Observation of the $\gamma\gamma \to \tau\tau$ process in heavy-ion collisions and the first LHC limits on $(g-2)_\tau$

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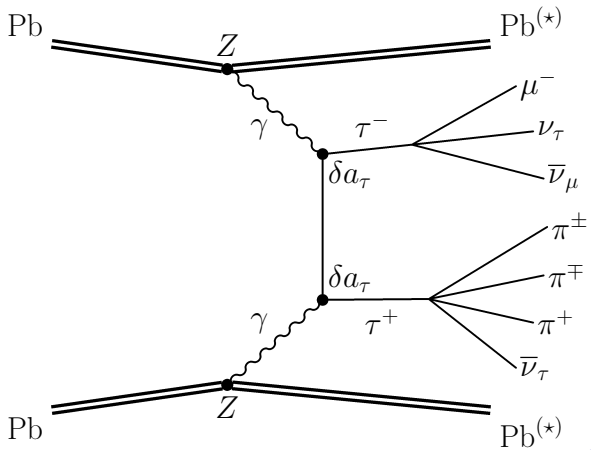
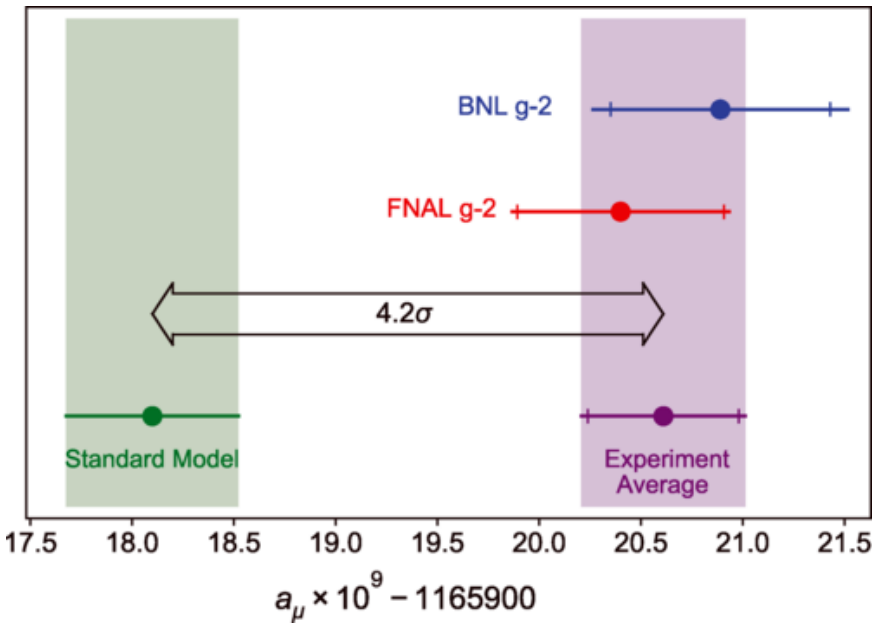


Introduction

- Anomalous magnetic moment: $a_\ell = \frac{(g-2)_\ell}{2}$
- Precision measurement of QED, electroweak, and QCD
- BSM:
  - a_ℓ as one of the best tests for lepton compositeness.
    - Corrections of $O(\frac{m_\ell}{m_{\text{constituent}}})$
  - SUSY corrections of $\delta a_\ell \sim \frac{m_\ell^2}{M_S^2}$
    - a_τ can be $\frac{m_\tau^2}{m_\mu^2} \approx 280$ times more sensitive to BSM than a_μ



