# Measurement of light-by-light scattering in ultra-peripheral Pb+Pb collisions with the ATLAS detector

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[based on JHEP 03 (2021) 243]

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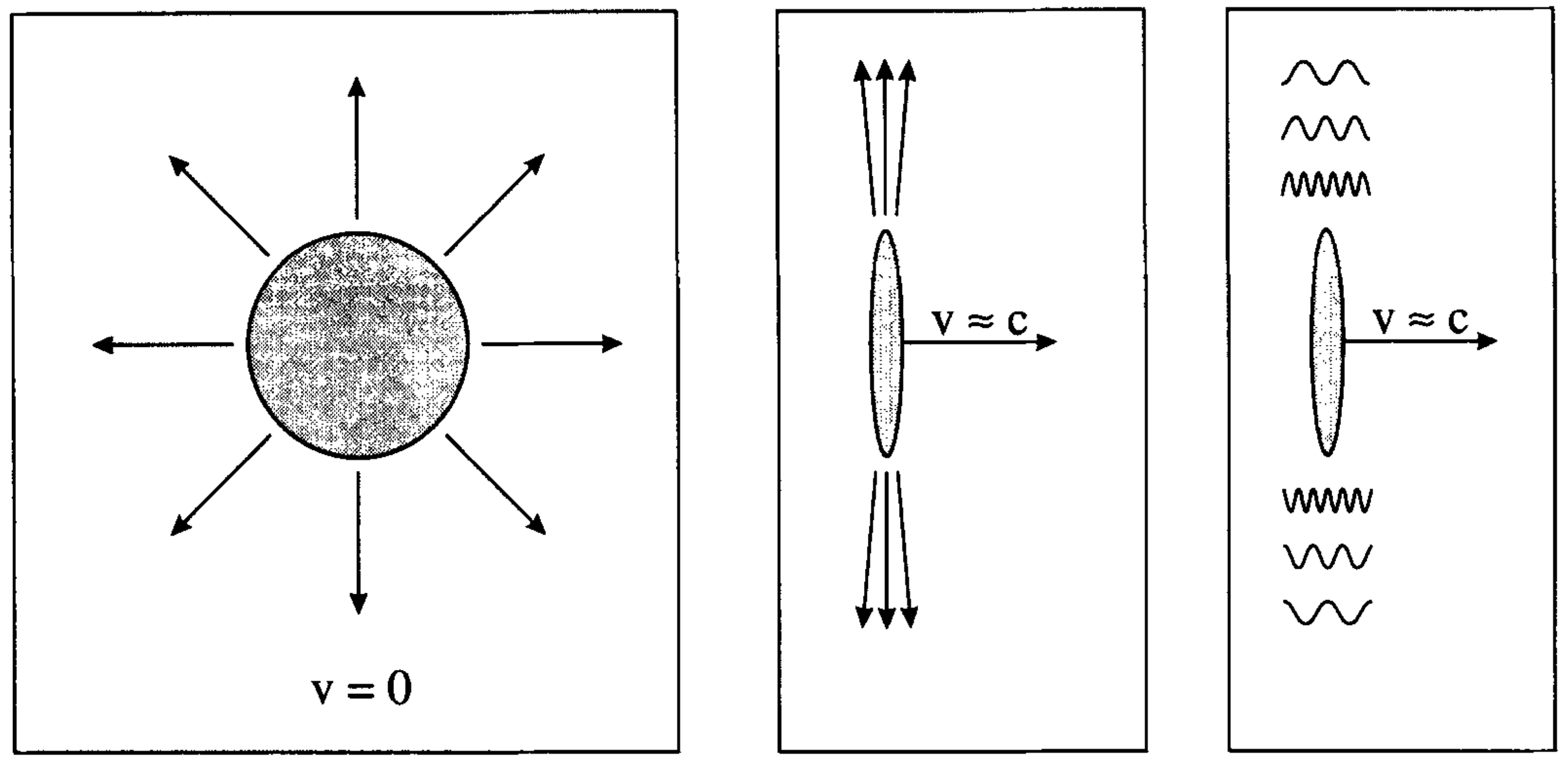
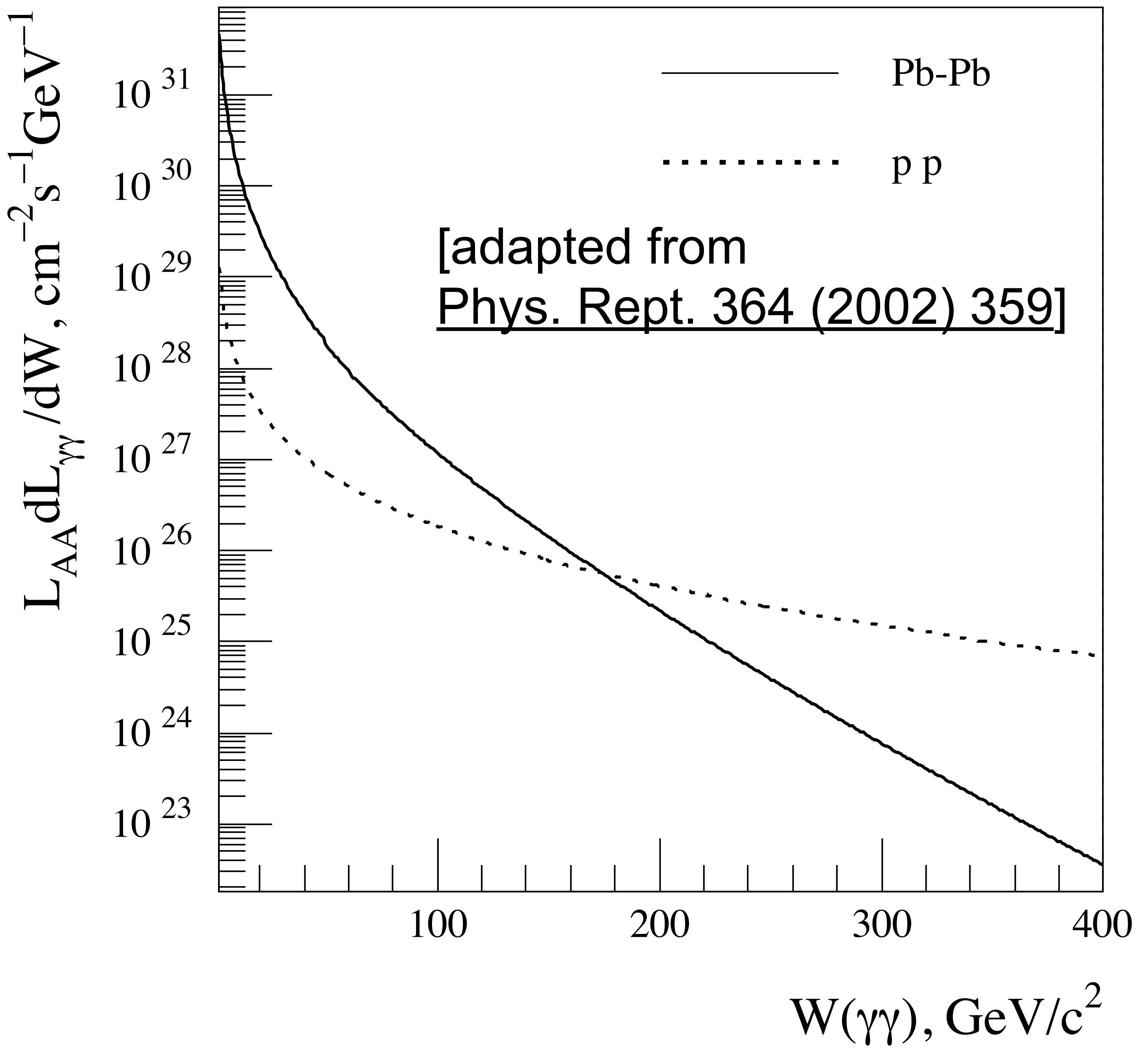
# Introduction

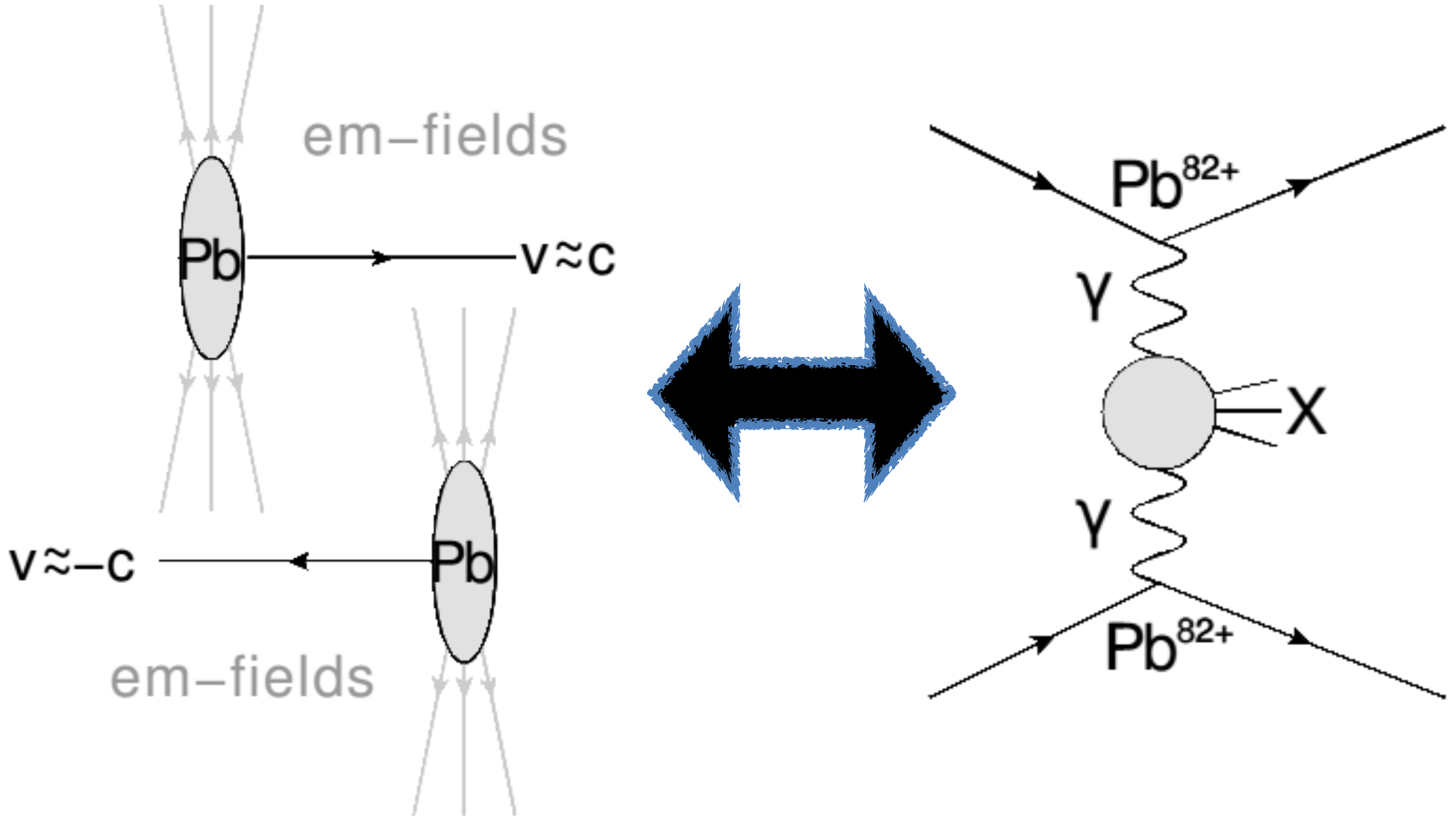
[from Prog. Part. Nucl. Phys. 39 (1997) 503]




- **Boosted charged-particles** are intense source of photons
- **Quasi-real photon flux**
  - $\mathbf{E_{max}}$ ~γ/R **~2 TeV** (protons @LHC)
    **~80 GeV** (Pb ions @LHC)

