Observation of light-by-light scattering and new results from ultra-peripheral heavy-ion collisions in the ATLAS experiment

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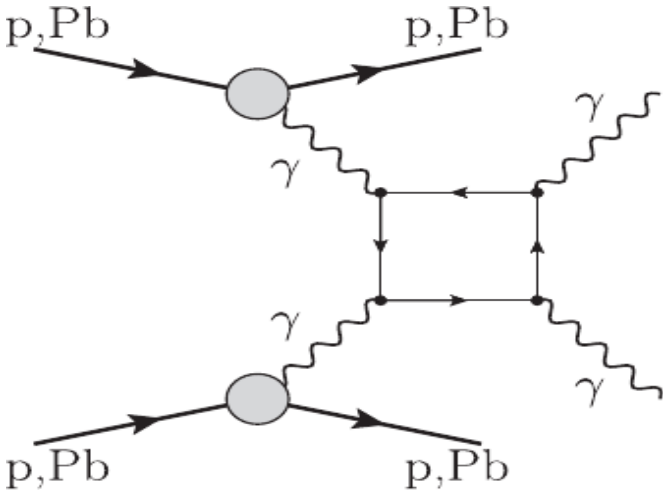
Outline

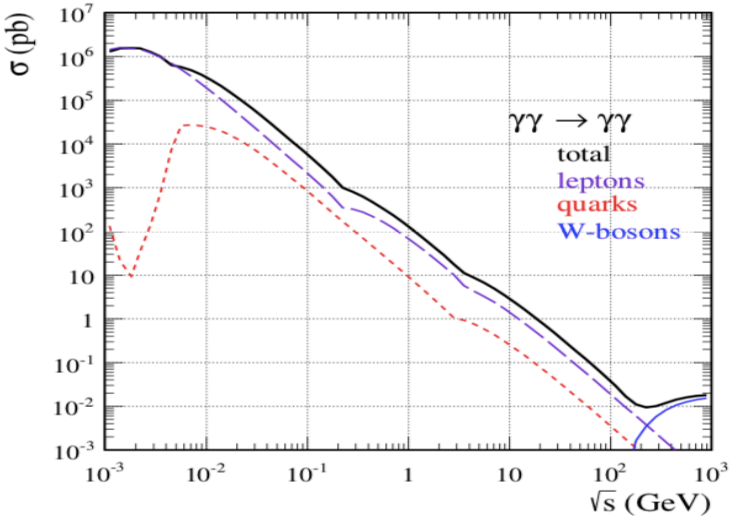
- Standard Model light by light scattering
- Experimental evidences and new ATLAS measurements
- New results from ultra-peripheral heavy-ion collisions (UPC)

One-loop process

- The standard Model predicts the possibility of light by light scattering via 1-loop diagrams
- Loops contains virtual charged particles ($q, l, W^{\pm}$) from SM
- Heavy ions create huge EM fields (10^{14}T) from coherent action of Z protons: cross section Z^4
- UPC provide a flux of quasi-real photons probing the nuclear structure
- The process sensitive to BSM physics



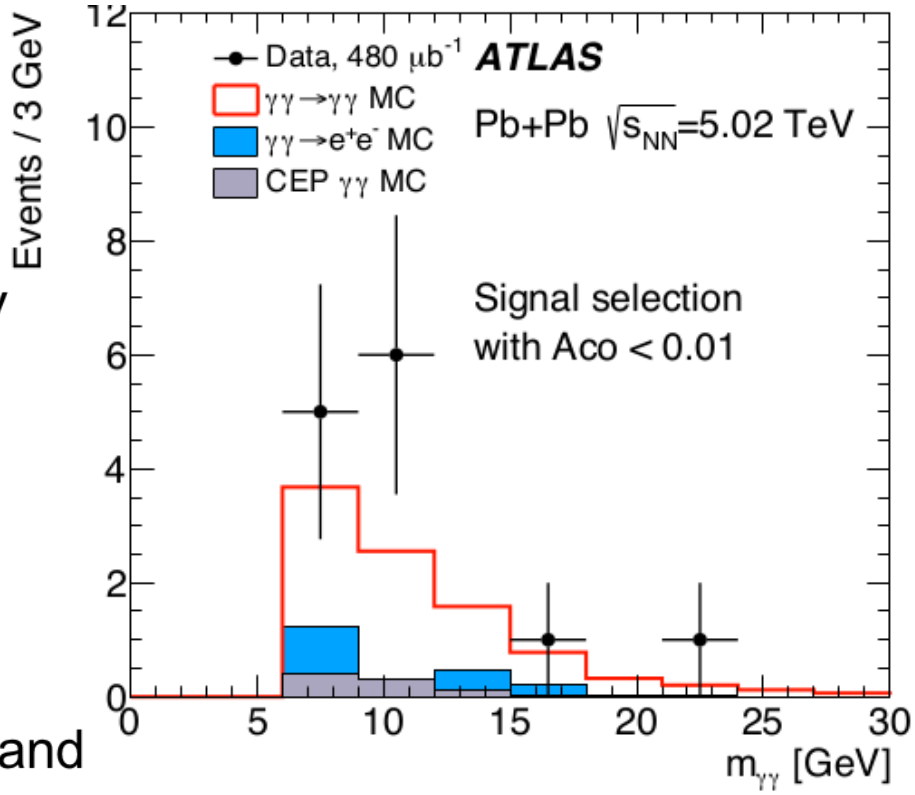
$\sigma(\gamma\gamma \to \gamma\gamma \propto \alpha^4)$



First evidence

- **2015 Pb+Pb data 0.48 nb-1**

Nature Physics 13 (2017) 852



- **Event selection** :

2 back to back photons and nothing else in the central detector

$E_T > 3$ GeV and $|\eta| < 2.4$, $m_{\gamma\gamma} > 6$ GeV

$P_{T\gamma\gamma} < 2$ GeV

$$\text{Acoplanarity} = 1 - \frac{|\Delta\varphi|}{\pi} < 0.01$$

- **Results :**

13 events observed (**7.3** signal events and **2.6** background events are expected)

The excess corresponds to 4.4σ statistical significance over background only hypothesis