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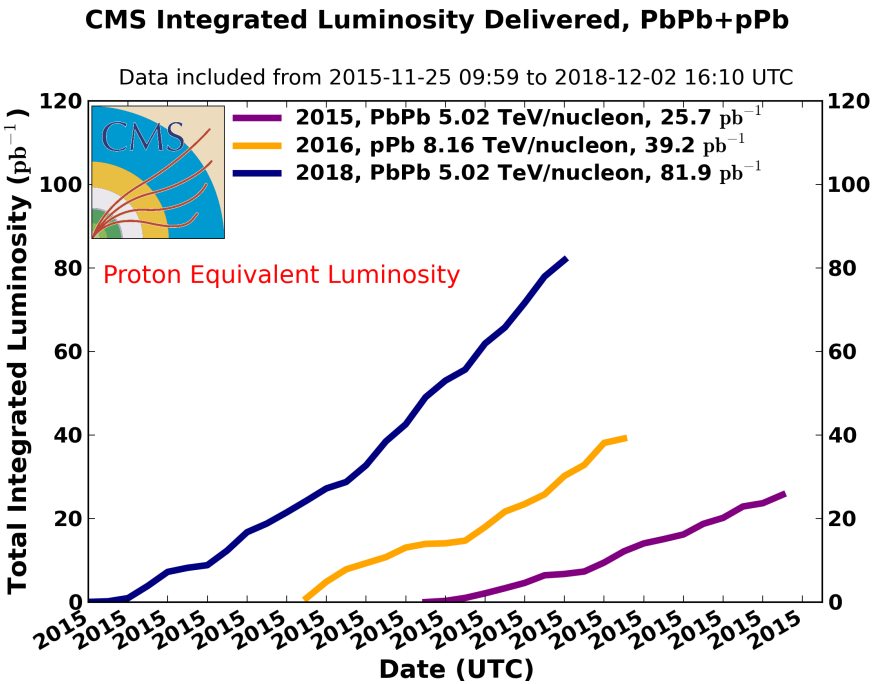
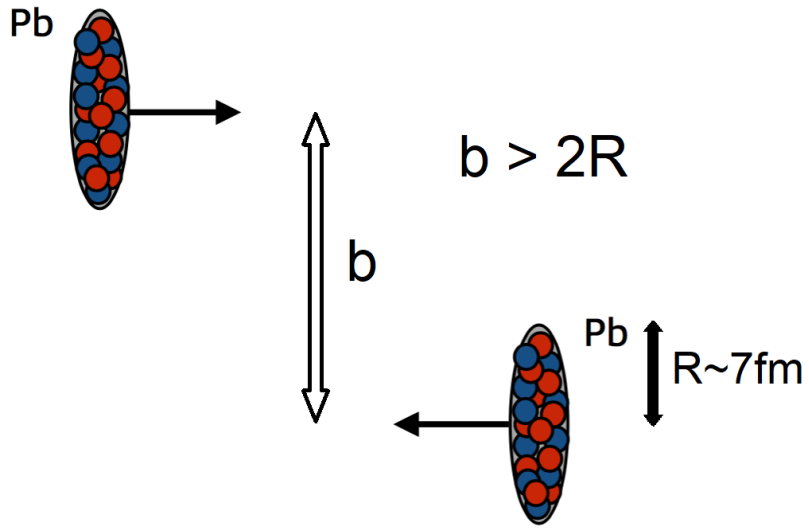
Heavy ion collisions at LHC

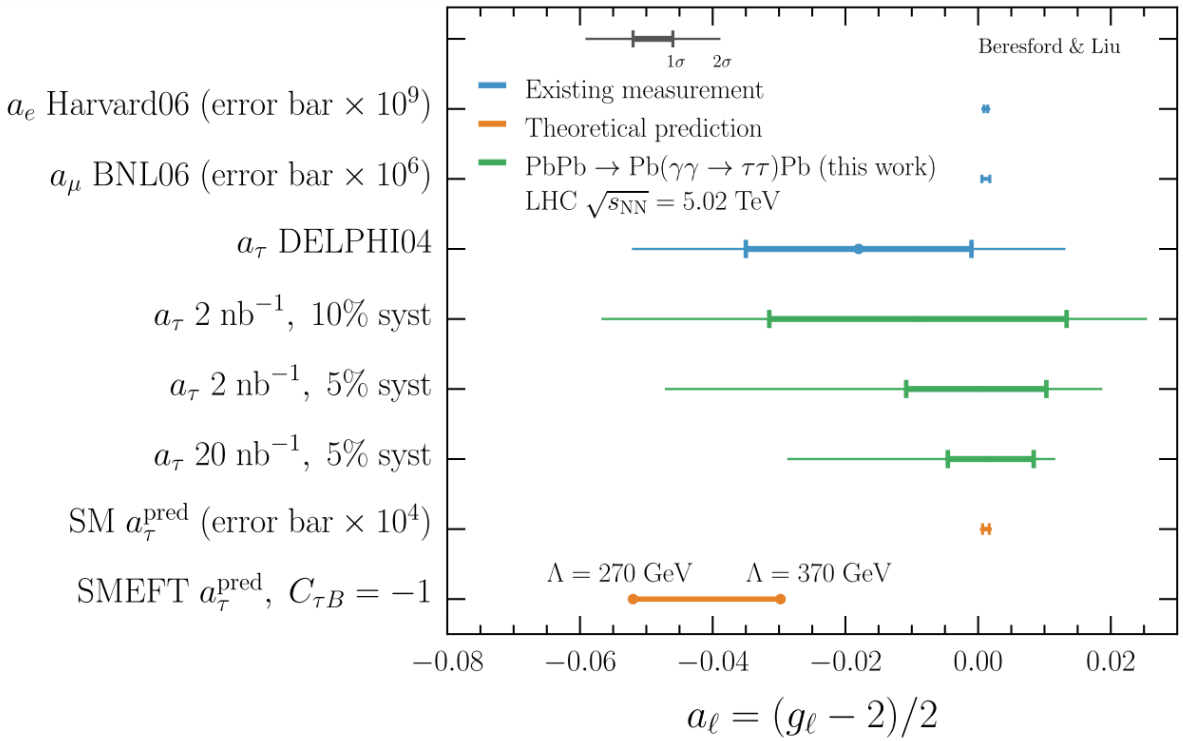
- 3 periods of heavy ion collisions during Run2
- Ultraperipheral Collisions (UPC) of PbPb at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV
- Elastic & diffractive
- Small energy deposit at the Hadronic Forward (HF) calorimeters at $3 < |\eta| < 5$

