Photoproduction of vector mesons in ultra-peripheral collisions with ALICE

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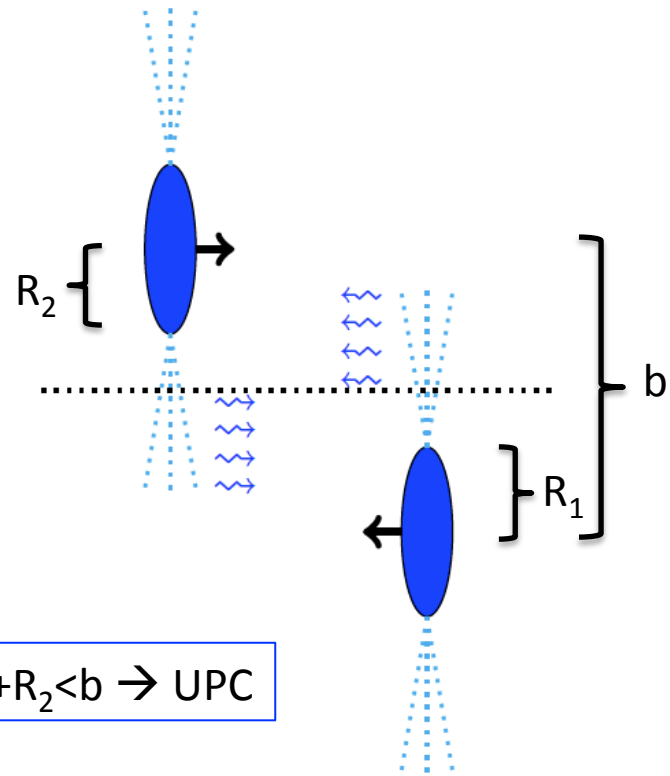
Beams of quasi-real photons at the LHC

The LγHC and LγγC

The EM field of protons and ions at the LHC can be viewed as a beam of quasi real photons



$R_1+R_2<b \rightarrow$ UPC

Note 1:

There are two potential sources, correspondingly two potential targets.

Note 2:

The photon is coherently emitted by the source and its virtuality is restricted by the radius of the emitting particle: $Q^2 \approx hc/(2\pi R)^2$

✓ γ from Pb: $Q^2 \approx (30\ \text{MeV})^2$

Note 3:

The intensity of the photon beam is proportional to Z^2

Note 4:

The max energy of the photons in the lab system is determined by the boost of the emitting particle

✓ Run2: larger energies possible

Note 5:

Interactions at large impact parameters are of electromagnetic origin.

Why Pb-ions as source of photons?

The LHC accelerates both protons and Pb nuclei

As mentioned before, the intensity of the photon beam depends on the square of the electric charge of the accelerated particle:
→ The intensity is orders of magnitude larger for Pb w.r.t. proton beams.

It is necessary to separate the collisions of hadrons, for which the LHC and its detectors were optimized, from the collisions involving quasi-real photons.

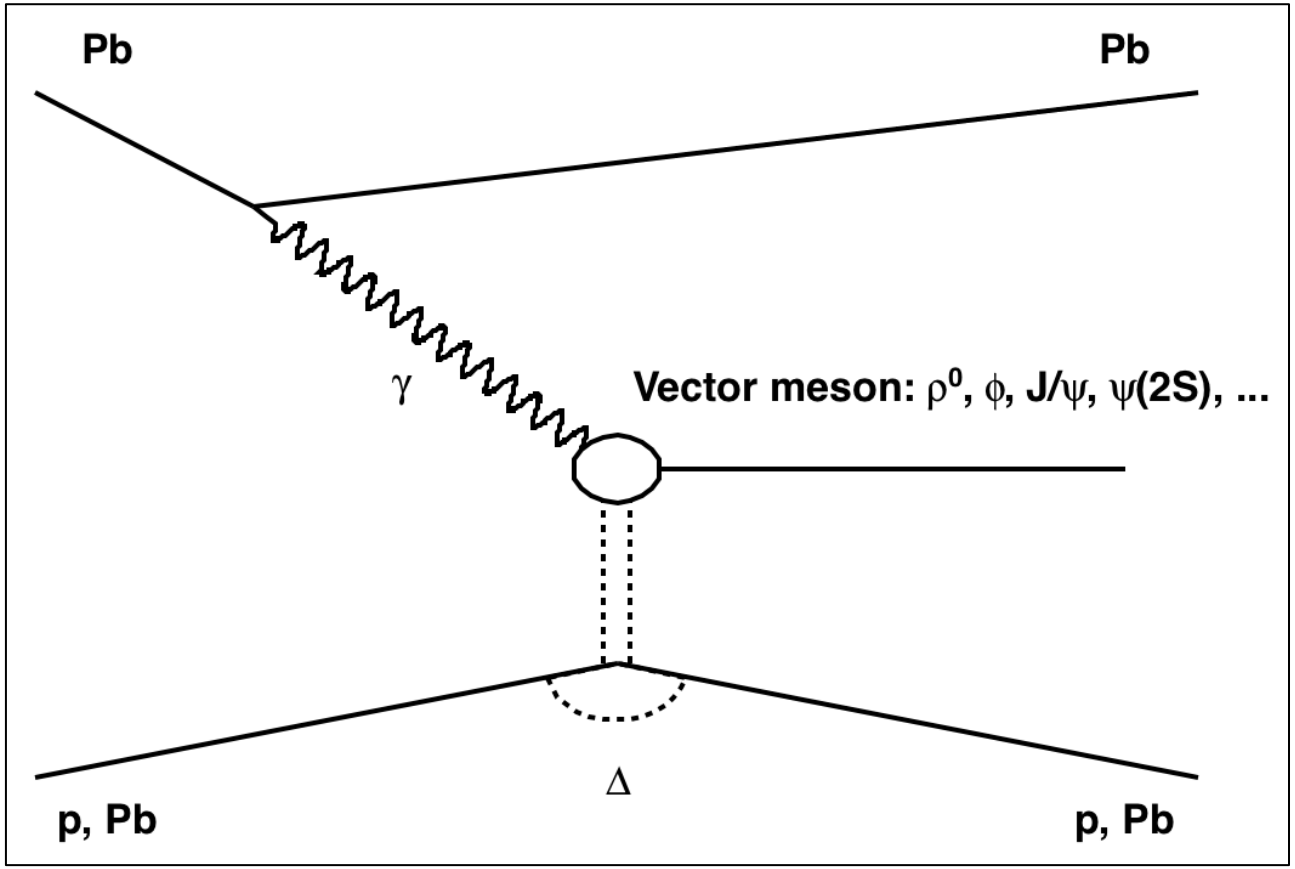
The strategy is to use the facts that
1. Strong interactions tend to produce particles at all rapidities, while electromagnetic interactions produce large rapidity gaps
2. Pb nuclei are very fragile objects, which break in all hadronic interactions … and ALICE is able to detect with very high efficiency if a Pb nucleus breaks (by measuring in the very forward direction neutrons from the nuclear fragmentation)

→ Look for processes with large rapidity gaps and (almost) intact outgoing nuclei

These are called Ultra-Peripheral Collisions (UPC)

Exclusive photoproduction of vector mesons and ALICE

Exclusive vector meson production



- Kinematics completely determined:
  - ✓ Rapidity measures the energy of the photon-target interaction
  - ✓ The square of the transverse momentum of the vector meson is related to Δ the momentum transferred in the target vertex
- The only particles reaching the detector are the decay products of the vector meson

Very clean signature

What do we need?

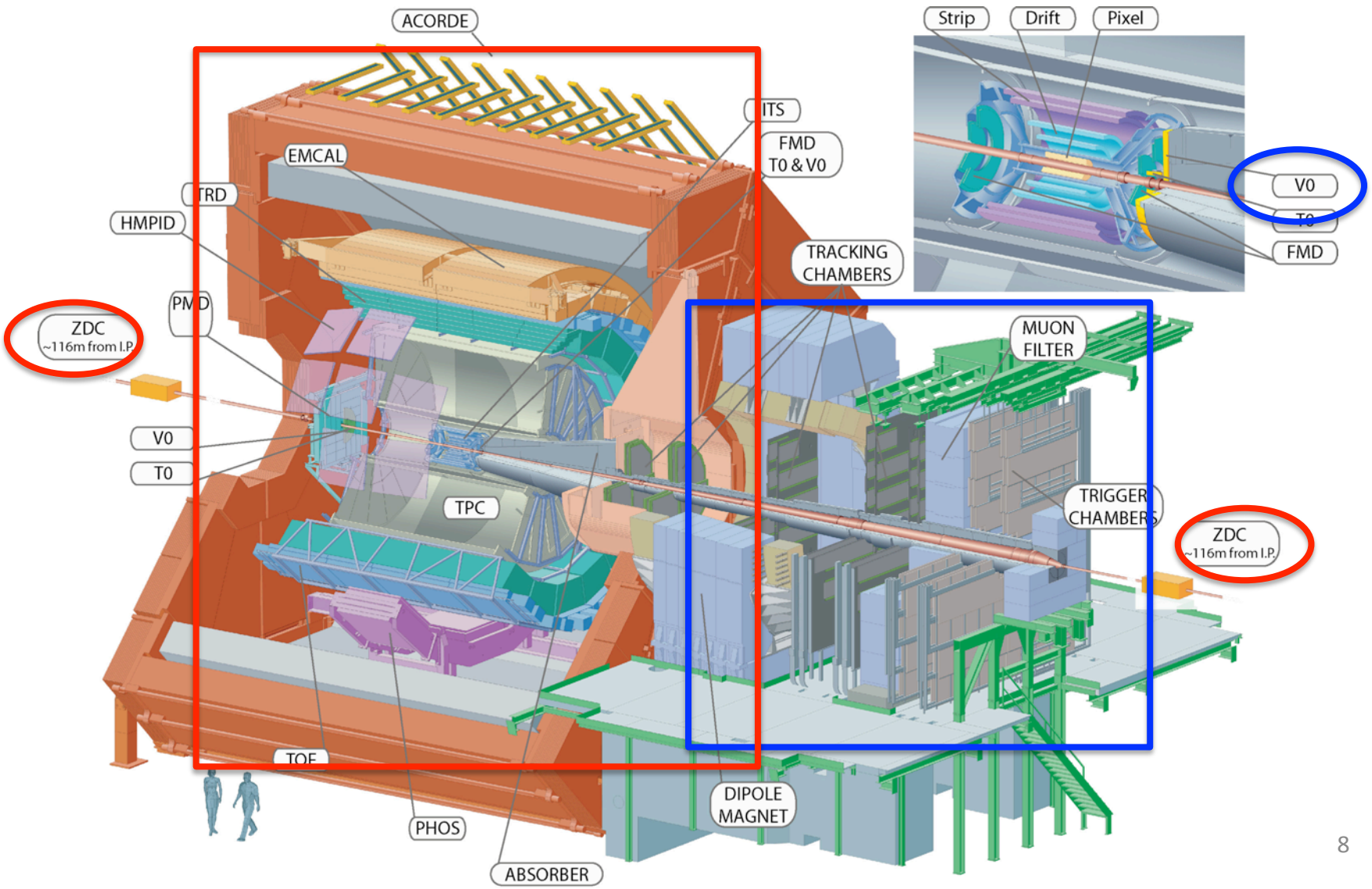
1. To measure the decay products of a vector meson with very low transverse momentum:
   - ρ to $\pi^+ + \pi^-$
   - J/ψ to $\mu^+ + \mu^-$ or to $e^+ + e^-$
   - $\psi(2S)$ to $\mu^+ + \mu^-$, $e^+ + e^-$ or to $J/\psi + \pi^+ + \pi^-$

