Evidence for light-by-light scattering and Searches for axion-like particles in Ultraperipheral PbPb collisions at 5 TeV with CMS

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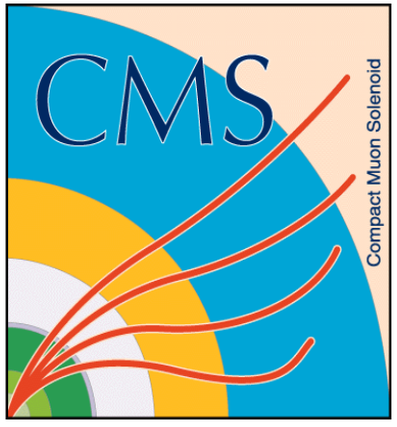

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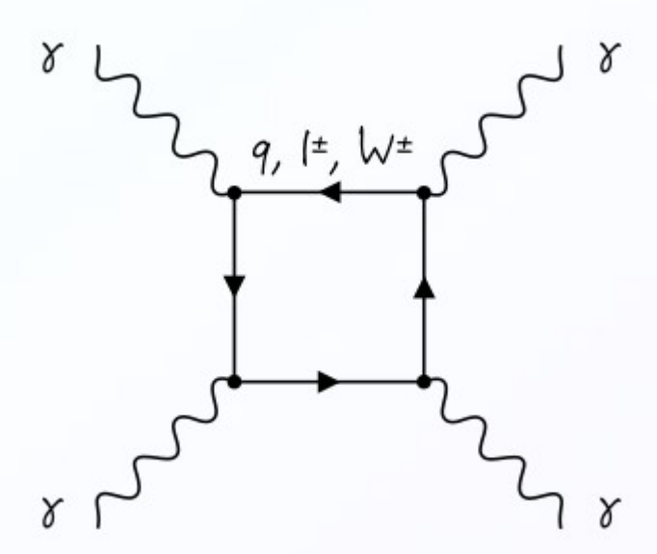
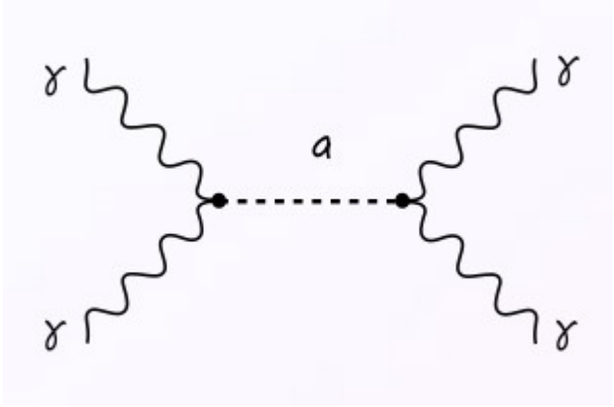
Light by light scattering and axion like particles

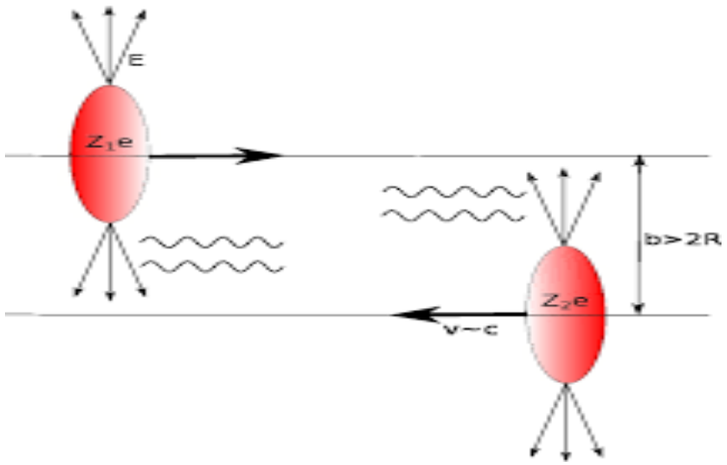


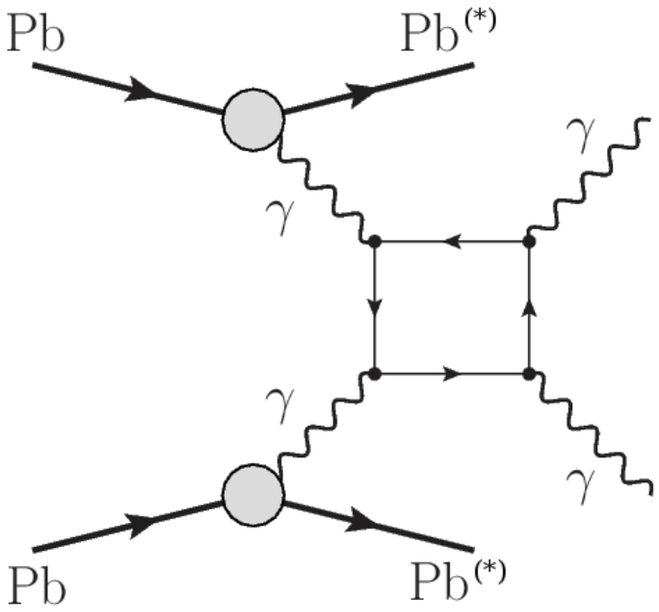
- Elastic light-by-light ($\gamma\gamma \rightarrow \gamma\gamma$) scattering, fundamental quantum-mechanical process
- Difficult to observe due to tiny cros-section: ~ O (α^4), Indirectly observed in Delbruck scattering & photon splitting
  Can be observed at the LHC using electromagnetic interaction from p, Pb beams
- In SM, the loop contains fermions and bosons but could also contain new charged particles (SUSY) or new spin-even resonances (axions, monopoles).
- Exclusive $\gamma\gamma \rightarrow \gamma\gamma$ sensitive to physics signals beyond the SM such as axions.



- Axions arise from Peccei-Quinn mechanism postulated to solve the strong CP problem, candidate of dark matter.
- Axion or axion-like particle occur in many extension of Standard Model.