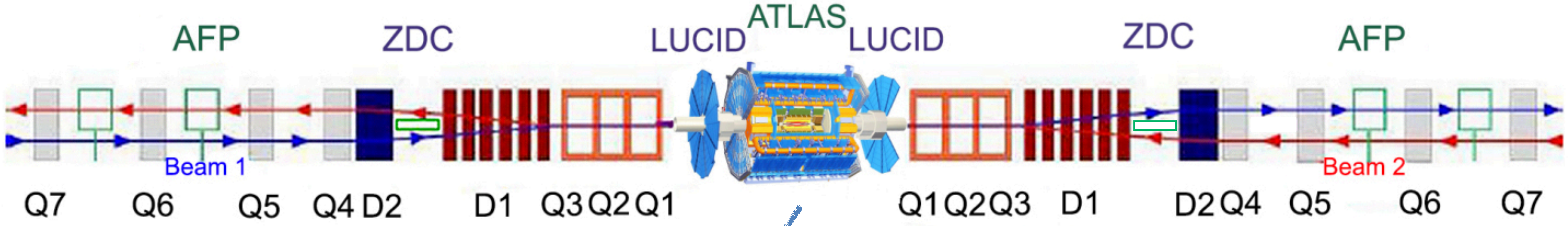


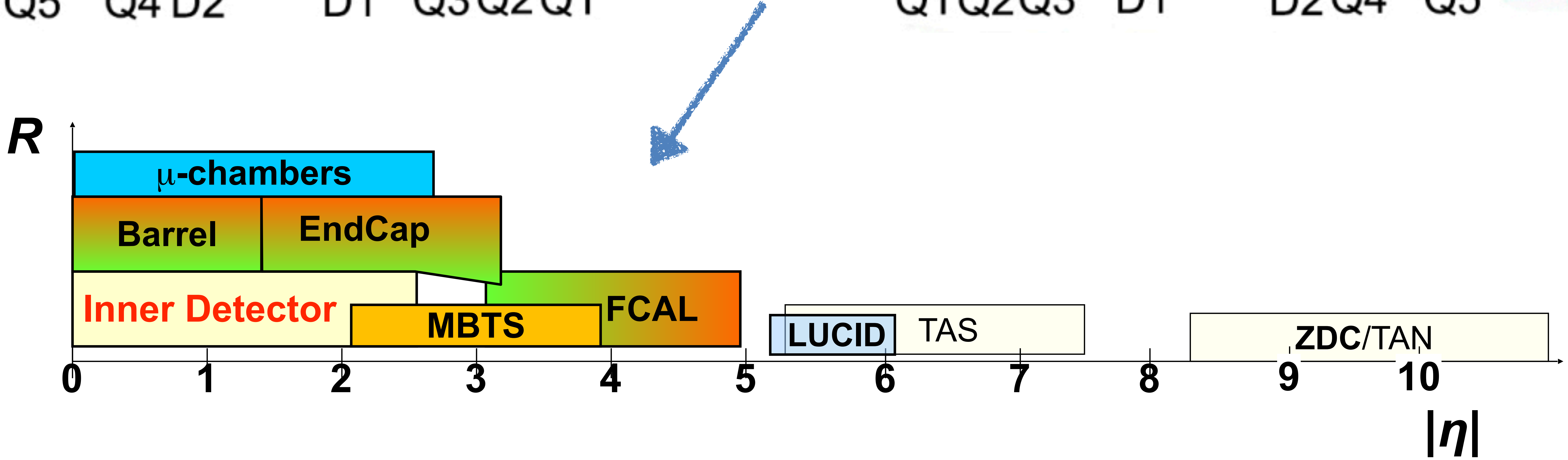

- Clean access to **high-energy electroweak interactions**



# Experimental approach

- **Exclusive final states → Exclusivity requirements** are essential
  - Many sub-detectors available in ATLAS
  - Outgoing ions escape into beampipe, neutrons from (EM) dissociation can be tagged by **Zero Degree Calorimeters (ZDC)**



# LbyL (γγ→γγ) scattering in PbPb

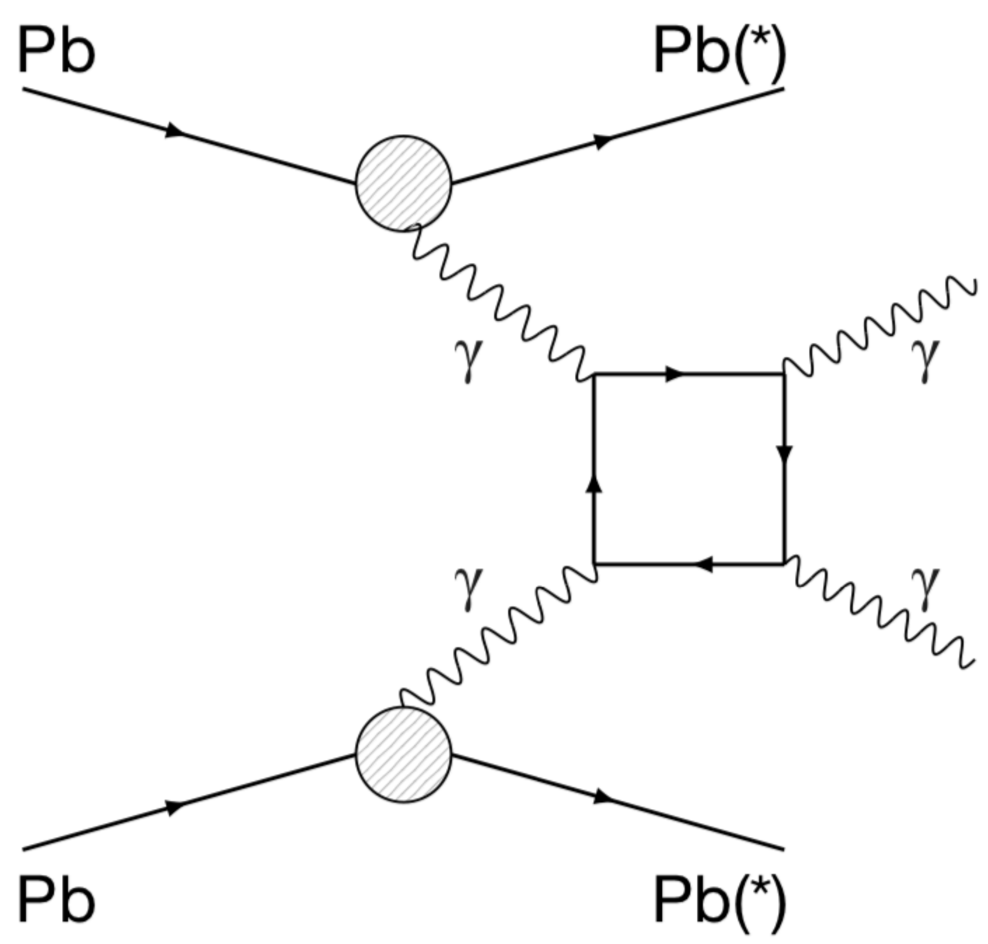
- Rare O($\alpha_{EM}^4$) process
  - Sensitive to BSM effects

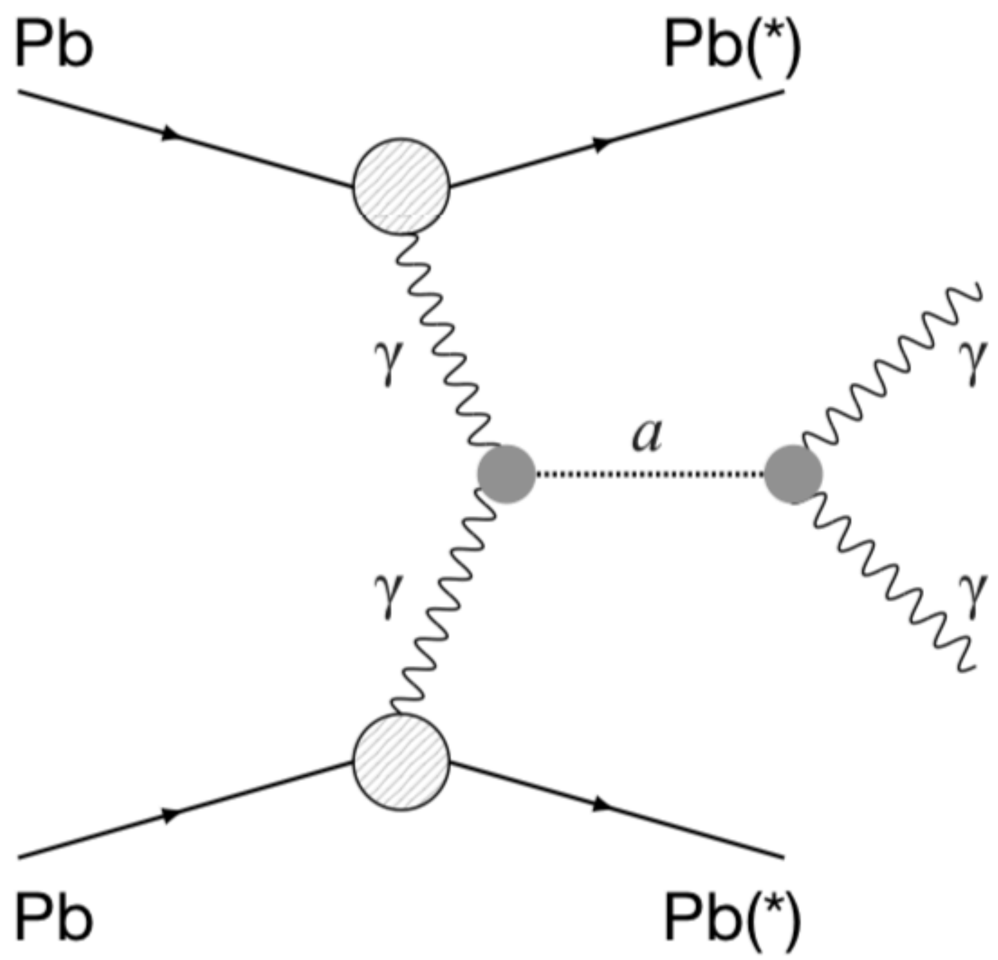
Original idea:
PRL 111 (2013) 080405

ATLAS, Nature Phys. 13 (2017) 852
CMS, PLB 797 (2019) 134826
ATLAS, PRL 123 (2019) 052001

- Previous LHC measurements:
  - 2015 data: ATLAS & CMS (~4σ evidence)
  - 2018 data: ATLAS (8.2σ observation)

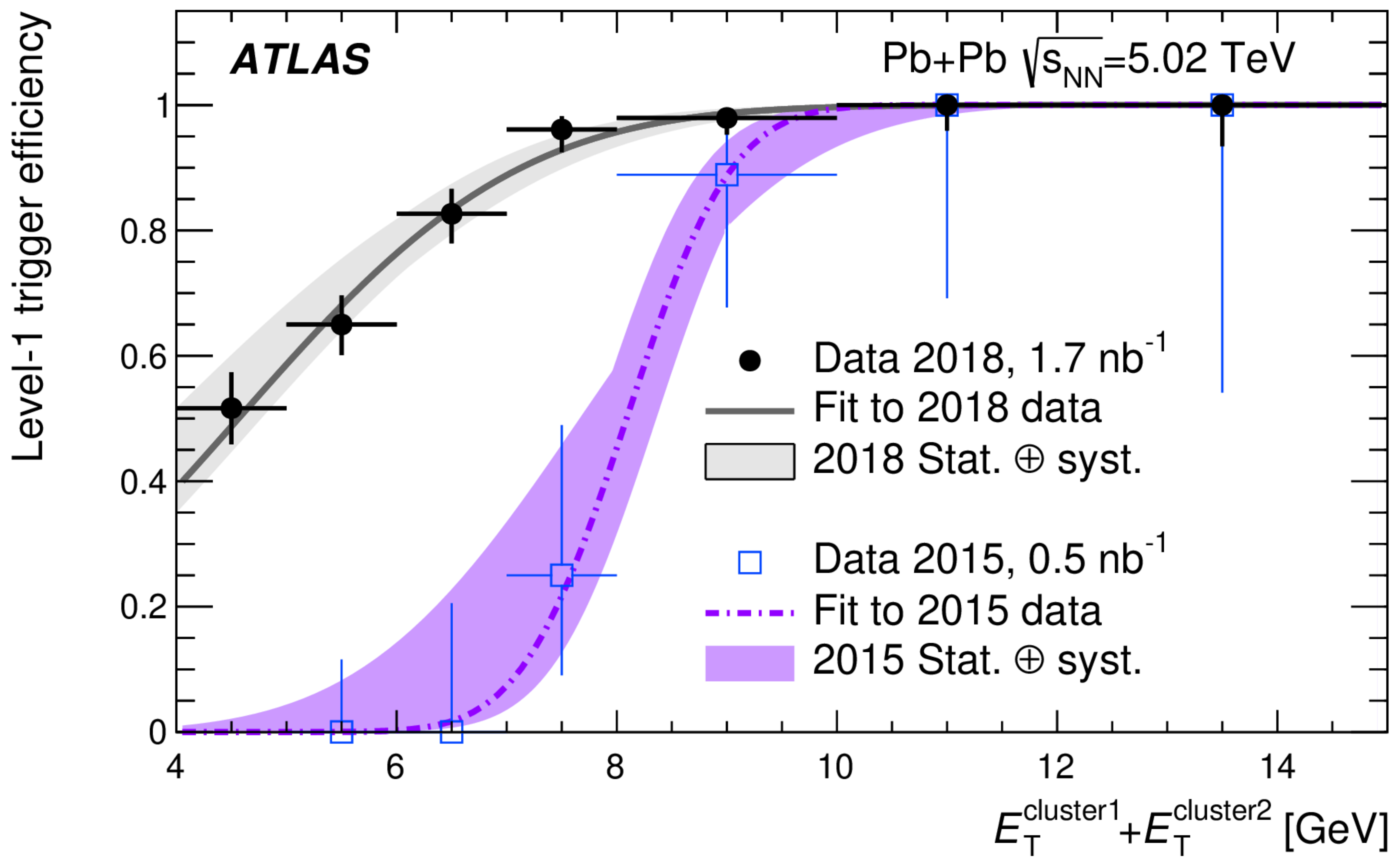
- **The new analysis [JHEP 03 (2021) 243] covers:**
  - Exploration of full Run-2 Pb+Pb dataset
  - Differential cross-section measurement
  - Search for axion-like particles

