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Chapter 1 - Microchannel plates

chapter 1

MICROCHANNEL PLATES

1.1. Theory

1.1.1. Introduction*

A microchannelplate electron multiplier (MCP) consists of an array of tubes, or channels, fused in the form of a thin disc (see Fig. 1-1). Its main application lies in image intensification but it can also be used for the detection of particles, X-rays and ultraviolet radiation. The operation of the MCP is best described in terms of that of a single-channel multiplier; that is in terms of one unit of the matrix. Single-channel electron multipliers, generally called "channeltrons"** have been successfully used for a number of years for the detection of particles, ultraviolet radiation, and X-rays. They offer several advantages over conventional discrete-dynode multipliers; in particular, high electron gain, low background countrate, and low power consumption, coupled with ruggedness, small physical size, and simplicity of use.

* Parts of this text are taken from: [Philips, 1976]. Other review articles: [Baumgartner, 1976], [Wiza, 1979] and [Lampton, 1981].

**"Channeltron" is a registered trademark of Galileo Electro-Optics Corporation, USA.

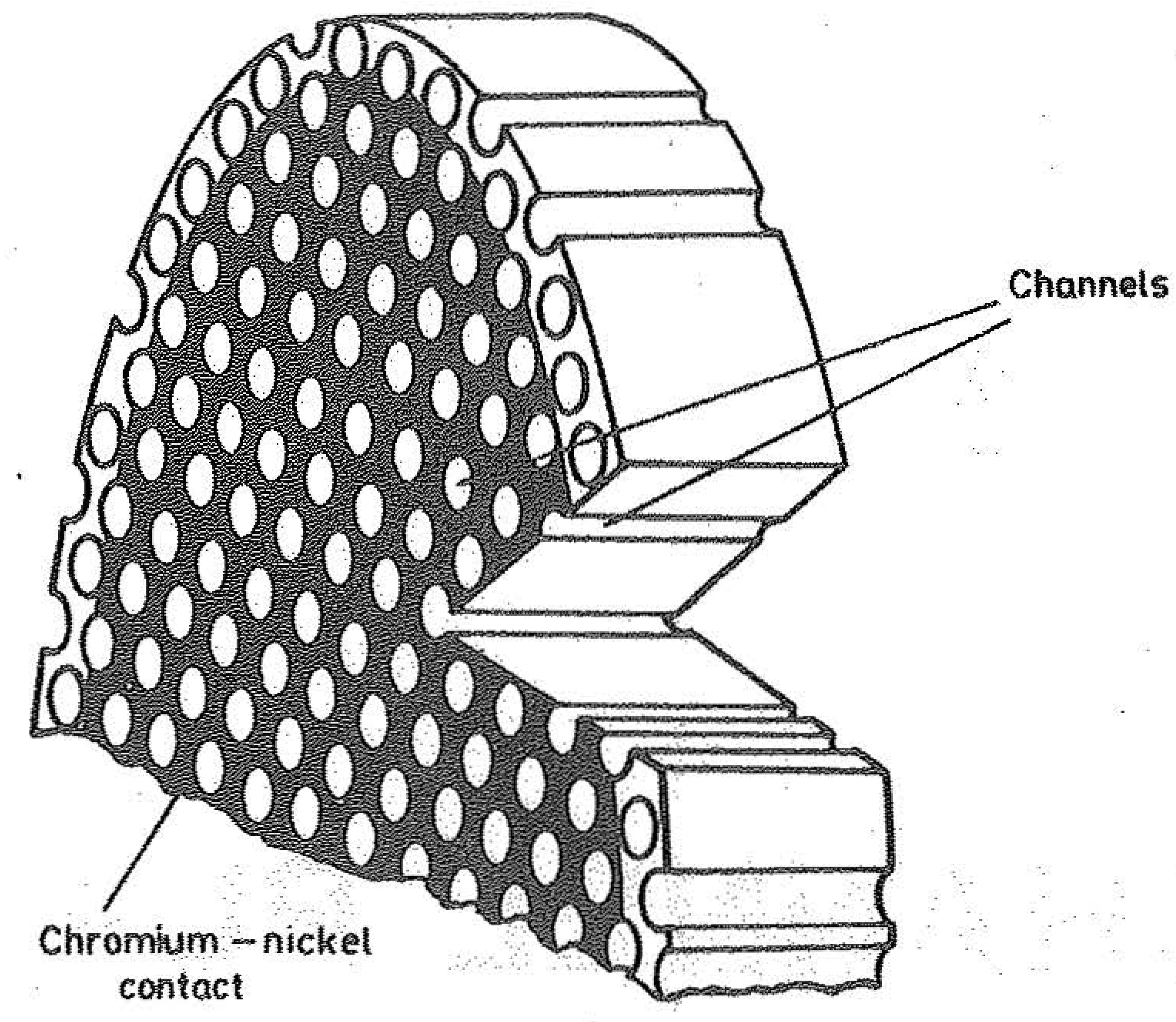

Fig. 1-1. Schematic representation of microchannel plate (not to scale).

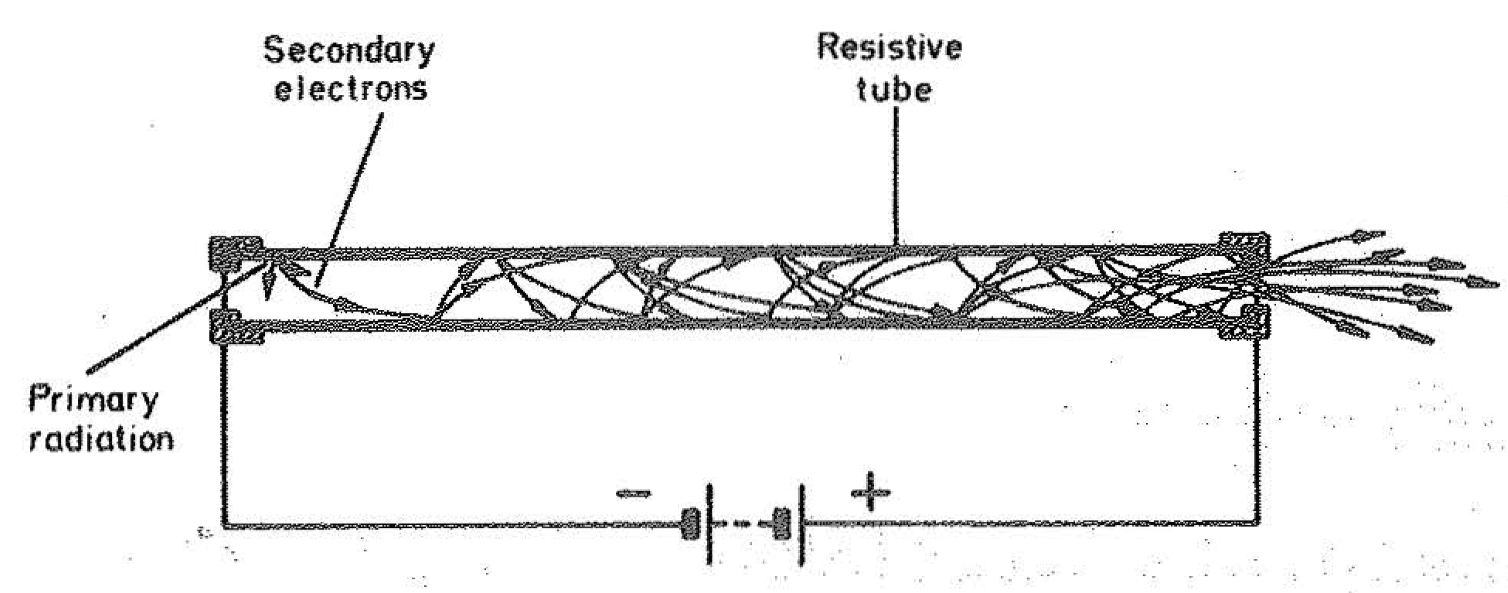

Fig. 1-2. Operation of single channel electron multiplier.

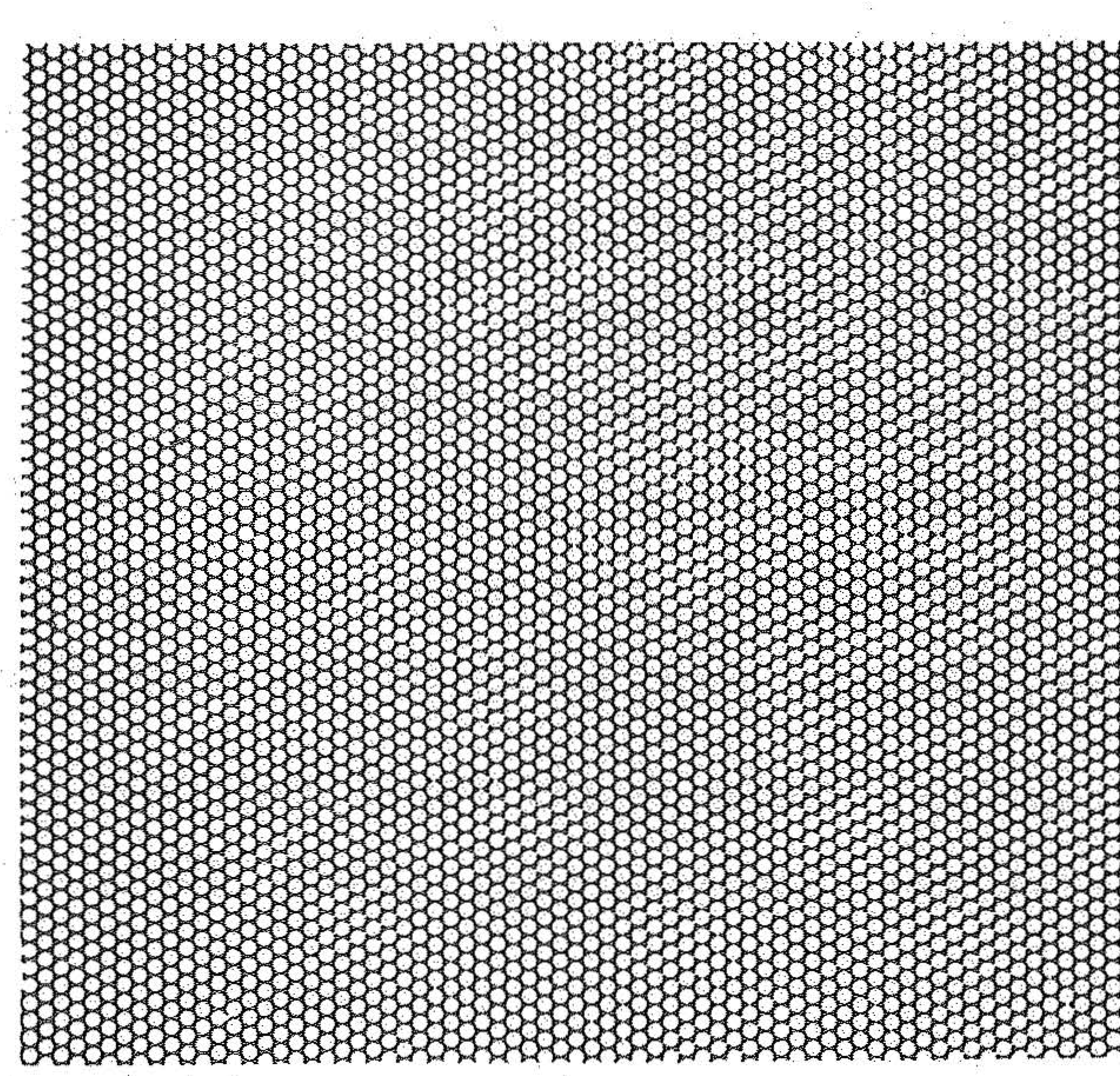

Fig. 1-3. Magnified view of face of microchannel plate (12.5 µm channels).

The principle of operation of the single-channel multiplier is illustrated in Fig. 1-2. The channel consists of a hollow glass tube, about 1 mm in diameter, with an internal resistive surface processed to have a high secondary emission coefficient. The multiplier is operated in vacuum with a potential difference applied between electrodes at the ends of the tube. When a particle or photon enters the low-potential end of the tube and collides with the wall, several secondary electrons may be produced. If so, these are accelerated by the applied axial field and in turn produce more secondaries. This process is repeated many times along the channel, and a large number of electrons (up to 10^8) finally leave the high-potential output.

The electron gain of the channel depends on the applied voltage, on the ratio of channel length to diameter, and on the secondary emission characteristics of the channel surface. Typically, the gain increases from about 10^3 at 0.9 kV to more than 10^8 at 3 kV. Because the gain is determined by the length to diameter ratio of the channel and not by its overall size, the dimensions can be scaled down without affecting performance. Thus, very small multipliers whose dimensions are limited only by the technology and the ability of the channel material to withstand electrical breakdown can be made.

By constructing a parallel array of straight single-channel multipliers, each having an internal diameter of about 25 µm, a device can be made which will amplify an electron image. Such a device (see Figs. 1-1 and 1-3) is called a channel-plate electron multiplier, or microchannel plate (MCP). It is normally operated at about 1 kV and has a gain of at least 10^3, typically 3×10^3.

1.1.2. Construction

As stated above, a microchannel plate comprises a matrix of single-channel electron multipliers. The number of multipliers, or channels, and their dimensions are determined primarily by resolution considerations. For most standard types,

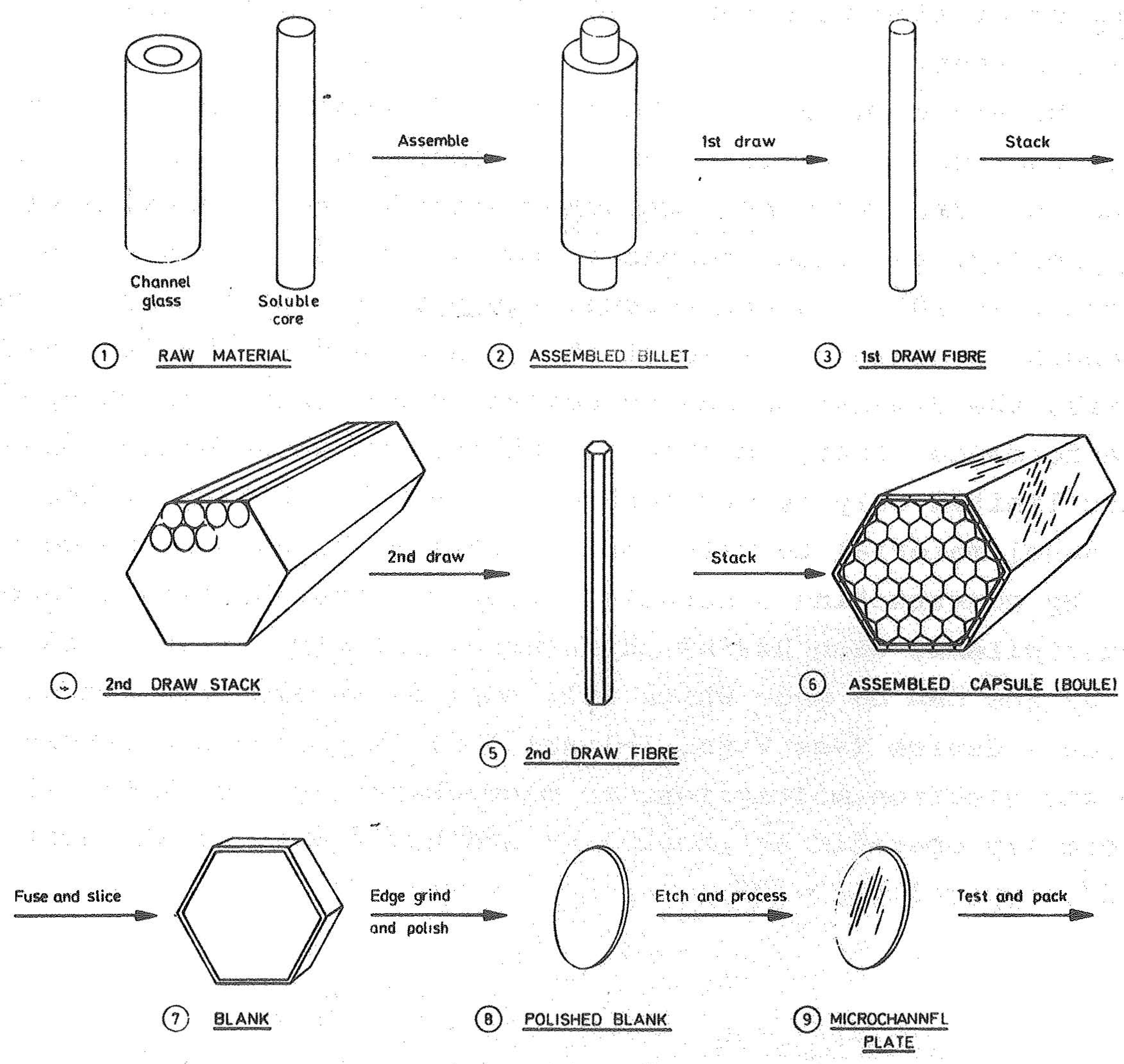

Fig. 1-4. Steps in the manufacture of microchannel plates.

the channels are 8, 12 or 25 μm in diameter, and the plates are between 20 and 75 mm in diameter and up to 1 mm thick.