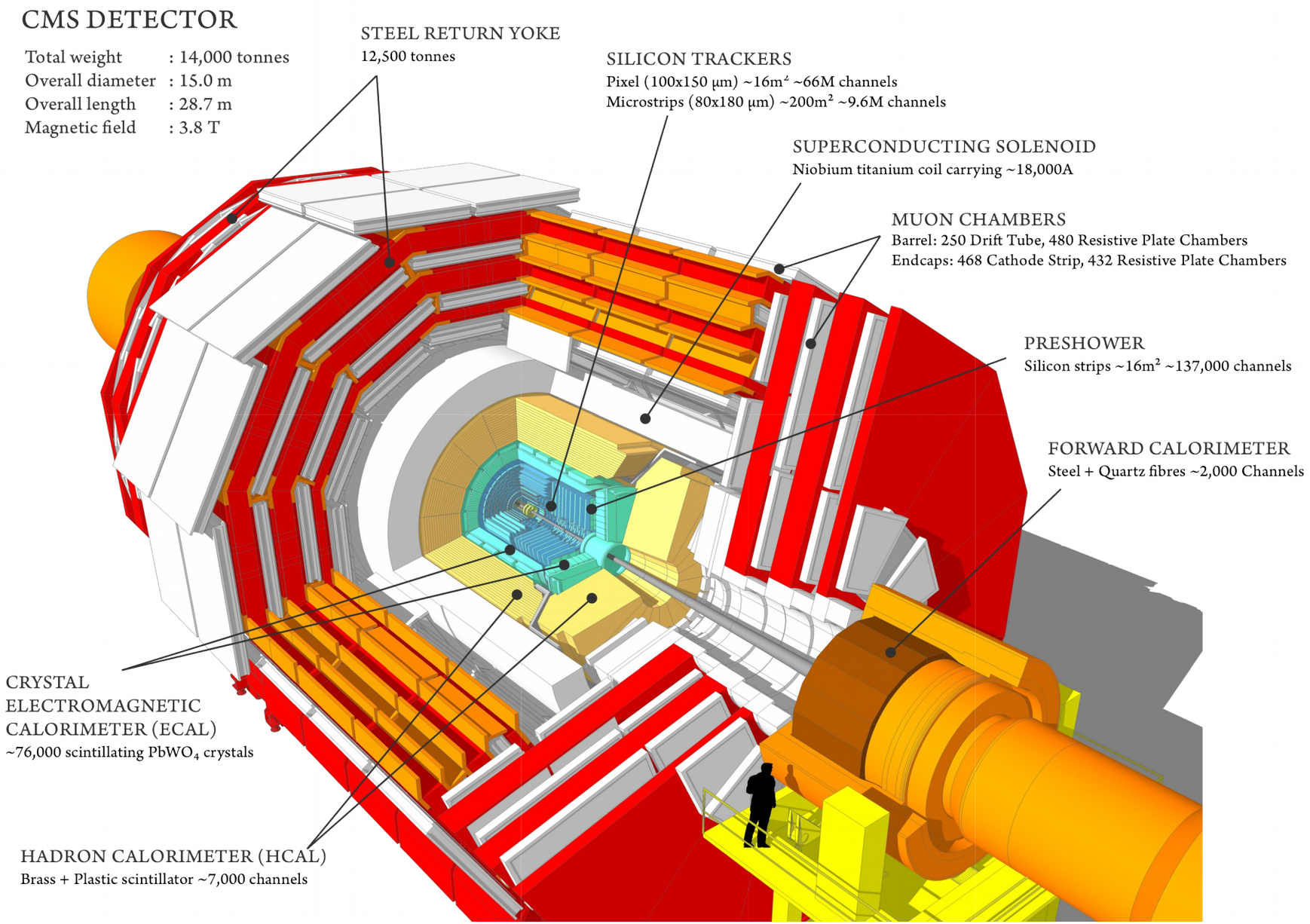
Light by light in ultra-peripheral PbPb collisions





- Light-by-light scattering can be observed at the LHC using electromagnetic interaction from p, Pb beams
- Ultraperipheral collisions (UPCs) : $b_{min} > R_A + R_B$
  Only electromagnetic interaction, no hadronic overlap
- Accelerating hadrons radiate photons
  Coherent e.m. field of Z proton(s) =
  Weizsäcker-Wiliams equivalent photon spectrum.
- Quasi-real photons, Q ~ 1/R ~ 0.06 GeV (Pb)
- Maximum photon energy : Emax ≤ γ/R ≈ 80 GeV (Pb)
- PbPb collisions favorable, Photon flux α Z^2,
  cross-section enhanced by Z^4 in AA
- Generated with MadGraph v.5 MC generator
- $W^{\pm}$ contributions only relevant for $m_{\gamma\gamma} > 2 \cdot m_W$,
  hadronic loops only for $m_{\gamma\gamma} \lesssim 2$ GeV.

The CMS detector



Search for LbyL in PbPb UPC at 5.02 TeV

Trigger

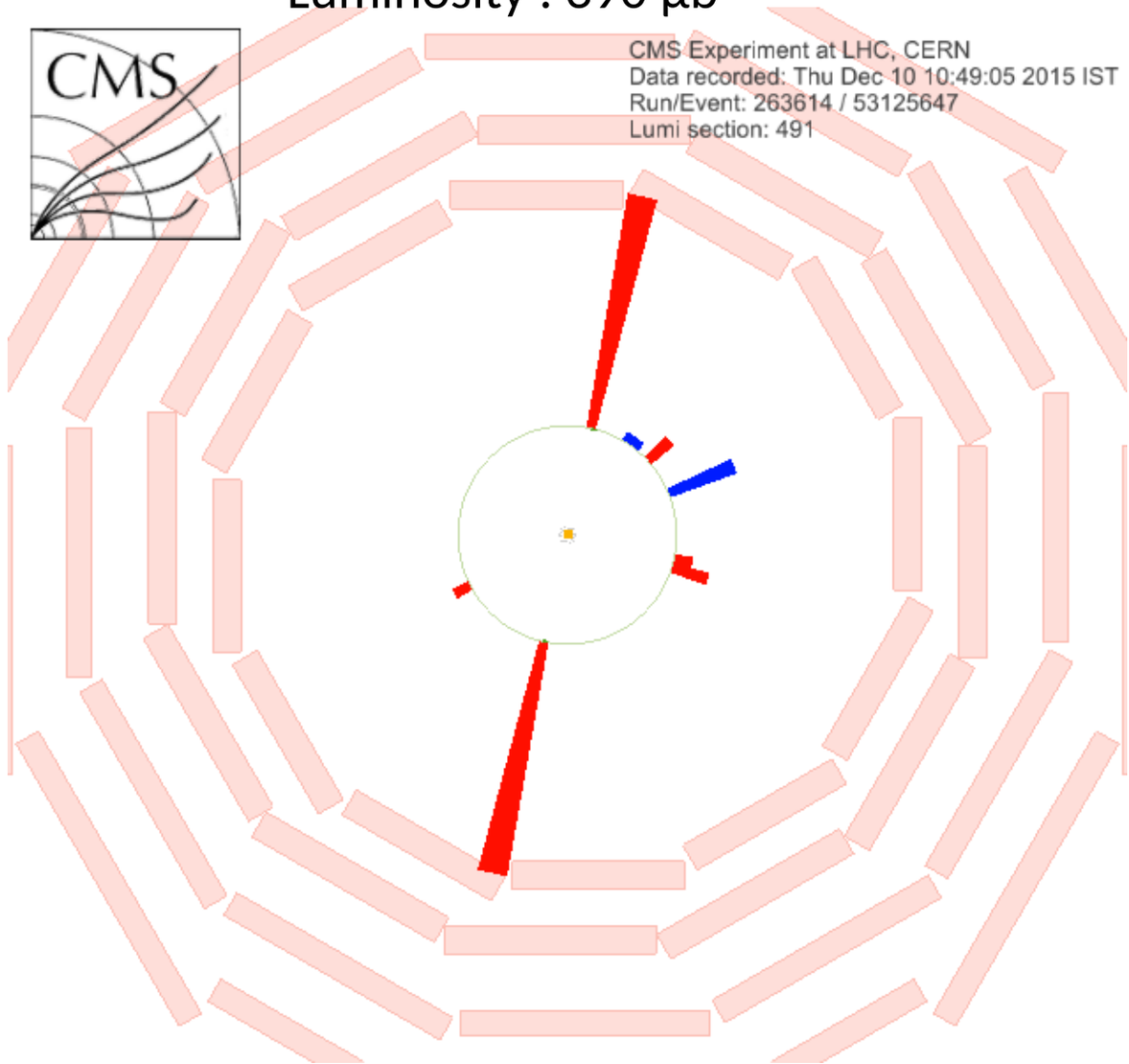
- 2 Electromagnetic shower with $E_T > 2$ GeV
- One of the Hadron Forward empty

