ALICE measurements relevant for GPD studies

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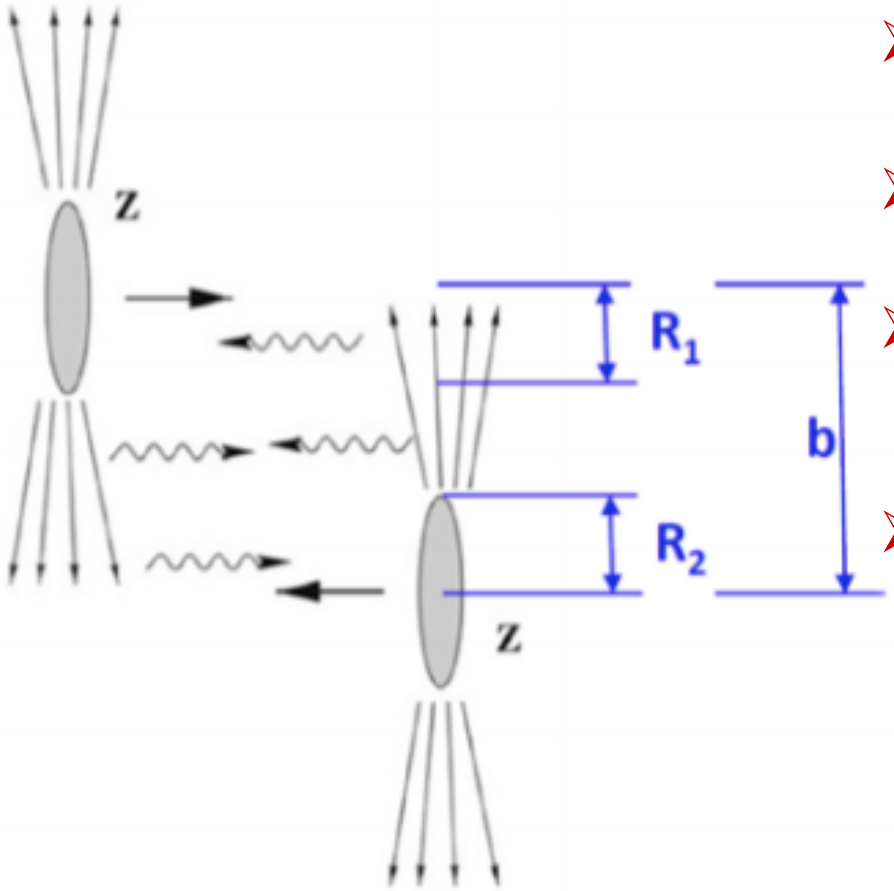
Outline

- Ultraperipheral collisions (UPCs)
  - Exclusive J/ψ & ψ(2S) in Pb-Pb (nuclear gluon distributions/shadowing)
  - Exclusive J/ψ in p-Pb (saturation)
- Hadronic collisions
  - R_{pPb} for inclusive J/ψ and Υ(1S) (nuclear gluon distributions/shadowing)

Photoproduction in ultra-peripheral collisions



PoS (DIS2016) 191

- Ultra-peripheral collisions have impact parameter $>R_1+R_2$.
- EM field of relativistic ion equivalent to photon flux.
- Photon flux $\propto Z^2$ (=6724 for Pb) so heavy ions are an excellent photon source.
- Photo-nuclear, photon-nucleon and yy interactions can occur in ultra peripheral collisions.

Photoproduction in ultra-peripheral collisions

- Photon fluctuates to $c\bar{c}$ pair that scatters off nucleus into a vector meson: J/ψ or ψ(2S). Therefore, it probes the nuclear parton distribution.

- Coherent photoproduction
  - Photon couples to entire nucleus (photo-nuclear interaction)
  - Larger wavelength, lower mean p_T (≈60 MeV/c)

- Incoherent photoproduction
  - Photon couples to single nucleon (photon-nucleon interaction)
  - Smaller wavelength, higher mean p_T (≈500 MeV/c)

Nuclear gluon distribution and dσ/dy

- The cross section dσ/dy for the interaction A+A → A+A+V is given by

$$\frac{d\sigma}{dy} = \omega_1 \frac{dn_\gamma}{d\omega_1} \sigma_{\gamma A \to VA}(\omega_1) + \omega_2 \frac{dn_\gamma}{d\omega_2} \sigma_{\gamma A \to VA}(\omega_2)$$

where 1, 2 label which colliding particle emitted the photon.

- Ryskin† (1993) relates dσ/dt and the gluon distribution g(x,Q^2):

$$\left.\frac{d\sigma}{dt}\right|_{t=0} = \frac{\alpha_s{}^2 \Gamma_{ee}}{3\alpha M V^5} 16\pi^3 \left[x g\left(x, \frac{M^2}{4}\right)\right]^2$$

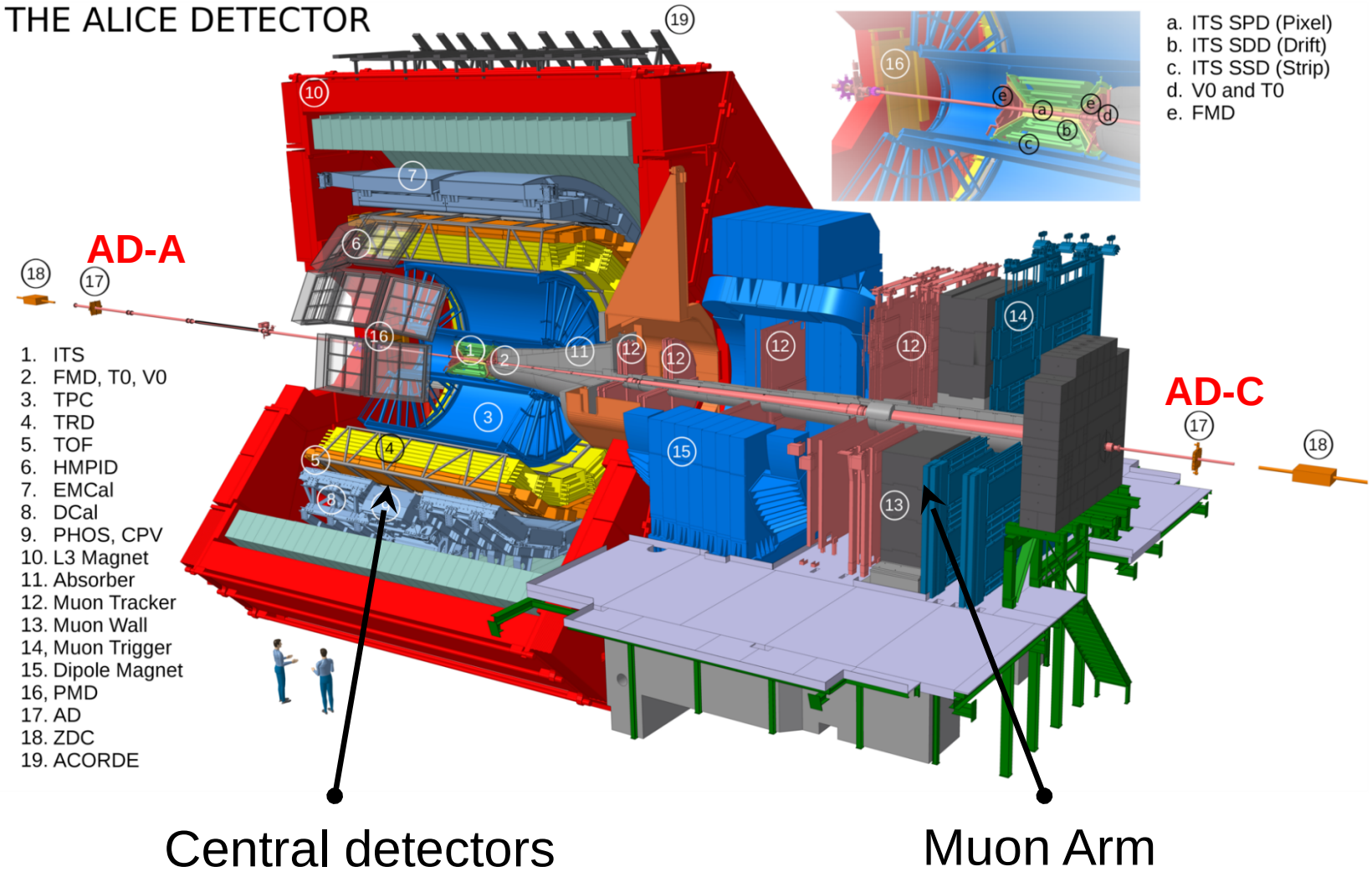
for the interaction γ + A → V + A.

- During the calculation of dσ/dy from dσ/dt the proportionality dσ/d$t \propto [g(x,Q^2)]^2$ factorizes, leading to

$$\frac{d\sigma}{dy} \propto [g(x,Q^2)]^2$$

† Z. Phys. C 57 (1993) 89-92

The ALICE detector



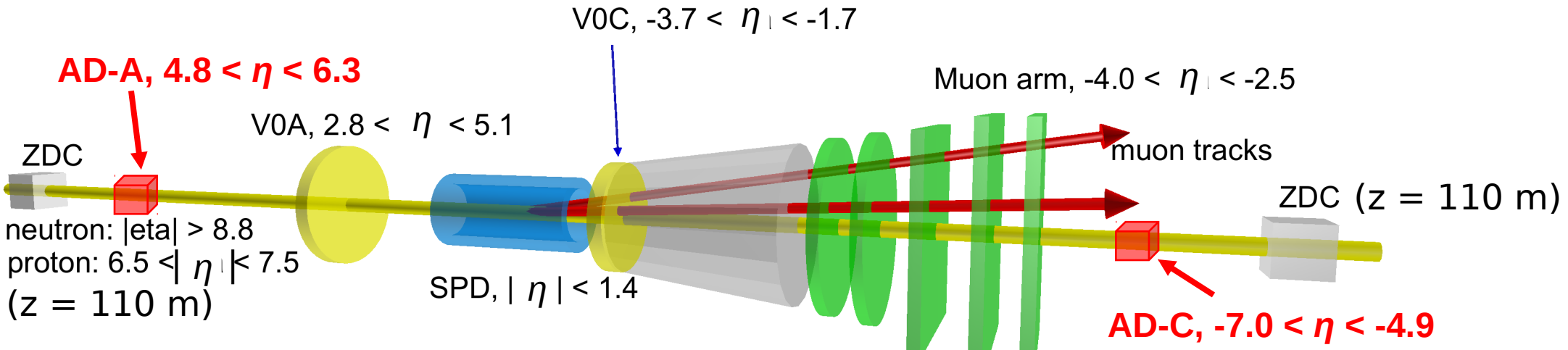
Central detectors:

- TPC for tracking and particle identification ($|\eta|<0.9$)
- TOF and SPD for triggering

Central UPC trigger:

- ≥ 2 back-to-back TOF hits
- ≥ 2 back-to-back SPD hits
- No hits in AD-A or AD-C
- No hits in V0-A or V0-C

Muon Arm and forward detectors



Distances are not to scale.

Forward UPC trigger:

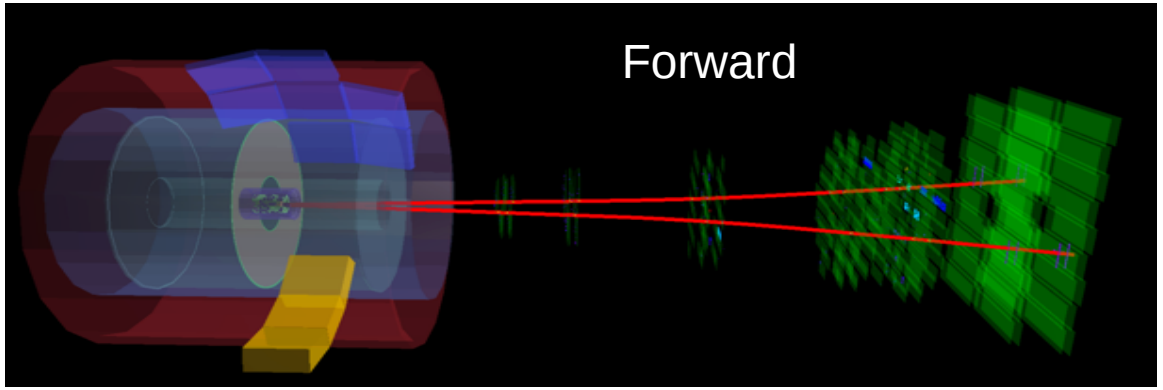
- 2 unlike-sign tracks, p_T>1 GeV/c
- No hits in AD-A or AD-C
- No hits in V0-A

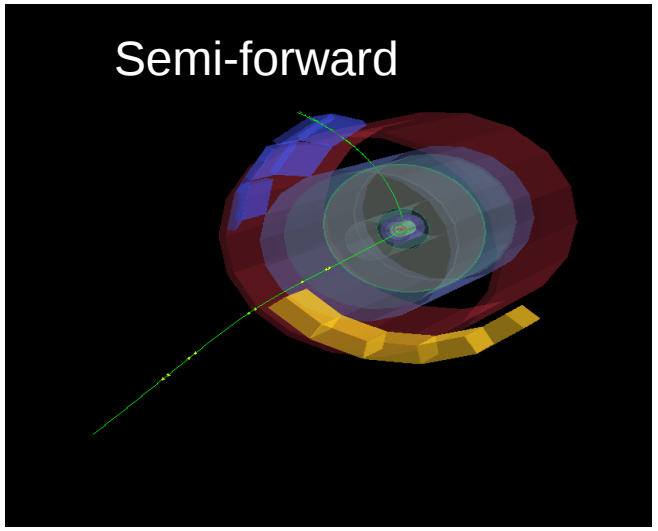
Muon Arm and trigger detectors:

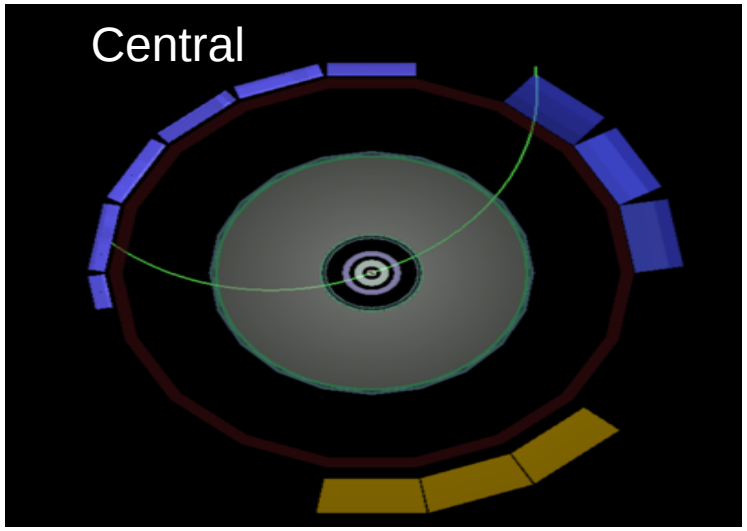
- Triggering, tracking and muon identification
- V0 counters provide veto to exclude events with hadronic interactions
- AD added for Run 2 for improved veto: (-7.0 < η < -4.9) and (4.8 < η < 6.3)
- ZDC can measure n & p from photo-dissociation

UPC measurement regions

- Central: two electrons in central barrel
- Semi-forward: 1 muon in central barrel, 1 muon in muon arm
- Forward: two muons in muon arm

