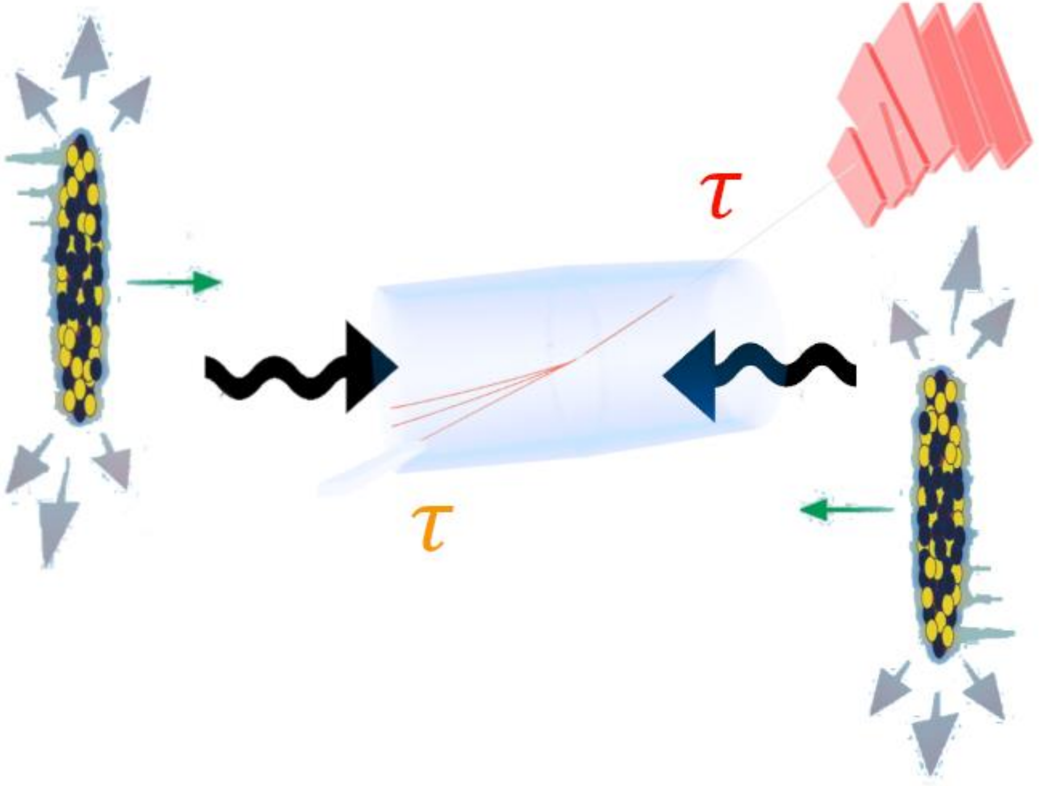

Observation of the $\boldsymbol{\gamma\gamma \rightarrow \tau^+\tau^-}$ production in PbPb collisions with the CMS experiment

Matthew Nickel on Behalf of the CMS Collaboration

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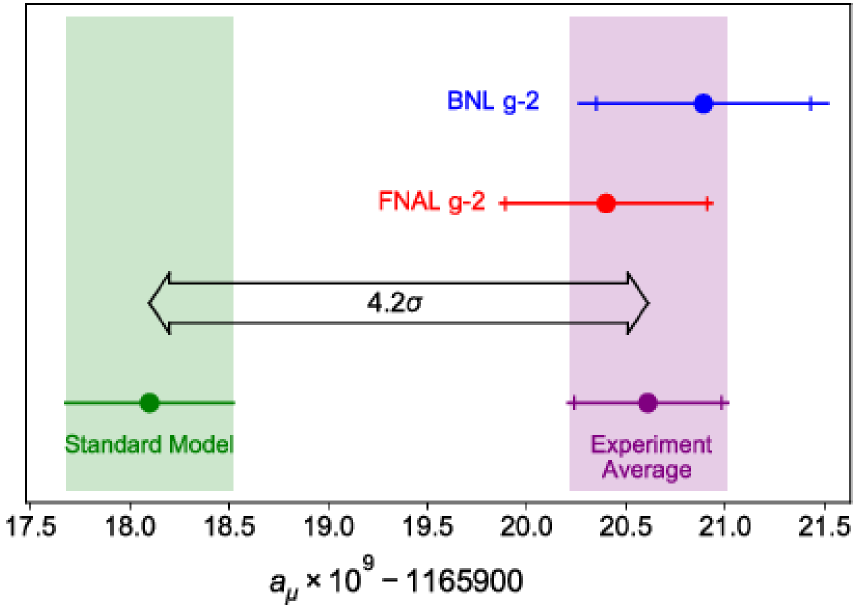
Anomalous Magnetic Moment

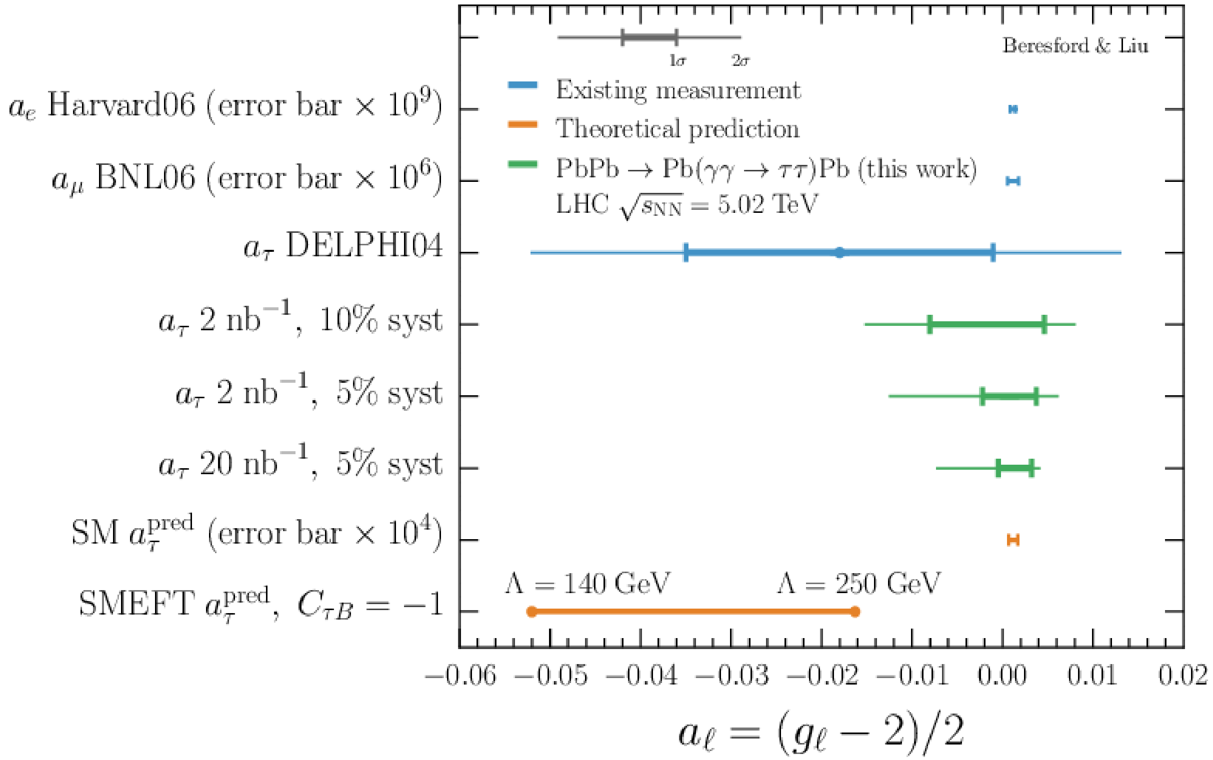
- Anomalous magnetic moment : $a_l = \frac{g_l - 2}{2}$
- Precise measurement of Standard Model
  - Measurements of a_μ have discrepancy with SM predictions
    - Ongoing work in theory community to improve Lattice QCD calculations
  - Deviations of a_l from SM could indicate lepton compositeness or other BSM physics
  - BSM effects are 280 times more sensitive to a_τ compared to a_μ due to τ mass

