LNF–89/056

C. Guaraldo

LOW ENERGY ANTIPROTON-NUCLEUS ANNIHILATION

Estratto da: Nucl. Phys. B (supp. Proc.), n.8 243 (1989)

Nuclear Physics B (Proc. Suppl.) 8 (1989) 243–254
North-Holland, Amsterdam

LOW ENERGY ANTIPROTON-NUCLEUS ANNIHILATION

Carlo GUARALDO

Laboratori Nazionali di Frascati dell'INFN
Casella Postale 13, 00044 FRASCATI, Italy

1. INTRODUCTION

The lot of new experimental results from LEAR at CERN, in the concluded pre-ACOL era; the recent data from USSR (Serpukhov) and Japan (KEK); the theoretical contributions beyond the conventional intranuclear cascade *(INC)* models, emphasize undoubtly the interest in investigating the interaction of intermediate energy antinucleons with nuclei.

Even though the bulk of the present experimental results is indeed consistent with the scenario of an intranuclear cascade as described by the current models, however the number of "exceptions" is increasing: experimental results which can not be explained in the conventional framework, indicating the possible evidence of unusual annihilations. Which represents the gate towards those "exotica" which have focused, since the beginning, a special attention onto antinucleon-nucleus annihilation.

In Section 2 we report the more recent results in antiproton-nucleus annihilation, and we discuss new or peculiar aspects of some of them.

In Section 3 we examine how the calculations, stimulated by the new results, have dealt with features put for the first time in clear evidence: features which seem to underlie to universal properties of inelastic collisions of elementary particles *(clan behavior)*; or which stress the role of local variations of nuclear density throughout the developing of the intranuclear cascade *(trawling effect)*; or which hypothesize the formation of a new state of nuclear matter *(supercooled quark matter)* already at the relatively low energy reached by the experiments .

In Section 4 we discuss the actual possible experimental evidences of annihilations with baryonic number greater than zero. Which is a specific problem of Nuclear Physics, since looking at these "unusual" annihilations one investigates precisely *if* and *how* nuclear matter influences the $N N$ annihilation mechanism. We call "unusual" these phenomena considering as a deviation from the standard scenario a "delocalization" of the annihilation site which can be pictured as an annihilation on two (or more) nucleons *(multinucleon annihilations).*

2. RECENT MEASUREMENTS ON ANTIPROTON-NUCLEUS ANNIHILATION

Together with the bulk of CERN results, product of advanced or completed analyses of the first generation of LEAR experiments, we report here data from Serpukhov and from KEK, at some higher energies. While the first LEAR data were mainly inclusive measurements, the new results are more exclusive and cover a broad variety of scientific items, as it appears from this, not exhaustive, list in which the LEAR number of the experiment, or the name of the laboratory where it was performed, are also reported:

Measurement of correlations between the emitted particles
- PS 179, ref. (1); Serpukhov, ref. (2)

Charged particle multiplicities
- PS 179, ref. (1)

Yields of residual nuclei
- PS 186, ref. (3)

Light particle spectra
- PS 186, ref. (4,5)

Strangeness production
- PS 179, ref. (6,7); PS 183, ref. (8); KEK, ref. (9)

Heavy hypernuclei
- PS 177, ref. (10)

Neutron spectra
- PS 183, ref. (11)

Antiproton induced fission
- PS 177, ref. (12); PS 183, ref. (11); PS 186, ref. (13,4)

Most of these experiments were dealing with annihilations at rest; correlations between emitted particles, charged particle multiplicities and strangeness production were measured also in flight.

Here we make the choice to limit our attention onto a specific problem, the measurement of the mass of residual nuclei after annihilations, that can be elected as a good example of the capabilities of the antiproton in exploring nuclear physics properties, and especially in studying the break-up of the nucleus under the injection of increasing excitation energy. The experiment PS 186 at LEAR has investigated such possibilities.

Studying the properties of the residual nuclei produced in the inelastic $\bar{N}A$ interaction is important since these properties contain the main information about the interaction between the multipion system formed in the $\bar{N}N$ annihilation and a nucleus *(MPNI)*. In this *MPNI* "uniformly heated" high excited nuclei are produced effectively.

