

## **J/ψ production at central rapidity in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with ALICE**

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**Abstract.** The ALICE detector is capable of reconstructing J/ψ at central rapidity through the  $e^+e^-$  decay channel, down to zero transverse momentum, and has measured its production cross section as well as the fraction of non-prompt J/ψ, produced by the decay of beauty-flavoured hadrons. The latter quantity was evaluated in both pp and Pb–Pb systems down to  $p_T = 1.3$  GeV/c. The results obtained by ALICE from the measurements of the inclusive J/ψ yield in p–Pb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV, as well as the statistical techniques and the status of the analysis concerning the non-prompt J/ψ measurement will be presented in this paper.

### **1 Introduction**

The observation of a suppression of the J/ψ yield in ultra-relativistic heavy-ion collisions relative to that expected from a bare superposition of elementary pp collisions has long been interpreted as a signature of the formation of a deconfined state of hadronic matter, known as Quark-Gluon Plasma (QGP) [1]. Various Cold Nuclear Matter (CNM) effects, such as nuclear shadowing or partonic energy loss, are however expected to affect J/ψ production in addition to the modifications due to the presence of the QGP.

The study of p–Pb collisions, where the formation of a QGP medium is not expected, represents a necessary baseline for characterizing the CNM effects affecting J/ψ production and is crucial for improving our understanding of Pb–Pb collision results. Moreover, the determination of the fraction of secondary non-prompt J/ψ originating from the decay of beauty-flavoured hadrons provides a measurement of the inclusive b-quark production, and its study in p–Pb systems allows the evaluation of CNM effects on beauty production.

### **2 J/ψ identification with the ALICE detector**

The ALICE experiment at the LHC consists of a central barrel embedded in a large solenoidal magnet, covering the pseudo-rapidity range  $|\eta| < 0.9$ , and a muon spectrometer in the forward direction [2]. At central rapidity ( $y$ ), the J/ψ resonance is detected through its di-electronic decay channel  $J/\psi \rightarrow e^+e^-$

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by means of the Time Projection Chamber (TPC) and Inner Tracking System (ITS) detectors, which provide excellent tracking performances within  $|y| < 0.9$ . The TPC is the main tracking detector of the barrel, consisting of a large cylindrical drift chamber which allows also charged particle identification through specific energy loss ( $dE/dx$ ) measurements. The ITS is a cylindrically-shaped tracker made up of six layers of silicon detectors which provide precise track and vertex reconstruction close to the interaction point, and in particular a good secondary vertex separation for non-prompt  $J/\psi$  extraction. Thanks to the unique acceptance and low-momentum electron identification potential of these detectors, ALICE is capable of reconstructing  $J/\psi$  down to zero transverse momentum ( $p_T$ ) and to separate, on a statistical basis, their non-prompt component down to  $p_T = 1.3$  GeV/ $c$ , in a momentum region complementary to other LHC experiments.

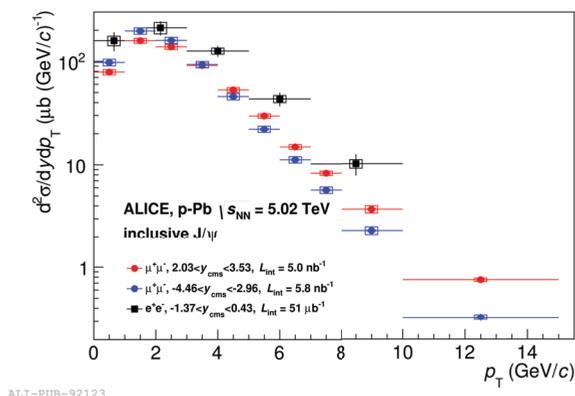
### 3 Inclusive $J/\psi$ measurement

ALICE has measured the inclusive  $J/\psi$  production as a function of  $p_T$  in p-Pb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV in the mid-rapidity region corresponding to  $-1.37 < y_{cms} < 0.43$  in the center of mass frame [3]. The analysis was based on a sample of about  $10^8$  Minimum Bias p-Pb events collected by ALICE in 2013 and corresponding to an integrated luminosity  $L_{int} = 51 \mu\text{b}^{-1}$ .

