Recent ALICE results relevant for PDFs at low and high-x, saturation

Anisa Khatun (for the ALICE Collaboration)
The University of Kansas

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U.S. DEPARTMENT OF ENERGY
Office of Science

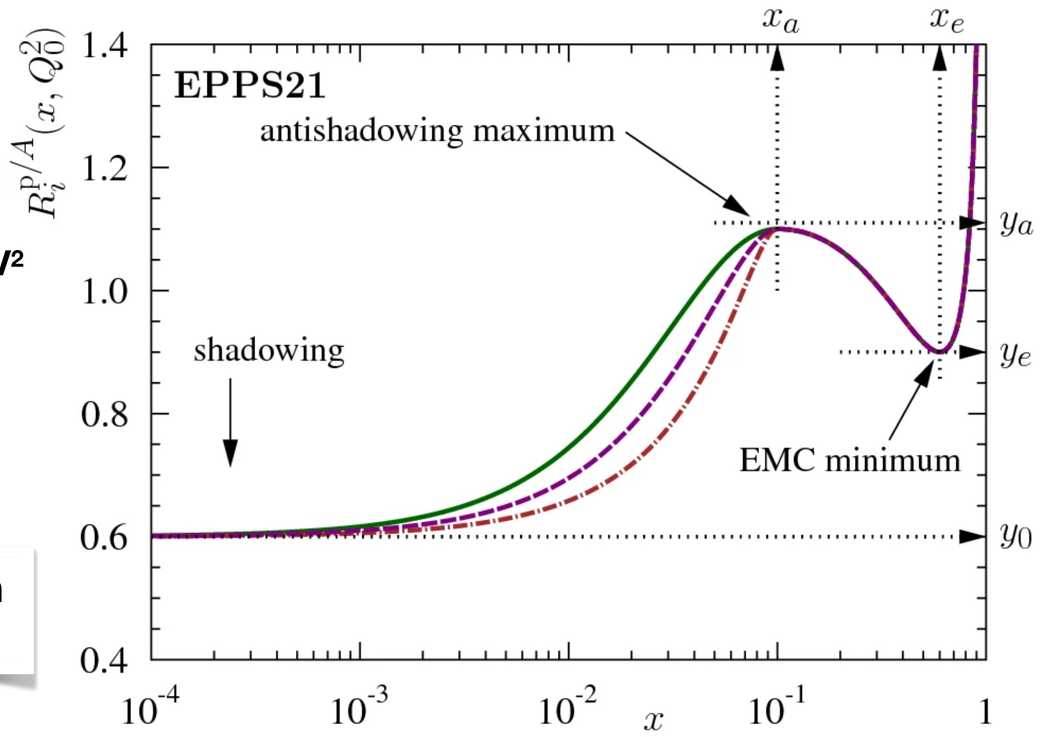
THE UNIVERSITY OF KANSAS

Outline

- ☑ Introduction
- ☑ Physics of Ultra-Peripheral Collisions (UPCs)
- ☑ The ALICE experiment in Run 2
- ☑ Coherent and exclusive J/ψ photoproduction
- ☑ Incoherent and dissociative J/ψ in p-Pb collisions
- ☑ The ALICE experiment in Run 3
- ☑ Future prospects

Introduction

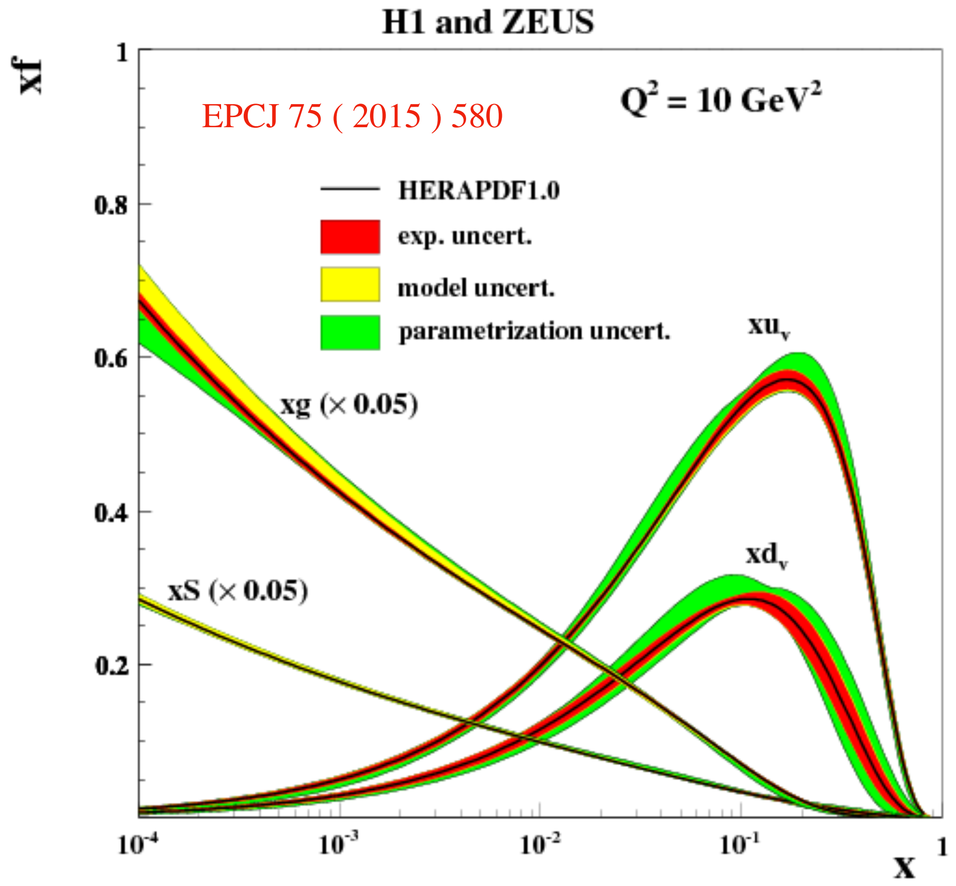
- ☑ Disentangle the CNM effects from QGP to interpret AA collisions
- ☑ Important to study nucleon and nucleus structure
- ☑ To study CNM via nuclear modification function $\rightarrow R_{iA}(x,Q^2) = \dfrac{f_{iA}(x,Q^2)}{f_i(x,Q^2)}$
- ☑ PDF depends on both x and Q^2, $R_{iA}(x,Q^2) = 1$, for no nuclear effect



Q^2 = 1.69 GeV^2

Eur.Phys.J.C 82 (2022) 413

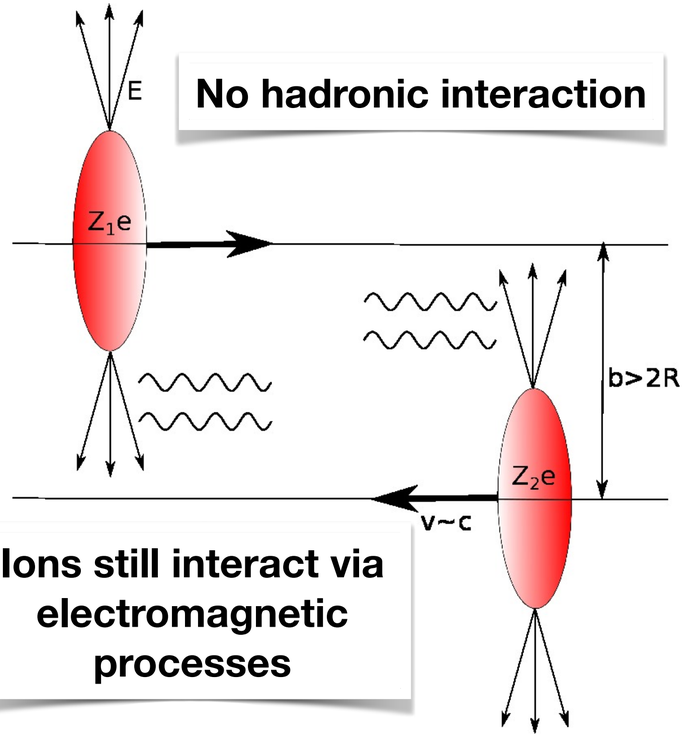
Saturation < 10^{-4}



Example PDFs for quarks and gluons at 10 GeV from HERA

- ☑ At low x the gluon density increases with the energy and reach to a saturation
- ☑ Two CNM effects: Search for gluon saturation, and gluon shadowing at LHC energies with UPC (Bjorken-x values down to ~10^{-6} at LHC energies)

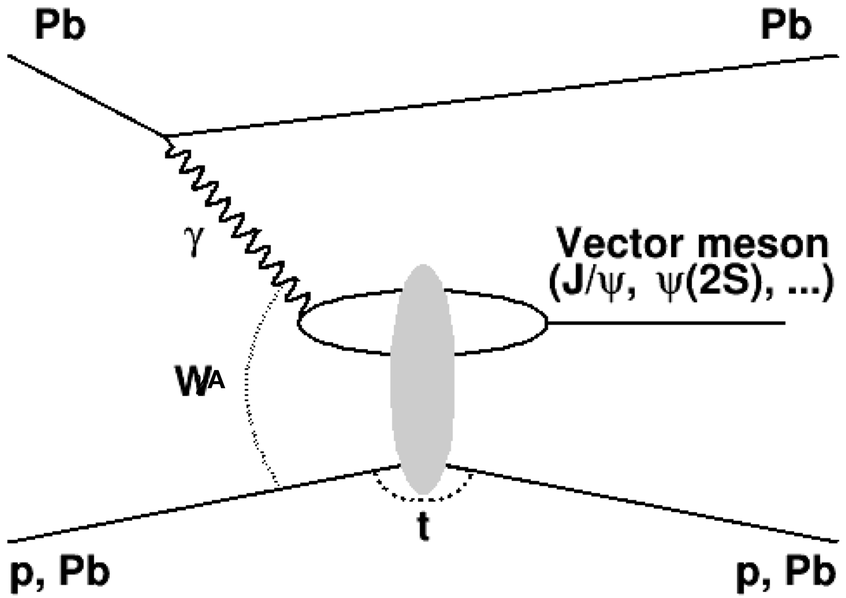
Physics of UPCs



No hadronic interaction

Ions still interact via electromagnetic processes

Typical exclusive VM production in UPC



A few tracks in an otherwise empty detector e.g. exclusive (Pb-Pb), dissociative (p-Pb) vector meson photoproduction

$$W_{\gamma A}^2 = \sqrt{s} M_{VM} e^{\pm y}$$

$$x = \frac{M_{VM}^2}{W_{\gamma A}^2} = \frac{M_{VM}}{\sqrt{s}} e^{\pm y}$$

$$t \approx -p_T^2$$

- ☑ Ultra-Peripheral Collisions (UPCs) provide a tool to probe the nucleus and nucleons
- ☑ A wealth of physics results over the last 10 years [Eur.Phys.J.C 84 (2024) 8]
- ☑ Unique in ALICE: Good acceptance for both charged particles, photons at low p_T and excellent particle identification at midrapidity
- ☑ Run 3 opens a new window to explore novel physics processes

The ALICE experiment in Run 2 (2015 - 2018)

UPC studies at mid rapidity

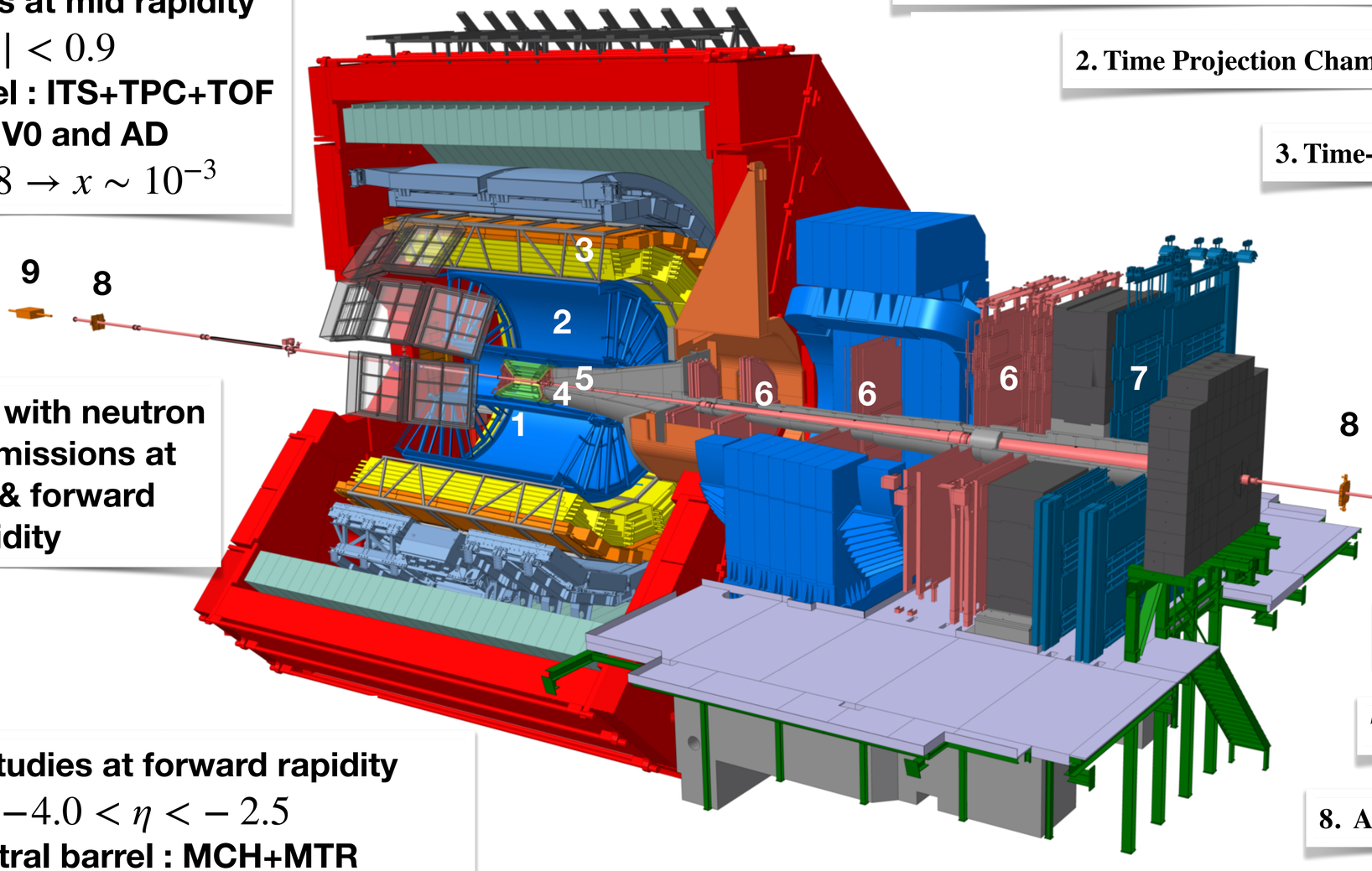
$|\eta| < 0.9$

Central barrel : ITS+TPC+TOF

Veto : V0 and AD

$|y| < 0.8 \rightarrow x \sim 10^{-3}$

UPC studies with neutron & proton emissions at both mid & forward rapidity



UPC studies at forward rapidity

$-4.0 < \eta < -2.5$

Central barrel : MCH+MTR

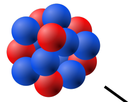
Veto : V0 and AD

$-4.0 < y < -2.5 \rightarrow x \sim 10^{-2}$ *or* 10^{-5}

1. Inner Tracking System (ITS) : Tracking, triggering, vertexing
2. Time Projection Chamber (TPC) : Tracking + PID
3. Time-Of-Flight (TOF) : Triggering + PID
4. V0 : Triggering and vetoing
5. T0 : Triggering
6. Muon Tracker (MCH) : Tracking
7. Muon Trigger (MTR) : Triggering
8. ALICE Diffractive (AD) : vetoing
9. Zero Degree Calorimeter (ZDC) : vetoing

