Observation of $\gamma\gamma \to \tau\tau$ in pp collisions with CMS and constraints on τ electromagnetic moments

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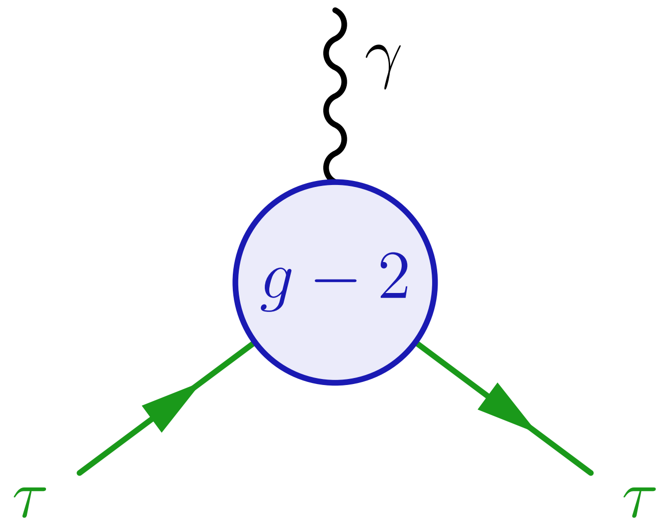
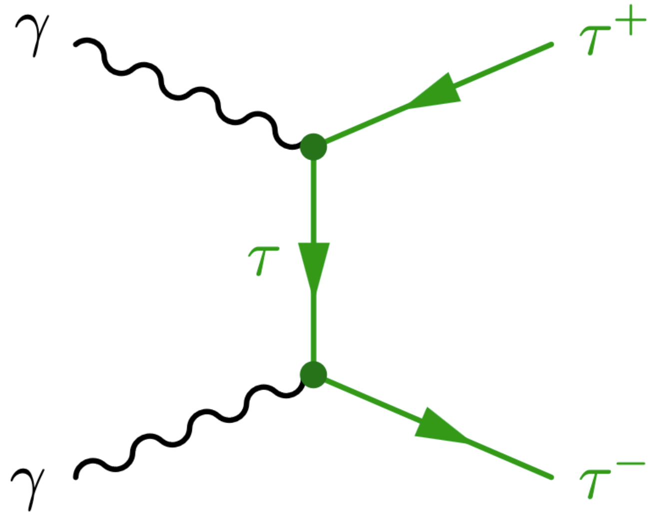
τ electromagnetic moments from $\gamma\gamma \rightarrow \tau\tau$ events

- τ g-2 (a_τ) and electric dipole moment (EDM, d_τ) can be probed from $\gamma\tau\tau$ vertex



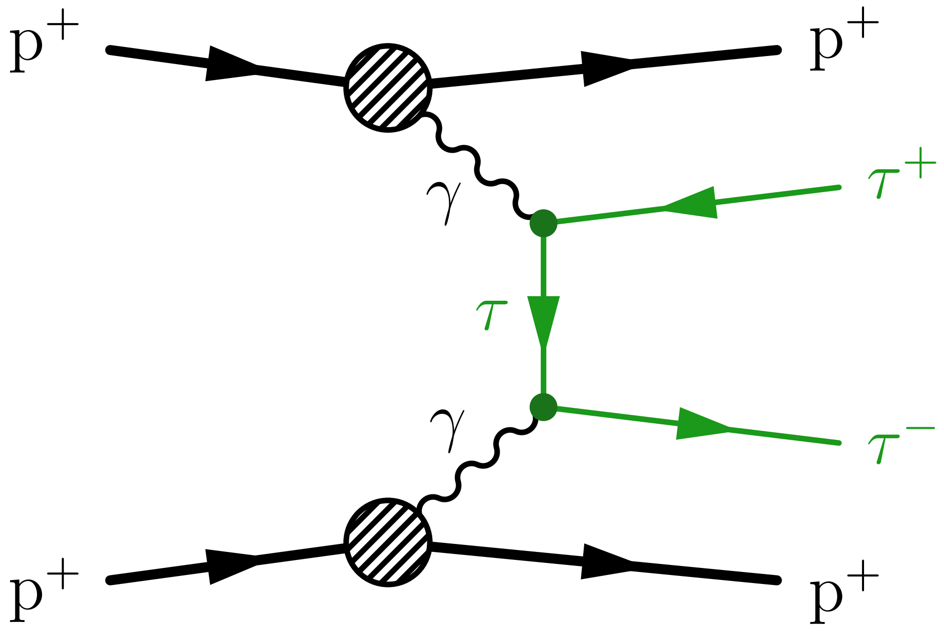
- The $\gamma\gamma \rightarrow \tau\tau$ process includes 2 $\gamma\tau\tau$ vertices



- Constraints on τ electromagnetic moments from form factor formalism or SMEFT approach
- In the SM, d_τ is extremely small (no appreciable CP violation) but it could be increased in BSM models

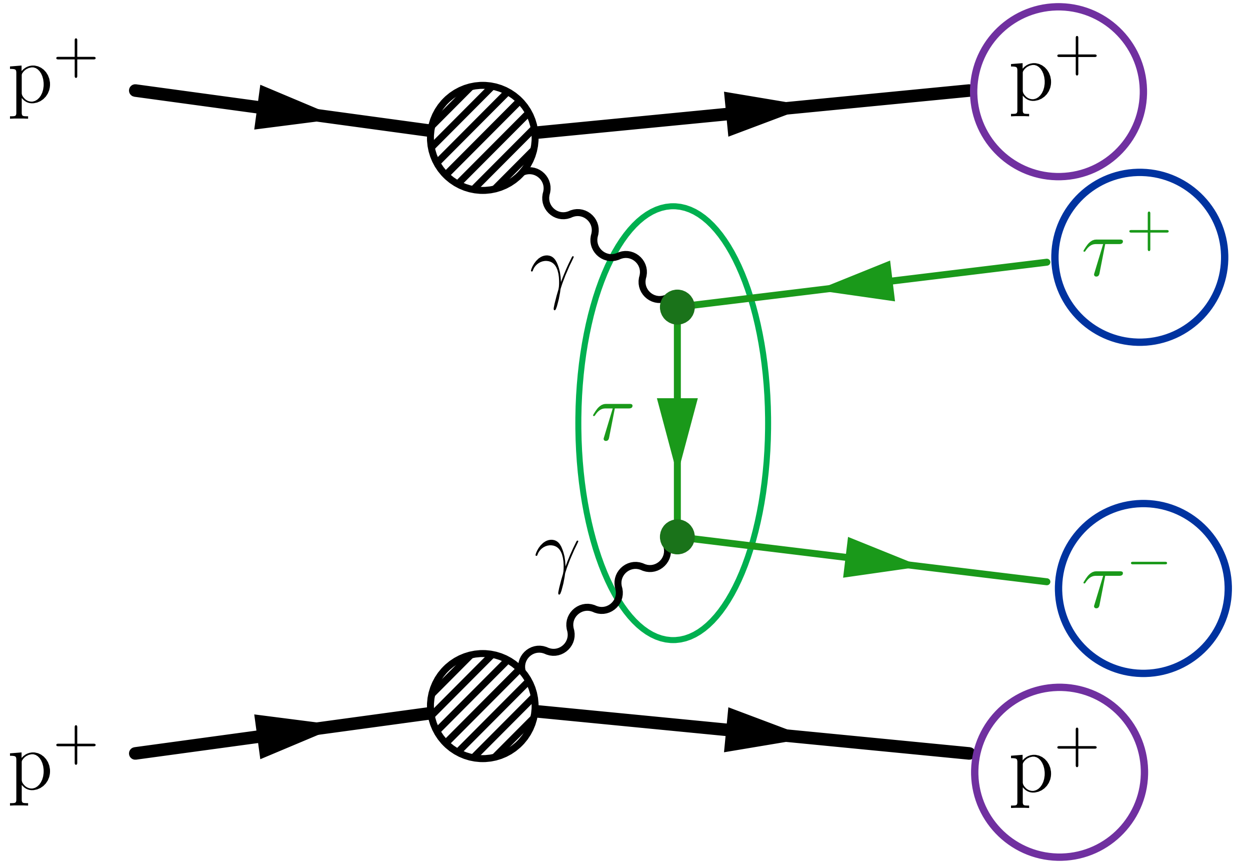
Can we see $\gamma\gamma \rightarrow \tau\tau$ in ultraperipheral pp collisions?

