TWENTIETH LOMONOSOV CONFERENCE ON ELEMENTARY PARTICLE PHYSICS

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MOSCOW STATE UNIVERSITY

ALICE

Recent results on ultra-peripheral collision studies with ALICE at the LHC

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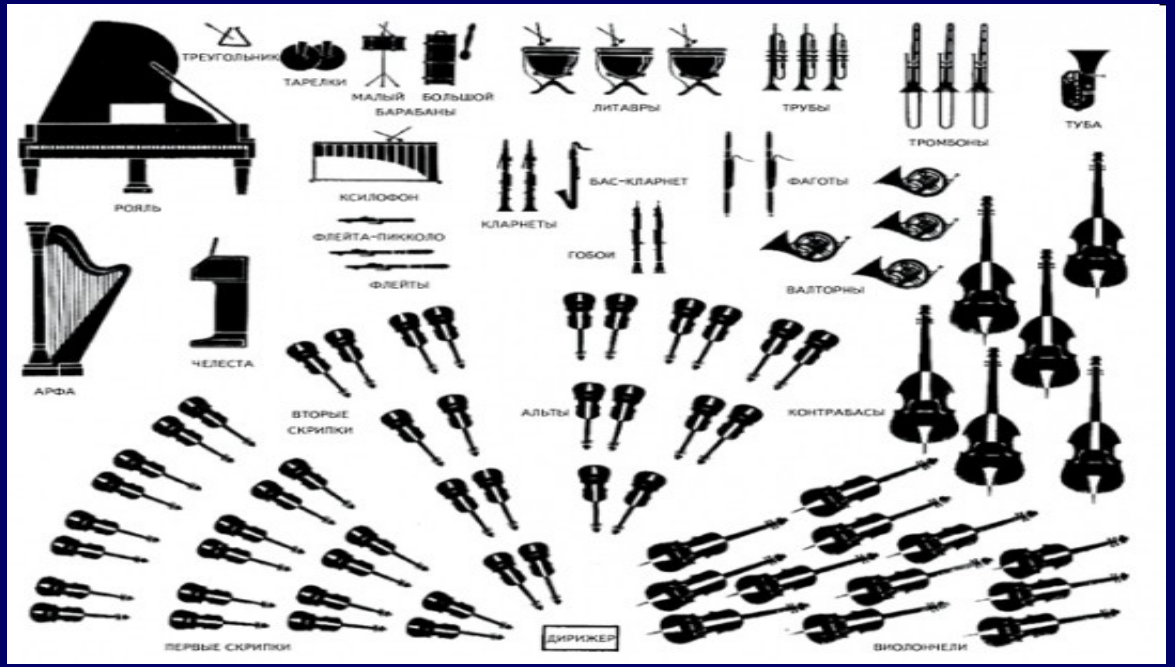


Outline:

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

– J/ψ photoproduction in p–Pb collisions;

– coherent production of J/ψ at forward rapidity in Pb–Pb UPC;

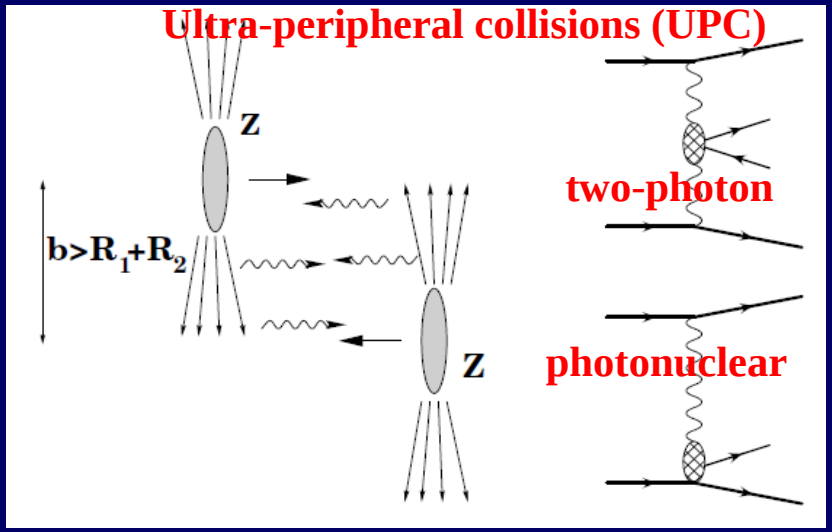
– coherent J/ψ and ψ′ photoproduction at midrapidity in Pb–Pb UPC;

– |t|-dependence of midrapidity coherent J/ψ photonuclear production;

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

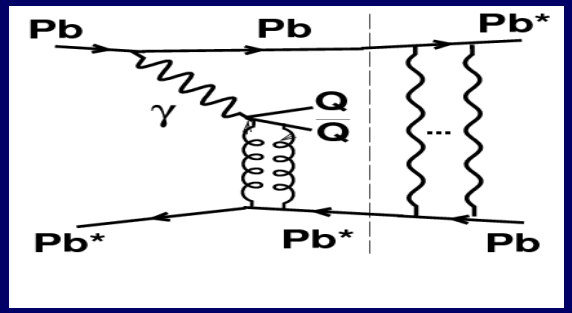
– summary and outlook.

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).
NB there is bidirectional photon ambiguity in case of heavy ions



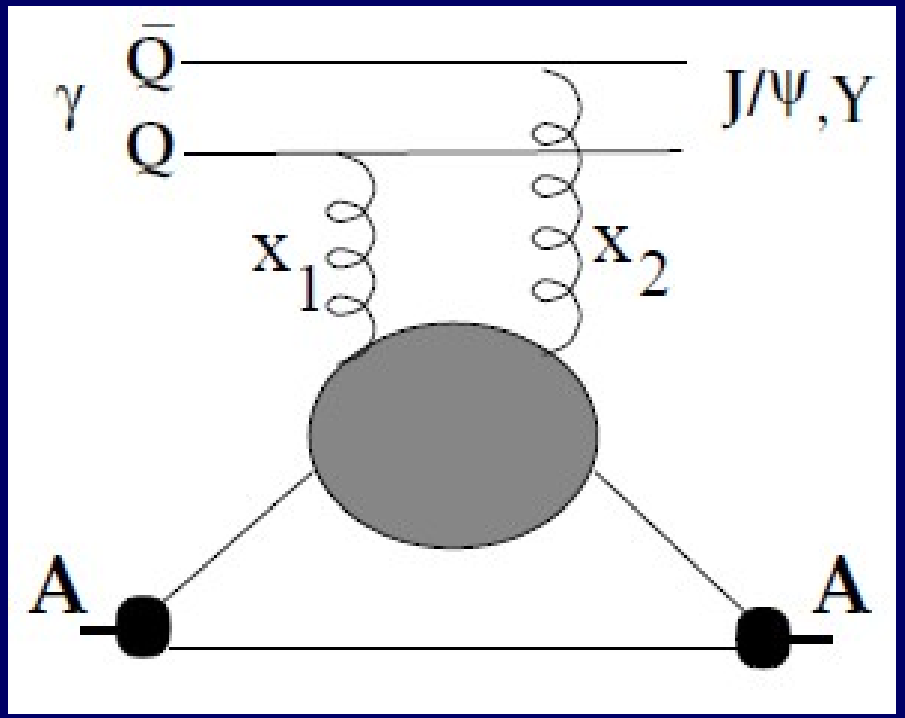
Large Z →
huge photon fluxes →
UPC can be accompanied by another photon exchange →
EM nuclei excitation →
neutron emission detected in Zero Degree Calorimeters.

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, 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. $x_1 \approx x_2$)

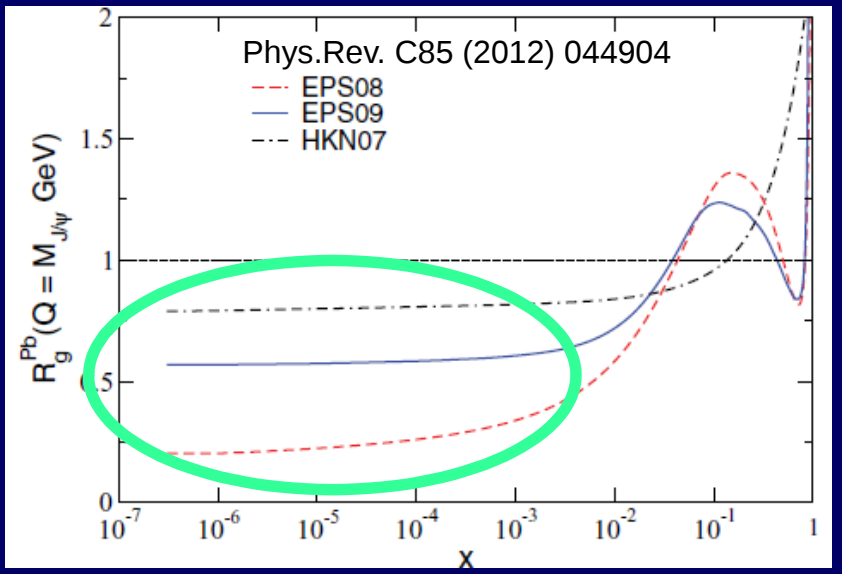
$$\left.\frac{d\sigma_{\gamma A\to J/\Psi A}}{dt}\right|_{t=0} = \xi_{J/\Psi}\left(\frac{16\pi^3\alpha_s^2\Gamma_{l^+l^-}}{3\alpha M_{J/\Psi}^5}\right)[xG_A(x,\mu^2)]^2$$

