Results on Λ and Ξ production in Pb-Pb collisions at 160 GeV/c per nucleon from the NA57 experiment

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The NA57 experiment has been designed to study the onset of enhanced production of multi-strange baryons and anti-baryons in Pb-Pb collisions with respect to p-Be collisions. Such enhancement, first observed by experiment WA97, is considered as evidence for a phase transition to a new state of matter – the Quark Gluon Plasma (QGP). In this paper, we report results on Λ and Ξ hyperon production for about the 60% most central Pb-Pb collisions at 160 GeV/c per nucleon beam momentum.

1 Introduction

The WA97 experiment at the CERN SPS has observed enhancements of strange and multi-strange baryon and antibaryon in Pb-Pb collisions with respect to p-Be collisions at 160 A GeV/c [1]. The enhancement increases with the strangeness content of the hyperon. Such a behaviour has been predicted as a signature of the QGP phase transition [2].
The aim of the NA57 experiment, which continues and extends the measurements of WA97, is to study the dependence of the enhancement *(i)* on the interaction volume and *(ii)* on the collision energy per incoming nucleon [3]. For the first purpose, the NA57 centrality range has been extended down to more peripheral collisions with respect to WA97; for the second, the experiment has collected data using both 160 and 40 A GeV/c beams a the CERN SPS.

2 The NA57 experiment

The NA57 apparatus has been described in details elsewhere [4]. The tracking device consists of a telescope made of 13 planes of silicon pixel detectors, each of them with a sensitive area of about 5×5 cm^2. The 30cm long telescope is placed inside a 1.4 T magnetic field, 60 cm downstream of the lead target, inclined with respect to the beam line and pointing to the target so as to accept particles produced at central rapidity.
Strange and multi-strange hyperons are identified by reconstructing their weak decays into final states containing only charged particles, e.g.: $\Xi^- \to \Lambda\pi^-$, with $\Lambda \to \pi^- p$.
The centrality of the Pb-Pb collisions is determined by analyzing the charged particle multiplicity measured in the pseudorapidity interval $2 < \eta < 4$ by two stations of silicon strip detectors. An array of scintillator counters, placed 10 cm downstream of the target, provides a signal to trigger on the centrality of the collisions. The most central 60% of the total inelastic cross section has been selected in Pb-Pb interactions at 160 A GeV/c.
To study the strange baryon and anti-baryon production at a lower center of mass energy, the experiment has also collected data at 40 A GeV/c beam momentum on both Pb-Pb and p-Be collisions. Reference data on p-Be and p-Pb at 160 GeV/c are available from the WA97 measurements.
The results on Ξ^-, $\overline{\Xi}^+$, Λ and $\overline{\Lambda}$ particles reported in this paper have been obtained analyzing the Pb-Pb data sample at 160 A GeV/c collected in 1998. A second sample of Pb-Pb data at 160 A GeV/c has been collected in year 2000: the 1998 and 2000 data sets together will allow to study the rarer Ω signal and to double the present statistics for Ξ^- and $\overline{\Xi}^+$.

3 Data analysis and results

The hyperon signals are extracted on the basis of kinematical selections with the same method used in the WA97 experiment [5].
Fig.1 shows the proton-pion and the lambda-pion invariant mass distributions after all the selection cuts and the corresponding kinematic windows (enclosed areas) selected in the y-p$_T$ distributions of the reconstructed particles. In the y-p$_T$ distributions the central rapidity is highlighted with a dashed line on the acceptance window.
The mass spectra for Λ and Ξ are centered at the nominal value and the FWHM is about 5 MeV and 8 MeV, respectively. All the signals show very low background. Nevertheless, in order to study the shape and the total amount of the residual combinatorial background, we have performed a study using the method of *event mixing*. Fake Λs are built by pairing all the negative charged particles from one event with all the positive ones from a different event, selecting events which are close in multiplicity. Then the fake Λs from mixed events are reconstructed as the real ones. With this method any signal from a real neutral particle decaying in two oppositely

