

Measurement of the tau anomalous magnetic moment using Ultra-peripheral collisions with the ALICE detector in Run 3 Pb–Pb data

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The anomalous magnetic moment of the tau lepton (a_τ) is a sensitive probe for the search for deviations from the Standard Model predictions and thus for new physics. This study investigates the feasibility of measuring a_τ using ultra-peripheral collisions (UPCs) at the LHC, where photon-photon interactions ($\gamma\gamma \rightarrow \tau^+\tau^-$) produce tau lepton pairs. We focus on events recorded by the ALICE detector during Run 3 Pb–Pb data-taking. Events are selected in the decay channel where one tau decays into an electron and neutrinos, and the other decays into a charged pion, or three charged pions, and neutrinos. These samples are enhanced with decays into muons, which are inseparable in the ALICE detector. The clean environment of UPCs minimizes hadronic background, while the advanced particle identification capabilities of the ALICE Time Projection Chamber (TPC) and Time-of-Flight (TOF) systems allow for efficient separation of electrons, pions, and background particles. In this talk, prospects for measuring this process by ALICE in Run 3, which benefits from high statistics and improved systematics uncertainties, will be discussed. Results will provide tighter constraints on a_τ , contributing to the broader effort to test the Standard Model's robustness and explore physics beyond it.

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1 Introduction

For a point-like Dirac fermion with spin 1/2, the gyromagnetic factor is $g = 2$. Quantum corrections introduced by Standard Model (SM) induce the *anomalous magnetic moment*,

$$a \equiv \frac{g - 2}{2}. \quad (1)$$

In case of leptons, electron a_e ¹ and muon a_μ ² are measured with extraordinary precision, the tau lepton remains poorly constrained due to its short lifetime and the consequent absence of spin-precession based measurements. Current limits are derived from high-energy production processes and leave orders of magnitude of parameter space unconstrained relative to the electron and muon³.

Given that sensitivity to new physics grows with the lepton mass squared, a precise determination of a_τ would strongly constrain TeV-scale scenarios beyond the SM. Ultraperipheral heavy-ion collisions (UPCs) at the LHC provide an intense flux of quasi-real photons with very small virtuality ($q^2 \rightarrow 0$), enabling studies of $\gamma\gamma \rightarrow \tau^+\tau^-$ that are directly sensitive to the $\gamma\tau\tau$ vertex⁴.

2 Theoretical Background and Status

The effective $\gamma\tau\tau$ vertex can be written as^{5,6}

$$\Gamma_{\gamma\tau\tau}^\mu(q) = -ie \left[\gamma^\mu F_1(q^2) + \frac{i}{2m_\tau} \sigma^{\mu\nu} q_\nu F_2(q^2) + \frac{1}{2m_\tau} \gamma^5 \sigma^{\mu\nu} q_\nu F_3(q^2) \right], \quad (2)$$

with $F_2(0) = a_\tau$. Constraints on a_τ have been derived from e^+e^- colliders (e.g. DELPHI at LEP⁷), LHC pp data (CMS³), and heavy-ion UPCs (ATLAS⁸ and CMS⁹), probing complementary $\gamma\gamma$ center-of-mass energies $W_{\gamma\gamma}$: below 10 GeV at LEP, $\mathcal{O}(10\text{--}50)$ GeV in Pb–Pb, and up to several hundred GeV in pp . The overall best bounds to date come from CMS in pp , while the ALICE program targets the intermediate $W_{\gamma\gamma}$ region with abundant low- p_T tracks and excellent PID at midrapidity. While in Run 2 the limited luminosity and detector performance did not allow a meaningful measurement of a_τ , the upgraded ALICE detector and larger datasets of Run 3 open the possibility to perform this measurement for the first time.

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3 Experimental Setup and Run 3 Performance

The ALICE detector underwent major upgrades for Run 3¹⁰. Subsystems relevant to this analysis include:

- **DAQ:** the triggered readout of all relevant detectors was replaced with streaming readout;
- **ITS:** improved vertexing and low- p_T tracking;
- **TPC:** main tracking detector with excellent dE/dx resolution for PID of low-momenta tracks;
- **TOF:** timing-based PID extending electron–kaon/proton separation up to $p_T \sim 1.5$ GeV/c;
- **FIT:** quartz radiators and scintillators at forward rapidities for interaction time and multiplicity;
- **ZDC:** forward hadronic calorimeters to detect neutrons.