- **Much larger integrated luminosity ($\mathcal{O}(10^8)$)**
- But:
  - No gain from Z^4 enhancement
  - Low signal acceptance (soft signal)
  - Large backgrounds
  - High pileup



- If we can see $\gamma\gamma \rightarrow \tau\tau$ in pp runs, tight constraints on τ g-2 could be set because **a_τ modifications from BSM physics are enhanced at large τ p_T and ditau mass**

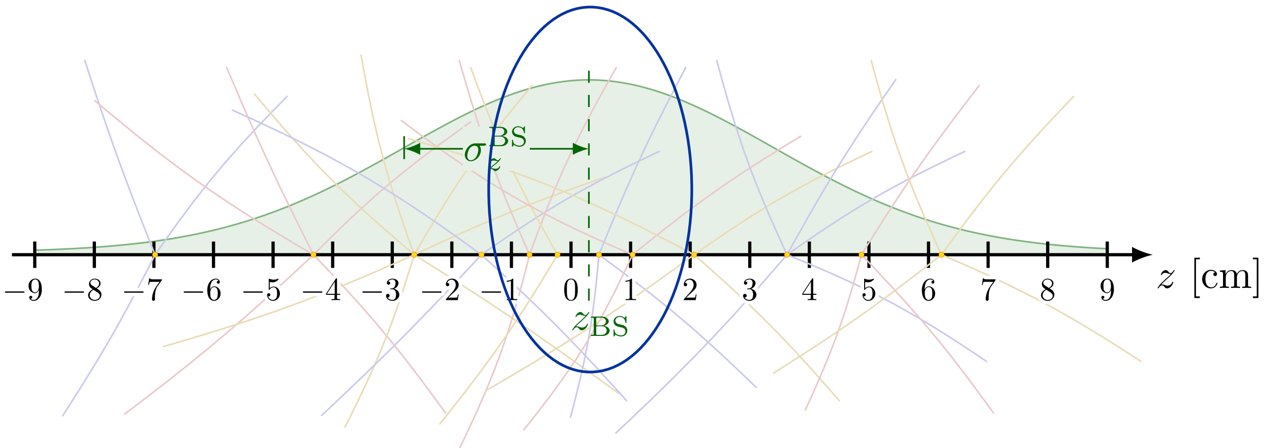
Signature



- 2 diffracted protons: not reconstructed
- 2 back-to-back OS τ leptons: acoplanarity < 0.015
- No hadronic activity close to the di-τ vertex: $N_{tracks} = 0$

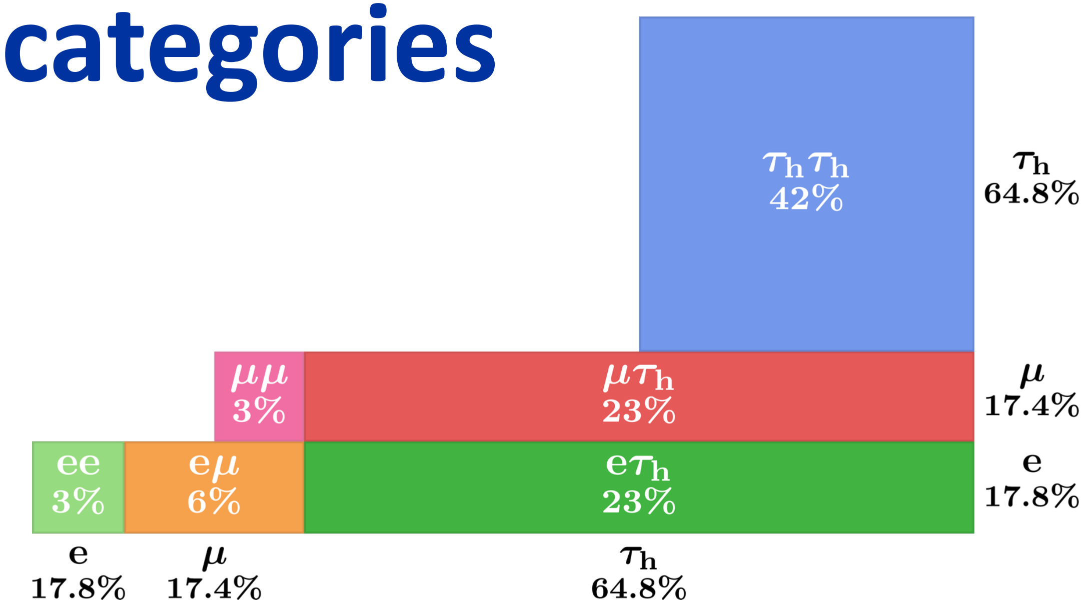
Counting tracks

- Define **z position of di-tau vertex** as average z position of selected tau leptons
- Define $\mathbf{N_{tracks}}$ as the number of tracks
  - with $p_T > 0.5$ GeV and $|\eta| < 2.5$
  - within a window of **0.1 cm** around the di-tau vertex
  - Excluding tracks from tau leptons



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

Final states and categories



- 4 di-tau final states: $e\mu$, $e\tau_h$, $\mu\tau_h$, $\tau_h\tau_h$
- In each di-tau final state, 2 signal regions: N_{tracks} = 0 or 1
  - **N_{tracks} = 0**: ~50% of the signal, inclusive backgrounds reduced by $O(10^3)$
  - **N_{tracks} = 1**: ~25% of the signal, larger background
- Dimuon control region to derive corrections to the simulations

Strategy

- In each of the 8 categories ($e\mu$, $e\tau_h$, $\mu\tau_h$, $\tau_h\tau_h$) x (N_{tracks} =0, N_{tracks} =1), fit visible invariant mass of tau pair (m_{vis})
  - SM $\gamma\gamma \rightarrow \tau\tau$ measurement: S/B ratio increases with m_{vis} because Drell-Yan background concentrated at lower masses
  - BSM a_τ and d_τ measurements: deviations from SM predictions increase with the mass

