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The outer tracking detectors for the E760 experiment at Fermilab

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1 Introduction

Experiment E760 at Fermilab [1,2] will perform precision measurements of charmonium spectroscopy. Charmonium states are directly produced by collisions of an antiproton beam circulating in the Fermilab antiproton accumulator onto an internal hydrogen jet target.

The E760 detector (figure 1) includes an inner tracking system, an outer tracking system, a central and an end cap electromagnetic calorimeter, trigger scintillators and a luminosity monitor device.

The physics program of E760 requires as a fundamental tool the reconstruction of charged particles tracks and the identification of electrons.

The detector design was strongly constrained by the smallness of the available space (all the charged particle detectors had to fit within a cylinder of 60 cm radius), the high luminosity ($\sim$ 1 MHz of particles crossing the barrel detector), and the need of good accuracy in reconstructing tracks, particularly near the beam pipe.

Such requirements were met by a three system based detector:

- an inner tracking detector, consisting of a straw tube chamber [3], a radial projection chamber and a cylindrical multiwire proportional chamber [4],
- a threshold Cherenkov counter [5], capable of discriminating electrons against pions over the whole kinematical range;

- an outer tracking detector, consisting of a barrel of limited streamer tubes (L S T) and an end cap multiwire proportional chamber, which will improve the accuracy in the event reconstruction because of the larger lever arm. Here the requirements of compactness are more stringent than the space resolution, and the less expensive technique of L S T 's was used in the barrel detector, while the end cap region required the use of MWPC's, which allow handling larger particle intensities.

The outer tracking detector and its performance in laboratory tests and in a test run in the antiproton accumulator are described in this paper.

2 Limited streamer tubes barrel

The cylindrical outer detector that we designed and built has diameter 128 cm, length 135 cm, total thickness 4 cm, and is formed by two layers of Iarocci tubes [6].

In the limited streamer mode [7] saturated ionization and strong fast signals are obtained. This gives high and stable detection efficiency even if one uses, as in our case, a capacitive signal readout, by means of conductive strips [8].

This technique offers a good advantage in decoupling the readout from the high voltage supply so that tube substitutions do not imply major dismountings of the L S T barrel.

Our readout is digital for most channels; a channel subset is read out by ADC's to improve the spatial resolution on the measure of one coordinate.

The selected solution, namely to read out the strips through thin coaxial cables, solves the problem set by the restricted free space: the L S T barrel in fact is allowed to occupy only a thin cylindrical shell; this prevents from mounting the front end electronics on the detector directly. The readout cable induced attenuation is coped with by the high amplification gain.

The forementioned geometrical constraints, together with the transparency requirement, led naturally to the use of non metallic materials also for the support structure, with connected difficulties in assuring mechanical rigidity.

The resulting radiation length (in a direction orthogonal to the cylindrical surface) is $\sim 5\ \%\ X_o$. As it will be clear considering the detailed barrel structure, the traversed radiation length varies as a function of the azimut ϕ having as upper bound $\sim 9\ \%\ X_o$ in the intermediate regions where the tube spacers are located.

2.1 Basic module structure

The barrel basic module is a polymeric vinyl chloride [9] tube, 135 cm long, into which a PVC profile, forming 7 coverless cells [10], is inserted. The density is $\sim 1.2\ g\ cm^{-3}$ for this kind of PVC. The side of the square section cells is 9 mm. As a matter of fact the coverless design has been slightly modified, since the cell sides are graphite coated on the fins only (by fins we mean the faces which are orthogonal to the larger side of a tube cross section).

A gold plated tungsten anodic wire, of diameter 100 μm, is streched (with $\sim 200\ g$ tension) at the centre of each cell. A tube cross section, with its profile inside, is shown in figure 2.

Two wire supporting plastic holders are placed in intermediate positions, at 45 cm distance from the tube sealing plugs.

The cathode surface is obtained by graphite coating, as usual [11,12], but the coating is restricted to the profile fins only and the resistivity brought to a value lower than usual: $\sim 2k\Omega/\sqcap$ [13]. These devices, together with an enhanced gas flux, allow to operate up to particle rates of $\sim 15\ sec^{-1}$ for cm^2 ; moreover they imply a better spatial resolution [14].

The sensitive elements are placed in contact with the larger tube faces. They are made of aluminium strips, 40 μm thick, set in raws on a plastic PVC support, 1.5 mm thick, with a 10 mm pitch. The strip width is 4 mm for elements parallel to the wires, 8 mm for elements orthogonal to them.

2.2 Limited streamer mode operation

The strong quenching required for the limited streamer mode operation [15] is obtained by fluxing hydrocarbons or carbon dioxyde rich mixtures through the tubes.

The detectors are operated at atmospheric pressure (i.e., less than a few $mbar$ corresponding to bubblers of the exhaust lines). The regime gas rate through the tubes is $\sim 1l/h$ per sector.

The results that are presented in the following sections concern mainly runs with the standard mixture

$$A(25\%) + isoC_4H_{10}(75\%).$$

Another useful mixture is that one studied by SLD [16] :

$$A(2.5\%) + isoC_4H_{10}(9.5\%) + CO_2(88.0\%)$$

which has properties much alike the standard mixture ones, with the advantage of being non flammable and cheaper.

For the cell type described, by fluxing the forementioned mixtures and setting at operating high voltages around 4500 V, the streamer events yield typical signals of 5 to 10 mV induced on the strips. These correspond to 4 to 8 mV at the first stage amplifier input, after the attenuation in the coaxial cables.

2.3 The L S T barrel structure

The E760 barrel outer detector covers the region $22^o < \theta < 68^o$, where θ is the polar angle referred to the $\overline{p}$ beam direction, see figure 3. It is made of two L S T layers, situated at an average radial distance of 62 cm.

The detector occupies a cylindrical shell between the radii $R_1 = 597$ mm and $R_2 = 637$ mm; the details of the alternate tube layout inside the shell is shown in figure 4 (a cross section), where the intermediate supporting bar in between two of the three sectors is shown too.

The selected modularity (7 cell tubes) and the alternating layout allow to optimize the geometrical efficiency for the ϕ coverage, since, except at the sector borders, each non active region in between two adjacent tubes of one layer results ϕ aligned to an active cell belonging to the other layer; moreover the inefficiency due the cathodic fins in one layer is partially compensated by the other layer coverage.

The supporting structure, all by non metallic material, is built as follows.

Four rigid polycarbonate rings are glued and screwed to three bars, also of polycarbonate, having a ϕ separation of 120^o in between each two.

Three polygonal boxes are circumscribed to the supporting structure so obtained; these boxes form the three barrel sectors (see figure 5). Each box is built from PVC foils, 1.5 mm thick, from rigid spacers and from the two supporting bars at the ϕ ends.

The elastic coefficient with respect to bending is 23500 Kg/cm^2 for the polycarbonate which bars and spacers are made of.

Inside each sector one can get 32 cell cavities in order to house and position 32 tubes, which can slide into them. There are 16 tubes for each of the two layers in one sector.

The PVC foils are screwed on the spacers by means of small nylon screws. They bring on their inner surfaces the pick up strips that are to measure the coordinate along the cylinder axis, hence the polar coordinate θ, while the other coordinate, the azimut ϕ, is measured by a second set of strips. These are longitudinally fixed on PVC larger strips, 1.5 mm thick, which slide into the cavities together with the tubes, on the cavity side formed by the spacers.

