Recent ALICE results on vector meson photoproduction

S. Ragoni for the ALICE Collaboration

University of Birmingham, UK

Outline

- Introduction to ultraperipheral collisions (UPC) and Central Exclusive Production (CEP)
- The ALICE detector
- Exclusive 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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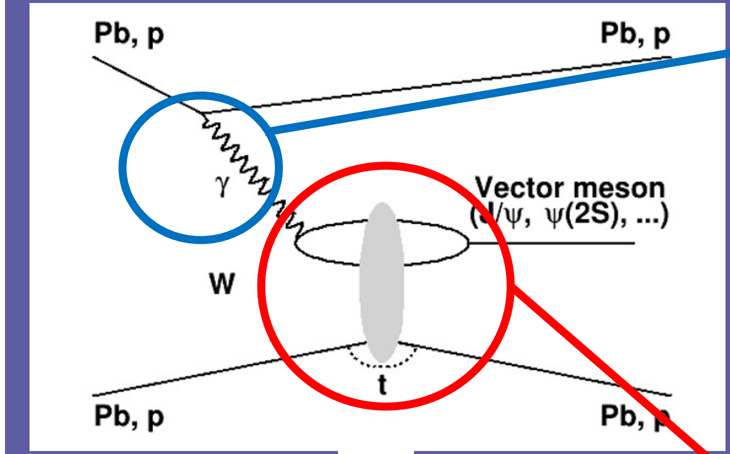
Introduction to UPC and CEP



- 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!

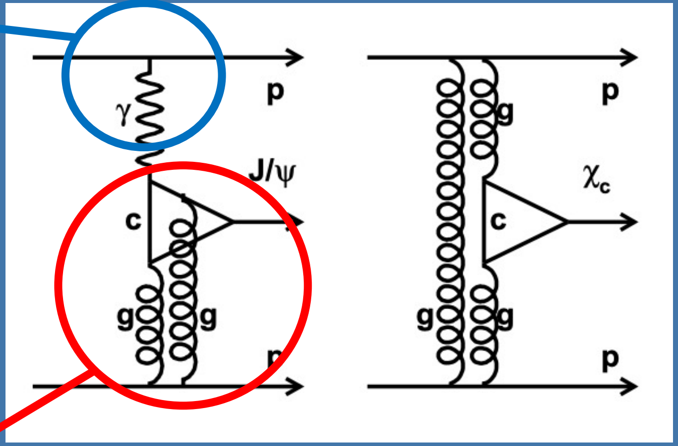
$$\frac{d\sigma^T(\gamma p \to J/\Psi + p)}{dt} = \frac{|M|^2}{16\pi s^2}$$

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

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



- $p + p \to p + p + X$
- One or two gluon ladders involved (one in photoproduction)

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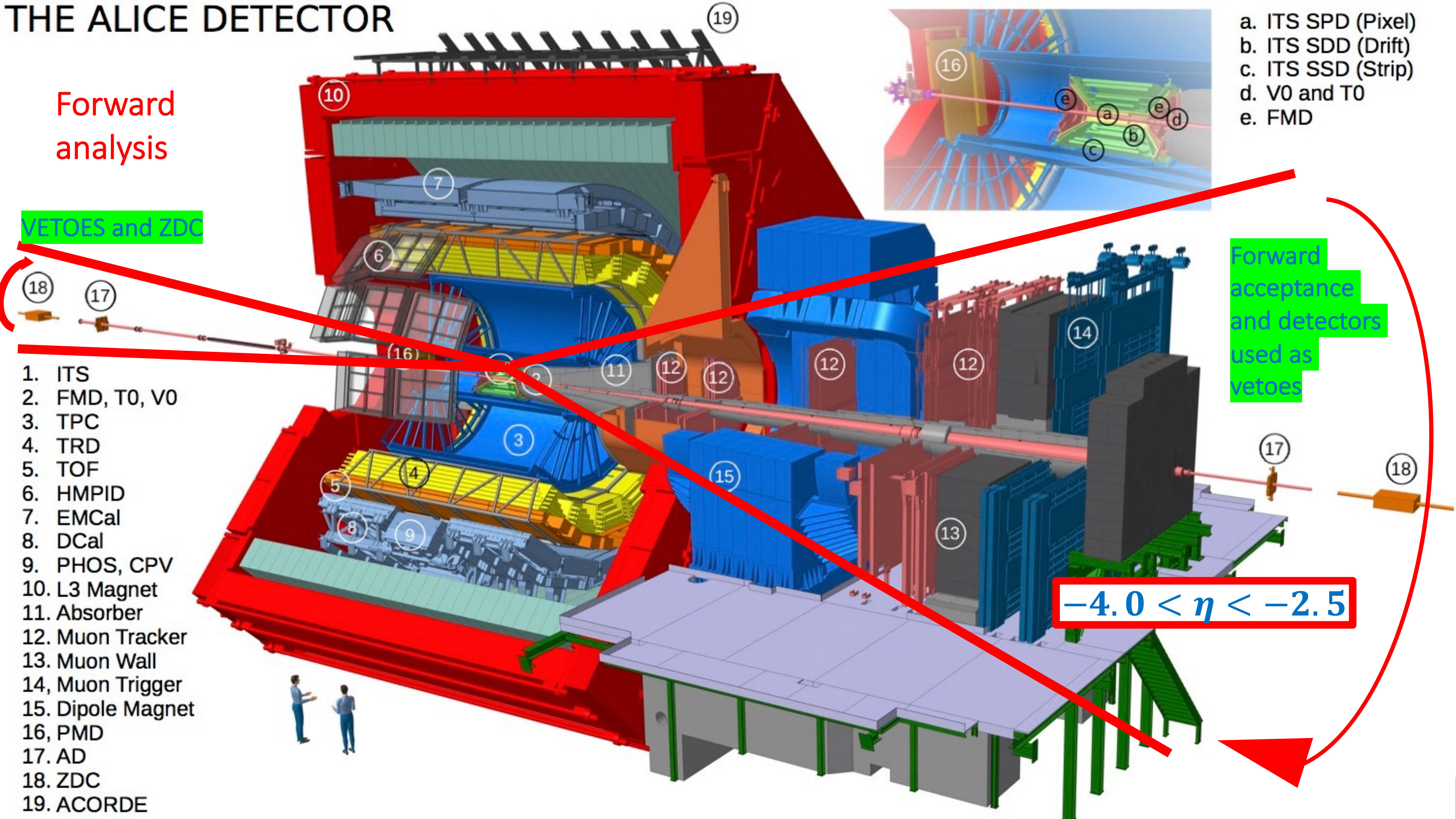
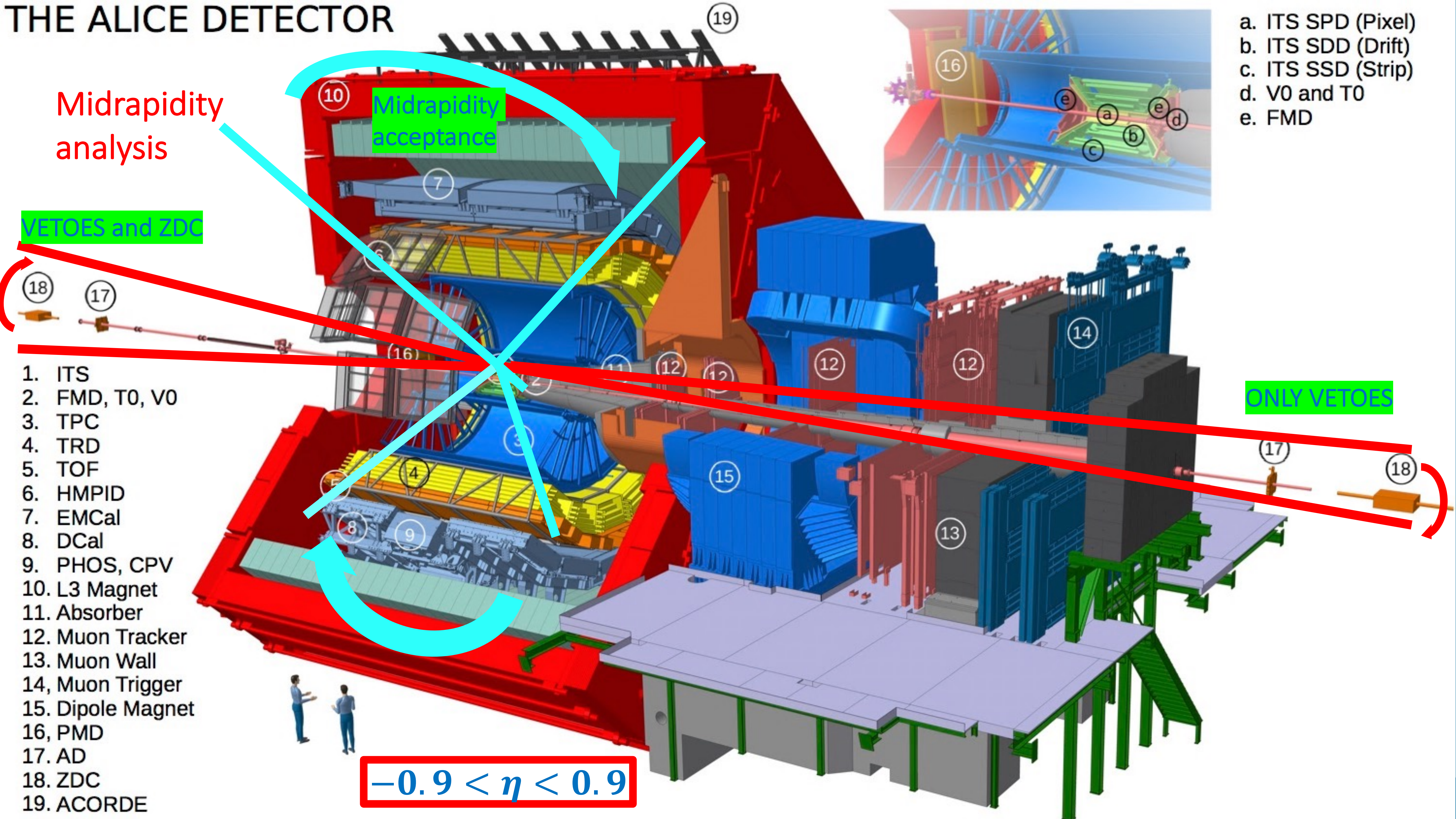

