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Strangeness production in the ALICE experiment

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Abstract
In this survey, the topics which can be addressed through a study of strange particle production in ALICE are reviewed. The current status of the experiment as regards selection methods for hyperons and resonances are described.

1. Introduction

Strangeness has been proposed as a signature for the quark–gluon plasma (QGP) for many years [1–3]. Initially, when there were no experimental data on ultra-relativistic heavy-ion collisions, it was proposed that strangeness production should be considered as a 'diagnostic probe for the onset of a QGP'. This approach guided most of the early papers on this subject [4], where data were analysed with a view to showing that the observed strangeness enhancements were difficult to explain except as a consequence of a phase transition.

This initial agenda must now be modified. In the light of more recent measurements, it can be assumed that in heavy-ion collisions at the LHC a QGP will be formed [5], and what remains is to study its properties. The observed strange particle spectrum can be influenced up until chemical freeze-out of the hot system, or even possibly later through the effect of final-state interactions. A full study of strange particle production then yields a number of pieces of information about the development of the system.

One such piece of information is the value obtained for the baryochemical potential and temperature coming from a 'chemical' analysis of the final-state particles [6]. For a system that has been produced from the hadronization of a QGP, and may be supposed to have reached chemical equilibrium, these parameters should reflect the state of the system at chemical freeze-out. The degree to which the abundances of all the particle species can be described in terms of these two numbers is taken as evidence of the degree to which chemical equilibrium has been achieved.

Very impressive agreement has already been seen at RHIC for a wide variety of different particle species [7]. In order to reach this level of agreement it is necessary to take into account the production of resonances, whose contributions can be very significant as their weight in the partition function includes the statistical weight factors. Their contribution to the yields of 'stable' strange particles is relatively insensitive to the effects of final-state interactions, because these are elastic two-body processes that change neither the multiplicity nor the flavour content. They can change the momenta of the final-state particles with respect to the initial-state particles, however, and therefore it may no longer be possible to find two particles whose effective mass gives that of the resonance that originally generated them [8]. Such mechanisms are thought to account for the observed discrepancies between observed resonance yields and their predicted values in an otherwise successful thermal description. This field needs to be further pursued to extract a more detailed description of the later stages of the heavy-ion collision.

A feature that has already been observed is that the distribution of strangeness between different stable species appears to change as the energy increases, presumably because this is strongly affected by the onset of new resonance contributions made evident through the feed-down from their decay products. It means that many strangeness contributions need to be followed in order to understand how much strangeness is produced overall. The Wroblewski factor [9] gives a way to estimate the overall strangeness from the individual hadronic channels. In principle, a generalized version would be needed to take into account all contributions, including, for example, those from multistrange baryons.

The study of transverse momentum (or, equivalently, transverse mass) spectra for different hadron species gives much interesting information. In the first place, the systematics of the inverse slopes of transverse mass distributions in the low m_{T} region can be parametrized quite successfully in terms of a 'blast-wave' model, as described by Schnedermann *et al* [10, 11]. In this picture, the observed slope comes about as a result of thermal and collective flow components, and values for both of these parameters are obtained. Recently, data from RHIC indicate that other phenomena become important for larger p_{T} values. The baryon/meson ratios increase dramatically [12], so that in central Au+Au collisions at $\sqrt{(s)} = 200$ GeV p/π ratios larger than 1 are obtained for $p_{\mathrm{T}} \geqslant 3$ GeV/c. This observation is a consequence of a more fundamental property, revealed through the ratios R_{CP} and R_{AA} [13], where

$$R_{\mathrm{CP}} = \frac{\mathrm{Yield}_{\mathrm{central}} \big/ \langle N_{\mathrm{bin}}^{\mathrm{central}} \rangle}{\mathrm{Yield}_{\mathrm{peripheral}} \big/ \langle N_{\mathrm{bin}}^{\mathrm{peripheral}} \rangle}, \tag{1}$$

$$R_{\mathrm{AA}} = \frac{1}{T_{\mathrm{AA}}} \frac{(\mathrm{d}^2 N/\mathrm{d}p_{\mathrm{T}}\,\mathrm{d}y)_{\mathrm{AA}}}{(\mathrm{d}^2 N/\mathrm{d}p_{\mathrm{T}}\,\mathrm{d}y)_{\mathrm{NN}}}. \tag{2}$$

