Recent ALICE results on charmonium photoproduction

S. Ragoni for the ALICE Collaboration

Creighton University, USA

Outline

- Introduction to Ultraperipheral Collisions (UPC)
- The ALICE detector
- Exclusive and dissociative J/ψ in p-Pb
- J/ψ in Pb-Pb (or better, *coherent* J/ψ)
- Disentangling low and high Bjorken-*x*
- Beyond Run 2

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Introduction to Ultraperipheral Collisions (UPC)

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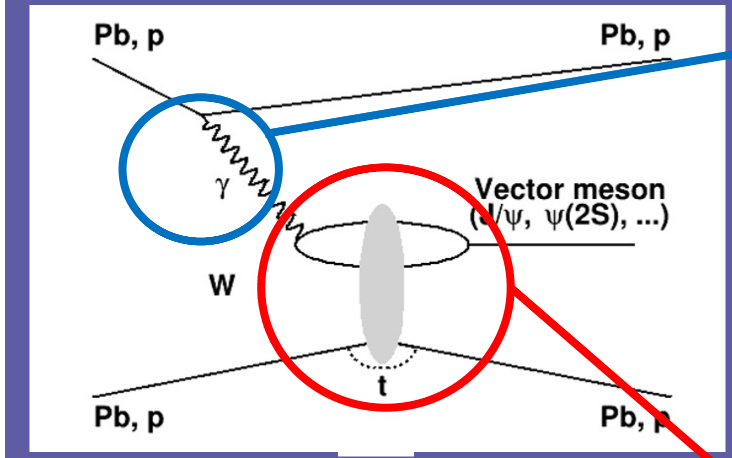

- High impact parameter (beyond the reach of the strong interaction)
- Vector meson production
- E.g. $\rho^0, J/\psi, \psi(2S)$

Only QED involved at this vertex!

LO

$$\frac{d\sigma^T(\gamma p \to J/\Psi + p)}{dt} = \frac{|M|^2}{16\pi s^2}$$

$$= [F_N^{2G}(t)]^2 \frac{\alpha_s^2 \Gamma_{ee}^J m_J^3}{3\alpha_{e.m.}} \pi^3 \left[\bar{x}G(\bar{x},\bar{q}^2)\frac{2\bar{q}^2 - |q_t^J|^2}{(2\bar{q}^2)^3}\right]^2$$

Ryskin: Z. Phys. C 57, 89-92 (1993)

Hard scale assured by high mass states i.e. $J/\psi, \psi(2S)$

Semi-hard scale for ρ^0

- *Coherent photoproduction:* photon couples with the entire nucleus
- *Incoherent photoproduction:* photon couples with a single nucleon only
- Different average p_T of the vector mesons for the two processes

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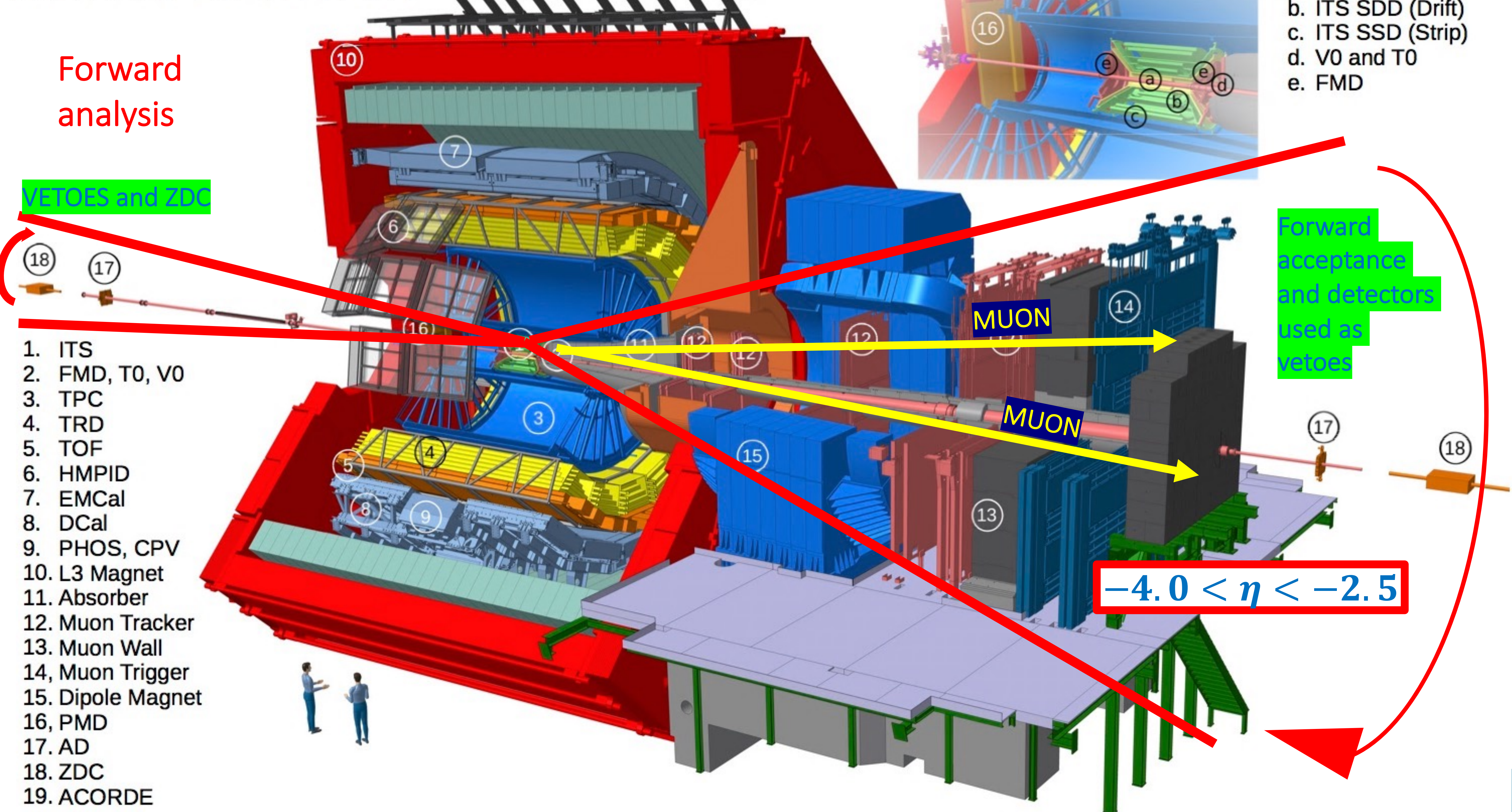
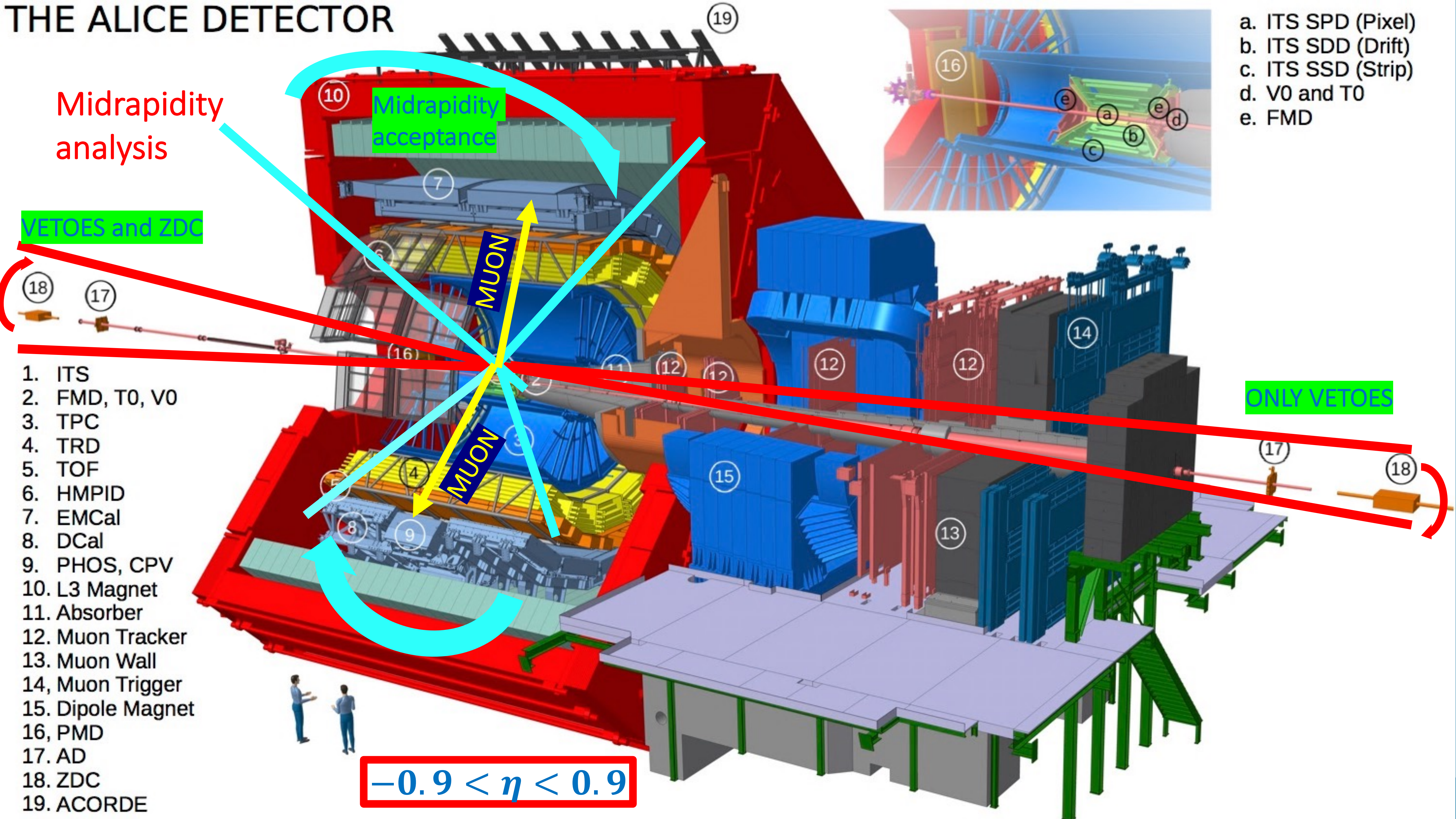
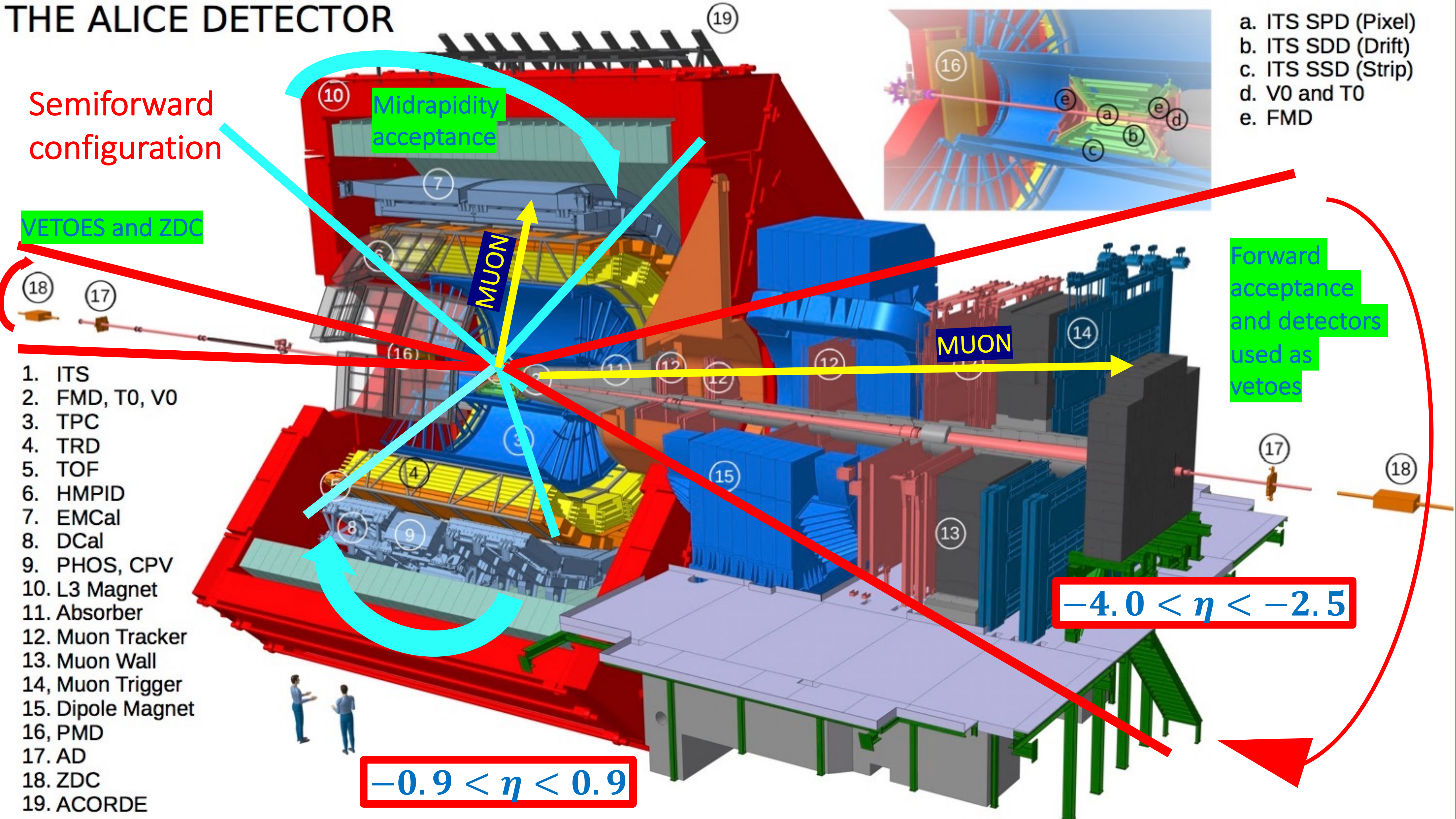
THE ALICE DETECTOR




