Coherent photoproduction of ρ^0 vector mesons in ultra-peripheral Pb-Pb and Xe-Xe collisions with ALICE

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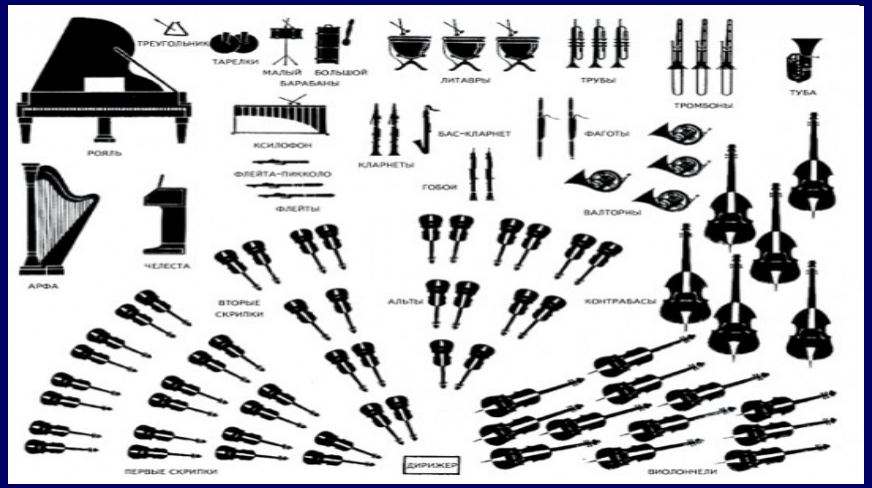
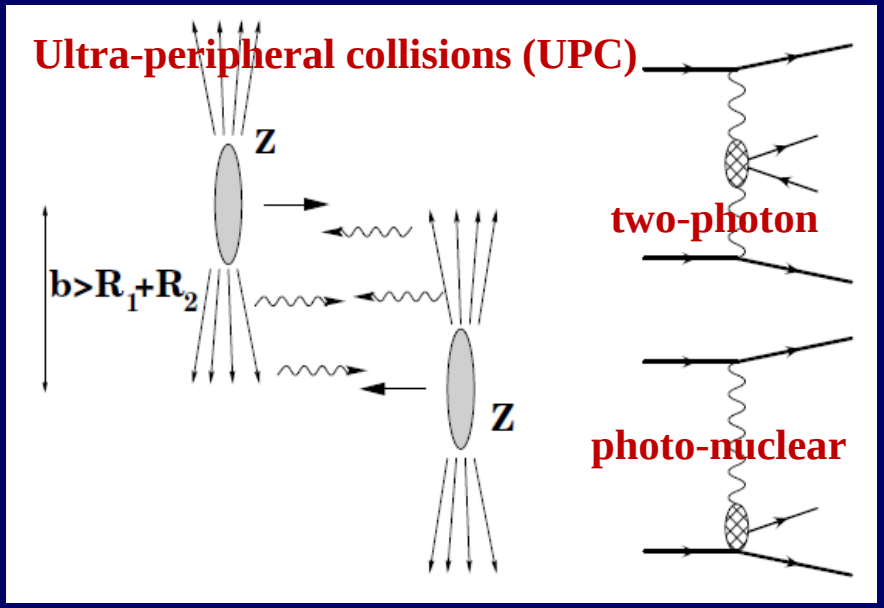
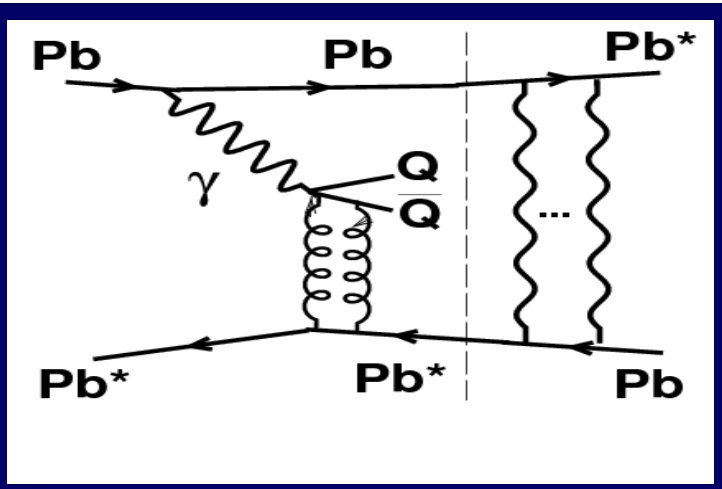


Ultra-peripheral Collisions (UPC) of heavy ions



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

Photon → a vector meson (VM) → scatters off target either coherently off whole nucleus (VM p_T ~30 MeV/c) or incoherently off nucleons (VM p_T~300 MeV/c)

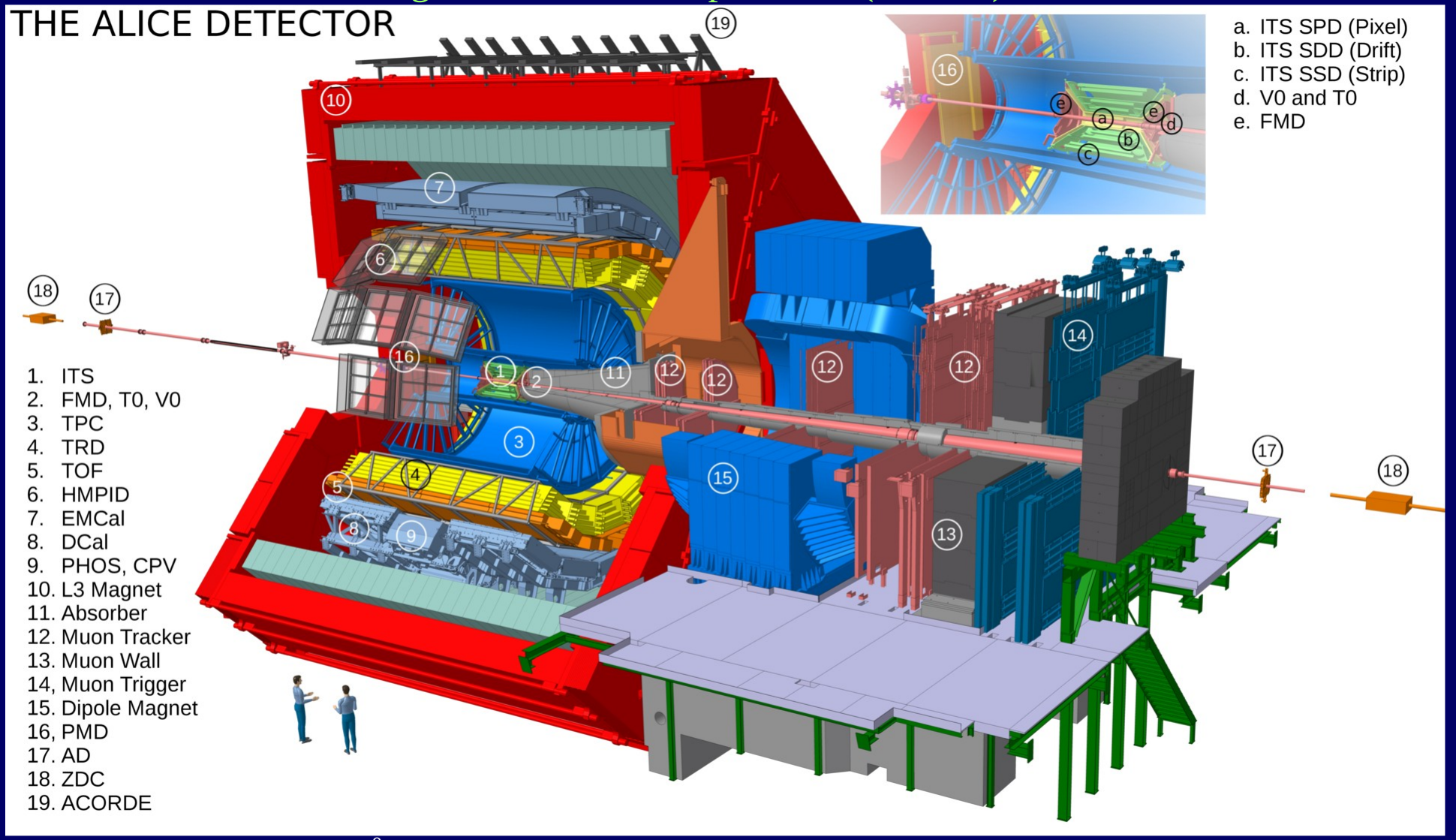


Large Z →
huge photon fluxes →
UPC can be accompanied by another photon exchange →
EM nuclei excitation →
neutron emission detected in Zero Degree Calorimeters.

