Measurements of coherent J/ψ and coincident photon-induced processes in Pb+Pb UPC with ATLAS

Mateusz Dyndal
AGH University of Krakow
on behalf of the ATLAS Collaboration

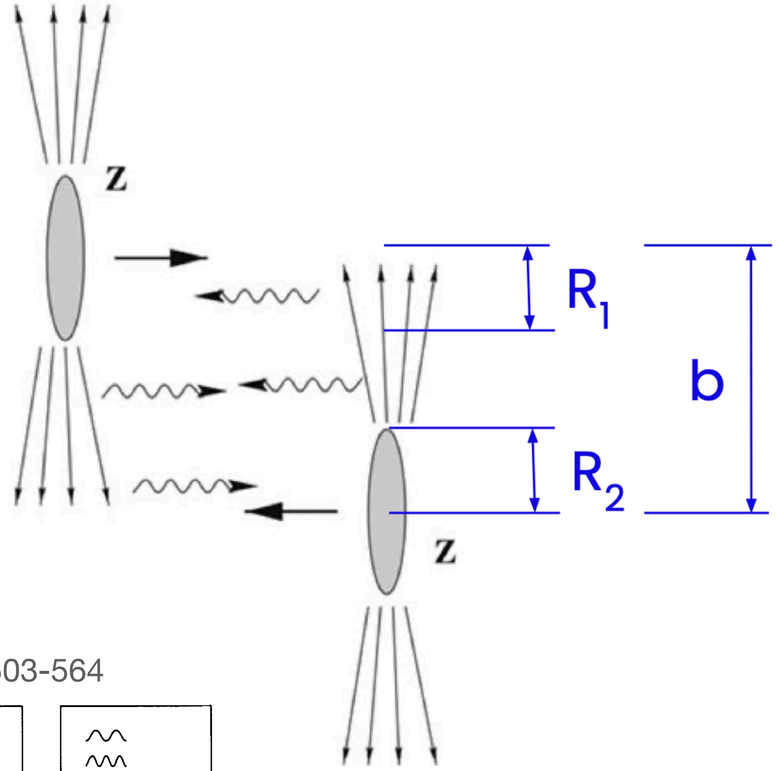
QM 2025

LHC as a photon collider

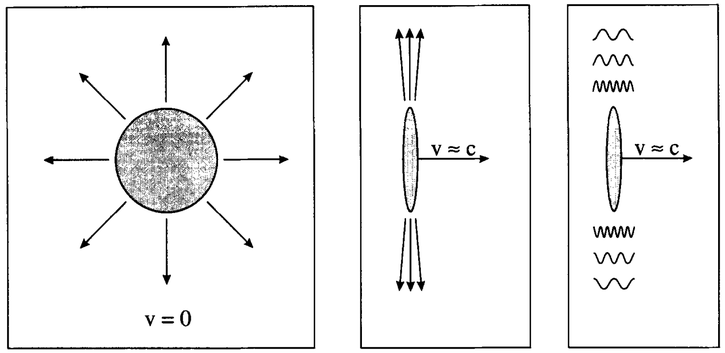
- Accelerated nuclei are intense source of EM fields

- Ultraperipheral collisions (**UPC**)
  - **Impact parameter: b > 2R**
  - Hadronic interactions strongly suppressed

- EM fields
  - Treated as **quasi-real photon** fluxes
  - Small virtuality Q < 1/R ~ 30 MeV
  - Proportional to $\mathbf{Z^2}$



