ALICE Results on UPCs and peripheral collisions

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On behalf of the ALICE Collaboration

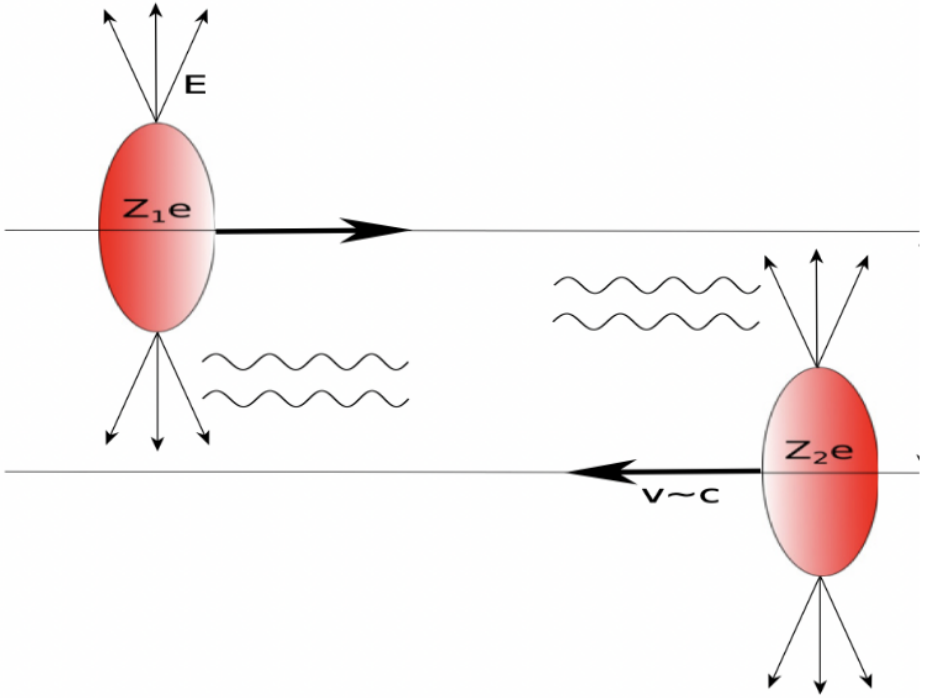
Towards improved hadron femtography with hard exclusive reactions,
21st July 2022, Virginia Tech, VA, USA

Outline

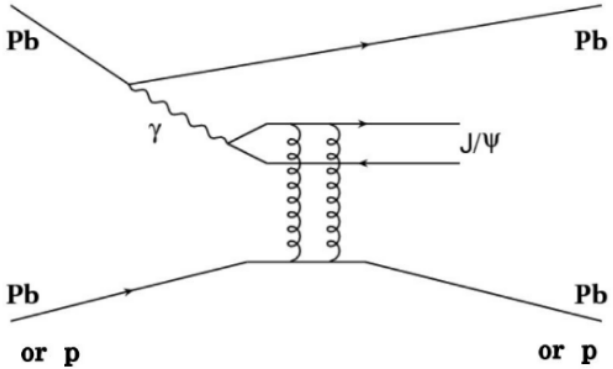
- Motivation
- ALICE Detector
- Photo-nuclear reactions in UPC and non-UPC PbPb
- Vector meson and two-photon interactions in pPb UPCs
- XeXe UPCs
- Summary

Photon induced processes in heavy ion collisions

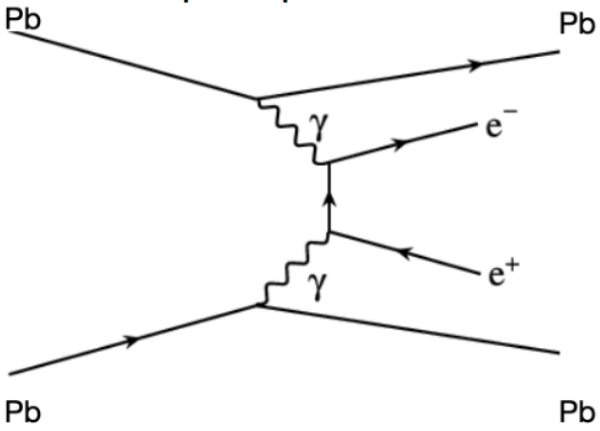
- Ultrarelativistic moving nuclei produce strong electromagnetic (EM) fields that can be treated as a **quasi-real photons flux**



Production of vector mesons

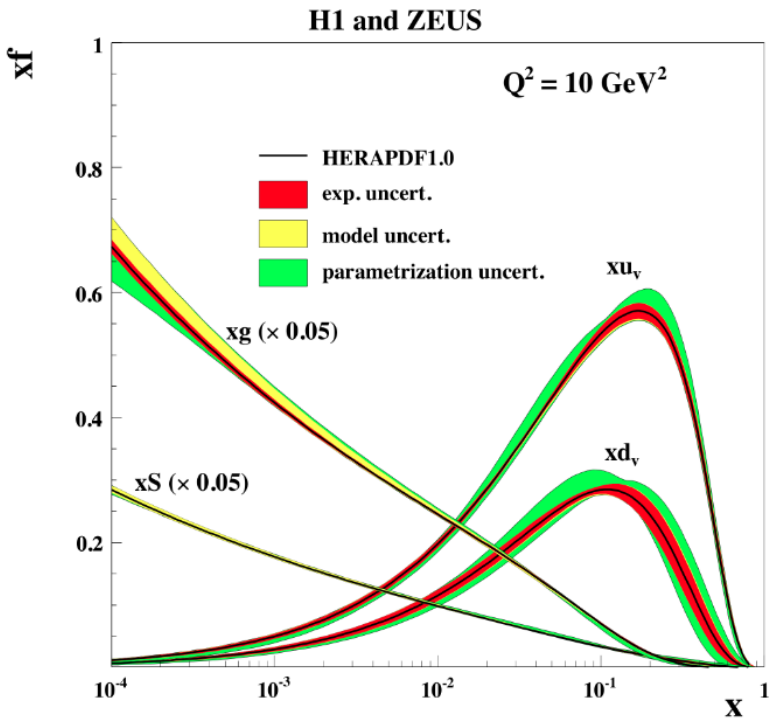


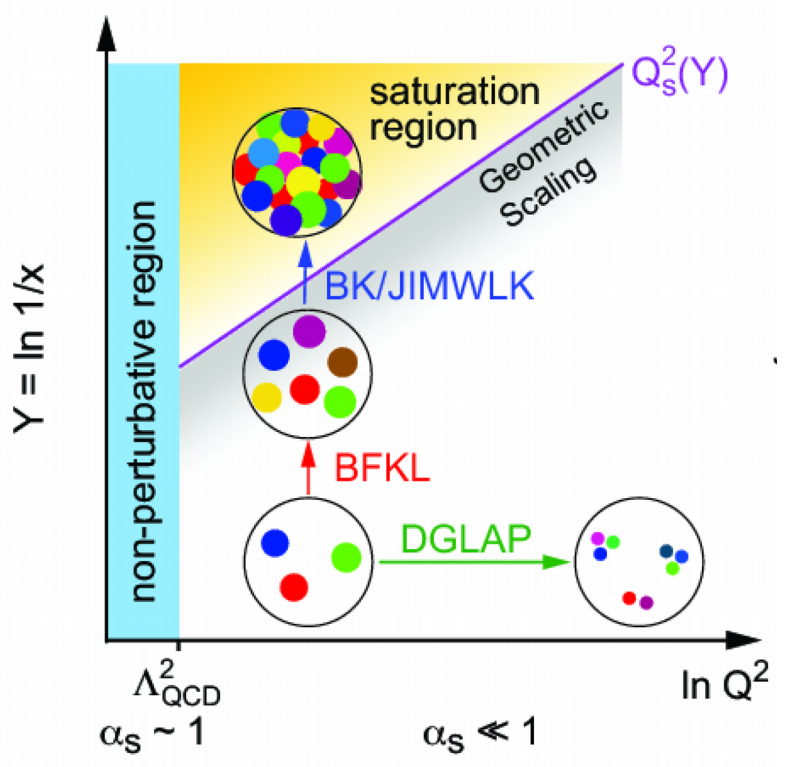
Dilepton production



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)

