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

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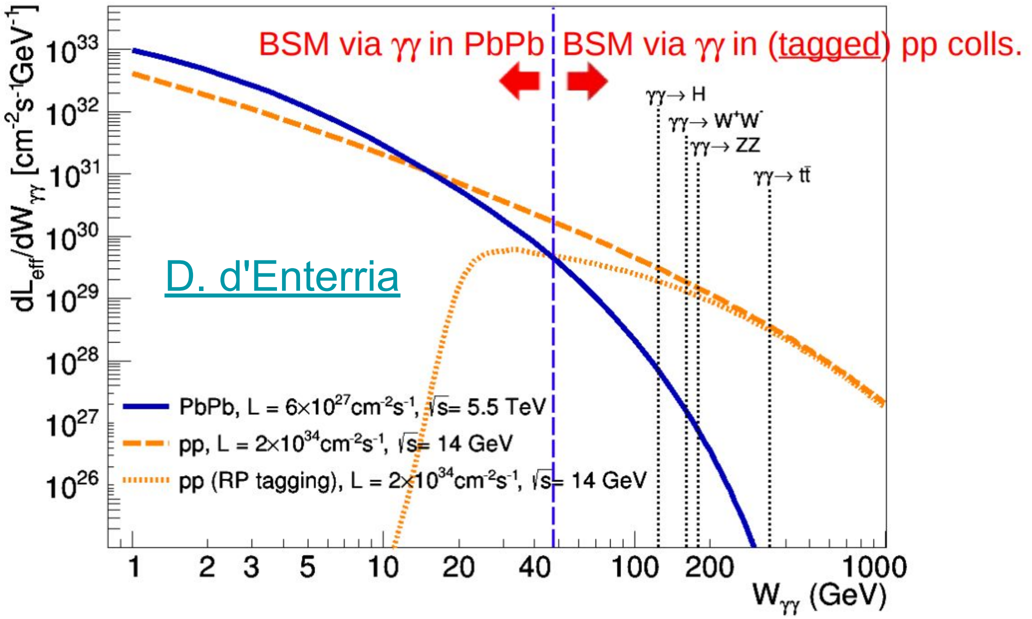
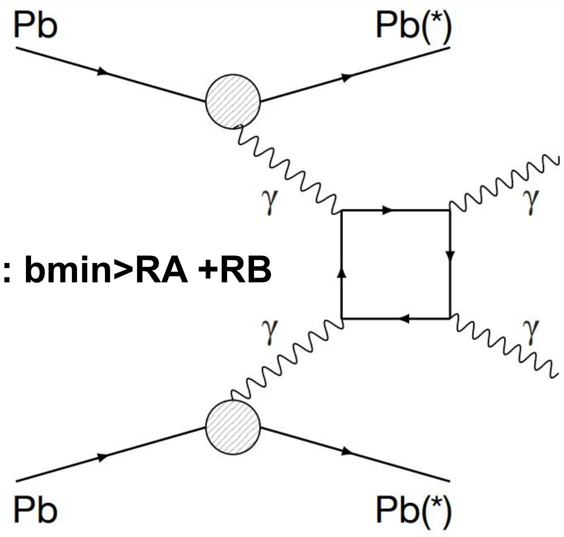
Introduction to **LbyL scattering (with UPC)**

- BSM **at high masses**: Increase √s
- BSM at **low couplings**: Increase 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

