EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Enhancement of Strange and Multi-Strange Baryons and Anti-Baryons in SW Interactions at 200 GeV/c

The WA85 Collaboration

F. Antinori[5)a)], R.P. Barnes[4)], A.C. Bayes[4)], W. Beusch[5)], R. Caliandro[2)], B. de la Cruz[7)], J.P. Davies[4)], D. Di Bari[2)], D. Elia[2)], D. Evans[4)], R. Fini[2)], B. Ghidini[2)], H. Helstrup[3)], A.K. Holme[5)], A. Jacholkowski[5)], J.B. Kinson[4)], A. Kirk[5)], K. Knudson[5)], J.C. Lassalle[5)b)], V. Lenti[2)], J.A. Lien[8)], R.A. Loconsole[2)], V. Manzari[2)], F. Navach[2)], E. Quercigh[5)], K. Šafařík[5)], M. Sené[6)], R. Sené[6)], G. Vassiliadis[1)b)], M. Venables[4)], O. Villalobos Baillie[4)], A. Volte[6)], and M.F. Votruba[4)].

Abstract

Strange and multistrange baryon production is expected to be enhanced in heavy ion interactions if a phase transition from hadronic matter to a Quark-Gluon Plasma takes place. The production yields of Λs, $\overline{\Lambda}$s, Ξ^-s, and $\overline{\Xi}^+$s relative to the production of negative particles are presented for sulphur-tungsten interactions at 200 GeV/c per nucleon. These production yields are compared to those produced in proton-tungsten interactions and the enhancements of strange and multistrange baryons and antibaryons are presented.

(Submitted to Physics Letters B)

[1)] Athens University, Athens, Greece.
[2)] Dipartimento I. A. di Fisica dell'Università e del Politecnico di Bari and Sezione INFN, Bari, Italy.
[3)] Universitetet i Bergen, Bergen, Norway.
[4)] University of Birmingham, Birmingham, UK.
[5)] CERN, Geneva, Switzerland.
[6)] Collège de France and IN2P3, Paris, France.
[7)] CIEMAT, Madrid, Spain.
[8)] Universitetet i Oslo, Oslo, Norway.
[a)] Permanent address: Dipartimento di Fisica dell'Università and Sezione INFN, Padua, Italy.
[b)] Deceased.

Strange and multistrange baryon and antibaryon production is considered to be an important tool for studying the dynamics of hot hadronic matter[1, 2]. In particular, it is considered to be an important test of whether phase transitions from hadronic matter into a Quark-Gluon Plasma (QGP) occurs in relativistic heavy ion collisions[1-4]. If a QGP were formed in heavy ion interactions then the yields of strange particles would be enhanced relative to those produced in normal hadronic interactions such as proton-proton or proton-nucleus collisions. The formation of a dense, longlived hadronic gas could also produce an increased yield of strange particles through pair production and associated production[3-5]. The amount of strangeness enhancement is, however, sensitive to the lifetime of the fireball created in a heavy ion collision. In the QGP scenario the approach to chemical equilibrium for strange quarks is much faster than in the hadronic gas case because of the low threshold for $s\overline{s}$ production in a QGP. In the hadron gas scenario the time needed for strange baryons to reach chemical equilibrium is considered to be much greater than the lifetime of the fireball[2].

The onset of QGP formation can be studied by comparing the yields of baryons and antibaryons, with different strangeness content, produced in central heavy ion interactions with those produced in proton induced reactions where no QGP formation is expected. The WA85 experiment[6] has studied the production of hyperons in sulphur-tungsten and proton-tungsten interactions at 200 GeV/c per nucleon. Strangeness enhancement in sulphur-tungsten interactions, with respect to production of strangeness in proton induced interactions, can be measured by comparing the two systems in the same kinematic window. We have presented preliminary results on enhancements from low statistics data with single field polarity elsewhere[7]. In this paper we discuss the analysis of the WA85 sulphur-tungsten and proton-tungsten data and present, on the full statistics, the enhancement of Λ, $\overline{\Lambda}$, Ξ^-, and $\overline{\Xi}^+$ hyperon yields in central sulphur-tungsten interactions with respect to those found in proton-tungsten interactions.

