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Heavy flavour and quarkonium production with ALICE at the LHC

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Summary. — Heavy flavour and quarkonia are important probes of the hot and dense QCD medium formed in high energy heavy-ion collisions, through the modification of their yields and kinematical distributions. Moreover, quarkonium production in ultra-peripheral heavy ion collisions is a powerful tool to study the gluon distribution in the nuclei at low Bjorken-x. Quarkonia and heavy flavour production is measured in ALICE at both forward and mid-rapidity, by exploiting several experimental techniques. The main results obtained in Pb-Pb and pp collisions are presented.

PACS 25.75.-q – Relativistic heavy-ion collisions.
PACS 12.38.Mh – Quark-gluon plasma.
PACS 47.70.-n – Reactive and radiative flows.
PACS 14.40.Pq – Heavy quarkonia.

1. – Introduction

The ALICE [1] experiment at the Large Hadron Collider (LHC [2]) was designed to study nuclear matter in ultra-relativistic heavy-ion collisions, at energy densities much larger than that of ordinary nuclear matter. Under these conditions, finite temperature QCD calculations on the lattice (see *e.g.* [3]) predict a transition to a deconfined state of matter known as Quark-Gluon Plasma (QGP).

Heavy flavour particles (charm and beauty hadrons) are a major tool for probing the properties of QGP. They are sensitive to the medium density, through the mechanism of in-medium parton energy loss, which causes modifications of the momentum distributions in Pb-Pb collisions with respect to those in pp. Due to the colour charge and mass dependence of energy loss, the nuclear modification factor R_{AA} of charmed mesons is expected to be larger than that of mesons containing light quarks and smaller than that of beauty mesons [4]. Thermalisation of heavy quarks in the medium can be studied via the azimuthal angle distribution of heavy flavour particles in non-central collisions. Quarkonium production suppression by colour screening was one of the first signatures

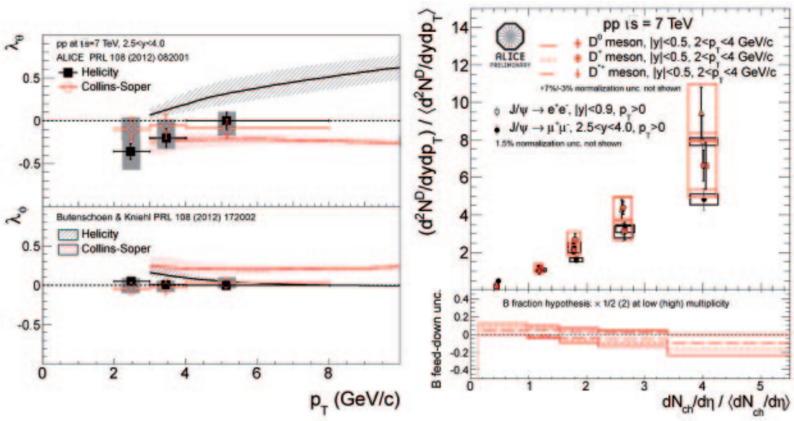

Fig. 1. – Left: J/ψ polarisation parameters λ_θ and λ_φ in helicity and Collins-Soper reference frames, as a function of the J/ψ transverse momentum, compared to NLO NRQCD calculations in the same frames [17]. Right: J/ψ and D meson yield as a function of the charged particle multiplicity density. Both the yield and the multiplicity density are normalized to their average values in minimum bias pp collisions.

proposed for the QGP [5]. Charmonium regeneration due to the recombination of initially uncorrelated c and $\bar{c}$ quarks may also become relevant at LHC energies [6]. When measured in ultra-peripheral heavy-ion collisions [7], quarkonium production is a powerful probe of the gluon distribution in the nuclei. Finally, the measurement of quarkonium and open heavy flavour production in pp collisions is also crucial to the ALICE physics program, both as normalisation for the main observables in heavy-ion analysis and as a test of perturbative QCD and production models.

Open heavy flavour particles produced at mid-rapidity ($|y| < 0.9$) are detected in ALICE by full reconstruction of D-meson decay topologies with displaced vertices, and by measuring the spectra of electrons from decays of heavy-flavour hadrons. Open heavy flavour production at forward rapidity ($2.5 < y < 4$) is studied via their semi-muonic decays. J/ψ production is measured at mid-rapidity via di-electron decays and at forward rapidity via di-muon decays; for both channels, the acceptance extends down to $p_T = 0$.

