Observation of γγ→ττ in ultraperipheral lead-lead collisions and constraints on τ g-2 with the ATLAS detector

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Improved precision of a_τ measurements is a vital part of the τ-lepton compositeness test and the physics beyond the Standard Model. The τ-lepton pair production in ultra-peripheral heavy-ion collisions, Pb+Pb → Pb($\gamma\gamma \to \tau\tau$)Pb, is observed by ATLAS with a significance exceeding 5σ in 1.44 nb^{-1} of $\sqrt{s_{NN}}$= 5.02 TeV data. The $\gamma\gamma \to \tau\tau$ process gives sensitivity to anomalous electromagnetic couplings of τ-lepton since it contains two $\tau\tau\gamma$ vertices. To measure a_τ, a profile likelihood fit is performed to the leading lepton transverse momentum distribution, using a control region to constrain systematic uncertainties. The observed 95% confidence-level intervals are $a_\tau \in (-0.058, -0.012) \cup (-0.006, 0.025)$. The results are competitive with existing lepton-collider constraints.

1. Introduction

- **Tau production and decay at ATLAS**

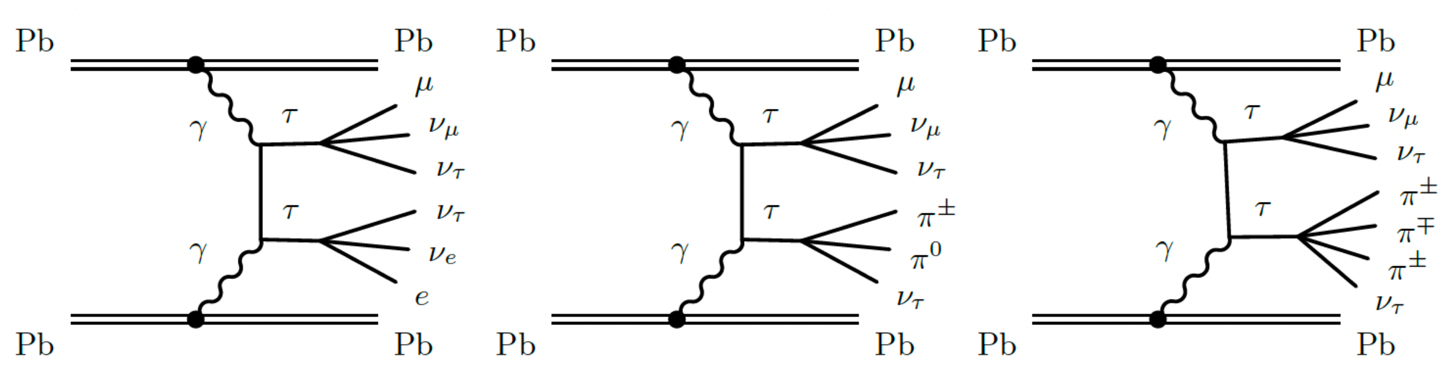

Figure 1: Diagrams showing photon-induced τ-lepton pair production in UPC, with the τ-leptons decaying into signatures targeted by the event selection. The cross-section is enhanced by $Z4$ relative to pp collisions.

- **The Tau anomalous magnetic moment**

a_τ calculations are based on the $\tau\tau\gamma$ vertex parameterization with the general form-factor decomposition. It exploits the near-zero virtuality of initial-state photons to directly relate $a\tau$ to the form factors. $\tau\tau\gamma$ vertex function:

$$i\Gamma_\mu^{(\gamma\ell\ell)}(p',p) = -ie\left[\gamma_\mu F_1(q^2) + \frac{i}{2m_\ell}\sigma_{\mu\nu}q^\nu F_2(q^2) + \frac{1}{2m_\ell}\gamma^5\sigma_{\mu\nu}q^\nu F_3(q^2)\right]$$