UPC studies are mainly intended to address gluon shadowing in nuclei.

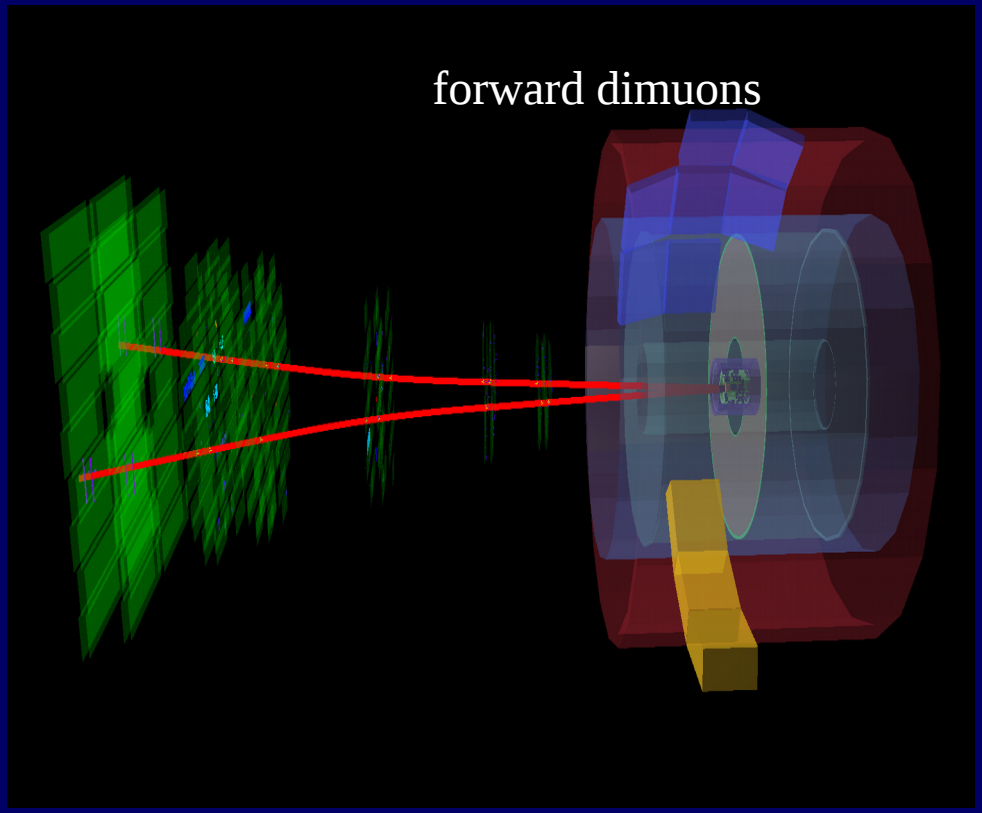
UPC review : A.J. Baltz et al., Phys. Rept. 458 (2008) 1
S. R. Klein and P. Steinberg, Ann. Rev. Nucl. Part. Sci. 70 (2020) 323

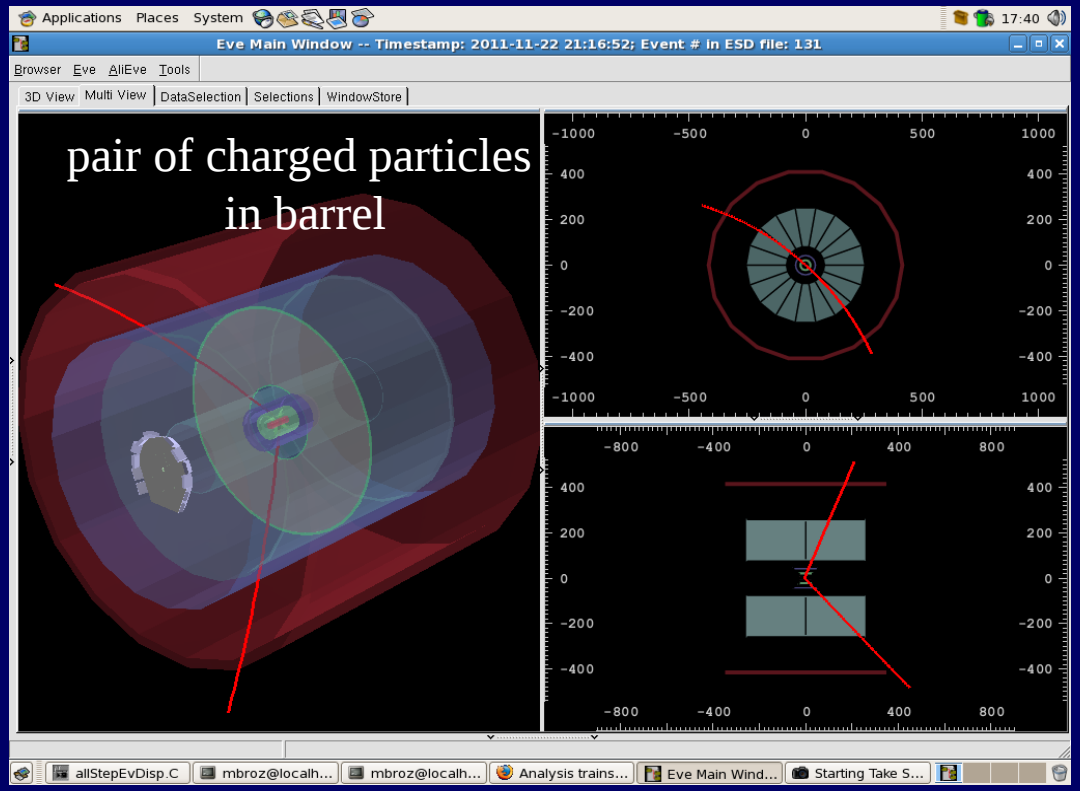
A Large Ion Collider Experiment (ALICE) at LHC



- TPC (15) to reconstruct ρ^0 decays into pions;
- Trigger detectors: pixels (6), V0 (17), AD (2), TOF (12);
- Zero Degree Calorimeters (18) to detect neutrons from nucleus EM dissociation.

