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IFUSP/P-967

COLLECTIVE EFFECTS AS A POSSIBLE SOURCE OF STRANGENESS ENHANCEMENT

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Fevereiro/1992

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ABSTRACT

Enhanced strangeness production in nuclear collisions has been studied as a signature of quark-gluon plasma formation. Here we investigate the possibility that collective sources in nuclei (presumably due to Lorentz contraction) could lead to strangeness enhancement as well. A preliminary comparison with NA35 data on strangeness enhancement is also presented.

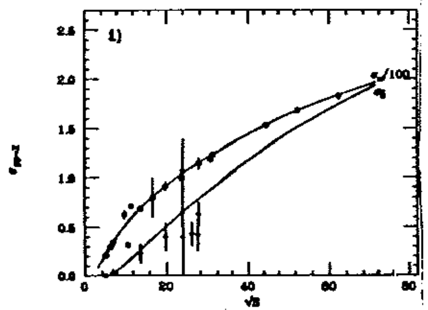
† To appear in the Proceedings of the International Workshop in Nuclear Physics, Rio de Janeiro, Brazil, August 1991.

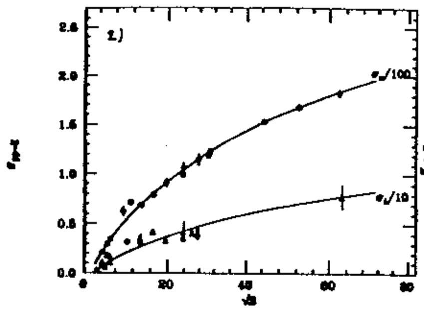
1. INTRODUCTION

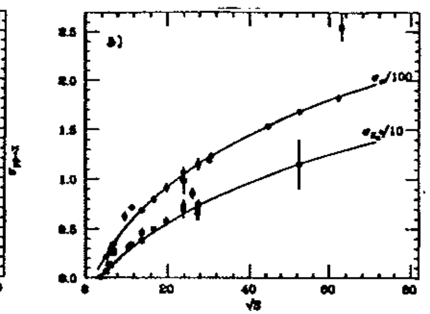
An increase in strange particle production has long been suggested to be a consequence of quark-gluon plasma formation. In fact, strangeness is also high in a thermally and chemically equilibrated hadronic gas. Overall strangeness enhancement as compared to p-p collisions may simply reflect the beginning of evolution towards equilibrium. However, for certain channels, hadron gas and quark-gluon plasma may lead to very different predictions, this could be the case for example of strange antibaryons. (For more details, see e.g. [1,2].)

In this contribution, we will investigate a possible alternative way of increasing strangeness that may be present in proton-nucleus and nucleus-nucleus collisions at high energies. We start from the remark that the cross section for production of $\bar{\Lambda}$ in proton-proton collisions, increases very rapidly with $\sqrt{s}$, the center of mass energy (in the ISR energy range). This is shown in figure 1. This increase is much faster than that for negatives. A stronger increase than for negatives is also observed for K^0_s in figure 2. The increase in Λ's is comparable to that of negatives as can be seen in figure 3.

Figure 1: Cross section for production of $\bar{\Lambda}$ in p-p collisions as function of center mass energy. For comparison, the pion cross section is also shown. Figure 2: Same as 1 for K^0_S. Figure 3: Same as 1 but for Λ.







The following fits[1] can be used

$$\sigma_{\bar{\Lambda}} = 0.79 - 0.48 \ln s + 0.07 \ln^2 s \tag{1}$$

$$\sigma_{K^0_s} = 0.32 - 0.8 \ln s + 0.28 \ln^2 s \tag{2}$$

$$\sigma_{\Lambda} = -0.08 - 0.20 \ln s + 0.14 \ln^2 s \tag{3}$$

and for negatives

$$\sigma_{h^-} = -0.229 - 2.55 \ln s + 3.00 \ln^2 s \tag{4}$$

This suggests that collective sources in nuclei would lead to strangeness enhancement (because the center-of-mass energy in the p-collective source collision is higher than in a p-p collision) and we explore this idea in more detail in this paper. The collective sources that we have in mind could for instance be due to parton cloud overlapping [4-6] resulting from Lorentz contraction and in that case are alike (partially deconfined) nucleon tubes. They could also be nucleon clusters with two nucleons, three, four, etc, or quark clusters, with six quarks (dibaryons), nine, twelve, etc. Clusters, have been widely advocated to explain a different phenomena, involving hard physics, the EMC effect (cf for example [7]). If there preexist in nuclei, it should have been possible to see them e.g. via scattering. Likely therefore, they would need to be formed during the collision. For large momentum exchange as is the case for the EMC measurement, clusters could come from coherent recoiling of a stricked nucleon or quark with other nucleons or quarks. For small momentum transfer (but high energies), Lorentz contraction might form some (transversal) clusters. Let us also mention that though we are going to concentrate here on kaons and strange hyperons, the mecanism that we describe, enhances other types of particles (e.g. $\bar{p}$ or ϕ) compared to pions because their cross section in p-p collisions also rises fast.

2. APPROXIMATE CALCULATIONS OF THE YIELDS

When a hadron collide with a collective source containing ν_T nucleons, rather than with an individual hadron, the center-of-mass energy of the collision is

$$\sqrt{s_{eff}} \sim \sqrt{\nu_T \, s_{pp}} \tag{5}$$

[1] Since we are interested in strangeness enhancement, we do not make least square fits but instead use eye-picked conservative fits. For example the higher point at $\sqrt{s} \sim 63$ GeV in $\sigma_{K^0_s}$ is ignored though its finders consider it more reliable than their own lower point at $\sqrt{s} \sim 53$ GeV that we include. Note that the data points for $\bar{\Lambda}$ are scatered, in particular around $\sqrt{s} \sim 20$ GeV. Also the lower bounds of [3] for $\sigma_{\bar{\Lambda}}$ at $\sqrt{s} = 53$ and 62 GeV lie on our curve.

where $\sqrt{s_{pp}}$ is the c.m.s. energy for a proton-proton collision. Similarly, if a collective source containing ν_P nucleons collide with a collective source containing ν_T nucleons, the source-source collision has a center-of-mass energy of

$$\sqrt{s_{eff}} \sim \sqrt{\nu_P \, \nu_T \, s_{pp}} \tag{6}$$

Since these two types of collisions arise at a higher center-of-mass energy than the p-p collisions, more particles will be produced in average (but the number of collisions is smaller as will be seen in more detail later). We are going to suppose that the yield for a given particle species for these two types of collisions is related to the yield in p-p collisions via

$$N(s)_{\nu_P+\nu_T} = N(\nu_P \nu_T s)_{p-p\,collision} \tag{7}$$

($\nu_P = 1$ corresponds to a pA collision). This is probably an overestimate since in the collision center of mass frame, it corresponds to three quarks (plus some sea contribution) in a source carrying all the energy with the other quarks in the same source at rest. Though desirable, a microscopic picture of a nucleon-source or source-source collision will involve various hypothesis (e.g. does the source color-fragment in the collision as in the Dual Parton Model and if yes, is it in a quark and quark multiplet, a diquark and a quark multiplet, etc?). Work is in progress in this direction. We can see another possible limitation of our approximation in the following way. In the same spirit as above, we would expect that the rapidity distribution for the nucleon-source or source-source collisions to be related to that in p-p collisions via

$$\frac{dN}{dy}(s,y)_{\nu_P+\nu_T} = \frac{dN}{dy}(\nu_P \nu_T s, y + \frac{1}{2}\ln\frac{\nu_P}{\nu_T})_{p-p\,collision} \tag{8}$$

If $\nu_T > \nu_P$, the distribution is moved towards negative values. If $\nu_T < \nu_P$, it is moved towards positive values. The shape of dN/dy as predicted by eq.8, is symmetric (as for p-p) with respect to its peak. In the case of a proton-nucleus collision ($\nu_P = 1$) we know that the rapidity distributions are not only shifted towards the target but also asymmetric. It remains to be seen if upon summing on various impact parameters (i.e. various ν_T), the distribution (8) reproduces this assymetry. Our approximation should be considered as only a starting point to study the effect of collective sources.

Denoting by p the probability that a nucleon in a nucleus A is inside a collective source, the total yield of a given particle species in p-A collisions is

$$N^{tot}_{pA}(s) \sim [pN(\nu_T s) + (1-p)N(s)] \times X_{pA} \tag{9}$$

In the right hand side of this equation, we have dropped the index "$p-p\,collision$". N is the number of particles from a given species produced in a p-p collision and may be calculated via equations (1-4). The term in square brackets is therefore the average yield per individual collision. X_{pA} is the total number of individual collisions (i.e. p-hadron or p-collective source collisions). (There is an implicit average on the number of nucleons per source.) Similarly, for a nucleus-nucleus collision

$$N^{tot}_{AB}(s) \sim [p^2 N(\nu_P \nu_T\, s) + p(1-p) N(\nu_T\, s) + p(1-p) N(\nu_P\, s) + (1-p)^2 n(s)] \times X_{AB} \quad (10)$$

To simplify the notation, we have assumed that the probality p is the same for nucleus A and B. X_{AB} is the total number of collisions hadron-hadron, hadron-collective source and collective source-collective source.

3. RESULTS

Let us now apply this model to a concrete case and see if collective effects could be enough to explain the strangeness enhancement observed by NA35. We concentrate on the NA35 sulphur data because they are the only ones completely corrected for cuttoffs. (No strangeness enhancement bias such as in [8] exists there.) These results are summarized in table 1 below.

	h^-	Λ	K^0_s	$\bar{\Lambda}$
p-p	2.85±0.04	0.095±0.010	0.17±0.01	0.013±0.004
p-S	5.0±0.2	0.22±0.02	0.28±0.03	0.028±0.004
S-S centr.	103±5	8.2±0.9	10.7±2.0	1.5±0.4
p-Au	-	0.081±0.009	0.044±0.008	0.006±0.002
O-Au	-	1.507±0.111	0.665±0.086	0.098±0.026
pS/pp	1.72±0.07	2.3±0.4	1.6±0.2	2.2±0.7
SS/pp centr.	36±2	86±12	63±18	115±47
SS/pS centr.	21±2	37±6	38±10	54±16
Oau/pAu	-	19.0±3.5	16.0±4.9	20.0±11.0
OAu/pAu central	15.9±1.2	18.6±2.5	15.1±3.4	16.3±7.0

Table 1: NA35 S data in 4π phase space [9] and O data in restricted phase space [10].

Strangeness enhancement is the fact that the production of strange particles increases faster than for non-strange in going from p-S or p-p to S-S. Namely $\bar{\Lambda}_{SS}/\bar{\Lambda}_{pS\,or\,pp}$, $K^0_{s\,SS}/K^0_{s\,pS\,or\,pp}$ and $\Lambda_{SS}/\Lambda_{pS\,or\,pp}$ are higher than $h^-_{SS}/h^-_{pS\,or\,pp}$ [2].

In order to use equations (9) and (10), we need to know the average number X of collisions of all types as a function of p. We expect X to be smaller than the number of hadron-hadron collisions if no collective sources are present. So when computing the total yields with equations (9) and (10), this decrease of X will oppose the increase due to the higher center-of-mass energies. X depends on the number of nucleons per source, the distribution of the sources, their nature, etc, and this will be very model-dependent. On the other side, in order to test whether collective effects are effective enough to overcome the decrease of X and explain the NA35 data, we may simply use the experimental results on the yield of negatives

$$X_{pS}(p,\nu_S) = \frac{h^-_{pS,exp}}{p h^-(\nu_S\, s) + (1-p) h^-(s)} \quad (11)$$

and

$$X_{SS}(p,\nu_S) = \frac{h^-_{SS,exp}}{p^2 h^-(\nu_S^2\, s) + 2p(1-p) h^-(\nu_S\, s) + (1-p)^2 h^-(s)} \quad (12)$$

We know that part of the pions (which consists the bulk of h^-) are pions that come from resonance decays. Presumably that part is the same (in proportion) for p-p and p-S or S-S so will cancel top and bottom in equations (11) and (12). However, part of the pions may also created in secondary collisions This contribution is neglected here and it introduces some error in the calculation of X. We are working on calculating (11) and (12) directly without using the yield of negatives.

We then know everything to compute the yields of K^0_s, Λ and $\bar{\Lambda}$ as function of p for given values of ν_S. In table 2, we present the values of p that permits to reproduce the experimental yields of strange particles found by NA35 in p+S and S+S collisions.

The numbers in parentheses correspond to the case where more $\bar{\Lambda}$ or K^0_s are produced in the initial collisions than observed. These may be later be destroyed by absorption, (see next section). We see that to reproduce or surpass both p+S and S+S data for $\bar{\Lambda}$, with the similar values of p, $\geq 70\%$ of $\nu_s = 2$ sources, $\geq$ 35-40% of $\nu_s = 3$ sources, or $\geq 20\%$ of $\nu_s = 4$ sources are required. The same values of p also reproduce the K^0_S abundances. The Λ's would be underproduced in SS but there we expect recreation to be at work (see next section). In addition, the production of

[2]The p-p data used by NA35 are our points at $\sqrt{s} \sim 20$ GeV in figures 1-3. As already mentionned the $\bar{\Lambda}$ data points are scaterred around 20 GeV, so the comparison to p-p may not be very meaningful; the production cross section could be two or three times higher. This is unfortunate as this particle may be a good probe of quark-gluon plasma formation.

A depends on the number of available valence quarks not just the energy available, and this is not treated correctly by our approximation.

	$\bar{\Lambda}$	K^0_s	Λ
pS ν_S=2	20-70 (100) %	0-10 (100) %	0-100 %
SS ν_S=2	70-100 %	50-100 %	$\sim$ none
pS ν_S=3	10-40 (100) %	0-10 (100) %	0-100 %
SS ν_S=3	35-100 %	30-100 %	$\sim$ none
pS ν_S=4	5-20 (100) %	0-10 (100) %	0-40 (100) %
SS ν_S=4	20-80 (100) %	20-100 %	70-100 %

Table 2: Probability p for various cluster types (i.e. various ν_S) required to explain the observed abundances. Numbers in parentheses corespond to the case where overproduction in the primary collisions is permitted (see text).

Let us now look at two extreme cases. First we consider the case where a projectile sees one nucleon tube and no independent nucleons on its path through the nucleus. Then $p = 100$ %. Also since the average number of nucleons encountered in a sulphur nucleus is ~ 2.5, so these tubes have $2 < \nu_S < 3$. This allows produce a priori enough strangeness to reproduce NA35 data. but $p = 100$ % implies

$$h^{-\,tot}_{SS}/h^{-\,tot}_{pS} = 1.28 \times X_{SS} \qquad (13)$$

X_{SS} is in this case equal to the number of tubes and from table 1 its value is ~ 16 ($X_{pS} = 1$). So we now have a contradiction, a sulphur nucleus with 16 tubes and an average of 2.5 nucleons per tube, would have more than 32 nucleons. We can rule out tubes with p= 100%. Let us look at another extreme case. Let us suppose that sulphur nuclei contain one source with a high number of nucleons, e.g. 4, in it. If there is just one such cluster, the probability to encounter it in the middle of the 28 other independant nucleons is small. This case also allows to reproduce NA35 data. However it is not clear how such clusters would arise. If they are due to Lorentz contraction, we would expect also ~ 2.5 nucleons in general, 4 is not ruled out but rather extreme. The best candidates seem to be intermediate cases e.g. $\sim$ two $\nu_S = 3$ clusters.

4. SECONDARY REACTIONS

A certain number of a given strange particle type is created initially in primary collisions as we have calculated above and this number may be modified later by the secondary collisions occuring inside the nuclei or in the interaction region between the receding nuclei. For simplicity we restrict ourselves to the same reaction set as [1]. In the case of the fragmentation region of a pA or AB collision, it is enough to consider reactions with a nucleon N in the initial state. We see that Λ can be recreated via $\pi N \longrightarrow \Lambda K$ and $\bar{K}N \longrightarrow \Lambda\pi$ and not absorbed (in reality more complicated but more rare reactions could lead to absorption). For the K^0_s, the reactions to be considered are the same but of course the first one (with cross section of order 0.1 mb) leads to recreation and the second one (with cross section of order 1 mb) to absorption. It is not very clear which process wins because the lower cross section in the first case may be compensated by the higher number of π than $\bar{K}$'s. For $\bar{\Lambda}$, we can only have absorption via $\bar{\Lambda}N \longrightarrow K + \sim 4\pi$. If a baryon-poor high density region is created at midrapidity in an A-B collision, we picture it as mostly a pion gas so we concentrate on reactions with one or two pions in the initial state. Λ may be created via $\pi N \longrightarrow \Lambda K$ and destroyed via $\pi\Lambda \longrightarrow \Xi K$ with comparable cross sections and abundances of initial participants. For K^0_S, we can have recreation via $\pi\pi \longrightarrow K\bar{K}$. For $\bar{\Lambda}$, the same reactions than for Λ should be taken into account but with anti-particles. In the case of S-S, the eventual high density phase between the receding nuclei may not last very long because the transverse energies reached are smaller than for bigger nuclei, so the secondary reactions in the pion gas should not be very effective. We conclude that Λ and to a lesser extent K^0_s may be recreated in secondary collisions but $\bar{\Lambda}$ can only be absorbed and this makes it a good probe of strangeness enhancement in the primary collisions.

5. CONCLUSION

Though various steps in our description need to be improved (microscopic description of the collision involving sources, calculation of the number of collisions), we have showed that collective sources (which could arise due to Lorentz contraction) provide an efficient strangeness enhancement mecanism. More details about strangeness production should become available in the near future from NA36 and E810, to complement the NA35 data on $\bar{\Lambda}$, K^0_s and Λ. So we are now working on a more precise prediction of the effects of collective sources (rapidity distributions including that of pions which is known with a good precision already, dependence of the yields on centrality, etc).

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