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

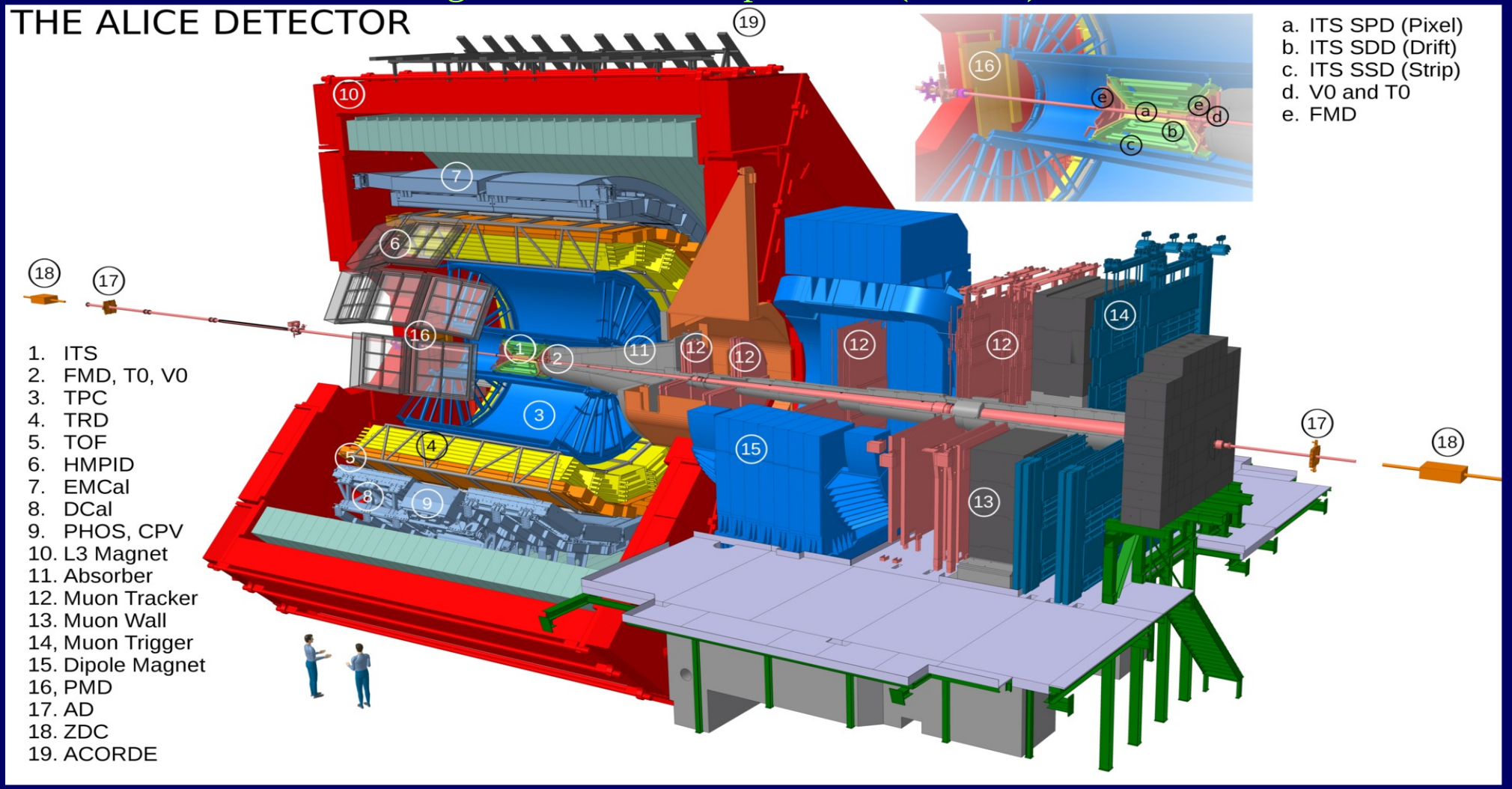
extensions of the calculations to NLO are discussed in

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

how to properly incorporate nuclear shadowing at small x?



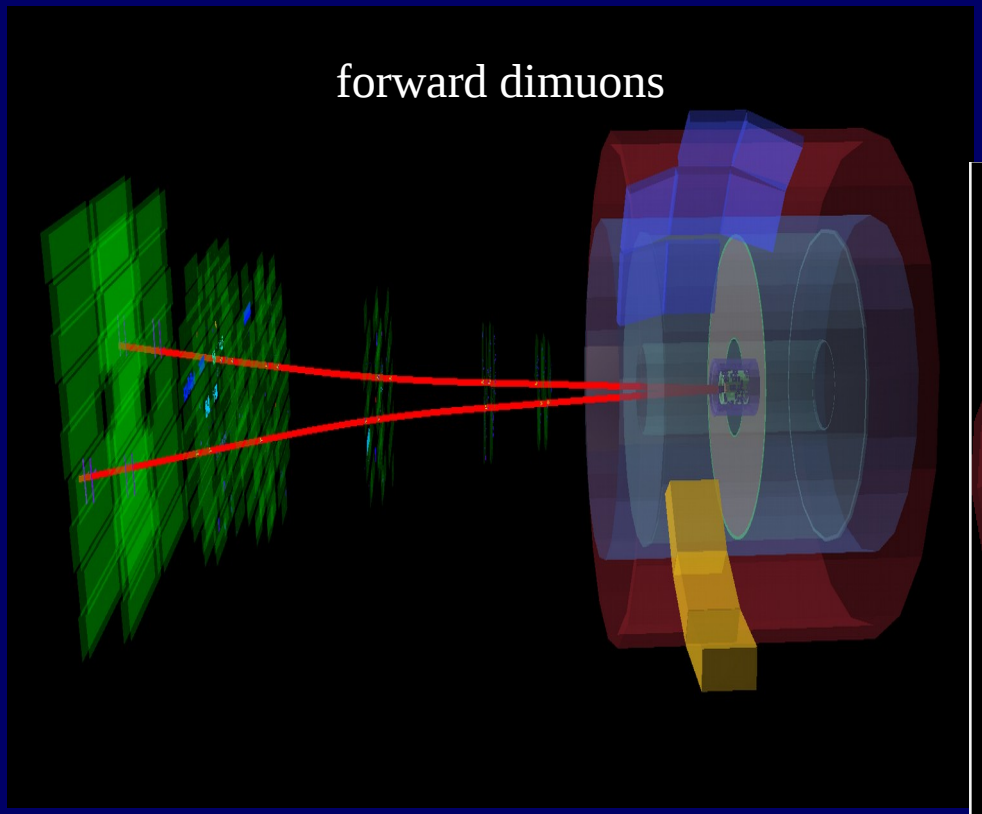
A Large Ion Collider Experiment (ALICE) at LHC

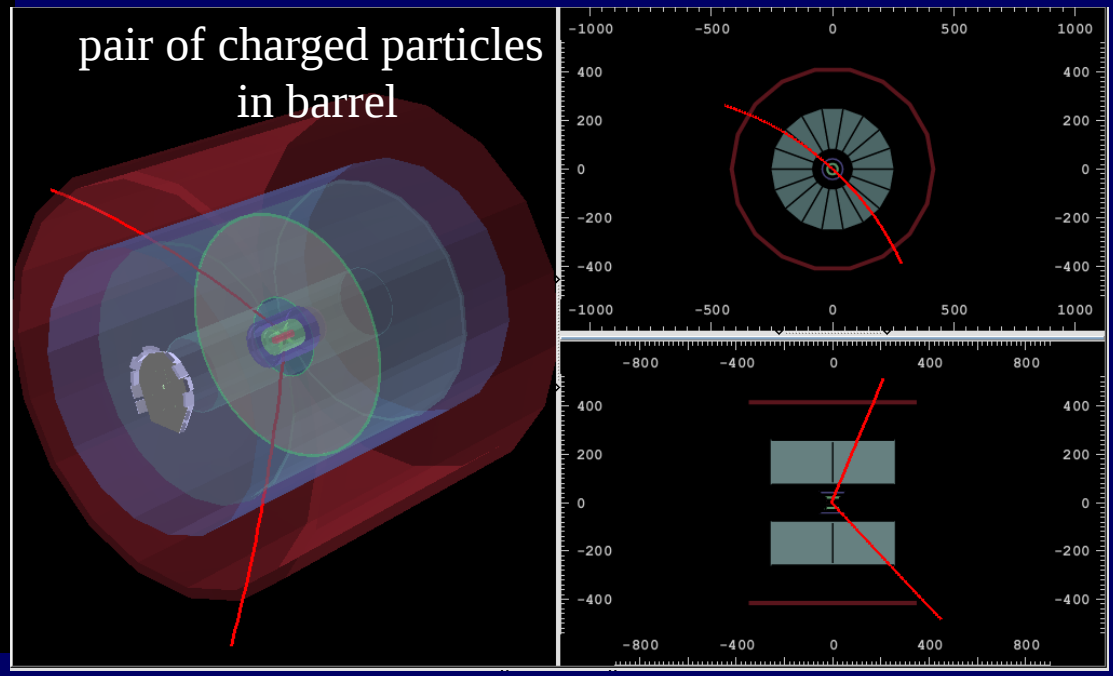


ALICE systems relevant for J/ψ / ρ^0 photoproduction measurements:

- 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

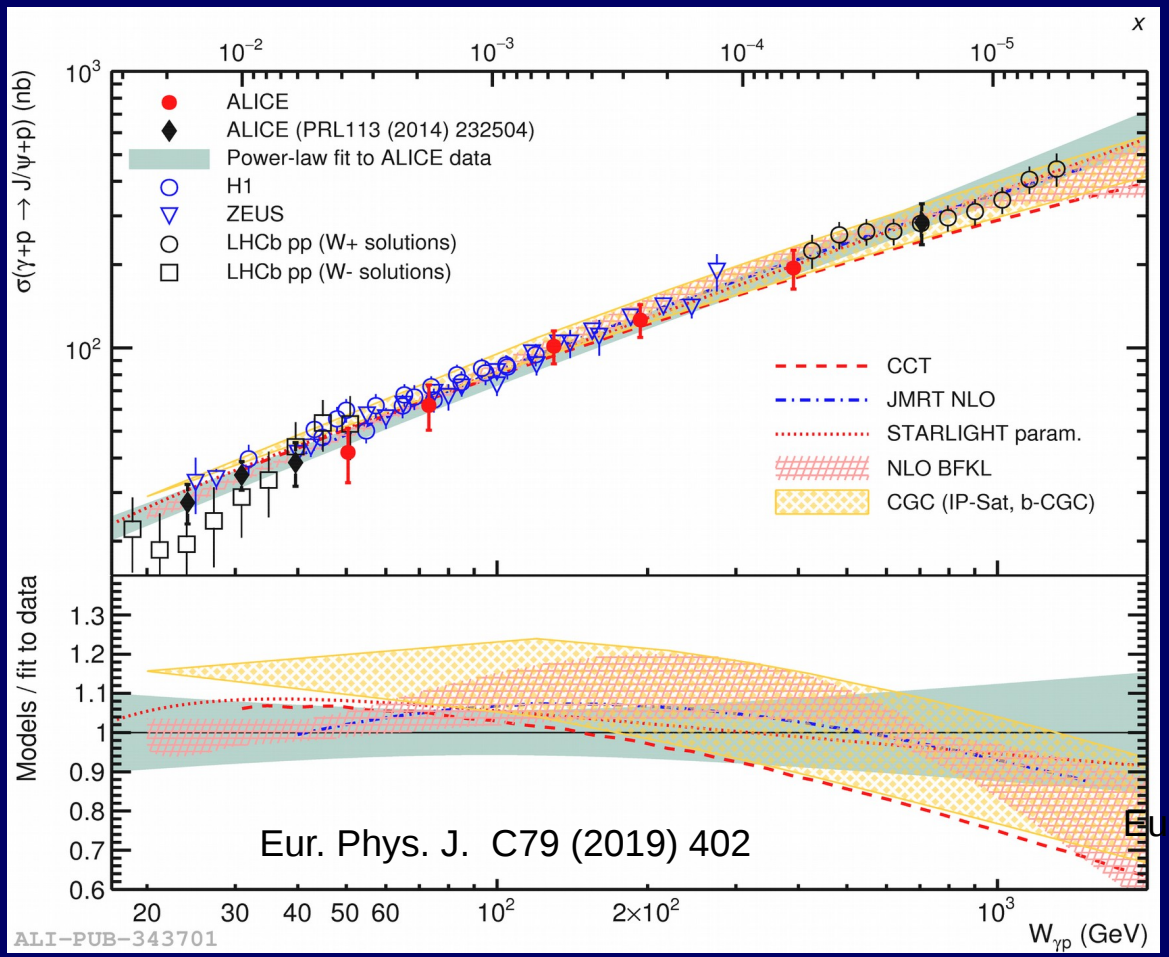




Main features of UPC vector meson photoproduction:
- exclusive events, only vector meson decay particles detected;
- transverse momentum balance of final state particles.

J/ψ photoproduction in p-Pb collisions

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 [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.

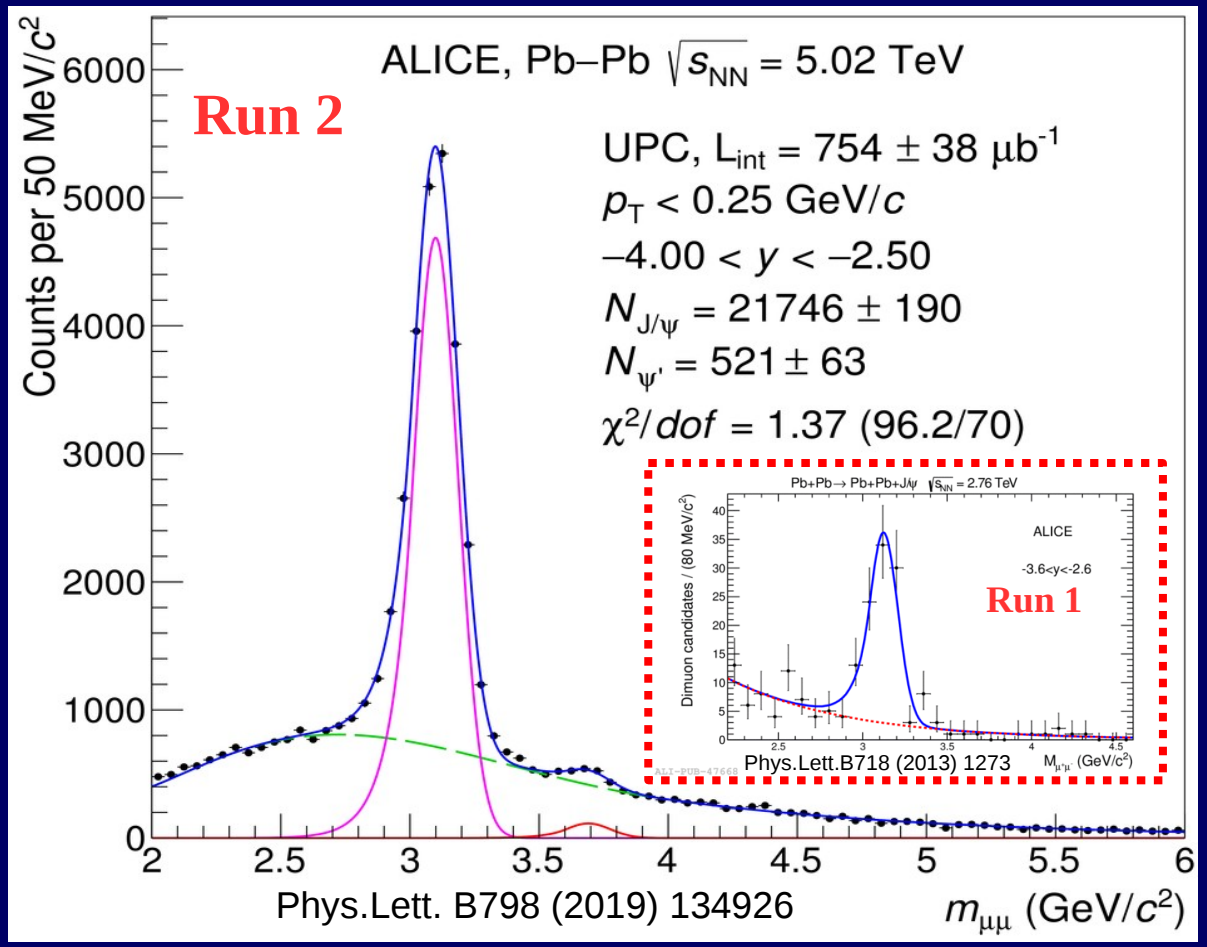
JMRT (S.P. Jones, A.D. Martin, M. Ryskin, T. Teubner, JHEP 11, 085 (2013)):
the parameters for calculations obtained by a fit to the data and their energy dependence.

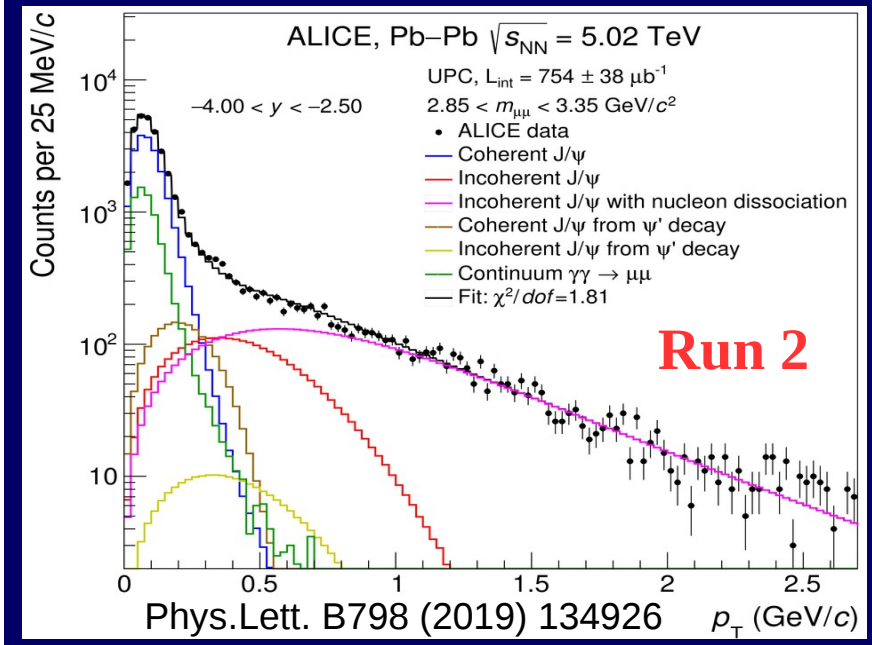
CGC (N. Armesto, A.H. Rezaeian, Phys. Rev. D 90(5), 054003 (2014))
colour dipole model.

