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# Non-prompt J/$\psi$ measurements at midrapidity in pp, p–Pb and Pb–Pb collisions with ALICE

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The J/$\psi$ production is sensitive to the presence of the deconfined state of quarks and gluons, quark-gluon plasma (QGP), which is expected to form in ultrarelativistic nuclear collisions. Measurements of non-prompt J/$\psi$ originating from the weak decays of b-hadrons, can provide an estimate of beauty quark production in nuclear collisions. It is observed that the production of non-prompt J/$\psi$ is modified in Pb–Pb collisions in comparison to that in pp collisions at the same energy scaled by the number of binary collisions, as quantified by nuclear modification factors ($R_{\rm AA}$). It is related to hot medium effects taking place during the QGP phase. The measurement of nuclear modification factors in p–Pb collisions is used to assess the so called Cold Nuclear Matter (CNM) effects which can further modify the production yields of non-prompt J/$\psi$ in collisions involving heavy-ions. The ALICE detector has excellent capabilities to measure J/$\psi$ in the $e^+e^-$ decay channel at midrapidity down to zero transverse momentum ($p_{\rm T}$) allowing the statistical separation of the non-prompt J/$\psi$ component for $p_{\rm T}$ down to $p_{\rm T}$ = 1 GeV/$c$.

In this contribution, ALICE midrapidity results on non-prompt J/$\psi$ production cross sections in pp collisions are presented and compared with the theoretical models. Moreover, $R_{\rm AA}$ of non-prompt J/$\psi$ at midrapidity as a function of $p_{\rm T}$ in p–Pb collisions at the center-of-mass energy per nucleon pair $\sqrt{s_{\rm NN}}$ = 5.02 TeV are presented and further compared with $R_{\rm AA}$ of non-prompt J/$\psi$ in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV. Furthermore, results are compared with theoretical predictions.

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## 1. Introduction

In nuclear collisions, heavy quarks (such as beauty and charm) are predominantly produced in the initial stages of collisions due to hard partonic scatterings, i.e. large momentum transfer processes, and their production cross section is described by perturbative QCD (pQCD). Charmonia, such as J/$\psi$ mesons, are bound states of c and $\bar{\mathrm{c}}$. The evolution of c$\bar{\mathrm{c}}$ pair into a charmonium state is a non-perturbative process and it is described by various phenomenological models [1, 2, 3]. Such mechanisms yield to the so-called "prompt" J/$\psi$ , either produced directly or from the feed-down of higher charmonium states, while those originating from the weak decays of beauty hadrons are referred to as "non-prompt" component. Non-prompt J/$\psi$ production is directly related to that of beauty quarks, as these fragment in beauty hadrons. Measurement of non-prompt J/$\psi$ component is important to assess the beauty production in all colliding systems. In pp collisions, such measurements allow to test the pQCD models effectively and also provide a reference for Pb–Pb collisions where non-prompt J/$\psi$ can be used for studying the beauty quark energy loss in the QGP. In p–Pb collisions, QGP formation is not expected due to insufficient energy density, therefore cold nuclear matter (CNM) effects on particle production, such as modification of nuclear PDFs (Parton Distribution Function), can be estimated.

Nuclear modification factors ($R_{\mathrm{AA}}$ or $R_{\mathrm{pA}}$ ) are used to quantify the effects in particle production in Pb–Pb and p–Pb collisions compared to pp which is given by

$$R_{\mathrm{AA}}(y,p_{\mathrm{T}}) = \frac{1}{\langle T_{\mathrm{AA}}\rangle}\frac{\mathrm{d}^2N_{\mathrm{AA}}/\mathrm{d}y\mathrm{d}p_{\mathrm{T}}}{\mathrm{d}^2\sigma_{\mathrm{pp}}/\mathrm{d}y\mathrm{d}p_{\mathrm{T}}} \quad \text{or} \quad R_{\mathrm{pA}}(y,p_{\mathrm{T}}) = \frac{1}{\mathrm{A}}\frac{\mathrm{d}^2\sigma_{\mathrm{pA}}/\mathrm{d}y\mathrm{d}p_{\mathrm{T}}}{\mathrm{d}^2\sigma_{\mathrm{pp}}/\mathrm{d}y\mathrm{d}p_{\mathrm{T}}} \tag{1}$$

where $\mathrm{d}^2\sigma_{\mathrm{pp}}/\mathrm{d}y\mathrm{d}p_{\mathrm{T}}$ ($\mathrm{d}^2\sigma_{\mathrm{pA}}/\mathrm{d}y\mathrm{d}p_{\mathrm{T}}$) are the double-differential cross sections in pp (p–Pb), $\mathrm{d}^2N_{\mathrm{AA}}/\mathrm{d}y\mathrm{d}p_{\mathrm{T}}$ is the double-differential yield in Pb–Pb while $\langle T_{\mathrm{AA}}\rangle$ is the average nuclear overlap function and A the atomic mass number.