2. To make sure there is nothing else in the detector:
   Large rapidity coverage to veto particles

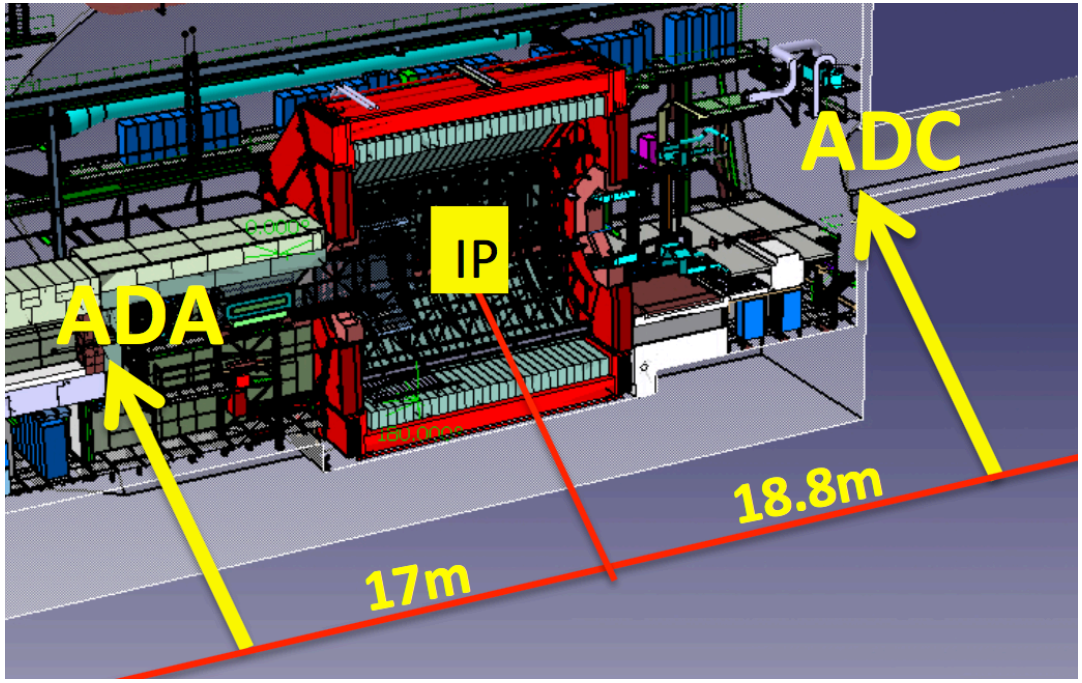
3. To make sure that the source/target do not break:
   neutron Zero Degree Calorimeters (ZDC)

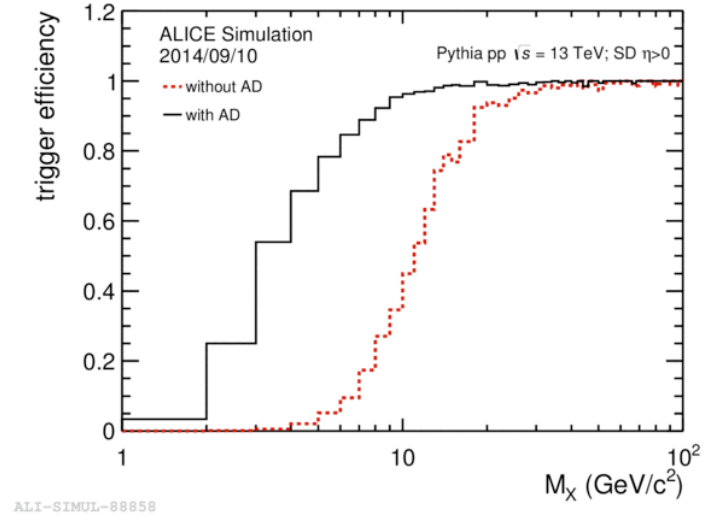
ALICE

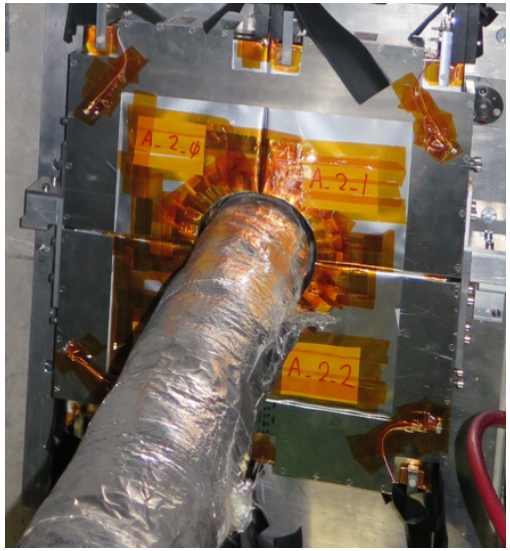
Magnetic field of 0.5 T in the central region

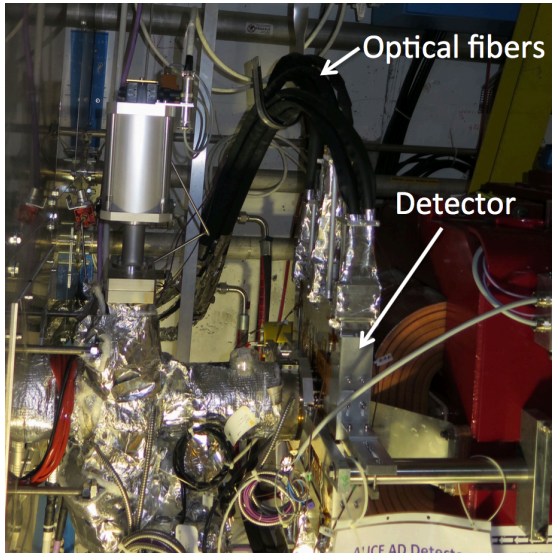


New for Run2: The AD detector









- ✓ Modules of plastic scintillator read out with PMTs
- ✓ Time resolution 300 (500) ps in C (A) side, allows to reject out of time background
- ✓ Enlarges ALICE geometric rapidity coverage to
  - ✓ $-6.9 < \eta < -4.9$
  - ✓ $4.9 < \eta < 6.3$
- ✓ It increases ALICE capability to impose a veto on extra activity for exclusive processes in UPC

γ-Pb: Results from Pb-Pb collisions in Run1

Four topics:
① Coherent ρ production
② Coherent and incoherent J/ψ production
③ Coherent $\psi(2S)$ production
④ A surprise!

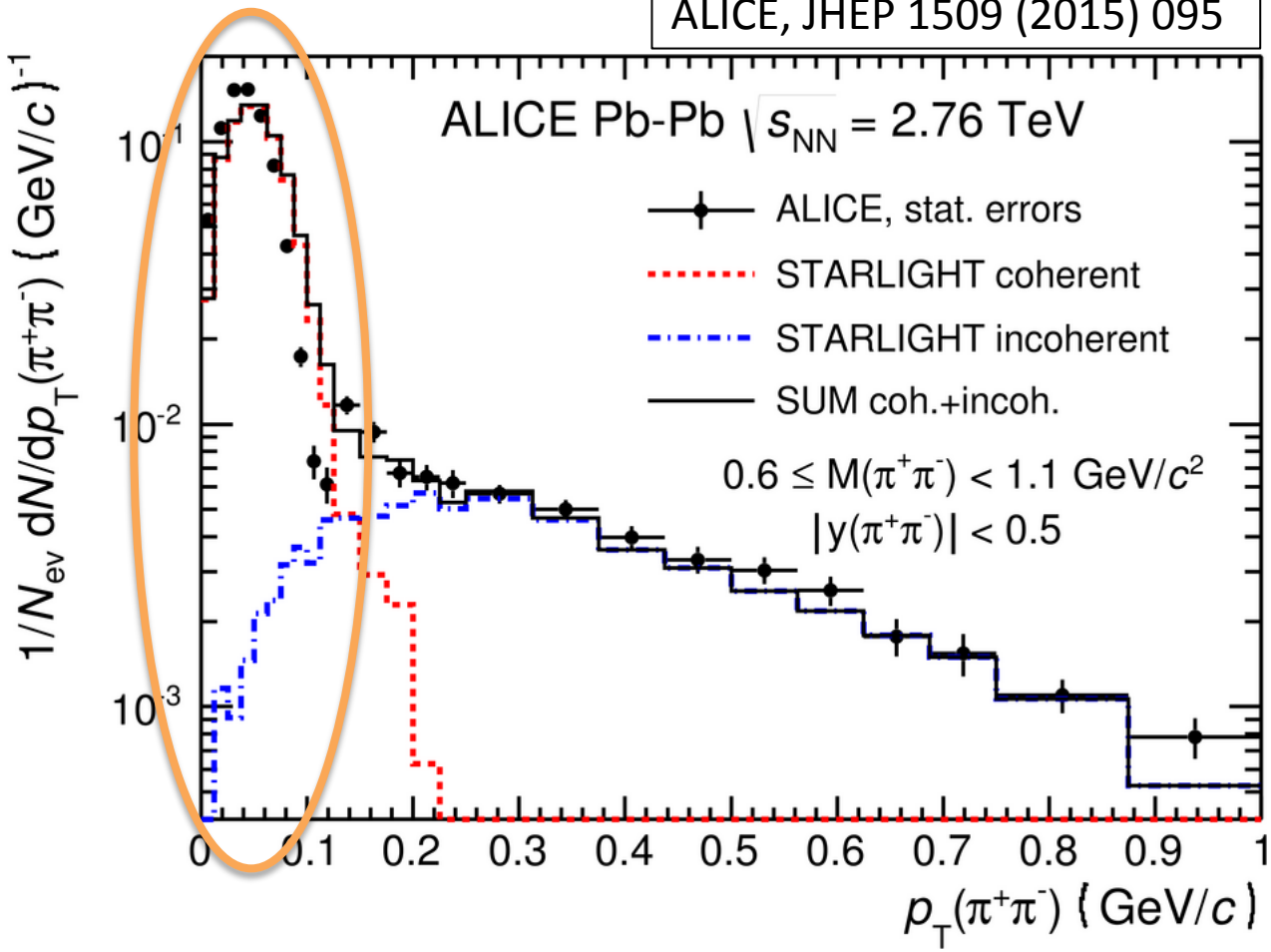
Coherent ρ production

- ✓ Coherent: photon couples to full nuclei: VM has **very** low transverse momentum
- ✓ Incoherent: photon couples to one nucleon: VM has low transverse momentum

ALICE, JHEP 1509 (2015) 095

- ✓ 2010 data
- ✓ Decay into $\pi^+\pi^-$

Distribution of transverse momentum for coherent ρ is wider in STARLIGHT than in data
To be studied in Run2



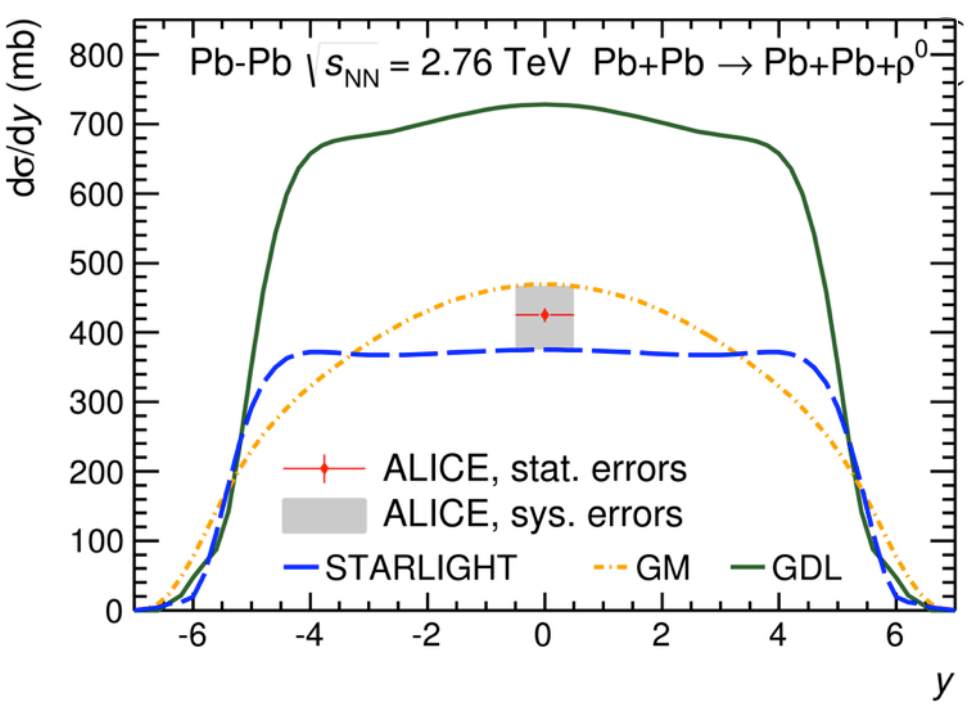
- ✓ Transverse momentum less than 150 MeV/c to reject incoherent contribution