2. Detection with ATLAS

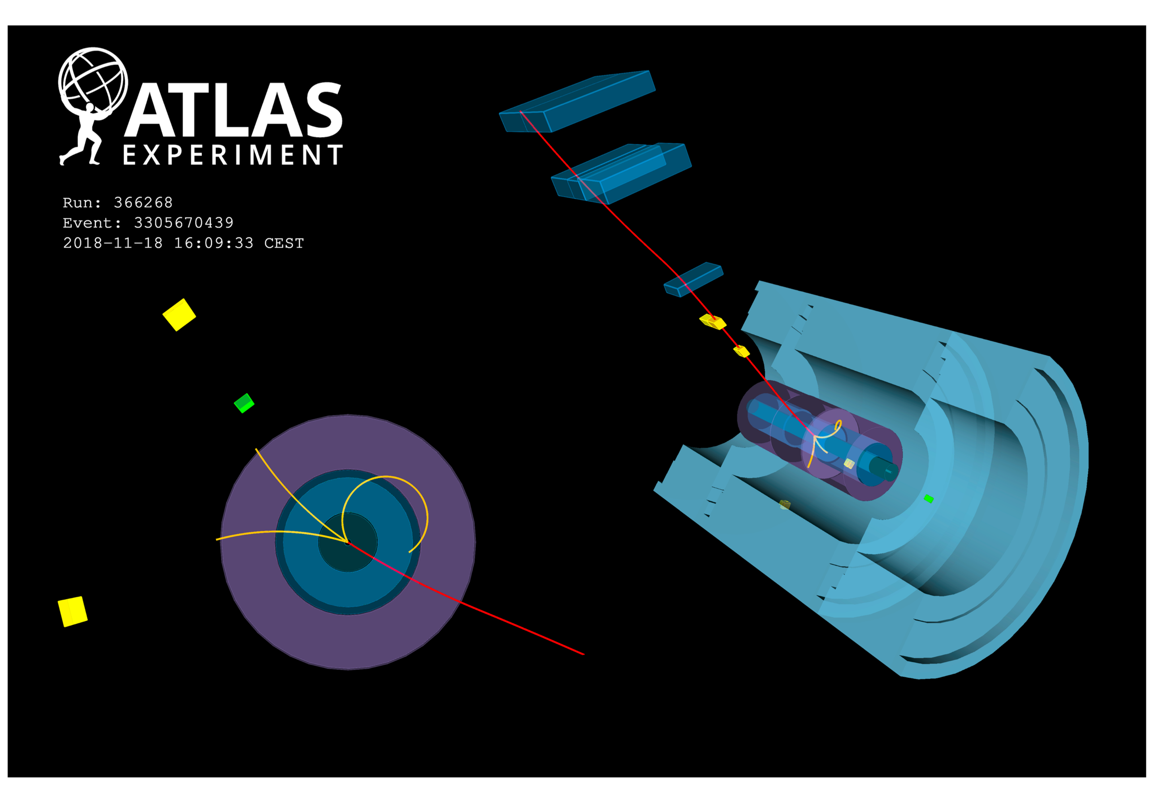

Figure 2: Event display for an exclusive $\gamma\gamma \to \tau\tau$ candidate from μ3T-SR in lead-lead collision during Pb+Pb data recorded by ATLAS in 2018.

3. Zero Degree Calorimeters (ZDC)

- Require zero neutrons in both ion directions as detectable in to suppress the photonuclear background events. For $\gamma\gamma \to \tau\tau$ or $\gamma\gamma \to ll$ production expect 60-70% of events to have no neutrons on either side (0n0n).

