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FINUDA, the Facility

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The status of the FI.NU.DA. (Fisica Nucleare a *DAΦNE*) facility of Frascati Laboratories is reviewed. The performance of FINUDA, in terms of resolution and rates of produced hypernuclei, is compared with the other existing facilities. The breakthrough in the field of hypernuclear studies, due to the unique combination of slow, monochromatic, low-background K^-'s produced at the *DAΦNE* ϕ-factory with the high resolution, large acceptance spectrometer is underlined.

1. INTRODUCTION

The *DAΦNE* (e^+e^-) collider [1] has been built at the Laboratori Nazionali di Frascati of INFN and is presently in the commissioning phase. The design of the collider is optimized for operation at a c.m. energy of 1020 MeV with a top luminosity of $L = 5 \times 10^{32}$ cm^{-2}s^{-1}. The selected c.m. energy corresponds to the rest mass of the ϕ meson, which decays mainly into kaons. In particular, it decays with a branching ratio of 49.1% into K^+K^- pairs. Kaons are emitted back-to-back, with a momentum of 127 MeV/c. For this reason, the produced K^-'s can be stopped in very thin targets and, hence, the prompt π^-'s emitted following hypernucleus formation on target nuclei are minimally degraded, thus allowing a high resolution spectroscopy. Moreover, the K^-'s are emitted isotropically around the azimuth angle, and with a $\sin^2(\theta)$ dependence with respect to the beam axis. Thus, by employing a high acceptance spectrometer with a solenoidal field along the machine axis, high counting rates can be achieved, stopping as many as 1000 K^- per second (at the top luminosity) on a ≈ 250 mg/cm^2 thin target surrounding the beam pipe.

2. THE FINUDA PHYSICS AIMS

FINUDA [2] is a high-resolution spectrometer cylindrically arranged around the *DAΦNE* beam pipe, optimized for large geometrical acceptance ($> 2\pi$ sr) and high momentum resolution ($\Delta p/p \leq 0.3\%$), exploiting dedicated triggers.

FINUDA is a nuclear physics experiment carried out at a collider, using as *beam* the K^-'s resulting from the decay of the primary ϕ mesons. It uses hence a completely unconventional technique, which gives the possibility to determine with great accuracy the K^- stopping point inside a thin target. Thus, the hypernuclei formed through the reaction:

$$K^-_{stop} + {}^A Z \rightarrow {}^A_\Lambda Z + \pi^- \qquad (1)$$

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are produced close to the outer target surface, making possible very good resolution (minimizing straggling) on the measurement of the momentum of the outgoing prompt π^-'s emerging from the two-body reaction (1). In conventional fixed target experiments employing kaon beams, conversely, the need to use thick targets introduces the major limitation on the achievable resolution in spite of the very good performance of the employed spectrometers.

Moreover, the FINUDA facility permits reconstruction of the hypernuclear production vertex in the target inside the spectrometer, therefore allowing detection the hypernuclear decay products with large solid angle and good momentum resolution: a difficult (if not impossible) task in conventional experiments.

3. THE FINUDA SPECTROMETER

The FINUDA spectrometer is formed of two parts: a superconducting solenoid (operating field 1.1 T, inner length 2.4 m, cryostat inner diameter 2.7 m) with its iron yoke, and multilayered arrays of detectors surrounding the $DA\Phi NE$ beam pipe for triggering and tracking purposes.

A precisely manufactured removable mechanical structure, called *Clepsydra*, sustains all detectors and the beam pipe itself. It includes also some of the machine quadrupoles since the solenoid is, in fact, part of the accelerator lattice itself. Fig. 1 shows a pictorial 3-D view of the FINUDA experimental setup.

3.1. The magnet

The FINUDA solenoid [3], manufactured by ANSALDO, has a double layer coil, with 2.92 m inner diameter and 2.1 m total length. It is made of a total of 6100 m of pure aluminium stabilized NbTi/Cu superconducting cable of different cross sections. The central coil (1.17 m long) employs a larger cross section cable with respect to the (0.465 m long) end parts, in order to increase the field uniformity through circulation of higher current densities at the extremities (2850 A/cm^2 and 4021 A/cm^2, respectively) at the fixed operating current of 2764 A. The solenoid is inserted into an octagonally shaped iron barrel, 2.4 m long and 4.2 m external diameter, closed, at both ends, by two iron end-caps, properly shaped, with a 38 cm diameter central hole to house the beam pipe with elements of the machine lattice and their services. The weight of the full magnet is 240 tonnes.

The field of the magnet has been measured throughout the inner volume using an already existing device furnished by CERN, modified to fit with the FINUDA dimensions. Both the axial, (main) z-component, and the radial and tangential (minor) components have been measured, and show that the quality of the field and its uniformity over the tracking volume can assure the designed resolution in tracking charged particles from hypernuclear formation and decay.

In Fig. 2 and Fig. 3 the measured axial component (B_z) and radial component (B_r) are plotted versus the z coordinate at a radius r = 13 cm and r = 8.6 cm, respectively, from the magnet axis. The absolute error of the used set of Hall probes is $\approx$ 5 Gauss.