THE ALICE DETECTOR
Midrapidity analysis
Midrapidity acceptance
VETOES and ZDC
ONLY VETOES
MUON
MUON
a. ITS SPD (Pixel)
b. ITS SDD (Drift)
c. ITS SSD (Strip)
d. V0 and T0
e. FMD
1. ITS
2. FMD, T0, V0
3. TPC
4. TRD
5. TOF
6. HMPID
7. EMCal
8. DCal
9. PHOS, CPV
10. L3 Magnet
11. Absorber
12. Muon Tracker
13. Muon Wall
14, Muon Trigger
15. Dipole Magnet
16, PMD
17. AD
18. ZDC
19. ACORDE
$-0.9 < \eta < 0.9$

THE ALICE DETECTOR



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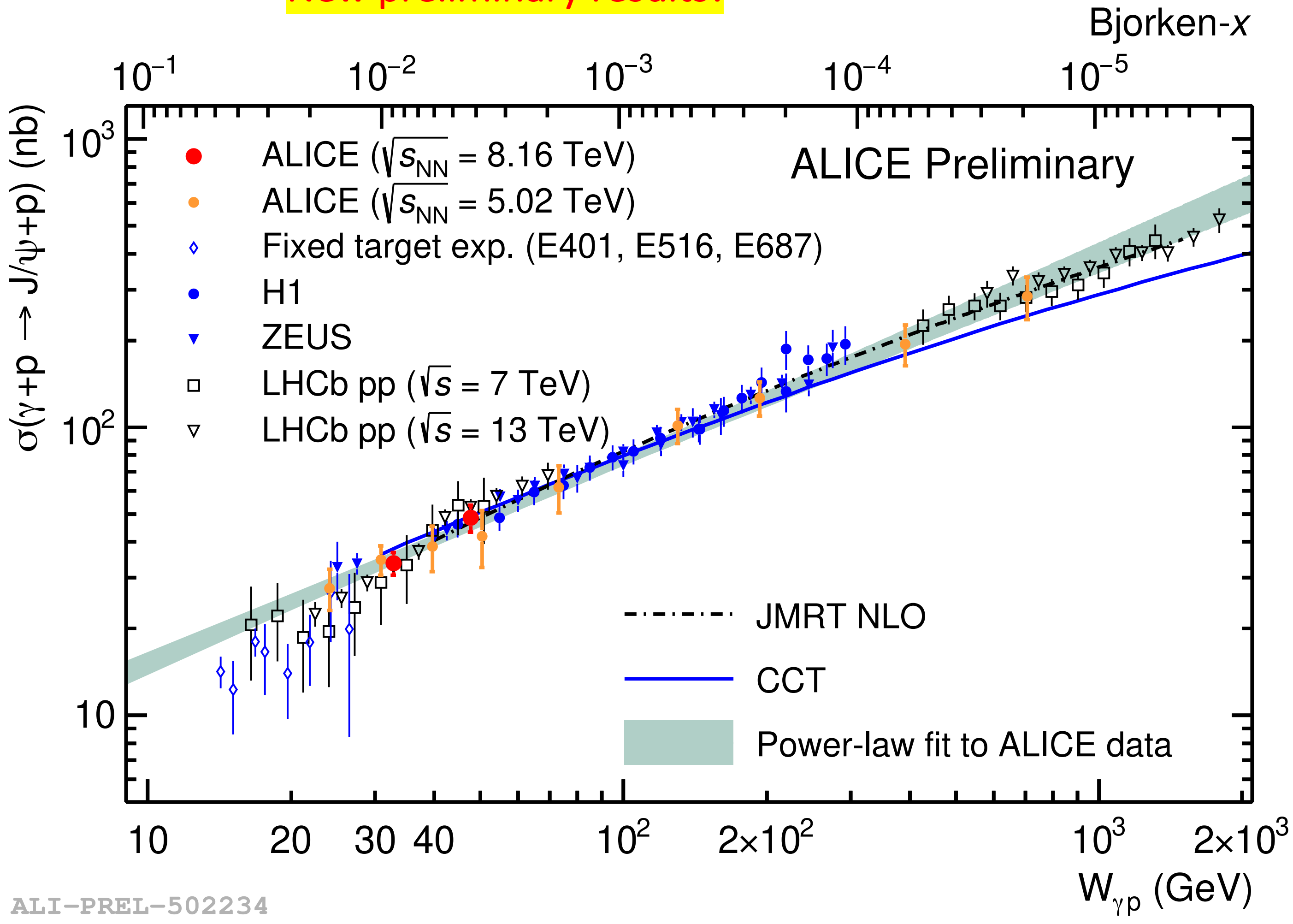
Exclusive J/ψ in p-Pb

- $x = e^{\pm|y|}\ {}^{M_{\mathrm{J}/\psi}}/_{2\mathrm{E_p}}$
- Probing Bjorken-$x \sim 10^{-5}$ with ALICE data
- power-law growth of cross-sections → power-law growth of gluon distributions down to $x \sim 10^{-6}$ -> no clear signs of gluon saturation
- ALICE points: forward, semiforward and midrapidity configurations
  - Forward: two muons in the spectrometer
  - Semiforward: one in the spectrometer, one in the central barrel
  - Midrapidity: two muons/electrons in the central barrel

New preliminary results!



Eur. Phys. J. C (2019) 79: 402 (ALICE midrapidity and semiforward),
Phys. Rev. Lett. 113 no. 23, (2014) 232504 (ALICE forward)

Exclusive J/ψ in p-Pb

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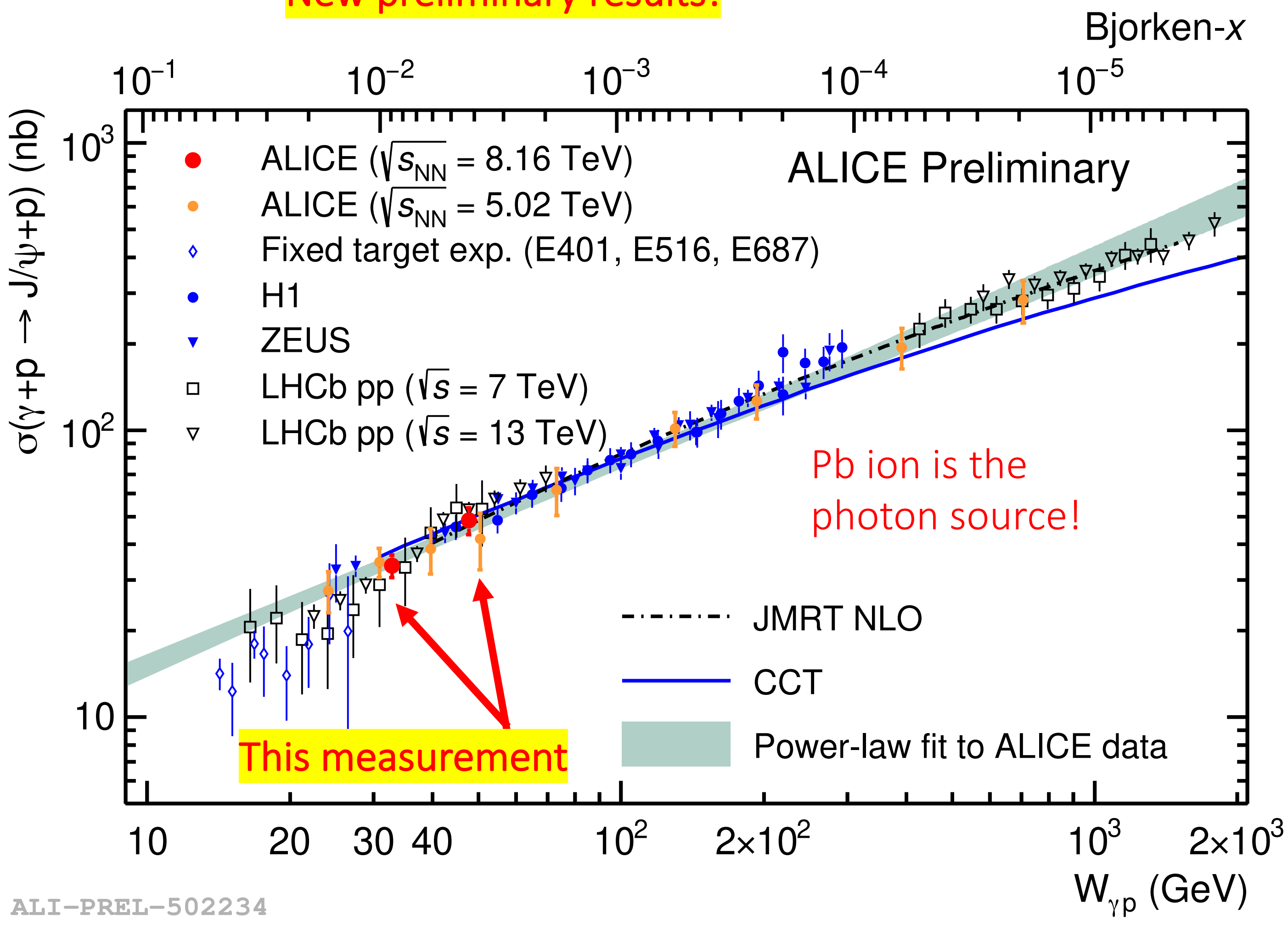

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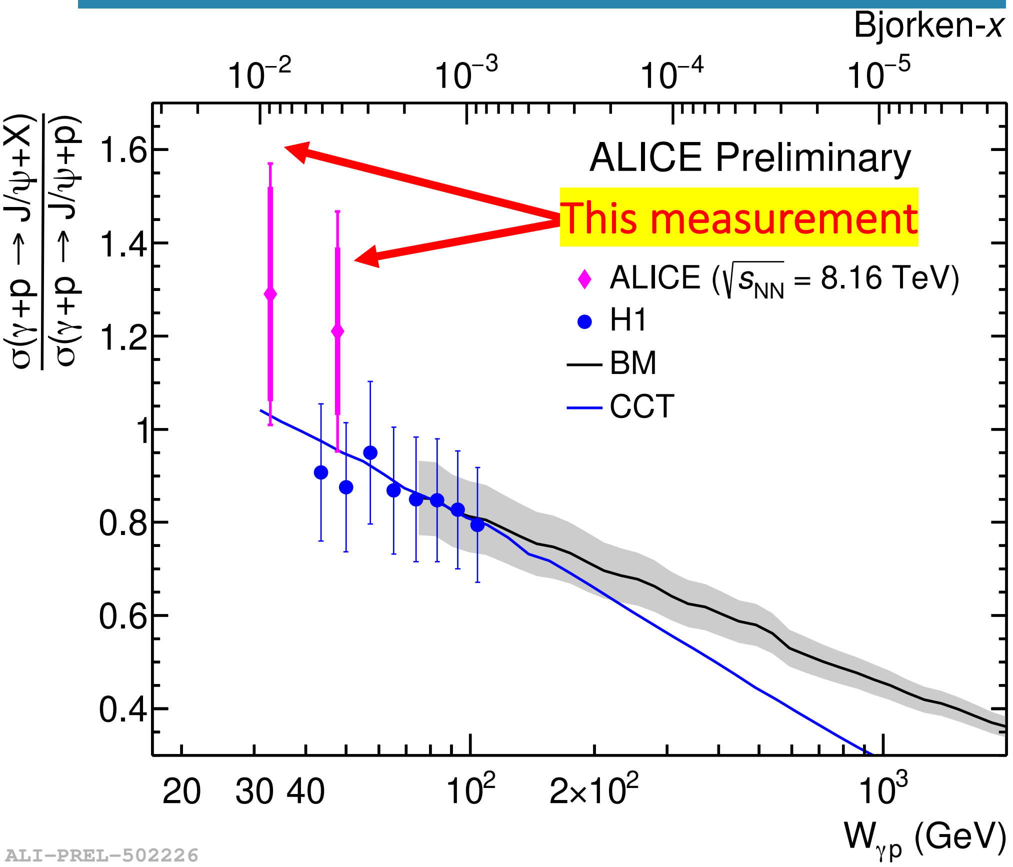
Phys. Rev. Lett. 113 no. 23, (2014) 232504 (ALICE forward)