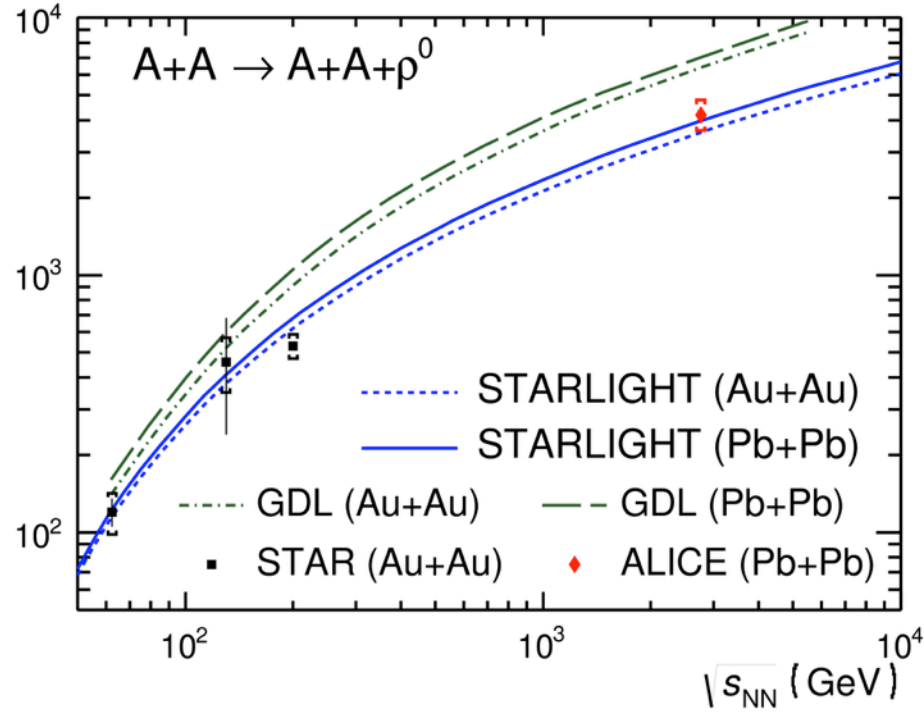
Coherent ρ production: cross section

[1] L. Frankfurt, M. Strikman, M. Zhalov (GDL): QM Glauber + DL fit to HERA data

[2] V.P. Gonçalves, M.V.T. Machado (GM): Color dipole model with CGC-like saturation

[3] S.R. Klein, J. Nystrand (STARLIGHT): Classical Glauber model + fit to HERA data





- ✓ Agreement with STARLIGHT
- ✓ Disagreement with GDL model may be explained by inelastic nuclear shadowing (see Phys.Lett. B752 (2016) 51-58)

ALICE, JHEP 1509 (2015) 095

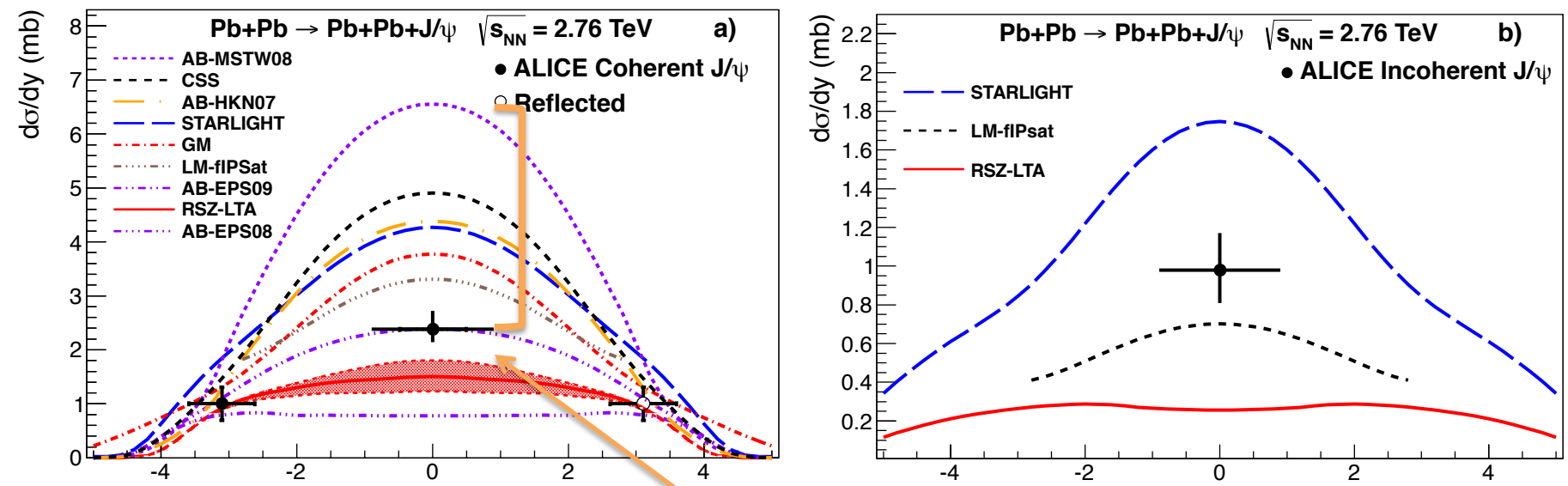
Coherent and incoherent J/ψ production: cross sections

ALICE: Phys.Lett. B718 (2013) 1273-1283 and Eur. Phys. J. C (2013) 73:2617

[1] L. Frankfurt, M. Strikman, M. Zhalov (GDL1): QM Glauber + DL fit to HERA data

[4] T. Lappi, H. Mäntysaari : color dipole model with saturation + Glauber

[3] S.R. Klein, J. Nystrand (STARLIGHT): Classical Glauber model + fit to HERA data



x~10^{-2}

x~10^{-3}

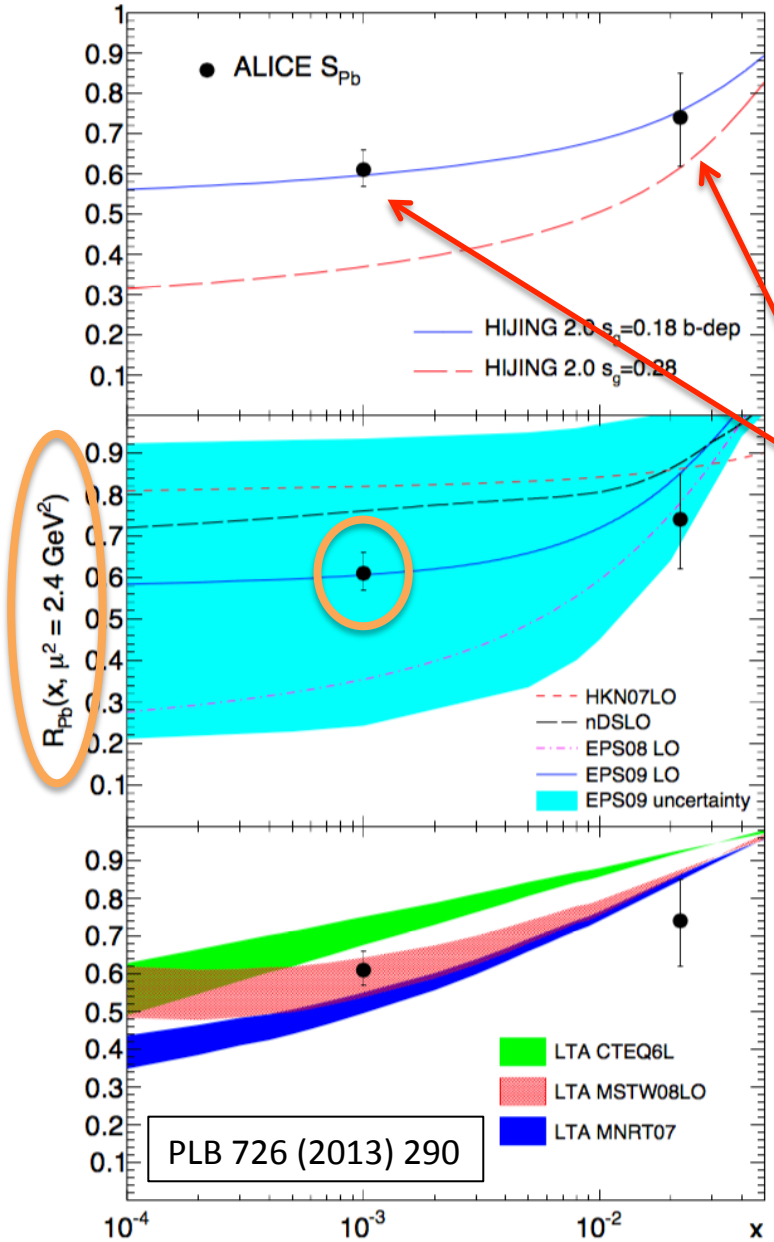
Direct observation of (moderate) gluon shadowing

[5] Cisek, Szczurek, Schäfer (CSS): Color dipole model with unintegrated gluon distribution

[2] V.P. Gonçalves, M.V.T. Machado (GM): Color dipole model with CGC-like saturation

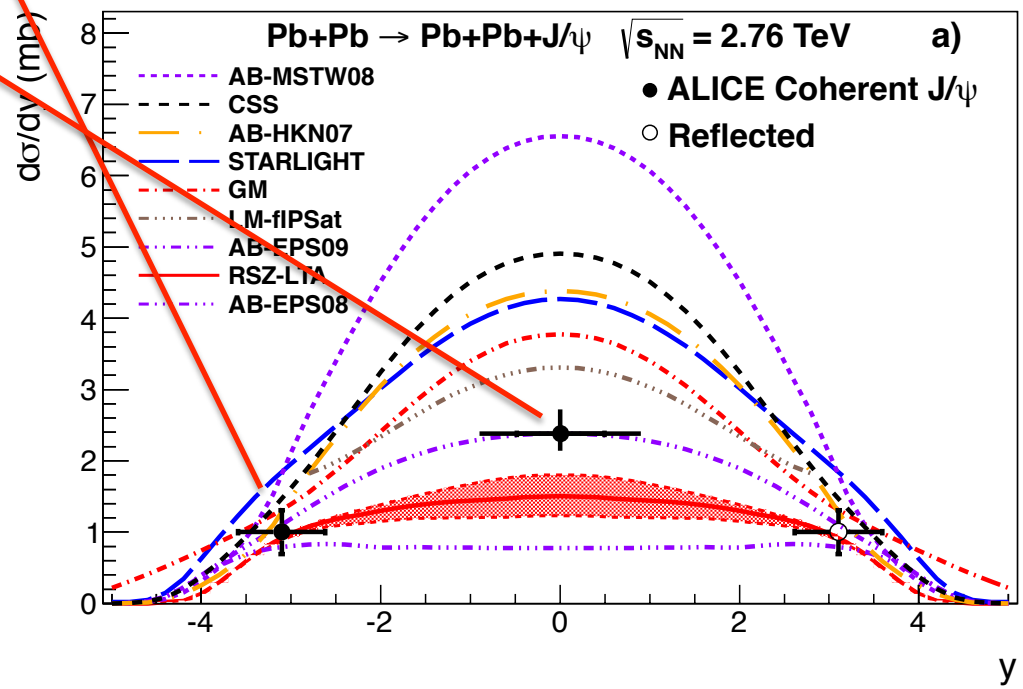
[6] Adeluyi and Bertulani, (AB): LO pQCD + K-factor + nuclear PDFs

