Quarkonium and heavy flavour physics with the ALICE Muon Spectrometer at the LHC

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ALICE, the dedicated heavy ion experiment at the LHC, has also an important physics program with proton-proton collisions. The main purpose of the experiment is to investigate the properties of strongly interacting matter at extreme energy density where the formation of the Quark Gluon Plasma is expected. In this regard, quarkonia and heavy flavours are especially relevant. They will be measured in ALICE through the electron channel and the hadron channel in the central barrel as well as through the muon channel in the forward muon spectrometer. In this contribution, the ALICE muon spectrometer is presented and selected heavy flavour physics topics are reviewed. Special attention is given to the capabilities of the apparatus for the first measurements performed with p-p collisions at $\sqrt{s} = 7$ TeV.

1. INTRODUCTION

The LHC (Large Hadron Collider) is designed to collide protons at $\sqrt{s} = 14$ TeV and lead ions at $\sqrt{s_{NN}} = 5.5$ TeV. This energy which exceeds the one reached at RHIC for Au + Au collisions by about a factor 30 will provide new insights for the study of the properties of strongly interacting matter under extreme thermodynamical conditions [1]. One of the most important aspects of this new energy range is the abundant production of heavy quarks (charm and beauty) which will allow to investigate their production mechanisms, propagation and hadronization in the hot and dense nuclear medium. Moreover, the study of quarkonia is of particular interest since their suppression by color screening [2] in nucleus-nucleus collisions was first proposed as one of the manifestations of the Quark Gluon Plasma (QGP) formation. The successful achievement of the heavy ion program requires also the study of proton-proton, proton-nucleus and light nucleus-nucleus systems. Besides providing the necessary baseline for the study of medium effects in Pb-Pb collisions, p-p collisions are of great interest as an important test of QCD in a new kinematic region of unprecedented small Bjorken-x values.

ALICE (A large Ion Collider Experiment) [3], the experiment designed for and devoted to heavy ion physics at the LHC, also measures p-p collisions. The LHC delivered its first proton beams in November 2009 and will collide Pb ions at $\sqrt{s_{NN}} = 2.75$ TeV at end of 2010. p-p collisions have been measured at $\sqrt{s} = 0.9$ TeV, $\sqrt{s} = 2.36$ TeV and are presently collected at $\sqrt{s} = 7$ TeV.

2. ALICE MUON SPECTROMETER

The ALICE apparatus [3] consists of a central barrel ($|\eta| < 0.9$) placed in the L3 magnet, a forward muon spectrometer and other sub-detectors of smaller acceptance.

The main aim of the ALICE muon spectrometer [3] is the study of quarkonium production and heavy flavour production in the (di)muon channel. In addition, the production of weakly interacting probes (Z^0 and $W^{\pm}$ bosons) and low mass resonances (ρ, ω, ϕ) is also investigated. The main design criteria are driven by the requirements that the detector should operate in the high multiplicity environment of central Pb-Pb collisions at $\sqrt{s_{NN}} = 5.5$ TeV and should reach a mass resolution of 100 MeV/c^2 in the Υ mass region in order to resolve the $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$ states. The muon spectrometer covers the polar angular range $171^\circ < \theta < 178^\circ$

($-4.0 < \eta < -2.5$). It is composed of a passive front absorber, a beam shield, a 3 T·m dipole magnet, five stations of high granularity tracking chambers, each based on two planes of Cathod Pad Chambers. Finally, two stations of trigger chambers equipped with two planes of Resistive Plate Chambers each, are located downstream of the tracking system, after a 1.2 m thick iron wall.