THE ALICE DETECTOR
Forward analysis
VETOES and ZDC
Forward acceptance and detectors used as vetoes
$-4.0 < \eta < -2.5$
1. ITS
2. FMD, T0, V0
3. TPC
4. TRD
5. TOF
6. HMPID
7. EMCal
8. DCal
9. PHOS, CPV
10. L3 Magnet
11. Absorber
12. Muon Tracker
13. Muon Wall
14, Muon Trigger
15. Dipole Magnet
16, PMD
17. AD
18. ZDC
19. ACORDE
a. ITS SPD (Pixel)
b. ITS SDD (Drift)
c. ITS SSD (Strip)
d. V0 and T0
e. FMD


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

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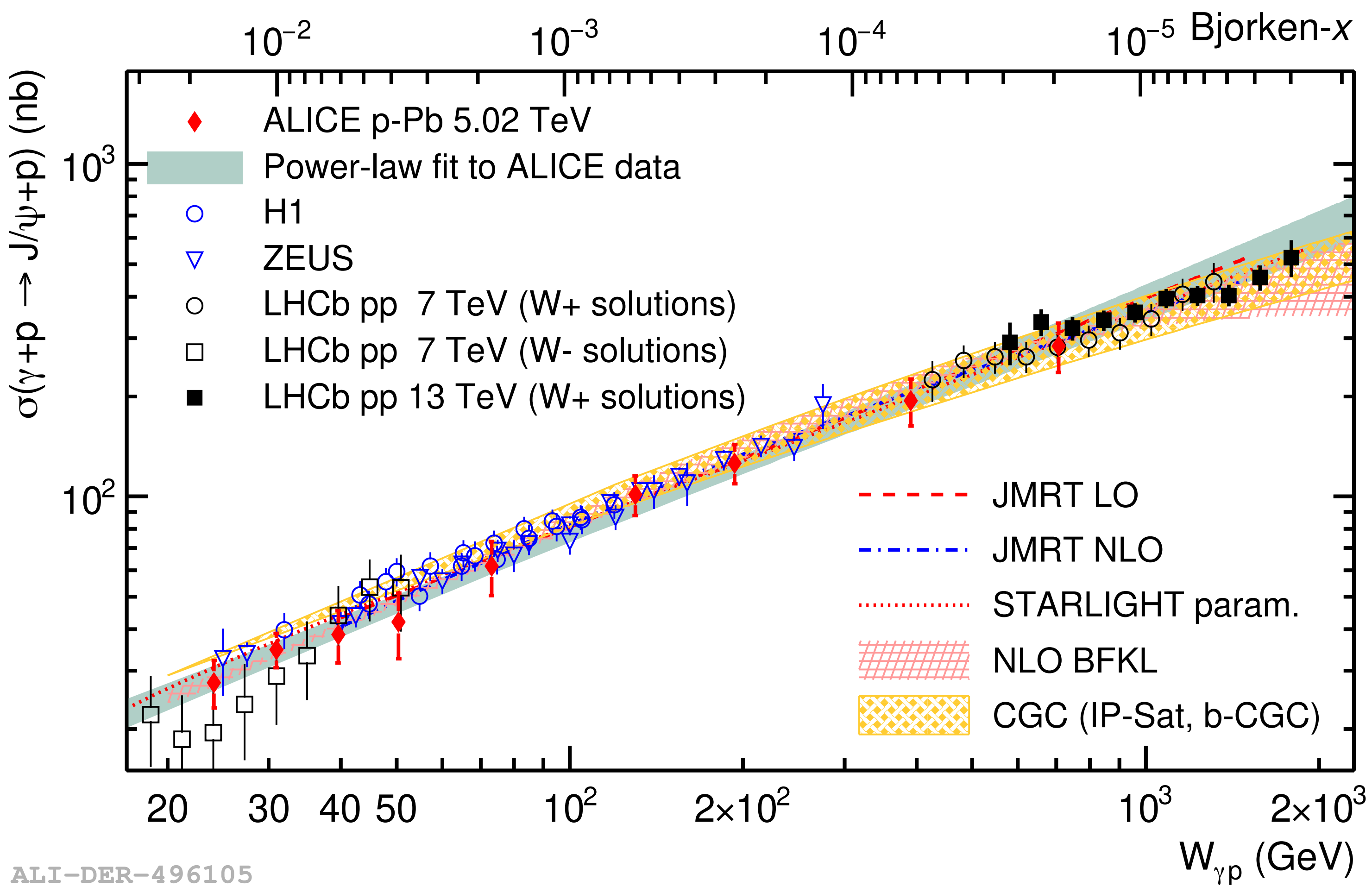
Exclusive J/ψ in p-Pb

- $x = e^{\pm|y|}\, {}^{M_{J/\psi}}/_{2E_p}$
- 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

JHEP 10 (2018) 167 (LHCb pp 13 TeV)

S.Ragoni, LHCP 2021 proceedings, arXiv:2109.03066



ALI-DER-496105

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

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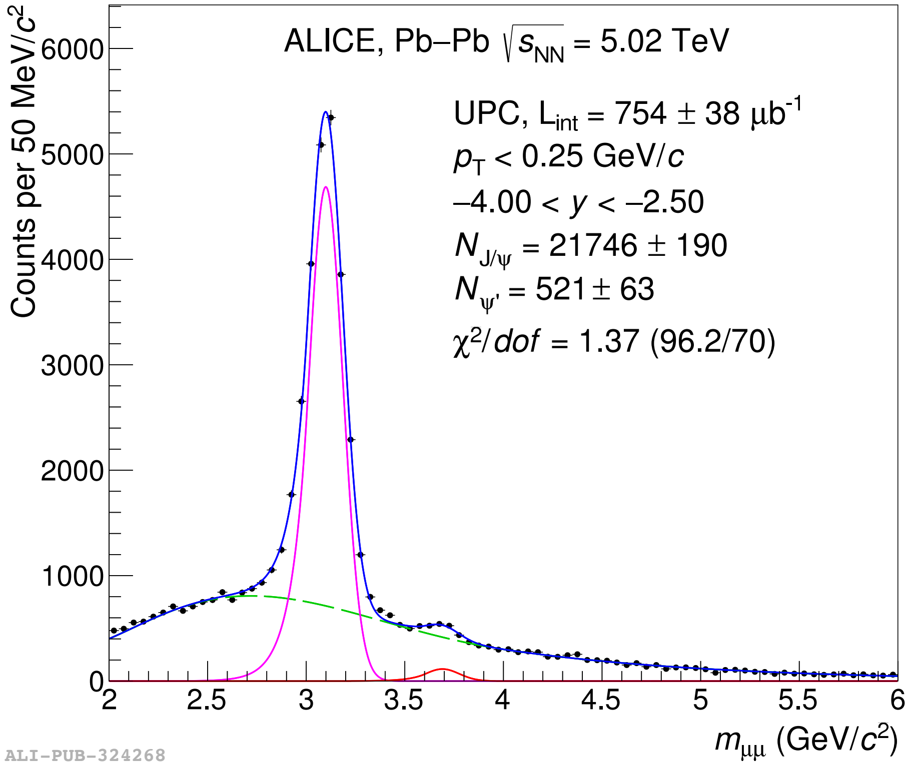
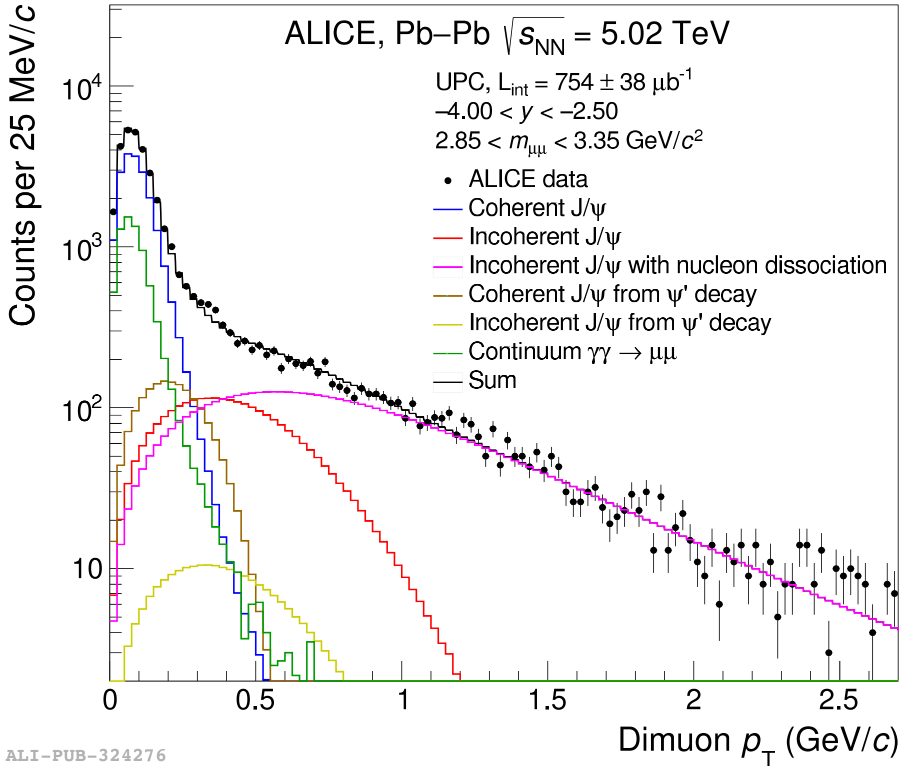
Coherent vs incoherent J/ψ