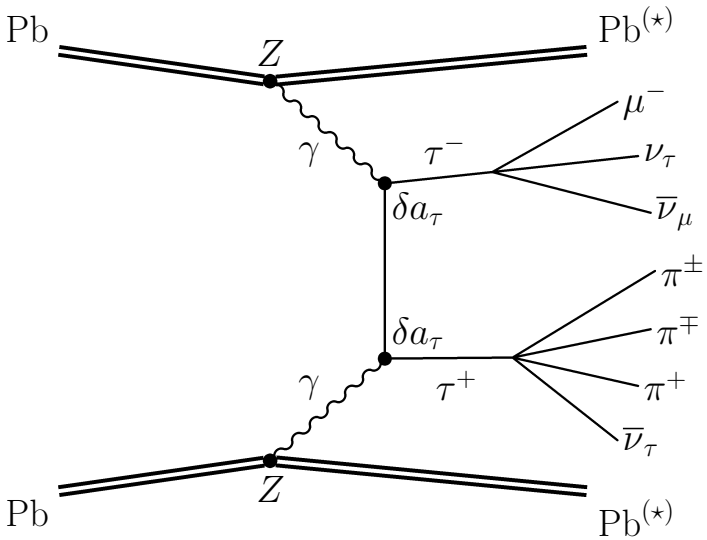




a_τ measurement at LHC?

- di-τ photo production in UPC events of PbPb
  - di-τ production cross section $\sim Z^4$ 😀
- Cross section and τ kinematics sensitive to a_τ





