Recent ALICE Results on UPCs

Alexander Bylinkin

On behalf of the ALICE Collaboration

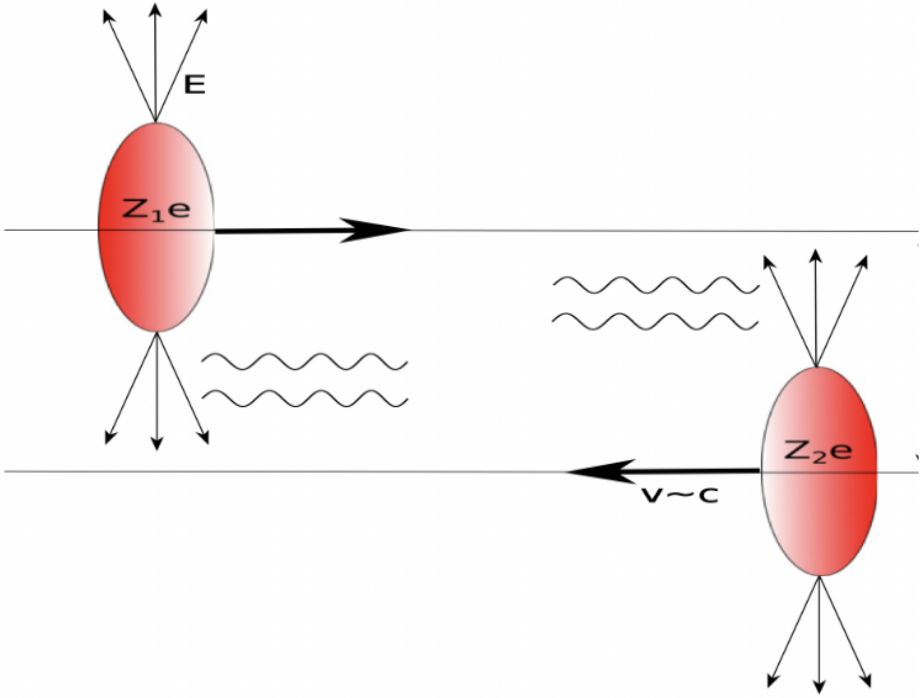
Diffraction and Low-x Workshop, 24-29th September 2022
Corigliano Calabro, Italy

Outline

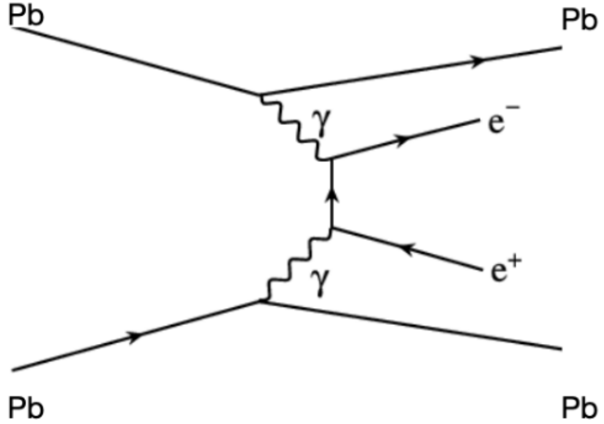
- Motivation
- ALICE Detector
- Vector meson photoproduction in pPb UPCs
- Photo-nuclear reactions in PbPb UPCs
- Vector meson production XeXe UPCs
- Prospects for Run 3 & 4 measurements
- Summary

Photon induced processes in heavy ion collisions

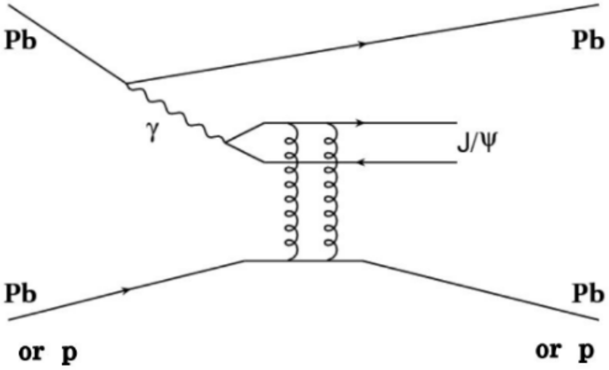
- Nuclei "miss" each other (b > 2R)
- Electromagnetic interaction dominates over strong
- Photon flux grows with the square of the charge, Z^2



Dilepton production

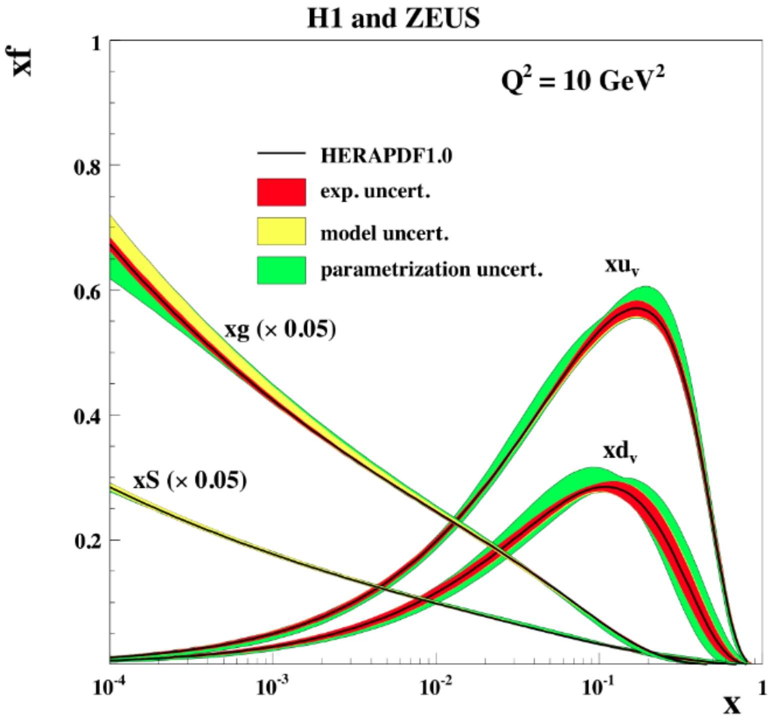


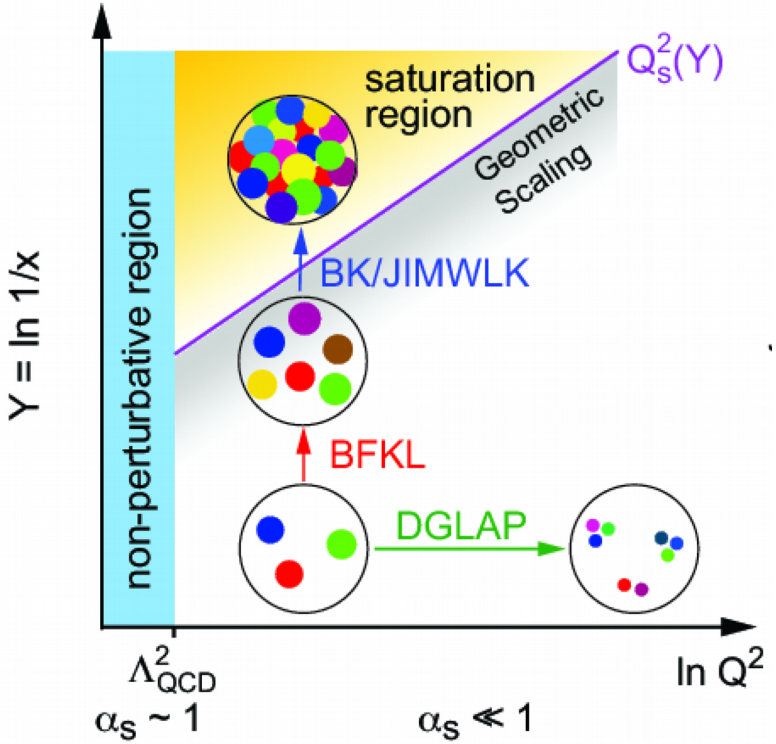
Vector meson production



Probes of nuclei in UPC

- UPCs at LHC: the most energetic photon-nuclei interactions
- Low-x physics and search for the nonlinear parton dynamics (saturation regime)





Exclusive vector meson photoproduction

- Photoproduction is sensitive to the gluon density at LO

$$\frac{d\sigma_{\gamma p,A\rightarrow V p,A}}{dt}\Big|_{t=0} = \frac{\alpha_s^2 \Gamma_{ee}}{3\alpha M_V^5} 16\pi^3 [xG(x,Q^2)]^2$$

$$\sigma_{\gamma p\rightarrow VMp} = \frac{1}{b}\frac{d\sigma_{\gamma p,A\rightarrow VM\, p,A}}{dt}\Big|_{t=0}$$

