Suppression of ψ(2S) production in p-Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV with ALICE

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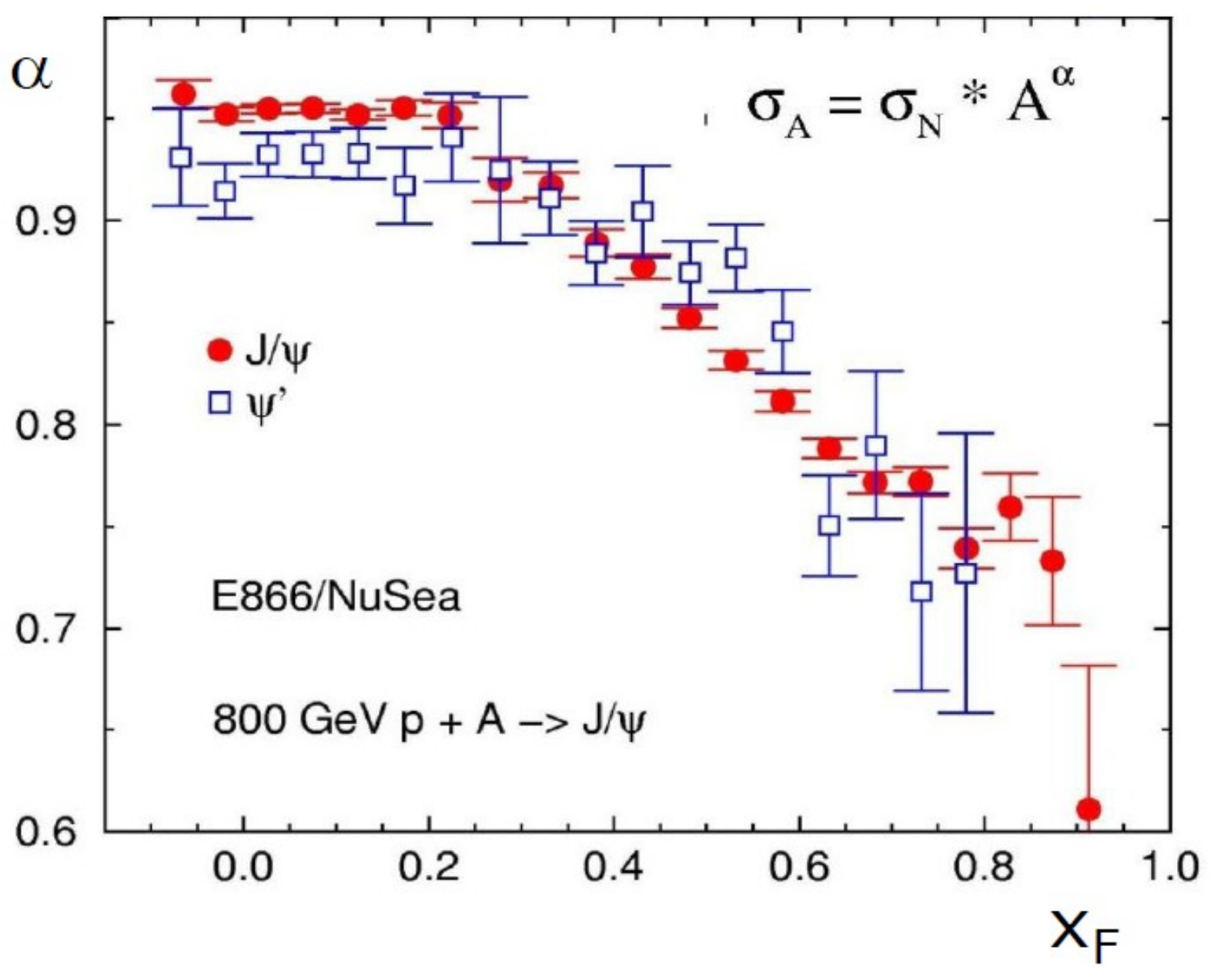
Introduction