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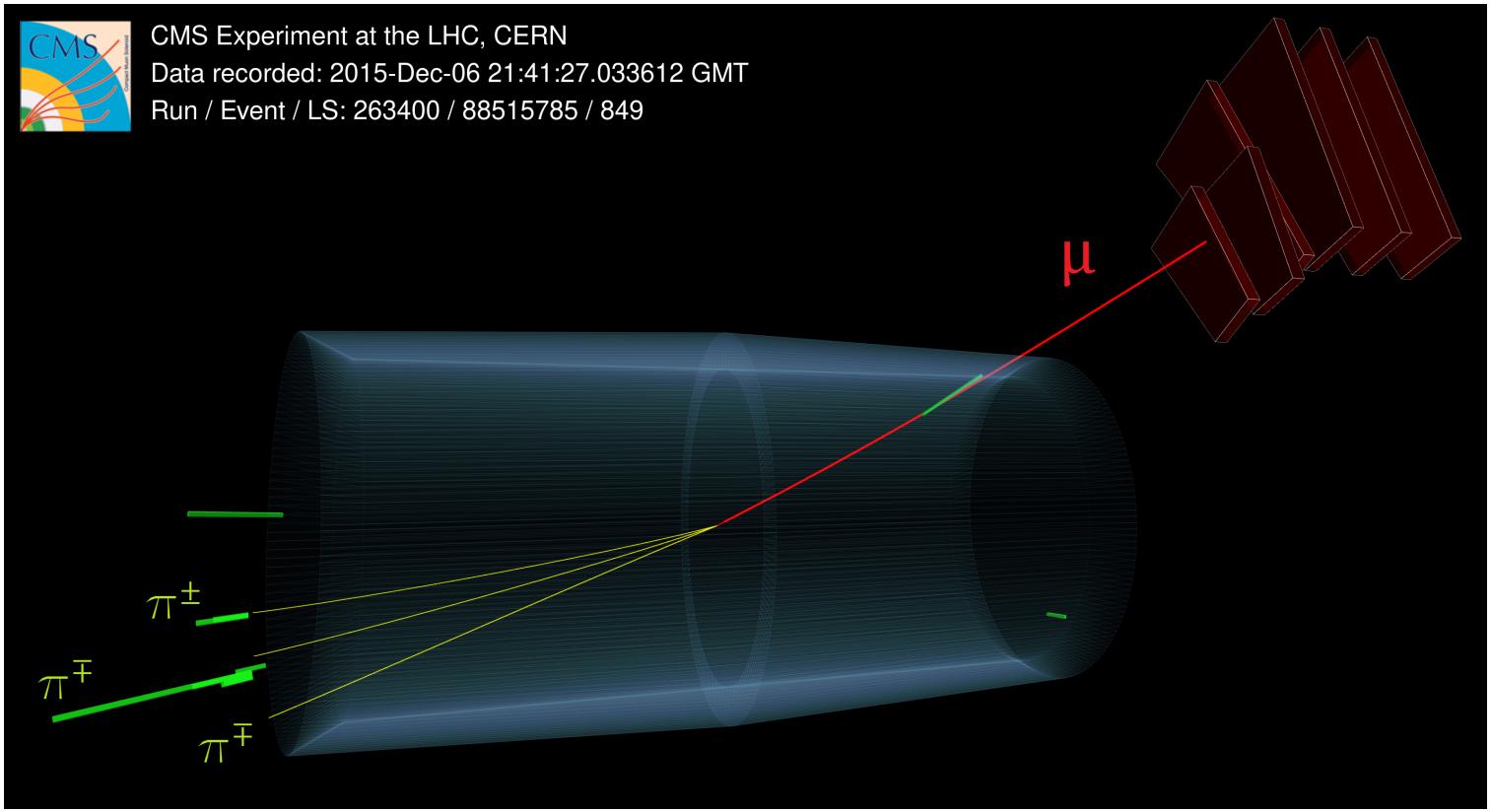
Analysis strategy

- Extracting the number of signal events (N_{signal})
- Measuring a fiducial cross section for the $\gamma\gamma \to \tau\tau$ process
- Putting limits on a_τ



