EW results in two-photon collisions at CMS and ATLAS

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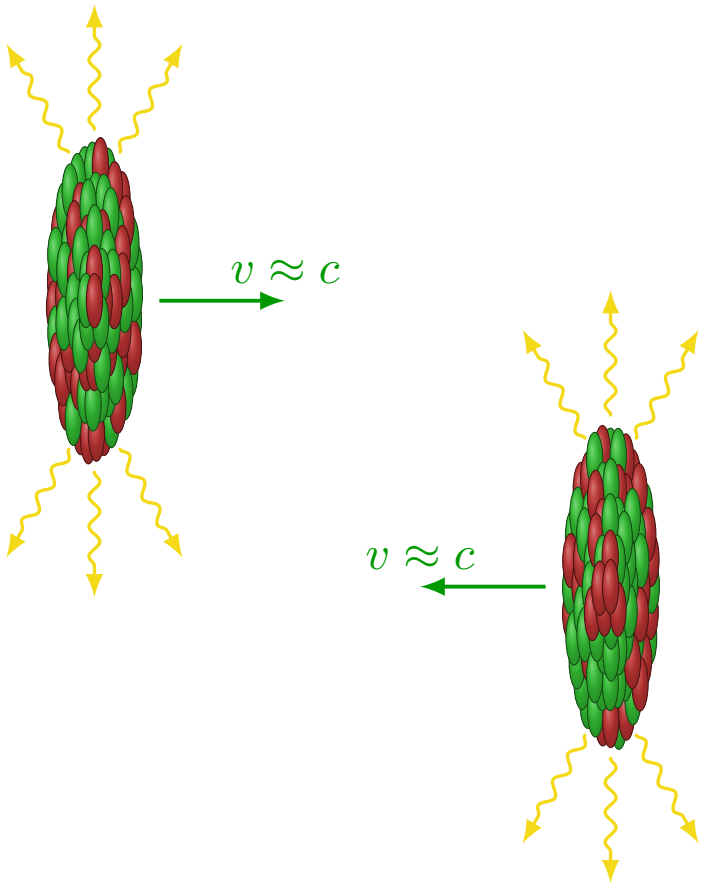
Moriond EW 2024

Photon-induced processes

- As two charged particles (e.g. protons or ions) pass each other at relativistic velocities, they generate intense electromagnetic fields → **photon-photon collisions** can happen

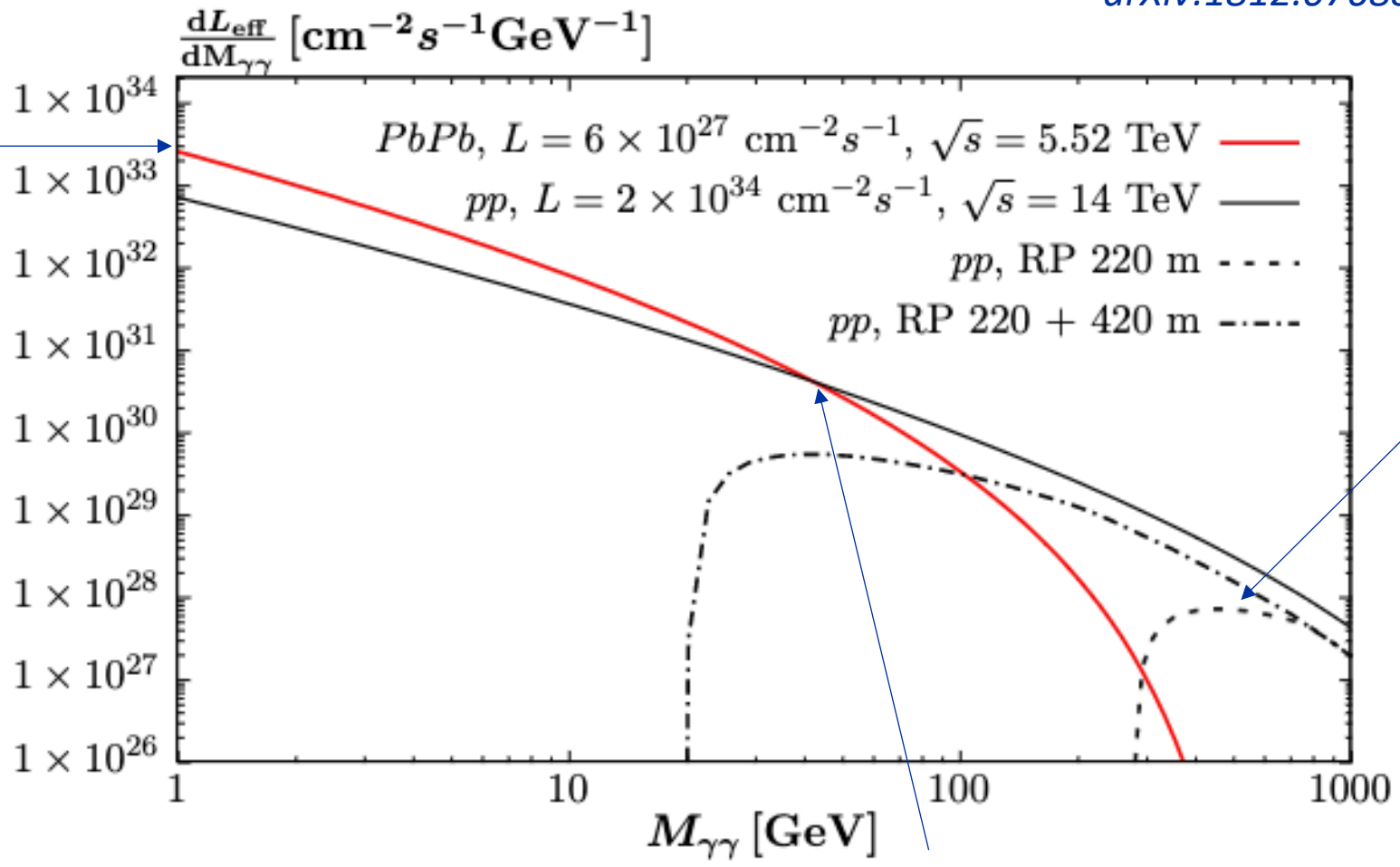


- **Cross section proportional to Z^4** → huge enhancement in Pb-Pb runs (Z = 82) compared to pp runs (Z = 1)

