Feasibility study of tau-lepton anomalous magnetic moment measurements with ultra-peripheral collisions at the LHC

Paul Bühler[1], Nazar Burmasov[2], Evgeny Kryshen[2], Roman Lavicka[1]

[1] Stefan Meyer Institute, Vienna (SMI)

[2] Petersburg Nuclear Physics Institute, St. Petersburg (PNPI)

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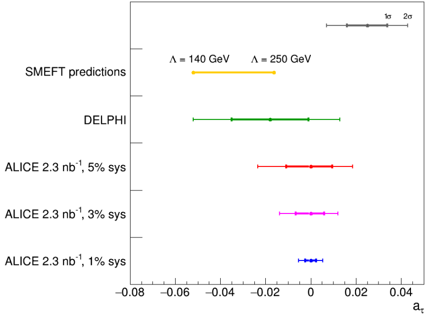
Summary

- The measurement of the anomalous magnetic moment of leptons is a sensitive test of the Standard Model.
- The large weight of the tau-lepton provides the best sensitivity.
- UPC PbPb collisions at LHC together with the ALICE detector with good low-momentum resolution provides a unique opportunity to measure it.
- PbPb collisions in upcoming Run 3 will deliver enough luminosity to improve current experimental limits significantly.

current best limits $\longrightarrow$



Anomalous Magnetic Moment of leptons

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

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

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

- Dirac: $g_l = 2$

  Corrections due to QED, Electro-Weak, and Hadron loops
  + New Physics contributions

- Anomalous magnetic moment of l

  $a_l = \frac{g_l - 2}{2}$

l	$a_{l,exp}$	$a_{l,thr}$	
e	0.001’159’652’180’91(26)	0.001’159’652’181’643(764)	😀
μ	0.001’165’920’61(41)	0.001’165’918’10(43)	😰
τ	[-0.052, 0.013]	0.001’172’1(5)	🤔

Anomalous Magnetic Moment of leptons

- 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

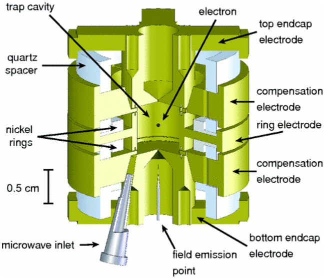
  Sensitivity of a_l to NP scales with m_l^2

$$\begin{aligned} \mu : e &\propto 42750 : 1 \\ \tau : \mu &\propto 280 : 1 \end{aligned}$$

$\longrightarrow a_\tau$ highly sensitive to NP

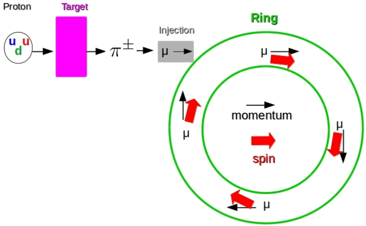
Measurement of a_l

- a_e
  - One electron quantum cyclotron (Penning trap)
  - Profit from infinite lifetime of electron



Phys. Rev. Lett. 100 (2008) 120801.

- a_μ
  - Measure precession in a magnetic storage ring
  - Mean life time $t_\mu \approx 2.197 \times 10^{-6}$ s



Phys. Rev. Lett. 126 (2021) 141801

Measurement of a_l

- 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: NP contributions alter the cross-section
  - photon-lepton vertex function - part of the cross-section

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

$q = p_{\gamma_1} - p_{\gamma_2}$

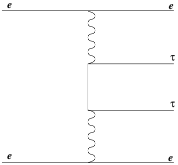
$F1$: Dirac form factor	$F1(0) = 1$
$F2$: Pauli form factor	$F2(0) = a_l$
$F3$: electric dipole form factor	$F3(0) = d_l \frac{2m_l}{e}$

Measurement of a_τ

- Was measured by DELPHI in $e^+e^- \to e^+e^-\tau^+\tau^-$

  Eur. Phys. J. C 35 (2004) 159

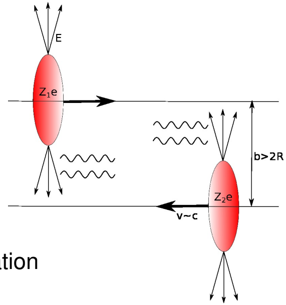
  provides currently best limits.



