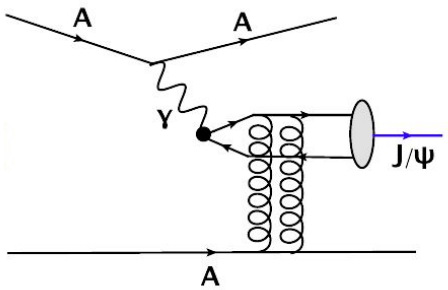
J/ψ photoproduction in Pb-Pb collisions with nuclear overlap at $\sqrt{s_{NN}}$ = 5.02 TeV with ALICE

Afnan Shatat
(IJCLab, Orsay)

Rencontres QGP France, Bagnoles de l'Orne, 28 June 2023

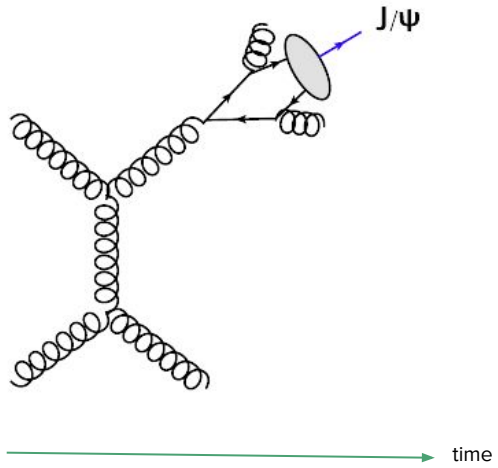
J/ψ production mechanisms in heavy ion collisions

- **Photoproduction**
  - Ultrarelativistic Pb ions are strong EM field emitter
  - Photoproduction could be
    - Coherent:
      photon sees the whole target nucleus ➔ nucleus doesn't break ➔ small transferred momentum ➔ low p_T J/ψ ($\langle p_T \rangle \approx 60$ MeV/c).
    - Incoherent: photon sees one nucleon ➔ larger momentum transfer
      ➔ slightly larger p_T J/ψ ($\langle p_T \rangle \approx 500$ MeV/c).



Exclusive production

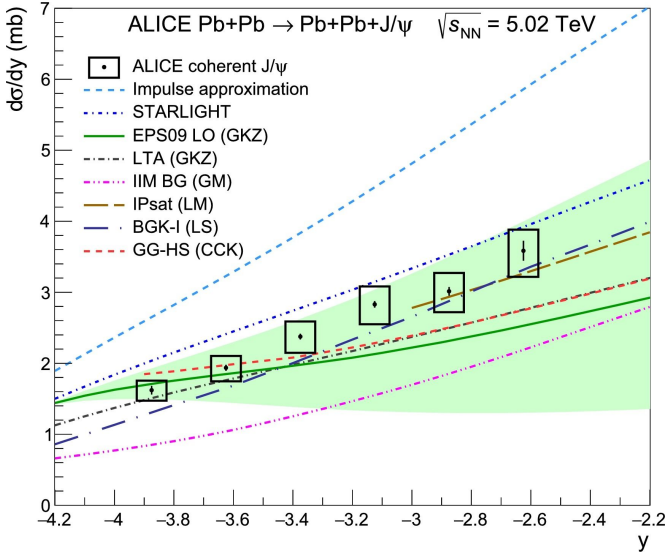
- **Inclusive hadronic production**
  - Direct J/ψ:
    (dominated by gluon fusion at high energies).
  - Indirect feed down:
    e.g., ψ(2S) ➔ J/ψ
  - Non prompt: b hadrons ➔ J/ψ



J/ψ photoproduction in ultraperipheral collisions UPC

- Ultraperipheral collisions (UPC)
  - Since b > ($R_1 + R_2$)
  - ➔ Suppressed hadronic interactions

    ➔ Allow to study the photo-nuclear interaction & photon-photon interactions.



- J/ψ photoproduction in heavy ion collisions is well studied in UPC, e.g,
  - **PHENIX** in Au+Au collisions at $\sqrt{s_{NN}}$= 200 GeV, [PLB 679 (2009) 321–329]
  - **ALICE** in Pb-Pb collisions at $\sqrt{s_{NN}}$= 2.76 TeV, [PLB 718 (2013) 1273–1283]
  - **CMS** in Pb-Pb collsioins at $\sqrt{s_{NN}}$= 2.76 TeV, [PLB 772 (2017) 489–511]
  - **ALICE** in Pb-Pb collisions at $\sqrt{s_{NN}}$= 5.02 TeV, [PLB 798 (2019), 134926]

