Exclusive and dissociative J/ψ photoproduction off protons with ALICE

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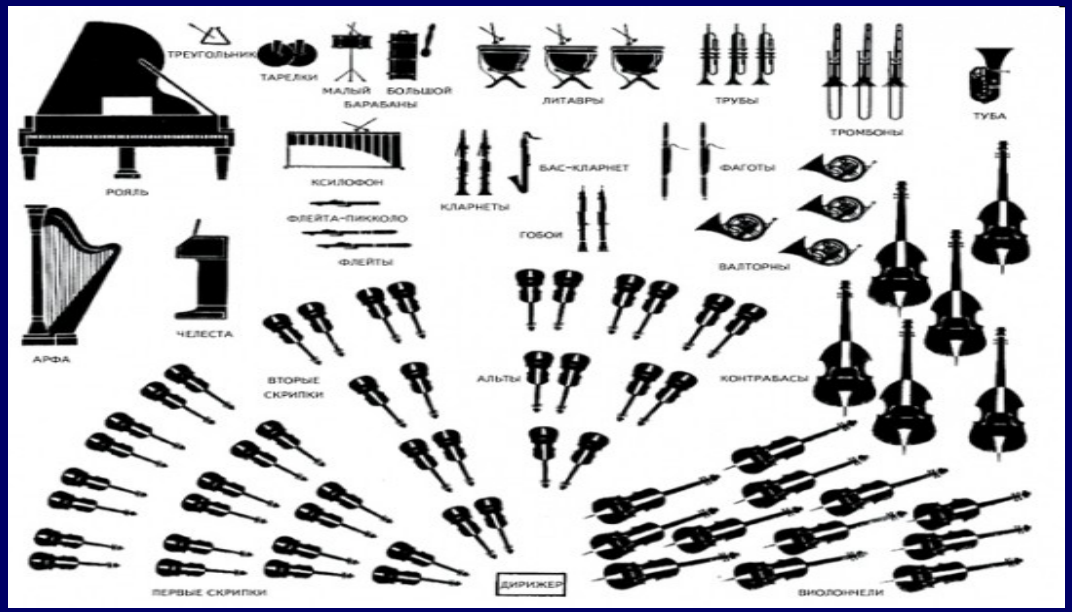
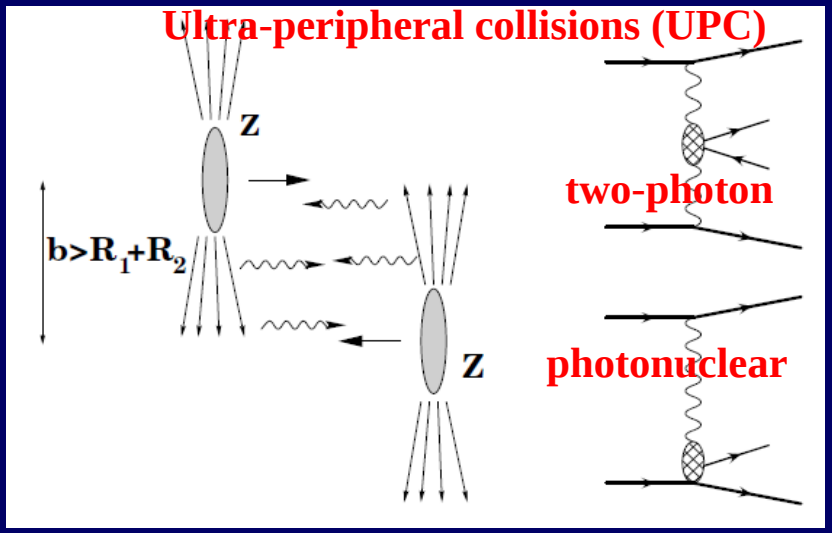
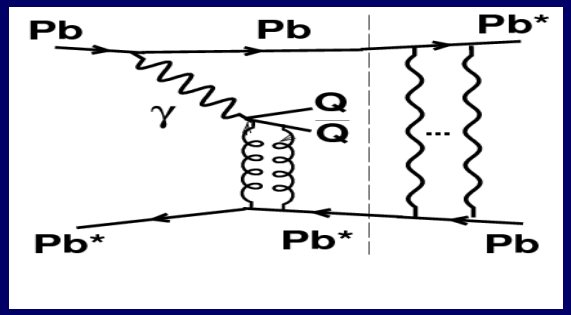


UPC of heavy ions



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 symmetric system



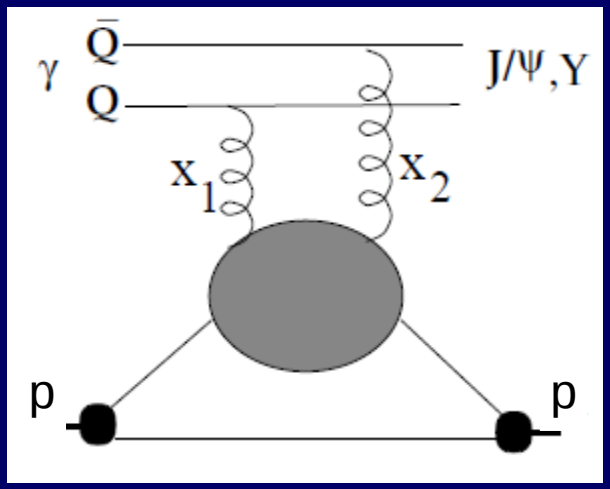
Large Z →
huge photon fluxes →
UPC can be accompanied by another photon exchange →
EM nuclei excitation →
neutron emission detected in Zero Degree Calorimeters.

