# THE $K_{e2}$ DECAY WITH FINUDA AT DAΦNE

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

[a] *Dipartimento di Fisica del Politecnico di Torino, C.so Duca degli Abruzzi 24, I-10124 Torino, Italy*
[b] *INFN, Sezione di Torino, Via Giuria 1, I-10125 Torino, Italy*
[c] *TRIUMF, 4004 Wesbrook Mall, Vancouver, BC, V6T 2A3, Canada*
[d] *INFN, Laboratori Nazionali di Frascati, Via Fermi 40, I-00044 Frascati, Italy*
[e] *Dipartimento di Fisica Sperimentale, Università di Torino, Via Giuria 1, I-10125 Torino, Italy*
[f] *Dipartimento di Fisica Generale, Università di Torino, Via Giuria 1, I-10125 Torino, Italy*
[g] *Dipartimento di Fisica, Università di Trieste, Via Valerio 2, I-34127 Trieste, Italy*
[h] *INFN, Sezione di Trieste, Via Valerio 2, I-34127 Trieste, Italy*
[i] *Dipartimento di Fisica, Università di Bari, Via Amendola 173, I-70126 Bari, Italy*
[l] *INFN, Sezione di Bari, Via Amendola 173, I-70126 Bari, Italy*
[m] *INFN, Sezione di Pavia, Via Bassi 6, I-27100 Pavia, Italy*
[n] *Department of Physics, Shahid Beheshty University, 19834 Teheran, Iran*
[o] *CNR, Istituto di Cosmogeofisica, C.so Fiume 4, I-10131 Torino, Italy*
[p] *Dipartimento di Fisica Nucleare e Teorica, Università di Pavia, Via Bassi 6, I-27100 Pavia, Italy*
[q] *Dip. di Chimica e Fisica per i Materiali, Università di Brescia, Via Valotti 9, I-25133 Brescia, Italy*

## ABSTRACT

The ratio $\Gamma(K^+ \to e^+\nu_e)/\Gamma(K^+ \to \mu^+\nu_\mu) = (2.45 \pm 0.11) \times 10^{-5}$ was measured more than 20 years ago. An improvement on the precision of this ratio will be achieved by the FINUDA spectrometer, which will be installed at the second interaction region of DAΦNE, Frascati. In a year of operation, several thousands of events will be collected, improving by at least a factor 3 the present statistics on the decay. The measurement will be a by-product of the data taking runs on production of hypernuclei.

# 1 Introduction

FINUDA is one of the two magnetic detectors approved for operation at DAΦNE. As anticipated in the acronym (FIsica NUcleare a DAΦNE) the physics program is fully complementary to that of KLOE, discussed in detail during this Workshop. The main physics aim of FINUDA is the study of hypernuclear physics, following the stopping of $K^-$ (from $\phi$-decay) in thin nuclear targets:

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

FINUDA is the first, unique, example of a Nuclear Physics Experiment, which is inherently fixed target physics, carried out at a Collider. The main physics argument that makes (1) more appealing to be carried out at DAΦNE than at other $K^-$ sources is that the low energy ($\sim 16$ MeV) $K^-$ from the $\phi$-decay can be stopped in very thin targets ($\sim 100$ mg/cm$^2$). If a high resolution magnetic spectrometer, optimized to measure $\pi^-$ with momenta around $250 \div 280$ MeV/$c$, as those from (1), is used to determine the energy of the produced hypernuclear states, no problems arise from the uncertainty in the stopping point in the target and from the straggling of the energy loss. On the contrary that is the major drawback of the huge stopping targets used at Hadron machines. In this last case, the final energy resolution on (1) is not determined by the spectrometer, but by the target thickness.

