EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/ISRC/70-13
8 September 1970

Memorandum

From: A. Fainberg, E. Radermacher, C. Rubbia and A. Staude

To: Members of the ISRC

Subject: Tests on ionization detector for many-particle events at the ISR.

We are considering the possibility of constructing a multiplane ionization detector, of the type described in the enclosed NP Report 70-25, in view of its general applicability to ISR experiments. If expectations of the small-scale work are born out, it would be possible to reach a precision of ±4% in dE/dX, which would be sufficient to distinguish between relativistic electrons, pions, kaons, and protons of known momentum ($p_1 > 3$ GeV/c) even in events in which several particles are traversing the detector. Furthermore, also heavier particles such as deuterons, or lightly ionizing particles such as quarks (!), can in principle be identified.

We envisage the future work being carried out in the following stages:

i) Construction of a full-scale counter of 64 planes and tests with cosmic-ray particles, in order to demonstrate the feasibility of our ionization measurement at the "target" accuracy of ±4%.

ii) Demonstration of the ability to separate particles of different masses in a high momentum ($p > 6.0$ GeV/c) beam at the PS.

iii) Installation of two such counters at the magnetic spectrometer of the elastic scattering group in Interaction Region I6. A first exercise could be the one of separating protons from pions and kaons in low multiplicity events, in which, however, more than one particle is emitted within the acceptance of the spectrometer.

We believe that although the full potentialities of the detector can be understood only after the above-mentioned tests (i), (ii), and (iii), precise ionization measurements coupled with momentum measurements can render very useful services in many applications at the ISR.

Finally we remark that it may be possible to construct almost all such counters using financial resources and manpower other than those of CERN.

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

For internal distribution only

NP Report 70-25
1 September 1970

PARTICLE IDENTIFICATION BY IONIZATION MEASUREMENTS. APPLICATION TO THE ISR.

C. Rubbia*)

ABSTRACT

A proportional counter, intended as one layer of a multiplane ionization detector, has been constructed and tested. On the basis of the results it is concluded that in approximately 1 metre of particle path in propane at NPT it is possible to separate unambiguously the relativistic ($P \geq 3.0$ GeV/c) protons, kaons, pions, and electrons when associated with momentum determination. The ionization is sampled in approximately fifty equal intervals. The counter can operate for many-particle events.

A simple and cheap (≤ Sw.frs. 40) channel for recording electronics has been designed and tested.

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1970

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1. INTRODUCTION

Several practicable methods for identifying the mass of the secondary charged particles from collisions in the ISR have been discussed in the literature[1]. The most obvious method is a combination of momentum and time-of-flight or Cerenkov radiation. Time-of-flight measurements are generally applicable only for the lower momentum tail of the secondary particle that is produced (≤ 1.0 GeV/c). Threshold Čerenkov counters are convenient for discriminating between two different classes of particles: "fast" and "slow". More than one counter is required in order to differentiate between several different types of particle, such as electrons, pions, kaons, and protons, or if the momentum range is particularly wide. In the presence of several particles, the response of the counters is generally ambiguous.

We consider here yet another possibility of particle recognition based on the measurement of the total energy loss for relativistic particles in the region of logarithmic increase[2]. A gas is required, since in the case of solid materials the logarithmic rise of the collision losses, proportional to log p/mc, is soon stopped by the density effect. As is well known, this effect consists of the polarization of the atoms close to the path of the particle which diminishes the electric field acting on the electrons at longer distances.

The average fluctuations in the total collision losses are in general larger than the separation to be expected between different particles of the same momentum (Fig. 1). Therefore it is only by combining the information from several counters that it is possible to perform a meaningful discrimination[3,4].

For most types of probability distributions, the best value of a set of N similar measurements of the same physical quantity is given by the arithmetic mean of the results. In our case this would be equivalent to taking a single measurement in a counter N times thicker. However, the Landau distribution[5] of the collision losses $\phi(E)$ is characterized by an extraordinarily long tail towards larger energy losses, which decreases like $1/E^2$. The variance integral

$$\int_{-\infty}^{+\infty} \phi(E)E^2\, dE \sim \int_{-\infty}^{+\infty} (1/E^2) \cdot E^2\, dE$$

does not converge and the arithmetic mean is not the best way of combining the results. One can show$^{3)}$ that, compared to the error in a single measurement, the error in the arithmetic mean of N measurement is not $1/\sqrt{N}$ but only $1 - (\ln N/10)$ times smaller. For instance, solid materials have Landau widths at half maximum, which is only two or three times smaller than the one for a gas at atmospheric pressure, in spite of the several orders of magnitude in the total energy losses.

Simple methods of analysis which make more efficient use of the results than the simple arithmetic mean, have been discussed in the classic work of Alikhanov, Lubimov and Eliseev$^{3)}$. The idea behind this is the one of introducing some kind of cut-off in the high-energy tail of the Landau distribution, in order to ensure the convergence of the $\int_{-\infty}^{+\infty} \phi(E)E^2\, dE$ integral. Two methods appear to be particularly simple and effective: the "cut off" method and the "logarithmic mean" method.

The "cut-off" method consists in removing from the N measured ionization values the $(1 - \alpha)N$ largest values, and the most probable ionization is determined as the mean of the remaining values. The error in the value found in this way is approximately$^{3)}$ $\delta\bar{E} = \sigma/\sqrt{\alpha N}$, where σ is the half width of the Gaussian-like distribution obtained by removing the long Landau tail. The parameter α is chosen such that the centre of gravity of the retained measurements coincides with the position of the most probable value. This corresponds to rejecting 35% of the largest ionization values.

The "logarithmic mean" method consists in sampling the higher ionization measurements by taking the logarithmic rather than the arithmetic mean of all measurements:

$$\bar{E} = \exp\left[\frac{1}{N}\Sigma \ln E_i\right] = \sqrt[N]{E_1 \cdot E_2 \ldots E_N} \ .$$

Only for N large does the accuracy of the logarithmic mean method tend to become equal to the one of the cut-off method. For a small number of measurements the asymmetry of the error curve is still considerable and the cut-off method is preferable.

2. CHOICE OF PARAMETERS

The momentum dependence of the specific ionization for protons, kaons, pions, and electrons is shown in Fig. 2. Apart from a region from 1.0 GeV/c to 3.0 GeV/c centred around the minimum of ionization where the assignment can be ambiguous, at least in principle the various particles can be separated with momentum and precise ionization measurements. The relative separation in the relativistic region is independent of energy, at least until the density effect limit is reached. The influence of the density effect as a function of the gas pressure for an argon gas, is shown in Fig. 3 from Steinheimer's calculation[6]. Filling at atmospheric pressure is adequate up to the highest momentum of the ISR.

The experimental distribution of the energy losses for relativistic particles in gases has been found to be substantially broader than the Landau predictions, at least for small counter depths[7,8]. The deviation is understood[7], since Landau's treatment neglects electron bindings. Widths for different gases can be made to lie on a universal curve if expressed as a function of the parameter[7]: $\xi/\overline{I_0 Z}$ (Fig. 4). The parameter $\overline{I_0 Z}$ is the mean ionization potential of the atoms of atomic number Z and ξ, is an energy such that on the average one delta of energy greater than ξ is produced over the track length examined. Delta-rays of energy approximately equal to ξ are mostly responsible for the spread in the distribution[9]. The value of ξ is given by

$$\xi = \left\{1.54 \times 10^5/(v/c)^2\right\}\left\{\Sigma\ \mu_i \frac{Z_i}{A_i}\right\} \text{eV} ,$$

when μ_i is the mass per cm^3 of the element of atomic number liquid atomic weight A_i. In the theory of Landau, $\xi/\overline{I_0 Z} >> 1$.

In order to obtain the most compact counter, a gas which gives the highest value for $\xi/\overline{I_0 Z}$ per unit length is required. All noble gases have almost exactly the same properties, since I_0 = const $\simeq$ 13.5 eV and $\xi/I_0 Z = \mu/A\ I_0$ = constant, and densities are proportional to A for all perfect monoatomic gases.

The quantity $\xi/\overline{I_0 Z}$ can be easily calculated for several interesting gases (see Table 1). Experimental work on argon [West$^{7)}$, Eiben et al.$^{10)}$], on methane (West) and on propane [Alikhanov et al.$^{3)}$] is in agreement with the entries of Table 1.

Table 1

Comparative widths of Landau distributions

Gas	Value of $\xi/\overline{I_0 Z}$ for 1 cm at atmospheric pressure and T = 25°C
Argon, krypton	0.50
Methane (CH_4)	0.970
Propane (C_3H_8)	2.58
Isobutane (C_4H_{10})	3.38

For a given resolution, a propane counter needs to be only $1/5$ in length compared to a counter filled with noble gas and the same number of planes.

This ratio decreases further to $1/6.76$ for isobutane.

We have investigated the number of counters required to achieve a given resolution. We follow again the classic work of Ref. 3. The experimental Landau distribution for relativistic cosmic-ray particles for a counter with $\xi/\overline{IZ} = 2.5$ has been measured$^{10)}$, and it is shown in Fig. 6. In order to calculate the effect of combining N counters, we have generated with a Monte Carlo technique a large number of events. At each time the probability distribution of Fig. 6 has been generated N times. Events have been analysed with the "cut-off" and with the "logarithmic mean" techniques. The calculation is, of course, exact to the extent that the N ionization measurements are independent, i.e. that there is no delta-ray which crosses two counters. Of course this is, by all means, a valid approximation, since in any case in the analysis procedure we reject the larger energy losses.