Coherent production of J/ψ at forward rapidity in Pb–Pb UPC

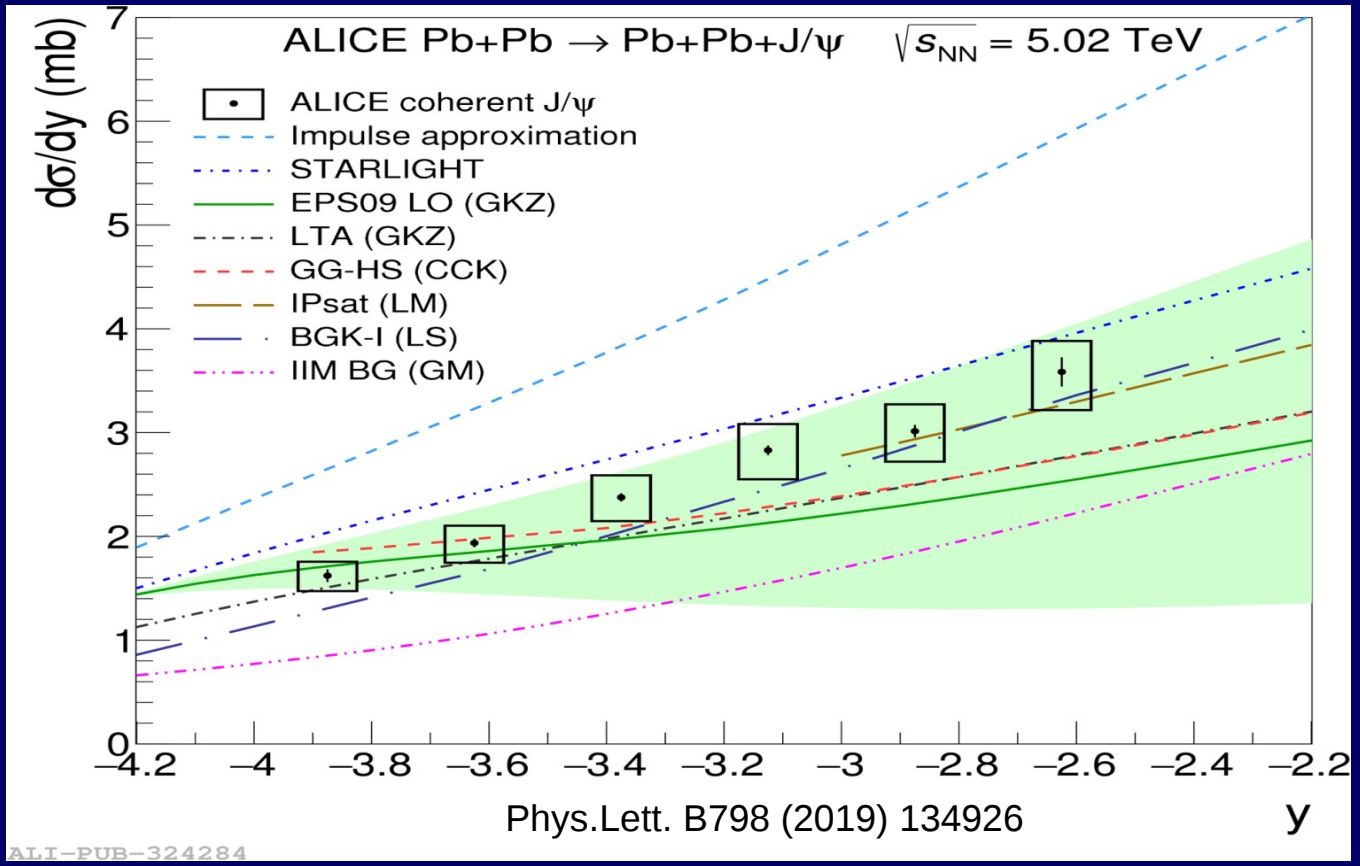
Increased LHC Run 2 Pb-Pb luminosity ($\int L > 700\ \mu b^{-1}$), larger J/ψ production cross section and more efficient event triggering provides ~200 times larger J/ψ yield as compared to the Run 1 data.

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





Coherent production of J/ψ at forward rapidity in Pb–Pb UPC (cont'd)

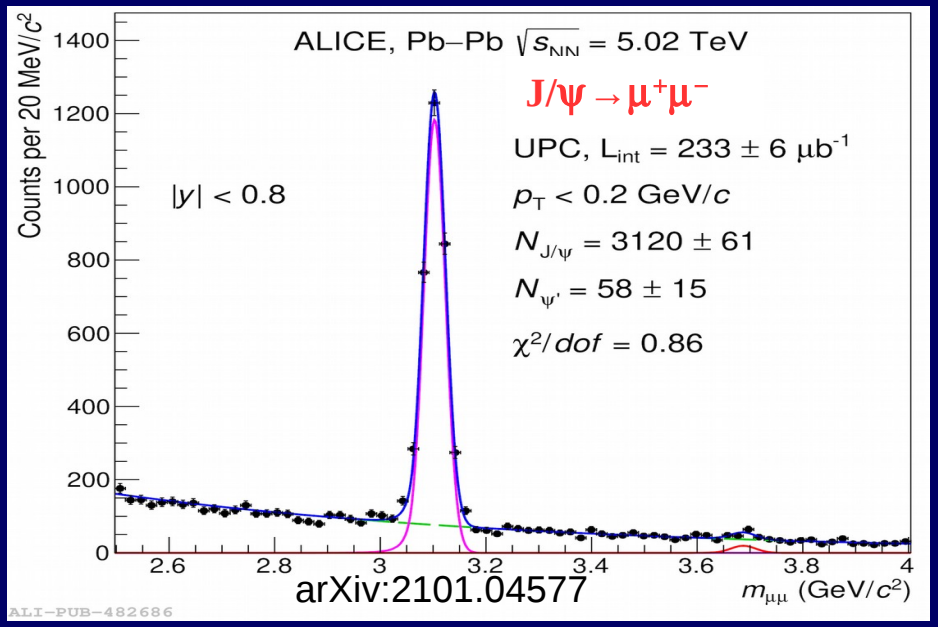


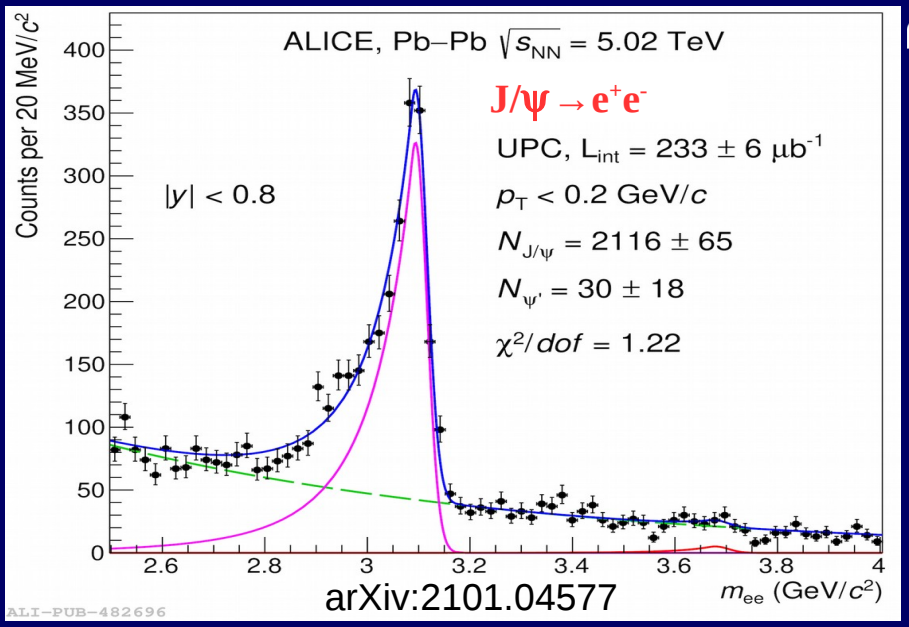
impulse approximation: no nuclear effects

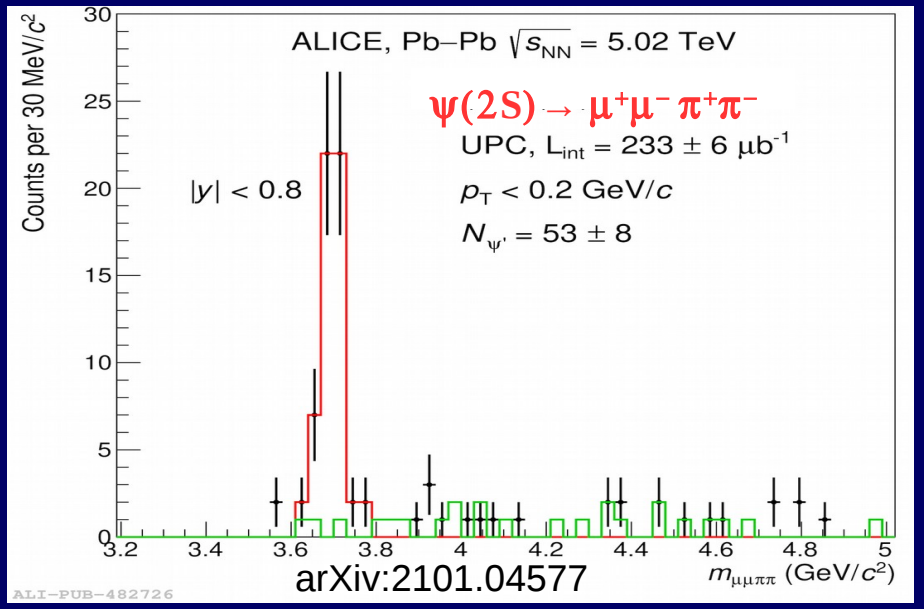
STARLIGHT: VDM + Glauber	Comput. Phys. Commun. 212 (2017) 258
EPS09 LO (GKZ) / LTA (GKZ)	PRC93 (2016) 055206
GM: color dipole + IIM / bCGC CGC	PRC 90 (2014) 015203, JPG 42 (2015) 105001
Ipsat (LM): color dipole + IPSat CGC	PRC 83 (2011) 065202, PRC 87 (2013) 032201
GG-HS (CCK): color dipole + energy dependent hot-spot model	PL B766 (2017) 186, PRC 97 (2018), 024901
BGK-I (LS): color dipole + CGC	Phys. Rev. C 99, 044905 (2019)

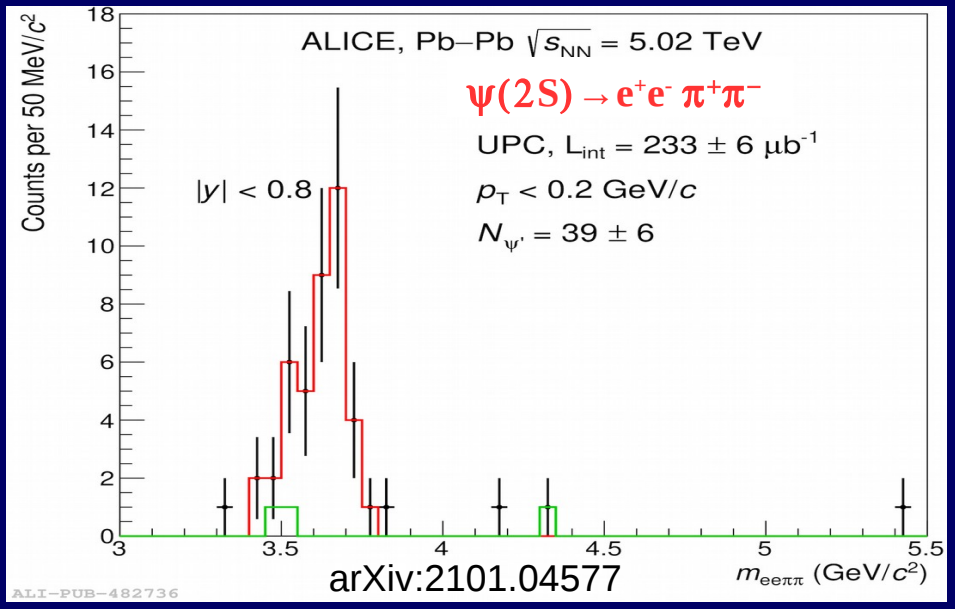
Coherent J/ψ photoproduction cross section implies moderate gluon shadowing in nuclei.

