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Physics perspectives with the ALICE muon spectrometer

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ALICE (A Large Ion Collider Experiment) will be the detector dedicated to the study of nucleus–nucleus collisions at the LHC. The muon spectrometer of ALICE is dedicated to the measurement of heavy flavors in the muon channel. A brief description of the ALICE muon spectrometer and its physics program is reported. The expected performances for open and hidden charm and bottom measurements are presented.

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Key words: Relativistic heavy ion collision, muon, quarkonium, heavy flavor

1 Introduction

The LHC heavy-ion physics program aims at investigating the properties of strongly interacting matter at extreme energy density where the formation of the Quark–Gluon Plasma is expected. Among the most promising observables, open heavy quarks and heavy quarkonium states are especially relevant since they provide, via their leptonic decays, an essential probe of the earliest and hottest stages of heavy-ion collisions. Moreover, these studies should take advantage of the copious production of charm and bottom which is expected at LHC, more than one hundred charm pairs and a few bottom pairs per central Pb–Pb collision [1].

The energy density which should be reached in heavy-ion collisions is such that the melting of the Υ resonance by Debye screening effect could be observed, in line with the so-called J/ψ anomalous suppression measured by NA50 at SPS [2]. Such a phenomenon should be peculiar to LHC energy because the Υ dissociation is expected at a temperature significantly above the critical temperature [3], which might not be reachable at RHIC. The spectroscopy of the Υ family should then reveal an unique set of information on the characteristics of the QGP [4].

Also very interesting, a competition of phenomena inducing charmonium absorption or enhancement, during the QGP [5] or the hadronic phase [6, 7], should occur. For example, the statistical hadronization model [7, 8], which reproduces to a large extent the SPS data, predicts a strong enhancement of J/ψ production at LHC simply induced by the fact that the initial production of charm pairs is large. As a consequence, the measured J/ψ yield versus collision centrality could be very different from those at SPS or RHIC.

The quarkonium study must be led in parallel with that of open heavy flavors, which are produced by the same mechanism at partonic level. Understanding open heavy-flavor production patterns should be helpful for the normalization of the quarkonium yields versus system size or collision centrality. Moreover, the

study of open heavy flavors is interesting by itself, especially in the context of nucleus–nucleus collisions, since it provides information on effects like shadowing or quenching [9].

These simple arguments show that heavy-quark production at LHC will open a rich physics program associated with a complex background. It is evident that the simultaneous measurement of hidden and open heavy flavors, for different colliding systems and different collision centralities, will be a must for the understanding of the underlying production mechanism.

2 ALICE muon spectrometer: description and performances

ALICE is a very challenging multi-purpose experiment. The forward muon spectrometer [10], as represented in Fig. 1, is composed of a front absorber, a small angle absorber or beam shielding, five stations of tracking chambers, a dipole magnet, a muon filter and trigger chambers. The spectrometer covers the polar angular range $2 < \theta < 9^\circ$ ($2.5 < \eta < 4$).

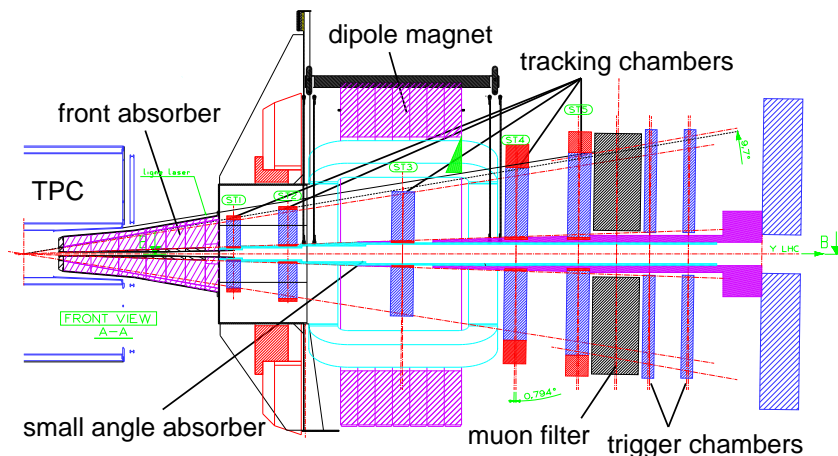


Fig. 1. Layout of the ALICE muon spectrometer.