Exclusive and dissociative J/ψ in p-Pb

- First result at the LHC of the measurement of dissociative J/ψ



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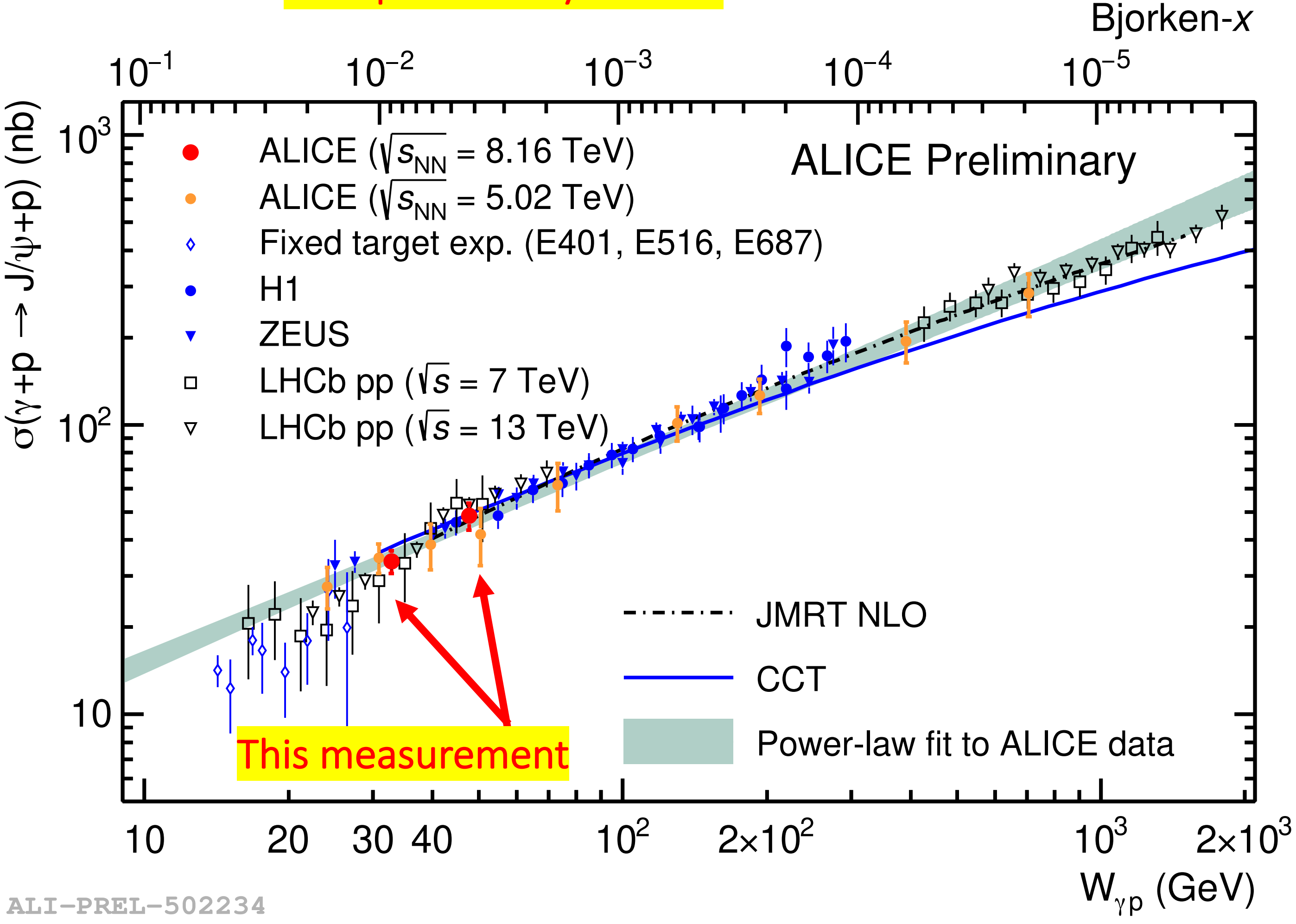

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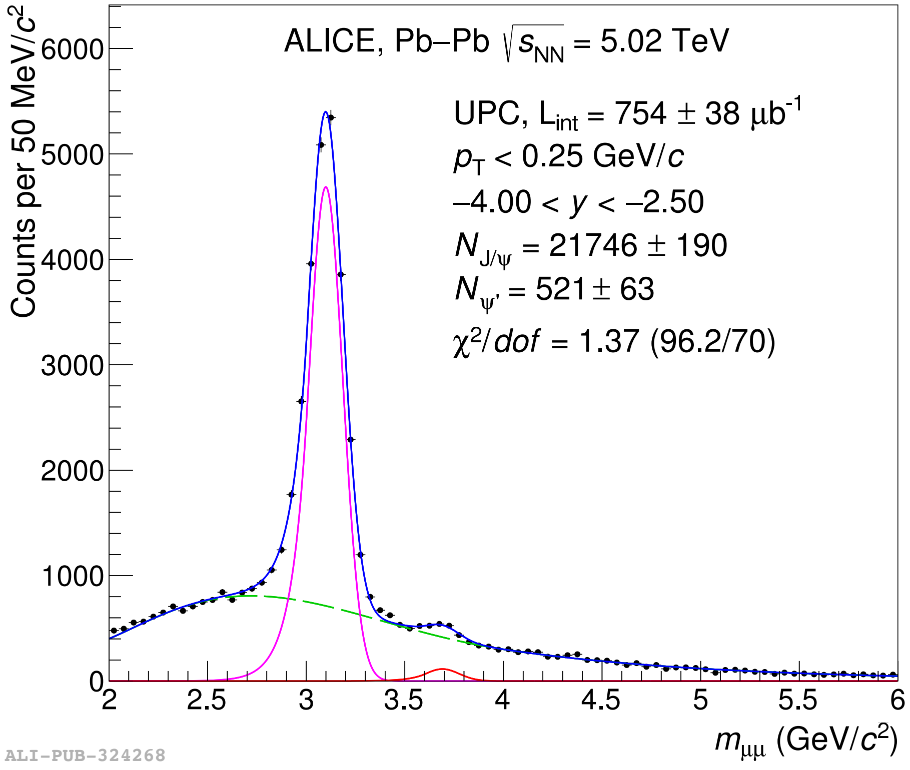
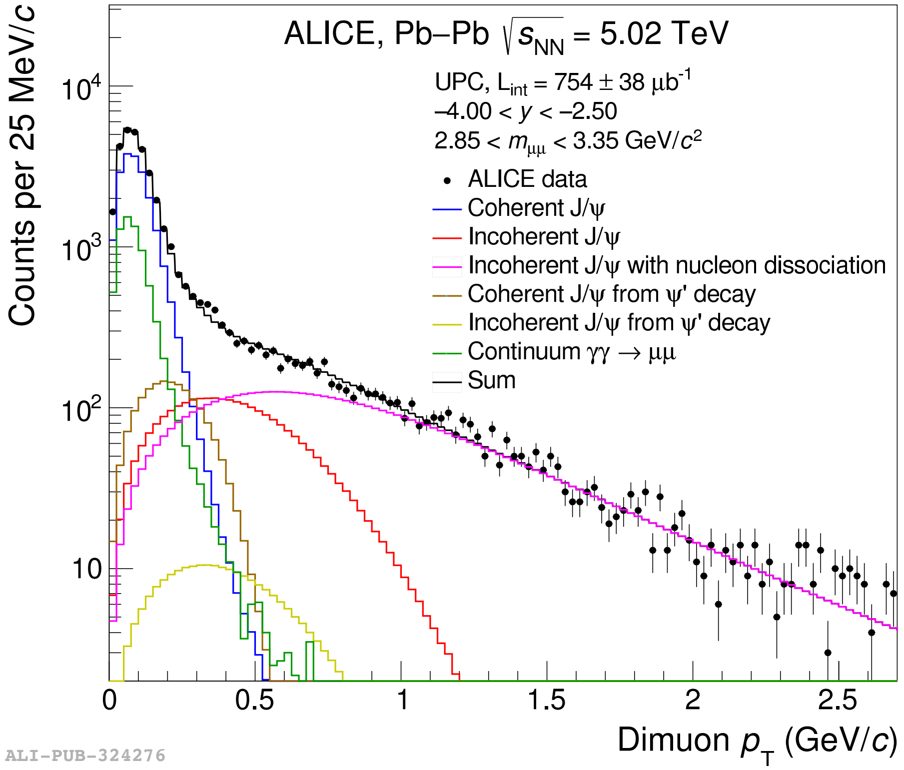
Coherent vs incoherent J/ψ