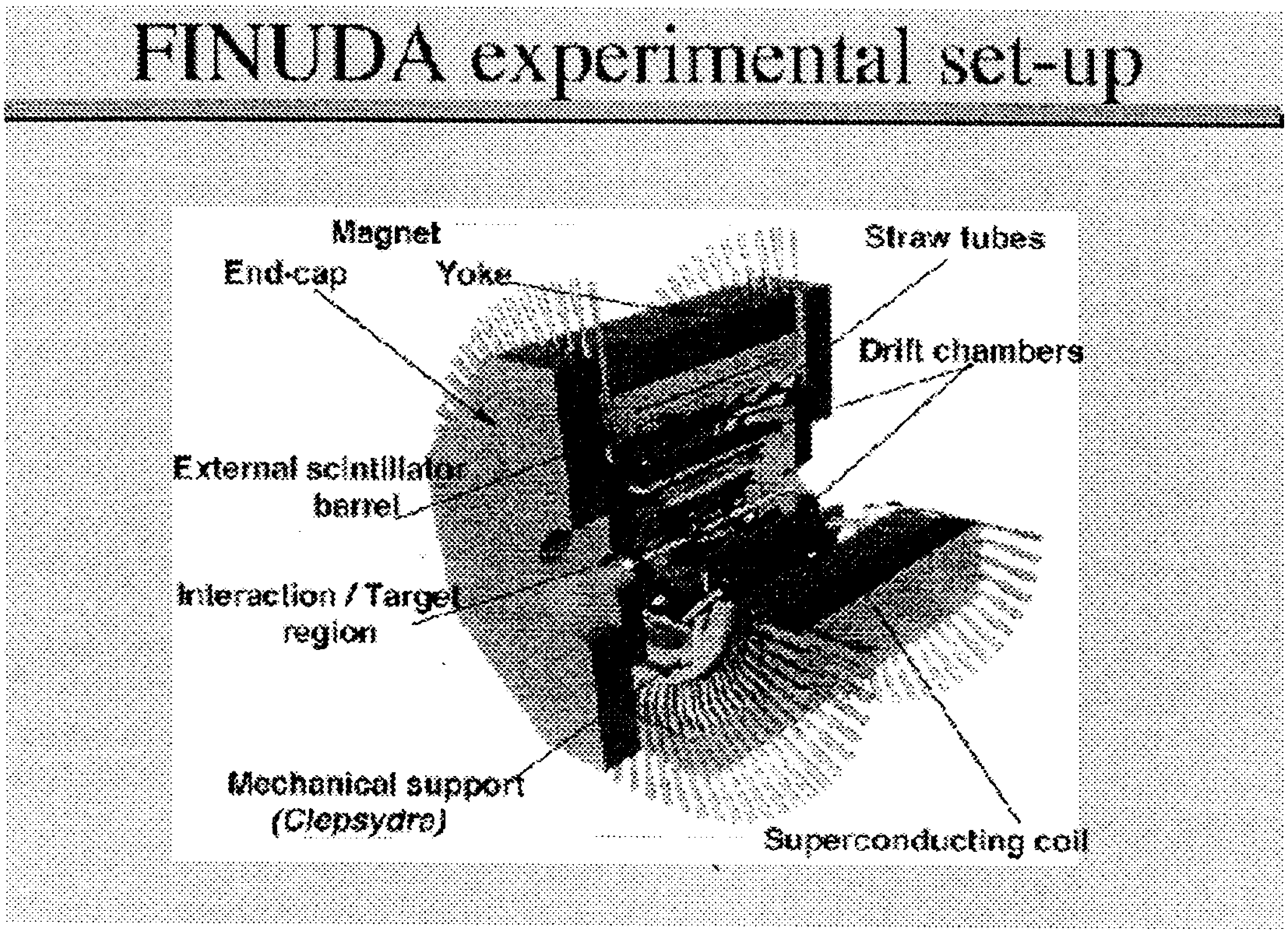

Figure 1. Pictorial 3-D view of the FINUDA facility.

