

Recent results from NA57 on strangeness production in p-A and Pb-Pb collisions at 40 and 158 A GeV/c

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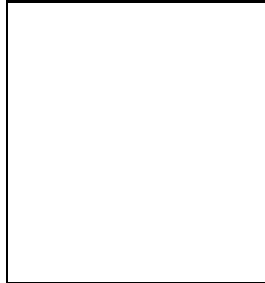
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The production of hyperons in Pb-Pb and p-Be interaction at 40 A GeV/c beam momentum has been measured by the NA57 experiment. Strange particle enhancements at 40 A GeV/c are presented and compared to those measured at 158 A GeV/c. Their transverse mass spectra have been studied in the framework of the blast-wave model. The multiplicity of charged particles as a function of the energy is also discussed.

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1 Introduction

The experimental programme with heavy-ion beams at CERN SPS aims at the study of hadronic matter under extreme conditions of temperature, pressure and energy density.

NA57 at the CERN SPS is a dedicated second-generation experiment for the study of the production of strange and multi-strange particles in Pb-Pb and p-Be collisions¹. In this paper we present results on strangeness enhancements at 40 A GeV/c and 158 A GeV/c. A study of the transverse mass ($m_T = \sqrt{p_T^2 + m^2}$) spectra for Λ , Ξ , Ω hyperons, their antiparticles and K_s^0 measured in Pb-Pb collisions at 158 A GeV/c, is also discussed. The multiplicity of charged particles in the central rapidity region has been measured in Pb-Pb collisions at both beam momenta: 158 A GeV/c and 40 A GeV/c. The value of $dN_{ch}/d\eta$ at the maximum and its behaviour as a function of centrality is here presented for the first time.

2 Analysis and results

The NA57 apparatus has been described in detail elsewhere². The strange particle signals are extracted by reconstructing the weak decays into final states containing only charged particles, using geometric and kinematic constraints, with a method similar to that used in the WA97 experiment³. For each particle species we define the fiducial acceptance window using a Monte Carlo simulation of the apparatus and excluding the border regions.

All data are corrected for geometrical acceptance and for detector and reconstruction inefficiencies on an event-by-event basis, with the procedure described in reference⁴.

2.1 Multiplicity measurement

The procedure for the measurement of the multiplicity distribution and the determination of the collision centrality for each class is described in reference⁵. As a measure of the collision centrality we use the number of wounded nucleons N_{wound} . The distribution of the charged particle multiplicity measured in Pb-Pb interactions has been divided into five centrality classes (0,1,2,3,4), class 0 being the most peripheral and class 4 being the most central. The fractions of the inelastic cross section for the five classes are given in table 1.

The charged multiplicity measured in the central unit of pseudorapidity η is also used to determine the maximum of the pseudorapidity distribution ($dN_{ch}/d\eta|_{max}$). This is the variable most frequently used to characterize the multiplicity of the interaction; ($dN_{ch}/d\eta|_{max}$ is about 2% larger than the charged multiplicity in the central unit of η).

In fig. 1 the values of $\langle dN/d\eta|_{max} \rangle$ are reported as a function of N_{wound} for both 40 GeV/c (right) and 158 GeV/c (left) beam momenta. In the same figure are reported the values measured by the NA50⁶ and NA49⁷ collaborations. At 158 A GeV/c a reasonable agreement is observed, with a small discrepancy for the most central classes. At 40 A GeV/c a strong disagreement among the three experiments is observed. The values of the participants for a given fraction of total inelastic cross-section determined by the three experiments are similar.

In proton-proton collisions, the charged multiplicity at central rapidity is found to scale approximately with the logarithm of the centre of mass energy⁸. Assuming the same dependence one would expect: $dN_{ch}/d\eta|_{max}(158 \text{ A GeV}/c)/dN_{ch}/d\eta|_{max}(40 \text{ A GeV}/c) \simeq \ln(17.3)/\ln(8.77)=1.31$. The value measured in NA57 for the most central class is 1.37 ± 0.05 .

