Letter of intent: Search for deeply bound k^- systems via their two body decay

E. Piasetzky, Tel Aviv University, Tel Aviv, Isarel.
P. Markowitz, Florida International University, U.S.A
J. LeRose, Thomas Jefferson Lab., U.S.A
F. Garibaldi, M. Iodice, F. Cusanno, INFN/Sanita, Roma, Italy
S. Marrone, INFN/Sezione Baril , Bari, Italy.

1. *Scientific Background and Motivation*

Recent experimental and theoretical studies suggest the possible existence of nuclear systems with K^- bound states. If the I=0 attractive K^-N interaction is strong enough to deeply bind the K^- and to energetically block the main decay channel to $\Lambda\pi$, then the bound states are expected to have relatively small widths. Detailed studies are available in the literature for different K^- nuclei. The expected binding energies are about 100 MeV and the widths are about 20-50 MeV [1, 2, 3].

The current knowledge on the K^-N interaction cannot uniquely determine the K^- nucleus potential. The first statement of a very deep potential came in 1994 from analyzing the K^- atomic data by Batty, Friedman, Gal [8], however they had no theoretical basis to get such a deep potential. Ref.[2] is the first theoretical prediction of deeply bound states
based on a deep K^- nuclear potential. The authors do not use all the Kbar-N information at low energies in order to constrain the potential. Works that use all the low-energy data get fairly shallow potentials (50-60 MeV). These are Ramos and Oset from around 2000, and Cieply, Friedman, Gal, Mares from 2001, all of which are cited in [3]. In a recent work, Oset and Toki present a critical analysis of the theoretical calculations that lead to the predication of a deeply bound state [9].

Can atomic data produce a reliable extrapolation into the nuclear center? There are arguments for and against. Because the situation is so unclear, a good experiment is a must. Clear direct experimental searches for such states are necessary to confirm or deny their existence.

At the last HYP2003 conference at Jlab, two experimental groups using the missing mass method reported the possible signatures of such states. One group at KEK studied (K^-stop,N) with N=n,p on ^{4}He [4,5] and another group at BNL/AGS studied the (K^-,n) reaction on ^{16}O[6]. The analysis of this data required the extraction of small, wide peaks over non-negligible background, which makes the conclusion questionable. A recent analysis by Oset and Toki [9] criticizes the interpretation of the data as a signature for a

K- bound state. They claim that the observed signal is due to a true absorption of the K- that results in a back-to-back outgoing proton and Lambda pair.

A more direct study was reported very recently by the FINUDA collaboration at DAΦNE. In this experiment the particles from the two-body decay to a Λ and a proton were detected and the invariant mass was reconstructed. The well reconstructed Λ from the detected proton and pion is shown in fig 1 (a), the back-to-back nature of the decay is demonstrated by the angular correlation shown in fig 1 (b). The resulted Λp invariant mass, combined from measurements on ^{6}Li, ^{7}Li, and ^{12}C is shown in Fig 2 and was interpreted by the authors as evidence for a formation followed by a two body decay of a bound K^-pp system with binding energy of 115±6±4 MeV and width of 67±14±3 MeV. A rough estimate on the K-pp→Λp yield from this measurement is 0.1% per A stopped K-. Oset [10] claims that the wide peak in fig 2, interpreted in ref [7] as evidence of a bound K- state decay, is actually a result of FSI following the true two body absorption K-p→pΛ. The unperturbed absorption process produces the narrow peak at 2.34 GeV/C^2.

2. *Motivation*

The significance of an experimental verification of bound K- nuclei is clear and evident:

1. If the K^-N attraction is strong enough the K- can be used to create nuclear bound systems that do not exist otherwise like: pp, pn T=1, ppp, ppn T=3/2 etc.

2. If K^- bound systems exist they are expected to have a nuclear density which is 3-5 times the nuclear densities at the center of known nuclei. Such systems would be the first laboratory-created objects with densities assumed for neutron stars. In a recent work Brown et al. [11] discuss the possibility of strangeness condensation at 3 times the normal nuclear density and its impact on astrophysical phenomena.

