Strange particle production p-Be, p-Pb, Pb-Pb at 158 A GeV/c

F. Antinori, H. Bakke, W. Beusch, I.J. Bloodworth, R. Caliandro, N. Carrer, D. Di Bari, S. Di Liberto, D. Elia, D. Evans, et al.

ELSEVIER

Nuclear Physics A681 (2001) 141c–148c

NUCLEAR PHYSICS A

www.elsevier.nl/locate/npe

Strange particle production in p–Be, p–Pb, Pb–Pb at 158 *A* GeV/*c* (WA97 experiment)

Presented by R. A. Fini for the WA97 collaboration:

F. Antinori[e,i], H. Bakke[b], W. Beusch[e], I.J. Bloodworth[d], R. Caliandro[a], N. Carrer[i], D. Di Bari[a], S. Di Liberto[k], D. Elia[a], D. Evans[d], K. Fanebust[b], R.A. Fini[a], J. Ftáčnik[f], B. Ghidini[a], G. Grella[l], H. Helstrup[c], A.K. Holme[h], D. Huss[g], A. Jacholkowski[a], G.T. Jones[d], J.B. Kinson[d], K. Knudson[e], I. Králik[f], V. Lenti[a], R. Lietava[e], R.A. Loconsole[a], G. Løvhøiden[h], V. Manzari[a], M A. Mazzoni[k], F. Meddi[k], A. Michalon[m], M.E. Michalon-Mentzer[m], M. Morando[i], P.I. Norman[d], B. Pastirčák[f], E. Quercigh[e], G. Romano[l], K. Šafařík[e], L. Šándor[e,f], G. Segato[i], P. Staroba[j], M. Thompson[d], T.F. Thorsteinsen[b†], G.D. Torrieri[d], T.S. Tveter[h], J. Urbán[f], O. Villalobos Baillie[d], T. Virgili[l], M.F. Votruba[d] and P. Závada[j].

[a] Dipartimento I.A. di Fisica dell'Università e del Politecnico di Bari and Sezione INFN, Bari, Italy
[b] Fysisk institutt, Universitetet i Bergen, Bergen, Norway
[c] Høgskolen i Bergen, Bergen, Norway
[d] School of Physics and Astronomy, University of Birmingham, Birmingham, UK
[e] CERN, European Laboratory for Particle Physics, Geneva, Switzerland
[f] Institute of Experimental Physics, Slovak Academy of Sciences, Košice, Slovakia
[g] GRPHE, Université de Haute Alsace, Mulhouse, France
[h] Fysisk institutt, Universitetet i Oslo, Oslo, Norway
[i] Dipartimento di Fisica dell'Università and Sezione INFN, Padua, Italy
[j] Institute of Physics, Academy of Sciences of the Czech Republic, Prague, Czech Republic
[k] Dipartimento di Fisica dell'Università "La Sapienza" and Sezione INFN, Rome,Italy
[l] Dipartimento di Scienze Fisiche "E.R. Caianiello" dell'Università and INFN, Salerno, Italy
[m] Institut de Recherches Subatomiques, IN2P3/ULP, Strasbourg, France
† Deceased

The CERN experiment WA97, which studies strange particle production at central rapidity in Pb–Pb, p–Pb, p–Be collisions at 158 *A* GeV/*c*, has already reported a pronounced enhancement of hyperon production. This is considered a sensitive signature for a phase transition to a new state of matter – the Quark Gluon Plasma (QGP). A comprehensive study, including the most recent results, of yields and transverse mass spectra of K^0_S, Λ, Ξ^-, Ω^- (and antiparticles) and negative particles as a function of the number of nucleons partecipating in the collisions is presented.

1. INTRODUCTION

The aim of the WA97 experiment is the study of the production of strange particles, in particular strange and multi–strange baryons and antibaryons, in Pb–Pb interactions and, for comparison, in p–Be and p–Pb interactions at the same beam momentum.

