FINUDA, the physics program

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The performances of the FINUDA detector foreseen by a full Monte Carlo simulation are summarized.

1. The main reaction

The FINUDA detector [1] is designed for a systematic study of the hypernuclei production and decay by stopping the K^- meson in different targets.

The production reaction is:

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

while the non-mesonic decay goes through:

$$\begin{aligned} {}^A_\Lambda Z &\rightarrow {}^{(A-2)}Z + n + n \\ {}^A_\Lambda Z &\rightarrow {}^{(A-2)}(Z-1) + p + n \end{aligned}$$

These reactions have been studied in the past with limited statistics. The new electron-positron collider $DA\Phi NE$ [2] which is now under construction at Frascati, Italy, opens a completely new scenario. The $DA\Phi NE$ collider is tuned to the energy $\sqrt{s} = 1.02\,GeV/c^2$, in order to enhance the ϕ meson production. The ϕ meson decays in 49% of cases into the K^+K^- final state. As the kinematic is fixed, the K momenta are 127 MeV/c.

$DA\Phi NE$ will run in 1998 with an initial luminosity of $10^{32}cm^{-2}s^{-1}$, corresponding to a production of 500 ϕ per second.

The conventional experiments with stopped K^- carried out up to now used high momentum kaons degraded and then stopped in a thick target [3]. This introduces a large uncertainty on the outgoing particle momenta, due to the error on the reconstruction of the interaction point. In FINUDA the use thin targets reduces the energy straggling to a very low level.

Moreover a large solid angle acceptance is available for the detection of both the π^- after hypernucleus formation and of its decay products: 40 % solid angle with 0.3 % momentum resolution on charged particles (protons and pions) and 12 % efficiency on neutrons.

A full Monte Carlo simulation program allows us to generate and reconstruct the hypernuclei events as far as background events. In this report we breifly summarize the results.

2. The background reactions

Following the idea of H. Tamura [4], we have simulated some background reactions.

The most common interaction of stopped K^- in matter is the free Λ production:

$$
\begin{aligned}
K^-n \rightarrow\ & \Lambda \quad \pi^- \\
& \Lambda \quad \rightarrow p\pi^-
\end{aligned}
$$

The momentum distributions for the negative π in the final state are shown in Fig 1, where the curve with label (d) is relative to the prompt π^-, and with the curve with label (a) is relative to the decay π^-.

Another possible source of background is the free Σ production, in two-body reactions like:

$$
\begin{aligned}
& K^-p \rightarrow \Sigma^+\pi^- \\
& \qquad \Sigma^+ \rightarrow n\pi^+ \qquad\qquad \Sigma^+ \rightarrow p\pi^0
\end{aligned}
$$

$$
\begin{aligned}
& K^-n \rightarrow \Sigma^0\pi^- \\
& \qquad \Sigma^0 \rightarrow \Lambda\gamma \\
& \qquad\qquad \Lambda \rightarrow p\pi^-
\end{aligned}
$$

$$
\begin{aligned}
& K^-n \rightarrow \Sigma^-\pi^0 \\
& \qquad \Sigma^- \rightarrow n\pi^-
\end{aligned}
$$

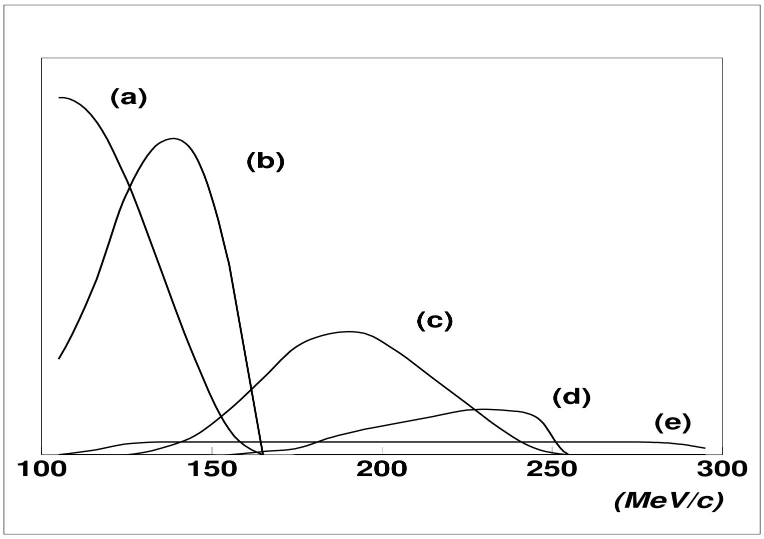

Figure 1. *π^- momentum from:*
a) Λ decay,
b) $\Sigma^+ \Sigma^0$ formation,
c) Σ^- decay,
d) Λ formation,
e) Σ^- decay from a three-body reaction.

