25th International Symposium on Spin Physics

# *Vector meson photoproduction in UPC with ALICE*

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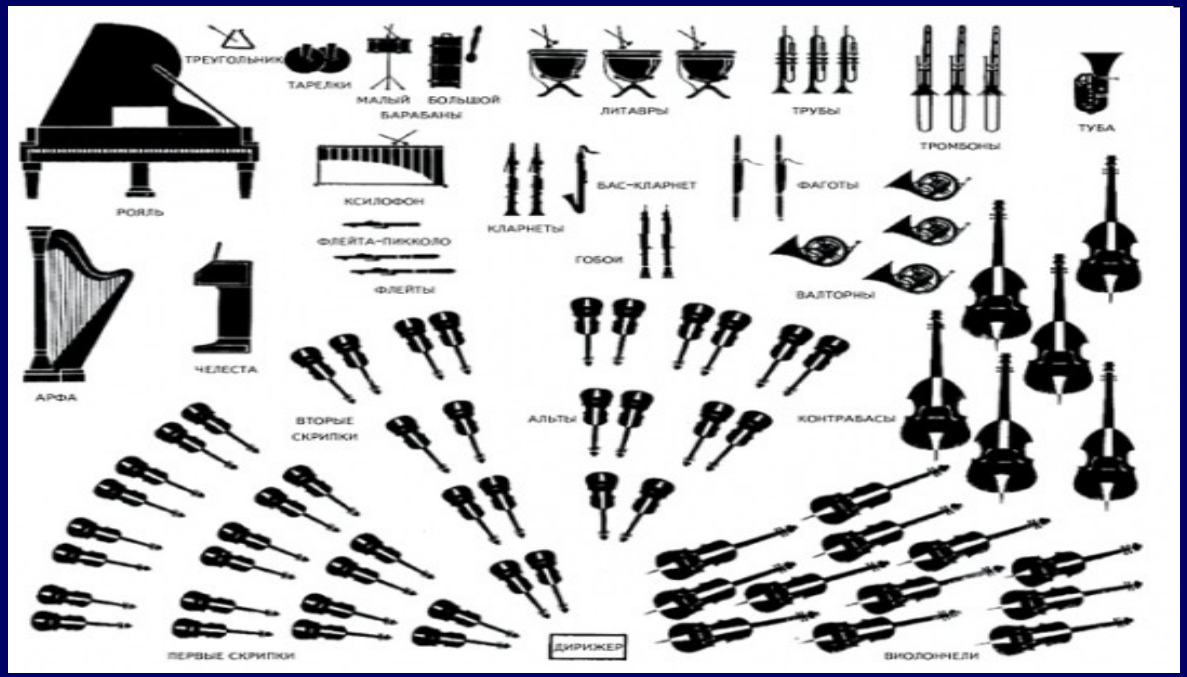
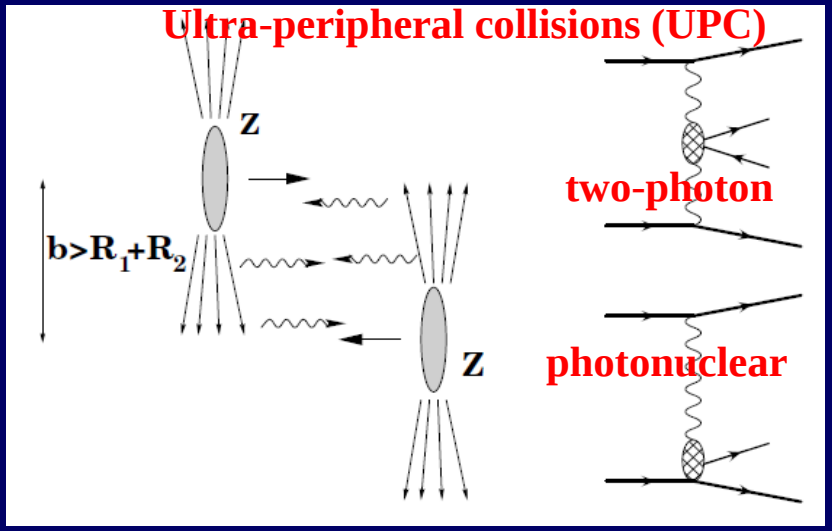
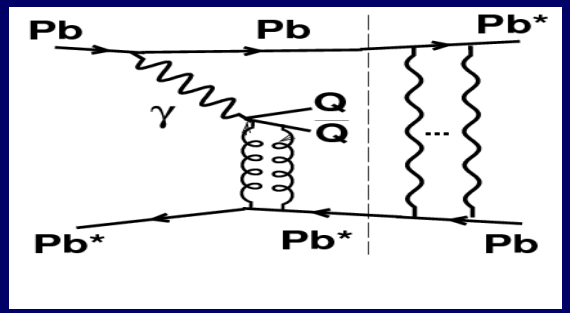


# UPC of heavy ions




The LHC in heavy-ion mode →
powerful source of quasi-real photons with intensity ~$Z^2$.

Photon →
a vector meson (VM) →
scatter off a target
either coherently off whole nucleus (VM $p_T$ ~30 MeV/c)
or incoherently off nucleons (VM $p_T$~300 MeV/c).
*NB there is bidirectional photon ambiguity in case of heavy ions*



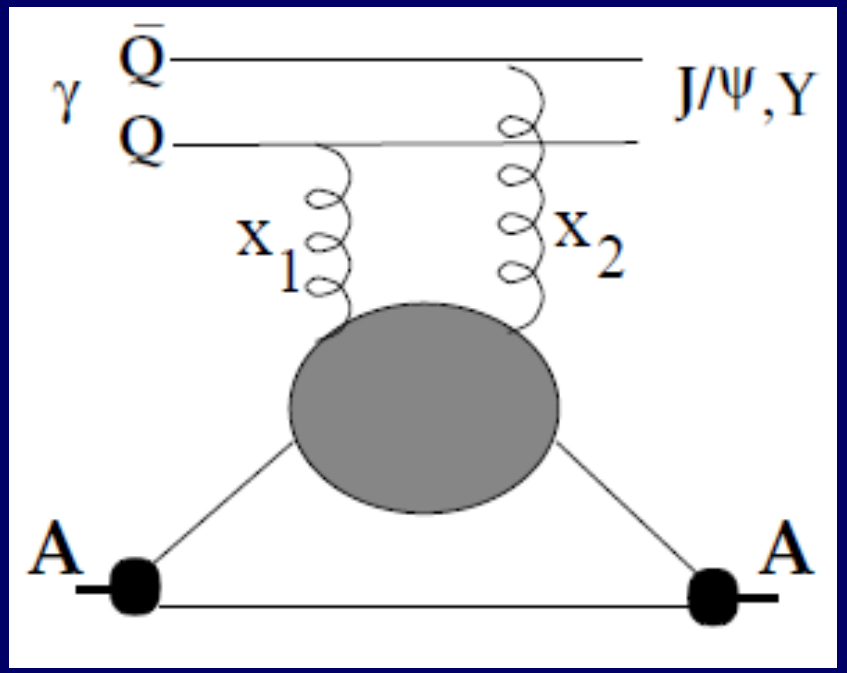

Large Z →
huge photon fluxes →
UPC can be accompanied by another photon exchange →
EM nuclei excitation →
neutron emission detected in Zero Degree Calorimeters.