3. PERFORMANCE STUDIES

3.1. Heavy flavour production

At the LHC, hard processes contribute significantly to the total cross section. The $c\bar{c}$ and $b\bar{b}$ yields, obtained from perturbative QCD (pQCD) calculations at next-to-leading-order (NLO) and assumed as the baseline for ALICE simulation studies, are 0.16 and 0.007 for p-p collisions at $\sqrt{s} = 14$ TeV, respectively [4] (they are lower by about 40% and 55% at 7 TeV, respectively). The predictions vary within a factor 2-3 [5], depending on free parameters of NLO pQCD calculations. On the other hand, the uncertainty on the ratio of heavy quark cross-section at 14 TeV to that at 5.5 TeV is only about 10% [4]. Therefore a high precision measurement of charm and beauty cross sections at $\sqrt{s} = 14$ TeV is essential. In addition, the study of beauty production is mandatory to estimate the contribution of secondary J/ψ (from B decay) to the total J/ψ yield. Finally, the large charm and beauty cross sections allow to investigate new observables [6,7] for the study of heavy quark quenching. Indeed, the ratio of the nuclear modification factor of D (B)-hadrons to that of light hadrons allows to probe the color charge (mass) dependence of parton energy loss and the ratio of beauty to charm nuclear modification factor allows to isolate the mass dependence of the energy loss. Furthermore, $W^{\pm}$ can provide a baseline to observe medium-induced effect on heavy quark production [7].

The performance of the ALICE muon spectrometer for the measurement, via single muons, of the B (D)-hadron inclusive production differential cross section has been evaluated in p-p collisions at $\sqrt{s} = 14$ TeV [8,9] by means of full simulations. The principle is first to estimate the muon yield from heavy flavour decay from

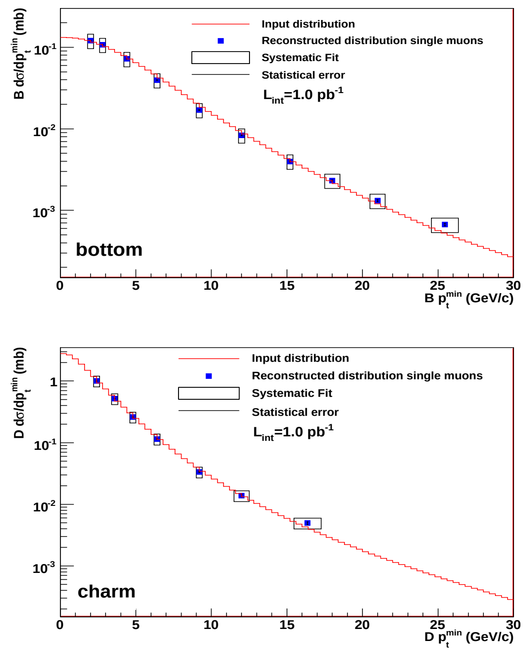

Figure 1. Inclusive differential B-hadron (up) and D-hadron (down) cross sections in p-p collisions at $\sqrt{s} = 14$ TeV. See [8,9] for more details.

the total transverse momentum ($p_{\rm t}$) distribution. Then, beauty and charm muon components are unraveled via a combined fit which includes predicted shapes of the different components[1]. Finally, the B-hadron and D-hadron production cross sections are determined after corrections for efficiency, luminosity branching ratios and decay kinematics by using the method initially developed by the UA1 collaboration [10]. Figure 1 shows the reconstructed B-hadron (upper panel) and D-hadron (lower panel) cross sections as a function of $p_{\rm t}^{\rm min}$. The statistics corresponds to an integrated luminosity of 1.0 pb^{-1} (t $= 10^6$ s, $< L > = 10^{30}$ cm^{-2}s^{-1}). The measurement of the B-hadron (D-hadron) cross section can be performed over a large $p_{\rm t}$ range going from about 2 GeV/c to 25 GeV/c (16 GeV/c) with statistical errors lower than 10% at high $p_{\rm t}$. The expected

[1] Note that charm and beauty components have never been disentangled with this method in the past.

systematic uncertainties, mainly due to the fit assumptions, are about 20%. A similar analysis has been successfully carried out in the dimuon channel [9] and a nice agreement between the different channels has been evidenced.

