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AN OBSERVATION OF A LEADING MESON IN $\bar{p}$+Ne REACTION AT 607 MeV/c INCIDENT MOMENTUM

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A pion or a kaon may behave as a leading particle in low-energy antiproton–nucleus reactions, in qualitative agreement with a quark model picture describing beam fragmentation.

The antiproton–nucleus interaction is clearly one of the new and exciting tools available for the exploration of the nucleus and hadronic physics in general. Among the effects resulting from the deposition of a large amount of energy in a well-defined region of space, strange particle production has stimulated a number of recent experimental works [1–9] and has been theoretically studied from various points of view [10–24].

The specific reasons of interest are the dynamics of multinucleon absorption of antiprotons in nuclear matter and the possibility that, under appropriate conditions, a collection of nucleons could be transformed in a quark–gluon plasma. Λ^0 hyperon production, due to the fact that for baryonic number conservation two target nucleons are necessarily involved in the $\bar{p}$ absorption process, is an ideal reaction for a study of collective effects.

One of the typical signatures of the dehadronization of a region of nuclear matter could be an enhancement in strangeness production: in fact, according to Rafelski [12], the growing volume of large quark bags due to $B>0$ annihilations, can favour an increasing production of $s\bar{s}$ pairs. The same conclusion was reached by Cugnon and Vandermeulen [15] with a model based on kinematical constraints operating in a pure hadronic phase. Moreover, if multinucleon annihilations occur, some unusual reactions may also have the possibility of happening. For instance, reactions with doubly strange final state should become feasible. Because of the destruction of a unit of baryon number of the capturing cluster, these reactions possess a larger Q-value than would otherwise be the case.

However, despite experimental and theoretical investigations, details of the strangeness production mechanisms are still far from being completely understood.

In a previous work [8] we reported Λ^0 and K^0_S production cross sections and rapidity distributions for the reaction $\bar{p}+Ne\rightarrow V^0+X$ ($V^0=\Lambda^0$, K^0_S) at 607 MeV/c. In the same paper, rapidity distributions of π^-, both associated and not to strangeness production, were shown. Some conclusions on the effective targets involved were drawn, but without taking into account the role of the associated π^-'s. It was tried to identify, not quite correctly, two different multinucleon clusters as responsible for Λ^0 and K^0_S production, in agreement with the conclusions of a KEK experiment [4].

In this letter we examine in more details our results on rapidity and present them in a different way, trying, within the limits of the present statistics, to give an explanation to the puzzling feature inherent in the previous analysis: the fact that both (Λ^0 associated and K^0_S associated) π^- rapidity distributions – a parameter not measured in the Japanese experiment [4] – present just quite different average values compared to those of the associated strange particles: as if pions were produced from totally different effective targets.

In our data [8] the emission of the Λ^0's is nearly isotropic in the laboratory system, with an average rapidity $\langle y\rangle=0.07\pm0.03$. The distribution of the kinetic energy of the observed lambdas corresponds to a nuclear temperature smaller than 10 MeV, according to the Weisskopf formula [25]

$$P(E,V,T)\,\mathrm{d}E=\frac{E-V}{T^2}\exp\left(-\frac{E-V}{T}\right)\mathrm{d}E\,,$$

where E is the kinetic energy of the evaporated particle in the system of the evaporating nucleus, T is the temperature of the nucleus, and V is the potential barrier. One gets the temperature $T=E$ when P is maximum.

The average longitudinal rapidity of the kaons is significantly larger, namely $\langle y\rangle=0.33\pm0.07$. As it is shown in fig. 1, the rapidity distribution of the kaons can be considered, within the limits of our statistics, as the sum of two distributions: a first one, about symmetrical around zero (fig. 1b) and a second one given by the difference between the full distribution and the symmetrical one. This difference is characterized by an excess of large rapidity kaons (fig. 1a). The distribution of the excess extends from $y\simeq0.1$ to $y\simeq1.3$, with an average value $\langle y\rangle\simeq0.7$, which corresponds to a longitudinal kaon momentum of about 400 MeV/c. Thus, two groups of kaons seem to exist, one emitted from a system with an average rapidity about zero, the other emitted in the forward direction with an average rapidity about 0.7.