UPC studies address gluon shadowing in nuclei in photoproduction of vector mesons, two-photon processes like light-by-light scattering, dilepton production etc.

*UPC review and current status*:

A.J. Baltz *et al.*, Phys.Rept. 458 (2008) 1;
V. Guzey *et al.*, Eur.Phys.J. C74 (2014) 7;
L. Frankfurt *et al.*, Phys.Lett.B 752 (2016) 51;
E. Kryshen, EPJ Web Conf. 204 (2019) 01011;
CMS Collab., Phys.Lett.B 797 (2019) 134826;
ALICE Collab., Phys.Lett. B798 (2019) 134926;
S. R. Klein and P. Steinberg, Ann.Rev.Nucl.Part.Sci. 70 (2020) 323

# J/ψ photoproduction in UPC

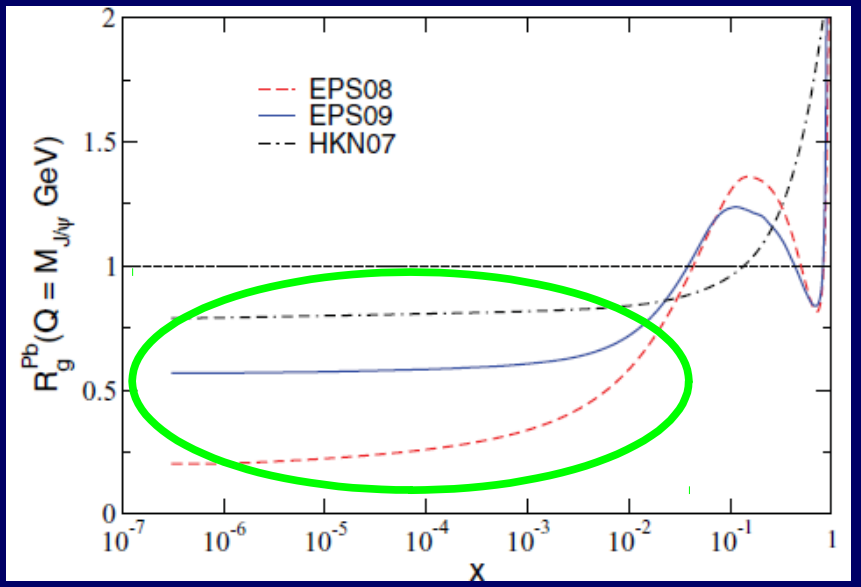



Quarkonium photoproduction (γA → J/ψ A) at LHC ALICE probes high $W_{\gamma p}$ (small $x$) range.

The leading order cross section (assuming that gluons have ~ same $x$, i.e. $x_1 \approx x_2$) ~ to squared gluon parton density function

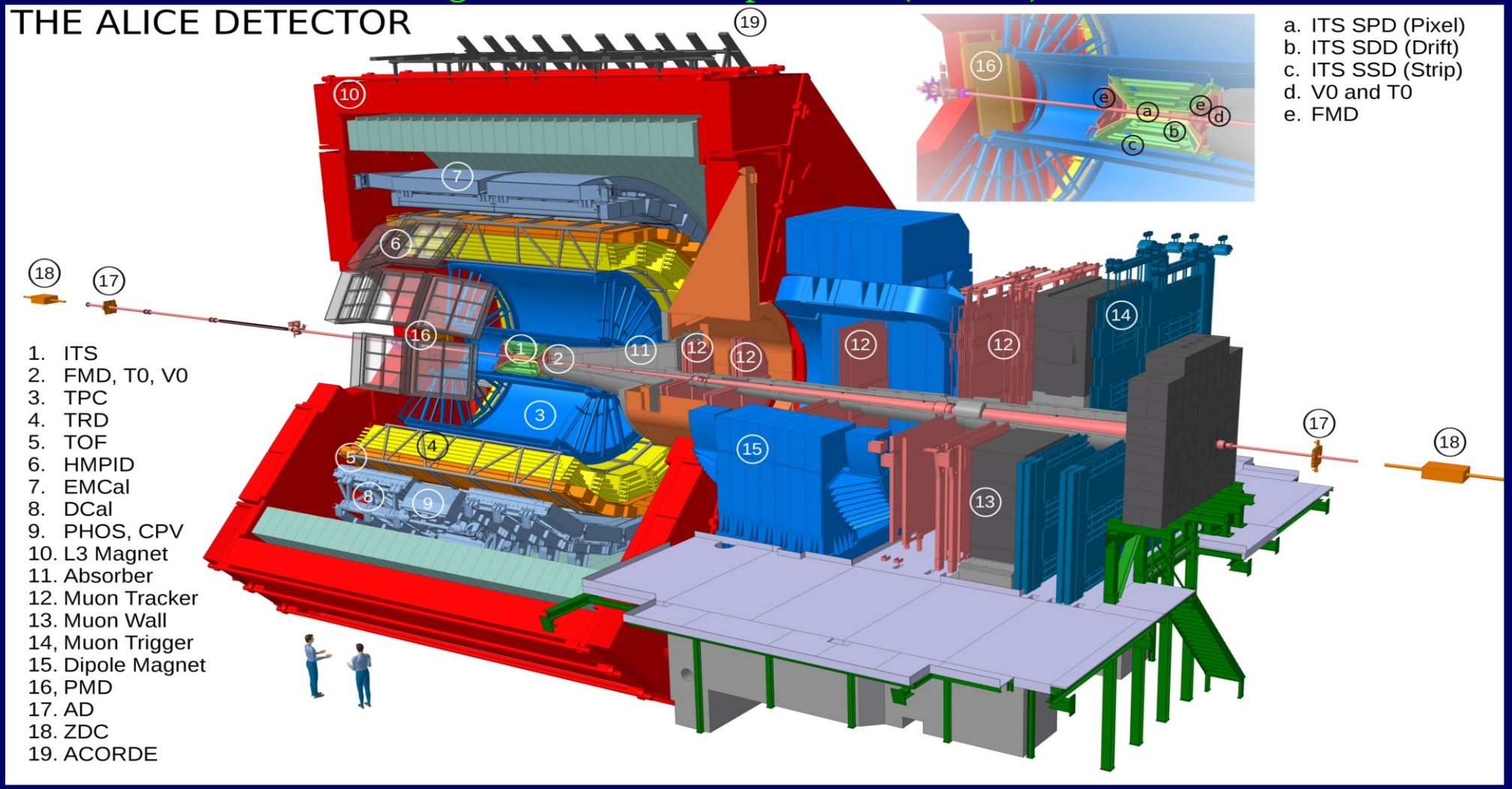
$$\left.\frac{d\sigma_{\gamma A\to J/\Psi A}}{dt}\right|_{t=0} = \xi_{J/\Psi}\left(\frac{16\pi^3\alpha_s^2\Gamma_{l+l-}}{3\alpha M_{J/\Psi}^5}\right)[xG_A(x,\mu^2)]^2$$

