Hypernuclear physics with FINUDA

Luigi Benussi

on behalf of FINUDA Collaboration

Laboratori Nazionali di Frascati dell'INFN, via E. Fermi 40 Frascati, Italy

Introduction

FINUDA (FIsica NUcleare a DAΦNE) is an non focusing magnetic spectrometer devoted to hypernuclear physics. The aim of FINUDA is to study simultaneously the formation and decay of hypernuclei produced by the strangeness exchange reaction induced by the stopped K^- coming from the decay of the $\phi(1020)$ mesons produced at the DAΦNE ϕ-factory. An hypernucleus is a many-body system composed of conventional (non-strange) nucleons and one or more hyperons (Λ, Σ or Ξ). A Λ hyperon embedded in a nucleus is stable for mesonic decay and strong interaction; therefore it survives for a while, maintaining its own identity among other nucleons. In addition it can deeply penetrate inside the nucleus since the Pauli principle is not effective due to the strangeness degree of freedom. For these reasons hypernuclei can provide invaluable information concerning the behavior of a baryon deeply embedded in nuclear matter. The FINUDA apparatus, described in detail in [1] and references therein, consists of an inner section surrounding the interaction-target region, an external tracker, an outer scintillator array and a superconducting solenoid providing a magnetic field of 1.0 T. The whole tracking volume (~ 8 m^3) is immersed in a He atmosphere to minimize Multiple Coulombian Scattering. The geometry of the spectrometer, the position of the detectors and the value of the maximum magnetic field have been optimized for maximizing the momentum resolution and acceptance for the prompt π^- from hypernuclear formation $K^-_{stop} + {}^AZ \rightarrow {}^A_\Lambda Z + \pi^-$. For such π^- (250-280 MeV/c), the design momentum resolution is $\Delta p/p = 3.5 \times 10^{-3}$ $(FWHM)$, corresponding to a resolution of 830 keV in the hypernuclear energy levels.

Results on ${}^{12}_{\Lambda}C$ hypernuclear spectroscopy

The first FINUDA data taking started on December 1st 2003 up to March 22, 2004. DAΦNE[2] delivered in total an integrated luminosity of 250 pb^{-1}, of which 33 were used for machine tuning, 10 for FINUDA detector debug, the useful data correspond to 190 pb^{-1}. The maximum daily integrated luminosity delivered to FINUDA was 4.0 pb^{-1}, with a maximum peak instantaneous Luminosity of 6×10^{31} cm^{-2}s^{-1}. The analysis started with a detailed study of the ${}^{12}_{\Lambda}C$ hypernucleus, which will be used as a reference; the whole sample of $\sim 3 \times 10^7$ collected events has been processed selecting hypernuclear candidate events for the formation of hypernuclei by means of the following requirements selected to optimize the signal-to-noise ratio:

1) a negative track from a K^- (pion candidate), 2) a fitted track with 4 points in the spectrometer, 3) a forward track, i.e. not crossing back the interaction/vertex region, 4) the particle momentum reconstructed and corrected for the energy loss in the crossed materials, 5) quality cuts on track fitting. Background reactions giving a π^- following K^-–Nucleus interactions have been simulated and the corresponding events have been reconstructed and selected following the same selection criteria of the data hypernucleus formation candidates. The obtained spectra are then converted into Λ binding energy spectra. Hence the shape background spectrum

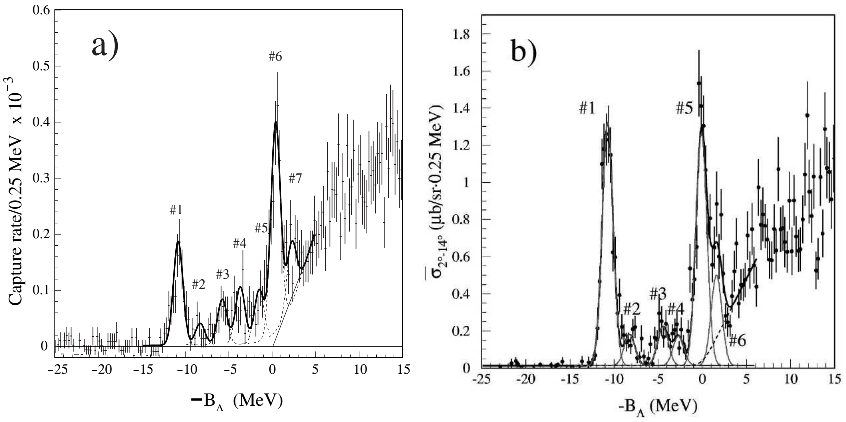

Figure 1: a) FINUDA ^{12}C hypernuclear mass spectrum after background subtraction with fitting curve described in the text and for comparison b) The ^{12}C hypernuclear mass spectrum obtained by E369[3] at KEK.

