

J/ψ production and polarization in photon-induced reactions in Pb–Pb collisions with ALICE

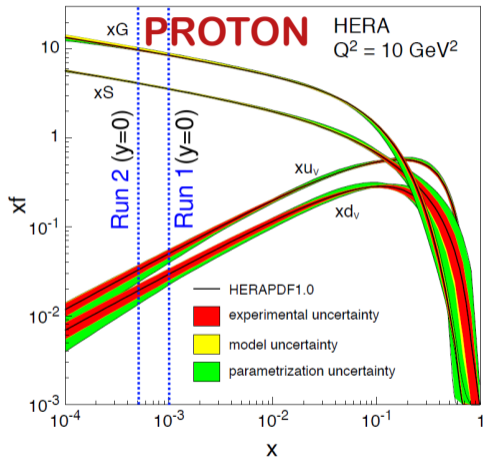
International Conference on High Energy Physics 2024

Roman Lavička on behalf of the ALICE Collaboration

July 18, 2024, Prague, Czechia

Where QCD is now

- The proton is dominated by gluons for Bjorken- $x < 10^{-2}$ (HERA).

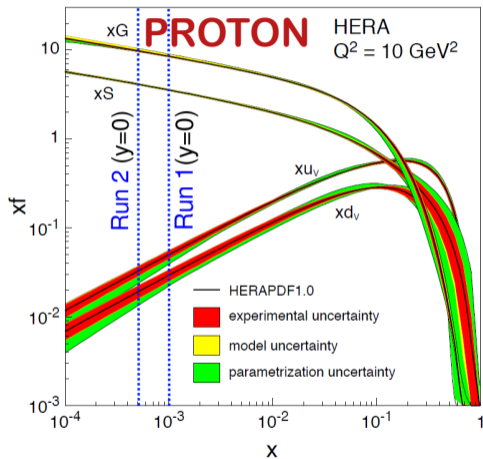


Accardi et. al.: Eur.Phys.J.A 52 (2016) 9, 268

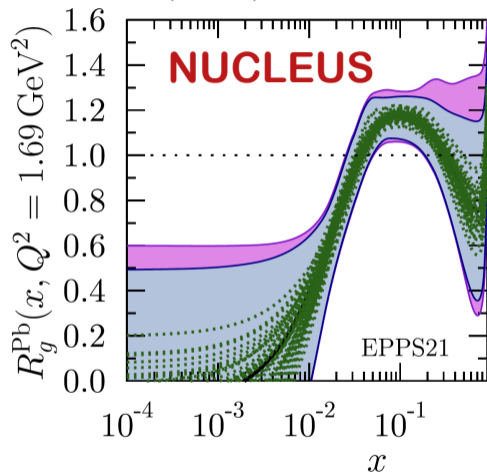
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Accardi et. al.: Eur.Phys.J.A 52 (2016) 9, 268



Eskola et. al.: Eur.Phys.J.C 82 (2022) 5, 413

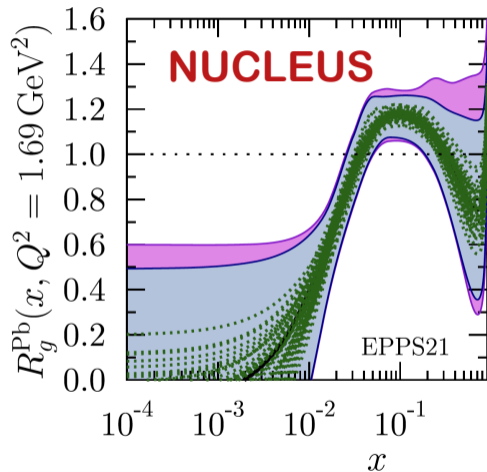
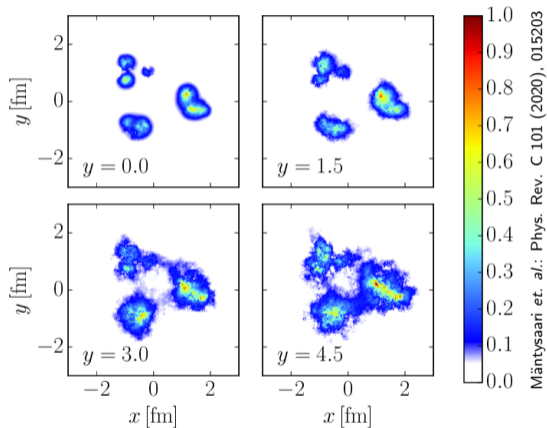
- The LHC gives the possibility to measure the gluonic structure of the **proton** and **nuclei** to study **saturation** and **shadowing** at small Bjorken- x .