Coherent J/ψ cross section



PLB 726 (2013) 290

Under some assumptions, ALICE measurements can be translated into LO pQCD constraints for gluon shadowing at small x



ALICE: Phys.Lett. B718 (2013) 1273
Eur. Phys. J. C (2013) 73:2617

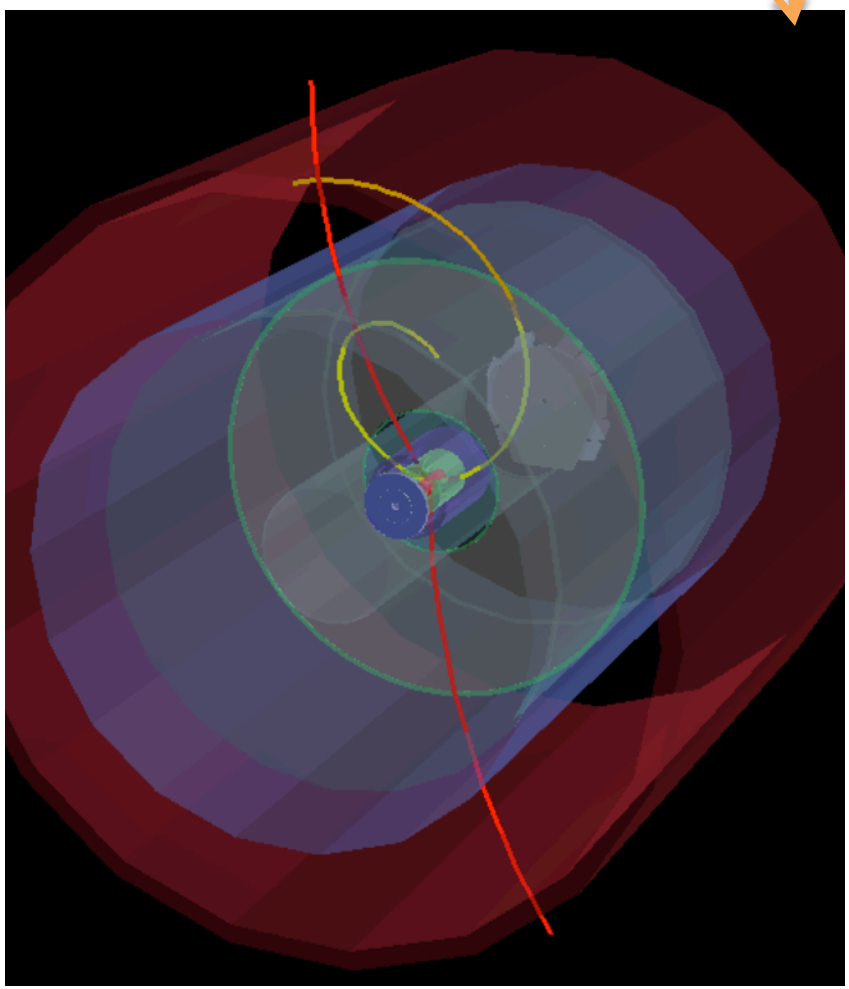
.I-PUB-66209

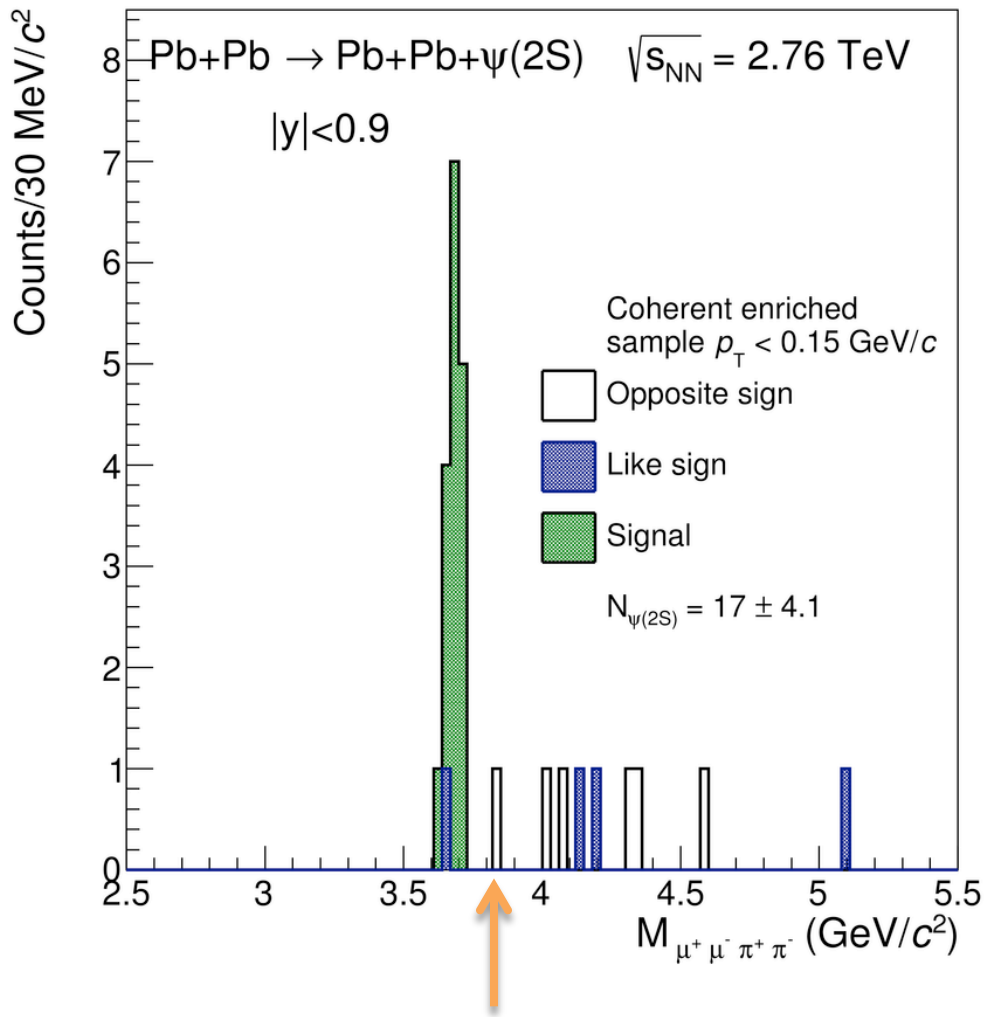
Note: $R_{Pb}(x,\mu^2) = g_{Pb}(x,\mu^2)/(A_{Pb} g_p(x,\mu^2))$

Coherent ψ(2S) production

✓ Measured decay channels:
$\psi(2S) \rightarrow l^+l^-$ and $\psi(2S) \rightarrow J/\psi\pi^+\pi^-$

