Search for New Physics in ultra-peripheral heavy-ion collisions in the ATLAS experiment at the LHC

Project duration: 1.11.2020–30.04.2023
Project manager: Prof. Dr hab. Iwona Grabowska-Bołd
Faculty of Physics and Applied Computer Science

AGH University of Krakow
RESEARCH UNIVERSITY
EXCELLENCE INITIATIVE

INTRODUCTION:

The Dirac equation predicts the magnetic moment of charged leptons with the gyromagnetic factor $g_l=2$. However, quantum loop effects lead to small calculable deviation parametrized by the anomalous magnetic moment $a_l=(g_l-2)/2$. The anomalous magnetic moments of electron and muon are measured with extraordinary experimental precision providing the opportunity to test the Standard Model (SM) predictions. The **τ-lepton anomalous magnetic moment**, a_τ, is well predicted theoretically but so far strikingly **evades precision measurements**. Its value is **sensitive** to many **Beyond Standard Model** (BSM) effects (lepton compositeness, supersymmetry, TeV-scale leptoquarks, ...).

ATLAS provides the **first measurement** of the **τ-lepton properties** in **ultra-peripheral collisions** (UPC) of heavy-ions. A UPC occurs when the distance separating the interacting nuclei exceeds the sum of their radii. The large electromagnetic fields generated by relativistic ions give rise to photon-induced processes. The exceptional characteristics of a UPC: huge cross-section enhancement and suppression of hadronic interactions, make it an **excellent tool** for studying **rare processes** and **searching for BSM phenomena**.

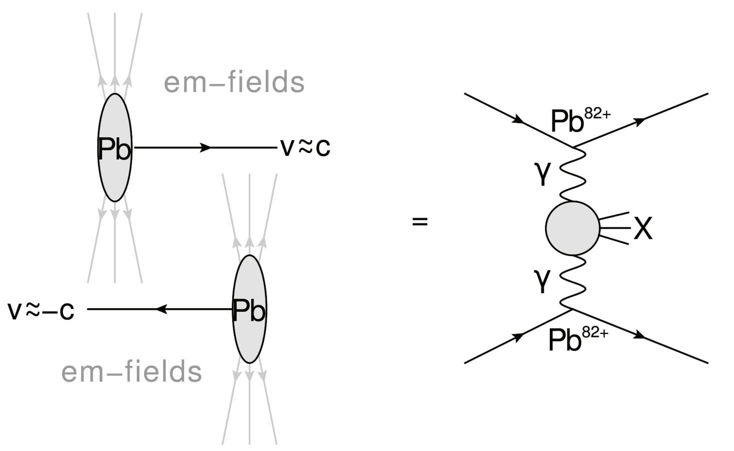

Figure 1. Illustration of an ultra-peripheral collision of two lead ions.

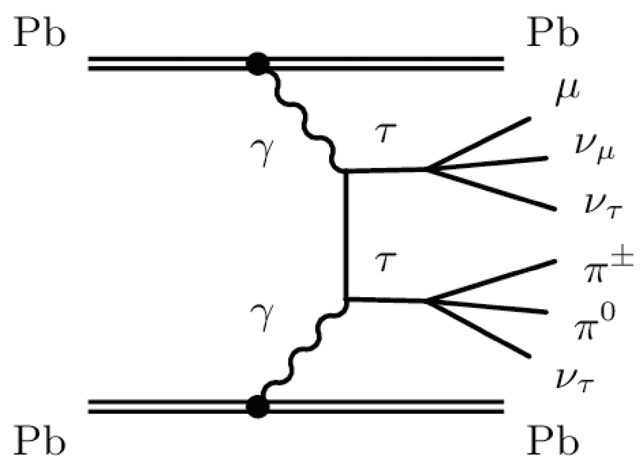

Figure 2. Schematic diagrams showing photon-induced τ-lepton pair production in ultraperipheral lead-lead interactions, Pb+Pb → Pb(γγ→ ττ)Pb, with the τ-leptons decaying into one muon and one charged pion.

