Light-by-light scattering cross-section measurements at LHC

arXiv:2204.02845

G. K. Krintiras[1a], I. Grabowska-Bold[2b], M. Kłusek-Gawenda[3c], É. Chapon[4d], R. Chudasama[5e], and R. Granier de Cassagnac[6f]

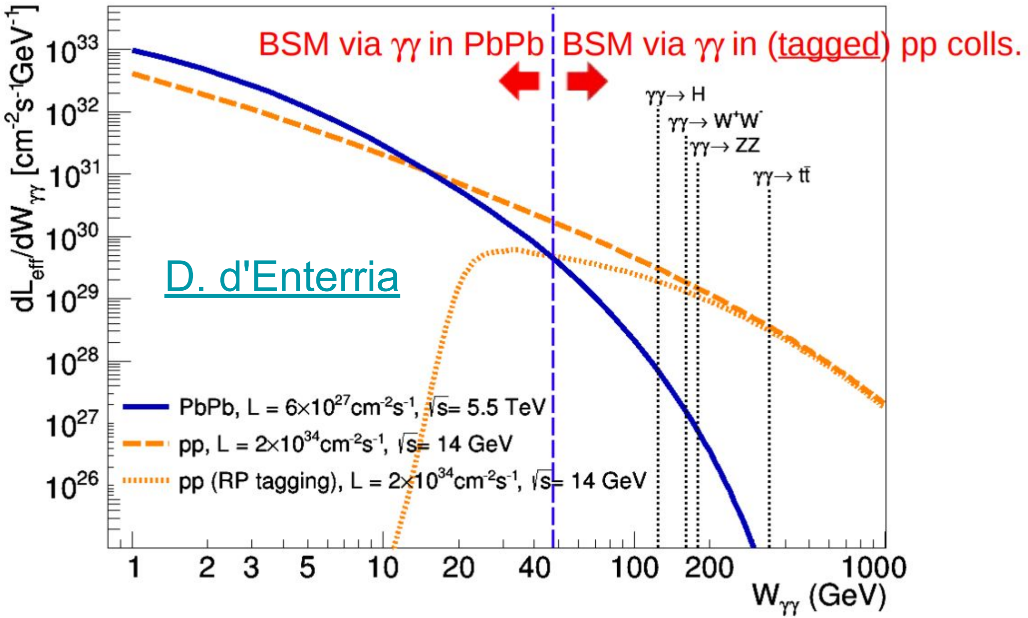
[1] Department of Physics and Astronomy, The University of Kansas, Malott Hall, 1251 Wescoe Hall Dr., Lawrence, KS 66045
[2] Department of Physics and Applied Computer Science, AGH University of Science and Technology, Al. Mickiewicza 30, 30-059 Kraków
[3] Institute of Nuclear Physics Polish Academy of Sciences, Radzikowskiego 152, PL-31-342 Kraków, Poland
[4] IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France
[5] Department of High Energy Physics, Tata Institute of Fundamental Research, Mumbai 400005, India
[6] Laboratoire Leprince-Ringuet, Ecole polytechnique, CNRS/IN2P3, Palaiseau, France

U.S. DEPARTMENT OF ENERGY | Office of Science

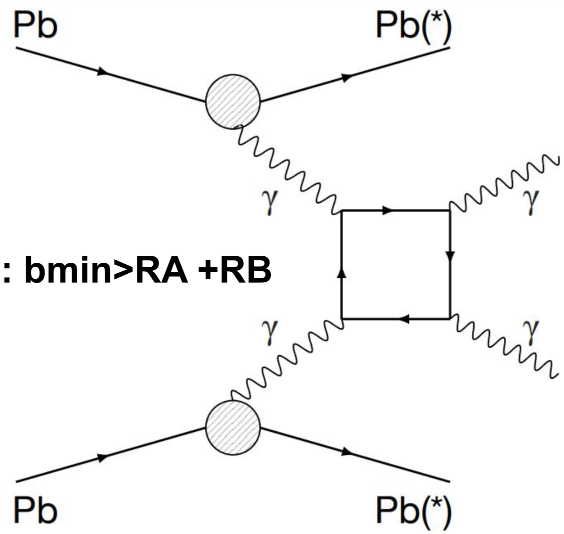
Quark Matter 2022

Introduction to **LbyL scattering (with UPC)**

- BSM **at high masses**: Increase √s
- BSM at **low couplings**: Increase $\mathscr{L}$
  - plus **taking advantage of** reduced pileup, kin. thresholds, and clean final states
- Thanks to Z^4 **~10^7** factor in PbPb, γγ luminosities >> pp ones at low Wγγ

