Strangeness measurements at LHC with ALICE

A. Badalá and J. Stachel for the ALICE collaboration

1 INFN - Sezione di Catania - V. Santa Sofia, 64, I95123, Catania (Italy)
2 Physikalisches Institut, University of Heidelberg (Germany)
E-mail: Angela.Badal@ct.infn.it

Abstract.
A review of the first results obtained on strangeness production in pp collisions at 0.9 and 7 TeV c.m. energy with the ALICE detector at LHC will be presented. About 250,000 minimum bias events recorded in 2009 during the very first LHC runs at 0.9 TeV were analyzed. Preliminary results on central rapidity production of mesons containing strange quarks (K±, K0S, φ(1020)) as well as single and double strange baryons (Λ, ¯Λ, Ξ− + Ξ+) are reported. More than 400 million minimum bias events have been collected up to now at 7 TeV by the ALICE experiment. Using only a fraction of the collected events the signals of many strange mesons (K0S), hyperons (Λ, ¯Λ, Ξ−, Ξ+, Ω, ¯Ω) and resonances (K∗(892)0, φ(1020) and Σ(1385)) have been extracted. The φ(1020) invariant mass and the raw yield of Ω as a function of transverse momentum will be shown.

1. Introduction
Besides being the necessary baseline for the future heavy-ion collision analysis, pp collisions at LHC will give the opportunity to test QCD in a new energy domain. In ultrarelativistic heavy-ion collisions, strange particles can be used to probe the chemical equilibration of the QGP expected to be formed for very high energy densities. In proton-proton collisions, production of particles is thought to be governed by two mechanisms: soft processes which populate the low momentum part of the particle spectra (the so-called underlying events) and the hard parton-parton interaction processes. These soft processes are often treated in the frame of phenomenological approaches by the superposition of several parton interactions. Studying strange particle production in elementary collisions will help for the characterization of the underlying event structure and could be useful to validate statistical models and/or QCD-inspired models.

The ALICE experiment[1] at the CERN LHC has excellent capabilities in particle identification, momentum resolution, as well as primary and secondary vertex resolution. Its performance in the identification of resonances by their hadronic decay, as well as the study of events with V0 or cascade topologies has been studied extensively [2].

The paper is organized as follows. Section 2 presents a brief description of ALICE and of the main detectors used for the strange particle reconstruction. Conditions of data collection are also presented. Strange particle identification and data analysis at 0.9 TeV are described in Section 3. Section 4 and 5 will be devoted to illustrate some preliminary results at 7 TeV and to report some conclusions.
2. Experimental set-up and data collection

The ALICE experiment [1] consists of a central detector system, covering the mid-rapidity region (|η| < 0.9) over the full azimuth, and additional detection systems, placed at mid- and forward rapidity. The central system is installed inside the large L3 solenoidal magnet providing a magnetic field of up to 0.5 T. Within the barrel, the two tracking detectors used for the present analysis are the Inner Tracking System (ITS) consisting of six cylindrical layers of position-sensitive detectors and a cylindrical Time Projection Chamber (TPC), made of a large field cage filled with a mixture of Ne/CO2/N2, with end plates equipped by multi-wire proportional chambers with cathode pad readout. The two innermost ITS layers are made by silicon pixel detectors (SPD), which are fundamental for the determination of the primary vertex as well as for the measurement of the track impact parameter. The middle two and the outer two layers consist of silicon drift detectors and double-sided silicon strip detectors, which provide a charge deposit measurement and a position measurement. In the central barrel, besides the TPC and the ITS which provide dE/dx information, and are used for the identification of charged particles (π, K, and p), an important role is played by the Time Of Flight detector (TOF). This is a cylindrical assembly of Multi-gap Resistive Plate Chambers (MRPC), with a time resolution better than 80 ps, which permits to get a separation of 3σ between pions and kaons up to 2.5 GeV/c. Two scintillator hodoscopes, called VZERO counters, were used as trigger detectors and for background rejection. These counters placed on either side of the interaction region cover the pseudorapidity ranges 2.8 < η < 5.1 and -3.7 < η < -1.7 and record amplitude and time signals produced by charged particles. The data at 0.9 and 7 TeV were collected with a trigger requiring a hit in the SPD or in either one of the VZERO counters. The events were collected in coincidence with the signals from two beam pick-up counters (BPTX), one on each side of the interaction region, indicating the presence of passing bunches. For the first collisions at 0.9 TeV provided by LHC at the end of 2009, about 300,000 minimum bias events were collected and results shown in this paper come from this set of data. At 3.5+3.5 TeV about 450 millions of minimum bias proton-proton events have been recorded up to the end of July 2010, with an evolution in the luminosity and in the event rate, constantly increasing, arriving to a luminosity of 1.4x10^30 cm^-2 s^-1 with 7 colliding bunches per beam. In this paper only some performance plots will be shown from the analysis of the first 20 million events.