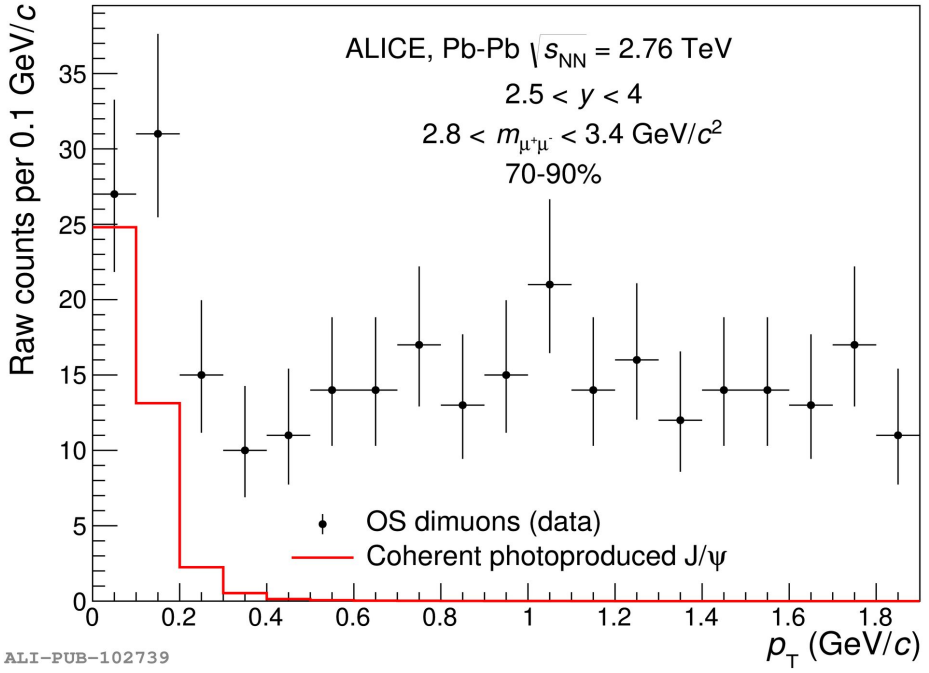
- Physics of interest with J/ψ photoproduction in UPC
  - **Probe of the gluon distributions in the target nuclei g(x_g, Q^2),** where x_g is the fraction of the nucleon longitudinal momentum carried by the gluon, Q^2 is the transferred momentum in the process.

Excess yield of J/ψ at low p_T at forward rapidity in peripheral Pb-Pb collisions

- ALICE reported the first observation of an excess in the yield of J/ψ over the expected hadronic yield at low $p_T < 0.3$ GeV/c at $\sqrt{s_{NN}} = 2.76$ TeV in Pb-Pb collisions in the centrality class (70-90)% at forward rapidity.
  [Phys. Rev. Lett. 116 (2016) 222301].

- Interpreted as a coherent photoproduction of J/ψ.

ALICE Collaboration, Phys. Rev. Lett. 116 (2016) 222301

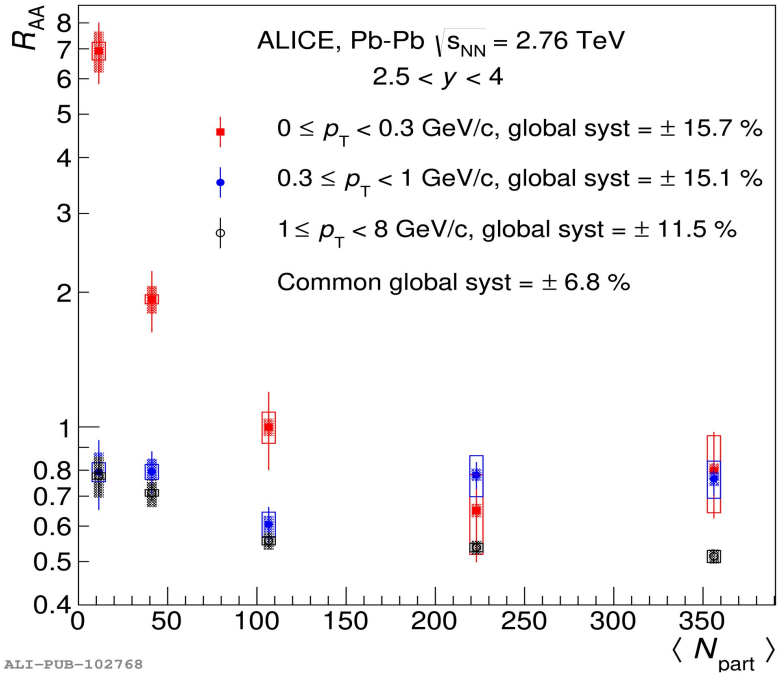


p_T distribution of the dimuon yield in the J/ψ mass window.

Nuclear modification factor R_{AA} in peripheral Pb-Pb collisions

$$R_{AA} = \frac{N_{AA}}{< T_{AA} > .\sigma_{pp}}$$

- ALICE reported a dramatic increase in the J/ψ R_{AA} at p_T< 0.3 GeV/*c* in Pb-Pb collisions in the centrality classes (70-90)% and (50-70)%)at $\sqrt{s_{NN}}$= 2.76 TeV [Phys. Rev. Lett. 116 (2016) 222301].
- A production mechanism other than the hadronic mechanism is expected ⇒ supporting the photoproduction hypothesis along with the previous excess yield p_T shape.



