

Coherent charmonium photoproduction and polarization in HICs with nuclear overlap

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Afnan Shatat for the ALICE Collaboration
IJCLab Orsay, CNRS/IN2P3, Université Paris Saclay
afnan.shatat@cern.ch

université
PARIS-SACLAY

 IJCLab
Irène Joliot-Curie
Laboratoire de Physique
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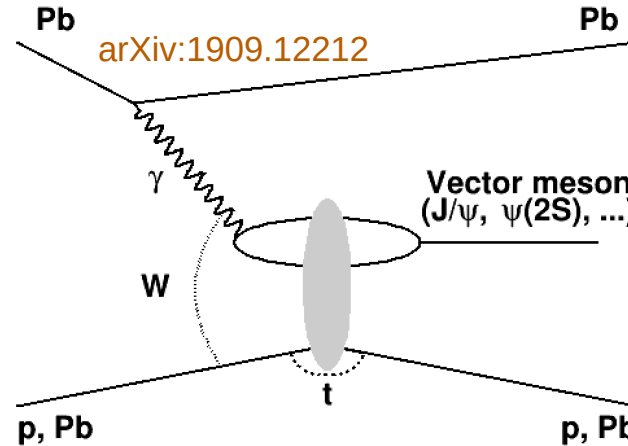
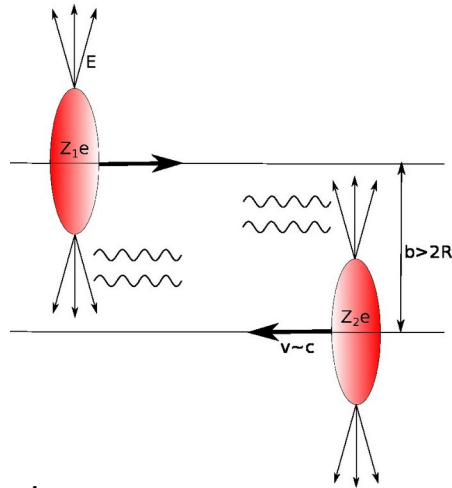
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Les deux infinis

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Vector meson photoproduction in HICs

Relativistic heavy ions are strong EM field emitters

Vector Meson (VM): meson of $J^P = 1^-$



Coherent, $\langle p_T \rangle \approx 60 \text{ MeV}/c$

Incoherent, $\langle p_T \rangle \approx 500 \text{ MeV}/c$

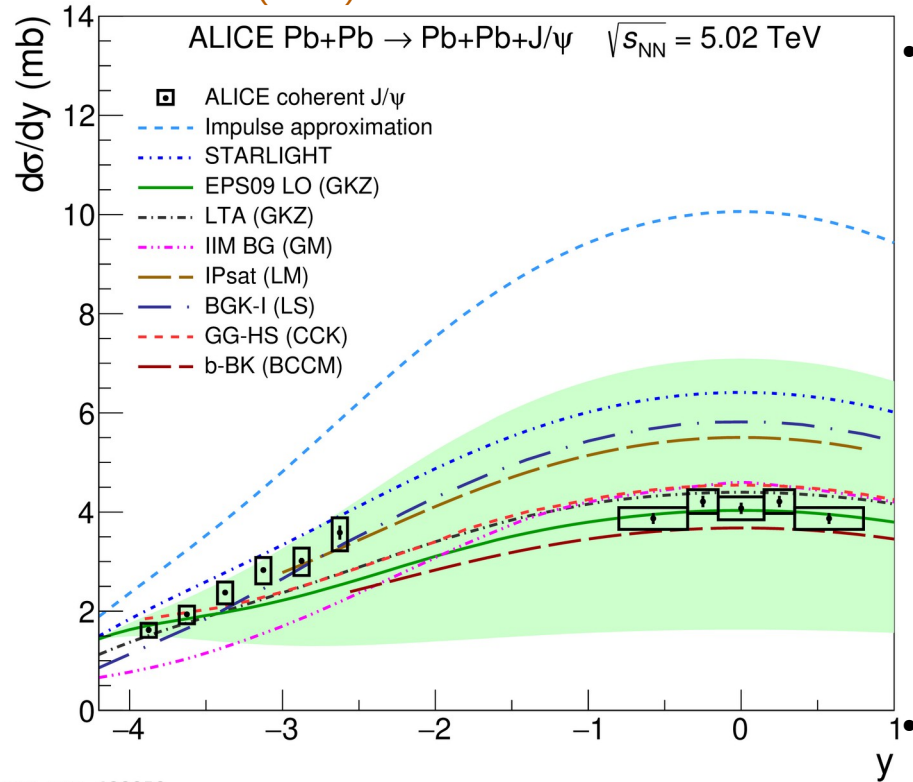
b : impact parameter

- Ultra Peripheral Collisions (UPC): $b > 2R$
- Peripheral Collisions (PC): $b < 2R$ and b large

More about J/ψ photoproduction in [Simone Ragoni's talk](#) (Sept. 6th, 09:10)

Vector meson photoproduction in UPC

EPJC 81 (2021) 712



ALI-PUB-499958

- Models including nuclear shadowing are in agreement with the measurement, but **cannot describe at the same time the mid and forward rapidity cross section**

Impulse approximation: [[PRC88, 014910 \(2013\)](#)]

STARLIGHT: [[Comp. Phys. Comm. 212 \(2017\) 258](#)]

EPS09 LO (GKZ): [[PRC. 93\(5\), 055206 \(2016\)](#)]

LTA (GKZ): [[Phys. Rep.512, 255–393 \(2012\)](#)]

IIM BG (GM): [[P.RC 90, 015203 \(2014\)](#)] and [[J. Phys.G 42\(10\), 105001 \(2015\)](#)]

Ipsat (LM) : [[PRC. 83,065202 \(2011\)](#)] and [[PRC. 87, 032201 \(2013\)](#)]

BGK-I (LS): [[PRC. 99\(4\), 044905 \(2019\)](#)]

GG-HS (CCK): [[PRC. 97\(2\), 024901 \(2018\)](#)], and [[PLB 766, 186–191 \(2017\)](#)]

b-BK (BCCM): [[PLB 817, 136306 \(2021\)](#)]

VM photoproduction serves as a probe of the gluon distribution in the target nucleus at low Bjorken- x

