Production of identified charged and neutral hadrons in pp and Pb-Pb collisions at LHC with ALICE detector

Martha Spyropoulou-Stassinaki for the ALICE collaboration, Department of Physics, University of Athens
E-mail: mspyrop@phys.uoa.gr

Abstract. The ALICE detector at the LHC, designed to perform in a high multiplicity environment, has powerful capabilities for identifying hadrons, both charged and neutral, with techniques including measurements of specific ionization (TPC and ITS detectors), time-of-flight and topology of weak decays. During 2010, ALICE collected samples of 7 TeV pp collisions and Pb-Pb interactions at 2.76 TeV per pair of nucleons. Results on the spectra of the identified hadrons at mid-rapidity, will be presented. Characteristics of charged kaons identified through their weak decay (kink topology) will be discussed in detail. The yields and the transverse momentum spectra of the different particle species provide information about their production mechanisms in pp and Pb-Pb collisions.

1. Introduction, Particle IDentification (PID) methods and results

The ALICE experiment has implemented almost all known techniques for particle identification. An extensive presentation of the methods used and physics results can be found in references [1,2,3,4].

The particle identification in the Inner Tracking System (ITS) and the Time Projection Chamber (TPC) is based on the specific energy loss of particles which, for a given momentum, depends only on the charge and the rest mass. So, the simultaneous measurement of track momentum (or rigidity p/z, momentum over charge) and signal amplitude in a sensitive detector volume allows one to identify particles. The measured mean energy deposit of a track is denoted as dE/dx and can be described by a parametrization of the Bethe-Bloch formula. Particle identification via dE/dx requires additional information for momenta where the Bethe-Bloch curves cross each other. If the momenta of particles in this region are high enough to reach the Time-Of-Flight detector (TOF), which is used to measure the particle’s velocity, it is possible to determine its mass for a measured momentum. The particle identification can be extended to higher momenta with the detection of Cherenkov radiation in the High Momentum Particle Identification Detector (HMPID) as well as with a statistical analysis of the dE/dx measurements at the relativistic rise in the TPC. High momenta electrons are identified via the Transition Radiation Detector (TRD).

The Silicon Drift Detectors (SSD) and the Silicon Strip Detectors (SSD) of the ITS system, which form the two intermediate and the two outer layers of the this detector, respectively, provide analogue read-out for up to four samples for a truncated mean calculation [4,8] of the
\( \frac{dE}{dx} \). A resolution of \( \sigma(\frac{dE}{dx}) \cong 10\text{-}15\% \) is achieved. The ITS allows pion identification above a minimum momentum of \( p_t \) 100 MeV/c (Fig.1).

The ALICE TPC with its 557568 readout channels provides up to 159 ionization samples in a gas mixture of Ne and \( CO_2 \) (90% / 10%). A truncated mean used to reduce the Landau tail results in a Gaussian distribution with a resolution of \( \sigma(\frac{dE}{dx}) \cong 5\% \). Figure 2 shows the measured \( \frac{dE}{dx} \) versus the momentum of a track. The lines show a parametrization of the Bethe-Bloch curve. The large dynamic range allows one to detect particles with an average energy loss of 26 times minimum ionizing providing a clear identification of (anti)-nuclei\(^3\).

The TOF detector is composed of 1638 multigap resistive plate chambers which provide an intrinsic resolution of about 80 ps. Taking into account the time-0 uncertainty of an event, the overall time resolution is of the order of \( \sigma \text{ (TOF)} \cong 86 \text{ ps} \) for Pb-Pb and \( \cong 120 \text{ ps} \) for pp collisions. Consequently, a 2\( \sigma \) separation between protons and kaons up to 5 GeV/c can be achieved.

The TRD detector provides electron identification for momenta above 1 GeV/c by the detection of transition radiation, which is produced by relativistic charged particles when they cross the many interfaces of two media of different dielectric constants in the radiator and is detected by the high-Z gas mixture of Xe and \( CO_2 \) (85% / 15%).

The HMPID detector, a proximity focusing Ring Imaging Cherenkov detector with a liquid \( C_6F_{14} \) radiator, provides a separation of kaons and protons up to 5 GeV/c.

\[ \begin{align*}
\text{Figure 1.} & \quad \text{dE/}\text{dx of charged particles vs. their momentum, both measured by the ITS alone, in Pb-Pb collisions at 2.76 TeV.} \\
\text{Figure 2.} & \quad \text{A dE/}\text{dx spectrum versus momentum in the ALICE TPC for 7 TeV pp collisions. The lines are a parameterization of the Bethe-Bloch curve.}
\end{align*} \]

If a clear separation in \( dE/dx \) signals exists, an identification of individual tracks is possible by assigning the particle type with the closest distance to an expected response function value. For detectors with a Gaussian response function this distance is specified in multiples of the resolution (so called \( n\sigma \) cuts). This method is applied successfully in indirect particle identification especially for the removal of background in invariant mass analyses. For the direct extraction of spectra, statistical unfolding methods can be applied in regions of limited separation.