Coherent J/ψ and ψ′ photoproduction at midrapidity in Pb-Pb UPC

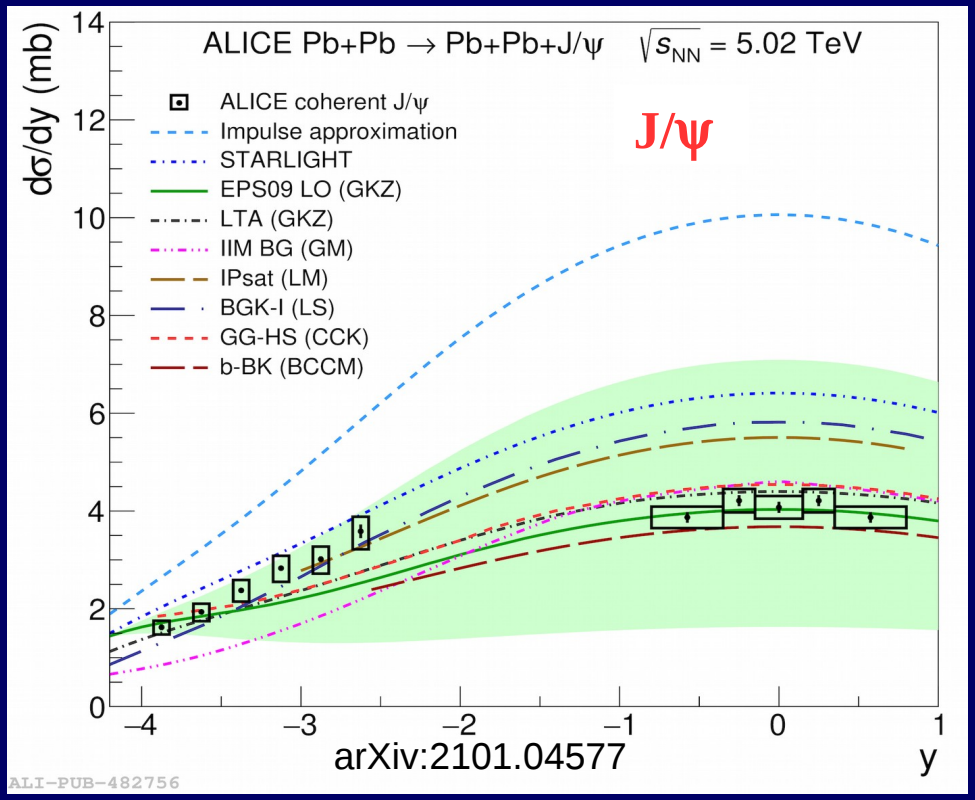


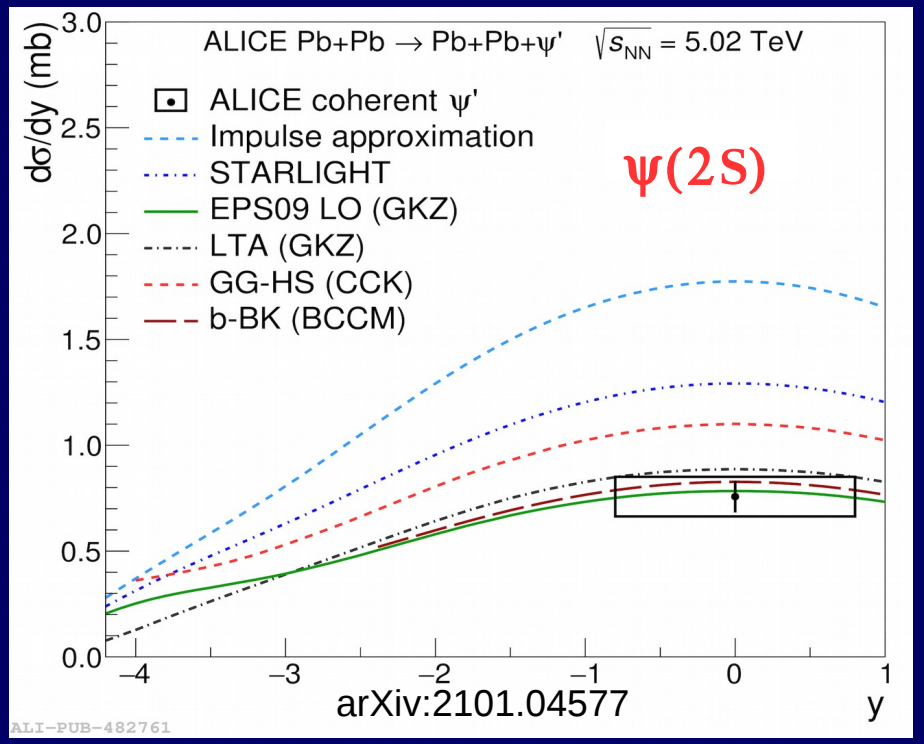






Coherent J/ψ and ψ′ photoproduction at midrapidity in Pb-Pb UPC (cont'd)





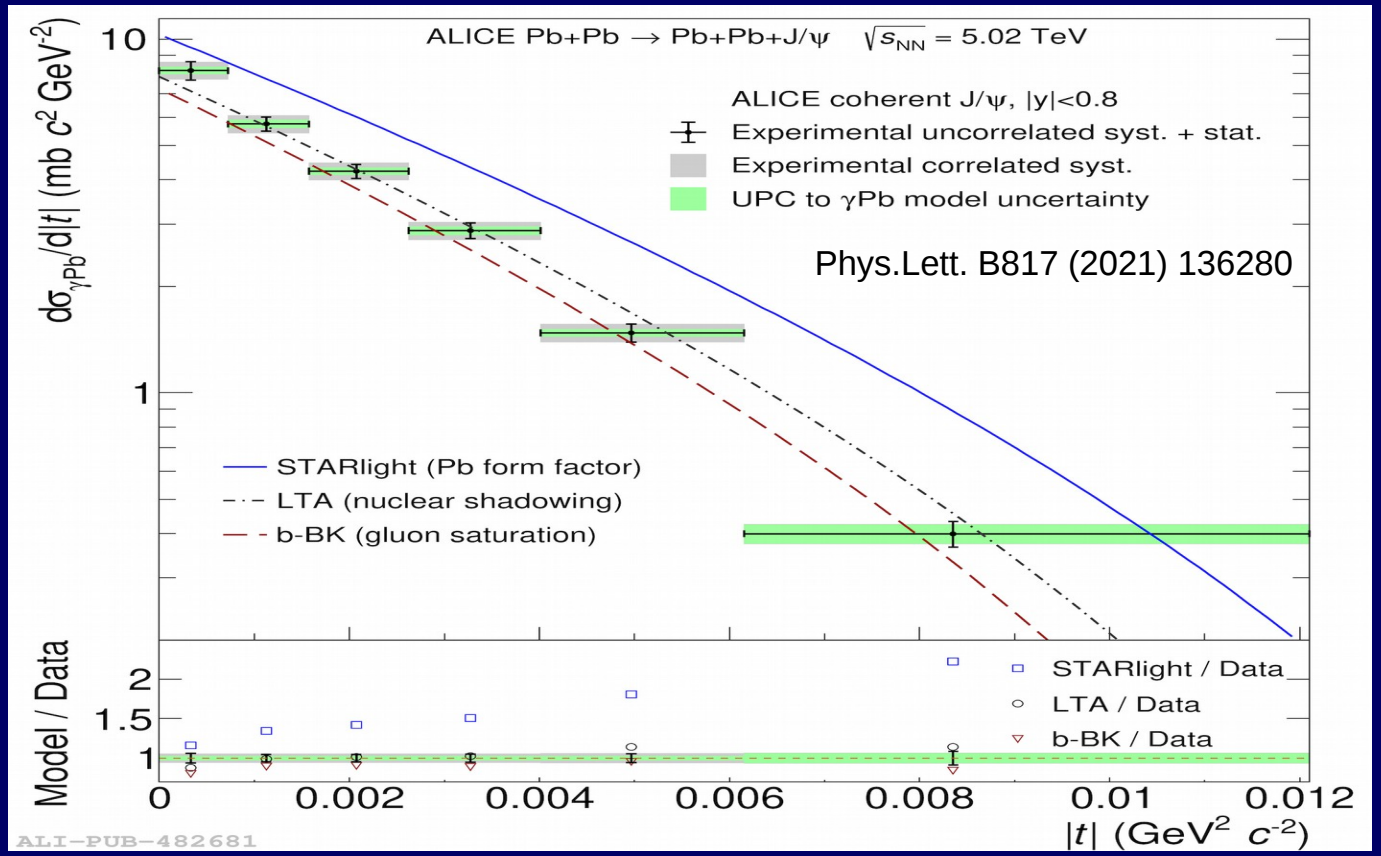
(models described on slide 8)

The nuclear gluon shadowing factor is found to be ~0.65 at ***x*** values ~10^{-3}.

Few models (based on leading twist approximation of nuclear shadowing, on the EPS09 parameterization or the energy-dependent hot-spot model) describe the measured coherent J/ψ cross sections at forward and in central rapidities with a tension at semi-forward rapidity.

|t|-dependence of midrapidity coherent J/ψ photonuclear production

The dependence on |t|, the square of the momentum transferred between the incoming and outgoing target nucleus, of coherent J/ψ photoproduction at Bjorken-x range ~10^{-3} was measured thus provided an info to the transverse gluon nPDF.

