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Ratios of strange antibaryons to baryons in relativistic nucleus-nucleus collisions

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Abstract

Ratios of strange antibaryons to baryons in the reaction S + Pb at 200 A GeV beam energy have been computed using a new version of the Fritiof event generator, Luciae, with collective string interaction and rescattering. Theoretical ratios of $\overline{\Lambda}/\Lambda$, Ξ^-/Λ, $\overline{\Xi^-}/\overline{\Lambda}$ and $\overline{\Xi^-}/\Xi^-$ are comparable with experimental data within the range of the deviation among the data of different collaborations. It seems to indicate that the ratios of production of strange antibaryons to baryons might be explained within a hadronic scenario.

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Strangeness production is expected to be a powerful probe for studying nucleus-nucleus collisions. Since, in the phase of a quark-gluon plasma (QGP) the threshold energy for strange quark production (E_{th} ~300 MeV for $q\bar{q} \rightarrow s\bar{s}$ or $gg \rightarrow s\bar{s}$) is much lower than that in the phase of hadronic matter (HM, E'_{th} ~600 MeV for e.g., $\pi N \rightarrow K\Lambda$), strangeness production might be a sensitive

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signature of the QGP formation in ultrarelativistic nucleus-nucleus collisions [1]. Especially, the formation of a QGP phase during such collisions is expected to enhance the antibaryon yield with respect to that obtained from the HM phase. Thus strangeness production has been studied with great interest over the past few years both experimentally and theoretically.

Due to the low yield and the serious contamination from parent decay, strangeness production is quite hard to measure. Although the reaction system and the acceptance window (as set for Λ, $\bar{\Lambda}$, Ξ^- and $\overline{\Xi^-}$ in experiments) were quite different among the existing strangeness production data [2-5], all these data were assembled for comparison and have become known as the world data. Therefore, the present state of the investigation of strangeness production is not yet very refined. Strangeness production is also very difficult to deal with theoretically due to the low yield, the large number of contributing inelastic reactions and the limited knowledge of the relevant cross sections.

Recently the NA36 collaboration has published their results of the ratios $\overline{\Lambda}/\Lambda$, Ξ^-/Λ, $\overline{\Xi^-}/\overline{\Lambda}$ and $\overline{\Xi^-}/\Xi^-$ in S + Pb reaction at incident energy 200 A GeV [2]. Those results are quite different from the old world data [3-5]. The ratio of $\overline{\Xi^-}/\overline{\Lambda}$ measured by the NA36 collaboration was 0.127 ± 0.022. The corresponding enhancement factor, with respect to p + p or p + A reactions , is then going down from 5 [4] to 2. One might ask that whether the explanation of this enhancement is still need to invoke the QGP formation. Although the NA36 data of $\overline{\Xi^-}/\Xi^-$ was not too far away from the old world data [3-5], the corresponding theoretical answer does not yet exist, to our knowledge. Thus, the NA36 data arise challenge to the theorists indeed.

We report, in this paper, the theoretical results of those ratios (mentioned above) by using a new version of Fritiof event generator, Luciae [6], including the collective interactions among strings [6] and the rescattering of produced particles [7]. The theoretical results are comparable with the corresponding experimental data within the range of the deviation among the data of different collaborations. It seems to indicate that the experimental data of the ratios of strange antibaryons to baryons might be explained within the hadronic scenario and need not to invoke the QGP formation.

One knows that in the Fritiof event generator 7.02 [8] two colliding hadrons are excited due to the longitudinal momentum transfer and/or a Rutherford parton scattering. The highly excited states will emit gluon bremsstrahlung according to the soft radiation model. The deexcited states are then treated as Lund strings allowing to decay into final state due to the Lund fragmentation scheme. However, in the relativistic nucleus-nucleus collisions there are generally many excited strings formed close by each other. Those strings would behave like vortex lines in a color superconducting QCD vacuum and will interact with each other (as the repulsive interaction suffered by the "ordinary" vortex lines in a type II superconductor). This kind of collective interaction among strings, not included in the Fritiof event generator 7.02, is depicted by the firecracker model [6]. In that model it is assumed that the groups of neighboring strings might form interacting quantum states, the large common energy density (corresponding to the collective interaction among strings) [9] might then effect both the emission of gluonic bremsstrahlung [9] as well as the fragmentation properties [10].