M. G. Ryskin, Z. Phys. C57 (1993), 89
extensions of the calculations to NLO
K. J. Eskola et al. Phys.Rev.C 106 (2022) 3, 035202




How to properly incorporate nuclear shadowing at small ***x?***

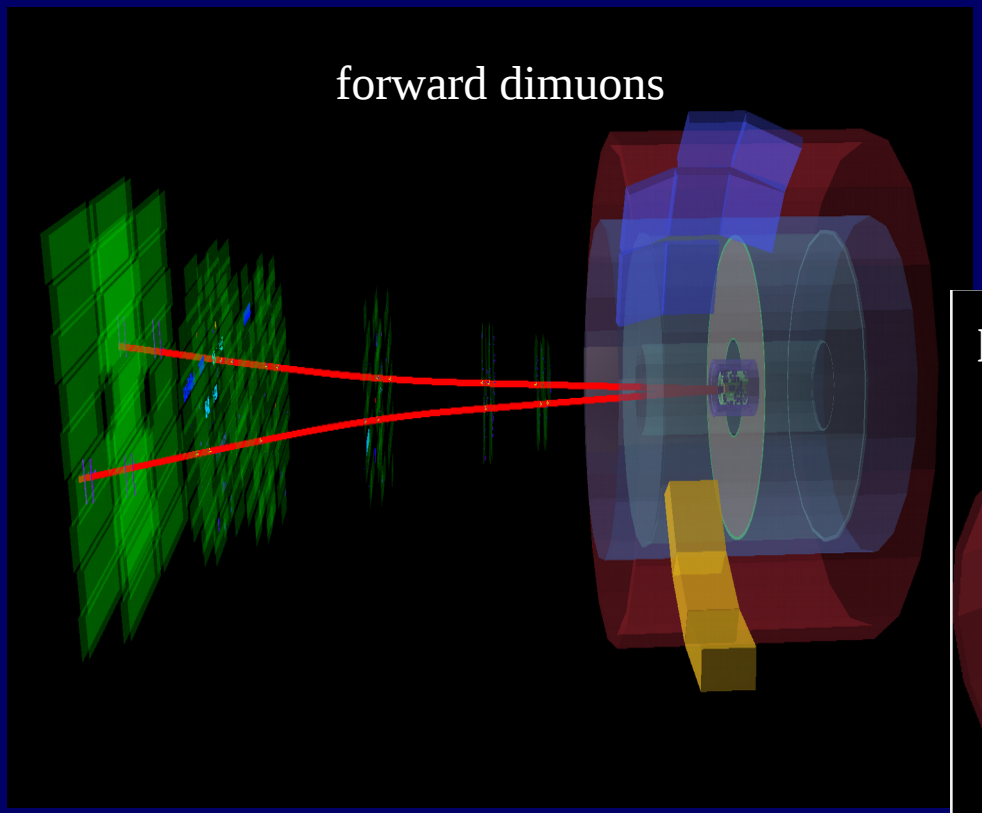
# A Large Ion Collider Experiment (ALICE) at LHC

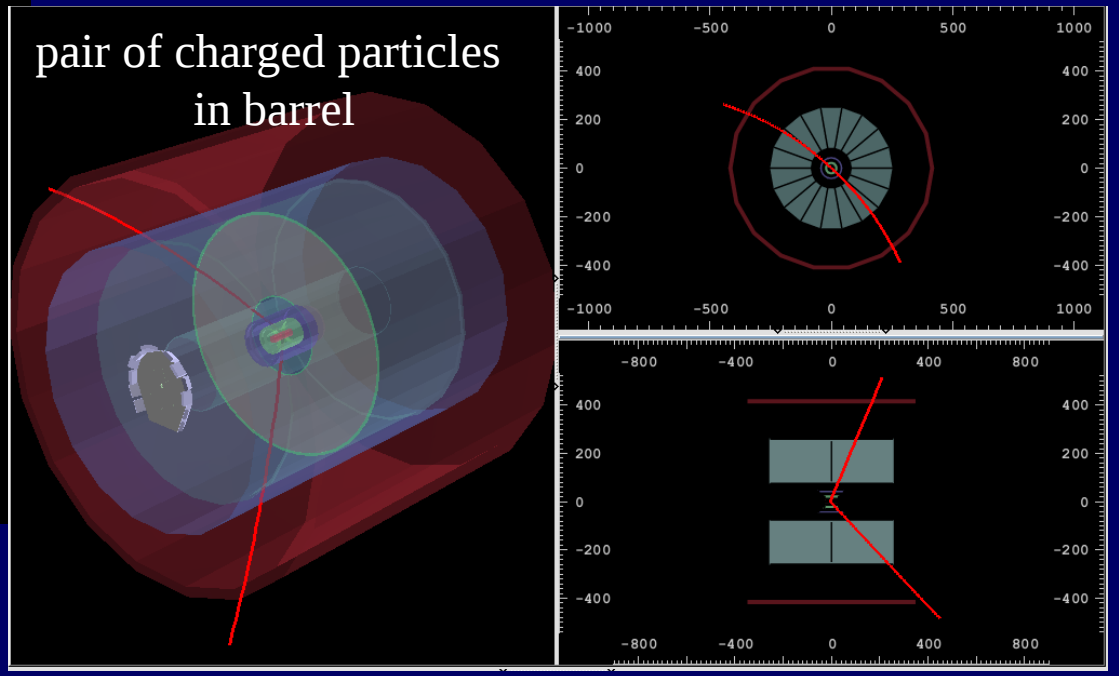



ALICE systems relevant for J/ψ photoproduction measurements:

- Muon spectrometer (item 12 on scheme) /TPC (3) to reconstruct J/ψ;
- Trigger detectors: ITS SPD (1), V0 (2), AD (17), TOF (5) and muon trigger chambers (14);
- Zero Degree Calorimeters (18) to detect neutrons from nucleus EM dissociation.