ALICE event display



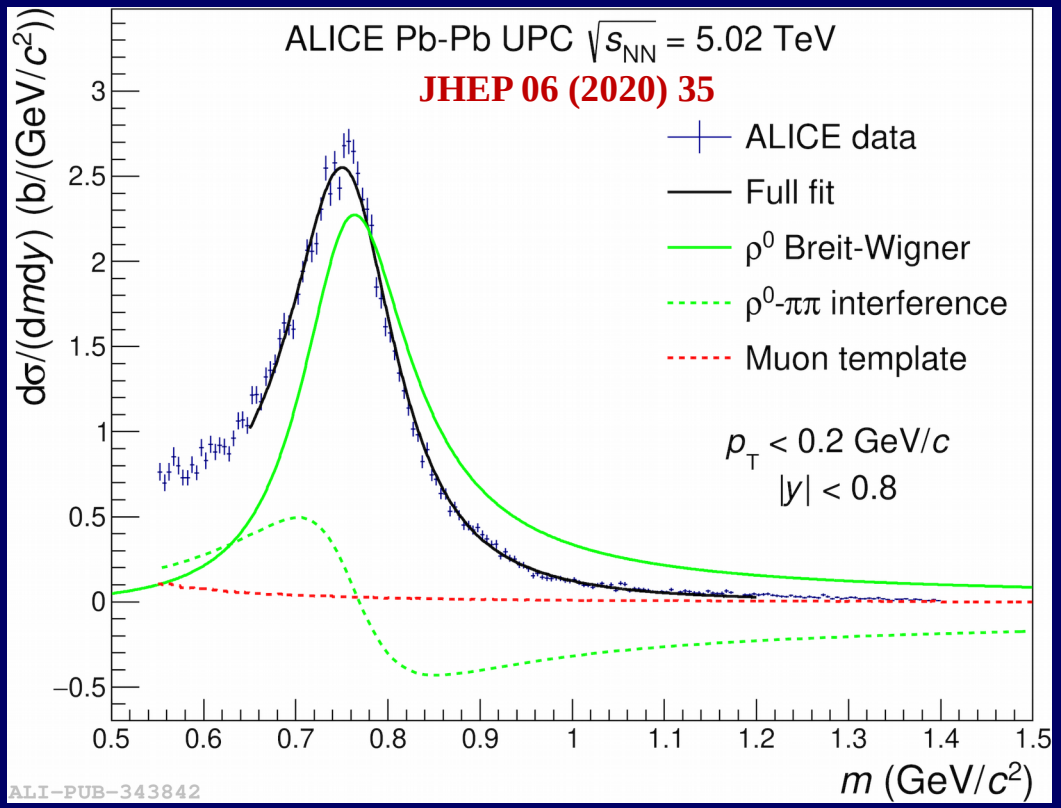


Main features of UPC vector meson photoproduction:
- exclusive events, only vector meson decay particles detected;
- transverse momentum balance of final state particles.

see also the talk of T.Herman on J/ψ production in UPC

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.

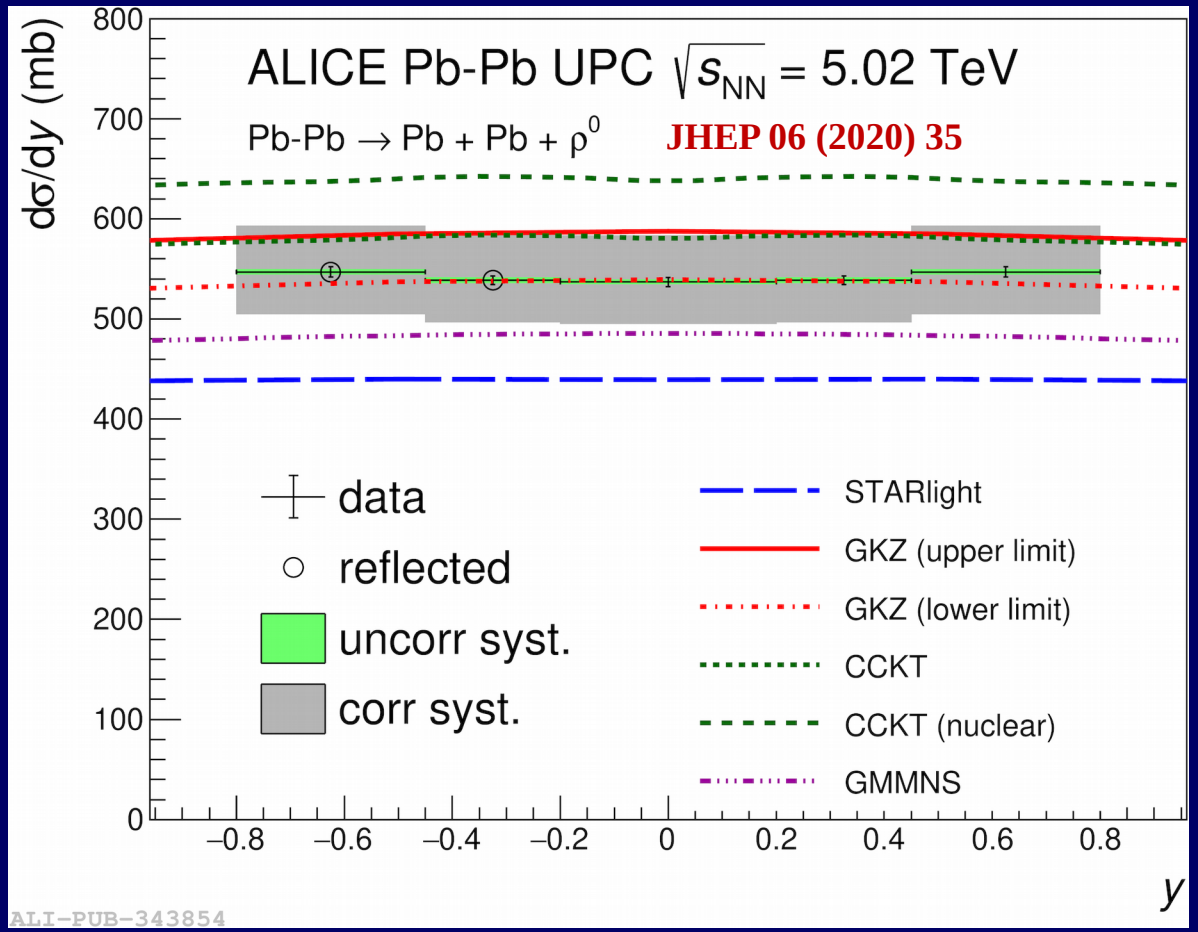


The integrated luminosity is of ~485 mb^{-1}.
The signal sample contains ~57 thousand events which passed selection:
– |pair rapidity| < 0.8;
– pair transverse momentum p_T < 0.2 GeV/c;
– 0.55 < pair mass < 1.4 GeV/c^2.

overall experimental efficiency of ~17%

Fit by
Breit-Wigner for 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)

