BEAUTY PRODUCTION WITH THE ALICE DETECTOR

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Heavy flavour pairs produced in hadronic reactions provide a valuable laboratory for the study of strong interactions. Due to their relatively large mass, the production of heavy quarks should be reliably calculable in the perturbative approach. Charm and beauty quarks once produced in a heavy ion collision have to propagate through the surrounding quark-gluon matter. Heavy quark states are then a sensitive probe of the properties of the dense medium. ALICE is a general-purpose experiment equipped to reconstruct, among other signals, leptons from open charm and beauty via their leptonic decays in p-p, p-A and A-A collisions. In these proceedings, we present feasibility studies for ALICE measurements of beauty production in central Pb-Pb collisions at $\sqrt{s_{NN}} = 5.5$ TeV using semileptonic decays.

1 Why studying heavy quarks in high energy nuclear collisions?

ALICE (A Large Ion Collider Experiment) is a detector dedicated to the study of nucleus-nucleus interactions at the LHC. It will investigate the physics of strongly interacting matter at extreme energy densities, where the formation of a new phase of matter, the QGP (Quark-Gluon Plasma) is expected. Heavy flavour physics is an important part of the ALICE experimental programme in many respects. As an intrinsically perturbative phenomenon heavy quark production is a key benchmark for testing QCD and parton model concepts in a novel kinematic region of large $Q^2$ and very low Bjorken-$x$ (as low as about $10^{-5}$) becoming accessible at the LHC. In the context of heavy ion collisions, open heavy quark production is sensitive to gluon shadowing effects in nuclei. Moreover, due to their long lifetime heavy quarks live through the thermalization phase of a QGP and therefore carry information about the deconfined medium. Measuring the beauty hadron production down to the very low $p_t$ region where the ALICE detector has been optimized for tracking and particle identification (cf. section 3) – is essential to minimize the extrapolation uncertainty on the total cross section. In addition, the low $p_t$ region will be influenced by non-perturbative effects which can differ from p-p to A-A collisions. For heavy quarkonium physics, the measurement of the beauty quark yield in the same kinematic region as for the $\Upsilon$ measurement will provide a valuable reference against which to compare $\Upsilon$ production in order to observe a possible suppression in A-A collisions. In the following, we will present the expected performance of the ALICE detector – presently under construction – for beauty production measurements in semileptonic decay channels.

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2 Production of $b$-quarks at LHC

Heavy quarks are produced in hadron-hadron collisions at LHC energies by strong interaction processes described within the QCD theory. Production cross section can be computed in the framework of the factorization theorem of the QCD parton model as the convolution of parton-parton scattering cross sections (calculable in pQCD) with parton distribution functions. QCD higher order corrections to the Born reactions have to be considered at LHC energies. Fixed-order NLO calculations of heavy quark production cross sections are available and have been used to define the ALICE baseline. In the analysis presented hereafter, the Pythia 6.214 event generator has been used to produce heavy quarks after tuning to reproduce the relevant NLO differential distributions (namely single quark $p_t$, rapidity, heavy quark pair invariant mass and azimuthal correlation). Rates in heavy ion collisions are then obtained from binary scaling in accordance with the Glauber multiple scattering model. “Known” initial state effects are included (namely primordial transverse momentum and nuclear shadowing). The expected production rates are presented in Table 1.

| Centrality bin | N-N cross section [mb] | EKS98 shadowing factor | N_QQ/Pb-Pb collision | N_QQ/10^6 s [x10^{10}] |
|----------------|------------------------|------------------------|-------------------|------------------------|
| $0 \div 5\%$     | $6.64$                 | $0.65$                 | $115.8$           | $2.1$                  |
| Min. Bias        |                        |                        | $25.3$            | $9.3$                  |
| $0 \div 5\%$     | $0.21$                 | $0.86$                 | $4.8$             | $0.09$                 |
| Min. Bias        |                        |                        | $1.0$             | $0.4$                  |

3 Overview of the ALICE detector for lepton detection

Both electrons and muons are measured in ALICE, electrons in the central barrel and muons in a dedicated forward spectrometer. Central detectors, covering mid-rapidity ($|\eta| \leq 0.9$) over the full azimuth, are embedded inside the L3 solenoidal magnet providing a magnetic field of $\leq 0.5$ T. Electrons are identified in ALICE combining the TRD (Transition Radiation Detector) and TPC (Time Projection Chamber) particle identification capabilities. TRD provides an $e/\pi$ rejection power of 100 supplemented by the specific electron energy loss in the TPC which allows to reach a combined pion rejection factor of 10,000. The ALICE forward muon spectrometer has been designed to detect muons emitted in the pseudo-rapidity region $-4 \leq \eta \leq -2.5$. The forward muon spectrometer is made of a passive front absorber of 10 interaction lengths to absorb hadrons and photons from the interaction vertex, a high-granularity tracking system of 10 cathod pad chambers, a large dipole magnet creating a field of 0.7 T (field integral of $3 \text{T} \cdot \text{m}$), and a trigger system performing the selection of heavy flavour decay muons by a transverse momentum cut-off made of four resistive plate chambers. Muons penetrating the whole spectrometer length are finally identified with a momentum resolution of about 1% and 90% efficiency (for $p_t > 3$ GeV/c).