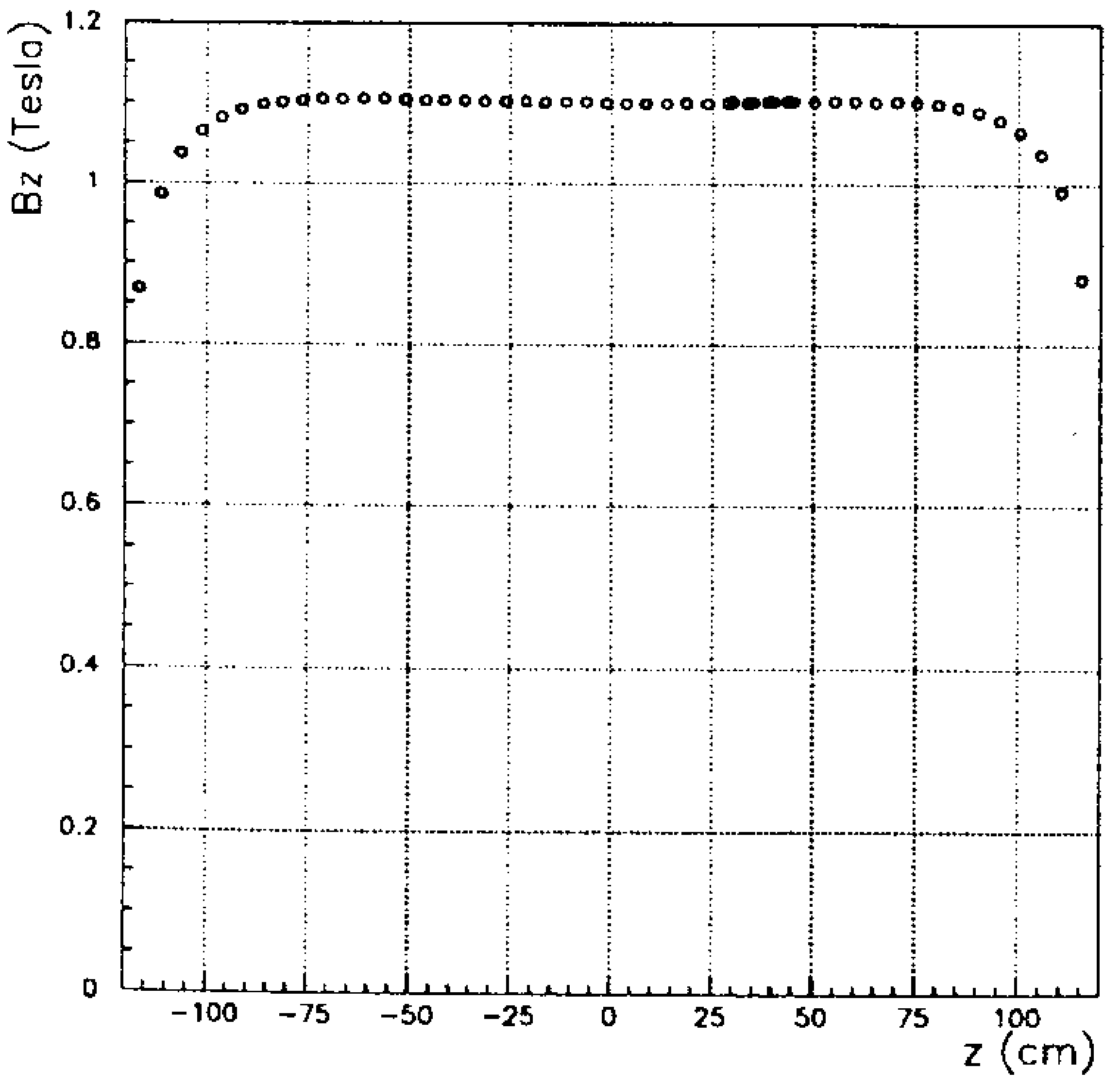

Figure 2. The main, axial B_z component of the FINUDA magnet, at the maximum current, measured in the inner volume versus the z coordinate at a distance r=13 cm from the magnet axis.

