Observation of light-by-light scattering in lead-lead collisions in the ATLAS experiment

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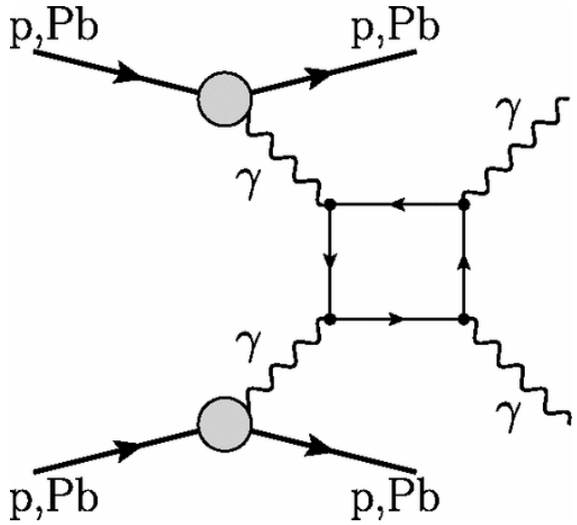
on behalf of the ATLAS Collaboration

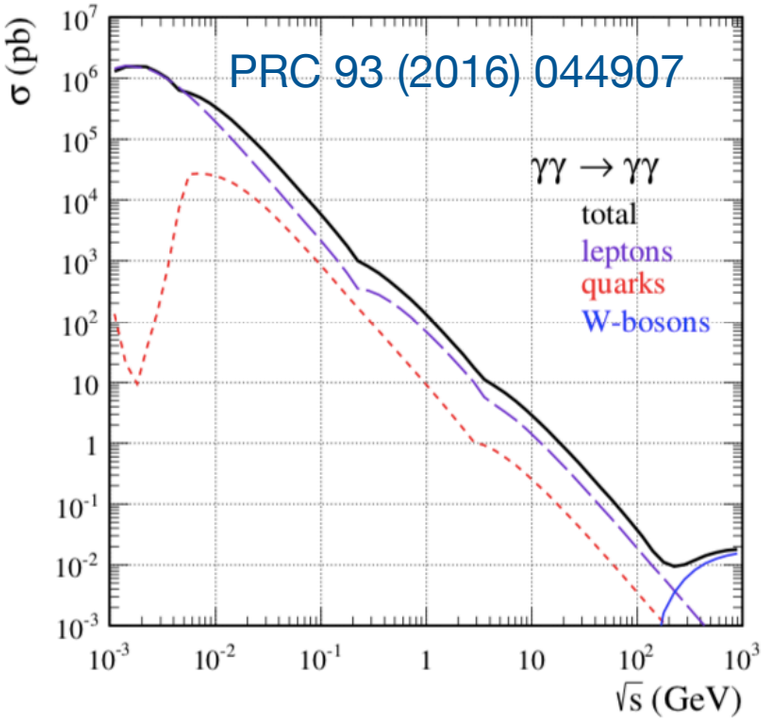
Interpreting the LHC Run 2 Data and Beyond, 27.05-31.05.2019

Introduction

- **Light-by-light** (LbyL) scattering is a **rare QED process**, which is forbidden in classical electrodynamics
- In QED, the γγ → γγ reaction proceeds at lowest order in the fine-structure constant (α_{em}) via virtual one-loop box diagrams involving fermions
- Photon-photon interactions can be observed in **heavy-ion collisions** due to large EM fields associated with relativistic ions (cross-sections scale with ~Z^4)

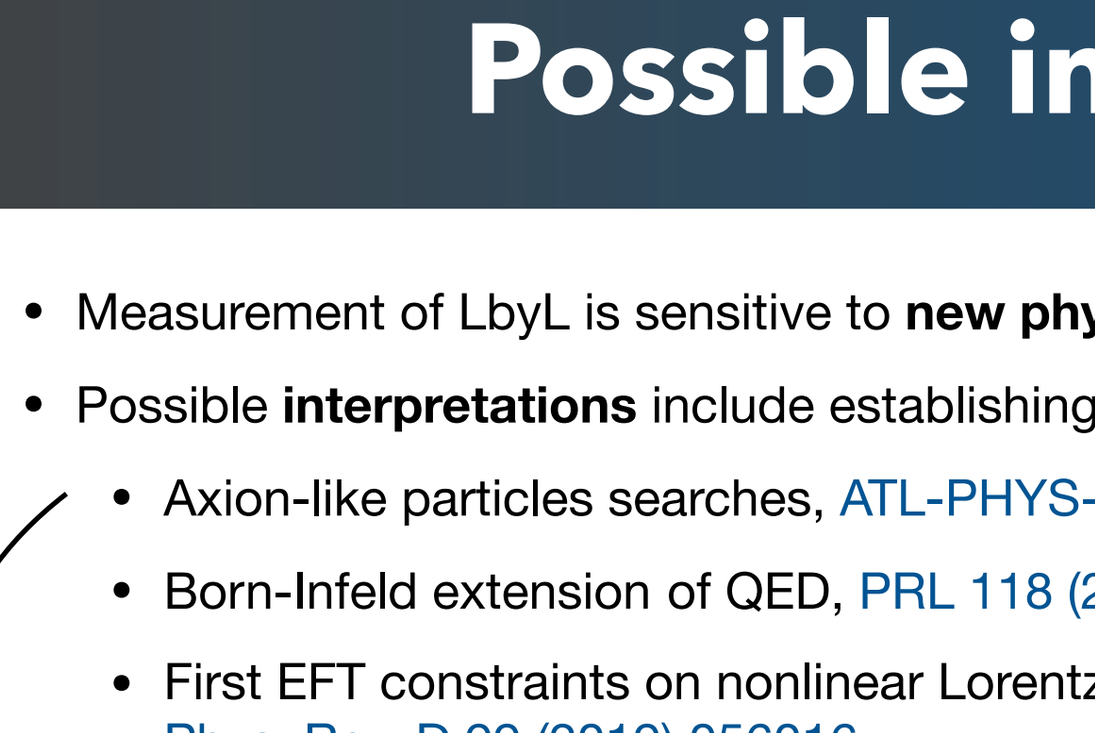


- EM field is treated as a **beam of quasi-real photons** with small virtuality (equivalent photon approximation)
- Two datasets from Pb+Pb collisions at 5.02 TeV were collected by ATLAS detector and resulted in LbyL measurements
  - **0.48 nb^{-1}** in 2015: Nature Physics 13 (2017) 852
  - **1.73 nb^{-1}** in 2018: arXiv:1904.03536 **NEW**
- Also CMS experiment reported evidence of LbyL based on 2015 Pb+Pb data: arXiv:1810.04602