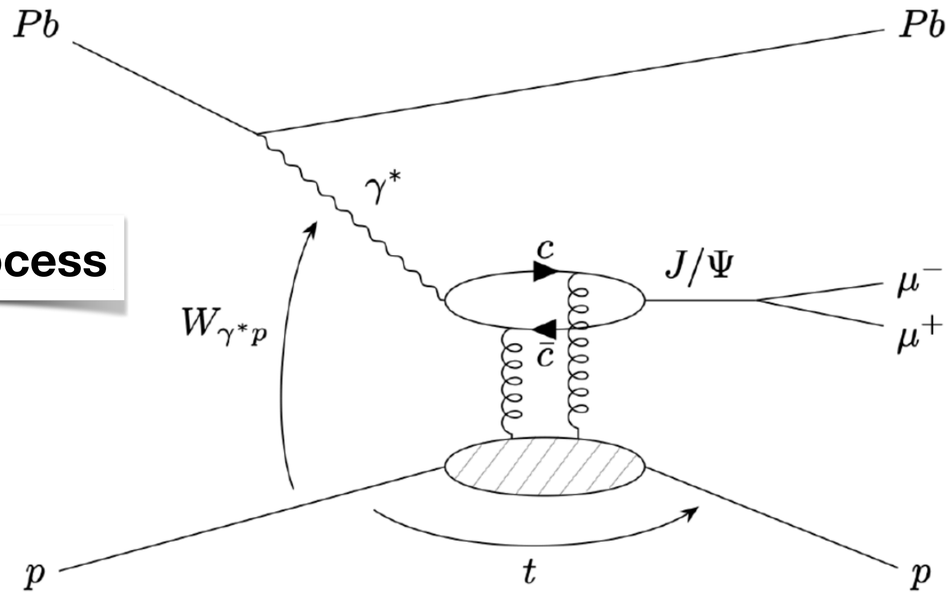
Coherent and exclusive J/ψ measurements with ALICE