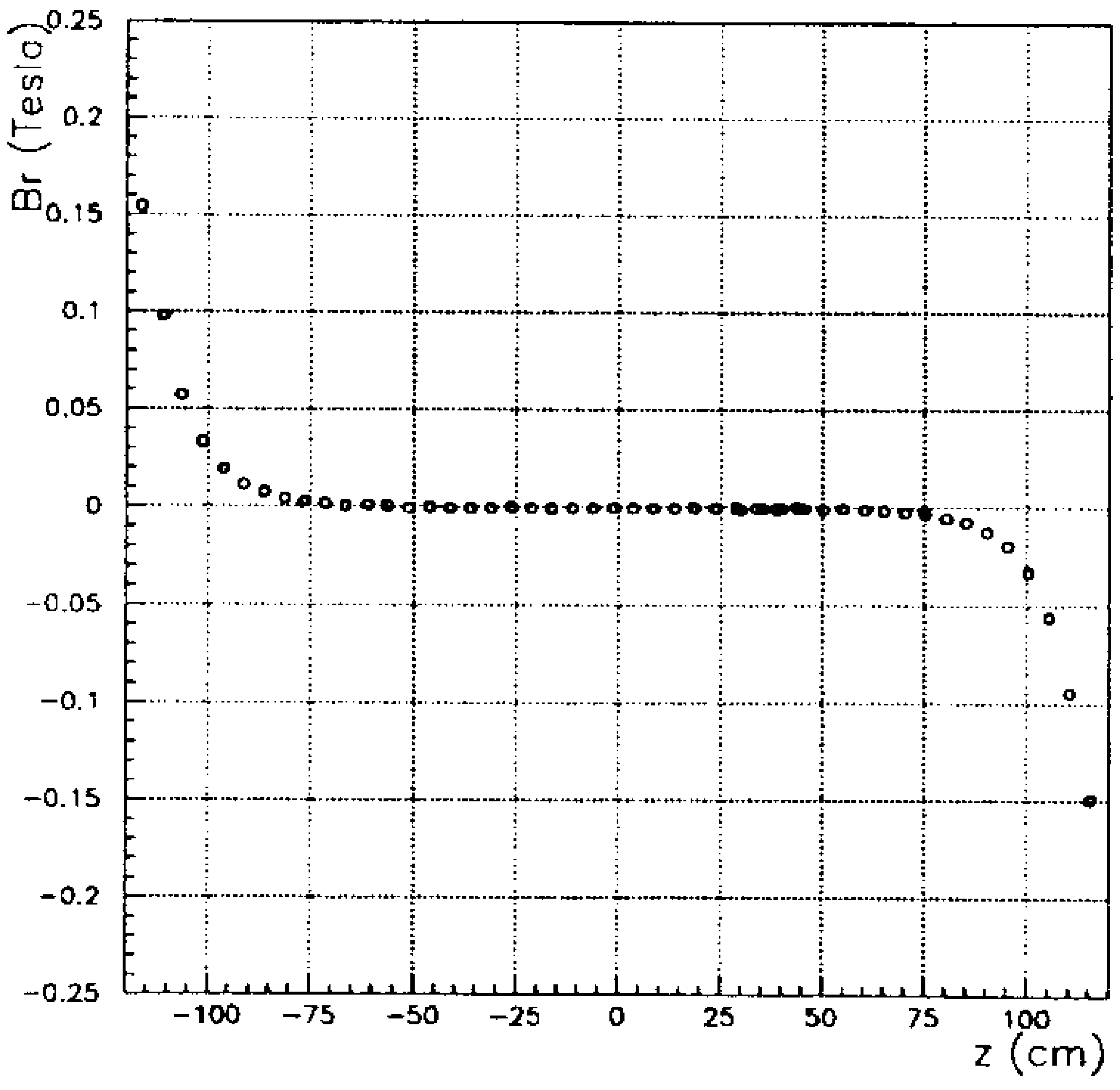

Figure 3. The minor, radial B_r component of the FINUDA magnet, at the maximum current, measured in the inner volume versus the z coordinate at a distance r=8.6 cm from the magnet axis.

3.2. The detectors

The detectors of FINUDA can be divided into three regions around the beam pipe: vertex region, tracking region, and external scintillator barrel region.

3.2.1. Vertex region

The beam pipe (made of Be, 400 μm thick and 102 mm diameter) is surrounded by a barrel of 12 thin scintillators whose inner diameter is 112 mm. Each slab (2.3 mm thick, 20 cm long) is seen at both sides, through short light guides, by Hybrid Photo-Diodes (HPD), able to work inside the magnetic field with good gain. This inner scintillator barrel (*tofino*) will select, at trigger level, the charged, slow K^+, K^- from the minimum-ionizing particles (MIP: π, μ, e), by measuring their energy loss and back-to-back topology.

The *tofino* detector has been fully mounted and tested, including also measurements inside a 1.1 T magnetic field, and is ready for final installation. Its performances assure very good separation between charged kaons and MIP's with a time resolution of 250-300 ps (fwhm).

Going outwards, after *tofino*, there is an octagonally-shaped layer (ISIM) followed by a decagonally-shaped layer (OSIM) of double-sided Si microstrips, 300 μm thick each. The Si microstrip detectors have a resolution of 20 μm fwhm both in z and ϕ coordinates.

As shown in test beams, they also provide good dE/dx discrimination between charged slow momentum particles and MIP's (see Fig. 4).

