Proc. 23rd Winter Workshop on
Nuclear Dynamics (2007) 000–000

23rd Winter Workshop
on Nuclear Dynamics
Big Sky, Montana, USA
February 11–18, 2007

Reconstructing Bottom mesons using displaced vertices from semi-leptonic decays

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Abstract. Precise determination of heavy flavor production cross-sections at LHC energies will be of primary importance. The produced heavy quarks are expected to be sensitive probes of parton energy loss in the medium formed in heavy-ion collisions. Through the measurement of charm and bottom suppression in $Pb + Pb$ with respect to $p + p$, we hope to obtain insight into the color-charge and quark mass dependence of the energy loss mechanism. The ALICE experiment with its large acceptance is well suited to investigate the intermediate transverse momentum spectrum of heavy flavor mesons where these energy loss effects are expected to be visible. ALICE has very good electron PID capabilities over a large kinematical range using Time Projection Chamber (TPC), Transition Radiation Detector (TRD) and the Electromagnetic Calorimeter (EMCal). In addition the EMCal, to be installed for the $Pb + Pb$ runs, is planned to allow efficient triggering on high-p_T jets. We first introduce the EMCal project and an overview of detector specifications. Then we introduce a method developed to select preferentially electrons from heavy flavor decays by reconstructing displaced secondary vertices. The strategy is to reconstruct displaced vertices from semi-leptonic heavy flavor meson decays using the excellent spatial resolution of the Inner Tracking System (ITS). We show preliminary results of an efficiency study from charm vs. bottom vertices.

Keywords: ALICE, EMCal, bottom, jet-tagging
PACS: 25.75.Dw, 25.40.Ep, 24.10.Lx

1. Introduction

The ALICE experiment is a dedicated heavy-ion experiment at the Large Hadron Collider (LHC) at CERN in Geneva, Switzerland. The LHC will provide for $p + p$ collisions at $\sqrt{s} = 14$ TeV as well as $Pb + Pb$ and $p + Pb$ heavy-ion collisions at $\sqrt{s} = 5.5$ TeV respectively $\sqrt{s} = 8.8$ TeV.

The EMCal in ALICE will be ideally suited for the study of QCD matter at high temperatures by probing the hard parton scattering processes. Once integrated into ALICE the EMCal will allow triggering on high-p_T particles such as photons, π^0 and electrons. In particular, one of the goals is to study fragmentation functions by tagging jets with a specific quark content, e.g. heavy flavor or b-jets.

The importance of identifying heavy flavor jets at ALICE is twofold. First, from a basic perturbative QCD standpoint the precise determination of transverse momentum spectra for charm and bottom hadrons is of primary importance in understanding the production mechanisms of heavy quarks. The current theoretical fixed-order next-to-leading log calculations (FONLL) still carry large uncertainties due to poorly known heavy quark masses and differences in parton distribution functions [1]. Second, the propagation and energy loss of heavy quarks in the dense medium created in heavy-ion collisions is of great interest since these 'hard' probes will help determine basic properties of the medium. Recent measurements at RHIC have shown that the non-photonic electrons, expected to mainly originate from heavy flavor decays, are strongly suppressed, possibly indicating that the energy loss of charm and bottom quarks is larger than predicted by theoretical calculations using radiative energy loss [2, 3, 4]. In order to understand this discrepancy we need to measure charm and bottom energy loss separately at the LHC. In section 3 of this paper a method is described for measuring B-mesons via their semi-leptonic decay channel.

