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Heavy flavour in ALICE

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Open heavy flavours and heavy quarkonium states are expected to provide essential information on the properties of the strongly interacting system formed in the early stages of heavy-ion collisions at very high energy density. Such probes are especially promising at LHC energies where heavy quarks (both c and b) are copiously produced. The ALICE detector shall measure the production of open heavy flavours and heavy quarkonium states in both proton-proton and heavy-ion collisions at the LHC. The expected performances of ALICE for heavy flavour physics is discussed based on the results of simulation studies on a selection of benchmark channels.

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1. Introduction

The Large Hadron Collider (LHC) will deliver ion beams at ultra-relativistic energies and produce proton-proton, proton-nucleus and nucleus-nucleus collisions with a center-of-mass energy per nucleon-nucleon collision up to $\sqrt{s} = 14$ TeV and $\sqrt{s} = 5.5$ TeV for p-p and Pb-Pb systems respectively. ALICE [1, 2] is the dedicated heavy-ion experiment at the LHC. Its main physics goal is to study the properties of the strongly-interacting matter in the conditions of high energy density (> 10 GeV/fm^3) and high temperature (> 0.6 GeV) expected to be reached in central Pb-Pb collisions. Under these conditions, according to lattice QCD calculations, the quarks should be no longer confined into hadrons and a deconfined Quark-Gluon Plasma (QGP) should be formed.

Heavy quarks are expected to be produced in the primary partonic scatterings and to coexist with the surrounding medium due to their long life-time. Therefore, the measurement of open heavy flavours and heavy quarkonium states is expected to provide essential information on the properties of the strongly interacting system formed in the early stages of heavy-ion collisions [1, 3]. In particular, the nuclear modification factor of open heavy flavours could provide stringent constraints on the parton energy loss models. Believed to be at the origin of the jet quenching phenomena observed in Au-Au collisions at the Relativistic Heavy Ion Collider (RHIC) [4], energy loss is expected to depend on the properties of the medium (gluon density and volume), but also on the properties of the probe (colour charge and mass). The total open charm (open beauty) cross-sections will also provide a natural normalization for the charmonia (bottomonia) production. According to the colour-screening or gluon dissociation models, measuring the in-medium dissociation probability of the different quarkonium states is expected to provide an estimate of the initial temperature of the medium. Indeed, the J/ψ suppression has been proposed in 1985 as one of the most powerful probes of the QGP [5].

2. Heavy flavour production at LHC energies

The next-to-leading order (NLO) perturbative QCD (pQCD) calculations [6] predict that heavy quarks will be abundantly produced at LHC energies predominantly via gluon-gluon fusion. The expected yields of $Q\overline{Q}$ pairs per event in 4π in p-p collisions at $\sqrt{s} = 14$ TeV are reported in Table 1 [8]. In the table we also report the expected yields in p-Pb and Pb-Pb collisions, at $\sqrt{s} = 8.8$ TeV and $\sqrt{s} = 5.5$ TeV respectively, obtained by scaling with the mean number of binary nucleon-nucleon collisions (N_{coll}) and accounting for the nuclear modification of the parton distribution functions (PDFs) with the EKS98 parametrization [7]. These values have large uncertainties, of about a factor 2-3, estimated by varying the values of the calculation parameters. The measurements of the heavy flavour production cross-section in p-p and p-nucleus collisions will not only serve as a reference for the study of the in-medium effects in nucleus-nucleus collisions. They are of great interest *per se*, to constraint both the pQCD predictions and the non-perturbative models of quarkonia formation in a new energy domain, and to probe the gluon distribution functions and their nuclear modification in the unexplored small Bjorken-x region ($x \in [10^{-6}, 10^{-3}]$) accessible within the ALICE acceptance [1].

