Strange baryon production in Pb-Pb collisions at 158 A GeV/c

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Abstract

The experiment WA97 is dedicated to the study of strange baryon production in Pb–Pb interactions at SPS energy. Results on the production of strange and multistrange baryons at midrapidity in Pb–Pb at 158 A GeV c^{-1} are reported and compared with those from p–Pb and p–Be reactions at the same energy. The evidence for deconfinement emerging from the observed pattern of strange baryon production is discussed.

(Some figures in this article are in colour only in the electronic version; see www.iop.org)

1. Introduction

The study of the production of strange baryons is considered one of the most useful tools in the search for the transition from hadronic matter to a quark–gluon plasma (QGP) phase in relativistic heavy-ion collisions [1]. In particular, multistrange baryons and especially antibaryons are interesting since hadronic production (i.e. without QGP) of such particles is suppressed by high mass thresholds.

The WA97 experiment has been designed for a systematic study of the production of Λ, $\bar{\Lambda}$, Ξ, $\bar{\Xi}$, Ω and $\bar{\Omega}$ in Pb–Pb interactions at SPS energy.

This paper describes the results of the WA97 experiment on the production of strange and multistrange baryons and antibaryons. Section 2 recalls some characteristics of the data and the analysis; in section 3 the results are reported and discussed; section 4 contains the conclusions.

2. Data analysis

The WA97 apparatus is described in detail elsewhere [2]. The main tracking device, consisting of a silicon telescope made of pixel and microstrip planes (5×5 cm^2 of sensitive area), is sketched in figure 1. It is placed in a 1.8 T uniform magnetic field provided by the OMEGA magnet; the high granularity and the bidimensional readout of the pixel planes allow track reconstruction with high efficiency and resolution up to the most central Pb–Pb event. A multiplicity detector (not shown in the figure), consisting of silicon microstrips, samples the charged particle multiplicity for off-line centrality analysis.

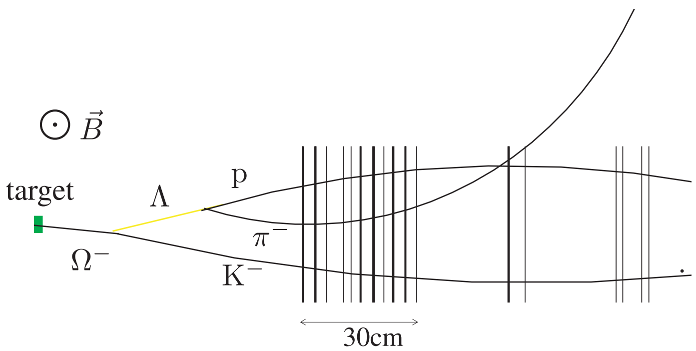


Figure 1. Example of reconstruction of Ω decay.

The strange particles are identified through their weak decays into charged particles, e.g.:

$$\Lambda \rightarrow p + \pi^- + \text{c.c.}$$

$$\Xi^- \rightarrow \Lambda + \pi^- \quad \hookrightarrow p + \pi^- + \text{c.c.}$$

$$\Omega^- \rightarrow \Lambda + K^- \quad \hookrightarrow p + \pi^- + \text{c.c.}$$

