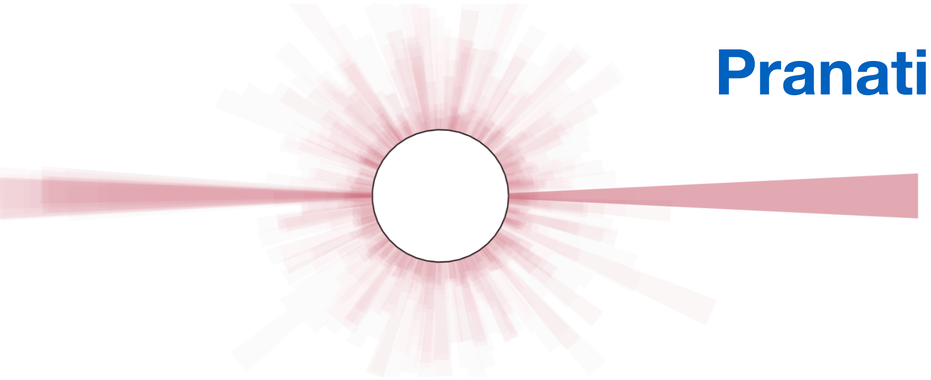
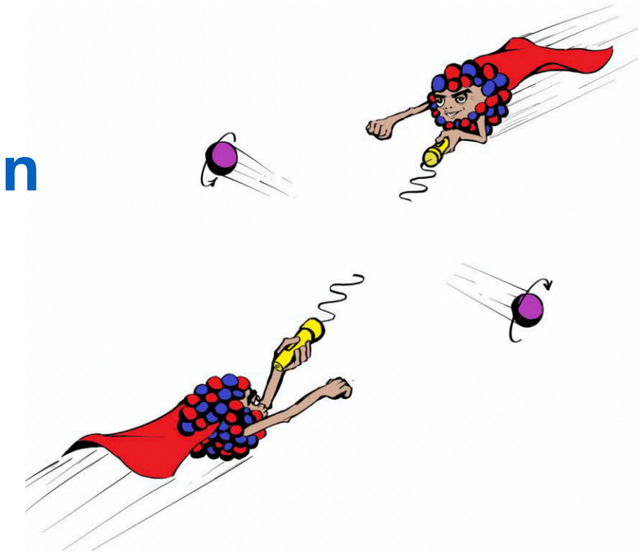
Exclusive photon and lepton production in UPC PbPb @ 5.02 TeV at CMS



Pranati Jana[1] for the CMS collaboration

[1]IIT Madras



17th International Conference on Interconnections between Particle Physics and Cosmology

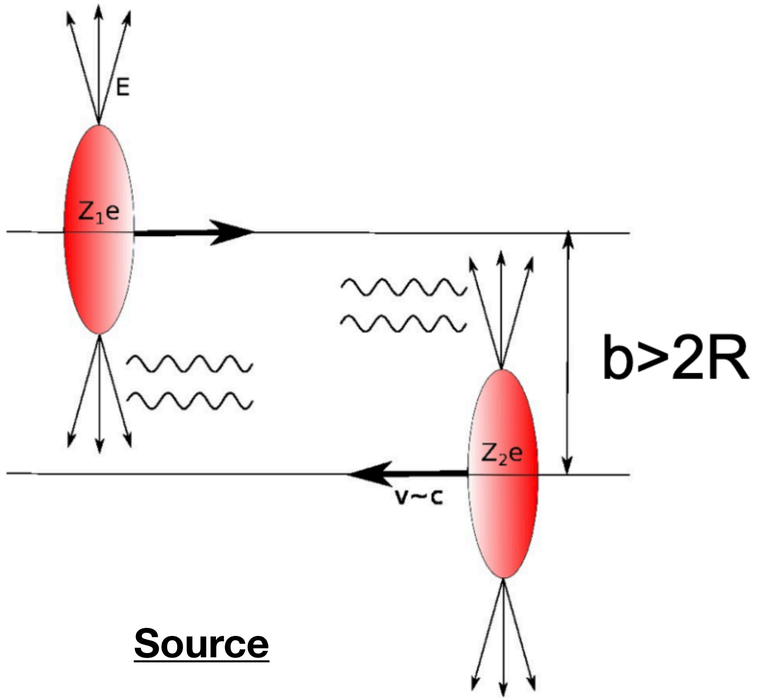
PPC 2024

14 -18 October 2024, Hyderabad, India

Photon induced processes in ultra-peripheral (UPC) collisions

- Accelerated charged particles generate huge electromagnetic fields (10^{14} T), source of huge photon fluxes

- Cross-section, $\sigma(\gamma\gamma) \sim Z^4$ (for PbPb, 5.10^7 times larger than p, $e^{\pm}$)



Source

Photon induced processes in ultra-peripheral (UPC) collisions

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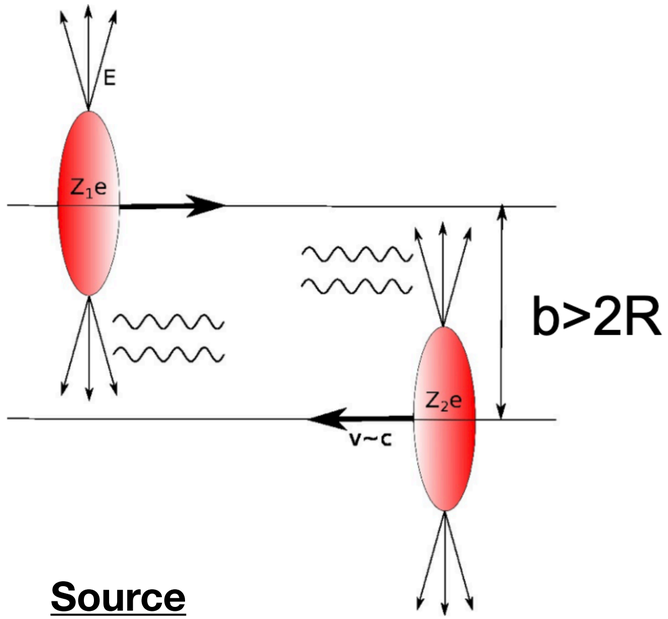
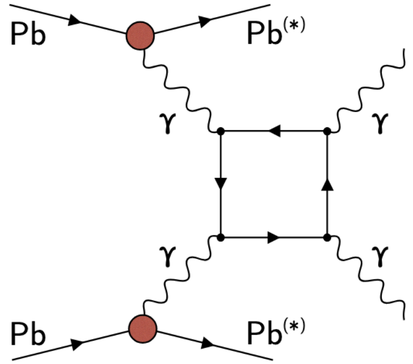
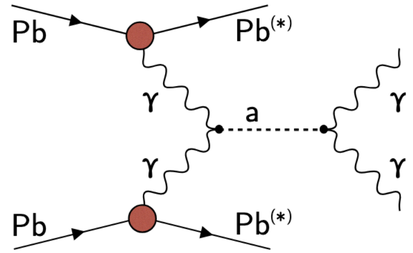


Source

Photon pair production

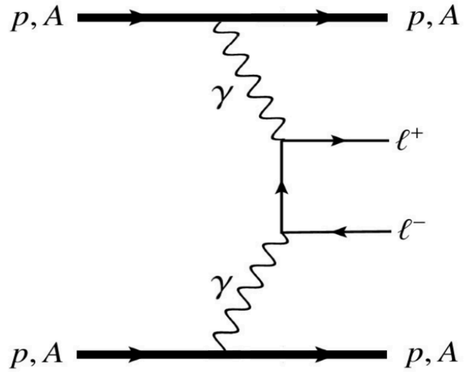


Light-by-light scattering proceeds through box diagram



Axion-like particles (ALPs)

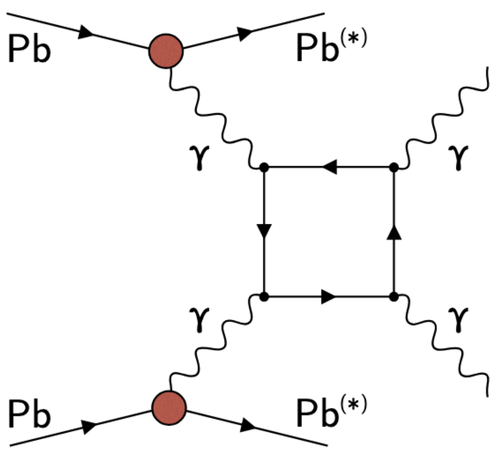
Lepton pair production

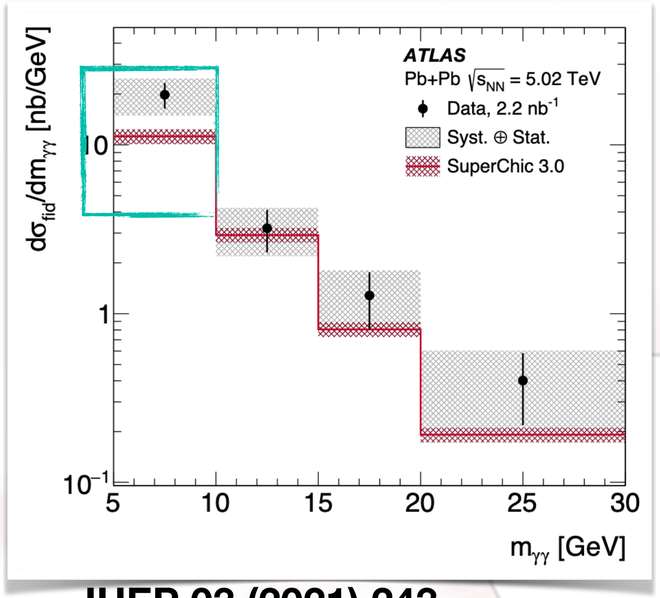


- Breit-Wheeler ($\gamma\gamma \rightarrow$ ee) process
- Muon and tau lepton pair production

A unique tool for precision test of Standard Model and searches for new physics

Photon pair production





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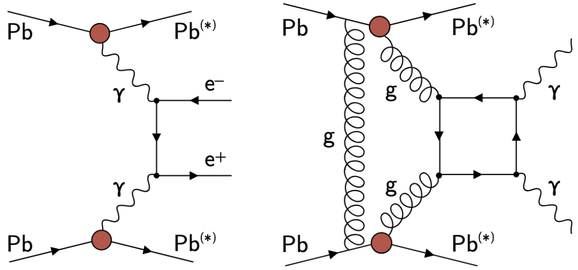
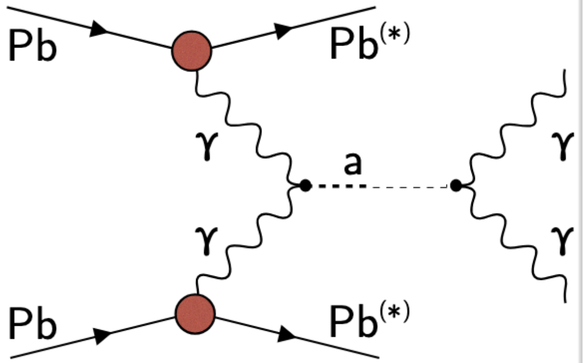
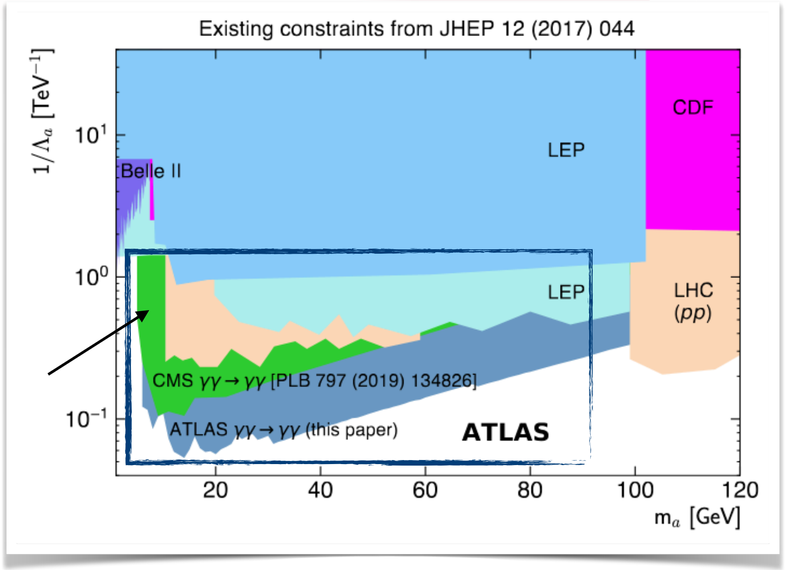
- Evidence by ATLAS (2017) and CMS (2019), observation by ATLAS (2019) in UPC PbPb collisions
- 2σ excess seen by ATLAS
- Backgrounds:
  - Breit-Wheeler process
  - Central exclusive production (CEP)



- CMS PbPb UPC (2019) set first competitive limits in ALPs production ($\gamma\gamma \rightarrow a \rightarrow \gamma\gamma$) in the 5-90 GeV mass range
- ATLAS (2019) measurement now superseded except in the lowest mass