2. A confirmation of such states will point clearly to the deep K^-nucleus potential as the correct solution and will resolve uncertainties resulting from phenomenological analyses

3. Experimental Details

We propose to create the K- bound system using the (e,eK+) reaction and to measure its back-to-back two body decay to Λ and X, where X=p for the K^-pp, n for the

K^-pn , d for the K^-ppn etc. We plan to detect all the products of the two body decay and determined the invariant mass of the decay system that produced them.

The proposed measurement:

Step 1: creation and identification of a K^-A system

We plan to use the (e, K+) reaction at the same kinematics as for hypernuclei production (experiment E94-107) since in both cases what one needs is to optimize the number of K- produced with relatively low momentum. The set up for that will be HRS+RICH+septum at 6 deg.

Step 2: Detection of a back-to-back two body decay of the bound system to Λ and another particle: p, n ,d etc. For the rest of the discussion we will assume a K^-pp system decaying to Λp which is the simplest reaction. For the bound k-pp system the proton will be identified and detected by the BigBite spectrometer. The BigBite spectrometer will detect the K+ at relatively forward angle (about 40-50 deg.). The Λ to be detected is in a well defined direction (determined by the proton in BigBite) and will emerge at backward angle. The proton and π- from the Λ decay essentially are emitted within a cone of about 20 deg. around the direction of the Λ. These will be detected and identified by a large solid angle scintillator array.

A tentative experimental setup is shown in Fig 3. The K^+ is to be detected as forward as possible with the septum setup in order to increase the virtual photon flux, the rate of the K production cross section and to minimize the momentum of the produced K^- in order to maximize its overlap with the nucleus. Based on the experience with the Hall A hypernuclei experiment E94-107 we estimate that we can detect about 400 Hz of K^+ per hour. The limiting factor is the maximum luminosity determined by the singles rates in the VDC.

The stopped K^- experiment at FINUDA/DAΦNE reported a rough estimate of the yield of K-pp→ Λp of 0.1% per stopped K^- [6]. This means that the "sticking factor" which is the probability that a K^- ends up being bound in the nucleus (followed by a two body decay) is an order of magnitude lower than hypernuclear production (about 1%). Using the information from FINUDA we expect about 1400 bound K-pp to be produced and decay to Λp per hour.

The decay pair of Λ->p π^- and X resulting from the two body decay of the K^-A system will be emitted almost back to back in the Laboratory as can be seen in Fig 1 (b). The Λ will be reconstructed from its decay product. The heavy proton is emitted in roughly the direction of the Λ. The pion is emitted in a cone around the Λ (or roughly the proton) direction. Both the proton and the pion will be detected in a large solid angle scintillator array, like the one used in the SRC experiment (E01-015) or to be used for the Gen experiment (E02-013). The arrays are on site and composed of plastic scintillators with two PMTs , one on each side. A special frame to hold the counters is the only element of this array that needs to be custom made for this experiment.

The proton emitted opposite to the Λ direction is to be detected with BigBite. The well defined direction and the known momentum will be used to select the events corresponding to the two body decay and reduce the background from random coincidences.
The measurement of the proton and Λ momenta will allow rejection of the K- true absorption contribution discussed in [9] as the source of the KEK events.
Absorbing of the k- on a proton pair at rest yield a proton and a Λ with momenta of about 600MeV/c. The 100 MeV binding reduce the momenta of the proton and the Λ from the weak decay to about 450 MeV/c. The signal (decay of the bound system) and the background (true absorption) will be simulated.