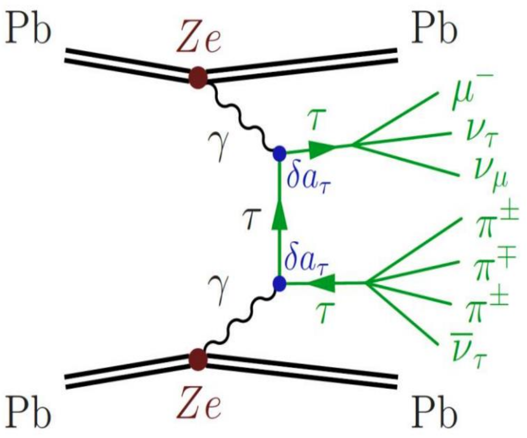
https://arxiv.org/abs/2104.03281



$\gamma\gamma \rightarrow \tau\tau$ process

- $\gamma\gamma \rightarrow \tau\tau$ cross-section can help determine a_τ
- Using UPC heavy Ion events means:
  - Have clean sample with few backgrounds
  - Have Z^4 photon flux enhancement
- With luminosity already achieved by LHC, measurements of a_τ should exceed precision of DELPHI





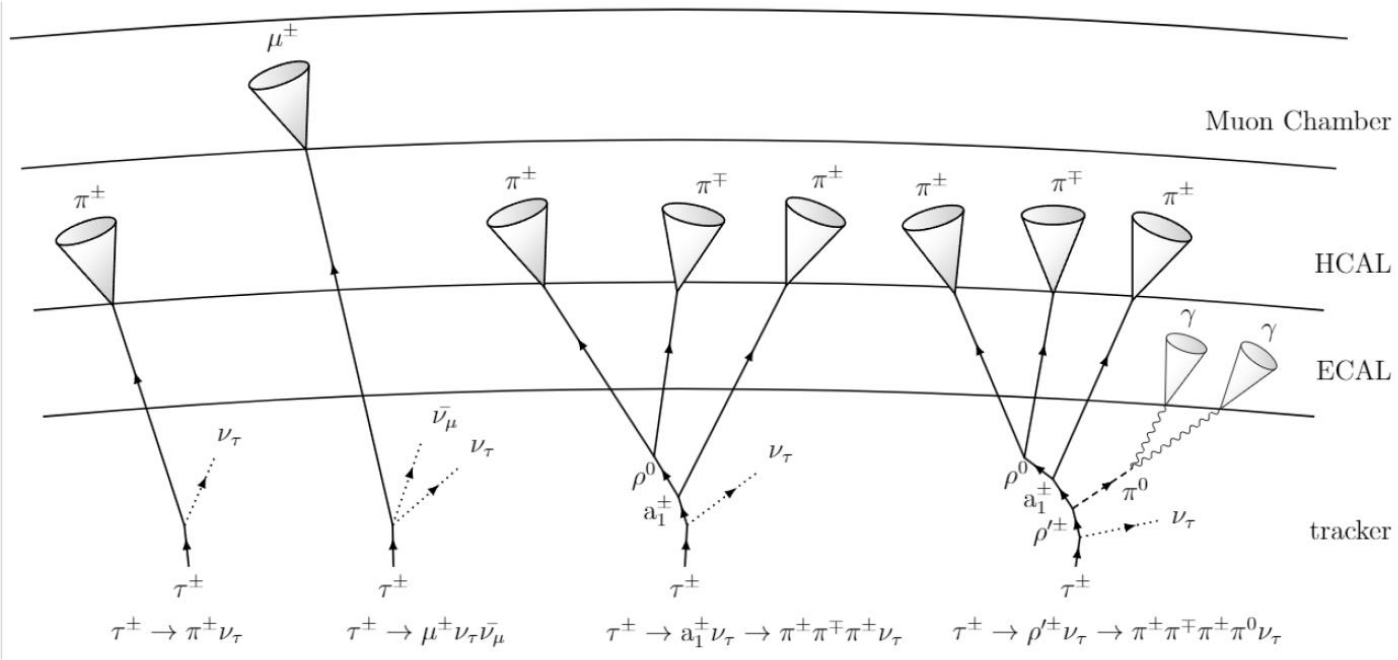
https://arxiv.org/abs/1908.05180

Tau decays

- τ has mean lifetime of $2.9 \times 10^{-13} s$
  - Will decay within millimeters of IP
- CMS detector will only see decay products of 2 tau leptons

