Measurements of J/ψ and the impact of coincident photon-induced processes in ultra-peripheral Pb+Pb collisions at $\sqrt{s_{NN}}$ = 5.36 TeV with the ATLAS detector

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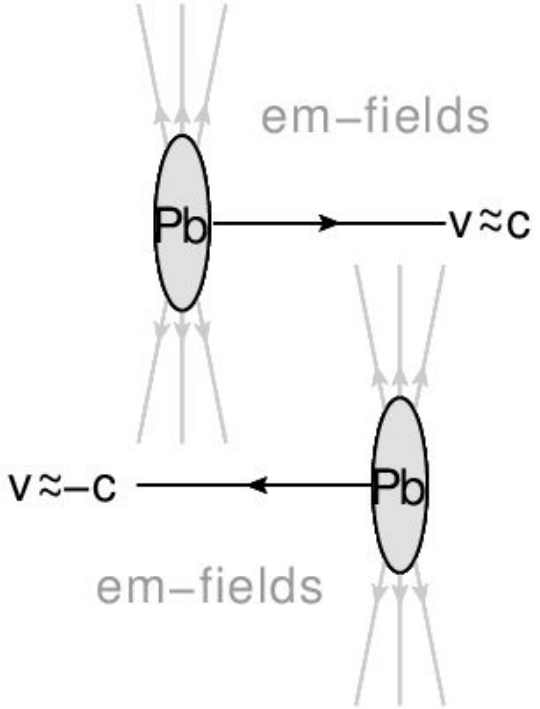
on behalf of the ATLAS Collaboration

ATLAS EXPERIMENT

DIS 2026

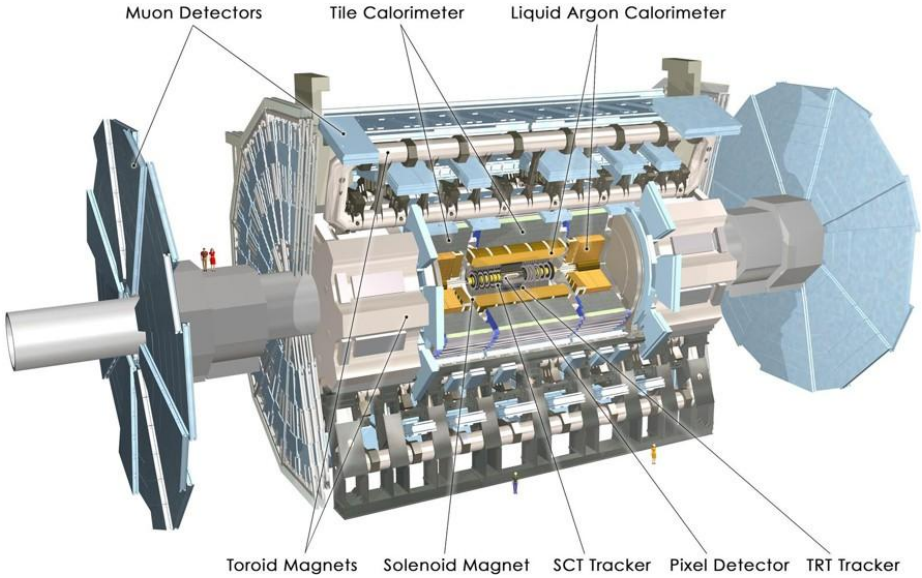
Ultraperipheral collisions

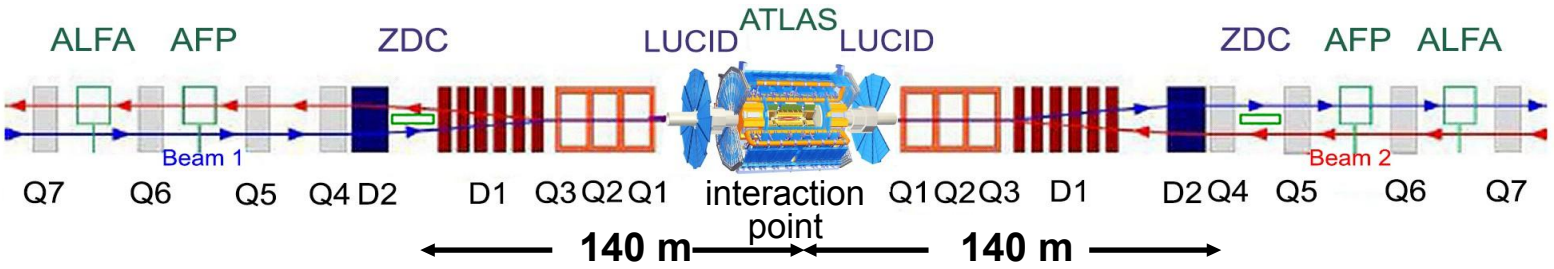
- In **ultra-peripheral heavy-ion collisions (UPC)** we observe photon-photon interactions
- Electromagnetic (EM) fields of relativistic ions considered as **fluxes of photons** (they scale with ~ Z^2)
    - Described in a **Equivalent Photon Approximation** (EPA) formalism
- Strong interactions suppressed