Results of the calculations are shown in Figs. 7 and 8. The full width at half maximum is of the order of 8% for $\xi/\overline{I_0 Z} = 5$ and $N = 50$, and it is found to vary as $\sqrt{N}$ for different numbers of equally thick layers. The "cut-off" method looks better than the "logarithmic mean", since the former gives more symmetric peaks. In general, it is possible to separate pions, electrons, and protons easily. The regeneration between kaons and protons is somewhat marginal, and an increased number of layers would be advisable.

The dependence of the resolution on the number of layers for a given total counter depth is shown in Fig. 9, calculated for $\xi/\overline{I_0 Z} = 258$, equivalent to a 1 metre long counter filled with propane at NPT. Above about $N = 50$, there is no appreciable gain from increasing the number of layers, since the advantage of the additional measurements is cancelled by the broadening of the resolution of the individual counters.

To conclude, with as little as one metre of path in propane at NPT, it is possible to separate unambiguously relativistic protons, kaons, pions, and electrons when associated with a momentum determination, by sampling the total ionization over approximately fifty equal intervals.

3. DESIGN CONSIDERATIONS AND TESTS OF A PROPORTIONAL COUNTER

A modular proportional counter has been built*), intended as one layer of a multiplane ionization detector (Fig. 10). The main parameters are:

Number of wires : 50 + two 0.5 mm Cu guard-wires
Wire diameter : 50 μ gold-plated molybdenum wire tension 15 g.
Spacing between wires : 4 mm
HV foils : 25 μ aluminized mylar
Distance between wire plane and HV foils : 5 mm

The HV foils do not cover the whole length of the wires. They are cut at ∿ 20 mm from each end. In order to decrease the field at the edges,

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*) The counter was constructed by Mr. K. Bussmann. Early tests have been performed by Mr. L. Andersson.

the HV foils are terminated on 1 mm Ø copper wire along the free edge. The chamber unit is housed in a gas-tight box filled with argon-methane mixtures.

The gas amplification as a function of the applied voltage is shown in Fig. 11. The intrinsic energy resolution of the counter has been measured with an ^{55}Fe source, and an FWHM of 17% has been found, which is much narrower than the width at half maximum of the Landau distribution (≃ 60%).

The pulse shape after amplification is shown in Fig. 13. The total input capacitance to the amplifier is of the order of 20 pF, out of which about 5 pF are due to the wire alone. The input resistance is of the order of 5 kΩ. A faster rise-time (∿ 35 nsec) is obtained by reducing the time constant of the input circuit. Several wires can be parallel, since the induced positive pulse on nearby wires is very small (≤ 10%).

Increasing the distance between the HV electrodes and the wire plane from 5 mm to 1 cm does not change the performance of the counter appreciably, except that the operating voltage increases by about 50%.

An important question is the one of the pulse recording electronics. We have tested an amplifier and analogue memory device with two field effect transitions (FET) as switching elements (Fig. 14). When the gate is on, the forward resistance of the FET is small, of the order of 50-100 Ω. Signals of both polarities are transmitted. When the gate is off, a very weak drain current traverses the gate, usually less than a fraction of 10^{-9} A. Hence the memory time of the storage capacitor is very long (seconds).

The capacitor is charged by the first FET at the value of the counter pulse after amplification. The contents of several analogue memory elements are read-out sequentially through the second FET analogue switch, multiplexed with the output of several other memory units.

The delay in the store-gate pulse has to be such that the pulse reaches its maximum shortly before the gate closes. Typical on- and off-times are 20-30 nsec (2N 48564). All preceding information contained in the storage capacitor is automatically cancelled since the FET conducts in the two directions. Finally, if the delay of the gate pulse is longer than the rise-time of the pulse from the counter, a delay line (twisted pair) has to be inserted between the low-impedance amplifier output and the FET.

The cost of the recording electronics is estimated to be Sw.frs. 20-40 per channel. Integrated circuits can be used for the amplifier and for the read-out FET analogue switch. The store gate probably has to be a discrete component (2N 4856A). The only high-precision components required are resistors R_1, R_2, which set the gain of the amplifier. The stored voltage is, at a first approximation, independent of the actual value of C_s.

4. DESIGN CONSIDERATIONS FOR A FULL-SCALE MULTIPLANE IONIZATION DETECTOR FOR EXPERIMENTATION AT THE ISR

We are considering the possibility of realizing a pair of multiplane ionization detectors for identifying particles from p-p collision at the ISR. On the basis of the considerations of Section 2, we propose a 64-layer modular proportional counter, about 1.20 m deep and filled with propane at NPT *). Following the model work of Section 3, each module consists of several 50 μ wires, 1 cm apart, and a pair of HV electrodes made of thin aluminized mylar foils. The depth of each module is about 2 cm. Since it is of great interest to be able to operate the counter also in cases in which several particles are traversing the detector, wires are divided into 16 independent groups going to independent recording circuits. Several wires may be connected in parallel to extend the sensitive surface. The 64 planes have the wire oriented alternatively in orthogonal directions (x-chambers and y-chambers). Since the trajectory of the particles traversing the counters are supposed to be known from the measurements in ordinary multiwire proportional chambers, one can retain for the ionization measurement only those segments of counters in which no ambiguity arises. Even if several of the layers have to be discovered, the ionization measurement can still be precise enough, as elucidated in Fig. 9. Coupled to momentum determination, it is expected that one can distinguish unambiguously, above approximately 3 GeV/c, electrons, pions, kaons, and protons in the cases in which some 40-50 layers are giving an unambiguous ionization measurement. Also, heavier particles such as deuterons, or lightly ionizing events such as quarks can, in principle, be identified.

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*) An additional improvement would consist in filling the counter with isobutane, perhaps at a lower temperature to increase the gas density.

In Fig. 15 it is shown how the pair of multiplane ionization detectors could be added to the magnetic spectrometer of the elastic scattering group in the interaction region I6.

5. CONCLUDING REMARKS

Although the counter has been primarily designed with the ISR experimentation in mind, it is likely that a device of this kind could also render useful service in some PS experiments; in particular, it could be embodied in the Omega detector. For higher energies, the protons, kaons, and pions can be separated out up to perhaps 100 GeV/c.

Acknowledgements

I would like to thank Dr. M. Holder for supplying me with much information on the Aachen proportional counters[10)], and Drs. V. Bisi, J. Deutsch, A. Staude and Mr. E. Radermacher for very stimulating discussions.

Earlier work on the counter was performed in collaboration with Mr. L. Andersson. The counter was constructed by Mr. K. Bussmann.

REFERENCES

1) Report on Design Study of Intersecting Storage Rings for the CERN Proton Synchrotron, CERN report AR/Int.SG64/9, 12 May 1964.

2) The possibility of using a streamer chamber at the ISR for primary ionization measurements has been put forward by R.D. Fortune, CERN-ISR/DI/69-63, CERN-ISR/DI/69-68, and CERN-ISR/DI/69-73.

3) A.I. Alikhanov, V.A. Lubimov, G.P. Eliseev, Proc. Int. Conf. on Instrumentation for High-Energy Physics (1956), pp. 87-98; and also
P.V. Ramanamurthy and G.D. De Meester, Nuclear Instrum. Methods 56, 93 (1967).

4) E.H. Purcell, BNL 772 Rev. (T 290), 28 August 1969, pp. 95-97.

5) L. Landau, Journal of Physics (Russian) 8, 201 (1944).

6) R. Sternheimer, Phys. Rev. 88, 851 (1952).

7) D. West, Proc. Phys. Soc. A, 66, 306 (1953).

8) O. Blunck and S. Leisengang, Z. Phys. 128, 500 (1950).
O. Blunck and K. Westphal, Z. Phys. 130, 641 (1951).

9) T.E. Cranshaw, Progress in Nuclear Physics, (London, Pergamon Press, 1952), Vol. II.

10) B. Eiben et al., Nuclear Instrum. Methods 73, 83 (1969).

Figure captions

Fig. 1 : Landau distributions. The two curves are for protons and pions in the region of the relativistic logarithmic increase of ionization.

Fig. 2 : Total energy loss I, normalized to the minimum I_0, versus momentum for different particles.

Fig. 3 : The influence of the density effect on the most probable energy loss for argon gas versus pressure. (From Ref. 6.)

Fig. 4 : Experimental widths at half maximum of the Landau fluctuation versus the universal parameter $\xi/\overline{I_0 Z}$. The dotted line is the prediction of Landau's theory. (From Ref. 7.)

Fig. 5 : Experimental widths at half maximum of the Landau fluctuation of various reported measurements versus counter depth.

Fig. 6 : Experimental distribution of energy loss for relativistic particles at counter depth $\xi/\overline{I_0 Z} = 2.5$.

Fig. 7 : Resolution in the most probable energy loss obtained folding the experimental distribution of Fig. 6 N = 100 times.

Fig. 8 : Distribution in the energy loss for various particles obtained folding the experimental Landau distribution 50 times. Results are for a 1 metre deep propane counter at NPT. Data reduction is performed with the "cut-off" method.

Fig. 9 : Dependence of the FWHM of the energy loss measurement (cut-off method) for a counter 1 metre deep filled with propane at NPT versus the number of layers N.