3.2. Quarkonium measurement

The measurement of quarkonium production in p-p collisions is of great interest since it is expected to provide information on production mechanisms and on parton distribution functions (PDF). It is also mandatory for the determination of the nuclear modification factor. Quarkonium production has been simulated in the forward region by means of the unlike-sign dimuon invariant mass distribution [4]. Table 1 summarizes the expected yield (S), signal to background ratio (S/B) and significance ($S/\sqrt{S+B}$) for quarkonia reconstructed in the acceptance of the ALICE muon spectrometer in a nominal p-p run (t $= 10^7$ s, $< L > = 3 \cdot 10^{30}$ cm^{-2}s^{-1}). All quarkonium states are identified with good significance and the signal to background ratio is always greater than one, except for ψ'. The statistics is very large, in particular for J/ψ and should allow for detailed analysis as a function of rapidity (y) and p_t. It has been shown that the y dependence of the J/ψ yield should be a relevant observable to unravel PDF at very low Bjorken-x values [11]. It is worth pointing out that in a nominal Pb-Pb run at $\sqrt{s_{NN}} = 5.5$ TeV (t $= 10^6$ s, $< L > = 5 \cdot 10^{26}$ cm^{-2}s^{-1}), statistics and mass resolution are sufficient to clearly resolve charmonium and bottomonium states [4].

Table 1
Expected characteristics of quarkonia measured in the acceptance of the ALICE muon spectrometer in a standard p-p run at $\sqrt{s} = 14$ TeV [4].

	S	S/B	$S/\sqrt{S+B}$
J/ψ	$2.8 \cdot 10^6$	12.0	1610
ψ'	$0.075 \cdot 10^6$	0.6	170
Υ(1S)	$27 \cdot 10^3$	10.4	157
Υ(2S)	$6.8 \cdot 10^3$	3.4	73
Υ(3S)	$4.2 \cdot 10^3$	2.4	55

On the other hand, quarkonium polarization is a promising observable to be addressed in p-p collisions to disentangle between different production mechanisms since different models predict different amount of polarization. In heavy ion collisions, an increase of the J/ψ polarization might be expected if the QGP is formed. Simulations have shown that differential measurements of both J/ψ and Υ polarization can be performed in p-p collisions after one year of data taking in nominal conditions [12]. In a nominal Pb-Pb run, J/ψ polarization will be studied as a function of the collision centrality while for Υ, only integrated measurements will be possible.

4. FIRST p-p COLLISIONS AT 7 TeV

The ALICE detector is collecting p-p collisions at $\sqrt{s} = 7$ TeV since end of March 2010. The present analyses performed with the ALICE muon spectrometer concern the reconstruction of the p_t distribution of single muons from heavy flavour decay and the J/ψ measurement.

The ALICE muon spectrometer has collected data for minimum bias collisions with at least one charged particle in 8 units of pseudo-rapidity (INT1B trigger) and for events where at least one muon has been produced in the acceptance of the muon spectrometer (MUS1B trigger). The alignment of the tracking chambers, a crucial step for the J/ψ analysis, has been carried out using the MILLEPEDE package [13], by analyzing tracks collected without magnetic field in the dipole. In what follows a sample of about $4.7 \cdot 10^6$ ($8 \cdot 10^6$) events, where the MUS1B trigger has been fired, is used for the single muon (dimuon) analysis. Note that an offline selection has been applied to reject beam induced background.

Figure 2 depicts the resulting uncorrected p_t distribution of muons from charm and beauty decay, in the acceptance of the ALICE muon spectrometer. The contribution of hadrons has been removed by requiring that the reconstructed track in the tracking system matches a corresponding track in the trigger system. The muon yield from primary π and K decay has been subtracted using Pythia (tune ATLAS-CSC) data normalized to the data in the low p_t region. In the considered