The subsequent decay mechanism of the residual nucleus is determined by the excitation energy it acquired:

I) *Moderate excitation ($E^* \lesssim 2$ MeV/nucleon).*

The best decay mechanism is the successive emission (evaporation) from the compound nucleus and fission.

As a result of these processes a wide spectrum of residual nuclei are produced far from the target nucleus and far from the β-stability line, as seen in the PS 186 experiment[3]. The predictions of the calculations[14] are that the mass regions of the observed nuclides ($60 < A < 95$ for Mo targets; $110 < A < 160$ for ^{165}Ho target) correspond indeed to product of evaporation of not too hot residual nuclei. Fig. 1 shows the good agreement between experimental mass distribution[3] and INC model result[14] for the case of stopped antiprotons in a ^{95}Mo target.

II) *Excitation close to the total binding energy of the nucleus ($E^* \gtrsim 5$ MeV/nucleon).*

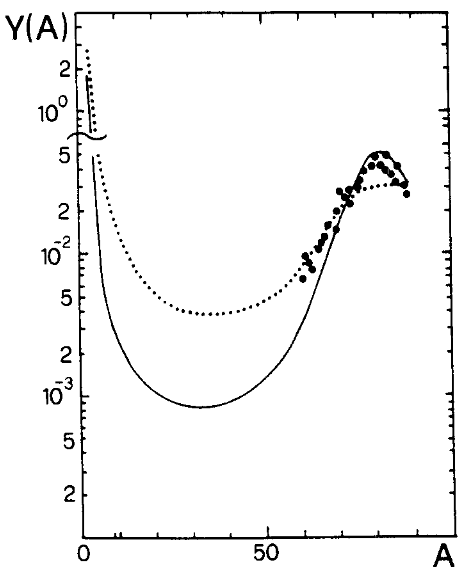

FIGURE 1
Mass yield of residual nuclei from $\bar{p}$ annihilation at rest on ^{95}Mo. Dots: exp. values, ref.(3). Solid and dotted lines: Iljinov model predictions with and without trawling, ref.(14).

In this highly excited nuclear matter there can occur a *phase transition* of the liquid-gas type. Its specific signal is the multiple production of nuclear fragments (of the order of *C* or *O*) resulting from the explosive decay of the residual nucleus, a feature referred to as *multifragmentation*. Needless to stress the conceptual significance of this phenomenon: it is important to understand how a nucleus loses its cohesion as to understand the origin of its self-boundedness. The properties of this phase transition should bear some relationship with the saturating properties of nuclear forces and the nuclear surface tension[15].

Unfortunately, the experimental method of induced radioactivity applied in the PS 186 experiment was not sufficiently sensitive or applicable in the mass regions $10 < A < 50$ for Mo targets or $10 < A < 100$ for the ^{165}Ho target, where multifragmentation takes place. Therefore, no experimental evidence is up to now available about this relevant physical process induced by antiprotons.

The theoretical predictions[14] are rather explicit for multifragmentation. Accompanying the many-body break up of the hot nucleus into light fragments, in moderately hot nuclear systems ($3 \leq E^* \leq 5$ MeV/nucleon), "quasi-evaporation" (i.e. the break down into a large residual nucleus and one or two small fragments or nucleons) and "quasi-fission" (i.e. the break down into two fragments with approximately equal masses) can be observed[16]. This gives a characteristic *U*-shaped inclusive mass distribution which can be seen in fig. 1.

In order to study multifragmentation, an initial energy of antinucleons $E_N \cong 100 \div 200$ MeV is, evidently, most favorable. According to Iljinov[3] the yield of fragments produced by a 180 MeV antiproton should increase by a factor 2÷3 compared with the one at rest shown in fig. 1.

3. RECENT THEORETICAL CONTRIBUTIONS ON ANTIPROTON-NUCLEUS INTERACTION

A substantial contribution in understanding the new bulk of antinucleon-nucleus results has come from recent *ad hoc* developed theoretical models, the success of which is striking in some cases, while in other ones more accurate experiments or more refined or better established theoretical efforts are still needed in order to draw definite conclusions.

We want to mention here three out of them, and precisely:

- *Negative binomial analysis of multiplicity distributions*: refs. (19, 21, 22)
- *Trawling effect in intranuclear cascade*: ref. (14)
- *Supercooled quark-matter formation in $\bar{p}$-heavy nuclei annihilation @ 4 GeV/c*: ref. (23).