The results presented here are based on data collected in 2010 and 2011, when the LHC provided pp collisions at $\sqrt{s} = 7$ TeV and 2.76 TeV and Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV.

2. – Results

2·1. *Results in pp collisions*. – The cross sections and transverse momentum distributions of D mesons and of electrons and muons from heavy-flavour decays have been measured in pp collisions at $\sqrt{s} = 2.76$ and 7 TeV [8-12]. Perturbative QCD calculations in the FONLL [13] scheme were found to be in agreement with the measured spectra.

The J/ψ rapidity- and p_T-differential cross sections were measured at $\sqrt{s} = 2.76$ and 7 TeV [14, 15]. Non-Relativistic QCD calculations (NRQCD [16]) are in agreement with the measured spectra. The J/ψ polarisation at $\sqrt{s} = 7$ TeV was also measured for $2 < p_T < 8$ GeV (fig. 1, left): the results are compatible with weak or null polarisation, in agreement with NRQCD predictions [17] in the same p_T range.

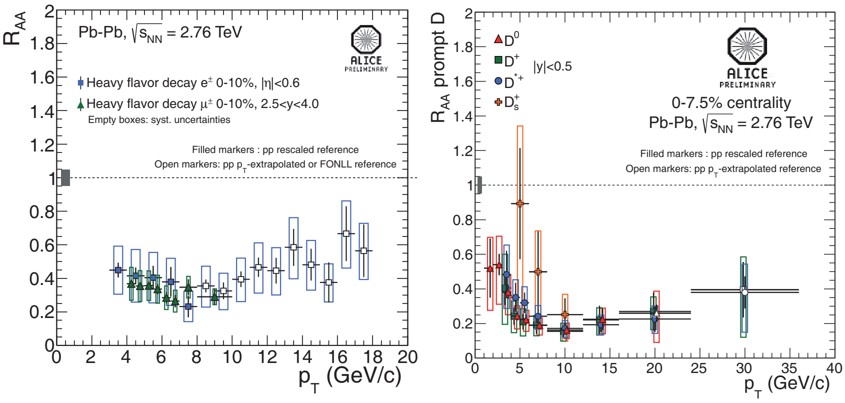

Fig. 2. – Nuclear modification factor as a function of p_{T} for central Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} =$ 2.76 TeV. Left: Heavy-flavour decay electrons at mid-rapidity and heavy-flavour decay muons at forward rapidity. Right: Prompt D^0, D^+, D^{*+} and D_s^+ mesons at central rapidity.

The D meson and J/ψ [18] yields were measured as a function of the event multiplicity (fig. 1, right): in both cases, an approximately linear increase of the yield with multiplicity was observed.

2·2. *Results in Pb-Pb collisions.* – The nuclear modification factor of electrons and muons [11] from heavy flavour decays is shown as a function of transverse momentum in fig. 2, left. A strong suppression of up to a factor of 3 is observed. The pattern and the magnitude of the suppression are very similar for mid- (electrons) and forward (muons) rapidity. The D meson R_{AA} is shown in fig. 2, right. Suppression by a factor up to 5 for $p_{\mathrm{T}} > 5\,\mathrm{GeV}/c$ is observed. The magnitude and pattern of suppression are similar for the three D meson species, and are compatible within uncertainties with that of charged hadrons, although with a hint for larger D meson R_{AA} [19]. The measured D meson suppression is larger than the one measured by the CMS collaboration for J/ψs from B meson decays [20], as expected from the mass hierarchy in energy loss models. In fig. 2, right, the D_s^+ meson R_{AA} is shown: although the measurement is not conclusive due to the large uncertainties, a hint for larger D_s^+ meson R_{AA} is observed at low to intermediate p_{T}, as expected from coalescence models [21].

The J/ψ nuclear modification factor was measured at both forward(1) and mid-rapidity. Figure 3, left, shows the J/ψ R_{AA} as a function of centrality (number of participants). The observed suppression is independent of centrality at large number of participants, an effect compatible with a scenario where a large fraction of the J/ψ yield comes from regeneration. Figure 3, right shows the J/ψ R_{AA} at forward rapidity as a function of transverse momentum: a relatively small suppression is observed at low p_{T}. Such p_{T} dependence, not observed at RHIC energies [23], is reproduced by models [24,25] assuming J/ψ regeneration.