Event selection

- Photons of interest: low E_T (2-10 GeV)
  standard CMS high-E_T e/γ reco
  ($E_T > 10$ GeV) retuned for this analysis.
- 2 γ, $E_T > 2$ GeV, $|\eta| < 2.4$, m (γγ)> 5 GeV
- **Charged exclusivity:**
  Reject events with any track
  with $p_T > 0.1$ GeV
- **Neutral exclusivity:**
  Reject events with any activity above
  noise threshold in the calorimeter
- **Back-to-back 2 γ:**
  p_T (γγ) < 1 GeV, A_Φ: (1-ΔΦ/Π) < 0.01

Data sample
2015 PbPb
Luminosity : 390 μb^{-1}

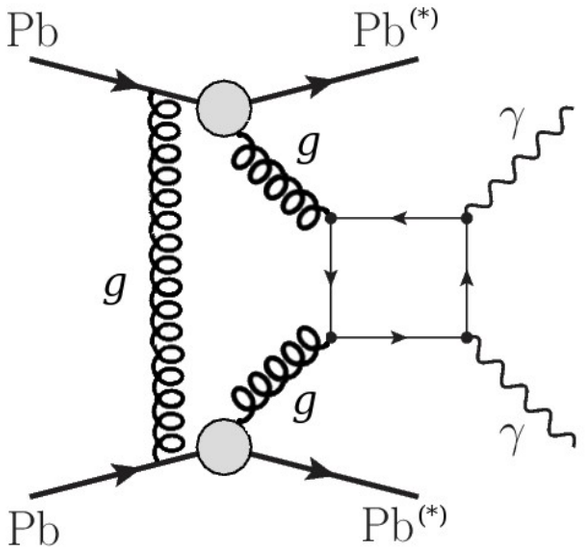
arXiv: 1810.04602

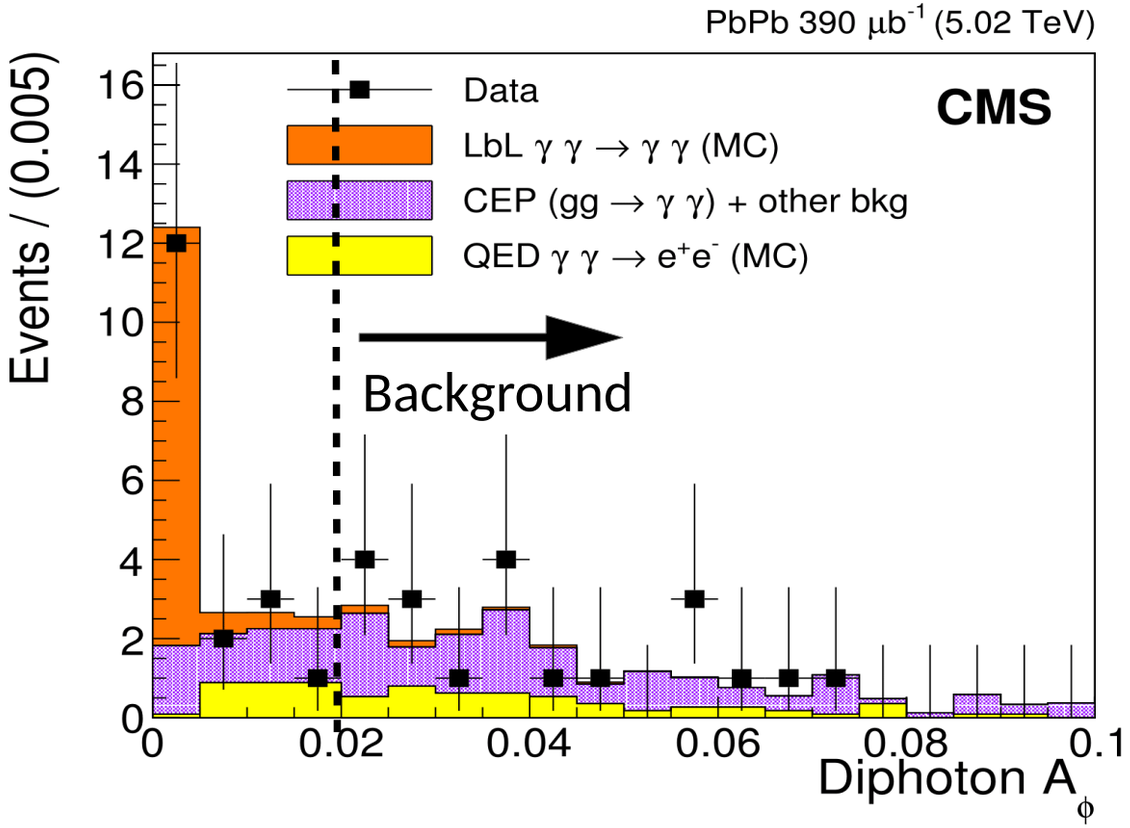


Background estimation

Central exclusive production (CEP) + residual background

- Generated with SUPERCHIC (pp scaled by $A^2 R_g^4$, S^2=100%).
- Larger theoretical uncertainty for CEP in PbPb collisions
- Normalized to data in control region $A_\Phi > 0.02$





- The background normalization factor:

$$f^{\text{norm}}_{\text{nonacoplanar}} = \frac{N_{\text{data}}(A_\phi > 0.02) - N^{\text{MC}}_{\text{LbL}}(A_\phi > 0.02) - N^{\text{MC}}_{\text{QED}}(A_\phi > 0.02)}{N^{\text{MC}}_{\text{CEP}}(A_\phi > 0.02)}$$

$f^{\text{norm}}_{\text{nonacoplanar}} = 1.06 \pm 0.35$ (stat).

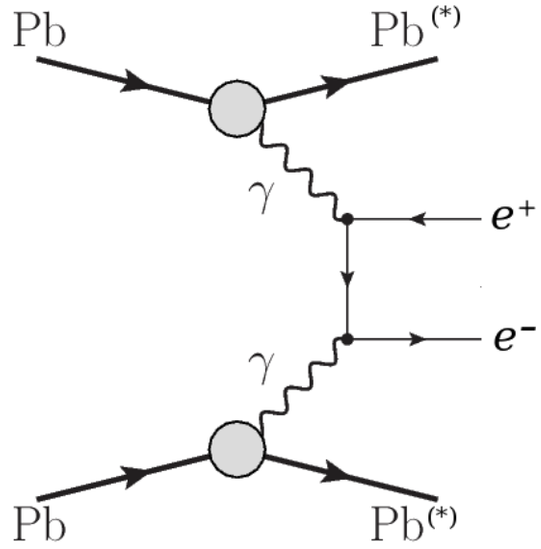
- CEP + residual backgrounds in LbL signal region: 3.0 ± 1.1 (stat).

