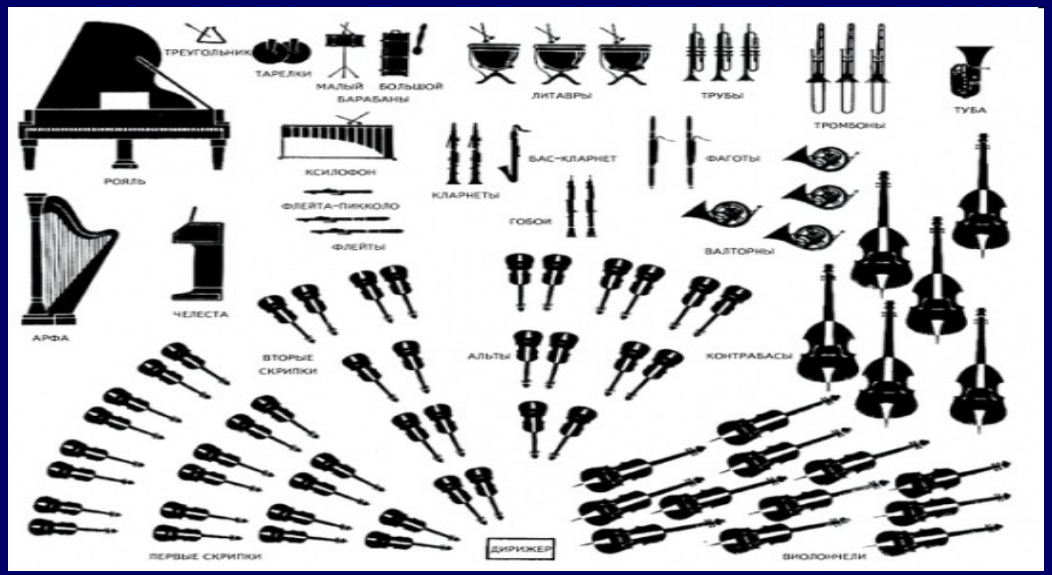
Vector meson photoproduction in ultra-peripheral Pb-Pb collisions at the LHC with ALICE

Valery Pozdnyakov for the ALICE Collaboration

Joint Institute for Nuclear Research, Dubna, Russia



Outline:

– an introduction to the physics of ultra-peripheral collisions (UPC);

– previous results obtained with Run 1 data;

– coherent ρ^0 production in Pb–Pb UPC with Run 2 data;

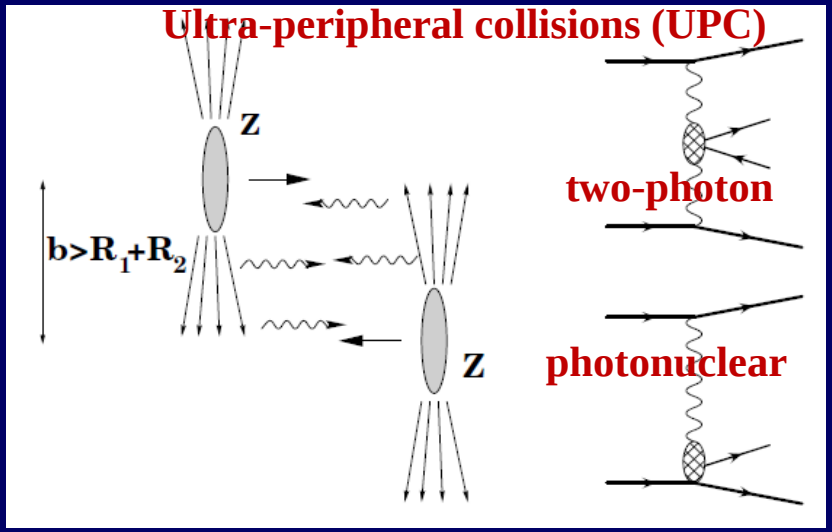
– results on the coherent production of J/ψ at forward rapidity in Pb–Pb UPC at $\sqrt{s_{NN}}$ = 5.02 TeV compared with model expectations;

– J/ψ photoproduction in p-Pb collisions with Run 1 and Run 2 data;

– ongoing analyses;

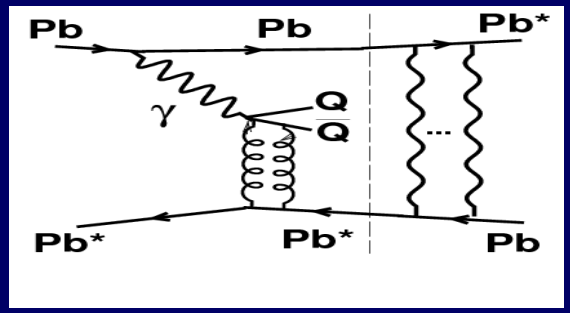
– summary and outlook.

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).

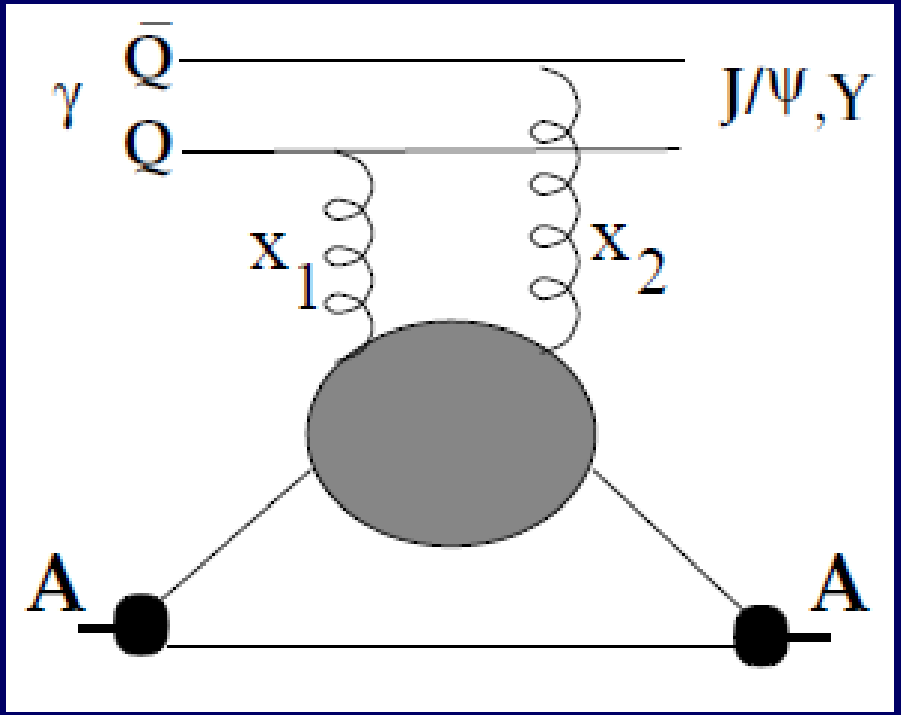


Large Z →
huge photon fluxes →
UPC can be accompanied by another photon exchange →
EM nuclei excitation →
neutron emission detected in Zero Degree Calorimeters.

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, arXiv:2005.01872 [hep-ph] (2020)

Coherent J/ψ photoproduction in UPC



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

The leading order cross section

(assuming that gluons have ~ same x, i.e. $x_1 \approx x_2$)

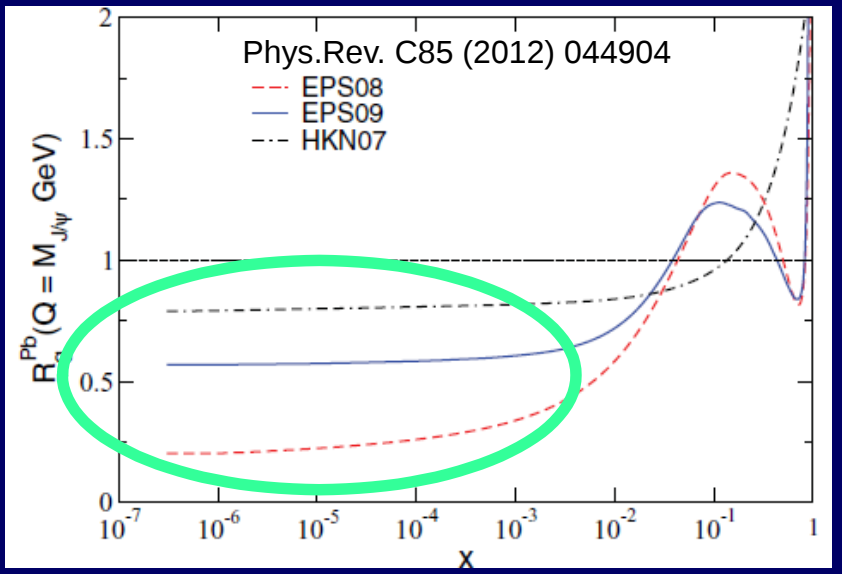
$$\left.\frac{d\sigma_{\gamma A\to J/\Psi A}}{dt}\right|_{t=0} = \xi_{J/\Psi}\left(\frac{16\pi^3\alpha_s^2\Gamma_{l^+l^-}}{3\alpha M_{J/\Psi}^5}\right)[xG_A(x,\mu^2)]^2$$

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

extensions of the calculations to NLO are discussed in

Flett CA, et al. arXiv:1912.09128 [hep-ph] (2019)

