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Exclusive dilepton production in ultraperipheral lead-lead collisions in the ATLAS experiment

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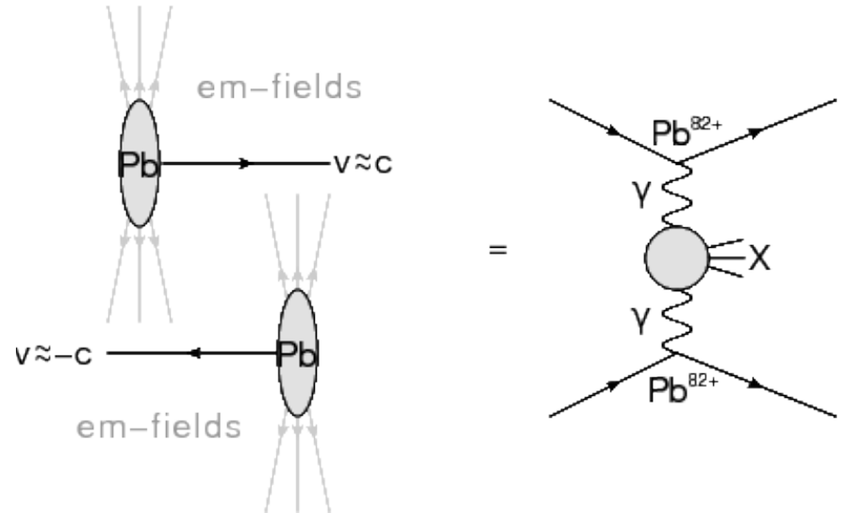
Motivation



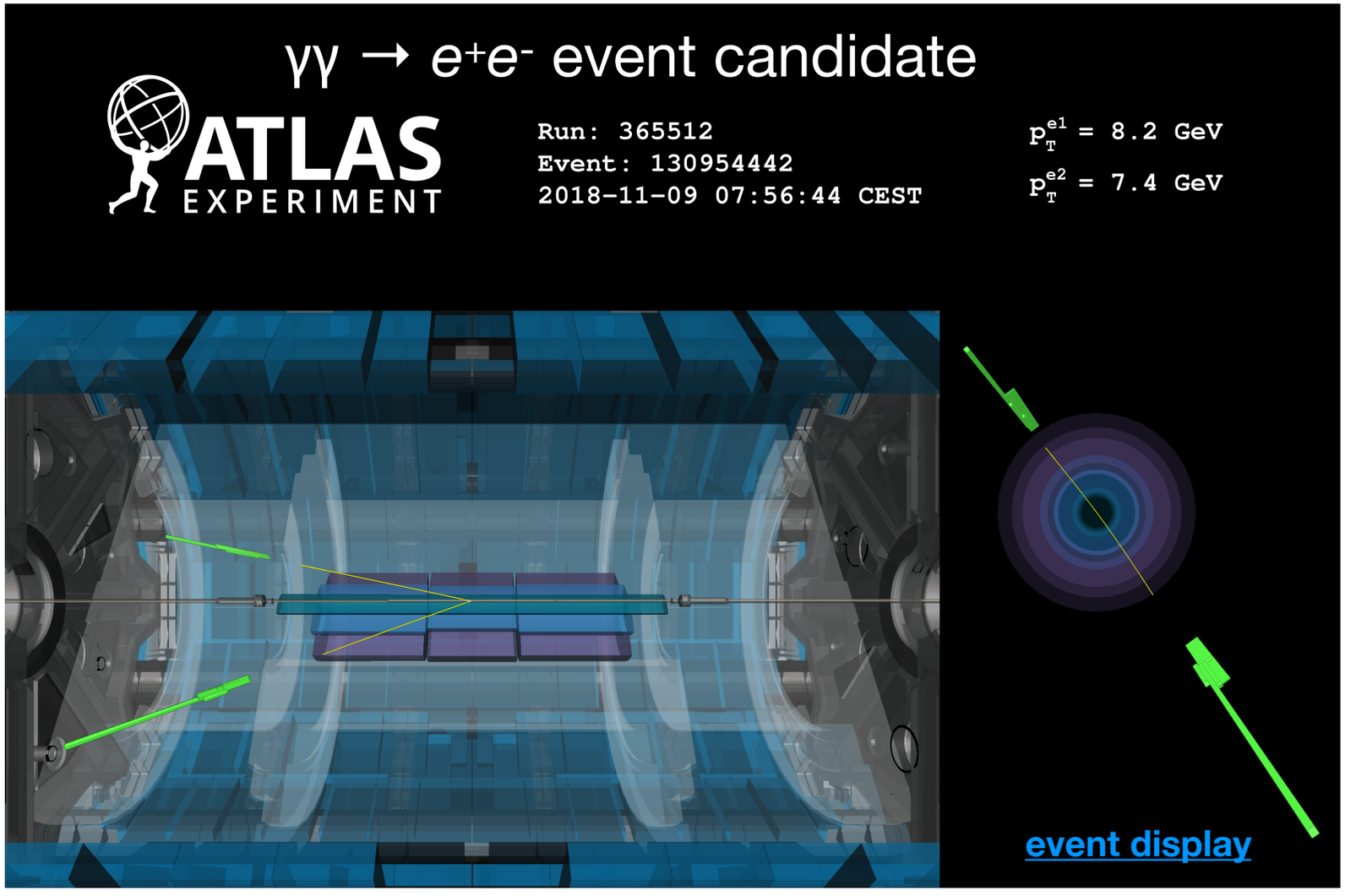
- **Photon-photon interactions** can be observed in **ultraperipheral heavy-ion collisions** at the LHC due to large EM fields associated with relativistic ions (cross-sections scale with ~ Z^4)
- EM field is treated as a beam of quasi-real photons with small virtuality (equivalent photon approximation)
- Exclusive production of dileptons ($\gamma\gamma \rightarrow l^+l^-$, with $l^{\pm} = e^{\pm}$ or $\mu^{\pm}$) is one of the **basic processes** in photon-photon interactions - recently exclusive dimuon production was measured by ATLAS based on 2015 Pb+Pb data: https://arxiv.org/pdf/2011.12211.pdf

NEW!