Drell-Yan $Z/\gamma^* \rightarrow \tau\tau/ee/\mu\mu$
Resonant
From simulation

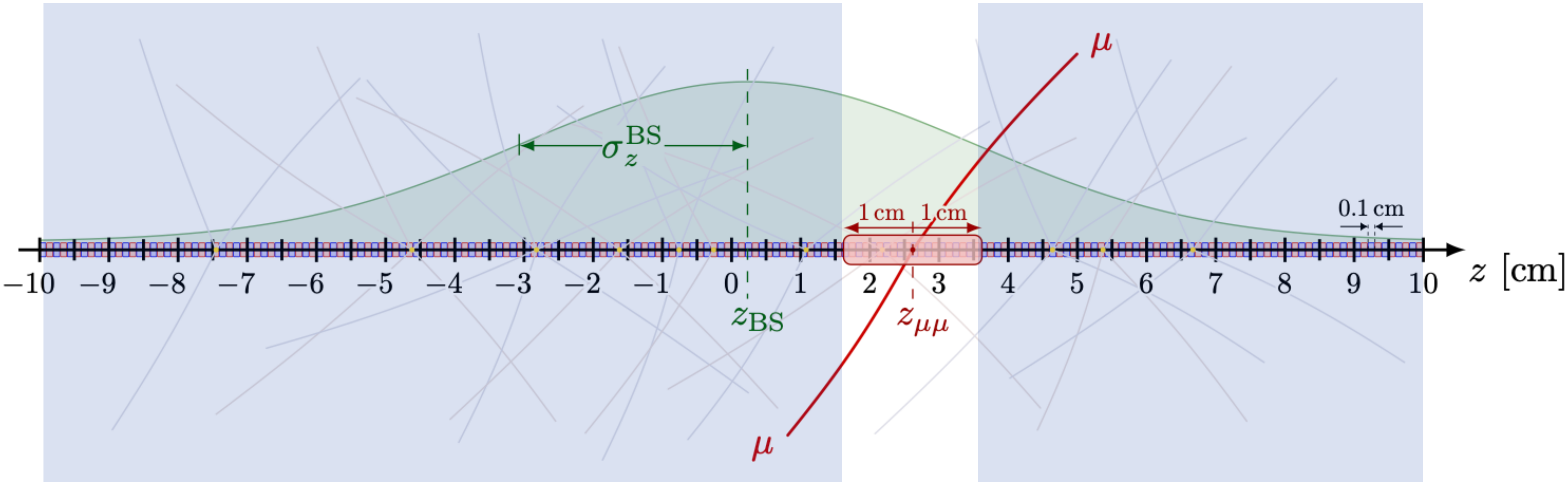
Jet $\rightarrow e/\mu/\tau_h$ mis-ID
Non-resonant
From data

Exclusive $\gamma\gamma \rightarrow ee/\mu\mu/WW$
Small but at low N_{tracks}
From elastic simulation

$\gamma\gamma \rightarrow \tau\tau$
Signal, non resonant
From elastic simulation

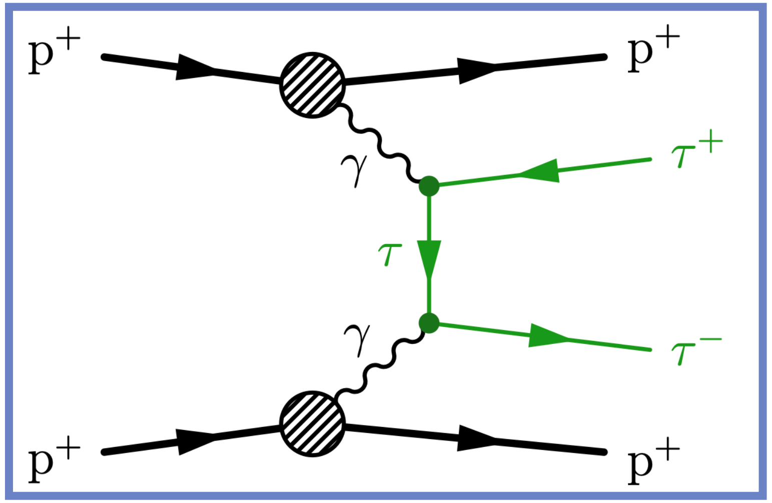
Corrections from $Z \rightarrow \mu\mu$ CR:
1. Acoplanarity
2. N_{tracks} from pileup
3. N_{tracks} from hard interaction
4. Dissociative contributions

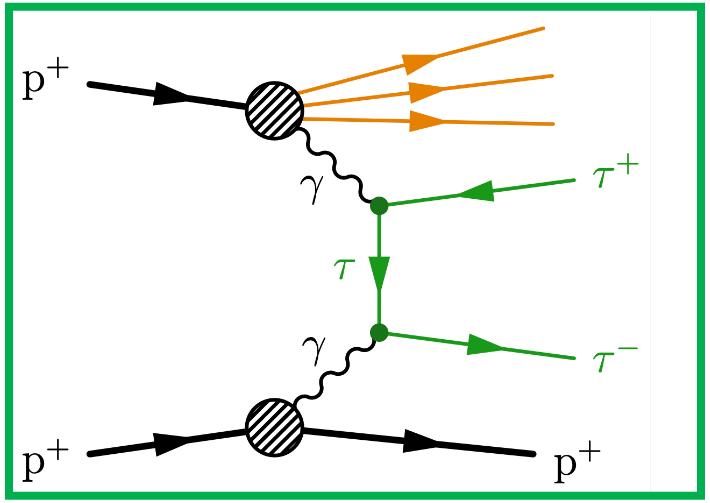
Track multiplicity correction from μμ region

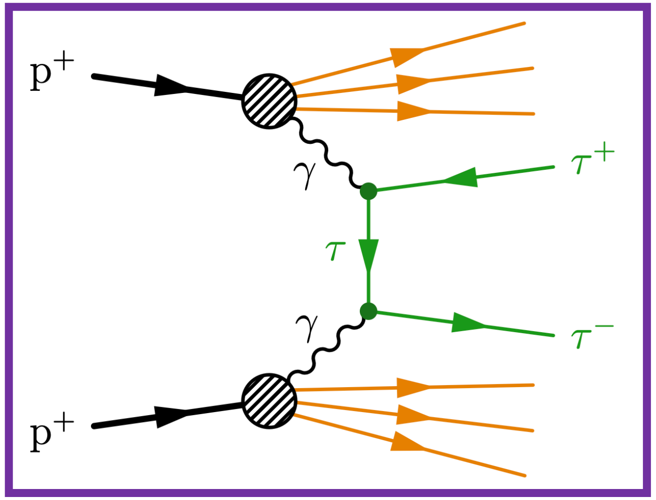


- Compare N_{tracks} distribution in Z→μμ data and Z→μμ MC, inside windows sampled over the z axis
- Away from the μμ vertex: correct pileup track multiplicity
- Close to the μμ vertex: correct hard scattering track multiplicity

Including (semi-)dissociative contributions







- **Elastic-elastic (ee)** signal process modeled with gammaUPC
- **Single-dissociative (sd)** and **double-dissociative (dd)** processes have larger cross section and may end up with an exclusive signature → rescale elastic signal to include these contributions
- Scaling factor = $(\mathbf{ee} + \mathbf{sd} + \mathbf{dd})_{obs}$ / $\mathbf{ee}_{\mathrm{sim}}$ can be measured with $\gamma\gamma \rightarrow \mu\mu$ in the $\mu\mu$ CR and applied to $\gamma\gamma \rightarrow ee/\mu\mu/\tau\tau/WW$ in the signal region