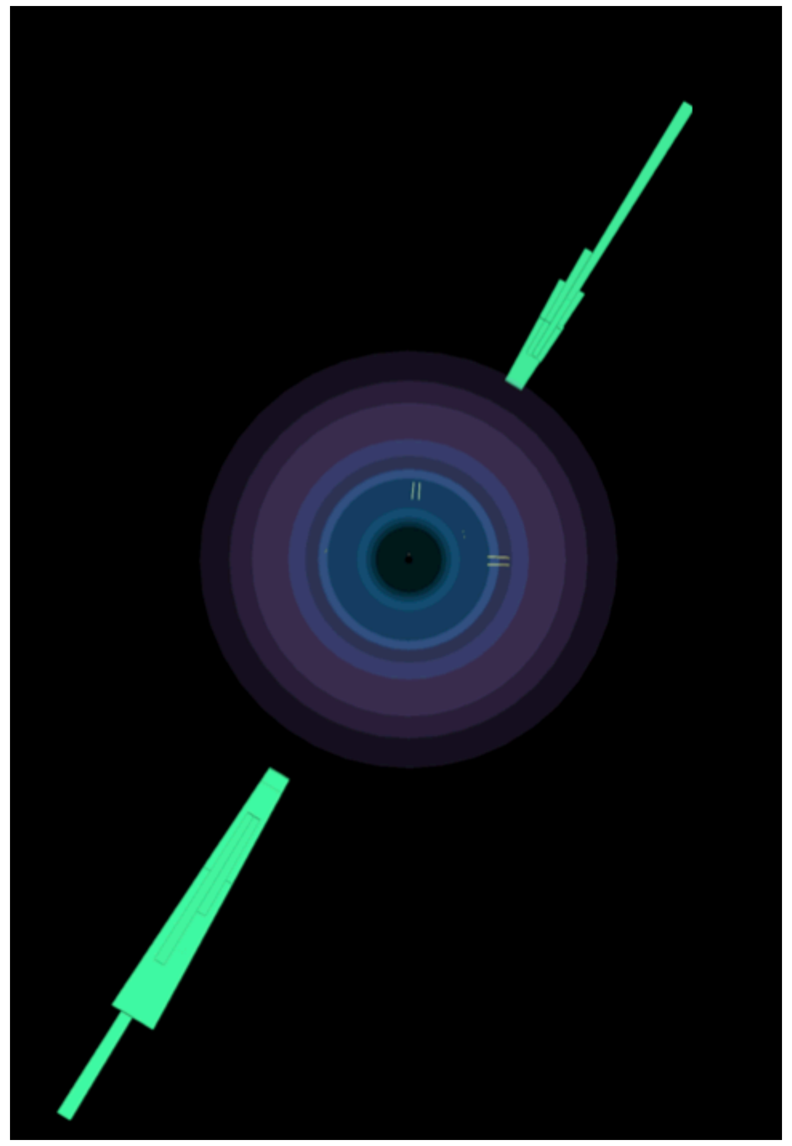


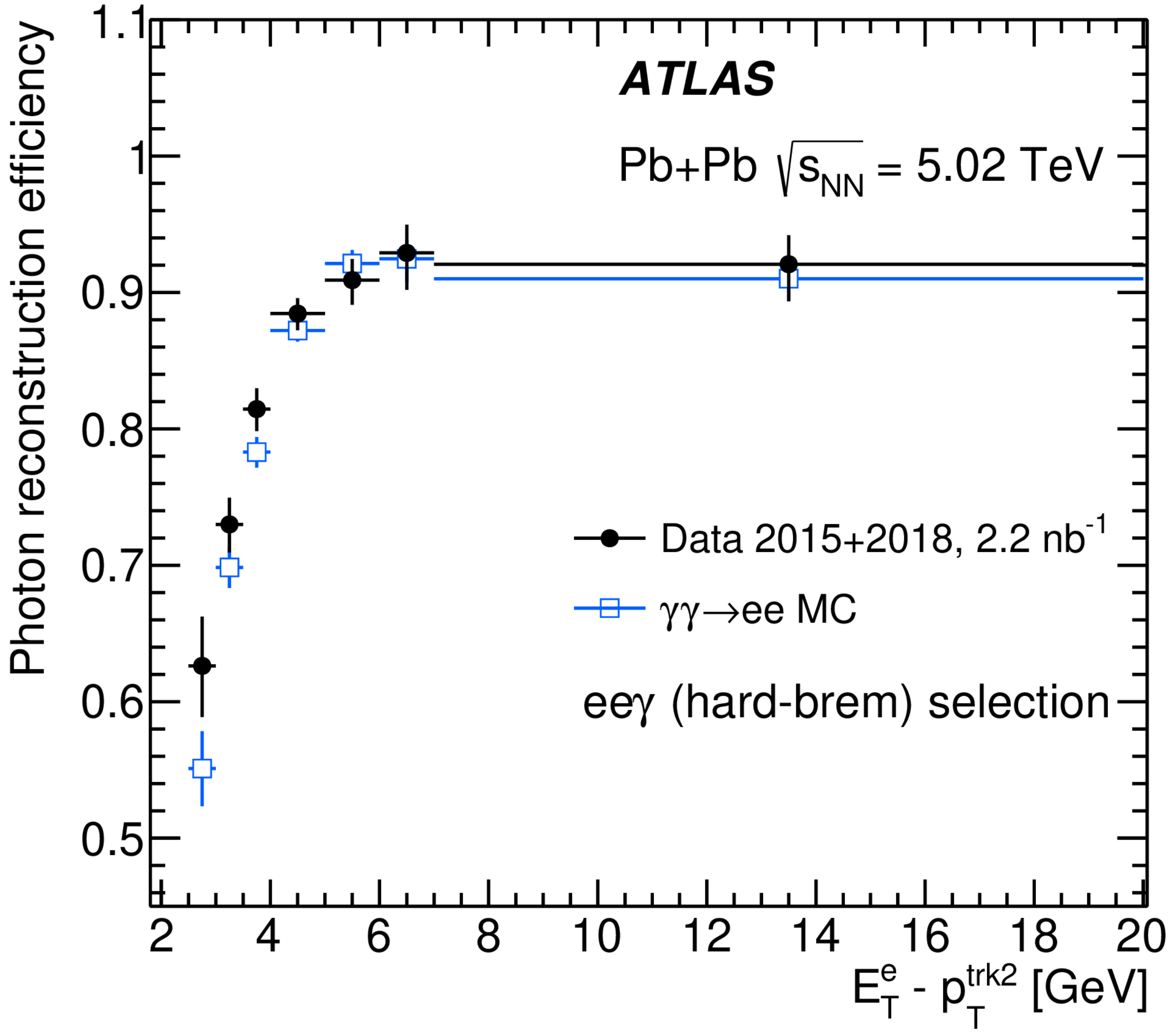
# Analysis selection

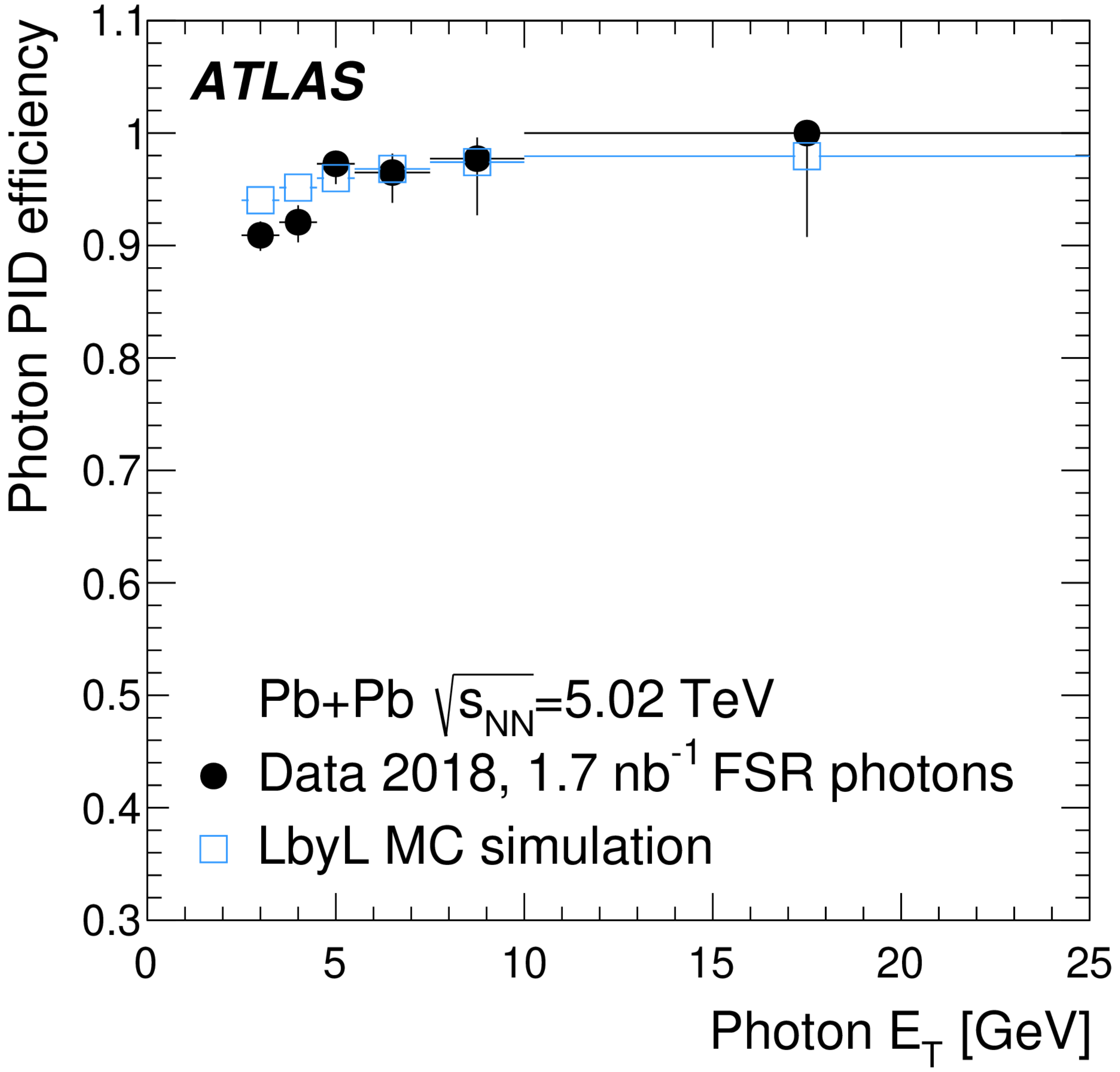
- Good-quality data in the detector (2.2/nb of Pb+Pb data from 2015+2018 runs)
- Trigger based on low activity in the calorimeter
  - great improvement of trigger efficiency at low photon $E_T$ in 2018 comparing to 2015
- Detectors are pushed to the limits
  - Very low $E_T$ photons (**$E_T$ > 2.5 GeV**, $|\eta| < 2.37$)
  - Invariant diphoton mass **M(γγ) > 5 GeV**
  - Track veto ($p_T$ >100 MeV) + pixel track veto ($p_T$ >50 MeV)
- Back-to-back topology
  - $p_T(\gamma\gamma) < 1$ GeV
  - Acoplanarity: $Aco = 1 - |\Delta\phi_{\gamma\gamma}|/\pi < 0.01$