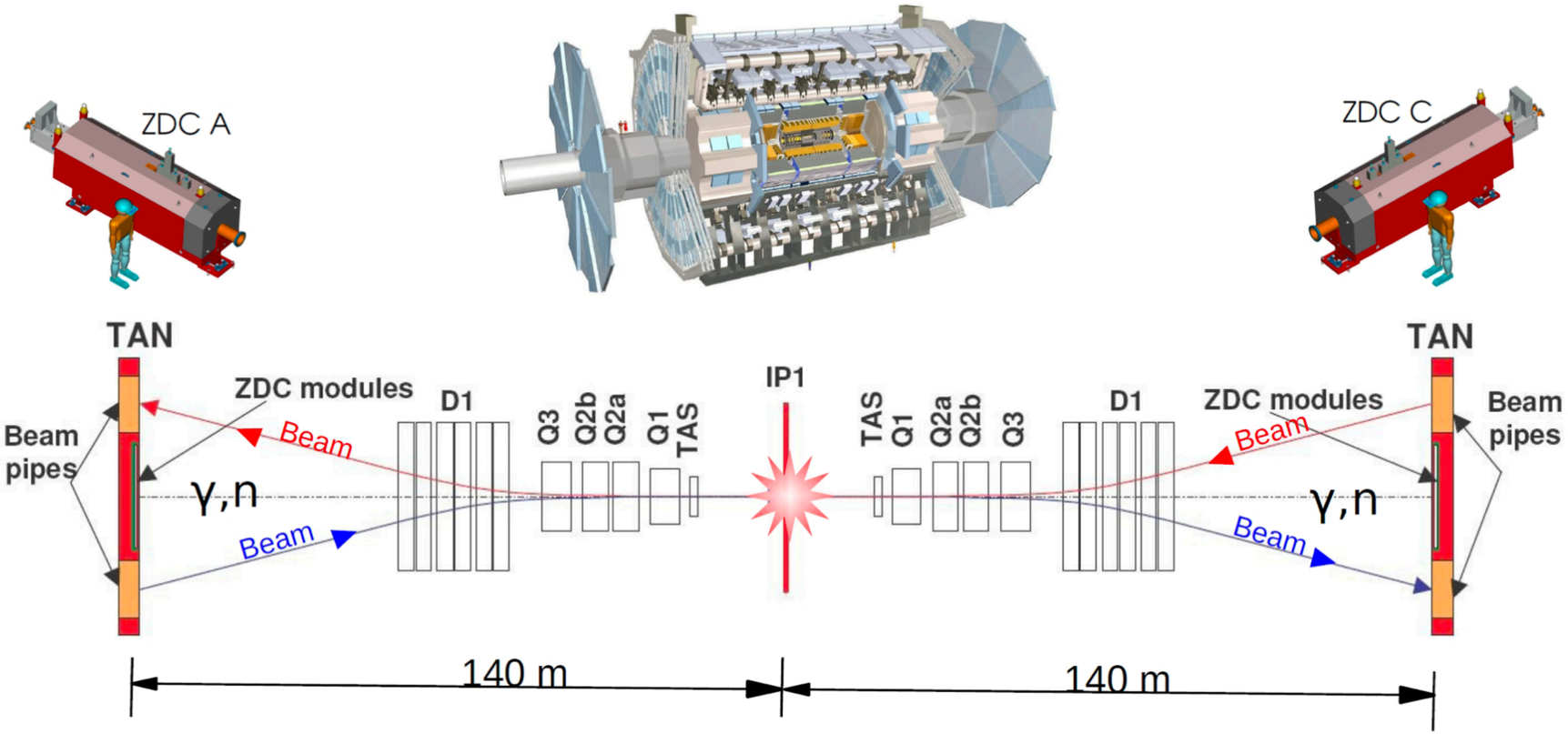
Prog.Part.Nucl.Phys. 39 (1997) 503-564



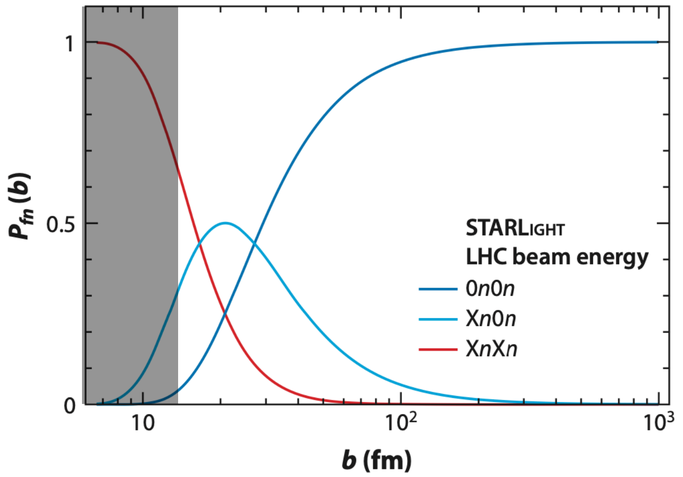
UPC reviews:
Baltz et al., Phys. Rept. 458 (2008) 1-171; Klein & Steinberg, Ann. Rev. Nuclear Part. Sci. 70 (2020) 323

Experimental considerations

- **Rapidity gaps** & **Exclusive final states** → Veto requirements are essential
  - Many sub-detectors available in ATLAS for particle vetos (**|eta|<4.9**)
  - Caveat: veto requirements may be sensitive to soft particles from coincident photon-induced interactions
- EM ion dissociation can be tagged with **Zero Degree Calorimeters (ZDC)**
  - Distinct ZDC event classes: **0n0n**, **0nXn**, **XnXn** → probe different average impact parameter (b)



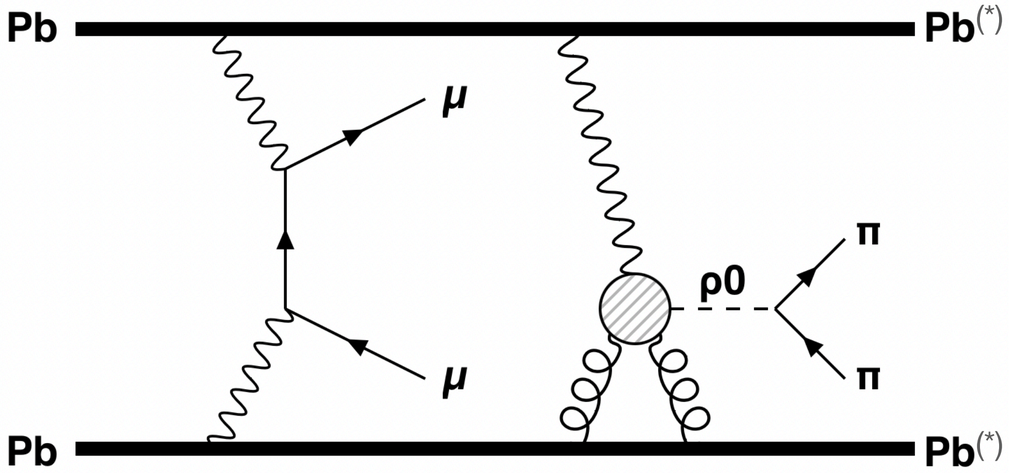
Ann. Rev. Nuclear Part. Sci. 70 (2020) 323



CERN-EP-2025-071 NEW

Measurement of $\gamma\gamma \to \mu\mu$ + $\rho^0 \to \pi\pi$ production in UPC

- Extreme EM fields in Pb+Pb UPC @ LHC allow to produce **double photon-induced reactions**
- Aim is to measure the **coincident rate** for $\gamma\gamma \to \mu\mu$ (higher energy tagged process) + $\rho^0 \to \pi\pi$ (coincident additional process)



- Analysis strategy:
  - Trigger on muon from the pair
  - Dedicated tracking selection (pixel tracks) to maximise the efficiency for $\rho^0 \to \pi\pi$
  - Study **relative rate** (not absolute cross-section) over UPC $\gamma\gamma \to \mu\mu$ process
- Data set
  - Run 2 (2018) + Run 3 (2023 and **2024**) Pb+Pb data is used (**~4.5/nb**)

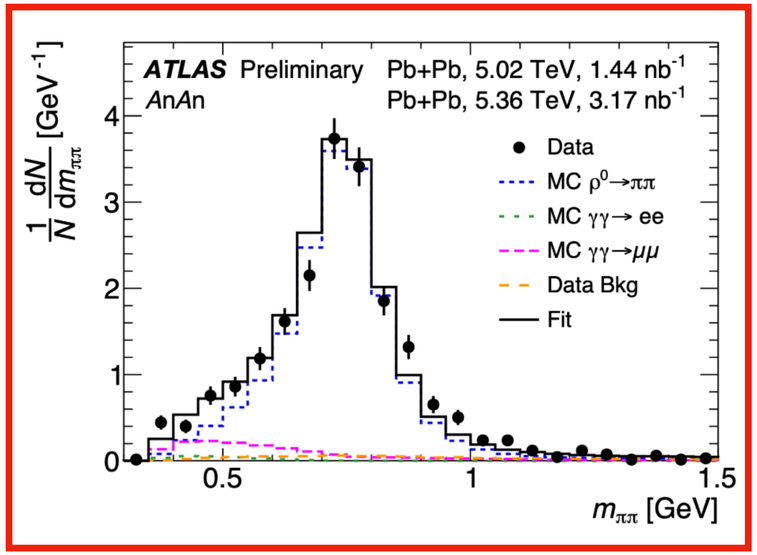
First ATLAS HI result using 2024 dataset