$$x_B = (m_{J/\psi} / \sqrt{s_{NN}}) \times \exp(\pm y)$$

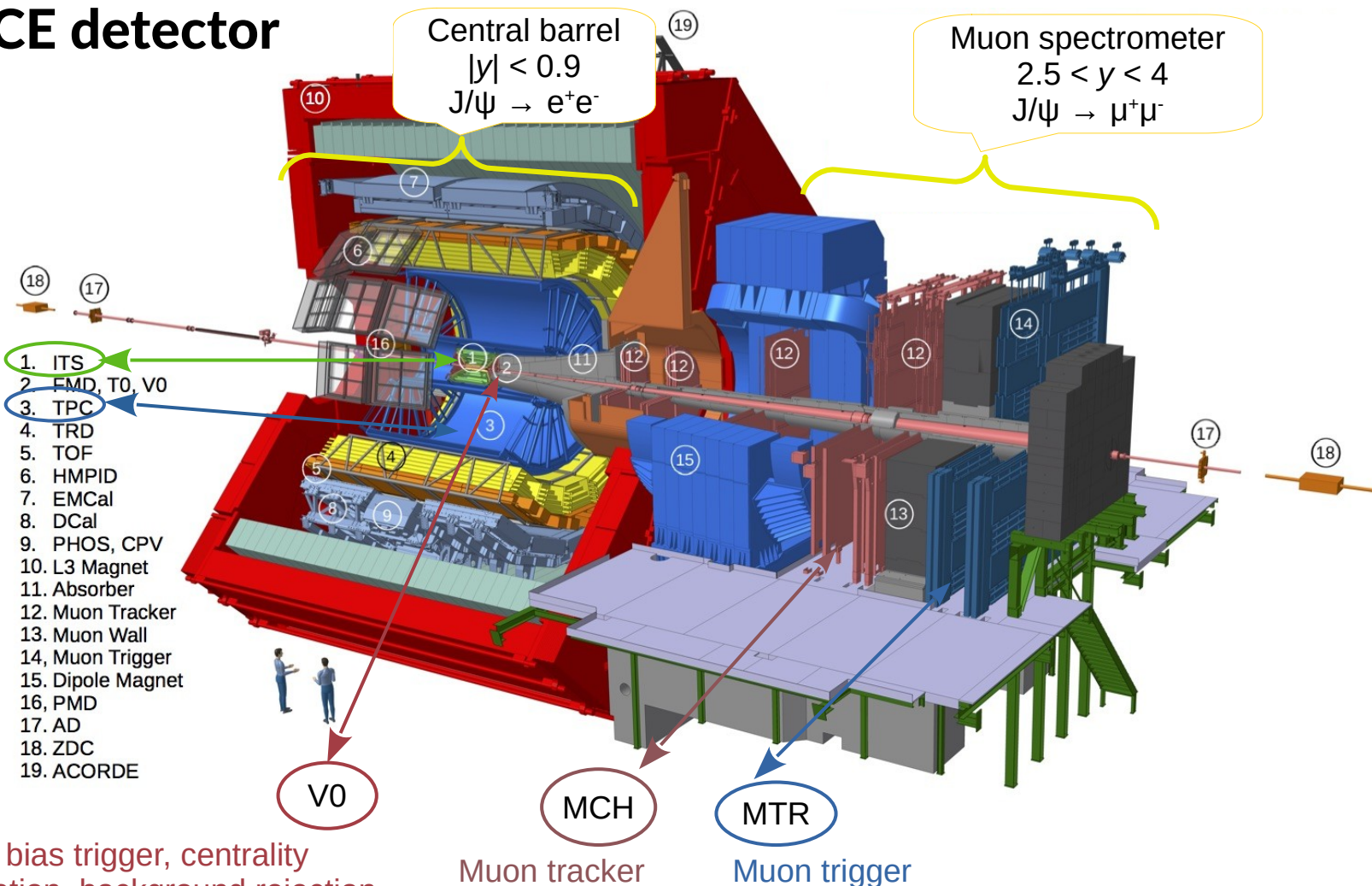
The ALICE detector

In Run 2



ITS:
inner tracker,
vertexing

TPC:
tracking and
PID



Coherent J/ψ photoproduction in Pb–Pb collisions with nuclear overlap

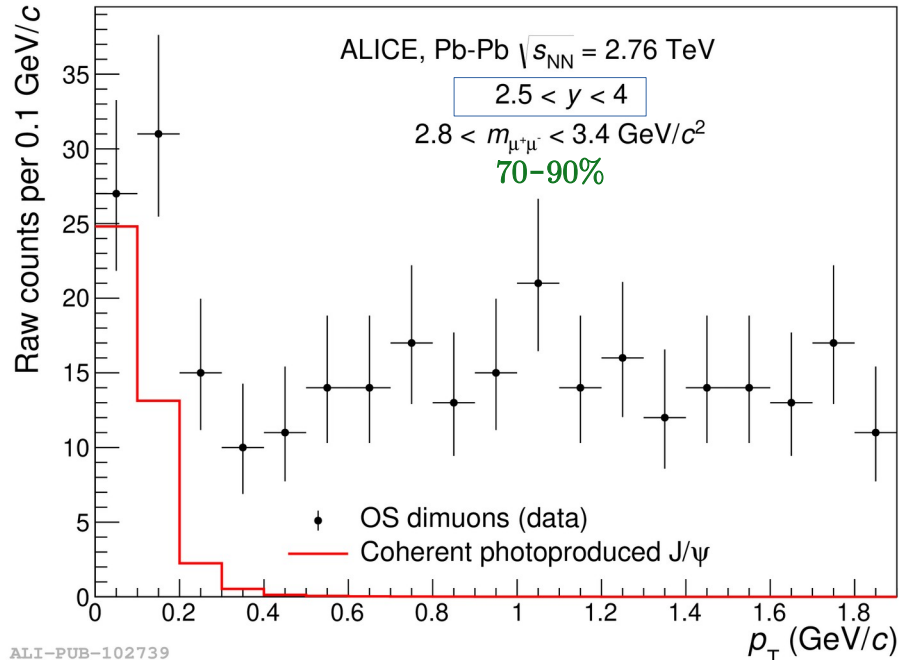


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Significant J/ψ excess for $p_T < 0.3$ GeV/c in 70–90% Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ and 5.02 TeV.

[PRL 116, 222301\(2016\)](#)

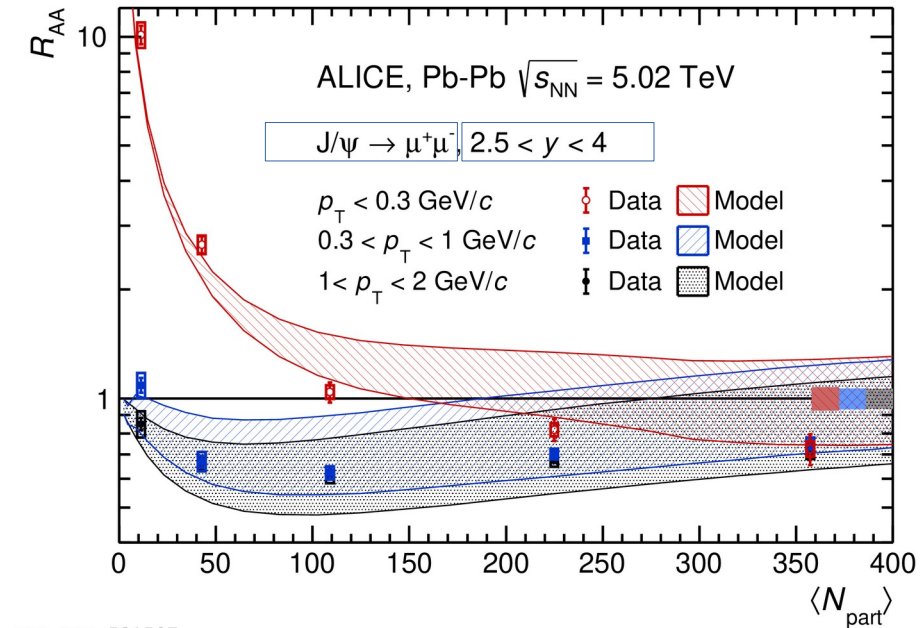
[STARlight MC : Comp. Phys. Comm. 212 \(2017\) 258.](#)



Associated with a dramatic increase of the $R_{AA}^{J/\psi}$

$$R_{AA}^{J/\psi} = \frac{Y_{AA}^{J/\psi}}{\langle T_{AA} \rangle \times \sigma_{pp}^{J/\psi}}$$

[arXiv:2204.10684](#) Model: W. Shi et al., [Phys. Lett. B 777 \(2018\)](#)



ALI-PUB-521507

70–90%

0–10%

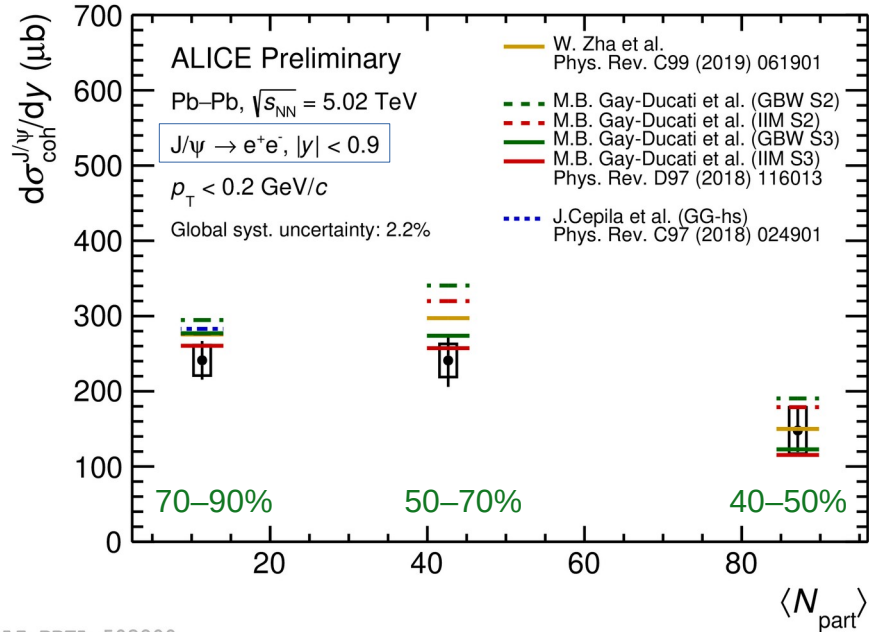
Observed also by STAR [\[PRL 123, 132302 \(2019\)\]](#) and LHCb [\[PRC. 105 \(2022\) L032201\]](#).