# ALICE event displays



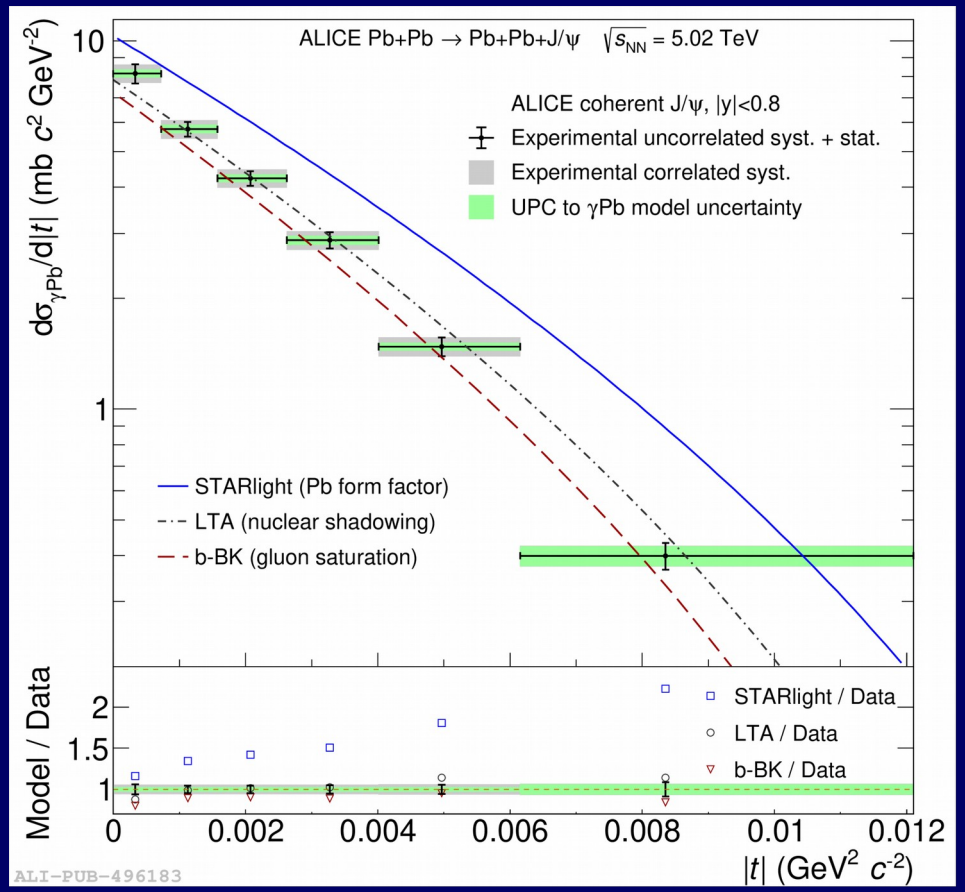




Main features of UPC vector meson photoproduction:

- exclusive events, only vector meson decay particles detected;
- transverse momentum balance of final state particles.

# Coherent J/ψ photoproduction cross section as a function of |t|

Momentum transfer to target nucleus |t| relates to gluon distribution in plane transverse to the interaction and the study of |t|-dependence of coherent J/ψ photoproduction provides information about the spatial distribution of gluons in nuclei.




***ALICE Collab., PLB 817 (2021) 136280***

***LTA***

V. Guzey, M. Strikman and M. Zhalov, Phys. Rev. C 95 no. 2, (2017) 025204

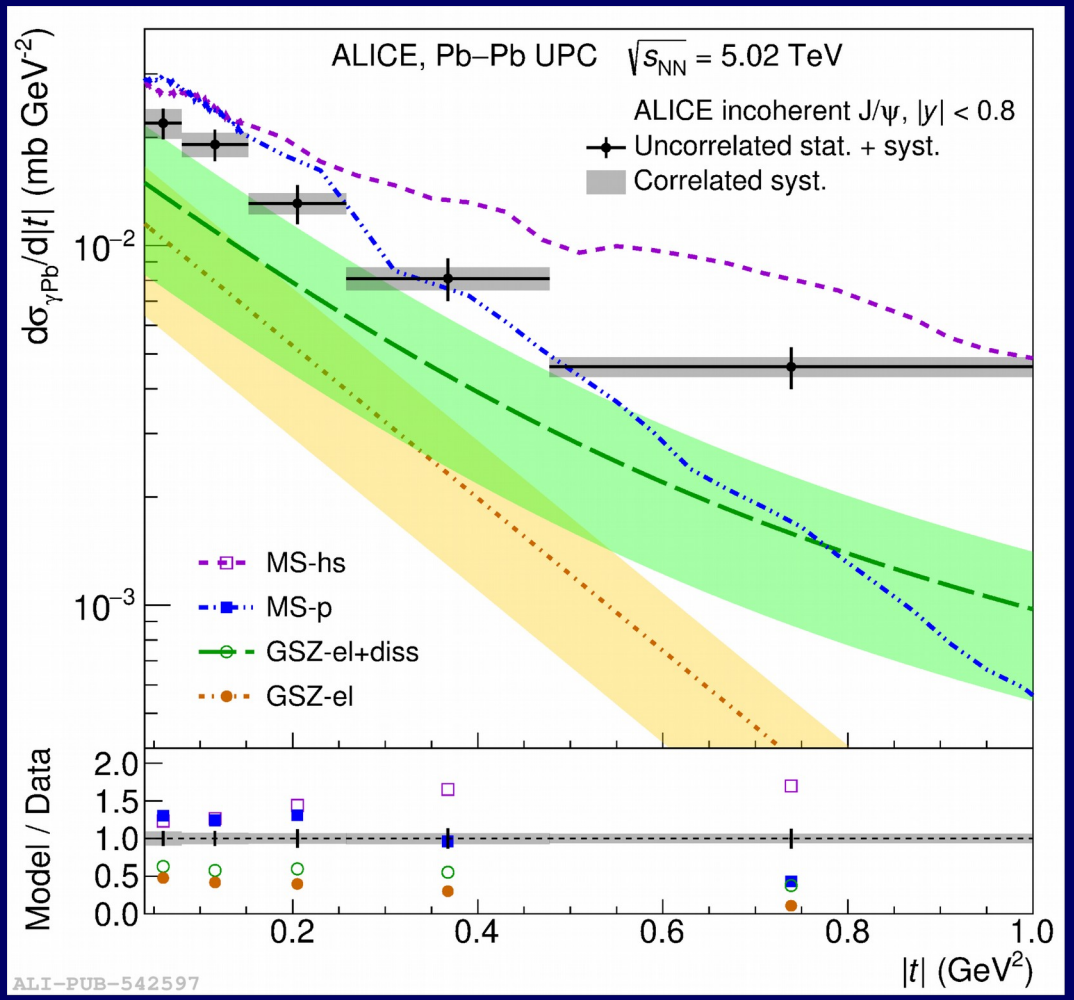
***b-BK***

D. Bendova et. al., Phys.Lett.B 817 (2021) 136306

Cross section as a function of |t| differs from a model based on nuclear form factor (STARlight) and in agreement (within experimental uncertainties) with models including QCD dynamical effects either shadowing (LTA) or saturation (b-BK).

# Incoherent J/ψ photoproduction cross section as a function of |t|

In case of incoherent process (photon scattered on nucleon), |t| relates to variance of average spatial gluon distribution in plane transverse to the interaction.




***ALICE Collab., arXiv:2305.06169***

***GSZ***

V. Guzey, M. Strikman and M. Zhalov, Phys. Rev. C 99 (2019) 015201

***MS***

D. H. Mantysaari and B. Schenke, Phys. Lett. B 772 (2017) 832

None of present models describes both the absolute normalization and |t|-slope measured for incoherent photoproduction.