The LHC is (also) a photon collider

arXiv:1812.07688

At low masses, PbPb runs have the largest effective $\gamma\gamma$ luminosity



At very high masses, diffracted protons can be tagged by forward detectors

At intermediate masses, pp takes over but need to handle pileup

The low-energy regime

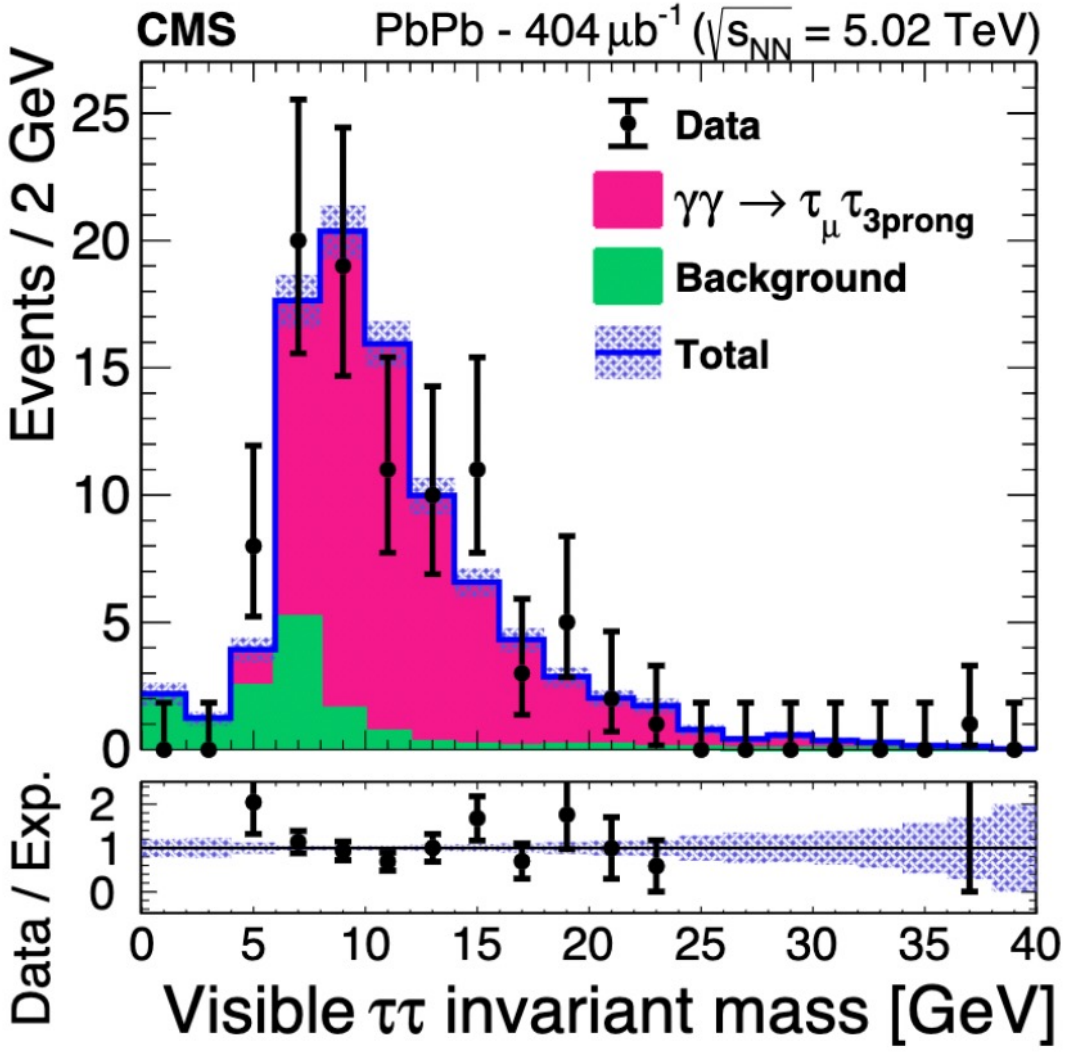
PbPb ultraperipheral collisions

$\gamma\gamma \rightarrow \tau\tau$ in PbPb collisions

Phys. Rev. Lett. 131 (2023) 151803
arXiv:2206.05192

Phys. Rev. Lett. 131 (2023) 151802
arXiv:2204.13478

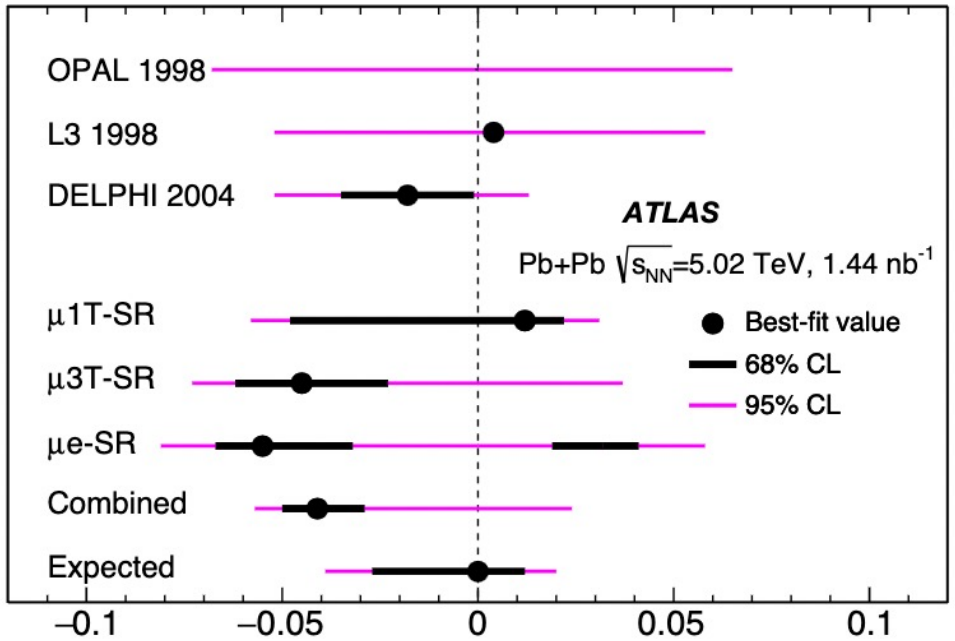
- Clear observation by both ATLAS and CMS, compatible with predictions
- CMS:
  - 0.4 nb^{-1} collected in 2015
  - $\mu + \tau_h$(3prong) final state
- ATLAS:
  - 1.4 nb^{-1} collected in 2018
  - e+μ, $\mu + \tau_h$(1prong), $\mu + \tau_h$(3prong)

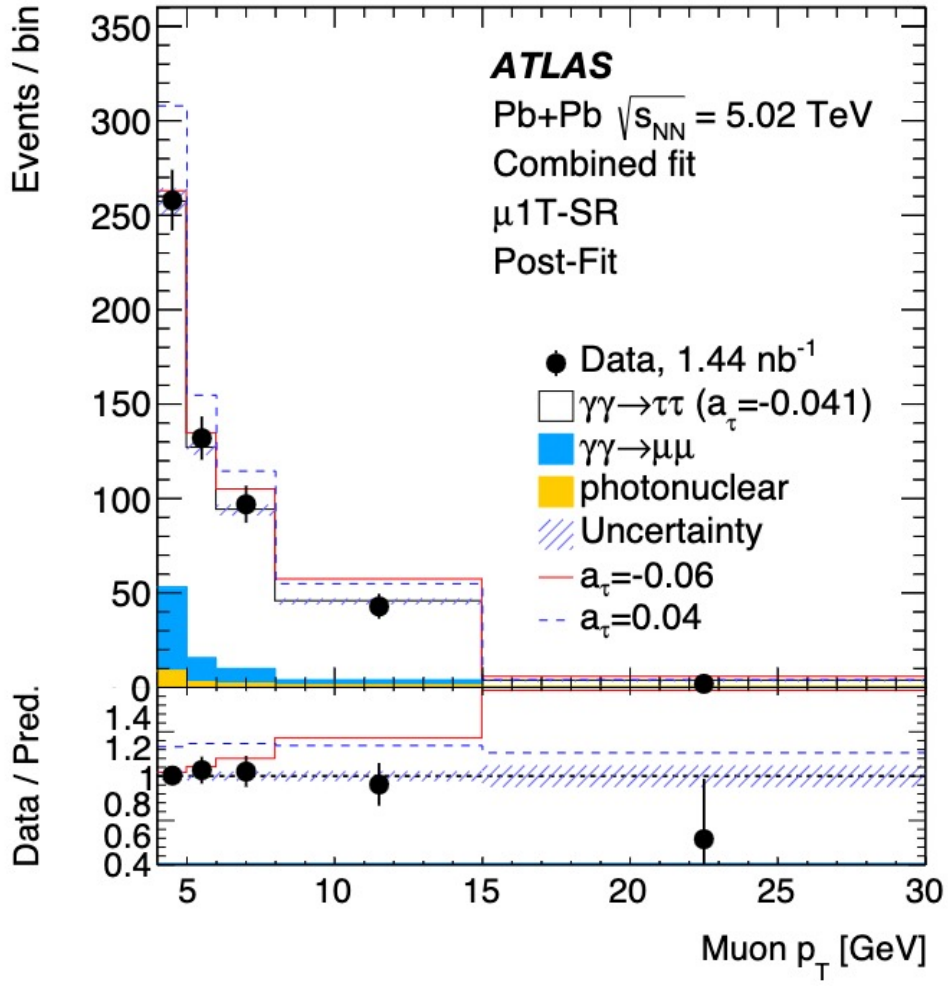


Sensitive to $m_{vis}(\tau,\tau) <\tilde{} 25$ GeV

Extracting τ g-2 from γγ→ττ observation

- Modifying the τ g-2 modifies the γγ→ττ cross section and modifies the p_T and mass distributions of the signal
- CMS uses cross section information only, ATLAS also uses shape variations (BSM effects enhanced at high mass and p_T)





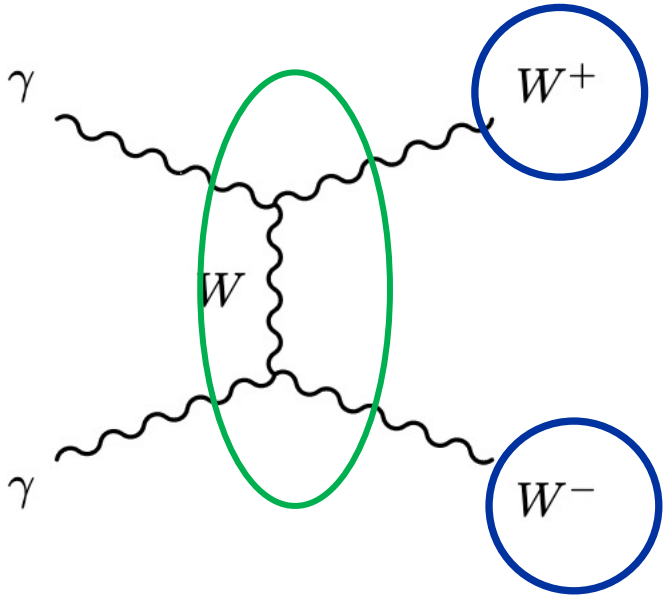
The intermediate-energy regime

pp collisions with track counting

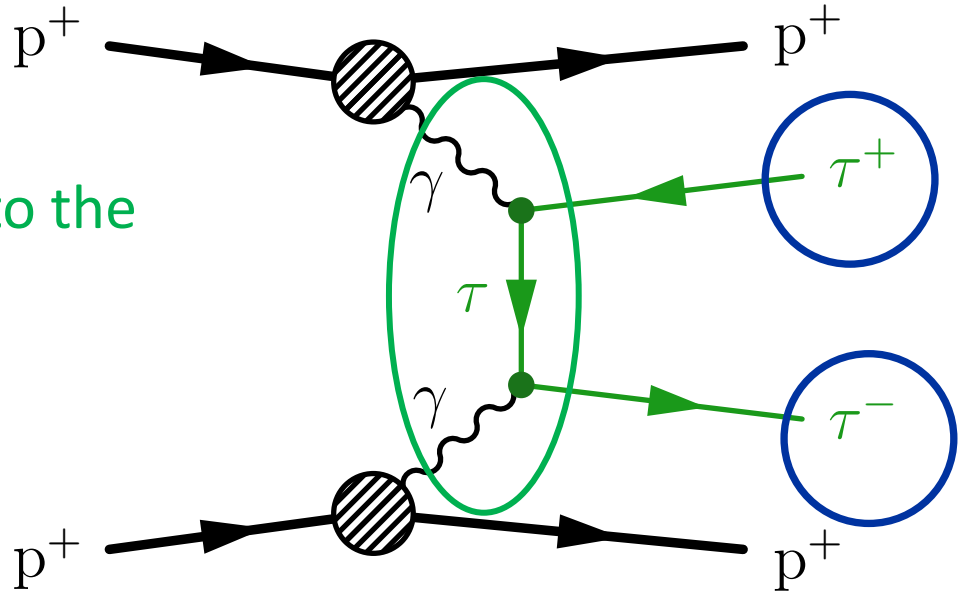
γγ→WW/ττ in pp collisions

Phys. Lett. B 816 (2021) 136190
arxiv:2010.04019

NEW
CMS-PAS-SMP-23-005



- 2 back-to-back objects
- No hadronic activity close to the di-W/τ vertex
  - $N_{tracks} = 0$