Scaling is according to the number of collisions. These ratios show there is a suppression of high p_{T} production in central Au+Au collisions relative to peripheral ones, though the corresponding ratios for R_{AA} can be larger than one for some strange particle species. A systematic difference between mesons and baryons has been observed [14]. These observations can be accounted for in terms of the recombination model, which proposes that in a dense medium a high p_{T} particle may be formed from the coalescence of lower p_{T} valence quarks in addition to the usual mechanism through fragmentation of a higher momentum parent parton. The interplay between these mechanisms yields information about the density of the system. In addition, it is expected that at sufficiently high p_{T} a simple fragmentation picture is regained, as in this case the high p_{T} quark can escape from the dense region. This second feature has not yet been observed.

2. Strangeness detection

All these considerations indicate that the key feature for pursuing such studies in ALICE is to have good particle identification out to as high a p_{T} as possible. The ALICE detector offers

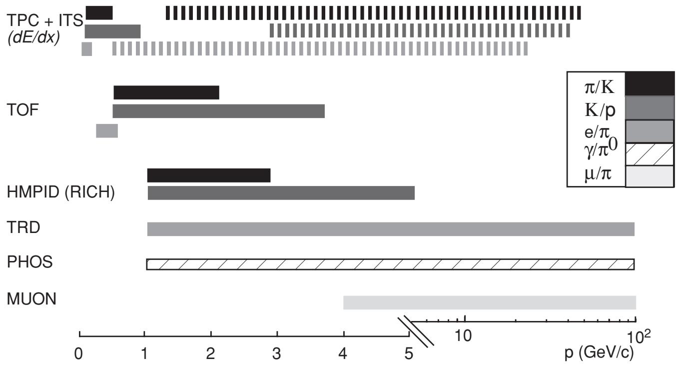

Figure 1. Momentum ranges over which different detectors can resolve particle species ambiguities. The dotted ranges for the dE/dx method indicate the region of relativistic rise.

a variety of different methods for identifying particles, and as a result has excellent particle identification capabilities.

The detectors that can be used for particle identification and their useful ranges for resolving different particle ambiguities are given in figure 1. Two principal methods are employed with full azimuthal coverage: the TPC and ITS give dE/dx measurements which can be used for particle identification below a p_T of about 1 GeV/c in the Bethe–Bloch region; for p_T above about 0.6 GeV/c the time-of-flight (TOF) system can identify particles through the time taken to reach the TOF barrel from the interaction point. The high momentum particle identification (HMPID) system uses proximity focusing RICH detectors with limited solid angle coverage to identify particles, and so extends the useful range by a few GeV/c over its geometrical acceptance region. Beyond this, dE/dx measurements can again be used for particle identification using the relativistic rise phenomenon, but this is not sufficiently reliable to give unambiguous assignments for individual tracks. Instead, it can be used to estimate the composition of an ensemble of tracks. As measurements of the same track in different detectors count as independent measurements, these can in principle be combined to extend the range.

3. Topological signatures

Another method that can be used to identify stable particles is to study their weak decays, which have distinctive topological signatures. Combining topological and kinematic information it is possible to arrive at unambiguous mass assignments. The limitation on this technique is that it can only be used for the particles that decay inside the detector volume, a relatively small proportion for those high p_T particles which are the main interest.

The techniques for identifying particles by their decay topologies are currently being optimized. The selections used depend strongly on the backgrounds present. The most advanced study is that for V^0 decays, and this will be presented in detail. The selections for cascade decays and kink decays have yet to be finalized, but some preliminary results will be presented.