Theoretical models of J/ψ photoproduction in heavy ion collisions

J/ψ photoproduction cross section can be written as

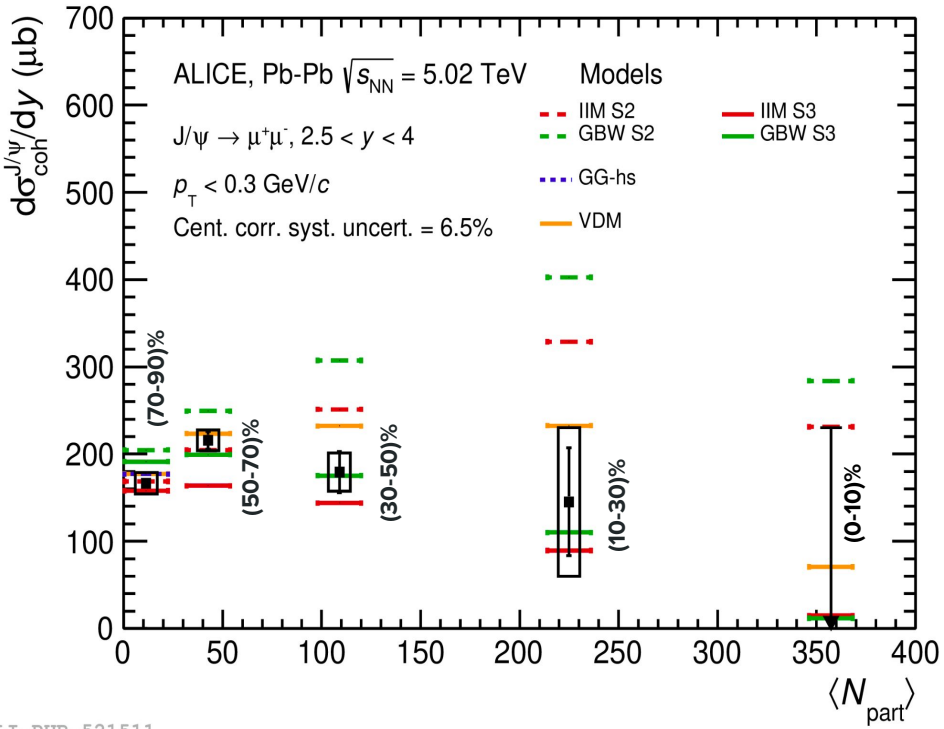
$$\sigma(\mathrm{AA} \to \mathrm{AAJ}/\psi) = \int d\omega_\gamma \frac{dN_\gamma(\omega_\gamma)}{d\omega_\gamma} \sigma(\gamma A \to \mathrm{J}/\psi A)$$

Modify the γ-flux from ultraperipheral to peripheral collisions, e.g., the IIM S2, GBW S2 [1], GG-hs [2] and VDM [3] models

Both the γ-flux and the photo-nuclear cross section is modified from ultraperipheral to peripheral collisions, e.g., IIM S3, GBW S3 [1] and W.Zha [4].

[1] M.B. Gay Ducati et al., Phys. Rev. D 97, 116013
[2] J. Cepila et al., Phys. Rev. C 97, 024901
[3] M. Kłusek-Gawenda and A. Szczurek, Phys. Rev. C 93, 044912
[4] W. Zha et al., Phys. Rev. C 99, 061901

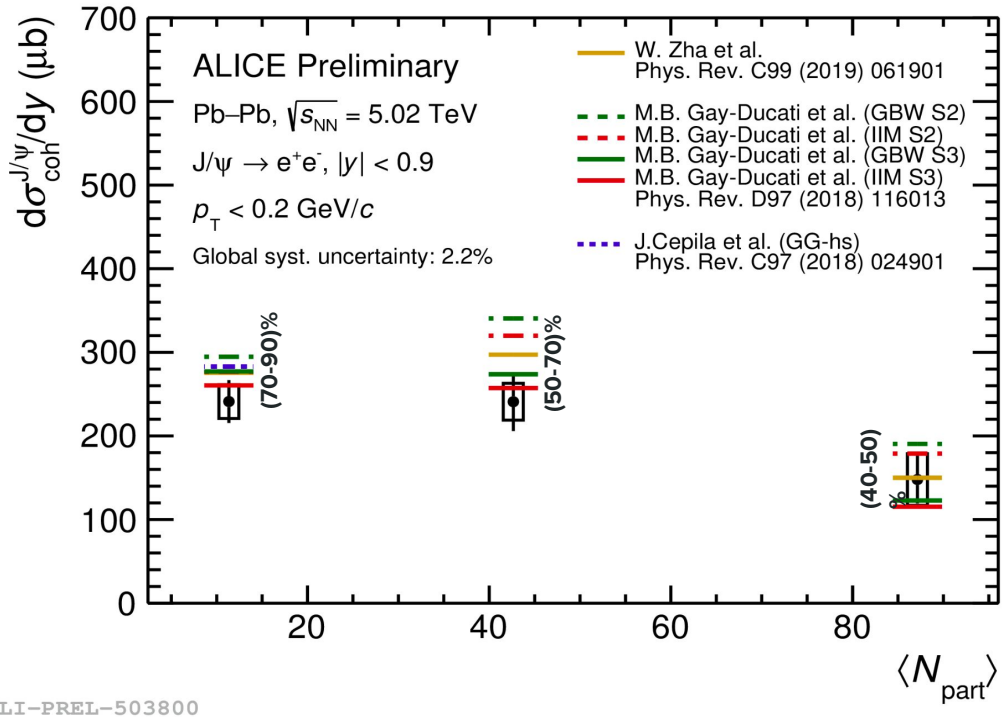
Coherent J/ψ photoproduction cross section at forward rapidity