- Dielectron pair production is background contribution in other rare processes (e.g. light-by-light scattering, https://arxiv.org/pdf/2008.05355.pdf)
- **Precise measurement** of exclusive dilepton production cross-section would provide a **reference** for other photonuclear and photo production processes (also suggested in some theoretical papers: https://arxiv.org/pdf/1908.05180.pdf,10.1016/j.physletb.2020.135682)
- The ratio of the cross-sections for certain process to the **exclusive dilepton production cross section** results in cancellation of some systematic uncertainties, including the one related with modeling of initial photon-fluxes

Event characteristics

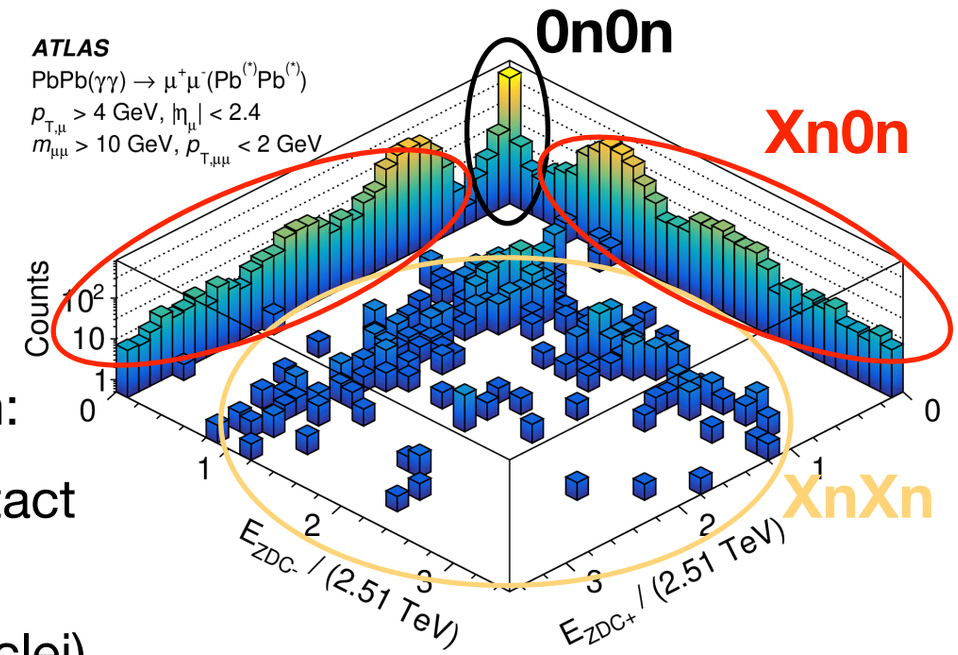
- Exclusive dilepton events are characterized by :
  - Two low-p_T opposite sign leptons (of the order of a few GeV) and otherwise empty detector
  - Leptons are produced back-to-back in azimuthal angle (described by low dilepton transverse momentum, $p_{T,ll}$)
- ATLAS was optimized to detect high-energy particles - low kinematic requirements necessitate careful estimation of trigger and particle reconstruction efficiency