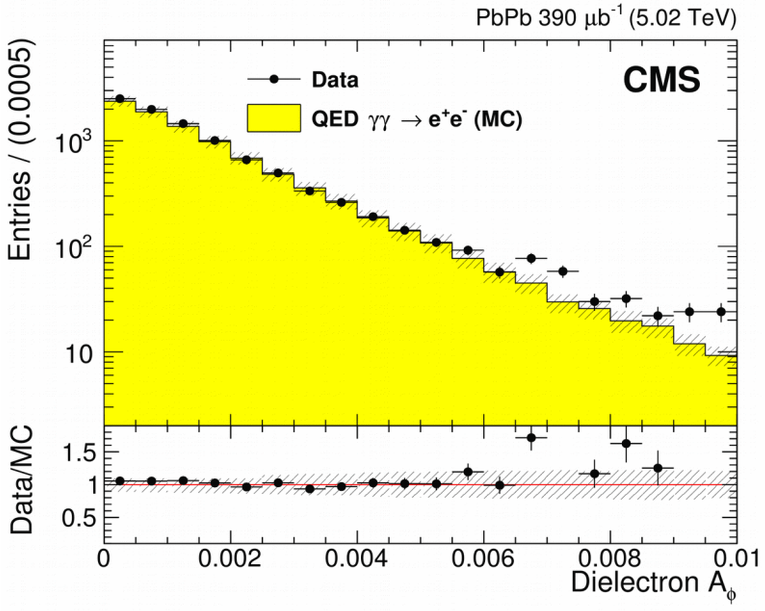
arXiv: 1810.04602

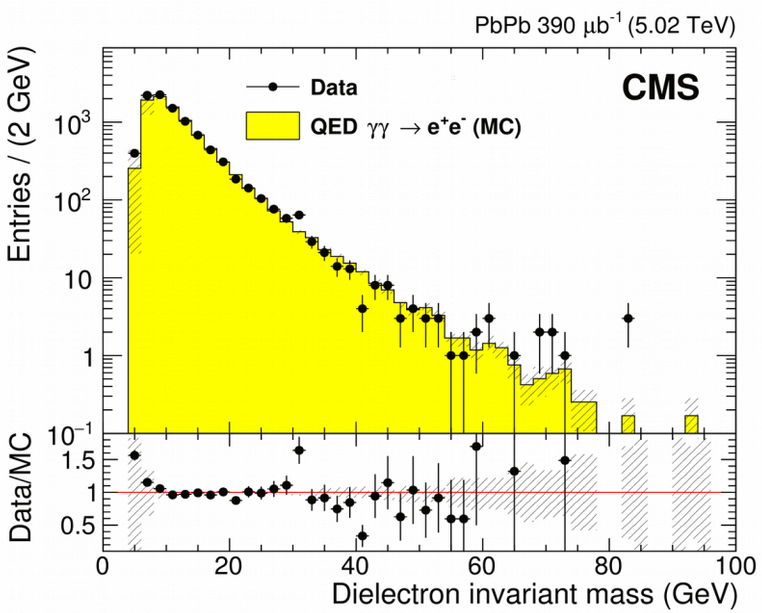
Background estimation

QED background : γγ → $e^+ e^-$

- Electrons mis-identified as γ, if track not reconstructed / undergo hard bremsstrahlung.
- Generated with STARLIGHT
- Analysis re-done with LbyL cuts, except requiring 2 opposite-sign electrons





