Latest ALICE results on J/ψ photoproduction in ultra-peripheral collisions at the LHC

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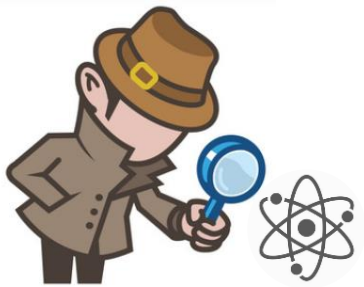
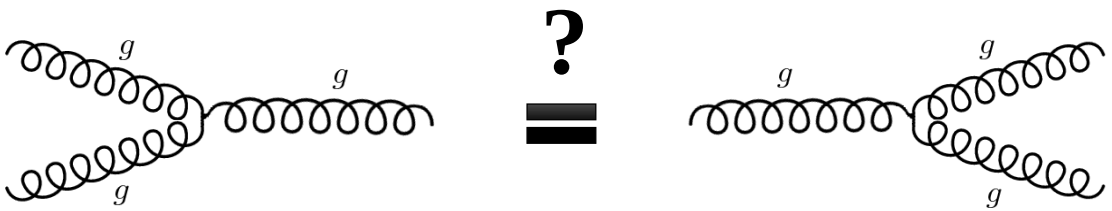
Introduction

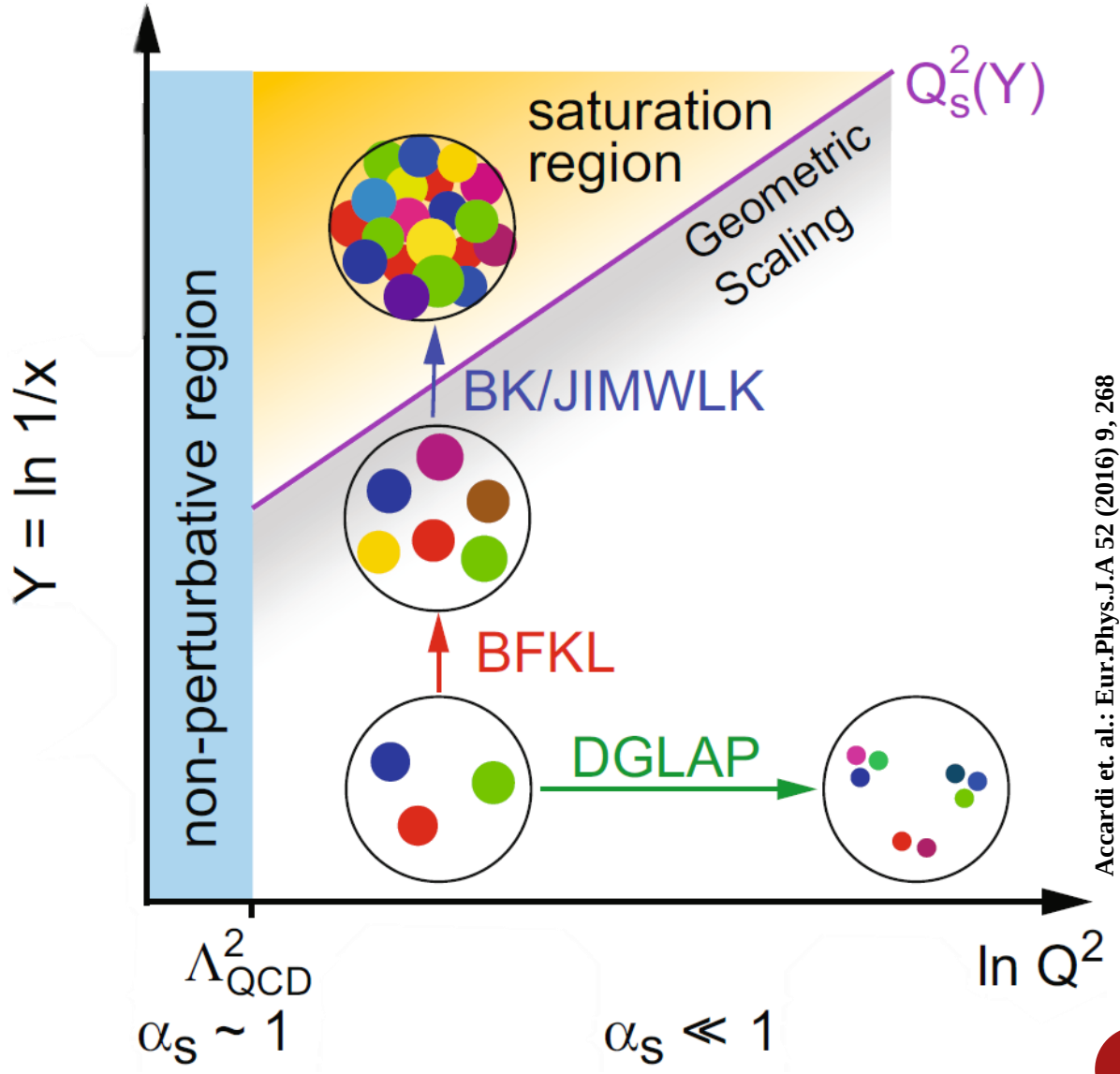
Proton structure

- Active search for **saturation** at **low *x***!



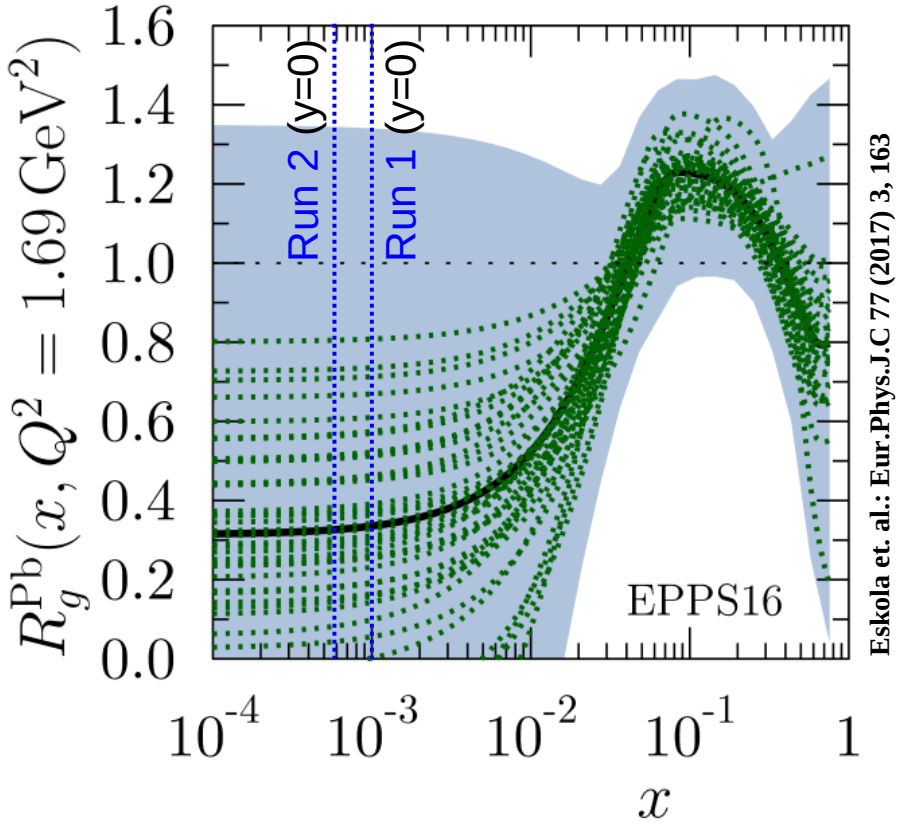
- No conclusive evidence observed yet.





Nuclear structure

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



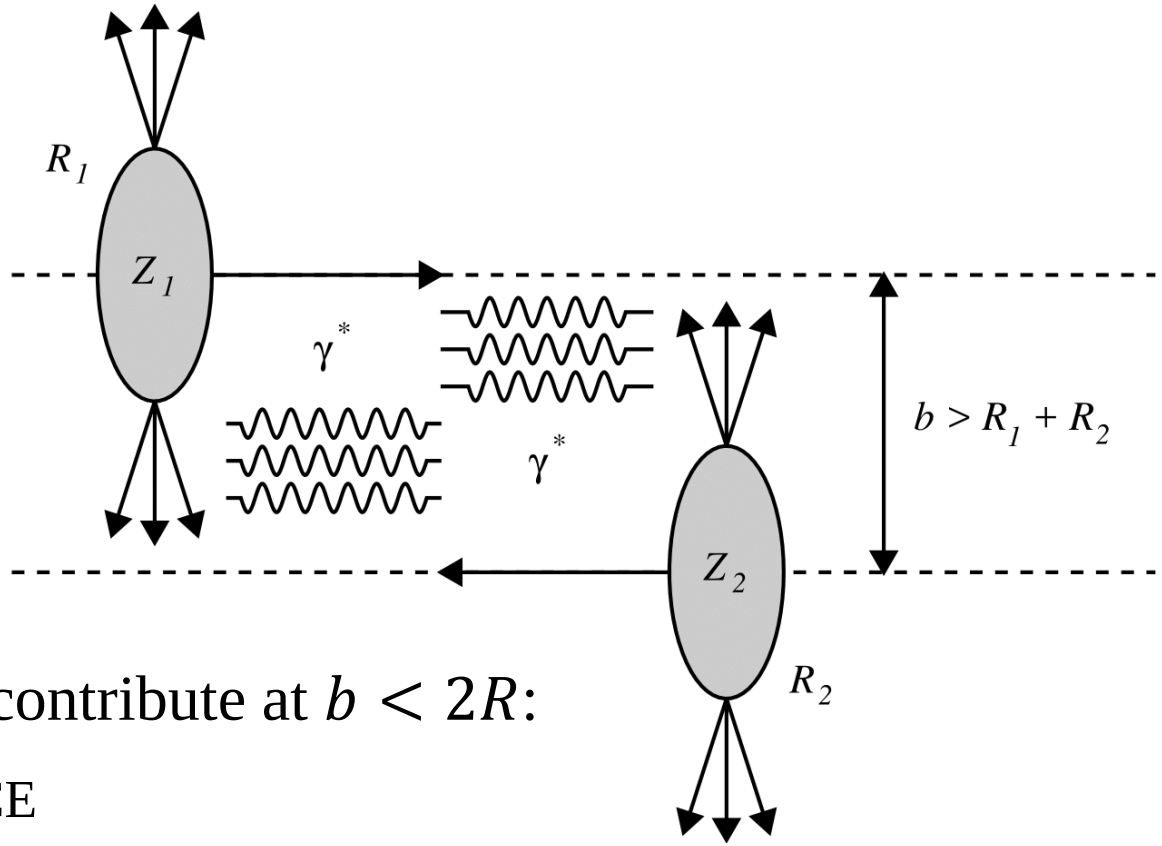
- Onset of saturation is expected to depend on the atomic mass number.

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

Ultra-peripheral collisions

- Hadronic interactions are suppressed.