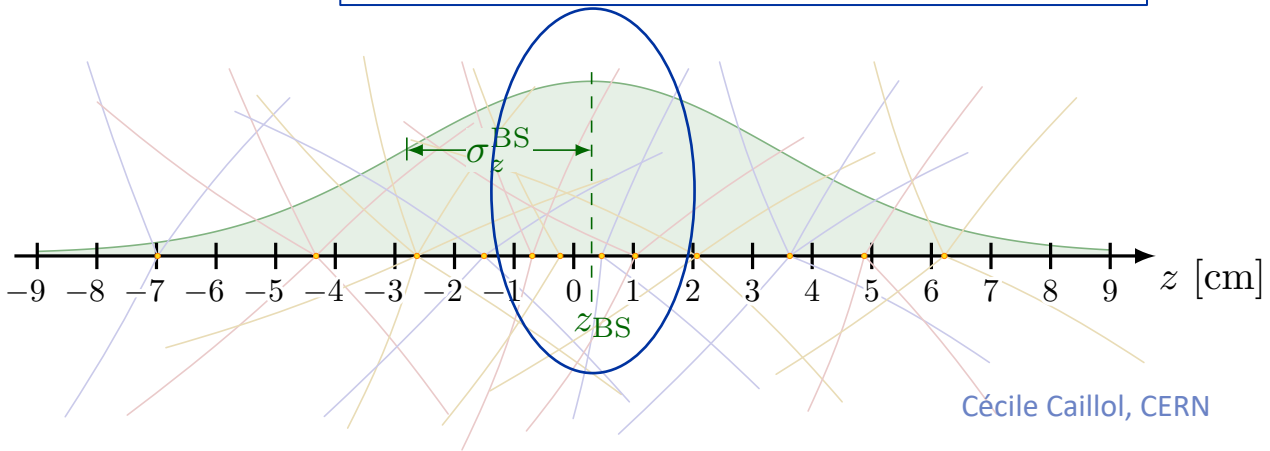
Elastic process, protons do not dissociate

Counting tracks

- Define **z position of interaction vertex:**
  - average z position of selected tau leptons
  - Weighted average for leptons from W:

$$z_{\mathrm{vtx}}^{\ell\ell} = \frac{z_{\ell_1}\sin^2\theta_{\ell_1} + z_{\ell_2}\sin^2\theta_{\ell_2}}{\sin^2\theta_{\ell_1} + \sin^2\theta_{\ell_2}}$$

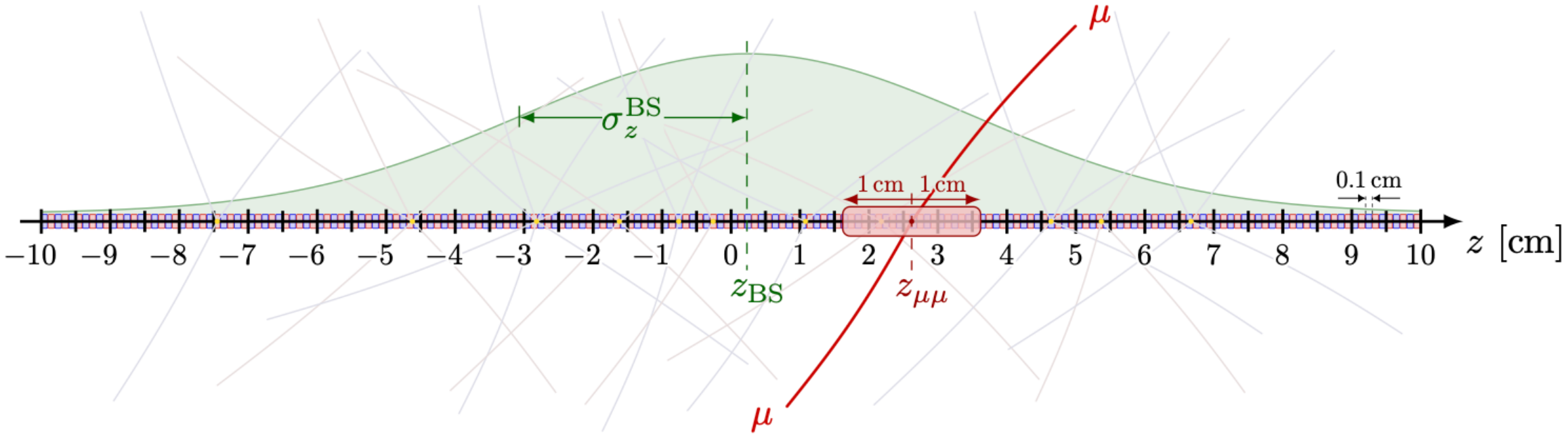
Extraordinary tracking capabilities of the ATLAS and CMS detectors!



- Define N_{tracks} as the number of tracks
  - with $p_T > 0.5$ GeV and $|\eta| < 2.5$
  - within a window of **0.2/0.1 cm** around the interaction vertex
  - Excluding tracks from W/τ

- About 30% of the 1mm windows at the center of the beamspot do not contain any pileup track

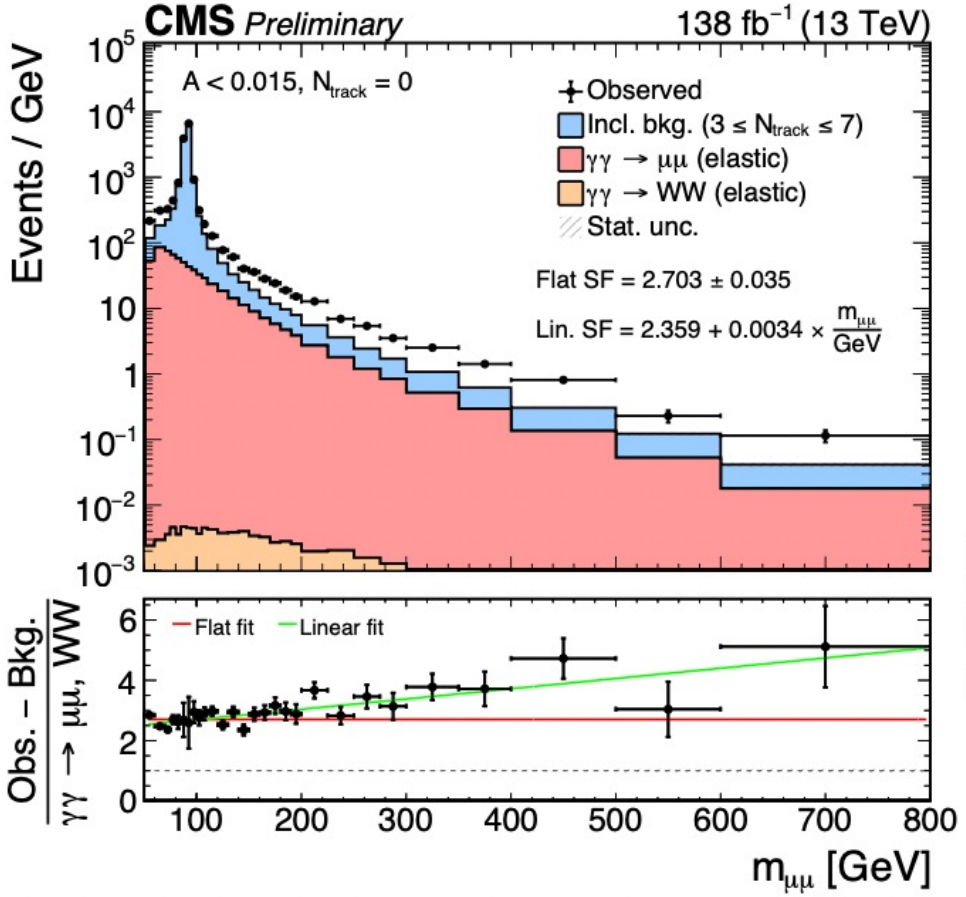
Correcting simulated track multiplicity

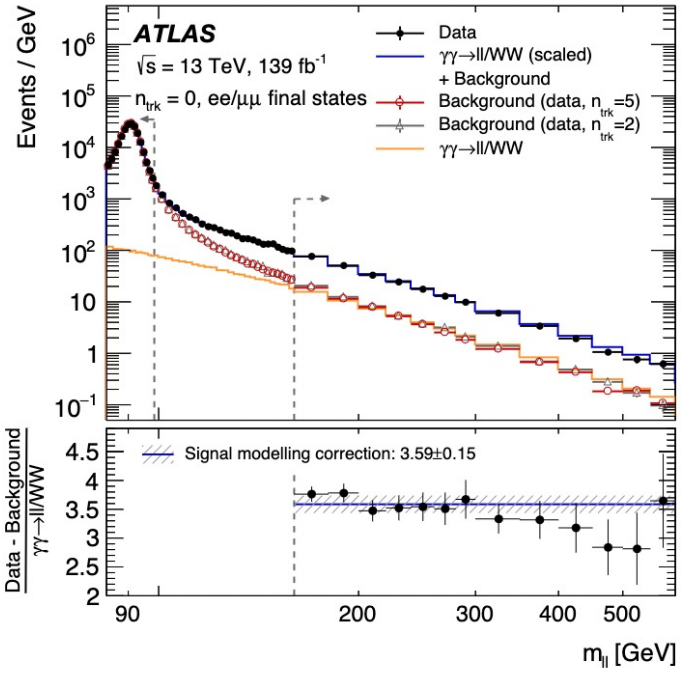


- Pileup tracks:
  - Compare N_{tracks} distribution in Z→μμ data and Z→μμ MC in windows far from the μμ vertex
- Hard scattering tracks:
  - Compare N_{tracks} distribution in Z→μμ data and Z→μμ MC inside window centered at the μμ vertex