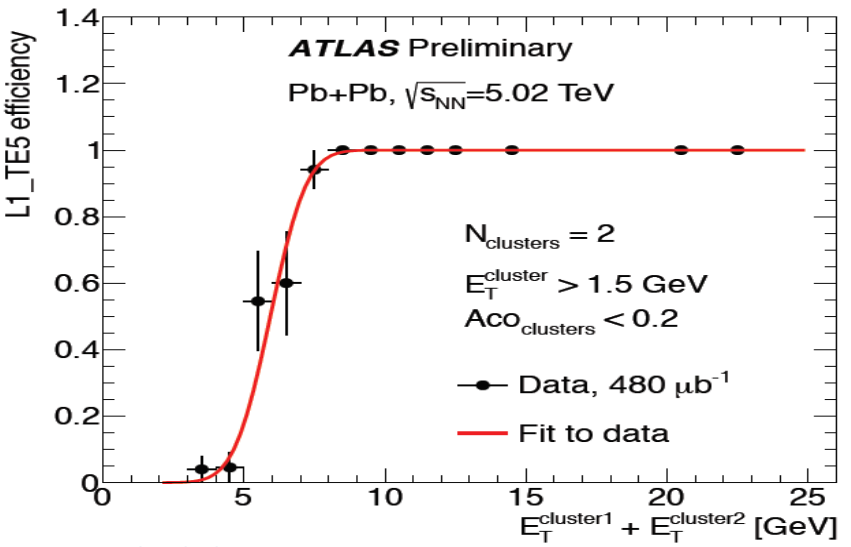
New Measurements

❖ **2018 data:**

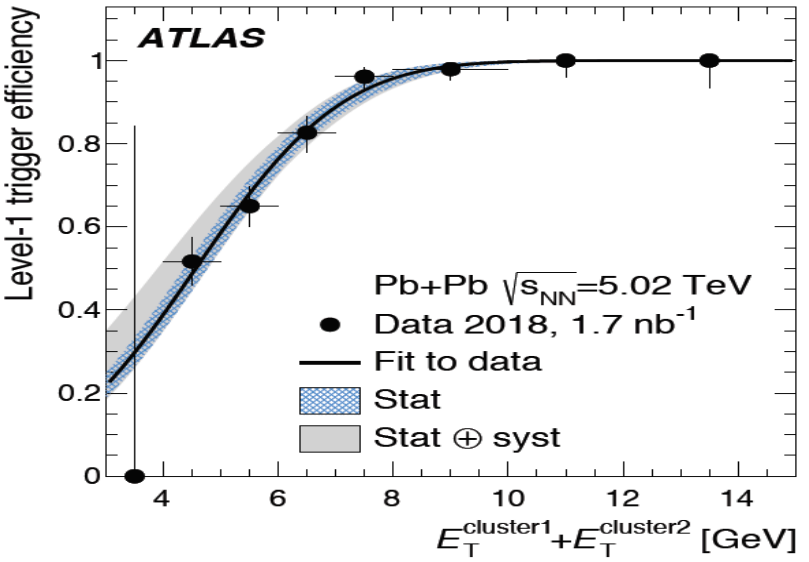
- 1.73 nb^{-1} data
- More than 3 times stat w.r.t. 2015 dataset

❖ **Improvements:**

- Strong emphasis was put to improve the trigger strategy (especially at the Level-1)
- Trigger with higher efficieny at low E_T
- NN Photons PID instead of cut based
- Better background rejection



ATLAS-CONF-2016-111

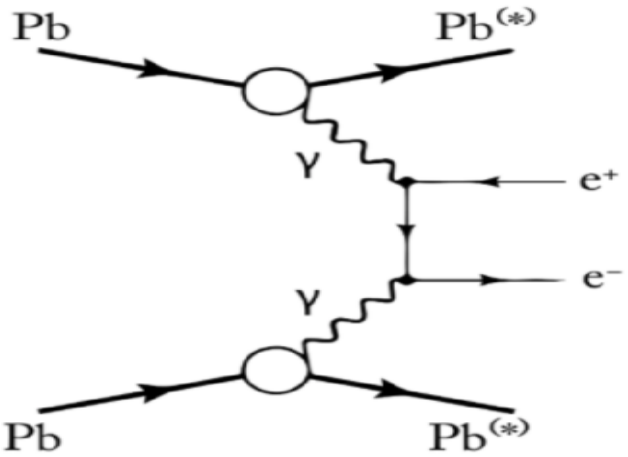


arXiv: 1904.03536 (accepted for PRL)

New Measurements

❖ **Signal :**

- γγ → γγ Generator : **Superchic3**
  100k events (167 nb)



❖ **Background Considered :**

- Exclusive dielectron production **γγ → e+e-**

Generator : **Starlight**

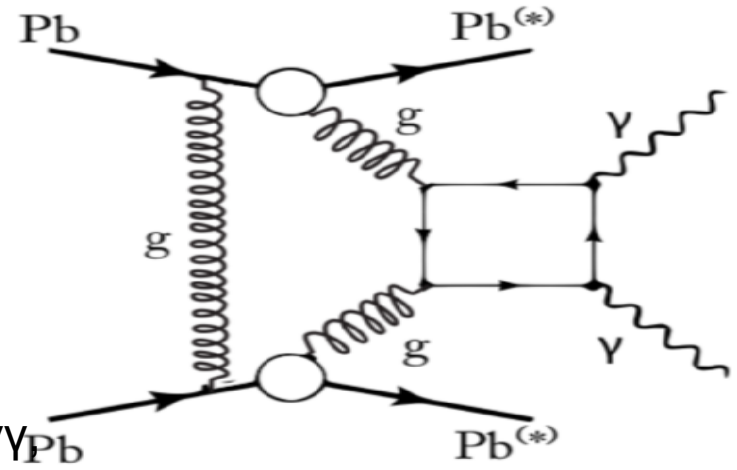
1.5 M events (419 b) 3.6 < M_{inv} <8 GeV