Fig. 10	:	Prototype module of proportional counter.
Fig. 11	:	Relative gain variation versus high voltage for counter of Fig. 10, filled with propane-argon mixture. Measurements are done with an ^{55}Fe source.
Fig. 12	:	Experimental resolution for ^{55}Fe γ-rays.
Fig. 13	:	Picture of pulses after amplification. Horizontal 100 nsec/cm, vertical 1 V/cm. Measurements are performed with an ^{55}Fe source.
Fig. 14	:	Schematics of the pulse recording electronics.
Fig. 15	:	Layout of the double magnetic spectrometer in I6. A pair of multiplane ionization detectors are added in front of the spectrometer magnets.

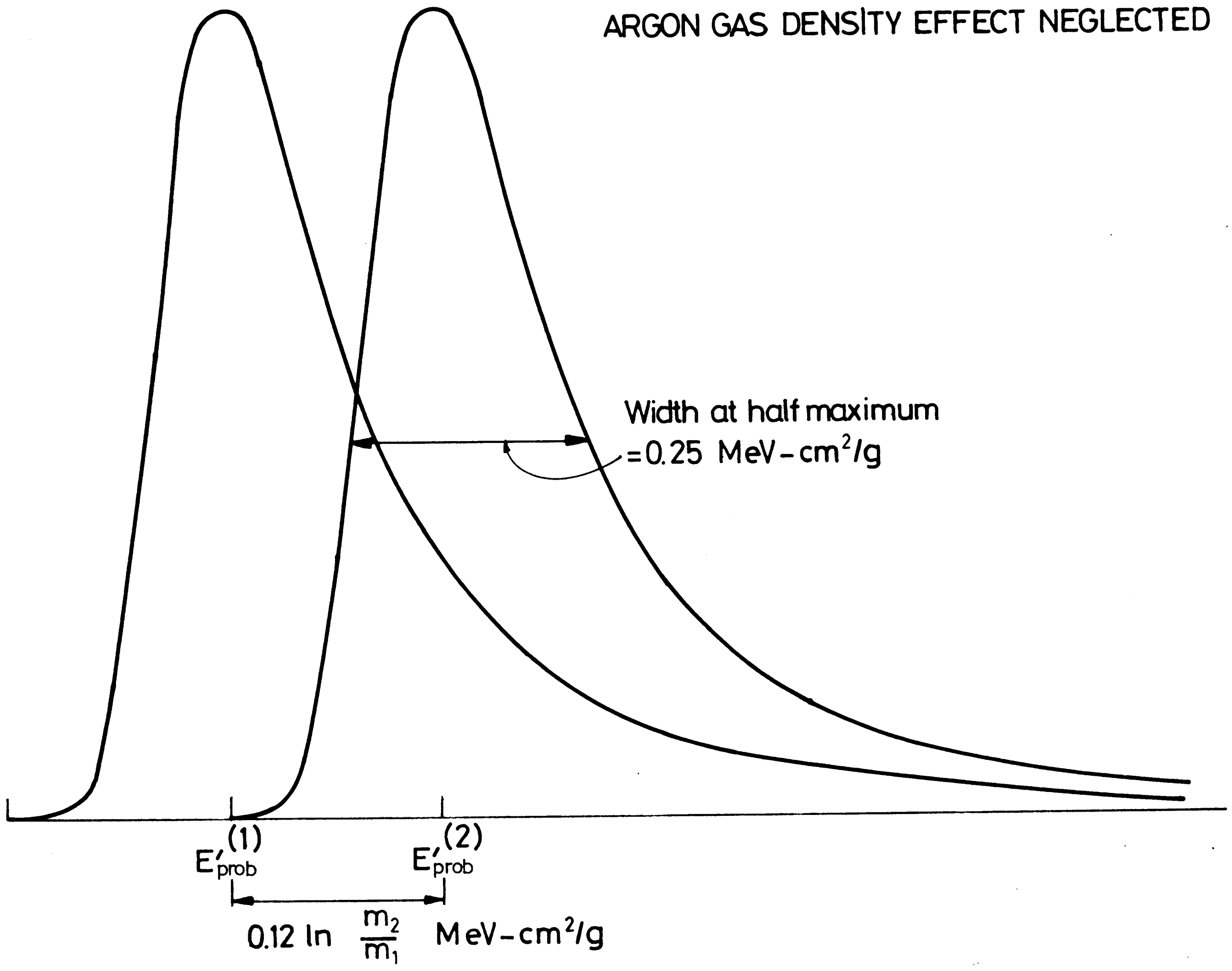

ARGON GAS DENSITY EFFECT NEGLECTED
Width at half maximum
=0.25 MeV-cm^2/g
$E'^{(1)}_{prob}$
$E'^{(2)}_{prob}$
$0.12 \ln \frac{m_2}{m_1}$ MeV-cm^2/g

Fig. 1

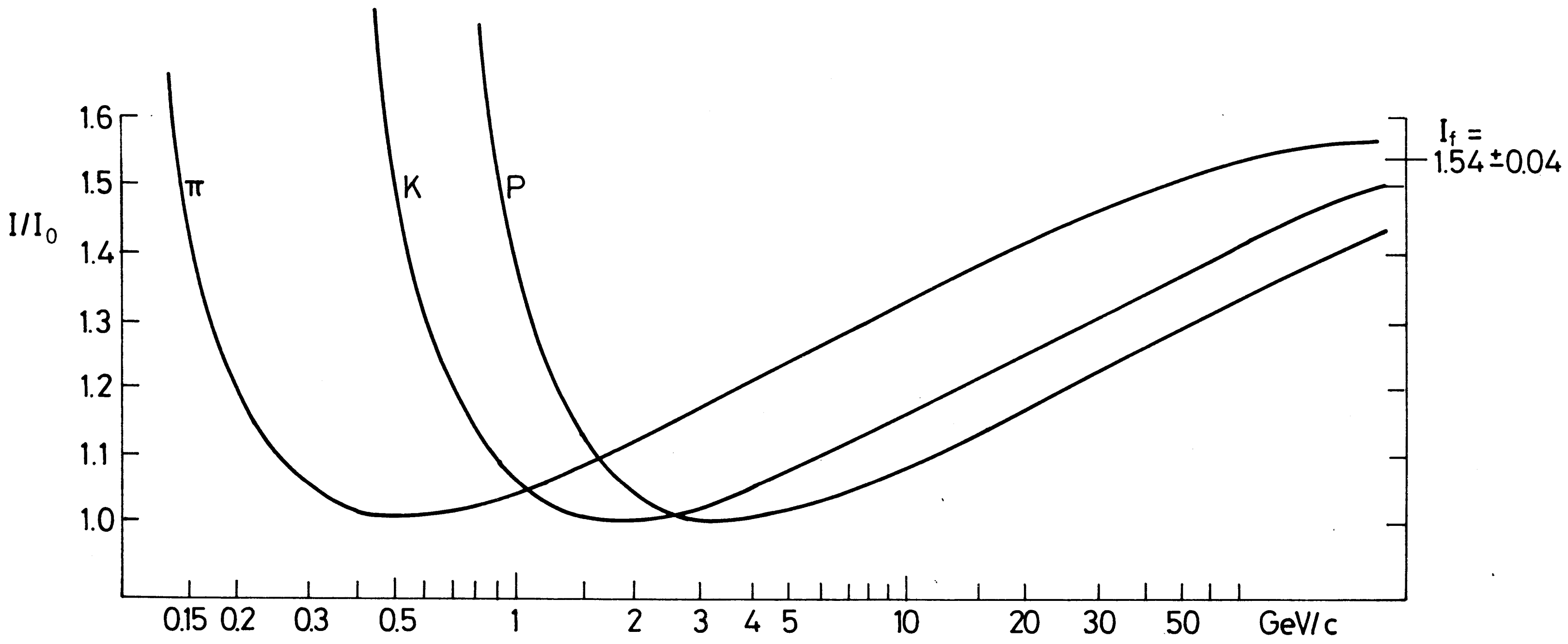

I/I$_0$
1.6
1.5
1.4
1.3
1.2
1.1
1.0
π
K
P
I_f =
1.54 ± 0.04
0.15
0.2
0.3
0.5
1
2
3
4
5
10
20
30
50
GeV/c