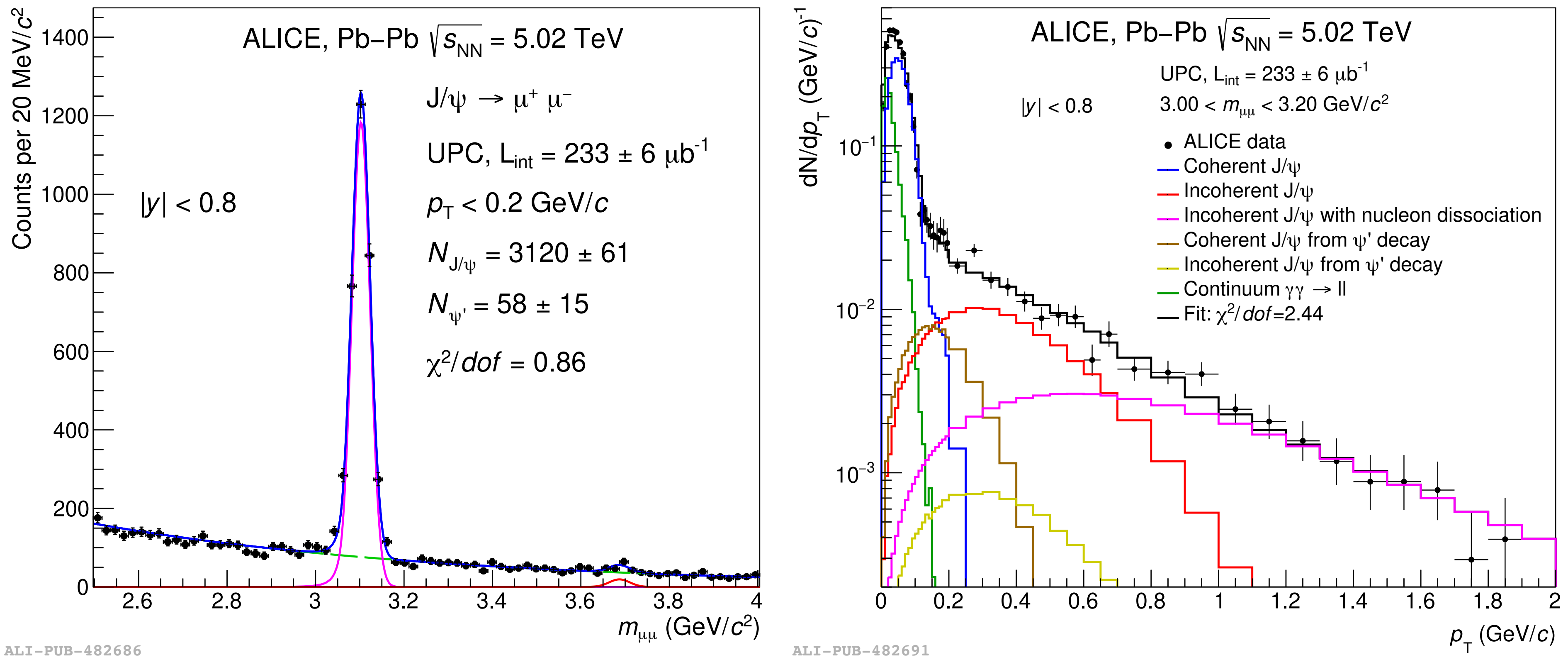


Plots in the dimuon channel (only available channel at forward rapidity)

Phys.Lett. B798 (2019) 134926

- Coherent (dimuon $p_T < 0.25\ \mathrm{GeV}/c$) cleaner peak – 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



Plots at midrapidity

ALICE, arxiv: 2101.04577 [nucl-ex]

Submitted to EPJC

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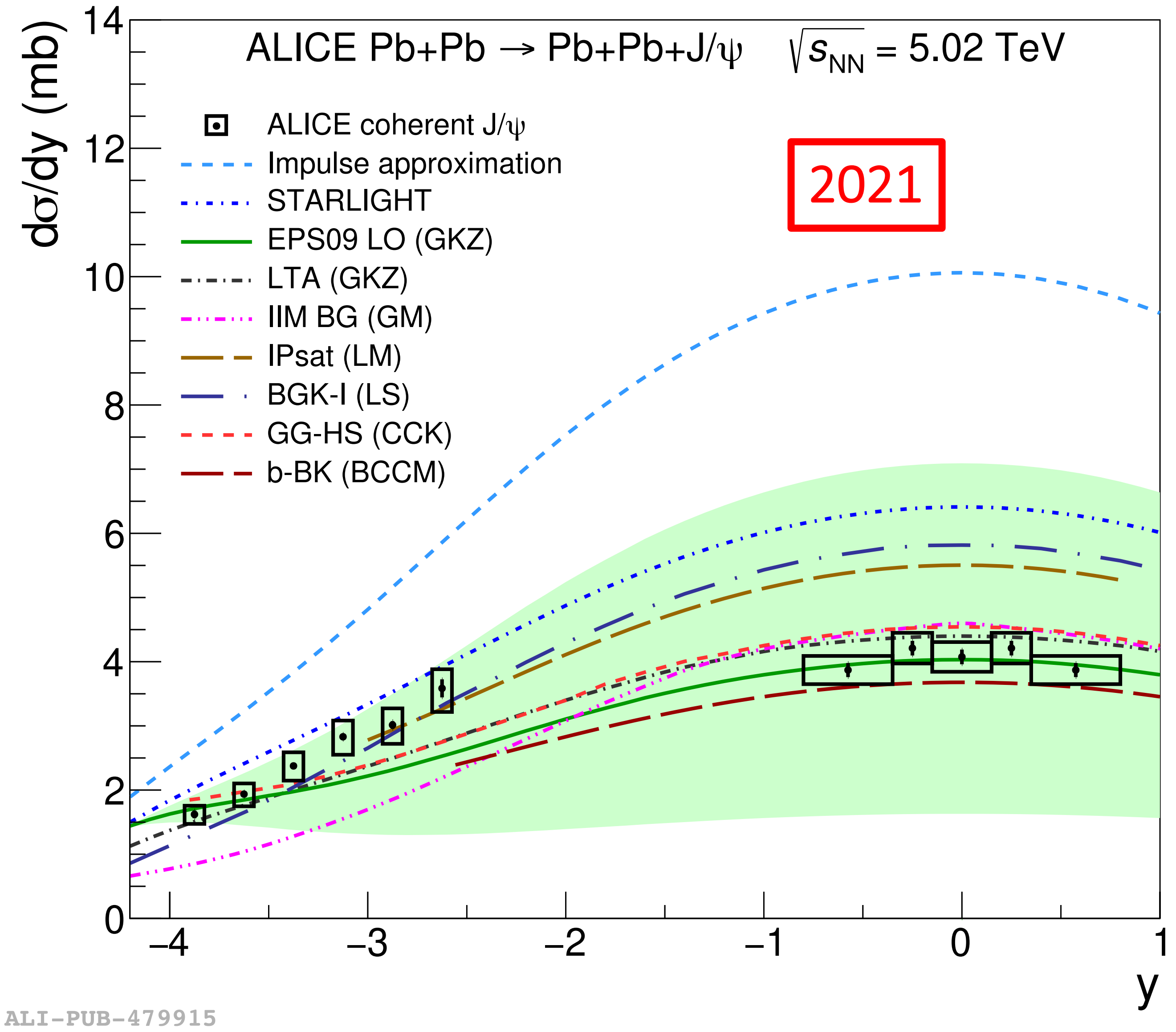
Coherent J/ψ cross section