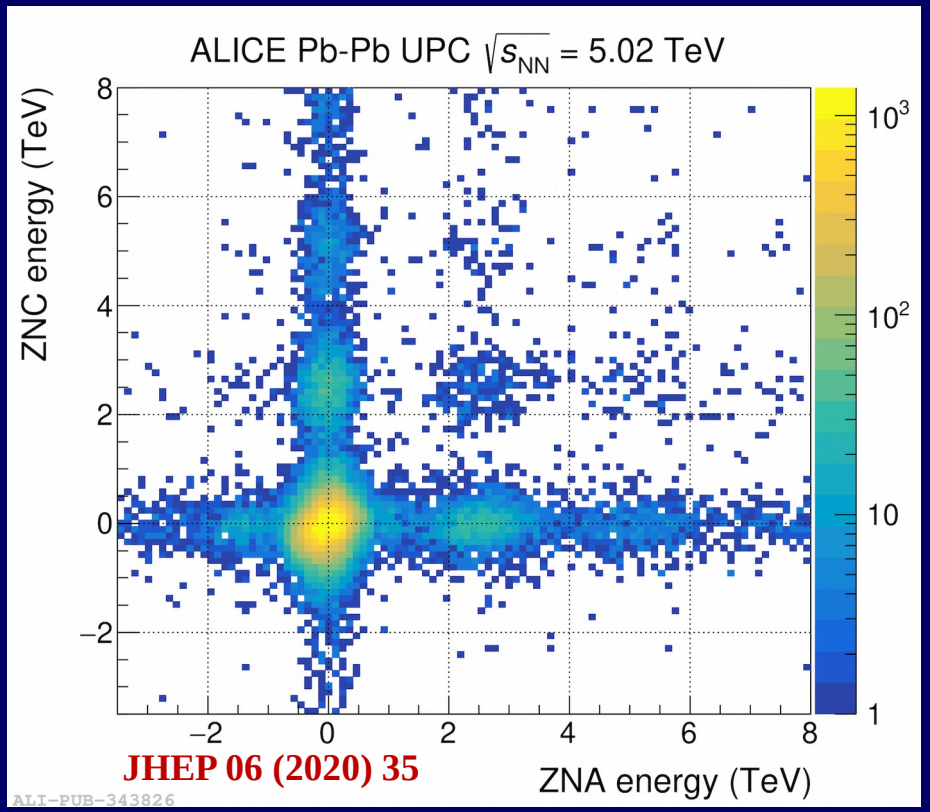


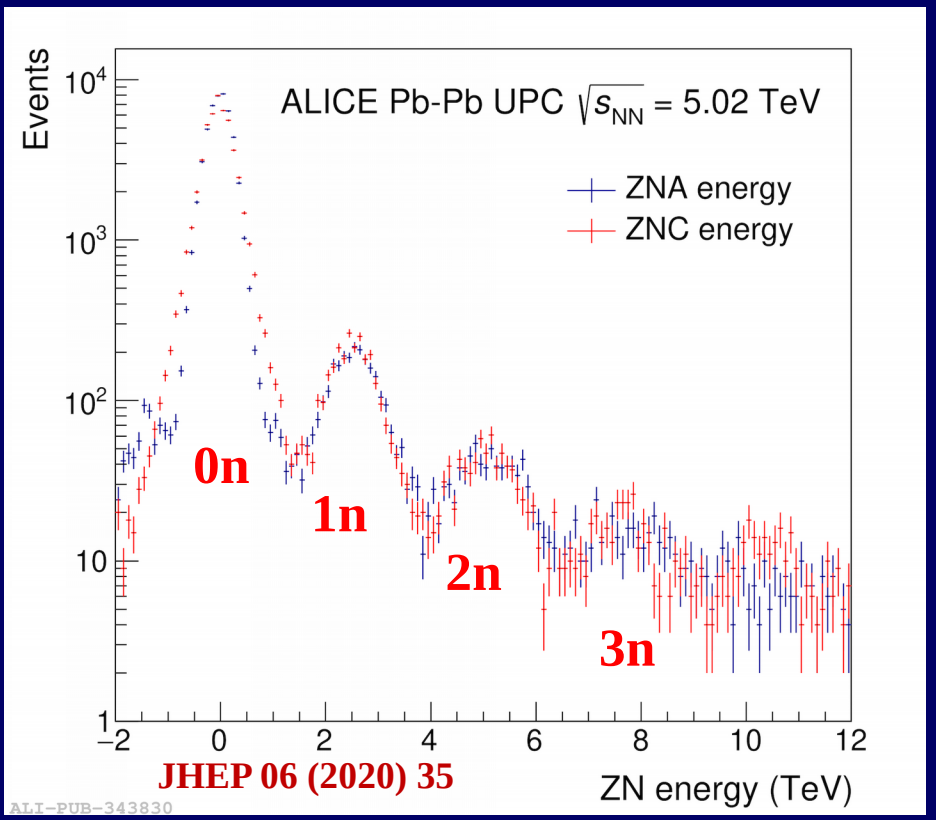
GKZ (V. Guzey, E. Kryshen and M. Zhalov, Phys. Rev. C93 (2016) 055206):
VDM+ Gribov-Glauber model of nuclear shadowing accounting for photon fluctuations into intermediate diffractive states;
CCKT (J. Cepila, J. G. Contreras, M. Krelina, and J.Tapia Takaki, Nucl. Phys. B934 (2018) 330–340):
colour-dipole model + gluon "hot spots" in 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 + Glauber-like eikonal formalism.

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

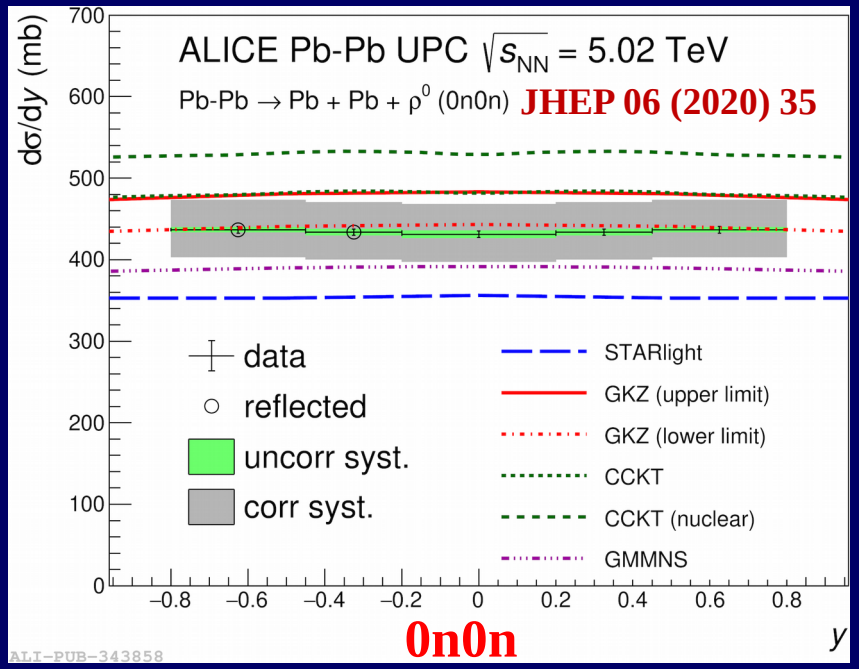
ALICE is equipped with two Zero Degree Calorimeters (ZDC)

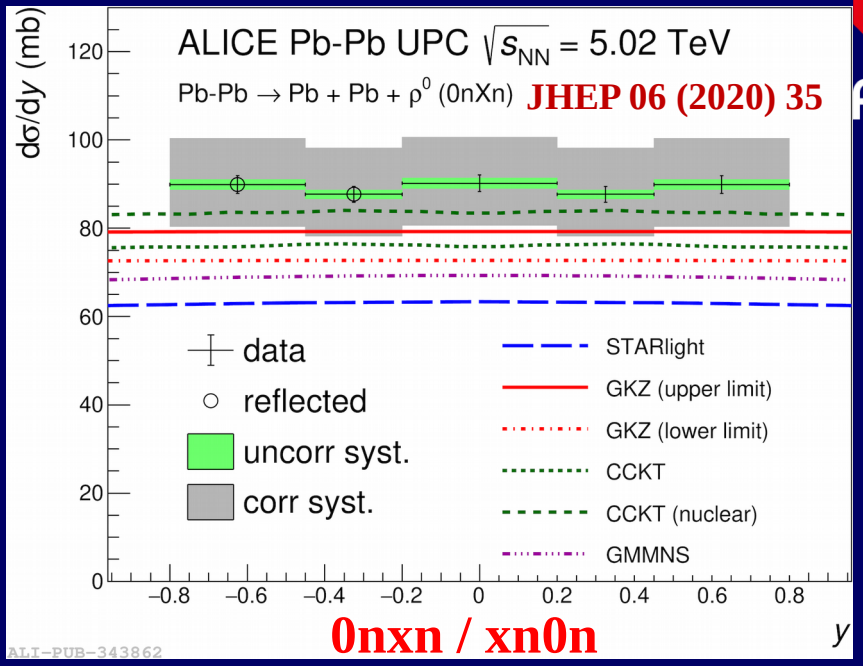
– located at either side of interaction point at ±112.5 m along the z-axis;
– intended for measurement of neutrons at beam rapidity;
– provided time resolution enough to separate beam–beam and beam–gas interactions;
– with a good efficiency to detect neutrons coming from electromagnetic dissociation (EMD, $|\eta| > 8.8$);
– 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.