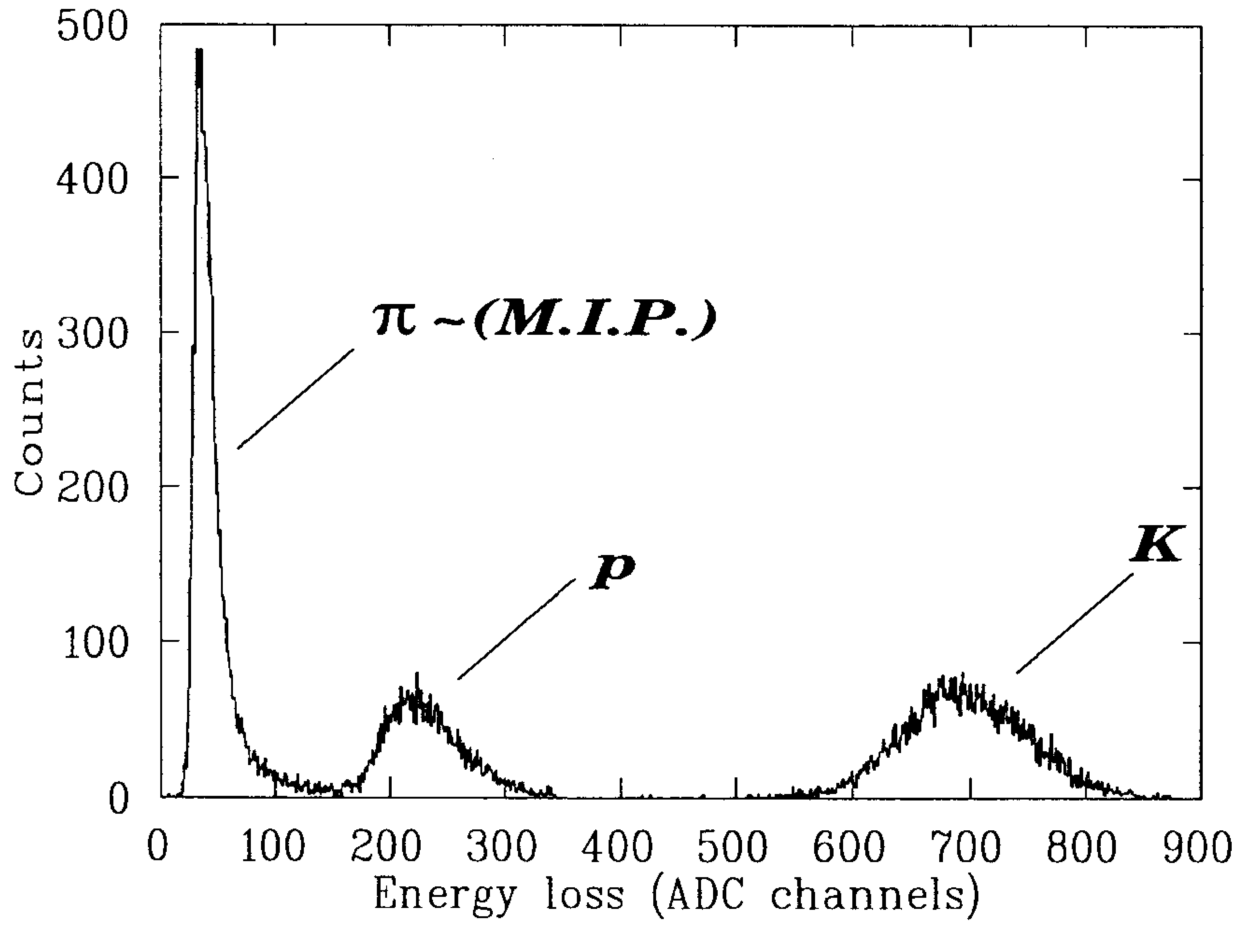

Figure 4. Cluster charge histogram from a complete FINUDA module tested at TRIUMF. The three peaks correspond to energy loss in the Si microstrip of pions of 407 MeV/c (π), protons of 407 MeV/c (p) and protons of 270 MeV/c (K), the latter corresponding to the energy release of charged kaons from ϕ-decay at rest.

