Exotic Nuclear Physics: From Cold Fusion To Antikaonic Nuclear Clusters

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Abstract. A short review of the status of the experimental searches and theoretical speculations on the possible existence of the AntiKaonic Nuclear Clusters is given. There are no scientific relationships with the possible Cold Fusion phenomena, but some similarities and differences in the perception and acceptance by other communities of physicists.

1. Introduction

I am very happy to attend again a Conference on Cold Fusion, ICCF15 and meet old colleagues and friends. As a matter of fact I had the opportunity to hear, nearly exactly twenty years ago (November 1989) the first seminar given in Europe, at CERN, on Cold Fusion by Martin Fleishmann.

I will never forget the enormous interest by the audience, and also the strong, a priori, skepticism. I have always worked in experimental Nuclear Physics, with quite huge detectors in big international Laboratories, but the strong interest in this potentially new class of phenomena convinced me to start with some of my younger collaborators an experimental activity, following a brief theoretical speculation [1]. From 1989 to 1998 I performed several experiments, mainly with the gas-loading technique paying a particular care to the detection of 2.5 MeV neutrons [2,3] and afterwards of ^4He [4,5]. The results were in line with those reported by other Groups, i.e. the possible detection of sporadic emissions of particles, with low statistical significance and not reproducible. During these years I attended all ICCF's from 1 to 7. As a matter of fact I organized also, with G. Preparata, ICCF2 at Villa Olmo, on the Como Lake.

My activity on Cold Fusion was stopped in 1999, not for overwhelming difficulties in the funding by public Agencies or private Companies but by the awareness of not having enough personal competence in Condensed Matter Physics, which is to my opinion the key point for understanding Cold Fusion.

However I never denied the reality of the scientific case of Cold Fusion, whereas I was (and I still am) very skeptical about possible applications.

A few years after my return at full time to Nuclear Physics, I faced a scientific problem that presents some similarities with Cold Fusion, but also differences in the acceptance by the other colleagues. This is the reason for which I accepted to give the present talk, scientifically very far from Cold Fusion and not easy to follow for many colleagues not experts of the sector. It is interesting to follow the conclusions.

2. The AntiKaonic Nuclear Clusters

I report here a brief account of a recent Invited Talk that I gave to the big Conference PANIC08 [6]. By AntiKaonic Nuclear Clusters (AKNC) we indicate nuclear states in which a $\overline{K}$ (K^-) is strongly bound to some nucleons.

The first speculation about the possible existence of AKNC's is due to Wycech [7], based on the observation that the driving $\overline{K}N$ interaction in the isospin I=0 channel is strongly attractive near threshold. A large Binding Energy B of about 100 MeV was found, but with a similarly large value of the width Γ.

The theme received a strong boost by the prediction from [8] of the possible existence of narrow discrete AKNC few-body nuclear systems. The $\overline{K}$-nucleus potential was derived from a phenomenological ($\overline{K}N$) potential accounting for several observables, with particular emphasis to the rôle of the Λ(1405), assumed to be a bound (K^-p) system.