UPC studies probe gluon shadowing in nuclei in photoproduction of vector mesons and 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 p-Pb UPC



Quarkonium photoproduction ($\gamma p \rightarrow J/\psi\ p$) at the LHC 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

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

M. G. Ryskin, Z. Phys. C57 (1993), 89

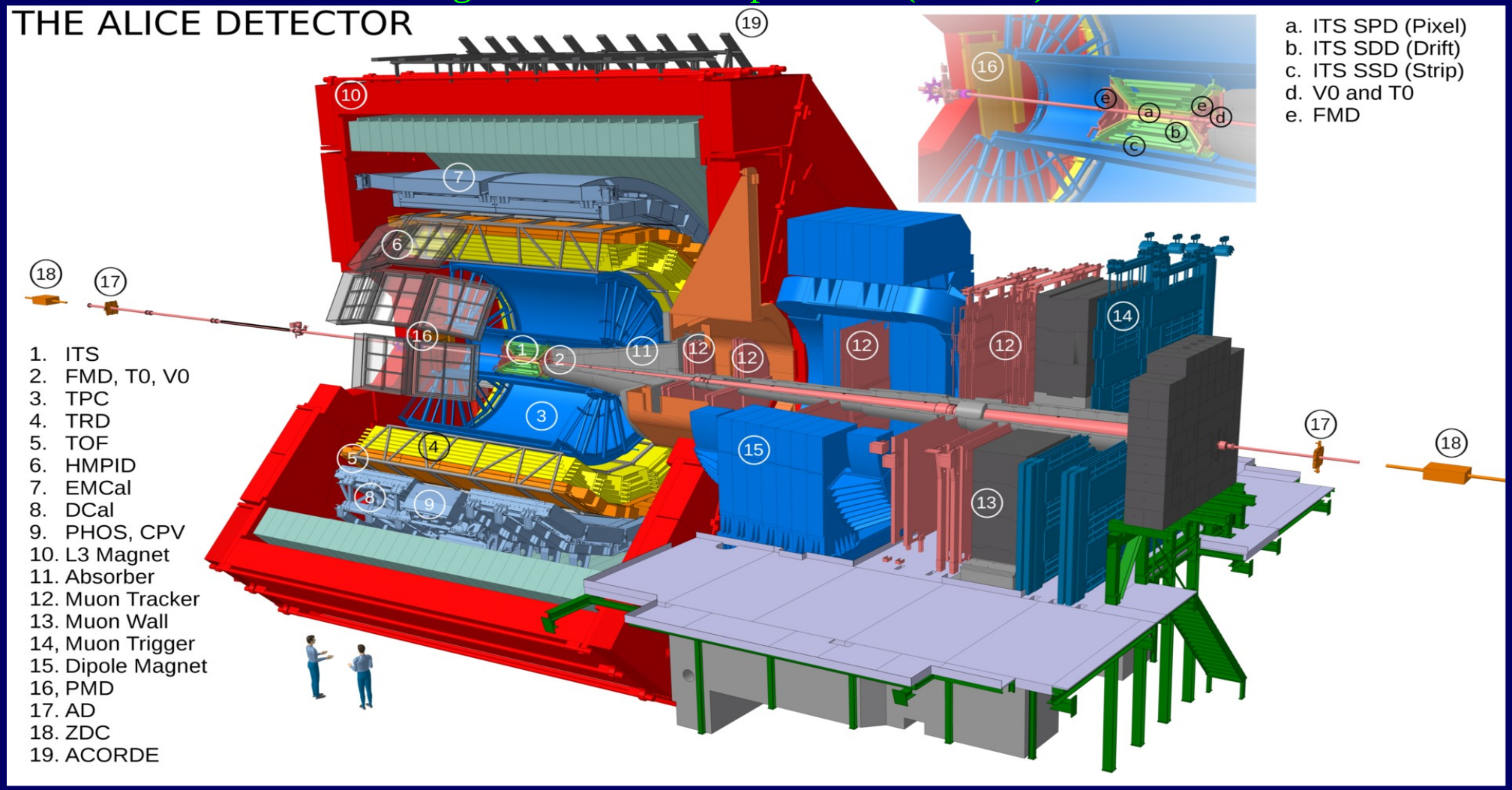
any reduction in cross section growth at high $W_{\gamma p}$ would signal non-linear QCD dynamics

a source of cross section dependence non-linearity may come from
gluon recombination → the growth of gluon distributions → gluon saturation phenomenon

Subnucleonic fluctuations of parton initial state in the proton may lead to proton dissociation process

new measurements of exclusive and dissociative J/ψ photoproduction cross section (as a function of $W_{\gamma p}$) are welcome.

