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THE HIGH PRESSURE GAS CALORIMETER FOR ATLAS.

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1 The forward calorimeter design.

As it has been discussed in LoI[1] the forward calorimeters (FC) ATLAS set up:

- have to operate in the high radiation dose environment;
- to have fast response of the order bunch crossing time (25 ns);
- can have moderate granularity and energy resolution;

After intensive study using Monte Carlo[2, 3] and beam tests of several prototypes [4]-[7] at Protvino we propose to build the FC for ATLAS - as a gas ionization calorimeter, that should work at the pressure of the gas mixture 25-30 atm. The calorimeter has a modules structure (Fig.1a) and consists of 2m long 912 identical modules of the hexagonal shape. The outer shell of module is the hexagonal industrial stainless steel tube with the diameter of inner circle 92 mm. We think ,that this size is adequate to the transversal segmentation of FC. The discussion of that one can find in the paper[8].

The inner design of each module can be seen in the Fig.1b. In the longitudinal direction the module has two sections. The first one consists of parallel plate ionization chambers with the anode plane between two absorber plates. The absorber is 20 mm iron plates (20piec.) covered by copper. The anode plane is made from copper plate 0.4mm thick. The gas gaps are 2mm. This section has 2.5 interaction length.

The second section is made of using the cylindrical ionization chambers. The outer electrode of each chamber is the stainless steel tube with inner diameter 4 mm. The anode is copper-berillium wire, 0.4mm. Aiming for reasonable uniformity, the layout of the tubes shown in the figure with relevant dimensions. Each module has 61 ionization tubes. These tubes (~1.4m long) run parallel to the module axis. The absorber in this part is a lead.

The electrical isolation between the electrodes ensures the radiation resistant ceramic spacers everywhere in the module.

At the ends of the module and between two sections there are 45-50 mm gaps to locate the printed boards, H.V. capacitors and resistors,summing circuits and output signal connectors.

To obtain the fast response from the calorimeter we assume to fill up it with a gas mixture 95%Ar+5%CF4 or 90%Ar+10%CF4. The working point on H.V. at different pressure can be taken from drift velocity curvers to get the electric field in the chambers with maximum drift velocity at minimum high voltage.

The charge collection time for the second gas mixture is $\sim$ 17-19 ns.

The end walls of the module are welded to the hexagonal tube.

To sum signals from gas gaps in the first section we are building the waveguide line with wave impedance ~20ohm from parallel plates capacities and inductances that we put between plates . The principal scheme those waveguide line presented in Fig.2. The signals from waveguide lines come to the transformer,that summing signals from two parts of the first section and matching waveguide lines and output strip line.The time delay of signal in the waveguide line is ~8 ns. The transformer is a ferrite ring with outer diameter 10mm. The bandwidth of the waveguide line is 180 MHz.

For the second section we have considered three schemes (Fig.3) to sum signals from the tubes.

Scheme 1 - outputs of the chambers summing through the impedance matching transformer;

Scheme 2 - an individual tube output connects with the matching preamplifier. The output signals from preamps are summing together on input resistance of the second cascade amplifier;

Scheme 3 - the tube outputs come to the common point, the transformer matches the impedances of the detector and the amplifier;

We are working now with two of them (Fig.3a,c), the most economical and will sum all tubes to one short signal (~25 ns at the base) without deterioration.

2 Why we propose the hybrid version of the ionization gas calorimeter.

In our early paper[4] issued before LoI we have discussed the calorimeter with ionization tubes only,but after some search we found that hybrid version is more adequate for ATLAS purpose.

The spaghetti calorimeter with cylindrical ionization chambers allow to have the fast signal 25-30ns (the full width at the base) summing several tens of tubes. In Fig.4 we show the example of those signal obtained in hadron beam summing ten 2 m long chambers using the transformer (Fig.3a).

But,the spaghetti ionization calorimeter has essential deficiency. The value of the response amplitude depends strongly on the entrance coordinate of incoming particles,their slope angle to the tube axis,the disposition of tubes. In consequence of the physics parameters of that calorimeter (energy resolution, coordinate resolution, e/h ratio) have large variation. The Monte Carlo study these items has been done in papers[2, 3]. In the following two figures (Fig.5,6) from this papers we show the behaviour some parameters on tube's diameters,distances between tubes and incline angle. In the working region of FC angles (< 6 degrees) parameters variation is the most visible.

The obtained effects are similar to a spaghetti calorimeter with scintillating fibres. But it can be seen more prominently here because we have rougher inside structure.

As example the amplitudes of the signals in electron beam 26 GeV/c presented (Fig.7) for spaghetti prototype[5].The lager variation of amplitudes at small angles is clearly seen. For hadron beam the dependence of the amplitude on the initial particle entrance is less,but its distribution dose not coincide also with Gaussian distribution and is not symmetric at small angles (Fig.8) for our hadron prototype[4].

The structure effects for a spaghetti ionization calorimeter are nicely shown also in recently paper of another group[13].

We obtained the energy resolution for the prototype Fig.9[4]. In Fig.10 the average amplitude response and energy resolution for zero degree incline angle at 31 GeV hadron beam are shown as a gas pressure function. We see that at pressure above 25-30 atm the resolution improves slightly and we assume to work with those pressure. The resolution is quite crude but coincide with Monte Carlo simulation[3] and we may expect to improve it in accordance with the prediction[2, 3], if a proper structure of a gas calorimeter will be made (diameter tubes,distances between tubes,incline angle).

We estimated the electronic noise contribution to the energy resolution using the relation:

$$RMS(noise) = RMS(ped) * E / < S >,$$

where RMS(ped) - root mean square of pedestals distribution [ADC counts]; E- energy of the beam [GeV]; $< S >$ - mean signal [ADC counts].

For our test set up 7 modules the electronic noise is ~4 GeV/module. We expect the proper development electronics will allow to improve it at factor two-three [7].

Using the first momentum prediction:

$$X = \sum E_i * X_i / \sum E_i$$

we estimated the coordinate resolution for our spaghetti prototype and the results presented in the Fig.11 for 0 and 5 degrees incline angle. The resolution is worse for 5 degrees.

For the first section of the calorimeter we propose to use parallel plates chambers. Those type calorimeters have been intensive examined also in the work of other group[14].

The main problem is there to have the fast signal from summing many gas gaps. We found the technical solution for that and made the test of the parallel plates prototype in electron beam. To sum signals from 28 gas gaps we built the waveguide line from parallel plates capacity and inductance that we put between anode plates. The obtained signal shown in Fig.12. Its width at the base is less than 30ns with cable length 2.5m. The estimated bandwidth of detecting signals is 124 MHz.

The energy resolution of that prototype shown in Fig.13. At pressure 30 atm it is near the same as the resolution a scintillator calorimeter prototype for PHENIX project (shish kebab type) exposed in the same beam and coincides to Monte Carlo predictions. We have used here the Lab. made electronics.

3 The discussion.

Thus,we propose to design the hybrid version a gas calorimeter for ATLAS. The real prototype does not build yet for financial reason. From the Monte Carlo simulation we expect the following energy resolution:

$RMS/E = 30\%/\sqrt{E} + (10 \div 15)\%$ for electrons

$RMS/E = 90\%/\sqrt{E} + (8 \div 12)\%$. for hadrons

For Monte Carlo we used the beam with the transverse size of the module,centered to the point of four modules at the angle 1.5 degrees. The constant term in the energy resolution for electrons can be made smaller, if we will find the technical solution to decrease the wall thickness of modules (the passive material between modules).If we are centering electron beam in the middle of module the constant term is 3 times less. The improvement of energy resolution for hadrons is also possible by optimization of the length and thickness of the absorber plates, and using partly lead plates in the first section. We are doing now this work.

We would like to underline that because asymmetric amplitude distributions we show here the resolutions obtained from the histograms without any fitting. In the case of fit the amplitude distributions, as usually people do, the constant term for electrons is at least three times less and for hadrons 2-3% less.

From our study we expect an electronic noise on the level 1-3 GeV per module. But till now we have not used a powerful factor to manage signal/noise ratio - quality of waveguide system in the second section. Selecting the material of tubes we can increase the response amplitude from spaghetti part and decrease an electronic noise contribution to energy resolution,accordingly.

Comparing hybrid and complete parallel plates versions, we found that hybrid version promises to have smaller constant term for hadrons and to be more compensated. The cost of hybrid calorimeter is less.

The calorimeter can be placed on the platform (Fig.14a,b) that we are able to move up and dawn on 3.5 m, using two hydraulic cylinders. Under the metalice farm there is additional hydraulic cylinder,which allow us to move the whole system into the garage position along the beam. The calorimeter itself will have a pneumatic system to open it before moving dawn. The vacuum pipe of the beams will be left on its place. The volume under the mobile platform we are going to use as a room for the front end electronics,local trigger electronics and for some gas equipment. The distance between the beam pipe and this place-5:8 m.