Coherent J/ψ photoproduction in Pb–Pb collisions: centrality dependence



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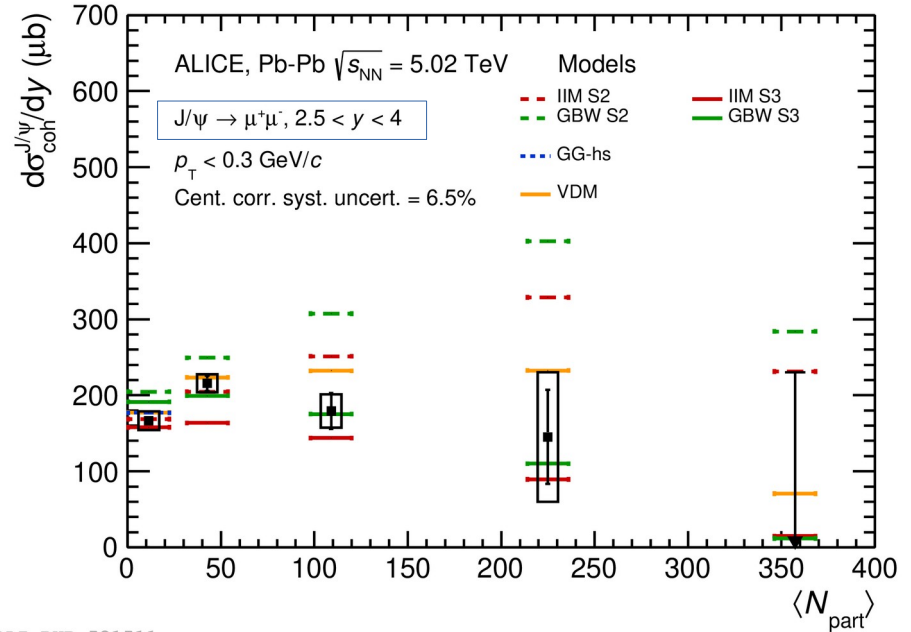
- Both measurements at mid and forward rapidity don't show a significant centrality dependence*
- Measurements are qualitatively described by a large number of models developed for UPC and extended to account for the nuclear overlap



ALI-PREL-503800

* The cross section is not normalized to the centrality interval width

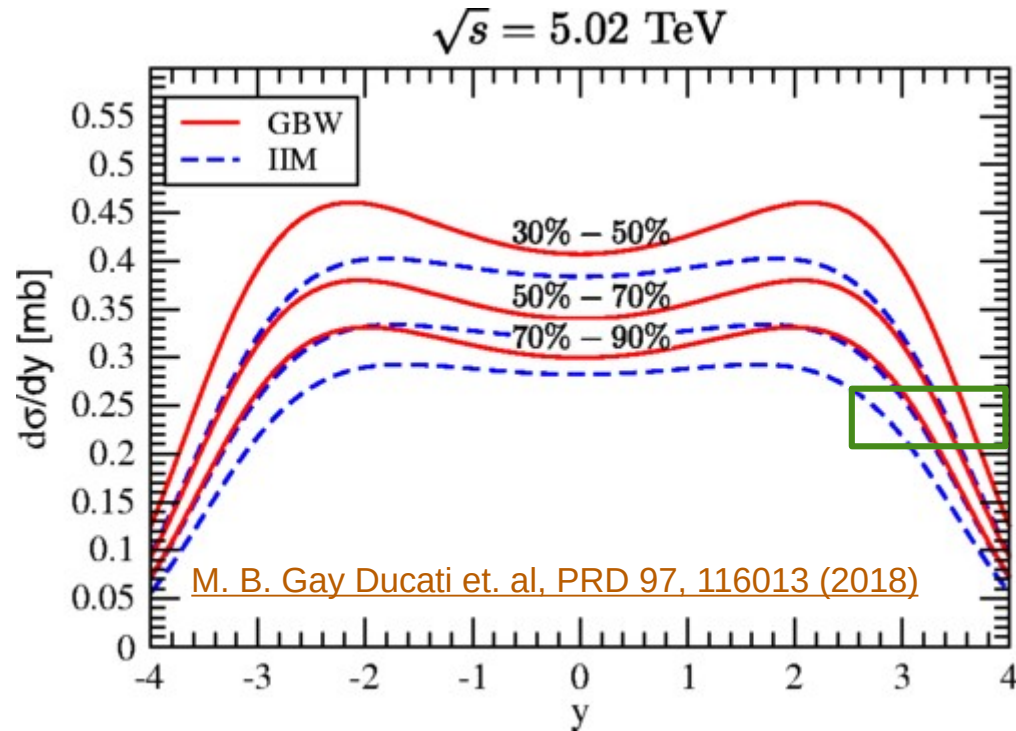
arXiv:2204.10684



ALI-PUB-521511

γ -dependence in Pb–Pb collisions

- Models predict a strong y -dependence of the VM photoproduction cross section
- **Additional differential measurements are needed to better constrain models, as in UPC**



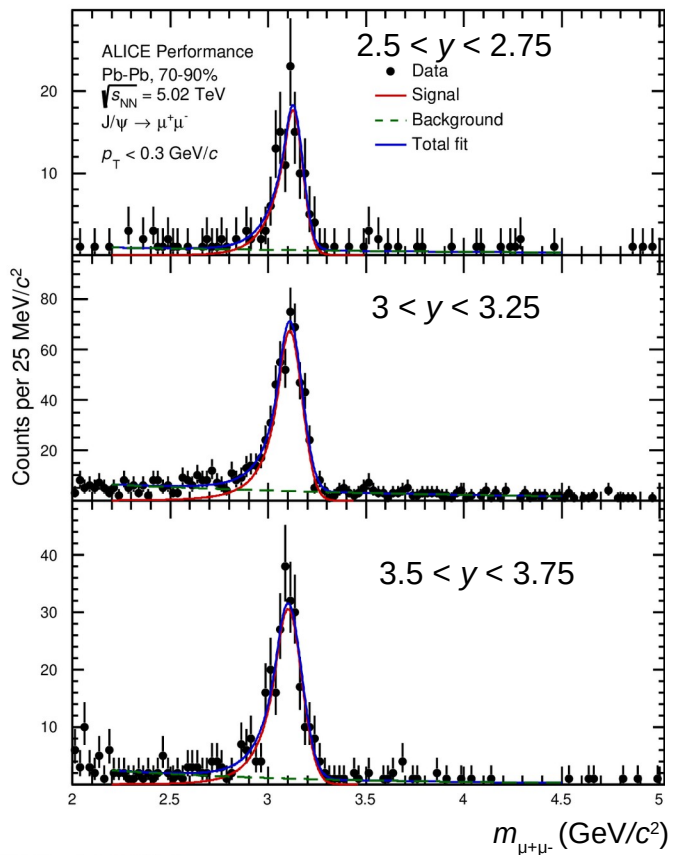
→ A new measurement is performed as a function of rapidity in Pb–Pb collisions with nuclear overlap