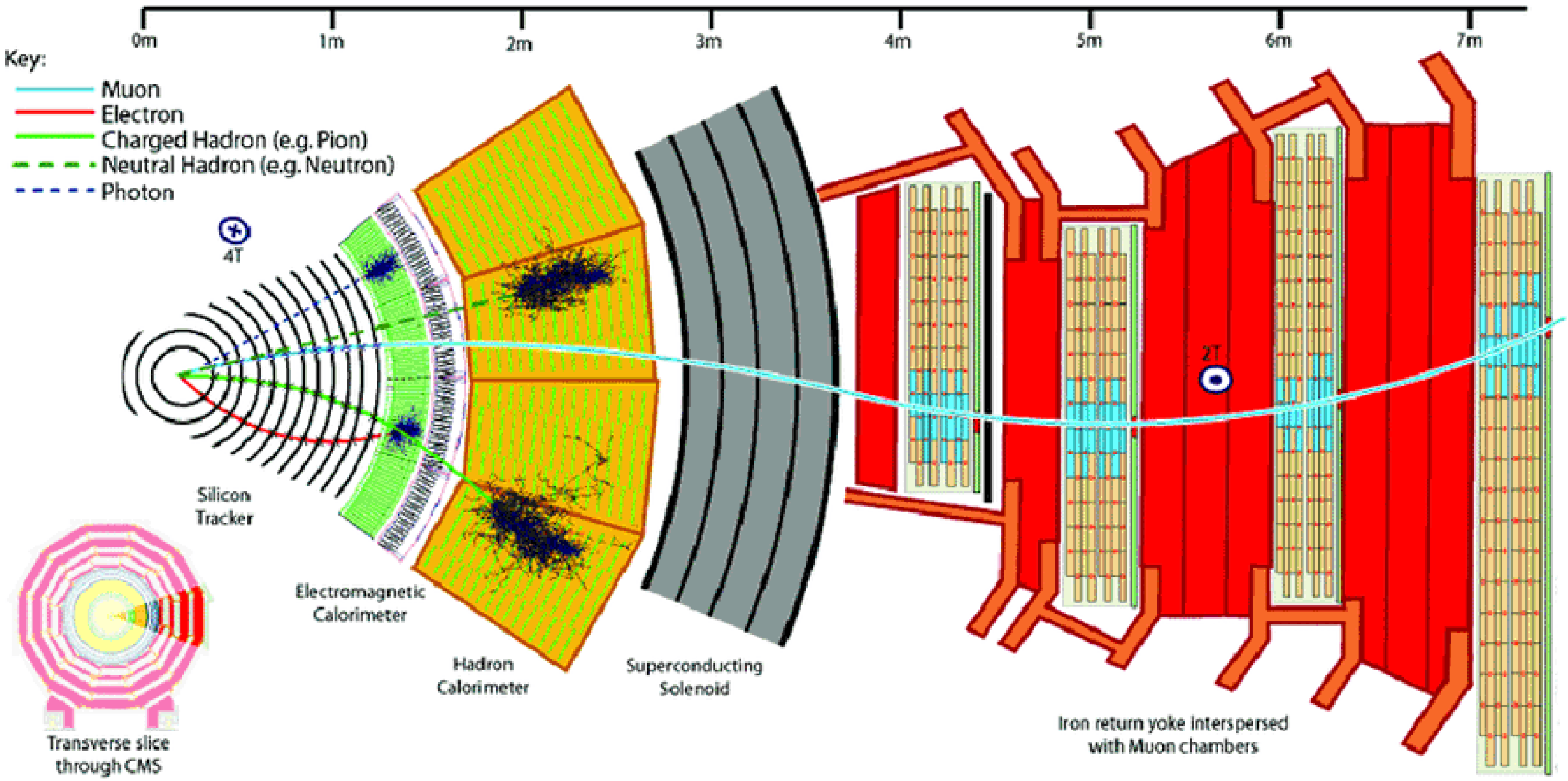
Decay Channel	Branching Ratio
$\boldsymbol{\mu^- \bar{\nu}_\mu \nu_\tau}$	**17.4%**
$e^- \bar{\nu}_e \nu_\tau$	17.8%
$\pi^- \nu_\tau + n * \pi^0$	47.9%
$\boldsymbol{\pi^- \pi^+ \pi^- \nu_\tau + n * \pi^0}$	**14.6%**
Other	2.3%

