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Ultra-peripheral physics with ATLAS

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ON BEHALF OF THE ATLAS COLLABORATION

ATLAS EXPERIMENT

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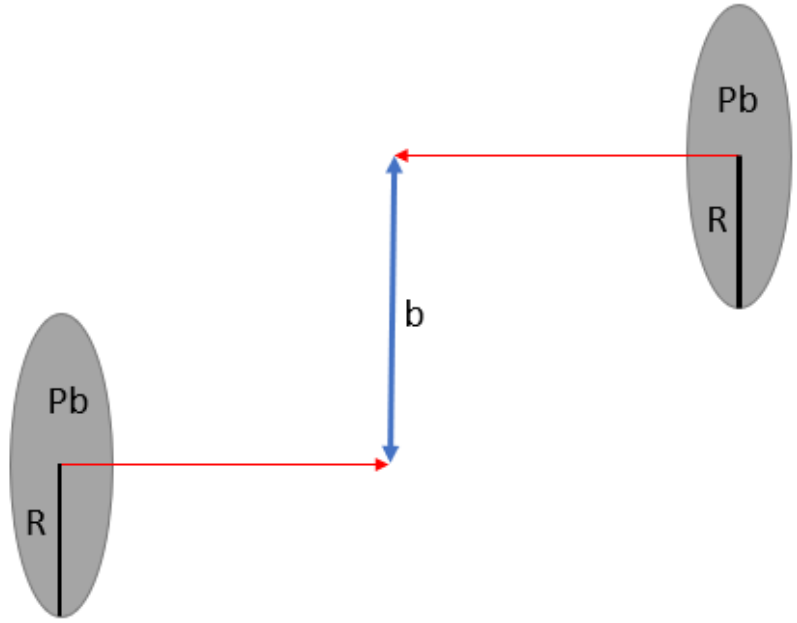
Outline

- Introduction
- Light by light scattering
- Exclusive dimuon production
- Two-particle azimuthal correlation
- Summary

Introduction

Ultraperipheral Heavy ions collision induce a Huge EM fileds which act as a source of high-energy, quasi real photons (Equivalent Photon Approximation)
The photons produce a wide variety of exclusive final states in lead-lead collisions
The photon may also interact with a parton in the nucleus (photonu-clear interactions.)



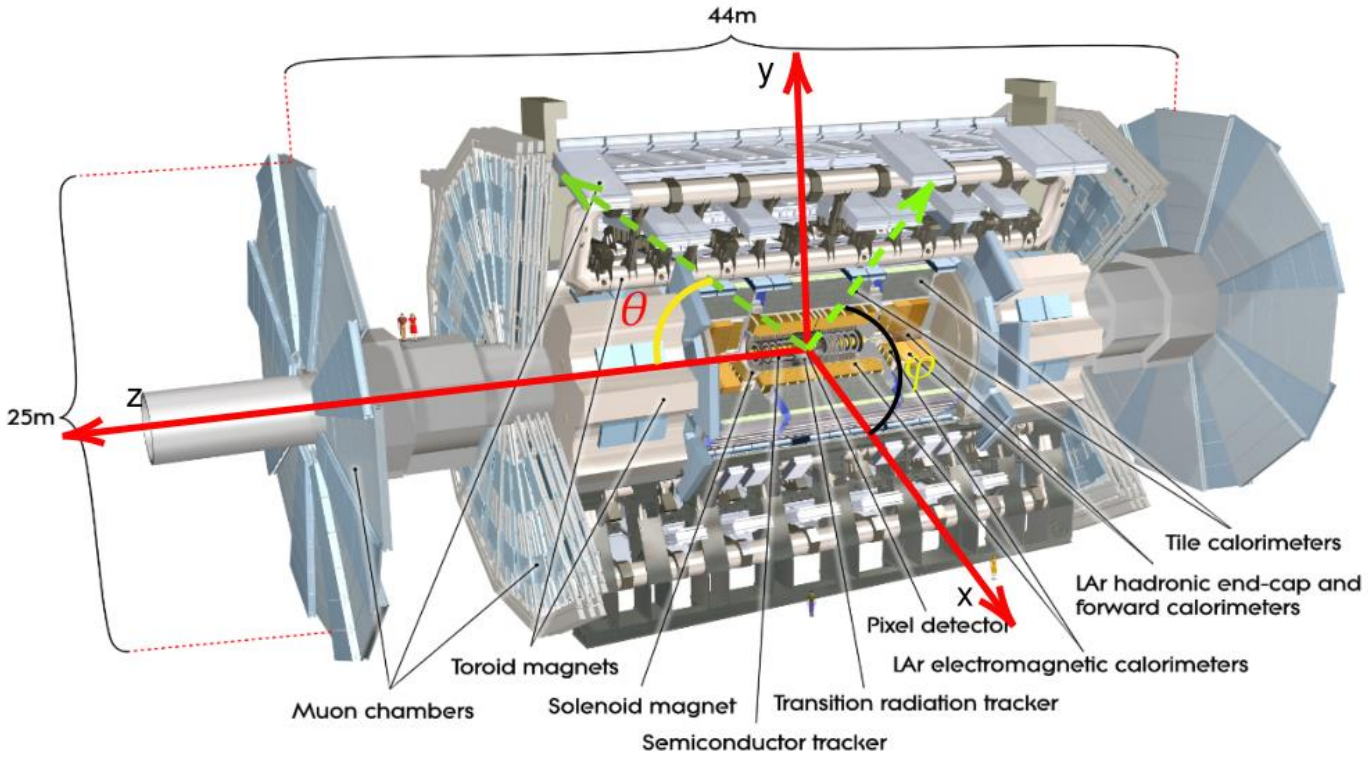
b ≈ 0	b≈2R	b>2R
Central	Peripheral	**Ultraperipheral**

The following results are presented :

- Light by light scattering JHEP 03 (2021) 243
- Exclusive dimuon production Phys. Rev. C 104 (2021) 024906
- Two-particle azimuthal correlation Phys. Rev. C. 104 014903

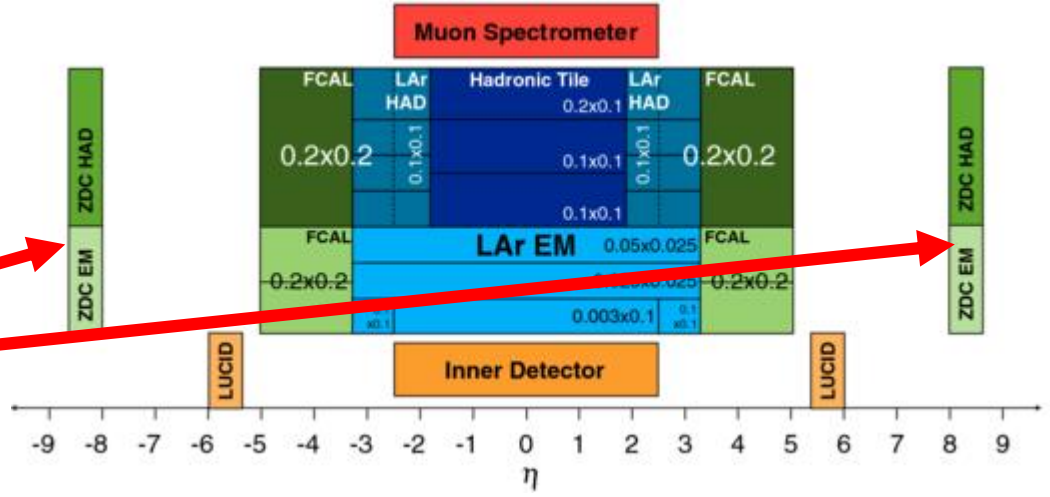
See also ATLAS Heavy ions presentations
- Adam Trzupek
- Martin Krivos

The ATLAS detector



- Inner Tracker
- EM and Had calorimeter
- Muon system

Used to identify UPC events in HI Collisions

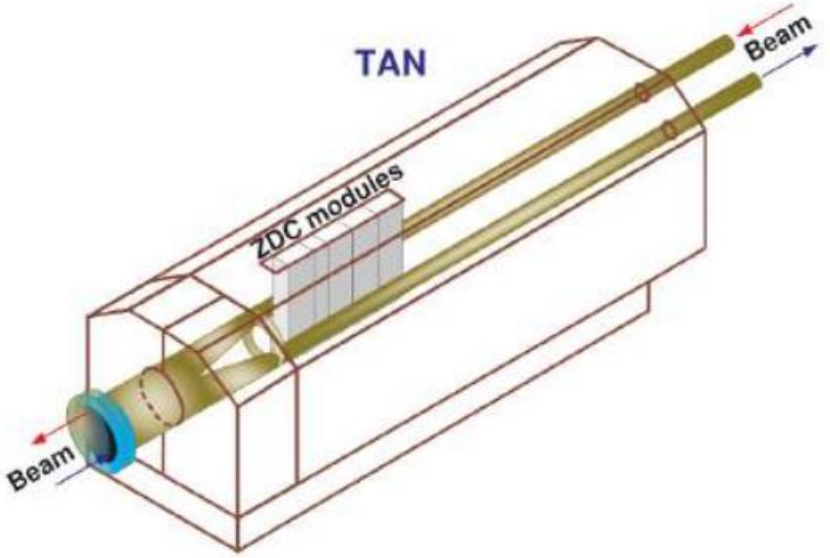


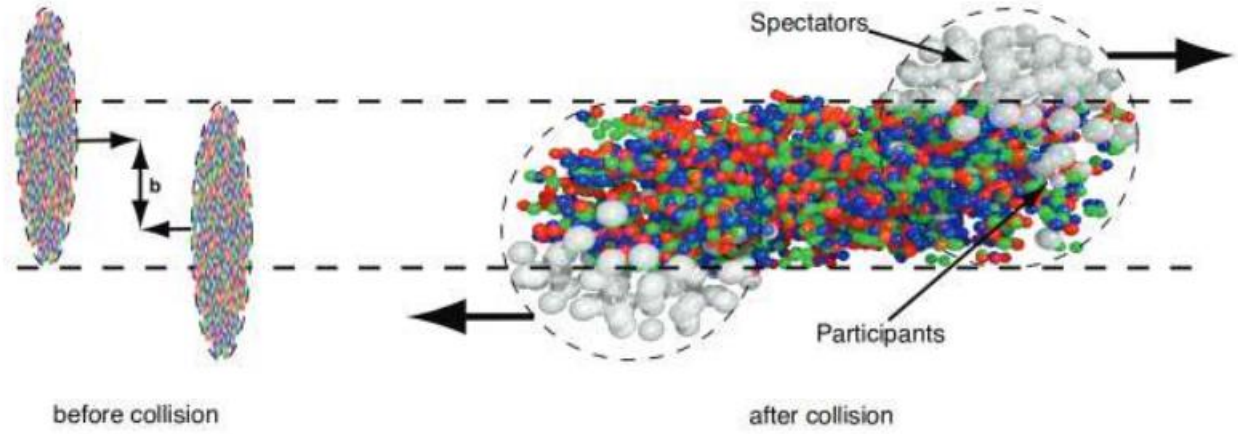
The Zero Degree Calorimeter

The ZDC take care of counting the spectator neutron.

The energy of the spectator neutrons as measured by the ZDC allows us to determine their number

Measurement of the number of spectator neutrons is equivalent to measuring the magnitude of the impact parameter or centrality of collision.



