FINUDA at DAΦNE. Status and perspectives

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DAΦNE, the Frascati 1.02 GeV c.m. electron/positron Φ-factory, is now in operation at the INFN laboratory. This machine is a "special" source of low energy K^- which can be very useful to perform new hypernuclear studies. The FINUDA Collaboration has designed and built a magnetic spectrometer to perform both hypernuclear spectroscopy and hypernucleus decay studies. Up to now, this is a unique capability in the hypernuclear physics panorama.

1. INTRODUCTION

FINUDA is a hypernuclear physics experiment that will be carried out at the DAΦNE e^+e^- Φ-factory of Frascati INFN laboratory [1]. Kaons from Φ decay offer the opportunity to produce new and high quality data on a wide set of hypernuclear states. DAΦNE commissioning was done in 1998, and after one year of machine tuning, the accelerator is now providing collisions for the KLOE and the DEAR experiments.

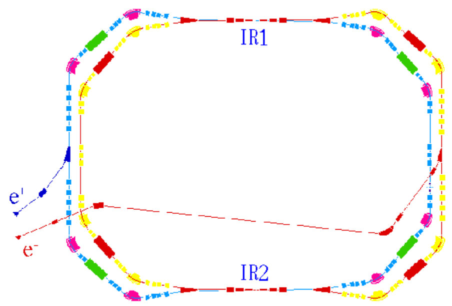
FINUDA experiment [2] will carry out a very ambitious hypernuclear physics program including high statistics p-shell hypernuclear spectroscopy, study of hypernuclear mesonic and non-mesonic decays, search for neutron rich hypernuclear states. To perform these tasks a magnetic spectrometer with cylindrical geometry has been built, optimised to provide the best momentum resolution and acceptance for the prompt π^- emitted in the Λ-hypernucleus formation from capture of K^- at rest by nuclei. Therefore, the same detector has also excellent detection capability for the products of the Λ particle decay.

The FINUDA detector components have been assembled and tested, and now are ready for the final installation inside the superconducting magnet, which is already in place inside the DAΦNE hall.

The status and the perspective of the DAΦNE accelerator, together with the main characteristics of the FINUDA detector are reported in this work.

2. STATUS AND PERSPECTIVES OF THE DAΦNE MACHINE

DAΦNE is a Φ-factory e^+e^- collider. The Φ resonance (1.020 GeV) is produced by annihilating electrons and positrons circulating inside two separated rings which overlap in two straight sections (Interaction Regions - IR). The interest on the Φ relies on the fact that this resonance is a source of monochromatic, collinear and taggable $K\bar{K}$ pairs:



Single beam energy	0.51 GeV
Number of particles per bunch	8.9x10^{10}
Number of bunches per ring	up to 120
Crossing frequency	up to 368.25 MHz
Horizontal emittance	1.0 mm.mrad
Vertical emittance	0.01 mm.mrad
Horizontal beta function at crossing	4.5 m
Vertical beta function at crossing	0.045 m
Total crossing angle in the horizontal plane	20 to 30 mrad
Horizontal beam-beam tune shift per	0.04
Vertical beam-beam tune shift per crossing	0.04
Bunch length	30 mm r.m.s.
Horizontal beam size at crossing	2.0 mm r.m.s
Vertical beam size at crossing	0.02 mm r.m.s.
Maximum stored current per ring	5.2 A
Maximum luminosity	5.3x10^{32} cm^{-2} s^{-1}

Figure 1. DAΦNE machine layout. The table on the right side shows some relevant machine design parameters.

$$\Phi \rightarrow \begin{array}{cc} K^+K^- & 49\% \\ K^0_S K^0_L & 33\% \\ \rho\pi & 13\% \end{array} \tag{1}$$

Neutral kaons are used at DAΦNE by the KLOE experiment [6] to study CP and CPT violations; charged kaons are used by the FINUDA experiment to produce hypernuclei, and also by the DEAR experiment [7] to measure $K - N$ scattering lengths.