In the central barrel, electrons are cleanly separated from muons, pions, kaons and protons with TPC+TOF for $p_T < 1.5$ GeV/c, see Figure 1. Pions and muons are not separable via TPC/TOF alone, but this does not limit the mixed electron+pion/muon channel used below.

4 Analysis Strategy

Tau decays are categorized into 1-prong ($\sim 80\%$) and 3-prong ($\sim 20\%$) modes. ALICE focuses on final states with an *electron* and an oppositely charged track system:

- **1-prong:** $e^\pm + e^\mp$ or $(\pi^\mp/\mu^\mp)$;
- **3-prong:** $e^\pm + 3\pi^\mp$ (with neutral pions unconstrained).

The dominant backgrounds are $\gamma\gamma \rightarrow e^+e^-$, $\gamma\gamma \rightarrow \mu^+\mu^-$, $\gamma\gamma \rightarrow \pi^+\pi^-$ and continuum coherent photonuclear production of $\pi^+\pi^-$. The selection employs:

1. **Exclusivity:** two-prong topology at midrapidity with minimal additional activity;
2. **Acoplanarity:** back-to-back pairs veto to suppress continuum; a requirement on system p_T (e.g. > 0.2 GeV/c) is used to reduce e^+e^- -contamination;
3. **PID:** TPC dE/dx and TOF to tag electrons and reject hadrons.
4. **No neutrons:** veto on events with neutrons in forward direction to reject nuclear break-up events (in figures referred as 0n0n class).

Residual background is estimated using like-sign and mixed-event techniques. For the $e + 3\pi$ channel, an invariant-mass selection $m_{3\pi} < m_\tau$ further suppresses combinatorics.

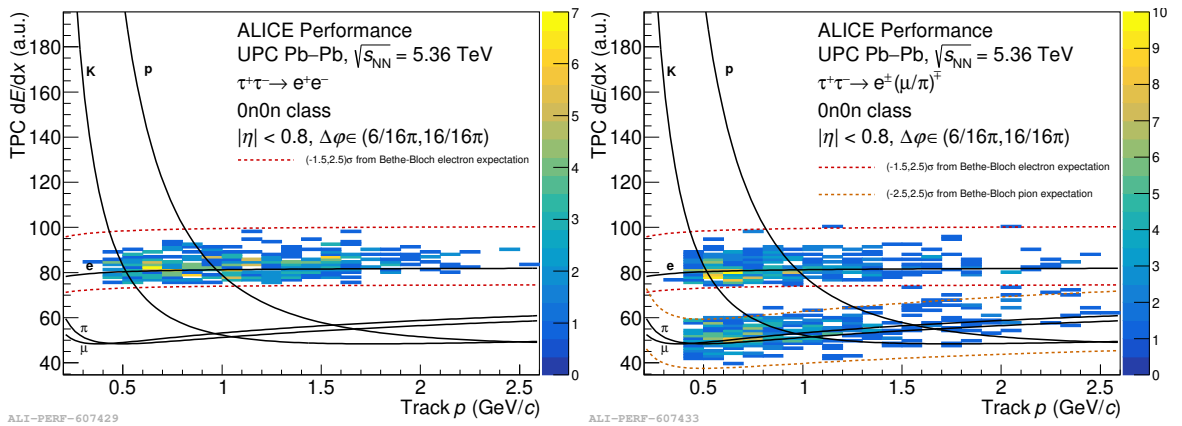


Figure 1 – TPC dE/dx vs. track momentum distributions showing electron–muon/pion separation and the absence of kaon/proton contamination in the selected samples. Black curves indicate Bethe-Bloch expectations for various particles.