Including (semi-)dissociative contributions

- **Inclusive backgrounds:**
  - Shape from data with 2 < N_{tracks} < 8 → Negligible exclusive contributions
  - Normalized to Z peak in events with N_{tracks} = 0 or 1
- **Elastic γγ→μμ/WW:**
  - Estimated from gammaUPC
  - Rescaled with linear $m_{\mu\mu}$ function to match data





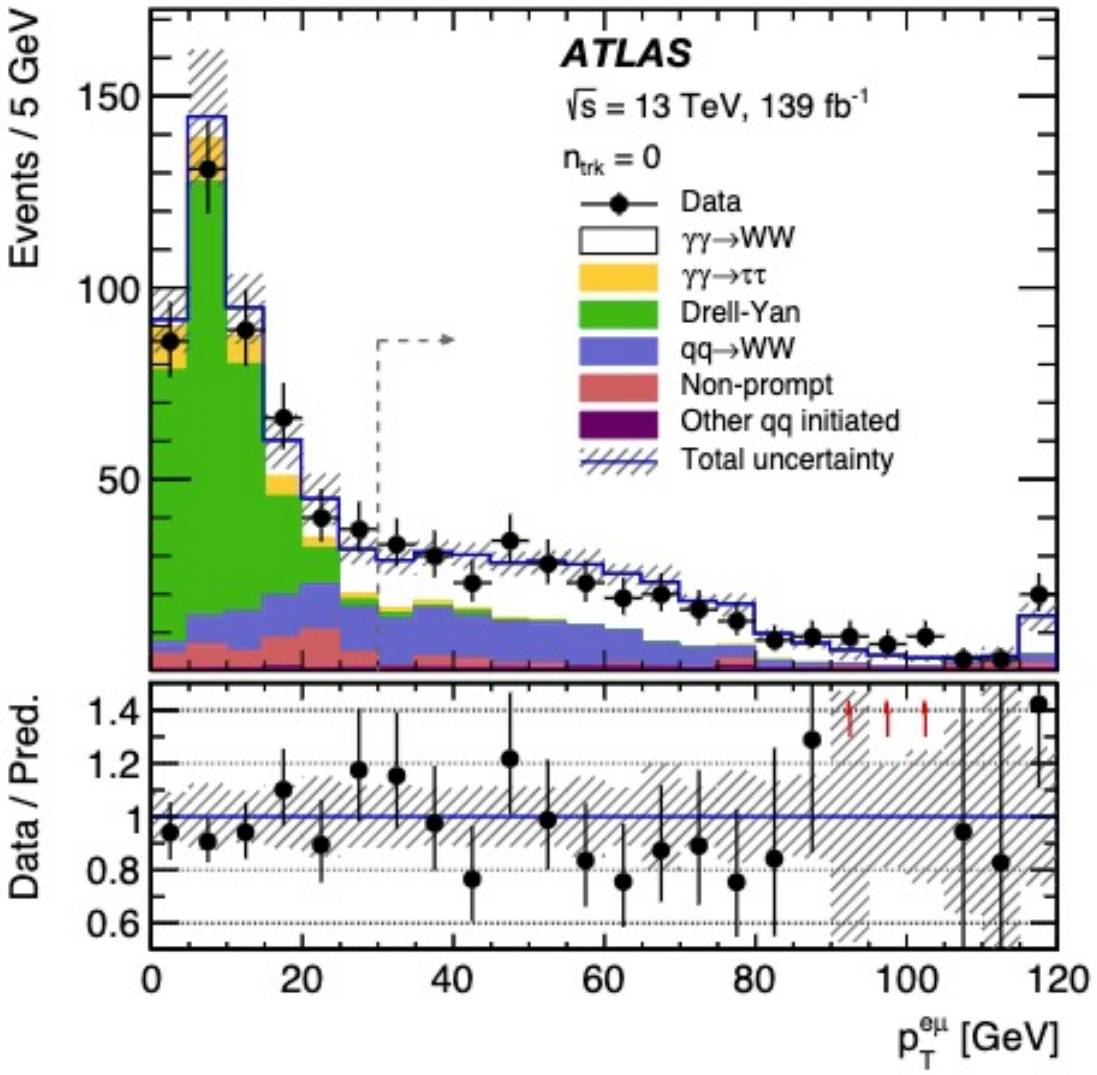
Elastic simulation to be scaled by a factor of ~3

Differences between ATLAS and CMS related to $|\Delta\phi(\mu\mu)|$ selection (acoplanarity)

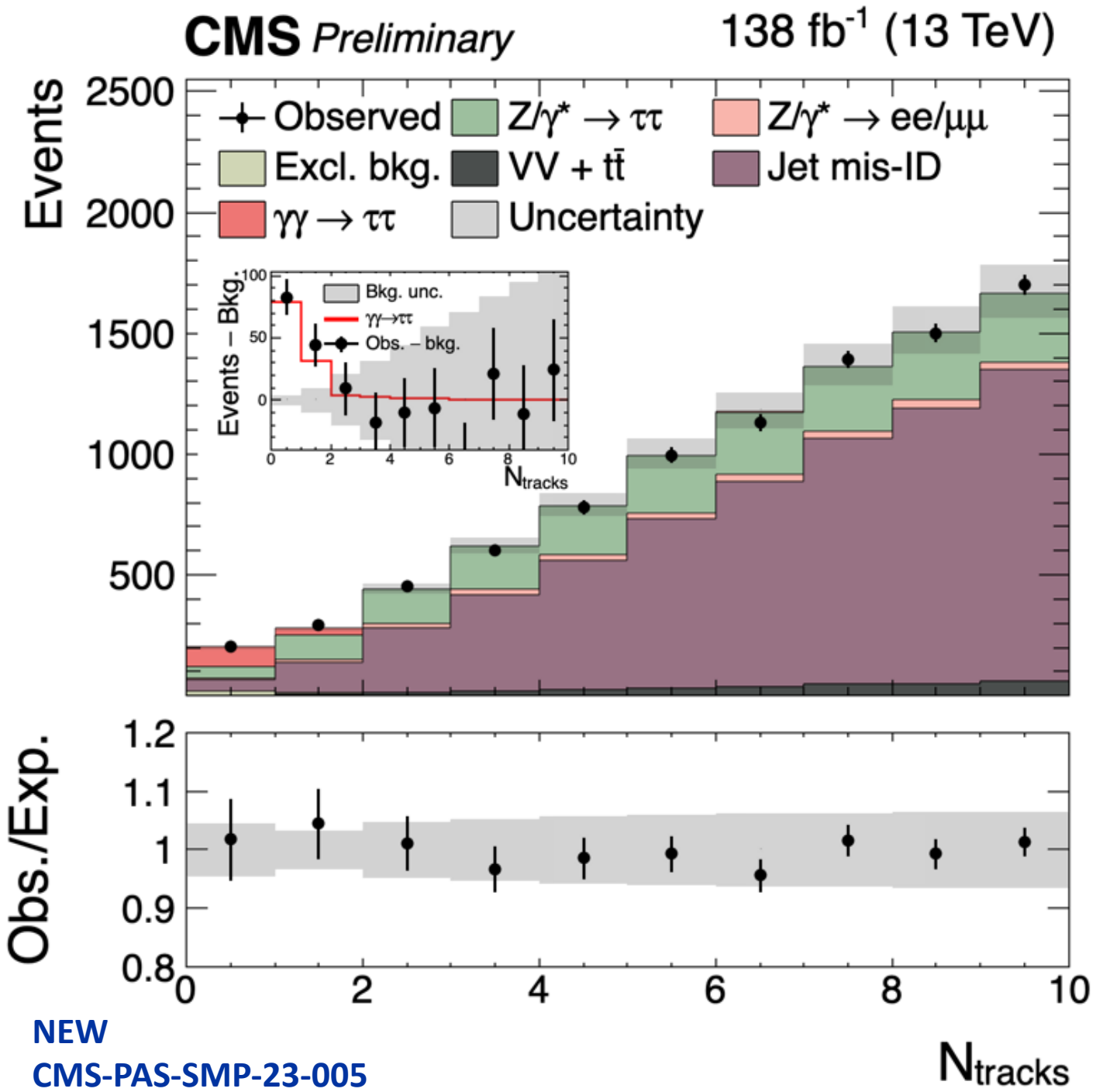
Observation of γγ→WW in pp collisions

Phys. Lett. B 816 (2021) 136190
arxiv:2010.04019

- eμ final state
- Signal visible at high p_T(eμ) (MET proxy) and N_{tracks}= 0
- Significance well above 5σ
- Fiducial xs: = 3.13 ± 0.31 (stat.) ± 0.28 (syst.) fb, in agreement with theoretical predictions



Observation of $\gamma\gamma \rightarrow \tau\tau$



- **5.3 σ observed, 6.5 σ expected**
- **First observation of $\gamma\gamma \rightarrow \tau\tau$ in pp collisions**
- Systematic and statistical uncertainties comparable in size

