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FIRST RESULTS OF FINUDA ON HYPERNUCLEAR SPECTROSCOPY

The FINUDA Collaboration *

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ABSTRACT

FINUDA is an experiment 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. In this paper preliminary results concerning hypernuclear spectroscopy from the first FINUDA data set will be presented.

1 Introduction

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. Moreover a hypernucleus is an excellent tool to extract information on the Hyperon-Nucleon interaction and compare them with theoretical predictions, based either on meson-exchange mechanism or quark-gluon models. FINUDA is a non-focusing magnetic spectrometer with the typical, high-acceptance ($> 2\pi$sr), cylindrical geometry of collider experiments, providing high hypernuclear formation rates: 40 hypernuclei/hour at a luminosity of 5×10^{31}cm^{-2}s^{-1} with a 10^{-3} capture rate. The apparatus, described in detail in [2, 3] 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.

The first FINUDA data taking started on December 1^{st} 2003 up to March 22, 2004. DAΦNE [1] 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 first events triggered by FINUDA were Bhabha events, i.e. $e^+e^- \to e^+e^-$ and $e^+e^- \to e^+e^- + \gamma$, useful for in-beam calibration of the detectors and for luminosity evaluation. The e^+e^- invariant mass is shown in Fig.1 where the beam energy (1020 MeV) peak is clearly seen togheter with the peak due to $K_S \to \pi^+\pi^-$ (from $\phi \to K_S K_L$) (recorded in the Bhabha trigger) while small bump on the right of the K_S peak corresponds to the decay of the $\rho^0(770) \to \pi^+\pi^-$ coming from the $\phi \to \rho^0\pi^0$ decay. In Fig.1 is also shown the momentum distribution of positive tracks coming from the K^+ stopping points: the two peaks at 236 MeV/c and 205 MeV/c correspond respectively to the two-body decays $K^+ \to \mu^+\nu_\mu$ and $K^+ \to \pi^+\pi^o$. From the width of the μ^+ peak the momentum resolution of the apparatus can be estimated as $\Delta p/p = 0.8\%$ FWHM, about $\sim 4/3$ of the one for pions of 270 MeV as reported in next section. A typical candidate for a hypernucleus formation event is shown in Fig.2, with superimposed the reconstructed tracks emerging from the interaction region: the μ^+ from the K^+ decay and a 260 MeV/c negative pion from the hypernucleus formation on a ^6Li target.

2 First Preliminary Results on $^{12}_{\Lambda}C$ hypernuclear Spectroscopy

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: 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. In Fig.3 the momentum distribution for the selected π^- in the eight targets is shown, where clean hypernuclear structures appear in the expected momentum range. All the cuts above mentioned have been chosen in order to optimize the signal-to noise-ratio. We start with the detailed study of the $^{12}_{\Lambda}C$ hypernucleus, which will be used as a reference. In the following we refer to only one ^{12}C target (about 20% of the available statistics on ^{12}C). 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.

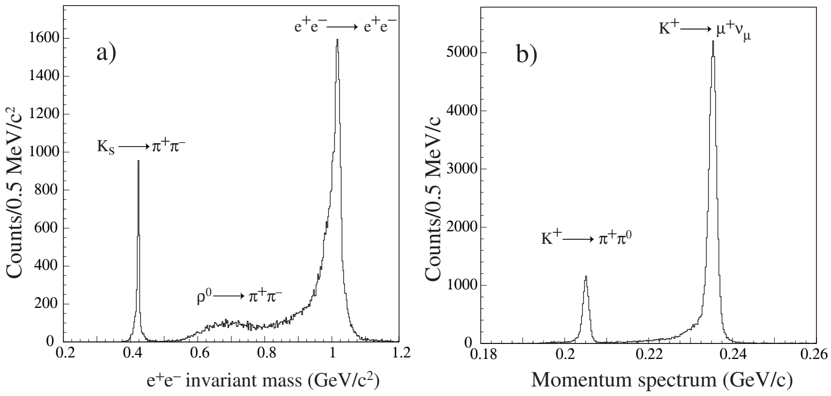

Figure 1: *a) Reconstructed invariant mass of the* e^+e^- *system with the* ϕ *peak at 1020 MeV. b) Reconstructed momentum distribution of the positive particles coming from the decay of positive kaons.*

