Detection of $D^0$ mesons via hadronic decays in Pb–Pb collisions at LHC with ALICE

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Abstract
The ALICE experiment is devoted to the study of heavy-ion collisions at the CERN LHC collider. We present the results of a feasibility study for the detection of $D^0\to K^-\pi^+$ decays in Pb–Pb collisions with ALICE.

1 Physics motivation

The aim of the ALICE experiment is to study the behaviour of nuclear matter in the conditions of high densities and temperatures in which a transition to a deconfined QCD phase (Quark Gluon Plasma) is expected.

The study of open charm production is of primary interest for two main reasons:

- the interaction of the produced charm quarks with the plasma may reduce their momenta because of elastic collisions and in-medium gluon emissions (see e.g. Ref. [2] and references therein);

- secondary parton scattering in the high-density partonic system produced may provide an additional source of charm quarks [3].

The measurement of the total charm production cross section and of the transverse momentum distribution of charm quarks in Pb–Pb collisions, as well as in pp and in pA interactions, is essential to study these open issues. The exclusive reconstruction of $D^0$ mesons in the hadronic decay channel ($D^0\to K^-\pi^+$, branching ratio $= 3.83\%$) will provide a direct measurement of charm kinematical distributions.
2 Detection strategy

The $D^0$ meson decays through a weak process and has a mean proper length $c\tau = (123.7 \pm 0.8) \mu$m. Therefore, the distance between the interaction point (primary vertex) and the decay point (secondary vertex) is measurable. The selection of the $D^0 \to K^-\pi^+$ decay (and charge conjugate) allows the direct identification of the $D^0$ particles by computing the invariant mass of fully-reconstructed topologies originating from displaced secondary vertices. Figure 1 shows a sketch of the decay: the main feature of this topology is the presence of two tracks with impact parameters of the order of 100 $\mu$m, the impact parameter ($d_0$) being the distance of closest approach of a particle trajectory to the primary vertex.

The identification of these topologies requires precise measurements of the tracks momenta and impact parameters. Charged-particle tracks are reconstructed using the Time Projection Chamber and the Inner Tracking System, which provide measurements of the momentum and of the impact parameter of the $D^0$ decay products with resolutions $\sigma(p)/p \sim 1\%$ and $\sigma(d_0) \simeq 50 \mu$m, respectively, using a magnetic field of 0.4 T. Particle identification via time-of-flight allows to reject a large fraction of ($\pi^\pm, \pi^\mp$) pairs, thus significantly reducing the large combinatorial background of opposite-charge track pairs from the underlying high-multiplicity Pb–Pb event.

3 Analysis and results

The $c\bar{c}$ production rate in central Pb–Pb collisions at the LHC is estimated [4] from next-to-leading order pQCD [5] to be $N(c\bar{c}) = 115$/event; this gives 0.53 $D^0$ mesons per unit of rapidity decaying in the $K\pi$ channel.
Figure 2: Left: $K\pi$ invariant mass distribution for $10^7$ events (after background subtraction in the inset). Right: statistical significance of the signal as a function of the $D^0$ transverse momentum. The marker shows the significance obtained in the bin $1 < p_T < 2$ GeV/c requiring the identification of the kaon from its time of flight.

The charm signal is generated using PYTHIA \[6\], while the underlying Pb–Pb events are generated using HIJING \[7\], which gives a multiplicity of about 6000 charged particles per unit of rapidity.

The initial value of the signal-to-background ratio is $S/B \simeq 4.5 \cdot 10^{-6}$. The most effective selection in order to extract the charm signal out of the large combinatorial background is based on the requirement to have two tracks with large impact parameters and a good pointing of the reconstructed $D^0$ momentum to the collision point (i.e. the pointing angle $\theta_P$ between the $D^0$ momentum and its flight line should be close to 0, as shown in Fig. 1). The selection strategy is described in detail in Ref. \[8\].

After selection cuts, which have been optimized as a function of the $D^0$ meson transverse momentum ($p_T$), the ratio $S/B$ is 0.1 and the statistical significance of the signal is $S/\sqrt{S+B} = 37$ for $10^7$ Pb–Pb events, corresponding to 1 month of data-taking of ALICE. Figure 2 (left) shows the corresponding $K\pi$ invariant mass distribution. On the same figure (right) the significance is displayed as a function of the $D^0$ transverse momentum: the significance is larger than 10 up to $p_T \simeq 10$ GeV/c. The lower $p_T$ limit of 1 GeV/c will allow a rather safe extrapolation to $p_T = 0$ and hence the measurement of the total charm production cross section with good accuracy.
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