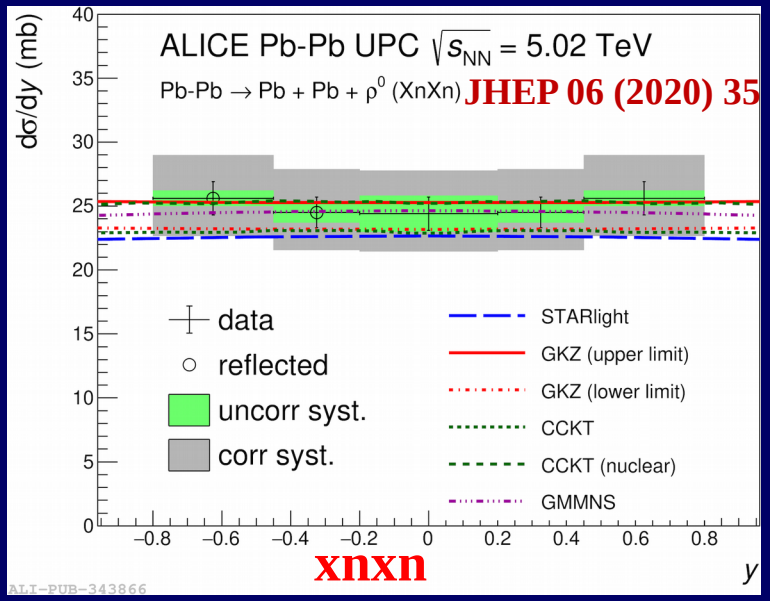




Coherent ρ^0 production in Pb–Pb UPC at $\sqrt{s_{NN}}$ = 5.02 TeV (cont'd)



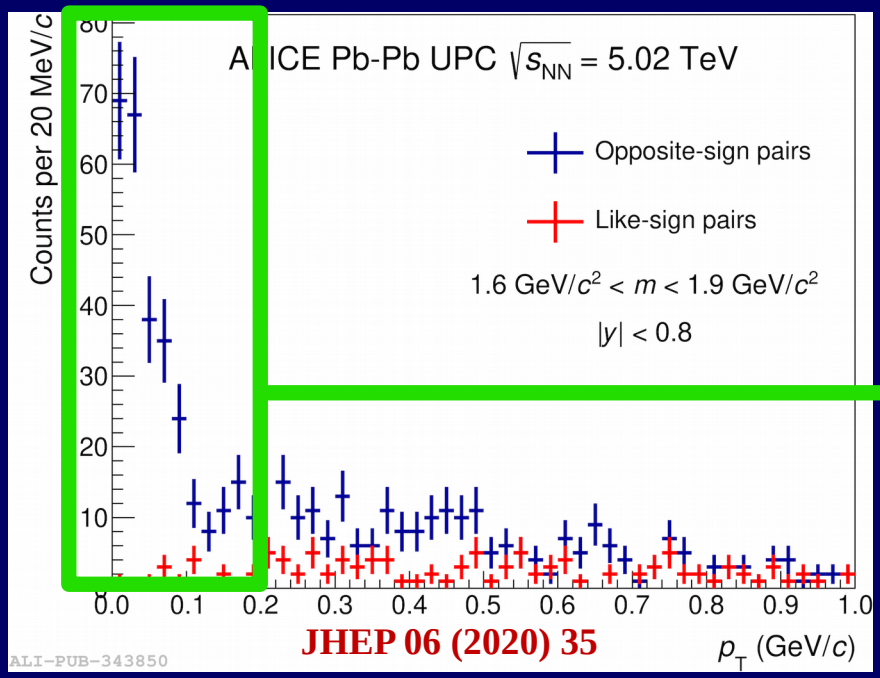


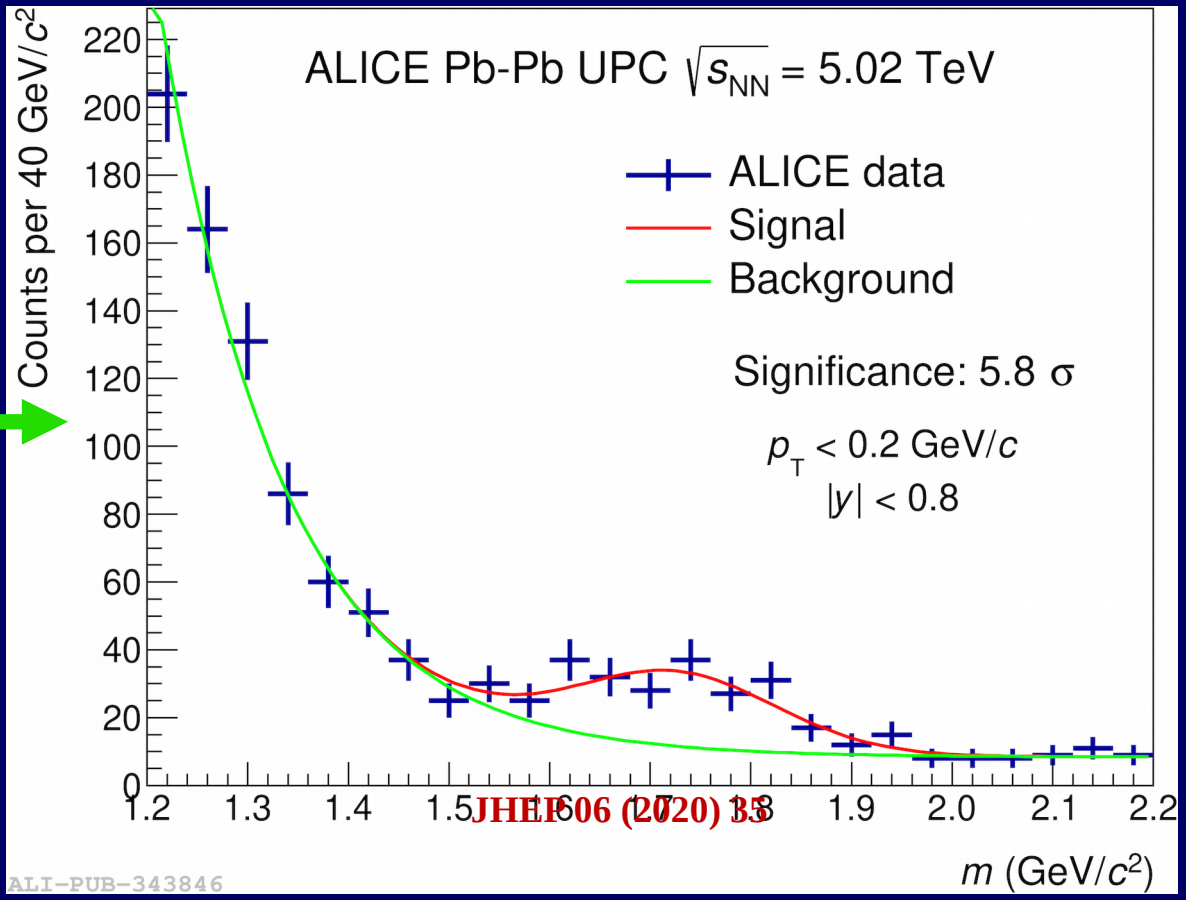


agreement both with models based on colour-dipole approach and with Gribov-Glauber shadowing.