NEW
CMS-PAS-SMP-23-005

NEW
SMP-23-005

Constraining a_τ and d_τ with an EFT

SMEFT-sim_general alphaScheme_UFO

- Two dimension-6 operators modify tau g-2 (a_τ) and electric dipole moment (d_τ) at tree-level in SMEFT:

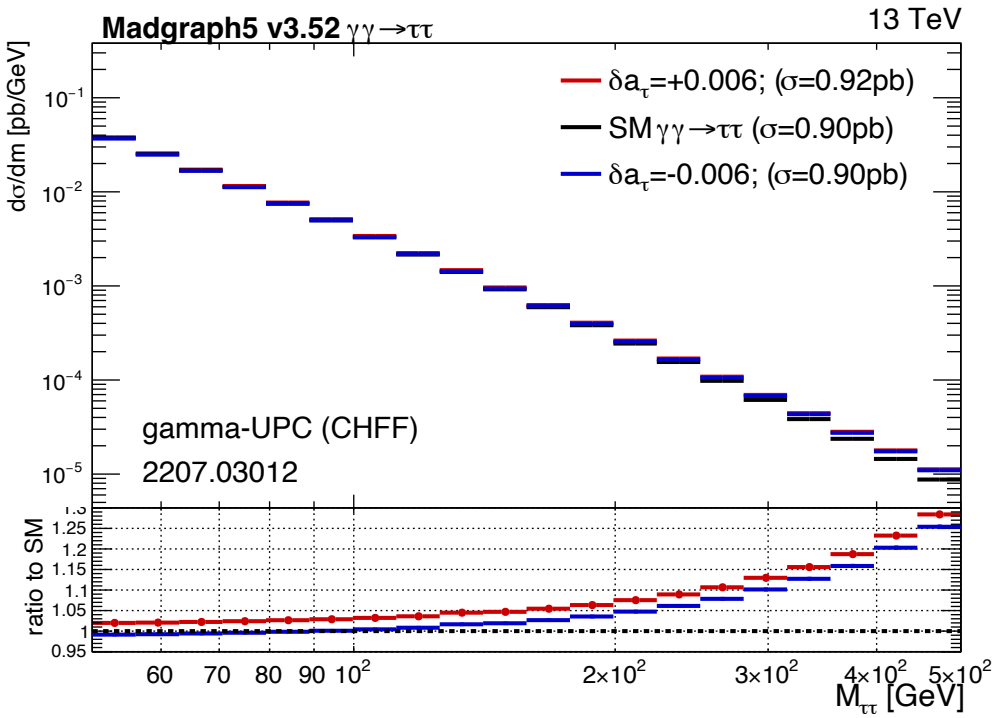
$$\mathcal{L}_{\mathrm{BSM}} = \frac{C_{\tau B}}{\Lambda^2}\bar{L}_L\sigma^{\mu\nu}\tau_R H B_{\mu\nu} + \frac{C_{\tau W}}{\Lambda^2}\bar{L}_L\sigma^{\mu\nu}\tau_R\sigma^i H W^i_{\mu\nu} + \mathrm{h.c.}$$

- BSM contributions to a_τ and d_τ:

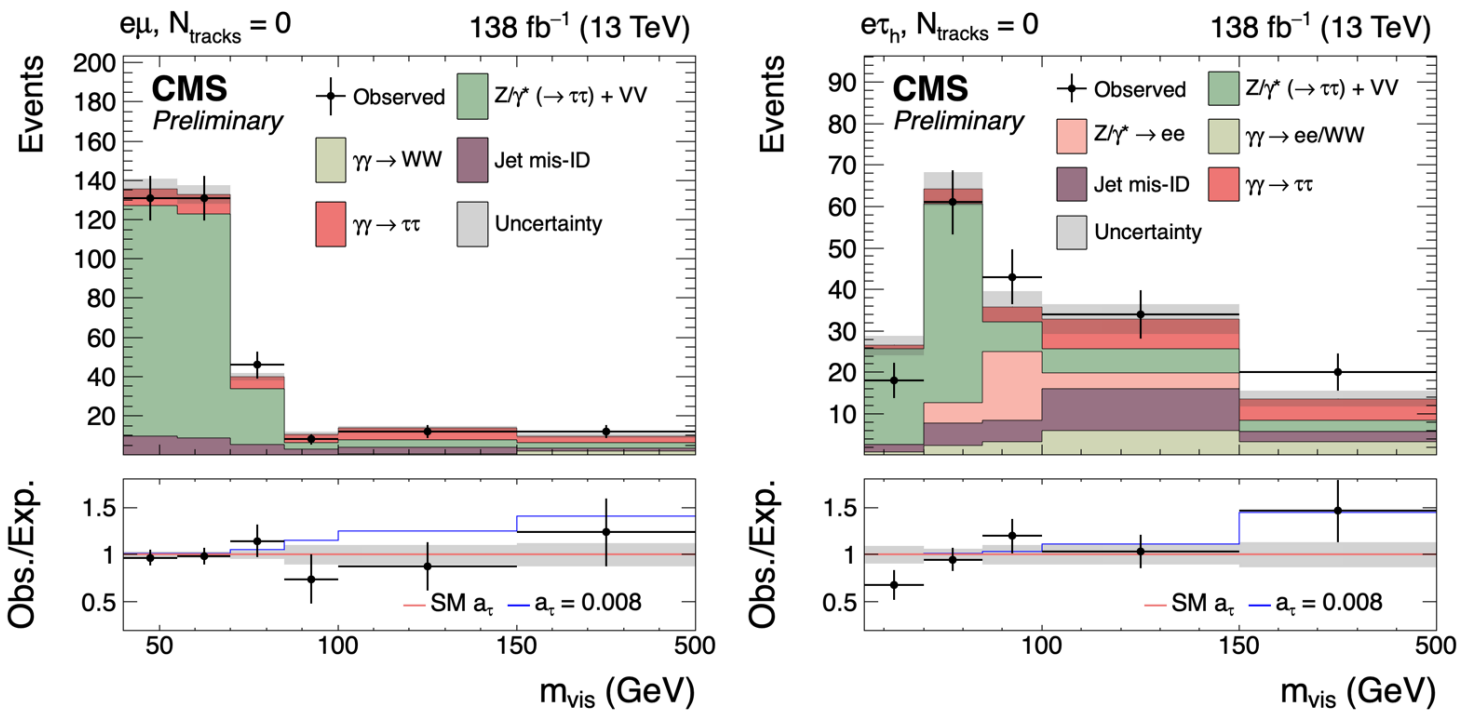
$$\delta a_\tau = \frac{2m_\tau}{e}\frac{\sqrt{2}v}{\Lambda^2}\,\mathrm{Re}\left[C_{\tau\gamma}\right] \qquad \delta d_\tau = \frac{\sqrt{2}v}{\Lambda^2}\,\mathrm{Im}\left[C_{\tau\gamma}\right]$$

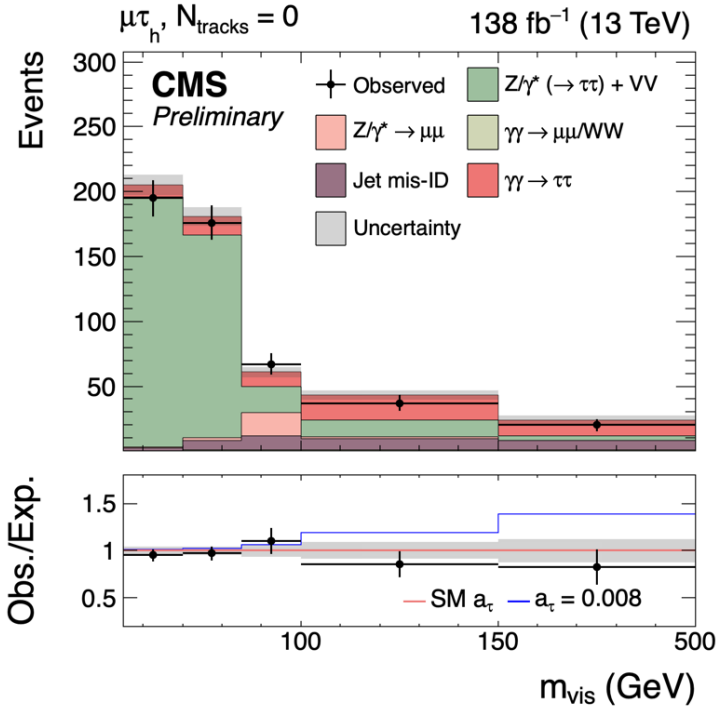
- where $C_{\tau\gamma} = \left(cos\theta_W C_{\tau B} - \sin\theta_W C_{\tau W}\right)$

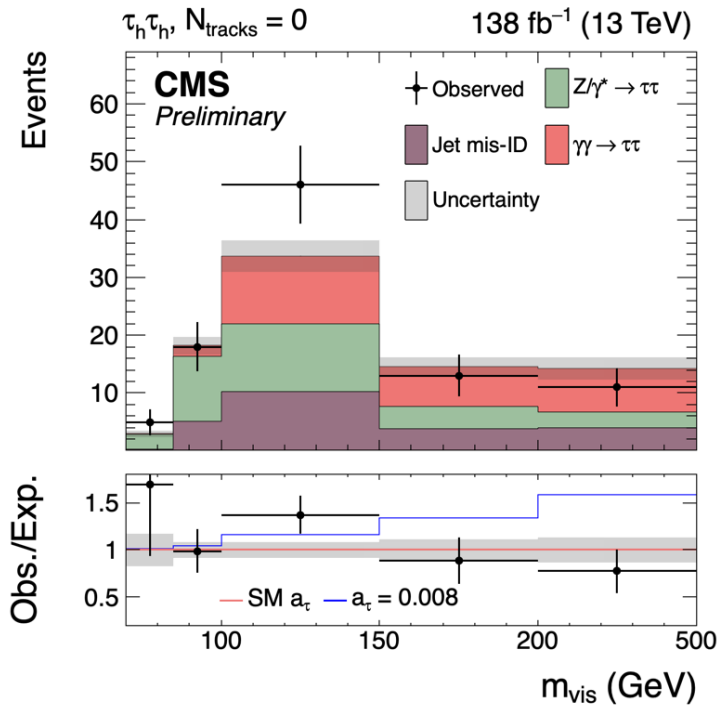
- Matrix element reweighting to model signal for BSM values of a_τ and d_τ, setting $C_{\tau W}$ to 0 and scanning over $C_{\tau B}$ without loss of generality