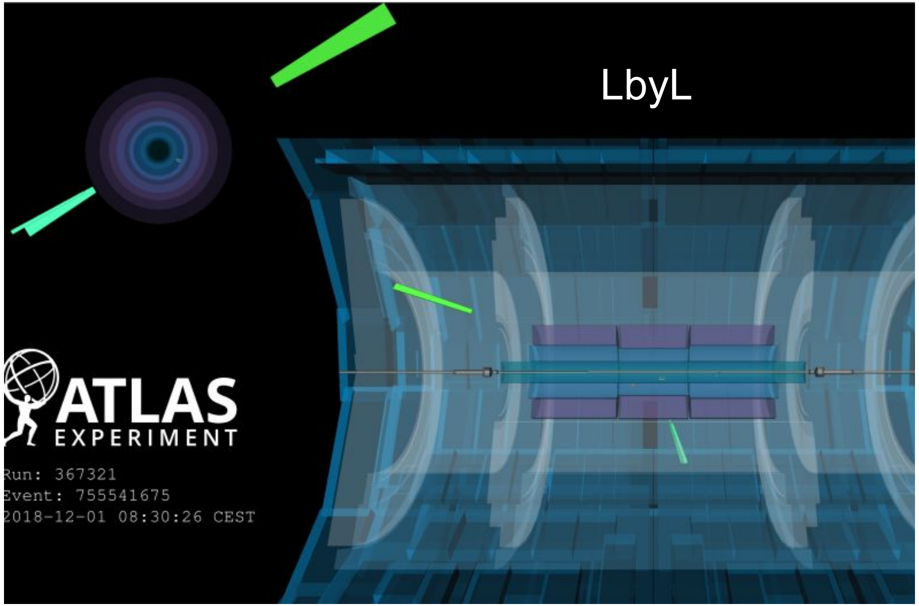


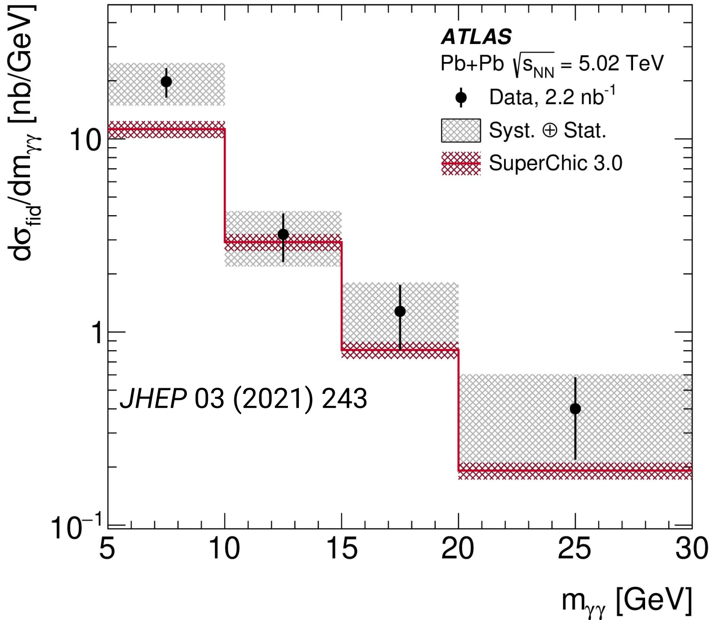
UPC: bmin>RA +RB



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

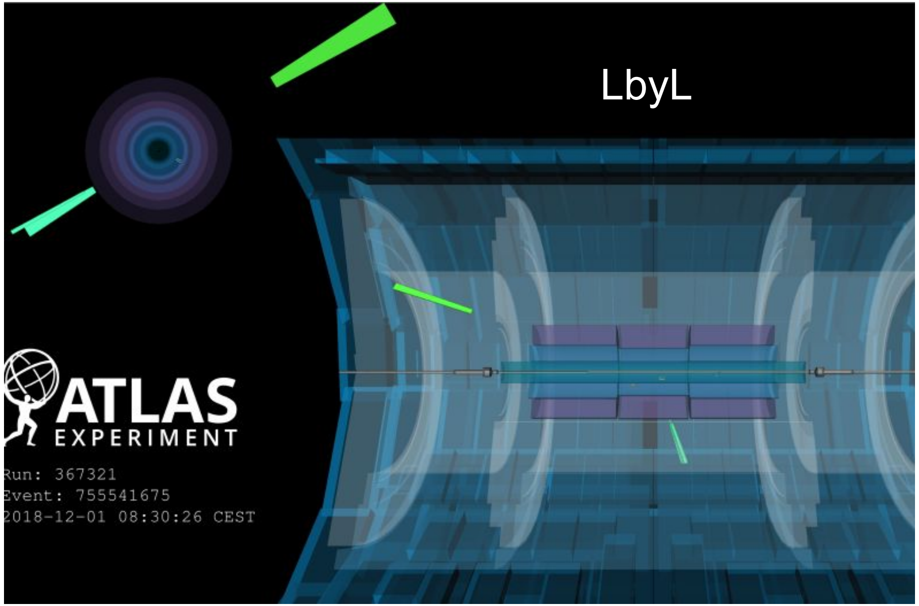


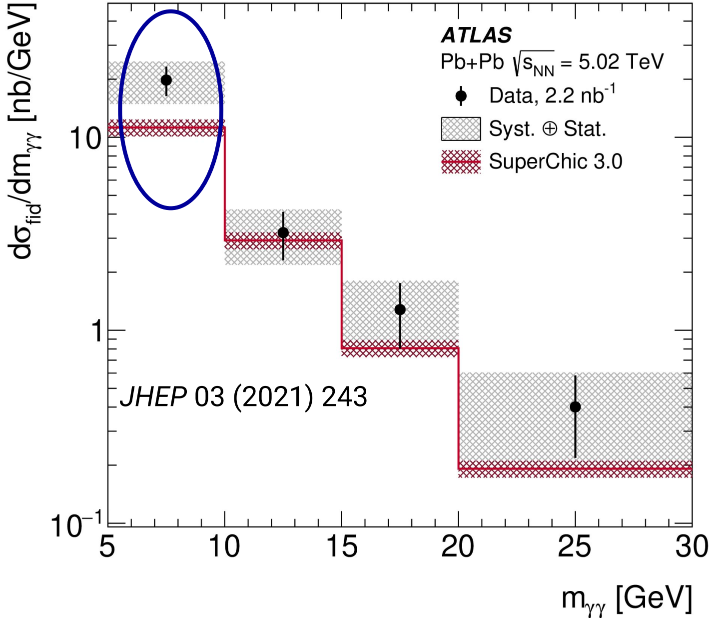


Goals of this analysis

- 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
    - more recent insights (cf. slides 12-13)