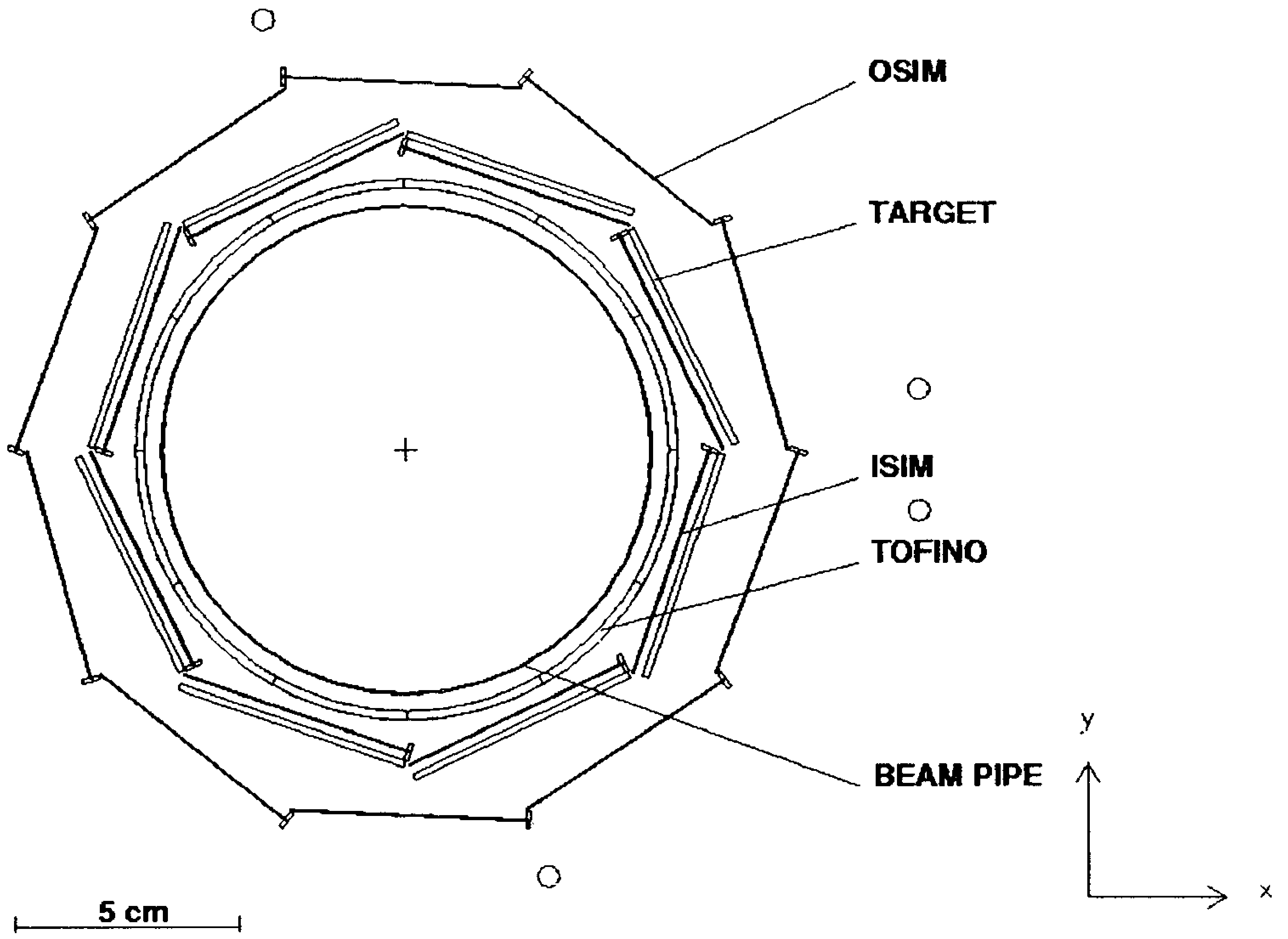

Figure 5. Schematic front view of the vertex region.

Charged kaons are stopped in a thin target located between the two layers. The target is composed of eight independent slabs.

The inner Si microstrip layer ISIM will provide very accurate information on the impinging point of charged kaons on the target, while the outer Si microstrips OSIM will provide with high precision the first point on the trajectory of the outgoing prompt π^- from hypernucleus formation. The two pieces of information can be used to determine to a level better than 200 μm the hypernuclear production point inside the target, improving then significantly the final momentum resolution.

To build these detectors, 18 identical modules (52.6 × 65.4 mm^2 each) are needed. Twelve of them are ready and the rest (plus 2 spares) will be available in March 1998.

In Fig. 5 a schematic drawing of the vertex region is shown.

3.2.2. The tracking region

The tracking region is composed of two layers of planar low-mass drift chambers and a multilayered stereo array of long straw tubes.

The drift chamber layers are located at about 30 cm and 60 cm from the center of the pipe, each layer being formed by eight planar drift chambers arranged as an octagon around the pipe. They employ very thin windows (6 μm) to minimize multiple scattering. For the same reason a He-based gas mixture is employed (He-iC_4H_{10} 70%-30%). The chambers of the first layer are 1230 mm long and 396 mm wide, while those of the second layer are 1870 mm long and 686 mm wide. The chambers provide, according to test beams, a measured spatial resolution 100 μm rms in x, y coordinates, and 0.51 mm rms in z (by charge division) [4]. All chambers have been built and tested and are ready for final installation.

Starting at a radius of 116 cm from the beam pipe, six layers of straw tubes are positioned, each straw having a diameter of 15 mm and a length of 2.5 m. Two layers are parallel to the beam axis, while two layers are at an angle of +12.5 degrees and two at an angle of -12.5 degrees respect to it (stereo straws). In each layer, the straws are staggered at a distance equal to their radius. A total of 2424 straw tubes is used in the FINUDA spectrometer. Each straw is made of mylar, 30 μm thick, aluminized inside, with a 30 μm thick gold-plated W wire as anode. FINUDA is the first experiment using mylar straws in such a large number and with such big dimensions.

The performance in resolution is very good, showing, according to test beams, 100 μm rms in x, y coordinates using a gas mixture of Ar-Ethane (50% -50%) or Ar-CO_2 (50% -50%) (at normal pressure) [5]. The stereo straws will allow the determination of the z-coordinate with a fwhm of 500 μm.

All straws have been installed and tested one-by-one inside the *Clepsydra* mechanical structure, including the preamplifiers, the individual gas piping and cabling.

In Fig. 6 a schematic frontal view of all the FINUDA detectors is shown.