For V^0 decays, the important geometrical parameters are the impact parameters b_+, b_- for positive and negative tracks, respectively; the distance of closest approach (DCA) between the two tracks; and the 'pointing angle' θ between the momentum vector resulting from combining the momenta for the positive and the negative tracks and the line of flight between

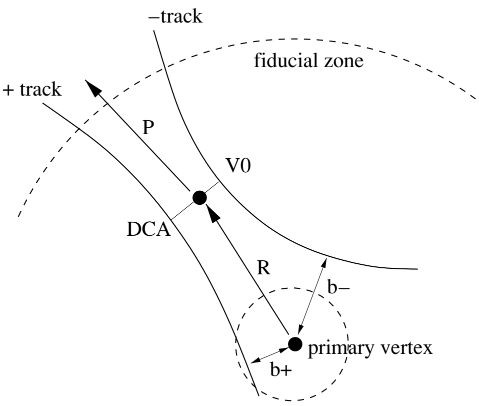

Figure 2. Schematic diagram of a V^0 decay showing the geometrical parameters which are used to select the V^0 sample.

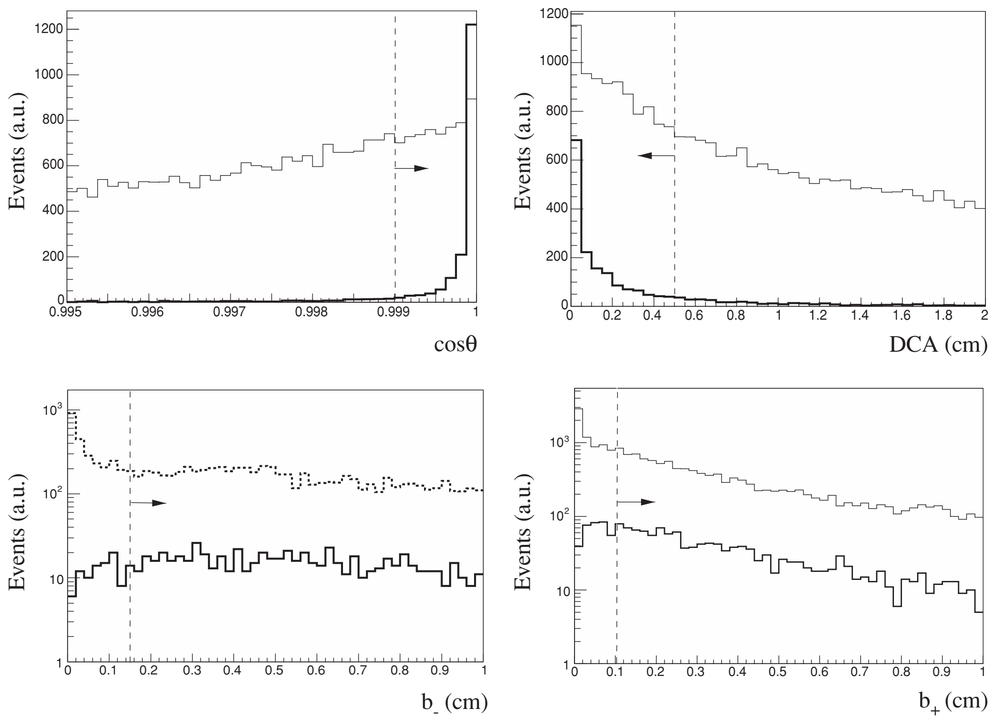

Figure 3. Distribution of geometrical variables for Λ^0 candidates. Top left: distribution for cosine of pointing angle θ. Top right: distribution for distance of closest approach of the two tracks (DCA). Bottom left: distribution for negative track impact parameter b_-. Bottom right: distribution for positive track impact parameter b_+. In each distribution both signal and (signal plus background) are shown superimposed.

the primary vertex and the estimated position of the V^0 vertex. These quantities are indicated in the diagram in figure 2.

In this study, V^0 decays were implanted into HIJING background events with $\mathrm{d}N/\mathrm{d}y = 4000$. Decays were required to take place in the TPC. Figure 3 shows the distributions for the

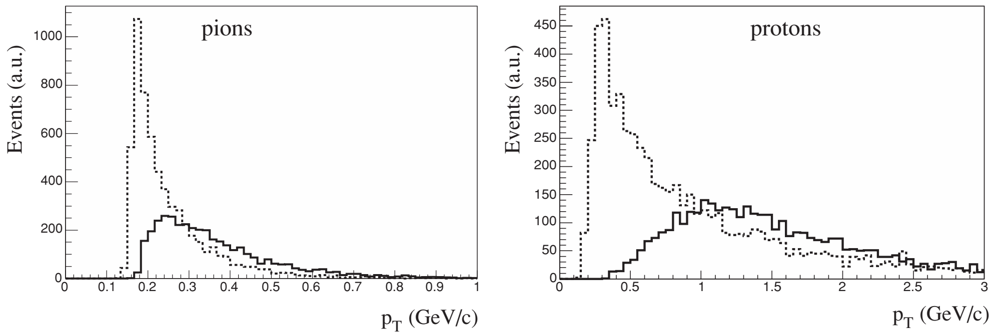

Figure 4. p_T distribution for (left) pion and (right) proton decay tracks in a sample of Λ^0 candidates.