# Detector calibration

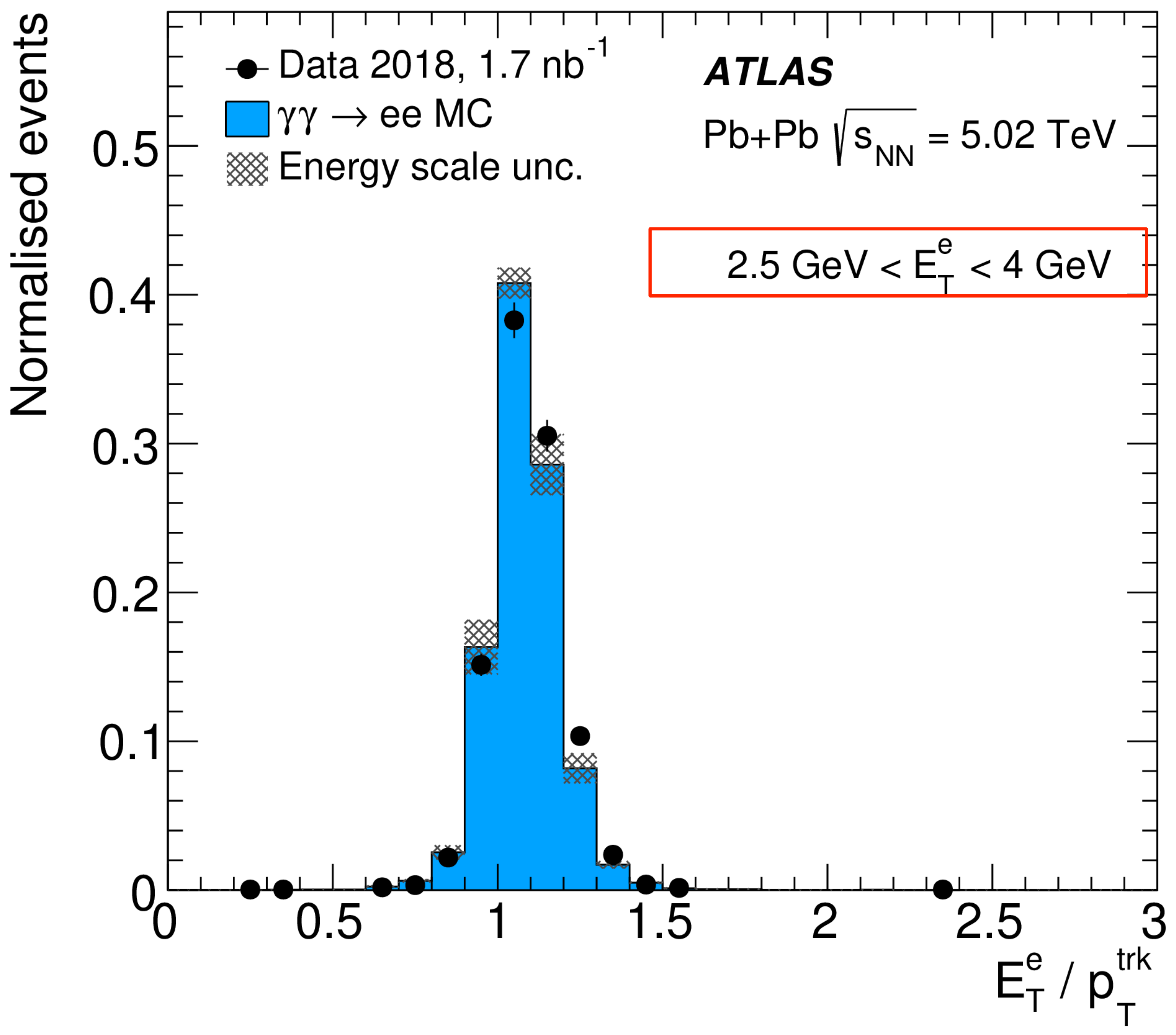


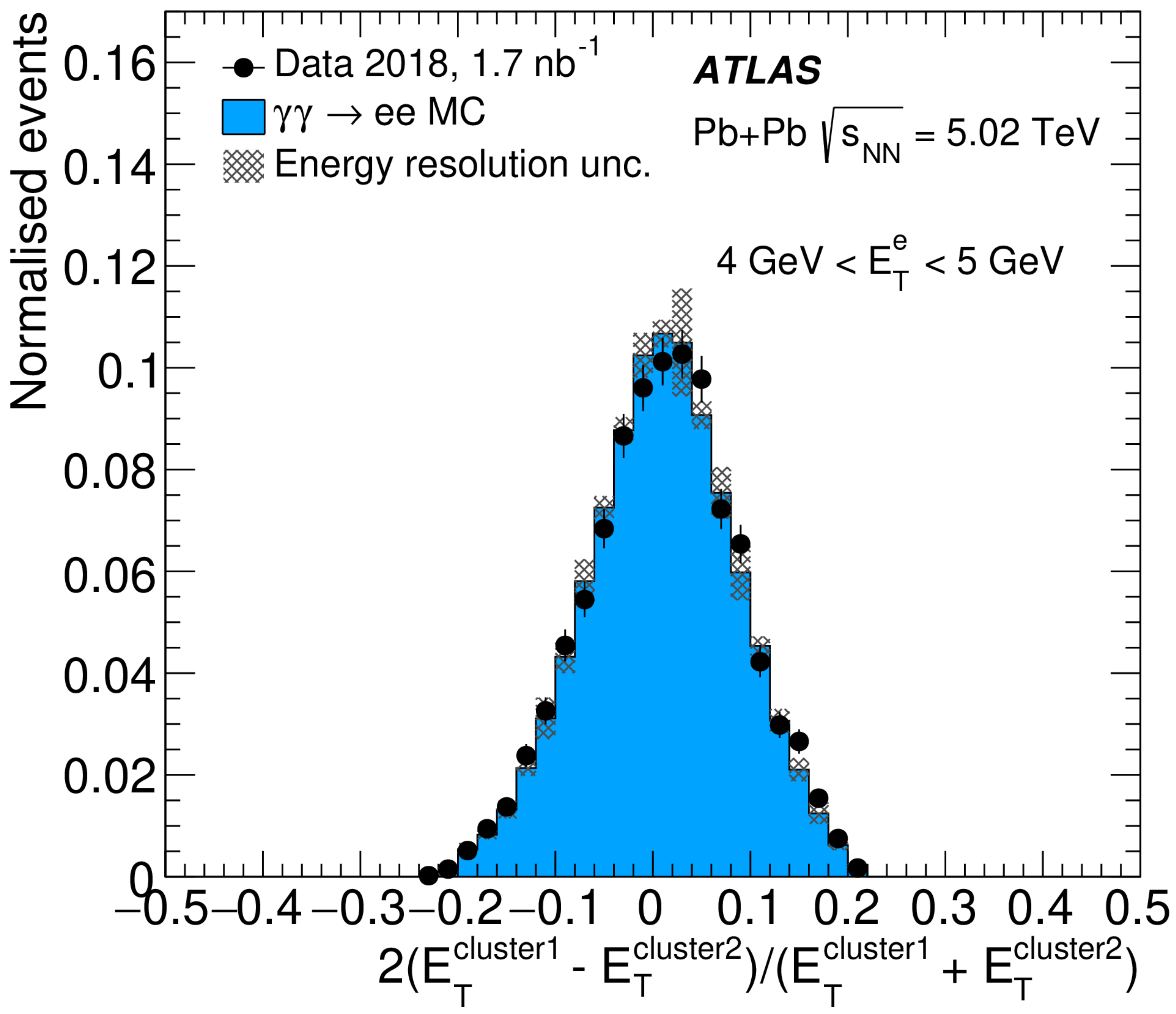




- Photon reconstruction efficiency
  - Use hard bremsstrahlung photons from yy→ee to extract efficiency in data and MC simulation
- Identification efficiency → optimised for low-ET photons
  - yy→ll events with FSR are used for data-driven efficiency measurement
- Differences between data and MC included in dedicated corrections

# Detector calibration

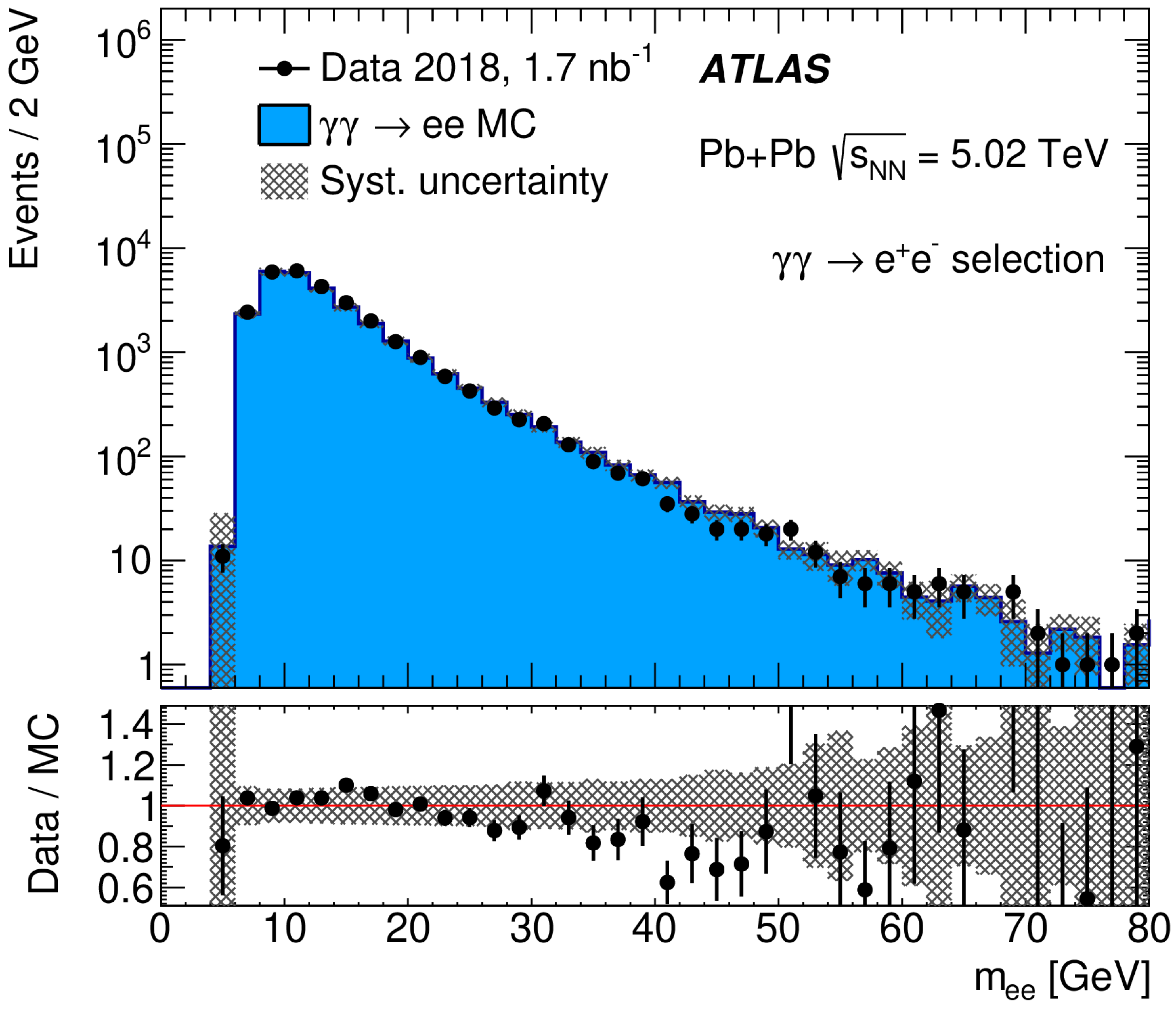
- Exclusive dielectron events ($\gamma\gamma \rightarrow ee$) are also used to validate EM calorimeter response