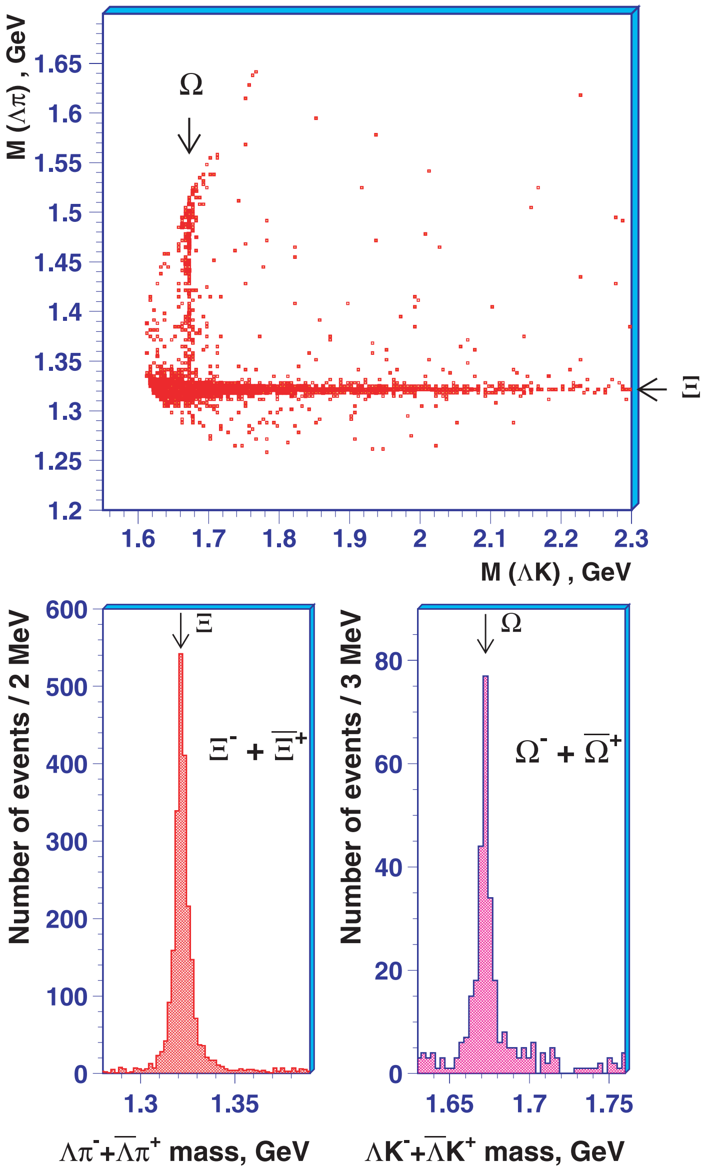


Figure 2. Top, scatter plot of the $\Lambda\pi$ effective mass versus the ΛK effective mass for cascade candidates in the Pb–Pb sample; bottom, effective masses for Ξ and Ω.

Figure 1 shows, for example, how a Ω decay is reconstructed. All the charged tracks from the decay are required to go through the compact part of the telescope (30 cm long), in which the pattern recognition is performed; then they are traced backwards to the main vertex (60 cm far from the telescope). Both the cascade and the subsequent Λ decay vertices are required to be well separated from each other and from the main vertex at the target.

The quality of the cascade signal is shown in figure 2, on the top. The Ξ and Ω signals are very clear over a little background. The plots shown on the bottom are obtained by projecting the scatter plot on the y- and x-axes. For the Ω mass plot the region of ambiguity with the Ξ

visible in the scatter plot has been excluded to get rid of the Ξ reflection. The resolution on the mass peak is less than 6 MeV.

Both Pb–Pb and p–A (A = Be, Pb) interactions at the same beam momentum are studied, for comparison. The kinematical region is about one unit of rapidity centred at midrapidity and the p_T starts from a few hundred MeV c^{-1}, depending on the particle type. The acceptance windows for the hyperons Λ, Ξ and Ω have been published for the Pb–Pb and the p–Pb set-up in [2]. The p–Be window is very similar to the p–Pb one.

3. Results

For all the studied particles the inverse slope T of the m_T distributions and the particle yields are determined.

The transverse mass distributions are parametrized as

$$\frac{\mathrm{d}^2 N(m_\mathrm{T}, y)}{\mathrm{d}m_\mathrm{T}\,\mathrm{d}y} = f(y)\, m_\mathrm{T} \exp\left(-\frac{m_\mathrm{T}}{T}\right). \tag{1}$$

The rapidity function $f(y)$ is assumed to be constant within the limited acceptance region of the experiment. The systematic error that this assumption introduces in the proton data is largest in p–Pb and has been estimated by substituting the constant rapidity function with an empirical fit on published data, as discussed in [2]: the difference for Λ is about 10% on the m_T slope and 6% on the yields while the difference for $\bar{\Lambda}$ is less than 5% both on the m_T slope and on the yields.

By integrating formula (1) over one unit of rapidity and extrapolating to $p_\mathrm{T} = 0$ we obtain the particle yields over the whole p_T range:

$$Y = \int_m^\infty \mathrm{d}m_\mathrm{T} \int_{y_\mathrm{cm}-0.5}^{y_\mathrm{cm}+0.5} \mathrm{d}y\, \frac{\mathrm{d}^2 N(m_\mathrm{T}, y)}{\mathrm{d}m_\mathrm{T}\,\mathrm{d}y}. \tag{2}$$

Both of these quantities can be studied as a function of the collision centrality.

We use as a centrality measure the number of wounded nucleons, i.e. the nucleons which take part in the initial collision [3]. For a discussion on this subject see [4].

In the proton data, the number of wounded nucleons is computed as an average over all inelastic collisions (see table 1). In the Pb–Pb data, the number of wounded nucleons is computed from the wounded nucleon model (WNM) [5] with a fit to the charged track multiplicity measured by the multiplicity detector, assuming that the number of charged tracks is proportional to the number of wounded nucleons.

The Pb–Pb data are divided into the four classes reported in table 1.