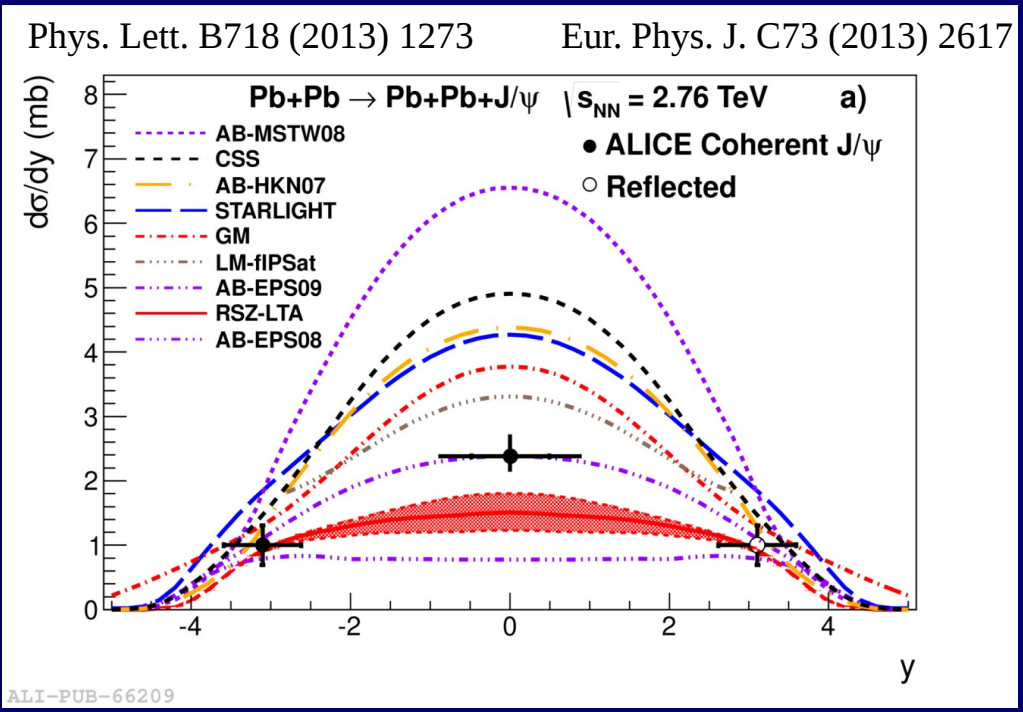
how to properly incorporate nuclear shadowing at small x?



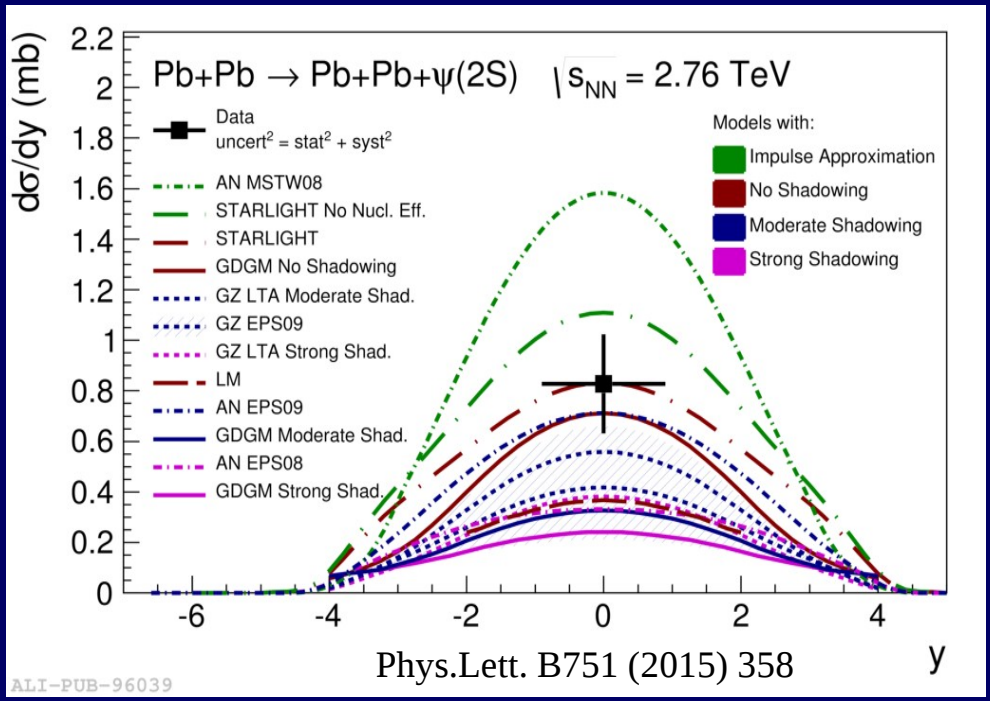
Charmonium photoproduction from ALICE Run 1 (Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV)

J/ψ

Phys. Lett. B718 (2013) 1273 Eur. Phys. J. C73 (2013) 2617



ψ(2S)

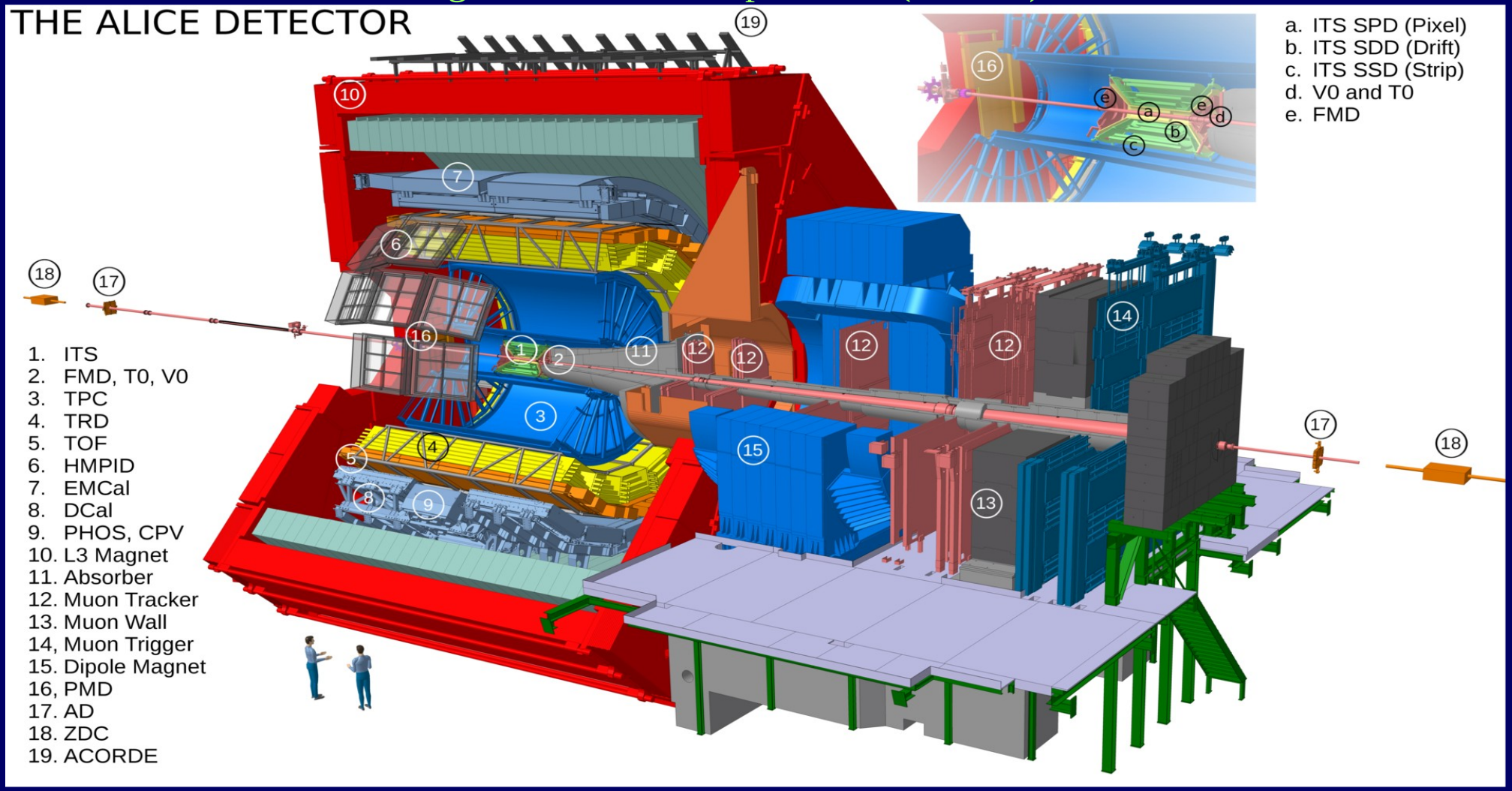


Phys.Lett. B751 (2015) 358

ALICE measurement supports calculations which include a moderate shadowing of gluons in nuclei.

Models with all nucleons equally involved in the scattering (*Impulse Approximation with no shadowing*, upper curve on plots) and those with a strong shadowing are disfavored.