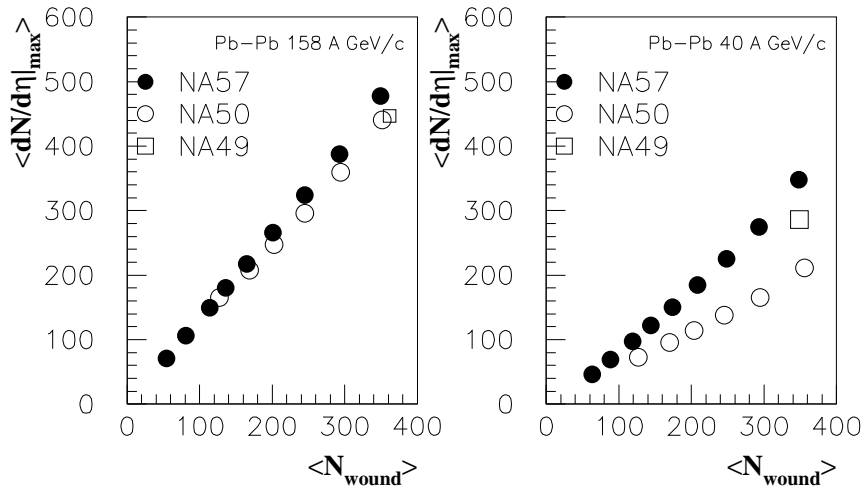


Figure 1: $\langle dN/d\eta \rangle_{max}$ as a function of the average number of participants.

2.2 Transverse mass spectra in Pb-Pb at 158 A GeV/c

The double-differential (y, m_T) distributions for each of the measured particle species can be parametrized using the expression

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

Assuming the rapidity distribution to be flat within our acceptance region ($f(y) = \text{const}$), the inverse slope parameters T_{app} (“apparent temperature”) have been extracted by means of maximum likelihood fits of equation 1 to the data. The $1/m_T dN/dm_T$ distributions are well described by exponential functions⁹.

The inverse slope parameters T_{app} are given in table 1 as a function of centrality, which is expressed for Pb-Pb intractions in terms of % of inelastic cross section.

Table 1: Inverse slopes (MeV) of the m_T distributions for the five Pb-Pb centrality classes (0,4), and for p-Be and p-Pb interactions. Only statistical errors are shown. Between parenthesis the fractions of inelastic cross section are reported for each class.

	p-Be	p-Pb	0 (56 – 42%)	1 (42 – 25%)	2 (25 – 12%)	3 (12 – 5%)	4 (5 – 0%)
K_s^0	197 ± 4	217 ± 6	239 ± 15	239 ± 8	233 ± 7	244 ± 8	234 ± 9
Λ	180 ± 2	196 ± 6	237 ± 19	274 ± 13	282 ± 12	315 ± 14	305 ± 15
$\bar{\Lambda}$	157 ± 2	183 ± 11	277 ± 19	264 ± 11	283 ± 10	313 ± 14	295 ± 14
Ξ	202 ± 13	235 ± 14	290 ± 20	290 ± 11	295 ± 9	304 ± 11	299 ± 12
$\bar{\Xi}$	182 ± 17	224 ± 21	232 ± 29	311 ± 23	294 ± 18	346 ± 28	356 ± 31
$\Omega + \bar{\Omega}$	169 ± 40	334 ± 99	274 ± 34		274 ± 28	268 ± 23	

An increase of T_{app} with centrality is observed in Pb-Pb for Λ , Ξ and possibly also for $\bar{\Lambda}$. Inverse slopes for p-Be and p-Pb collisions¹⁰ are also given in table 1. In central and semi-central Pb-Pb collisions (i.e. classes 1 to 4) the baryon and antibaryon m_T distributions have similar slopes. This suggests that strange baryons and antibaryons are produced by a similar mechanism.

Within the blaste-wave model¹¹ the apparent temperature can be interpreted as due to the thermal motion coupled with a collective transverse flow of the fireball. The model predicts a double differential cross-section of the form:

$$\frac{d^2N_j}{m_T dm_T dy} = \mathcal{A}_j \int_0^{R_G} m_T K_1 \left(\frac{m_T \cosh \rho}{T} \right) I_0 \left(\frac{p_T \sinh \rho}{T} \right) r dr \quad (2)$$

where $\rho(r) = \tanh^{-1} \beta_{\perp}(r)$ is a transverse boost, K_1 and I_0 are modified Bessel functions, R_G is the transverse geometric radius of the source at freeze-out and \mathcal{A}_j is a normalization constant. The transverse velocity field $\beta_{\perp}(r)$ has been parametrized according to a power law:

$$\beta_{\perp}(r) = \beta_S \left[\frac{r}{R_G} \right]^n \quad r \leq R_G \quad (3)$$

With this type of profile the numerical value of R_G does not influence the shape of the spectra but just the absolute normalization (i.e. the \mathcal{A}_j constant). The parameters which can be extracted from a fit of equation 2 to the experimental spectra are thus the thermal freeze-out temperature T and the *surface* transverse flow velocity β_S . Assuming a uniform particle density, the latter can be replaced by the *average* transverse flow velocity, $\langle \beta_{\perp} \rangle = \frac{2}{2+n} \beta_S$ ⁹. The use of the three profiles $n = 0$, $n = 1/2$ and $n = 1$ results in similar values of the freeze-out temperatures and of the average transverse flow velocities, with good values of χ^2/ndf . The quadratic profile is disfavoured by our data⁹.

The global fit of equation 2 with $n = 1$ to the spectra of all the measured strange particle describes the data with $\chi^2/ndf = 37.2/48$, yielding the following values for the two parameters T and $\langle \beta_{\perp} \rangle$ for the most central class: $T = 118 \pm 13 \text{ MeV}$, $\langle \beta_{\perp} \rangle = 0.45 \pm 0.02$. The T and $\langle \beta_{\perp} \rangle$ parameters are statistically anti-correlated. The systematic errors on T and $\langle \beta_{\perp} \rangle$ are correlated; they are estimated to be 10% and 3%, respectively.

2.3 Strangeness enhancement

By using equation 1 we can extrapolate the yield measured in the selected acceptance window to a common phase space window covering full p_T and one unit of rapidity centered at midrapidity:

$$Y = \int_m^{\infty} dm_T \int_{y_{cm}-0.5}^{y_{cm}+0.5} dy \frac{d^2N}{dm_T dy}. \quad (4)$$

The enhancement E is defined as

$$E = \left(\frac{Y}{\langle N_{wound} \rangle} \right)_{Pb-Pb} / \left(\frac{Y}{\langle N_{wound} \rangle} \right)_{p-Be} \quad (5)$$

In figure 2 and figure 3 we show the enhancements as a function of N_{wound} for 158 and 40 A GeV/c respectively.

The enhancements are shown separately for particles containing at least one valence quark in common with the nucleon (left) and for those with no valence quark in common with the nucleon (right).

The 158 A GeV/c results confirm the picture which emerged from WA97 — the enhancement increases with the strangeness content of the hyperon — and extend the measurements to lower centrality. For all the particles except for $\bar{\Lambda}$ we observe a significant centrality dependence of the enhancements, although a saturation cannot be excluded for the two or three most central classes.

A significant enhancement of strangeness production when going from p-Be to Pb-Pb is observed also in the 40 A GeV/c data. For the $\bar{\Xi}$ particle, due to the limited statistics in

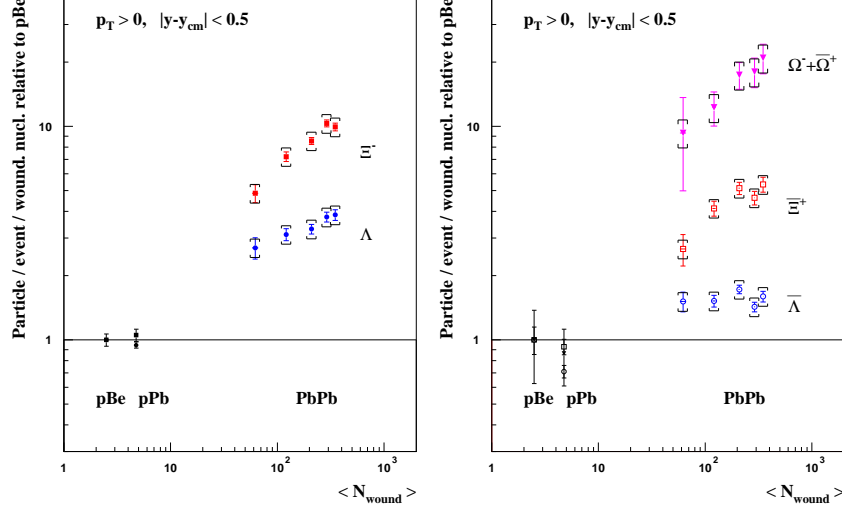


Figure 2: Hyperon enhancements E as a function of the number of wounded nucleons at 158 A GeV/ c . The symbol \square shows the systematic error.

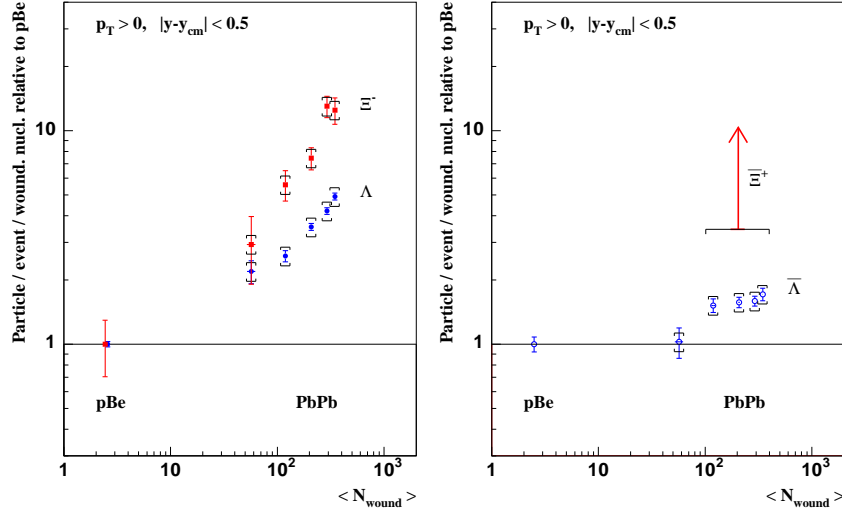


Figure 3: Hyperon enhancements E as a function of the number of wounded nucleons at 40 A GeV/ c . The symbol \square shows the systematic error.

p-Be collisions at 40 GeV/ c , we could estimate only an upper limit to the production yield. This limit for the four most central classes at 95% confidence level is indicated by the arrow in figure 3 (right). The enhancement pattern follows the same hierarchy with the strangeness content observed at 158 GeV/ c : $E(\Lambda) < E(\Xi)$ and $E(\bar{\Lambda}) < E(\bar{\Xi})$. Comparing the measurements at the two beam momenta: for the most central collisions (bins 3 and 4) the enhancements are higher at 40 than at 158 GeV/ c , the increase with N_{wound} is steeper at 40 than at 158 GeV/ c .

3 Conclusions

We have reported an enhanced production of Λ , $\bar{\Lambda}$, Ξ and $\bar{\Xi}$ when going from p-Be to Pb-Pb collisions at 40 A GeV/ c . The enhancement pattern follows the same hierarchy with the strangeness content as at 158 GeV/ c : $E(\Lambda) < E(\Xi)$, $E(\bar{\Lambda}) < E(\bar{\Xi})$. For central collisions (classes 3 and 4) the enhancement is larger at 40 GeV/ c . In Pb-Pb collisions the hyperon yields increase with N_{wound} faster at 40 than at 158 A GeV/ c .

The analysis of the transverse mass spectra at $158 A \text{ GeV}/c$ in the framework of the blast-wave model suggests that after a central collision the system expands explosively and then it freezes-out when the temperature is of the order of 120 MeV with an average transverse flow velocity of about one half of the speed of light.

Finally, the measurements of the charged particle multiplicity indicate that $dN_{ch}/d\eta$ at the maximum is close to a logarithmic scaling with the centre of mass energy.

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