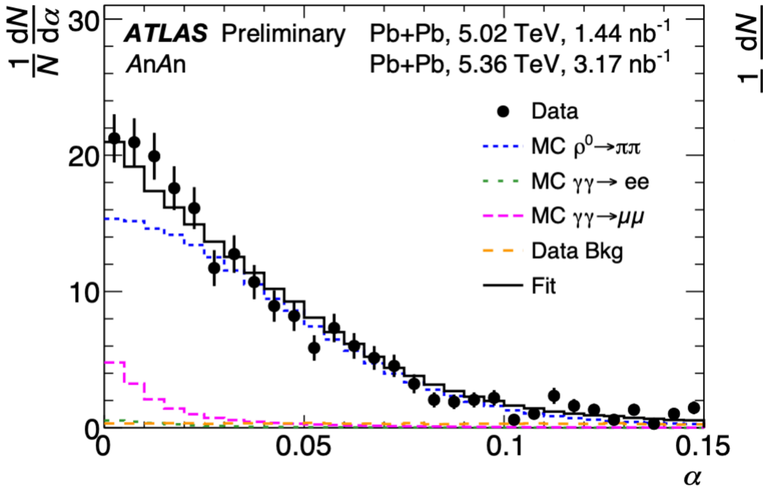
CERN-EP-2025-071

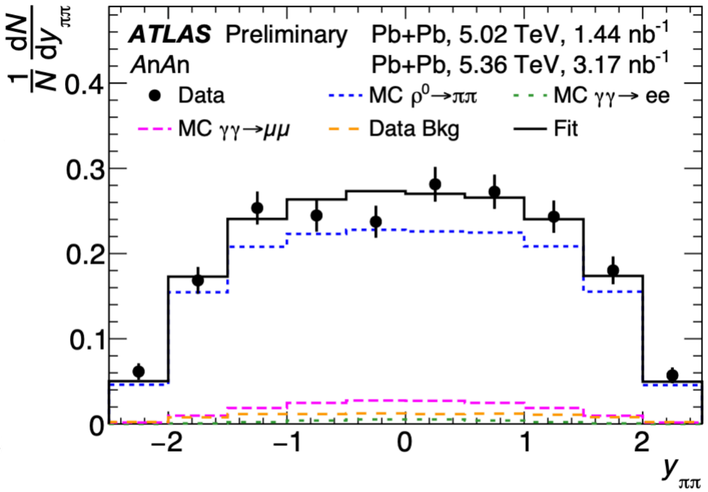
NEW

Measurement of $\gamma\gamma \to \mu\mu + \rho^0 \to \pi\pi$ production in UPC

- Event selection
  - Two OS muons with p_T>4 GeV
  - Small dimuon pair p_T
  - Exactly two extra tracks (unassociated w/ muons, but from same vertex)
- Backgrounds
  - Soft $\gamma\gamma \to ee/\mu\mu$ pairs, combinatorics
- Signal extraction
  - Template fits performed to dipion **mass**
- Signal efficiency corrections
  - Studied using STARlight MC simulated events
- Systematic uncertainties subdominant over stat.







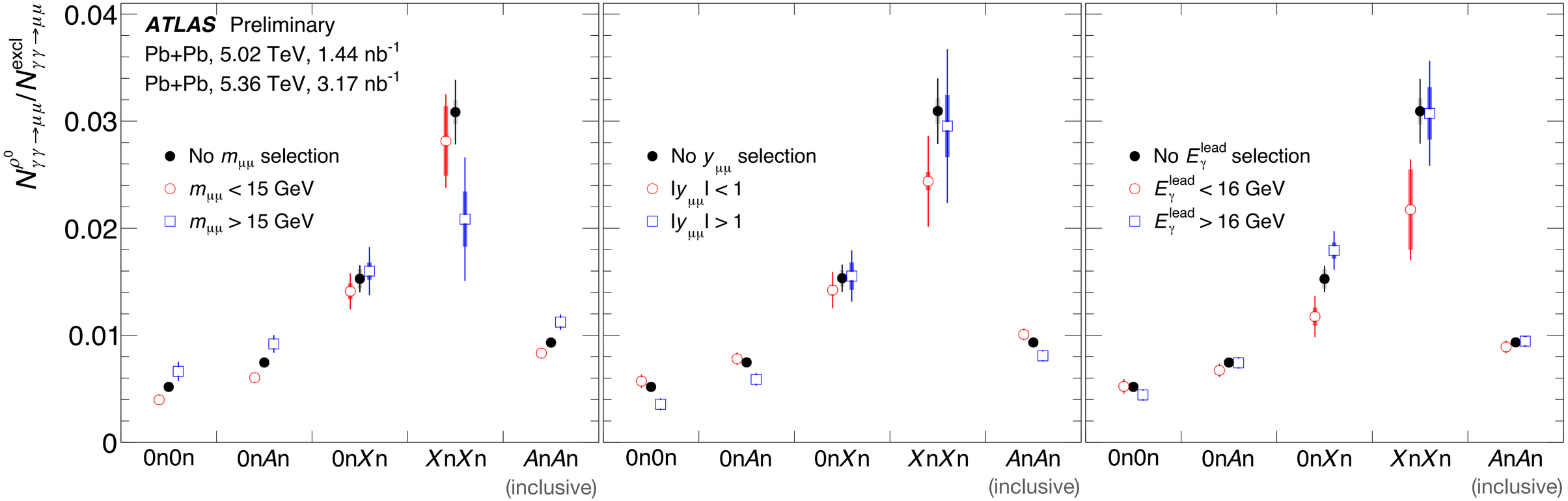
Control distributions

CERN-EP-2025-071

NEW

Measurement of $\gamma\gamma \to \mu\mu + \rho^0 \to \pi\pi$ production in UPC

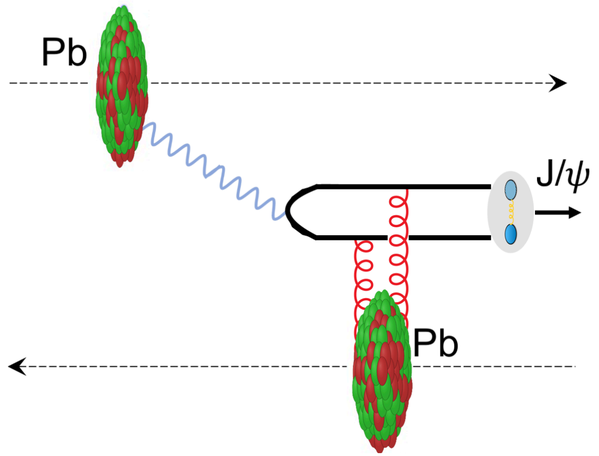
- Dependence of coincidence rate on **ZDC activity** and **dimuon kinematics**
- Coincidence rate **increases**
  - with increasing ZDC activity and/or with increasing dimuon mass (smaller b)
  - Other variables also studied to provide additional constraints on model calculations