https://pdg.lbl.gov/2019/reviews/rpp2019-rev-tau-branching-fractions.pdf



https://tikz.net/tau_decay/

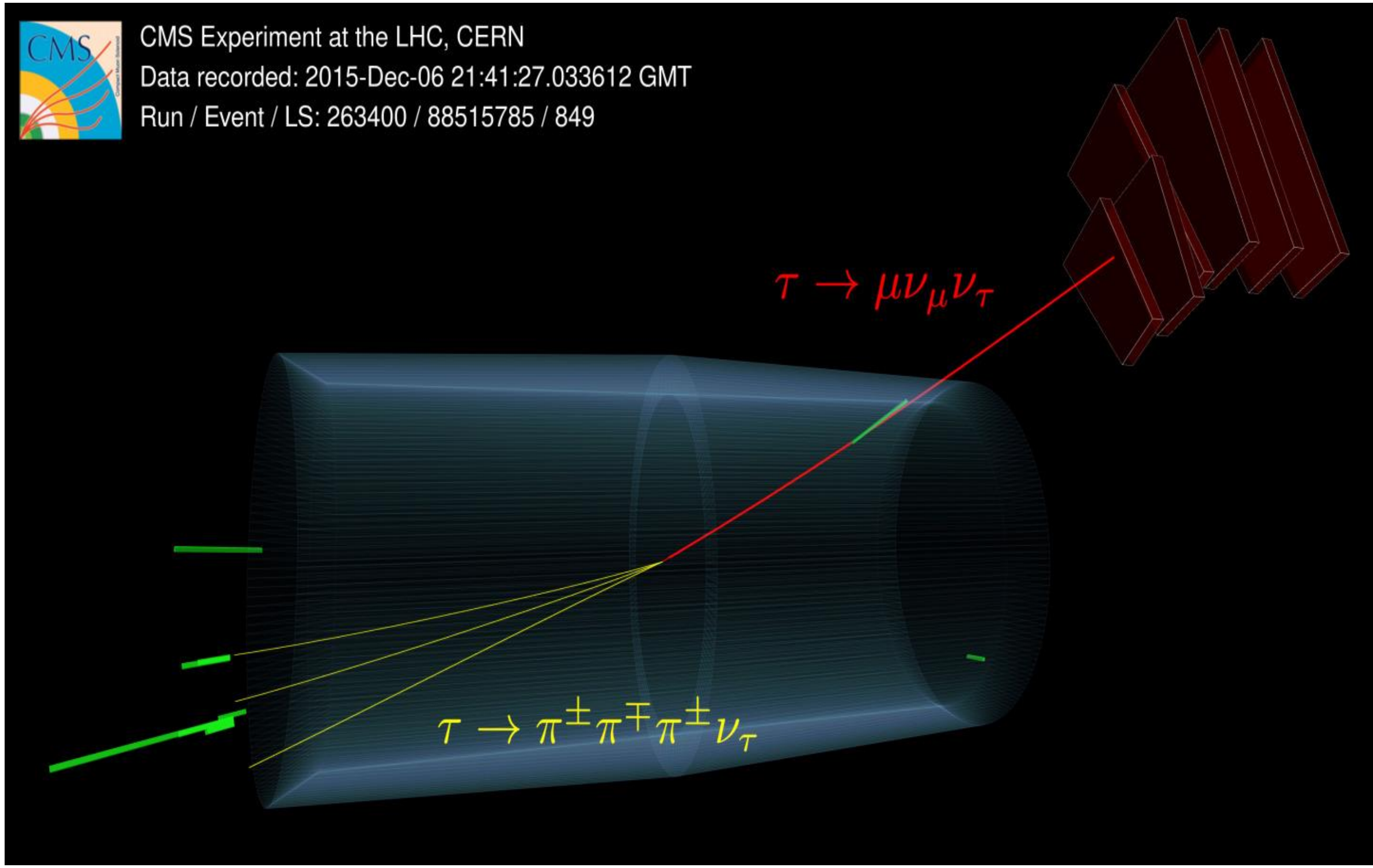
CMS Detector



https://www.mpoweruk.com/CMS-Detector.htm

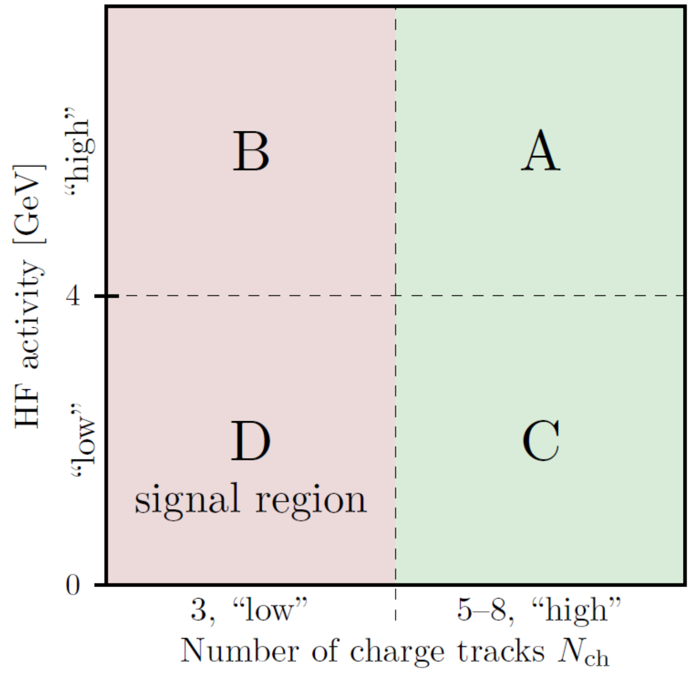
$\gamma\gamma \rightarrow \tau\tau$ candidate events at CMS

- Analysis considers events with decay $\tau + \tau \rightarrow \mu^{\mp}\nu_{\mu}\nu_{\tau} + \pi^{\pm}\pi^{\mp}\pi^{\pm}\nu_{\tau}$
- Accounts for 5% of τ decays.
- Expect ~100 events after cuts with available luminosity
- Provides cleanest sample
- Lepton + 1 track events have contamination from dilepton photoproduction
- Future analysis plan to add more channels to increase precision



Identifying signal and background

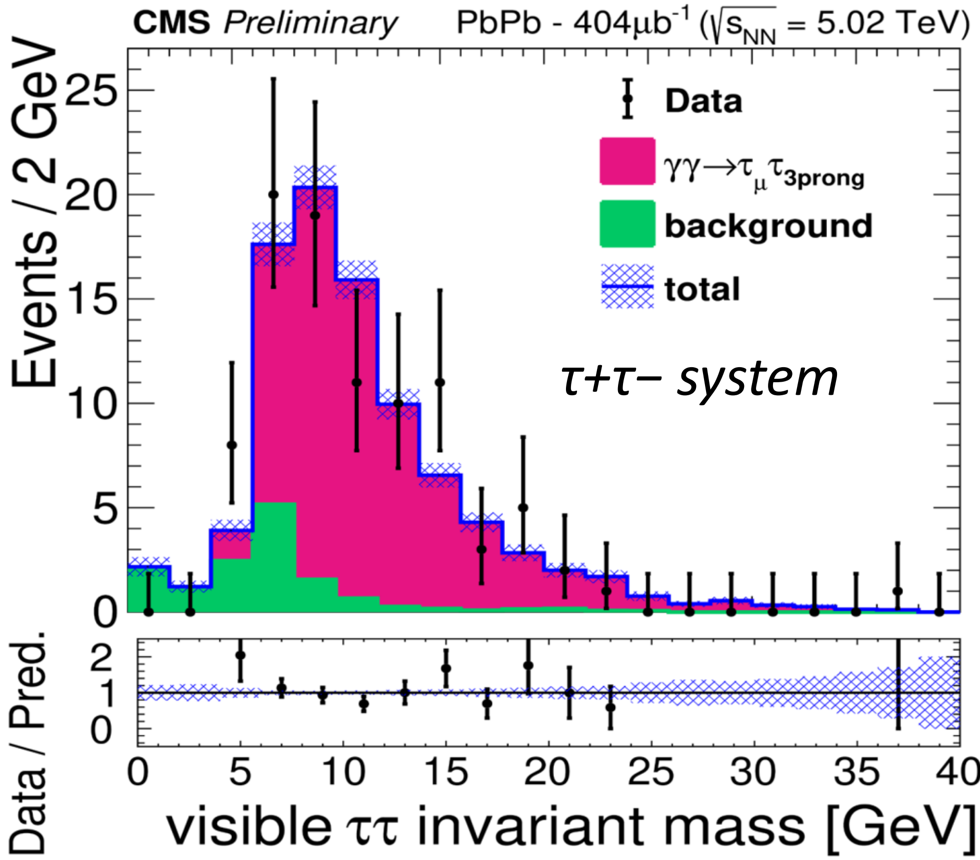
- Trigger requires 1 muon w/ 1 hit in pixel detector and no HF activity on at least 1 side
- Offline selections are shown in table
- After Cuts only signal MC events remain
- Signal region (D) consists of 1 muon and 3 charged hadrons
- Background estimates used ABCD method
  - ABCD regions shown in figure