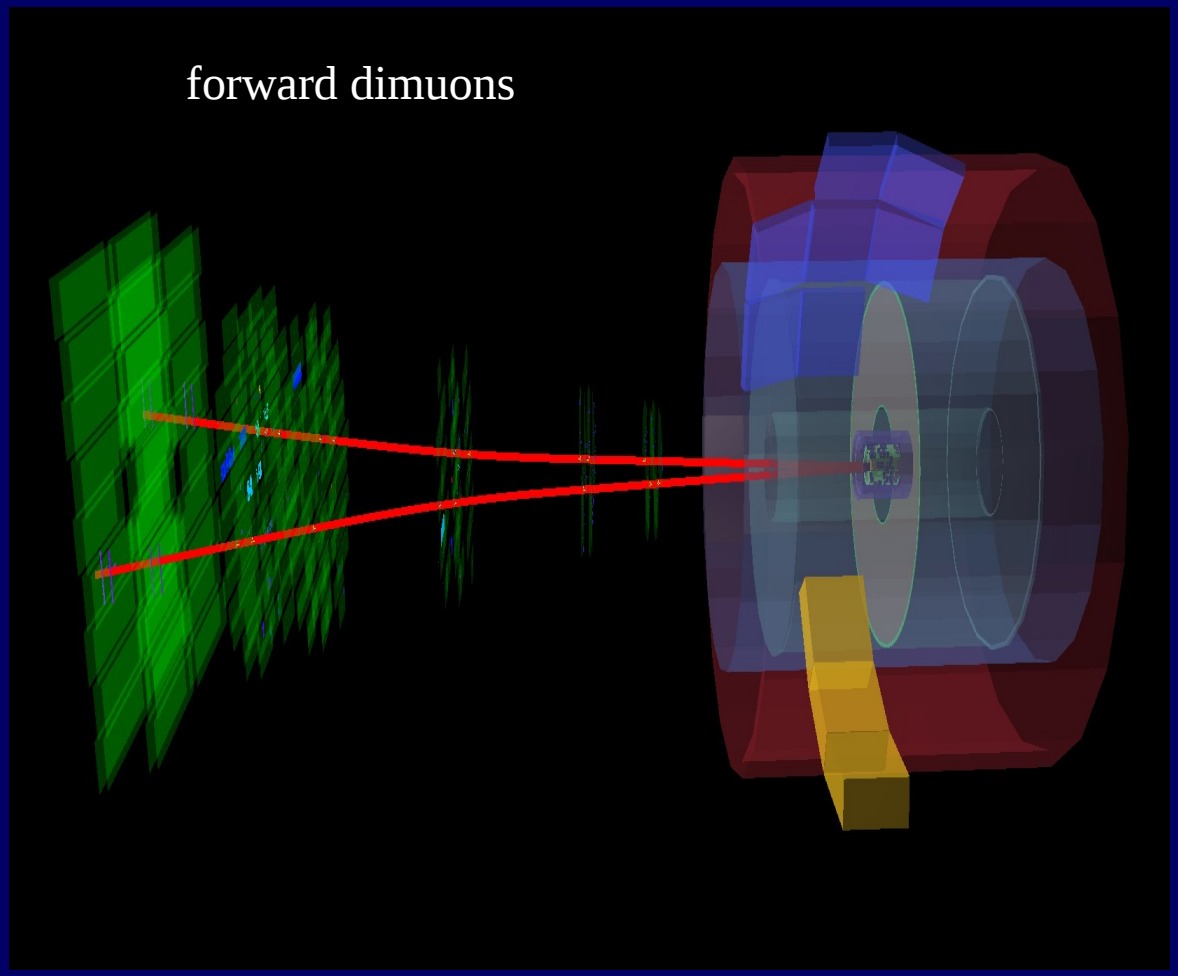
A Large Ion Collider Experiment (ALICE) at LHC



ALICE systems relevant for J/ψ photoproduction measurements:

- Muon spectrometer (item 12 on scheme) to reconstruct J/ψ;
- Trigger detectors: V0 (2), AD (17), 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.

Exclusive J/ψ photoproduction in p–Pb collisions

The analyzed p–Pb data were collected in 2016 at $\sqrt{s_{NN}}$ = 8.16 TeV and correspond to an integrated luminosity of $\mathcal{L} = 7.90 \pm 0.14\ nb^{-1}$

The dimuon rapidity in between $2.5 < y < 4.0$ and the dimuon $p_T < 3$ GeV

→ $27 < W_{\gamma p} < 57$ GeV and gluon x-range in the proton $5 \times 10^{-3} < x < 2 \times 10^{-2}$

Exclusive J/ψ photoproduction signature – $\mu^+\mu^-$ pairs in an otherwise empty detector including systems at large rapidities.

	located at	pseudorapidity
V0C	$z = -90$ cm	$-3.7 < \eta < -1.7$
V0A	$z = 330$ cm	$2.8 < \eta < 5.1$
ADC	$z = -19.5$ cm	$-7.0 < \eta < -4.9$
ADA	$z = 16.9$ cm	$-4.7 < \eta < 6.3$

But the photoproduction with a dissociative proton can be accompanied by particles registered in scintillator counters on the proton C-side.

