Non-prompt J/ψ measurements at midrapidity in pp, p–Pb & Pb–Pb collisions with ALICE at the LHC

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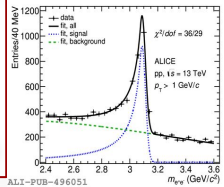
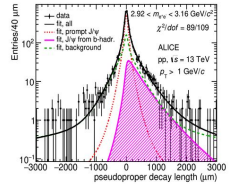
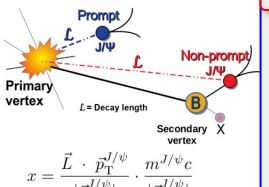






$$x = \frac{\vec{L} \cdot \vec{p}_T^{\,J/\psi}}{|\vec{p}_T^{\,J/\psi}|} \cdot \frac{m^{J/\psi} c}{|\vec{p}_T^{\,J/\psi}|}$$

1) Introduction & Motivation

- J/ψ-meson: vector *charmonium* ($c\bar{c}$) state with lowest mass [3.096 GeV/c^2]
- Origin of J/ψ:→ **Prompt J/ψ**: direct production / decay of heavier charmonium states e.g. ψ(2s)
  → **Non-prompt J/ψ**: weak-decays of b-hadrons (b → J/ψ)
  ✔ ***Opportunity to access beauty quark production***

o Non-prompt J/ψ production:

⇒ pp collisions, provides a test for pQCD models & reference for larger collision systems

⊙ Production of non-prompt J/ψ modified in Pb–Pb and p–Pb with respect to the pp collisions

⇒ Pb–Pb collisions → due to the presence of a hot quark gluon plasma (QGP)

$\tau_b \sim 0.02 < \tau_c \sim 0.07 < \tau_{(QGP)} \sim 0.1$ – 1 fm/c ⇒ heavy quarks are excellent probes to study the QGP

- ⊙ Study of in-medium parton energy loss ⇒ information about parton mass dependence; energy-density, temperature and medium size.
- ⊙ Study of sensitivity of bulk properties on quark diffusion constants.

⇒ p–Pb collisions → due to cold nuclear matter (CNM) effects (without QGP formation) *i.e. nuclear shadowing & partonic energy loss*; important for understanding the QGP production in Pb–Pb collisions → provides an evaluation of CNM effects on beauty production

o Nuclear Modification factor (R_{pA}/R_{AA}):

$$R_{AA}(p_T) = \frac{1}{\langle N_{coll}\rangle} \cdot \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T}$$

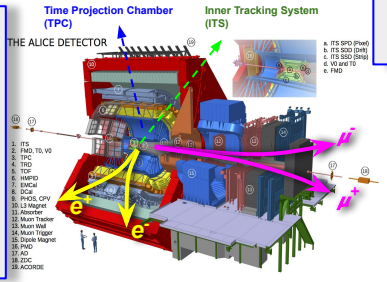
- Energy-loss / nuclear modification effects in p–Pb & Pb–Pb collisions can be quantified by measuring R_{pA} or R_{AA}

$$R_{pA}(p_T) = \frac{1}{\langle N_{coll}\rangle} \cdot \frac{dN_{pA}/dp_T}{dN_{pp}/dp_T}$$

- o $R_{pA/AA} = 1$; p–Pb or Pb–Pb behaves as scaled pp collisions
- o $R_{pA/AA} \neq 1$; Modifications observed in the non-prompt J/ψ production due to ***cold*** or ***hot nuclear matter effects*** in the nuclear collisions.

2) b→J/ψ in ALICE [1]

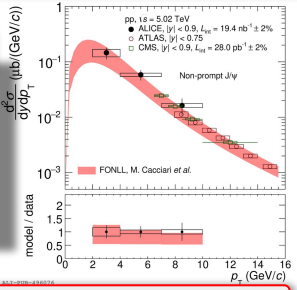
- J/ψ→e^+e^- (BR ~ 5.9%) reconstruction for transverse momentum (p_T) down to 0
- Electron identification by TPC down to low momentum (using d*E*/d*x* loss) within central barrel region **|η| < 0.9**
- Reconstruction of b → J/ψ vertices using inner layers of ITS, close to interaction point
- J/ψ → $\mu^+\mu^-$ in forward region **-4 < η < -2.5** measured, but not possible to measure non-prompt component !
  ⊙ Possible with upgraded ALICE (LHC Run 3)



- J/ψ reconstruction via invariant-mass analysis of dielectron pairs
- Larger lifetime of b-hadrons → displaced with respect to primary vertex ($c\tau \sim 500\ \mu m$)
- non-prompt J/ψ *x*-distribution distinguishable from prompt J/ψ, allow the separation on a statistical basis down to ~ 1 GeV/*c*
- Fraction (f_B) of non-prompt J/ψ → Likelihood fits on inv. mass and pseudoproper decay-length (x)[2]

