PROCEEDINGS OF SCIENCE

Quarkonium and heavy flavour production measurements in Pb-Pb collisions with the ALICE experiment at the LHC

Lizardo Valencia Palomo[∗ †]
Université de Paris-Sud 11 and Institut de Physique Nucléaire d'Orsay, France
E-mail: `valencia@ipno.in2p3.fr`

ALICE, one of the main experiments of the LHC, aims to study the Quark Gluon Plasma, a state of matter created in high-energy heavy-ion collisions where quarks and gluons behave as free particles, rather than confined into hadrons. In this proceeding I focus on the measurements carried out with the 2010 Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV and briefly describe the pp results at 7 and 2.76 TeV. Results on heavy flavours will be presented at central rapidity in the hadron and electron decay channels and at forward rapidity in the muon decay channel. Quarkonium production is measured down to $p_{\rm t} = 0$ and forward rapidity measurements in the muon decay channel are presented.

Sixth International Conference on Quarks and Nuclear Physics,
April 16-20, 2012
Ecole Polytechnique, Palaiseau, Paris

[∗]Speaker.
[†]For the ALICE collaboration

PoS(QNP2012)156

1. Introduction

Ultra-relativistic heavy-ion collisions are used to recreate in the laboratory the conditions of high energy density and temperature that would have prevailed during the first microseconds after the Big Bang. In such conditions, it is expected that a phase transition from ordinary nuclear matter to a deconfined state of quarks and gluons called Quark Gluon Plasma (QGP) occurs.

Since 1980's the quarkonium family has been proposed as a tool to characterize the QGP: color screening of the heavy quarks potential, due to the deconfined state, would lead to a suppression of quarkonium production [1]. The quarkonium states have different binding energies and these can be translated into different dissociation temperatures, something that is commonly refered as sequential dissociation [2]. Quarkonium suppression has already been observed at SPS and RHIC [3, 4]. Even though the latter has achieved higher collision energies, a similar amount of quarkonium suppression was observed at central rapidity relative to the former. To explain this energy dependence, charm quarks recombination [5] was needed at RHIC. At the LHC, a central Pb-Pb collision will create approximately ten times more $c\overline{c}$ pairs than at RHIC. Models have predicted that the J/ψ suppression in the QGP could be counterbalanced by a production from recombination of charm quarks.

As heavy flavours are produced on a very short time-scale in the initial hard-scattering processes, they experience the whole evolution of the system. For this reason, they can be used as a probe to understand the in-medium partonic energy loss in the dense QCD matter created in a central heavy-ion collision. This energy loss can occur either via inelastic (medium-induced gluon radiation) or elastic (collisional) mechanisms. The amount of energy lost by a parton in a medium is proportional to its Casimir factor implying that quarks would suffer a smaller energy loss than gluons. In addition the 'dead-cone effect', which prevents the small-angle gluon radiation from quarks in a colour charged medium, becomes more important with increasing mass [6]. The QCD energy loss model predicts a $\Delta E_{\rm Q} < \Delta E_{\rm q} < \Delta E_{\rm g}$ hierarchy. This can be experimentally verified if $R^{\pi}_{\rm AA} < R^{\rm D}_{\rm AA} < R^{\rm B}_{\rm AA}$ is measured [7], where $R_{\rm AA}$ is the Nuclear Modification Factor defined as

$$R^{\rm i}_{\rm AA} = \frac{Y^{\rm i}(\Delta p_{\rm t}\Delta y)}{\langle T^{\rm i}_{\rm AA}\rangle \times \sigma^{\rm pp}(\Delta p_{\rm t}\Delta y)}. \tag{1.1}$$

The upper index i refers to a given collision centrality class, Y is the corrected yield of the measured particle in nucleus-nucleus collisions normalized by the number of Minimum Bias (MB) events, $\langle T^{\rm i}_{\rm AA}\rangle$ the nuclear overlap function and $\sigma^{\rm pp}$ the cross section measured in pp at the same $\sqrt{s}$. Recent RHIC results have not shown significant difference between the $R_{\rm AA}$ measured for non-photonic electrons, which are dominated by heavy quark decays, and charged hadrons.