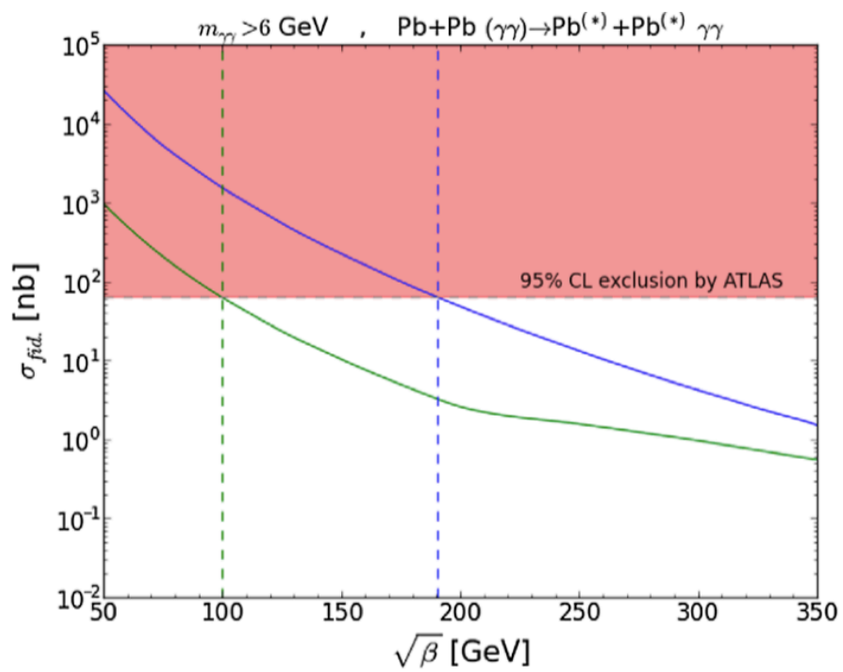
Possible interpretations

- Measurement of LbyL is sensitive to **new physics**
- Possible **interpretations** include establishing new limits on specific BSM models
  - Axion-like particles searches, ATL-PHYS-PUB-2018-018
  - Born-Infeld extension of QED, PRL 118 (2017) 261802
  - First EFT constraints on nonlinear Lorentz-violating operators in QED, Phys. Rev. D 99 (2019) 056016



$$\mathcal{L}_{\mathrm{QED}} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} \rightarrow$$

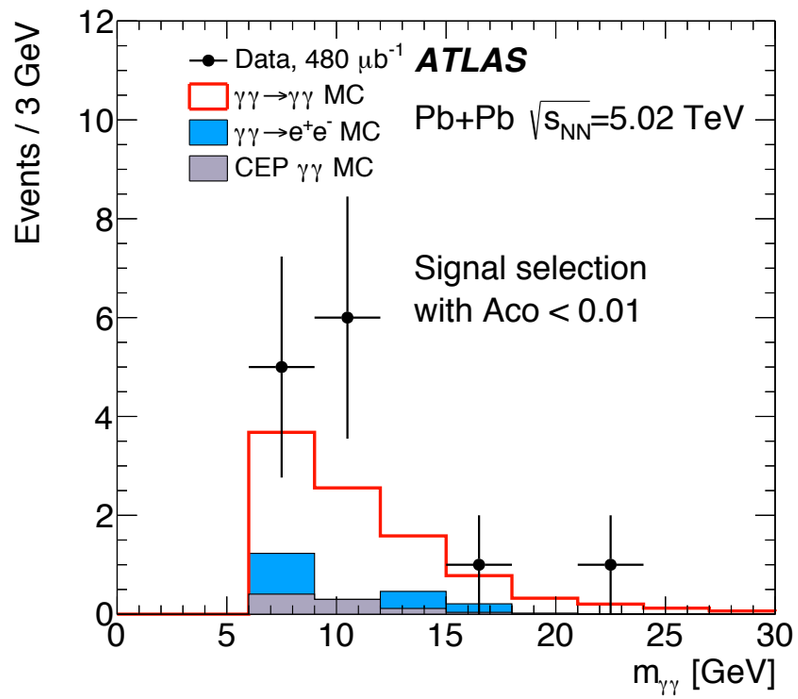
$$\mathcal{L}_{\mathrm{BI}} = \beta^2 \left(1 - \sqrt{1 + \frac{1}{2\beta^2} F_{\mu\nu} F^{\mu\nu} - \frac{1}{16\beta^4} (F_{\mu\nu} \tilde{F}^{\mu\nu})^2} \right)$$