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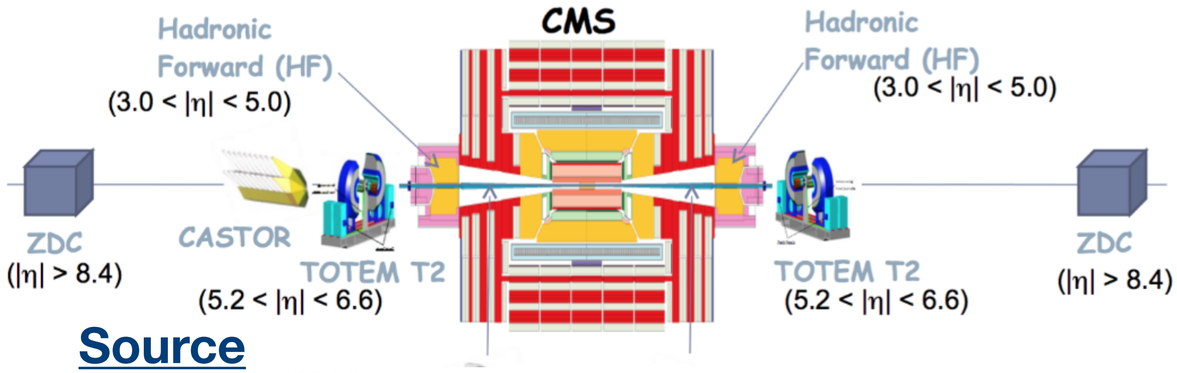
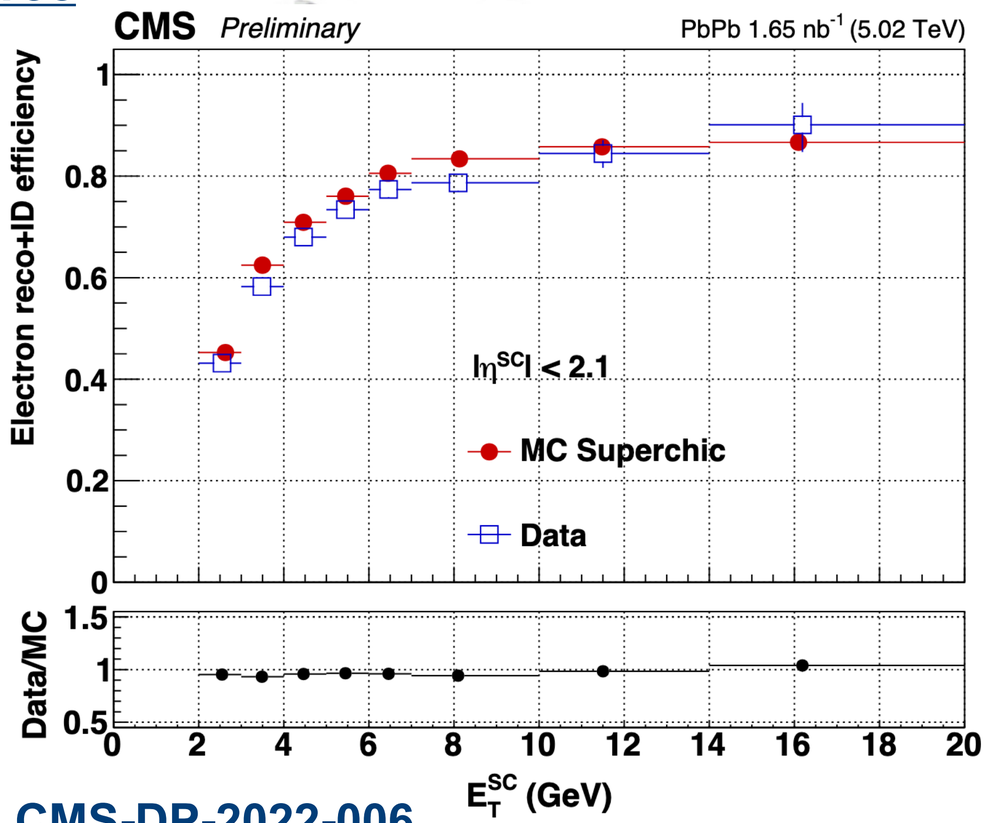
Signal Selection

- Modified low E_T γ/e reconstruction to go down to $E_T > 2$ GeV
- Two well reconstructed electrons/photons: invariant mass $m^{ee,\gamma\gamma} > 5$ GeV, $p_T^{ee,\gamma\gamma} < 1$ GeV, acoplanarity $(A_\phi = 1 - \Delta\phi^{ee,\gamma\gamma}/\pi) < 0.01$
- Excluding any other neutral particles and charged particles
- Less than 3 neutron emissions in both side Zero degree calorimeters



Source



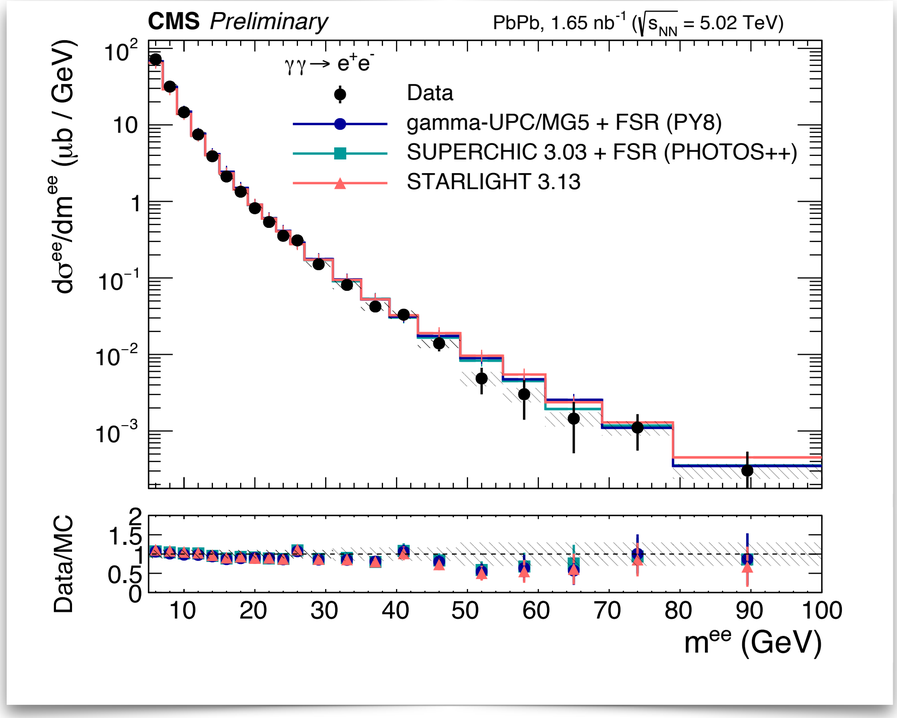
CMS-DP-2022-006

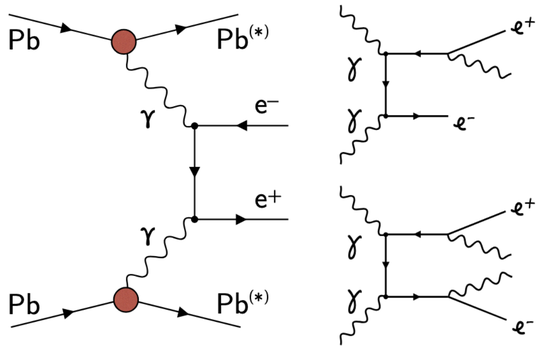
Breit-Wheeler Process

$$\sigma_{\text{fid}}(\gamma\gamma \to e^+e^-) = \frac{N^{ee,\text{data}}}{C^{ee}\mathcal{L}_{\text{int}}} = 271.5 \pm 1.9\,(\text{stat}) \pm 18.3\,(\text{syst})\ \mu\text{b}$$

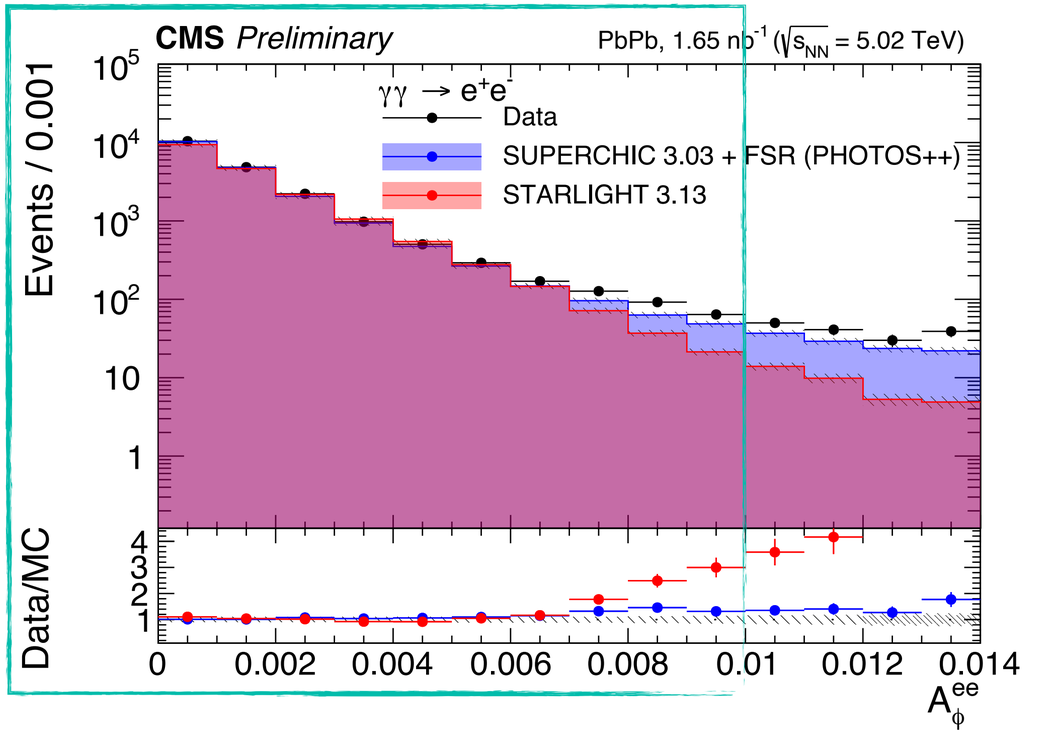
Theoretical predictions:

NLO: gamma-UPC/MG5 + FSR (PY8) : 265 μb





Acoplanarity distribution $A_\phi^{ee} = 1 - \Delta\phi^{ee}/\pi$



CMS-PAS-HIN-21-015

Unfolded distribution:

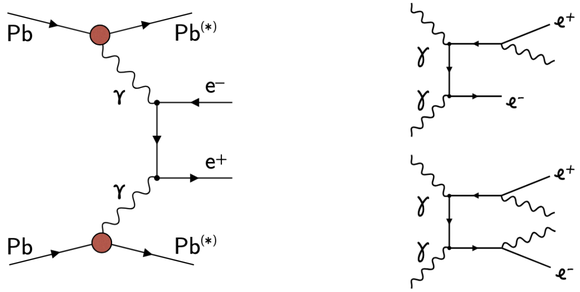
- Within uncertainties very good agreement between data and predictions
- NLO QED is in better agreement with data

Light-by-light Process : Background Estimation

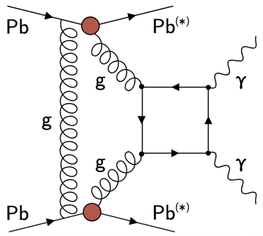
- In light-by-light process, two photons are expected to be exactly back to back, acoplanarity (A_ϕ) ≈ 0