The negative pions have an average longitudinal rapidity in the laboratory system which, for the events without a neutral strange particle and for the events with a lambda, is about 0.3 (0.25 ± 0.02 and 0.31 ± 0.08, respectively), but, for the events with a neutral kaon, is about zero (-0.01 ± 0.06).

In the same way as for the kaons, also the rapidity of the π^- with a Λ can be considered, within the lim-

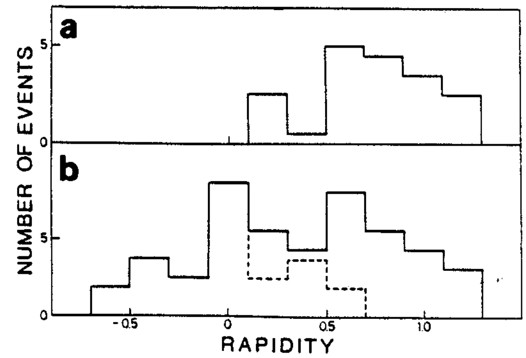

Fig. 1. For events with a neutral kaon: (a) the distribution of the excess; (b) the distribution of rapidity of kaons as sum of two distributions.

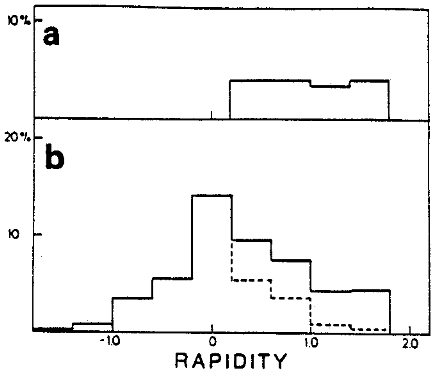

Fig. 2. For events with a lambda: (a) the distribution of the excess; (b) the distribution of rapidity of pions as sum of two distributions.

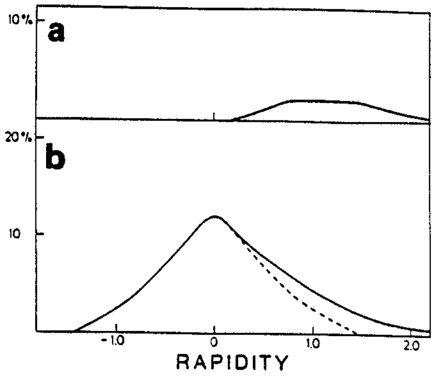

Fig. 3. For events without strange particles: (a) the distribution of the excess; (b) the distribution of rapidity of pions as sum of two distributions.

its of our statistics, as the sum of two distributions: one with a mean value about zero, and the other one with an excess of large rapidity pions (see fig. 2). The distribution of the excess extends from $y \simeq 0.2$ to $y \simeq 1.8$. The average value is $\langle y \rangle \simeq 1$, corresponding to a pion longitudinal momentum of about 200 MeV/*c*. Therefore, also two groups of pions seem to exist, one emitted from a system with an average rapidity about zero, the other one due to some other emission in the forward direction with an average rapidity about 1.

The fraction of kaons or pions produced, respectively, in the slow system or in the forward direction can be estimated from their excess of positive rapidities. While about 50% of the kaons are produced in each system, about 30% of the lambdas are produced with a negative pion which is emitted in the forward direction.

Pions or kaons as leading particles carry some fraction of the momentum of the incident antiproton in the forward direction in the final state. This fraction of the incident momentum is not absorbed by any target system.

As far as the pions emitted in events without strangeness are concerned, similarly to the case of a π^- with a Λ, also their rapidity distribution can be considered as the sum of a distribution around an average value $\simeq 0$ and an other one with an excess of large rapidity pions (fig. 3). The distribution of the excess extends from $y \simeq 0.2$ to $y \simeq 2.3$, with an average value $\langle y \rangle \simeq 1$, corresponding to a longitudinal pion momentum of about 200 MeV/*c*. Again now, two groups of pions seem to exist, one emitted from a system with an average rapidity about zero, the other one due to some other emission in the forward direction, with an average rapidity about one. In this case, however, a fraction of the excess has a clear physical origin. It pertains to the so called "primordial pions" which, isotropically emitted in the $\bar{N}N$ CM system, do not interact with the nucleus and appear forwardly produced in the laboratory, due to the velocity of the $B=0$ fireball.

