Measurement of a_τ in ultraperipheral collisions with ALICE at the LHC

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On behalf of the ALICE collaboration

Anomalous magnetic moment - sensor for BSM physics

- $\underline{\mu_l} = -g_l \cdot \frac{e}{2m_l} \cdot \underline{s}$

lepton $l = e, \mu, \tau$

$\underline{\mu_l}$; magnetic moment
g_l: g-factor
m_l: lepton mass
$\underline{s}$: spin angular momentum

- Dirac (1928): $g_l = 2$
- Anomalous magnetic moment of l
  $a_l = \frac{g_l - 2}{2}$
- Schwinger (1948): $a_l = \frac{\alpha}{2} \approx 0.00116$

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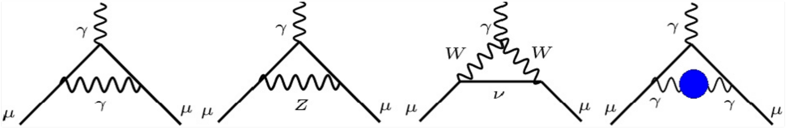

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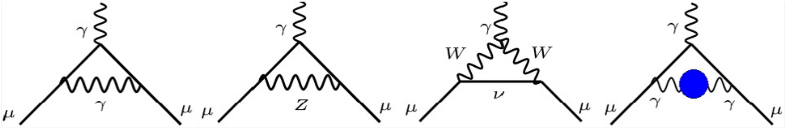
- Further corrections due to QED, Electro-Weak, and Hadron loops + **New Physics contributions**



+ BSM physics

Anomalous magnetic moment - sensor for BSM physics

$$\alpha_\tau^{SM} = \alpha_\tau^{QED} + \alpha_\tau^{EW} + \alpha_\tau^{HAD} + \alpha_\tau^{BSM}$$
$$= 117721\ (5) \times 10^{-8}$$

Eidelman & Passera, 2007

$$\alpha_\tau^{QED} = 117324\ (2) \times 10^{-8}$$

$$\left.\begin{aligned} \alpha_\tau^{EW} &= 47.4\ (5) \times 10^{-8} \\ \alpha_\tau^{HAD} &= 350.1\ (4.8) \times 10^{-8} \end{aligned}\right\} \sim 0.34\ \%$$

$$\alpha_\tau^{BSM} = ?$$

Anomalous magnetic moment - sensor for BSM physics

l	$a_{l,exp}$	$a_{l,thr}$		
e	0.001'159'652'180'59(13)	0.001'159'652'182'031(720)	😀	T: PRD 96 (2017) 019901 E: PRL 130 (2023) 071801
μ	0.001'165'920'59(22)	0.001'165'918'10(43)	😰	T: PR 887 (2020) 1 E: PRL 131 (2023) 161802
τ	[-0.052, 0.013]	0.001'172'1(5)	🤔	T: MPLA 22 (2007) 159. E: EPJC 35 (2004) 159.

Anomalous magnetic moment - sensor for BSM physics

- Deviation of $a_{l,exp}$ from $a_{l,thr}$ indicates:
  - compositeness of l
  - New Physics (NP)
- NP contributions are expected to scale with $\left(\frac{m_l}{m_\Lambda}\right)^2$

  m_Λ mass scale of NP

  Sensitivity of a_l to BSM scales with m_l^2

$$\mu : e \quad \propto \quad 42750 : 1$$
$$\tau : \mu \quad \propto \quad 280 : 1$$

$\longrightarrow a_\tau$ highly sensitive to BSM physics

Measurement of a_τ

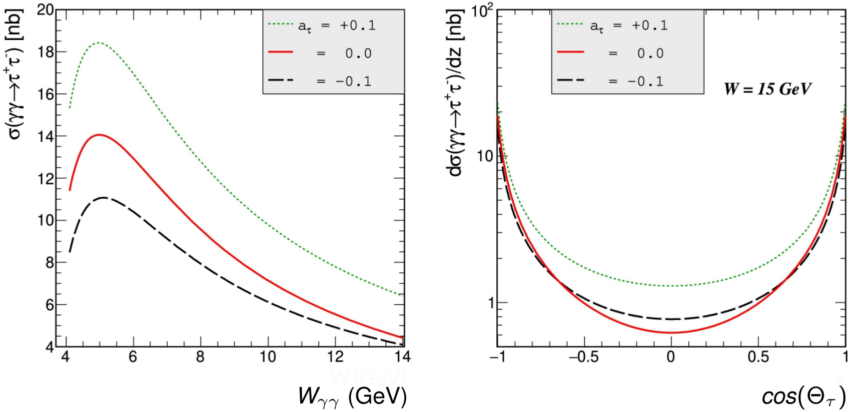
- a_τ:
  - Can not be stored
  - Mean life time $t_\tau \approx 2.903 \times 10^{-13}\ s$
  - **Exploit the fact that the cross section $\sigma_{\gamma\gamma\to\tau\tau}$ depends on a_τ**
    - SM: $\sigma_{\gamma\gamma\to\tau\tau}$ can be calculated to high accuracy
    - BSM: contributions alter the cross section
  - photon-lepton vertex function - element of the τ production cross section

