Strange particle production in 158 and 40 $A$ GeV/c Pb-Pb and p-Be collisions

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Abstract. Results on strange particle production in Pb-Pb collisions at 158 and 40 $A$ GeV/c beam momentum from the NA57 experiment at CERN SPS are presented. Particle yields and ratios are compared with those measured at RHIC. Strangeness enhancements with respect to p-Be reactions at the same beam momenta have been also measured: results about their dependence on centrality and collision energy are reported and discussed.

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1. Introduction

An enhanced production of multi-strange baryons and antibaryons in ultrarelativistic nucleus-nucleus collisions with respect to proton-induced reactions has been predicted long time ago as a signal of quark-gluon plasma formation [1]. Enhancements increasing with the strangeness content of the particle have been first observed by WA97 at 158 $A$ GeV/c beam momentum [2]. With the NA57 experiment those measurements have been extended over a wider centrality range and to lower beam momentum [3]. The NA57 apparatus was designed to detect strange and multi-strange hyperons by reconstructing their weak decays into final states containing only charged particles ($\Lambda \rightarrow \pi^- p$, $\Xi^- \rightarrow \Lambda \pi^-$ and $\Omega^- \rightarrow \Lambda K^-$ with $\Lambda \rightarrow \pi^- p$ and the corresponding decays for antiparticles). Tracks are measured in the silicon telescope, a 30 cm long array of pixel detector planes with $5 \times 5$ cm$^2$ cross section: the acceptance coverage corresponds to about half a unit of rapidity at central rapidity and medium transverse momentum. Additional pixel planes and double-sided silicon microstrip detectors, placed behind the telescope, were used as a lever arm detector to improve the momentum resolution for high momentum tracks. The centrality trigger, based on a scintillator petal system placed 10 cm downstream of the target, selected the most central 60% of the inelastic cross section for Pb-Pb collisions. The centrality of the collision is estimated from the charged particle multiplicity sampled at central rapidity by two stations of silicon strip detectors. The apparatus was placed inside the 1.4 Tesla magnetic field of the GOLIATH magnet. Further details can be found in [4]. In the following section we give

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some details of the analysis procedure, then in section 3 we show the dependence of the $K^0_s$, $\Lambda$, $\Xi$ and $\Omega$ yields on centrality and energy for the Pb-Pb collisions. The NA57 yields are also compared with results from the higher energy data on Au-Au collisions at RHIC. Finally, the centrality dependence of hyperon enhancements at both energies are presented and discussed in section 4.

2. Data samples and analysis

The results on Pb-Pb collisions presented in this paper are based on the full statistics collected at 158 and 40 A GeV/c beam momentum. Samples of p-Be collisions at low energy have been also collected, while for the reference data at 158 A GeV/c the p-Be data from WA97 have been used.

Clean particle signals with negligible residual background have been obtained with geometrical and kinematical cuts: for details see [5].

The Pb-Pb sample has been divided into five centrality classes. As an estimate of the number of participant nucleons we use the number of wounded nucleons ($N_{wound}$) computed from the event multiplicity and the measured trigger cross section via the Glauber model: for details on the multiplicity analysis see [6]. Going from the most peripheral (class 0) to the most central (class 4) bin, the average $N_{wound}$ for the Pb-Pb collisions at 158 A GeV/c are $58 \pm 4$, $117 \pm 4$, $204 \pm 3$, $287 \pm 2$ and $349 \pm 1$ respectively. The most central class and the full range covered by all the five classes correspond to 5% and 53% most central collisions respectively. For each selected particle a weight is calculated by means of a Monte Carlo procedure based on GEANT [7] used to estimate geometrical acceptance and reconstruction efficiency losses.

The double-differential distributions in rapidity $y$ and transverse mass $m_T = \sqrt{m^2 + p_T^2}$ for each particle type have been fitted according to the following expression:

$$\frac{d^2 N}{dm_T dy} = f(y) \frac{m_T}{T_{app}} \exp \left( -\frac{m_T}{T_{app}} \right) . \quad (1)$$

The inverse slope parameters ($T_{app}$) have been extracted using the maximum likelihood method, assuming a flat rapidity distribution within our acceptance region. Results on the inverse slope parameters both in Pb-Pb and in p-Be collisions, together with a study of the transverse mass spectra for Pb-Pb in the framework of a blast wave model, are discussed in [8].

Particle yields have been calculated as the number of particles per event extrapolated to a common phase space window, covering full $m_T$ and one unit of rapidity around midrapidity:

$$Y = \int_{m}^{\infty} dm_T \int_{y_{cm} + 0.5}^{y_{cm} - 0.5} dy \frac{d^2 N}{dm_T dy} . \quad (2)$$

The hyperon yields measured in p-Be collisions allow to determine the strangeness enhancement factors. These have been defined as

$$E = \left( \frac{Y}{< N_{wound>}} \right)_{Pb-Pb} / \left( \frac{Y}{< N_{wound>}} \right)_{p-Be} . \quad (3)$$
3. Energy and centrality dependence of the yields in Pb-Pb collisions

$K^0_S$ and hyperon yields in Pb-Pb collisions have been obtained as a function of the centrality at both 158 and 40 $A \, GeV/c$ [9]. The corresponding mid-rapidity yields have been measured at higher energy by the STAR Collaboration for central Au-Au collisions at RHIC [10]. By restricting our data to the same centrality ranges used in STAR (i.e., most central 6%, 5%, 10%, 11% collisions for $K^0_S$, $\Lambda$, $\Xi$ and $\Omega$ respectively), we can compare results over a wide energy range: in Figure 1 our yields per unit rapidity at 40 $A \, GeV/c$ ($\sqrt{s_{NN}} = 8.8$ GeV) and 158 $A \, GeV/c$ ($\sqrt{s_{NN}} = 17.3$ GeV) are shown together with those from STAR at $\sqrt{s_{NN}} = 130$ GeV.