METHODOLOGY:

Our measurement uses ultra-peripheral collisions of lead-lead beams at centre-of-mass energy of $\sqrt{s_{NN}}$ = 5.02 TeV recorded by the **ATLAS experiment** at the **Large Hadron Collider** at **CERN**. The data sample corresponds to an integrated luminosity of 1.44 nb^{-1}. **Exclusive ditau production**, γγ→ττ, is studied. Candidate events contain one muon from the τ-lepton decay and an electron or charged-particle track(s) from the other τ-lepton decay. Three signal regions (SR) are defined:

- μe-SR → muon + electron
- μ1T-SR → muon + 1 track
- μ3T-SR → muon + 3 tracks

Signal events are selected with a single muon trigger requiring muon transverse momentum, p_T, above 4 GeV. To ensure the exclusivity of the selected events, vetoes on forward neutron activity and on additional low-p_T tracks are imposed.
The main sources of background contributions arise from the exclusive dimuon production, γγ→μμ, with the final-state radiation and diffractive photonuclear interactions. The γγ→μμ background is constrained with a dimuon control region, 2μ-CR.
The analysis strategy is to exploit the γγ→μμ cross-section dependence and muon p_T shape dependence on a_τ. A fit to the muon p_T distribution in the SRs and CR is performed to extract the value of a_τ.

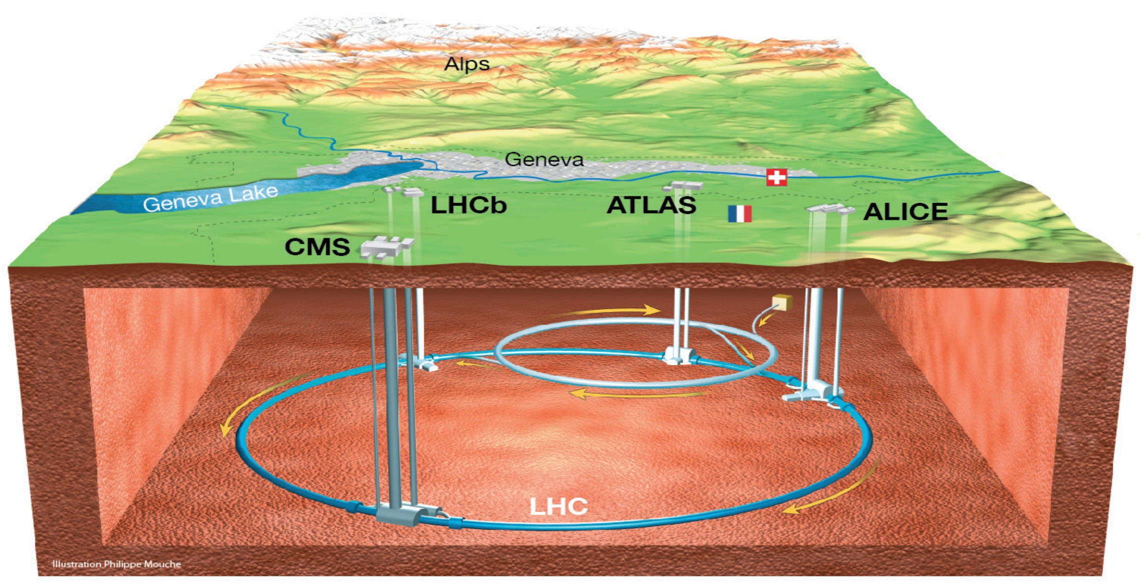

Figure 3. Overall view of the LHC, including 4 LHC detectors: ALICE, ATLAS, CMS and LHCb.