→ **Photon-induced reactions can be measured!**



- Photon-induced reactions also contribute at $b < 2R$:
  - J/ψ excess at very low p_{T} - ALICE
  - Dilepton excess at low p_{T} - STAR

Photoproduction

- LHC is a **Light-Hadron Collider** at the highest available energies.
- Many photoproduction processes can be studied in ALICE.

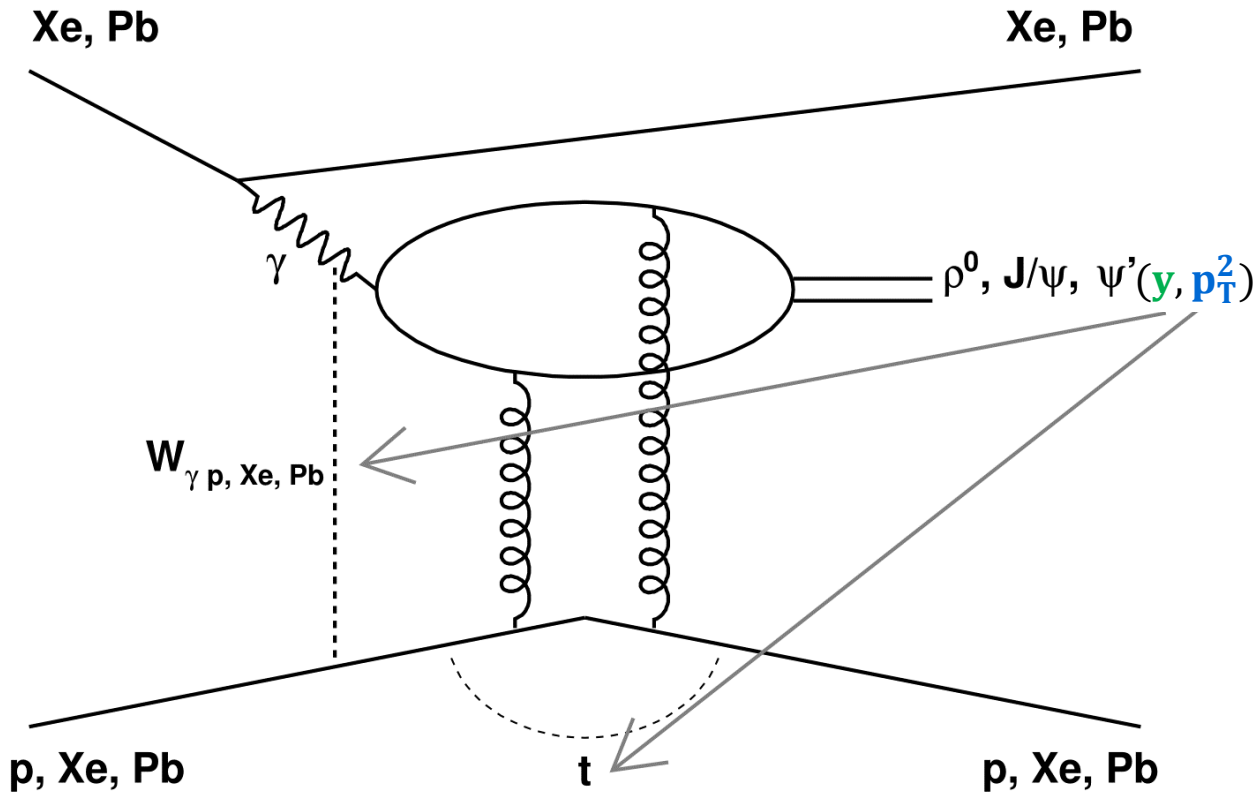
ρ^0 results - 14 Apr 2021, Valeri Pozdnyakov
https://indico.bnl.gov/event/9726/contributions/45486/

- Bjorken-*x* evolution of the gluon distribution.

$$\rightarrow \quad x = \frac{M_{J/\psi}}{\sqrt{s_{NN}}} e^{\pm y}$$

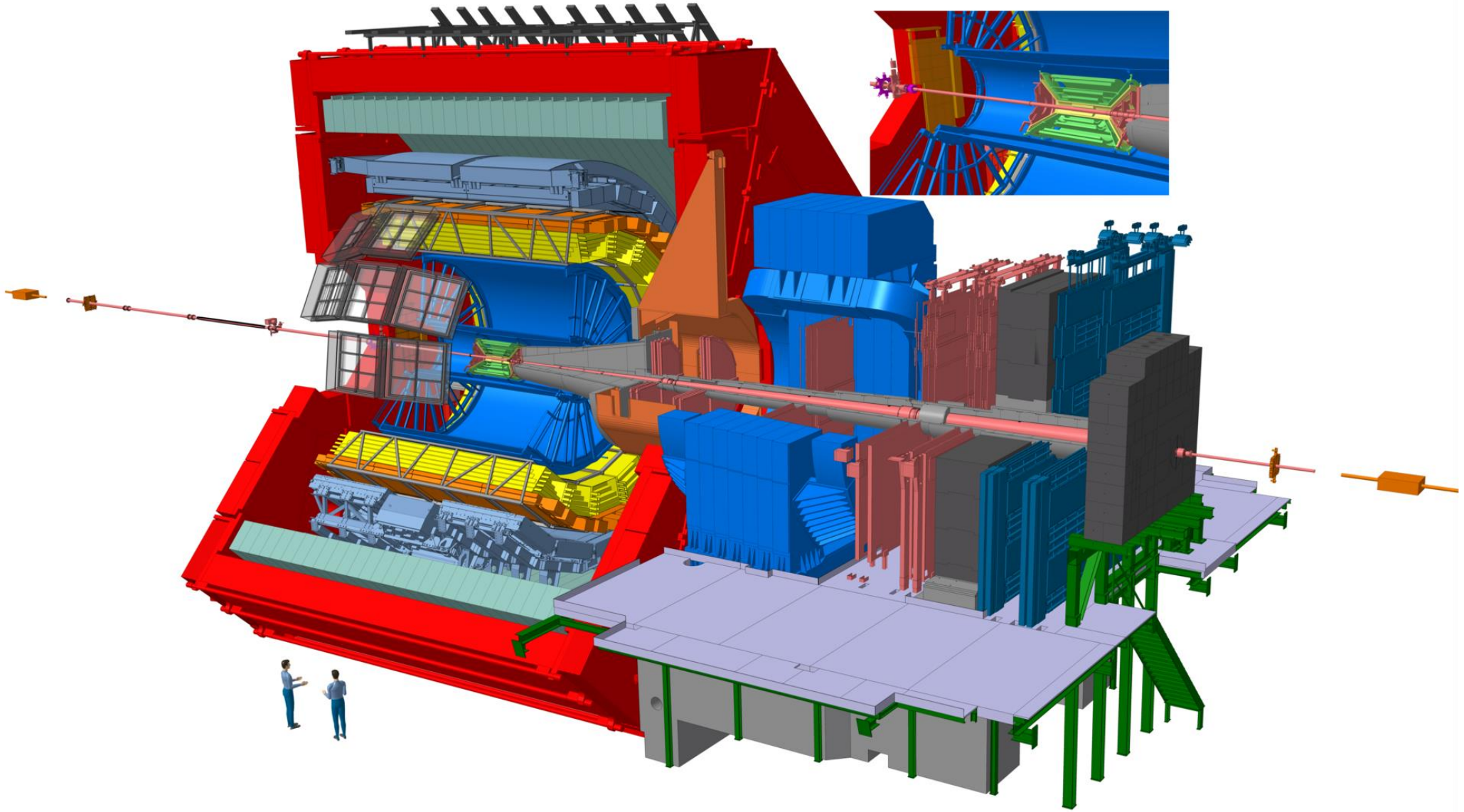
- Transverse-plane distribution of the gluons.

→ Related by a **2D Fourier** transform to the $|t|$ ($\sim p_T^2$) **dependence.**