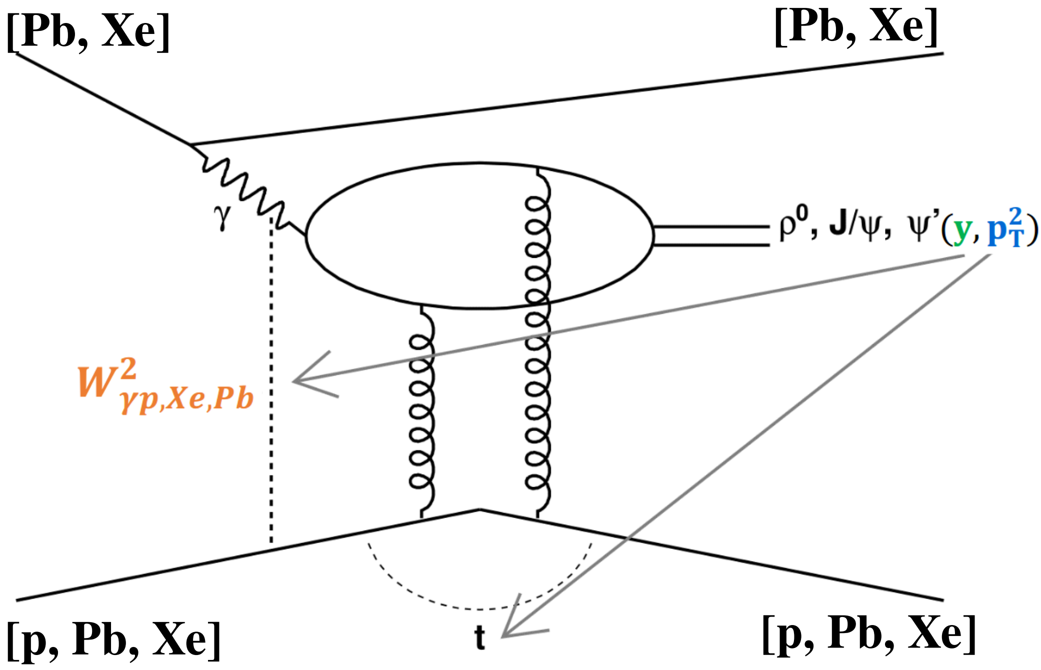
- Energy of the γp collision

$$W_{\gamma p}^2 = 2\cdot E_p \cdot M_{VM}\cdot \exp(-y)$$

E_p – proton beam energy

M_{VM} – mass of the vector meson

y – rapidity of the vector meson



- Probe gluon distributions in the proton at low-x

$$x = (M_{VM}/W_{\gamma p})^2$$

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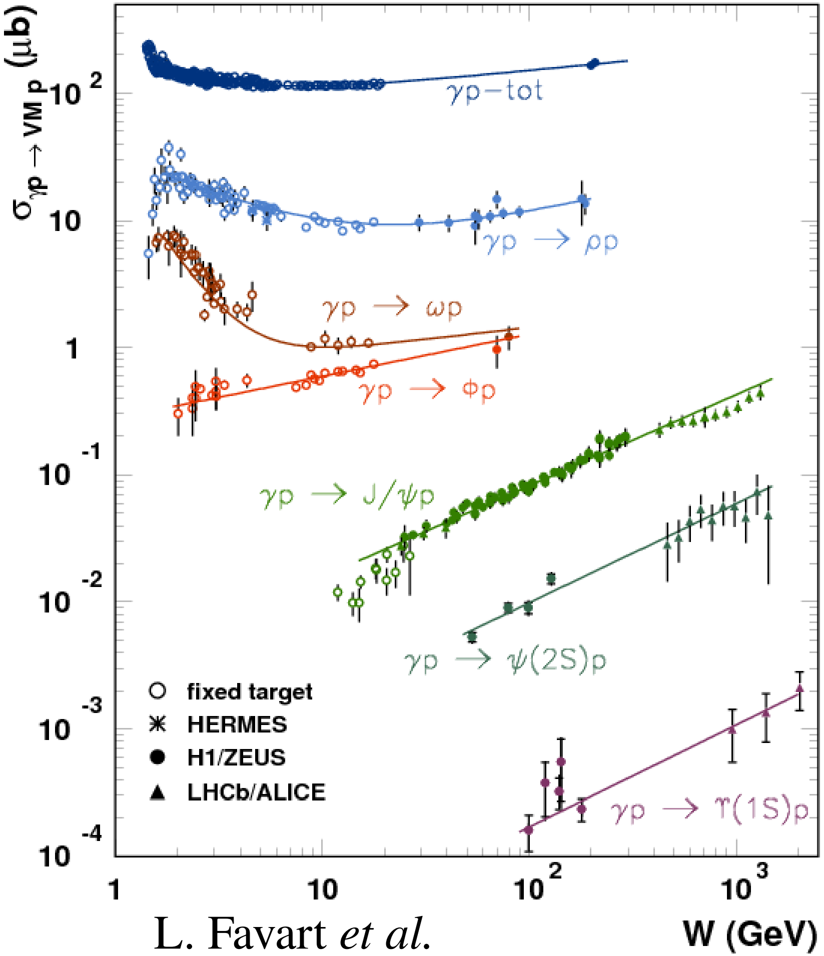
- Probe gluon distributions in the proton at low-x

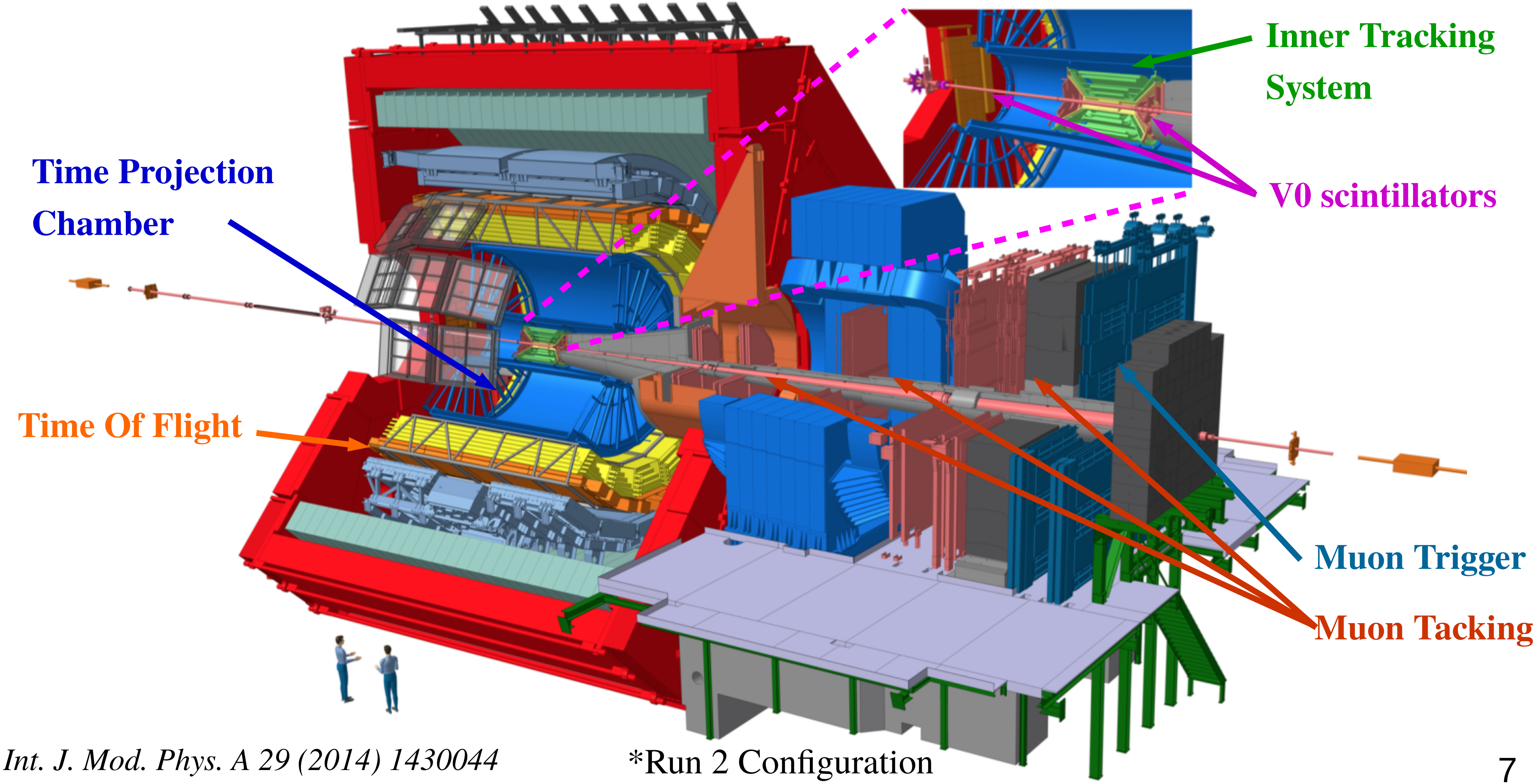
$x = (M_{VM}/W_{\gamma p})^2$

- Photonuclear cross section shows power law dependence with $W_{\gamma p}$ $\sigma \propto W_{\gamma p}^{\delta}$



L. Favart *et al.*
Eur. Phys. J. A **52** (2016) 158

ALICE (A Large Ion Collider Experiment)



Int. J. Mod. Phys. A 29 (2014) 1430044

*Run 2 Configuration

ALICE Detector: J/ψ at mid-rapidity

Time Projection Chamber (TPC)

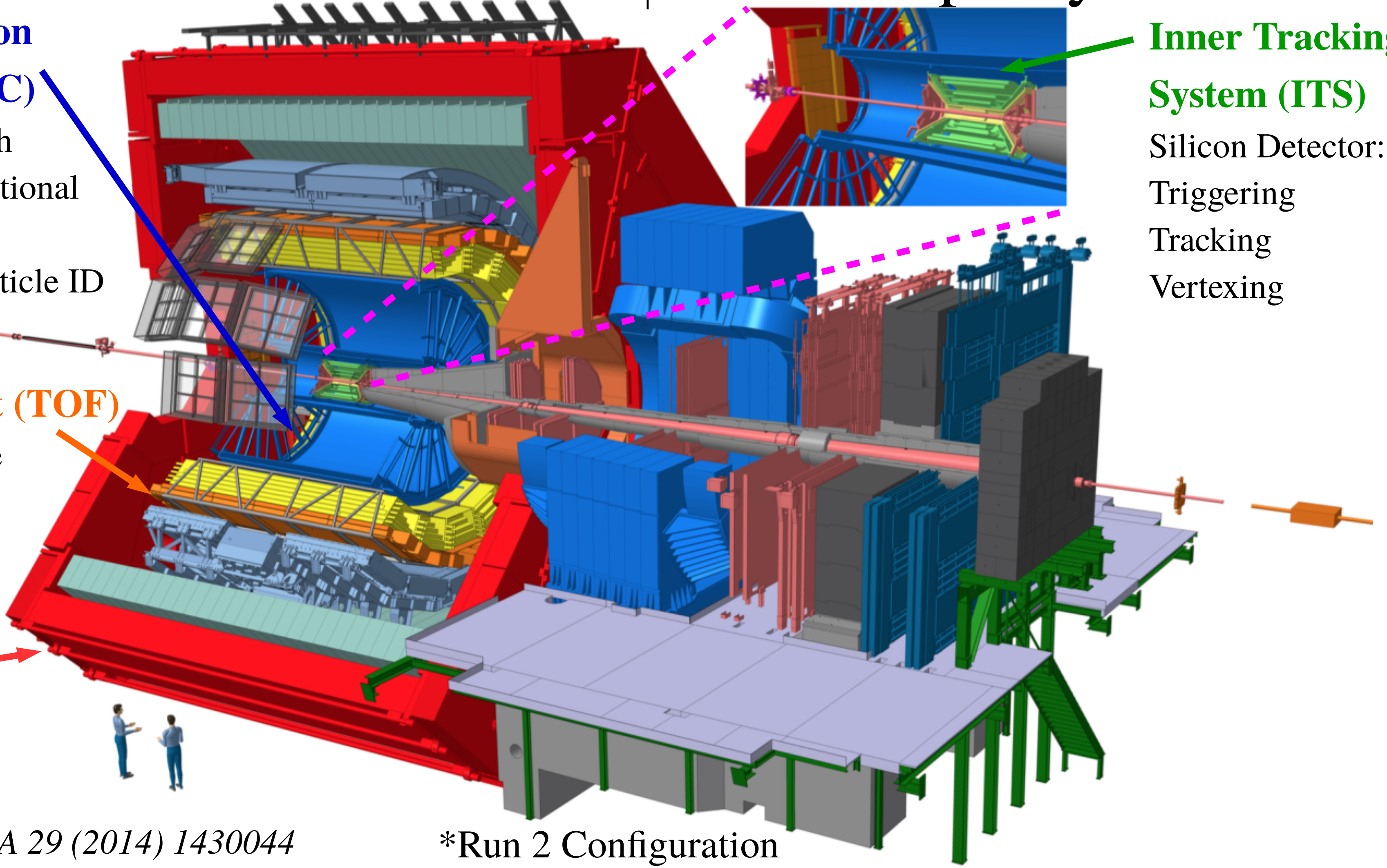
Drift volume with multiwire proportional chambers:
Tracking and Particle ID