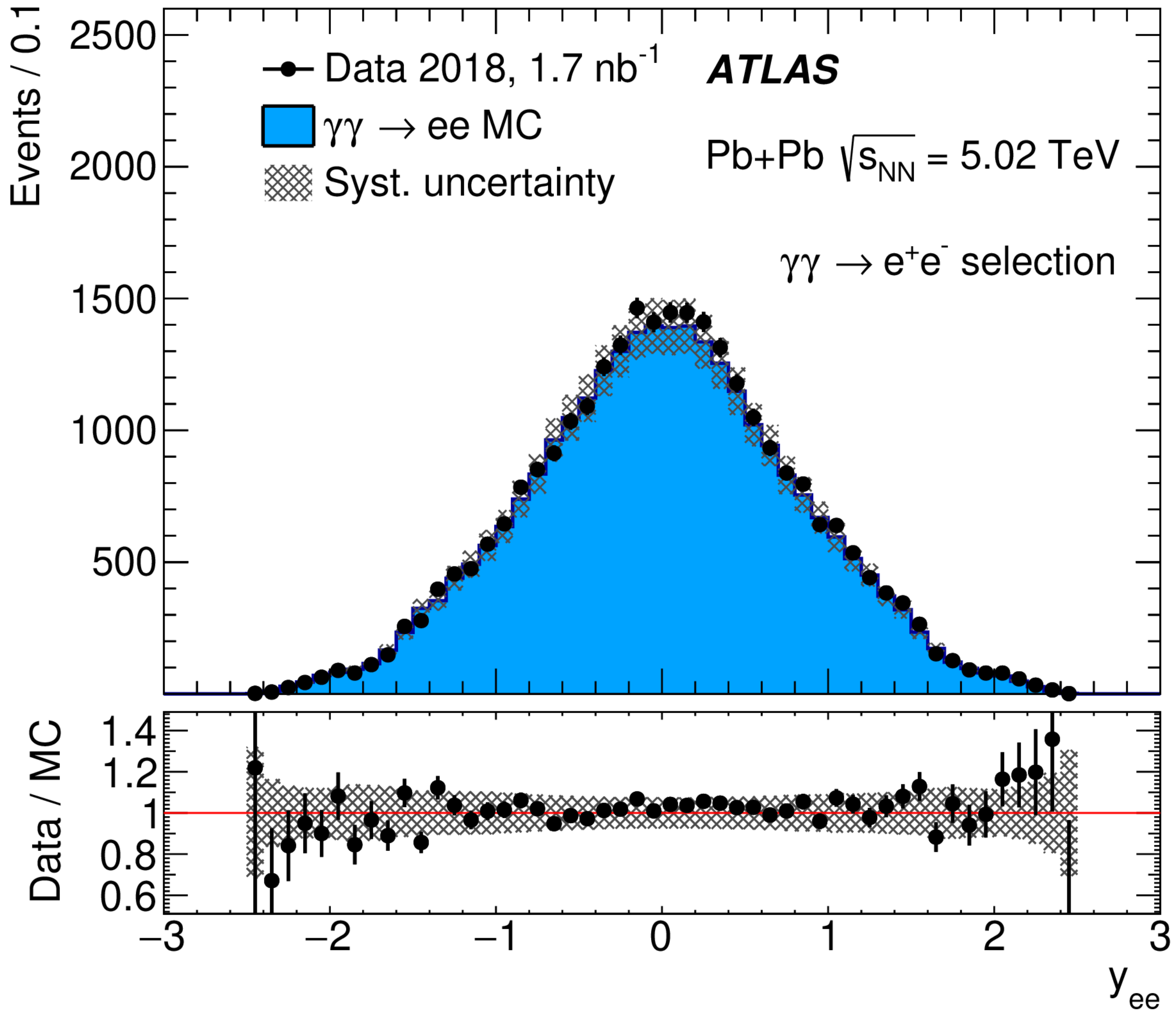


# Other checks with exclusive dielectrons

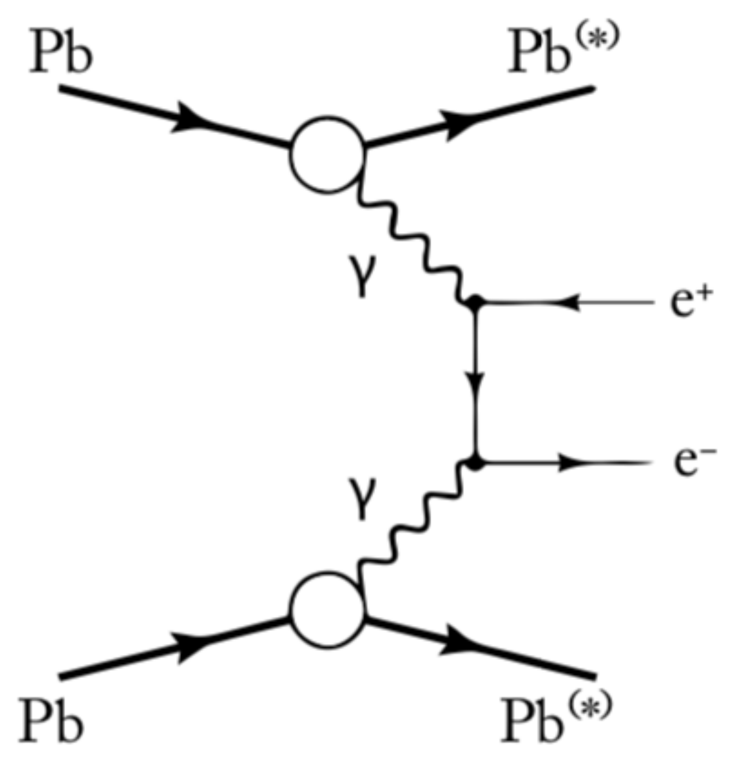
- Overall yield & kinematic distributions in reasonable agreement with MC simulation



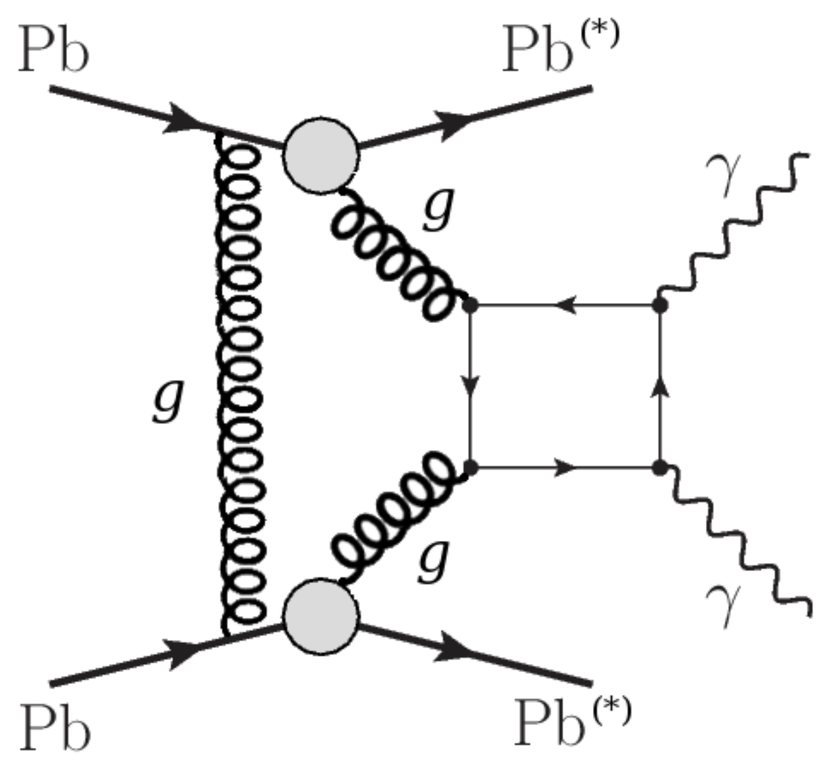



# Background processes

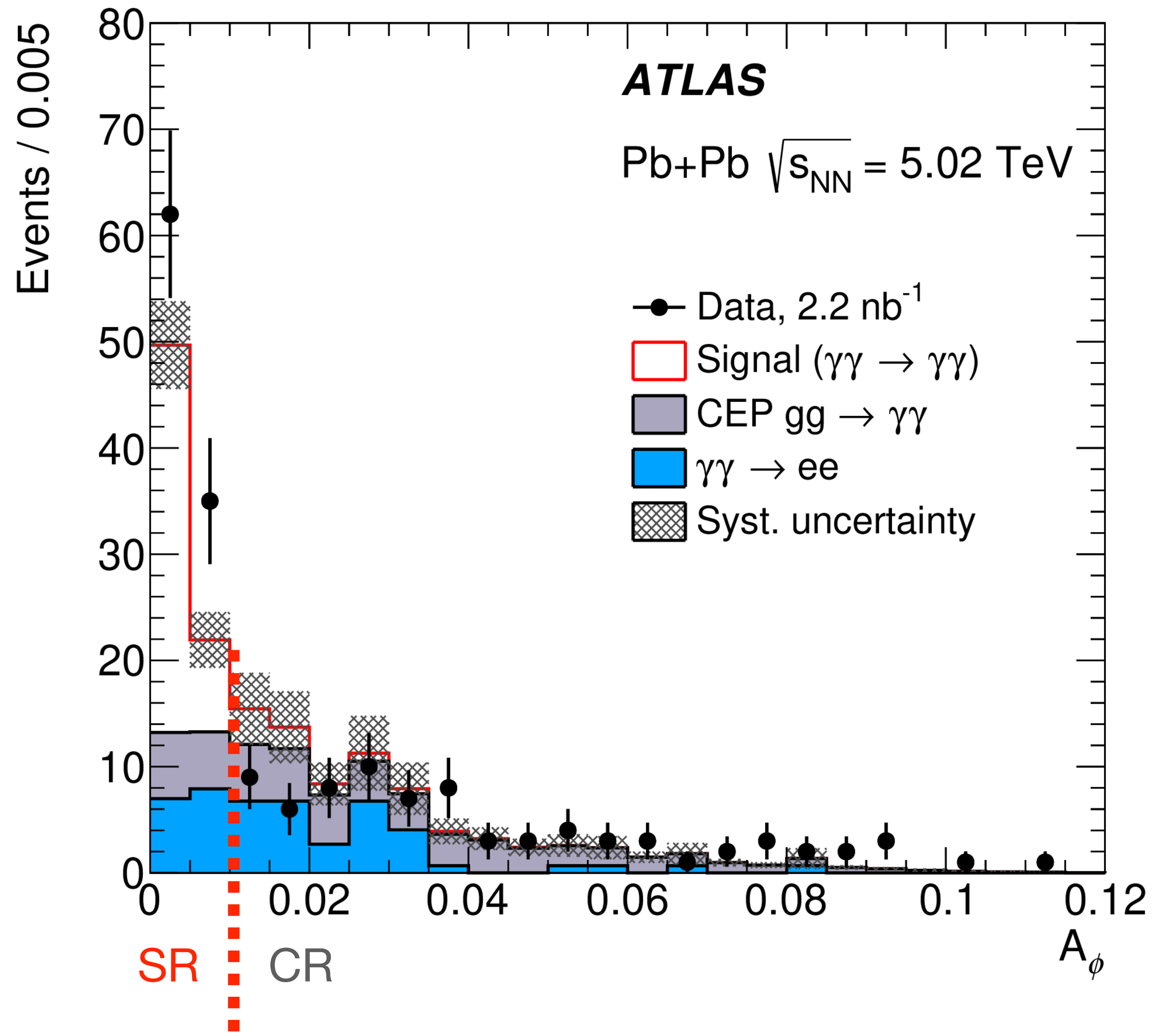
- Several background sources considered:
  - **γγ → ee**
    - Suppressed with track and pixel-track vetos
    - Remaining contribution evaluated using control regions
  - Diffractive/CEP **gg → γγ**
    - Fit to Aco shape after relaxing Aco < 0.01 (template from MC)
  - other processes e.g. γγ → qq, $\pi^0\pi^0$, $\pi$+$\pi$-, γγ → eeγγ, …, are found to be negligible