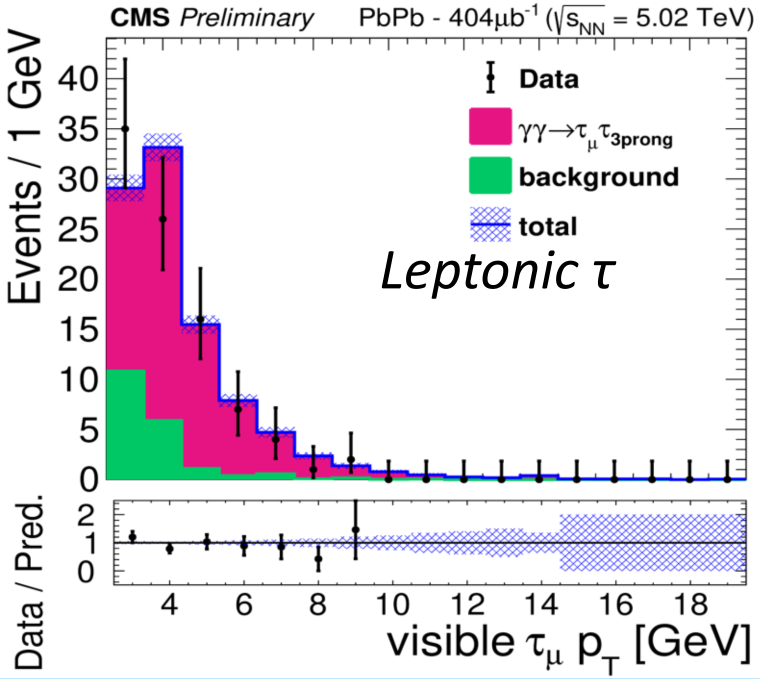


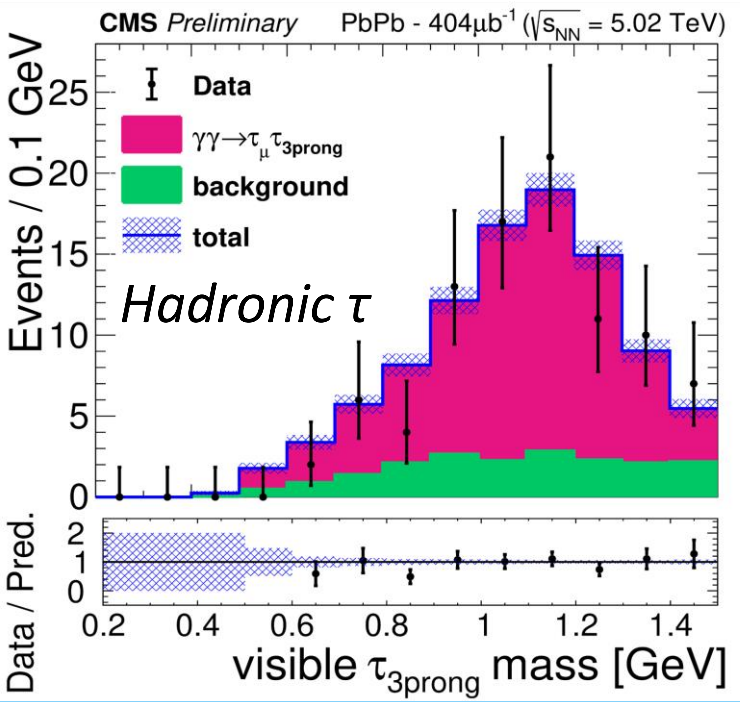
Muon selection	$p_T > 3.5\,\mathrm{GeV}$ for $\lvert\eta\rvert < 1.2$ $p_T > 2.5\,\mathrm{GeV}$ for $1.2 < \lvert\eta\rvert < 2.4$
Pion selection	$p_T > 0.5\,\mathrm{GeV}$ for the leading $p_T > 0.3\,\mathrm{GeV}$ for the (sub-)subleading $\lvert\eta\rvert < 2.5$
τ_{3prong} selection	$p_T^{vis} > 2\,\mathrm{GeV}$ and $0.2 < m_\tau^{vis} < 1.5\,\mathrm{GeV}$

Data and MC have consistent kinematics

- Have agreement in full $\tau\tau$ system (muon and 3 prong decay + combined system)
- Monte Carlo is scaled to luminosity