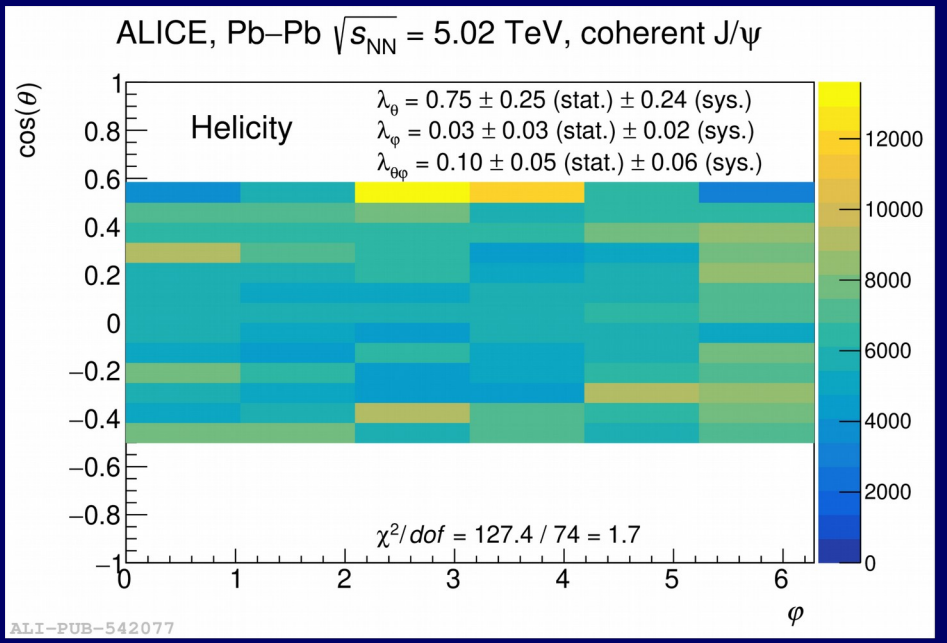
Inclusion of sub-nucleon fluctuations into calculations (MS-hs, GSZ–el+diss) provides better agreement with the data for the *slope* of the |t|-dependence.

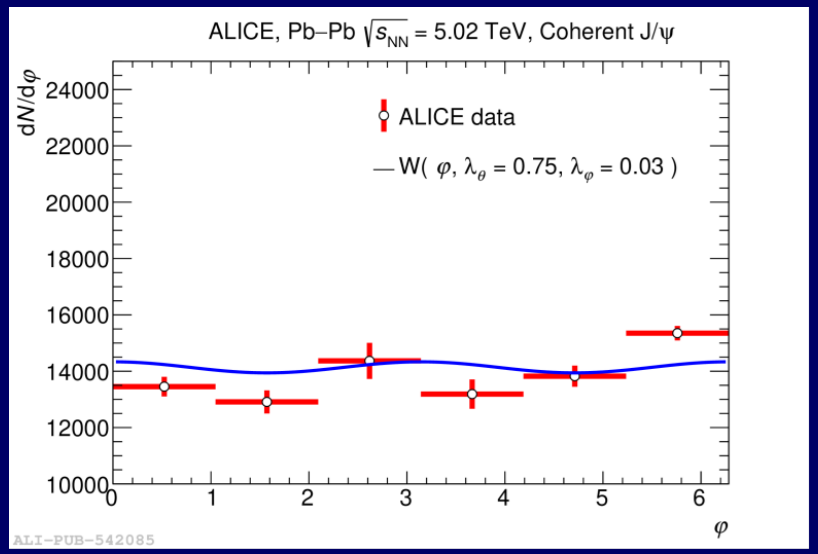
# Polarisation of coherent J/ψ photoproduction

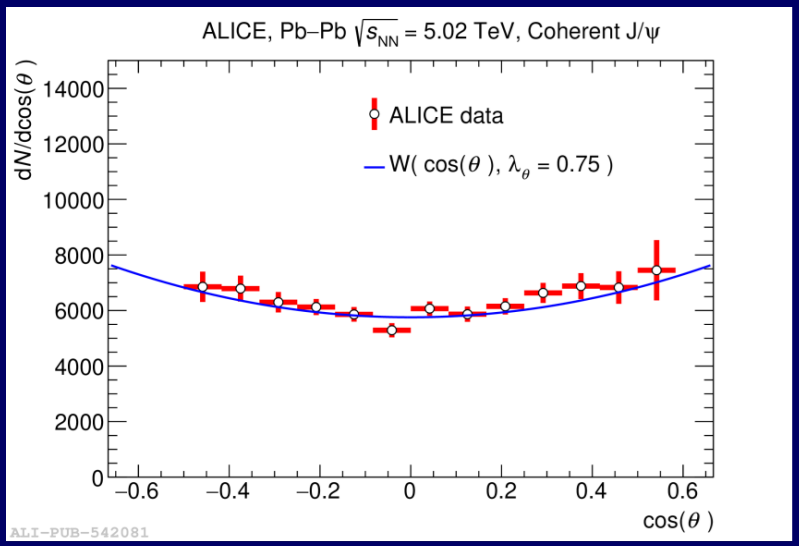
The angular distribution of J/ψ decay muons depends on polarisation parameters $\lambda_\theta$ , $\lambda_\varphi$ and $\lambda_{\theta\varphi}$ as

$$W(\cos\theta, \varphi) \sim (1 + \lambda_\theta \cos2\theta + \lambda_\varphi \sin2\theta \cos2\varphi + \lambda_{\theta\varphi} \sin2\theta \cos\varphi) / (3 + \lambda_\theta)$$

The J/ψ meson is reconstructed in the forward rapidity $-4.0 < y < -2.5$.