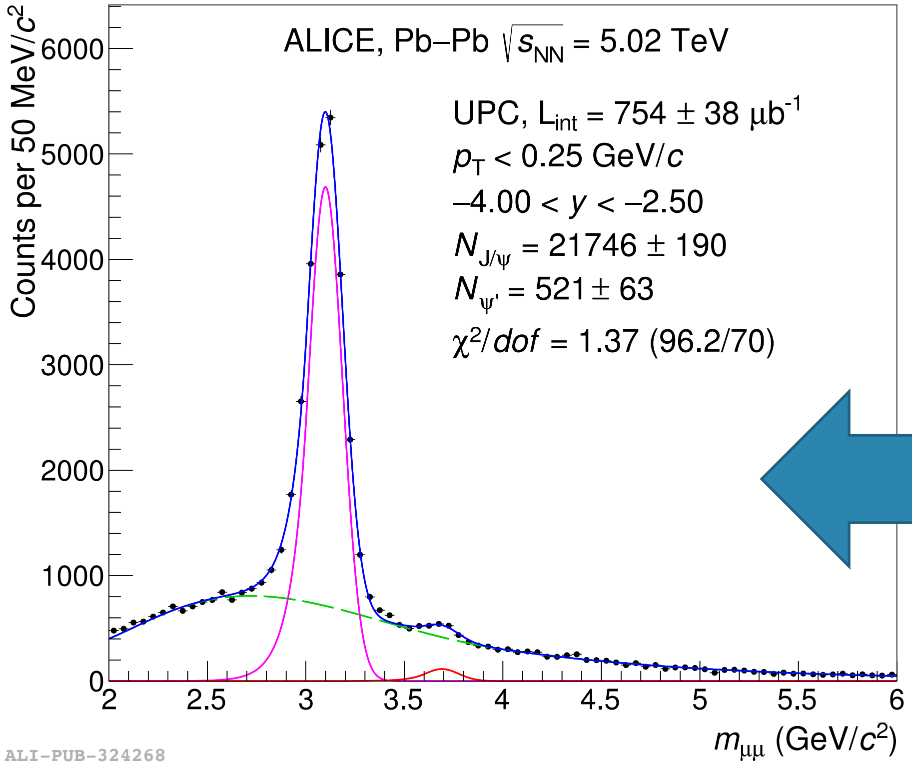


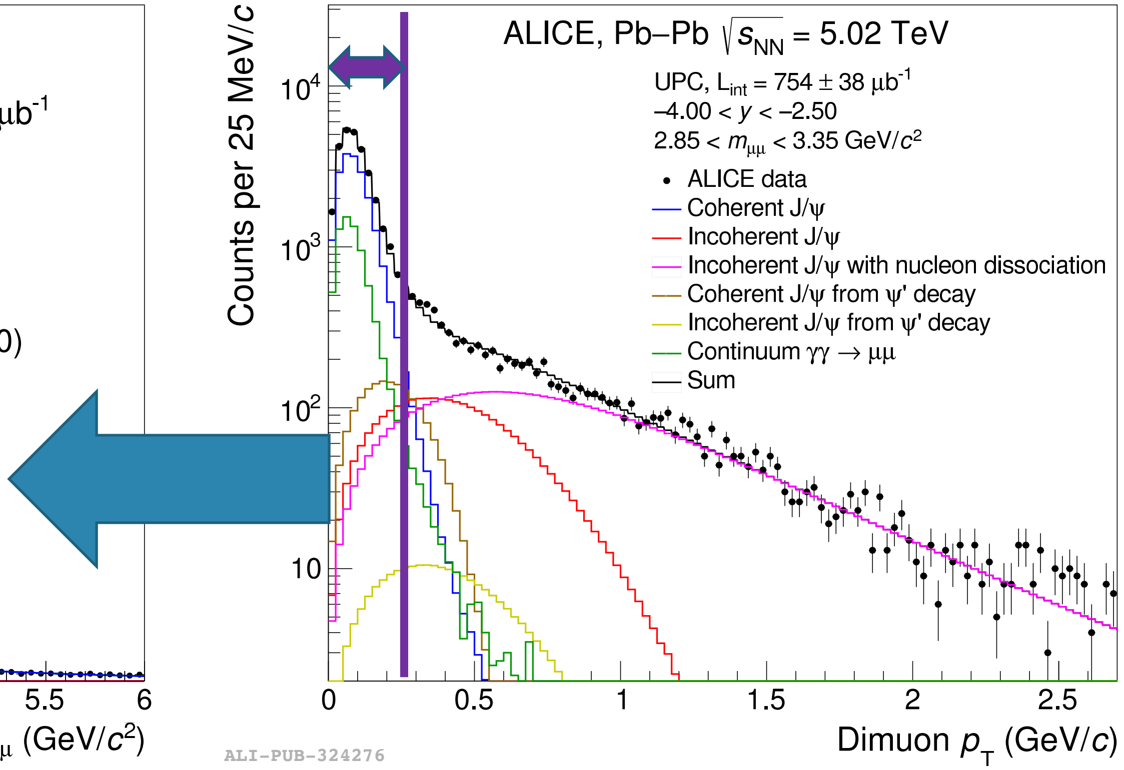
Plots in the dimuon channel (only available channel at forward rapidity)

Phys.Lett. B798 (2019) 134926

- Coherent (dimuon $p_T < 0.25$ GeV/c) – photon couples to entire nucleus *coherently*
- Incoherent much wider p_T distribution – photon interacts with a single nucleon of the target nucleus

Coherent vs incoherent J/ψ





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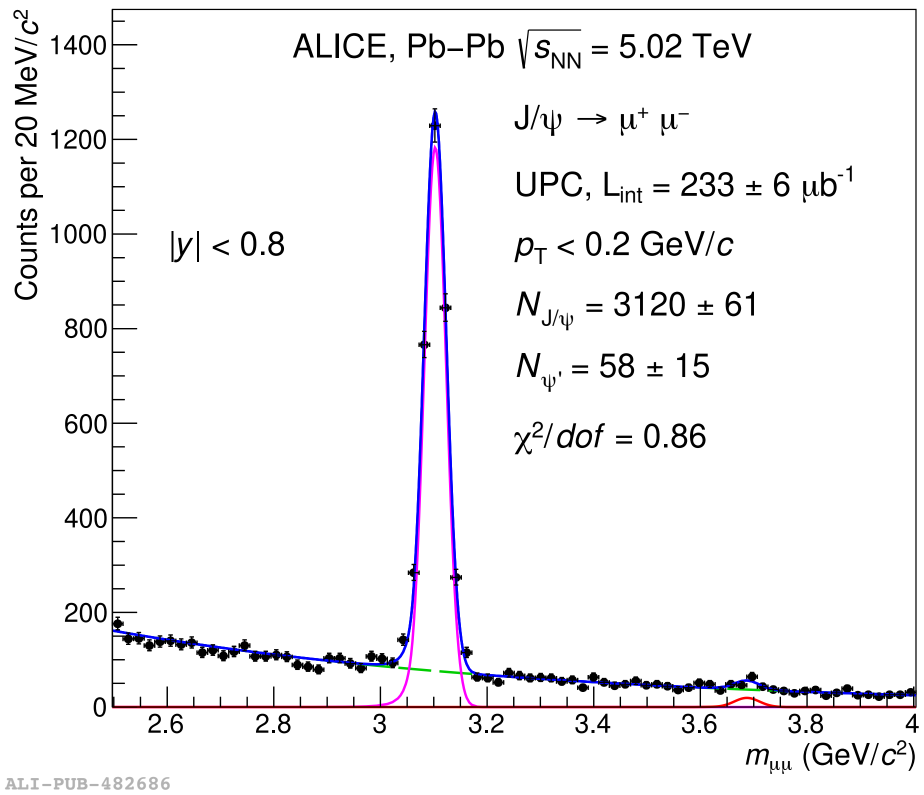

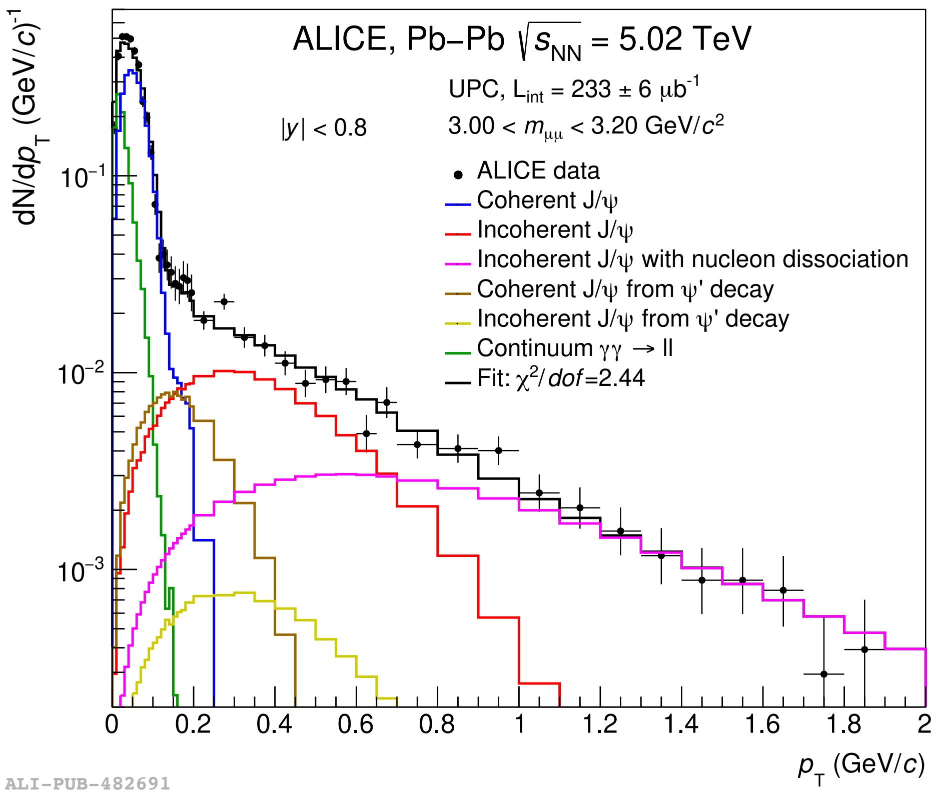

Plots at midrapidity

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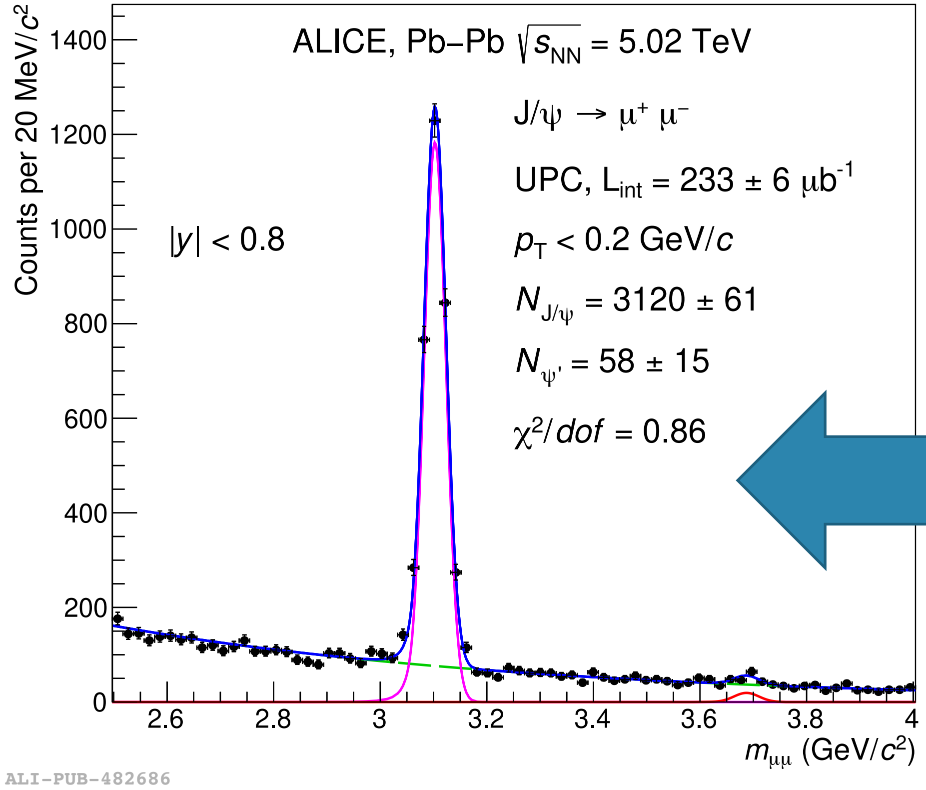