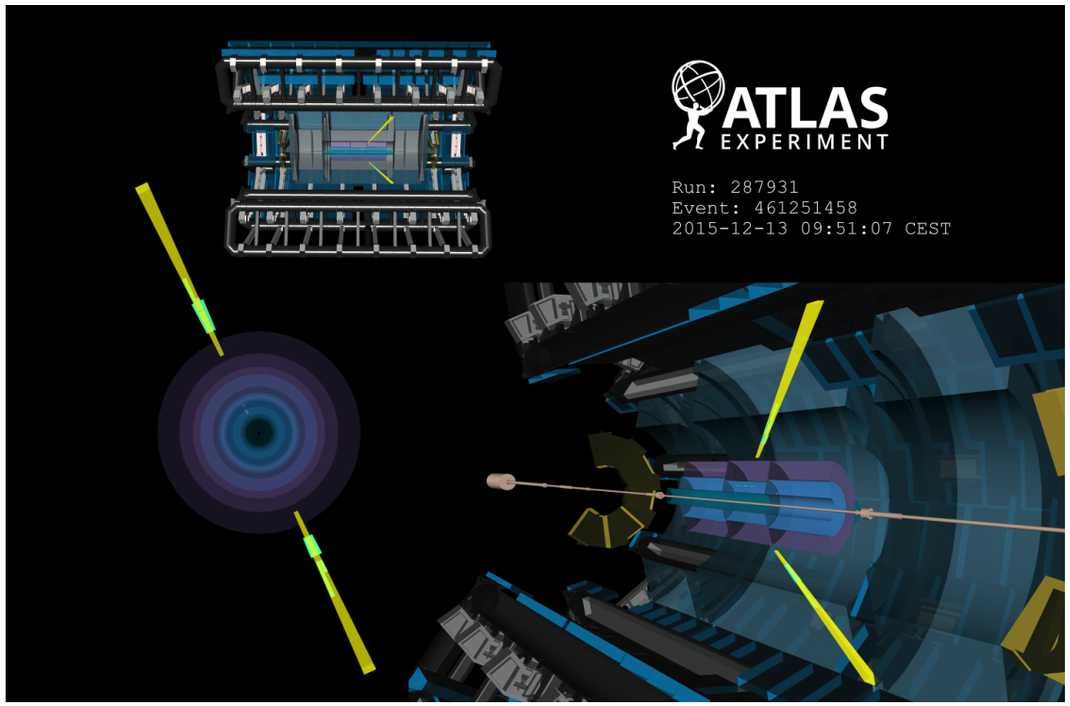


First ATLAS LbyL result

- ATLAS detector is optimised for detection of high energy particles
  - Many ingredients inefficient for **low-E_T region:** trigger, photon reconstruction, photon identification
- LbyL scattering events have a very **simple signature:** the **signal selection** included:
  - Two photons with $E_T > 3$ GeV and $|\eta| < 2.4$, $m_{\gamma\gamma} > 6$ GeV
  - Back-to-back topology: $p^{\gamma\gamma}_T < 2$ GeV, diphoton reduced acoplanarity, $Aco = 1-|\Delta\phi|/\pi < 0.01$
- 13 events found in the signal region, 7.3 signal events and 2.6 background events are expected
- Excess corresponds to **4.4σ** statistical significance over background only hypothesis
  - Considered as an **evidence** of the process

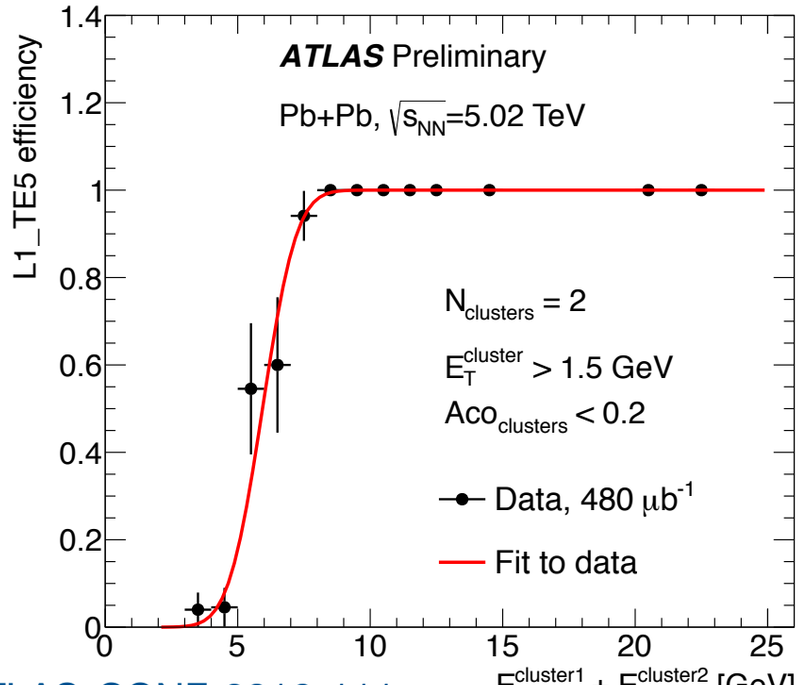
Nature Physics 13 (2017) 852





Analysis setup in 2018 - trigger

- In the 2015 ATLAS LbyL analysis the trigger was a major source of inefficiency
- Strong emphasis was put to **improve the trigger strategy** in 2018 heavy-ion data-taking (especially at the Level-1)
- Main improvements are:
  - Optimised calorimeter noise settings
  - **Lower requirement** on total E_T **at Level-1**:
    - Finally two approaches used: requirement of two EM clusters with $E_T > 1$ GeV OR one such EM cluster and total E_T at Level-1 above 4 GeV
- Optimisation performed on Xe+Xe sample from 2017
- Some **modifications at High Level Trigger** (redefinition of forward gap & relaxing the veto on activity in the tracker)
- Efficiency at Level-1 improved in 2018 wrt 2015



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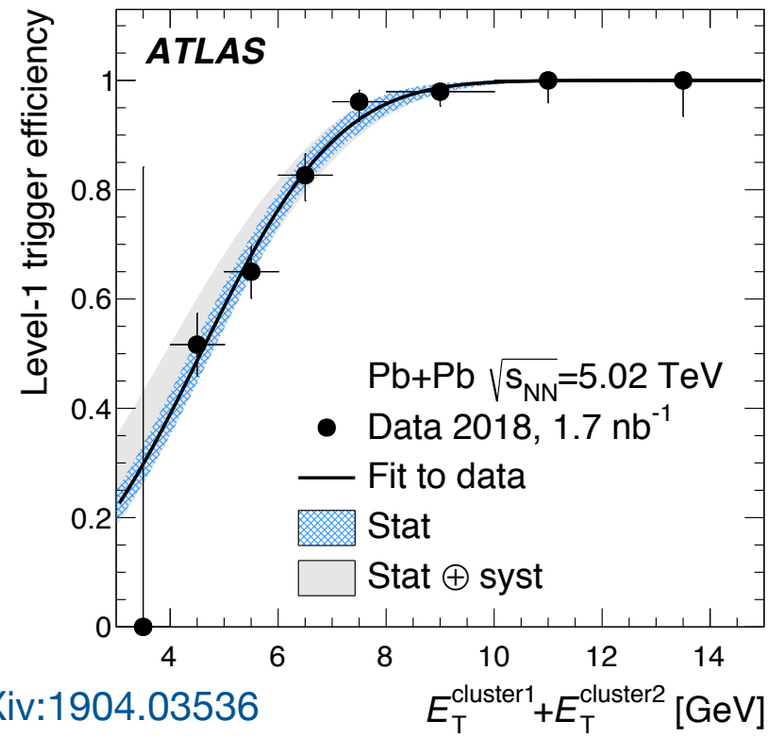

arXiv:1904.03536

Analysis setup in 2018 - photon ID

- The nominal ATLAS photon ID working points optimised for high-E_T photons
- Already in 2015 a **dedicated photon ID** was used to increase the efficiency in low-E_T region
- The **improvements** introduced in 2018 analysis:
  - Switch from cut-based selection to neural network based
  - Use three additional shower shape variables
  - Use η dependent ID
  - Better background rejection
- ID **efficiency** on signal MC maintained **95%**, in agreement with efficiency measured with FSR photons