The state of art: raw J/ψ yield in rapidity intervals



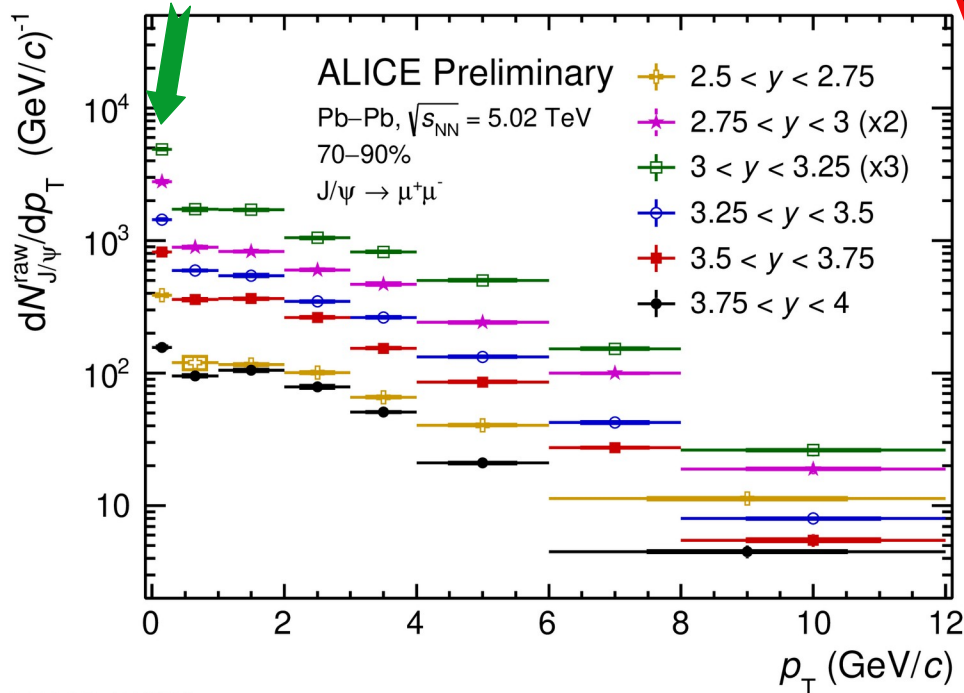
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J/ψ → μ⁺μ⁻, 70–90%, 2.5 < y < 4, p_T < 0.3 GeV/c



- J/ψ signal extraction from the invariant-mass distribution of the decay daughters
 - Raw yield excess is observed for p_T < 0.3 GeV/c for all y intervals
- Raw = hadronic + photoproduction

NEW

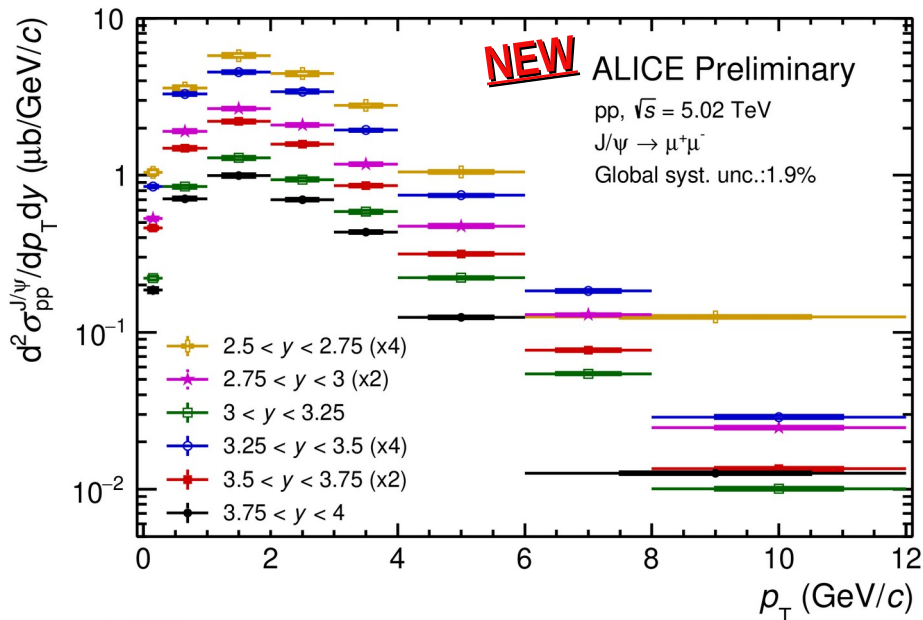


ALI-PERF-538924

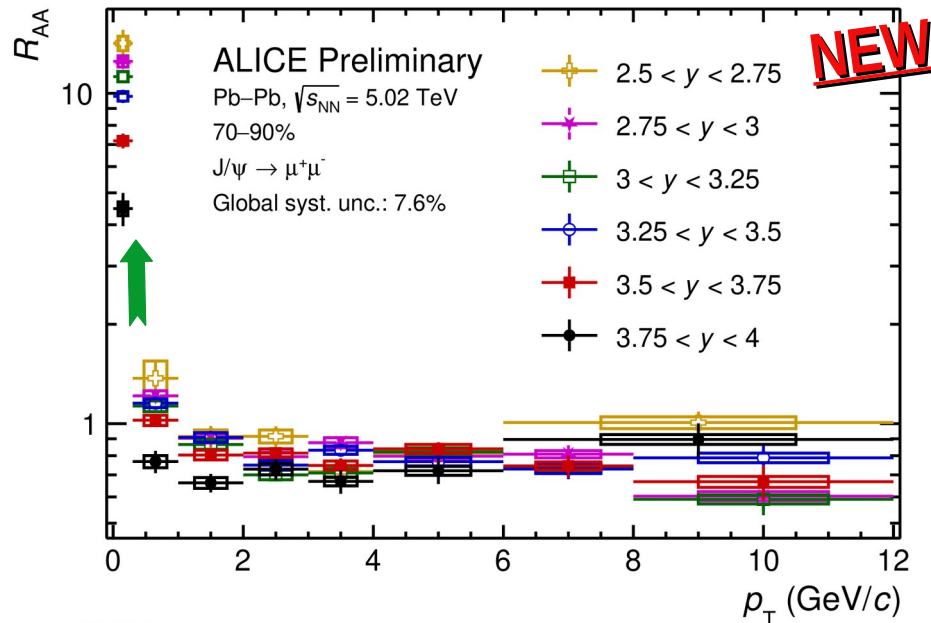
A. Shatat, QM, Sept. (3-9) 2023

ALI-PREL-548019

Modelization of hadronic J/ψ yield contribution for $p_T < 0.3$ GeV/c



ALI-PREL-548013



ALI-PREL-547989

- The R_{AA} largely increases for $p_T < 0.3$ GeV/c and it has a hierarchy in y , the most forward R_{AA} is the least enhanced
- The J/ψ cross section in pp collisions and the J/ψ R_{AA} are used as inputs for modeling the expected hadronic J/ψ yield
- J/ψ excess yield = J/ψ raw yield – J/ψ hadronic yield
- The coherent J/ψ yield is obtained by correcting the excess yield for the fraction of incoherent J/ψ and the fraction of coherent $\psi(2S) \rightarrow J/\psi$ evaluated in UPC.

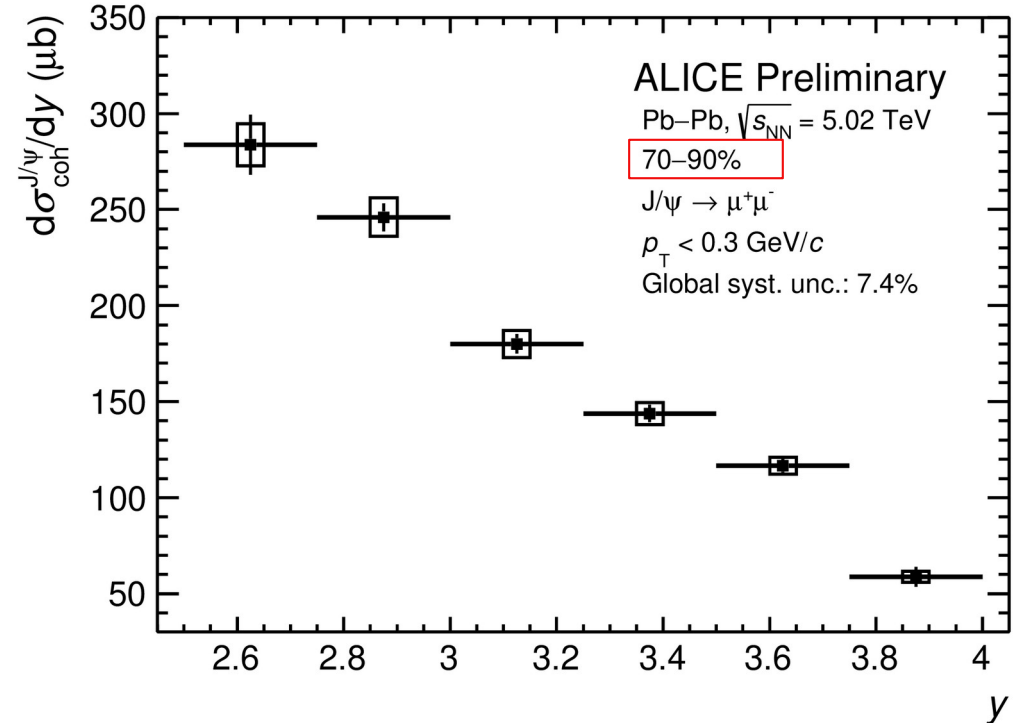
y-dependence of the coherent J/ψ photoproduction cross section



