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Strange and Non-Strange (Anti-)Baryon Production at 200 GeV per Nucleon

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Strange and Non-Strange (Anti-)Baryon Production at 200 GeV per Nucleon

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Abstract. Rapidity distributions of net hyperons ($\Lambda - \overline{\Lambda}$) are compared to distributions of participant protons ($p - \overline{p}$). Strangeness production (mean multiplicities of produced Λ/Σ^0 hyperons and $\langle K + \overline{K} \rangle$) in central nucleus-nucleus collisions is shown for different collision systems at different energies. An enhanced production of $\overline{\Lambda}$ compared to $\overline{p}$ is observed at 200 GeV per nucleon.

1. Introduction

Information about baryons and anti-baryons in the hadronic final state is important for the understanding of the reaction dynamics of ultrarelativistic nucleus–nucleus collisions. Experiment NA35 at the SPS measured baryons, antibaryons and mesons for various collisions systems at 200 GeV per nucleon [1, 2, 3, 4, 5]. Data on $\Lambda/\overline{\Lambda}$ hyperons can shed light on various aspects of ultrarelativistic nucleus–nucleus collisions. By comparing net hyperon ($\Lambda - \overline{\Lambda}$) rapidity distributions to distributions of participant protons ($p - \overline{p}$) in minimum bias p+A and central A+A collisions the process of nuclear stopping can be studied.

Stangeness production is a potential signal for a Quark Gluon Plasma created in central nucleus–nucleus collisions [6, 7]. NA35 data on mean multiplicities of strange particles and non-strange mesons in comparison with results of other experiments at different energies allow a systematic study of strangeness production. The mean multiplicity of produced Λ/Σ^0 hyperons and $\langle K + \overline{K} \rangle$ relative to the pion yield is a good measure for the total strangeness ($s\overline{s}$) production relative to non-strange mesons. This ratio shows an increase in central A+A collisions compared to nucleon–nucleon interaction. This strangeness enhancement is observed at Dubna ($p_{LAB} \approx 4.5$ A·GeV/c), as well as at BNL AGS (≈ 15 A·GeV/c) and CERN SPS energies (≈ 200 A·GeV/c).

The study of antibaryons, such as $\overline{\Lambda}$ and $\overline{p}$, near midrapidity in central nucleus-nucleus collisions may shed light on the mechanisms of antiquark production. The ratio $\overline{\Lambda}/\overline{p}$ is expected to be a good measure for strange quark production as compared to the production of non-strange quarks, because the valence antiquark content of the $\overline{\Lambda}$ is $\overline{u}\overline{d}\overline{s}$ and that of the $\overline{p}$ is $\overline{u}\overline{d}\overline{u}$. This ratio reflects the yield of $\overline{s}$-quarks relative to that of non-strange light quarks $\overline{q}$. Furthermore, the antiquarks of these antibaryons are newly created so that their distributions should not directly reflect the distributions of the valence quarks of the incoming nuclei.

2. Net Hyperon Rapidity Distributions

Participant baryons are the final state of those incoming nucleons, which participate in the interaction. Some of the nucleons are converted into hyperons still carrying two quarks of the participant nucleon; their contribution concerning stopping must be also considered. The rapidity distributions of $(p - \overline{p})$ and $(\Lambda - \overline{\Lambda})$ for various collision systems at 200 GeV per nucleon are shown in Figs. 1 and 2.

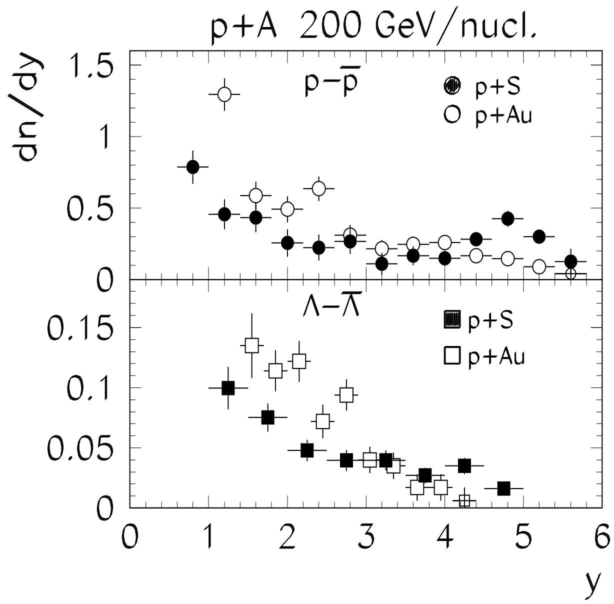

Fig. 1. Rapidity distributions of participant protons $p - \overline{p}$ (top) and net hyperons $\Lambda - \overline{\Lambda}$ (bottom) in minimum bias p+S and p+Au interactions at 200 GeV per nucleon.