ATLAS detector

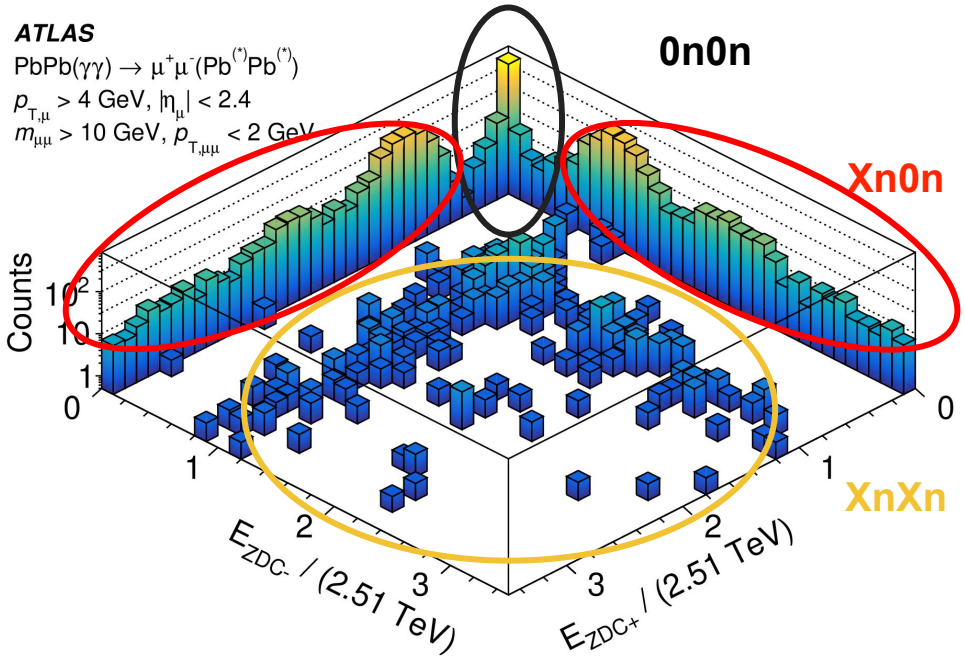
- Large general-purpose detector with almost 4π coverage
- $\eta = -\log(\tan(\theta/2))$
- Inner detector $|\eta| < 2.5$
- Muon system $|\eta| < 2.7$ (trig. 2.4)
- Calorimetry out to $|\eta| < 4.9$
- Zero-Degree-Calorimeters capture neutral particles with $|\eta| > 8.3$





ZDC neutron classes

- **Three classes** defined, based on the signal in the ZDC
  - 0n0n: no neutrons on both sides
  - Xn0n: some neutrons on one side
  - XnXn: some neutrons on both sides



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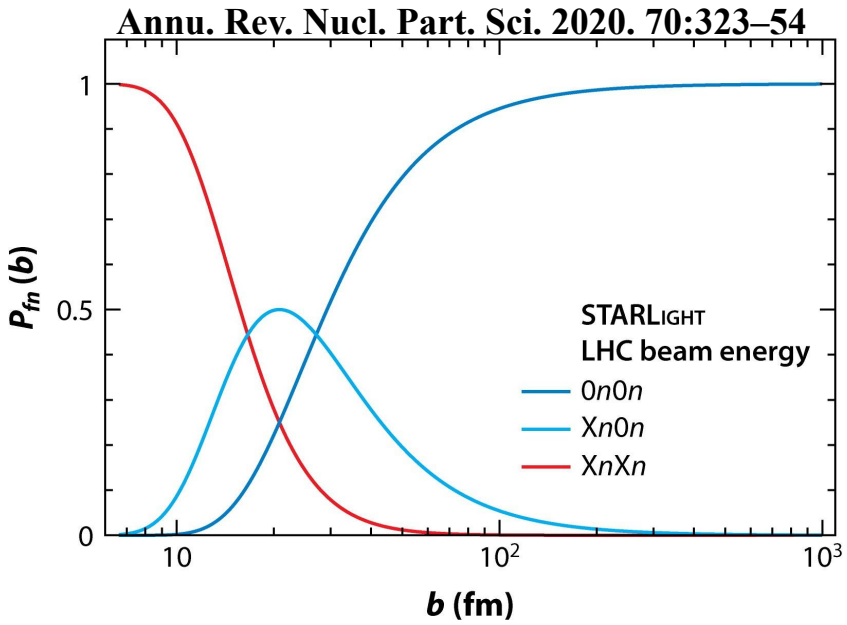
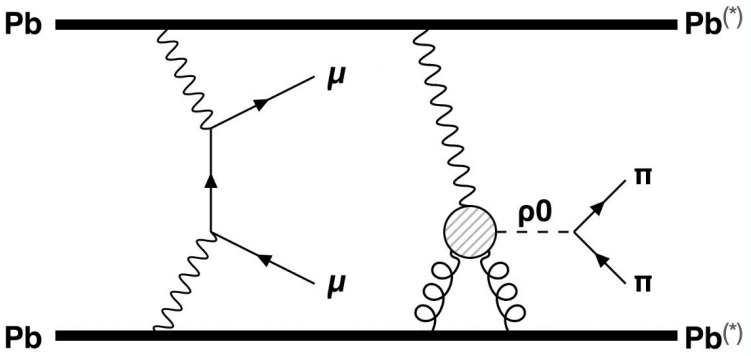
- The probability of producing a given **ZDC category depends on** the value of the **impact parameter**, *b* (based on the Coulomb excitation probabilities ~ $1/b^2$)