The main physics topics of the FINUDA experimental program are:

- fine spectroscopy ($\Delta E \leq 700$ keV) of $\Lambda$-hypernuclei;
- systematic study of non-mesonic ($\Lambda N \rightarrow NN$) decays of hypernuclei;
- search for neutron rich $\Lambda$-hypernuclei ($^6_\Lambda H$, $^7_\Lambda H$, $^9_\Lambda He$, ...), through the reaction

$$K^-_{stop} + \ ^AX_Z \rightarrow \ ^A_\Lambda X_{Z-2} + \pi^+ \tag{2}$$

More details can be found in the Proposal of the Experiment[1]. We furthermore studied whether the detector, optimized and dedicated to the investigation of reactions like (1), could be used also for the study of other reactions and/or decays, possibly as a by-product of the same data taking runs. A first, positive, answer was found for the charge exchange reaction:

$$K^- + p \rightarrow K^0 + n \tag{3}$$

never studied at momenta around 100 MeV/$c$, and which is quite important for testing chiral symmetry theories[2]. Another possibility is the determination of the branching ratio for the $K_{e2}$ decay:

$$K^+ \rightarrow e^+ + \nu_e \tag{4}$$

which will be discussed in the following.

# 2 Structure of the FINUDA detector

The FINUDA detector is a high resolution magnetic spectrometer with cylindrical geometry, optimized for large solid angle ($> 2\pi$ sr) and good momentum resolution ($\Delta p/p \leq 0.3\%$ FWHM), exploiting dedicated triggers.

Fig. 1 shows a sketch of the detector. It consists of a superconducting solenoid, providing a homogeneous magnetic field of 1.1 T inside a cylindrical volume of radius 146 cm and length 211 cm. The ($e^+$, $e^-$) collide at the center of the magnet and the current distribution in the

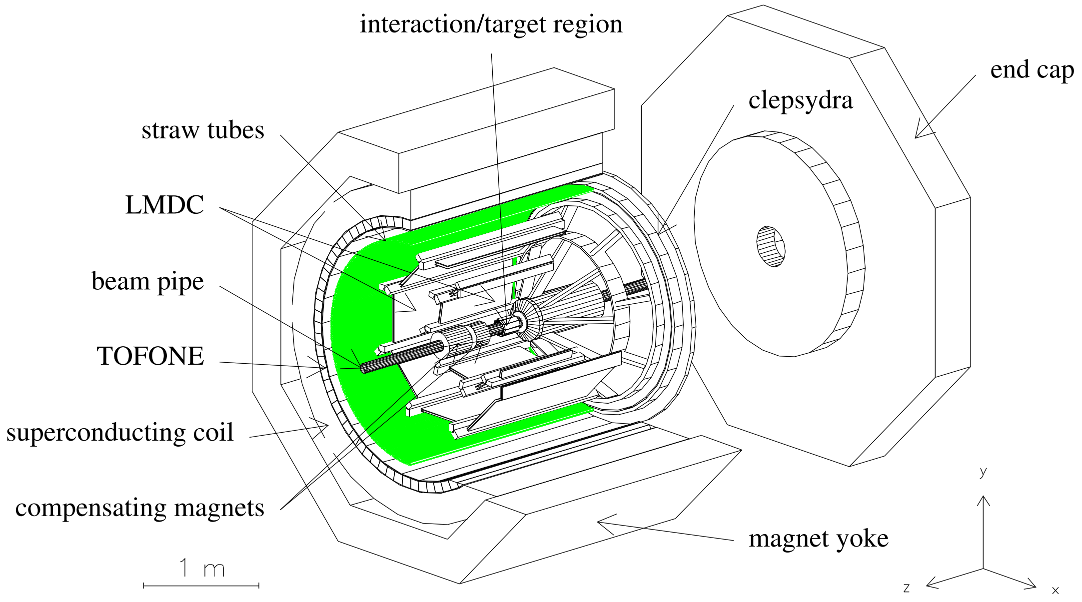


Figure 1: Schematic view of the FINUDA apparatus; the "right" end-cap has been shifted outward, while the "left" end-cap and the "left" part of the mechanical structure (clepsydra) have not been drawn.

coil as well as the shape of the Iron yoke and of the end-caps were designed in such a way as to have a 1% homogeneity inside the tracking volume, having the shape of a clepsydra.

We may define the following functional sub-structures of the detector, consisting each of different arrays of sub-detectors:

- the interaction/target region;
- the tracking device;
- the external scintillator barrel.