It the following, we shall limit our discussion to the negative binomial approach.

Negative binomial multiplicity distributions

Recently, it has been discovered by the UA5 collaboration[17] that charged particle multiplicity distributions in the high energy $\bar{p}p$ collisions closely follow a negative binomial *(NB)* form. Further analyses at different energies (from a few tens to a few hundreds GeV c.m. energy) and for various systems (pp, $\bar{p}p$, πp, e^+e^-, ...) seem to establish the general validity of the *NB* both for total multiplicities and for restricted intervals of pseudorapidity[18]. It is not clear yet whether this universal property is a signature of a peculiar aspect of the underlying dynamics or not. Anyway, some arguments and observational facts support the idea[18] that the existence of *NB* distribution is linked to an underlying cascade process in which primary objects *("ancestors")* are created independently and subsequently generate the final particles. Each of the observed particles belongs to one of N clans; each clan is initiated by an ancestor and contain n_c particles. A *NB* distribution is obtained if N is a *Poisson* variable *(independent clans)* and if n_c follows a *logarithmic* law.

The possible existence of similar properties at lower energy in nuclear processes has been analyzed by Cugnon[19]. Specifically the ability of the *INC* dynamics to develop *NB* distributions has been investigated. It has been shown that the antiproton-nucleus interaction, especially at rest, is a good system for observing *NB* distributions, since the latter liberates a few pions which are expected to cascade more or less independently inside the nucleus. In fact, excellent best fit by *NB* distributions of the charged particle multiplicities measured in $\bar{p}$ annihilation in emulsion both at rest and at 300 MeV/c by PS 179 experiment[20] were obtained[21].

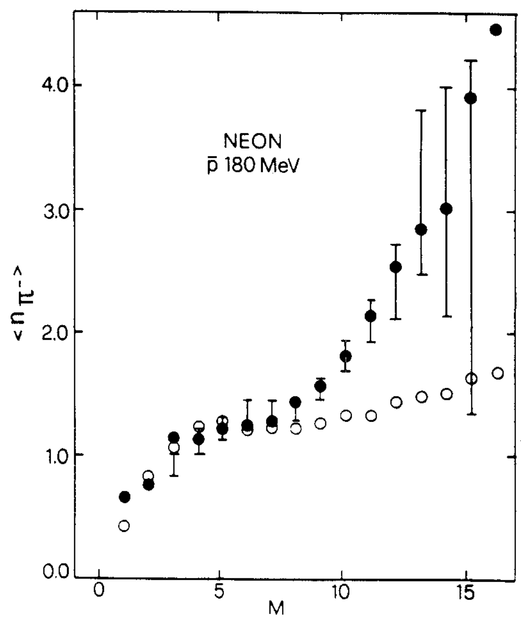

FIGURE 2
Correlation between the average number of π^- and the number of charged tracks. Bars: exp. data, ref.(1). Full and open circles: predictions of the compound Poissonian model with and without charge conservation, ref.(22).

A comparison with *INC* calculations gives a result remarkably close to the fit mentioned above. Thus the picture of clan formation, the ancestors being the interacting pions, seems to emerge both from the model calculation and from experiment.

In the new clan picture recently developed by Cugnon *et al.*[22], not only the number of ancestors in *Poissonian*, but also the number of secondaries (size of the clans) follows a *Poissonian* distribution *(compound Poissonian model)*. This is largerly supported by the results of the *INC* model, as demonstrated by the authors. The model has been applied to the recent correlation and multiplicity measurements of PS 179 experiment[1].

The PS 179 streamer chamber results, obtained using 180 MeV antiprotons on Ne[1], present a striking behavior in comparison with what, in principle, one might expect from the *INC*.

Indeed, according to the well established mechanism of "pionic" energy transferring along the intranuclear cascade, via Δ formation and absorption, assuming that high multiplicity events, and hence in general high ejected nucleon multiplicity, are allowed by a higher deposited energy, one might expect a *decreasing* number of (survived) final pions at high *M*. The experimental trend found by PS 179 experiment contradicts this apparently general conclusion, since the average number of π^- is an *increasing* function of the overall multiplicity, at high *M* values (see fig. 2). However, nothing "unusual" is underlying this result, as shown by Cugnon *et al.*[22]. Their (modified) clan picture reproduces in fact beautifully this behavior, as a direct consequence of *charge conservation* handled exactly at each step of the cascade (and not only on the average, as usually done). To check this feature, the model was run in picking at random the charge of each pion. The result is shown in fig. 2 by open circles. The difference between the two cases clearly shows that the correlation observed at high *M* is a result of the constraint and has no dynamical content.