2. The ALICE experiment

A Large Ion Collider Experiment (ALICE) [10] is the LHC experiment designed to study heavy-ion collisions. It consists of a central barrel covering $|\eta| < 0.9$ embedded in a solenoidal magnet and a forward Muon Spectrometer with a $-4 < \eta < -2.5$ acceptance. Given the variety and complexity of all the subsystems located in the central barrel, only the detectors employed in these analyses will be mentioned. The two inner most layers of the Inner Tracking System (ITS), the Silicon Pixel Detector (SPD), contributes to the primary vertex reconstruction. The V0 detector consists of two plastic scintillators (V0A and V0C), located at both sides of the ITS, designed to trigger on the collisions and to reject beam-gas events. In the 2010 Pb-Pb data taking period, the MB events were defined as the events producing signals in V0A, V0C and SPD. Surrounding the ITS we find the Time Projection Chamber (TPC), the Transition Radiation Detector (TRD) and the Time of Flight (TOF). The Muon Spectrometer is composed of ten tracking chambers behind a hadron absorber. Two of these tracking chambers are embedded in a magnetic dipole which bends charged particles allowing to extract the sign of their electric charge and their momentum. The last components are four trigger chambers located after an iron wall that absorbs hadrons that punch through the front absorber, secondary hadrons and low momentum muons.

3. Analysis

The Pb-Pb analysis was performed over an integrated luminosity of 2.9 μb^{-1}. The centrality of the collisions was estimated using a Glauber based Monte Carlo fit to the V0 amplitude [11].

The J/ψ raw yield was obtained from the distribution of opposite-sign tracks that survived the track selection. The inclusive J/ψ cross section in pp used for normalization was measured by the ALICE experiment in a special run at $\sqrt{s} = 2.76$ TeV at the beginning of 2011 (Fig. 1 left) [12].

Heavy flavours are studied in the charm hadronic decays ($\mathrm{D}^0 \rightarrow \mathrm{K}\pi$, $\mathrm{D}^+ \rightarrow \mathrm{K}\pi\pi$ and $\mathrm{D}^{*+} \rightarrow \mathrm{D}^0\pi$ at $|y| < 0.5$) and in the leptonic decays (inclusive $\mathrm{D/B} \rightarrow \mathrm{e} + X$ at $|y| < 0.8$ and $\mathrm{D/B} \rightarrow \mu + X$ at $2.5 < y < 4$).

D mesons are reconstructed exploiting their displaced vertex topology. In order to reduce the high combinatorial background, the Particle IDentification (PID) from TOF information and the dE/dx measured by the TPC is used. D mesons raw yields are then corrected for B decays contributions ($\sim 10-15\%$) using FONLL calculations to obtain the production yields for primaries.

Open charm production can also be addressed via single electron measurements, based on electron identifications provided by TPC and TOF both in pp and Pb-Pb collisions. In the former case the TRD is also employed. The inclusive single electrons contribution from heavy flavours was obtained by subtracting, from the overall electron spectrum, a cocktail of background electron sources: π^0, η, ρ, ϕ. At low p_{t}, in central collisions a residual background remains after the previous subtraction, most probably from thermal photons not included in the cocktail. In pp collisions electrons with large impact parameter can be selected in order to extract the direct contribution from B's. In the single electron analysis the large systematic uncertainties in the single electron results are mainly due to the PID, cocktail and pp reference.

For the single muons analysis at forward rapidity, the main sources of background are: muons from light hadron decays, muons from light hadrons produced in the front absorber and hadrons that punch-through the front absorber. The analysis in Pb-Pb has been restricted to $p_{\mathrm{t}} > 4$ GeV/c because according to HIJING, heavy flavour decays dominate in this p_{t} range.

Due to the limited heavy flavour statistics collected in the $\sqrt{s} = 2.76$ TeV pp collisions, the reference for these are obtained at 7 TeV (center and right panels of Fig. 1) [13, 14]. Depending on the analysis, these results correspond to an integrated luminosity of 2.6-16.5 nb^{-1}. The cross sections obtained are scaled to 2.76 TeV using a $\sqrt{s}$-scaling assuming that the factorization and renormalization values and that the c and b quark masses do not vary with $\sqrt{s}$. The scaling factor