Detector

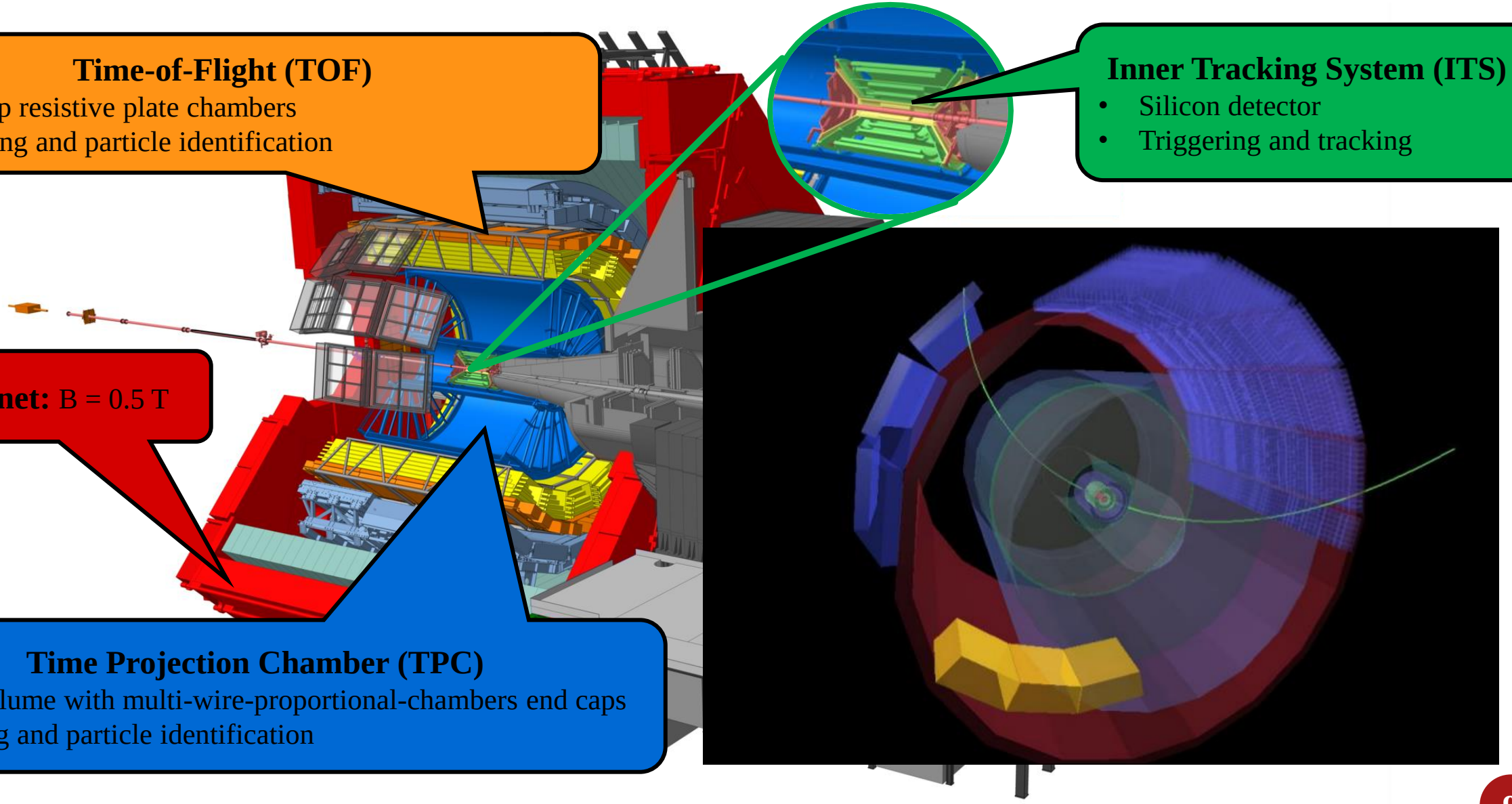
ALICE



ALICE: J/ψ measurement at midrapidity

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

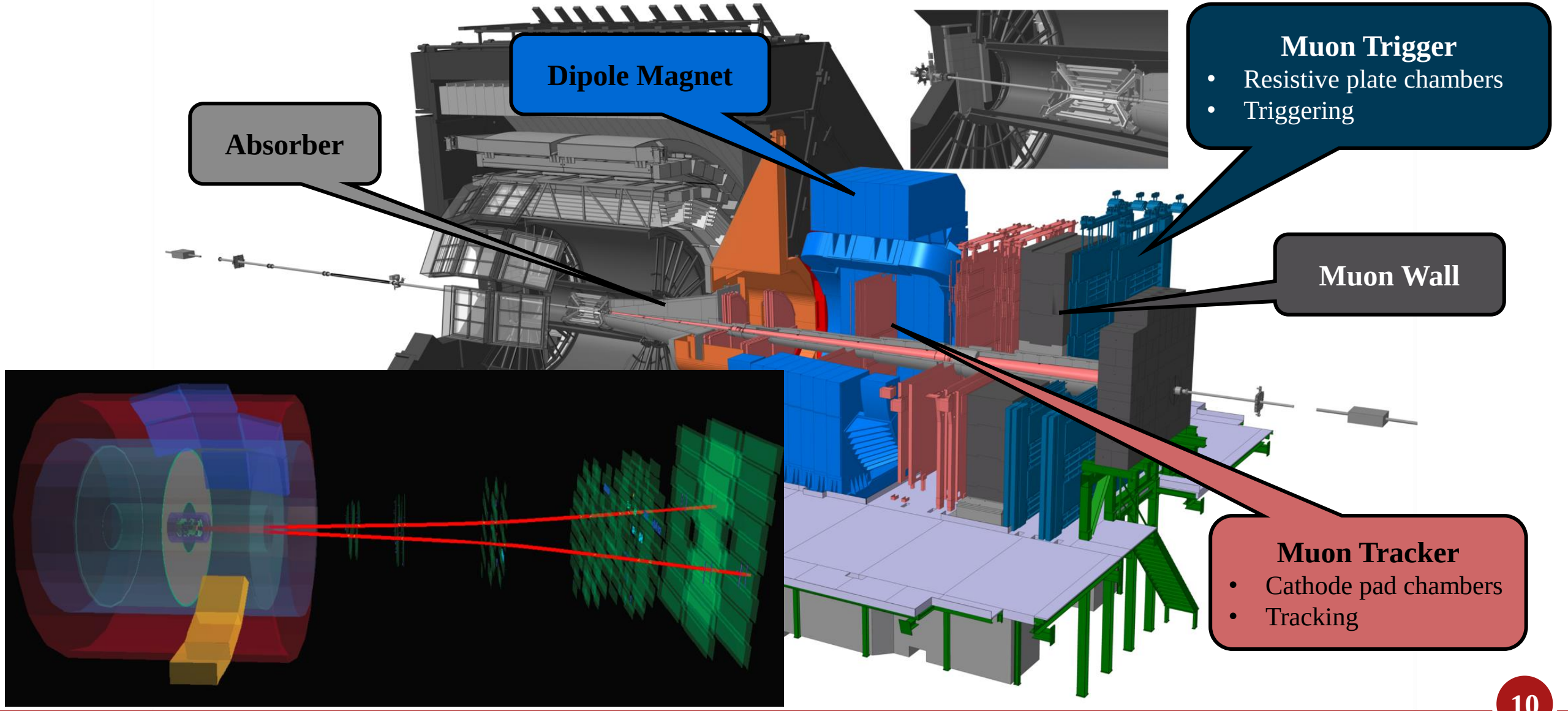
Inner Tracking System (ITS)
- Silicon detector
- Triggering and tracking



L3 Magnet: B = 0.5 T

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

ALICE: J/ψ measurement at forward rapidity

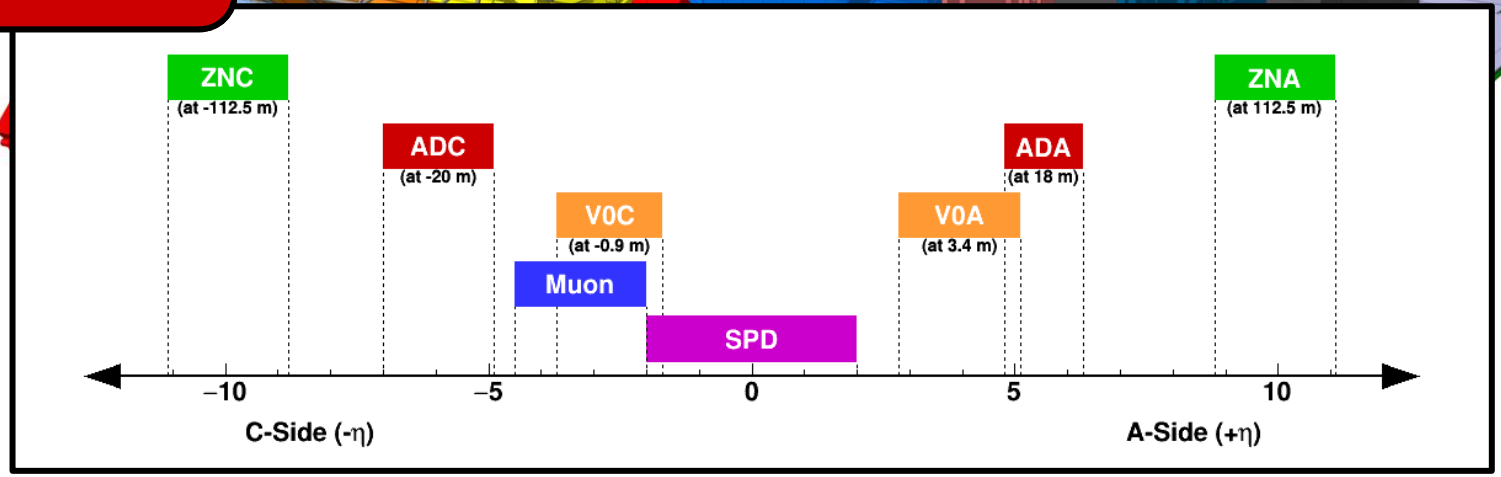


ALICE: Vetoes to enforce exclusivity condition

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

V0
- Scintillator counter
- Veto activity
- Luminosity determination

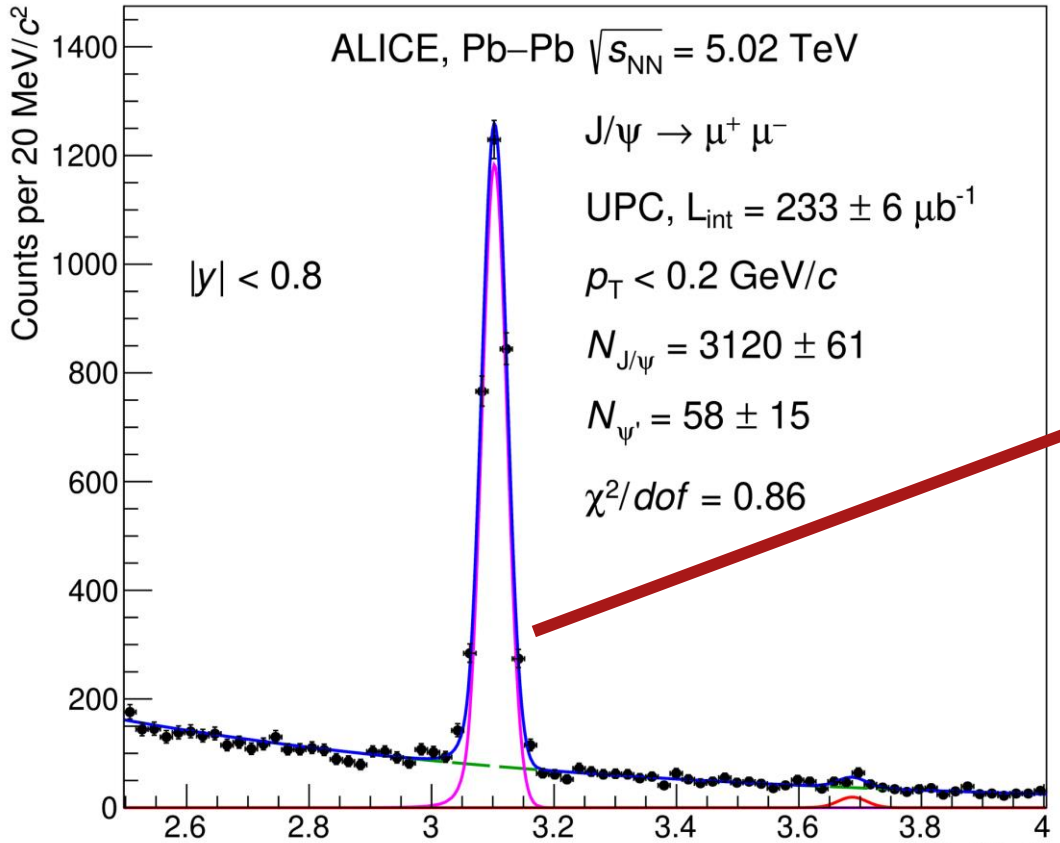
ALICE Diffractive (AD)
- Scintillator counter
- Veto activity



