Straw Tube Detector of FINUDA Experiment.

L. Benussi, M. Bertani, S. Bianco, F. L. Fabbri, P. Gianotti, M. Giardoni, C. Guaraldo, A. Lanaro, V. Lucherini, A. Mecozzi, L. Passamonti, V. Russo, S. Sarwar, and V. Serdiuk.

Laboratori Nazionali di Frascati,
Via E. Fermi 40, I-00044 Frascati, Italy.

The FINUDA detector is a magnetic spectrometer optimized to study hypernuclear physics at DAΦNE. The tracking part of detector contains a large cylindrical array of 2424 straws which are 2.55 m long and are required to provide a space resolution of $\sim$ 100 μm. The FINUDA straw tube detector is now in an advanced phase of construction at National Laboratories of Frascati. The straw tube detector design, structural components, and readout electronics are presented in this work. A discussion of experimental results obtained from prototypes and treatment of systematic effects, inevitably present in the case of long straw tubes, is included.

1. Introduction

The Frascati Φ-factory DAΦNE, being an e^+e^- collider operating at a center of mass energy corresponding to Φ mass, will provide $\sim$ 1000 K^+K^- pairs/sec. These low energy (16 MeV) monochromatic Kaons are background free and will be used in the nuclear physics experiment FINUDA [1],[2].

Stopping the K^- from DAΦNE in a thin target, FINUDA is aiming to study Λ-hypernuclei using the (K^-_{stop},π^-) reaction. Spectroscopy of Λ-hypernuclei is one of the main physics goals of FINUDA. Products from non-mesonic decay of Λ-hypernuclei will also be detected which will allow the lifetime measurements and the possibility to study the violation of Δ I = 1/2 rule in the weak interactions of strongly interacting particles. K–N scattering, search for a π^+ decay mode of hypernuclei, and K^+–Nucleus total cross section are other examples of physics possibilities of FINUDA.

FINUDA experimental apparatus (fig.1) is in an advanced stage of construction and is composed of a superconducting magnet which provides a solenoidal field of 1.1 T. Charged particle tracking is realised by a set of detectors providing $\sim$70 % of the solid angle coverage. These tracking devices consist of silicon microstrips and gas filled detectors (drift chambers and straw tubes). Tracking will be possible with a typical precision of 100 μm and low-mass design of the apparatus should guarantee a momentum resolution of 0.3 % for π^- produced during the hypernuclei formation. This corresponds to a resolution of 0.7 MeV in determination of energy levels of hypernuclei.

2. Straw tube detector

The outer most tracking device of the FINUDA apparatus employes 2424 straw tubes. The straws are expected to measure the passing point of charged particles both in x–y plane (100 μm resolution) and along the z-axis (300 μm resolution). FINUDA straws are geometrically arranged in one axial and two stereo layers as shown in fig.2. Each layer contains two sub–layers of staggered straws with an inner diameter of 15 $\pm$ 0.05 mm. The straw length, as determined by the required geometrical acceptance, is 2.55 m. The tubes are made of mylar with a wall thickness of 30μm and the inside of each straw is metalized by vapor deposition of a thickness of 0.2 μm of aluminum.

Gold plated tungsten wire with a diameter of 30 μm is used as anode. The anode wire is crimped in copper pins at both extremes. Each straw is held in its position by employing a feedthrough assemblies at both ends. The feedthrough consists of an aluminum cylinder which, on the straw side, has an external diameter

