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Edited by **S. Charalambous**
C. Papastefanou
Univ. of Thessaloniki
GR-54006 Thessaloniki

P. Pavlopoulos
CERN-EP
CH-1211 Geneva 23
Switzerland

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ENERGY DEPOSIT IN A NUCLEUS FOLLOWING $\bar{p}$-ANNIHILATION

J. Cugnon and J. Vandermeulen

Université de Liège, Institut de Physique B5,
Sart Tilman, 4000 Liège 1, Belgium.

1. INTRODUCTION

The $\bar{p}$-annihilation by nuclei has received much attention, since the speculative considerations of ref. [1] on the possible formation of a quark-gluon blob and on a nuclear explosion following the deposit of about 2 GeV in the nucleus. For the moment, there is no real indication of the first possibility, but the observation of the target desintegration in streamer chambers [2] and the production of high energy protons [3] are consistent with the second possibility. However, the problem is to know whether such explosive events really involve the bulk of the (hot) nuclear matter. No sound answer can be given without knowing the dynamics of the $\bar{p}$-nucleus interaction. Here, we will review the simplest dynamical scheme and single out the interest of the $\bar{p}$-annihilation for nuclear physics.

2. DYNAMICS OF THE $\bar{p}$-NUCLEUS SYSTEM

2.1. The simplest dynamical scheme

This scheme assumes that the incoming antiproton annihilates (instanteneously) with a single nucleon of the target, giving birth to ~ 5 pions. The latter cascade down through the nucleus by successive collisions with the nucleons. This multiple scattering of the pions is handled by the so-called intranuclear cascade (INC) model [4,5], which simulates the successive collisions by a random walk picture, according to the known elementary cross sections. The pion absorption is accounted for by the $\pi N \to \Delta$, $N\Delta \to NN$ processes. This dynamical scheme in principle allows for a nuclear explosion if the fast pions and nucleons have a sufficiently small mean free path.

Already successful in heavy ion physics, the INC model is able to reproduce the main features of the inclusive proton and pion cross sections [4]. In particular, it can reproduce the forward-backward asymmetry of the pion emission pattern [5]. The proton (as well as pion) spectra have thermal high energy tails, with temperatures of 50-80 MeV. This suggests the formation and decay of a hot piece of matter. However a careful analysis of the INC dynamics shows that pions issued from the annihilation hit a few nucleons only, most of which are ejected. Some of them can rescatter, but, by and large, the pions involve a limited fraction only of the nucleus. This picture is corroborated by several features : (a) the high energy tail of the pion spectrum is essentially due to the primordial pions ; (b) the ejected nucleons suffer only a few collisions ; (c) the nucleons which are scattered only once by the pions show a high energy tail ; (d) the interacting pions are scattered (through $\pi N \to \Delta \to \pi N$ process) twice. Point (c) is illustrated by Fig. 1, which refers to the $\bar{p}$ (180 MeV) + ^{98}Mo case at b = 0.

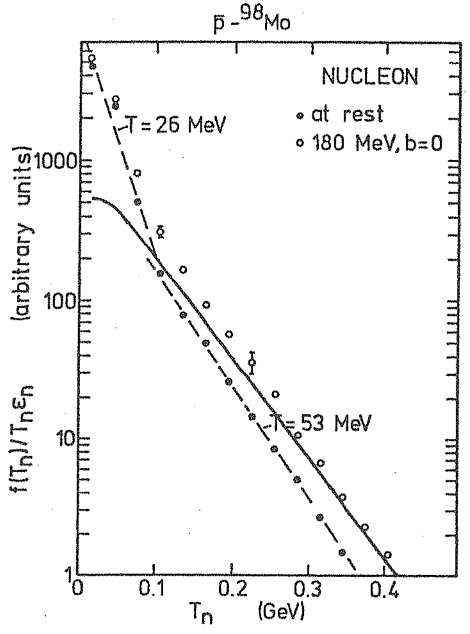

Fig. 1.

Nucleon spectrum after $\bar{p}$ (180 MeV) annihilation on ^{98}Mo nuclei (open dots). The full curve refers to those nucleons who have been involved once and only once in a $\pi N \rightarrow \Delta \rightarrow \pi N$ process.