## 2. Analysis and Results

The ALICE detector is capable to reconstruct J/$\psi$ mesons at midrapidity ($|y| < 0.9$) in the dielectron decay channel down to zero $p_{\mathrm{T}}$. A complete description of the ALICE detector can be found in [4]. The inner tracking system (ITS) is the detector closest to the interaction point used for the precise determination of the event vertex and tracking. Thanks to the excellent spatial resolution provided on the determination of secondary vertices, it also allows to reconstruct secondary vertex for beauty hadron decays. The time projection chamber (TPC) is the main tracking detector and it is also used for particle identification through the specific energy loss of the charged particles traversing the TPC gas in a solenoidal magnetic field of 0.5 T. The forward V0 detector is used for triggering as well as for collision centrality determination. Results presented in these proceedings are obtained analyzing the LHC Run 1 data for Pb–Pb and Run 2 data for pp and p–Pb collisions at mid-rapidity. The corresponding integrated luminosities are $\mathcal{L}_{\mathrm{int}}$: 292 $\mu$b$^{-1}$ for p–Pb, 19.04 nb$^{-1}$ for pp ($\sqrt{s}$ = 5.02 TeV) and 26.4 $\mu$b$^{-1}$ for Pb–Pb. The number of reconstructed J/$\psi$ is extracted by an invariant mass analysis of electron and positron tracks originating from J/$\psi$ decays in different $p_{\mathrm{T}}$ ranges. The non-prompt J/$\psi$ fraction ($f_{\mathrm{B}}$ ) is obtained using an unbinned log-likelihood fit on invariant mass ($m_{ee}$) and pseudoproper decay length ($x$) of dielectrons. Figure 1 shows as an example the projections of likelihood fits on $m_{ee}$ and $x$ performed in pp collisions at $\sqrt{s}$ = 13 TeV for $p_{\mathrm{T}} > 1$ GeV/$c$.

In pp collisions at $\sqrt{s}$ = 5.02 TeV, the $p_{\mathrm{T}}$-differential cross section of non-prompt J/$\psi$ has been

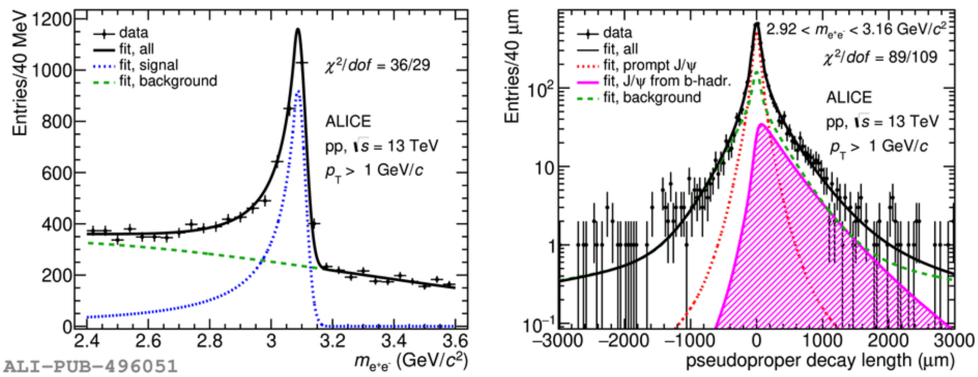


**Figure 1:** Projections of two dimensional unbinned log-likelihood fits on invariant mass (left) and pseudoproper decay length (right) of dielectron pairs performed in pp collisions at $\sqrt{s}$ = 13 TeV [5]

measured in the central rapidity region down to $p_T$ = 2 GeV/$c$ [5]. The results are compatible with measurements from CMS [6] and ATLAS [7] for $p_T$ larger than 6 GeV/$c$, as shown in figure 2. Furthermore, results are compared with pQCD calculations at fixed order with next-to leading-log re-summation (FONLL) [8] for non-prompt J/$\psi$ production and the calculations describe the data well within uncertainties.

Similarly, $f_B$ is measured in p–Pb collisions at $\sqrt{s_{NN}}$= 5.02 TeV for $p_T$ down to 1 GeV/$c$. The non-prompt J/$\psi$ $R_{pPb}$ [9] is shown as a function of $p_T$ in fig 3, and the corresponding $p_T$-integrated value is found to be 0.79 ± 0.11(stat) ± 0.13(syst). $R_{pPb}$ measurements suggest the presence of nuclear effects for non-prompt J/$\psi$ production. Results are found to be compatible with similar measurements from ATLAS experiment [7] available at higher $p_T$ (>8 GeV/$c$). In addition, results are consistent with theoretical models which include CNM effects, such as nuclear modifications of the PDFs [10].