is parameterized and subtracted from the experimental one; the results is shown in Fig.1(a): two prominent peaks at $B_\Lambda \simeq 11$ MeV and 0 MeV correspond to the ground state (s_Λ) configuration and to the excited state of the $^{12}_{\Lambda}C$ hypernucleus with the Λ in the p-shell (p_Λ). The FINUDA spectrum has been fitted with seven Gaussian curves all with the same sigma, fixed and set at $\sigma_E = 550$ keV ($\Delta E = 1.29$ MeV, $\Delta p/p = 0.4\%$), given by the peak at $B_\Lambda = 0$. In the fit the Gaussian widths were constrained to be the same and equal to σ_E. The FINUDA fit result on $^{12}_{\Lambda}C$ is compared (Fig.1(b)) with the result of experiment KEK-E369[3] which used the (π^+, K^+) hypernuclear production mechanism: peaks #1 , #2 #6 and #7 in Fig.1(a) are consistent with peaks #1, #2, #5, #6 in Fig.1(b), while in the region between peak #2 and #6 of FINUDA data does not match the data in E369 spectrum. The capture rate for $^{12}_{\Lambda}C$ formation is $(1.01 \pm 0.11(stat) \pm 0.1(sys)) \times 10^{-3}/K^-_{stop}$ for the ground state and $(2.1 \pm 0.17) \times 10^{-3}/K^-_{stop}$ for the p_Λ state. The measured ground state capture rate measured by FINUDA agrees very well with the value $(0.98/pm0.12) \times 10{-}3/(K^-_{stop}$ measured at KEK [3].

Study of kaon-bound K^-pp states

The existence of $\overline{K}$-nucleus bound states crucially depends on the shape of the $\overline{K}$-nucleus optical potential. There is a controvercial interpretation of existing experimental data from theoretical point of view; some authors deduce a shallow potential

[4] while others [5, 6] claim it is very deep. If the K$^-$-nucleus potential is as deep as 200MeV $\overline{K}$-nucleus bound states could be experimentally visible. Recently Akaishi and Yamazaki [5] discussed the possibility of formation of discrete nuclear $\overline{K}$ bound states in few body systems and they derived a very deep $\overline{K}$ nucleus interaction. The resulting binding energies for these light systems are so large ($\geq$ 80MeV) that the main decay channel of the I=0 $\overline{K}$N pair to $\Sigma\pi$ is forbidden; as a consequence the deeply bound state becomes narrow enough ($\sim$ 20 MeV for the $^3_K H$ state) to be experimentally visible. Recently two experimental groups reported [7] possible signatures of deeply bound kaonic states but their results are still subject to some ambiguities about whether the K$^-$ was really bound or not. FINUDA can measure directly the invariant mass of the bound system by detecting its decay products. Our initial study is focussed on the search for a deeply-bound K^-pp system. When a K$^-$ interacts with two protons, one expects, ignoring final state interaction, a hyperon-nucleon pair (Λ+p, Σ+N) to be emitted with a back-to-back angular correlation. Our analysis is focused on the search of Λp, back-to-back events and

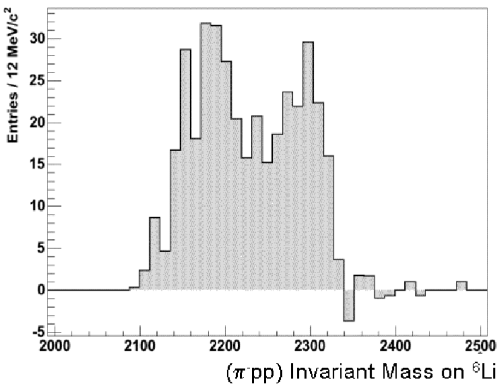

Figure 2: backgroung subtracted momentum distribution of π^-'s when in coincidence with (π^-p) pairs with invariant mass matching the Λ mass.