While for the ϕ coordinate an improvement in the geometrical efficiency is implied by the fact the strips measuring ϕ are aligned with the tube wires and alternate themselves in the two barrel layers as the tubes do, for the θ coordinate a similar effect is given by a half pitch shift of one θ strip layer with respect to the other one.

The total weight of the LST barrel, coax cables excluded, comes out to be ~ 168 Kg, of which 67 Kg are accounted for by the streamer tubes and 55 Kg by the sensitive strip PVC supports.

The high voltage cables, gas inlet and exhaust tubes are attached to the cylinder base ring nearer to the interaction region; the coax signal cables exit is from the cylinder forward base, where the access is very limited due to the central calorimeter coverage. This technical solution derives from the need to maximize the acceptance at the lower θ angles, hence to minimize the non active region at one of tube ends. To this purpose the tube sealing plug not keeping the HV connector is non standard, as well as the wire anchorage, yielding a total dead region of only 29 mm longitudinally.

As far as the gas flux is concerned, there are six independent lines, both for the inlet and for the exhaust. Each of them serves a set of 16 streamer tubes connected in series by little gas transfer blocks, 15 mm large longitudinally. Each 16 tube group corresponds to one of the two layers in a sector.

2.4 Signal read out from the strips

The signals induced by streamer ionization events on the read out strips are sent, via coaxial cables (type FILOTEC VMTX 50), having external diameter 1.3 mm, length $\sim$ 6 m, to highly sensitive preamplifiers.

- For the digital read out the first stage of the preaplifier was designed in order to invert the strip positive signals and to give an additional gain of $\sim$ 5. In this way it can drive a standard two stage preamplifier (CERN type 4261), with a resulting total gain fitting the digital receiver.

- For the analogue read out the use of high sensitivity preaplifiers already designed for wire chamber special applications [17,18] was possible. This electronics chain has a total sensitivity of 190 mV/pC, a noise level of $\sim 2000 electrons R.M.S.$ in a dynamic range 4 V on a 50 Ω output load. The gain stability is $<$ 2 %. In this case a small attenuation is introduced not to exceed the useful range of the receiver.

From the preamplifiers, through twisted pair delay cables, $\sim$ 120 m long, push pull signals go to the counting room electronics. Either after discrimination they enter a digital read out system (CERN Receiver Memory Hybrid type [20,21]) which is read by CAMAC or, for a subset of channels, they enter receivers [17,19] that can pass the information to Lecroy FERA ADC's in order to get an analogue measure of the induced charge [22,23].

The coaxial cables are soldered on the aluminium strips. The coax screenings are soldered on the 40 μm thick aluminium foils that cover the PVC supports on the opposite side with respect to the sensitive strips. These foils have a twofold purpose: to screen the sensitive strips from the external e.m. noise and to decouple the two tube layers, by suppressing the cross talk between them.

Crates of preamplifiers (32 channels each) drive 32 twisted pair cables. The delay in the twisted pair cables is about 400 $nsec$.

- The RMH modules strobe into memories the received signals that are above threshold. The strobe signal, typically a few 100 $nsec$ long, is supplied by the trigger system. All the RMH modules in one RMH crate can be strobed in parallel and have a common threshold adjustment, ranging from 2 to 25 mV. The read out is performed by a crate encoder (CE) in each crate. A system encoder (SE) reads serially the chain of CE 's receiving all the coded sequence of hit channel patterns. Only significant data are transferred. The SE is housed in a CAMAC crate and communicates with a CAMAC RMH interface [24] via the internal output bus. The read out time by the RMH interface is of the order of a few μsec with our multiplicities.

- The trigger system also supplies a gate to the ADC FERA system to perform signal conversion.

The RMH IF and the FERA driver are finally read by a Jorway 411Q CAMAC-to-μ VAX interface.

As for the read out organization, each of the three barrel sectors has two layers of tubes; each layer has a ϕ set of strips and a θ one. As a result we have six groups of ϕ and six groups of θ read out channels. Each ϕ read out group includes 112 channels; each θ read out group includes 135 channels.

The total number of channels is then 1482.

The three θ inner strip groups are read out through analogue electronics, for a total of 405 out of 1482.

2.5 Tests with a radioactive source

A tube prototype was tested with collimated electrons from a ^{90}Sr source.

The trigger was a coincidence between two small scintillators (1 cm^2 x 1.5 mm) placed very close to the Iarocci tube.

In all these tests the tube and strip geometry is the one previously described and the reference gas mixture argon+isobutane in the ratio 1 to 3 was used.

Different tube prototypes, both of the coverless type and of the modified coverless type, were tested. For both sets we had different graphyte coatings corresponding to resistivity values ranging from $\sim$ 2 to 200 $k\Omega/\sqcap$.

We also measured the attenuation introduced by coaxial cables ($\sim$ 2 dB for a length of 6 m) and twisted pair cables ($\sim$ 4 dB) and we tested different gains of the prototype first stage preamplifier for the digital chains.

Figure 6 show the efficiency plateau for two cases: longitudinal and transversal strip on a streamer tube with graphyte coating only on the fins, resistivity $\sim$ 2 $k\Omega/\sqcap$. Here we had digital read out with threshold 10 mV.

2.6 Test of the analogue strip read out

Using the same setup as for the previous test, but changing the read out electronics, we tried the analogue read out from a set of 8 strips put transversally on the Iarocci tube.

The outputs from the receiver which are internally shaped with 200 $nsec$ FWHM, were sent to an ADC 2249W for the integration of the induced charge. The ADC gate, of duration 1 μsec, was again formed by the coincidence of the same two small scintillator signals, and an appropriate delay added before it. The average scintillator distance from the radioactive source was $\sim$ 10 cm in this case, in order to reduce the electron divergence.

After pedestal subtraction the charge read out from the ADC channels was used for the calculation of the streamer centre of gravity, by giving each strip central coordinate a weight proportional to the charge measured on that strip. Besides the centre of gravity, a charge spread was calculated for every trigger, as the second moment of the measured charges. The mean value of this parameter is directly related to the spatial resolution.

In the experimental conditions already described, at $H\ V = 4600\ V$ and at electron normal incidence on the tube, the ADC spectra for the two strips nearest to the source show a peak at $\sim 210\ pC$ and an average value of $\sim 240\ pC$ for the first strip, a peak at $\sim 10\ pC$ and an average value of $\sim 70\ pC$ for the second strip. The charge cut was set at $7.5\ pC$.

The ADC charge spectrum is reported in figure 7 for the strip nearest to the source.

From a second moment calculation the spatial resolution is measured to be $(0.7 \pm 0.6)\ mm$. This value roughly doubles when the electron incidence angle is 75^o with respect to the tube.

2.7 Tests with cosmic rays

The whole L S T barrel was tested with cosmic rays. A scintillator hodoscope of cylindrical shape segmented in the ϕ coordinate into 63 elements was mounted around the barrel to provide the definition of the trigger. The trigger was defined as a coincidence of two hodoscope elements at 180^o; events with one track only traversing the hodoscope were accepted.