$\sqrt{s_{NN}}$	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	$77 \pm 8^{\dagger}$ [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, $A_\phi < 0.01$

(boxed rows) → **used as extrapolation correction**

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**

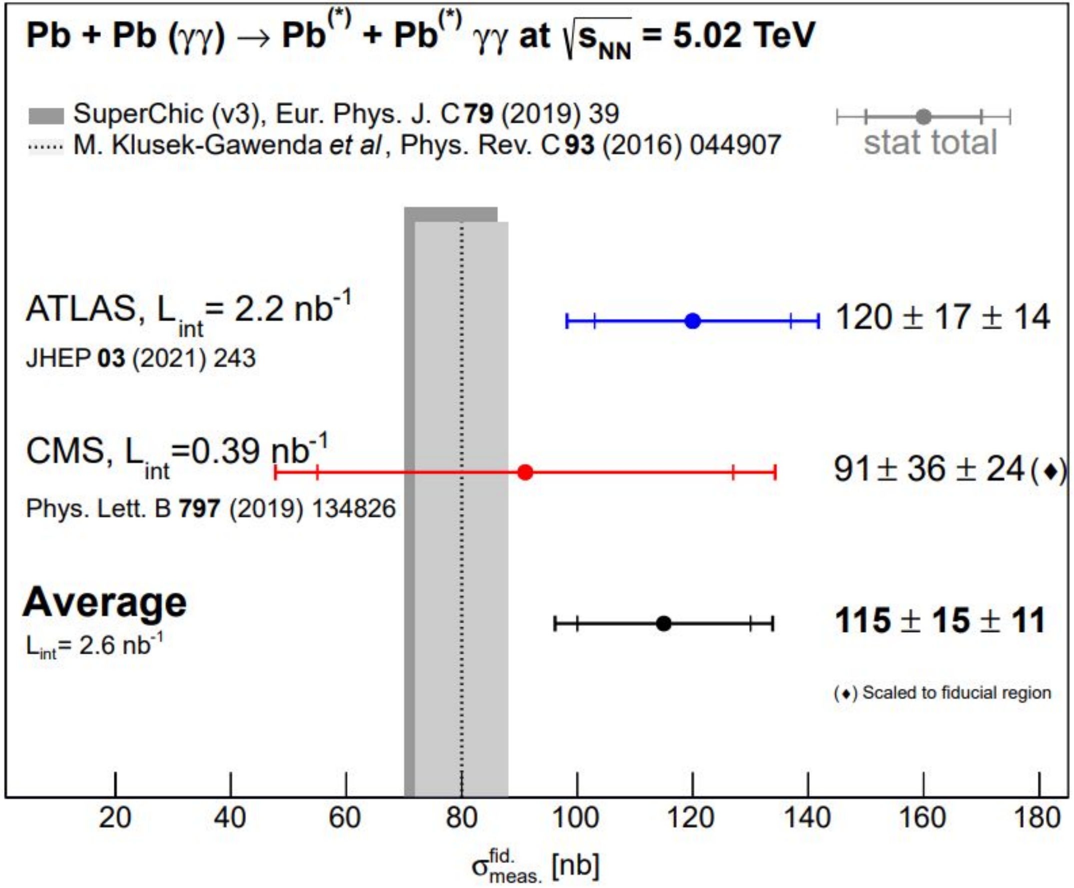
- Statistical unc still **dominates**
  - **~10%** improvement to input measurement
- <10% foreseen with **future data/analyses**