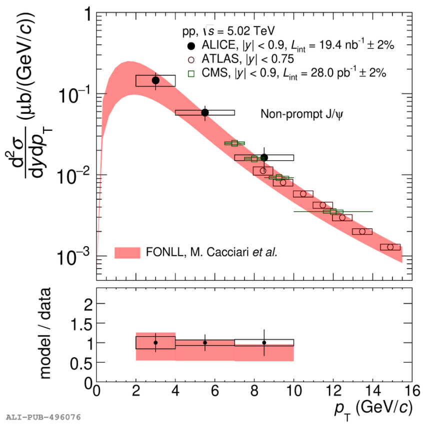


**Figure 2:** Differential cross section of non-prompt J/$\psi$ [5] as a function of $p_T$ in pp collisions at $\sqrt{s}$ = 5.02 TeV measured by ALICE, CMS[6] and ATLAS[7] in comparison to FONLL predictions [8]

$R_{AA}$ of non-prompt J/$\psi$ is measured down to $p_T$ = 1.5 GeV/$c$ in 0-50% most central Pb–Pb collisions at $\sqrt{s_{NN}}$= 2.76 TeV, in rapidity region $|y|$ < 0.8. $R_{AA}$ is found below unity, suggesting that non-prompt J/$\psi$ production is suppressed for $p_T$ > 1.5 GeV/$c$ in Pb–Pb collisions. Results show a stronger suppression for $p_T$ > 4.5 GeV/$c$ than in low $p_T$ region for 0-50% central collisions [11]. A comparison is also done with CMS measurements [12] performed within the $p_T$ region (6.5-30 GeV/$c$), in two centrality classes (0-20% and 20-100%). In addition, results are compared with theoretical models which include different effects regarding transport approaches of heavy quarks in the QGP. Most of the models predict less suppression for $p_T$ > 4.5 GeV/$c$ than the one observed in the experiment.

## 3. Conclusions and future prospects

Results on the non-prompt J/$\psi$ production performed by the ALICE Collaboration at central rapidity are presented. The obtained results of differential cross sections and nuclear modification

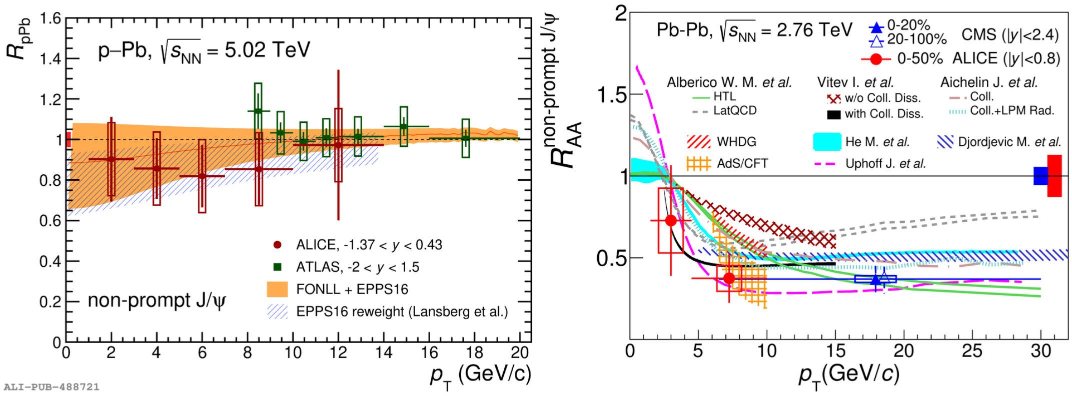


**Figure 3:** Nuclear modification factors of non-prompt J/$\psi$ as a function of $p_T$ in p–Pb collisions (left) at $\sqrt{s_{NN}}$= 5.02 TeV [9] and Pb–Pb collisions (right) at $\sqrt{s_{NN}}$= 2.76 TeV [11] in comparison to ATLAS [7] and CMS [12] results as well as with theoretical predictions.

factors are consistent with similar measurements from other LHC experiments and theoretical calculations. Non-prompt J/$\psi$ production is modified by nuclear effects in Pb–Pb as well as p–Pb collisions. In Pb–Pb, most of the transport models predict larger values of $R_{AA}$ than the ALICE measurements for $p_T > 4.5$ GeV/$c$. Ongoing analyses, based on Pb-Pb collisions at $\sqrt{s_{NN}}$= 5.02 TeV collected during the LHC Run 2, will provide more precise results. Looking forward to LHC Run 3 (2022-23), statistics will be increased by a factor 100 compared to Run 2, with improved track and vertex reconstruction resolution at midrapidity [13]. Moreover, it will be possible to separate prompt and non-prompt J/$\psi$ in the dimuon (J/$\psi \rightarrow \mu^+\mu^-$) decay channel at forward rapidity with newly installed Muon Forward Tracker ($-3.6 < \eta < -2.5$) [14] with 10 times more statistics than Run 2.

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