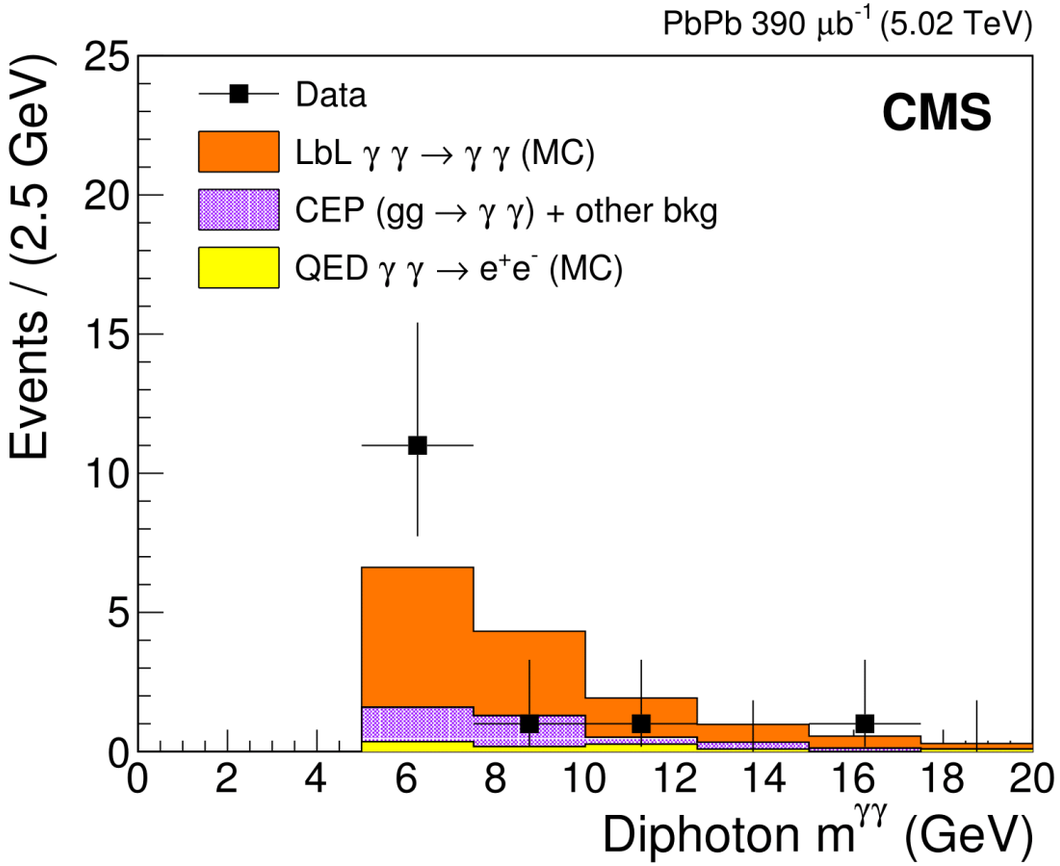


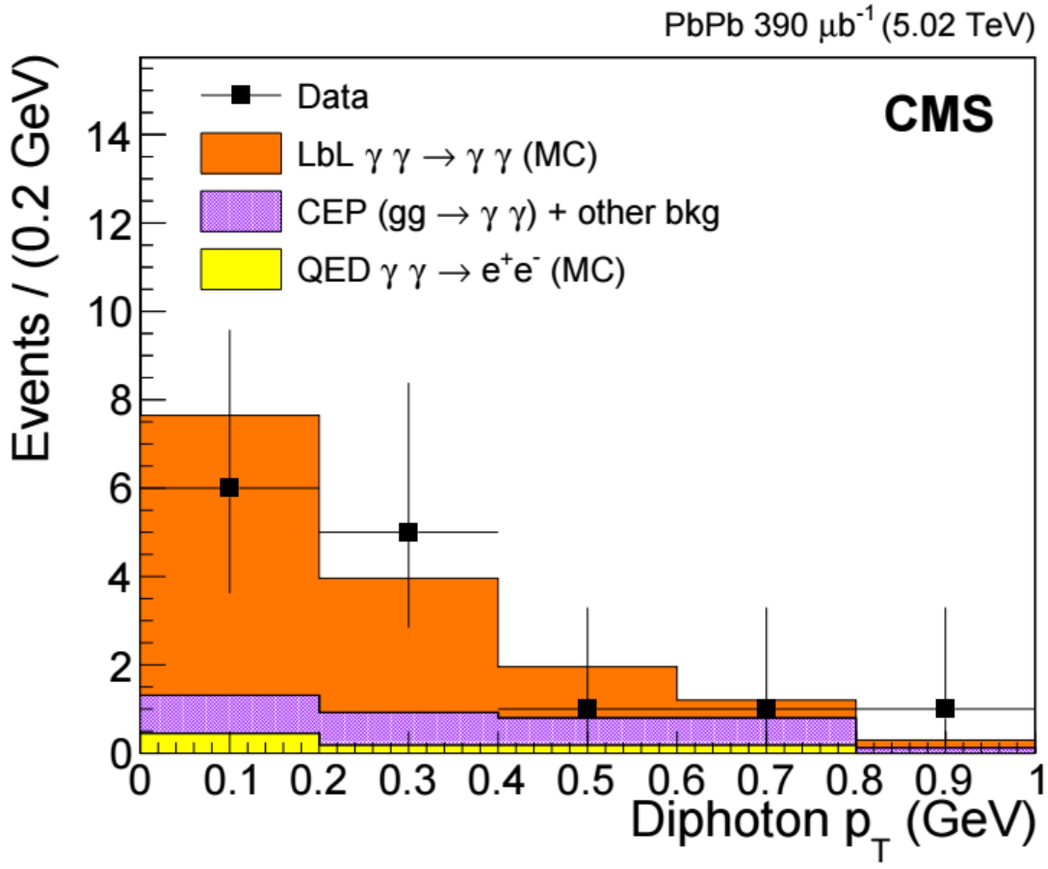
- Very good data-MC agreement over m_{ee} ~ 5-90 GeV.
- Confirms quality of e/γ reco. validity of exclusive event selection criteria, as well as of MC predictions for PbPb UPCs.
- QED background in LbL signal region: 1.0 ± 0.3 (stat).

arXiv: 1810.04602

γγ differential distributions (after all cuts)

arXiv: 1810.04602





Data: 14 evts, **Nsig =11.1 ± 1.1**, **Nbkg = 4.0 ± 1.2** expected.
The measured yields and kinematic distributions
are in good agreement with the MC
expectations (LbyL + QED + CEP + other)

LbyL cross-section & signal significance

- Measured the ratio of LbyL to QED e+e- cross section
  - Reduces uncertainties related to luminosity
  - The main sources of uncertainties: trigger, single $\gamma/e^{\pm}$ efficiencies

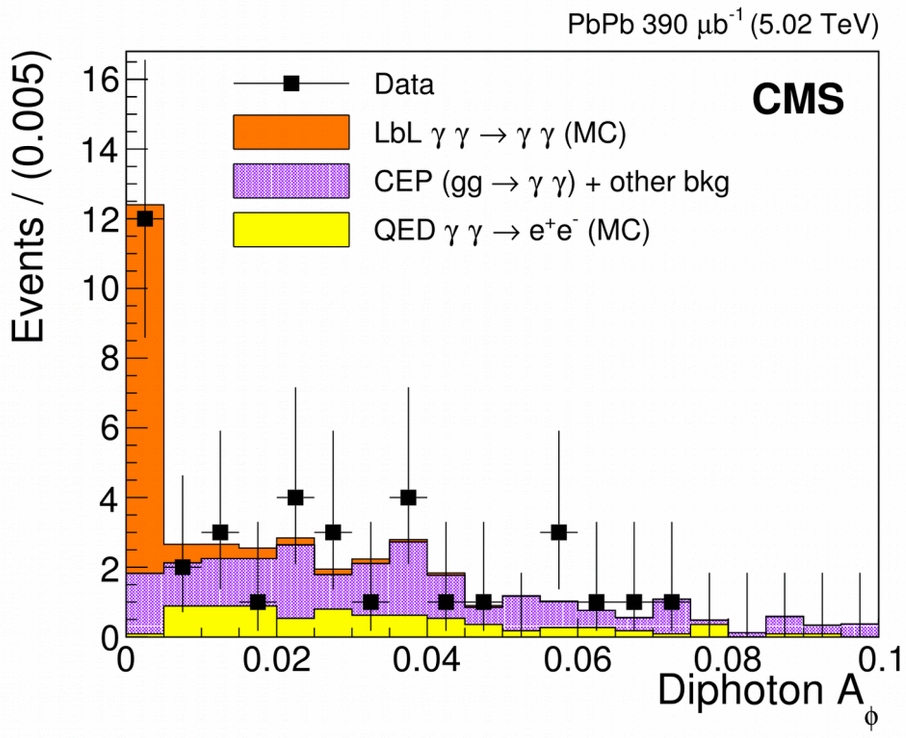
arXiv: 1810.04602

Photon reconstruction and identification ($SF^{\gamma,reco+ID}$)	$(2\times9)\%$
Electron reconstruction and identification ($SF^{e,\ reco+ID}$)	$(2\times2.5)\%$
Trigger	12%
Size of simulated background samples	6%
Total	23%

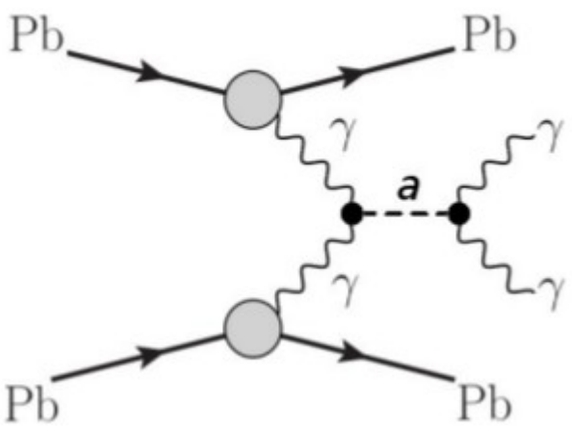
- $R = \sigma_{fid}(\gamma\gamma \rightarrow \gamma\gamma)/\sigma(\gamma\gamma \rightarrow e^+e^-)$
  $= [25.0 \pm 9.6\ (stat.) \pm 5.8\ (syst)\ ] \times 10^{-6}$

- Fiducial LbyL cross section derived from R and QED e^+e^- X-section from STARLIGHT = 4.82 ± 0.15 (th) mb
  $\sigma_{fid}(\gamma\gamma \rightarrow \gamma\gamma) = 120 \pm 46\ (stat) \pm 28\ (syst) \pm 4\ (th)$ nb,
  consistent with SM prediction: σ(fid) = 138 ± 14 nb.