Weak decays of strange particles with a sufficiently long lifetime and \( \gamma \)-conversions can be identified via their characteristic decay topology. Spectra of kaons are obtained from five independent techniques: via the measurement of \( dE/dx \) (ITS, TPC), TOF, HMPID as well as the \( V^0 \) decay, e.g. \( K^0 \rightarrow \pi^++\pi^- \) and the kink-topology e.g. \( K^\pm \rightarrow \mu^\pm + \nu_\mu \) (see next paragraph).

The spectra of pions, kaons and protons-antiprotons over a wide \( p_t \) range are extracted based on the methods outlined above [1,2,3,4]. Different strategies are followed by the individual
detectors: in the ITS and stand-alone TOF analysis, the distribution of the response function for tracks within $|y| < 0.5$ is sliced in bins of $p_t$ and fitted with a superposition of Gaussian-like functions, to extract the yield of the different species following a statistical approach in the respective $p_t$-coverage of the individual detectors. The combined TPC-TOF analysis is based on a $3\sigma$-cut in the TPC at lower $p_t$ and in the TOF towards intermediate momenta, where track-by-track PID is still possible. Results are shown in Fig. 3 and 4 [2,3] where the extracted spectra of $\pi$, K and p are shown as well as the compilation of $K/\pi$ ratio as a function of centre-of-mass energy. As can be seen in Fig. 4 this ratio is rather constant over a wide range of energy.

1.1. Results in Pb-Pb collisions at $\sqrt{s} = 2.76$ TeV. The baryon-meson anomaly through the $\Lambda/K^0_s$ ratio.

One of the most interesting results obtained at RHIC in Au-Au collisions was the observation that the baryon (anti-baryon) production at intermediate transverse momentum becomes comparable to that of mesons. Measurements performed by STAR collaboration, showed that the baryon/meson ratio reaches its maximum at $p_t \sim 2.5$ GeV/c and starts decreasing at higher momenta. The maximum value of the $\Lambda/K^0_s$ ratio in central collisions was found to exceed
The question of why, in nucleus-nucleus collisions, baryons at intermediate $p_t$ appear to be more easily produced than mesons is still open. Possible explanations involve interplays between soft and hard mechanisms for particle production. The evolution of the baryon/meson ratio with collision energy may yield additional information about this "baryon anomaly".

The $\Lambda/K^0_s$ ratios as a function of $p_t$ for different centralities in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV are discussed together with the same ratios for minimum bias pp events at 0.9 and 7 TeV in ref. [1]. The baryon/meson ratio in pp interactions always stays below 1 and is quite similar to what is observed in peripheral Pb-Pb collisions. As the collision centrality increases, the baryon/meson ratio develops a maximum at $p_t$ GeV/c reaching a value of $\sim 1.5$ for the 0-5% most central events.

Comparing these preliminary $\Lambda/K^0_s$ ratios with those measured by the STAR Collaboration in Au-Au collisions at $\sqrt{s_{NN}} = 200$ GeV [1] it is observed that in the case of most central events, the baryon/meson ratio at the LHC decreases less rapidly with $p_t$ than at RHIC (Fig. 5) and at $p_t \sim 6$ GeV/c it is a factor 2 higher compared with that at RHIC [1]. The position in $p_t$ of the $\Lambda/K^0_s$ maximum measured at Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV is slightly shifted towards higher transverse momenta with respect to that observed in AuAu events at $\sqrt{s_{NN}} = 200$ GeV, as shown in Fig. 6.

2. Kaon Identification using their weak decay: method and results

In this section, the determination of the yields of charged kaons identified by their weak decay (kink topology) inside the TPC detector is described. This procedure allows one to extend the study of charged kaons to intermediate momenta, on a track-by-track level.

The two-body kinematics of the kink topology, measured as a secondary vertex with one mother and one daughter track of the same charge, allows one to separate kaon decays from the main source of 'background' kinks coming from charged pion decay. The decay channels for kaons and pions together with their branching ratios can be found in Table 1.

The algorithm for a kink reconstruction as a secondary vertex is applied inside a fiducial volume of the TPC with radius $120 \text{ cm} < R < 210 \text{ cm}$, because a reasonable length giving the necessary number of clusters is needed for reconstructing both mother and daughter TPC tracks. Inside this volume a sufficient number of kinks can be found as the $c\tau$ of kaon and pion decays are 3.7 m and 7.8 m respectively.

The mother track of the kink has been selected with similar criteria as the regular TPC tracks (for $\chi^2$/number of clusters), except that the minimum required number of clusters per track is
Table 1. Weak decay modes of kaons and pions contributing to kink topology

| Decay Modes                     | Branching ratios |
|---------------------------------|------------------|
| $K^\pm \rightarrow \mu^\pm + \nu_\mu$ | 63.55%           |
| $K^\pm \rightarrow \pi^\pm + \pi^0$ | 20.66%           |
| $K^\pm \rightarrow e^\pm + \pi^0 + \nu_e$ | 5.07%           |
| $K^\pm \rightarrow \pi^\pm + \pi^0 + \pi^0$ | 1.76%           |
| $K^\pm \rightarrow \pi^0 + \mu^\pm + \nu_\mu$ | 3.35%           |
| $K^\pm \rightarrow \pi^\pm + \pi^+ + \pi^-$ | 5.59%           |
| $\pi^\pm \rightarrow \mu^\pm + \nu_\mu$ | 99.99%           |

30, because the length of the kink-mother track is shorter than the full TPC tracks.