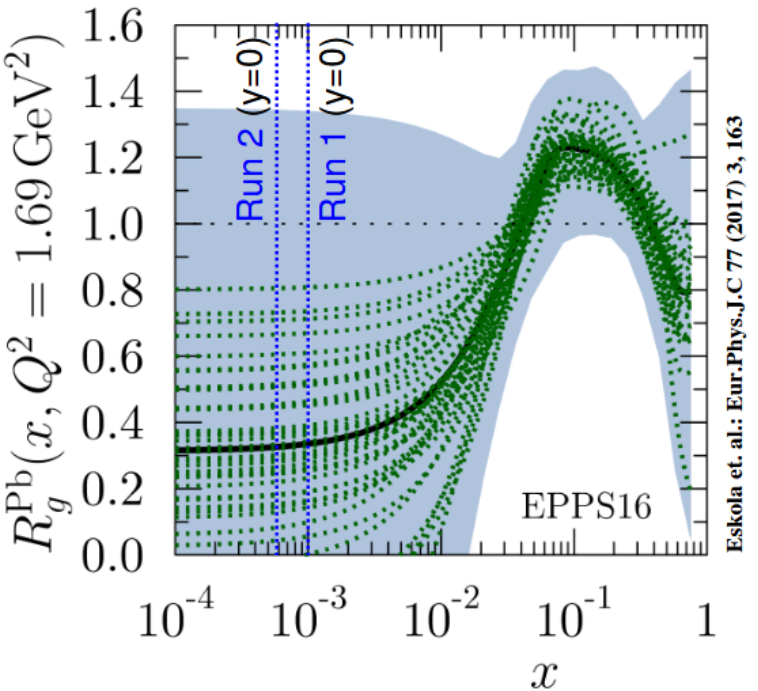




Nuclear structure

- **Nuclear shadowing effects** on gluon PDFs **at low *x***

$$R_g^A(x,Q^2) = \frac{g_A(x,Q^2)}{A g_p(x,Q^2)} < 1$$



- Onset of saturation is expected to depend on the atomic mass number

→ **Saturation may contribute to nuclear shadowing!**

Photoproduction in UPCs

- Many photoproduction processes can be studied in ALICE → Vector meson production
- Bjorken-x evolution of the parton distribution

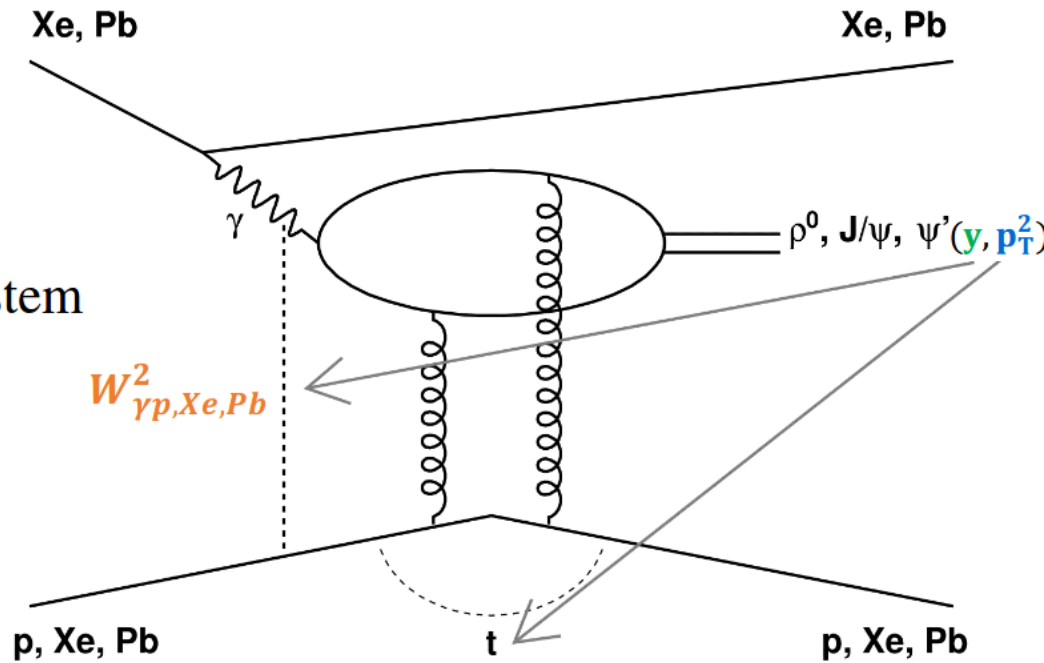
→ $$x = \frac{M_{VM}}{\sqrt{s_{NN}}} e^{\pm y}$$

- Centre-of-mass energy of the photon–target system

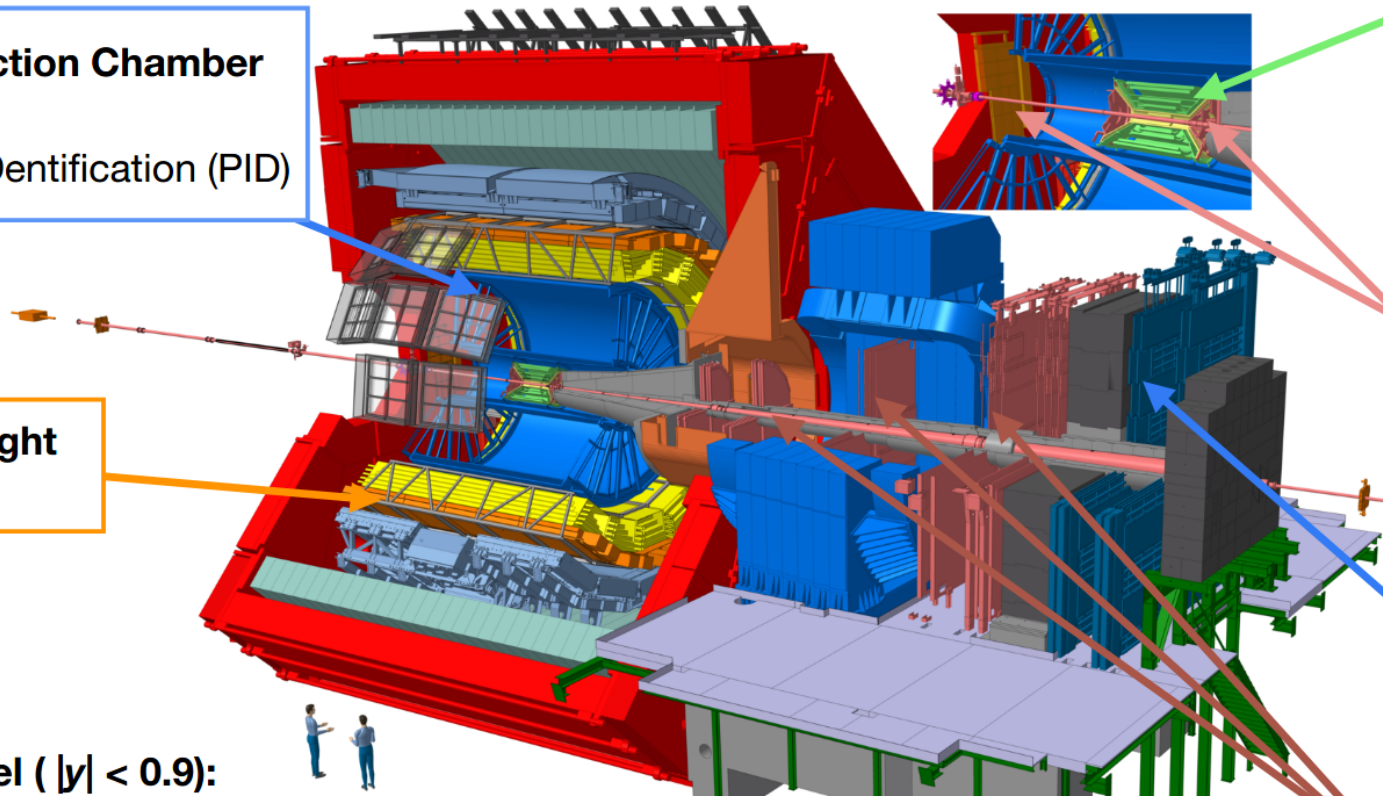
→ $$W^2_{\gamma p,Xe,Pb} = 2E_{p,Xe,Pb} M_{VM} e^{\mp y}$$

- Transverse-plane distribution of the partons

→ **2D Fourier** transform to the $|t|$ ($\sim p_T^2$) **dependence** in coherent interaction



ALICE (A Large Ion Collider Experiment)



