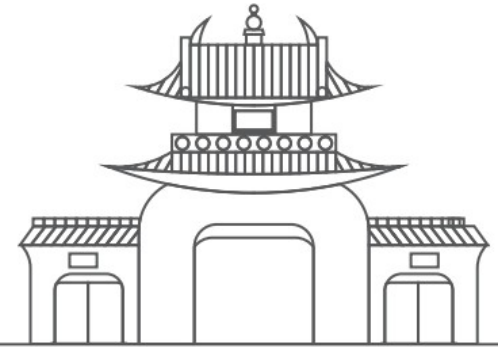
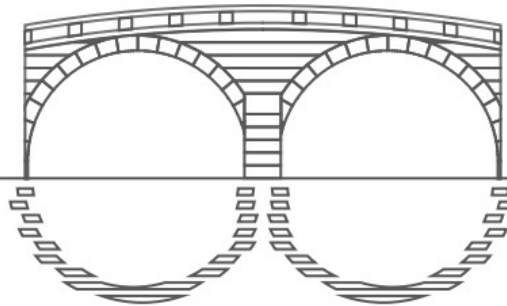


# $J/\psi$ photoproduction and polarization in peripheral Pb–Pb collisions with ALICE

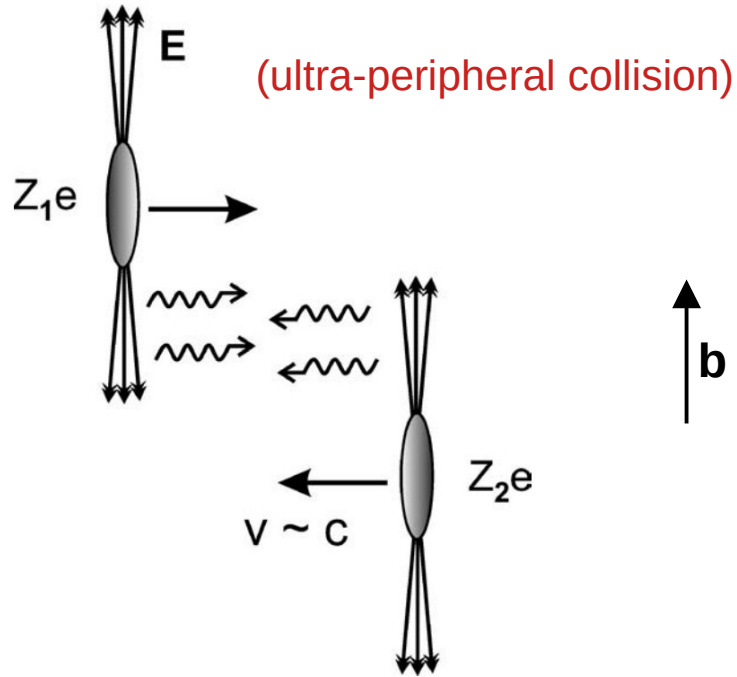
Ionut-Cristian Arsene  
on behalf of the ALICE Collaboration  
University of Oslo



**ALICE**



**HP2024**  
NAGASAKI

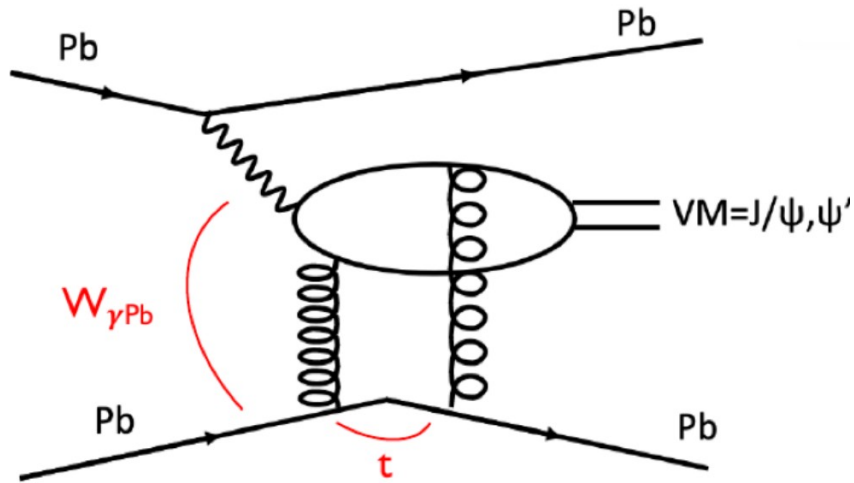


- **EM field of nuclei:** beam of quasi-real photons
  - › Photons achieve a large boost at the LHC: photon-hadron and photon-photon collisions
- **Ultraperipheral collisions (UPC):**  $b > R_1 + R_2$ 
  - › Hadronic interactions suppressed
  - › Electromagnetic interactions are dominant
  - › Very small number of tracks produced, with large gaps in rapidity

**Minjung Kim, Wednesday 9:40**

**Sigurd Nese, Wednesday 10:00**

# Vector meson photoproduction in UPCs



$$\sigma(AA \rightarrow AAJ/\psi) = \int d\omega_\gamma \frac{dN_\gamma(\omega_\gamma)}{d\omega_\gamma} \sigma(\gamma A \rightarrow J/\psi A)$$

- Many studies focused on the exclusive photoproduction of vector mesons, both at the LHC and RHIC
- Vector mesons production cross section constrain nuclear gluon PDFs in the range  $10^{-5} < x < 10^{-2}$  at the LHC

## Coherent photoproduction

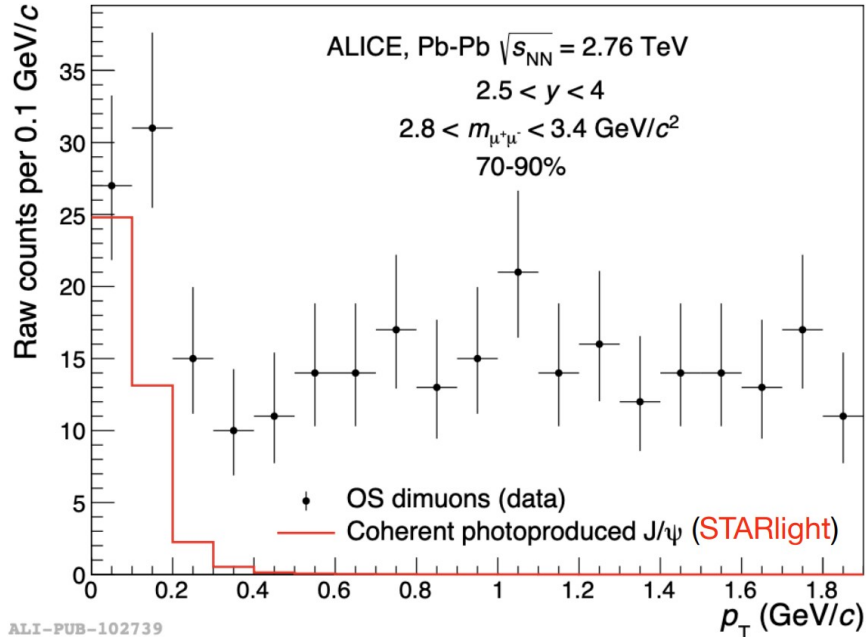
- Photon couples to the entire nucleus
- $\langle p_T \rangle(\psi) \sim 60 \text{ MeV}/c$

## Incoherent photoproduction

- Photon couples to one nucleon
- $\langle p_T \rangle(\psi) \sim 500 \text{ MeV}/c$

# J/ψ photoproduction in AA collisions at $b < R_1 + R_2$

PRL 116, 222301 (2016)

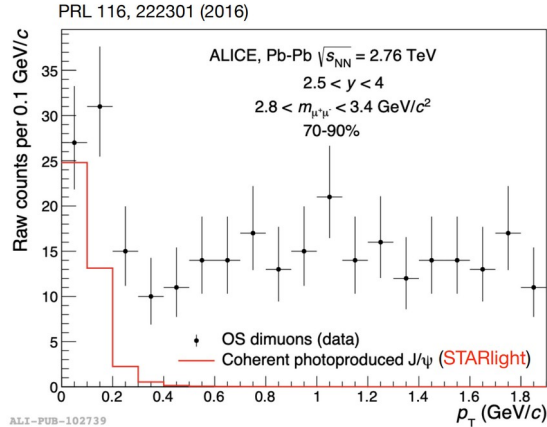


ALI-PUB-102739

- In Run 1, ALICE reported an excess of J/ψ wrt expectations from hadro-production in peripheral collisions at very low  $p_T$ 
  - Good agreement with STARLight simulations
  - Similar observation by STAR