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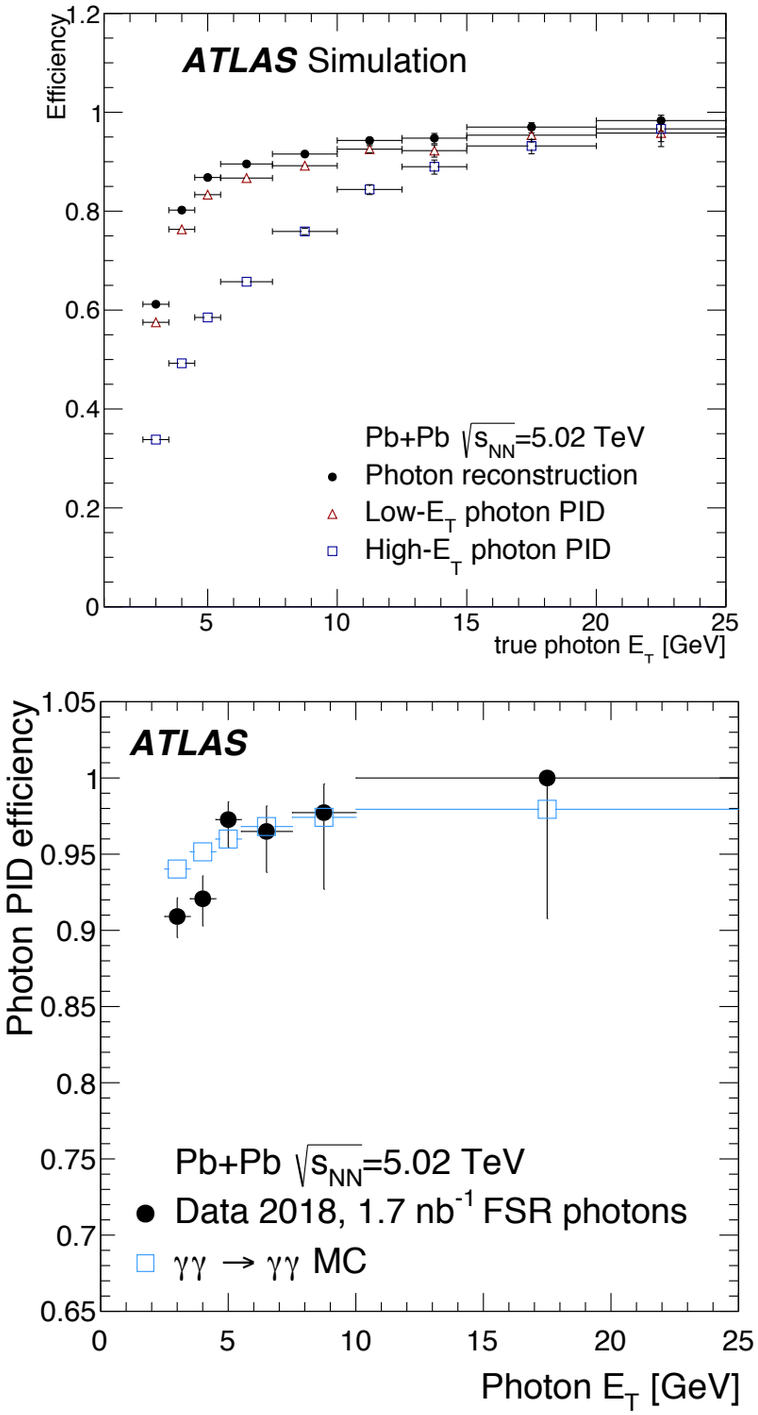
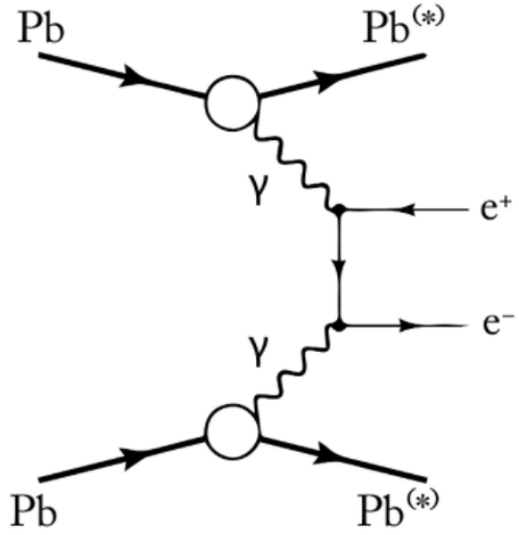
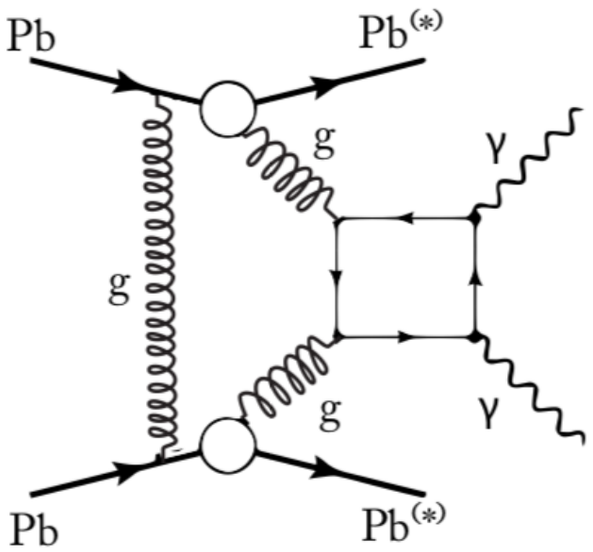


Backgrounds

- Various background sources considered:
  - Exclusive dielectron production **γγ → e+e-:**
    - Contribute to the signal region when tracks not reconstructed, or bremsstrahlung photons emitted
  - Central Exclusive Production (CEP) **gg → γγ:**
    - Event kinematics very similar to signal, but different shape of acoplanarity distribution
  - **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)