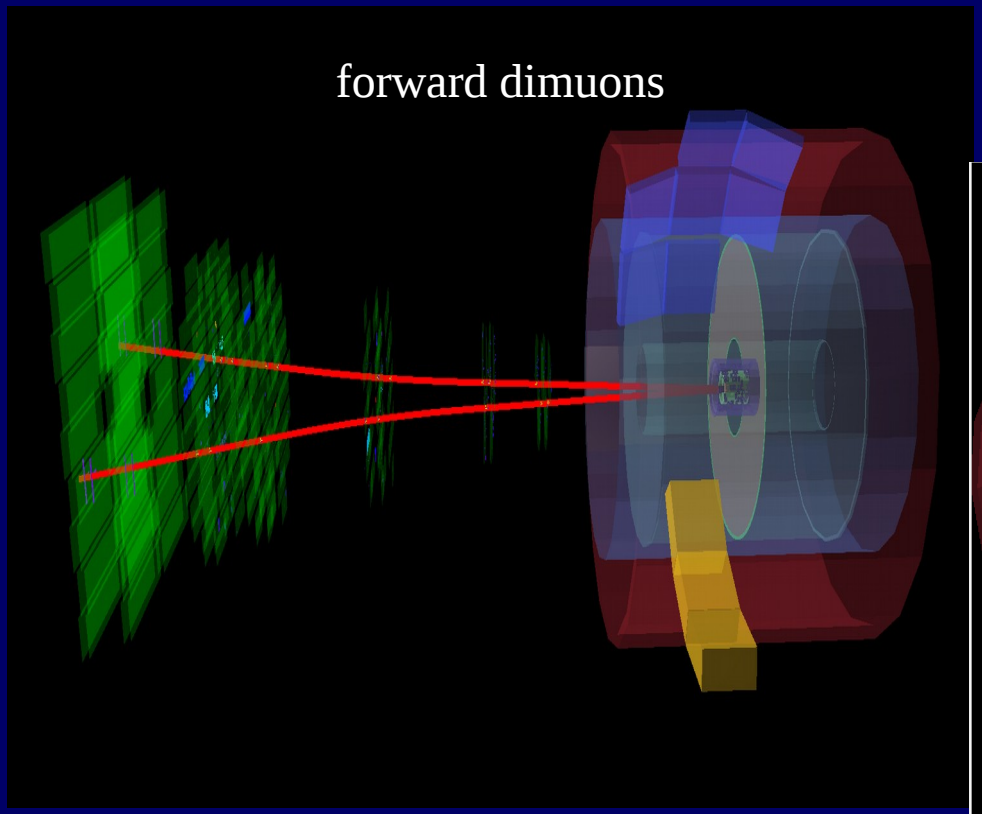
A Large Ion Collider Experiment (ALICE) at LHC

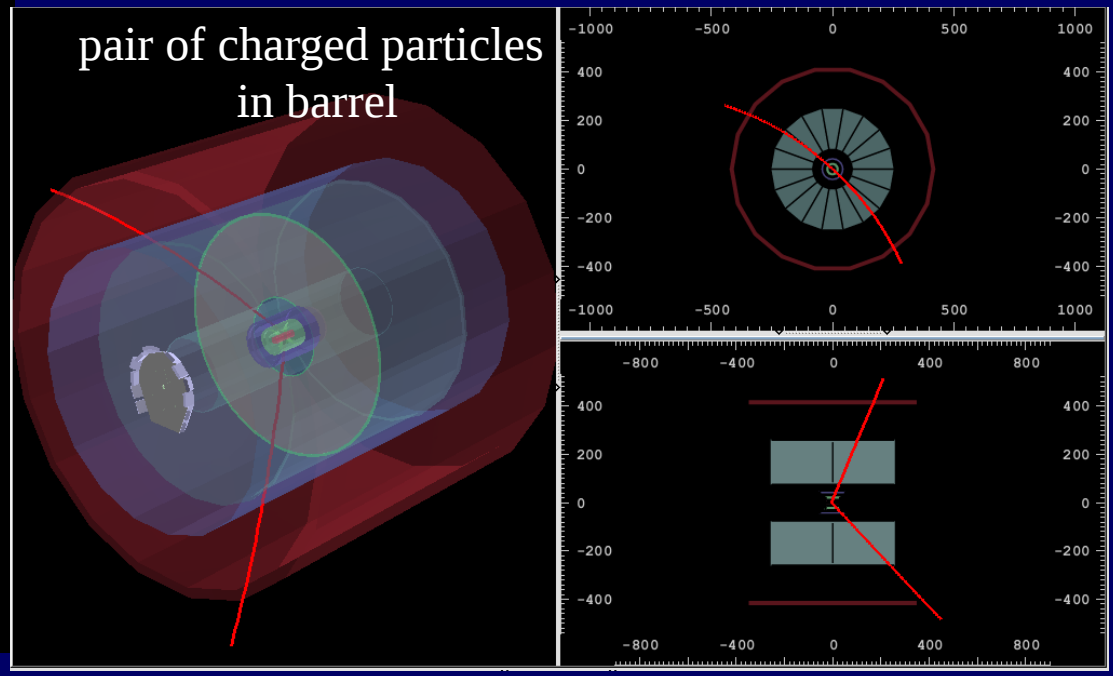


ALICE systems relevant for J/ψ / ρ^0 photoproduction measurements:

- Muon spectrometer (item 12 on scheme) /TPC (3) to reconstruct J/ψ or ρ^0 decays;
- 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

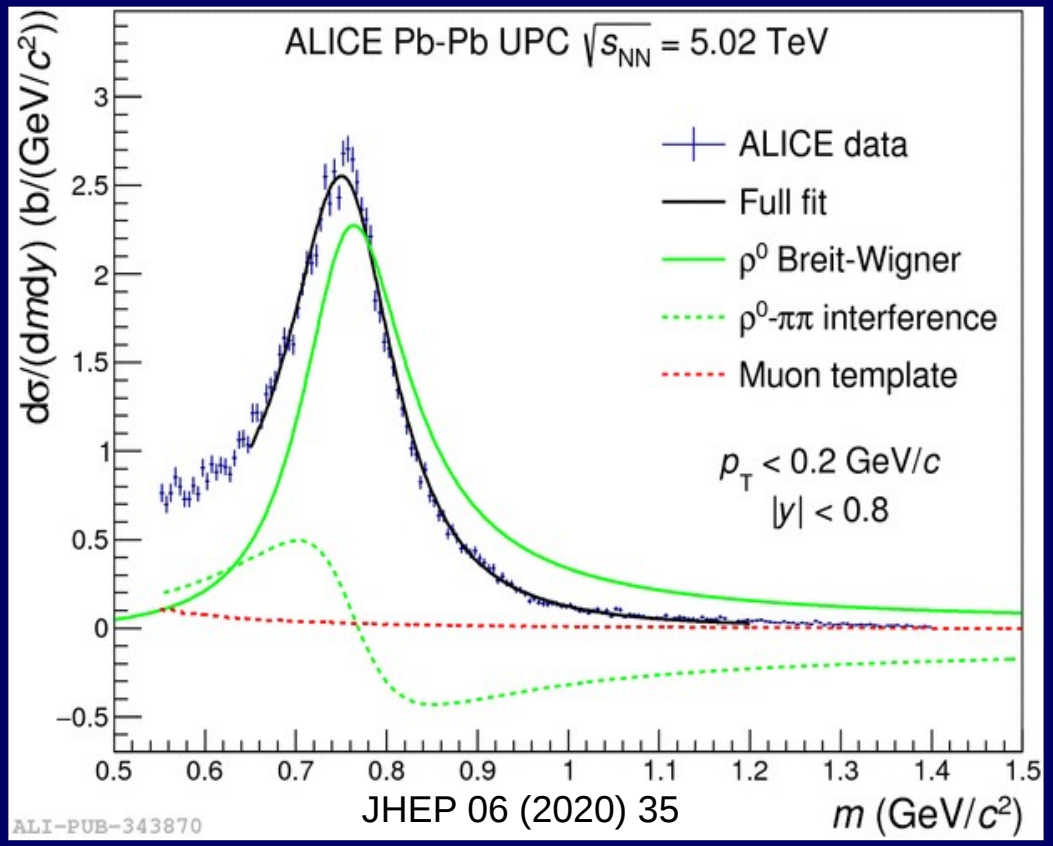




Main features of UPC vector meson photoproduction:
- exclusive events, only vector meson decay particles detected;
- transverse momentum balance of final state particles.

Coherent ρ^0 production in Pb–Pb UPC at $\sqrt{s_{NN}}$ = 5.02 TeV

Photonuclear production of ρ^0 in Pb–Pb UPC at the LHC has a large cross section which makes it a good tool to study the approach to the black-disk limit of QCD.