The study of Pb–Pb collisions at high energy has the ultimate goal of observing the transition to a new state of matter, the Quark Gluon Plasma (QGP). In this respect, the production of strange particles has been predicted to be a powerful diagnostic tool.

PII S0375-9474(00)00495-4

Indeed, if a QGP state is formed, one expects an enhancement of s quark production with respect to normal hadronic interactions because the $s\bar{s}$ production becomes competitive with respect to the u, d quarks production thanks to the partial restoration of the chiral symmetry and, at SPS energies, to the Pauli blocking. Therefore, the $s\bar{s}$ production is expected to equilibrate in a few fm/c [1]. The net result, after statistical hadronization, would be the enhancement of strange and multistrange particle production with respect to normal hadronic interactions and, given the $\bar{s}$ availability, a more marked enhancement of multi–strange antibaryons.

From such a scenario, some prediction can be drawn on measurable quantities such as transverse mass distribution and yields, discussed in many papers in last years. They can be summarized in three points:

- the particle transverse mass spectra should show a characteristic thermal behaviour to which a global expansion flow effect (the so called blue-shift of the "little bang")[2] is superimposed;
- the strange baryons and antibaryons abundances should reflect the conditions of the source and are expected to be close to the hadronic thermal and chemical equilibrium;
- the strange particle are expected to be enhanced following a hierarchical behaviour, that is the enhancement should affect more strongly particles with higher strangeness content [1], namely:

$$Enhanc.(\Lambda) < Enhanc.(\Xi) < Enhanc.(\Omega) \quad (1)$$

Such a pattern contradicts the expectations from rescattering in a hadronic fireball because the multi–strange particle production is suppressed by high thresholds and low cross sections.

This paper describes the main results obtained by the WA97 experiment. A brief description of the experiment is given in section 2; section 3 contains the results while the conclusions are discussed in section 4.

2. THE WA97 EXPERIMENT

The WA97 set-up, sketched in figure 1, is placed in the 1.8 T uniform magnetic field provided by the OMEGA magnet; the full description of all the parts can be found in previous pubblications [3–5]. The main tracking device is a silicon telescope made of pixel and microstrip planes. A multiplicity detector, consisting of silicon strips, samples the charged particle multiplicity for the off-line centrality analysis. The silicon telescope is raised above the beam line and inclined in order to detect particles at central rapidity and p_T greater then a few hundreds MeV/c; the high granularity and the bidimensional readout of the pixel planes allow track reconstruction with high efficiency and resolution up to most central Pb–Pb events.

The particle studied are Λ, Ξ and Ω hyperons, K^0_S, and negative particles (mainly pions). The strange particles are identified through their weak decay into charged particles, i.e:

$$\Lambda \rightarrow p + \pi^- \qquad + c.c.$$

$$\Xi^- \rightarrow \Lambda + \pi^- \quad \hookrightarrow p + \pi^- \qquad + c.c.$$

$$\Omega^- \rightarrow \Lambda + K^- \quad \hookrightarrow p + \pi^- \qquad + c.c.$$

$$K^0_S \rightarrow \pi^+ + \pi^-$$

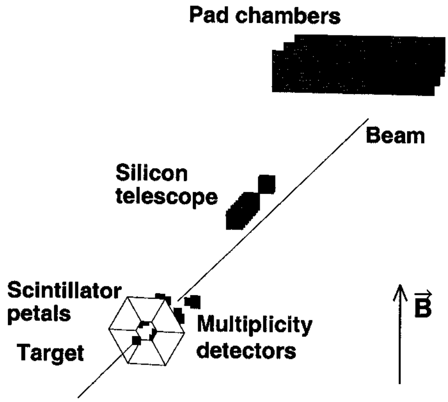

Figure 1. Sketch of the WA97 set-up

requiring that all the secondary charged tracks are reconstructed in the telescope. For cascades candidates, the reconstructed Λ decay vertex is required to be downstream of the cascade vertex and both be well separated from each other and from the main vertex at the target.