The experiment was performed using the CERN OMEGA Spectrometer. The apparatus was sensitive to particles of central rapidity and medium p_{T}, so that for a central sulphur-tungsten collision only a few particles were recorded out of the several hundred produced. This was achieved by using seven modules of multiwire proportional chambers (MWPCs) in their *butterfly* mode[8]. The chambers were modified so that they were only sensitive in the narrow phase space window of $p_{\mathrm{T}} > 0.6$ GeV/c and $2.0 < \mathrm{y}_{\mathrm{lab}} < 3.2$. The experimental layouts and triggers used for the sulphur-tungsten and proton-tungsten data are explained in detail in references [9] and [10] respectively. Proton-tungsten data were taken using two trigger modes, level 1 and level 2. The level 1 trigger used scintillator hodoscopes in order to select events with at least one track in the MWPCs, while the level 2 trigger used these MWPCs to select events with at least two tracks in order to enhance V^0 and cascade detection. The apparatus was symmetric with respect to charge, providing equal acceptance for particles and antiparticles. In addition, the data were taken with both magnetic field polarities in order to reduce possible residual systematic effects. The strange particle samples used in this analysis were taken from 60 million central sulphur-tungsten and 30 million proton-tungsten triggers.

The selection procedure for V^0s and cascades has been described elsewhere [9, 10]. The effective mass distributions for cascade candidates, from the sulphur-tungsten data, interpreted as $\Lambda\pi^-$and $\overline{\Lambda}\pi^+$are shown in figures 1(a) and 1(b). Those from the proton-tungsten data are shown in figures 1(c) and 1(d). As can be seen from figure 1, we find clear signals with little background. We select $\Lambda(\overline{\Lambda})$ candidates in a 50 MeV mass interval centred on the P.D.G. value[11] of the Λ mass and $\Xi^-(\overline{\Xi}^+)$ candidates in a 100 MeV mass interval centred on the P.D.G. value of the Ξ^- mass. The resulting numbers of hyperons and antihyperons from the two data samples are given in table 1. The net effect of smearing outside the mass interval and background under the signal has been calculated by Monte Carlo and event mixing and is found to be less than 2%.

In order to reduce contamination from K^0_s decays the Λ and $\overline{\Lambda}$ samples used in this analysis have the additional requirement of $\cos\theta^* < -0.5$ where θ^* is the angle between the line of flight of the (anti)lambda and the decay (anti)proton in the (anti)lambda rest frame. The remaining number of Λ and $\overline{\Lambda}$ candidates after this selection are shown in brackets in table 1. The resulting K^0_s contamination, after this requirement, has been calculated to be less than 1%[12]. The hyperon and antihyperon candidates have been corrected for geometrical acceptance, unseen decay modes, and reconstruction efficiencies. In addition, the $\Lambda(\overline{\Lambda})$ candidates have been corrected for feed-down from $\Xi(\overline{\Xi})$ decays. The calculation procedure has been described in a previous publication[13]. The amount of contamination from Ξ decays for Λs and $\overline{\Lambda}$s is 19% and 34% respectively in sulphur-tungsten interactions and 11% and 21% respectively in proton-tungsten interactions.

The NA35 experiment has shown that negative particle production (treated as pions) in S-A interactions is similar to that expected from a superposition of p-A interactions[14]. That is, that negative particle production in p-A and S-A interactions is proportional to the number of participating nucleons in the interaction. Normalising hyperon yields to the negative particle yields is, therefore, an appropriate way of comparing hyperon production in p-W and S-W interactions.