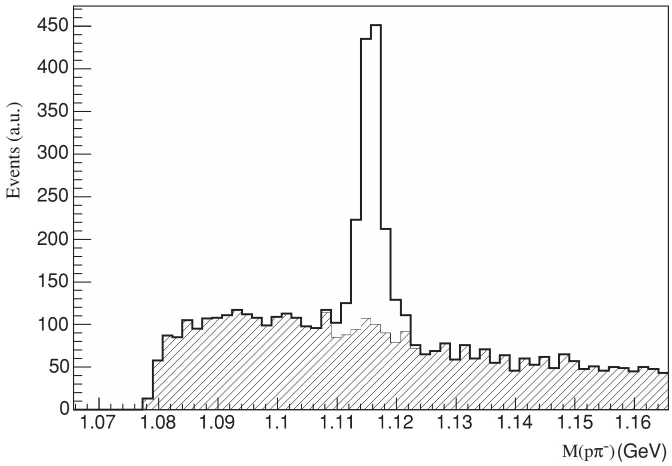

Figure 5. Proton pion effective mass distribution for Λ^0 candidates after the selections described in the text. A clear Λ^0 peak is seen above the background.

'geometrical' variables b_+, b_-, DCA and θ. Both good events and those identified as fakes are shown, and the selected cuts are shown.

In addition to these geometrical cuts, kinematic cuts can also be applied where there are clear differences between the signal and background distributions. In figure 4, the p_T distributions for positive and negative tracks are shown. It can be seen that fake V^0 candidates tend to be made from lower p_T tracks than those from true V^0s. The cuts shown are optimized to keep as much signal as possible while rejecting as much background as possible. The resulting Λ peak is shown in figure 5 based on 100 events.

It is noted that, although the cuts shown so far have been global in nature, some can be applied more effectively in a momentum-dependent form. For example, for the negative track impact parameter b_-, the distribution of background (from the primary vertex) becomes more sharply peaked at small impact parameters as the p_T increases, and therefore a better selection is obtained by using different b_- cuts for different momentum ranges.

Similar selections will be used to select samples of Ξs, Ωs and kaons. For these particles, the selections have not yet been finalized. As examples of the progress so far, figure 6 shows

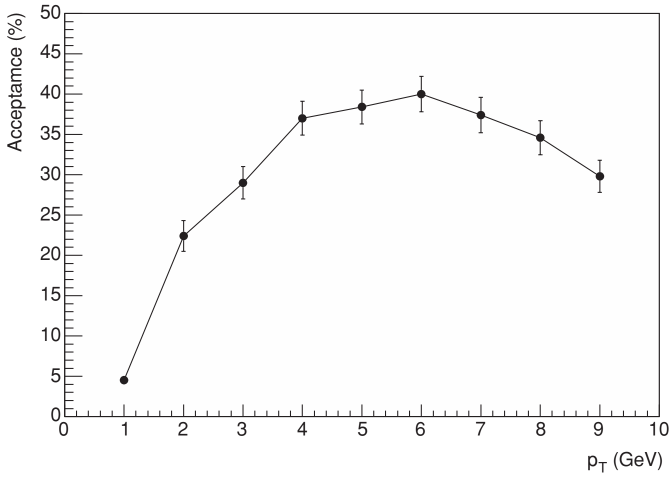

Figure 6. Preliminary estimate of acceptance for Ξ^- candidates as a function of p_T.