The predicted B for $\overline{K}$-few nucleons systems were quite large (from 50 to more than 100 MeV), but the distinctive feature was the narrowness (Γ of 20-30 MeV). It was due to the circumstance that, due to the high value of B, the main decay channel (K^-p) (I=0)→Σπ is energetically forbidden, and the decay to Λπ is suppressed by the isospin selection rules.
A very important feature predicted for AKNC was a large density, up to 10 times the normal nuclear density. This possibility is very interesting for explaining the structure and the evolution of the neutron stars.
The K^-pp bound system was studied in Ref [9] by a coupled-channel Faddeev calculation obtaining a B of (55-70) MeV and a quite large Γ, of the order of 95-100 MeV.
Recently Ref [10] examined the possible existence of AKNC by using energy dependent ($\overline{K}$N) interactions derived with the s-wave coupled-channel amplitudes involving the Λ(1405) and resulting from the chiral SU(3) dynamics, plus p-wave amplitudes dominated by the Σ(1385). It was concluded that AKNC can possibly exist with B from 60 to 100 MeV, but with Γ of similar magnitude. This paper contains a quite complete list of the theoretical papers on the subject.
In 2004 the Collaboration KEK-PS E471, working at the 12 GeV PS at Tsukuba (Japan) published a paper with the triumphant title:"Discovery of a strange tribaryon S° (3115) in ^{4}He (stopped K^-,p) reaction" [11] based on a narrow peak observed in the semi-inclusive proton spectrum. There were some discrepancies between the features of the A=3 AKNC supposedly discovered and the original prediction but anyway this result played the major role at several Conferences and Workshops in the following two years. Unfortunately the same Group, from a further data taking with larger statistics whitdrawn the result as due to an experimental artifact [12].
Thanks to the clever design of the FINUDA spectrometer, installed at one of the two interaction regions of the DAΦNE collider at Laboratori Nazionali di Frascati (Italy) and aiming at a series of studies of Hypernuclear Physics [13], the detector was able to identify in a clean way Λ-hyperons emitted following the interaction of stopped K^- with light nuclei (^{6}Li, ^{7}Li, ^{12}C). Fig 1a) shows the invariant mass (I.M.) of a proton and a π^- for the events in which these two particles are observed out from the nuclear targets [14]. The peak position agrees well with the known Λ mass and the width of the peak is as narrow as 6 MeV/c^2. Quite surprisingly the above events in coincidence with a further proton emitted in the interaction of the stopped K^- are strongly back-to-back (b.t.b.) correlated. Fig. 1b) shows the angular correlation, acceptance corrected, for the (Λ,p) events.

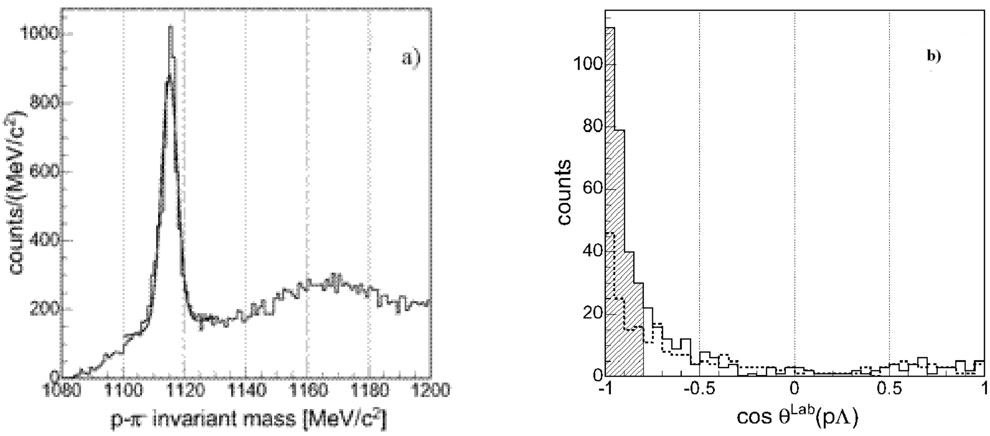

Fig. 1. - a) I. M. distribution of a (p,π−) pair for all the events in which these two particles are observed [4]. b) Opening angle distribution between a Λ and a p: solid line, ^{6}Li, ^{7}Li and ^{12}C targets; dashed line, ^{27}Al and ^{51}V targets. The shaded area is selected as that of b. to b. events . From [14]

A logical consequence of the observation of the Λ–p b.to.b. correlated events was that of determining their I.M in order to verify whether they could be the result of the decay of an A=2 AKNC. Fig.2 shows the I.M. spectrum for the Λ–p events for the lighter targets. A relatively narrow bump is observed, with B=115±9MeV, Γ=67±15MeV. I notice that, whereas the value of Γ is rather compatible with the prediction of [8], the value of B not; the experimental value is about twice.
Alternative conventional explanations for the above observed bumps were put forward. In [15] the bump in the Λ–p I.M. spectrum was explained as an artifact of the angular cuts applied to the flat spectrum of I.M. of Λ–p events resulting from genuine b.t.b. pairs formed in simple K^-–(np) interactions in the target nuclei that suffered a Final State Interaction.
Even though such a mechanism cannot be completely excluded, other arguments are contradicting it as discussed in [6].

