Strangeness enhancement at mid-rapidity in Pb-Pb collisions at 158 A GeV/c

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Abstract

$\mathrm{K^0_S}$, Λ, Ξ, Ω and negative particle h^- yields and transverse mass spectra, measured at central rapidity in p-Pb and Pb-Pb collisions at 158 A GeV/c, are presented and discussed. Yields are studied as a function of the number of nucleons participating in the collision N_{part}, which have been estimated using the Glauber model. From p-Pb to Pb-Pb collisions the particle yields per participant increase substantially. Such an enhancement is more pronounced for multiply strange particles, and reaches an order of magnitude for Ω. For a number of participants $N_{part} > 100$, however, all yields per participant appear to be constant.

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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). A number of experimental signatures which could signal the QGP have been proposed (for a recent review see [1]). They are being studied in experiments at the BNL AGS and CERN SPS. Several experimental results [2, 3, 4, 5] which could be due to the onset of a phase transition to the QGP in high energy Pb-Pb collisions have been recently presented.

Strange particles produced in heavy ion collisions give important information on the collision mechanism. In particular, the enhanced yield of strange and multi-strange particles in nucleus-nucleus with respect to proton-nucleus interactions has been suggested as one of the sensitive signatures for a phase transition to a QGP state [6, 7]. It is expected that the enhancement should be more pronounced for multi-strange than for singly strange particles [8].

Recently, we published data on the Λ, Ξ and Ω transverse mass distributions and yields at central rapidity both in p-Pb and Pb-Pb collisions at 158 A GeV/c [2]. New results with improved statistics have been presented at this conference [9]. In this paper we present the transverse mass distributions and yields for $\mathrm{K^0_S}$ and negative particles h^- and we compare them to the corresponding hyperon results [9]. Finally, we analyze in detail the behaviour of the particle yields as a function of the number of nucleons participating in the collision N_{part}.

The paper is organized as follows: after the definition of the selection criteria of the experimental sample for the h^- and $\mathrm{K^0_S}$ (which were not defined in [9]), the results on transverse mass spectra, particle yields as function of centrality, and strangeness enhancement in Pb-Pb relative to p-Pb, both for hyperons and $\mathrm{K^0_S}$ and h^-, are presented.

Table 1 gives the numbers of h^- and $\mathrm{K^0_S}$ particles used for the present analysis and the expected increase in statistics after processing and correcting all collected data. The corresponding table for hyperons is in [9]. We selected as h^- those negative tracks which pointed to the interaction vertex and had hits in each telescope pixel plane. In the p-Pb run the trigger required at least one track in the silicon telescope. For the Pb-Pb particle sample the trigger corresponded to the most central 40% of the total inelastic cross section.

The $\mathrm{K^0_S}$ were identified by their decay

$$\mathrm{K^0_S} \rightarrow \pi^- + \pi^+$$

To ensure that $\mathrm{K^0_S}$ are not ambiguous with Λ, a cut for $|\alpha| < 0.45$ was made, where α is Podolanski-Armenteros variable [10]. The $\mathrm{K^0_S}$ mass resolution was better than 6 MeV (FWHM). The weighting of h^- and $\mathrm{K^0_S}$ was done by the same procedure as for hyperons [9]. The acceptance windows for negatives (h^-) and $\mathrm{K^0_S}$ are shown in fig. 1 (for hyperon acceptances see [9]).

The double differential distributions for the measured particles were fitted in their

Table 1: Particle statistics used in the present analysis and expected increase in the statistics after processing all available data.