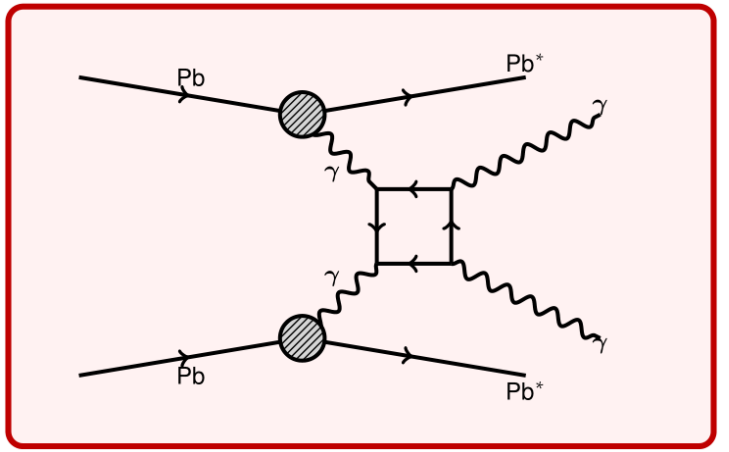


Light by light scattering

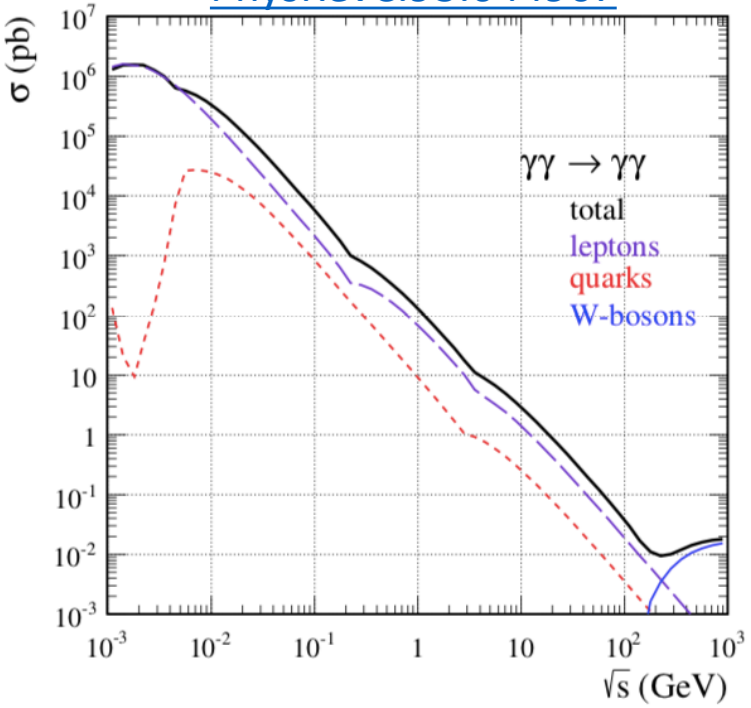
JHEP 03 (2021) 243

One loop process predicted by QED

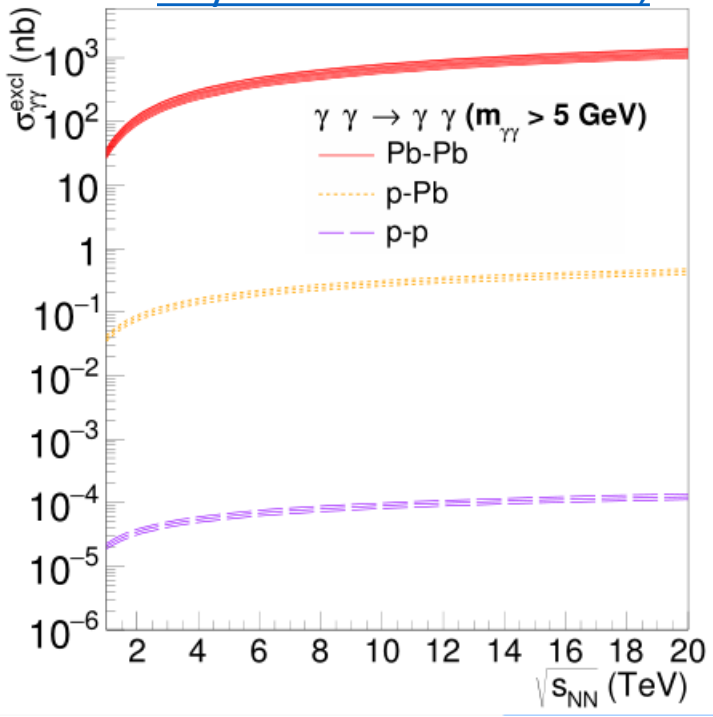
Loop with contribution from charged particles : l , q, $W^{\pm}$
Cross section enhanced with Z^4 wrt PP
The process is sensitive to BSM Physics



PhysRevC.93.044907



PhysRevLett.111.080405,



Light by light scattering

JHEP 03 (2021) 243

Data : 2015+2018 UPC HI collision.

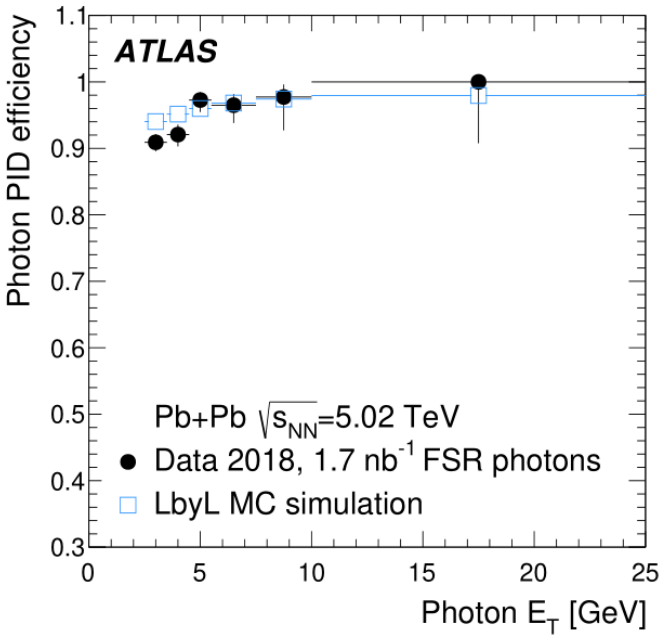
Improvements:

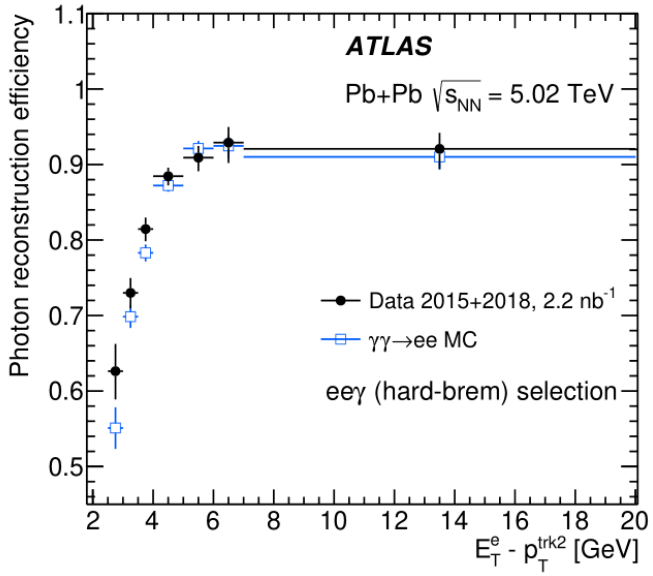
- 4.5 times stats wrt to evidence paper

[Nat. Phys. 13 (2017) 852–858]

Strong emphasis was put to improve the trigger strategy (especially at the Level-1)

- Trigger with higher efficiency at low ET
- NN Photons PID instead of cut based
- Better background rejection

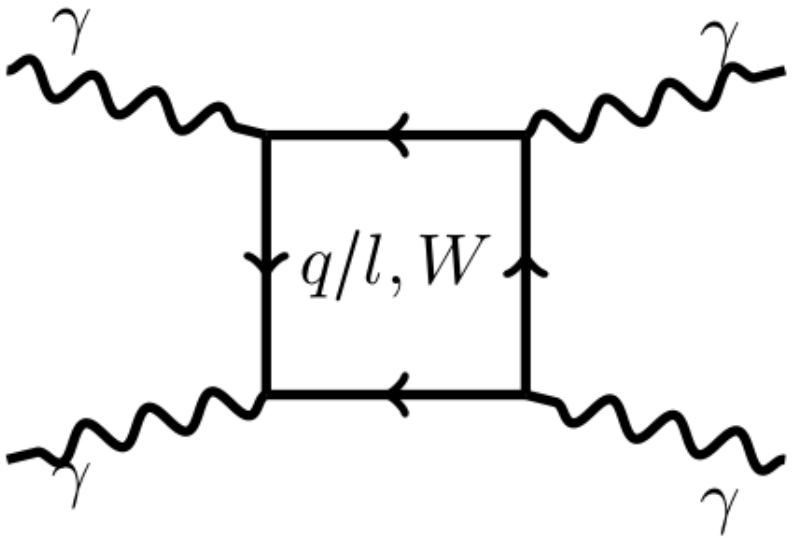




Light by light scattering

JHEP 03 (2021) 243

Signal selection



- 2 photons : NN PID
- E_{T}> 2.5 GeV and $|\eta|$ < 2.37
- $m_{\gamma\gamma}$ > 5 GeV
- Veto charged particle activity } to suppress e+e- backgtound
- $p_{\mathrm{T}}^{\gamma\gamma}$ < 1 GeV for $m_{\gamma\gamma}$ < 12 GeV
- $p_{\mathrm{T}}^{\gamma\gamma}$ < 2 GeV for $m_{\gamma\gamma}$ > 12 GeV } to suppress fakes and CEP
- Aco = $(1 - \frac{|\Delta\phi_{\gamma\gamma}|}{\pi})$ <0.01

Light by light scattering

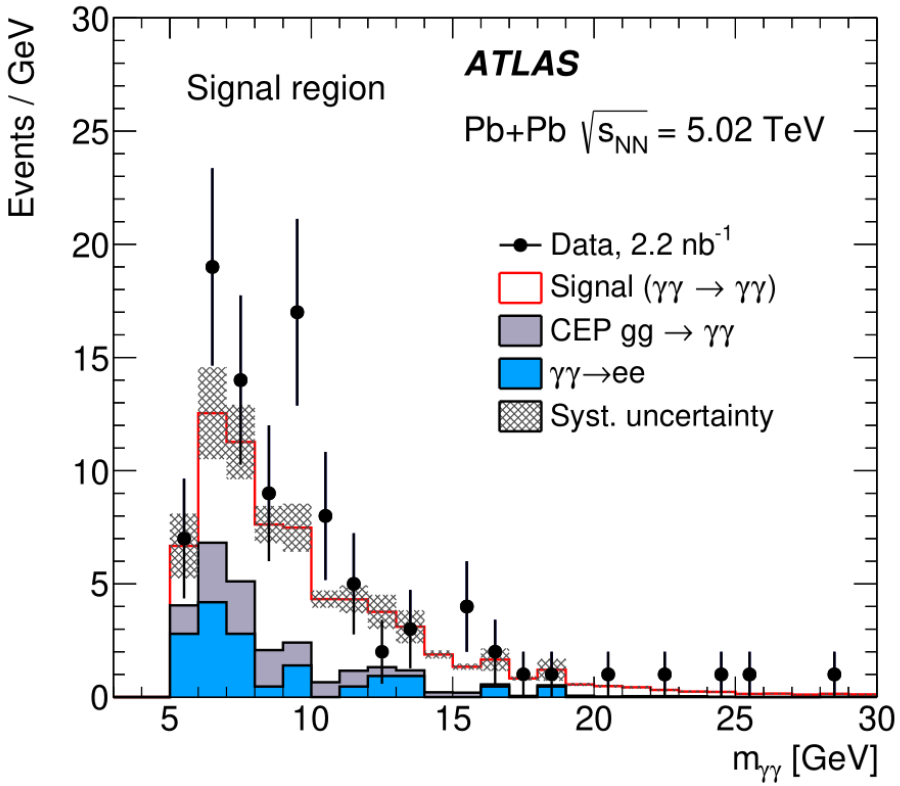
JHEP 03 (2021) 243

Cross section measurement

97 events are observed in data
where 45 signal + 27 background event expected.
The measured fiducial cross section :
$\sigma = 120 \pm 17 (stat .) \pm 13 (syst .) \pm 4 (lumi .)$ nb

Comparable to predicted values of :