is based on the following steps: i) selection of $pp\pi^-$ events; ii) selection of ($p\pi^-$) pairs with invariant mass corresponding to the Λ mass; iii) selection of $\Lambda - p$ pairs emitted with back-to-back opening angle ($\cos(\theta_{open}) \leq$–0.86). The θ_{open} opening angle distribution between a Λ and a proton (not shown) is strongly peaked around $\cos(\theta_{open})$=–1, which clearly indicates that most of the Λp events are coming from an intermediate "K^-pp"system almost at rest. If the reaction process were simply a two-nucleon absorption process, the mass of the system should be close to the sum of a kaon and two proton masses, namely 2.37 GeV/c^2, minus the separation energy of the two protons, which amounts to approximately 30 MeV. A significant mass decrease of the K^-pp system is observed instead with a lot of strength accumulated below the K^-pp absorption peak. The main background contribution coming from the $K^-pp \to \Lambda + p$ two nucleon absorption, which shows up as a peak at about 2.34 GeV, has been simultated and filtered with the same recostruction cuts of the experimental data. The background was subtracted after normalizing it to the experimental data at the $K^-pp \to \Lambda + p$ absorption peak. The result is shown in Fig.2: the $\Lambda - p$ invariant mass distribution is sensibly shifted toward lower values with respect to the absorption peak with two wide structures peaked at about 2.290 GeV and 2.190 GeV, 50 MeV and 75 MeV wide respectively (Lorentzian fit). The higher peak can be interpreted as a K^-pp bound state, with a binding energy of approximately 90 MeV (value obtained without applying any acceptance correction). Events from $K^-pp \to \Sigma^0 + p$ can contribute to the Λp invariant mass via the $\Sigma^0 \to \Lambda\gamma$ decay: they should still present a Λp back-to-back correlation and the distribution should be shifted by ~74 MeV and broadened because of the missing γ.

Conclusion

In this proceeding have been presented some preliminary results from the analysis presently being performed on data collected at the DAΦNE ϕ-factory with the FINUDA spectrometer. The first effort of the collaboration was put in the analysis of the Λ hypernuclei formation on ^{12}C. The analysis results compare well with the best existing literature data, which allowed us to prove FINUDA's ability to perform high resolution hypernuclear spectroscopy. Data analysis on several different nuclear targets is under way. As to be underlined the capability of FINUDA to fully reconstruct multitrack events with high momentum resolution, which allows to dramatically reduce backgrounds and make exclusive measurements. Another topic presented regards the search for deeply bound kaonic nuclei. FINUDA have searched for kaon-bound (K^-pp) states by studying the invariant mass of a possible decay channel, namely $\Lambda - p$ events emitted back-to-back. Although the analysis is not completed, (i.e. no acceptance corrections have been made), it can be stated that the $\Lambda - p$ invariant mass distribution presents a strong accumulation ($\sim$ 2290) of strength below the (K^-pp) total free mass.

References

[1] The FINUDA Collaboration, M. Agnello *et al.*, **LNF-93/021(IR)** (1993); The FINUDA Collaboration, M. Agnello *et al.*, **LNF-95/024(IR)** (1995).

[2] G. Vignola, The Dafne Project Team, *Proc. PAC'91* 68 (1991); C. Milardi *et al.*, *Proc. 9th EPAC'04* (2004) in publication.

[3] H. Hotchi, *et al.*, *Phys. Rev.* **C64**, 044302 (2001).

[4] Schaffner-Bielich *et al.*, Nucl.Phys. **A669** (2000); Ramos *et al.*, Nucl. Phys. **A671** (2000) 481, Cieply *et al.*, Nucl.Phys. **A696** (2001), 173

[5] Akaishi *et al.* Phys. Rev. **C65** (2002), 044005

[6] Kaiser *et al.*, Nucl. Phys. **A594** (1995), 325

[7] Iwasaki M. *et al.*, nucl-ex/0310018, Suzuki T. *et al.*, Phys.Lett. **B 597**(2004), 263

Contact e-mail: Luigi.Benussi@lnf.infn.it

Web page: http://www.lnf.infn.it/esperimenti/finuda/finuda.html