For all the studied particles the transverse mass distributions have been parametrized as:

$$\frac{d^2N(m_T, y)}{dm_T dy} = f(y)\; m_T^{\alpha} exp(-\frac{m_T}{T}) \tag{2}$$

and the inverse slope T has been extracted by a maximum likelihood fit, both with $\alpha = 1$ and $\alpha = 3/2$. The rapidity function is assumed to be constant in the limited acceptance region of the experiment.

By integrating formula (2) over one unit of rapidity and extrapolating to $p_T = 0$ the particle yields are computed according to the following expression:

$$\text{Yields} = \int_m^\infty dm_T \int_{y_{cm}-0.5}^{y_{cm}+0.5} dy \frac{d^2N(m_T, y)}{dm_T dy} \tag{3}$$

These quantities have been studied as a function of the collision centrality, estimated from the number of wounded nucleons, i.e. participants to the reaction, by means of a Glauber model. In the proton data, the number of wounded nucleons is computed as an average on all inelastic collisions; in the lead–lead data, the number of wounded nucleons is computed from the Wounded Nucleon Model (WNM) [6] with a fit to the measured charged track multiplicity, assuming that the number of charged tracks is proportional to the number of wounded nucleons. The considered multiplicity classes are shown in Table 1.

Table 1
Multiplicity classes.

	p–Be	p–Pb	Pb–Pb (4 classes)
$\langle N_{wound} \rangle$	2.5	4.75	120 205 289 351

Table 2
Inverse slope parameter T (MeV) for $\alpha = 1$.

Particle(s)	p–Be	p–Pb	Pb–Pb
h^-	*186± 3*	*185± 5*	**197± 2**
K^0_S	*197± 4*	*217± 6*	**230± 2**
Λ	*180± 2*	*196± 6*	**289± 3**
$\bar{\Lambda}$	*157± 2*	*183± 11*	**287± 4**
Ξ^-	**202±13**	**235±14**	**286± 9**
Ξ^+	**182±17**	**224±21**	**284±17**
$\Omega^-+\Omega^+$	**169±40**	**334±99**	**251±19**

3. RESULTS

3.1. Transverse mass distributions

The parametrization (2) works well in our m_T range for all the particles in each of the three reactions studied. The values of the parameter T estimated by the fit are reported in Table 2.

For simplicity, in the table results for case $\alpha = 1$ only are quoted; the bolded characters mean that the fit is performed on the full available sample while the slanted ones refer to partial samples.

From the value reported in the table it can be concluded that for each particle there is an increase of T when going from p–Be to Pb–Pb interactions. By examining the last column of the table, one can see that for Pb–Pb there is an increase of T when going from lighter particles to heavier ones and it seems that there is a flattening for hyperons.

This can be better investigated if one plots the inverse slope parameters T versus the particle mass, as illustrated in figure 2, where results from different experiments are collected.

The WA97 data agree well with the measurement of other experiments and follow the same linear increase with the particle mass. This is represented by the straight line and can be interpreted as a result of the global expansion flow. However, Ω (and possibly Ξ) deviates from this general trend.

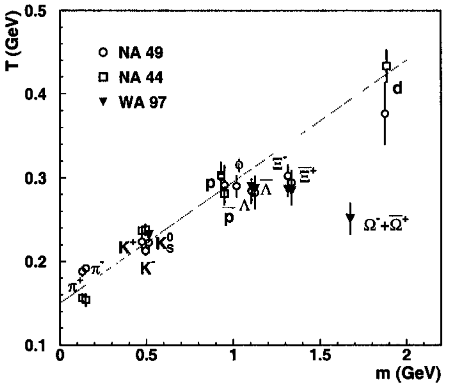

Figure 2. Dependence of the m_T spectra inverse slope T on the particle mass m.

This behaviour has been well reproduced by a RQMD simulation [8] and understood as an early decoupling of the Ω (and possibly Ξ). That means that the production of Ω is very little affected by the later stages of the reaction.