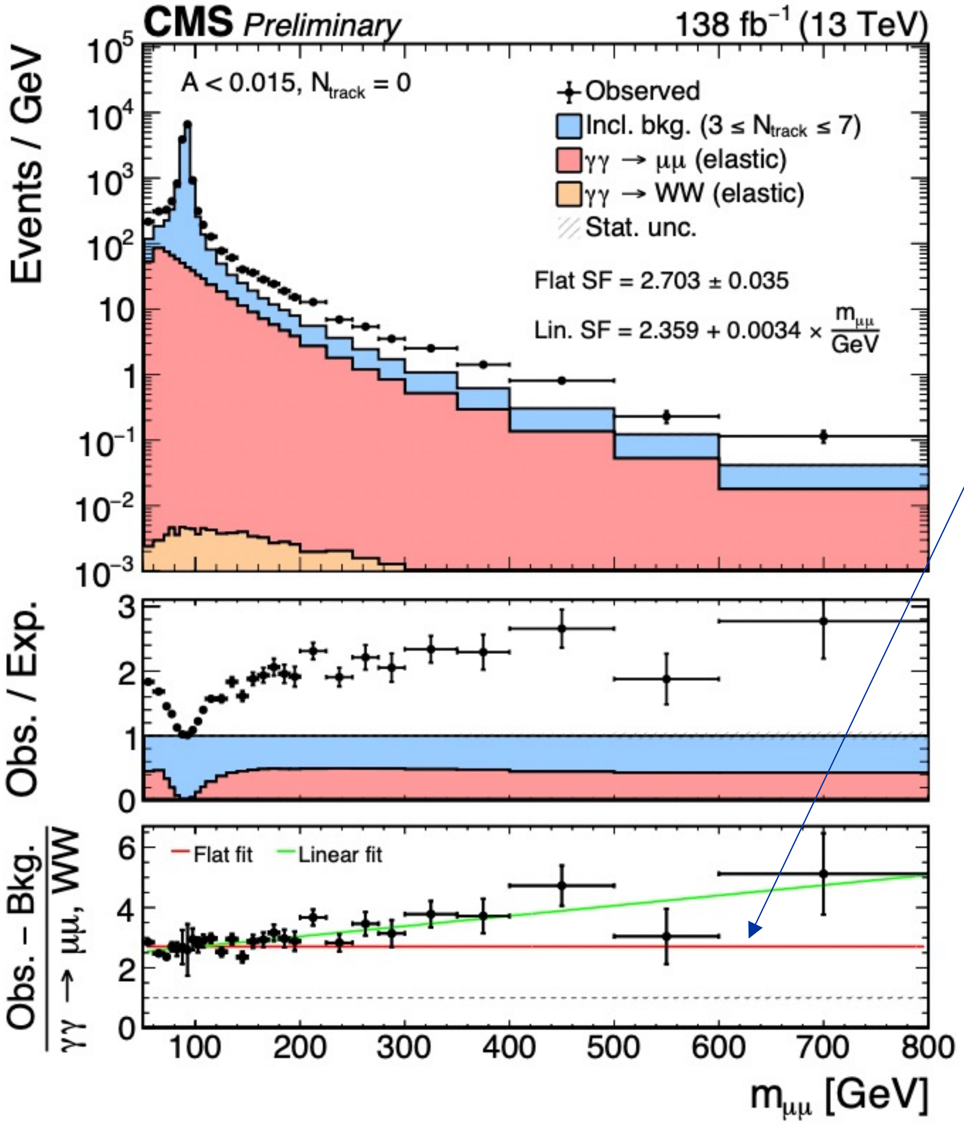
Applied to all photon-induced processes

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 $\gamma\gamma \rightarrow \mu\mu/WW$:**
  - Estimated from gammaUPC
  - Rescaled with linear $m_{\mu\mu}$ function to match data



Elastic simulation should be scaled by ~2.7 to describe all photon-induced contributions