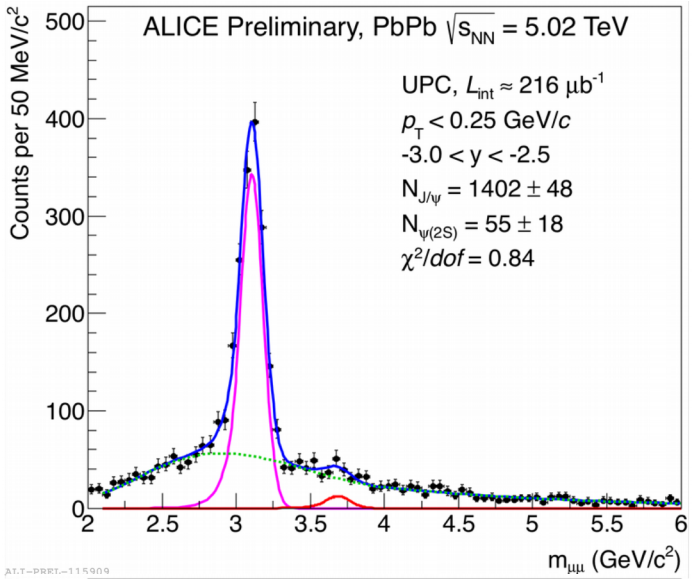


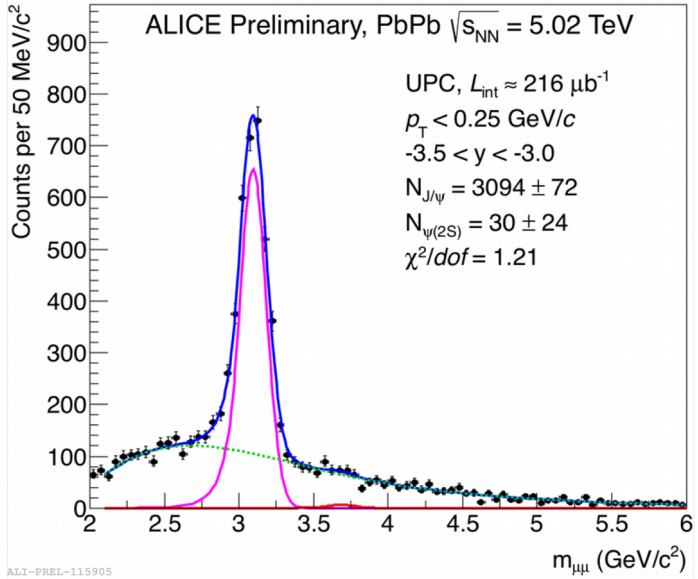


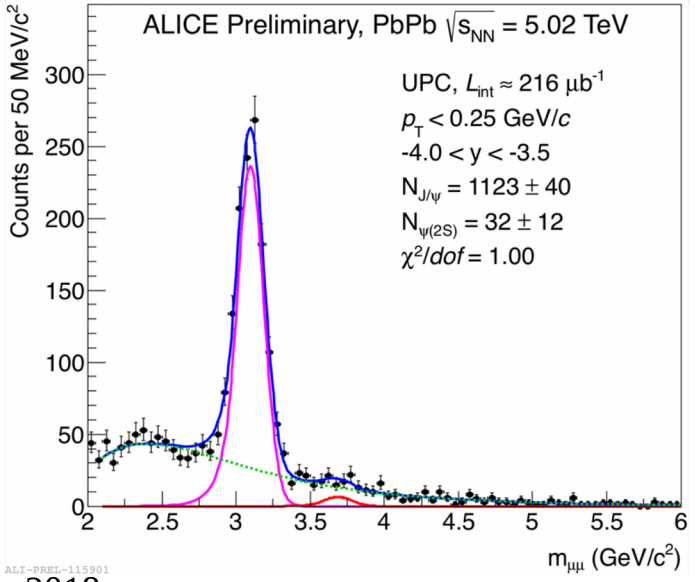


Exclusive J/ψ in Pb-Pb

Mass distributions at forward rapidity



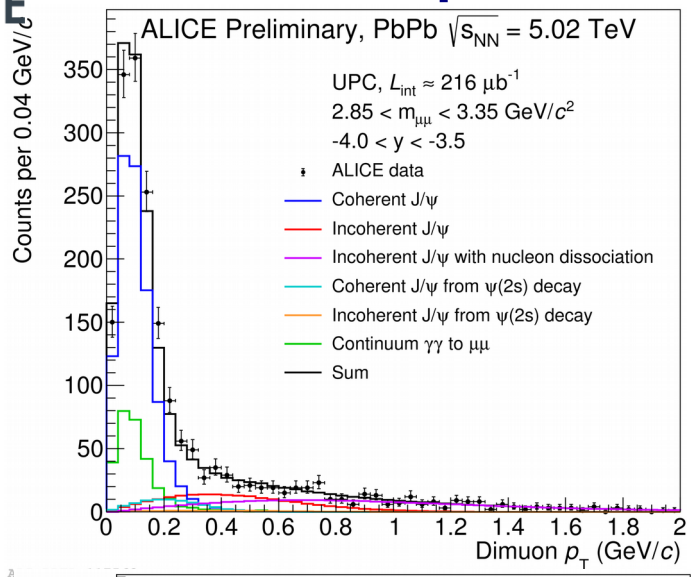


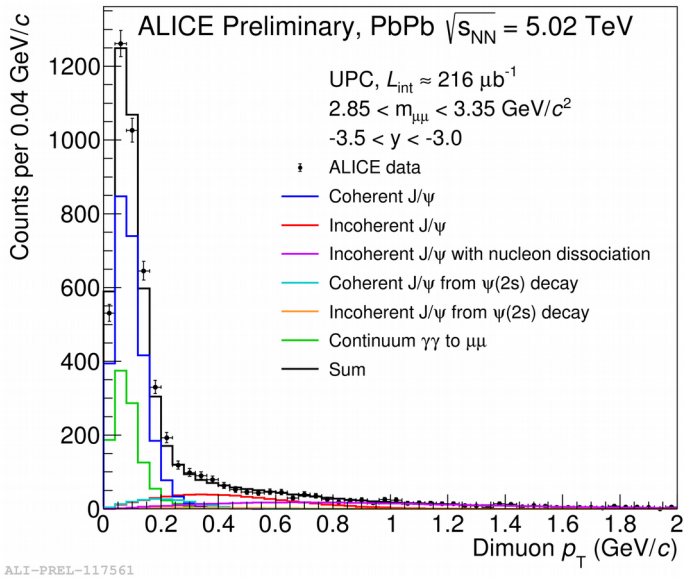


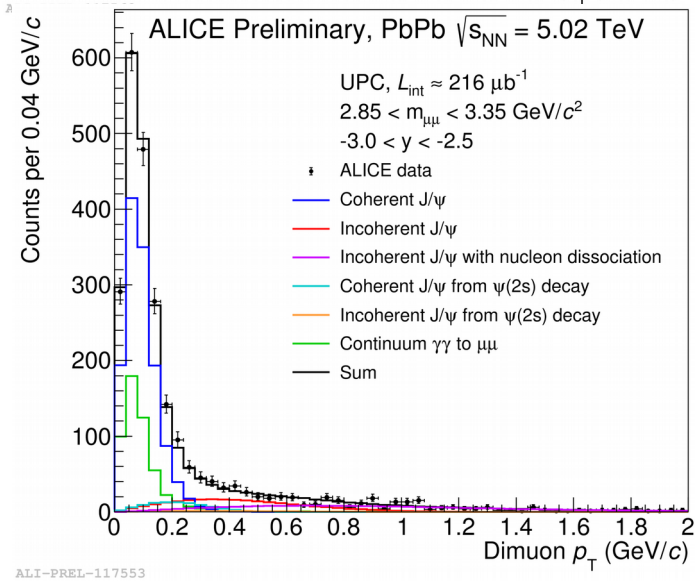
- Forward rapidity J/ψ measurement.
- Fit with Crystal Ball functions including both J/ψ and ψ(2S).
- Exponential function for γγ continuum background
- Better statistics allow three forward rapidity measurements.

Rapidity	Number J/ψ	Number ψ(2S)
-3.0 < *y* < -2.5	1402 ± 48	55 ± 18
-3.5 < *y* < -3.0	3094 ± 72	30 ± 24
-4.0 < *y* < -3.5	1123 ± 40	32 ± 12

P_T distributions at forward rapidity



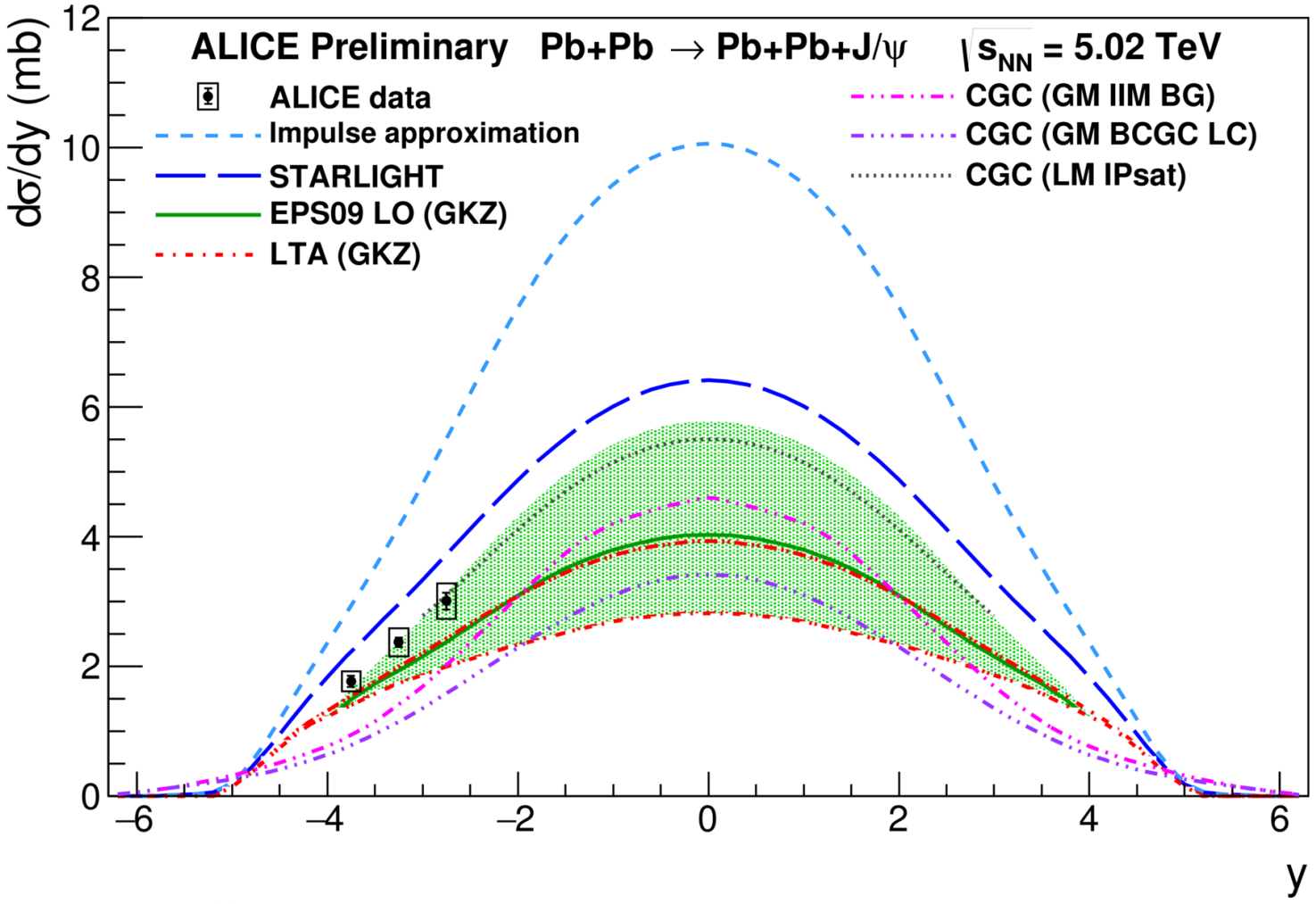




- Forward rapidity J/ψ measurement.
- Fit to templates reproduce the p_T distributions well.
- Templates allow extraction of coherent signal from mass distributions.

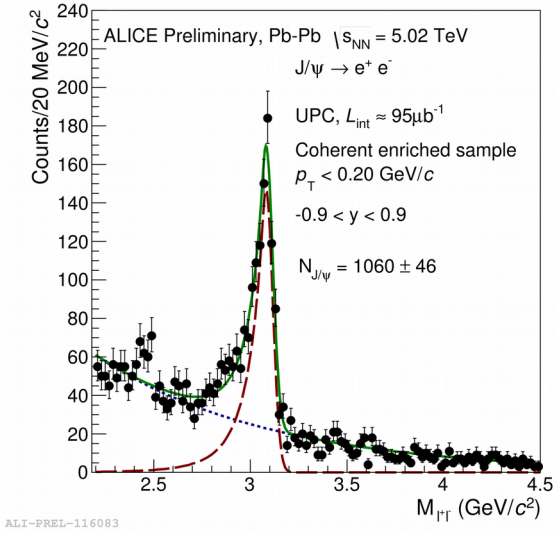
- Coherent J/ψ
- Incoherent J/ψ
- Incoherent J/ψ with nuclear dissociation
- Coherent J/ψ from ψ(2S) decay
- Incoherent J/ψ from ψ(2S) decay
- Continuum γγ to e^+e^- or $\mu^+\mu^-$
- Sum

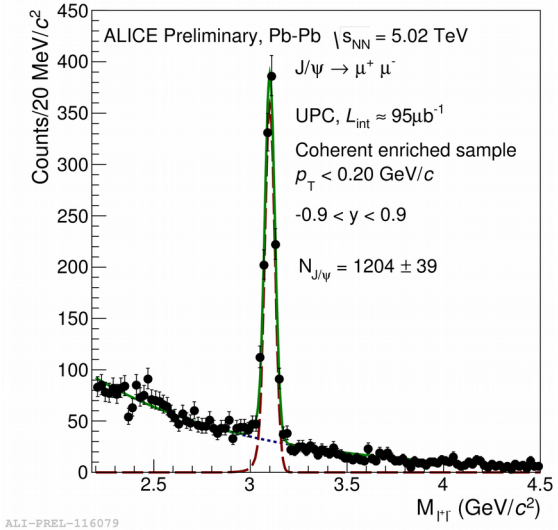
Cross sections for exclusive J/ψ

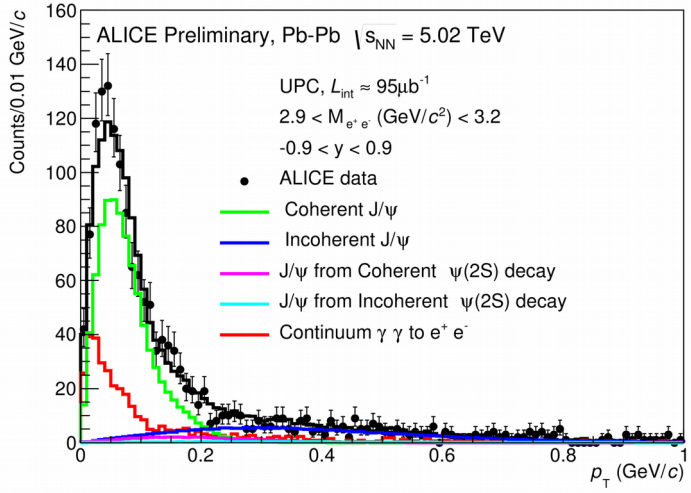


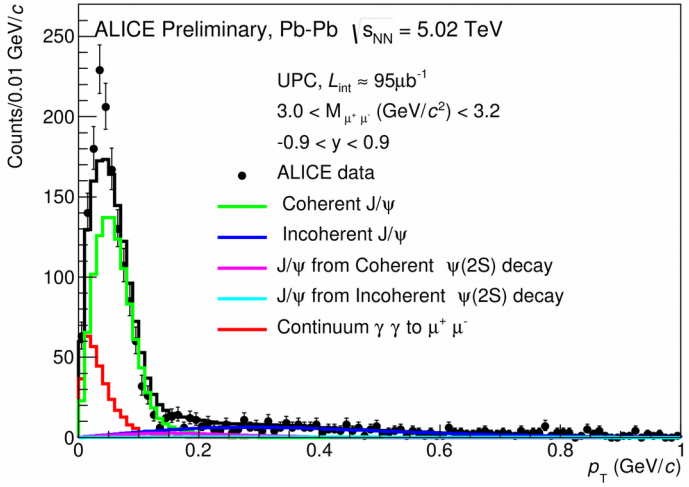
- Direct evidence of moderate gluon shadowing.
- Models with moderate amount of shadowing best describe the data.
- Green shaded region is uncertainty on EPS09.
- Consistent with ALICE Run 1 results
  - Phys. Lett. B718 (2013) 1273-1283
  - Eur. Phys. J. C (2013) 73:2617