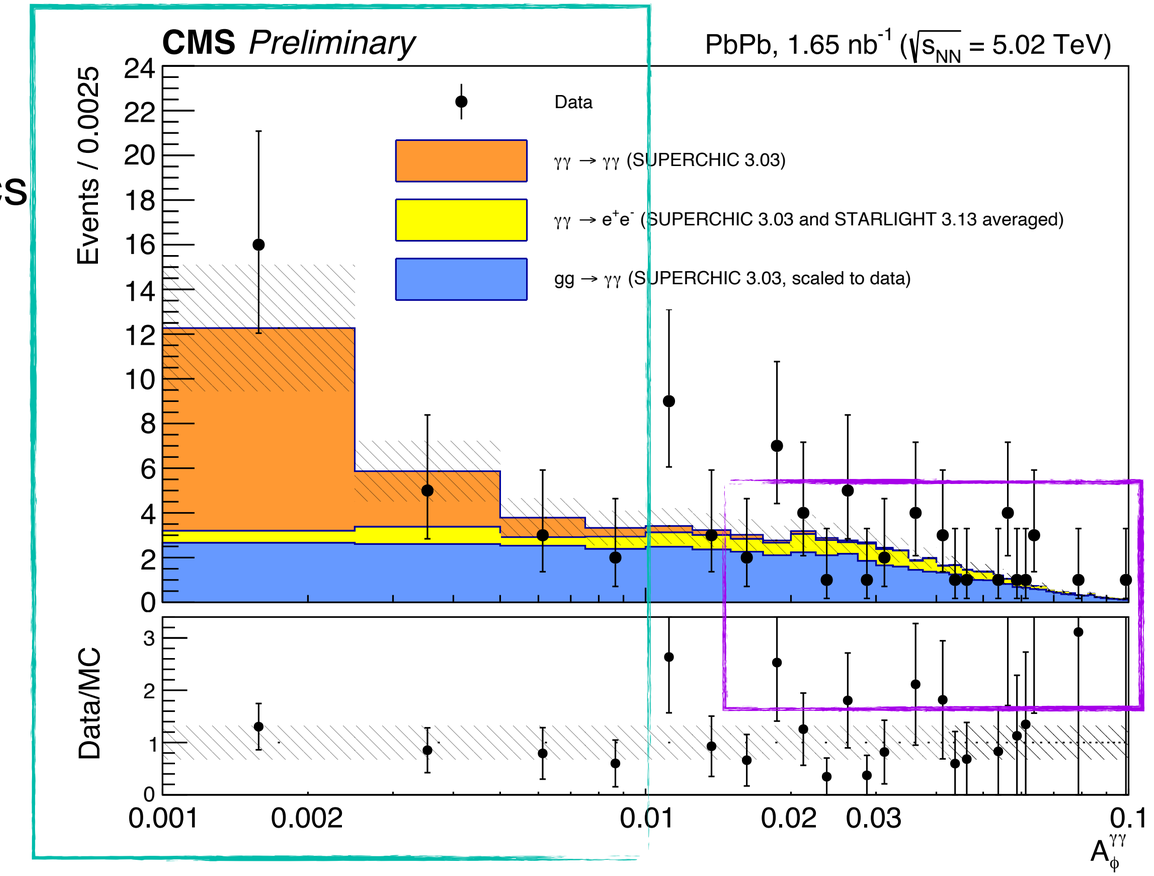
Background estimation:

- Breit-Wheeler :
  - Averaging Superchic and Starlight MC to increase statistics



- CEP :
  - Large theoretical uncertainty in cross section
  - Normalized to data in the acoplanarity tail ($A_\phi > 0.015$)





CMS-PAS-HIN-21-015

- In the $A_\phi < 0.01$ region, total 26 data, 12.8 signal MC, 10.1 CEP MC, 1.9 QED e^+e^- events
- Significance observed (expected): 5.8σ (4.4σ)

Light-by-light Process: Unfolded Distribution

Total uncertainty (statistical/non statistical) : 24% (15%/19%)

$$\sigma_{\text{fid}}(\gamma\gamma \to \gamma\gamma) = \frac{N^{\gamma\gamma,\text{data}} - N^{\gamma\gamma,\text{bkg}}}{C^{\gamma\gamma}\mathcal{L}_{\text{int}}} = 107 \pm 33\,(\text{stat}) \pm 20\,(\text{syst})\,\text{nb}$$

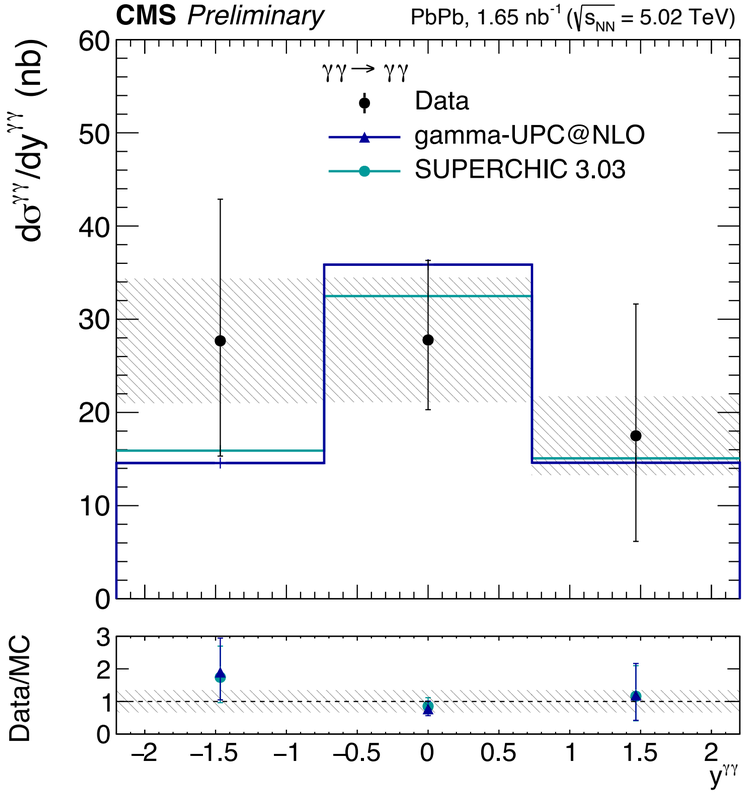
CMS-PAS-HIN-21-015

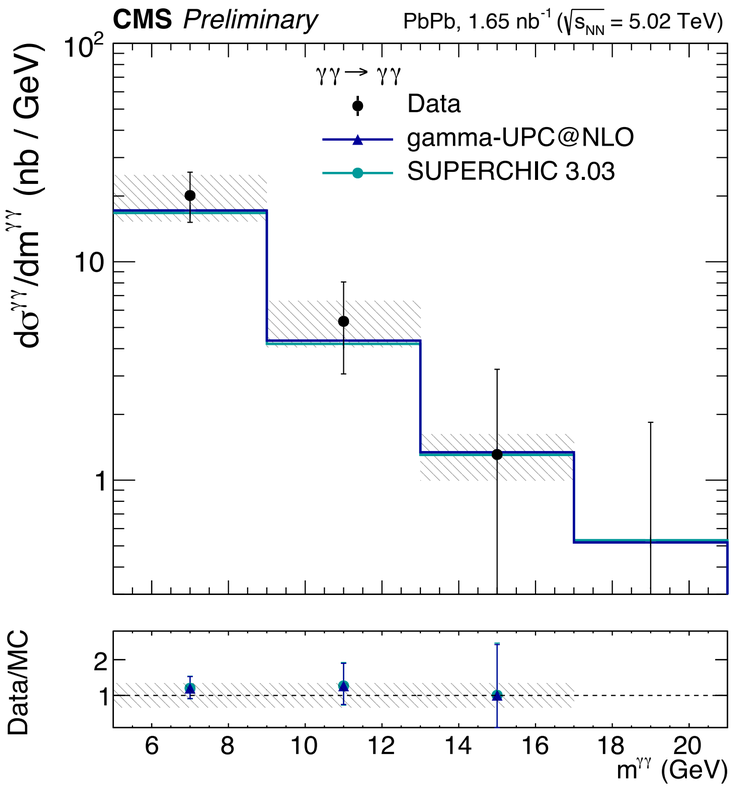
Theoretical predictions:

LO (Superchic): 93 nb

NLO (gamma-UPC): 95.4 ± 2 nb

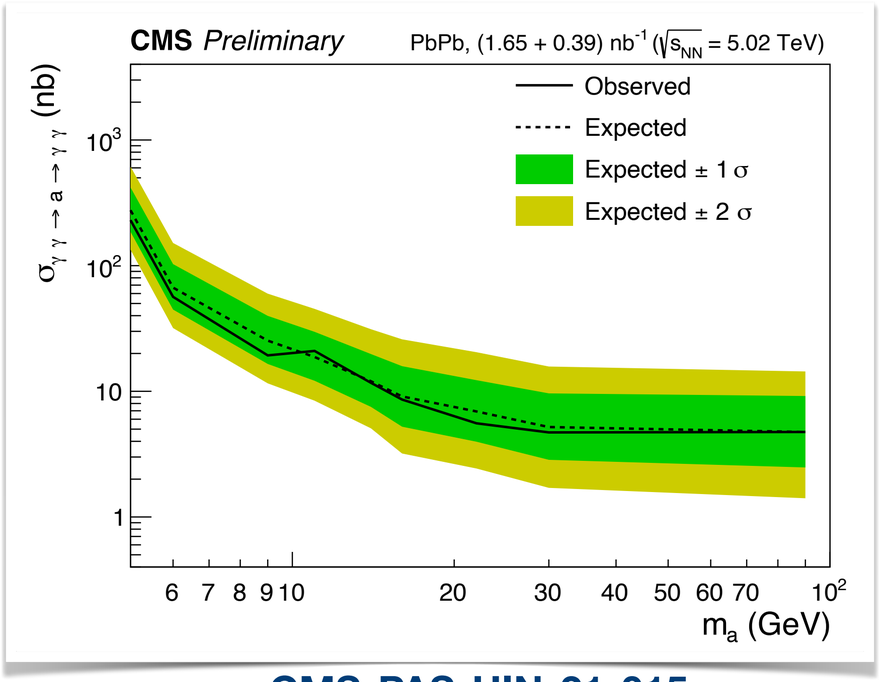
- Within uncertainty agreement with NLO is good





Limits on Axion-Like Particles

- Measured diphoton invariant mass distribution used to search for narrow resonances (ALPs) on top of the light-by-light continuum
- This limit on cross section σ ($\gamma\gamma \rightarrow a \rightarrow \gamma\gamma$) for ALPs with mass range 5-90 GeV used to determine the exclusion region in the $g_{a\gamma}$ vs. m_a plane
- Achieved the most stringent limit from 5-10 GeV