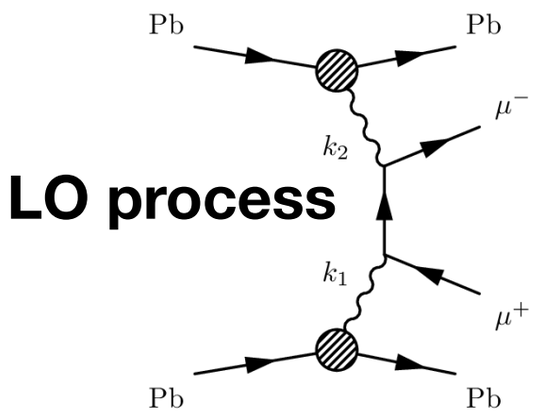
Exclusive dimuon production - selection

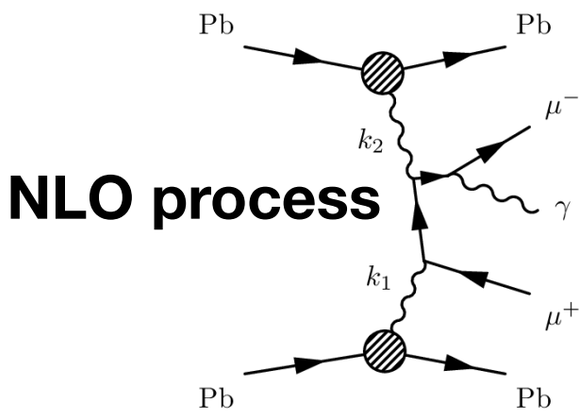
arXiv:2011.12211

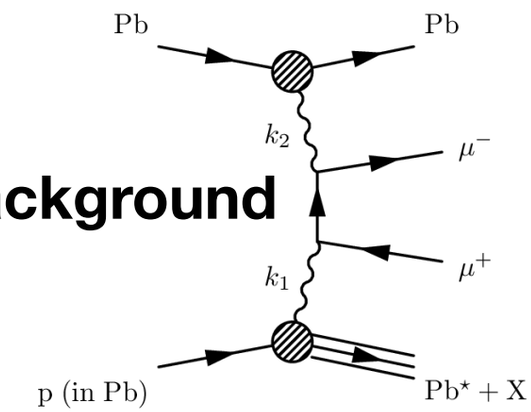
- Recent measurement based on 0.48 nb^{-1} of Pb+Pb collision data at $\sqrt{s_{NN}}$ = 5.02 TeV
- Fiducial region defined by several requirements: $p_{T\mu} > 4$ GeV, $|\eta_\mu| < 2.4$, invariant mass $m_{\mu\mu} > 10$ GeV, and $p_{T\mu\mu} < 2$ GeV
- Events are divided into 3 classes based on the signal in the Zero-Degree Calorimeter (ZDC), which describes forward neutron activity
- In selected events one can identify several processes that should present different activity in the forward region:
  - Signal events: for both LO and NLO process ion is intact
  - Background events with ion dissociation: photon is emitted from substructure of one nucleus (or both nuclei)



- The association between given ZDC signal and given process is nontrivial due to possible ion excitation and presence of EM pile-up







Exclusive dimuon production - background

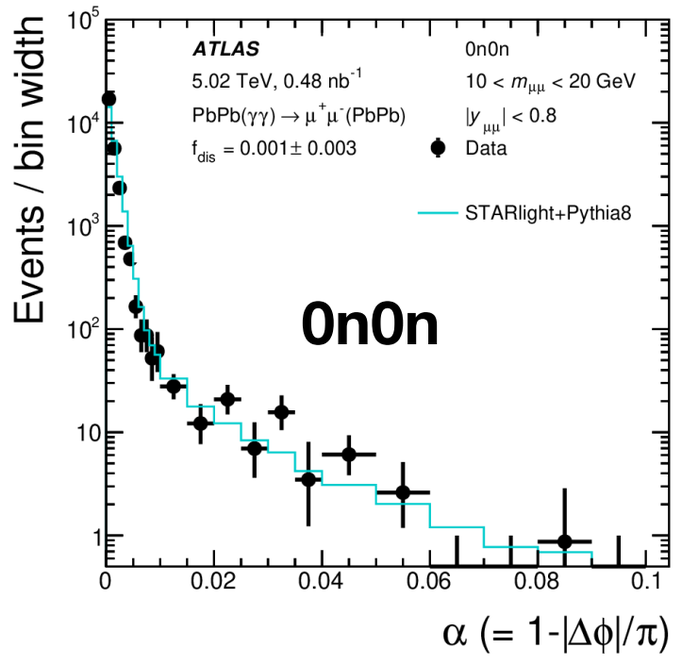
arXiv:2011.12211

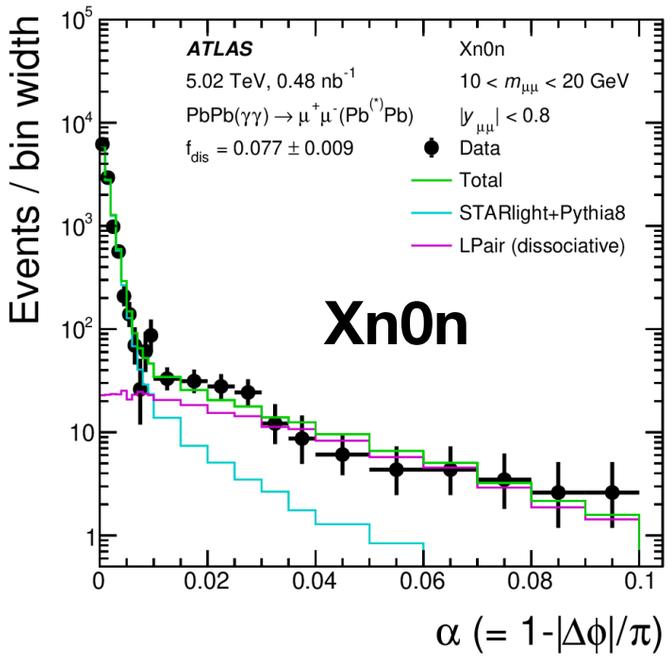
- Based on number of neutrons detected in ZDC, events are categorized in 0n0n, Xn0n and XnXn classes

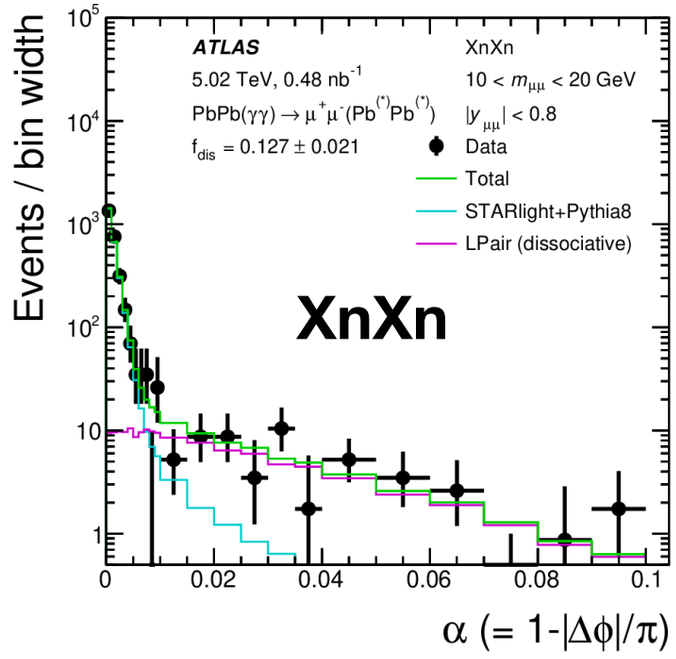
- The differences between these classes are strongly pronounced in acoplanarity distribution