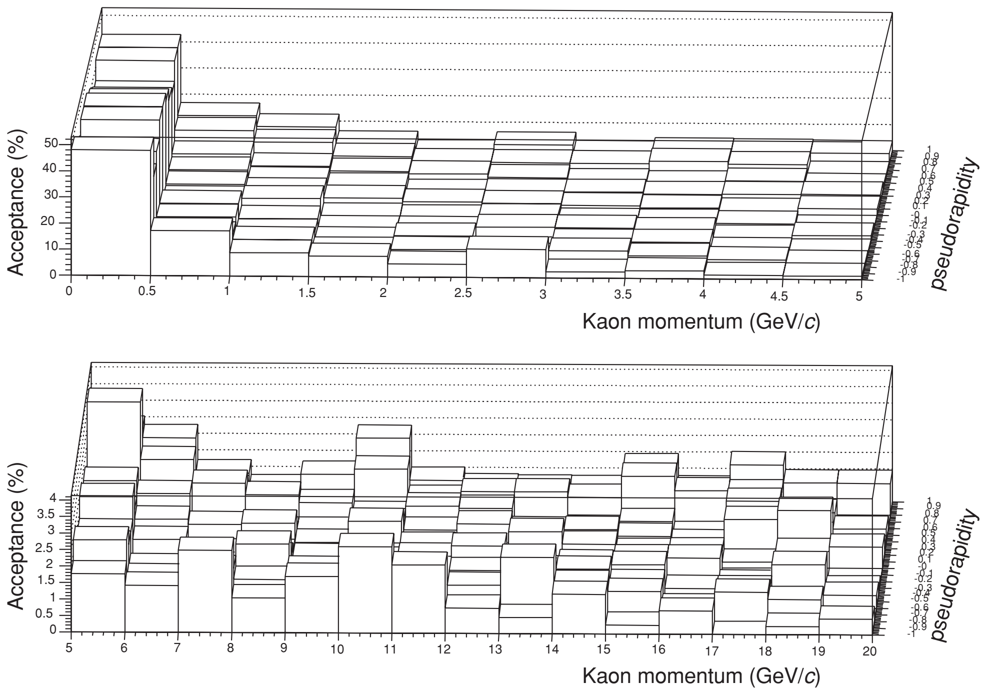

Figure 7. Preliminary estimate of acceptance for K^+ candidates for the decay $K^+ \rightarrow \mu^+\nu$ as a function of pseudorapidity and p_T. The acceptance remains high enough to allow a useful sample of kaons to be obtained for p_T values up to at least 10–12 GeV/c.

the acceptance as a function of p_T for Ξs, and figure 7 the acceptance as a function of p_T and η for charged kaons. Both of these indicate that it will be possible to identify these particle to p_T values greater than 10 GeV/c.

4. Resonances

Resonance production has not yet been much studied for ALICE. At present, two resonances have been studied: the $K^*(890)$ and the $\phi(1020)$. Of these, the $\phi(1020)$ study is the more advanced and shows that it will be possible to detect this particle at its expected (equilibrium) production rates over a wide range of p_T even in central collisions ($dN/dy = 6000$). At low p_T the combinatorial background is high, but the use of particle identification (PID) information, particularly from the time-of-flight (TOF) system allows a ϕ to be seen at, for example, 2 GeV/c with significance $S/\sqrt{(B+S)} = 32$. Above $p_T = 2$ GeV/c, it is no longer possible to use PID for the two decay kaons, but at this p_T the combinatorial background is greatly reduced, so the significance in this range is higher with no PID than it is at lower p_T, when PID is used (e.g., $S/\sqrt{(B+S)} = 80$ at $p_T = 5$ GeV/c).

5. Summary

In summary, strangeness production remains a way of characterizing chemical equilibrium in a heavy-ion collision. At LHC this process will be combined with that of jet fragmentation, owing to the greatly increased relative cross section for hard processes. Disentangling these contributions requires the ability to measure strange particle production for given species to large values of p_T. Topological signatures provide the best way to achieve this, and studies are in progress for Λ, $K^{\pm}$, Ξ and Ω decays; these indicate that it will be possible to measure the momentum spectra for these particles greater than 10 GeV/c. Finally, resonance production studies are starting in ALICE. These show that the $\phi(1020)$ can be detected through its hadronic decay $\phi \to K^+K^-$ in central Pb+Pb collisions for p_T values up to at least 7 GeV/c.

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