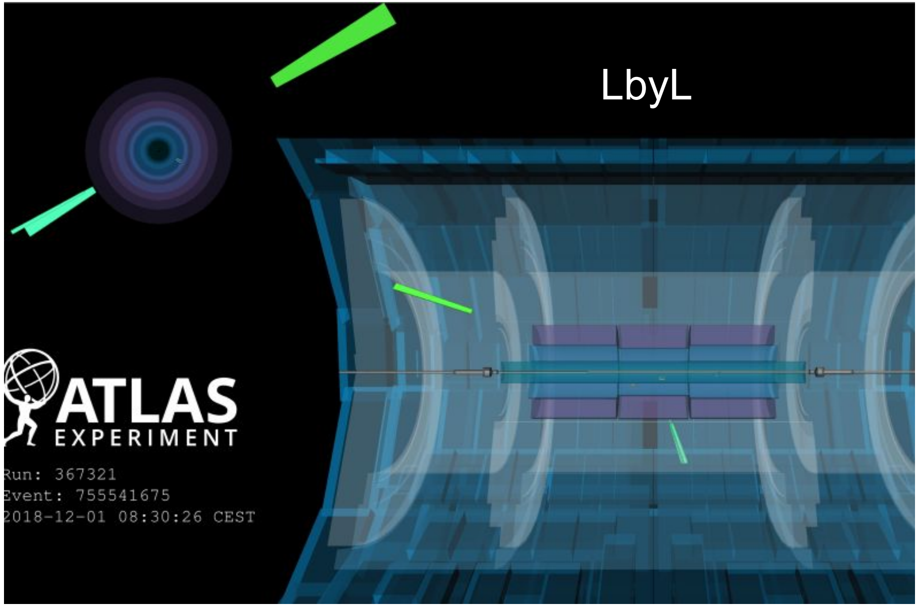


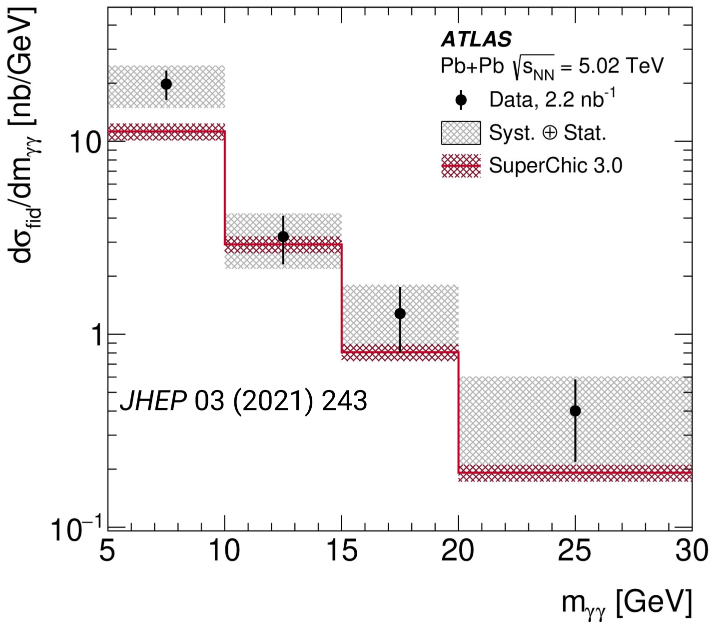
UPC: bmin>RA +RB



Available LbyL UPC measurements (so far)

- ATLAS
  - 2015 data, 0.48/nb, *Nature Phys.* 13 (2017) 9, 852-858
  - 2018 data, 1.73/nb, *Phys.Rev.Lett.* 123 (2019) 052001
  - **2015+18 data**, 2.2/nb, *JHEP* 03 (2021) 243
- CMS
  - **2015 data**, 0.39/nb, *Phys.Lett.B* 797 (2019) 134826