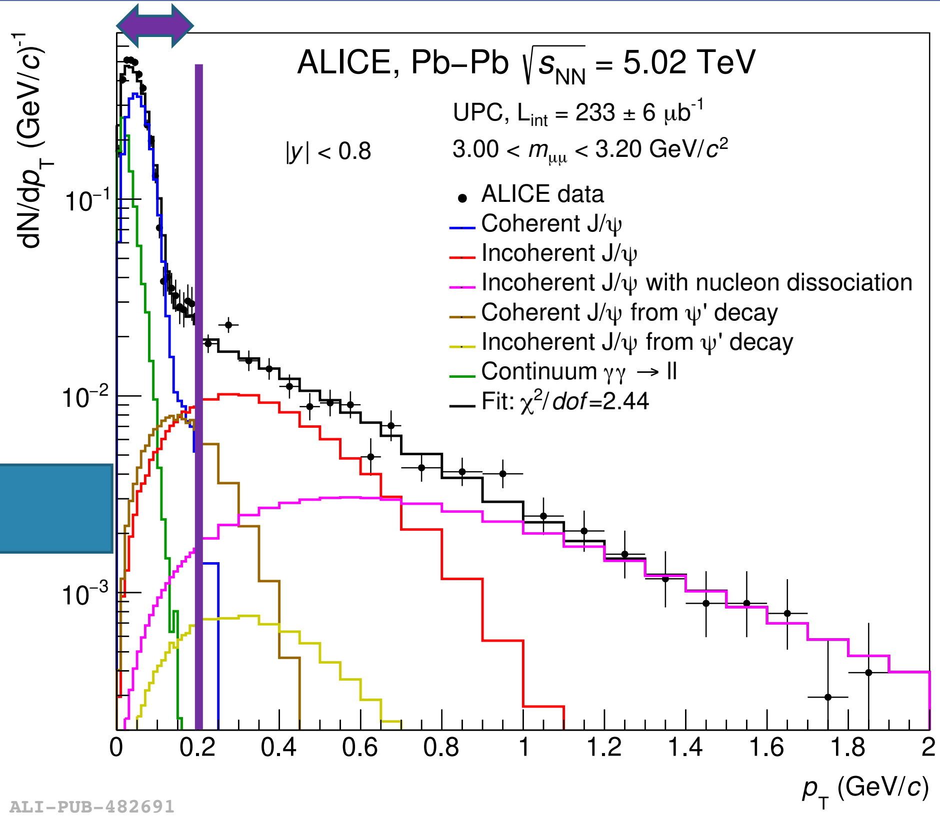

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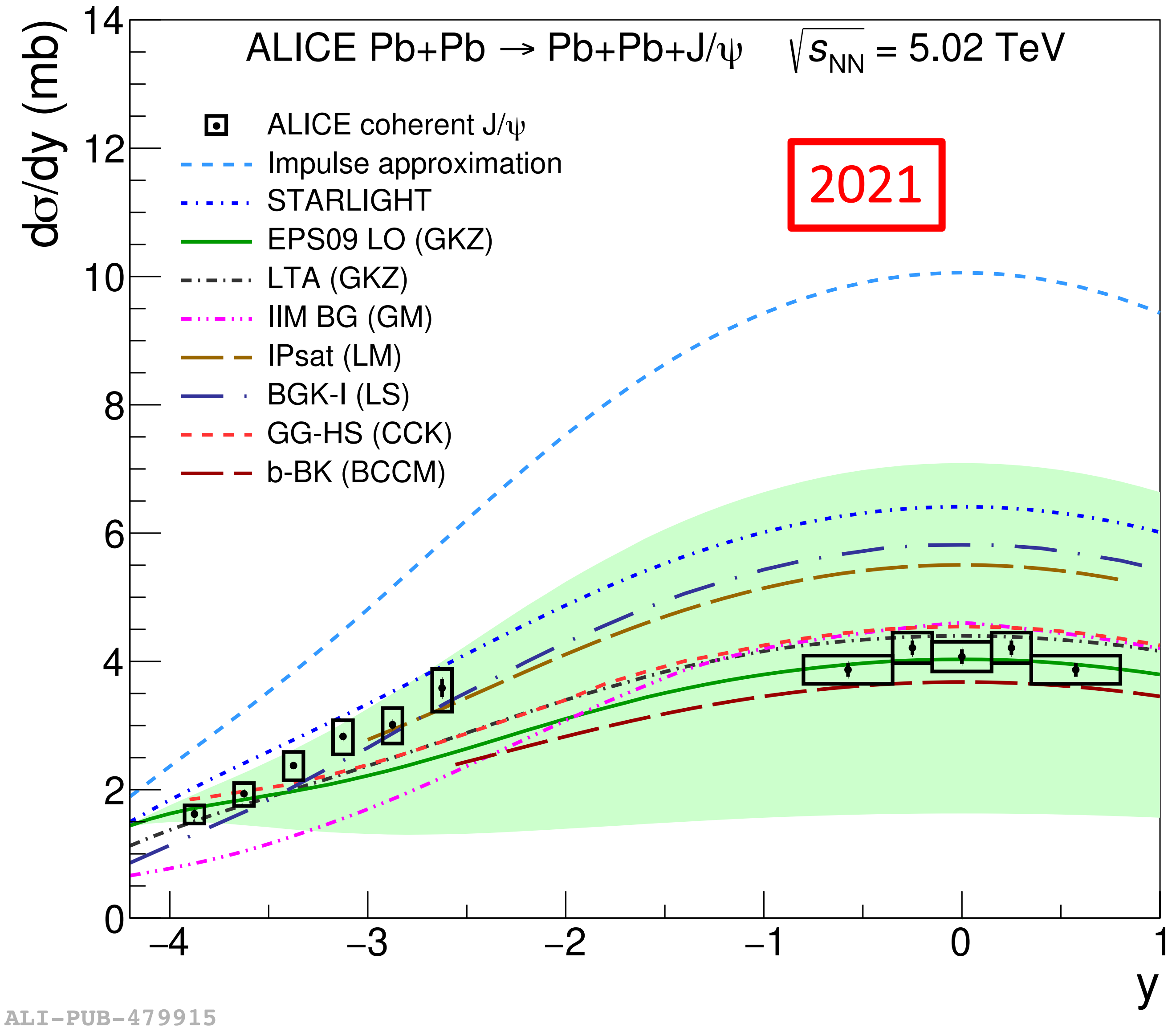
Coherent J/ψ cross section

- Impulse approximation: coherent sum of nucleons but nuclear effects ignored
- STARlight: Glauber-like model accounting for multiple interactions by a single dipole moving through the nucleus
- EPS09 (GKZ [1]): nuclear shadowing
- ALICE data exhibit moderate nuclear shadowing

[1] Guzey, Kryshen, Zhalov, PRC 93 (2016) 055206

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



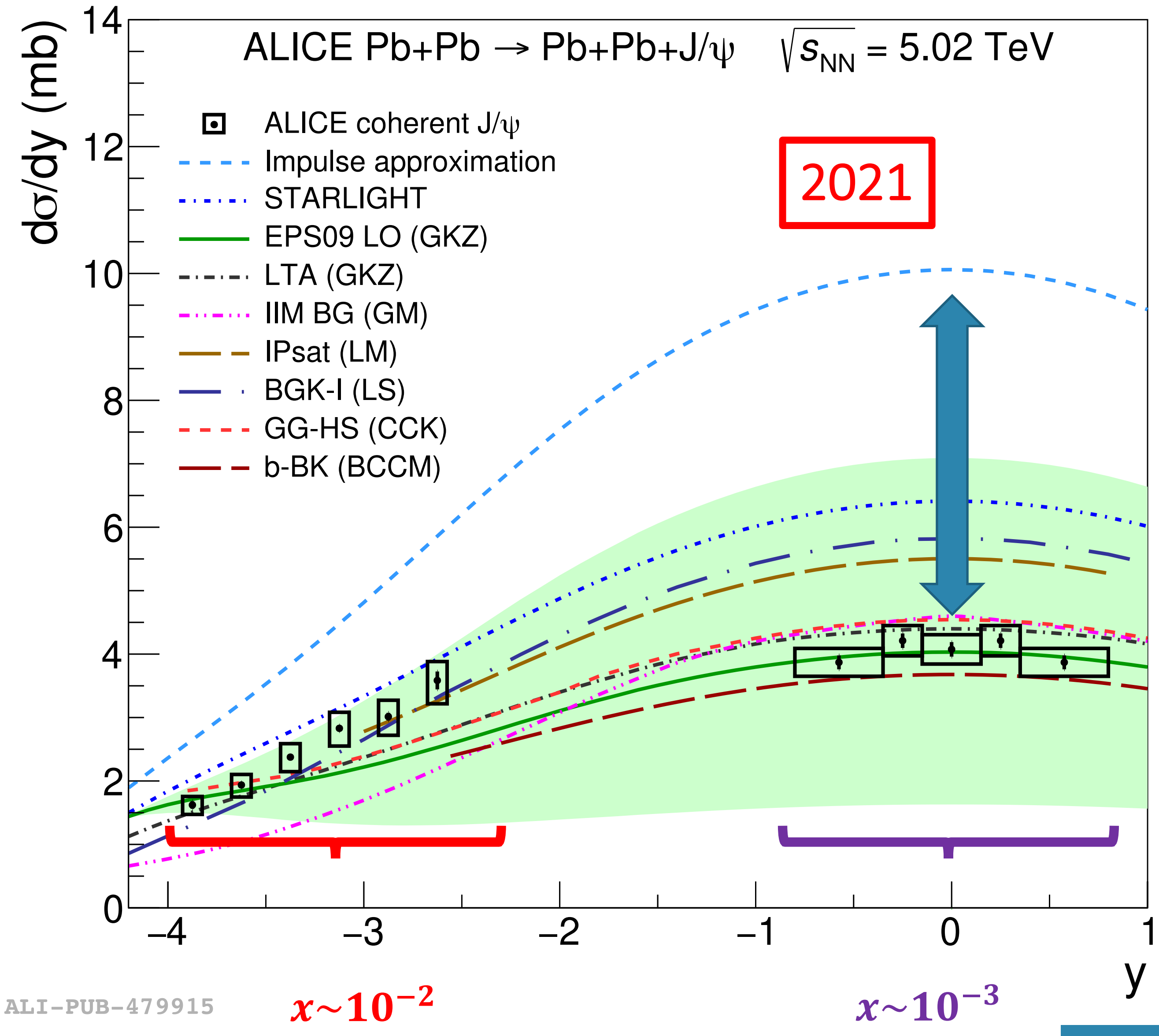
Coherent J/ψ cross section

- Nuclear suppression factor

$$S_{\mathrm{Pb}}(y \sim 0) = \sqrt{\frac{d\sigma}{dy}_{\mathrm{data}} \bigg/ \frac{d\sigma}{dy}_{\mathrm{IA}}} \sim 0.63$$

- IA = Impulse Approximation (no nuclear effects)
- $S(W_{\gamma p})$ - Nuclear Suppression Factor - provides a way to test the consistency of the data with the available nuclear and nucleon PDFs and to measure the gluon shadowing factor

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



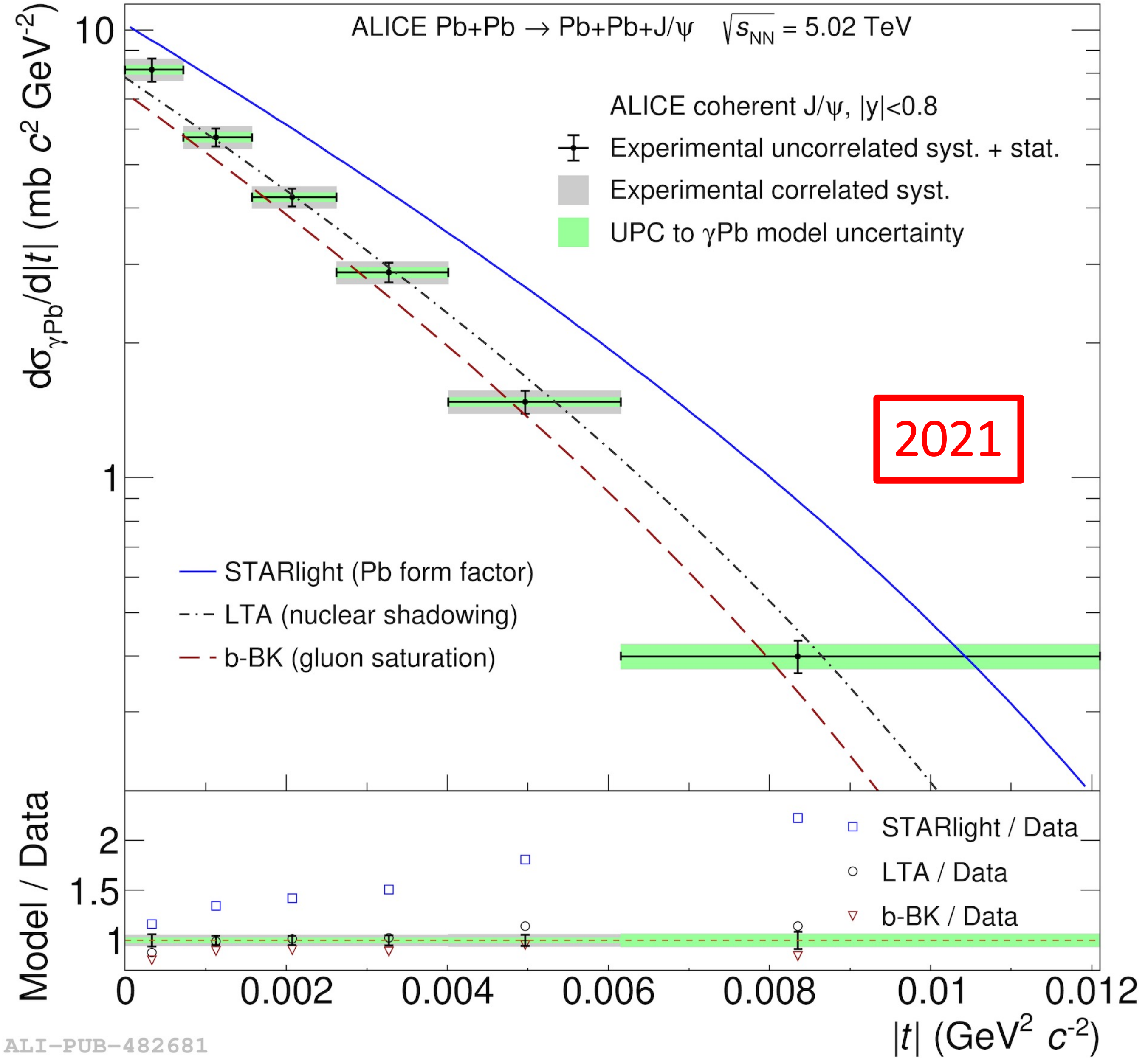
Coherent J/ψ *t*-dependence

ALICE, Phys.Lett.B 817 (2021) 13628

- From p_T^2-dependent photoproduction to $|t|$-dependent photonuclear production