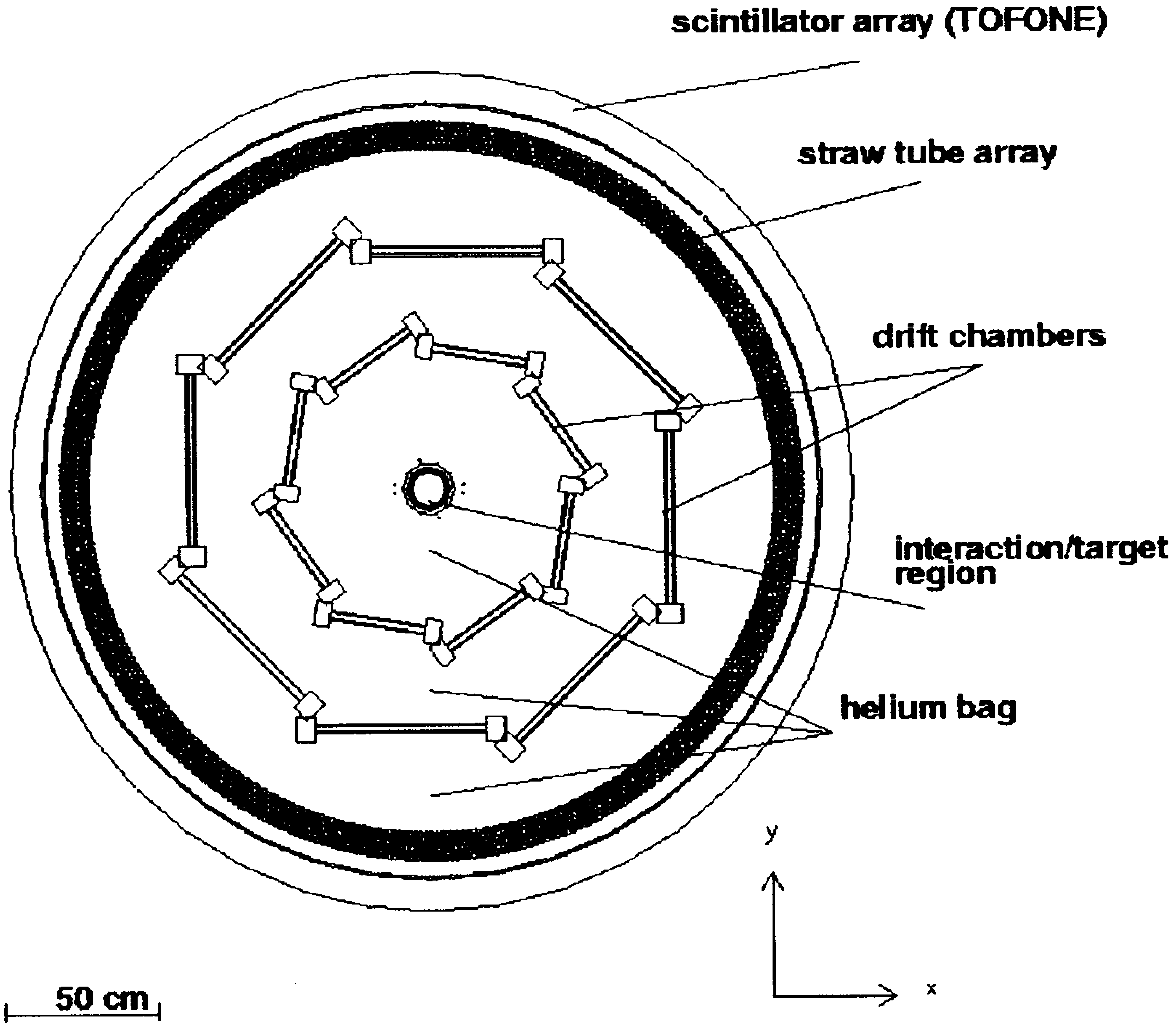

Figure 6. Schematic front view of the FINUDA detectors.

To preserve the performance of the FINUDA facility, all the factors worsening the resolution must be kept at the minimum level. The main factor turns out, from detailed Monte Carlo simulation, to be the multiple scattering of charged particles on the air between the tracking detectors. For this reason, all the volume between OSIM and the straw tubes will be filled by He at NTP, using a complex setup of properly shaped, radially wall-free bags, which are undergoing the final phase of construction. These bags will reduce multiple scattering by more than a factor of two with respect to air.

3.2.3. The outer scintillation detector

To improve the trigger capabilities for selection of hypernuclear events and to exploit the FINUDA capability of detecting the products of hypernuclear decay, an outer barrel of scintillators is employed. Its aim is the detection of both the prompt π^- emitted in hypernuclear formation and the nucleons from non-mesonic hypernuclear decay. The barrel (*Tofone*), located at a distance of 127 cm from the beam axis, is formed by 72 scintillator bars, each 255 cm long and 10 cm thick. Each slab has trapezoidal shape (major, outer base 12 cm, minor, inner base 11 cm), and is seen at both sides by an XP2020 phototube. The phototubes are operated outside the magnetic field, using a 90 degree deflector prism, coupled, through a conical connection, to a straight cylindrical light guide. This system provides a 80% light collection efficiency. The measured performances of this detector are a time resolution of 240 ps (rms), a neutron acceptance of 40% of full solid angle and a 12% neutron detection efficiency.

This detector is ready to be installed on the inner surface of the cryostat.

4. INFRASTRUCTURES AND INSTALLATIONS

As mentioned, FINUDA is a very unconventional nuclear physics experiment, being performed on a collider. This fact poses severe constraints on the hardware, the infrastructure, the installation (in an already working collider), and the interfacing of the experiment to the machine, that are much more demanding than in a conventional nuclear physics experiment performed with an extracted beam on a fixed target.

Moreover, the running of the experiment itself has to rely on a smooth operation of all parts of the facility (superconducting magnet, detectors, controls) for long period of time, since any access to the machine hall implies killing the beam for all users.

In such respects, definite progress has been made in defining and settling all the above aspects, and the FINUDA facility is going to match all the requirements to be installed and operated on $DA\Phi NE$.

5. CONCLUSIONS

The FINUDA facility is undergoing the final assembly of its components.

All detectors have (or are being) been built, and test beam experiments performed on all of them show that they have the performance required to match the physical goals of FINUDA.