JHEP 06 (2020) 35

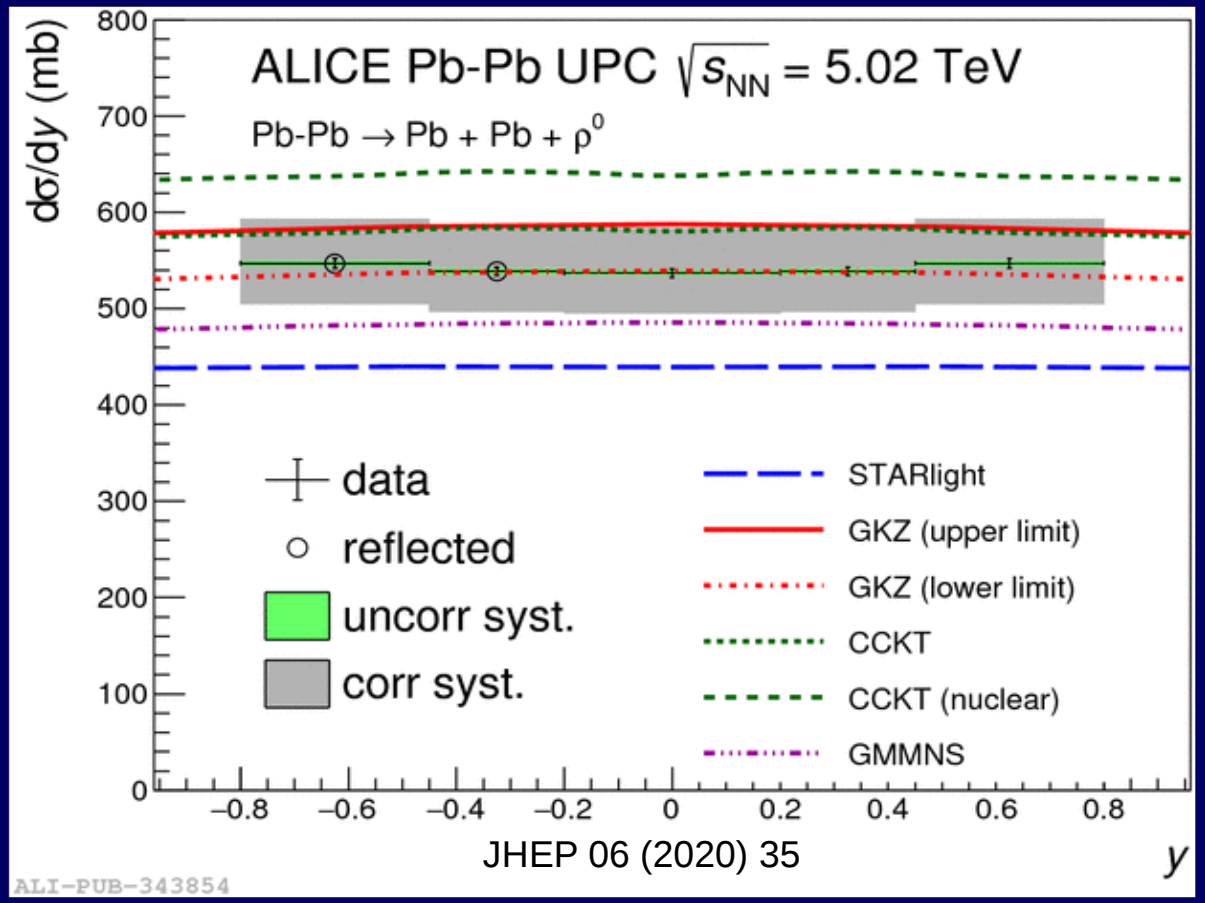
The integrated luminosity is of 485 mb^{-1}.

The signal sample contains ~57 thousand events which passed selection:
– |rapidity of a pair| < 0.8;
– pair transverse momentum p_T < 0.2 GeV/c;
– 0.55 < pair mass < 1.4 GeV/c^2.

overall experimental efficiency of ~17%

Fit by
Breit-Wigner for ρ^0 resonance shape
+ constant term for direct pion pair production
+ interference between them
+ dimuons from gamma-gamma interactions.

Coherent ρ^0 production in Pb–Pb UPC at $\sqrt{s_{NN}}$ = 5.02 TeV (cont'd)



JHEP 06 (2020) 35

Model predictions:

GKZ (V. Guzey, E. Kryshen and M. Zhalov, Phys. Rev. C93 (2016) 055206):
VDM + Gribov-Glauber model of nuclear shadowing for fluctuations of the photon-nucleons interaction.

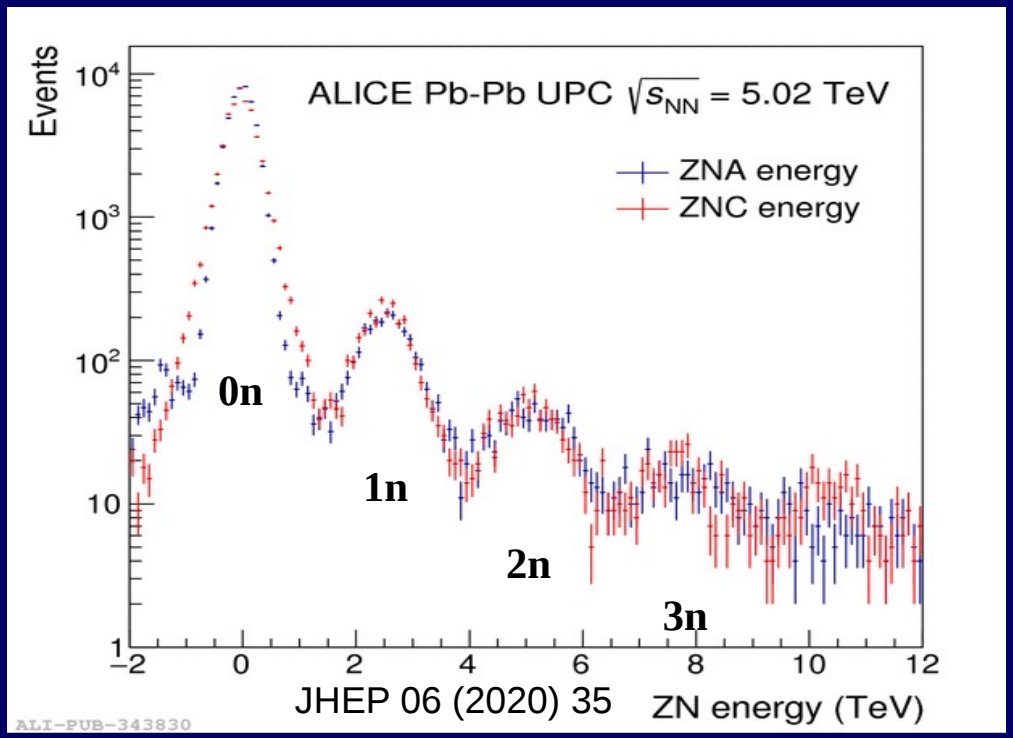
CCKT (J. Cepila, J. G. Contreras, M. Krelina, and J.D. Tapia Takaki, Nucl. Phys. B934 (2018) 330–340):
colour-dipole model + gluons "hot spots" of the structure of the nucleon in the transverse plane + Glauber model for nuclear effects.

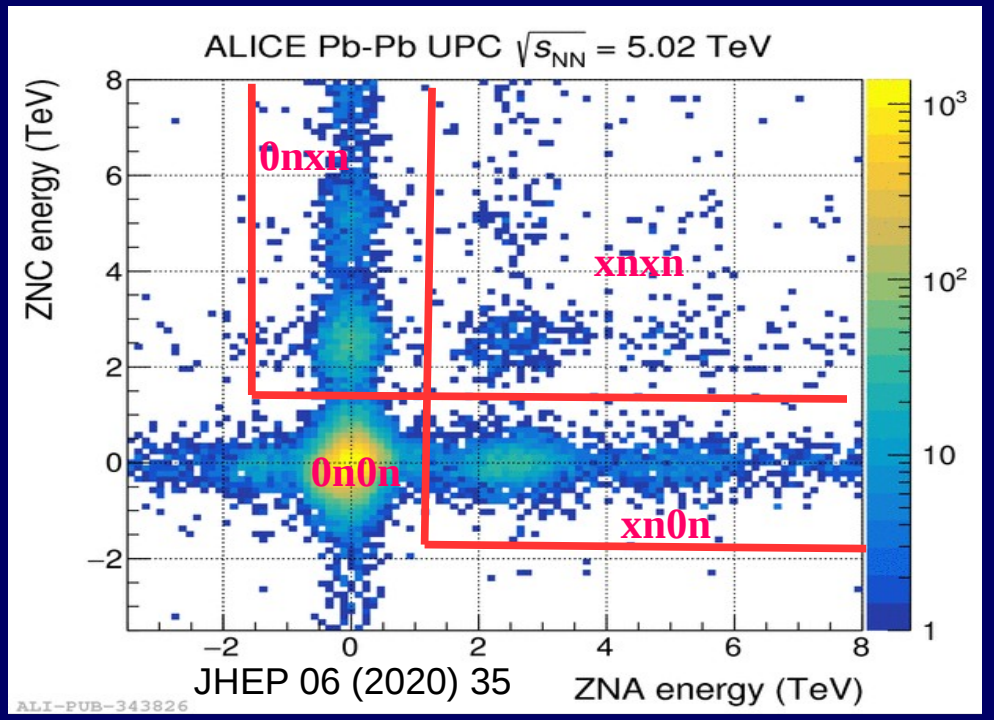
GMMNS (Goncalves, Machado, Morerira, Navarra and dos Santos, Phys. Rev. D96 (2017) 094027):
Iancu-Itakura-Munier (IIM) approach for gluon saturation + colour-dipole model.

