Study of D-mesons using hadronic decay channels with the ALICE detector

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At LHC energy, heavy quarks will be abundantly produced and the design of the ALICE Experiment will allow us to study their production using several channels. We investigate the feasibility of the study of D mesons reconstructed in their exclusive hadronic decay channel. After reviewing the ALICE potential for such studies, we will present some results for the two more promising decay channels i.e. $D^0 \rightarrow K^- \pi^+$ and $D^+ \rightarrow K^- \pi^+ \pi^+$ obtained with 7 TeV pp data and 5.5 A TeV Pb-Pb Monte Carlo data.

1. Motivation

ALICE\textsuperscript{1} is one of the six experiments running at the CERN Large Hadron Collider (LHC). It is conceived for the study of heavy-ion collisions up to an energy of 5.5 A TeV and in particular to explore the QGP phase transition. Since charm and bottom quarks have large mass, they are produced almost exclusively in the initial parton--parton interactions in the heavy-ion collisions. The time scale for a $c\bar{c}$ pair production is $\sim \hbar / (2 m_Q c^2) \approx (0.2 \text{ GeV fm} \text{ c}^{-1})/ (2.4 \text{ GeV}) \approx 0.1 \text{ fm/c}$, which is much smaller than the expected lifetime of the Quark Gluon Plasma $\sim 10 \text{ fm/c}$. Thus heavy quarks are expected to provide information about the hottest initial phase. The measurement of D-mesons can be used to extract the charm production cross section. The measurement of charm cross section in both pp and AA collisions is useful to evaluate the scaling mechanisms which govern the charm production from pp to AA collisions. Several nuclear effect can break the binary scaling estimated on a geometrical basis with the Glauber model\textsuperscript{2}. They are divided into two classes: initial and final state effects. The former, such as nuclear shadowing, affect heavy quark production by modifying the parton distribution functions in the nucleus. Initial state effects can be studied by comparing proton-proton and proton-nucleus collisions. The later can be due to the interaction of the partons in the medium. Partonic energy loss in the medium is the main example of such an effect.

2. The ALICE detector

The ALICE detector consists of two parts: a central barrel, which includes the Inner Tracker System (ITS), the Time-Projection-Chamber (TPC), the Transition Radiation Detector(TRD), the Time-Of-Flight system (TOF), Electro Magnetic Calorimeter (EMCAL) and High Momentum Particle Identification detector (HMPID) all with the full acceptance of $|\eta| < 0.9$ and the forward Muon Spectrometer, covering the pseudorapidity range between 2.4 and 4. For the present study we used the information from the following detector sub-system: The two inner detectors, the ITS and the TPC, allow the reconstruction of charged particle tracks with very good impact parameter and momentum resolution due to their high granularity and provide particle identification via dE/dx measurement. The ITS\textsuperscript{3}, in particular, is a key detector for open heavy flavour studies because it allows to measure the track impact parameter (i.e. the distance of closest approach of the track to the primary vertex) with a resolution better than 80 $\mu$m for $p_t > 1.0$ GeV/c thus providing the capability to detect the secondary vertices originating from heavy-flavour decays. TOF provides particle identification by time of flight measurement and is used for the K/π separation below 2 GeV/c.
3. Charm Reconstruction in the hadronic decay channels

An intensive simulation study of D mesons from hadronic decays has been already done using the decay channels $D^0 \rightarrow K^-\pi^+$ [4,5], $D^+ \rightarrow K^-\pi^+\pi^+$ [6] and $D^{*+} \rightarrow D^0\pi^+$, $D^0 \rightarrow K^-\pi^-\pi^+$ and $D^+_s \rightarrow K^+K^-\pi^+$ [7] showing that ALICE has an excellent capability to carry out such studies. The Reconstruction of heavy-flavoured mesons is a challenging task as these are rare signals and are having large combinatorial background. The detection strategy to cope with such large combinatorial background is based on the selection of displaced-vertex topologies i.e the identification of single track and secondary vertices that are displaced from the interaction vertex. A good alignment between reconstructed D momentum and flight line is required. After the reconstruction, an invariant-mass analysis is used to extract the raw signal yield, which is then corrected for selection and reconstruction efficiency and for detector acceptance. Here we will briefly explain the selection strategy for two decay channel $D^0 \rightarrow K^-\pi^+$ and $D^+ \rightarrow K^-\pi^+\pi^+$ and will show the very first results obtained from a sample of $1.4 \times 10^8$ minimum bias proton-proton events at a centre of mass energy $\sqrt{s} = 7$ TeV [8] collected during April-May 2010 with the ALICE detector at LHC. $D^0 \rightarrow K^-\pi^+$: The main feature of this decay topology (shown in the upper panel of the fig 1) is the large impact parameter of daughter tracks which is of order $100 \mu m$. Two main variables are used to separate the signal from the combinatorial background of opposite sign track pairs: the product of the impact parameters of the two tracks ($d_0^K \times d_0^\pi$) and the cosine of the pointing angle ($\theta_{point}$). The tuning of the cuts has been done in the present study for each separate $D^0$ transverse momentum bin. With $10^9$ p-p events we expect a $p_t$ integrated significance of 50 and larger than 10 for $p_t$ up to $\sim 10$ GeV/c.