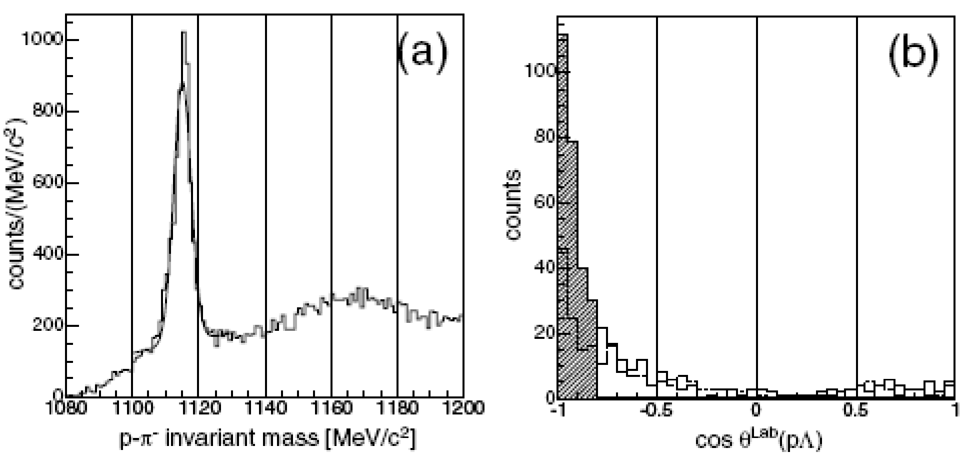
Assuming an almost isotropic decay of the K-pp system in the laboratory frame, the 100 msr BigBite will allow detection of about 1% of the protons recoiling against the Λ in the two body decay. If we build the scintillator array to detect 50% of the pion and protons pair from the Λ decay the rate of events will be:

1400 *1%*50%=7 events/Hr (about 1000 events in 6 days).

The TOF and momentum measurement in BigBite will allow identification of p as well as other particles that will be produced as a result of decay of other bound K-nuclear systems if produced. For example a deuteron in BigBite with Λ will be the indication for a production of K-ppn bound state. We will measure all these simultaneously. Adding a n-array behind BigBite like in the SRC experimental setup will also allow us to detect and identify neutrons from a potential K-pn decay.

The bound state, if it exists, might be specific to the target it is formed in. The FINUDA/DAΦNE results are mixed from Carbon and Li. For these measurements we plan to separately study the contributions from a few light nuclei. A recent work [12] discusses the expected binding energies for 1s and 1p k^- nuclear states in different nuclei with A>8.

[1] T. Yamazaki, Y. Akaishi, PL B 535 (2002) 70-76.
[2] Y. Akaishi T. Yamazaki, PR C65 (2002) 0044005.
[3] J. Mares, E. Friedman, A. Gal, PL B606 (2005) 295-302.
[4] T. Suzuki et al. PL B597 (2004) 263-269.
[5] T. Suzuki et al. NP A754 (2005) 375c-382c.
[6] T. Kishimoto et al. NP A754 (2005) 383c-390c.
[7] M. Agnello et al. PRL 94 (2005), 212303.
[8] C. J. Batty, E. Friedman, A.Gal, Nucl. Phys. A579 (1994), 518.
[9] E. Oset, H.Toki nucl-th/0509048 Sep. 2005.
[10] E. Oset, private communication.
[11] G.E. Brown, C.H. Lee, H.J. Park, and M. Rho, nucl-th/0504029, May 2005.
[12] X. H. Zhong, L. Li, G.X. Peng, and P. Z. Ning, nucl-th/0508031 Aug. 2005.