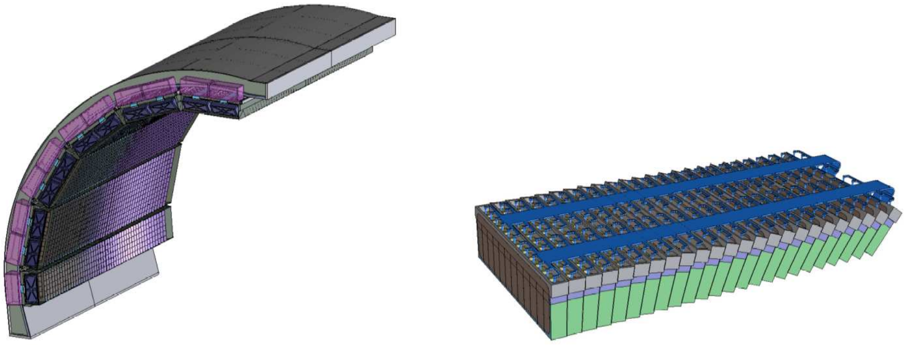

(a) (b)

Fig. 1. (a) Drawing of complete EMCal with 11 supermodules mounted on the support structure, (b) Drawing of supermodule consisting of 12 x 24 modules

2. ALICE EMCal

The ALICE EMCal is proposed to enhance ALICE's high momentum particle measurements and, in particular, improve its capabilities for the jet quenching measurements. It will also allow implementation of high-level jet-triggers which should significantly improve both the statistics and the energy resolution of jets. Further, the EMCal will complement ALICE's particle identification (PID) capabilities for high momentum photons, neutral pions and electrons.

The project is jointly funded by US, French and Italian institutes. The ALICE-USA collaboration counts 12 member institutions involved in the EMCal project. After initial funding approval, expected in September 2007, the construction will commence and first supermodules should be delivered to CERN in early 2009. The installation of all 11 supermodules, to be assembled in the US and France, is foreseen to be completed in 2011.

The conceptual design of the EMCal is based on the Shashlik technology as implemented for example in the PHENIX experiment at RHIC [5]. Figure 1(a) shows the EMCal supermodules mounted in the installed position on their support structure. They each span about 20 degrees in azimuth and about 0.7 units of pseudorapidity. There are 10 full size and 2 half-sized supermodules in the full detector acceptance. Figure 1(b) shows a detail of the supermodule which is the basic structural unit of the calorimeter and consists of 288 modules (12x24). The full detector spans $\eta = [-0.7, 0.7]$ with an azimuthal acceptance of $\Delta\phi = 110\,\text{deg}$.

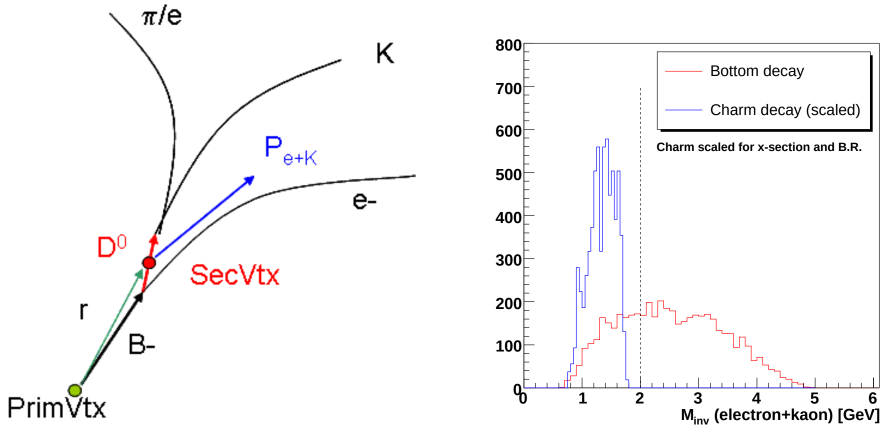
The chosen technology is that of a layered Pb-scintillator sampling calorimeter with a longitudinal pitch of 1.44mm Pb and 1.76 mm scintillator with longitudinal wavelength shifting fibre light collection (Shashlik). The EMCal is segmented into 12672 towers, grouped into 2x2 modules, each of which is approximately projective to the interaction vertex in η and ϕ. The front face dimensions of the towers are 6x6 cm^2 (Moliere radius $\sim$ 2cm) resulting in individual tower acceptance of $\Delta\eta \times \Delta\phi = 0.014 \times 0.014$. The energy resolution as determined from GEANT simulation is $12\%/\sqrt{E} + 2\%$. A more detailed description of the detector and its expected performance can be found in [6].