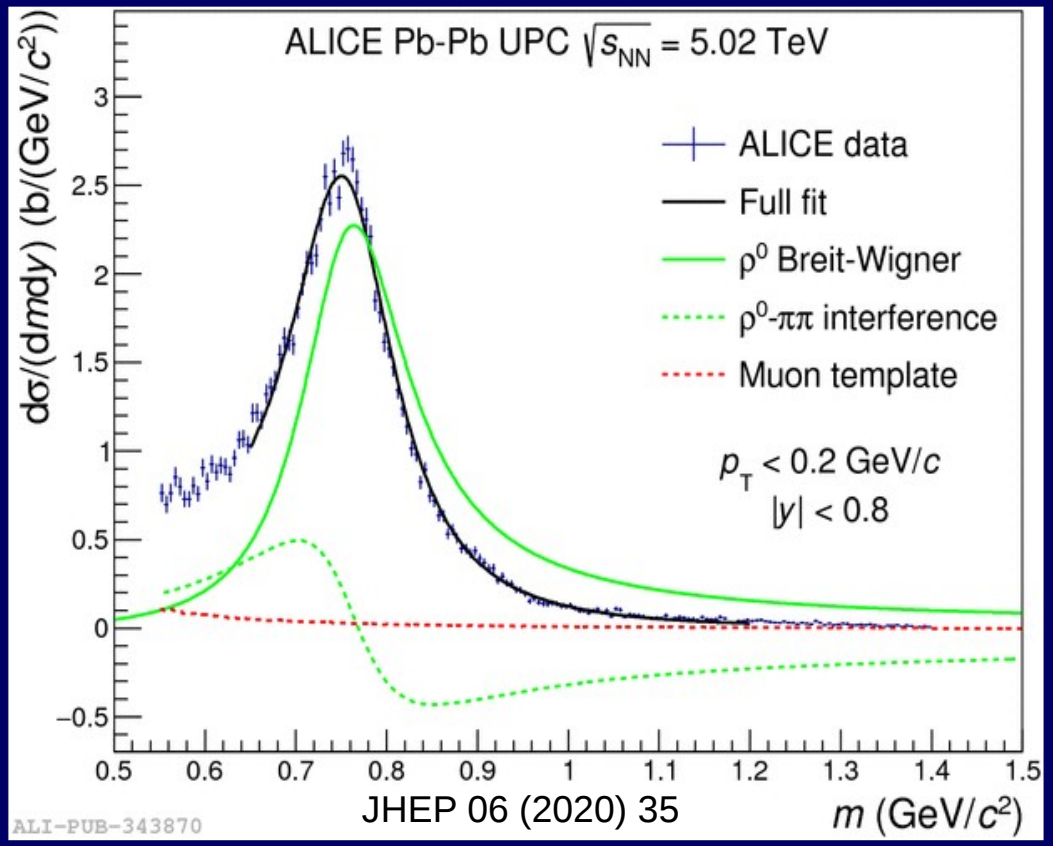


Poor description by STARlight model used only Pb nuclear form factor.

Better agreement with models with shadowing by the leading-twist approximation or gluon-saturation effects from the impact-parameter dependent Balitsky–Kovchegov approach.

Coherent ρ^0 production in Pb–Pb UPC with LHC Run 2 data

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.



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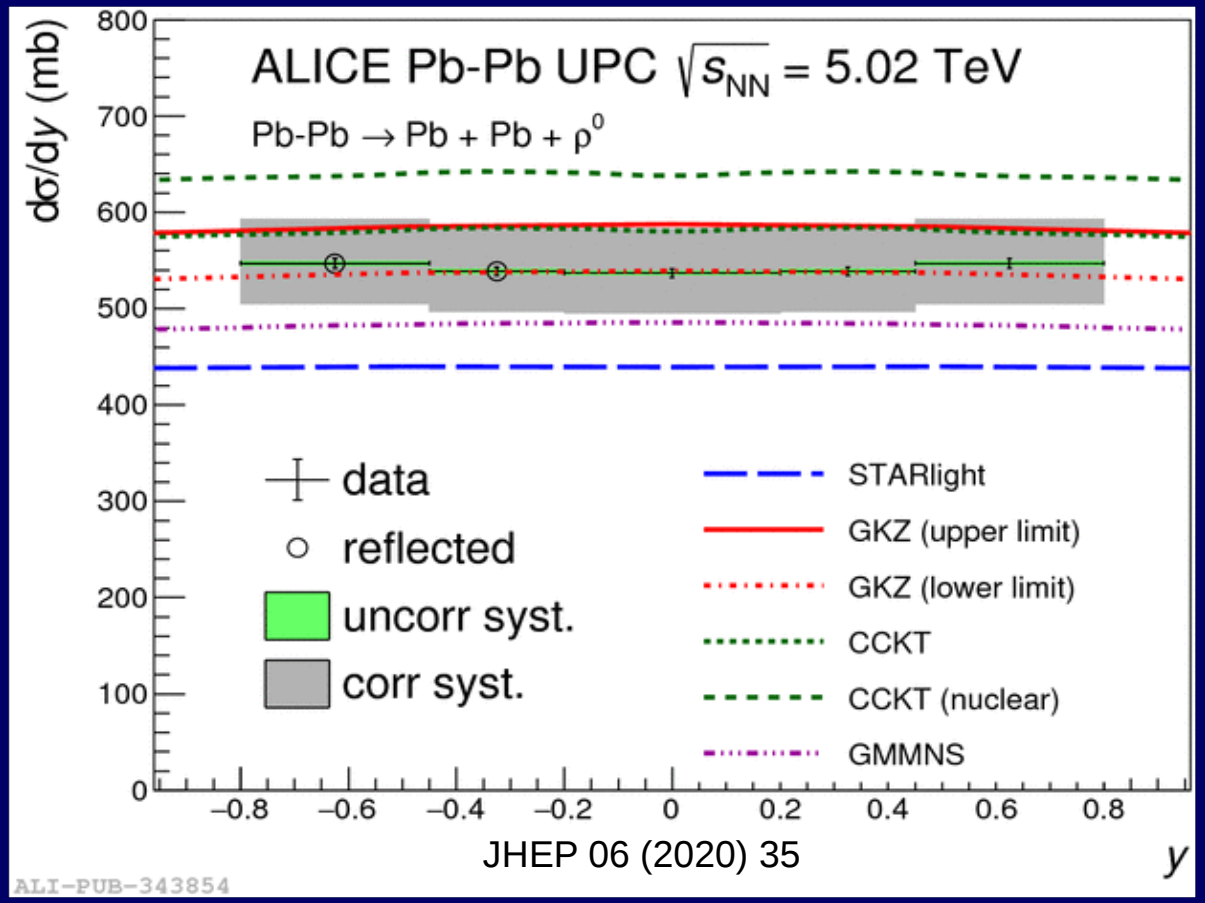
The integrated luminosity is of 485 mb^{-1}.

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 with LHC Run 2 data (cont'd)



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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.

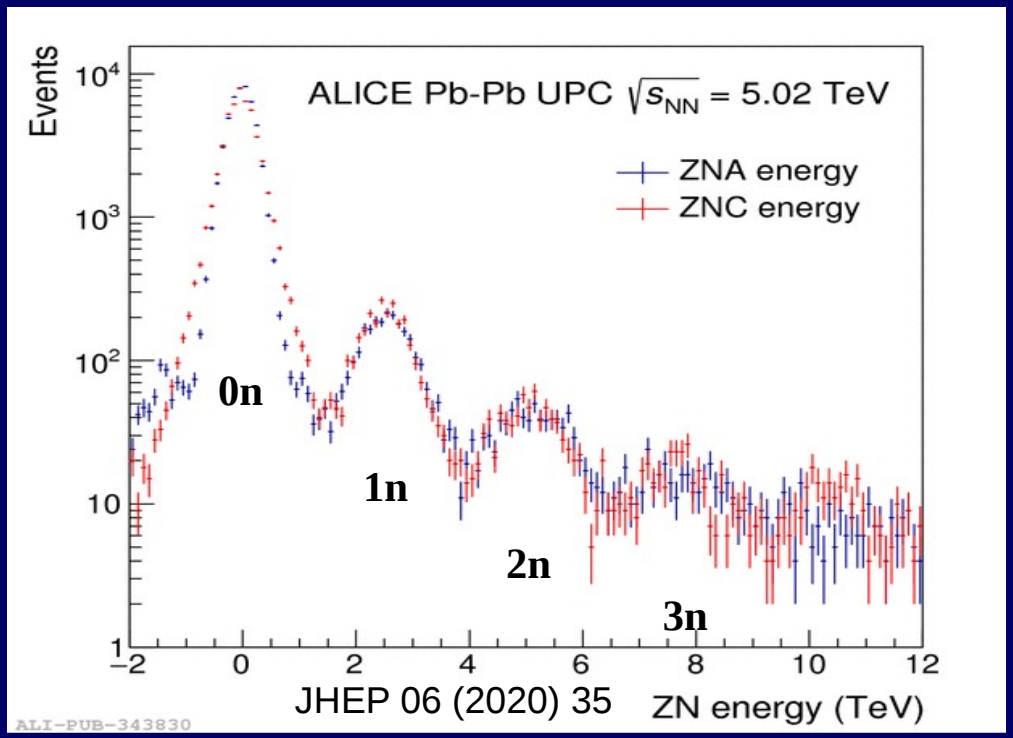
CCKT (J. Cepila, J. G. Contreras, M. Krelina, and J.D. Tapia Takaki, Nucl. Phys. B934 (2018) 330–340):
colour-dipole model + gluons "hot spots" of the structure of the nucleon in the transverse plane + Glauber model for nuclear effects.

