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Strangeness production in hadron-hadron, hadron-nucleus, and nucleus-nucleus collisions in the dual parton model

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Λ, $\bar{\Lambda}$, and K_S^0 production is studied in a Monte Carlo dual parton model for hadron-hadron, hadron-nucleus, and nucleus-nucleus collisions with an SU(3) symmetric sea for chain formation (chain ends) but strangeness suppression in the chain fragmentation process. Additionally, (qq)-$(\bar{q}\,\bar{q})$ production from the sea was introduced into the chain formation process with the same probability as for the $q \rightarrow qq$ branching within the chain decay process. With these assumptions, multiplicity ratios and Feynman-x distributions for strange particles in h-h and multiplicity ratios in heavy ion collisions are reasonably well reproduced.

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The dual parton model (DPM) as a particular realization of the Reggeon field theory has been very successful in describing within a unified framework particle production in hadron-hadron, hadron-nucleus, and nucleus-nucleus interactions at high energies [1]. A Monte Carlo version of the model generating complete inelastic events is in reasonable agreement with many properties of soft multiparticle production processes in h-A and heavy ion collisions [2,3].

Here we address the problem of strangeness production in heavy ion collisions—enhanced generation of strange particles, in particular, of strange antibaryons, has been proposed as a signal for the formation of quark gluon plasma (QGP) in dense hadronic matter [4]. Recent data from experiments at the CERN Super Proton Synchrotron (SPS) have already been interpreted within this scheme. However, we find it worthwhile to pursue the study of conventional models without QGP formation such as the DPM before drawing final conclusions.

Details of our Monte Carlo model are described in Refs. [2,5]; in the following we summarize those features of the model that are most important for the actual investigation. The model starts with a frozen discrete spatial distribution of nucleons sampled from standard density distributions. The primary interaction of the incident high-energy projectile proceeds via totally n elementary collisions between n_p and n_t nucleons from the projectile (for incident hadrons $n_p = 1$) and the target nuclei, respectively. Actual numbers n, n_p, and n_t are sampled from a Monte Carlo realization of Glauber's multiple-scattering formalism. Note that individual hadrons may undergo several interactions. Particle production in each elementary collision is described by the fragmentation of two color-neutral parton-parton chains. Those chains are constructed from the valence quark systems or, in the case of repeated scatterings of single hadrons, from sea-$q\bar{q}$ pairs of the interacting hadrons. The independent hadronization of single chains is handled by the Monte Carlo code BAMJET [6]. From previous studies we know that the assumption of an SU(3) symmetric sea of $q\bar{q}$ pairs allows a reasonable description of strange meson and Λ production [2]. However, the rate of $\bar{\Lambda}$ observed in heavy ion collisions cannot be obtained without further assumptions. This problem is met in all independent string-type models: At energies reached at the SPS typical string (chain) masses are too small to allow for a sufficient $\bar{\Lambda}$ rate. This kinematical argument applies to all antibaryons. Actually, several mechanisms to overcome this problem are discussed. For instance, many-body interactions of hadrons or quarks are considered to increase the effective collision energy [7]; fusion of strings overlapping in coordinate space is also studied [8–12].

In this paper we investigate the influence of another mechanism on the production rate of baryons and antibaryons: We allow the creation of (qq)-$(\bar{q}\,\bar{q})$ pairs from the vacuum within the chain formation process. The rate of diquark pair production as compared to that for q-$\bar{q}$ is assumed to be the same as the ratio of the $q \rightarrow (qq)$ and $q \rightarrow q$ branchings in the chain fragmentation [6]. This mechanism is implemented in the new version of our Monte Carlo model DTUNUC 1.1.