arXiv:2504.07795

Coincident photon-induced processes in UPC

- High photon flux enables the occurrence of multiple photon-induced processes in a single collision
- Aim to measure coincident rate of $\gamma\gamma \to \mu\mu$ and $\gamma + A \to \varrho^0 + A$
  - the $\gamma\gamma \to \mu\mu$ is a tagging process (also at the trigger level)
  - ϱ^0 detected as pairs of very low-p_T tracks
  - measured rate of coincident $\gamma\gamma \to \mu\mu$ and $\gamma + A \to \varrho^0 + A$ production with respect to exclusive $\gamma\gamma \to \mu\mu$



- Providing insight on the potential bias caused by exclusivity criteria
- Coincident processes may constitute background for some UPC measurements

arXiv:2504.07795

Analysis procedure

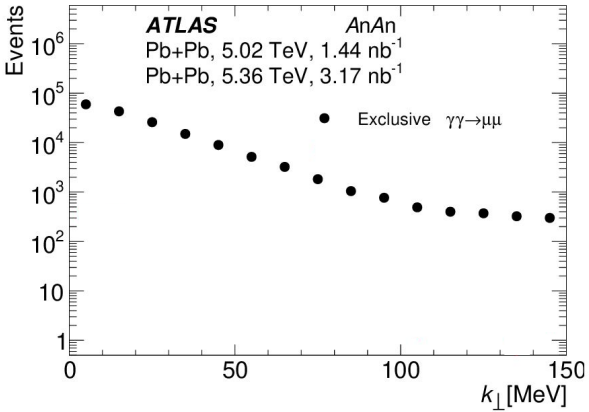
- Using Pb+Pb data at 5.02 TeV and 5.36 TeV
- Event selection:
  - passing trigger requiring muon p_T > 4 GeV and total transverse energy below 50 GeV
  - two reconstructed opposite charge offline muons with $|\eta|$ < 2.4 and p_T > 3.7 GeV
  - muons are back to back: A < 0.06, and $k_\perp$ < 150 MeV

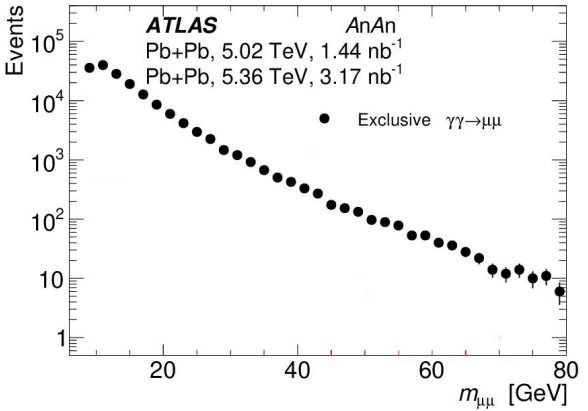
$$k_\perp \equiv \pi \alpha \bar{p}_\mathrm{T}$$