Due to the large yield of $c\overline{c}$ pairs expected in nucleus-nucleus collisions, and according to kinetic recombination and statistical hadronization models, secondary charmonium production could

Table 1: Expected $Q\overline{Q}$ yields per event in different colliding systems at LHC energies [8], obtained from NLO pQCD calculations. For p-Pb and Pb-Pb, N_{coll} scaling is assumed and modification of the PDFs is taken into account with the EKS98 parametrization.

colliding system	$\sqrt{s_{NN}}$	centrality	$c\overline{c}$ pairs	$b\overline{b}$ pairs
p-p	14 TeV	-	0.16	0.0072
p-Pb	8.8 TeV	min. bias	0.78	0.029
Pb-Pb	5.5 TeV	0-5% σ^{inel}	115	4.6

occur as a consequence of QGP formation, which might result in an enhancement instead of a suppression of charmonium states. Measuring the J/ψ production at LHC will help us to disentangle between the different suppression/regeneration scenarii. In addition, the much higher energy offers the possibility of measuring with 'significant' statistics the bottomonium yields thus providing an additional probe for QGP studies. We must note that the large beauty cross-section will also lead to an important production of secondary J/ψ (ψ') from B decays, with an expected yield of about 22% (39%) in absence of medium-induced effects [9], which has to be measured and taken into account in the analyses.

3. Heavy flavour detection in ALICE

The design of the ALICE apparatus [1, 2] will allow the detection of open heavy flavours and quarkonia in the high multiplicity environment of central Pb-Pb collisions at LHC energies, with a full azimuthal coverage and a broad p_t acceptance. At central rapidity ($|\eta| < 0.9$), the tracking and particle identification capabilities of the Inner Tracking System (ITS), Time Projection Chamber (TPC), Transition Radiation Detector (TRD) and Time Of Flight (TOF) detectors will allow to measure heavy flavours in both electron and hadron channels, while at large rapidities ($-4 < |\eta| < -2.4$) they will be measured in the muon channels by the muon spectrometer. In the following, we present a selection of the main analyses in preparation.

3.1 Quarkonia in the di-electronic and di-muonic decay channels

ALICE can detect quarkonia down to $p_t = 0$ at both central and forward rapidity, with an invariant-mass resolution for charmonia (bottomonia) expected of to be around 30 (90) MeV/c^2 in the di-electron channel, and around 70 (100) MeV/c^2 in the di-muon channel, sufficient to resolve the individual Υ states [3]. The high-p_t reach in a Pb-Pb run of 1 month at nominal luminosity is expected to be 10 (20) GeV/c for the J/ψ in the di-electron (di-muon) channel. The corresponding yield in the 10 (5) % most central collisions, in absence of medium-induced effects, are of the order of 12×10^4 (13×10^4) for the J/ψ with a significance of 254 (150), and about 900 (1300) for the Υ with a significance of 21 (29) [3, 10]. In addition, about 3×10^6 J/ψ and 3×10^4 Υ will be collected in 1 year of p-p data taking at a luminosity of 3×10^{30} cm^{-2}s^{-1} in the di-muon channel, with a significance of 1610 and 157 respectively [11]. Simulation studies are in progress to measure the fraction of secondary J/ψ from B decays by using the excellent vertexing capabilities of the ITS [3]. This analysis should also provide a measurement of the beauty p_t-differential cross-section.