Particle	p-Pb		Pb-Pb	
	Present	Expected	Present	Expected
$\mathrm{K^0_S}$	1100	$\times$ 200	750	$\times$ 1000
h^-	1500	$\times 5 \cdot 10^4$	1800	$\times 3 \cdot 10^5$

respective acceptance windows using the expression

$$\frac{d^2N}{dm_\mathrm{T}dy} = f(y)\, m_\mathrm{T}{}^{\alpha} \exp(-\frac{m_\mathrm{T}}{T}) \tag{1}$$

The fit was performed using the method of maximum likelihood. Due to the limited statistics, for the present analysis we have assumed the rapidity distributions to be flat at mid-rapidity, *i.e.* $f(y) = constant$ in expression (1). We have investigated the systematic error which this assumption could introduce in the case of the h^- and $\mathrm{K^0_S}$ (for hyperons see [9]) taking into account existing data for p-S, p-Au [11, 12, 13] and Pb-Pb [3] collisions. We find that using a flat rapidity distribution instead of one obtained from a fit to the published data gives a difference of $< 2\%$ on the slope and $< 10\%$ on the yield defined by equation (2) in the case of the h^-, and 5% and 5% respectively in the case of the $\mathrm{K^0_S}$ distribution.

The transverse mass distributions for all measured particles in p-Pb and Pb-Pb collisions are shown in fig.2 and the corresponding inverse slope parameters T are summarized in table 2. The slopes have been fitted using expression (1), where we have chosen the value $\alpha = \frac{3}{2}$ in order to facilitate a comparison with WA85 [14] and WA94 [15] and $\alpha = 1$ to compare with the NA49 [16] results. Due to the limited statistics the data on Ω^- and $\overline{\Omega}^+$ were combined, both for Pb-Pb and p-Pb data. Quoted errors are statistical only.

We note that the inverse slope parameter T increases from p-Pb to Pb-Pb for h^-, $\mathrm{K^0_S}$, Λ and Ξ, while the large statistical error on the p-Pb data precludes firm conclusions regarding the inverse slope for Ω.

The values of T for Pb-Pb collisions shown in table 2 and those reported by NA49 collaboration [3, 16], are displayed together in fig. 3 as a function of the particle mass. It appears that T increases with the mass of the particle for pions, kaons, protons and deuterons. However this is not the case for hyperons, whose fitted inverse slope parameter T values seem to level out, with perhaps a slight decrease for Ω. A possible origin of such a behavior has been recently discussed in [17].

The WA97 multiplicity detectors allow us to study particle yields as a function of collision centrality as measured by the number of nucleons participating in collision, N_{part}. The procedure to calculate N_{part} is described in [2, 9]. The particle production

Table 2: Inverse $m_{\rm T}$ slope parameters T in MeV for p-Pb and Pb-Pb interactions.

	p-Pb		Pb-Pb	
Particle	$\alpha = 3/2$	$\alpha = 1$	$\alpha = 3/2$	$\alpha = 1$
h^-	163 ± 4	185 ± 5	183 ± 6	213 ± 8
$\mathrm{K^0_S}$	197 ± 5	217 ± 6	210 ± 7	232 ± 9
Λ	184 ± 5	196 ± 6	266 ± 7	289 ± 8
$\overline{\Lambda}$	172 ± 10	183 ± 11	264 ± 11	287 ± 13
Ξ^-	222 ± 12	235 ± 14	266 ± 8	286 ± 9
$\overline{\Xi}^+$	211 ± 19	224 ± 21	265 ± 15	284 ± 17
$\Omega^- + \overline{\Omega}^+$	312 ± 86	334 ± 99	238 ± 17	251 ± 19

yield is defined by the integral

$$Yield \; = \int_0^\infty dp_T \int_{y_{cm}-0.5}^{y_{cm}+0.5} (\frac{d^2N}{dydp_T})dy \qquad (2)$$

where the extrapolation to the window $|y - y_{cm}| < 0.5$ and $p_{\rm T} > 0$ GeV/c is done according to expression (1).

Fig. 4 shows the yields for h^-, $\mathrm{K^0_S}$, Λ, $\overline{\Lambda}$, Ξ^-, $\overline{\Xi}^+$, $\Omega^- + \overline{\Omega}^+$ both for p-Pb and Pb-Pb interactions as a function of the number of participants N_{part}. The vertical bars corresponds to statistical uncertainties and do not include systematic errors due to decay feed-down [9] or to the assumption of a flat rapidity distribution in our acceptance window. However, these are estimated to be small relative to the statistical errors. Horizontal bars show the root-mean-square values of the number of participants in the selected multiplicity bins for Pb-Pb collisions, and the full range in p-Pb [9]. The effect of the trigger in the p-Pb sample has been taken into account.