In order to investigate how the T parameter depends on the centrality, we have performed the fits on the particle transverse mass spectra in the four subsamples of centrality. The results are fully described in [7], where we conclude that for $\bar{\Xi}^+$ and Ω there is no significant centrality dependence; that is, the decoupling of the Ω is there for all the measured centrality range.

3.2. Yields

The WA97 results on yields and particle ratios have been already reported in previous publications. Recently, thermal fits to particle ratios using our data have been performed [9]: they show that particle ratios are close to chemical equilibrium values and the data are well described by a thermal model with a temperature of about 170 MeV.

The particle yields as a function of the number of wounded nucleons are plotted in figure 3: the left plots concern particles having at least one quark in common with the incoming nucleons, while particles with no quark in common with the incoming nucleons are reported on the right.

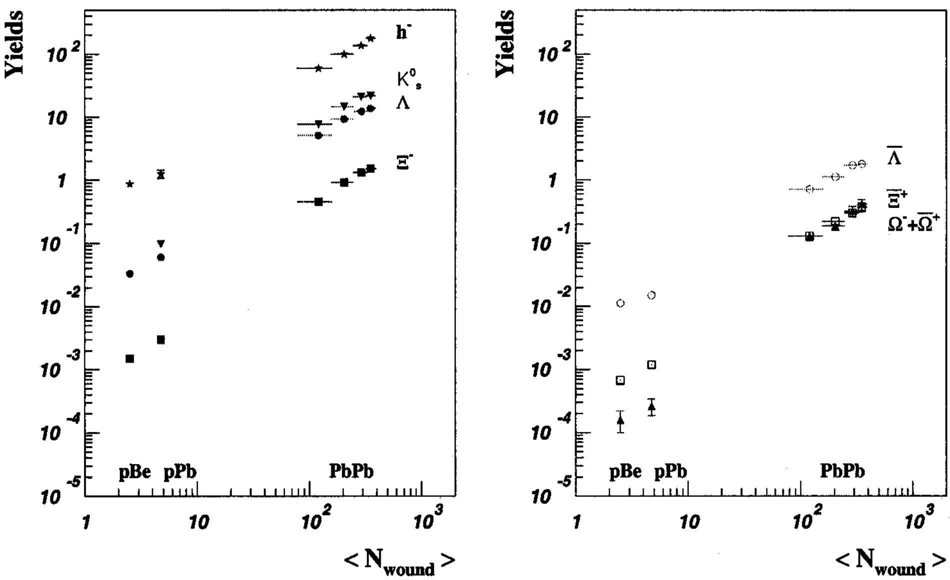

Figure 3. Yields per unit of rapidity at central rapidity as a function of the number of wounded nucleons for negative particles, K^0_S, Λ and Ξ^- (left) and for $\bar{\Lambda}$, $\bar{\Xi}^+$ and $\Omega^- + \bar{\Omega}^+$ (right).

A steady increase of the particle yields as a function of participants is observed.

In figure 4 the same particle yields are normalized to the p–Be data; results for K^0_S are no more considered in the following, as the analysis of the p–Be sample is not yet completed.