- HERE: Exploit strong γ flux in UPC collisions

  Phys. Lett. B 271 (1991) 256.

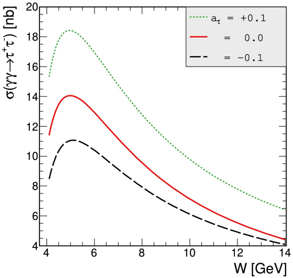
$$\frac{\mathrm{d}\sigma(\mathrm{PbPb} \to \mathrm{PbPb} + \tau\tau)}{\mathrm{d}Y\mathrm{d}M} = \frac{\mathrm{d}N_{\gamma\gamma}}{\mathrm{d}Y\mathrm{d}M}\sigma(\gamma\gamma \to \tau\tau, \omega_{1,2})$$

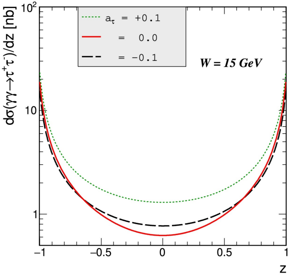


$\frac{\mathrm{d}N_{\gamma\gamma}}{\mathrm{d}Y\mathrm{d}M}$: Number of $\gamma\gamma$, apply equivalent photon approximation

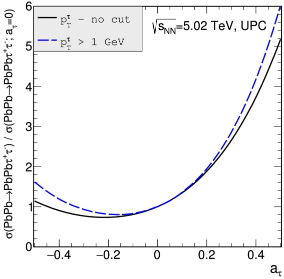
Measurement of a_τ

$\gamma\gamma \to \tau^+\tau^-$





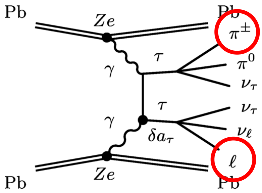
$PbPb \to PbPb\tau^+\tau^-$



Dyndal et al., Phys. Lett. B, 809 (2020) 135682.

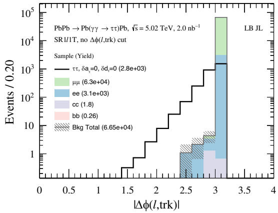
Measurement of *PbPb* $\rightarrow$ *PbPb* $\tau^+\tau^-$

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



Backgrounds

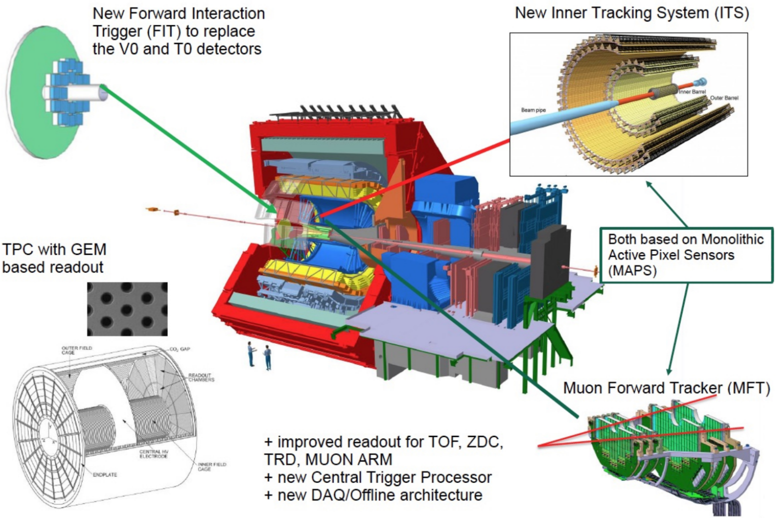
$\gamma\gamma \rightarrow ll$	acoplanarity
$\gamma\gamma \rightarrow q\bar{q}$	exclusivity requirements
semileptonic decays of B, D	small cross-section / BR
Pomeron exchange	veto neutrons in ZDC