Results

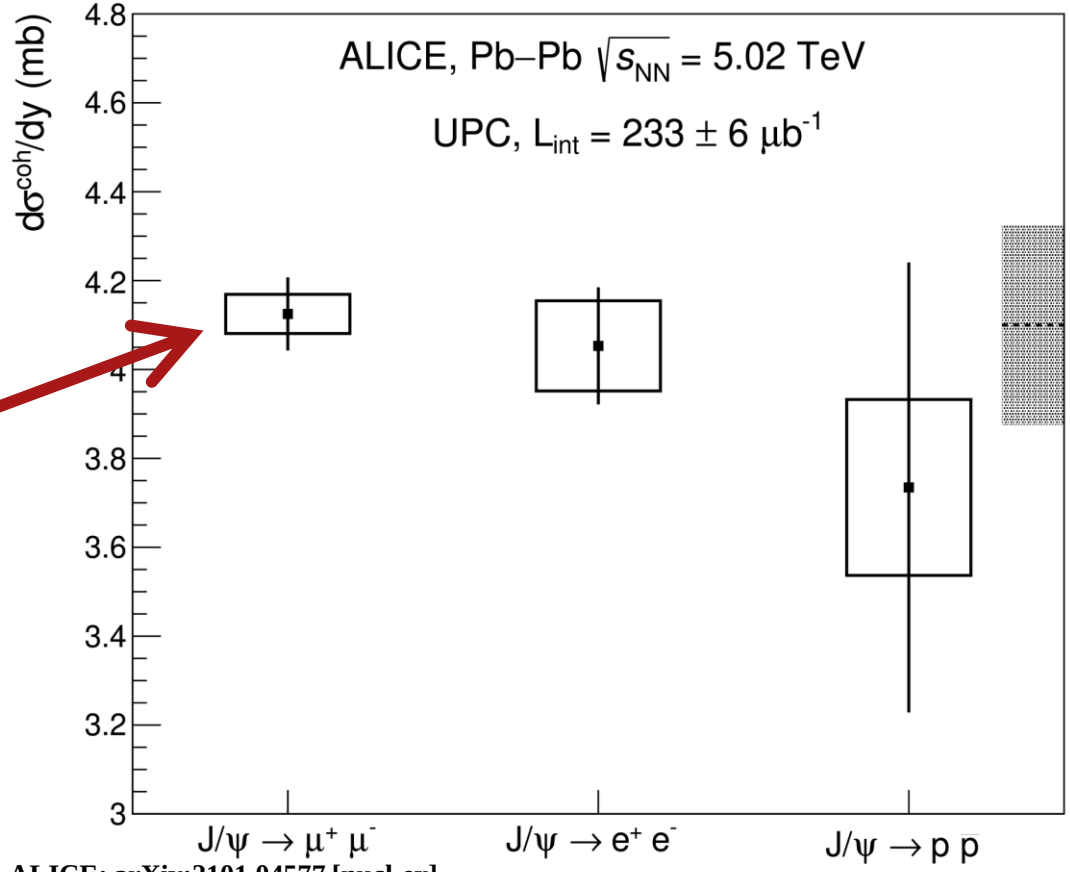
Coherent J/ψ cross section

- Very clear signal.
- Measured in 3 decay channels: $\mu^+\mu^-, e^+e^-, p\bar{p}$.



ALICE: arXiv:2101.04577 [nucl-ex]

ALI-PUB-482686

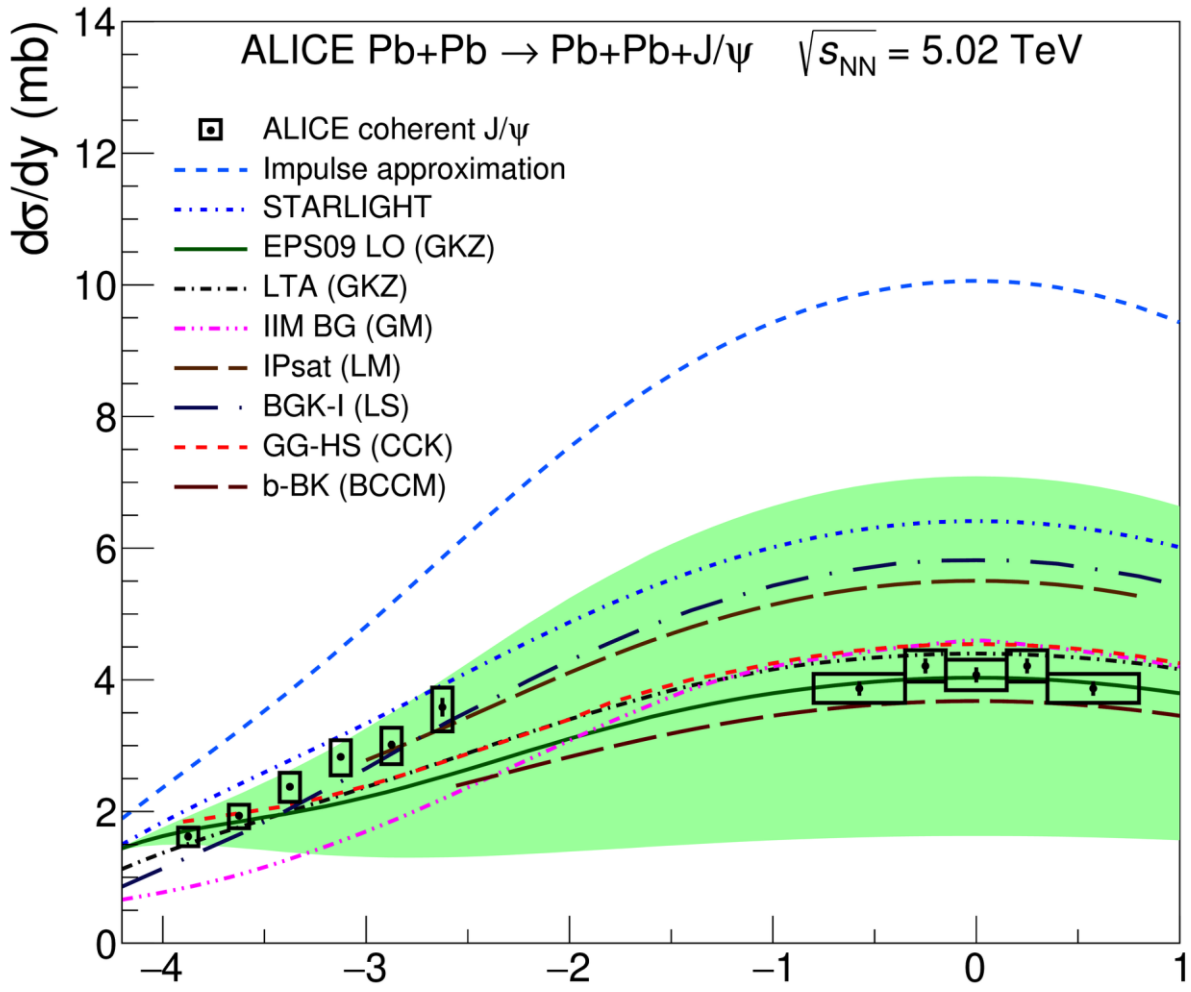


ALICE: arXiv:2101.04577 [nucl-ex]

ALI-PUB-482746

Coherent J/ψ cross section: y - dependence

- **Impulse approximation (IA):** Photoproduction data from protons, does not include nuclear effects except coherence.
- **STARlight:** Photoproduction data from protons + Vector Meson Dominance model, includes multiple scattering but no gluon shadowing.
- **EPS09 LO:** parametrization of nuclear shadowing data.
- **LTA:** Leading Twist Approximation of nuclear shadowing.
- **IIM BG, IPsat, BGK-I:** Color dipole approach coupled to the Color Glass Condensate formalism with different assumptions on the dipole-proton scattering amplitude.
- **GG-HS:** Color dipole model with hot spots nucleon structure.
- **b-BK:** Color dipole approach coupled with impact-parameter dependent Balitsky-Kovchegov equation.



ALICE: arXiv:2101.04577 [nucl-ex]

ALI-PUB-482756

Coherent J/ψ cross section: y - dependence

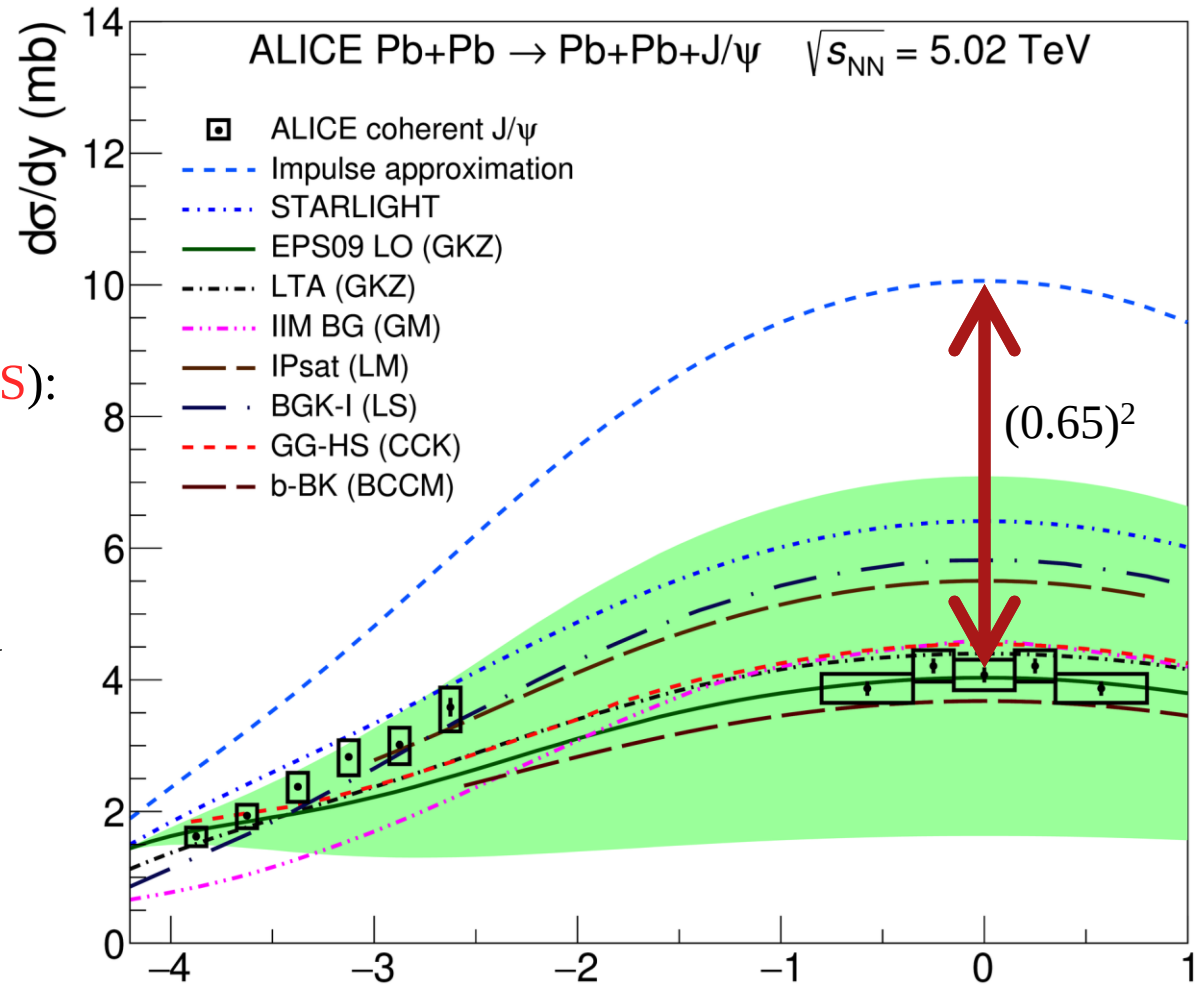
- **Nuclear suppression factor:** for $x \in (0.3,1.4) \cdot 10^{-3}$

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

- Models with **shadowing** (EPS09, LTA) and **saturation** (GG-HS):
  - Describe central and forward data.
  - Underestimate semi-forward data.
- Other models describe either the central or the forward rapidity region.