Time Projection Chamber
- Tracking
- Particle IDentification (PID)

Time of Flight
- PID

Inner Tracking System
- Tracking
- Vertexing
- PID

V0 scintillators
- Trigger
- Centrality
- Event plane
- Background rejection

MTR
- Muon trigger

MCH
- Muon tracking

Central barrel ($|y| < 0.9$):
- $J/\psi \rightarrow e^+e^-$, low mass dielectrons

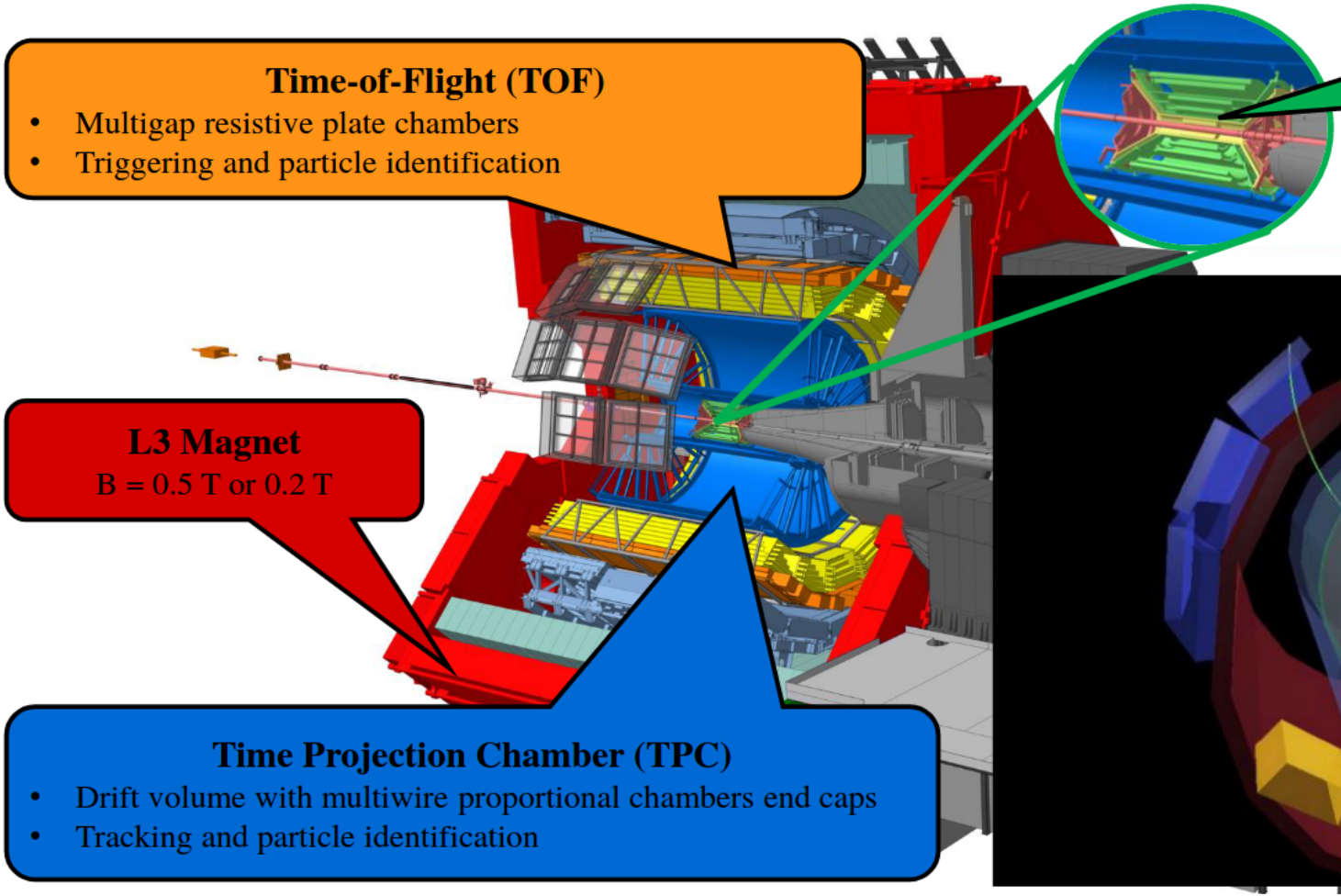
Muon Spectrometer ($2.5 < y < 4$):
- $J/\psi \rightarrow \mu^+\mu^-$

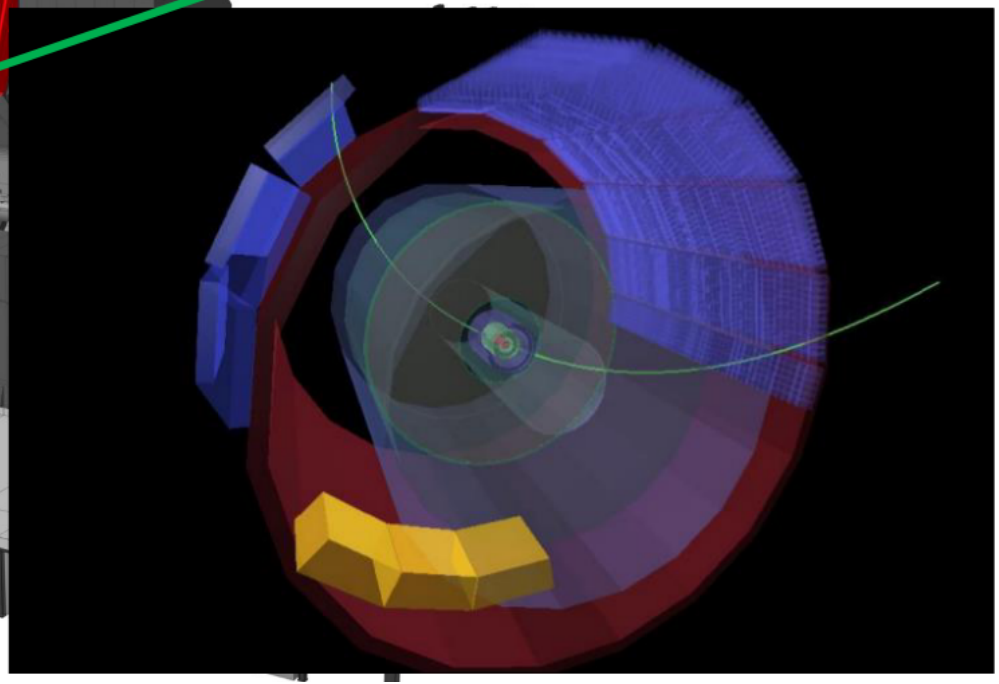
Int. J. Mod. Phys. A 29 (2014) 1430044

ALICE Detector: J/ψ at mid-rapidity

Time-of-Flight (TOF)
- Multigap resistive plate chambers
- Triggering and particle identification