$$A \equiv |p_\mathrm{T}^a - p_\mathrm{T}^b|/(p_\mathrm{T}^a + p_\mathrm{T}^b)$$

$$\alpha \equiv (1 - |\phi^a - \phi^b|/\pi)$$

$$\bar{p}_\mathrm{T} \equiv (p_\mathrm{T}^a + p_\mathrm{T}^b)/2$$





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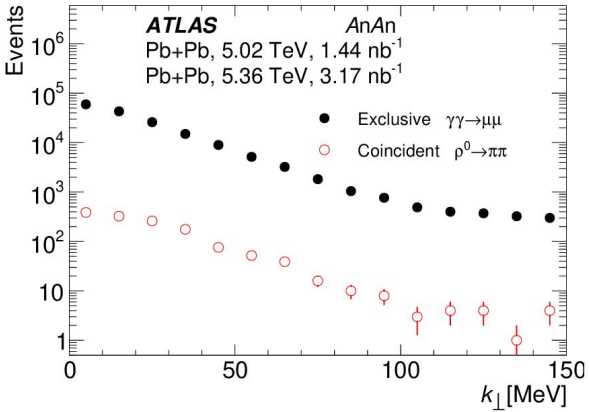
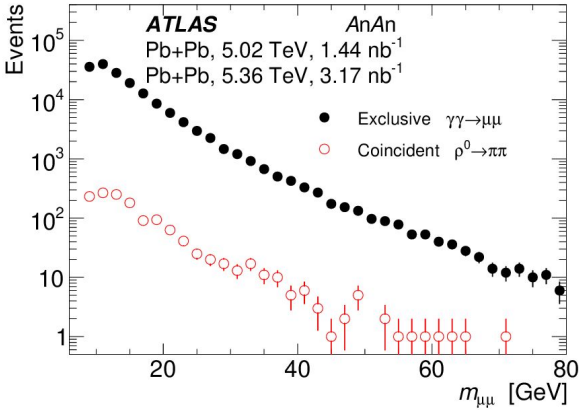
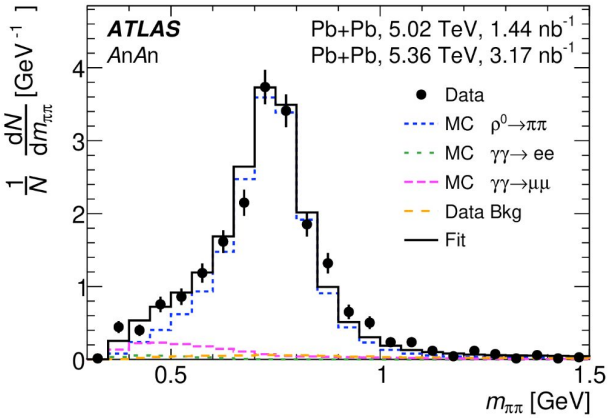
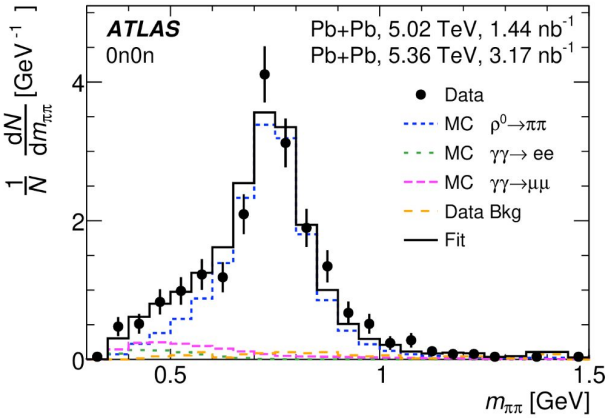
Analysis procedure cont.

- Allowing exactly two additional opposite charge tracks originating from the same vertex as μμ
  - fit to mass distribution assuming pion mass of the tracks, consistent with ϱ^0 signal
  - dimuon kinematics qualitateively same for those events









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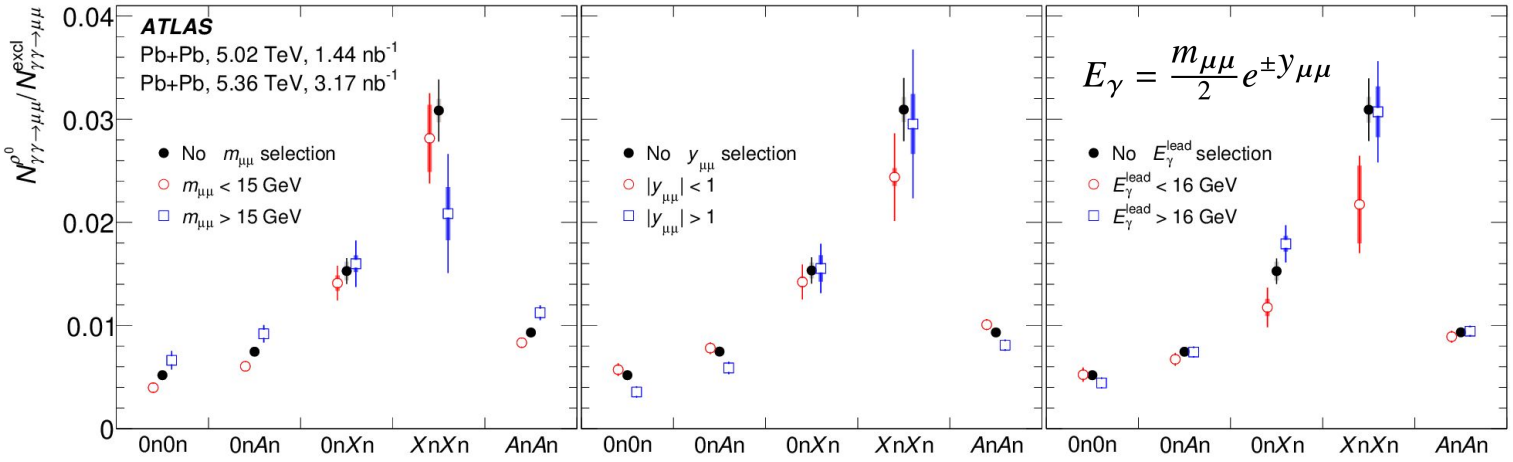
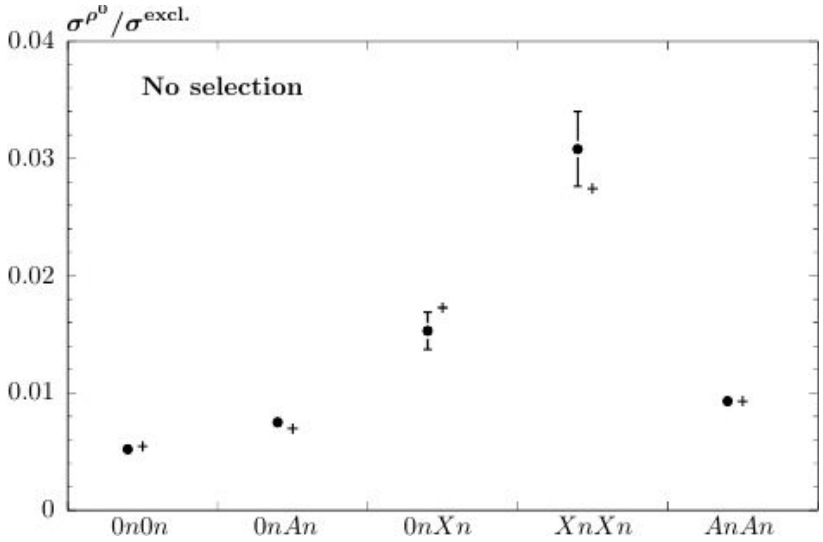
Results