arXiv:2204.10684

- Measurement is in a qualitative agreement within uncertainties with models that modify the photoproduction cross section computations from UPC to PC
- In (70-90)% centrality, all models work fine, as expected, since the overlap effect (if any) is expected to be small.
- In semicentral and central collisions, data is reproduced by GBW/IIM S3 (γ-flux and $\sigma_{\gamma\text{-nucleus}}$ modified) and by VDM (γ-flux modification only).

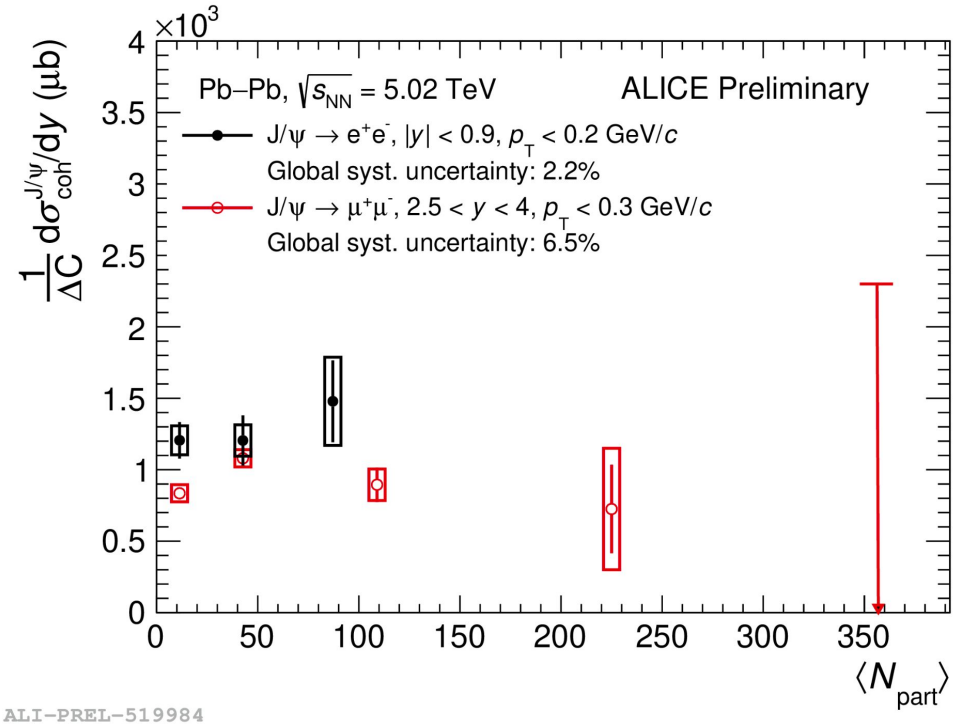
Coherent J/ψ photoproduction cross section at midrapidity



ALI-PREL-503800

- Measurements are in agreement with most of the models within uncertainties. Better experimental precision is needed in semicentral events to constrain the models.
- Many models can reproduce the data qualitatively both at forward and midrapidity.