The L S T barrel was equipped with an RMH digital read out system. Amplification and electronics thresholds were adjusted in order to provide full efficiency compatible with a low noise level.

Tests were performed with the two different gas mixtures already quoted. Results with the two mixtures in terms of efficiency and cluster size are comparable.

The efficiency was calculated projecting the track defined by the hodoscope hits onto the L S T layers and looking for hits within $\pm 7.5^o$ in ϕ. Hits outside the track window were considered as noise. Cluster size and cluster multiplicity were calculated too. Figure 8 a) shows the detector efficiency as a function of high voltage; the plateau region extends from 4.25 to 4.7 kV. The lower value for the outer layer (83% compared to 88% for the inner layer) is due to the larger geometrical dead areas in the former. Figure 8 d) shows the cluster size distribution in the plateau region.

Correction factors were applied to the raw efficiency to take into account the presence of dead areas due to detector geometry. The intrinsic detector efficiency thus obtained (figure 8 b)), of the order of 95% in the plateau region, is in agreement with the results of single cell tests with a radioactive source.

The overall detector efficiency (figure 8 c)) is defined as the efficiency if one of the two layers is efficient at least; in this way the contributions to inefficiencies due to detector geometry cancel, and in fact the overall efficiency results $(96 \pm 1)\%$, comparable to the intrinsic detector efficiency.

2.8 Tests with a proton beam

The L S T barrel was installed with the jet target and part of the E760 detectors in the Fermilab antiproton accumulator for a test run with a proton beam. All the channels were equipped with digital read out.

The trigger, requiring at least one hit in hodoscope H1 and two hits in hodoscope H2 with an approximate back to back correlation in the ϕ angle, isolated events with charged multiplicity in the angular region covered by the L S T barrel.

The analysis of the L S T barrel proton beam data [25] was performed associating ϕ hits in the L S T's to ϕ correlated hits in the trigger hodoscope elements. The efficiency and cluster size obtained in this test are comparable to those reported for the test with cosmic rays.

Moreover, restricting the analysis to a very clean sample of events with one hit in both ϕ layers and in at least one θ layer, a first evaluation of the efficiency of the θ strips was done by comparison with the ϕ strips response (the trigger had no θ segmentation). At a $\sim 15\ mV$ RMH threshold, the θ strips behaviour looks as satisfactory as the ϕ strips one.

The L S T barrel provided a good efficiency both in presence of a low ($3.5\ mA$) and high ($11.9\ mA$) beam intensity. From a total proton - proton cross section of $40\ mb$ and an average charged multiplicity of 4 at the energies set during these tests, one can calculate that the high beam intensity value roughly correspond, in terms of L S T rate capability, to a lower bound of 9 $particles\ cm^{-2}\ sec^{-1}$ at the forward end of the barrel. This confirms the validity of the tube modified coverless cell design.

3 Multiwire proportional chamber

The E760 outer charged track detector, in the forward region, consists of a multiwire proportional chamber [26,27] of anular shape, covering the polar angle range $10^o < \theta < 18.5^o$.

This device is to sustain larger rates than $\sim 20\ sec^{-1}$ per cm^2.

We believe it is a unique MWPC as far as several design features are concerned.

3.1 Structure of the detector

The forward tracking chamber (F T C) is made by three independent equal gaps packed together.

The gap active surface extends from an inner radius $r_1 = 288\ mm$, to an outer radius $r_2 = 568\ mm$.

In order to resolve multihit ambiguities the gaps are mounted in such a way that the wires of each gap form a 60° angle with the wires of the neighbouring one when projected onto a plane parallel to the wireplanes (see figure 9). This was obtained by using frames almost identical, but required the holes for the packing screws to be drilled with the precision $\pm 0.05\ mm$ on the position along diameters.

The gold plated tungsten wires, 20 μm in diameter, are stretched along parallel cords of the outer frame. The wire spacing is 2 mm and the gap parameter (i.e. the distance between the wire plane and the two cathodic planes) is 6 mm. The separation between wire planes is 17 mm; the total chamber thickness is 56 mm.

The cathodes are ring shaped, graphyte coated [28] pieces made of glass fibre [29]. They have very low surface resistivity, and also perform the support function for the inner and outer ring shaped glass fibre frames (see figure 10). The thickness of the four cathode support pieces is 20 mm, representing $\sim$ 10% X_o for particle normal incidence.

The chamber total gas filled volume is $\sim$ 27.4 l; the gaps are isolated from each other also with respect to gas fluxing.

The total weight of the F T C, read out cables excluded, is $\sim$ 46 kg.

3.2 Wire read out organization

The wires are read out by three, i.e. every three consecutive PCB wire tracks go to a same signal output track. This regrouping allows to save read out electronics while the spatial resolution remains good enough on the polar angles, because of the large lever arm, the F T C being located at a longitudinal distance of $\sim$ 165 cm from the interaction region.

Each signal output PCB track is connected to a digital read out channel through a thin coaxial cable, of the same kind as the ones used for the L S T barrel.

The CERN RMH read out system [20,21] is also used. This choice gives the possibility of having the same digital read out standard for both the detectors in the outer tracking system.

The CERN type 4261 is a 32 channel two stage preamplifier with a total gain of $\sim$ 17, which is sufficient to operate the chamber at full efficiency even in presence of

- the larger capacitance of the parallel formed by the three wires of one channel with respect to the usual situation of one wire per channel,
- the attenuation added by the 6 m long coaxial read out cables to the one due to the 120 m long delay cables after the preamplifier.

The total number of read out channels in each wire plane is 284. They are subdivided into four groups, two of 46 and two of 96. In the 46 channels groups the wires are full cords, their ends being soldered at the outer frame, while for the 96 channels groups the wires are soldered at the outer and at the inner frame.

3.3 Cosmic rays test

The F T C has been succesfully tested with cosmic rays.

A gas "magic" mixture was chosen in the proportions:

$$A(69.6\%) + isoC_4H_{10}(30\%) + CBrF_3(0.4\%)$$

A trigger was formed by the coincidence of two plastic scintillators, 20 x 20 cm^2, 2 cm thick, placed at horizontal planes at a distance of $\sim$ 70 cm. The chamber was supported horizontally in between them, together with a small test chamber, 25 x 25 cm^2, used as a reference. This reference gap has the same constructive features as the F T C, except for the cathodes made of metallic mesh. The very similar behaviour of the two chambers gave us confidence in the good performance of the graphyte coated glass fibre cathodes. This was then confirmed by detailed measures.

The efficiency plateau measured during this test is reported in figure 11. It shows a comfortable operating H V range in between 3650 and 3950 V, though the behaviour in the ramp region is slightly different for the three gaps.

4 Acknowledgements

We gratefully acknowledge precious suggestions from E. Iarocci about the modified coverless L S T design.

The support from the I.N.F.N. technical staff in Genova, the M.Bindi firm and the Fermilab Research Division was fundamental.

We are also indebted to H.Wendler for his assistance about the RMH system and to B.Mouellic for his advice about the analogue read out electronics.