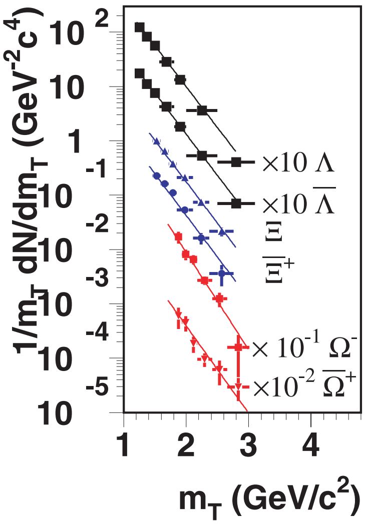
Table 1. Multiplicity classes.

	p–Be	p–Pb	Pb–Pb (four classes)			
$\langle N_\mathrm{wound} \rangle$	2.5	4.75	120	205	289	351

3.1. Transverse mass distributions

The interest of the transverse mass distribution comes from the fact that it can give information on the fireball temperature at freeze-out and on the global collective expansion [6].

Figure 3 shows the transverse mass distributions of the hyperons for the Pb–Pb interactions (1995 full statistics). The superimposed straight lines are the results of the fit with the



Particle	T (MeV)
Λ	289 ± 3
$\bar{\Lambda}$	287 ± 4
Ξ^-	286 ± 9
$\bar{\Xi}^+$	284 ± 17
Ω^-	245 ± 21
$\bar{\Omega}^+$	273 ± 38

Figure 3. Transverse mass distributions for hyperons.

function (1). Details on the fitting method can be found in [7]. The values of the corresponding parameter T are reported in the table on the right of the figure. One can see that the inverse slopes of Λ, $\bar{\Lambda}$, Ξ, $\bar{\Xi}$, Ω and $\bar{\Omega}$ are all compatible within errors. Their behaviour has been well reproduced by a RQMD simulation [8] and understood as an early decoupling of the Ω and possibly of the Ξ.

A study of the T parameter as a function of the centrality has been performed repeating the fits on the four subsamples of centrality. The results are discussed in detail in [7]. The values of T for Λ, $\bar{\Lambda}$, and probably also for Ξ^-, exhibit a slow but steady rise, up to 15% in the centrality range under study ($N_{\rm wound} > 100$). The inverse slopes of Ξ^+ and Ω spectra do not exhibit a significant centrality dependence.

3.2. Particle yields

Particle yields, computed with formula (2), have already been published by WA97 and compared with the corresponding results coming from the p–Pb and the p–Be data [2, 9–11].

In a QGP scenario it is expected that the strange baryons and antibaryons are close to hadronic thermal and chemical equilibrium and that there is an enhanced production of strange particles [1]; in particular, the hyperon and antihyperon enhancement is expected to increase with the strangeness content of the particle following the hierarchical behaviour:

$$\text{Enhancement}(\Lambda) < \text{Enhancement}(\Xi) < \text{Enhancement}(\Omega). \tag{3}$$

Indeed, thermal fits to particle ratios including WA97 data [12] shows that particle ratios are close to chemical equilibrium values and the data are well described by a thermal model with a temperature of 168 MeV.

The particle yields, computed with (2), plotted as a function of the number of wounded nucleons and normalized to the p–Be data, are shown in figure 4. The data for the particles which have at least one quark in common with the incoming nucleons are shown on the left and on the right the particles with no quark in common with the incoming nucleons. The two groups are kept separate since it is empirically known that they may exhibit different production