Coherent J/ψ photoproduction cross section

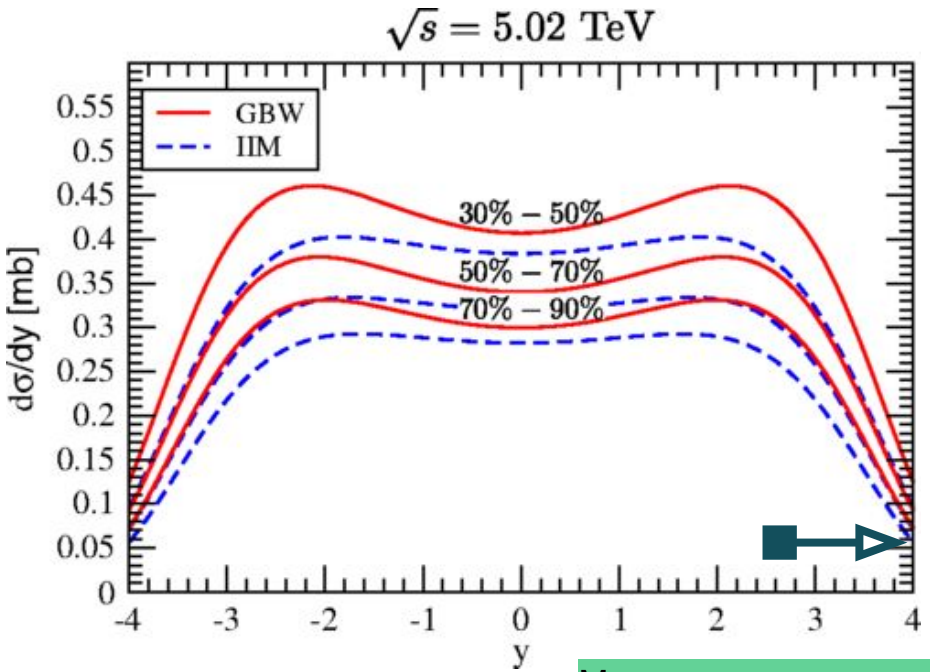


ALI-PREL-519984

The measured cross section is centrality independent within uncertainties both at mid rapidity and forward rapidity.

y-differential study of coherent J/ψ photoproduction at forward rapidity

[1] M.B. Gay Ducati et al., Phys. Rev. D 97, 116013



Muon spectrometer y coverage

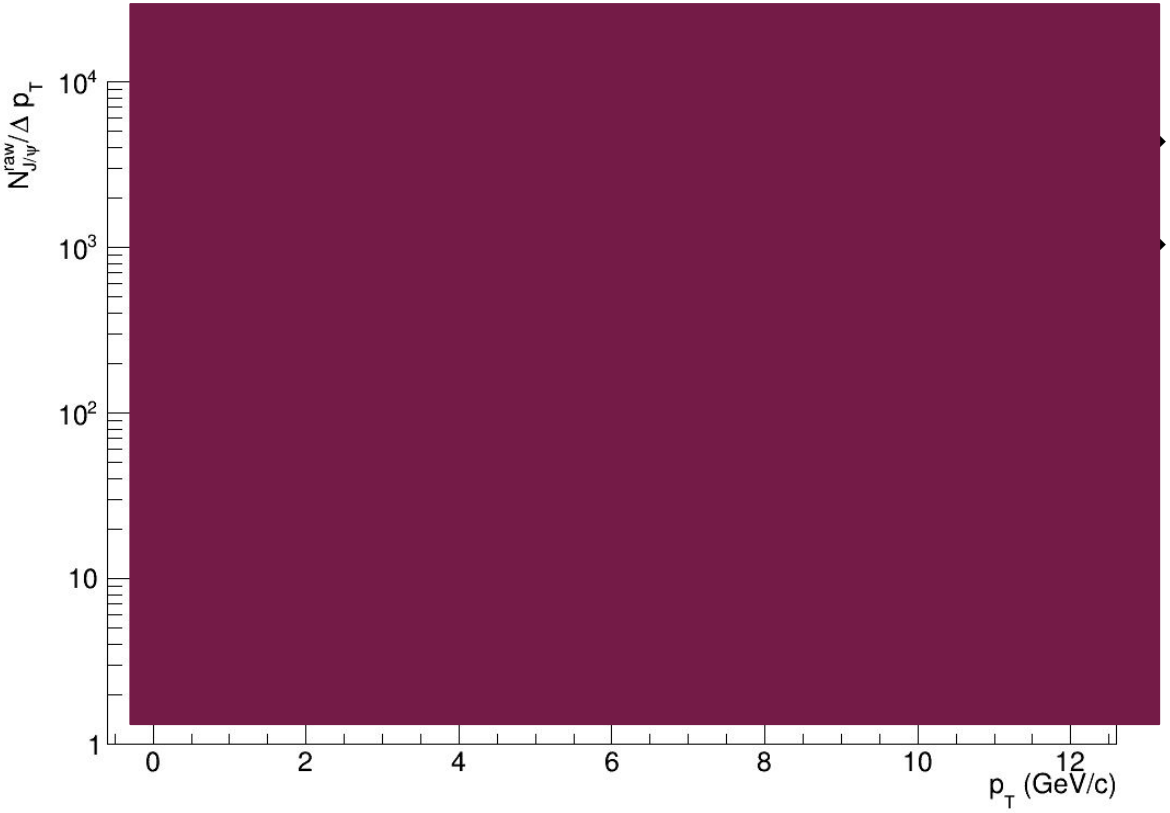
- Theoretical models expect a strong y-dependence in the forward rapidity region.
- More precise and differential measurements are needed to constrain theoretical models describing the coherent J/ψ photoproduction mechanism.

