PHYSICS AT LEAR WITH LOW ENERGY ANTIPROTONS

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DYNAMICS OF THE $\bar{p}$-NUCLEUS ANNIHILATION

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Abstract The overall properties of $\bar{p}$-nucleus annihilation are consistent with a model whose main ingredients are annihilation on a single nucleon followed by intranuclear cascade. Possible deviations from this scheme are mentioned.

INTRODUCTION

The most plausible dynamical scheme for $\bar{p}$-nucleus annihilation at rest is embodied by a three stage process : (1) The antiproton annihilates on a single nucleon from its Coulomb state, freeing a certain number of pions (5 on the average) slightly outside the nuclear surface ; (2) These pions can travel inside the nucleus, hitting and ejecting nucleons. They can also be absorbed; (3) After this fast process, lasting for 10 ~ 30 fm/c depending upon the target size, the nucleus is left with some excitation energy, which can be carried away by evaporation of light particles. We have modelled (Cahay et al., 1983) the three stages by a phase space model for the creation of the primordial pions at a well-defined point in spacetime, an intranuclear cascade model including all possible two-body reactions between π , N and Δ particles and a simplified evaporation model for the last stage (Cugnon, Jasselette and Vandermeulen, 1987a).

THE MULTIPION CASCADE

About half of the pions from annihilation penetrate the nucleus and produce a cascade, hitting a few nucleons, transforming into Δ 's, which scatter, decay back or disappear by collision with nucleons. Between 0.5 and 1 pion is so absorbed. Energy is transferred from the pion system to the nucleus. The evolution of the excitation energy of the nuclear system is depicted by Figure 1. The energy is carried away on a fast time scale by the ejected nucleons. After ~ 30 fm/c, the energy is dissipated more slowly as in an evaporation process. The number of ejected particles during the fast process is rather small. Even the number of participants, i.e. the nucleons involved in the cascade, be they ejected or not, is also rather small (see Figure 2). Altogether, annihilation at rest involves a limited part of the nucleon system and can be characterized as a rather gentle process in view of the energy available. Figure 1 indicates that the ratio energy transfer/available energy is of the order of 25%.

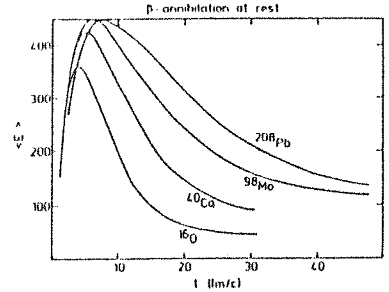

FIGURE 1 Time evolution of the target excitation energy following $\bar{p}$-annihilation (at t=0) on various nuclei.

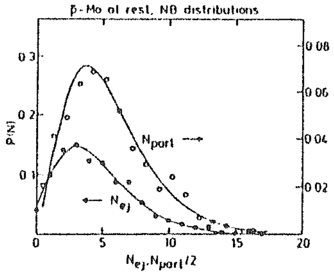

FIGURE 2 Distribution of the number of fast ejected nucleons (N_{ej}) and of participants (N_{part}). The curves provide a negative binomial fit.

The energy spectrum of the ejected particles shows slopes with a "temperature" of the order of 70 MeV. This does not result from the formation of an equilibrated hot system, but rather from the direct ejection by the primordial pions.

EXPERIMENTAL SIGNATURES

The overall agreement of the cascade picture with experiment has been demonstrated by McGaughey et al. (1986), who measured the pion and proton production cross-sections in $\bar{p}$-annihilation in flight. The energy spectrum is consistent with the characteristics mentioned above. The number of collisions undergone by the participants is shown to be rather small, a feature inconsistent with a thermally equilibrated system (McGaughey, Clover and DiGiacomo, 1986).

The global validity of the cascade + evaporation picture is also supported by Figure 3, which shows our predictions along with the measured residual mass distribution in $\bar{p}$-^{98}Mo annihilation

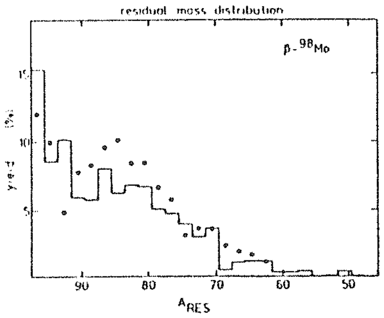

FIGURE 3 Residual mass distribution. Dots : experimental data (Von Egidy, 1987). Histogram : cascade calculation (Cugnon, Jasselette and Vandermeulen, 1987a).

at rest (Von Egidy, 1987). It should be noticed that the mass 97 is represented with a substantial probability. This corresponds to events where the pions do little damage to the nucleus. Furthermore, the average number of charged particles in $\bar{p}$-Ne streamer chamber experiments (Guaraldo, 1987) and in $\bar{p}$-emulsion (Batusov et al., 1986) is reproduced by cascade calculations. Finally , the charged particle multiplicity distributions in $\bar{p}$-emulsion are well fitted by a negative binomial function. It is explained in Cugnon, Jasselette and Vandermeulen (1987b) that this observation is consistent with the cascade picture.

POSSIBLE DEVIATIONS

There may be deviations from the above scenario probably with a limited frequency. The first possible effect is a "delocalization" of the annihilation site. This can be pictured as a $\bar{p}$-annihilation on two (or more) nucleons (Rafelski, 1980, 1987; Cugnon and Vandermeulen, 1984) (see below). Other possibilities can take the form of a modification of the annihilation properties (like pion multiplicities) due to medium effects or a replacement of the evaporation process by a multifragmentation process. They are more probable in annihilation in flight because the first one requires deep annihilation and the second one a larger energy deposit. The delocalization of the annihilation process involving a deconfinement of quarks in a sizeable volume was suggested by Rafelski (1980, 1987) and there may be indications for that in the neutron spectrum in $\bar{p}$-U measured recently (Büche, Lewis and Smith, 1987). However, the high "temperature" of the neutrons could result from the specific parametrization used to disentangle the various components of the spectrum.

A simple phase space model (Cugnon and Vandermeulen, 1984, 1987) predicts an enhancement of the strange particle yield in B = 1 annihilation. There are already some indications in favour of this process in experimental data. The hypernuclei formation yield (PS 177) (Bocquet et al., 1987) cannot be explained without calling for B = 1 annihilation. A preliminary analysis of these data seems to require a relative probability of B = 1 annihilation of the order of 10 %. The strange particle yield in $\bar{p}$-nuclei annihilation is hard to evaluate because of the distortion due to the propagation through the nucleus, except for K^+ which interact little with nucleons. The measurements of the streamer chamber group (Guaraldo, 1987) are grossly consistent with the predicted enhancement of strangeness yield.

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