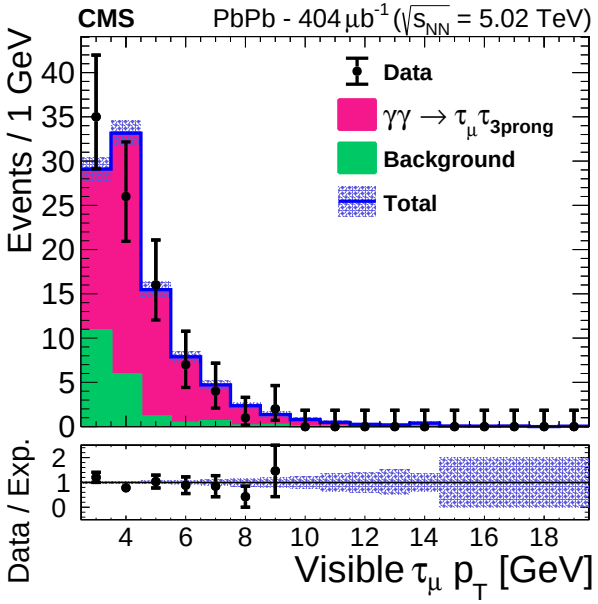
signal candidate from 2015 data

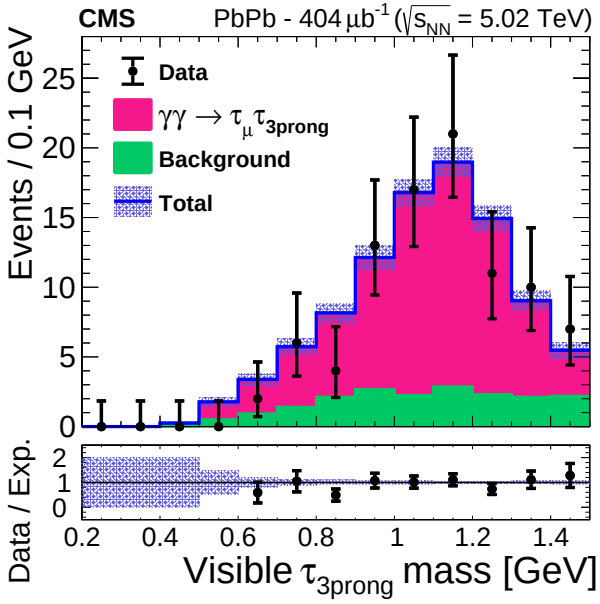
Event Selection

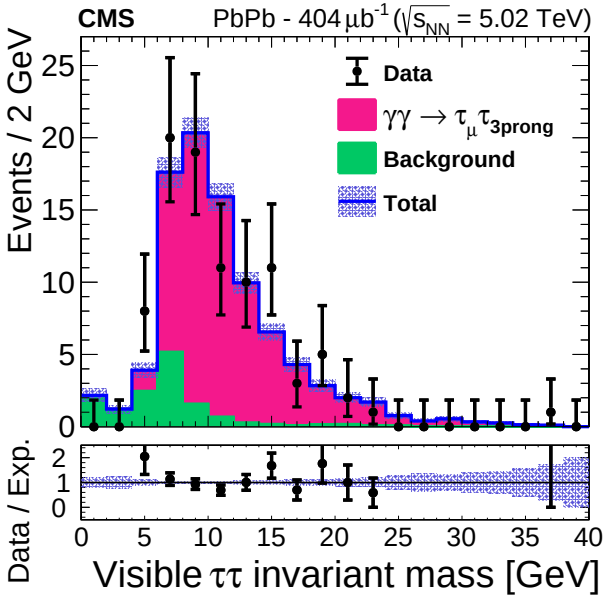
- Trigger: 1 muon + 1 track in the pixel detector + no Hadronic Forward (HF) calorimeter activity on one side
- Leading HF tower < 4 GeV
- Keeping events with exactly 3 charged pions ($\mathrm{N_{ch}}$) and 1 muon

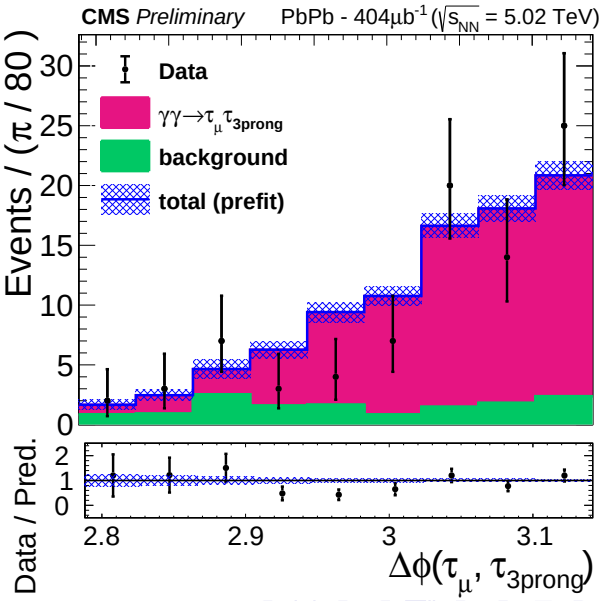
Object	**Criteria**
μ	$p_T > 3.5$ GeV for $\lvert\eta\rvert < 1.2$ $p_T > 2.5$ GeV for $1.2 < \lvert\eta\rvert < 2.4$
$\pi^{\pm}$	$p_T > 0.5$ GeV for leading $\pi^{\pm}$ $p_T > 0.3$ GeV for (sub-)sub-leading $\pi^{\pm}$ $\lvert\eta\rvert < 2.5$
τ_{3prong}	$p_T^{vis} > 0.2$ GeV & $m_{\pi\pi\pi} < 1.5$ GeV

