Measuring tau g-2 using ATLAS Pb+Pb collisions

New Frontiers in Lepton Flavor 2023

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Deutsches Elektronen-Synchrotron DESY

ATLAS EXPERIMENT

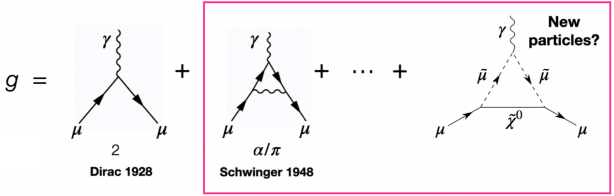
DESY.

Charged particles with spin have an intrinsic magnetic moment:

$$\vec{\mu} = g\frac{q}{2m}\vec{s} \qquad \text{for spin } \frac{1}{2} \text{ particles,} \tag{1}$$

where:

- $\vec{s}$ - spin angular momentum,
- $g = 2 + \frac{\alpha}{\pi} + \ldots$



Anomalous magnetic moment:

$$a = \frac{g-2}{2} \tag{2}$$

Lepton magnetic moments

- a_e, a_μ are precisely measured observables in Nature:

Electron g-2: 10^{-8} precision, -2.5σ, $+1.6\sigma$ discrepancy
Muon g-2: 10^{-7} precision, up to $\sim 4.2\sigma$ discrepancy

Phys. Rev. Lett. 97 (2006) 030801, Phys. Rev. Lett. 126 (2021) 141801

- a_τ is much less constrained:

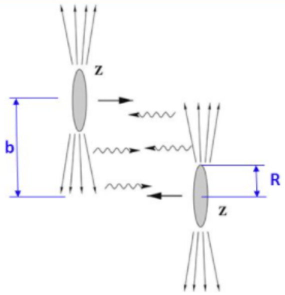
Tau g-2: $0.052 < a_\tau < 0.013$ **(95% CL)**

DELPHI, EPJC 35 (2004) 159

- Tau is extremely hard to measure (lifetime 10^{-13} s)
- a_τ is more sensitive to some BSM effects

Proposal: Measure a_τ in Pb+Pb collisions

- **Ultraperipheral heavy-ion collisions (UPC):**
  - UPC occurs when the impact parameter is larger than twice the radius of the ions ($b > 2R$)
  - Photon-photon interactions can be observed.
- Advantages of UPC Pb+Pb over pp collisions
  - huge photon fluxes $\rightarrow Z^4$ cross-section enhancement
  - $\sim$ no hadronic pile-up $\rightarrow$ exclusivity selections
  - low p_T thresholds in trigger and offline reconstruction