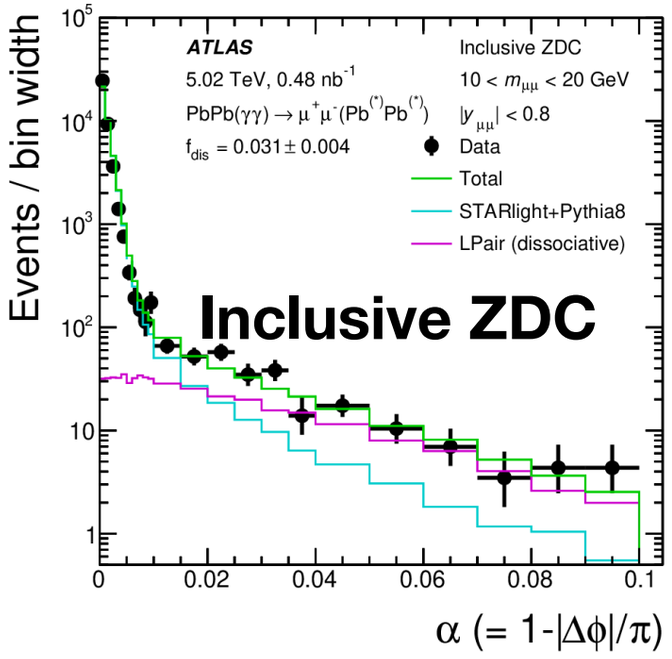
- The data is compared with STARlight+Pythia8 simulation for $\gamma\gamma \rightarrow \mu^+\mu^-$ process with FSR and LPair for dissociative events (for pp collisions)

- The simultaneous fit is performed in all ZDC topology classes to estimate fraction of dissociative events









Exclusive dimuon production - results

arXiv:2011.12211

- The cross-sections are measured as a function of several kinematic variables as:

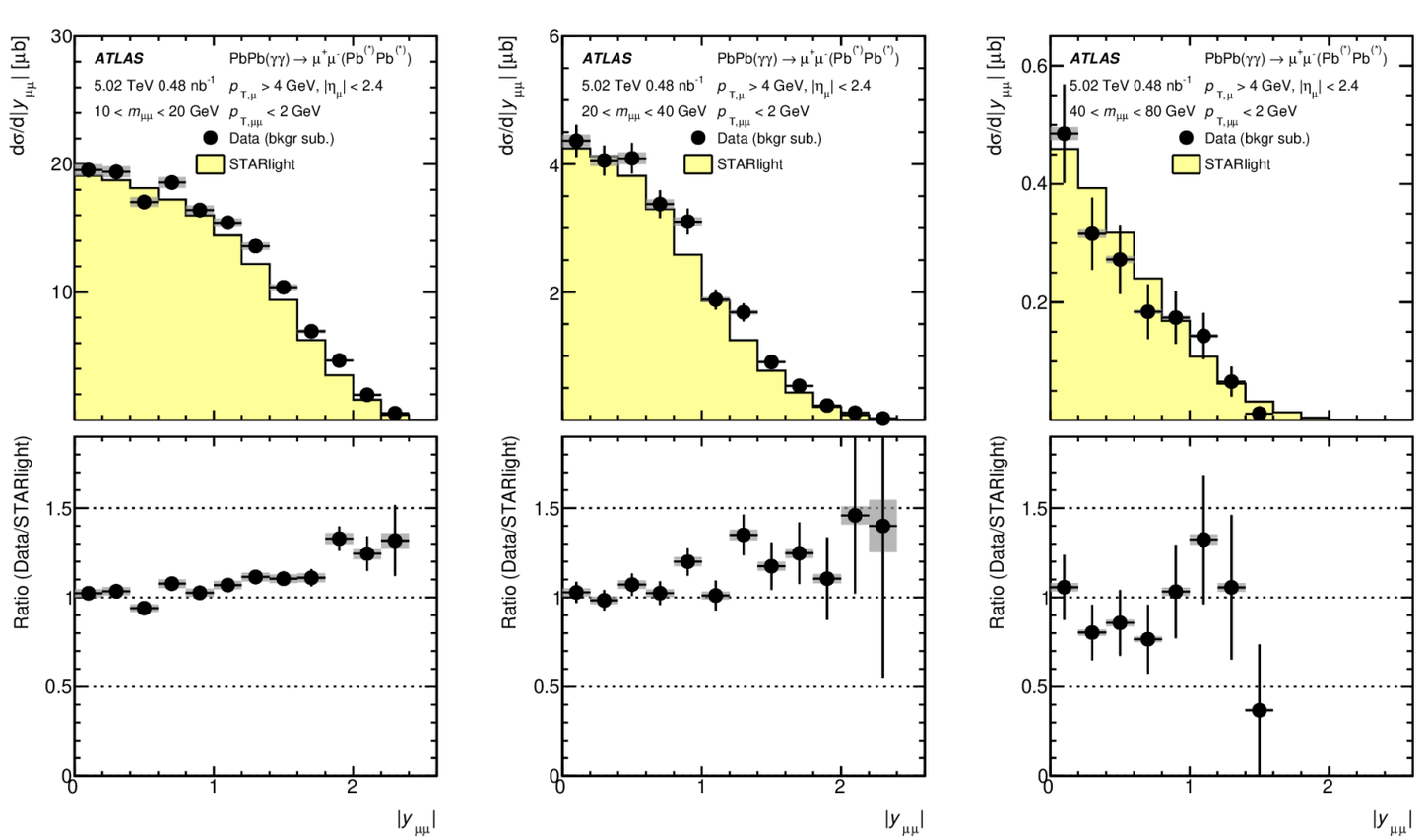
Bin migration — Background from dissociative events