The EMCal will improve the PID coverage for photon/π^0 discrimination through cluster shape analysis. Further electron/hadron separation can be achieved by the energy/momentum method (chapter 7.4 [6]).

3. Reconstructing B-jets via displaced vertices

Several methods for identifying heavy flavor decays via the semi-leptonic channel have been discussed in the ALICE PPR Vol 2 [7]. The method described herein is complementary to these methods and is especially well suited for high-p_T electrons which can be identified with a combination of ALICE detectors as mentioned earlier.

The method was first utilized in the CDF experiment to identify bottom via their muon decay channels [8]. It relies on the fact that the approximate position of the semi-leptonic B-decay vertex can be reconstructed using two tracks, one of which is the lepton. B-meson decays have a $c\tau \sim 500\mu$m making it easier to resolve this secondary vertex than for charm ($c\tau 100 - 300\mu$m). At the B-decay vertex a lepton and a charmed meson ($D^0, D^\pm, D^*$) is often produced and subsequently decays into charged hadrons. The method starts off by finding high-p_T electrons



(a) (b)

Fig. 2. (a) Scheme of the preferred B^- decay (only charged tracks shown), (b) Invariant mass (assuming the kaon mass for the hadron) before geometrical cuts of electron+hadron pair for charm vs bottom decays. The charm curve (blue) was scaled for the expected ratio (pQCD) in cross-section (factor 22.0) and semi-leptonic branching ratios (factor 0.87). The vertical line indicates the chosen cut value for this study.

and combining them with all charged particles within a wide jet-cone of radius $dR^2 = \Delta\eta^2 + \Delta\phi^2 < 1.5$. As shown in figure 2(a) using any two tracks (electron + kaon/pion) an approximate secondary vertex can be calculated from their distance of closest approach (DCA). For this study we assume that the charm decay length is not resolved and therefore the length of the vector r (see figure 2(a)) approximates the displaced vertex. There are other decays in which the electron originates from a D or the associated hadron is produced directly at the B-vertex. Using r and the momentum-sum of the electron and pion/kaon $p_{e+K/\pi}$ (which carries most of the B-meson momentum) a quantity called the signed decay-length, L_{xy} is defined in the bending plane according to equation 1.

$$L_{xy} = \frac{r \cdot p_{e+K}}{|p_{e+K}|} = |r| \cdot cos(\theta) \tag{1}$$

For ‘real’ decays this quantity naturally has to be larger than 0 since the angle θ between r and p_{e+K} is less than 90 degrees. Background pairs, on the other hand, are assumed to be evenly distributed over all values of θ. The background trigger electrons for this method will mainly consist of electrons from photonic decays (conversions, $\pi^0 \rightarrow \gamma\gamma$), π^0 dalitz decays, and electrons from semi-leptonic decays of primary charm hadrons.