0.5 M events (116 b) M_{inv} > 8 GeV)

- Central Exclusive Production (CEP) **gg → γγ**

Generator : **Superchic3**

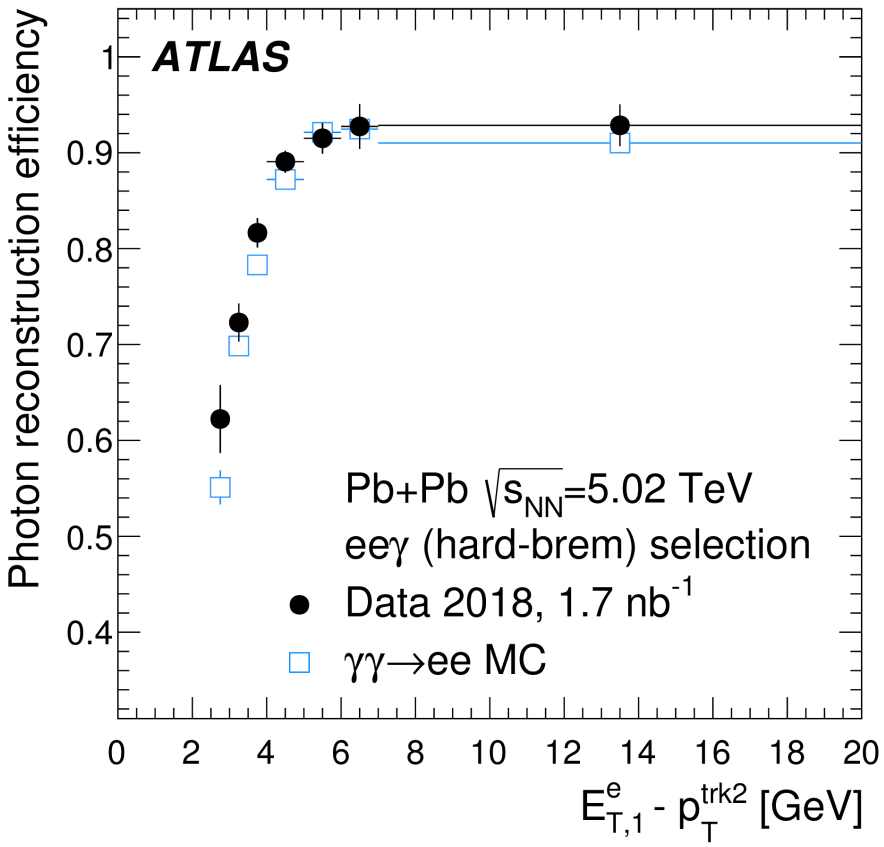
100k events

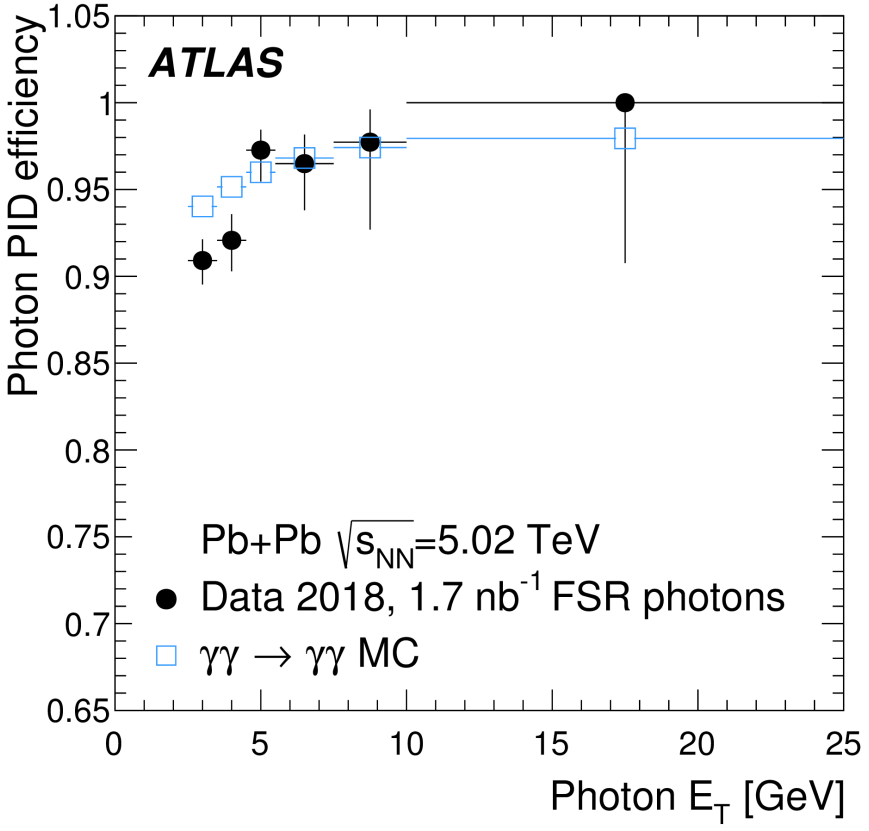


❖ **Negligible Background**

- **Fakes** (calo noise, cosmics)
- **Others, found negligible** (exclusive di-meson production (e.g. $\pi^0\pi^0$), γγ → ττ, γγ → qq, γγ → eeγγ, γγ → η_b → γγ, γPb → Υ → 3γ, ion bremsstrahlung)

Photon Performance studies





Reconstruction efficiency is extracted from data $\gamma\gamma \rightarrow e^+e^-$ events
Tag and prob : 1 electrons and 2 charged-particle tracks

Neural network based PID
Trained on background photons from data + photons from the signal MC

arXiv: 1904.03536 (accepted for PRL)

Signal selection

❖ Two photons

- Identification: NN working point
- $E_T > 3$ GeV, $|\eta| < 2.37$

❖ LbyL scattering topology

- $m_{\gamma\gamma} > 6$ GeV
- Veto extra particle activity

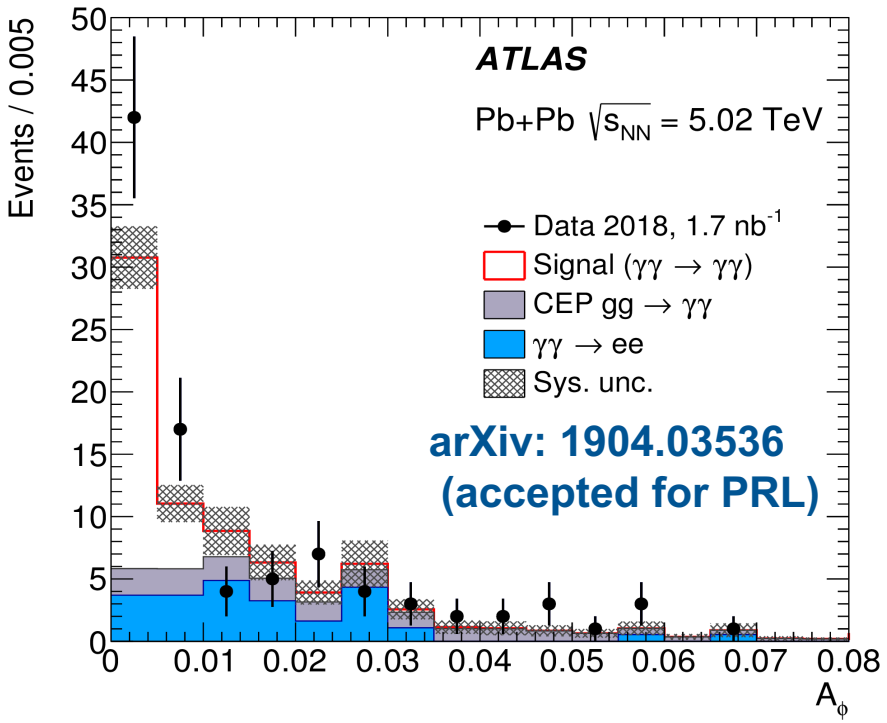
to suppress e+e- background

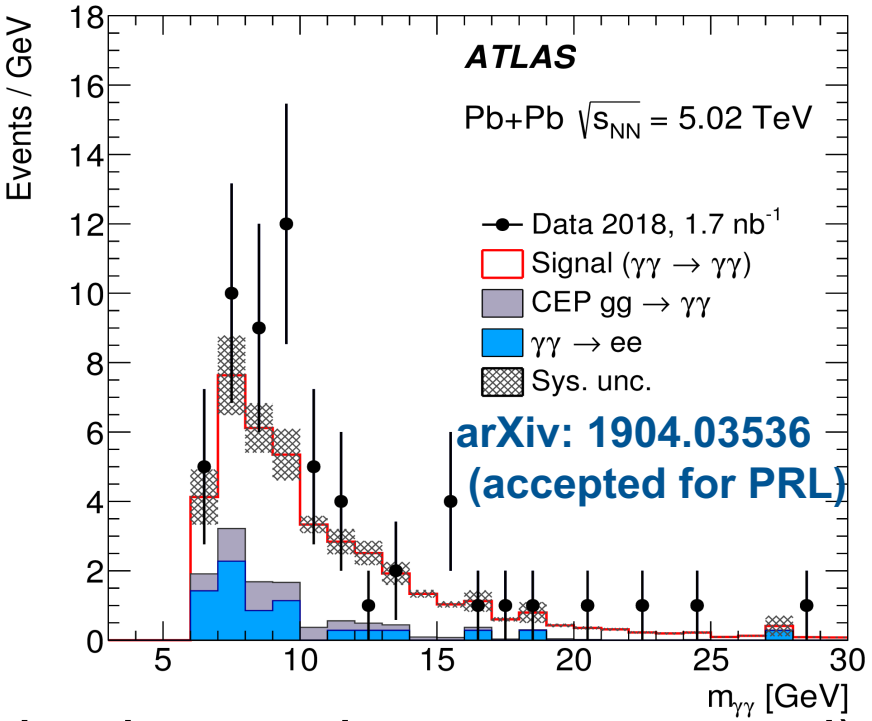
- Requiring no tracks (pT > 100 MeV)
- and no pixel tracks ($p_T > 50$ MeV, $|\Delta\eta| < 0.5$ photon-pixelTrk matching)

to suppress fakes and CEP background

- $p_{T\gamma\gamma} < 1$ GeV (2 GeV for $m_{\gamma\gamma} > 12$ GeV)
- Diphoton acoplanarity < 0.01