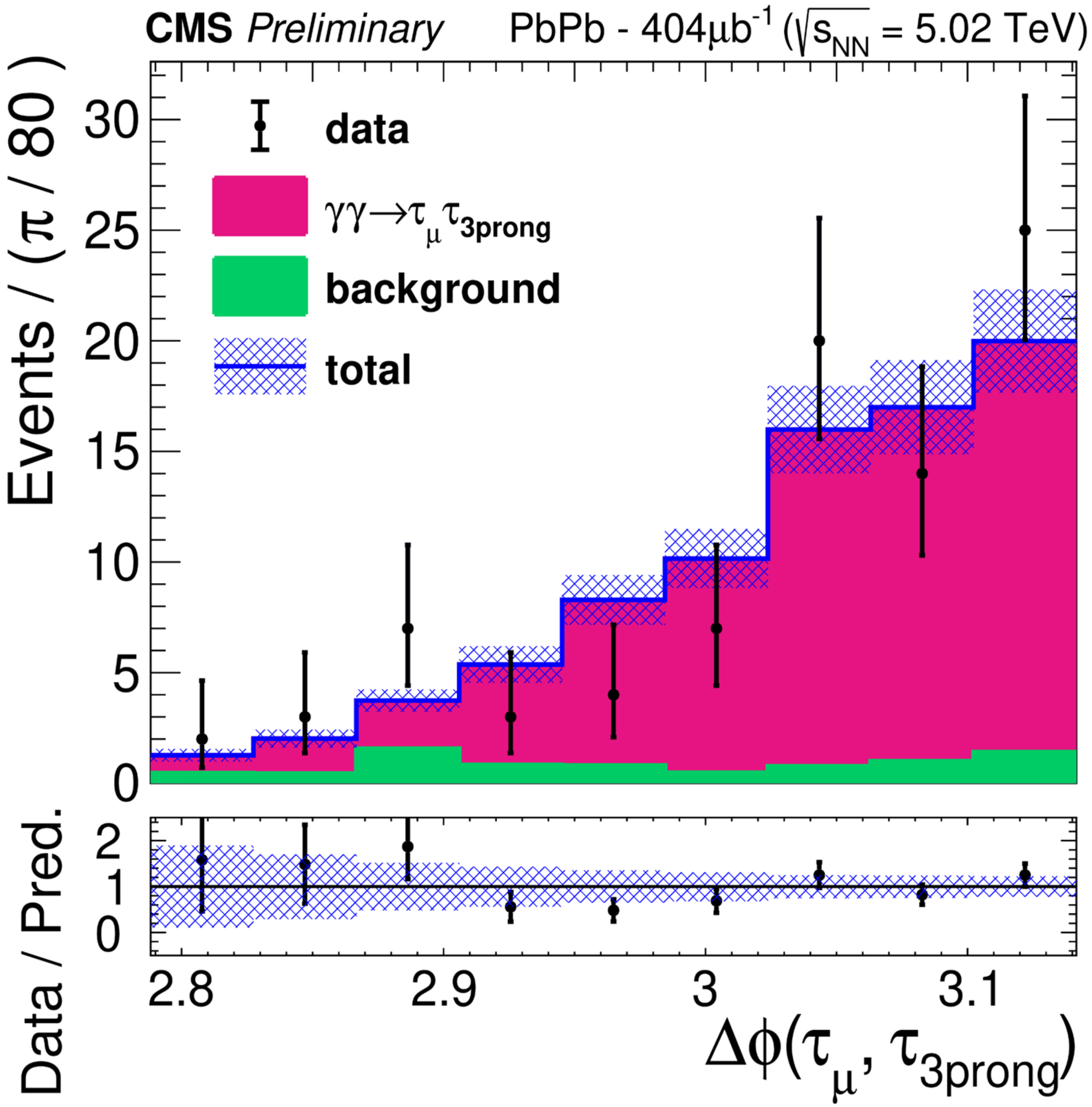






Signal yield estimations

- Signal yield calculated with binned likelihood
- Discriminating variables is $\Delta\phi$
  - $\Delta\phi = |\phi_\mu - \phi_{3prong}|$
  - $\Delta\phi < \pi$ due to neutrinos
- $\mathbf{77 \pm 12}$ **events** after fit
  - Over 5.0 σ observed significance



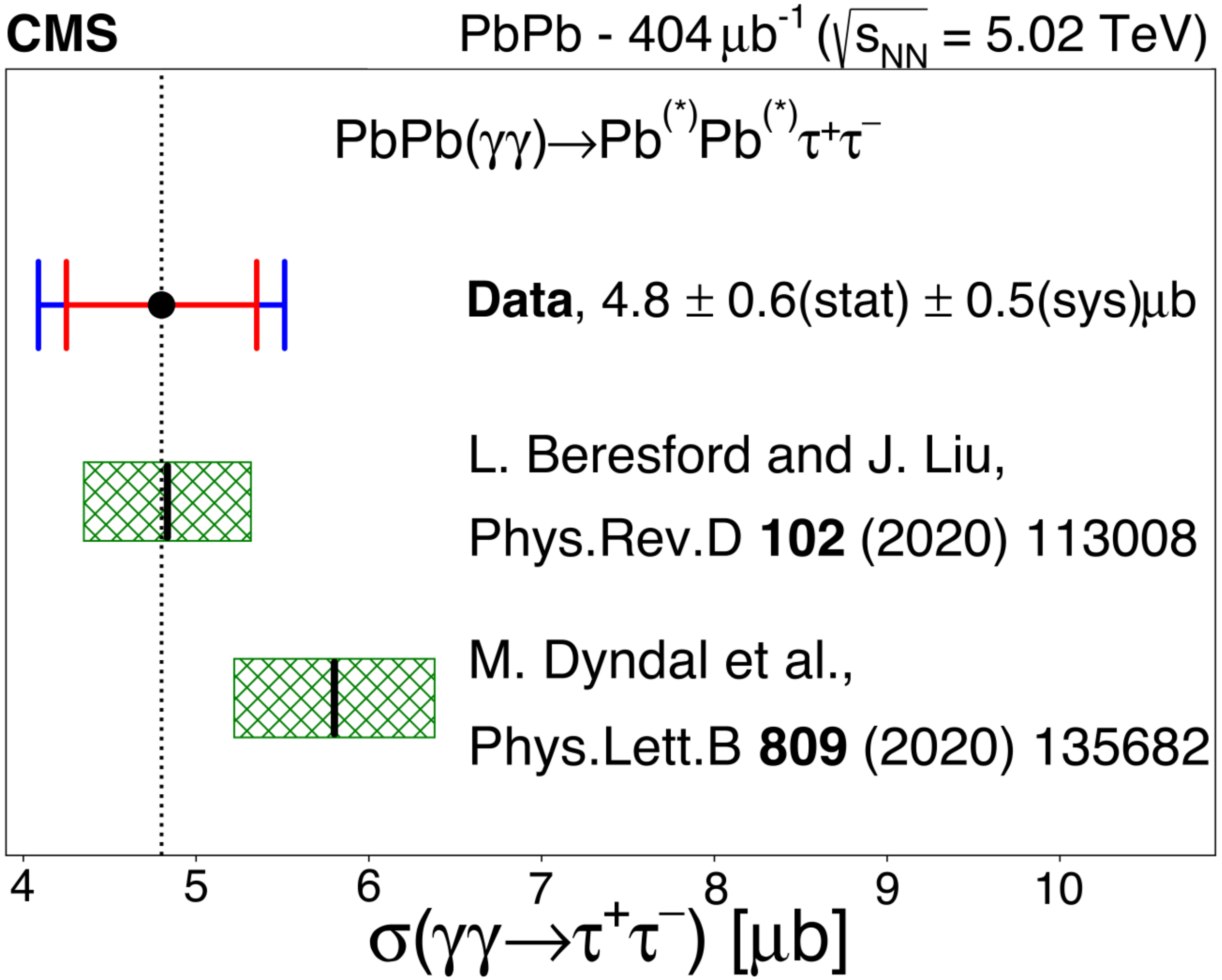
Uncertainties are dominated by statistics

- Largest source of uncertainty is statistical (13%)
- Main systematic uncertainties: trigger, tracking and luminosity
- Total uncertainty 16%

Source	Relative uncertainty (%)
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 N_{ch} on background shape	0.2
Total	9.7

