NA57 results

F. Antinori[a], P. Bacon[b], A. Badalà[c], R. Barbera[c], A. Belogianni[d], I. Bloodworth[b], M. Bombara[e], G. .E. Bruno[f], S.A. Bull[b], R. Caliandro[f], M. Campbell[g], W. Carena[g], N. Carrer[g], R.F. Clarke[b], A. Dainese[a], D. Di Bari[f], S. Di Liberto[h], R. Divià[g], D. Elia[f], D. Evans[b], G. Feofilov[i], R.A. Fini[f], P. Ganoti[d], B. Ghidini[f], G. Grella[j], H. Helstrup[k], K.F. Hetland[k], A.K. Holme[l], A. Jacholkowski[c], G.T. Jones[b], P. Jovanovic[b], A. Jusko[b], R. Kamermans[m], J.B. Kinson[b], K. Knudson[g], V. Kondratiev[i], I. Králik[e], A. Kravčáková[e], P. Kuijer[m], V. Lenti[f], R. Lietava[b], G. Løvhøiden[l], V. Manzari[f], M. A. Mazzoni[h], F. Meddi[h], A. Michalon[n], M. Morando[a], P.I. Norman[b], A. Palmeri[c], G.S. Pappalardo[c], B. Pastirčák[e], R.J. Platt[b], E. Quercigh[a], F. Riggi[c], D. Röhrich[o], G. Romano[j], K. Šafařík[g], L. Šándor[e], E. Schillings[m], G. Segato[a], M. Sené[p], R. Sené[p], W. Snoeys[g], F. Soramel[a], M. Spyropoulou-Stassinaki[d], P. Staroba[q], R. Turrisi[a], T.S. Tveter[l], J. Urbán[r], P. van de Ven[m], P. Vande Vyvre[g], A. Vascotto[g], T. Vik[l], O. Villalobos-Baillie[b], L. Vinogradov[i], T. Virgili[j], M.F. Votruba[b], J. Vrláková[r] and P. Závada[q]

[a]University of Padua and INFN, Padua, Italy
[b]University of Birmingham, Birmingham, UK
[c]University of Catania and INFN, Catania, Italy
[d]Physics Department, University of Athens, Athens, Greece
[e]Institute of Experimental Physics, Slovak Academy of Science, Košice, Slovakia
[f]Dipartiemnto IA di Fisica dell'Università e del Politecnico di Bari and INFN, Bari, Italy
[g]CERN, European Laboratory for Particle Physics, Geneva, Switzerland
[h]University "La Sapienza" and INFN, Rome, Italy
[i]State University of St. Petersburg, St. Petersburg, Russia
[j]Dipartiemnto di Scienze Fisiche "E.R.Caianiello" dell'Università and INFN, Salerno, Italy
[k]Høgskolen i Bergen, Bergen, Norway
[l]Fysisk institutt, Universitetet i Oslo, Oslo, Norway
[m]Utrecht University and NIKHEF, Utrecht, The Netherlands
[n]IReS/ULP, Strasbourg, France
[o]Institutt for fysikk og teknologi, Universitetet i Bergen, Bergen, Norway
[p]Collège de France, Paris, France
[q]Institute of Physics, Prague, Czech Republic
[r]P.J.Šafárik University, Košice, Slovakia

Abstract. Hyperon enhancements at 160 and 40 A Gev/c are presented and compared. The momentum spectra are analysed in the framework of the blast wave model and freeze-out temperature, transverse and longitudinal flows are extracted. Nuclear modification factors are presented and discussed.

Keywords: heavy ions, QGP, strangeness, flow, nuclear modification factor
PACS: 12.38Mh, 25.75Dw, 25.75Ld, 25.75Nq

Introduction

The study of relativistic heavy ion collisions provides a unique opportunity to search for a new predicted state of matter - the quark-gluon plasma (QGP) [1]. A number of experimental signatures which could signal the QGP have been proposed (for a recent review see [2]).

Strange particles have proved over the past years to be a powerful tool for the study of reaction dynamics in high-energy heavy-ion collisions. NA57 is a dedicated experiment at the CERN SPS for the study of the production of strange and multi-strange particles in Pb-Pb collisions [3]. It continues and extends the study initiated by its predecessor the WA97 experiment, by (i) enlarging the trigger fraction of the inelastic cross section, thus extending the centrality range towards less central collisions and (ii) collecting data also at lower (40 A GeV/c) beam momentum in order to study the energy dependence of the strangeness enhancement.