The method of identification of kaons from kink topology [8,9] and its separation from pion decay is based on the kinematical properties of their two-body decay modes, namely:

- The transverse momentum of the daughter with respect to the mother’s direction, $q_t$. The decay upper limit of this quantity to $\mu + \nu_\mu$, is 236 MeV/$c$ for muons from kaons and 30 MeV/$c$ for muons from pions. The corresponding upper limit for pion daughters from the two body decay $K^\pm \rightarrow \pi^\pm + \pi^0$ is 205 MeV/$c$. All three can be seen as peaks in Fig. 7, where all the measured kinks inside the selected volume and rapidity range are plotted. A cut in $q_t$ lower than 40 MeV/$c$ removes the majority of $\pi$-decays.

- The decay angle of the kink (the angle between mother and daughter) as a function of the mother momentum. At a given mother momentum, the opening angle of pion decay is smaller than the corresponding one for kaon decay to the same products ($\mu + \nu_\mu$), because of the mother K/$\pi$ mass difference. In Fig.10, the candidate kaon kinks after applying the $q_t$ cut at 40 MeV/$c$, are shown together with the upper limit curves for K/$\pi \rightarrow \mu + \nu_\mu$ decays. Most pion kinks, which are populating the small decay angle-low mother’s momentum region, have already been removed by the $q_t$ cut.

- The invariant mass of $K \rightarrow \mu + \nu_\mu$ decay. It is calculated from the measured mother-daughter momentum, their decay angle and assuming zero mass for neutrino. In Fig. 11 the above variable is plotted for the full sample of kinks (dashed+full line) and after applying the preceding cuts (full line). The masses of pions and kaons are well reconstructed at their nominal values. The third peak reflects the $K^\pm \rightarrow \pi^\pm + \pi^0$ decay whose kinematics is calculated with wrong assumptions. The broad structure originates from three-body decays of kaons.

- At this stage, most of the tracks are within a $3.5\sigma$ band corresponding to the Bethe-Bloch line of kaons. The tracks outside this limit have been removed in the final analysis (see Fig. 12). An estimate of the purity and background for kaons from kinks is shown in Fig. 9. From the analysed samples in pp ($\sim$22 M events) and Pb-Pb data ($\sim$560k events) it is clear that the study of charged kaons in kink topology can be extended at least up to 8 GeV/$c$ (fig. 8 and 13). An application of kaons from kinks can be found in reference 10.
Figure 10. Two dimensional plot of kinks mother momentum versus the kink-decay angle for the candidate kaons after ONLY the $q_t > 40 \text{MeV}/c$ cut.

Figure 11. Invariant mass $K^\pm/\pi^\pm \rightarrow \mu^\pm + \nu_\mu$ for all kinks (K and $\pi$ decays) as well as for the kaon candidates after the $q_t$ cut (full blue curve).

Figure 12. Two dimensional plot of kinks mother momentum versus the kink-decay angle for the 'identified' kaons in Minimum Bias Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. The purity is similar to the one in Fig. 9.

Figure 13. RAW $p_t$ distribution of 'identified' Kaons in the kinks analysis of Minimum Bias Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV ($\sim 560k$ events).

References
[1] Iouri Belikov : $K^0_s$ and $\Lambda$ production in Pb-Pb collisions with the ALICE experiment, arXiv:1109.4807v2 [hep-ex] 23 Sep 2011 and references therein
[2] Marek Chojnacki : Measurement of $\pi$,K,p transverse momentum spectra with ALICE in proton-proton collisions at $\sqrt{s} =0.9$ and $7$ TeV, Proc. of Quark Matter 2011, Annecy, France, May 2011 and references therein
[3] Michele Floris :Identified particles in pp and PbPb collisions at LHC energies with the LICE detector, arXiv: http://arxiv.org/abs/1108.3257 and references therein
[4] Alexander Kalweit : Particle Identification in the ALICE Experiment, arXiv:1107.1514v1 [hep-ex] 7 Jul 2011 and references therein
[5] J. Alme et al., Nucl. Instrum. Meth. A622 (2010) 316-367. [arXiv:1001.1950 [physics.ins-det]]
[6] K. Aamodt et al., Eur. Phys. J. C 71 (2011) 1594 [arXiv:1012.3257 [hep-ex]].
[7] H. Agakishiev et al. [ STAR Collaboration ], Nature 473 (2011) 353-356.
[8] Alessandro B et al. (ALICE Collaboration) J.Phys. G32 (2006) 1295
[9] Aamodt K et al. (ALICE Collaboration) Eur.Phys.J.C 71(6): 1655, 2011, arXiv:1101.4110
[10] Ivan C. et al. Poster: Identified particle flow methods in ALICE at LHC (QM2011 conference).