Mid-rapidity mass & p_T distributions





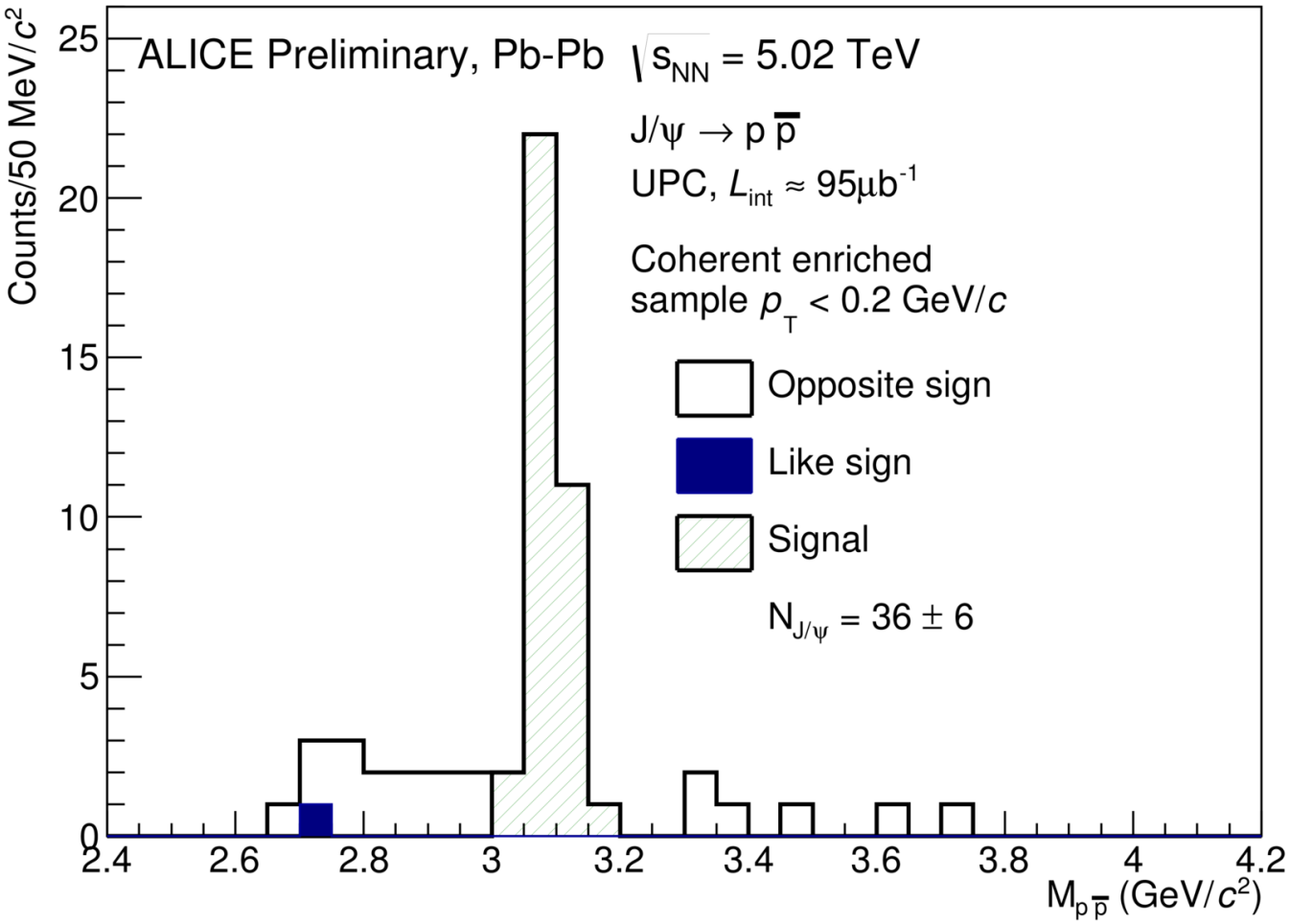




- Preliminary mid-rapidity mass distributions and p_T distributions.
- Fit to templates reproduce the p_T distributions well.
- Allows identification of non-exclusive signal.
- Templates allow extraction of exclusive signal from mass distributions.

- Coherent J/ψ
- Incoherent J/ψ
- Coherent J/ψ from ψ(2S) decay
- Incoherent J/ψ from ψ(2S) decay
- Continuum γγ to e^+e^- or $\mu^+\mu^-$
- Sum

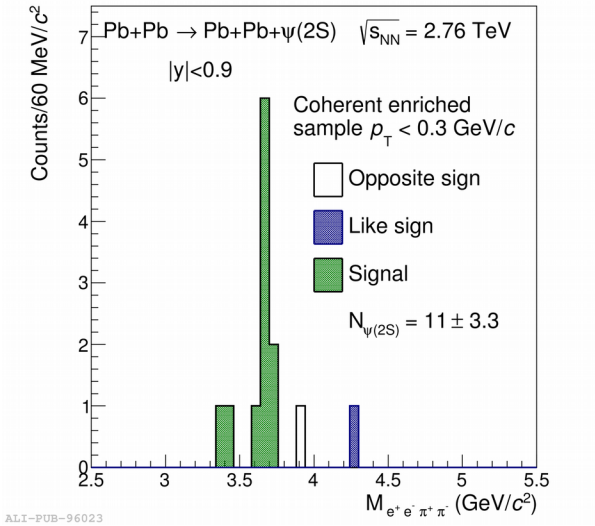
New channel for exclusive J/ψ in Pb-Pb

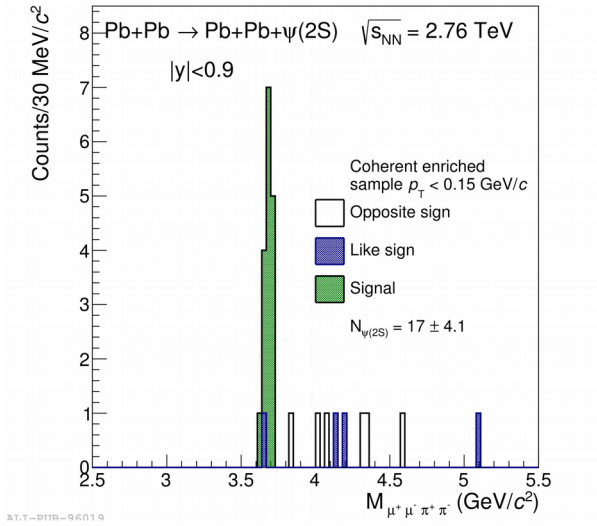


- First observation of coherent photoproduction of J/ψ in the $p\bar{p}$ channel.
- May also contain some $\gamma\gamma \rightarrow p\bar{p}$.

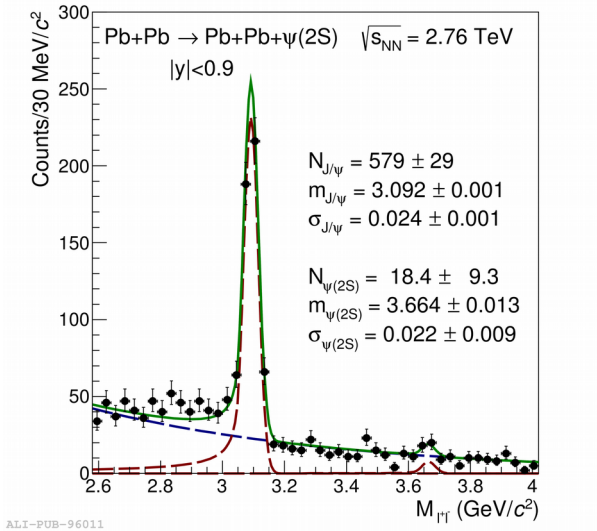
ψ(2S) in Pb-Pb

Mass distributions for ψ(2S)



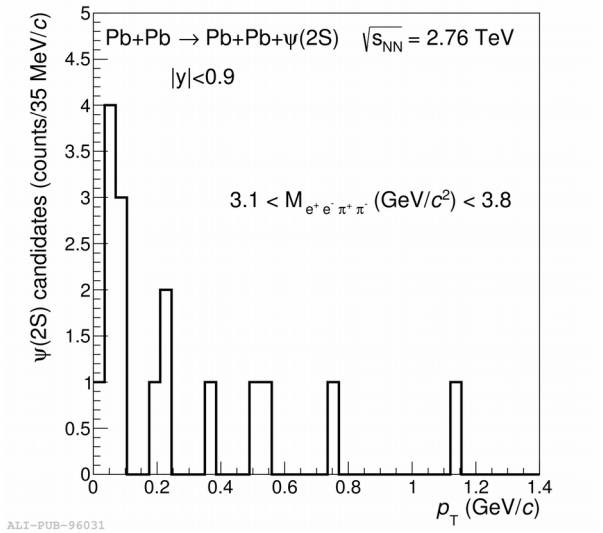


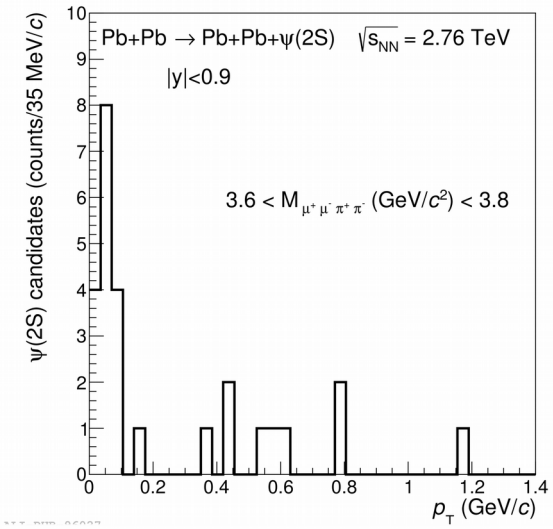
Phys. Lett. B 751 (2015) 358-370



- Mass distributions for ψ(2S) in three channels from Run 1.
- Run 2 will allow more significant cross section determination.

P_T distributions for ψ(2S)





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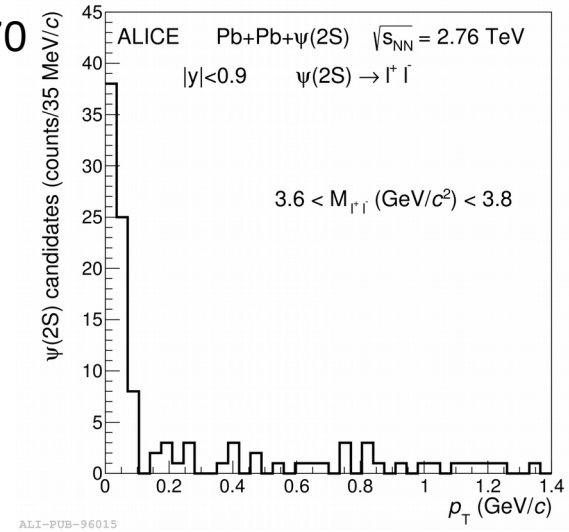
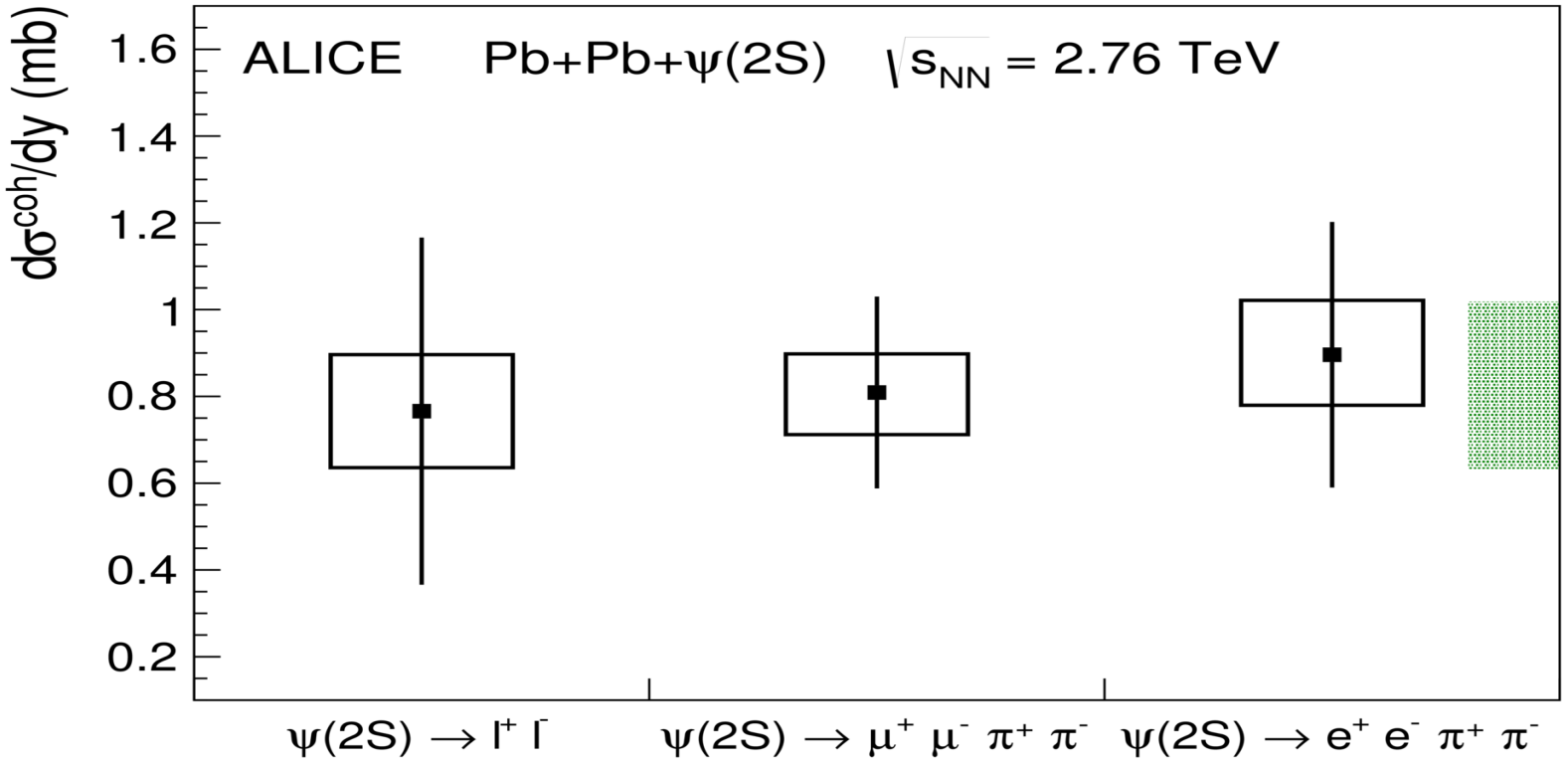


- p_T distributions for ψ(2S) in three channels from Run 1.
- Clear coherent peak observed.
- Run 2 will allow more significant cross section determination.

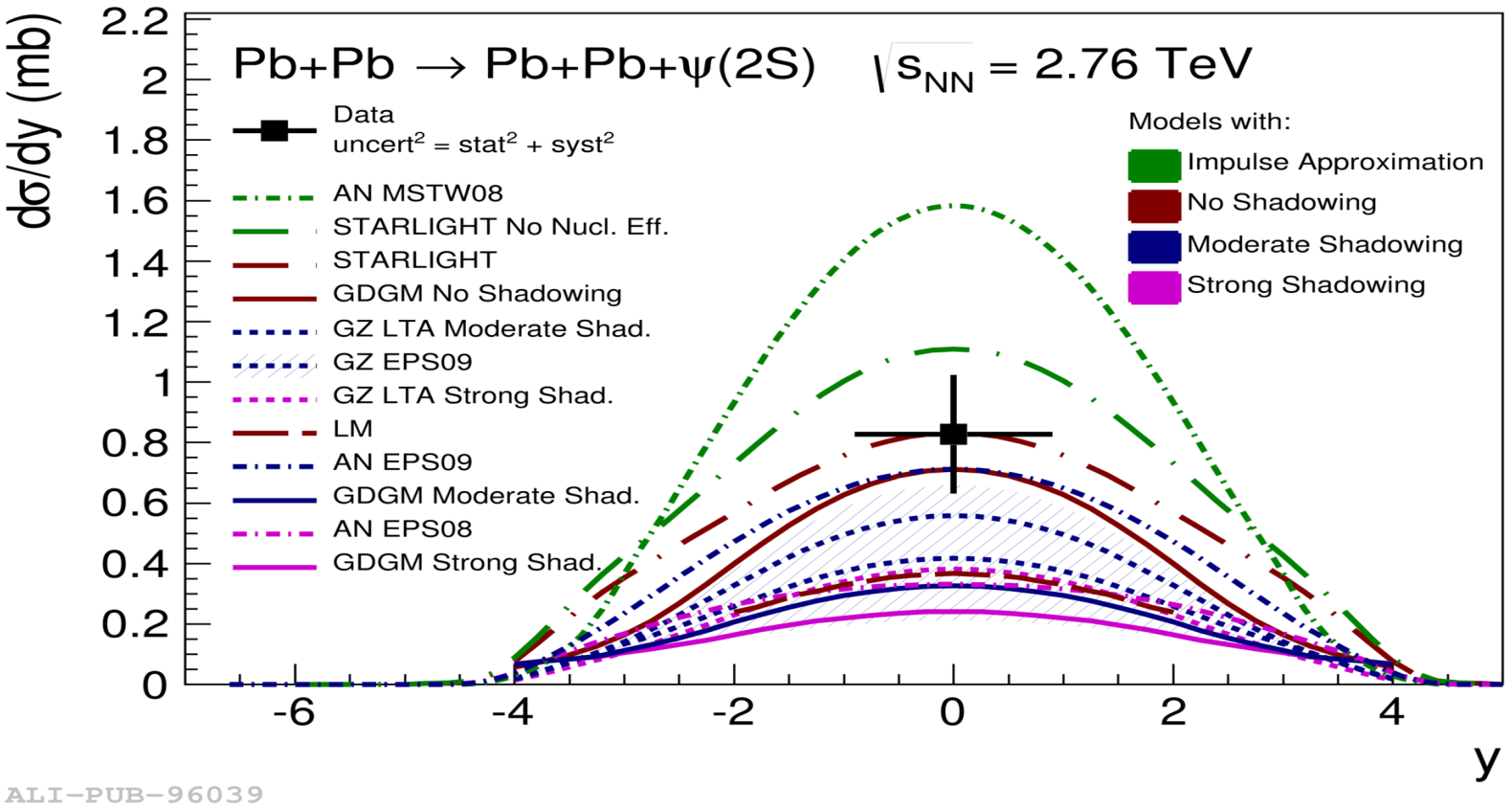
Cross sections for ψ(2S) in Pb-Pb



Phys. Lett. B 751 (2015) 358-370

- Good agreement between the three channels.
- Can combine results because of low statistics.