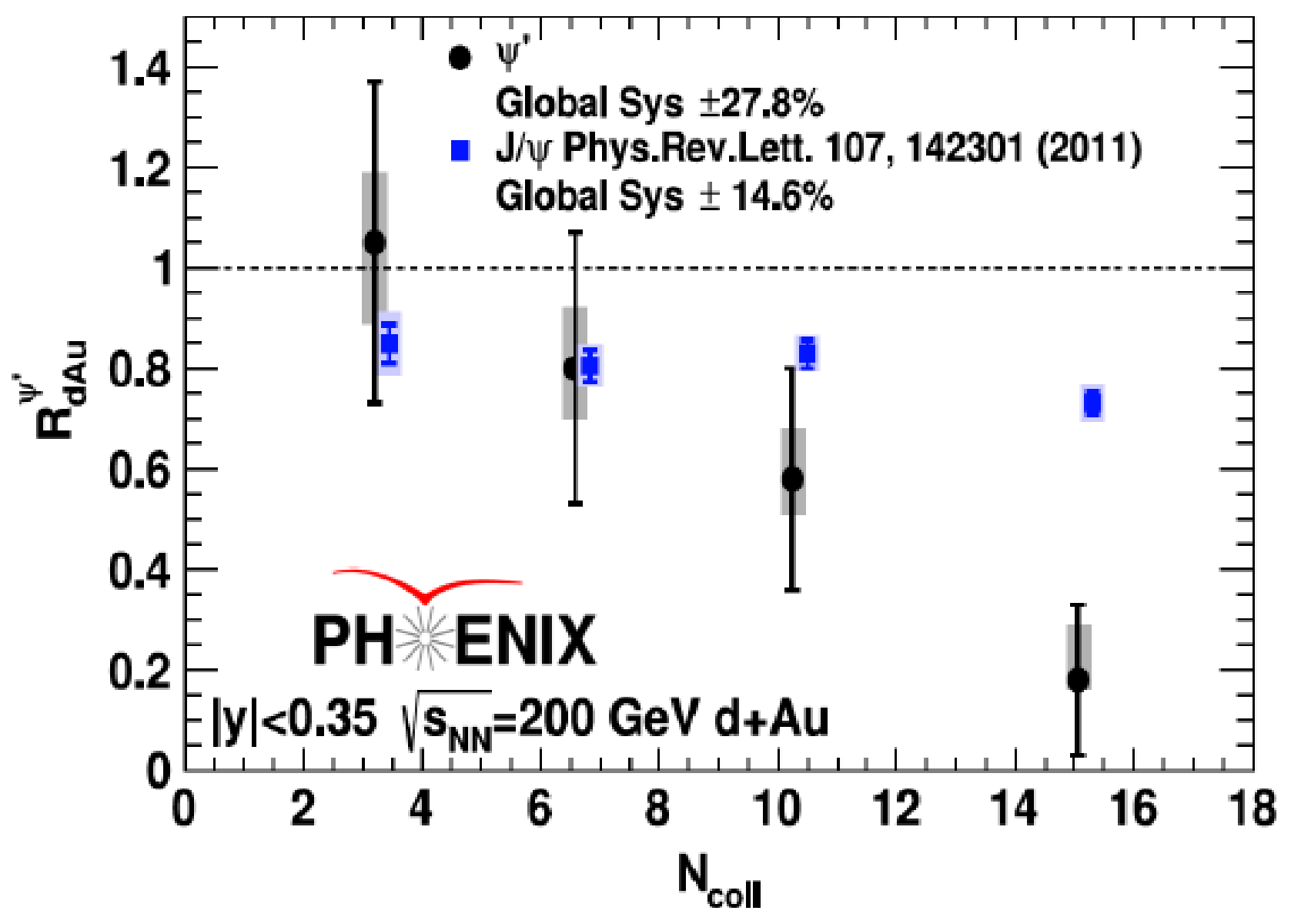
Charmonia, bound states of *c* and $\bar{c}$ heavy quarks, are useful probes to study the properties of the Quark Gluon Plasma (QGP) which can be considered as a deconfined state of quarks and gluons. The high color density typical of a QGP can screen the charmonia binding potential, resulting in a suppression of the resonances yields. The strongly bound J/ψ and the weakly bound ψ(2S) states have received a lot of attention in the context of QGP studies: the results from NA50 collaboration, in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 17 GeV, showed a bigger ψ(2S) suppression, compared to the J/ψ one, in agreement with sequential melting scenario in a QGP.

It was soon discovered that charmonia states can also be suppressed by Cold Nuclear Matter (CNM) effects in proton-nucleus (p-A) collisions, where the formation of QGP is not expected. Several mechanisms such as nuclear parton shadowing, $c\bar{c}$ break-up via interaction with nucleons and initial/final state energy loss, were taken into account to describe experimental data.



The E866 experiment at the Fermilab has studied the J/ψ and ψ(2S) production in 800 GeV p-A collisions: a stronger ψ(2S) suppression relative to J/ψ at central rapidity was observed, while at forward rapidity no difference was found. This result was interpreted in term of pair break-up: at central rapidity the time for the $c\bar{c}$ state to cross the nucleus is larger than the formation time of the resonances: the loosely bound ψ(2S) can be more easily dissociated than the J/ψ. Conversely, at forward rapidity the crossing time is smaller than the formation time and the nuclear effects are expected to be the same, independently of the resonance being produced.

[E866 Collaboration: PRL 84 (2000) 3256]