The negative particle samples were treated as pions when corrected for geometrical acceptance and reconstruction efficiencies. For this analysis, a phase space window has been chosen where negative particles, Λs, and Ξ^-s from both S-W and p-W interactions all have good acceptance. The phase space window used is shown in figure 2 and covers the y_{lab}-p_T interval $2.5 < y_{lab} < 3.0$, $1.4 < p_T < 3.0$ GeV/c . The level 2 data sample from p-W interactions is biased towards particles with at least two decay tracks and so the level 1 data sample was used to determine the Λ/h^- and $\overline{\Lambda}/h^-$ ratios in p-W interactions. The Ξ^-/h^- and $\overline{\Xi}^+/h^-$ ratios can then be deduced using the Ξ^-/Λ and $\overline{\Xi}^+/\overline{\Lambda}$ ratios from the level 2 data and the Λ/h^- and $\overline{\Lambda}/h^-$ ratios from the level 1 data. There are no such problems from the S-W data sample, because only a centrality trigger was used, and so the Ξ^-/h^- and $\overline{\Xi}^+/h^-$ ratios can be calculated directly. Table 2 shows the hyperon to negative ratios from the p-W and S-W data samples.

As can be seen from table 2, the hyperon to negative ratios in S-W interactions ($(Y/h^-)_{\mathrm{SW}}$) are larger than those in p-W interactions ($(Y/h^-)_{\mathrm{pW}}$). We define strangeness enhancement as the ratio of the number of hyperons per negative particle produced in sulphur induced reactions to the number of hyperons per negative particle produced in proton induced reactions i.e.

$$E_{\mathrm{S}} = \left(\frac{Y}{h^-}\right)_{\mathrm{SW}} / \left(\frac{Y}{h^-}\right)_{\mathrm{pW}} .$$

If the production of negative particles (mainly pions) in sulphur induced reactions is what is expected from the superposition of interacting nucleons as reported by NA35, then our definition gives the actual strangeness enhancement with respect to this superposition. If, however, negative particles, themselves, are enhanced in sulphur induced reactions then our definition understates the strangeness enhancement with respect to the superposition on interacting nucleons. We can see from table 3 that Λ and $\overline{\Lambda}$ hyperons are enhanced by a factor of about 2.7 and Ξ^- and $\overline{\Xi}^+$ hyperons are enhanced by a factor of about 3.8. These enhancements are shown in figure 3 where the horizontal line indicates where the points would lie if there were no enhancement. As can be seen from figure 3, there is an eight standard deviation difference between the Λ enhancement point and the no enhancement line.

In conclusion, we have presented strange and multistrange baryon production in proton-tungsten and sulphur-tungsten interactions at 200 GeV/c per nucleon. The hyperons have been normalised to negative particle yields in the phase space window $2.5 < \mathrm{y}_{\mathrm{lab}} < 3.0$, $1.4 < p_{\mathrm{T}} < 3.0$ GeV/c . Comparison of the data from p-W and S-W interactions show that strange hyperons are enhanced by a factor of about 2.7 and multistrange hyperons are enhanced by a factor of about 3.8 in S-W interactions with respect to p-W interactions.

References

[1] J. Rafelski and B. Müller, Phys. Rev. Lett. **48** (1982) 1066.
J. Rafelski and B. Müller, Phys. Rev. Lett. **56** (1986) 2324.

[2] P. Koch, B. Müller and J. Rafelski, Physics Reports **142** (1986) 167.

[3] T. Matsui, B. Svettisky and L.D. McLerran, Phys. Rev. **D34** (1986) 2047.

[4] K.S. Lee, M. Rhoades-Browne and U. Heinz, Phys. Rev. **C37** (1988) 1452.

[5] E. Schnedermann, J. Sollfrank and U. Heinz; Fireball Spectra in 'Particle Production in Highly Excited Matter', NATO-ASI Series B, Vol. 303. Ed. H.H. Gutbrod and J. Rafelski (Plenum Press, New York, 1993) p. 175.