Cross sections for ψ(2S) in Pb-Pb



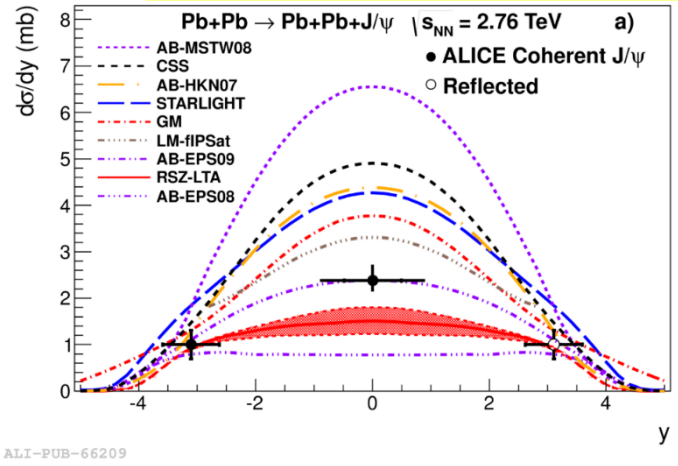
Phys. Lett. B 751 (2015) 358-370

- ψ(2S) cross section also agrees with moderate shadowing.
- However, could also be consistent with no shadowing.
- Run 2 Pb-Pb data taken in 2015 and later this year will allow an improved cross section determination.

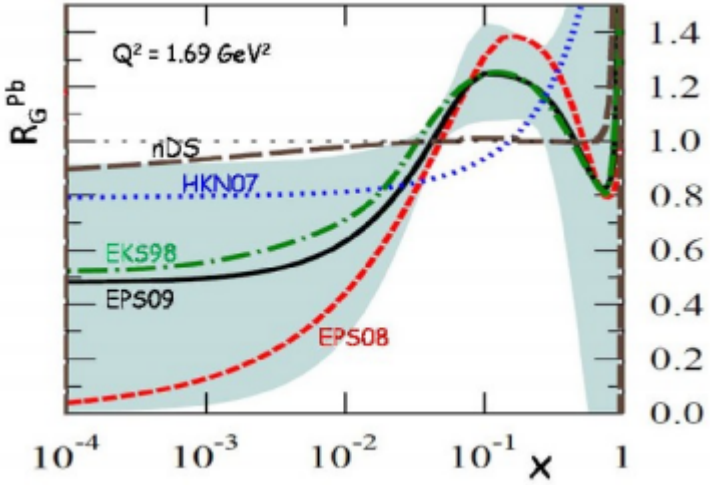
Exclusive J/ψ production (Run1 data)

Phys. Lett. B 718 (2013) 1273 (Muon arm), EPJC 73 (2013) 2617 (Central Barrel)

Phys. Lett. B 726 (2013) 290-295



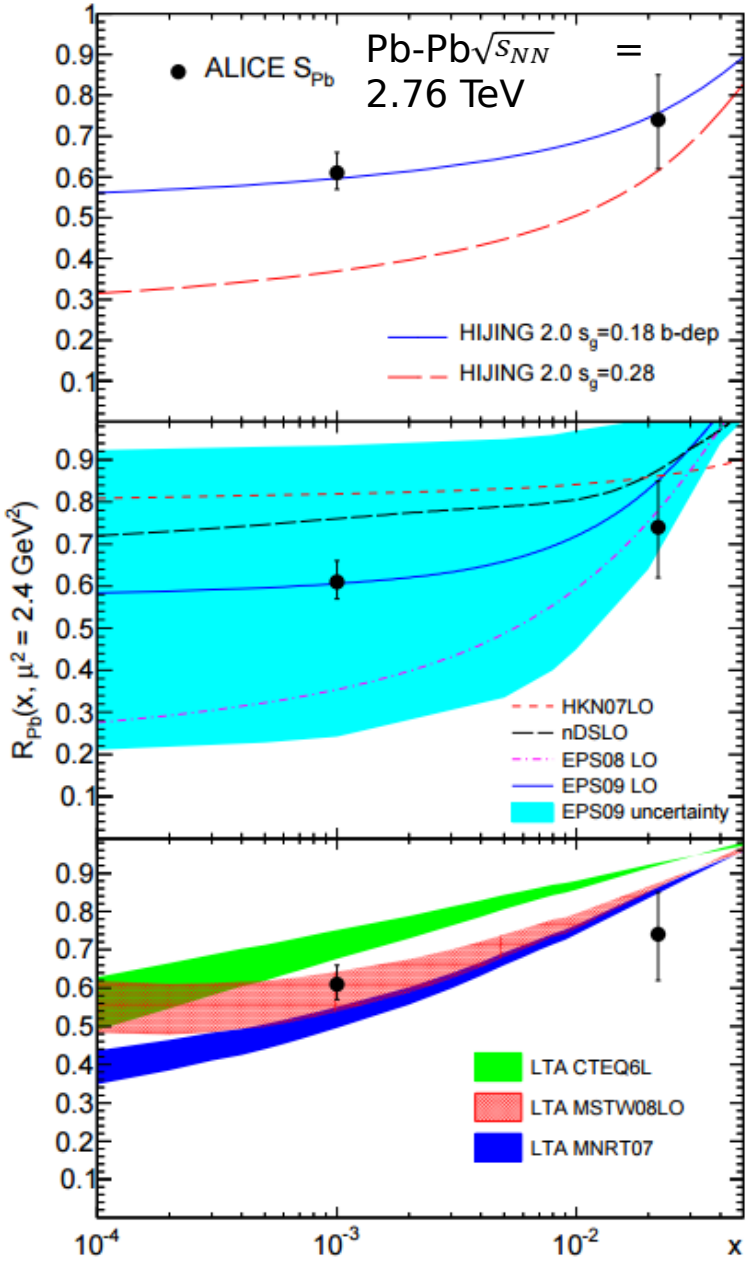
JHEP 0904 (2009) 065 & arXiv:1106.5682



- Correspondence between uncertainty in nuclear gluon distributions and cross-sections.
- Modification as a function of *x* due to nucleus:

$$R_G^A = \frac{g_A(x,Q^2)}{A \cdot g_p(x,Q^2)}$$

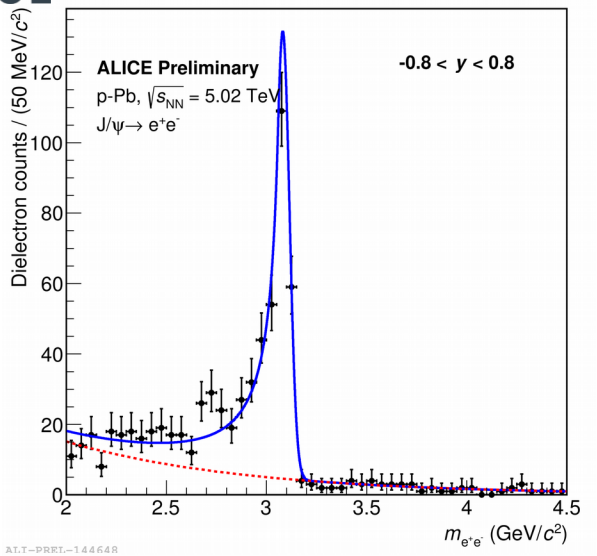
- Guzey, Kryshen, Strikman and Zhalov (2013) converted ALICE dσ/dy values back to R_G^{Pb} values. Requires some assumptions though.
- Demonstrates that dσ/dy measurements provide significant constraints on the models.

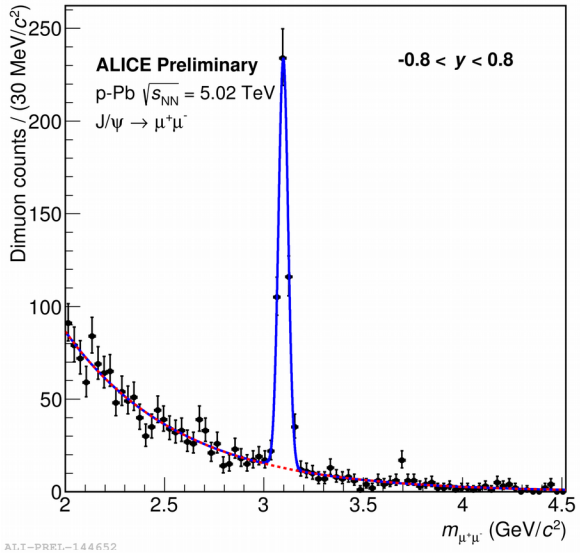


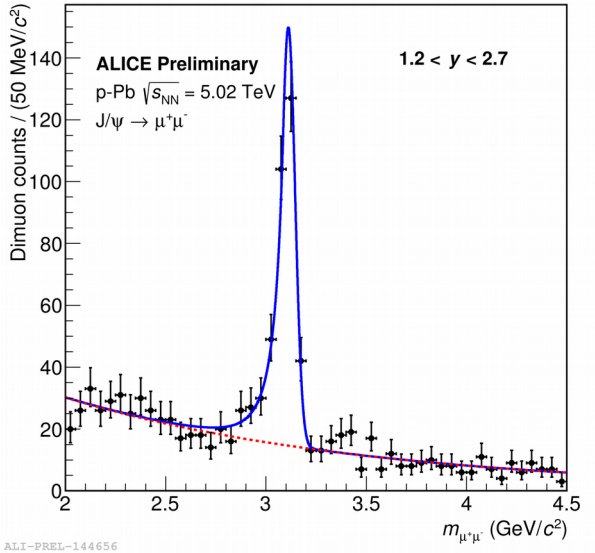
J/ψ in ultra-peripheral p-Pb and Pb-p

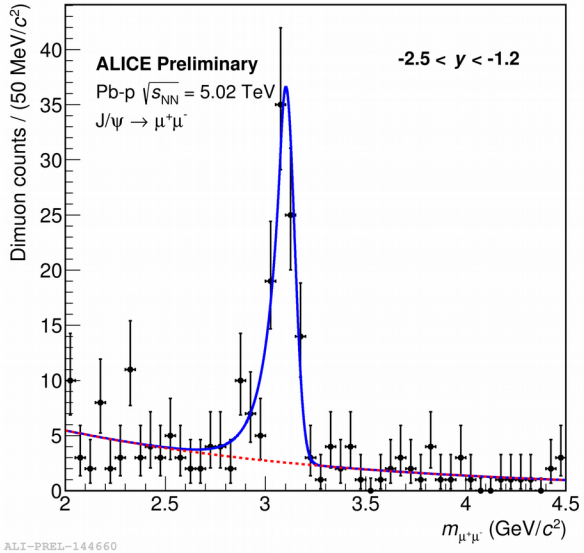
- Nomenclature: For p-Pb and Pb-p the first particle indicates which beam is directed toward the Muon Arm.
  - p-Pb the proton beam moves toward the Muon Arm which is considered forward rapidity
  - Pb-p the Pb beam moves toward the Muon Arm which is considered negative rapidity.
- Due to asymmetric energy for the Pb and proton beams the rapidity ranges covered by detectors are all shifted by 0.465 in the direction of the proton beam.

Mass distributions for J/ψ in p-Pb (& Pb-p)



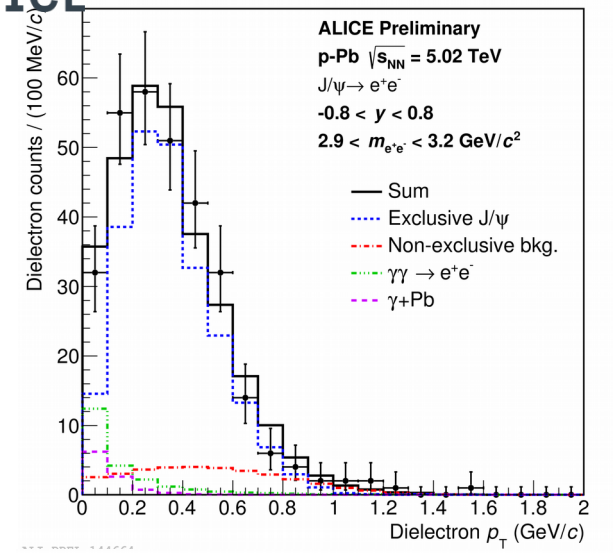


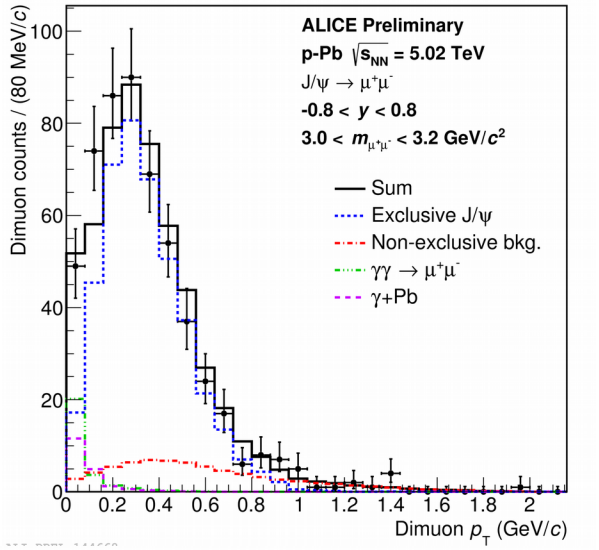


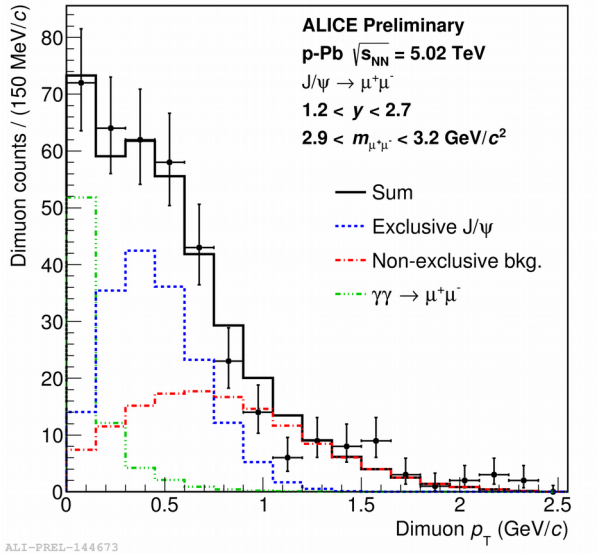


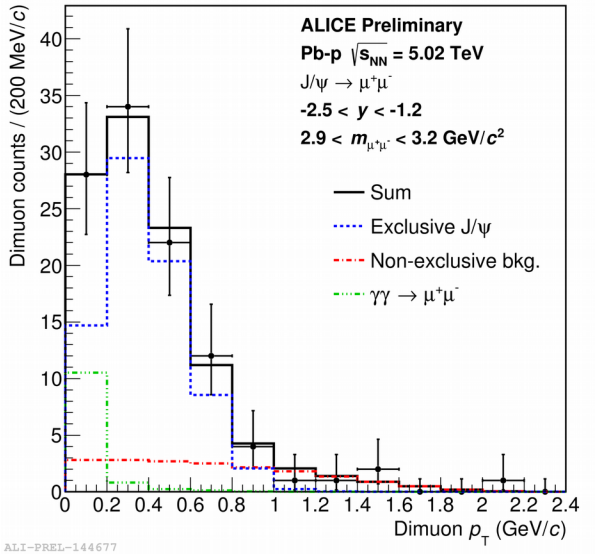
- Very clean signals.
- Fit with Crystal Ball + exponential background.
- Two channels near mid-rapidity
  - Top left =J/ψ→ e^+e^-
  - Top right = J/ψ→ $\mu^+\mu^-$
- At forward and backward rapidities
  - J/ψ→$\mu^+\mu^-$
    - Bottom left (1.2 < *y* < 2.7)
    - Bottom right (-2.5 < *y* < -1.2)

P_T distributions for J/ψ in p-Pb (& Pb-p)





