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SOME PROSPECTS WITH GASEOUS DETECTORS

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INTRODUCTION

Since the last Vienna Conference our knowledge of gaseous detectors has been enriched in several ways.

i) Some important large-size detectors, mostly equipping electron storage-ring intersection regions, have come into operation. They are based on properties that are already well established in medium and small-size detectors. Generally, their main aim is to have simultaneously the best accuracy, the best multitrack resolution, and the best particle identification; and, since a wide variety of solutions have been adopted, it is of the highest interest to establish the properties of these detectors under operational conditions. This congress, and the next Uppsala conference on LEP detectors in June 1980, should help us to clarify the respective advantages of these monsters in view of future enterprises, either with LEP or with other storage rings.

ii) During this two-year period a deeper insight has been gained into some basic processes in gaseous electronics, which play a role in quite a range of familiar detectors. More specifically, the role of light-emission in multiplying processes, having so far been ignored by most particle physicists, now appears to be of great interest, if understood and controlled, for the following reasons:

- it plays a role in new structures such as the multistep avalanche chambers¹⁻³), which offer serious advantages as high-rate counters with about one order of magnitude greater rate capability, as compared to wire chambers; one application of these structures to an important routine technique used in chemistry -- paper chromatography -- will be described at this meeting⁴);
- new localizing ultraviolet counters derived from the multistep chambers offer important prospects in such different fields as Čerenkov imaging counters⁵), photon light-amplifiers, high-resolution X-ray imaging counters⁶).

iii) The exploration of low and high pressures in gaseous detectors, from 0.3 Torr ^{7,8}) to 300 atm ⁹), has opened the way to detectors with exciting properties: 100 ps time resolutions, gaseous sensitive volumes of several hundred tons, new vertex detectors.

Since, at this conference, it is likely that most of the authors of new contributions will present their own work, I will limit my talk to the aspects of those developments with which I am associated.

1. THE EMISSION OF VUV PHOTONS BY ELECTRONS
DRIFTING IN ELECTRIC FIELDS

In some gases and in definite electric fields, drifting electrons may induce the emission of light along their path, without ever reaching an energy sufficient for ionizing the gas.

The exploitation of this light for X-ray detection was started by the work of the Coimbra group¹⁰⁾, and has raised interest in the few laboratories where having a gaseous detector with a resolution of 8.5% (FWHM) at 5.9 keV, instead of the commonly obtained 14% with a wire counter, was of the highest importance, mainly for astrophysical investigations^{11,12)}. It should, however, be pointed out that quite extraordinary and rare energy resolutions are claimed to be obtained also with wire counters¹³⁾: 10.7% FWHM at 5.9 keV. The advantage over solid-state detectors, having an even better resolution at 5.9 keV, lies in the fact that it is much easier and cheaper to make large-area gaseous detectors.

At a very low energy such as 149 eV, the resolution is even better than with solid-state detectors, since a width of 80 eV has been observed¹⁴⁾. The basic process underlying this emission of light plays a major role in some of the developments concerning the multistep or photo-ionization counters.

Figure 1 from Suzuki and Kubota¹⁵⁾, shows the spectrum of the light emitted by some common noble gases. It consists of a broad spectrum of VUV light with a width of about 1 eV. It is now rather well established that this emission is due to the decay of eximers, i.e. a molecule made of an atom excited below its ionization potential, bound to a ground-state atom, and decaying into two ground-state atoms plus a photon. In mixtures of gases, much work has still to be done to clarify the spectrum of emitted photons.

Since photons of such energy traverse only expensive and inconvenient windows, the way to exploit this light has so far been to convert it into visible light by

fluorescence on a thin transparent deposit on a window that is transparent to visible light, such as quartz.

I want to mention two developments concerning these detectors.

1.1 The high-pressure gas scintillation counter

In order to extend its application to nuclear medicine, high-pressure xenon filling has been investigated, with the aim of reaching efficiencies comparable to those of scintillating crystals in the region of 140 keV; this is of paramount importance for nuclear medicine, the expected advantage being an improved energy resolution.