In this contribution the NA57 results on enhancements and transverse flow at both SPS energies are summarised, and the longitudinal flow and nuclear modification factors at 160 A GeV/c are presented.

Enhancement at 160 and 40 A GeV/c

The enhanced yield of strange and multi-strange particles in nucleus-nucleus reactions with respect to proton-nucleus interactions has been suggested as one of the sensitive signatures for a phase transition to a QGP state [4, 5]. It is expected that the enhancement should be more pronounced for multi-strange than for singly strange particles [6]. The NA57 experiment measures *enhancement* as the particle yield per wounded nucleon in Pb-Pb centrality class $'Class'$ relative to the particle yield per wounded nucleon in p-Be collisions:

$$E = \frac{\langle N_{wound} \rangle_{p-Be}}{\langle N_{wound} \rangle_{Class}} \times \frac{dN^{Class}_{Pb-Pb}/dy}{dN_{p-Be}/dy}. \tag{1}$$

The Pb-Pb data are divided into five centrality classes [7] corresponding to 0-4.5%, 4.5-11%, 11-23%, 23-40% and 40-53% most central collisions of the total inelastic Pb-Pb cross section. At 160 A GeV/c in Fig.1 the hierarchy of hyperon enhancements $E(\Lambda) < E(\Xi) < E(\Omega)$ is observed in agreement with WA97 measurement [8]. The comparison of Λ, $\bar{\Lambda}$ and Ξ^- enhancements at two energies is shown in Fig.2.

We do not observe an indication of threshold behaviour at the lower energy suggesting that the properties of the medium created in collisions at both energies are similar.

The centrality dependence of the enhancement at 40 A GeV/c is steeper than at 160 A GeV/c. This is in qualitative agreement with canonical suppression models although the size of the effect is larger in data [9, 10].

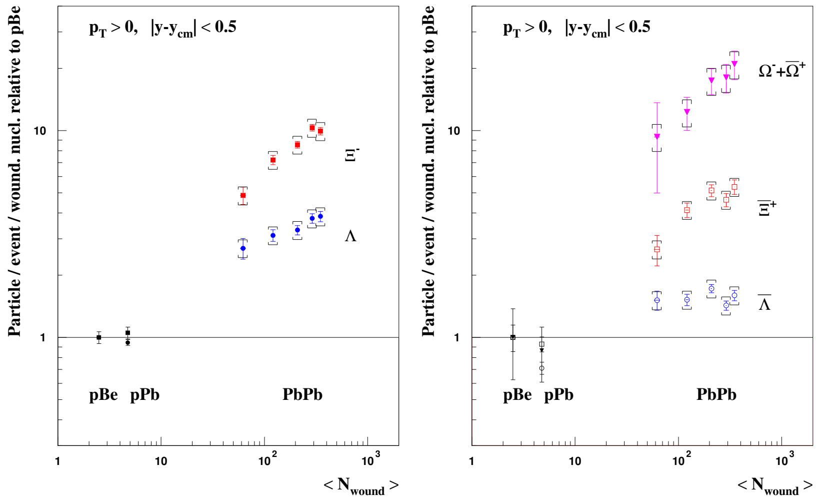

FIGURE 1. The centrality dependence of hyperon enhancements at 160 A GeV/c. The error bars inidcate the statistical errors only, while the bracket symbols represent the systematic errors.