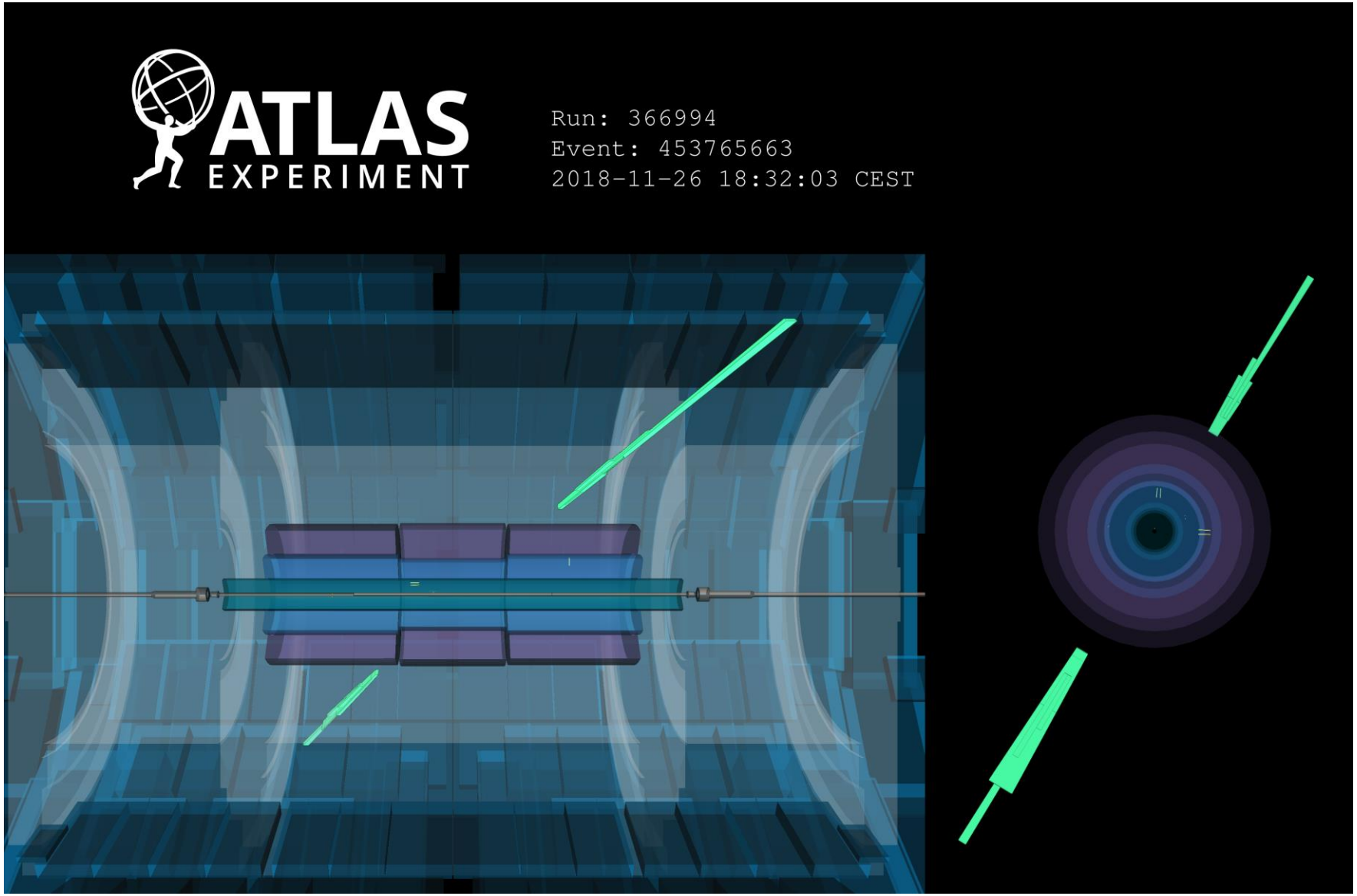
Predicted	Data/theory
80 ± 8 from Phys.Rev.C 93 (2016) 4, 044907	1.50 ± 0.32
78 ±8 from Eur.Phys.J.C 79 (2019) 1, 39	1.54 ± 0.32



Light by light scattering

JHEP 03 (2021) 243

High mass event display mγγ=29GeV



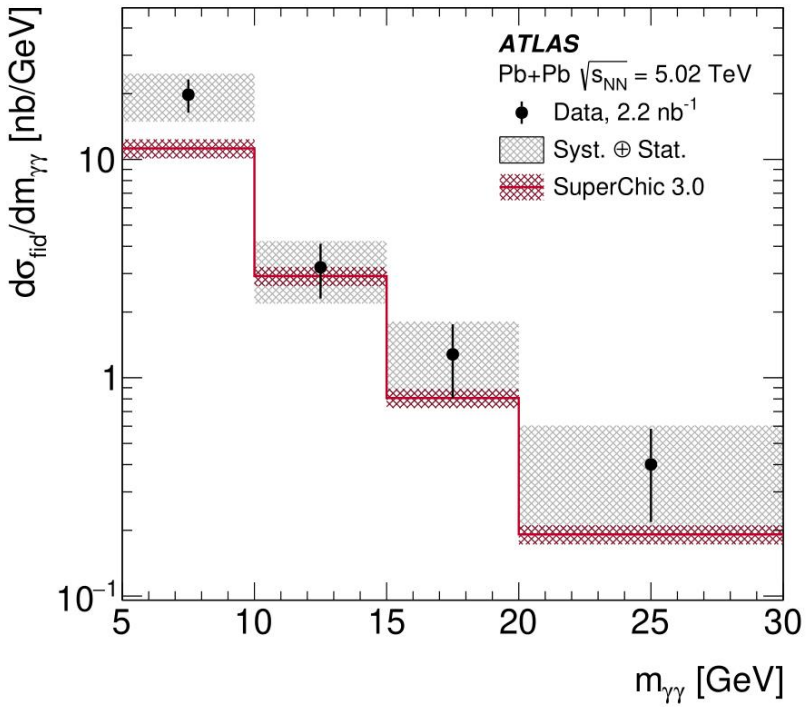
Light by light scattering

JHEP 03 (2021) 243

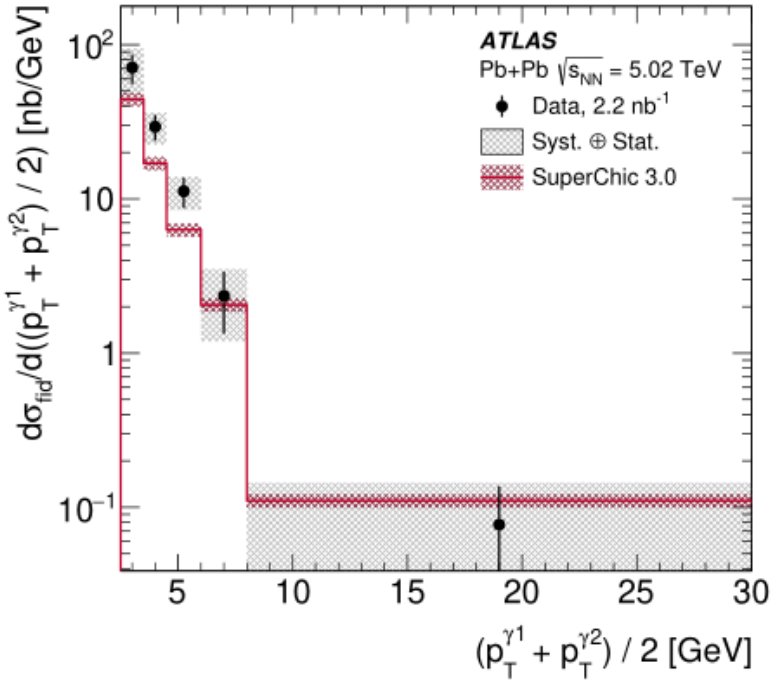
Differential cross section measurement

as a function of diphoton invariant mass, absolute rapidity, average photon transverse momentum and diphoton | cos θ∗|

SuperChic v3.0 provide a fair description of the data, except for the overall normalization differences