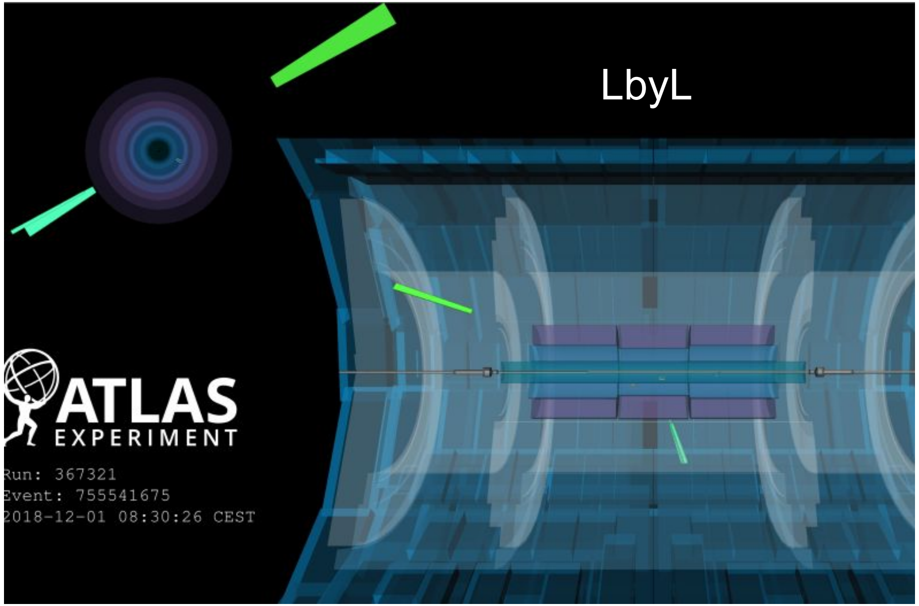


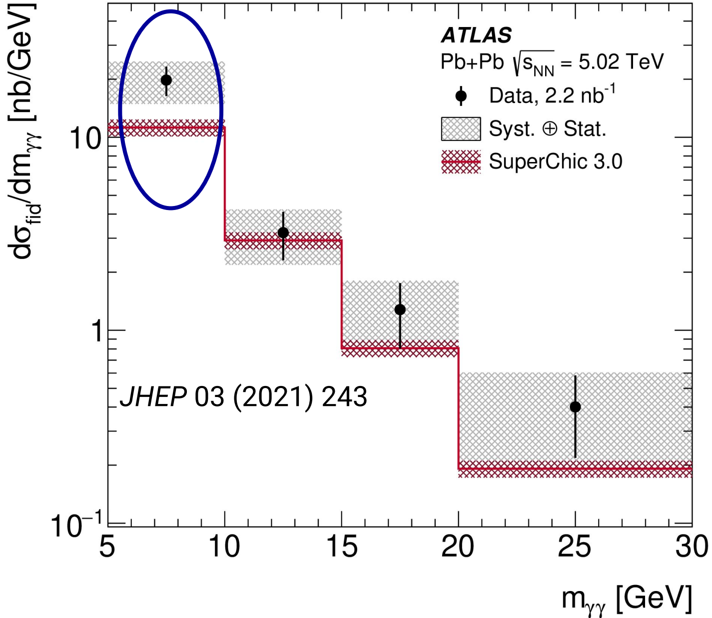


Goals of this analysis

- ATLAS
  - 2015 data, 0.48/nb, *Nature Phys.* 13 (2017) 9, 852-858
  - 2018 data, 1.73/nb, *Phys.Rev.Lett.* 123 (2019) 052001
  - 2015+18 data, 2.2/nb, *JHEP* 03 (2021) 243
- CMS
  - 2015 data, 0.39/nb, *Phys.Lett.B* 797 (2019) 134826

1. How an **averaged value** compared to theory?
2. Could some **SM bkg** explain the excess?





Theory **predictions**

- **LbyL** cross sections calculated based on **SuperChic v3** [16] and **M. Klusek-Gawenda *et al*** [17]
  - for **three** phase space regions, reflecting experiments' **fiducial regions**
    - based on **single-/pair- photon kinematics**
  - **good agreement** between the two predictions found
  - **lower** value in comparison to the one in *Phys.Lett.B* 797 (2019) 134826
    - the assigned theory unc (10%) **comparable** to the difference