Where QCD is now



ALICE

- Transverse gluon distribution is non-trivial due to quantum fluctuations.



- The LHC allows us to measure the gluonic structure of **nuclei** at **different** small Bjorken- x .

Some important QCD questions



Some important QCD questions



What is the Bjorken- x evolution of the gluon structure?
Measure the dependence on the transferred energy.

Some important QCD questions



What is the Bjorken- x evolution of the gluon structure?

Measure the dependence on the transferred energy.

Can we learn more about structures inside nucleus?

Measure the dependence on the momentum transfer $|t|$.

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Can we find more tools for studying above?

Identify the coherent photoproduction in events with nuclear overlap.

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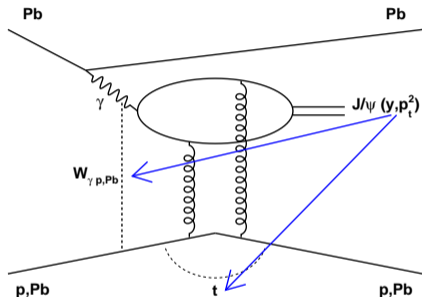
Can we find more tools for studying above?

Identify the coherent photoproduction in events with nuclear overlap.

ALICE has made extensive studies of these topics!

Vector meson photoproduction to study gluon distributions

- At lowest order:

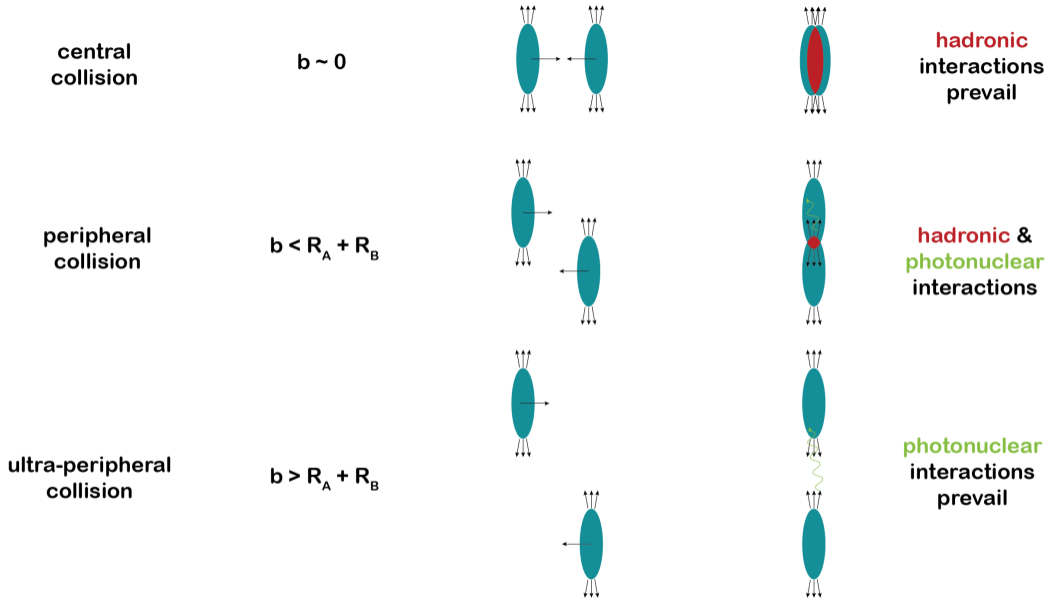


$$W_{\gamma\text{Pb}}^2 = 2E_{\text{Pb}} M_{J/\psi} e^{-y}$$

$$\text{Bjorken-}x = \frac{M_{J/\psi}^2}{W_{\gamma\text{Pb}}^2}$$

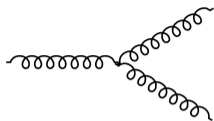
$$t = (p_{i,\text{target}} - p_{f,\text{target}})^2 c^2$$

- Different mesons, rapidities, transverse momenta, targets \rightarrow different transferred energies (Bjorken- x), transferred momenta.
- Provides information on gluon distribution in proton and nuclei.