Kinematics consistent with signal



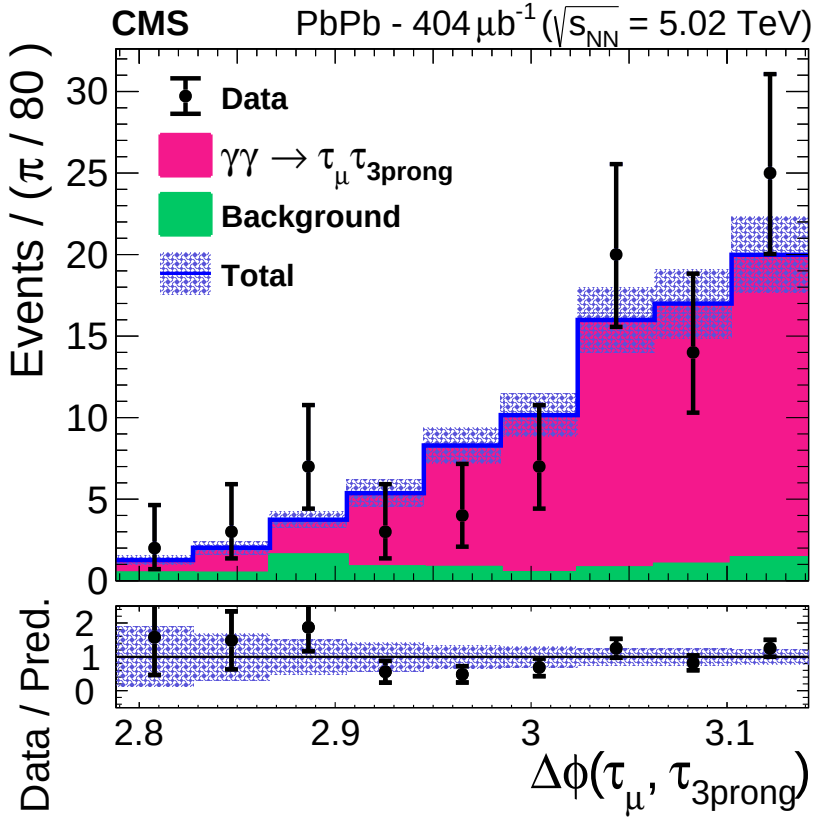






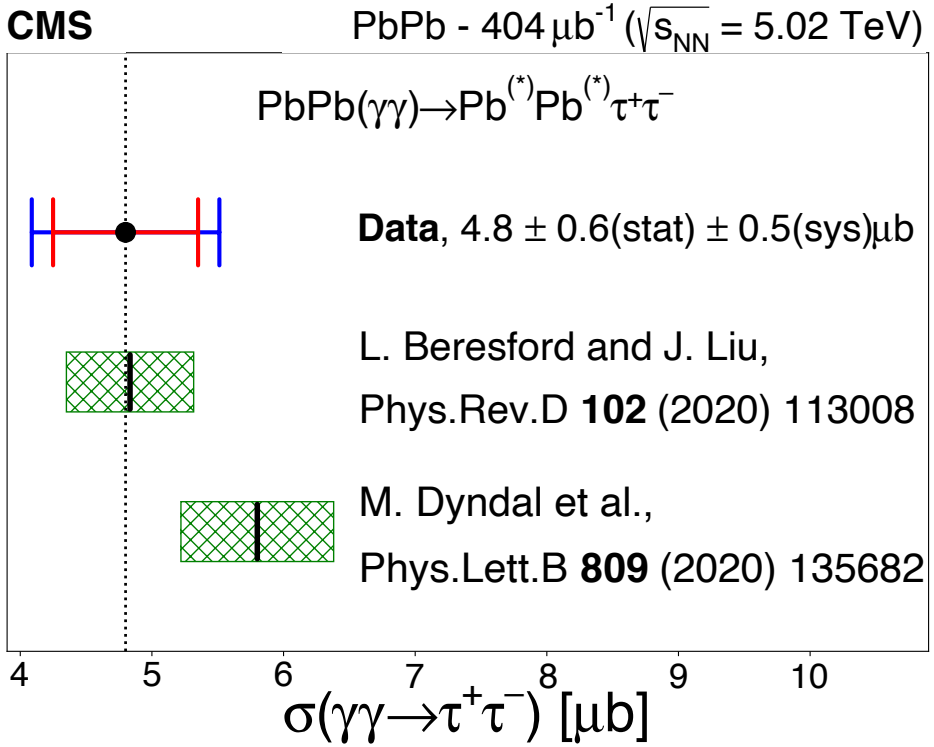
Signal yield estimation

- Binned maximum likelihood fit on the distribution of $\Delta\phi(\tau_\mu, \tau_{3\text{prong}})$
  - ABCD background + MC signal (free scale) $\rightarrow$ data
- Postfit signal events: 77 ± 12
- Observation significance well above $5\,\sigma$



Fiducial cross section

- efficiency (ϵ) from MC $= \frac{\text{reconstructed events}}{\text{gen events within acceptance phase space}}$
- $\epsilon = 78.5\%$
- $\mathrm{BR}_{\mu-3\mathrm{prong}} = 5.06\,\%$
- $\mathrm{L} = 404.3\,\mu\mathrm{b}^{-1}$
- $\mathrm{N}_{\mathrm{signal}} = 77$
- $\sigma_{\mathrm{fiducial}} = \frac{\mathrm{N}_{\mathrm{signal}}}{L \times \mathrm{BR} \times \epsilon}$



