D. Kar 133g, K. Karava 125, M.J. Kareem 155b, E. Karentzos 85, I. Karkanias 151, S.N. Karpov 138, Z.M. Karpova 138, V. Kartvelishvili 9, A.N. Karyukhin 137, E. Kasimi 151, C. Kato 162d, J. Katzy 148, S. Kaur 134, K. Kawade 139, K. Kawagoe 138, T. Kawaguchi 110, T. Kawamoto 134c, G. Kawamura 35, E.F. Kay 164, F.I. Kaya 137, S. Kazakos 13, V.F. Kazanian 137, Y. Ke 144, J.M. Keaveney 133a, R. Keeler 164, G.V. Kehris 61, J.S. Keller 134, A.S. Kelly 95, D. Kelsey 145, J.J. Kempter 120, J. Kendrick 20, K.E. Kennedy 41, O. Kepka 130, B.P. Kerridge 176, S. Kersten 119, B.P. Kerševan 92, L. Keszeghova 28a, S. Ketabchi Haghhighat 154, M. Khandoaga 126, A. Khanov 120, A.G. Kharlamov 137, T. Kharamelova 137, E.E. Khoda 137, T.J. Khoo 148, G. Khoriali 165, J. Khubua 148b, Y.A.R. Khwaira 86, M. Kiehn 136, A. Kilgallon 122, D.W. Kim 17a,47b, E. Kim 153, Y.K. Kim 49, N. Kimura 195, A. Kirchhoff 155, D. Kirchmeier 10, C. Kirfel 24, J. Kirt 133, A.E. Kiryunin 109, T. Kishimoto 152, D.P. Kisliuk 154, C. Kitsaki 10, O. Kivernyk 24, M. Klassen 63a, C. Klein 34, L. Klein 165, M.H. Klein 105, M. Klein 91, U. Klein 191, P. Klimek 36, A. Klimentov 199, F. Klimpel 110, T. Klingl 24, T. Kloutchnikova 136, F.F. Klitzner 108, P. Kluit 113, S. Kluth 109, E. Knerner 78, T.M. Knight 154, A. Knue 55, D. Kobayashi 88, R. Kobayashi 66, M. Kocian 142, T. Kodama 152, P. Kodyš 152, D.M. Koeck 145, P.T. Koenig 174, T. Koffas 34, N.M. Köhl 36, M. Kolb 134, I. Kolesneu 14, T. Komarek 121, K. König 54, A.Y. Kong 1, T. Kono 117, N. Konstantinidis 95, B. Konya 97, R. Kopelianski 67, S. Koperny 64a, K. Korcyl 35, K. Kordas 151, G. Korén 150, A. Korn 95, S. Korn 155, I. Kornolkov 13, N. Korotkova 137, B. Kortman 113, O. Kortner 109, S. Kortner 109, W.H. Kostecka 114, V.V. Kostyukhina 140, A. Kotsokechagia 156, A. Kottwal 151, A. Koulouris 136, A. Kourkoumelis-Charalampidi 172a,72b, C. Kourkoumelis 109, E. Kourliftis 86, O. Kovanda 145, R. Kowalewski 164, W. Kozanecki 134, A.S. Kozhin 137, V.A. Kramarenko 137, G. Kramberger 92, P. Kramer 79, M.W. Krasny 126, A. Krasznahorkay 36, J.A. Kremer 79, T. Kresse 150, J. Kretzschmar 101, K. Kreul 108, P. Krieger 154, F. Krieter 108, S. Krishnamurthy 102, A. Krishnan 138b, M. Krivos 132, K. Krixka 17a, K. Kroeninger 149, H. Kroha 109, J. Kroll 140, J. Kroll 127, S.P. Krowman 106, U. Kruchonak 138, H. Krüger 24, N. Krunnack 80, S. Kruse 51, J.A. Krzysiat 185, A. Kubota 153, O. Kuchinskaia 137, S. Kuday 34a, D. Kuechler 48, J.T. Kuechler 48, S. Kuehn 36, T. Kuhl 48, V. Kukhtin 86, Y. Kulchitsky 37a, S. Kulesskov 136a,136b, M. Kumar 33b, N. Kumari 101, M. Kuna 85, A. Kupco 130, T. Kupfer 49, A. Kupich 137, O. Kuprash 124, H. Kurashige 133, L.L. Kuchaninov 155a, Y.A. Kurochkin 137, A. Kurova 137, E.S. Kuwertz 156a, M. Kuze 153, A.K. Kvan 102, J. Kvita 121, T. Kwan 103, K.W. Kwok 164a, N.G. Kyriacou 135, L.O. Laatu 101, C. Lacasta 116, F. Lacava 174a,74b, H. Lacker 138, D. Lacour 128, N.N. Lad 195, E. Ladygin 24, B. Laforge 126, T. Lagouri 136e, S. Lai 35, I.K. Lakomiec 84a, N. Lalloue 100, J.E. Lambert 159, S. Lammers 157, W. Lampel 79, C. Lampoudis 151, A.N. Lancaster 114, E. Lançon 29, U. Landgraf 154, M.P.J. Landon 93, V.S. Lang 74, R.J. Langenberg 102, A.J. Lankford 159, F. Lanni 129, K. Lantzsch 154, A. Lanza 12a, A. Lapertos 157b,57a, J.F. Laporte 134, T. Lari 170a, F. Lasagni Manghi 23b, M. Lassnig 36, V. Latonova 130, T.S. Lau 64a, A. Laudrain 109, A. Laurier 34, S.D. Lawlor 94, Z. Lawrence 130, M. Lazزارoni 10a,70b, B. Le 100, B. Leban 102, A. Lebedev 158, M. LeBlanc 36, T. LeCompte 30, F. Ledroit-Guillon 80, A.C.A. Lee 85, G.R. Lee 156, L. Lee 161, S.C. Lee 147, S. Lee 47a,47b, T.F. Lee 191, L.L. Leeuw 133c, H.P. Lefebvre 194, M. Lefebvre 164, C. Leggett 17a, K. Lehmann 141, G. Lehmam Miotto 136, W.A. Leight 152, A. Leisos 151u, M.A.L. Leite 81c,
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