The material used for plate manufacture is glass because the techniques for working it are well-known and relatively straightforward. Its use allows accurate control of channel diameter and regularity of array, both of which are of prime importance if the spatial fidelity of an electron image is to be preserved. Also, the special glass developed for MCP's has the conduction and secondary-emission characteristics required for channel multiplication, as well as good stability and high-vacuum performance. Also many glass recipes have been employed in making channel multipliers, by far the most successful has been a mixture of about 50 percent lead oxide, 40 percent silicon dioxide and smaller quantities of several alkali oxides. Glass of this composition has a high electrical resistivity which can be decreased by removing the oxygen from the lead by reduction in an atmosphere of hydrogen gas for several hours at 400°Centigrade. Most of the reduced lead evaporates from the surface. The remaining lead coalesces into metallic clusters, giving the characteristic black colour. The high secondary electron emission coefficient is caused by a layer consisting of Si, O_2, K and Pb [Siddiqui, 1977].

Microchannel plates are manufactured using soluble glass-core techniques. Fig. 1-4 shows the main steps in production The two-draw process illustrated is capable of producing a wide variety of plate and channel sizes. The first stage is to assemble a billet of channel glass and solid core. The diameter of the core rod is made the same as the internal diameter of the channel glass tube. Essentially, the purpose of the core is to prevent distortion and collapse of the channels during the fusing stages. The core and channel glasses must be compatible, particularly with regard to expansion, viscosity, diffusion, and solubility. The assembled billet is clamped to the feed mechanism and drawn slowly through an oven, its diameter being reduced from about 35 mm to 0.8 mm. The oven temperature must be closely controlled, and air turbulence must be avoided. The first-draw fibre is next cut into lengths, stacked, and fused into a symmetrical hexagonal

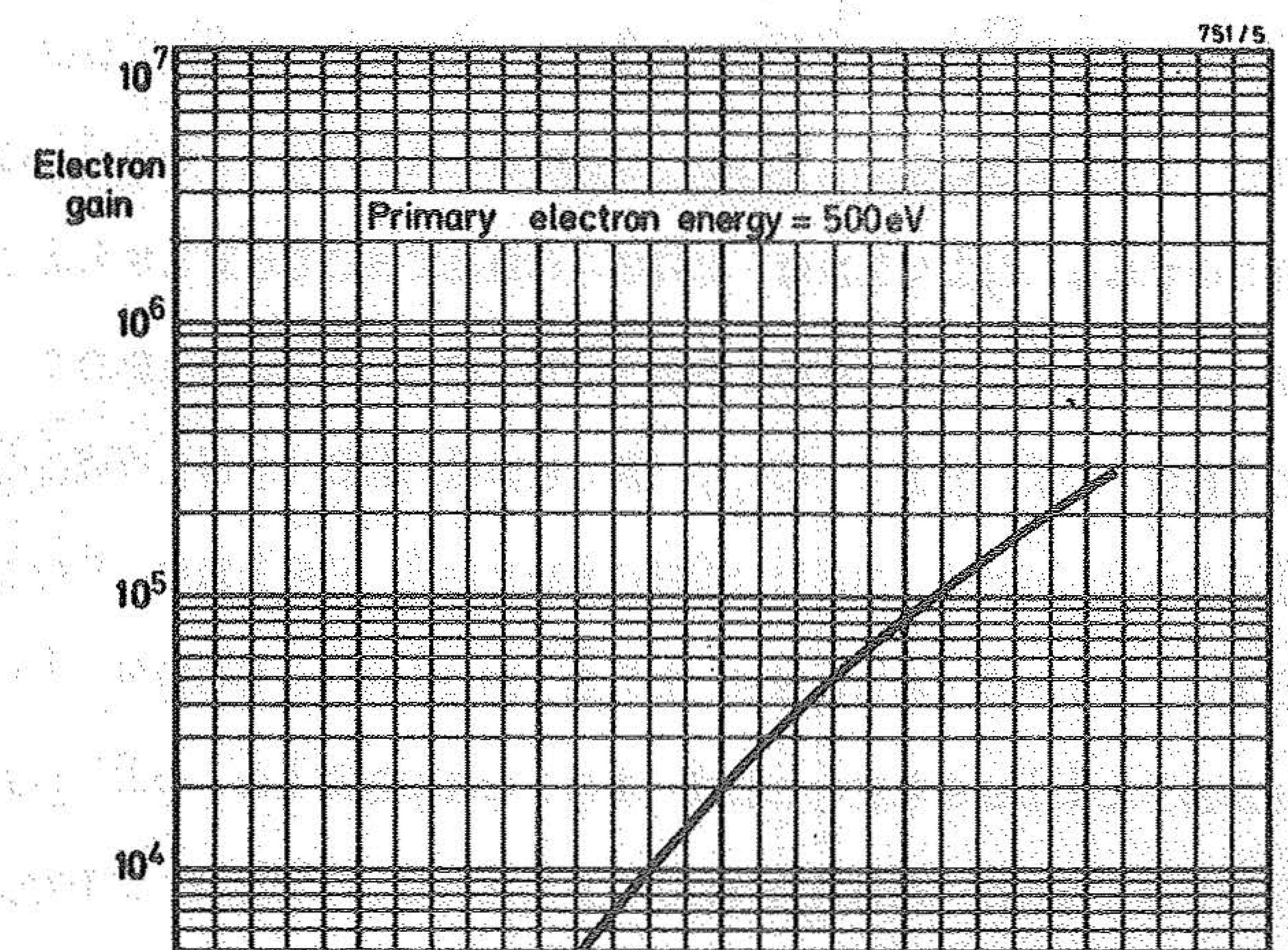

Fig. 1-5. Current gain plotted against applied voltage.

array. This bundle is then drawn a second time to produce hexagonal multi-fibre, again about 0.8 mm in diameter. This in turn is cut, stacked in a hexagonal glass capsule, and fused under vacuum. The resulting fused stack, or boule, is then cut into slices, which are ground to the required shape and size, and polished. Finally the solid core glass is etched away, leaving the channel matrix intact and ready for processing. The polished blanks are now baked in the above mentioned reducing atmosphere to produce in each channel a resistive layer with the required secondary-emission characteristics. Metallic layers are then vacuum-deposited on to the polished surfaces of each plate. These act as electrodes which connect all the channels in parallel. An alloy of nickel and chromium is used. Finally, the plates are tested and packed.

1.2. Characteristics

1.2.1. Gain

A typical plot of current gain as a function of applied voltage for an MCP is shown in Fig. 1-5. The channels have a length-to-diameter ratio of 40. With 0.5 keV primary electrons at the input, the gain rises from about 10^3 at 900 V to 2×10^4 at 1200 V (maximum voltage in practice).

For each value of applied voltage, there is an optimum value of the length-to-diameter ratio which gives maximum gain. Near this optimum, the gain is least sensitive to the small variations in channel diameter which occur in practice, and so the spatial uniformity of the plate will be at its best. A value of the length-to-diameter ratio between 40 and 60 represents a suitable choice for imaging applications.

Ionic feedback

The useful gain which may be achieved with an MCP is limited to about 10^6 by ionic feedback. Residual gas molecules near the output of the plate are ionized by electron impact. The ions are accelerated back down the channels and may start

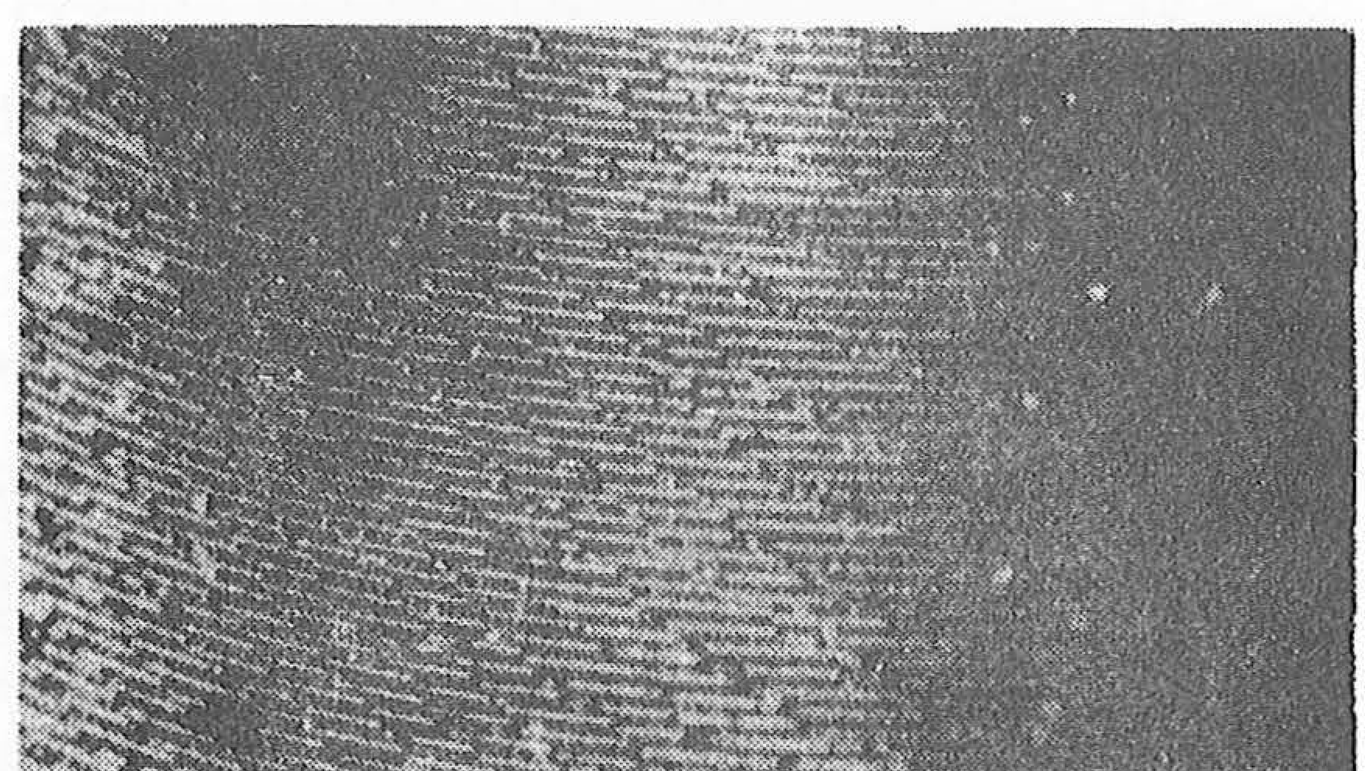

Fig. 1-6. Cross-section through an early experimental curved-channel plate.

additional cascades by striking the channel wall near the input. The incidence of ionic feedback depends on the residual gas pressure and the electron density. At sufficiently high pressures and gains, a self-sustaining discharge can occur. However, at pressures below 1×10^{-3} pascal, MCP's can be operated with gains in excess of 10^5 without trouble, while at 0.1 pascal plates have been operated successfully with gains of several thousand [Langendam, 1977].

In single-channel multipliers, ionic feedback effects are prevented by curving or spiralling the multiplier. Any ions formed can move only a short way down the multiplier before striking the wall. The energy on impact is scarcely sufficient to produce secondary electrons, and those that are generated can hardly multiply in the available length of channel. In these single multipliers, gains higher than 10^8 can be achieved before the gain is limited by space-charge effects. To obtain comparable gains with microchannel plates, two options are open. Either two plates can be operated in cascade, or a single plate with curved channels can be used.

Microchannel plates in cascade

Standard MCP's have channels which are set at an angle (some 10^o) to the axis of the plate. If two or more plates are mounted in cascade with their axial directions opposed, ionic feedback to the input of the first plate is prevented. Such a combination, generally called a "chevron" configuration, allows the maximum gain to be increased, up to 10^8 for two plates, but with some loss in spatial resolution if used as image intensifier, because of the charge spreading between the two MCP's. Even with a distance of 150 μm between the MCP's, 100 to 300 channels in the second MCP will be excited by one channel in the first MCP [Wiza, 1977].
As position sensitive detector, using the centre of gravity method (see chapter 2) there is no loss of resolution.

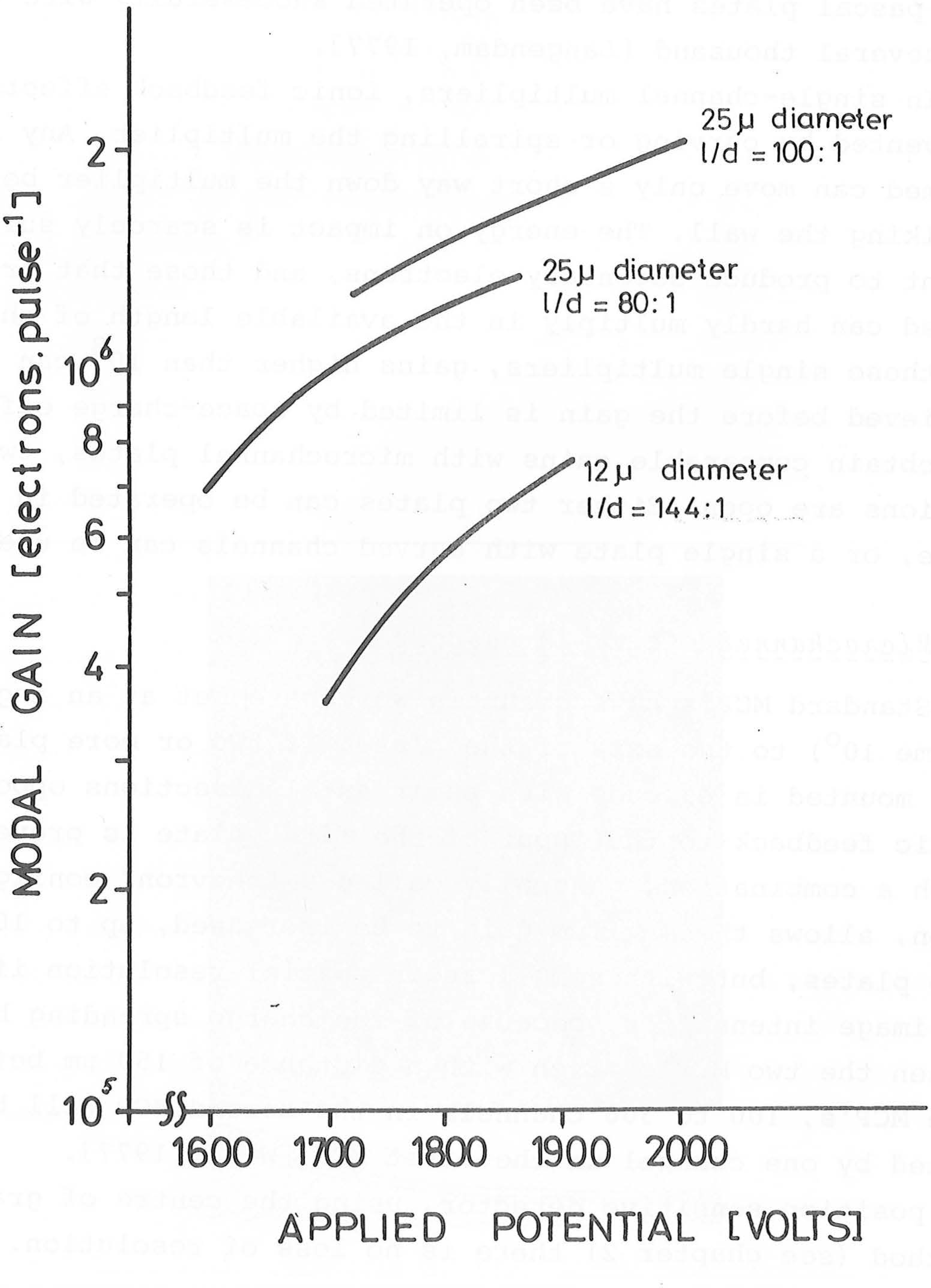

Fig. 1-7. Variations of model gains for curved-channel MCPs as a function of the applied voltage [Timothy 1981].