Muon kinematic variable

$$\frac{d\sigma_{\mu\mu}}{dX_{\mu\mu}} = \frac{C_{\mathrm{mig}}}{\mathcal{L}_{\mathrm{int}}} \sum_{\mathrm{events}} \frac{(1-f_{\mathrm{dis}})}{\varepsilon_{\mathrm{R}\mu\mu}\,\varepsilon_{\mathrm{T}\mu\mu}}$$

Reconstruction and trigger efficiencies

- Measured fiducial cross section is σ = 34.1±0.3(stat.)±0.7(syst.) μb, compared with 32.1 μb from STARlight and 30.8 μb from STARlight+Pythia8
- The cross-sections on the right are presented as a function of absolute dimuon rapidity in 3 mass slices
- Data is compared with STARlight MC simulation of γγ → $\mu^+\mu^-$ process w/o FSR
- Good agreement is found in central region of rapidity distribution (small $|y_{\mu\mu}|$), but data/simulation ratio increases with $|y_{\mu\mu}|$



What can we learn about initial photon fluxes?

arXiv:2011.12211

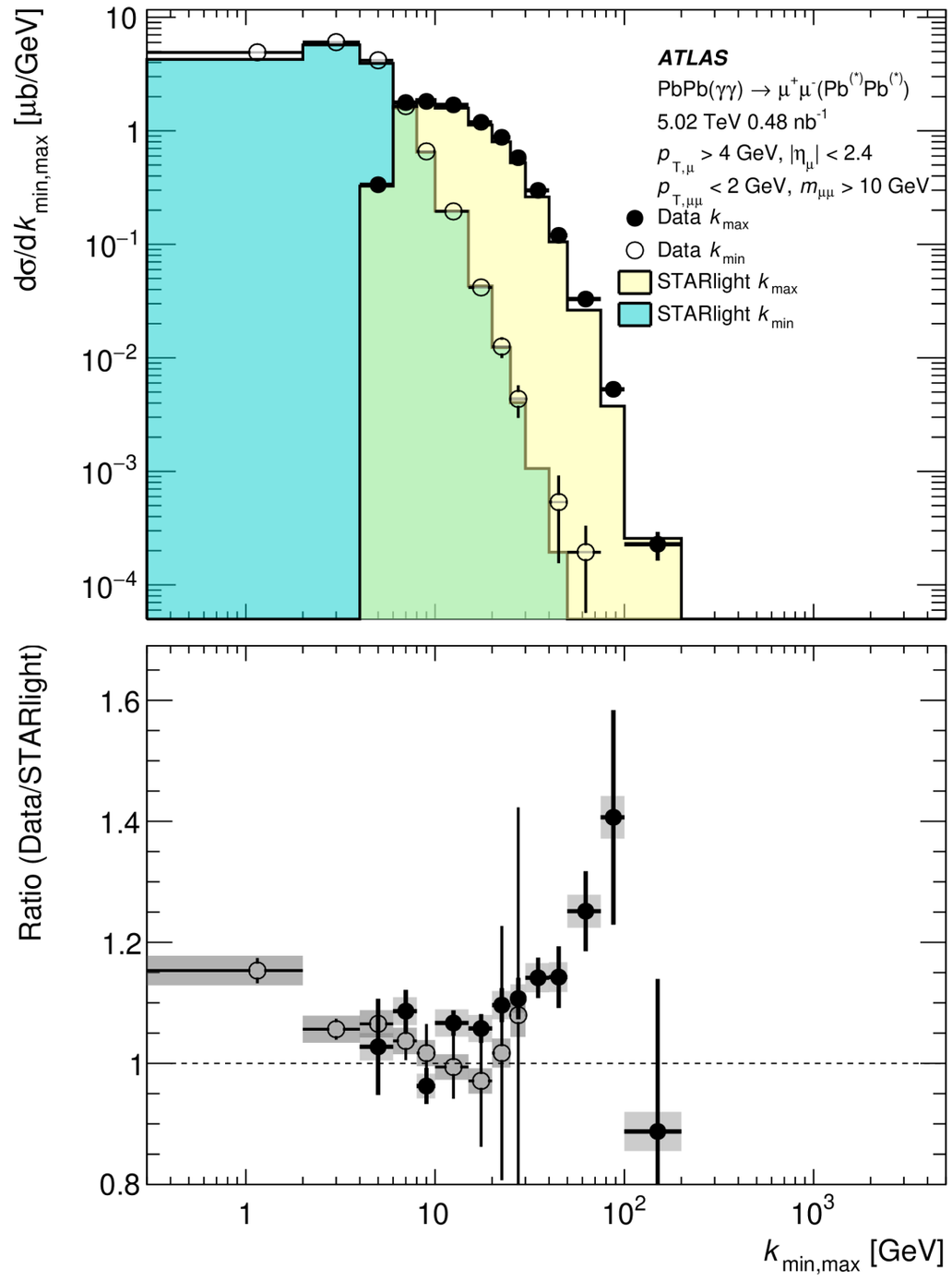
- The muon kinematics can be used to estimate initial photon energies

$$k_{\mathrm{min,max}} = (1/2) m_{\mu\mu} \exp(\pm y_{\mu\mu})$$

- The cross section is presented as a function of maximum and minimum photon energies