γγ→ee



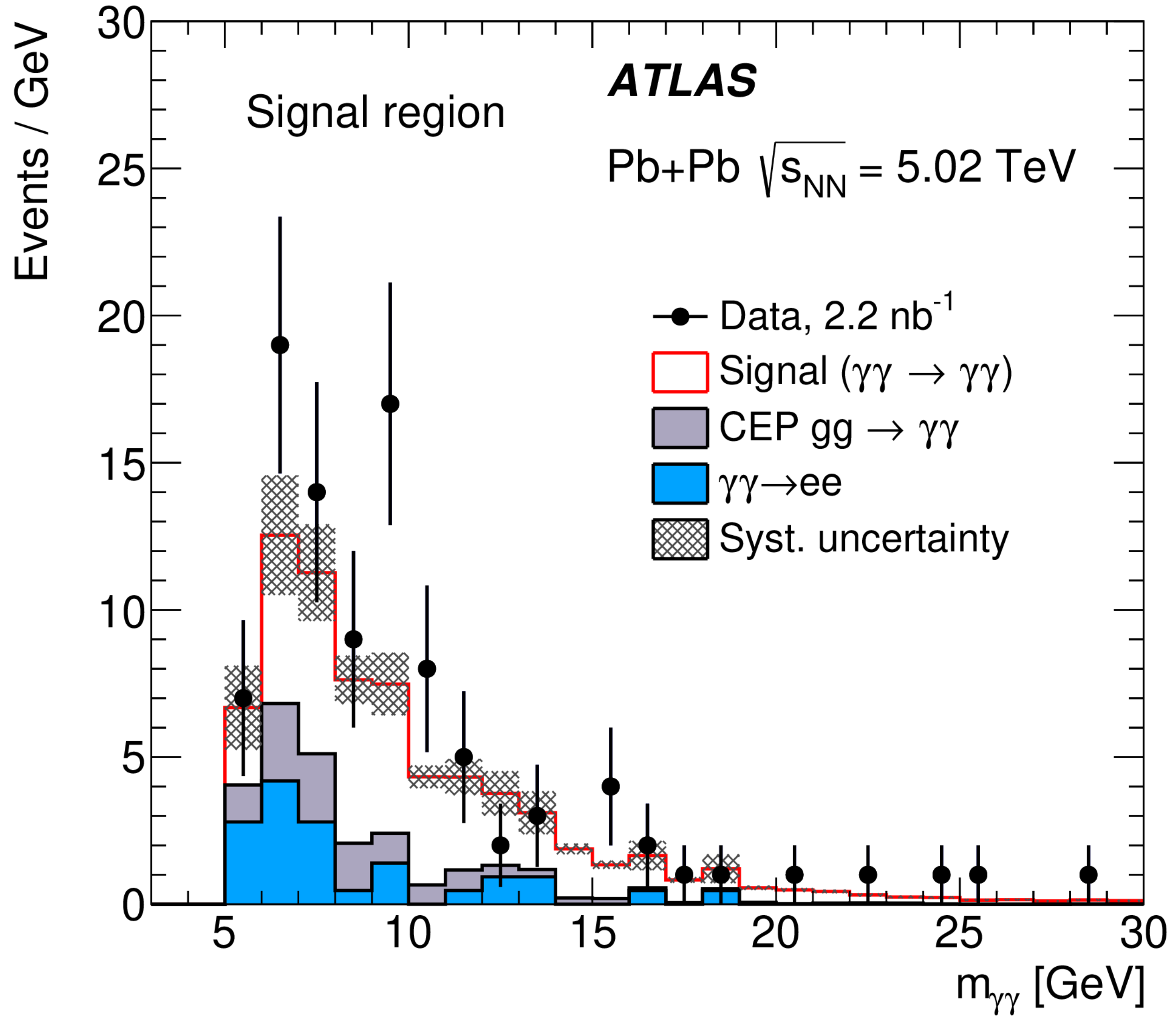

CEP γγ

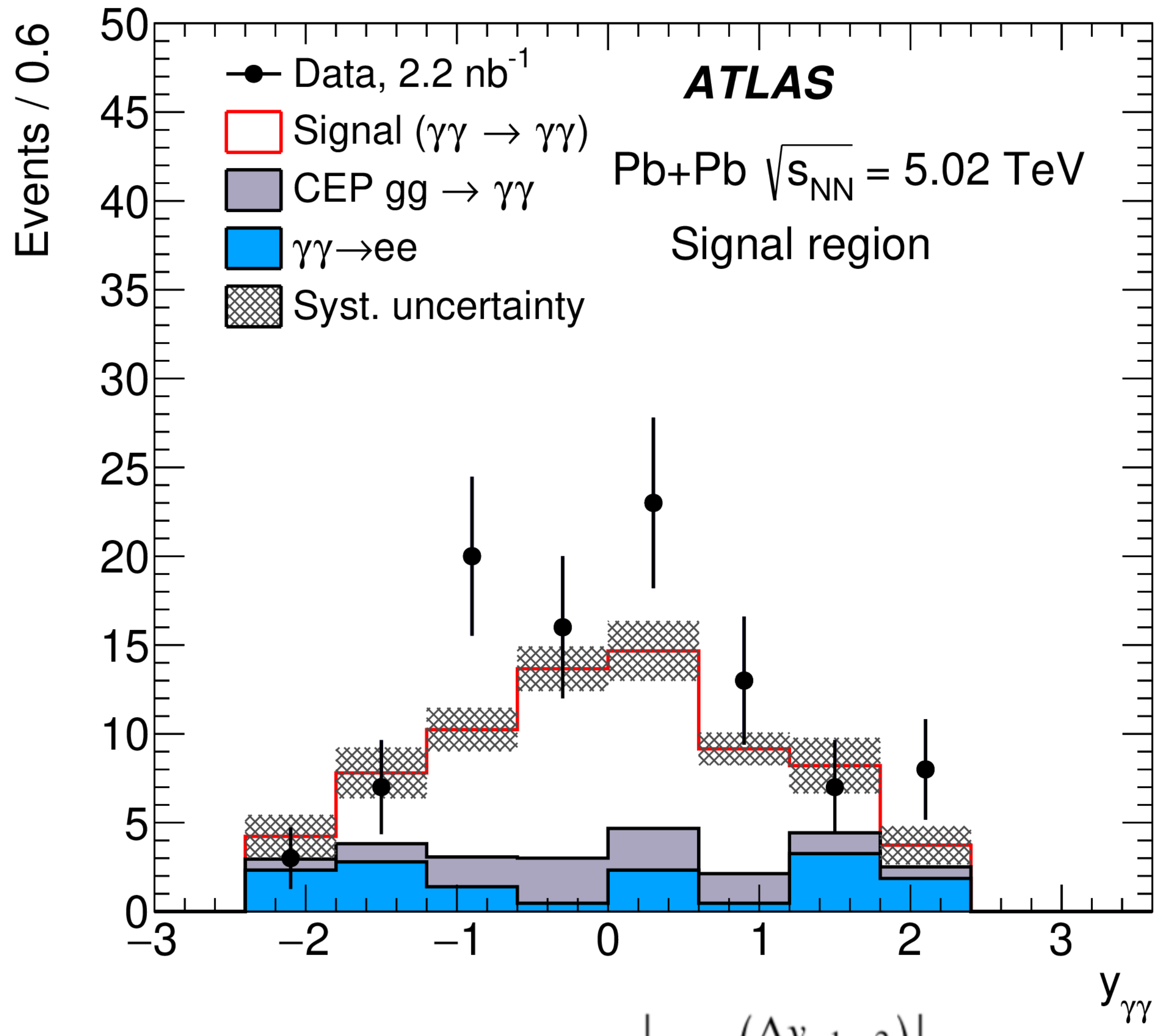


# Systematic uncertainties and control distributions

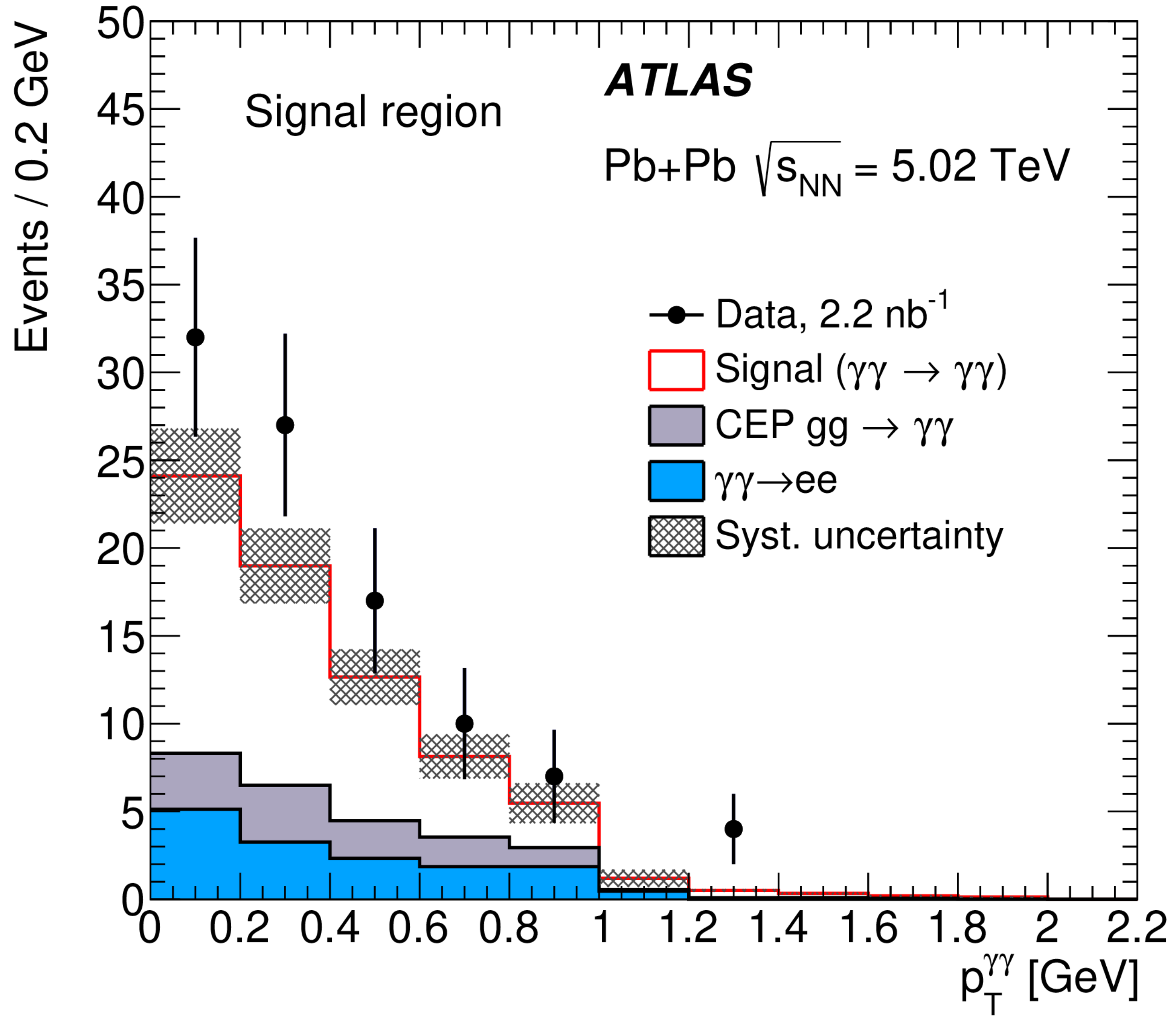
| Source of uncertainty | Detector correction ($C$) |
|---|---|
| | $0.263 \pm 0.021$ |
| Trigger efficiency | 5% |
| Photon reco. efficiency | 4% |
| Photon PID efficiency | 2% |
| Photon energy scale | 1% |
| Photon energy resolution | 2% |
| Photon angular resolution | 2% |
| Alternative signal MC | 1% |
| Signal MC statistics | 1% |
| Total | 8% |

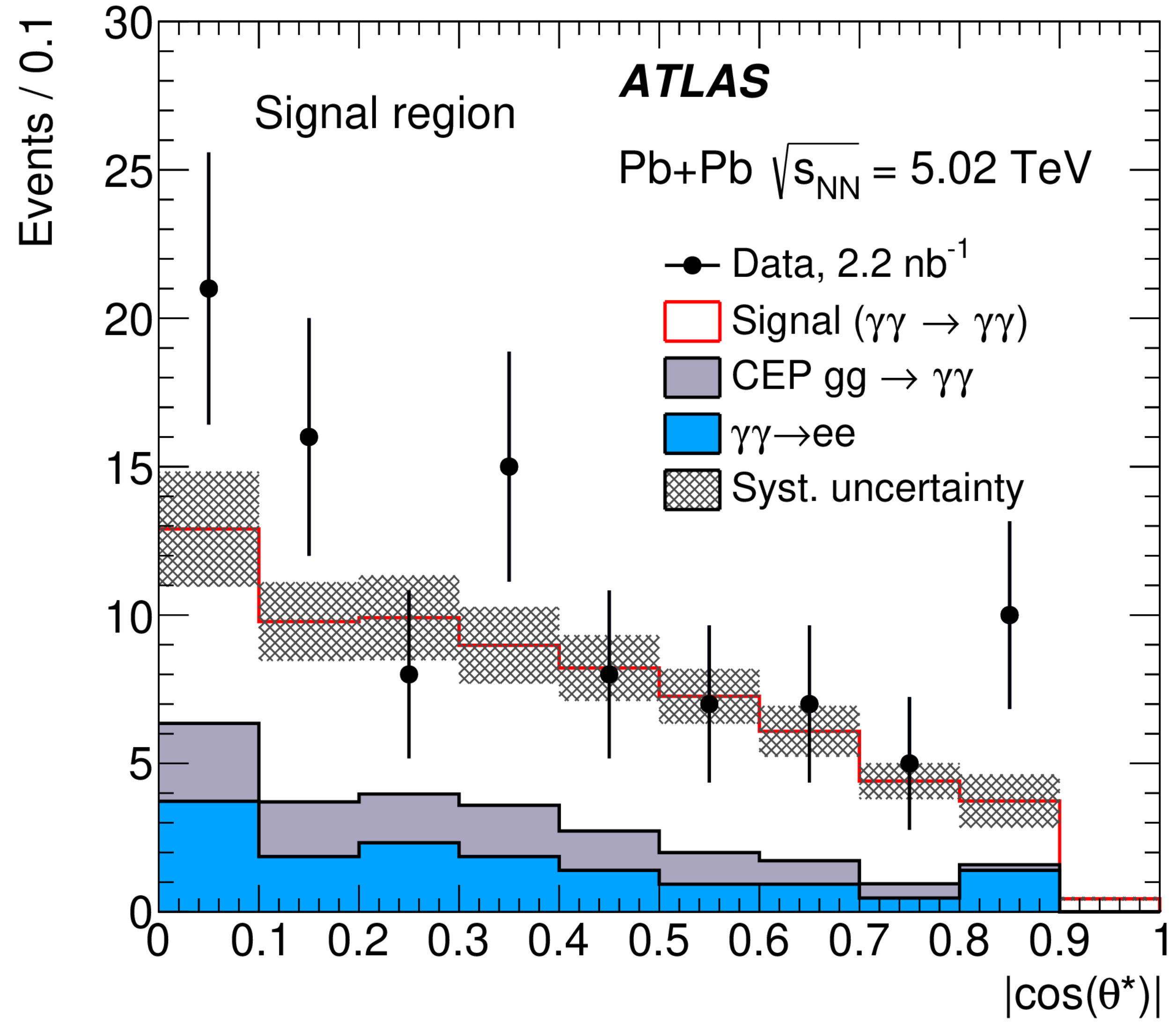
- Cf with data stat. uncertainty of **14%** and impact of background uncertainty (**7%**)




$$|\cos(\theta^*)| = \left|\tanh\left(\frac{\Delta y_{\gamma 1,\gamma 2}}{2}\right)\right|$$