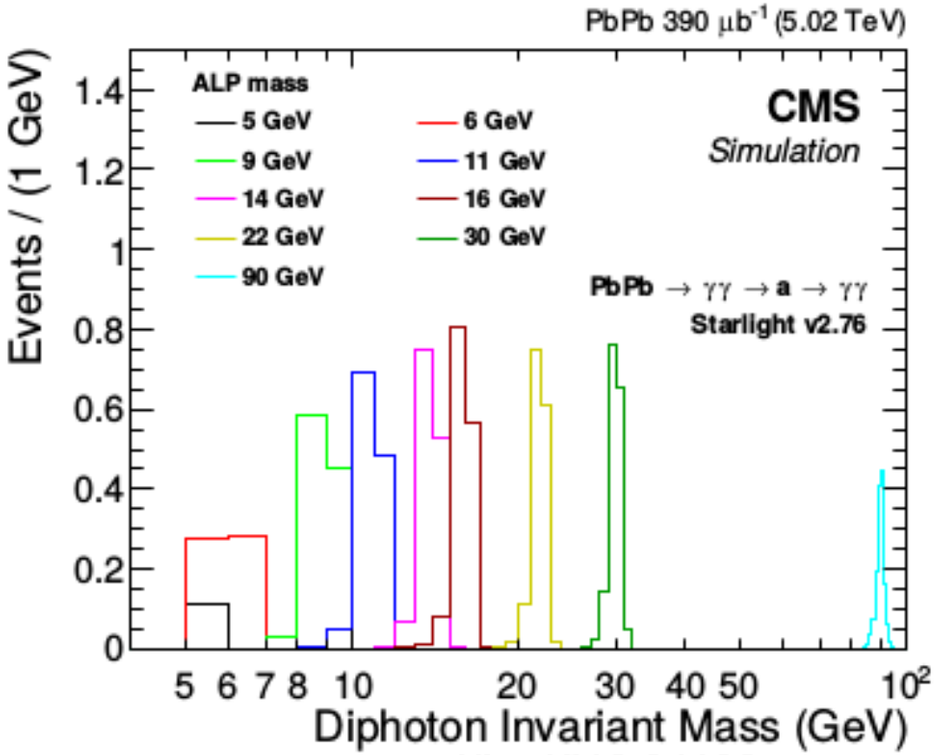
- Compatibility of the data with background-only hypothesis, via profile-likelihood ratio of acoplanarity distribution:
  LbyL significance: 4.1σ observed (4.4σ expected).



Search for axion-like particles



- The measured diphoton invariant mass distribution used to search for pseudoscalar axion-like particles $\gamma\gamma \rightarrow a \rightarrow \gamma\gamma$
- ALP samples for masses : 5-90 GeV, generated from STARLIGHT
- No significant ALP excess observed in data above LbL+ backgrounds
- Limits in σ ($\gamma\gamma \rightarrow a \rightarrow \gamma\gamma$) at 95% confidence,100% $\gamma\gamma$ branching ratio (CLs criterion with a profile likelihood as a test statistics).



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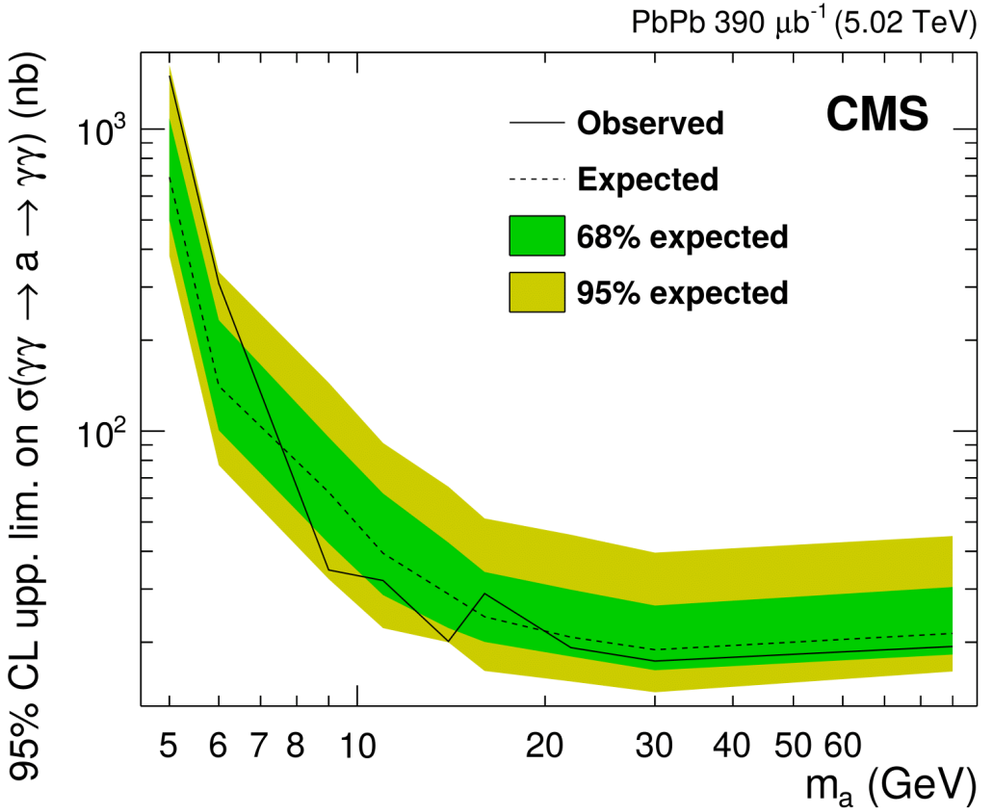
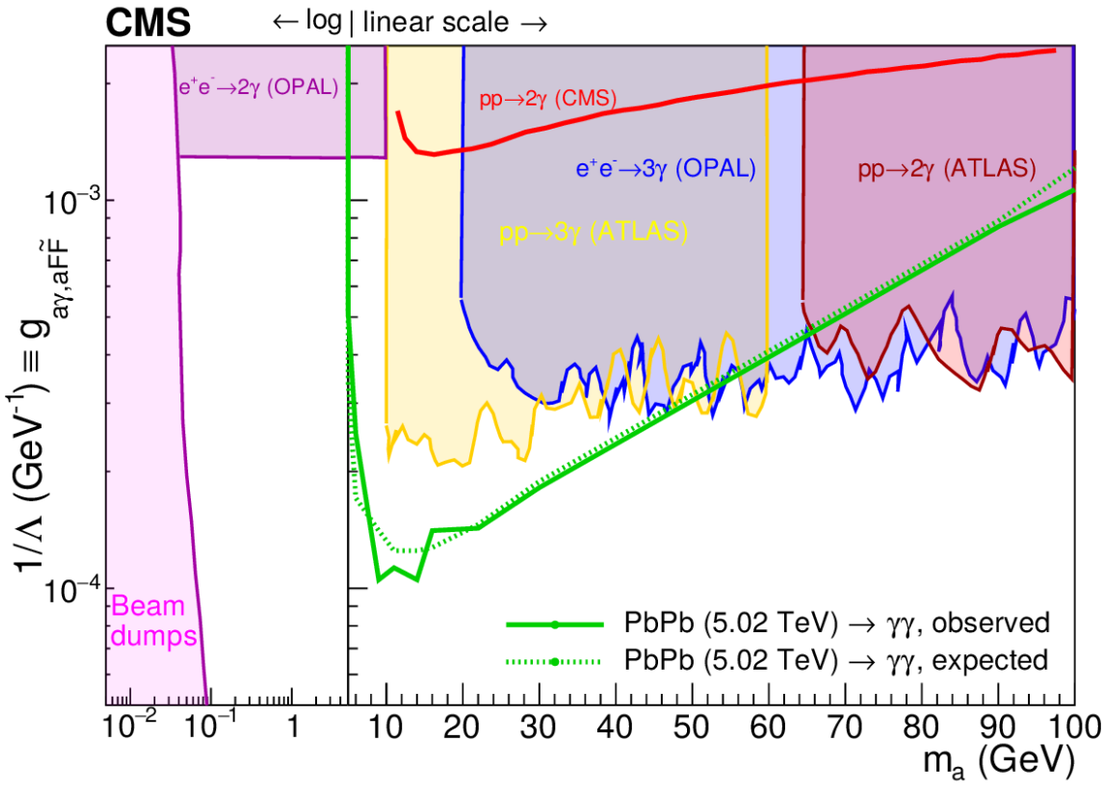
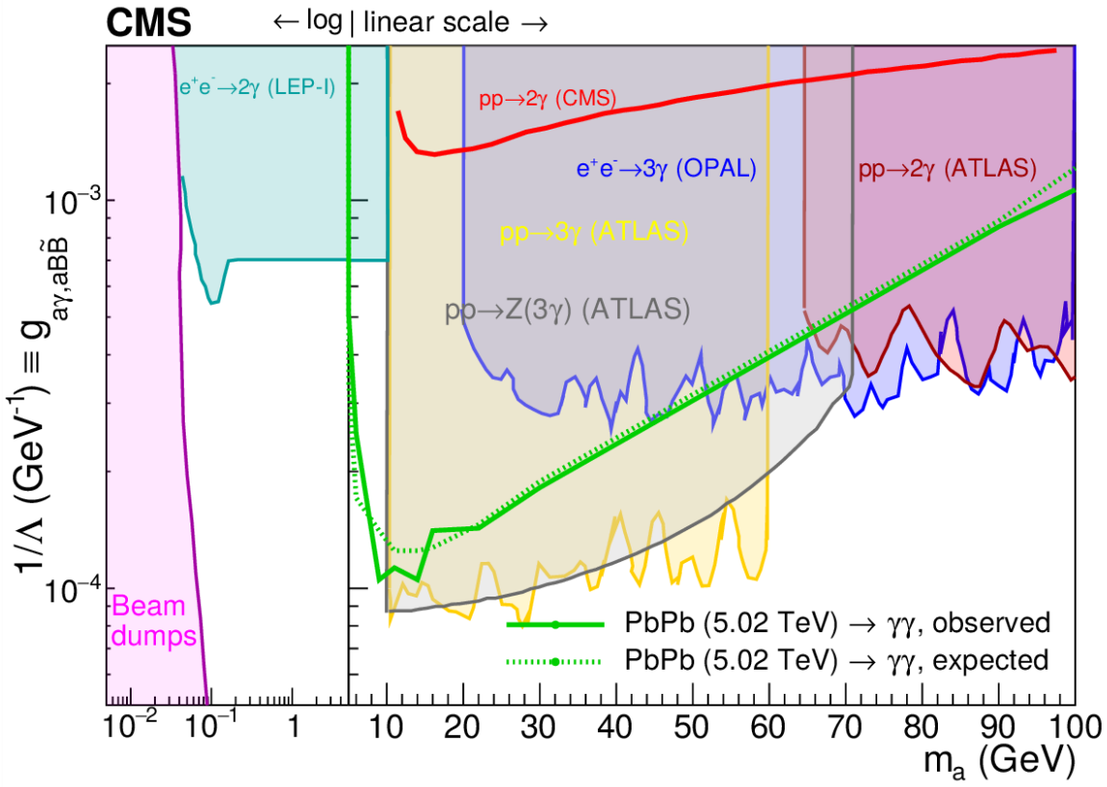