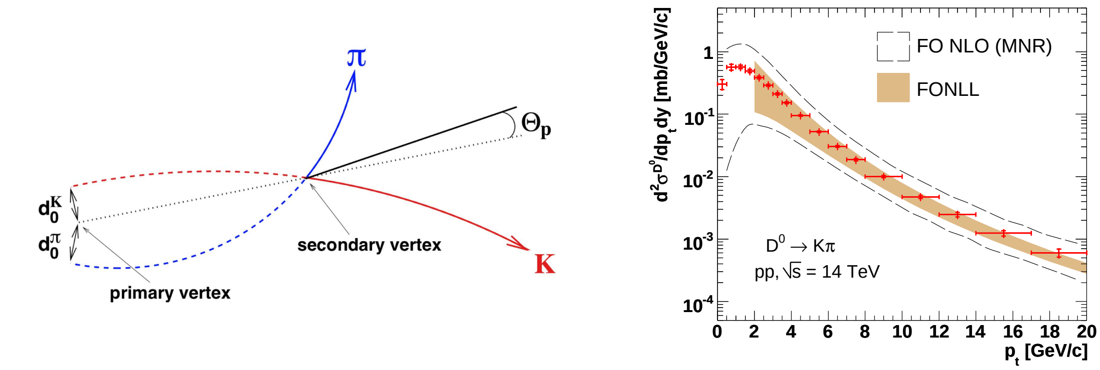

Figure 1: Left: schematic representation of the $D^0 \to K^-\pi^+$ decay. **Right:** sensitivity on the differential D^0-meson production cross-section with 10^9 p-p minimum-bias events, compared to pQCD predictions from MNR [6] and FONLL [12] calculations. Statistical errors (inner bars) and quadratic sum of statistical + p_t-dependent systematic errors (outer bars) are shown, while a normalization error of 5% is not shown.

3.2 Open charm in the hadronic decay channels

The most promising channel for open charm detection is the $D^0 \to K^-\pi^+$ decay ($c\tau \simeq 123$ μm, branching ratio $\simeq 3.8\%$) whose topology is shown in Fig. 1. The large combinatorial background of the underlying event is reduced by applying cuts on the secondary vertex quality, on the distance between primary vertex and secondary tracks (d_0^K, d_0^π) and on the pointing angle (Θ_p) of the reconstructed mother particle. The raw signal yield is then extracted from invariant-mass analysis and corrected for selection and reconstruction efficiencies and detector acceptance. The differential D^0 production cross-section can be measured down to $p_t \simeq 1$ GeV/c in Pb-Pb collisions and down to $p_t \simeq 0.5$ GeV/c in p-p and p-Pb collisions [3]. The expected sensitivity after 1 year of data taking in p-p collisions is presented Fig. 1 and compared to pQCD predictions with their uncertainties. Similar analysis can also be performed in the $D^+ \to K^-\pi^+\pi^+$ decay channel ($c\tau \simeq 312$ μm, branching ratio $\simeq 9.2\%$) [13] and studies of D_s and Λ_c are in progress.

3.3 Open beauty in the electronic and muonic decay channels

The B-hadron inclusive differential cross-section can be extracted from the single lepton p_t distribution using a method developed by the UA1 collaboration [14] and further used by the CDF and D0 collaborations at Tevatron. In the ALICE central barrel, the precise vertexing allows to isolate the electrons from B-hadron decay by means of combined cuts on the electrons' p_t and their distance of closest approach to the primary vertex. The residual contamination of electrons from D-hadron decay can be evaluated and subtracted based on Monte Carlo simulations tuned to reproduce the measured charmed meson production. At large rapidities, the muon spectrometer does not provide precise vertexing and only a low-p_t cut is applied to the reconstructed muons to remove the main background contribution from $\pi^\pm$ and $K^\pm$ decays. After subtraction of the residual background, a combined fit of the single muon p_t distribution allows to extract simultaneously the charm and beauty contributions. Fig. 2 shows the expected sensitivity of this measurement in p-p collisions in both single electron and single muon channels [15, 16]. Similar performances are expected in central Pb-Pb collisions [3]. Beauty production can also be measured in the $B \to D(\to \mu^-)\mu^+$ and $B\overline{B} \to \mu^+\mu^-$ channels by analysing the unlike-sign di-muon invariant-mass distribution [3]. Other possibilities like 3-muon analysis are under study.