The DAΦNE collider design has been tuned in order to achieve high luminosity (more than $10^{32} cm^{-2} s^{-1}$). The luminosity is a typical figure of merit of a collider since it is proportional to the number of interactions available per unit of time. In the case of an e^+e^- machine this quantity is given by the following expression:

$$\mathcal{L} = N\mathcal{L}_0 = Nf\frac{n_1 n_2}{4\pi\sigma_x\sigma_y} \tag{2}$$

where $\mathcal{L}_0$ is the single bunch luminosity and N is the total number of stored bunches. n_1/n_2 is the number of particles in the e^+/e^- bunch, f is the revolution frequency, and σ_x, σ_y are bunch cross-sections. To achieve the high luminosity goal, the DAΦNE design has chosen a high current approach based on multibunch operation mode following PEP-II and KEKB examples. Fig. 1 shows the "day one" DAΦNE machine layout with two provisional IRs and no experimental detectors installed.

The DAΦNE commissioning was concluded successfully in November 1998 [8] measuring a single bunch luminosity $\mathcal{L}_0 = 1.6 \times 10^{30} cm^{-2} s^{-1}$. Therefore, at the beginning of 1999 KLOE and DEAR detectors were rolled in and at the end of March 1999, the first collisions were available in the KLOE interaction region (IR1). Unfortunately, with the KLOE solenoid inserted on the machine, many beam instabilities appeared, and the single bunch luminosity decreased of almost one order of magnitude. Therefore, all the subsequent efforts were dedicated to the compensation of these perturbations, and in the whole 1999 only 2.5 $pbarn^{-1}$ and 600 $nbarn^{-1}$ were collected by the KLOE and the DEAR experiments, respectively.

After the 1999 Christmas shutdown, during which some hardware improvements were realized, in the year 2000 the machine study continued with many improvements. At present, the DAΦNE accelerator status is the following:

- collisions are available only for one IR at time;
- the single bunch luminosity is $\sim 4 \times 10^{29} cm^{-2} s^{-1}$ which result in a total luminosity (with 45 bunches) of $\sim 1.6 \times 10^{31} cm^{-2} s^{-1}$;
- the per day luminosity delivered to the experiments is ~ 500 $nbarn^{-1}$.

Presently, DAΦNE is facing two main challenges: to increase both the single bunch luminosity, and the stored beam current in the multibunch mode. This work is going on in parallel with the KLOE and DEAR data taking and this is limiting the luminosity that the two experiments can integrate. The big amount of work done so far about machine dynamics has explained some present limitations due to beam instabilities and has suggested the proper cures. The injection kickers have been rebuilt, new RF cavities are under study, a transverse feedback system has been installed and will be soon potentiated. New passive scrapers, to cut particles scattered by Touscheck effect, are under preparation and other work is under way to improve lattice modelling. Therefore, the machine team is confident to be able to achieve as soon as possible an increase of the luminosity and a reduction of the background.

3. THE FINUDA EXPERIMENT

The central idea of the FINUDA experiment is to stop the low energy kaons (~ 16 MeV) from the Φ resonance decay, inside a thin nuclear target to produce Λ-hypernuclei through the reaction:

$$K^-_{stop} + ^A Z \rightarrow ^A_\Lambda Z + \pi^- \qquad (3)$$

With respect to the hypernuclear physics experiments performed using K^- extracted beams on a fix target, FINUDA at DAΦNE has many advantages:

- the low energy DAΦNE kaons can be stopped in a target thickness ~ 0.1 g/cm^2 reducing the energy straggling of the outgoing π^- which is a factor limiting the present achievable resolution on hypernuclear levels;
- the kaons are emitted isotropically; therefore, the experiment acceptance can be quite large. This element, combined with a proper machine luminosity, could provide high hypernuclear counting rates (with $\mathcal{L} = 10^{32}$ $cm^{-2} s^{-1}$ 80 ev/h are expected);