In fig. 4 the particles are divided in two groups. In fig. 4a we plot the yields of those particles with at least one valence quark common with the nucleon: Ξ^-, Λ and h^- together with $\mathrm{K^0_S}$, which can be either $\bar{d}s$ or $\bar{s}d$.

Fig. 4b refers to particles with no common valence quark with the nucleon: $\overline{\Lambda}$, $\overline{\Xi}^+$ and $\Omega^- + \overline{\Omega}^+$.

It could be instructive to analyze them separately since particles in these two groups are empirically known to exhibit different production features: *e.g.* Λ and $\overline{\Lambda}$ have different rapidity spectra both in p-S and S-S [12].

In order to facilitate a comparison of the enhancements for the various particle yields when going from p-Pb to Pb-Pb, fig. 5 shows the particle yields expressed in units of the corresponding yield per p-Pb interaction (*i.e.* each yield is rescaled so that the value for p-Pb is set to one). The particle yields in Pb-Pb are compared to a yield curve (full line) drawn through a p-Pb point and proportional to the number of participants N_{part}.

As already pointed out in [2], the Λ, Ξ and Ω yields increase from p-Pb to Pb-Pb much faster than the number of participants, *e.g.* the Ω yield increased as $\langle N_{part}\rangle^{1.72\pm0.05}$. At present the improved statistics allows us to study how the yields increase within the Pb-Pb centrality range, *i.e.* for $N_{part} > 100$. In this range, as shown by fig.5, we observe that all particle yields follow closely the dotted lines which correspond to proportionality between yield and the number of participants N_{part}. More quantitatively, a fit made through the Pb-Pb data points assuming a power law dependence $\langle N_{part}\rangle^{\beta}$, as shown in fig. 6, gives fitted values of β for all particle species consistent with unity.

From the average yield per participant

$$\frac{Y}{\langle N_{part}\rangle}$$

where yield Y is calculated using equation (2) we can compute the strangeness enhancement E when going from p-Pb to Pb-Pb collisions

$$E = (\frac{Y}{\langle N_{part}\rangle})_{Pb-Pb}/(\frac{Y}{\langle N_{part}\rangle})_{p-Pb} \tag{3}$$

The enhancement values obtained are displayed in fig. 7. Similar enhancement values are obtained if we use the data before the extrapolation to the full $y-p_T$ window.

We note that the enhancement E increases with strangeness:

$$E(\Omega^- + \overline{\Omega}^+) > E(\overline{\Xi}^+) > E(\overline{\Lambda})$$

and for particles with at least one quark in common with the nucleon it is found that

$$E(\Xi^-) > E(\Lambda) \approx E(\mathrm{K^0_S})$$

In summary, from p-Pb to Pb-Pb the strange particle yields at central rapidity increase faster than linearly with the number of participants N_{part}. This enhancement is more pronounced for multiply strange particles, and is one order of magnitude in the case of the Ω. However, in the participant range $N_{part} > 100$, corresponding to our Pb-Pb data, our best fit gives all yields increasing proportionally to N_{part}, which would suggest that all the reported enhancements reach their maximum values for N_{part} below 100 and then remain constant. More statistics are required to confirm this effect.

Two questions arise from these observations:

(i) How do the yields behave at lower values of N_{part}, *i.e.* are they smooth or is there a sudden change ?

(ii) How does this pattern depend on the collision centre of mass energy ?

Both questions will be addressed by the forthcoming NA57 experiment [18].

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Figure caption.

Figure 1. Acceptance windows for h^- and K^0_S. For Pb-Pb collisions, the symmetry of the system around midrapidity allows symmetrization of the acceptance windows around y_{cm}.

Figure 2. m_T-spectra for the measured particles.