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

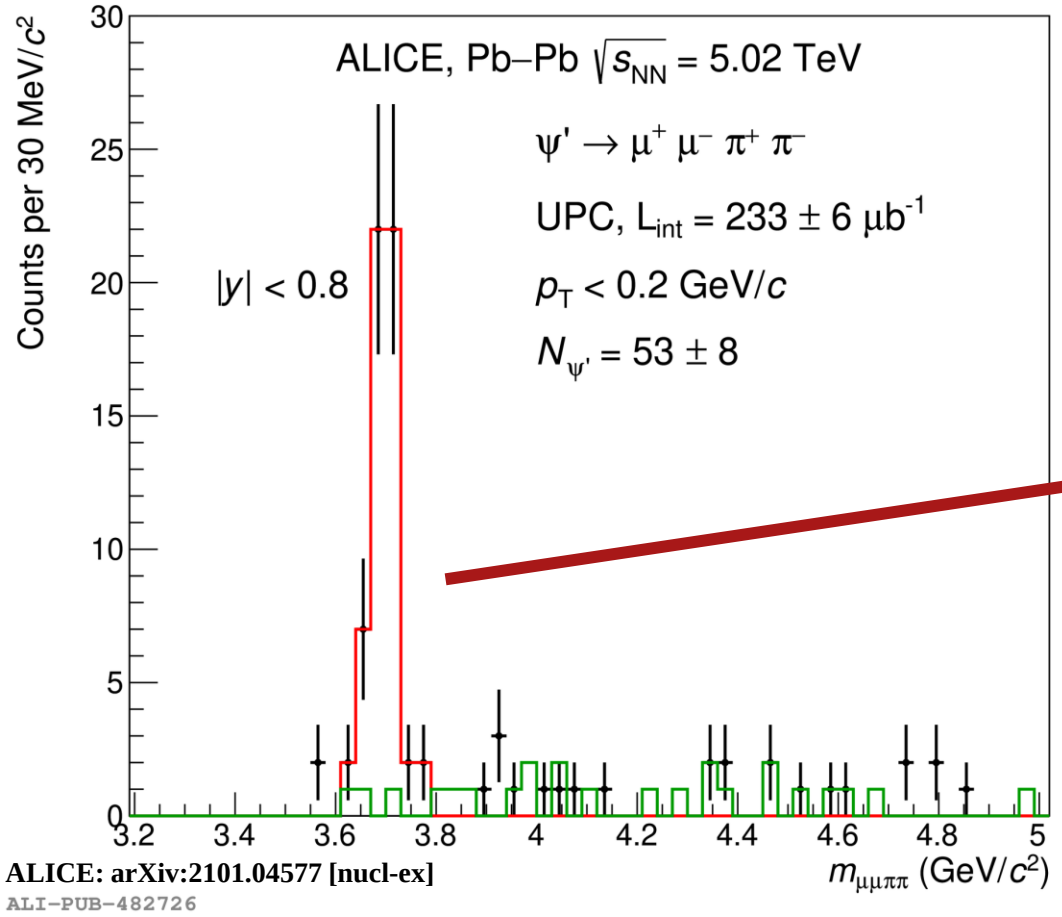
- Model with less shadowing at $x \sim 10^{-2}$ or $5 \cdot 10^{-5}$, $|y| \in (2.5,3.5)$, might describe the data better.



ALICE: arXiv:2101.04577 [nucl-ex]
ALI-PUB-482756

Coherent ψ' cross section

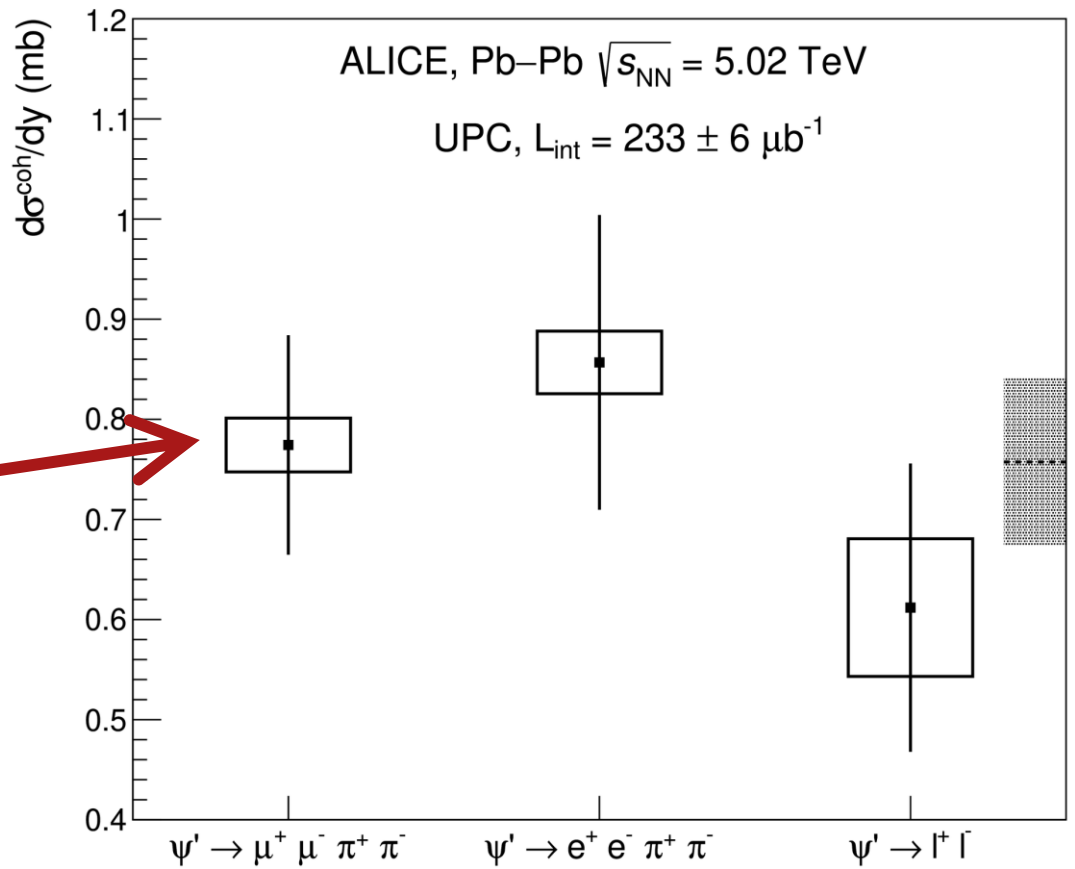
- Clear signal even with less events.



ALICE: arXiv:2101.04577 [nucl-ex]

ALI-PUB-482726

- Measured in 3 decay channels:
  $\mu^+\mu^-\pi^+\pi^-, e^+e^-\pi^+\pi^-, l^+l^-$.



ALICE: arXiv:2101.04577 [nucl-ex]

ALI-PUB-482751

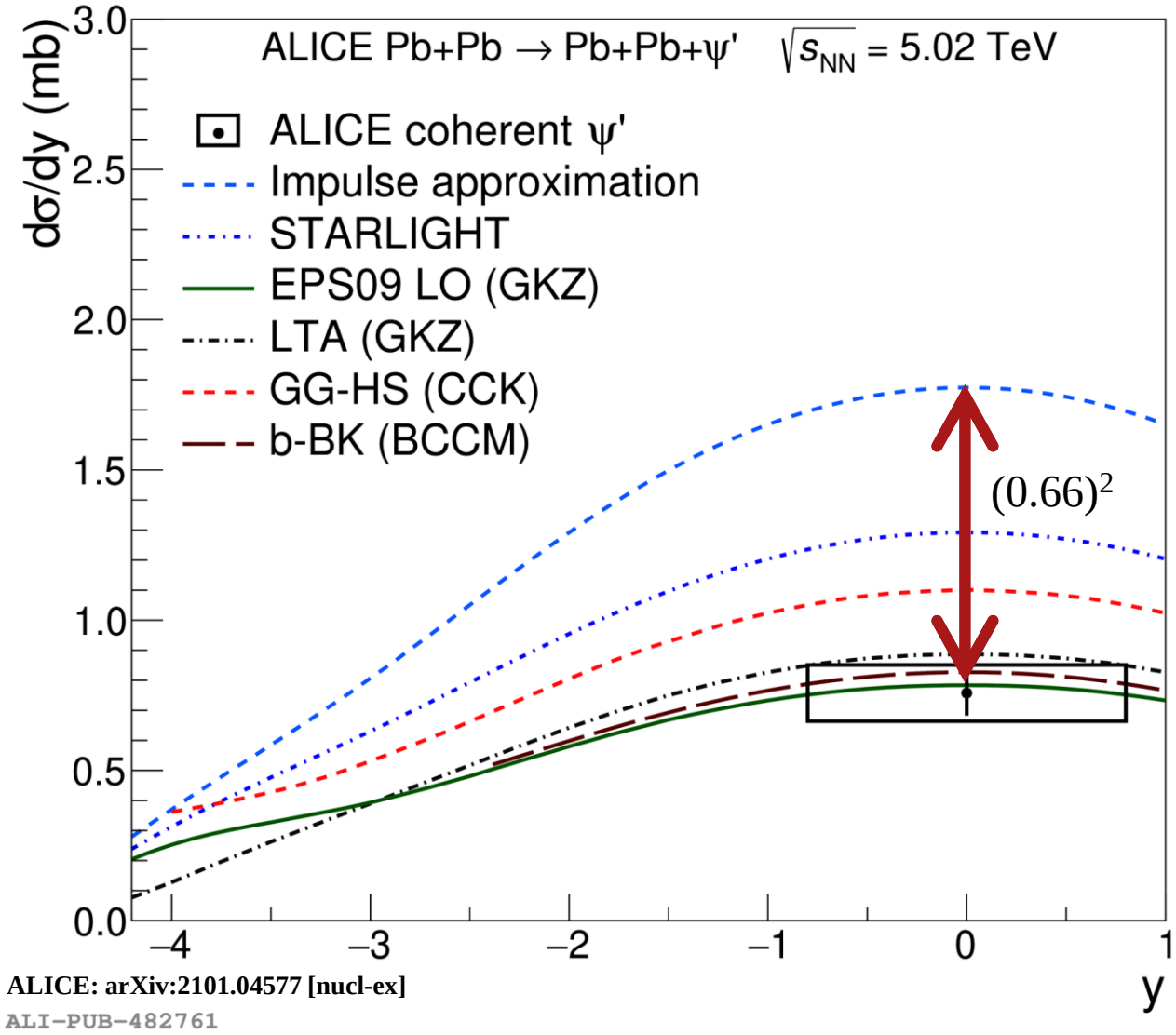
Coherent ψ' cross section: y - dependence