In Fig 1 the momentum distribution of π^- coming from Σ^+ or Σ^0 formation is plotted with label (b), while that of the π^- coming from Σ^- decay is plotted with label (c).

The last possible source of background is the free Σ production in a three-body reaction:

$$K^-(np) \to \Sigma^- p$$
$$\Sigma^- \quad \to \quad n\,\pi^-$$

The momentum distribution for π^- coming from this Σ^- decay is broader than the others (Fig. 1, plot (e)), due to the bigger Σ^- momentum.

The weight of each reaction has been computed by fitting the π^- spectrum measured in the KEK experiments. In Fig 1 all the contributions have been plotted with the relative weights coming from the fit.

The result shows that in the momentum range between 250 and 300 MeV/c (where the π^- coming from hypernuclear formation are expected to lie), the three-body Σ^- reaction is the major source of background.

The three-body Σ^- production has a special feature that can help to reduce its contribution to the final π^- spectrum: the Σ^- and the proton are emitted back-to-back (apart from a small contribution due to the Fermi motion of the nucleons), and the Σ^- momentum is almost completely transfered to the lightest particle it decays into. Thus, in the final state the proton and the π^- are then "almost" back-to-back.

3. Monte Carlo simulation

All the ingredients described in the previous section have been inserted in the FINUDA Monte Carlo simulation in order to reproduce the π^- spectrum shape measured in the KEK experiments [4].

We have then superimposed four peaks, located at 261, 265, 270 and 273 MeV/c with values which correspond to capture rates of $3 \cdot 10^{-3}$, $2 \cdot 10^{-4}$, 10^{-4} and 10^{-3} per stopped K^-.

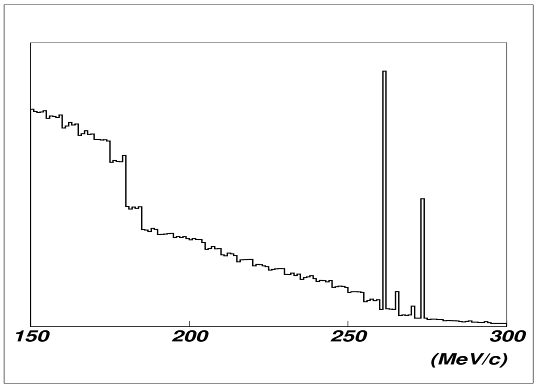

Figure 2. π^- *momentum distribution injected in the Monte Carlo.*

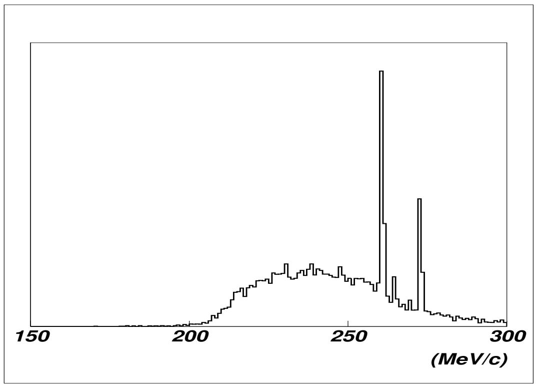

Figure 3. π^- *momentum distribution reconstructed by the Monte Carlo.*

The final π^- spectrum injected in the Monte Carlo is shown in Fig. 2. In Fig. 3 the reconstructed π^- spectrum is shown. The FINUDA spectrometer threshold of about 200 MeV/c (due to the spiralizing of charged particle inside the magnet) is here clearly seen.

Selecting the events with a spectator proton in the momentum range between 250 and 450 MeV/c, the background is reduced (Fig. 4), because the two-body Σ production does not have a proton in the final state.