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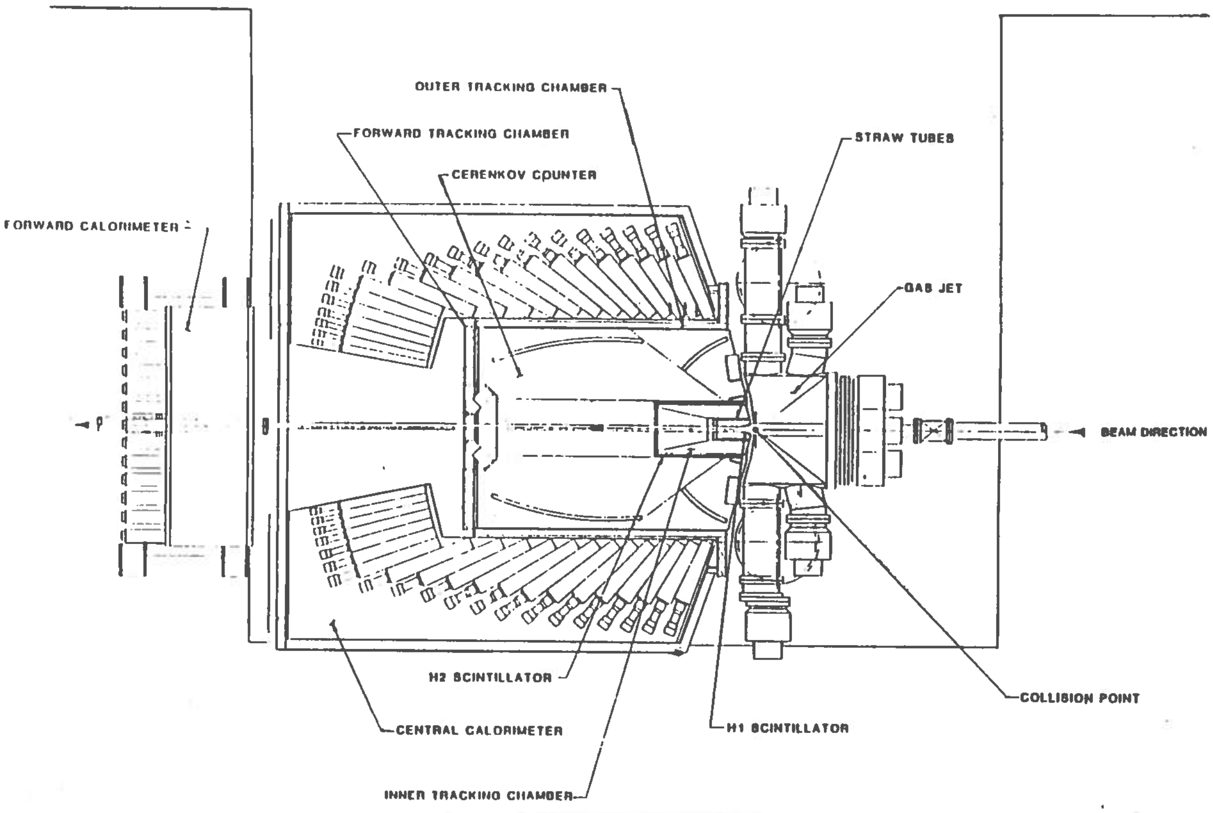