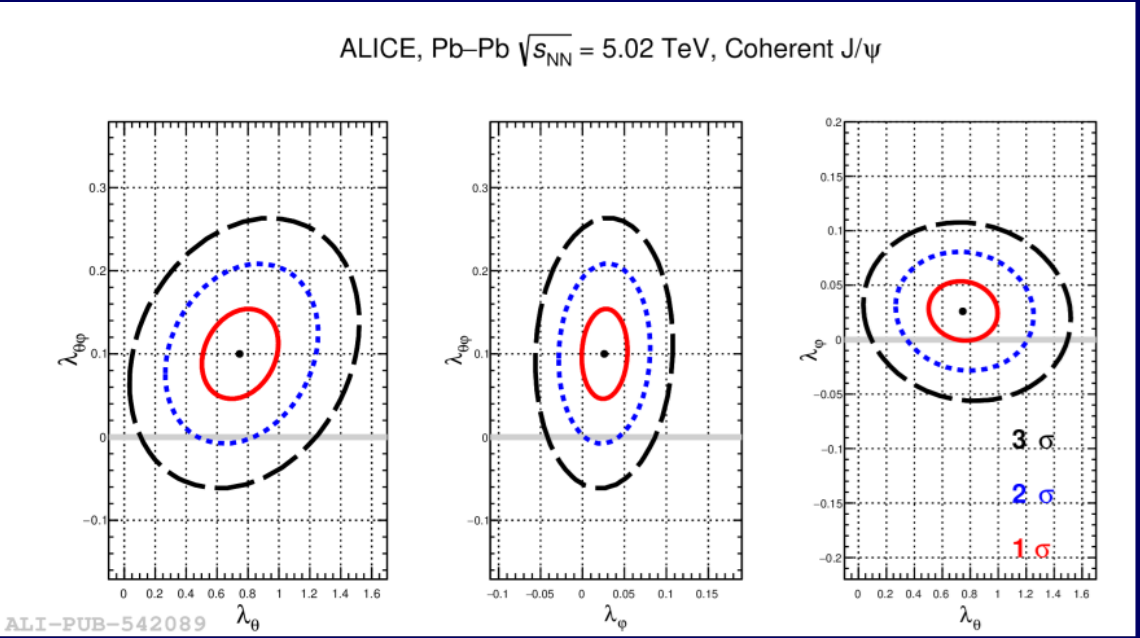



***ALICE Collab., arXiv:2304.10928***

# Polarisation of coherent J/ψ photoproduction




The fitted results for the three polarisation parameters with a central value and contours at 68.3%, 95.4%, and 99.7% confidence level.

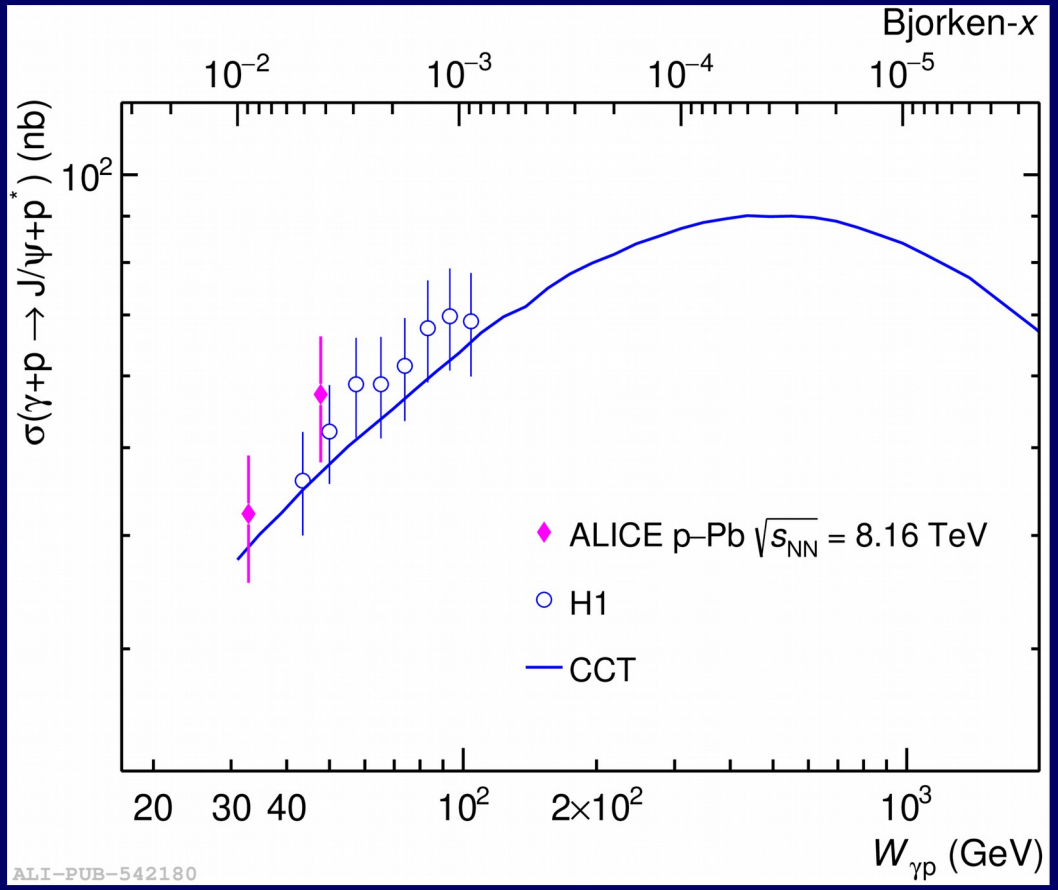
No strong correlation is observed among the measured λ parameters.

The $\lambda_\varphi$ parameter found to be consistent with unity,
the other two parameters of J/ψ polarisation in Pb–Pb UPC consistent with zero,

indicating that coherently produced J/ψ mesons are transversely polarised as required for s-channel helicity conservation.

# Dissociative J/ψ photoproduction

ALICE forward detectors allow to measure cross sections for both elastic/exclusive ($A + p \rightarrow A + p + J/\psi$) and proton-dissociative ($A + p \rightarrow A + X + J/\psi$) scatterings separating them with detectors located in the proton-going direction.




***ALICE Collab., arXiv:2304.12403***

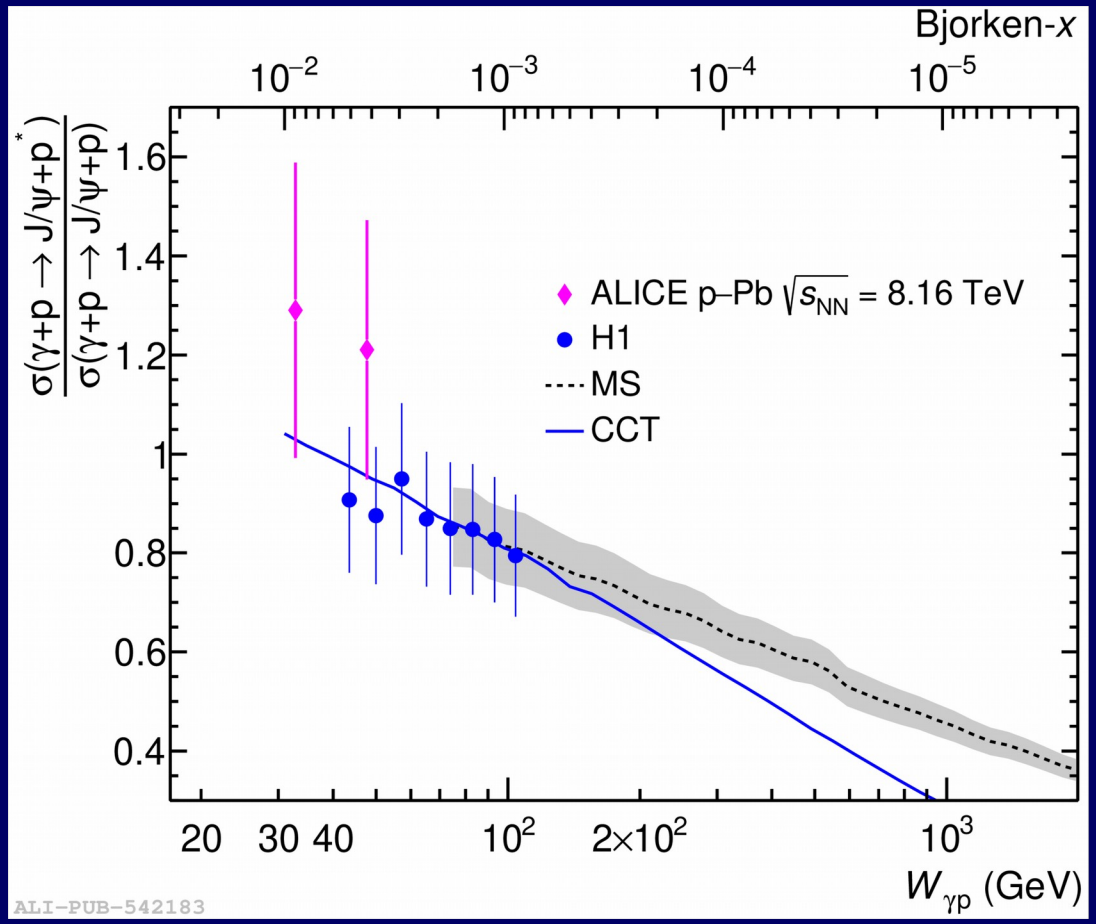
The data are in an agreement with Cepila-Contreras-Takaki model (Phys. Lett. B 766 (2017) 186 )