Detailed theoretical framework: PRD 102 (2020) 113008, PLB 809 (2020) 135682

Tau decays

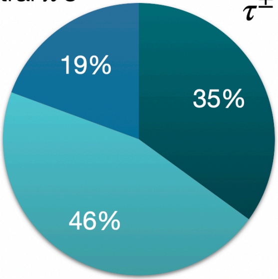
3 prong

$\tau^{\pm} \rightarrow \pi^{\pm}\pi^{\mp}\pi^{\pm}\nu_{\tau}$

$+ \geq 0$ neutral π's

Leptonic

$\tau^{\pm} \rightarrow l^{\pm}\nu_{l}\nu_{\tau}$



1 prong

$\tau^{\pm} \rightarrow \pi^{\pm}\nu_{\tau}$

$+ \geq 0$ neutral π's

Experimental realisation

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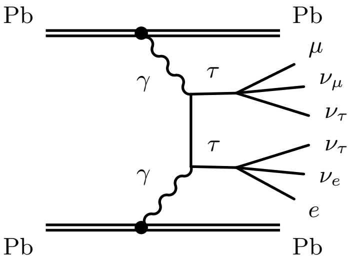
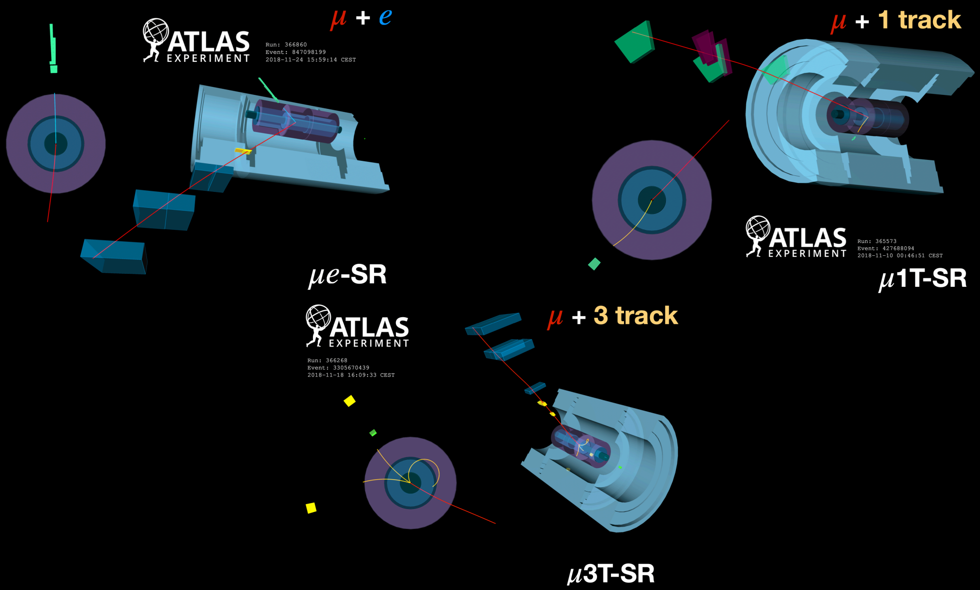
- Measurement uses 1.44 nb^{-1} of 2018 UPC data, $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV

Signal candidates are selected using muonic τ decays and categorised using electrons or low-p_T tracks:

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

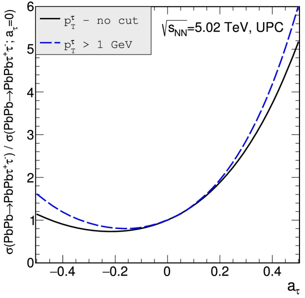


see Lydia Beresford's talk
see also CMS result


μ + e
ATLAS EXPERIMENT
Run: 366860
Event: 847098199
2018-11-24 15:59:14 CEST
μe-SR
μ + 1 track
ATLAS EXPERIMENT
Run: 365573
Event: 427688094
2018-11-10 00:46:51 CEST
μ1T-SR
ATLAS EXPERIMENT
Run: 366268
Event: 3305670439
2018-11-18 16:09:33 CEST
μ + 3 track
μ3T-SR

Analysis strategy

- Exploit $\gamma\gamma \rightarrow \tau\tau$ cross-section to set limits on a_τ
- Reduce uncertainties using $\gamma\gamma \rightarrow \mu\mu$ control region (2μCR)
- Fit muon p_T in signal regions + di-muon control region to extract a_τ



PLB 809 (2020) 135682

Experimental challenges:

- hadronic backgrounds
- neutrinos in the final state

τ leptons never directly targeted in measurements using nucleus-nucleus data

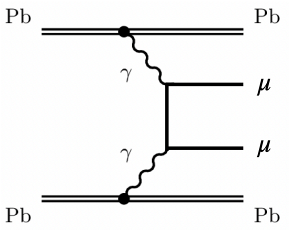
Main backgrounds

Di-muon

Estimated with MC:

$\gamma\gamma \to \mu\mu$: Starlight+Pythia8

$\gamma\gamma \to \mu\mu\gamma$: Madgraph5

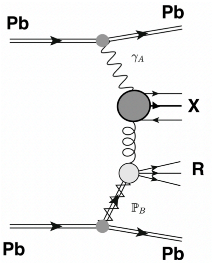


see Jakub Kremer's talk

Photonuclear

Data-driven estimation:

Built CR requiring an additional low-p_T track



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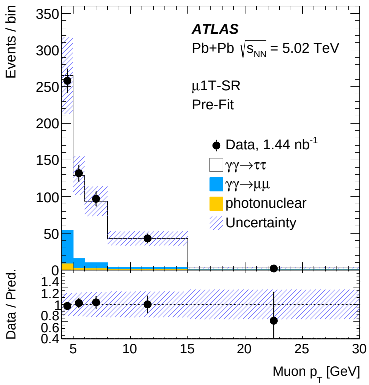
Observation of the $\gamma\gamma \to \tau\tau$ in Pb+Pb: Fit setup

Extract signal strength and a_τ using profile likelihood fit:

- Build templates for different a_τ values: $a_\tau =$ $[0, \pm0.01, \pm0.02, \pm0.03, \pm0.04, \pm0.05, \pm0.06, \pm0.1]$
- Pre-fit distribution of p_T^μ in the μ1T-SR:



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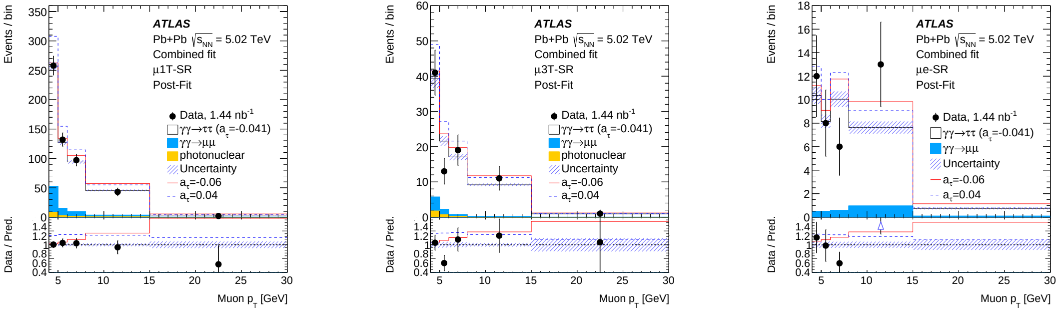
Post-fit distributions



- uncertainties decrease in post-fit distributions
- differences between SM and BSM values of a_τ increase with muon p_T

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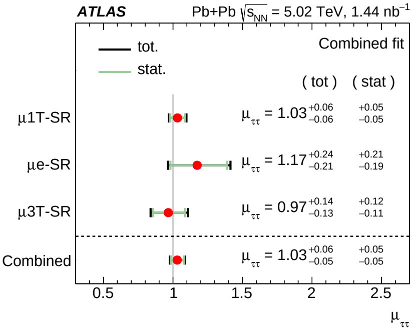
Observation of the $\gamma\gamma \to \tau\tau$ in Pb+Pb: Signal strength



- Result for each signal region compatible with unity
- Combined fit reaches 5% precision
- limited by statistical uncertainties

$$\mu_{\tau\tau} = \frac{\text{observed yield}}{\text{SM prediction}}$$

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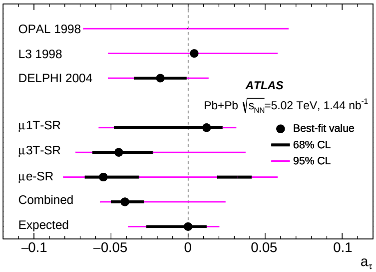
Observation of the $\gamma\gamma \to \tau\tau$ in Pb+Pb: a_τ



- Expected 95% CL limits from combined fit: **-0.039 $<$ a$_\tau$ $<$ 0.020**
- Observed 95% CL limits: **-0.057 $<$ a$_\tau$ $<$ 0.024**
- Result competitive with electron-collider studies

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Summary and outlook

Hadron-collider studies may be used to measure electromagnetic τ properties

New constraints on a_τ competitive with electron-collider results

Results limited by statistical uncertainties: inclusion of 2015 data in progress + future plans for run 3 heavy-ion data

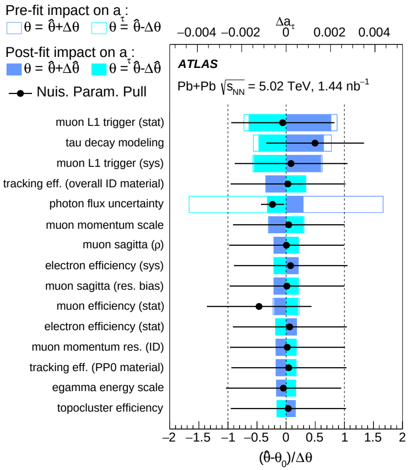
THANK YOU

QUESTIONS?