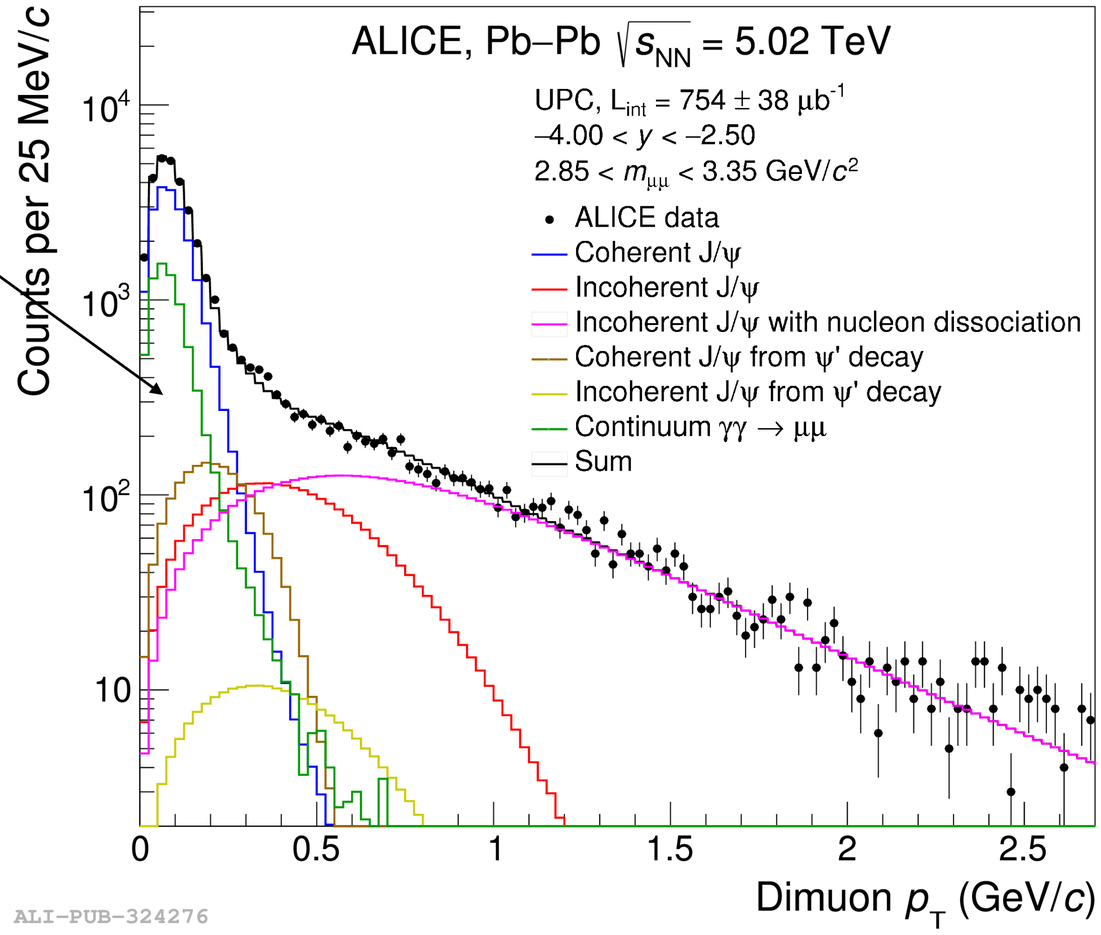
Coherent

γ 

$p_T < 0.2$ GeV/c

Exclusive process

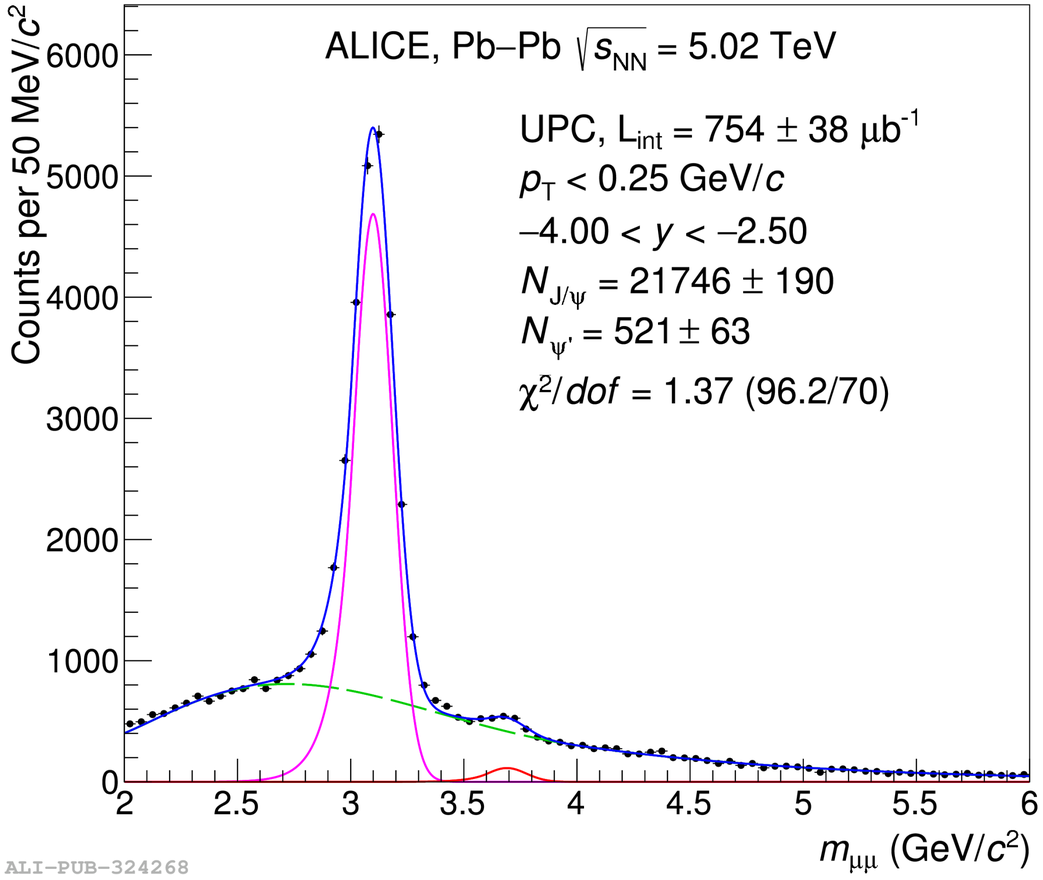


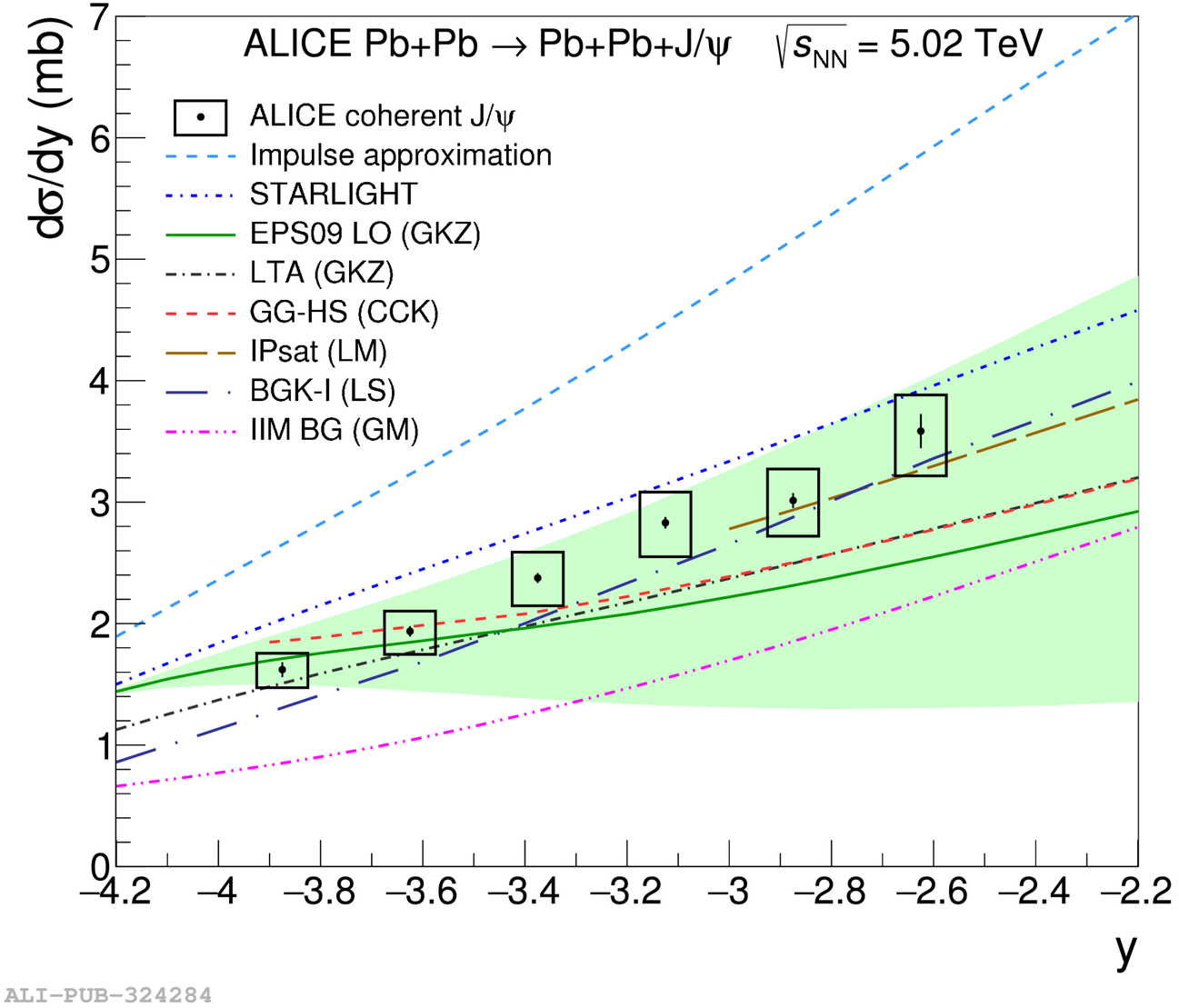


Phys.Lett. B798 (2019) 134926

Coherent J/ψ measurement at forward rapidity

Phys.Lett. B798 (2019) 134926

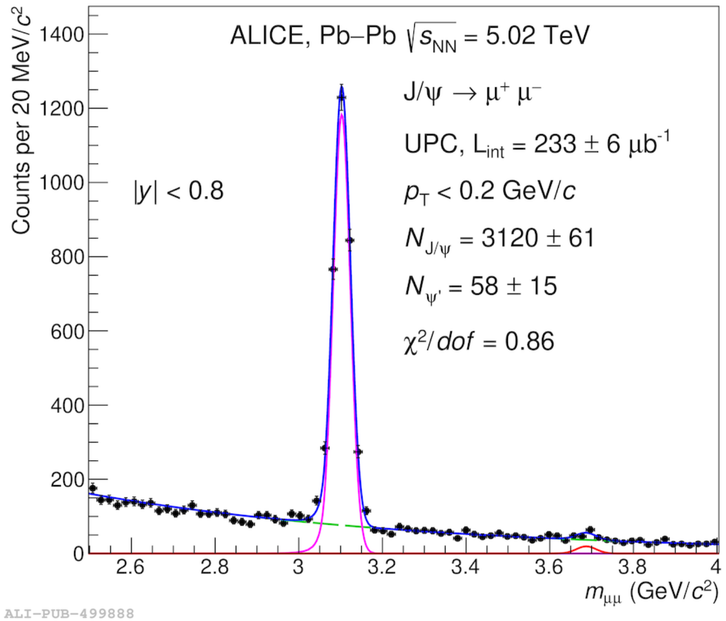


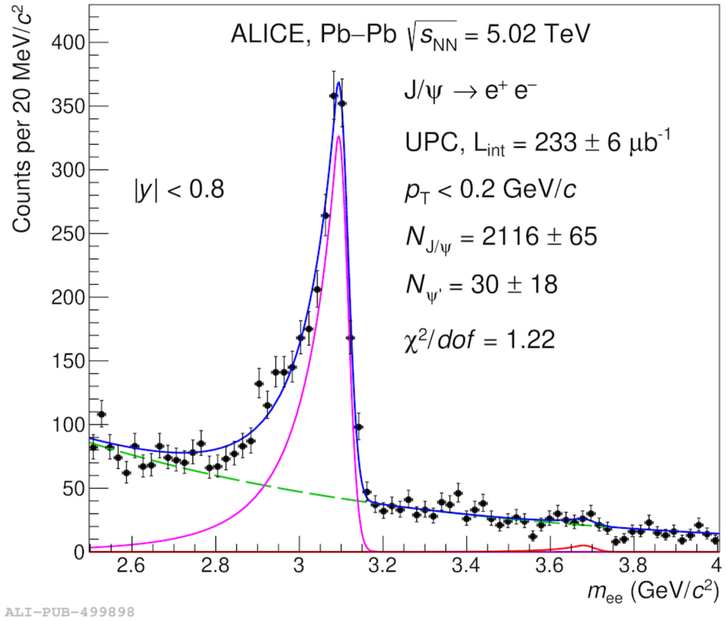


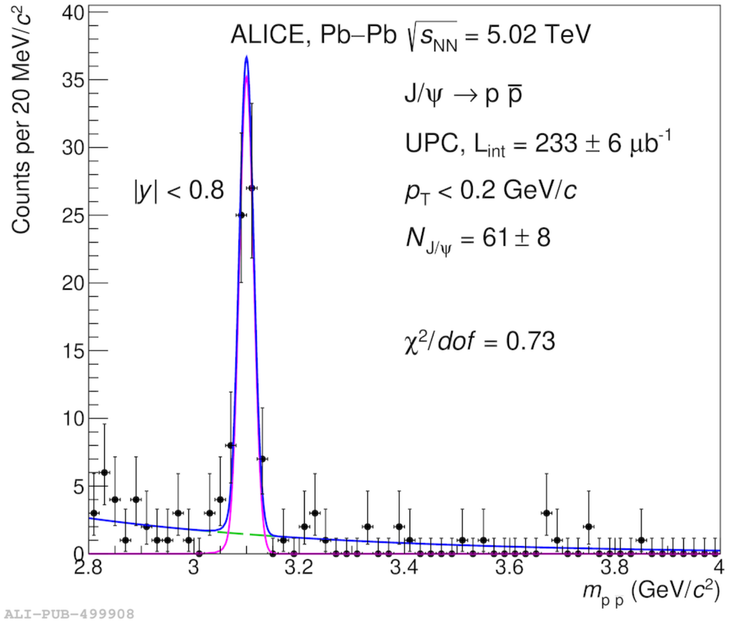
- ☑ $J/\psi \rightarrow \mu^+ + \mu^-$
- ☑ Differential photonuclear cross-section of coherent J/ψ are measured in terms of y shows indication of gluon shadowing

Coherent J/ψ measurement at mid rapidity

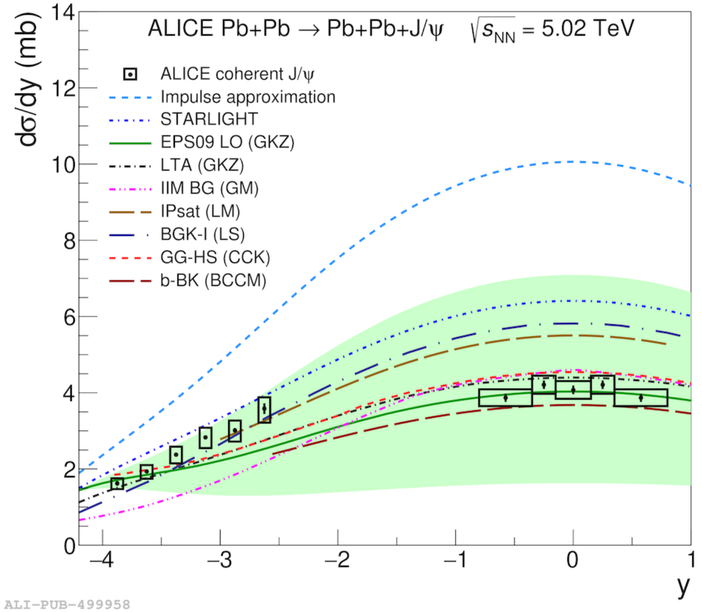
Eur. Phys. J. C 81 (2021) 712

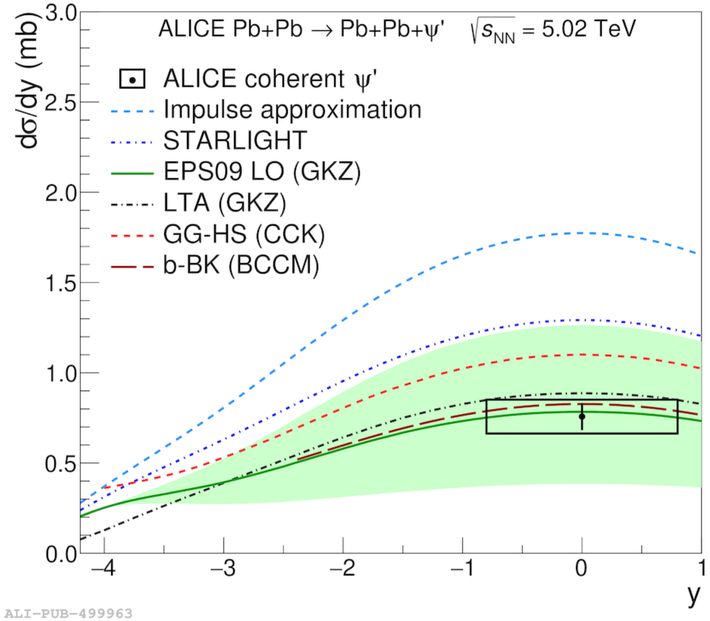




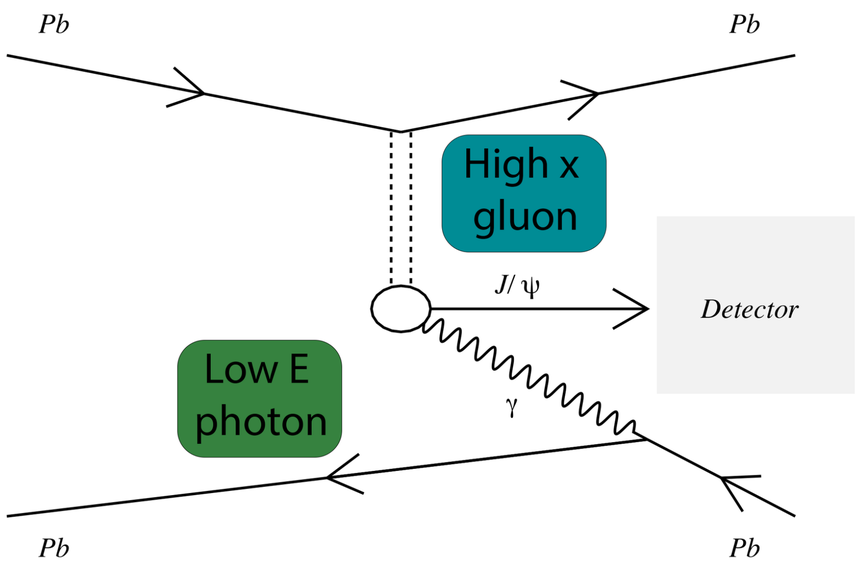


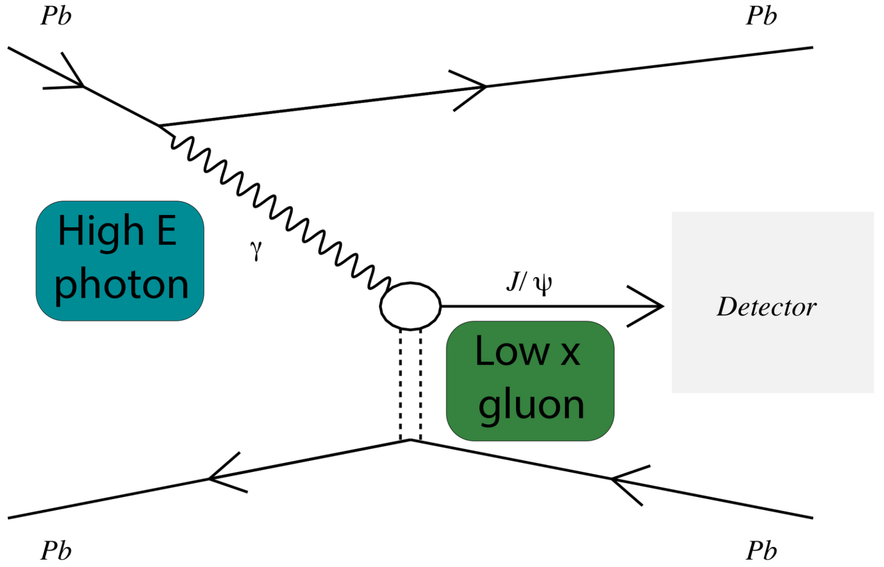
- ☑ At mid rapidity three channels are explored thanks to excellent PID of TPC
- ☑ $J/\psi \rightarrow l^+ + l^-, \psi(2s) \rightarrow l^+ + l^-$
- ☑ $\psi(2s) \rightarrow l^+ + l^- + \pi^+ + \pi^-$
- ☑ Good agreement with theory prediction including gluon shadowing of about 0.65 at x ~ 6 x 10^{-4} at midrapidity





Souce/target photon direction ambiguity





$$\frac{d\sigma_{PbPb}(y)}{dy} = n_\gamma(y)\sigma_{\gamma Pb}(y) + n_\gamma(-y)\sigma_{\gamma Pb}(-y)$$

[Baltz et. al. PRL 89 (2002) 012301]

[Guzey et. al. EPJC 74 (2014) 7]