$\sqrt{s_{NN}}$	Process	Accuracy	$\sigma^{fid.}_{theo.}$ [nb]	Phase space region
5.02 TeV	$Pb+Pb(\gamma\gamma)\rightarrow Pb^{(*)}+Pb^{(*)}\,\gamma\gamma$	LO	101 ± 10 [16]	$E_T>2.0$ GeV, $\lvert\eta\rvert<2.4$, $m_{\gamma\gamma}>5$ GeV, $p_T{}^{\gamma\gamma}<1$ GeV, $A_\phi<0.01$
		LO	103 ± 10 [17]	$E_T>2.0$ GeV, $\lvert\eta\rvert<2.4$, $m_{\gamma\gamma}>5$ GeV, $p_T{}^{\gamma\gamma}<1$ GeV, $A_\phi<0.01$
		LO	$77\pm8^{\dagger}$ [16]	$E_T>2.5$ GeV, $\lvert\eta\rvert<2.4$, $m_{\gamma\gamma}>5$ GeV, $p_T{}^{\gamma\gamma}<1$ GeV, $A_\phi<0.01$
		LO	80 ± 8 [17]	$E_T>2.5$ GeV, $\lvert\eta\rvert<2.4$, $m_{\gamma\gamma}>5$ GeV, $p_T{}^{\gamma\gamma}<1$ GeV, $A_\phi<0.01$
		LO	50 ± 5 [16]	$E_T>3.0$ GeV, $\lvert\eta\rvert<2.4$, $m_{\gamma\gamma}>6$ GeV, $p_T{}^{\gamma\gamma}<1$ GeV, $A_\phi<0.01$
		LO	51 ± 5 [17]	$E_T>3.0$ GeV, $\lvert\eta\rvert<2.4$, $m_{\gamma\gamma}>6$ GeV, $p_T{}^{\gamma\gamma}<1$ GeV, $A_\phi<0.01$

[box] → **used as extrapolation correction** (rows 1 and 3 boxed)

Extrapolation correction

- Fiducial-region definition **differs** between input measurements in **single-photon E_T**
  - ATLAS: > 2.**5** GeV
  - CMS: > 2.**0** GeV

- We need to “scale down” the CMS result by **76%**
  - using the predictions from SuperChic (highlighted in the previous table)
  - we found the pair photon p_T<1 GeV to have **no significant effect** (same for the accoplanarity)
    - for future reference

		ATLAS		CMS	
$\sqrt{s_{NN}}$	Year (Lumi. [nb^{-1}])	$\sigma^{fid.}_{raw}$ [nb]	$\sigma^{fid.}_{cor.}$ [nb]	$\sigma^{fid.}_{raw}$ [nb]	$\sigma^{fid.}_{cor.}$ [nb]
5.02 TeV	2015 (0.39–0.48)	70 ± 29 [11]	108 ± 45	120 ± 55 [12]	91 ± 42†
	2018 (1.73)	78 ± 15 [15]	120 ± 23	—	—
	2015+2018 (2.2)	120 ± 22 [10]	120 ± 22†	—	—

☐ → **used in the average**

How we **averaged** them

- **Different** tools on the market
  - we used [iterative BLUE]
    - [BLUE Software Version 2.4.0]
  - In each iteration BLUE minimizes
    - a global χ^2, considering correlations

- Simplified set of correlations (cf. backup)
  - variations from nominal scheme **checked**