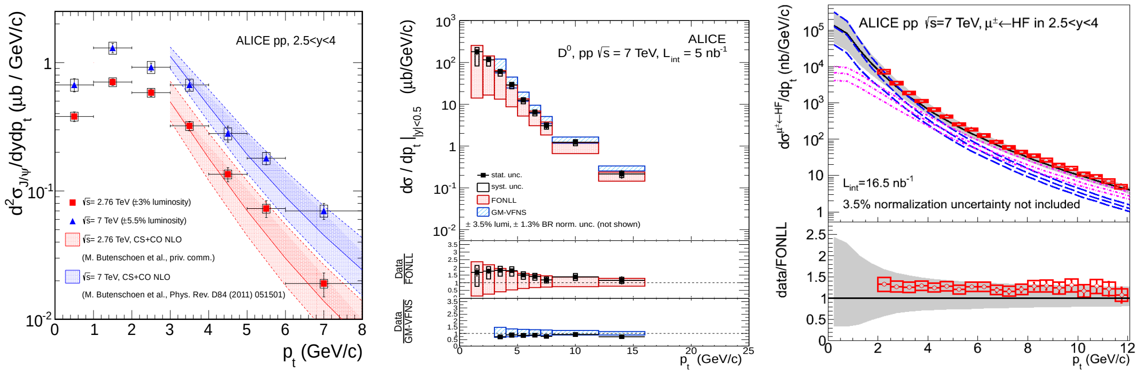

Figure 1: *Left:* Inclusive $J/\psi \to \mu^+\mu^-$ cross section at $\sqrt{s} = 2.76$ and 7 TeV in red and blue points respectively, compared to NLO NRQCD predictions. *Center:* Differential cross section of $D^0 \to K\pi$ measured at $\sqrt{s} = 7$ TeV showing a good agreement with pQCD calculations. *Right:* Differential cross section of heavy flavours in their semileptonic decay to muons at $\sqrt{s} = 7$ TeV and compared to pQCD.

was then taken as the ratio of the cross section from FONLL pQCD calculation at 2.76 and 7 TeV [15]. In the specific case of D mesons the procedure was validated by scaling the ALICE data to the Tevatron energy ($\sqrt{s} = 1.96$ TeV) in order to compare with CDF results [16]. For D^0 and D^+ the cross sections were also measured at $\sqrt{s} = 2.76$ TeV but with large uncertainties and were found to be compatible with the 7 TeV scaled results.

4. Results

Figure 2 shows the inclusive J/ψ R_{AA} as a function of the number of participant nucleons indicating a clear suppression [17]. Our results show no significant centrality dependence and $R_{AA}^{ALICE} \approx 3 \times R_{AA}^{PHENIX}$ for $N_{part} > 180$ at forward rapidity. Three theoretical predictions describe the centrality dependence of the data. In the Statistical Hadronization Model the charmonium production occurs at the phase boundary by statistical hadronization of charm quarks considering 100% of J/ψ regeneration [18]. The Transport Models differ in the rate equation of the J/ψ dissociation and regeneration, in both models 50% of the measured yield in central collisions is due to regeneration [19, 20], while the remaining comes from the initial production.

Prompt D mesons R_{AA} is presented as a function of N_{part} (left) and p_t (right) in Fig. 3 [21]. In the first one the suppression increases as a function of the collision centrality as expected in case of parton energy loss in the medium and it is similar for the three D meson species. In the second one the D mesons R_{AA} is compatible with that of charged hadrons (non-prompt J/ψ, most of which comes from decay of B mesons) within errors, with a possible hint of a smaller (larger) suppression which may be due to the predicted energy loss hierarchy, but more precise measurements are needed to reduce the uncertainties.

Finally Fig. 4 shows the R_{AA} for single electron (left) and single muon (right) as a function of the collision centrality after background subtraction. Although the large systematic uncertainties, the Nuclear Modification Factor of single electrons shows a centrality dependent behaviour with a suppression factor of about 2 in the 10% most central collisions. A similar trend is present in the

R_{AA} for single muons but with a stronger suppression with increasing centrality, reaching a factor of around 3-4 in the same 10% most central collisions.

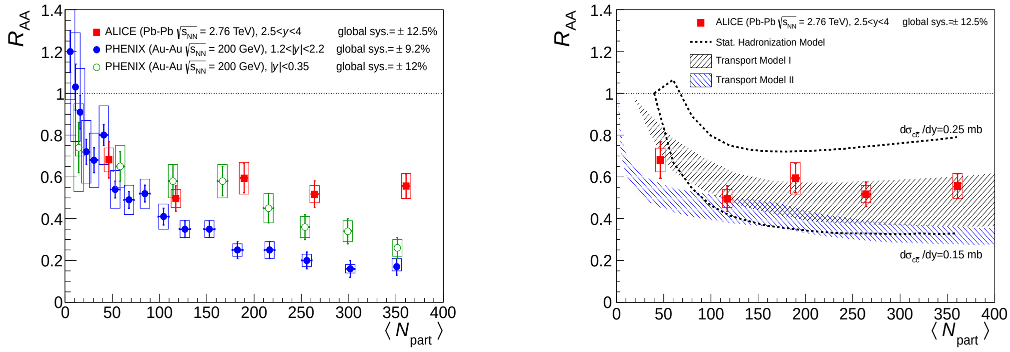

Figure 2: *Left:* J/ψ R_{AA} measured by the ALICE experiment compared to PHENIX results as a function of the number of participant. *Right:* comparison with theoretical models.