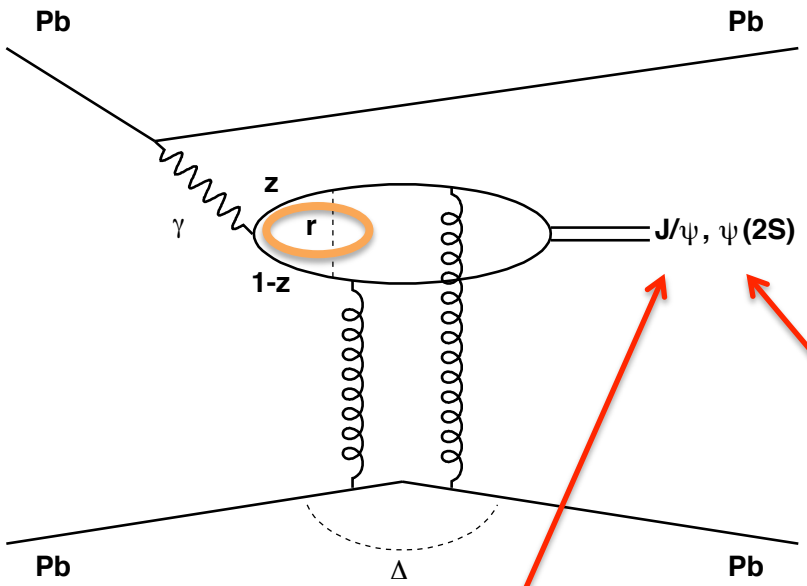
ALICE, PLB 751 (2015) 358

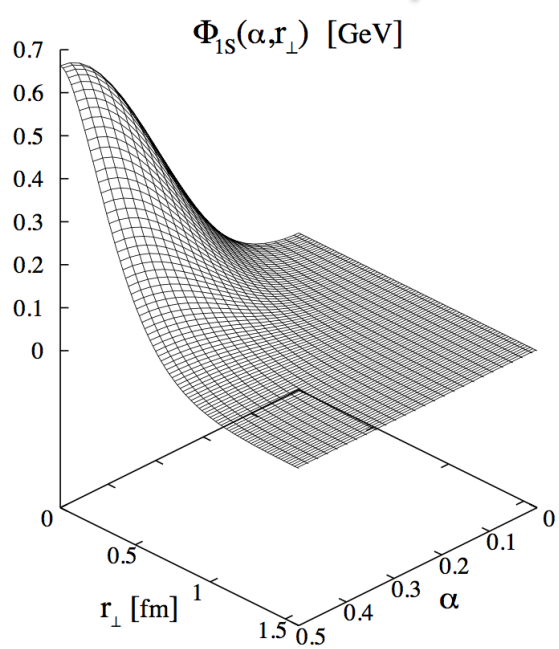


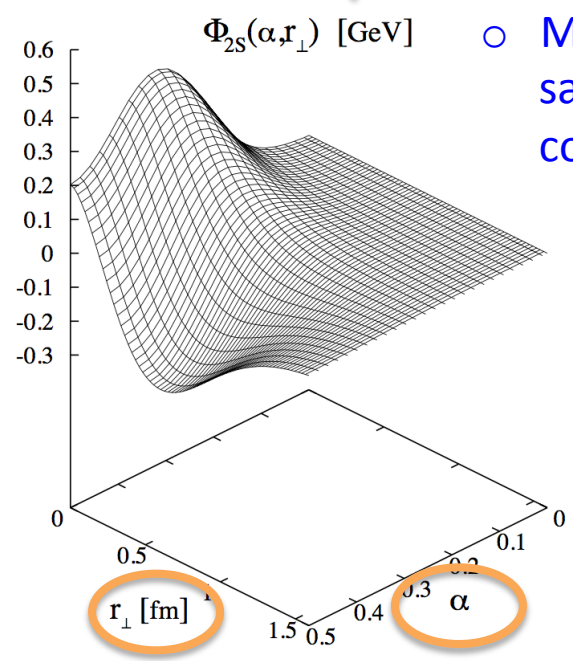


✓ Few signal events with almost no background

ψ(2S) wave function







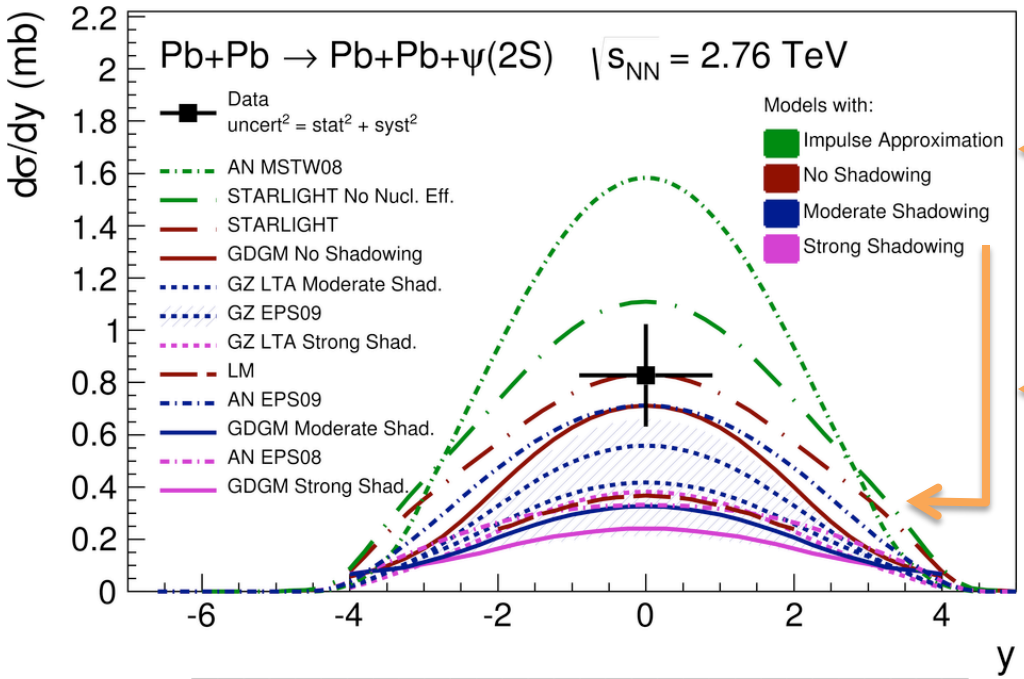
PRD 62 (2000) 094022

- The wave function of excited states present so called nodes (Nemchik et al, ZPC75 (1997) 71)
- These nodes have a negative contribution for large dipole sizes, where saturation effects are expected
- Measure J/ψ and ψ(2S) in the same kinematic region and compare them

(α=z, see diagram)

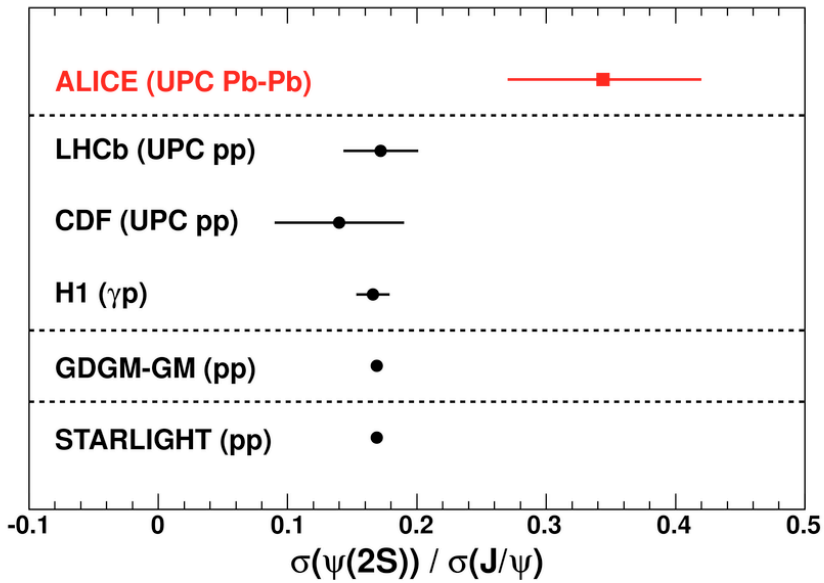
Coherent ψ(2S) production: cross section

ALICE, PLB 751 (2015) 358



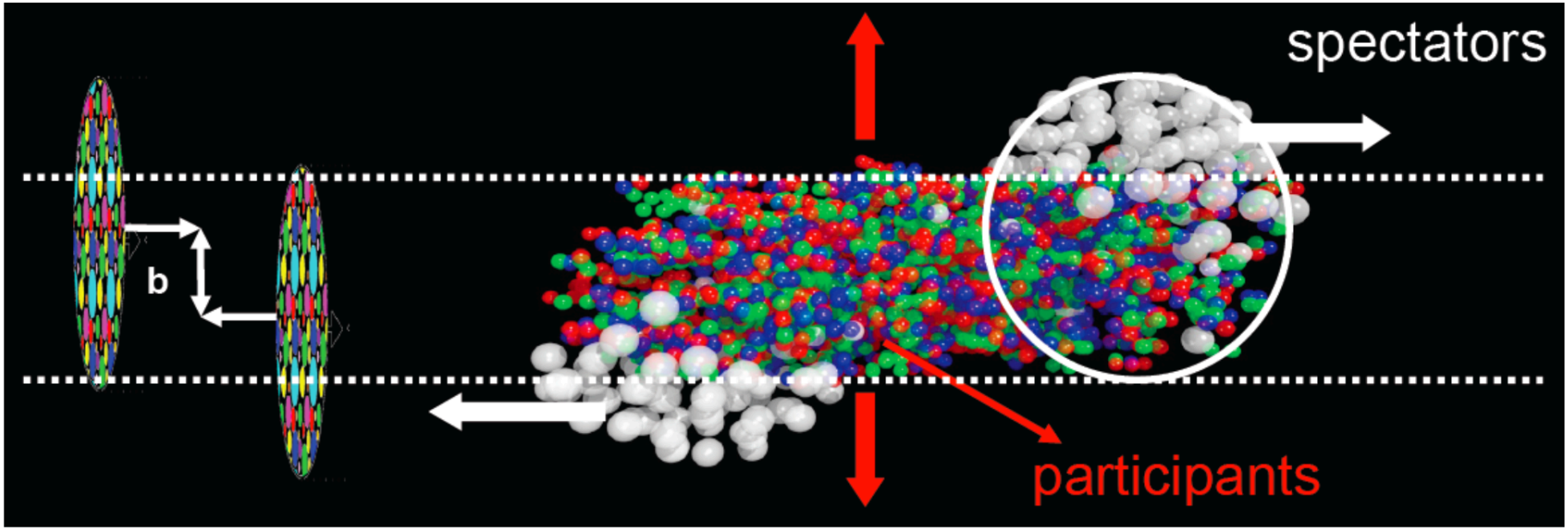
Both impulse approximations should be equal …

Strong shadowing is disfavoured …



Do nuclear effects affect differently 1S and 2S states?
Need more precise data!

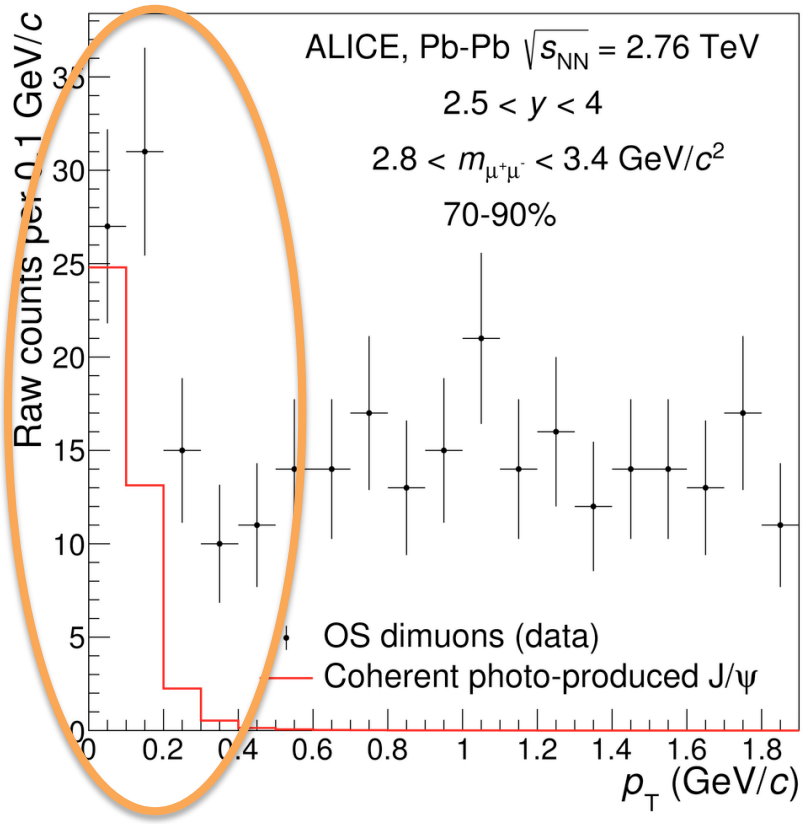
Pb-Pb collisions for $b<2*R_A$

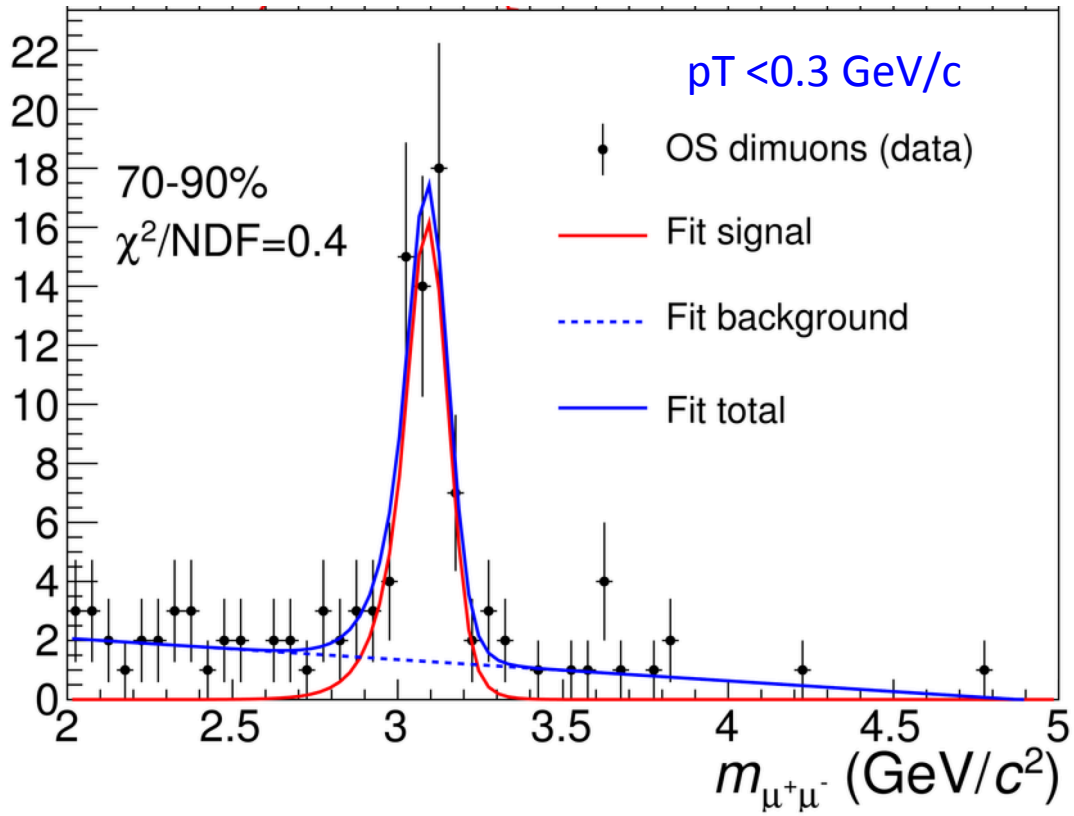


For collisions at impact parameters smaller than the sum of radii of the interacting particles, the nuclei interact hadronically and they break

