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THE FINUDA EXPERIMENT: STATUS AND PERSPECTIVES

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Abstract

FINUDA is a hypernuclear physics experiment that will be carried out at DAΦNE, the e^+e^- ϕ-factory currently in operation at the INFN Frascati Laboratory. The apparatus, which is assembled in the DAΦNE hall, consists of a magnetic spectrometer with high resolution tracking capabilities. In this paper the status of the experiment is presented, together with the main features of the apparatus and of its physics program.

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1 Introduction

An hypernucleus is a many-body system composed of conventional (non-strange) nucleons and one or more hyperons (Λ, Σ or Ξ). The presence of the strangeness degree of freedom in a hypernucleus adds a new dimension to the evolving picture of nuclear physics.

The FINUDA Collaboration [1] has a very ambitious program in hypernuclear physics including high statistics and high resolution spectroscopy, study of hypernuclear mesonic and non-mesonic decay modes, search for Σ-hypernuclei and neutron-rich hypernuclear states.

The peculiar idea of the FINUDA experiment is to stop the large flux of slow and monochromatic K^- (127 MeV/c) coming from the main ϕ decay $\Phi \to K^+K^-$ (49%) in thin nuclear targets ($0.1 \div 0.3\,\mathrm{g\,cm^{-2}}$) with minimum straggling. After degradation and nuclear capture Λ -hypernuclei are produced through the reaction:

$$K^-_{stop} + \ ^AZ \to \ ^A_\Lambda Z + \pi^- \tag{1}$$

and the spectroscopy of hypernuclear states can be performed by measuring the momentum of the isotropically emitted π^-. This feature provides unprecedented momentum resolution, as long as transparent detectors are employed before and after the target.

In the case of Λ hypernucleus formation, the following weak-interaction non mesonic decay modes of the Λ are strongly favored in medium-heavy nuclei:

$$\Lambda + n \to n + n \qquad , \qquad \Lambda + p \to n + p \tag{2}$$

which are interesting for studying the validity of the empirical $\Delta I = 1/2$ rule.

The FINUDA magnetic spectrometer has the typical cylindrical geometry of collider experiments, therefore it is capable of detecting the π^- from hypernuclear formation, eq. 1, in coincidence with the products of the Λ decay, eq. 2. Up to now, this is a unique capability in the hypernuclear physics panorama.

2 The FINUDA spectrometer

FINUDA is a high resolution spectrometer ($\Delta p/p \simeq 0.3\%\,\mathrm{FWHM}$)with cylindrical geometry, characterized by a large solid-angle ($\sim 70\%$ of 4π), good triggering capabilities, state-of-the-art tracking, particle identification and neutron detection.

The apparatus, described in detail in [1, 2] and references therein, is sketched in fig. 1 and consists of an inner section surrounding the interaction region (beam pipe, thin

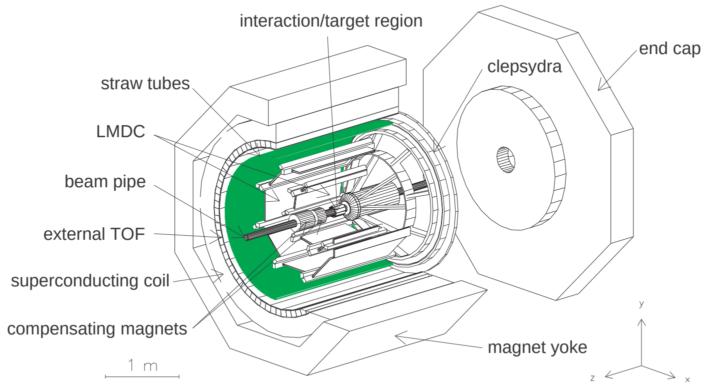

Figure 1: Layout of the FINUDA apparatus.

scintillator counter barrel, 8-fold nuclear target, silicon microstrip detectors), an external tracker (low-mass planar drift chambers (LMDC) and a straw tube array detector), an outer scintillator array and a superconducting solenoid providing a maximum magnetic field of 1.1 T. The whole tracking volume ($8\ \mathrm{m}^3$) 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 (eq. 1). For such π^- (250-280 MeV/c), a momentum resolution of 0.3%(FWHM) is obtained, corresponding to a resolution of 700 KeV in the hypernuclear energy levels.