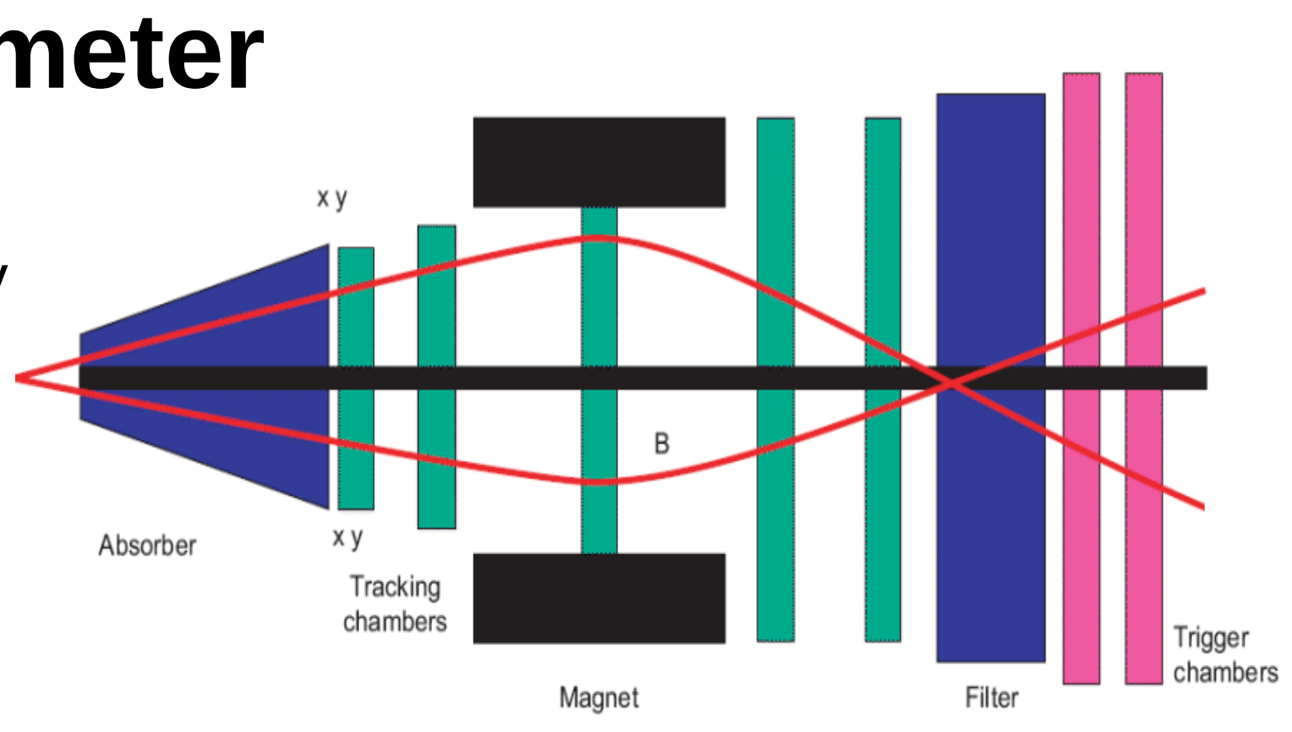


The PHENIX collaboration at RHIC recently published results in d-Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV. The ψ(2S) suppression is larger than the J/ψ one and increasing from peripheral to central collisions. The stronger ψ(2S) suppression is unexpected because at RHIC energies the crossing time of the $c\bar{c}$ state is expected to be comparable to the formation time of the resonance.

[PHENIX Collaboration: PRL 111 (2013) 202301]

In this poster we present the inclusive ψ(2S) production, in p-Pb collisions, at the nucleon-nucleon center of mass energy $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV, studied with the ALICE detector at the CERN LHC [ALICE Collaboration: JHEP 12 (2014) 073]. The measurement has been performed as a function of rapidity (*y*), transverse momentum (p_T) and collision centrality. ALICE data can shed further light on the CNM effects at previously unexplored energies: in particular, the $c\bar{c}$ pair breakup effects are expected to be negligible, because of the very small (~10^{-4} fm/c) crossing time in the nuclear medium.

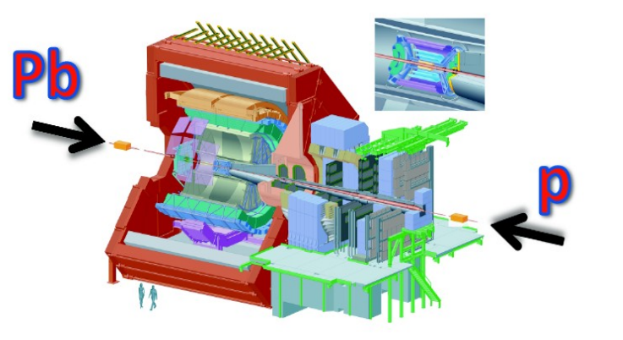
The ALICE Forward Muon Spectrometer



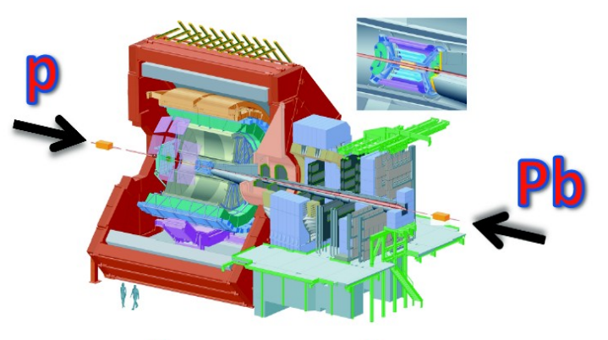
The ψ(2S) is detected in the dimuon decay channel, using the Forward Muon Spectrometer, which covers the pseudorapidity range $-4 \leq \eta_{lab} \leq -2.5$, and is composed by:

- a front absorber;
- 10 planes of tracking chambers;
- a dipole magnet (3 T·m field integral);
- 4 planes of trigger chambers behind an iron wall.

Data sample and signal extraction



backward
(-4.46<y_{cms}<-2.96)
Pb-p



forward
(2.03<y_{cms}<3.53)
p-Pb

Data sample and kinematic cuts:

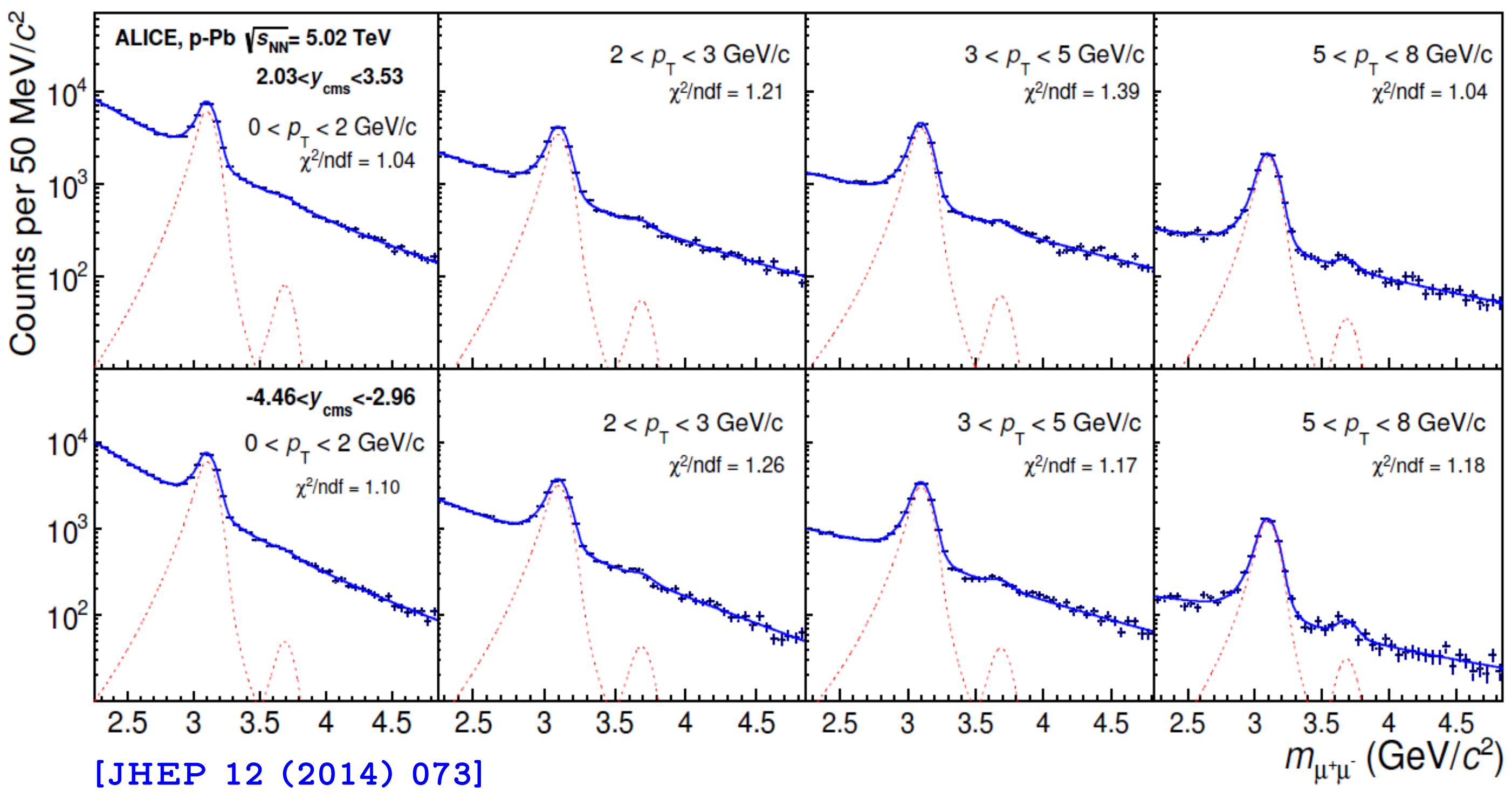
- 2013 data sample, $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV, two rapidity regions studied (inverting the beam direction in the LHC);
- $L_{int}^{\text{Pb-p (backward)}} = 5.81 \pm 0.18\ \mathrm{nb}^{-1}$;
- $L_{int}^{\text{p-Pb (forward)}} = 5.01 \pm 0.17\ \mathrm{nb}^{-1}$;
- muons are in the range: $-4 \leq \eta_{lab} \leq -2.5$;
- muon radial position at the absorber end is in the range: $17.6 \leq R_{abs} \leq 89.5$ cm;
- muon p·DCA < 6 standard deviation (DCA = transverse distance to the primary vertex);
- dimuon is in the range: $2.5 \leq y_{lab} \leq 4$;
- muon trigger-tracking matching;
- dimuon trigger: detection of two opposite sign muon candidates above a 1 GeV/c p_T threshold.

Signal extraction:

- Charmonium yields are extracted through a fit to the opposite-sign invariant mass spectra, using a combination of signal and background shapes;
- signal: extended Crystal Ball (CB2) or pseudo-Gaussian functions for J/ψ and ψ(2S);
- background: variable width Gaussian or 4th-degree polynomial times exponential functions;
- ψ(2S) position and width are tied to the J/ψ, using the following formulas:

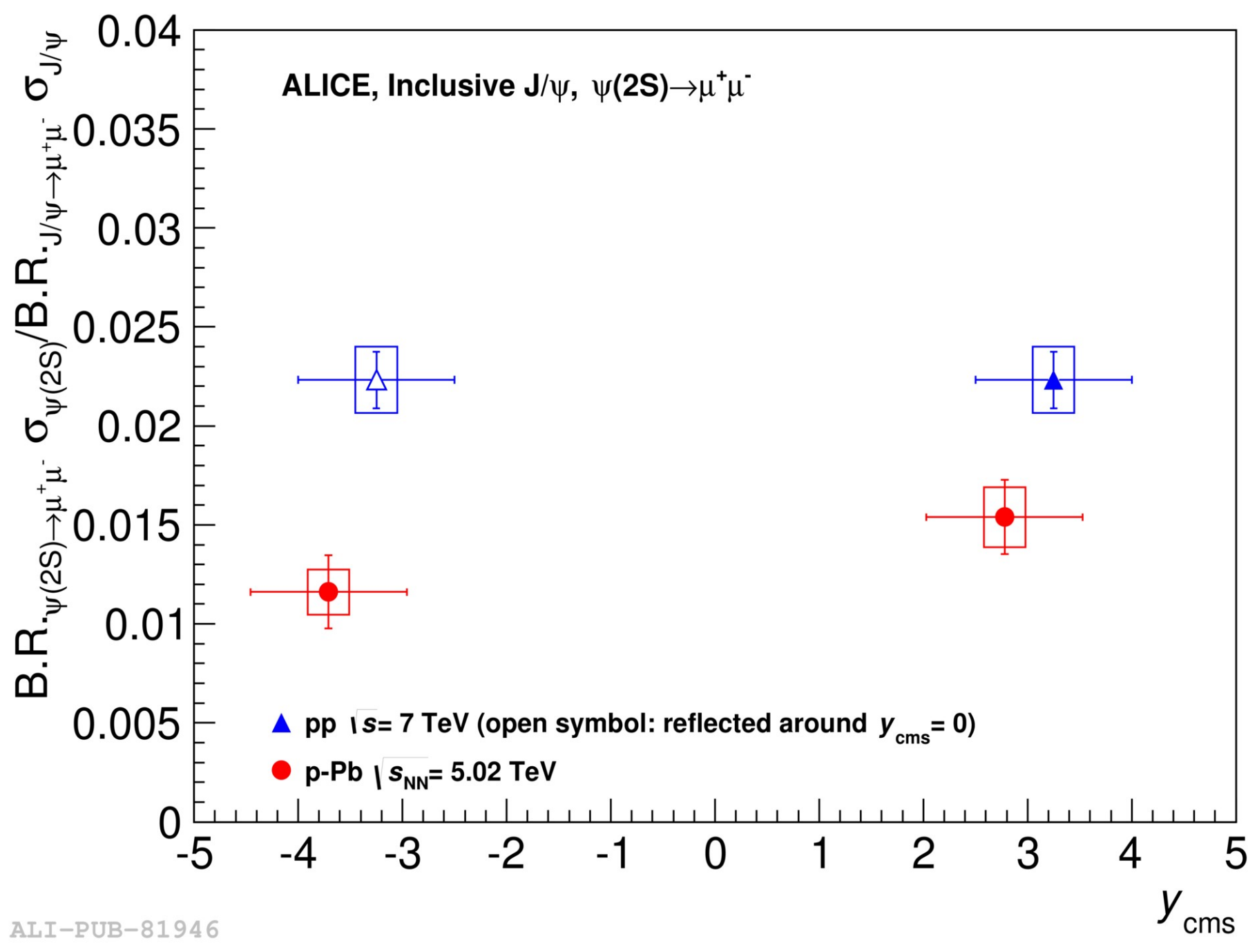
$$m_{\psi(2S)} = m_{J/\psi} + (m^{MC}_{\psi(2S)} - m^{MC}_{J/\psi}) \qquad \sigma_{\psi(2S)} = \sigma_{J/\psi} \cdot (\sigma^{MC}_{\psi(2S)}/\sigma^{MC}_{J/\psi})$$

- tail parameters of CB2 and pseudo-Gaussian functions.



[JHEP 12 (2014) 073]