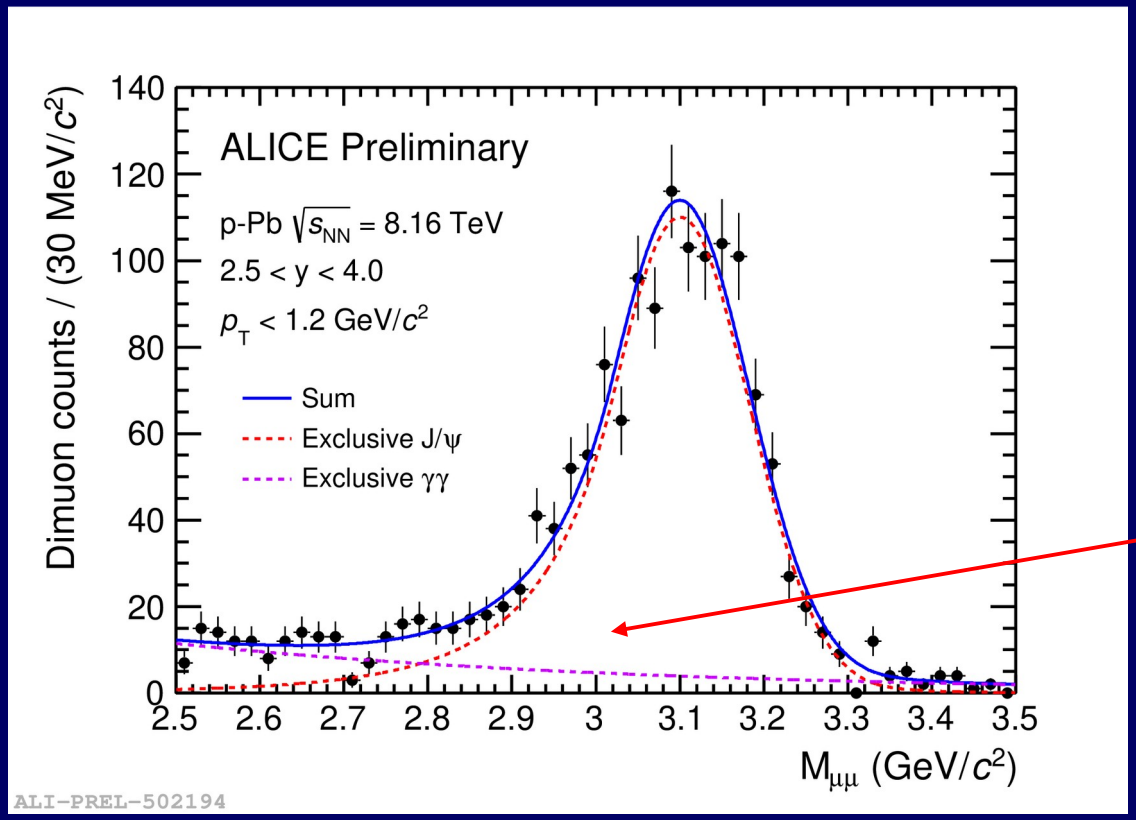
V0 consists of thirty-two cells forming four concentric rings with eight sectors each.

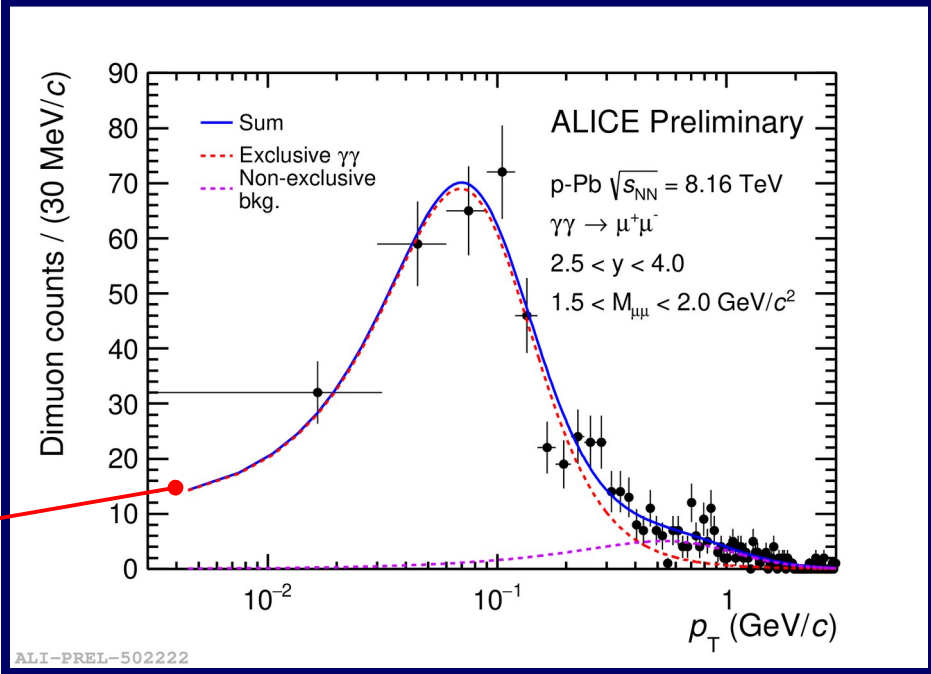
AD detector – two scintillator tile arrays.