- On average almost 1% of dimuon events coincide with ϱ^0 production in studied kinematic range
  - likely higher for softer tracks from ϱ^0 production
- Increased coincident rate for smaller impact parameters
  - experimentally indicated by higher dimuon mass, smaller dimuon rapidities, presence of more forward neutrons
- No clear systematic dependence observed on the leading photon energy



Impact of results

- No predictions for multi-UPC processes were available at the time of the measurement
- In response these results the SuperChic MC generator was updated to include coincident photon-induced interactions (Phys.Rev.D 112 (2025) 5, 054049)
- ATLAS data (black dots) in good agreement with SuperChic prediction

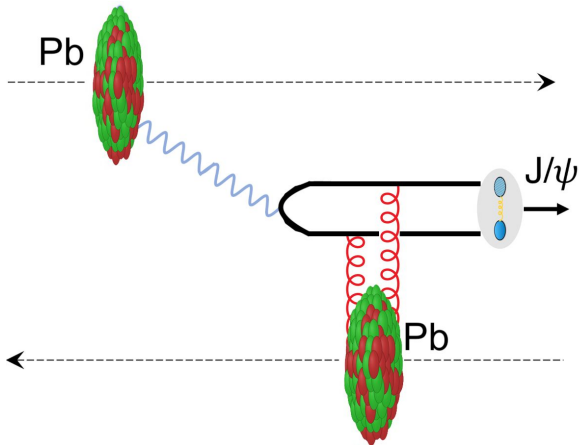


Phys.Rev.D 112 (2025) 5, 054049

JHEP 04 (2026) 020

Coherent J/ψ production

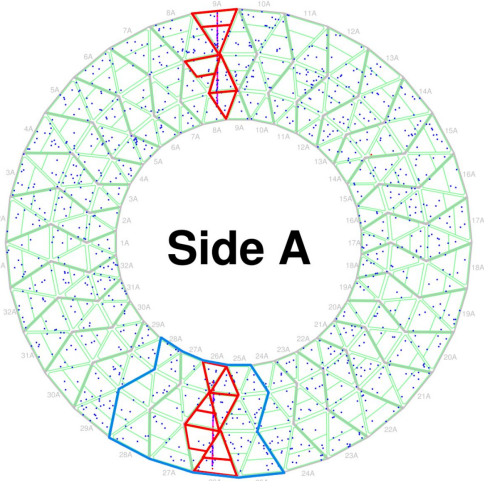
- Probing **nuclear gluon distributions** (shadowing effects)
- First ATLAS measurement of coherent J/ψ production
  - Using 79 nb^{-1} of Pb+Pb data at 5.36 TeV
- Focusing on dimuon final state
- Final state muons with p_T ~ 1.5 GeV too soft for standard muon detection in ATLAS
  - very challenging in terms of triggering strategy