5 Simulation Studies

Dedicated simulations of UPC Pb–Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$ based on Upcgen generator¹¹ corresponding to integrated luminosities of $2.7\text{--}13 \text{ nb}^{-1}$ predict $\sim 3.6 \times 10^4$ $\tau^+\tau^-$ events within the central-barrel acceptance when requiring one electron and one oppositely charged track (pion/muon) at midrapidity. The relative yield fractions for the accessible channels are approximately $(e + e) : (e + \pi/\mu) : (e + 3\pi) = 1 : 5.6 : 1.7$.

Sensitivity to a_τ is driven by distortions of the lepton p_T spectra. We form ratios of the differential cross section across 10 p_T intervals and perform a χ^2 combination assuming uncorrelated systematics. Depending on the achievable systematic uncertainty (1–5%), the projected ALICE limits improve upon the DELPHI constraint by factors of 2–8 with the full Run 3+4 dataset.

6 First Results from Run 3

Using the current Pb–Pb UPC dataset of $\sim 1 \text{ nb}^{-1}$ at $\sqrt{s_{\text{NN}}} = 5.36 \text{ TeV}$, we report the following performance and observations:

- **PID:** TPC dE/dx shows clean electron separation with no indications of kaon/proton contamination in the selected samples; π/μ remain indistinguishable in the central barrel, consistent with expectations, see Figure 1.
- **Acoplanarity:** Data agree with STARlight^{12,13} MC in both e^+e^- and $e + (\pi/\mu)$ selections after imposing a system- p_T requirement of $0.2 \text{ GeV}/c$, see Figure 2.
- **$e + 3\pi$ channel:** A clear enhancement is observed for $m_{3\pi} < m_\tau$. Background-subtracted acoplanarity distributions reveal a signal consistent with MC expectations, see Figure 3.
- **Electron p_T spectra:** The shapes in the e^+e^- and $e + (\pi/\mu)$ channels are in fair agreement with STARlight predictions. Observed statistics match expectations given the delivered luminosity and selection efficiencies, see Figure 4.

7 Discussion and Outlook

These first Run 3 results validate the UPC-based strategy to access a_τ with ALICE. The central-barrel focus on low- p_T leptons provides sensitivity in a kinematic regime complementary to pp analyses by CMS and ATLAS. With the anticipated Run 3+4 integrated luminosity of order $10\text{--}13 \text{ nb}^{-1}$, ALICE is projected to set world-leading constraints in the intermediate $W_{\gamma\gamma}$ range.

8 Conclusions

- UPCs at the LHC enable a direct probe of the $\gamma\tau\tau$ vertex and the tau anomalous magnetic moment.
- ALICE is uniquely capable of reconstructing low- p_T leptons in mixed tau-decay final states.
- First Run 3 data confirm detector performance and the analysis strategy, with distributions consistent with STARlight expectations.
- With the full Run 3+4 dataset, ALICE can improve the current bounds on a_τ and offer coverage complementary to CMS/ATLAS in pp .

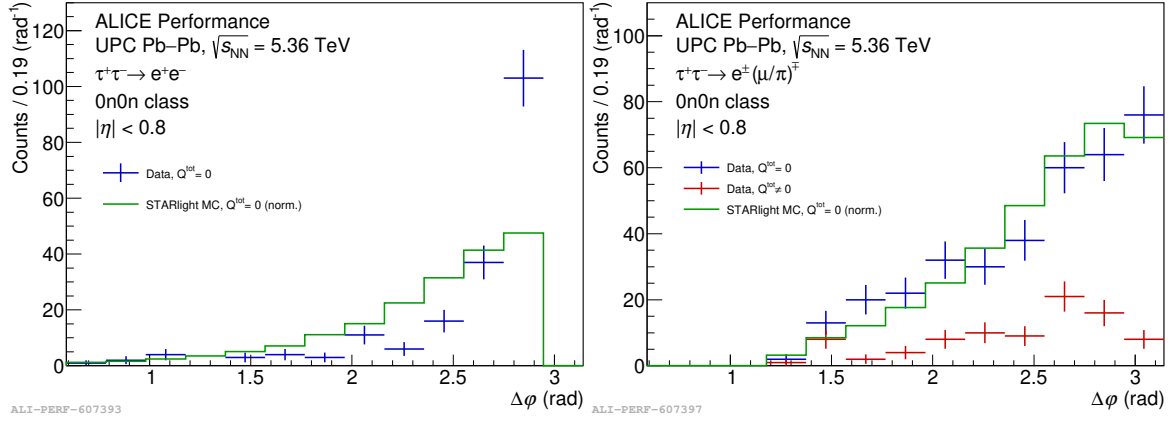


Figure 2 – Acoplanarity distributions in data vs. STARlight MC for the e^+e^- and $e^+(\pi/\mu)$ channels after requiring system $p_T > 0.2$ GeV/c.