- 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, arxiv: 2101.04577 [nucl-ex]   Submitted to EPJC



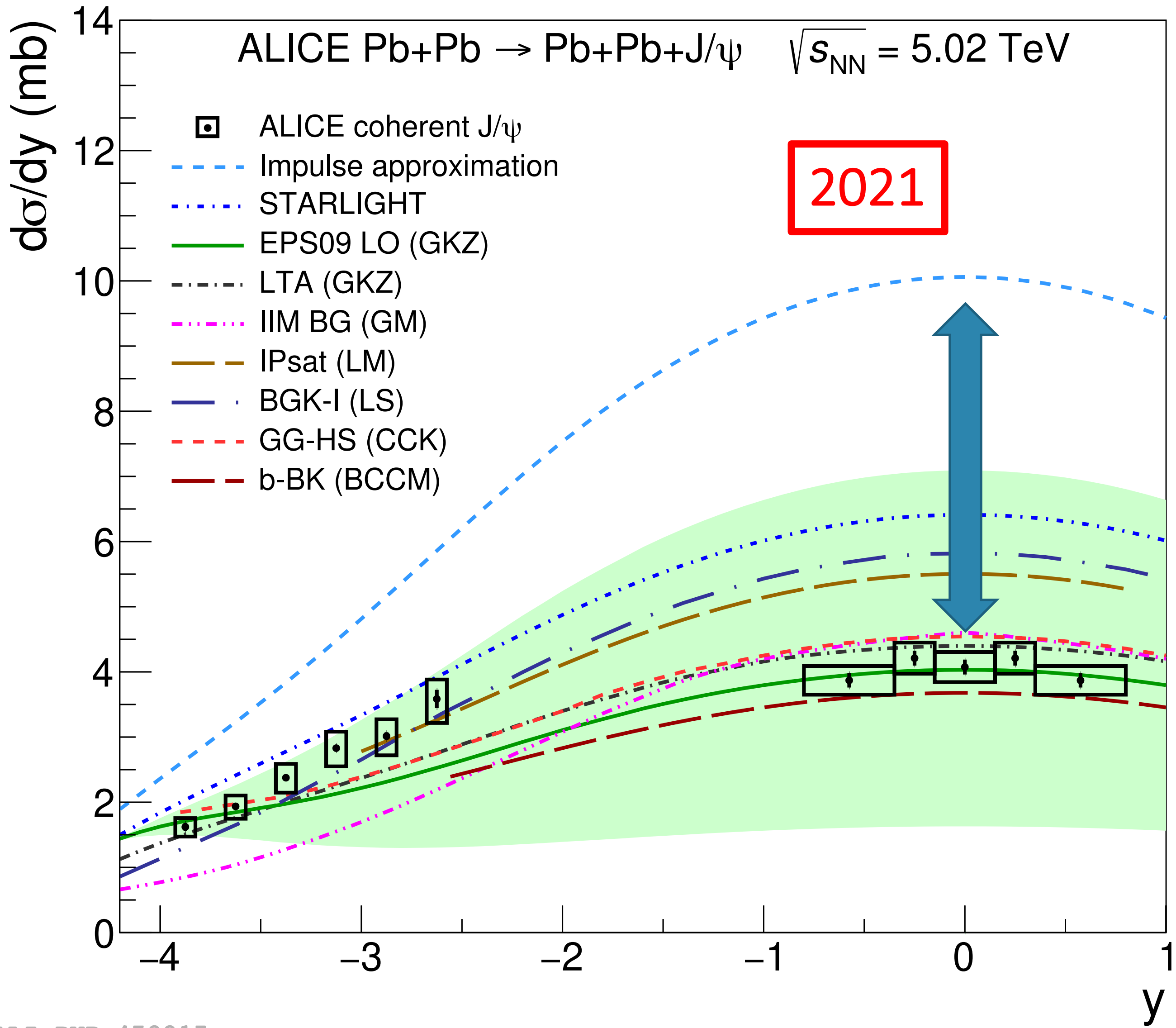
Coherent J/ψ cross section

ALICE, arxiv: 2101.04577 [nucl-ex]   Submitted to EPJC

- Nuclear suppression factor (easier at midrapidity)

$$S_{\mathrm{Pb}} = \sqrt{\frac{d\sigma}{dy}_{\mathrm{data}} \Big/ \frac{d\sigma}{dy}_{\mathrm{IA}}} \sim 0.63$$