ALICE

- A strong rapidity dependence is seen

NEW



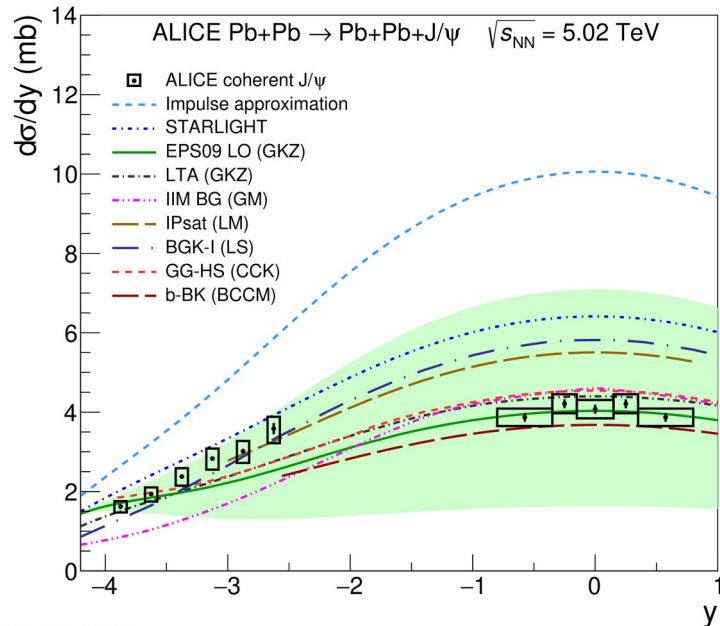
ALI-PREL-548022

y-dependence of the coherent J/ψ photoproduction cross section

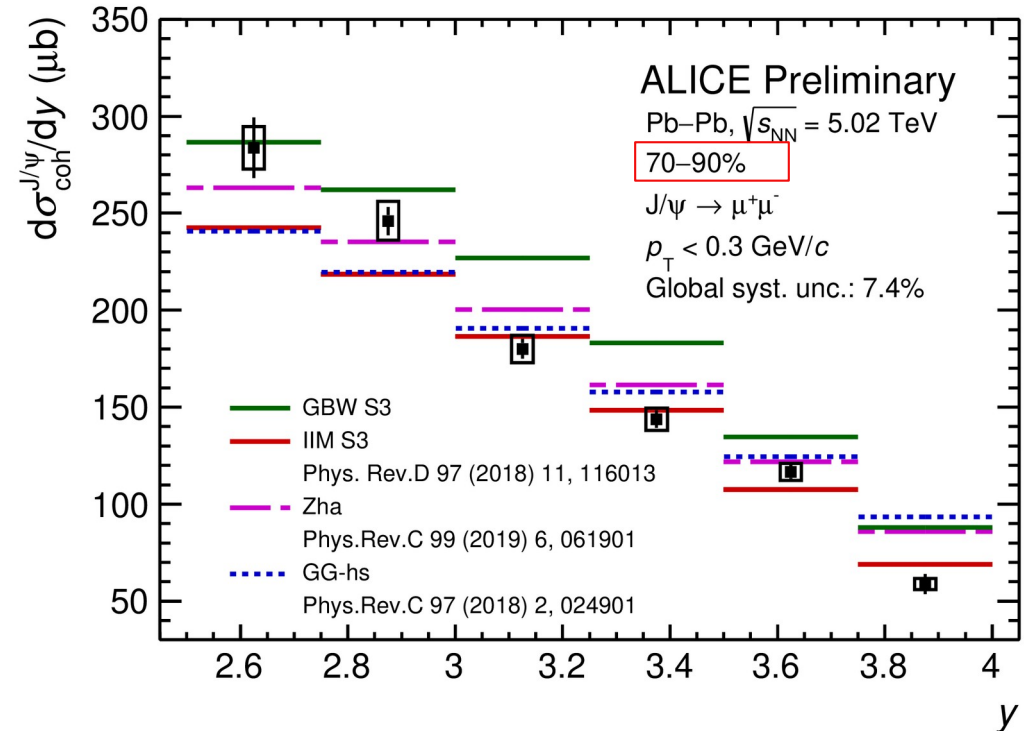


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- A strong rapidity dependence is seen
- Models initially developed for VM photoproduction in UPC and modified for PC are able to describe qualitatively the magnitude of the cross section, but fail at reproducing the y-dependence, **NEW** similarly to UPC.



ALI-PUB-499958



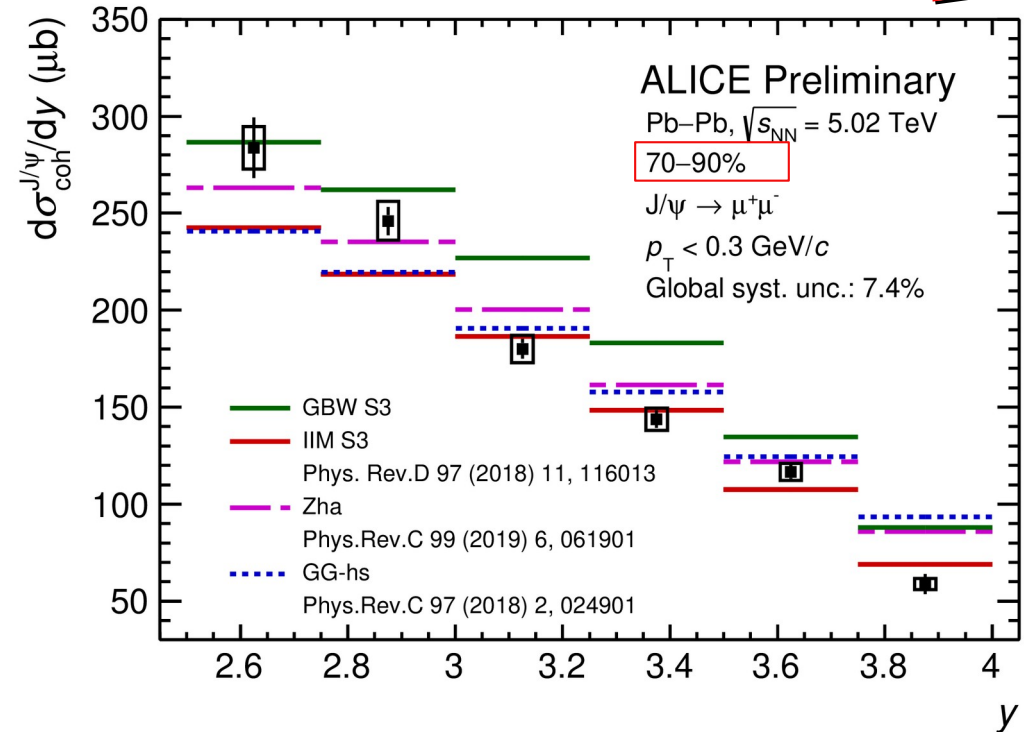
ALI-PREL-547942

y-dependence of the coherent J/ψ photoproduction cross section

- A strong rapidity dependence is seen
- Models initially developed for VM photoproduction in UPC and modified for PC are able to describe qualitatively the magnitude of the cross section, but fail at reproducing the y-dependence, **NEW** similarly to UPC.