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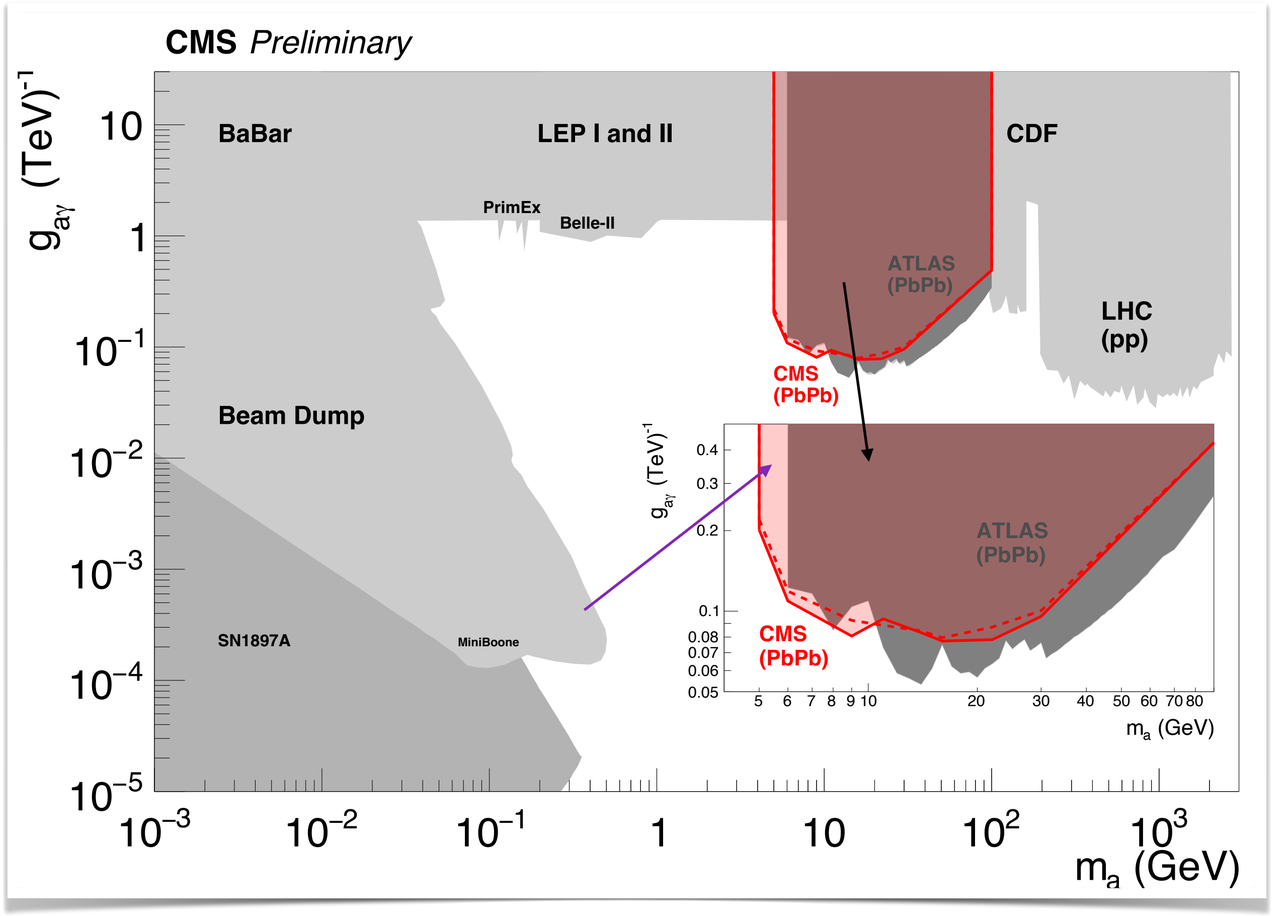
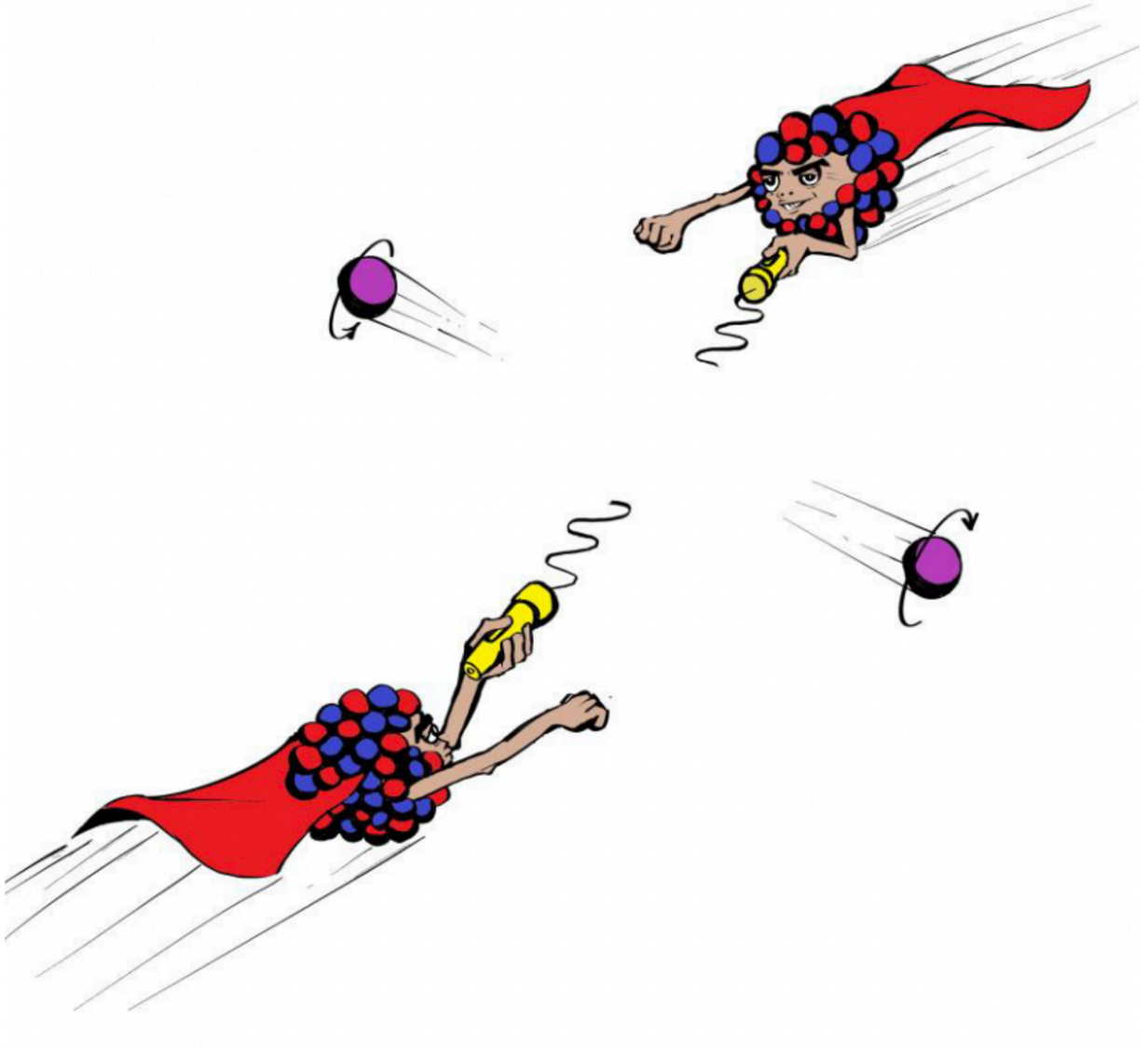
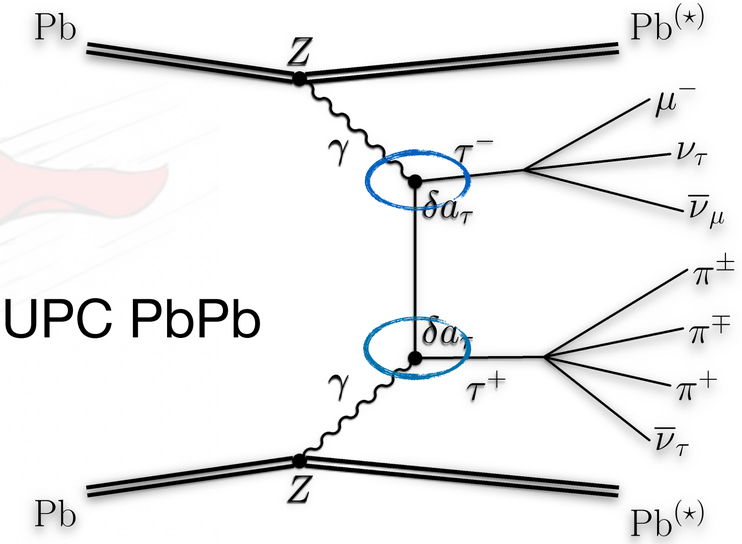


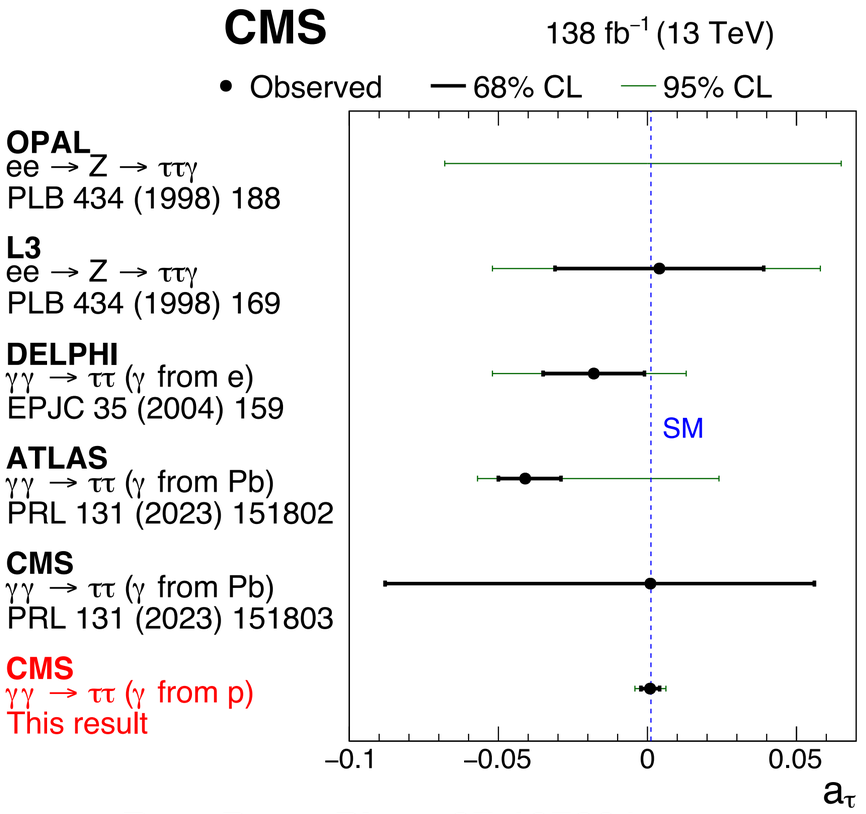
τ-leptons pair production



τ-leptons pair production and previous a_τ measurements

- $\gamma\tau\tau$ vertex is sensitive to $a_\tau = (g\text{-}2)_\tau / 2$
- DELPHI had the best measurement since 2004
- First LHC observations by CMS (2015 data) and ATLAS (2018 data) in UPC PbPb



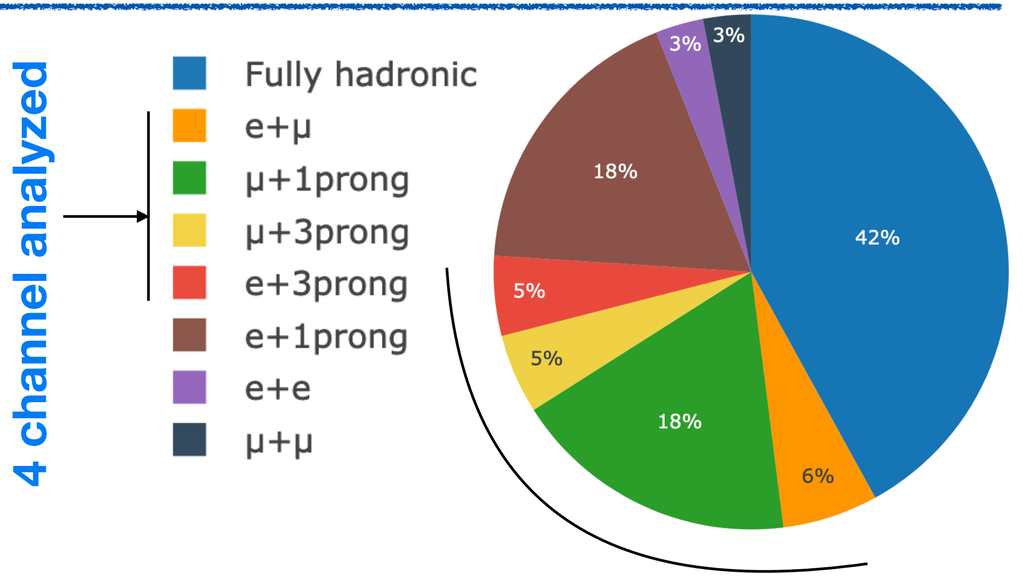


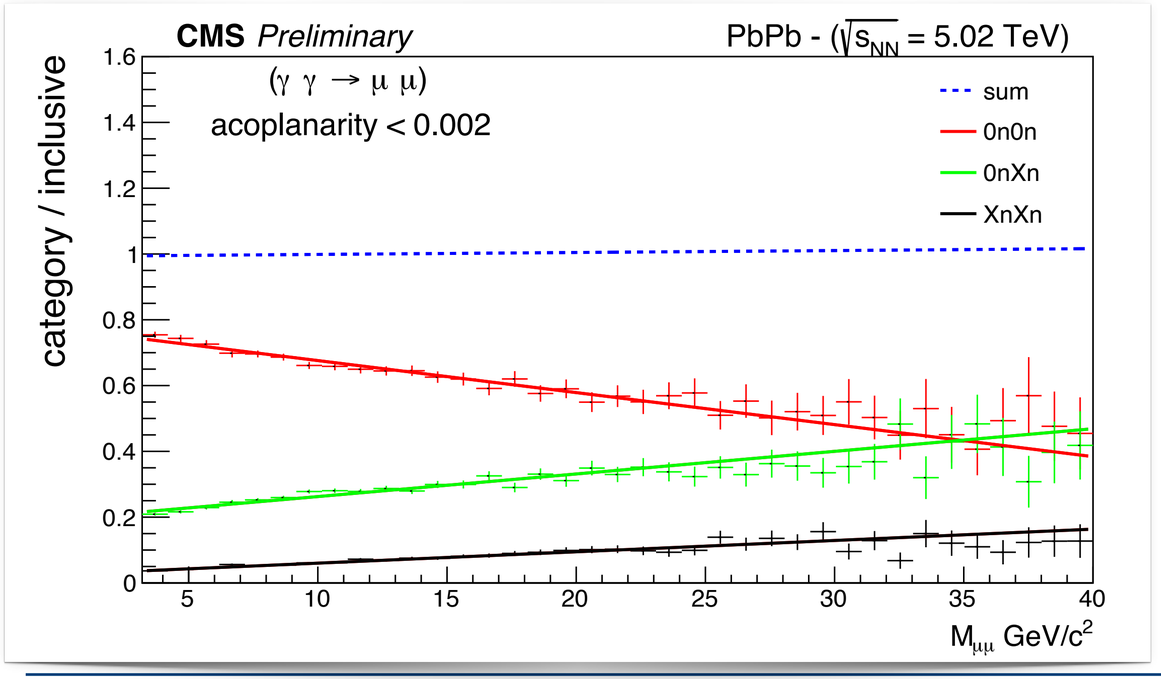
Rep. Prog. Phys. 87 107801

- CMS measurement in pp improved the previous best a_τ measurement by DELPHI, exploiting the a_τ sensitivity in high $\tau\tau$ mass

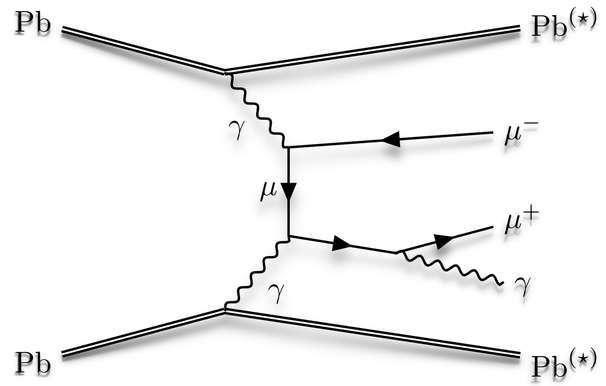
Analysis strategy

- Low $\tau\tau$ invariant mass: complementary to the pp analysis
- 2018 dataset ~ 4 times larger dataset than 2015
- Low pT e/γ study exploited from light-by-light analysis
- In μ+1prong, no neutrons in the Zero Degree Calorimeters (ZDC) (0n0n)