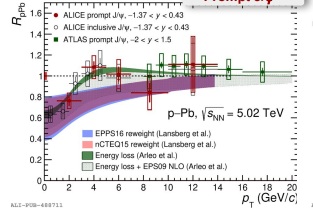
3) pp: p_T differential cross section at $\sqrt{s_{NN}}$ = 5.02 TeV

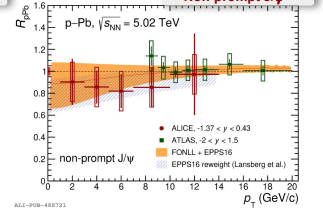
- p_T-differential production cross sections for non-prompt J/ψ measured as a function of p_T in central rapidity region down to p_T = 2 GeV/*c* [2]
- Measurements compatible with perturbative QCD (Fixed-order next to leading log: FONLL model) predictions within the uncertainties
- Consistent with CMS/ATLAS results in p_T > 6 GeV/*c* region within uncertainty bands



4) p–Pb: prompt & non-prompt J/ψ R_{pPb} at $\sqrt{s_{NN}}$ = 5.02 TeV

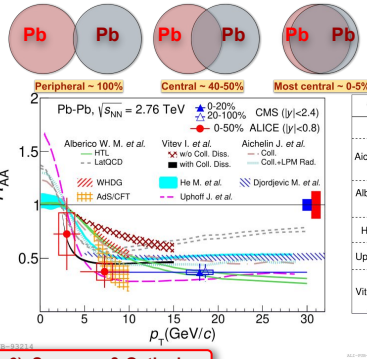
- R_{pPb} measured as function of p_T for |η| < 0.9 for non-prompt as well as prompt J/ψ
- J/ψ production is suppressed in p–Pb collisions relative to the scaled pp collisions at low-p_T
- Degree of *Suppression* compatible within uncertainties with theoretical models included CNM effects *i.e.* nuclear modifications of the PDFs, (anti)Shadowing of parton distributions etc;
- In addition, compatible with ATLAS measurements for $p_T \geq 9$ GeV/*c*
- hint of R_{pPb} [b→J/ψ] > R_{pPb} [prompt J/ψ] for p_T < 3 GeV/*c*





5) Pb–Pb: non-prompt J/ψ R_{AA} at $\sqrt{s_{NN}}$ = 2.76 TeV

- R_{AA} shown for low p_T [1.5 < p_T < 4.5 GeV/*c*] and high p_T [4.5 < p_T < 10 GeV/*c*], central collisions at $\sqrt{s_{NN}}$ = 2.76 TeV [3]
- R_{AA} < 1 ⇒ Suppression is observed in the J/ψ production yield
- Measurements are compatible with CMS results for [6.5 < p_T < 30 GeV/*c*]
- No significant dependence on the collisions centrality *i.e.* medium size
- Results are compared with various theoretical models included different effects regarding various transport approaches of heavy quarks in the QGP.
  - o Most of the models predict larger values of R_{AA} than measured values
  - o more precise measurements are needed to discriminate among different models



6) Summary & Outlook

- Measured non-prompt J/ψ cross section agrees with pQCD predictions in pp collisions.
- Non-prompt J/ψ production is modified in p–Pb & Pb–Pb collisions as compared to scaled pp collisions due to *cold or hot nuclear matter effects*, respectively.
- To discriminate between various models, more precise measurements needed → non-prompt J/ψ R_{AA} measurements at $\sqrt{s_{NN}}$ = 5.02 TeV will be important (ongoing)

Opportunities with ALICE for Run 3 (2022-23)

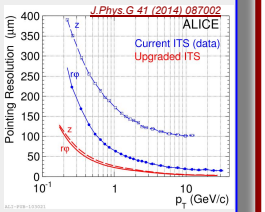
- 10-100 x increase in the integrated luminosity (10 nb^{-1}) for Pb–Pb
- Improved vertexing & pointing resolution at specially low-p_T (< 1 GeV/*c*)

o ***Upgraded ITS***: innermost layer closer to IP
⇒ J/ψ → e^+e^- in |η| < 0.9 region

o ***Muon forward tracker (MFT): (latest for Run 3)***
⇒ J/ψ → $\mu^+\mu^-$ in -3.6 < η < -2.5 region
⇒ Allows prompt/non-prompt separation J/ψ

More precise!!

COMING SOON! **charmonium measurements**



References

[1]The ALICE at LHC-CERN *JINST 3 (2008) S08002*
[2]CDF Collaboration, *Phys.Rev.D 71, 032001 (2005)*
[3]ALICE Collaboration, *arxiv/2108.02523*
[4]ALICE Collaboration, *arXiv/2105.04957*
[5]ALICE Collaboration, *JHEP 07 (2015) 051*