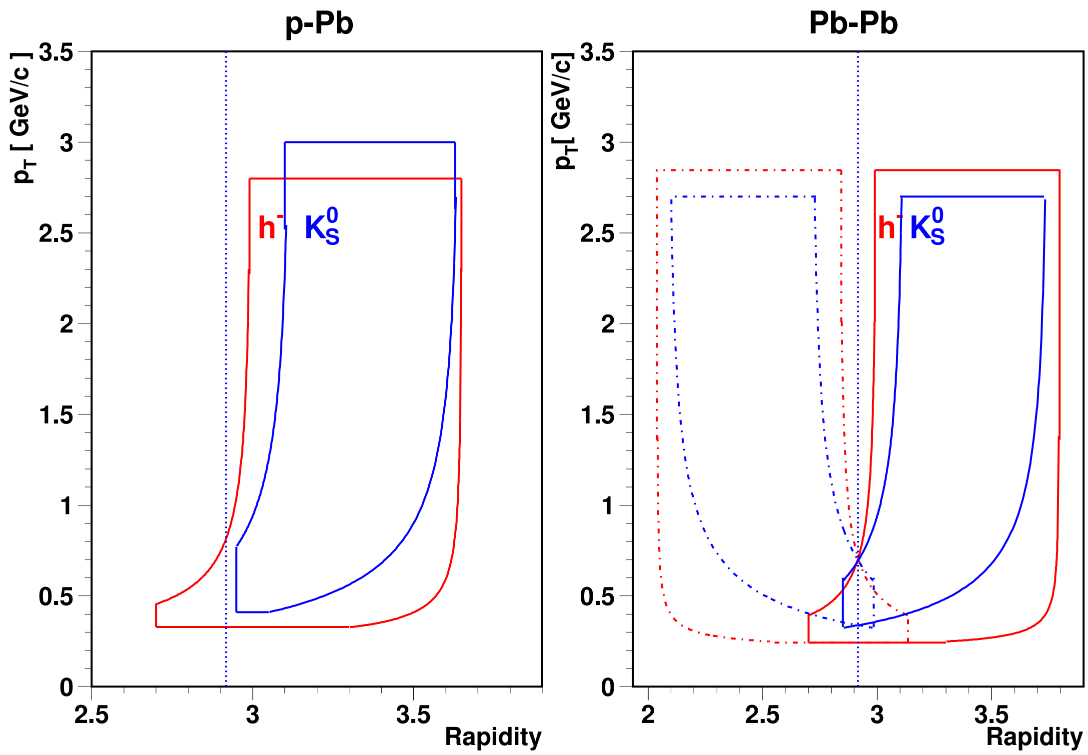
Figure 3. Inverse slope T versus particle mass.

Figure 4. Yields as a function of the number of participants for a) h^-, K^0_S, Λ and Ξ^- b) $\overline{\Lambda}$, $\overline{\Xi}^+$ and $\Omega^- + \overline{\Omega}^+$. See text for details.

Figure 5. Yields, expressed in units of yields observed in p-Pb collisions, as a function of the number of participants for a) h^-, K^0_S, Λ and Ξ^- b) $\overline{\Lambda}$, $\overline{\Xi}^+$ and $\Omega^- + \overline{\Omega}^+$. The solid and dotted lines represent functions proportional to the number of participants. See text for details.

Figure 6. Fitted values of the exponent β.

Figure 7. Strangeness enhancement versus strangeness.