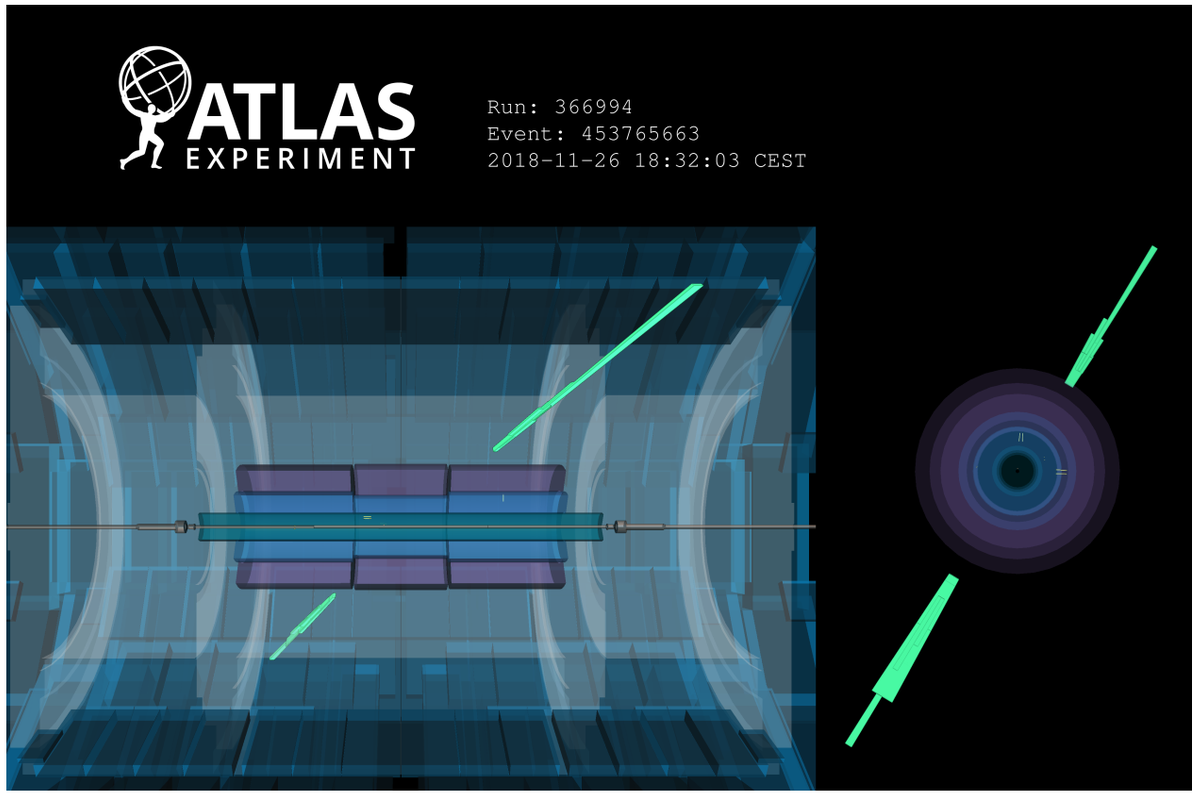




Signal selection

arXiv:1904.03536

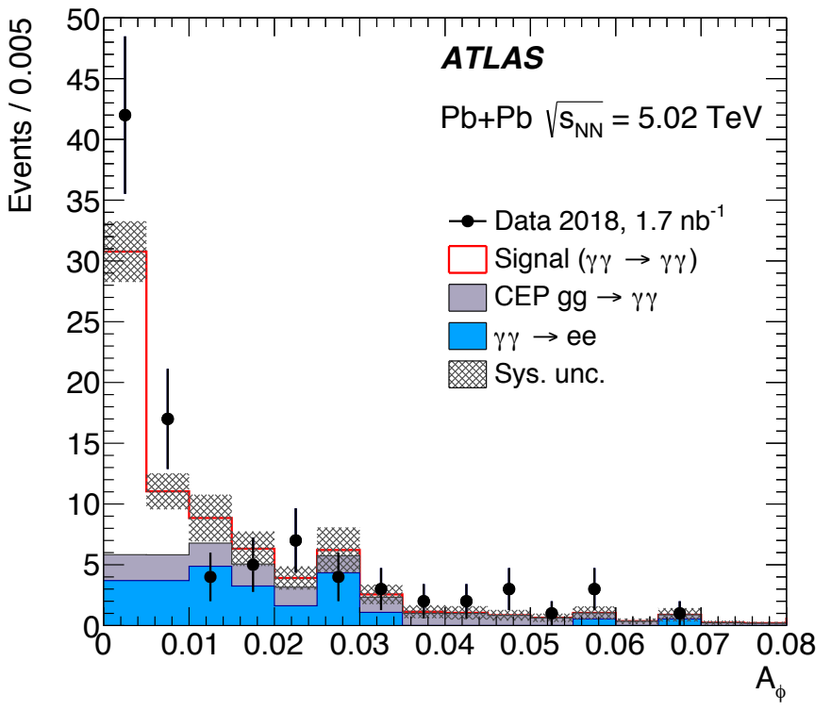
- Events are selected using following requirements:
  - **Two photons**
    - Identification: NN working point
    - $E_T > 3$ GeV, $|\eta| < 2.37$
  - LbyL scattering topology
    - $m_{\gamma\gamma} > 6$ GeV
  - **Veto extra particle activity**:
    to suppress e+e- background
    - Requiring no tracks ($p_T > 100$ MeV)
      and no pixel tracks ($p_T > 50$ MeV, $|\Delta\eta| < 0.5$ photon-pixelTrk matching)
  - Selecting **back-to-back topology**: to suppress fakes and CEP background
    - $p_T^{\gamma\gamma} < 1$ GeV (2 GeV for $m_{\gamma\gamma} > 12$ GeV)
    - Diphoton acoplanarity < 0.01