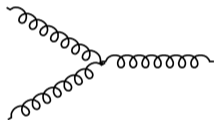


Ultra-peripheral collisions Hunting down gluon saturation in the proton

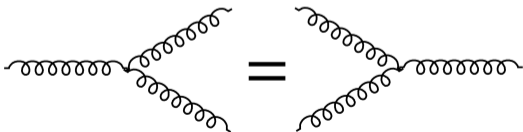
When gluons abundance saturate



Gluon splitting



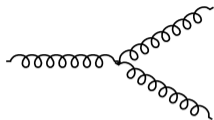
Gluon recombination



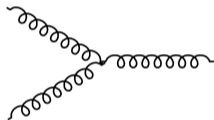
Gluon saturation

- QCD allows gluons-only vertex.
- Gluon abundance different at different scales.
- When splitting dominates, gluon density rises.
- With higher energies, probability of gluon recombination increases.
- At some point, these two processes equal and gluon density stops rising with energy.
- **Gluon saturation.**
- **Q:**

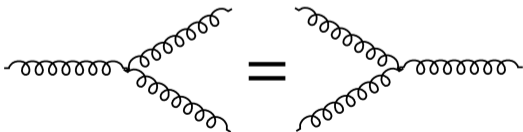
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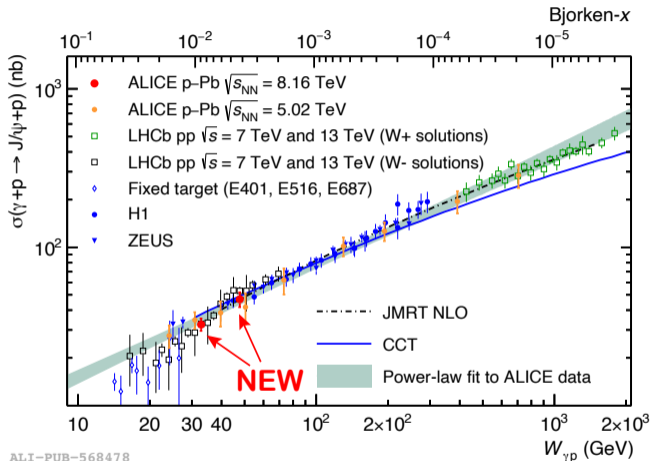
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- **Gluon saturation.**
- **Q: When does this regime start?**

Exclusive J/ψ in proton-lead collisions



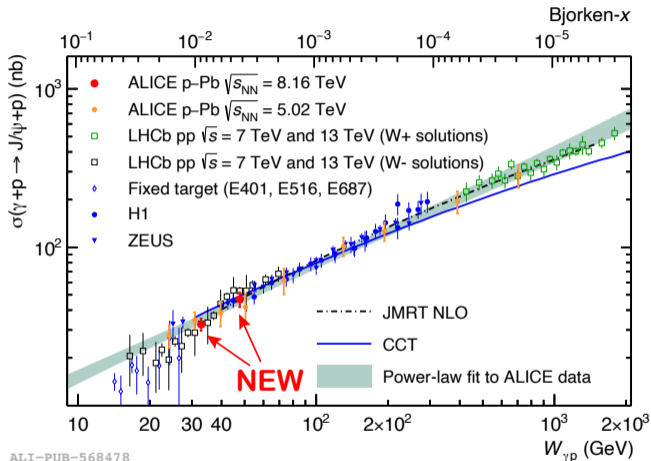
ALICE: Phys. Rev. D 108, 112004 (2023)

- Pb is source of photons

$$\text{Bjorken-}x = \frac{M_{J/\psi}}{2E_p} \exp^{\pm y}$$

- Proton probed down to $x = 10^{-5}$

Exclusive J/ψ in proton-lead collisions



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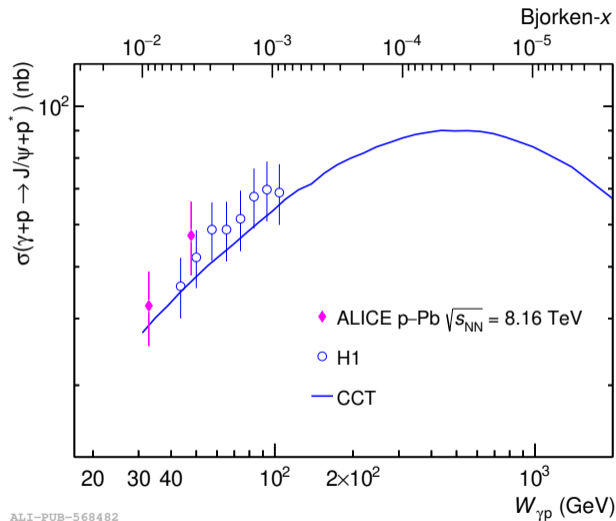
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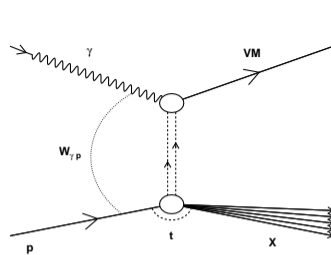
- **Current data compatible with power-law growth.**