Search for axion-like particles

- Limits in cross-section → limits in $g_{a\gamma}$ vs. m_a plane
- ALPS coupling only to photons (left plot)
  - Best exclusion limits so far over the m_a = 5–50 GeV
- ALPS coupling to photons or hypercharge (right plot)
  - New constraints in the m_a = 5-10 GeV.

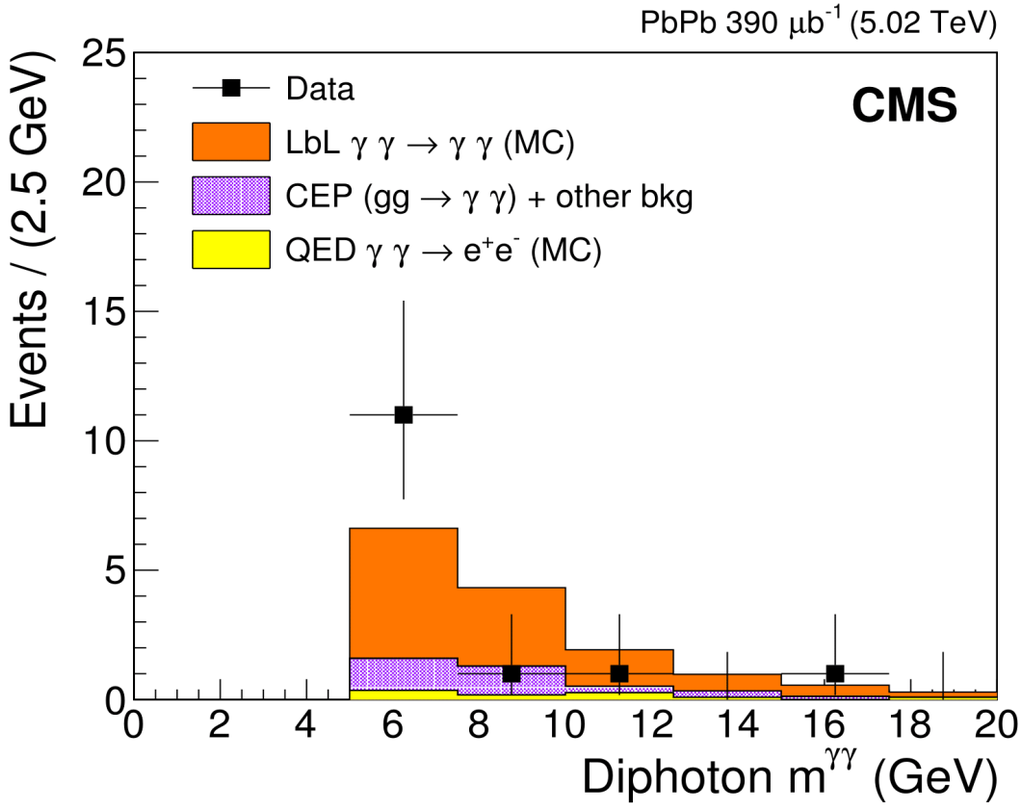
arXiv: 1810.04602



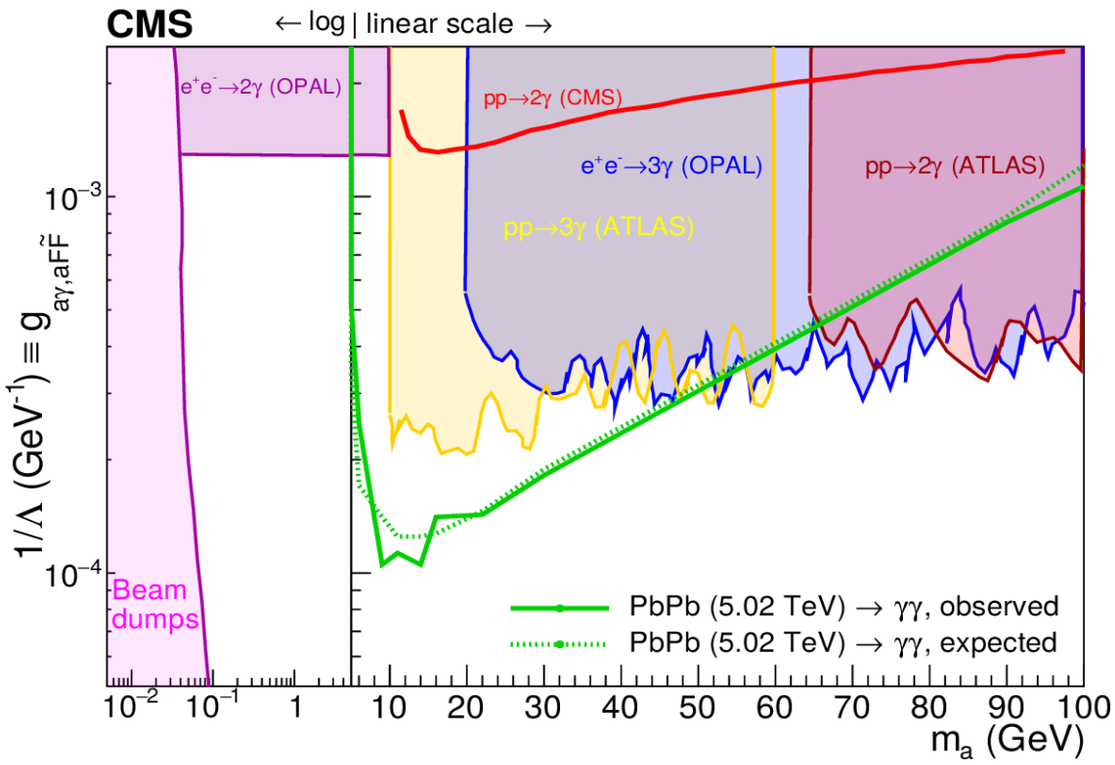


Summary

- Evidence for light by light scattering, 4.1 (4.4)σ observed (expected)