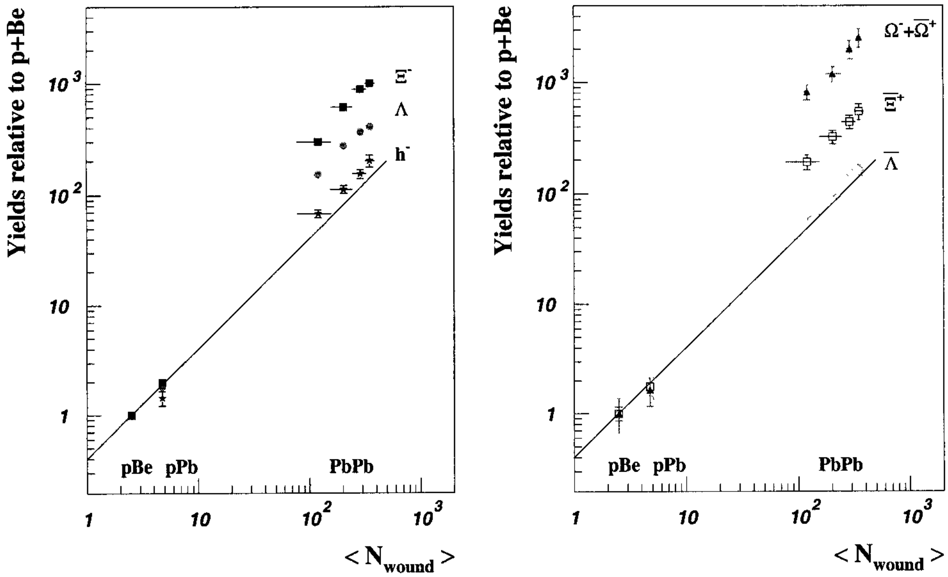

Figure 4. Yields per unit of rapidity relative to the p–Be yields.

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, here represented by the straight line: this means that there is an enhanced production of particles in Pb–Pb (even for negatives). Moreover, Λ is more enhanced respect to negative, Ξ^- is enhanced respect to Λ as well as $\bar{\Xi}^+$ is enhanced respect to $\bar{\Lambda}$ and Ω respect to $\bar{\Xi}^+$: in other words, the enhancement is larger for particles of higher strangeness content.

This is maybe more evident if the yields are further normalized to the number of participants, as shown in figure 5. The enhancements are saturated for $\langle N_{wound} \rangle > 100$, that is, they are proportional to the number of wounded nucleons in our centrality range.

A global enhancement factor computed as:

$$E = \left(\frac{\langle \mathrm{Yields} \rangle}{\langle N_{wound} \rangle} \right)_{Pb-Pb} / \left(\frac{\langle \mathrm{Yields} \rangle}{\langle N_{wound} \rangle} \right)_{p-Be} \tag{4}$$

is reported in figure 6. One can see that $E \sim 16$ for $\Omega + \bar{\Omega}$. This value is not or hardly reproduced by hadronic microscopic models [5,10].

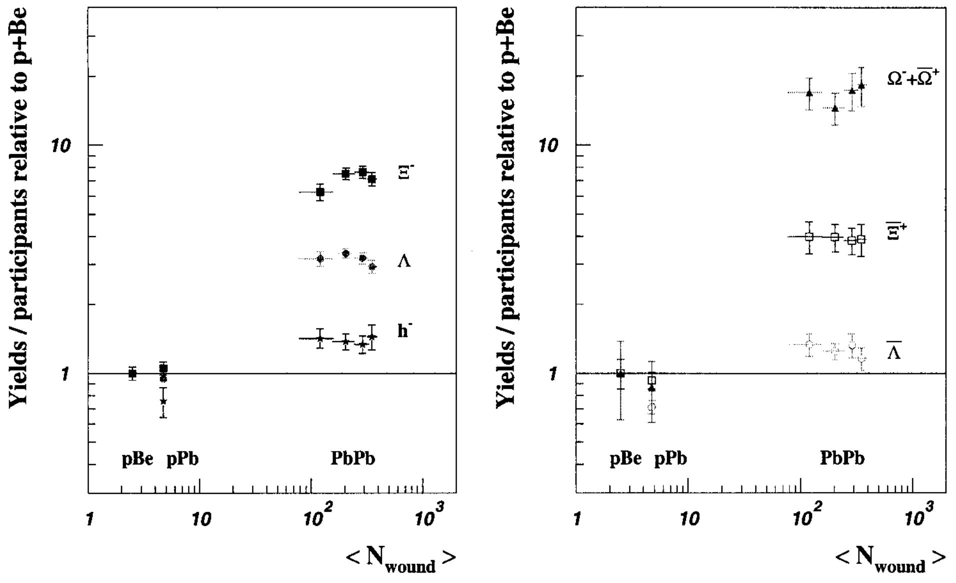

Figure 5. Yields per unit of rapidity per participant relative to the p–Be yields.