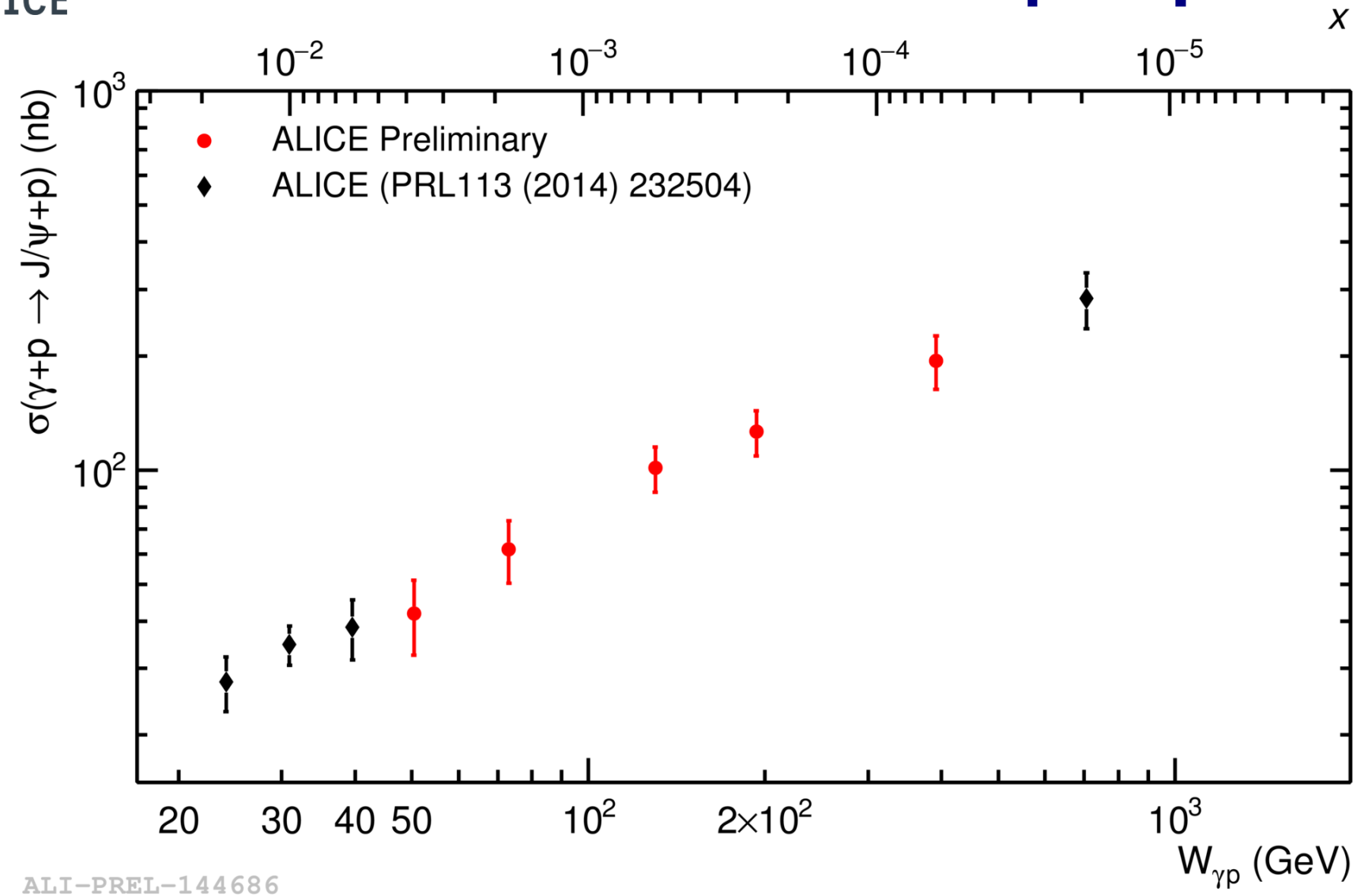




- Fit to templates reproduce the p_T distributions well.
- Allows identification of non-exclusive component.
- Templates allow extraction of exclusive signal from mass distributions.

- Exclusive J/ψ
- Non-exclusive J/ψ background
- γγ to e^+e^- or $\mu^+\mu^-$
- γ+Pb
- Sum

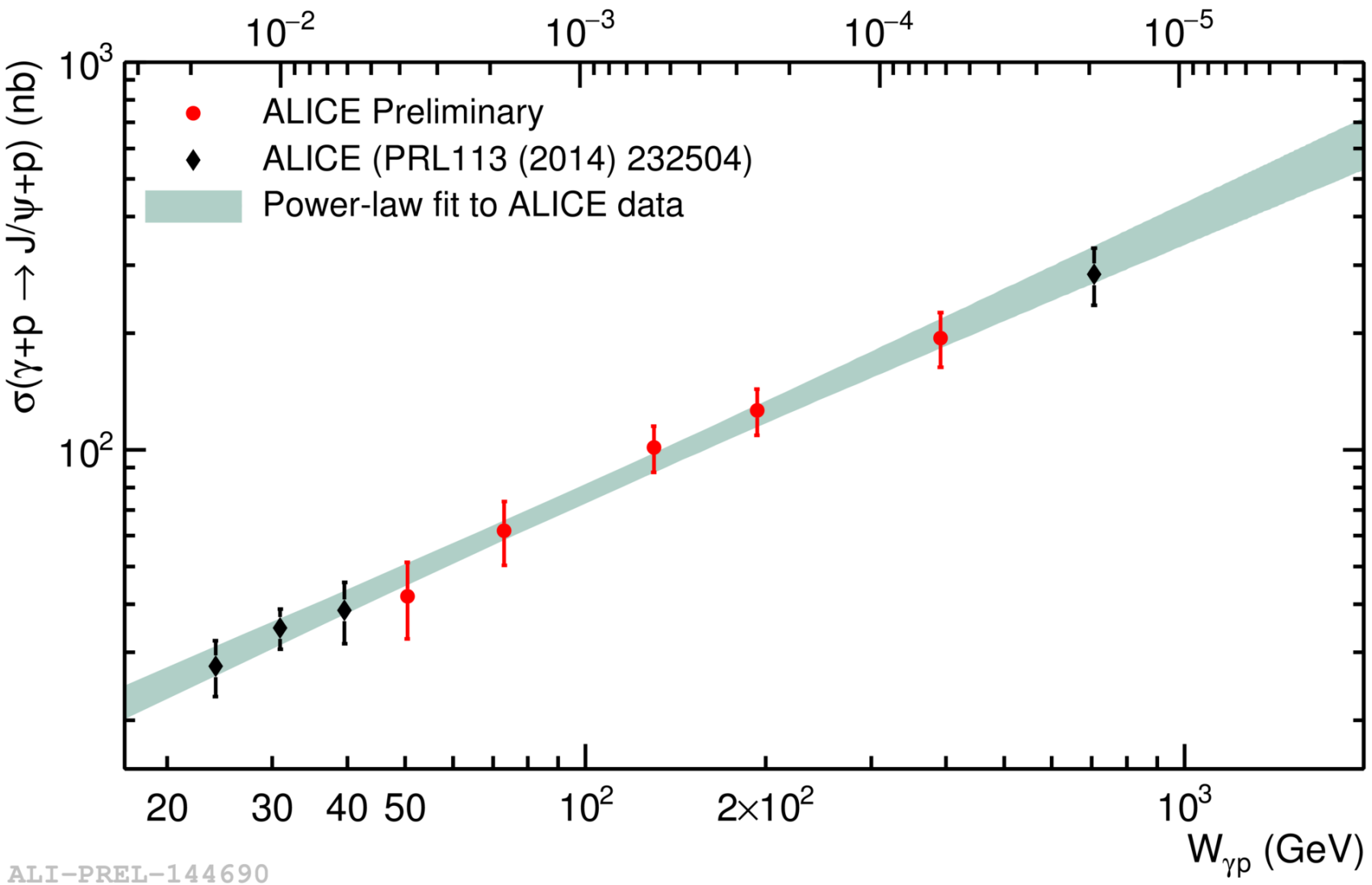
Cross sections for J/ψ in p-Pb (& Pb-p)



- New results fill in middle region of $W_{\gamma p}$ and x.
- p-Pb data taken last two years will allow measurement for $W_{\gamma p}$>1 TeV and x<10^{-5}.

ALI-PREL-144686

Cross sections for J/ψ in p-Pb (& Pb-p)



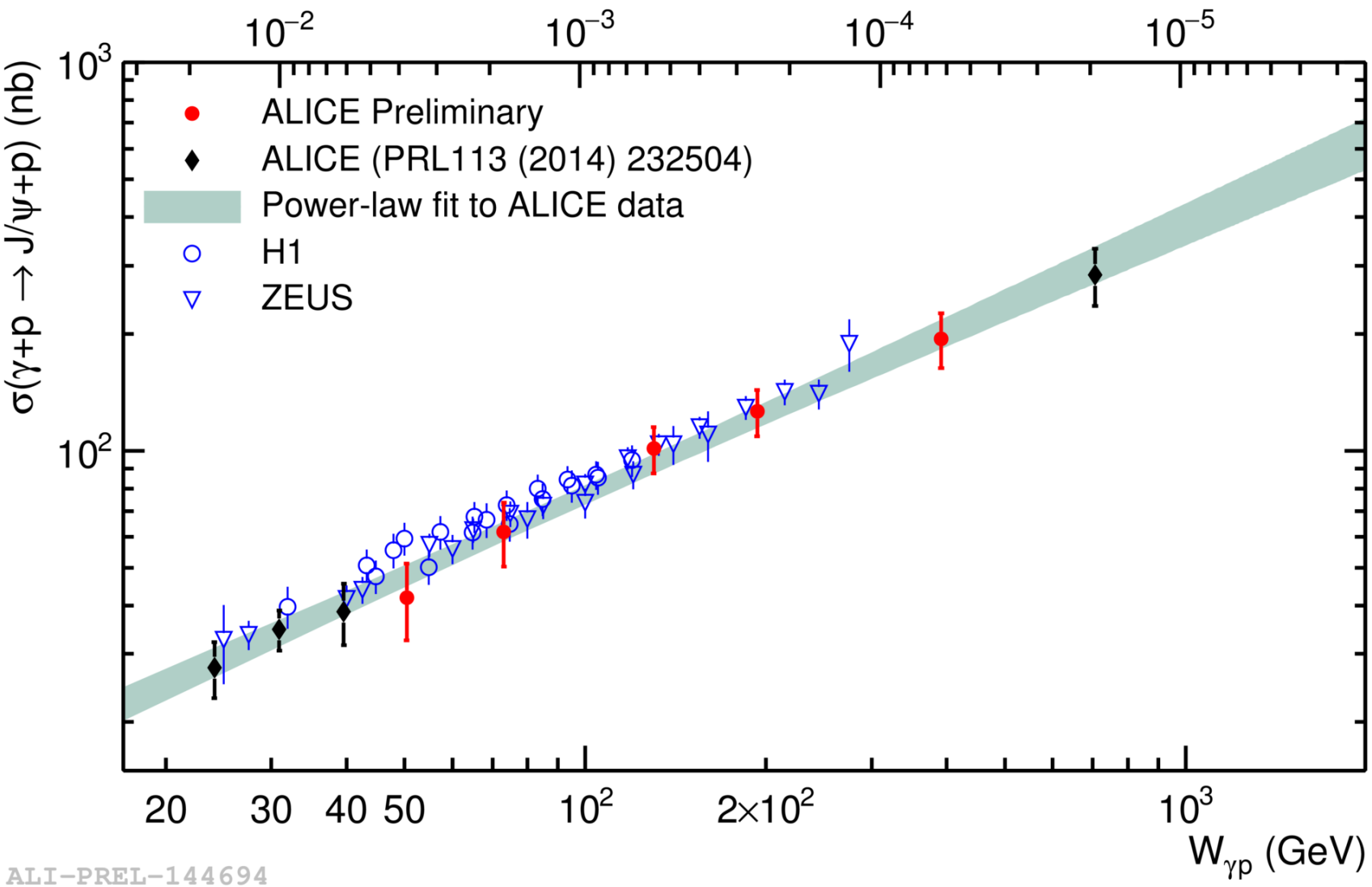
- Power law fit has exponent

  $\alpha=0.70\pm0.05$

- Consistent with other experiments.

ALI-PREL-144690

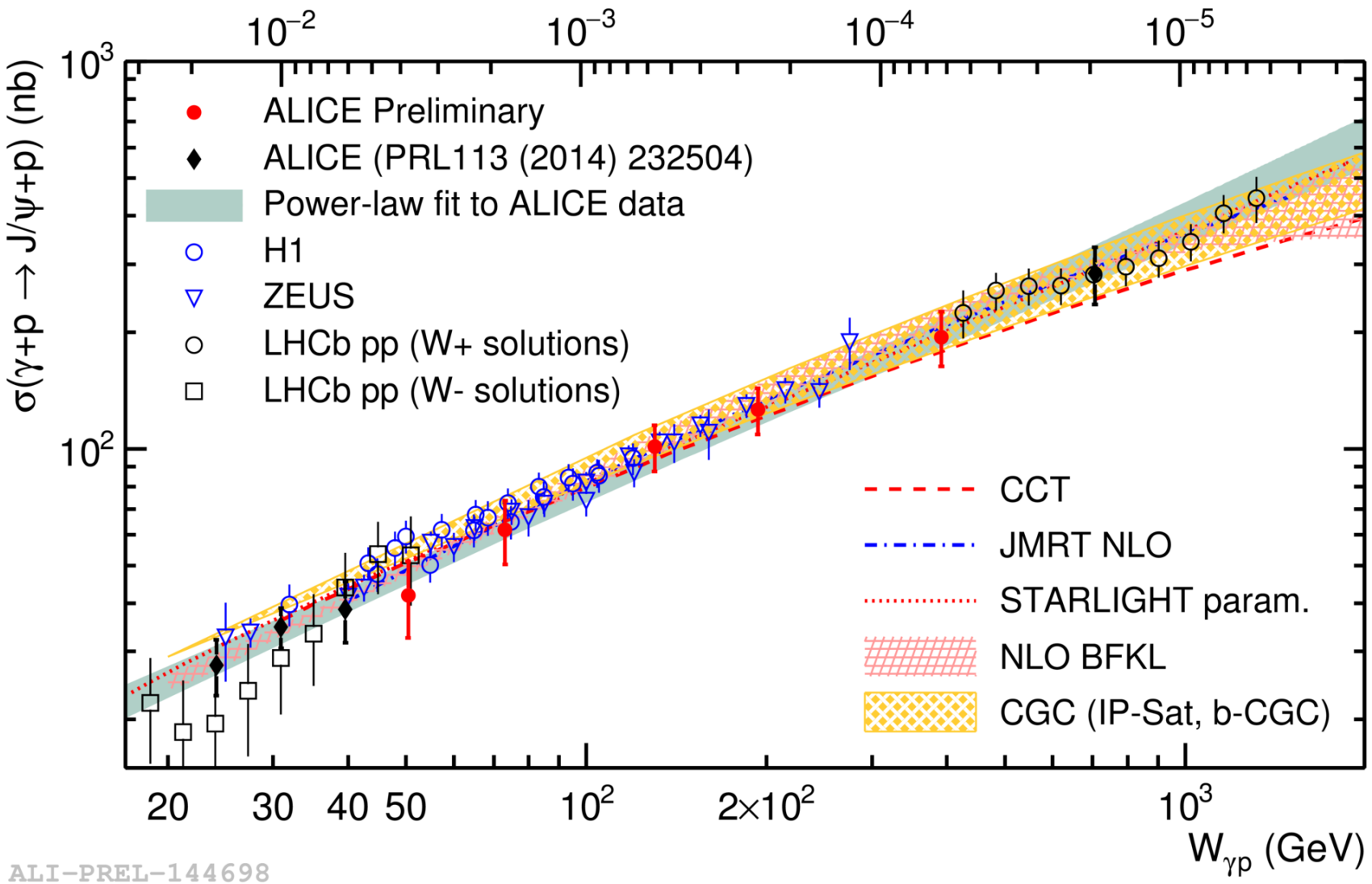
Cross sections for J/ψ in p-Pb (& Pb-p)