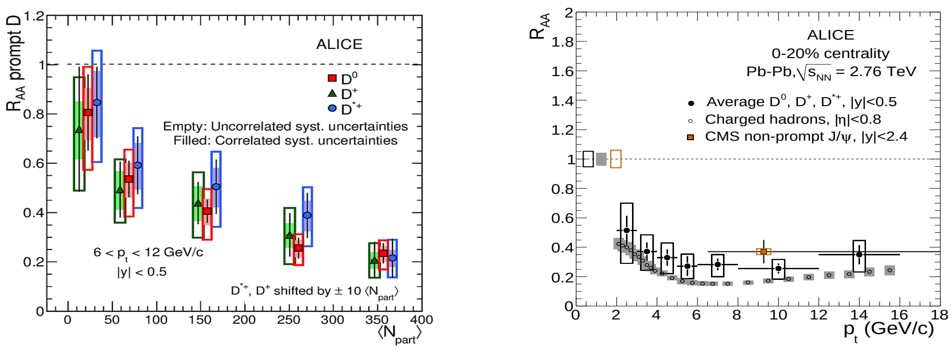

Figure 3: *Left:* R_{AA} vs N_{part} for prompt D^0, D^+ and D^{*+}. *Right:* average D mesons R_{AA} compared to charged hadrons and non-prompt J/ψ measured by CMS as a function of p_t in the most central collisions.

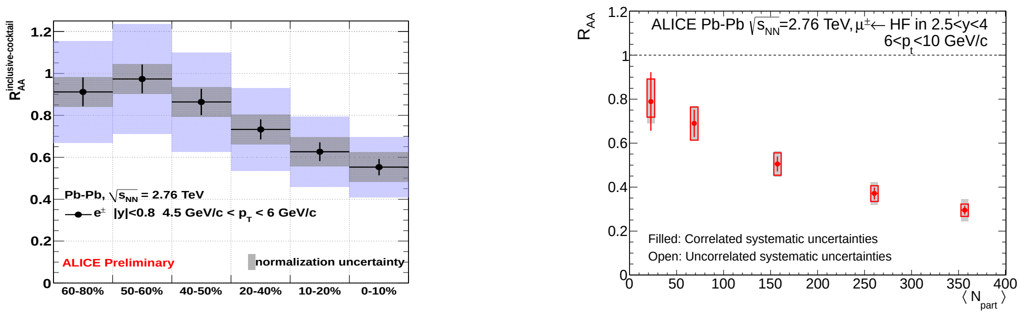

Figure 4: *Left:* Background subtracted R_{AA} for single electrons. *Right:* R_{AA} of muons coming from heavy flavours after background subtraction.

5. Conclusions

Open and hidden heavy flavour results from pp collisions at $\sqrt{s} = 2.76$ and 7 TeV and from the first Pb-Pb run at 2.76 TeV were presented. The pp cross sections were used to normalize the yields obtained in Pb-Pb.

The inclusive J/ψ production shows a clear suppression with a flat centrality dependent $R_{\rm AA}$. The Nuclear Modification Factor is larger than PHENIX measurements in central collisions, specially at forward rapidity and is well described by regeneration models.

For open heavy flavours, the $R_{\rm AA}$ for hadron and electron decay channels in the mid-rapidity and that for the muon decay in the forward rapidity exhibit a clear centrality dependent suppression, indicating a heavy flavour suppression. There are possible hints for a difference between charm and gluon energy loss, but more accurate measurements are needed to disentangle the energy loss mechanisms between heavy quarks.

References

[1] T. Matsui and H. Satz, Phys. Lett. B 178 416 (1986).

[2] F. Karsch et al., Phys.Lett. B 637 (2006).

[3] B. Alessandro et al., Eur. Phys. J. C39 (2005).

[4] A. Adare et al., Phys. Rev. Lett. 98 (2007).

[5] A. Andronic et al., Phys. Lett. B 652 (2007).

[6] Y. L. and Dokshitzer and D. E. Kharzeev, Phys. Lett. B 519 199 (2001).

[7] N. Armesto et al, Phys. Rev. D 71 054027 (2005).

[8] STAR Collaboration , Phys. Rev. Lett. 98 192301 (2007).

[9] PHENIX Collaboration, Phys. Rev. Lett. 98 172301 (2007).

[10] ALICE Collaboration, JINST 3 S08002 (2008).

[11] ALICE Collaboration, Phys. Rev. Lett. 106 032301 (2012).

[12] ALICE Collaboration, arXiv:1203.3641.

[13] ALICE Collaboration, JHEP 01 128 (2012).

[14] ALICE Collaboration, Phys. Lett. B 708 265 (2012).

[15] M. Cacciari et al., arXiv:1205.6344.

[16] CDF Collaboration, Phys. Rev. Lett 91 (2003).

[17] ALICE Collaboration, arXiv:1202.1383.

[18] A. Andronic et al, J.Phys. G 38 (2011).

[19] X. Zhao and R. Rapp, Nucl. Phys. A 859 (2011).

[20] Y.-P. Liu et al, Phys. Lett. B 678 (2009).

[21] ALICE Collaboration, arXiv:1203.2160.

[22] ALICE Collaboration, arXiv:1205.6443.

PoS(QNP2012)156