The rapidity distributions of participant protons $(0.8 < y < 6.0)$ for minimum bias p+S and p+Au interactions are shown in Fig. 1 (top). While the rapidity densities around midrapidity for both reactions are not very different, clear differences are observed for rapidities below 1.2 and larger than 4.4. In p+Au collisions more target nucleons participate in the reactions and are therefore shifted by about one unit of rapidity. For the projectile the gold nucleus looks black, i.e. the probability of the projectile to traverse the target nucleus without loosing any or little energy is small. For p+S interactions on the other hand, a clear projectile fragmentation peak at rapidity 4.7 is visible. To investigate the effect of changing the nuclear thickness of the target in heavy ion interactions, rapidity distributions of participant protons were measured for central S+S, S+Ag and S+Au collisions. The data are shown in Fig. 2 (top). The S+S and S+Ag data were measured at $0.2 < y < 3.0$ and S+Au data at $2.6 < y < 6.0$. For the symmetric system S+S, the data points reflected at $y_{c.m.}$ are also shown. The shape of the participant proton rapidity distribution changes from being relatively flat for the light symmetric system (S+S) to a shape for the asymmetric systems which monotonically decreases with rapidity.

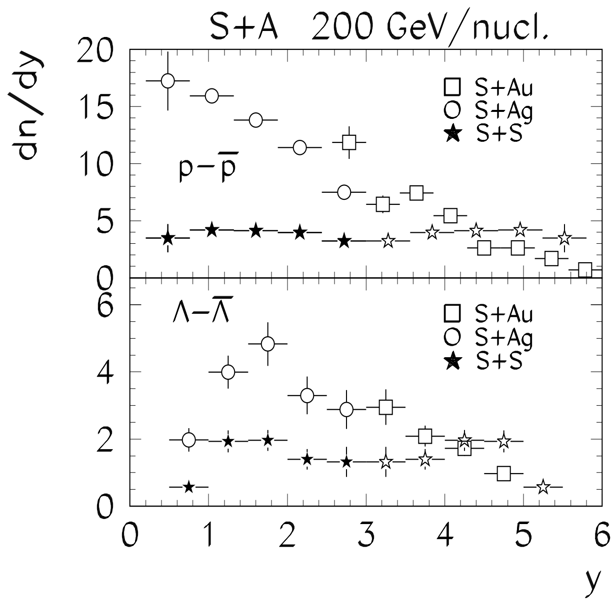

Fig. 2. Rapidity distributions of participant protons $p - \overline{p}$ (top) and net hyperons $\Lambda - \overline{\Lambda}$ (bottom) in central S+S, S+Ag and S+Au collisions at 200 GeV per nucleon.

The rapidity distributions of net hyperons $\Lambda - \overline{\Lambda}$ for minimum bias p+S ($1.0 < y < 5.0$) and p+Au ($1.4 < y < 4.4$) collisions are displayed in Fig. 1 (bottom), those for central collisions of S+S ($0.5 < y < 3.0$), S+Ag ($0.5 < y < 3.0$), and S+Au ($3.0 < y < 5.0$) are displayed in Fig. 2 (bottom). The trends in the rapidity distributions for net hyperons as a function of the target nucleus are similar to those for net protons, but the distributions are clearly compressed along the rapidity scale, they are pushed towards midrapidity by about half a unit of rapidity due to the energy of ≈ 0.5 GeV that is needed to produce a hyperon in a pp-collision.

3. Strangeness Production

The measurement of strange particle multiplicities in central S+A and Pb+Pb collisions by NA35 and NA49 [8, 9] allow for a systematic study of strangeness production as a function of the number of participant nucleons, $\langle N_P \rangle$, and as a function of the collision energy [10, 11]. The A+A results are compared with the corresponding results for all inelastic nucleon–nucleon (N+N) interactions. In the case of N+N interactions the number of participant nucleons is taken to be 2.

The total production of strangeness relative to pion production is studied using the ratio [4]:

$$E_S = \frac{\langle \Lambda \rangle + \langle K + \overline{K} \rangle}{\langle \pi \rangle}, \tag{1}$$

where $\langle \Lambda \rangle$ is the mean multiplicity of produced Λ/Σ^0 hyperons and $\langle K + \overline{K} \rangle$ is the mean multiplicity of kaons and antikaons. The dependence of the E_S ratio on $\langle N_P \rangle$ is shown in Fig. 3 for three different collision energies.