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

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

→ **Consistent with the J/ψ result**

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

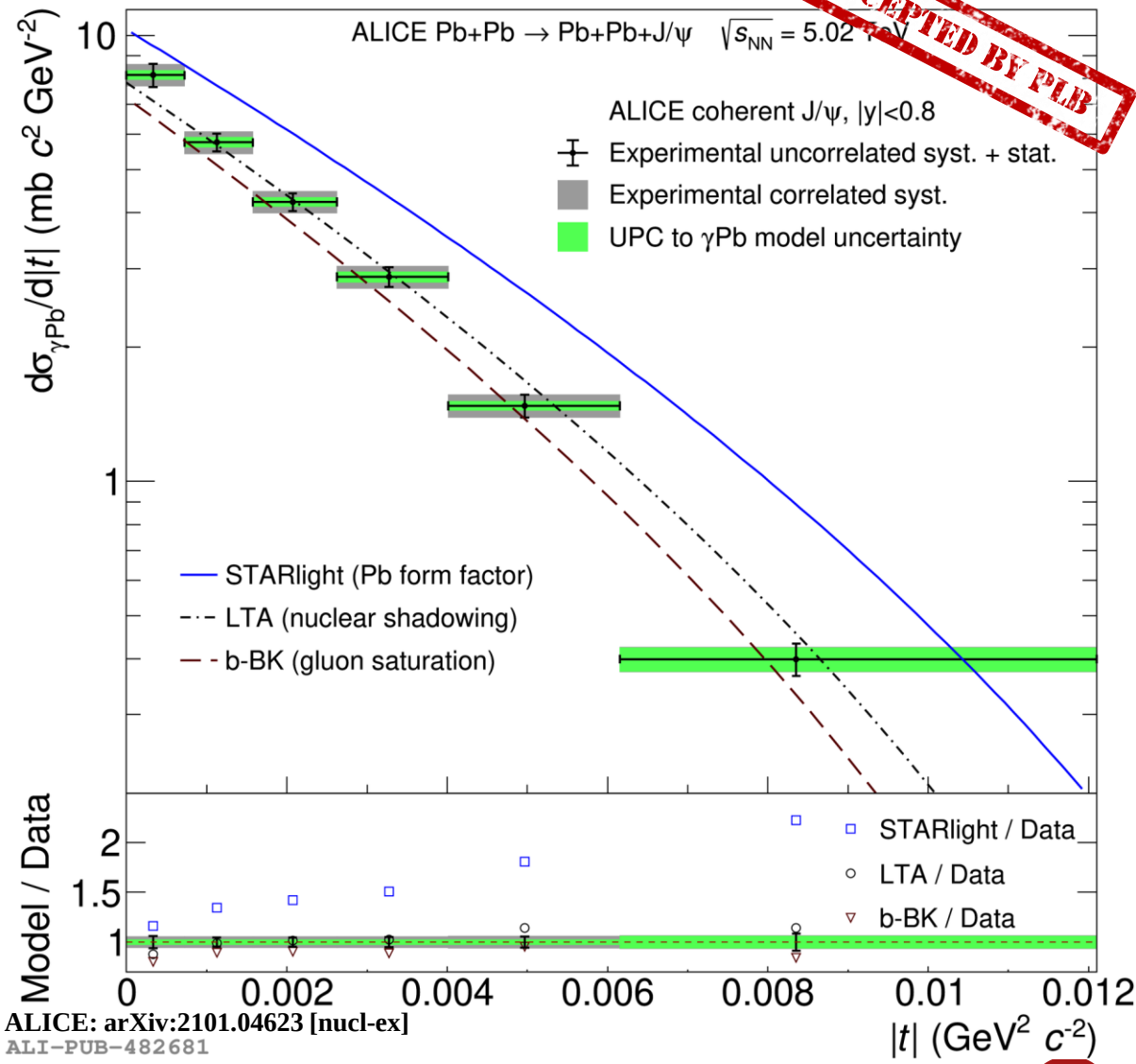


First measurement of coherent J/ψ cross section: $|t|$- dependence

- From p_{T}^2-dependent photoproduction to $|t|$-dependent photonuclear production:
  - p_{T}^2 to $|t|$ transition with two different unfolding methods.
  - Correction on interference of photon sources.
  - From UPC to photonuclear cross section using the photon flux, see e.g., Phys. Rev. C 96, 015203 (2017).

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

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

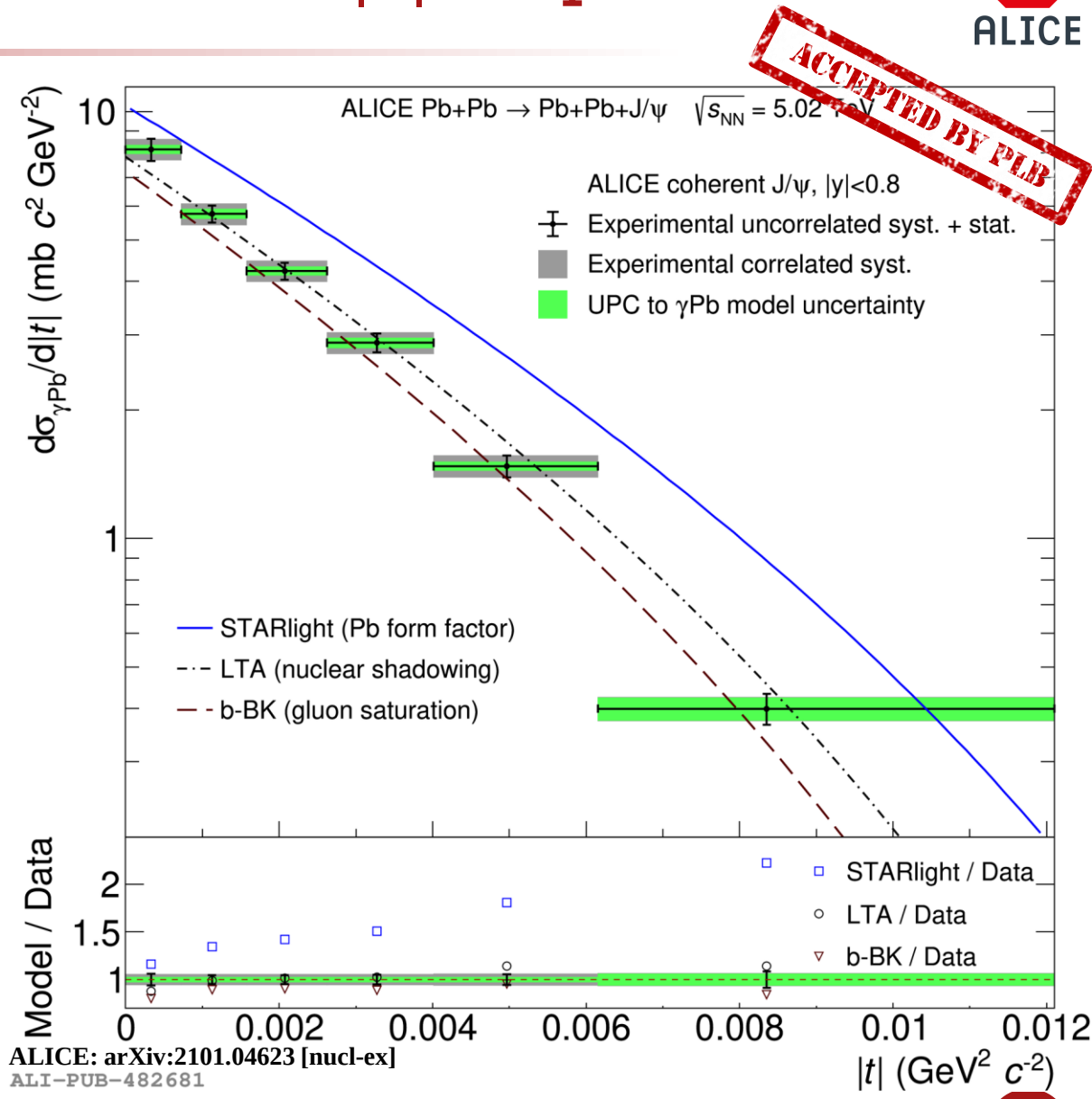


First measurement of coherent J/ψ cross section: $|t|$ - dependence

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

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

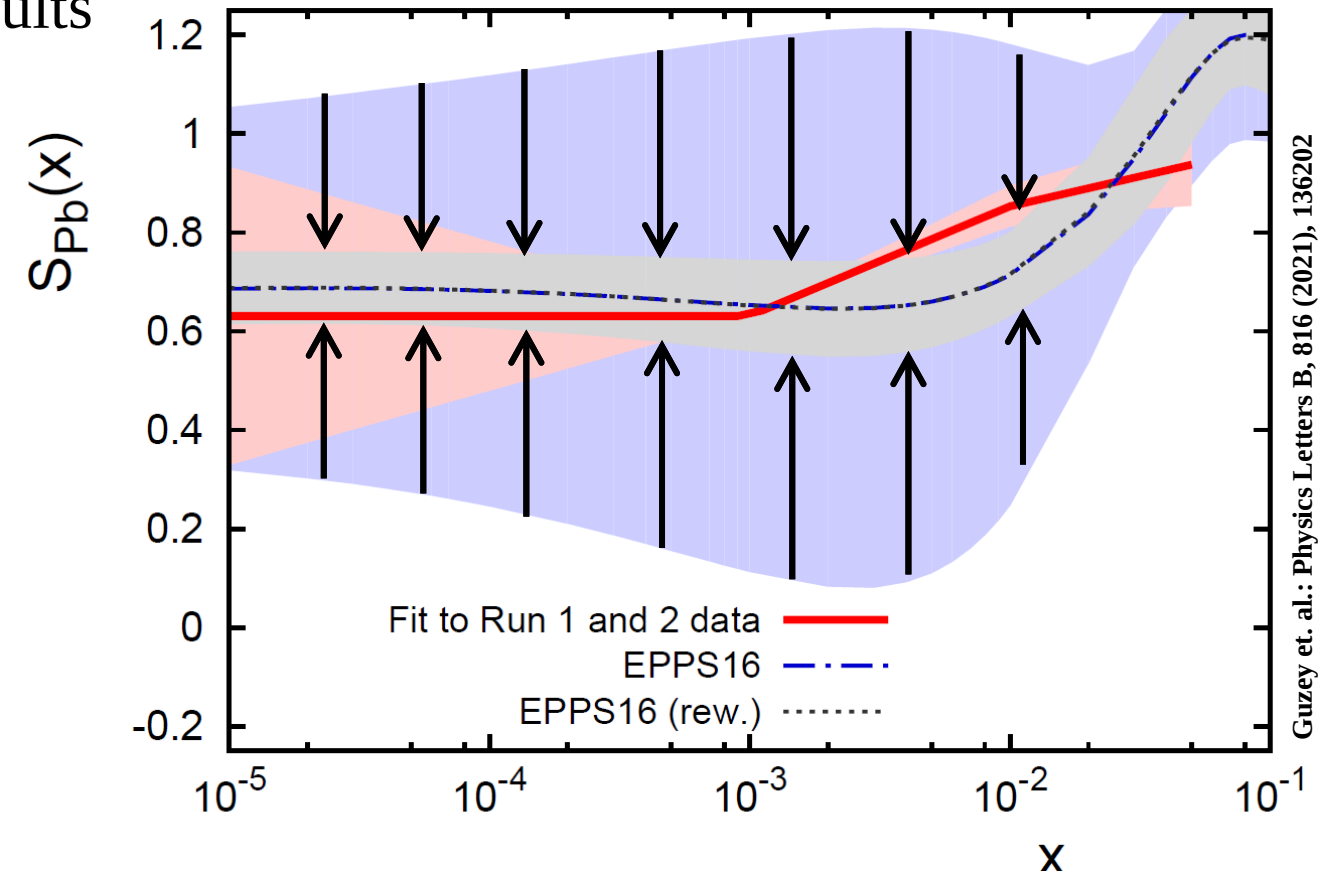
- Models based on pQCD describe data within current uncertainties:
  - Nuclear shadowing (LTA)
  - Gluon saturation (b-BK)
- Future measurements should allow to distinguish between the predictions.