[6] WA85 Proposal, CERN/SPSC/84-76 P206 (1984)
CERN/SPSC/87-18 P206 Add. (1987), CERN/SPSC/88-20 P206 Add. (1988).

[7] The WA85 Coll., D. Evans *et al.*, Nucl. Phys. **A566** (1994) 225.

[8] W. Beusch et al., Nucl. Inst. Meth. **A249** (1986) 391.

[9] The WA85 Coll., S. Abatzis *et al.*, Phys. Lett. **B359** (1995) 382.

[10] The WA85 Coll., S. Abatzis *et al.*, Phys. Lett. **B392** (1997) 210.

[11] Particle Data Group, European Physical Journal **C3** (1998) 1.

[12] The WA85 Coll., S. Abatzis *et al.*, Phys. Lett. **B376** (1996) 251.

[13] The WA85 Coll., S. Abatzis *et al.*, Phys. Lett. **B270** (1991) 123.

[14] The NA35 Coll., D. Röhrich *et al.*, Nucl. Phys. **A566** (1994) 35.

Figure Captions

Figure 1: Effective mass distributions for (a) $\Lambda\pi^-$ and (b) $\overline{\Lambda}\pi^+$ in sulphur-tungsten interactions and (c) $\Lambda\pi^-$ and (d) $\overline{\Lambda}\pi^+$ in proton-tungsten interactions.

Figure 2: Phase space window of overlapping good acceptance used for this analysis.

Figure 3: Λ, $\overline{\Lambda}$, Ξ^-, and $\overline{\Xi}^+$ enhancements in sulphur-tungsten interactions with respect to proton-tungsten interactions, as defined in the text.

Tables

Table 1: Raw hyperon yields in proton-tungsten and sulphur-tungsten interactions (numbers in brackets show the $\Lambda(\overline{\Lambda})$ samples that are unambiguous with K^0s).