Models considerations:

- GG-hs: photon flux with constraints on impact parameter range
- Zha: assumptions on photon-pomeron coupling (nucleus+spectator)
- GBW S3 } effective photon flux and photonuclear cross section considered w.r.t UPC calculations (see next slide)
- IIM S3 }



ALI-PREL-547942

y-dependence of the coherent J/ψ photoproduction cross section

GBW/IIM: extending UPC models to PCs considering the overlap region

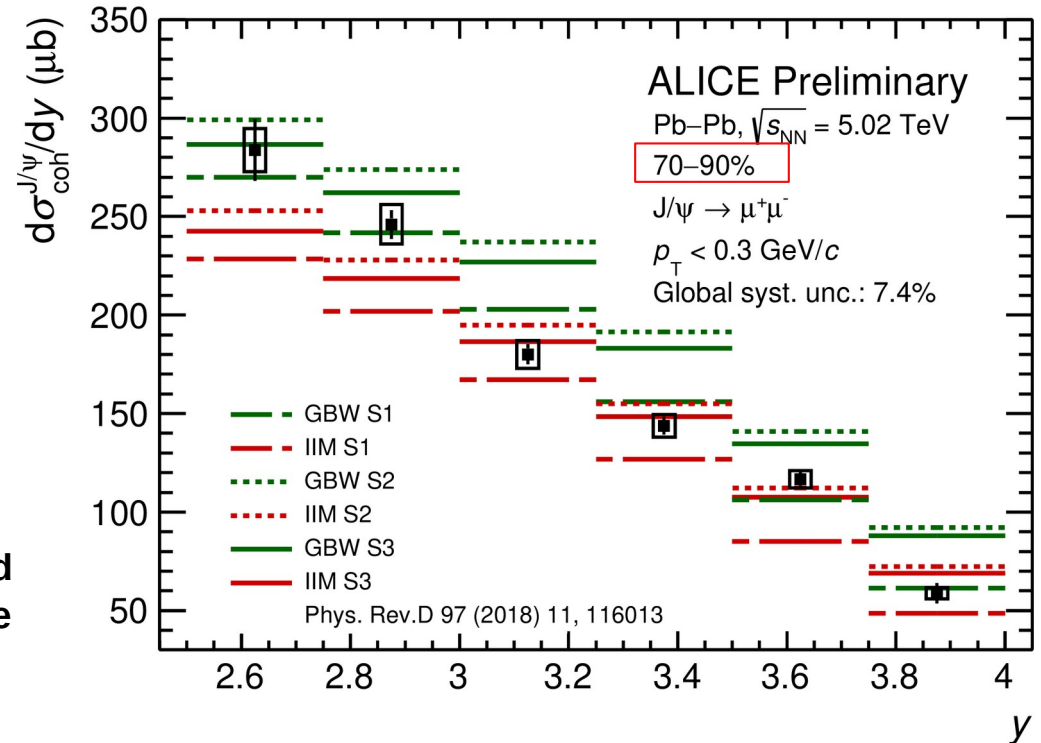
- GBW S1 } no relevant modifications w.r.t the
- - IIM S1 } UPC calculations

- - - GBW S2 } effective photon flux where only
- - - IIM S2 } photons reaching the spectator
 region are considered

- GBW S3 } S2 + modification of the
— IIM S3 } photonuclear cross section (exclusion
 of the overlap region)

- The three scenarios are qualitatively describing the cross section
- **Any effect related to the nuclear overlap is expected to be small in the peripheral 70-90% centrality range**
- Understanding the impact of the nuclear overlap on the VM photoproduction cross section measurement is a theoretical challenge

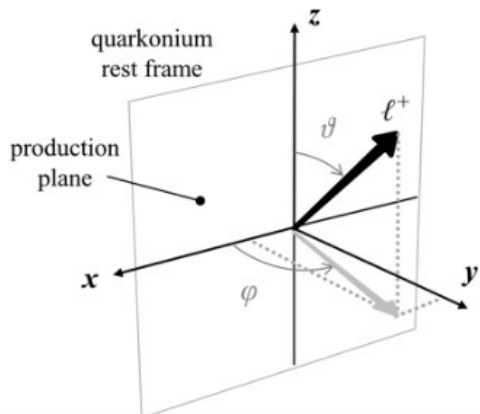
NEW



ALI-PREL-547985

The coherent photoproduced J/ψ polarization in Pb–Pb collisions

P. Faccioli et al., EPJC 69 (2010) 673



- **S-channel helicity conservation** suggests that the photon helicity is transferred to the produced vector meson, J/ψ .
- In helicity frame, J/ψ polarization is its spin alignment with respect to the J/ψ flight direction in the lab frame.
- **A transverse polarization is observed for coherently photoproduced J/ψ in UPC.**

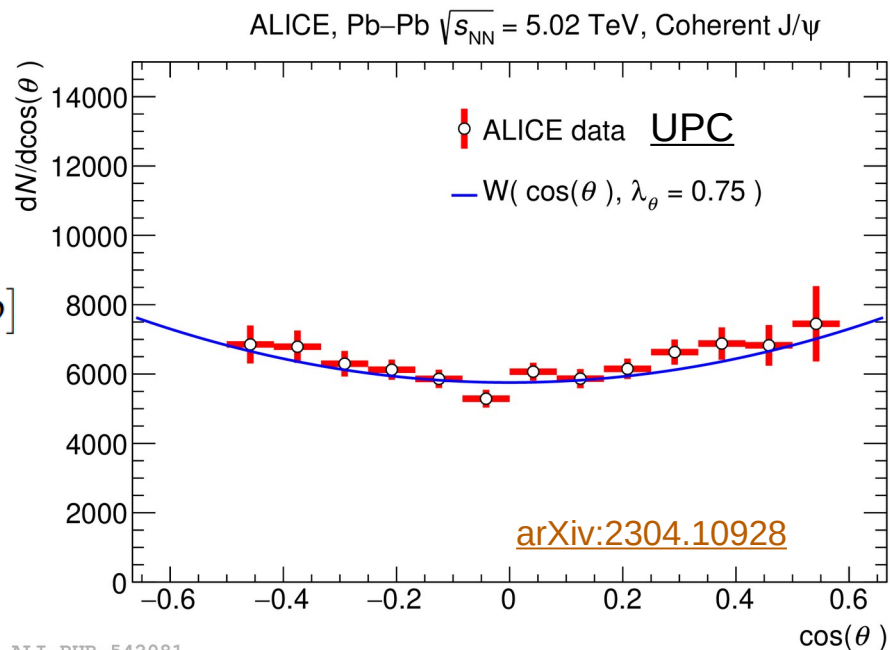
J/ψ polarization is studied via decay to dimuons, the corresponding **dimuon angular distribution** is:

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

$$(\lambda_\theta, \lambda_\varphi, \lambda_{\theta\varphi}) = (0, 0, 0) \Rightarrow \text{No polarization}$$

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

$$(\lambda_\theta, \lambda_\varphi, \lambda_{\theta\varphi}) = (-1, 0, 0) \Rightarrow \text{Longitudinal polarization}$$