STARLIGHT (S.Klein, J.Nystrand et al. Comp.Phys.Comm. 212 (2017) 258) :
γ+p → VM+p cross section + the optical theorem + a Glauber-like eikonal formalism

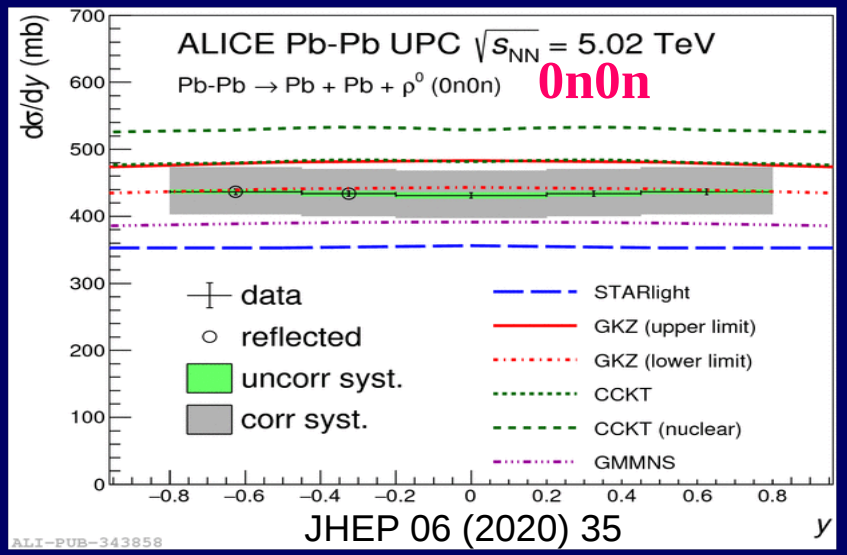
Coherent ρ^0 production in Pb–Pb UPC at $\sqrt{s_{NN}}$ = 5.02 TeV (cont'd)

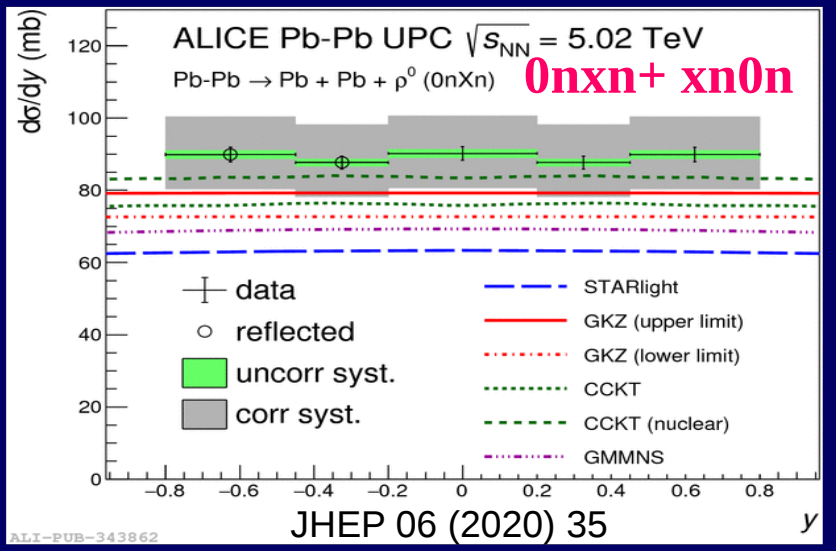
ALICE is equipped with two ZDC detectors (ZNA and ZNC)
– located at either side of interaction point at ±112.5 m along the z-axis;
– intended for measurement of neutrons at beam rapidity;
– which provide time resolution enough to separate beam–beam and beam–gas interactions;
– which have a good efficiency to detect neutrons coming from electromagnetic dissociation (EMD) with |η | > 8.8;
– which have a relative energy resolution of around 20% for a neutron which allows to separate events with either zero or a few neutrons at beam rapidities.

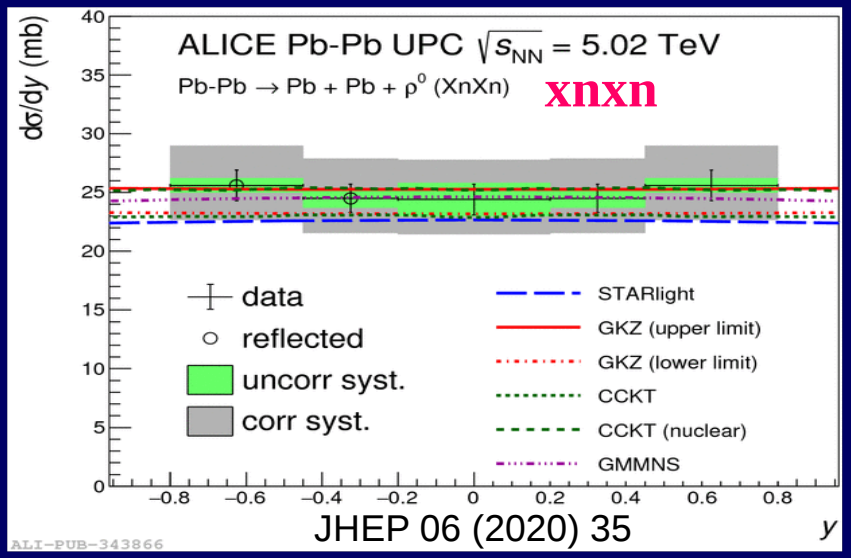




Coherent ρ^0 production in Pb–Pb UPC at $\sqrt{s_{NN}}$ = 5.02 TeV (cont'd)



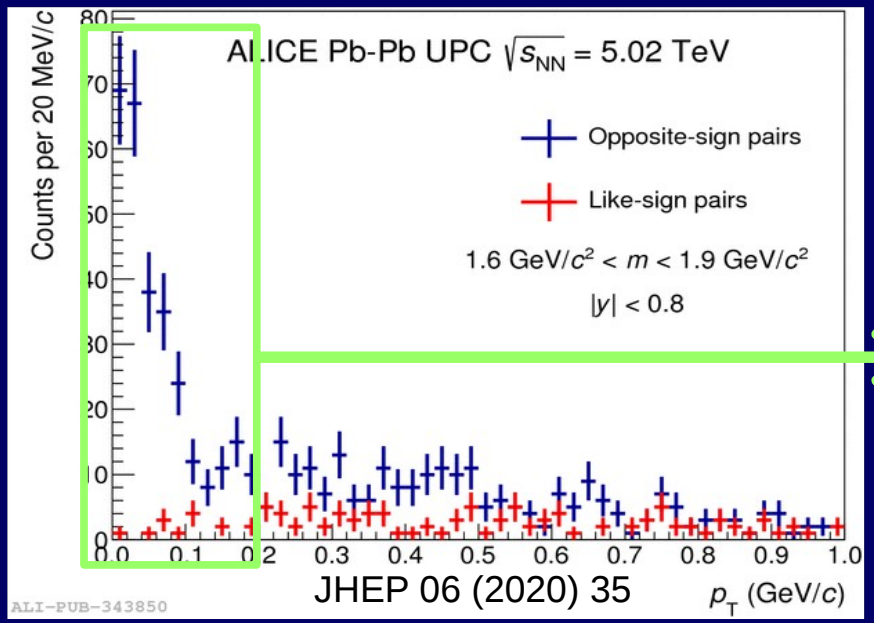


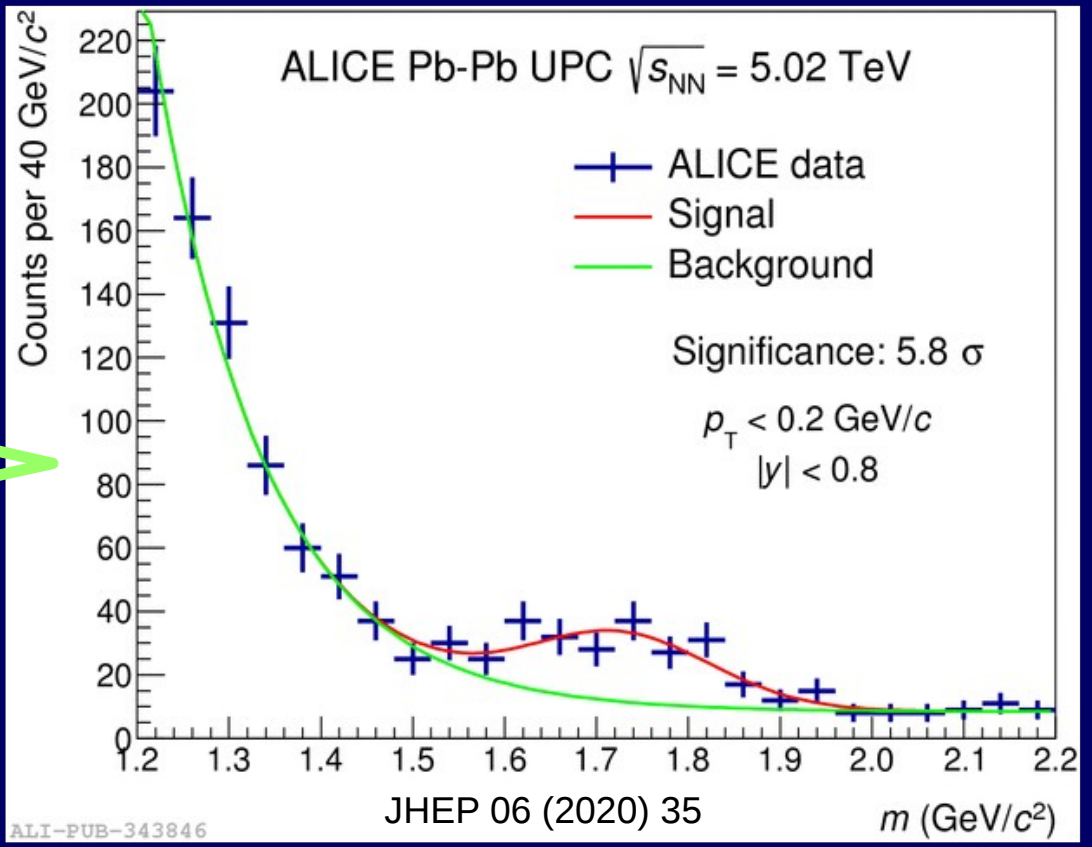


agreement both with models based on colour-dipole approach and with Gribov-Glauber shadowing.