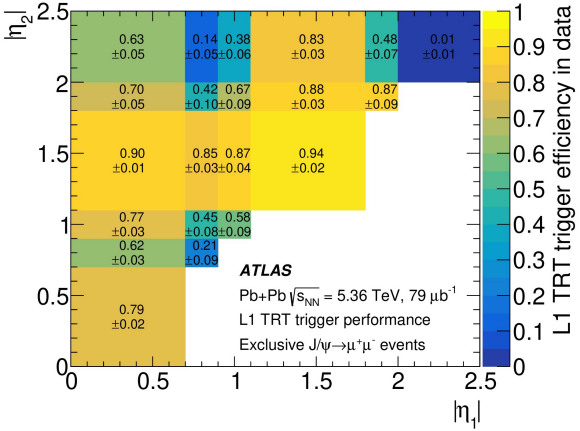


JHEP 04 (2026) 020

Trigger advancements

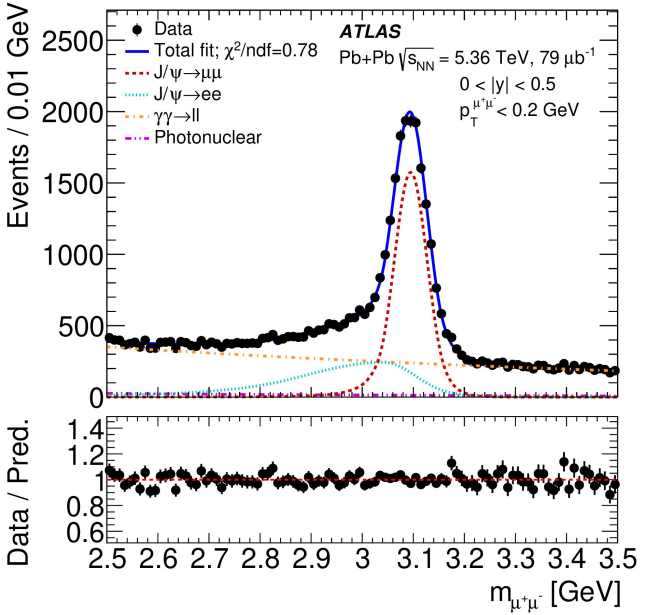
- TRT - Transition Radiation Tracker
  - outermost tracking detector in ATLAS
  - reaching up to $|\eta|<2.0$
- Dedicated settings allowing to trigger on very low-p_T particles
  - hit when energy deposited in straws slightly larger than MIP
- Coarse information, but ideal for very exclusive final states with low-p_T signals
- Measured efficiency reflects the detector geometry
- Additionally, total transverse energy in the event was required to be below 20 GeV





Signal extraction

- Selecting events with exactly two opposite charged tracks with $p_T > 1$ GeV
  - no other track with $p_T > 100$ MeV is allowed
- Signal region requirements:
  - J/ψ mass window: $2.9 < m_{\mu^+\mu^-} < 3.2$ GeV
  - low pair transverse momentum: $p_T^{\mu^+\mu^-} < 0.2$ GeV
- Normalization of the $J/\psi \to \ell^+\ell^-$ and shape of $\gamma\gamma \to \ell^+\ell^-$ constrained with the fit to dimuon mass
- Raw yields of exclusive $J/\psi \to \mu^+\mu^-$ include coherent, incoherent and $\psi(2S)$ production



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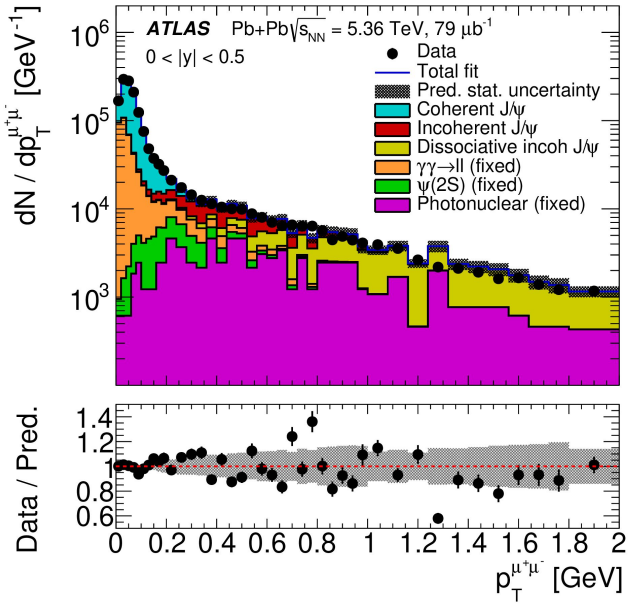
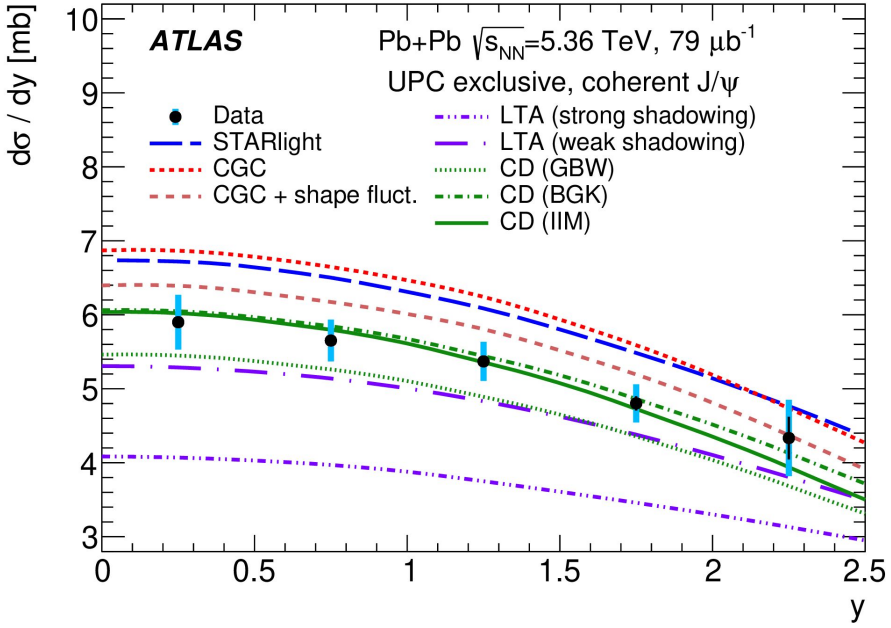
- Raw yields of exclusive $J/\psi \to \mu^+\mu^-$ include coherent, incoherent and $\psi(2S)$ production
- Distinguished by separate fit in $p_T^{\mu^+\mu^-}$
  - $\psi(2S)$ and photonuclear normalized in control regions