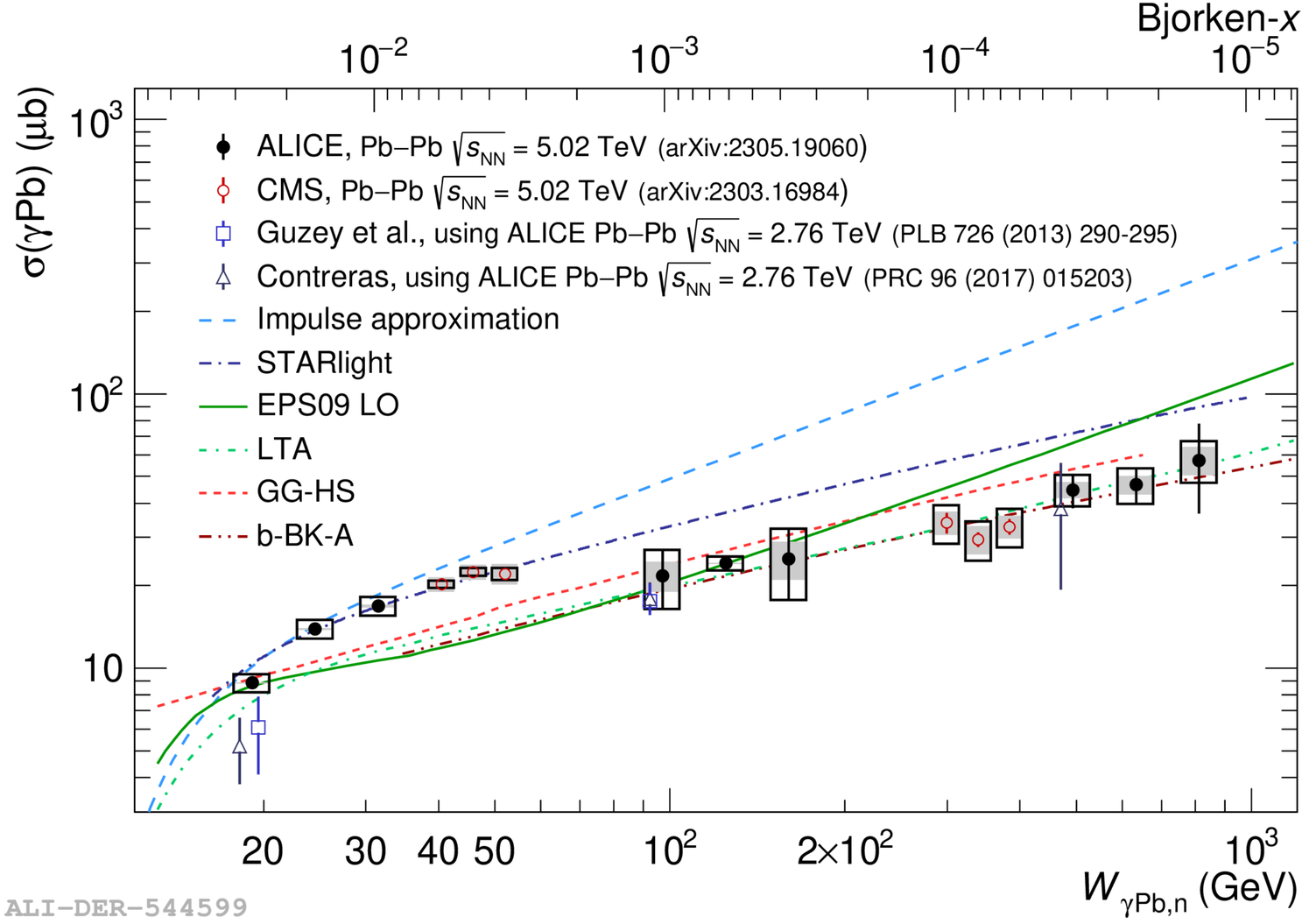
- ☑ UPC cross section = Photon flux (QED) x photo nuclear cross section (QCD)
- ☑ At mid rapidity contribution are equal
- ☑ Disentangle in terms of neutron emission classes (impact parameters)-> electromagnetic dissociation (EMD) of a nucleus via an independent photon exchange

- ☑ Access to impact parameter (b) with different neutron emission classes
- ☑ XnXn = neutrons on either side of beam (small b)
- ☑ 0nXn or Xn0n = neutrons only on one side (medium b)
- ☑ 0n0n = no neutrons are detected (large b)

Energy dependence of photonuclear cross section

JHEP 10 (2023) 119

- ☑ Results includes both mid and forward rapidity data
- ☑ Measurement covers 17 < $W_{\gamma Pb,n}$ < 920 GeV with Bjorken-x interval 1.1x10^{-5} < x < 3.3 10^{-2}
- ☑ No model describe the data completely
- ☑ STARLight, impulse approximation describe well low energy data
- ☑ At high energy data described by both models that include shadowing and saturation effects
- ☑ CMS performed similar measurements at lower energies

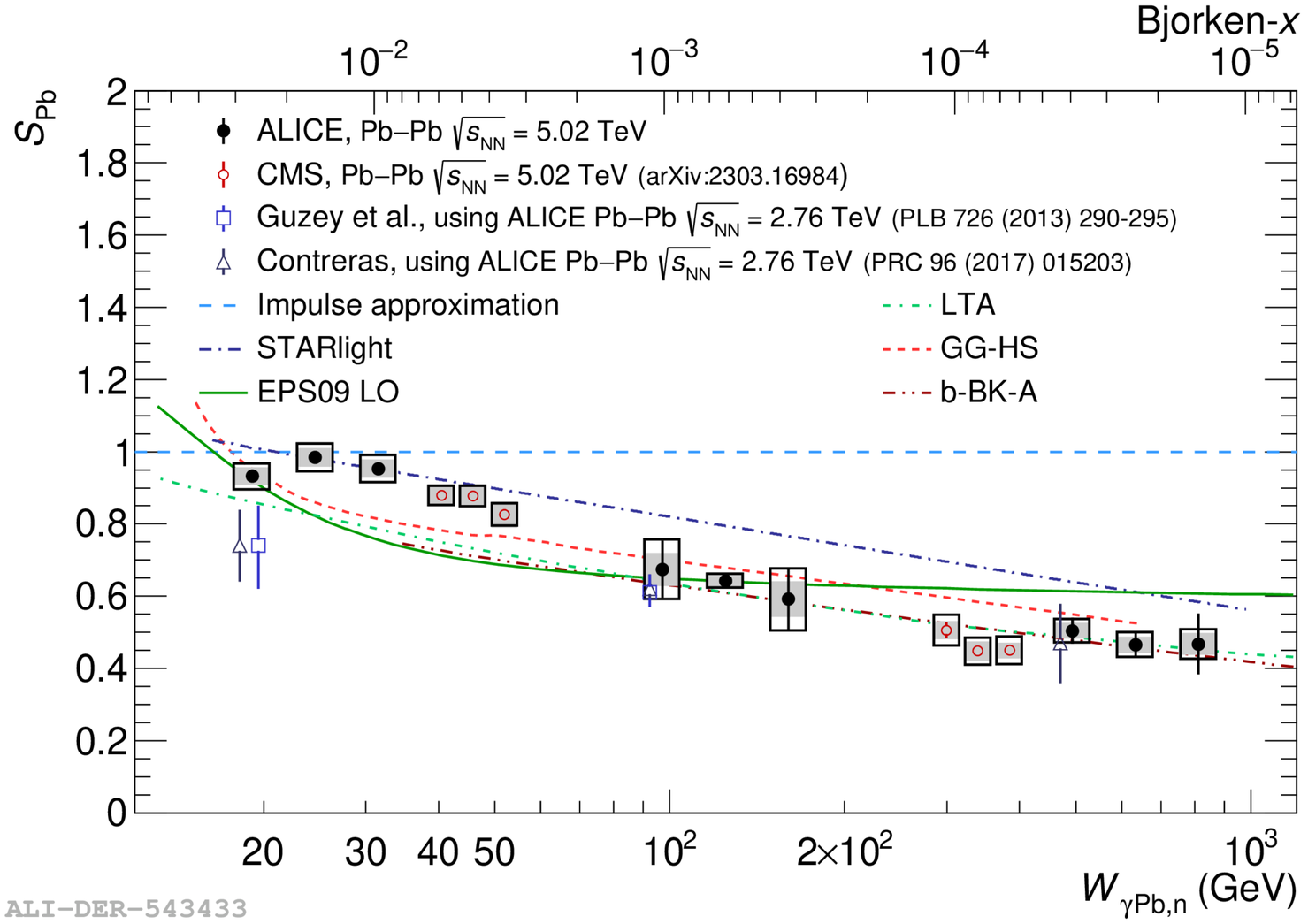


Nuclear suppression factor

JHEP 10 (2023) 119

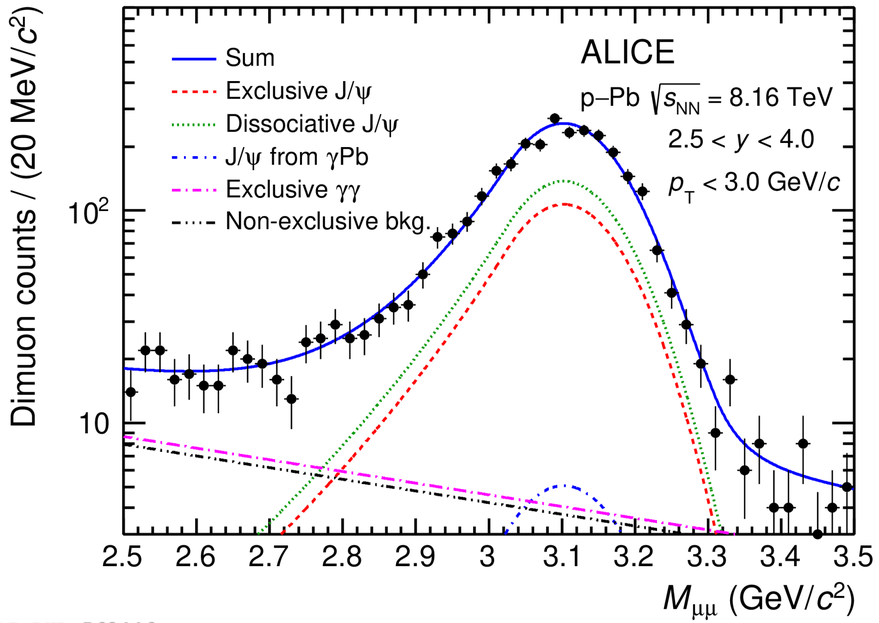
$$S_{\mathrm{Pb}}(W_{\gamma\mathrm{Pb,n}}) = \sqrt{\frac{\sigma_{\gamma\mathrm{Pb}}}{\sigma^{\mathrm{IA}}_{\gamma\mathrm{Pb}}}}$$

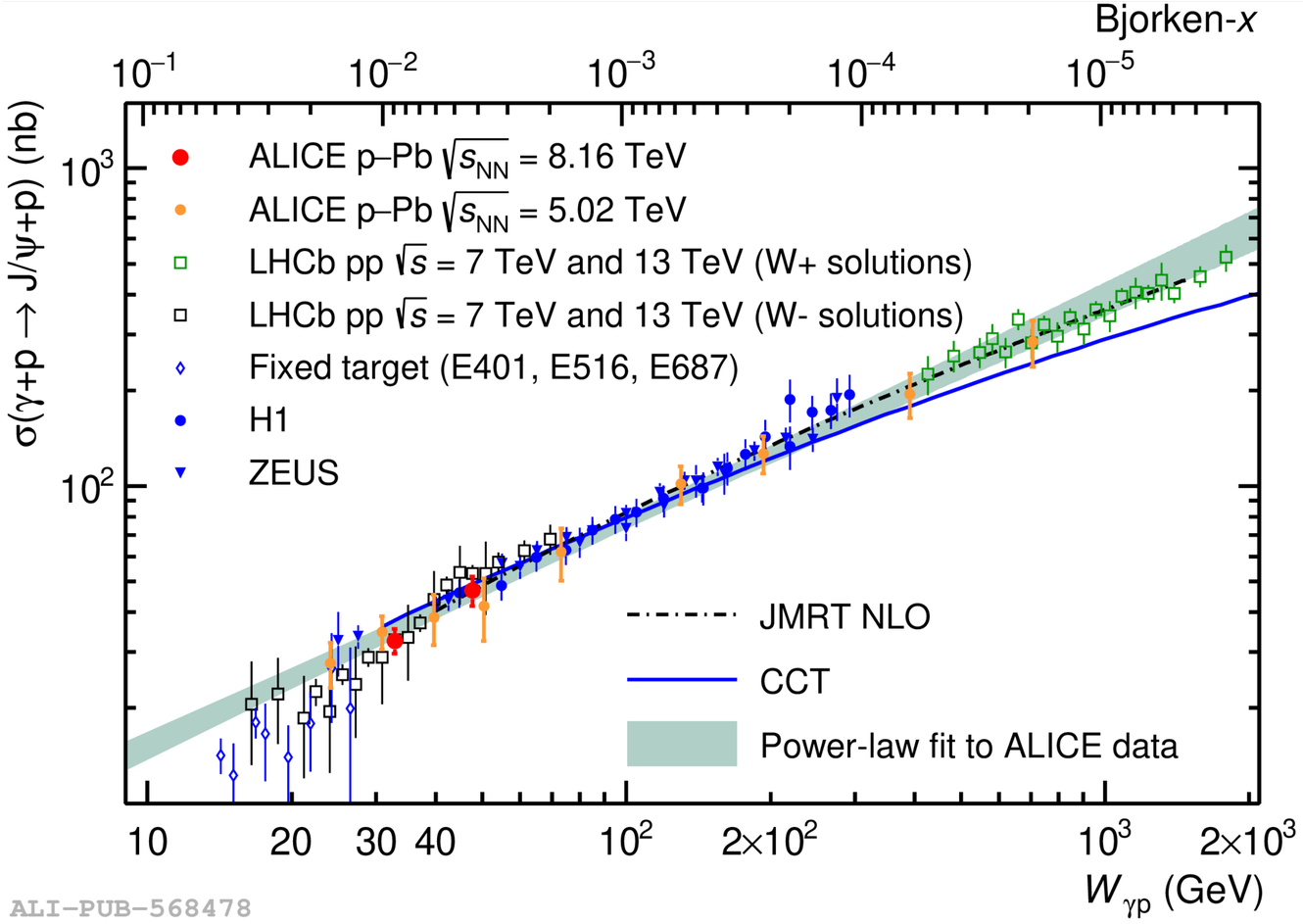
- ☑ Suppression gets stronger with energy
- ☑ Quantitive measurement of nuclear gluon shadowing
- ☑ Impulse approximation without any nuclear effect overshoots the data



Energy dependence of exclusive J/ψ measurement

Phys. Rev. D 108, 112004 (2023)