Rescattering model has devised to describe the reinteraction of produced particles, from the Fritiof event generator, with each other and with the participant and the spectator nucleons. In the model, the produced particles and the participant (wounded) nucleons, from the Fritiof event generator, are distributed randomly in the geometrical overlapping region between the projectile and the target nuclei under given impact parameter. The target (projectile) spectator nucleons are distributed randomly outside the overlapping region and inside the target (projectile) sphere. Rescattering cascade process is evolved since then, cf. Ref.7 for the detail. Due to the interest of this paper the produced particles considered, are not only the pion and the kaon but also the Λ, the Σ and the Ξ^-, thus the number of corresponding inelastic reactions are increased considerably. They are cataloged into:

$$
\begin{array}{ll}
\pi\pi \rightleftharpoons K\bar{K}; & \\
\pi N \rightleftharpoons KY, & \pi\bar{N} \rightleftharpoons \bar{K}\bar{Y}, \\
\pi Y \rightleftharpoons K\Xi^-, & \pi\bar{Y} \rightleftharpoons \bar{K}\overline{\Xi^-}; \\
\bar{K}N \rightleftharpoons \pi Y\ , & K\bar{N} \rightleftharpoons \pi\bar{Y}, \\
\bar{K}Y \rightleftharpoons \pi\Xi^-, & K\bar{Y} \rightleftharpoons \pi\overline{\Xi^-}; \\
\bar{K}N \rightleftharpoons K\Xi^-, & K\bar{N} \rightleftharpoons \bar{K}\overline{\Xi^-};
\end{array}
$$

$\bar{N}N$ annihination;

where Y refers to the Λ or the Σ. There are 195 inelastic reactions involved altogether. The cross section of $\pi\pi \rightarrow K\bar{K}$ is taken to be 2.0 mb as usual [11]. The isospin averaged parametrization of Ref.12 is adopted for the cross sections of the reactions $\pi N \rightarrow KY$ and of the other strange quark production reactions. Of course, the difference in threshold energy among reactions is taken into account. Following Ref.12, the cross sections of strange quark exchange reactions, $\bar{K}N \rightarrow \pi Y$ for instance, are assumed to be equal to ten times the value of the cross section of strangeness production reaction. As for the cross section of the reverse reaction, the detailed balance assumption [13] is required.

The theoretical results of the ratios of $\overline{\Lambda}/\Lambda$, Ξ^-/Λ, $\overline{\Xi^-}/\overline{\Lambda}$ and $\overline{\Xi^-}/\Xi^-$ and their comparing with world data [2-5] are, respectively, displayed in Fig.1-4. In each of Fig.1-4 the error bars are the experimental data (identifying separately into the collaboration in each figure). The crosses in each of those figures, from left to right, are the results of the Luciae event generator with parametrized cross section, of the Luciae event generator with constant cross section assumption of $\sigma_{\pi N \rightarrow KY}$=0.3 mb, of the Fritiof event generator 7.02 with collective string interaction and of the Fritiof event generator 7.02 (without both collective interaction among strings and rescattering of produced particles), respectively. In generally speaking, the results of Luciae, no matter the parametrized or the constant cross section, are comparable with the world data within the range of deviation among the data of different collaborations. Although the results of Fritiof 7.02 are always close to the results of Fritiof 7.02 with collective string interaction, the discrimination between the results of the Fritiof event generator and the results of the Luciae event generator can be seen generally. It seems to indicate that the rescattering of produced particles plays stronger role than the collective string interaction in reproducing the data. There are also visual discriminations between the results of Luciae event generator with parametrized cross section and with constant cross section. Therefore, it is extremely important to have the correct cross sections of the relevant reactions for eventual conclusions.

In Table 1 are given the average multiplicity (averaged over 4000 generated events with a maximum impact parameter 9 fm) of π^+ and strangeness particles. The entries in the second and the third rows are results of the Luciae event generator with constant cross section (the results of the Luciae event generator with parametrized cross section are similar to the constant ones) and of the Fritiof event generator 7.02 (multiplicity of π^+ and strangeness particles resulted from Fritiof event generator 7.02 with collective string interaction are similar to the results of Fritiof 7.02), respectively. One learns from Table 1 that the collective string interaction and the rescattering of produced particles do really enhance the strangeness production.

It is interest to look at the ratio $\overline{\Xi^-}/\overline{\Lambda}$, which has long time been put forward as an important signature of QGP formation [4]. One knows from Fig.3 that the theoretical results are all quite close to the NA36 data [2]. The experimental enhancement factor 2 [2] of this ratio in nucleus-nucleus collisions comparing to p+p or p+A collisions, might be explained in the HM scenario.