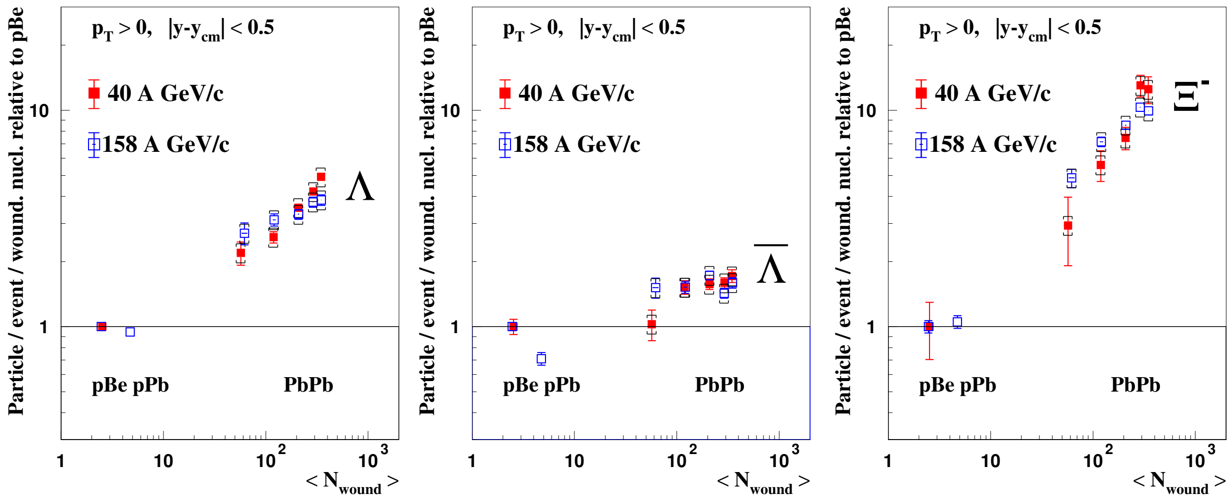

FIGURE 2. Centrality dependence of Λ, $\bar{\Lambda}$ and Ξ^- enhancements at both 160 and 40 A GeV/c. The error bars indicate the statistical errors only, while the bracket symbols represent the systematic errors.

Transverse mass and rapidity spectra

The momentum spectra of produced particles are sensitive to the details of the production dynamics [11]. For the fireball in local thermal equilibrium the shapes of the m_T and rapidity spectra depend both on the thermal motion of the particles and on the collective flow driven by pressure. To disentangle the two contributions, namely the thermal motion and the transverse and longitudinal flows, one has to rely on models. In the present analysis we consider the blast wave model [11]. The detailed procedure of the NA57 analysis can be found in [12].

The parameters which characterise the expanding fireball are local temperature T,

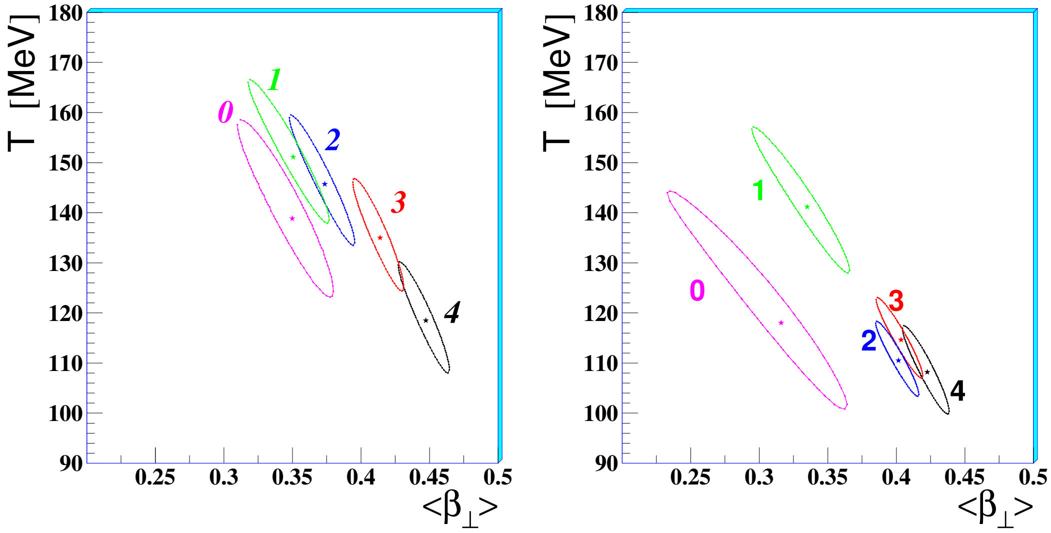

FIGURE 3. The 1 σ confidence level contours at 160 A GeV/c (left) and 40 A GeV/c (right). The data are divided into 5 centrality classes [12], most peripheral labelled 0 to most central labelled 4.

average transverse expansion velocity $\langle \beta_\perp \rangle$ and average longitudinal velocity $\langle \beta_L \rangle$. Fig.3 shows the centrality dependence of the temperature T and velocity $\langle \beta_\perp \rangle$ which are extracted from the transverse mass spectra [12].

We do not observe a different pattern of centrality dependence at two energies. At both energies we observe a decrease of T and an increase of $\langle \beta_\perp \rangle$ with centrality, indicating earlier freeze-out in peripheral collisions.