3. Data analysis at 0.9 TeV

In the following analysis, only events with a reconstructed vertex within a longitudinal (z) distance of ±10 to the nominal vertex are used. With this vertex selection the total number of events at 0.9 TeV was about 250,000. For the analyzed pp collisions, the distribution of the coordinates (x and y) of the primary vertex in the transverse plane has a Gaussian shape. In high multiplicity events, σ is changing from about 0.23 mm to about 0.10 mm for x, and from about 0.27 mm to about 0.12 mm for y, going from 0.9 to 7 TeV, due to the smaller beam profile. In order to improve the momentum and energy loss resolution and to reject fake tracks, it is required that a track contains at least 80 TPC clusters out of a maximum of 159. Moreover, at the reconstruction level, split tracks are rejected as well as the ones which may correspond to daughters of kaons and pions decaying in the TPC.

The φ(1020) particle is a resonance with its daughters indistinguishable from primary particles. These can be selected by cuts on the track impact parameter (d_{vtx} < 5 mm, d_{z} < 3 cm). Moreover, for the tracks, a normalized χ^2 smaller than 4 is required. In this analysis a large improvement in the track impact parameter definition is achieved requiring tracks with at least 1 cluster in the SPD. The K^0_S, Λ, Λ, Σ^-, Ξ^+, Ω^- and Ω^+ are reconstructed by their weak decay topologies into charged particles, i.e. into π^+ + π^−, p + π^−, p + π^+, Λ + π^−, Λ + π^+, Λ + K^−, Λ + K^+, respectively. The measurement of K^0_S, Λ and Λ is based on the reconstruction of the secondary vertex V0 associated to their weak decay, i.e. all the possible combinations of
secondary tracks (those with a large impact parameter) are accepted as V0 candidates if the distance of closest approach of the two tracks is smaller than a given value (0.5 cm) and the secondary vertex is inside a fiducial volume (0.2÷100 cm decay radius). The Ξ−, Ξ+, Ω− and Ω+ are identified by their cascade decay topology: in this case V0’s are selected with looser cuts, then they are combined with all secondary tracks, under the hypothesis to be a pion or a kaon (bachelor candidate). A V0-bachelor association is accepted if the distance of closest approach between the V0 and the bachelor is small enough (< 5 cm) and if the momentum of the reconstructed cascade candidate points to the primary vertex.

The signal is extracted from the invariant mass spectrum after background subtraction using the sideband method. The background regions are different for different transverse momentum bins and different particles. In general, the background is either fitted simultaneously with a polynomial function or a square root function, or averaged just counting the number of entries. The background under the signal is then estimated using the normalized area in the region ±4σ around the pole. Normally σ is extracted from a simultaneous fit of the background and of the signal by a polynomial + Gaussian function. For the φ(1020), the σ was fixed according to the Γ value provided by the PDG. As an example, (π+π−), (pπ−) and (¯pπ+) invariant mass distributions for pp collisions at 0.9 TeV are shown in fig. 1. The K0S ( Λ and ¯Λ) peak is clearly visible in the left (right) panel. A mass of (498.7 ± 0.4) MeV/c² and a width of (3.83 ± 0.04) MeV/c² is obtained fitting the K0S peak by a Gaussian function.