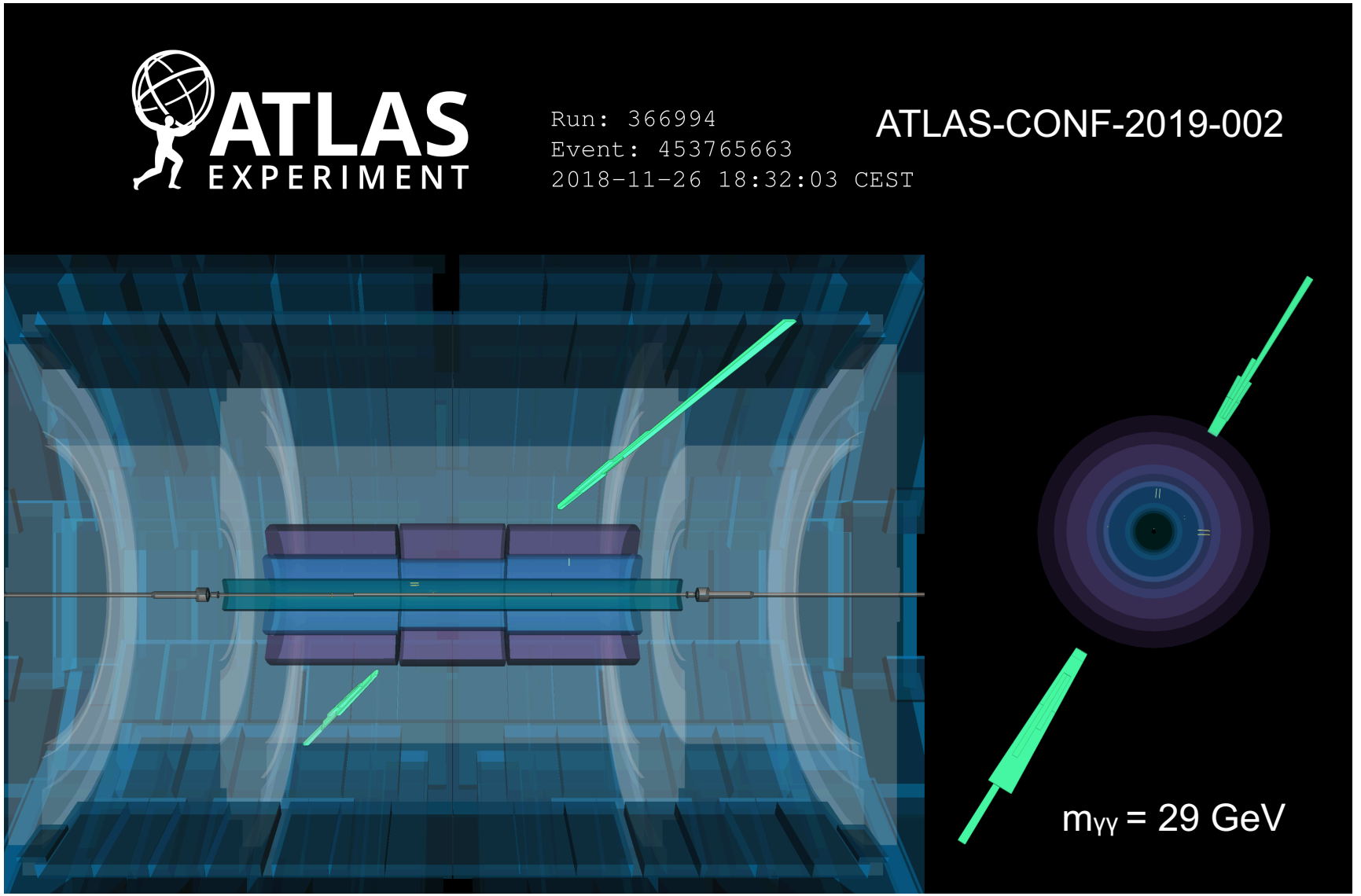
Results





- **59** events observed (where **12 ± 3** background events expected)
- Observed signal significance over the background only hypothesis is of **8.2σ** (expected **6.2σ**)
- Updated cross-section: **σ = 78 ±13 (stat) ±8 (sys) nb**
- SM predictions: **51 ±5 nb** Phys. Rev. C 93 (2016) 044907
  50 ±5 nb Eur. Phys. J. C 79 (2019) 39

Results


ATLAS
EXPERIMENT
Run: 366994
Event: 453765663
2018-11-26 18:32:03 CEST
ATLAS-CONF-2019-002
$m_{\gamma\gamma}$ = 29 GeV

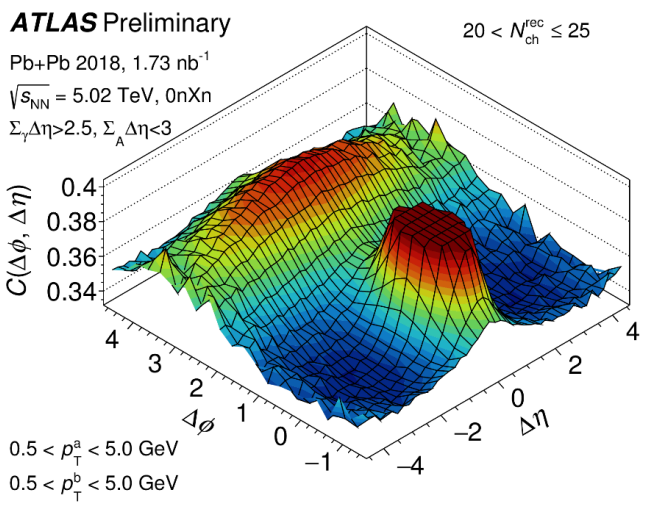
Two-particle azimuthal correlations

- 2018 data (1.73 nb^{-1}, 5.02 TeV)

- Dedicated photo-nuclear event trigger
- Looking to charged-particle tracks in the event