Diphoton invariant mass

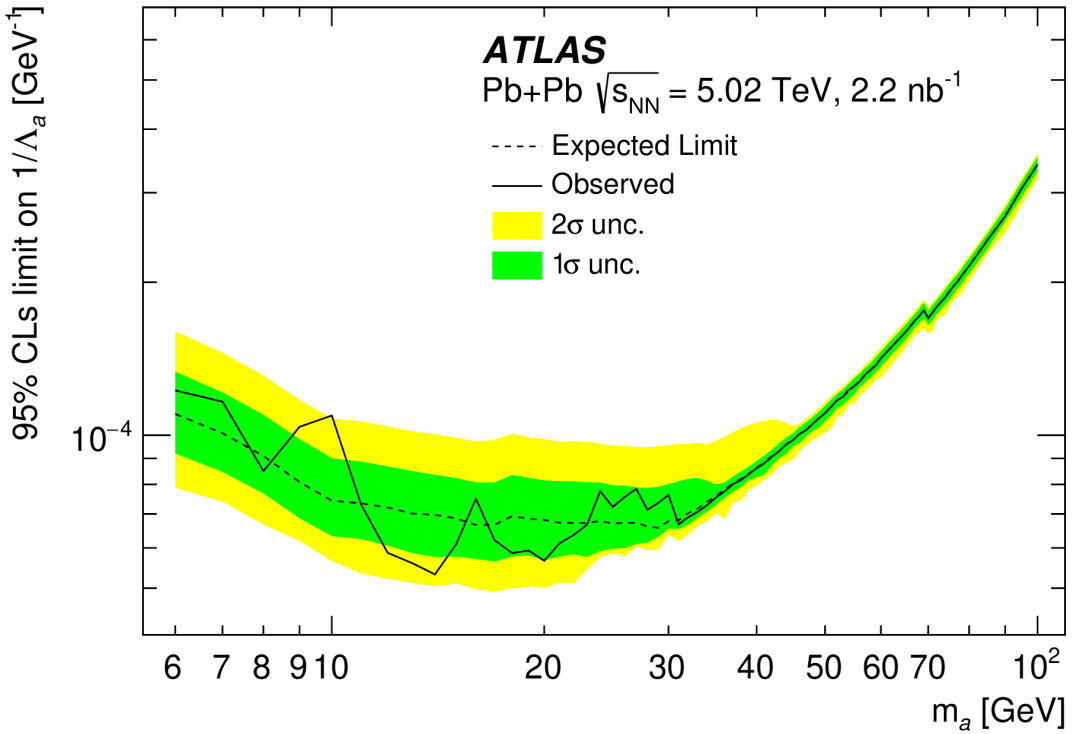


Average photon transverse momentum

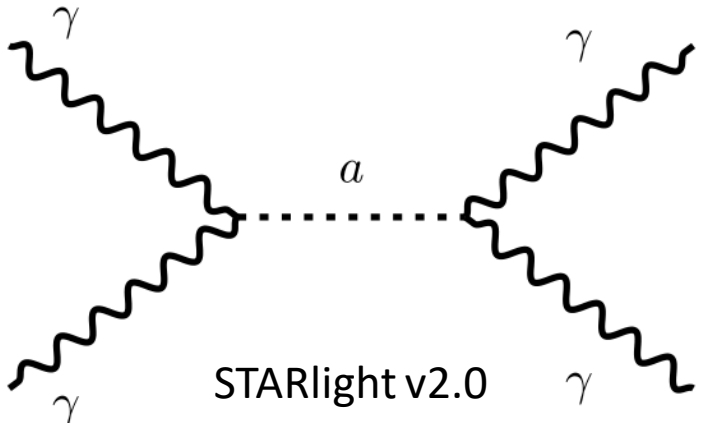
Light by light scattering

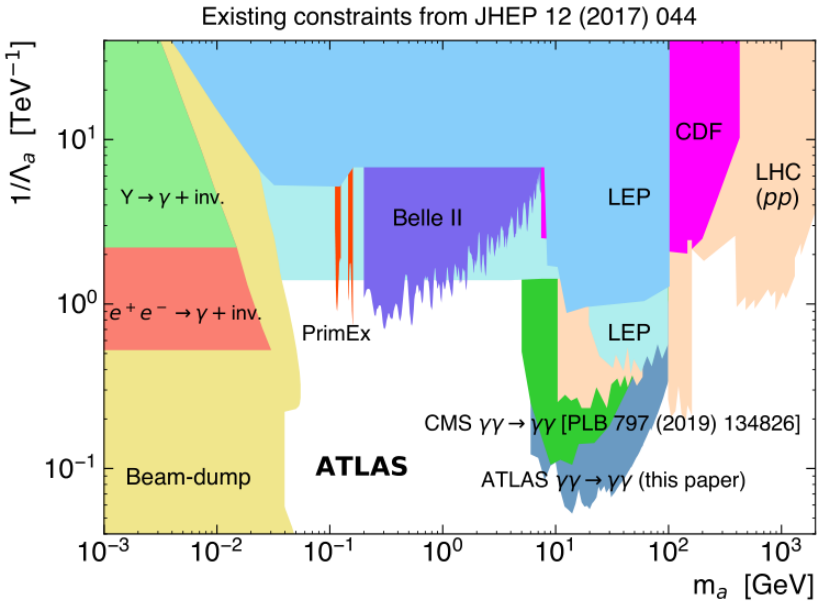
JHEP 03 (2021) 243

Search for ALPs



No significant excess from the background-only hypothesis is observed



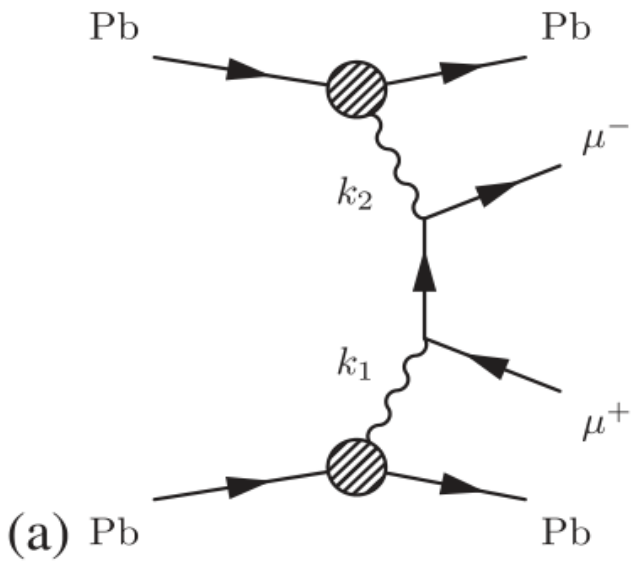


Most stringent limits on ALP at 6<ma<100 GeV

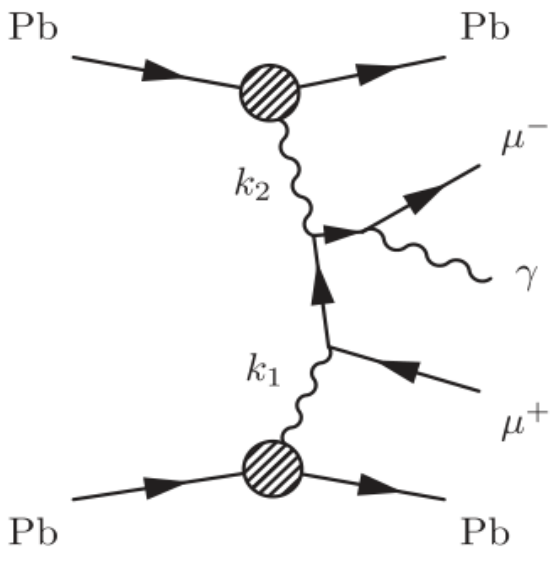
Exclusive dimuon production

Phys. Rev. C 104 (2021) 024906

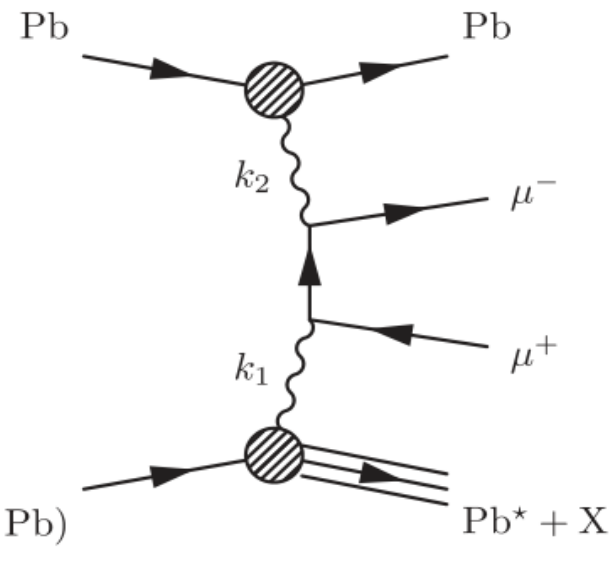
Leading Order



Next to Leading Order



Dissociative process



Starlight 2.0 + QED showering using PYTHIA8

LPAIR 4.0

Exclusive dimuon production

Phys. Rev. C 104 (2021) 024906

Data : 2015 Pb+Pb 5.02 TeV $0.48\ \mathrm{nb}^{-1}$

L1 trigger : Coincidence of a muon track in the MS with max of 50 GeV in calorimeter system

HLT :ID to select events with a well-reconstructed track with pT > 200MeV.

Signal selection:

Exclusivity selection : 2 oppositely charged muons

Suppress hadronic processes : No further activity in the ATLAS ID

Transverse momentum of single muon : $p_{T,\mu} > 4$ GeV,

Pseudorapidity : $|\eta_\mu| < 2.4$

Invariant mass : $m_{\mu\mu} > 10$GeV

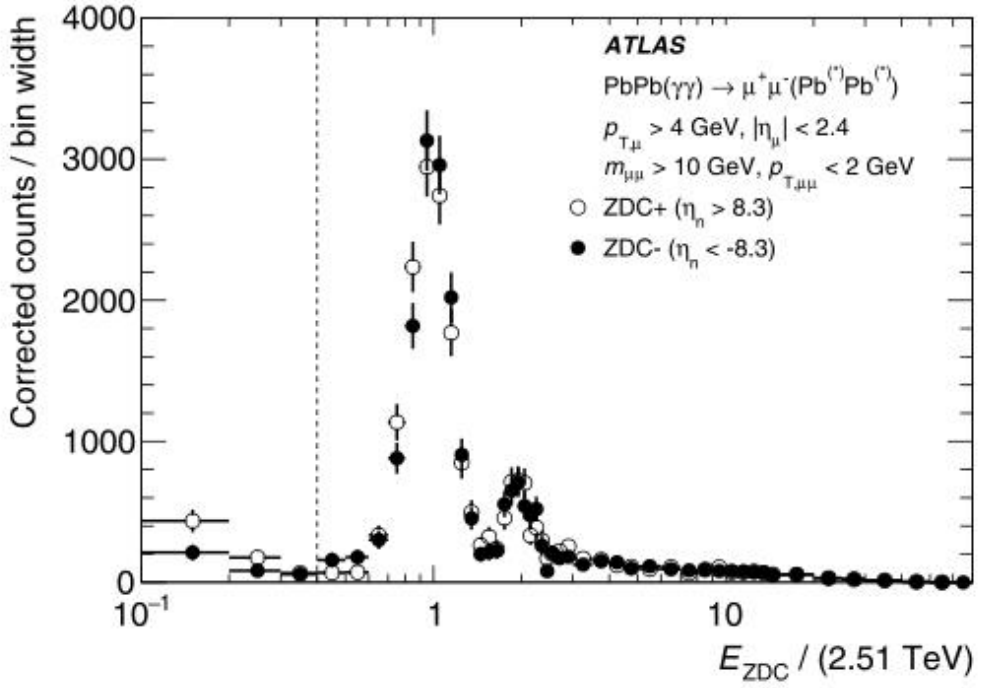
Transverse momentum of the dimuon system : $p_{T,\mu\mu} < 2$ GeV

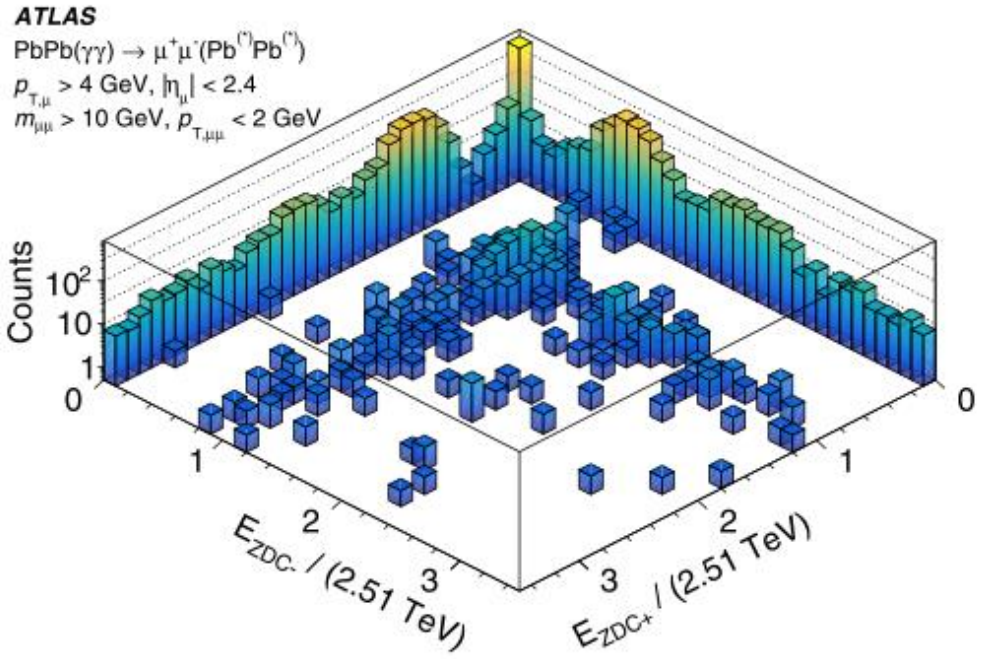
12132 candidate events pass the selection

Exclusive dimuon production

Phys. Rev. C 104 (2021) 024906

Three primary topologies available for these events



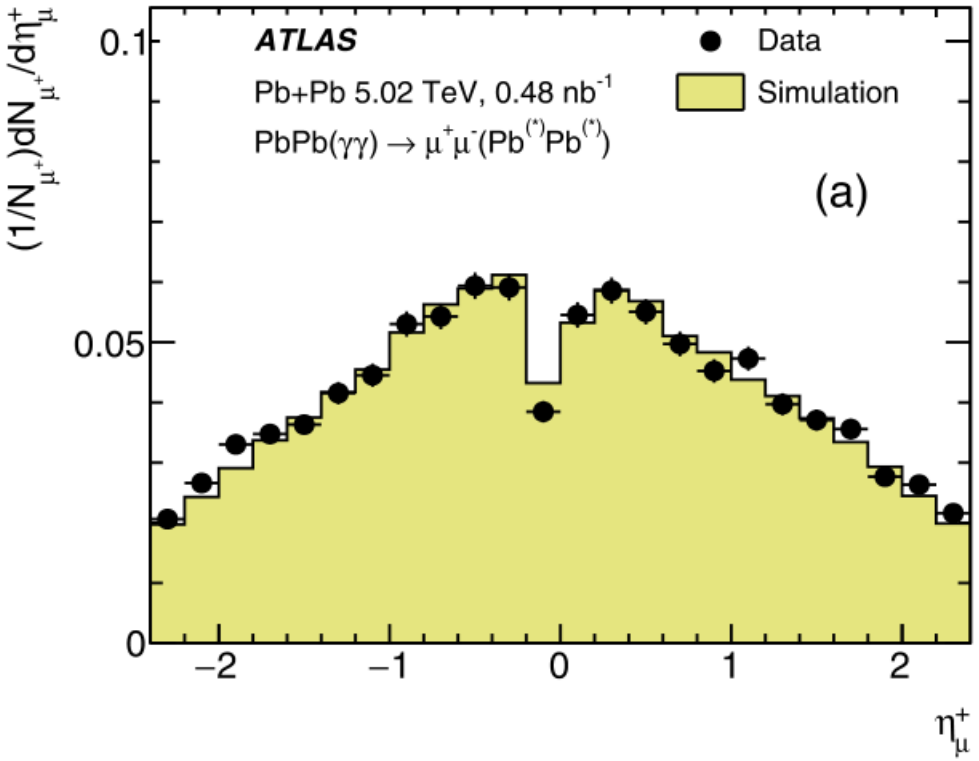


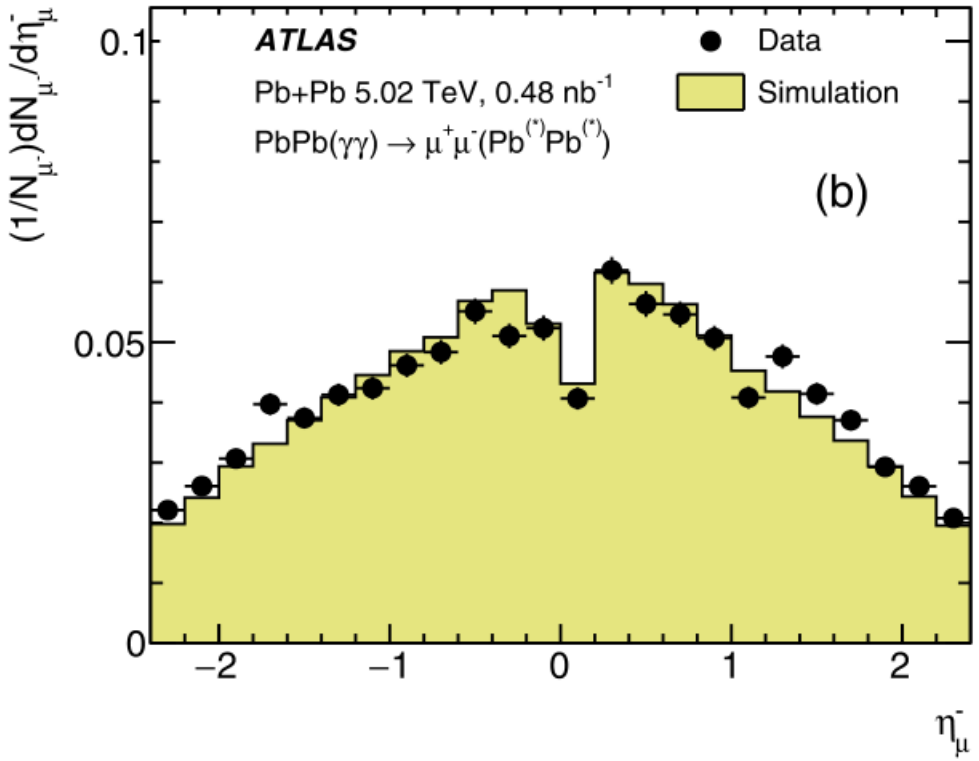
no activity in either ZDC sides	$0n0n$
activity in one ZDC side	$0nXn$
activity in both ZDC side	$XnXn$

Exclusive dimuon production

Phys. Rev. C 104 (2021) 024906

Data MC comparison





The measured fiducial cross section : $\sigma = 34.1 \pm 0.3\,(\text{stat.}) \pm 0.7\,(\text{syst.})$ μb