Methodology to extract the coherent J/ψ photoproduction cross section in rapidity intervals, in peripheral Pb-Pb collisions (70-90)%

1. Raw J/ψ yield extraction in (y, p_T) intervals.
2. Modeling the hadronic J/ψ background to get the excess yield of J/ψ at low p_T, using σ_{pp} and $R_{AA}(y, p_T)$ as a baseline for the computations.
3. Calculate the coherent J/ψ yield by correcting the J/ψ yield excess for the incoherent J/ψ and the coherent ψ(2S) feed down contributions.
4. The coherent J/ψ cross section is calculated as follows

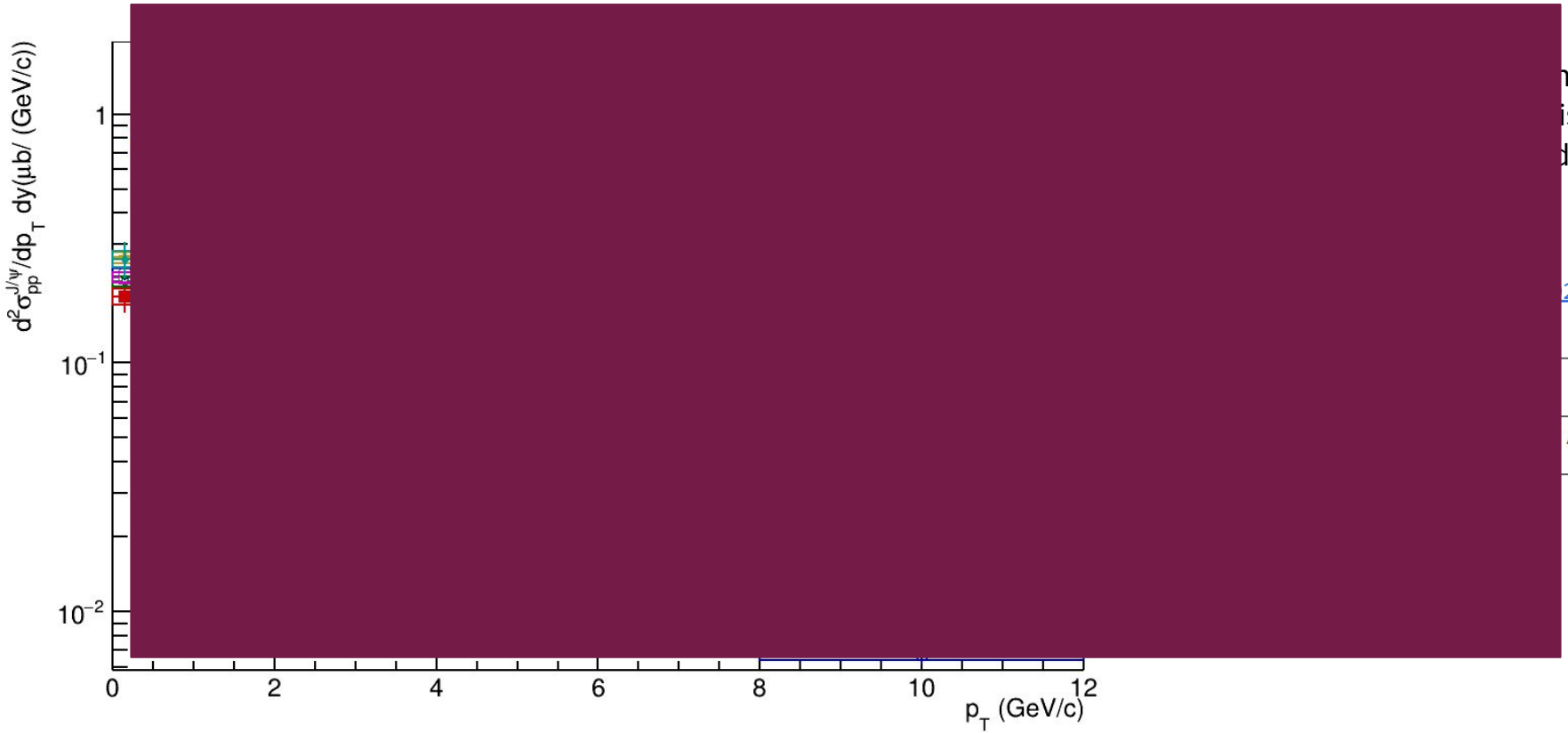
$$\frac{d\sigma_{Pb-Pb}^{coh\ J/\Psi\ photo}}{dy}\left[p_T < 0.3\,GeV/c\right] = \frac{N_{J/\Psi}^{coh}}{(\mathscr{A} * \varepsilon)^{coh\ J/\Psi}.BR(J/\Psi \to \mu^+\mu^-).\mathscr{L}.\Delta y}$$

p_T-differential raw J/ψ yield in y-intervals in (70-90)% Pb-Pb collisions



An excess in $N_{J/\psi}$ at $p_T < 0.3$ GeV/c is clearly visible in all y-intervals. Similarly, the raw J/ψ yield is extracted in pp collisions at the same center of mass energy, in the same kinematic bins.