- A template fitting method is employed to subtract the non-flow contribution

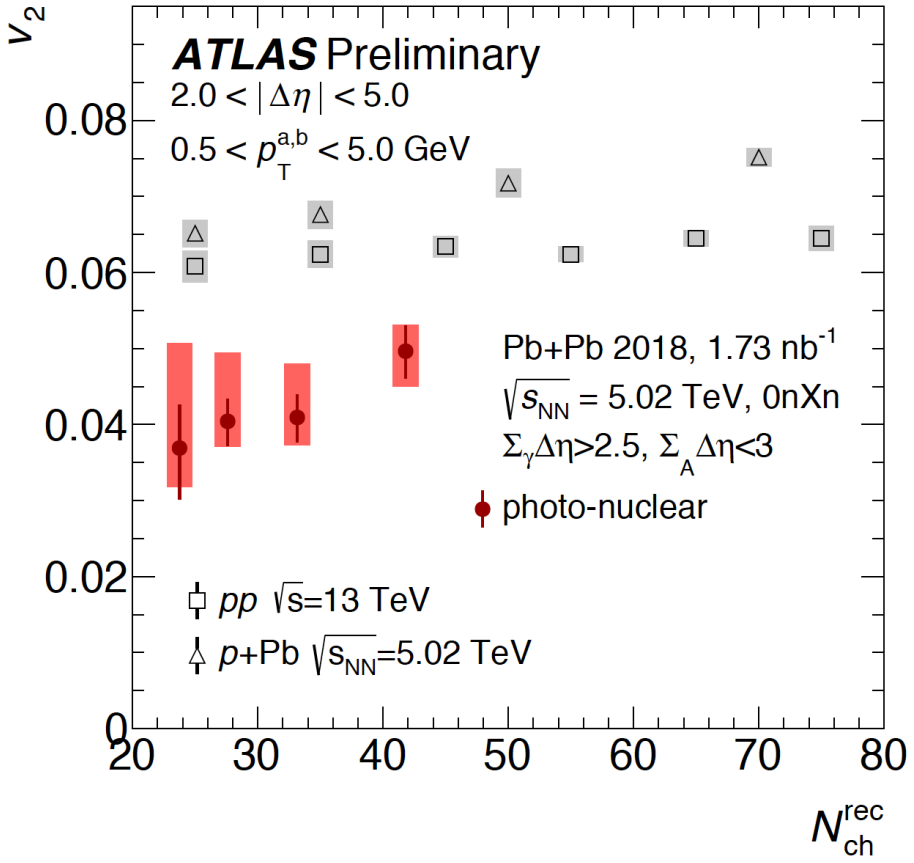
ATLAS-CONF-2019-022



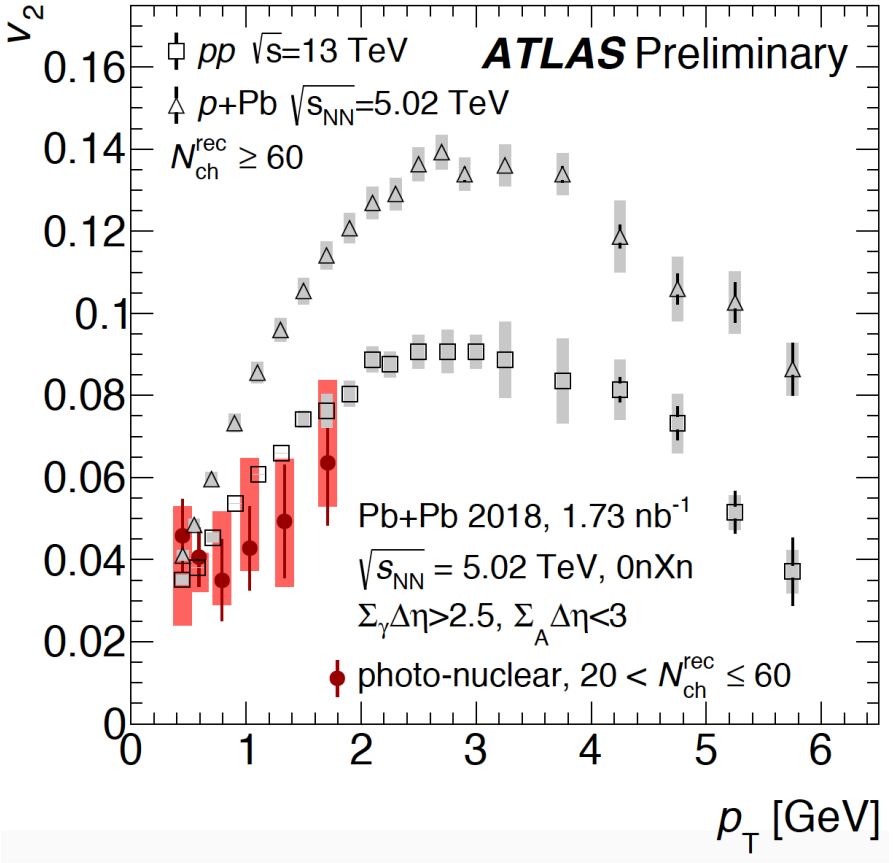
$$Y^{\mathrm{HM}}(\Delta\phi) = FY^{\mathrm{LM}}(\Delta\phi) + G\left\{1 + 2\sum_{n=2}^{3} v_{n,n}\cos(n\Delta\phi)\right\}$$
$$= FY^{\mathrm{LM}}(\Delta\phi) + Y^{\mathrm{ridge}}(\Delta\phi).$$

Two-particle azimuthal correlations

ATLAS-CONF-2019-022



Flow coefficients $\mathbf{v_2}$ as a function of charged-particle multiplicity



Flow coefficients $\mathbf{v_2}$ as a function of particle P_T

Summary

Using LHC as a photon-photon collider works very well :

- Light-by-light scattering was observed with the ATLAS detector using data from Pb+Pb collisions at 5.02 TeV from 2018

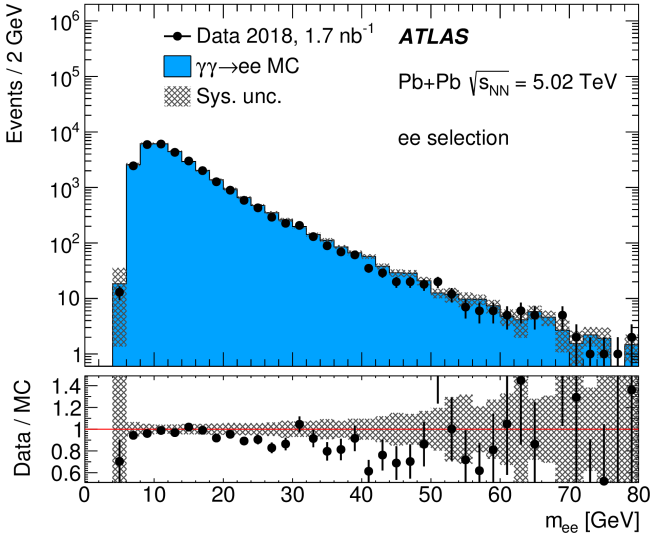
•The signal significance gives an observation with 8.2σ
Measured fiducial cross-section: $\sigma = 78 \pm 13$ (stat) ± 8 (sys) nb

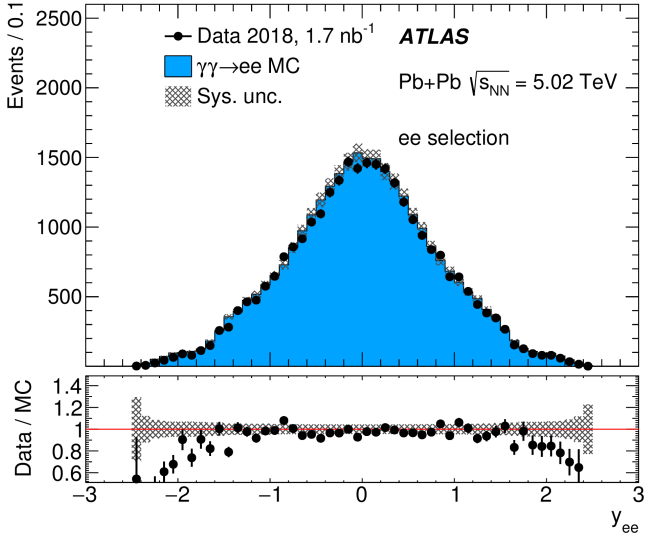
- UPC data will improve the understanding of the strong electromagnetic fields surrounding the nucleus, which enable future UPC measurements utilizing these high energy probes

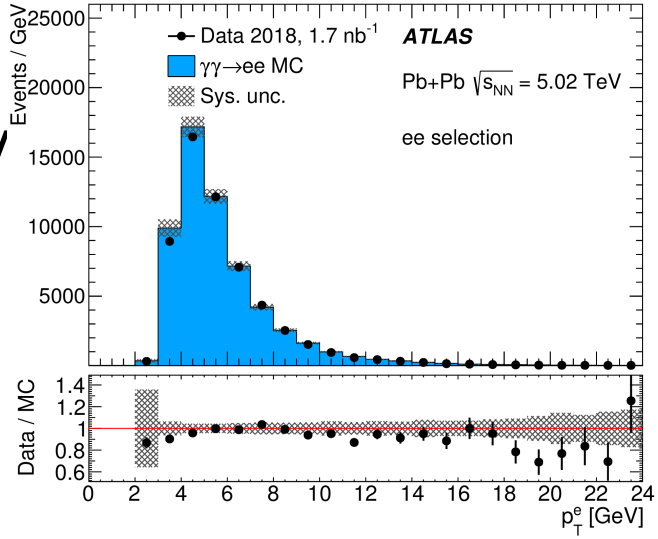
Backup

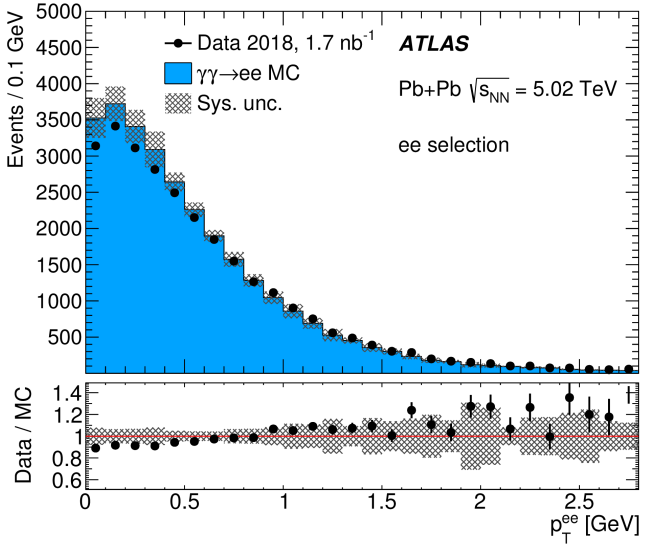
exclusive dielectron pairs are used for various aspects of the analysis

