Measuring beauty production in Pb–Pb collisions at the LHC via single electrons in ALICE

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We present the expected ALICE performance for the measurement of the p_t-differential cross section of electrons from beauty decays in central Pb–Pb collisions at the LHC.

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1 Introduction

The ALICE experiment[1] will study proton–proton, proton–nucleus and nucleus–nucleus collisions at the LHC, with centre-of-mass energies per nucleon–nucleon (NN) pair, \( \sqrt{s_{NN}} \), of 5.5 TeV for Pb–Pb, 8.8 TeV for p–Pb, and 14 TeV for pp. The primary physics goal of ALICE is the study of the properties of QCD matter at the energy densities of several hundred times the density of atomic nuclei that will be reached in central Pb–Pb collisions. Under these conditions a deconfined state of quarks and gluons is expected to be formed. Heavy quarks, and hard partons in general, would probe this medium via the mechanism of QCD energy loss. In particular, measuring the high-\( p_t \) suppression of beauty hadrons and comparing it to that of light-flavour and charm hadrons, would allow us to investigate the predicted quark-mass dependence of parton energy loss[2]. Besides energy loss studies, the measurement of the beauty cross section provides the normalization for quarkonia production, needed to address medium effects on quarkonia.

2 Expected rates and detection strategy

Beauty decays with an electron in the final state have a ‘global’ branching ratio of \( \approx 21\%: \approx 11\% \) for direct semi-electronic decays, \( B \to e\nu + X \), and \( \approx 10\% \) for semi-electronic decays via a charm hadron, \( B \to D(\to e\nu + X) + X’ \)[3]. The heavy-flavour production yields in Pb–Pb collisions, used as a baseline for the ALICE performance studies, are obtained[4] by scaling, according to the number of binary collisions, the results of QCD calculations at next-to-leading order accuracy for pp collisions[5]. The expected yields of beauty hadrons and beauty-decay electrons in a 0–5% central Pb–Pb collision at \( \sqrt{s_{NN}} = 5.5 \) TeV are about 9.0 and 1.9, respectively, of which about 1/4 within the ALICE central barrel acceptance \( |\eta| < 0.9 \).

As in central Pb–Pb collisions at the LHC between 3000 and 10000 charged hadrons may be produced in the region \( |\eta| < 0.9 \), high-performance electron identification will be necessary. In ALICE, a combined selection on \( dE/dx \), measured...
in the Time Projection Chamber (TPC), and transition radiation, measured in the Transition Radiation Detector (TRD), is expected to reject 99.99% of the pions (10^{-4} misidentification probability) and 100% of the heavier hadrons, while correctly tagging 80% of the electrons.

The main sources of background electrons are: decays of primary D mesons, which have a branching ratio of \approx 10% in the semi-electronic channels [3], and an expected production yield larger by a factor about 20 with respect to that of B mesons [4]; \pi^0 Dalitz decays and decays of light mesons (mainly \rho, \omega, K); conversions of photons in the beam pipe or in the inner layer of the Inner Tracking System (ITS), and pions misidentified as electrons.

Given that electrons from beauty have average transverse impact parameter (distance of closest approach to the interaction vertex in the plane transverse to the beam direction) \( d_0 \approx 500 \, \mu \text{m} \), it is possible to minimize the background contributions by selecting electron tracks displaced from the primary vertex. Tracking in the TPC and ITS, that includes two layers of silicon pixel detectors, provides a measure of the impact parameter with a resolution \( \sigma_{d_0} [\mu \text{m}] \approx 11+53/(p_t [\text{GeV}/c]) \), i.e. better than 65 \, \mu \text{m} for \( p_t > 1 \, \text{GeV}/c \). The \( d_0 \) distributions reported in Fig. 1 (left) show that a lower cut on the impact parameter allows to reject misidentified \( \pi^\pm \) and \( e^\pm \) from Dalitz decays and photon conversions (the former mostly come from the primary vertex and the latter have small impact parameter for \( p_t > \sim 1 \, \text{GeV}/c \)).