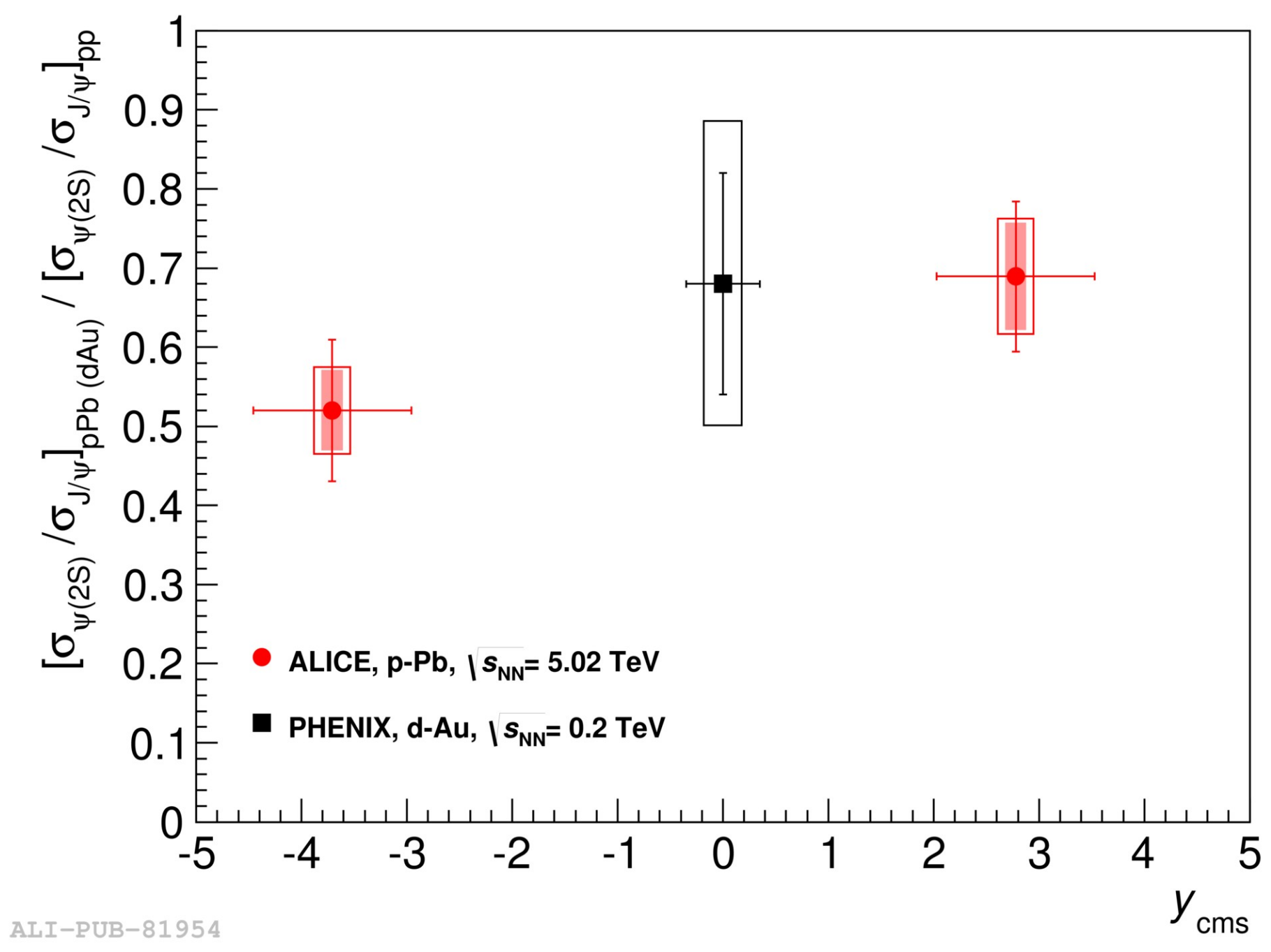
Results



ψ(2S)/J/ψ ratio

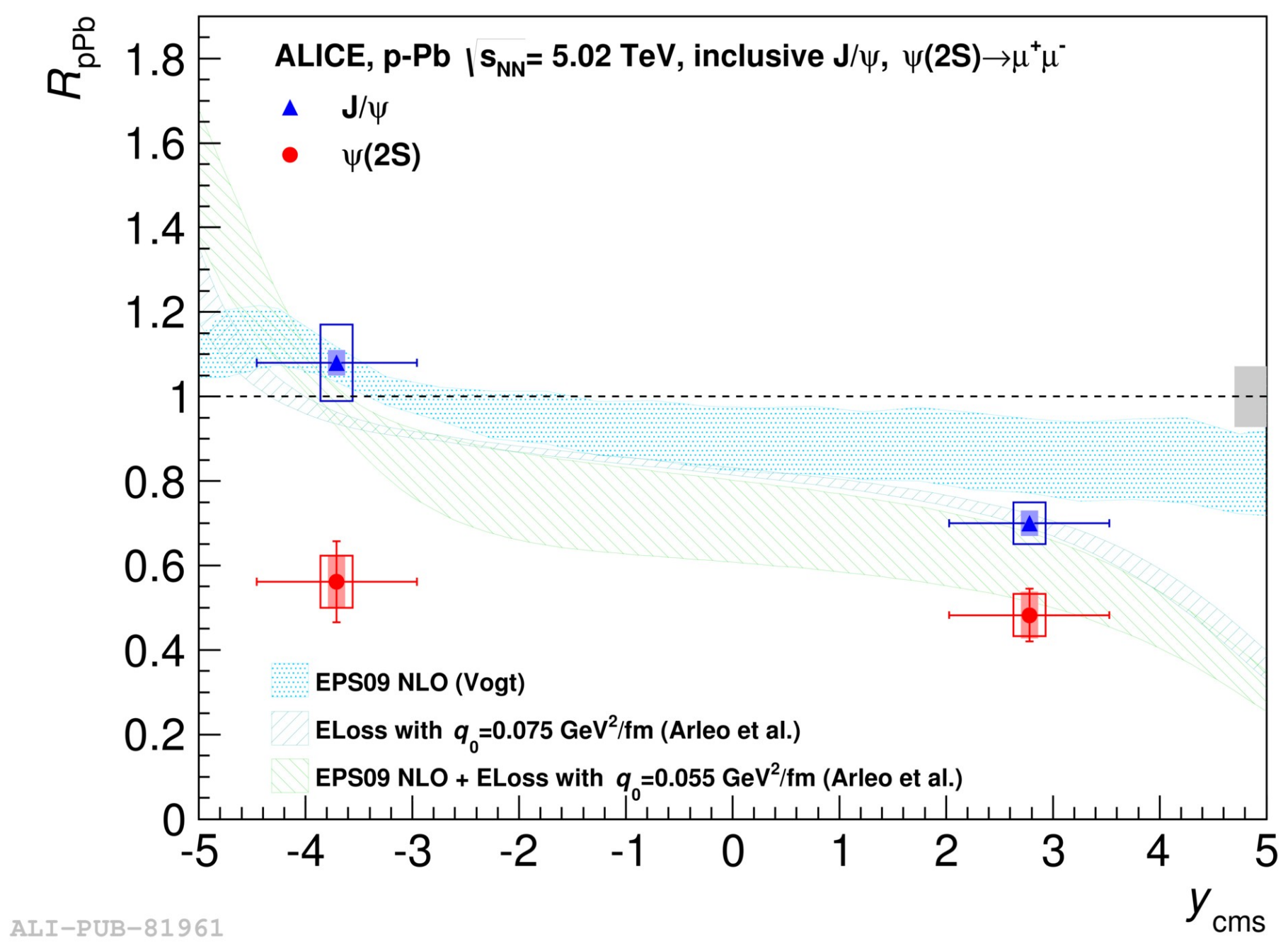
The ratio between the ψ(2S) and J/ψ cross sections is interesting to investigate the effect of the nuclear matter on the charmonium production. Also, some systematic uncertainties cancel out in the ratio. The ψ(2S) suppression is larger (compared to the J/ψ one) in p-Pb with respect to $\sqrt{s}$ = 7 TeV pp collisions. The significance of the suppression is:

- 2.0 σ-level at forward-y
- 3.2 σ-level at backward-y



$[\psi(2S)/J/\psi]_{pPb}/[\psi(2S))/J/\psi]_{pp}$ double ratio

The double ratio is useful to compare the relative suppression of the two states between different experiments. The collision energy and the rapidity ranges are different in pp and p-Pb collisions: possible dependences on the energy and y are included in the systematic uncertainties. PHENIX results in d-Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 0.2 TeV at mid-rapidity are in qualitative good agreement with ALICE data, in spite of the energy gap between the two experiments.