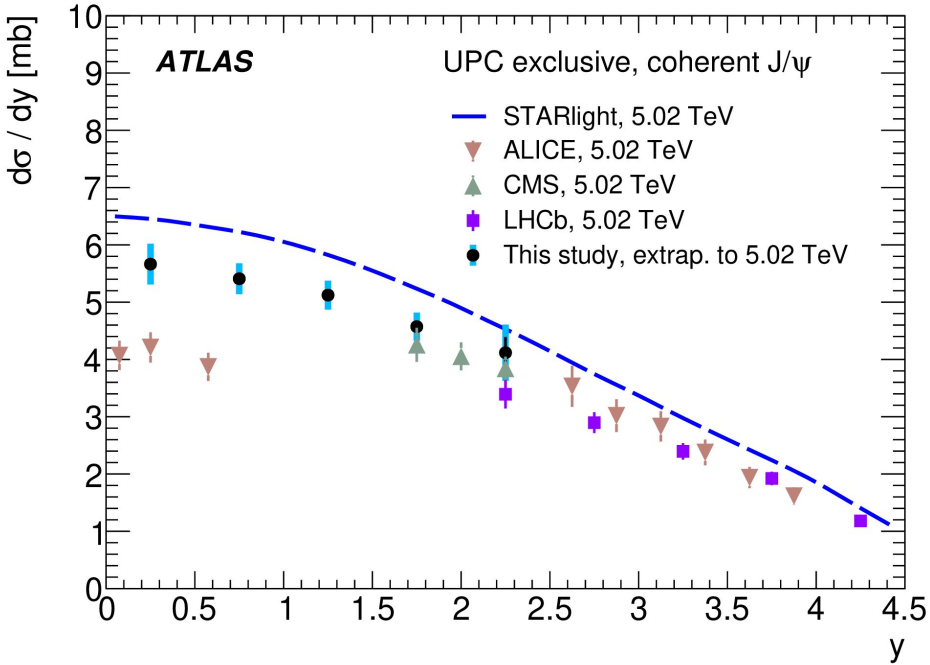
Results

- Differential cross-section measured as a function of J/ψ rapidity
- Compared with Color Glass Condensate (CGC), Leading-Twist Approximation (LTA) and Color Dipole (CD) models
- The best agreement is found with CD model



Results scaled to 5.02 TeV

- New ATLAS measurement scaled to lower collision energy
  - Allowing comparison with previous measurements of coherent J/ψ photoproduction by ALICE, LHCb and CMS
  - New ATLAS result has complementary rapidity coverage
- Tension with previous ALICE result
- Possible impact of coincident photon-induced interactions?



ALICE: Eur. Phys. J. C 81 (2021) 712
CMS: Phys. Rev. Lett. 131 (2023) 262301
LHCb: JHEP 07 (2022) 117