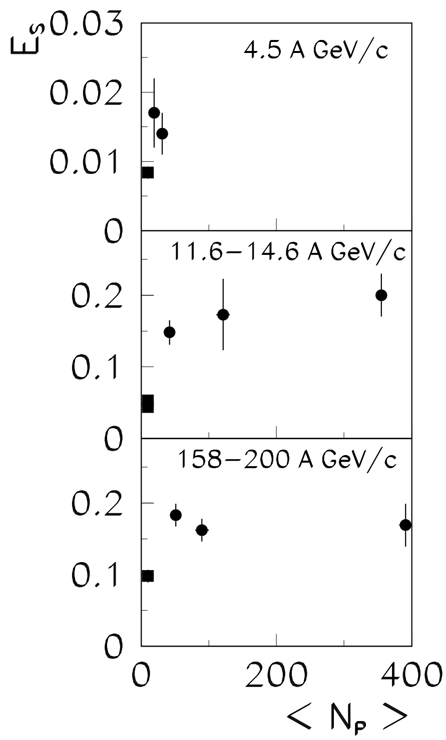

Fig. 3. The dependence of the E_S ratio on $\langle N_P \rangle$ at three different collisions energies (p$_{LAB}$ = 4.5 (top), 11.6–14.6 (middle) and 158–200 (bottom) A·GeV/c.

The results for central A+A collisions [12] are shown together with the results for N+N interactions. There is a significant increase in the relative strangeness production (measured by the E_S ratio) at all studied collision energies when going from N+N interactions to central A+A collisions. This increase is called **strangeness**

enhancement. The relative strangeness production seems to saturate at sufficiently large values for $\langle N_P \rangle$. The saturation effect can not be established at 4.5 A·GeV/c as the results for collisions of heavy nuclei do not exist at this collision energy. The effect of strangeness enhancement is largest at AGS-energies ($\approx$ factor of 4) as shown in Fig. 4.

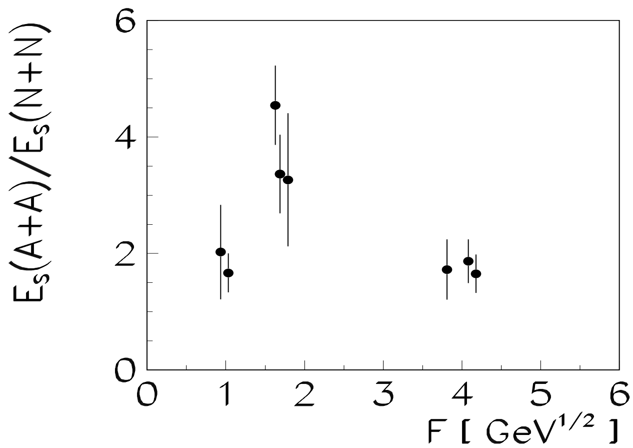

Fig. 4. The dependence of the E_S ratio (see Eq. 1) in central A+A collisions relative to the ratio in N+N interactions on the collision energy measured by the Fermi energy variable, F (see Eq. 2).

The collision energy dependence is studied using Fermi energy variable [13, 14]

$$F = \frac{(\sqrt{s}_{NN} - 2m_N)^{3/4}}{\sqrt{s}_{NN}^{1/4}}, \tag{2}$$

where $\sqrt{s}_{NN}$ is the c.m. energy for a nucleon–nucleon pair and m_N is the mass of the nucleon. For a detailed discussion of this analysis see the contribution of Marek Gaździcki to this conference [15].

The collision energy dependence of the E_S ratio for central A+A collisions is shown in Fig. 5 (bottom), the results for N+N interactions are shown in Fig. 5 (top). A monotonic increase of E_S for N+N interactions between Dubna energy (p_{LAB} = 4.5 A·GeV/c) and CERN SPS energy (p_{LAB} = 200 A·GeV/c) is observed; in the range from 15 A·GeV/c to 200 A·GeV/c the E_S ratio increases by a factor of about 2. A qualitatively different energy dependence of the E_S ratio is observed for central A+A collisions. The rapid increase of the E_S between Dubna and BNL AGS energies is followed by a weak change in the E_S between BNL AGS and CERN SPS collision energies. For a detailed discussion see the contribution of Marek Gaździcki to this conference [15].

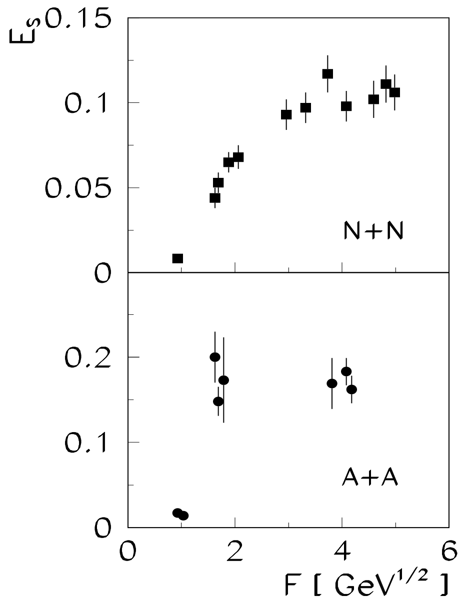

Fig. 5. The dependence of the E_S ratio for N+N interactions (top) and central A+A collisions (bottom) on the collision energy measured by the Fermi energy variable, F (see Eq. 1).