In Fig. 5 a further cut has been applied, selecting the events in which the angle between the π^- and the proton has $\cos\theta > -0.5$ for reducing the contribution from the three-body Σ production.

These spectra are simulated with a luminosity of $10^{32} cm^{-2} s^{-1}$ and with 7 hours of data taking, corresponding to an integrated luminosity of $2.52\,(pb)^{-1}$.

Two of the four peaks are clearly seen out of the background: the peak at 261 MeV/c ($2 \cdot 10^{-3}$ of capture rate) has a σ_p/p at FWHM of 0.257 %, with a systematic error smaller then 0.1 %, while the peak at 273 MeV/c (10^{-3} of capture rate) has a σ_p/p at FWHM of 0.263 %, with the same systematic error.

The peak at 265 MeV/c (capture rate of $2 \cdot 10^{-4}$) is also visible.

4. Hypernucleus life time

In FINUDA the hypernucleus lifetime can be directly measured from the difference between the hit time of the prompt π^- on Tofone and the hit time of the proton on Tofone or Tofino, which is delayed by the hypernucleus lifetime. The hit times have to be

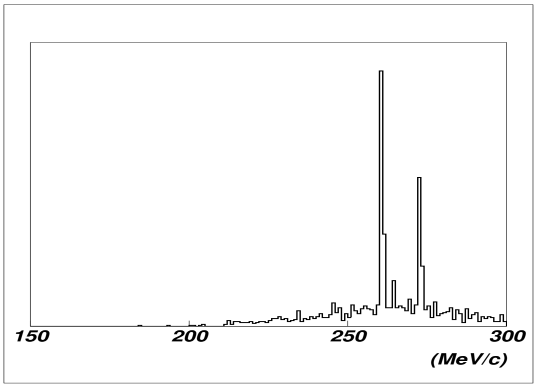

Figure 4. π^- *momentum distribution when a spectator proton is detected.*

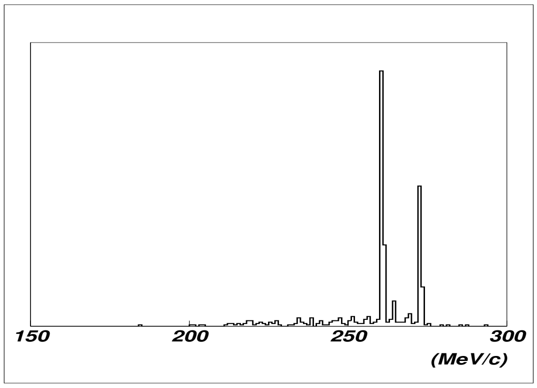

Figure 5. π^- *momentum distribution when the detected spectator proton has* $\cos\theta > -0.5$.

corrected for the time of flight of the particles, which gives little contribution to the time uncertainty since momenta and trajectories are very accurately measured. This technique has been already adopted with success at BNL[5] and KEK[6].

Using the expected time resolution of $\sim 210\ ps$ 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 10% statistical error with $\sim$ 2000 events reconstructed in the hypernucleus ground state peak. Assuming a capture rate of 10^{-3} for the ground state, this number of events can be obtained, with the FINUDA apparatus, in 1 day of data taking at $\mathcal{L} = 10^{32} cm^{-2} s^{-1}$ luminosity.

Using the $\Delta T = t_p - t_\pi$ from the external barrel, we obtain ΔT distributions plotted in Fig 6, with a simulated life time of the hypernucleus of 0 ps, 150 ps and 300 ps.