The design of the muon spectrometer has been essentially driven by the requirements for the separation of the ($\Upsilon, \Upsilon', \Upsilon''$) states in the large background environment of central Pb–Pb collisions. A mass resolution better than 100 MeV at dimuon effective mass of 10 GeV is needed to achieve this goal.

Very detailed simulations, summarized in Fig. 2, indicate that this goal is reached for nominal background. What is called nominal background (background level 1) is certainly overestimated since it corresponds to the sum of two central Pb–Pb Hijing events with 6000 charged particles per unit of rapidity, around mid-rapidity, each. The Υ reconstruction efficiency is better than 90%. Its total acceptance is of the order of 5% and is almost flat in transverse momentum. The J/ψ

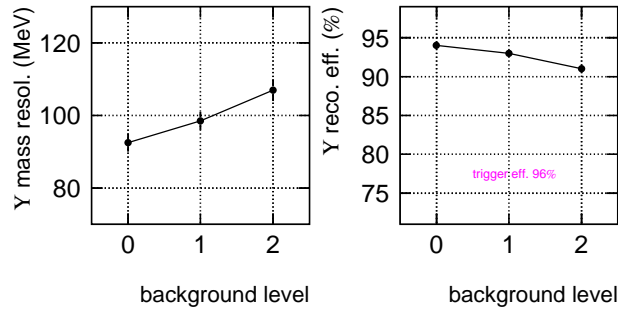


Fig. 2. Υ mass resolution and reconstruction efficiency for different levels of background (see background level definition in the text).

Table 1. Cross sections for open charm and open bottom [11] as well as for various resonances [1] in $p-p$ collisions at $\sqrt{s} = 5.5$ TeV.

	$c\bar{c}$	$b\bar{b}$	J/ψ	ψ'	Υ	Υ'	Υ''
σ_{pp} (μb)	$6.64 \cdot 10^3$	$0.21 \cdot 10^3$	30.5	4.7	0.50	0.25	0.10

acceptance is of the same magnitude and it is significant even at zero transverse momentum which is one of the advantages of having the spectrometer at forward angles.

3 Quarkonium measurements

The centrality dependence of the quarkonium production in Pb–Pb, including a detailed evaluation of the ALICE setup effects, has been studied. Quarkonia are generated using the parameterizations proposed in [1], corrected for nuclear shadowing effects (extra absorption or production from color screening or other collective effects are not introduced). Heavy-quark production is described in [11]. Muons from π and K decays are simulated using parameterizations of Hijing. A summary of the used cross sections is given in Table 1. Extrapolation of the cross sections from $p-p$ to Pb–Pb is done using the Glauber model.

The unlike-sign dimuon mass spectra, included all possible muon combinations and the resonances, are displayed in Fig. 3 for three centrality classes. The background corresponding to each source of muon pairs (correlated or uncorrelated) is also shown. A single muon p_t cut of 1 GeV/c (3 GeV/c) is applied for the study of the J/ψ (Υ) family in order to reduce the background. The correlated component from bottom decays is always sizable and dominates the background in the most peripheral centrality class.