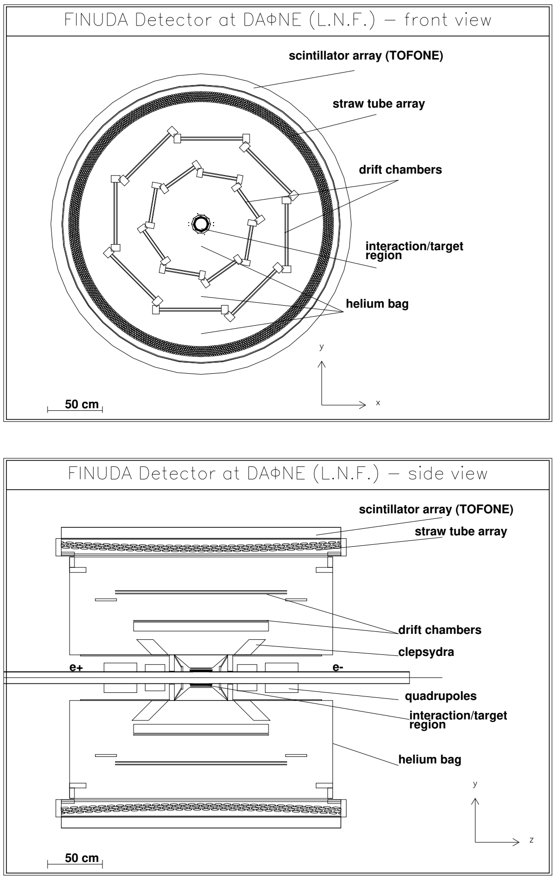

Figure 1. FINUDA experimental setup.

equal to the straw inner diameter. The inner surface of the straw is glued on to feedthrough using a silver–based conductive glue. The endplate side of the feedthrough is externally threaded which when tightened with the corresponding nut permits the feedthrough to move along the axis of the endplate hole while pulling the straw to the required tension. The feedthrough contains an inner delrin body which accommodates the wire pin and provides the gas inlet/outlet for the straws.

During the assembly the inner surface of the straw on the two ends is glued on to feedthroughs. When the glue is hardened, feedthroughs are inserted in a fixture and the straw is tensioned to 15 N. The straws are held in a vertical position and the wire is strung through the feedthroughs

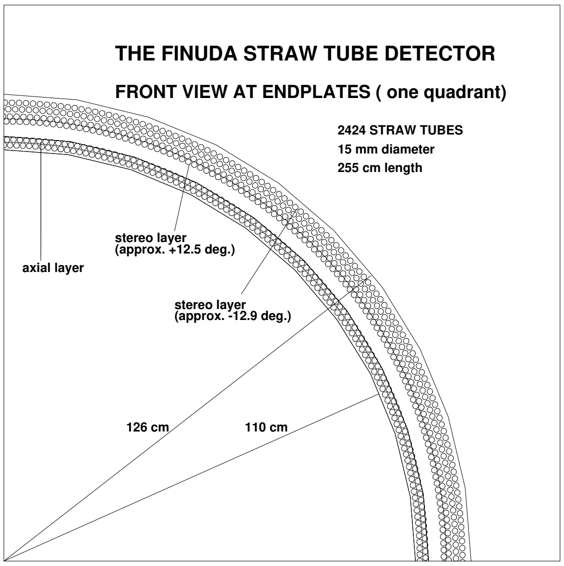

Figure 2. Geometrical layout of FINUDA straws. A cross section in x–y plane is shown.

and straw. The wire is now made to pass through the pins which in turn get inserted in feedthroughs. The top pin is then crimped, wire is tensioned to 1 N, and finally the bottom pin is crimped.

A trans–impedance amplifier is used to amplify the straw signal. The circuit is mounted on printed boards using surface mount devices. The input impedance of the circuit is 300 Ω and it has a gain value of 2 V/mA. The circuit operates with $\pm$ 6 V dissipating 50 mW per channel.

3. Performance tests with prototypes

In order to investigate the straw tube performance, different prototype arrays of aluminized mylar straws have been assembled at LNF. These prototypes have been tested with cosmic rays, with a one GeV/c π^- beam at T10 area of PS (CERN) and with a 300 MeV/c beam of negative pions at M11 channel of TRIUMF.

Different gas mixtures, including pure DME, Ar(50%)+C_2H_6(50%) and Ar(50%)+CO_2(50%) have been used to estimate the straw gain and space resolution. In a typical test setup, a pair

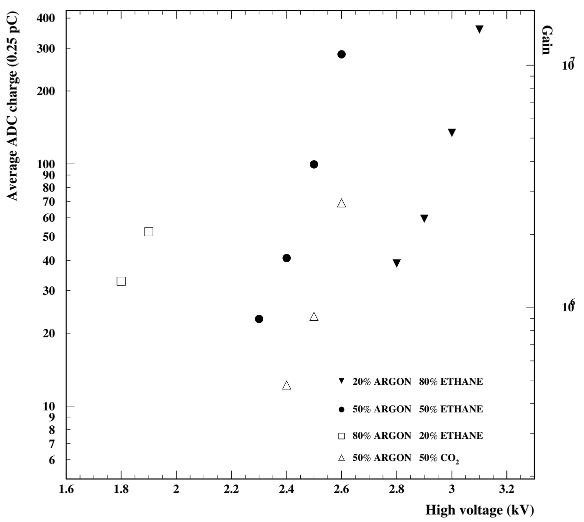

Figure 3. Average ADC charge for signals started by single electrons. The scale for gas gain is shown on the right.