Exclusive J/ψ photoproduction in p–Pb collisions (cont'd)

Pb ion remains → Pb-side detectors V0A, ADA, ZDC have no activity at offline level.
According to RAPGAP (used for dissociative J/ψ photoproduction in *ep* collisions),
proton remnants do not leave a signal in the acceptance of the V0C detector
even proton dissociates.

Thus the sample is efficiently cleaned from background from multihadron production.

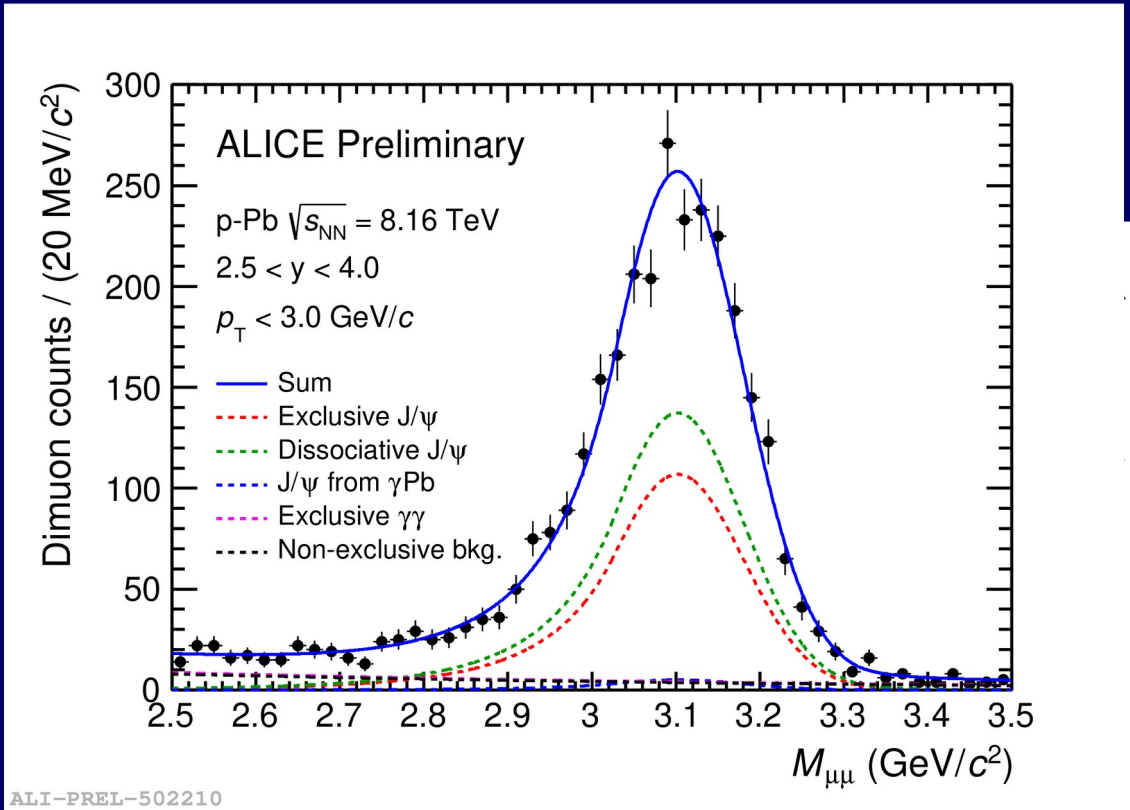


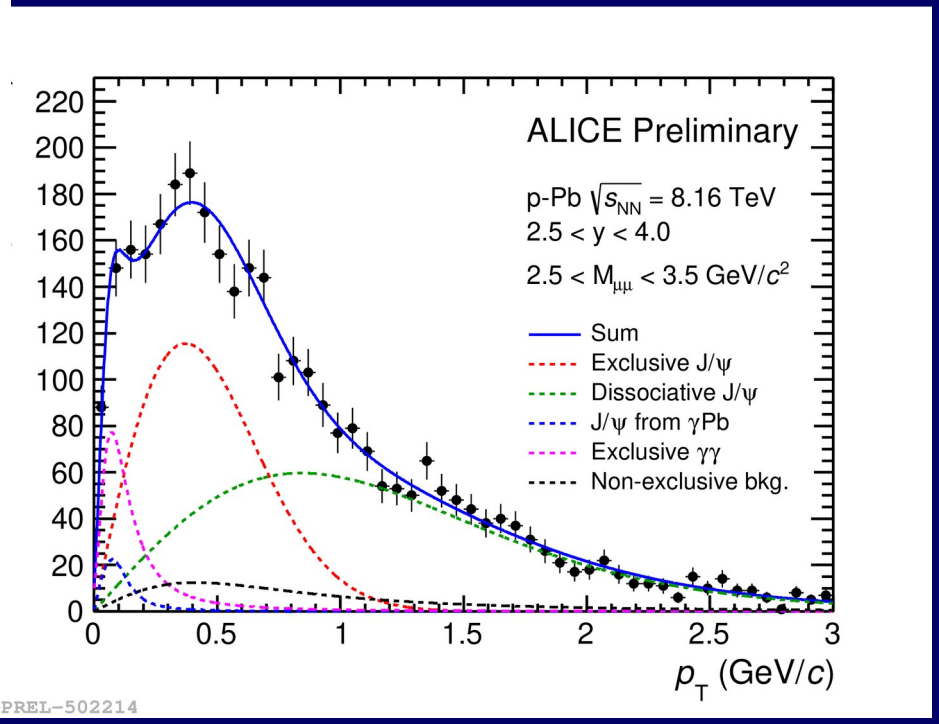


Exclusive J/ψ photoproduction in p–Pb collisions (cont'd)

Exclusive and dissociative J/ψ yield is obtained with unbinned log-likelihood fit made for the invariant mass and transverse momentum of muon pair simultaneously.

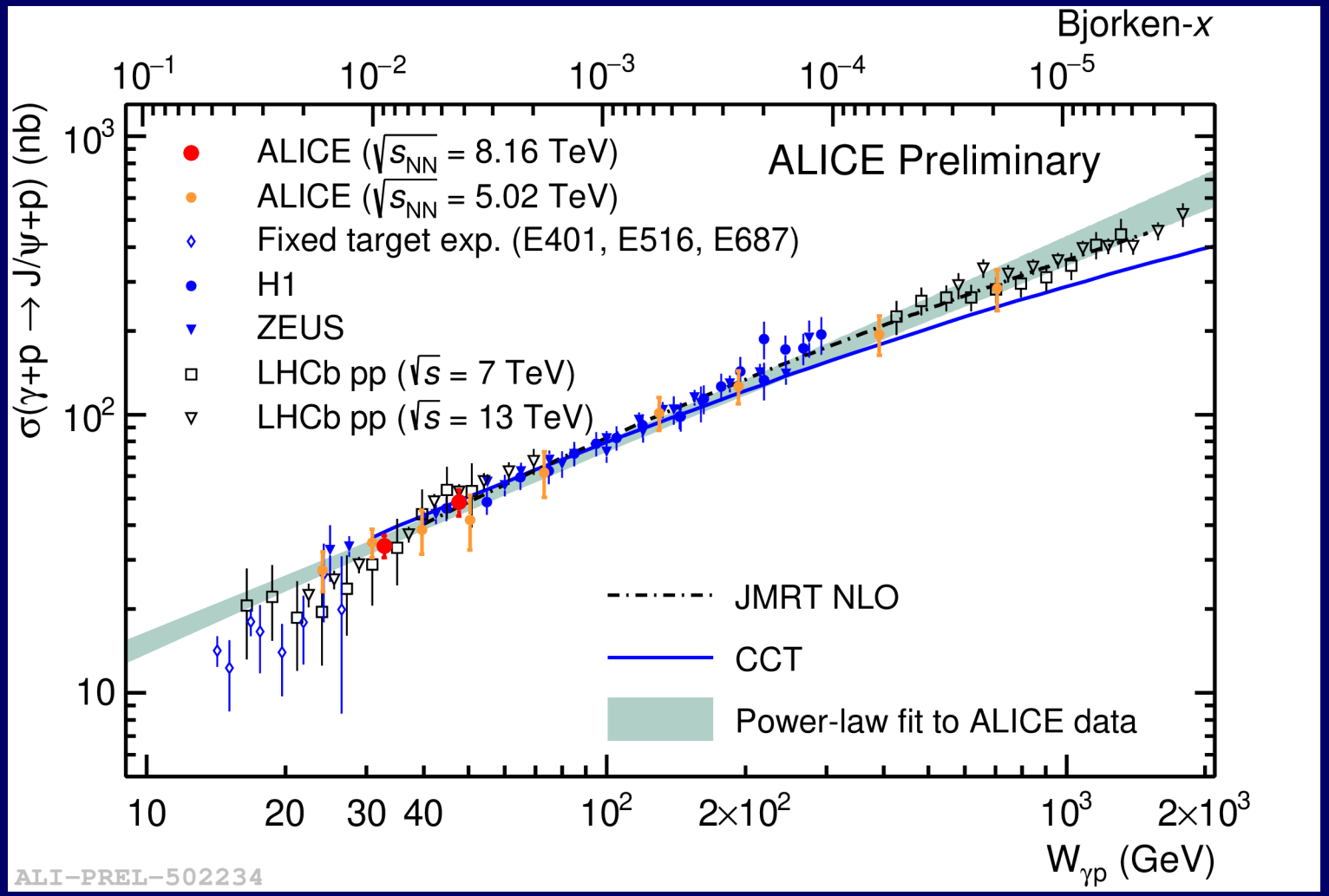
For the fit the events within $2.5 < M_{\mu\mu} < 3.5$ GeV and $p_T < 3$ GeV were used.