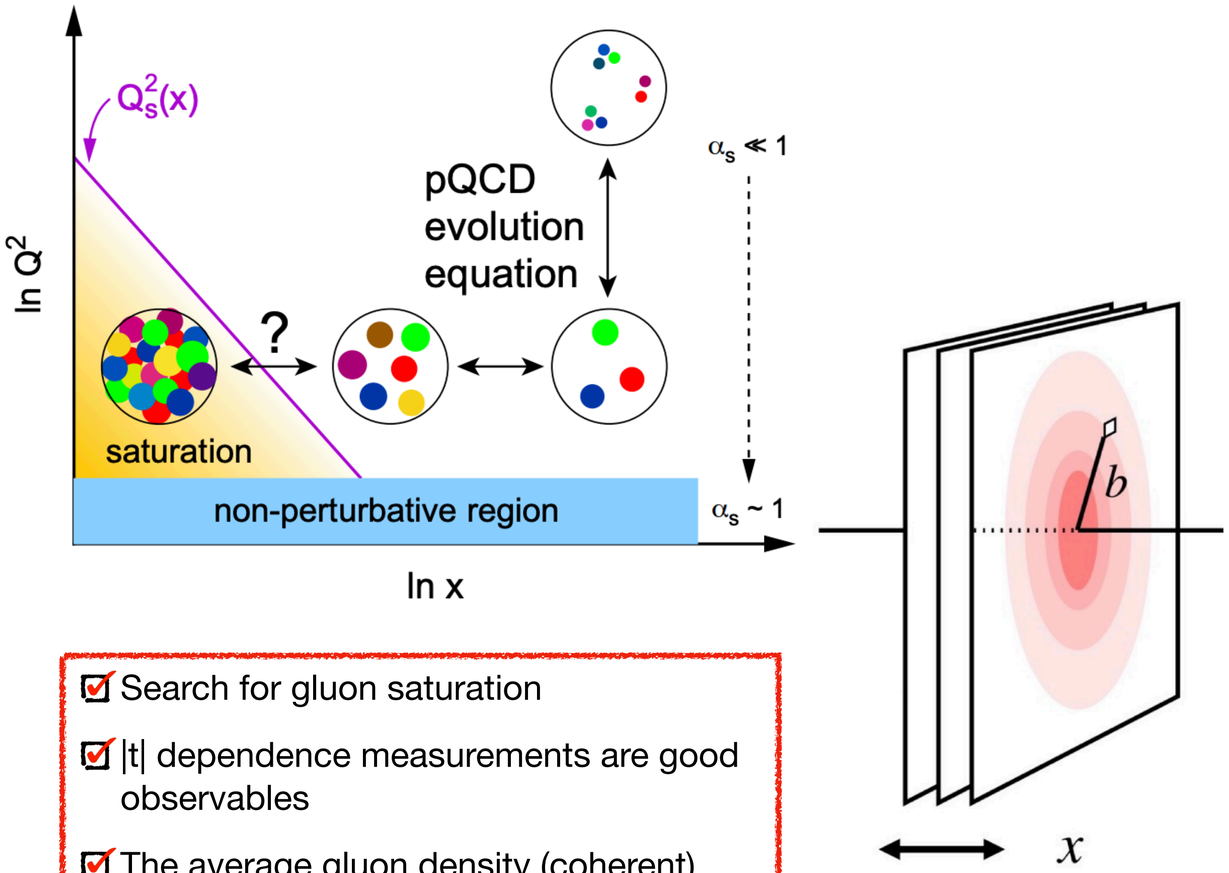




- ☑ Asymmetric system, no source/target ambiguity in the $W_{\gamma p,n}$ energy
- ☑ Incoming hadron energy known
- ☑ ALICE coverage at 8.16 TeV -> 27 < $W_{\gamma p,n}$ < 57 GeV
- ☑ Low energy photon emitter coming from nucleus (Pb)
- ☑ ALICE measurement at mid, semi forward and forward rapidities
- ☑ New measurements in UPC p-Pb at high energies are needed

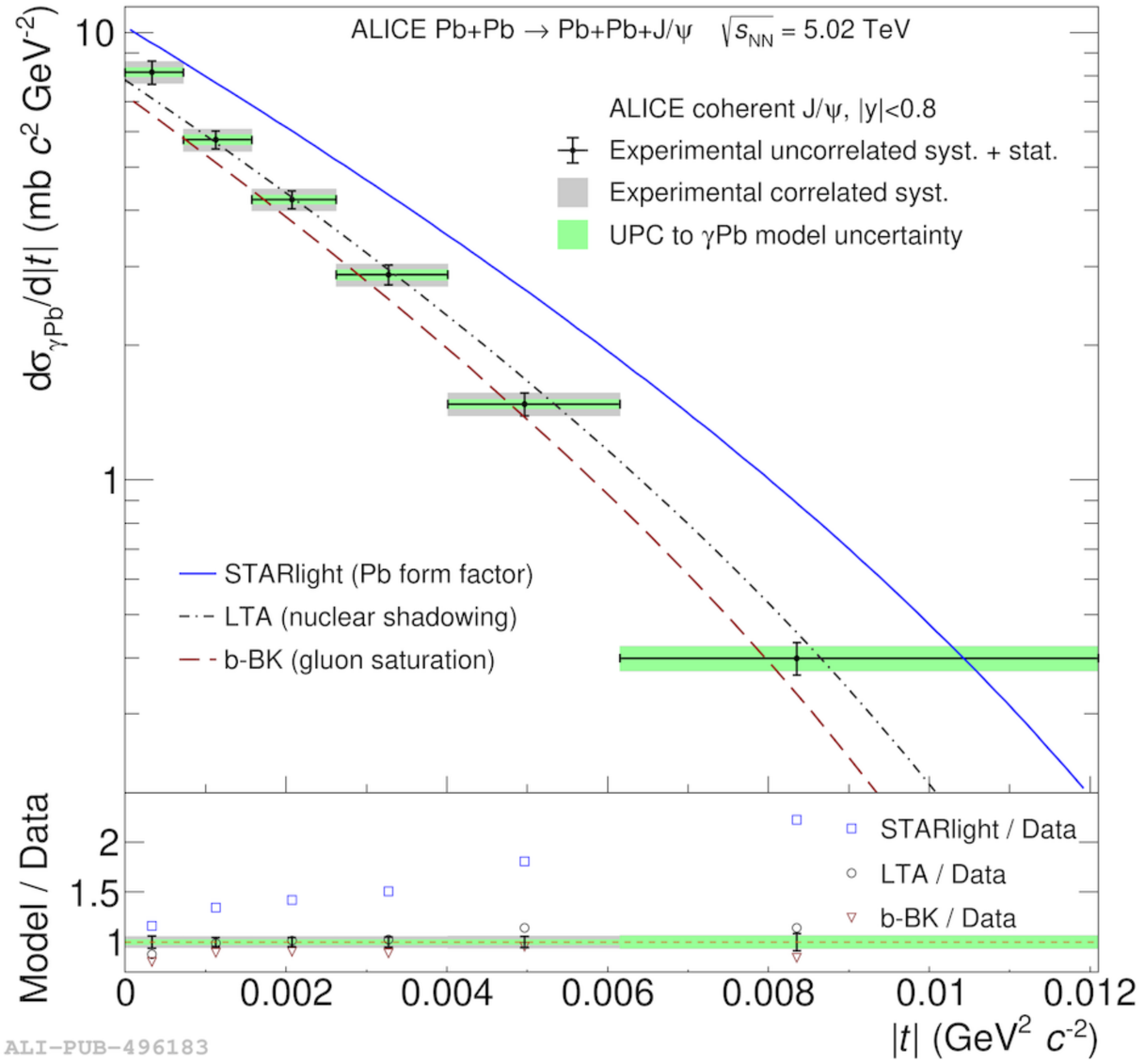
|t| dependence of coherent J/ψ measurement

PLB 817 (2021) 136280

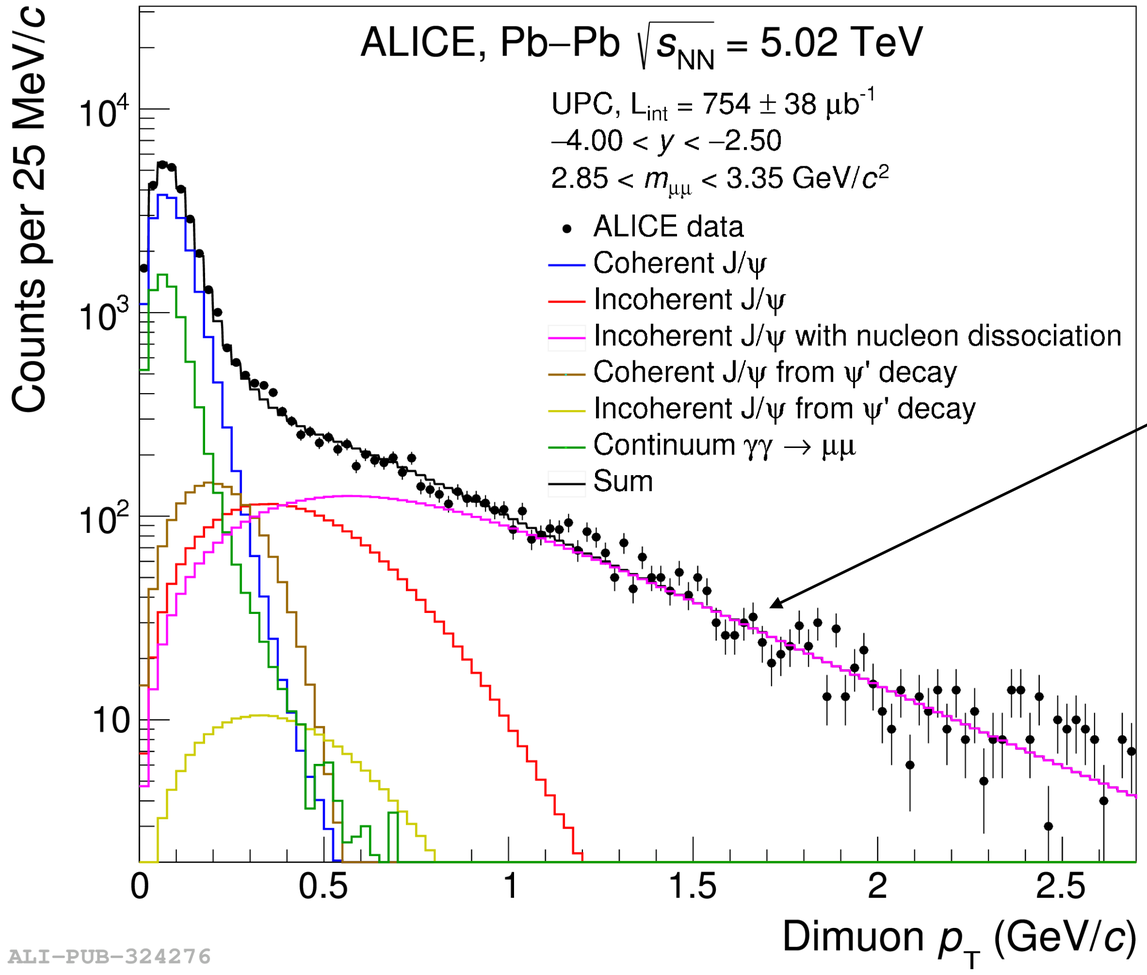


- ☑ Search for gluon saturation
- ☑ |t| dependence measurements are good observables
- ☑ The average gluon density (coherent)

- ☑ Cross section sensitive to the spatial gluon distribution
- ☑ STARLight overestimates the data
- ☑ Both models LTA (includes shadowing effects) and b-BK (includes gluon saturation effect) describe qualitatively data



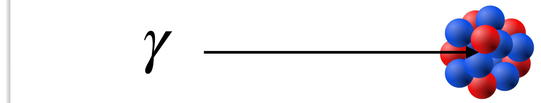
Incoherent and dissociative J/ψ measurements with ALICE