- 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



ALI-PUB-479915

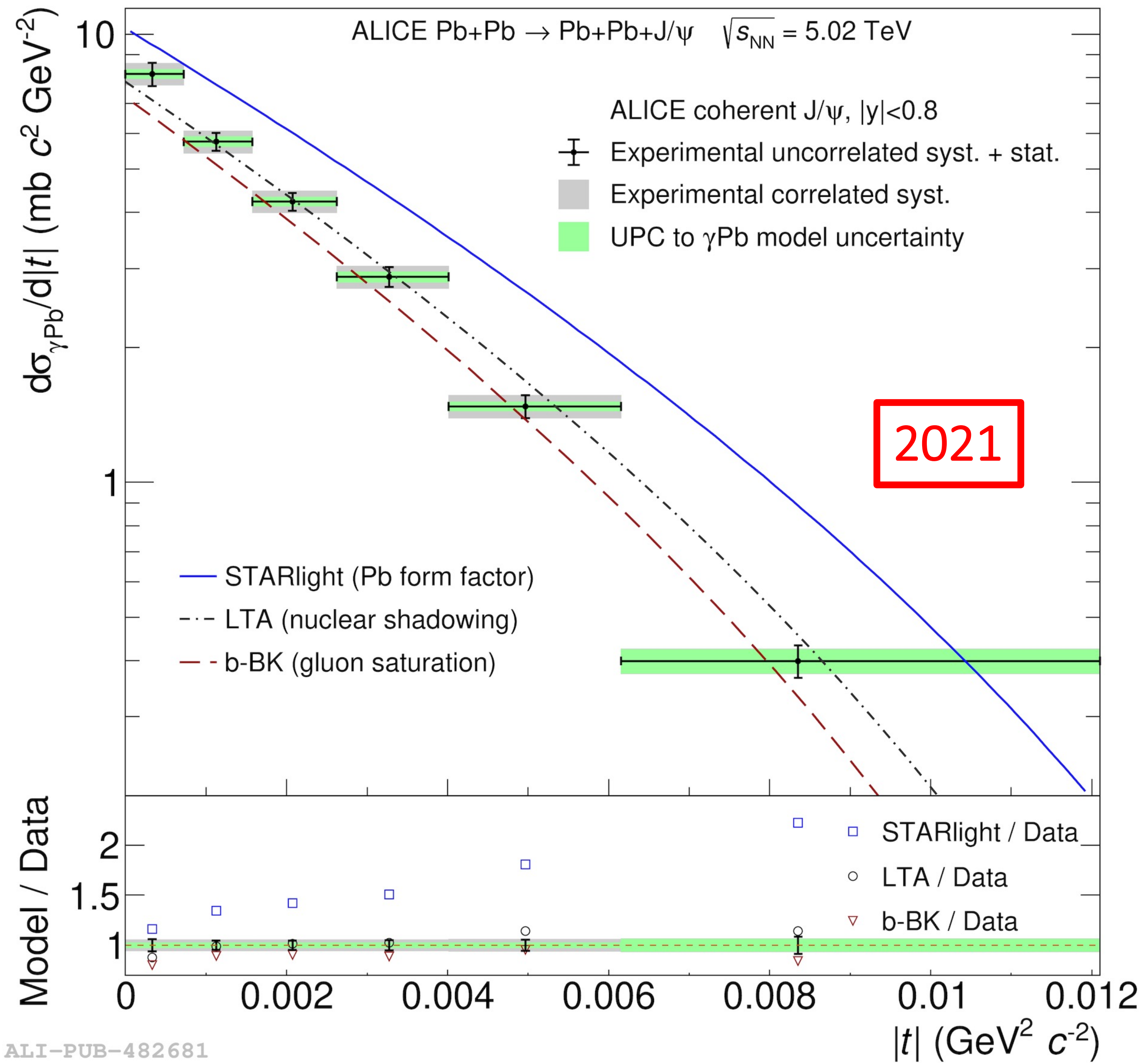
Coherent J/ψ *t*-dependence

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

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

- Probing the transverse gluonic structure of the nucleus at low *x*

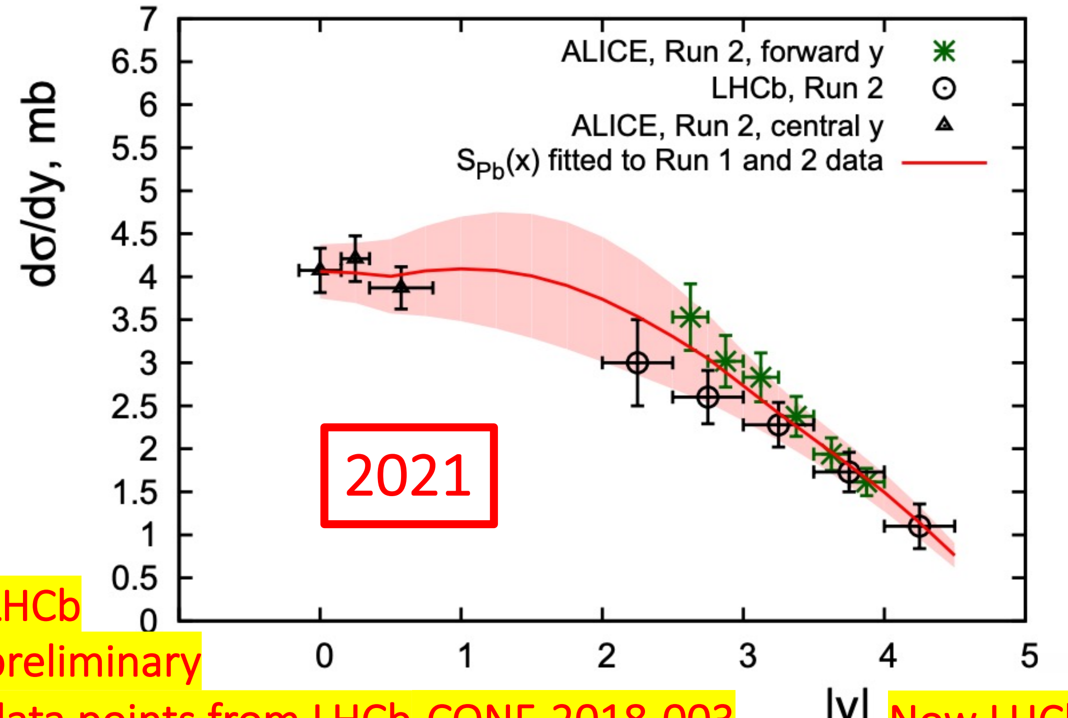
ALICE, Phys.Lett.B 817 (2021) 13628

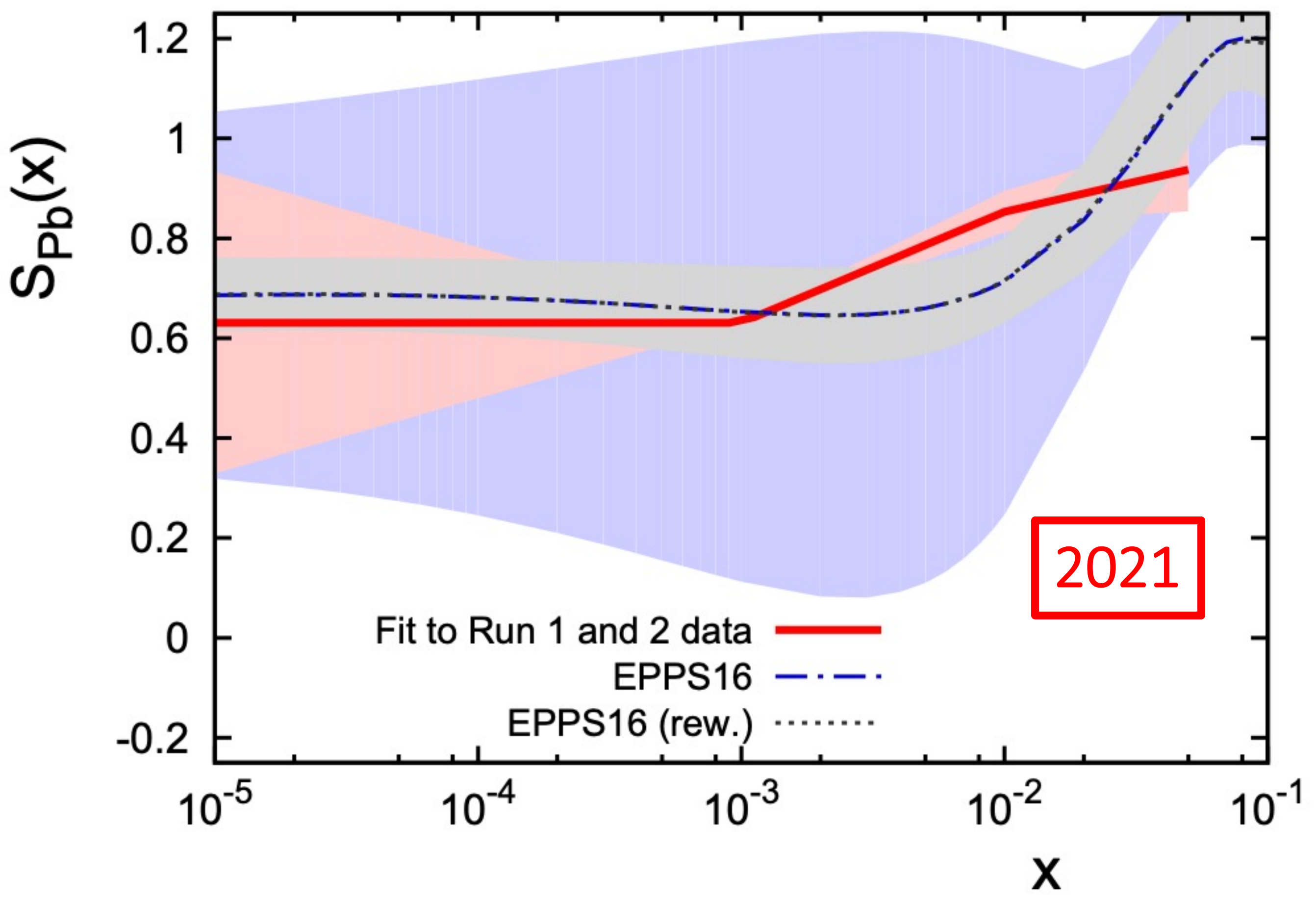


ALICE results have already advanced the field

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

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





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

Now LHCb published points: arXiv 2107.03223

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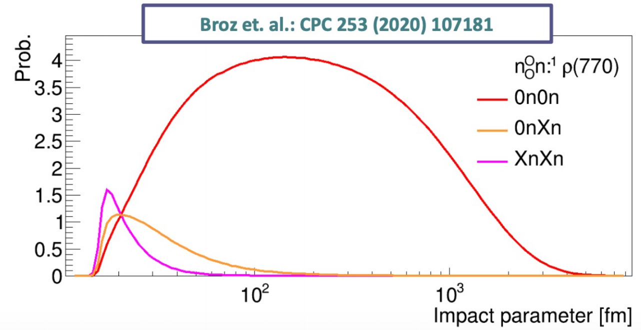
Techniques to solve the Bjorken-x ambiguity

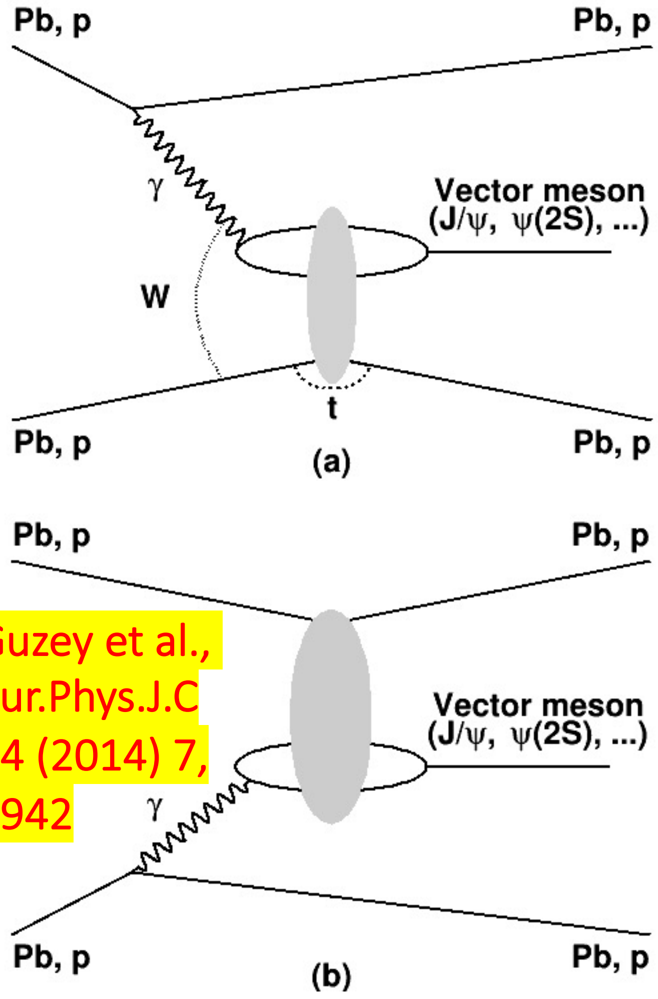
Neutron emission principle:

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

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

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





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

Peripheral photoproduction:

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

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

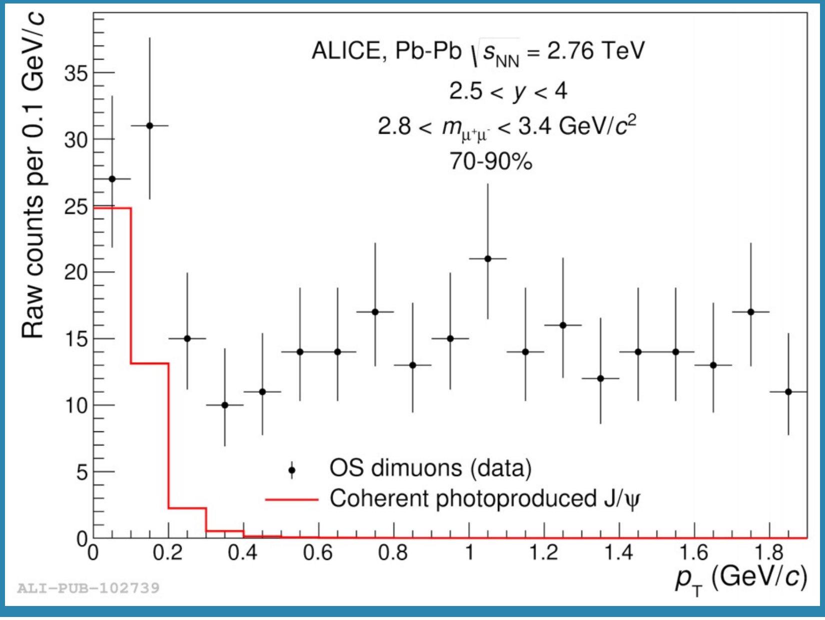
$$\frac{d\sigma^{U}_{PbPb}}{dy} = n_{U}(\gamma,+y)\cdot\sigma_{\gamma Pb}(+y) + n_{U}(\gamma,-y)\cdot\sigma_{\gamma Pb}(-y)$$

J.G. Contreras PRC 96 (2017) 015203

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

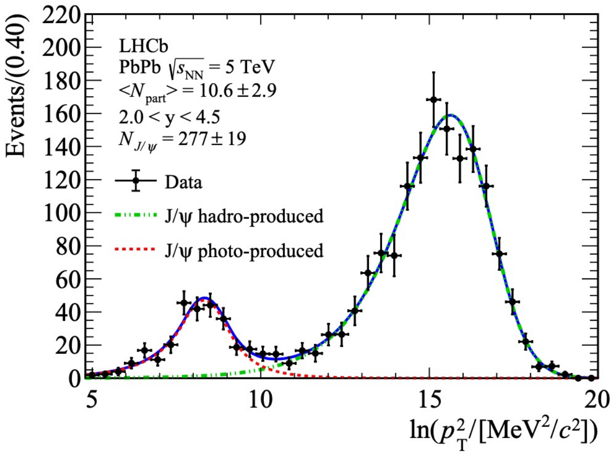
Peripheral J/ψ photoproduction

- First observed with Run 1 data by ALICE
- Now confirmed with Run 2 statistics by both ALICE and LHCb. STAR also reports this

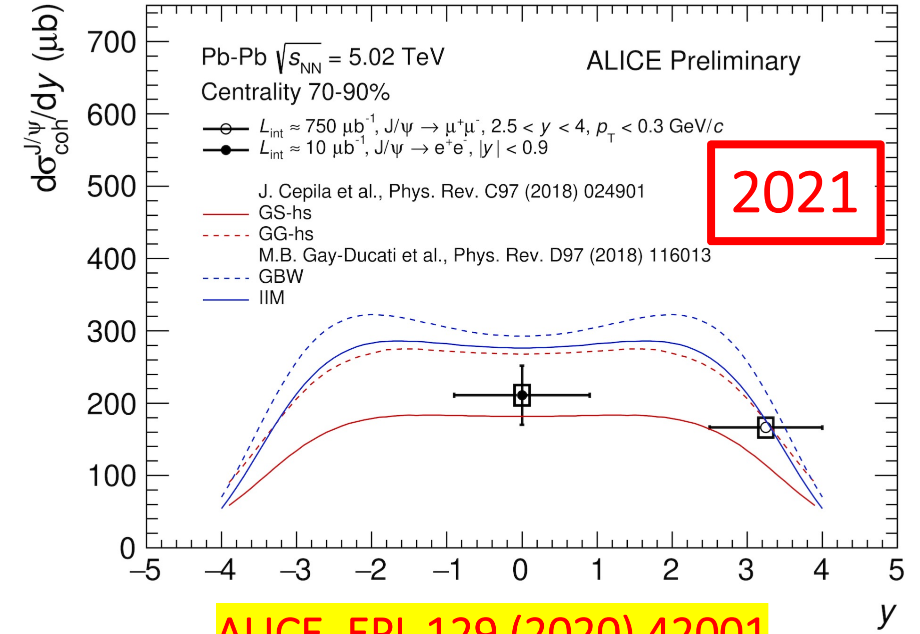


ALICE, PRL 116 (2016), 222301

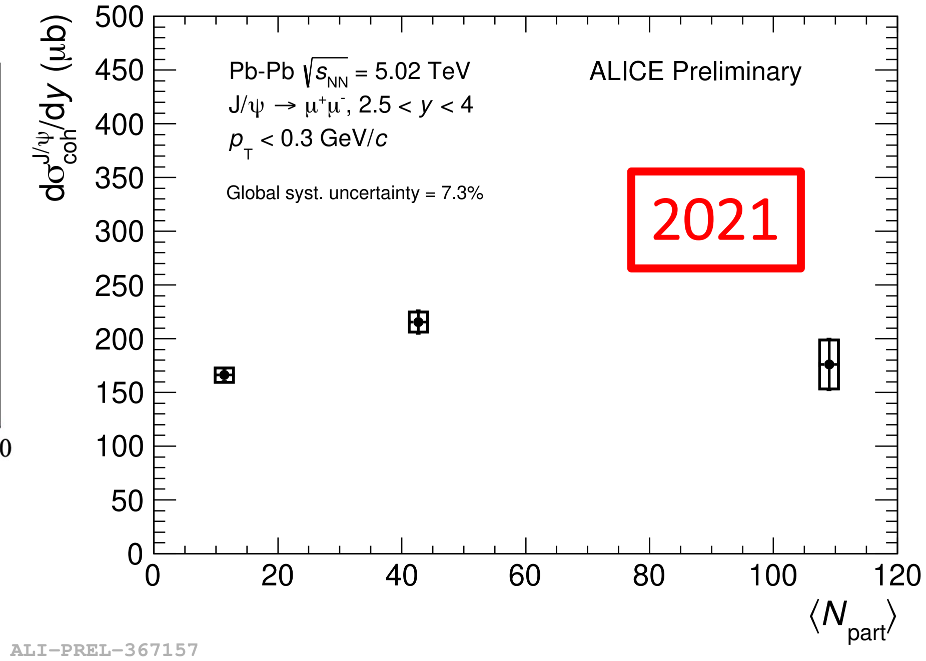
STAR Collaboration, PRL 123, 132302 (2019)