We see a few open questions at the moment that should be solved on the next stage of our design:

- the coherent noise in the accelerator environment; How to protect our high frequency wide bandwidth system (detector) from high frequency noise that accelerator produces?

- the absolute calibration of modules using normalized pulses in high energy range; We will not be able to calibrate calorimeter modules in the range a few TeV in external beams of particles. Possibly external ion beams will partially help to make high energy calibration.

- because we should detect particles from GeV to TeV energies we expect the large dynamic range of signals from 100×10^3 to 100×10^6 electrons. How to manage with it?

The proposed design of forward calorimeter meets all ATLAS requirements. It is radiation hard. We are using in its construction the metal and radiation hard ceramic. We can put front end electronics (preamplifiers) far from detector and do not enlarge the signal length. It has a fast response ($\sim$25ns) and acceptable energy and coordinate resolutions[8]-[12]. We have demonstrated on the prototypes key points the proposed version (signal length, energy resolution, technical reliability).

References

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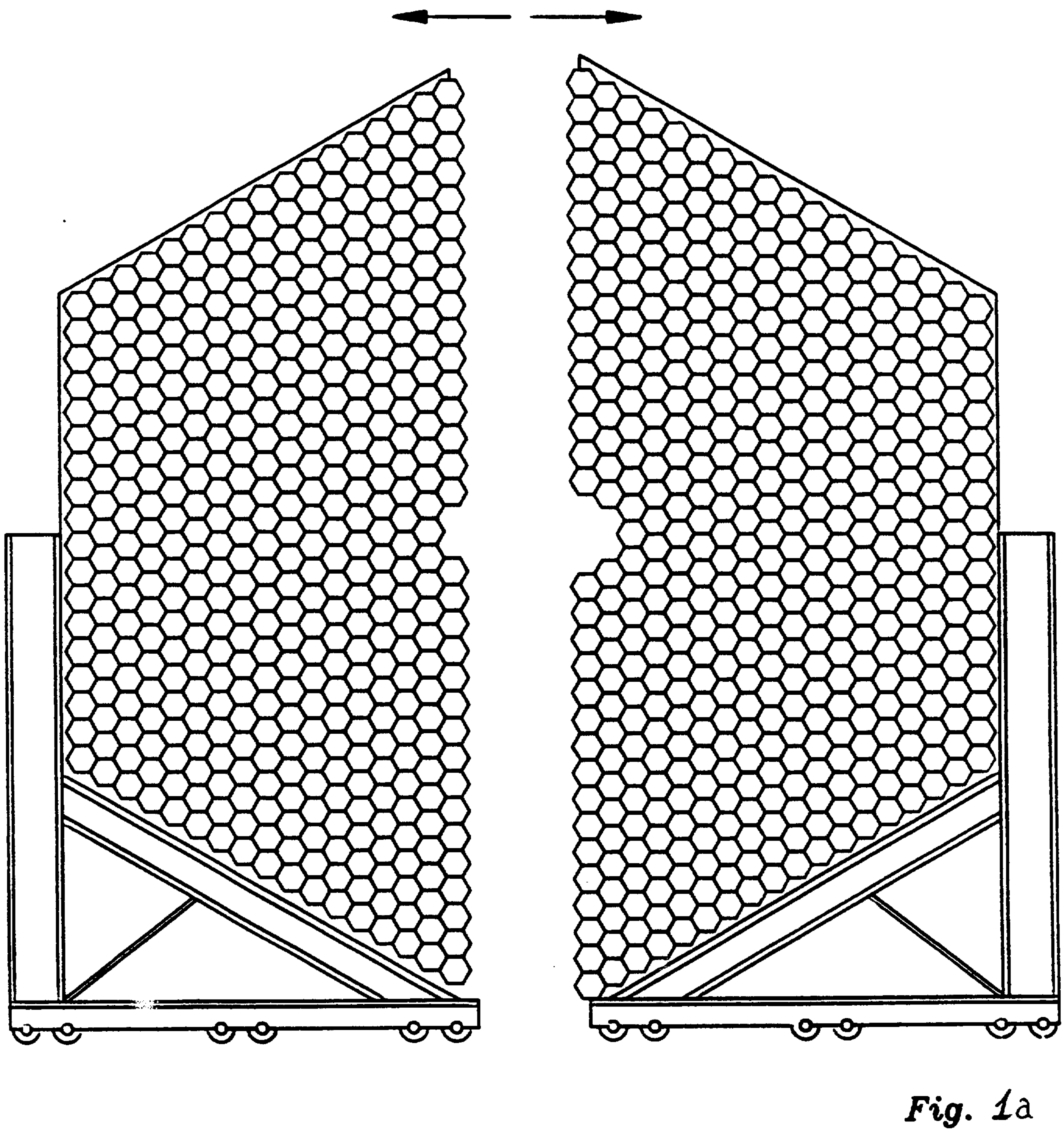


Fig. 1a

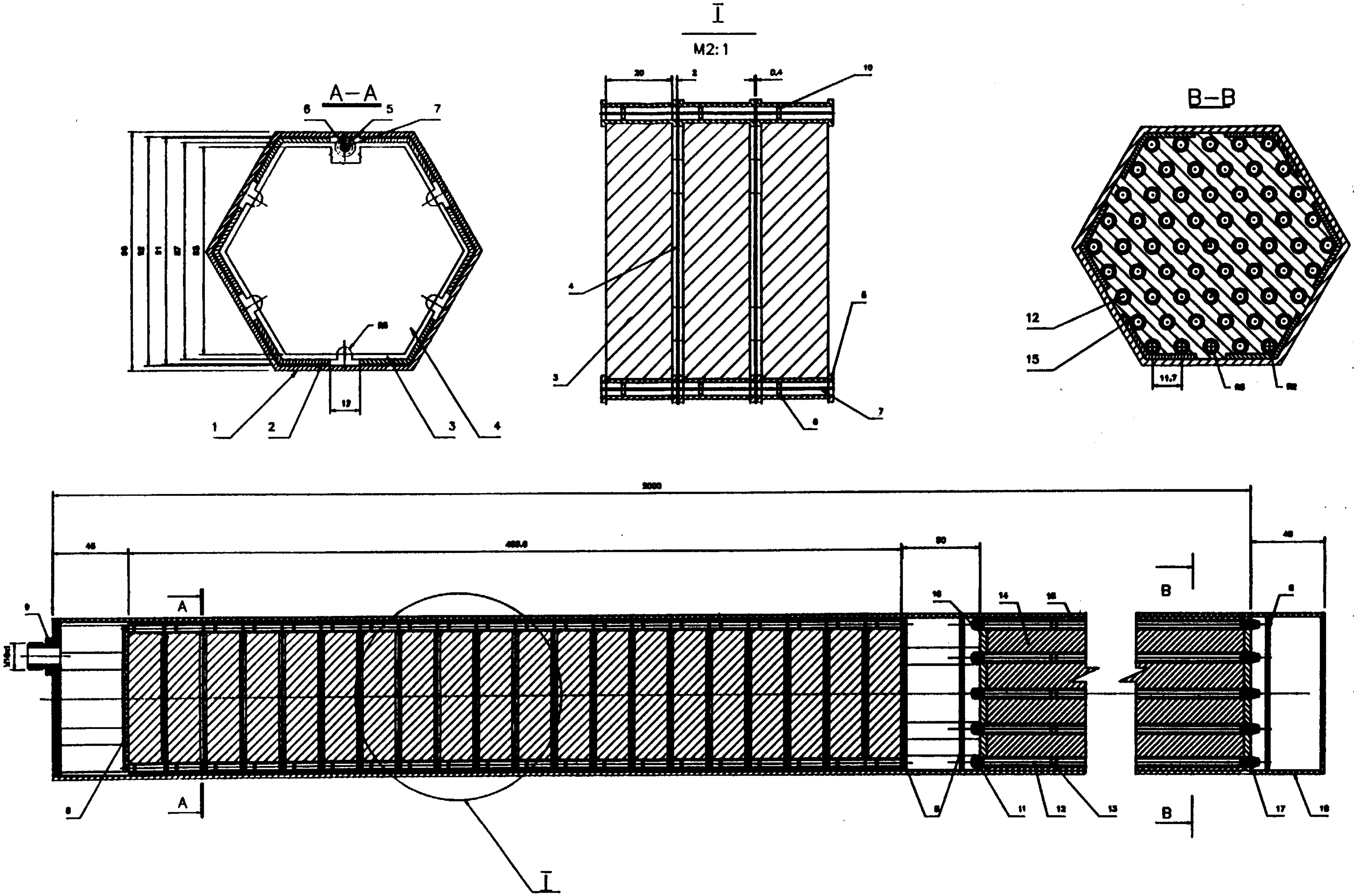
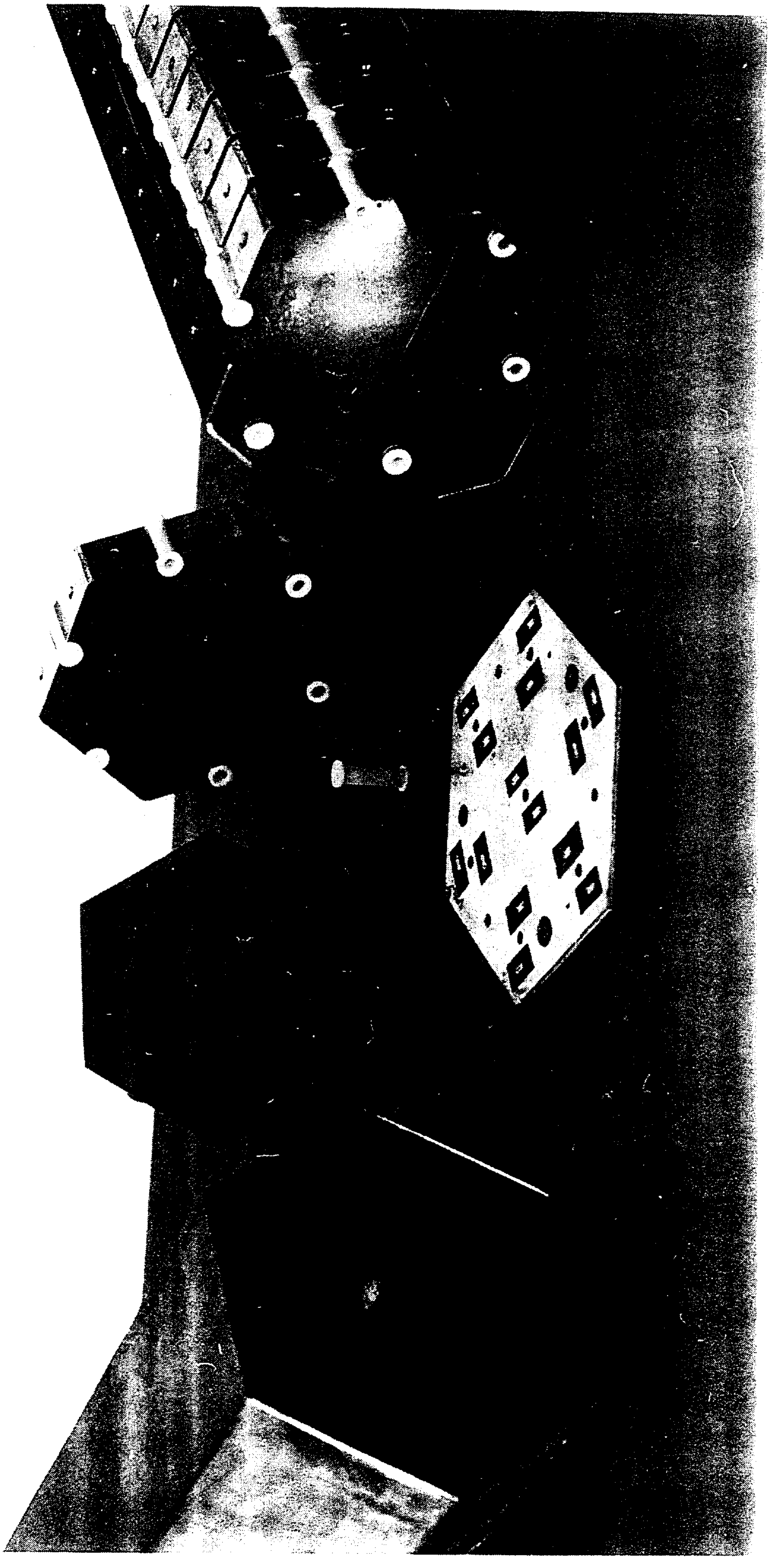