- 14 light-by-light events observed - consistent with the SM predictions,



- No significant excess observed
- Competitive exclusion limits on axion-like particles



Analysis ongoing with four times more luminosity with 2018 PbPb data.

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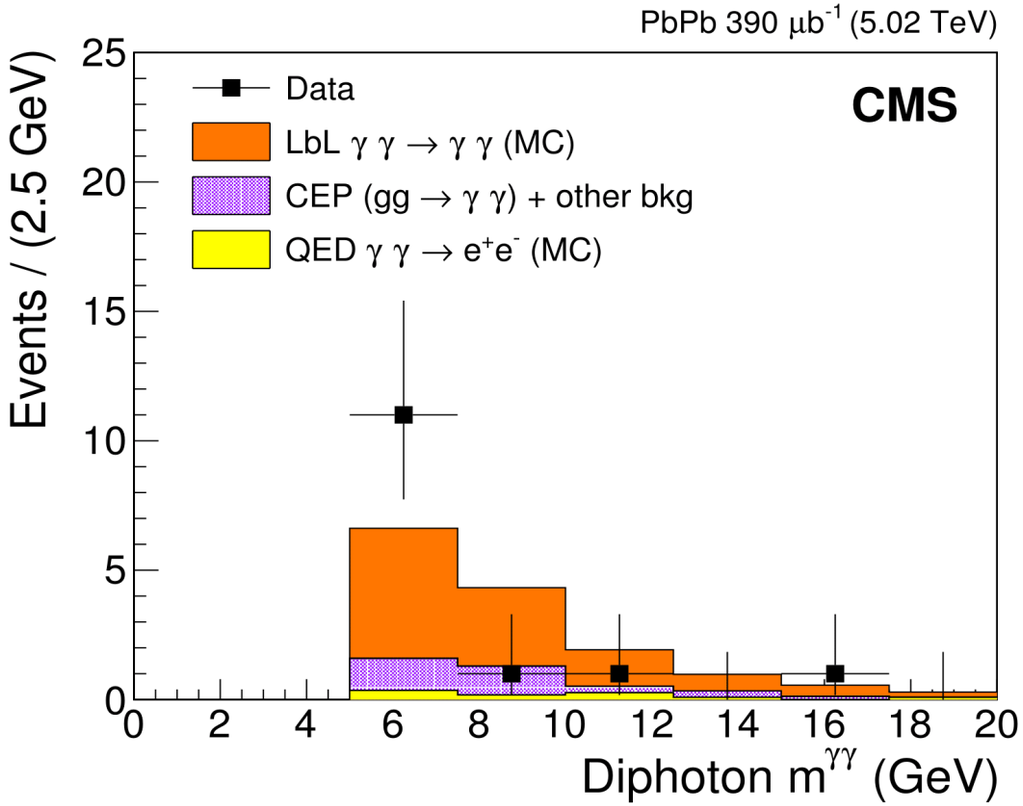

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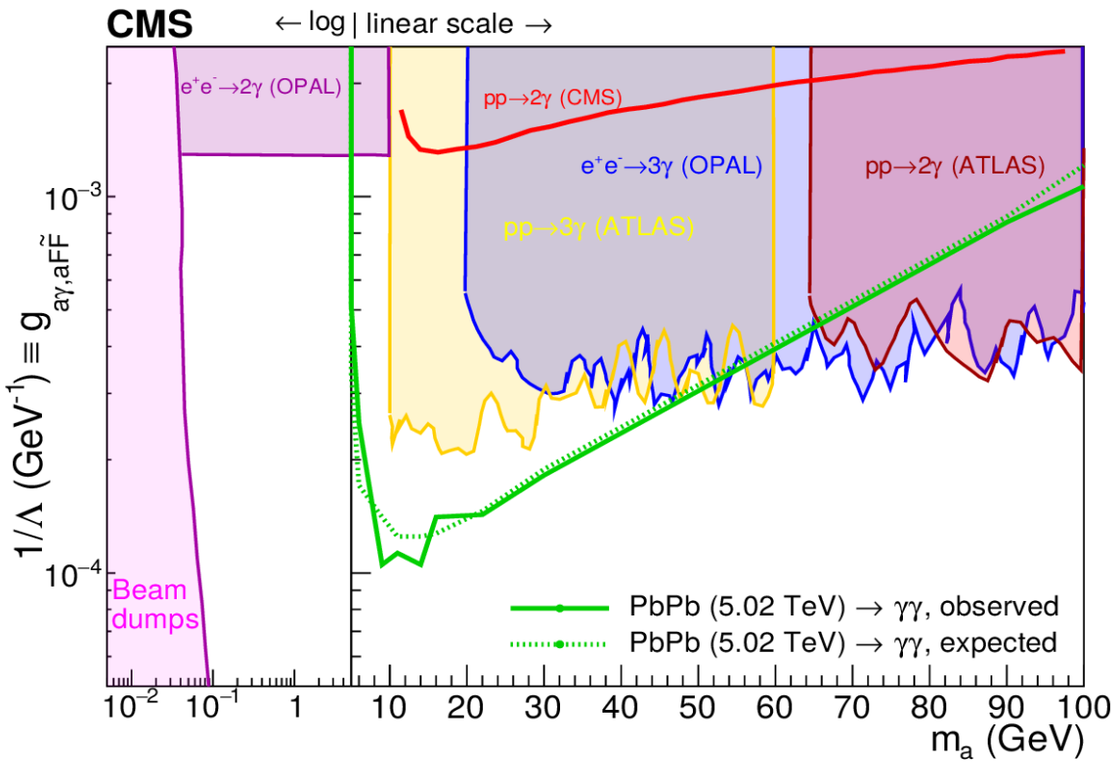

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Stay tuned!