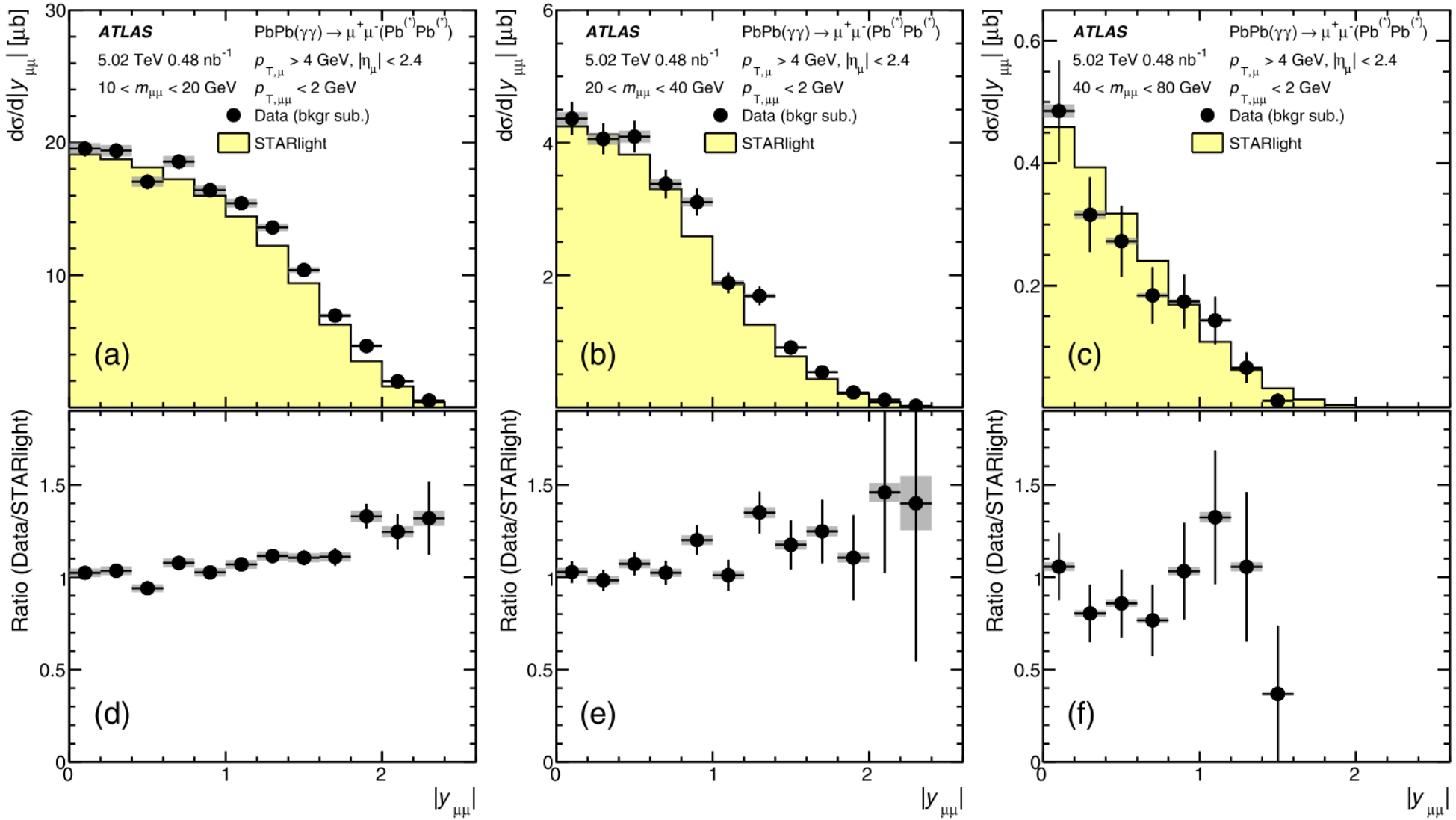
Compared to 32.1 μb for STARlight and 30.8 μb for STARlight+PYTHIA8.

Exclusive dimuon production

Differential cross section as function of absolute rapidity

In bins of invariant mass

Phys. Rev. C 104 (2021) 024906

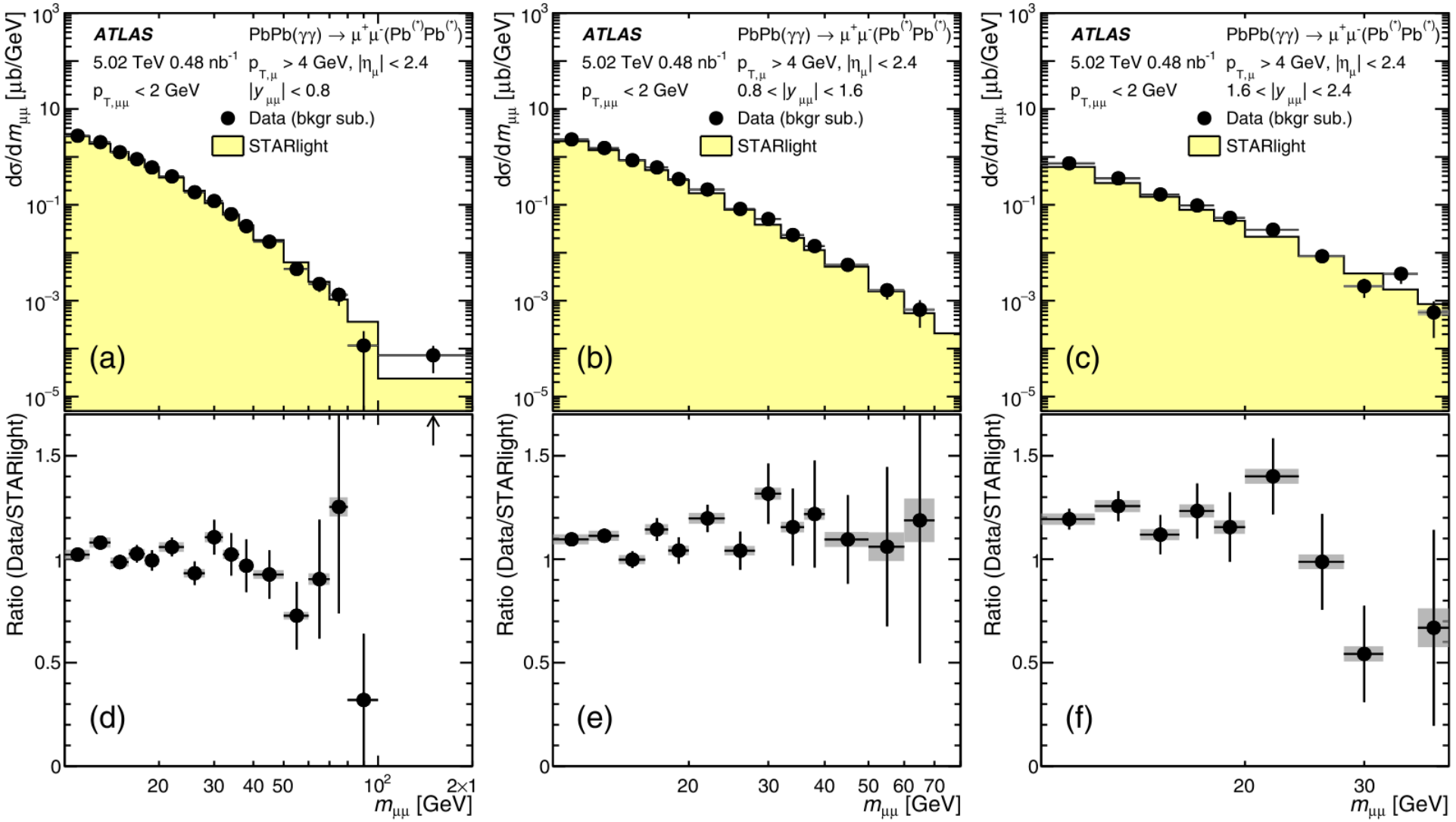


Exclusive dimuon production

Differential cross section as function of invariant mass

In bins of absolute rapidity

Phys. Rev. C 104 (2021) 024906

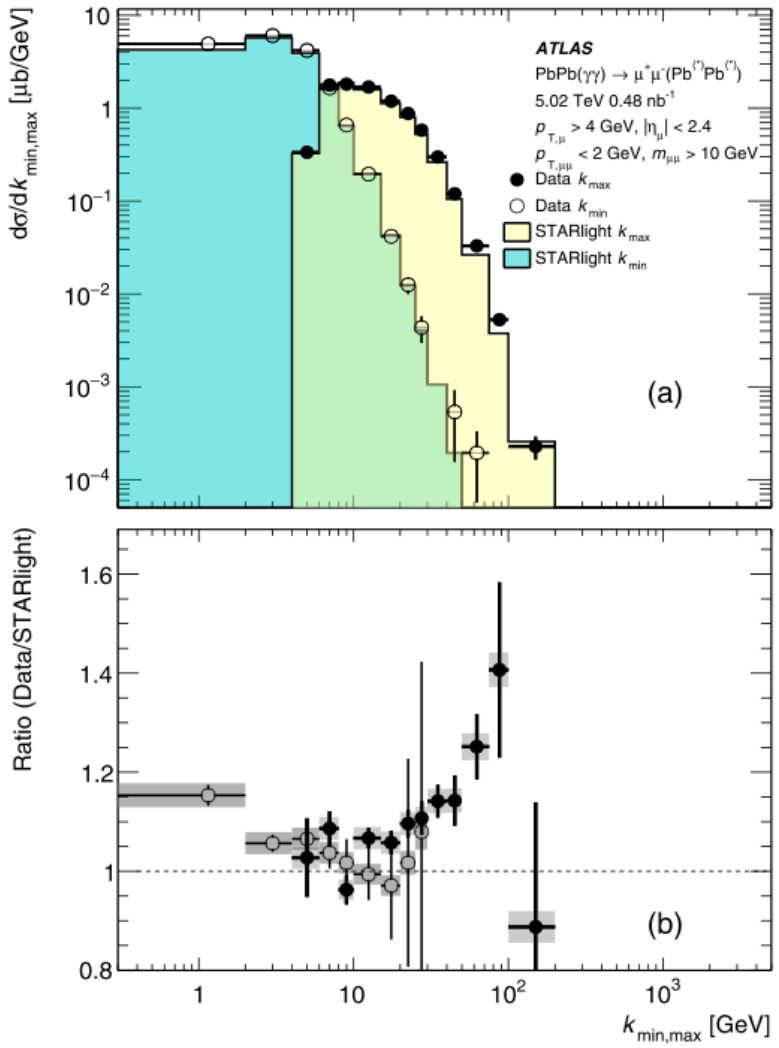


Exclusive dimuon production

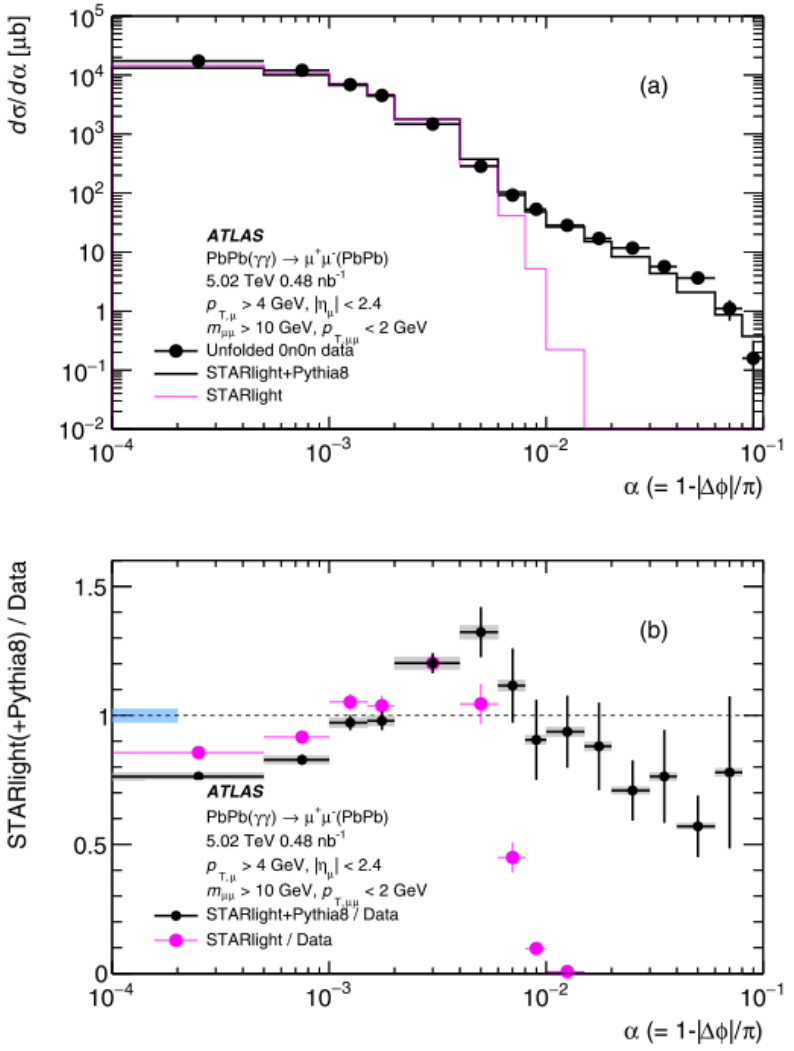
Differential cross section as function of :