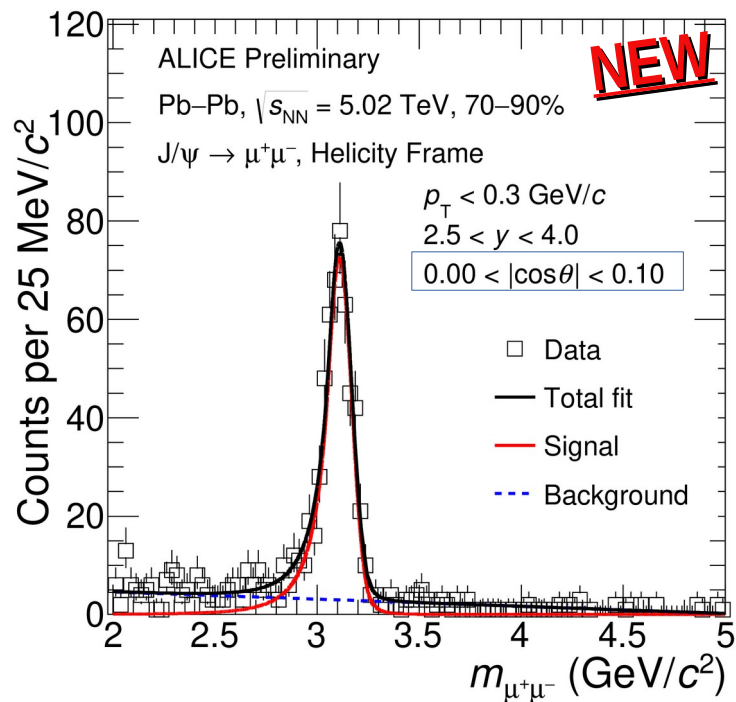


ALI-PUB-542081

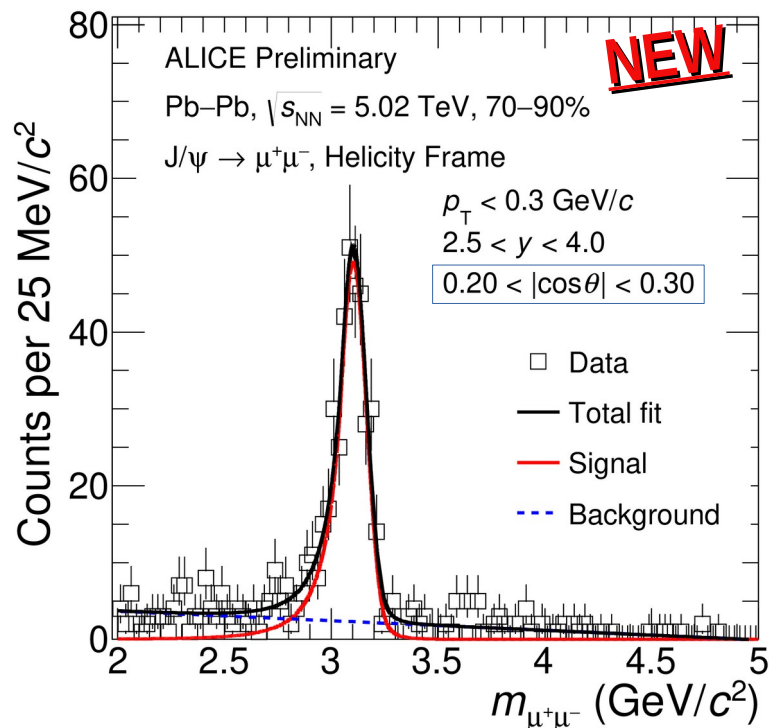
J/ψ signal extraction in angular intervals

J/ψ → μ⁺μ⁻, 70–90%, 2.5 < y < 4, p_T < 0.3 GeV/c

The J/ψ signal is extracted in six cosθ intervals using the dimuon invariant mass distribution



ALI-PREL-546762

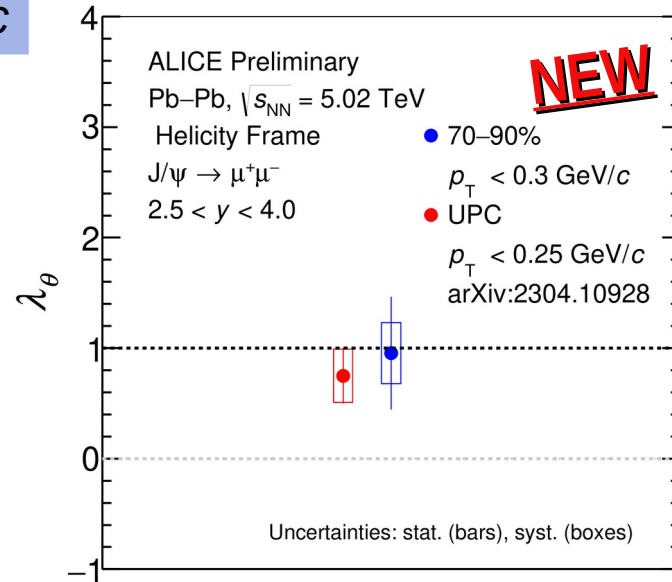
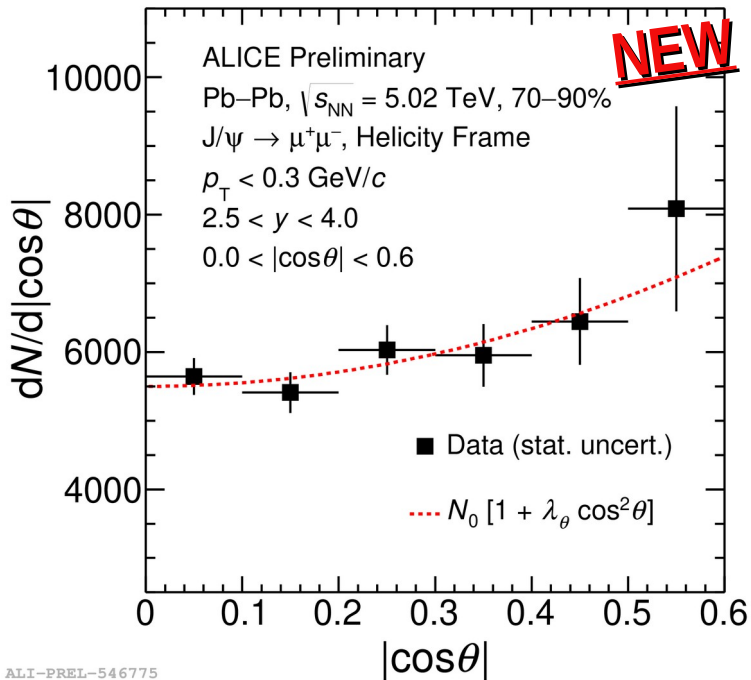


ALI-PREL-546765

Inclusive J/ψ polarization in Pb–Pb collisions

J/ψ → μ⁺μ⁻, 70–90%, 2.5 < y < 4, p_T < 0.3 GeV/c

- A hint for transverse polarization from cosθ angular distribution



ALI-PREL-546778

- The λ_θ parameter is consistent with the UPC measurement for coherently photoproduced J/ψ within uncertainties
 - As expected in this kinematic region, where J/ψ coherent photoproduction dominates over the J/ψ hadronic production [[arXiv:2204.10684](https://arxiv.org/abs/2204.10684)]

ALI-PREL-546775

- **First y -differential measurement of coherent J/ψ photoproduction cross section** in peripheral Pb–Pb collisions (PC) with nuclear overlap at $\sqrt{s_{\text{NN}}} = 5.02$ TeV for $p_{\text{T}} < 0.3$ GeV/ c
 - **Shows a strong y -dependence similar to that observed in Ultraperipheral collisions (UPC).**
 - Measurements are qualitatively described by a large number of vector meson photoproduction models developed for UPC and extended to PC, but fail at reproducing the y -dependence (similarly to UPC)
- **First inclusive J/ψ polarization measurement for $p_{\text{T}} < 0.3$ GeV/ c** in peripheral Pb–Pb collisions with nuclear overlap at $\sqrt{s_{\text{NN}}} = 5.02$ TeV
 - In **agreement with the UPC transverse polarization** measurement and **consistent with a major contribution from a photoproduction** process in the region of study.

- **The coherent J/ψ photoproduction cross section measurement can be exploited to extract photonuclear cross sections in two Bjorken- x regions** [[J.G. Contreras, Phys. Rev. C 96, 015203 \(2017\)](#)]
- **ALICE Run 3 will provide a large Pb-Pb data sample**
 - **will permit to study J/ψ photoproduction in the most central collisions, to better constrain models (especially the role of spectator nucleons in the coherence condition)**
 - **Look at heavier vector mesons could become also possible to pin down possible QGP effects on the measured probes.**

Backup

Luminosity in Run2



- LHC Run 2 (2015-2018) @ $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$,