4. UNUSUAL ANNIHILATIONS

4.1. Introduction

Hunting for processes which can favour multinucleon annihilations can start from investigating, preferentially, the ensemble of *reactions which present intrinsically a typical two- (or more -) body nature*. As early as 1956, just half a year after the discovery of the antiproton, Bruno Pontecorvo was the first who realized[24] that there must exist unusual annihilation processes ("extraordinary" annihilations, as dubbed by Pontecorvo) forbidden on a free nucleon but allowed on nucleons bound in nuclei.

Such are annihilation reactions *(Pontecorvo reactions)* with only one meson in the final state *(one-meson annihilations)*, for example:

$$\bar{p} + d \rightarrow \pi^- + p \qquad (1)$$

$$\bar{n} + {}^3He = \pi^+ + d \qquad (2)$$

or annihilations without any meson at all *(mesonless annihilations)*, for example:

$$\bar{p} + {}^3He \rightarrow p + n \qquad (3)$$

$$\bar{n} + {}^3He \rightarrow p + p \qquad (4)$$

These reactions are strictly forbidden in $\bar{N}N$ annihilation in vacuum by charge and baryonic number conservation.

The influence of nuclear matter on the annihilation mechanism can manifest itself in many ways. For instance, in a mesonless annihilation, alongside a more or less "conventional" process in which all pions are absorbed, there may exist the mechanism of *direct interaction* of the produced fireball with the surrounding nuclear matter, *skipping the stage of pion production*. In particular, following the first suggestion of Rafelski[25], the initial fireball, enriched with gluons and $q\bar{q}$ pairs, can melt the surrounding nuclear matter and create inside the nucleus a bubble of *quark-gluon plasma*.

4.2. Interest in Pontecorvo reactions

Studying multinucleon annihilations, and in particular Pontecorvo reactions, has straightforward implications.

Antinucleon absorption on a two-nucleon pair reminds the well known dominant process of pion absorption in nuclei, which is also of two-body nature, since absorption on a single nucleon is very suppressed due to the nucleon large momentum (~ 500 MeV/c) required. But there is a significant difference between pion-nuclear absorption and Pontecorvo reactions: in antiproton annihilation the delivered energy is seven times larger, which means a correlation radius correspondingly reduced, and hence the peculiar possibility of investigating *short range correlations in nuclei*.

Moreover, taking for instance in consideration the simplest reaction, $\bar{p}d$ absorption, a standard triangular rescattering diagram, in which in the beam vertex is created a pair of mesons and one is absorbed on the second nucleon, is intrinsically suppressed (since it involves the rare process of meson absorption on one nucleon) in comparison with the corresponding quark diagram, in which the impinging antiquarks annihilate on quarks of both the target bags. In the case of mesonless annihilations three quark bags can be directly involved. More generally, one can therefore claim that such an investigation can be essential in clarifying the role of *multiquark configurations*.

We want also to mention the sensitivity of Pontecorvo reactions to *high momentum components of the nuclear wave function*, where quark gluon degrees of freedom may play an important role[26]. More generally, the high momentum tail of the nuclear wave function is related to the problem of the behavior of *highly excited nuclear matter*.

Other strong motivations are the already mentioned search for *new quark degrees of freedom*[25] (quark-gluon plasma) and the recent suggestion pointed out by Brodsky[27] of *testing the basic QCD dynamics in the* *intermediate momentum transfer domain* using the so called "reduced amplitude" formalism.

4.3. Signatures of unusual annihilations

The properties of the system which represents the minimal departure from the standard annihilation, i.e. the fireball with B=1, have been studied by Cugnon and Vandermeulen[28] under the simplest assumption, namely that its decay is governed by phase space. The most important prediction is a considerable *enhancement of strange particles* production for $B=1$ annihilations compared with B=0. This is a pure consequence of phase space, since the threshold for ΛK production in B=1 is below the $K\bar{K}$ channel in B=0.