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

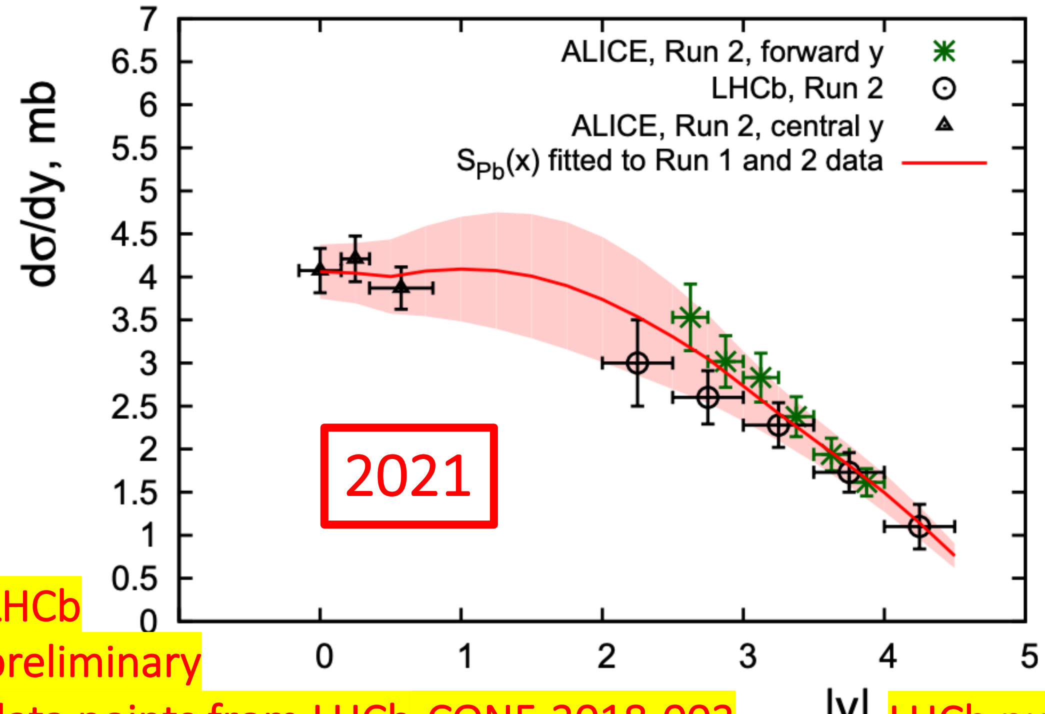
- Transverse momentum of the photon accounted for by unfolding with a response matrix built from p_T^2- and $|t|$-distributions
- Probing the transverse gluonic structure of the nucleus at low *x*
- Models including QCD dynamical effects are favoured
- Run 3 data will also allow to push further in $|t|$

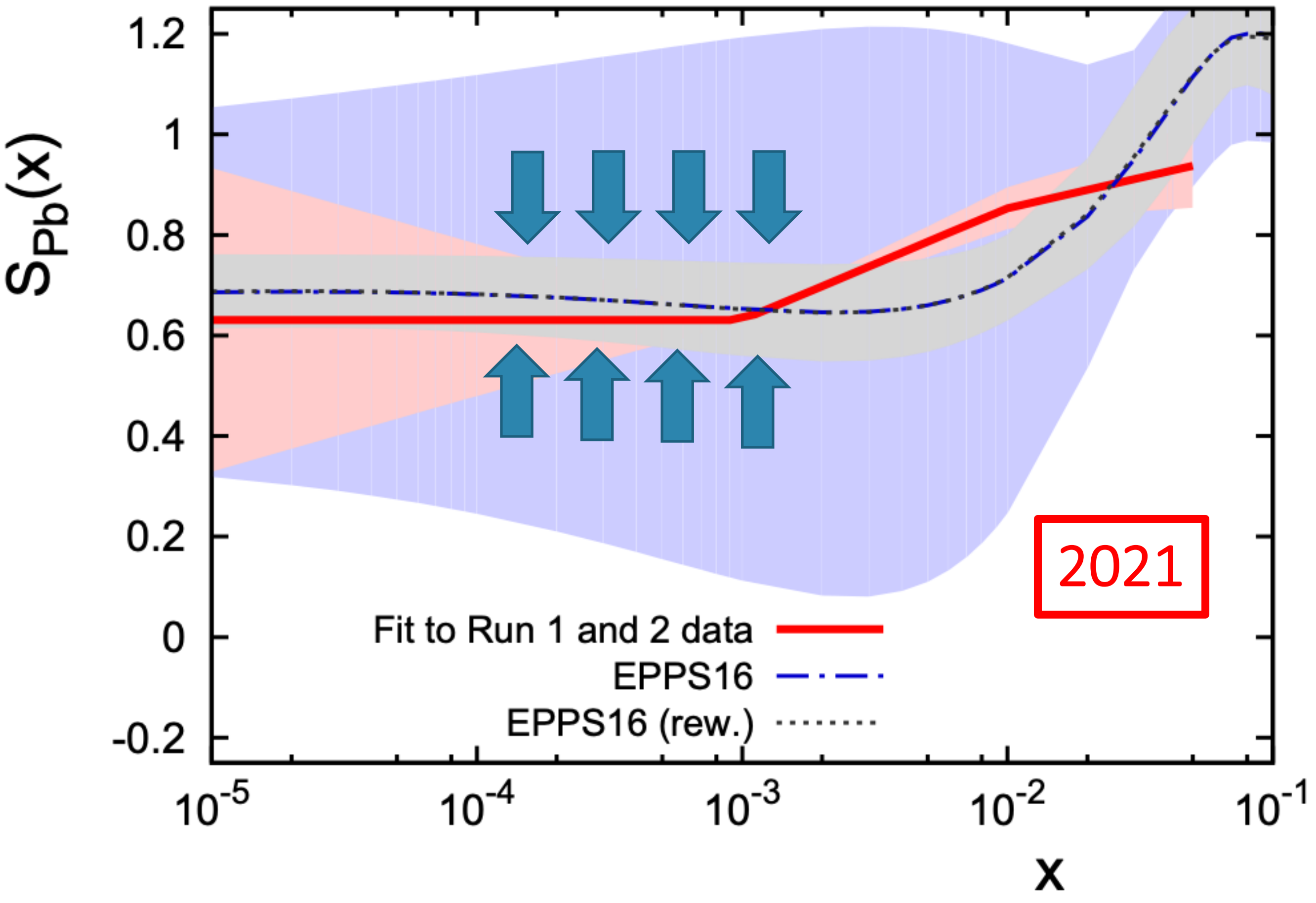


Suppression factors with ALICE data

Guzey, Kryshen, Strikman, Zhalov, Phys.Lett.B 816 (2021) 136202

$$S(W_{\gamma p}) = \left[\frac{\sigma^{\text{exp}}_{\gamma Pb \to J/\psi Pb}(W_{\gamma p})}{\sigma^{\text{IA}}_{\gamma Pb \to J/\psi Pb}((W_{\gamma p})} \right]^{1/2}$$





LHCb preliminary data points from LHCb-CONF-2018-003

LHCb published points: JHEP 07 (2022) 117 and arXiv 2206.08221

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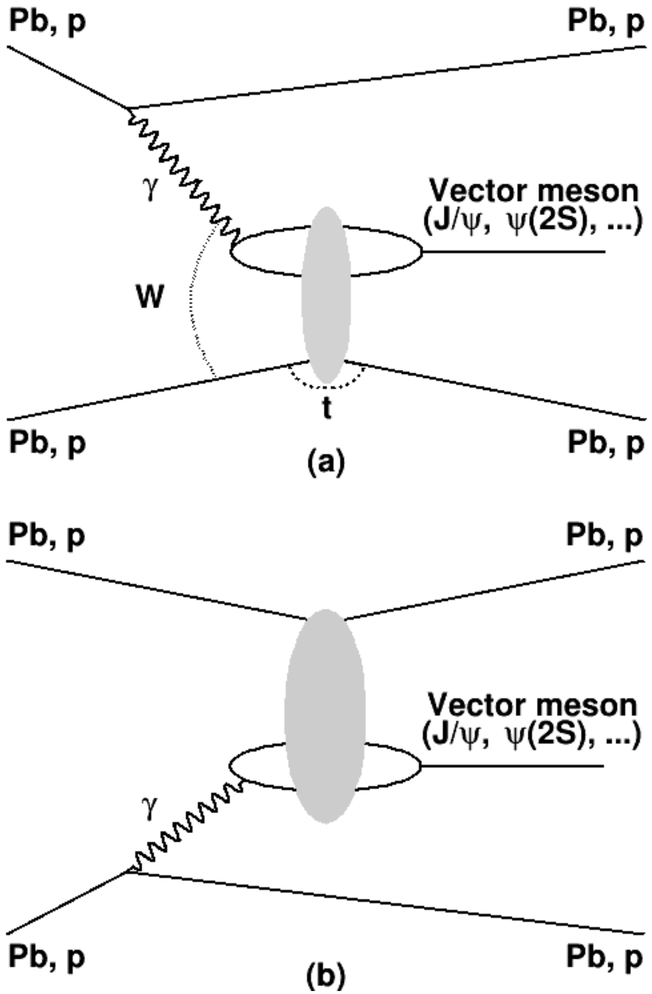
Techniques to solve the Bjorken-*x* ambiguity

Creighton University

- Symmetric collision systems
- $x = \frac{M_{VM}}{\sqrt{s_{NN}}} \cdot e^{\pm y}$
- Ambiguity due to sign in the rapidity of the photon emitter → $10^{-2}, 10^{-5}$??

- Leveraging on the impact parameter can help in disentangling the two components!



Peripheral photoproduction:

- $b < R_1 + R_2$
- Hadronic interactions + photoproduction maybe…?
- If so:

$$\frac{d\sigma^{P}_{PbPb}}{dy} = n_P(\gamma,+y)\cdot\sigma_{\gamma Pb}(+y) + n_P(\gamma,-y)\cdot\sigma_{\gamma Pb}(-y)$$

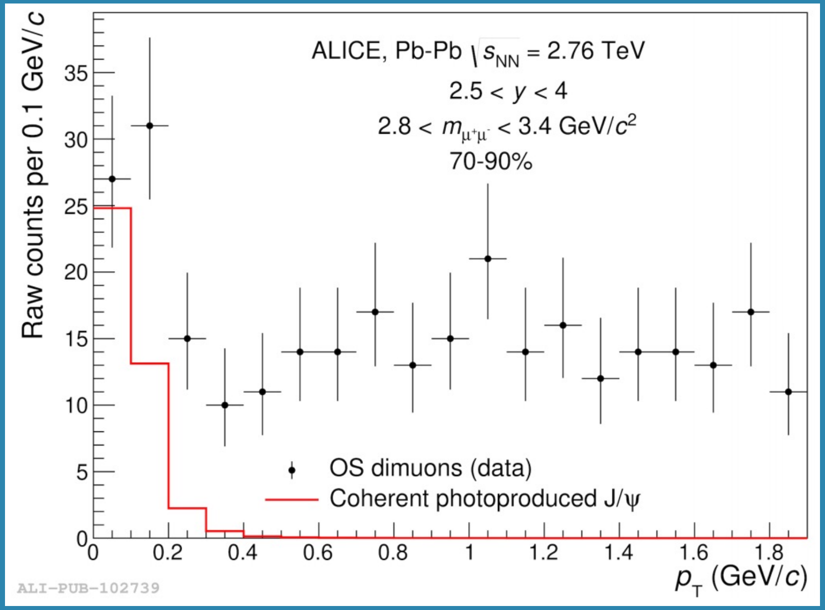
$$\frac{d\sigma^{U}_{PbPb}}{dy} = n_U(\gamma,+y)\cdot\sigma_{\gamma Pb}(+y) + n_U(\gamma,-y)\cdot\sigma_{\gamma Pb}(-y)$$

J.G. Contreras PRC 96 (2017) 015203

- Simultaneously use UPC and peripheral results to get rid of the ambiguities!