Time Of Flight (TOF)

Multigap resistive plate chambers:
Triggering and Particle ID

L3 Magnet

B = 0.5 or 0.2 T



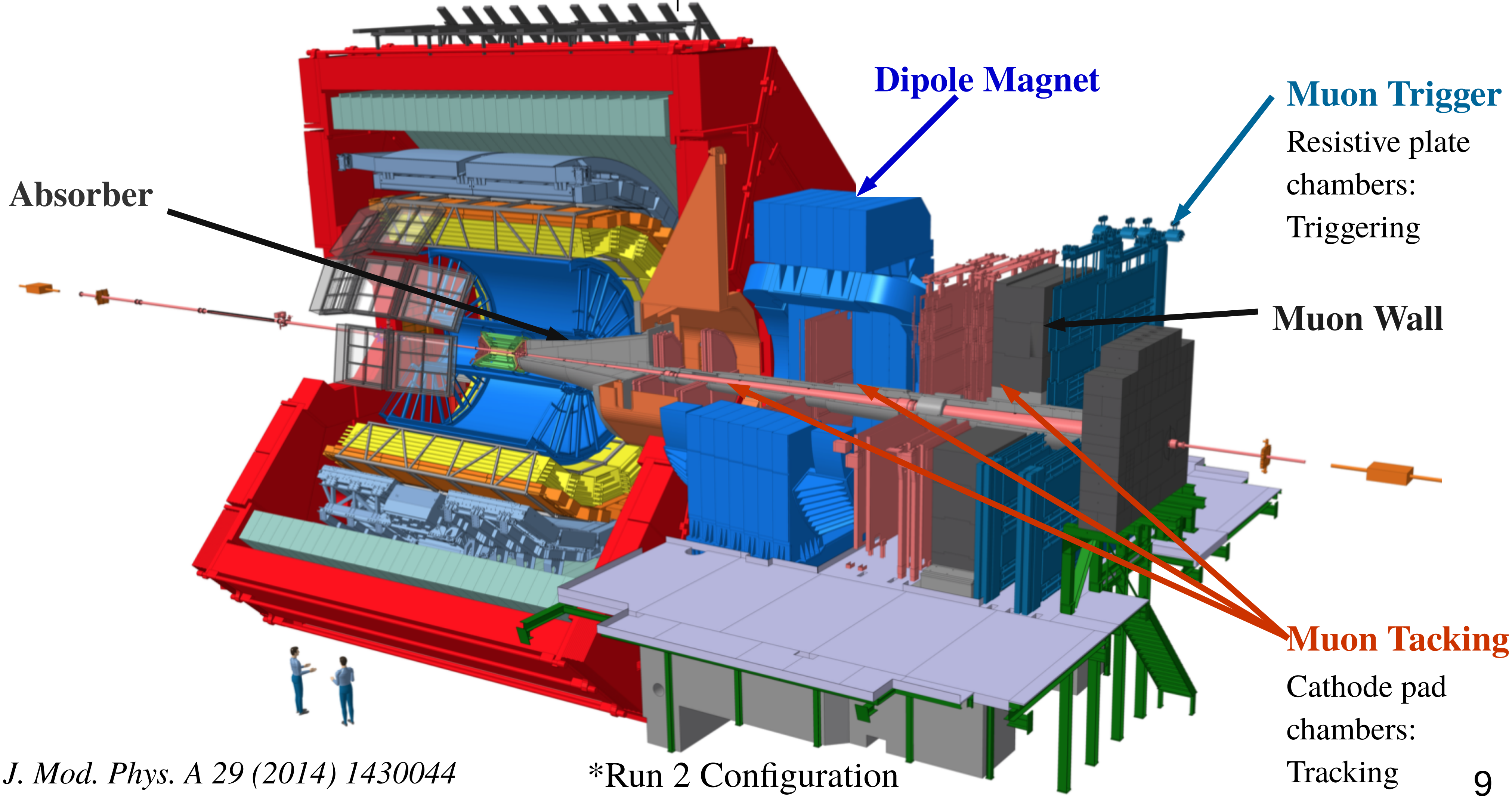
Inner Tracking System (ITS)

Silicon Detector:
Triggering
Tracking
Vertexing

Int. J. Mod. Phys. A 29 (2014) 1430044

*Run 2 Configuration

ALICE Detector: J/ψ at forward rapidity



Int. J. Mod. Phys. A 29 (2014) 1430044

*Run 2 Configuration

ALICE Detector: exclusivity condition

Zero Degree Calorimeter (ZDC)

Sampling Calorimeters:

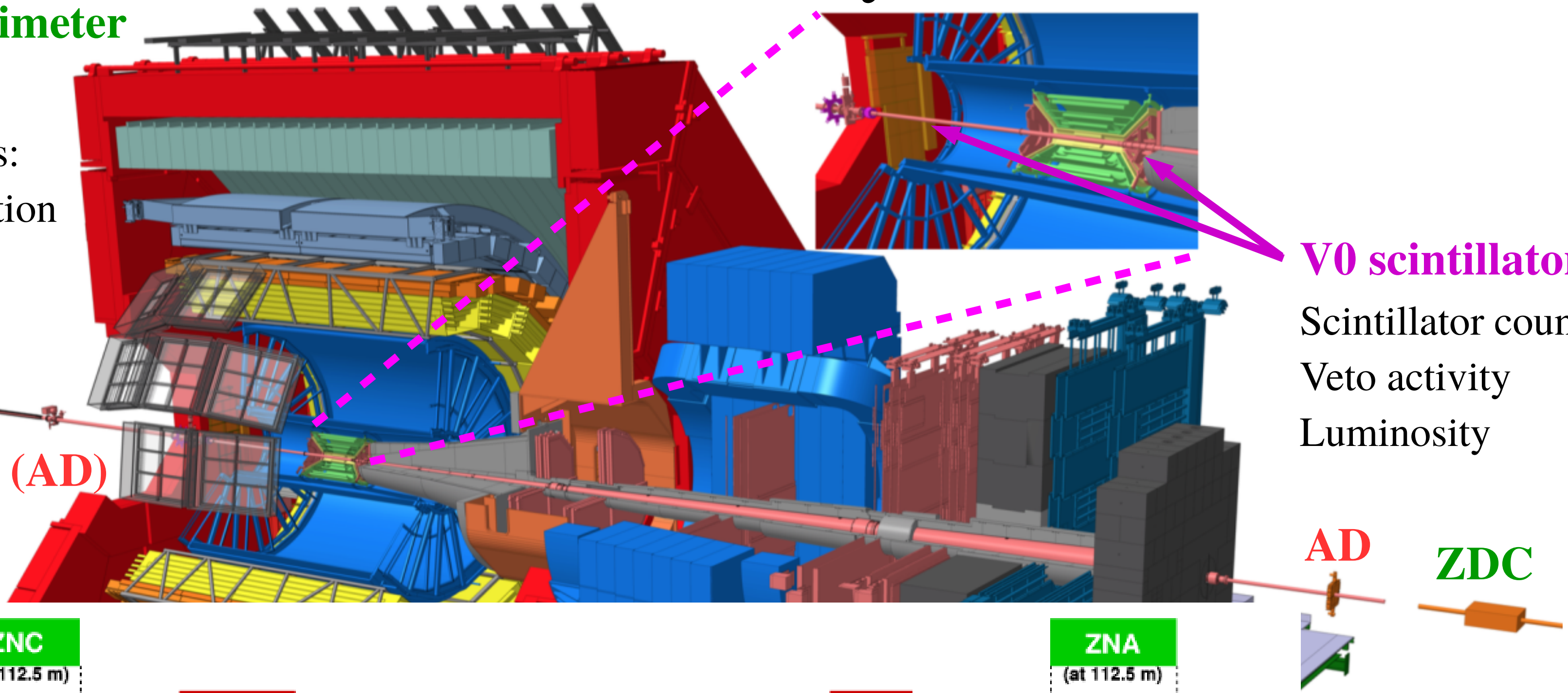
Luminosity determination

Neutron detection

ALICE Diffractive (AD)

Scintillator counter:

Veto Activity

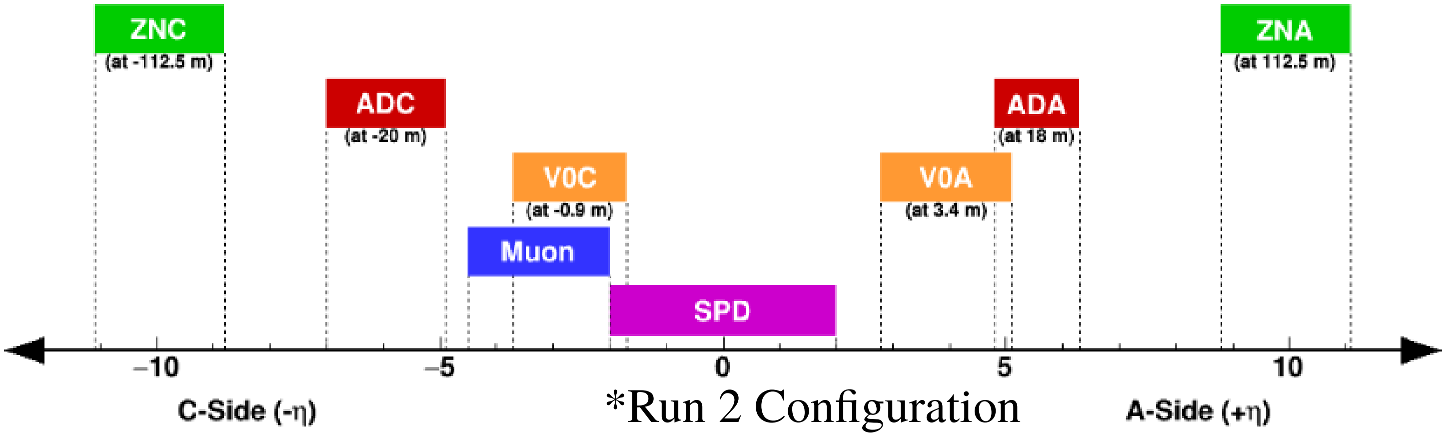


V0 scintillators

Scintillator counter:

Veto activity

Luminosity



*Run 2 Configuration

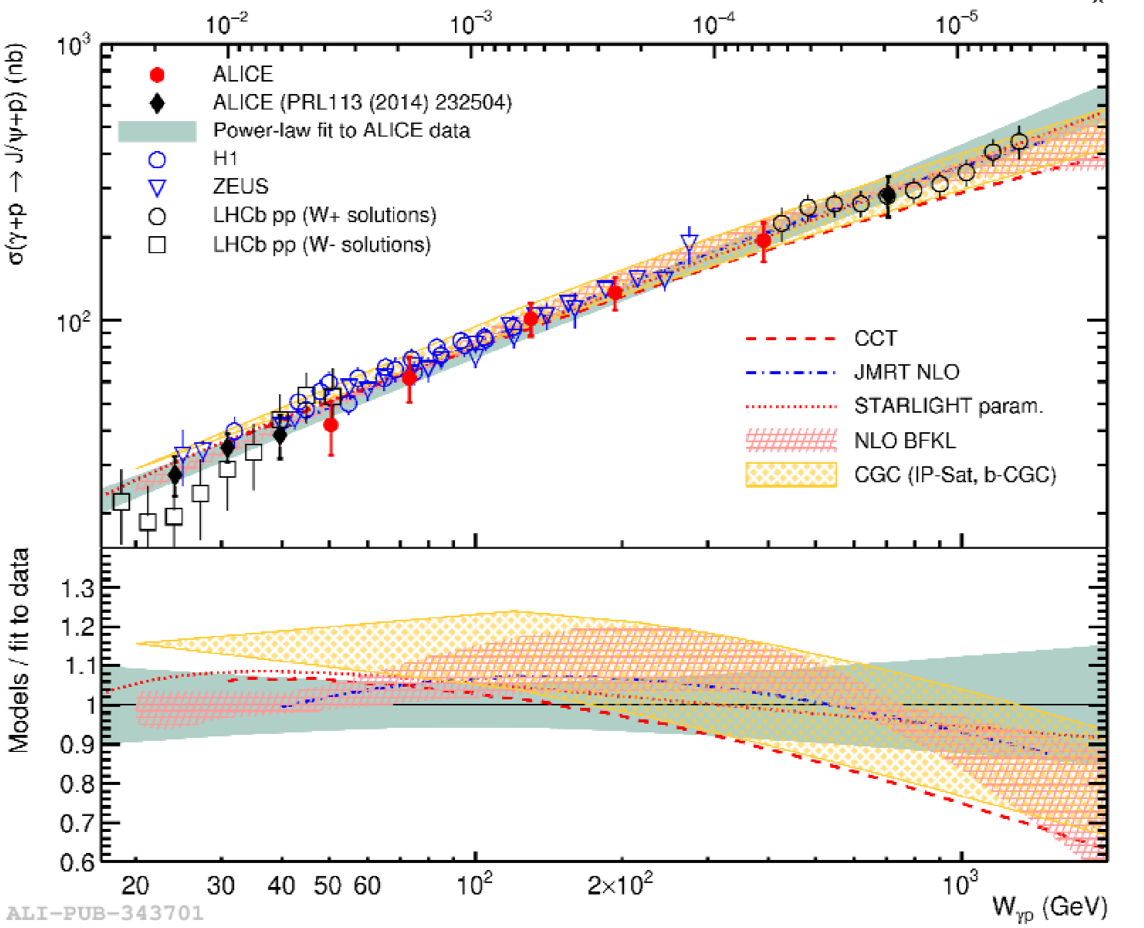
J/ψ photoproduction in pPb UPC

The cross section of J/ψ photoproduction as a function of photon-proton c.m.s. energy allows the comparison with other experiments at HERA and LHC.

Exclusive J/ψ cross section: energy dependence

- In pPb UPCs the photon flux from the Pb-nucleus dominates
  → access to γp interactions
- Power law fit to ALICE data
  Exponent: δ = 0.70 ±0.04
- The same trend as observed at HERA and LHCb

Eur.Phys.J.C 79 (2019) 5, 402

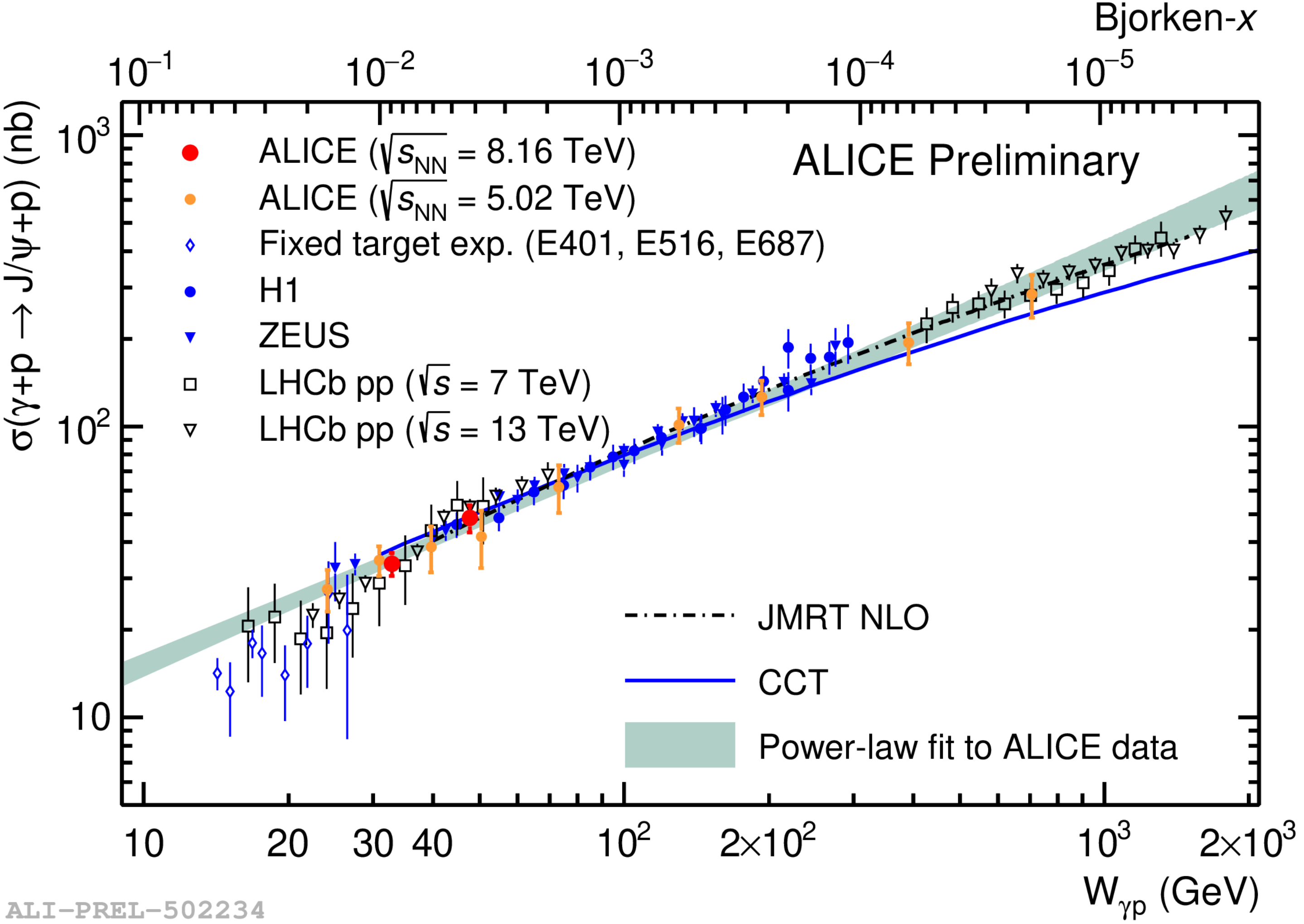


- Agreement with models:
  - JMRT NLO: DGLAP formalism with main NLO contributions
  - CCT: Saturation in an energy dependent hot spot model
  - NLO BFKL: BFKL evolution of HERA values (HERA Fit 2) with a photoproduction scale
  - CGC: colour dipole model