Coherent J/ψ production in peripheral collisions

ALICE, arXiv 1509.08802, accepted in PRL



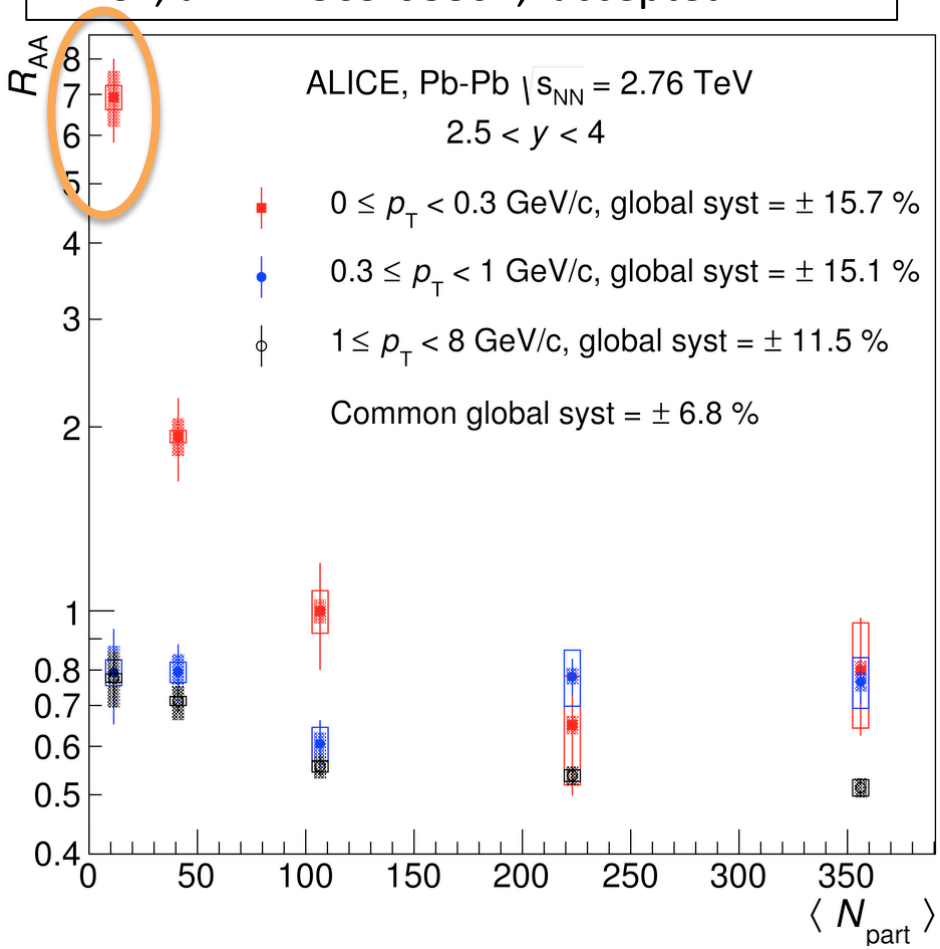


Clear excess in the yield at low p_T for peripheral collisions

And the excess is clearly from J/ψ

Coherent J/ψ production in peripheral collisions

ALICE, arXiv 1509.08802, accepted in PRL



If photoproduction is assumed as the underlying interaction we obtain

Centrality class	Cross section (μb)
0-10 %	<318
10-30%	<290
30-50%	$73 \pm 44_{-27}^{+26}$
50-70%	$58 \pm 16_{-10}^{+8}$
70-90%	$59 \pm 11_{-10}^{+7}$

No theoretical calculations available for coherent photoproduction in peripheral collisions

(A first try is in PRC93 (2016) 044912)

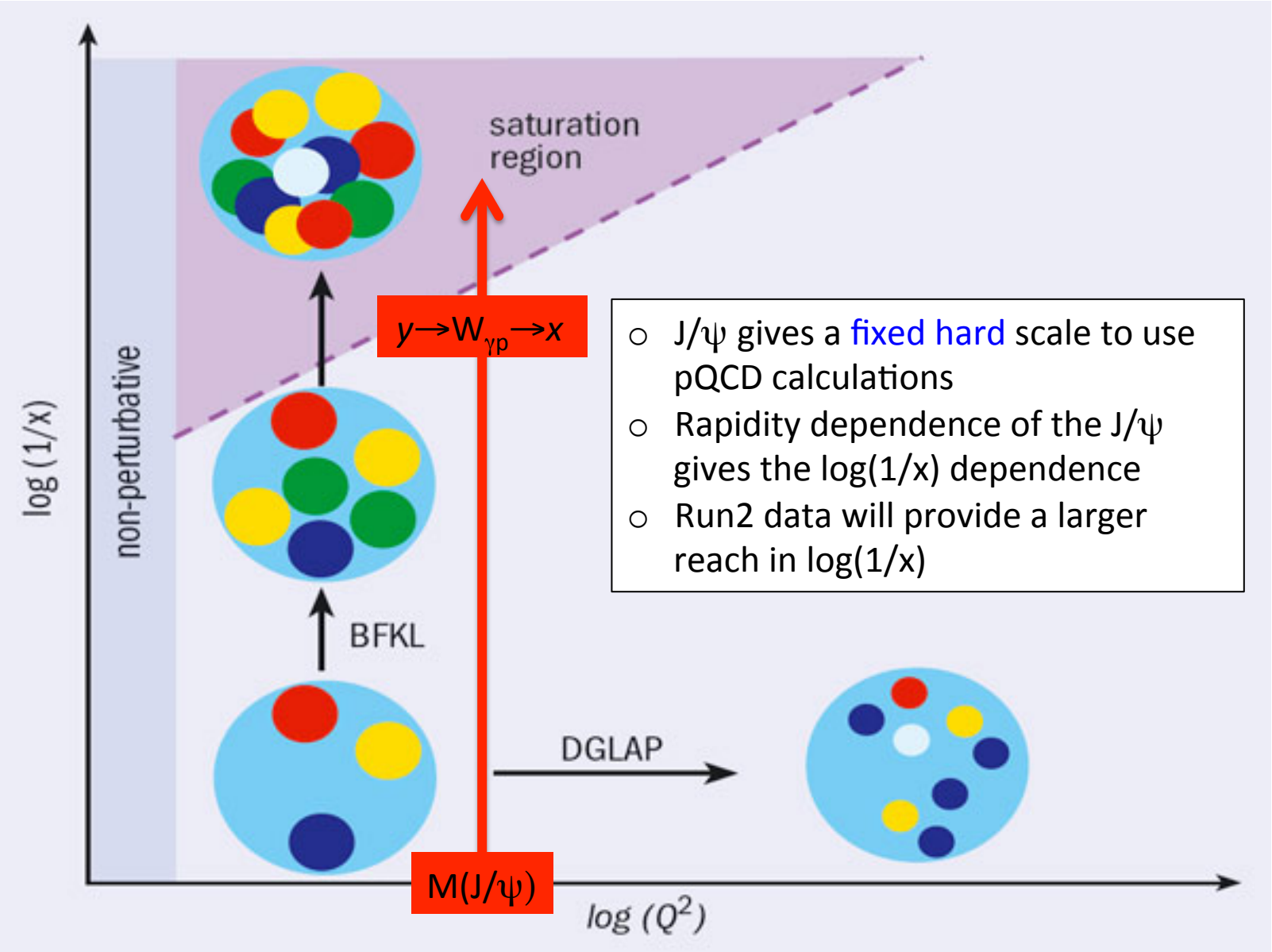
If the excess were from hadronic production, the R_{AA} would reach up to 7! (Standard expectation is $R_{AA} \sim O(1)$)

γp: Results from p-Pb collisions in Run1

Exclusive J/ψ production:
① Published results
② Work in progress

The evolution of the gluon in the proton

Diagram from CERN Courier, http://cerncourier.com/cws/article/cern/43194

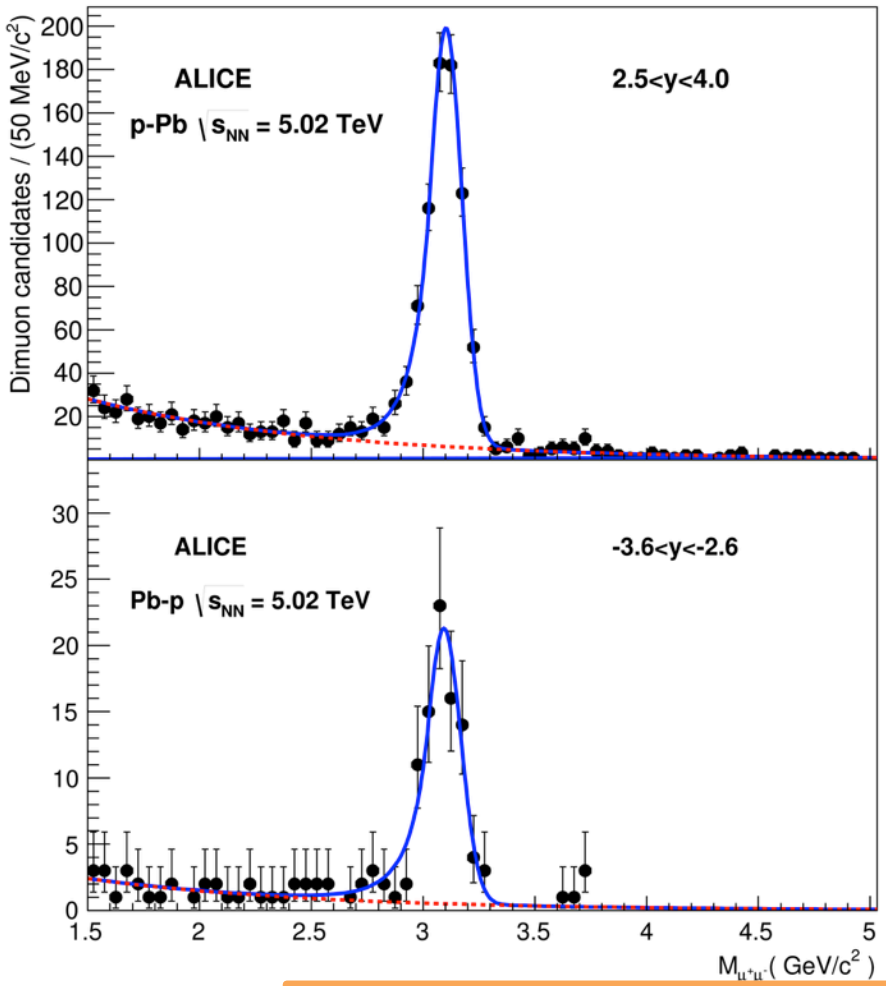


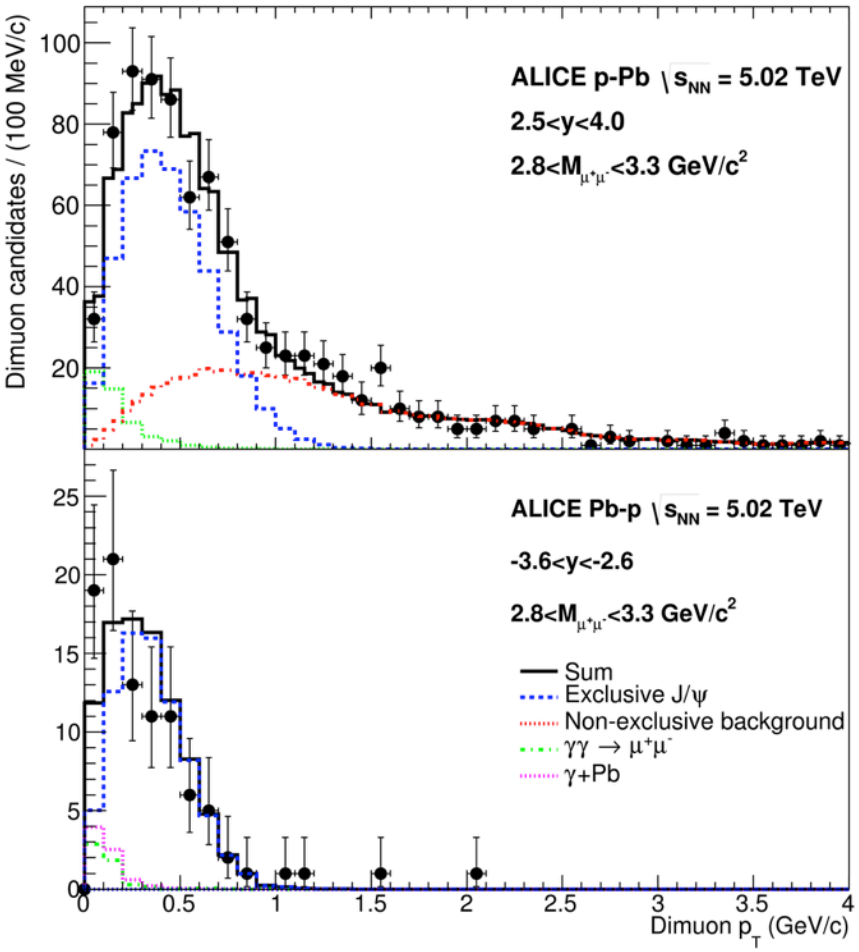
- J/ψ gives a fixed hard scale to use pQCD calculations
- Rapidity dependence of the J/ψ gives the log(1/x) dependence
- Run2 data will provide a larger reach in log(1/x)