Since the charm cross-section is about 20 times larger (at 14 TeV) than the

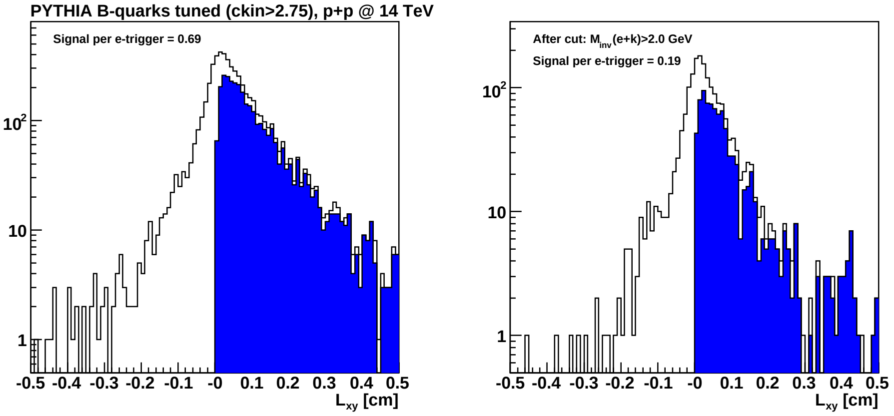


Fig. 3. L_{xy} of bottom sample before (left) and after (right) invariant mass cut. The blue histograms are signal distributions after subtraction of the negative L_{xy} part.

bottom cross-section it is necessary to find an efficient way of eliminating the charm signal in our sample. As shown in figure 2(b) this can be done by applying a lower cut on the invariant mass of the electron and the hadron, under the assumption that the hadron is a kaon (using the pion mass works equally). For charm decays this quantity is approximately bounded by the charm meson mass, i.e. ~ 1.9 GeV. For bottom decays it is bounded by the bottom meson mass, 5.279 GeV, which is much higher.

4. Simulation results

We started by applying this method to ALICE PYTHIA simulations in order to get a first estimate of bottom signal efficiency and charm rejection rate. Since the simulation code is still subject to frequent modifications it is useful to state that these results are based on the ALIROOT HEAD version of November 2006 [9]. These simulation do not yet include all detector material and misalignment they are to be considered idealistic.

In order to obtain initial efficiency estimates of this method three simulation samples were produced:

a. PYTHIA (tuned to match NLO) bottom sample ($b - \bar{b}$) from 14 TeV $p + p$ collisions with forced semi-leptonic decay. 40k events.

b. PYTHIA (tuned to match NLO) charm sample ($c - \bar{c}$) from 14 TeV $p + p$ collisions with forced semi-leptonic decay. 40k events.

c. PYTHIA minbias sample (suppressed B,D decays) from 14 TeV $p{+}p$ collisions. 100k events.

The first sample (a) allowed signal efficiencies for different particle and vertex selection cuts to be determined. The second (b) and third sample (c) were used to estimate the backgrounds from charm decays respectively photonic conversions and π^0 decays in $p+p$ collisions. For this first study we applied the following electron, hadron and vertex selection cuts. To reduce the computing time for simulations we here only used electron PID from the TPC, but will include TRD and EMCal in the future.

- Electrons: TPC-PID probability $>$ 80% (dE/dx, as implemented in class AliPID, Section 5.4.6 of [7]), p_T >1.5 GeV/c, 4 or more ITS-Hits, impact(xy)< 0.5 cm, impact(z)< 1.0 cm
- Hadrons: 4 or more ITS-Hits, impact(xy)< 0.5 cm, impact(z)< 1.0 cm
- Vertex: DCA between electron-hadrons< 1 mm, distance to primary vertex < 1 cm,

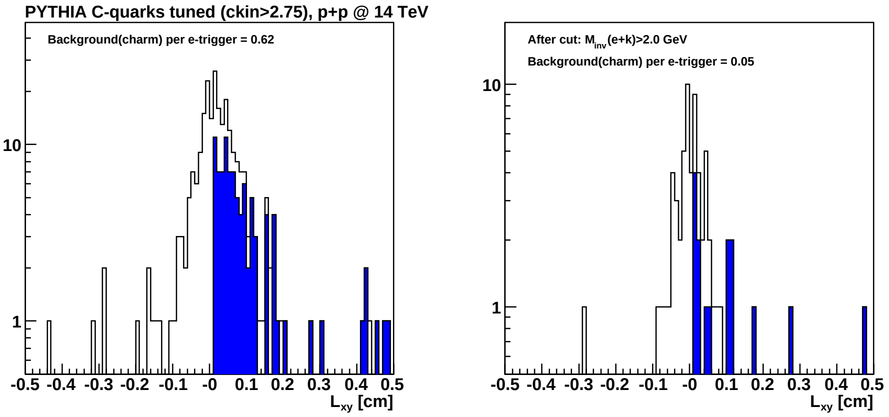


Fig. 4. L_{xy} of Charm sample before (left) and after (right) invariant mass cut