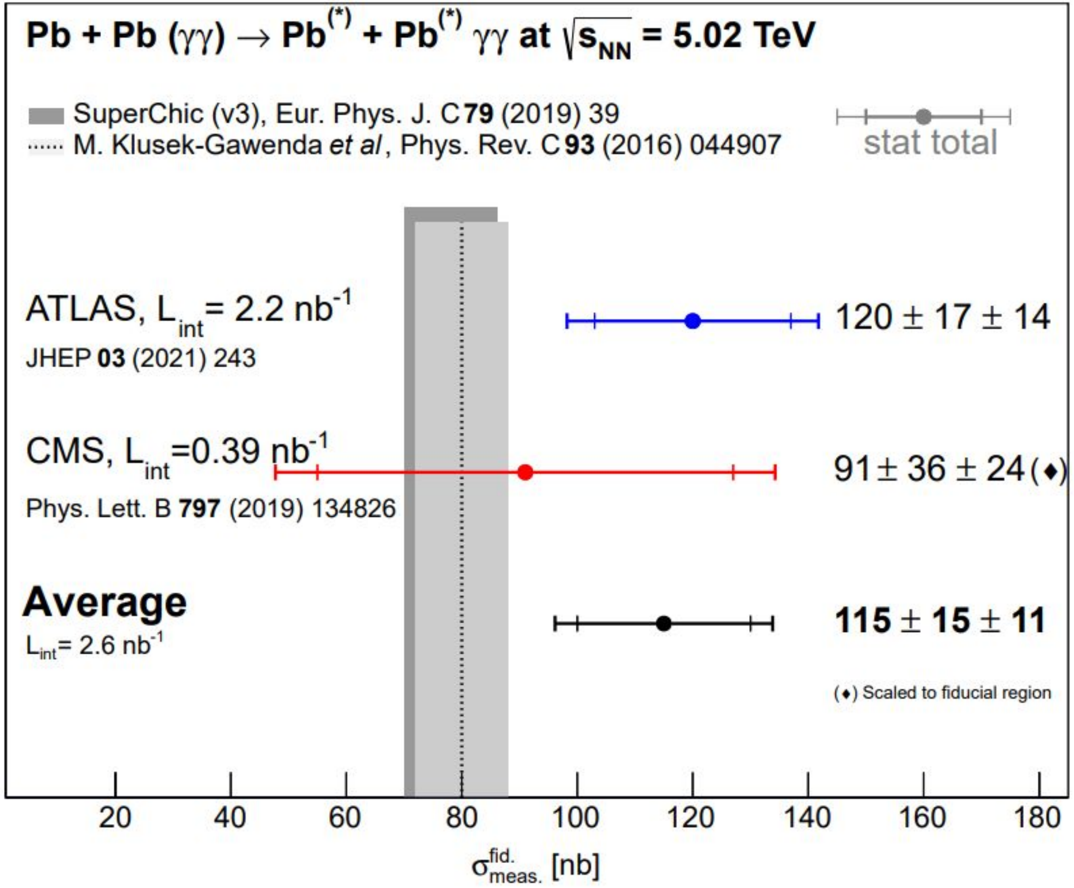
- Statistical unc still **dominates**
  - **~10%** improvement to input measurement
- <10% foreseen with **future data/analyses**

$$\sigma^{\text{fid.}}_{\text{meas.}} = 115 \pm 15\ (\text{stat.}) \pm 11\ (\text{syst.}) \pm 3\ (\text{lumi.}) \pm 3\ (\text{theo.})\ \text{nb}$$
$$= 115 \pm 19\ \text{nb}$$

$\sigma^{\text{fid.}}_{\text{meas.}}$, $\sqrt{s_{\text{NN}}} = 5.02\,\text{TeV}$		
Averaged cross-section	115 nb	
Uncertainty category	Uncertainty	
	[%]	[nb]
Statistical	13	15
Integrated luminosity	3	3
Background determination	5	6
Photon reconstruction and identification	6	7
Photon angular resolution	1	2
Electron reconstruction and identification	< 1	1
Trigger	5	5
Theory modeling	3	3
Total syst. unc. (excl. lumi.)	9	11
Total syst. unc. (excl. theo.)	9	11
Total syst. unc.	10	12
Total uncertainty	17%	19 nb

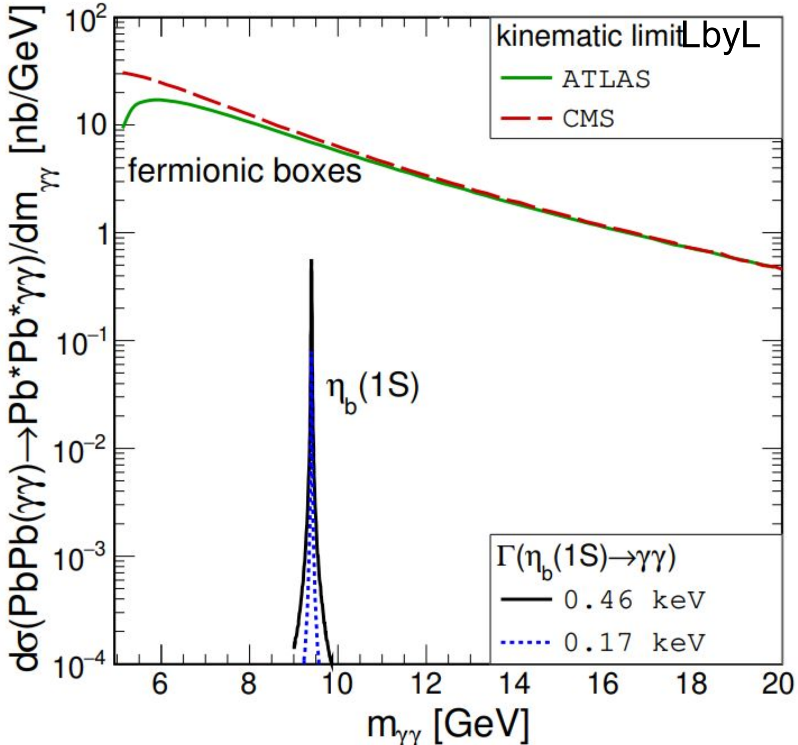
Averaged result and **comparison to theory**