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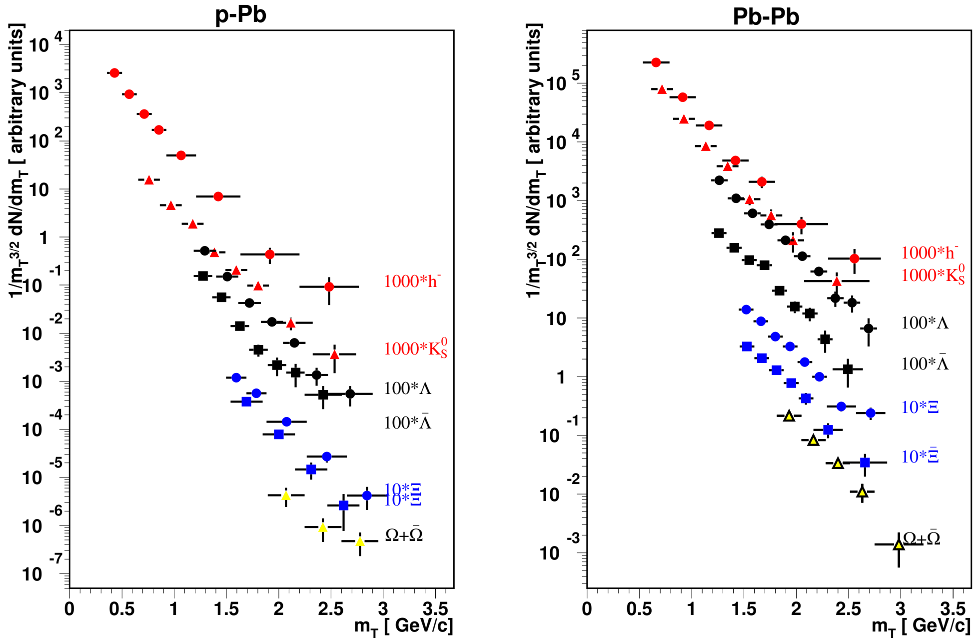

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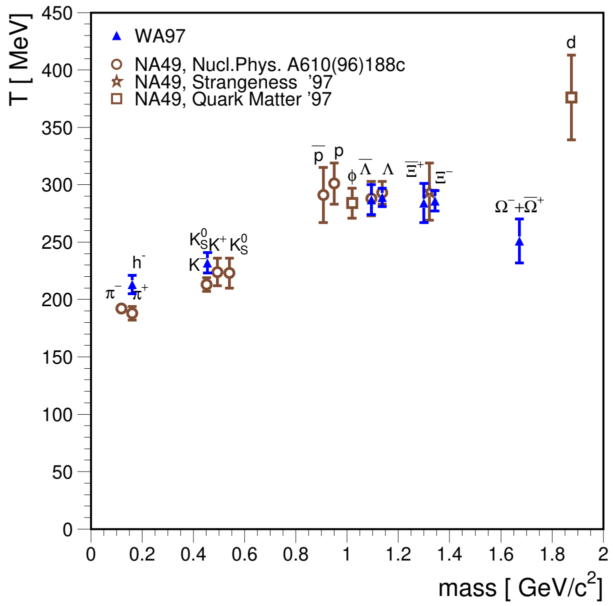