Exclusive J/ψ cross section: energy dependence

New preliminary results with **Run 2** data

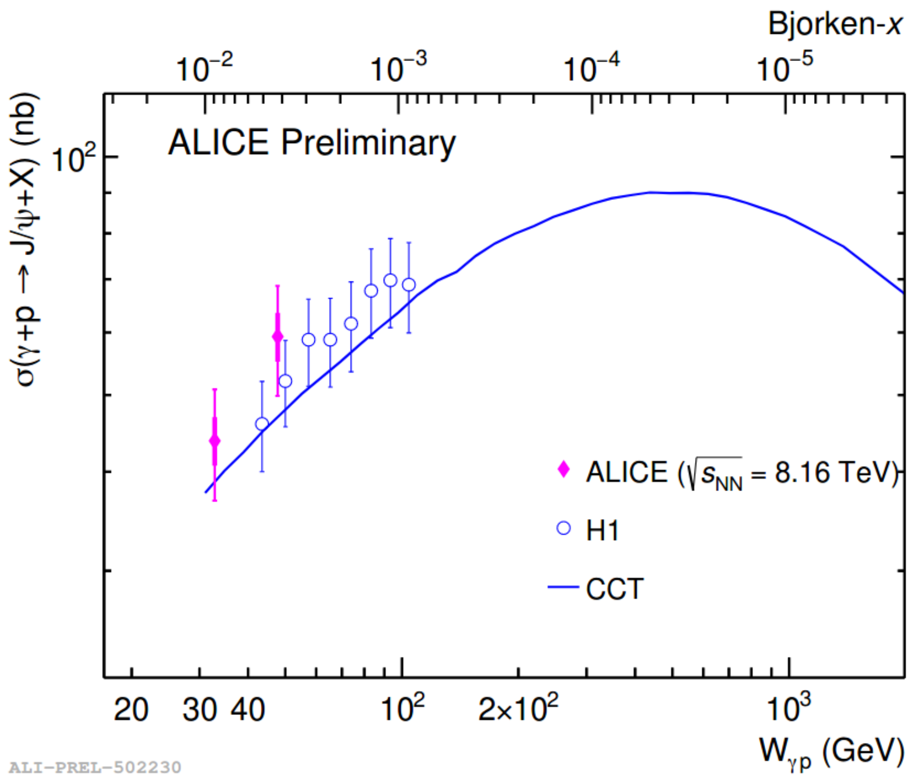
Good agreement with previous measurements

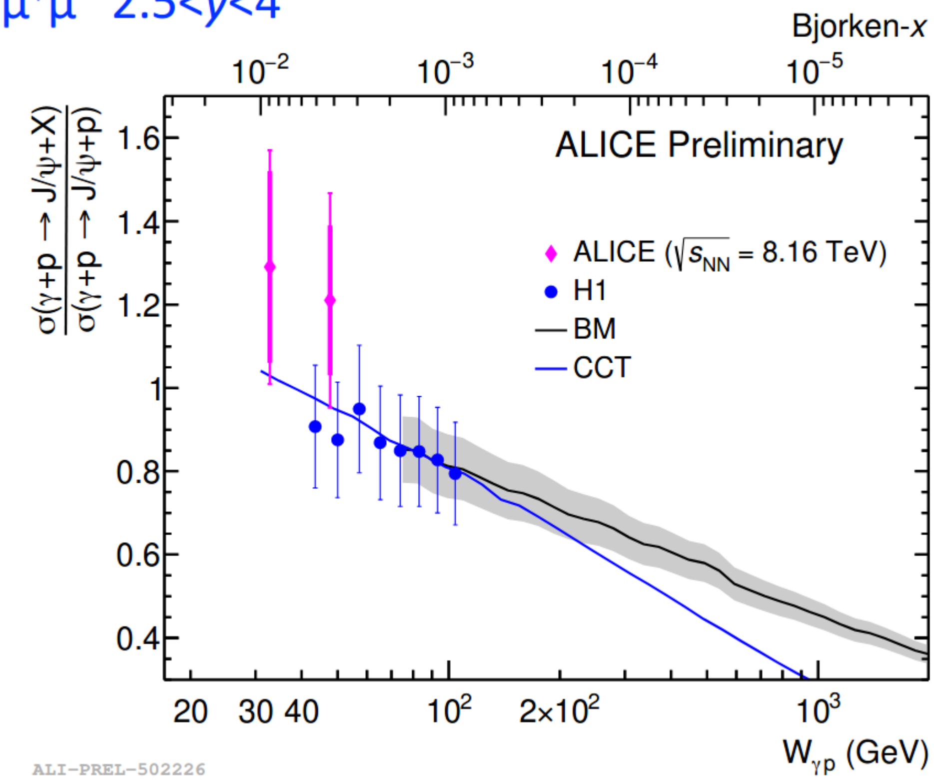


Dissociative J/ψ cross section: energy dependence

First measurement of the dissociative cross section (with the proton break up) at the LHC!

$J/\psi \rightarrow \mu^+\mu^-$ $2.5<y<4$



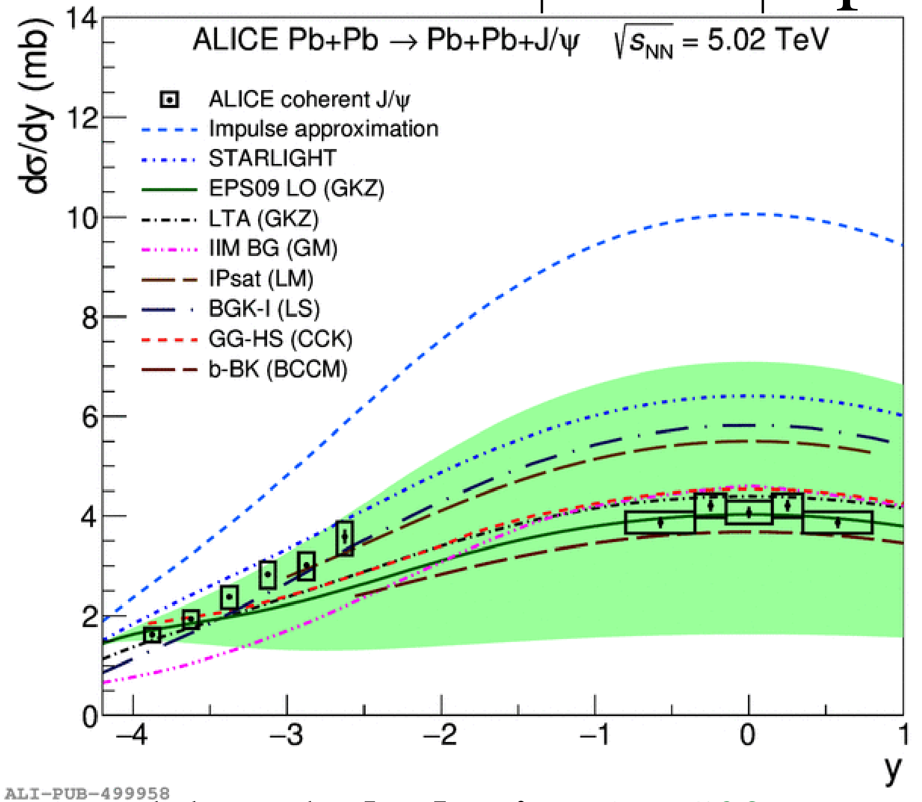


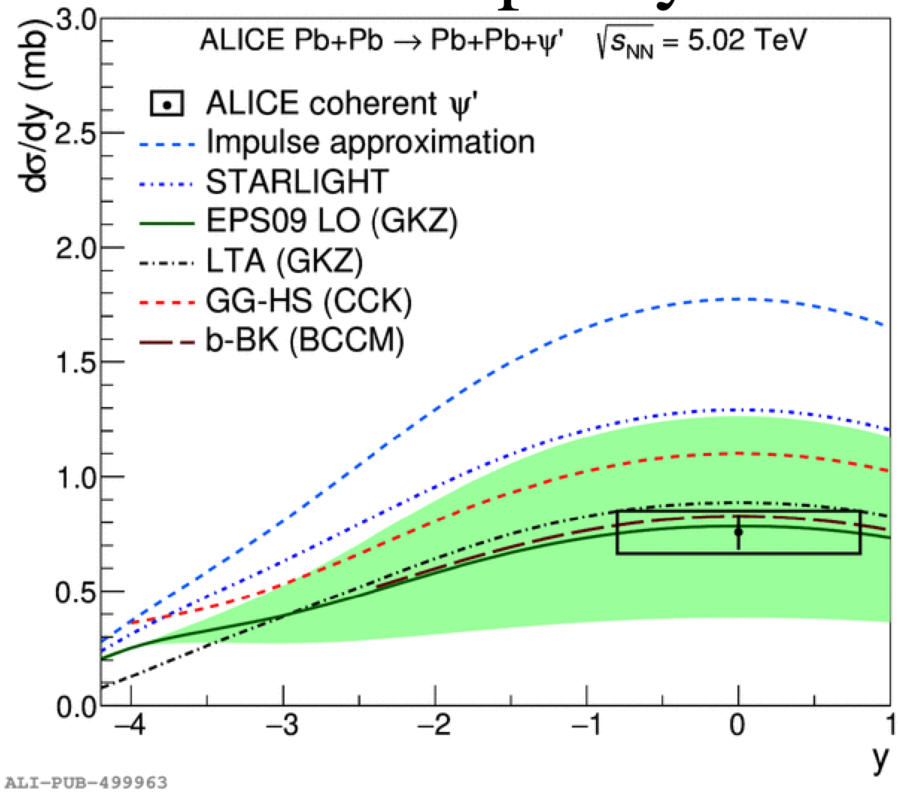
- Compatible with HERA measurements
- Well described by CCT, *J. Cepila, J. G. Contreras and J. D. Tapia Takaki Phys.Lett. B766 (2017) 186*

Probes of nuclei in UPC: J/ψ and ψ' in PbPb UPC

The cross section of coherent J/ψ and ψ' photoproduction as a function of rapidity or |t| can probe the nuclear shadowing and saturation effects.