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





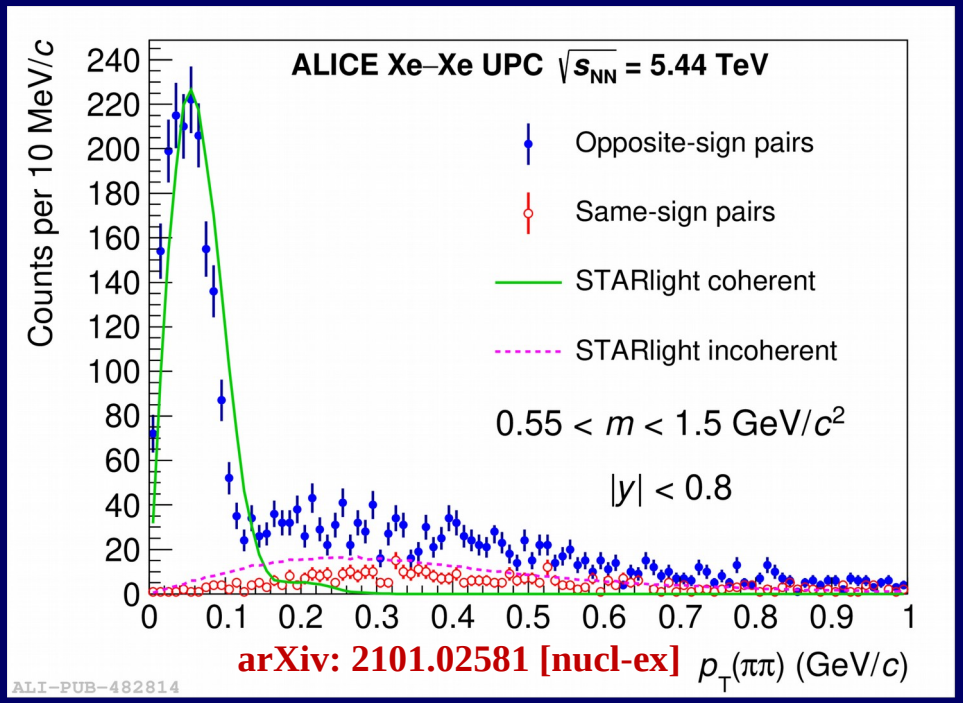
Distribution is fitted according to the STAR approach (S. R. Klein for STAR Collab., PoS DIS2016 (2016) 188) and the fit provides mass of (1725 ± 17) MeV/c^2 and width (143 ± 21) MeV/c^2

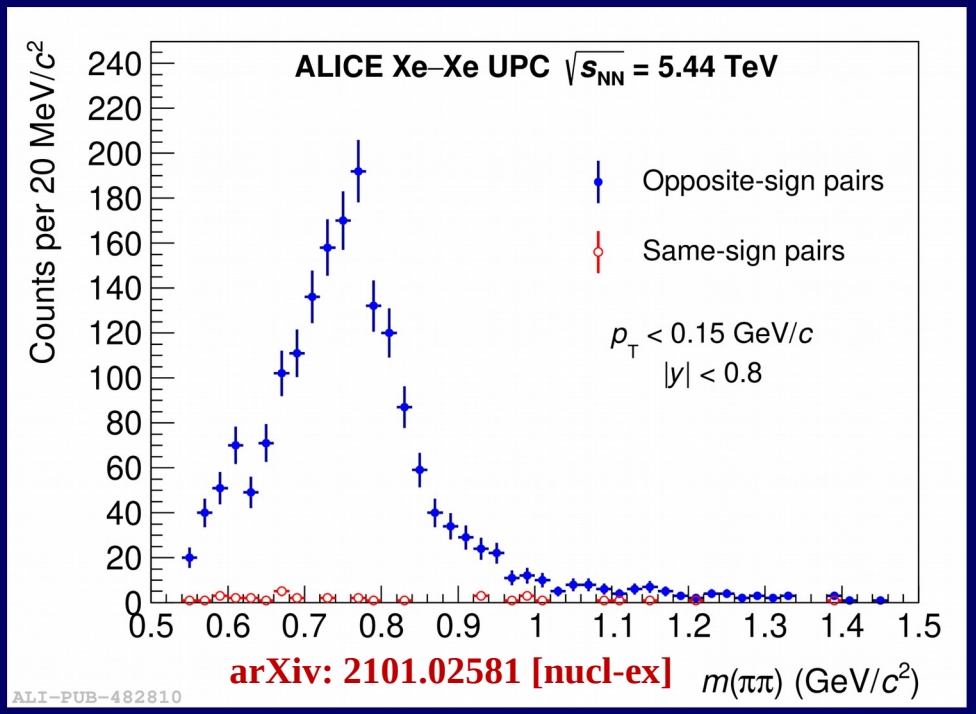
several candidates listed in PDG are compatible with it

Coherent ρ^0 production in Xe–Xe UPC at $\sqrt{s_{NN}}$ = 5.44 TeV

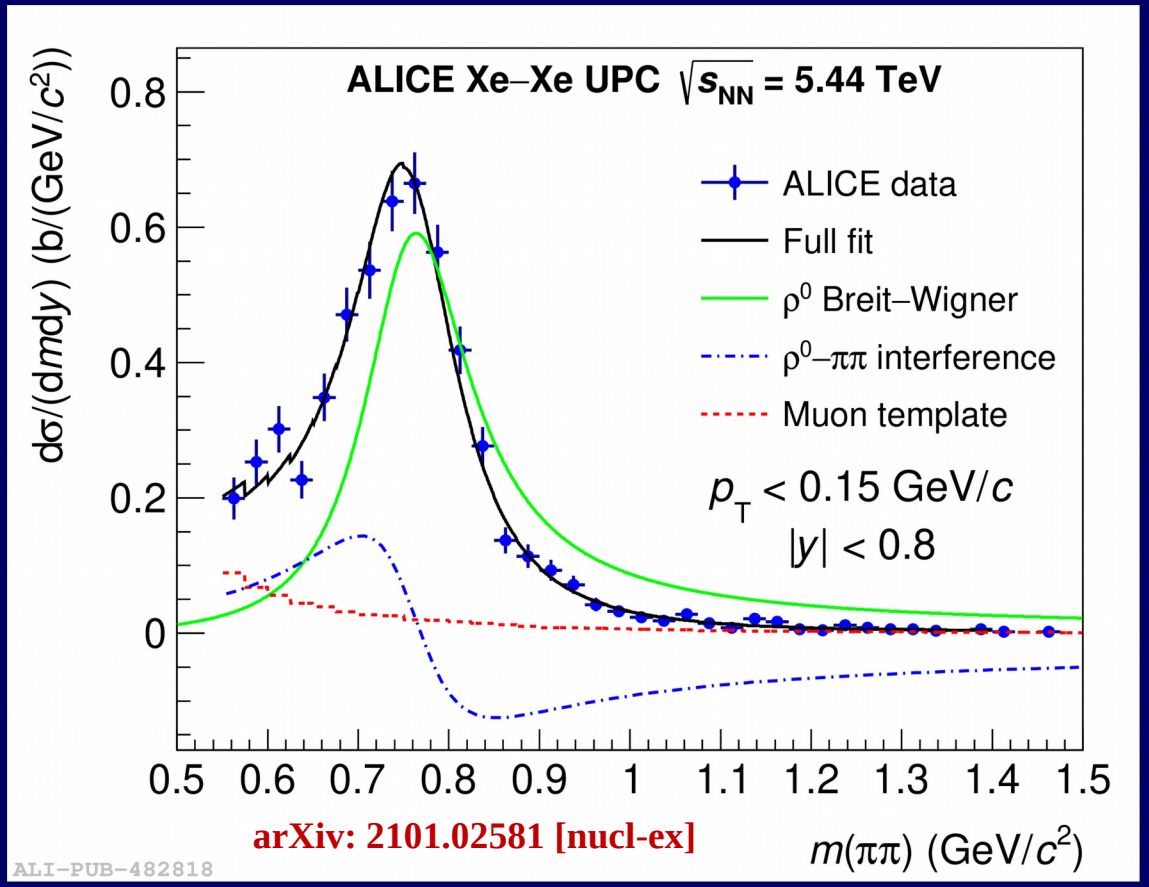
Shadowing effects are expected to depend on the atomic number of the nucleus →
UPC measurements for different A extend the study of the shadowing
at high energies and semi-hard scales.

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





Coherent ρ^0 production in Xe–Xe UPC at $\sqrt{s_{NN}}$ = 5.44 TeV (cont'd)



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.