Using the above selection cuts we have analyzed the 3 simulation samples and obtained signed decay-length distributions. Figure 3 shows the result of the pure bottom production (sample a). The signal (blue area) is defined as all positive entries ($S+B: L_{xy}^{pos} > 0$) minus all negative entries ($B: L_{xy}^{neg} < 0$). The total signal is normalized by the number of electron triggers. For the pure B-sample the efficiency with these cuts is $\sim$ 70%, whereas we reject $\sim$ 30% of the signal due to other B-decay topologies and resolution effects. Figure 3(b) shows the signed decay-length distribution after applying the invariant mass cut.

In figure 4 we have applied the same method to a comparable sample of charm mesons. Although the number of trigger electrons passing our p_T cut is lower due to the different kinematics, the signal per electron trigger is not very different, i.e. 62%. This invariant mass cut reduces our bottom-efficiency to $\sim 20\%$ and our charm-efficiency to $\sim 5\%$. According to pQCD, the decay electron yield from charm and bottom at 2-3 GeV/c is of comparable magnitude. By imposing an even tighter cut this charm contamination can be reduced even more.

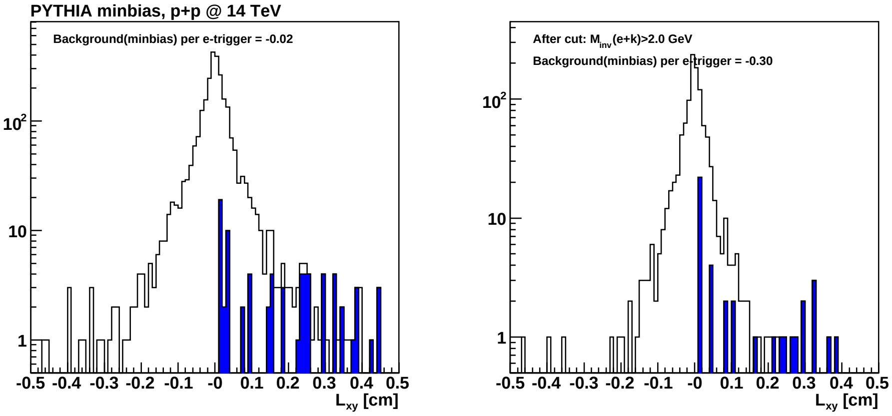


Fig. 5. L_{xy} of Minbias PYTHIA sample before (left) and after (right) invariant mass cut

Finally, figure 5 shows the signal for the PYTHIA Minbias sample containing no B-decays with and without invariant mass cuts. Clearly the statistics is not sufficient to make any quantitative statements, however using these cuts the signal from this sample is negative, due to the large contribution from photonic conversion decays. The goal is to find optimal cuts to reduce as much as possible these contributions. These studies are still ongoing.

5. Summary and Outlook

A method for identifying heavy flavor jets is presented based on the reconstruction of displaced vertices from semi-leptonic decays. This method can distinguish between bottom and charm contributions to the non-photonic electron spectra. First simulation results in $p + p$ collisions indicate an efficiency for reconstructing B-vertices of $\sim 20\%$. The ALICE EMCal will allow for high-level electron triggering and complement electron PID capabilities of the TPC and TRD.

In the near future more realistic simulations will be produced to fully investigate the potential using also TRD and EMCal electron PID. Next, the backgrounds from conversions and combinatorics in $p + p$ and heavy ion events need to be studied. Finally, possible effects of misalignment in the ITS also need to be simulated.

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