Inner Tracking System (ITS)
- Silicon detector
- Triggering and tracking

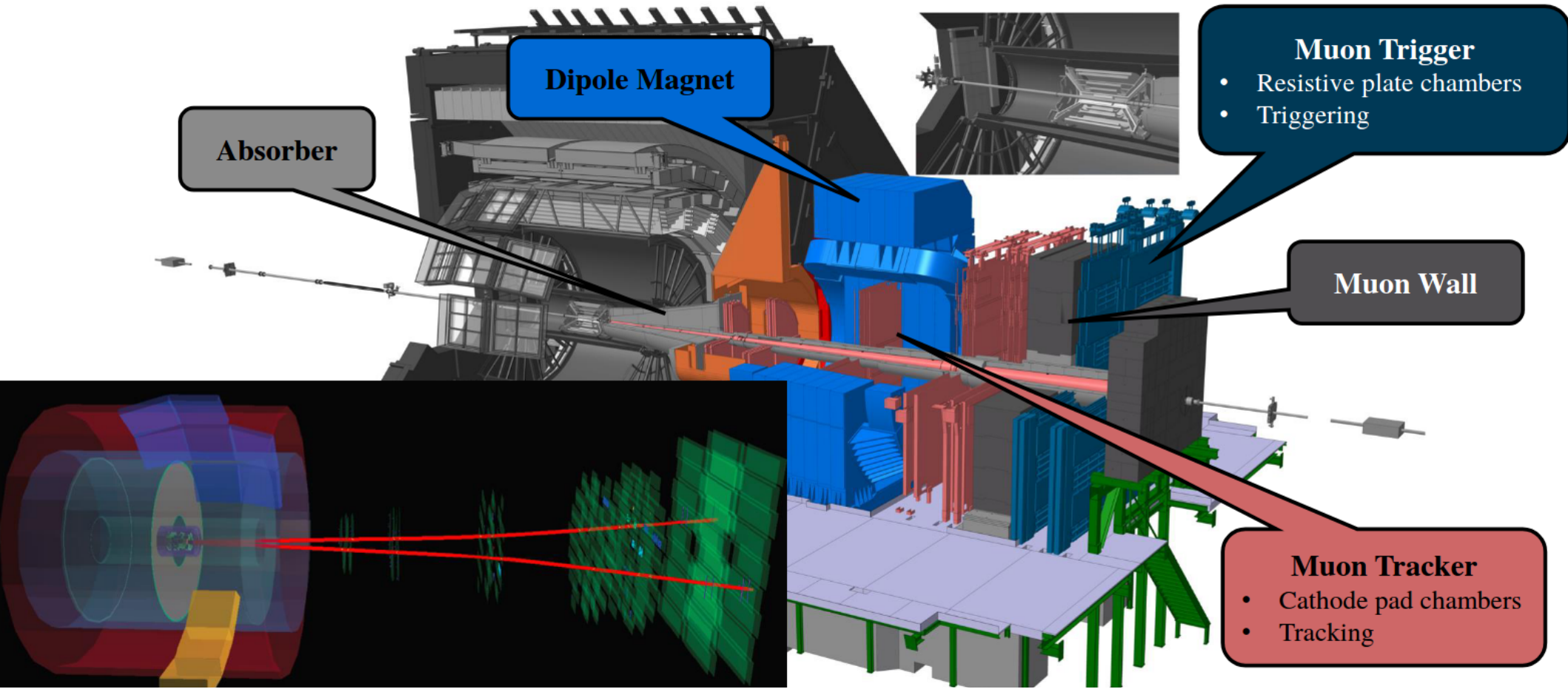




L3 Magnet
B = 0.5 T or 0.2 T

Time Projection Chamber (TPC)
- Drift volume with multiwire proportional chambers end caps
- Tracking and particle identification

ALICE Detector: J/ψ at forward rapidity

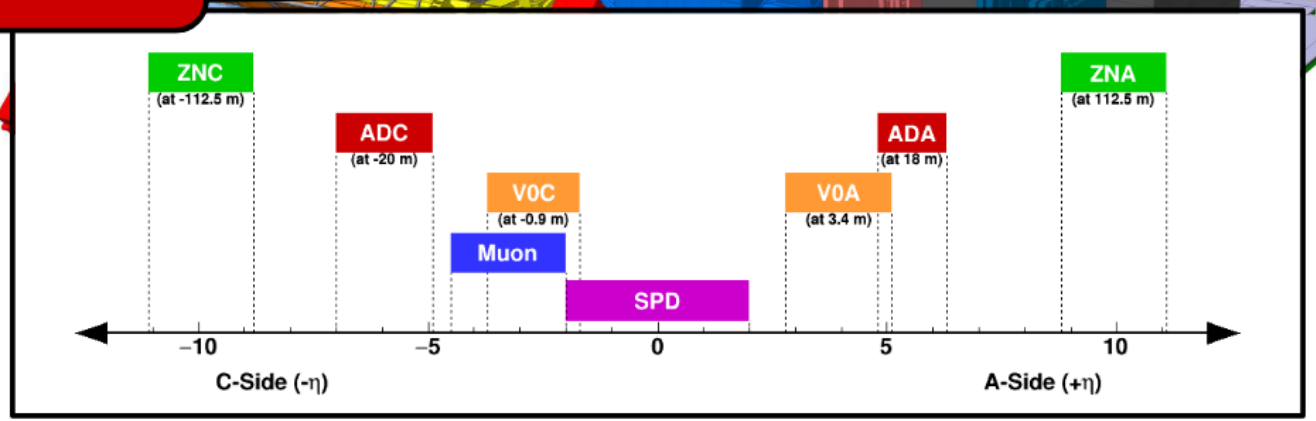


ALICE Detector: exclusivity condition

Zero-Degree Calorimeter (ZDC)
- Sampling calorimeters
- Luminosity determination

V0
- Scintillator counter
- Veto activity
- Luminosity determination

ALICE Diffractive (AD)
- Scintillator counter
- Veto activity



Pb-Pb UPC Results

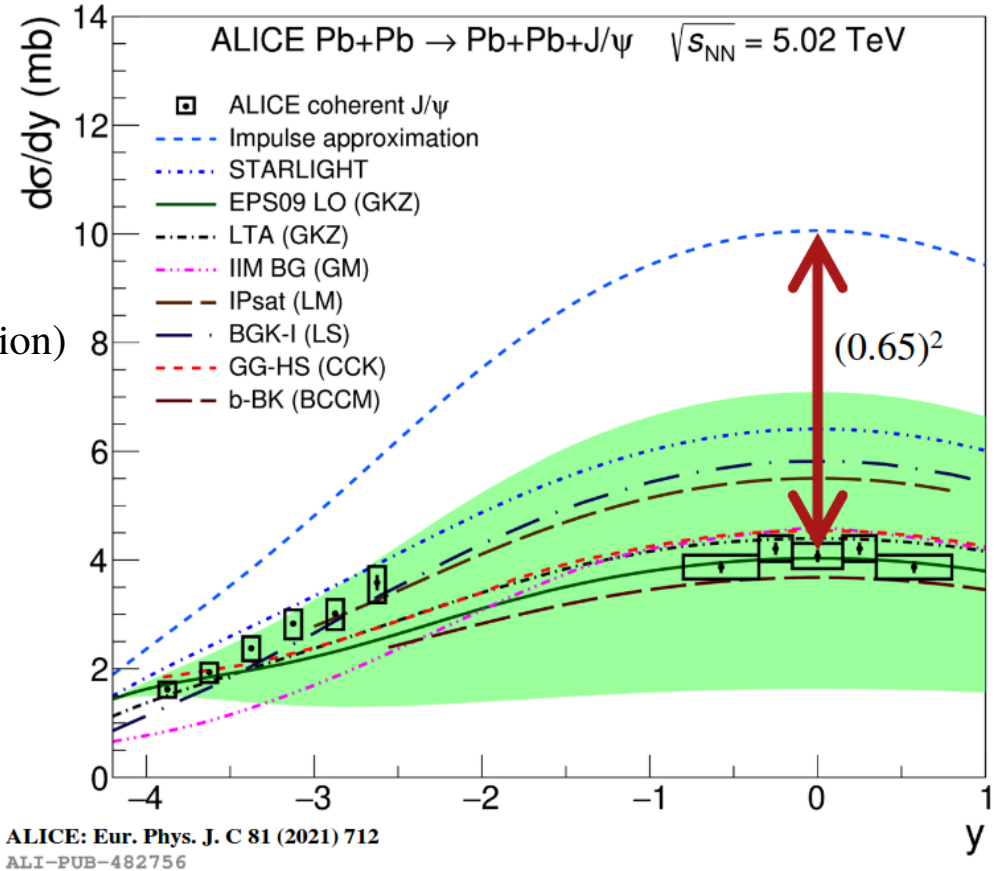
Coherent J/ψ photoproduction rapidity dependence

- **Nuclear suppression factor:** for $x \in (0.3, 1.4) \cdot 10^{-3}$

$$S_{\mathrm{Pb}} = \sqrt{\left(\frac{\mathrm{d}\sigma}{\mathrm{d}y}\right)_{\mathrm{data}} \Big/ \left(\frac{\mathrm{d}\sigma}{\mathrm{d}y}\right)_{\mathrm{IA}}} = \mathbf{0.65 \pm 0.03}$$

- 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
- Other models describe either the central or the forward rapidity region