4. Antibaryon production

The ratio $\overline{\Lambda}/\overline{p}$ provides information on the production of strange antiquarks compared to light antiquarks. Antibaryon yields in central nucleus-nucleus collisions are expected to exhibit the subtle interplay between various partonic and/or hadronic production and annihilation processes as well as properties of a possible partonic equilibration of the system [16]. Theoretical consideration of the possible creation of a Quark Gluon Plasma in ultrarelativistic nuclear collisions [6] has indicated that strange/antistrange quark pairs might be copiously produced resulting in an approximate flavour symmetry among light quarks, namely up, down and strange [7]. Under such conditions the $\overline{\Lambda}/\overline{p}$-ratio, which roughly reflects the $\overline{s}/\overline{u}$-ratio, should approach unity (or larger for non-zero baryon densities) [7], far exceeding the value of ~ 0.25 observed in proton-proton collisions.

The $\overline{\Lambda}/\overline{p}$-ratio near midrapidity in proton-proton, minimum bias proton-nucleus and central nucleus-nucleus collisions is shown in Fig. 6 as a function of the rapidity density at midrapidity of negatively charged hadrons h^- [1, 2, 4, 5]. The ratio increases from a value of 0.25 for p+p (and p+A) collisions to a value of approximately 1.4 for central S+A collisions

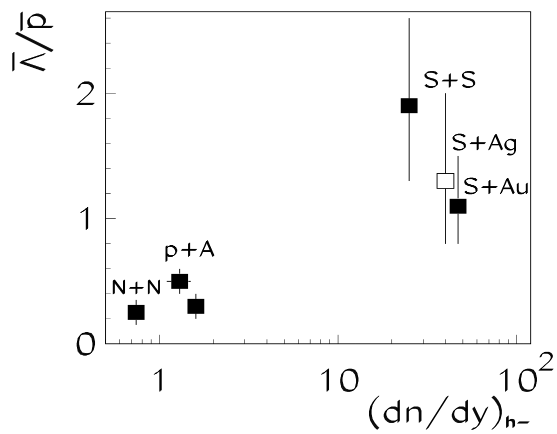

Fig. 6. $\overline{\Lambda}/\overline{p}$-ratio near midrapidity in proton-proton, minimum bias proton-nucleus and central nucleus-nucleus collisions ($3 < y < 4$) at 200 GeV per nucleon as a function of the rapidity density of negatively charged hadrons at midrapidity. The result for S+Ag (open symbol) is not the result of a direct measurement, the $\overline{\Lambda}$ yield was interpolated between S+S and S+Au collisions.

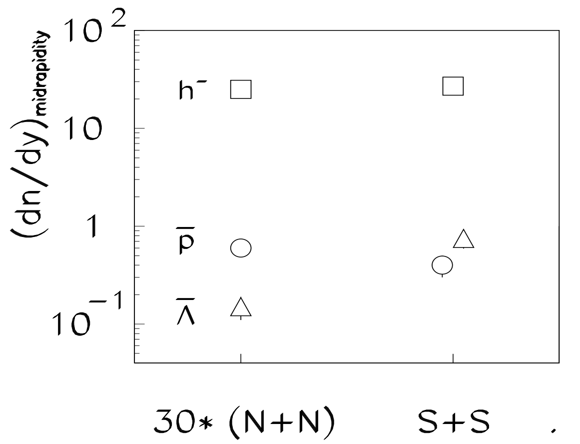

Fig. 7. $\overline{\Lambda}$ and $\overline{p}$ yields near midrapidity in nucleon-nucleon and central S+S collisions at 200 GeV per nucleon. The N+N data are scaled by the ratio of the total h^--multiplicities.

The increase in the ratio can be studied in more detail for the S+S system. If rapidity densities at midrapidity in nucleon-nucleon collisions are scaled by the ratio of h^--multiplicities in central S+S and in nucleon-nucleon collisions (Fig. 7), the $\overline{p}$ production decreases by about 30 % and the $\overline{\Lambda}$ abundance at midrapidity is strongly enhanced by a factor of 5.

5. Summary

The trends in the rapidity distributions of net hyperons $\Lambda - \overline{\Lambda}$ as a function of projectile and target nucleus are similar to those for net protons, but the distributions are different. The experimenal data on strangeness production indicate a saturation of strangeness production with the number of participant nucleons and a change in the collision energy dependence occuring between 15 A·GeV/c and 200 A·GeV/c. The ratio of strange antibaryon $\overline{\Lambda}$ to the non-strange antibaryon $\overline{p}$ in central A+A collisions at 200 GeV per nucleon is larger than one and therefore significantly larger than the ratio in nucleon–nucleon interactions.

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