Outlook

Outlook: Impact of ALICE and LHC UPC results

- Reweighted EPPS16 nPDFs with LHC results
  - **Run 2**: **ALICE** + **LHCb**
  - **Run 1**: **ALICE** + **CMS**



→ **Decrease in EPPS16 uncertainties!**

Outlook: LHC Runs 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**

ALICE Upgrades - 15 Apr 2021, Markus Fasel
https://indico.bnl.gov/event/9726/contributions/46030/

→ **Millions of J/ψ to be recorded by ALICE!**

	PbPb					
Meson	σ	All Total	Central 1 Total	Central 2 Total	Forward 1 Total l	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

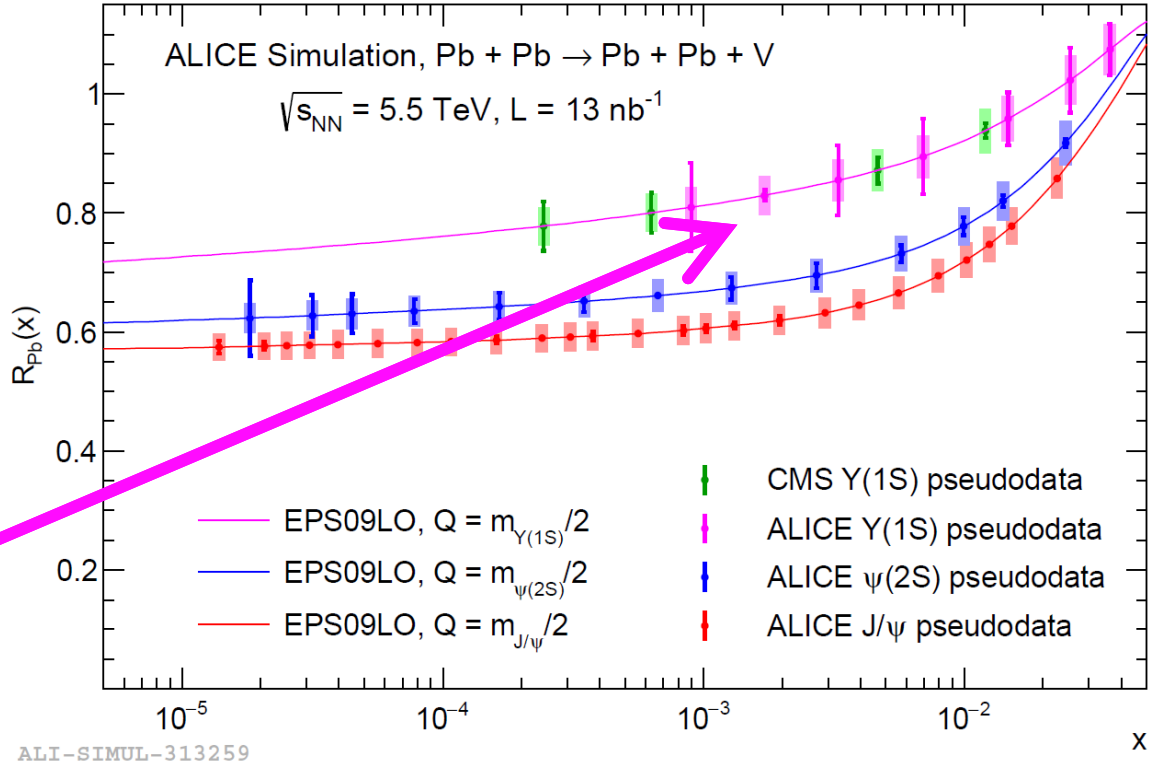
CERN Yellow Rep.Monogr. 7 (2019) 1159-1410

Outlook: LHC Runs 3 & 4

- **Improvements** in **statistical** precision, **systematic** uncertainties and **efficiency:**

  → Increased precision on all previous measurements.

- **New differential** measurements:
  - $\frac{\mathrm{d}^2\sigma}{\mathrm{d}y\mathrm{d}|t|}$
  - Angular dependences between l^+l^-
  - …
- **Completely new** measurements:
  - Υ(1S) - Q^2 factor 10 larger than J/ψ
  - Interference effects
  - ….



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Conclusion

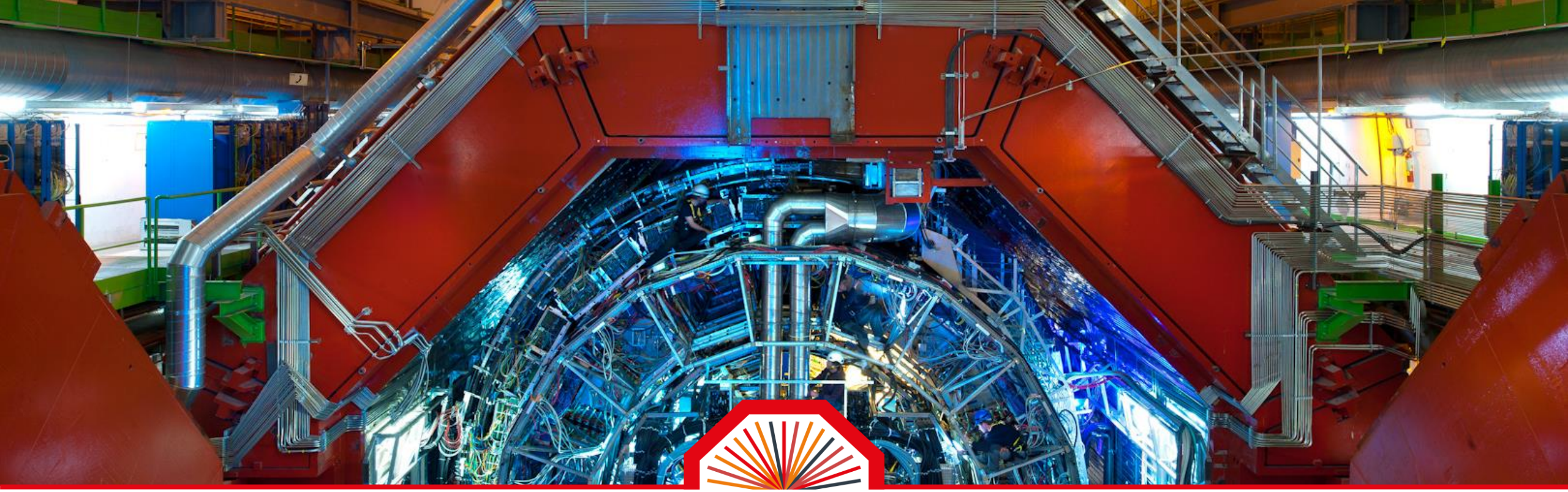
Conclusion

- Gluon structure at Bjorken $x \in (0.3, 1.4) \cdot 10^{-3}$:
  - $S_{\mathrm{Pb}} \approx 0.65$
  - $|t|$ dependence sensitive to gluon distribution in the transverse plane!
  - Models with shadowing or saturation describe data within uncertainties!

→ **Potential to significantly decrease nPDFs uncertainties!**

- Major improvements for Runs 3 & 4:

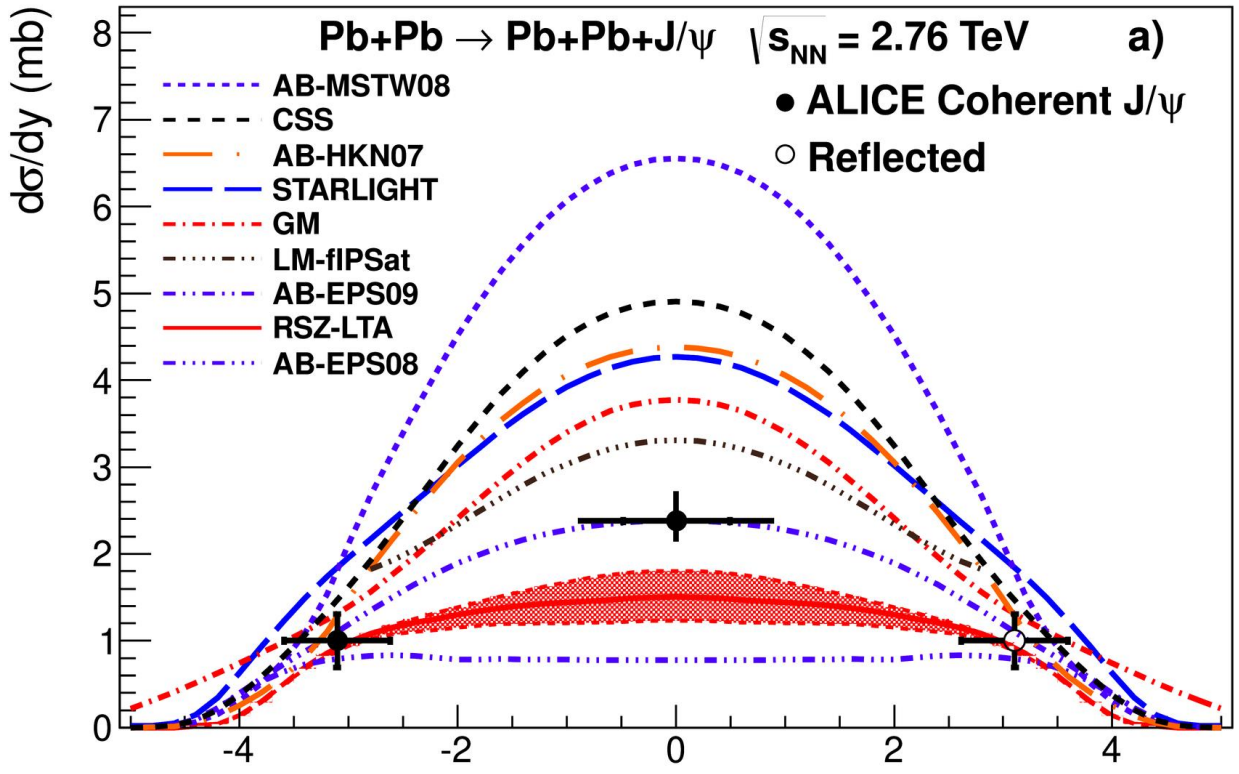
→ **Plenty of new results anticipated!**



Thank you for your attention!