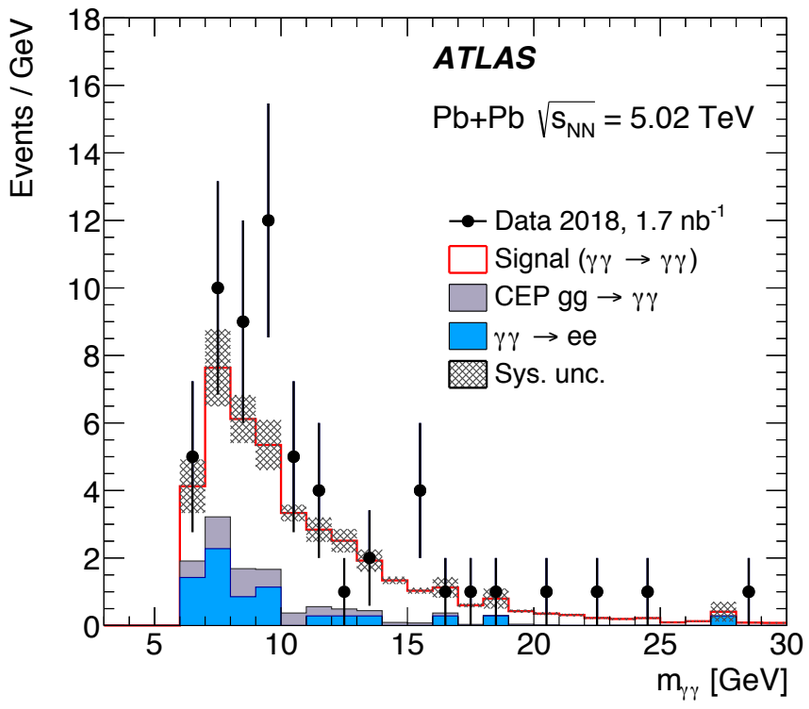


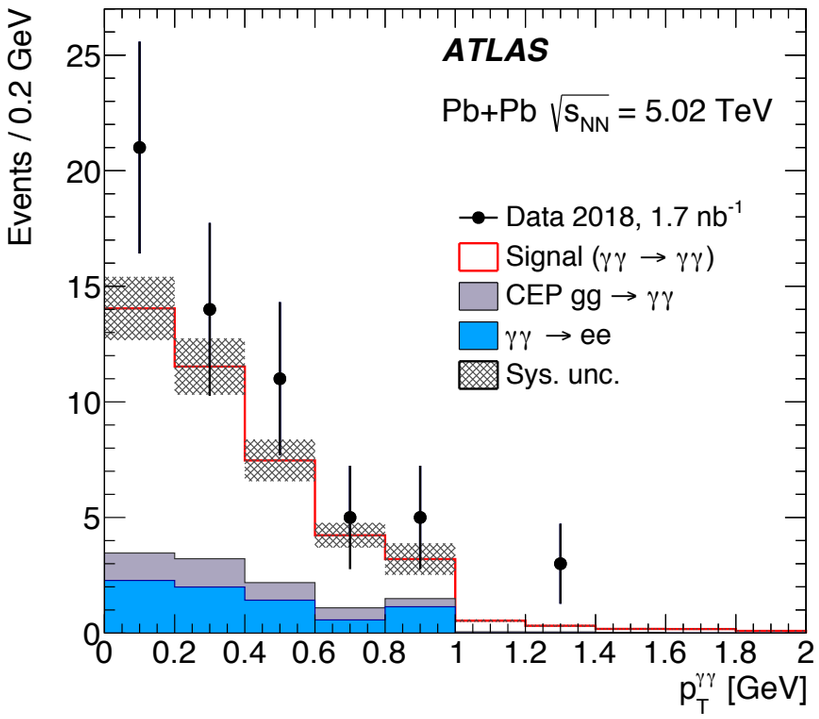
Results from 2018

arXiv:1904.03536

- In total **59 events** passing the signal selection are observed, with a background expectation of 12 ± 3 events
- Signal significance measured with events having Aco < 0.005, where 42 events pass signal selection and 6 ± 2 background events are expected
- Observed **signal significance** over the background only hypothesis is of **8.2σ** (expected 6.2σ)
- The corresponding fiducial cross section is **78 ± 13 (stat.) ± 7 (syst.) ± 3 (lumi.) nb**
- SM predictions: **51 ± 5 nb** (Szczurek et al.) and **50 ± 5 nb** (SuperChic3)







Summary

- **Light-by-light scattering** was observed with the ATLAS detector using data from **Pb+Pb collisions** at 5.02 TeV from 2018
- Precision of the new measurement greatly improved thanks to the larger dataset and improved analysis techniques:
  - The **signal significance** gives an observation with 8.2σ
  - Measured fiducial **cross-section**:
    78 ± 13 (stat.) ± 7 (syst.) ± 3 (lumi.) nb
- **Ratio** of the measured cross-section **to the SM predictions, 51 ± 5 nb** (Szczurek et al.) and **50 ± 5 nb** (SuperChic3), is 1.53 ± 0.33 and 1.56 ± 0.33, respectively

Backup

- Performance of exclusive e+e- pairs - they are used for many cross-checks in the analysis
- MC simulation is normalized to integrated luminosity