Microchannel plates with curved channels

A more advanced and less cumbersome solution to the problem of ionic feedback is to provide the MCP with curved channels. Such devices are commercially available (Galileo Electro-Optics Corporation). Their performance characteristics have been described extensively [Timothy, 1981]. A cross section through an early experimental curved-channel plate is shown in Fig. 1-6. (It is not implied that all curved channel plates have this geometry.) Variations of modal gains for curved-channel MCP's as functions of the applied potential are plotted in Fig. 1-7. Note the relatively low gain (10^6) of a curved channel plate which is a disadvantage. An advantage is that these MCP's will have no loss in positional resolution due to charge spreading between two plates in a chevron arrangement.

1.2.2. Pulse height distribution

Single MCP

The output pulse height distribution of an MCP is nearly an exponential function, of the form: $n(q) = n_o \exp(-q/\bar{q})$ [Galanti, 1971], see Fig. 1-8, where n(q) is the number of pulses with height q and n_o is a normalization factor. $\bar{q}$ is called the mean gain of the distribution, it is a function of the voltage V over the MCP. The mean gain has been measured as a function of V by several authors [Galanti et al., 1971; Wiza, 1979]. A typical result is shown in Fig. 1-5. Normally the MCP is operated with a voltage of 500 - 1200 V and corresponding gains of $10^3 - 10^4$. The upper limit is set by the onset of ionic feedback and the resulting performance instabilities.

The chevron type channelplate detector

A commonly used method to suppress ion feedback while containing high gain space charge saturated output pulses is the chevron set-up of two micro-channelplates, shown schematically

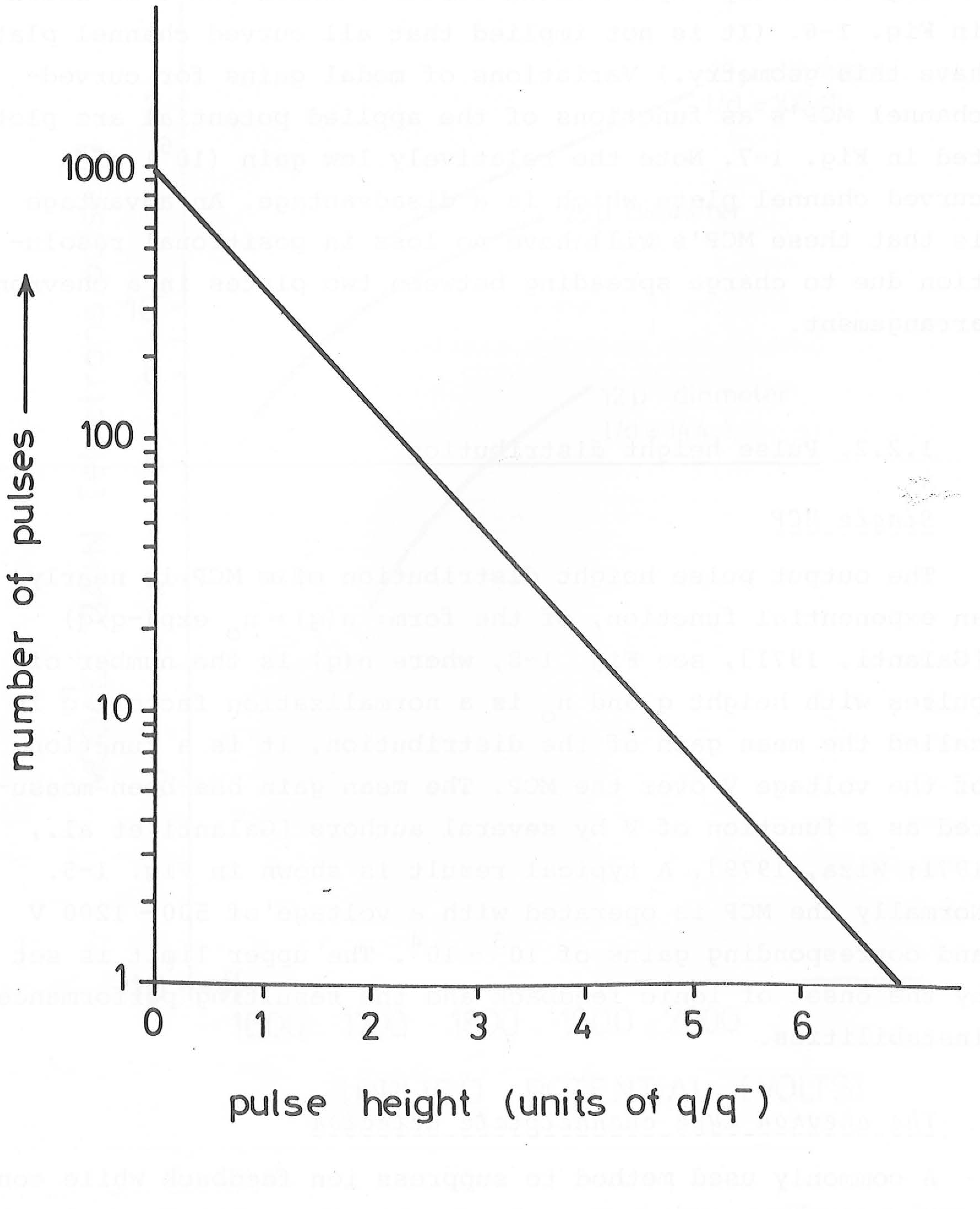

Fig. 1-8. Pulse height distribution of a single MCP.

in Fig. 1-9. The distance between the channelplates is d_1 (typically 50 - 150 μm), the distance between the second plate and the collector plate is d_2, the voltages over the first and second plate are V_I and V_{II} respectively; between the plates a bias voltage $V_{I,II}$ is applied and between the second plate and the collector plate we have $V_{II,C}$. V_I and V_{II} are in the order of 1 kV, resulting in a mean gain of a few times 10^3 for each channel plate. At these gain levels the first channel plate does not produce "charge saturated pulses" (see 1.2.3). However, since each channel of MCP 2 might be triggered by many electrons from the first plate (see Fig. 1-9), saturation does occur in the output pulses of MCP 2. This results in a completely different pulse height distribution for the chevron set-up, as compared with that of a single MCP. A typical distribution for the chevron set-up is shown in Fig. 1-10. The peak gain is typically 10^7, and the distribution is quite broad (FWHM ~ 170%). This distribution is often called the "resolution" which is defined as the ratio of the width of the pulse height distribution, generally called FWHM i.e. Full Width at Half Maximum, and the peak gain, see Fig. 1-11. Both peak gain and FWHM of the distribution have been measured as a function of the interplate bias voltage $V_{I,II}$ [Wiza, 1979]. The result is shown in Fig. 1-12 and 1-13. If a bias voltage is applied there is less time for the charge cloud from MCP 1 to spread out radially, and fewer channels of MCP 2 are excited, but each one is driven more into saturation. After an initial fall-off, the peak gain (Fig. 1-12) remains constant, but the FWHM (Fig. 1-13) continues to decrease to about 60% at $V_{I,II}$ = 700 V, or $V_{I,II}/d_1 \approx 5 \times 10^6$ V/m.

We measured the FWHM of the distribution with the channelplate detector of a monochromator, with $V_I = V_{II} = 1$ kV and $d_1 = 50$ μm. We found a similar behaviour, but noted that the FWHM remained constant for $V_{I,II} > 300$ V, or $V_{I,II}/d_1 > 6 \times 10^6$ V/m.

It is of advantage to have a narrow pulse height distribution: one can easily discriminate noise from the preamplifier from real pulses by setting an appropriate discriminator

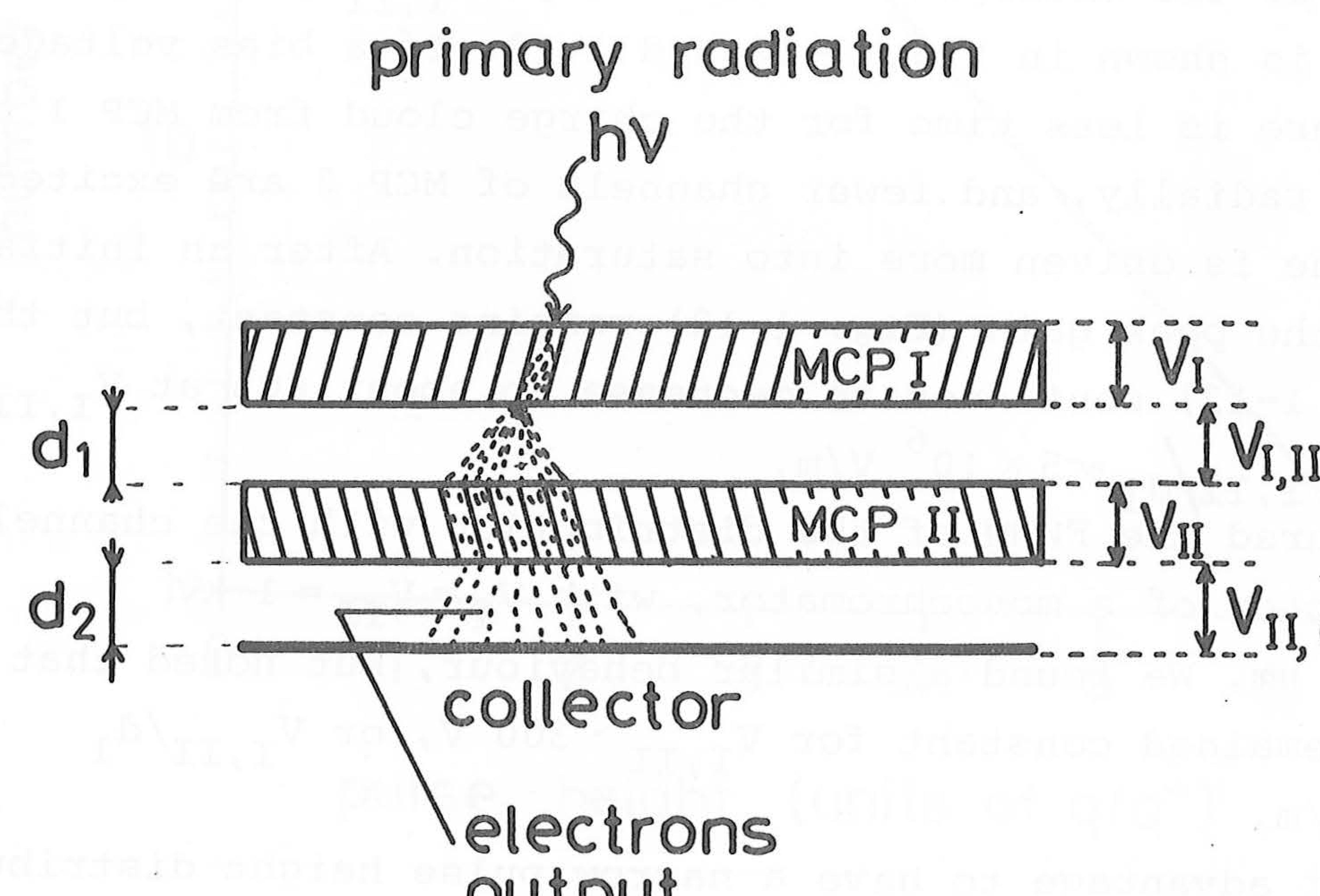

Fig. 1-9. The chevron set-up of two MCPs.

level, and a narrow distribution requires less dynamic range from all the electronics (preamplifier, main amplifier, ADC etc.). We recommend a bias voltage of about 1 kV for both MCP's and an interplate bias voltage of about 300 V at an interplate distance of 50 μm. The distance and voltage between MCP 2 and the collector plate have no influence on the pulse height distribution, at least not for $V_{II,A} > 100$ V.

Another method to obtain a narrow pulse height distribution was reported by Henkel [1978]. By placing a metal mesh (having square holes of 44 μm on a side) between the MCP's of a chevron, a FWHM of 50% at a gain of 2×10^7 was achieved.

The curved-channel MCP

Wiza [1979] measured the output pulseheight distribution for curved-channel MCP's (see Fig. 1-14). He states that the gain value at a given level of the applied voltage as well as the resolution are highly affected by a clean-up procedure. Fig. 1-15 shows the same plot [Philips, 1976].

1.2.3. Current transfer characteristics

The current transfer characteristics of a microchannel plate are shown in Fig. 1-16. With a resistance of $10^9\ \Omega$ and an operating potential of 1000 V, the conduction current in the channelplate is 1 μA. The transfer characteristic of the plate is linear for output currents up to 10% of the standing current. For higher input currents, the plate begins to show saturation effects, and the characteristic begins to level out. If the resistance of the plate remained constant, the output would saturate at a value close to the conduction current. However, the effective resistance of the plate changes slightly in operation because the cascade of electrons forms a parallel resistive path. This produces a more gradual saturation effect than might otherwise be expected, and allows an output current to be drawn which can exceed the nominal conduction current of 1 μA. As the individual multipliers in the plate are virtually independent of one another, each channel will

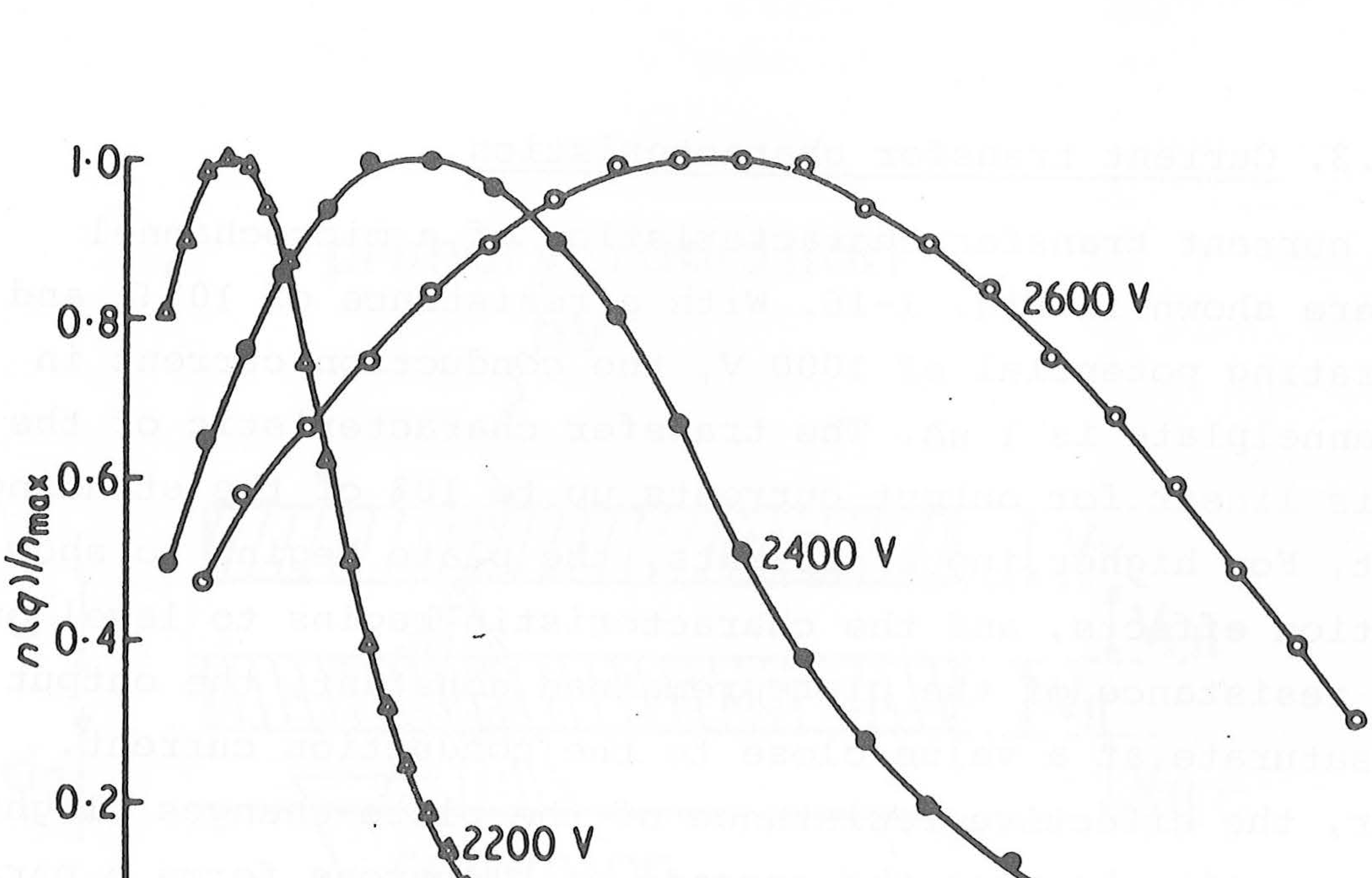

Fig. 1-10. Pulse height distributions of the cascaded channelplates.

saturate if the current drawn from it approaches its standing current (that is, the current flowing in the channel wall). The saturation effect can be more easily understood by concentrating the attention to the behaviour of one single channel. The multiplication process is highly depending on the electrical field strength within the channel.