[Phys. Rev. C 104 (2021) 024906]

Max and min photon energy



acoplanarity



Two-particle azimuthal correlations

Phys. Rev. C. 104 014903

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

- Dedicated photo-nuclear event trigger
- Looking to charged-particle tracks in the event with $2 < |\Delta\eta| < 5$
- pT > 0.4 GeV, $|\eta| < 2.5$,

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

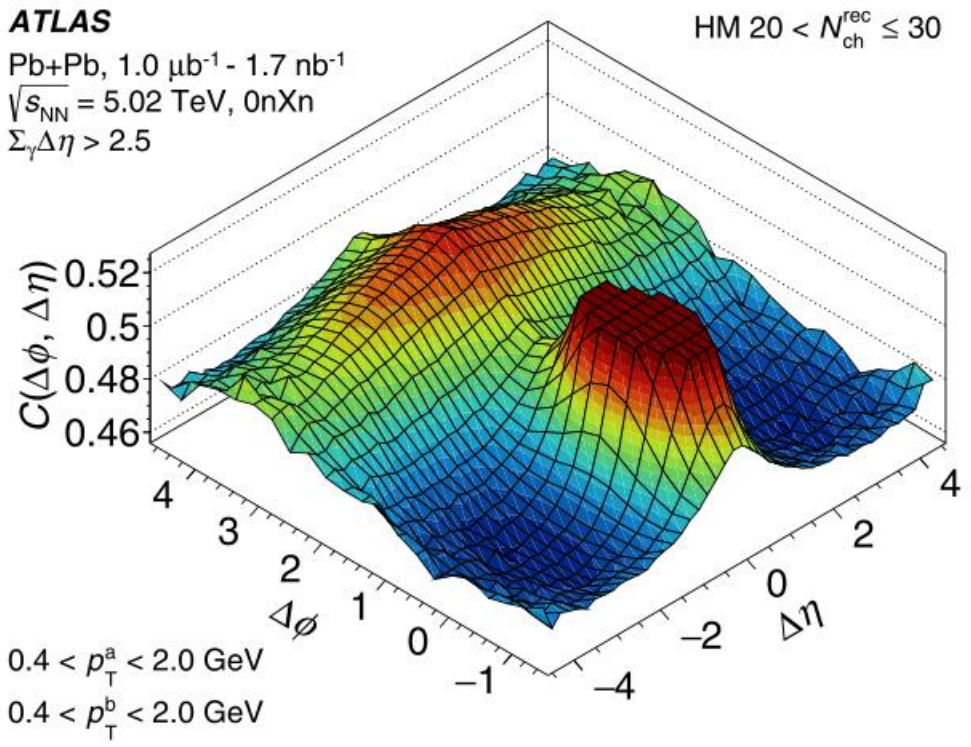
$$C(\Delta\phi, \Delta\eta) = \frac{1}{N_a}\frac{d^2N_{\text{pair}}}{d\Delta\phi\, d\Delta\eta} \Big/ \frac{1}{N_{\text{pair}}^{\text{mixed}}}\frac{d^2N_{\text{mixed}}}{d\Delta\phi\, d\Delta\eta},$$

correlation function in LM events

$$Y^{\text{HM}}(\Delta\phi) = FY^{\text{LM}}(\Delta\phi) + G\left\{1 + 2\sum_{n=2}^{4} v_{n,n}\cos(n\Delta\phi)\right\}$$

$$= FY^{\text{LM}}(\Delta\phi) + Y^{\text{ridge}}(\Delta\phi).$$

flow coefficients

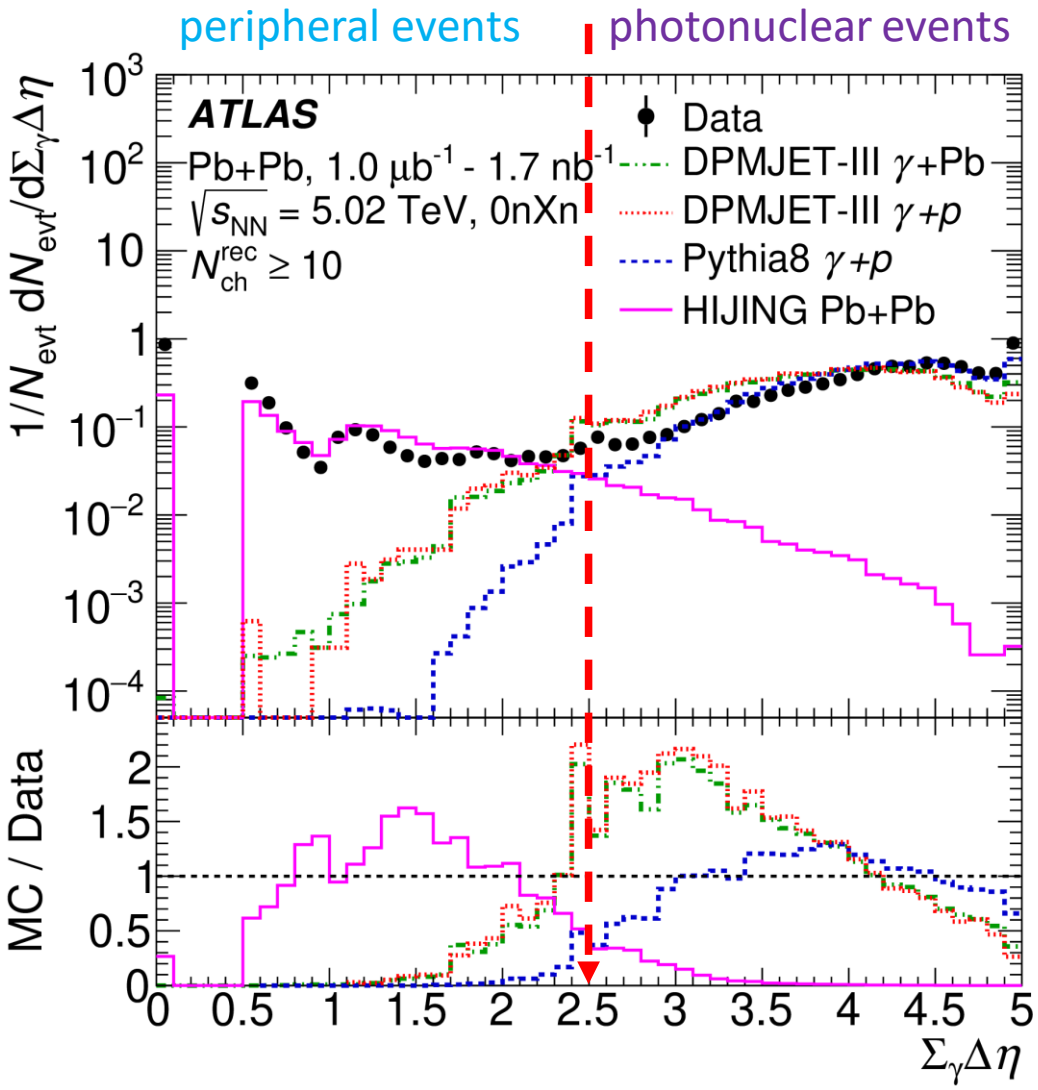


Two-particle azimuthal correlations

Phys. Rev. C. 104 014903

The trigger-selected events contain a mixture of peripheral Pb+Pb events and genuine photonuclear events, with the latter dominant at $\sum_\gamma \Delta\eta > 2.5$.

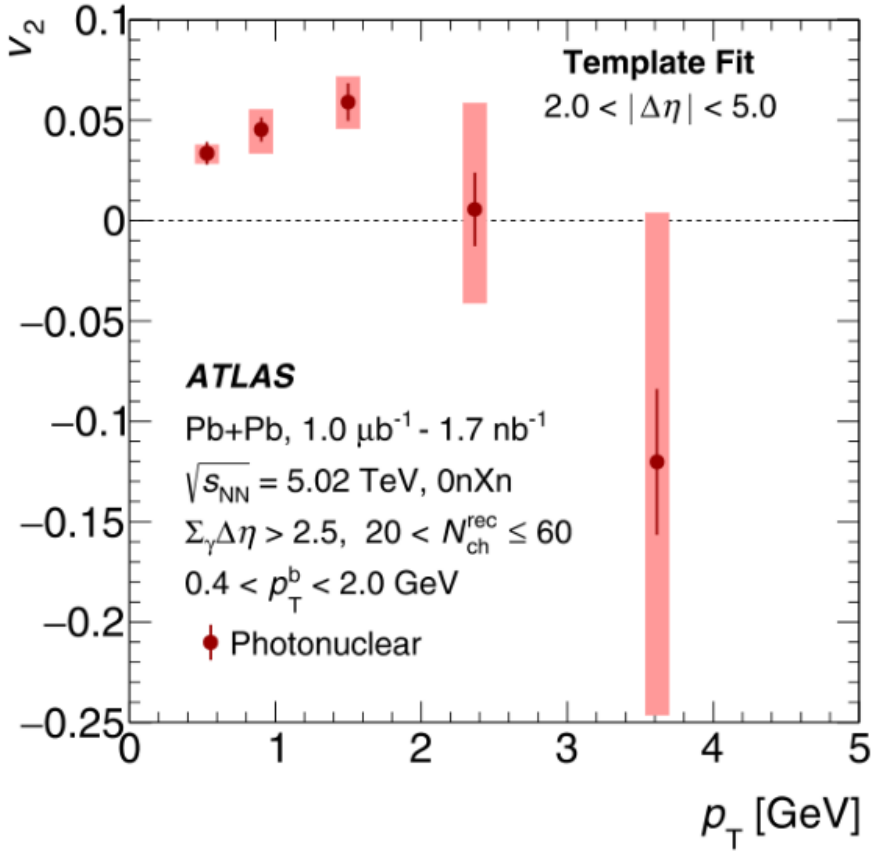
The purity for the $\sum_\gamma \Delta\eta > 2.5$. selection is estimated to be greater than 98% in all N_{ch}^{rec} selections used in the analysis.
No correction for impurity is performed



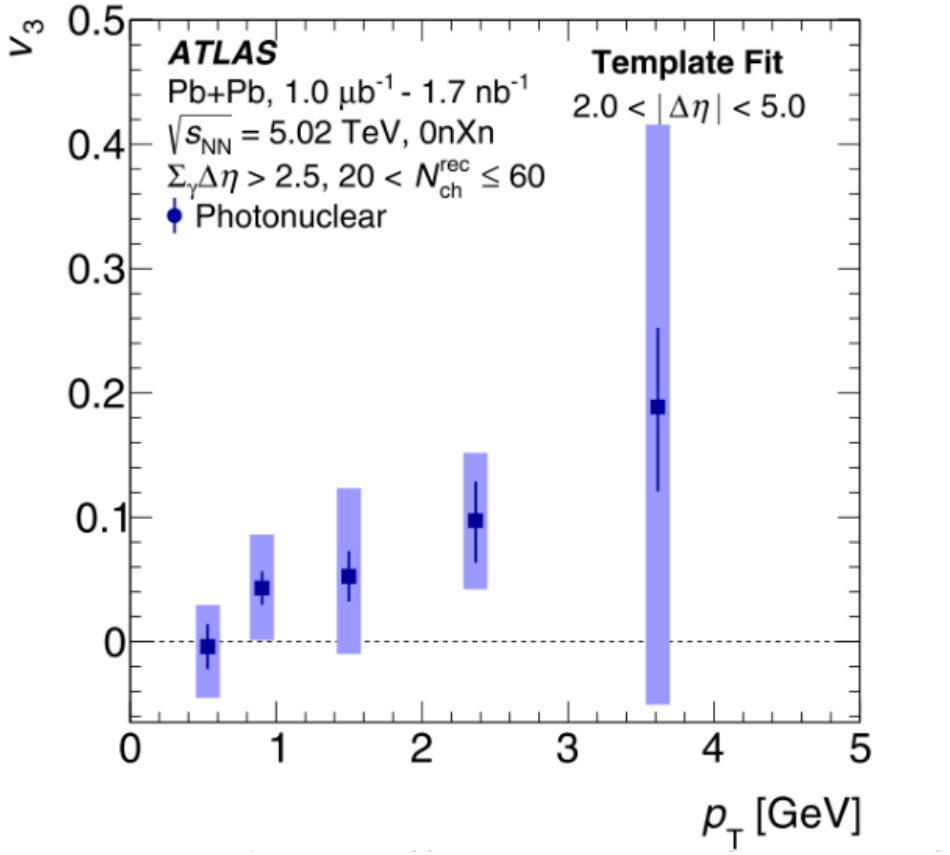
Two-particle azimuthal correlations

Phys. Rev. C. 104 014903

Significant, nonzero v2 and v3 values are observed in photonuclear events, particles produced in these events participate in azimuthally dependent, collective motion.