- Non-exclusive background in semi-leptonic channels is estimated with a data-driven method
- Exclusive $\gamma\gamma \rightarrow$ ee, $\gamma\gamma \rightarrow \mu\mu$, & $\gamma\gamma \rightarrow \mu\mu\gamma$ can be removed by acoplanarity cut

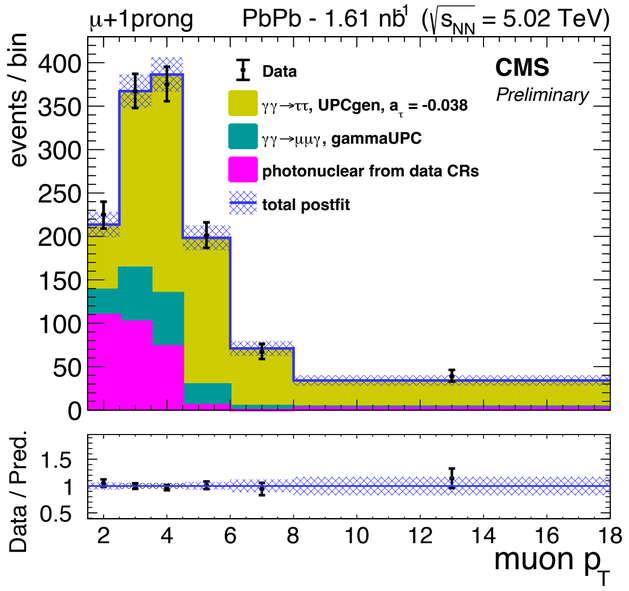


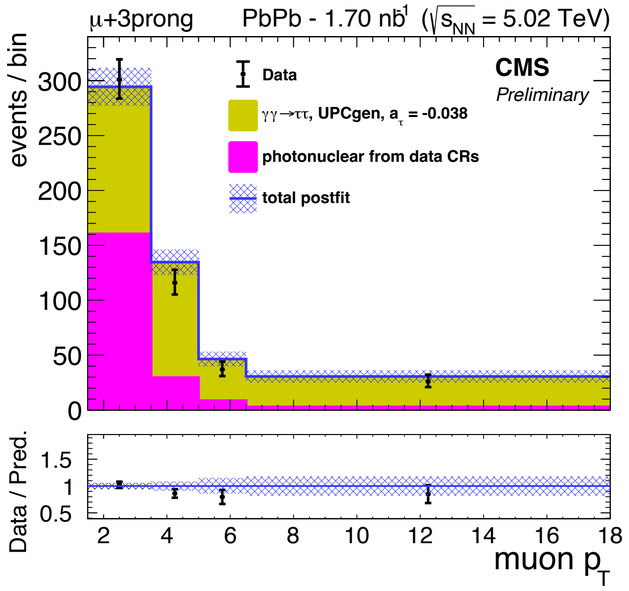
CMS-PAS-HIN-24-011

Data-MC comparison

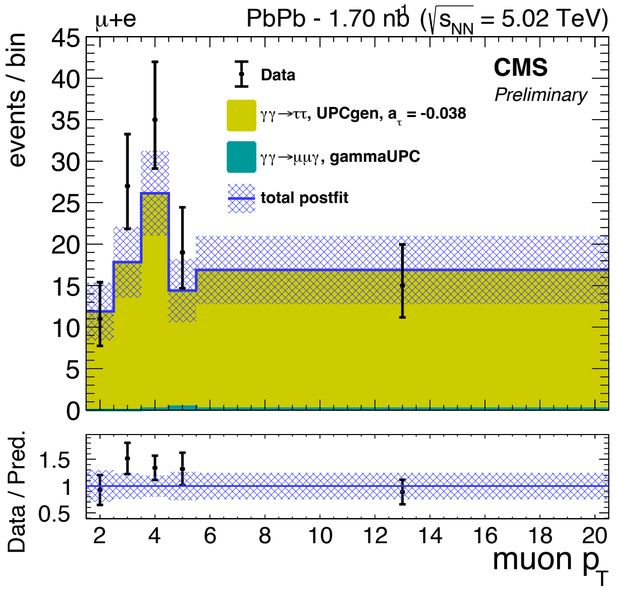
- Signal stacked on top of background(s), compared to data
- Good agreement between data and the signal+background model

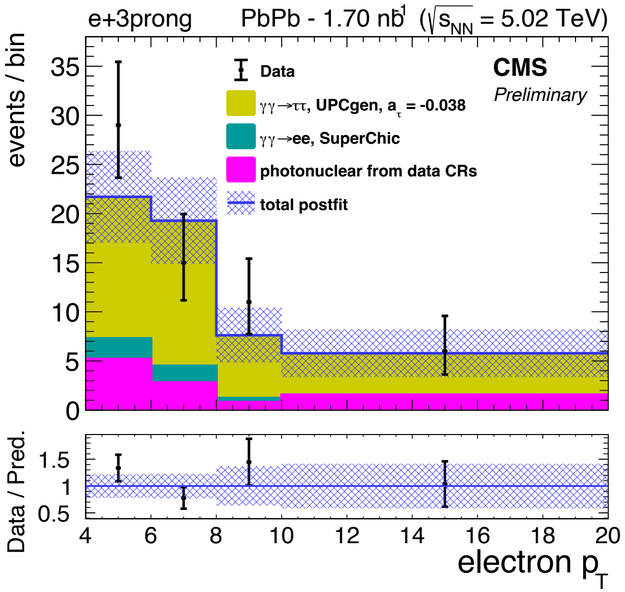
Highest yield





Cleanest channel





CMS-PAS-HIN-24-011

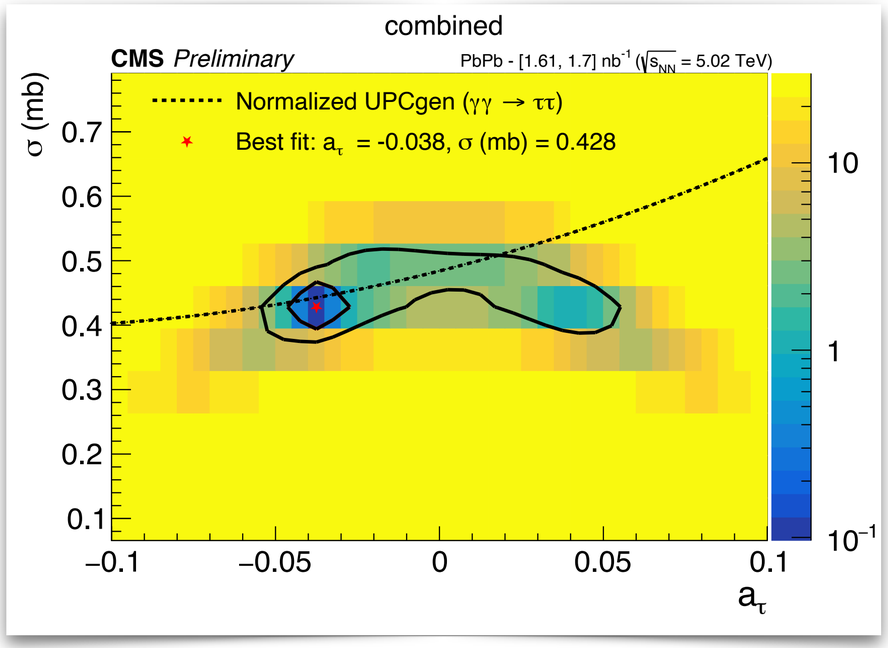
Extraction of a_τ

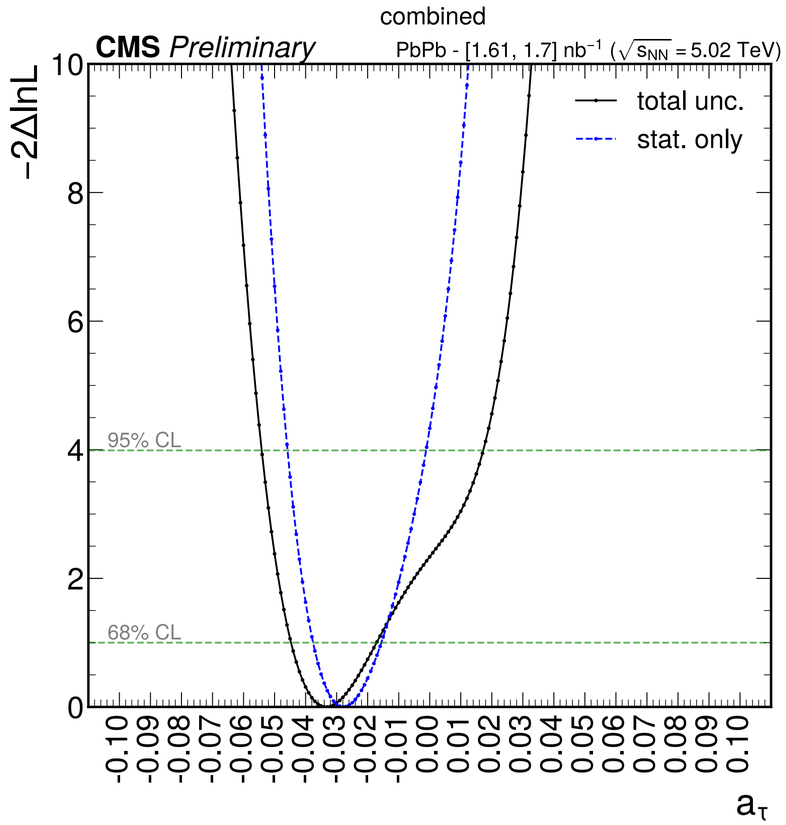
- $\gamma\gamma \rightarrow \tau\tau$ samples with $-0.1 < a_\tau < 0.1$ generated with UPCgen

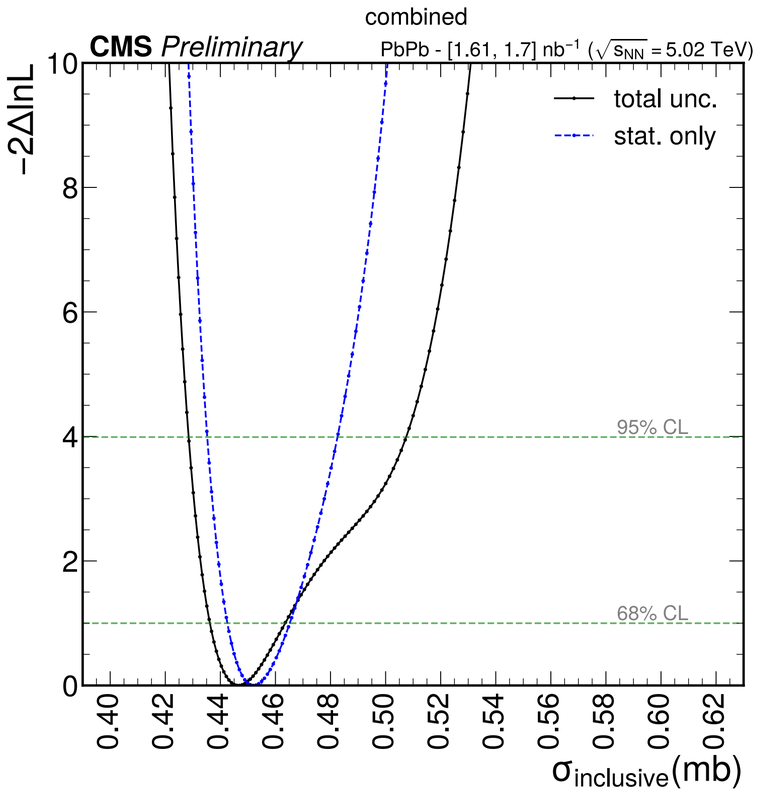
CMS-PAS-HIN-24-011

- Fit performed on lepton p_T with the most sensitivity to a_τ

- Limits on a_τ and fiducial cross section are extracted





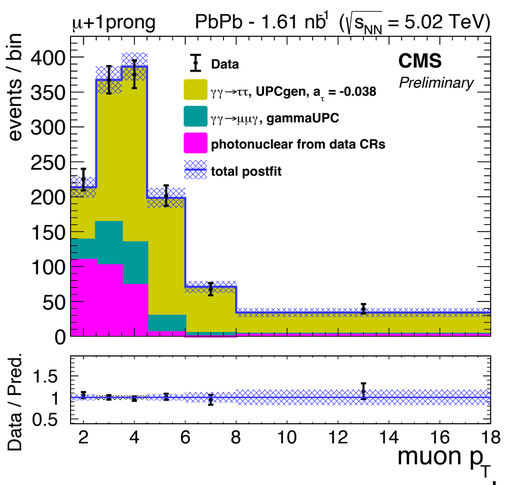


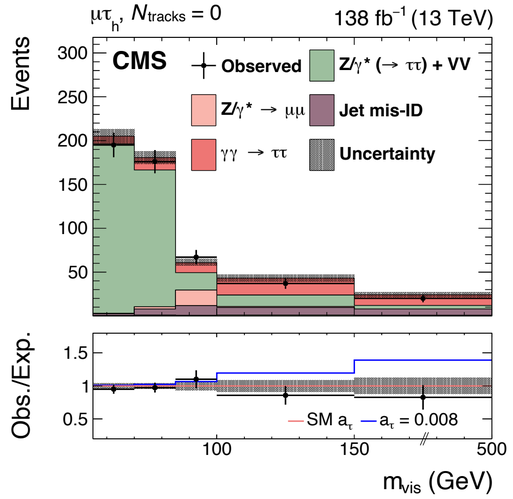
a_τ measurement

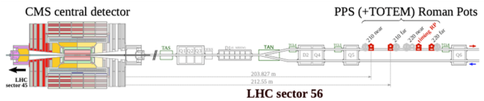
- Limits on a_τ from this Analysis: $a_\tau = -35^{+11(stat)+18(stat+sys)}_{-3(stat)-10(stat+sys)} \times 10^{-3}$
  - SM prediction: a_τ = 0.001 177 21(5)
- Total systematics ~ 5%, dominated by muon and pion efficiency and lumi
- The most precise measurement of $\gamma\gamma \rightarrow \tau\tau$ cross section