A development program aimed at reaching good efficiencies for γ -rays has been initiated at the Laboratoire de l'Accélérateur Linéaire, Orsay, by Nguyen et al. The localization of the absorbed photon is done by properly weighting the intensity of pulses from five photomultipliers viewing the quartz window covered with a thin layer of p-terphenyl, converting the VUV light into visible light. An accuracy of 3 mm FWHM has been obtained¹⁶). A similar approach has been undertaken by a space laboratory aiming to build a broad-band spectrometer in the focal plane of an imaging X-ray telescope¹⁷). They reached an accuracy of 5 mm (FWHM) with three photomultipliers. Nguyen et al. have to some extent reached their goal: they have obtained a resolution of 5% FWHM at 27 keV, corresponding to the K-shell energy of iodine -- which is an important energy for many experiments concerned with the thyroid -- and an excellent resolution at 10 atm of xenon, where the efficiency of the 140 keV line of technetium-99 is close to 20%. Figure 2 shows the spectra obtained at 5 atm of Xe in two energy regions. The results are good enough to encourage the authors to undertake the construction of a prototype for clinical use, where the capability to reduce the Compton background and obtain a better spatial resolution should offer interesting advantages over scintillation cameras.

1.2 The proportional scintillation photo-ionization counter

The progress in the photo-ionization counters which resulted from the developments of the multistep chamber and the search for appropriate imaging detectors for Čerenkov VUV radiation^{18,19}) led to the development of this new

approach for the localization of the absorption point in the scintillation gaseous detector: the VUV photons of the scintillation proportional counter traverse a window and are converted into detectable electrons in an appropriate gas filling a multiwire chamber.

Figure 1 showed the ionization potentials of a few vapours. Using krypton as the scintillating gas and triethylamine (TEA) as an absorbing vapour seemed a favourable combination.

LiF was used as a window. Figure 3 ^{5,18)} shows the transmission properties of LiF, and the photoelectric yield of triethylamine and some other vapours.

A detector, built according to fig. 4 (from ref. 6), was used. The TEA was added in the proportion of 2% to a multiwire proportional chamber (MWPC) built in such a way as to minimize the distortions of the potential in the vicinity of the anode wires.

The comparison of the pulse heights obtained by irradiating the MWPC directly and by irradiating the scintillation proportional counter and then detecting the pulses induced by the VUV converted in the MWPC, shows that an additional gain of about 10 in the MWPC chamber can be obtained with the converted VUV photons, as compared with direct absorption of the X-rays in the gas.

The resolution is then 9.5% (FWHM) against 14% for the direct pulses (fig. 5). The width of the charge distribution in the MWPC is 6 mm, and we can then reasonably expect an accuracy of 100 μ m with any of the read-out methods commonly used.

This is a considerable gain with respect to any approach so far made to localize the photons in the scintillation proportional detector, and an unexpected fall-out from a research aimed primarily at increasing the rate capability of gaseous detectors!

However, more important applications of this method can be foreseen, and I will mention them in the section concerning future developments.

2. PROPERTIES OF PARALLEL GRID STRUCTURES

For our group the stimulus to start a study of the amplification properties of parallel grids, used since the dawn of nuclear physics in some rare applications

mainly for heavily ionizing particles, started from the desire to develop a two-step amplification structure permitting an intermediate gating-off of unwanted events¹⁾. The idea was to decrease the space-charge problems connected with the fact that these unwanted events give rise to obnoxious space-charge effects in high-rate experiments.

The results of this study²⁾ were surprising to us. It led us to the conclusion that parallel-plate amplification is interesting by itself, for minimum ionizing particles and for X-ray detection. Our efforts to understand the operation of multistep chambers helped us in developing gaseous photo-ionization detectors, adequate for an efficient localization of single photoelectron events -- although we sometimes have the impression that some of our early interpretations of the observed phenomena were not fully founded.

2.1 Amplification factors

The study of the amplification properties of parallel gaps was performed with the structure illustrated in fig. 6:

- a detection gap D, where X-rays of ^{55}Fe can be converted into photoelectrons;
- an amplifying gap A, of 5 mm depth, where avalanche multiplication in a uniform field can be obtained;
- a transfer gap T, where the electrons produced in A can be partly transferred.

The exit grid b limiting A is made of 50 μm wires spaced every 0.5 mm.