More subtile signatures of unusual mechanisms can also be looked for. It is obvious that the complicate rearrangement of quarks in the course of annihilation can be disturbed by the proximity of other nearby nucleons. Compared to free space annihilation, the distribution of the emitted pions can, in principle, be altered. The average numbers are more or less fixed by the energy released, but the *widths of the total charged pion multiplicities* may be affected by the multinucleon process.

Moreover, if some "delocalization" of the annihilation site occurs, the *spectrum of "primordial" pions* - which is a high temperature thermal one - can be affected, in the sense that a *high energy tail* might appear.

Finally, an other predicted characteristics of a multinucleon annihilation is a typical *tail of high energy protons*[25], associated to the enhanced strangeness production.

4.4. Experimental evidences for unusual annihilations

The very observation of a Pontecorvo reaction is already an evidence of a $B > 0$ event. But as far as specific branching ratios are concerned, comparing predictions with data is a hard job. The model of Cugnon and Vandermeulen[28], which, at present, is the only one to give specific predictions for some strangeness producing channels, especially two-body channels[29], is unable to predict the formation frequency of the fireball. For the $\bar{p}d$ reaction this difficulty could be overcome by taking advantage of some experimental evidences[30] which can be used to deduce the $B=1$ component of annihilations. But for the mesonless annihilations - never explored experimentally - and, more generally, for the NA case, the problem is totally open, apart from simple estimations, using a geometrical model, of relative probabilities for various values of B, as discussed in a recent work of Cugnon and Vandermeulen[31].

As a consequence, as far as the strangeness signature is concerned, one has to follow, for the moment, and *indirect* way: namely, to see whether experimental data involving strangeness can, or not, be understood in terms of pure *B=0* annihilations. At this regard, moreover, one has also to take into account the distortion that a strange particle yield necessarily suffers passing through a nucleus. This is not the case of K^+, which scatters only elastically.

The list of the possible experimental evidences for not conventional annihilations contain at present the following cases:

1) *Measurement of the one-meson reaction $\bar{p}d \to \pi^- p$:* refs. (8,32,33);
2) *Measurement of the increasing of the ratio K^+/π^- in nuclear matter:* ref. (8);
3) *Measurement of the strangeness enhancement in $\bar{p}$ annihilation on complex nuclei:* refs. (6,9);
4) *Hypernuclei formation in $\bar{p}$ annihilation on heavy nuclei:* ref. (10);
5) *Leading meson effect in neutral strangeness production:* ref. (7);
6) *Correlations measurements between emitted particles:* ref. (1,2);
7) *Measurement of a high energy tail in the primordial pion spectrum:* ref. (34);
8) *Measurement of a high energy tail in the inclusive proton spectrum from $\bar{p}d$ annihilation under strangeness trigger:* ref. (30).

We shall focus our attention on some of them.

Measurement of the reaction $\bar{p}d \to \pi^- p$

There is an old measurement of Bizzarri *et al.*[32] with 6 bubble chamber events and a measured b.r. of $(0.9 \pm 0.4) \cdot 10^{-5}$ and a recent measurement at LEAR of PS 183 experiment[8] giving a b.r. of $(2.8 \pm 0.3) \cdot 10^{-5}$. An other LEAR group has recently communicated[33] a measurement of the $\bar{p}d \to \pi^- p$ yield: $(14 \pm 7) \cdot 10^{-6}$, somewhat lower than the value of ref. (8). As said above, in this case exists a theoretical prediction, since an assumed frequency of about 10% for *B*=1 formation from the data of ref. (30), allows to the Cugnon and Vandermeulen model[29] to predict a b.r. of $3 \cdot 10^{-5}$, in fair agreement with the experimental result of ref. (8). It is noteworthy to mention that a recent elaborated calculation by Kondratyuk and Sapozhnikov[35], in the framework of the classical triangle rescattering diagram, with a realistic deuteron wave function, misses the experimental result of about one order of magnitude.