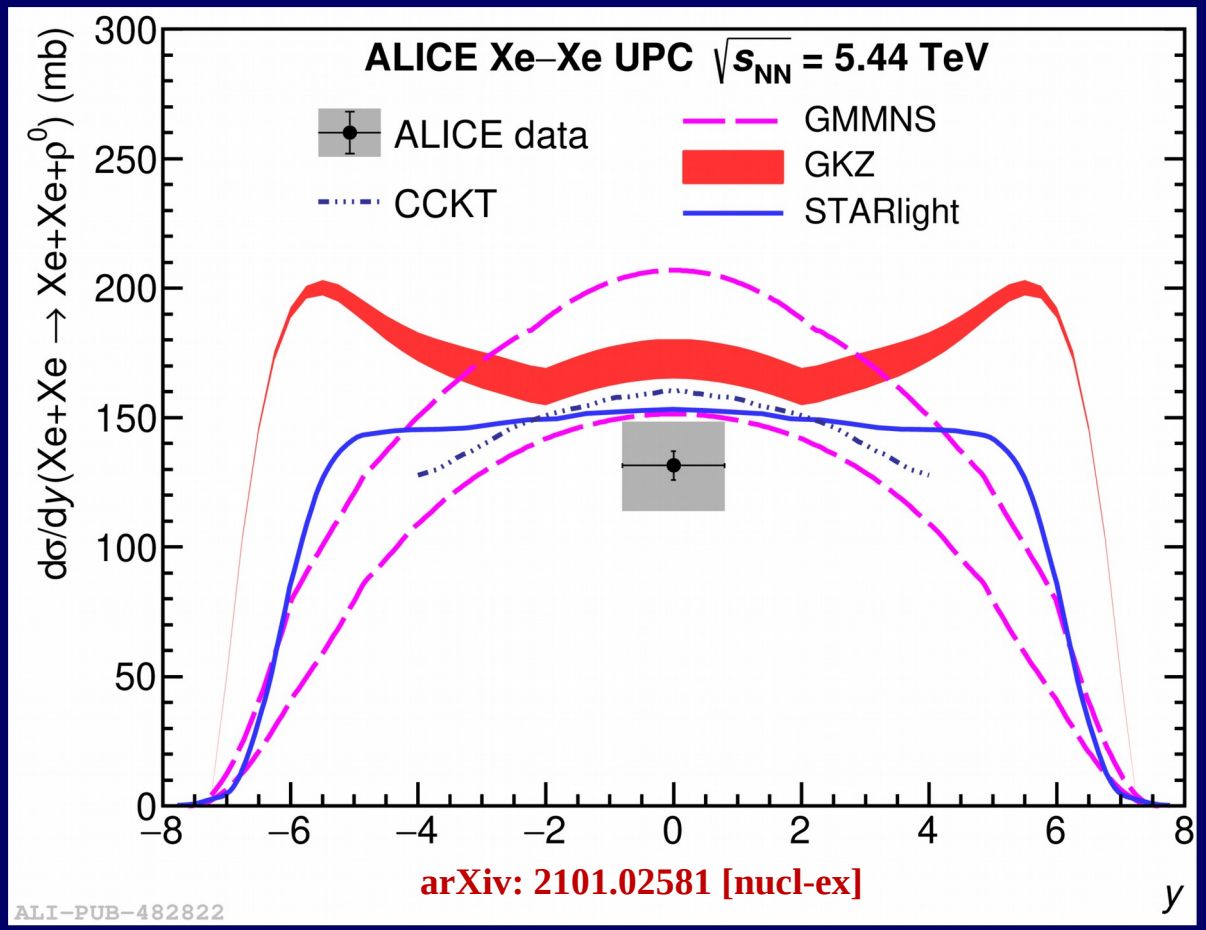
Around 1.8 thousand events were identified as Xe-Xe UPC ones with overall experimental efficiency of ~15%.

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

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

Overall systematic uncertainty ~13% with main contribution coming from luminosity uncertainty.

Coherent ρ^0 production in Xe–Xe UPC at $\sqrt{s_{NN}}$ = 5.44 TeV (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):
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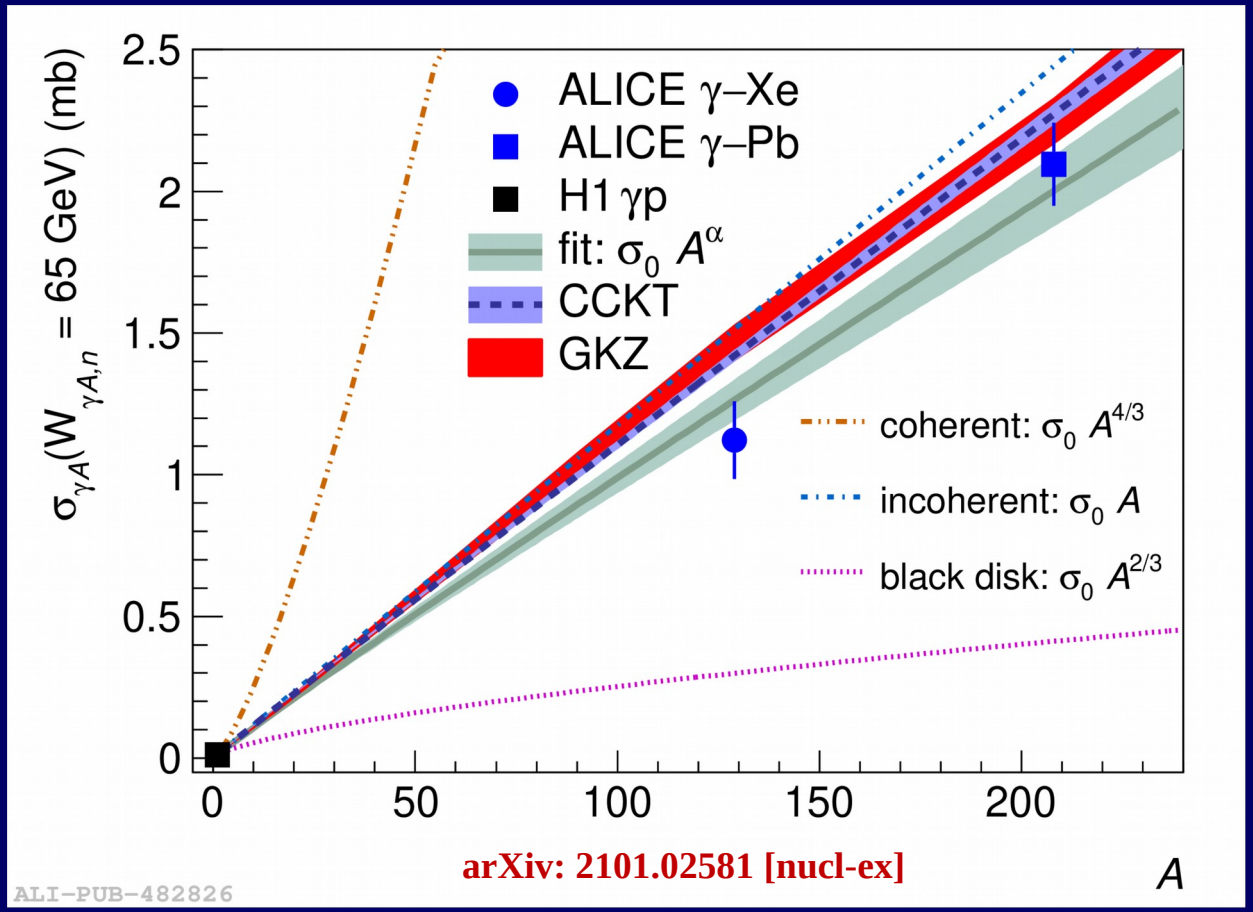
γ+p → VM+p cross section + the optical theorem + Glauber-like eikonal formalism.

Coherent ρ^0 production in Xe–Xe UPC at $\sqrt{s_{NN}}$ = 5.44 TeV (cont'd)



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).