Dissociative J/ψ in proton-lead collisions



ALI-PUB-568482

ALICE: Phys. Rev. D 108, 112004 (2023)



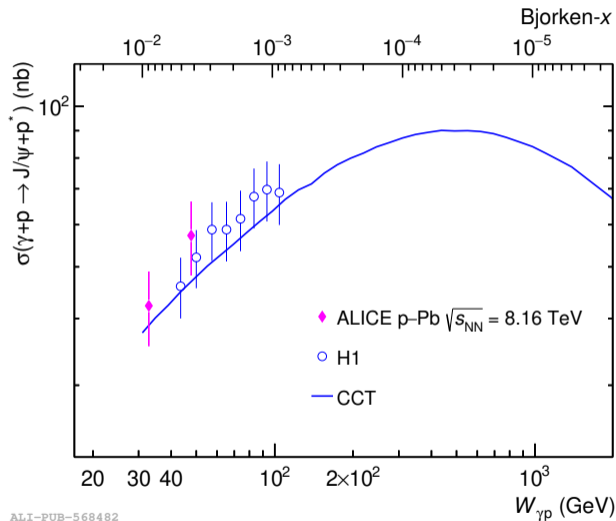
$$\text{Bjorken-}x = \frac{M_{J/\psi}^2}{W_{\gamma p}^2}$$

- CCT model describes data well.

Cepila et. al.: Phys. Lett. B 766 (2017) 186

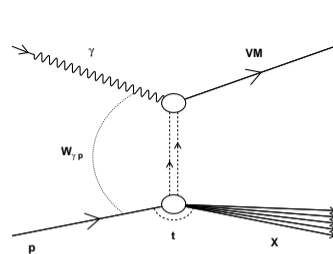


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- **Predicts saturation at 500 GeV.**

- More data needed.



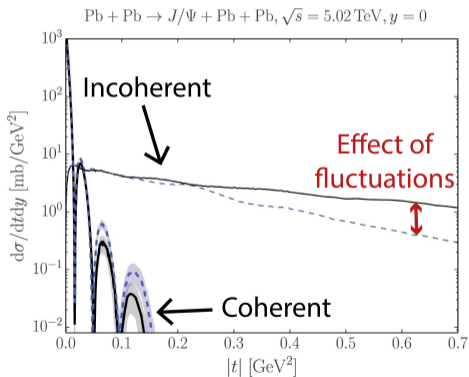
Ultra-peripheral collisions
 $|t|$ -dependence
of the photonuclear cross section

Coherent vs incoherent photonuclear production



ALICE

Type of process	γ interacts with	Target final state	$\sigma_{\gamma\text{Pb}}$ sensitive to	$\langle p_T \rangle$ of J/ψ
Coherent	whole nucleus	intact	average target configuration	~ 60 MeV
Incoherent elastic Incoherent dissociative	single nucleon	breaks up	variance over target configuration	~ 300 MeV ~ 500 MeV



$$t = (p_{i,\text{target}} - p_{f,\text{target}})^2 c^2$$

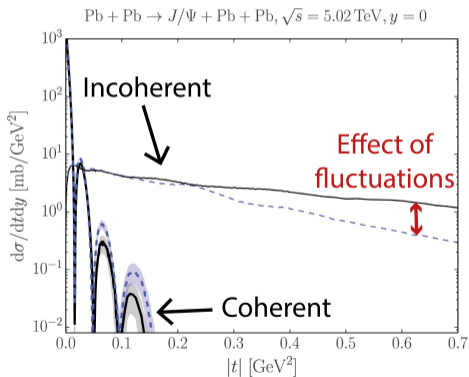
- Wider $|t|$ -distribution \rightarrow scatter of smaller object.
- Variations \rightarrow quantum fluctuations.
- Fluctuations = subnucleon degrees of freedom.
- **Q:**

Mäntysaari *et. al.*: Phys. Lett. B 772 (2017) 832-838

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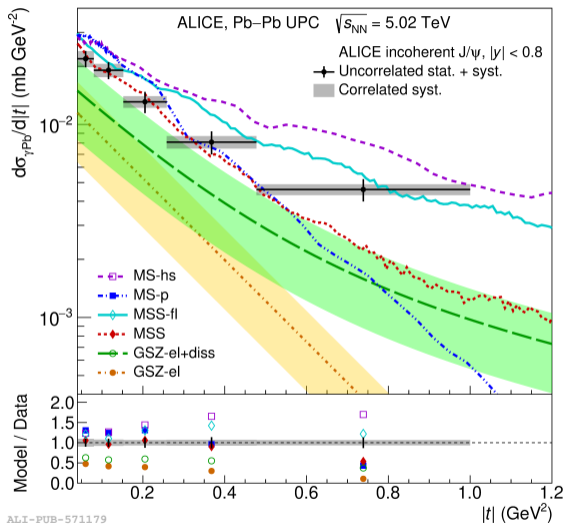
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- **Q: Are subnucleon dof. significant?**