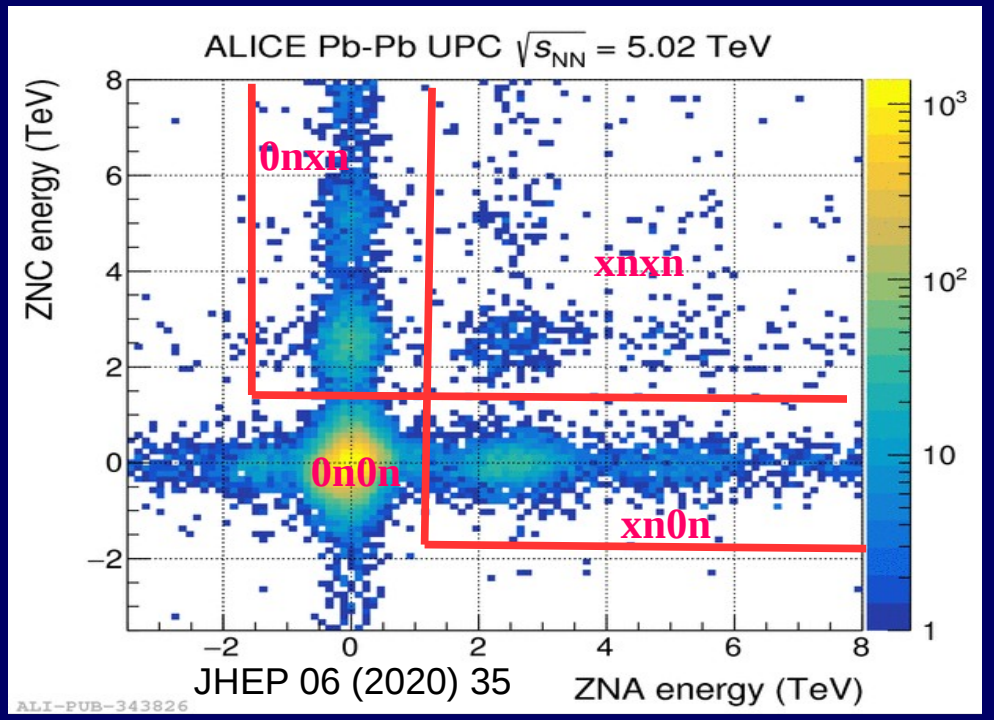
GMMNS (Goncalves, Machado, Morerira, Navarra and dos Santos, Phys. Rev. D96 (2017) 094027):
Iancu-Itakura-Munier (IIM) approach for gluon saturation + colour-dipole model.

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

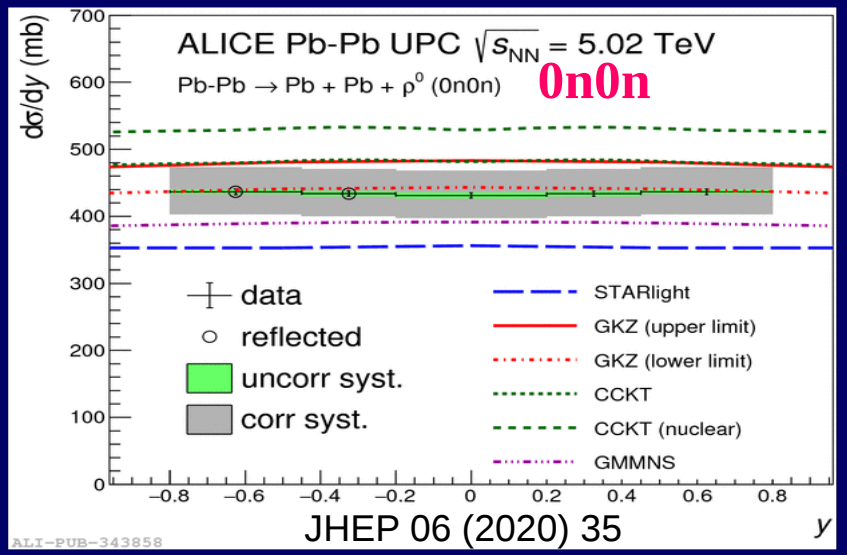
Coherent ρ^0 production in Pb–Pb UPC with LHC Run 2 data (cont'd)

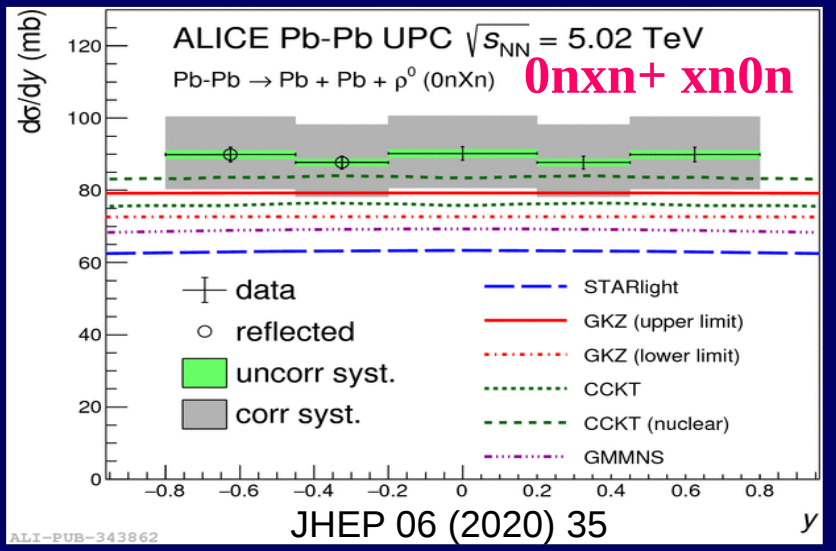
ALICE is equipped with two ZDC detectors (ZNA and ZNC)
– located at either side of interaction point at ±112.5 m along the z-axis;
– intended for measurement of neutrons at beam rapidity;
– which provide time resolution enough to separate beam–beam and beam–gas interactions;
– which have a good efficiency 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.

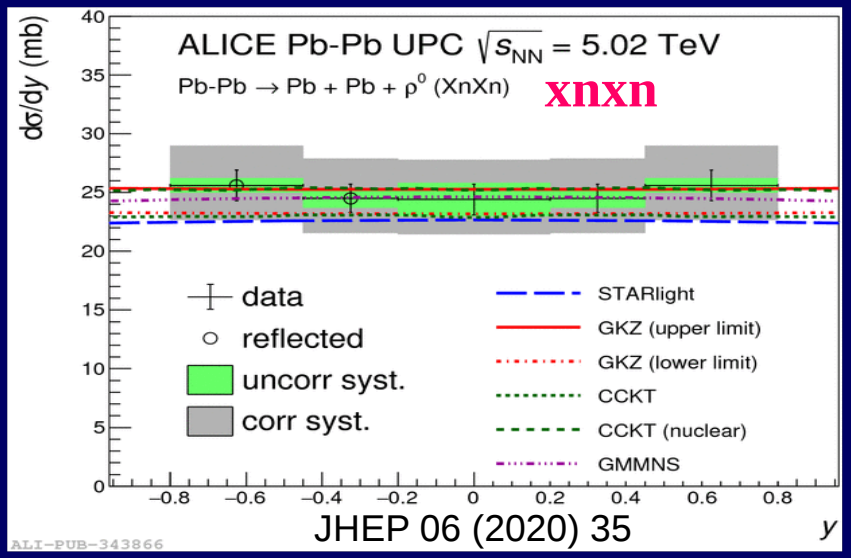




Coherent ρ^0 production in Pb–Pb UPC with LHC Run 2 data (cont'd)







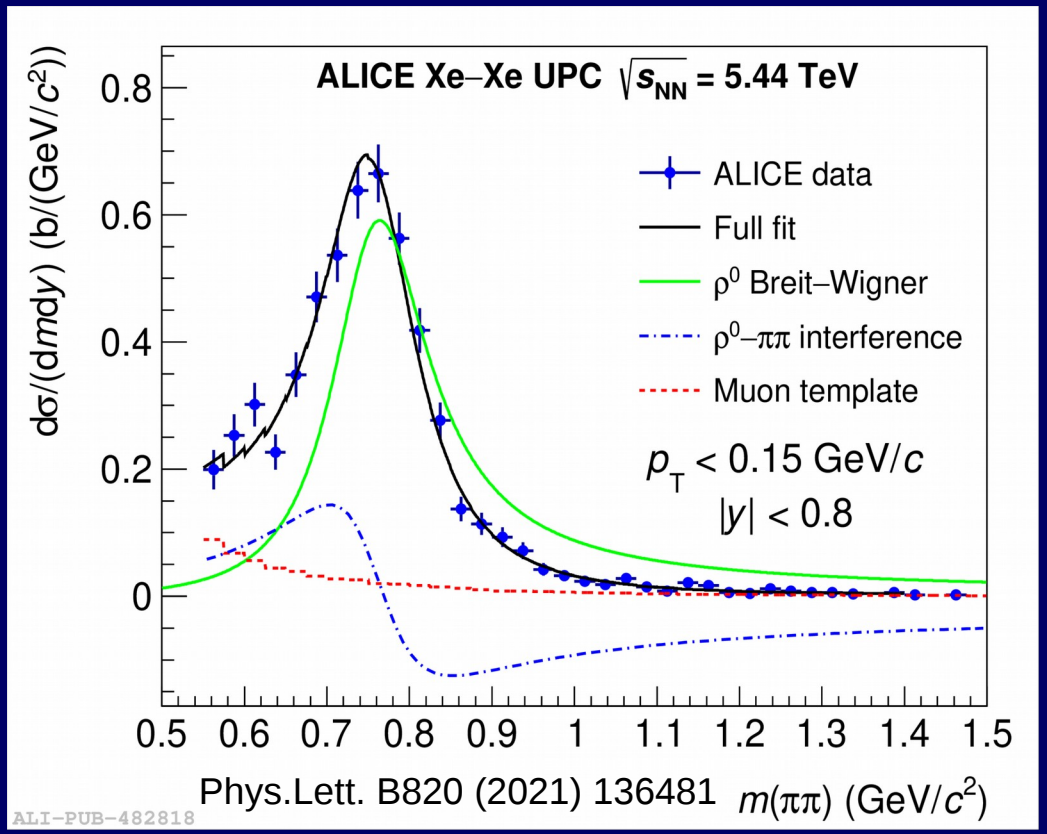
agreement both with models based on colour-dipole approach and with Gribov-Glauber shadowing.