Signal regions with $N_{tracks} = 0$







- m_{vis} distributions in the different final states after the maximum likelihood fit, assuming SM a_τ and d_τ
- **Signal visible in high m_{vis} bins**
- Effects of BSM a_τ increase with m_{vis}

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CMS-PAS-SMP-23-005

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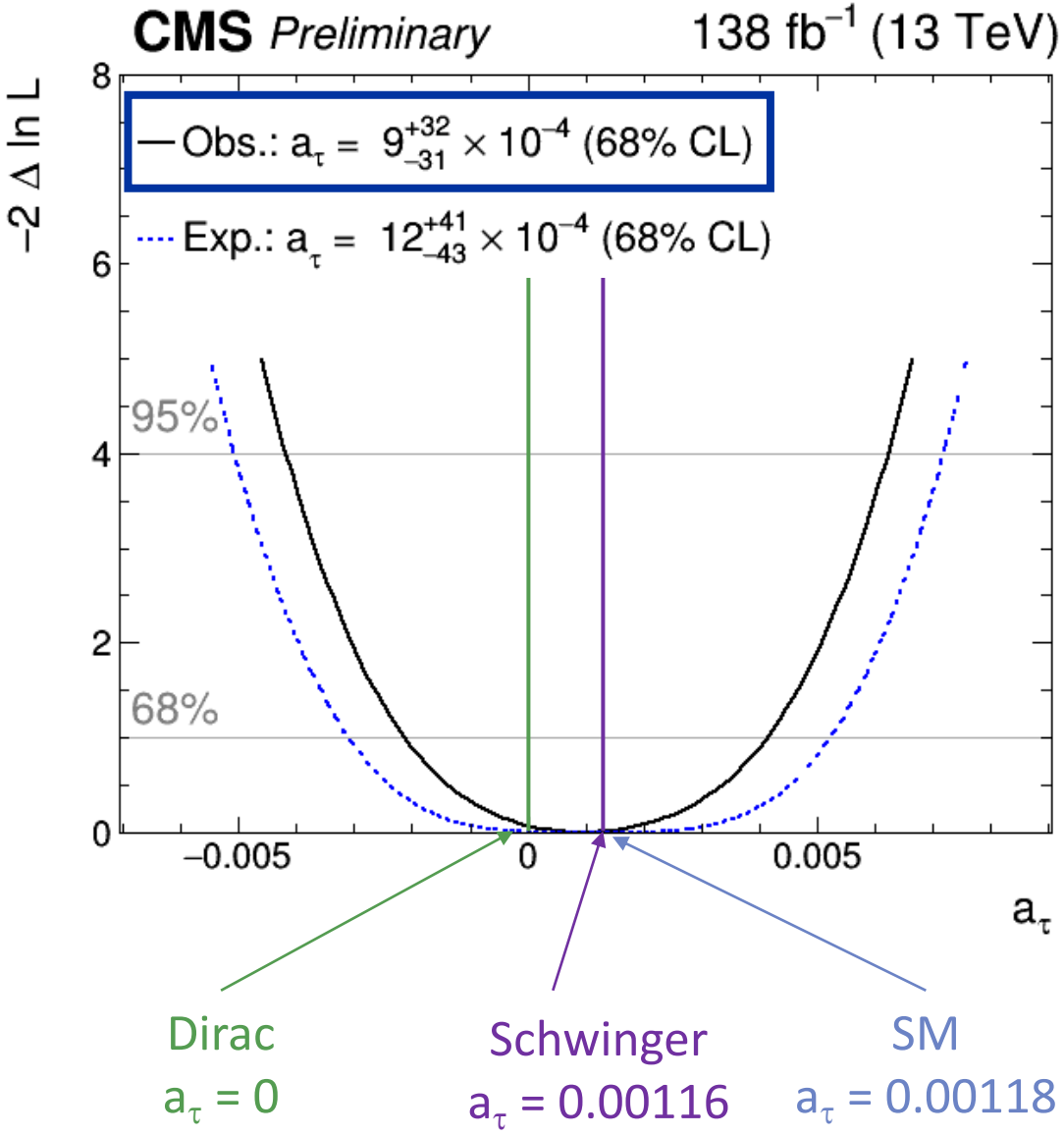
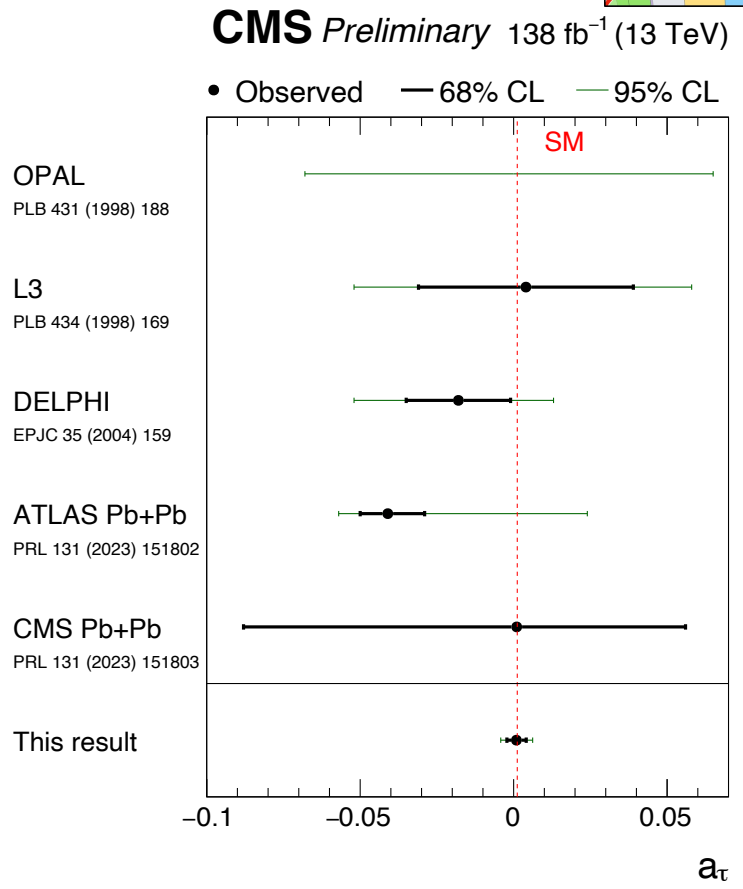
CMS-PAS-SMP-23-005

Extracting a_τ



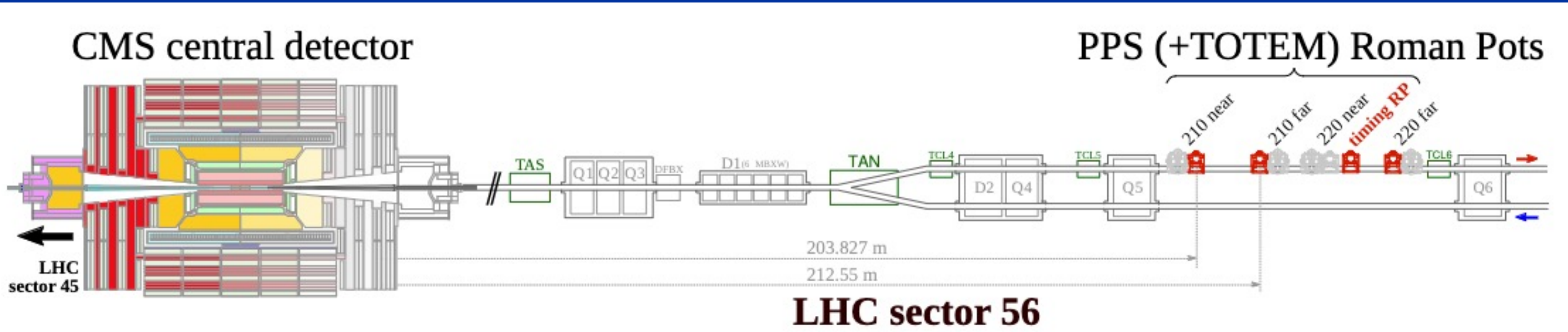
- Using m_{vis} distributions in the SR, perform negative log likelihood scan over δa_τ, which modifies the signal shape and normalization

$a_\tau = \delta a_\tau + \text{SM } a_\tau$



1σ uncertainty of 0.003

Only 3 times the Schwinger term!