Nuclear modification factor

The effects of the nuclear matter on the charmonium states can be quantified with the nuclear modification factor R_{pA}:

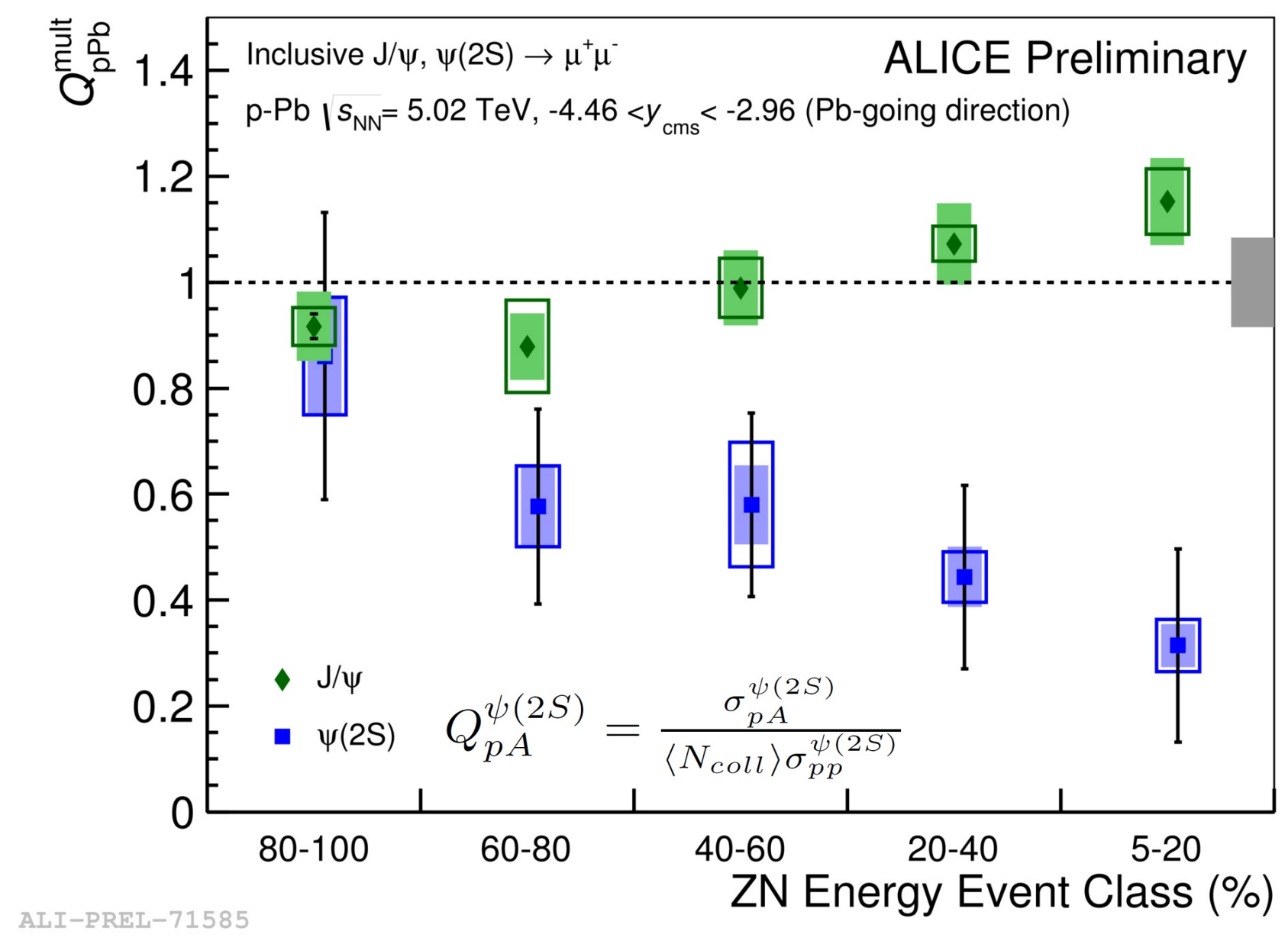
$$R^{\psi(2S)}_{pA} = \frac{\sigma^{\psi(2S)}_{pA}}{A_{Pb} \cdot \sigma^{\psi(2S)}_{pp}} \begin{cases} R_{pA} = 1 \rightarrow \text{no medium effects} \\ R_{pA} \neq 1 \rightarrow \text{medium effects} \end{cases}$$