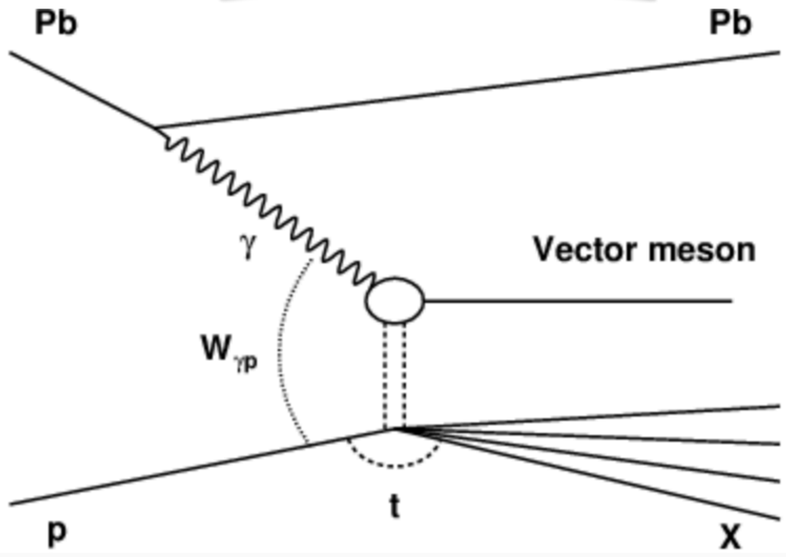
Phys.Lett. B798 (2019) 134926

$p_T > 0.2$ GeV/c

Incoherent

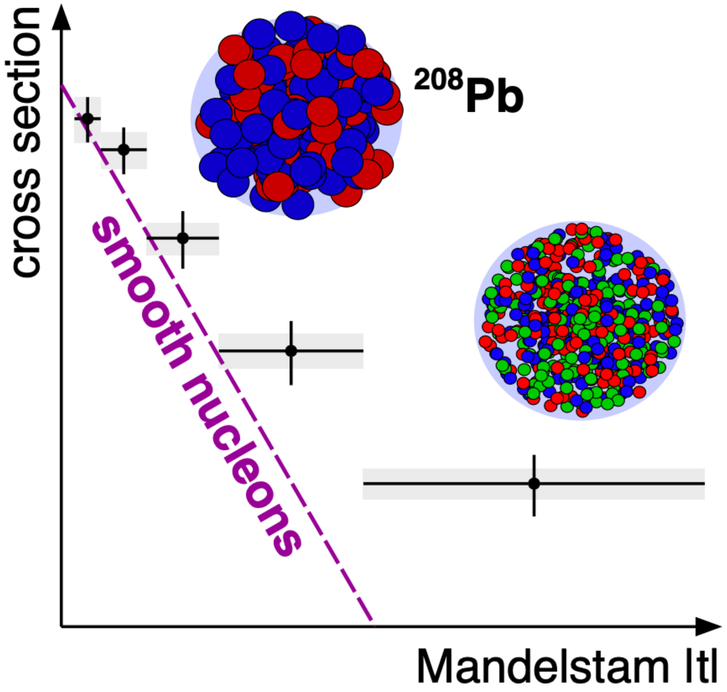


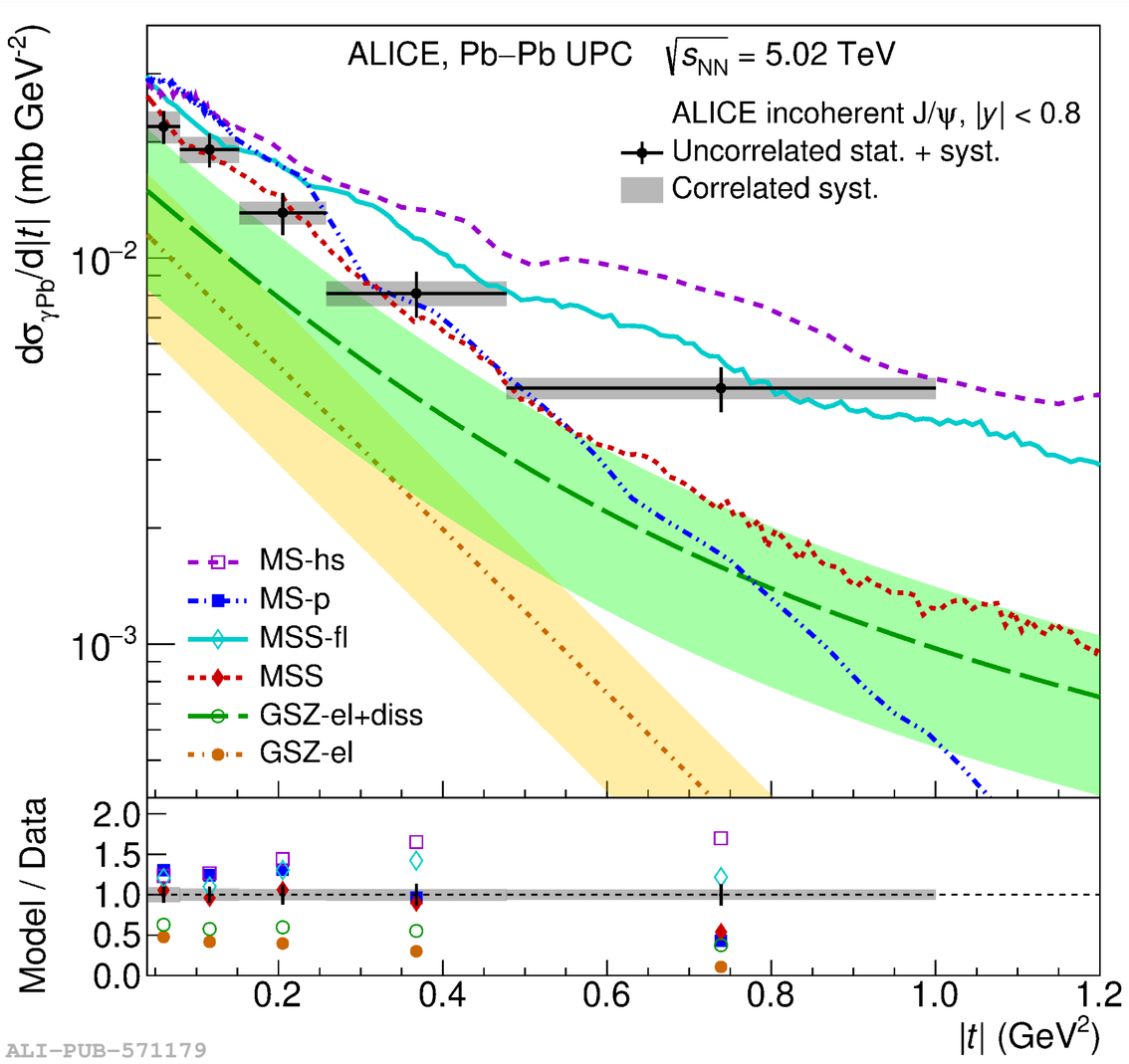
Dissociative process



|t| dependence of incoherent J/ψ measurement

Phys. Rev. Lett. 132, 162302 (2024)

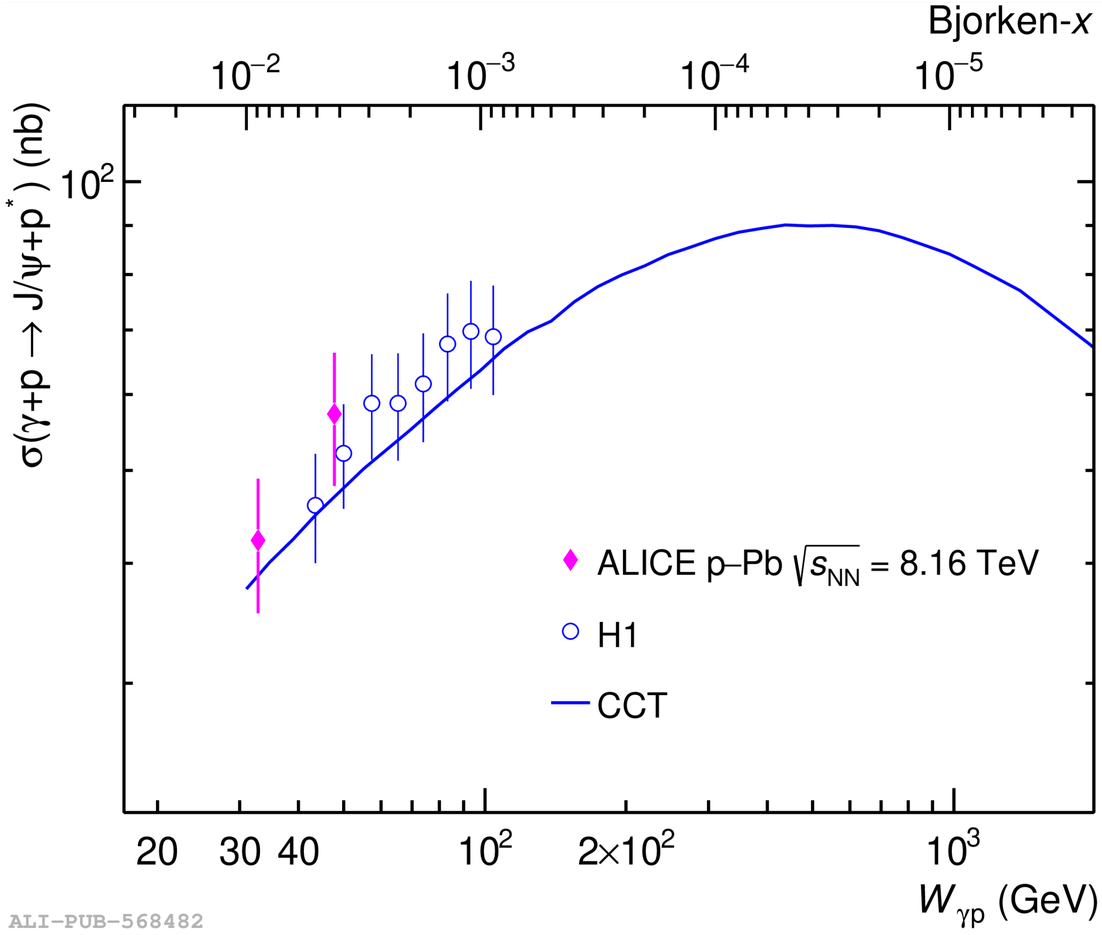




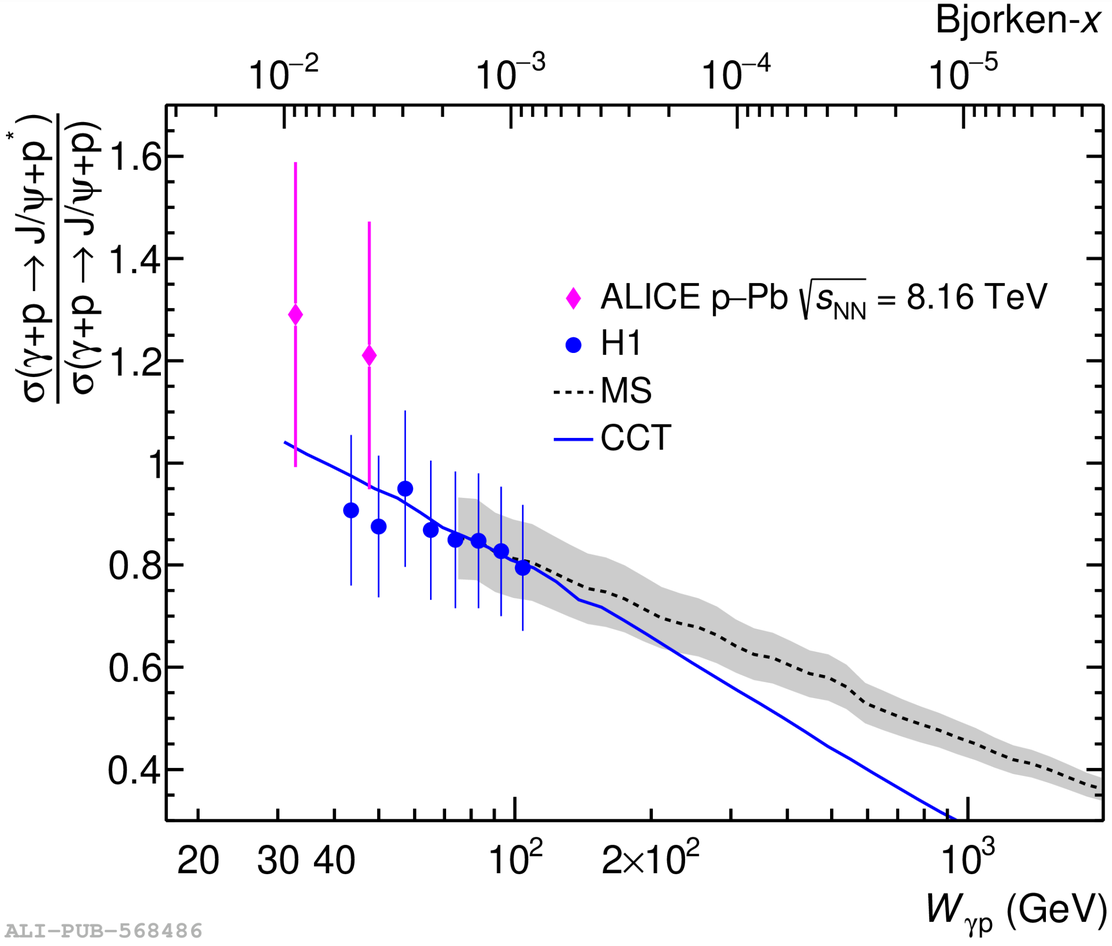
- ☑ Variance -> Quantum fluctuation (incoherent)
- ☑ Models that include quantum fluctuations of the gluon density describe the data better than the models without
- ☑ No model describes data fully (normalisation proton to nuclear target)
- ☑ Slope is sensitive to the spatial gluon fluctuation
- ☑ Probing gluonic “hot spot” in Pb for the first time!

Energy dependence of dissociative J/ψ measurement

Phys. Rev. D 108, 112004 (2023)



ALI-PUB-568482



ALI-PUB-568486

- ☑ First measurement at collider energies
- ☑ ALICE results consistent with H1 data
- ☑ Data is in good agreement with CCT “hot spot” model which predicts maximum cross section at 500 GeV
- ☑ Probe to measure subnucleonic fluctuation inside proton

The ALICE experiment in Run 3

FT0-A : $3.8 < \eta < 5.0$

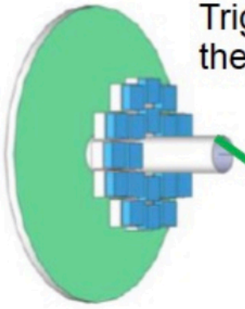
FT0-C : $-3.4 < \eta < -2.3$

FV0 : $2.2 < \eta < 5.0$

FDD-A : $4.7 < \eta < 6.3$

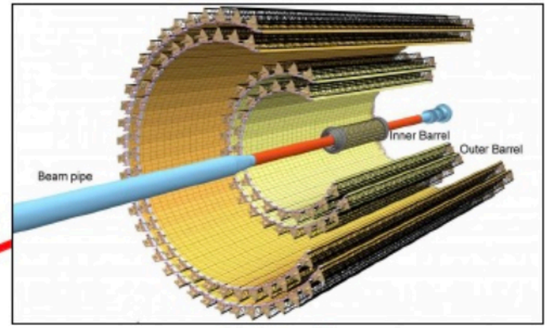
FDD-C : $-6.9 < \eta < -4.9$

New Forward Interaction Trigger (FIT) to replace the V0 and T0 detectors
and also AD