4 Beauty production measurements from semileptonic decays

The copious beauty production at the LHC will be measured with the ALICE detector using $b$-hadron semileptonic decays characterized by large branching ratios. Leptons can indeed be produced both from direct decay $b \rightarrow \ell^-$ (BR $\simeq 10\%$) and cascade $b \rightarrow c \rightarrow \ell^+$ (BR $\simeq 8\%$).
After extracting the beauty signal in lepton data sets, $b$-hadron production cross sections are assessed by unfolding $b \rightarrow \ell$ decay.

**Single inclusive $b$-quark production via muon detection**

Beauty production in Pb-Pb collisions will be measured in ALICE using semileptonic decay muons in the pseudo-rapidity region $-4 \leq \eta^\mu \leq -2.5$. Both inclusive muon and opposite sign dimuon productions are considered, the dimuon sample being divided into two topologically distinct contributions: $b$-chain decays (named BD$_{\text{same}}$ hereafter) of low mass $M_{\mu\mu} < 5\, \text{GeV}/c^2$ and high transverse momentum (cf. Fig. 1(a)) and muon pairs where the two muons originate from different quarks (BB$_{\text{diff}}$) emitted at large angles resulting in large invariant masses $M_{\mu\mu} > 5\, \text{GeV}/c^2$ (cf. Fig. 1(b)). Beauty signal is enhanced with respect to other sources (charm and $\pi/K$ decay-in-flight) applying a low $p_t$ cut-off of $1.5\, \text{GeV}/c^{11}$. Using Monte Carlo predicted line shapes for $bb$, $cc$, and decay background, fits are carried out to find the $b\bar{b}$ fraction in the different data sets as presented in Fig. 1(a), (b), and (c). Finally muon level cross sections are converted into inclusive $b$-hadron cross section following the method initially developed for the UA1 experiment$^{12}$. The $b$-hadron cross section measurement is plotted in Fig. 1(d), it shows no systematic bias with respect to the initial distribution used in the simulation to produce beauty signal even if a detailed study of systematic uncertainties has still to be done. $b$-decay muon statistics is large over the whole $p_t$ range allowing a tight mapping of the production cross section up to $p_t = 30\, \text{GeV}/c$.

![Figure 1](image-url)

*Figure 1:* Background subtracted invariant mass distributions of $\mu^+\mu^-$ pairs produced in the 5% most central Pb-Pb collisions at 5.5 TeV in the low (a) and high mass regions (b). A $p_t > 1.5\, \text{GeV}/c$ cut-off has been applied to muon tracks. Charm and beauty signals are plotted in green dashed and red dotted line respectively. (c) Single muon transverse momentum distribution. (d) Inclusive $b$-hadron cross section in $-4 < y^B < -2.5$ as a function of $p_t^{\text{min}}$. Also shown the PYTHIA prediction (dotted line) used to produce the signal.
**Single inclusive b-quark production via electron detection**

Electrons from semileptonic decay of b-quarks are characterized by a hard $p_t$ spectrum and a large average impact parameter $\langle d_0 \rangle \sim 300 \mu m$ with respect to other electron sources (pion misidentification, charm, light mesons, and photon conversions). The beauty signal purity and statistics as a function of the impact parameter cut-off for different values of the $p_t$ threshold are shown in Fig. 2 a) and b) respectively. $p_t > 2 \text{ GeV}/c$ and $200 < |d_0| < 600 \mu m$ provide an electron sample of $8 \times 10^4$ with a 90% purity\(^{12}\). An upper limit on $d_0$ is needed to reduce long lived strange particles and tracks suffering from large angle scatterings in detector materials.

![Figure 2](image_url)

**Figure 2:** Signal to background ratio (a) and signal (b) for beauty decay electrons in $10^7$ central Pb-Pb events (5%), corresponding to about one month of LHC data taking.

### 5 Conclusion

The ALICE detector has good capabilities for heavy flavour measurements\(^{14}\) with the unique ability to address the b-quark sector in p-p, p-A and A-A collisions with relatively low transverse momentum thresholds. The measurement of $b$ production provides an important test of the theory of QCD in heavy ion collisions where new effects are expected as compared to nucleon-nucleon interactions. A precise measurement of the inclusive $d \sigma^B/dp_t$ cross section will allow to probe in-medium quenching effects. Channels discussed in these proceedings will be supplemented by measuring dilepton correlations, multi-muon topologies, and $b$-tagged jets. Quantitative studies are currently underway.

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\(^{6}\)Defined as the distance of closest approach of the electron track to the primary vertex in the transverse plane. $d_0$ is measured by the ALICE Inner Tracking System (ITS) with a resolution $\lesssim 70 \mu m$ at $p_t = 1 \text{ GeV}/c$. 
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