Coherent J/ψ and ψ' photoproduction vs rapidity





Eur.Phys.J.C 81 (2021) 8, 712

- Models with **shadowing** (*EPS09*, ***L****eading* ***T****wist* ***A****pproximation*) and **saturation** (***G****lauber*-***G****ribov* ***H****ot* ***S****pot*):

→ Describe only central and most forward data

- *EPS09* and ***LTA*** **–** agree with the data
- GG-HS – overpredicts
- Balitsky-Kovchegov (b-BK) - agrees

Coherent J/ψ and ψ' photoproduction vs rapidity

- Nuclear suppression factor (exctracted from the central region data):

$$S_{Pb} = \sqrt{\left(\frac{d\sigma}{dy}\right)_{data} \Big/ \left(\frac{d\sigma}{dy}\right)_{IA}}$$

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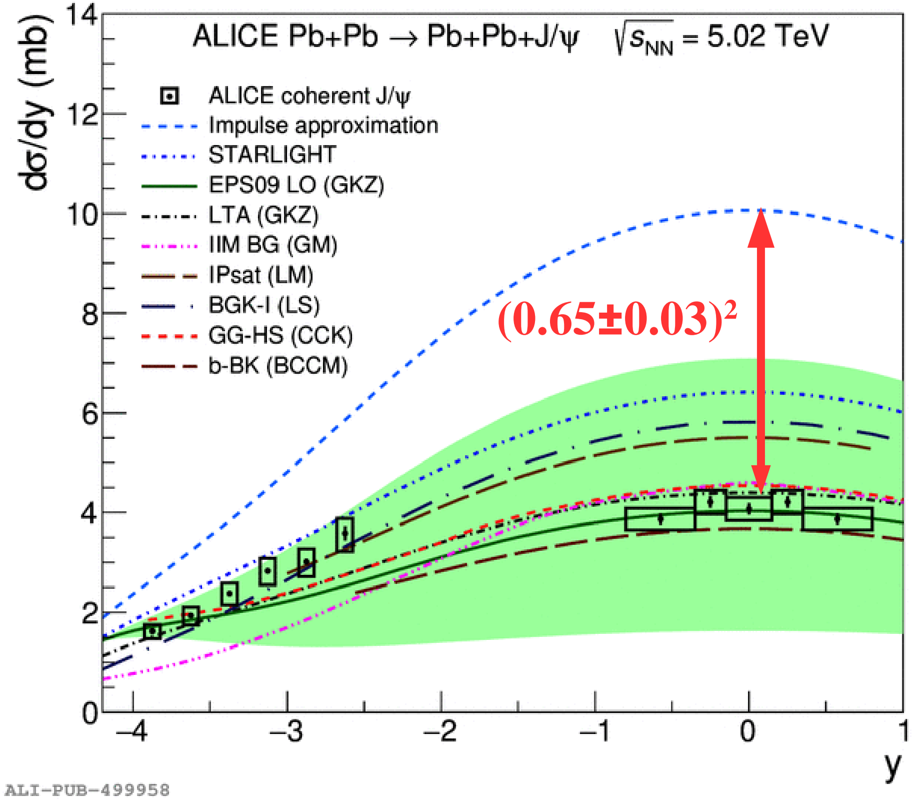
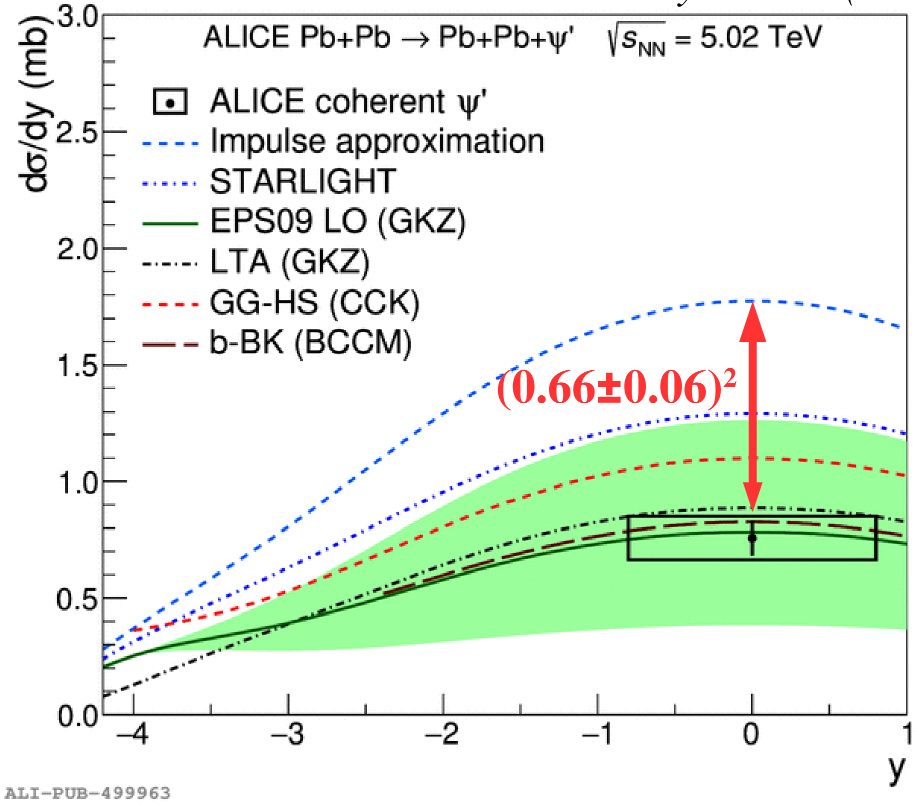
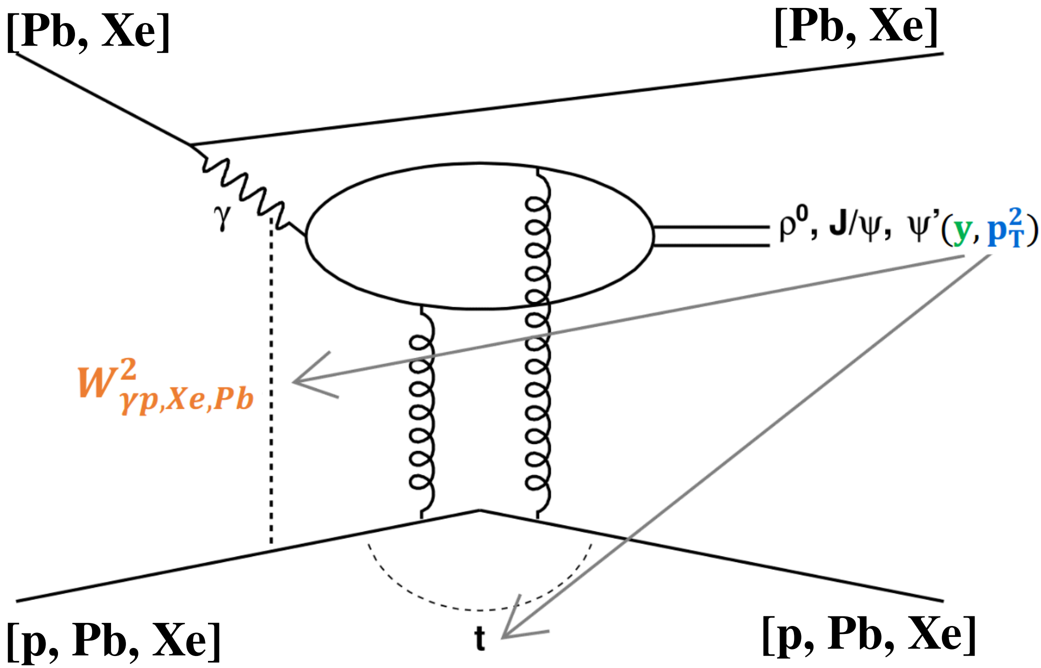




The same for J/ψ and ψ': corresponds to the central value for EPS09

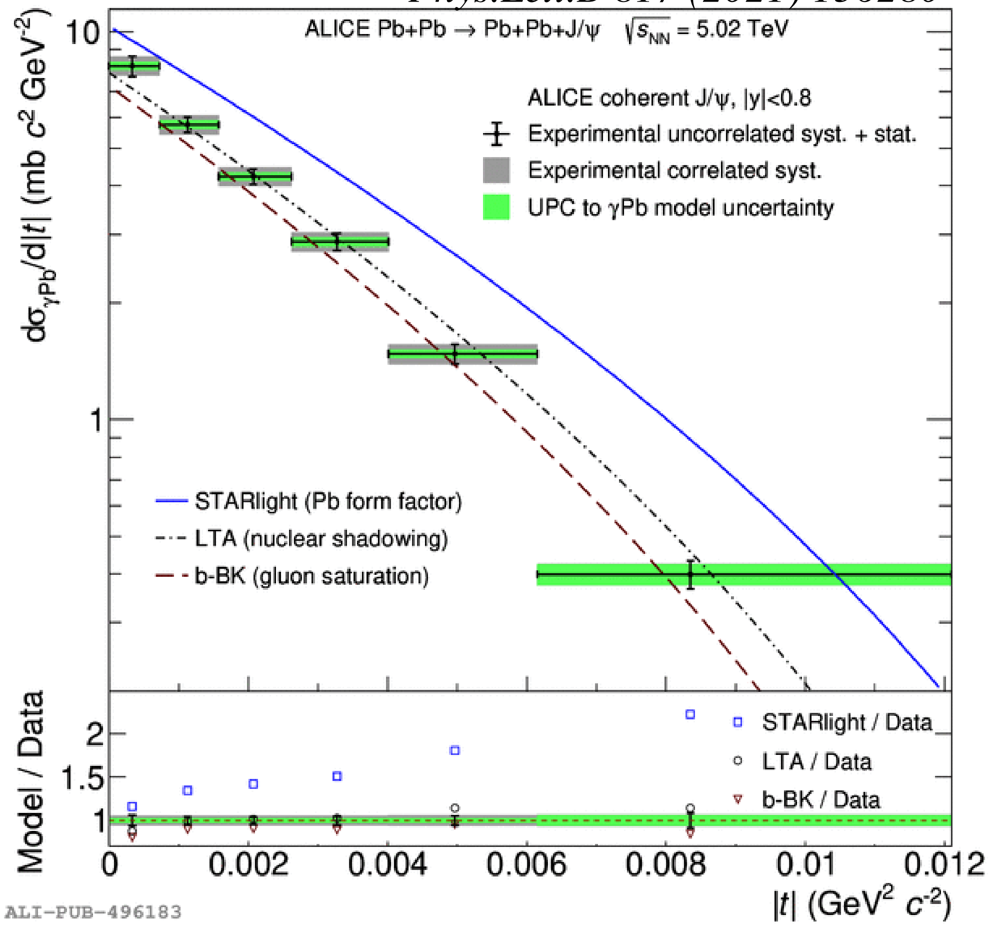
|t| dependence of exclusive J/ψ

- The Fourier transform of the |t| ~ p_T^2 spectra gives the distribution of interaction sites within the nucleus



|t| dependence of exclusive J/ψ

Phys.Lett.B 817 (2021) 136280



Photon flux used to calculate the photonuclear cross sections from the UPCs

$$\left.\frac{d^2\sigma^{coh}_{J/\psi}}{dy\,dp_T^2}\right|_{y=0} = 2n_{\gamma Pb}(y=0)\frac{d\sigma_{\gamma Pb}}{d|t|}$$