→ **No model describes the full rapidity dependence**



ALICE: Eur. Phys. J. C 81 (2021) 712
ALI-PUB-482756

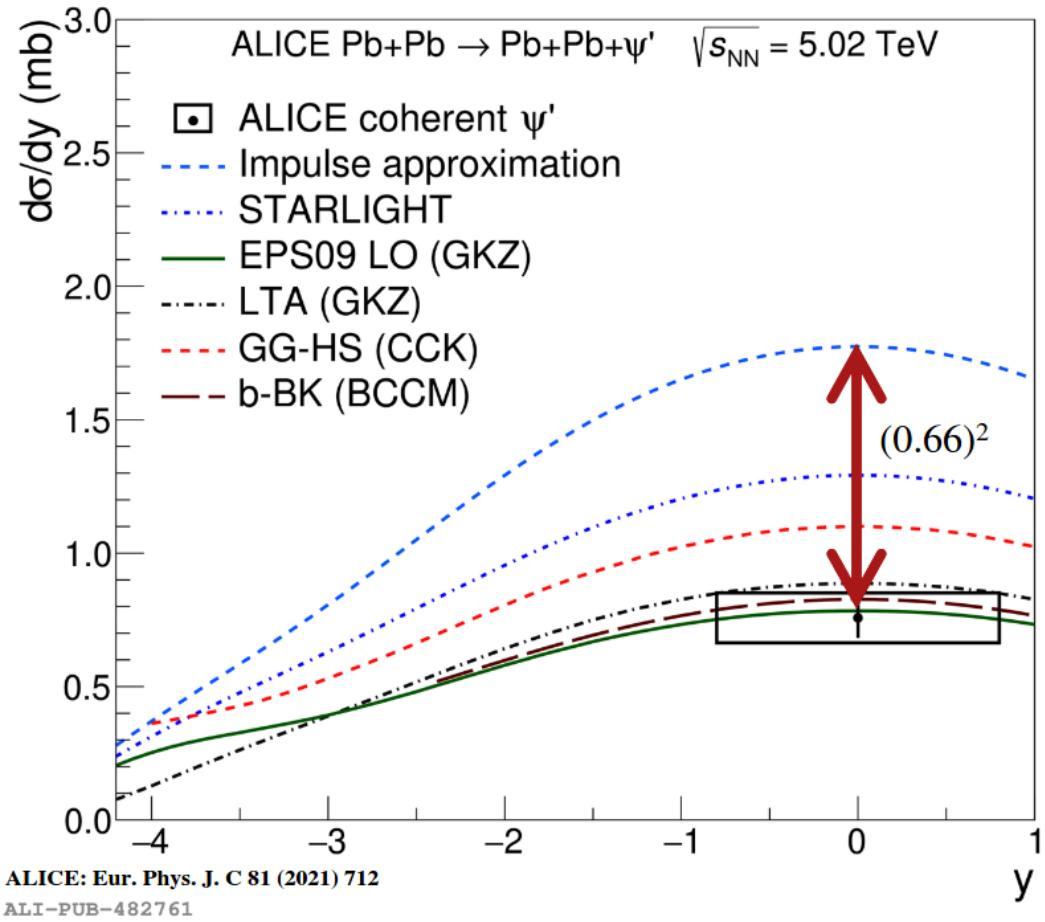
Coherent ψ' photoproduction

- **Nuclear suppression factor:** for $x \in (0.3,1.6) \cdot 10^{-3}$

$$S_{Pb} = 0.66 \pm 0.06$$

→ **Consistent with the J/ψ result**

- Models with **shadowing:**
  - EPS09 - agrees
  - LTA - agrees
- Models with **saturation:**
  - Balitsky-Kovchegov (b-BK) - agrees
  - GG-HS - overpredicts
- Other models overpredict the results

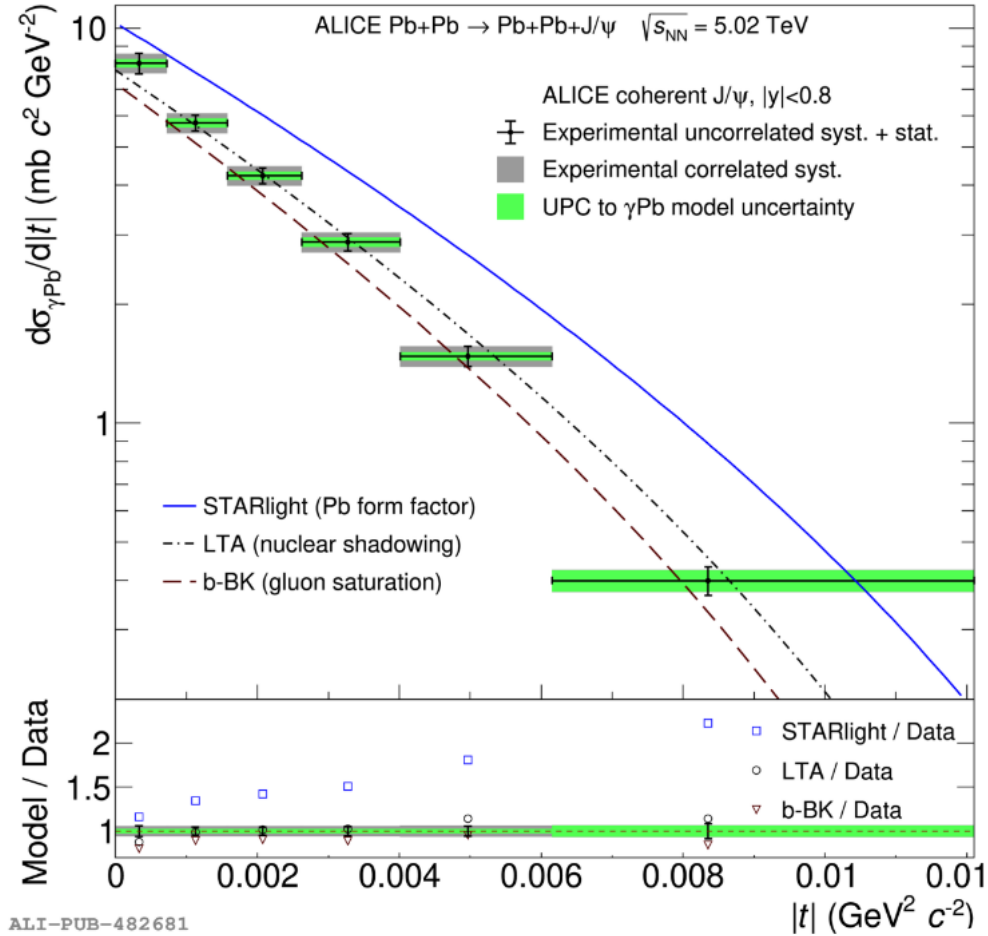


Coherent J/ψ photoproduction |t|-dependence

- From p_T^2-dependent photoproduction to $|t|$-dependent photonuclear production:
  - p_T^2 to $|t|$ transition with two different unfolding methods (Deconvolution of the photon p_T contribution from the photonuclear |t|)
  - Correction on interference of photon sources
  - From UPC to photonuclear cross section using the photon flux