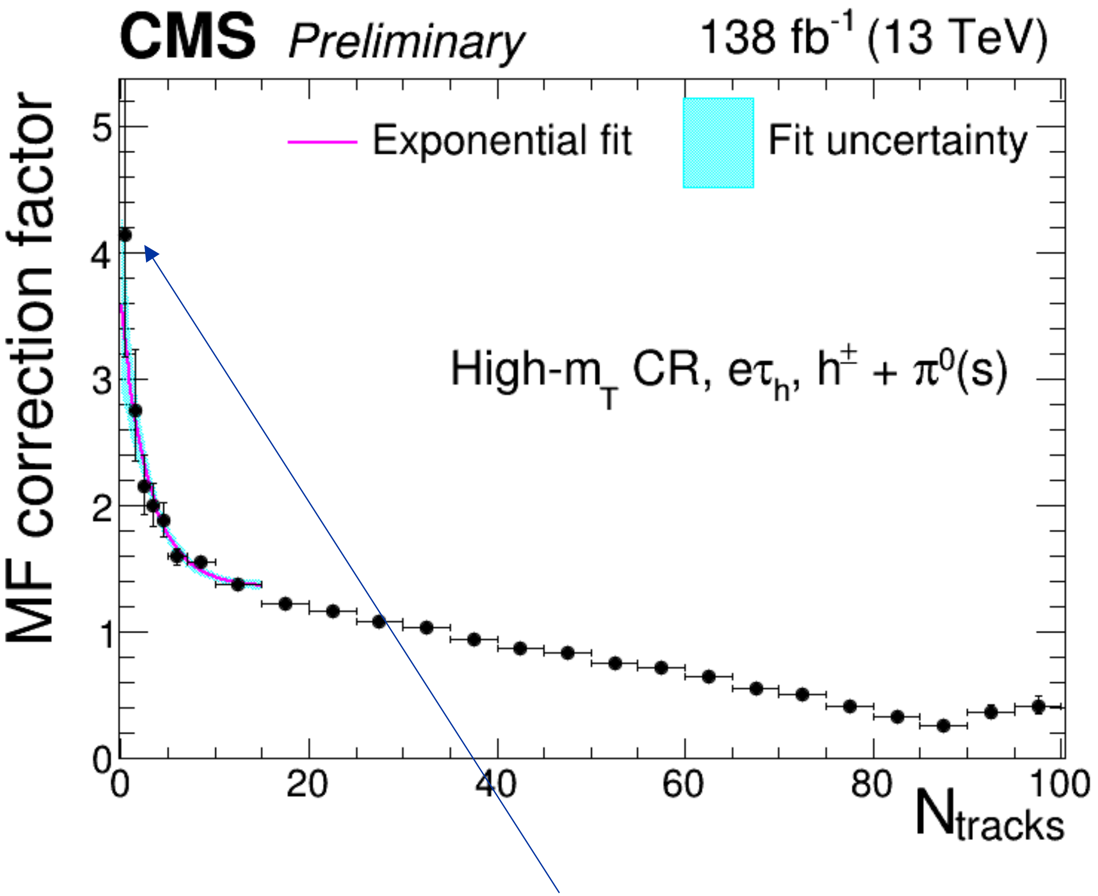
Compatible with SuperChic predictions

Jet→τ_h mis-ID background

- Measure "mis-ID factor", MF, for jets as

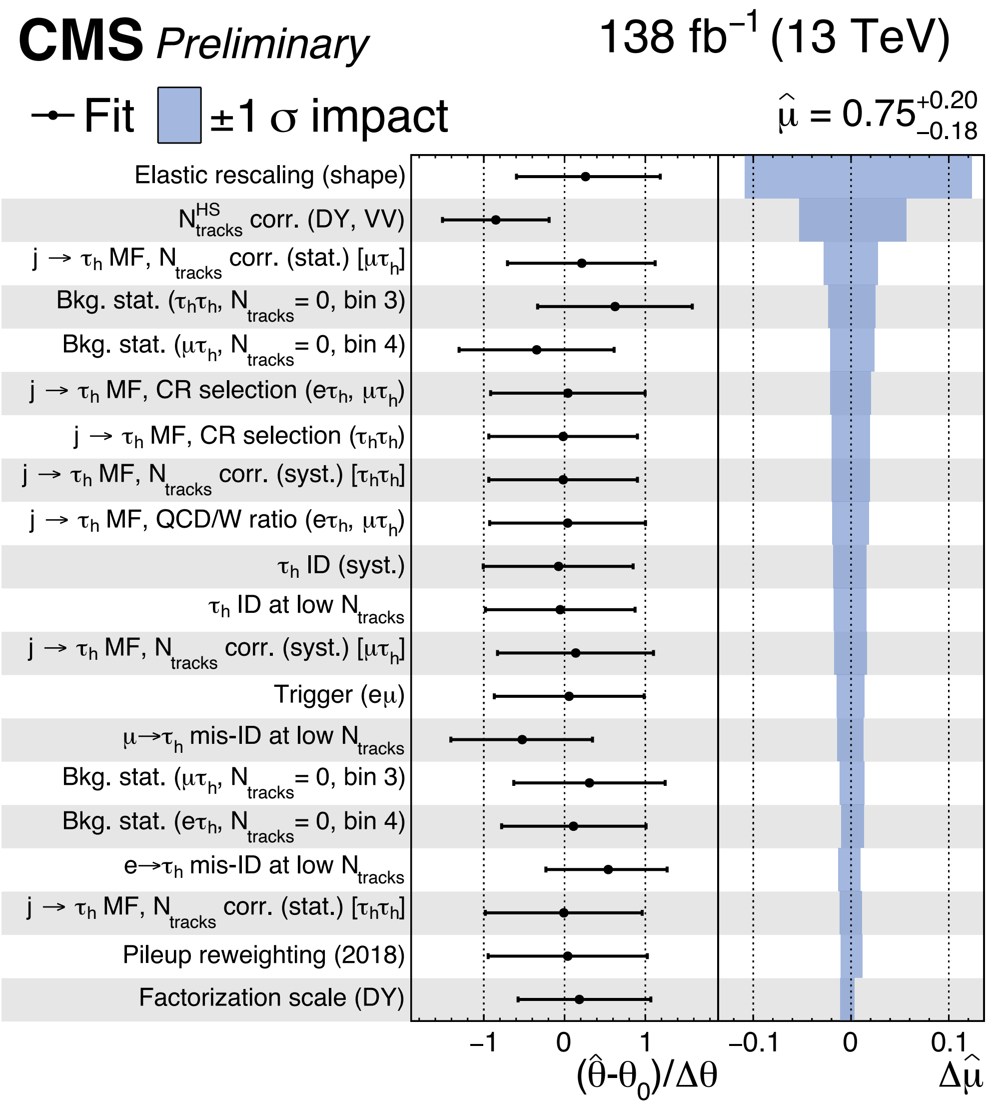
$$MF = \frac{N(\text{jets passing nominal } \tau_h \text{ ID})}{N(\text{jets failing nominal } \tau_h \text{ ID but passing very loose } \tau_h \text{ ID})}$$

- If there is less track activity around the τ_h candidate:
  - The τ_h candidate is more isolated
  - It is more likely to pass the ID criteria
  - MF is higher
- Model N_{tracks} dependence with a multiplicative correction to the mis-ID rates
  - Parameterized with exponential at low N_{tracks}

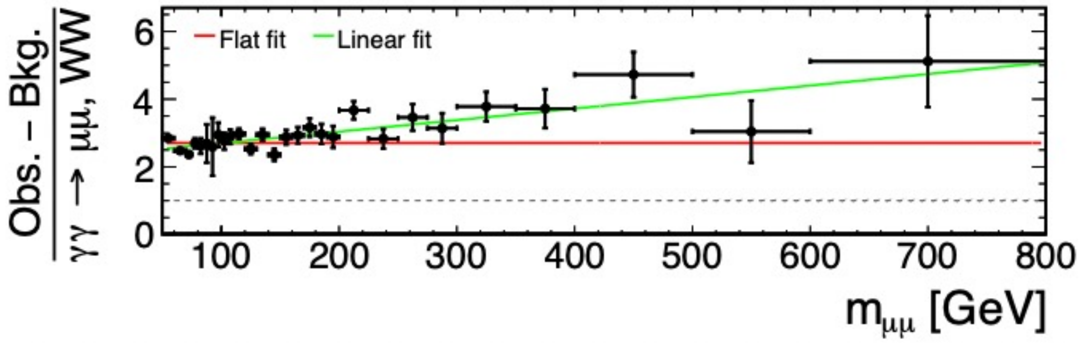


The jet is 4 times more likely to pass the nominal τ_h ID criteria if there is no other track at the vertex

Leading systematics



Considering the constant rescaling for the elastic simulations instead of the $m_{\mu\mu}$-dependent one