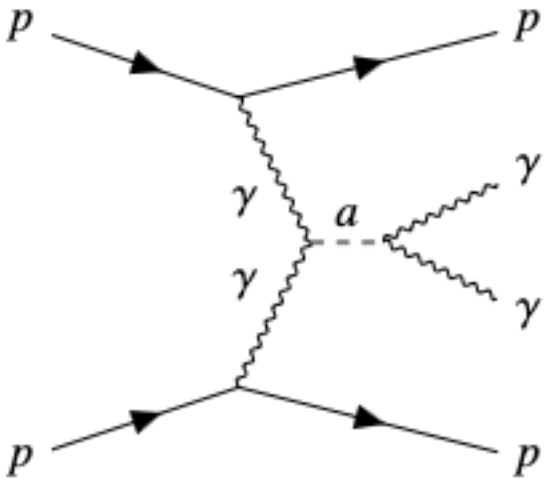
The high-energy regime

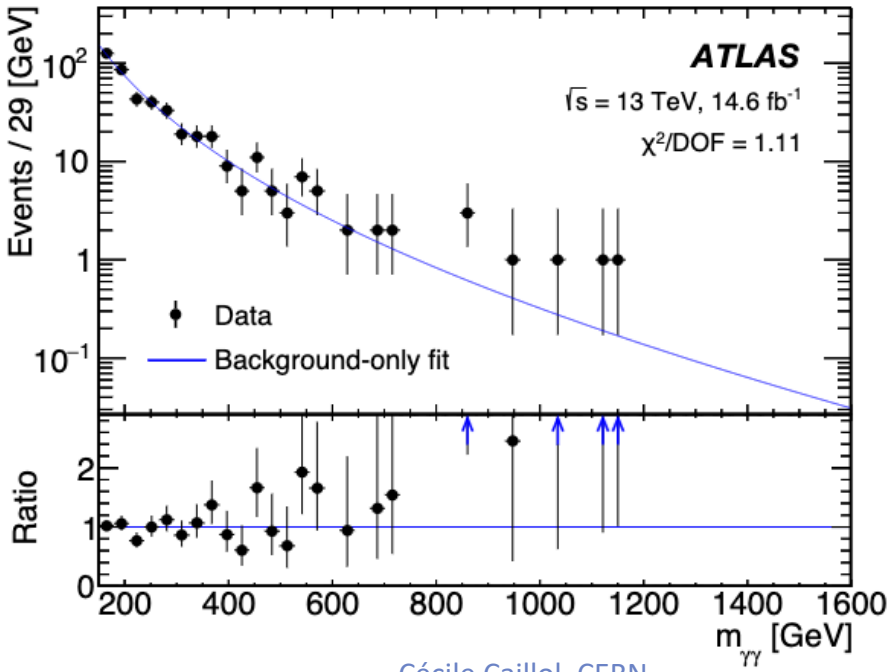
pp collisions with proton tagging with dedicated spectrometers

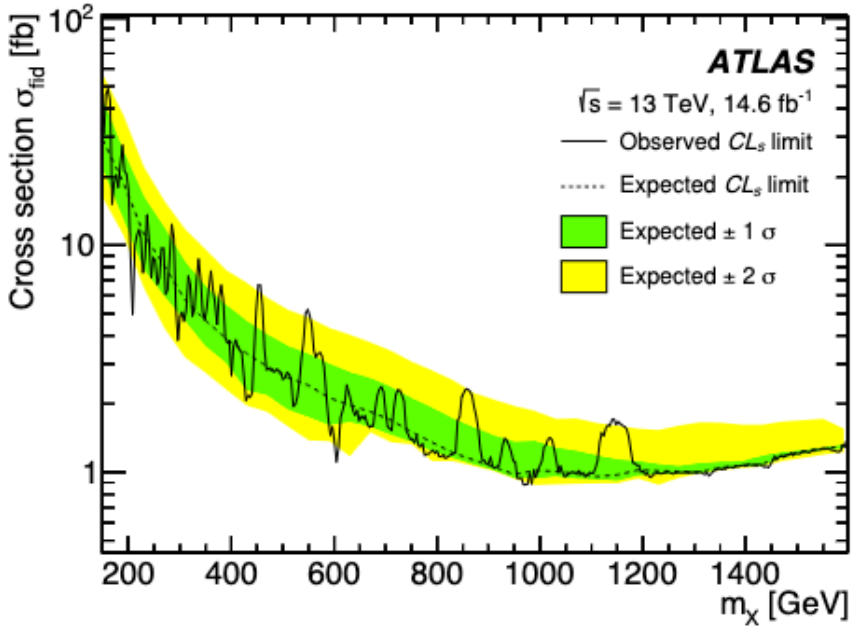
ALP in diphoton final state

JHEP 07 (2023) 234
arXiv:2304.10953

- Forward proton scattering in association with light-by-light scattering mediated by ALP
- Diphoton events selected if kinematic matching with a proton in at least one side of AFP
- Unbinned maximum likelihood fit, no significant excess (largest local significance = 2.5σ)





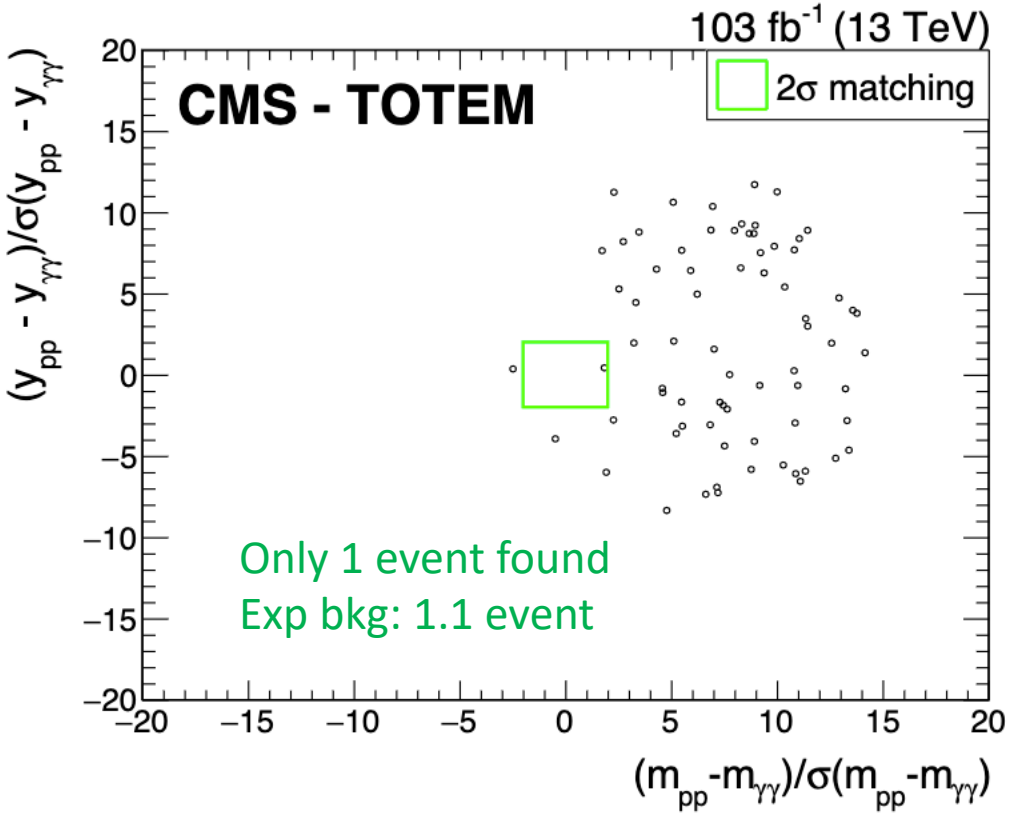


Submitted to PRD
arXiv:2311.02725

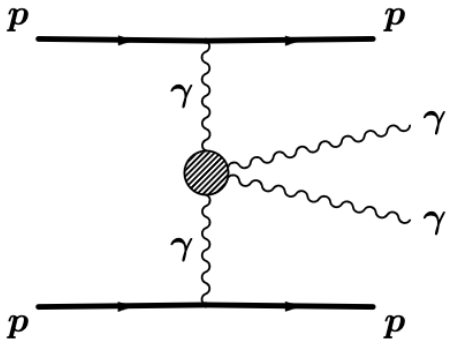
Exclusive diphoton at high mass

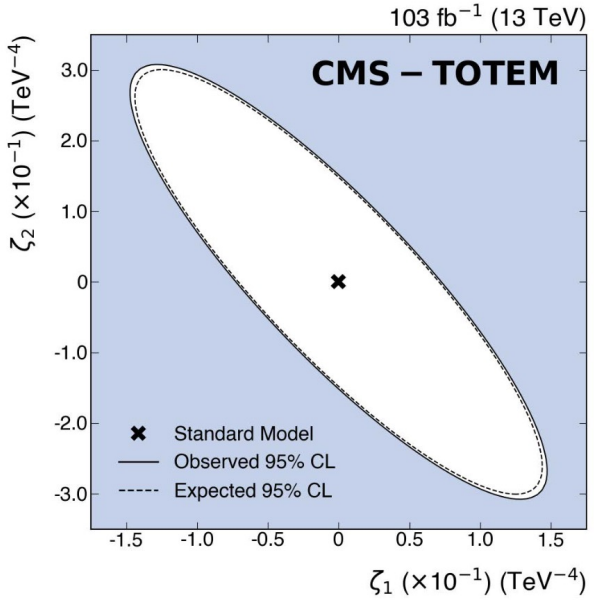
- Matching the mass and rapidity of pp and $\gamma\gamma$ systems within 2 standard deviations:

$$-2 < \left(m_{pp} - m_{\gamma\gamma}\right) / \delta\left(m_{pp} - m_{\gamma\gamma}\right) < 2$$
$$-2 < \left(y_{pp} - y_{\gamma\gamma}\right) / \delta\left(y_{pp} - y_{\gamma\gamma}\right) < 2$$



- Constraints on aQGC coupling parameters from high mass exclusive diphoton production





- Also interpreted as constraints on ALPs with mass between 0.5 and 2 TeV – no significant excess