Exclusive J/ψ production in p-Pb

The photon source is known: it is the lead ion in > 95% of the cases → rapidity of the J/ψ measures $W_{\gamma p}$, the center of mass energy of γp system

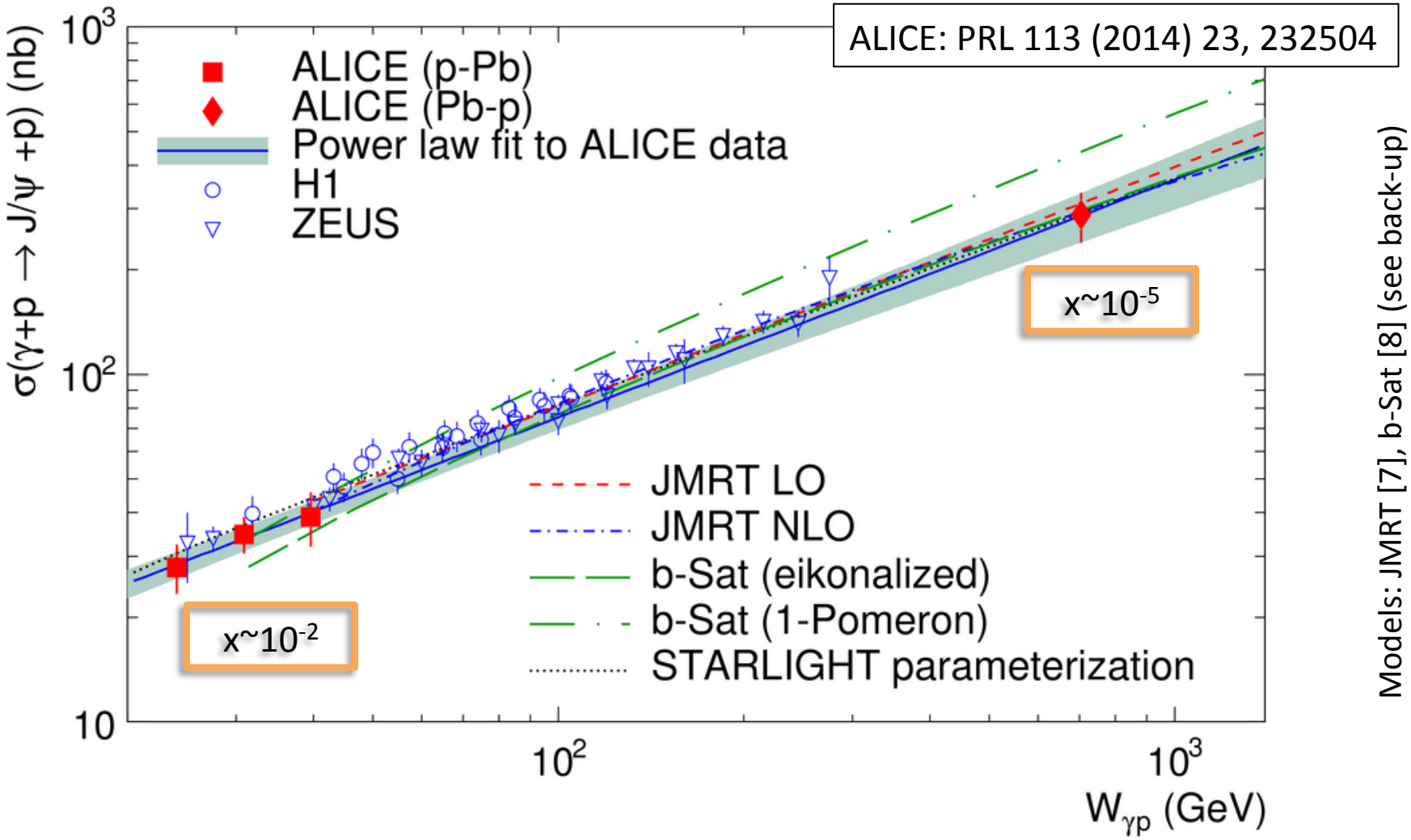
ALICE: PRL 113 (2014) 23, 232504





Clean signals, small background

Exclusive J/ψ production in p-Pb: cross sections

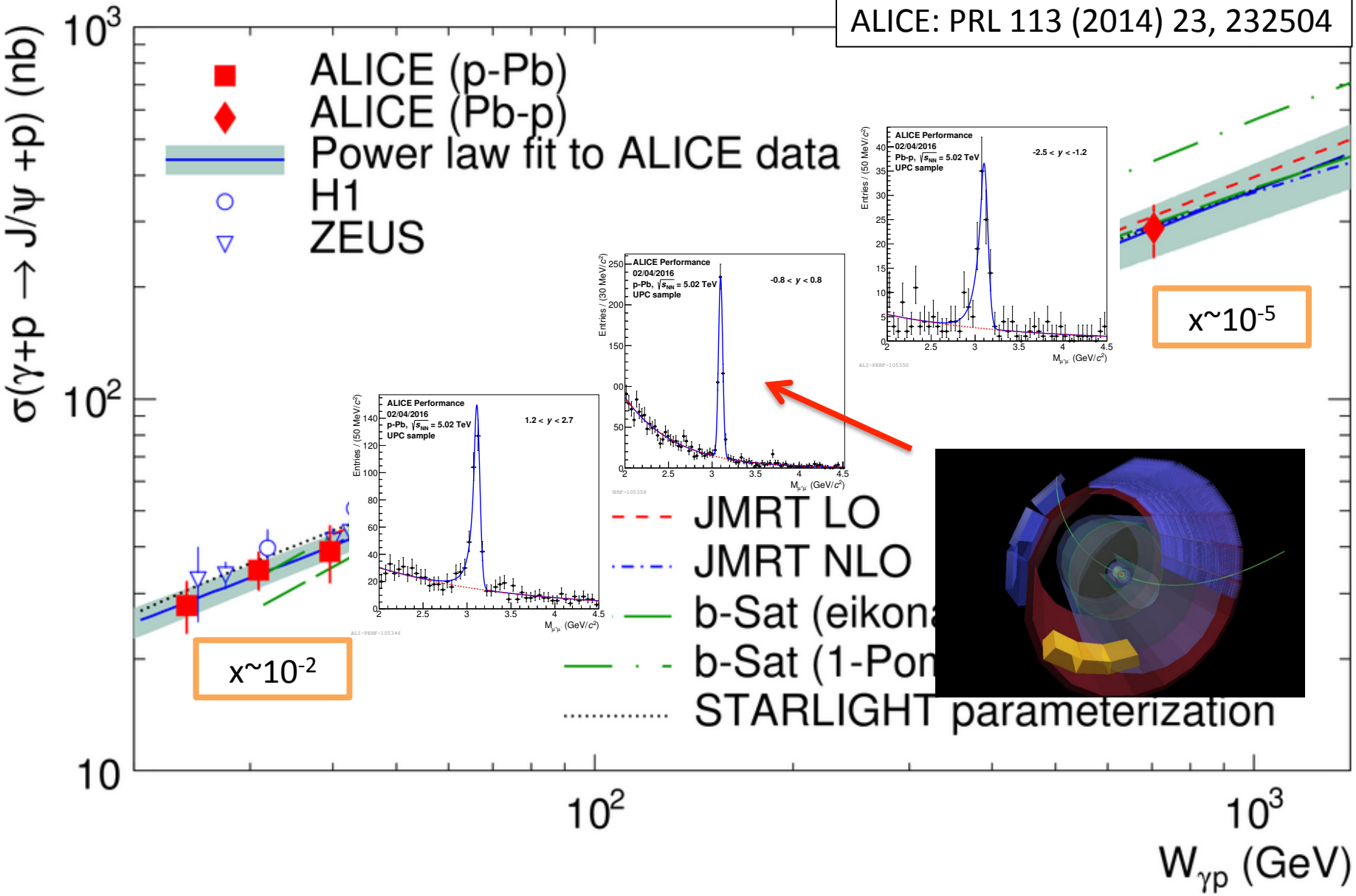


- ✓ ALICE data reaches more than twice the largest energy reached at HERA
- ✓ ALICE data alone compatible with a power law with exponent ~0.67±0.06
- ✓ Exponent is compatible with those from H1 (0.67±0.03) and ZEUS (0.69±0.02±0.03)

No change in the behavior of the cross section observed from HERA to LHC ... yet ...