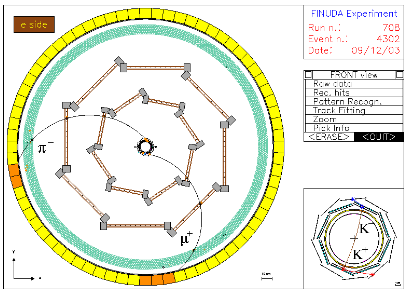

Figure 2: *Display of a typical hypernuclear formation event with reconstructed* μ^+ *and a* π^- *tracks. Enlarged view of the vertex region with the* (K^+, K^-) *trajectories is shown in the inset.*

Hence the shape background spectrum is parameterized and subtracted from the experimental one; the results is shown in Fig.4(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 four Gaussian after having excluded the region between the two main peaks due to the low statistical significance in this region. The energy resolution has been set at $\sigma_E = 600$ keV ($\Delta E = 1.45$ MeV, $\Delta p/p = 0.6\%$), 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 results of the fit are summarized in Table 1. The FINUDA preliminary result on ${}^{12}_{\Lambda}C$ is compared (Fig.4(b)) with the result of experiment KEK-E369 [4] which used the (π^+, K^+) hypernuclear production mechanism: peaks #1 , #3 and #4 in Fig.4(a) are consistent with peaks #1, #5, #6 in Fig.4(b), while peak #2 does not appear in E369 data.

Peak number	Yield (events)	B_Λ (MeV)
1	185 ± 14	10.79 ± 0.04
2	131 ± 15	1.58 ± 0.09
3	338 ± 22	0.17 ± 0.06
4	131 ± 25	-1.99 ± 0.24

Table 1: *Preliminary results of the fitting for the ${}^{12}_{\Lambda}C$ spectrum. The quoted errors are statistical.*

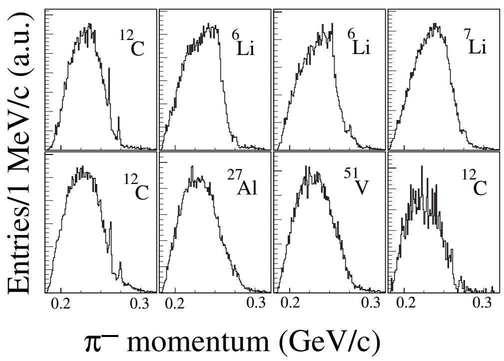

Figure 3: *Distribution of the momentum of the selected forward pions on the eight nuclear targets.*

The capture rate for ${}^{12}_{\Lambda}C$ formation is estimated to be $\sim\ 1.8\times\ 10^{-3}/K^-_{stop}$ for the ground state and $3.3\times\ 10^{-3}/K^-_{stop}$ for the p_Λ state. The structure in the region between the two peaks will be investigated soon with the whole statistics on ${}^{12}C$.

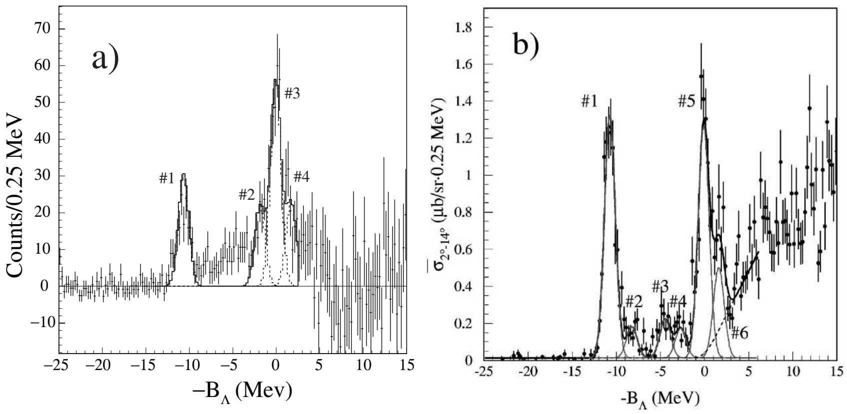

Figure 4: *a)* ${}^{12}C$ *hypernuclear mass spectrum after background subtraction with fitting curve described in the text and for comparison. b) The* ${}^{12}C$ *hypernuclear mass spectrum obtained by E369* [4] *at KEK representing the previous world best result in hypernuclear spectroscopy.*

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