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

	at $q^2 \approx 0$
$F1$: Dirac form factor	$F1(0) = 1$
$F2$: Pauli form factor	$F2(0) = a_l$
$F3$: electric dipole form factor	$F3(0) \propto d_l$

Measurement of a_τ

$\gamma\gamma \rightarrow \tau^+\tau^-$



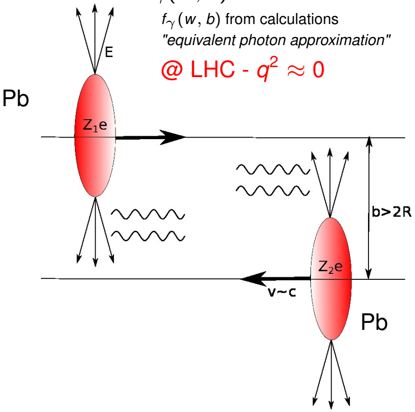
Dyndal et al., PLB, 809 (2020) 135682

Ultra-peripheral Collisions (UPCs) - source of colliding photons

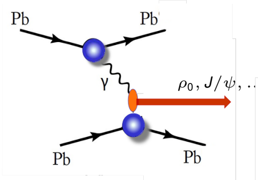
$f_\gamma(w, b) \propto Z^2$

$f_\gamma(w, b)$ from calculations
"equivalent photon approximation"

@ LHC - $q^2 \approx 0$

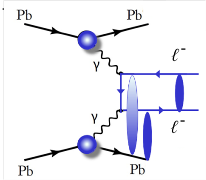


photoproduction



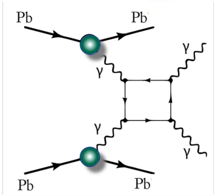
Production of vector mesons
Study gluon-density distributions

lepton-pairs



τ anomalous magnetic moment

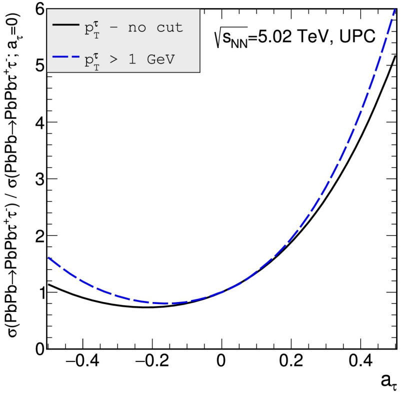
light-by-light



Physics beyond the SM
e.g. axions

Measurement of $PbPb \to PbPb\,\tau^+\tau^-$

$PbPb \to PbPb\tau^+\tau^-$



Dyndal et al., PLB, 809 (2020) 135682

Further reading:

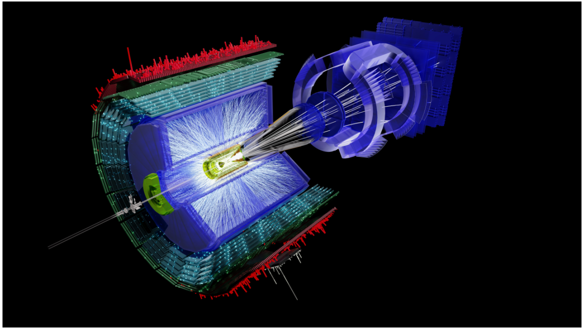
F. del Aguila et al, PLB 271 (1991) 256

L. Beresford, J. Liu, PRD 102 (2020) 113008

Measurement of $PbPb \rightarrow PbPb\,\tau^+\tau^-$

General HI collision

- Up to several hundred tracks



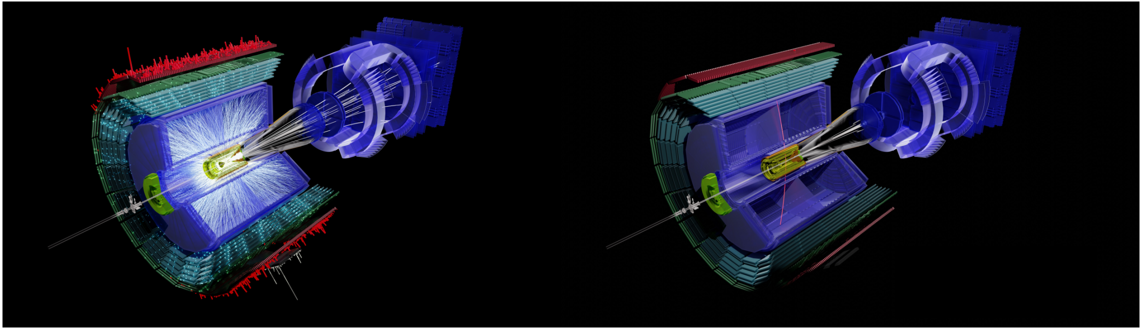
Measurement of $PbPb \rightarrow PbPb\,\tau^+\tau^-$

General HI collision

- Up to several hundred tracks

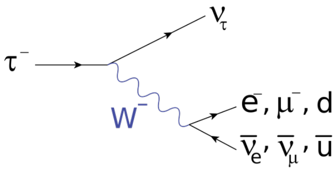
Example UPC

- Few tracks (clean environment)
- Allows selection with little background



Measurement of *PbPb* $\rightarrow$ *PbPb* $\tau^+\tau^-$

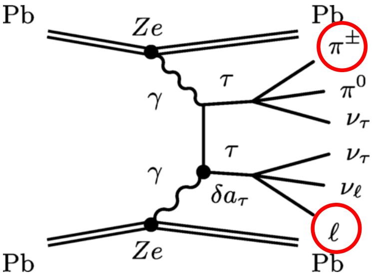
$$
\begin{aligned}
\mathrm{BR}(\tau^\pm \rightarrow \mathrm{e}^\pm + \nu_\mathrm{e} + \nu_\tau) &= 17.8\% \\
\mathrm{BR}(\tau^\pm \rightarrow \mu^\pm + \nu_\mu + \nu_\tau) &= 17.4\% \\
\mathrm{BR}(\tau^\pm \rightarrow \pi^\pm + \mathrm{n}\pi^0 + \nu_\tau) &= 45.6\% \\
\mathrm{BR}(\tau^\pm \rightarrow 3\ \mathrm{prong}) &\approx 20\%
\end{aligned}
$$



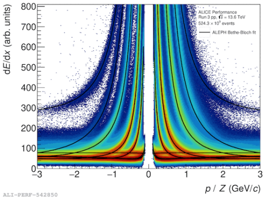
Analysis strategy

- 1 lepton + 1 charged particles
- 1 lepton + 3 charged particles

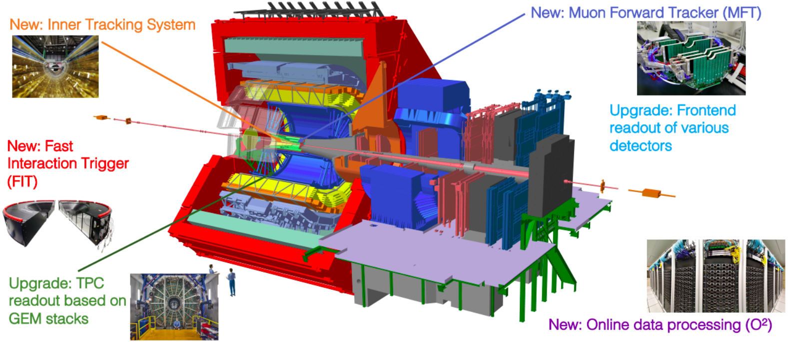
  combination of central and forward trackers



ALICE detector in Run 3



- Inner barrel
  ITS + TPC + TOF
- PID down to $p_{\mathrm{T}} > 0.1$ GeV/c



- Fast Interaction Trigger (FIT)
- Veto on activity at $\eta > 1.5$

- Online/Offline (O2) data processing system
- Continuous readout
- Event selection applied offline