### 3 Results: sensitivity on the b-decay electron cross section

As it can be seen from Fig. 1 (left), the impact parameter cut \( d_0 > 200 \, \mu \text{m} \) is expected to give a b/c ratio larger than unity for the electron sample with \( p_t > 1 \, \text{GeV}/c \). This cut also removes most of the background electrons from \( \pi^0 \) Dalitz decays and \( \gamma \) conversions, as well as the primary \( \pi^\pm \) misidentified as electrons.

The expected statistics for electrons from b decays for \( 10^7 \) central Pb–Pb events (one month of data taking at nominal Pb–Pb luminosity) is shown in the right-hand panel of Fig. 1 along with the residual background contributions. About \( 8 \times 10^4 \) beauty electrons are expected above 2 \, GeV/c in \( p_t \), allowing the measurement of the \( p_t \)-differential cross section in the range \( 2 < p_t < 18 \, \text{GeV}/c \). The residual contamination of about 10% of electrons from prompt charm decays, from misidentified charged pions and \( \gamma \)-conversion electrons is accumulated in the low-\( p_t \) region.

After applying the \( d_0 \) cut, in a given \( p_t \) interval [e.g. the bins in Fig 1(right)], \( N \) ‘electrons’ will be counted, being the sum of different contributions, \( N = N_b \) (beauty) + \( N_c \) (charm) + \( N_{bkg} \) (bkg e and misid. \( \pi \)). The following procedure is foreseen to extract the cross section of electrons from beauty.

1. Subtraction of charm decay electrons. We plan to use the cross section for \( D^0 \) mesons, measured in ALICE in the \( K^-\pi^+ \) decay channel [3, 7], to estimate the \( N_c \) contribution. This will introduce a systematic error coming from the statistical and systematic errors on the \( D^0 \) cross section. The error is expected to be smaller than 5% for \( p_t > 2 \, \text{GeV}/c \).

2. Subtraction of the remaining background electrons and misidentified pions,
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Fig. 1. Left: impact parameter distribution for identified electrons from beauty decays, from charm decays, identified electrons from the background and pions tagged as electrons. Combined TPC–TRD identification is applied. Right: expected statistics in counts/bin for $10^7$ central Pb–Pb events (one month of data taking) for electrons from beauty, from charm and for the background (misidentified pions or electrons from other sources), with the cut $d_0 > 200 \, \mu m$.

on the basis of Monte Carlo simulations tuned on the measured light-flavour hadron production. This subtraction also introduces a systematic error, which we currently assume to be small, i.e. negligible with respect to other error sources.

3. Correction of the number of beauty electrons, $N_b = N - N_c - N_{bkg}$, for efficiency ($d_0$ cut, electron ID, tracking) and acceptance: $N_b^{corr} = N_b / \epsilon$. The correction will be done via Monte Carlo and we assume a systematic error of about 10% on the correction factor $1 / \epsilon$.

4. Normalization of the corrected yield to a cross section for beauty electrons per binary collision in a given Pb–Pb centrality class (e.g. 0–5%), $\sigma_{b}^{NN}$. For the 0–5% class, a systematic error of about 9% is expected to be introduced in the determination of the correction factor, which is proportional to the average number of binary collisions in the considered centrality class.

Figure 2 (left) shows a summary of the relative errors on beauty electrons, as a function of $p_t$. Besides the systematic errors, we also show the relative statistical error $\sqrt{N_b + N_c + N_{bkg}} / N_b$: it is expected to increase from less than 1% at $p_t = 2 \, \text{GeV/c}$ to about 12% at 18 GeV/c, for $10^7$ central events (one month at nominal luminosity). The expected quality of the measured beauty electron cross section is shown in Fig. 2 (right). A procedure to extract, starting from the $e$-level cross section, a B-level cross section (as a function of $B_p_{t\min}$) is under study. Note that
no medium-induced high-$p_t$ suppression is included in the results shown in Fig. 2; the predicted suppression of a factor 4–5 [2] would increase the relative statistical errors by a factor about 2.

Preliminary simulation results on the ALICE capability to perform this measurement in pp collisions indicate that, combining Pb–Pb and pp data, the nuclear modification factor of electrons from beauty can be obtained with good precision in the range $2 < p_t < 20$ GeV/c. This would allow us to test the predicted mass-dependence of parton energy loss in the medium formed in Pb–Pb collisions.

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