Figure 1: The E760 detector

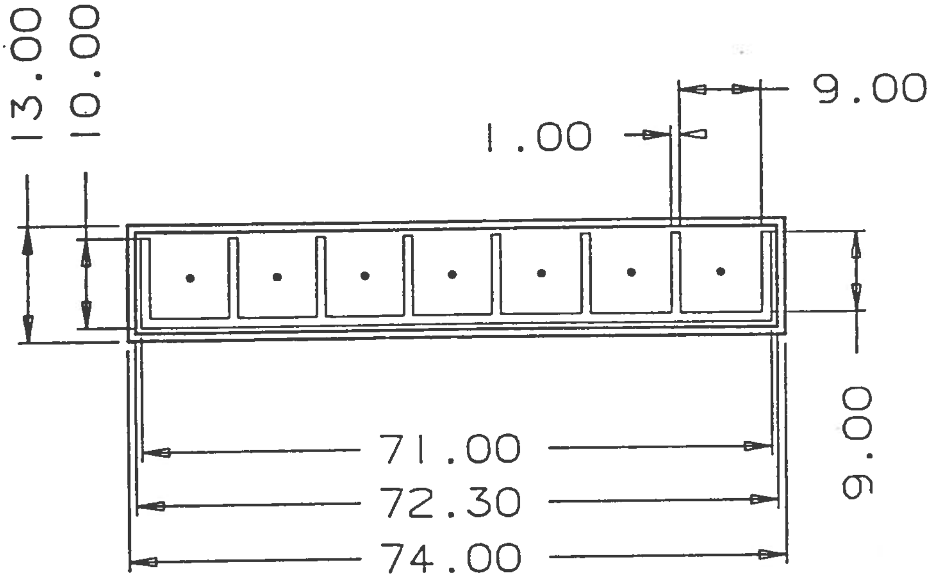

Figure 2: LST 7-cell module profile inside a tube, cross section

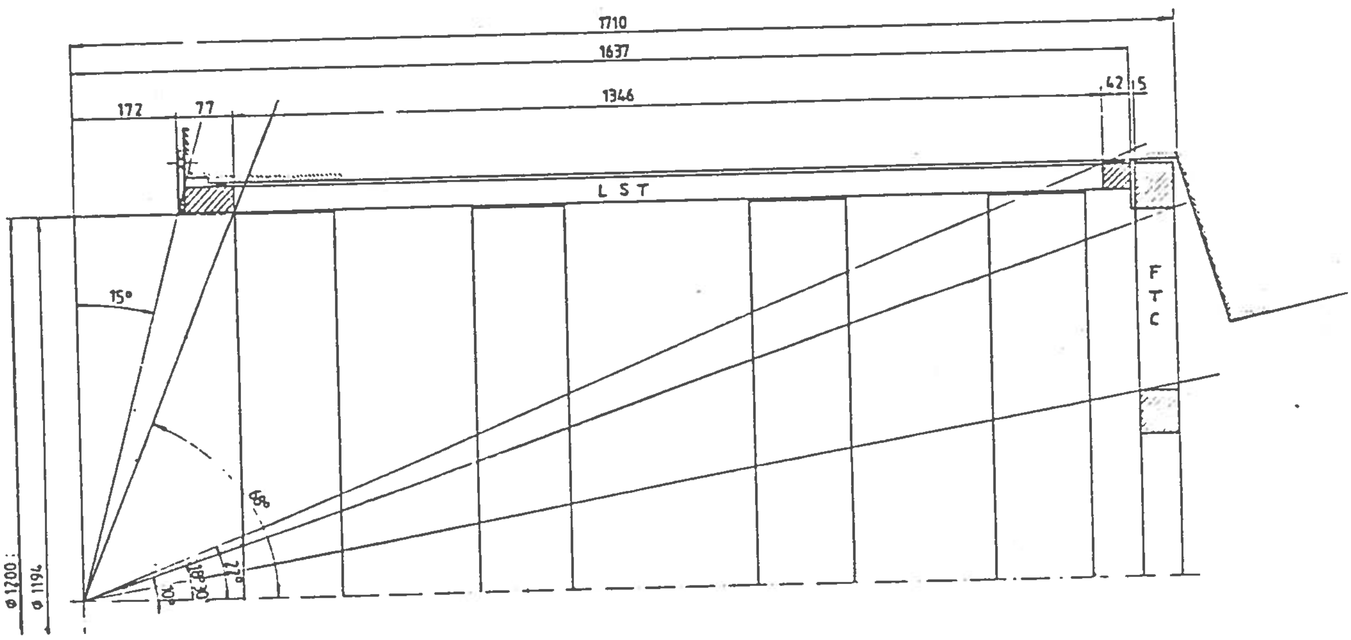

Figure 3: LST barrel side view

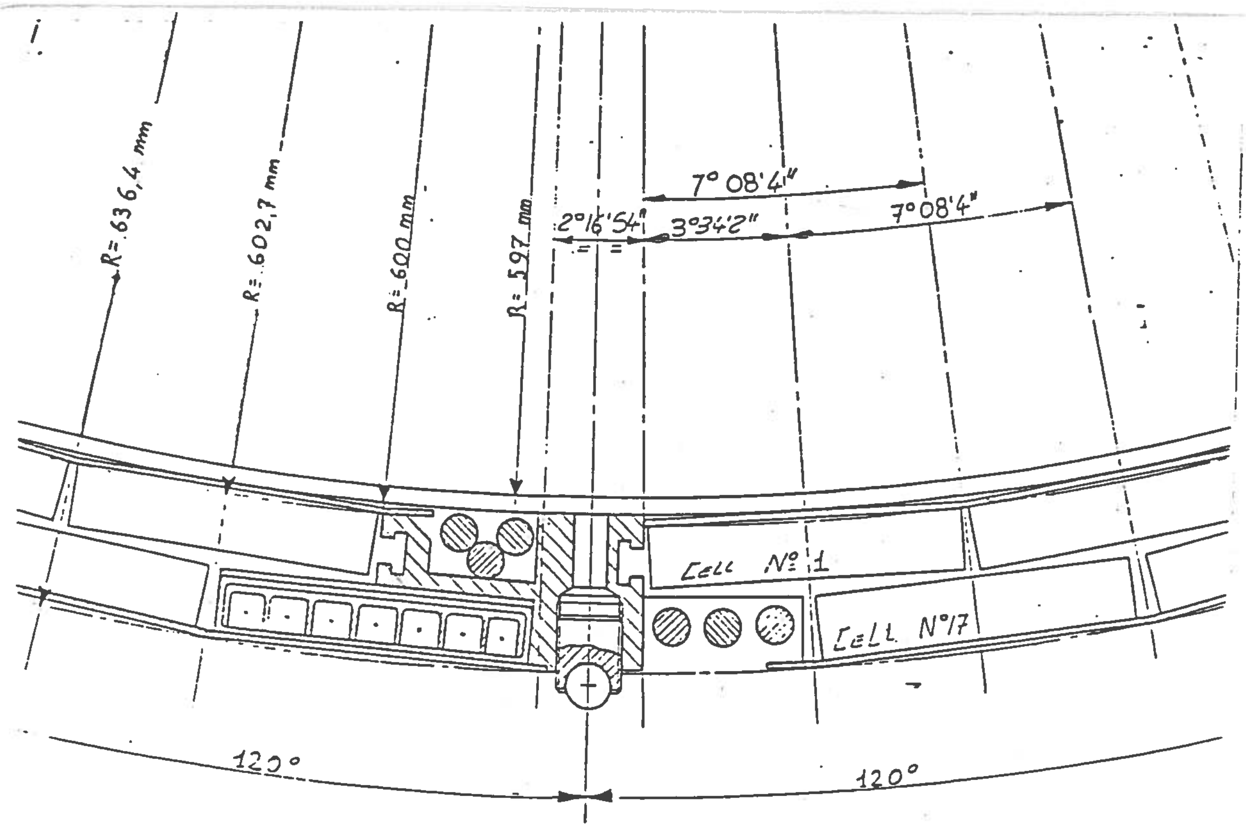

Figure 4: LST barrel front view (details from final drawing)