The ratio of $\overline{\Xi^-}/\Xi^-$ calculated with Luciae event generator (cf. Fig.4) is reasonably good in comparing with the data of NA36 [2]. It seems to indicate that in HM regime, relying on the rescattering of produced particles, it is able to supply enough strange antibaryons for reproducing the data of the ratios of strange antibaryons to baryons in relativistic nucleus- nucleus collisions.

In summary, we have used new version of Fritiof event generator, Luciae (abbreviation of Lund University and China Institute of Atomic Energy), including the collective interaction among strings and the rescattering of produced particles, to calculate the ratios of strange antibaryons to baryons in the reaction S + Pb at 200 A GeV incident energy. The theoretical results are comparable with the corresponding world data [2-5] within the range of deviation among the data of different collaborations. That means that the HM regime might be sufficient to explain the observed ratios of strange antibaryons to baryons in relativistic nucleus-nucleus collisions.

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References

1. M. Jacob and J. Tran Van, Phys. Rep. **88**, 321 (1982);
   J. Rafelski, Phys. Rep. **88**, 331 (1982);
   P. Koch and J. Rafelski, Nucl. Phys. **A444**, 678 (1985);
   J. Ellis and U. Heinz, Phys. Lett. **B233**, 223 (1989).
2. E. Andersen et al., Phys. Lett. **B327**, 433 (1994).
3. T. Åkesson et al., Nucl. Phys. **B246**, 1 (1984).
4. S. Abatzis et al., Phys. Lett. **B270**, 123 (1991).
5. D. Evans et al., Nucl. Phys. **A566**, 225c (1993).
6. B. H. Sa and A. Tai, Lund University preprint: LU TP 94-22; B. Andersson and A. Tai, LU TP 95-2.
7. Sa Ben-Hao, Wang Zhong-Qi, Zhang Xiao-Ze, Song Guang, Lu Zhong-Dao and Zheng Yu-Ming, Phys. Rev. **C48**, 2995 (1993).
8. B. Andersson, G. Gustafson and Hong Pi, Z. Phys. **C57**, 485 (1993).
9. B. Andersson, Phys. Lett. **B256**, 337 (1991).
10. B. Andersson and Peter A. Henning, Nucl. Phys. **B355**, 82 (1991).
11. R. Mattiello, H Sorge, H. Stöcker and W. Greiner, Phys. Rev. Lett. **63**, 1459 (1989).
12. P. Koch, B. Müller and J. Rafelski, Phys. Rep. **142**, 16 (1986).
13. G. Bertsch and S. Das Gupta, Phys. Rep. **160**, 189 (1988).

Figure Captions

Fig.1 The ratio of $\overline{\Lambda}/\Lambda$

case 1: data of WA85 (1991) in SW interaction [4],

case 2: data of WA85 (1993) in SW interaction [5],

case 3: data of NA36 (1994) in SPb interaction [2],

case 4: Luciae event generator with parametrized cross section,

case 5: Luciae event generator with constant cross section,

case 6: Fritiof event generator 7.02 with collective string interaction,

case 7: Fritiof event generator 7.02.

Fig.2 The ratio of Ξ^-/Λ

case 1: data of WA85 (1991) in SW interaction [4],

case 2: data of NA36 (1994) in SPb interaction [2],

case 3: Luciae event generator with parametrized cross section,

case 4: Luciae event generator with constant cross section,

case 5: Fritiof event generator 7.02 with collective string interaction,

case 6: Fritiof event generator 7.02.

Fig.3 The ratio of $\overline{\Xi^-}/\overline{\Lambda}$:

case 1: data of AFS (1984) in pp interaction [3],

case 2: data of WA85 (1991) in SW interaction [4],

case 3: data of WA85 (1993) in SW interaction [5],

case 4: data of NA36 (1994) in SPb interaction [2], case 5: Luciae event generator with parametrized cross section,

case 6: Luciae event generator with constant cross section,

case 7: Fritiof event generator 7.02 with collective string interaction,

case 8: Fritiof event generator 7.02.