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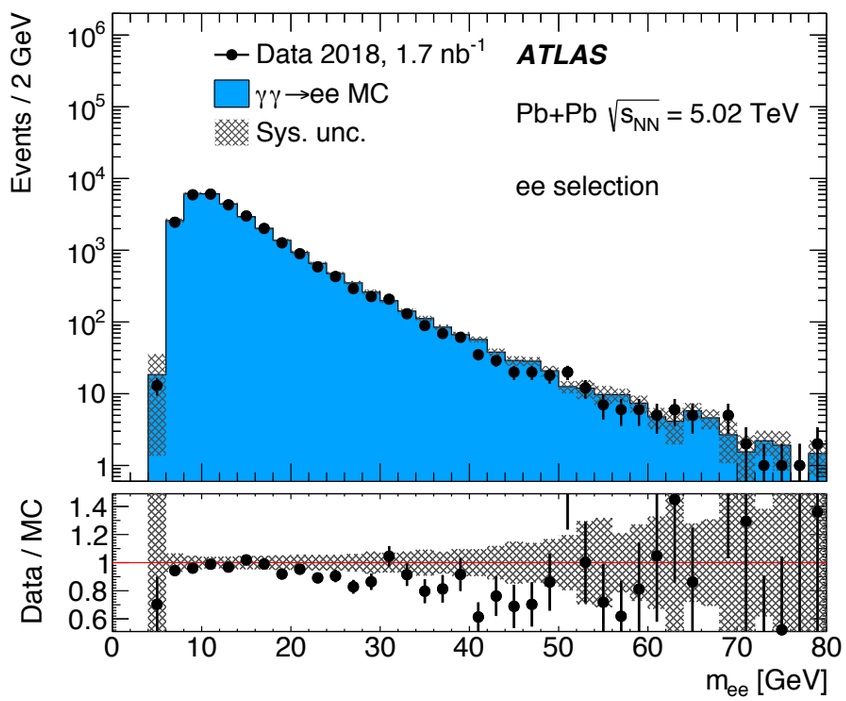
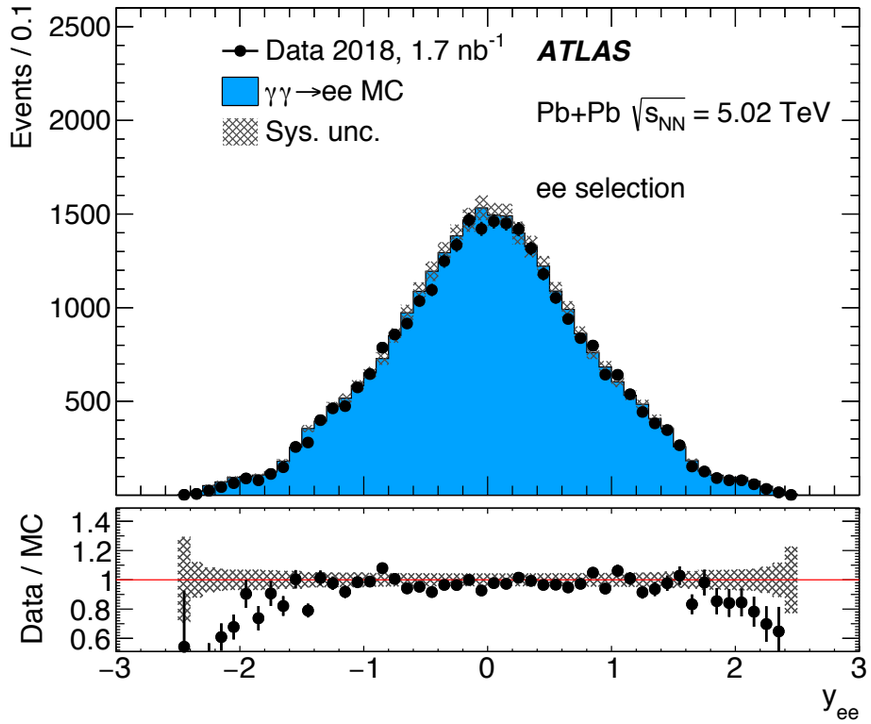
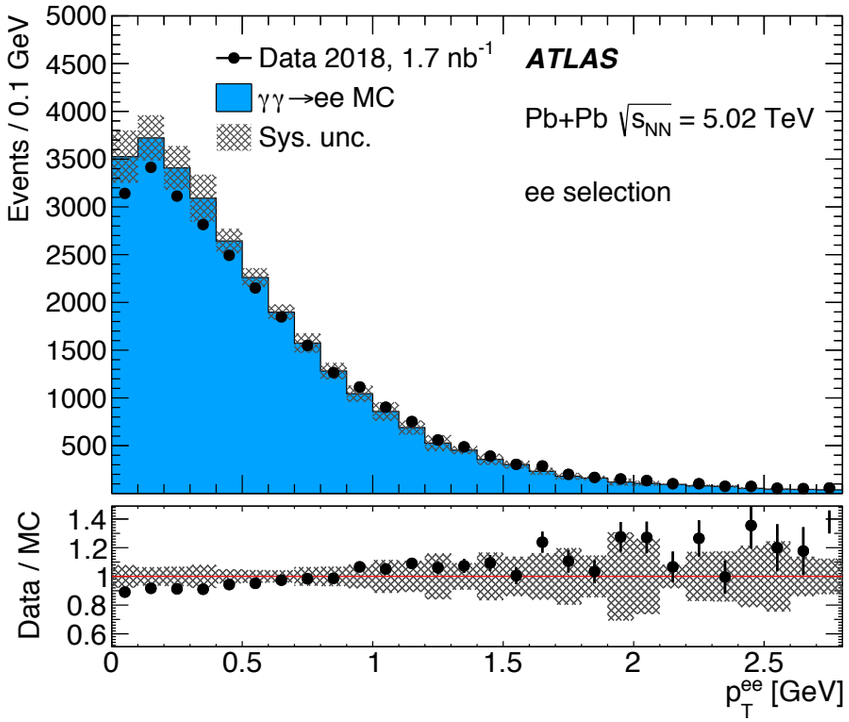
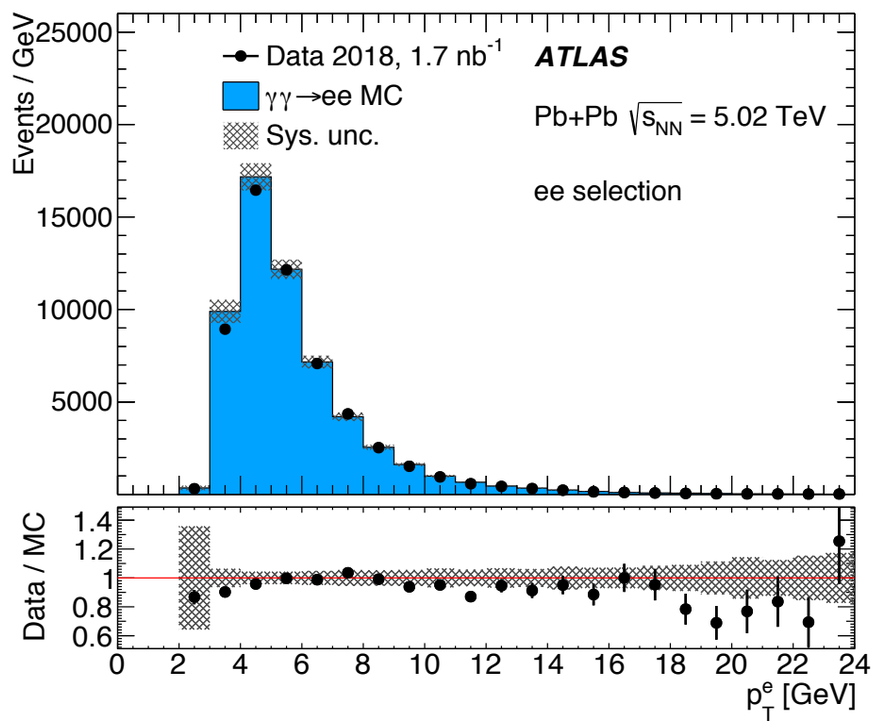