J/ψ σ_{pp} for six y-intervals in 2.5 < y < 4 at 5.02 TeV



The $R_{AA}(p_T)$ evolution with rapidity in $2.5 < y < 4$

[1] ALICE Collaboration, arXiv:2303.13361
[2] ALICE Collaboration, arXiv:2204.10684

Estimation of coherent J/ψ yield at low p_T

Hadronic J/ψ in p_T range [0, 0.3] GeV/c is estimated using the following model

$$\int_0^{0.3} \frac{dN_{AA}^{h\,J/\psi}}{dp_T} dp_T = \mathcal{N} \times \int_0^{0.3} \frac{d\sigma_{pp}^{h\,J/\psi}}{dp_T} \times R_{AA}^{h\,J/\psi} \times (\mathcal{A} \times \varepsilon)_{AA}^{h\,J/\psi}(p_T)\, dp_T$$

$N_{AA}^{J/\psi}$

$N_{J/\psi}^{coh}$

Whe

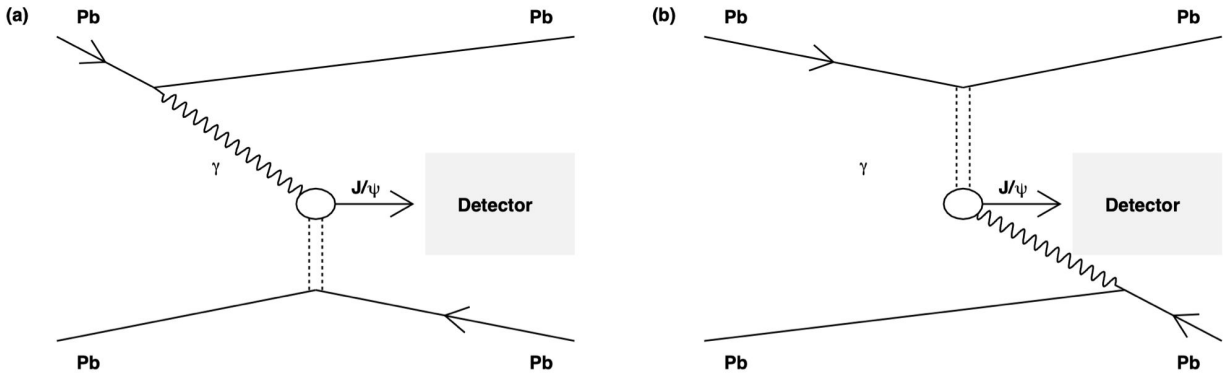
f_D: c

❖

❖

An idea to disentangling the low and high x_g contributions in J/ψ photoproduction

- Each colliding nucleus could serve as a photon emitter, the other acts as a target (±y)
  - Contribution from low/ high x_g $\quad x_g = (M_{J/\Psi}/\sqrt{S_{NN}})\, e^{\pm y}$
  - Proposed solution by J. G. Contreras (PRC 96, 015203 (2017):
    Considers the photon-nucleus cross sections in both PC and UPC to be the same.
    One can use PC measurement with the previous UPC measurement (same binning in y) to disentangle the contribution from the low and high energy photon-nucleus interaction.