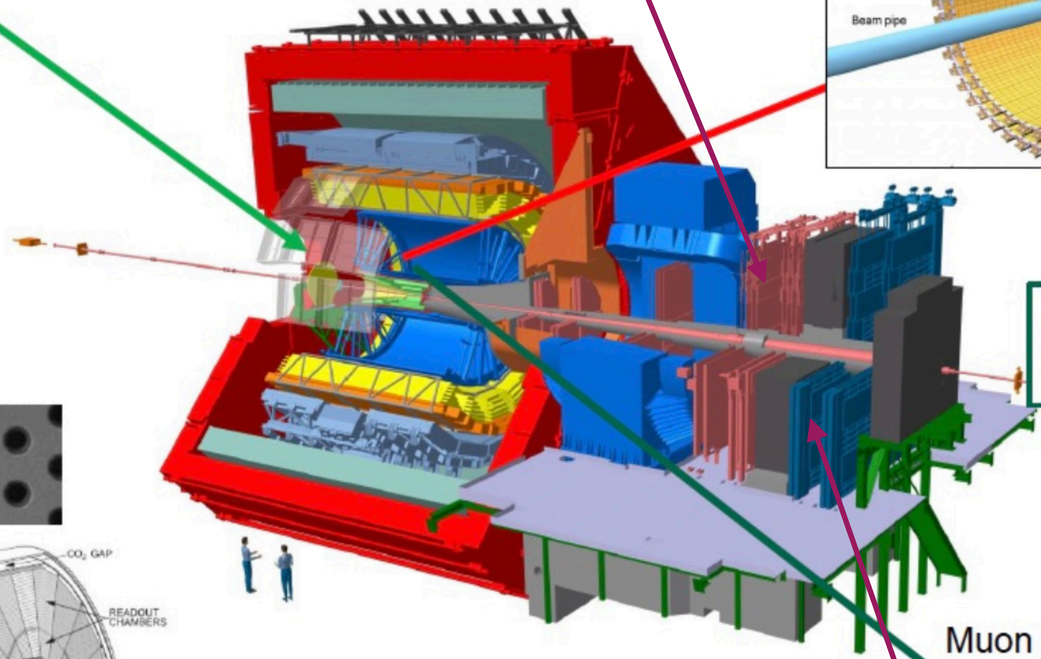
MCH
Muon Trackers

New Inner Tracking System (ITS)



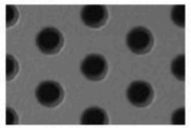
ZDC
Zero Degree Calorimeter

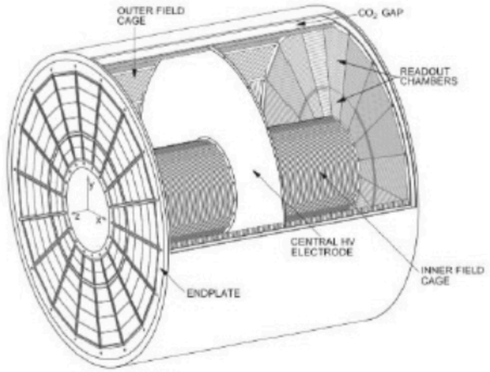
$ZDC : 4.8 < \eta < 5.7$



Both based on Monolithic Active Pixel Sensors (MAPS)

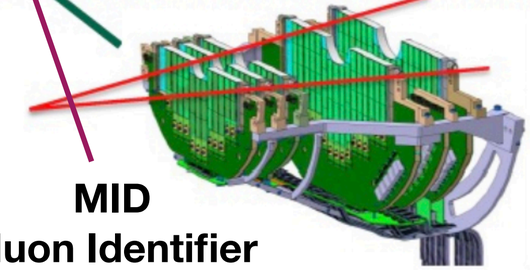
TPC with GEM based readout





ZDC
Zero Degree Calorimeter

Muon Forward Tracker (MFT)



$ITS : -1.22 < \eta < 1.22$

$TPC : -0.9 < \eta < 0.9$

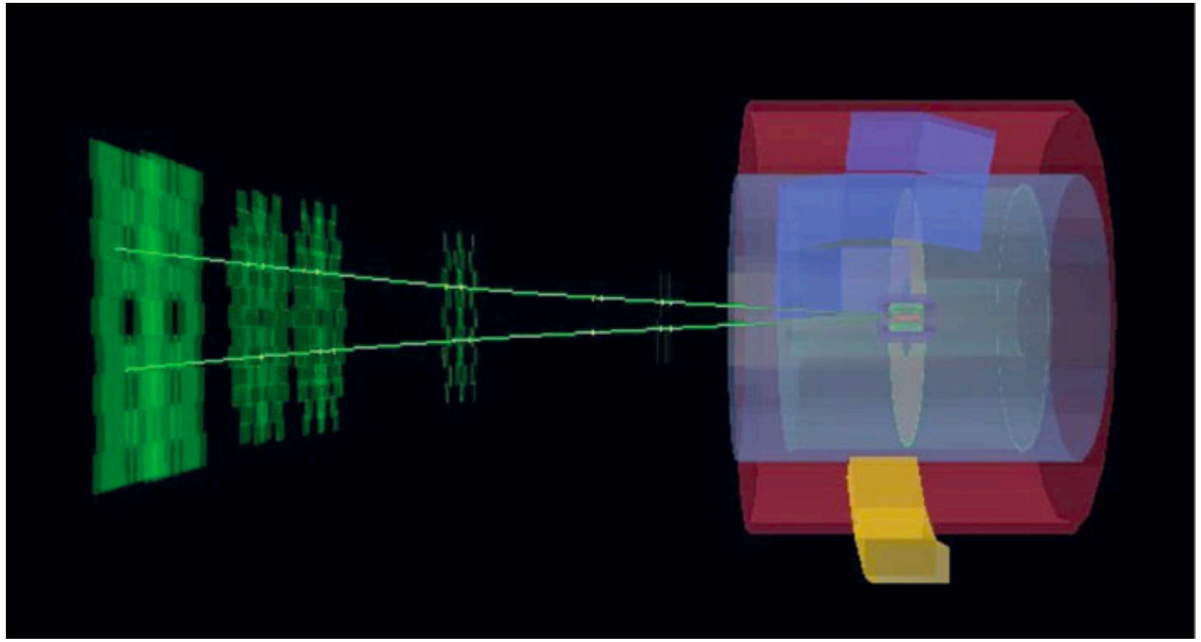
$MCH : -4.0 < \eta < -2.5$

$MFT : -3.6 < \eta < -2.5$

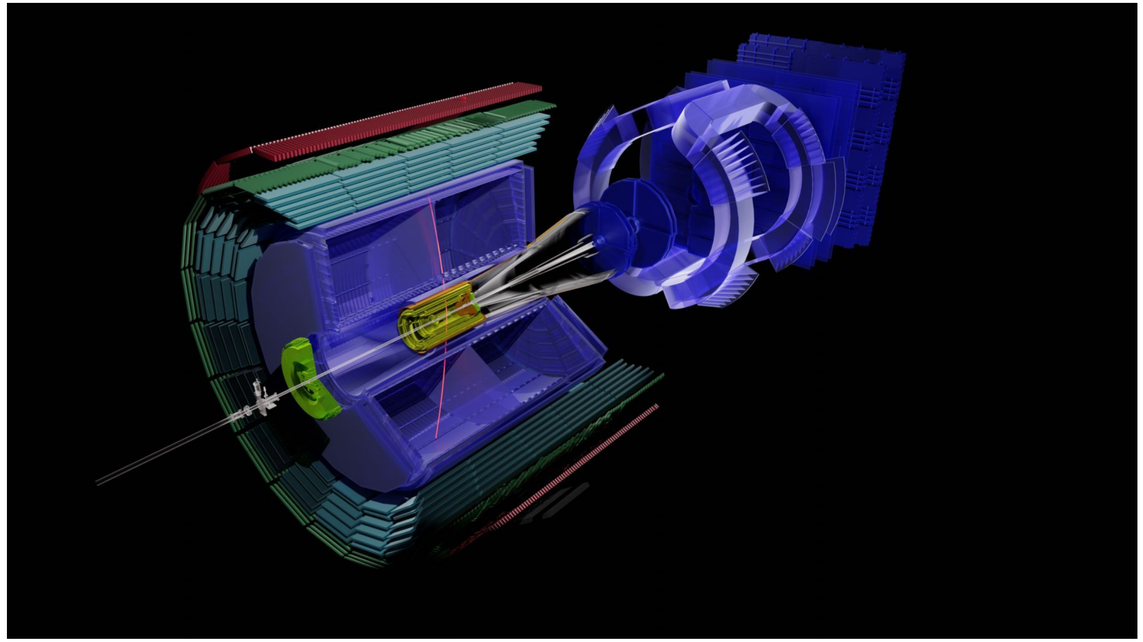
+ improved readout for TOF, ZDC, TRD, MUON ARM
+ new Central Trigger Processor
+ new DAQ/Offline architecture

MID
Muon Identifier

UPC event selection



RUN 2 UPC event

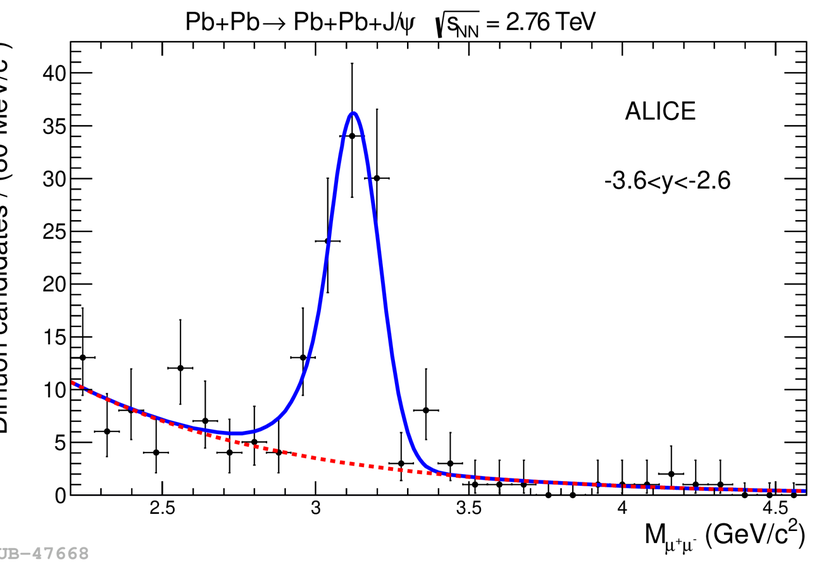


RUN 3 UPC event

- ☑ As in Run 2, to select a exclusive vector meson UPC event we require no signal in the FIT and further empty ZDCs
- ☑ Possible to veto signals in individual detectors in Run 3
- ☑ More flexibility, possible to select inclusive, semi-inclusive UPC events

Progress on UPCs at ALICE

Phys. Lett. B 718 (2013) 1273



Run 1 : ~ 80 events

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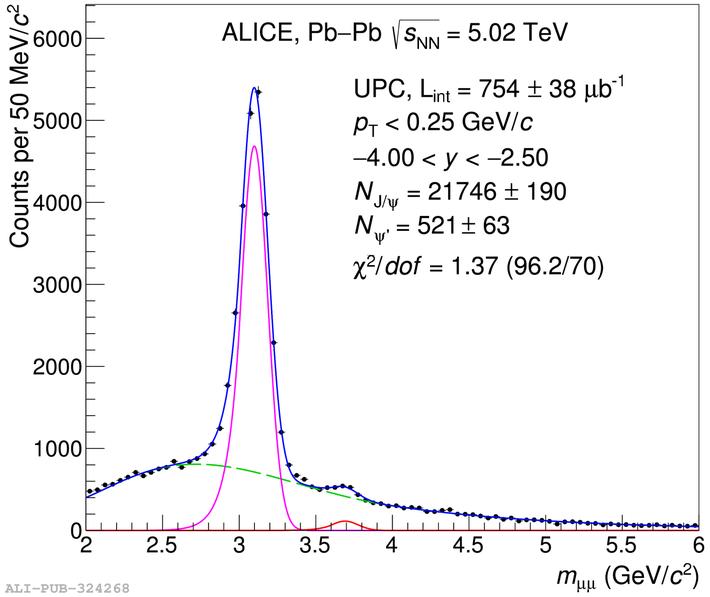
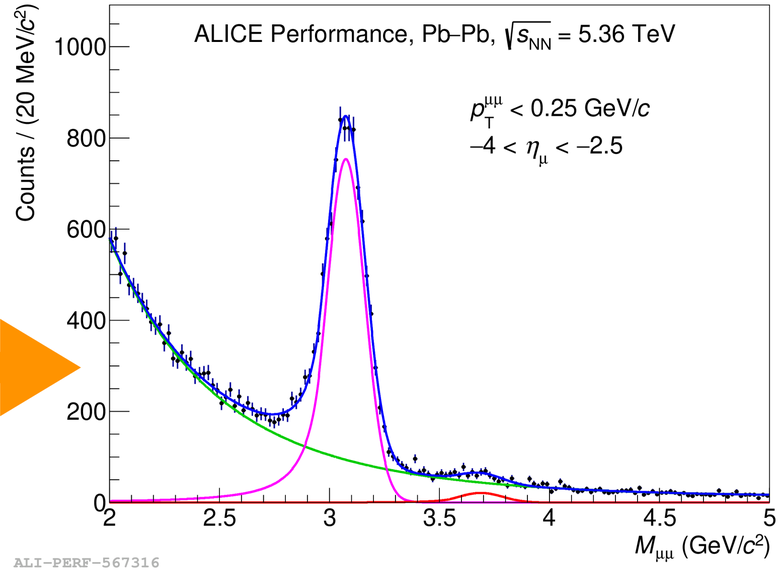


Run 2 : ~ 22k events



Run 3 : ~ 70k events

PbPb

Meson	σ	Central 1 Total	Forward 1 Total 1
$\rho \to \pi^+\pi^-$	5.2b	5.5 B	4.9 B
$\rho' \to \pi^+\pi^-\pi^+\pi^-$	730 mb	210 M	190 M
$\phi \to K^+K^-$	0.22b	82 M	15 M
$J/\psi \to \mu^+\mu^-$	1.0 mb	1.1 M	600 K
$\psi(2S) \to \mu^+\mu^-$	30μb	35 K	19 K
$\Upsilon(1S) \to \mu^+\mu^-$	2.0 μb	2.8 K	880