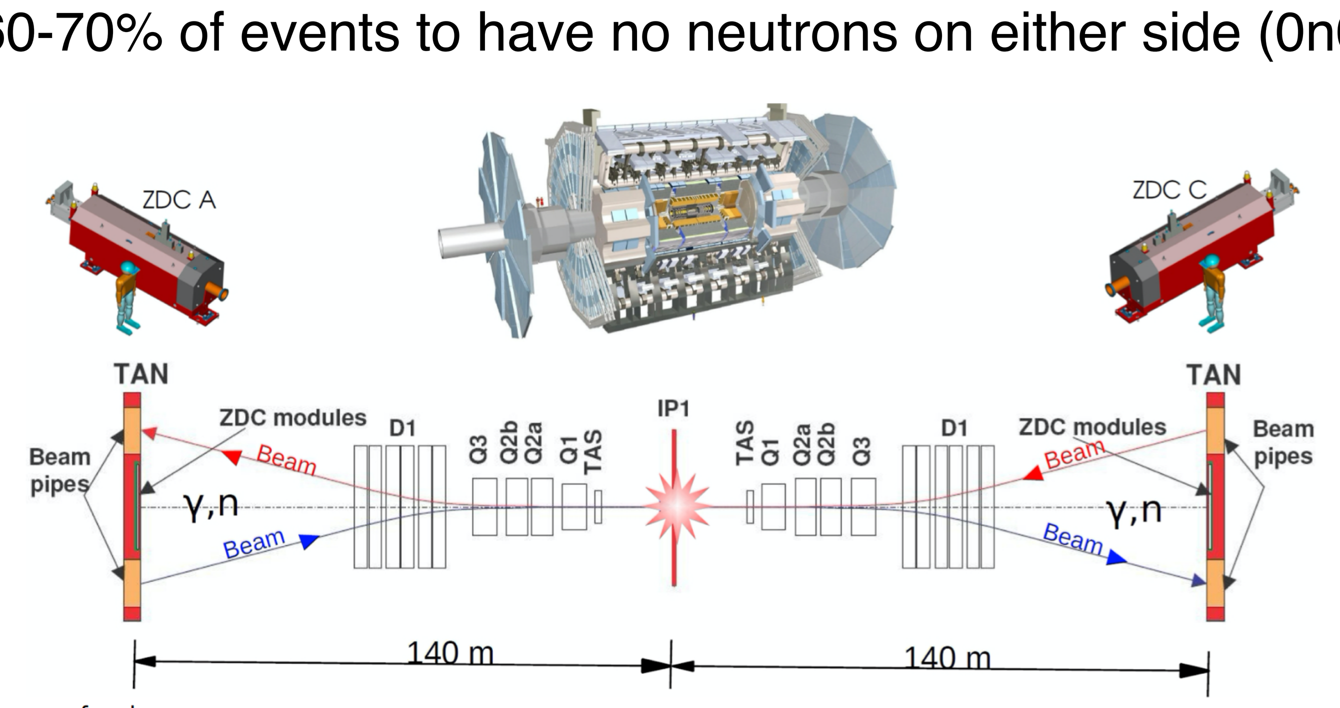

Figure 3: Energies of forward neutral particles measured in two ZDC arms.

4. Analysis strategy

- Tau not very energetic
  → standard (jet-based) ATLAS leptons reconstruction not applicable
  → rely on reconstructing charged decay products
- Events categorized based on decay of second τ. Selected events must contain exactly one muon, which targets a muonic decay of one of the τ. Three signal regions categorize events by decay signature of the other τ:
  → muon + 1 track (μ1T-SR)
  → muon + 3 tracks (μ3T-SR)
  → muon + electron (μe-SR)
- Using 2 muons (2μ-CR) control region for the $\gamma\gamma \to$ μμ process to constrain systematic uncertainties.