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

$\sigma^{\text{fid.}}_{\text{meas.}}, \sqrt{s_{\text{NN}}} = 5.02\,\text{TeV}$		
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

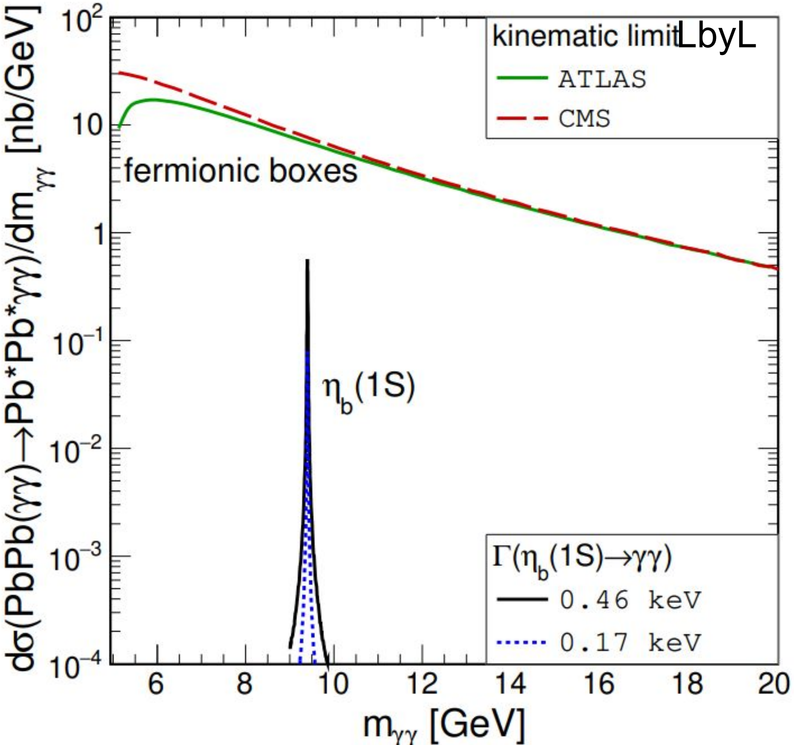
Averaged result and **comparison to theory**

- 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 γγ decay rates)
- this contribution **isn't significant**
- alternative efforts exist, e.g., γγ decay of the recently discovered X(6900) exotic meson



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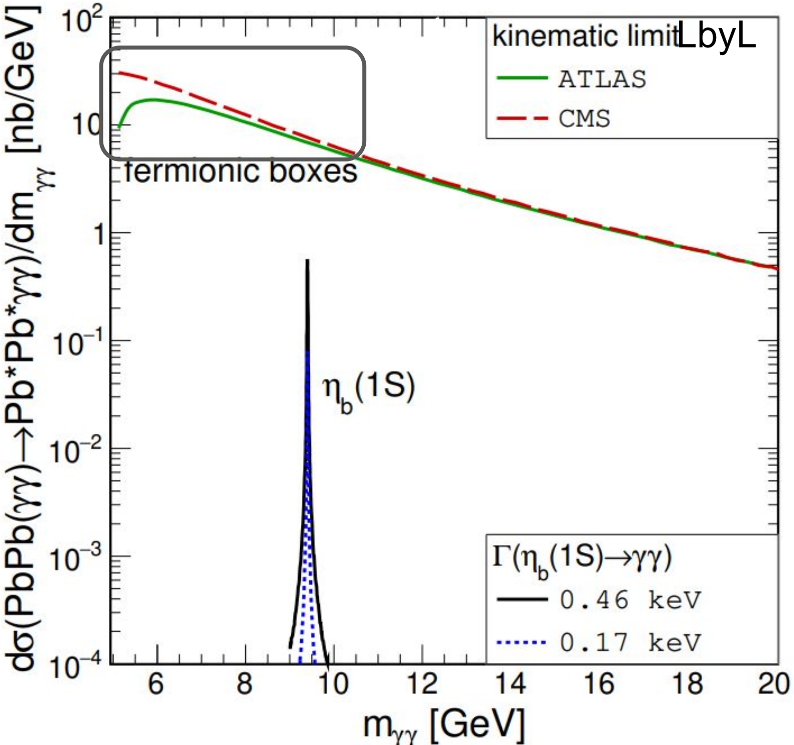
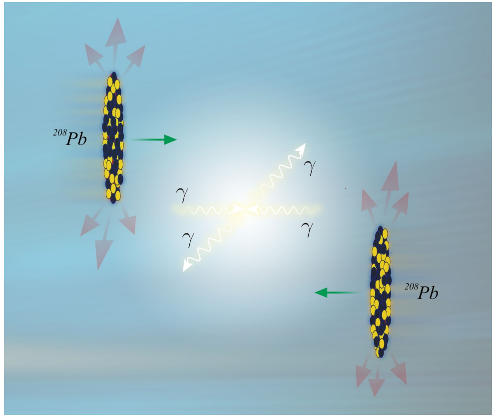