Mäntysaari *et. al.*: Phys. Lett. B 772 (2017) 832-838

$|t|$ -dependence of incoherent J/ψ photonuclear cross section



ALICE



ALI-PUB-571179

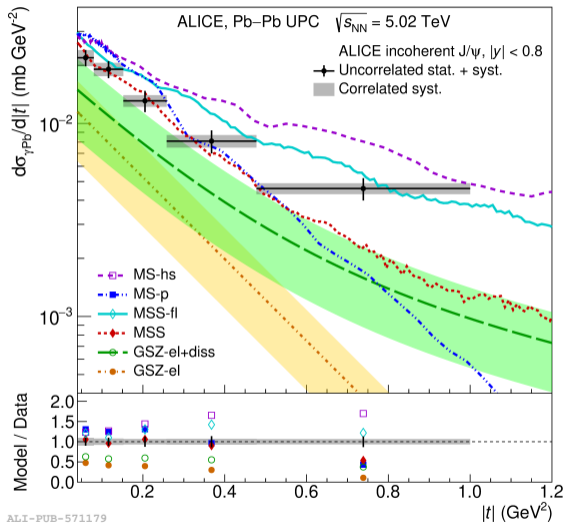
ALICE: Phys. Rev. Lett. 132, 162302 (2024)

- Two groups, each offering two options:
 - Nucleon has no internal structure:
MS-p, **MSS**, **GSZ-el**.
 - Nucleon has subnucleon dof:
MS-hs, **MSS-fl**, **GSZ-el+diss**.
- No model fully describes data, but...

$|t|$ -dependence of incoherent J/ψ photonuclear cross section



ALICE



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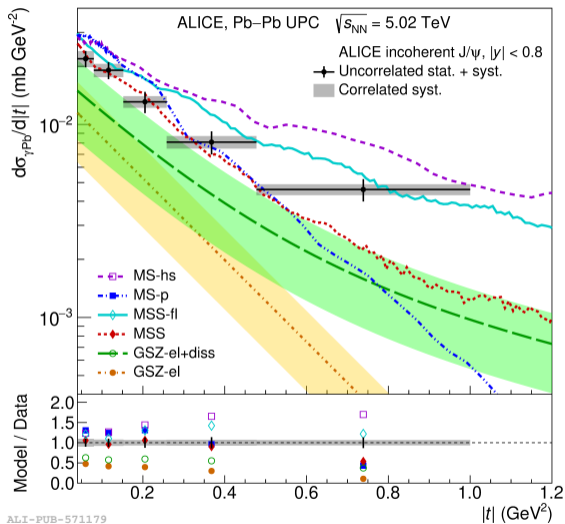
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- Normalization linked to the scaling from proton to nuclear targets.

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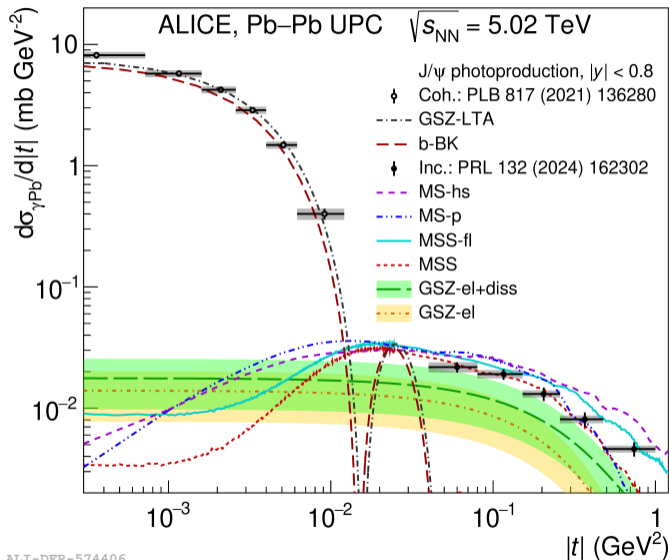


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- **...slope favors subnucleon dof!**
- Normalization linked to the scaling from proton to nuclear targets.
- **Probing for gluonic "hot spots" in Pb for the first time!**

Larger picture: coherent + incoherent J/ψ photoproduction



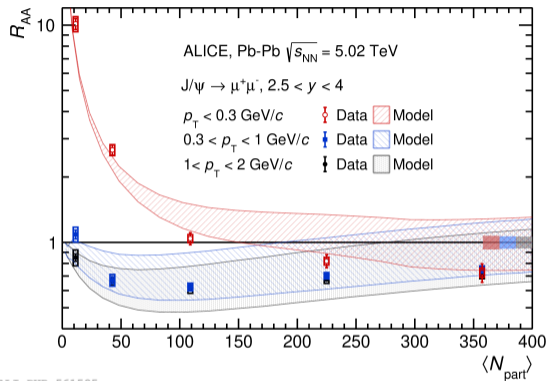
- ALICE covers three orders of magnitude in $|t|$ with a HERA-like accuracy.