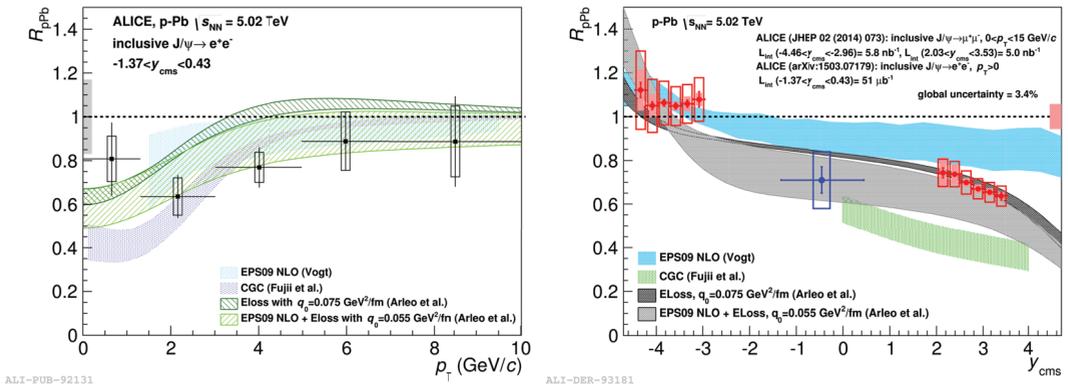
$J/\psi$  candidate selection is performed by combining opposite charged tracks within the ALICE central barrel acceptance. Electron identification is performed by requiring each track to have a specific energy loss signal in the TPC gas compatible with that of an electron and by rejecting tracks compatible with the pion and proton assumptions. Dedicated kinematic and quality selection criteria are furthermore applied to each track in order to reduce combinatorial background from low-momentum electrons and to reject the background electrons from photon conversions.

The raw  $J/\psi$  yields are obtained by counting the number of entries within the di-electron signal invariant mass range  $2.92 < m_{e^+e^-} < 3.16$  GeV/ $c^2$  after the subtraction of the background, which is evaluated from the invariant mass distribution of mixed-event electron pairs.

In order to extract the  $p_T$ -differential cross section  $d^2\sigma/dydp_T$ , the raw yields measured in five transverse momentum intervals are corrected by the product of the acceptance times efficiency ( $A \times \epsilon$ ),



**Figure 1.**  $p_T$ -differential  $J/\psi$  cross sections measured by ALICE in different rapidity regions [3]. Vertical bars stand for statistical uncertainties while open and shaded boxes show the uncorrelated and correlated systematic uncertainties, respectively.



**Figure 2.**  $J/\psi$  nuclear modification factor as a function of  $p_T$  (left) and rapidity (right). Vertical bars stand for statistical uncertainties while open and shaded boxes show the uncorrelated and correlated systematic uncertainties, respectively. Results are compared to various theoretical models including pure shadowing [4] (with EPS09 parametrization), CGC [5] and coherent energy loss [6] predictions.

which is evaluated by means of a Monte Carlo (MC) simulation taking into account a realistic description of the ALICE experimental set-up.

The measured differential  $J/\psi$  cross section is shown in Figure 1 along with similar measurements performed at forward rapidities through the  $J/\psi$  di-muon decay channel in the ALICE muon spectrometer.

Systematic uncertainties affecting the cross section measurements are mainly due to the signal extraction procedure, the di-electron reconstruction efficiency and to the choice of the  $J/\psi$   $p_T$  and  $y$  distributions used as input in the MC simulation.

The modifications affecting the  $J/\psi$  production due to the presence of the nuclear medium are evaluated by means of the nuclear modification factor  $R_{pPb}$ , which is obtained as the ratio of the differential cross sections of proton-nucleus and proton-proton collisions, scaled by the Pb mass number  $A_{Pb}$ :

$$R_{pPb} = \frac{d^2\sigma_{pPb}^{J/\psi}/dydp_T}{A_{Pb} \cdot d^2\sigma_{pp}^{J/\psi}/dydp_T}.$$

Figure 2 shows the  $p_T$ -differential (left) and  $y$ -differential (right) nuclear modification factors of inclusive  $J/\psi$  compared to predictions from various theoretical models based on calculations for  $J/\psi$  production. The main uncertainties on the measured  $R_{pPb}$  values come from the  $d^2\sigma_{pp}^{J/\psi}/dydp_T$  reference cross sections at  $\sqrt{s} = 5.02$  TeV, which were obtained by means of an interpolation/extrapolation procedure, as described in [3].

A  $J/\psi$  suppression at low  $p_T$ , which tends to vanish at high  $p_T$ , is observed from data. Calculations including cold nuclear matter effects such as shadowing and coherent energy loss reproduce within uncertainties the observed  $p_T$  dependence suppression for  $p_T > 1.5$  GeV/c. Predictions based on the Color Glass Condensate (CGC) framework appear in fair agreement with the  $p_T$ -differential data at mid-rapidity, but clearly underestimate the measurements performed in the full  $p_T$  range at forward rapidity.

## 4 Non-prompt $J/\psi$ fraction measurement

At LHC energies, a significant contribution to  $J/\psi$  production comes from non-prompt  $J/\psi$  which are produced after the weak decay of beauty-hadrons at an experimentally resolvable distance from the primary interaction vertex.