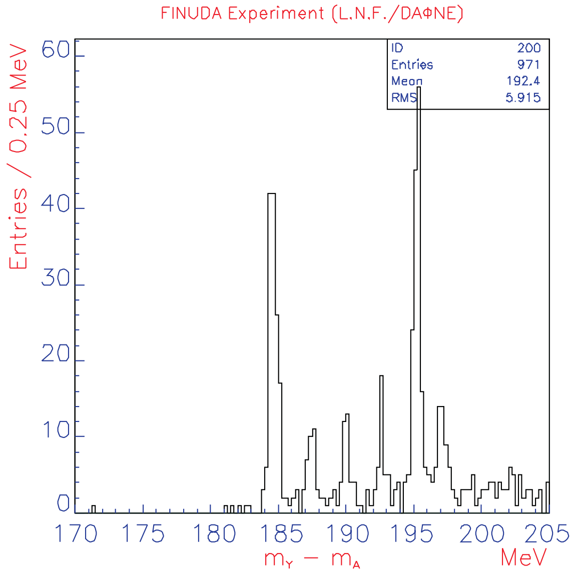


Figure 2. Montecarlo spectrum of ${}^{12}_{\Lambda}C$. In the simulation the 5 hypernuclear levels detected by KEK E369 experiment have been inserted. The good spectrometer energy resolution ($\sim 0.7\ MeV$) and the requirement to have in the final state a proton from Λ decay emitted with respect to the π^- with $cos\theta > -0.5$ allows to reduce the background contamination.

- the kinematic of reaction (3) gives to the Λ particle a momentum of about 250 MeV/c; therefore, many hypernuclear excited levels can be populated. On the other hand, the use of K^- in flight results only in hypernuclear substitutional levels;
- FINUDA is a $\sim 2\pi$ magnetic spectrometer able to detect either the π^- emitted in hypernucleus formation, or the products of the hypernucleus decay. This is a unique feature in the hypernuclear physics panorama.

Thanks to these characteristics, FINUDA will investigate a wide physics program consisting both of hypernuclear spectroscopy and of hypernuclear decays. High statistics p-shell hypernuclear studies are foreseen: ${}^{12}_{\Lambda}C$, ${}^{7}_{\Lambda}Li$, ${}^{9}_{\Lambda}Be$, ${}^{10}_{\Lambda}B$. Even the light ${}^{5}_{\Lambda}He$ will be produced using a ${}^{6}Li$ target. Moreover, at the same time the decay modes of these hypernuclei could be studied. This double capability of FINUDA spectrometer is up to now unique and will give for some signals the possibility to reduce the background contamination. As an example, fig. 2 shows the result of a Montecarlo simulation in which the 5 hypernuclear levels observed by the E369 experiment at KEK [3] have been injected in the FINUDA reconstruction program. The results is a very clean spectrum with practically no background. In fact, by asking to have in the final state a proton of momentum between 250 and 450 MeV/c with $cos\theta > -0.5$ (θ is the angle between π^- and p trajectories) the background is highly reduced. More details on the FINUDA physics program can be found in ref. [4,5].