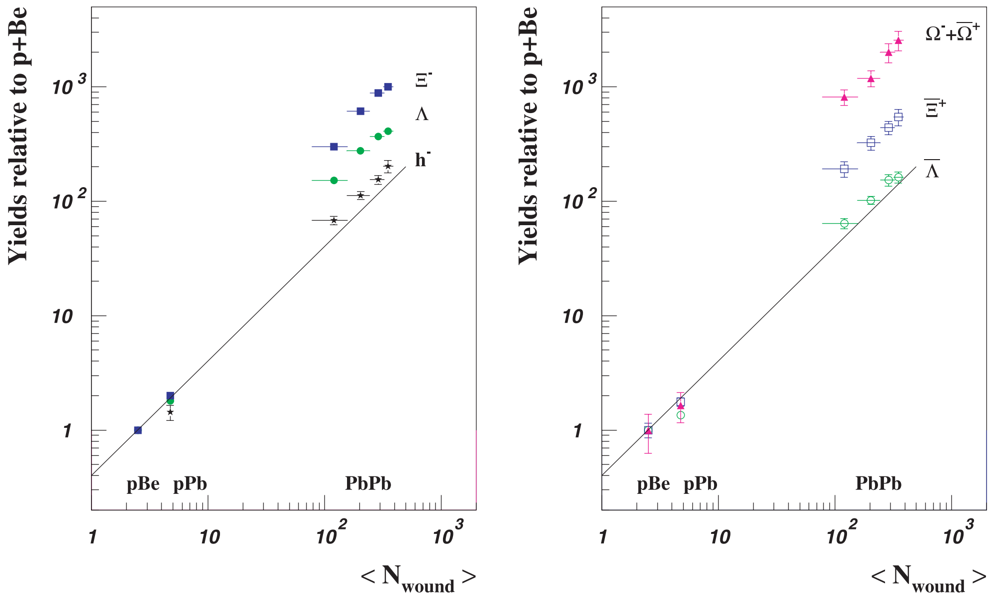


Figure 4. Yields per unit of rapidity relative to the p–Be yields.

features, e.g. Λ and $\bar{\Lambda}$ have different rapidity spectra both in p–S and in S–S [13]. One can see that the yields in Pb–Pb are above what one would expect if they were proportional to the number of wounded nucleons (straight line), that is the Pb–Pb yields per participant are enhanced with respect to p–Be; the enhancement increases with the strangeness content of the particles. Moreover, the yields are proportional to the number of wounded nucleons in the considered Pb–Pb centrality range. This proportionality has been investigated [5] by fitting the yields as a function of the number of wounded nucleons with a power law:

$$Y \propto N_{\text{wound}}^{\alpha}. \tag{4}$$

The result is that $\alpha \sim 1$ for all the particles with a good χ^2.

Including the p–Be yields in the fit, the exponent α becomes different for each particle. However, the fit generally worsens, indicating that the hypothesis of a power-law dependence (4) from p–Be to central Pb–Pb is not favoured.

As the enhancements are saturated in the considered centrality range, that is for $N_{\text{wound}} > 100$, a global enhancement factor can be computed with this formula:

$$E = \left(\frac{\langle \text{yields} \rangle}{\langle N_{\text{wound}} \rangle}\right)_{\text{Pb–Pb}} \Big/ \left(\frac{\langle \text{yields} \rangle}{\langle N_{\text{wound}} \rangle}\right)_{\text{p–Be}}. \tag{5}$$

This is shown in figure 5. The values of Ω and $\bar{\Omega}$ have been separated but they are compatible within errors. The enhancement reaches a value of about 16 for $\Omega + \bar{\Omega}$.

4. Conclusions

The WA97 experiment studies the strange baryon production in Pb–Pb collisions at SPS energy. The main results are:

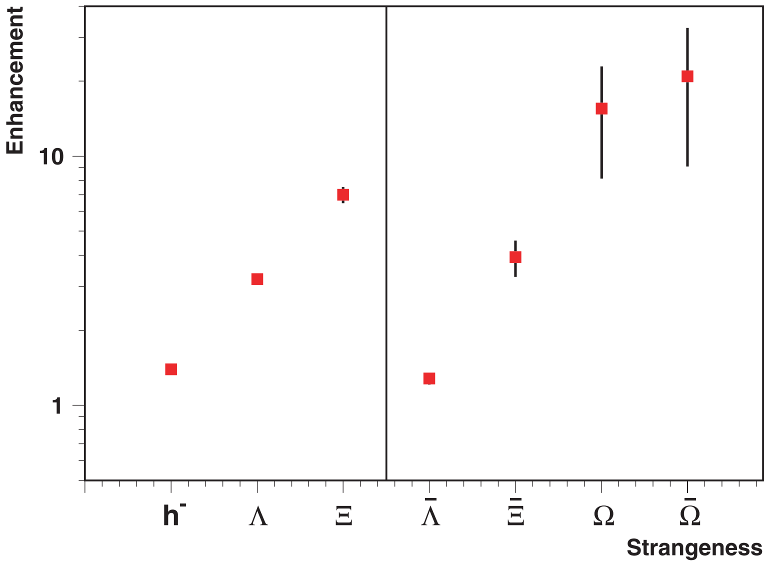


Figure 5. Strangeness enhancement versus strangeness.

- the particle transverse mass spectra agree with the expected thermal plus flow character and show the effect of the early decoupling of Ω, in agreement with the microscopic calculation;
- thermal fits to particle ratios, including WA97 data, confirm quantitatively the chemical equilibrium in all measured strange baryon and antibaryon abundances in Pb–Pb interactions;
- there is an enhanced production of strange particles in Pb–Pb with respect to p–Be that increases with the strangeness content of the hyperon and reaches a factor of 16 for $\Omega + \bar{\Omega}$.

These results nicely match 'old' QGP predictions [1], while for multistrange baryons no hadronic microscopic model has predicted a strangeness enhancement leading to chemical equilibrium.

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