LHCb, arXiv: 2108.02681



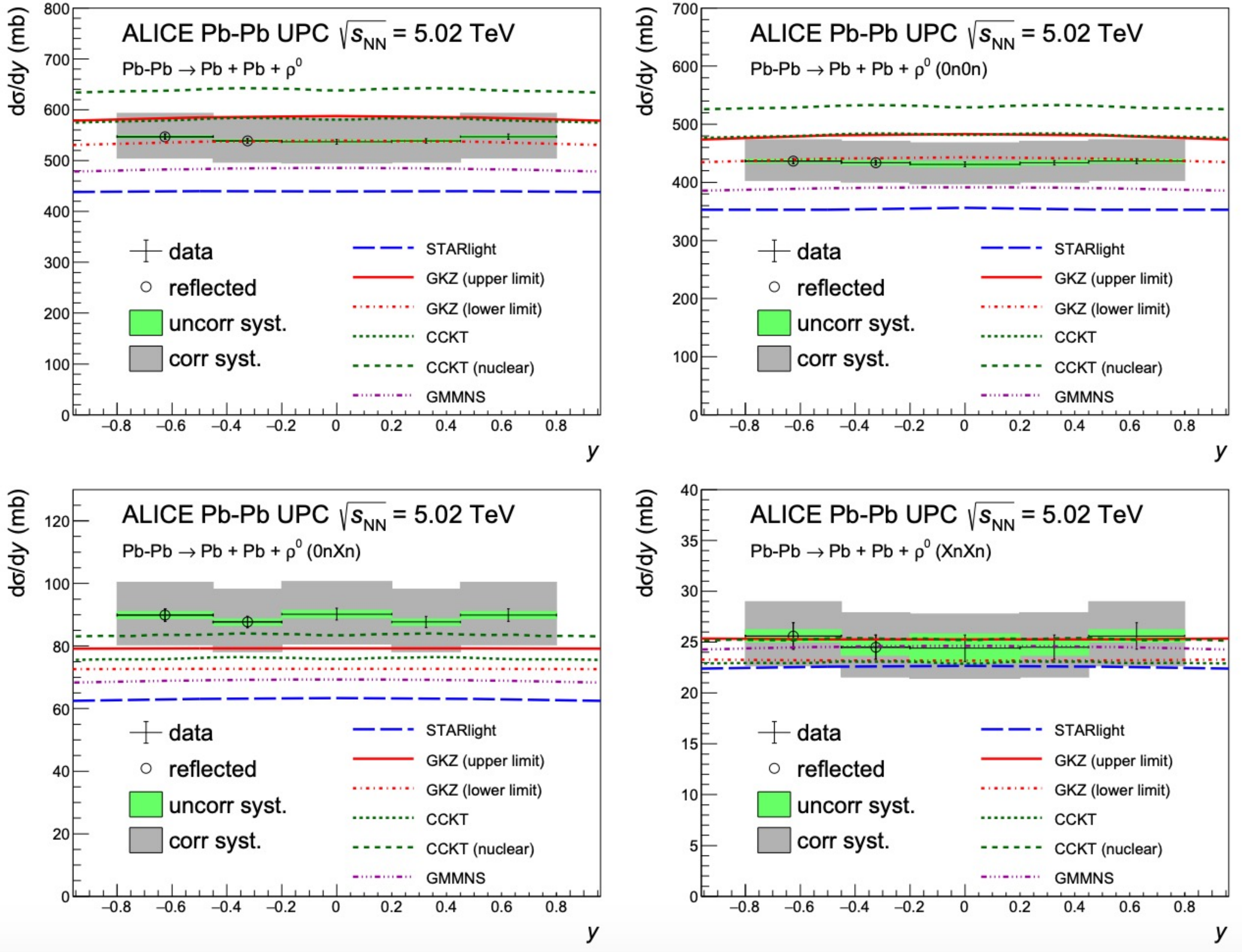
ALICE, EPL 129 (2020) 42001



ALICE, EPL 129 (2020) 42001

Coherent ρ^0 in Pb-Pb with neutron emission

- Generally good agreement with models on the market
- A good proof-of-principle while waiting for reduced uncertainties and better agreement between models
- Different neutron emission classes = different impact parameters
- $\langle b_{XNXN} \rangle < \langle b_{XN0N} \rangle < \langle b_{0N0N} \rangle$
- Factorization holds



ALICE, JHEP06 (2020) 35

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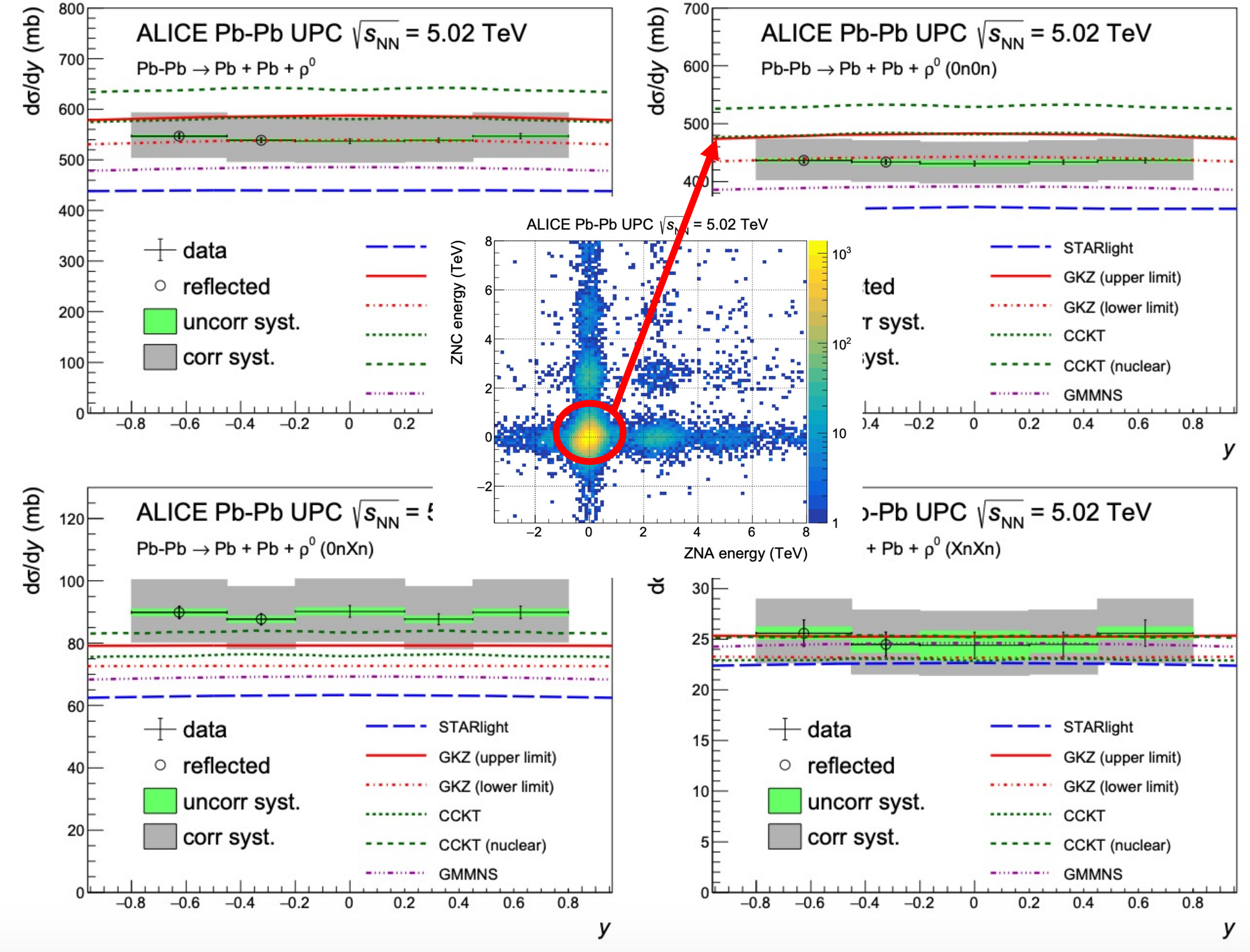

