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# PERSPECTIVES FOR THE MEASUREMENT OF BEAUTY PRODUCTION VIA SEMILEPTONIC DECAYS IN ALICE *

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In the present talk we report results from a study of the performance for the detection in ALICE of (a) $B \to e+X$ decays with the central barrel and (b) $B \to \mu + X$ decays with the muon spectrometer. We include an evaluation of the expected statistical and systematic uncertainties on the measurement of the cross section of beauty hadrons. We also discuss the possibility of detecting the modifications of beauty hadrons' transverse momentum ($p_{\mathrm{t}}$) distribution induced by in-medium gluon radiation calculated by a phenomenological model.

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## 1. Introduction

ALICE (A Large Ion Collider Experiment) [1] is an experiment in preparation at the Large Hadron Collider (LHC) designed for the study of heavy ion collisions at a centre of mass energy of 5.5 ATeV. The aim of the experiment is to study the behaviour of nuclear matter under extreme conditions of density and temperature, where a transition is expected to occur to a phase where quarks and gluons are deconfined and chiral symmetry is partially restored (Quark Gluon Plasma, QGP) [2]. In the context of the heavy ion physics programme of ALICE, beauty is an especially interesting probe. The measurement of high-$p_{\mathrm{t}}$ meson suppression should provide information on the properties of the medium, in particular on its gluon density, and on the effective value of heavy quarks masses in the mechanism of gluon radiation [3].

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In addition, the knowledge of the beauty quark cross section is important for practical reasons, particularly in the study of quarkonium suppression, which is considered one of the main signatures of QGP formation. It will provide (a) the natural normalisation for the analysis of bottomonium production and (b) the amount of $B \to J/\psi$ contamination to the direct $J/\psi$ yield, expected to be 20% at LHC energies.

ALICE will detect electrons in the central barrel and muons (singles and pairs) in the muon arm. The semi-leptonic decays of beauty hadrons are a good candidate to perform these studies, having a branching ratio (BR) of $\simeq 21\%$[1]. In the following we report results from the study of the ALICE performance for the detection of beauty hadrons in these channels. As the comparison between $pp$ and $AA$ reactions is mandatory in order to disentangle nuclear effects, the performance analyses have been performed in both cases, nonetheless we focus in this paper on Pb–Pb only, referring the reader to [3, 4] for the $pp$ case.

## 2. The ALICE experiment

The ALICE experiment is described in detail elsewhere [1]. The detector consists of two main components: the central barrel and the forward muon spectrometer. The central barrel, which spans the range $-0.9 < \eta < 0.9$, is embedded in a large magnet providing a solenoidal field $|B_z| \leq 0.5$ T along the beam direction. The muon spectrometer covers the pseudorapidity range $-4 < \eta < -2.5$. Electrons' detection, in the $p_{\rm t}$ range of interest for this study, involves the following detectors of the central barrel: the Inner Tracking System (ITS), the Time Projection Chamber (TPC) and the Transition Radiation Detector (TRD) [1]. TPC and ITS are the main tracking devices; electrons are separated from pions, muons and heavier particles using the TRD and TPC particle identification capabilities. Muons are selected in the muon spectrometer by an absorber and 14 layers of tracking and trigger chambers, traversing a total of about 15 interaction lengths. Due to the high longitudinal momentum, the $p_{\rm t}$ threshold can be as low as 1 GeV/$c$.

The large number of particles produced in the collision of heavy ions constitutes a major experimental challenge. There is a considerable spread in the predictions of the charged particle rapidity density in nuclear reactions at LHC, ranging up to 8000 charged particles per unit of rapidity at midrapidity for a central Pb–Pb collision. However, extrapolations of RHIC results to LHC energy favour multiplicities lower by about a factor 3 [5]. The results presented here assume $dN_{\rm ch}/dy|_{y=0} = 6000$.

[1] 11% and 10% approximately from $B \to l$ and $B \to D \to l$ decays respectively.

## 3. Beauty detection in the semielectronic channel

### *3.1. Detection strategy*

The current predictions for heavy flavour production at LHC energies are affected by large uncertainties. We have fixed a reference based on recent NLO [6] calculations for *pp* collisions. The prediction for the Pb–Pb system are obtained by extrapolating the *pp* calculations (for details see [7,8]). The expected number of electrons per Pb–Pb central event (5% centrality) is $\simeq 1.9$ from beauty and $\simeq 19$ from direct charm. In the former we have accounted for the $b \to c \to e$ process, assuming 100% BR of $b$-hadrons to $c$-hadrons. The main sources of background electrons are: (a) decays of primary $D$ mesons, which have an expected production yield about 25 times larger than the one for $B$ mesons [7]; (b) decays of light mesons (*e.g.* $\pi^0$, $\rho$, $\omega$, $K$); (c) conversions of photons in the beam pipe or in the inner layers of the Inner Tracking System (ITS) and (d) pions tagged as electrons. The strategy for beauty detection in the semi-electronic decay channels is based on electron identification and selections based on the tracks' impact parameter $d_0$[2] and on the electrons' $p_{\rm t}$.