The observation of leading mesons is well known from $\bar{p}p$ reactions [26], where, in the annihilation CM system, in the final state the negative pions tend to follow the direction of the antiproton, and the positive ones the direction of the proton.

Nevertheless, at the low energy of the experiment there are no quantitative explanations on the basis of the different models mentioned at the beginning and studies are now in progress by specialists in the specific fields. In fact, the only present model of unusual annihilations (Cugnon and Vandermeulen [15]) is not able to give quantitative predictions, in the case of $\bar{p}$–nucleus interaction, of a well established signature like strangeness enhancement, since it cannot predict the formation frequency of the $B>0$ fireball, besides rough geometrical estimations. The existence of a possible leading effect as further signature of unusual annihilation is not taken into account at the present stage. The nuclear temperature of about 20 MeV found from the distribution of energy of the lambdas is much too low for a phase transition to a

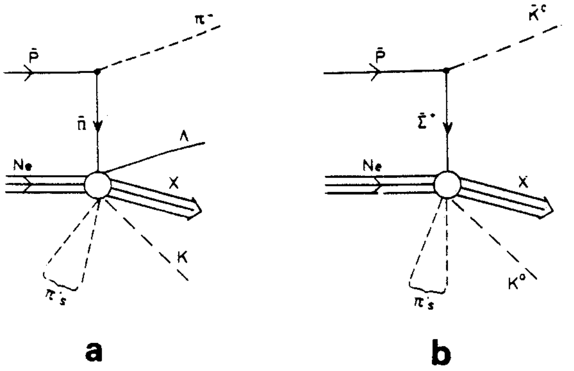

Fig. 4. Leading meson diagrams for: (a) Λ production; (b) K_S^0 production.

quark–gluon plasma and also for the formation of supercooled quark matter according to the recent suggestion by Rafelski [27]. However, this temperature is consistent with the nuclear evaporation model. Models involving quark–gluon dynamics are in their infancy phase and allow only qualitative predictions.

If a leading particle is seen in the final state, the emission of a pion or a kaon in the forward direction may be depicted by diagrams like those shown in fig. 4, and others similar. The associated ΛK production can occur both in the target vertex (fig. 4a) through nucleon exchange and a leading pion emitted from the beam vertex and in the beam vertex through double baryon exchange and without a leading pion. A pair of $K\bar{K}$ may, in principle, be produced on any vertex, although the production of $K\bar{K}$ in the target vertex with a leading pion from the beam vertex has not been observed in this experiment ($\langle y \rangle \simeq 0$ for π^- associated to K_S^0 events). Production of a fast $\bar{K}$ at the beam vertex and a slow K in the target vertex is possible through the exchange of a $\bar{\Sigma}$ (fig. 4b). $\Lambda\bar{\Lambda}$ production was found of the order of a percent at 4 GeV/c [4] and can be considered negligible at the energy of our experiment.

In terms of a quark model picture describing beam fragmentation, fig. 5 shows the quark flow diagrams of the leading meson effect. The leading pion and the leading kaon are produced when one antiquark of the impinging antiproton picks up a light quark (fig. 5a) or a strange quark (fig. 5b), respectively, from the sea-quark of the struck nucleon of the target system, while the other two antiquarks are absorbed by the target to produce the exchanged baryon.

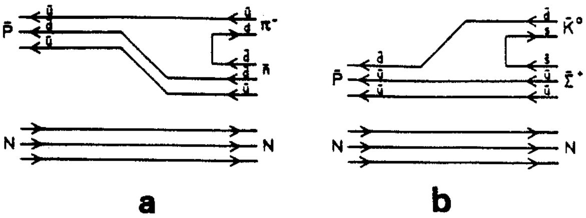

Fig. 5. Quark flow diagrams describing beam fragmentation with: (a) a leading pion; (b) a leading kaon.

The baryon exchange and the quark model in this case both describe Bremsstrahlung-like production of a leading meson. The Bremsstrahlung-concept may be relevant since the observed maximum longitudinal momentum of the leading mesons is about 600 MeV/c, i.e. equal to the incident momentum of the antiproton, corresponding to the maximum rapidities seen in figs. 1, 2 and 3.

The total momentum of the incident antiproton is carried by the three valence antiquarks and the gluon field. Since the total momentum is low, only 607 MeV/c, maybe only one of the valence antiquarks has a sufficiently high momentum to penetrate the Ne-nucleus and make a leading meson.

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