Current saturated mode

Every charge pulse, leaving the channel, is composed of electrons extracted from its wall. Due to the high resistivity of the channel wall nearly all the electrons of the pulse are extracted from the distributed capacitance of the channel wall. When the gain is low the charge removed per pulse is so small the electric field within the channel remains undistorted, preserving the multiplication process. If the mean output current is small compared with the standing current, there is no current saturation and the transfer function is linear. Current saturation is important if one uses the channel plate as a preamplifier in electrometer applications.

Pulse saturated mode (space charge saturation)

This mode is to be preferred when counting of individual pulses is required. The advantage of the pulse saturated mode is that all the output pulses tend to reach the same saturated amplitude. This improves the detection efficiency at low count rates appreciably. However, the low count rate can be a disadvantage. Each single output pulse distorts momentarily the electric field within the channel in such a way that the multiplication process is impeded seriously.

Pulse saturation occurs for random count rates exceeding 10^6 counts.s^{-1}.cm^{-2}. Because 1 cm^2 contains about 10^5 channels (25 μm channels) and at least 10 channels are activated in the second plate, every channel is visited more than 100 times a second for 10^6 counts.cm^2. Thus the 'dead' time of a channel is less than 10 msec. Wiza [1979] gives a comparable number in his paper.

At higher count rates both pulse saturation as well as current saturation may occur in the same channel at the same time.

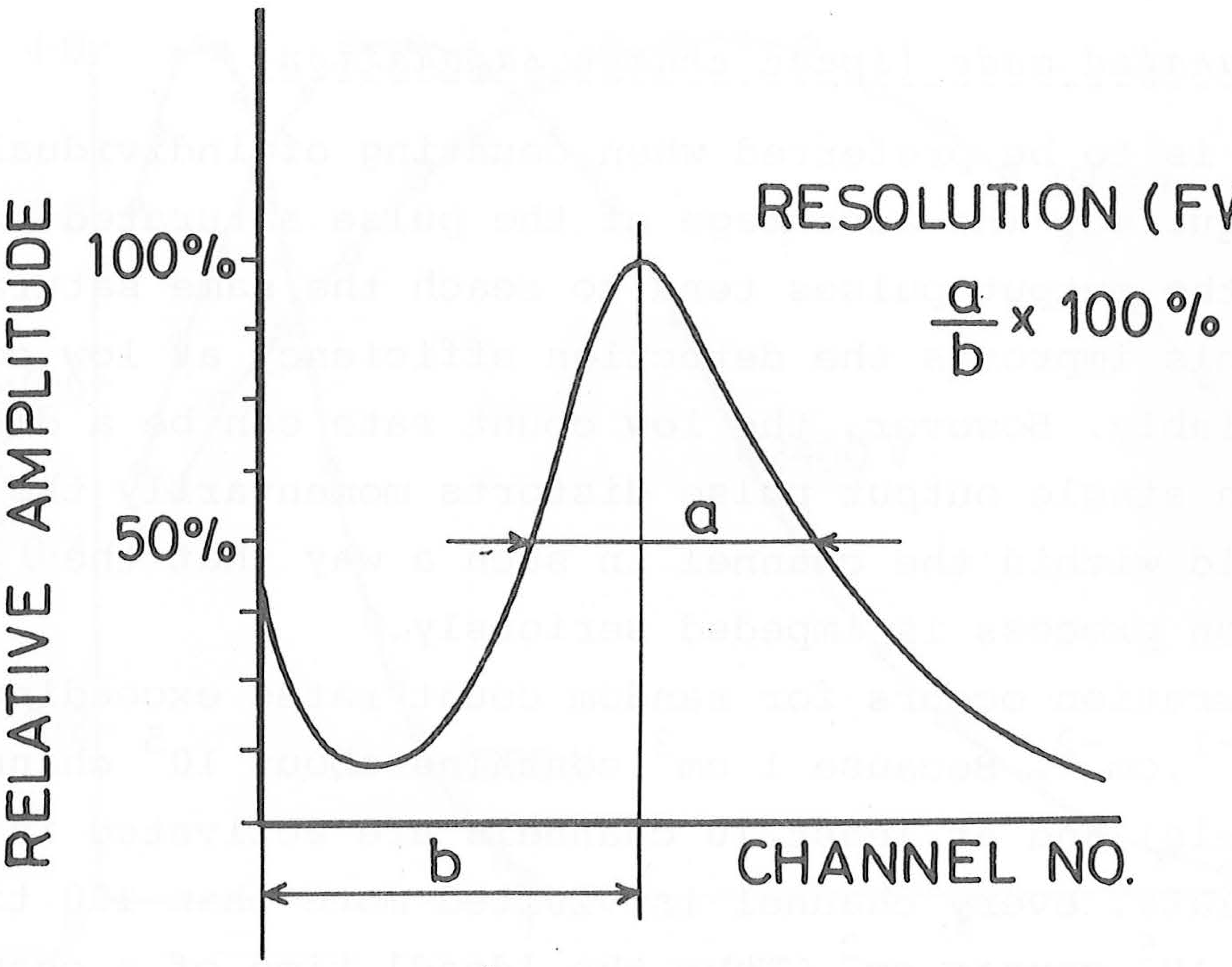

Fig. 1-11. Definition of the resolution.

1.2.4. Transit time

The microchannel plate offers significant improvements in transit time compared with the discrete dynode system of a conventional photomultiplier. This is because the electron paths in a microchannel plate are much shorter (1 mm compared with 100 mm) and the field strength much greater (1 kV/mm compared with 10 V/mm). Transit times are typically less than 1 ns compared with 30 ns for a fast conventional photomultiplier. The width of the pulse in a chevron configuration, or transit time spread as measured with a 100 MHz oscilloscope, amounts to a few nanoseconds with a rise time of some 0.5 nanosecond. From observation with a 1 GHz oscilloscope there is evidence, the true pulse shape is, at least partly, scope bandwidth limited.

1.2.5. Noise

The noise of present-day microchannel plates is exceptionally low, and background count rates of less than 1 count.s^{-1}.cm^{-2} are possible, when operated under carefully controlled conditions.

1.2.6. Lifetime

As a large chevron channel plate assembly can be a rather expensive item, useful lifetime immediately comes into mind. About the useful lifetime of a channelplate the opinions of quite a number of authors differ.

Initially all the reports were referring to the behaviour of single channel electron multipliers, like channeltron etc. MCP's being made of similar material were expected to behave like those multipliers. In the more recent literature, however, several authors have reported about appreciably shorter useful lifetime of MCP's compared to that of channeltrons, under similar conditions of testing [Timothy 1981, Sandel 1977]. Under useful lifetime should be understood the time over which the MCP behaves as a detector with a sufficiently high detection efficiency and gain together with low background countrate to ensure an efficient signal acquisition. This

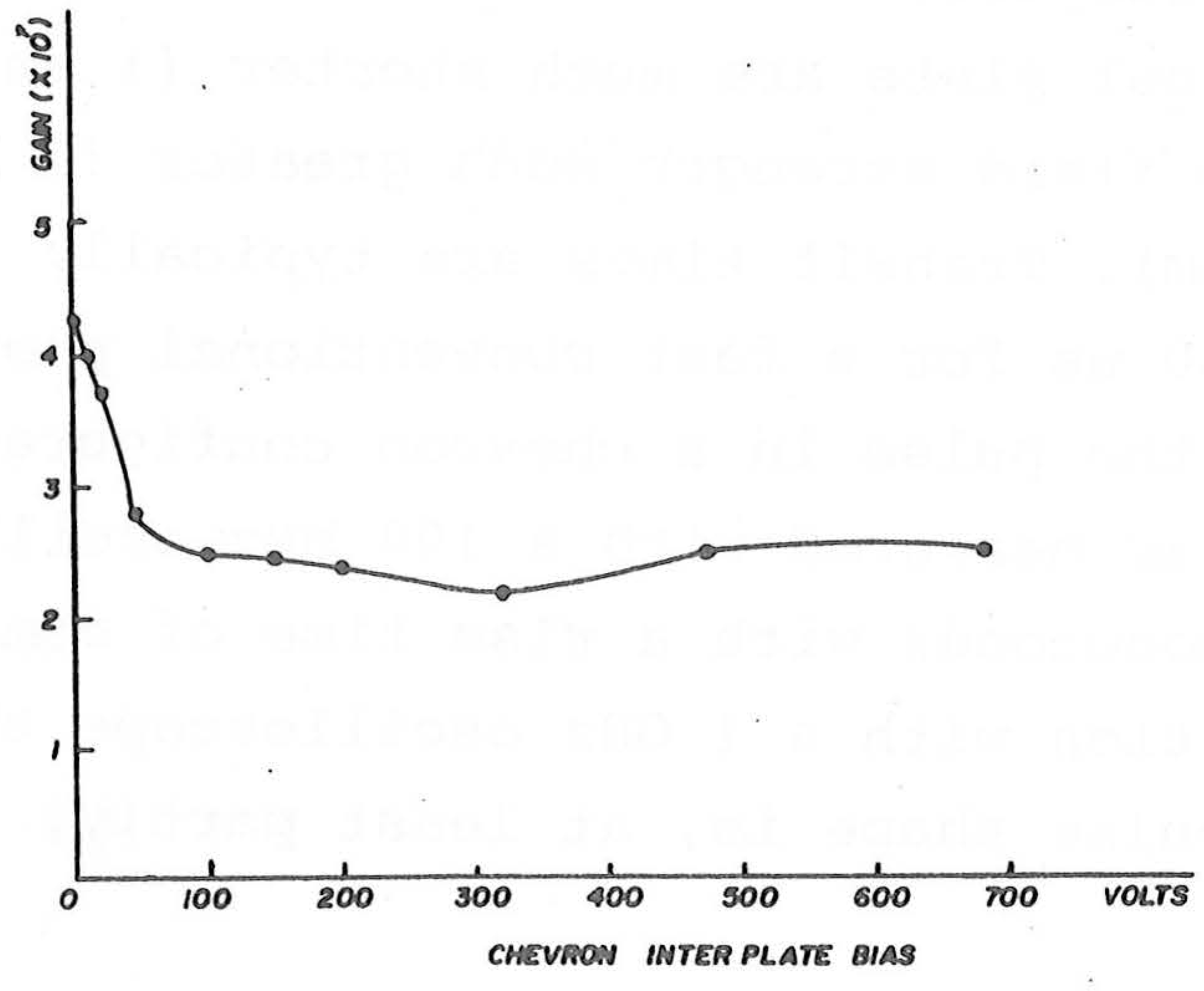

Fig. 1-12. Peak gain versus interplate bias voltage of a chevron MCP [Wiza 1979].

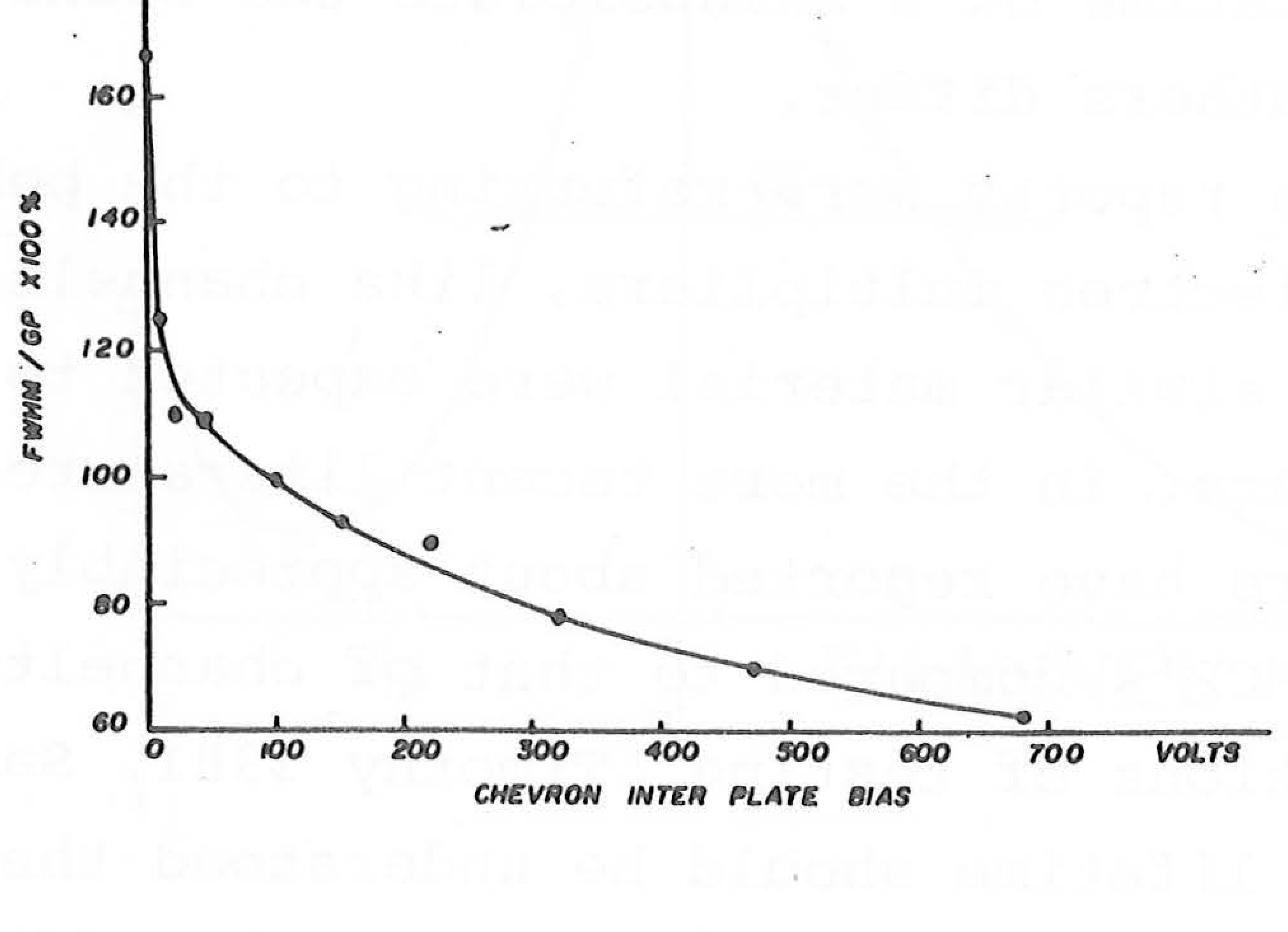

Fig. 1-13. Resolution versus interplate bias voltage of a chevron MCP [Wiza 1979].

lifetime might be influenced by several causes, to be distinguished in:

a) external causes,

b) internal causes.

External causes

The external causes are the most elusive ones. After being exposed to the atmosphere, different gases and vapours may have adsorbed to the channel wall. This may give rise to an increased or unstable channelwall current or even minor discharges, noticable by a high background countrate. Therefore it is a wise precaution, especially when the MCP is operated for the first time, to monitor the channelwall current whilst gradually increasing the MCP voltage; after it has reached a stable value under nominal voltage the current should be measured. This value is quite useful later on when problems in signal detection arise. The comparison of the actual current with the original one will give additional information of whether or not the MCP is to be suspected of being the cause of the problems.

To stabilize the gain, baking and/or electron scrubbing is advised by several authors. Timothy [1981] suggests for the curved MCP's:

a) a bake out, with no voltage applied to the MCP, at a temperature of greater than 270^{o}C for a period of not less than 10 hours;

b) a "burn-in" at a voltage below that at which the onset of significant ion feedback can be observed, at a rate not exceeding 10.000 counts mm^{-2} s^{-1}, to a total signal of 10^{8} counts mm^{-2}.