- **Study target size and subnucleonic structure!**

Collisions with nuclear overlap

Disentangle hadro- and photoproduction

VM photoproduction in collisions with nuclear overlap



ALI-PUB-561525

ALICE: Phys. Lett. B 846, 137467 (2023)

$$R_{AA}(p_T) = \frac{N_{J/\psi}^{\text{Pb-Pb}}}{\langle T_{AA} \rangle \sigma_{J/\psi}^{\text{PP}}}$$

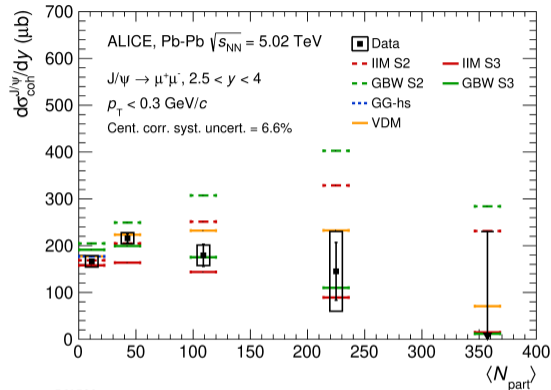
- Dramatic increase of R_{AA} at low p_T !
- **Model:** coherent photoproduction + hadroproduction with QGP effects (colour screening and c-quark recombination)

Shi et. al.: Phys. Lett. B 777 (2018) 399-405

- Model describes the data very well \rightarrow enhancement interpreted as

coherent photoproduction.

Coherent J/ψ photoproduction centrality dependence: fwd rapidity



ALI-PUB-561530

ALICE: Phys. Lett. B 846, 137467 (2023)

■ Mild centrality dependence

within uncertainties compatible with no variation at (semi-)peripheral centralities.

■ GG-hs: W-dependent hot-spot model

Klusek-Gawenda *et. al.*: Phys. Rev. C 93, 044912 (2016)

■ γ flux constrains on b range.

■ VDM: Vector dominance model

Gay Ducati *et. al.*: Phys. Rev. D 9,7 116013 (2018)

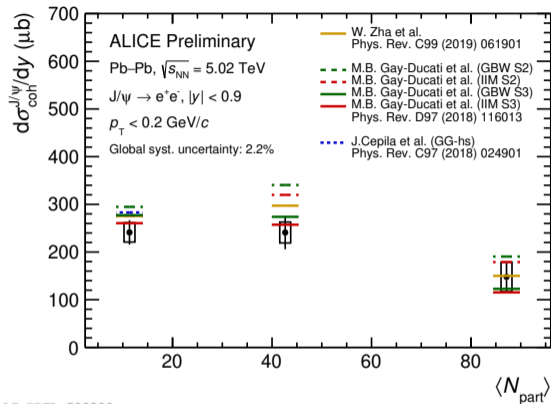
■ γ flux on the spectator region only.

■ GBW/IIM: Dipole models

Cepila *et. al.*: Phys. Rev. C 97, 024901 (2018)

- S2: γ flux like VDM + unmodified $\sigma_{\gamma Pb}$
- S3: S2, but modified $\sigma_{\gamma Pb}$ (no overlap region).

Coherent J/ψ photoproduction centrality dependence: midrapidity



ALI-PREL-503800

■ Mild centrality dependence

within uncertainties compatible with no variation within the studied centrality range.