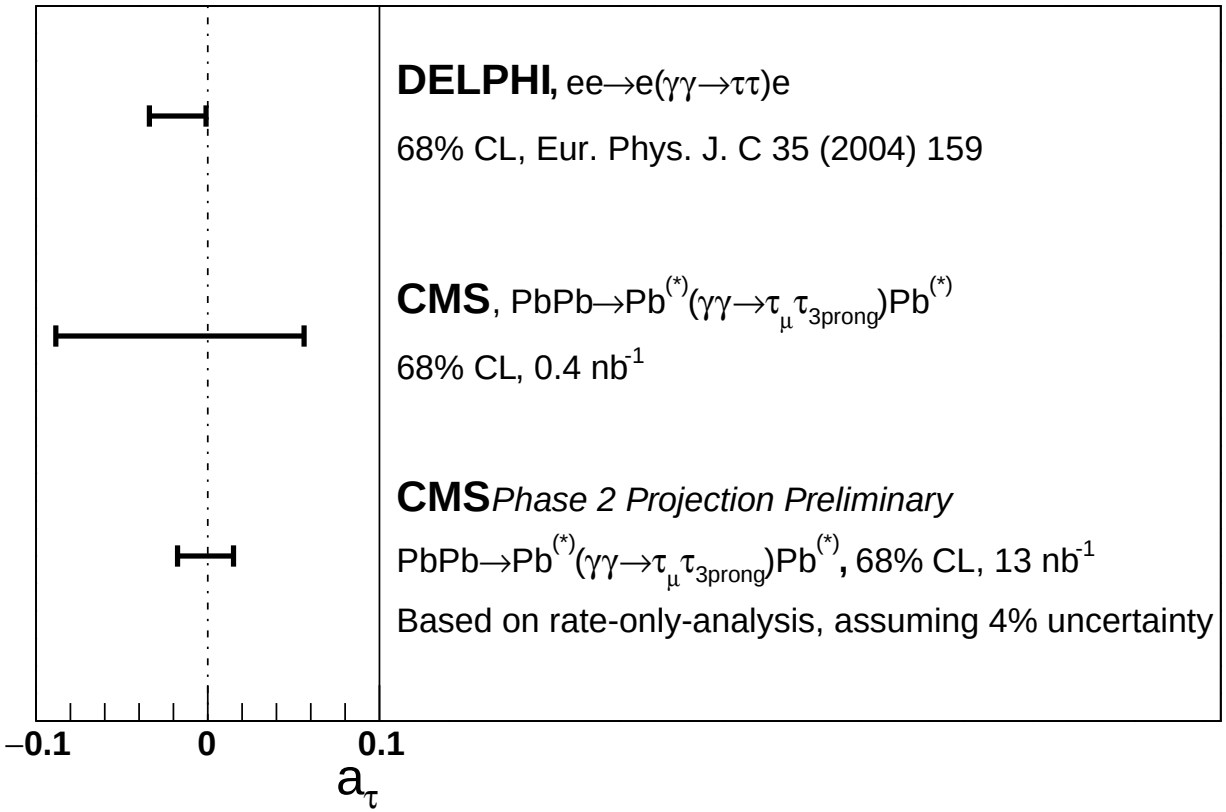
- $\sigma_{\mathrm{fiducial}} = 4.8 \pm 0.6(\mathrm{stat}) \pm 0.5(\mathrm{syst})\,\mu\mathrm{b}$

Systematics

Syst. Uncertainty Source	Uncert. (%)
Muon scale factor	6.7
Luminosity measurement	5.0
Pion scale factor	3.6
MC sample size (bin by bin)	3.0
MC sample size (efficiency)	1.1
HF scale effect on background shape	0.9
τ lepton branching fraction measurement	0.6
Effect of high $\mathrm{N_{ch}}$ on background shape	0.2
Total	**9.7**