Electron identification is performed by a combined TPC–TRD procedure, as explained in [8]. This technique is expected to provide a $10^4$ rejection factor for pions with 80% efficiency for electrons.

Thanks to the two pixel layers (Silicon Pixel Detector, SPD) which instrument the innermost part of the ITS [9], the tracks' $d_0$ will be measured in ALICE with a resolution $\sigma_{d_0} \leq 50$ $\mu$m for $p_{\rm t} \geq 1.3$ GeV/$c$ [9]. Given that beauty mesons have mean proper decay lengths of $\sim 500$ $\mu$m, their decay electrons are characterised by large impact parameters with respect to the interaction vertex. Therefore, a cut imposing a minimum value of $d_0$ allows to reject a large fraction of the electrons from sources (b) and (c), as well as primary pions misidentified as electrons.

Finally, one expects a $p_{\rm t}$-cut to be effective in decreasing the charm contamination in the beauty sample because, due to the larger mass of the $b$ quark, electrons from $B$ meson decays have a harder $p_{\rm t}$ distribution than electrons coming from $D$ mesons.

The signal purity has been studied as a function of the $d_0$ and $p_{\rm t}$ thresholds. As an example, the cuts $p_{\rm t} > 2$ GeV/$c$ and $200 < |d_0| < 600$ $\mu$m are expected to yield a sample of electrons from $B$-meson decays with a purity $S/(S+N)$ of 80%, where $S$ is the number of beauty-decay electrons and $N$ includes electrons from all other sources, and a statistics $S \simeq 8 \times 10^4$.

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[2] $d_0$ is defined as the projection of the impact parameter on the transverse plane.

### 3.2. Electron spectrum and uncertainties evaluation

In Fig. 1 (left), we show the $p_{\rm t}$ spectra after applying the analysis strategy to $5 \times 10^6$, $2 \times 10^6$, and $2 \times 10^4$ simulated events with beauty-decay electrons, charm-decay electrons and of background, respectively. Statistics has been normalized to $10^7$ Pb–Pb central (5%) collisions. In the same figure (right) are the statistical and systematic errors introduced on the beauty electron $p_{\rm t}$ distribution. The systematic error includes a 10% estimated ($p_{\rm t}$-independent) error from MC corrections (acceptance, efficiency, *etc.*) and the $p_{\rm t}$ dependent errors from background subtraction. The charm contribution to the total electron spectrum will be subtracted using the measured value of the $D^0$ cross section [10].

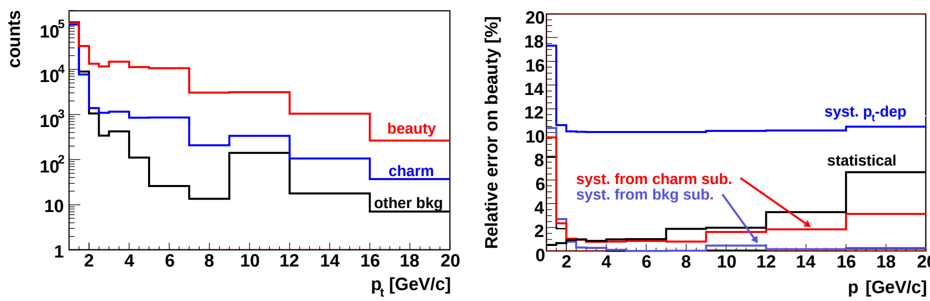


Fig. 1. Left: Expected statistics (counts/$p_{\rm t}$-bin) in $10^7$ central Pb–Pb events for electrons from beauty, from charm and for the non-charm background. Right: Summary of all error contributions for the measurement of the $p_{\rm t}$-differential cross section of electrons from beauty decays.

### 3.3. Meson level cross section

A method, developed by the UA1 Collaboration [11], has been applied to extract the minimum-$p_{\rm t}$-differential cross section at the $B$-meson level from the decay-electron $p_{\rm t}$-differential cross section. This method relies on the fact that the $B$-meson decay kinematics, measured and studied in several experiments (see *e.g.* [12] for a review), is rather well understood. Fig. 2 shows the expected ALICE performance for the measurement of the $p_{\rm t}^{\rm min}$-differential cross section of $B$ mesons, $d\sigma^B(p_{\rm t} > p_{\rm t}^{\rm min})/dy$ *versus* $p_{\rm t}^{\rm min}$ at $y = 0$. The points correspond to the nine electron $p_{\rm t}$ bins in the range $2 < p_{\rm t}^e < 20$ GeV$/c$ from Fig. 1 (left). The relative errors are equal to those of the electrons' cross section in the corresponding bin. The additional systematic error due to the extrapolation method is smaller than 5% and, thus, negligible with respect to the other systematic uncertainties. In the same picture, predictions for two quenching scenarios with $m_b = 0$ and $m_b = 4.8$ GeV are reported. The two bands, delimited by lines with the same thickness, cover the extreme values of $\hat{q} = 25$ and 100 $\text{GeV}^2/\text{fm}$. The variable $\hat{q}$ is the time-dependent BDMPS model [13] transport coefficient and it is defined as the time-averaged squared transverse momentum transferred from the medium to the hard parton per unit path length. Comparison of Pb–Pb and *pp* data will allow us to test the predicted mass dependence of parton energy loss (see [14] for details).

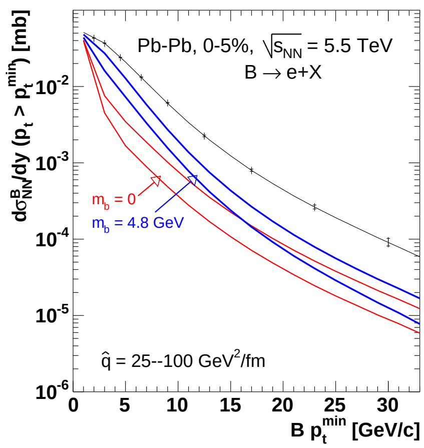


Fig. 2. Top line: minimum-$p_t$-differential production cross section per nucleon–nucleon collision for $B$ mesons, as it can be measured with $10^7$ central Pb–Pb events. The errors, statistical and systematic, are reported for completeness. A normalisation error of 9% on the absolute cross section is not shown.

## 4. Beauty detection in the semimuonic channel

The ALICE muon spectrometer is equipped with a front absorber $\sim 10$ interaction lengths thick (the total thickness traversed in the muon arm is 15 interaction lengths) able to suppress charged particles heavier than muons, electrons and photons. It is worth to note that pions and kaons are stopped mostly before their weak decay. Tracking chambers, all two-layered, are placed in 5 stations. The minimum requirement for trackability is a signal in one layer in each of the first three stations and 3 signals in stations 4 and 5. Two stations of 4 chambers each provide trigger capability. The $p_t$ resolution is better than 2% and triggering is possible at a threshold as low as 1 GeV.

### *4.1. Muon sample composition*

Fig. 3 (left) shows the number of muons per central Pb–Pb event detected in the spectrometer with a trigger cut $p > 1$ GeV/$c$, as a function of their minimum transverse momentum. Below a transverse momentum of

$\sim 1.5$ GeV/$c$, contributions from charm and decay muons dominate while at larger transverse momentum beauty decays become the largest source. This value of $p_{\rm t}$ has been chosen as an additional threshold at the analysis level also to reduce the effect of trigger inefficiencies. The main source of background are the muonic decays of $\pi/K$, which contribute with 8 muons (if no momentum threshold is applied) in the spectrometer acceptance per Pb–Pb event. The combinatorial background generated will be subtracted by the event mixing technique. In this study the hypothesis has been done of perfect background subtraction. In the same figure (right) is reported the total efficiency for single muon detection and the contribution from trigger, acceptance and tracking efficiencies, in order of decreasing importance. The total value of 88% is attainable at $p_{\rm t} > 4$ GeV, with a minimum value of 80%.

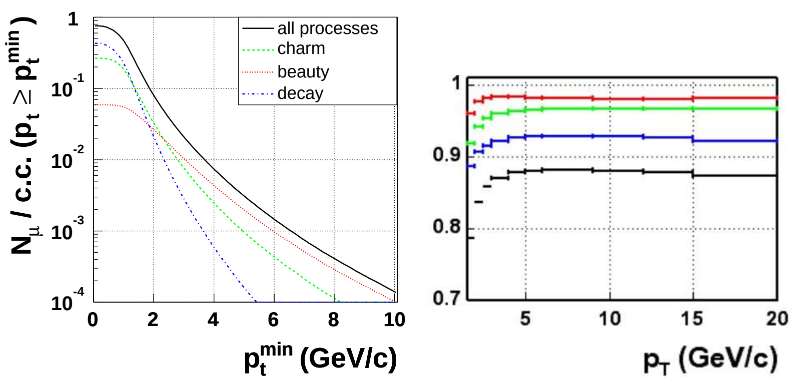


Fig. 3. Left: Number of muons above a threshold $p_{\rm t}^{\rm min}$ per central Pb–Pb collision (5% centrality) detected in the muon spectrometer including the trigger cut-off $p > 1$GeV/$c$. Right: Efficiency for the detection of single muons. Lines refer, from top to bottom, to: trigger, acceptance, tracking, total.

### *4.2. B meson level cross section*

In order to extract the beauty cross section a global fit has been applied to three different samples: low and high mass dimuons ($M < 5$ GeV/$c^2$ and $5 < M < 20$ GeV/$c^2$, respectivly) and single muons. The shapes of muons $p_{\rm t}$ distribution and dimuons mass distribution have been assumed, based on available calculations. Then, only the amplitudes of beauty and charm cross section are the free parameters of the fit. In order to perform a more stringent test, the dimuon sample has been divided in two parts containing same-sign and opposite-sign pairs, originated by different processes.

The cross section of beauty-decays muons is then extrapolated to the $b$-hadron level by the same method as for the electrons. The result is shown in Fig. 4, where the input distribution is also reported.

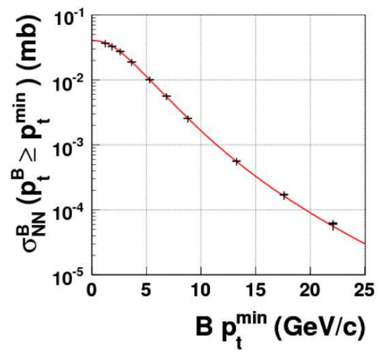


Fig. 4. Inclusive $b$-hadron cross section in $-4 < y^B < -2.5$ as a function of $p_{\rm t}^{\rm min}$. The line represents the input distribution (see [15] for details).

Error bars take into account both statistical and systematic errors. The latter include the error on the $\sigma$ calculation, the background model and the extrapolation to the $b$-hadron cross section, the total systematic $p_{\rm t}$-dependent error being is 10–11% up to $p_{\rm t} = 12$ GeV/$c$. Monte Carlo corrections are accounted for with a conservative 10%. The error on absolute normalization (9%) is not included. For more details the reader is referred to [15].

## 5. Conclusions

ALICE will measure at the same time beauty production in the semielectronic and semimuonic channels, in two different rapidity ranges. The beauty promises to be a particularly interesting probe for the study of hot and dense matter formed in nucleus–nucleus collisions at LHC. Our ability to measure $b$-hadrons in a wide transverse momentum range will allow us to constrain pQCD calculations. The measurement of the $p_{\rm t}$-differential production cross section will provide a tool to probe the properties of the partonic medium through the quenching mechanism. It will also provide us with the baseline against which the studies of quarkonia suppression should be performed.

## REFERENCES

[1] ALICE Collaboration, Physics Performance Report vol. I, *J. Phys.* **G30**, 1517 (2004).

[2] J.C. Collins, M.J. Perry, *Phys. Rev. Lett.* **34**, 1353 (1975); N. Cabibbo, G. Parisi, *Phys. Lett.* **59B**, 67 (1975); E.V. Shuryak, *Phys. Rep.* **61**, 71 (1980).

[3] ALICE Collaboration, Physics Performance Report, vol. II, *J. Phys.* **G32**, 1295 (2006).

[4] C. Bombonati *et al.*, ALICE Internal Note, to be published.

[5] K.J. Eskola, P.V. Ruuskanen, S.S. Räsänen, K. Tuominen, `hep-ph/0104010`.

[6] M. Mangano, P. Nason, G. Ridolfi, *Nucl. Phys.* **B373**, 295 (1992).

[7] N. Carrer, A. Dainese, ALICE Internal Note INT-2003-019 (2003), `hep-ph/0311225`.

[8] F. Antinori, A. Dainese, M. Lunardon, R. Turrisi, ALICE Internal Note INT-2005-033 (2005).

[9] A. Dainese, R. Turrisi, ALICE Internal Note INT-2003-028 (2003).

[10] A. Dainese, Ph.D. Thesis, Università degli Studi di Padova (2003), `nucl-ex/0311004`.

[11] C. Albajar *et al.*, UA1 Coll., *Phys. Lett.* **B213**, 405 (1988); C. Albajar *et al.*, UA1 Coll., *Phys. Lett.* **B256**, 121 (1991).

[12] D. Abbaneo *et al.*, ALEPH Coll., CDF Coll., DELPHI Coll., L3 Coll., OPAL Coll., SLD Coll., SLAC-PUB-9500, CERN-EP-2001-050, `hep-ex/0112028`.

[13] R. Baier, Y.L. Dokshitzer, A.H. Mueller, S. Peigné, D. Schiff, *Nucl. Phys.* **B420**, 583 (1994).

[14] N. Armesto, A. Dainese, C. Salgado, U.A. Wiedemann, *Phys. Rev.* **D71**, 054027 (2005).

[15] P. Crochet, R. Guernane, A. Morsch, E. Vercellin, ALICE Internal Note ALICE-INT-2005-018 (2005).