Figure 4 shows the measured v_2 of D mesons [26] (left) and J/ψ [27] (right). The D meson v_2 is similar in magnitude to that of charged hadrons [28], suggesting that charm

(1) The preliminary results on the J/ψ R_{AA} at forward rapidity presented here, based on 2011 data, were found to be in good agreement with the published results [22], based on 2010 data.

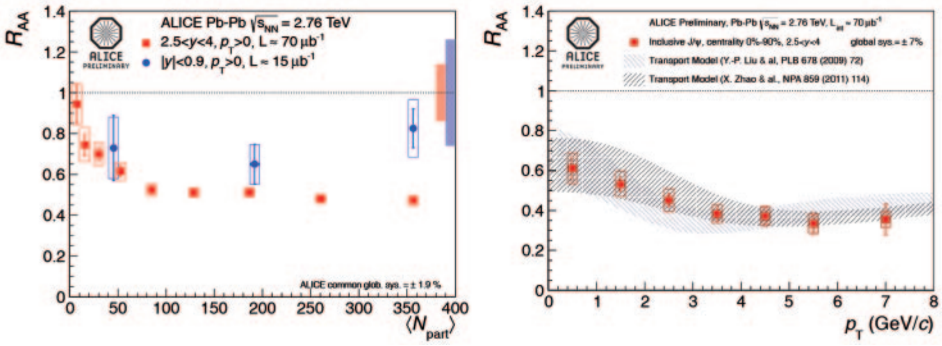

Fig. 3. – Left: J/ψ nuclear modification factor as a function of the number of participant nucleons at mid- and forward rapidity. Right: J/ψ nuclear modification factor at forward rapidity as a function of p_T, compared to the predictions of transport models [24, 25].

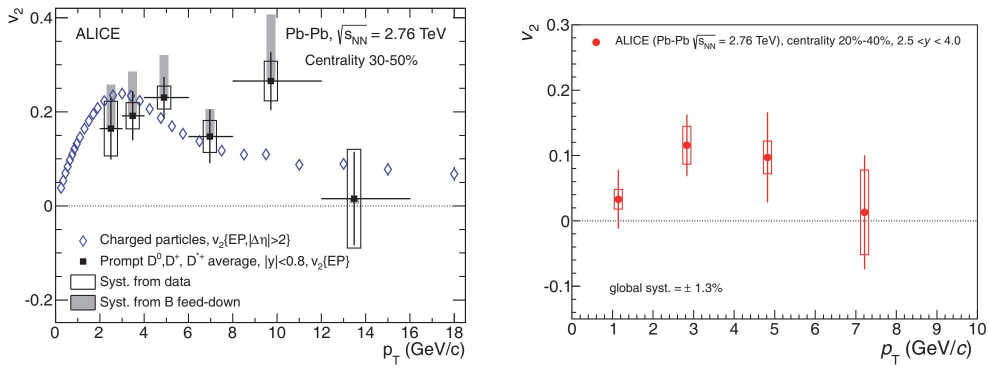

Fig. 4. – Left: Average of D^0, D^+, D^{*+} v_2 as a function of p_T, compared to charged-particle v_2 [28], measured with the event plane (EP) method. Right: J/ψ v_2 as a function of transverse momentum.

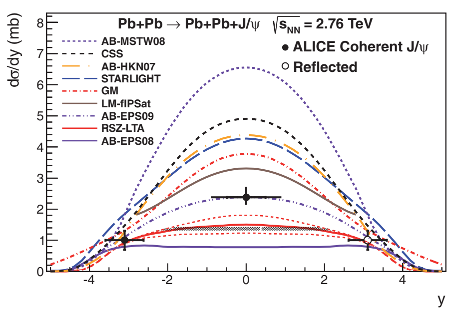

Fig. 5. – Measured differential cross section of J/ψ photoproduction in ultra-peripheral Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76\,\text{TeV}$, for coherent events, compared to models (references given in [29]).

quarks take part in the collective expansion of the medium. Indications for non-zero J/ψ v_2 are observed in the intermediate p_T region: such result suggests that a significant fraction of the observed J/ψ yield is produced via regeneration mechanisms.