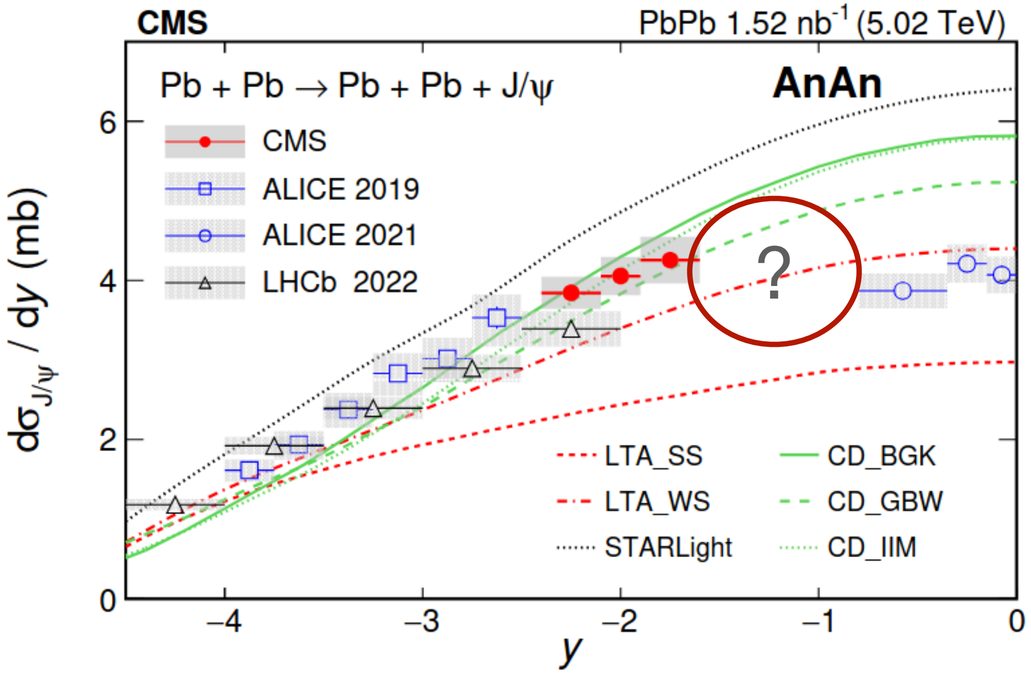
ATLAS-CONF-2025-003 NEW

Measurement of coherent J/ψ in UPC at 5.36 TeV

- Process sensitive to nuclear gluon dynamics at low-x
- Filling the gap in measurements for 0.8<|y|<1.6 (uncovered by previous studies)
- Focusing on **dimuon** decay channel
- Key experimental challenge in ATLAS:
  - Trigger on soft ($\mathbf{p_T}$ **~1.5 GeV**) leptons



CMS collaboration, Phys. Rev. Lett. 131 (2023) 262301

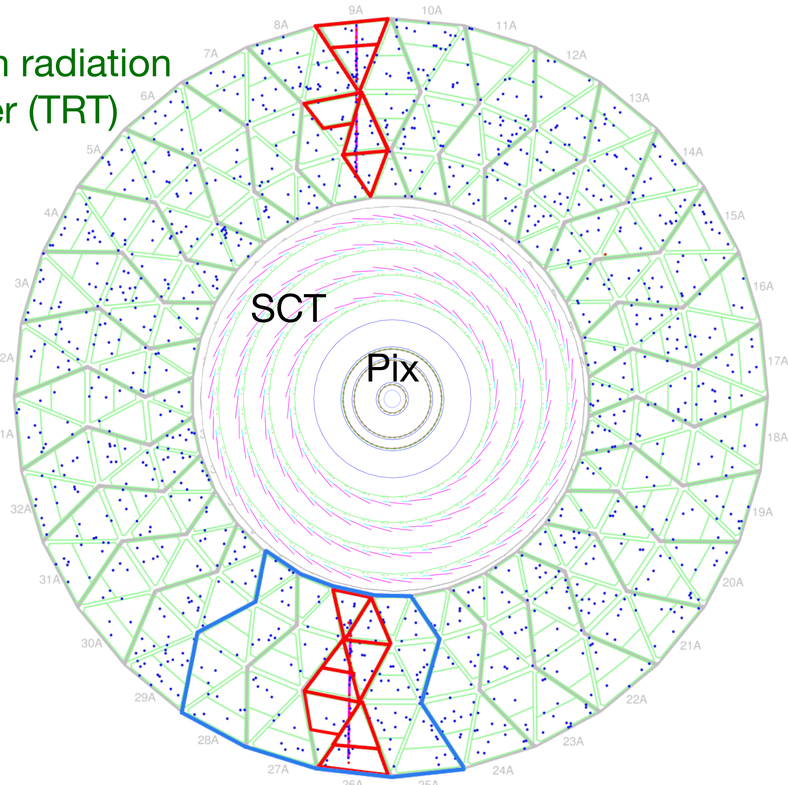


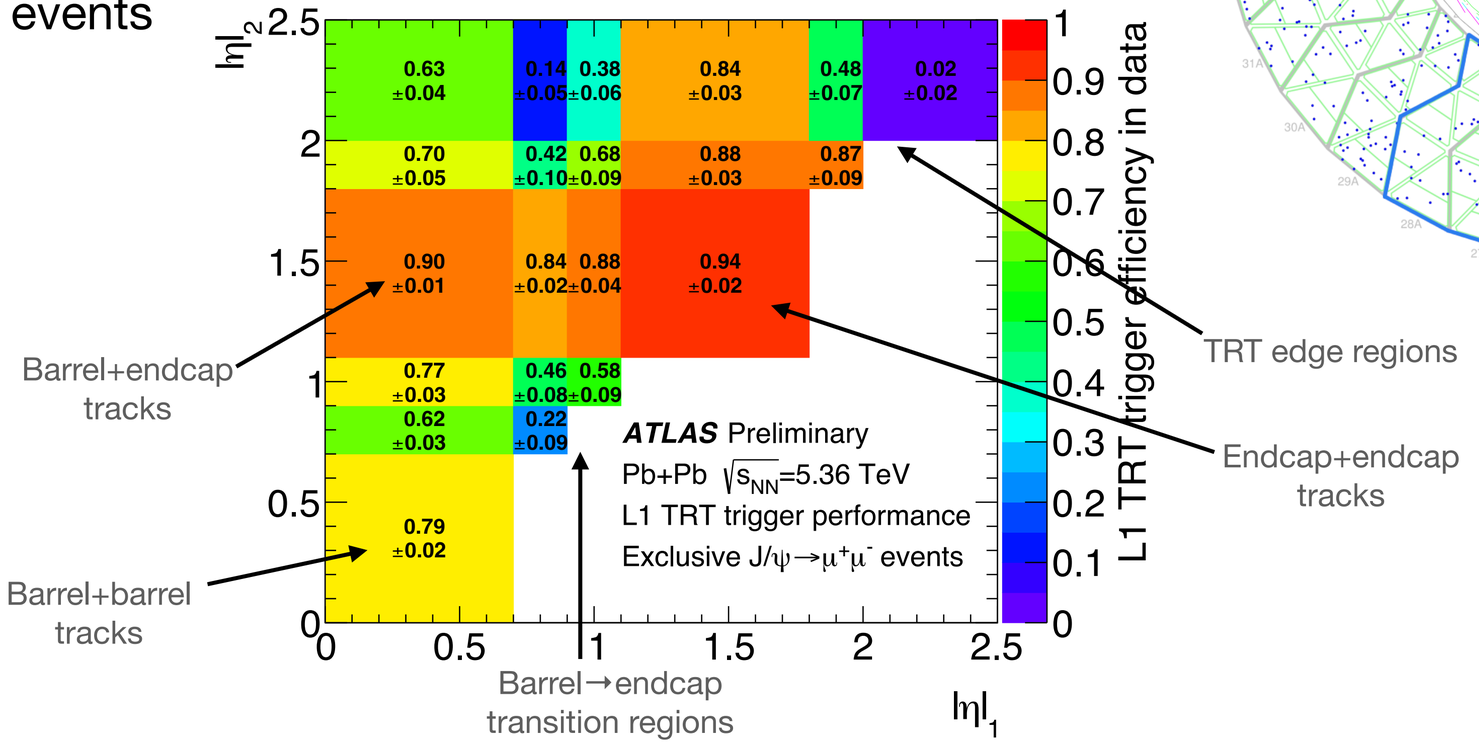
ATLAS-CONF-2025-003

NEW

Measurement of coherent J/ψ in UPC at 5.36 TeV

- 2023 Pb+Pb data used, 76.5/ub
- Use events triggered by **L1TRT "FastOR"** trigger
  - Crude segmentation, but ideal for triggering on few-particle exclusive states in UPC!
  - First-ever **track-sensitive trigger** running at O(MHz) (?)
  - Trigger efficiency estimated in data → used to correct MC simulated events



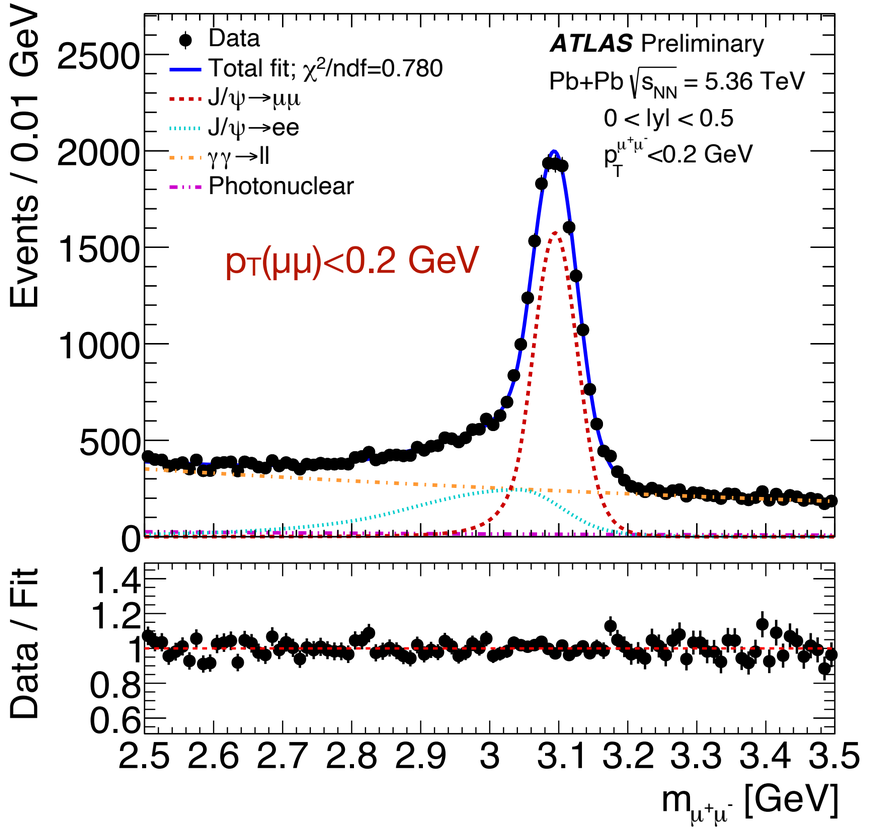


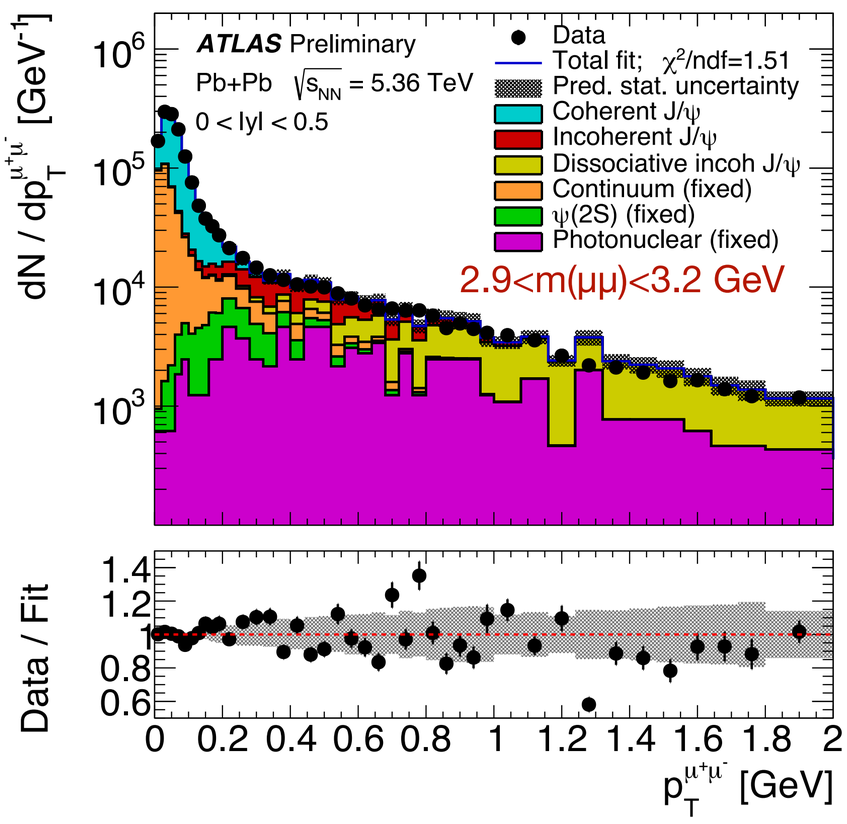
ATLAS-CONF-2025-003 NEW

Measurement of coherent J/ψ in UPC at 5.36 TeV

- Event selection
  - Exactly 2 tracks (OS, p_T>1 GeV)
  - SR: **p_T(μμ)<0.2 GeV**, **2.9<m(μμ)<3.2 GeV**
  - No muon ID is used → fits to mass lineshape
- Backgrounds
  - J/ψ→ee, ψ(2S), incoherent J/ψ, combinatorial (pions)
- Signal extraction
  - Template fits to **two-track inv. mass** and **system p_T**

Signal and main backgrounds modelled with STARlight MC (+Pythia8 for QED FSR)





ATLAS-CONF-2025-003 NEW

Measurement of coherent J/ψ in UPC at 5.36 TeV

- Differential cross section measurement:

$$\frac{d\sigma}{dy} = \frac{N^{coh}_{J/\psi\to\mu^+\mu^-}}{A \times \epsilon_C \times BR \times \mathcal{L}_{int} \times \Delta y}$$

Raw coherent yield from p_T fits

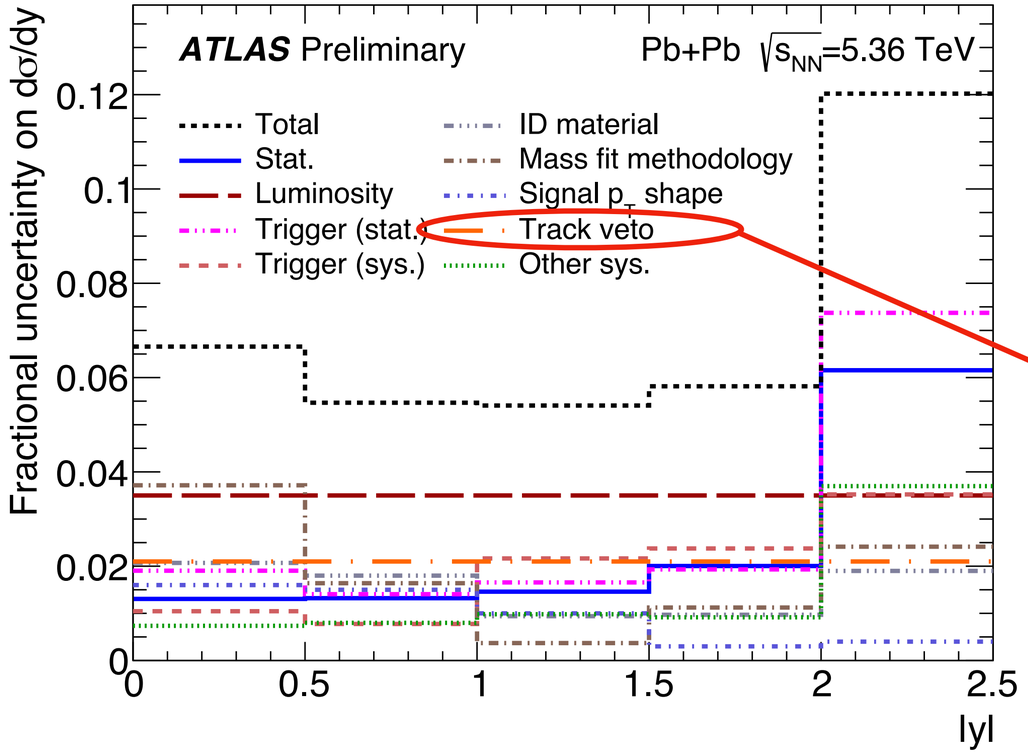
Acceptance correction (from MC)

Efficiency correction (from MC with data-driven corr. factors)

J/ψ →μμ BR

Integrated lumi

- Uncertainties
  - Dominated by **systematics** (lumi, fit methodology, …)



≈**1.9%** impact from coincident pair production (mainly $\rho^0\to\pi\pi$) on exclusivity requirement

+ ≈**0.2%** effect from pile-up pairs

total effect: 2.1%, fully taken as a systematic uncertainty

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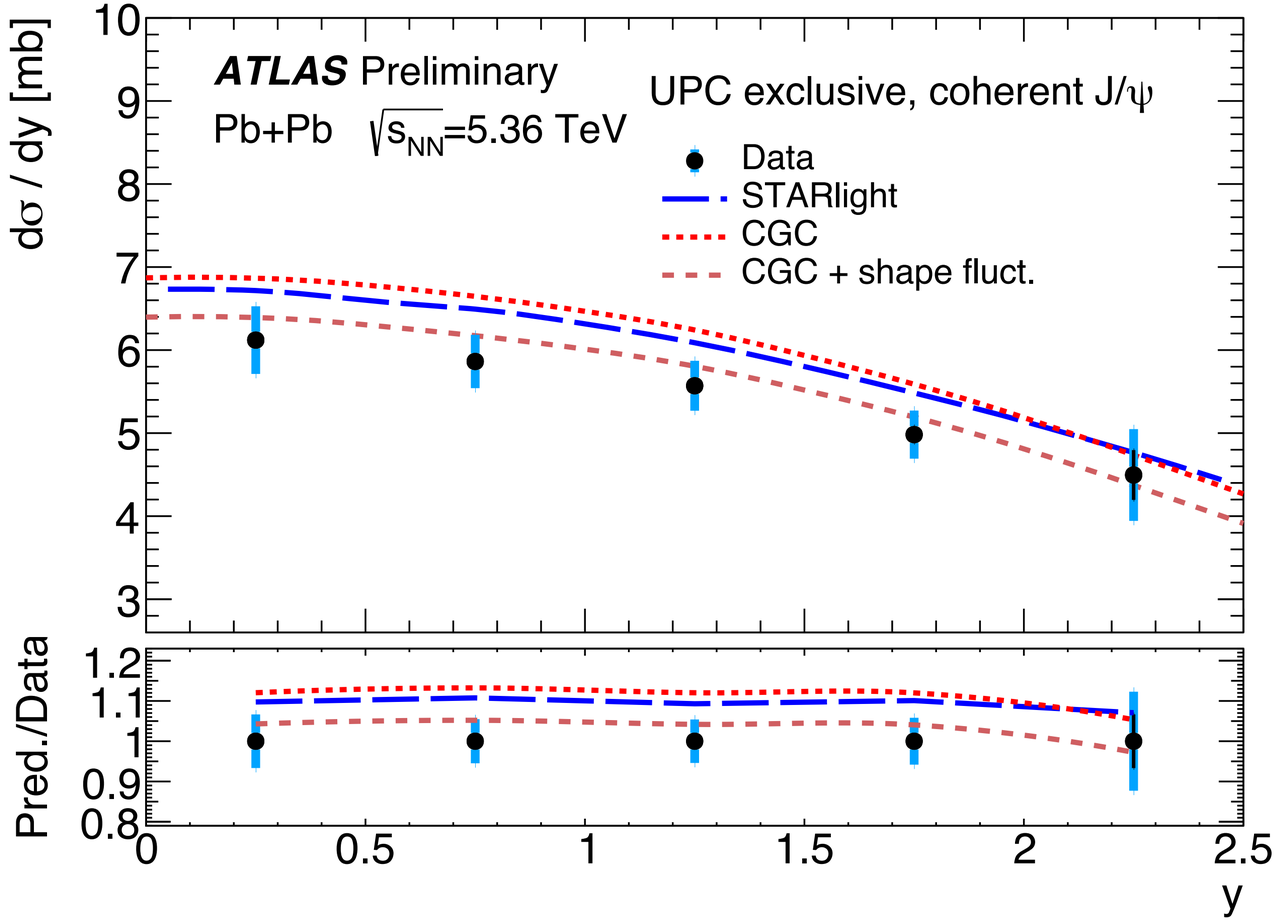