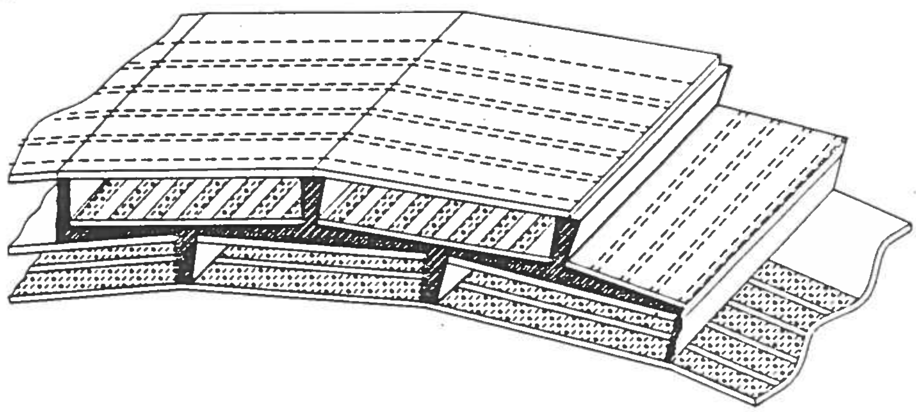

Figure 5: LST barrel polygonal box with sketch of the read out strips

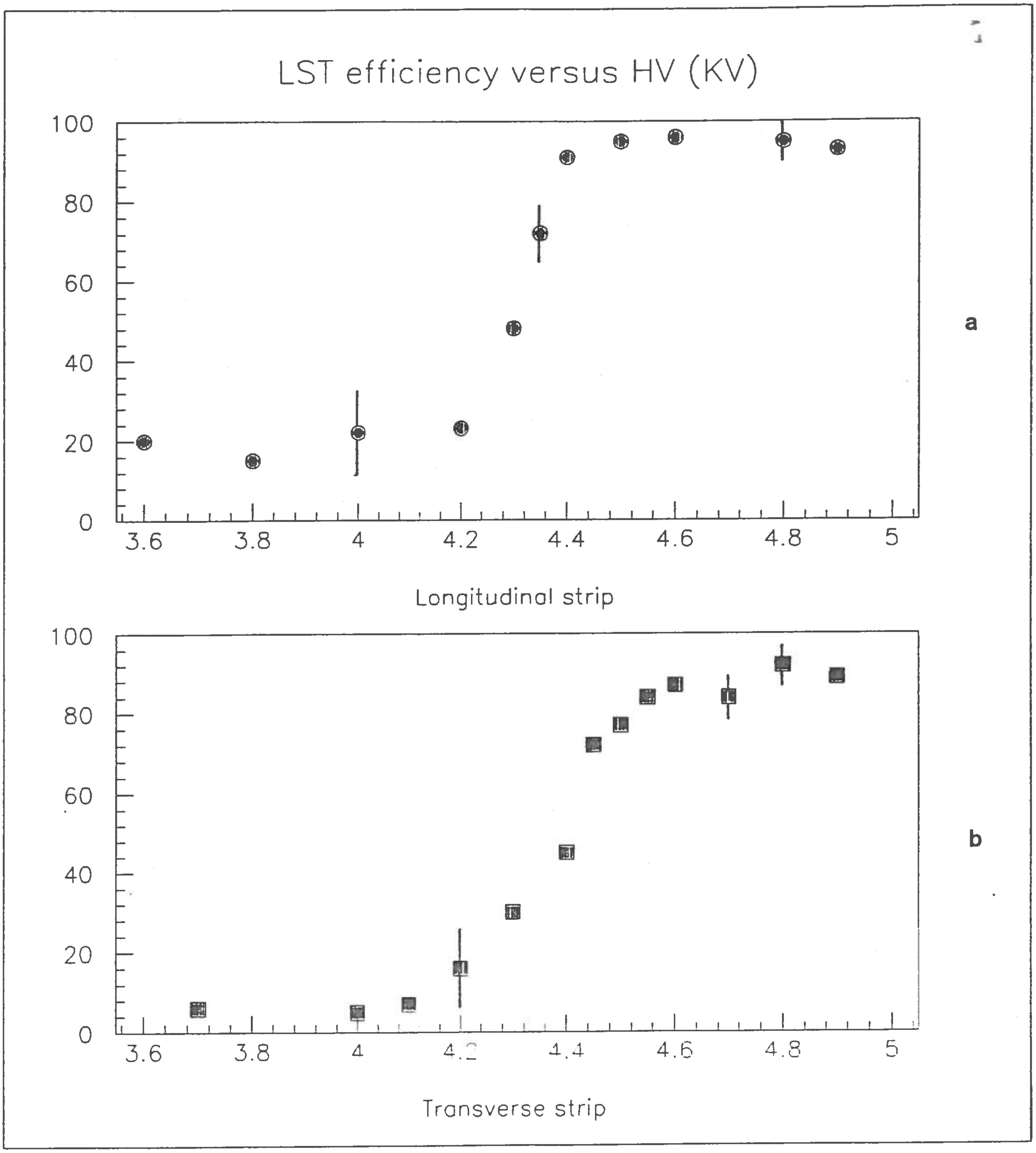

Figure 6: LST module test with a radioactive source:
a) longitudinal strip
b) transversal strip