Backup

Systematic uncertainties

Uncertainty	Impact on $\mu_{\tau\tau}$ [%]
muon Level-1 trigger (sys)	1.0
τ decay modeling	1.0
tracking eff. (overall ID material)	0.9
muon Level-1 trigger (stat)	0.7
topocluster reco. eff.	0.6
muon reco. eff. (stat)	0.6
tracking eff. (PP0 material)	0.6
topocluster energy calib.	0.5
muon reco. eff. (sys)	0.5
photonuclear template var. (μ1T-SR)	0.5
Total systematic	2.6

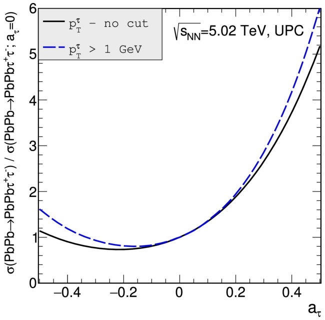


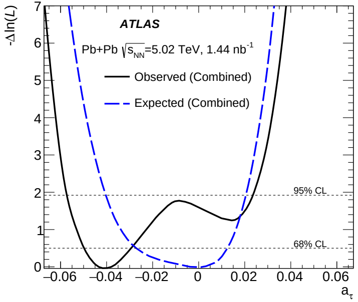
Event yields

Requirement	Number of $\gamma\gamma \to \tau\tau$ events
Common selection	
$\sigma \times \mathcal{L}$	352611
$\sigma \times \mathcal{L} \times \epsilon_{\text{filter}}$	28399
$\sigma \times \mathcal{L} \times \epsilon_{\text{filter}} \times w_{\text{SF}}$	35383
Pass trigger	1840
$E_{\text{ZDC}}^{\text{A,C}} < 1$ TeV	1114
μ1T-SR	
$N_{\mu}^{\text{preselected}} = 1$	1023
$N_{\mu}^{\text{signal}} = 1$	900
$N_e = 0$	867
N_{trk} (with $\Delta R_{\mu,\text{trk}} > 0.1$) = 1	575
Zero unmatched clusters	552
$\sum$ charge = 0	546
$p_{\text{T}}^{\mu,\text{trk}} > 1$ GeV	503
$p_{\text{T}}^{\mu,\text{trk},\gamma} > 1$ GeV	482
$p_{\text{T}}^{\mu,\text{trk,clust}} > 1$ GeV	462
$A_{\phi}^{\mu,\text{trk}} < 0.4$	459

μ3T-SR	
$N_{\mu}^{\text{preselected}} = 1$	1023
$N_{\mu}^{\text{signal}} = 1$	900
$N_e = 0$	867
N_{trk} (with $\Delta R_{\mu,\text{trk}} > 0.1$) = 3	88.1
Zero unmatched clusters	85.2
$\sum$ charge = 0	84.1
$m_{\text{trks}} < 1.7$ GeV	83.4
$A_{\phi}^{\mu,\text{trks}} < 0.2$	83.3
μe-SR	
$N_{\mu}^{\text{signal}} = 1$	958
$N_e = 1$	33.9
N_{trk} (with $\Delta R_{\mu/e,\text{trk}} > 0.1$) = 0	32.6
$\sum$ charge = 0	32.5

BSM Tau g-2





- Re-weight SM signal MC to BSM values of a_τ
- 3D weighting in $|m_{\tau\tau}|$, $|y_{\tau\tau}|$, $|\Delta\eta_{\tau\tau}|$
- same parametrisation as LEP

Pre-fit distributions