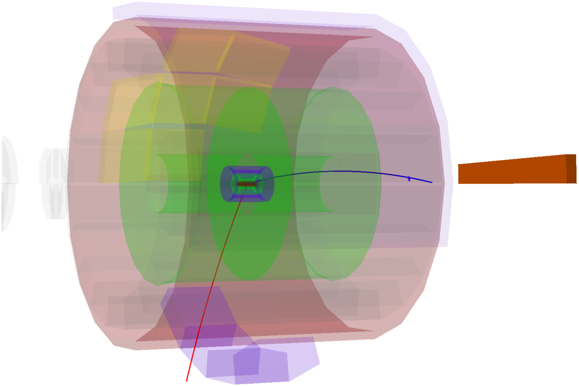
CMS/ATLAS acceptance

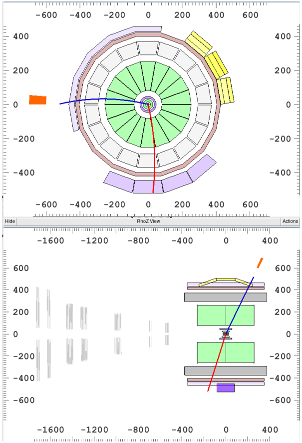
Beresford & Liu, Phys. Rev. D, 102 (2020) 113008.

ALICE experiment



ALICE experiment



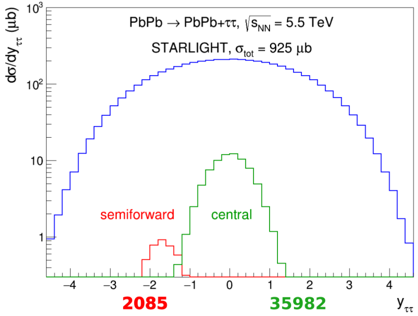


Measurement of $PbPb \rightarrow PbPb\, \tau^+\tau^-$

- Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.5\,\mathrm{TeV}$
- Integrated luminosity of 2.3 nb^{-1} (= Run 3 2022)
- 36000 reconstructed events with one electron in the barrel
- 2000 reconstructed events with one muon in the muon arm

ALICE Run 3

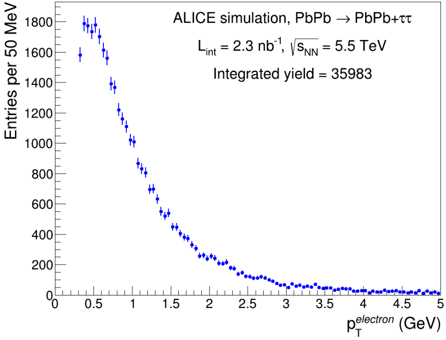
- select 2-prong events
- central: *e* and π/μ in central barrel
- semiforward: forward μ and barrel track

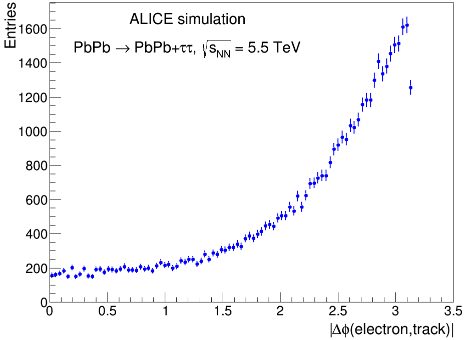


Perspectives with Run 3 data - ALICE

- Measurement down to low p_T
- Relatively broad $\Delta\phi$ distribution

Large coverage!





Perspectives with Run 3 data - ALICE

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

p_T differential