Our current practice in handling MCP's is to expose them as short as reasonably possible to the atmosphere and mount them as clean as proper (ultra-)high vacuum technique requires. Before mounting the plates check the high voltage circuitry under atmospheric conditions with the aid of a corona-tester. The input side of the channelplate, where conversion of primary particles into secondary electrons have to take place, can be damaged both by mechanical action and presumably by chemical action. We know of harmful effect of

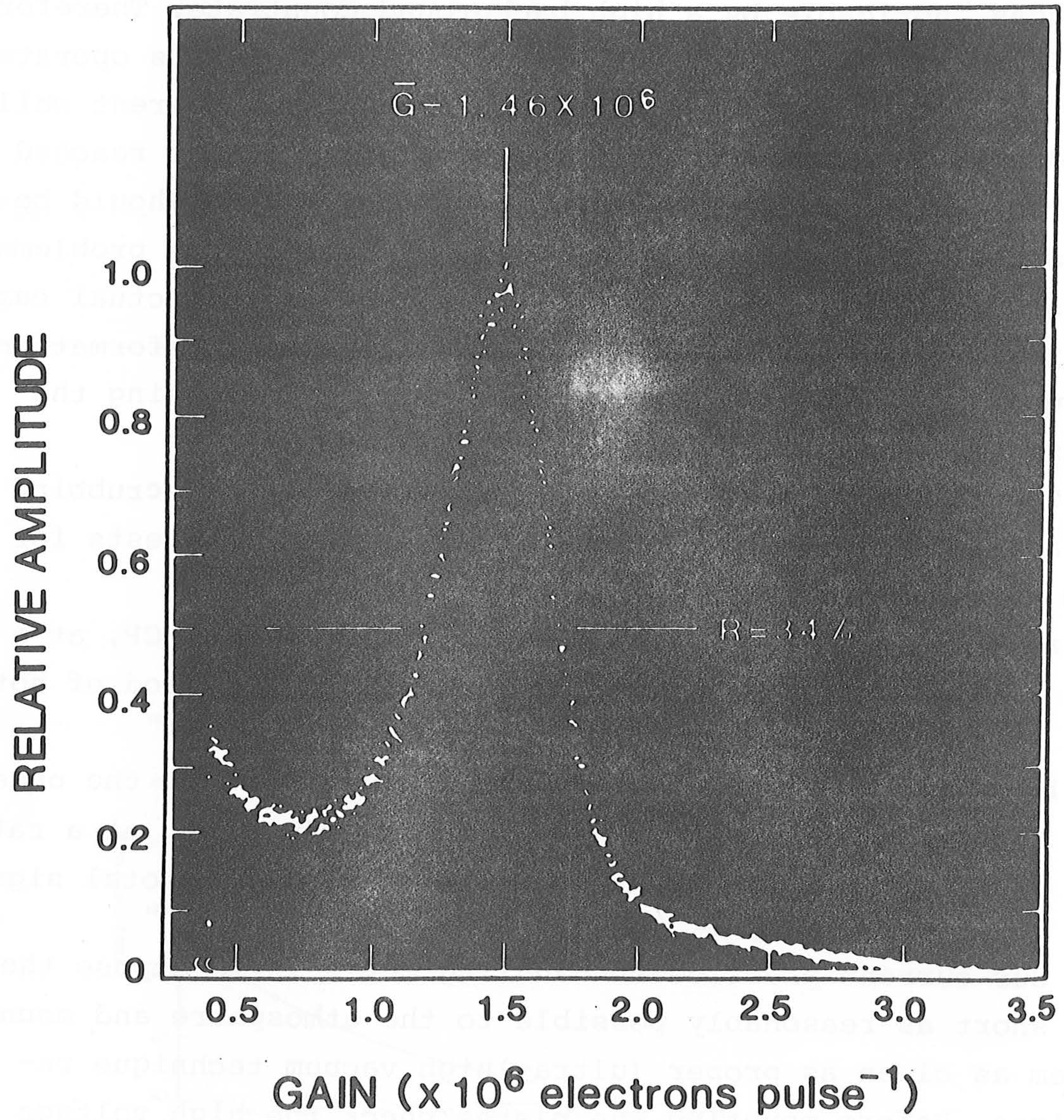

Fig. 1-14. Output pulse height distribution for a curved-channel MCP [Wiza 1979].

heavy ion bombardment and halogens like bromium and iodium. Hydrocarbons of non-trapped diffusion pump oil give rise to non-reversible loss of gain. A high partial pressure of hydrogen causes a rapid decrease in gain. However, just leaving the detector overnight in a dry atmosphere of normal pressure and composition, or injecting pure oxygen of some 10^{-3} pascal into the vacuum for some hours has proven to be the remedy repeatedly. Although the gain and detection efficiency are hardly temperature dependent we have information about the uselessness of a channeltron below 150 K, when there has been helium in the system.

Internal causes

The aforementioned causes of loss of gain are supposed to be dominantly effecting the conversion efficiency at the input side of the MCP. The secondary electron multiplication process within the channels deteriorates with time, too. An exact explanation of the cause(s) of it is unknown, but there are indications it occurs at the output end of the channels. The secondary emission coefficient of the surface of the channelwall diminishes for reasons not quite clear, due to the high density bombardment of clouds of secondary electrons. As to that it might be worthwhile to interchange the two plates of a chevron-configuration if a marked decrease in gain is observed. Several authors did report on this gain degradation and on the possible nature of the processes involved. They more or less agree that this degradation is related to the total charge delivered per channel and is hardly dependent on charge density, which means many small or fewer large amplitude pulses makes little difference.

Sandell [1977] tested MCP's of two different makes under well-controlled conditions. From his work this rule of thumb is extracted: for the first 0.05 coulomb per square centimeter MCP surface a factor of ten decrease in gain; for the next 0.05 coulomb a factor two.

Let us apply this rule to a chevron MCP, with an open area of 60% and a channel diameter of 12 µm. With a mean charge of 1×10^{-12} coulomb per output pulse the figure of

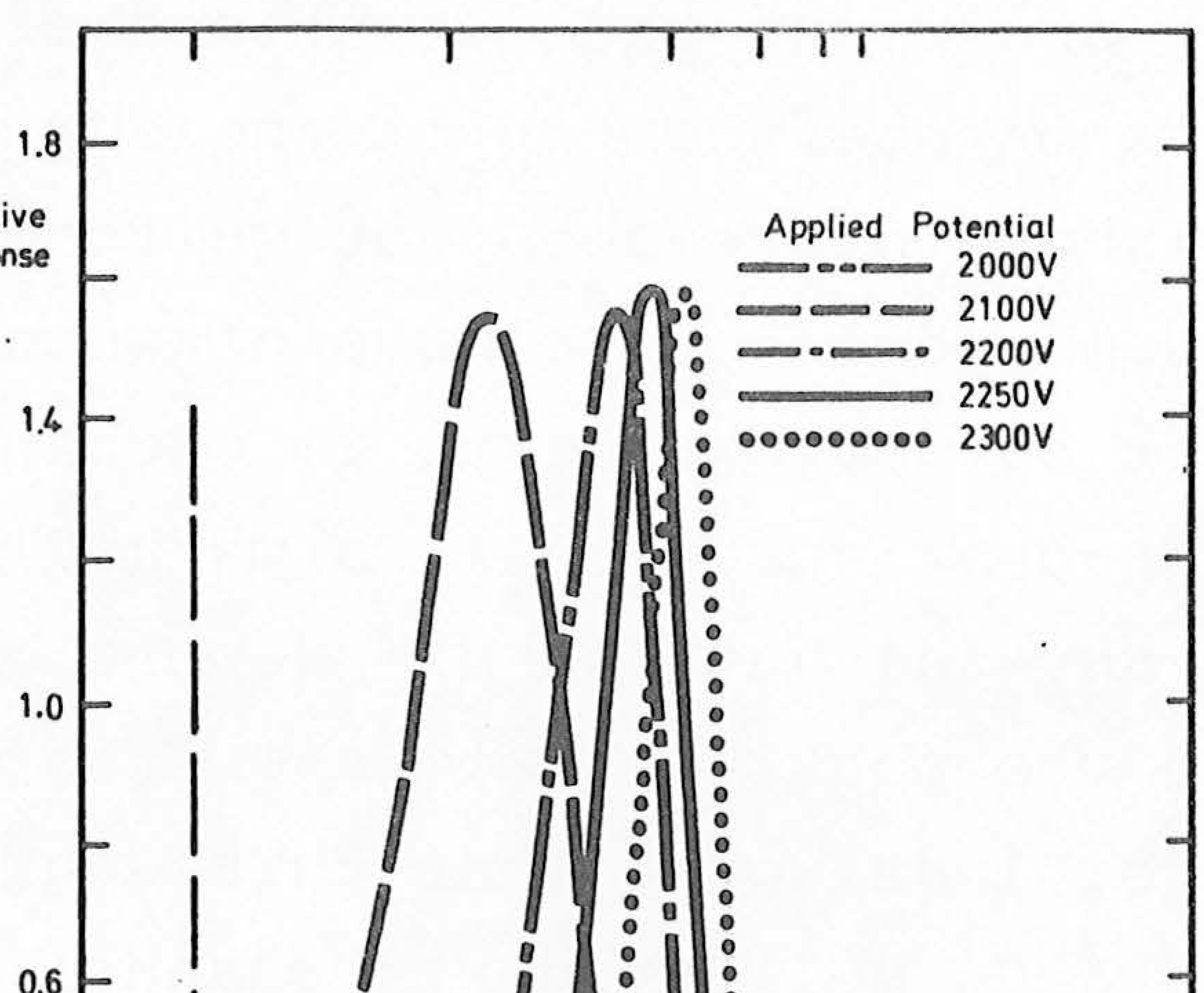

Fig. 1-15. Relative response plotted against gain for a curved channel plate operated at various applied voltages with α-particles as the input [Philips 1976].

0.05 coulomb per square centimeter is reached after 10^5 counts per channel. With a maximum random countrate of one pulse per channel per second we thus may reach an irreversible loss of gain with a factor of ten in some thirty hours. So be careful with high (local) counrates.

It should be noted that Rees [1980] gives much higher values (a factor of 10 decrease in gain after a total charge of 50 $C.cm^{-2}$). He compares his results with Sandels ones and concludes that a changed specification of the MCP's under test and a lower contamination might be the cause of this difference.

A consequence of the decreasing gain as a function of total local dose is the position dependent sensitivity which might considerably change in time. This happens for instance if the MCP is used to detect particles or radiation coming from an analyser or monochromator giving some kind of spectrum. When a high density part in such a spectrum always falls on the same spot of the MCP, spectrum distortion will take place in course of time. We have seen this effect several times. One way to measure whether this effect did occur or not is to measure the pulse height distortion as a function of position on the MCP. This is rather easy as the MCP is used as a position sensitive detector with electronic readout of the delivered charge.

1.2.7. Quantum efficiency

Introduction

The quantum efficiency of channelplates, or any other detection device in single particle counting mode, can be defined as the fraction of the incoming particles that produce a 'detectable amount of charge' at the output. This efficiency depends on the following factors:

1) The secondary electron coefficient.
2) The conversion to get the first electron(s).
3) The gain of the plate.

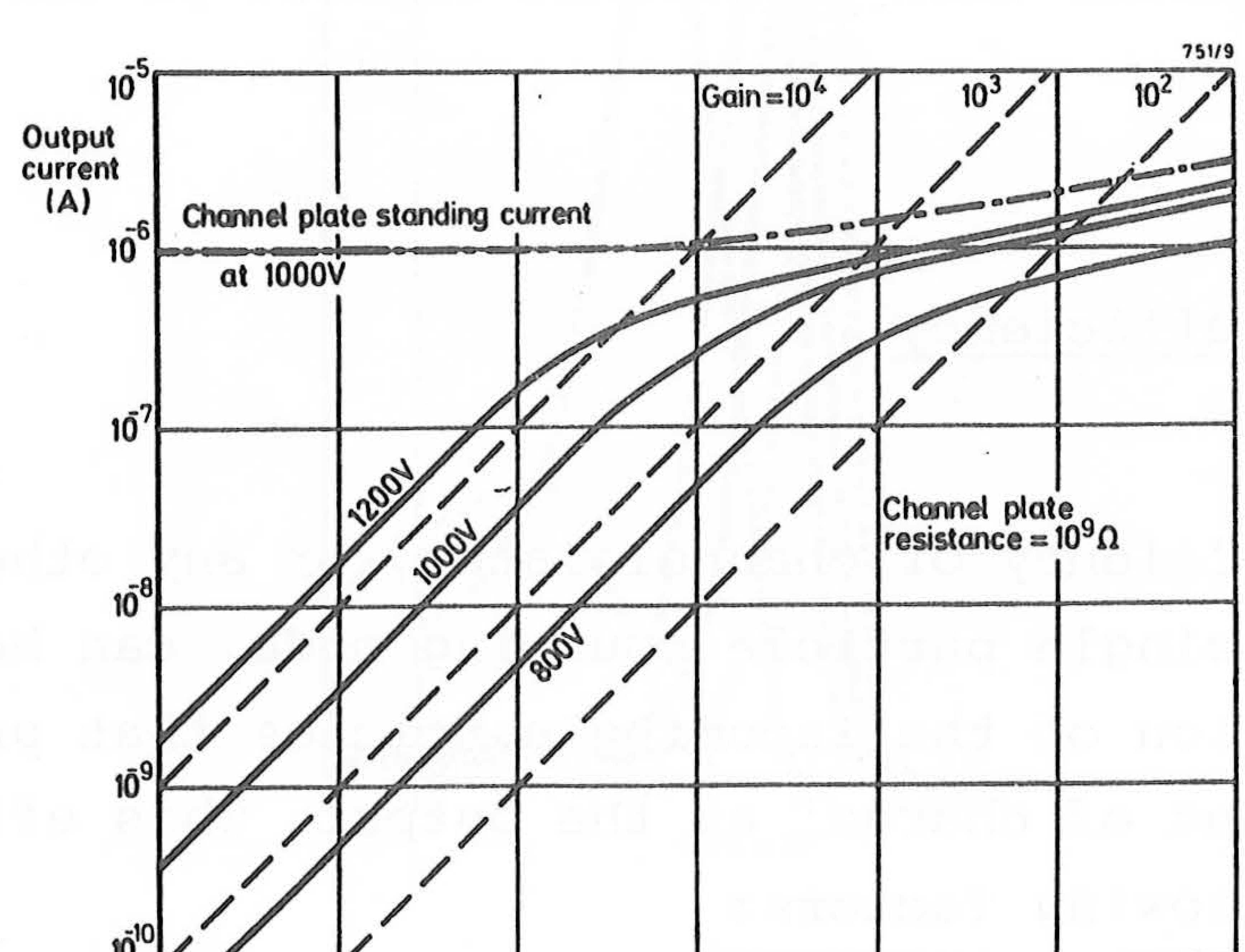

Fig. 1-16. Current transfer characteristics [Philips 1976].

ad 1: The secondary electron coefficient of the material (especially treated lead glass and metal coating) depends highly on the type of particles, their energy and the angle of incidence. Also the condition of the material is important, which is one of the reasons for differences in efficiency between detectors.

ad 2: The conversion to get the first electron(s) into a channel depends on the geometry of the channelplate and thus also on the type of plate used. The electric field in front of the detector can enlarge the open area by guiding charged particles into the channels (lens effect), e.g. more primary particles are converted into secondary electrons (see 1.3).

ad 3: The gain of the detector and especially the spread of it (see chapt. 1.2.2) give a certain chance that the amount of charge produced is detectable above the amplifier noise.

Because of several of the afore mentioned efficiency factors are detector- and even time-dependent 'the' efficiency of a channelplate cannot be given. This is clearly demonstrated by the large differences in the results of several authors as Macau e.a. [1976] show in their review article. The general problem of absolute measurements is also a source of discrepancies between different authors.

- *efficiency curves*

To get a general impression of the quantum efficiency of channelplate detectors Figures 1-17, 1-19 and 1-21 can be consulted for electrons, heavy particles and electromagnetic radiation respectively. The figures in between represent the angle dependence of the efficiency for the different types of particles. With these curves (Figs. 1-17 - 1-22) it should be possible to make out if a certain experiment is feasible. If accurate knowledge of the efficiency is needed it is inevitable to do efficiency measurements with that detector under the given experimental conditions.

