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Measurement of (di)muons from heavy flavour decay in p-p collisions at 14 TeV with ALICE at the LHC*

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Abstract We present the performance of the ALICE muon spectrometer for measuring the charm and beauty inclusive p_t differential production cross sections via single muons and unlike-sign dimuons in proton-proton collisions at $\sqrt{s}=14$ TeV.

Key words ALICE muon spectrometer, heavy flavour, pQCD

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1 Introduction

With a nucleus-nucleus center-of-mass energy $\sqrt{s_{\rm NN}}=5.5$ TeV, which is nearly 30 times larger than the one reached at RHIC, the LHC will open a new era for studying the properties of strongly interacting matter under extreme thermodynamical conditions. One of the most important aspects of this energy range will be the abundant production of hard probes and, in particular, of heavy quarks (charm and beauty). These heavy quarks are produced at the early stage of the collision and are particularly sensitive to the properties of the QCD medium they pass through before they fragment into heavy hadrons.

The main motivation to measure the B(D)-hadron production cross-section in p-p collisions at LHC energies is to test Next-to-Leading Order (NLO) pQCD calculations [1]. Such a measurement is also mandatory for understanding [2]:

1) heavy quark production in p-A collisions where the study of shadowing and anti-shadowing will give information on parton distribution function modifications in the nucleus.

2) heavy quark production at high transverse momentum (p_t) in A-A collisions where the study of the parton energy loss in QCD medium will give information on the initial gluon density and the dissipative properties of the medium.

3) quarkonium cross-sections in p-p, p-A and A-A collisions.

4) production cross-section of secondary J/ψ from B-hadron decay in p-p collisions which serves as a baseline for the analogous measurements in p-A and A-A collisions.

The ALICE muon spectrometer [3, 4] covers the forward pseudo-rapidity region $-4<\eta<-2.5$. It consists of a front absorber, a dipole magnet, ten high-granularity tracking chambers, a muon filter and four large area trigger charmbers. It is designed for the measurement of quarkonia (both charmonia and bottomonia states) and can measure open heavy flavour (D and B hadrons) too.

2 Simulation inputs

Proton-proton collisions are simulated by means of a “cocktail” which includes i) minimum-bias p-

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p collisions according to PYTHIA [5] with the so-called ATLAS tuning [6], the CTEQ 5L Parton Distribution Function (PDF) and a $p_{\rm t}^{\rm hard}$ threshold of 2.76 GeV/c; and ii) heavy quark resonances (J/ψ, ψ', $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$). As PYTHIA underestimates the total charm production cross-section with respect to NLO pQCD calculations [7], this cross-section is scaled by a factor ~ 2. In order to reduce the computing time and to optimize the statistics, a software trigger has been implemented. It consists of selecting events, at the generation level, for which at least either one muon or two muons are produced in the acceptance of the muon spectrometer with $p_{\rm t} > 0.5$ GeV/c (as a result, the number of muons from π and K decay is underestimated). The selected events are then treated and reconstructed with the ALICE software framework AliRoot [8]. This is done on the computing grid within the so-called Physics Data Challenge.

The processed events correspond to 1×10^6 and 2.5×10^6 software triggered muons ($\mu^\pm$) and dimuons, respectively. The statistics for the single muon sample allows to exploit the muon $p_{\rm t}$ distribution up to ~ 10 GeV/c. In order to cope with such a small statistics, the muon $p_{\rm t}$ distributions have been fitted and extrapolated to $p_{\rm t} = 20$ GeV/c.

3 Analysis method

We use the method developed by UA1 collaboration [10] and further used by the CDF [11] and the D0 [12] collaborations at the Tevatron. This method allows to extract the inclusive differential cross-section of D and B hadrons from $\mu^\pm$ $p_{\rm t}$ distribution and from $\mu^-\mu^+$ invariant mass ($M_{\rm inv}$) distribution.

$$\sigma^{\rm B/D}(p_{\rm t} > p_{\rm t}^{\rm min}, -4<\eta<-2.5) = \frac{N_{\mu^\pm(\mu^-\mu^+)\leftarrow{\rm B/D}}(\Phi^{\mu^\pm(\mu^-\mu^+)})}{\int \mathfrak{L}{\rm d}t} \times \frac{1}{\epsilon}\times F^{\rm MC}_{\mu^\pm(\mu^-\mu^+)\leftarrow{\rm B/D}}(\Phi^{\mu^\pm(\mu^-\mu^+)}, p_{\rm t}^{\rm min}). \tag{1}$$