- Good agreement with HERA measurements

ALI-PREL-144694

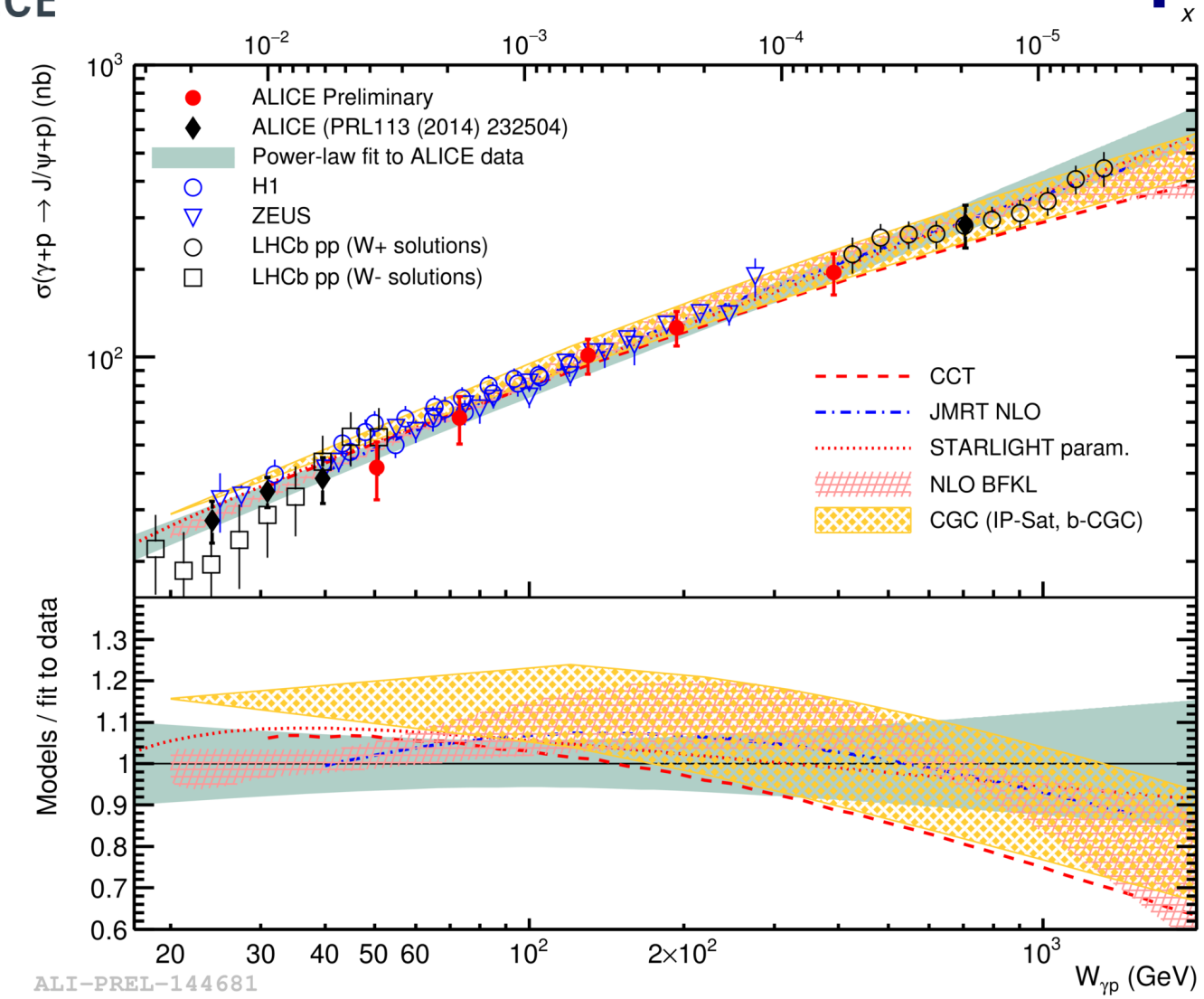
Cross sections for J/ψ in p-Pb (& Pb-p)



ALI-PREL-144698

- Good agreement with LHCb measurements too.
- All models do a reasonable job explaining current measurements.
- p-Pb data taken last two years will allow measurement for $W_{\gamma p}$>1 TeV and x<10^{-5}.

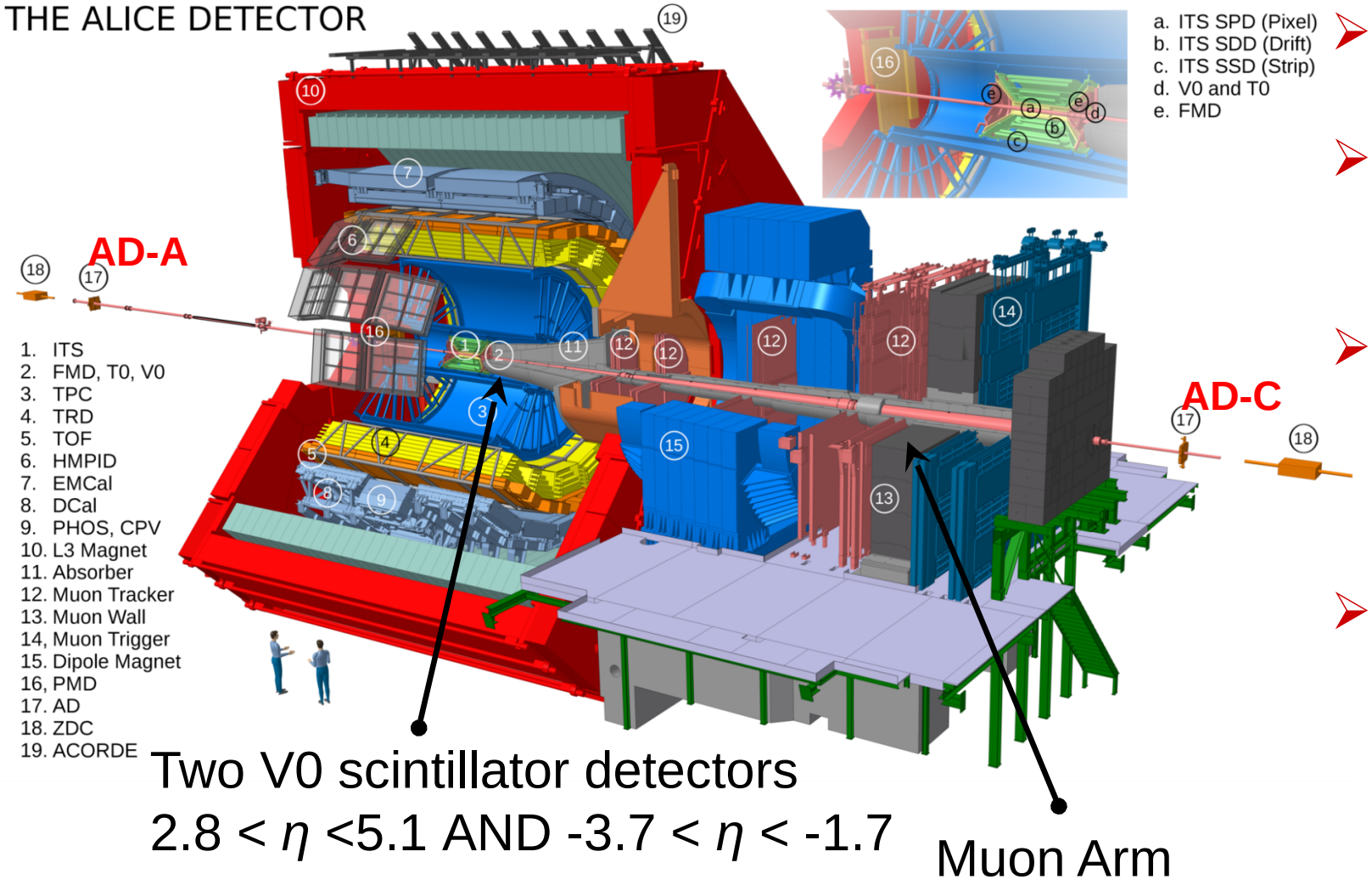
Cross sections for J/ψ in p-Pb (& Pb-p)



- Ratio of models to fit to data is also interesting.
- Reasonable agreement between models and power law fit.
- p-Pb data taken in 2016 will allow measurement for $W_{\gamma p}$>1 TeV and x<10^{-5}.

Inclusive J/ψ & Υ(1S) in hadronic p-Pb

Inclusive J/ψ in hadronic p-Pb (& Pb-p)
Trigger for inclusive J/ψ

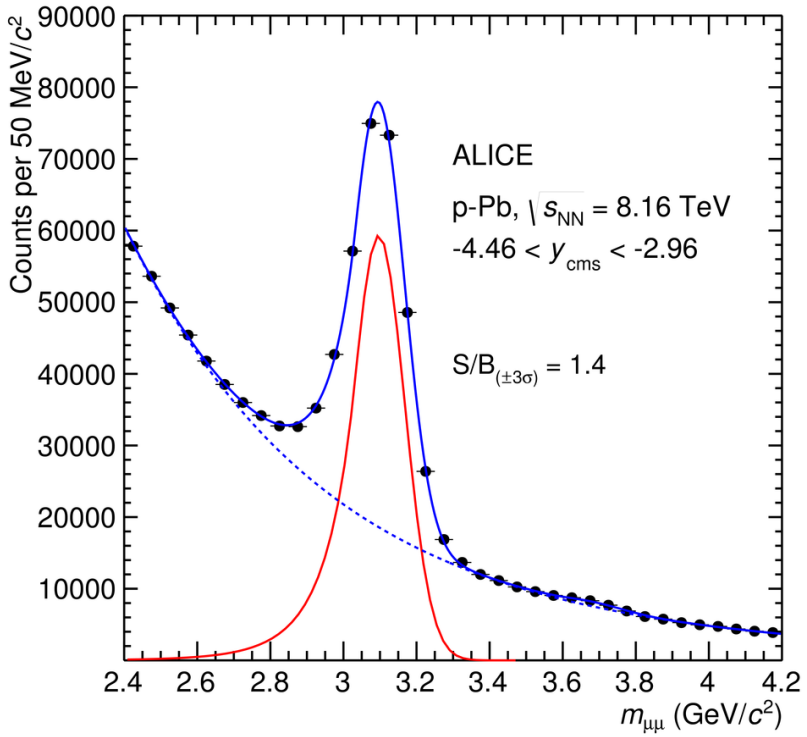


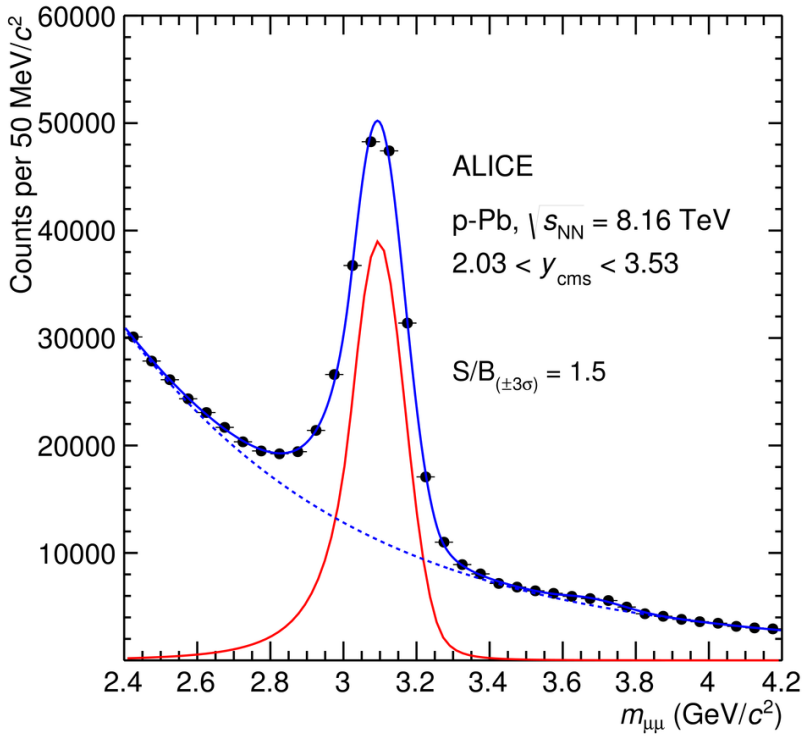
Two V0 scintillator detectors
$2.8 < \eta < 5.1$ AND $-3.7 < \eta < -1.7$

Muon Arm

- Muon Arm for tracking and PID.
- Minimum Bias (MB) trigger
  - Coincidence in V0A and V0C.
- μμ trigger
  - 2 unlike sign tracks in Muon Arm with $p_T > 0.5$ GeV/*c*.
- μμ-MB trigger requires both to be satisfied simultaneously.

Inclusive J/ψ in hadronic p-Pb (& Pb-p) Mass distributions





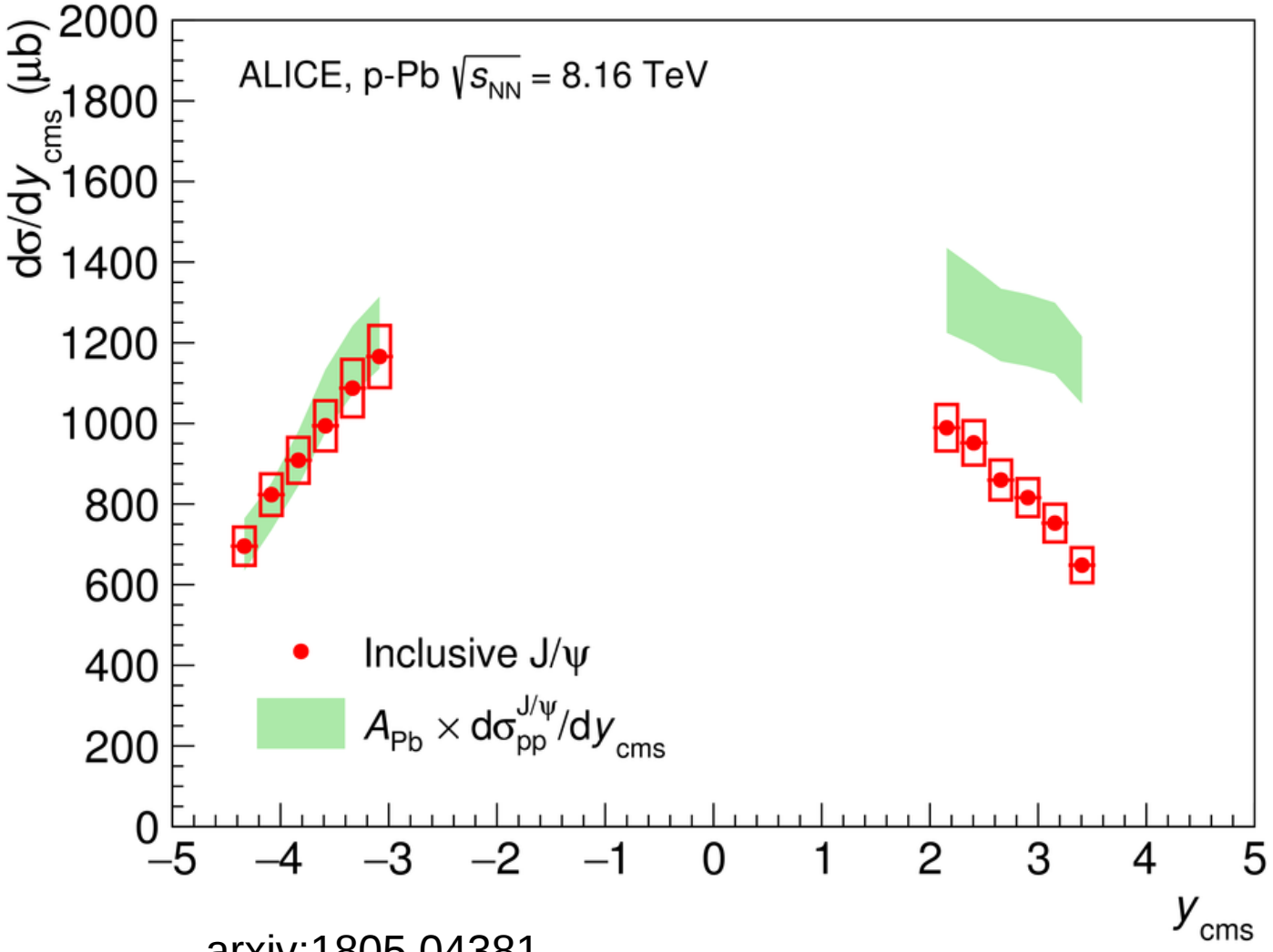
Extracted signals for J/ψ and ψ(2S)

Background component

arxiv:1805.04381

- Measured in Pb-p (left, negative rapidity) and p-Pb (right, positive rapidity).
- "Extended" Crystal Ball functions and pseudo-Gaussian fits tried.
- Exponential*Fifth order polynomial and Gaussian (with mass dependent width) tried for background.