Fig. 2

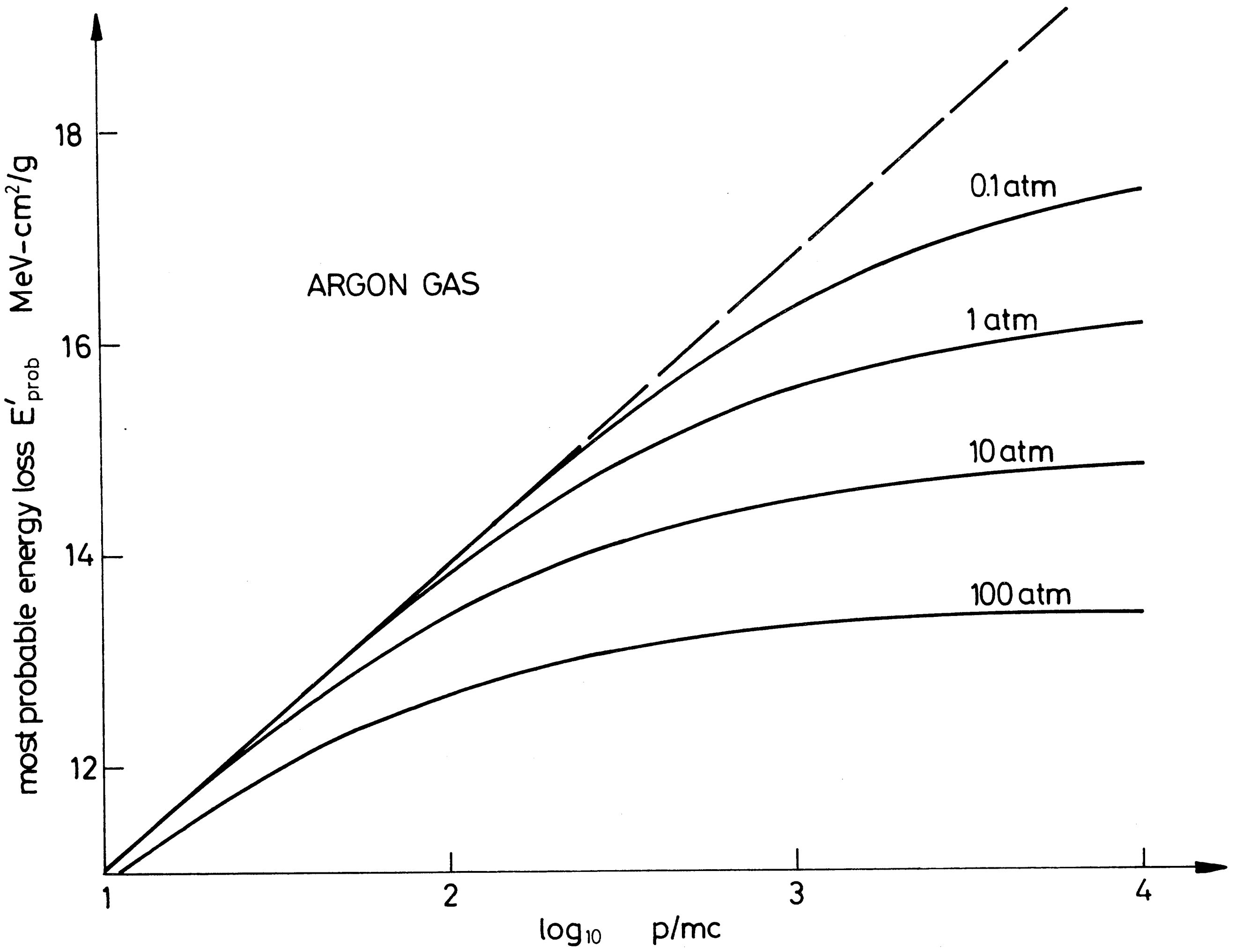

ARGON GAS
most probable energy loss E'_{prob} MeV-cm^2/g
18
16
14
12
0.1 atm
1 atm
10 atm
100 atm
1
2
3
4
$\log_{10}$ p/mc

Fig. 3

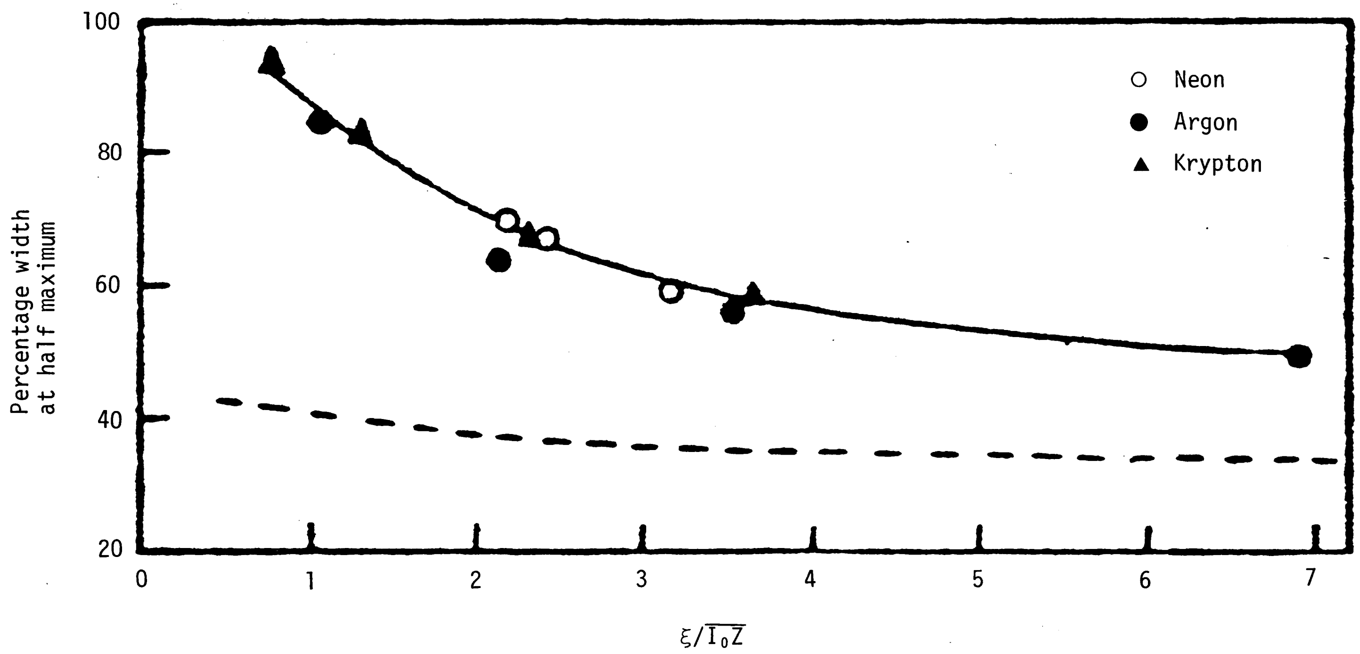

100
80
60
40
20
Percentage width at half maximum
0
1
2
3
4
5
6
7
$\xi/\overline{I_0 Z}$
○ Neon
● Argon
▲ Krypton

Fig. 4

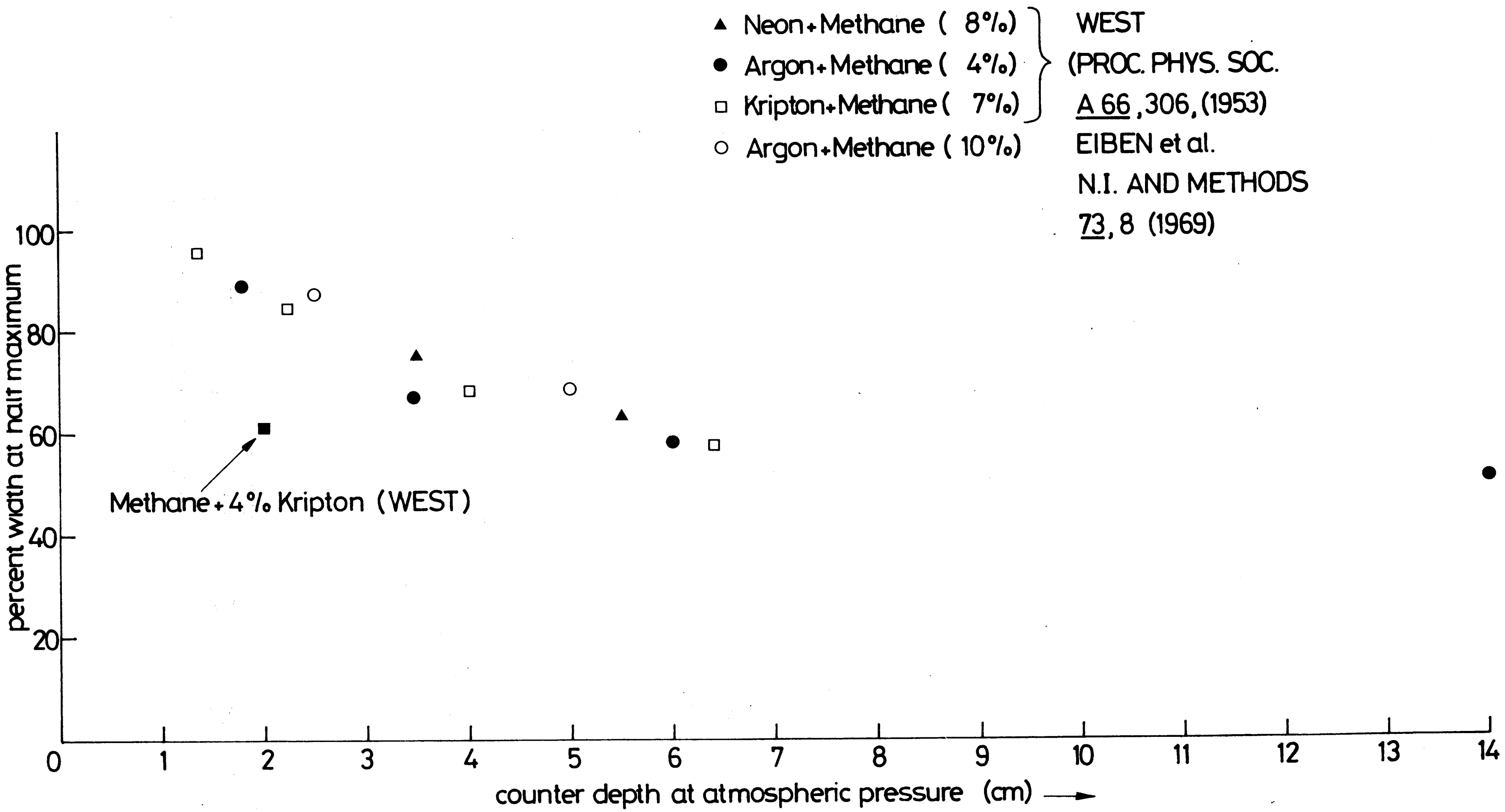

▲ Neon+Methane (8%)
● Argon+Methane (4%)
□ Kripton+Methane (7%)
WEST
(PROC. PHYS. SOC.
A 66, 306, (1953)
○ Argon+Methane (10%)
EIBEN et al.
N.I. AND METHODS
73, 8 (1969)
Methane + 4% Kripton (WEST)
percent width at half maximum
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
counter depth at atmospheric pressure (cm) →