Equation (1) shows how the heavy hadron cross-section is reconstructed. Here $N_{\mu^\pm(\mu^-\mu^+)\leftarrow{\rm B/D}}(\Phi^{\mu^\pm(\mu^-\mu^+)})$ is the number of (di)muons from B(D)-hadrons in the phase space region $\Phi^{\mu^\pm(\mu^-\mu^+)}$ ($-4<\eta<-2.5$, $p^\mu > 4$ GeV/c and a given $p_{\rm t}$ ($M_{\rm inv}$) range for $\mu^\pm(\mu^-\mu^+)$), $\mathfrak{L}$ is the luminosity, ϵ is the detection efficiency and $F^{\rm MC}_{\mu^\pm(\mu^-\mu^+)\leftarrow{\rm B/D}}$ is the correction for hadron decay kinematics.

In the following we assume that the muon component from the background and from resonance decay is subtracted from the total (di)muon yield. After correction for detection efficiency ϵ [9], the (di)muon yield from charm and beauty is obtained by unfolding the corresponding components in the total (di)muon yield. This is done according to:

$$(T-B)\cdot(f_{\rm c}+R\times f_{\rm b}), \tag{2}$$

where T is the total number of $\mu^\pm$; $B = N_{\mu^\pm(\mu^-\mu^+)\leftarrow{\rm B}}$, $R = \frac{N_{\mu^\pm(\mu^-\mu^+)\leftarrow{\rm B}}}{N_{\mu^\pm(\mu^-\mu^+)\leftarrow{\rm D}}}$ are two free parameters; $f_{\rm c}$ and $f_{\rm b}$ are the normalized shape functions of the (di)muons distributions for charm and beauty, respectively. The shape function of $\mu^\pm$ $p_{\rm t}$ distribution is [4],

$$f_{\rm c/b} = c\times\frac{1}{(1+(p_{\rm t}/a)^2)^b}, \tag{3}$$

where a, b and c are fixed parameters. In the case of $\mu^-\mu^+$ $M_{\rm inv}$ analysis, the shape functions are,

$$\begin{aligned} f_{\rm c} &= p_0\cdot\exp\left[-\frac{1}{2}\left(\frac{x-p_1}{p_2}\right)^2\right]+p_3\cdot\exp\left[-\frac{1}{2}\left(\frac{x-p_4}{p_5}\right)^2\right]+p_6\cdot\frac{1+p_7\cdot(x-p_8)}{[p_9^2+(x-p_8)^2]^{p_{10}}}, \\ f_{\rm b} &= p_0\cdot\exp\left[-\frac{1}{2}\left(\frac{x-p_1}{p_2}\right)^2\right]+p_3\left\{\frac{1+p_4\cdot(x-p_5)}{[p_6^2+(x-p_5)^2]^{p_7}}+p_8\cdot\exp\left[-\frac{1}{2}\left(\frac{x-p_9}{p_{10}}\right)^2\right]\right\}, \end{aligned} \tag{4}$$

where p_0 to p_{10} are free parameters and x is the $\mu^-\mu^+$ $M_{\rm inv}$.

Figure 1 shows the results of the fits. The considered statistics corresponds to a luminosity of $<\mathfrak{L}> = 10^{30}$ cm$^{-2}\cdot$ s^{-1} and a data taking time of $t = 10^6$ s. This corresponds to 7×10^{10} p-p collisions. The quality of the fits is very good in both $\mu^\pm$ and $\mu^-\mu^+$ channels. Indeed, the number of (di)muons from beauty and charm decay extracted from the fits corresponds to that in the histograms at the percent level.

The systematic error on $N_{\mu^\pm(\mu^-\mu^+)\leftarrow{\rm B/D}}(\Phi^{\mu^\pm(\mu^-\mu^+)})$ is estimated from biased shape functions $f_{\rm c}$ and $f_{\rm b}$. For the $\mu^\pm$ $p_{\rm t}$ channel, these functions are taken from theoretical predictions obtained under different assumptions on the PDFs, the quark masses and the QCD factorisation and renormalisation scales [1]. For the $\mu^-\mu^+$ $M_{\rm inv}$ channel, the functions are obtained by changing "by hand" the free parameters in Eq. (4). After fitting the $\mu^\pm$ $p_{\rm t}$ distributions and $\mu^-\mu^+$ $M_{\rm inv}$ distributions with these biased shape functions, we estimate the systematics uncertainty to be about 15% (20%) for $\mu^{\pm}$ and 20% (15%) for $\mu^-\mu^+$ from charm (beauty) (for this estimation, we exclude fits which do not converge).