Summary

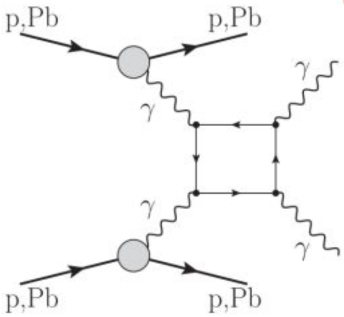
- LbyL in UPC **sensitive** to BSM at low couplings
- Averaged **existing** LbL UPC cross section measurements at LHC
  - corresponding to an effective luminosity of **2.2+0.4** /nb
- The fiducial phase space regions **differ** for the inputs
  - performed an **extrapolation** correction
- The averaged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



IFJ PAN

arXiv:2204.02845

Light-by-light scattering: Data vs. gamma-UPC



- LbL scattering $\gamma\gamma \to \gamma\gamma$ (1[st] proposed in PRL 111 (2013) 080405):

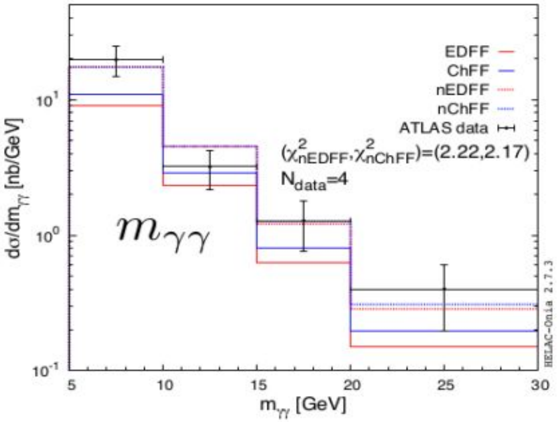
Integrated fiducial cross-section:

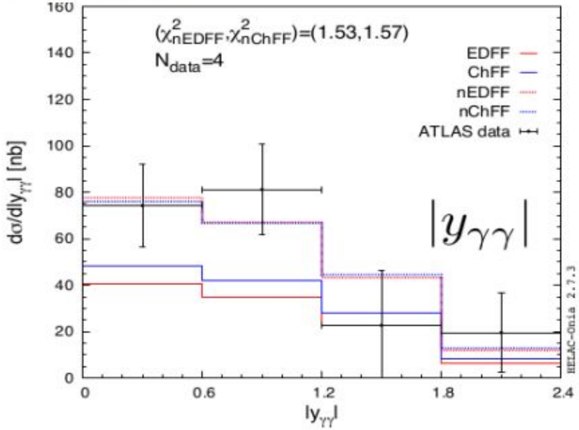
- Measurement:

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

ATLAS data [15]	gamma-UPC σ			SuperChic σ
	EDFF	ChFF	average	
120 ± 22 nb	63 nb	76 nb	70 ± 7 nb	78 ± 8 nb