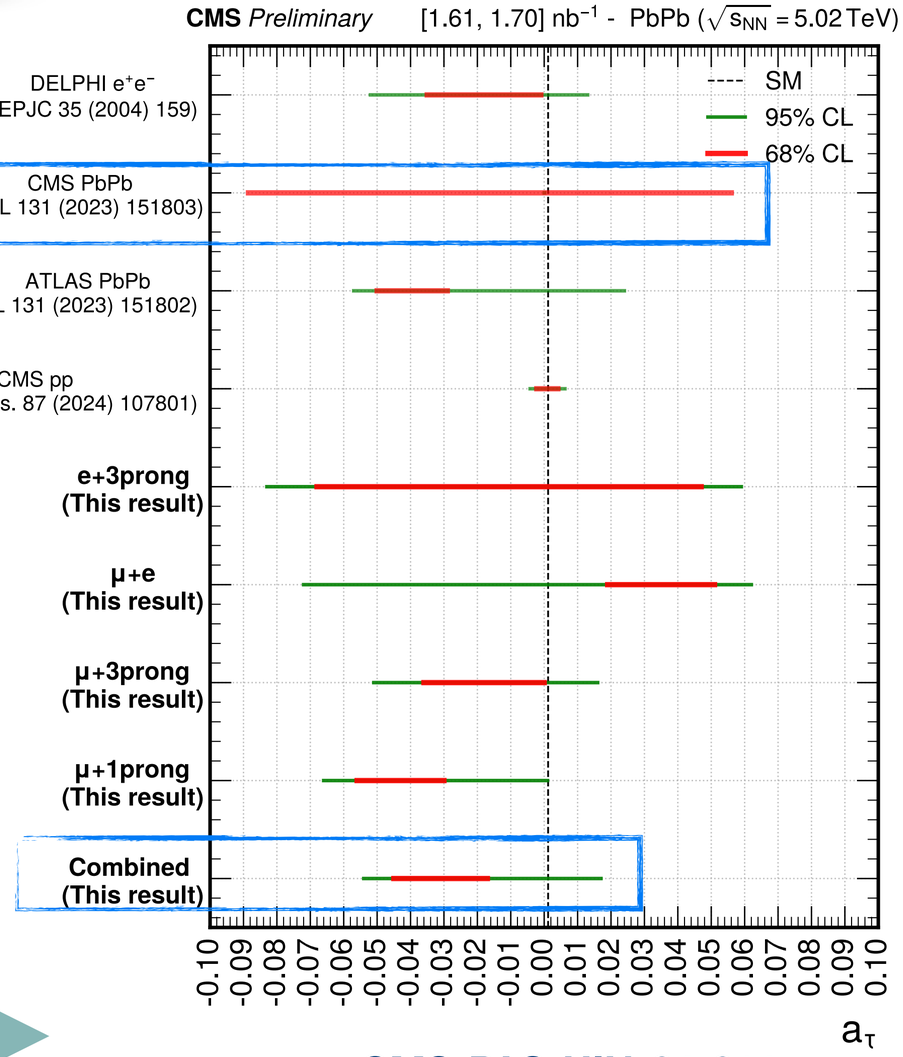
$$\sigma_{fiducual}(ub) = 447^{+18(stat)+16(stat+sys)}_{-5(stat)-11(stat+sys)}$$

Heavy ion runs | **pp runs with track counting** | **pp runs with proton tagging**









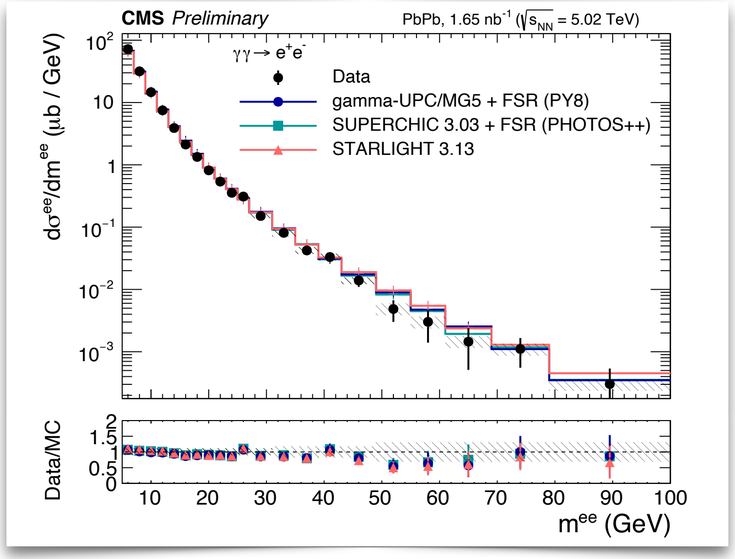
50 GeV — 350 GeV — 2 TeV

CMS-PAS-HIN-24-011

LHC seminar by Cecile Sarah Caillol

Summary

- Breit-Wheeler process: NLO QED prediction is well agreement with data



Summary

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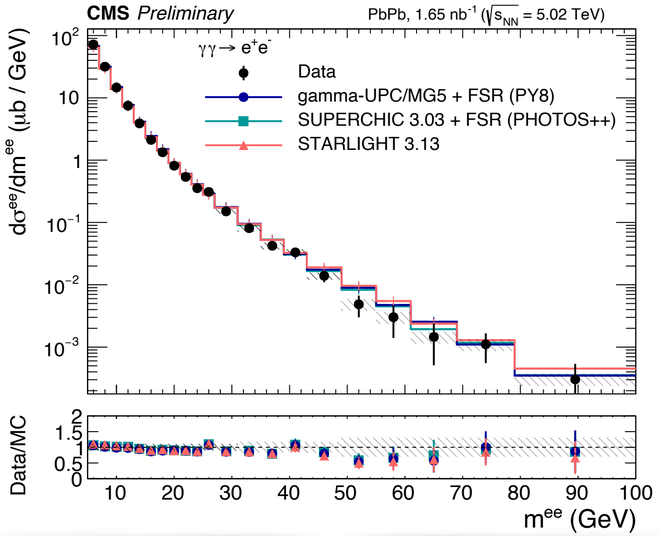
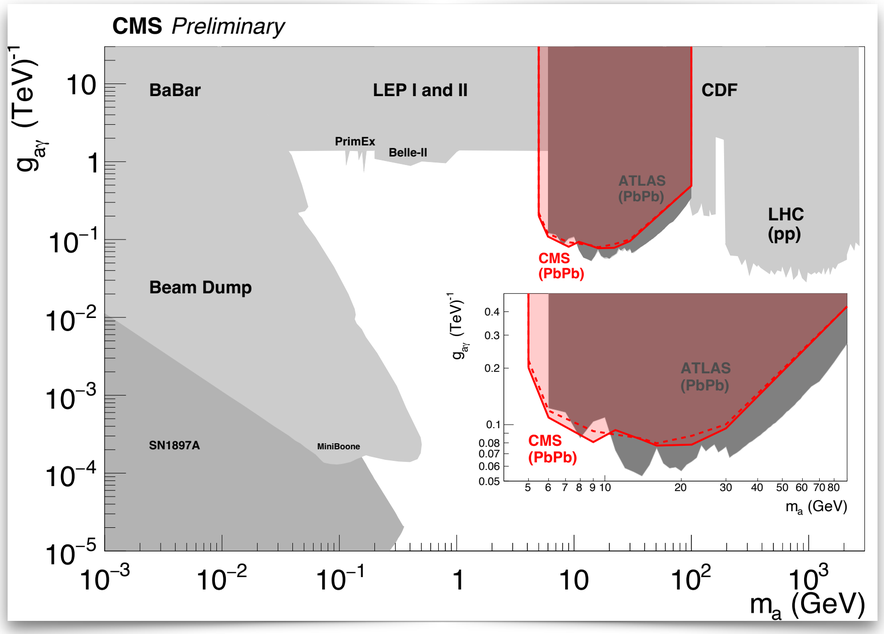
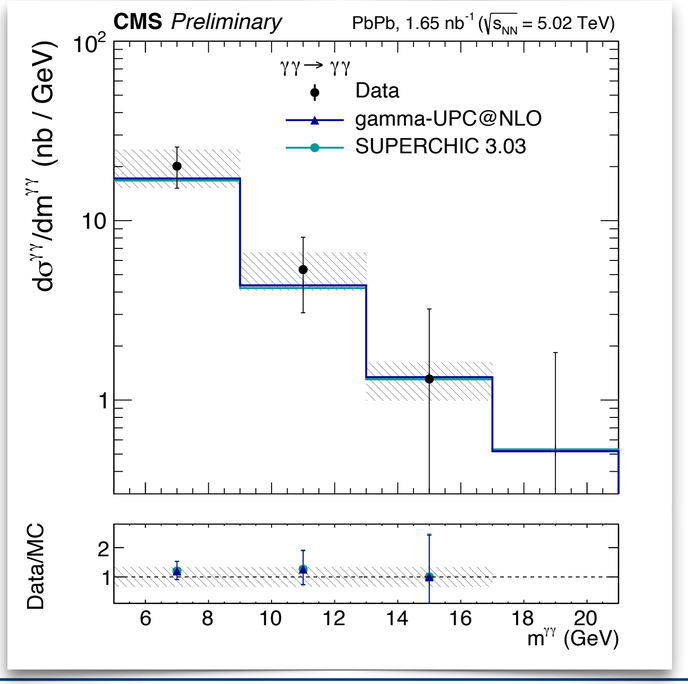
- σ_{fid} ($\gamma\gamma \to \gamma\gamma$) = 107 ± 33 (stat) ± 20 (syst) nb well in agreement with NLO prediction
- ALPs limit: Stringent limit for 5-10 GeV ALPs masses







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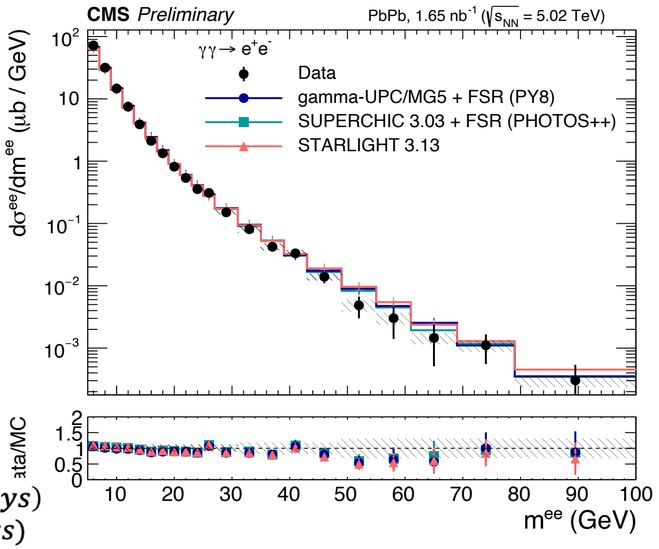
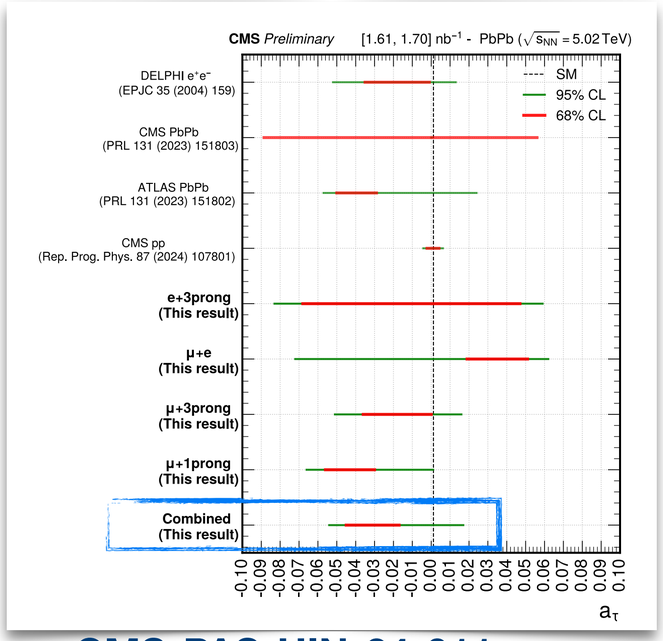
CMS-PAS-HIN-21-015