Fig. 2 shows a sketch of the interaction/target region. The function of the detectors arranged around the Be beam pipe (radius = 5.5 cm, thickness = 400 $\mu$m) is that of selecting the $(K^+,\ K^-)$ pairs from the $\phi$-decay and giving the first level trigger. We find a first barrel of scintillators (tofino), 2 mm thick, sliced in 12 slabs viewed at both ends by Hybrid PhotoDiodes (HPD) through suitably shaped Lucite light guides. $(K^+,\ K^-)$ pairs crossing the barrel are very efficiently selected at trigger level by $\Delta E/\Delta x$ measurements and back-to-back correlation. There is furthermore an array of Si $\mu$-strip detectors (ISIM), arranged following the sides of an octagonal prism, with bi-dimensional read-out. It localizes, with a precision better than 50 $\mu m$, the $K^-$ $(K^+)$ before stopping in the nuclear target, facing ISIM at a distance of less than 2 mm. In addition ISIM allows a further measurement of $\Delta E/\Delta x$ of the particle, very useful for the pattern recognition and the determination of the interaction vertex. The thickness of the nuclear targets (solid materials, ranging from Li to Pb) is such as to stop the $K^-$ $(K^+)$; its magnitude varies between 200 and 300 mg/cm$^2$.

The tracking device must allow the determination of the $\pi^-$ momenta from (1) with a $\Delta p/p$ of 0.3 % FWHM. It consists of three different types of sub-detectors, all of them immersed in Helium atmosphere, in order to minimize the multiple Coulomb scattering, which largely affects the momentum resolution in a non-focusing spectrometer like FINUDA. The $\pi^-$ emitted

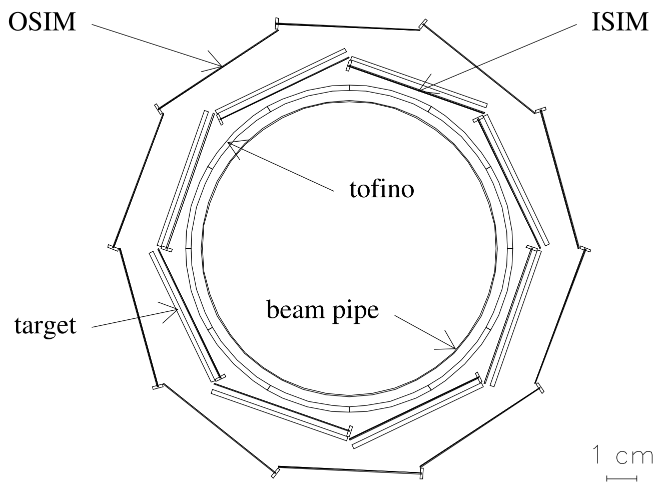


Figure 2: Schematic frontal view of the interaction/target region.

isotropically from the nuclear targets encounter a first array of Si $\mu$-strip detectors (OSIM), arranged following the sides of a decagonal prism.

There are afterwards (see Fig. 1) two layers of Low-Mass, high precision planar Drift Chambers (LMDC), arranged again following the sides of an octagonal prism. A He-i$C_4H_{10}$ (70/30) gas mixture will be used. A systematic study performed on a real-scale prototype has shown that the performances are the same, or even better, than those obtained with Ar based mixtures[3)]. The precision on the localization across the drift cell is 100 $\mu m$, along the wire 1 cm, by the charge division method. The two prisms are rotated by an angle of 11° and well held in position by a stiff Al structure (clepsydra). This geometry ensures the best acceptance for $\pi^-$ of $250 \div 280$ MeV/$c$ from (1).

The last array of detectors composing the tracking device consists of six layers of aluminized mylar straw tubes. There are three super-layers (one axial and two $\pm$ 12° stereo super-layers) each with two layers of staggered straws. The choice for this kind of detector was dictated by the fact that particles hit the last array of detectors with a large angle ($\geq 50°$). Extensive tests on prototypes showed excellent localization properties (better than 100 $\mu$m)[4)].