- MC simulation normalized to integrated luminosity





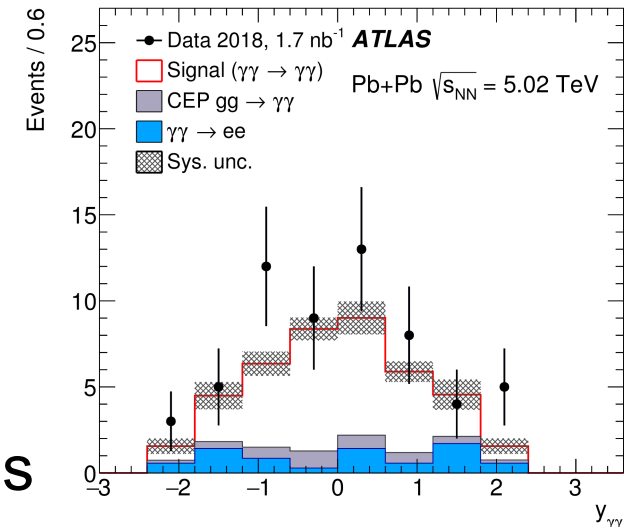


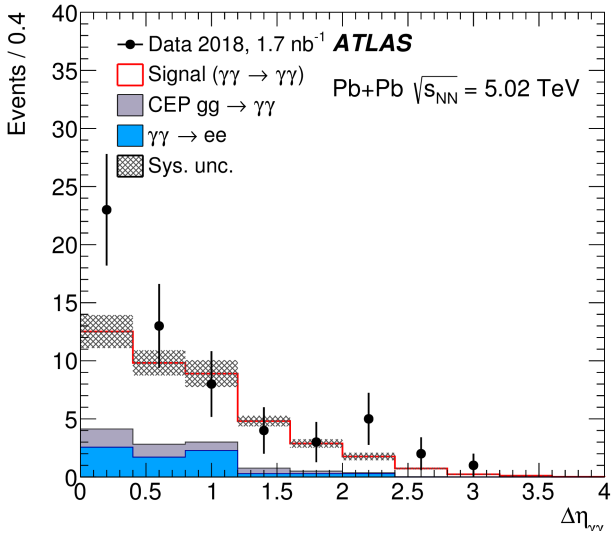


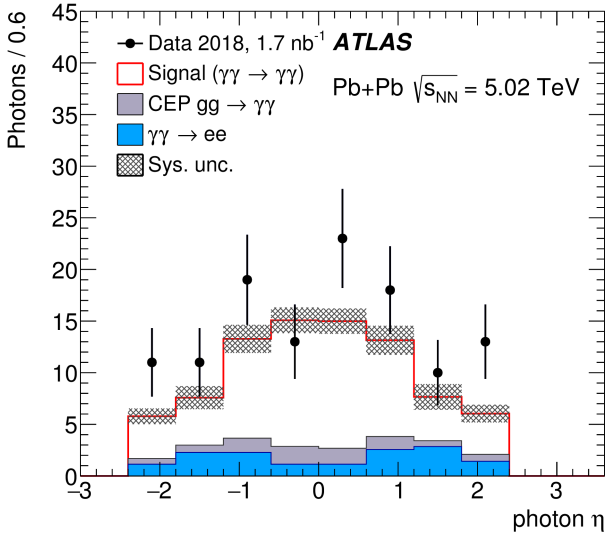
arXiv:1904.03536

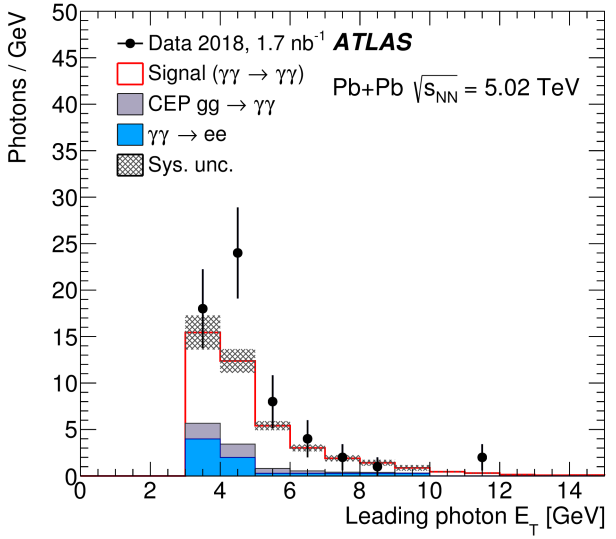
Backup

Kinematic distributions for γγ→ γγ event candidates:









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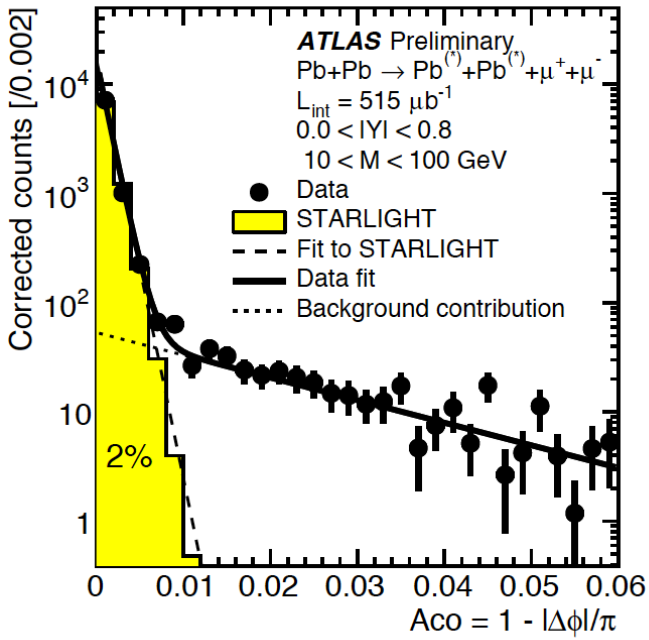
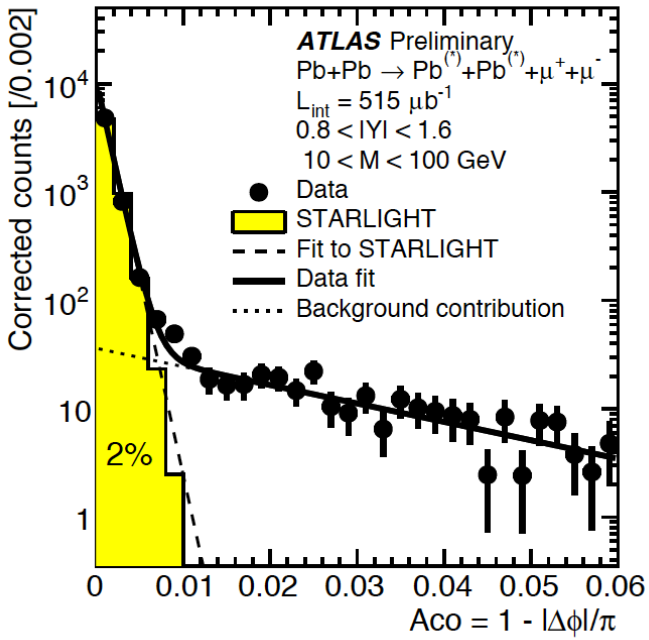
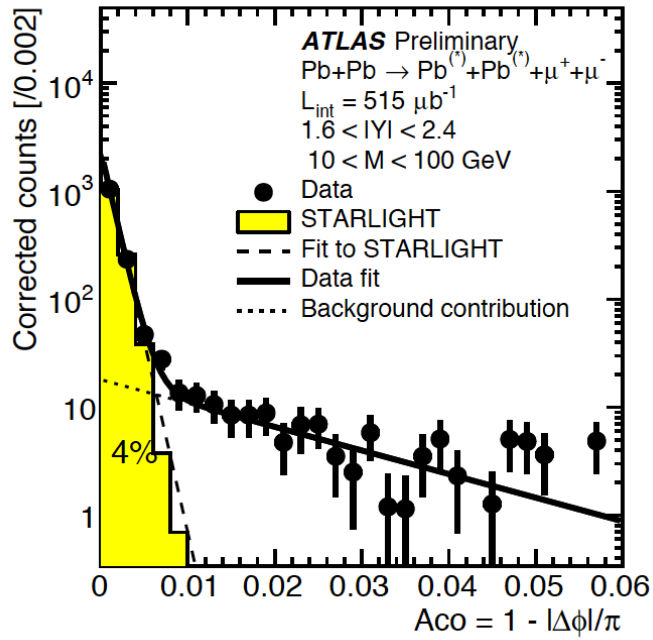
Backup