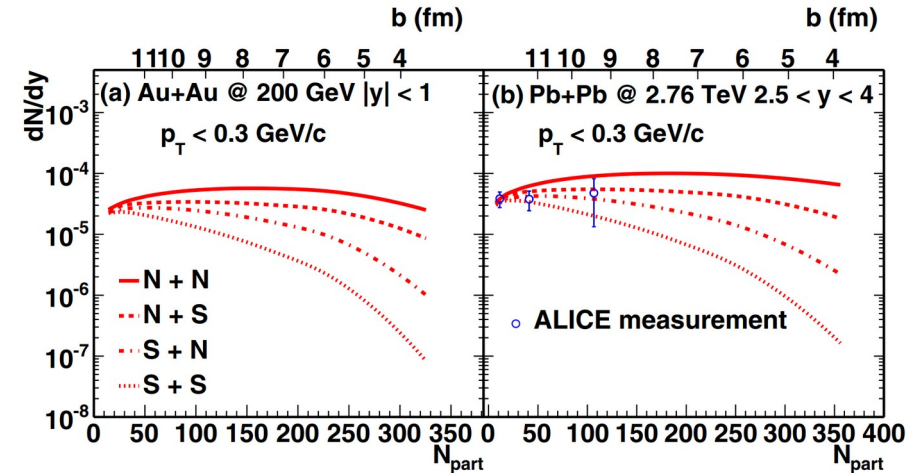
STAR, PRL 123 (2019) 132302

# J/ψ photoproduction in AA collisions at $b < R_1 + R_2$



- In Run 1, ALICE reported an excess of J/ψ wrt expectations from hadro-production in peripheral collisions at very low  $p_T$ 
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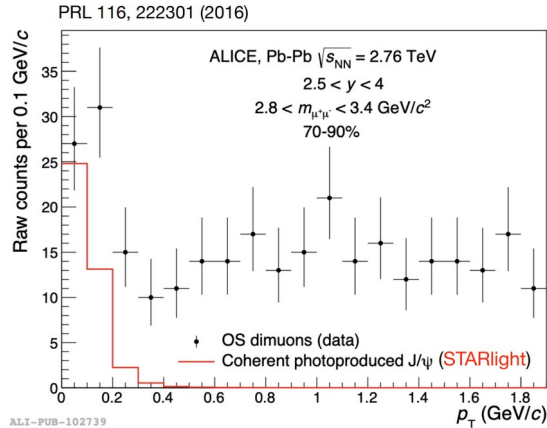
STAR, PRL 123 (2019) 132302



- Phenomenological understanding of the production cross section ongoing
  - Role of spectator (**S**) and participant (**N**) nucleons
  - Survival of the coherence condition
  - Time ordering of the hadro and photoproduction

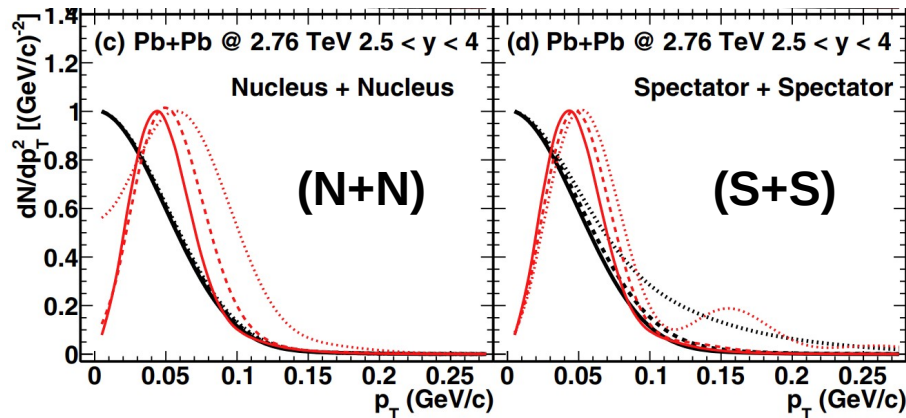
Zha et al., PRC97 (2018) 044910

# J/ψ photoproduction in AA collisions at $b < R_1 + R_2$



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  - Good agreement with STARlight simulations
  - Similar observation by STAR

STAR, PRL 123 (2019) 132302



- Destructive interference due to the possibility of switching the role of the two nuclei

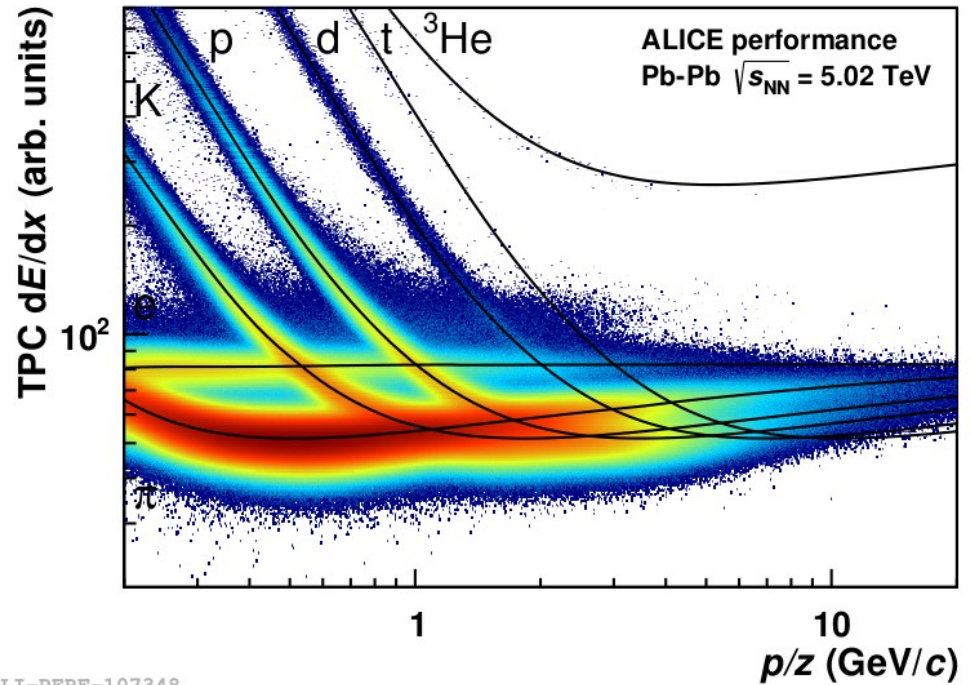
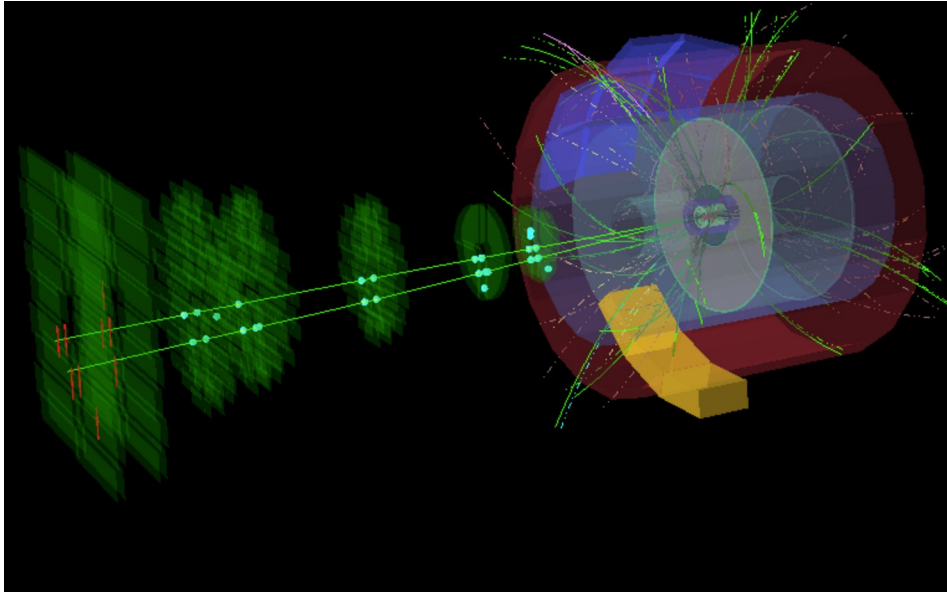
S.Klein and J.Nystrand, PRL84(2000)11

STAR, PRL102 (2009) 112301

w/o interference  
 w/ interference

Zha et al., PRC97 (2018) 044910

# The ALICE detector and kinematics

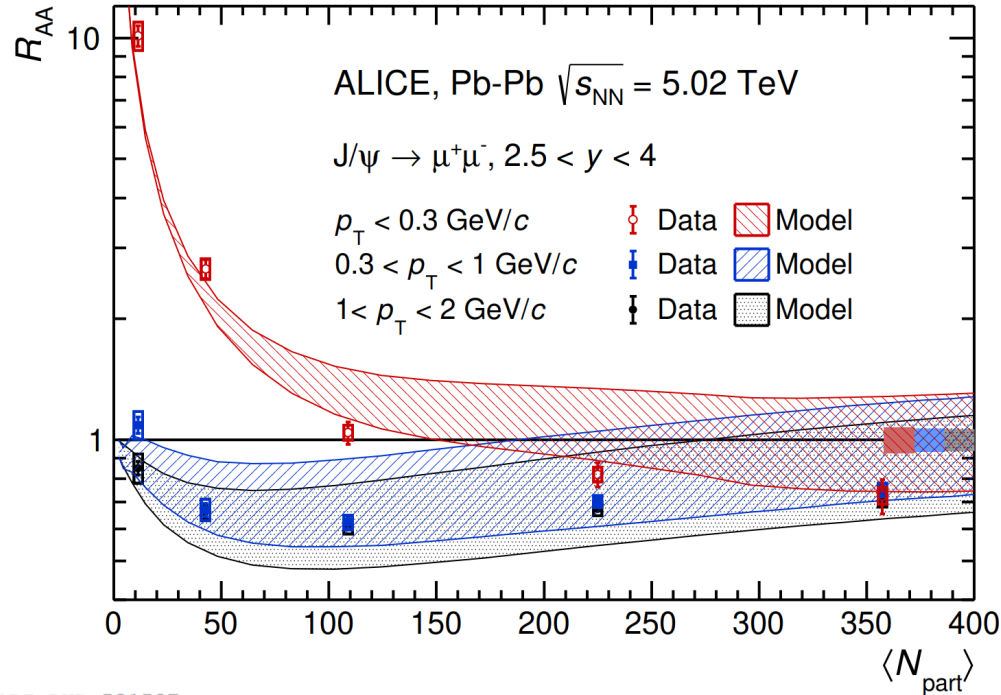


- $J/\psi$  reconstructed using
  - muon spectrometer: dimuons in  $2.5 < y < 4.0$
  - central barrel: dielectrons in  $|y| < 0.9$
- $J/\psi$  coverage down to zero  $p_T$

# J/ψ excess at forward rapidity in Run 2

ALICE, PLB846 (2023) 137467

Model: Shi et al., PLB777 (2018) 399



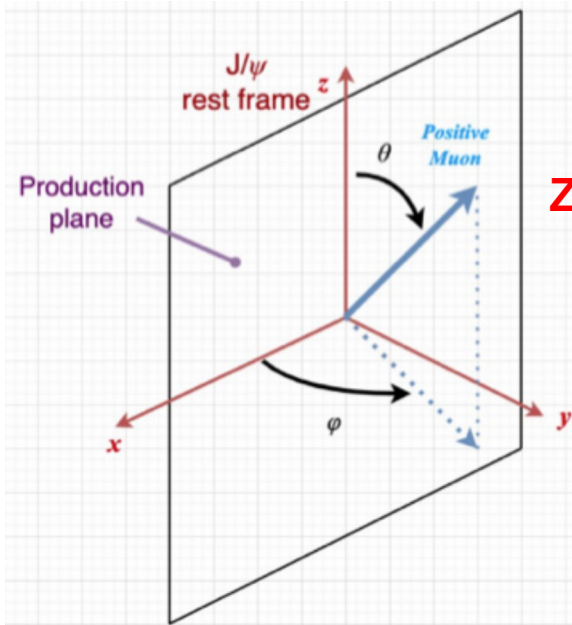
ALI-PUB-521507

Hadronic J/ψ production:  
Yiping Wang, Tuesday 9:00  
Yuan Zhang, Tuesday 10:00

- Low- $p_T$  J/ψ excess measured with Run 2 Pb–Pb dataset up to central collisions
  - J/ψ  $R_{AA}$  for  $p_T < 0.3$  GeV/c  $\sim 10$  !
  - Significant excess up to semicentral collisions



# Coherent J/ψ polarization in helicity frame

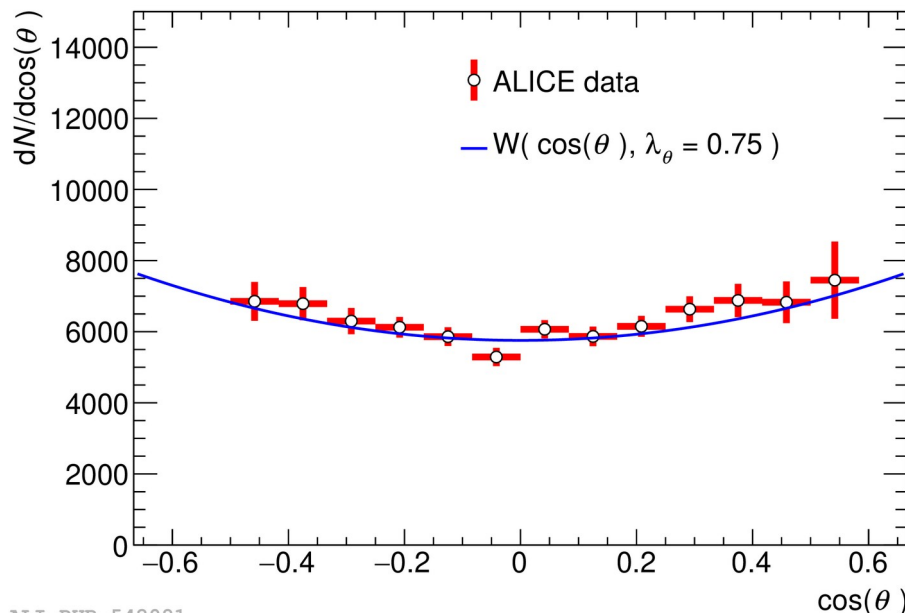


$$W(\cos \theta, \varphi) \propto \frac{1}{3 + \lambda_\theta} [1 + \lambda_\theta \cos^2 \theta + \lambda_\varphi \sin^2 \theta \cos(2\varphi) + \lambda_{\theta\varphi} \sin(2\theta) \cos \varphi]$$

$$(\lambda_\theta, \lambda_\varphi, \lambda_{\theta\varphi}) = (+1, 0, 0) \rightarrow \text{transverse polarization}$$

**Zhenjun Xiong, Tuesday 11:30**

ALICE, Pb-Pb  $\sqrt{s_{NN}} = 5.02$  TeV, Coherent J/ψ

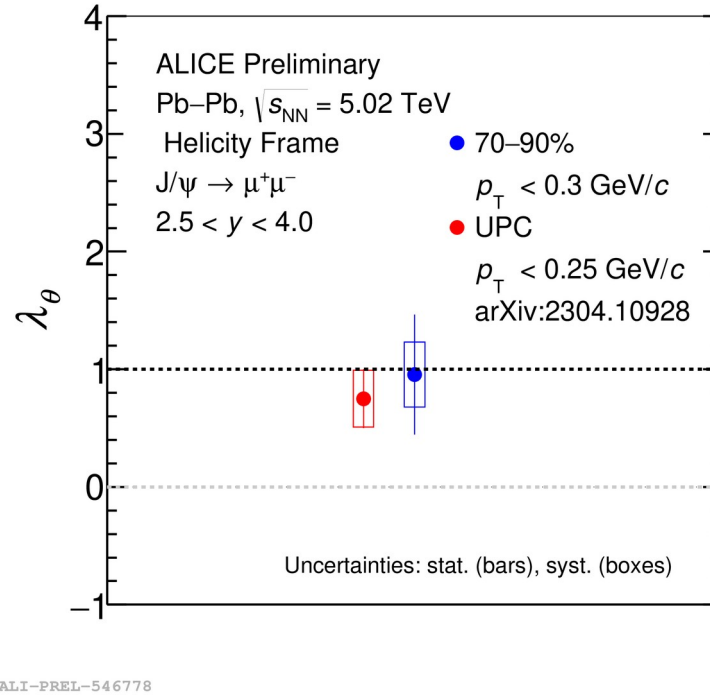
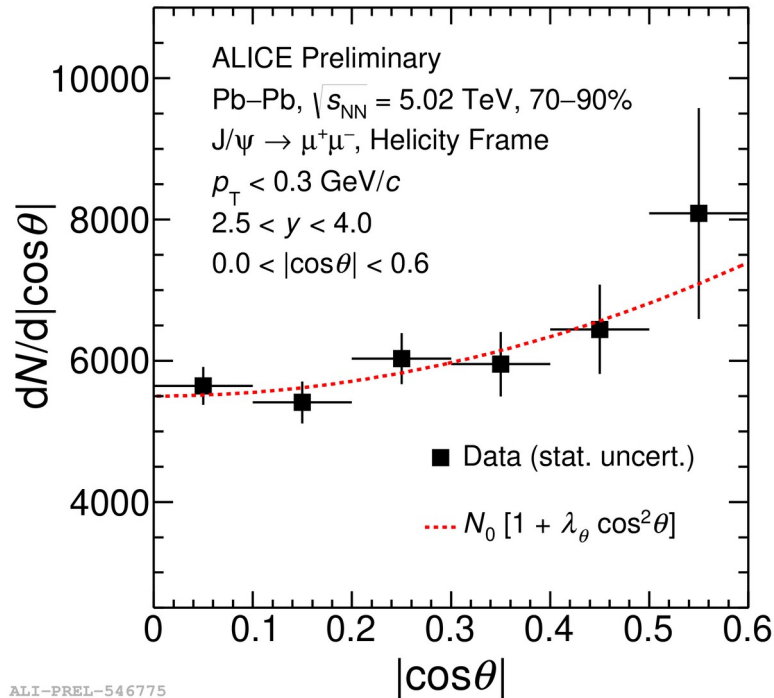


ALI-PUB-542081

ALICE, arxiv:2304.10928

- Expectation that photoproduced J/ψ inherits the photon's helicity (s-channel helicity conservation)
- Are the photoproduced J/ψ polarized also in non-UPC collisions ?

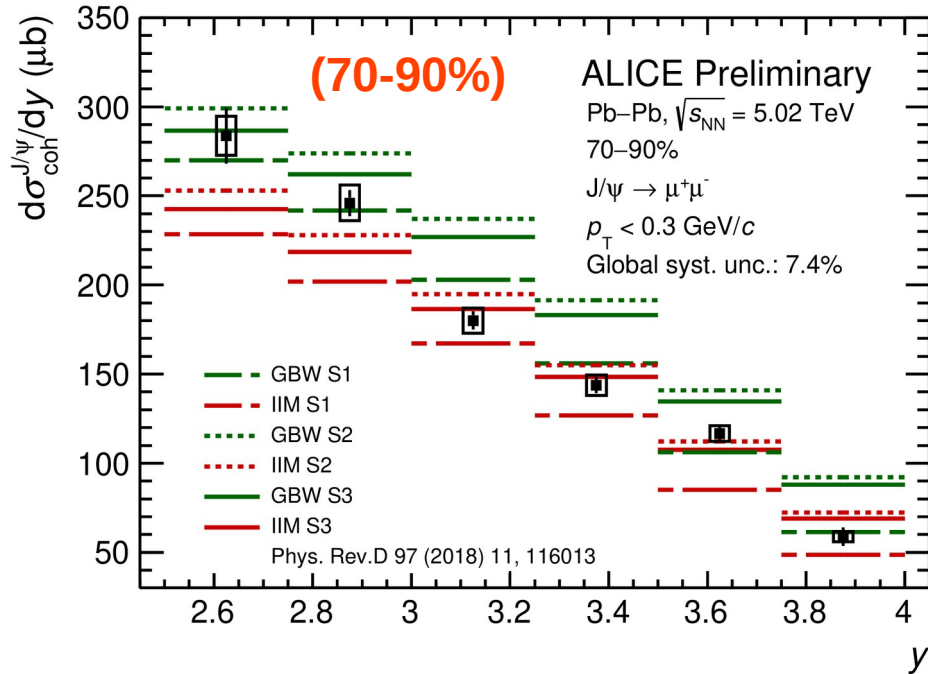
# Coherent J/ψ polarization in peripheral Pb–Pb



- Measurement in peripheral Pb–Pb compatible with the UPC observations and transverse polarization

# Rapidity dependence of coherent J/ψ production

IIM/GBW: M.Gay Ducati et al., PRD 97 (2018) 116013



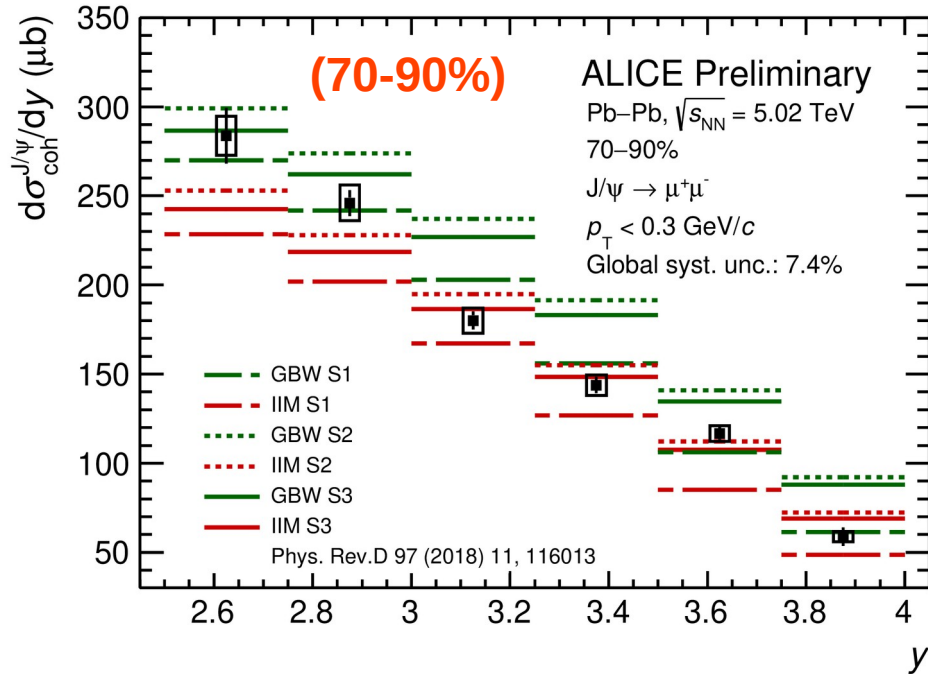
- S1:** no modification wrt UPC ( $\gamma$  flux in  $b$  range)
- S2:** photon flux in spectator region
- S3:** photon flux in spectator region and  $\sigma_{\gamma Pb}$  excludes participant region

ALI-PREL-547985

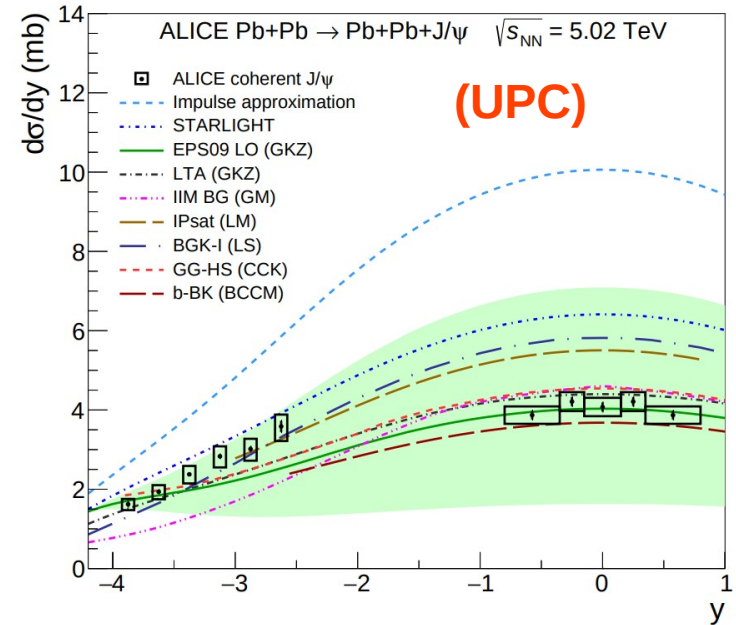
- Strong rapidity dependence observed at forward- $y$
- Overall magnitude in qualitative agreement to models

# Rapidity dependence of coherent J/ψ production

IIM/GBW: M.Gay Ducati et al., PRD 97 (2018) 116013



ALICE, EPJC81 (2021) 712



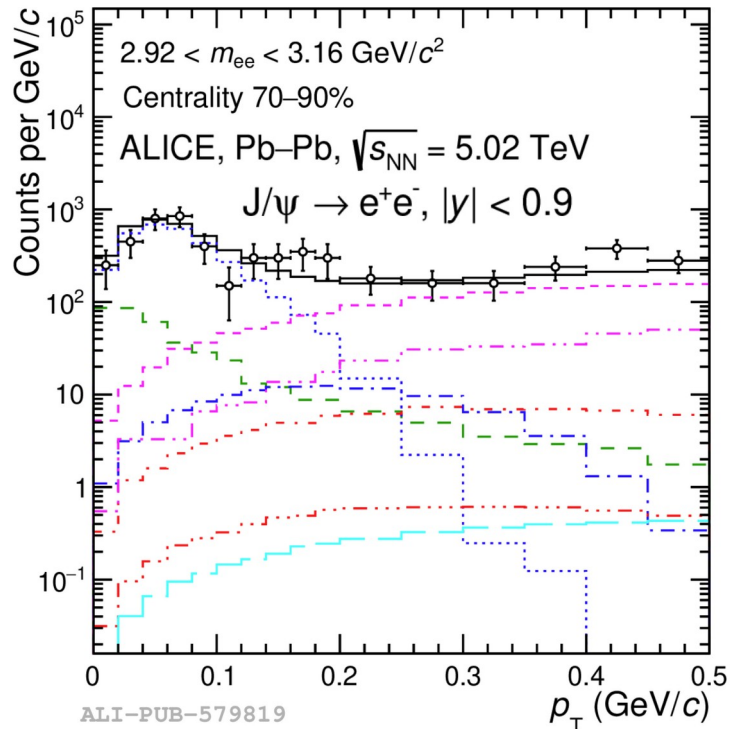
ALI-PREL-547985

Minjung Kim, Wednesday 9:40

- Strong rapidity dependence observed at forward-y
- Overall magnitude in qualitative agreement to models
- Difficulties in reproducing the fast y-dependence, similar to the UPC results

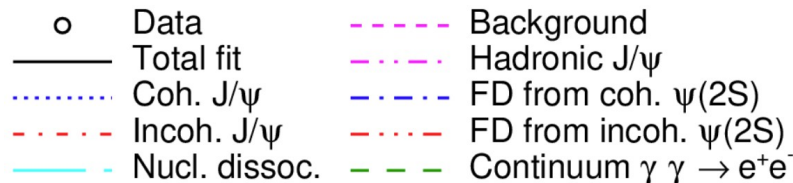
# J/ψ photoproduction in peripheral collisions at mid-y

ALICE, arxiv:2409.11940



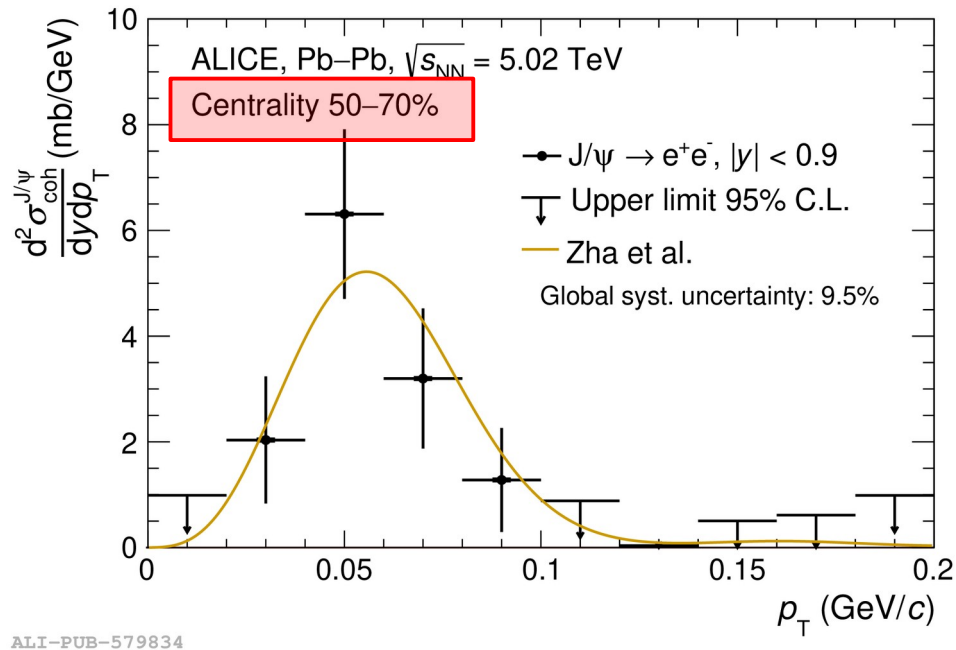
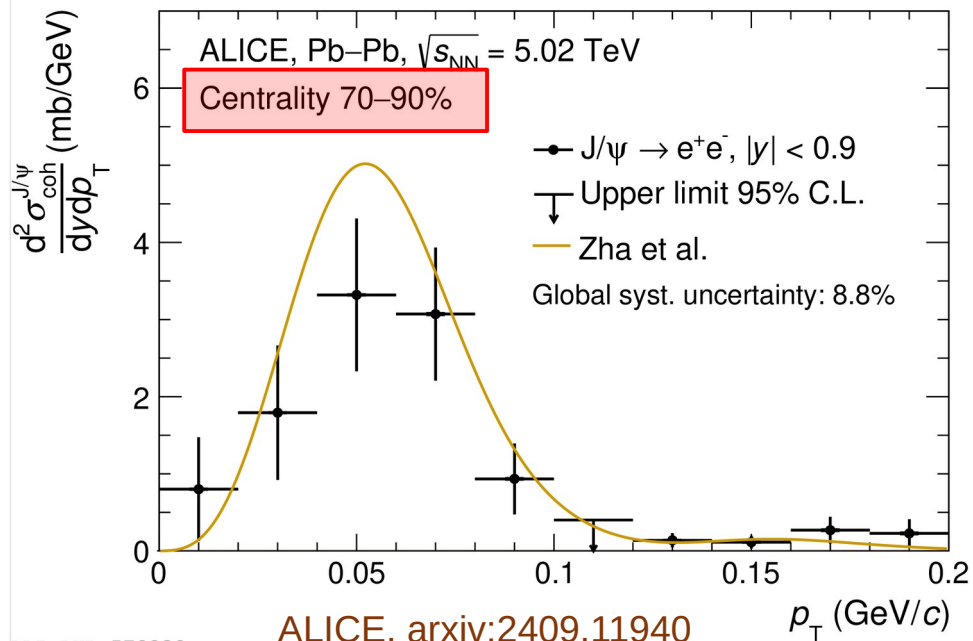
## NEW on arXiv

- Recent measurement at midrapidity
- Coherent yield extracted via a template fit:
- **Photo-production components (STARlight)**
  - Coherent J/ψ
  - Incoherent J/ψ
  - Feed-down from coherent and incoherent  $\psi(2S)$
  - $\gamma\gamma$  continuum
- **Hadronic J/ψ production** (data driven)
- **Combinatorial and correlated background** (data driven)