A scintillator barrel (TOFONE) composed by 72 elements, 10 cm thick, encloses the tracking device. It is used for trigger purposes and it is very useful in reducing the machine induced background. Simulations based on calculated beam losses in the target region (mostly Touschek scattering) showed that this background would be lower than 1 Hz at $\mathcal{L} = 10^{32}$ cm$^{-2}$s$^{-1}$. Furthermore TOFONE will detect neutrons emitted following the non-mesonic decay of the produced hypernuclei. The energy of neutrons (ranging up to $\sim$ 80 MeV) will be determined by time-of-flight, with a time resolution of $\sim$ 500 ps FWHM and an efficiency of $\sim$ 15%. These features will allow an unprecedented step forward in the experimental study of these decays, very important and interesting (they correspond to fully baryonic weak decays $\Lambda N \to NN$), but very poorly known up to now due to experimental difficulties.

The expected event rate for the production of hypernuclei will be $\sim$ 80 per hour at $\mathcal{L} = 10^{32}$ cm$^{-2}$s$^{-1}$, for a typical production rate of $10^{-3}$ $K^-_{stop}$ s$^{-1}$.

The Data Acquisition system allows to write on tape more than 200 events per second.

No one of the proposed sub-detectors is fully innovative, but each one exhibits some new performance or not-standard utilization: excellent timing performance of HPD ($\Delta$t start-stop $\leq$ 1 ns), large LMDC safely and continuously operated with He-based mixtures[3]), utilization of ISIM for $\Delta E/\Delta x$ measurements, first operation of a large array (> 2400 elements) of straw tubes[4]), full reliability of a large array of scintillators for neutron detection.

The present schedule of the installation of FINUDA is the following:

end 1996: completion of delivery and tests of all sub-detectors;

mid 1997: delivery of the super-conducting solenoid to INFN National Laboratory of Frascati, installation of the apparatus in the pit;

end 1997: end of the debugging of the apparatus with beam, start of data taking.

# 3 $K_{e2}$ decay in FINUDA

The branching ratio for the rare decay $K_{e2}$ is measured to a precision of 4%. The PDG value[5]):

$$\Gamma(K^+ \to e^+\nu_e)/\Gamma(K^+ \to \mu^+\nu_\mu) = (2.45 \pm 0.11) \times 10^{-5} \tag{5}$$

is in agreement, within 1 standard deviation with the theoretical value:

$$\left(\frac{m_k^2 - m_e^2}{m_k^2 - m_\mu^2}\right)^2 \frac{m_e^2}{m_\mu^2} = 2.57 \times 10^{-5} \tag{6}$$

It is based on a total of 1050 events, collected by 3 experiments[6–8]). The most significant contribution is due to the last two measurements, performed by the same Collaboration (CERN – Heidelberg) with an apparatus slightly improved in the last version. It consisted of a magnetic spectrometer equipped with planar drift chambers, with high-efficiency Čerenkov counters selecting the positrons. The momentum resolution ($\sim$ 6 MeV/$c$ FWHM) was sufficient to isolate the peak due to $K_{e2}$ decay ($p_e$ = 247 MeV/$c$) from that due to the few, still surviving, events from $K_{\mu 2}$ decay ($p_\mu$ = 236 MeV/$c$).

In FINUDA the situation is completely different. $K^+$ stopping in the nuclear target will decay following the relative branching ratios, without selection of $K_{e2}$ decay by dedicated triggers. The most abundant decay $K_{\mu 2}$ will be continuously recorded for calibration purposes and stability checks. We will collect some tens of $K_{\mu 2}$ decays per second at $\mathcal{L} = 10^{32}$ cm$^{-2}$s$^{-1}$ and, accordingly, more than 30 events per day from $K_{e2}$ decay. This would correspond to more than $3 \times 10^3$ $K_{e2}$ decays per year of operation of DA$\Phi$NE ($\geq$ 100 days of data taking).