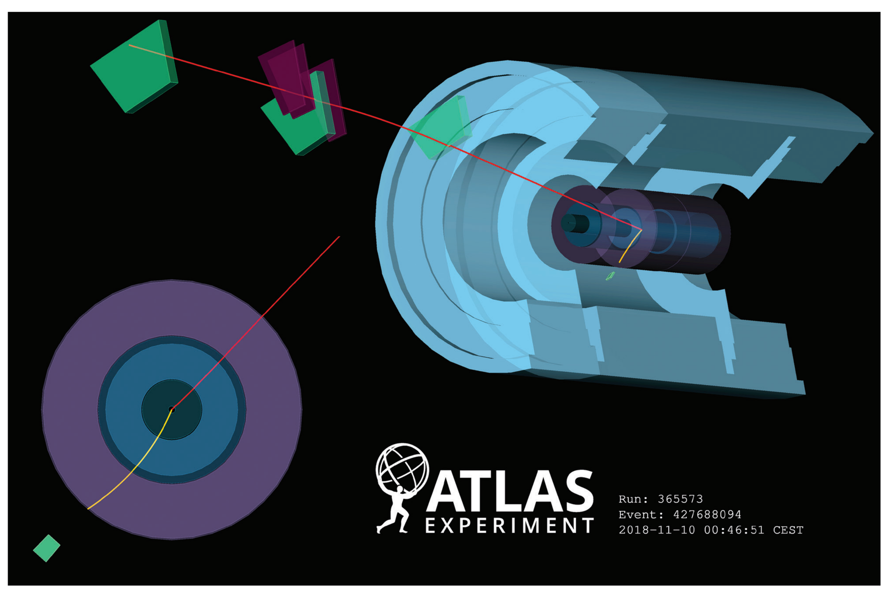

Figure 4. Event display for an exclusive γγ→ ττ candidate from μ1T-SR in lead-lead collision data.

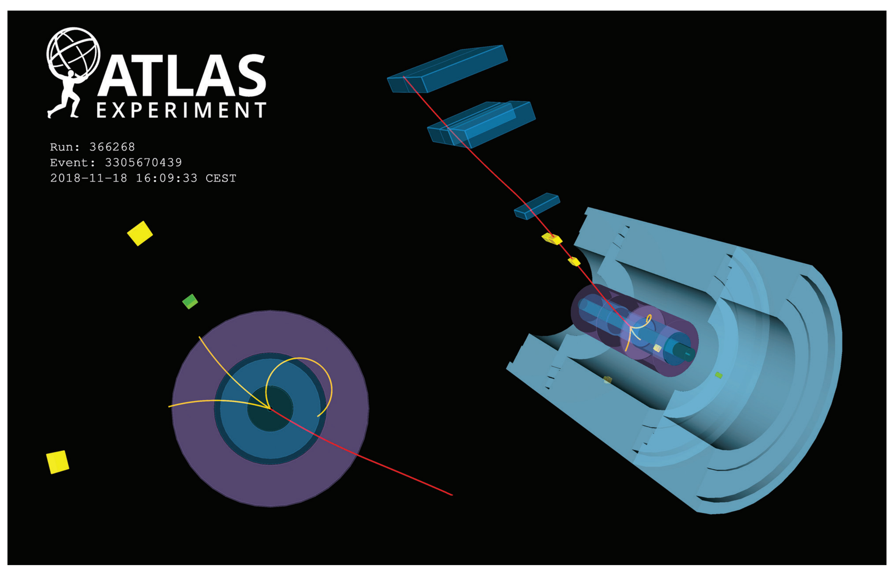

Figure 5. Event display for an exclusive γγ→ ττ candidate from μ3T-SR in lead-lead collision data.

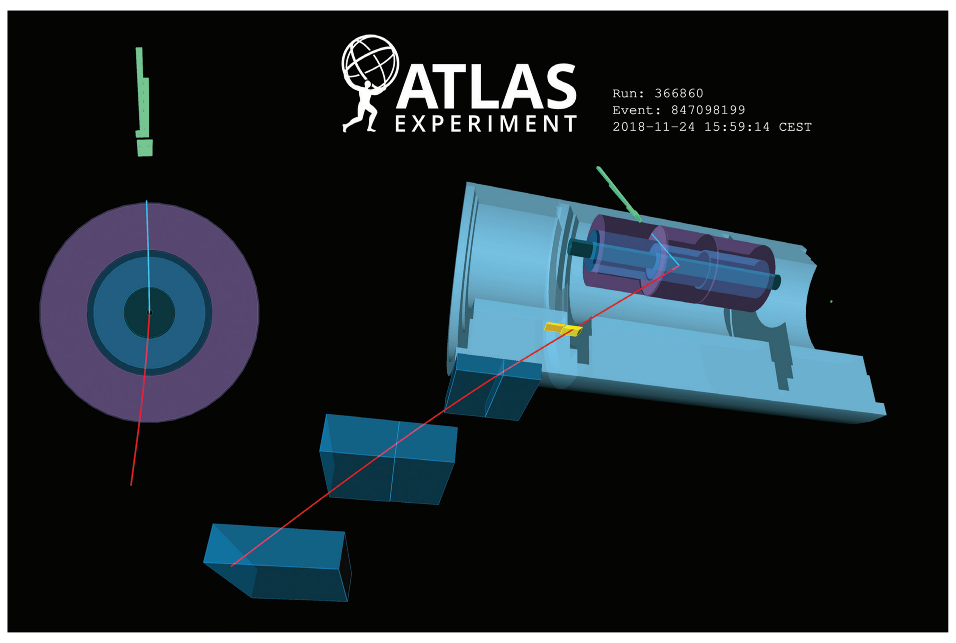

Figure 6. Event display for an exclusive γγ→ ττ candidate from μ e-SR in lead-lead collision data.