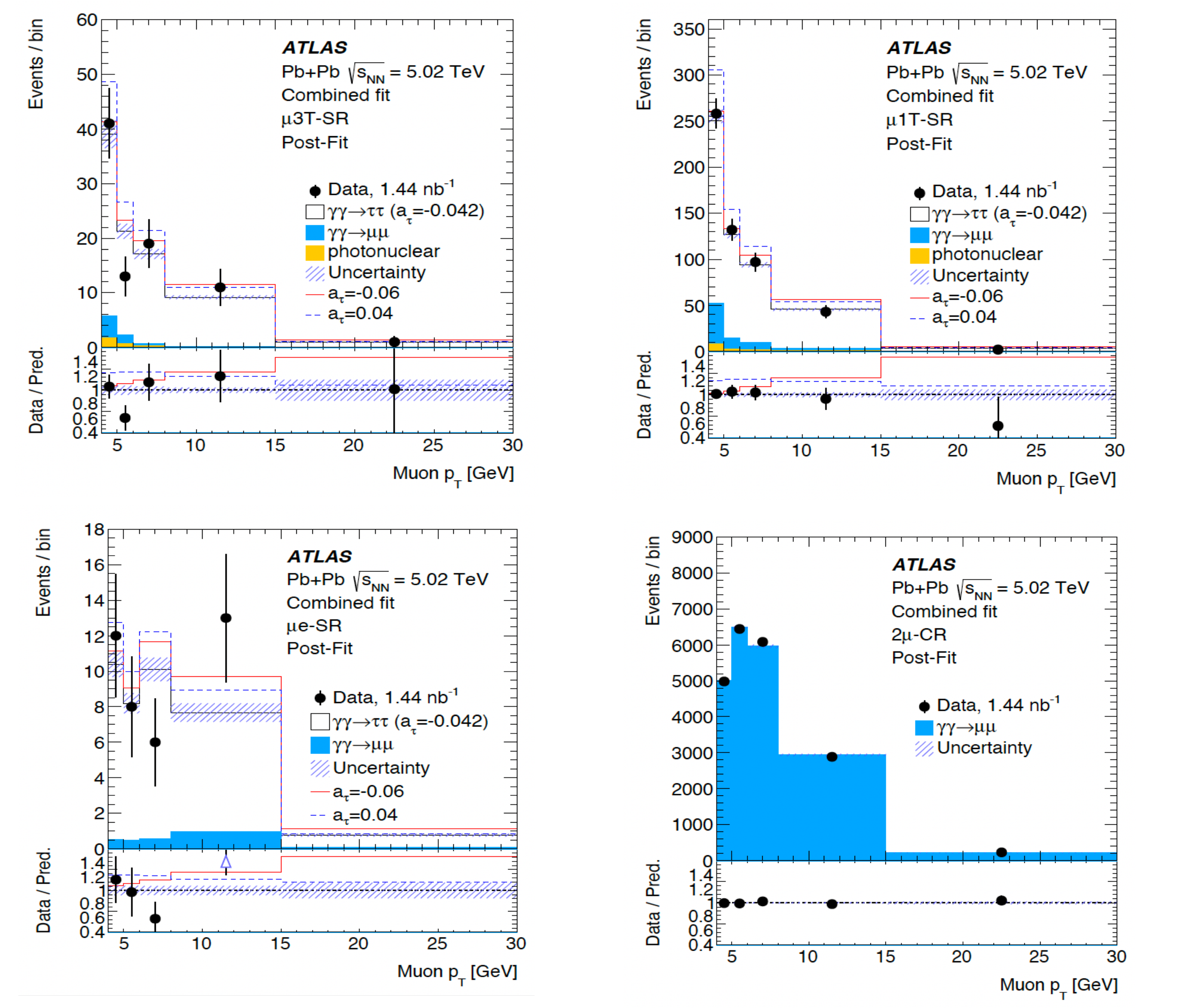

Figure 4: p_T^μ distributions of the four analysis regions for the data and post-fit expectation, The fit describes the data well.

5. Background estimation

- **Exclusive dimuon production in association with exclusive ρ^0**
  γA → ρ^0 → $\pi\pi$ produced simultaneously with $\gamma\gamma \to \mu\mu$ event as a background in μ3T-SR. Require three-track system mass m_{3trk}<1.7 GeV to suppresses this background and can be considered negligible.
- **Diffractive photonuclear events**
  This background is caused by the low particle activity and event topologies with rapidity gaps and we estimated using fully data-driven method.
- **γγ → μμγ production**
  The $\gamma\gamma \to \mu\mu\gamma$ background is estimated with the aid of MC samples. Comparing the $\gamma\gamma \to \mu\mu(\gamma)$ simulated events with data in 2μ-CR shows reasonable data-to-MC agreement in differential distributions.