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

→ **Probing the transverse partonic structure of the nucleus at low *x*!**



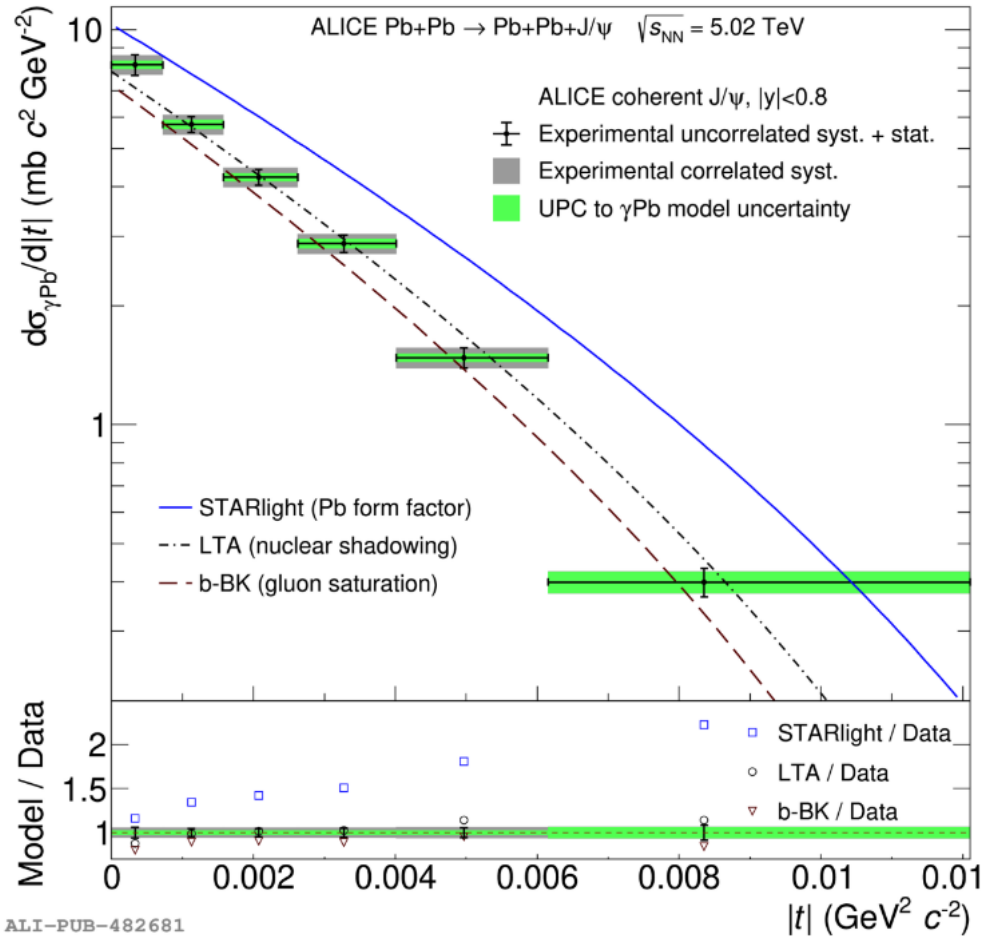
ALICE: Phys. Lett. B 817 (2021) 136280

Coherent J/ψ photoproduction |t|-dependence

- Difference from STARlight (driven by the nuclear form factor) in shape and magnitude

→ **|*t*| dependent QCD dynamical effects!**

- Models based on pQCD describe data within current uncertainties:
  - Nuclear **shadowing** (LTA)
  - Gluon **saturation** (b-BK)
- Future measurements should allow to distinguish between the predictions



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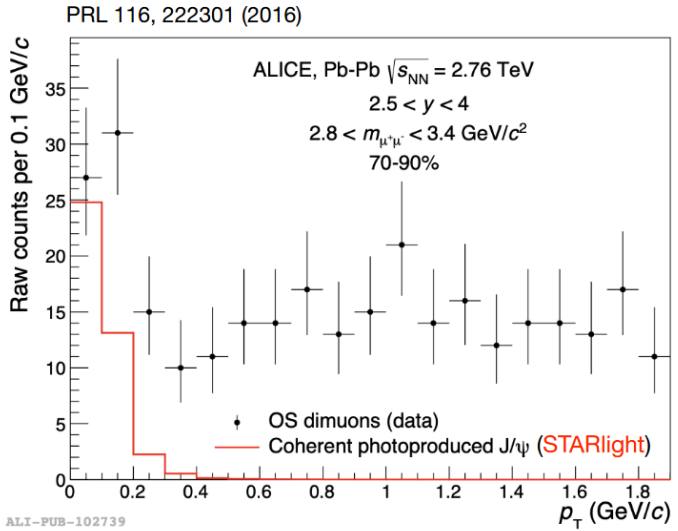
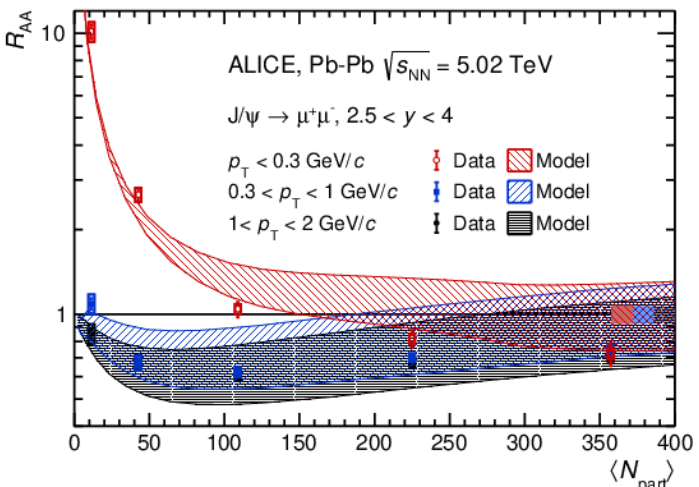
Pb-Pb Non-UPC Results

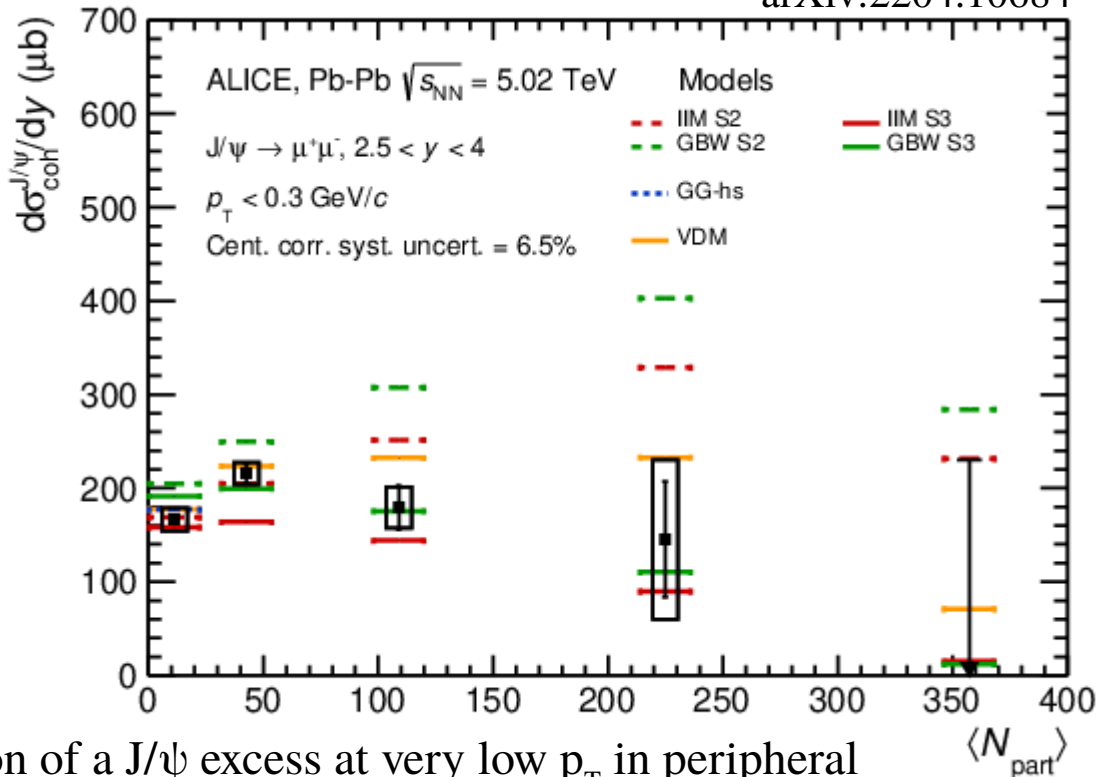
What happens when going from ultra-peripheral to peripheral collisions?