RESULTS:

After applying the event selection, a total of **656 data events are observed** in three signal regions in which the analysis is performed.
The **observation** of γγ→ττ in UPC Pb+Pb collisions is established with a **significance exceeding 5 standard deviations**. The significance is the highest in the μ1T-SR, while the largest signal-background ratio is observed in the μe-SR.
The signal strength, $\mu_{\tau\tau}$, defined as the ratio of the observed signal yield to the SM expectation is measured using a profile-likelihood fit to be $\mu_{\tau\tau}=1.03_{-0.05}^{+0.06}$, assuming the SM value of a_τ (a_τ^{SM} = 0.00117721(5)). To measure a_τ, a template fit to the muon p_T distribution is performed in the three SRs with a_τ being the only free parameter. The distribution of p_T is chosen because of its high sensitivity to a_τ. Templates with 14 different a_τ values are employed. In the nominal signal sample a_τ is set to the SM value. A control region with events from the γγ→μμ process is used in the fit to constrain systematic uncertainties from initial-photon fluxes.
The best-fit a_τ value is measured to be $a_\tau = -0.041$ with the corresponding observed 95% confidence-level interval being $-0.057 < a_\tau < 0.024$. Its precision **is competitive** with **the world-best limit** from the DELPHI experiment [2].

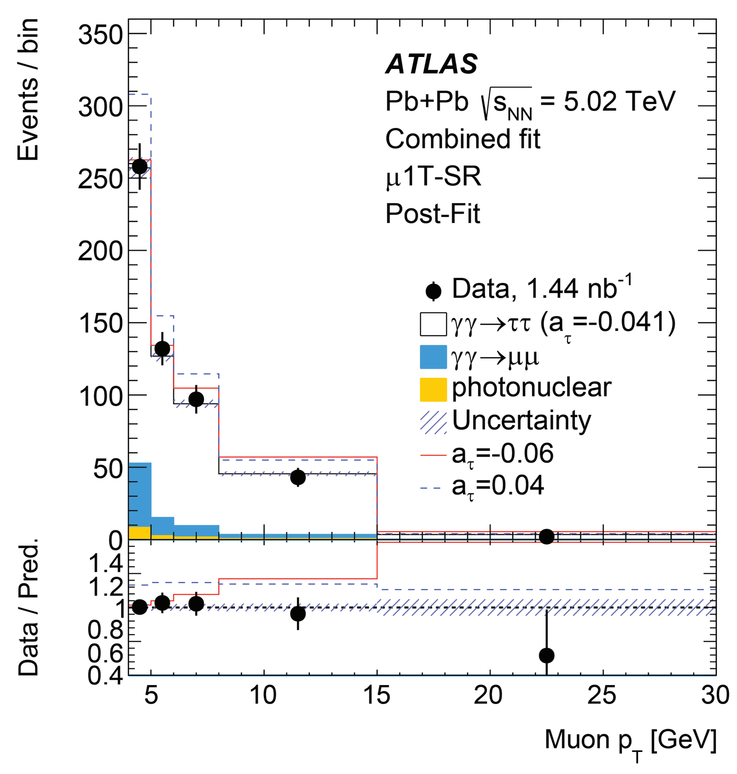

Figure 7. Muon transverse momentum distributions in the μ1T-SR category.