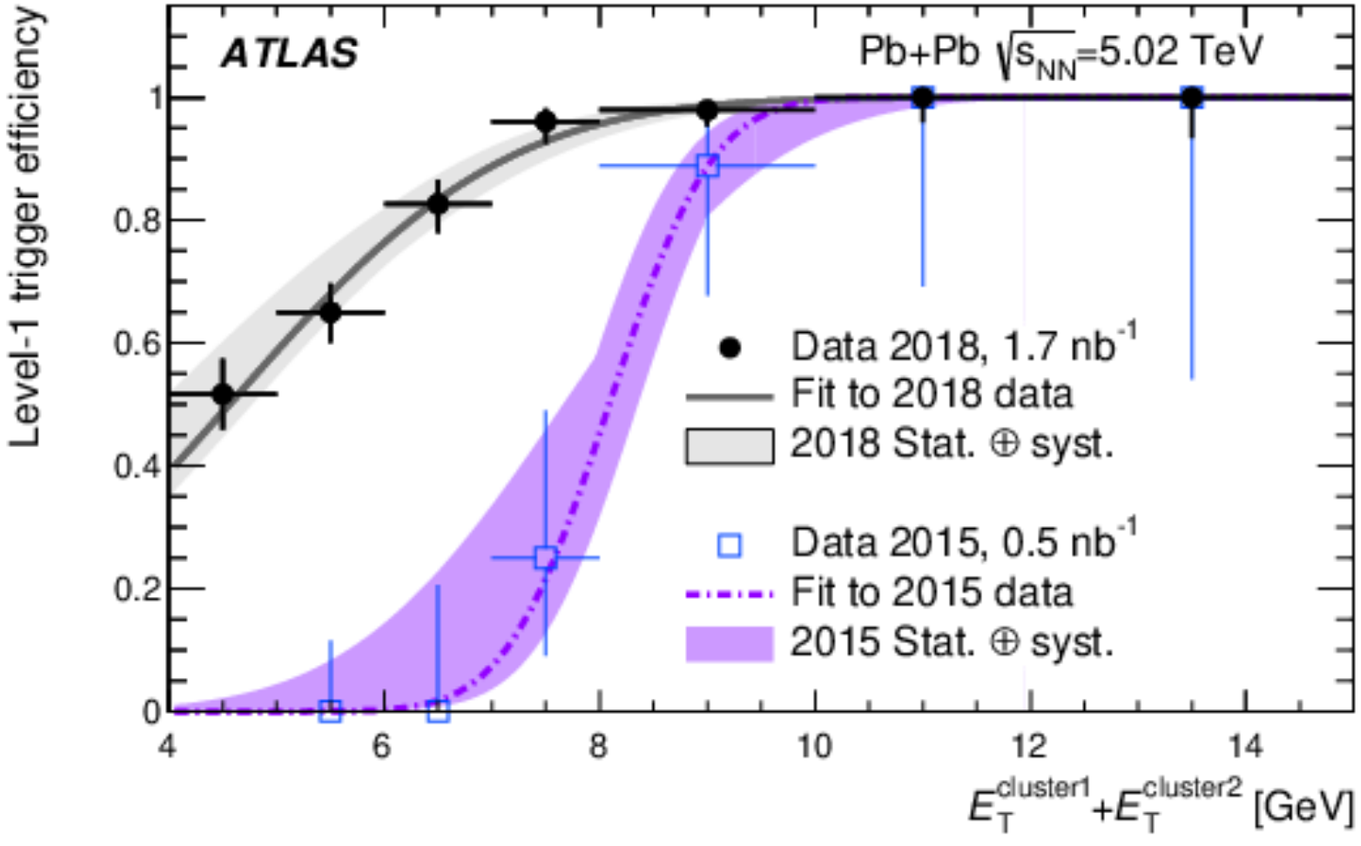
- The comparison with STARlight calculations shows that the predictions are correct in intermediate region 5-20 GeV, but there is a disagreement between the data and MC for lower k_{min} and higher k_{max}

- Perhaps there is a need for the refinement of the initial photon flux in the calculations