Backup

Run 1 ALICE Pb-Pb UPC at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV

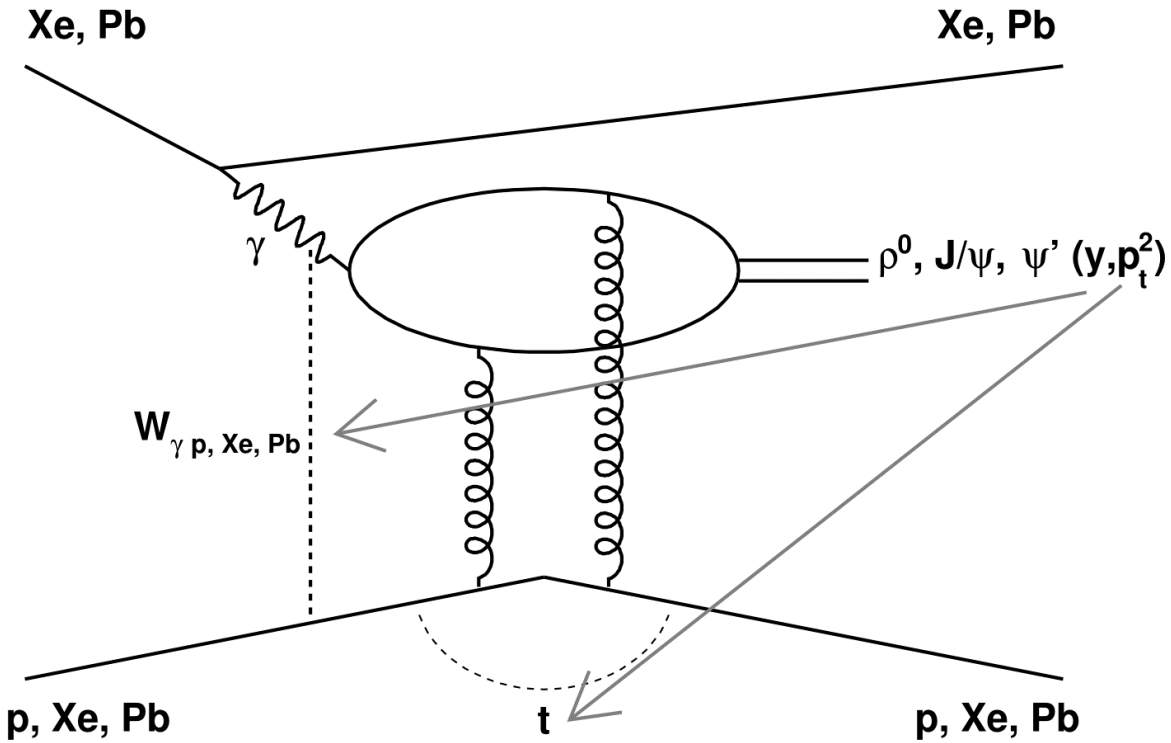


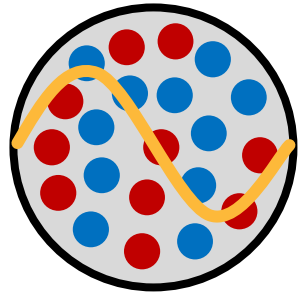
Phys. Lett. B 718 (2013) 1273-1283

ALI-PUB-66209

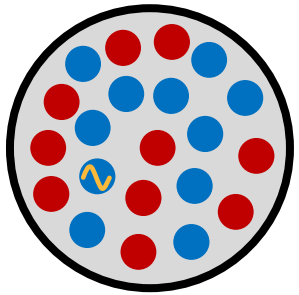
Photoproduction

- **Photoproduction** of **J/ψ** in **Pb-Pb** collision can be used to study nuclear structure:
  - Coherent - photon interacts with the whole nucleus $p_T \approx 60$ MeV/c ~ $1/R_{Pb}$
  - Incoherent - photon interacts with single nucleon $p_T \approx 300$ MeV/c ~ $1/R_N$



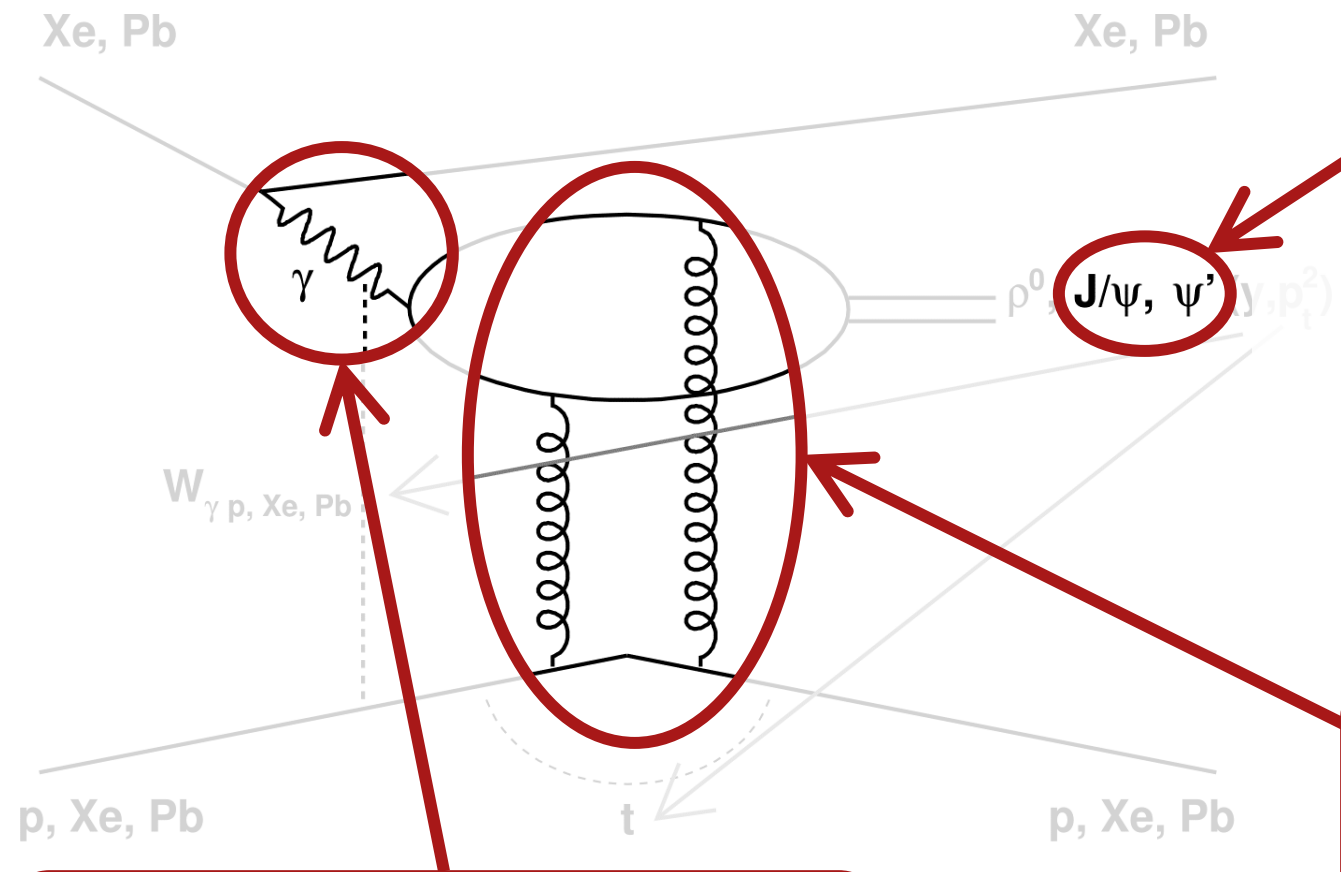


Coherent



Incoherent

Photoproduction



J/ψ, ψ'

- **Perturbative QCD** $Q^2 \sim \frac{M^2}{4}$
- **Clear** experimental **signal:**
  - Large lepton branching ratios
  - Small decay width
  - Exclusive production

Photon emission

- Flux **intensity** ~ Z^2
- Photon **energy** given by Pb **boost**

Photon target interaction

- In LO collinear pQCD:

$$\left.\frac{\mathrm{d}\sigma_{\gamma+A\to J/\psi+A}}{\mathrm{d}t}\right|_{t=0} = \frac{M_{J/\psi}^3 \Gamma_{ee} \pi^3 \alpha_s(Q^2)}{48 \alpha_{em} Q^8} \left[x g_A(x, Q^2)\right]^2$$

M.G. Ryskin, Z.Phys. C57 (1993) 89-92

Uncertainties

	$J/\psi \to \mu^+\mu^-$	$J/\psi \to e^+e^-$	$J/\psi \to p\bar{p}$
Signal Extraction	0.5	2.4	0.7
Incoherent contamination	0.8	0.5	0.8
Branching ratio	0.5	0.5	1.4
TOF matching	–	–	5.0
ITS-TPC matching	2.8	2.8	2.8
AD and V0 veto	3.0	3.0	3.0
SPD trigger efficiency	1.0	1.0	1.0
TOF trigger efficiency	0.7	0.7	0.7
Luminosity	2.7	2.7	2.7
EMD correction	2.0	2.0	2.0
Feed down	0.6	0.6	0.6
Channel uncorrelated	1.1	2.5	5.3
Channel correlated	5.5	5.5	5.5

ALICE: arXiv:2101.04577 [nucl-ex]

	$\psi' \to \mu^+\mu^-\pi^+\pi^-$	$\psi' \to e^+e^-\pi^+\pi^-$	$\psi' \to l^+l^-$
Signal Extraction	1.0	2.0	10.0
Incoherent contamination	1.4	1.8	1.8
Branching ratio	1.5	1.5	4.8
ITS-TPC matching pions	2.8	2.8	–
ITS-TPC matching leptons	2.8	2.8	2.8
AD and V0 veto	10.0	10.0	10.0
SPD trigger efficiency	1.0	1.0	1.0
TOF trigger efficiency	0.7	0.7	0.7
Luminosity	2.7	2.7	2.7
EMD correction	2.0	2.0	2.0
Channel uncorrelated	3.5	5.8	11.2
Channel correlated	11.0	11.0	11.0

ALICE: arXiv:2101.04577 [nucl-ex]

Uncertainties

Source	Uncertainty (%)
Signal extraction	(0.7,2.2)
f_{D}	(0.1,0.5)
f_{I}	(1.1,2.3)
p_{T}^2 migration unfolding	(0.6,2.3)
Luminosity	2.7
V0 and AD veto	3
EM dissociation	2
ITS-TPC tracking	2.8
SPD and TOF efficiency	1.3
Branching ratio	0.5
Variations in interference strength	(0.3,1.2)
Value of the photon flux at $y = 0$	2
$p_{\mathrm{T}}^2 \rightarrow \lvert t \rvert$ unfolding	(0.1,5.7)

ALICE: arXiv:2101.04623 [nucl-ex]