The models for EMD accompanying VM photoproduction describe the measured cross sections for different neutron emission classes which are sensitive to different impact parameter ranges.

Resonance-like structure at higher invariant masses in Pb–Pb UPC at $\sqrt{s_{NN}}$ = 5.02 TeV





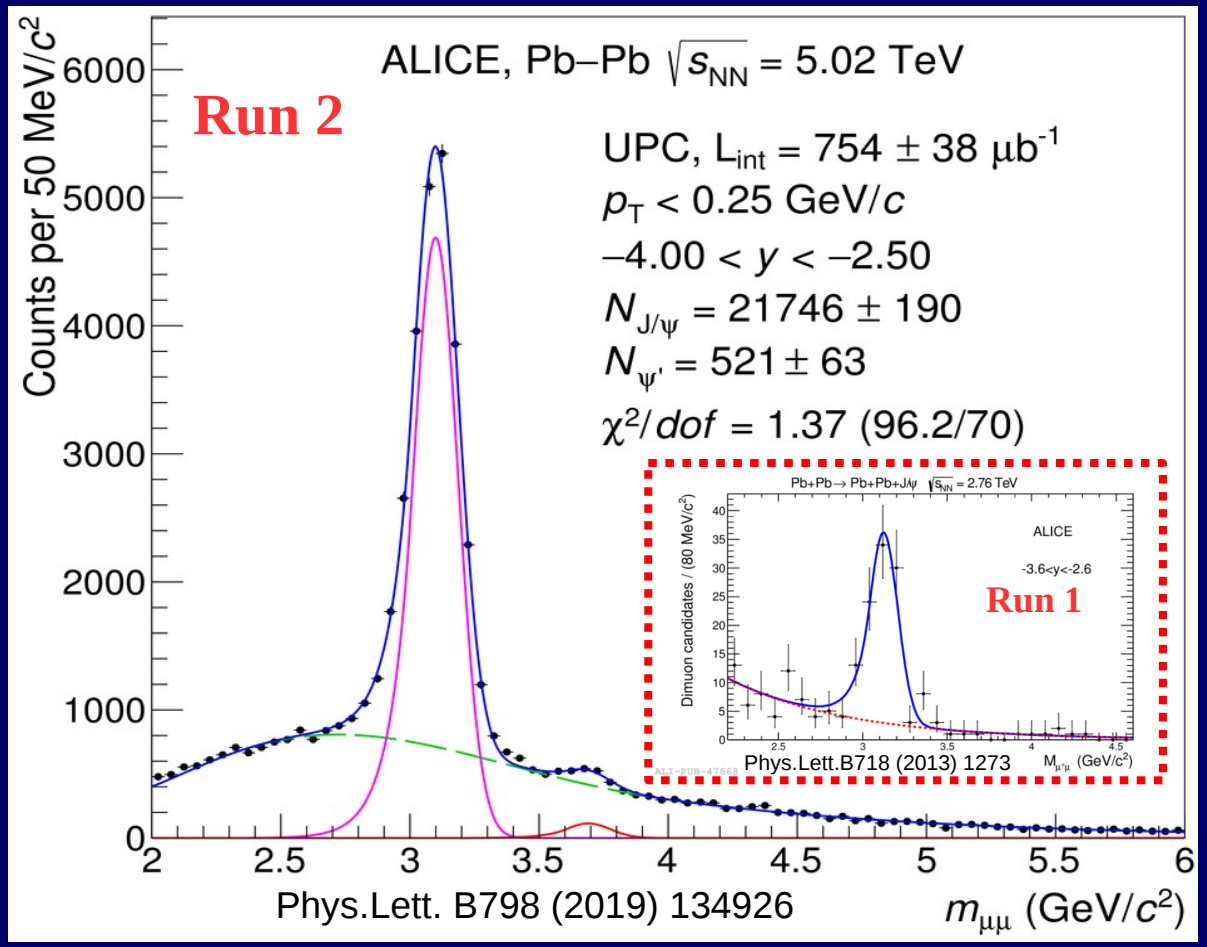
Mass distribution is fitted by STAR-like approach (S. R. Klein for STAR Collab., PoS DIS2016 (2016) 188)
and the fit provides
mass of (1725 ± 17) MeV/c^2 and width (143 ± 21) MeV/c^2

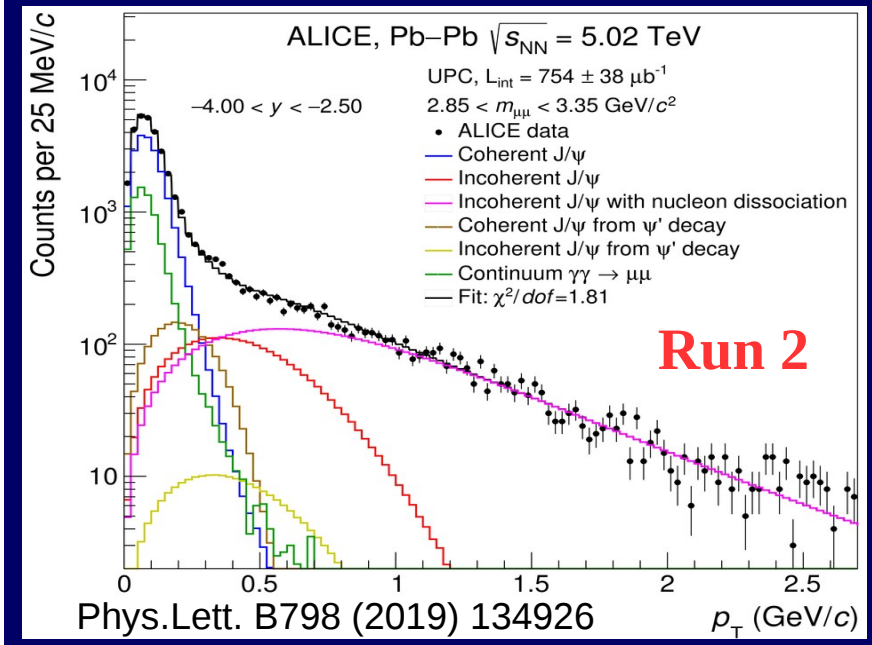
several candidates listed in PDG are compatible with it

Coherent J/ψ production in ultra-peripheral Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

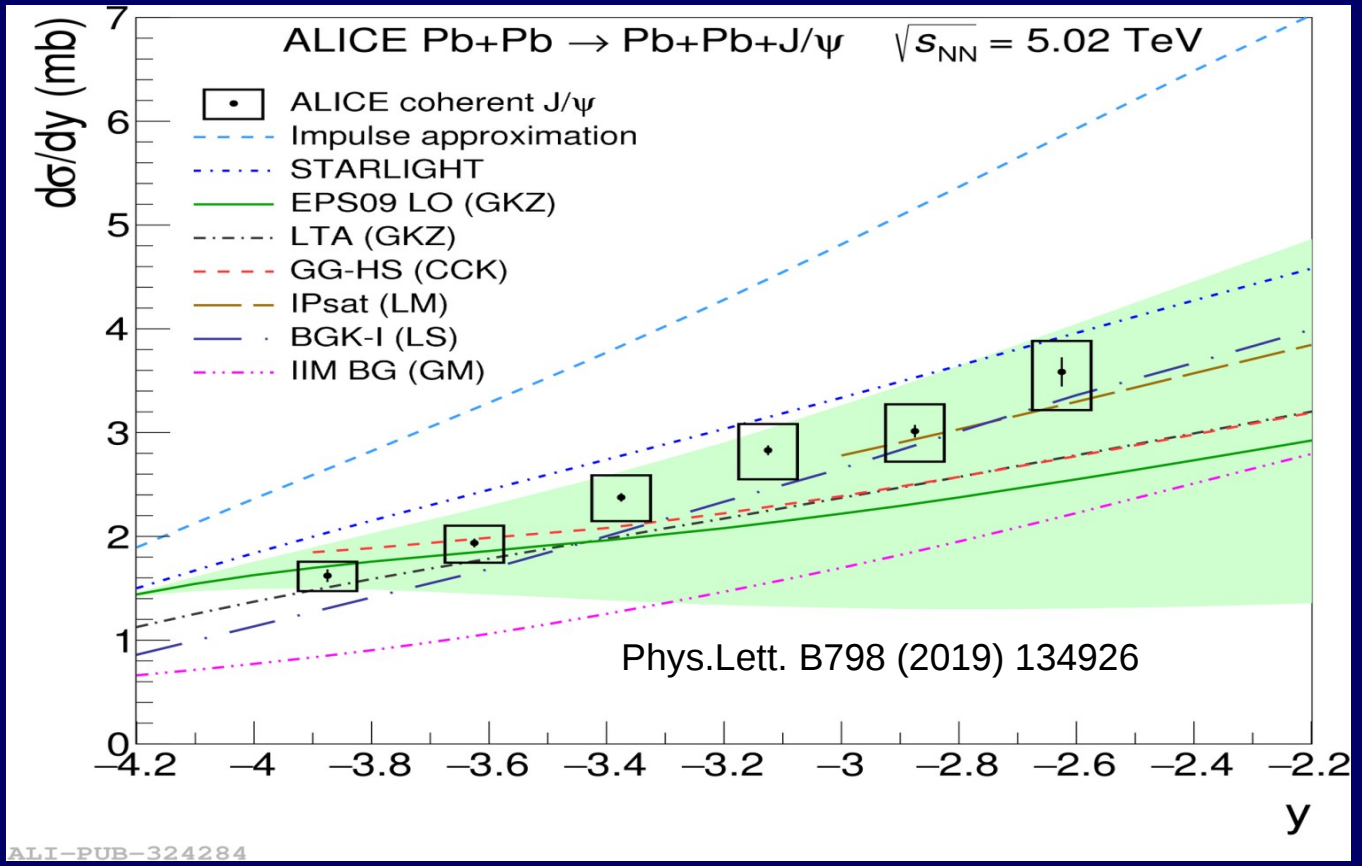
Increased LHC Run 2 Pb-Pb luminosity ($\int L > 700\ \mu b^{-1}$), larger J/ψ photoproduction cross section and more efficient event triggering provides ~200 times larger J/ψ yield at forward rapidities as compared to the Run 1 data.