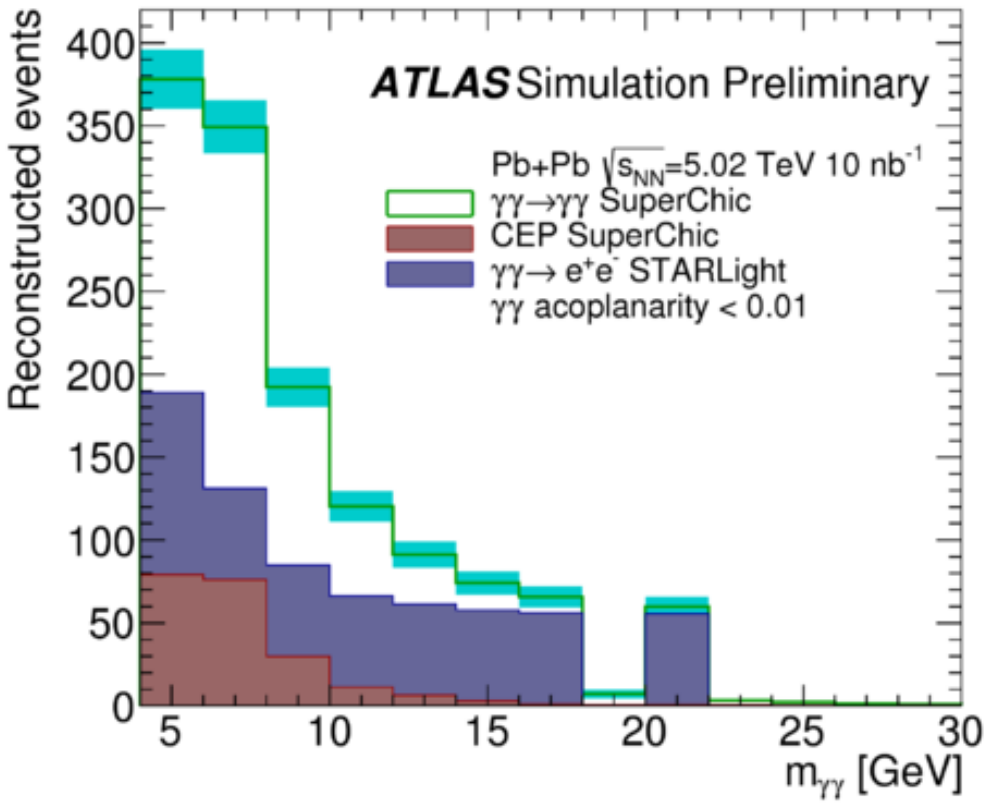






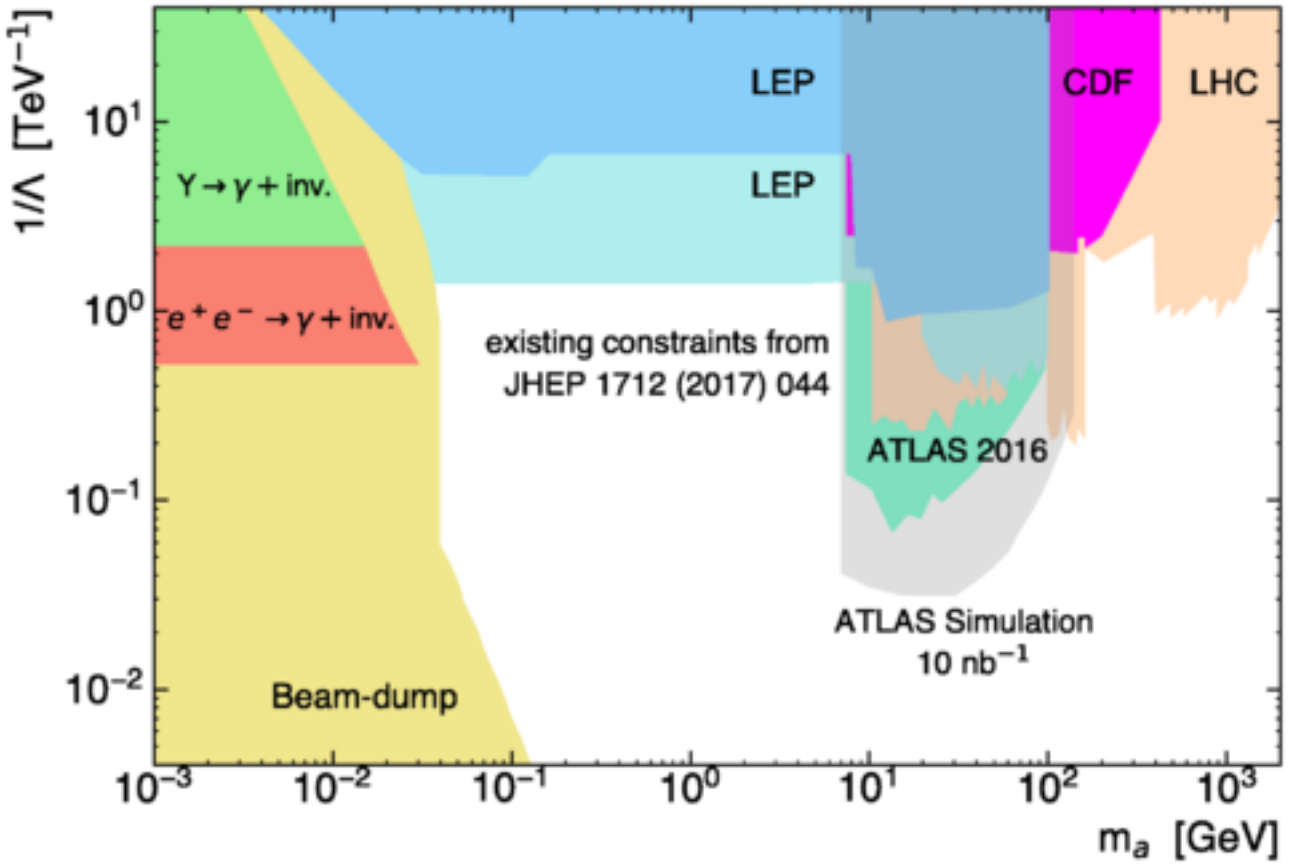
Acoplanarity distributions for different selections in pair rapidity.