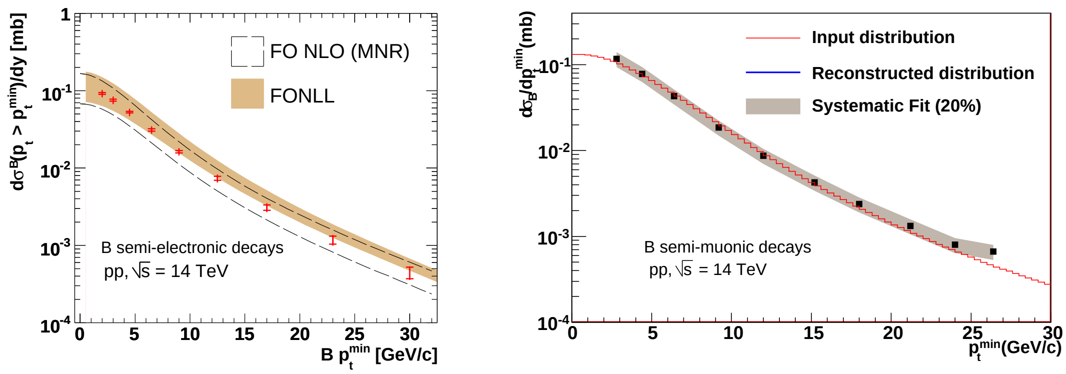

Figure 2: Left: inclusive differential B-meson production cross-section extracted from 10^9 p-p minimum-bias events in the single electron channel, compared to MNR [6] and FONLL [12] pQCD predictions. Errors bars are defined as in Fig. 1. **Right:** inclusive differential B-meson production cross-section in p-p collisions (assuming $L = 10^{30}$ cm^{-2}s^{-1} and $t = 10^6$ s) in the single muon channel. Statistical errors are negligible. The shaded area shows systematic errors. In both plots, a normalization error of 5% is not shown.

4. Conclusions

At LHC energies, heavy flavours are a very promising tool to study the properties of the strongly-interacting medium formed in heavy-ion collisions and to benchmark with precision QCD calculations in p-p collisions. The excellent traking, vertexing and particle identification capabilities of the ALICE experiment will allow to fully explore this rich phenomenology by measuring heavy flavour production in a large variety of hadronic and leptonic channels.

References

[1] ALICE collaboration, ALICE Physics Performance Report Vol I, J. Phys. G **30** (2004) 1517.

[2] ALICE collaboration, The ALICE experiment at the CERN LHC, JINST **3** (2008) S08002.

[3] ALICE collaboration, ALICE Physics Performance Report Vol II, J. Phys. G **32** (2006) 1295.

[4] M.J. Tannenbaum, Int. J. Mod. Phys. E **17** (2008) 771, arXiv:nucl-ex/0702028.

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

[6] M.L. Mangano, P. Nason, G. Ridolfi, Nucl. Phys. B **373**, 295 (1992).

[7] K.J. Eskola, V.J. Kolhinen, C.A. Salgado, Eur. Phys. J. C **9**, 61 (1999).

[8] N. Carrer and A. Dainese, ALICE Internal Note, ALICE-INT-2003-019 (2003).

[9] M. Bedjidian *et al.*, CERN Yellow Report (2003), arXiv:hep-ph/0311048.

[10] S. Grigoryan, A. De Falco, ALICE Internal Note, ALICE-INT-2008-016 (2008).

[11] D. Stocco, E. Vercellin, R. Guernane, ALICE Internal Note, ALICE-INT-2006-029 (2006).

[12] M. Cacciari, S. Frixione, M.L. Mangano, P. Nason, G. Ridolfi, JHEP **0407**, 033 (2004).

[13] E. Bruna for the ALICE collaboration, Int. J. Mod. Phys. E **16**, 2097 (2007).

[14] C. Albajar *et al.* [UA1 Collaboration], Phys. Lett. B **213** (1988) 405, Phys. Lett. B **256** (1991) 121 [Erratum-ibid. B **262** (1991) 497].

[15] F. Antinori *et al.*, ALICE Internal Note, ALICE-INT-2006-015 (2006).

[16] L. Manceau for the ALICE collaboration, proceedings of Hot Quarks 08, to appear in Eur. Phys. J. C.