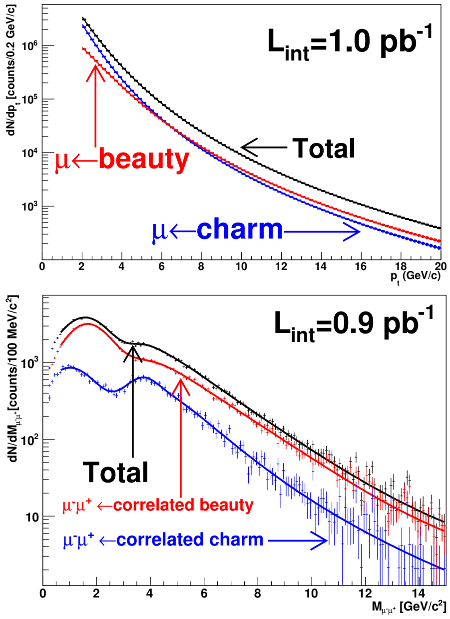

Fig. 1. (color online). Results of the fit for $\mu^{\pm}$ $p_{\rm t}$ distribution (up) and $\mu^-\mu^+$ $M_{\rm inv}$ distribution (down) with perfect shape functions. The statistics corresponds to the data taking scenario described in the text. The structures in the low $\mu^-\mu^+$ $M_{\rm inv}$ region result from the B-chain channel and from next-to-leading order processes.

In Eq. (1) the term $F^{\rm MC}$ can be written as:

$$F^{\rm MC}_{\mu^{\pm}(\mu^-\mu^+)\leftarrow{\rm B/D}}=\frac{\sigma^{\rm B/D}(p_{\rm t}>p_{\rm t}^{\rm min})}{\sigma^{\rm B/D}(\varPhi^{\mu^{\pm}(\mu^-\mu^+)})}. \qquad (5)$$

It corresponds to the ratio of the B(D)-hadron cross-section in the forward region ($-4<\eta<-2.5$) with $p_{\rm t}^{\rm B(D)}>p_{\rm t}^{\rm min}$ over the cross-section of B(D)-hadrons decaying to (di)muons in the phase space region $\varPhi$. $p_{\rm t}^{\rm min}$ is defined in order that 90% of accepted B(D)-hadrons decay into (di)muons in $\varPhi$ with $p_{\rm t}>p_{\rm t}^{\rm min}$. This term is estimated via a Monte-Carlo simulation.

4 Results and conclusion

Figure 2 shows the reconstructed charm and beauty hadron inclusive differential cross-section. The statistical uncertainty is negligible. As it can be seen, a good agreement is obtained from the $\mu^{\pm}$ and $\mu^-\mu^+$ analyses. The charm and beauty cross-sections are well reconstructed in a wide $p_{\rm t}$ range from about 3 GeV/c to 15 GeV/c and 2 GeV/c to 25 GeV/c, respectively. This corresponds to 17% (34%) of the total charm production cross section and 82% (84%) of the total beauty production cross-section via $\mu^{\pm}$ ($\mu^-\mu^+$) in the acceptance of the muon spectrometer.

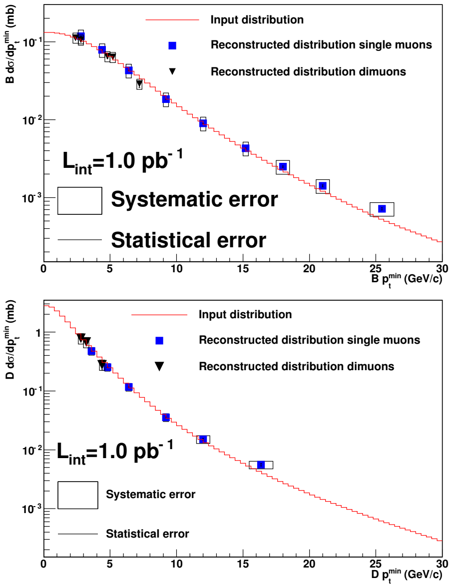

Fig. 2. (color online). Reconstructed inclusive differential cross-sections of B-hadron (up) and D-hadron (down) as a function of $p_{\rm t}^{\rm min}$ in p-p collisions at $\sqrt{s}=14$ TeV. Results from the $\mu^{\pm}$ (squares) and the $\mu^-\mu^+$ (triangles) analyses are compared to the input distributions (red histograms). The statistical errors are smaller than the symbol size. The open rectangles show the systematic uncertainties.

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