ATLAS: JHEP 03 (2021) 243 CMS: Phys. Lett. B 797 (2019) 134826



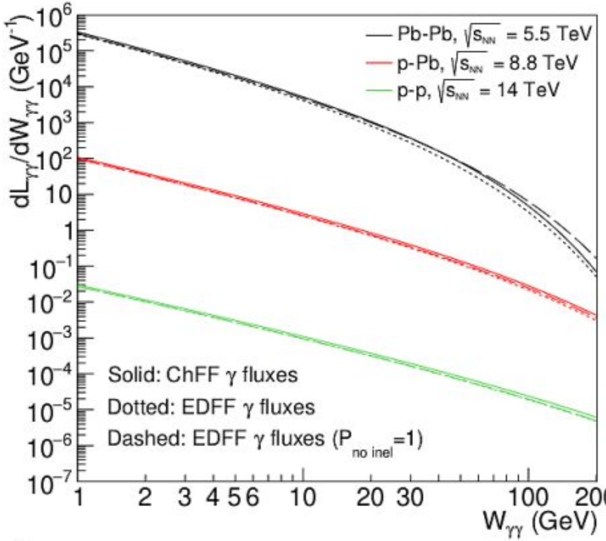


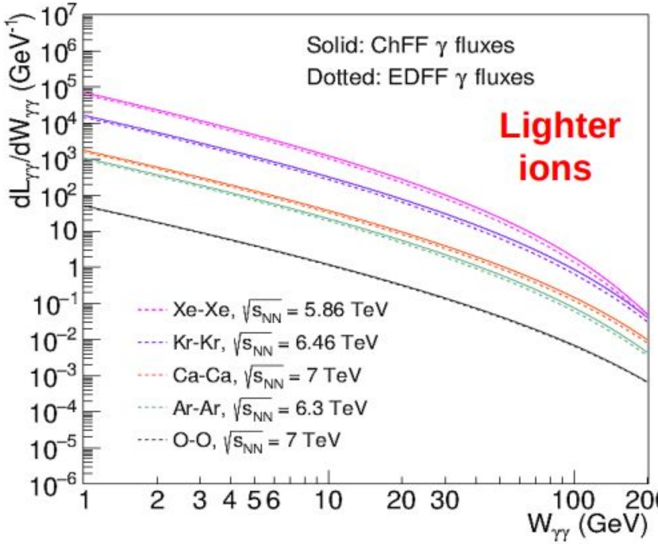
Slide here

- Shape well reproduced except lowest mass: Data is 2σ larger than theory
- Do we really control all (non)exclusive backgrounds at low masses?

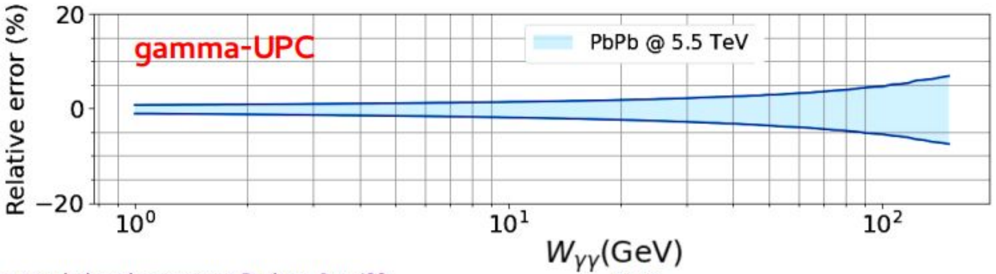
Effective γγ luminosities (LHC)

- Thanks to Z^4 boost, A-A γγ lumis (per collision) well above p-p ones:





- ChFF γγ luminosity uncertainties (PbPb): Low-mass: few %. High mass: <7%



ChFF γ spectra

Glauber MC:

Variations of R,a,σ_{NN}

Slide here

Data/ideas we have, fora we formed, where are the combinations?