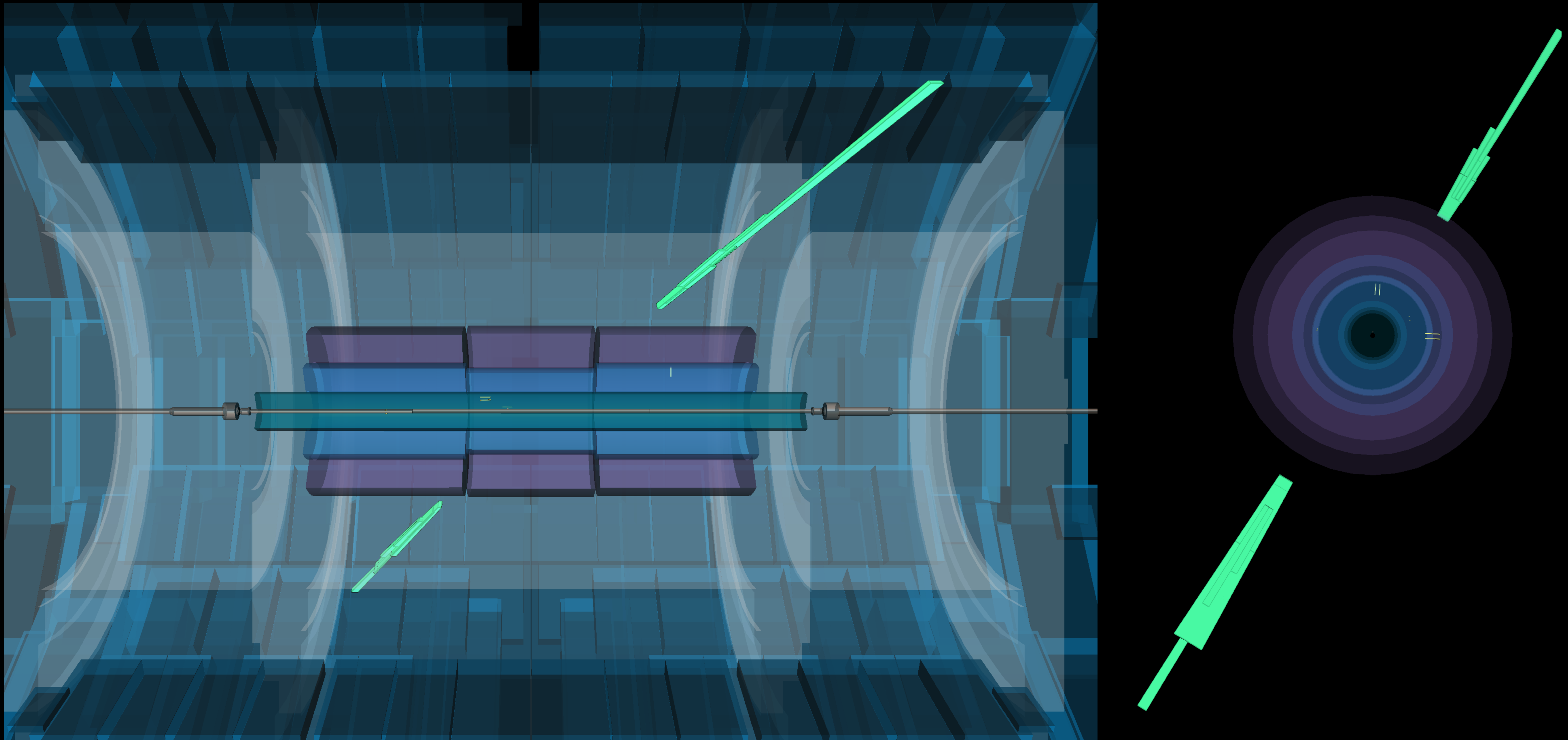


ATLAS EXPERIMENT

Run: 366994
Event: 453765663
2018-11-26 18:32:03 CEST

light-by-light event candidate, **M(γγ)=28 GeV**



# Results

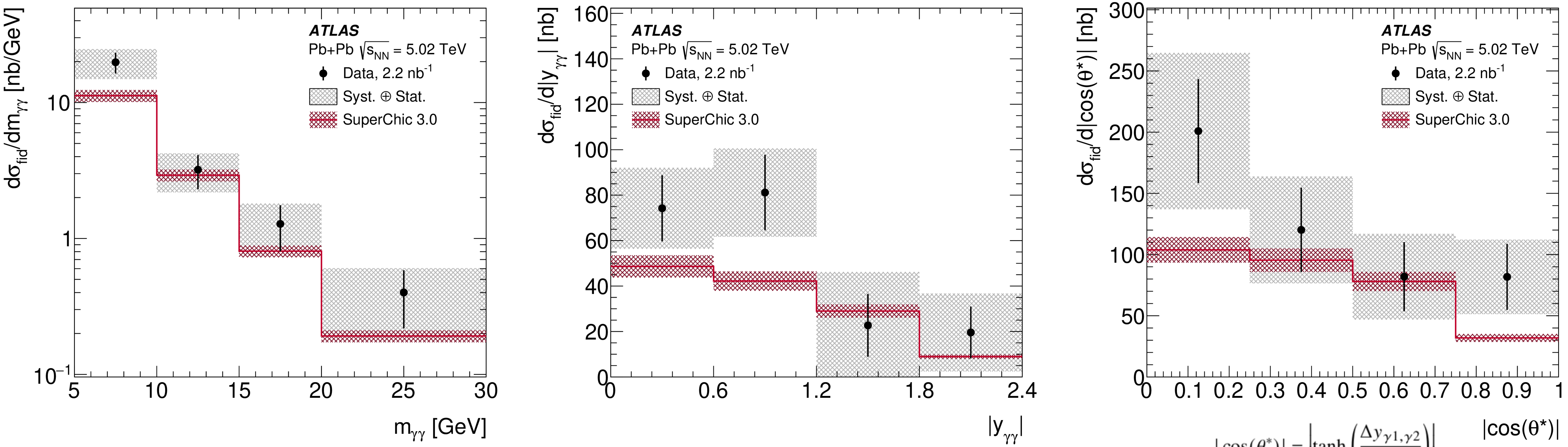
- Cross section measurements

$$\sigma_{\text{fid}} = \frac{N_{\text{data}} - N_{\text{bkg}}}{C \times \int L dt}$$

  - Fiducial and differential (**$m_{\gamma\gamma}$, $|y_{\gamma\gamma}|$, $|\cos(\theta^*)|$, average $p_T^{\gamma}$**) cross sections, comparison with **SuperChic 3 MC** [Harland-Lang et al. EPJC 79 (2019) 1, 39]

$$\sigma_{\text{fid}} = 120 \pm 17\,(\text{stat.}) \pm 13\,(\text{syst.}) \pm 4\,(\text{lumi.})\ \text{nb}$$

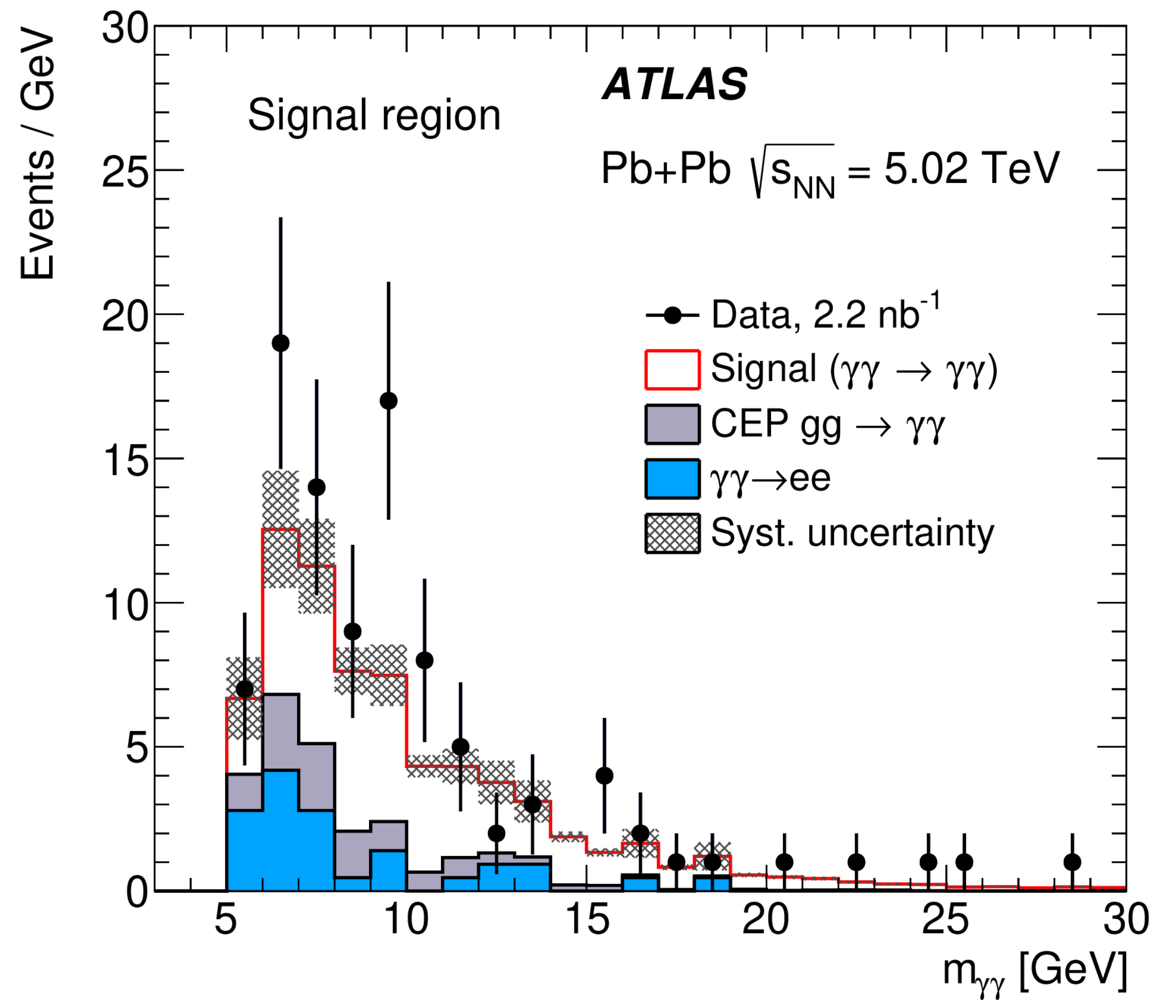
  - Integrated fiducial cross section about 1.7σ higher than the predictions [Klusek-Gawenda et al. PRC 93 (2016) 044907, Harland-Lang et al. EPJC 79 (2019) 39]