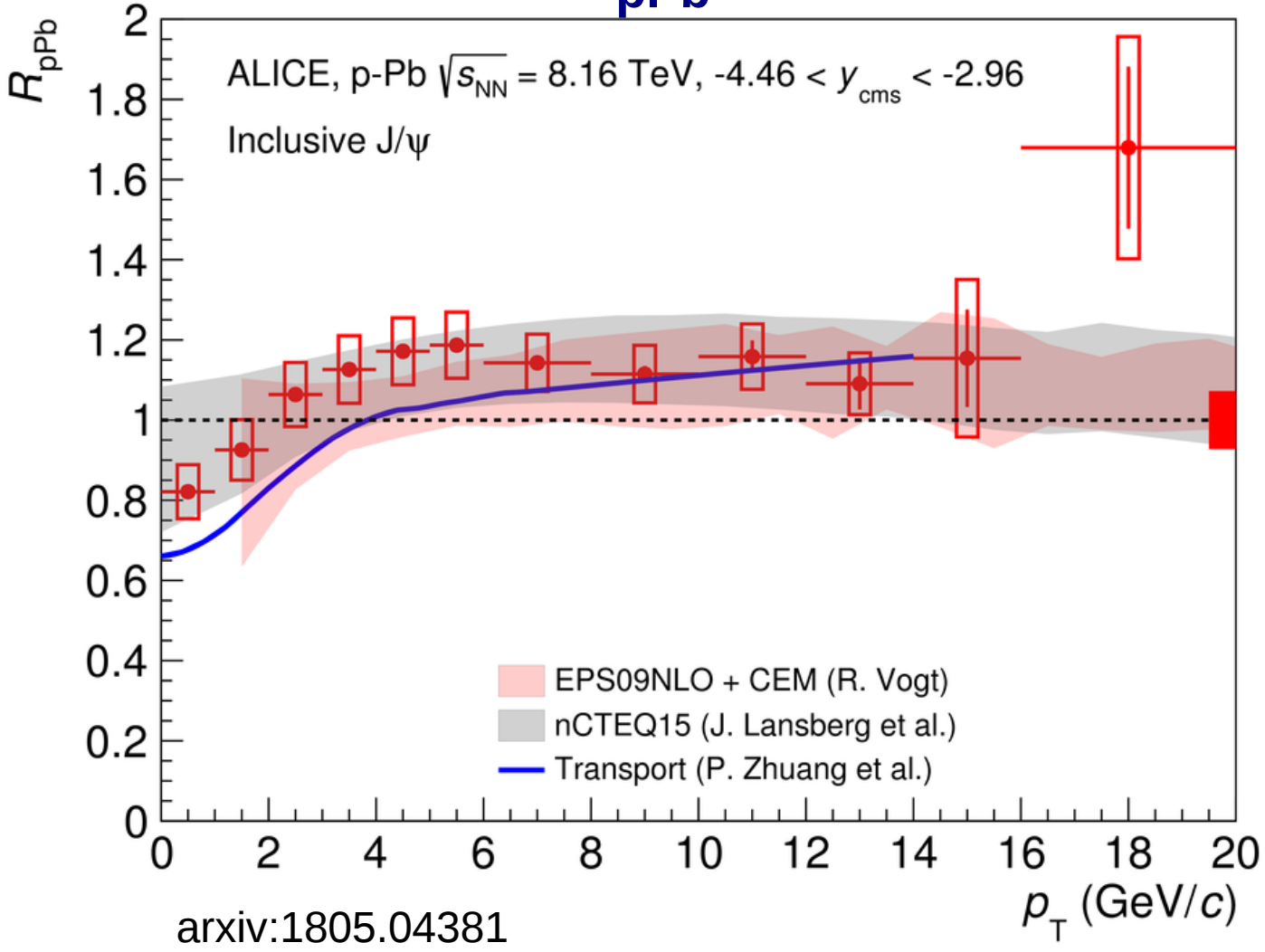
Inclusive J/ψ in hadronic p-Pb (& Pb-p) Cross sections



arxiv:1805.04381

- pp reference data obtained by interpolation and extrapolation from available energies.
- Similar cross sections for Pb-p and pp reference at backward rapidity.
- Large suppression for p-Pb compared to the pp reference data at forward rapidity.

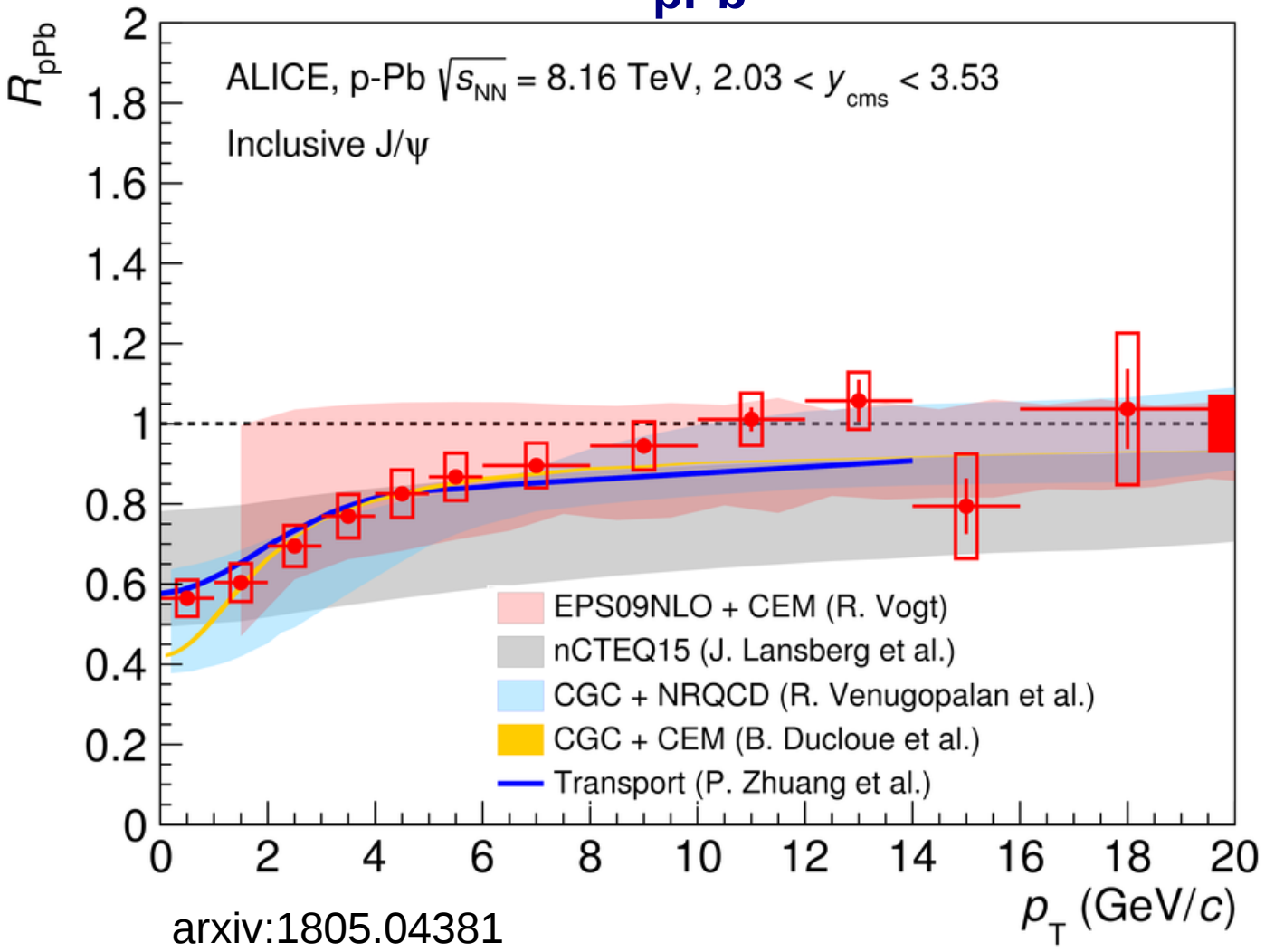
Inclusive J/ψ in hadronic Pb-p
R_{pPb} at backward rapidity



arxiv:1805.04381

- $R_{pPb}(y, p_T) = \dfrac{d^2\sigma^{J/\psi}_{pPb}/dydp_T}{A_{Pb} \cdot d^2\sigma^{J/\psi}_{pp}/dydp_T}$
- Models in good agreement with Pb-p data in backward rapidity region.
- R_{pPb} close to 1 for Pb-p collisions.

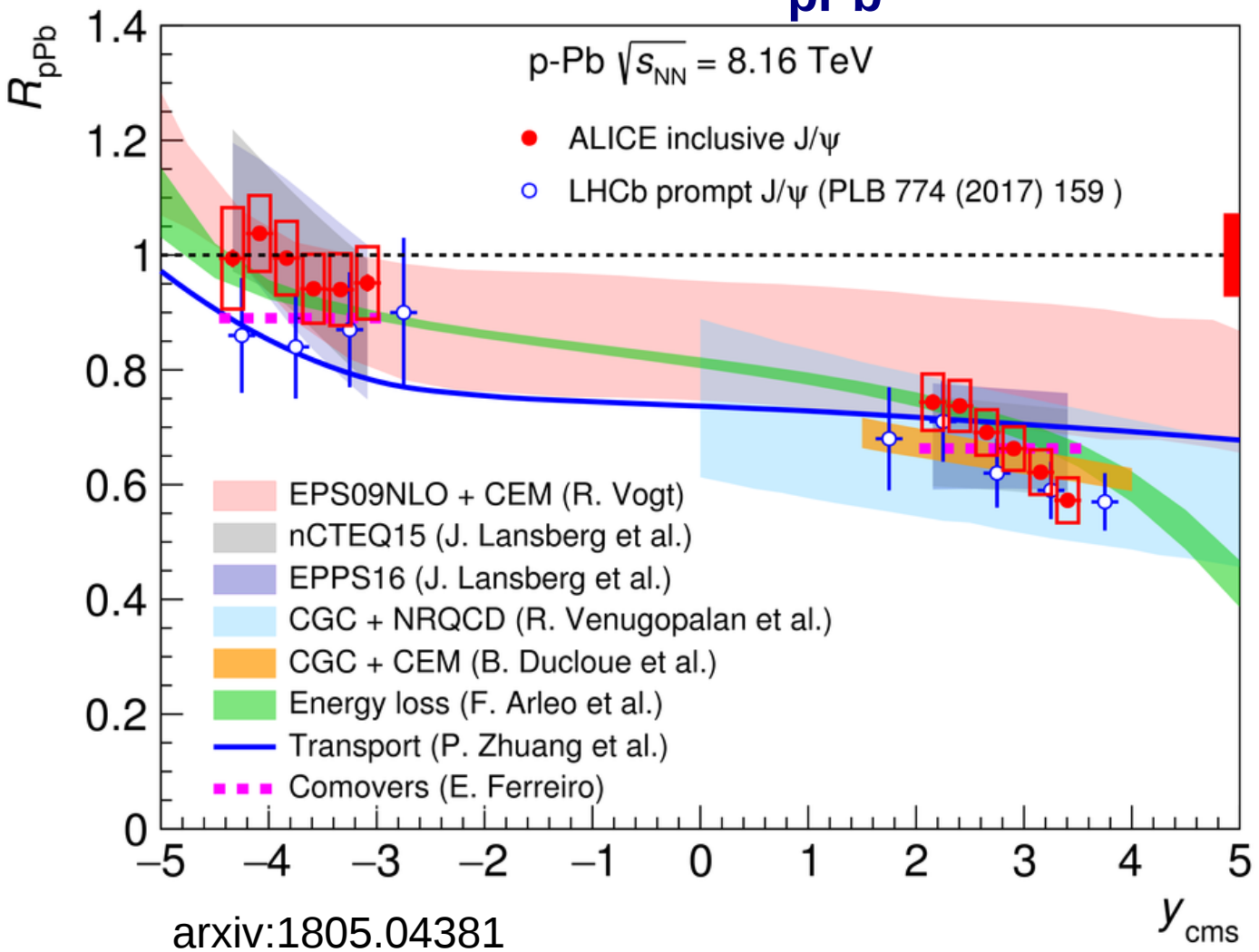
Inclusive J/ψ in hadronic p-Pb
R_{pPb} at forward rapidity



arxiv:1805.04381

- $R_{pPb}(y, p_T) = \dfrac{d^2\sigma^{J/\psi}_{pPb}/dydp_T}{A_{Pb} \cdot d^2\sigma^{J/\psi}_{pp}/dydp_T}$
- Models in good agreement with p-Pb data in forward rapidity region.
- R_{pPb} lower than 1 at low p_T.

Inclusive J/ψ in hadronic p-Pb (& Pb-p) R_{pPb} and models

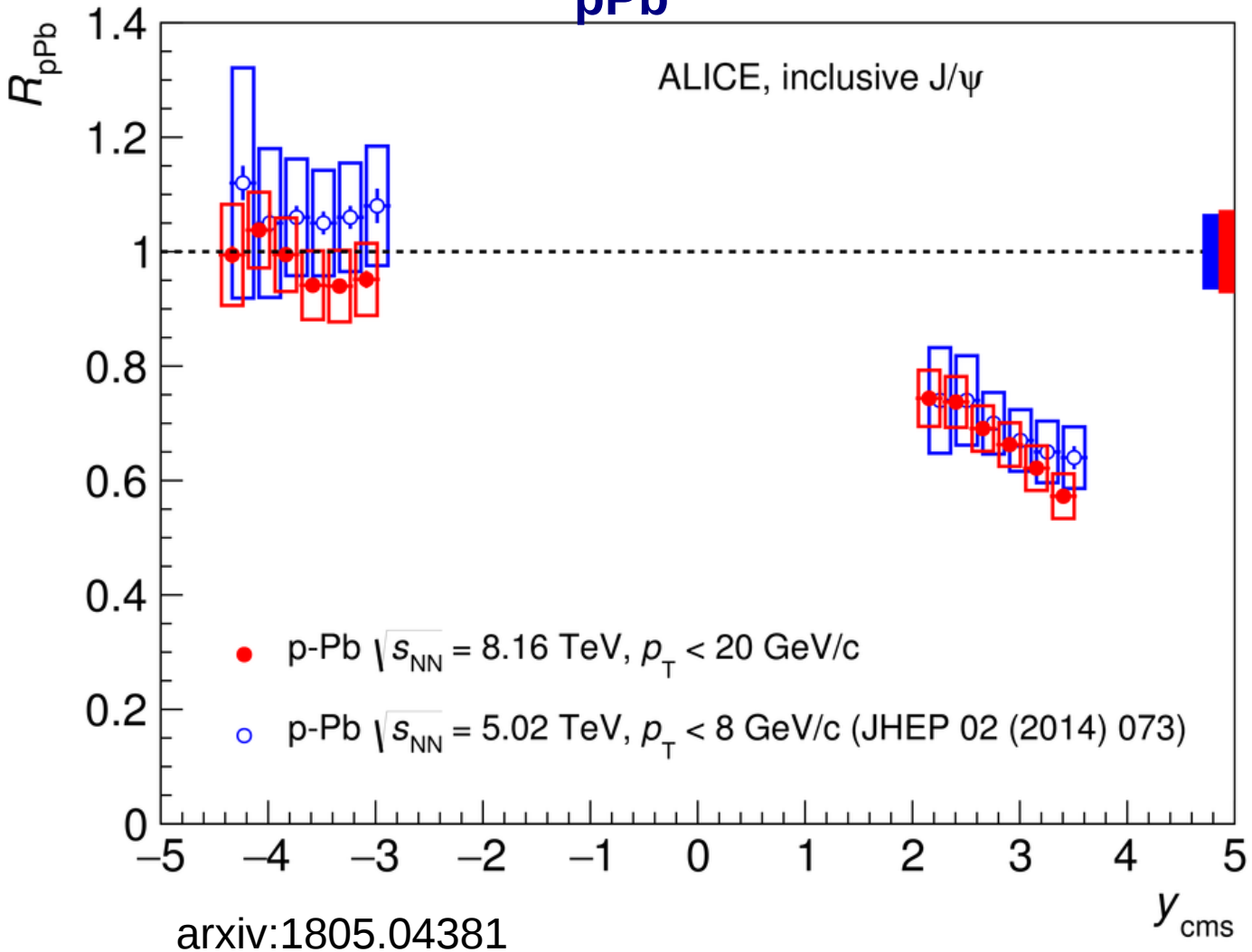


arxiv:1805.04381

$$R_{pPb}(y, p_T) = \frac{d^2\sigma^{J/\psi}_{pPb}/dydp_T}{A_{Pb}\cdot d^2\sigma^{J/\psi}_{pp}/dydp_T}$$

- Can be studied as a function of p_T or rapidity as shown here.
- Shown here are R_{pPb} for J/ψ.
- Models can reproduce R_{pPb} measurements in hadronic collisions.
  - May allow to constrain model & better understand Cold Nuclear Matter (CNM) effects.
  - Important also for separating QGP CNM effects.
- Models with moderate gluon shadowing also reproduce this data quite well.