3 The physics program: expected performances

FINUDA will investigate a wide physics program consisting both of hypernuclear spectroscopy and of hypernuclear decays [1, 3, 4, 5]. High statistics p-shell hypernuclear studies are foreseen: ${}^{12}_{\Lambda}C$, ${}^{7}_{\Lambda}Li$, ${}^{9}_{\Lambda}Be$, ${}^{10}_{\Lambda}B$ and the light hypernuclei ${}^{5}_{\Lambda}He$, ${}^{4}_{\Lambda}He$ and ${}^{4}_{\Lambda}H$ will be produced using a ${}^{6}Li$ target.

Fig. 2 (left side) shows the hypernuclear mass spectrum of ${}^{12}_{\Lambda}C$ recently measured by experiment E369 [6] at KEK with an energy resolution of 1.45 MeV (FWHM). An old spectrum form the previous E140 [7] experiment with an energy resolution of 1.9 MeV is superimposed in an arbitrary scale for comparison. This picture shows how the improvement in resolution is essential for the understanding of hypernuclear spectra. The E369 hypernuclear levels have been simulated with the FINUDA Monte Carlo and injected in the reconstruction program to test the physics performances of the apparatus. The result is a very clean spectrum with practically no background (right side of fig. 2): FINUDA with

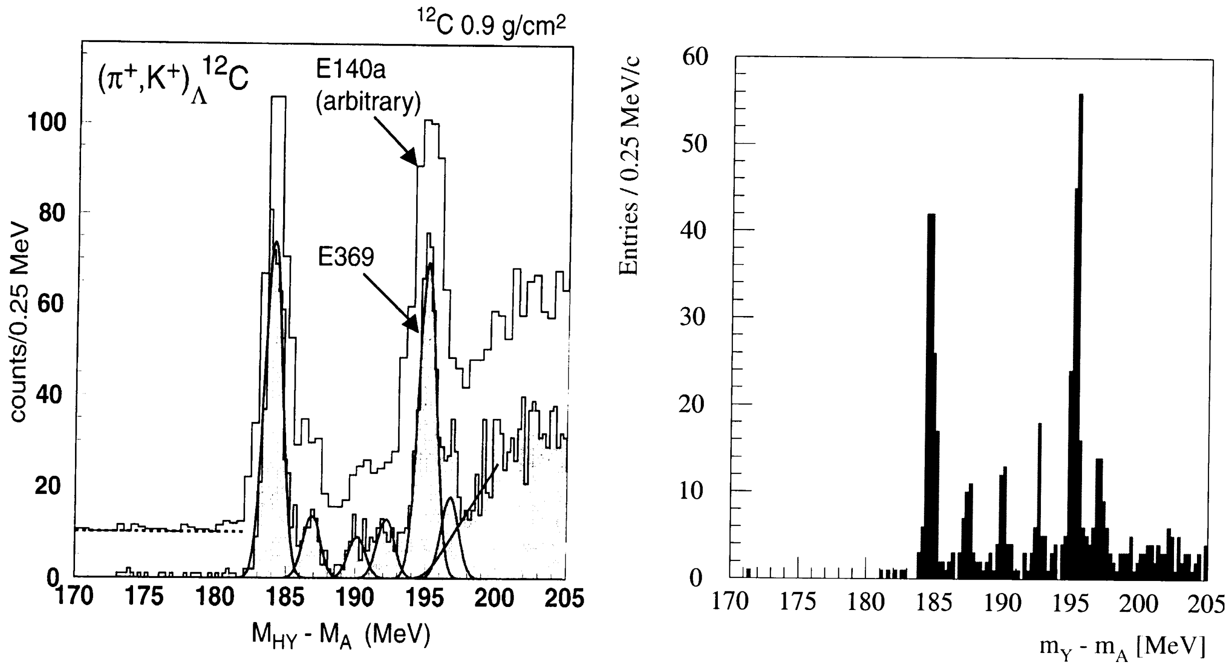

Figure 2: Left (from ref. [6]): hypernuclear mass spectrum of ${}^{12}_{\Lambda}C$ from KEK experiments E369 and previous E140a with energy resolution of 1.45 MeV and 1.9 MeV (FWHM) respectively. Right : FINUDA simulation of the E369 ${}^{12}_{\Lambda}C$ levels reconstructed with an energy resolution of 700 KeV (FWHM).

700 KeV (FWHM) energy resolution may reveal finer splittings in the same hypernuclear spectra. The simulated spectrum corresponds to an integrated luminosity of $5\,\mathrm{pb}^{-}1$, that is about 2 days at the present DAΦNE luminosity, $3 \times 10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

Concerning the weak decay studies of hypernuclei, FINUDA has the opportunity of measuring with good accuracy the ratio Γ_n/Γ_p between the p-induced and n-induced hypernuclear weak decay amplitudes (eq. 2) which is related to the validity of the $\Delta I = 1/2$ rule. In fact there are indications [8] that the rule may be violated in the non mesonic decay modes. As it has already been noted, the hypernuclear formation and decay products can be measured in coincidence and within the same apparatus. This double capability of FINUDA spectrometer is up to now unique with respect to existing hypernuclear facilities.

Table 3 shows the expected FINUDA performances in hypernuclear high resolution spectroscopy and weak decay studies for the ${}^{12}_{\Lambda}C$ which is the best known hypernuclear system and can be used as a reference mark. The table refers an integrated luminosity of $50\,\mathrm{pb}^{-1}$, corresponding to about 20 days of data taking at the present DAΦNE luminosity and to a formation rate of the ${}^{12}_{\Lambda}C$ ground state of 10^{-3} per stopped K^-. The comparison with existing measurement (second column of tab. 3) shows that, even with a reduced luminosity with respect to DAΦNE and FINUDA projects, FINUDA can in principle

observable	B.R.(%) ${}^{12}_{\Lambda}C$ g.s.	collected event	stat. err. (%)
high resolution hypernuclear spectroscopy		11.2×10^3	
$\Gamma_{tot}/\Gamma_\Lambda$	1.25 ± 0.18[12]	2.2×10^3	~ 2
$\Gamma_{\pi^-}/\Gamma_\Lambda$	$0.14 \pm 0.07 \pm 0.03$ [13]	7.0×10^2	~ 4
Γ_p/Γ_Λ only p detected both p and n detected	$0.31 \pm 0.07^{+0.11}_{-0.04}$[13]	 2.2×10^3 1.9×10^2	 ~ 2 ~ 7
Γ_n/Γ_Λ both n detected		96	~ 10
Γ_n/Γ_p	$1.87 \pm 0.59^{+0.32}_{-1.00}$[13] $1.33^{+1.12}_{-0.81}$[12] $0.59^{+0.17}_{-0.14}$[14]		~ 10

Table 1: Finuda expected performances in hypernuclear spectroscopy and decay studies for ${}^{12}_{\Lambda}C$, for an integrated luminosity of $50\,\mathrm{pb}^{-1}$.

significantly lower the statistical error: in some cases the reduction is even of one order of magnitude. In particular the accuracy that will be reached in the Γ_p/Γ_n ratio measurement will hopefully allow to discriminate among different theoretical predictions.

4 Present status and future plans

DAΦNE [9], the e^+e^- Frascati ϕ -factory, has been designed to achieve high luminosity ($1 \div 5 \times 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$) at the ϕ resonance energy (1.020 GeV) in two opposite interaction regions where the KLOE [10] and the DEAR [11] detectors are currently positioned. FINUDA spectrometer will take the place of DEAR in the second interaction region. DAΦNE commissioning started in 1998 and is now providing collisions to the KLOE and DEAR experiments with a maximum luminosity of about $3 \times 10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

FINUDA magnet is in the DAΦNE pit, next to the beam line, since 1998; all the subdetectors are ready and tested since 1999, they have all been installed and tested again inside the superconducting magnet during some machine shutdowns between the end of the year 2000 and August 2001. The roll-in of the apparatus in the second DAΦNE interaction region is scheduled for August 2002, and consequently data taking with colliding beams should finally start.

The FINUDA Collaboration plans to begin data taking using two sets of different nuclear targets, namely 4 ${}^{12}C$ and 4 ${}^{6}Li$ targets. The first set will be a sort of reference mark, being the ${}^{12}_{\Lambda}C$ the best known hypernuclear system, the second set will allow the study of the light hypernuclei ${}^{5}_{\Lambda}He$, ${}^{4}_{\Lambda}He$, and ${}^{4}_{\Lambda}H$ [4].

5 Conclusions

A powerful spectrometer for high quality hypernuclear studies is ready to start taking data at the Frascati DAΦNE ϕ-factory. It is scheduled to be rolled in the machine second interaction region in August 2002. As shown in table 3, even with a reduced luminosity with respect to DAΦNE and FINUDA designs, FINUDA can give world class results in hypernuclear spectroscopy and weak decay measurements thus allowing to discriminate among the different theoretical predictions.

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