![Figure 1. Invariant mass spectra in pp collisions at 0.9 TeV. The arrows in the left (right) panel show the K0S and the Λ mass value, respectively. Left panel: (π+π−) invariant mass spectrum. Right panel: (pπ−) (red/solid curve) and (¯pπ+) (black/dotted curve) invariant mass spectra.](image)

Different ALICE detectors contribute to identify particles in different momentum ranges. The basic identification strategy is based on a fit (by a sum of Gaussians) of the response function. For resonance, V0 and cascade analyses, PID information is extracted by a cut (3-5 times the TPC dE/dx resolution) on the relative difference between the TPC signal and Bethe-Bloch energy loss curves. In the φ(1020) analysis, to improve the Signal to Background (S/B) value, a cut was used on the difference between the TOF signal (if present) and the integrated flight time based on the momentum and the kaon hypothesis. For 0.9 TeV data, efficiency and acceptance corrections have been estimated through a PYTHIA (D6T tune) simulation sample with a number of events roughly equal to about 7 times the size of the real data sample. Transverse momentum spectra for π+, K+ and p, measured using PID information from ITS, TPC and
TOF are shown in left panel of fig. 2. The solid lines refer to fits using the Levy function which gives the best description of the spectra and that will be used to extract the total yield. Using also the ITS data points, the extrapolated fractions of the yields are about 10%, 12% and 20% of the total yield for pions, kaons and protons, respectively [3]. The obtained values for the fit parameters T in GeV and n are $(0.1271 \pm 0.0006, 0.165 \pm 0.004, 0.198 \pm 0.006)$ and $(7.84 \pm 0.08, 5.9 \pm 0.3, 8.8 \pm 0.9)$ for pions, kaons, and protons respectively.

\begin{align*}
T &\approx (0.1271, 0.165, 0.198) \\
n &\approx (7.84, 5.9, 8.8)
\end{align*}

**Figure 2.** Left panel: transverse momentum spectra of $\pi^+$, $K^+$, and p in pp collisions at 0.9 TeV, fitted by a Levy function. Right panel: transverse momentum spectrum for for $K^0_S$ multiplied by two (black solid squares) and for charged kaons measured by TPC and TOF (red open circles) and by their kink topology (blue open squares).

Kaons in ALICE are identified also by their two- or three-body weak decays with one charged daughter; the main one is $K \to \mu + \nu_\mu$, with a branching ratio of 63.43%. In this case the separation from pion decays is mainly based on a cut on the transverse momentum of the daughter with respect to the mother. Good agreement has been found between charged kaons identified by the TPC and TOF detectors and by their kink decay topology (fig. 2, right panel). Moreover also the $K^0_S$ measurement is consistent with the charged kaon data (fig. 2, right panel).

Transverse momentum spectra for $K^0_S$, $\Lambda$ [4] and for $\Xi^{\pm}$[5] in pp collisions at 0.9 TeV are shown in figures 3, 4 and 5, respectively. Comparisons with QCD inspired models such as PHOJET[6] and different PYTHIA[7] tunes (D6T[8], ATLAS[9], Perugia-0[10]) are shown in the same figures. One can observe how these models underestimate, for all transverse momenta, the hyperon and the cascade yields. In contrast, the strange meson yield at low momenta is reasonably well reproduced by all the models. However, in this case all the models, for $p_t < 1$ GeV/c, predict a steeper $p_t$ dependence than measured.