Fig. 1b



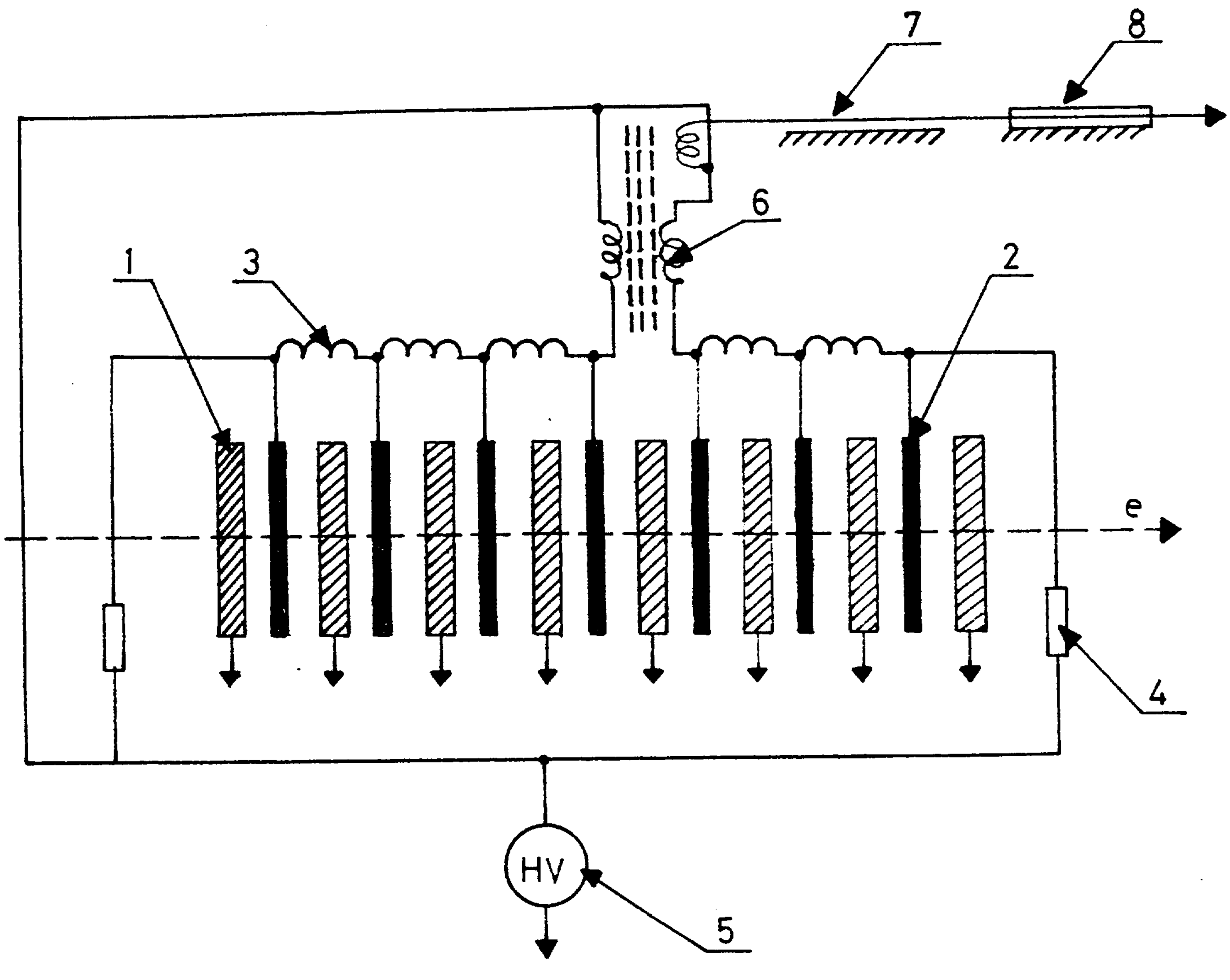


Fig. 2

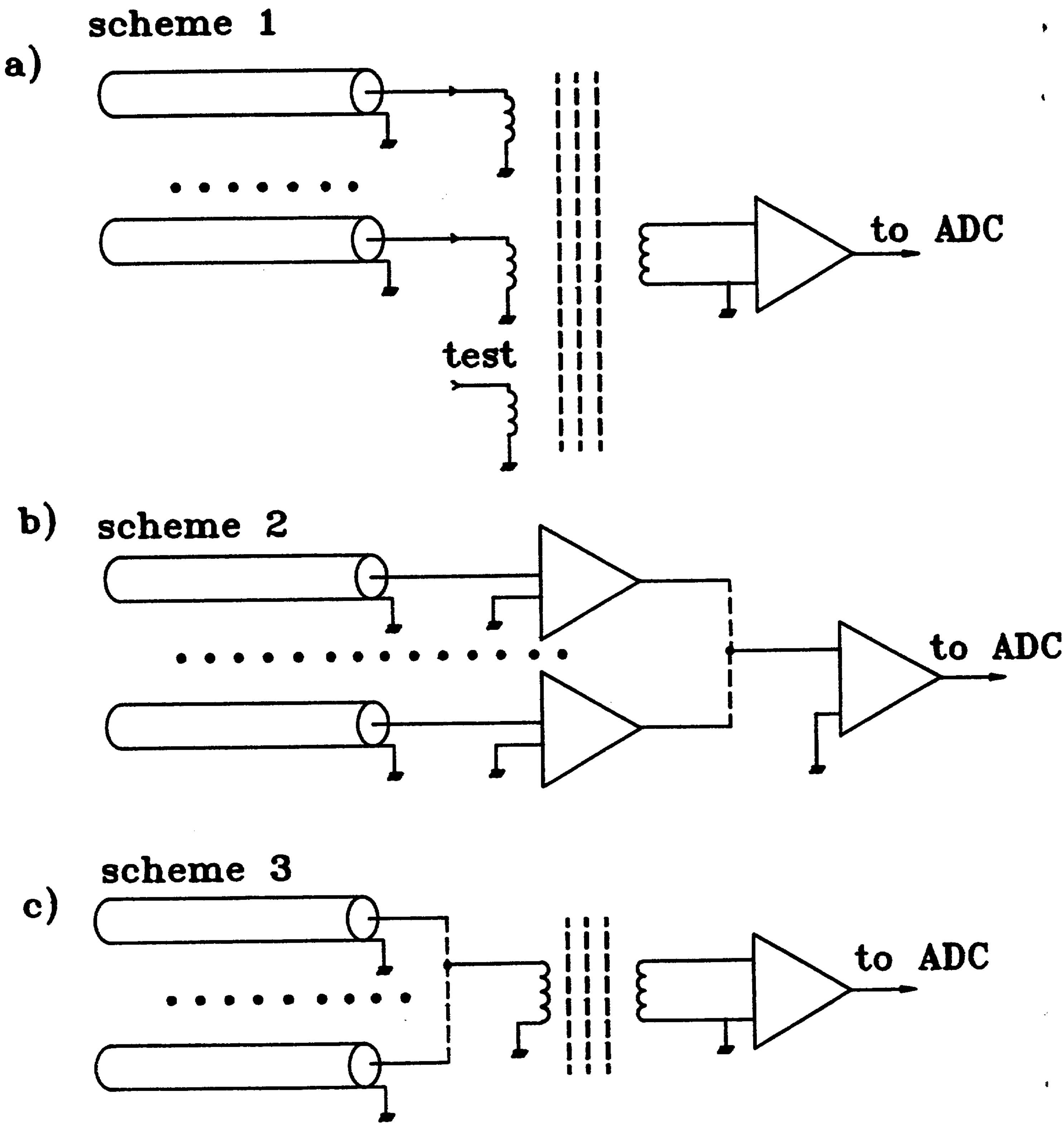


Fig.3

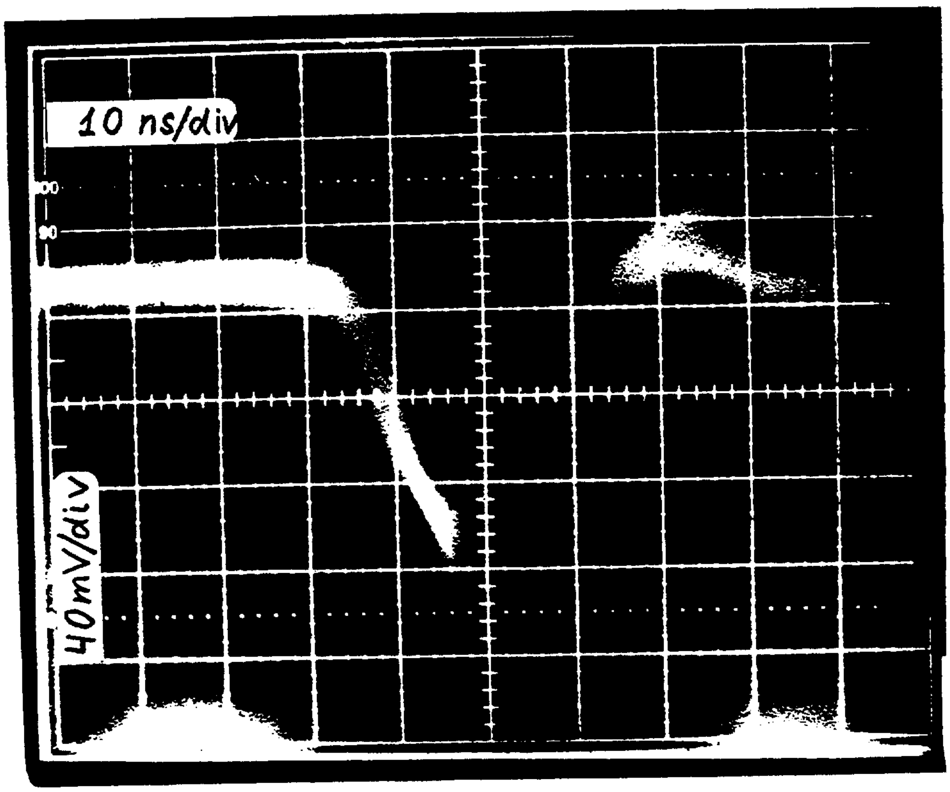


Fig. 4

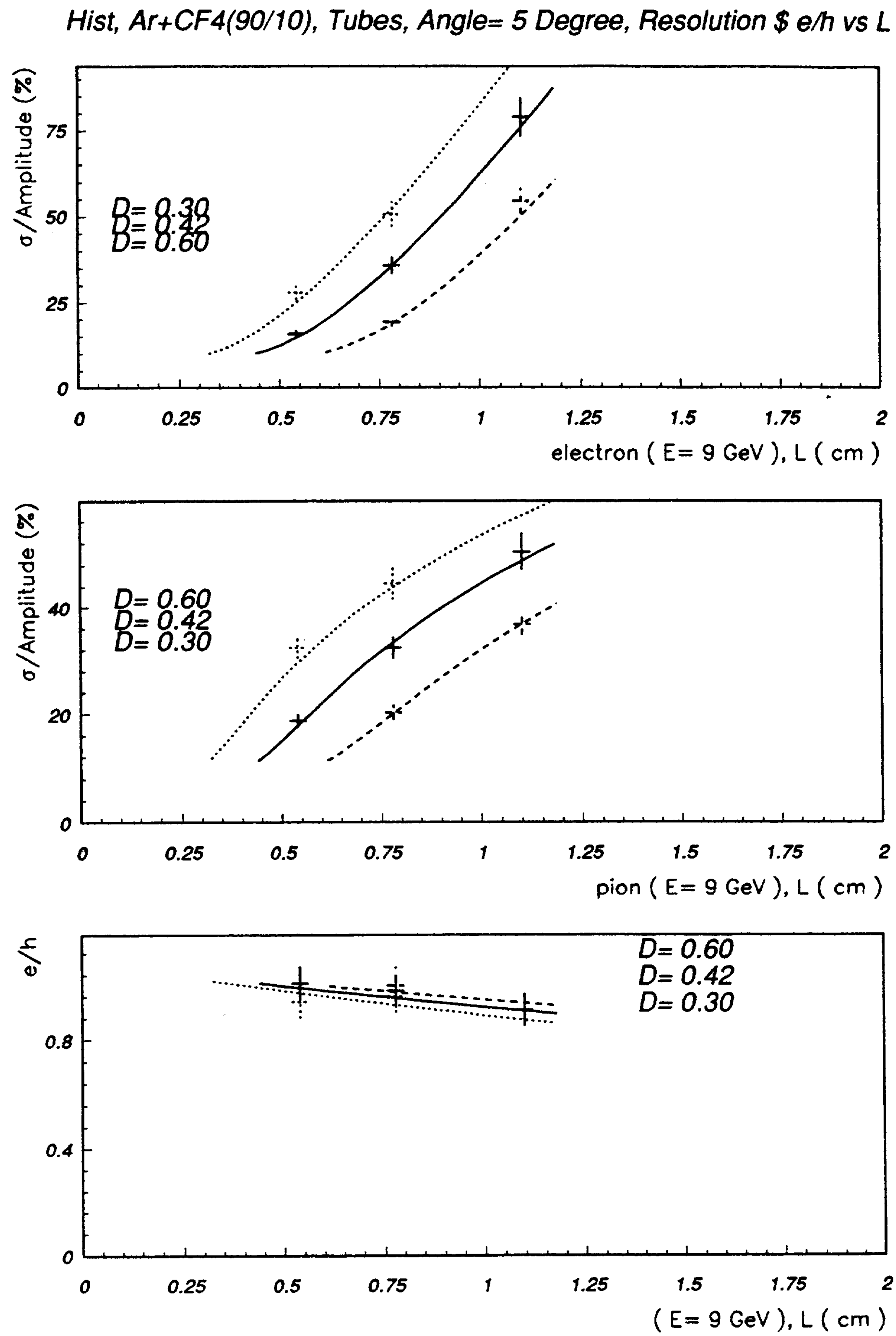
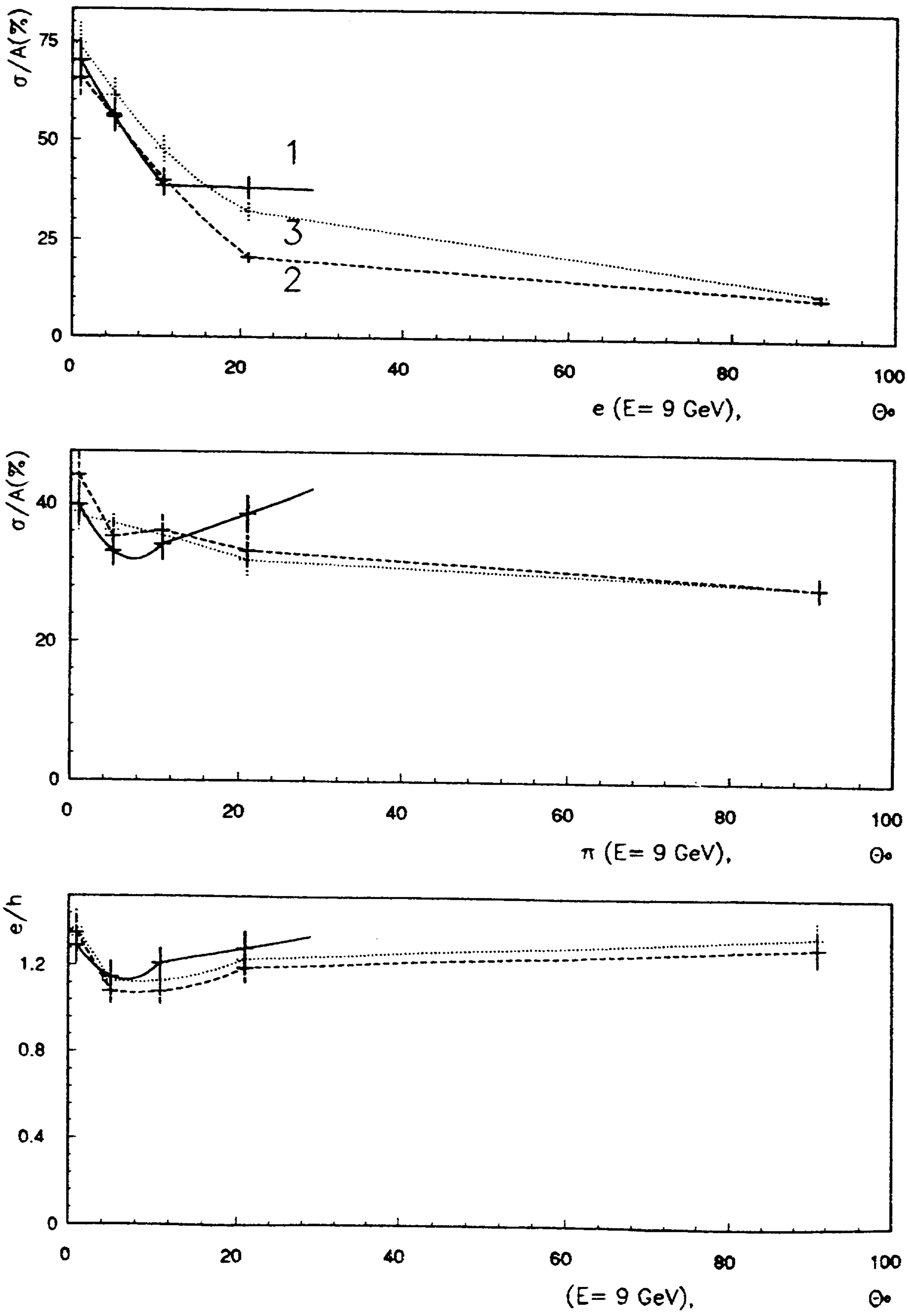

Hist, Ar+CF4(90/10), Tubes, Angle= 5 Degree, Resolution $ e/h vs L
σ/Amplitude (%)
D= 0.30
D= 0.42
D= 0.60
0
25
50
75
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
electron (E= 9 GeV), L (cm)
σ/Amplitude (%)
D= 0.60
D= 0.42
D= 0.30
0
20
40
pion (E= 9 GeV), L (cm)
e/h
D= 0.60
D= 0.42
D= 0.30
0
0.4
0.8
(E= 9 GeV), L (cm)

Fig. 5



σ/A(%)
75
50
25
0
1
3
2
0
20
40
60
80
100
e (E= 9 GeV),
Θ°
σ/A(%)
40
20
0
0
20
40
60
80
100
π (E= 9 GeV),
Θ°
e/h
1.2
0.8
0.4
0
0
20
40
60
80
100
(E= 9 GeV),
Θ°