which considers the gluon “hot spots” in the transverse plane inside nucleon

and with
H1 measurement
(Eur. Phys. J. C 73 (2013) 6, 2466)
carried out for electron-proton reactions.

# Dissociative J/ψ photoproduction

Dissociative to exclusive cross sections ratio adds new data to the expected behavior – the ratio vanishes if gluons are in saturated regime at small *x*.




The data are compared to:

– Cepila-Contreras-Takaki model
Phys. Lett. B 766 (2017) 186

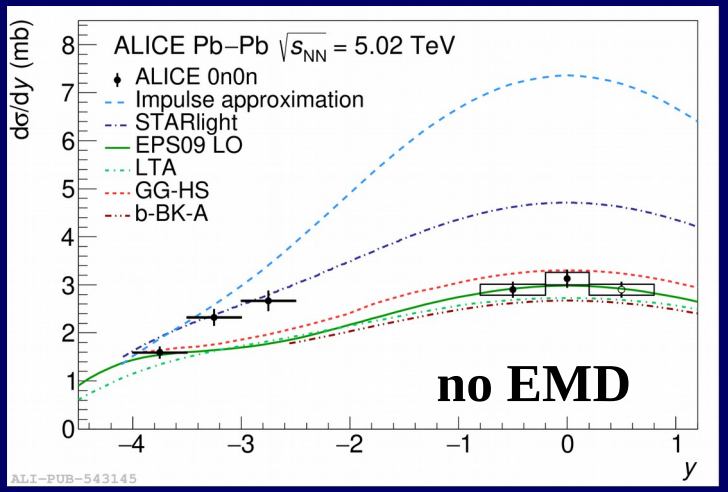
– H. Mantysaari and B. Schenke,
Phys. Rev. D 98 no. 3, (2018) 034013

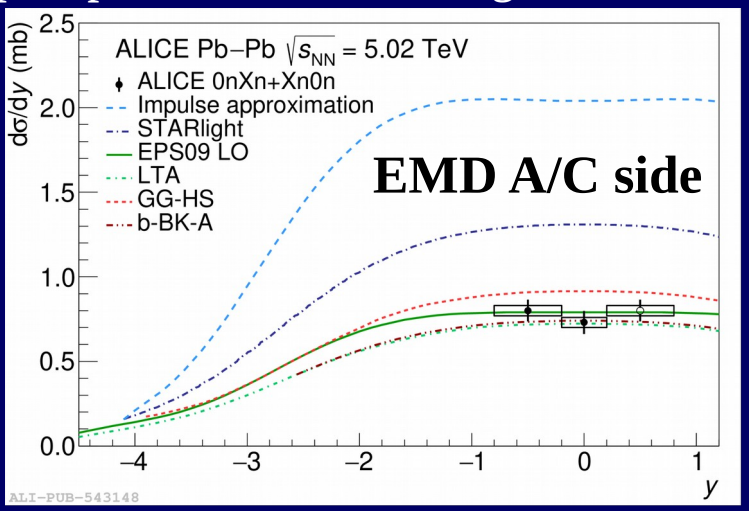
– H1 measurement
Eur. Phys. J. C 73 (2013) 6, 2466

# Energy dependence of the coherent J/ψ photoproduction

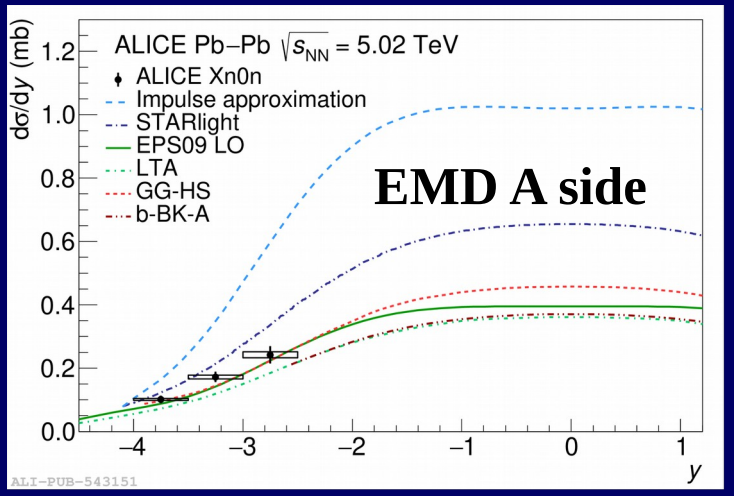
Coherent photoproduction of J/ψ off nuclear targets has a large cross section, sensitive to the gluon structure of hadrons and it is a tool to study the energy evolution of nuclei structure.

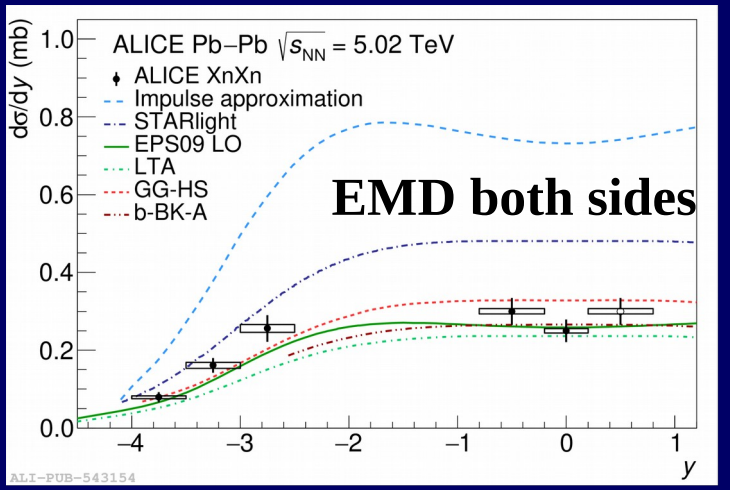
The ALICE analyzed the data depending on a presence of nuclei electromagnetic dissociation which allows to disentangle (at some level) events wrt impact parameter of colliding ions.