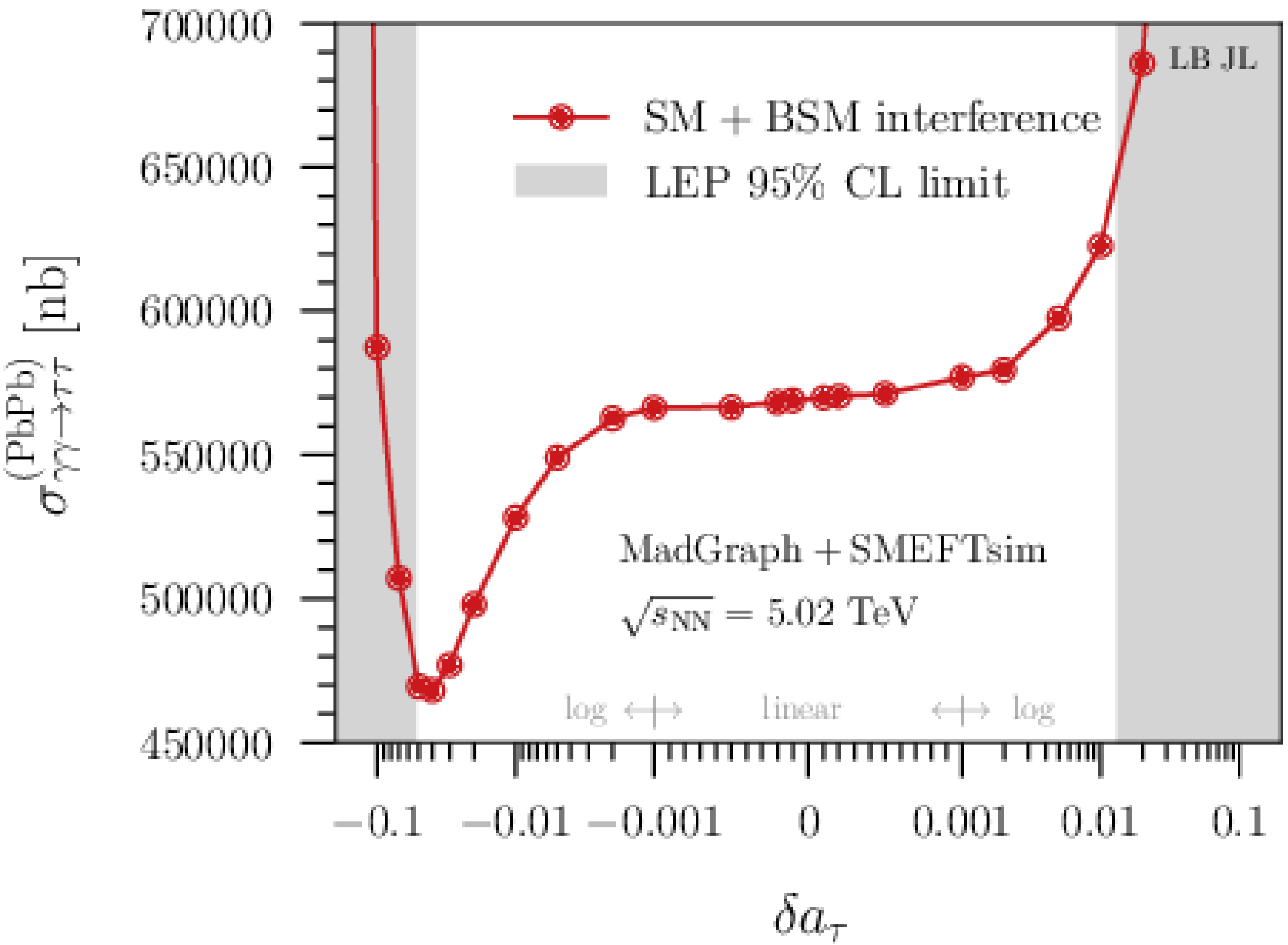
Cross section measurement is consistent with SM

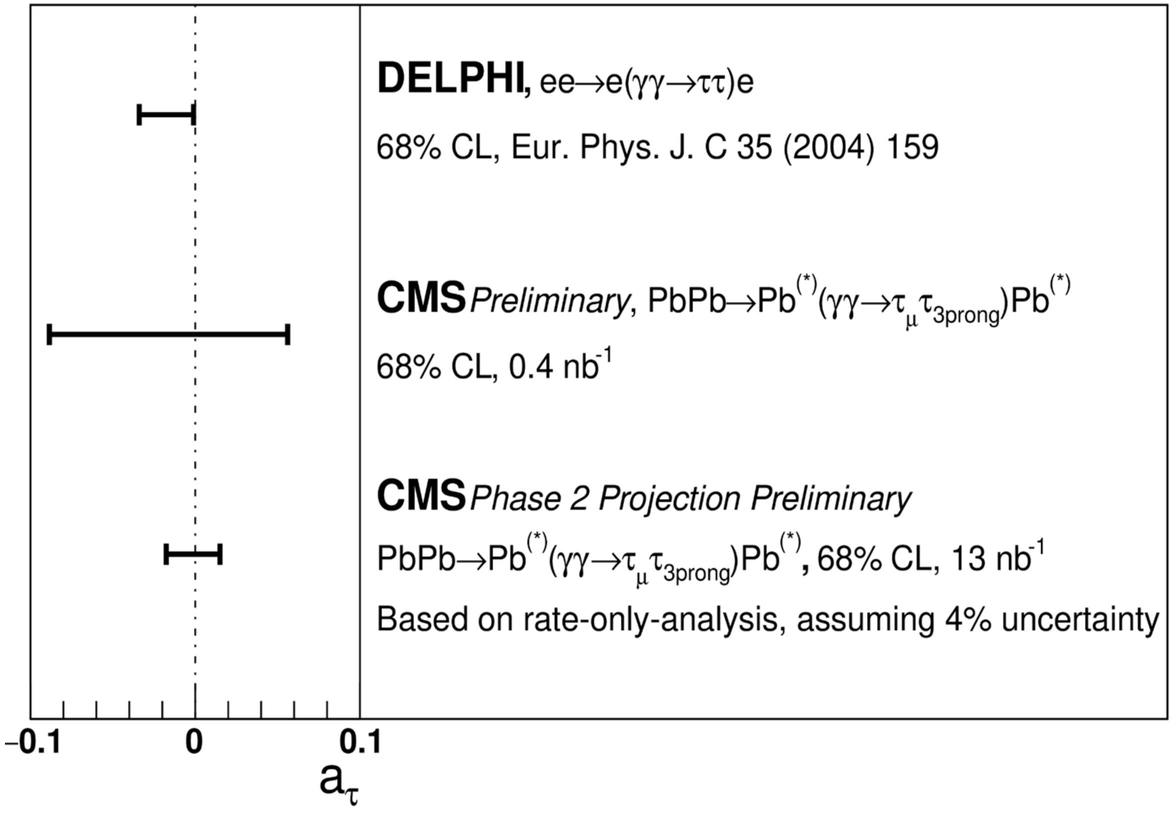
- $\sigma(\gamma\gamma \to \tau^+\tau^-) = \frac{N_{sig}}{2\epsilon\, L_{int} B_{\tau_\mu} B_{\tau_{3prong}}}$
- $L = 404\mu b\, , B_{\tau_\mu} = 17.39\%, B_{\tau_{3prong}} = 14.55\%, \epsilon = 78.5\%$
- $\boldsymbol{\sigma(\gamma\gamma \to \tau^+\tau^-) = 4.8 \pm 0.6(\mathrm{stat}) \pm .5(sys)\ \mu b}$