Fig.6

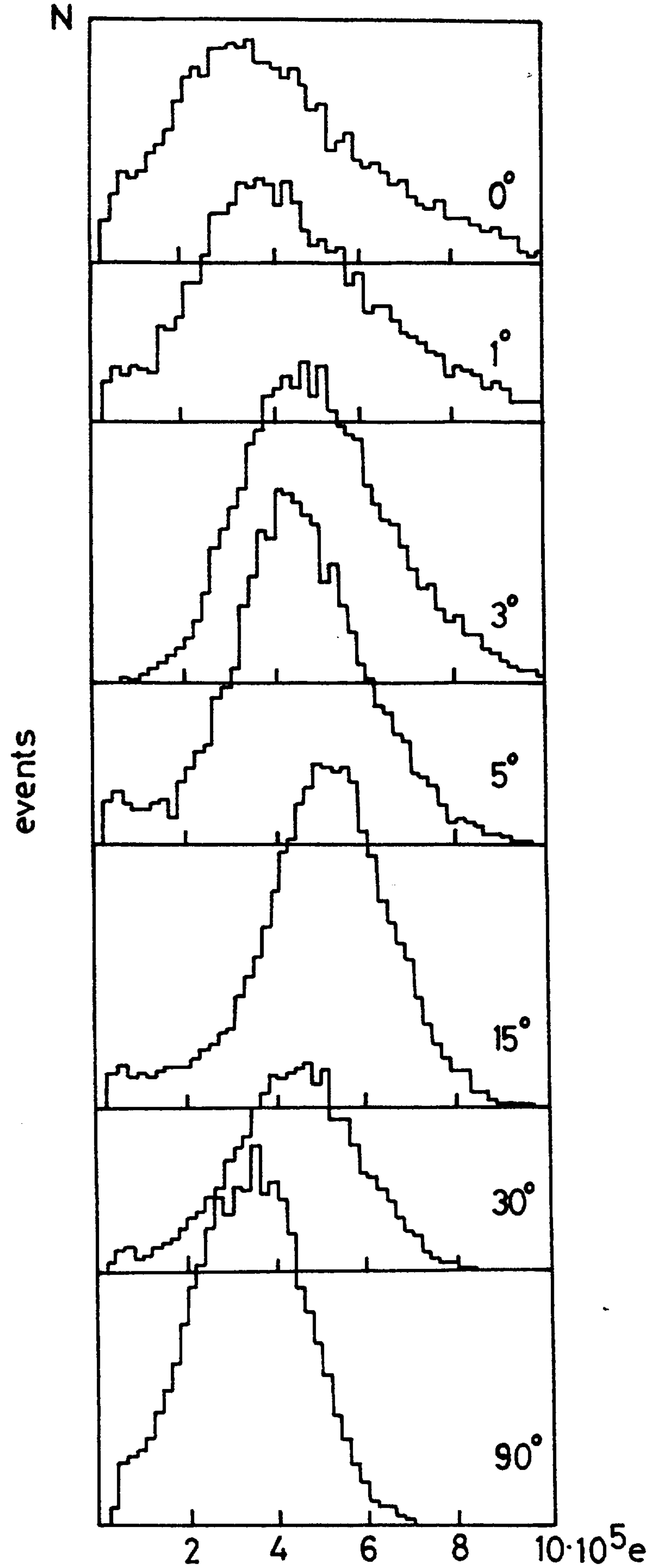


Fig. 7

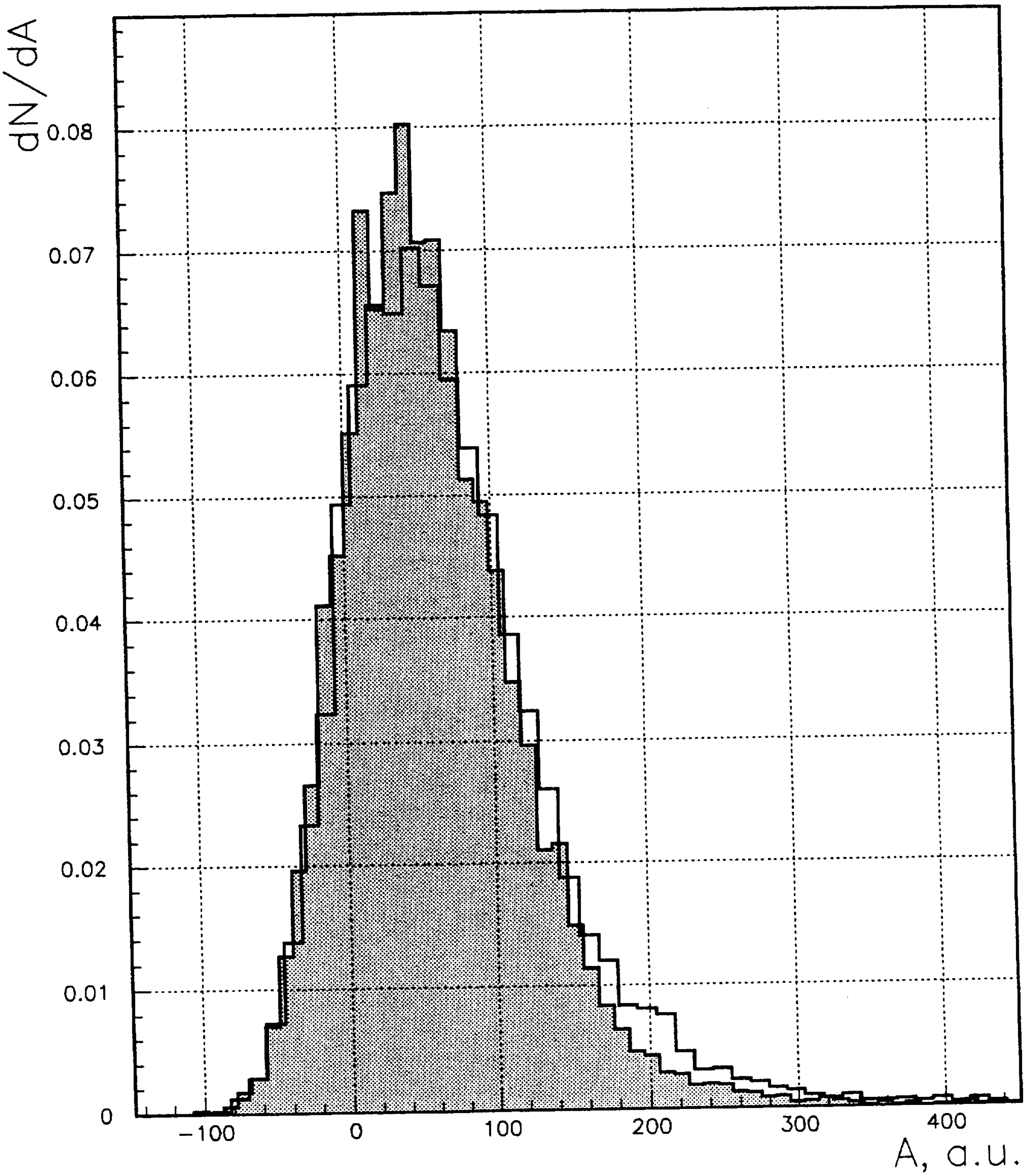


Fig. 8

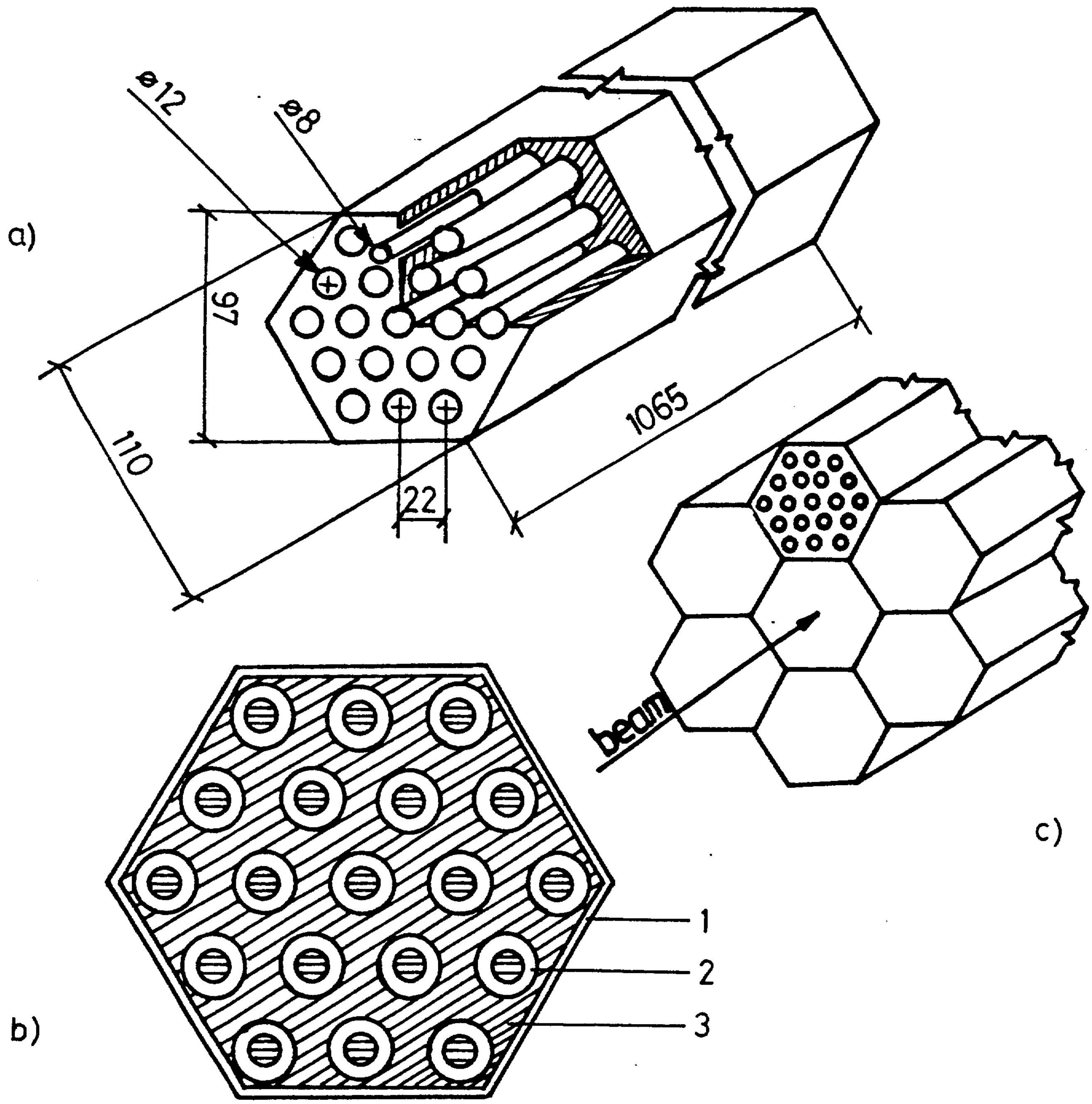


Fig. 9

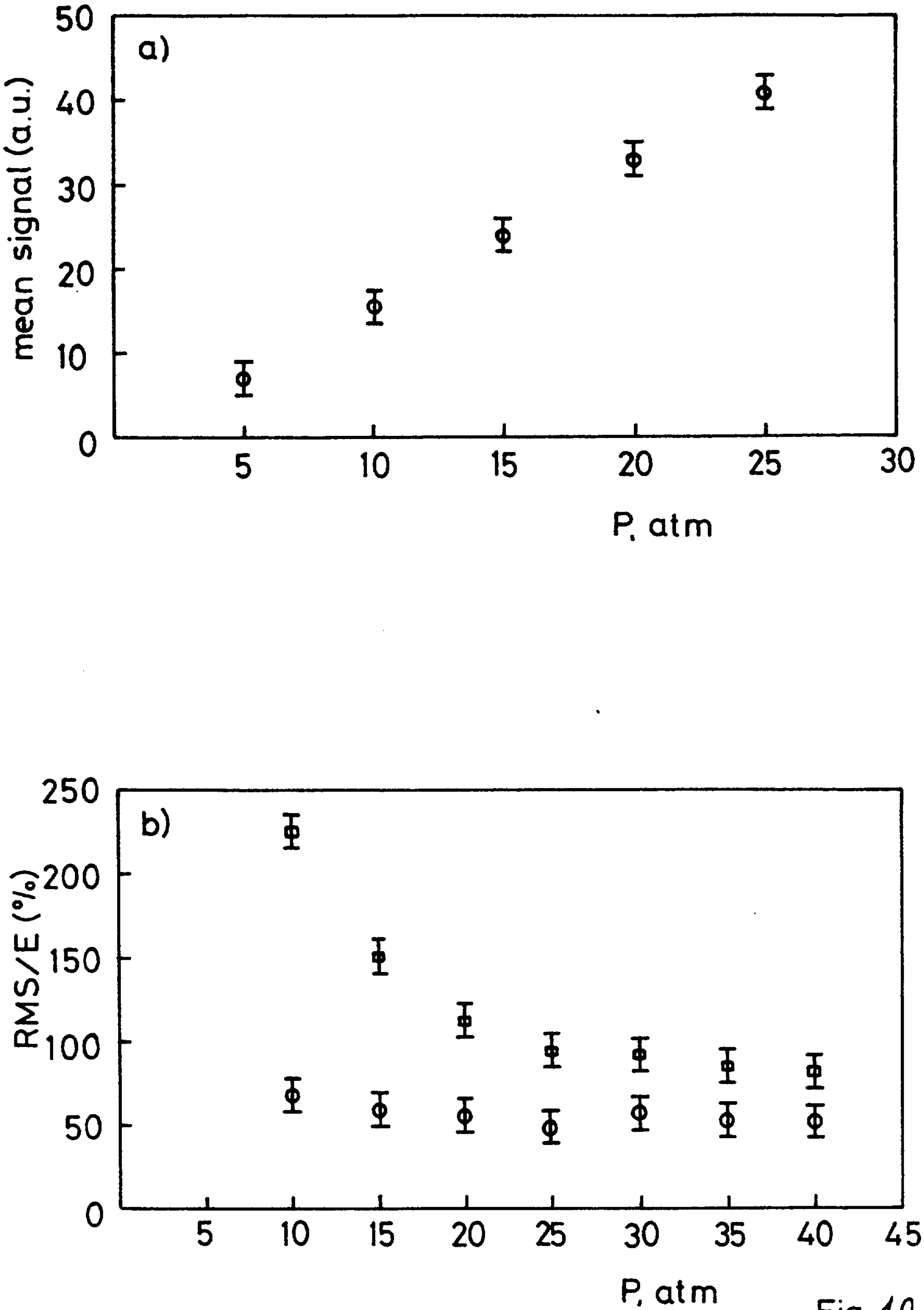