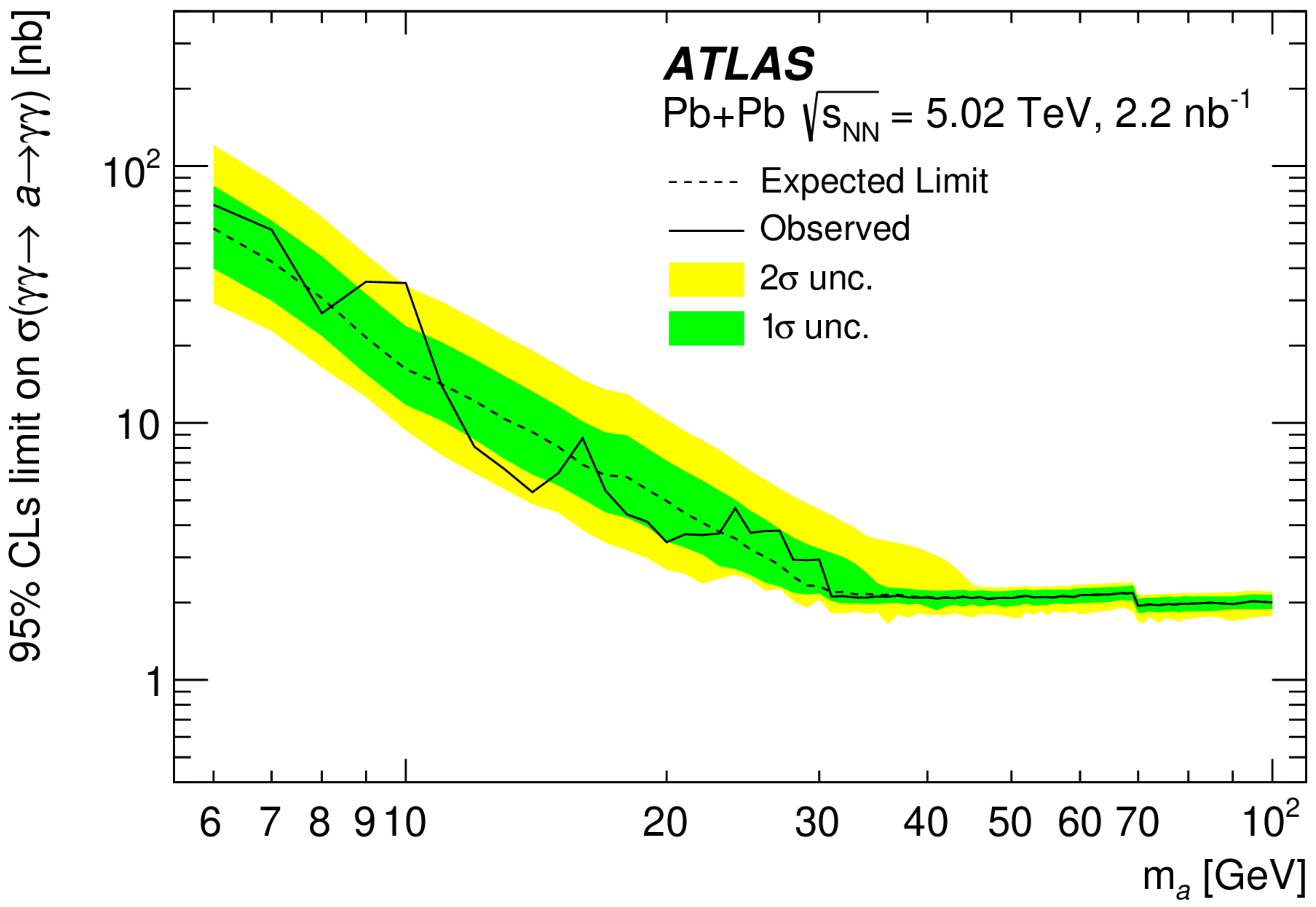


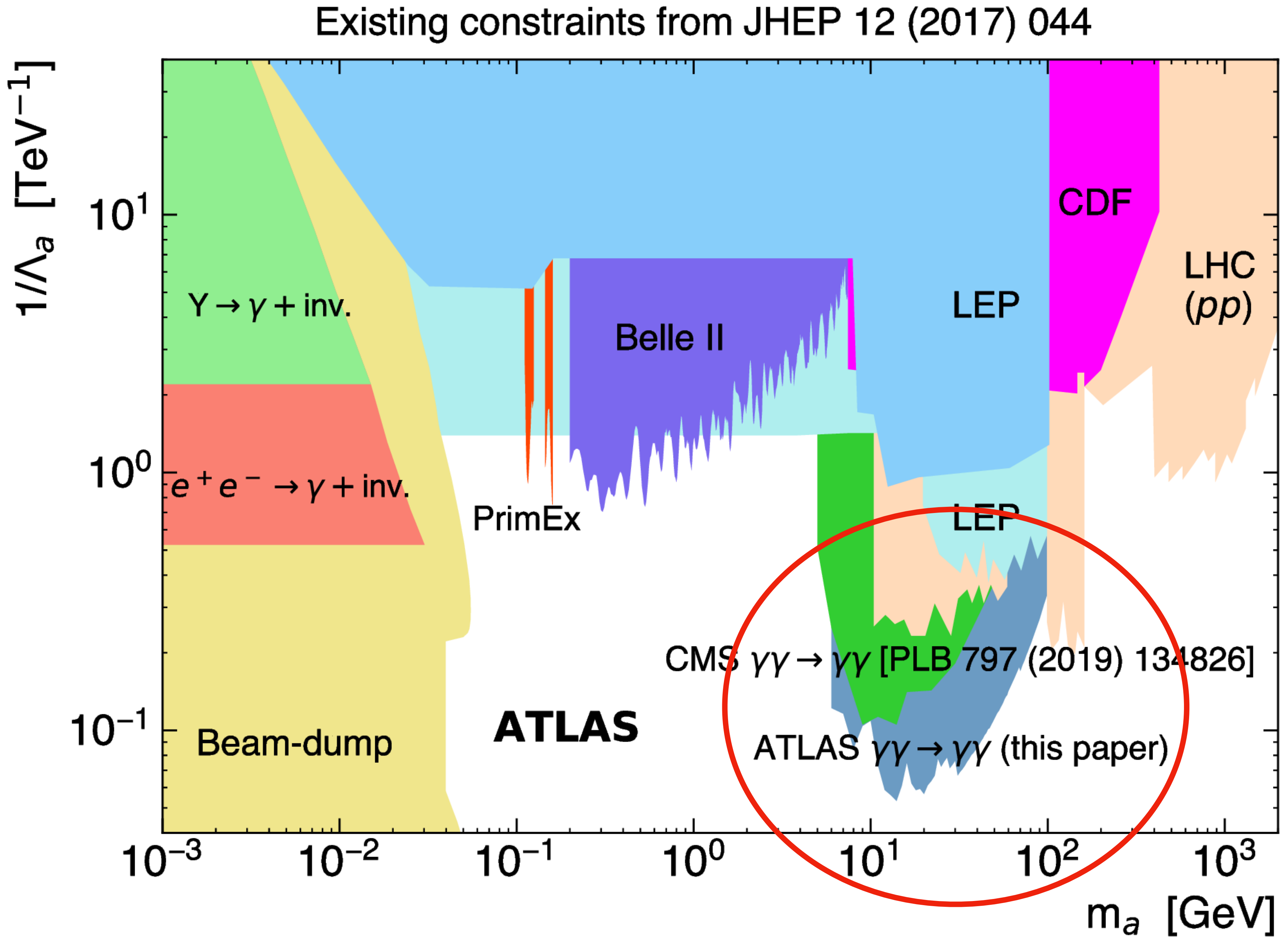

$$|\cos(\theta^*)| = \left|\tanh\left(\frac{\Delta y_{\gamma 1,\gamma 2}}{2}\right)\right|$$

# Search for Axion-like particles (ALPs)

- Idea: search for new **γγ→a→γγ** resonances
  - Background includes SM LbyL, CEP γγ and ee
  - ALP signal generated with STARlight MC for various $m_a$
- No significant deviation from SM predictions observed → limits on $\sigma_{\gamma\gamma\to a\to\gamma\gamma}$ are extracted
  - Limits on σ are cast into limits on $a\gamma\gamma$ coupling ($1/\Lambda_a$)
  - **Most stringent ALP constraints (6< $m_a$ <100 GeV) to date**



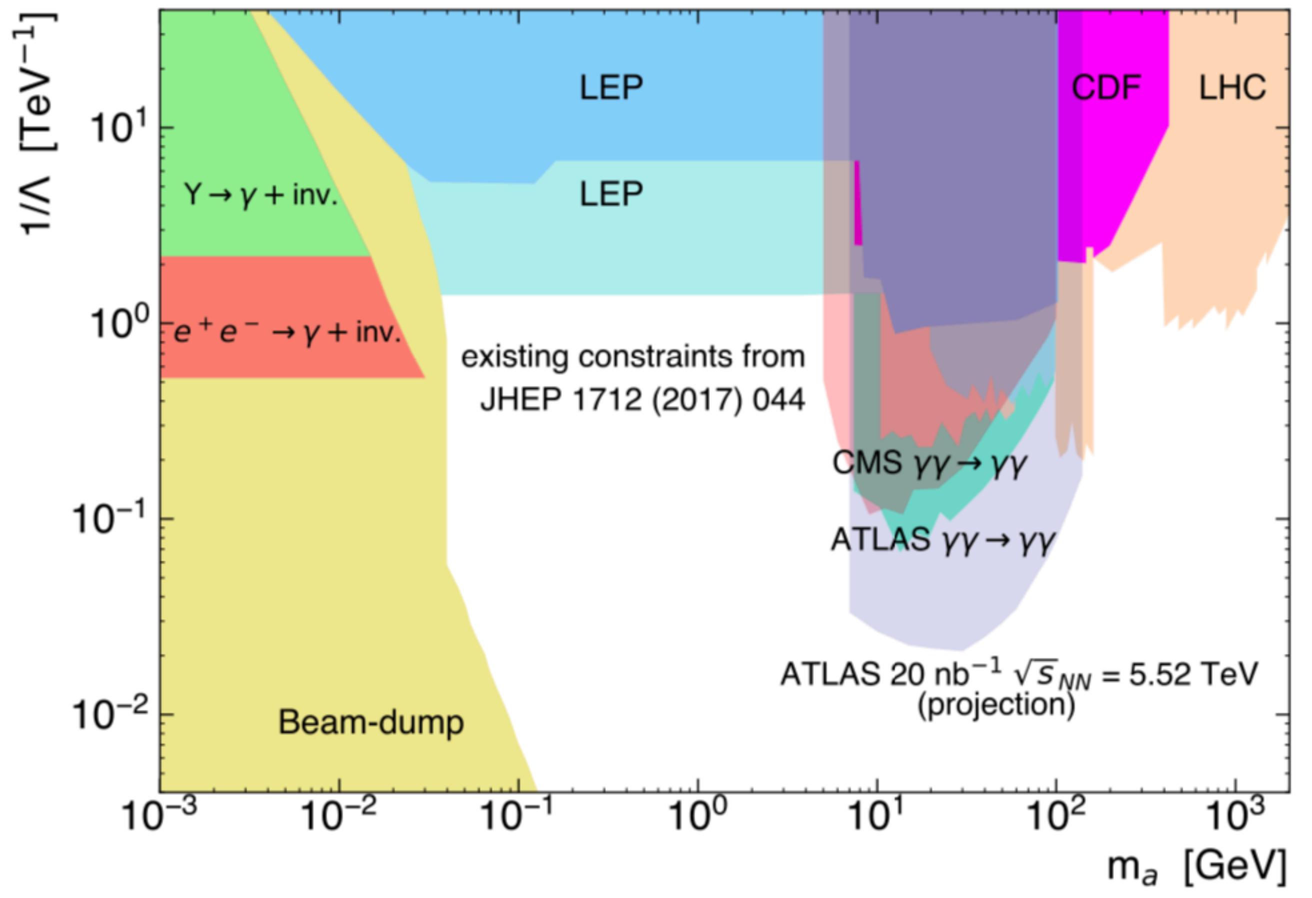



# Summary

- Light-by-light scattering (γγ→γγ) is a unique process that can be probed in ultraperipheral collisions at the LHC
- New ATLAS measurement exploits full Run-2 Pb+Pb dataset (2.2/nb) and photons down to $E_T$ =2.5 GeV
- Integrated fiducial and differential cross sections are measured
  - In fair agreement with theory predictions, though 1.7σ data/theory difference is intriguing…
- Search for new phenomena in γγ→γγ scattering
  - Resonant production of axion-like particles (ALPs)
  - No significant deviation from SM predictions is observed
  - Most stringent ALP constraints (6< $m_a$ <100 GeV) to date are obtained
  - **Excellent prospects for new searches with Run 3+4 data →**

arXiv:1812.06772

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# Backup

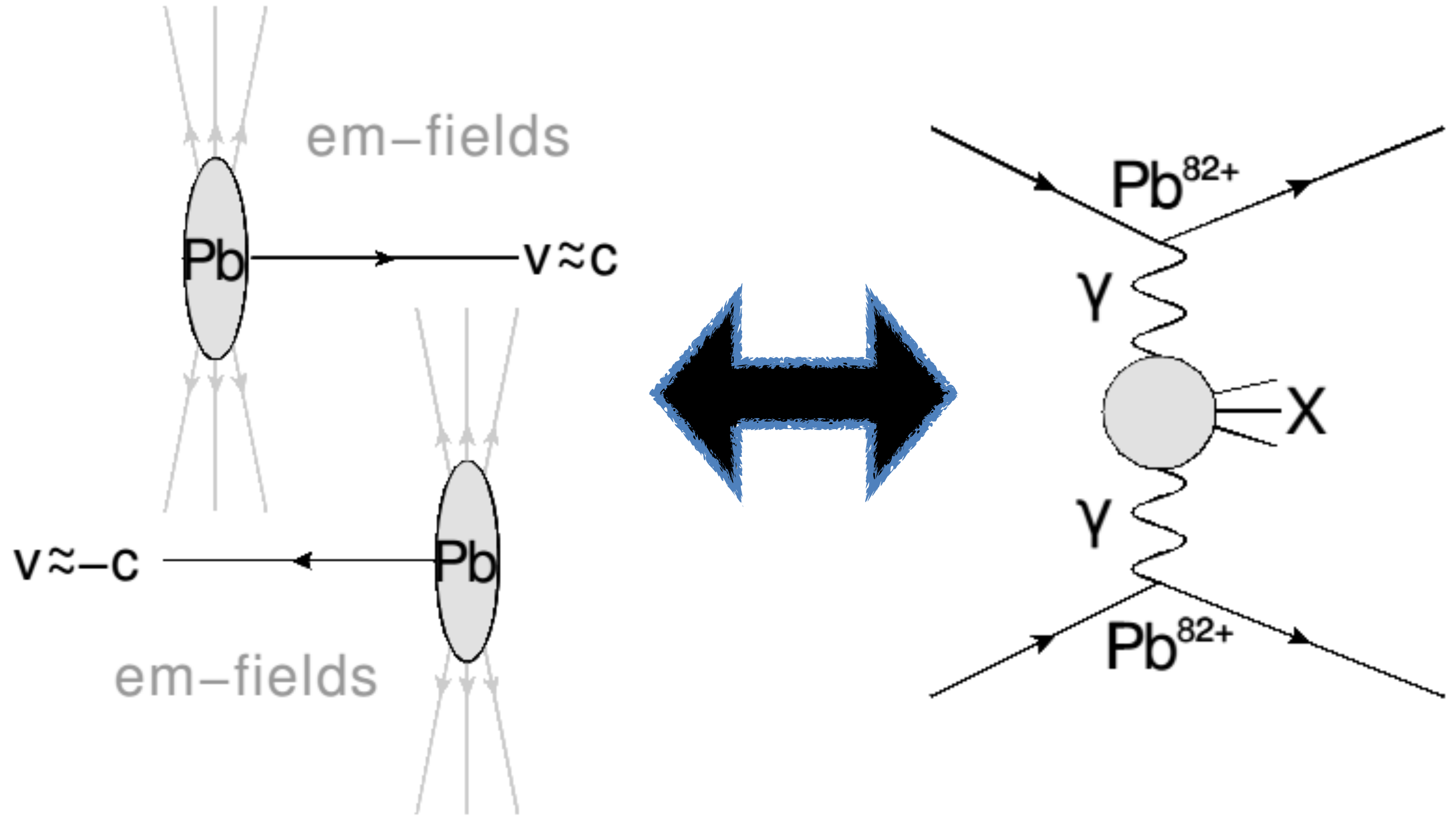
# Theoretical calculations (a simplified view)

- The cross section for AA (γγ) → AA X process can be calculated using:

**(1)** Number of equivalent photons (EPA) by integration of relevant EM formfactors:

$$\frac{Z^2\alpha_{em}}{\pi^2\omega}\left|\int \mathrm{d}q_\perp q_\perp^2 \frac{F(Q^2)}{Q^2} J_1(bq_\perp)\right|^2$$

$Q^2 < 1/R^2$




**(2)** EW γγ → X (elementary) cross section:

$$\sigma^{\mathrm{EPA}}_{A_1A_2(\gamma\gamma)\to A_1A_2X} = \iint \mathrm{d}\omega_1\ \mathrm{d}\omega_2\ n_1(\omega_1)\ n_2(\omega_2)\ \sigma_{\gamma\gamma\to X}(W_{\gamma\gamma})$$

**(3)** Extra absorptive corrections (when the ions/protons overlap in impact parameter space:

$$n_1(\omega_1)\ n_2(\omega_2) \to \int\int n(\vec{b}_1,\omega_1)n(\vec{b}_2,\omega_2)P_{non-inel}(|\vec{b}_1-\vec{b}_2|)d^2\vec{b}_1 d^2\vec{b}_2$$