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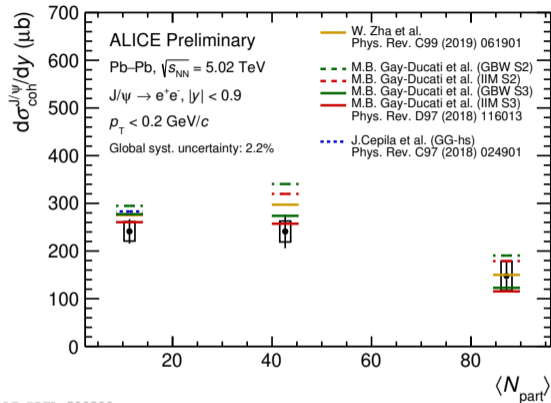
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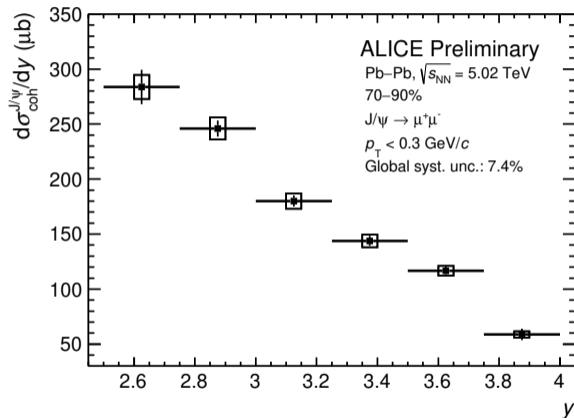
■ S2: γ flux like VDM + unmodified $\sigma_{\gamma Pb}$

■ S3: S2, but modified $\sigma_{\gamma Pb}$ (no overlap region).

■ Results in agreement with models which assume that only the **spectators act as target.**

Collisions with nuclear overlap

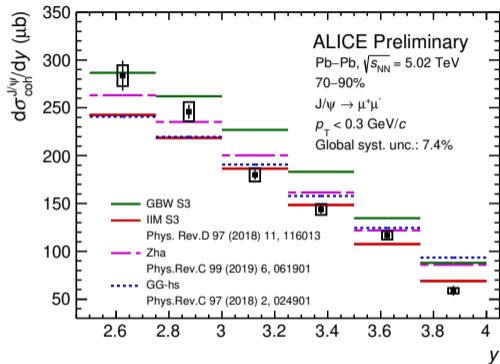
Coherent J/ψ photoproduction rapidity dependence



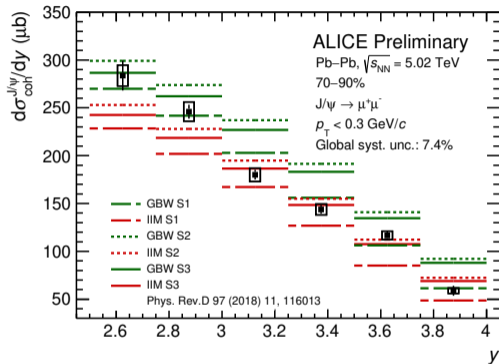
ALI-PREL-548022

- Estimated hadronic yield subtracted from raw yield.
- Corrected on incoherent production and the feed down from ψ' .
- **Cross section falls with y .**

Rapidity dependence in peripheral collisions: model comparison



ALI-PREL-547942



ALI-PREL-547985

- Models do a fair job to describe data, but not perfect.
- Similar observation also with UPC data. (ALICE: Eur. Phys. J. C 81 (2021) 712)

Collisions with nuclear overlap

Inclusive J/ψ polarization

Testing polarization conservation hypothesis



- Hypothesis: Produced vector meson keeps the (transverse) polarization of incoming photon due to **s-channel helicity conservation**

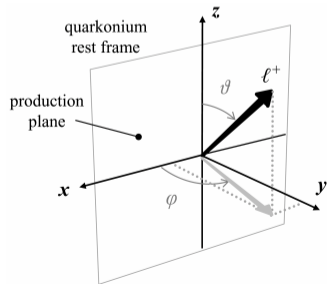
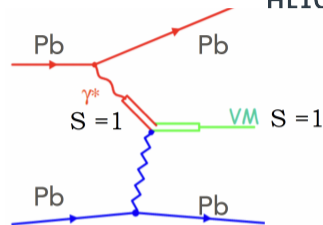
Gilman *et. al.*: Phys. Lett. B 31, (1970) 387-390

- Polarization: particle spin alignment wrt. a chosen direction.
- Helicity frame: momentum direction of the VM.
- Dilepton decay angular dist. *Faccioli et. al.*: Eur. Phys. J. C 69, (2010) 657-673

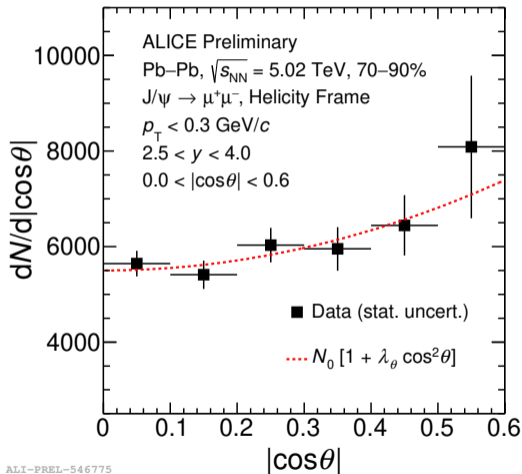
$$W(\cos\theta, \phi) \propto \frac{1}{3+\lambda_\theta} \cdot (1 + \lambda_\theta \cos^2\theta + \lambda_\phi \sin^2\theta \cos 2\phi + \lambda_{\theta\phi} \sin 2\theta \cos\phi)$$

$(\lambda_\theta, \lambda_\phi, \lambda_{\theta\phi})$	(0,0,0)	(+1,0,0)	(-1,0,0)
polarization	no	transverse	longitudinal

- Strong indication of photoproduction.