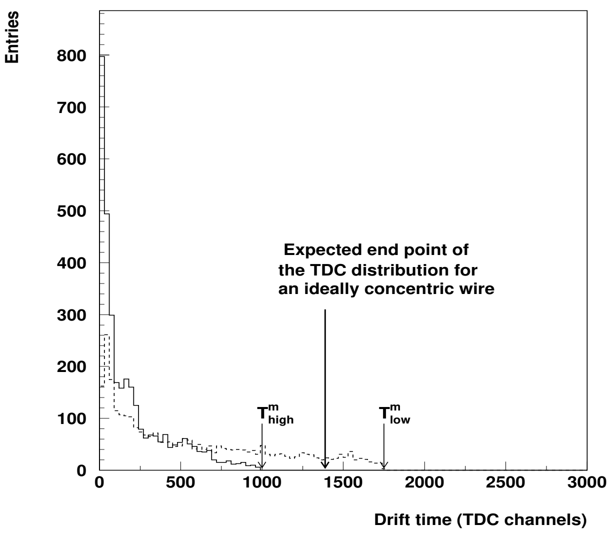

Figure 4. TDC distributions for tracks passing above (solid histogram) and below the wire (dashed histogram).

of scintillators is used to define the beam spot. Coincidence of these two gives the start signal to TDCs whereas the amplified and discriminated straw signals are used to provide the stop signal to TDC channels.

3.1. Gas gain

Gas gain obtained with pure DME has already been reported [3]. The same method of integrating wire pulses originated by single electrons produced by photoemission from cathode surface was used to measure the gas gain for $Ar+C_2H_6$ and $Ar+CO_2$. The dependence of gas gain on straw voltage is shown in fig.3. Straw tube operation with the FINUDA preamplifier, with a gain of 2 V/mA , requires a gas gain of the order of 10^6. From fig.3 it can be seen that for some of the mixtures, gas gain exceeding 10^6 can be reached leaving a margin of $\sim$ 300 V before the gas discharge sets in.

3.2. Time to space conversion

In the ideal case, when the wire and straw centers coincide, the electric field has a cylindrical symmetry and is inversely proportional to the distance from wire. However, due to gravitational and electrostatic forces the wire and straw centers do not coincide.

A simple method can be used to experimentally determine the straw eccentricity. For the test beam data the tracks passing above and below the wire can be separated and the corresponding TDC distributions in the case of pure DME are shown in fig.4. The straw eccentricity creates an asymmetry in the electric field resulting in zones of low and high field as compared with an ideally concentric straw. The drift velocity is lower than the ideal case for the tracks passing through the low field region (below the wire) and therefore the TDC distribution extends beyond the maximum value for the ideal case. On the other hand, the drift velocity is higher than the ideal case for the tracks passing through the high field region (above the wire) and correspondingly the TDC distribution terminates before the maximum value for the ideal case. In fig.5 the correlation between calculated T^m_{high} and T^m_{low} values for different values of straw eccentricity is shown together with experimental data for different straws and for different values of the beam distance from

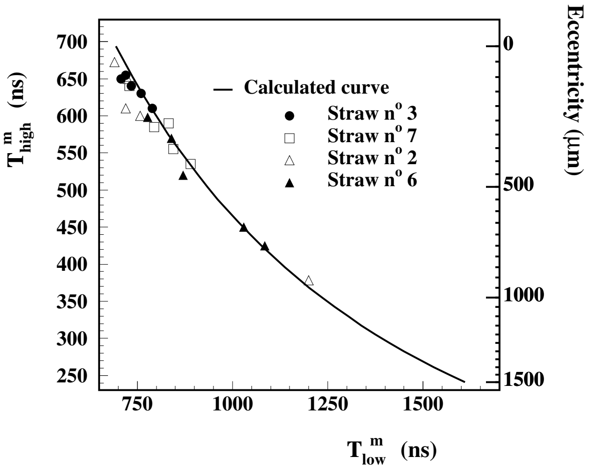

Figure 5. Correlation between the end points of TDC distributions for the high and low field zones. Both T^m_{high} and T^m_{low} values are determined by the straw eccentricity.