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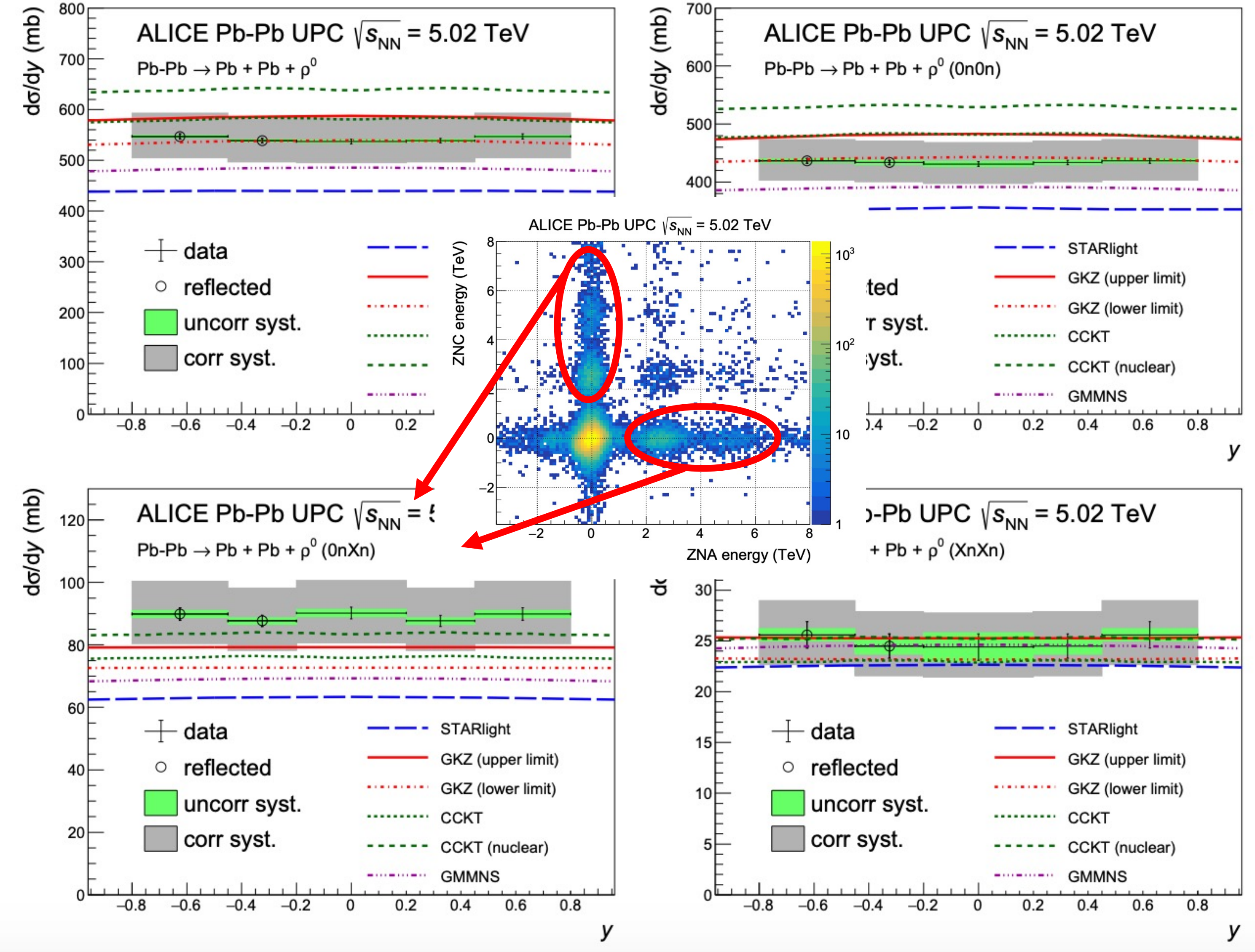

ALICE, JHEP06 (2020) 35

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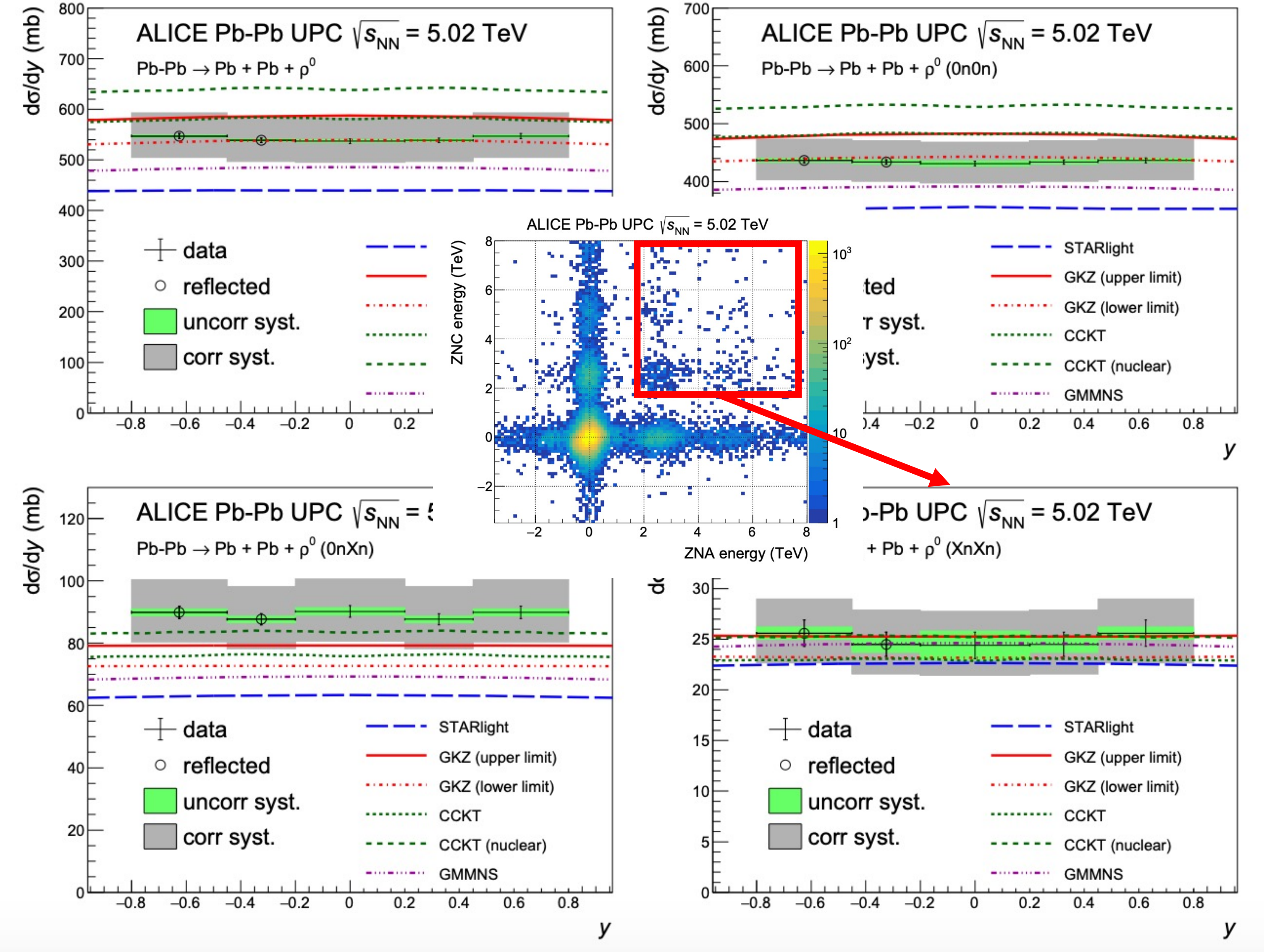

ALICE, JHEP06 (2020) 35

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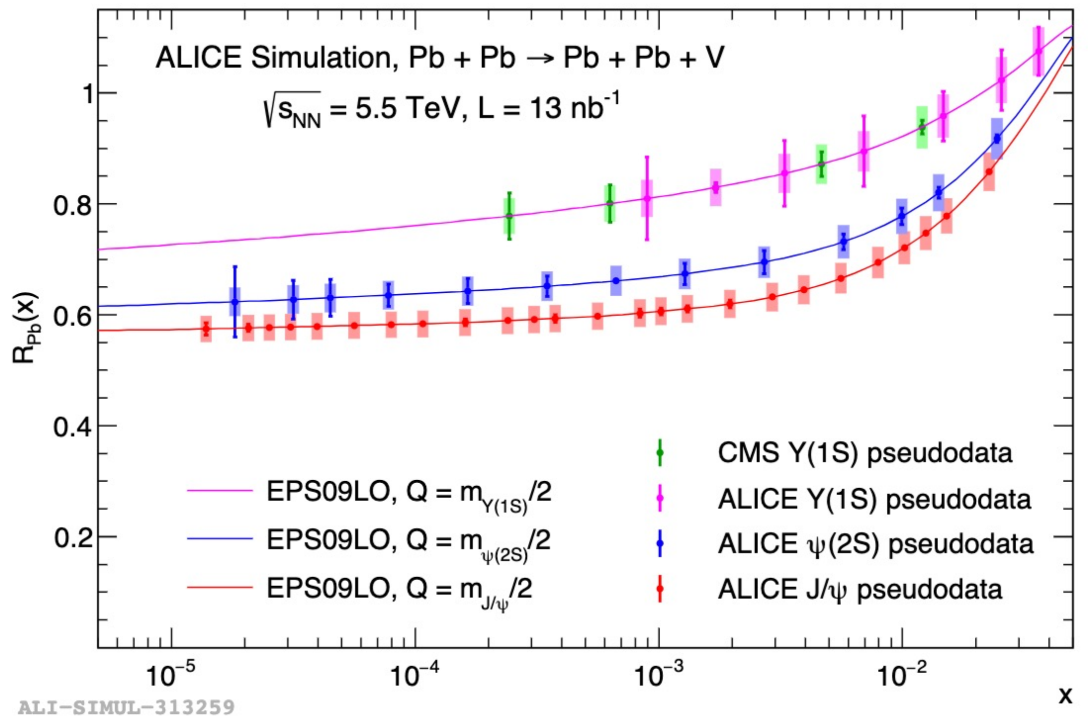
Beyond Run 2 data

- 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

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

Central: $|y| < 0.9$ Forward: $2.5 < |y| < 4$



Summary and a personal wishlist for the future

Shown here:

- 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)!

For all of us feeling nostalgic about CERN!

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