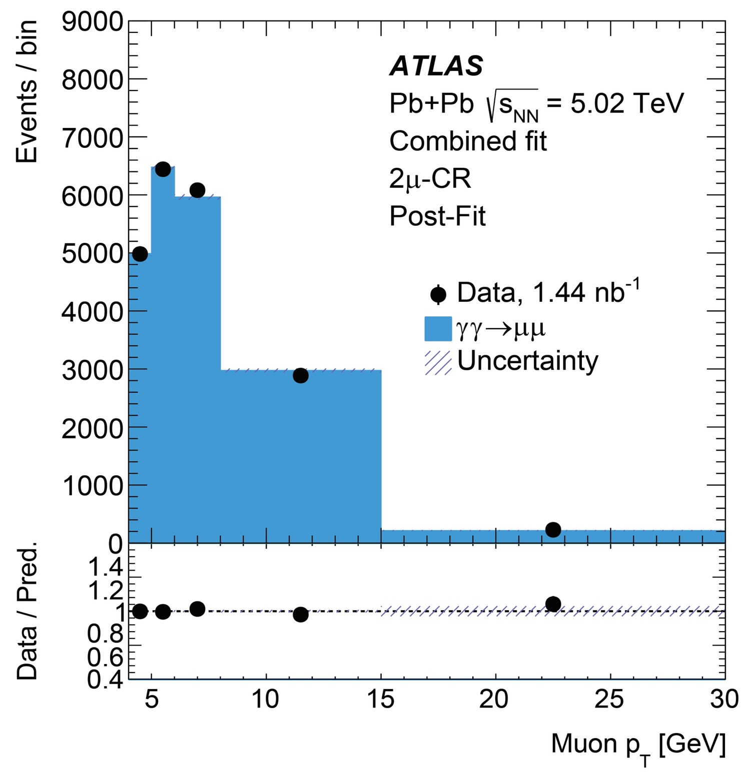

Figure 8. Muon transverse momentum distributions in the 2μ-CR category.

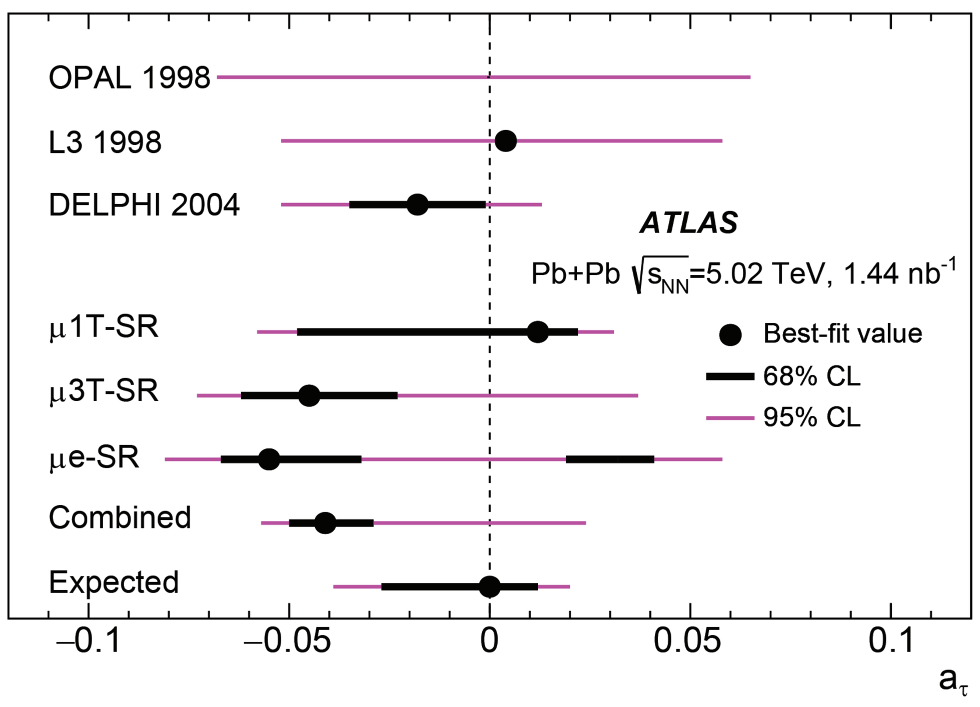

Figure 9. Measurements of a_τ from fits to individual signal regions (including the dimuon control region) and from the combined fit, including a comparison with existing measurements from the OPAL, L3 and DELPHI experiments at LEP.

SUMMARY:

Our project provides a **pioneering measurement** of tau leptons in heavy-ion collisions using **exclusive ditau production** in Pb+Pb **UPC** at the LHC. The γγ→ττ process is observed with above 5σ significance. The **signal strength** is **consistent** with the **SM expectation**. The **new constraints** on the **τ-lepton anomalous magnetic moment** are set and are **competitive** with the previous best limit from the LEP era [2]. **Further improvements** in precision are **expected** with new Pb+Pb data to be collected in 2023 as part of the **Run-3** campaign at CERN.

REFERENCES:

1. ATLAS Collaboration, arXiv:2204.13478 [hep-ex], accepted by PRL
2. DELPHI Collaboration, J. Abdallah et al., Eur. Phys. J. C 35 (2004) 159–170, arXiv:hep-ex/0406010

idub.agh.edu.pl