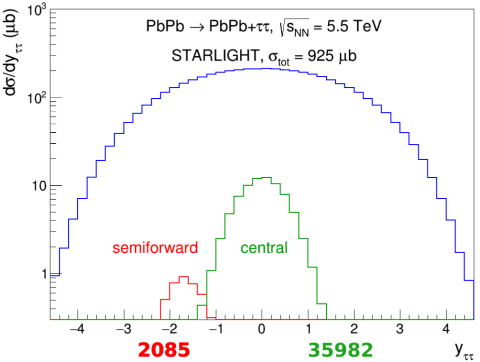
Perspectives with Run 3 data - ALICE

- Pb-Pb collisions at $\sqrt{s_{NN}} = 5.5\,\mathrm{TeV}$
- Integrated luminosity of ~~2.7~~ 1.6 nb^{-1} (= Run 3 202~~2~~3)
- 36000 reconstructed events with one electron in the barrel
- 2000 reconstructed events with one muon in the muon arm

Luminosity of > 2.7 nb^{-1} will be reached in 2024

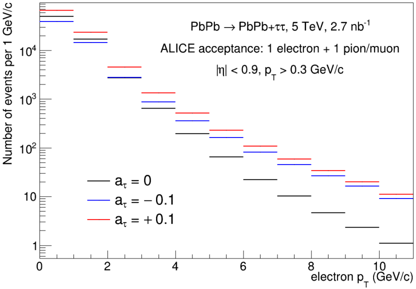
ALICE Run 3

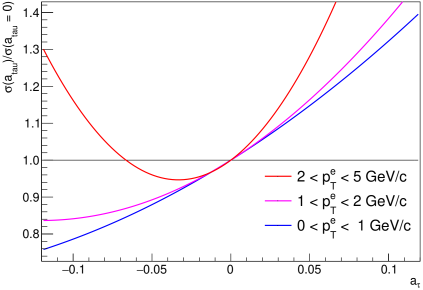
- select 2-prong events
- central: e and π/μ in central barrel
- semiforward: forward μ and barrel track



Perspectives with Run 3 data - ALICE

- Strategies to eliminate background described e.g. in Beresford & Liu, PRD 102 (2020) 113008
- In addition to total cross-section use p_T-differential information
- slope of $p_{T,e_{lead}}$ depends on a_τ





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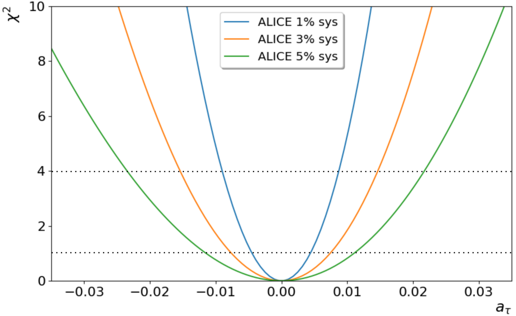
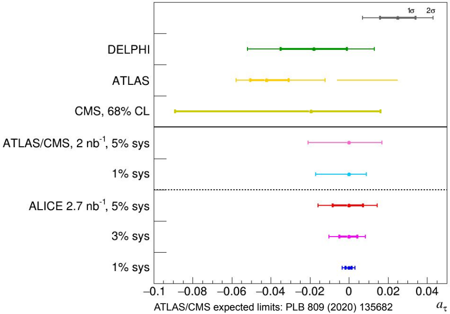
Perspectives with Run 3 data - ALICE

- Significant improvement of a_τ limits expected with Run 3 data!

$$\chi^2 = \sum_{i}^{p_T - bins} \frac{(S_{i,a_\tau} - S_{i,0})^2}{S_{i,a_\tau} + (\xi S_{i,a_\tau})^2}$$





ATLAS/CMS expected limits: PLB 809 (2020) 135682
ATLAS results: arXiv:2204.13478
CMS results: DIS 22' talk and CDS: CMS-PAS-HIN-21-009

Generated with upcgen (Burmasov et al., CPC 277 (2022) 108388)

Summary

- At LHC UPCs are suited to study the magnetic moment of the τ-lepton and set new limits on a_τ
- The PID capabilities down to low momenta enhance the sensitivity of ALICE
- The precision of the a_τ measurement is limited by systematic uncertainties
- The limits on a_τ we can expect from Run 3 data is at least $2 \times$ better compared to the limits listed in PDG and measured by DELPHI in 2004