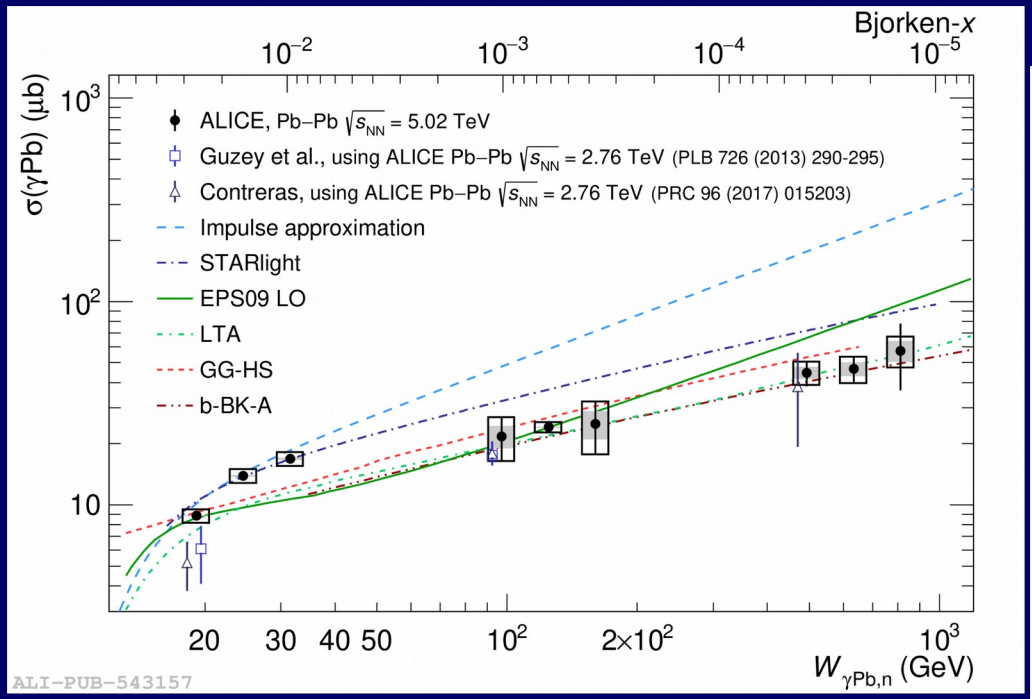

See next slide for the models

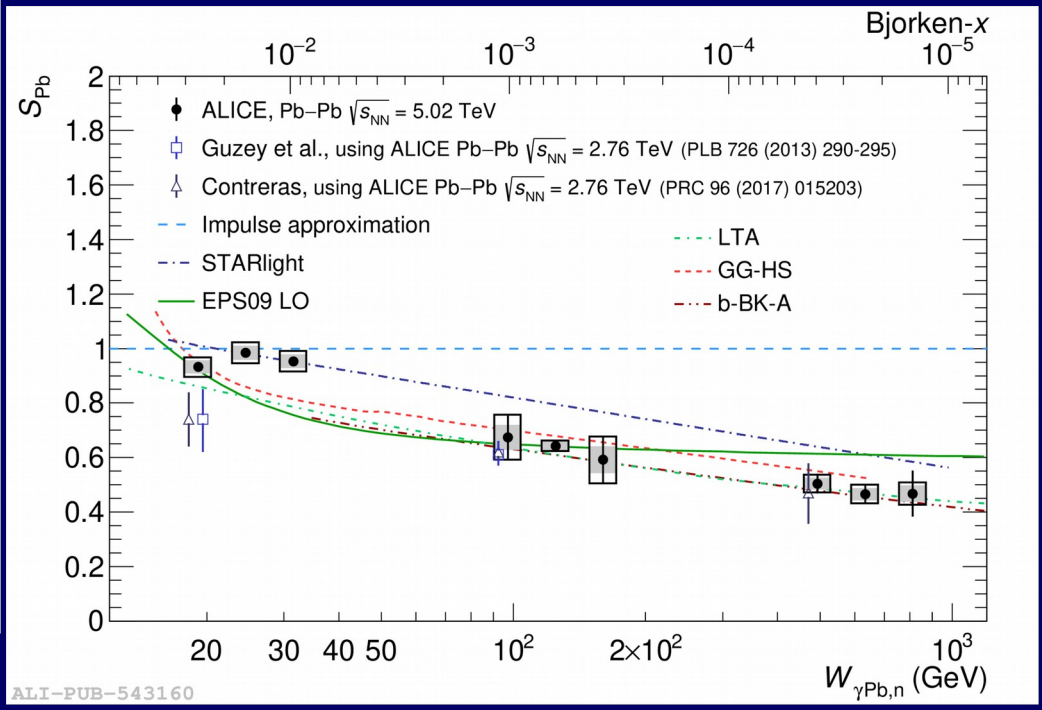



*ALICE Collab., arXiv:2305.19060*

# Energy dependence of the photonuclear cross section




| | |
|---|---|
| impulse approximation: no nuclear effects | |
| STARLIGHT: VDM + Glauber | Comput. Phys. Commun. 212 (2017) 258 |
| EPS09 LO (GKZ) / LTA (GKZ) | PRC93 (2016) 055206 |
| GM: color dipole + IIM / bCGC CGC | PRC 90 (2014) 015203, JPG 42 (2015) 105001 |
| Ipsat (LM): color dipole + IPSat CGC | PRC 83 (2011) 065202, PRC 87 (2013) 032201 |
| GG-HS (CCK): color dipole + energy dependent hot-spot model | PL B766 (2017) 186, PRC 97 (2018), 024901 |
| BGK-I (LS): color dipole + CGC | Phys. Rev. C 99, 044905 (2019) |

STARlight model describes the low energy data, the models based on EPS09-LO parameterization or leading-twist approximation of gluon shadowing, impact parameter dependent BK equation, energy-dependent hot-spot approach describe the data at high energy (small Bjorken-$x$).

# In summary, the ALICE experiment measured

– coherent J/ψ photoproduction cross section as a function of |t| and found in agreement with models including QCD effects of gluon shadowing or saturation;

– incoherent J/ψ photoproduction cross section as a function of |t| and shown that none of present models describes both the absolute normalization and slope.

Inclusion of sub-nucleon fluctuations into calculations becomes important to describe the slope of the |t|-dependence;

– J/ψ polarisation in coherent photoproduction and found transverse polarisation of mesons as expected for s-channel helicity conservation;

– coherent J/ψ photoproduction cross section in Pb-p scattering with proton dissociated indicates (together with H1 data) that dissociative to exclusive cross section ratio decreases if gluons in nuclei are saturated. More precise data are expected in LHC Run3;

– energy dependence of the coherent J/ψ photoproduction and STARlight model describing the low energy data while gluon shadowing models describe the data at high energies.