J/ψ photoproduction in peripheral collisions

arXiv:2204.10684





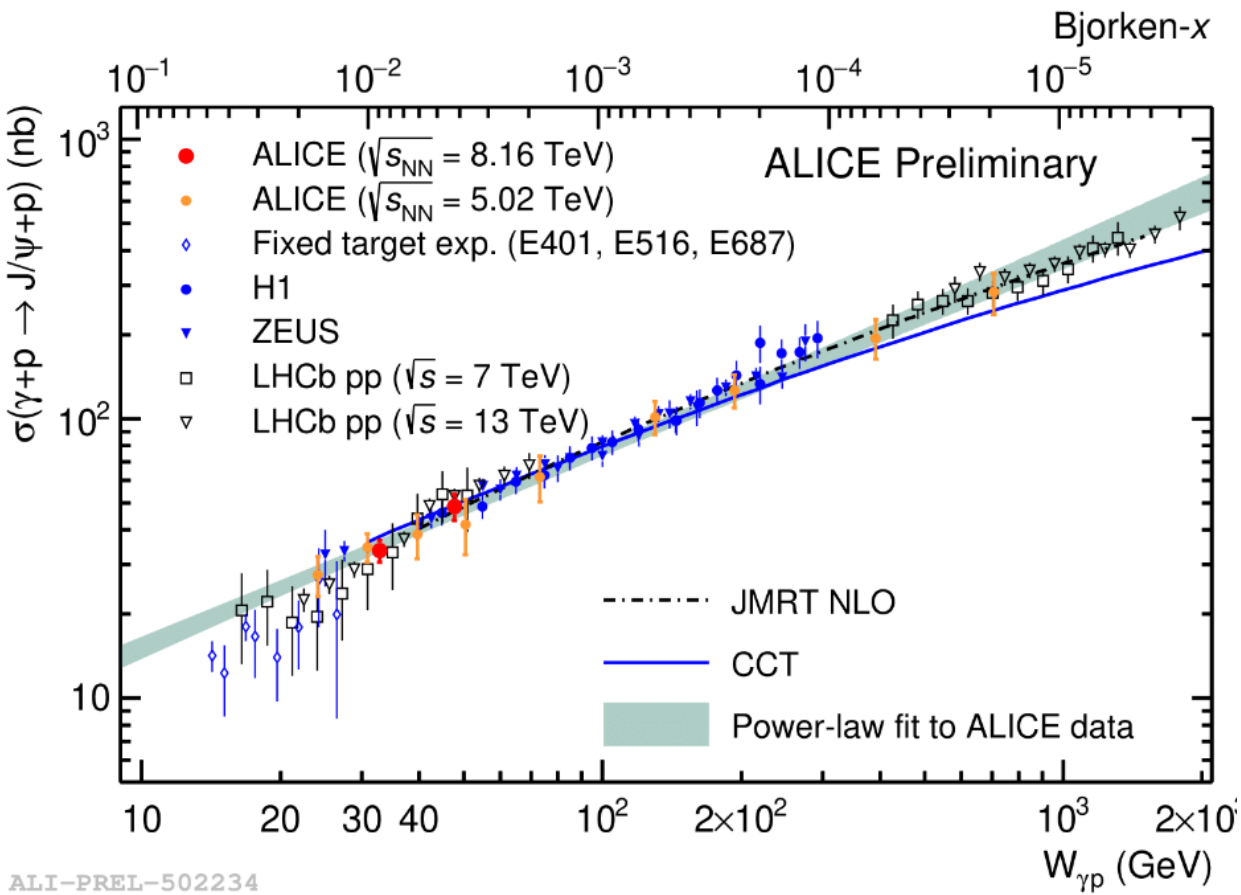


- Observation of a J/ψ excess at very low p_T in peripheral collisions due to coherent photoproduction
- Measurements extended towards more central collisions shed light on the production mechanism
- Scenario with modified photonuclear cross sections is favorable

p-Pb UPC Results

Exclusive J/ψ cross-section: energy dependence

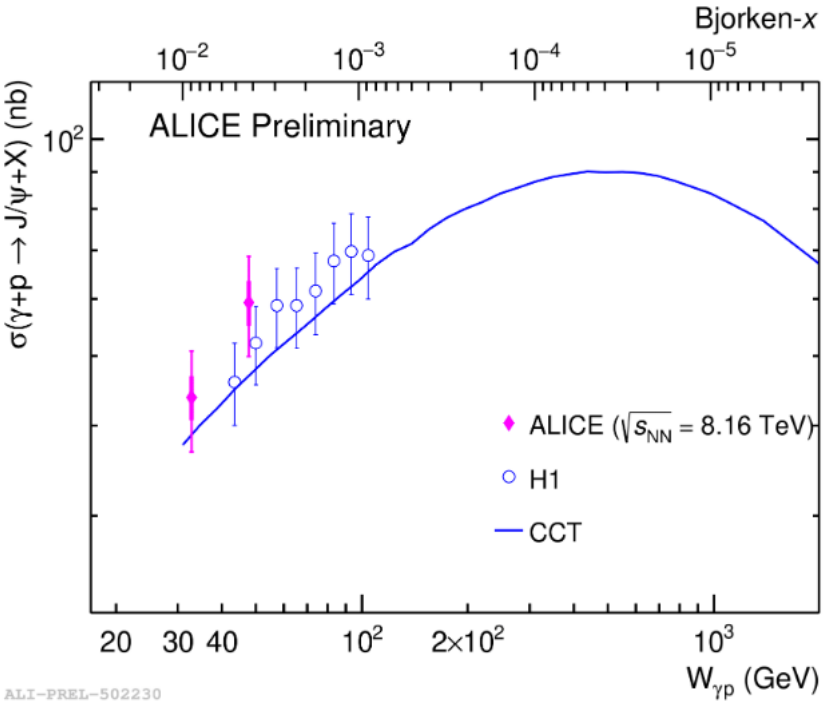
- In pPb UPCs the photon flux from the Pb-nucleus dominates
  → access to γp interactions
- Power law fit to ALICE data
  - Exponent: $\delta = 0.70 \pm 0.04$
- **No change** between HERA and LHC
- ALICE and LHCb are **compatible**
- **Agreement** with models:
  - **JMRT NLO**: DGLAP formalism with main NLO contributions
  - **CCT**: Saturation in an energy dependent hot spot model

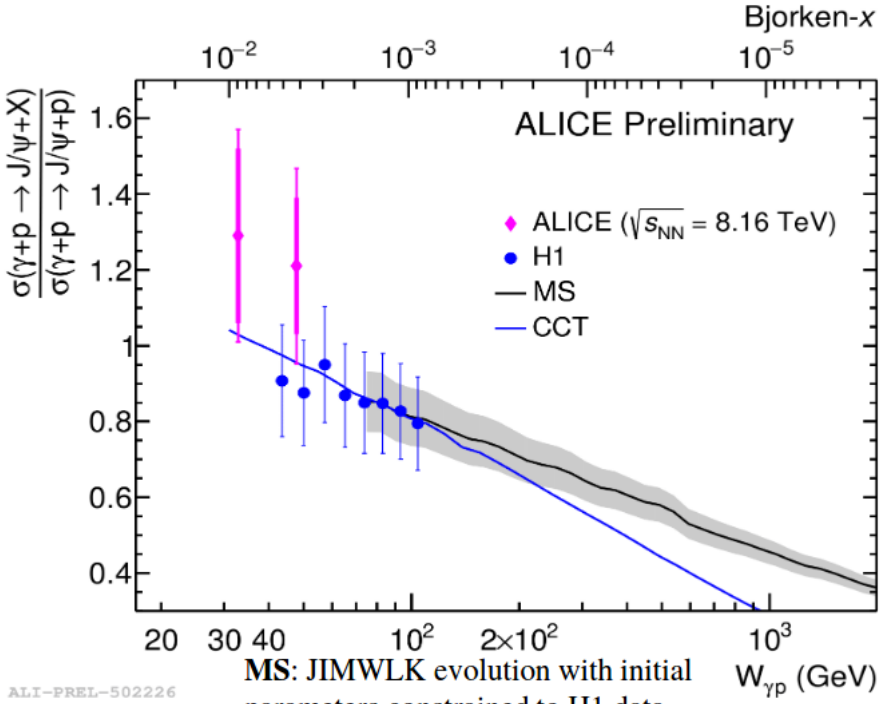


Dissociative J/ψ cross-section: energy dependence

- First measurement of the dissociative cross section (with the proton break up) at the LHC!
  - Agreement with **CCT**, predicts maximum at $W_{\gamma p} \approx 500$ GeV
  - Agreement with HERA results

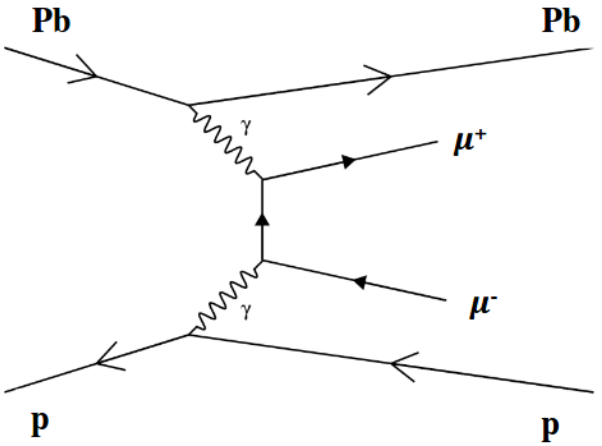
→ **Energies ≈ 1 TeV available in Run 3!**