Results shown in a single hemisphere (averaged on the full -2.5<y<2.5 range)

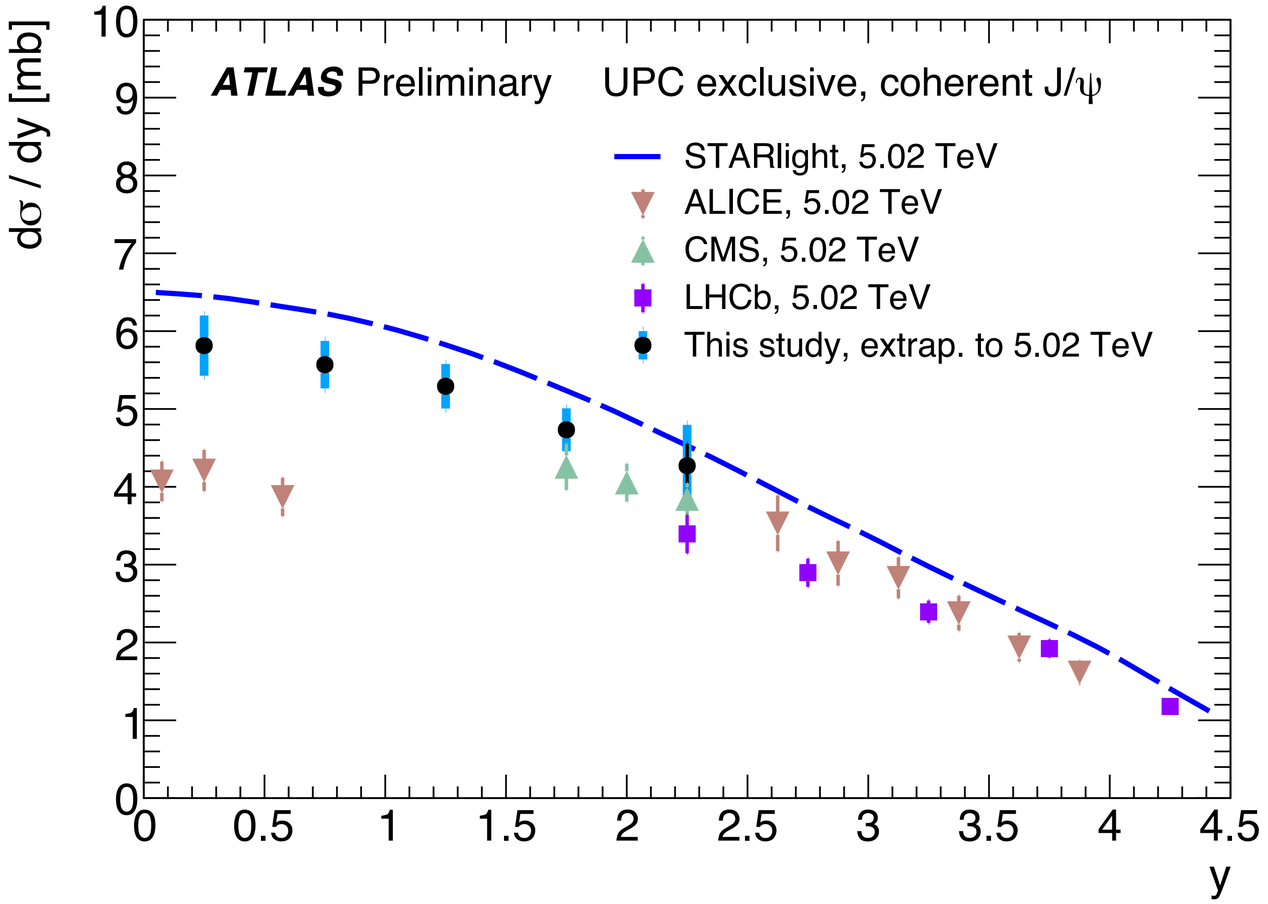
Blue vertical bars = total uncertainty

- Results
  - Comparison with several theory predictions → **CGC model w/ shape fluctuations** [Mäntysaari et al, Phys. Rev.D106 (2022)074019] reasonably describe the data

ATLAS-CONF-2025-003 NEW

Measurement of coherent J/ψ in UPC at 5.36 TeV

- **Extrapolation** to 5.02 TeV
  - Tension w/ previous ALICE mid-rapidity measurement [EPJC 81 (2021)712]
  - ALICE reports 8% correction due to $\gamma\gamma \rightarrow ee$ pile-up effect on forward veto
    → coincident additional processes ($\gamma\gamma \rightarrow ee$, etc.) from same collision taken into account?