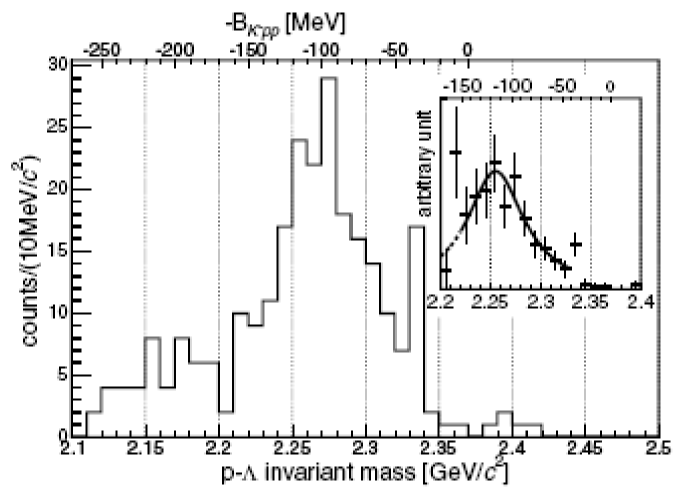
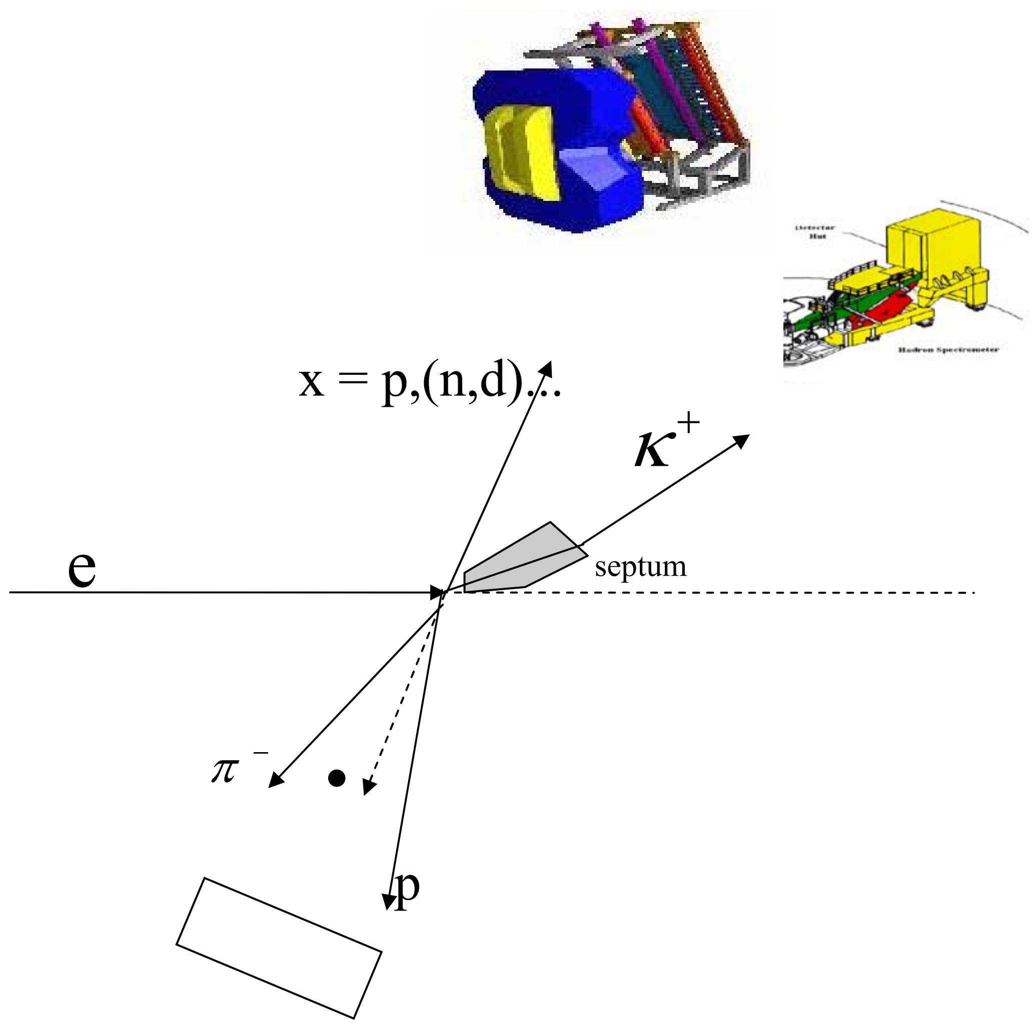


Fig1 (up) and Fig 2(down)



x = p,(n,d)...
κ+
e
septum
π −
p