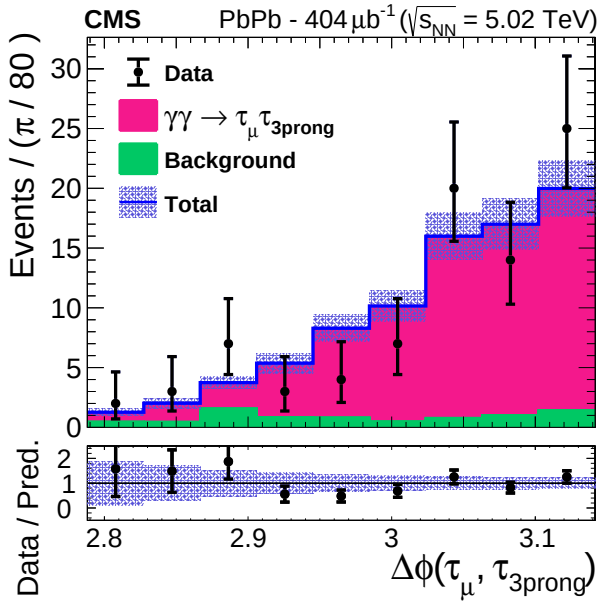
Limits on a_τ

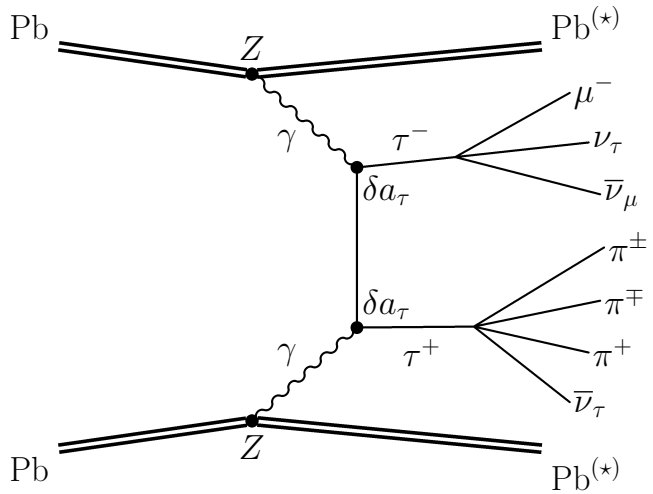
- DELPHI's 68% CL limit on a_τ is $(-3.5 < a_\tau < -0.1) \times 10^{-2}$
- Using the theoretical calculation of $\sigma_{\gamma\gamma\to\tau\tau}$ as a function of a_τ this analysis puts a 68% CL limit of $(-8.8 < a_\tau < 5.6) \times 10^{-2}$
- Projected CMS limit for Run3+4 is $(-1.8 < a_\tau < 1.5) \times 10^{-2}$



Summary

- First observation of the tau pair production in heavy ion collisions.
- Measured the fiducial cross section of $\gamma\gamma \to \tau\tau$ to be $\sigma_{\text{fiducial}} = 4.8 \pm 0.6(\text{stat}) \pm 0.5(\text{syst})\,\mu\text{b}$
- This analysis (CMS-HIN-21-009) puts a model-dependent limit of $(-8.8 < a_\tau < 5.6) \times 10^{-2}$.
- Accepted by PRL
- Ongoing analysis with a larger dataset & extra channels

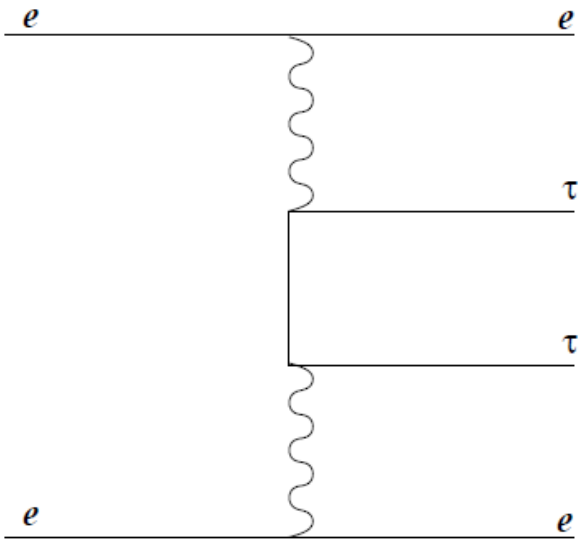




Backup

Current best measurement of a_τ

- Current best measurement at DELPHI, using 1997-2000 LEP2 data.
- $ee \to ee + \tau\tau$
- $\tau\tau \to$ e + (μ or hadron)
- Cross section is sensitive to a_τ.
- Cross section:
  - Observed: 429 $\pm$ 17 pb
  - Predicted: 447.7 $\pm$ 0.3 pb
- $-0.035 < a_\tau < -0.001$ (1σ level)
  - SM: $a_\tau = 0.00117721(5)$



Background estimation

- Background is estimated in a data-driven method called ABCD.

- Background in $D_i = \frac{B_i \times C_i}{A_i}$
  - bin by bin
  - Assuming factorization
  - Negligible signal in CR