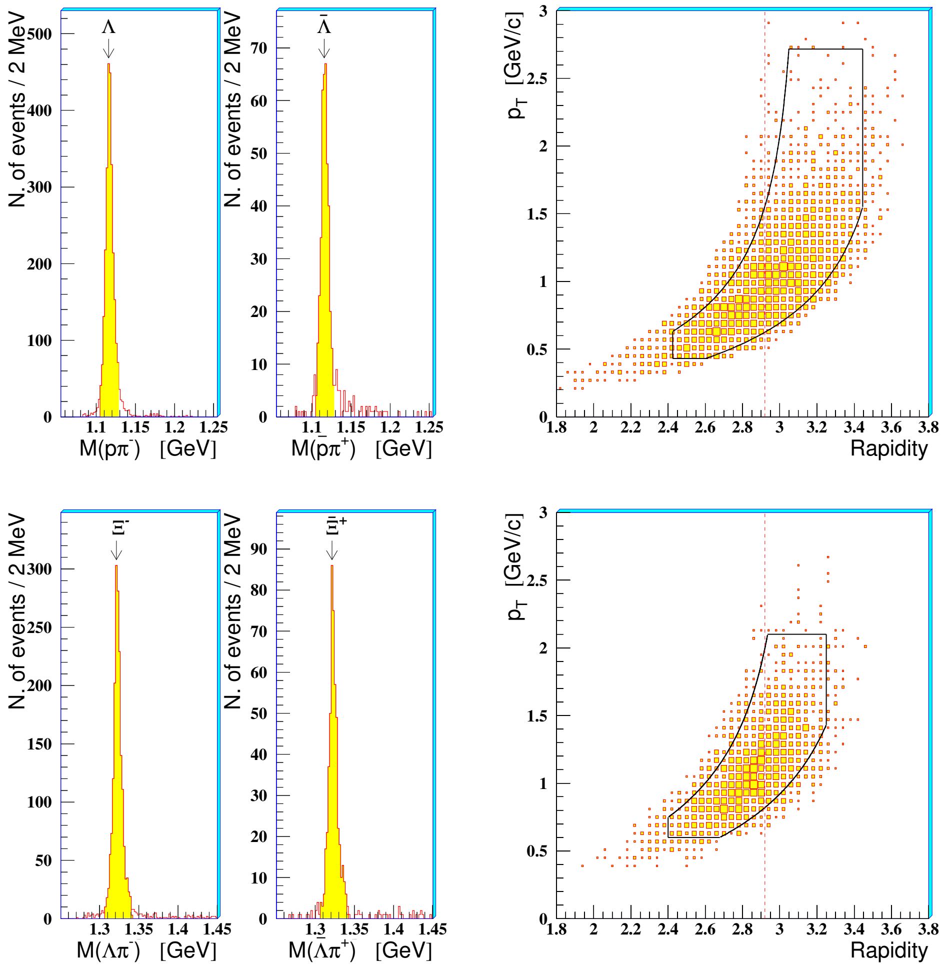

Figure 1: Proton-pion (**top**) and lambda-pion (**bottom**) invariant mass distributions (**left**) and corresponding p_T versus rapidity distributions (**right**). 86% (79%) of the reconstructed Λs (Ξs) falls within the selected fiducial window (enclosed area).

charged particles (e.g. $\Lambda \to \pi p$, $K^0_S \to \pi^-\pi^+$, γ conversion) is removed and what remains is the combinatorial background. The absolute normalization is based on the number of pairs of oppositely charged particles in real and mixed events. The mixed event sample describes very well the residual background in the physical distributions from real events where no signal is expected. As an example, Fig. 2 shows the $p\pi$ invariant mass distribution for real and mixed events *before* (left) and *after* (right) the application of the analysis cuts. The agreement in these distributions and in others, not shown here (e.g. the closest distance in space between the extrapolated π and p tracks coming from the decay, the π and p impact parameters[a], etc.), in regions far from any physical signal, gives confidence in the method. The total amount of combinatorial background is estimated to be about 0.3% for Λ and 1.0% for $\overline{\Lambda}$ and therefore can be safely neglected. The estimate of the total Ξ background, evaluated with a similar technique, is less than 4%.
In order to correct for acceptance and efficiency losses, a weight is calculated for each particle using the following procedure[6]:

- For each observed Λ (Ξ), about $35,000$ ($250,000$) Monte Carlo particles are generated with

[a]The impact parameter is defined as the distance (perpendicular to the beam direction) between the extrapolated lines of flight of the decay particles and the primary vertex position.