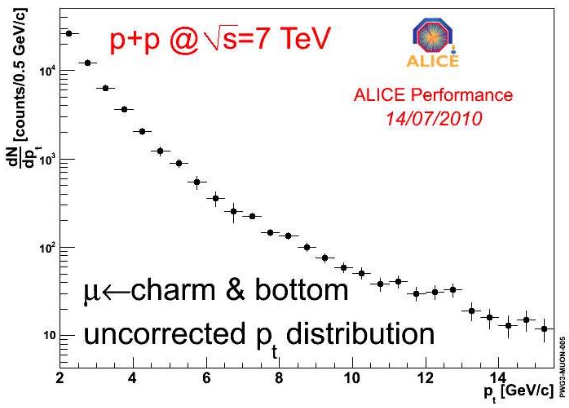

Figure 2. Transverse momentum distribution of muons from heavy flavour decay in the acceptance of the ALICE muon spectrometer for *p*-*p* collisions at $\sqrt{s} = 7$ TeV.

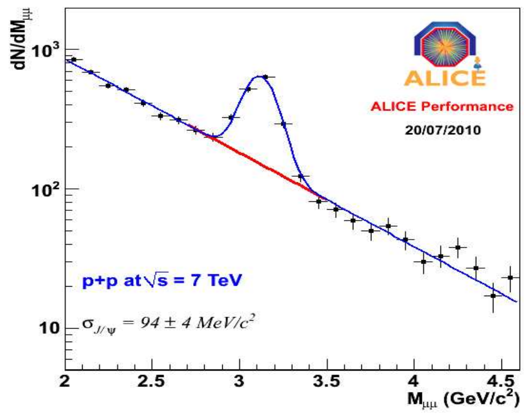

Figure 3. Invariant mass distribution of unlike-sign dimuons in the acceptance of the ALICE muon spectrometer, in *p*-*p* collisions at $\sqrt{s} = 7$ TeV. The J/ψ region is shown.

$p_{\rm t} > 2$ GeV/c range, the remaining background composed of muons from secondary light hadrons can be neglected. The present statistics allows to investigate the $p_{\rm t}$ range up to about 15 GeV/c.

Figure 3 displays the invariant mass distribution of unlike-sign muons measured in the acceptance of the ALICE muon spectrometer. A clear peak is evidenced at the nominal mass of the J/ψ. In order to extract the J/ψ signal, the resonance shape is parameterized by a Gaussian while the continuum is fitted with an exponential. With present alignment quality, the resolution ($\sigma = 94 \pm 4$ MeV/c^2) is close to specifications [4] and more than 1200 J/ψ have been identified.

5. CONCLUSION

An ambitious heavy flavour physics program will be carried out with the forward ALICE muon spectrometer at the LHC. The muon spectrometer is currently taking *p*-*p* data at $\sqrt{s} = 7$ TeV with excellent detector performance. Promising results have been obtained with first *p*-*p* collisions at $\sqrt{s} = 7$ TeV and detailed analyses are in progress. Pb beams are eagerly expected by the end of 2010.

REFERENCES

1. F. Carminati et al., ALICE Collaboration, J. Phys. G: Nucl. Part. Phys 30 (2004) 1517.
2. T. Matsui and H. Satz, Phys. Lett. B 178 (1986) 416.
3. K. Aamodt et al., JINST 3 (2008) S08002.
4. B. Alessandro et al., ALICE Collaboration, J. Phys. G: Nucl. Part. Phys 32 (2006) 1295.
5. J. Baines et al., arXiv:hep-ph/0601164.
6. A. Dainese, ALICE Collaboration, Eur. Phys. J. C49 (2007) 135.
7. Z. Conesa del Valle et al., Phys. Lett. B 663 (2008) 202.
8. L. Manceau et al., Eur. Phys. J. C 62 (2009) 9.
9. X. Zhang et al., Chinese Phys. C 34 (2010).
10. C. Albajar et al. UA1 Collaboration, Phys. Lett. B 213 (1988) 405, Phys. Lett. B 256 (1991) 121.
11. F. Ambroglini et al., arXiv:0902.0180 [hep-ph].
12. L. Bianchi, ALICE Collaboration, proceedings of Hot Quarks (2010).
13. V. Blobel and C. Kleinwort, arXiv:hep-ex/0208022