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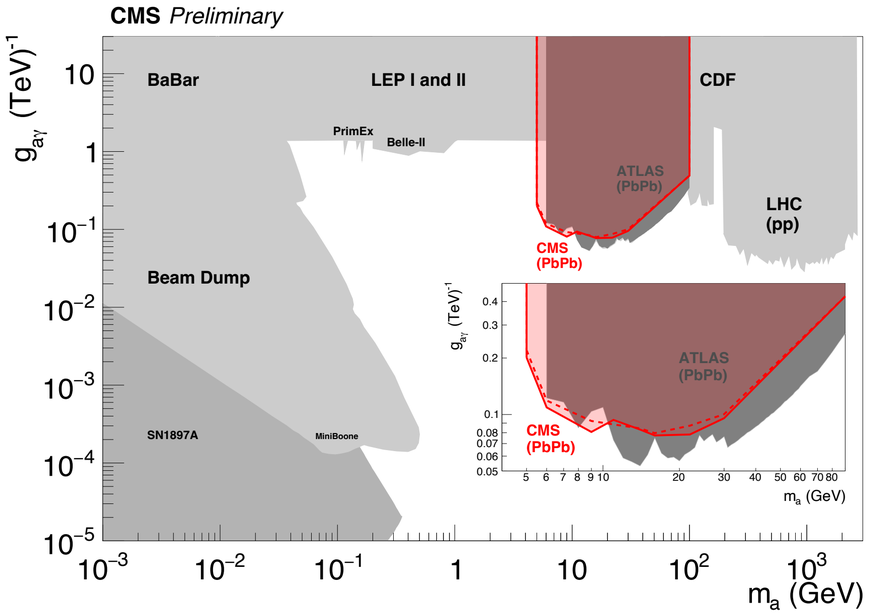

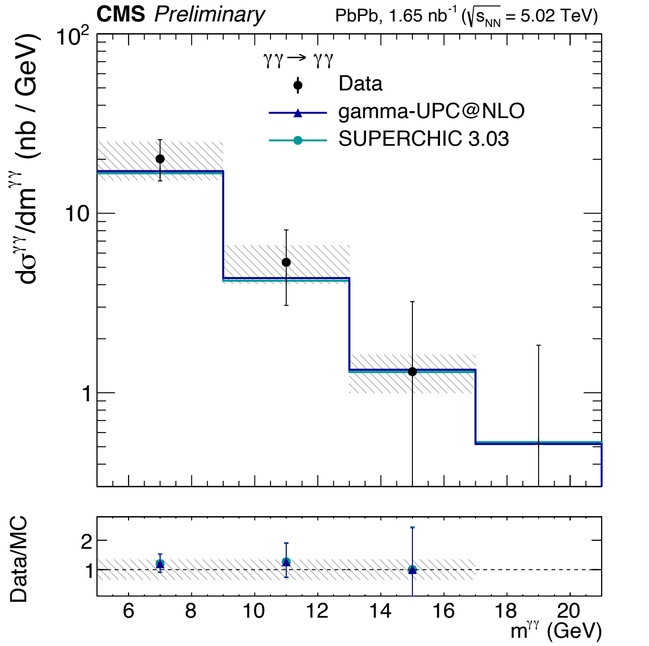

Thank you all !

Acknowledgement

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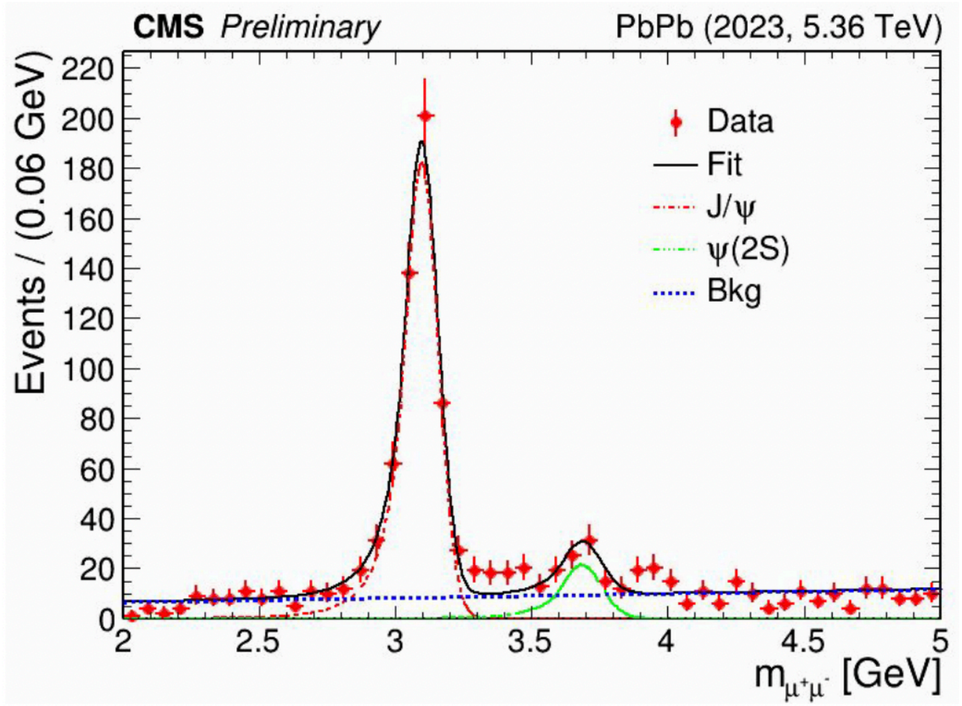
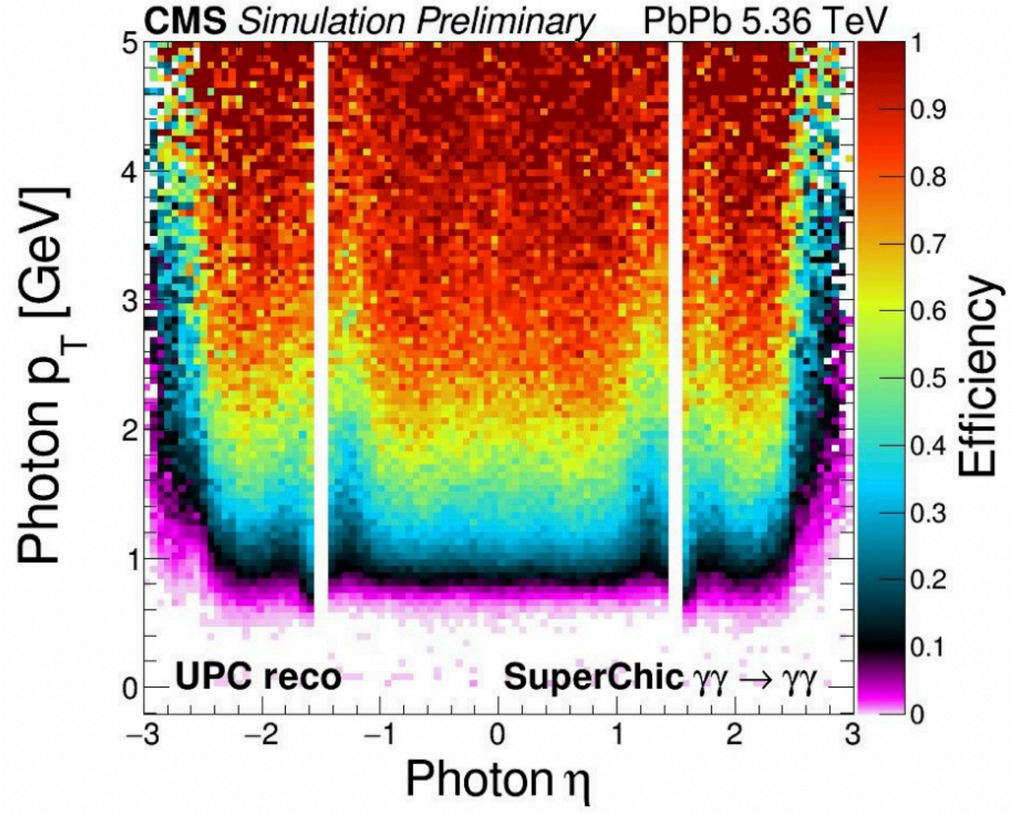
Extra

Run3 UPC PbPb performance @CMS

- Increased lumi in Run3

CMS-DP-2024-011

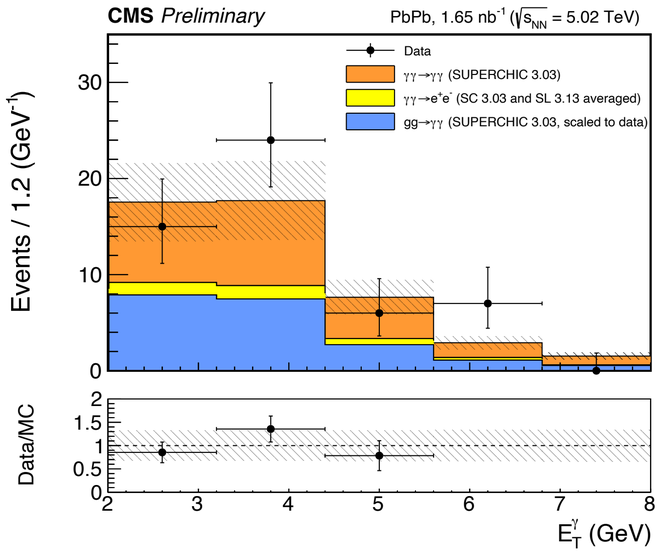


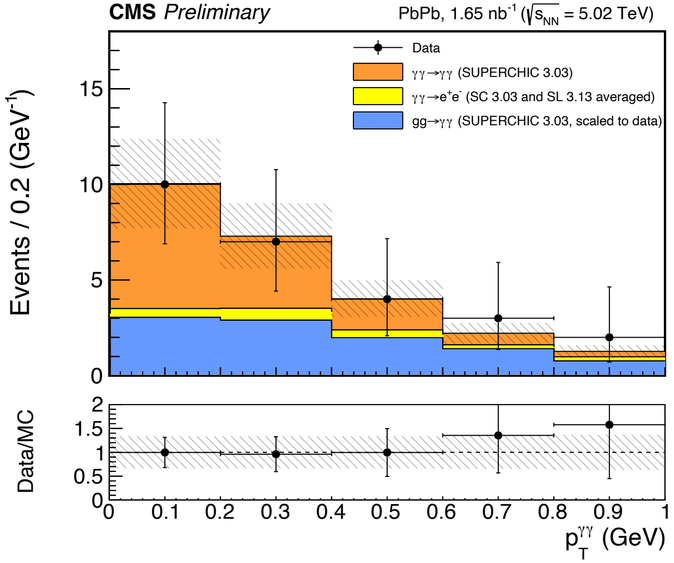


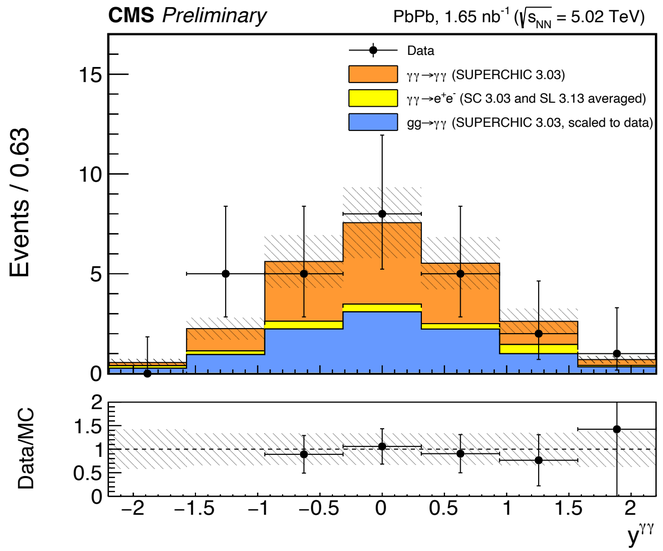
Stay tuned for the new results!