Flow coefficients v2 as a function of particle p_T

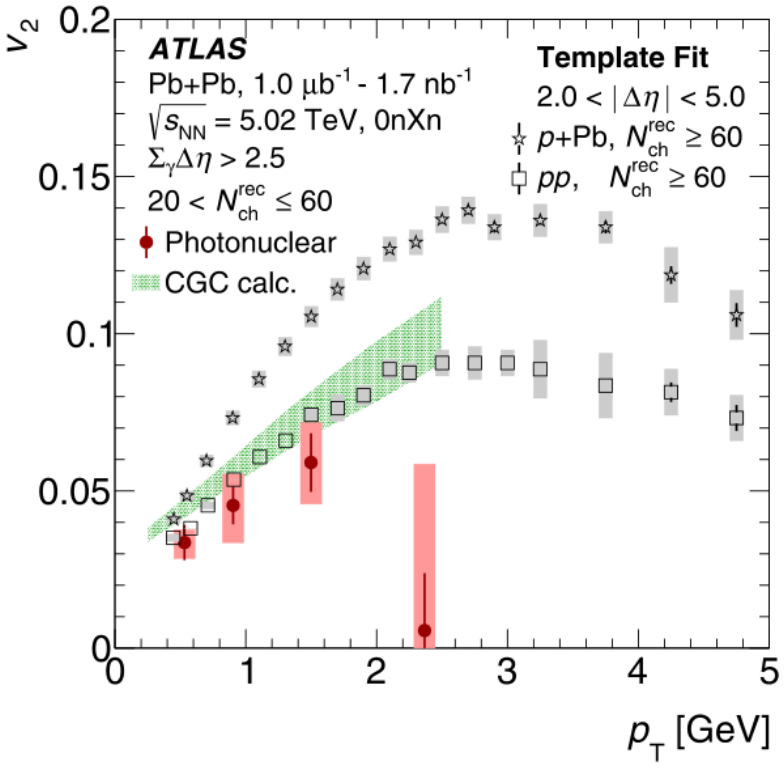


Flow coefficients v3 as a function of particle p_T

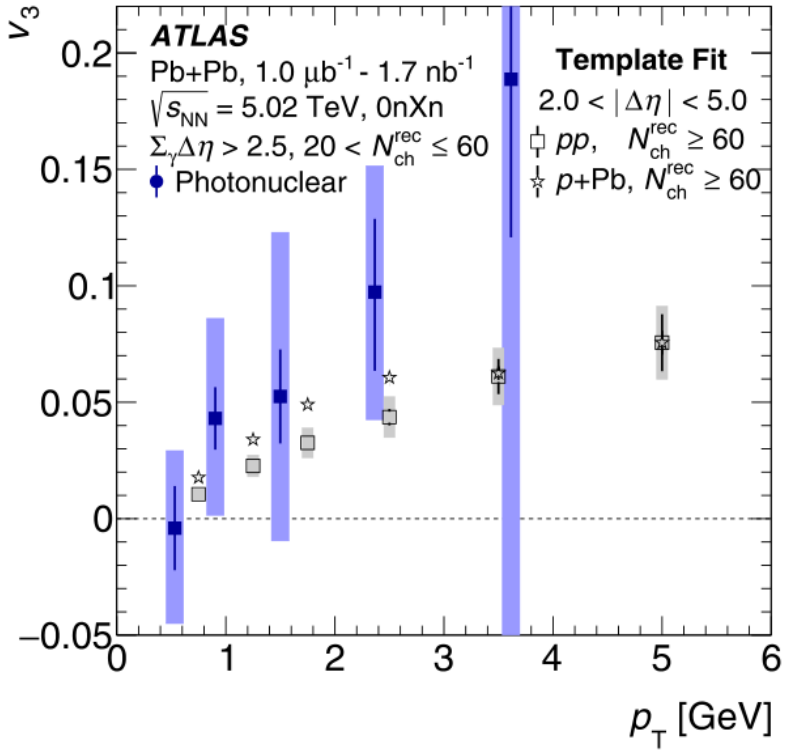
Two-particle azimuthal correlations

Phys. Rev. C. 104 014903

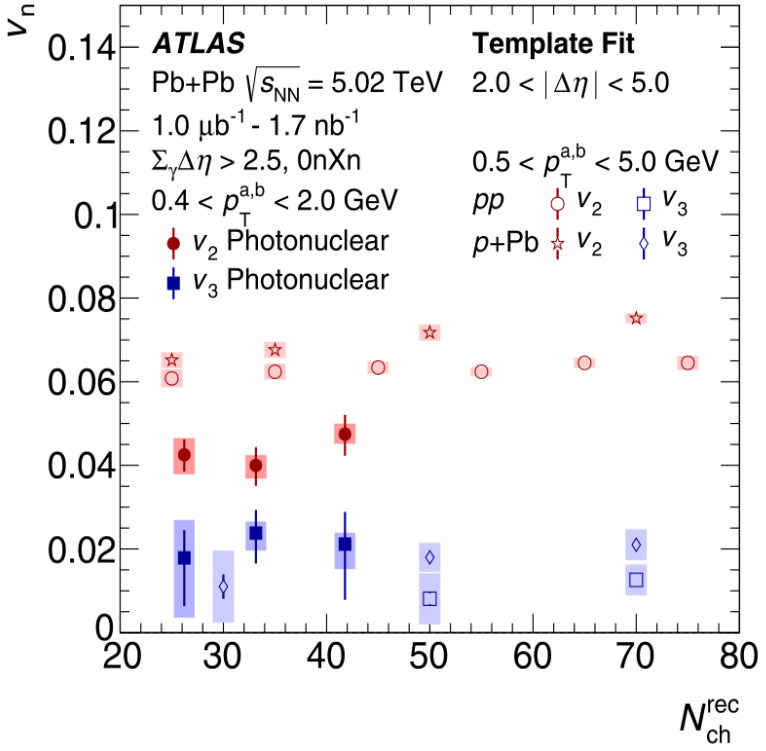
Comparison with in pp and p + Pb collisions : The v2 values are smaller at similar particle multiplicities



Flow coefficients v2 as a function of particle p_T



Flow coefficients v3 as a function of particle p_T



Flow coefficients v2 as a function of Charged particles multiplicity

Summary

- UPC heavy ion collisions allow to probe photon-induced interactions
- New testing ground for QED process.
- Clean way to search for particles that couples to photon such ALPs
- More understanding of systems to be studied in the future Electron Ion Collider (collectivity in electron-proton collision) PhysRevD.103.054017
- Stay tuned for more results from Run3 data taking @ LHC !

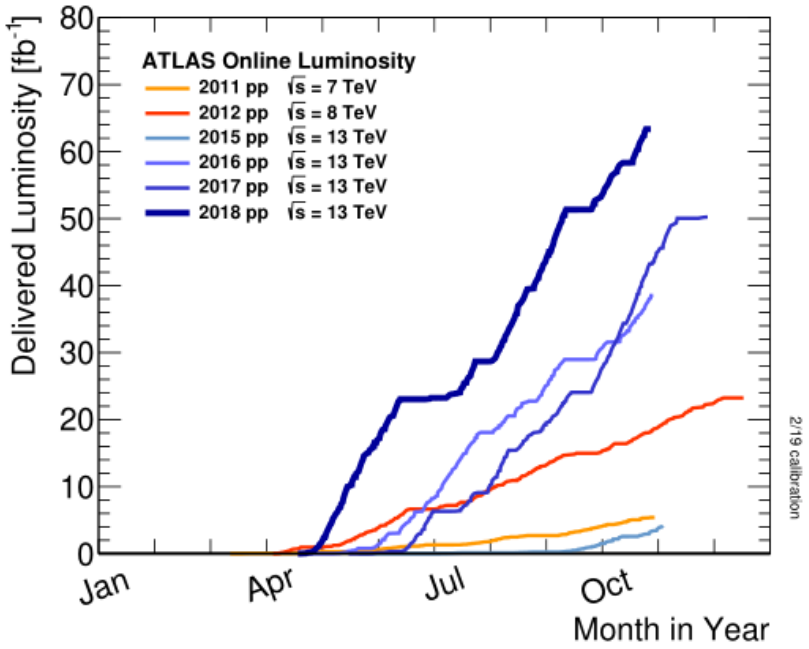
Backup

ATLAS

The Luminosity is a key parameter in collider physics

PP collision

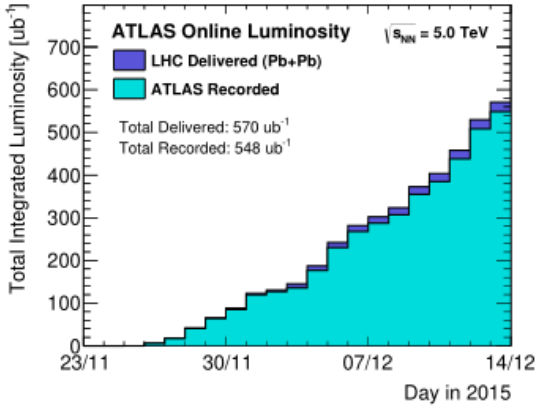
run1 + run2 : 189.3 fb^{-1}
run2 : 160 fb^{-1}



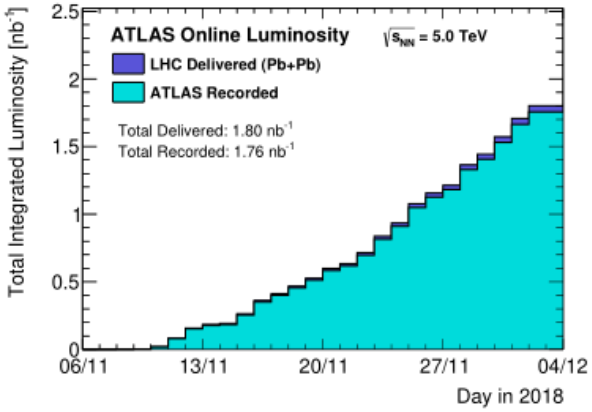
Integrated yearly luminosity between 2011 and 2018

Pb+Pb collision

2015 : 570 ub^{-1}



2018 : 1.8 nb^{-1}



ATLAS

Inner Detector

- ☆ Tracking and PID of charged particles

Calorimeters

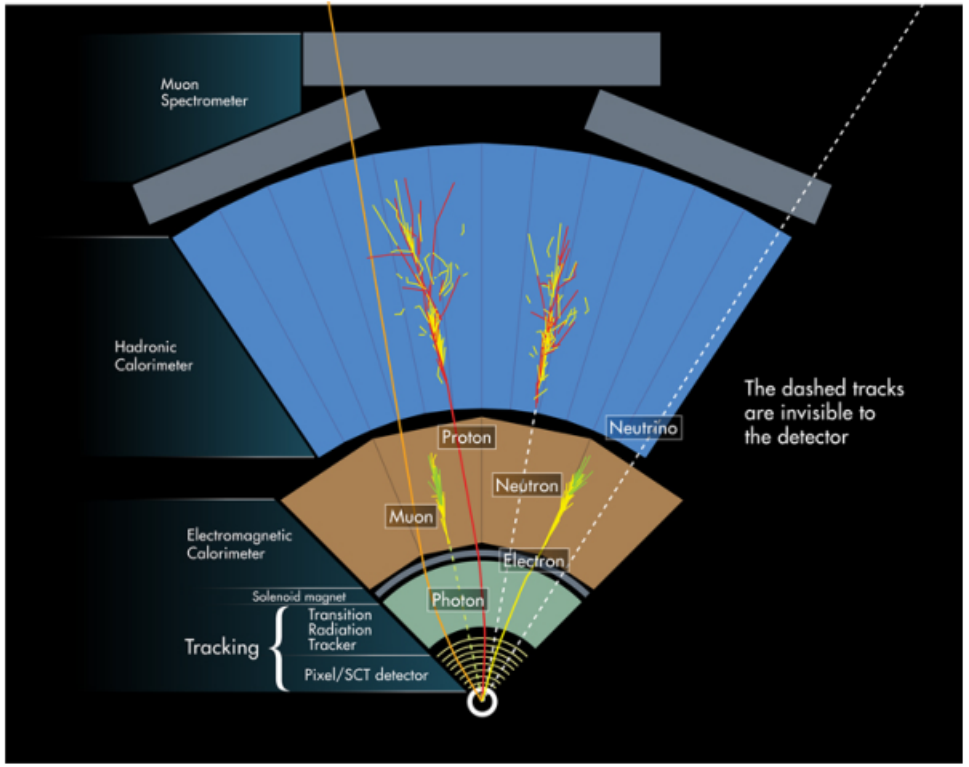
- ☆ Electromagnetic: Measure energy of electrons, positrons and photons
- ☆ Hadronic: Measure energy of hadrons