![Figure 1](image-url)  

**Figure 1.** $K^0_S$ and hyperon yields at central rapidity in nucleus-nucleus collisions at SPS and RHIC energies. Large error bars on the $\Xi$ and $\Omega$ yields are due to the restriction of the NA57 data sample to the STAR centrality ranges.

The $\Lambda$ and $\Xi^-$ yields do not vary much from SPS to RHIC, while a clear energy dependence is observed for $K^0_S$ and all three antihyperons. The antihyperon to hyperon ratios are plotted in Figure 2 as a function of $\sqrt{s_{NN}}$ from SPS to RHIC [11]. The ratios increase with increasing strangeness content of the hyperon, both at RHIC and SPS energies. They also increase as a function of the energy, the dependence being weaker for particles with higher strangeness content. This can be understood as due to
a decrease of the baryon density at midrapidity with increasing collision energy.

\[ \sqrt{s_{NN}} \text{ [GeV]} \]

Figure 2. Antihyperon to hyperon ratios in nucleus-nucleus collisions at SPS and RHIC.

The behaviour of the yields with the collision centrality has also been studied. As an example, in Figure 3 the \( \Lambda \) and \( \Xi^- \) yields are shown for each centrality class for both the 158 and 40 A GeV/c Pb-Pb collisions data samples.

Figure 3. Centrality dependence of \( \Lambda \) and \( \Xi^- \) yields in Pb-Pb collisions at SPS.

The dotted lines indicate the expected behaviour in case of a linear increase of the yields with the number of wounded nucleons. The \( \Lambda \) and \( \Xi^- \) yields for central collisions at the two energies are very close. The yields grow faster than linearly with the number of participants, with a steeper centrality dependence for the lower energy data. Similar behaviour is shown by \( K_S^0 \) and \( \Lambda \), while the low statistics in the 40 A GeV/c sample does not allow a firm conclusion for \( \Xi^+ \) and \( \Omega \).
4. Strangeness enhancements with respect to p-Be collisions

The results on strangeness enhancements at 158 A GeV/c are shown in Figure 4. Particles containing at least one valence quark in common with the nucleon (left) are kept separated from the others (right). These results confirm the strangeness enhancement hierarchy \((E(\Lambda) < E(\Xi) < E(\Omega))\) already observed by WA97 [2].

![Figure 4](image_url)  
*Figure 4.* Centrality dependence of hyperon enhancements at 158 A GeV/c. The error bars indicate the statistical errors only, while the bracket symbols represent the systematic errors.

We observe a significant centrality dependence of the yields per wounded nucleon for all hyperons except for \(\bar{\Lambda}\).

Similar enhancement factors are observed also at lower energy: in Figure 5 the \(\Lambda, \bar{\Lambda}\) and \(\Xi^-\) enhancements measured at both energies are shown together as a function of the collision centrality. The low statistics in the p-Be reference sample allows only to estimate a lower limit for the \(\Xi^+\) enhancements at 40 A GeV/c [12]. The enhancement pattern follows the same hierarchy observed at higher energy, i.e. \(E(\Lambda) < E(\Xi^-)\) and \(E(\bar{\Lambda}) < E(\Xi^+)\). As already seen for the yields, a steeper increase of the enhancements with the number of participants is observed for the lower energy sample. For the most central collisions (classes 3 and 4) the enhancements are found to be larger at 40 than at 158 A GeV/c (by about 15-20%).

The strangeness enhancement, when described as a consequence of the transition from the canonical to the asymptotic grand canonical limit, is indeed predicted to be a decreasing function of the collision energy [13]. However, that model neither reproduces the amount for central collisions nor the centrality dependence of the measured enhancements.
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5. Conclusions

Results on strange particle production from the NA57 experiment in 158 and 40 A GeV/c Pb-Pb and p-Be collisions have been reported and discussed. From $\sqrt{s_{NN}} = 8.8$ GeV to $\sqrt{s_{NN}} = 130$ GeV the $\Lambda$ and $\Xi^{-}$ yields per unit rapidity remain roughly constant. A clear increase of the yields with the collision energy is instead observed for all three antihyperons. The antihyperon to hyperon ratios increase with energy, with a stronger dependence for particles with lower strangeness content. Such a pattern is indicative of a decrease of the baryon density in the central region as
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the energy is increased. The centrality dependence of the yields and of the enhancements with respect to p-Be is steeper at 40 than at 158 A GeV/c. The enhancement pattern follows the same hierarchy with the strangeness content as seen in the higher energy data, with $E(\Lambda) < E(\Xi^-)$ and $E(\bar{\Delta}) < E(\Xi^+)$. For very central collisions (about 10%) the enhancements are larger at 40 than at 158 A GeV/c.

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