Leading meson effect in strangeness production

An intriguing feature of the PS 179 results on strangeness, is the behavior of rapidity distributions of π^- associated to Λ and K°_S[6]. In fact, the effective production sources, as deduced from the pion average rapidities, seem to clearly contradict the sizes already deduced from the strange particles rapidities. A possible explanation can be found[7] by disentangling all the rapidity distributions in such a way to put in evidence a common part plus an "excess", which can be interpreted as an evidence of a leading meson effect. The leading meson can be produced by the pick up from an impinging antiquark of a light or a strange quark of the sea quark of a target nucleon, according to a two-quarks bag involvement.

Correlation measurements between emitted particles

A correlation measurement recently performed at Serpukhov using 5.2 GeV antineutrons on Ta[2] present features which can not be explained within the framework of the conventional *INC* model, also in the recent version of the Jljinov model[14] which, in particular, gives a description of the elementary $\bar{N}N$ interaction in a wider energy region ($E_N \leq 10$ GeV). Average numbers of protons vs. average numbers of π^+ and of π^- are not reproduced (see fig. 3).

The relevant discrepancies are, seemingly, most strong in the channels of *mesonless* or *one-meson* annihilations: namely, there where, in principle, one should look for multinucleon annihilations.

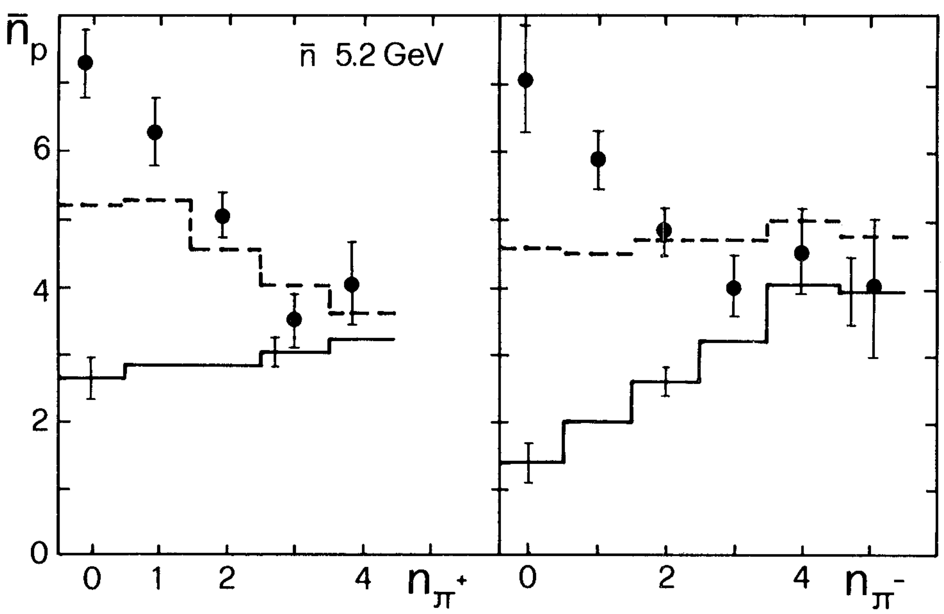

FIGURE 3
Correlations between the average number of protons and the numbers of $\pi^{\pm}$. Dots: exp. values, ref.(2). Solid and dotted lines: Iljinov model predictions with and without trawling, ref.(14).

It does not seem reasonable to draw any definite conclusions until more accurate experiments on the measurement of the correlations between protons and $\pi^{\pm}$ and also π° are performed. However, this might be the *first direct evidence* of a discrepancy from the conventional cascade mechanism to be ascribed to an unusual annihilation.