Fig. 5

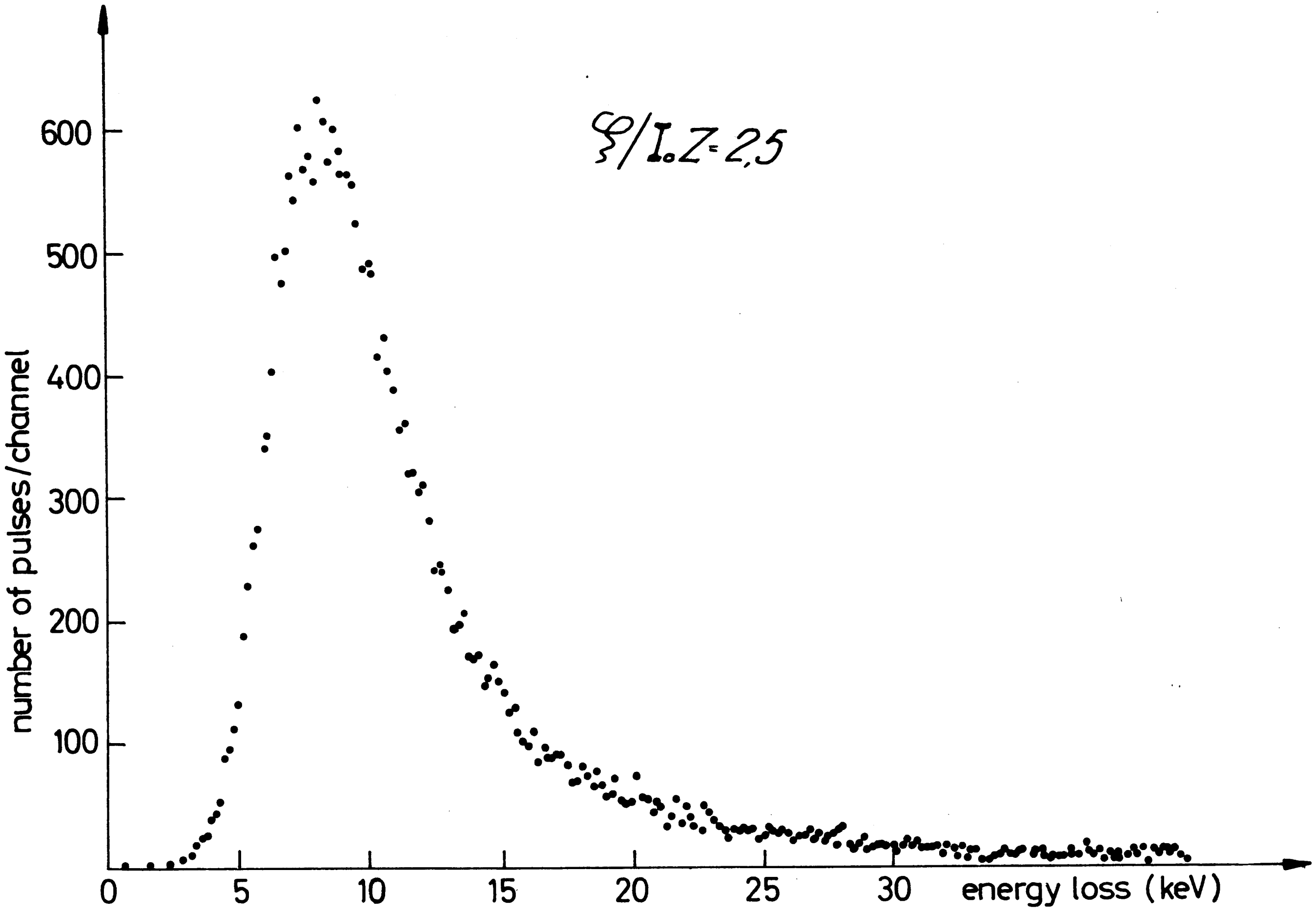

ξ/I₀Z=2,5
number of pulses/channel
600
500
400
300
200
100
0
5
10
15
20
25
30
energy loss (keV)

Fig. 6

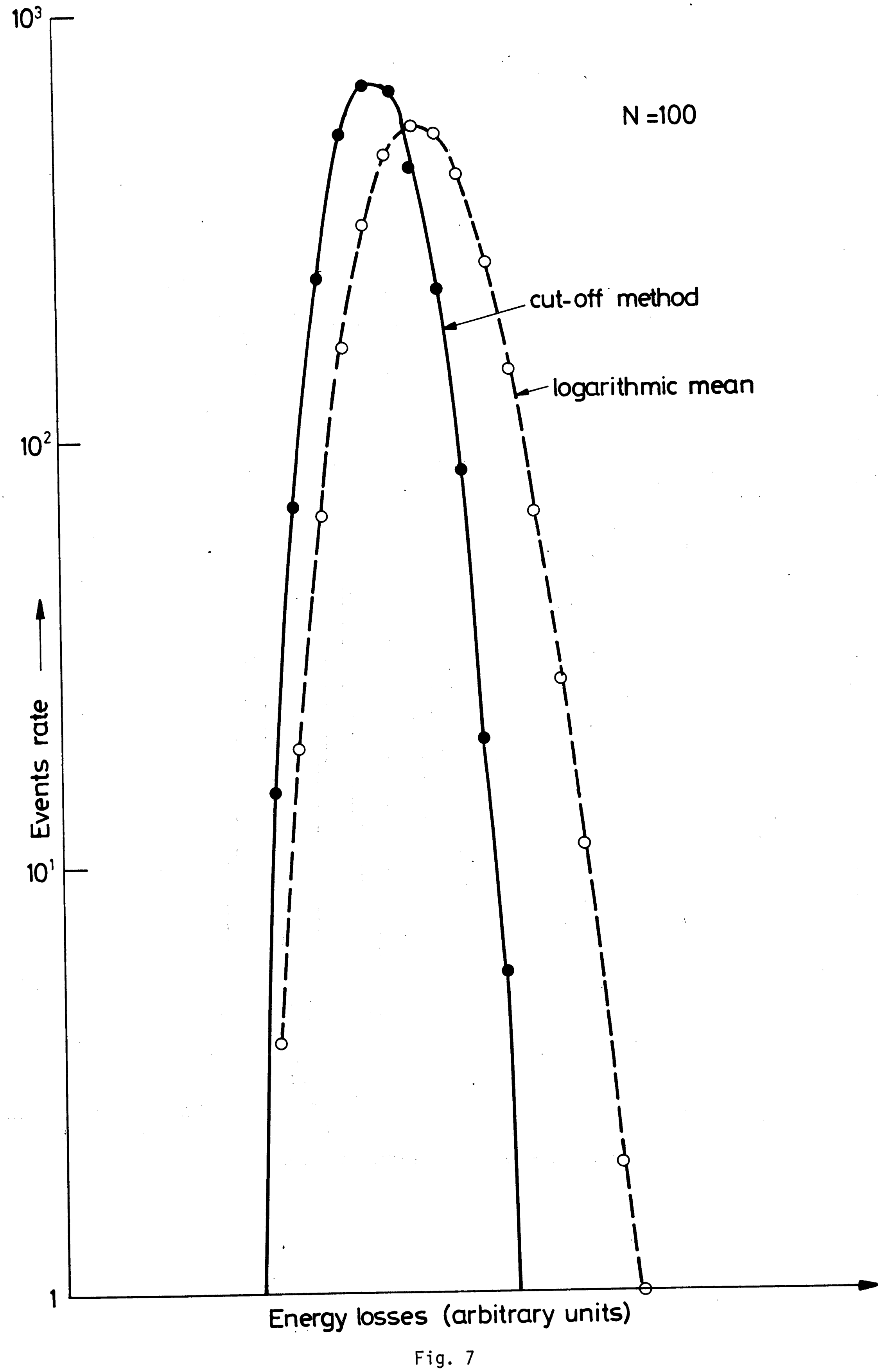

10³
10²
10¹
1
Events rate
N =100
cut-off method
logarithmic mean
Energy losses (arbitrary units)