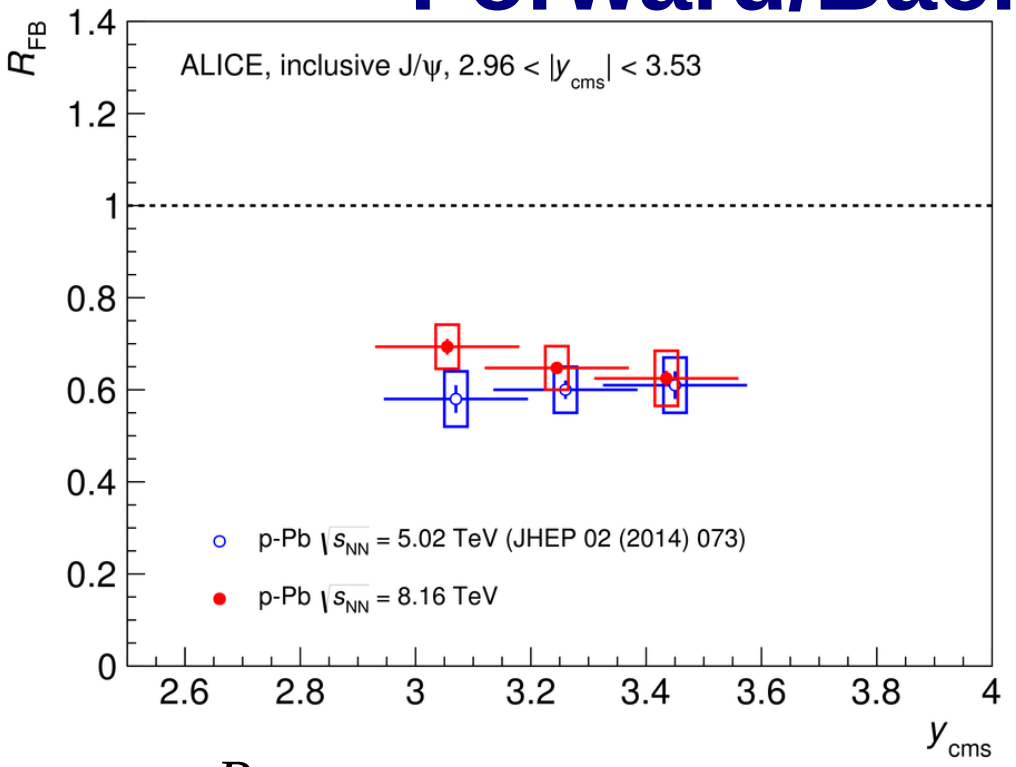
Inclusive J/ψ in hadronic p-Pb (& Pb-p)
R_{pPb} at 5.02 and 8.16 TeV

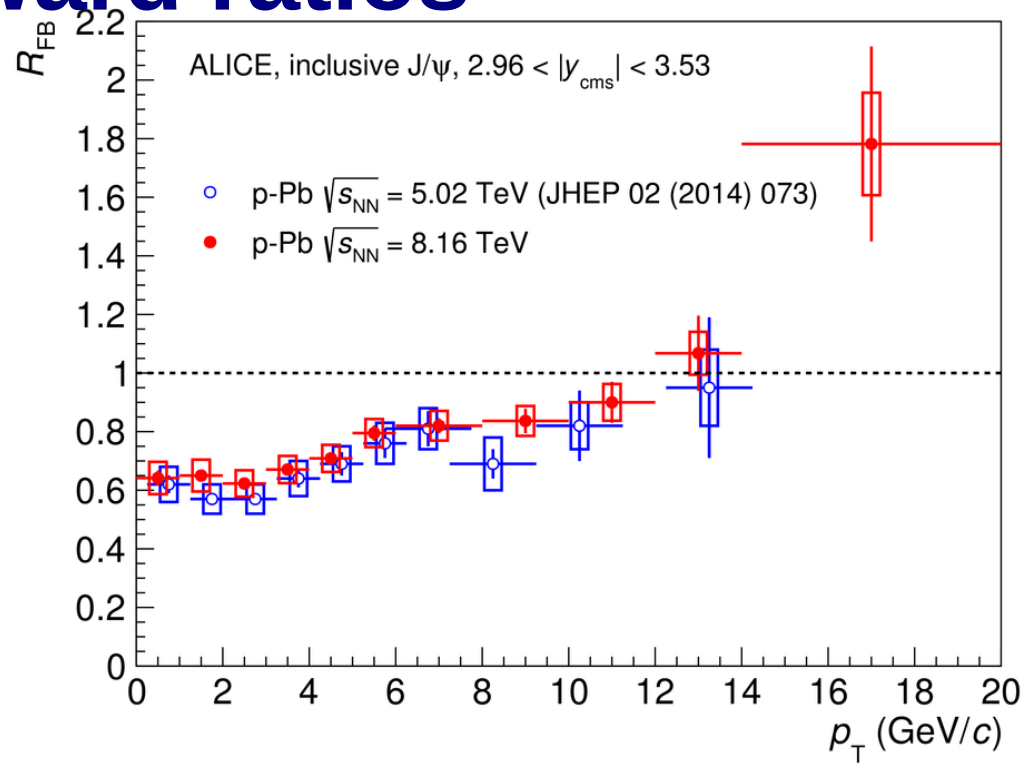


arxiv:1805.04381

- $R_{pPb}(y, p_T) = \dfrac{d^2\sigma^{J/\psi}_{pPb}/dydp_T}{A_{Pb} \cdot d^2\sigma^{J/\psi}_{pp}/dydp_T}$
- Earlier results for 5.02 TeV are very similar.
- Not very dependent on energy.

Inclusive J/ψ in hadronic p-Pb (& Pb-p) Forward/Backward ratios

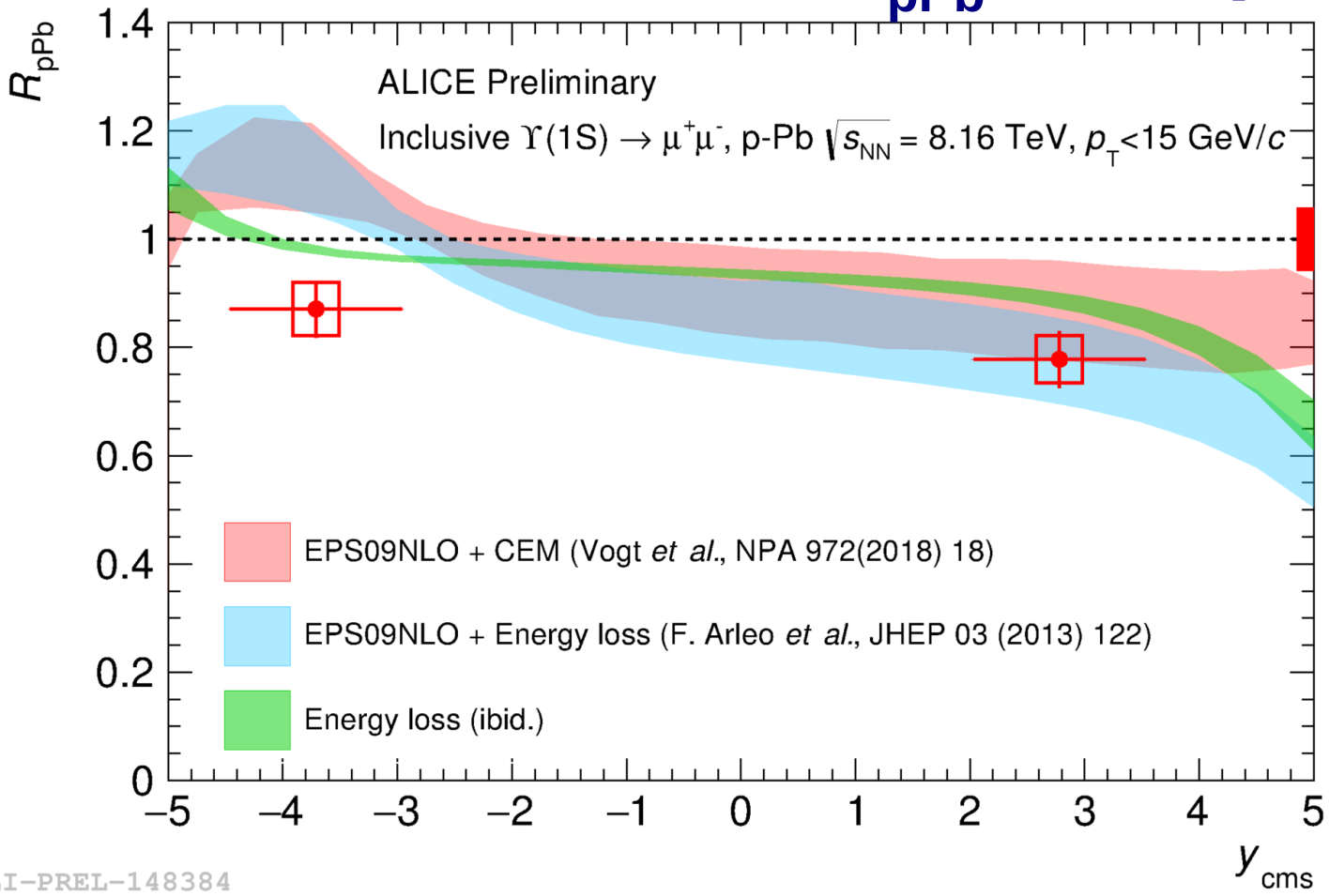




- $R_{FB} = \frac{R_{y>0}}{R_{y<0}}$
- Smaller uncertainties & pp reference cross section cancels.

arxiv:1805.04381

Inclusive Y(1S) in hadronic p-Pb (& Pb-p)
R_{pPb} for Y(1S)

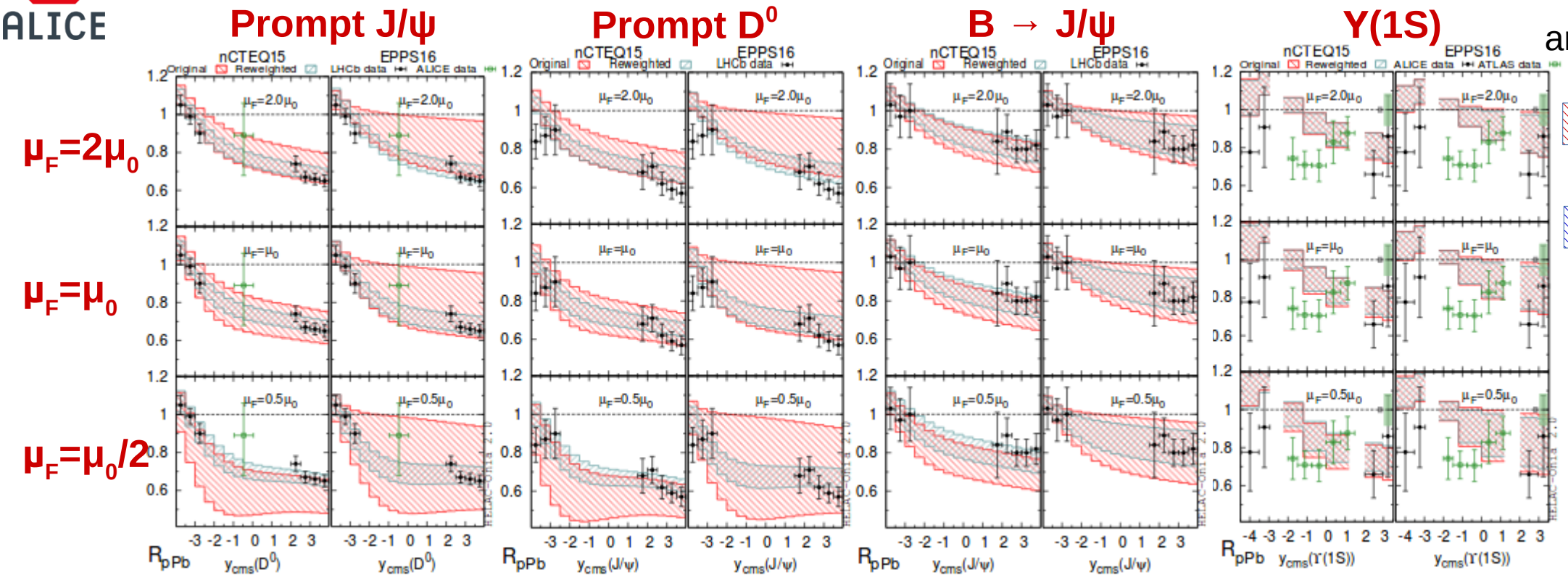


arxiv:1805.04381

$$R_{pPb}(y, p_T) = \frac{d^2\sigma^{\Upsilon(1S)}_{pPb}/dydp_T}{A_{Pb}\cdot d^2\sigma^{\Upsilon(1S)}_{pp}/dydp_T}$$

- Shown here are R_{pPb} for Y(1S).
- EPS09 model can be used to reproduce R_{pPb} measurements in hadronic collisions.
  - May allow to constrain model & better understand Cold Nuclear Matter (CNM) effects.
  - Important also for separating QGP CNM effects.

Constraints on nPDFs



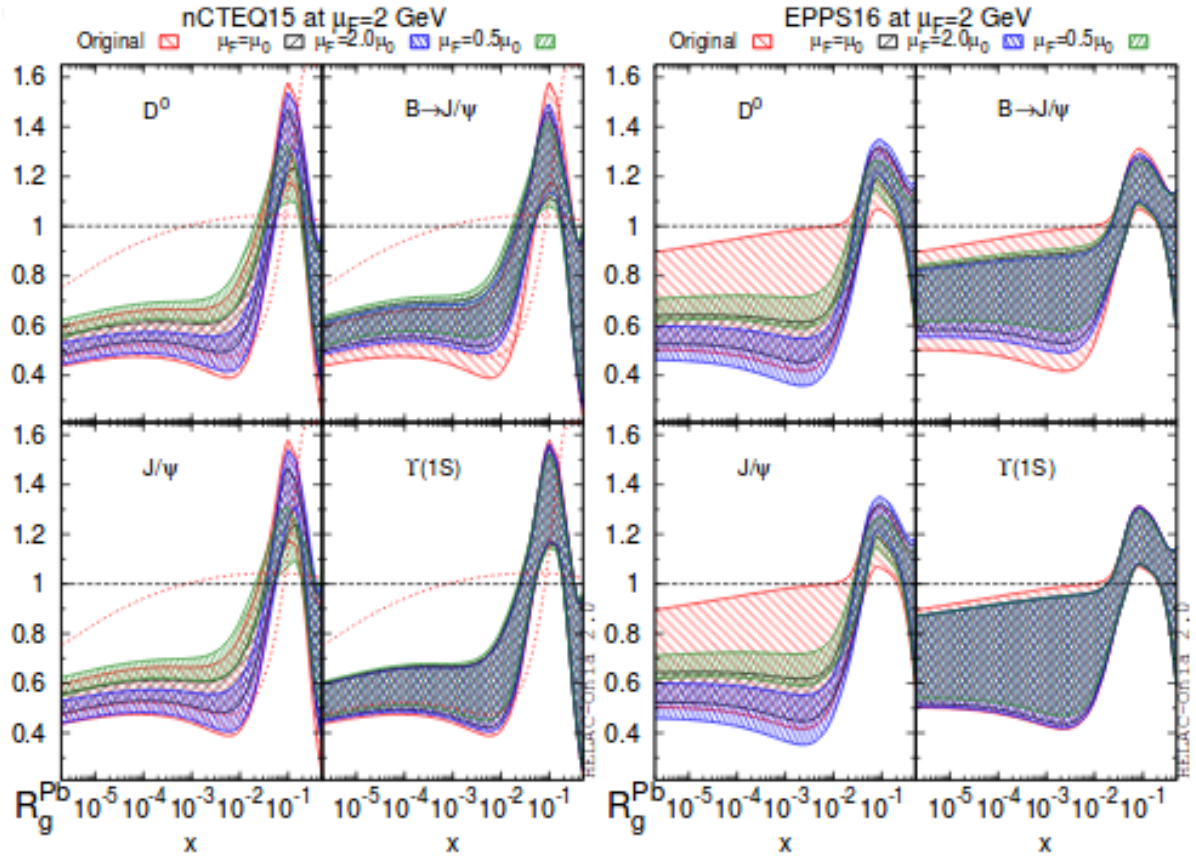
arXiv:1712.07024

Before re-weighting

After re-weighting

- Kusina, et al. show LHC R_{pPb} predictions & uncertainties with two nPDFs: **nCTEQ15 and EPPS16.**
- Both reasonably describe inclusive production for prompt J/ψ, prompt D^0, B→J/ψ and Y(1S).
- Both nPDFs use RHIC pion data (& LHC jet data for EPPS16) to constrain gluon distributions to $x \approx 10^{-3}$.
- LHC photoproduction and R_{pPb} (or Q_{pPb}) data not included.
- Re-weighting for the LHC inclusive R_{pPb} data greatly reduces uncertainties.

Constraints on nPDFs



arXiv:1712.07024

- Current data in global fits provide constraint down to $x \approx 10^{-3}$ for nuclear gluon distributions.
- Kusina, et al. studied the effect of including inclusive particle production in LHC p-Pb on nPDFs.
- Including just the LHC R_{pPb} data in the fit would
  - (i) leave the agreement with other data in the global fit still in very good agreement
  - (ii) lead to much smaller uncertainties at low x down to $x \approx 5 \cdot 10^{-6}$.

Summary

- Exclusive J/ψ measurements in Pb-Pb show direct evidence for moderate gluon shadowing.
- Exclusive J/ψ and ψ(2S) measurements in Pb-Pb provide important information that can constrain our understanding of nuclear gluon distributions
- Exclusive J/ψ measurements in p-Pb interactions show consistent behavior with earlier experiments.
- New p-Pb collected in 2016 will provide data for $W_{\gamma p}$>1 TeV and x<10^{-5}.
- New Pb-Pb data from 2015 and from later this year will provide more differential measurements and reduced uncertainties to better constrain nuclear gluon distributions and nuclear shadowing.
- R_{pPb} and Q_{pPb} measurements for J/ψ, ψ(2S) and Y in hadronic collisions may provide new constraints on models of nuclear gluon distributions down to x≈5•10^{-6}.