The consistent theoretical effort and the first results coming from experiments with K^- stimulated the search for AKNC also in reactions induced by other projectiles.

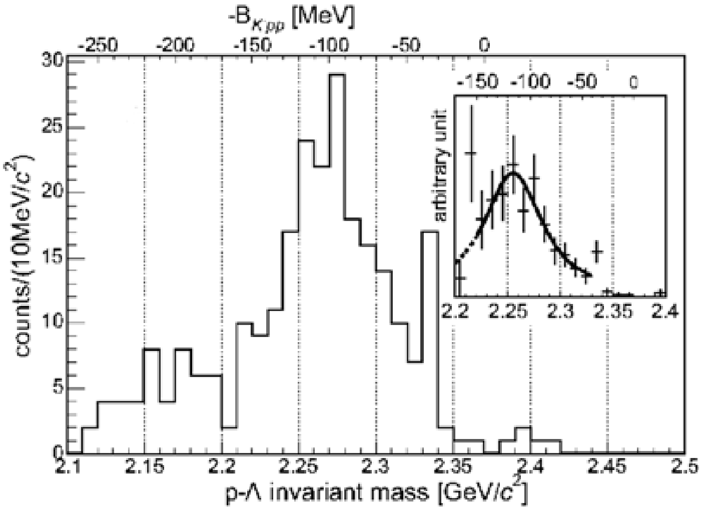

Fig. 2. - I. M. of a Λ and a p in a b. to b. correlation from light targets before the acceptance correction. The inset shows the result after the acceptance correction. From [14].

The best evidence for the possible existence of a narrow A=2 (K^-pp) AKNC was very recently provided by a reanalysis of the data on annihilations of p at rest on ^{4}H$\bar{e}$[16,17] collected with the OBELIX spectrometer which operated from 1991 to 1996 at the LEAR complex at CERN. Both the reactions of possible production of the A=2 AKNC and the steps in the data analysis are too complicated or technical to be outlined here. The final result of the I.M. of the Λ-p system, the same studied in FINUDA but produced with a different mechanism is shown by Fig.3). The signal has a statistical significance of 4.9 σ with a B of 151.0±4.4 MeV and a Γ less than 33.9 MeV.

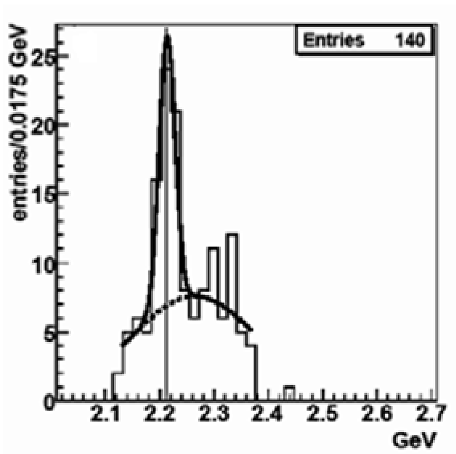

Fig. 3. - I.M. of a Λ and p observed in events produced by the annihilation of p at rest in ^{4}He. From [17].

Finally the data collected by the DISTO Collaboration at the Saturne accelerator in Saclay on the pp→pK^+Λ reaction at 2.85 GeV were reanalyzed with the aim of finding signatures compatible with the formation of the A=2 AKNC. A strong signal that may be interpreted as due to a state with B= (105±2)MeV and a similar Γ was reported [18]. I notice that the B value agrees within the errors with that reported in [14], but Γ is twice.

Table1. Comparison between the Binding Energies B and Widths Γ of the (K^-pp) system reported by experiments and Theory.