REFERENCES

1) F. Balestra et al., Nucl. Phys. 452A (1986) 576; Nucl. Phys. A (in press) and CERN EP/88-68 (June 1988).
2) V.F. Andreev et al., preprint Lebedev Institute of Moscow n. 33, FIAN (1987).
3) E.F. Moser et al., Phys. Lett. 179B (1986) 25; Zeitschrift für Physik (submitted).
4) W. Markiel et al., Nucl. Phys. 485A (1988) 445.
5) P. Hofmann et al., to be published.
6) F. Balestra et al., Phys. Lett. 194B (1987) 192.
7) F. Balestra et al., Phys. Lett. B (submitted) and CERN EP/88-61 (May 1988).
8) G.A. Smith, in *The elementary structure of matter*, ed. by J.M. Richard et al., (Springer-Verlag, Berlin, 1988) p. 219.
9) K. Miyano et al., Phys. Rev. C (submitted) and KEK 87-160 (February 1988).
10) J.P. Bocquet et al., Phys. Lett. 182B (1986) 146; 129B (1987) 312.
11) A. Angelopoulos et al., Phys. Lett. 205B (1988) 590.
12) J.P. Bocquet et al., in *Physics at LEAR with low energy antiprotons*, ed. by C. Amsler et al. (Harwood Acad. Publ., Chur, 1988) p. 793.
13) H. Machner et al., Phys. Rev. Lett. (submitted).
14) Ye.S. Golubeva et al., Nucl. Phys. 483A (1988) 539.
15) J. Cugnon, in *The elementary structure of matter*, ed. by J.M. Richard et al. (Springer-Verlag, Berlin, 1988) p. 211.
16) A.S. Botvina et al., Phys. Lett. 205 B (1988) 421.
17) UA5 Collaboration, G.J. Alner et al., Phys. Lett. 160B (1985) 193.
18) A. Giovannini and L. Van Hove, Z. Phys. C - Particles and Fields 30 (1986) 391.
19) J. Cugnon, Z. Phys. A Atomic Nuclei 327 (1987) 187.
20) Yu.A. Batusov et al., Europhys. Lett. 2 (1986) 115.
21) J. Cugnon et al., Europhys. Lett. 4 (1987) 535.
22) J. Cugnon et al., Phys. Rev. 38C (1988) 795.
23) J. Rafelski, Phys. Lett. B (in press) and preprint Texas University (April 1988).
24) B.M. Pontecorvo, Zh. ETP 30 (1956) 947.
25) J. Rafelski, Phys. Lett. 91B (1980) 281.
26) S.J. Brodsky, in *Physics at LEAR with low energy antiprotons*, ed. by C. Amsler et al. (Harwood Acad. Publ., Chur, 1988) p. 317.

27) S.J. Brodsky, *Proc. Fermilab LEAF Workshop* (FNAL, Batavia, 1986) p. 131.
28) J. Cugnon and J. Vandermeulen, Phys. Lett. 146B (1984) 16.
29) J. Cugnon and J. Vandermeulen, Phys. Rev. 36C (1987) 2726.
30) B.Y. Oh et al., Nucl. Phys. 51B (1973) 57.
31) J. Cugnon and J. Vandermeulen, Phys. Rev. C (submitted) and preprint Liegi University (September 1988).
32) R. Bizzarri et al., Lett. Nuovo Cimento 2 (1969) 431.
33) J. Riedlberger et al. (ASTERIX Collaboration), Communication to the Mainz Conference on $\bar{N}N$ Interaction (September 1988).
34) P.L. Mc Gaughey et al., Phys. Rev. Lett. 56 (1986) 2156.
35) L.A. Kondratyuk and M.G. Sapozhnikov, Phys. Lett. B (submitted).

QUESTIONS FOR SPEAKERS

Speaker's name: C. Guaraldo
Questioner's name: T. von Egidy
Questioner's institution: T.U. München

Question: Do you think that the trawling effect is confirmed or not?

Answer: The trawling effect represents one of the natural features in INC developing. In that sense it can not be ignored. The reasons of some spectacular failures should be looked for in other dynamical aspects or properties not properly taken into account by the INC model.

Speaker's name: C. Guaraldo
Questioner's name: O.D. Dalkarov
Questioner's institution: Lebedev Physical Institute

Question: Are there any new experimental results on the Λ/K ratio for different energy and for different nuclei (deuteron and heavy nuclei)?

Answer: Unpublished data from PS 179 experiment give for the Λ/K ratio at rest the following values: 1.09±0.10 for ^{4}He; 1.25±0.19 for ^{20}Ne.

Speaker's name: C. Guaraldo
Questioner's name: P. Truöl
Questioner's institution: University of Zürich

Question: I want to comment, that PS 171 (Asterix) has contributed results to this conference on antiproton absorption on nitrogen at rest, which were not referred in the list of LEAR results given by the speaker. These results include Λ-yield and momentum spectra, proton and pion multiplicities as well as momentum spectra.

Answer: The list of experiments on $\bar{p}$-nucleus interaction is comprehensive of most of the items recently investigated in the field but does not at all pretend to be exhaustive.