Region	Data	Signal $\gamma\gamma \to \tau\tau$	Background $\gamma\gamma \to \mu\mu(\gamma)$	Background $\gamma\gamma \to ee$	Background $\gamma\gamma \to$ jet	Background photonuclear
1M1T SR	532.0	462.4	70.2	0.0	0.1	13.5
1M3T SR	85.0	83.9	6.7	0.0	0.3	2.8
1M1E SR	39.0	32.7	2.8	0.0	0.0	0.0

Table 1: Summary of SR yields with breakdown of background contributions.

6. a_τ measurements result

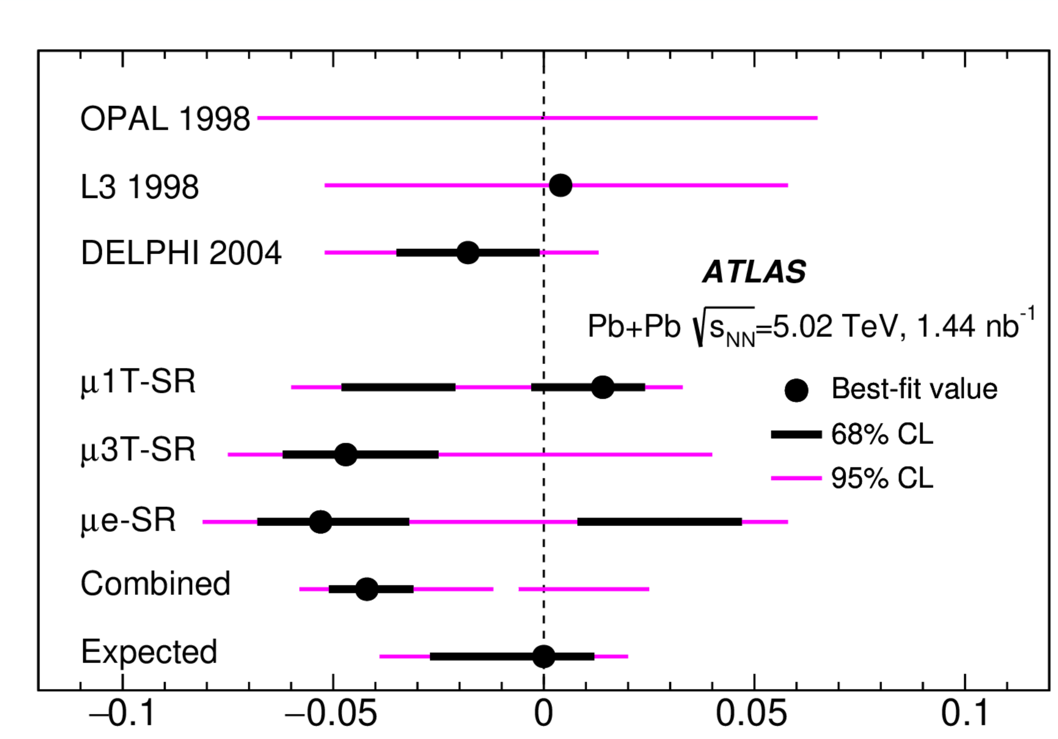

Figure 5: Measurements of a_τ from fits to individual signal regions, and from the combined fit compared with three existing measurements.

- The impact of systematic uncertainties on the final results is small relative to statistical uncertainties which limits the measurement precision.
- The best-fit value of a_τ is $a_\tau = -0.042$, with the corresponding 68% CL and 95% CL intervals being $(-0.051, -0.031)$ and $(-0.058, -0.012) \cup (-0.006, 0.025)$, respectively.