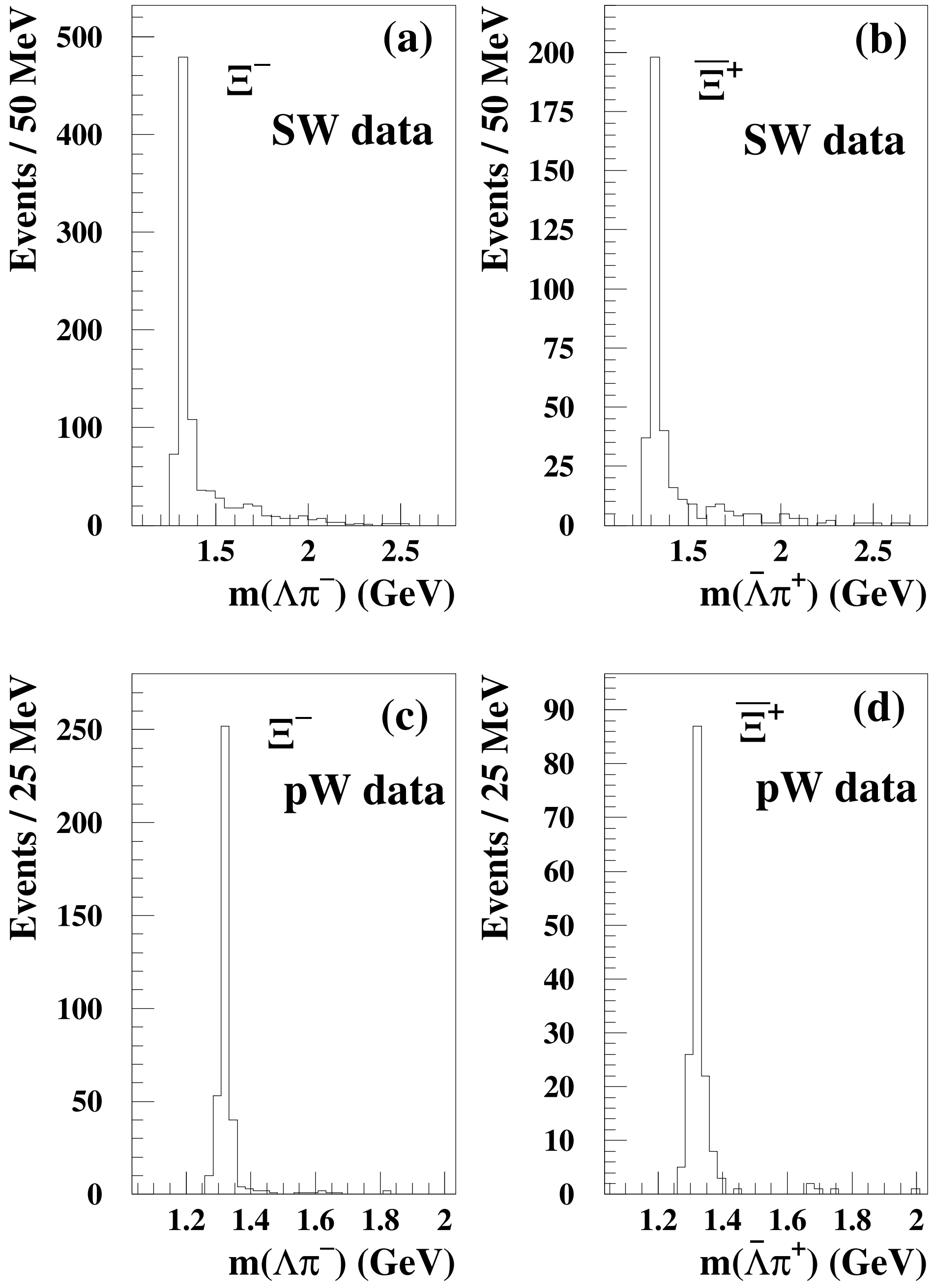
Particle	Raw Particle Yields		
	Level 1 p-W data	Level 2 p-W data	S-W data
Λ	2,628	31,114	61,071
	(1,154)	(13,841)	(27131)
$\overline{\Lambda}$	742	8,715	15,765
	(304)	(3,467)	(6581)
Ξ^-	–	294	610
$\overline{\Xi}^+$	–	136	253

Table 2: Hyperon to negative particle ratios.

$2.5 < y_{\mathrm{lab}} < 3.0$, $1.4 < p_{\mathrm{T}} < 3.0$ GeV/c		
Ratio	p-W Interactions	S-W Interactions
Λ/h^-	0.130 ± 0.010	0.358 ± 0.012
$\overline{\Lambda}/h^-$	0.029 ± 0.004	0.078 ± 0.003
Ξ^-/h^-	0.009 ± 0.001	0.035 ± 0.002
$\overline{\Xi}^+/h^-$	0.005 ± 0.001	0.018 ± 0.002

Table 3: Strange and multistrange baryon enhancements.

$2.5 < y_{\mathrm{lab}} < 3.0$, $1.4 < p_{\mathrm{T}} < 3.0$ GeV/c				
Particle	Λ	$\overline{\Lambda}$	Ξ^-	$\overline{\Xi}^+$
Enhancement Factor	2.76	2.69	3.82	3.87
Error	0.22	0.38	0.51	0.80



Events / 50 MeV
(a)
Ξ^-
SW data
$m(\Lambda\pi^-)$ (GeV)
(b)
$\overline{\Xi}^+$
SW data
$m(\bar{\Lambda}\pi^+)$ (GeV)
Events / 25 MeV
(c)
Ξ^-
pW data
$m(\Lambda\pi^-)$ (GeV)
(d)
$\overline{\Xi}^+$
pW data
$m(\bar{\Lambda}\pi^+)$ (GeV)

Figure 1:

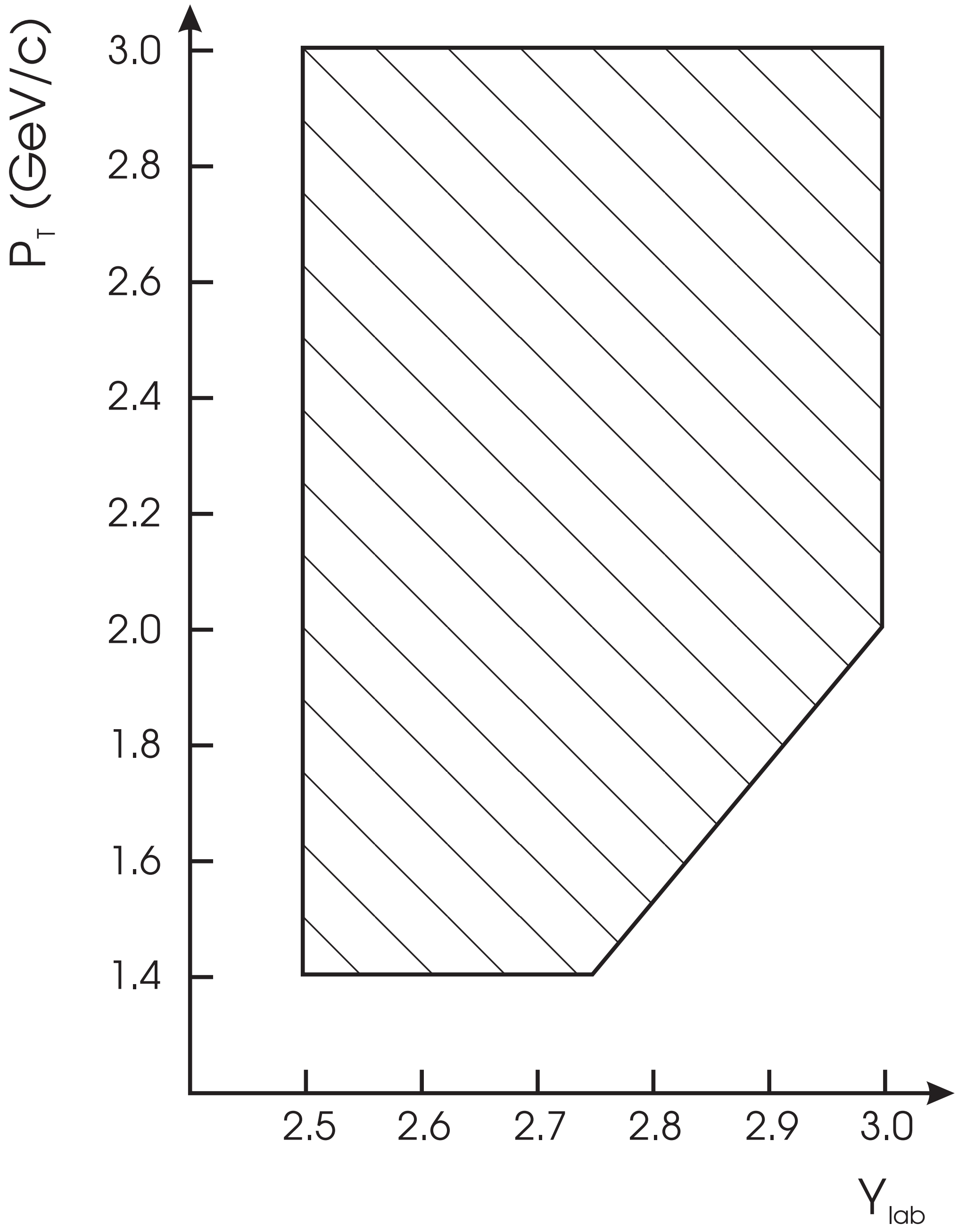


Figure 2:

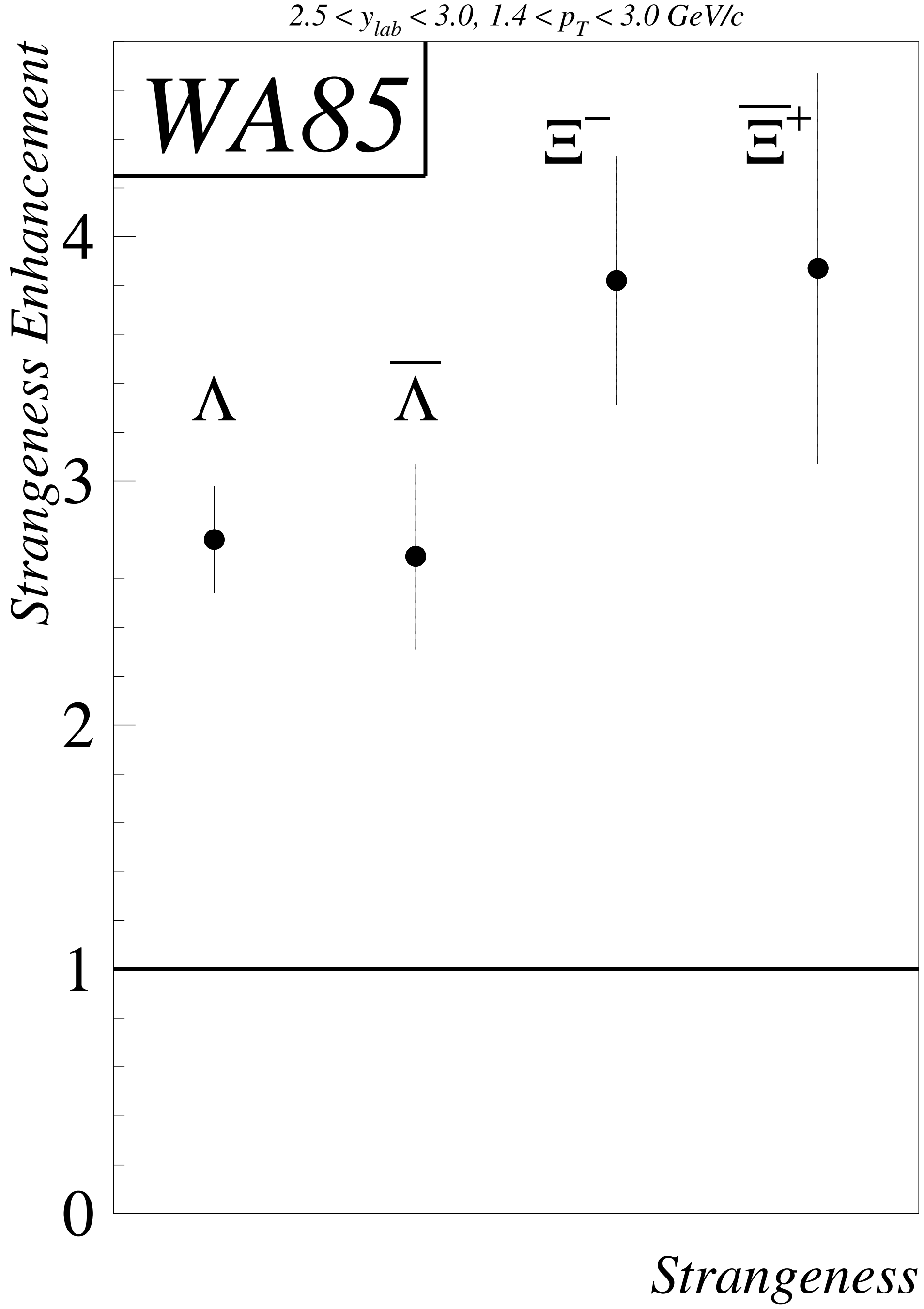

2.5 < y_lab < 3.0, 1.4 < p_T < 3.0 GeV/c
WA85
Strangeness Enhancement
Λ
Λ̄
Ξ⁻
Ξ̄⁺
0
1
2
3
4
Strangeness

Figure 3: