The FINUDA experiment

The FINUDA Collaboration

M. Agnello[a], P. Amaudruz[m], G. Beer[m], M. Bertani[b], S. Bianco[b], E. Botta[c], T. Bressani[c], L. Busso[d], D. Calvo[c], P. Camerini[e], C. Cattaneo[f], L. Celano[g], N. Colonna[g], M. Corradini[h], G. D'Erasmo[g], A. Donzella[h], F.L. Fabbri[b], A. Feliciello[c], A. Filippi[i], V. Filippini[f], E.M. Fiore[g], L. Fiore[g], P. Gianotti[b], M. Giardoni[b], D.R. Gill[m], N. Grion[e], C. Guaraldo[b], F. Iazzi[a], A. Lanaro[b], L. Lee[m], E. Lodi Rizzini[h], V. Lucherini[b], S. Marcello[c], G. Marciano[f], G.M. Marshall[m], B. Minetti[a], N. Mirfakhrai[n], P. Montagna[f], O. Morra[d], A.A. Nozdrin[m], A. Olin[m], A. Pantaleo[g], V. Paticchio[g], E. Rossetto[c], A. Rotondi[f], R. Rui[e], P. Salvini[f], S. Sarwar[b], A. Sharma[c], G. Smith[m], L. Venturelli[h], S. Yen[m] and A. Zenoni[l]

[a] *Dipartimento di Fisica del Politecnico di Torino and INFN, Sezione di Torino, C.so Duca degli Abruzzi 24, I-10124 Torino, Italy*
[b] *INFN, Laboratori Nazionali di Frascati, Via Fermi 40, I-00044 Frascati, Italy*
[c] *Dipartimento di Fisica Sperimentale, Università di Torino, and INFN, Sezione di Torino, Via Giuria 1, I-10125 Torino, Italy*
[d] *Istituto di Fisica Generale, Università di Torino, and INFN, Sezione di Torino, Via Giuria 1, I-10125 Torino, Italy*
[e] *Dipartimento di Fisica, Università di Trieste and INFN, Sezione di Trieste, Via Valerio 2, I-34127 Trieste, Italy*
[f] *Dipartimento di Fisica Nucleare e Teorica, Università di Pavia, and INFN, Sezione di Pavia, Via Bassi 6, I-27100 Pavia, Italy*
[g] *Dipartimento di Fisica, Università di Bari and INFN, Sezione di Bari, Via Amendola 173, I-70126 Bari, Italy*
[h] *Dipartimento di Chimica e Fisica per i Materiali, Università di Brescia and INFN, Sezione di Torino, Via Valotti 9, I-25133 Brescia, Italy*
[i] *Dipartimento di Fisica Nucleare e Teorica, Università di Pavia, and INFN, Sezione di Torino, Via Bassi 6, I-27100 Pavia, Italy*
[l] *Dipartimento di Chimica e Fisica per i Materiali, Università di Brescia and INFN, Sezione di Pavia, Via Valotti 9, I-25133 Brescia, Italy*
[m] *TRIUMF, 4004 Wesbrook Mall, Vancouver, BC, V6T 2A3, Canada*
[n] *Department of Physics, Shahid Beheshty University, 19834 Teheran, Iran*

ABSTRACT

Thanks to the imminent commissioning of DAΦNE, the new ϕ-factory currently under construction at the Laboratori Nazionali di Frascati of INFN, hypernuclear studies will be again carried out in Europe. The FINUDA detector has been conceived to this purpose and it will be put into operation to perform an extensive program of high resolution Λ-hypernuclei spectroscopy with K^- at rest and a systematic investigation of their non-mesonic decays.

1. Introduction

FINUDA is the acronym for FIsica NUcleare a DAΦNE (Nuclear Physics at DAΦNE) and indicates one of two experiments approved at the two intersection regions of DAΦNE[1,2] (Double Annular Φ-factory for Nice Experiments), the new ϕ-factory currently under construction at the Laboratori Nazionali di Frascati of INFN (Istituto Nazionale di Fisica Nucleare). DAΦNE is the first of the new generation of high luminosity (e^+e^-) colliders and it is expected to run in 1997 at the center of mass energy of the ϕ meson (1020 MeV) with an initial luminosity of $\mathcal{L} = 10^{32}\ cm^{-2}s^{-1}$ and a final luminosity one order of magnitude larger.

At the top luminosity of $\mathcal{L} = 10^{33}\ cm^{-2}s^{-1}$ DAΦNE will produce $\sim$ 4500 ϕ meson s^{-1}, providing a unique source of monochromatic, collinear, quantum defined and tagged pairs of neutral and charged kaons. The most frequent ($\sim 49\%$) ϕ decay mode into (K^+K^-) will provide low energy (16.3 MeV), background free K^- and K^+ to the FINUDA experiment.

FINUDA is the first, unique, example of an experiment of nuclear physics, which is inherently a fixed target physics, carried out at a collider. The leading, simple, physical idea[3] is to stop most of the low energy K^- from ϕ decay, tagged by the back-to-back K^+, in a very thin nuclear target for studies of high resolution Λ-hypernuclei spectroscopy.

It is worthwhile to remind very briefly the evolution of hypernuclear physics with different beams and consequently around the world. Up to the seventies, experiments were carried out with emulsion techniques at K^- beams both in Europe (CERN) and in USA (Berkeley, Brookhaven). In the decade 1970 – 1980 experiments with spectrometers and counters were started in Europe (CERN), initially with K^- at rest, afterwards in flight, and subsequently vigorously pursued in USA (Brookhaven). At the end of the decade the CERN management took the decision of closing all the K beams for physics, but, at the same time, a strong interest on hypernuclear physics with stopped K^- arose in Japan (KEK). From then on hypernuclear studies have been prosecuted in USA and in Japan, exploiting not only the K^- beams, but also π^+ beams for producing hypernuclei through the associated production of a Λ and of a K^+ in the final state. Now, after 20 years, experimental hypernuclear physics will be carried out in Europe again, at Frascati with FINUDA.

The advantages of using K^- at rest for high resolution hypernuclear spectroscopy become clear when the main features of the different production techniques are compared. When K^- or π^+ beams are used for "strangeness exchange" (K^-, π^-) reactions with K^- in flight or, respectively, "associated production" (π^+, K^+) reactions, thick targets of the order of some g/cm^2 must be employed. The target thickness limits the momentum resolution on the produced π^- or K^+, due to the uncertainty in the interaction point (where the hypernucleus has been formed) and the fluctuation in direction and energy lost in the target material. Hence the energy resolution of the hypernuclei spectra is dominated by such effects, not by the instrumental momentum resolution, $\Delta p/p$, of the magnetic spectrometers, usually better than $\sim 10^{-3}$.

Furthermore, the solid angle of such spectrometers is not more than $\sim 100\ msr$, and a limited angular acceptance is also available for the detection of the hypernuclear decay products.

The same problem occurs even in experiments with K^- at rest at proton machines, where intense fluxes of kaons are emitted from an external production target. The distance between such a source and the experimental area is at least of $\sim 10 \div 15\ m$, due to radiation safety requirements. $K^\pm$ of less than $400 \div 450\ MeV/c$ cannot obviously survive to such a path in a number suitable to give a reasonable beam intensity. Consequently experiments with stopped K^- must be performed by degrading in momentum a $\sim 500 \div 600\ MeV/c$ K^- beam, by means of a moderator just in front of the stopping targets; these have to be thick, hence, again, the errors introduced in measuring the momentum of the emitted particles, due to the uncertainty of the interaction point, renders often fruitless the good instrumental resolution of the magnetic spectrometers coupled to such stopping devices.

At DAΦNE, on the contrary, the low energy and quasi-monochromatic K^- from ϕ decay can be stopped in a material thickness of less than $100\ mg/cm^2$. Therefore very thin nuclear target ($300\ mg/cm^2$) can be employed in order to stop K^- very near to the target surface. This way outgoing π^- from the two-body reaction

$$K^-_{stop} \ + \ {}^AX_Z \ \rightarrow \ {}^A_\Lambda X_Z \ + \ \pi^-, \tag{1}$$

where ${}^A_\Lambda X_Z$ stands for the produced hypernucleus, do not cross any significant amount of material and do not undergo any momentum degradation. Hence the precision on the measurement of their momentum, and then on the energy of the different final hypernuclear states, is determined essentially by the performances of the magnetic spectrometer. Moreover, the FINUDA apparatus is characterized by a large solid angle of acceptance (typical of detectors at colliders), thus allowing the detection, with the same apparatus, both of the π^- from hypernucleus formation and of the hypernucleus decay products. Last but not least, the K^- from ϕ decay is always associated to a back-to-back K^+ and this tagging may be used as a constraint for background rejection and improvement in the momentum resolution.

2. The FINUDA apparatus

FINUDA is a high-resolution magnetic spectrometer[4–6] with cylindrical geometry around the (e^+e^-) crossing beam direction. Its design has been optimized in order to have a large solid angle, the best momentum resolution and good trigger capabilities.

Fig. 1 shows the arrangement of detectors around the (e^+e^-) intersection region. Immediately around the beam pipe, made of a $400\ \mu m$ thick Be tube, enough to transmit the low-energy K^+, K^- with an energy loss of only $3\ MeV$, there is a barrel of 12 thin ($2\ mm$) scintillators (TOFINO). They detect the highly ionizing (K^+K^-) pairs which are emitted from the interaction region and provide the most powerful first-level trigger. The (K^+K^-) pair angular distribution follows a $\sin^2\theta$ law, θ being the angle relative to the (e^+e^-) colliding beam axis (z-axis).

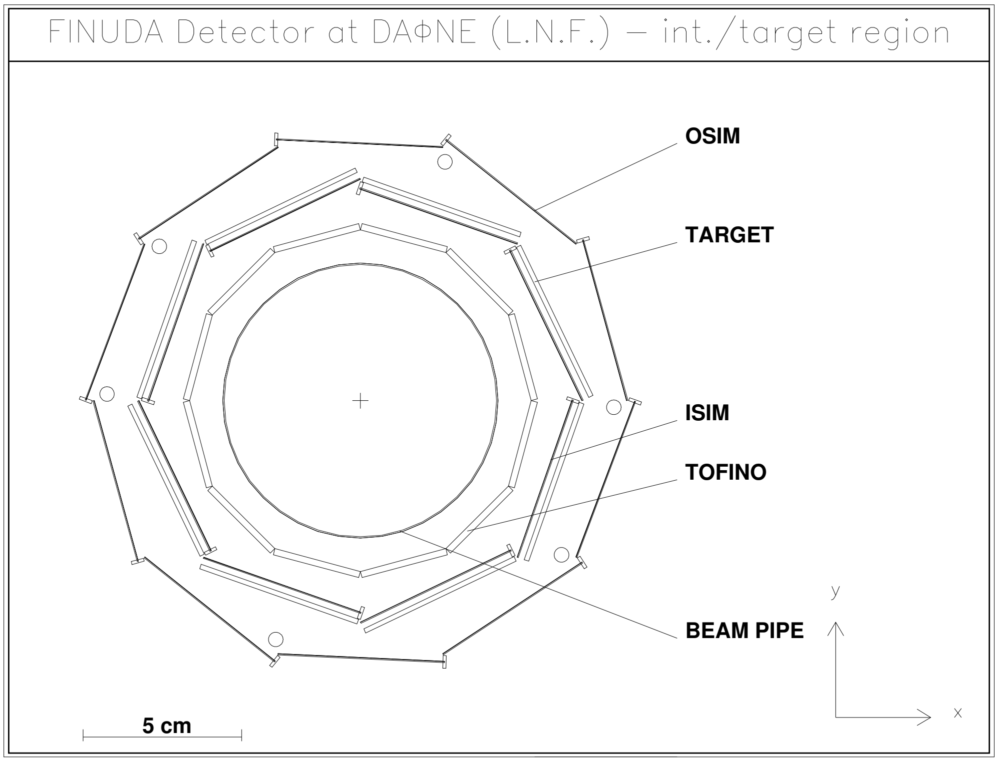

Figure 1: interaction/target region front view.

The position of the K^- track immediately before the thin nuclear target (1.5 mm of Carbon is a typical thickness) is measured, with very high spatial resolution ($\sigma \sim 30 \div 50\ \mu m$), by an octagonal array of Silicon μstrip detectors (ISIM), that provide also particle identification by energy loss. The interaction/target region is surrounded by a large magnetic spectrometer, formed by four arrays of detectors immersed in a homogenous magnetic field of 1.1 T, provided by a super-conducting solenoid. The super-conducting coil has an inner radius of 1460 mm and a length of 2112 mm. The superconducting cable is pure Aluminum stabilized NbTi/Cu, insulated by dry glass fiber ribbon, for a total of 764 turns. A two-layer winding option was chosen, to optimize the homogeneity of the magnetic field and to reduce the Helium consumption. The current density will be $\sim 2850\ A/cm^2$ at the center and 4021 A/cm^2 at the ends of the solenoid. The Iron yoke surrounding the coil has the shape of an octagonal prism, with a thickness of $\sim 400\ mm$. Two end caps, properly shaped and with a central hole for the passage of the beam pipe, close the solenoid. The magnetic field distribution shows a very good homogeneity, better than 1%, in most of the tracking volume. Fig. 2 shows a pictorial view of the magnet with part of the inner detectors.

The solenoid, weighting about 300 $tons$, will be installed in a pit on a trolley, which allows movements for assembly and inspections, but must ensure reproducibility of positioning to better than 200 μm in all directions. This unusual requirement is dictated by the circumstance that the apparatus during operation constitutes in fact a part of the magnetic field lattice of the machine, which is particularly critical near the interaction region.

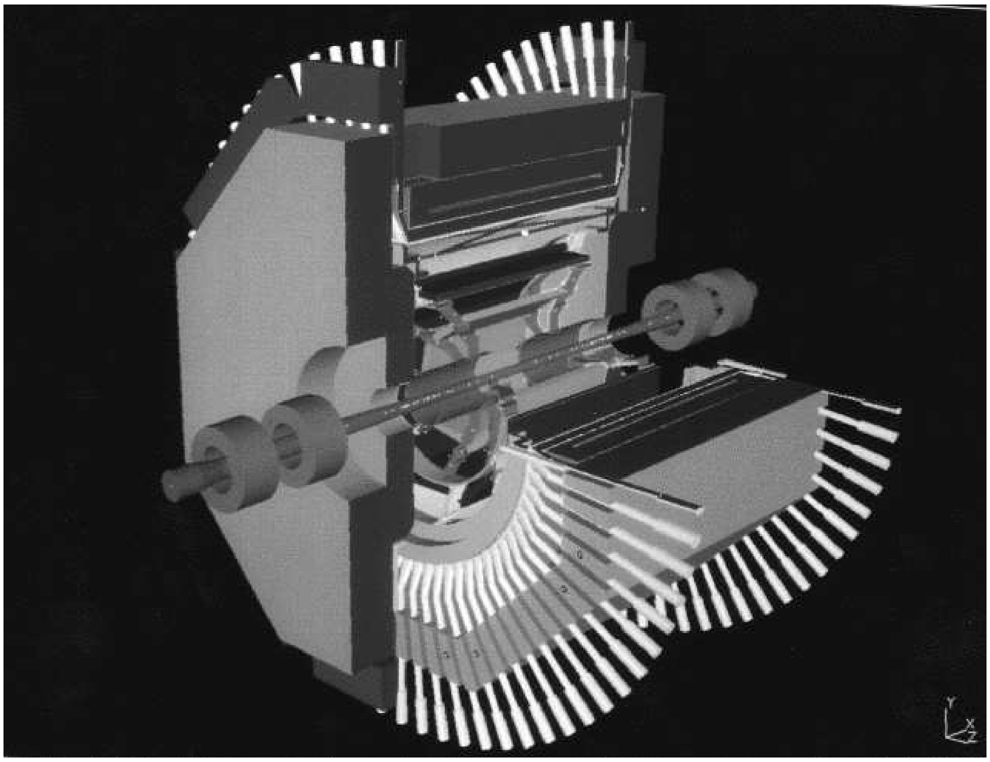

Figure 2: pictorial view of the FINUDA spectrometer.

The four arrays of detectors providing the tracking of the particles (π^- from hypernuclei formation, protons from non-mesonic (NM) hypernuclei decay, μ^+ from $K_{\mu 2}$ decay) emitted from the target are:

a) a decagonal array of Silicon μstrips (OSIM), made of the same modules of ISIM;

b) two octagonal arrays of planar low-mass drift chambers (LMDC), flushed with a He-C_4H_{10} (70/30) mixture and with very thin mylar windows (36 μm in total for each chamber);

c) a system of longitudinal (along the z-axis) and stereo (13°) straw tubes (ST). It is worthwhile to recall that a specific feature of the ST is to provide a very good spatial accuracy (better than 100 μm) independently from the particle incidence angle.

The tracking volume of the spectrometer is immersed in He atmosphere in order to minimize the effect of Coulomb multiple scattering, which is the limiting factor in a non-focussing magnetic spectrometer like FINUDA. Fig. 3 gives a sketch of the spectrometer.

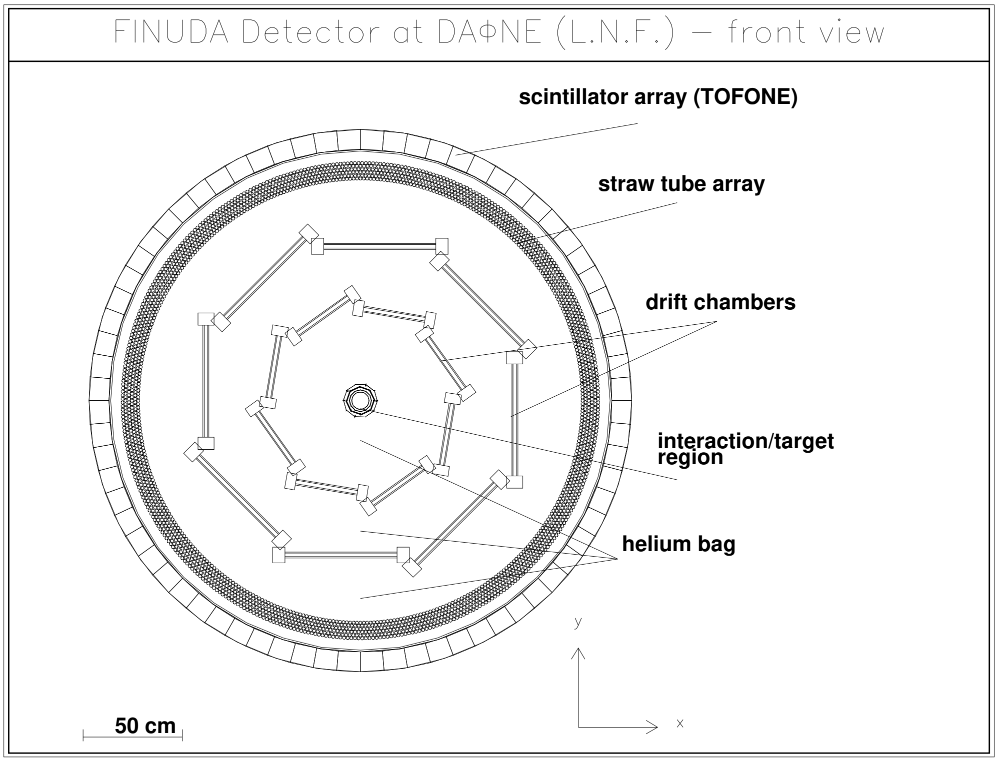

Figure 3: apparatus front view.

The geometry of the spectrometer, the position of the detectors and the value of the magnetic field have been optimized for maximizing the acceptance and the momentum resolution for π^- from Λ-hypernuclei formation, whose momentum is typically in the range $240 \div 270$ MeV/c. The momentum resolution of the apparatus is its most crucial feature. In fact, the resolution of the momentum of the π^- emitted in the hypernucleus formation is directly connected to the resolution on the hypernuclear energy levels. For a π^- of 270 MeV/c an uncertainty of 0.1% in momentum corresponds to an energy resolution of 240 KeV on the hypernuclear levels. Hence, to fulfill the physical expectations, FINUDA must feature not more than 0.3% in momentum resolution, which corresponds to $\sim 700\ KeV$ in energy.

Factors affecting the momentum resolution are: the size of the spectrometer, the value of the magnetic field, the spatial resolution of the detectors and the multiple scattering along the particle path. To fulfill the requested performances, low mass detectors with high spatial resolution have been adopted; in particular the requirement of low mass is very stringent on the detectors located along the particle trajectory, while it can be released for the detectors measuring the initial and final points of the tracks.

Thanks to the transparency of the tracking volume the average radiation length is 170.000 cm, to be compared with 540.000 cm for pure Helium and 34.000 cm for air. The design spatial resolutions of the detectors are reasonable extrapolations of the present technology and have been largely met in the tests performed on prototypes.[7,8] Finally, the size of the spectrometer and the intensity of the magnetic field represent the best compromise between minimum value of the magnetic field ($1.1\ T$), to minimize the effects on circulating beams, and minimum size of the spectrometer ($\sim 100\ cm$), to limit costs.

An evaluation of the momentum resolution for pions with the standard formulae shows that the requested performances are largely met in FINUDA apparatus.

Extensive simulations were carried out with a Monte Carlo program, with populations of tracks of different particles emerging from the target; the results confirm the expectations. The momentum resolutions are evaluated as 0.28% for π^- of 270 MeV/c, 0.79% for protons of 417 MeV/c and 0.24% for μ^+ of 236 MeV/c. The reduced thickness of the target allows the high momentum resolution of the spectrometer to be fully exploited; in any case a correction of the pion momentum, for the energy lost in the target, can be efficiently applied, since both the interaction point position and the exit point of the π^- from the target can be reconstructed within an uncertainty of some hundreds of microns.

The spectrometer is surrounded by a barrel of plastic scintillator (TOFONE), 100 mm thick, which provides a fast logic signal for the trigger and allows the detection of the neutrons emitted in the NM decay of Λ-hypernuclei with an efficiency better than 15% and a coarse energy resolution ($\sim 15\%$).

The aim of the trigger logic of FINUDA apparatus is to select hypernuclear events out of the background ones. In hypernuclear events the ϕ decays into K^+K^-, the K^- stops in the target, forms an hypernucleus and emits a prompt π^-. To be useful for high resolution spectroscopy the π^- must cross the full spectrometer and, therefore, must produce hits on one or more slabs of the external scintillator barrel at the end of its trajectory. Background events are due to Bhabha scattering and other decays of the ϕ as reported in Tab. 1. Bhabha events are naturally reduced by the geometrical acceptance covered by the TOFINO scintillator array ($135^0 \geq \theta \geq 45^0$). To select the ϕ decay into K^+K^- the trigger requirement exploits the back-to-back topology of the K^+K^- pairs and their large specific energy loss. In fact, low energy

Table 1: ϕ meson decay modes

Decay mode	B.R. (%)	p_{max} (MeV/c)
K^+K^-	49	127
$K^0_S K^0_L$	34	110
$\rho\pi$	13	132
$\pi^+\pi^-\pi^0$	2	462
η	1.3	362
others	~ 1	

kaons from ϕ decay have $dE/dx \sim 22\ MeV/cm$ against $dE/dx \sim 2\ MeV/cm$ for minimum ionizing particles from background reactions. Owing to the large difference in specific energy loss, the condition on energy loss discrimination is the very powerful one. Additionally, a coincidence in the external barrel of scintillators within 10 ns is requested, to select prompt pions crossing the spectrometer against μ^+ coming from the delayed K^+ decay.

Tab. 2 shows typical triggering efficiency for hypernuclear events and residual background contamination, calculated by Monte Carlo simulation. The counting rates are computed at a luminosity of $\mathcal{L} = 10^{32}\ cm^{-2}s^{-1}$. The efficiency of the trigger for hypernuclear events is very high and is limited essentially by the geometrical acceptance of the spectrometer. The background events are efficiently rejected and only the K^- interactions without formation of an hypernucleus produce an appreciable rate. For these events the fast coincidence is, in general, provided by a fast μ^+ from $K_{\mu 2}$ decay.

Accounting for the percentage of triggered events with π^- measured with high resolution ("forward" pions, not crossing the interaction region before entering the spectrometer) and assuming a chamber transparency of about 80%, a trigger rate of $8 \cdot 10^{-2}\ Hz$ provides about 80 $events/hour$ useful for high resolution hypernuclear spectroscopy for a production rate of 10^{-3}/stopped K^-. The apparatus provides a large angular acceptance ($\sim 2\pi\ sr$) both for π^- from hypernucleus formation and for the products of the hypernucleus decay (mostly neutrons and protons) which are detected with the same arrangement of detectors. This feature allows to reach good production rates of hypernuclei, comparable or better than those at the existing or proposed facilities (BNL, CEBAF, KEK) even at the initial luminosity of $\mathcal{L} = 10^{32}\ cm^{-2}s^{-1}$.

In FINUDA the hypernucleus lifetime can be directly measured from the difference between the hit time of the prompt π^- on TOFONE (or TOFINO) and the hit time of the proton, which is delayed by the hypernucleus lifetime. The hit times have to be corrected for the time of flight of the particles, which give anyway little contribution to the time uncertainty, since momenta and trajectories are very accurately

Table 2: trigger efficiency and rejection; counting rates.

Efficiency for hypernucleus formation events	
TOFINO back-to-back for energy threshold	81%
TOFONE prompt coincidence	46%
TRIGGER	39%
TRIGGER with π^- with 4 hits	29%
TRIGGER with high resolution "forward" π^-	13%
Rejection power	
Bhabha	$< 10^{-2}\%$
$\phi \to K_S K_L$	$3 \cdot 10^{-2}\%$
$\phi \to \rho\pi$	$4 \cdot 10^{-2}\%$
$\phi \to \pi^+\pi^-\pi^0$	$10^{-2}\%$
K^- interaction without hypernucleus formation	7%
Trigger rates at $\mathcal{L} = 10^{32}\ cm^{-2}s^{-1}$	Hz
Bhabha	$< 4 \cdot 10^{-2}$
$\phi \to K_S K_L$	$5 \cdot 10^{-2}$
$\phi \to \rho\pi$	$2 \cdot 10^{-2}$
$\phi \to \pi^+\pi^-\pi^0$	10^{-3}
K^- interaction without hypernucleus formation	15

measured. This technique has been already adopted with success at BNL and KEK.

Assuming a time resolution of $\sim 500\ ps$ FWHM for the FINUDA Time-Of-Flight system, a Monte Carlo simulation has shown that, thanks to the large acceptance of the FINUDA apparatus for the hypernucleus decay products, the lifetime of a hypernucleus can be reconstructed with a 10% statistical error with ~ 1000 events reconstructed in the hypernucleus ground state peak. Such a number of events can be obtained with the FINUDA apparatus in 12 hours of data taking at $\mathcal{L} = 10^{32}\ cm^{-2}s^{-1}$.

3. Physics program

3.1. Λ-hypernucleus spectroscopy

A large program of Λ-hypernucleus spectroscopy with high energy resolution, extended over the full nuclear mass range, certainly constitutes a top priority of the FINUDA physics program.

Hypernuclear spectroscopy can offer important experimental information both for nuclear and particle physics. From the nuclear physics point of view, a Λ-hyperon embedded inside a nucleus is expected to behave as a distinguishable baryon, not affected by Pauli blocking. Moreover, it is seen to experience an interaction with the nucleons appreciably weaker then the $\mathcal{N}-\mathcal{N}$ force and negligible spin-orbit central potential. The latter features of the $\Lambda-\mathcal{N}$ interaction are related, to a substantial extent, to the zero isospin of the Λ, which prevents the latter from exchanging an isovector meson, like the π or the ρ, with a nucleon and determines a lack of strong tensor components in the interaction.[9]

The relative weakness of the $\Lambda-\mathcal{N}$ interaction entails that the shell structure is not disrupted by the insertion of the Λ into a nucleus and the lack of Pauli blocking allows all the single particle states to be populated by a Λ. In the hypernuclear ground state, the Λ resides in the $1s$ shell and can explore very deeply the nuclear structure.

Fig. 4 shows, for an hypernucleus, what was never seen for an ordinary nucleus. The excitation spectrum[10] of $^{89}_{\Lambda}Y$ provides the best example of the validity of the

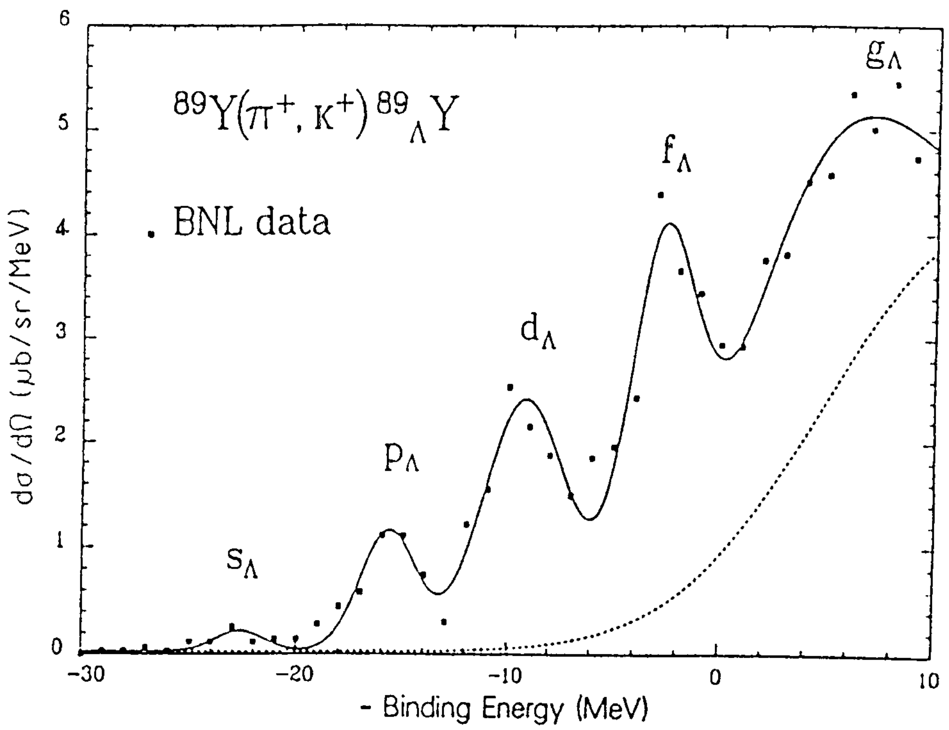

Figure 4: the excitation spectrum for the ^{89}Y $(K^+,\ \pi^+)$ $^{89}_{\Lambda}Y$ reaction at 1.05 GeV/c and $\theta_K = 10^\circ$ (from Ref.[10]).

single particle model, without the difficulties linked to the Pauli exclusion principle and to the pairing interactions, as it occurs in ordinary nuclei. In the spectrum, s, p, d, f and g Λ-orbitals are clearly seen and the validity of the concepts of shell model is demonstrated in a striking way, not just in the valence region, but deep within the nuclear interior. In non-strange nuclei a single particle deeply bound hole-state is so fragmented with excitation energy to be essentially unobservable. The spectrum of Fig. 4 has been obtained with a resolution of 2.6 MeV FWHM and only the major shell are resolved. With better resolution more details, due to the spin splitting of different states, might appear.

From the particle side, Λ-hypernuclei are interesting since they may allow to obtain, in an indirect way, information on the $\Lambda-\mathcal{N}$ interaction in the low momentum region, where direct scattering experiments cannot be done owing to the short lifetime of the Λ-hyperon. More interesting is the unique possibility offered by Λ-hypernuclei for testing a new approach to the description of nuclear matter. In fact, with the scarce energy resolution so far accessible to the experiments, the Λ seems to remain as a composite particle well distinguishable inside the nucleus. However, it is possible that high resolution experiments may reveal effects due to the partial deconfinement of the Λ in the nuclear matter.

At present, the knowledge concerning the hypernucleus phenomenology is strongly limited, both by the quality of the available experimental data and by the large gaps of ignorance in the chart of known Λ-hypernuclides (see Fig. 5).

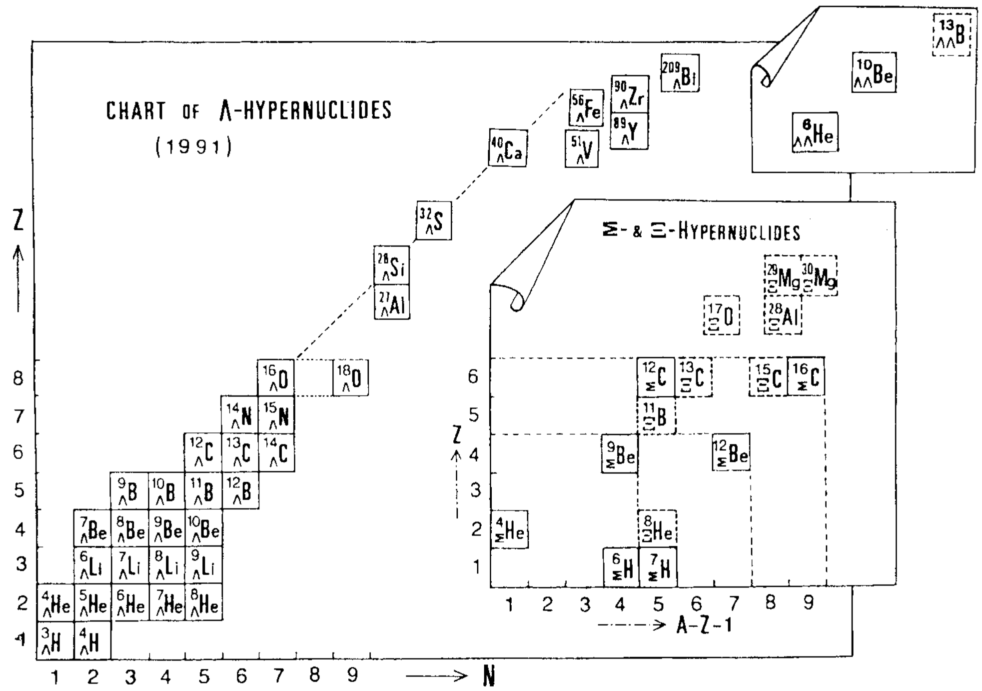

Figure 5: chart of Λ-hypernuclei. (from Ref.[11]).

FINUDA can perform a large scientific program of high resolution hypernuclear spectroscopy, on all nuclides that can be machined in solid targets and for which an acceptable formation rate is measured. The completion of this program could constitute a formidable step forward in the understanding of the main hypernuclear physics problems: from the origin of nuclear spin-orbit force, the short range correlations, the possible new symmetries in many body spectroscopy and the rôle of flavour symmetry, to the hyperon-nucleon interaction and the rôle of strangeness in strong interaction as well as the possible modifications of the baryon properties in the nuclear environment.

3.2. Non-mesonic decay of Λ-hypernuclei: $\Delta I = \frac{1}{2}$ rule

The decay of hypernuclei, in particular the study of the NM ones and of the validity of the well-known $\Delta I = \frac{1}{2}$ rule, is probably the most important subject that the FINUDA experiment will be able to investigate, both in term of physical interest and experimental feasibility.

The free Λ decays into two mesonic modes

$$\Lambda \rightarrow p + \pi^- \quad (\sim 64\%) \tag{2}$$

$$\Lambda \rightarrow n + \pi^0 \quad (\sim 36\%) \tag{3}$$

with a lifetime $\tau_\Lambda = (2.36 \pm 0.02) \cdot 10^{-10}\ s$. The decay may occur, in principle, with isospin change $\Delta I = \frac{1}{2}$ or $\frac{3}{2}$. However, the experimental decay branching ratios of the Λ and other hyperons, imply a dominance of a factor 20 of the $\frac{1}{2}$ component over the $\frac{3}{2}$ one.

The origin of this empirical rule is not understood in a fundamental way. Several authors have added strong interaction corrections to the simple W exchange diagram, including both soft gluon radiative corrections and penguin diagrams.[12] In particular the penguin diagram is emphasized because of its $\Delta I = \frac{1}{2}$ character.

The situation described above for the weak decay of the free Λ-hyperon changes dramatically when the Λ is embedded in the nuclear medium. The binding energy of the Λ-hyperon in the ground state increases linearly with A, reaching the saturation value of 25 MeV for heavy hypernuclei. Hence the phase space for the mesonic decay is greatly reduced ($p_{nucleon} \sim 100\ MeV/c$). Consequently, in all but the lightest nuclei, the mesonic decay mode is strongly inhibited by Pauli principle and the NM decay modes

$$\Lambda + p \rightarrow n + p \tag{4}$$

and

$$\Lambda + n \rightarrow n + n \tag{5}$$

are dominant, since they are not affected by Pauli blocking ($p_{nucleon} \sim 417\ MeV/c$).

The study of the weak decay of a Λ-hypernucleus aims to the understanding of the stability of the hypernuclear system and of the influence of the nuclear medium on the Λ itself. Moreover, through the study of the weak NM decays, which probe the high momentum and parity conserving part of the weak interaction, one can gain insight into the fundamental aspects of the pertinent four-Fermion, strangeness-changing weak-interaction process. Such weak process is masked by the strong interaction in non-strange $\mathcal{N}-\mathcal{N}$ interactions. In particular, it has been recently suggested,[13] after the analysis of some decay channels of s-shell hypernuclei, that the $\Delta I = \frac{1}{2}$ rule may be strongly violated in NM decay. So, precise measurement of the relative branching ratios for the NM channels (4) and (5), could provide information about the structure of the weak hamiltonian, in particular the relative importance of the $\Delta I = \frac{1}{2}$ and $\Delta I = \frac{3}{2}$ amplitudes.

Notwithstanding the considerable interest of this subject, experimental data are scarce and not precise.[14] This is due to the tremendous difficulty in producing abundantly Λ-hypernuclei in their ground state and detecting the products of their decay. Extremely hard is to study the NM decay (5) for which two fast neutrons have to be detected and related to the hypernuclear ground state.

The FINUDA apparatus seems ideal for the study of NM decays. In fact, the very transparent structure of the detector and the extremely reduced thickness of the target, allow the products of the hypernucleus decay to be efficiently detected. Moreover, the large solid angle of acceptance for both π^- from hypernucleus formation and decay products, provides quite high counting rates and allows the coincidence between the hypernucleus decay and the related hypernuclear ground state to be easily established.

However, the energy resolutions on protons (1.3 MeV) and neutrons (10 MeV) in the FINUDA apparatus will not allow, in general, the identification of the final nuclear states ${}^{A-2}(Z-1)$ and ${}^{A-2}Z$. In these inclusive measurements an average over the final states of the weak decays $\Lambda + \mathcal{N} \to \mathcal{N} + \mathcal{N}$ will be inherently present and a possible violation of the $\Delta I = \frac{1}{2}$ rule could be inferred only by a systematic study of the ratio of the B.R.'s, for the two NM channels, as a function of the mass number.

It has been suggested[15] that the use of a ${}^{6}Li$ target offers the possibility of performing an exclusive measurement of one of the NM decay modes of ${}^{6}_{\Lambda}He$

$$\begin{array}{l} K^-_{stop} + {}^{6}Li \to {}^{6}_{\Lambda}He + \pi^0 \\ \qquad\qquad\qquad\quad \searrow \\ \qquad\qquad\qquad\qquad {}^{4}He + (n+n). \end{array} \tag{6}$$

The ${}^{6}_{\Lambda}He$ hypernucleus will stop in matter before decaying and, when it decays into the $(n+n)$ NM mode, it may end to the ${}^{4}He$ nucleus. The very large particle emission threshold of ${}^{4}He$ (19.8 MeV) allows the FINUDA apparatus to recognize the exclusive process by kinematic constraints, in spite of the limited energy resolution on the $(n+n)$ mode (14 MeV). In FINUDA such channel may be easily triggered by requesting two hits on opposite slabs of the external scintillator barrel.

4. Conclusions

FINUDA will be installed in the second half of 1996 at DAΦNE and will be ready to perform its large program of hypernuclear physics at the starting time of the machine. The main physics priorities of the experimental program can be briefly summarized as follows.

a) The first item will be the re-measurement of the excitation spectrum (with resolution $< 1MeV$), decay modes and lifetime of the ${}^{12}_{\Lambda}C$ nucleus, which is one of the hypernuclei most extensively studied.

b) High statistic study of the production, decay and lifetime of the p-shell hypernuclei ${}^{7}_{\Lambda}Li$, ${}^{9}_{\Lambda}Be$, ${}^{10}_{\Lambda}B$ and ${}^{6}_{\Lambda}He$ will be studied too using a ${}^{6}Li$ target.

c) High statistic survey of the production of hypernuclei of higher mass with targets of ${}^{27}Al$, ${}^{51}V$, ${}^{133}Cs$, ${}^{165}Ho$ and ${}^{209}Bi$.

It is worth remarking that, for all targets, a survey of the low momentum π^- spectra will be obtained in parasitic way for the events in which the fast coincidence on TOFONE is given by a μ^+ or π^+ coming from K^+ decay. In these events the π^- from the stopping K^- is detected by the spectrometer over the full spectrum. Negative pions of momentum less than 180 MeV/c don't reach the straw tube array owing to their curvature; nevertheless they can be reconstructed as well, although with lower quality and worse momentum resolution.

References

1. The ϕ-factory Study Group, *"Proposal for a ϕ-factory"*, LNF-90/031 (R) (1990) 47 p. 1.
2. G. Vignola, *Proc. Workshop on Physics and Detectors for DAΦNE*, Frascati, Italy, April 9-12, 1991, (ed. G. Pancheri), p. 11.
3. T. Bressani, *Proc. Workshop on Physics and Detectors for DAΦNE*, Frascati, Italy, April 9-12, 1991, (ed. G. Pancheri), p. 475.
4. The Finuda Collaboration, *"FINUDA - A Detector for Nuclear Physics at DAΦNE"*, LNF-93/021 (IR) (1993) p. 1.
5. M. Agnello et al., *Nucl. Phys.* **A585** (1995) 271c.
6. The Finuda Collaboration, *"FINUDA Technical Report"*, LNF-95/024 (IR) (1995) p. 1.
7. M. Agnello et al., accepted for publication on *Nucl. Instr. and Meth.* (1995).
8. L. Benussi et al., *Nucl. Instr. and Meth.* **A361** (1995) 1809.
9. A. Molinari and H. Feshbach, in *The Second DAΦNE Physics Handbook*, eds. L.Maiani, G.Pancheri, N.Paver, S.I.S., Frascati (1995) p. 713.
10. R.E. Chrien, *Proc. LAMPF Workshop on* $(\pi,\ K)$ *Physics*, Los Alamos, NM, USA, October 11-13, 1990 (eds. B.F. Gibson, W.R. Gibbs, M.B. Johnson, AIP, New York, 1991) p. 28.

11. H. Bandō, T. Motoba and J. Žofka, in *Perspectives of Meson Science*, eds. T. Yamazaki, K. Nakai, K. Nagamine, North Holland (1992) p. 571.
12. P.D. Barnes, *Nucl. Phys.* **A479** (1988) 89c.
13. R.A. Schumacher, *Nucl. Phys.* **A547** (1992) 143c.
14. J. Cohen, *Prog. Par. Nucl. Phys.* **25** (1990) 139.
15. T. Bressani, *Il Nuovo Cimento* **108A** (1995) 649.