2.2. Discussion

Although the INC model seems quite satisfactory, there are at least two physical aspects which are neglected. (1) The annihilation is supposed to be a well defined event in space-time. Yet, the spectrum of the primordial pions looks thermal with a high temperature (over 100 MeV). This is rather contradictory and it is more likely that the annihilation presents some extension in space. Such a possibility may simply take the form of an annihilation on two nucleons, as suggested in ref. [6] and partly supported by the measure of the hypernuclei yield [7]. (2) The incoherent multiple scattering, embodied by the INC, is a satisfactory model for high energy pions and nucleons, as those encountered at the beginning of the cascade process, but not at the end, where the energy-momentum propagation would involve more coherent and more collective processes.

3. INTEREST FOR NUCLEAR PHYSICS

3.1. Nuclear fragmentation

If the $\bar{p}$-annihilation is not suited to the formation of a hot equilibrated matter, it is nevertheless interesting for nuclear physics. One of

the current problems is the way the nucleus looses its binding. It is known that if the excitation energy of the nucleus is small, the nucleus dissipates this energy by evaporating a few nucleons. If the excitation energy is much larger than the binding energy per particle, the nuclear system disentegrates in light particles, mainly nucleons and pions. In the intermediate domain, which can be characterized by an excitation energy of around 10 MeV per nucleon, nothing is well known. It is generally believed that if the excitation energy increases in this vicinity, the nucleus breaks into many pieces : this is the so-called multifragmentation. There are currently two (main) approaches to this phenomenon :

(1) Thermal model : if the (liquid) nuclear matter is heated to several MeV, it may undergo a liquid-gas phase transition and become a gas, loosing its self-boundedness. Because of microscopic effects, related to details of nuclear forces, the residues are not simply nucleons, but also other nucleids. Close to the transition point, the mass yield should show a power law

$$y(A) \propto A^{-\tau} \quad , \qquad (1)$$

where τ is a critical exponent, lying between 2 and 3. In this model, all the particles should be characterized by the same temperature.

(2) Percolation model : here it is assumed that hard processes eject a few fast nucleons, creating voids inside the nuclear volume. The basic premise of this model is that the fragmentation of the nucleus is totally determined by the geometrical properties of these voids. The latter give birth to clusters in just the same way as site percolation on a lattice. The remarkable aspect of this model is that it predicts a sudden onset of the multifragmentation when the number of voids reaches a critical value. Close to this value, the mass yield of the fragments follow a power law similar to Eq. (1) with a slightly different exponent, however. This model does not predict anything on the spectra, except that it admits the presence of high energy protons. Actually, the evolution of the mass yield in correlation with the number of these fast particles is a possible and rather easy check of the percolation ideas.

3.2. Specificity of the antiproton annihilation

Contrarily to what happens in heavy ion experiments and even in high energy proton experiments, the dynamics is much clearer. In the former, the system is rather inhomogeneous. In the latter, the energy flow is too much forward peaked. In $\bar{p}$-reactions, the energy flow initiated by the primordial pions is much more isotropic, since the pions are rather isotropically emitted. Furthermore, as we have said, the dynamics is close to what is required for having a "percolating" situation. Finally, even if the number of voids (or ejected nucleons) is limited, it is nevertheless sufficient to be of the order of the critical value ~ 40 % for the onset of multifragmentation, as Fig. 2 indicates.

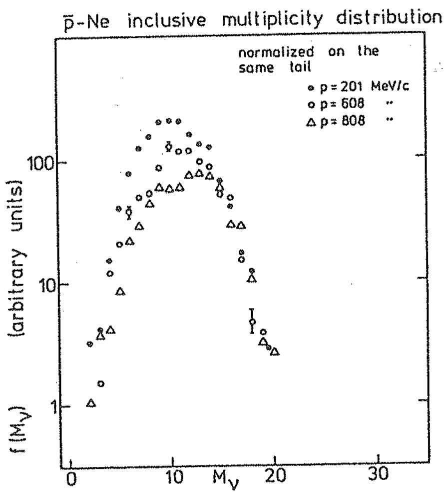

Fig. 2.

Distribution of the fast particles (including pions) for $\bar{p}$-Ne annihilation.

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