To test the tuning of the parameters in the chain fragmentation mechanism applied in our model, we first calculated the Feynman-x distributions for Λ's and $\bar{\Lambda}$'s in $\pi^- p$ and $K^- p$ collisions proceeding via two chains formed from valence quark systems. As demonstrated in Figs. 1(a)–1(d), we find good agreement with the data of the EHS-NA22 Collaboration [13]. In Table I we present the multiplicities of strange mesons and hyperons calculated for some typical hadron-nucleus and heavy ion reactions at SPS energies. We note that there seems to be an inconsistency between the good agreement of the model with the $\pi^- p$ and K^{-p} data in Fig. 1 and only moderate agreement with the pp data found in Table I. In Figs. 2(a) and 2(b) the relative strange particle yields with respect to the total negative multiplicities for

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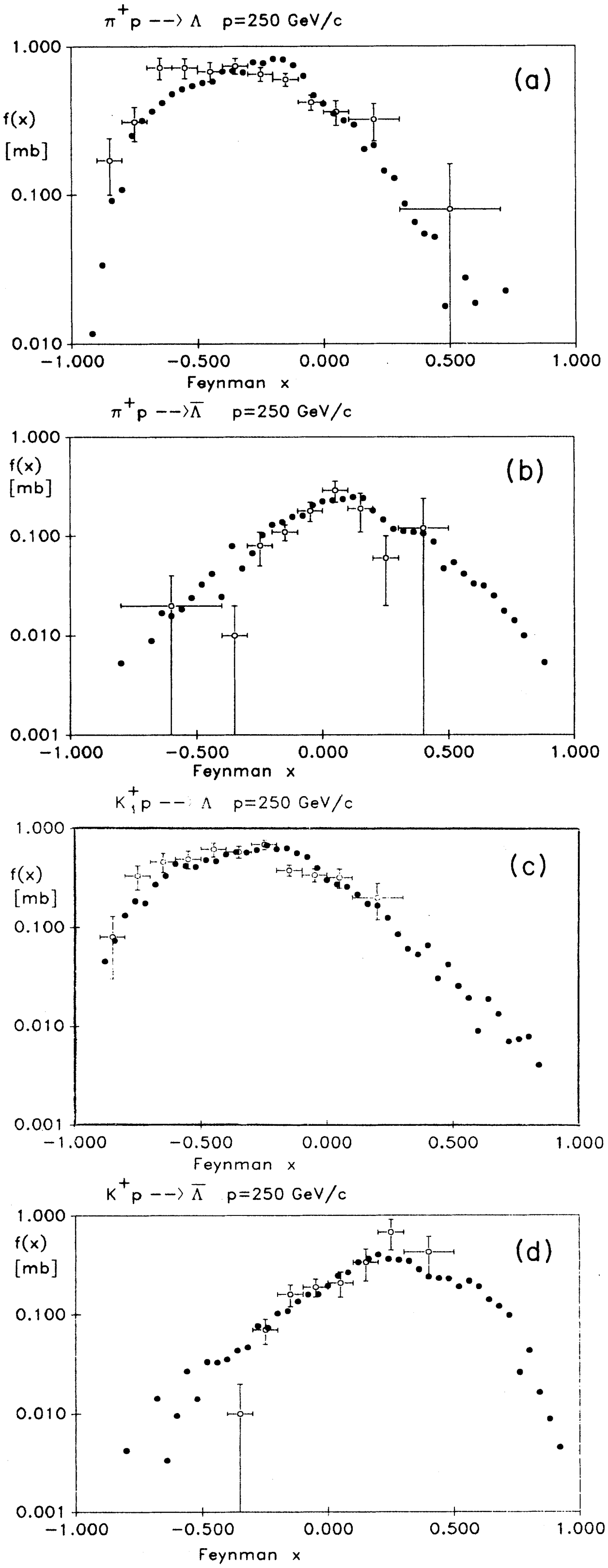

FIG. 1. Feynman-*x* distributions for Λ and $\overline{\Lambda}$ production in the following reactions: (a) $\pi^+p\rightarrow\Lambda$, (b) $\pi^+p\rightarrow\overline{\Lambda}$, (c) $K^+p\rightarrow\Lambda$, and (d) $K^+p\rightarrow\overline{\Lambda}$. Results from DTUNUC are compared to data from the EHS-NA22 Collaboration [13].

different interactions are compared to available data [14] (for the numbers see Table I). For K_S^0 and Λ production, the data are described reasonably well; in particular, a slight rise of their relative yields with increasing complexity of the collisions (rising $\langle n_- \rangle$) is found. Qualitatively, this effect is understood from the increasing contribution of sea-quark systems in the chain formation process. However, in the case of $\overline{\Lambda}$ production, even the inclusion of (qq)-$(\bar{q}\,\bar{q})$ pair creation in the string formation process cannot explain the rise of the relative yield indicated by the NA35 data [14] [compare Fig. 2(a)]. On the other hand, the calculated yield differs only by two standard

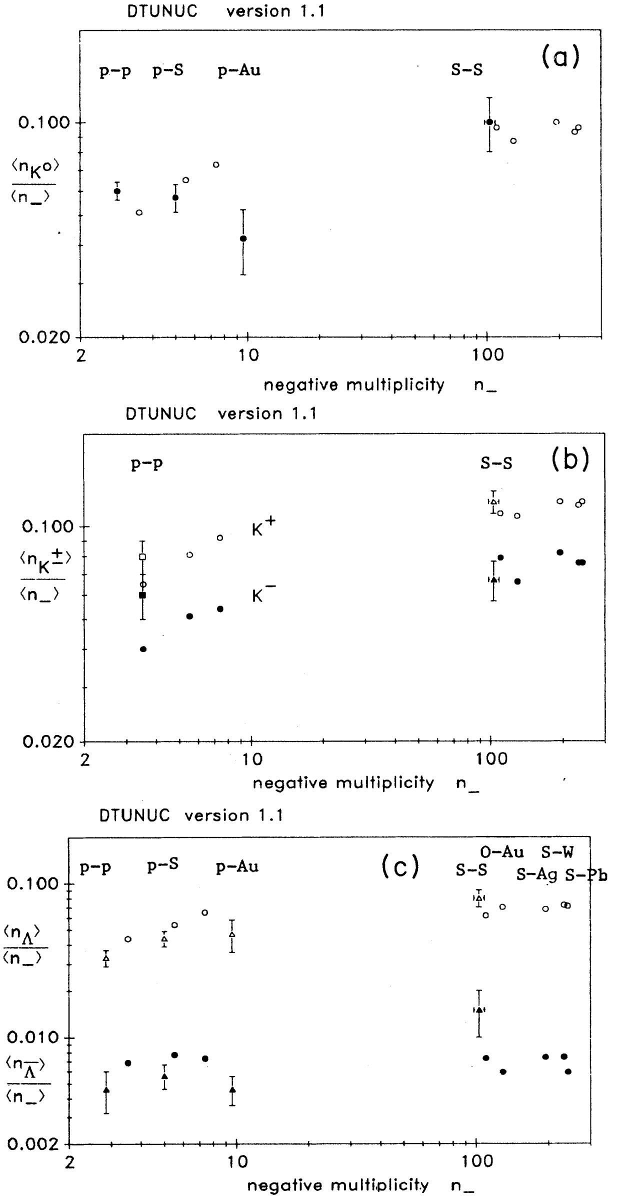

FIG. 2. Relative strange particle yields $\langle n_{K_S^0,\Lambda,\overline{\Lambda}}\rangle/\langle n_-\rangle$ for several hadron-nucleus and central heavy ion collisions (S-S, O-AU, S-Ag, S-W, and S-Pb) vs the multiplicity of negative secondaries. DTUNUC calculations (points without error bars) are shown together with data from Ref. [14]: (a) relative K_S^0 yields, (b) relative K^+ and K^- yields, and (c) Λ and $\overline{\Lambda}$ yields.

TABLE I. Multiplicities calculated by the Monte Carlo dual parton model DTUNUC (version 1.1) for various nuclear reactions at $E_{\text{lab}}=200$ GeV/nucleon. For comparison, some experimental data taken from Ref. [13] are given in parentheses.

Reaction	$\langle n_- \rangle$	$\Lambda+\Sigma^0$	$\bar{\Lambda}+\bar{\Sigma}^0$
pp	3.52	0.155	0.024
(nondiffr.)	(2.85±0.04)	(0.095±0.010)	(0.013±0.004)
p-S	5.53	0.30	0.043
	(5.0±0.2)	(0.22±0.02)	(0.028±0.004)
p-Au	7.40	0.48	0.054
	(9.6±0.2)	(0.45±0.10)	(0.044±0.010)
S-S centr.	109.8	6.83	0.80
	(103±5)	(8.2±0.9)	(1.5±0.4)
O-Au centr.	130	9.2	0.77
S-Ag centr.	195	13.3	1.45
S-W centr.	233	16.7	1.73
Reaction	K^+	K^-	K_S^0
pp	0.23	0.14	0.18
(nondiffr.)	(0.24±0.06)	(0.17±0.05)	(0.17±0.01)
p-S	0.45	0.28	0.36
			(0.28±0.03)
p-Au	0.68	0.40	0.54
			(0.40±0.10)
S-S centr.	12.6	8.73	10.6
	(12.5±0.4)	(6.9±0.4)	(10.7±2.0)
O-Au centr.	14.0	8.65	11.3
S-Ag centr.	23.5	15.9	19.4
S-W centr.	27.2	17.8	21.6

deviations from the NA35 $\bar{\Lambda}$ point. From the model point of view, this lack of $\bar{\Lambda}$ enhancement at SPS energies is again a kinematical effect. Without diquark pair creation, the relative yield of antibaryons even decreases with rising complexity of the collisions, since with the increasing number of interactions of individual nucleons, typical string masses become smaller. This decrease is approximately compensated by an additional $\bar{\Lambda}$ production resulting from diquark pair creation, but no net increase is obtained. This result holds not only for $\bar{\Lambda}$'s but also for antibaryons generally.

The WA85 collaboration has measured the relative yields of hyperons and cascade particles in central S-W collisions [15] at large $p_\perp$ in the central rapidity region. Our results for the $\bar{\Lambda}/\Lambda$ and the $\overline{\Xi}^-/\Xi^-$ ratios in the full phase space are 0.11 and 0.67, respectively. In the rapidity window used by the WA85 Collaboration, $2.4 \leq y_{\text{lab}} \leq 2.6$, we find the ratios 0.08 and 0.57, respectively. Unfortunately, these numbers cannot be compared with the results of WA85 obtained in addition in the large $p_\perp$ region $1 \leq p_\perp \leq 2$ GeV/c, 0.13±0.03 and 0.39±0.07, respectively. So far, our Monte Carlo model does not generate reliable distributions for heavy particles at large $p_\perp$.

Our results for the proton rapidity distribution in central S-S collisions do not completely agree with the NA35 data (compare Ref. [3]); they show a stronger dip in the central rapidity region, as seen in the data. A similar behavior is found in the case of Λ production. Note, however, that the measured proton distribution has been defined as the difference of negative and positive tracks and thus is not expected to be very precise. In our model, the stopping of baryons depends on details of the parton-x distributions as well as on the treatment of kinematical cuts, and will be considered separately in a forthcoming paper. The existence of strings with (qq) and $(\bar{q}\,\bar{q})$ from the sea at their ends is quite natural in the DPM. On the other hand, an SU(3) symmetric sea of $q\bar{q}$ pairs is an assumption which allows one to obtain an upper bound on the strangeness enhancement in the DPM without introducing collective effects. The present experimental situation (the lack of Λ, $\bar{\Lambda}$, and K_S^0 enhancement in OAu from NA35, the lack of a K_S^0 enhancement in SAg from NA36, etc.) does not allow one to draw a firm conclusion on the necessity of this assumption. We envisage also being able to determine the amount of strangeness suppression at the sea-chain ends from particle production data in p-p collisions at collider energies, where multiple chain production is also important.

To summarize our discussion, the main problem in the comparison of model predictions on strangeness production with the data is the description of the increasing antihyperon yield found by the NA35 Collaboration in central S-S interactions. However, these data have a large error. Therefore, the NA35 data need confirmation. Moreover, systematic measurements of baryon and antibaryon yields in a variety of hadron-nucleus and heavy ion collisions would be very useful for the discussion of potential string interaction mechanisms. If the effect were clearly established, an entirely different mechanism should be introduced into the model to understand in particular the behavior of antibaryon yields in hadron-nucleus and heavy ion collisions. At present, besides other mechanisms, string fusion [8,9] and many-body interactions on the parton and/or hadron level [7] are under study as potential candidates. In a forthcoming paper we investigate the effects of string fusion in our Monte Carlo dual parton model [10].

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