$D^+ \rightarrow K^-\pi^+\pi^+$: With respect to the decay $D^0 \rightarrow K^-\pi^+$, this topology is affected by higher combinatorial background but the longer decay length of the $D^+$ meson ($c\tau \approx 311\mu m$ compared to that of $D^0$ meson 123 $\mu m$ ) can be regarded as an advantage for the $D^+$ reconstruction since a more displaced secondary vertex should help in the separation of signal from the background. The main variables to separate the signal from combinatorial background of the three charged track combinations are: the distance between the primary and secondary vertex and the cosine of pointing angle ($\theta_{point}$). If the found vertex really corresponds to the $D^+$ vertex, then $\theta_{point} \approx 0$ and $\cos\theta_{point} \approx 1$. Fig 2 (lower panel) shows the invariant mass spectra for $D^+$ obtained after applying the topological cuts. With $10^9$ pp events, we expect the $p_t$ integrated significance of 49 and larger than 10 for $p_t$ up to $\sim 10$ GeV/c.

4. Expected sensitivity for the comparison to pQCD prediction in pp collisions

Fig. 3 shows the expected relative statistical error on the measured $D^0$ distribution for p-p coll-
lisions at 7 TeV (10^9 minimum bias pp events expected to collect in 2010) and central Pb-Pb collisions at 2.75 TeV (10^7 events expected to collect in 2010).

The accessible \( p_T \) range is 1-20 GeV/c for Pb-Pb and 0.5-20 GeV/c for p-p, with a point-by-point statistical error less than 15-20%. The systematic error (acceptance and efficiency correction, centrality selection for Pb-Pb) is expected to be smaller than 20%. For the case of pp collisions, the experimental errors on the \( p_T \) differential cross section are expected to be significantly smaller than the current theoretical uncertainty from perturbative QCD calculations.

In fig. 4 we superimpose the simulated ALICE measurement points to the prediction band from the MNR fixed order massive calculations and from the FONLL fixed order next-to-leading log calculations [9] for \( D^0 \) (same for \( D^+ \)) at 14 TeV. The perturbative uncertainty band were estimated by varying the values of charm quark mass and of the factorization and re-normalization scales. The comparison [2] shows that ALICE has an excellent capability to perform a sensitive test of the pQCD predictions for charm production at LHC energy.

Here results are shown for 14 TeV but also expected a good sensitivity at 7 TeV.

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**Figure 2.** Sketch of \( D^+ \) decay topology (left hand panel) and \( K^- \pi^+ \pi^+ \) invariant mass spectra for \( p_T > 2 \) GeV/c (right hand panel).

**Figure 3.** Expected relative statistical error in 1 year of data taking for \( D^0 \rightarrow K^- \pi^+ \).

**Figure 4.** Differential cross section of \( D^0 \) in pp at 14 TeV compared to NLO pQCD predictions from MNR and FONLL calculations.

5. Charm Energy Loss in Pb-Pb collisions: Nuclear Modification factor

The measured spectra in p-p and Pb-Pb can be used to compute the nuclear modification factor, $R_{AA}(p_t) = \frac{\int d^2 N_{AA}(p_t, y) / dp_t dy}{\int d^2 N_{pp}(p_t, y) / dp_t dy}$. This observable is supposed to be 1 if the nucleus-nucleus collision behaves as a simple superposition of independent nucleon-nucleon collisions (Binary Scaling).

![Diagram showing expected performance for the measurement of Nuclear Modification factor of $D^0$ mesons (upper panel) and $D^+$ (lower panel) after one year of data taking at nominal luminosity.]

The expected performance for the measurement of the nuclear modification factor for $D^0$ and $D^+$ mesons after one year of data taking at nominal luminosity is shown in figure 5. Theoretical calculations for different energy loss scenarios depending on the in-medium transport coefficient $\hat{q}$ and on the c-quark mass are also shown. The bands corresponding to $m_c = 1.2$ GeV and $\hat{q} = 25$–100 GeV$^2$/fm reflect the estimated uncertainty on the model expectations for $R_{AA}^{D^0}$. The small difference between the two bands ($m_c=0$ and $m_c=1.2$ GeV) indicates that with respect to energy loss, charm behaves similarly to light quarks. Therefore, the enhancement of the heavy to light ratio is a sensitive measurement, essentially free of mass effects, to study the colour charge dependence of parton energy loss [10].

6. Conclusions

The ALICE detector provides excellent tracking, vertexing and particle identification to allow a high precision measurement of the open charm cross section via hadronic decays, both in pp and Pb-Pb collisions and over a wide range of transverse momenta. We have shown the very first results for the 2 hadronic decay channels ($D^0 \rightarrow K^-\pi^+$ and $D^+ \rightarrow K^-\pi^+\pi^+$) with $1.4 \times 10^8$ minimum bias pp events and also shown that with $10^9$ pp events, these measurements will provide sensitive tests for pQCD at LHC energy. The corresponding measurements in Pb-Pb at 5.5 A TeV energy will allow us to measure energy loss with good precision.

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