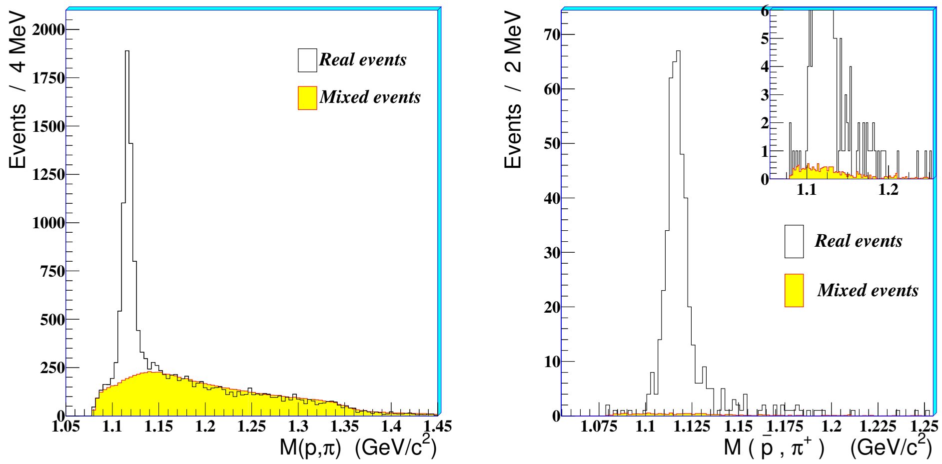

Figure 2: Comparison between real and mixed events for the $p\pi$ invariant mass distribution before analysis cuts (left panel, both Λ and $\overline{\Lambda}$) and after analysis cuts (right panel, $\overline{\Lambda}$ particles only). The insert in the right panel is a zoom on the vertical axis.

the measured transverse momentum and rapidity and with random azimuthal angle;

- the Monte Carlo particles are traced through the apparatus by GEANT [7] allowing them to decay according to their proper life-times and random internal decay angles;
- the hits of the Monte Carlo tracks are embedded into real events to account for background tracks and electronic noise;
- these events are reconstructed and processed by the same analysis programs used for real data and the weight is calculated as the ratio of the number of generated Monte Carlo particles to the number of particles selected by the analysis programs.

All the reconstructed Ξ^-s and $\overline{\Xi}^+$s from the 1998 data sample have been corrected with the above method; for the more abundant Λs and $\overline{\Lambda}$s only a fraction of the available statistics, respectively 1/200 and 1/25, has been individually weighted due to the high CPU-time expenses required to apply this method.
As a measure of centrality we use the number of wounded nucleons, i.e. the nucleons which take part in the initial collisions [8]. The multiplicity distribution is divided into five centrality classes $(0, I, II, III, IV)$ [b], class 0 being the most peripheral ($< N_{wound} >= 62$) and class IV the most central ($< N_{wound} >= 349$). The method to calculate the number of wounded nucleons is described elsewhere [9].
The transverse mass distributions have been parametrized as:

$$\frac{d^2N}{dm_T dy} = A\, m_T \exp\left(-\frac{m_T}{T}\right) \qquad (1)$$

and the inverse slopes T have been extracted by means of a maximum likelihood fit method. In Table 1 the inverse slopes for Ξ^- and $\overline{\Xi}^+$ and the preliminary results for Λ and $\overline{\Lambda}$ are presented. The values are found to be compatible for particles and their anti-particles, and with the WA97 ones. We observe a slight increase of Λ and $\overline{\Lambda}$ slopes with centrality, while no significant variation is observed [10] for Ξ^- and $\overline{\Xi}^+$ within the present statistics.

[b] The labels I-IV were introduced by WA97. The NA57 most peripheral bin is indicated with symbol 0 to keep the labelling of WA97 for the other centrality bins.

Table 1: Inverse slopes T (MeV) in the full centrality range (**0-IV**) and in different centrality classes.

	0-IV	**0**	**I**	**II**	**III**	**IV**
Λ	284 ± 6	258 ± 19	261 ± 11	276 ± 11	313 ± 13	310 ± 15
$\overline{\Lambda}$	287 ± 6	274 ± 18	258 ± 10	279 ± 10	307 ± 13	309 ± 14
Ξ^-	303 ± 11					
$\overline{\Xi}^+$	321 ± 23					

By extrapolating Eq. 1 to $\mathrm{p}_T = 0$ and integrating over one unit of rapidity, the particle yields over the whole p_T range are computed according to the following expression

$$Yields = \int_m^\infty \mathrm{d}m_T \int_{y_{cm}-0.5}^{y_{cm}+0.5} \mathrm{d}y \frac{d^2N}{\mathrm{d}m_T \mathrm{d}y} \tag{2}$$

where m is the rest mass of the particle.
In Fig.3 the NA57 yields per participant in Pb-Pb at 160 A GeV/c relative to the p-Be ones from WA97 are shown (open symbols) for Ξ^-, $\overline{\Xi}^+$, Λ and $\overline{\Lambda}$ in the five centrality classes, i.e. as a function of the centrality of the collision. The WA97 results are also reported in Fig.3