In the case of neutral or positive charged heavy particles, it may suffice to know the efficiency of one species. Therefore we refer to Schram [1966], Tuithof [1974] and Baumgartner

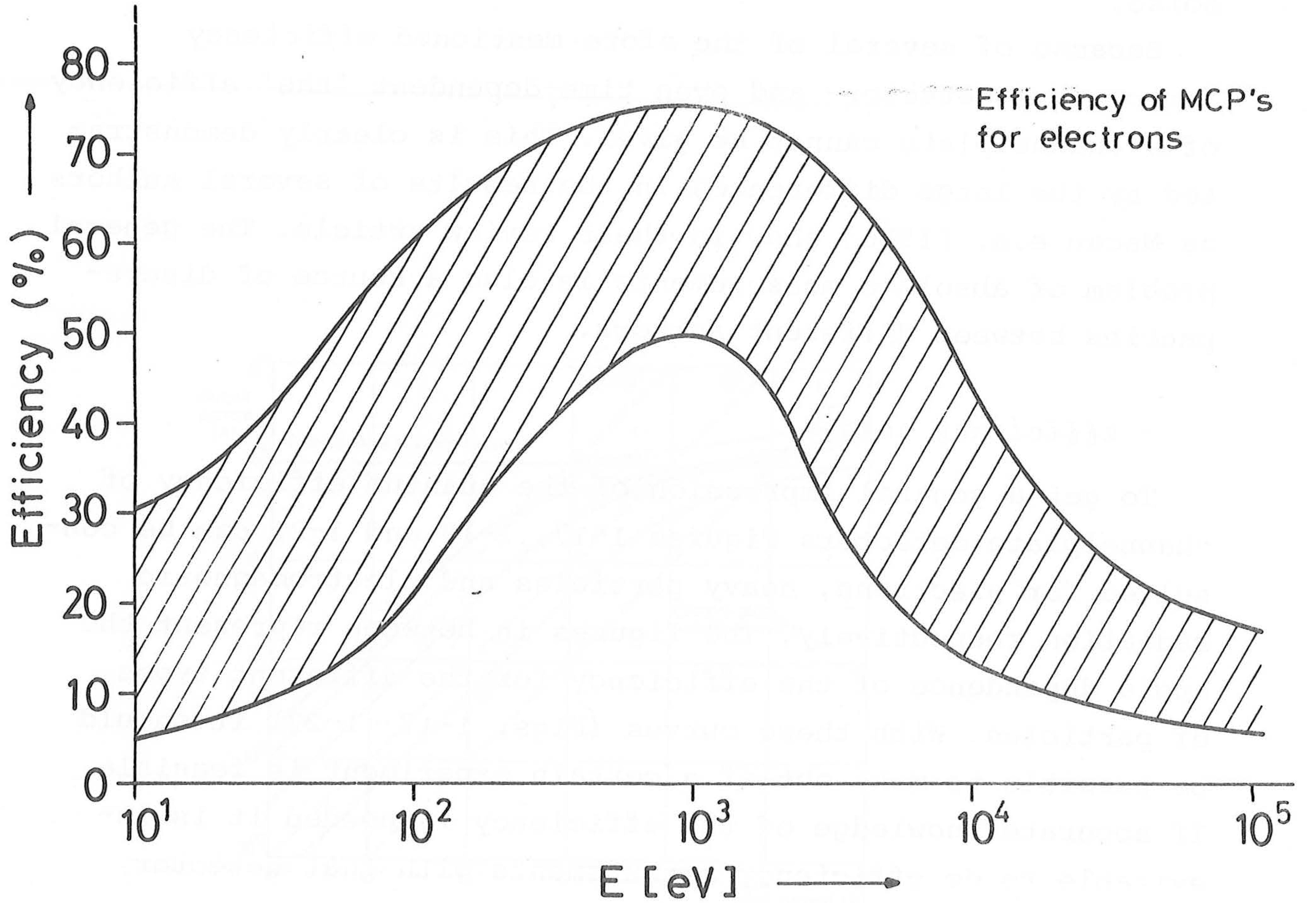

Fig. 1-17. Efficiency of MCPs for electrons.

[1976] who give amplification factors for continuous multipliers for many heavy particles. Since these types of measurements yield secondary electron coefficients and not the probability to produce at least one secondary electron, the information is only useful to estimate efficiencies in the low energy tail (below a few keV's).

A general rule is that the efficiency is almost equal for a neutral particle and its positively charged ion.
Light particles are better detectable than heavier ones with the same energy. For negative ions the efficiency is very high [Goodings, 1972] and the low energy tail resembles the efficiency for electrons.

High energetic particles have a low efficiency for direct detection with a channelplate detector as can be seen in the Figures 1-17, 1-19 and 1-21. The stopping power of the lead glass is too low and secondary electrons are not produced or to deep in the channels to get enough amplification. It is however possible to enhance efficiency by placing a suitable converter in front of the detector. The use of special photocathode coatings is well known, also to extend the sensitivity to longer wavelengths. For electrons and heavy particles a metal foil can be placed in front of the channelplate Manalio [1981] reported on the use of a MgO coating, which improved the efficiency for 7 keV electrons with a factor of 3.

1.3. Chevron construction

1.3.1. General remarks

As can be seen in chapter 1.2.7 (efficiency) the gain of a MCP is highly related to the angle with which a particle or the radiation enters a channel.

The ideal angle for maximum gain forces us to mount the channel plates of a chevron configuration quite carefully. One should check the direction of the channels while mounting the channel plates.

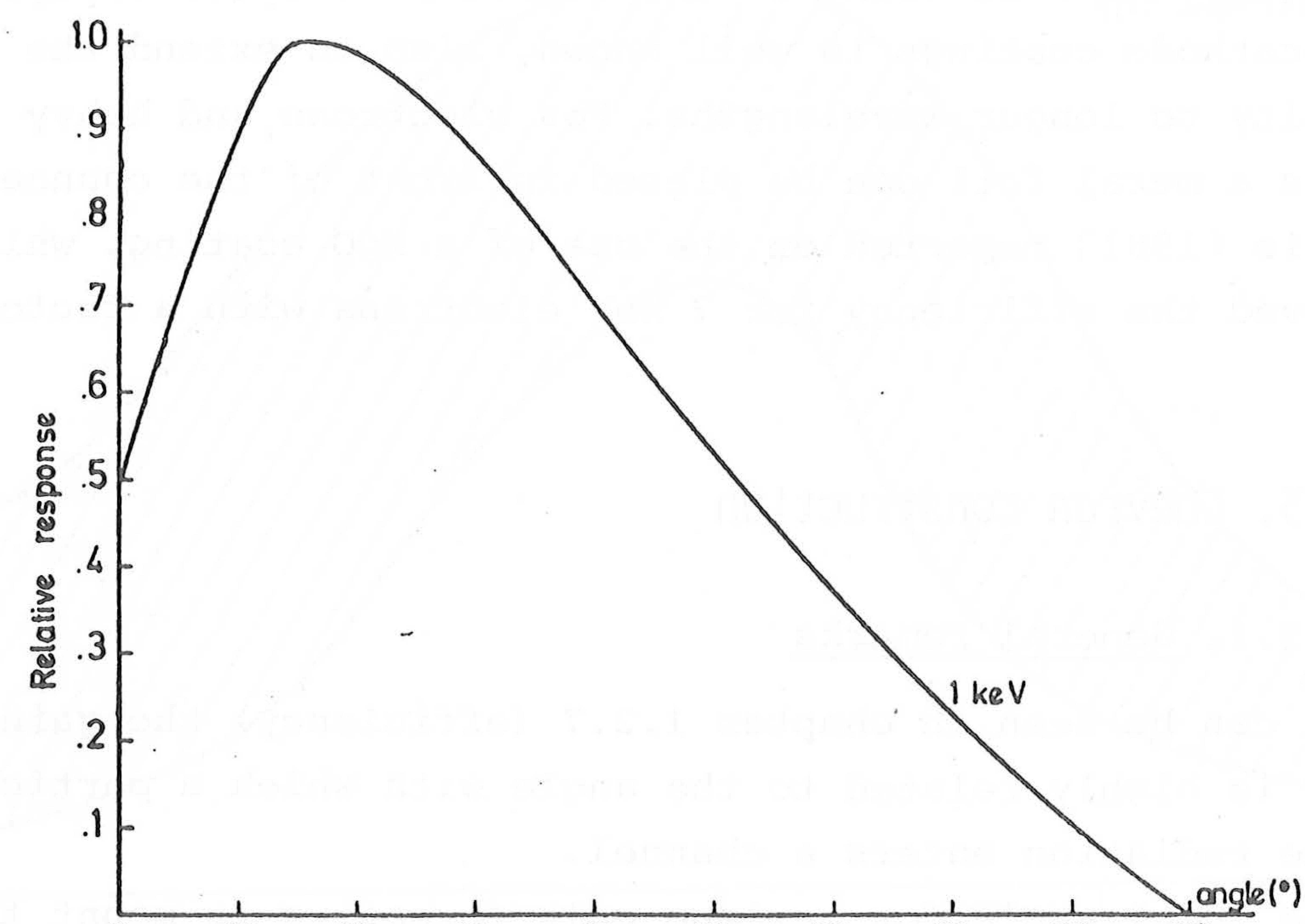

Fig. 1-18. Influence of incident angle of electrons on the sensitivity of channelplates [Galanti 1971].

MCP's show an exponential decrease in gain related to the output charge in the first few hundreds of hours of operation. If it is necessary to be sure of a constant gain over a long period of time, one should consider electron scrubbing and baking the MCP's (see 1.2.6), particularly in the case of sealed-off detectors (photomultipliers, etc.) [Rees 1980, Timothy 1981].

Sometimes it might be necessary to use three cascaded MCP's to obtain sufficient gain and a better pulse height distribution of the output pulses [Rees 1981]. Three cascaded MCP's (called Z-configuration), operated at lower gain, means a lower voltage across the plate and consequently a higher reliability.

1.3.2. Electrical details

How to design a circuit diagram for proper operation of the channel plates?

One should consider the nature of the incoming particles. Photons, neutrals and positive ions can be detected with a circuit diagram as given in Fig. 1-23. The ions will experience an extra acceleration only between grid and first channelplate. In position sensitive detection systems one should choose such a distance and potential between the grid and the channelplate that the position information will not be altered by this acceleration. This extra energy given to the ion can be useful in obtaining a higher detection efficiency. Another advantage in this electrical set up is the fact that the collector as well as the necessary electronics are on earth potential.

Negative ions and electrons need a more elaborate circuit (see Fig. 1-24). The approaching negatively charged particles are not influenced by the first channelplate surface which is on earth potential. The collector however has to be connected to a rather high positive potential, which calls for a much more complex electronic set up. If radiation or neutrals are to be detected, the input potential has no effect on the operation whatsoever, so it is wise to choose for the first set up (see Fig. 1-23).

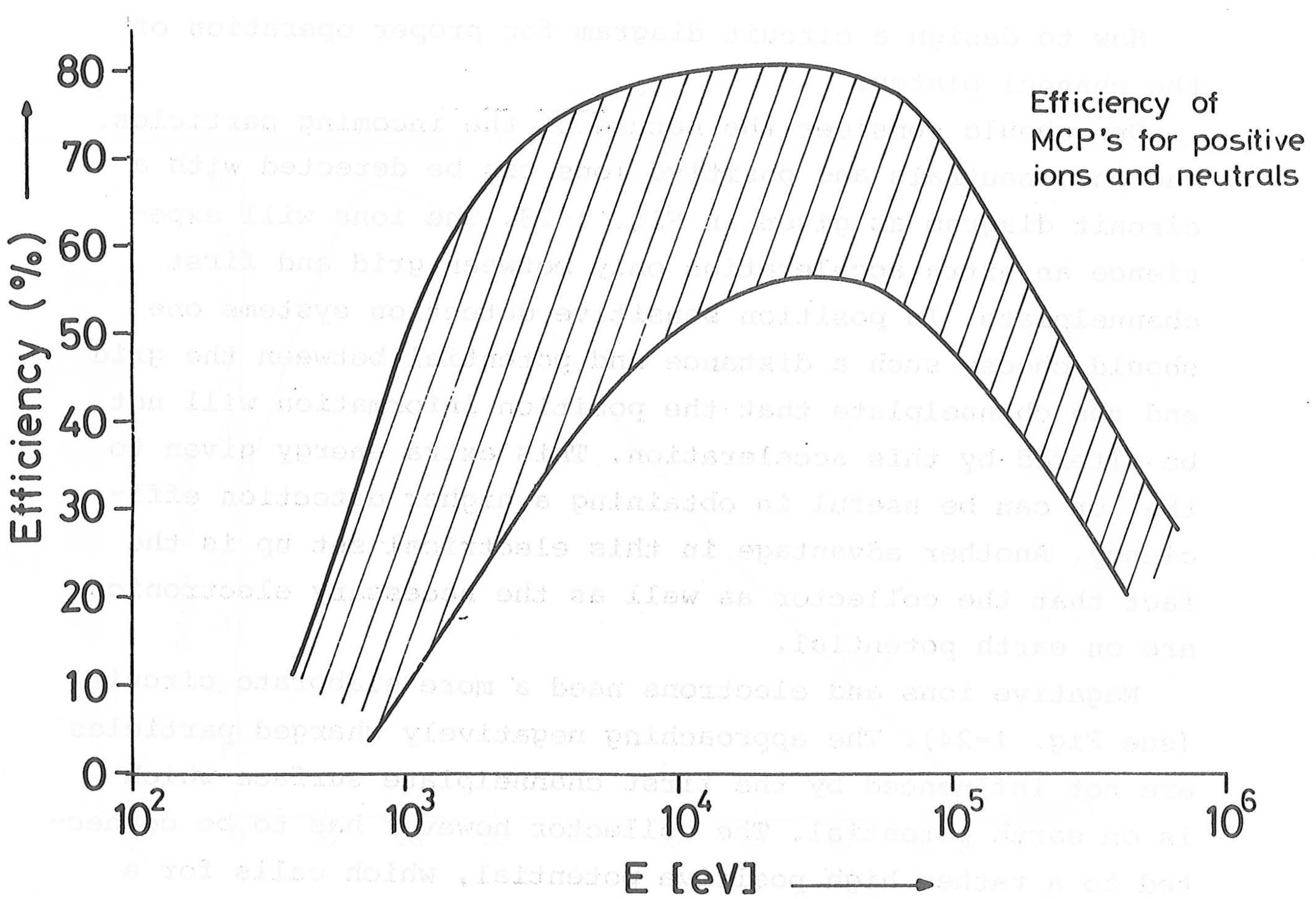

Fig. 1-19. Efficiency of MCPs for positive ions and neutrals.

Up till now we used the circuit diagrams as shown in Fig. 1-23 and 1-24. In both of these diagrams only a single voltage supply is needed with a voltage divider (R_2, R_3, R_4, R_5). They should be chosen such that a bleed current of about ten times the channel plate bias current is provided. Then, one does not have to bother about resistivity-matched channelplates. The bias current is measured by simple moving coil µA meters (50 or 100 µA full scale).

R_1 and R_6, together with the capacitors C, take care of RF suppression. Values of 100 kΩ and 10 nF have proven to be successful.

R_{11} (100 kΩ) with a gas-filled surge suppressor (90 V) in parallel keeps the divider and power supply floating with respect to ground potential. This is a standard provision to prevent ground loops.

R_7, R_8, R_9 and R_{10} limit the bias current through the channel plates in case of discharge or breakdown. Their value is chosen in the order of 5% of the channelplate resistance.

Although these precautions seemed to be efficacious, some colleagues proved at the cost of some MCP's that under these conditions MCP's could still burn out! In one case the grid in front of the first MCP (voltage difference 20 V) had a short circuit with the active area of that MCP. The current was limited to 40 µA but the MCP was locally (1 cm^{-2}) destroyed. As a solution to this problem we are now thinking of a crow-bar system which is to be triggered by the wide band noise appearing in the channelplate wiring in consequence of a discharge.

1.3.3. Mechanical details

Some considerations to design a channelplate construction for laboratory use.

- *Avoid sharp edges.*

Excessive electric fields can cause ionization of background gas, which can generate background noise or can even cause breakdown.