Limits on a_τ

- Determine a_τ via theoretical calculation of $\sigma_{\gamma\gamma\to\tau\tau}(\delta a_\tau)$
- With phase 2 luminosity, can match DELPHI precision

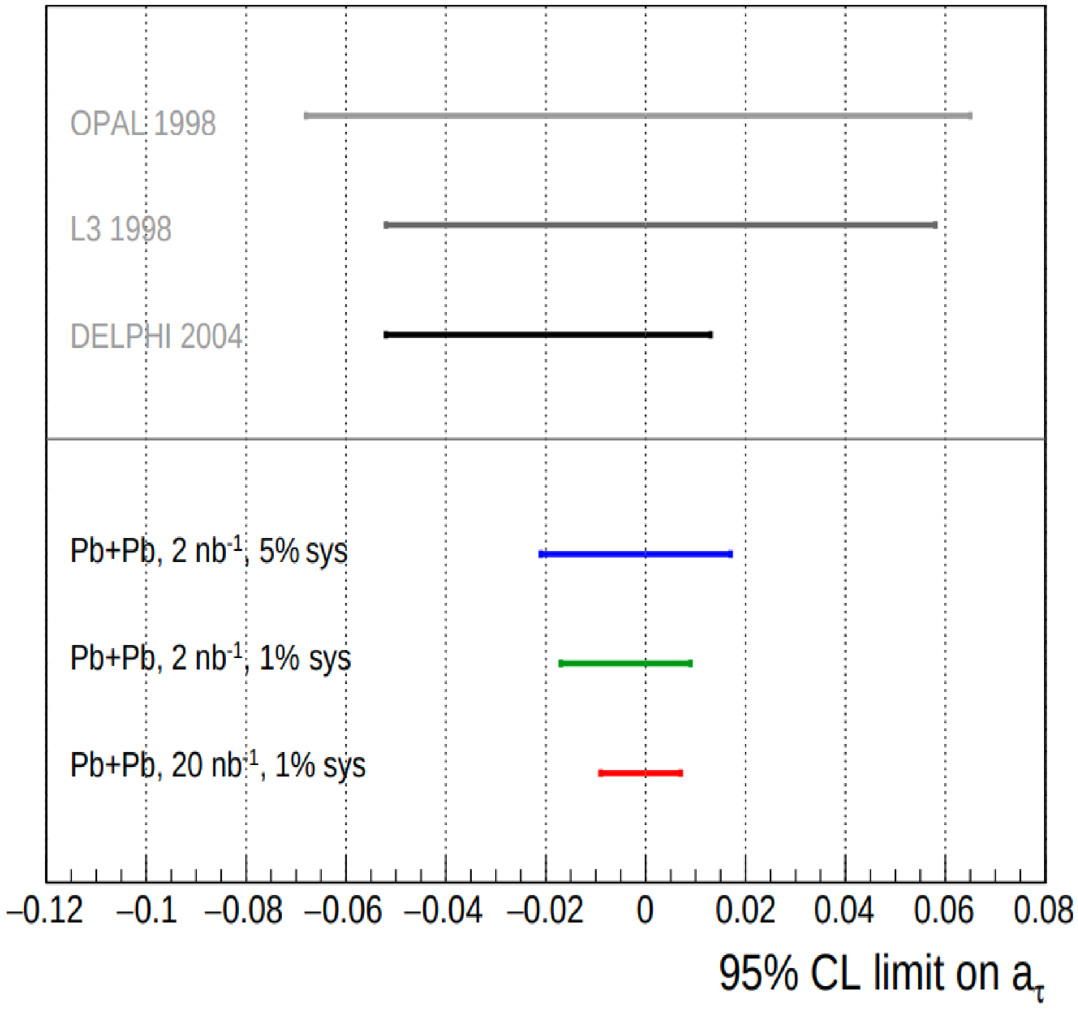




https://arxiv.org/abs/1908.05180

Outlook

- Searches for BSM phenomena via UPC data in multiple collaborations at LHC
  - Cross-experiment collaboration should lead to higher precision and statistical significance
- CMS has dedicated program studying a_τ
  - 2018 Results with additional channels expected early 2024
  - 2023 data have 20% more luminosity than 2018
  - 2023 Data have hadronic only triggers



Conclusion

- First observation of $\gamma\gamma \rightarrow \tau\tau$ in heavy ion collisions
- $\boldsymbol{\sigma(\gamma\gamma \rightarrow \tau^{+}\tau^{-}) = 4.8 \pm 0.6(\mathrm{stat}) \pm .5(sys)\ \mu b}$
- 68% CL limit of $(-8.8 < a_{\tau} < 5.6\ ) \times 10^{-2}$
- Projected Run 3 + 4 68% CL limit of $(-1.8 < a_{\tau} < 1.5\ ) \times 10^{-2}$
- Results published in PRL: Phys. Rev. Lett. **131**, 151803

Thanks

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Important Sources

- CMS $\gamma\gamma \rightarrow \tau\tau$: https://arxiv.org/abs/2206.05192
- ATLAS $\gamma\gamma \rightarrow \tau\tau$: https://arxiv.org/abs/2204.13478
- Theory $\gamma\gamma \rightarrow \tau\tau$: https://arxiv.org/abs/1908.05180
- Muon G-2: https://arxiv.org/abs/2308.06230