# $p_T$ dependence of $J/\psi$ photoproduction at mid-y

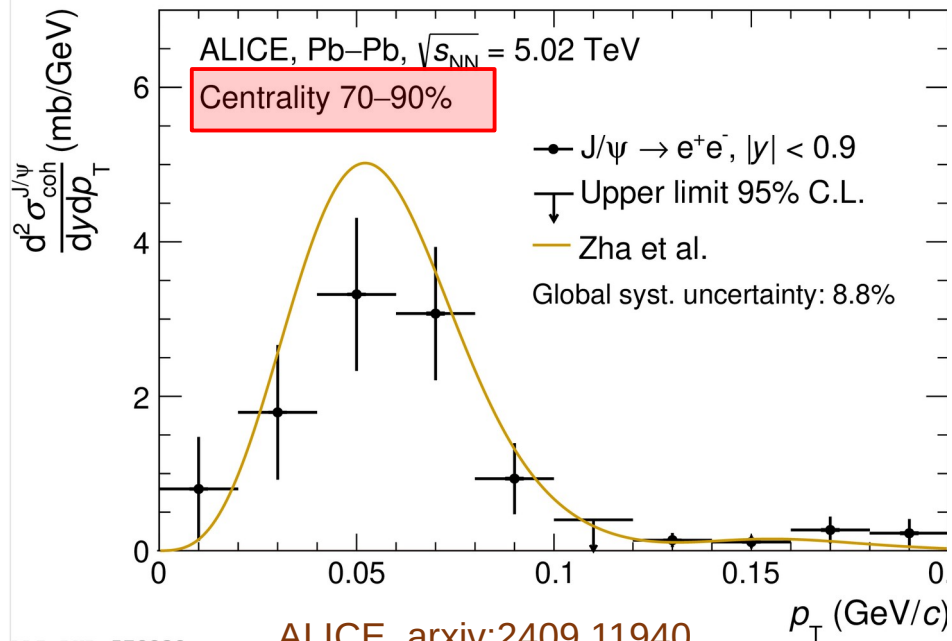
Zha et al., PRC 99 (2019) 061901



- Model calculations using destructive interference compatible with the data
- Modifications in the differential cross section with centrality still difficult to disentangle with the current datasets at mid-y

# $p_T$ dependence of $J/\psi$ photoproduction at mid-y

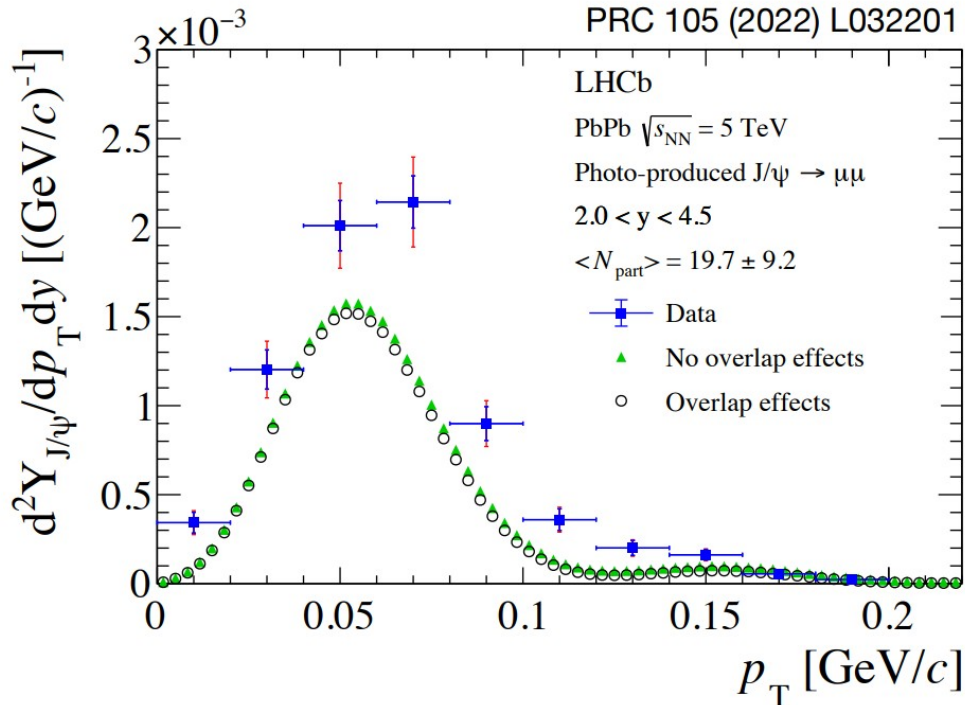
Zha et al., PRC 99 (2019) 061901



ALICE, arxiv:2409.11940

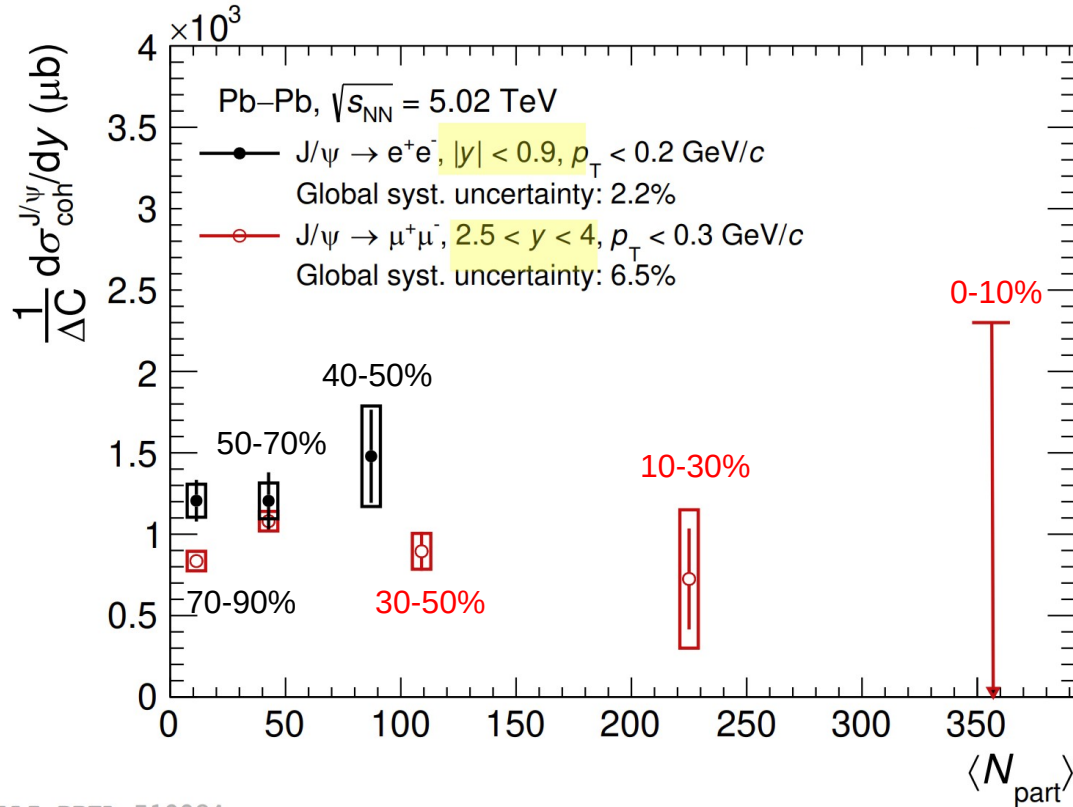
ALI-PUB-579839

PRC 105 (2022) L032201



- Model calculations using destructive interference compatible with the data
- Modifications in the differential cross section with centrality still difficult to disentangle with the current datasets at mid-y
- Similar observations reported by LHCb

# Coherent $J/\psi$ production as a function of centrality



Cross-sections are normalized to the width of the centrality interval ( $\Delta C$ )