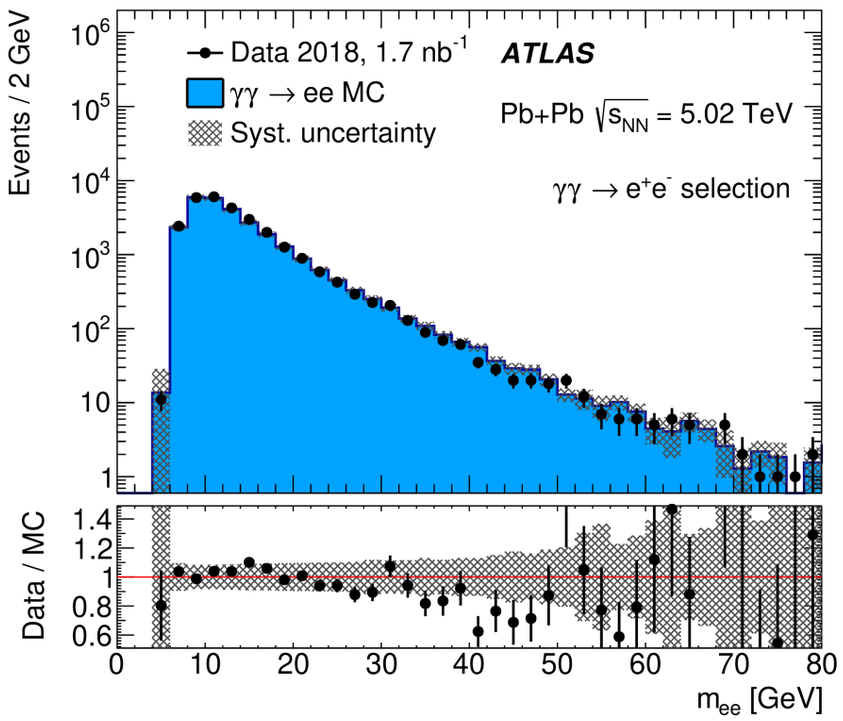
Performance studies using dielectron events

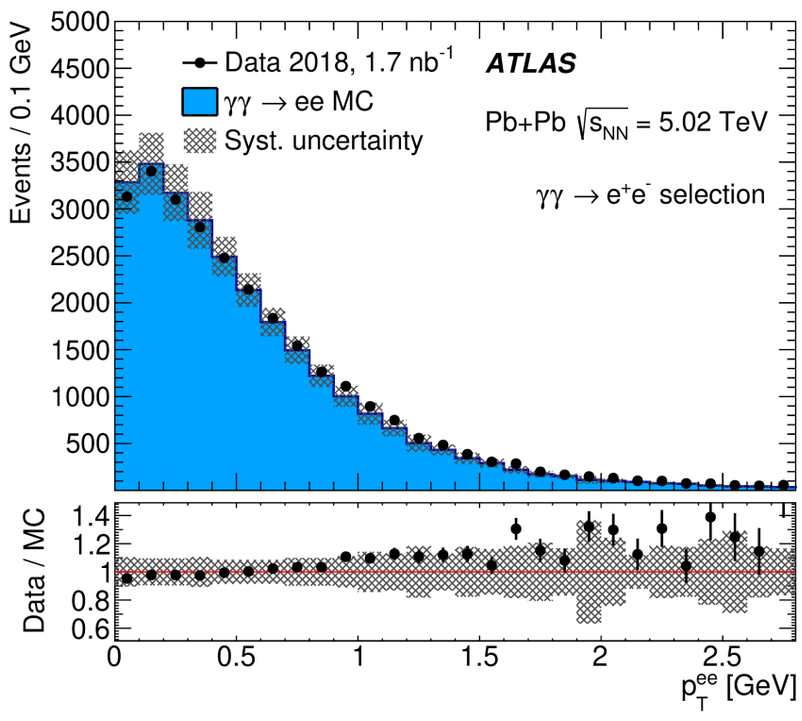
- The new Pb+Pb data was collected in 2018 with integrated luminosity of 1.7 nb^{-1}
- A dedicated trigger was designed, that allows to record exclusive dielectron events
- It required special optimization, especially at the Level-1 trigger, to improve the performance wrt similar trigger used in 2015
- Loosely selected exclusive dielectron events accepted by independent trigger are used to measure the Level-1 trigger efficiency
- The good trigger performance in the low energy region enables lowering of p_T requirement on single electron (compared to muon selection in dimuon analysis)

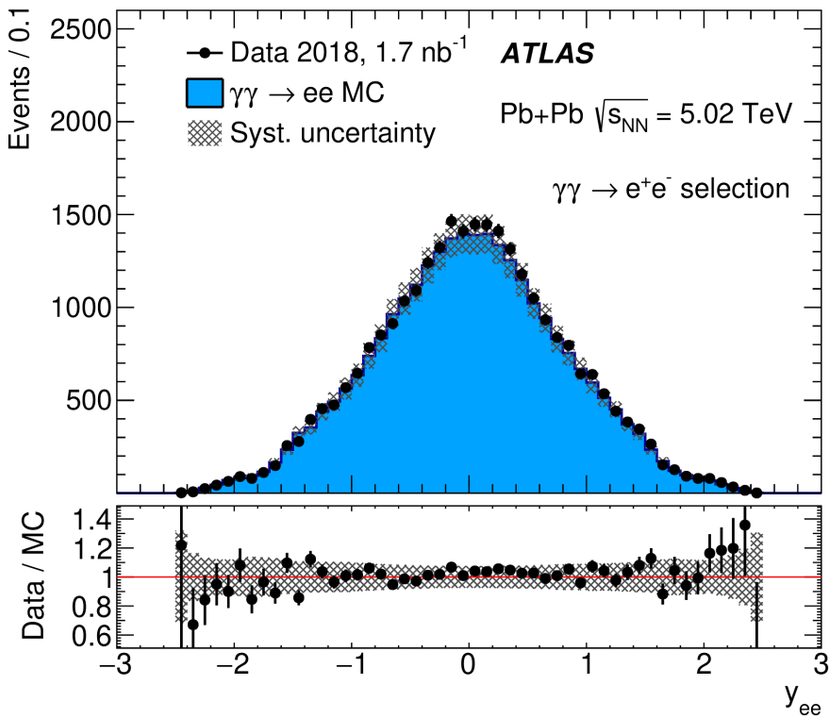


Dielectron events - control distributions

- Events are selected to pass the dielectron trigger and several requirements: exactly two oppositely charged electrons with $p_{Te} > 2.5$ GeV, $|\eta_e| < 2.47$ (excluding $1.37 < |\eta_e| < 1.52$), additional track veto and dielectron acoplanarity below 0.01
- About 28k dielectron events are selected
- The MC samples based on STARlight w/o FSR are corrected for trigger and reconstruction/ID efficiency
- In general good agreement is found between data and simulation
- An excess of data in the high $p_{T,ee}$ region likely due to a contribution of FSR







arXiv:2008.05355

Summary and outlook

- Exclusive dilepton pairs can be measured in ultraperipheral heavy-ion collisions with the ATLAS detector