- The data-to-theory discrepancy is at **~2σ level**

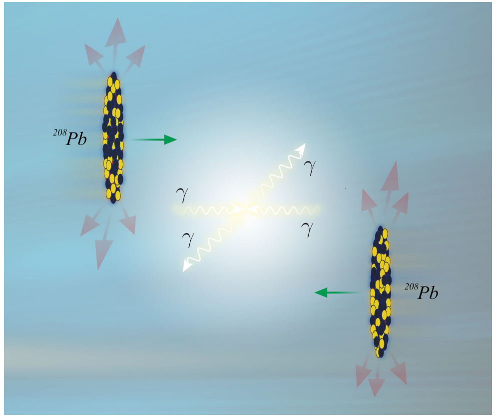


Trying to explain **the excess**

- We calculated the inclusive σ for the **photoproduction of η_b(1S)**
  - σ = (0.19−1.41) 10^−2 nb
  - range reflects max. and min. of two-photon decay rates, i.e., 0.46 and 0.17 keV
- this contribution **isn't significant**



Outlook



IFJ PAN

- LbyL in UPC **sensitive** to BSM at low couplings
- Averaged **existing** LbL UPC cross section measurements at LHC
  - corresponding to an effective luminosity of **2.2+0.4** /nb
- The fiducial phase space regions **differ** for the inputs
  - performed an **extrapolation** correction
- The averaged result brings an improvement of ~10%
  - still **statistically dominated**
  - robustness checks for the assumed correlation scheme **performed**
- **Difference** to state-of-the-art theory predictions **persists**
  - **photoproduction of η_b(1S)** cannot explain the excess
  - **further effort** for explaining the difference in the theory front
- **Importance** of combination measurements and **cross-experiment collaboration**
  - paves the way for **first-ever** combination at LHC using nuclear collisions

arXiv:2204.02845

slides

Nominal correlation scheme

- Systematic uncertainties in measured cross-sections
  - Statistical (Correlation 0)
  - Integrated luminosity (Correlation 0)
    - Only relevant for ATLAS
  - Background determination (Correlation 0)
    - uncertainty in the exclusive e+e− bkg due to the size of the data (MC) samples in ATLAS (CMS)
  - Detector modeling
    - Photon reconstruction and identification (Correlation 0.5)
      - although independent data and MC samples, a similar methodology for the corrections
    - Photon angular resolution (Correlation 0)
      - Only relevant for ATLAS
    - Electron reconstruction and identification (Correlation 0)
      - Only relevant for CMS
    - The level 1 and high-level triggers (Correlation 0)
      - dominated by the statistical uncertainty of each data set and are thus uncorrelated
- Systematic uncertainties in theoretical predictions
  - Theory modeling
    - Simulation statistical (Correlation 0)
    - Simulation systematic (Correlation 1)

Nominal correlation scheme

Table 4: Measured fiducial cross-sections, uncertainty components and their magnitudes (relative to the individual measurements) for the ATLAS and CMS Pb + Pb $(\gamma\gamma) \to$ Pb$^{(*)}$+Pb$^{(*)}$ $\gamma\gamma$ measurements at $\sqrt{s_{NN}}$ = 5.02 TeV. The CMS measurement is marked with † for its scaling by a correction factor to account for differences in the definition of phase space regions, as described in Section 3. Uncertainties in the same category can be compared between experiments, as detailed in the text. The naming conventions follow those of the corresponding experiments. The category subtotal and total uncertainties are emphasized, and are evaluated as the sum in quadrature of the individual uncertainties.