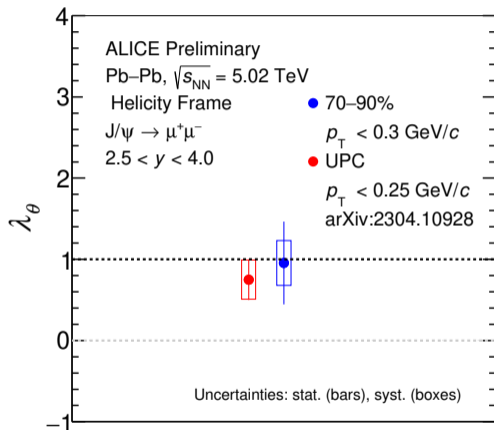
Inclusive J/ψ polarization in peripheral collisions



- $p_T < 0.3$ GeV/c in 70-90% centrality range.

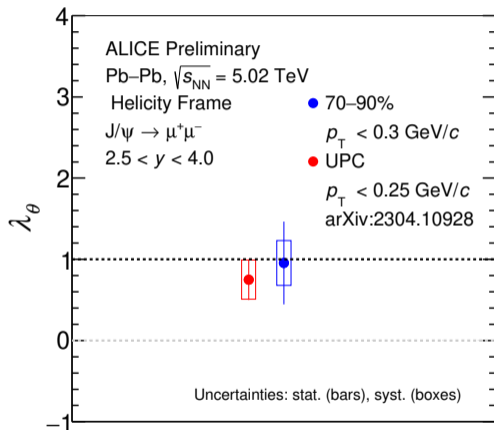
- $W(\cos\theta, \phi)$ with $(\lambda_\phi, \lambda_{\theta\phi}) = (0, 0)$
fits data well.

ALI-PREL-546775



■ λ_θ matches +1.

■ Hints a transverse polarization.



■ λ_θ matches +1.

■ **Hints a transverse polarization.**

■ Consistent with coherent J/ψ polarization results from UPCs.

■ **Final proof of photoproduction in events with nuclear overlap.**

(partial) answers to QCD questions





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New p-Pb measurements essential for probing the energy dependence of the cross section in a model-independent way.



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Yes, in 2D; target size and subnucleonic structure studied.

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Outlook for Run 3? See talk by Nazar Burmasov [here today at 17:02!](#)

BACK UP

- Energy dependence of coherent J/ψ photonuclear cross section:
 - Impulse approximation: G. F. Chew and G. C. Wick, Phys. Rev. 85 (1952) 636
 - STARlight: S. R. Klein and J. Nystrand, Phys. Rev. C60 (1999) 014903
 - EPS09 LO:K. 710 J. Eskola, H. Paukkunen, and C. A. Salgado, JHEP 04 (2009) 065
 - LTA: L. Frankfurt, V. Guzey, and M. Strikman, Phys. Rept. 512 (2012) 255–393
 - GG-HS: J. Cepila, J. G. Contreras, and M. Krelina, Phys. Rev. C 97 (2018) 024901
 - b-BK-A: D. Bendova, J. Cepila, J. G. Contreras, and M. Matas, Phys. Lett. B 817 (2021) 136306
- $|t|$ -dependence of incoherent J/ψ photonuclear cross section:
 - MS-hs: H. Mäntysaari and B. Schenke, Phys. Lett. B 772 (2017) 832–838
 - MS-p: H. Mäntysaari and B. Schenke, Phys. Lett. B 772 (2017) 832–838
 - MSS-fl: H. Mäntysaari, F. Salazar and B. Schenke, Phys. Rev. D 106 (2022) 074019
 - MSS: H. Mäntysaari, F. Salazar and B. Schenke, Phys. Rev. D 106 (2022) 074019
 - GSZ-el+diss: V. Guzey, M. Strikman, and M. Zhalov, Phys. Rev. C 99, 015201
 - GSZ-el: V. Guzey, M. Strikman, and M. Zhalov, Phys. Rev. C 99, 015201