The excellent momentum resolution of FINUDA will allow a very clean separation of the peaks corresponding to the two decays, as shown by the result of the FINUDA simulation program[9]) reported by Fig. 3 a), which was obtained assuming equal decay branching ratios. However, the signal corresponding to the $K_{e2}$ decay will be in reality five order of magnitude lower. We estimate that in the momentum region of the $K_{e2}$ peak there is a contamination from the $K_{\mu 2}$ events of the order of a few $10^{-5}$ (see Fig. 3 b)), i.e. comparable to the signal. Anyway these background events are originated by large angle Coulomb scattering in the LMDC mylar windows, which distorts the trajectory of the tracks and can be easily recognized and rejected.

# 4 Conclusion

The FINUDA detector will be operational and ready to take data at DA$\Phi$NE by the end of 1997. The initial physics program at $\mathcal{L} = 10^{32}$ cm$^{-2}$s$^{-1}$ will be focused on the study of

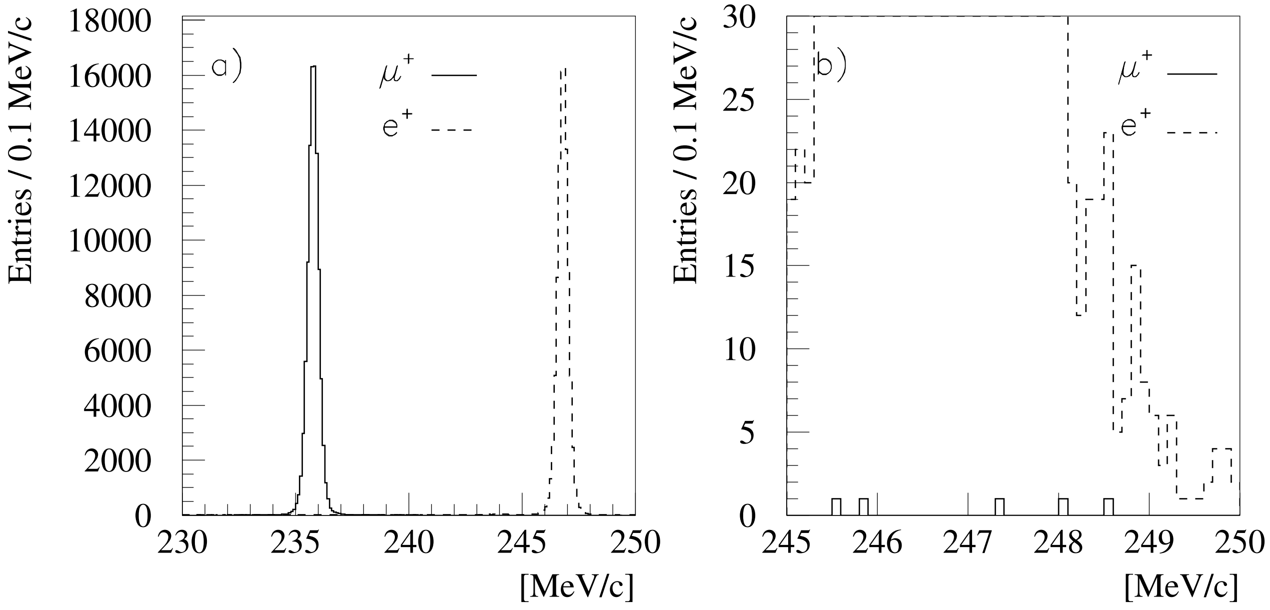


Figure 3: Reconstructed momentum of $\mu^+$ and e$^+$ from simulated $K_{\mu 2}$ and $K_{e2}$ decays. See text for more details.

the production and decay of light hypernuclei. As a by-product we could also determine the relative branching ratio $\Gamma(K^+ \to e^+\nu_e)/\Gamma(K^+ \to \mu^+\nu_\mu)$ with a statistical precision better than previous experiments (typically a factor 3 in a year of operation). At the design luminosity of DA$\Phi$NE ($\mathcal{L} = 5 \times 10^{32}$ cm$^{-2}$s$^{-1}$) the improvement in the statistical precision will be at least of one order of magnitude. Systematic errors, due in particular to backgrounds events, could become the dominant ones and we are investigating possible ways of reducing them.

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