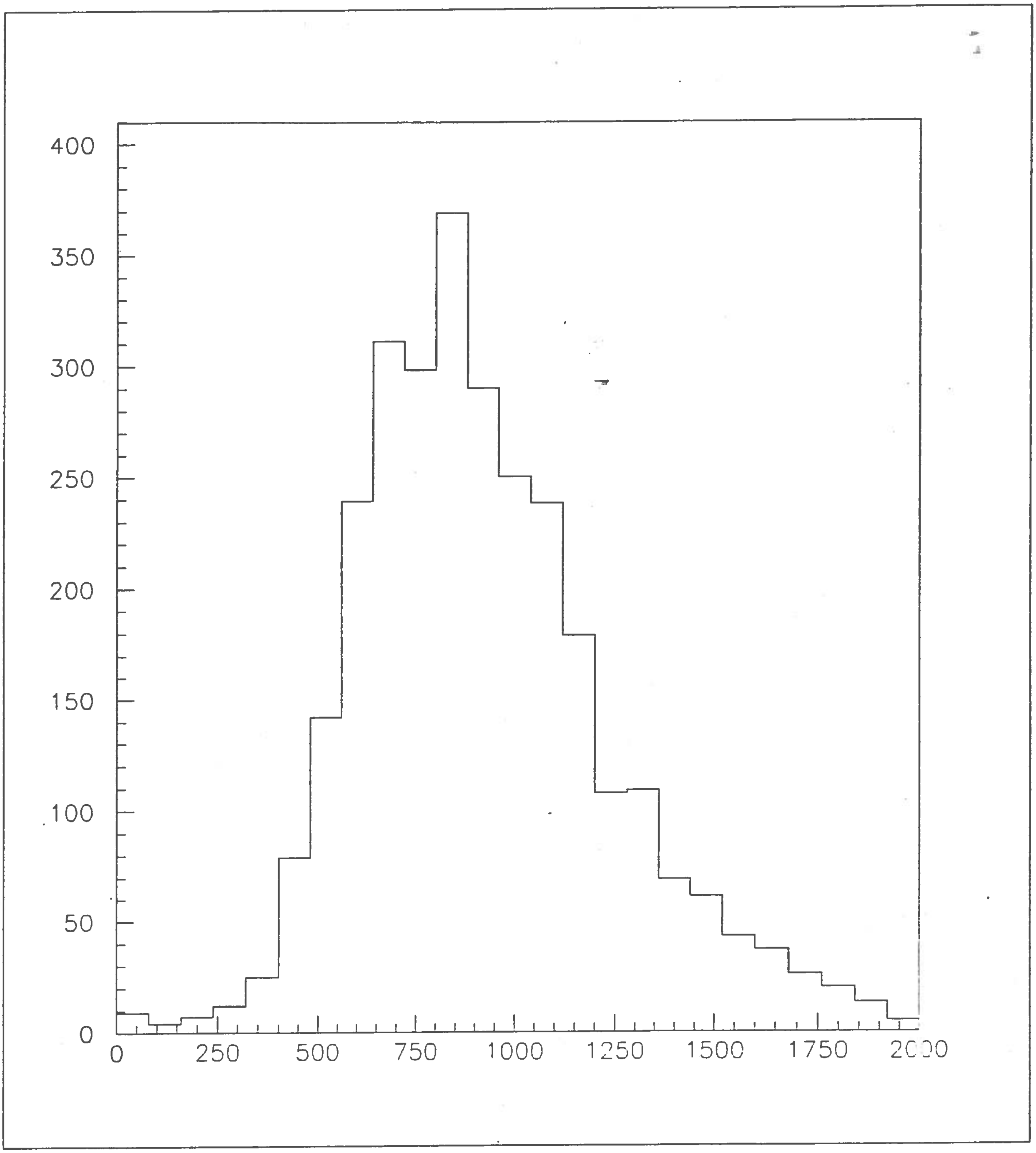

Figure 7: ADC charge spectrum from LST analogue read out

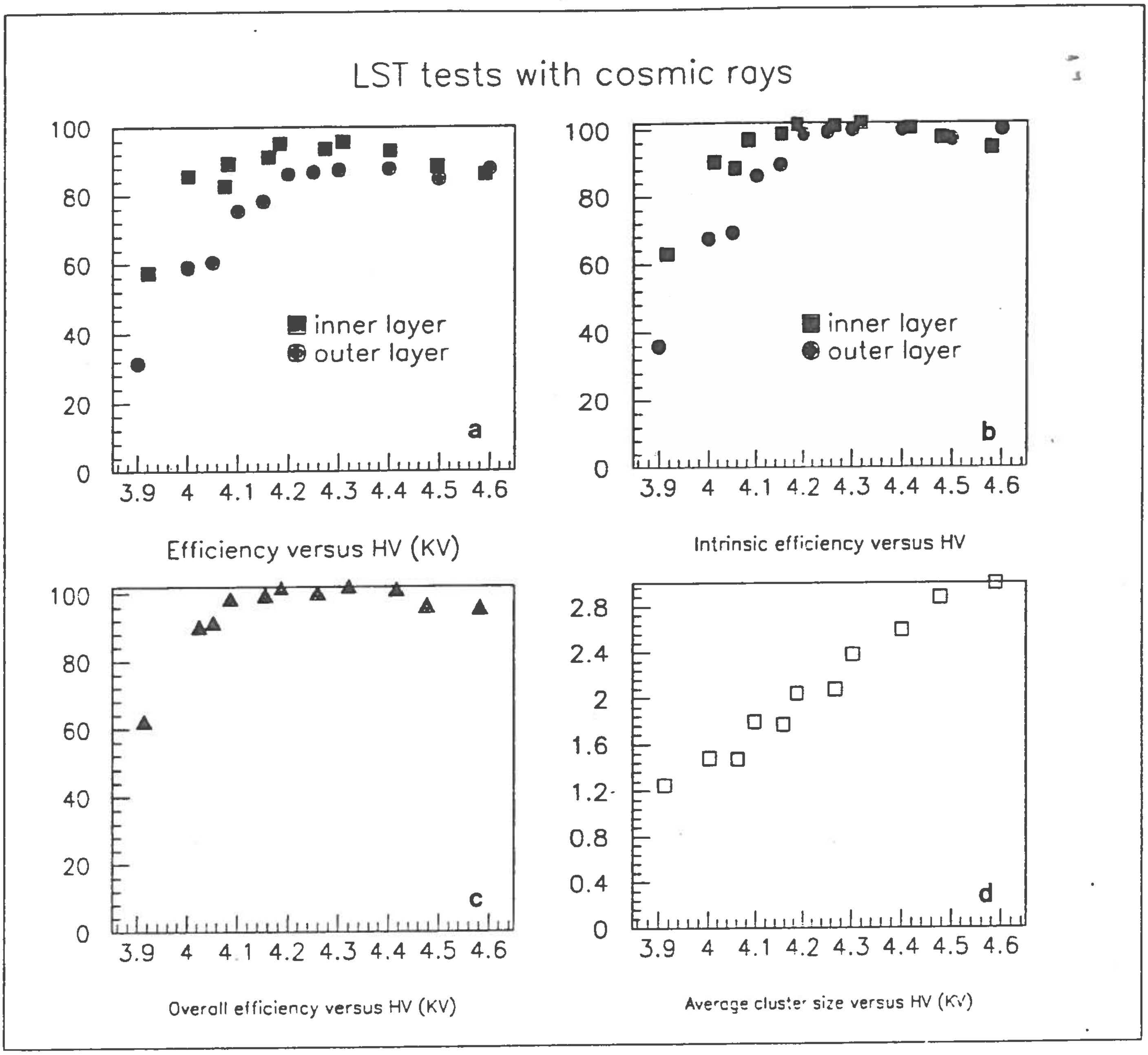

Figure 8: LST efficiencies and cluster size versus HV (errors 1 %):