The longitudinal velocity $\langle \beta_L \rangle = 0.42 \pm 0.03$ is extracted from the rapidity spectra [13]. The centrality dependence of the rapidity spectra and longitudinal flow is not observed in data [13].

Nuclear Modification Factors

The idea of jet quenching by parton energy loss was introduced in [14] and later revisited in [15]. The quenching of high transverse momentum p_T particles in central heavy ion collisions has indeed been observed at BNL RHIC. The effect is quantified using the nuclear modification factor:

$$R_{CP}(p_T) = \frac{\langle N_{coll} \rangle_P}{\langle N_{coll} \rangle_C} \times \frac{d^2 N^C_{AA}/dp_T dy}{d^2 N^P_{AA}/dp_T dy} \tag{2}$$

The observation of the effect at RHIC [16] triggered the reanalysis of SPS data by the WA98, NA57 and NA49 collaborations [17, 18, 19]. Although hard processes play a minor role at SPS energies, the nuclear modification factors may shed a light on a modification of particle production in a dense medium.

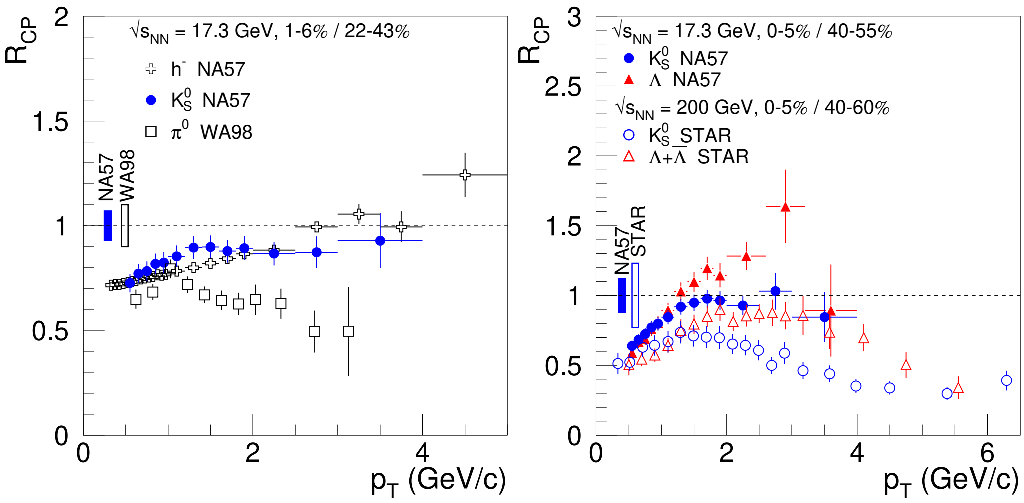

FIGURE 4. Left: $R_{CP}(p_T)$ for h^- and K^0_S from NA57 and π^0 from WA98 [17] in Pb-Pb collisions at $\sqrt{(s)}$=17.3 GeV. Right: $R_{CP}(p_T)$ for K^0_S and Λ at $\sqrt{(s)} = 17.3$ GeV (NA57) and in Au-Au at $\sqrt{(s)} = 200$ GeV (STAR) [20]: The bars centred at $R_{CP} = 1$ represent the normalisation errors; the point-by-point bars are the quadratic sum of statistical and systematic errors.

The NA57 experiment calculates $R_{CP}(p_T)$ for h^-, K^0_S, Λ and $\bar{\Lambda}$ using uncorrected p_T distributions for all reconstructed strange particles [18]. The acceptance, selection criteria and reconstruction biases are cancelled out in the ratio R_{CP} as has been checked explicitly [18].

In Fig.4 we compare our results to other R_{CP} measurements at the SPS and at RHIC. In the left panel, the WA98 π^0 data [17] in Pb-Pb collisions are plotted together with the NA57 h^- and K^0_S data for the same centrality classes. The R_{CP} of K^0_S is approximately constant at 0.8 for $p_T > 1$ GeV/c and is significantly larger than that measured by the WA98 collaboration for π^0, even when taking into account the normalisation systematic errors, which are independent for the two experiments. The h^- data from NA57 are compatible, within the systematic errors, with the π^0 data from WA98 for $p_T < 1.5$ GeV/c, where the h^- sample is expected to be dominated by π^-. For higher p_T, h^- have a larger R_{CP} than π^0; this may be due to increasing contributions from K^- and $\bar{p}$ in the h^- sample.