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.

Coherent ρ^0 production in Xe–Xe UPC with LHC Run 2

Shadowing effects are expected to depend on the atomic number of the nucleus
→ UPC measurements for different A extend the study of the shadowing

The LHC collided xenon nuclei for the first time with a short accelerator run in fall of 2017.
The experimental conditions for UPC triggering and reconstruction stay close to Pb runs.



The measured photoproduction cross section
131.5 ± 5.6 (stat.) +17.5−16.9 (syst.) mb

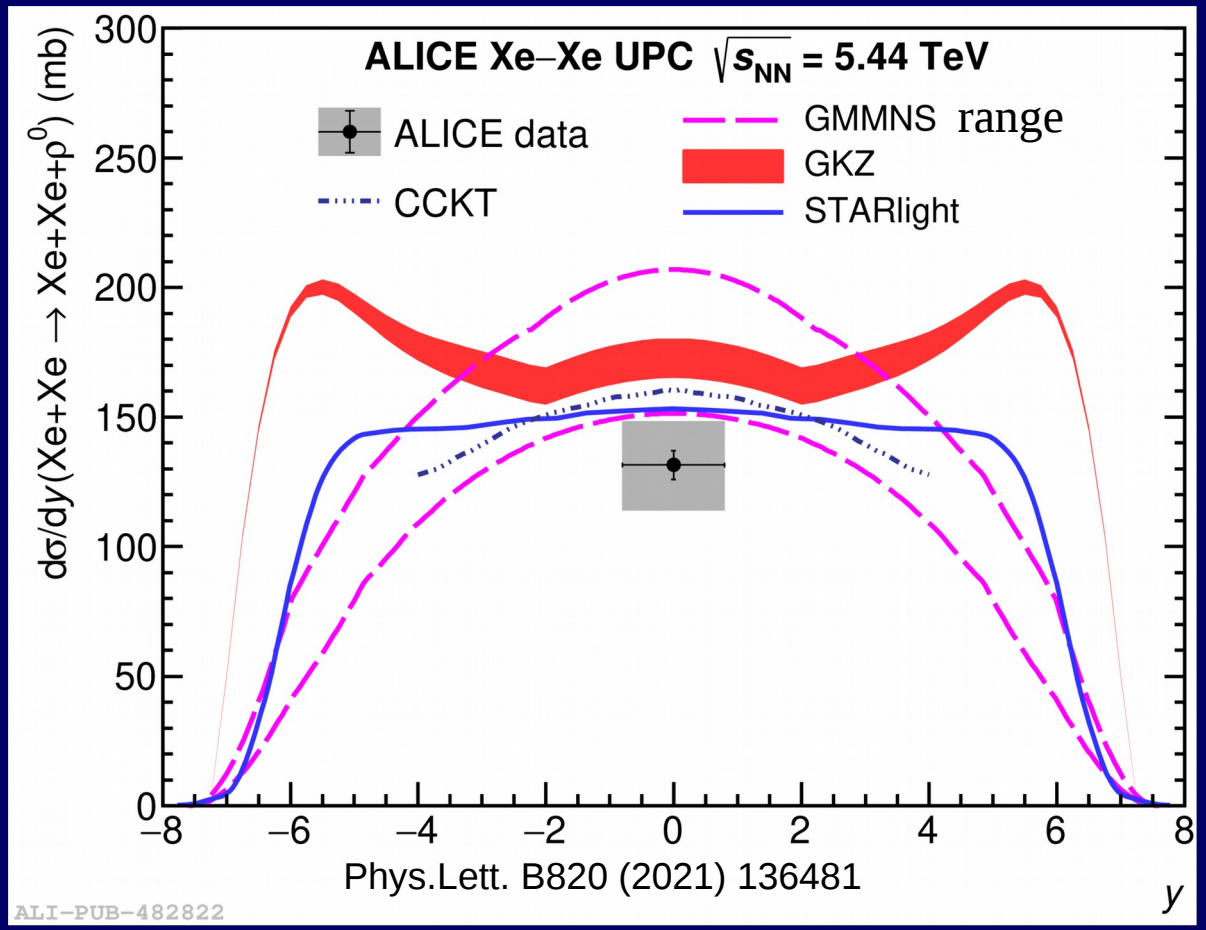
The luminosity is of (279.5 ± 29.9) mb^{-1}.
The events which passed selection:
– |pair rapidity| < 0.8;
– pair p_T < 0.15 GeV/c;
– pair mass > 0.55 GeV/c^2.

Around 1.8 thousand events were identified
experimental efficiency of ~15%.

Fit done similar to Pb-Pb analysis by
Breit-Wigner for resonance shape
+ constant term for direct pair production
+ interference between them
+ dimuons from γγ interactions.

Overall systematic uncertainty ~13%

Coherent ρ^0 production in Xe–Xe UPC with LHC Run 2 (cont'd)



The models are close to each other at zero-rapidity and overestimate the data.

GKZ (V. Guzey, E. Kryshen and M. Zhalov, Phys. Lett. B782 (2018) 251): VDM+ Gribov-Glauber model of nuclear shadowing for fluctuations of the photon-nucleons interaction;

CCKT (J. Cepila, J. G. Contreras, M. Krelina, and J.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;

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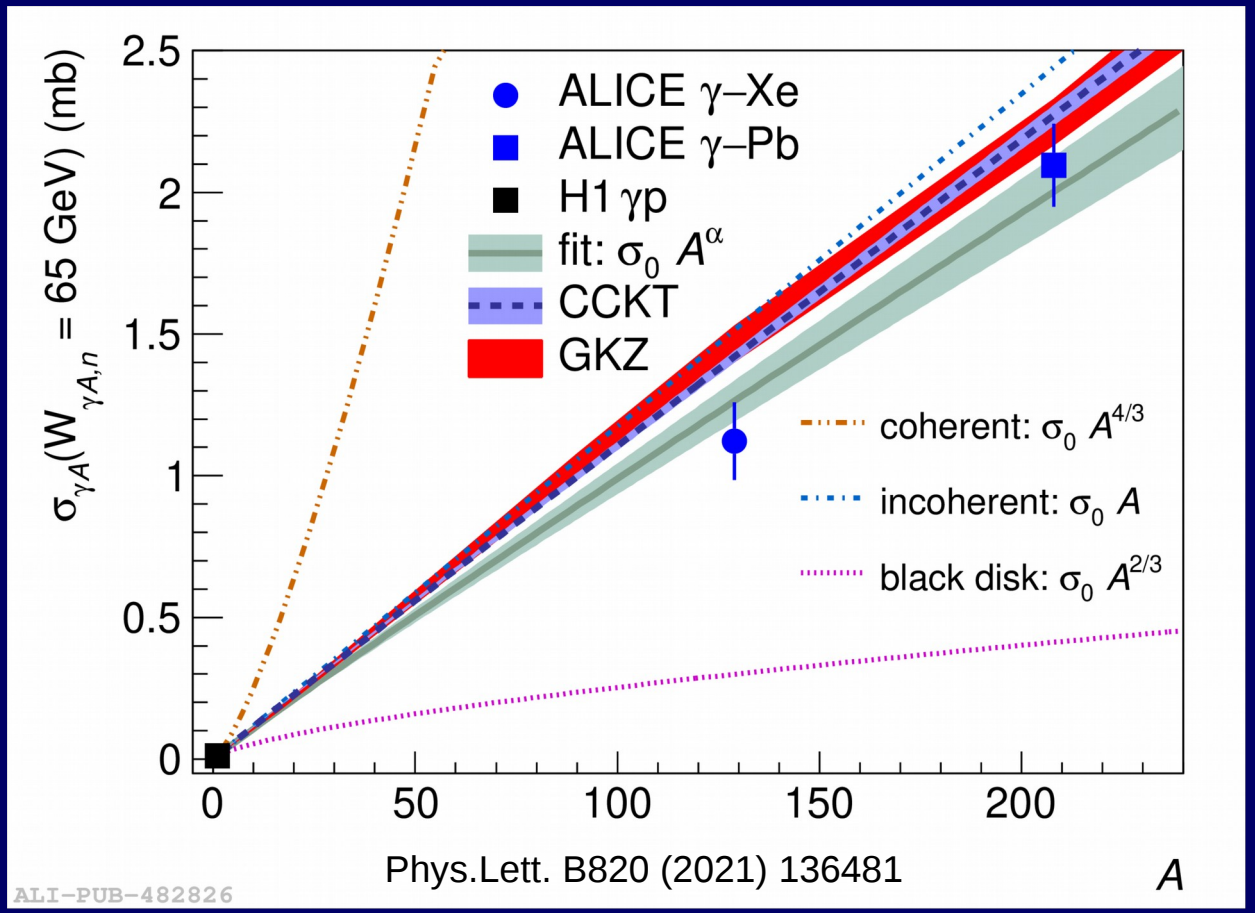
Coherent ρ^0 production in UPC



The coherent ρ^0 photoproduction cross section at zero-rapidity for Pb–Pb and for Xe–Xe converted into γA measurement by using the photon fluxes of
58.6 (for Xe) and
128.1 (for Pb).

The A-dependence is fitted by a power-law model, slope parameter is found to be:
0.963±0.019 (ALICE+H1)
0.985±0.007 (GKZ model)
0.983±0.004 (CCKT model)

Both slopes of GKZ and CCKT models are in good agreement with that found in the fit of the data.

Conclusions and outlook

– analysis of J/ψ and ρ^0 photoproduction is a tool to learn about the dynamics of γA interactions and the gluon content of nuclei;

– exclusive photoproduction of J/ψ off proton measured in p–Pb UPC in the γp mass interval $40 < W_{\gamma p} < 550$ GeV;

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

– ψ' production at mid-rapidity in Pb–Pb UPC was studied;

– 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;

– for the first time the cross section of coherent ρ^0 production in Xe–Xe UPC is measured. The A dependence of γA interactions is fitted using Pb–Pb, Xe–Xe UPC and H1 data as well.