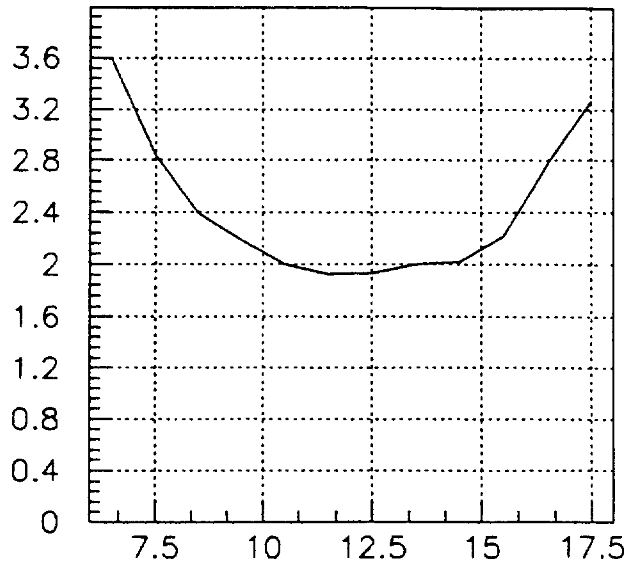

a)
mean signal (a.u.)
0
10
20
30
40
50
5
10
15
20
25
30
P, atm
b)
RMS/E (%)
0
50
100
150
200
250
5
10
15
20
25
30
35
40
45
P, atm