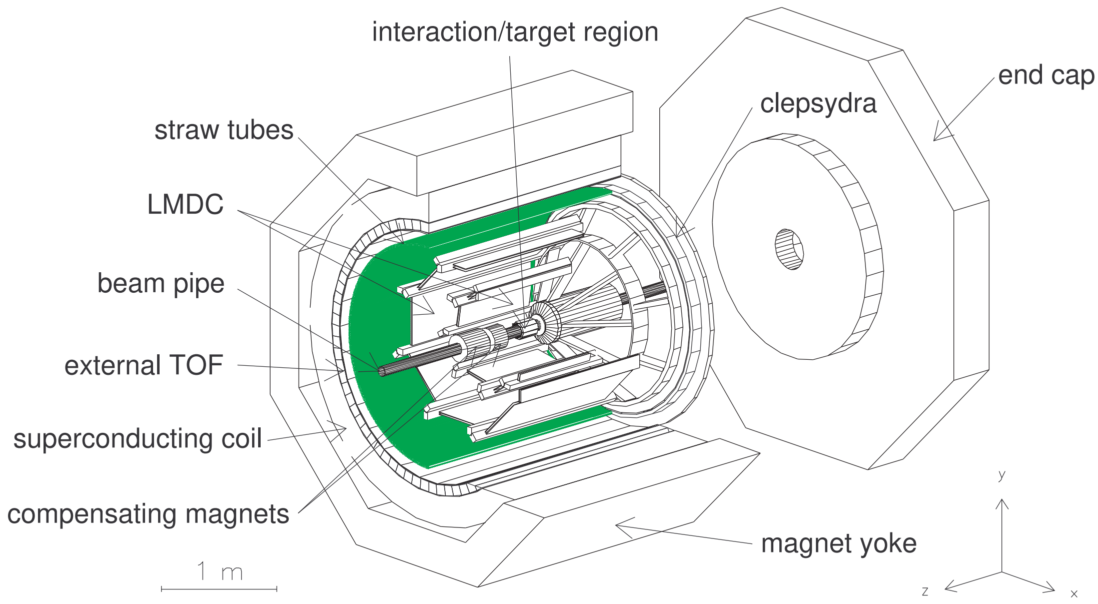


Figure 3. FINUDA detector layout.

4. THE FINUDA SPECTROMETER

The FINUDA detector has the typical cylindrical geometry of any collider experiment (see fig. 3); it consists of different coaxial sub-detectors housed inside a homogeneous magnetic field of 1.1 T. A detailed description of each component is the subject of the following sub-sections.

4.1. The interaction/target region

This is the region (see fig. 4) surrounding the accelerator beam pipe (400 μm of Be). It consists of 3 elements: first of all, an array of 12 NE102A scintillator slabs ($200 \times 31 \times 2.3\ mm^3$) connected at both ends to Hybrid Photo Diodes (HPD). This detector has to recognise, at trigger level, K^+K^- and Bhabha events among other Φ decays and background events. This is done by means of topological selections (back-to-back trigger) and dE/dx measurements. The second element is the Inner SIlicon Module (ISIM) [9]. This is a barrel of 8 double sided microstrip detectors (thickness 300 μm) which provides a spatial resolution of $\sim$ 200 μm r.m.s on the hypernucleus production vertex. This detector has also a very good capability of measuring the charged particle energy loss (20% $FWHM$). This information is exploited offline in the data analysis to perform particle identification. The last element is the target assembly. This is an 8 slot array that can house target of different materials. For the FINUDA early stage, 4 ^{12}C and 4 ^{6}Li slabs are foreseen. The thickness of each slab is very reduced ($\sim 0.1\ g\ cm^{-2}$) just the minimum necessary to stop the 16 MeV K^-.

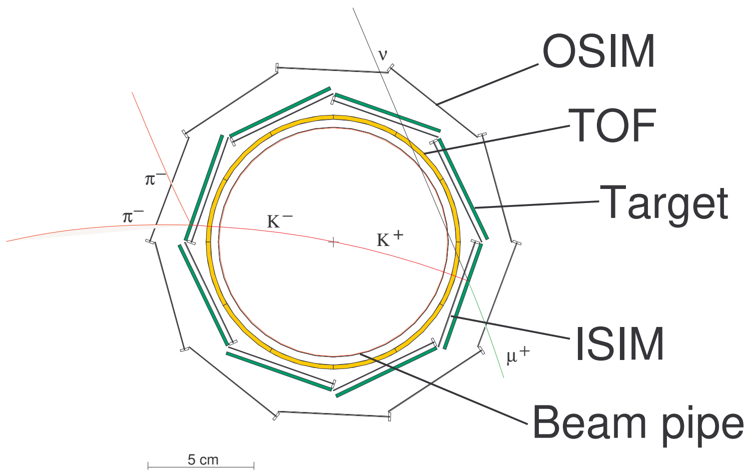


Figure 4. Enlarged view of the interaction/target region (see the text for details).