In ALICE, the non-prompt component of the  $J/\psi$  yield can be statistically separated by a maximum likelihood fit procedure which relies on the measurement of the pseudo-proper decay length  $x$  of each  $J/\psi$  candidate, which is defined as

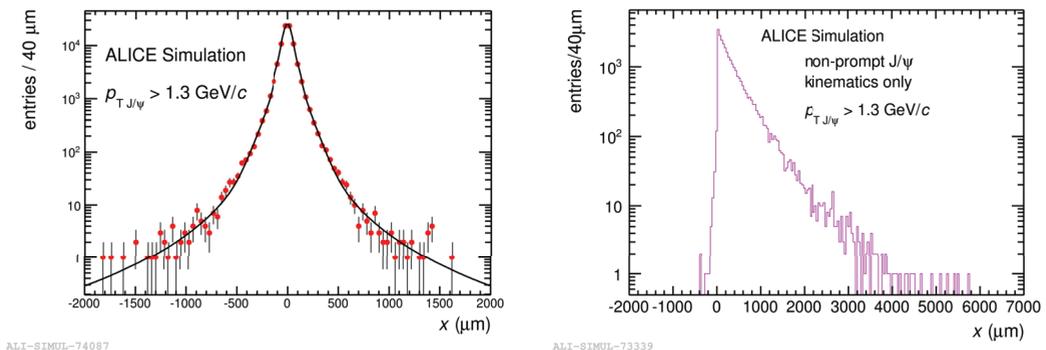
$$x = \frac{\vec{L} \cdot \vec{p}_T^{J/\psi}}{p_T^{J/\psi}} \cdot \frac{c \cdot m^{J/\psi}}{p_T^{J/\psi}}$$

with  $\vec{L}$  being the vector from the primary vertex to the  $J/\psi$  decay vertex.

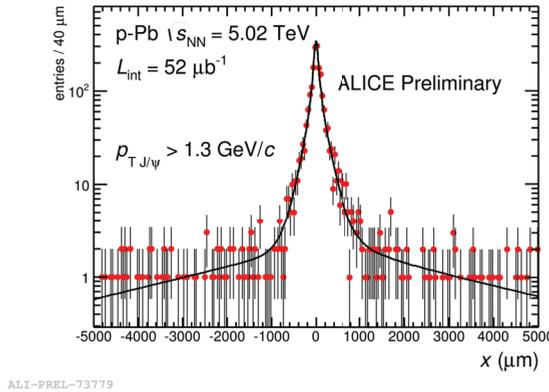
The measurement of the  $f_B$  fraction of non-prompt  $J/\psi$  is performed by means of an un-binned likelihood fit to the two-dimensional distribution of invariant mass  $m_{e^+e^-}$  and  $x$  distributions of the di-electron pairs. The likelihood probability density function (p.d.f.) is computed for each candidate as the product of different p.d.f. describing, for both the prompt and non-prompt component, the  $x$  and  $m_{e^+e^-}$  distributions of both signal and background pairs. The  $f_B$  fraction is included as a free parameter for the likelihood fit.

ALICE has published the measurement of the non-prompt  $J/\psi$  component at central rapidity as a function of  $p_T$  in pp collisions at  $\sqrt{s} = 7$  TeV [7] and as a function of  $p_T$  and multiplicity in Pb–Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV [8].

The analysis in the p–Pb system is being performed on the same data sample described for the inclusive cross section measurement.  $J/\psi$  candidates are considered down to transverse momenta as low as  $p_T \approx 1.3$  GeV/c in order to ensure a good resolution of secondary vertices as well as a better separation of the prompt and non-prompt components with respect to  $x$ . Prompt and non-prompt  $J/\psi$   $x$  distributions resulting from dedicated MC simulations are shown in Figure 3.



**Figure 3.** Pseudo-proper decay length distributions of prompt (left) and non-prompt (right)  $J/\psi$ , with  $p_T > 1.3$  GeV/c, resulting from MC simulations. Since prompt  $J/\psi$  production occurs at the primary interaction vertex, their distribution describes the effect of detector resolution on the the  $x$  observable.



**Figure 4.** Pseudo-proper decay length distribution of di-electron pairs within the  $J/\psi$  invariant mass region ( $2.4 < m_{e^+e^-} < 4.0 \text{ GeV}/c^2$ ). Solid line represents the scaled  $x$  projection of the likelihood fit function, which includes the prompt, non-prompt and background components.

The resulting maximized likelihood function, projected over the  $x$  distributions of  $J/\psi$  candidates with  $p_T > 1.3 \text{ GeV}/c$  from the p–Pb sample, is reported in Figure 4.

The raw value of  $f_B$  is extracted from the function and is corrected in order to take into account the different reconstruction efficiencies related to prompt and non-prompt  $J/\psi$  within the considered transverse momentum interval.

The analysis for the measurement of the non-prompt component is currently being finalized. The main contributions to the systematic uncertainties affecting this measurement are expected to be related to the evaluation of the functional terms involved in the fit. The result can be furthermore combined with theoretical predictions in order to extract the non-prompt  $J/\psi$  and  $b\bar{b}$ -quark pair production cross sections down to the lowest accessible transverse momenta.

## References

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