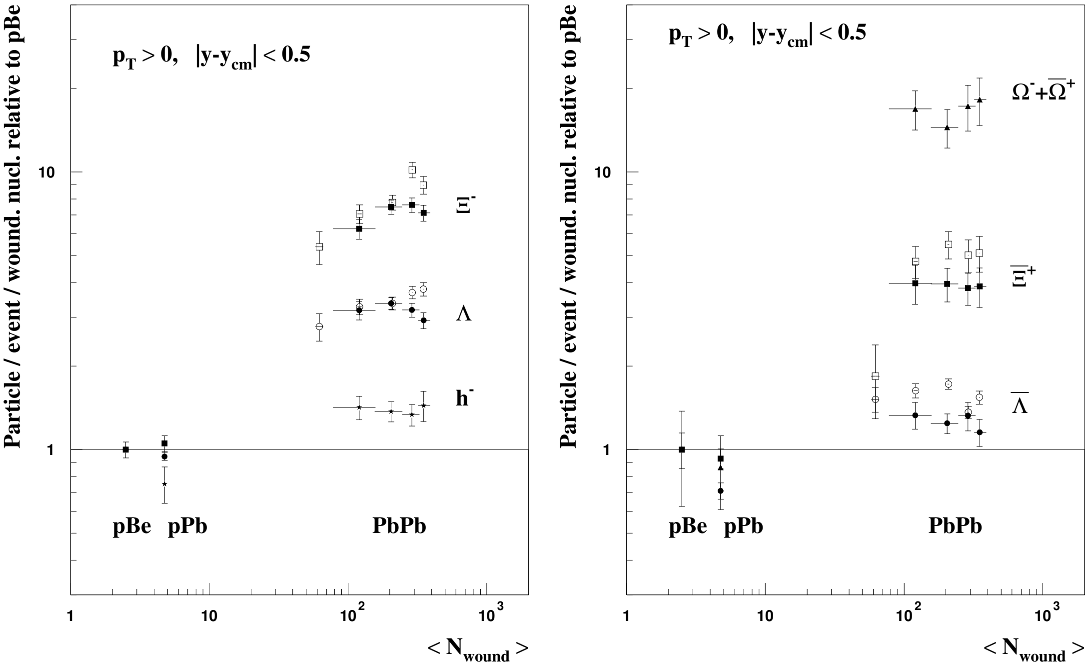

Figure 3: Yields per wounded nucleon relative to p-Be from WA97 for all measured particles (closed symbols) and from NA57 for Ξ^-, $\overline{\Xi}^+$, Λ and $\overline{\Lambda}$ (open symbols). NA57 Λ and $\overline{\Lambda}$ yields are preliminary.

using closed symbols. NA57 results confirm that the strange particle yields per participant are enhanced in Pb-Pb collisions with respect to p-A reference collisions. In the common centrality range the NA57 yields tend to be larger than WA97 by up to 20-30% for $\overline{\Xi}^+$ and $\overline{\Lambda}$. We have performed extended checks on the correction procedure applied for the Ξ [10], in particular for these variables exploited in the kinematic selection of the particles: the outcome gives us confidence in the NA57 results [11]. Similar checks are ongoing for the Λ hyperon. Ξ^-, $\overline{\Xi}^+$ and Λ yields per wounded nucleon drop when going from $< N_{wound} >= 121$ to $< N_{wound} >= 62$, i.e. from class I to class 0; the maximum effect is observed for the $\overline{\Xi}^+$ particle and it corresponds to a 3.5 σ effect. This drop might indicate the onset of the QGP phase transition.

4 Conclusions and outlook

Results from NA57 on Λ and Ξ production in Pb-Pb collisions at 160 A GeV/c have been reported. The Ξ^-, $\overline{\Xi}^+$ and Λ yields per wounded nucleon in the most peripheral bin drop significantly (up to a 3.5 σ effect for $\overline{\Xi}^+$) which might indicate the onset of the QGP phase transition. The ongoing data analysis will soon provide results on the rare Ω particle production at 160 A GeV/c and the full pattern of strange particle enhancements at 40 A GeV/c.

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