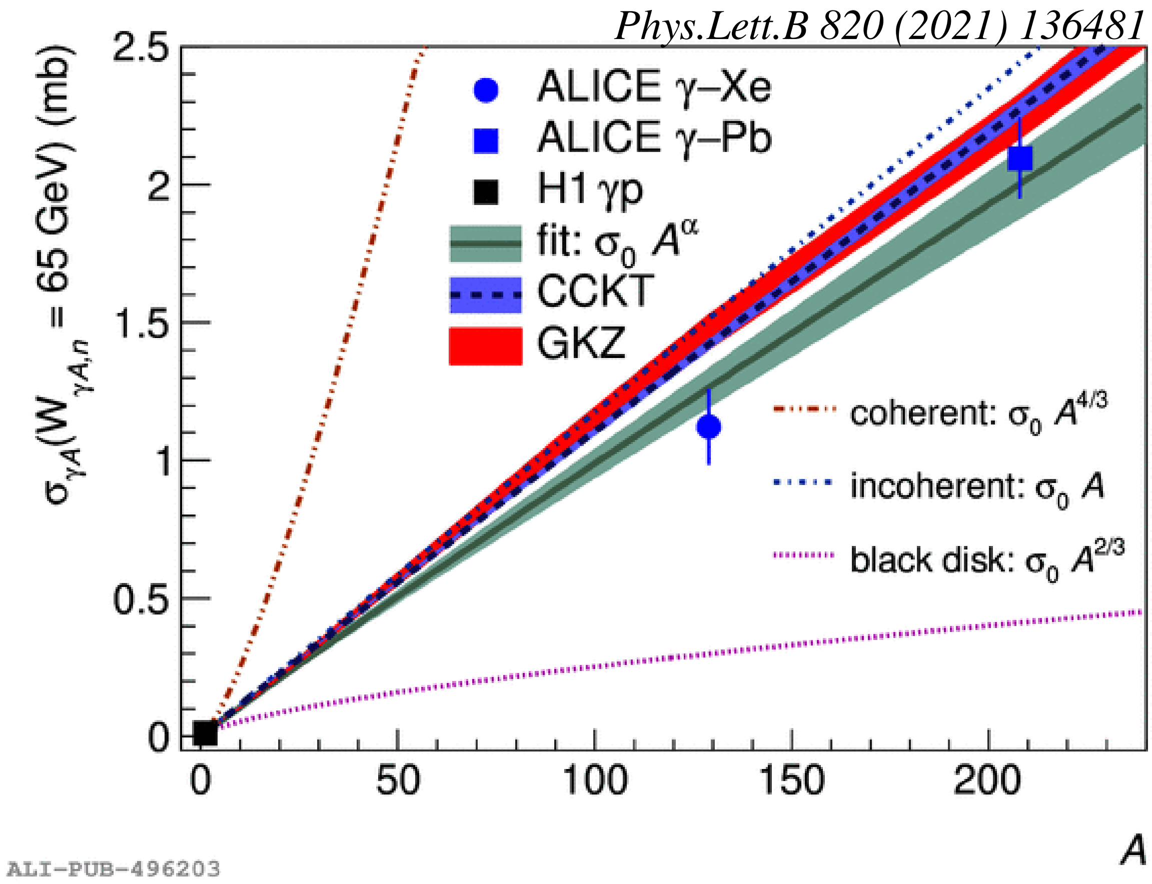
Cross section below Pb nuclear form factor model (**STARlight**) and closer to the shape predicted by shadowing (**LTA**) or saturation (**b-BK**) models.

Future measurements will allow to distinguish between these predictions.

Coherent ρ^0 photoproduction in XeXe UPC

Comparison between PbPb and XeXe UPCs allows to study the A-dependence

Coherent ρ^0 photoproduction: A-dependence



- Power-law fit: α=0.96±0.02
- Below coherent ↔ Shadowing effect
- Value close to incoherent is a coincidence caused by large shadowing effect
- Black-disc limit distant at $W_{\gamma A}$ = 65 GeV

- Models agree with the data:
- GKZ - shadowing
- CCKT - saturation

Prospects for Run 3 and Run 4 measurements

Outlook: Run 3 & 4

- *L* increase – 1 nb-1 (Run 2) → 13 nb-1 (Runs 3+4)
- Continuous readout → higher data collection efficiency
- Siginificant detector upgrades
- Proposed O-O run → new system size

Meson, channel	$\sigma^{Pb\text{-}Pb}$	N^{Tot}	$N^{\|\eta\| < 0.9}$	$N^{-4 < \eta < -2.5}$
$\rho^0 \to \pi^+ \pi^-$	5.2 b	68×10^9	5.5×10^9	-
$\rho' \to \pi^+ \pi^- \pi^+ \pi^-$	730 mb	9.5×10^9	210×10^6	-
$\phi \to K^+ K^-$	0.22 b	2.9×10^9	82×10^6	-
$J/\psi \to \mu^+ \mu^-$	1.0 mb	14×10^6	1.1×10^6	600×10^3
$\psi(2S) \to \mu^+ \mu^-$	30 μb	400×10^3	35×10^3	19×10^3
$\Upsilon(1S) \to \mu^+ \mu^-$	2.0 μb	26×10^3	2.8×10^3	880

$L^{Pb\text{-}Pb}$ = 13/nb

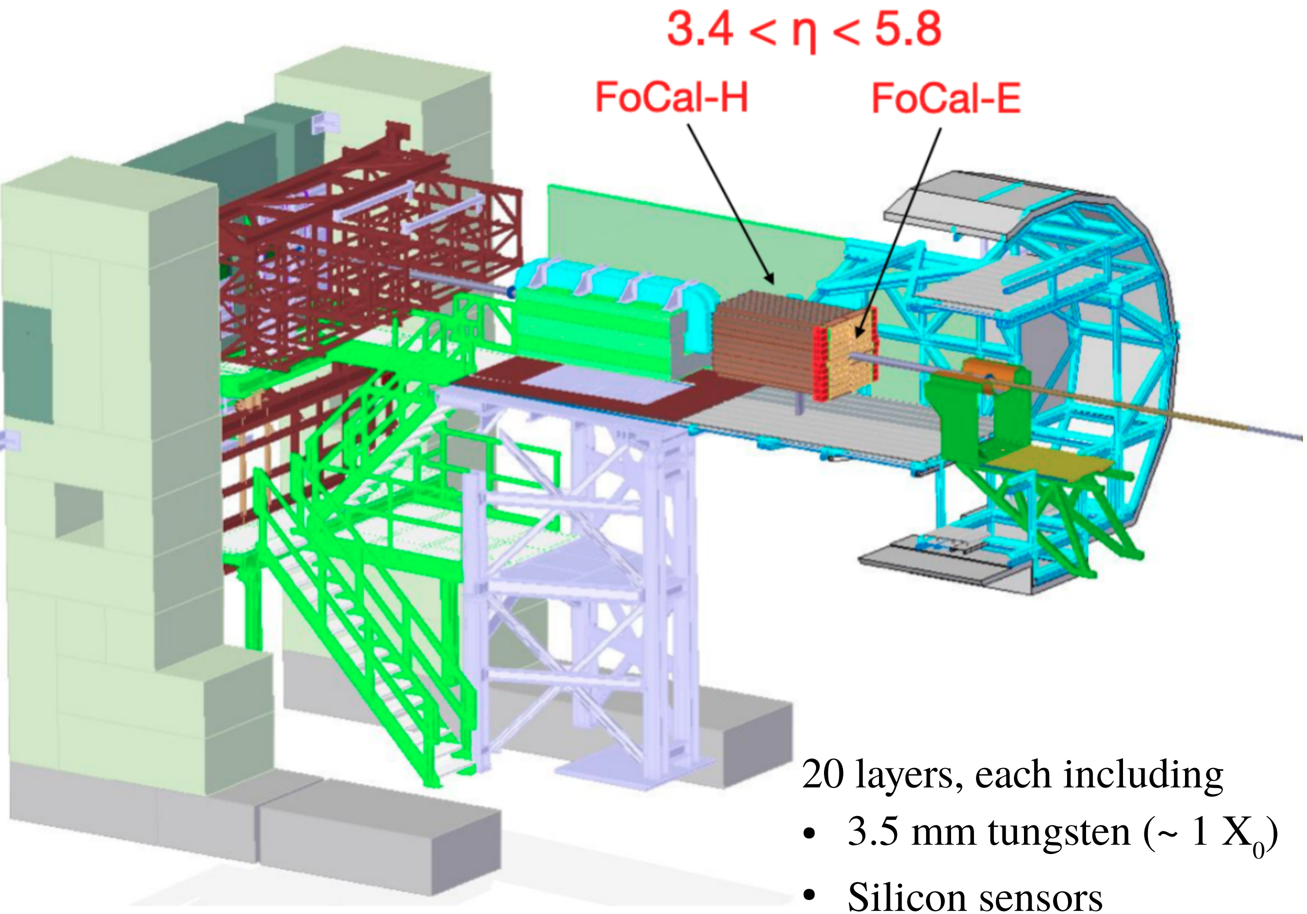
- **New differential measurements:**
  - $\frac{d^2\sigma}{dy\,d|t|}$
  - Angular distributions
  - Proton-dissociative production
- **New analyses:**
  - O-O UPCs
  - $\Upsilon(1S)$
  - Incoherent vector meson production
  - …