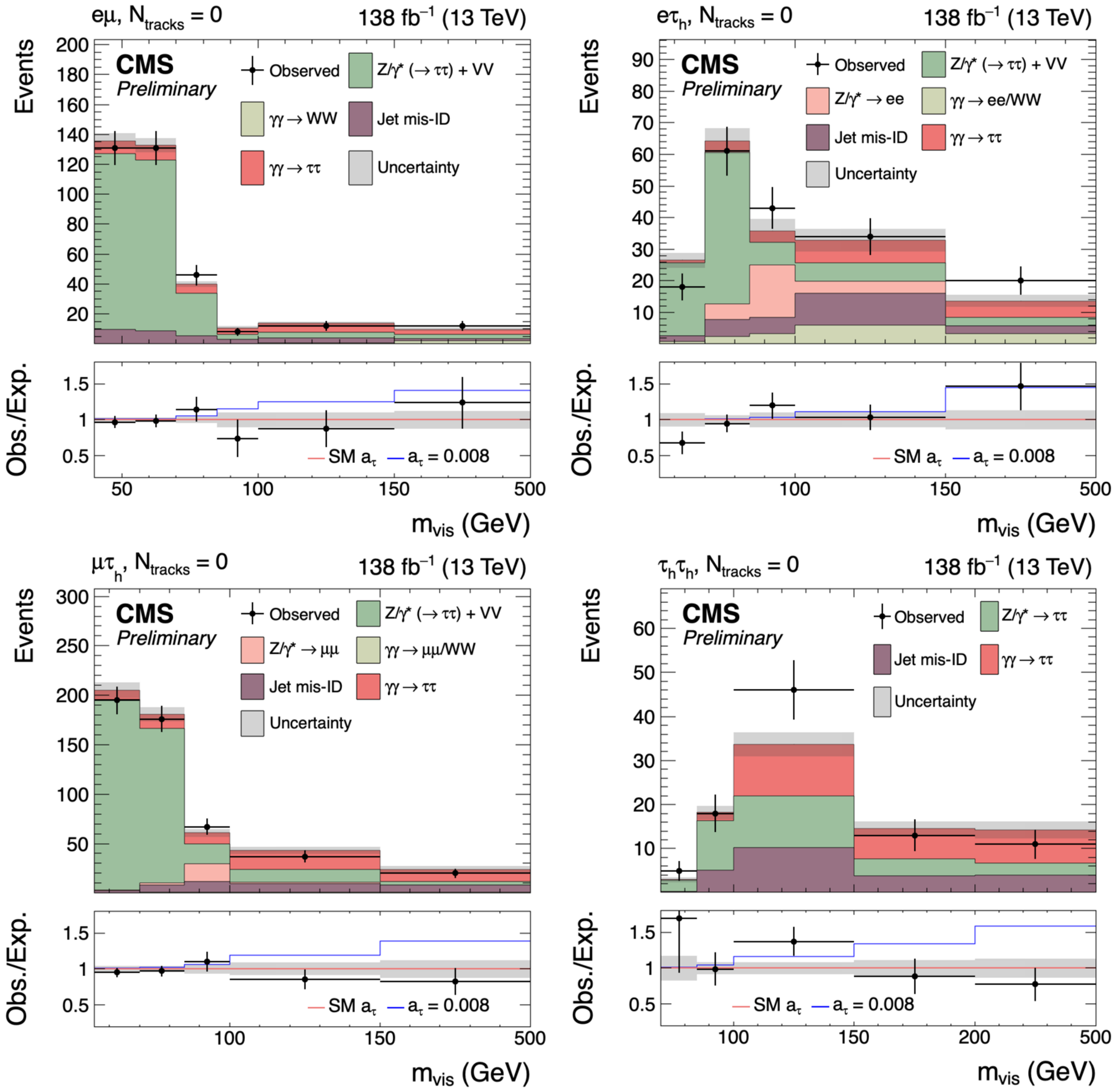


UE/HS track multiplicity correction to Drell-Yan (6.5% uncertainty for N_{tracks} = 0)

N_{tracks} extrapolation of the jet→τ_h MF to estimate jet mis-ID background (up to ~20%)

Real and fake τ_h identification (at low N_{tracks})

N_{tracks} = 0

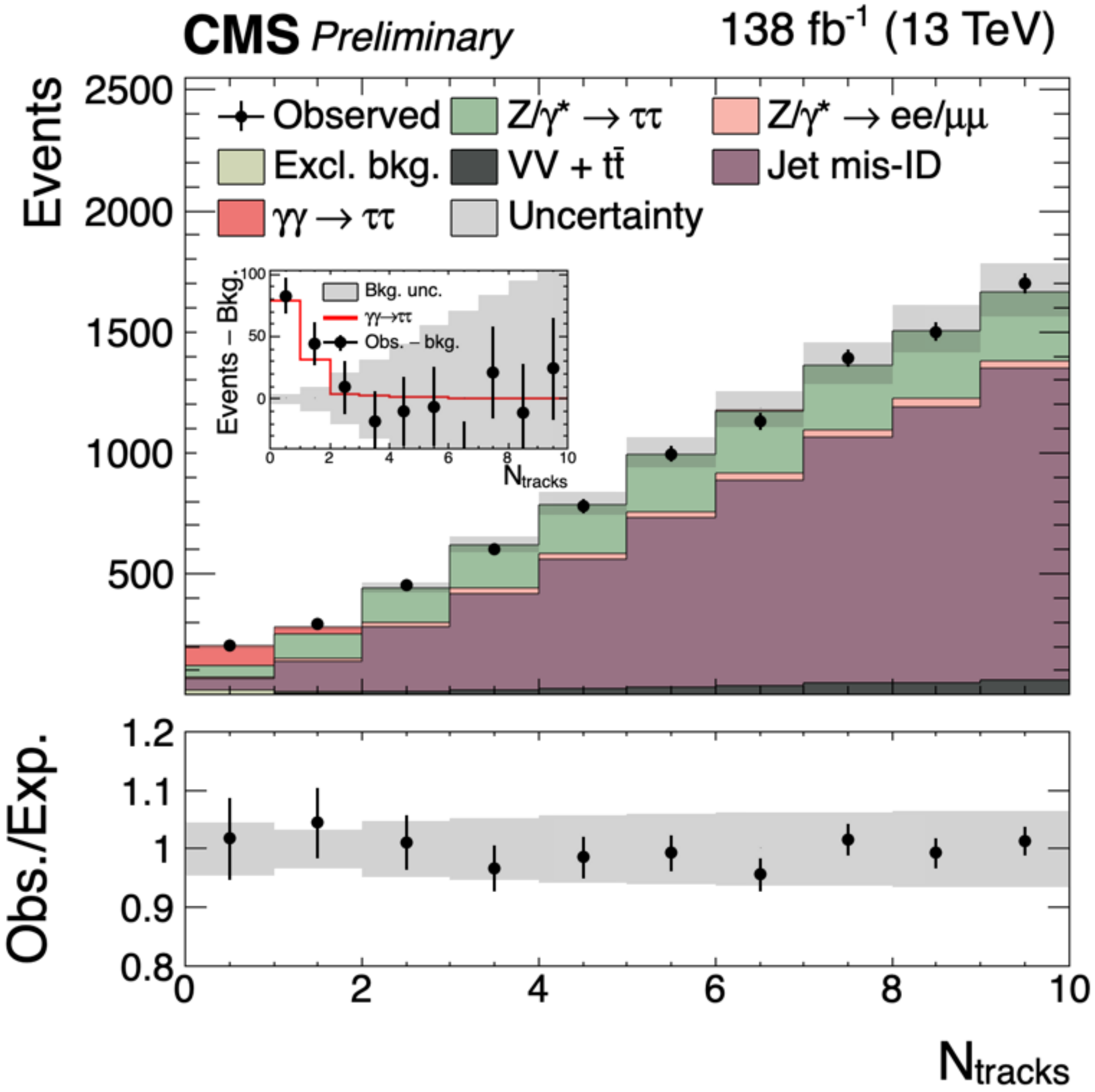


- m_{vis} distributions in the different final states after the maximum likelihood fit, assuming SM a_τ and d_τ

- **Signal visible in high m_{vis} bins**

Observation of γγ→ττ

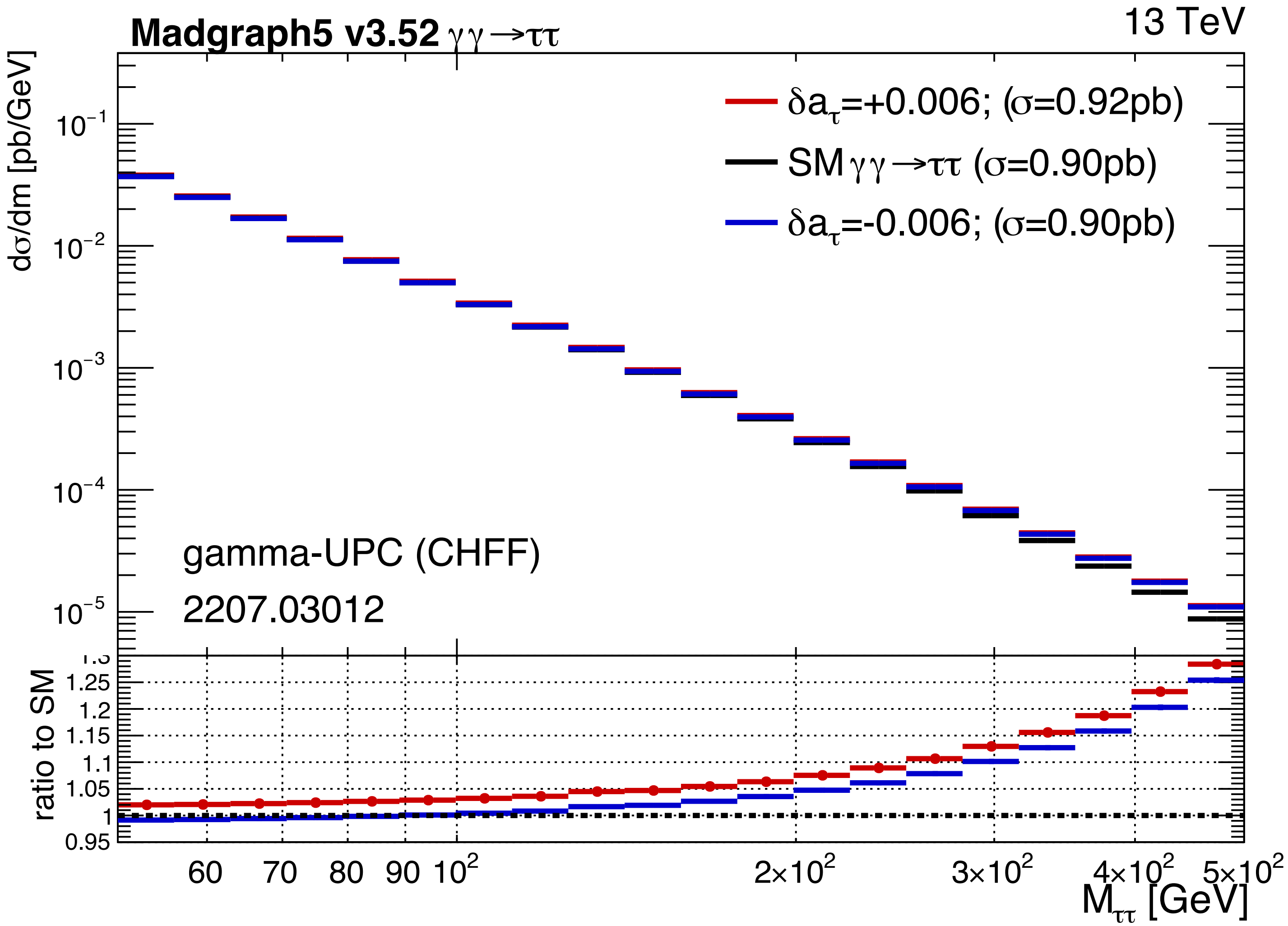
- 5.3 σ observed, 6.5 σ expected
- First observation of γγ→ττ in pp runs