$L_{\text{int}} \sim 700 \mu\text{b}^{-1}$ of Pb–Pb data

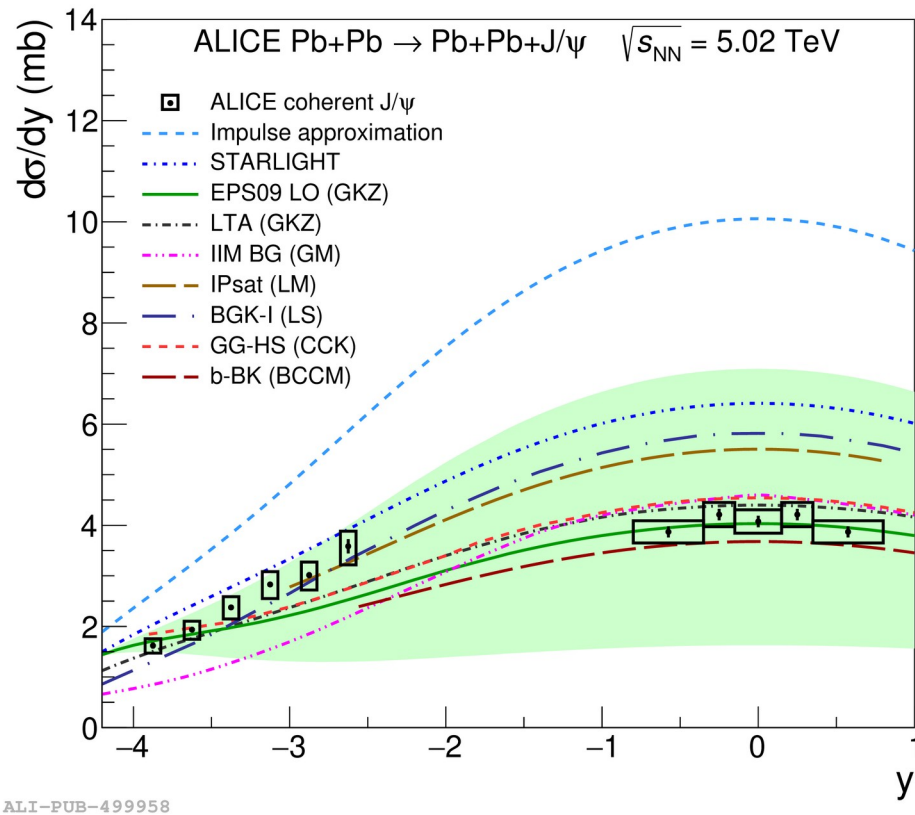
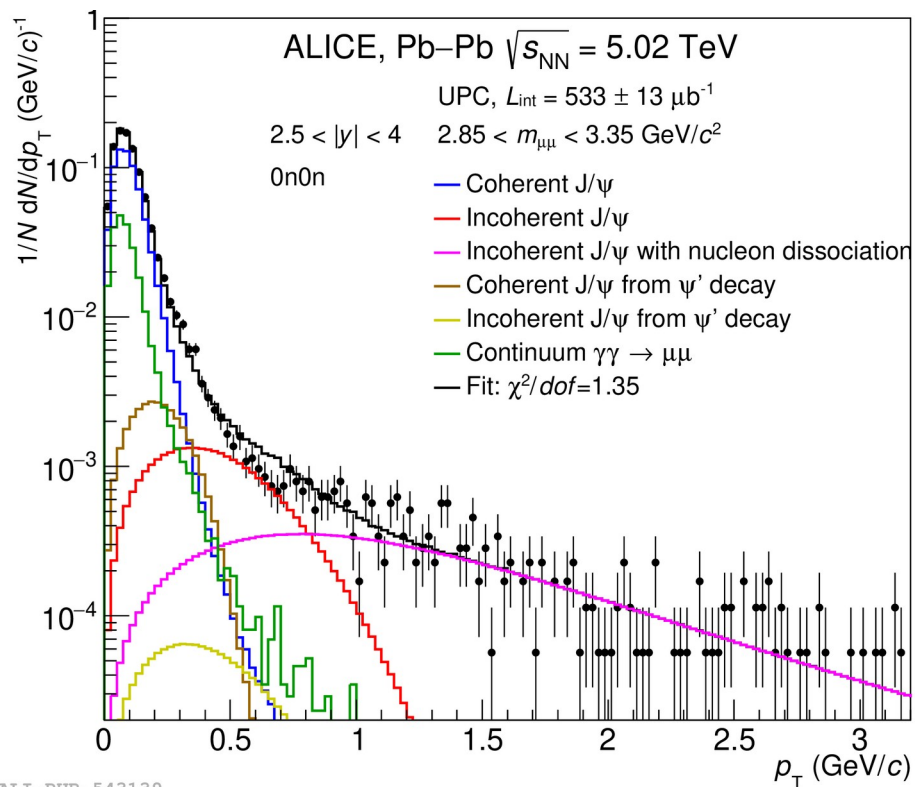
$L_{\text{int}} = 1.2 \text{ pb}^{-1}$ of pp data

collected with the dimuon trigger at $2.5 < y < 4$

Photoproduction in UPC



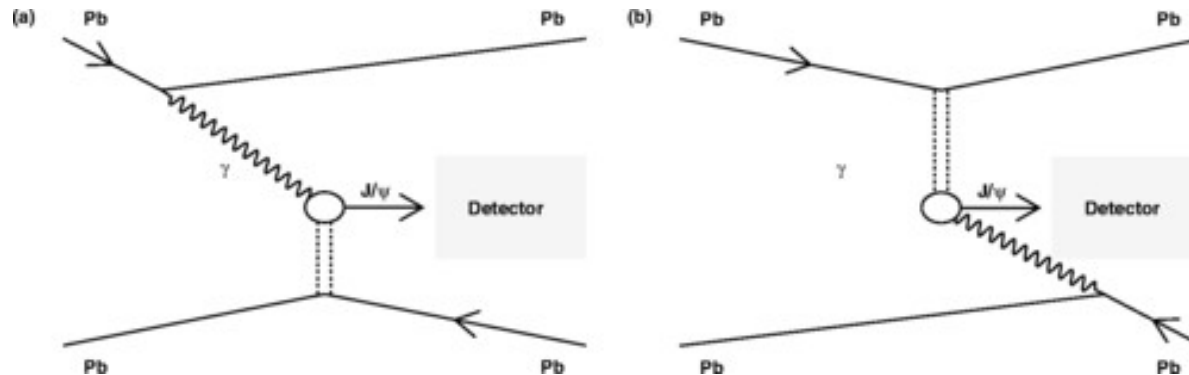
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Impulse approximation neglect nuclear shadowing, while data is consistent with models that consider the nuclear shadowing

Photon-emitter ambiguity

- Each colliding nucleus could serve as a photon emitter, the other acts as a target (+/- y)
- Contribution from low/ high x_g $x_B = (m_{J/\psi} / \sqrt{s_{NN}}) \times \exp(\pm y)$
- Proposed solution by [\[J. G. Contreras, PRC 96, 015203 \(2017\)\]](#) :
 - use PC measurement with the previous UPC measurement to disentangle the contribution from the low and high energy photon-nucleus interaction.
- Caveat: this suggestion considers the photon-nucleus cross sections in both PC and UPC to be the same.



Coherent J/ψ photoproduction scenarios via photon-pomeron coupling at ALICE

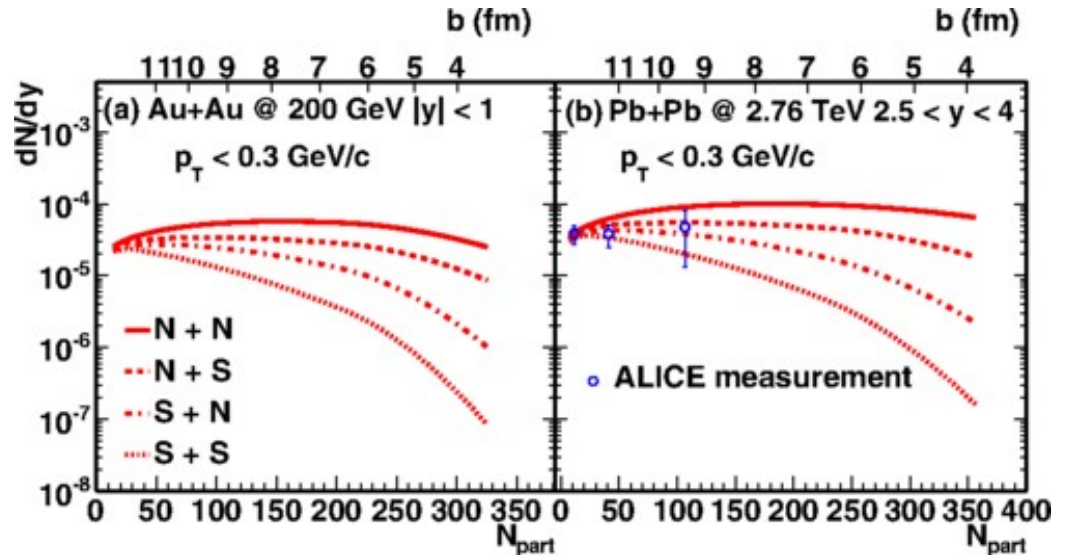


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- The coherent J/ψ photoproduction cross section is convolution of the photon flux and the photo-nucleus cross section.
- The γ -flux is extended from UPC \rightarrow PC by including the hadronic interactions.
- The $(\gamma$ -A) cross section is extended from UPC \rightarrow PC
 - Includes a destructive interference effect.
 - considers the hadronic interactions effect using the spectators as emitters instead of the whole nucleus.

- Photon emitter-Pomeron emitter coupling scenarios with interference:

- **Nucleus+Nucleus**
- - - **Nucleus+Spectator**
- · - · **Spectator+Nucleus**
- · · · **Spectator+Spectator**



[W. Zha et al., Phys. Rev. C 97, 044910 (2018)]