Forward AD detector installed for Run 2 and included into the trigger suppresses background from peripheral heavy-ion collisions.





Coherent J/ψ production in ultra-peripheral Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV



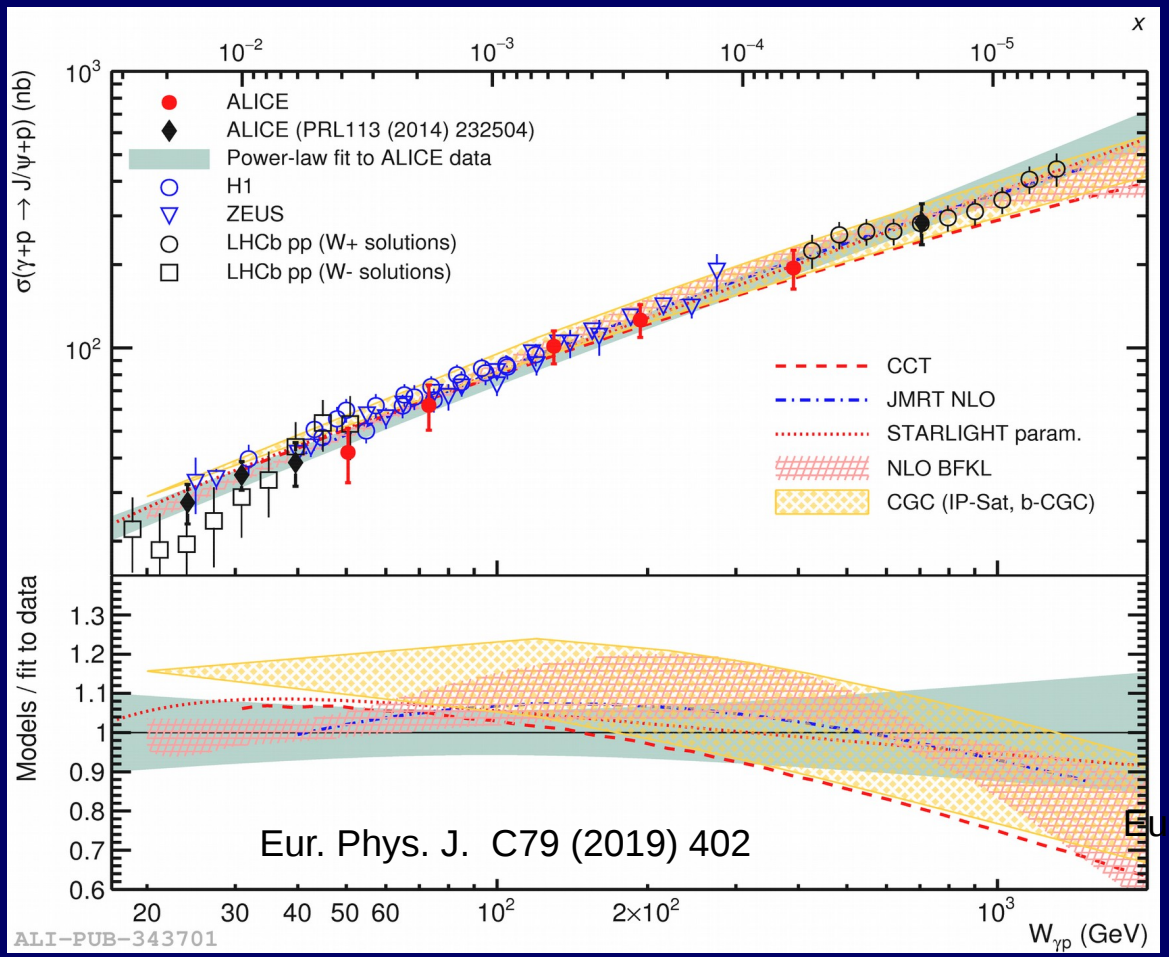
impulse approximation: no nuclear effects

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)

Coherent J/ψ photoproduction cross section implies moderate gluon shadowing in nuclei.

Exclusive J/ψ photoproduction off a proton at $\sqrt{s_{NN}}$ = 5.02 TeV

p-Pb collisions have
– no photon source uncertainty since photon flux comes almost entirely from Pb-side and gamma-proton centre-of-mass energy is calculated w/o ambiguity;
– background from gamma-gamma to lepton pair small;
– inelastic interactions effectively suppressed by no-ZDC signal requirement.



– $W_{\gamma p}$ ~ [20 – 700] GeV;
– $x \approx [10^{-5} – 10^{-2}]$
– Run 2 data should reach W beyond 1 TeV

CCT (J. Cepila, J.G. Contreras, J.D. Tapia Takaki, Phys. Lett. B 766, 186 (2017)):
colour dipole approach + energy dependence of geometrical fluctuations of the proton structure in the impact parameter plane.

JMRT (S.P. Jones, A.D. Martin, M. Ryskin, T. Teubner, JHEP 11, 085 (2013)):
the parameters for calculations obtained by a fit to the data and their energy dependence.

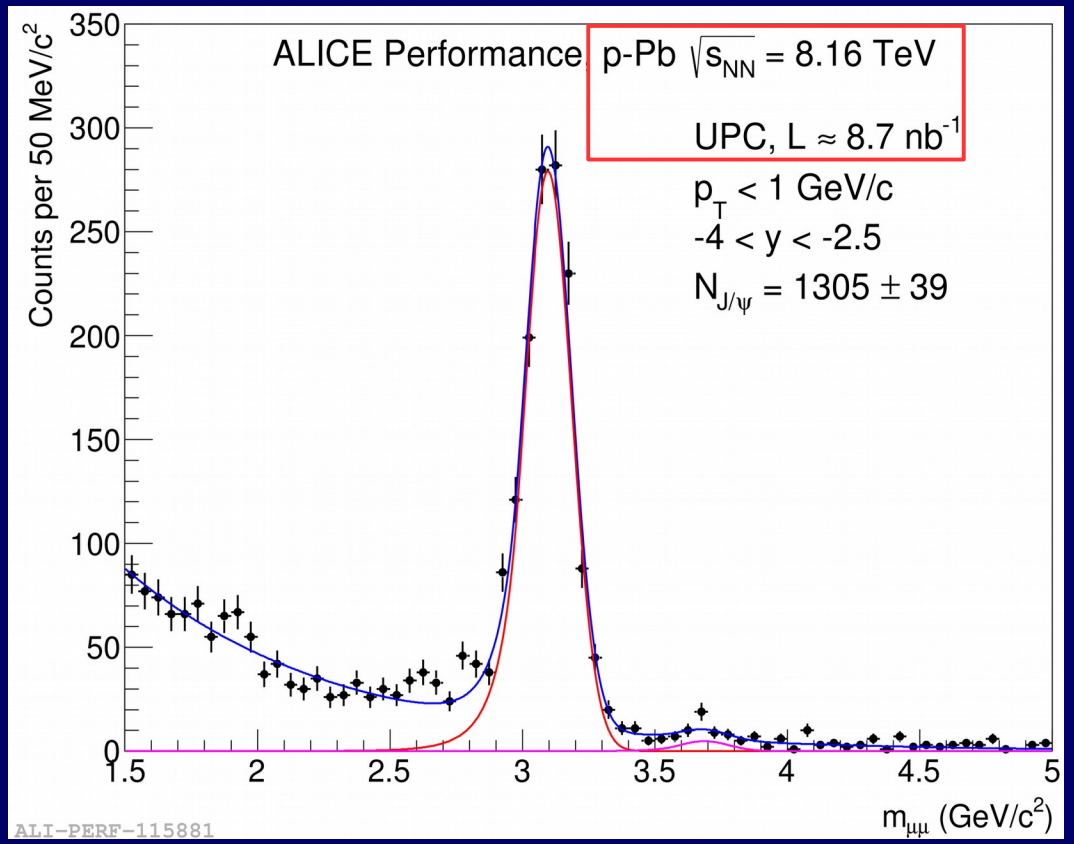
CGC (N. Armesto, A.H. Rezaeian, Phys. Rev. D 90(5), 054003 (2014))
colour dipole model.