Fig. 10

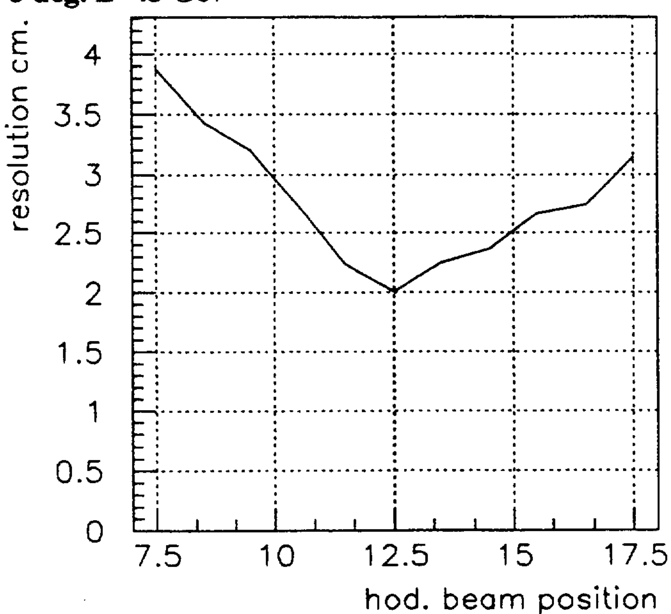
01/07/93 09.32

: 0 deg. E=43 Gev



x resolution

5 deg. E=43 Gev



x resolution

Fig. 11

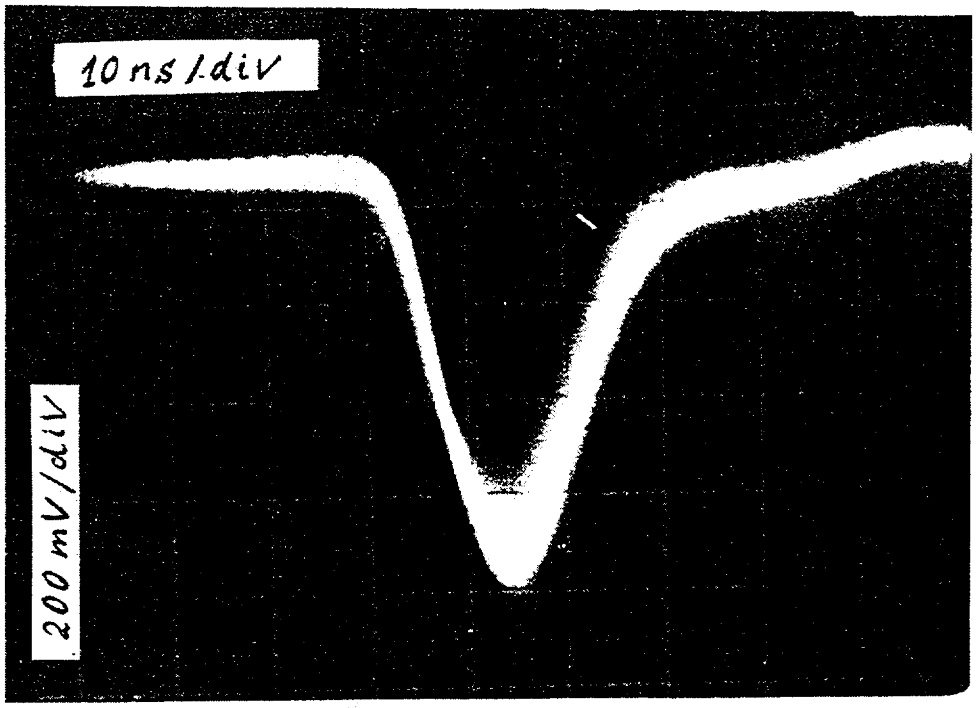


Fig. 12