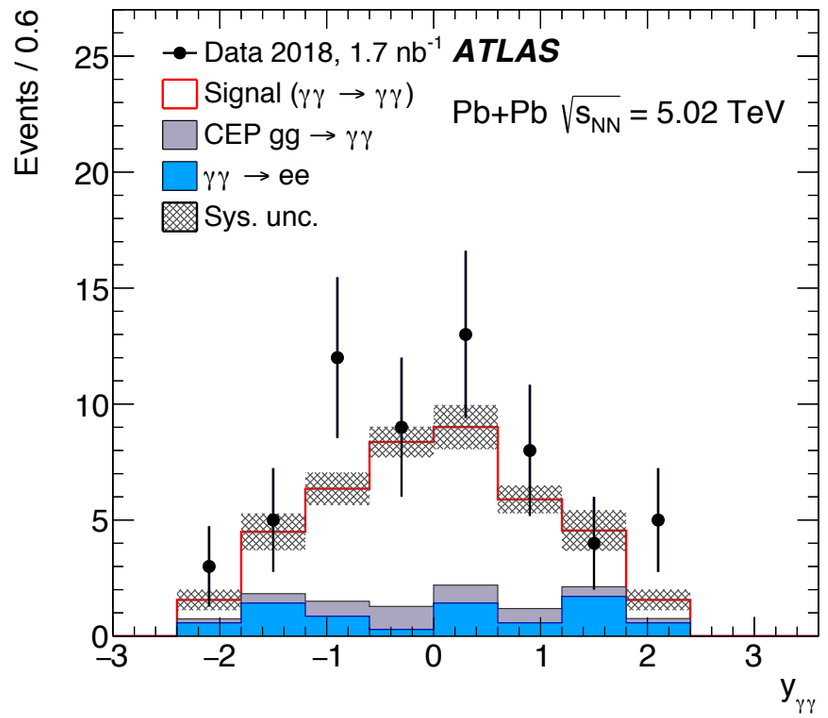


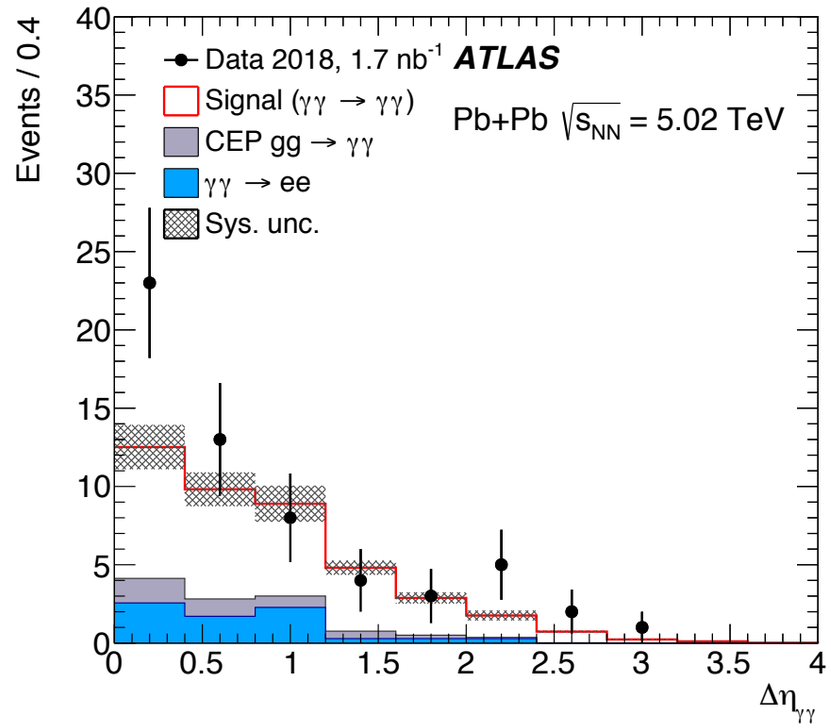


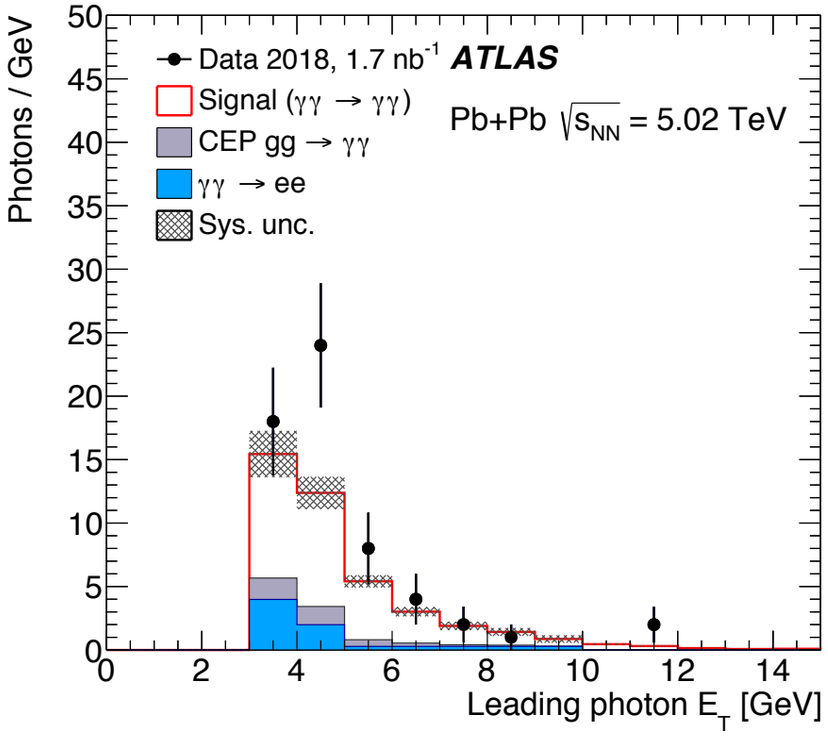


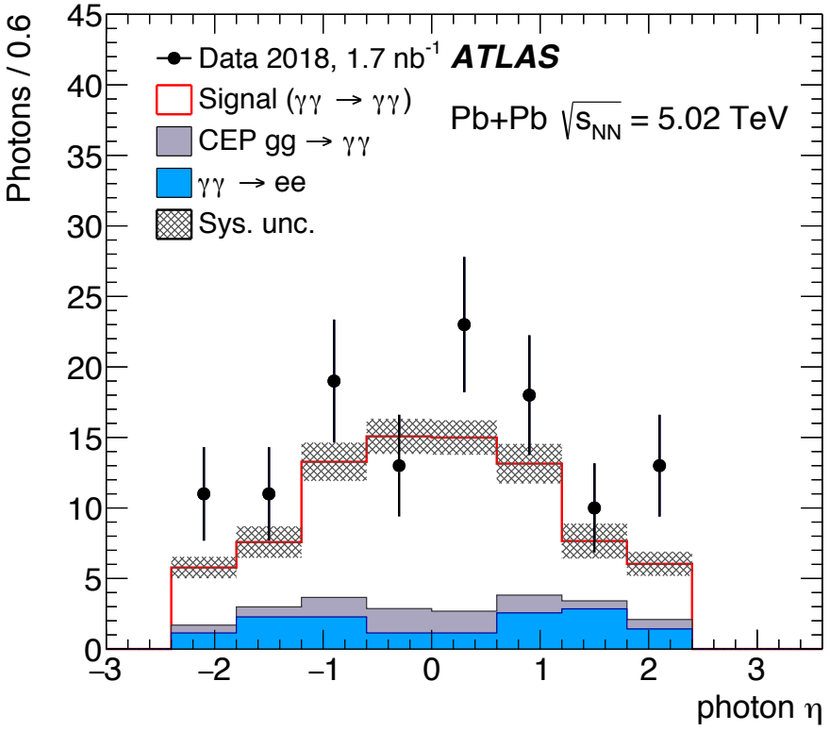
Backup

- Additional kinematic distributions for the signal region









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