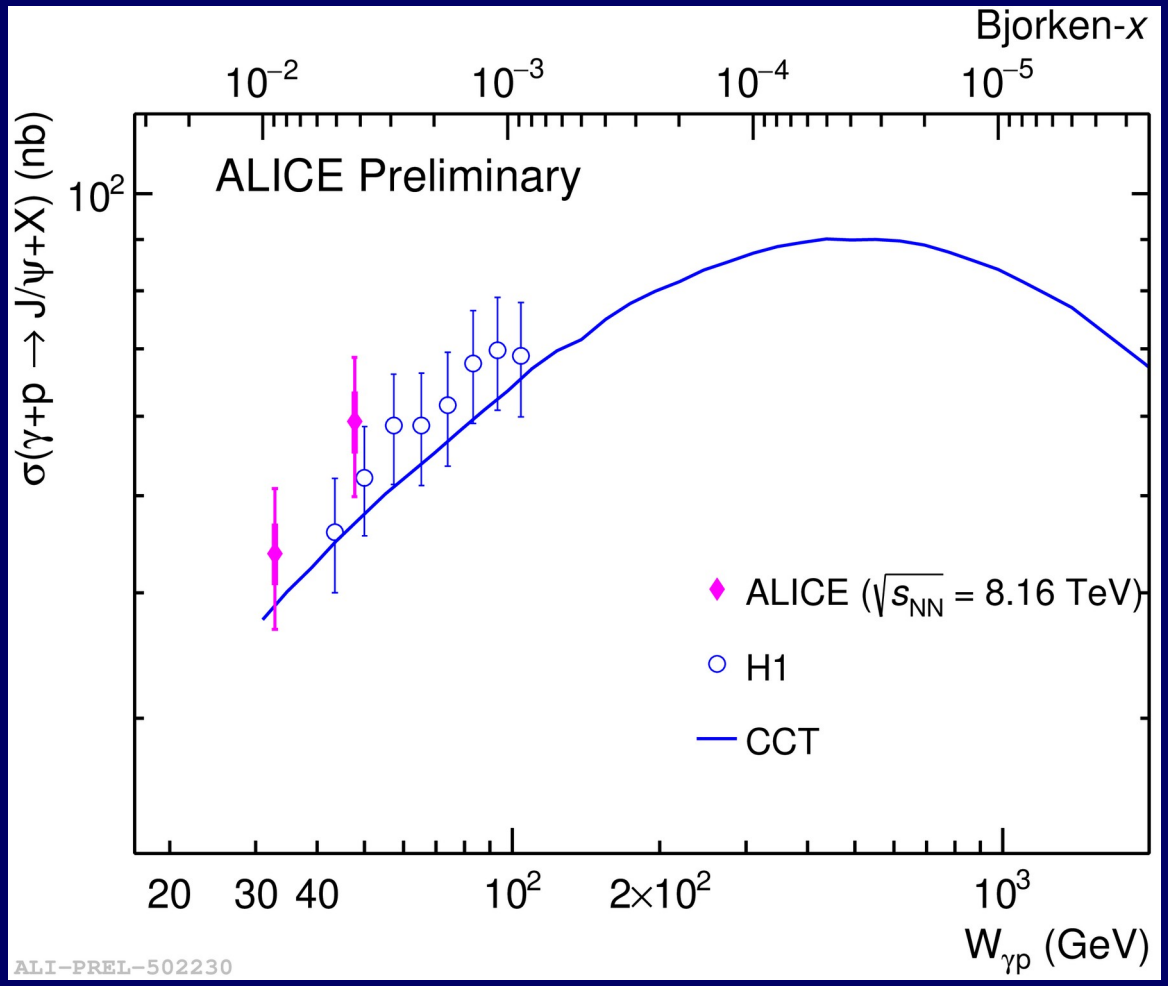
Exclusive J/ψ photoproduction in p–Pb collisions (cont'd)

Flattening of the cross section growth, as the photon-target system energy rises, would indicate the onset of gluon saturation effects