a) efficiency

b) intrinsic efficiency

c) overall efficiency

d) cluster size

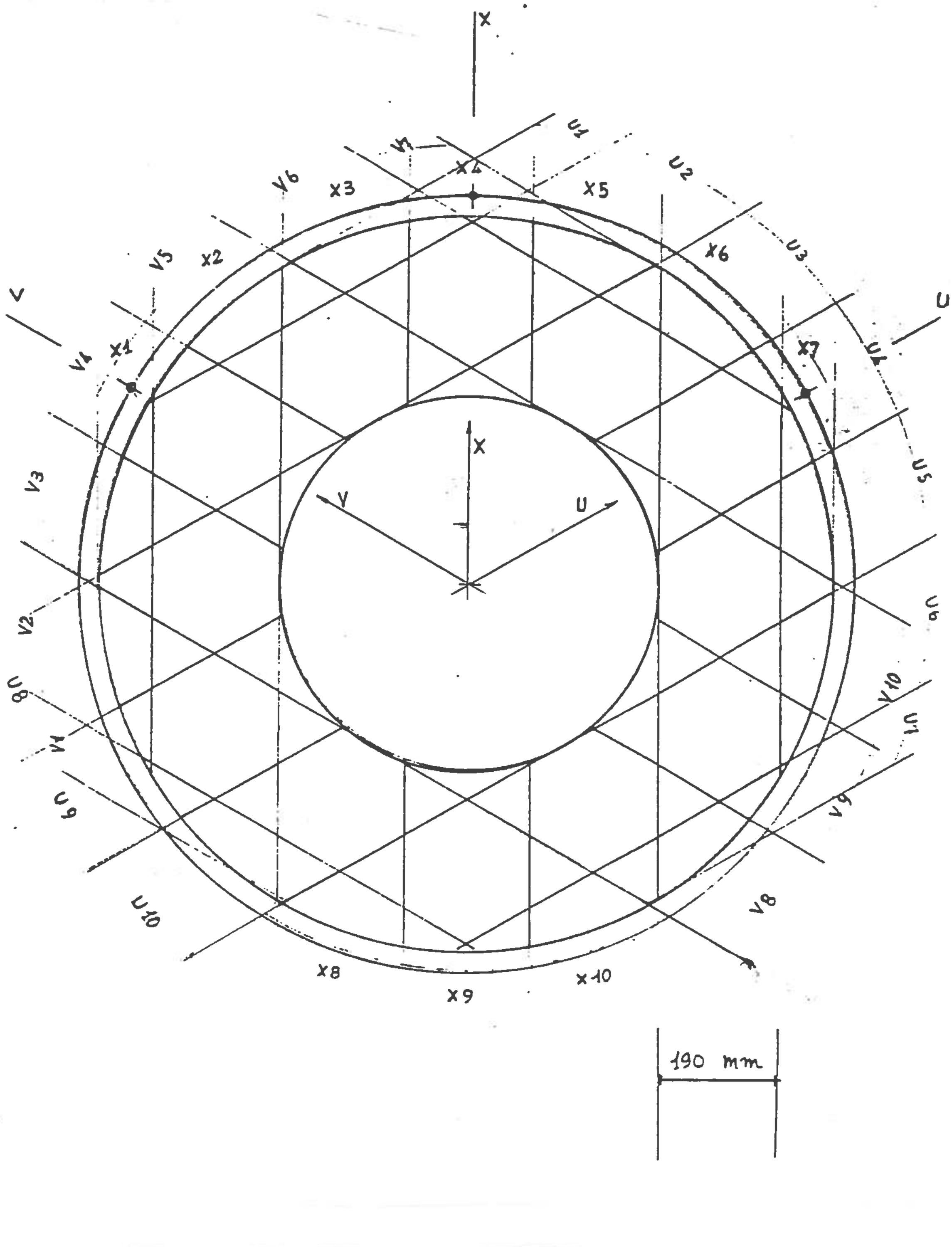

Figure 9: FTC front view: wire group layout

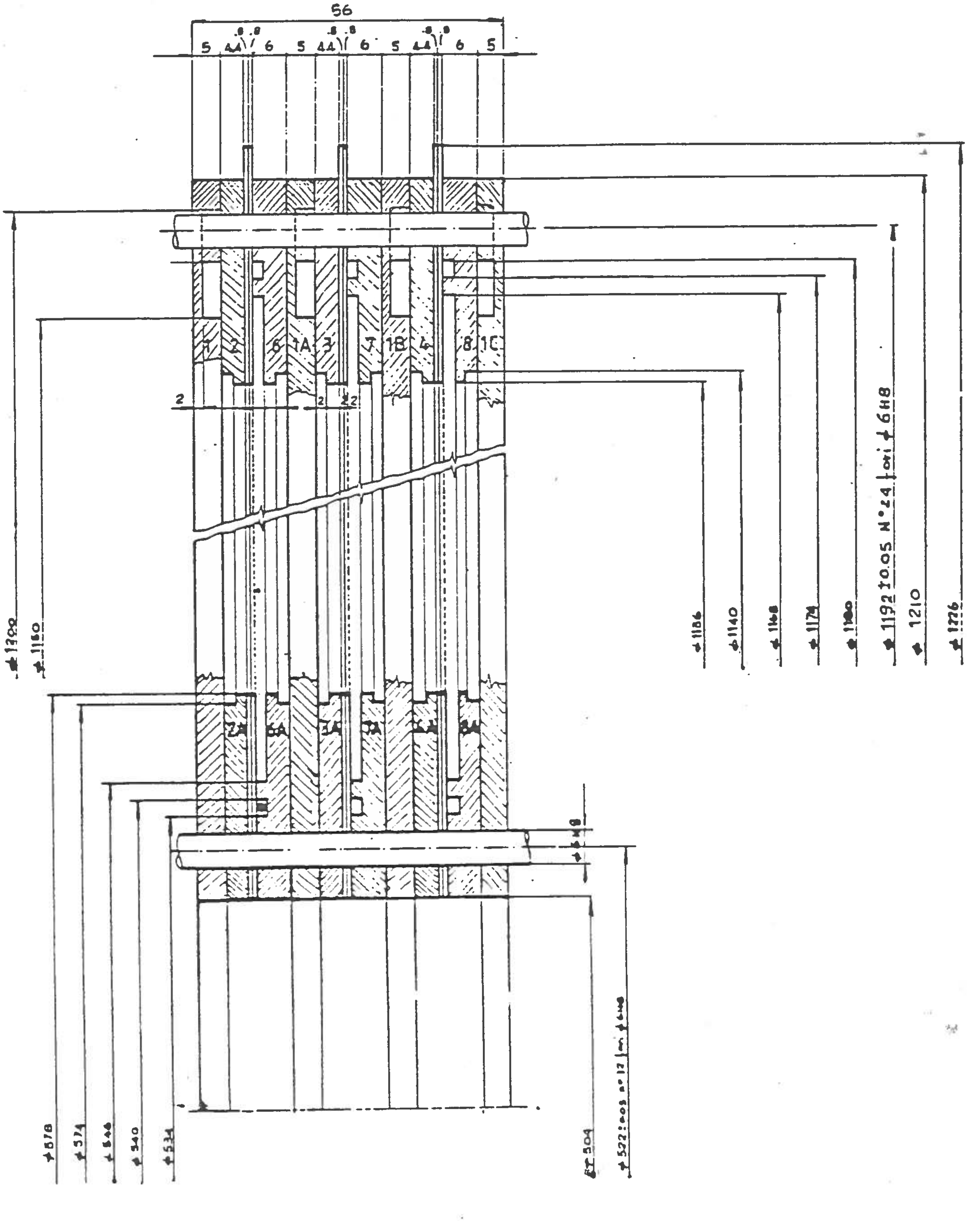

Figure 10: FTC cross section of frames (figures in mm)

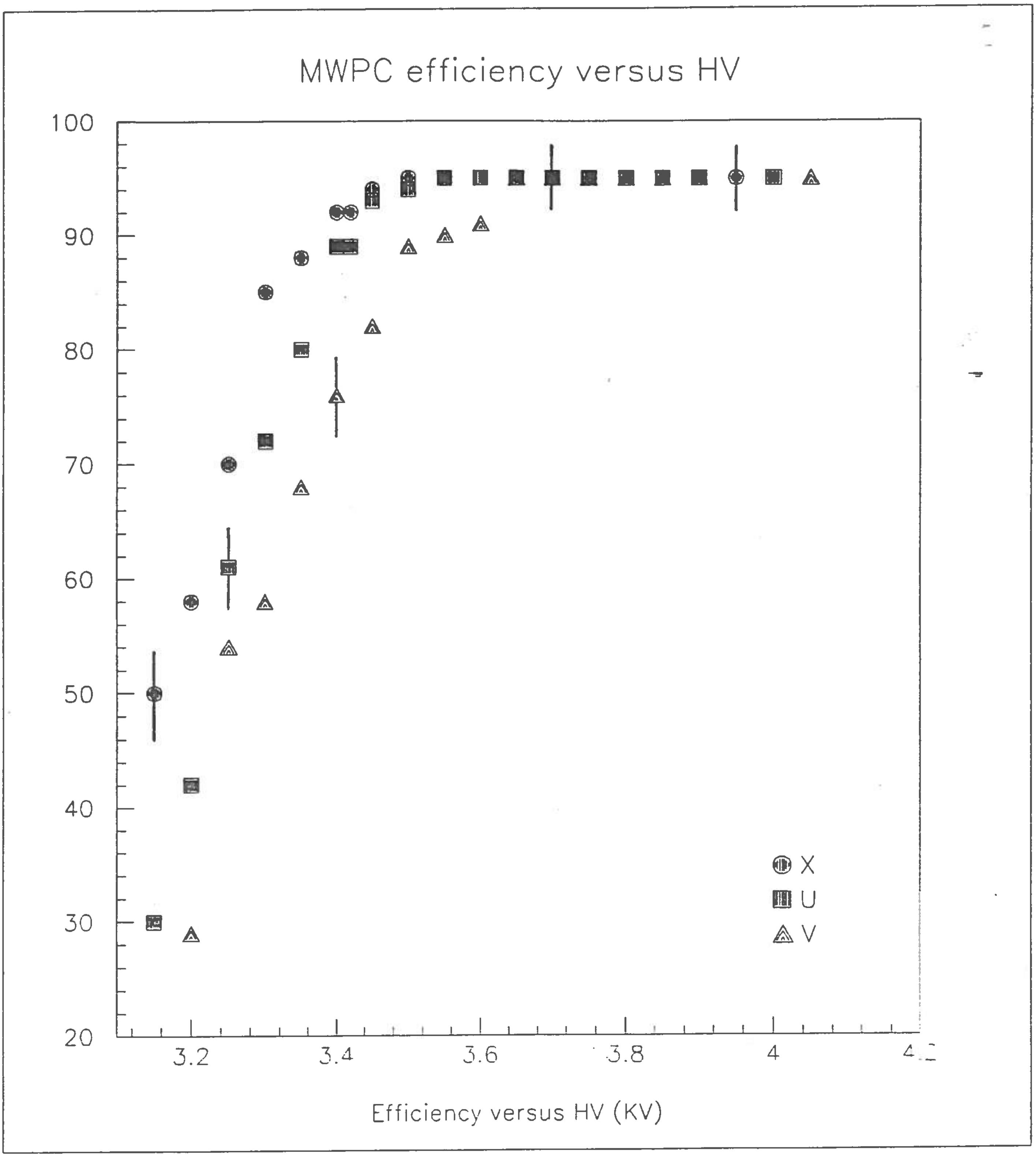

Figure 11: FTC efficiency plateau for the three gaps