A provocative talk from personal (i.e., biased) perspective given that

→ Since the kick-off meeting of the LPCC WG we **remained mostly silent**

→ the HonexComb effort successfully concludes it's mission in the **coming November**

GKK, 2023 CMS HIN Workshop

Outlook: **A restart is needed if we want to move fwd**

- All experiments welcomed the effort for the **official formation** of the LHC HI Working Group (WG)
  - **we're all open to** combination efforts
    - we even have already an extensive list of topics but ..
  - all experiments' involvement is (s)low and even initial practicalities yet to be done
- I think only **subgroups** could efficiently steer the effort
  - recheck with WG conveners their plans and form asap subgroups and their conveners
    - My biased view:
      - WG convs: more seniors but not heavily involved during their mandates in their experiment's activities
      - Subgroup convs: younger colleagues who can devote time (some experience preferable)
- Important to cover a **common ground**
  - **let's start gaining some momentum:** **summary plots** a good/promising starting point for the WG
  - **knowledge sharing** with other WGs can be beneficial
    - in review, analysis techniques, corrections, systematic uncertainties, ..
  - while the work remains experimental in nature, engaging with the **pheno/theory community is critical**
- Other/complimentary functionalities of WG can be
  - organizing dedicated **workshops**
  - a natural place to standardize the procedure on requesting **theoretical predictions**
  - potentially a good basis for discussions related to near-/far-future **running schedule**

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 ($\gamma\gamma$) $\rightarrow$ 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† 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 $\sigma^{\text{fid.}}_{\text{theo.}}(\gamma\gamma \rightarrow e^+e^-)$	10
Category subtotal		**1**		**10**
Integrated luminosity		3		
Category subtotal		**3**		
Background determination	Data-based $\gamma\gamma \rightarrow e^+e^-$ 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.$\oplus$ID efficiency	18
Category subtotal		**5**		**18**
Photon angular resolution	Photon angular resolution	2		
Category subtotal		**2**		
Electron reconstruction and identification			Electron reco.$\oplus$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

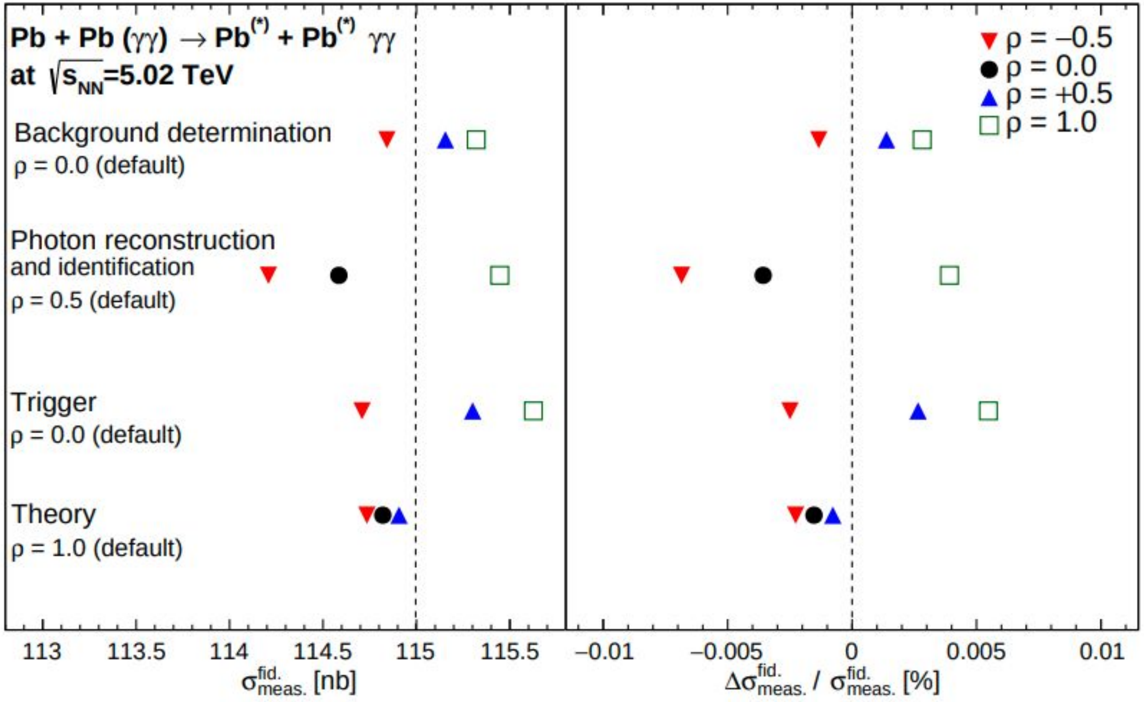


Fig. 4: (left panel) Results of the stability tests demonstrating impact of variations of the correlation assumptions in different uncertainty categories on the combined cross-section are shown. (right panel) The corresponding relative shifts (with Δ = varied − nominal) in the central value, $\sigma_{\text{fid.}}$,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