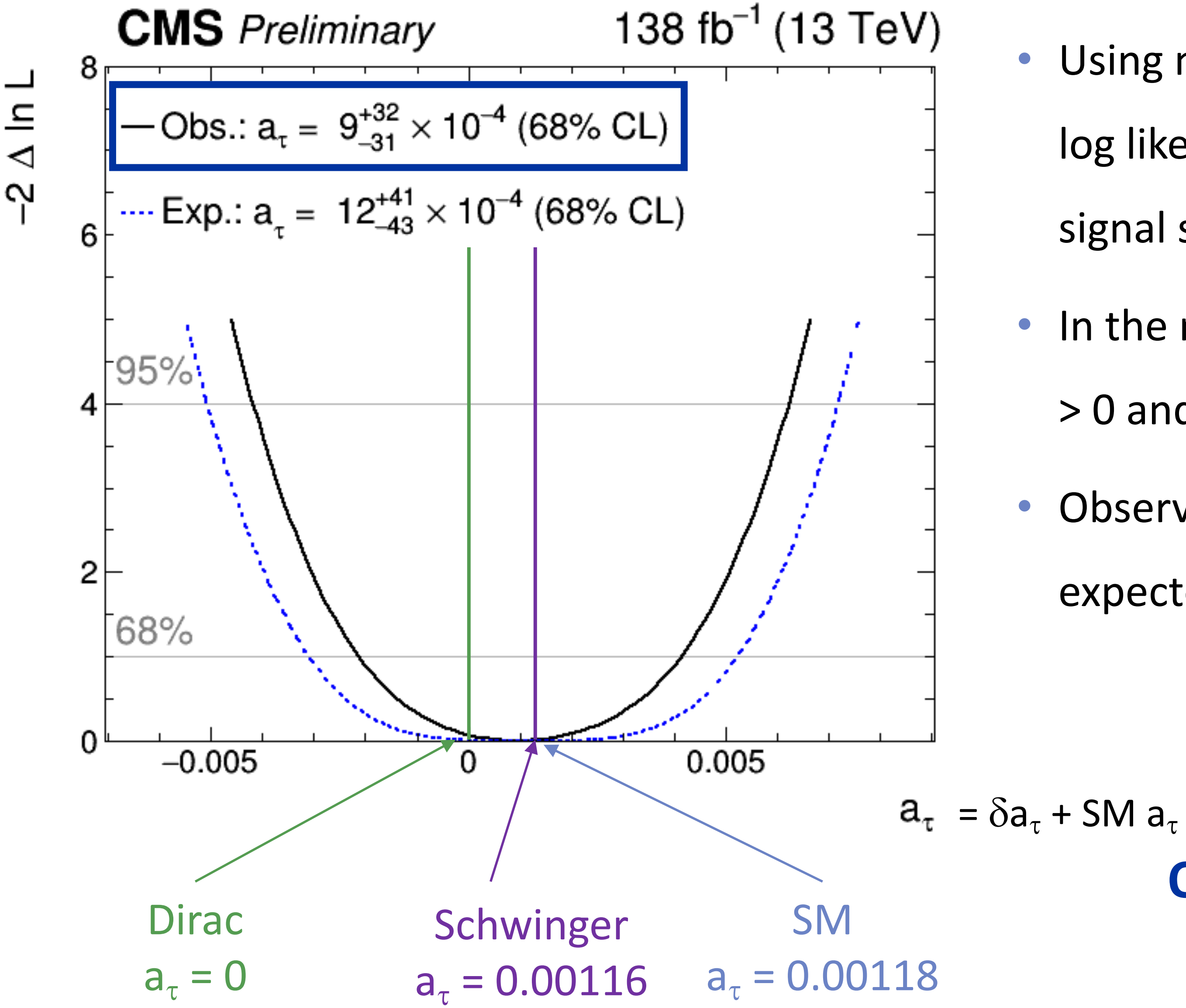
How BSM physics in a_τ affects $\gamma\gamma \rightarrow \tau\tau$

- At large $m_{\tau\tau}$, $\gamma\gamma \rightarrow \tau\tau$ cross section increases with both positive and negative variations to a_τ
- The effect grows with $m_{\tau\tau}$

- **We can constrain a_τ by looking at the yield and $m_{\tau\tau}$ distribution of the $\gamma\gamma \rightarrow \tau\tau$ process**
- Expect better BSM sensitivity than with Pb-Pb runs because of higher $m_{\tau\tau}$ range probed