The J/ψ cross section in ultra-peripheral collisions was measured at mid- [29] and forward [30] rapidity. The rapidity distribution resulting from such measurements is shown in fig. 5: it is found to be in good agreement with the prediction of a model which incorporates the nuclear gluon shadowing according to the EPS09 parameterization (AB-EPS09 [31]).

3. – Outlook

In 2013, the LHC delivered p-Pb collisions at $\sqrt{s_{NN}} = 5.02\,\text{TeV}$. The analysis of data collected is ongoing and is expected to provide information on cold nuclear matter effects at LHC energies, crucial for the interpretation of Pb-Pb results.

REFERENCES

[1] Aamodt K. *et al.* (ALICE Collaboration), *JINST*, **3** (2008) S08002.
[2] Evans L. *et al.*, *JINST*, **3** (2008) S08001.
[3] Karsch F., BNL-NT-06/2 (hep-lat/0601013).
[4] Majumder A. and Van Leeuwen M., *Prog. Part. Nucl. Phys*, **66** (2011) 41.
[5] Matsui T. and Satz H., *Phys. Lett. B*, **178** (1986) 416.
[6] Braun-Munzinger P. and Stachel J., *Phys. Lett. B*, **490** (2000) 196.
[7] Baltz A. J. *et al.*, *Phys. Rep.*, **458** (2008) 1.
[8] Abelev B. *et al.* (ALICE Collaboration), *JHEP*, **1201** (2012) 128.
[9] Abelev B. *et al.* (ALICE Collaboration), *JHEP*, **1207** (2012) 191.
[10] Abelev B. *et al.* (ALICE Collaboration), *Phys. Lett. B*, **708** (2012) 265.
[11] Abelev B. *et al.* (ALICE Collaboration), *Phys. Rev. Lett.*, **109** (2012) 112301.
[12] Abelev B. *et al.* (ALICE Collaboration), *Phys. Rev. D*, **86** (2012) 112007.
[13] Cacciari M. *et al.*, *JHEP*, **1210** (2012) 137.
[14] Aamodt K. *et al.* (ALICE Collaboration), *Phys. Lett. B*, **704** (2011) 442.
[15] Aamodt K. *et al.* (ALICE Collaboration), *Phys. Lett. B*, **718** (2012) 295.
[16] Butenschoen M. *et al.*, *Phys. Rev. D*, **84** (2011) 051501 and private communication.
[17] Butenschoen M. and Kniehl A., *Phys. Rev. Lett.*, **108** (2012) 172002.
[18] Abelev B. *et al.* (ALICE Collaboration), *Phys. Lett. B*, **712** (2012) 165.
[19] Abelev B. *et al.* (ALICE Collaboration), *JHEP*, **1209** (2012) 112.
[20] CMS Collaboration, CMS-PAS-HIN-12-014.
[21] Fries R. J. *et al.*, arXiv:1204.4442 [nucl-th].
[22] Abelev B. *et al.* (ALICE Collaboration), *Phys. Rev. Lett.*, **109** (2012) 072301.
[23] Adare A. *et al.* (PHENIX Collaboration), *Phys. Rev. C*, **84** (2011) 054912.
[24] Liu Y. *et al.*, *Phys. Lett. B*, **678** (2009) 72.
[25] Zhao X. *et al.*, *Nucl. Phys. A*, **859** (2011) 114.
[26] Abelev B. *et al.* (ALICE Collaboration), arXiv:1305.2707 [nucl-ex].
[27] Abelev B. *et al.* (ALICE Collaboration), arXiv:1303.5880 [nucl-ex].
[28] Abelev B. *et al.* (ALICE Collaboration), *Phys. Lett. B*, **719** (2013) 18.
[29] Abelev B. *et al.* (ALICE Collaboration), arXiv:1305.1467 [nucl-ex].
[30] Abelev B. *et al.* (ALICE Collaboration), *Phys. Lett. B*, **718** (2013) 1273.
[31] Adeluyi A. and Bertulani C. A., *Phys. Rev. C*, **85** (2012) 044904.