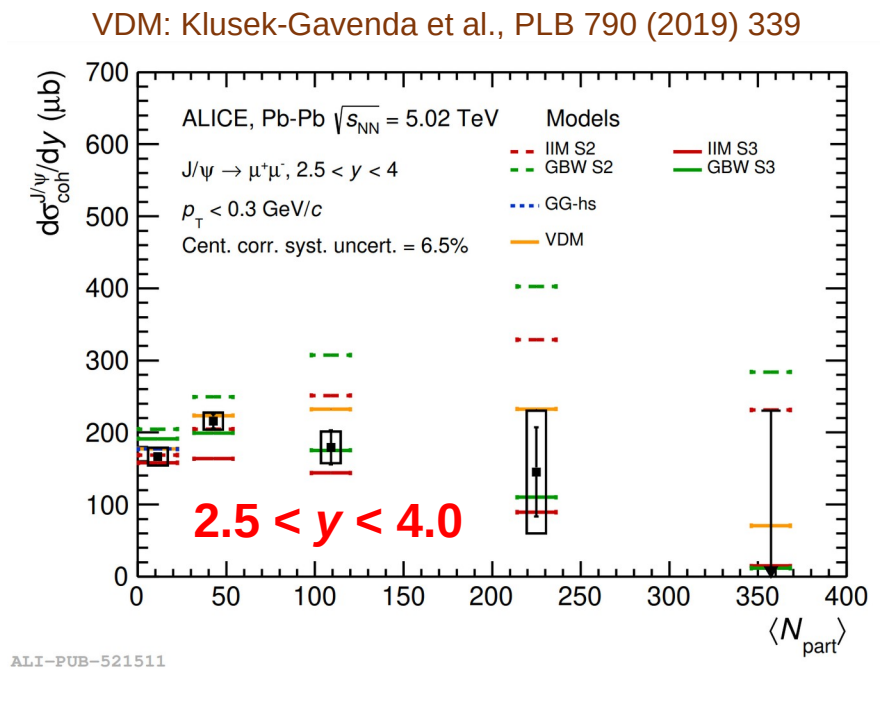
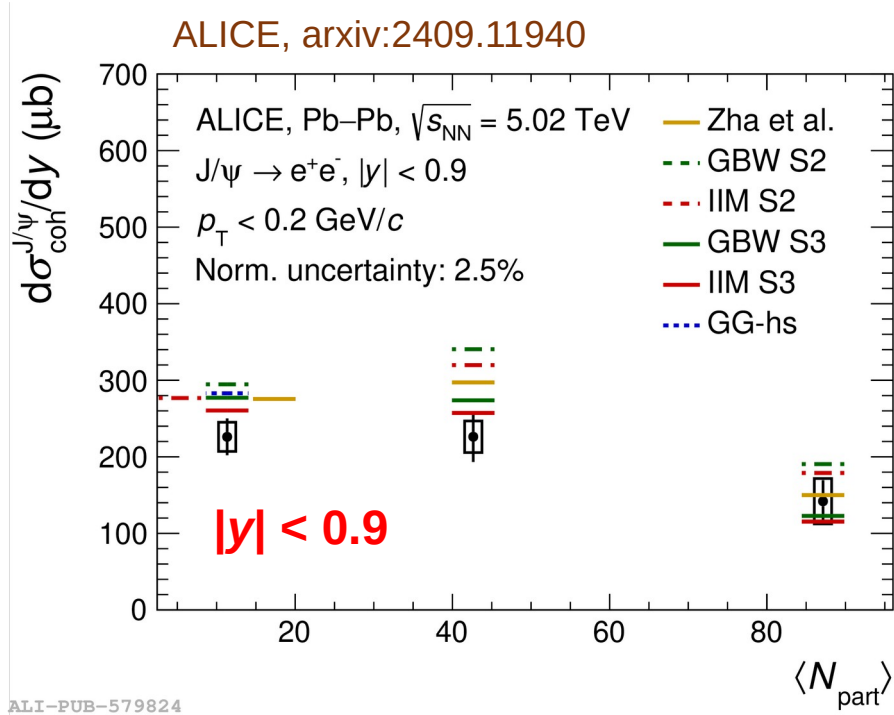
mid-y: ALICE, arxiv:2409.11940  
fwd-y: ALICE, PLB846 (2023) 137467

ALI-PREL-519984

- Cross section extracted up to nearly central (at forward) and semicentral collisions (at mid-y)
- No significant centrality dependence within uncertainties



# Coherent photoproduction, data vs models

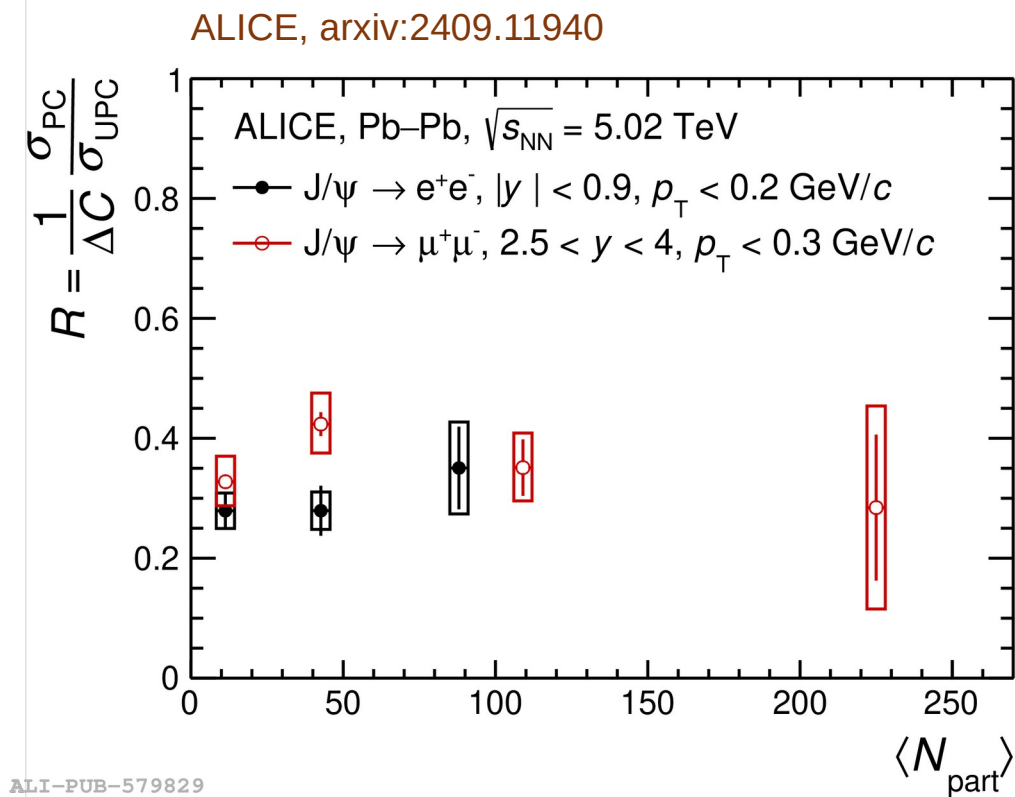


Modifications of photon-flux only:  
 GBW S2, IIM S2, VDM, GG-hs

Modifications of both photon-flux and  $\sigma(\gamma A)$ :  
 GBW S3, IIM S3, Zha et al.