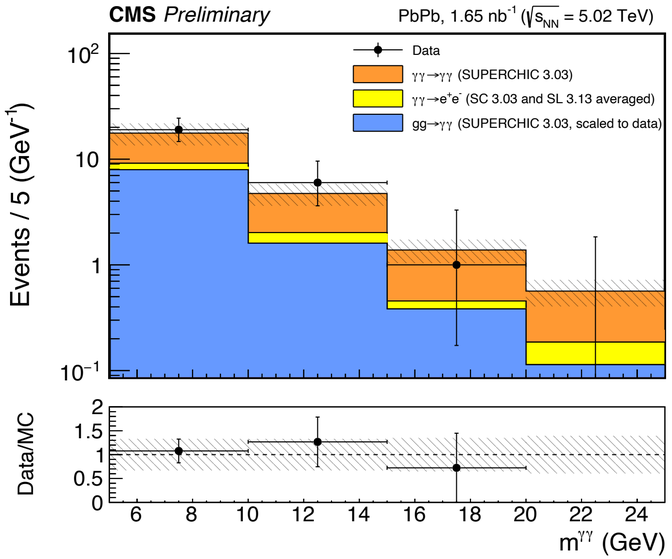
LbyL Process : Detector Level Distribution

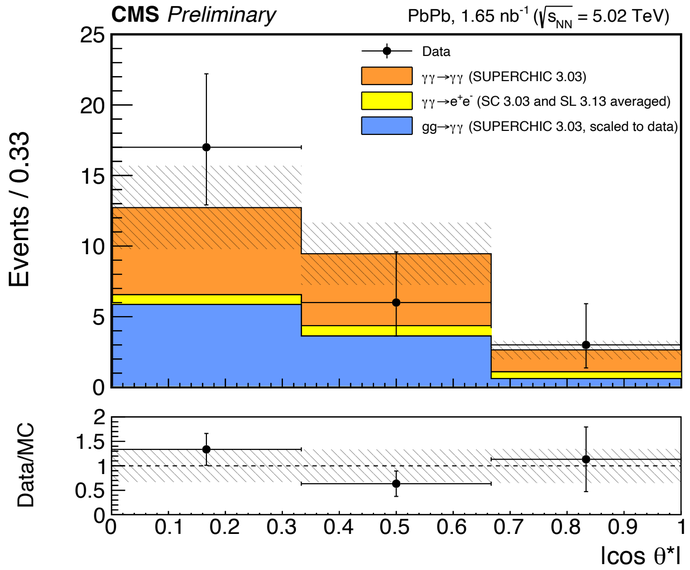
- Good agreement in the detector level distributions between data, signal and background MCs











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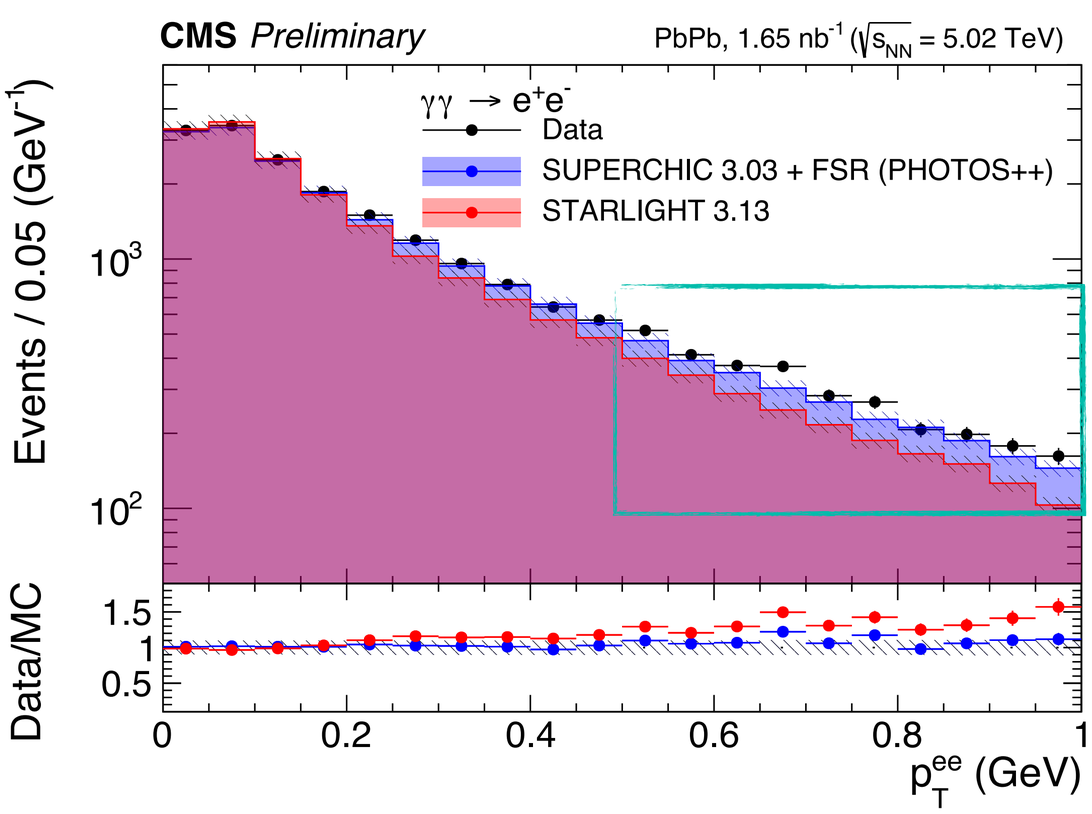
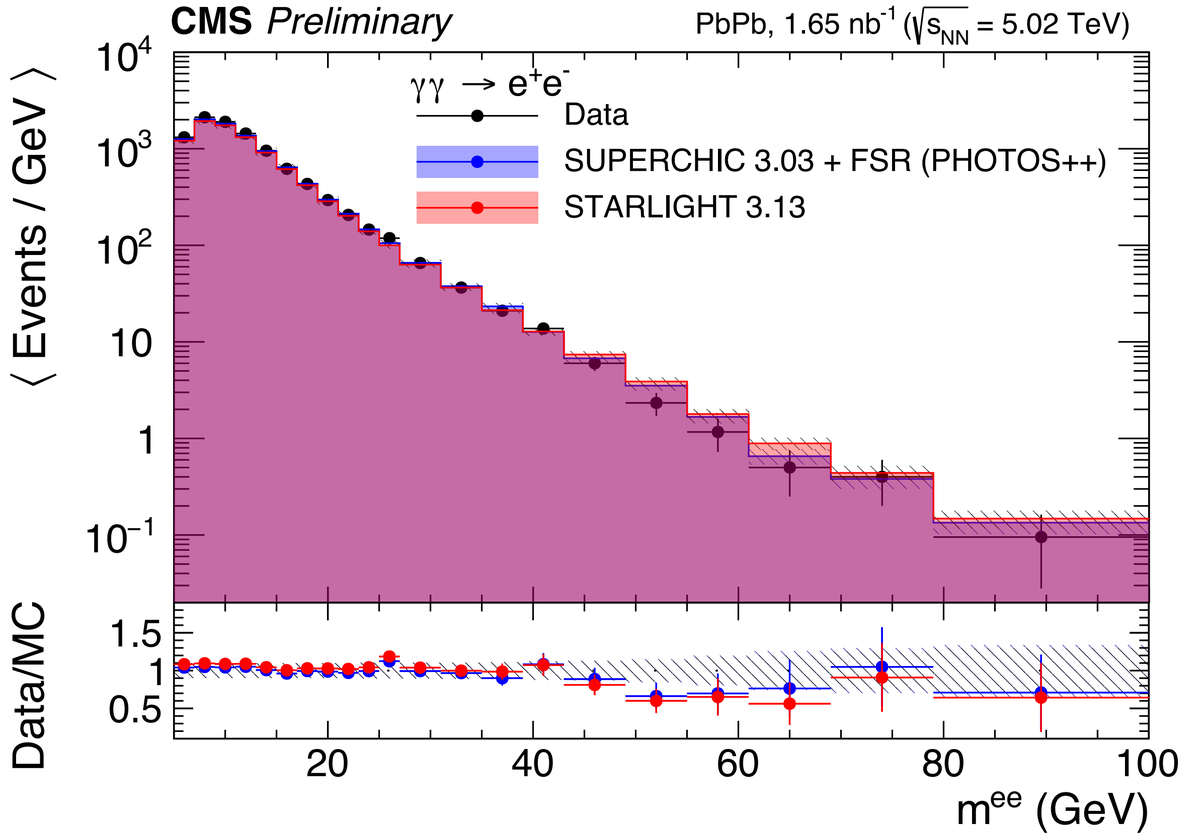
B-W Process : Detector Level Distribution

- Overall good agreement in the detector level distributions, Superchic + FSR (Photos++) describes the p_T^{ee} tail better than Starlight due to the adding of FSR





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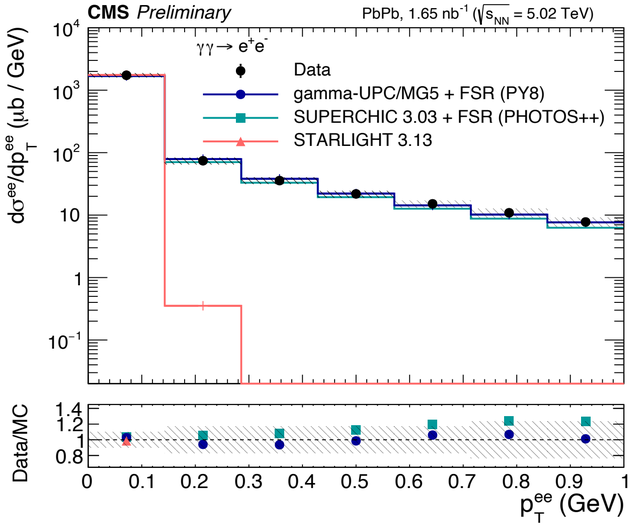
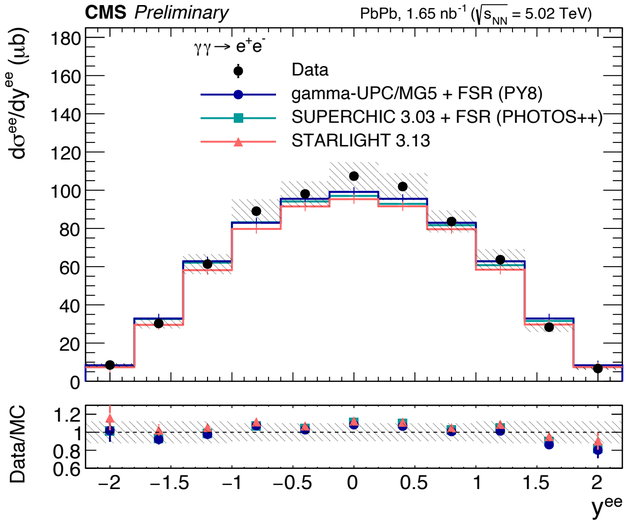
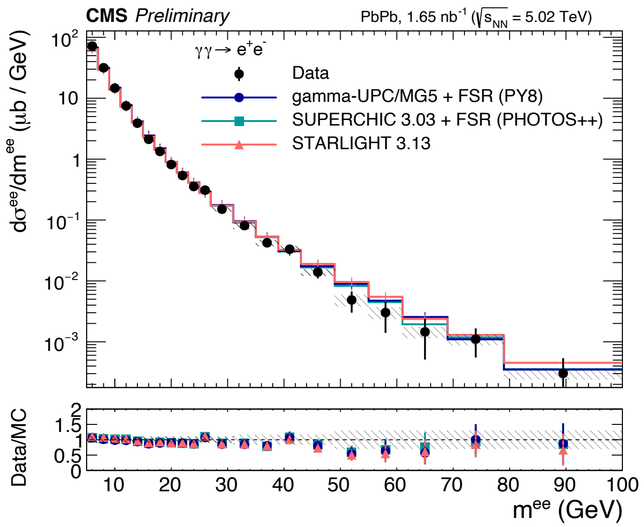
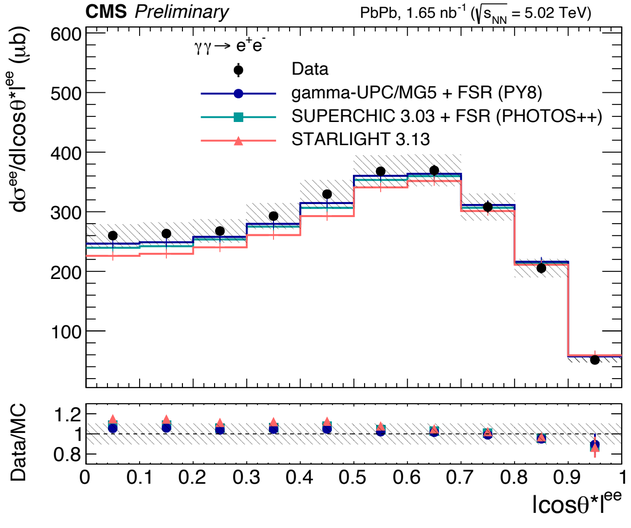
B-W Process: Unfolded Distribution

- Unfolded kinematic distributions compared with Superchic 3.03+FSR, gamma-UPC/MG5+FSR and Starlight 3.13, default unfolding performed with Superchic 3.03+FSR
- Average ±5% and in the tail ±15% uncertainty due to the unfolding added with the rest of systematics
- Within uncertainties very good agreement between data and predictions except the Starlight in p_T^{ee}









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τ-leptons pair production: Selection

Muon selection criteria

Variables	Allowed range
p_T	Soft ID > 3.5 GeV for $\|\eta\| < 1.2$ > 1.5 GeV for $1.2 < \|\eta\| < 2.4$

Neutral exclusivity

Table 8: Calorimeter thresholds

Sub-Calorimeters	η range	Threshold(GeV)
EB	$0 < \|\eta\| < 1.4442$	0.7
EE	$1.566 < \|\eta\| < 2.6$	3.0
HB	$0 < \|\eta\| < 1.305$	2.8
HE	$1.41 < \|\eta\| < 3$	1.0
HF^+	$3.15 < \eta < 5.2$	6.0
HF^-	$-5.2 < \eta < -3.15$	6.0