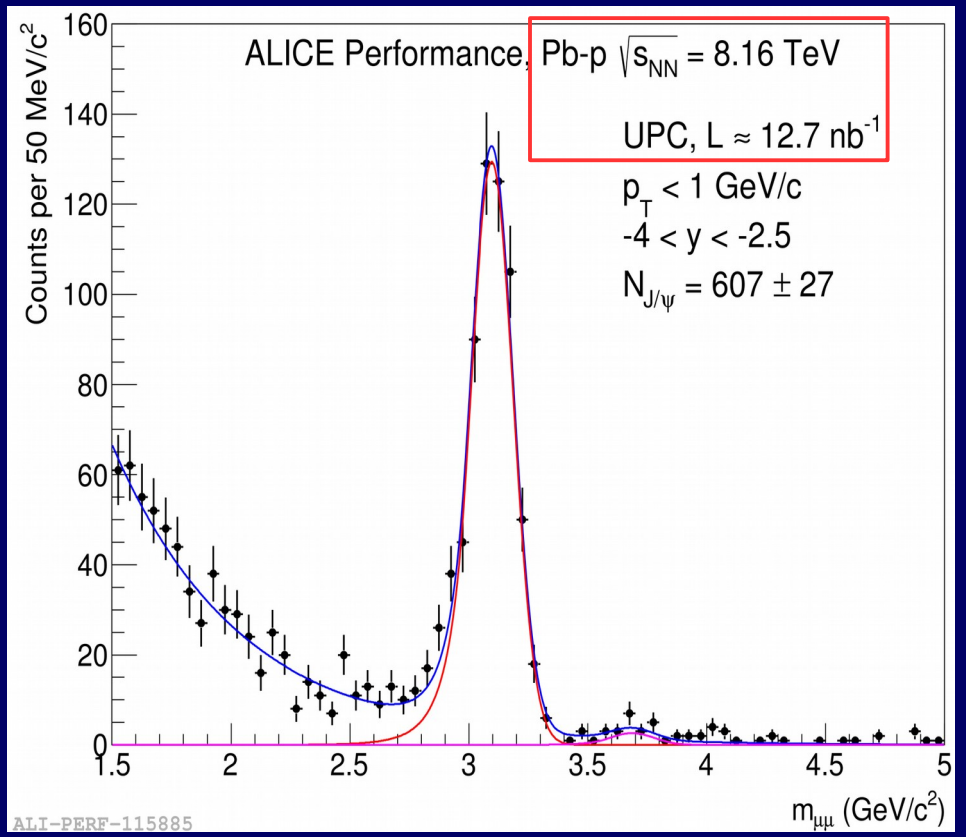
Exclusive J/ψ photoproduction off a proton at $\sqrt{s_{NN}}$ = 8.16 TeV (Run 2 data)

– collected statistics 2-5 times compared to Run 1 data due to more efficient triggering;

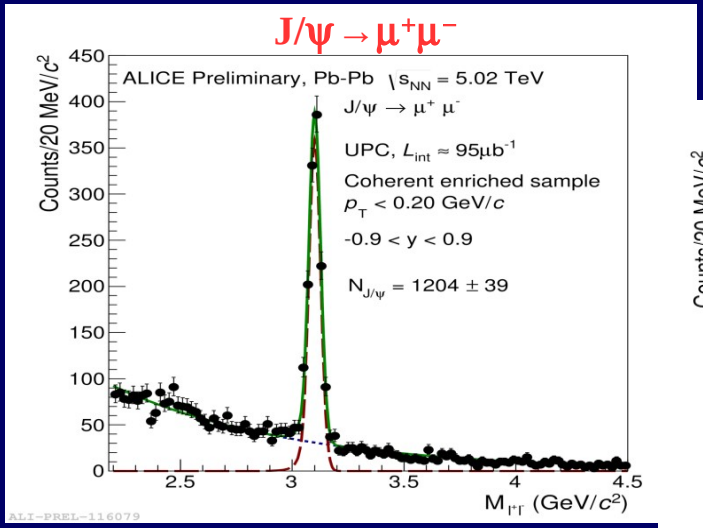
– reachable gamma-proton masses above 1 TeV;

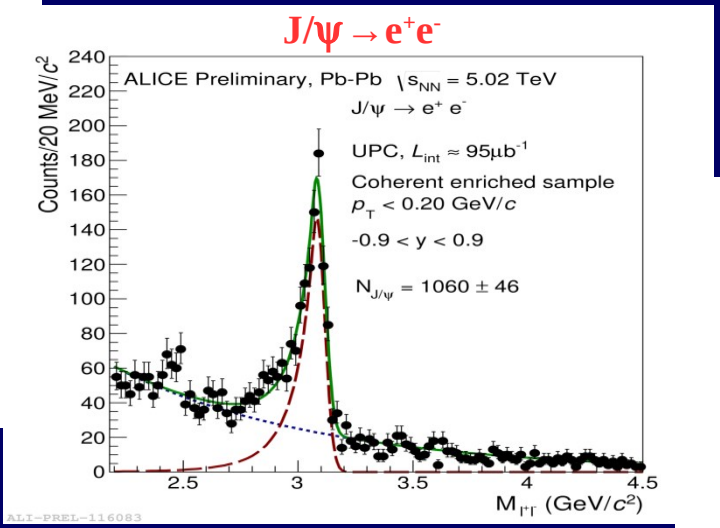
– x reaches 10^{-5}.

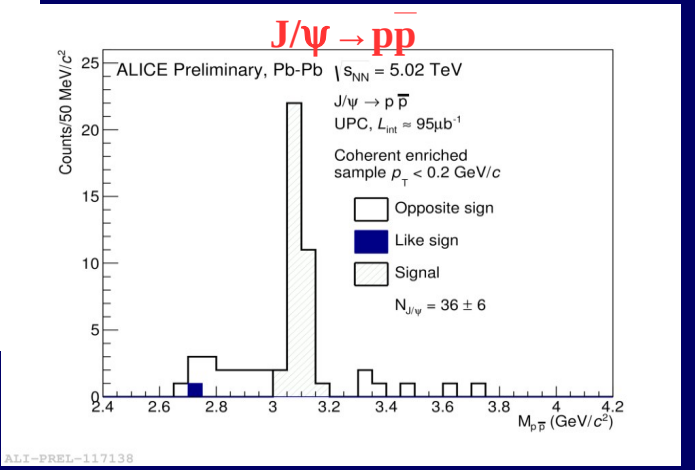


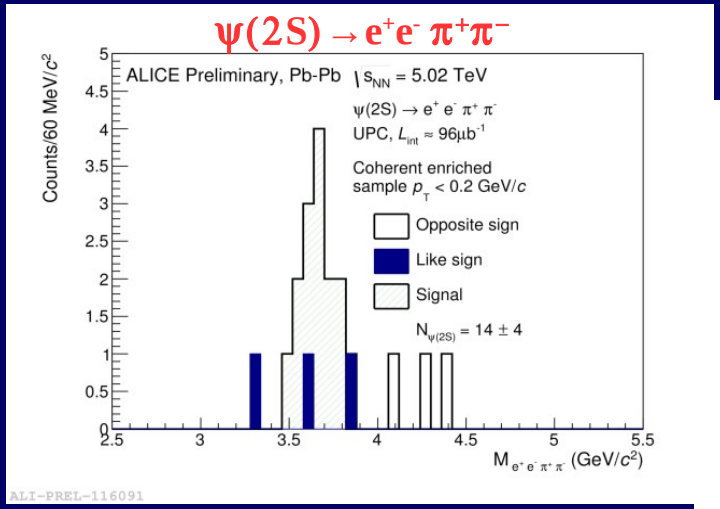


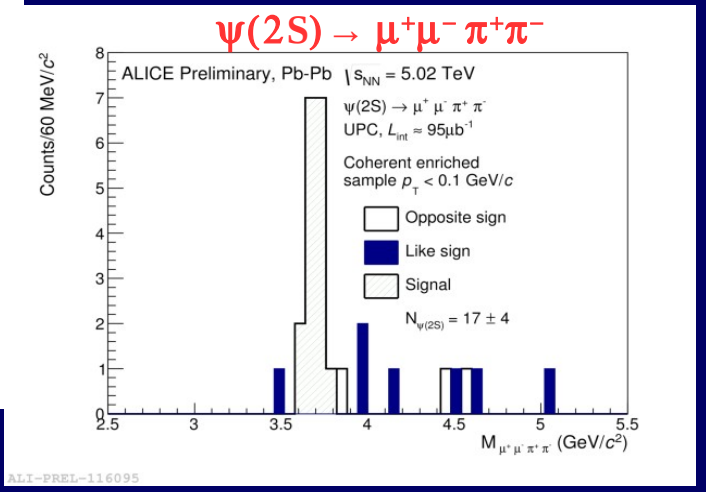
Charmonium photoproduction in Pb-Pb UPC with Run 2 data at midrapidity (preliminary)











Conclusions and outlook

– analysis of J/ψ photoproduction is a tool to learn about the dynamics of γA interactions and the gluon content of nuclei;

– rapidity dependence of the coherent ρ^0 production cross section in Pb–Pb UPC at $\sqrt{s_{NN}}$ = 5.02 TeV was measured for different cases of EMD accompanying VM photoproduction. The cross sections are compared with the main available models;

– coherent photoproduction of a resonance-like object with a mass ~1.7 GeV/c^2 which decays into a $\pi^+ \pi^-$ pair is observed;

– Pb–Pb UPC collisions at $\sqrt{s_{NN}}$ = 5.02 TeV were studied and the cross section of coherent J/ψ photoproduction measured. The result implies moderate gluon shadowing in nuclei;

– Studies of coherent and incoherent J/ψ and ψ' production at mid-rapidity, J/ψ in p-Pb collisions and ρ^0 production in Xe–Xe UPC are ongoing;

– with planned luminosity of LHC Pb-Pb Run 3 and Run 4, ALICE expect to collect 5×10^8 of J/ψ candidates decayed into dimuons.