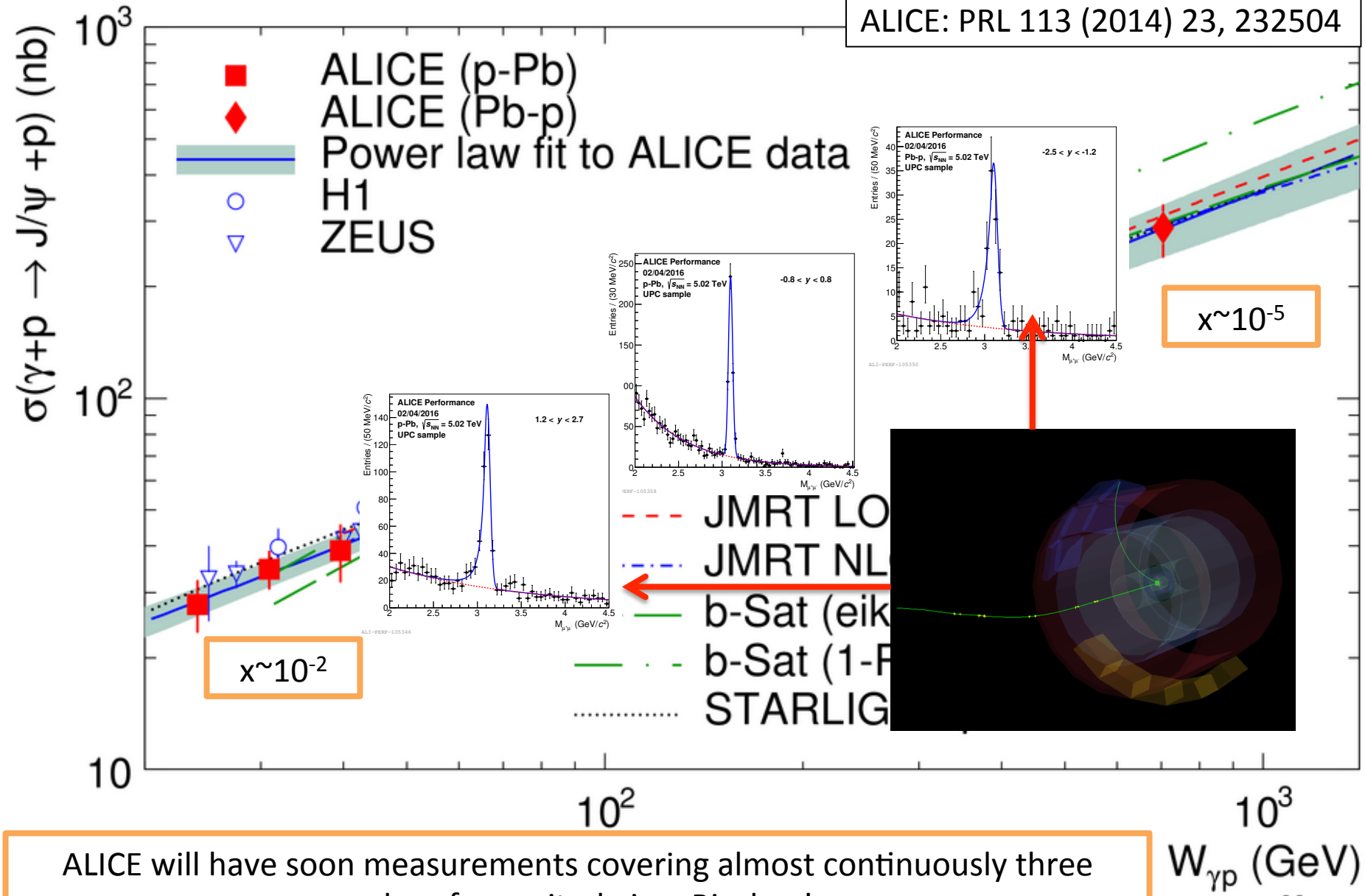
Work in progress

ALICE: PRL 113 (2014) 23, 232504



Work in progress

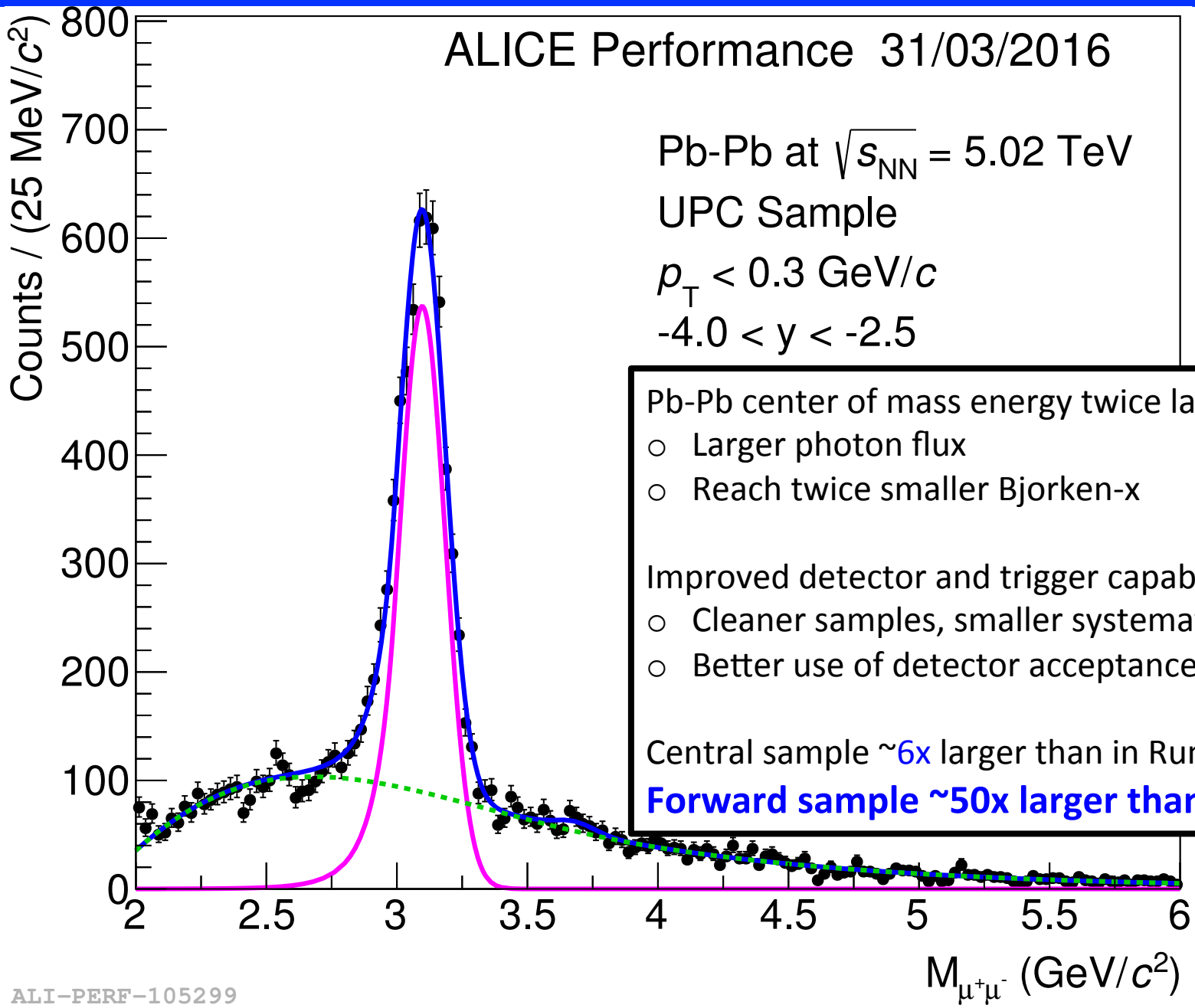
ALICE: PRL 113 (2014) 23, 232504



ALICE will have soon measurements covering almost continuously three order of magnitude in x-Bjorken!

Some comments on Run 2 plans

Pb-Pb Run2 data



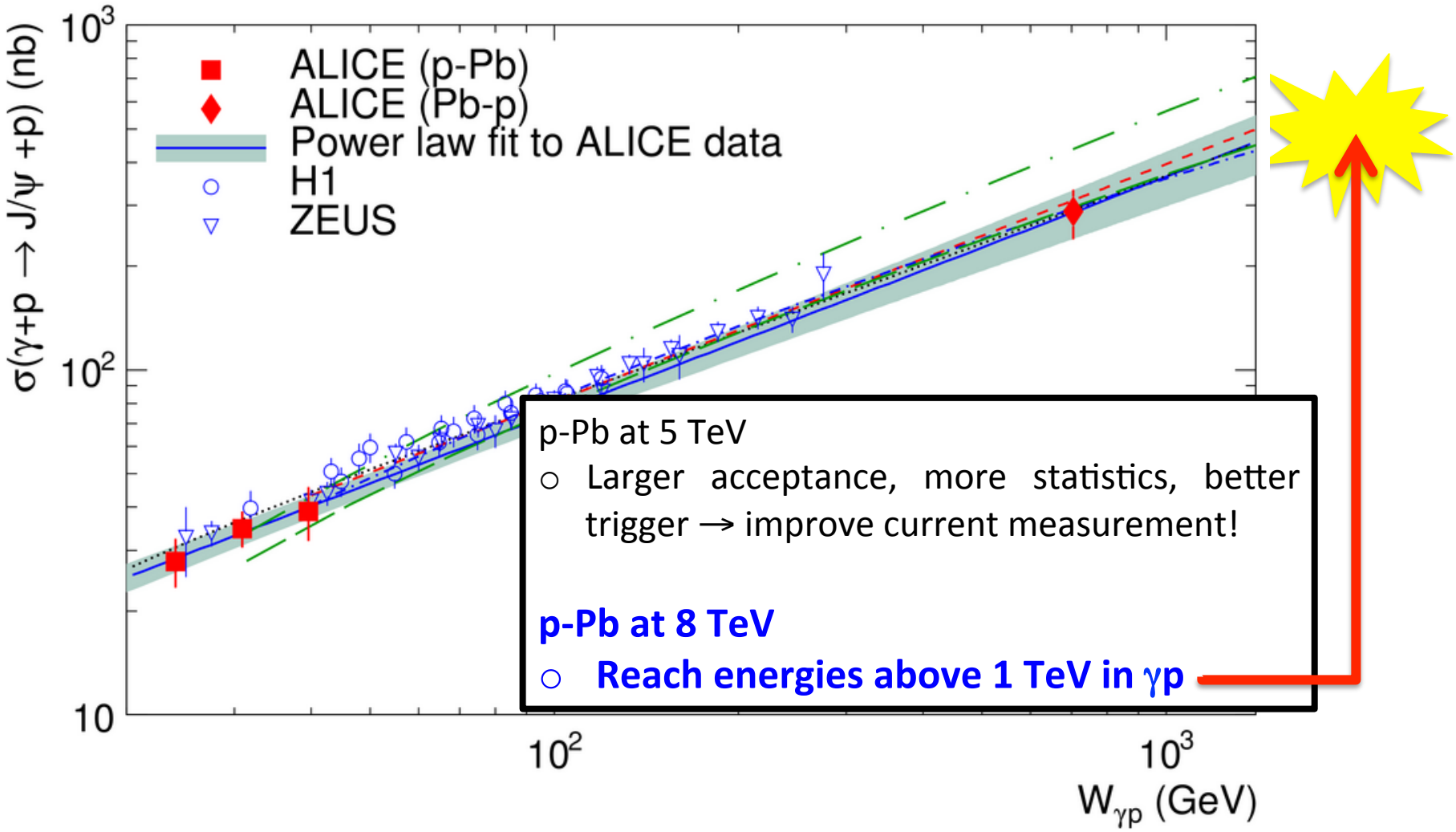
Pb-Pb center of mass energy twice larger
- Larger photon flux
- Reach twice smaller Bjorken-x

Improved detector and trigger capabilities
- Cleaner samples, smaller systematic error
- Better use of detector acceptance

Central sample ~6x larger than in Run1, and
Forward sample ~50x larger than in Run 1!

ALI-PERF-105299

p-Pb Run2 data



p-Pb at 5 TeV

- Larger acceptance, more statistics, better trigger → improve current measurement!

p-Pb at 8 TeV

- **Reach energies above 1 TeV in γp**

Summary and outlook

The LγHC (and L$\gamma\gamma$C) are delivering very interesting physics

Exciting times are ahead of us, so stay tuned!

References

References for ALICE UPC papers

Coherent J/ψ photoproduction in ultra-peripheral Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV
Phys.Lett. B718 (2013) 1273-1283
http://inspirehep.net/record/1185785?ln=en

Charmonium and e^+e^- pair photoproduction at mid-rapidity in ultra-peripheral Pb-Pb collisions at $\sqrt{s_{\rm NN}} $=2.76 TeV
Eur.Phys.J. C73 (2013) no.11, 2617
http://inspirehep.net/record/1232206?ln=en

Exclusive $\mathrm{J/}\psi$ photoproduction off protons in ultra-peripheral p-Pb collisions at $\sqrt{s_{\rm NN}}=5.02$ TeV
Phys.Rev.Lett. 113 (2014) no.23, 232504
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Coherent ρ^{0} photoproduction in ultra-peripheral Pb-Pb collisions at $ \sqrt{s_{\mathrm{NN}}}=2.76 $ TeV
JHEP 1509 (2015) 095
http://inspirehep.net/record/1357206?ln=en

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Accepted by PRL
http://inspirehep.net/record/1395296?ln=en

References for Models (1/2)

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Coherent rho and J/psi photoproduction in ultraperipheral processes with electromagnetic dissociation of heavy ions at RHIC and LHC,
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Vector Meson Production in Coherent Hadronic Interactions: An update on predictions for RHIC and LHC
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Exclusive vector meson production in relativistic heavy ion collisions
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J/Psi production in ultraperipheral Pb+Pb and p+Pb collisions at energies available at the CERN Large Hadron Collider
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Constraining Gluon Shadowing Using Photoproduction in Ultraperipheral pA and AA Collisions
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http://inspirehep.net/record/1083333?ln=en

[7] Jones, S. P. and Martin, A. D. and Ryskin, M. G. and Teubner, T.
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Exclusive diffractive processes at HERA within the dipole picture
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