MS: JIMWLK evolution with initial parameters constrained to H1 data

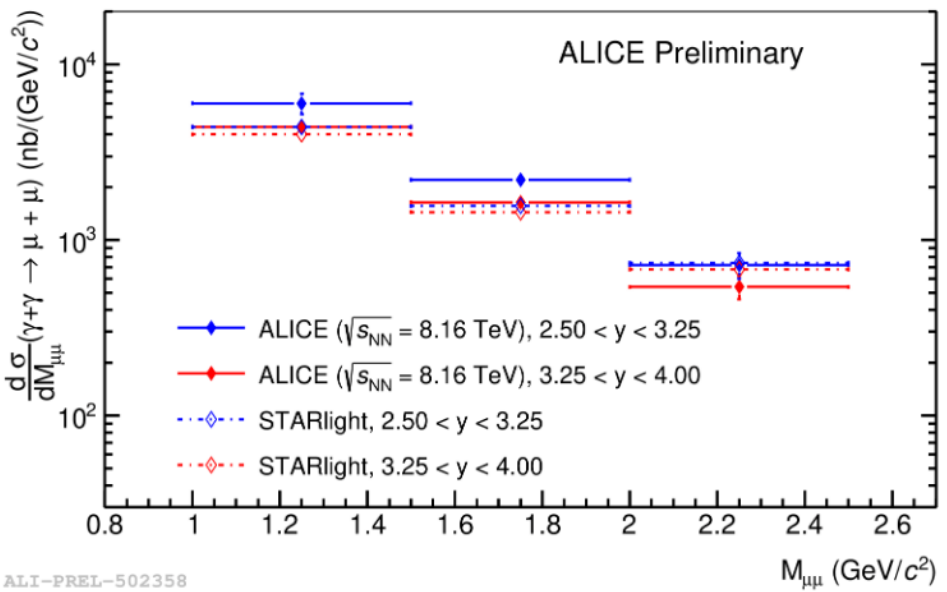
$\gamma\gamma \rightarrow \mu\mu$ cross section



- $\gamma\gamma \rightarrow \mu\mu$ cross section in the **low mass** region!
- STARlight:
  - LO QED without final-state radiation or other NLO effects
  - No interactions within the radius of the targets

→ **Slight excess in data**
agreement within 3 sigma

- Can be used to improve current models
  - **Fix background** for VM or jet **photoproduction**
  - Improve predictions for **light-by-light scattering**

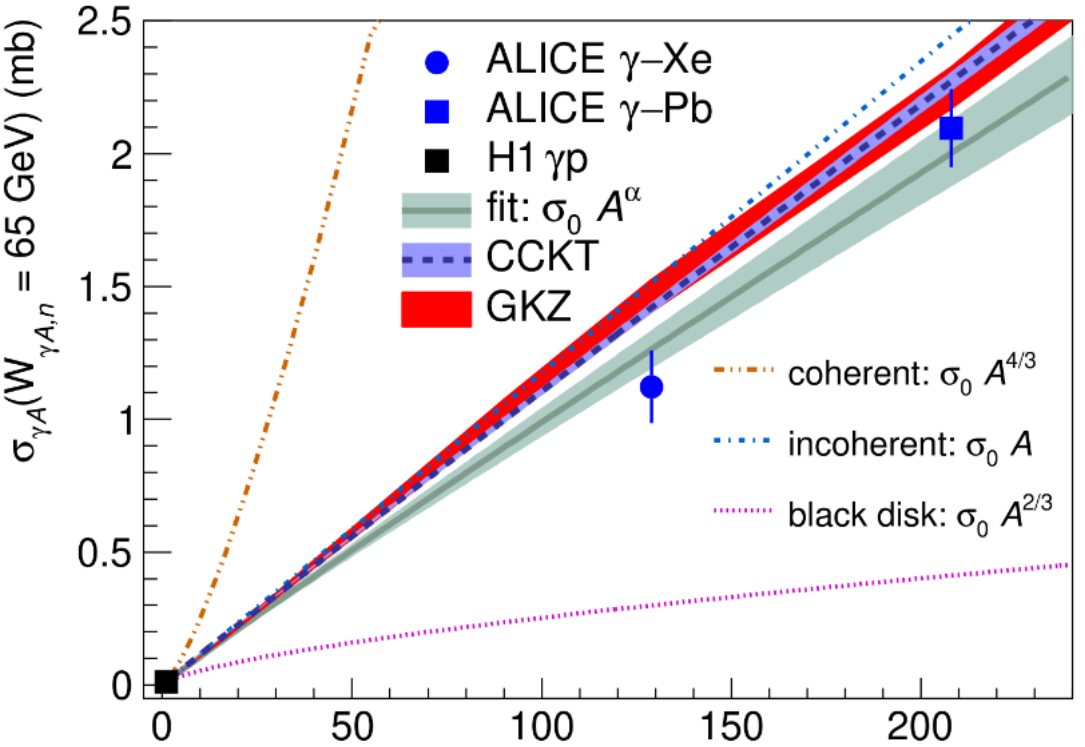


ALI-PREL-502358

Xe-Xe UPC Results

Coherent ρ^0 photoproduction: A-dependence

- Measurement with Pb and Xe collisions → **Study of the A dependence!**
- Power-law fit: $\alpha = 0.96 \pm 0.02$
  - Below coherent → **Shadowing**
  - 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**



ALICE: Phys. Lett. B 820 (2021) 136481
ALI-PUB-496203

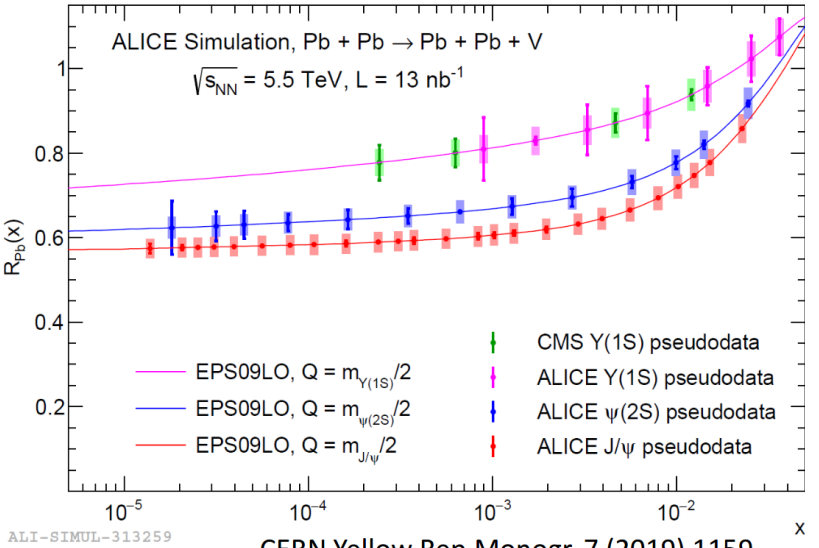
Outlook: Run 3 & 4

- **$\mathcal{L}$ increase -** 1 nb^{-1} (Run 2) → 13 nb^{-1} (Runs 3+4)
- **Continuous readout** → higher data collection efficiency
- Significant **detector upgrades**
- Proposed **O-O run** → new system size

Meson, channel	$\sigma^{\text{Pb-Pb}}$	N^{Tot}	$N^{\lvert\eta\rvert < 0.9}$	$N^{-4 < \eta < -2.5}$
$\rho^0 \to \pi^+ \pi^-$	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

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

- **New differential** measurements:
  - $\frac{d^2\sigma}{dy d|t|}$
  - Angular dependences between l^+l^-
  - Coherent ρ^0 evolution with A in O-O …
- **Completely new** measurements:
  - $\Upsilon(1S)$ - Q^2 factor 10 larger than J/ψ
  - Interference effects
  - Incoherent ρ^0 production …



CERN Yellow Rep.Monogr. 7 (2019) 1159

Summary

- PbPb UPCs
  - Models with shadowing or saturation describe vector meson cross sections in the central and most forward regions within uncertainties
  - |t|-dependence sensitive to parton distribution in the transverse plane
- PbPb non-UPCs
  - Excess of low-p_T vector mesons observed for the non-central collisions is consistent with the coherent photoproduction (scenario with the modified photonuclear cross section)
- pPb UPCs
  - Exclusive cross section agrees with previous results from HERA and LHCb
  - Proton dissociative cross sections measured for the first time at LHC
  - Low mass $\gamma\gamma \rightarrow \mu\mu$ measurement can be used to improve uncertainties on photon fluxes and higher-order effects such as Coulomb and unitarity corrections
- XeXe UPCs
  - A dependence is consistent with shadowing and saturation models

Thank you very much for your attention!