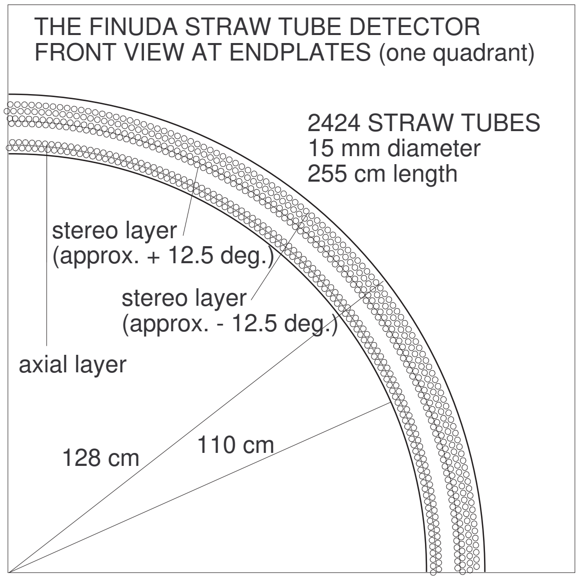


Figure 5. Straw tube detector layout.

4.2. The tracking system

To reconstruct the charged particle trajectories an ensemble of 3 different detectors will be used. The first one is an array of 10 double sided microstrip elements (Outer SIlicon Module - OSIM) [9] having the same characteristics of those located in the interaction region. This detector will provide, with high accuracy, the first point along the tracks. The second detector consists of 2 arrays of Low Mass Drift Chambers (LMDC) [10]. These are planar drift chambers operated with an helium based gas mixture. The spatial resolution of all the cells for tracks having different angles and hitting the wire along the whole length is 153 μm r.m.s. in the $r-\phi$ plane, and $\sim 1\ cm$ along z. Finally, the last information on particle trajectories is given by an array of 2424 straw tubes [11]. The tubes are arranged in 6 concentric layers mounted as shown in fig. 5. This detector gives a spatial resolution of $\sim 100\ \mu m$ r.m.s in the $r-\phi$ plane and of $\sim 500\ \mu m$ along z.

To reduce charged particle multiple scattering, the whole tracking volume ($8\ m^3$) is filled with helium. This has been realised by closing with plastic foils of different materials (PET, PA, PC, EVOH) the mechanical frame housing the FINUDA detectors. Gas leak is avoided by o-ring sealing, adhesive mylar tape and silicone. With an helium flow rate of 900 l/h the leak rate is $< 130\ ml/s$. The helium atmosphere is necessary in order to reduce the Coulomb multiple scattering that is the factor limiting the achievable momentum resolution. If air is left in the tracking volume the value of $\Delta p/p$ goes from 0.3 % to 1.5 %.

4.3. The external Time of Flight

The outermost detector of the FINUDA spectrometer is a barrel of 72 BC408 scintillator slabs ($200 \times 10 \times 10\ cm^3$) [12] viewed at both ends by photomultipliers. The aim of this scintillating counter is to detect the products of the hypernuclear non-mesonic decay and to enforce trigger requirements. The neutron detection efficiency is around 10% and the energy resolution $\sigma \sim 1.3\ MeV$ for neutron of 80 MeV energy.

5. CONCLUSIONS

A new magnetic spectrometer to perform high quality hypernuclear studies has been built at the Frascati INFN laboratory to be operated on the DAΦNE Φ-factory. This detector has the unique characteristic to allow the study of both hypernuclear spectroscopy and hypernuclear decay modes. Unfortunately, due to some accelerator problems, the FINUDA installation has been delayed and presently the experiment is in a stand by phase.

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