Dissociative J/ψ photoproduction

ALICE forward detectors allow to measure cross sections for both elastic/exclusive (A + p → A + p + J/ψ) and proton-dissociative (A + p → A + X + J/ψ) scatterings separating them based on AD detector located on side with proton scattered (ADA)



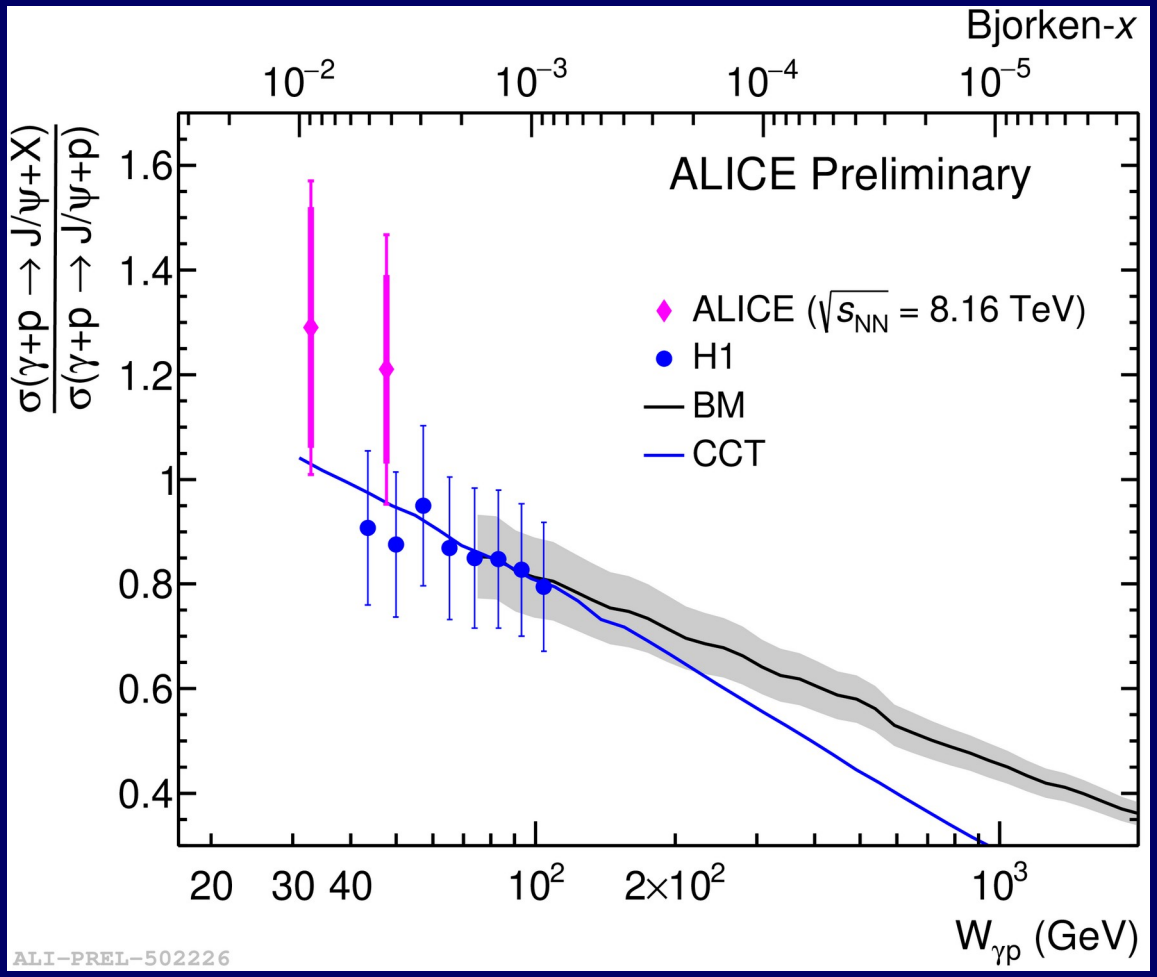
The data are in an agreement with Cepila-Contreras-Takaki model (Phys. Lett. B 766 (2017) 186)

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 … (cont'd)

ALICE forward detectors allow to measure cross sections for both elastic/exclusive (A + p → A + p + J/ψ) and proton-dissociative (A + p → A + X + J/ψ) scatterings, i.e. to measure dissociative-exclusive ratio to add new data to the expected behavior - raise of event yield of γ-p hard scattering with proton dissociative.



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

Summary

– photoproduction of J/ψ off proton was studied in p–Pb UPC in the γp mass interval $27 < W_{\gamma p} < 57$ GeV;

– exclusive cross sections of J/ψ production was measured at mean $W_{\gamma p}$ of 32.8 and 47.7 GeV and found to support a power-law dependence on $W_{\gamma p}$ for the data of fixed-target, HERA and LHC experiments.

They are also in agreement with Cepila-Contreras-Takaki and Jones-Martin-Ryskin-Teubner calculations;

– for the first time the cross section of dissociative photoproduction of J/ψ mesons measured at LHC and found in an agreement with H1 experiment data.