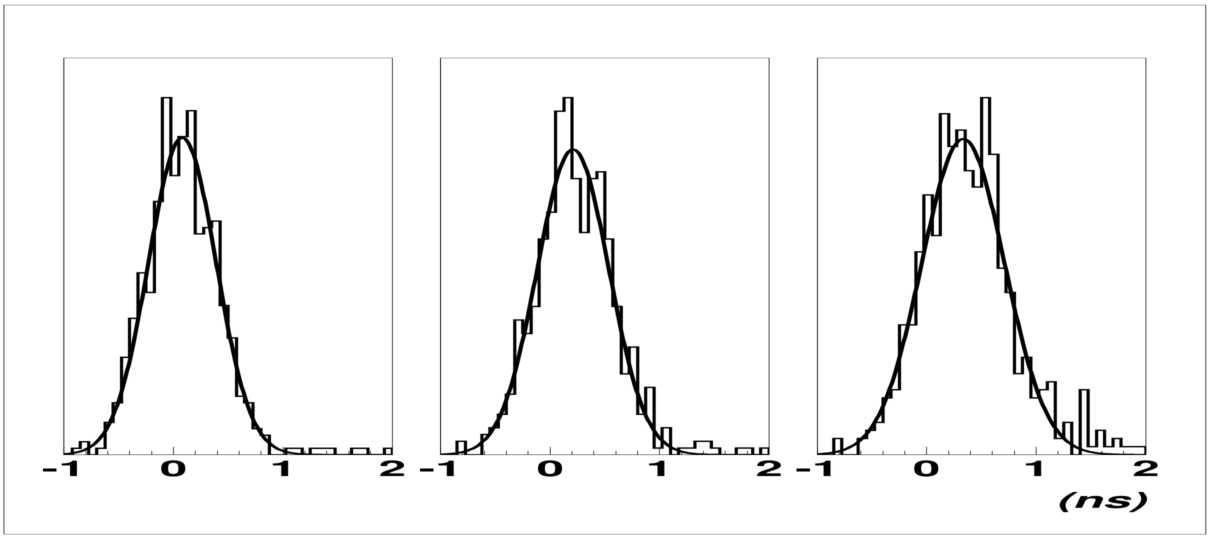

Figure 6. ΔT *with 0 ps, 150 ps and 300 ps hypernucleus life time.*

The mean values of the Gaussian fitting of these distributions are respectively $5 \pm 17\,ps$, $143 \pm 14\,ps$ and $307 \pm 20\,ps$

5. Non-mesonic decay and $\Delta I = 1/2$ rule

The free Λ decays in:

$$\Lambda \rightarrow p + \pi^-$$
$$\Lambda \rightarrow n + \pi^0$$

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 [7].

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 the Pauli principle and the non-mesonic decay modes are dominant,

$$\Lambda + p \rightarrow n + p \quad (2)$$

$$\Lambda + n \rightarrow n + n \quad (3)$$

It has been recently suggested[8], after the analysis of some decay channels of s-shell hypernuclei, that the $\Delta I = \frac{1}{2}$ rule may be strongly violated in non-mesonic decay. So, precise measurement of the relative branching ratios for the non-mesonic channels (2) and (3), 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.

The FINUDA detector can measure the ratio of these two reactions, using the external time-of-flight barrel as a neutron detector, with a mean efficiency in the neutron spectrum range of about 12%.

Studying an hypernucleus level with a capture rate of 10^{-3}, with a collider luminosity of $10^{32} cm^{-2} s^{-1}$, about 80 hypernucleus events per hour with a forward pion, and about 160 ev/h with both forward and backward pions are expected.

Now assuming the ratio of the two non-mesonic decays equal to 1, one gets:

$$80\, ev/h\ (pn) \qquad\qquad 80\, ev/h\ (nn)$$

and reconstructs:

$$35\, ev/h\ (pn) \qquad\qquad 0.7\, ev/h\ (nn)$$

in coincidence.

6. Conclusions

The FINUDA detector is now ready for insertion in one of the two DAΦNE intersection regions. The most recent schedule for operation in DAΦNE foresees the installation of FINUDA from June to September '98. By the end of '98 the first colliding beams will be available, and by that date FINUDA is expected to take the first physics runs.

Before that date a calibration run with cosmic rays will be performed in order to assess the relative alignment of subdetectors.

The main physics priorities of the experimental program can be briefly summarized as follows.

- Re-measurement of the excitation spectrum (with resolution $< 1\ MeV$), decay modes and lifetime of the $^{12}_{\Lambda}C$ nucleus, which is one of the hypernuclei most extensively studied.
- High statistic study of the production, decay and lifetime of the p-shell hypernuclei $^{7}_{\Lambda}Li$, $^{9}_{\Lambda}Be$, $^{10}_{\Lambda}B$.
  The $^{6}_{\Lambda}He$ will be studied using a ^{6}Li target.
- High statistics survey of the production of higher mass hypernuclei, with targets of ^{27}Al, ^{51}V, ^{133}Cs, ^{165}Ho and ^{209}Bi.

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