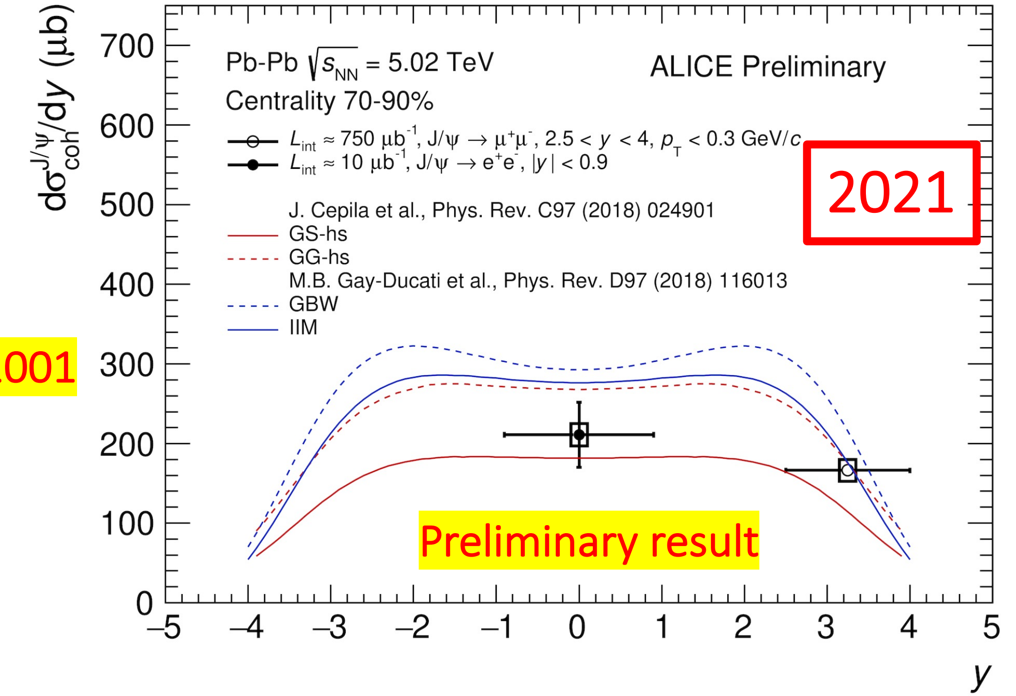
Peripheral J/ψ photoproduction

- $b < R_1 + R_2$!
- First observed with Run 1 data by ALICE
- Now confirmed with Run 2 statistics by both ALICE and LHCb. STAR also reports this

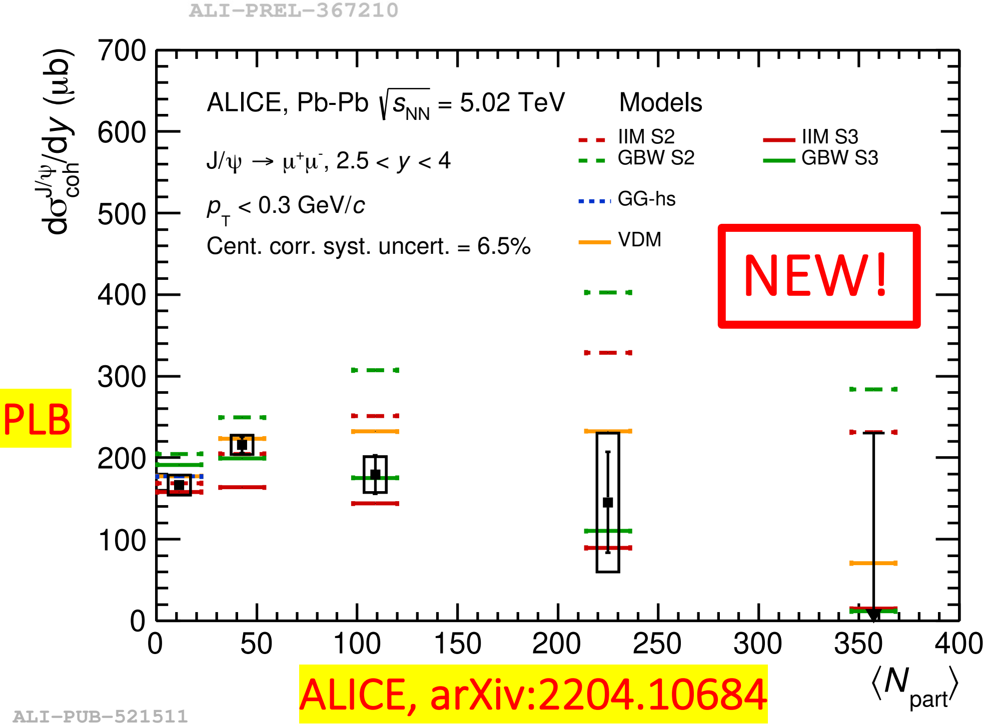


ALICE, PRL 116 (2016), 222301

ALICE, EPL 129 (2020) 42001



Submitted to PLB



ALICE, arXiv:2204.10684

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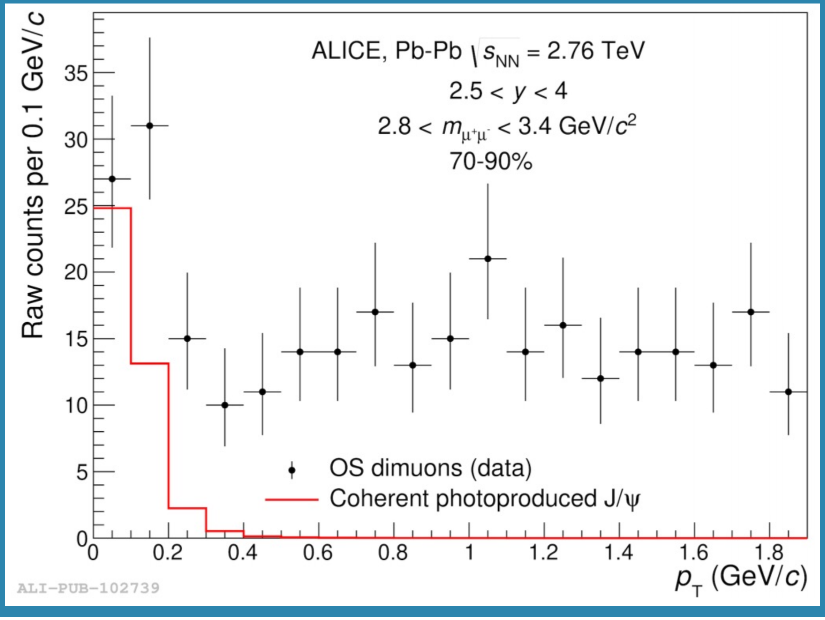

ALICE, PRL 116 (2016), 222301

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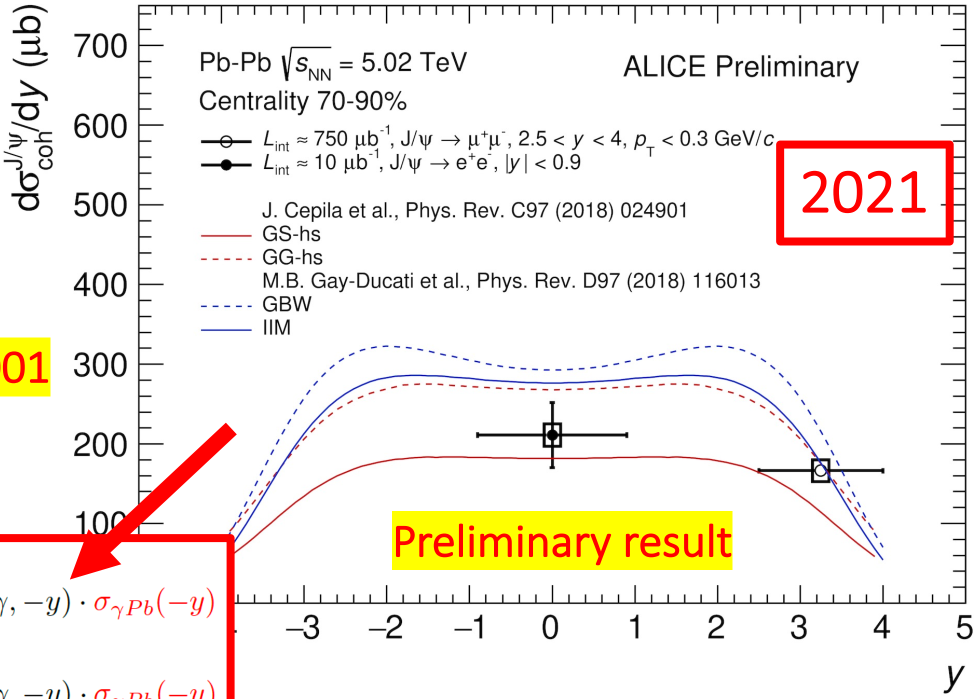

2021

Preliminary result

$$\frac{d\sigma^{P}_{PbPb}}{dy} = n_P(\gamma,+y)\cdot\sigma_{\gamma Pb}(+y) + n_P(\gamma,-y)\cdot\sigma_{\gamma Pb}(-y)$$

$$\frac{d\sigma^{U}_{PbPb}}{dy} = n_U(\gamma,+y)\cdot\sigma_{\gamma Pb}(+y) + n_U(\gamma,-y)\cdot\sigma_{\gamma Pb}(-y)$$

UPC results

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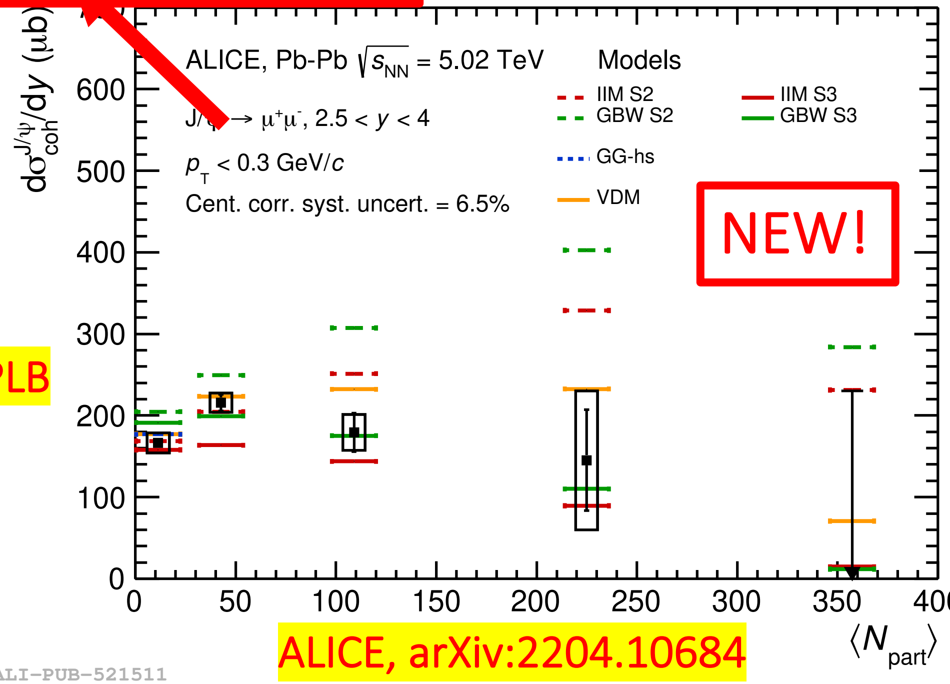
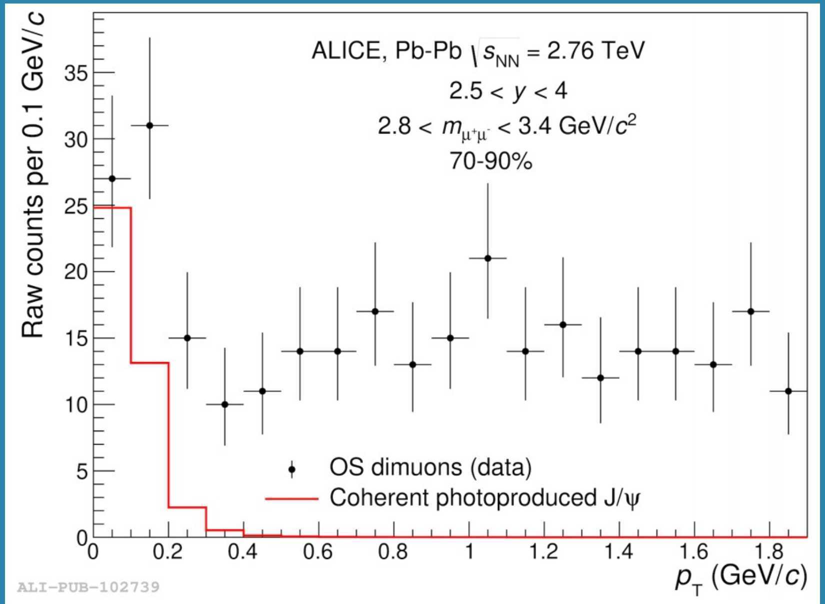


NEW!