Fig. 7

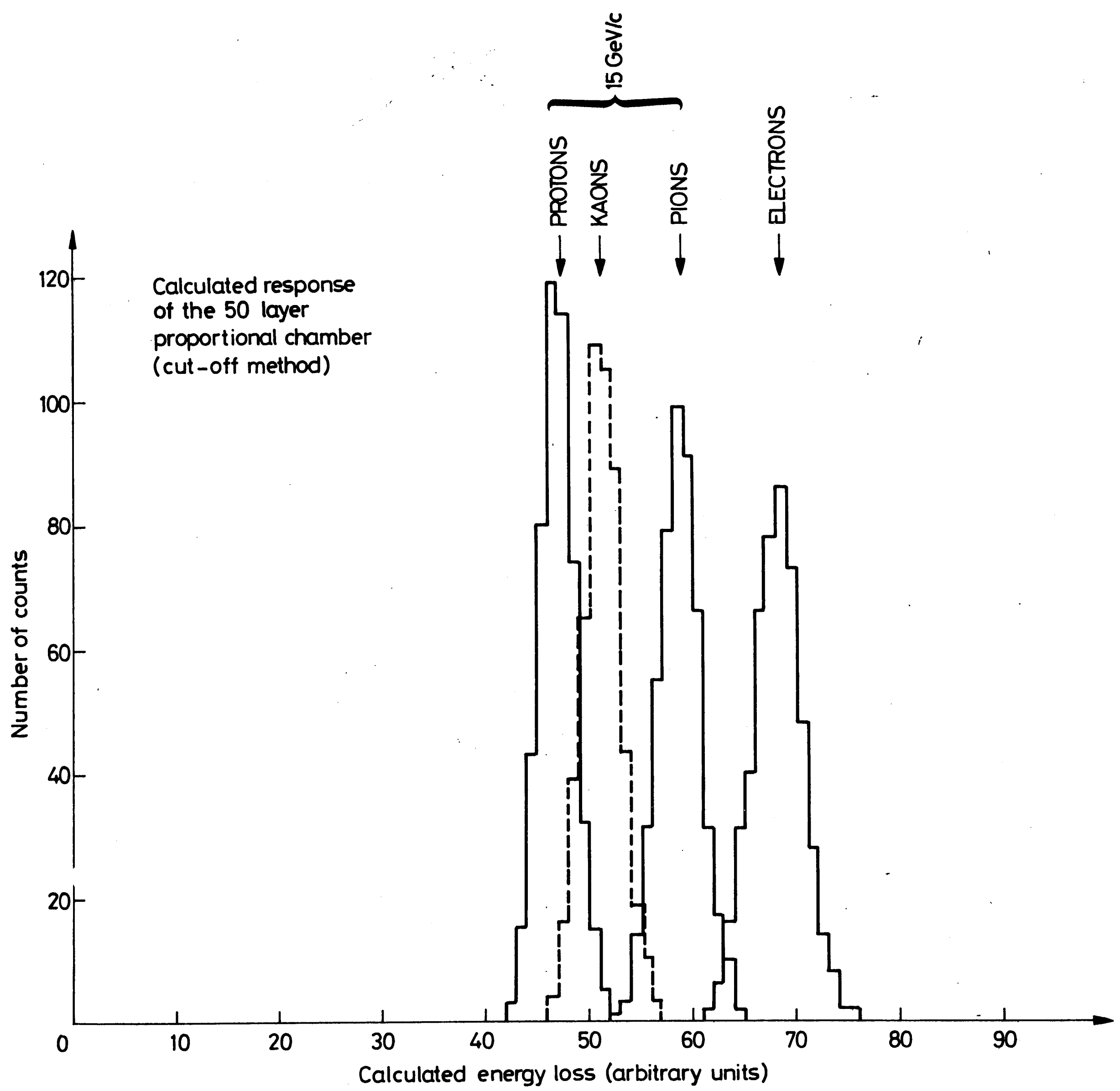

15 GeV/c
PROTONS
KAONS
PIONS
ELECTRONS
Calculated response
of the 50 layer
proportional chamber
(cut-off method)
Number of counts
120
100
80
60
40
20
0
10
20
30
40
50
60
70
80
90
Calculated energy loss (arbitrary units)

Fig. 8

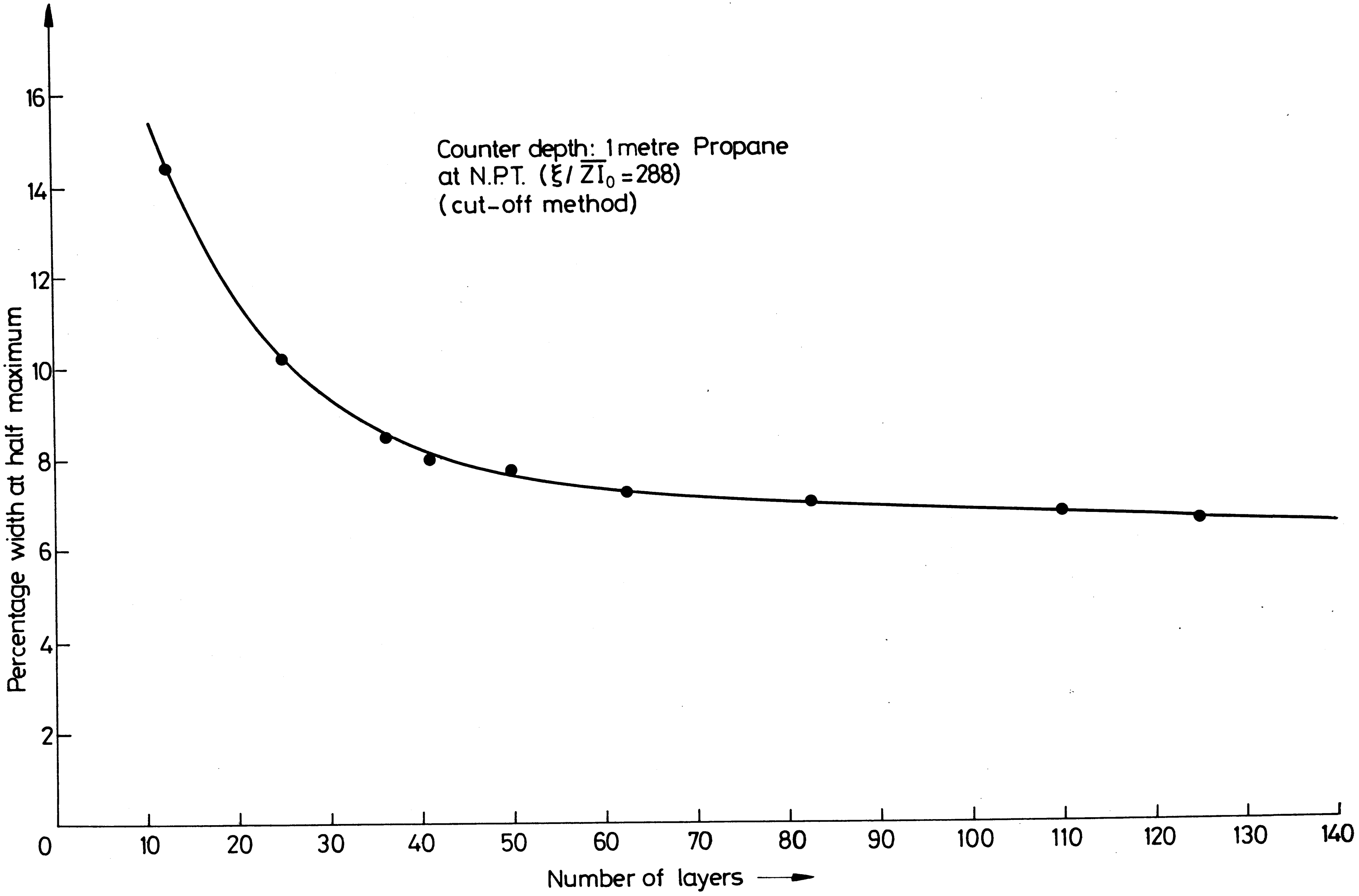

Counter depth: 1 metre Propane
at N.P.T. ($\xi / \overline{ZI_0} = 288$)
(cut-off method)
Percentage width at half maximum
16
14
12
10
8
6
4
2
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Number of layers →