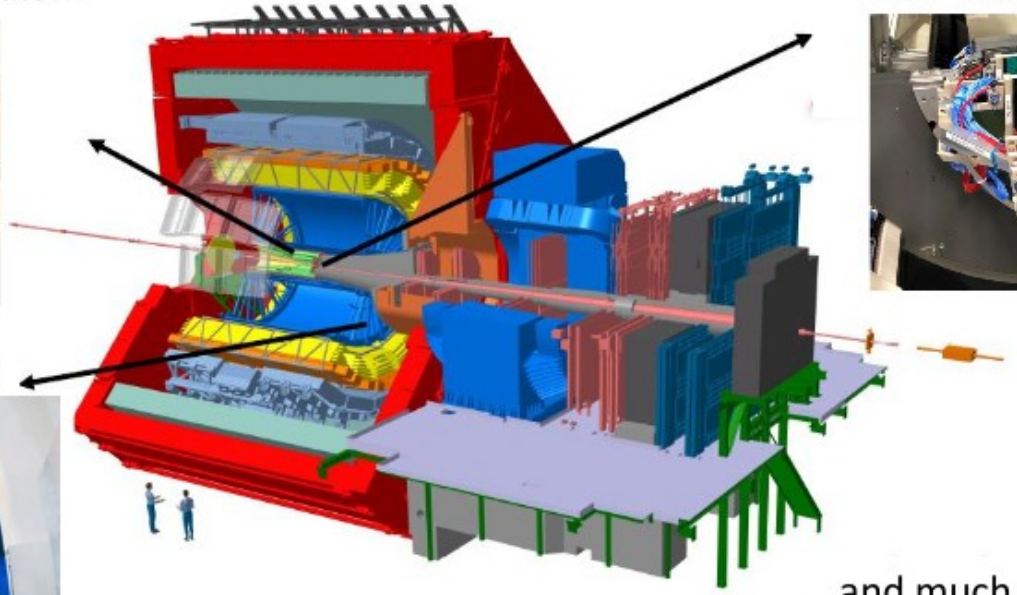
The A-dependence is fitted by a power-law model, slope parameter is found to be:
0.963±0.019 (ALICE+H1)
0.985±0.007 (GKZ model)
0.983±0.004 (CCKT model)

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

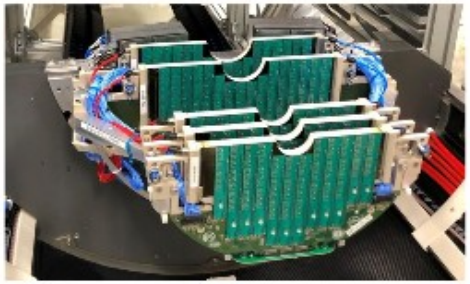
Prospects for studies of Pb–Pb UPC with Run 3–4 data

The ALICE upgrades for Run 3–4

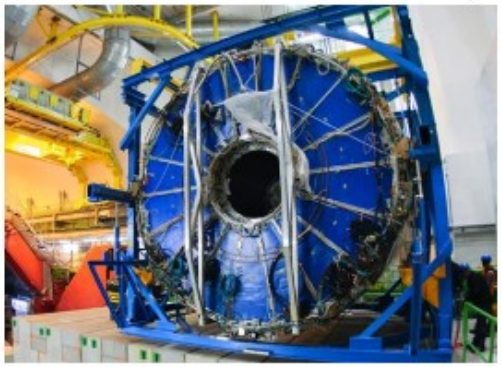
All-pixel Inner Tracking System



Pixel Muon Forward Tracker



GEM-based TPC readout



… and much more:

- Fast Interaction trigger
- New Online-Offline systems
- Readout upgrade of all detectors

Main goal:

- Record minimum-bias Pb-Pb data at 50kHz (~ 1 kHz in Run 2)
- Collect 13/nb in Run 3&4 → x 100 minimum bias statistics wrt Run 1&2

ALICE will take data in triggered and in continuous readout mode during Run 3–4. Continuous readout allows to collect full delivered luminosity without significant trigger and dead-time inefficiencies. Therefore the total acceptance&efficiency for UPC events will increase essentially.

Prospects for studies of Pb–Pb UPC with Run 3–4 data

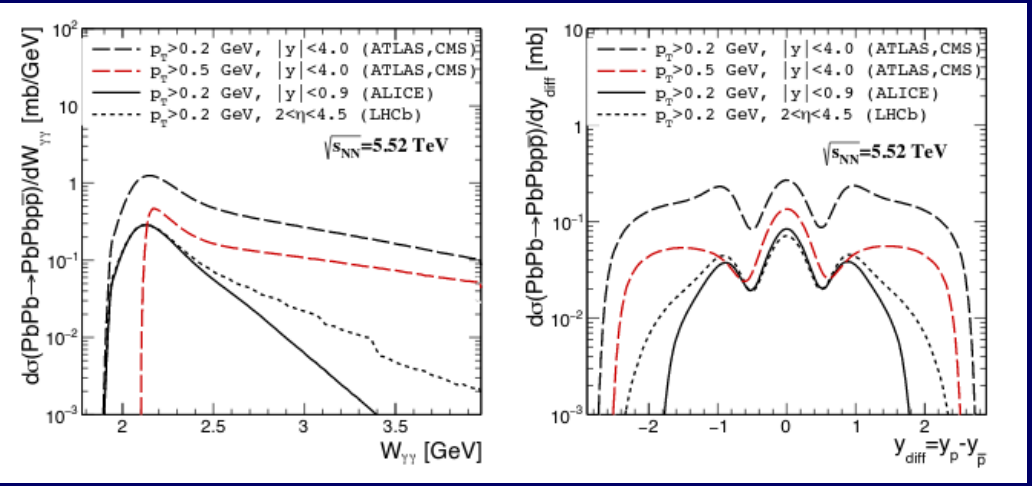
The estimations for vector meson photoproduction yields made with STARlight event generator for expected luminosity of 13 nb^{-1}.

CERN Yellow Rep.Monogr. 7 (2019) 1159-1410

Condition	Tot.	Central 1 Narrow	Central 2 Wide	Forward 1 Narrow	Forward 2 Wide
Rapidity	-	$\|y\| < 0.9$	$\|y\| < 2.4$	$2.5 < y < 4.0$	$2 < y < 5$
$e/\pi/\mu$ pseudorapidity	-	$\|\eta\| < 0.9$	$\|\eta\| < 2.4$	$2.5 < \eta < 4.0$	$2 < \eta < 5$

PbPb						
Meson	σ	All Total	Central 1 Total	Central 2 Total	Forward 1 Total 1	Forward 2 Total
$\rho \to \pi^+\pi^-$	5.2b	68 B	5.5 B	21B	4.9 B	13 B
$\rho' \to \pi^+\pi^-\pi^+\pi^-$	730 mb	9.5 B	210 M	2.5 B	190 M	1.2 B
$\phi \to K^+K^-$	0.22b	2.9 B	82 M	490 M	15 M	330 M
$J/\psi \to \mu^+\mu^-$	1.0 mb	14 M	1.1 M	5.7 M	600 K	1.6 M
$\psi(2S) \to \mu^+\mu^-$	30μb	400 K	35 K	180 K	19 K	47 K
$\Upsilon(1S) \to \mu^+\mu^-$	2.0 μb	26 K	2.8 K	14 K	880	2.0 K

The two-photon studies are expected to provide noticeable results.



Conclusions and outlook

Analysis of ρ^0 photoproduction in high-energy γA interactions is a tool to search for the black-disk limit of QCD;

Ultra-peripheral collisions (UPC) of Pb–Pb at $\sqrt{s_{NN}}$=5.02 TeV and Xe-Xe at $\sqrt{s_{NN}}$=5.44 TeV were studied with the ALICE experimental data, collected during LHC Run 2;

Cross section of coherent ρ^0 photoproduction in Pb–Pb UPC is measured and found to be in agreement both with models based on colour-dipole approach and with Gribov-Glauber shadowing approach. For the first time the cross sections were measured for different neutron emission classes;

Wide resonance-like structure at mass of (1725 ± 17) MeV/c^2 in Pb–Pb UPC was found;

For the first time the cross section of coherent ρ^0 production in Xe–Xe UPC is measured;

The A-dependence γA interactions is fitted using Pb–Pb, Xe–Xe UPC and H1 data as well;

The estimations for VM photoproduction in Pb–Pb UPC with Run 3–4 data are presented.