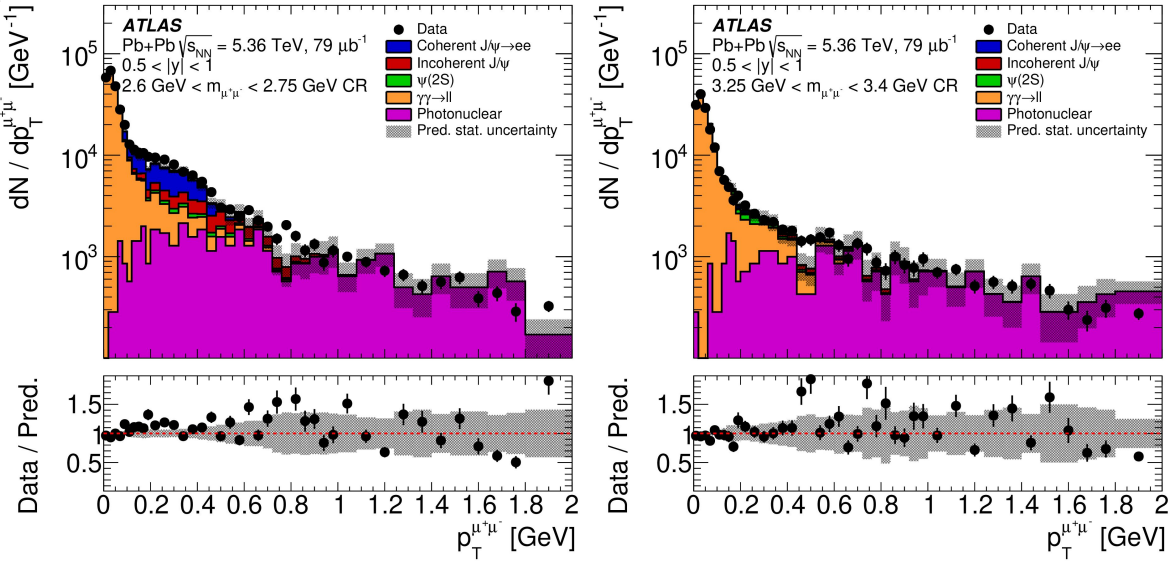
Summary

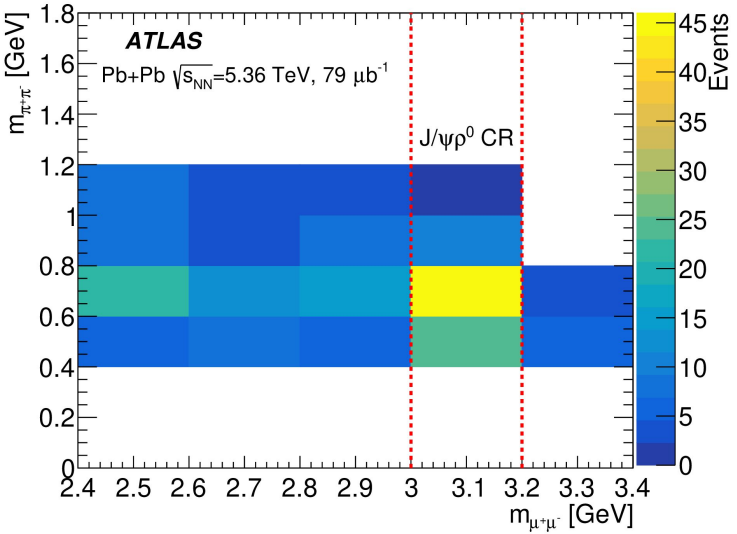
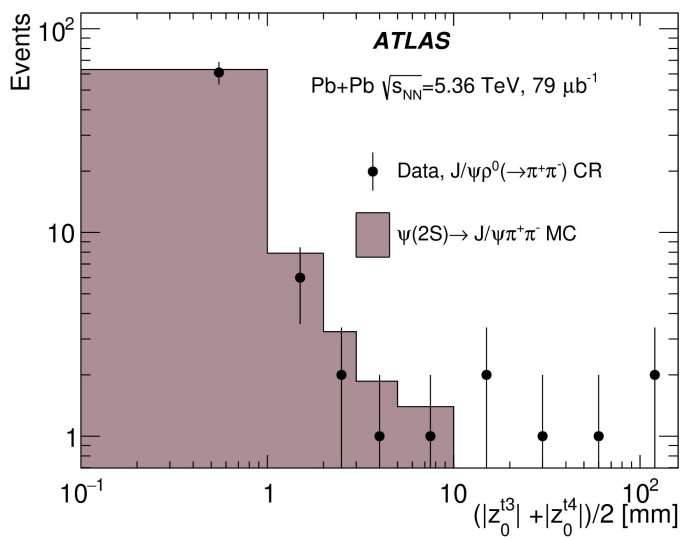
- Rate of coincident ϱ^0 production relative to exclusive $\gamma\gamma \to \mu^+\mu^-$ was measured by ATLAS
  - rate increases with increasing event activity measured by ZDC
  - confirmed the presence of multi photon-induced processes in UPC collisions stressing the critical role of exclusivity efficiency in precision measurements
  - can provide new insight into the impact-parameter dependence of photon-induced vector meson production
- ATLAS measured cross-section for the coherent J/ψ production at collision energy of 5.36 TeV
  - measurement feasible thanks to trigger strategy advancements
  - in agreement with previous measurements in forward region, tension wrt ALICE midrapidity result

Backup

Backgrounds

- Sources of background: coherent $J/\psi \to e^+e^-$, incoherent $J/\psi \to \ell^+\ell^-$, coherent and incoherent $\psi(2S)$, and $\gamma\gamma \to \ell^+\ell^-$ processes ($\ell = e, \mu$)
- Estimated from MC, or MC normalized using dedicated control region (CR)
- Additional photonuclear background estimated with template fit for events with $p_T^{\mu^+\mu^-}$ above 1 GeV in low-mass CR



Cross-check: J/ψ + ϱ^0 production

- allowing two extra tracks and assuming pion mass
- not explained fully by the ψ(2S) contribution