Backup



Invariant mass distributions of the di-photon system for photons from the LbyL signal and background processes in 5.02 TeV Pb+Pb collisions with an integrated luminosity of 10 nb^{-1}. The shaded band in cyan represents expected statistical uncertainties.

Backup



ATLAS 2016 represents the exclusion limit derived from the recent LbyL cross section measured in Pb+Pb collisions by ATLAS.

Backup

Source of uncertainty	Detector correction (C)
	0.350
Trigger efficiency	2%
Photon reco efficiency	4%
Photon PID efficiency	2%
Photon energy scale	2%
Photon energy resolution	2%
Photon angular resolution	2%
Alternative signal MC	1%
Signal MC statistics	1%
Total	7%

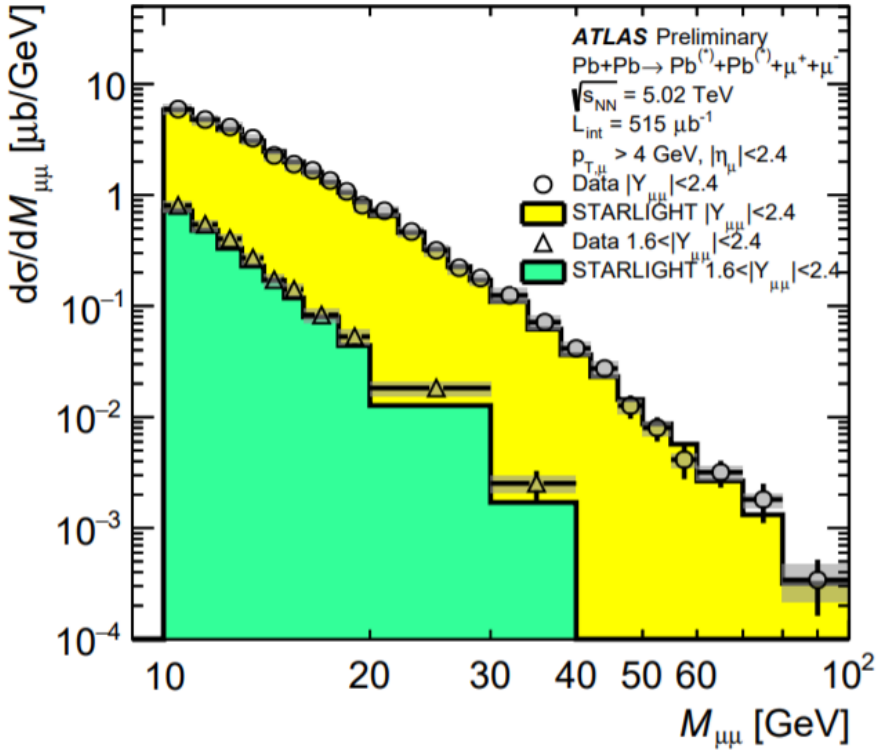
$$\sigma_{\text{fid}} = \frac{N_{\text{data}} - N_{\text{bkg}}}{C \times \int L\mathrm{d}t},$$

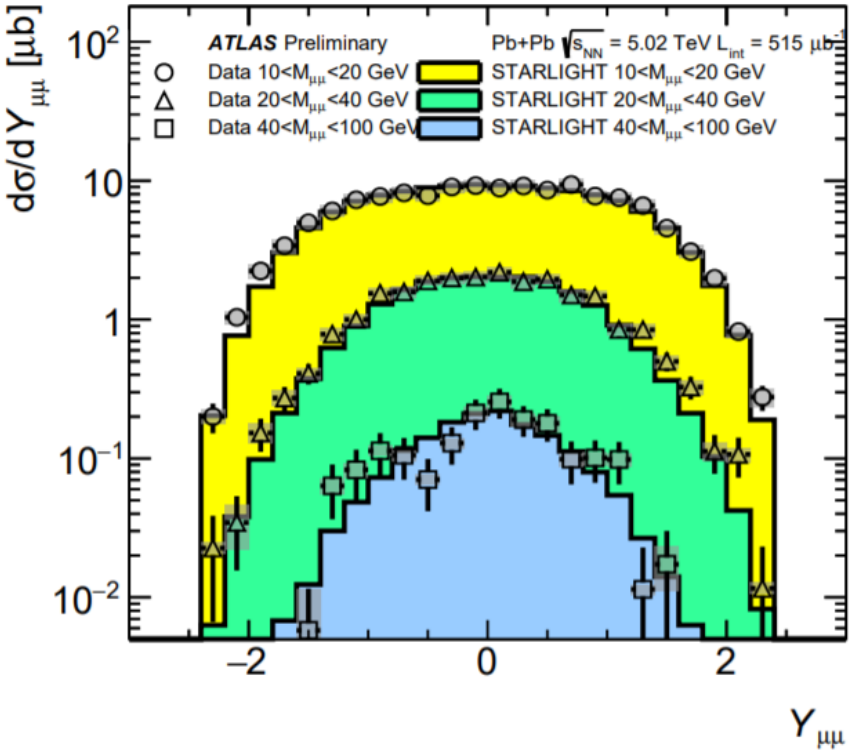
Backup

- First preliminary measurement of high-mass (beyond 10 GeV) exclusive dimuon events in ultra-peripheral heavy-ion collisions.
- The results are compared with the STARLIGHT 1.1

Monte Carlo

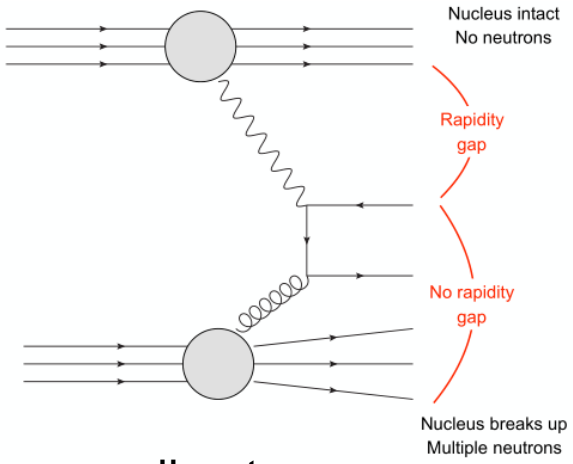
Pb + Pb → μ+ + μ− +Pb (*) + Pb (*) **ATLAS-CONF-2016-025**



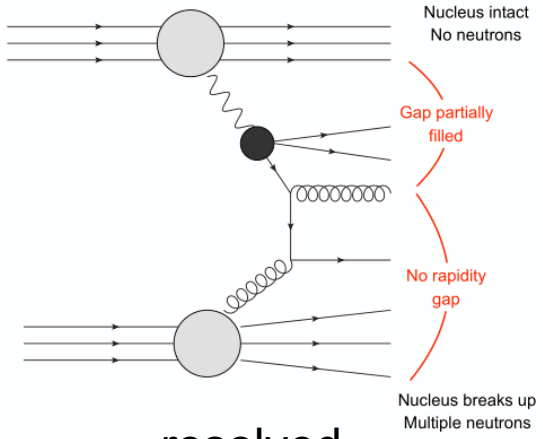


Backup

Cross-sections measurement taking into account 2 contributions



direct



resolved

$$H_T \equiv \sum_i PT_i$$

$$y_{\text{jets}} \equiv \frac{1}{2} \ln \left(\frac{\sum_i E_i + \sum_i p_{z\,i}}{\sum_i E_i - \sum_i p_{z\,i}} \right)$$

$$z_\gamma \equiv \frac{m_{\text{jets}}}{\sqrt{s}} e^{+y_{\text{jets}}}, \quad x_{\text{A}} \equiv \frac{m_{\text{jets}}}{\sqrt{s}} e^{-y_{\text{jets}}}$$

ATLAS-CONF-2017-011