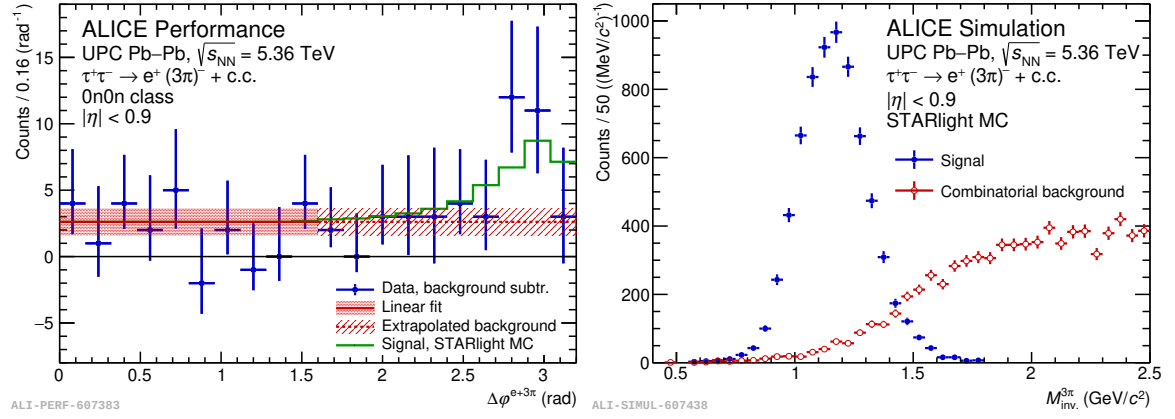


Figure 3 – Acoplanarity (left) and invariant mass (right) distributions in data vs. STARlight MC for the e^+e^- and $e^+3\pi$ channel after requiring system $p_T > 0.2$ GeV/c.

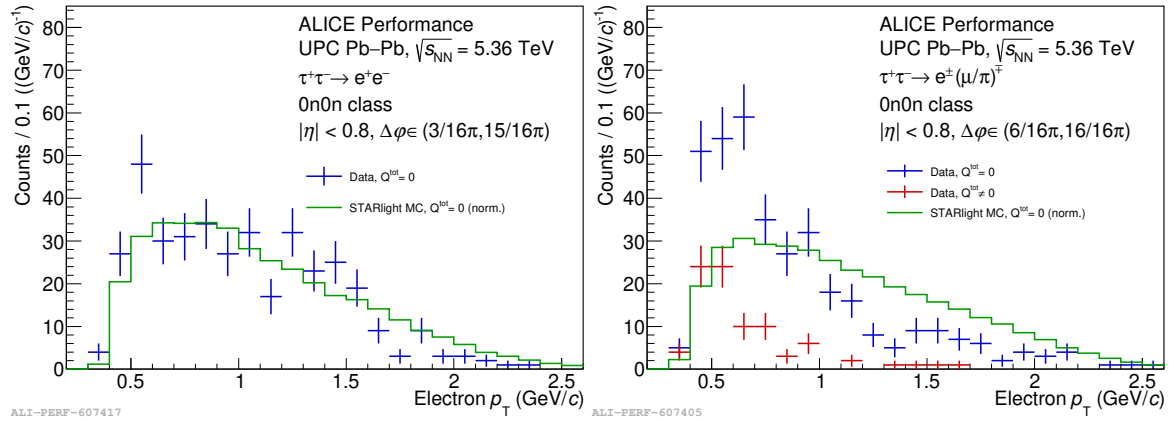


Figure 4 – The electron p_T spectra in the e^+e^- and $e^+(\pi/\mu)$ selection compared to STARlight.

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