- **Measurement of dimuon pairs** based on 0.48 nb^{-1} of Pb+Pb data from 2015 has been recently submitted for publication

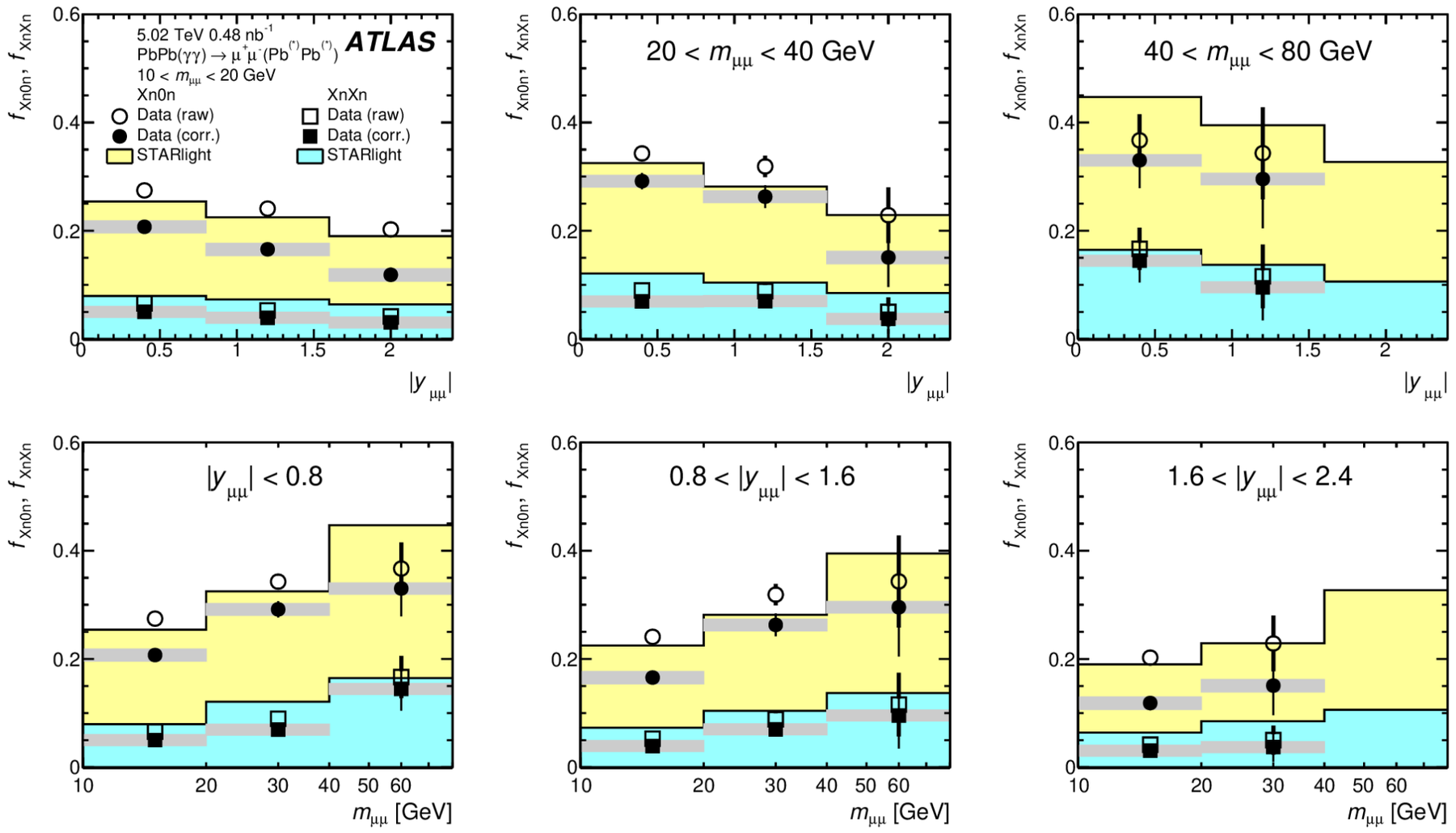
- Results provide a valuable reference for **theoretical approaches** in the modeling of the **initial photon flux**

- The Pb+Pb data from 2018 provide 3-3.5 times higher integrated luminosity, that should result in better precision measurements

- Exclusive **dielectron pairs** have relatively high production cross sections what make this process a benchmark process at the LHC for detector calibrations

Backup

- Fraction of events in each of Xn0n and XnXn classes is dependent on dilepton mass and rapidity



Backup

- The purpose of the ATLAS Zero-Degree Calorimeters (ZDC) is to detect forward neutrons with $|\eta| > 8.3$ in heavy-ion collisions
- The ZDC is installed ±140 m from the interaction point
- On each arm there are four modules - one EM module, and 3 hadronic modules