- *Take care of sufficient creeping distance along insulating materials.*

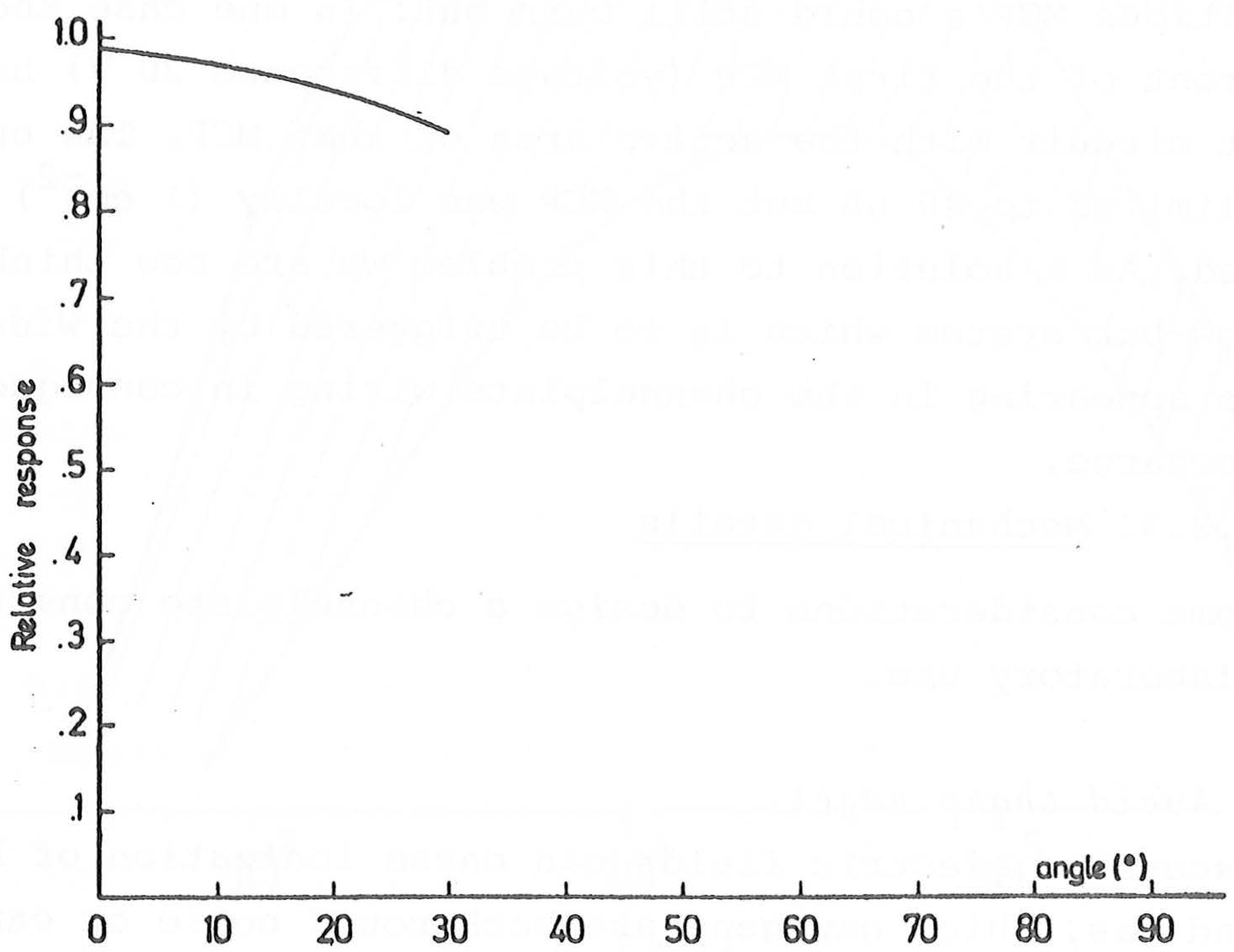

Fig. 1-20. Influence of incident angle of protons on the sensitivity of channelplates [Tatry e.a. NIM 69, p.254 (1969)].

- Avoid (flexible) wiring as much as possible.

Flexible wiring can cause problems because of the fact that one is not always able to predict the actual position of the wires if not visible.

- Avoid blocking of channels.

Although not yet proven it is not difficult to believe that due to blocking of channels, the pressure in these particular channels can reach an ideal value to create ionization which is amplified by the MCP. Burning out of that channel should be possible.

- Try to design channelplate mounting and collector set-up as separate parts, to increase the flexibility in usage.

- Special care should be taken to shield off electric fields due to the channelplates or wiring when low energy charged particles are to be detected.

- Some manufacturers advize to minimize exposure to the ambient atmosphere and recommend the use of a well-desiccated container for storage.

On the other hand in some cases a drop in gain can be recovered by re-exposure to the atmosphere [Rager 1974].

- Check the resistance between the surfaces of each channelplate in vacuum before operation.

- Do not use voltages above about 100 volts to measure the resistance, thus preventing the channelplates to get damaged.

- Avoid the channelplates to work in a pressure greater/higher than 10^{-2} pascal.

- Channelplates should be handled with care, they are fragile and get easily contaminated.

- Avoid touching the surfaces; the use of gloves (nylon, plastic, latex) is recommended.

- The channelplates can be cleaned with isopropyl alcohol in an ultrasonic bath.

- Outgassing up to 200°C with no voltage applied is allowwed [Roger 1974].

- Channelplates should not be exposed to hydrocarbon vapours; permanent damage will occur.

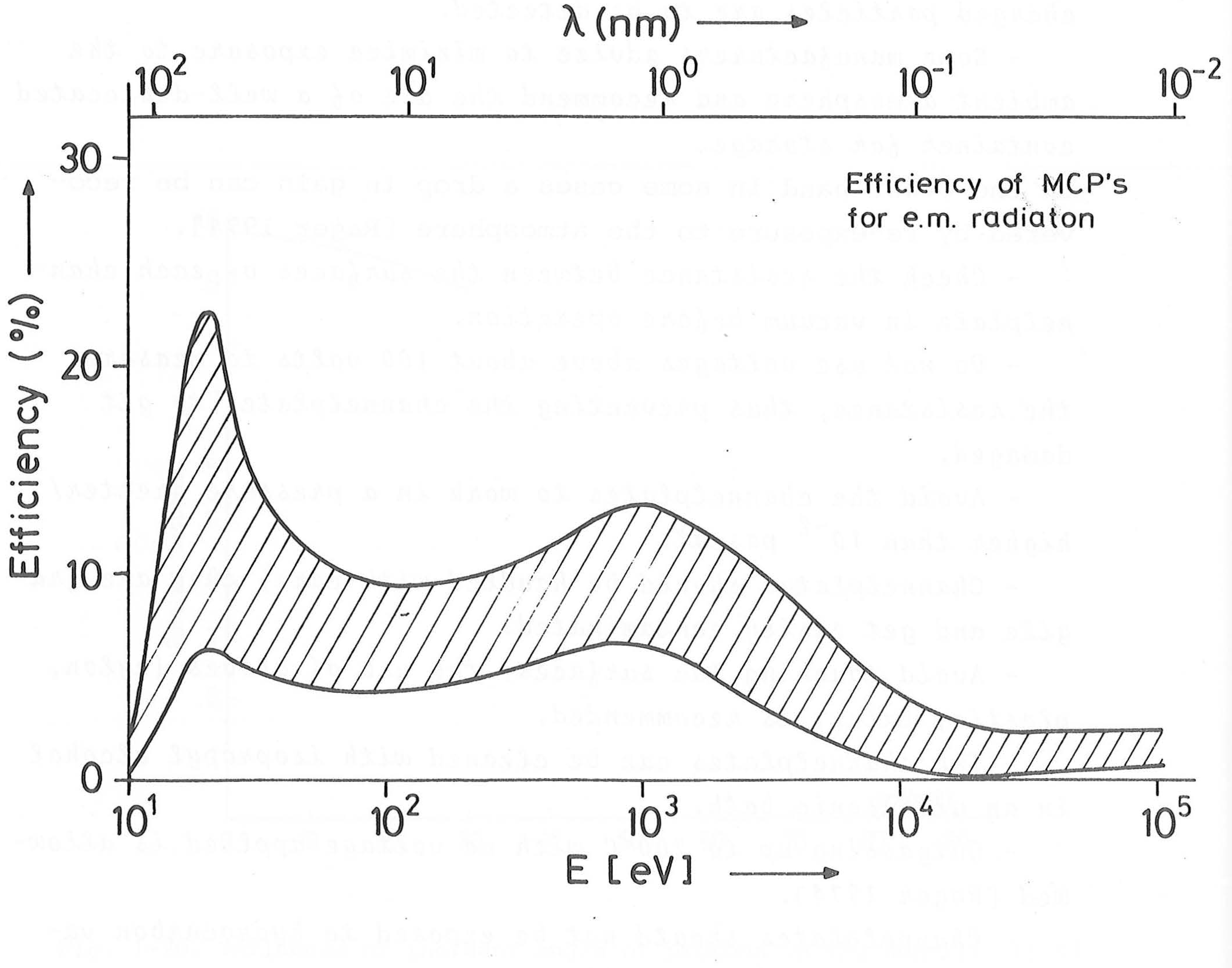

Fig. 1-21. Efficiency of MCPs for e.m. radiation.

- Notice the distance between both channelplates and the separate supplied voltages on all channelplate surfaces (see chapter 1.2.2).

Some manufacturers prefer to use specially selected pairs of channelplates to form a chevron configuration (matched pair). There is one potential on the inner surfaces which are just not touching each other.

We acknowledge the simplified handling but when more flexible and economical use is necessary then the choice for two channelplates of the same type but not matched is obvious.

To prevent the Moirê effect, the MCP's should be mounted with some distance between each other, implying the need for an interplate potential. Our experience is that interspacing of about 0,05 - 0,2 mm will do. The possibility to change the electric field between the channelplates gives us a tool to vary the spot size and the saturation of the second channelplate [Wiza 1977], see 1.2.2 and 3.2.

- Drawings and further details of the mechanical set up are given in Fig. 1-25.

- The use of gold or brass foil for the electrodes is recommended.

Other materials may cause spurious pulses due to a bad contact between the electrode and the channelplate surface.

1.4. Available types (august 1981)

There are several manufacturers of microchannel plates on the market. As MCP's emerge from classified research for military purposes - night viewers - there is still a considerable amount of restraints from manufacturers side. Two of them, Mullard in Great Britain (Philips) and Galileo Electro Optics Corp. of USA (Bendix), suffer less from that mysteriousness. When similar models are available Mullard is the least expensive in general. Galileo, however, has a much wider range of different types.

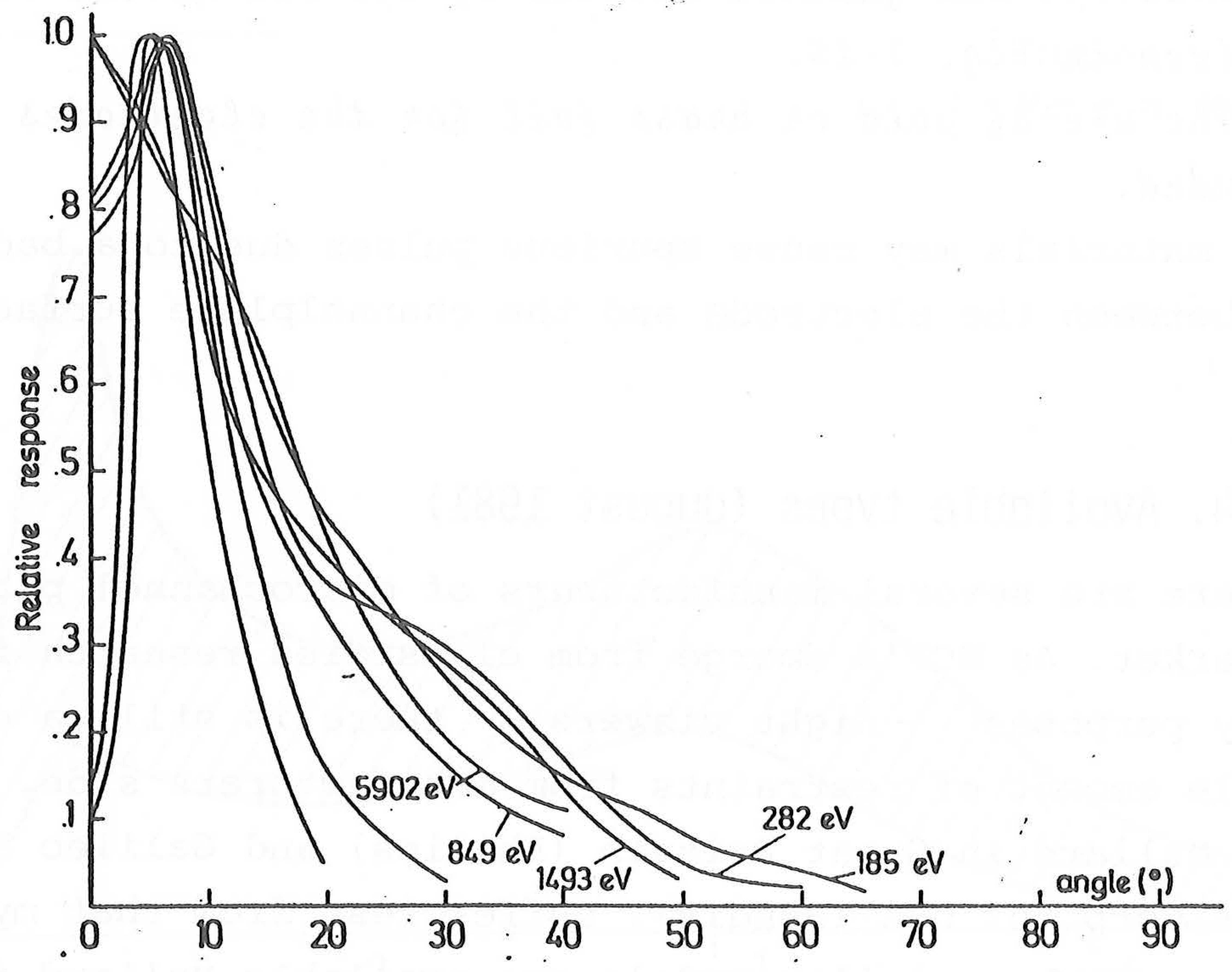

Fig. 1-22. Influence of incident angle of UV-X-γ ray on the sensitivity of channelplates [Smith e.a. IEEE Trans.Nucl.S. , NS15, p.541 (1968)].

In Table 1-1 the current type of MCP's of these two makes are put together with their major features. As can be seen just one curved channelplate appears in the list: the Galileo model SMCP 25. For the moment being Mullard does not have a commercial model available. The cost of that curved channelplate is roughly one and a half times the price of two equivalent straight channelplates. Their pro's and cons as position sensitive, particle detector under investigation here in the institute.

As an alternative to a curved channelplate Mullard manufactures a so-called "fused chevron" channelplate. Matched pair straight channelplates are fused together during production, before the soluble glass is removed from the channels. This assembly is supposed to behave similarly to a curved channelplate. For the moment being very little is known about relative performances: a typical example of the aforementioned mysteriousness.

A more closer lock to the table reveals a remarkable difference in the electrical conductivity between corresponding models of Galileo and Mullard make. That could imply, but it has not been proved yet as far as we know, the maximum count rate of a Mullard type might be up to ten times higher than the comparable Galileo one. At the same bias voltage Mullard states the gain of their plates to be greater than 10^3, while Galileo gives a figure of 10^4. That could mean the Mullard ones have a somewhat lower gain than the Galileo ones. If so that difference could be easily compensated for by a slight increase in bias voltage of the former ones.

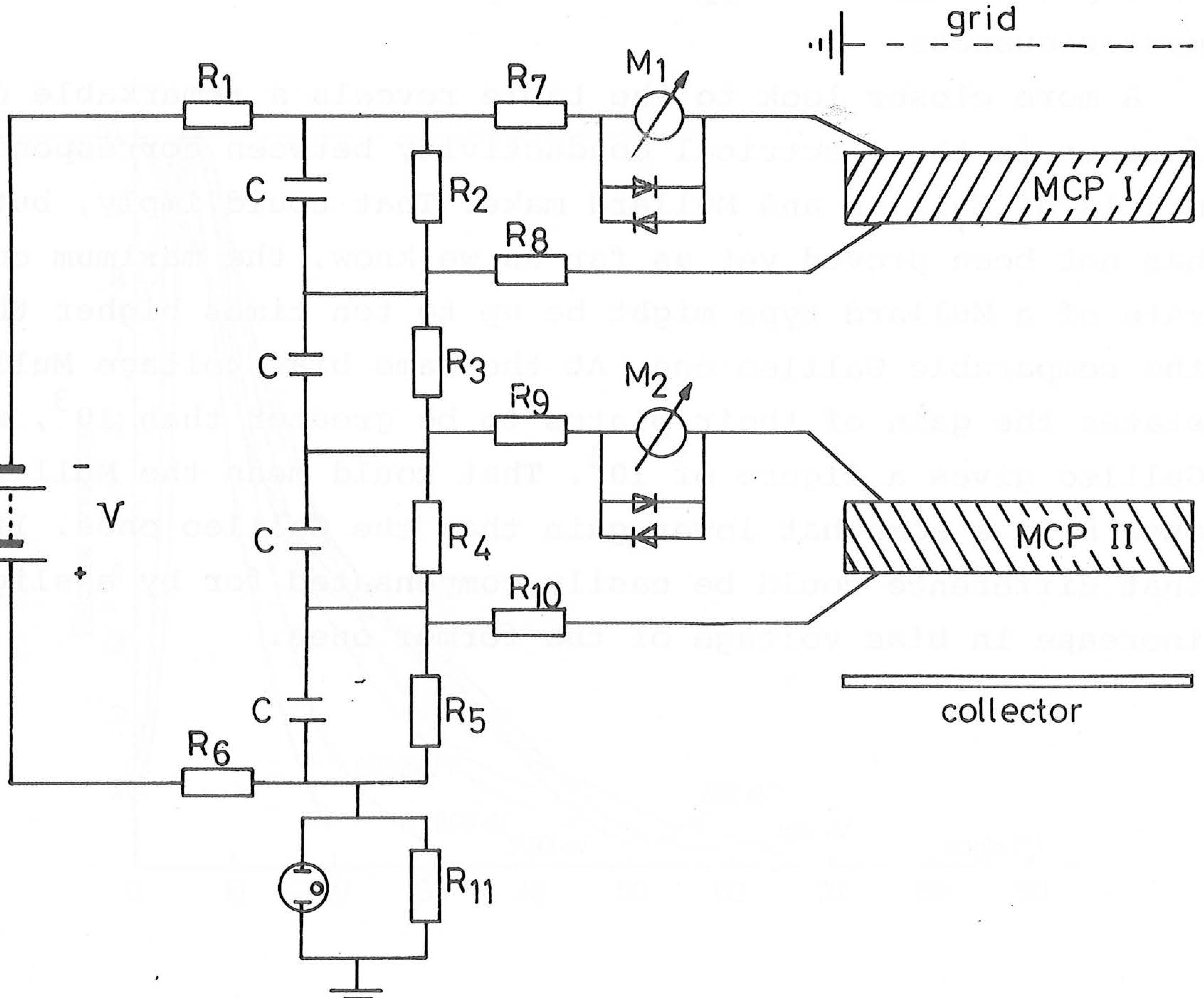

Fig. 1-23. Electrical details for a chevron MCP as used for the detection of photons, neutrals and positive ions.