ALICE, arXiv:2204.10684

Peripheral J/ψ photoproduction using ALICE Run 1 data

- First extraction of the photonuclear cross sections with Run 1 data



ALICE, PRL 116 (2016), 222301

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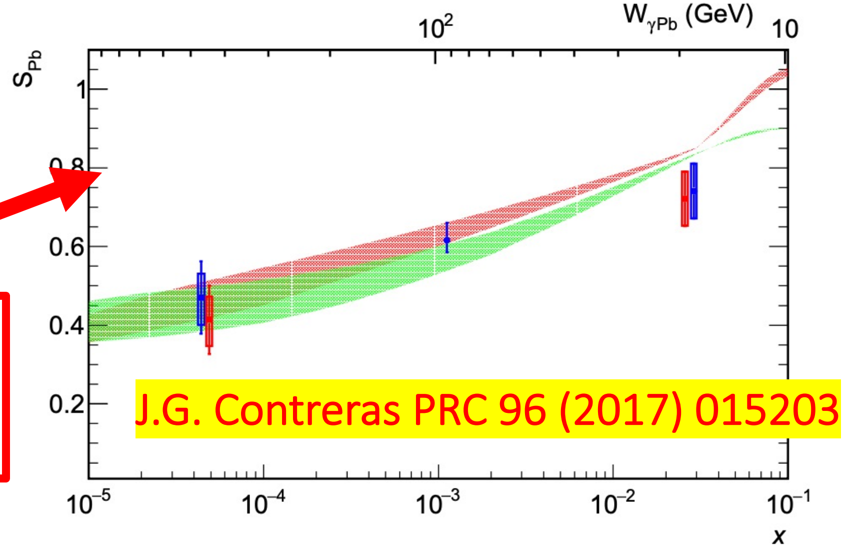
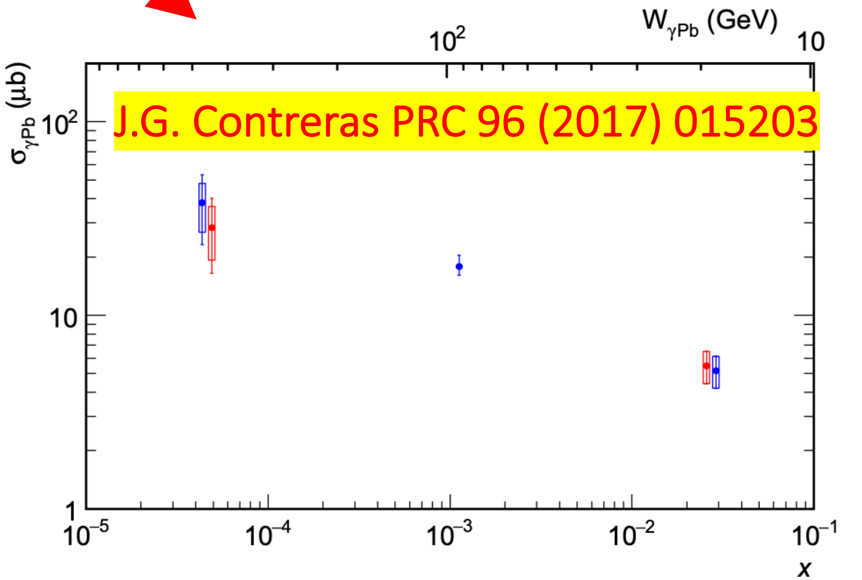


J.G. Contreras PRC 96 (2017) 015203

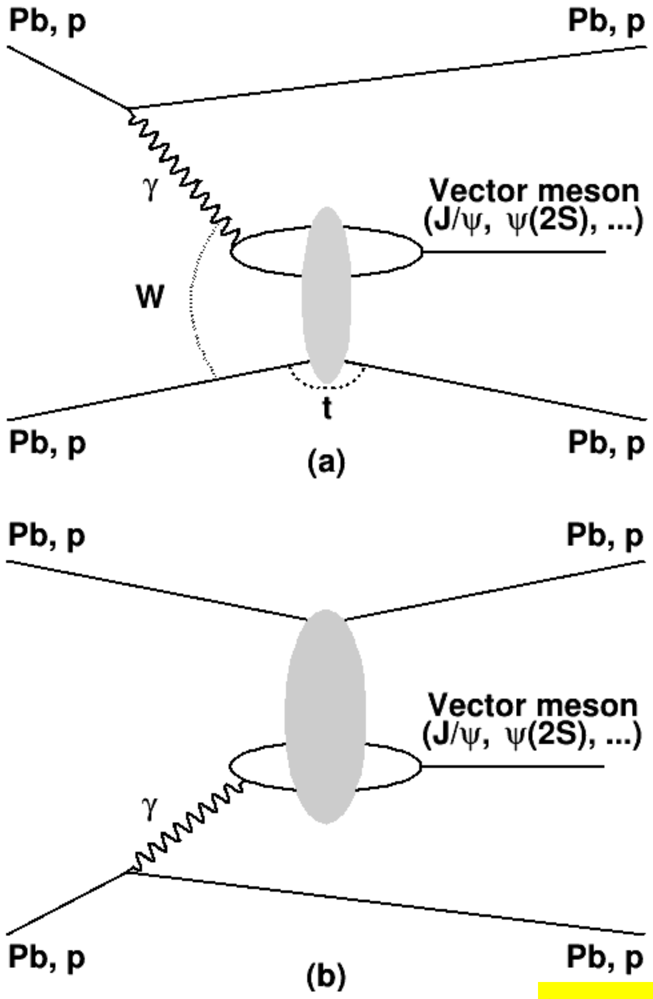


J.G. Contreras PRC 96 (2017) 015203

Techniques to solve the Bjorken-x ambiguity

Creighton UNIVERSITY

- Symmetric collision systems
- $x = \frac{M_{VM}}{\sqrt{s_{NN}}} \cdot e^{\pm y}$
- Ambiguity due to sign in the rapidity of the photon emitter → $10^{-2}, 10^{-5}$??
- Additional photon exchanges may lead to neutron emission



Neutron emission principle:

- $b > R_1 + R_2$
- Different break-up modes
- If so:

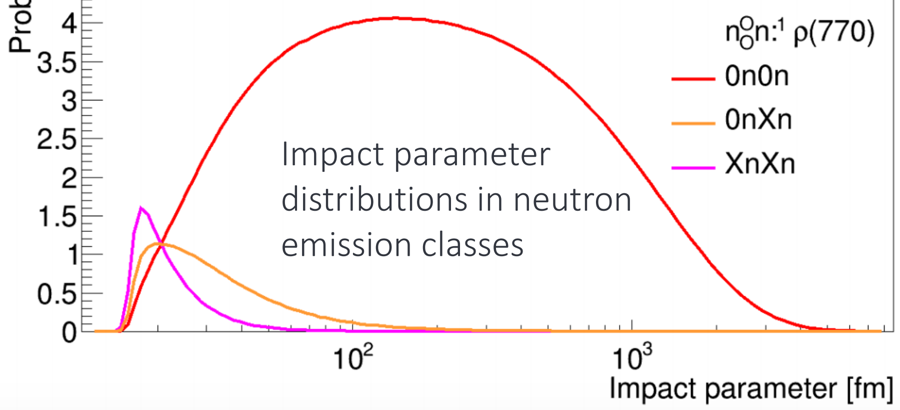
$$\frac{d\sigma^{0N0N}_{PbPb}}{dy} = n_{0N0N}(\gamma,+y)\cdot\sigma_{\gamma Pb}(+y) + n_{0N0N}(\gamma,-y)\cdot\sigma_{\gamma Pb}(-y)$$

$$\frac{d\sigma^{0NXN}_{PbPb}}{dy} = n_{0NXN}(\gamma,+y)\cdot\sigma_{\gamma Pb}(+y) + n_{0NXN}(\gamma,-y)\cdot\sigma_{\gamma Pb}(-y)$$

Guzey et al., Eur.Phys.J.C 74 (2014) 7, 2942

- Different neutron emission classes have different average impact parameters

Broz et. al.: CPC 253 (2020) 107181



See Valeri Pozdniakov's talk for coherent ρ^0 results also in neutron emission classes

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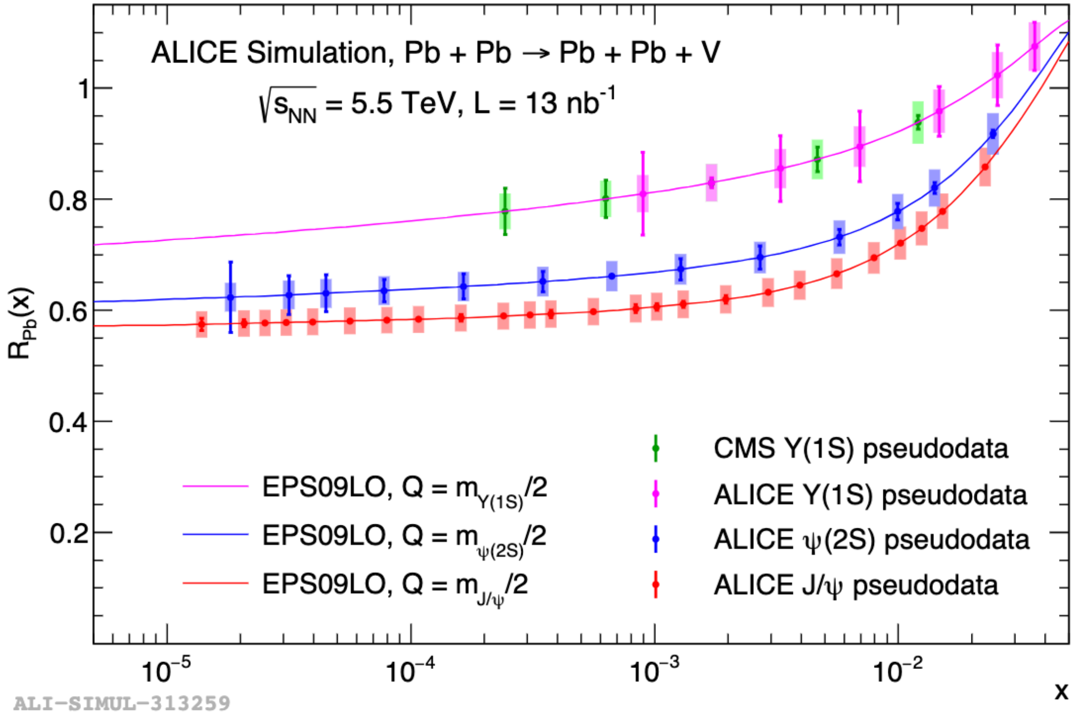
Beyond Run 2 data

- Significant increase in integrated lumi from $1\ \mathrm{nb}^{-1}$ for Run 2 to $13\ \mathrm{nb}^{-1}$ for Run 3 and Run 4 together
- Double vector meson photoproduction
- Uncertainties for nuclear suppression factor expected to be at the level of 4%
- More differential measurements e.g. in $|t|$
- New measurements e.g. bottomonium states

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

$|y| < 0.9$ $\quad$ $2.5 < |y| < 4$

CERN Yellow Rep. Monogr. 7 (2019) 1159-1410, arXiv 1812.06772



Summary and a personal wishlist for the future

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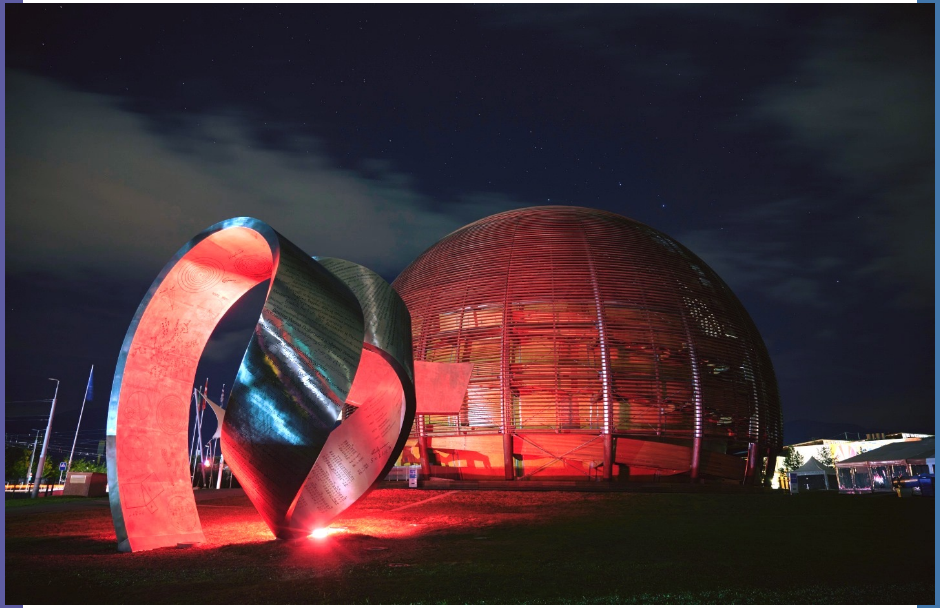
Shown here:

- First measurement of dissociative J/ψ at the LHC
- Coherent J/ψ: the current state-of-the-art for ALICE
- Nuclear suppression factor and how ALICE has already helped a lot
- Ways to extract $x \sim 10^{-5}$: neutron emission and peripheral photoproduction
- UPC still have a lot to say (look forward to Run 3)!



Questions for a future:

- Neutron emission with coherent J/ψ → $x \sim 10^{-5}$ with nuclear targets…?
- Increased statistics might lead to higher $|t|$ to improve our knowledge of the transverse gluonic distribution

Backup slides