Fig. 9

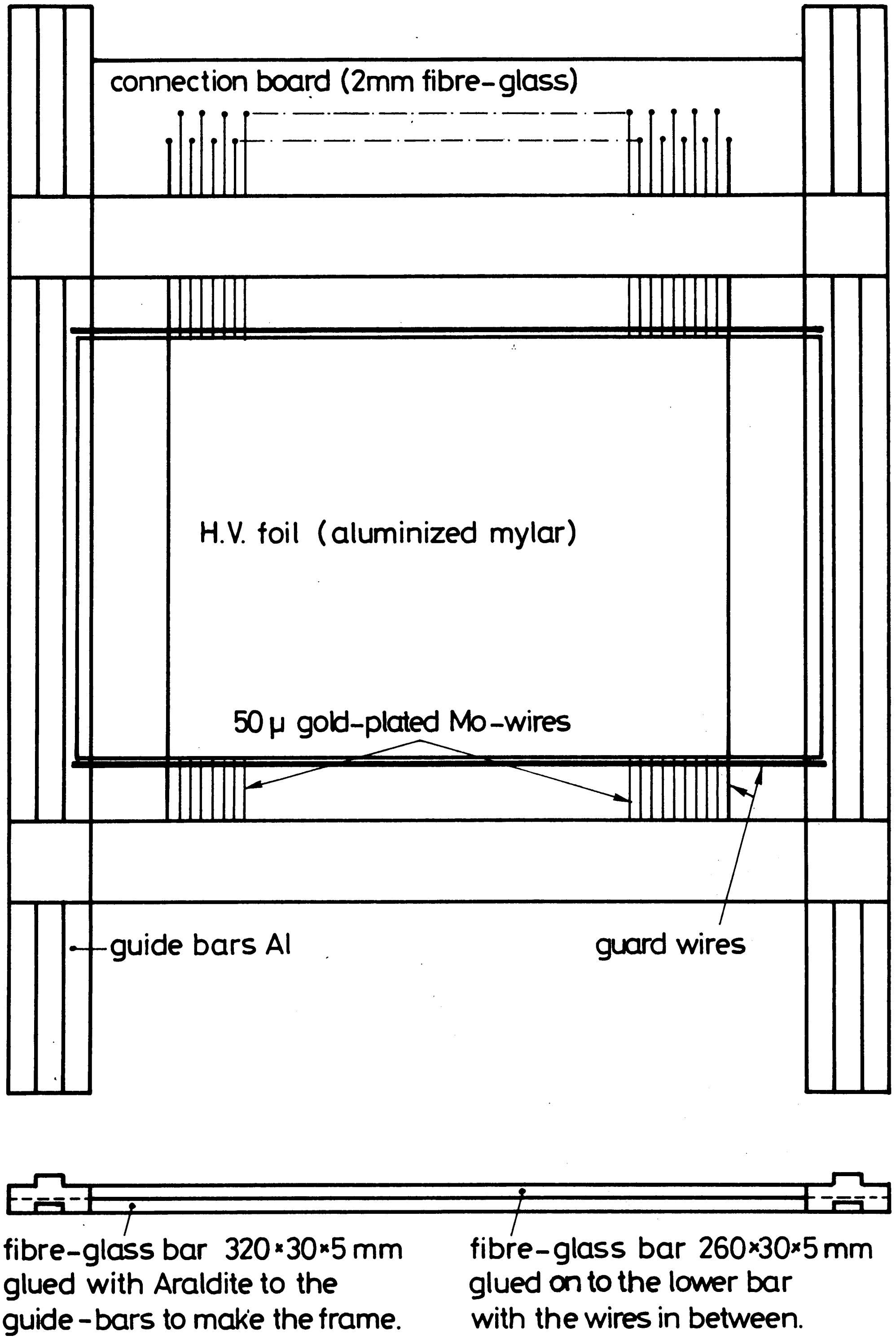

connection board (2mm fibre-glass)
H.V. foil (aluminized mylar)
50 μ gold-plated Mo-wires
guide bars Al
guard wires
fibre-glass bar 320×30×5 mm glued with Araldite to the guide-bars to make the frame.
fibre-glass bar 260×30×5 mm glued on to the lower bar with the wires in between.

Fig. 10

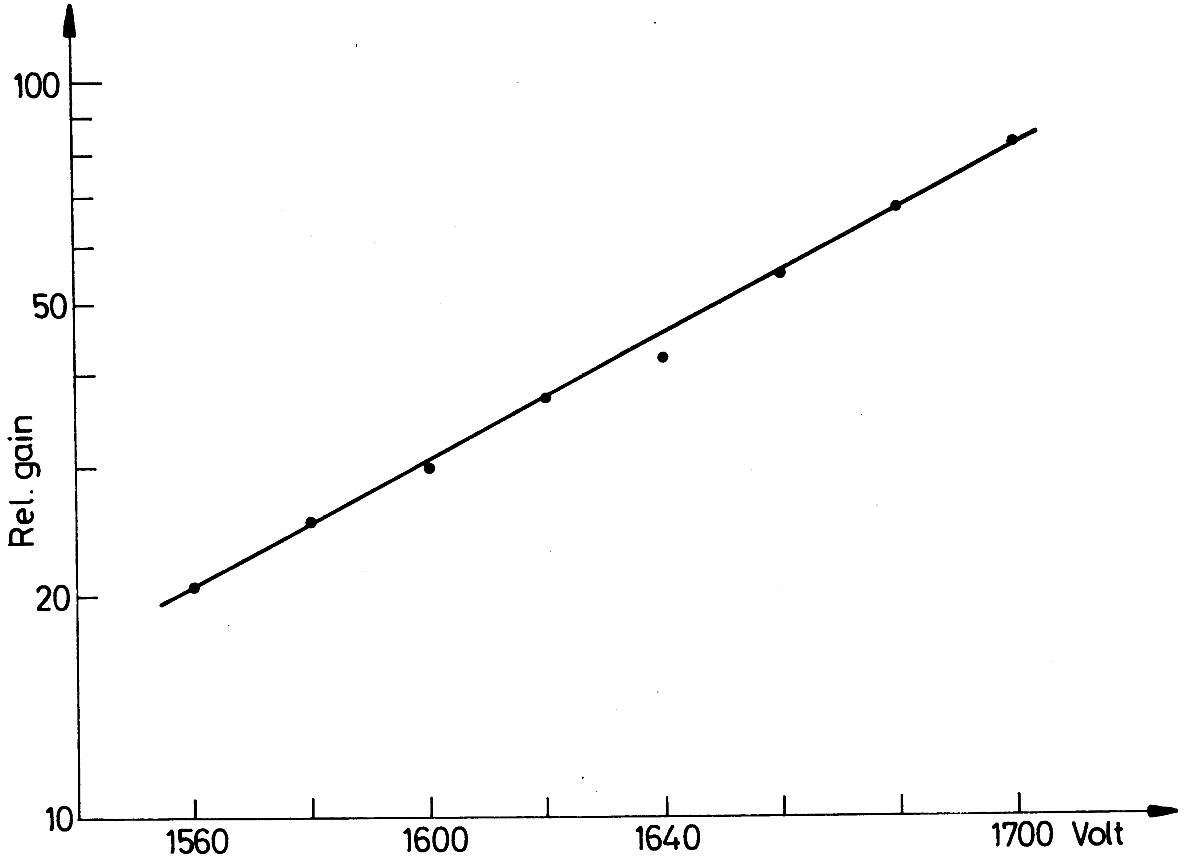


Fig. 11

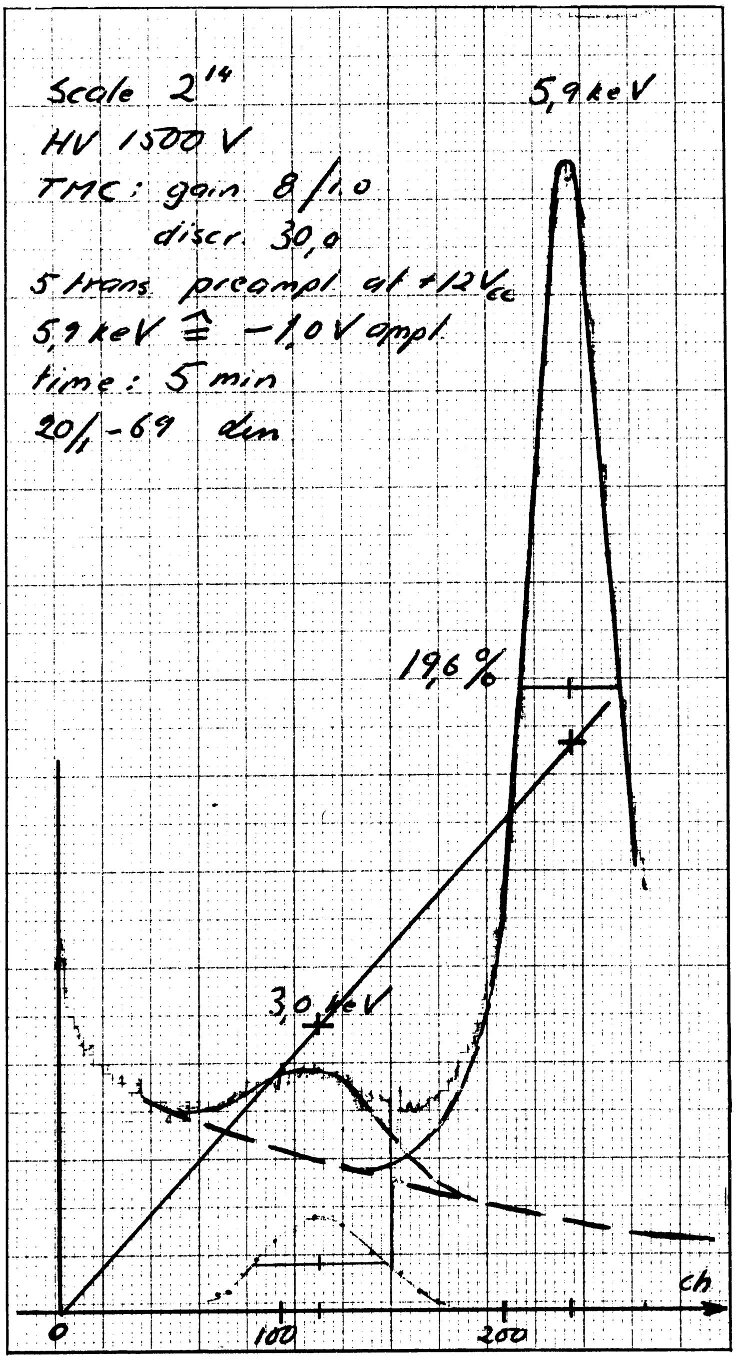

Scale 2^{14}
HV 1500 V
TMC: gain 8/1.0
discr. 30,0
5 trans preampl at +12 V_{cc}
5,9 keV ≙ −1,0 V ampl.
time: 5 min
20/1-69 dm
5,9 keV
19,6%
3,0 keV
ch
0
100
200