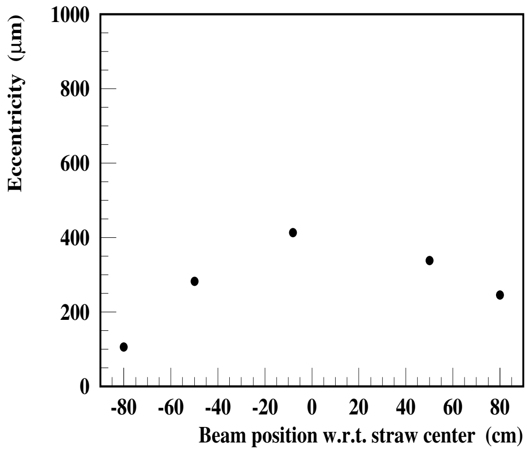

Figure 6. Measured straw eccentricity as a function of distance from the straw center. The eccentricity is determined from the end points of the TDC distributions.

the straw center. By observing the T^m_{high} and T^m_{low} values, the eccentricity for each straw can therefore be determined (fig.6).

Once the eccentricity is known, the electric field can be computed using the method of images [4]. The TDC values are transformed into drift distances for the hit straws using the corresponding time–to–space relationship. For DME the field dependence of drift velocity as parametrized by [5] is used to compute the time–to–space relationship. For $Ar+C_2H_6$, a constant drift velocity of 52 μm/ns is assumed. The time–to–space relationship for $Ar+CO_2$ is obtained from Garfield [6] simulation.

3.3. Space resolution

In order to determine the space resolution for the staggered straws one can define a function R_s:

$$R_s = (r_1 + r_2)/2 + r \quad (1)$$

where r is the drift radius measured by the central straw and r_1,r_2 are the drift radii measured by the two external straws. The rms of the function R_s, denoted by σ_s, is given by:

$$\sigma_s = \sqrt{\frac{\sigma^2(\Delta - r)}{2} + \sigma^2(r)} \quad (2)$$

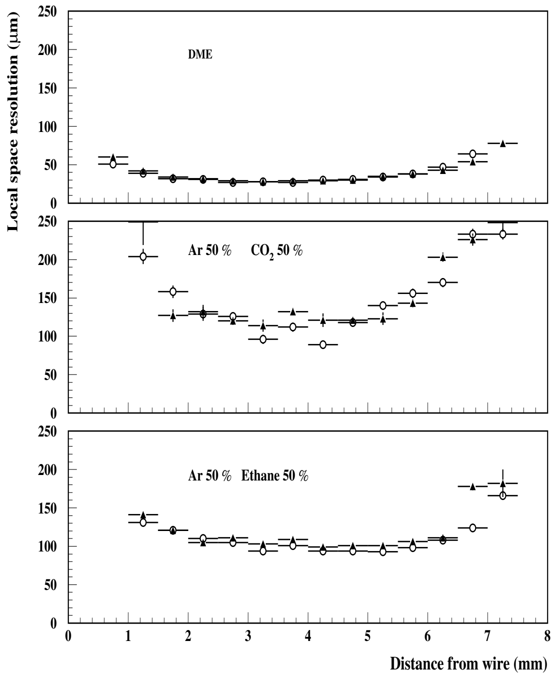

Figure 7. Dependence of local space resolution on drift distance measured with 15 mm diameter straws.

Table 1
Comparison of straw tube performance with pure DME, Ar+C_2H_6 and Ar+CO_2 .

	DME	Ar+C_2H_6	Ar+CO_2
Space resolution (μm)	40	100	150
HV plateau (V)	1000	300	50
Maximum systematic error due to $E \times B$ effect	negligible	200 μm	negligible
Saturated drift velocity	no	yes	no
Flammable	yes	yes	no
Material compatibility	poor	good	good
Relative operating cost	5	4	1

where Δ is the stagger distance between the straws and the function $\sigma(r)$ represents the straw *local space resolution* at drift distance r. The dependence of the local space resolution on drift distance, for different gas mixtures, as obtained from σ_a values by inverting eq.2, is shown in fig.7.

The best performance is shown by pure DME with a space resolution of 50 μm or better throughout the straw radius. In case of Ar+CO_2 the resolution varies between 100 μm to 200 μm. For tracks passing near the wire the space resolution is dominated by jitter in time measurements, whereas for tracks passing near the straw wall the resolution is determined by electron diffusion. For the major part of the straw radius the resolution is smaller than 150 μm. In case of Ar+C_2H_6 , for the most part of the straw radius, the resolution is dominated by jitter in time measurements and is smaller than 100 μm.

4. Effect of magnetic field

The Lorentz angle for pure DME is expected to be $1^o\sim2^o$ [7]. However in a gas mixture like Ar(50%)+C_2H_6(50%) the lorentz angle is a magnitude of order higher and the straw operation in a magnetic field of 1.1 T may be significantly influenced. The effect of magnetic field on the operation of straws has been investigated using Garfield simulations. For comparison, the Lorentz angle for a 15 mm straw with the three gases under consideration is shown in fig.8. For Ar+C_2H_6 the Lorentz angle varies from 46^o at the straw surface to about 4^o at the wire. The value of Lorentz angle for Ar+CO_2 is about 10^o and that for DME is less than 1.6^0.

The influence of $E \times B$ effect for the axial straws, operated with any of the three gases, can easily be handled with a modification in the used time–to–space relationship. For stereo straws there is a distortion in the circular nature of the isochrones. If the isochrones are still considered as perfect circles, the error introduced due to this simplifying assumption, in the case of Ar+C_2H_6 is 200 μm. Whereas this error is negligible in the case of Ar+CO_2 or DME.

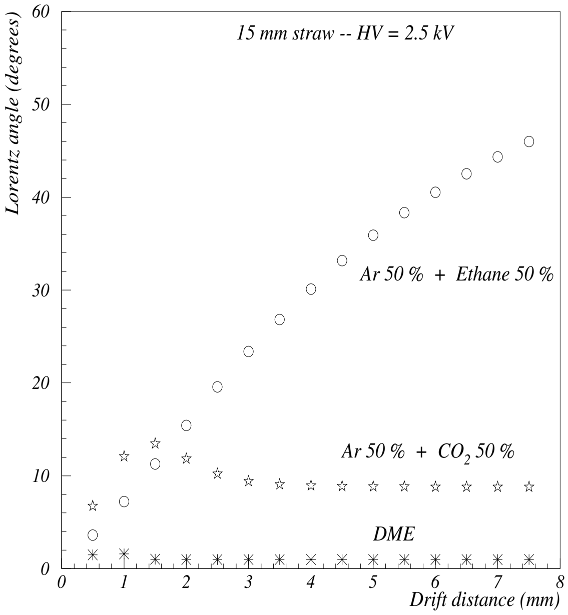

Figure 8. Calculated Lorentz angle as a function of drift radius. A solenoidal magnetic field of 1.1 T has been used.

5. Conclusions

The straw tube detector of FINUDA experiment, being under construction at LNF, has been designed to provide a tracking area of 10 m^2 with a resolution of 100 μm in the x–y plane and 300 μm along the z–axis. Operation feasibility of straw tubes has been investigated with gas mixtures of $Ar+C_2H_6$ and $Ar+CO_2$ and pure DME. A comparison of three gasses is shown in table 1.

The use of pure DME, not only gives a space resolution of 40 μm but is also insensitive to the presence of 1.1 T magnetic field. The singles count rate plateau is wider than 1000 V and therefore a large number of straws can be operated, while supplying their high voltage in parallel, from a single supply channel. On the other hand DME is known to interact with many of the plastics and is flammable.

$Ar+C_2H_6$ can reach a space resolution of 100 μm but is prone to systematic effects due to the presence of magnetic field. This mixture is flammable but has the advantage of providing a saturated drift velocity and therefore the straw operation is independent of variations in gas pressure and temperature.

$Ar+CO_2$ is non-flammable, has an acceptably small Lorentz angle and a space resolution of 150 μm can be reached. However the singles count rate plateau has a very short width and a stable operation of a large number of straws is critical.

REFERENCES

1. M. Agnello et al., LNF report LNF-93/021 (IR). 1993
2. M. Agnello et al., LNF report LNF-95/024 (IR). 1995.
3. L. Benussi et al., Nucl. Instr. and Meth. A361, (1995) 180
4. For instance see W. R. Smythe, Static and dynamic electricity (McGraw–Hill, New York, 1950).
5. G. Bari et al., Nucl. Instr. and Meth. A251, (1986) 292
6. Garfield, a drift–chamber simulation program, CERN Program Library entry W5050.
7. B. Zhou et al., Nucl. Instr. and Meth. A287 (1990) 439.