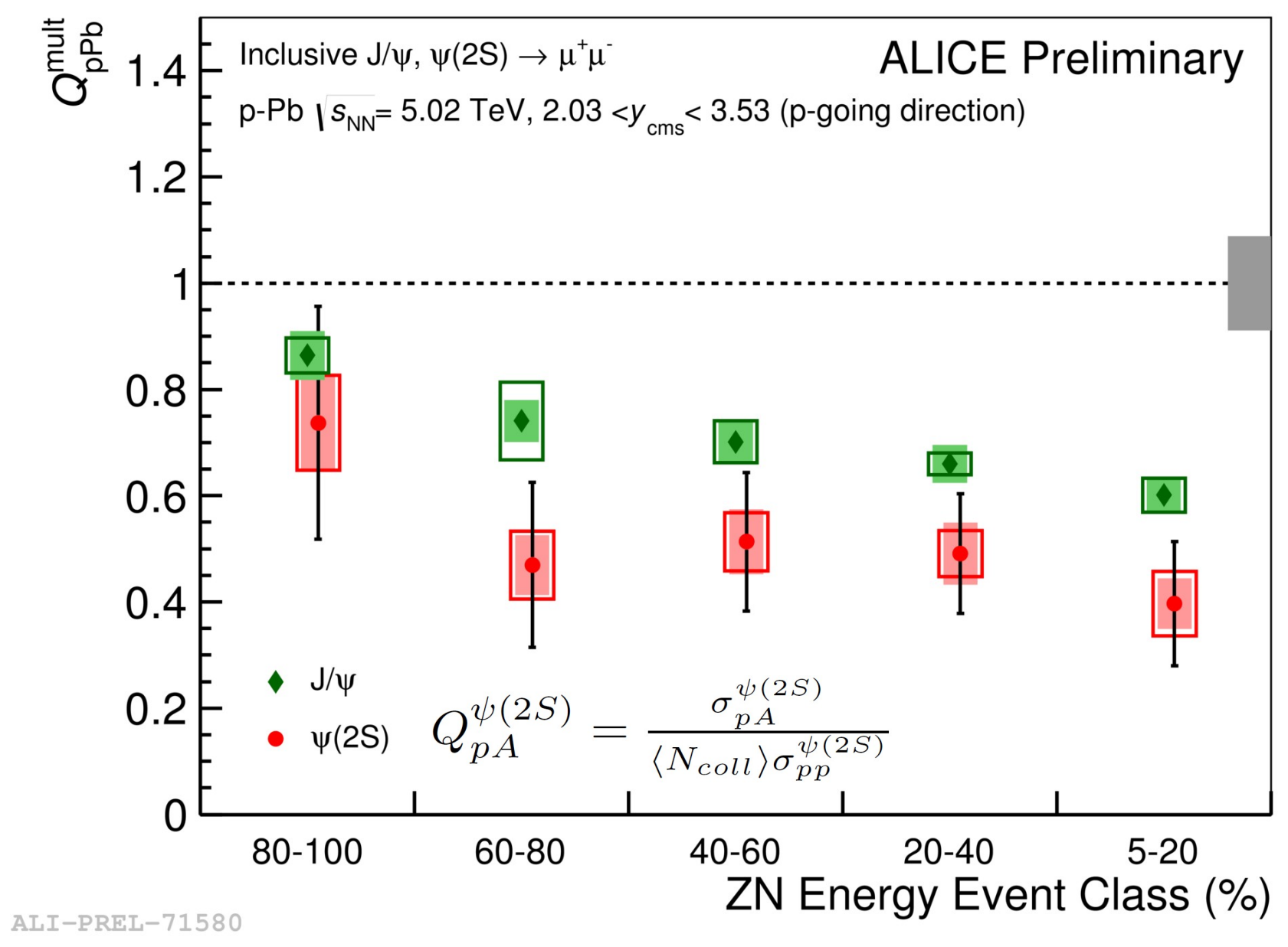
ALICE data show a larger ψ(2S) suppression compared to the J/ψ one. Being the same for J/ψ and ψ(2S), theoretical predictions (based on shadowing and on energy loss) do not describe the observed ψ(2S) suppression.

At LHC energies the ψ(2S) suppression can not be related to $c\bar{c}$ state breakup in the nuclear medium because this process becomes relevant only if the charmonium formation time τ_f is smaller than the time τ_c spent by the $c\bar{c}$ pair inside the nucleus. Estimates for τ_f are in the range between 0.05 and 0.15 fm/c [Phys. Rev. C 61 (2000) 054906]. The average proper time τ_c is: $\tau_c = \langle L \rangle / \beta_z \gamma$, where $\langle L \rangle$ is the average length of nuclear matter traversed by the $c\bar{c}$ pair, $\beta = tanhy^{rest}_{c\bar{c}}$ is the velocity of the $c\bar{c}$ pair along the beam direction in the nucleus rest frame and $\gamma = E_{c\bar{c}}/m_{c\bar{c}}$ [Phys. Rev. C 87 (2013) 054910].

- **Forward rapidity**: τ_c~$7 \cdot 10^{-2}$ fm/c: breakup effects alone can hardly explain the big difference between the ψ(2S) and J/ψ R_{pA}.
- **Backward rapidity**: τ_c~10^{-4} fm/c: breakup effects are excluded.

Other final state effects, including the interaction of the $c\bar{c}$ pair are required to explain the bigger ψ(2S) suppression in p-Pb collisions.





The ψ(2S) nuclear modification factor has also been studied as a function of the event activity (the Q_{pA} variable, instead of R_{pA}, is used because of a possible bias from the centrality estimator). At backward rapidity the ψ(2S) and J/ψ Q_{pPb} trends are different: the ψ(2S) Q_{pPb} decreases with increasing event activities. At forward rapidity the Q_{pPb} trend is similar for J/ψ and ψ(2S). This could be another hint that final state effects can influence the ψ(2S) production.

Conclusions

The ALICE Collaboration has studied the ψ(2S) production in p-Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV, as a function of rapidity, transverse momentum and event activity.

- The weakly bound ψ(2S) is more suppressed than the strongly bound J/ψ.
- This difference increases with event activity at backward rapidity, while at forward rapidity ψ(2S) and J/ψ suppression follow a similar trend.
- The relative suppression of the two states integrated over event activity is comparable to the one measured by PHENIX in d-Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 0.2 TeV and mid-rapidity.
- The ψ(2S) suppression is not explained by theoretical prediction based on shadowing and/or energy loss.
- Other final state effects, like the interaction of the $c\bar{c}$ pair with hadronic matter, should be invoked to explain the larger ψ(2S) suppression.

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