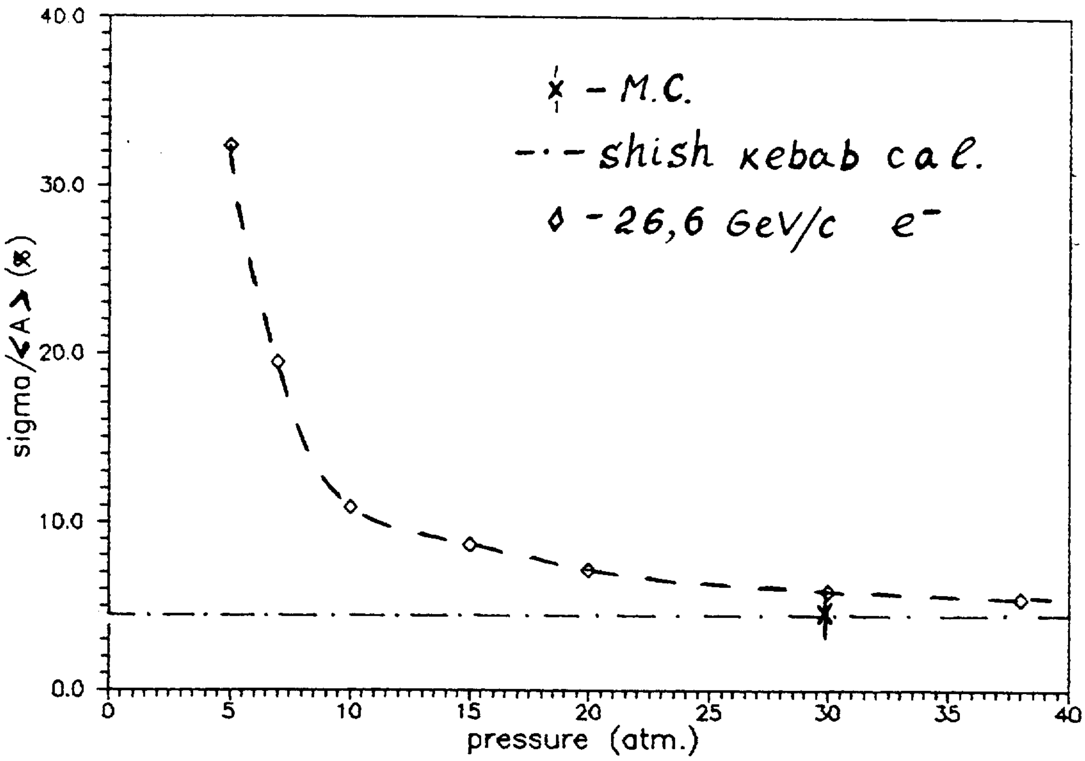


Fig. 13

Prototype: (5,6 mm Pb + 2,2 mm Gas) × 28

D = 60 mm

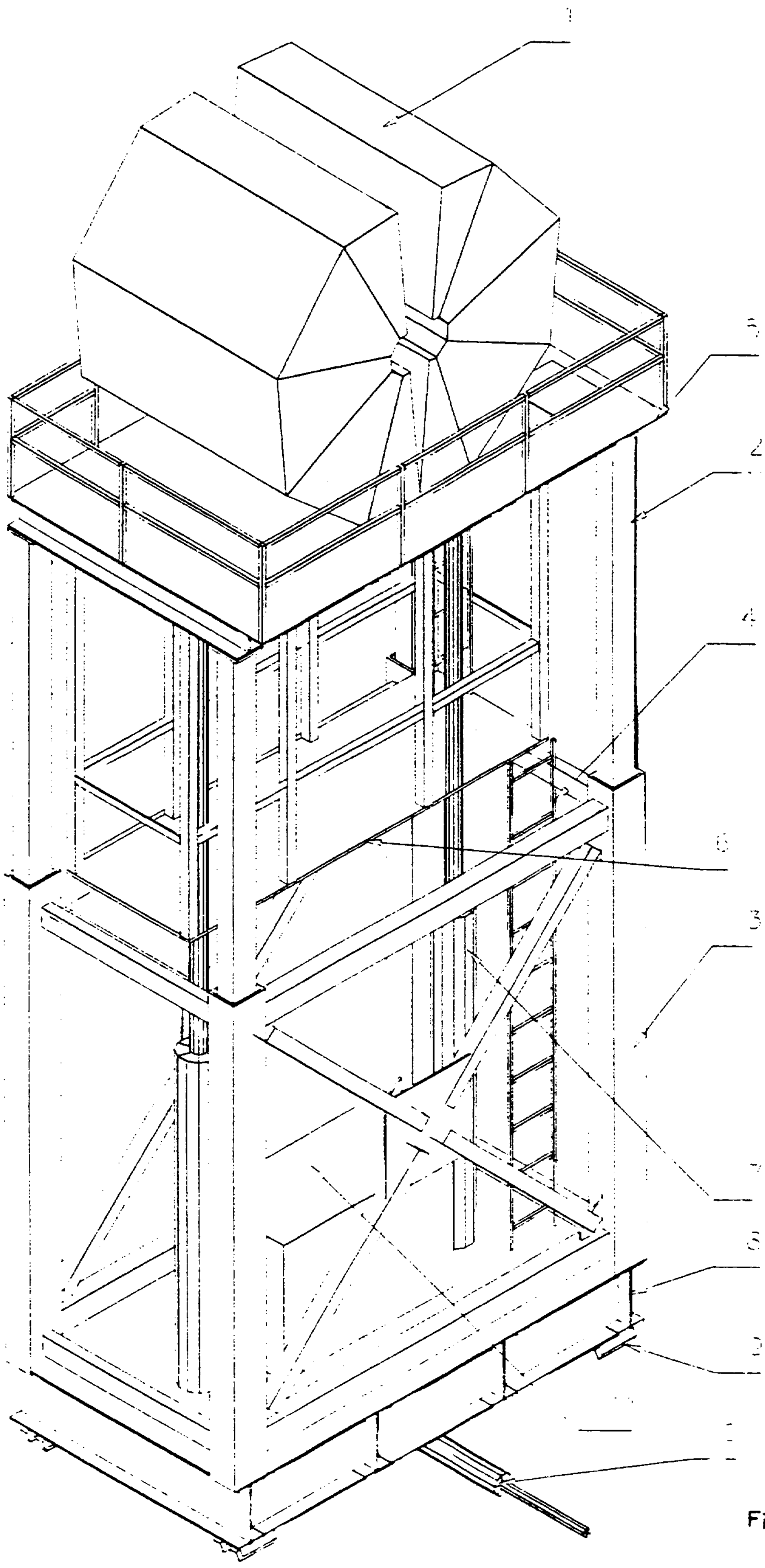


Fig. 14a

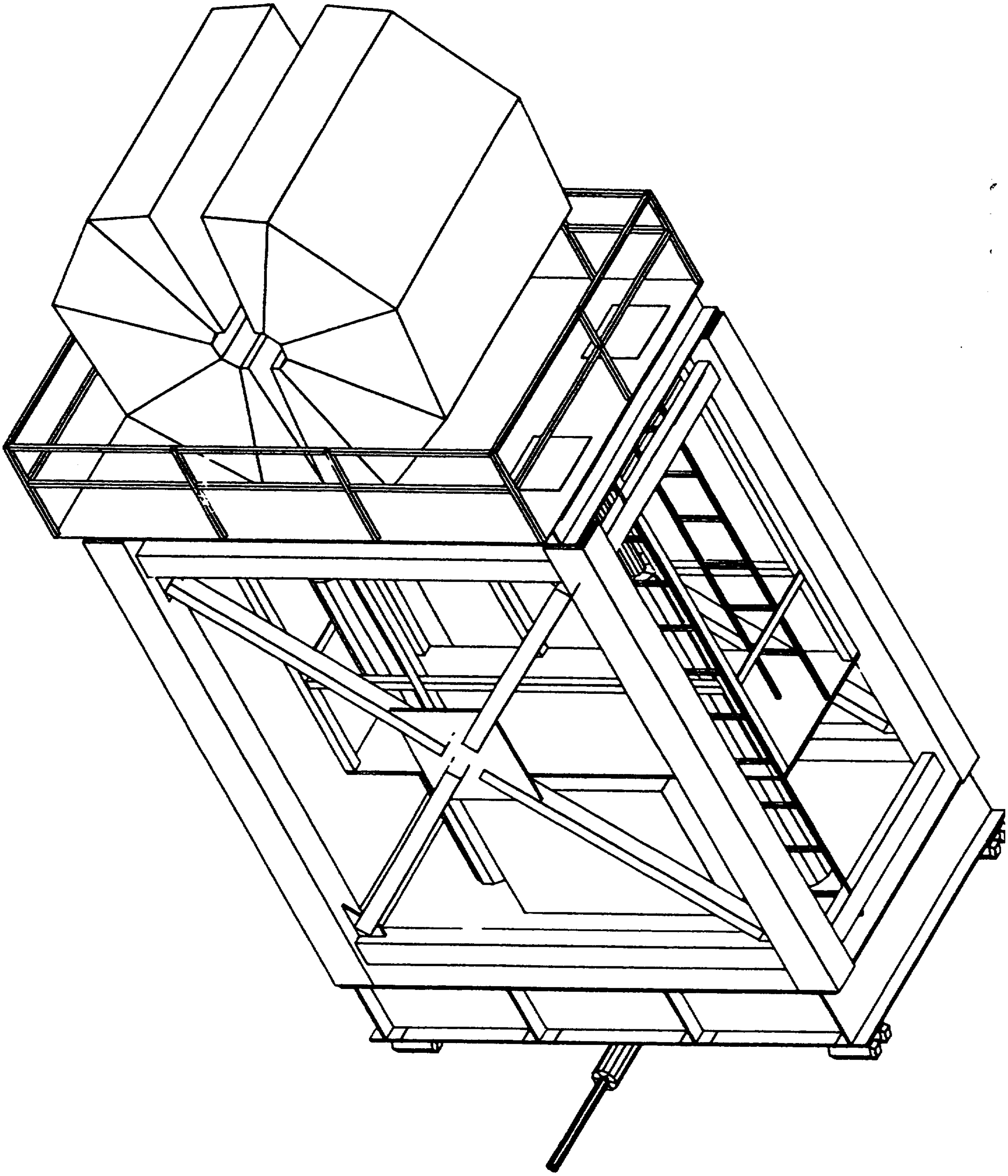


Fig. 14b