Fig. 12

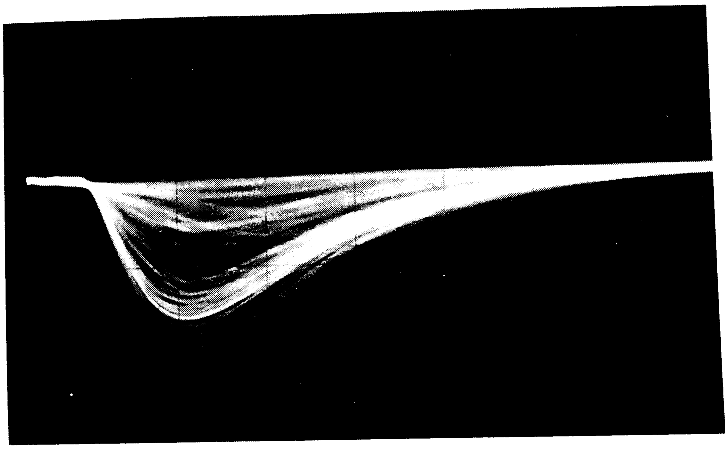


Fig. 13

Picture of pulses after amplification. Horizontal 100 nsec/cm, vertical 1 V/cm. Measurements are performed with an ^{55}Fe source.

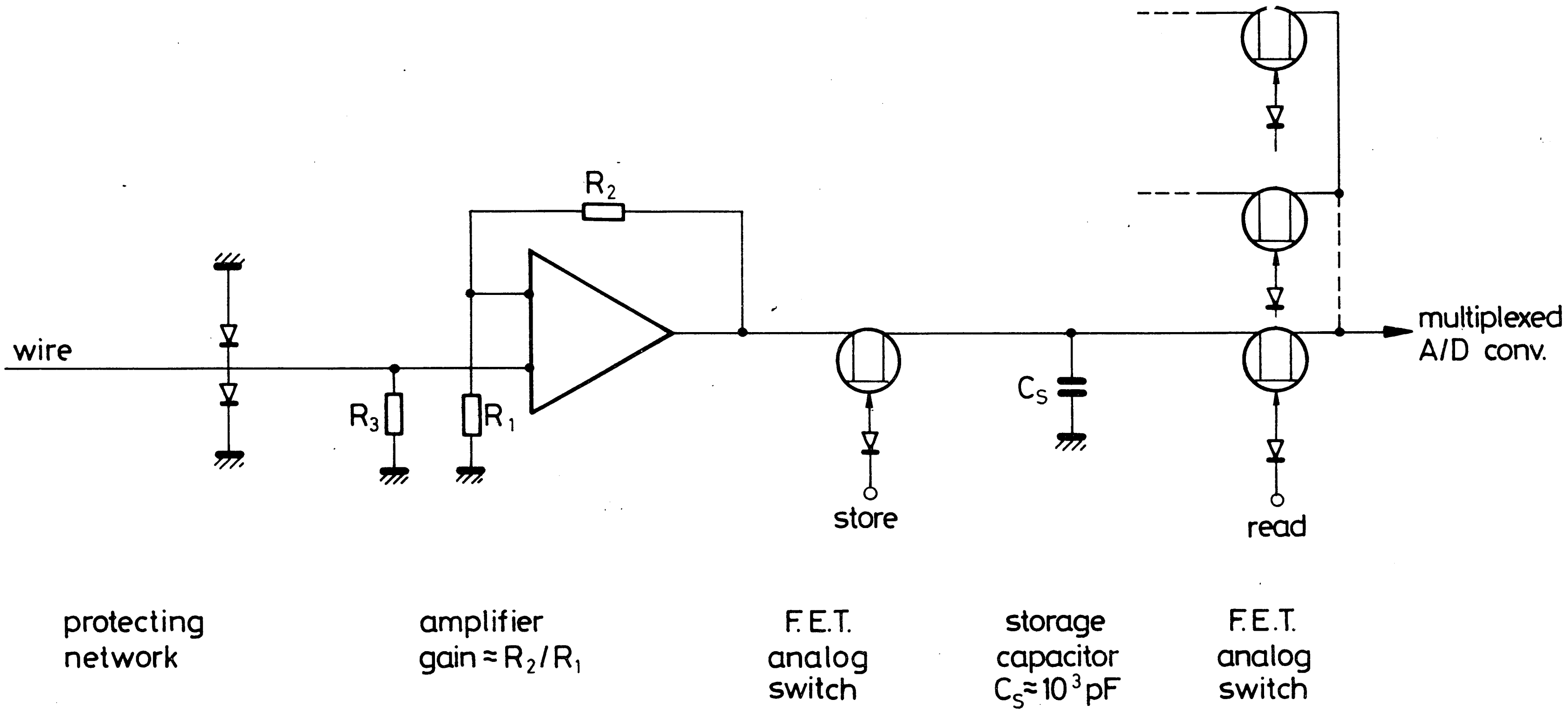
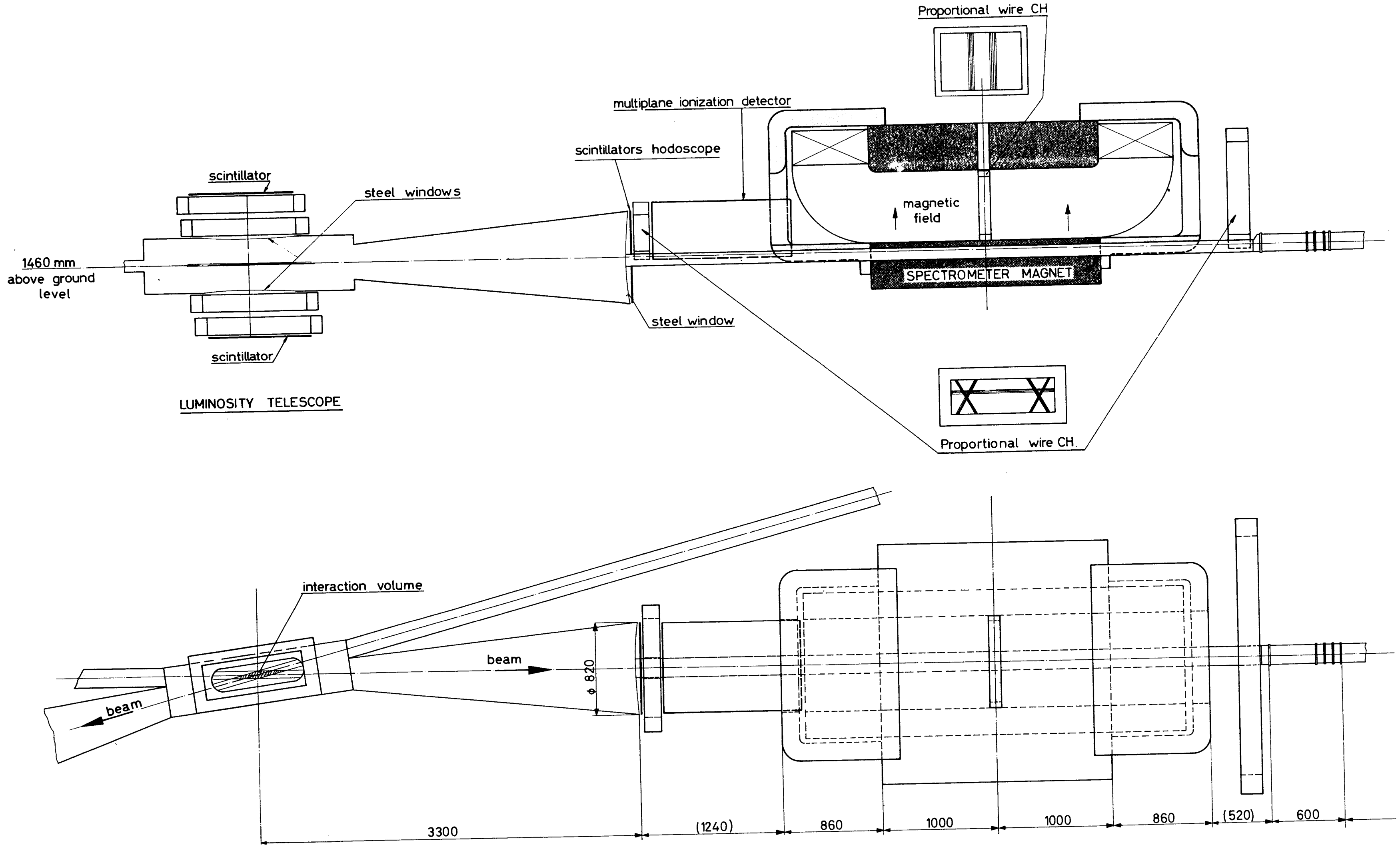

wire
R$_3$
R$_1$
R$_2$
store
C$_S$
read
multiplexed A/D conv.
protecting network
amplifier gain ≈ R$_2$/R$_1$
F.E.T. analog switch
storage capacitor C$_S$≈10^{3}pF
F.E.T. analog switch

Fig. 14



ELASTIC SCATTERING BEYOND THE COULOMB INTERFERENCE REGION

Fig. 15