Conclusion

- **The LHC is also a high-energy photon collider**
- Both SM measurements and BSM searches can be performed in different energy regimes
- Only a small fraction of results shown in these slides

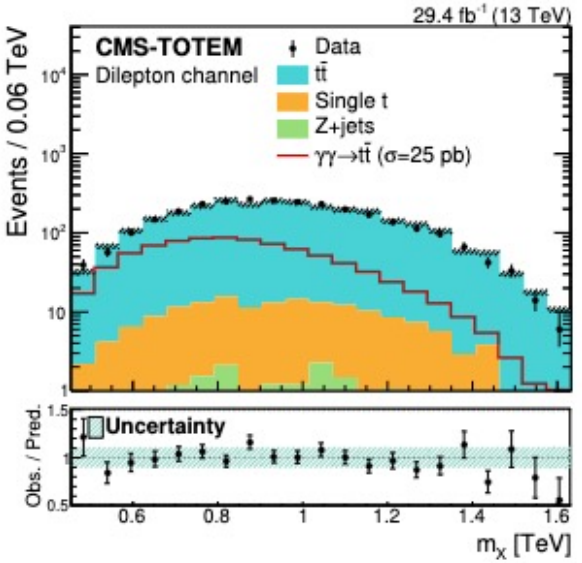
- **$\gamma\gamma \rightarrow \tau\tau$ observed for the first time in proton-proton ultraperipheral collisions at CMS**
- **Used to set limits on anomalous magnetic moment of the τ lepton ~5 times better than at LEP**
- Beginning of a precision chapter in measuring the τ g-2 at the LHC

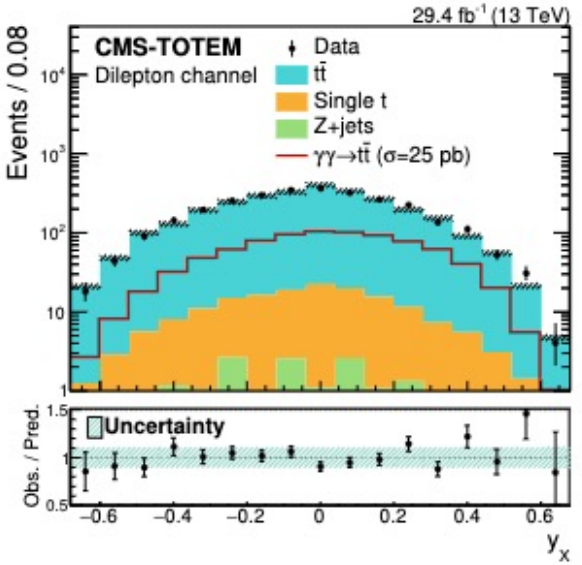
Backup

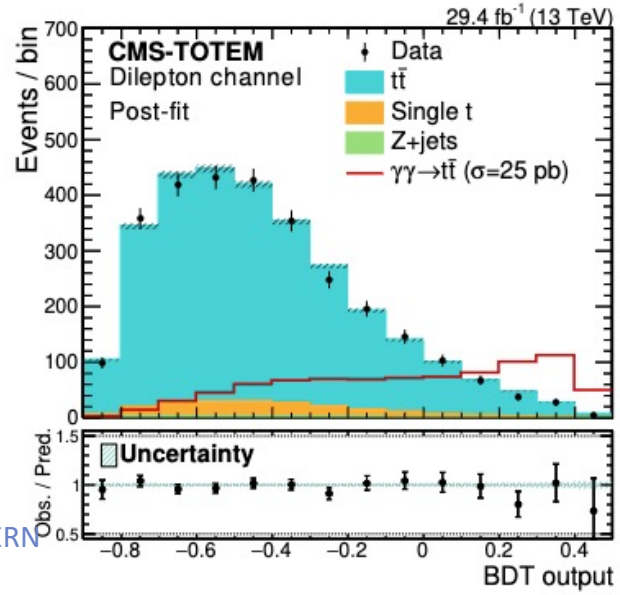
γγ→ttbar

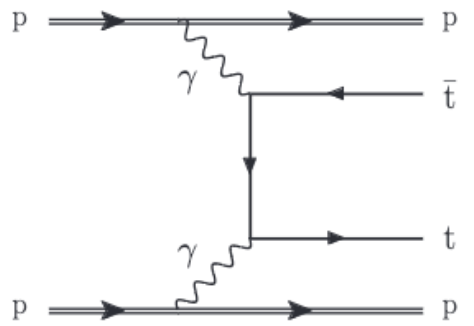
Submitted to JHEP
arXiv:2310.11231

- Dilepton and l+jets final states
- 2 diffracted protons reconstructed in PPS → used to estimate mass and rapidity of central system
- Results extracted from fit to BDT output
- Limits set on fiducial cross section
- ~4 orders of magnitude away from SM sensitivity

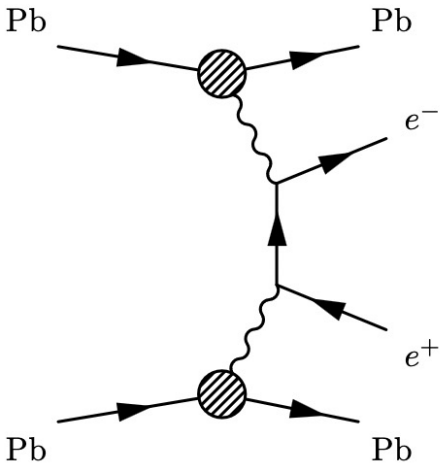






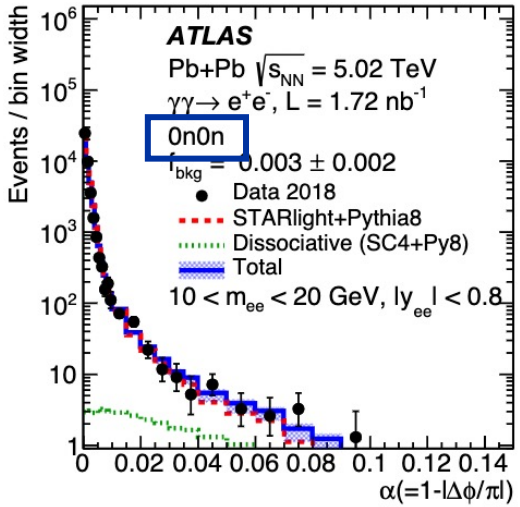


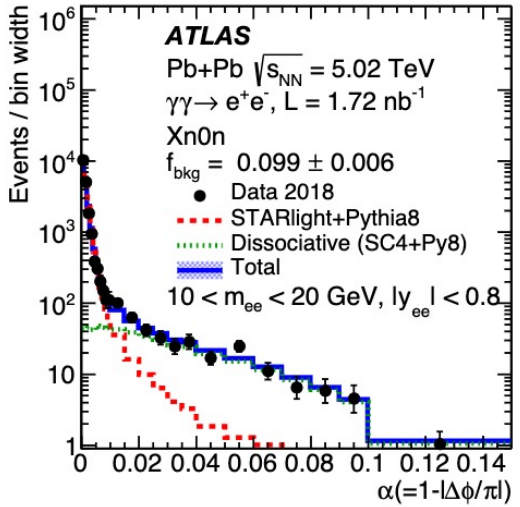
γγ→ee



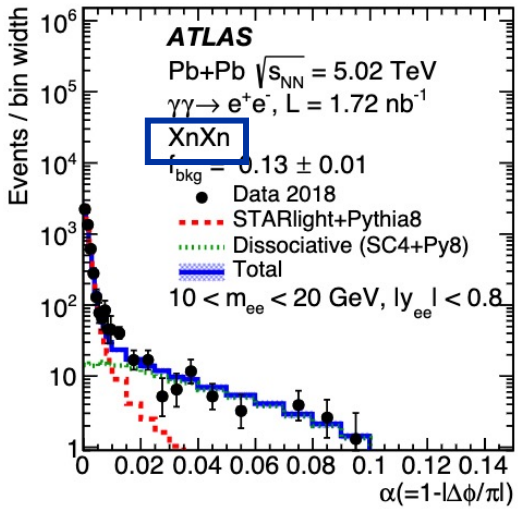
JHEP 06 (2023) 182
arXiv:2207.12781

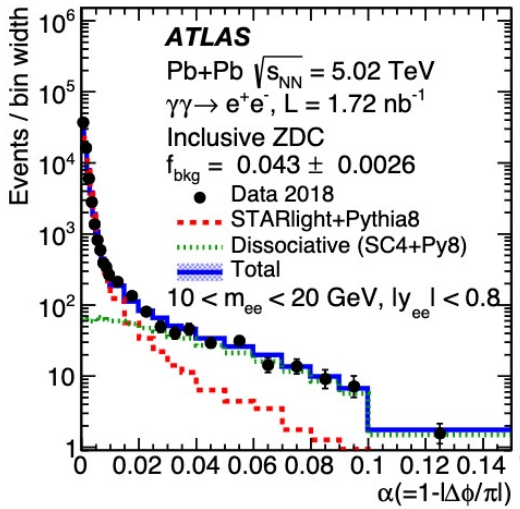
No neutron in both ZDCs





Neutrons in both ZDCs





- Ultraperipheral PbPb collisions to study γγ→ee production
- Zero Degree Calorimeter (ZDC) used to count neutrons to make categories, with different acoplanarity tails
- Measured fiducial cross section:
  $215 \pm 1(\text{stat.})^{+23}-20(\text{syst.}) \pm 4(\text{lumi.})\mu\text{b}$
- Generally good agreement with QED predictions from Starlight and SuperChic
- Discrepancies grow with $|y_{ee}|$
- Similar studies with γγ → μμ