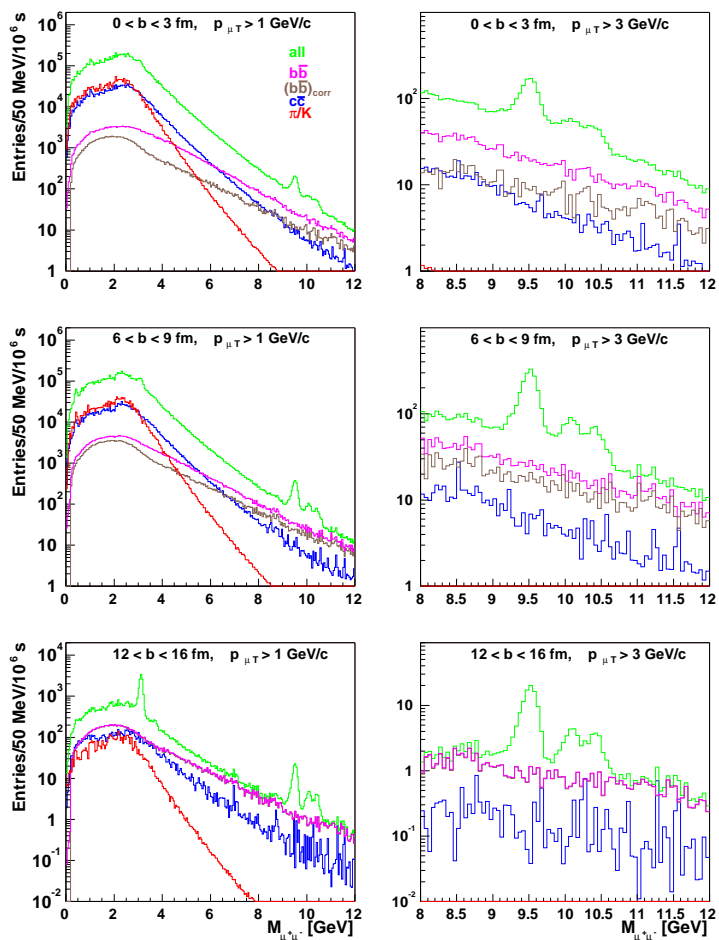


Fig. 3. Unlike-sign dimuon mass spectra for three centrality classes, as indicated in the various plots. Overview of the whole mass spectra (left column) and zoom in the Υ region (right column).

The expected quarkonium signal and background rates, as well as the significance, are given in Table 2. The numbers correspond to the interval at $\pm 2\sigma$ (where σ is obtained from the resonance gaussian fit) around the resonance mass. The J/ψ is well measured with a very good significance. Simulations indicate also a good statistics of about ten thousands for the whole Υ family in MB (Minimum Bias) events. The S/B ratio is larger than unity for all Υ species and the significance is also very good. Finally, it can be seen from the second line of Table 2 that a broad

Table 2. Centrality dependence of quarkonium yields in Pb–Pb collisions. Numbers are for one month of run at the luminosity $5 \times 10^{26} \text{ cm}^{-2} \text{ s}^{-1}$.

	b(fm)	0–3	3–6	6–9	9–12	12–16	MB
	$\epsilon \text{ (GeV/fm}^3\text{)}$	32	30	28	16	5	
	S ($\times 10^3$)	86.48	184.60	153.30	67.68	10.46	502.40
J/ψ	S/B	0.17	0.21	0.43	1.24	6.24	0.28
	$S/\sqrt{S+B}$	111.30	180.40	213.80	193.40	94.95	331.50
	S ($\times 10^3$)	1.99	4.23	3.55	1.57	0.24	11.57
ψ'	S/B	0.01	0.01	0.02	0.06	0.27	0.02
	$S/\sqrt{S+B}$	4.19	6.90	8.60	9.64	7.17	12.95
	S ($\times 10^3$)	1.11	3.38	1.97	0.83	0.12	6.41
Υ	S/B	2.08	2.73	4.31	7.98	12.01	3.25
	$S/\sqrt{S+B}$	27.39	41.71	40.03	27.16	10.42	69.99
	S ($\times 10^3$)	0.31	0.65	0.55	0.23	0.03	1.77
Υ'	S/B	0.81	1.04	1.66	2.87	4.32	1.24
	$S/\sqrt{S+B}$	11.68	18.26	18.48	13.02	5.08	31.28
	S ($\times 10^3$)	0.18	0.38	0.31	0.13	0.02	1.01
Υ''	S/B	0.57	0.72	1.18	1.94	3.02	0.87
	$S/\sqrt{S+B}$	7.95	12.55	13.00	9.27	3.73	21.67

range in energy density can be covered varying the collision centrality.

The p_t dependence of the quarkonium production, where p_t is the resonance transverse momentum, has also been investigated [11]. Indeed, the suppression pattern of a given resonance is expected to depend significantly on p_t and on the space-time characteristics of the hot medium [4, 12]. Figure 4, corresponding to the selection $4 < p_t < 6 \text{ GeV}/c$, is shown for illustration. For one month of Pb–Pb run, the significance on the J/ψ and on the Υ is good up to $p_t=10 \text{ GeV}/c$ for 2 GeV/c wide bins.

Low mass resonances are believed to be sensitive probes of the medium [13]. However, this measurement will be difficult at LHC, especially in collisions of very heavy ions like Pb–Pb because, on the one hand, the background at low mass is huge and, on the other hand, the single muon p_t cut of the spectrometer, of about 1 GeV/c, lowers considerably the acceptance of low mass resonances. As illustrated in Fig. 5, the ω resonance, which gives in dimuon spectra larger signal (about $5 \times 10^4 \omega$ expected to be measured in central Pb–Pb collisions for one month of run) than the ρ or the ϕ , should be however accessible with $S/B \sim 0.1$ [11].

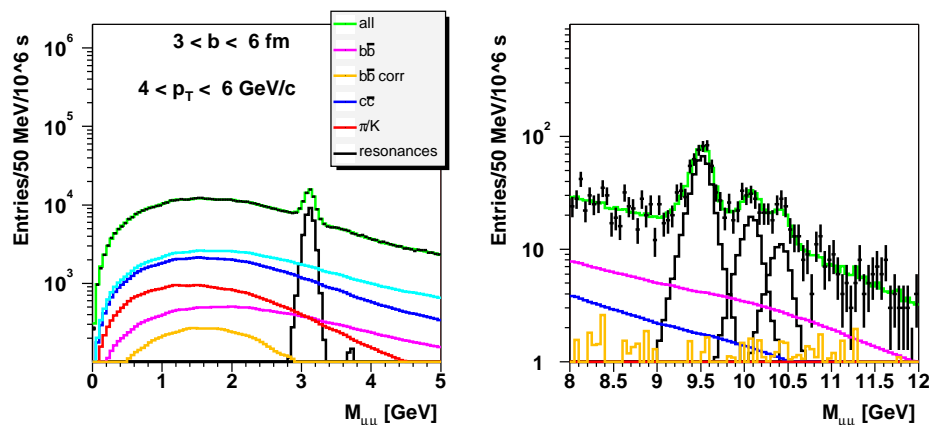


Fig. 4. Unlike-sign dimuon mass spectra, with a selection $4 < p_t < 6$ GeV/c (p_t is the dimuon transverse momentum), in Pb–Pb collisions ($3 < b < 6$ fm). J/ψ (left) and Υ (right) mass region with a single muon p_t cut of 1 GeV/c and 3 GeV/c respectively. An additional cut $p_t(\mu_1) + p_t(\mu_2) > 3.1$ GeV/c (9.2 GeV/c), where μ_1 and μ_2 are the two muons of the pair, is applied to further improve the S/B ratio in the J/ψ (Υ) mass region. The spectra are normalized to one month of run.

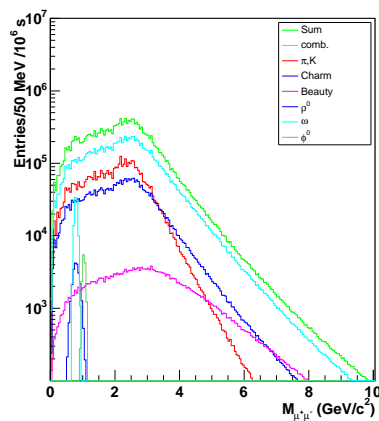


Fig. 5. Unlike-sign dimuon mass spectra in Pb–Pb central collisions ($b < 5$ fm) showing the contributions of low mass resonances.

4 Open heavy-flavor measurements

The inclusive single muon p_t distribution in the spectrometer, between 1.5–20 GeV/c, is shown in Fig. 6, for the 5% most central Pb–Pb collisions. For $p_t > 3$ GeV/c, open bottom is the dominant contribution. It can be seen that millions of muons from open bottom will be detected in one month of run.

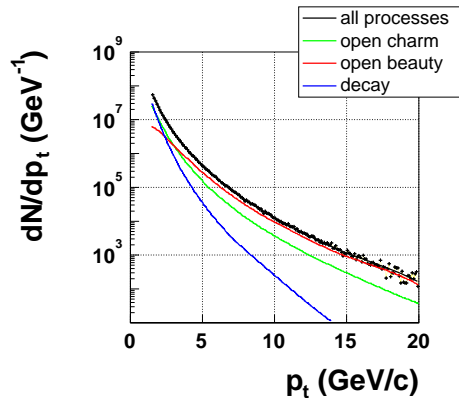


Fig. 6. Inclusive single muon p_t distributions, for the 5% most central Pb–Pb collisions, normalized to one month of run.

The open bottom cross section in ion–ion collisions should be measurable since a quite clean bottom sample can be selected by applying a single muon p_t cut [14]. The contribution of correlated-bottom pairs to the unlike-sign mass spectrum is shown in Fig. 7. At low mass (below 5 GeV), the contribution from the so-called BD_{same} (the two muons originate from the same B meson through cascade decays) dominates. It is followed, at higher mass, by the long tail from the so-called BB_{diff} (each muon originates from one quark of the $b\bar{b}$ pair). The like-sign mass spectra are also very rich and contain, in particular, the correlated component from $B^0-\bar{B}^0$ oscillations [15].

5 Conclusion

A very exciting physics program is foreseen with the ALICE muon spectrometer. The experimental setup has excellent capabilities. Quarkonia and open heavy flavors will be measured for a wide variety of colliding systems. Although not discussed in this paper, other interesting information should come from the study of multi-muon events and from correlations with signals measured in the central part of ALICE.

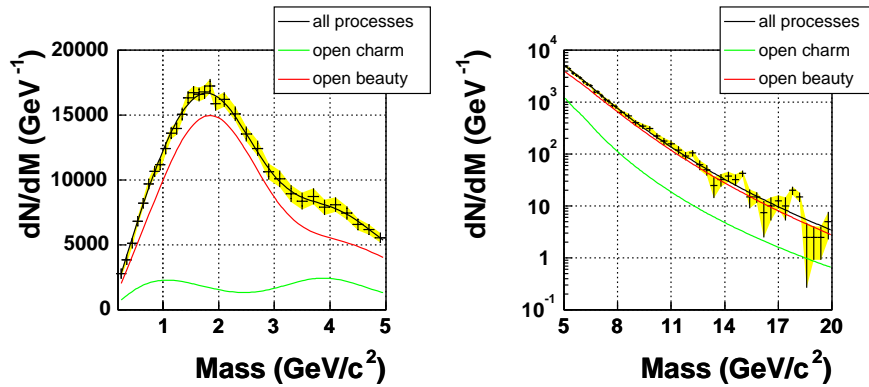


Fig. 7. Unlike sign mass distribution of muon pairs, for the 5% most central Pb–Pb collisions, in the low (left panel) and high (right panel) mass regions, normalized to one month of run. A single muon p_t cut of 1.5 GeV/c is applied. The correlated components from open charm and open bottom only are shown (background subtracted distributions).

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