FoCal in Run 4

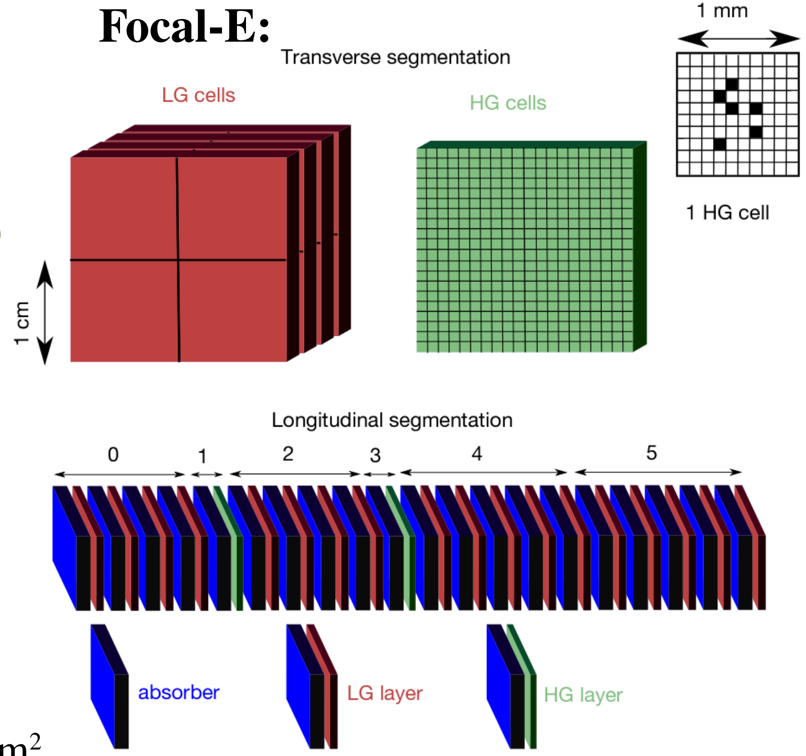
FoCal is a new high granularity calorimeter to be installed in the very forward region.

ALICE, LHCC-I-036 (2020)

TDR in preparation



Focal-E:



20 layers, each including

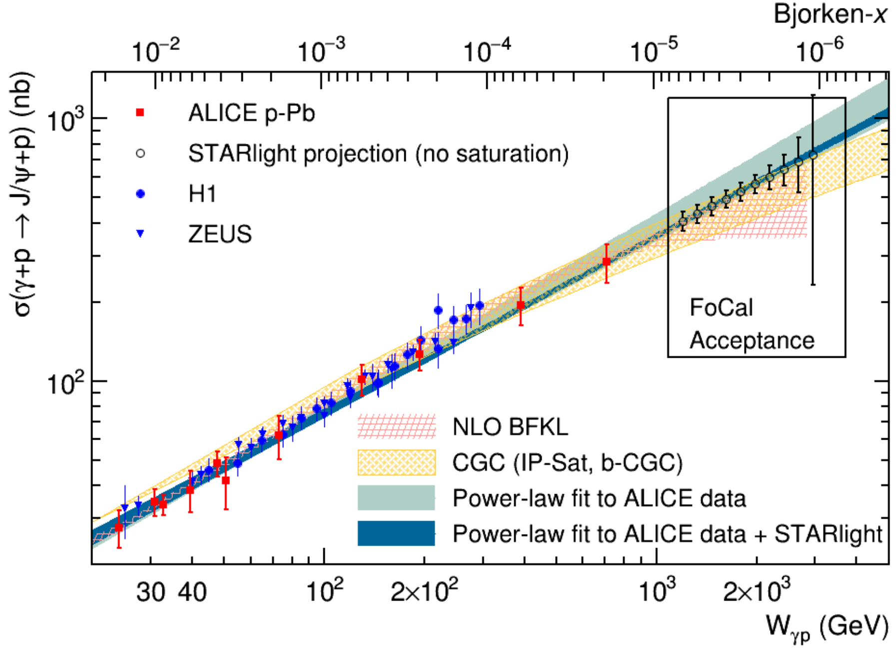
- 3.5 mm tungsten (~ 1 X_0)
- Silicon sensors
- CMOS pixels: ~ 30 x 30 μm^2

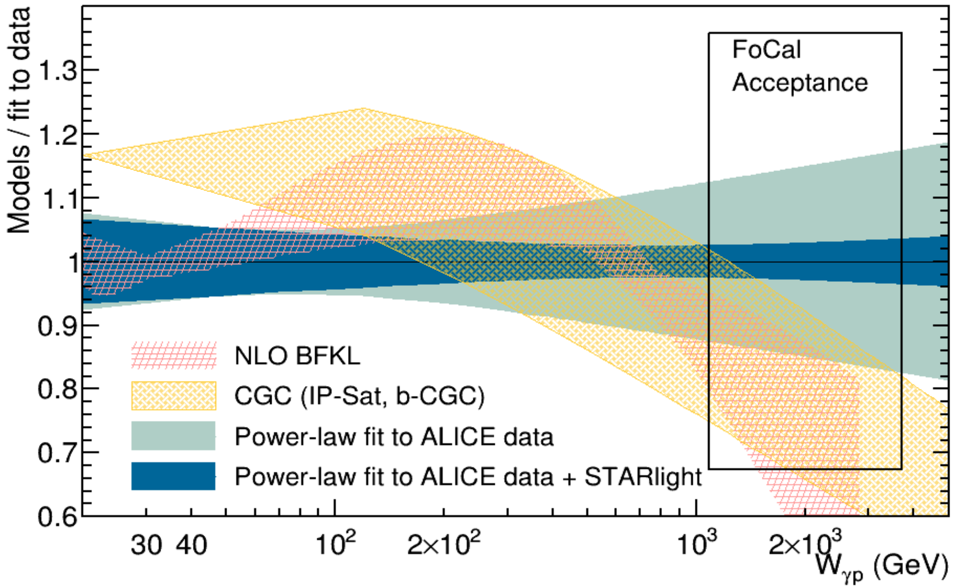
UPC measurements with FoCal in Run 4

A J/ψ detected in FoCal within **3.4 < *y* < 5.8**:

1.1 < $W_{\gamma p}$ < 3.6 TeV, ↔ 8·10^{-6} > *x* > 7·10^{-7}

**Studies by A. Bylinkin, D. Tapia Takaki and J. Nystrand*





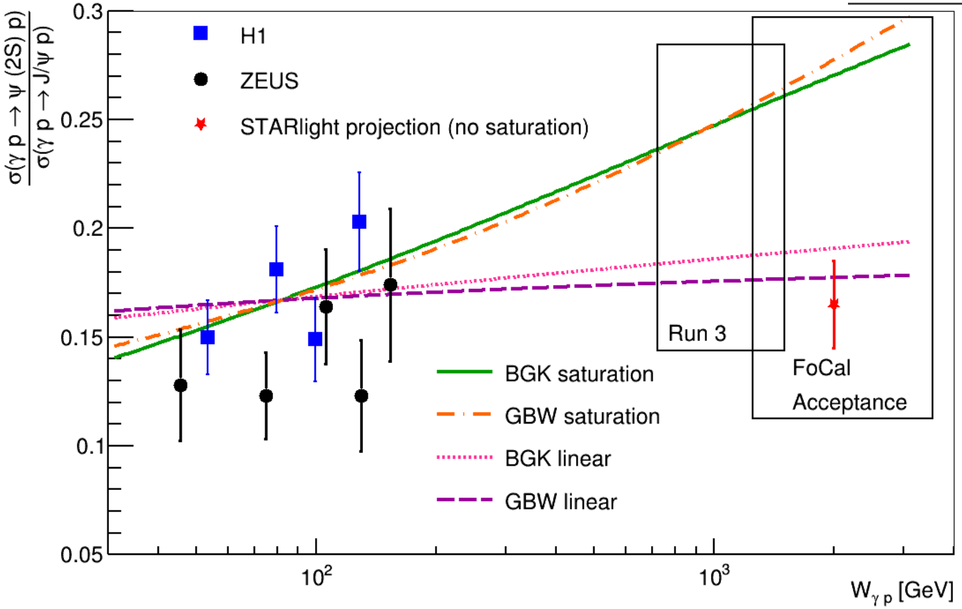
Measurement at unprecedentedly high energies will allow to distinguish between the theoretical models and significantly improve the precision.

UPC measurements with FoCal in Run 4

Measurement of ψ' with FoCal will also be possible.

Vector meson	$\sigma(p+Pb \to p+Pb+V)$	$\sigma(3.4 \leq \eta_{1,2} \leq 5.8)$ p → FoCal	Yield p → FoCal
J/ψ	98 μb	400 nb	60,000
$\psi(2S)$	16 μb	8.9 nb	1,300
$\Upsilon(1S)$	220 nb	0.38 nb	60
		Pb → FoCal	Pb → FoCal
J/ψ	98 μb	36 nb	5,400
$\psi(2S)$	16 μb	0.53 nb	80
$\Upsilon(1S)$	220 nb	0.67 pb	~ 0

**Studies by A. Bylinkin, D. Tapia Takaki and J. Nystrand*



Theoretical studies (by M. Hentschinski *et.al* [arxiv:2203.08129]) predict a clear onset of saturation effects in the **ψ' to J/ψ** cross section ratios as a function of c.m.s. energy.

Summary

- pPb UPCs
  - Exclusive cross section agrees with previous results from HERA and LHCb
  - Proton dissociative cross sections measured for the first time at LHC
- PbPb UPCs
  - Models with shadowing or saturation describe vector meson cross sections in the central and most forward regions within uncertainties
  - |t|-dependence is far below STARlight prediction
- XeXe UPCs
  - A dependence is consistent with shadowing and saturation models
- Prospects for Run 3 & 4
  - Many new exciting measurements to be done
  - Possibilities to look for saturation effects with the new FoCal detector at Run 4

Thank you very much for your attention!