The NA49 - NA57 comparison is at the moment not straight-forward, since different definitions of the reference peripheral class are used by the two experiments.

A comparison for K^0_S and Λ data at SPS and RHIC is presented in the right hand panel of Fig.4. In the p_T range covered by our data, the relative pattern for K^0_S and Λ is similar at the two energies, while the absolute values are higher at the SPS than at RHIC, where parton energy loss is believed to have strong effect. The larger R_{CP} for Λ than for K^0_S at p_T around $2-3$ GeV/c can be interpreted at both energies as due to parton coalescence, although it may be explained also in terms of larger Cronin effect for Λ with respect to kaons.

Conclusions

The NA57 experiment has measured:

- A hierarchical pattern of hyperon enhancements with respect to their strangeness content: $E(\Lambda) < E(\Xi) < E(\Omega)$. This pattern is a consequence of strangeness phase space saturation in Pb-Pb collisions [9, 21, 22] due to fast strange quark creation in the QGP phase [4].
- Strange particle transverse mass and rapidity distributions: The spectra are consistent with the blast wave model parametrisation. The centrality dependence results indicate that with increasing centrality the transverse flow velocity increases and freeze-out temperature decreases at both energies. At top SPS energy collective flow with similar transverse and longitudinal average velocities is observed.
- A central to peripheral R_{CP} pattern qualitatively similar to that observed at RHIC energy, although higher in absolute value. The difference between K_S^0 and Λ suggests recombination effects at medium transverse momenta.

ACKNOWLEDGMENTS

We thank T. Csörgö, U. Heinz and B. Tomášik for fruitful discussions on the blast wave model.

REFERENCES

1. N. Cabibbo and G. Parisi, *Phys. Lett.* **B59** 67 (1975).
2. U. Heinz, Concepts of Heavy Ion Physics,hep-ph/0407360.
3. K. Fanebust et al. (NA57 collaboration), *J.Phys.* **G28** 1607 (2002).
4. J. Rafelski and B. Müller, *Phys. Rev. Lett.* **48** 1066 (1982),
   J. Rafelski and B. Müller, *Phys. Rev. Lett.* **56** 2334 (1986).
5. P. Koch, B. Müller and J. Rafelski, *Phys. Rep.* **142** 167 (1986).
6. J. Rafelski, *Phys. Lett.* **B262** 333 (1991).
7. F. Antinori et al. (NA57 collaboration), *J. Phys.* **G31** 321 (2005).
8. E. Andersen et al. (WA97 collaboration), *Phys.Lett.* **B449** 401 (1999).
9. A. Tounsi et al., *Nucl.Phys.* **A715** 565c (2003).
10. F. Antinori, *J.Phys.* **G30** S725 (2003).
11. E.Schnedermann, J.Sollfrank and U.Heinz, *Phys.Rev.*, **C48**, 2462 (1993).
12. G. E. Bruno et al. (NA57 collaboration), *J.Phys.*, **G31**, S127 (2005),
    F. Antinori et al. (NA57 collaboration), *J.Phys.*, **G30**, 823 (2004).
13. F. Antinori et al. (NA57 collaboration), *J.Phys.* **G31** 1345 (2005).
14. J. D. Bjorken, Fermilab-Pub-82/59/THY (1982) and erratum (unpublished).
15. M. Gyulassy and M. Plümer, *Phys.Lett.* **B243** 432 (1990).
16. S.S. Adler et al. (PHENIX collaboration), *Phys.Rev C* **C69** 034910 (2004),
    J. Adams et al. (STAR collaboration), *Phys.Rev.Lett.* **91** 172302 (2003).
17. M.M. Aggarwal et al. (WA98 collaboration), *Eur.Phys.J.* **C23** 225 (2002).
18. F. Antinori et al. (NA57 collaboration), *Phys.Lett.* **B623** 17 (2005).
19. C. Höhne et al. (NA49 collaboration), A. Lásló et al. (NA49 collaboration), *Proceedings of Quark Matter 05*, Budapest, August 2005.
20. J. Adams et al. (STAR collaboration), *Phys.Rev.Lett.* **92** 052302 (2004).
21. F. Becattini, *Nucl.Phys.* **A702** 336 (2002).
22. A.Bialas, *Phys.Lett.* **B442** 449 (1998).