Channel diameter 8 µm

Usable dimensions [mm]	Manufacturer and type	Bias angle	% open area	µA/kV	Gain @ 1kV	Price incl. VAT (guilders)
ø 18	G 6) MCP 18	5°	50	4	10^4	
ø 25	G 6) MCP 25	8°	50	7	10^4	

Channel diameter 12 µm

Usable dimensions [mm]	Manufacturer and type	Bias angle	% open area	µA/kV	Gain @ 1kV	Price incl. VAT (guilders)
ø 18	G 6) MCP 18	5°	55	4	10^4	2400
	M 6) G12-25SE 1) 2)	13°	60	±2	$>10^3$	1800
ø 25	G 6) MCP 25	8	55	7	10^4	2800
ø 32	M 6) G12-36 2)	13°	60	15	$>10^3$	2600
	M 6) G12-36DT/6	0	60	8	$>10^3$	3200
	M 6) G12-36DT/13	13	60	8	$>10^3$	3500
ø 46	G 6) MCP 40	8°	55	18	10^4	4500
	M 6) G12-46 2)	13°	60	22	$>10^3$	3500
	M 6) G12-46DT/6	0°	60	13	$>10^3$	3900
	M 6) G12-46DT/13 2) 4)	13°	60	13	$>10^3$	4600

Channel diameter 25 µm

Usable dimensions [mm]	Manufacturer and type	Bias angle	% open area	µA/kV	Gain @ 1kV	Price incl. VAT (guilders)
ø 25	G 6) MCP 25	8°	55	2	10^4	2800
	M 6) G25-25	13°	60	20	$>10^3$	2500
	G 6) S.MCP 25 3)	10-15°			10^6	8900
ø 46	G 6) MCP 40	8°	55	4	10^4	4500
ø 50	M 6) G25-50 5)	13	60	100	$>10^3$	5500
ø 70	M 6) G25-70 5)	13	60	200	$>10^3$	7400
ø 75	G 6) MCP 75	8°	55	12	10^4	8600
50x8	G 6) MCP 508	8°	55	2	10^4	
50x20	M 6) G25-20x50	13°	60	29	$>10^3$	5300
100x15	G 6) MCP 115	8°	55	6	10^4	
92x75	G 6) MCP 810	19°	55	50	10^4	8600

1) SE means: SOLID EDGE
2) available in "A" version: resistance matched pair
3) curved channel plate
4) DT means: DOUBLE THICKNESS
5) maintenance type
6) MANUFACTURER M = MULLARD, G = GALILEO

TABEL 1-1

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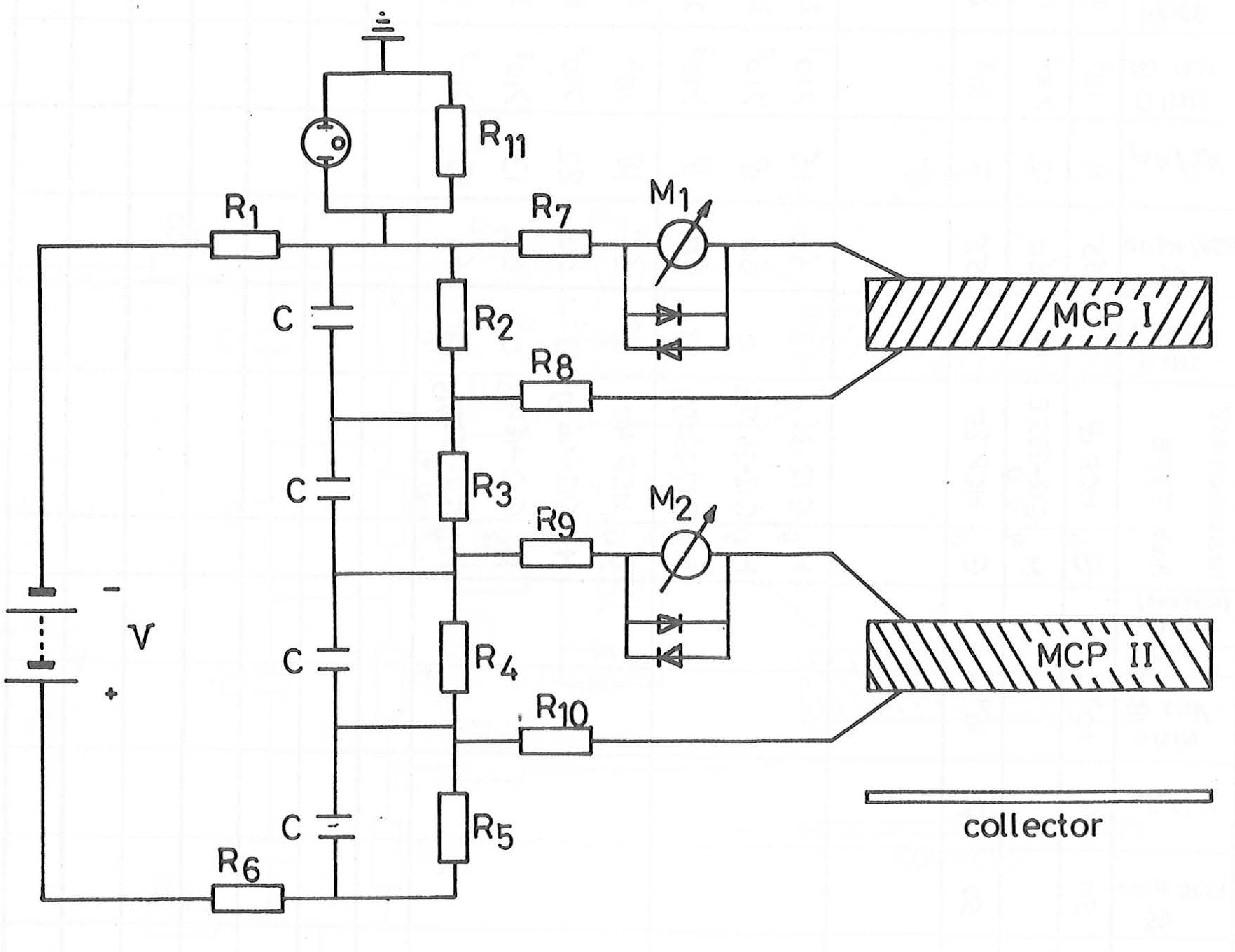

Fig. 1-24. Electrical details for a chevron MCP as used for the detection of negative ions and electrons.

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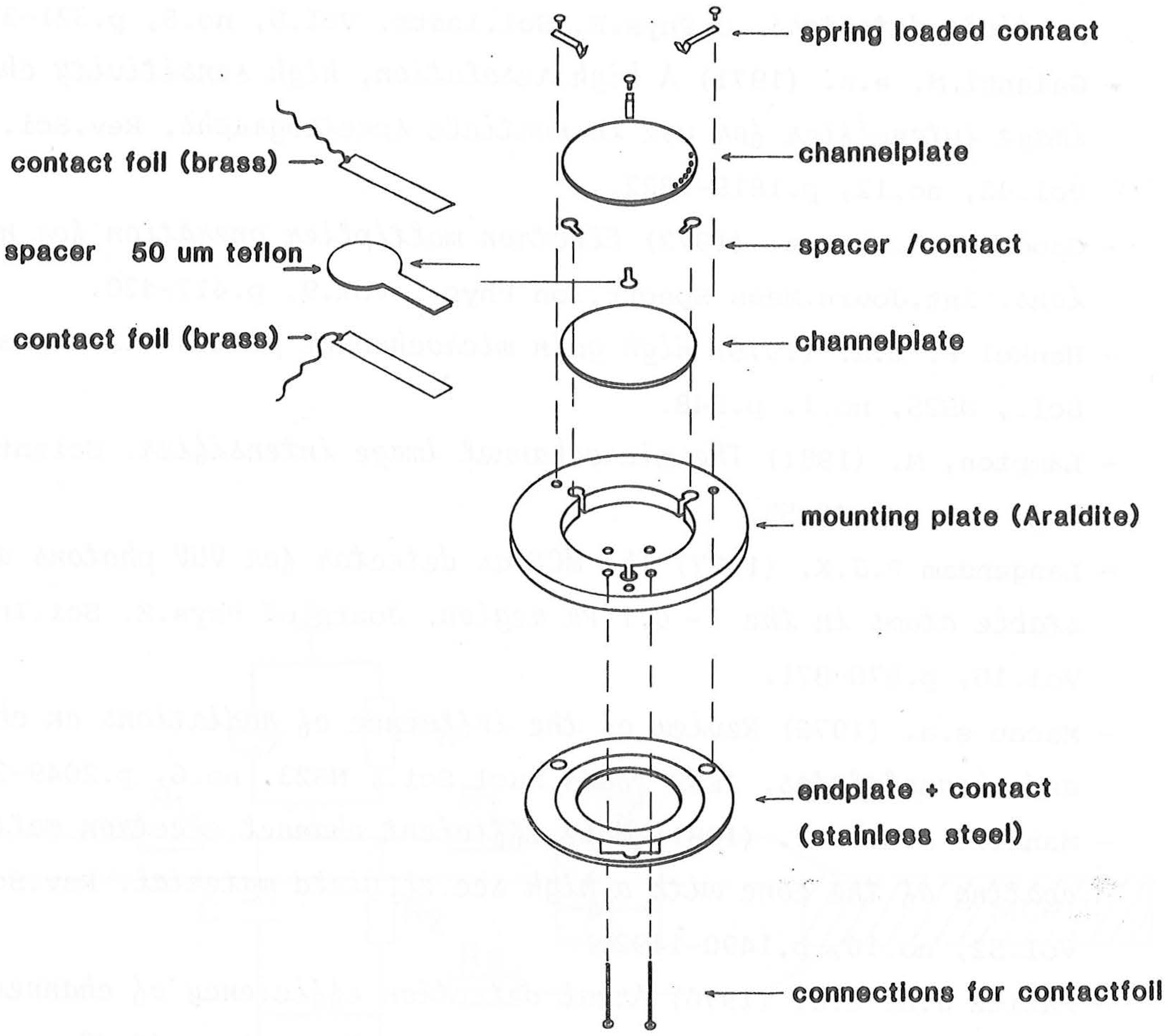

Fig. 1-25a. Mechanical details for an MCP mounting. In the latest version the endplate is made of double sided printed circuit board. The front layer is used as the MCP contact. The back layer is put on a potential between MCP and collector such that the lens effect of this plate is reduced (for better linearity). This construction is successfully used in high vacuum (10^{-4} Pa).

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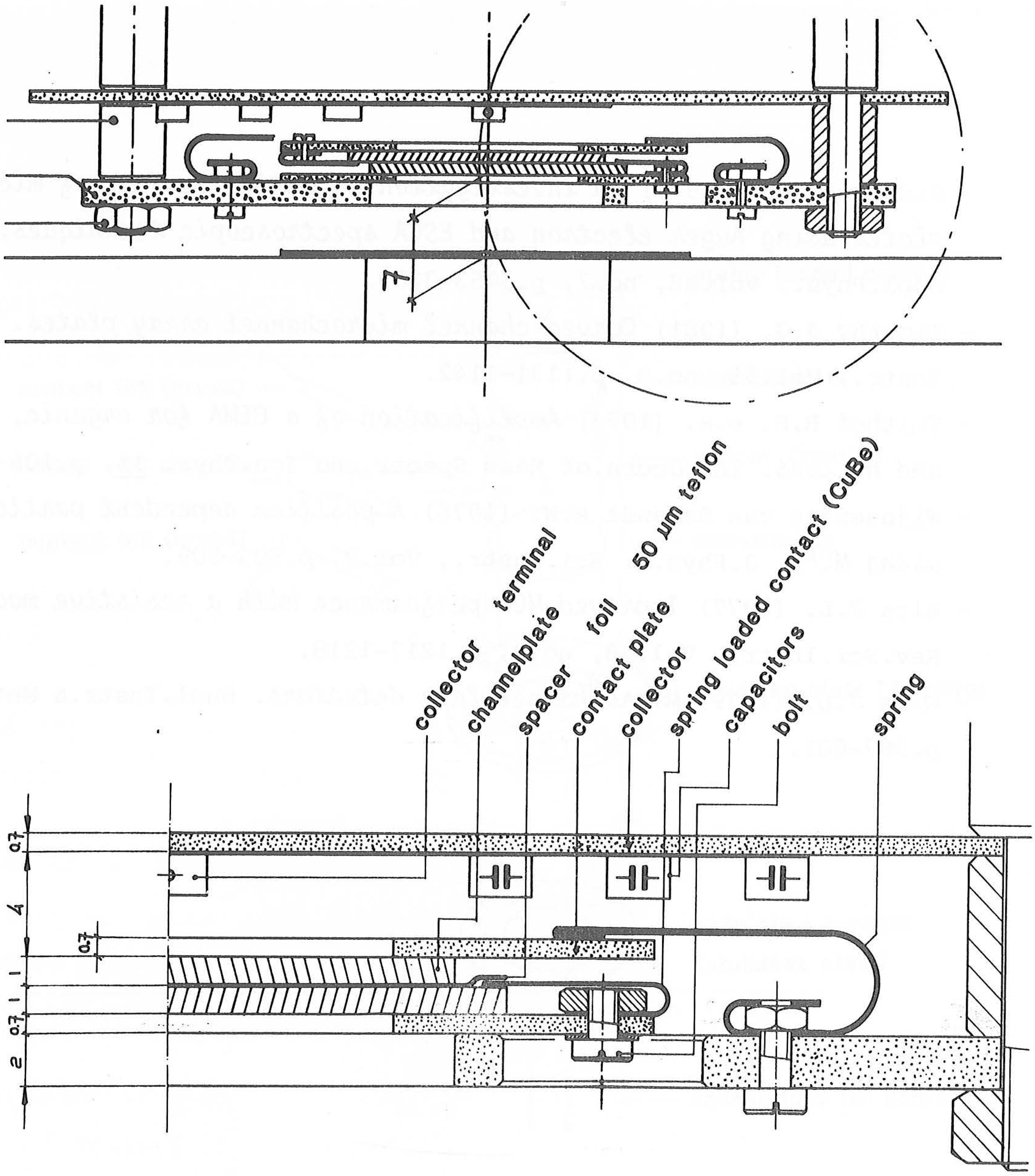

Fig. 1-25b. Mechanical details for an ultra high vacuum MCP holder. Note that the MCPs are shifted with respect to each other. Originally there was no need for an insulating spacer foil between the MCPs as the distance between the MCPs is fixed by the spacers between the contact plates. Unfortunately our large MCPs (90 mm × 25 mm) were not flat enough so Teflon foils were used again.

The gold contacts on the contact plates made using the screen printing technique (thickness 12 µm). The contact springs (3) on each MCP are not connected with each other. This gives us the opportunity to measure the contact resistance between them. If this resistance is low enough (< 1000 Ω) and constant, the contacts are interconnected. For the same reason the printed contacts on the contact plate are divided into two parts.