	ATLAS [10]		CMS [12]	
Cross-section	120 nb		$91^\dagger$ nb	
Uncertainty category	Uncertainty [%]		Uncertainty [%]	
Statistical	Data statistical	14	Data statistical CEP and QED bkg. normalization	37 10
Category subtotal		**14**		**38**
Theory modeling	Signal MC statistical Alternative signal MC	1 1	Derivation of $\sigma^{\text{fid.}}_{\text{theo.}}(\gamma\gamma \to e^+e^-)$	10
Category subtotal		**1**		**10**
Integrated luminosity		3		
Category subtotal		**3**		
Background determination	Data-based $\gamma\gamma \to e^+e^-$ method	6	Size of simulated background samples	6
Category subtotal		**6**		**6**
Photon reconstruction and identification	Photon reco. efficiency Photon PID efficiency Photon energy scale Photon energy resolution	4 2 1 2	Photon reco.⊕ID efficiency	18
Category subtotal		**5**		**18**
Photon angular resolution	Photon angular resolution	2		
Category subtotal		**2**		
Electron reconstruction and identification			Electron reco.⊕ID efficiency	5
Category subtotal				**5**
Trigger	Trigger efficiency	5	Trigger efficiency	12
Category subtotal		**5**		**12**
Total uncertainty		**18**		**46**

Alternative correlation schemes

- Combination result is **robust** against variations on the underlying assumptions
    - < 1% difference

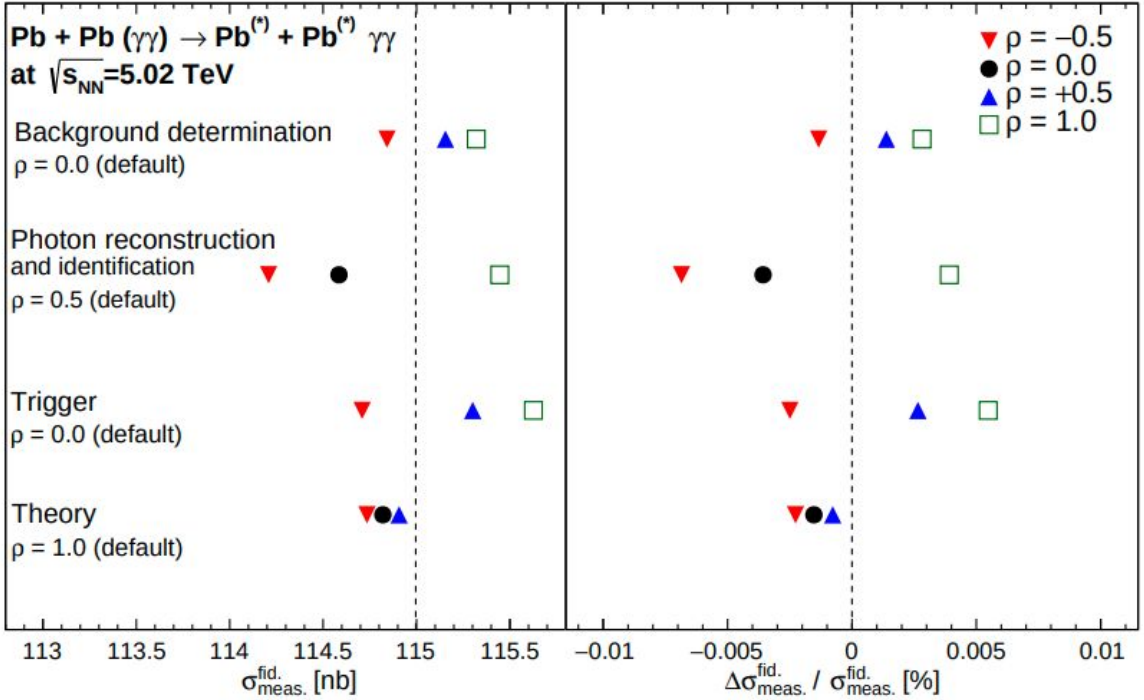


Fig. 4: (left panel) Results of the stability tests demonstrating impact of variations of the correlation assumptions in different uncertainty categories on the combined cross-section are shown. (right panel) The corresponding relative shifts (with Δ = varied − nominal) in the central value, $\sigma_{\mathrm{fid.}}$, and in its uncertainty, $\Delta(\sigma_{\mathrm{fid.}})/(\sigma_{\mathrm{fid.}})$, are shown.