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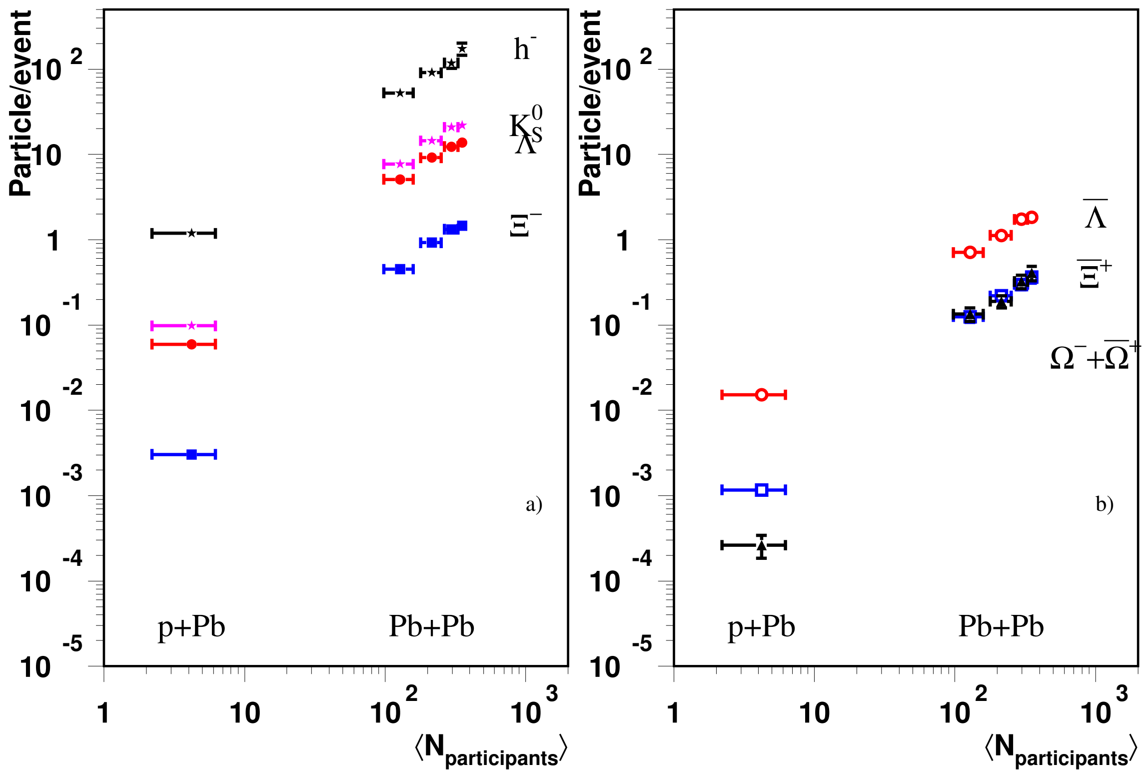

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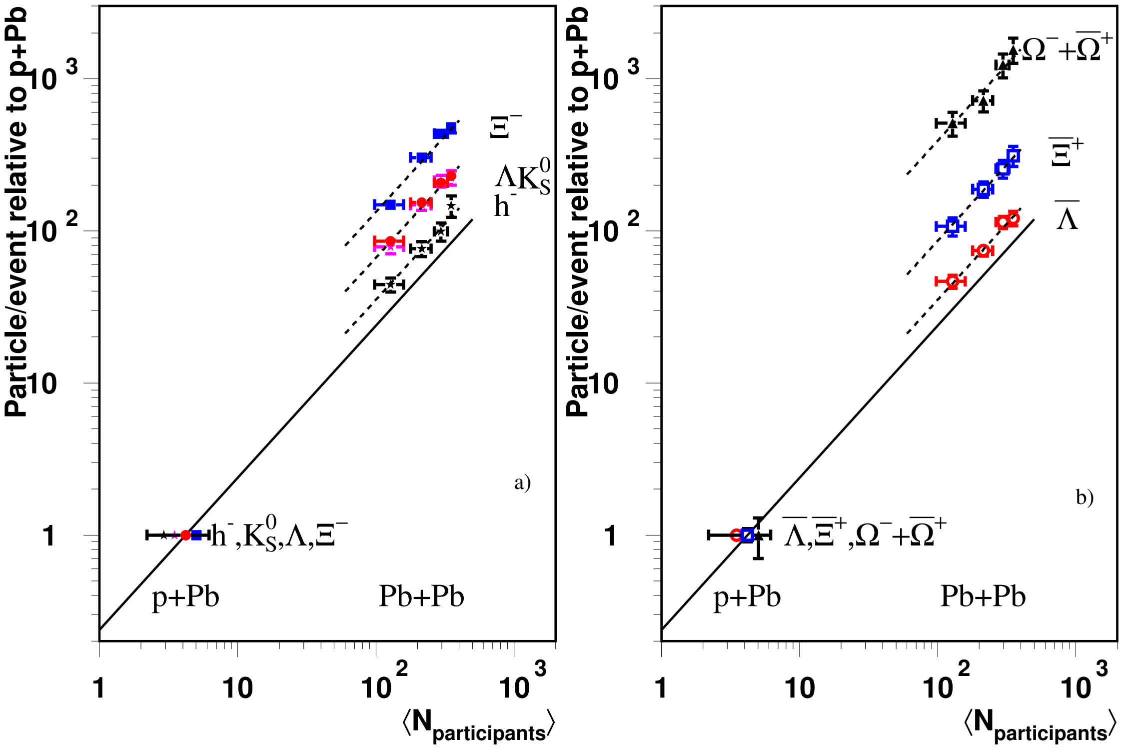