Regarding the resolution, the 0.3% project momentum resolution on the prompt π^- will permit the achievement of 700 keV resolution on hypernuclear levels. The counting rate, due to the large spectrometer acceptance (40% of 4π), permits detection of Λ-hypernuclear states at a rate of 75 per hour at the luminosity of 10^{32} cm^{-2}s^{-1} (for a yield of 10^{-3} formed hypernuclear states per $K^-_{stopped}$). Moreover, the study of non-mesonic hypernuclear decay, both into the *pn* and *nn* channels, will be fully accessible with FINUDA, while the possibility to use simultaneously up to 8 different targets will allow a flexible, systematic, high-quality study of hypernuclear physics.

The performance of the FINUDA facility well compares with existing and projected experiments for hypernuclear studies.

In Fig. 7 the performance of different facilities is summarized: as seen FINUDA will couple high resolution with high counting rates and the full feasibility to study hypernuclear non-mesonic decays.

The FINUDA installation on *DAΦNE* is a complex and lengthy operation, that has been coordinated with the commissioning phase of the machine, and has been fixed to take place in the second half of 1998.

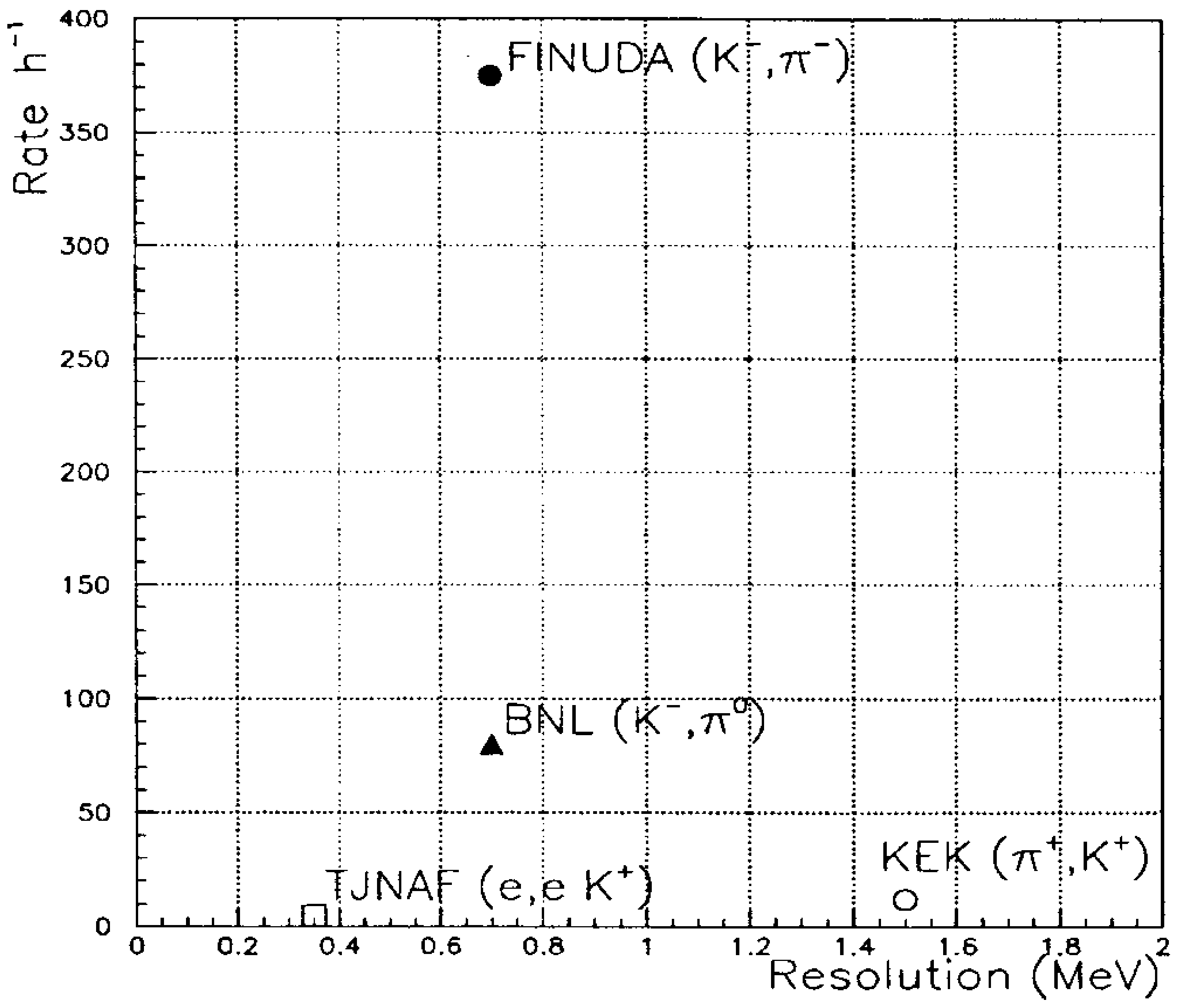

Figure 7. Comparison of different facilities for hypernuclear study, showing their projected resolution and counting rate and their feasibility to measure the non-mesonic hypernuclear decay (NMHD). The studied reaction is also shown. Full dots: NMHD fully feasible; open dots: NMHD feasible; full triangle: NMHD difficult; open square NMHD not possible.

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