Muon Spectrometer

Measure charge and momentum of muons

Magnet system

bend charged particles so that their momenta can be measured

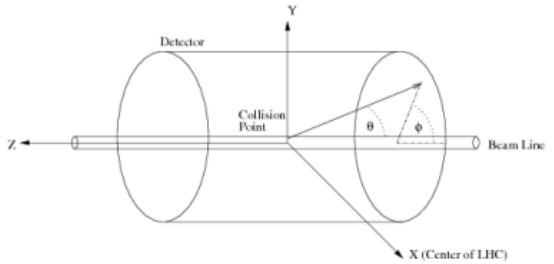


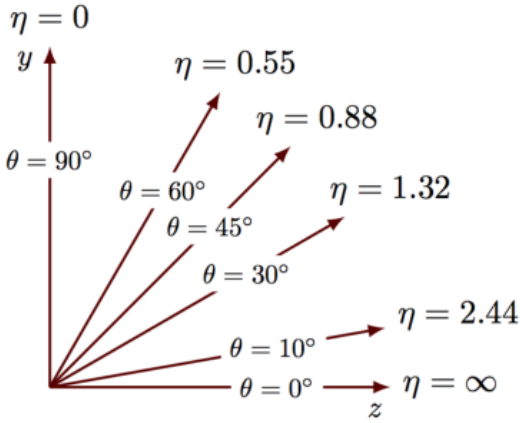
Forward detectors

- ☆ LUCID (LUminosity Cherenkov Integrating Detector)
- ☆ ZDC (Zero Degree Calorimeter)
- ☆ AFP (Atlas Forward Proton)

ATLAS Experiment coordinate and observable

- Pseudorapidity
  $\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$
- Transverse momentum,
  $\mathrm{P_T} = \mathrm{P}\sin(\theta)$
- Transverse energy
  $E_T = \sqrt{m^2 + p_T^2}$





In a two body decay **Invariant mass** $M \to 1 + 2$:

$$M^2 = (E_1 + E_2)^2 - \|\mathbf{p}_1 + \mathbf{p}_2\|^2 = m_1^2 + m_2^2 + 2\left(E_1 E_2 - \mathbf{p}_1 \cdot \mathbf{p}_2\right)$$

for massless particles :

$$M^2 = 2p_1 p_2(1 - \cos\theta)$$

Light by light scattering

Signal

- $\gamma\gamma \longrightarrow \gamma\gamma$ SuperChic v3.0 : 100k events (167 nb)

Backgrounds

- CEP $gg \longrightarrow \gamma\gamma$ Superchic v3.0 : 100k events
- $\gamma\gamma \longrightarrow e^+e^-$ Starlight:
  - 1.5 M events (419 b) 3.6 < Minv <8 GeV
  - 0.5 M events (116 b) Minv > 8 GeV)
- $\gamma\gamma \longrightarrow q\bar{q}$ (negligible)
- Fakes (calo noise, cosmics) (negligible)
- Others, found negligible (exclusive di-meson production (e.g. $\pi^0\pi^0$) , bottomonia production (for example, $\gamma\gamma \to \eta_b \to \gamma\gamma$ or $\gamma\mathrm{Pb} \to \Upsilon \to \gamma\eta_b \to 3\gamma$)

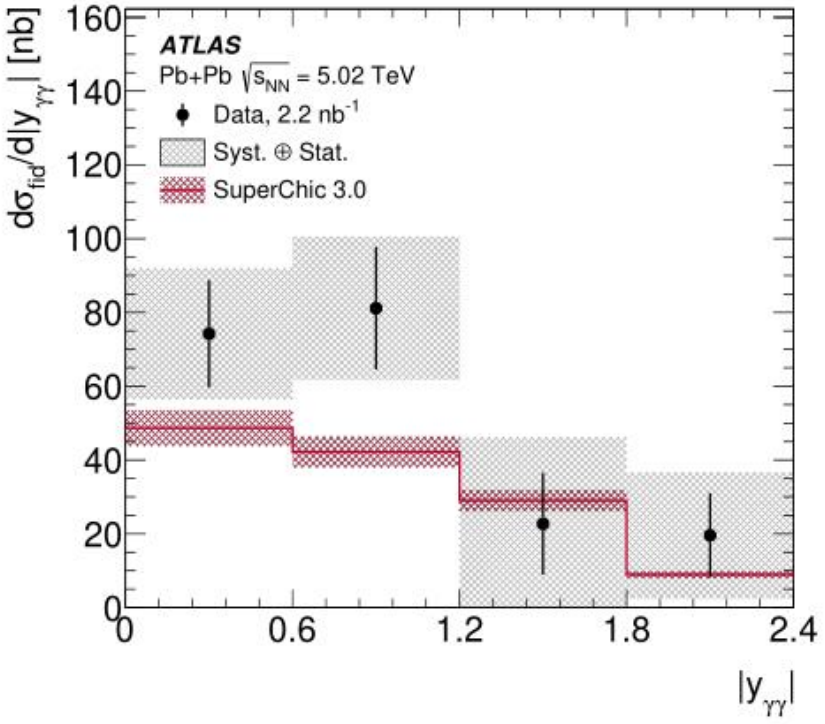
Light by light scattering

JHEP 03 (2021) 243

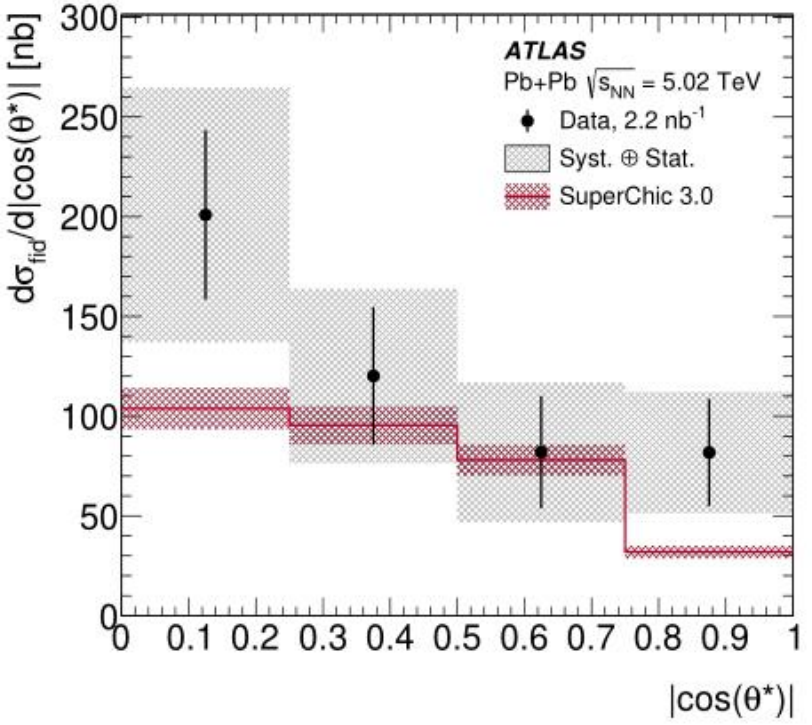
Differential cross section measurement

as a function of diphoton invariant mass, absolute rapidity, average photon transverse momentum and diphoton | cos θ∗ |

SuperChic v3.0 provide a fair description of the data, except for the overall normalization differences



absolute rapidity



diphoton | cos θ∗ |

Light by light scattering

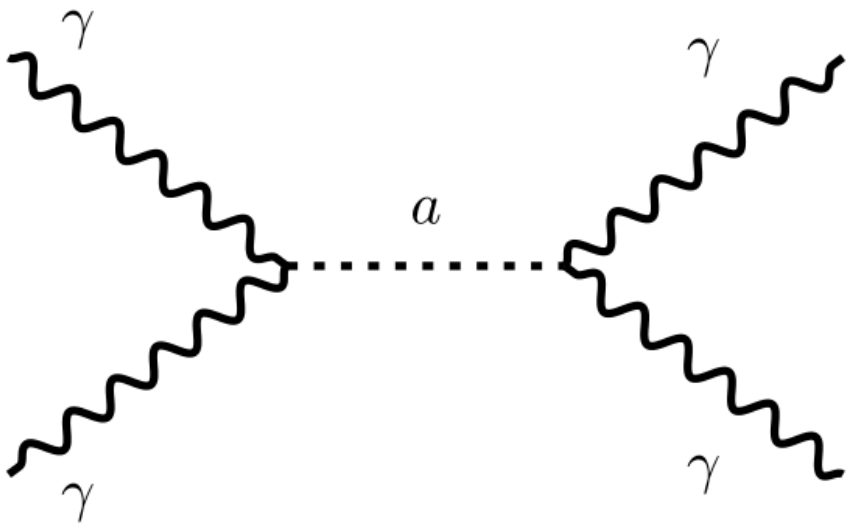
same event topology as for the light-by-light scattering

Data

- ☆ 2015+2018 : 2.2 nb^{-1}

Signal

- ☆ STARlight v2.0 for ALP masses $5 < m_a < 100$ GeV
- ☆ Assuming 100% ALP decay branching fraction to photons
- ☆ 1 GeV mass spacing For $5 < m_a < 30$ GeV
- ☆ 10 GeV mass spacing For $m_a > 30$ GeV



Backgrounds

- ☆ LbyL
- ☆ CEP $gg \longrightarrow \gamma\gamma$
- ☆ $\gamma\gamma \longrightarrow e^+e^-$

Light by light scattering

JHEP 03 (2021) 243

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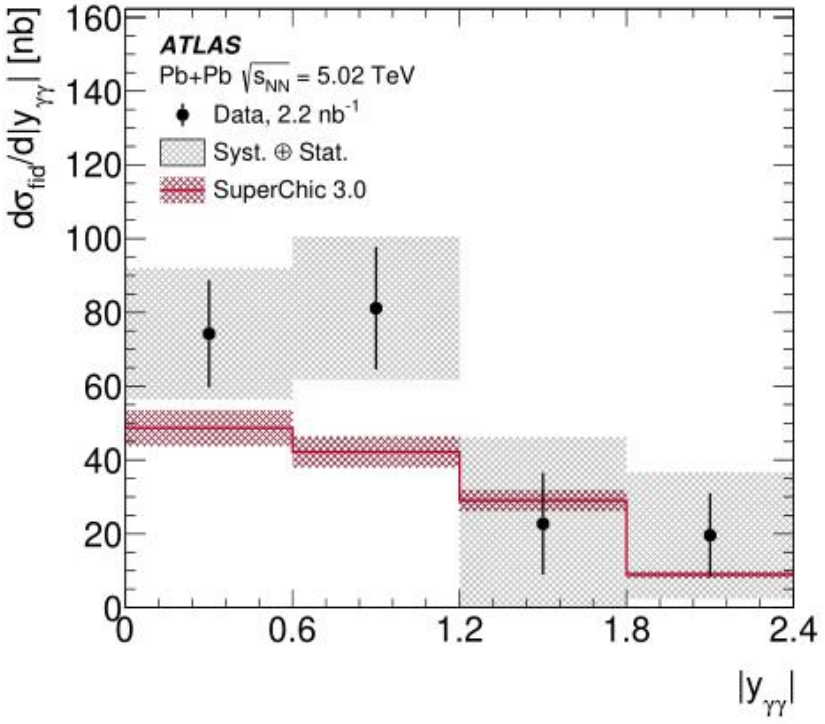
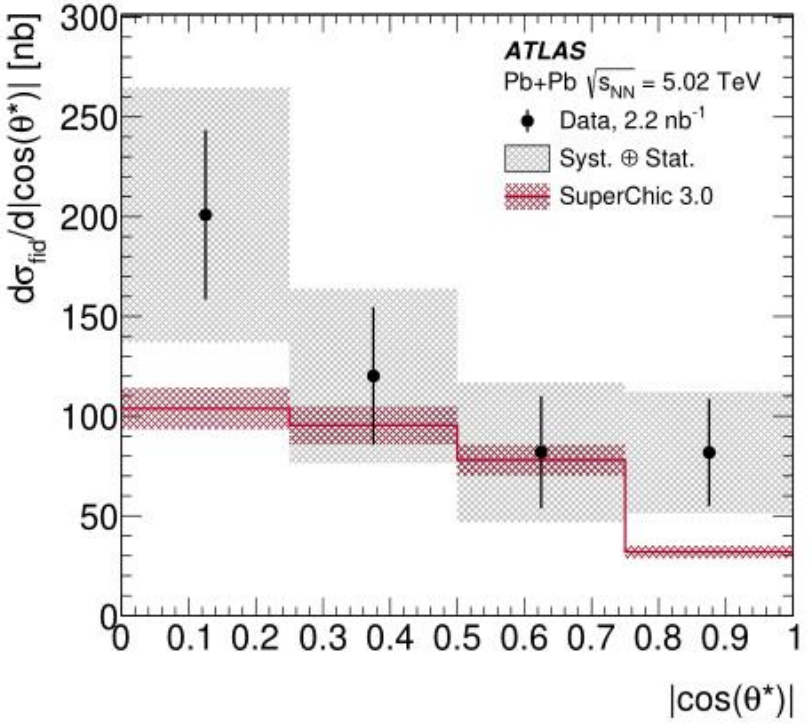


absolute rapidity



diphoton | cos θ∗ |

Exclusive dimuon production

Phys. Rev. C 104 (2021) 024906

Differential cross section as function of scattering angle In bins of invariant mass