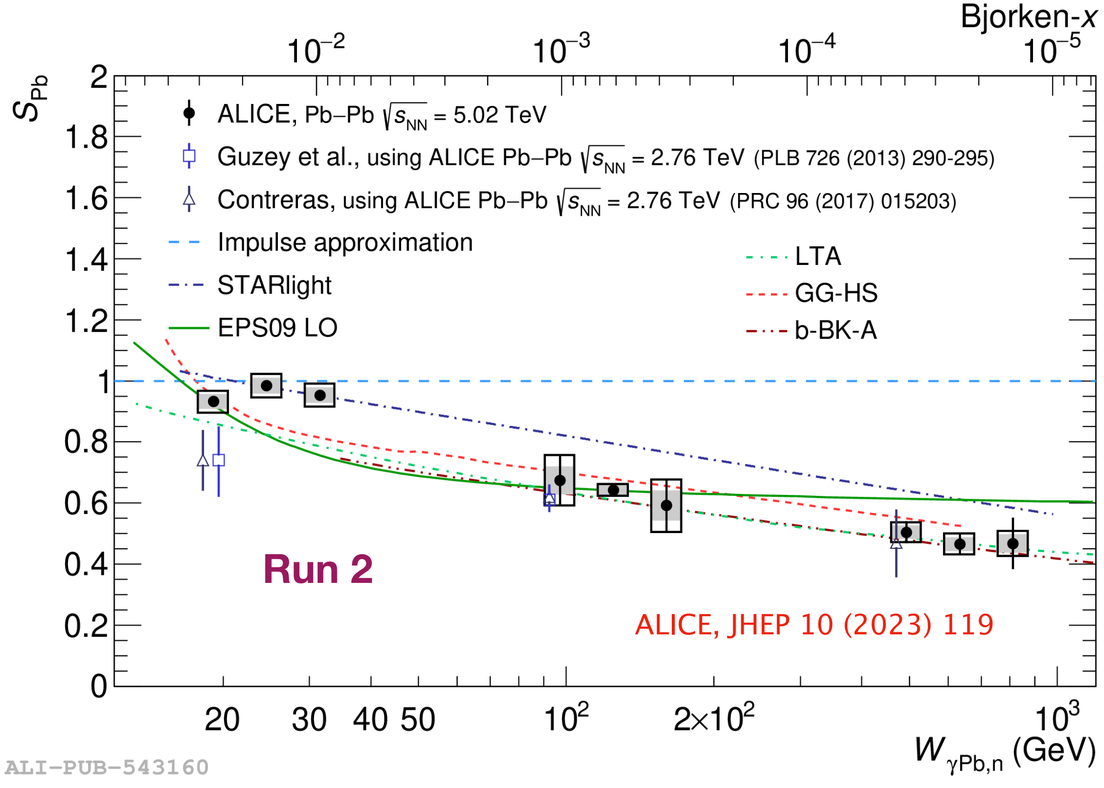
$|y| < 0.9$ $2.5 < y < 4$

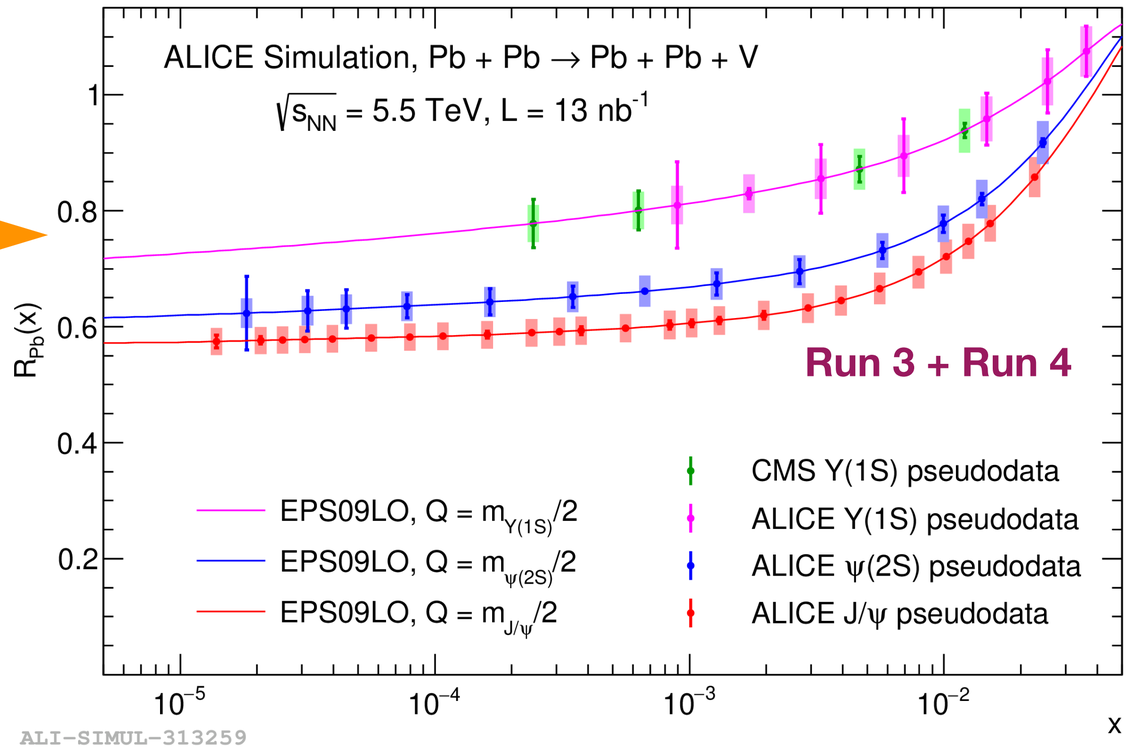
ALICE, JHEP 06 (2020) 035

Possible with continuous readout !
Significant increase in statistics in Run 3!
Integrated luminosity:
0.8 nb^{-1} (Run 2) -> 13 nb^{-1} (Run 3 + Run 4)

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

UPC physics prospects in Run 3 and beyond : Exclusive vector meson photoproduction

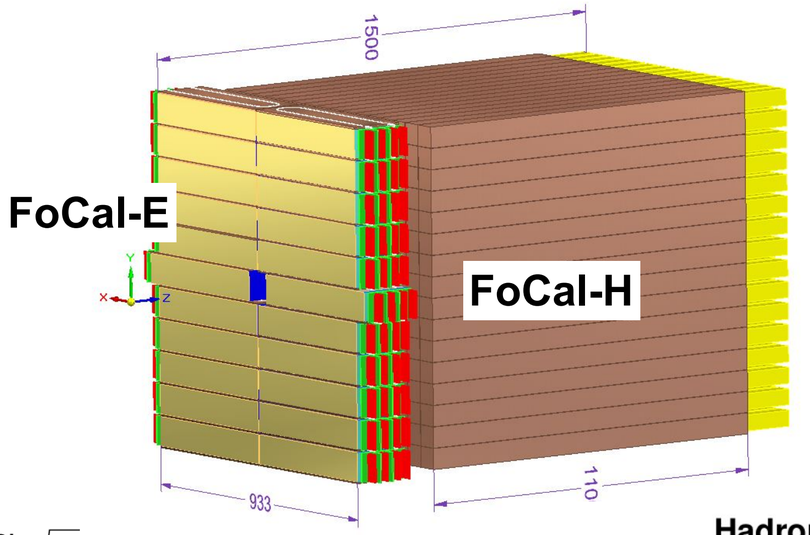




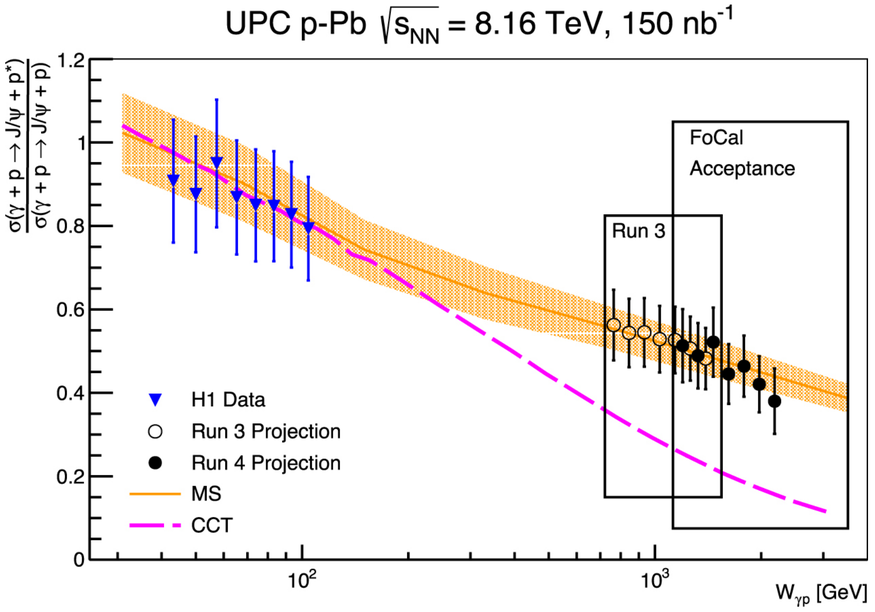
- ☑ Precision study of vector meson photoproduction in UPCs with significant increase in integrated luminosity
- ☑ Uncertainties for nuclear suppression factor are expected to be at the level of 4% [CERN Yellow Rep. Monogr. 7 (2019) 1159-1410].
- ☑ Possible new measurements e.g. double vector meson photoproduction
- ☑ UPC bottomonia production [arXiv:2303.03007v1]
- ☑ MFT in Run3 and FoCal in Run 4

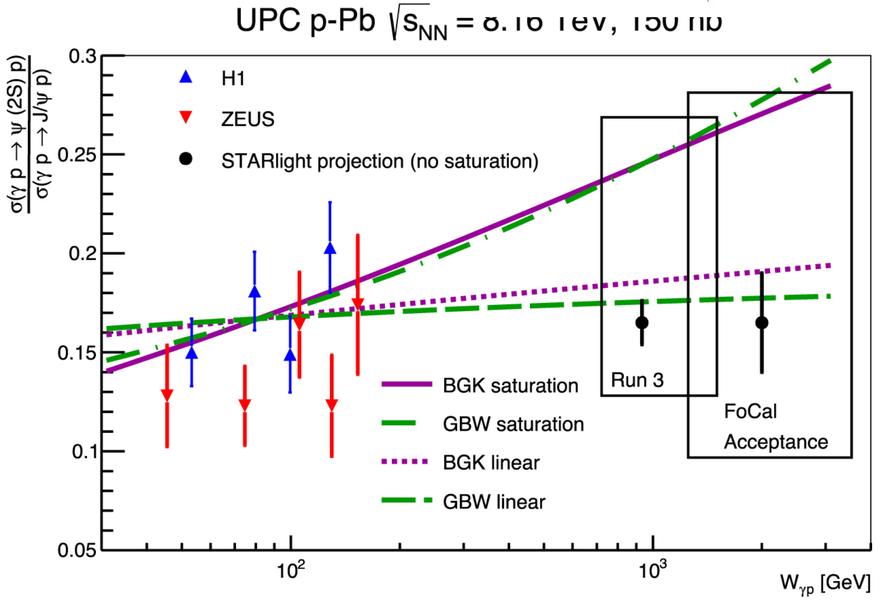
UPC Physics prospects in Run 3 and beyond : Exclusive vector meson photoproduction with FoCal

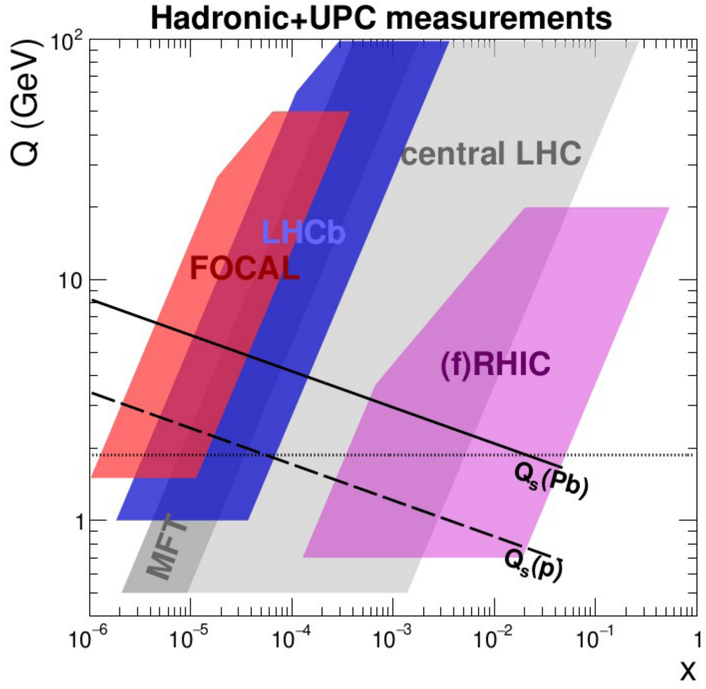
- ☑ **FoCal**: Part of ALICE upgrade for Run 4 (starting from 2029)
  Positioned 7 m from IP2 (A-side), covering $3.4 < \eta < 5.8$
- ☑ Dissociative J/ψ in Run 3 with FOCAL acceptance in Run 4
  [J. Phys. G: Nucl. Part. Phys. **50** 055105]
- ☑ Exclusive J/ψ and $\psi(2S)$ (+ Run 4 with Focal acceptance) in p-Pb UPCs [J. Phys. G: Nucl. Part. Phys. **50** 055105]



Run 4







[J. Phys. G: Nucl. Part. Phys. **50** 055105]

Conclusion and Outlook

- ☑ Important measurements by ALICE to probe some **QCD effects** at high energy via coherent, exclusive and dissociative J/ψ production
- ☑ Shed light into **gluon shadowing, gluon saturation** and **subnucleonic fluctuations** by comparing with theoretical models
- ☑ Exciting time for UPCs in Run 3 and Run 4
- ☑ New data taken in Run 3 and 4 will allow **precision measurements**, new measurements such as **Inclusive J/ψ in UPCs**
- ☑ Stay tuned!

Other recent ALICE results……..

- Overview of the latest ALICE UPC and photonuclear results by Simone Ragoni
- Pion and kaon pair production in double gap events in ALICE Run 3 by Rainer Martin Schicker
- Jet and jet substructure: ALICE results by Haidar Masud Alfanda
- Recent Diffraction studies with ALICE by Ernesto Calvo Villar

Grazie!