Extracting a_τ

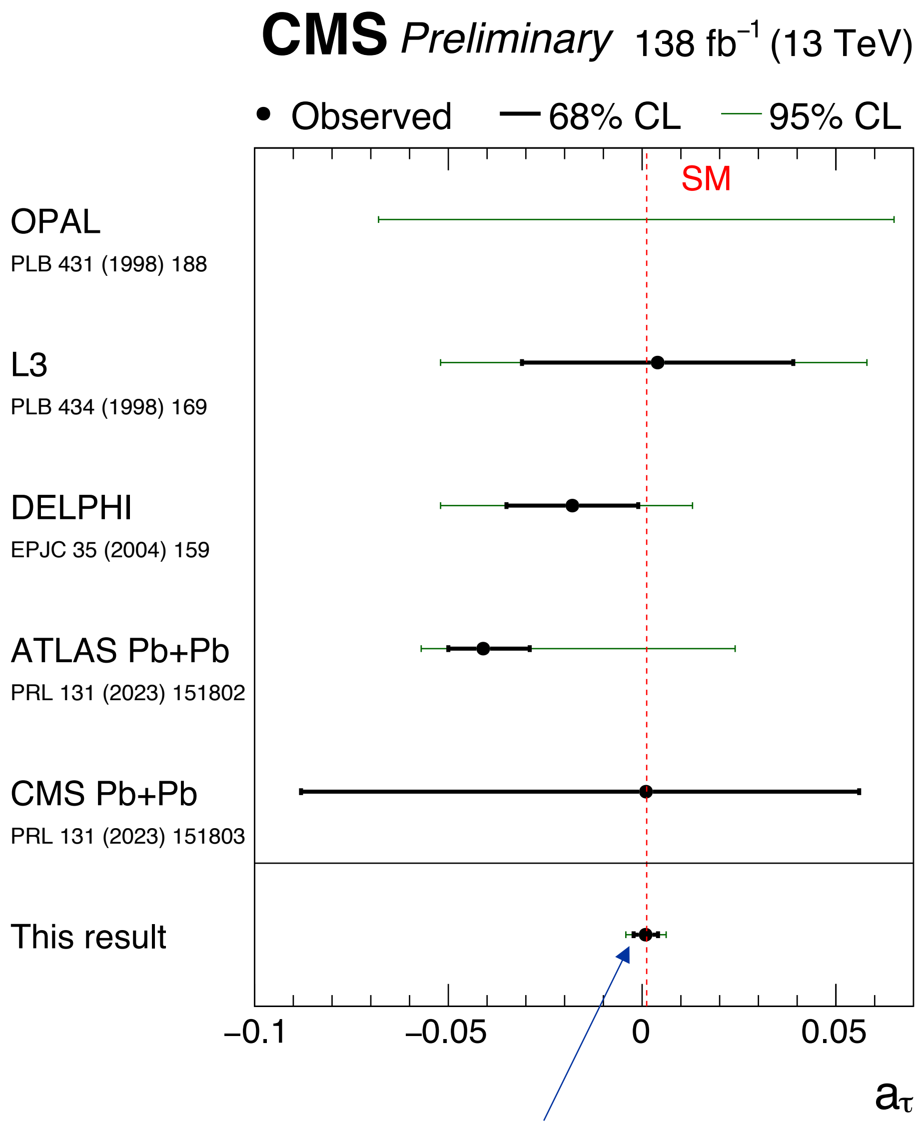


- Using m_{vis} distributions in the SR, perform negative log likelihood scan over δa_τ, which modifies the signal shape and normalization
- In the $m_{\tau\tau}$ range considered in this analysis, both $\delta a_\tau > 0$ and < 0 increase the signal prediction
- Observed $\gamma\gamma \rightarrow \tau\tau$ deficit: tighter constraints than expected, **compatibility with SM**

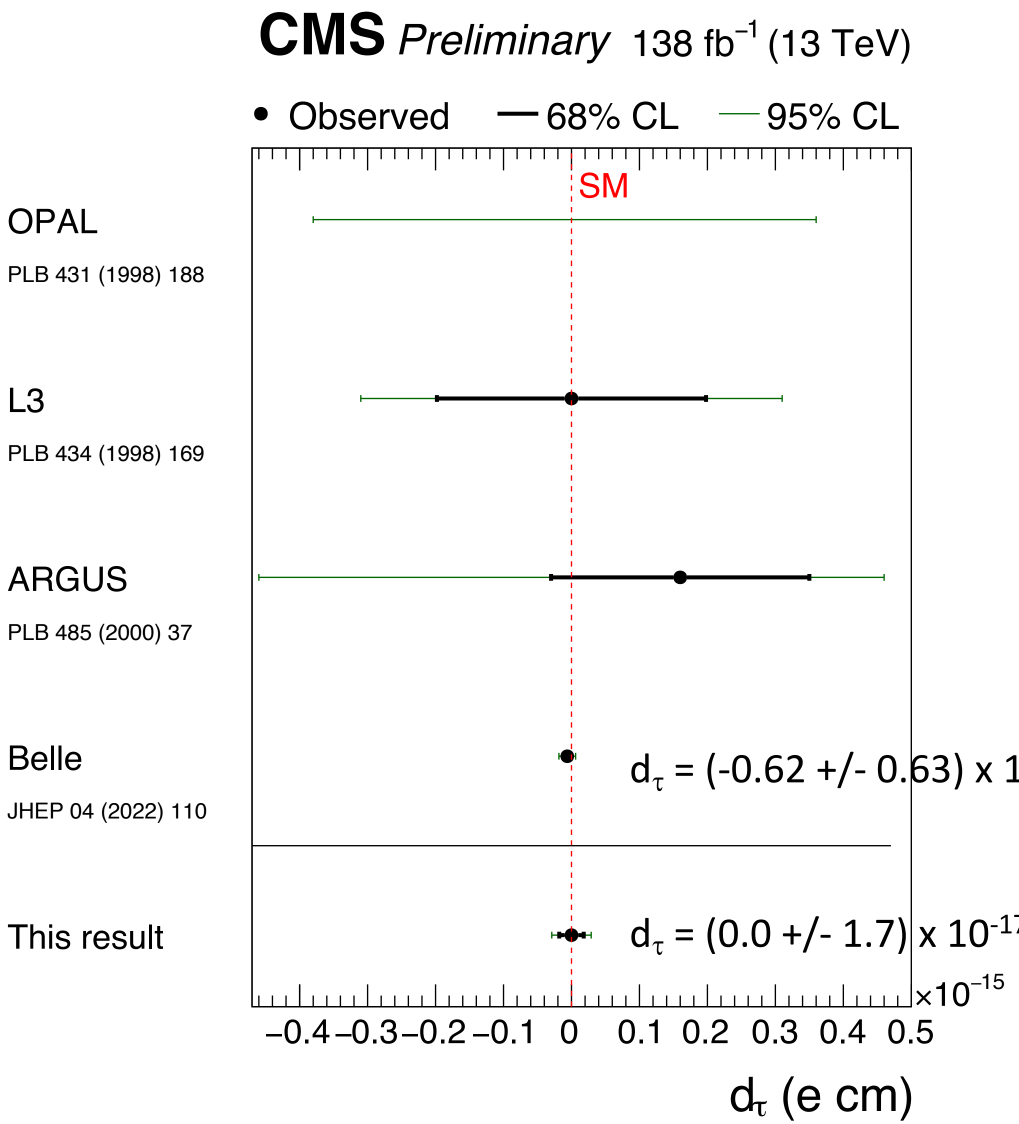
1σ uncertainty of 0.003

Only 3 times the Schwinger term!

Comparing to previous results



Large improvement over LEP and LHC Pb-Pb



d_τ = (-0.62 +/- 0.63) x 10^{-17} ecm

d_τ = (0.0 +/- 1.7) x 10^{-17} ecm

Approaching Belle precision

Conclusion

- Thanks to the excellent tracking performance of the CMS detector, we can isolate photon-induced events in ultraperipheral proton-proton collisions without tagging protons
- **The CMS Collaboration has observed, for the first time, $\gamma\gamma \rightarrow \tau\tau$ events in pp runs**
- These events were used to constrain the tau electromagnetic moments with an EFT approach

$$a_\tau = 0.0009 \, {}^{+0.0032}_{-0.0031} \text{ at 68\% CL}$$

$$-0.0042 < a_\tau < 0.0062 \text{ at 95\% CL}$$

- **Improving previous constraints on tau g-2 by a factor of ~5** (*PDG:* $-0.052 < a_\tau < 0.013$ *at 95% CL*) and approaching the precision of the Schwinger term (*0.00116*)

More info in [CMS-PAS-SMP-23-005]