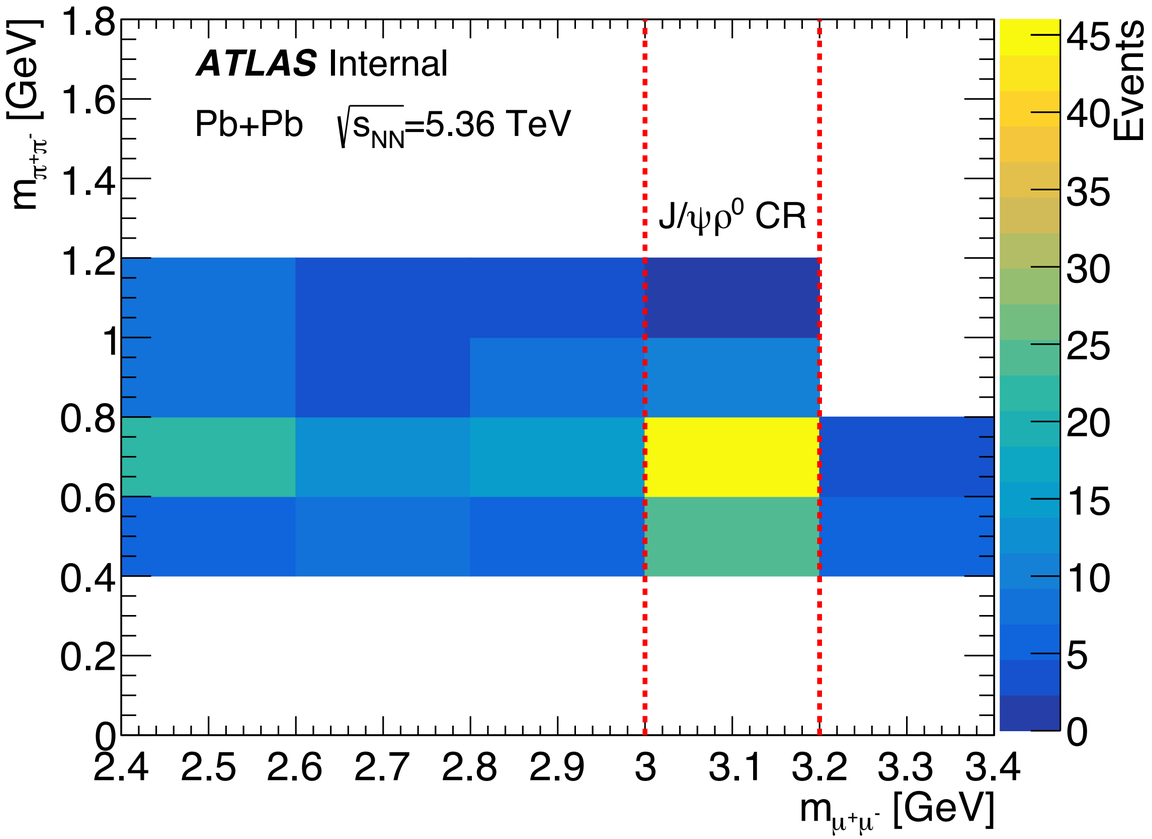
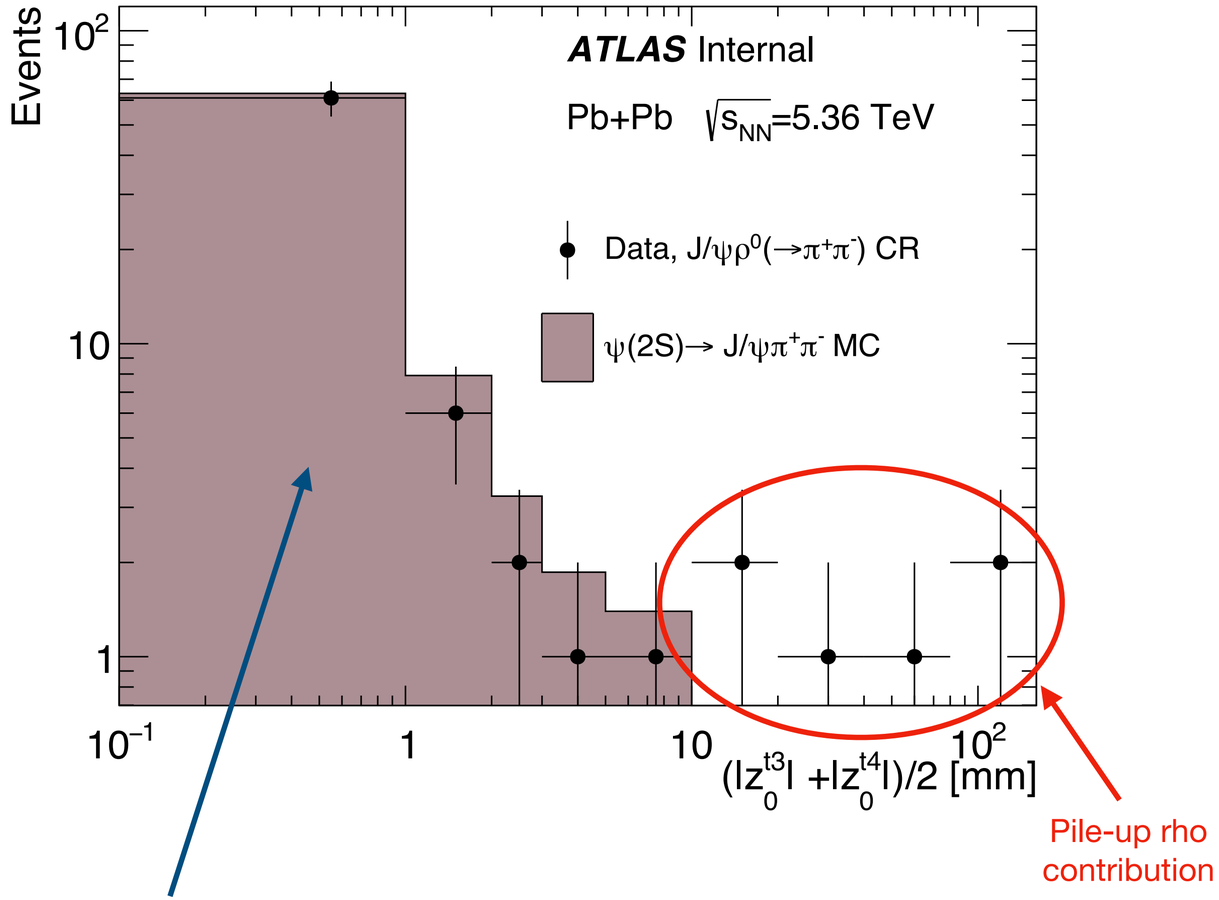


Summary

- First measurement of $\gamma\gamma \to \mu\mu + \rho^0 \to \pi\pi$ production rate in UPC
  - Can provide constraints on photon flux in ion-ion collisions and input on impact-parameter dependence of VM production
  - Observing (expected) dependence of coincidence rate on ZDC activity and dimuon kinematics
  - Quantitative evidence that the veto requirements in UPC measurement at the LHC may be sensitive to soft particles from coincident photon-induced interactions

- Coherent J/ψ production in UPC measured for the first time in ATLAS
  - Large event sample collected in Run 3 thanks to track-sensitive trigger at L1 (TRT FastOR)
  - Differential cross sections measured in the range $|y| < 2.5$
  - ALICE vs ATLAS tension at mid-rapidity observed

- From the theory side: would be very practical to have the predictions for double photon-induced processes in some MC generator

Backup

J/Psi+rho studies