Conclusion

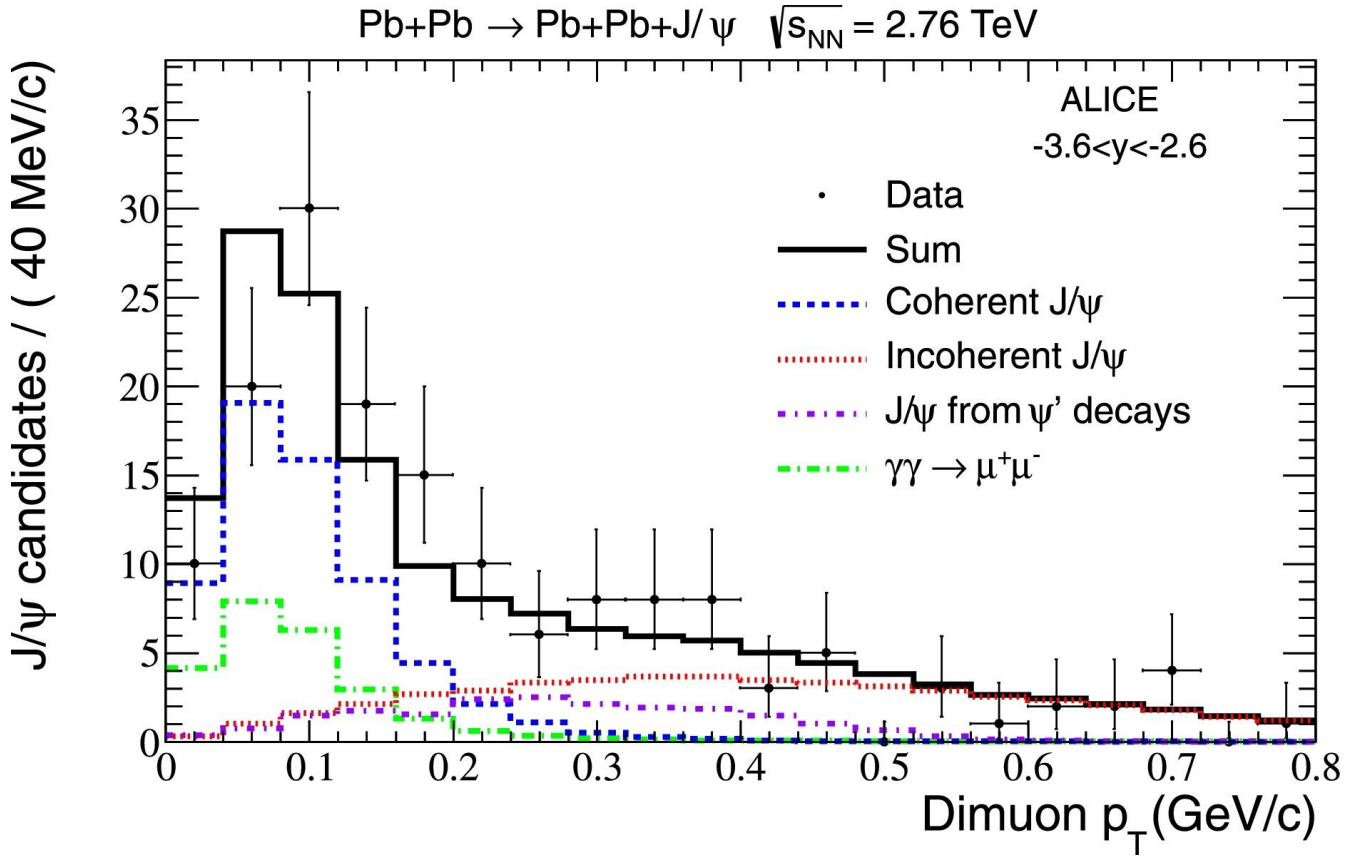
- ★ Coherent J/ψ photoproduction is studied in heavy ion collisions both at forward and mid rapidity in ALICE.
- ★ Many models can reproduce the data qualitatively, but further constraints are needed on the models.
- ★ Many theoretical challenges are raised, questioning about the coherence condition definition and its survival while the target nucleus is broken.
- ★ A rapidity differential coherent J/ψ photoproduction cross section measurement analysis is on going with Pb-Pb collisions with nuclear overlap in ALICE.
- ★ Along with the UPC measurement, this measurement will help to disentangle low and high Bjorken-x contributions to the photon-nucleus cross section.
- ★ Coherent J/ψ photoproduction cross section is to be computed along with the associated systematic uncertainties.

Backup

Theoretical models of the coherent J/ψ photoproduction

- In the hot spot models (GG-hs & GS-hs), Golec-Biernat and Wusthoff (GBW) and Iancu-Itakura-Munier (IIM) dipole models
  - The coherent J/ψ photoproduction cross section is factorized into the photon flux and the photo-nucleus cross section.
  - The γ-flux is extended from the known flux, the Weizsacker-Williams virtual photon spectra, in UPC ⇒ PC, considering the fact that there is a nuclear overlap.
- In the hot spot model [J. Cepila, J. G. Contreras, and M. Krelina, Phys. Rev. C 97, 024901 (2018)]
  - The proton structure in the b plane is an energy dependent hot spot profile; regions of high-gluon density.
  - To calculate the photo-nucleus cross section, it is interpolated from the γp case to γA case by two approaches: standard Glauber-Gribov(GG) formalism and Geometrical Scaling (GS).
  - Both uses the GBW dipole-proton cross section.
  - GG uses the proton saturation scale while GS calculates a nuclear saturation scale.
- In the Golec-Biernat and Wusthoff (GBW) and Iancu-Itakura-Munier (IIM) dipole models [M.B. Gay Ducati and S. Martins, Phys. Rev. D 97, 116013 (2018)]
  - To calculate the photo-nucleus cross section, the color dipole formalism is considered.
  - IIM model is based on a Color-Glass-Condensate approach.
  - GBW model implemented two scenarios, one includes modified γA cross section and one does not. The model we are comparing to in this presentation does not include the modification.

UPC: p_T spectrum of J/ψ candidates from various contributions



ALICE collaboration, Phys. Lett. B 718 (2013) 1273–1283