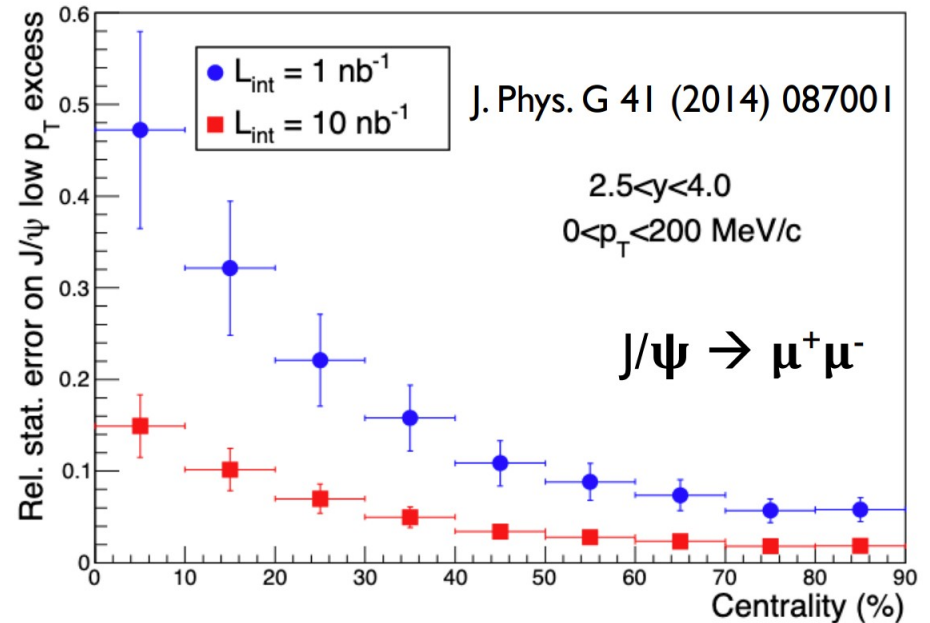
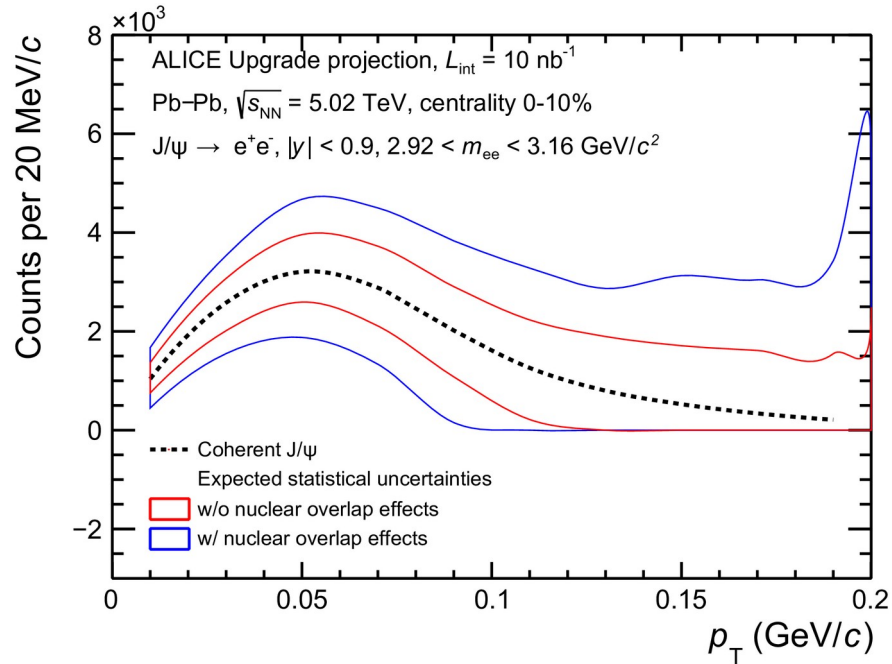
- Data tends to favor models where both the emitted photon flux and photonuclear cross section exclude the participant region
- VDM modifies only the photon flux but still gets a good agreement to data

# Coherent production in peripheral vs UPC collisions



- Possible rapidity dependent final state (medium) effects can be studied using  $\sigma(PC) / \sigma(UPC)$
- Good agreement between mid and forward-y results in most peripheral collisions (70-90%)

# Projections for Run 3 and Run 4

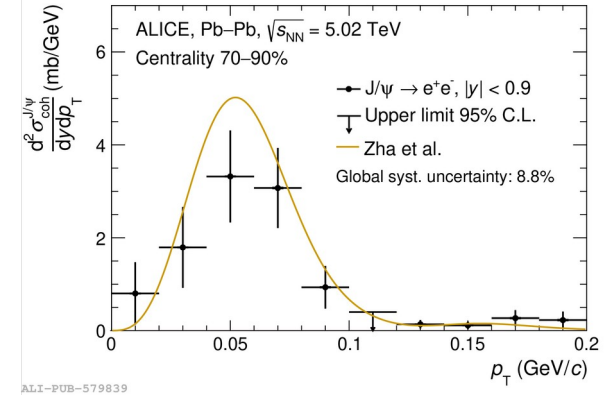


ALI-SIMUL-514006

- Expected integrated luminosity in Pb-Pb:  $\sim 10 \text{ nb}^{-1}$  at both mid and fwd-y
- In central collisions (0-10%), expected significance of coherent yields of 5-10
- Below 10% centrality:
  - Precise measurements of  $p_T$  spectrum, azimuthal correlations, polarization

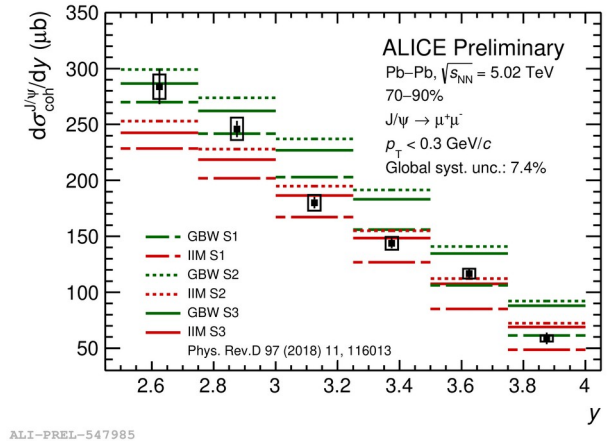
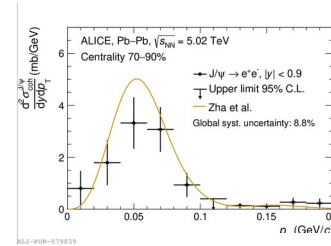
# Summary and conclusions

- $p_T$ -differential cross sections at midrapidity
  - peak at  $\sim 60$  MeV/c, as seen in UPC
  - compatible with hypothesis destructive interference



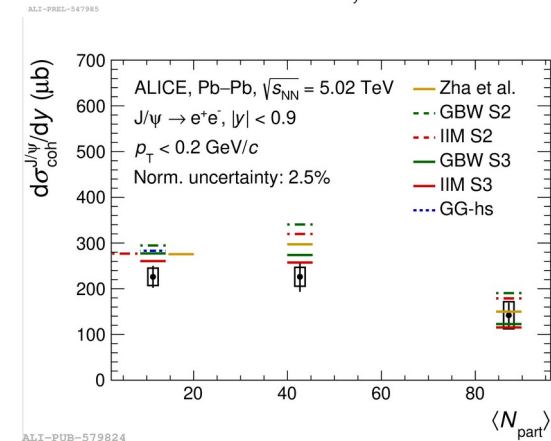
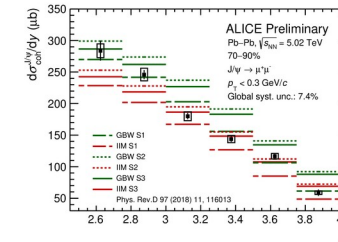
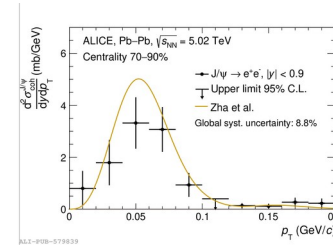
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- New results at forward- $y$ 
  - Coherent  $J/\psi$  polarization in Pb–Pb at 70-90% centrality
  - Fine  $y$ -differential coherent  $J/\psi$  cross sections



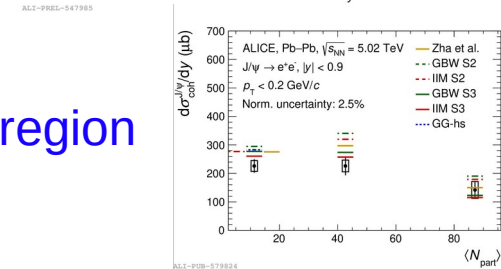
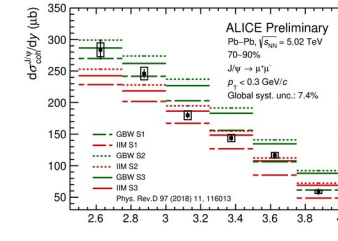
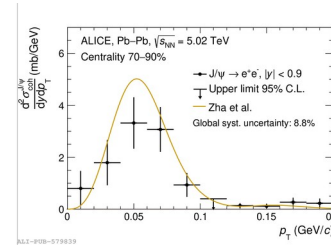
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  - Fine  $y$ -differential coherent  $J/\psi$  cross sections
- $p_T$ -integrated cross-sections
  - photon flux and  $\sigma(yA)$  sensitive to the participant region



# Summary and conclusions

- $p_T$ -differential cross sections at midrapidity
  - peak at  $\sim 60$  MeV/c, as seen in UPC
  - compatible with hypothesis destructive interference
- New results at forward- $y$ 
  - Coherent  $J/\psi$  polarization in Pb-Pb at 70-90% centrality
  - Fine  $y$ -differential coherent  $J/\psi$  cross sections
- $p_T$ -integrated cross-sections
  - photon flux and  $\sigma(yA)$  may be affected by the participant region
- Projections for Run 3 and Run 4
  - Central collisions: coherent  $J/\psi$  cross-section feasible with a significance better than 5
  - Semicentral and peripheral: precise differential measurements



# Backup

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