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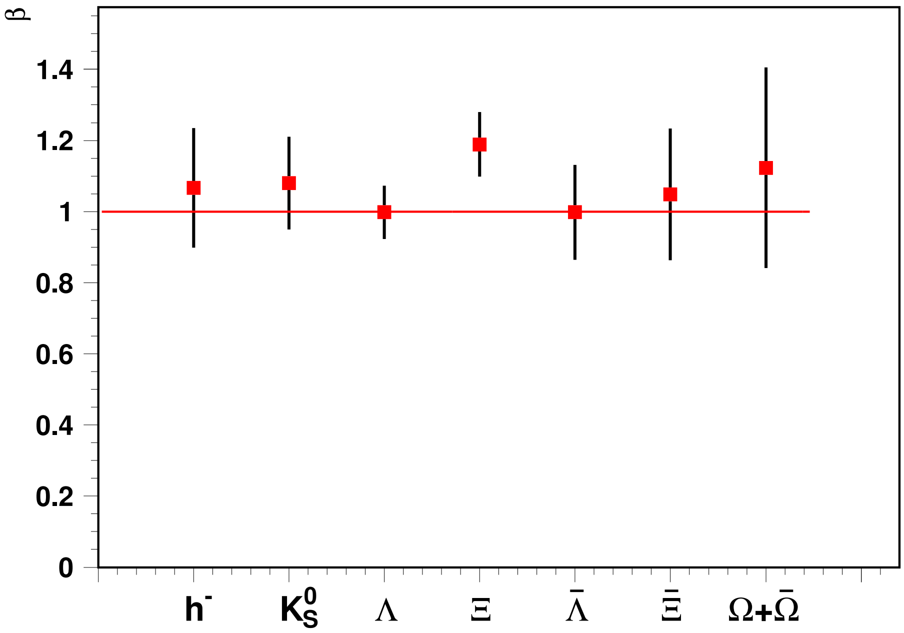

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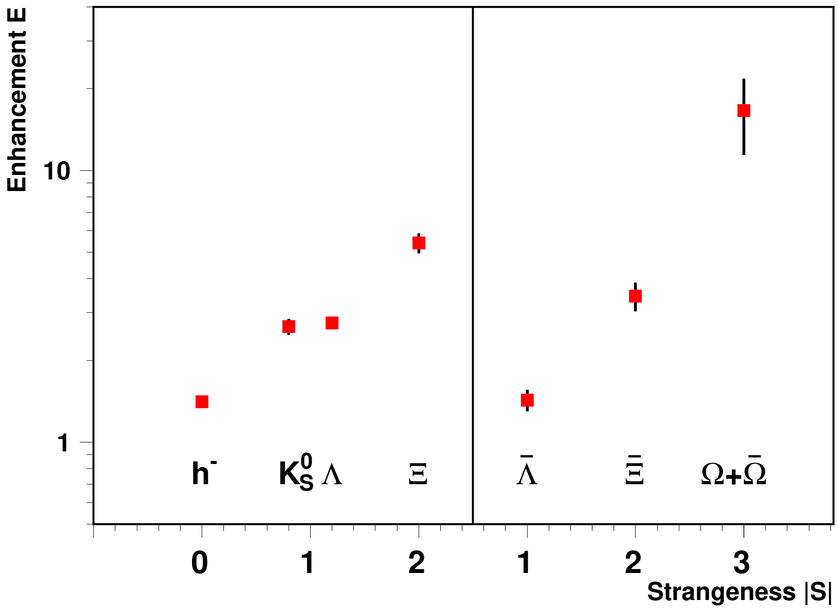

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