4. CONCLUSION

The WA97 experiment has measured the transverse mass spectra and yields of strange particles and negatives produced in Pb–Pb reactions at 158 A GeV/c and compared with the corresponding production in p–Be and p–Pb reactions at the same beam momentum. The results can be summarized as follows:

- the particle transverse mass distributions for the Pb–Pb data agree with the expected thermal plus flow character and show the effect of the early decoupling of Ω in agreement with microscopic calculations;
- thermal fits to particle ratios, including WA97 data, show chemical equilibrium in Pb–Pb interactions;
- there is an enhancement in the particle production in Pb–Pb with respect to p-Be increasing with the strangeness content of the particle up to reach a factor ~ 16 for $\Omega + \bar{\Omega}$.

For multistrange baryons, no hadronic microscopic model has predicted a strangeness enhancement leading to chemical equilibrium, while all these features nicely fulfill the predictions of a QGP scenario [10,11].

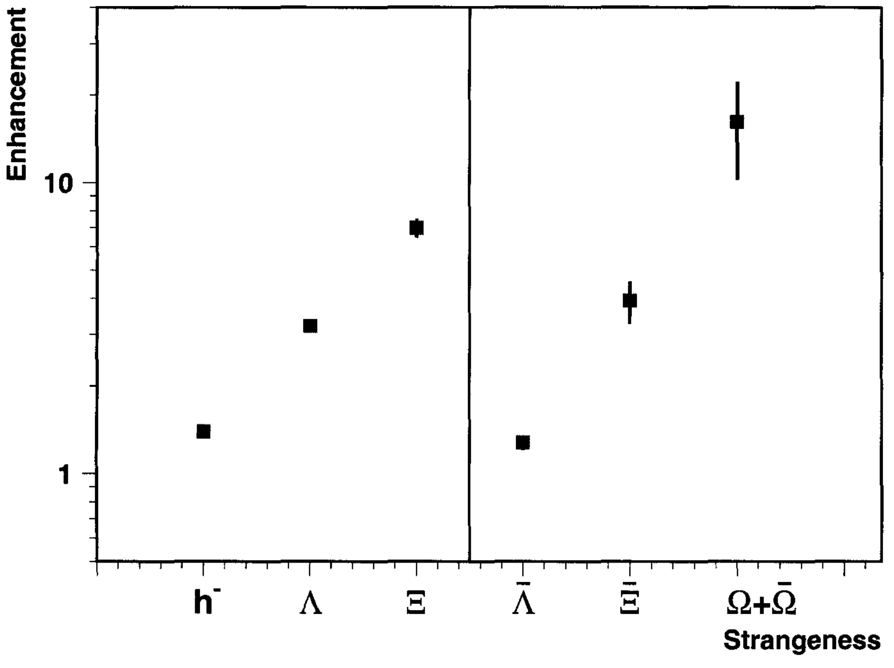

Figure 6. Strangeness enhancement versus strangeness

REFERENCES

1. J. Rafelski and B. Müller, Phys. Rev Lett. **48** (1982) 1066.
2. K.S. Lee, U. Heinz, E. Schnedermann, Z.Phys **C48** (1990) 525.
3. E. Andersen *et al.*, Phys. Lett. **B433** (1998) 209.
4. E. Andersen *et al.*, Phys. Lett. **B449** (1999) 401.
5. F. Antinori *et al.*, Eur. Phys. J. **C11** (1999) 79.
6. F. Antinori *et al.*, CERN-EP-2000-002, submitted to European Physics Journal C.
7. F. Antinori *et al.*, Eur. Phys. J. **C14** (2000) 633.
8. H. van Hecke, H. Sorge, N. Xu, Phys. Rev. Lett. **81** (1998) 5764.
9. P. Braun-Munzinger, I. Heppe, J. Stachel, Phys. Lett. **B465** (1999) 15.
10. U. Heinz, Nucl. Phys. **A661** (1999) 140c.
11. U. Heinz and B. Jacob, nucl-th/0002042 (2000).