Fig.4 The ratio of $\overline{\Xi^-}/\Xi^-$:

case 1: data of WA85 (1991) in SW interaction [4],

case 2: data of WA85 (1993) in SW interaction [5],

case 3: data of NA36 (1994) in SPb interaction [2],

case 4: Luciae event generator with parametrized cross section,

case 5: Luciae event generator with constant cross section,

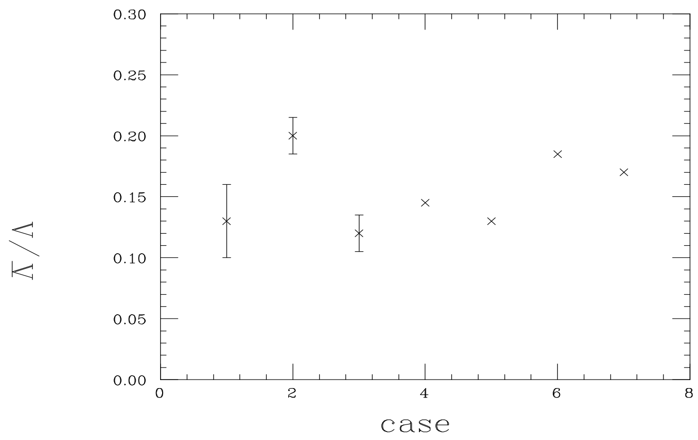
case 6: Fritiof event generator 7.02 with collective string interaction,

case 7: Fritiof event generator 7.02.

Table Captions

Table 1. The average multiplicity of π^+ and strangeness particles (per generated event)

	π^+	k^+	Λ	$\overline{\Lambda}$	Ξ^-	$\overline{\Xi^-}$
Luciae	93.1	15.1	6.46	0.832	0.427	0.0817
Fritiof 7.02	94.4	9.30	4.32	0.730	0.120	0.0627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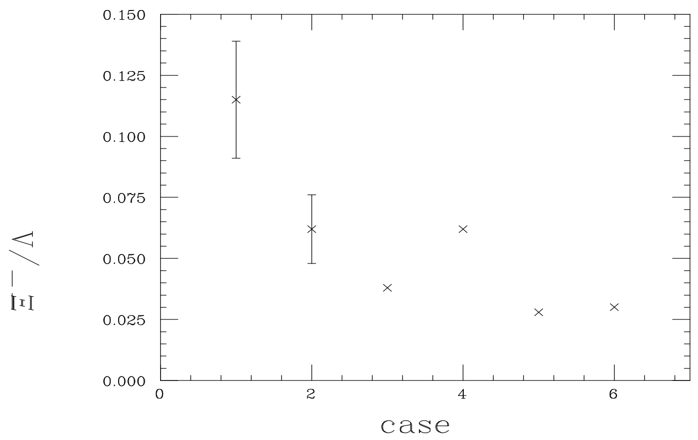
2
4
6
8
case
$\bar{\Lambda}/\Lambda$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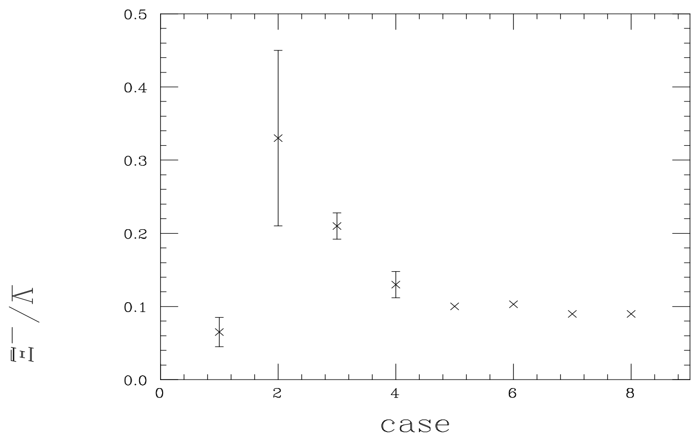
2
4
6
case
$\bar{\Xi}^-/\Lambda$



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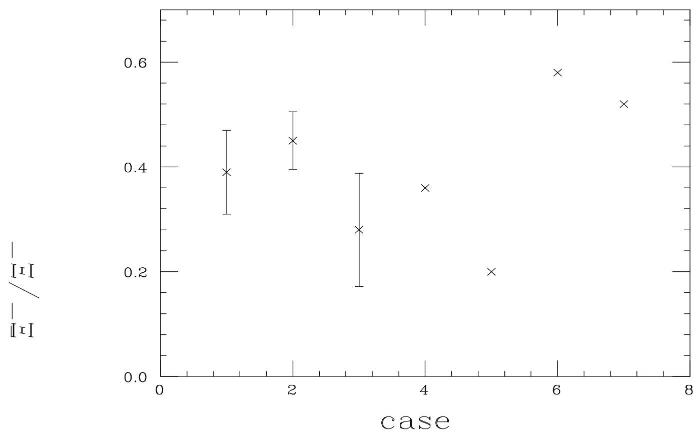
case



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6
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case