		B(MeV)	Γ (MeV)	Ref.
${}^{2}_{K}H$	K^- at rest	115±9	67±15	[14]
${}^{2}_{K}H$	$\bar{p}$ at rest	-151.0±4.4	≤33.9	[17]
${}^{2}_{K}H$	$pp \rightarrow pK^+\Lambda$	-105±2	118	[18]
${}^{2}_{K}H$	Theory	-48	61	[8]

Table 1 summarizes the values of B and Γ reported by the three experiments which investigated with different reactions the possible production of the archetype A=2 AKNC, as well as the theoretical prediction. A remarkable disagreement between the different sets of results is apparent. A similar disagreement exists if one tries to compare by a simple hadronic model the capture rates reported by FINUDA [14] for stopped K^- with those reported by OBELIX [16,17] for stopped p. A detailed discussion on this subject as well as a possible explanation based on the hypothesis of a Quark Gluon Plasma formation in p annihilation can be found in [19].

3. Conclusions on the present status of the search for AKNC

From the short review given in Sec.2 the following conclusions can be drawn:
a) the first experiment dedicated to the search of AKNC (KEK-PS E471), which claimed triumphally the discovery of such exotic systems [11] was afterwards obliged to whitdraw the claim, recognizing that it was due to an experimental artifact;
b) three other non-dedicated, general purpose experiments (facilities), namely FINUDA at LNF [14], OBELIX at CERN [16,17] and finally DISTO at Saclay [18] reported the observation of signals that could be interpreted as due to formation of the A=2 AKNC.
However:
i) the statistical significance is in some cases not very good
ii) the reported results disagree each other and with the theoretical prediction [8];
c) all theoretical approaches to the problem predict a quite large binding energy B (of the order of 100 or more MeV) of an Antikaon to few nucleons; however all approaches predict a width Γ for such a state of the same order of B. Only the phenomenological approach by (8) suggests a value of Γ of the order of about 30 MeV, then experimentally accessible.
In spite of the above difficulties the problem of the existence of AKNC is one of the hot spots in Hadronic Physics and the debate is very vivid at all the Conferences and Workshops in this sector. It is expected that the final analysis of the data collected by FINUDA with a six times larger statistics as well as the new data that will come from the dedicated experiments E15 and E27 at J-PARC (Japan) and FOPI at GSI (Germany) will clarify the situation in the near future.

Comparison of the AKNC and Cold Fusion cases

In table 2 I report a personal classification of the merits of Cold Fusion (C.F.) and AKNC scientific cases. I will not comment in detail the above classification, but add only a few remarks. The first is the similarity of the two cases with regards to the experimental and theoretical situation. Points a), b) and c) of Sec.3 are reminiscent of similar situations occurring in the C.F. research, in particular at the beginning. The second is the reaction by the community of Nuclear Physicists. After a short transient time, lasting not more than a couple of years, the result was a stopping of the financing by public Agencies in nearly all Countries, a disappearance of papers on C.F. in nearly all the more important Journals in Physics, a disappearance of the C.F. scientific case in all general Conferences of Nuclear Physics. Exactly the opposite occurs for the AKNC's scientific case. In addition, instead of stopping the activity, new dedicated experiments were approved by the Scientific Committees of world leading Laboratories with top priority and adequately financed.
As an old Nuclear Physicist, my concluding wish is that, after recognizing the excellent work carried out in twenty years by a few clever and motivated Groups, Cold Fusion physicists will return again in the community of Nuclear Physics.

Table 2. Personal classification of the merits of C.F. and AKNC scientific cases (*=minimum,*****=maximum)

	CF	AKNC
Applications	*****	*
Impact on media	*****	*
Scientific interest	*****	****
Acceptance by theoreticians	*	****
Acceptance by experimentalists	**	*****
Papers on Physics journals	*	*****
Financement by Public Agencies	*	*****
Positions for young reaserchers	*	***
Interest by students	*****	***

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