For the $\phi(1020)$ (fig. 6) the yield in the rapidity range $|y| < 0.60$ was measured in four $p_t$ bins from 0.7 to 3 GeV/c. Systematic errors were estimated to be about 0.9-6%[11]. They give a small contribution to the total error, due to the large statistical uncertainty. The $\phi(1020)$ transverse momentum spectrum was fitted by a Levy function and by a $p_t$-exponential function $(dN/dp_t \propto p_t \exp(-p_t/T))$ to extrapolate into the region where no experimental points are available (roughly half of the total integral). A value of 0.020 has been estimated for the integrated yield $dN/dy$. The error is estimated to be 0.001 or 0.002 if a Levy or a $p_t$ exponential function is used. The mean transverse momentum ($\langle p_t \rangle$) has a value of $0.98 \pm 0.07$ GeV/c.
or 0.88±0.06 GeV/c, if the information of the Levy or of the \( p_t \) exponential function are used. Comparison of the \( \phi \) (1020) (fig.6) yield with QCD-inspired models shows that the predictions of PHOJET and D6T and ATLAS PYTHIA tune reproduce roughly the data. In contrast, the Perugia-0 tune of PYTHIA underestimates the resonance production.

4. Preliminary results at 7 TeV

From 30 March 2010, the day of the first collisions at 7 TeV more than 450 million minimum bias events have been collected. Many strange particles \( (K^∗(892)^0, \phi(1020), \Sigma^+(1385), K^0_S, \Lambda, \Xi^±, \Omega^±) \) have been reconstructed using some ten million minimum bias events. Strange resonances \( K^∗(892)^0, \phi(1020), \Sigma^+(1385) \) [12] have been reconstructed by their decay into \( K^+\pi, K^0\bar{K} \) and \( \Lambda + \pi \). The \( K^+K^- \) invariant mass spectrum, with kaons identified by the TOF, is reported in fig.7. It has been fitted by a square-root plus a Breit-Wigner function, obtaining for the \( \phi \) a mass of \( (1019.48±0.03) \) MeV/c\(^2\) and a width of \( (5.94±0.04) \) MeV/c\(^2\), which originated...
from the convolution of the intrinsic resonance width with the experimental mass resolution. About 24 million \(pp\) minimum bias events were enough to extract the \(\Omega^-\) and \(\bar{\Omega}^+\) signal in four \(p_t\) bins from 0.5 to 4.5 GeV/c using only the TPC information. The raw yield of \(\Omega^-\) and \(\bar{\Omega}^+\) as a function of the transverse momentum are shown in fig.8.

**Figure 7.** \(K^+K^-\) invariant mass and \(\phi(1020)\) resonance extracted from about 17 million of \(pp\) minimum bias events at 7 TeV, using only TOF information for PID.

**Figure 8.** Raw yields of \(\Omega^-\) and \(\bar{\Omega}^+\) as a function of transverse momentum for \(pp\) collisions at 7 TeV.

5. Conclusions

First measurements of strange particles in \(pp\) collisions at 0.9 and 7 TeV with the ALICE detector have been shown. At 0.9 TeV, transverse momentum spectra for positive pions, kaons and protons have been reported. Consistency between different methods to identify charged kaons, using TPC and TOF detector information or kink topology and between charged and neutral kaons has been shown. The good agreement of the invariant mass of \(K^0_S\), \(\Lambda\), \(\bar{\Lambda}\) and \(\phi\) with their PDG value demonstrate the quality of the present TPC calibration. Transverse momentum spectra of \(K^0_S\), \(\Lambda\) and \(\bar{\Lambda}\), \(\Xi^\pm\) and \(\phi(1020)\) were reported. Furthermore, for the \(\phi(1020)\) detected by its KK decay channel the \(dN/dy\) and the \(< p_t >\) were measured. All these results provide a useful baseline for comparison with PHOJET and with recent tunes (D6T, ATLAS, Perugia-0) of the PYTHIA model. Hyperon and cascade production is significantly underestimated by these models; in contrast, the \(K^0_S\) and \(\phi(1020)\) meson yield are reasonably well reproduced. Large differences are reported only for PYTHIA Perugia-0 tune. The high collected statistics at 7 TeV will soon permit to measure with high precision the yields (also at high transverse momenta) of strange particles, in particular of multi-strange hyperons and resonances. This will be particularly important to test the QCD in an unexplored energy domain and to establish a baseline for future heavy ion measurements.

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