For rate-limit studies, a well-collimated source of 8 keV X-rays produced by an X-ray generator can irradiate D. The current induced in each wire of b can be measured, thus giving the lateral extension of the avalanche.

The study had two aims:

- to find the limits of amplification as a function of counting rate;
- to find the lateral extension of the avalanche in order to understand the transfer properties of the electron clouds in such structures.

It was limited to a particular gas filling: argon + acetone. The reason for this choice was that this gas proved to be suitable for an effective transfer from A to T, which was the starting point of our study.

The following observations were made: the energy resolution of the first gap for X-ray detection is 16% (FWHM) at 5.9 keV; it degrades to 21% in T for a 20% transfer efficiency.

The maximum gain G that can be reached is a function of counting rate. This gain limit is not set by a decrease in pulse height as in wire chambers, but by the appearance of a spark. Even at low gains a spark appears for a sufficiently high radiation density³). This limit of gain is clearly determined by the positive ion density and not by secondary effects of UV photons, since the sparks are strictly localized at the injection point of the beam. This should make us cautious about any information concerning the maximum gain reached with a given chamber: the limits strongly depend on the rate and on the spatial spread of the initial ionization. One gratifying fact is that at low rates the gains are sufficient to detect minimum ionizing particles with a good efficiency. It may be that this interesting detection possibility has been too neglected in recent years owing to the efficient development of wire chambers. At high rates, we will see that the gated multistep structures permit the problems of sparking to be largely overcome.

Some difficult problems do exist for large-surface detectors; this is obvious from preliminary studies done by the Saclay group working on a 90 cm $\times$ 60 cm parallel plate multigap detector, and presented at this meeting. The simple electrostatic forces lead to unacceptable gap variations requiring a high density of spacers. However, in X-ray detection, parallel-plate wireless detectors attract some interest, as can be seen from recent work by astrophysics groups.

The definition of the gain in a parallel-gap counter deserves some care. If the pulses are observed with a fast amplifier which is sensitive only to pulses induced by the electrons' motion, then the height of these pulses is proportional to $Q e^{\alpha \ell} / \alpha \ell$, where Q is the initial electron charge injected at the entrance of the counter, α is the number of ionizing collisions produced per cm by the electrons, and ℓ is the gap width. We assume a Townsend avalanche and neglect the influence of the propagation of the photons, which is a correct approximation if the ionization mean free path is small compared to ℓ , whatever the mechanism.

If the current in the chamber is measured, or if a very slow amplifier is used, sensitive to the positive ion motion, an apparent higher gain $e^{\alpha l}$ is obtained, which is not observable in a fast system.

If, on the other hand, the electrons are transferred to T with an efficiency f , the charge collected on the electrodes of T by a fast amplifier can be larger than the one collected in A if $f\alpha l > 1$. This is illustrated by fig. 7, where one clearly sees that the fast pulse induced by the motion of the electrons crossing b to go from A to T is larger than the pulse collected on b without transfer.

The lateral extension of the avalanche, for various concentrations of acetone in argon, is illustrated in fig. 8.

At 2% of acetone, commonly used for its efficient transfer of electrons, an extension of $\sigma = 320 \mu\text{m}$ is observed, with a source of almost $300 \mu\text{m}$ collimation (full width).

Even allowing for an incorrect estimate of the collimation, it appeared surprisingly narrow to us, since we thought a large lateral extension was necessary in order to explain the good transfer and energy resolution for 5.9 keV X-rays²⁾. A more careful analysis shows that even with a low lateral extension of only $500 \mu\text{m}$, equal to a wire spacing in the exit grid of A, the amount of electrons escaping from A to T is not very position dependent, and this position dependence can explain the variation of the energy resolution from 16% to 21% at 5.9 keV.

The variation of the lateral extension σ with respect to the acetone content would point to the interpretation of the extension as being due to the absorption of the VUV photons by the acetone vapour.

However, an approximate estimate of the diffusion as a function of acetone content leads to a variation in the same direction. Without a reliable measurement of the diffusion coefficients, it is impossible to exclude a major contribution of diffusion to the spatial extension, thus permitting a transfer proportional to the ratio of the number of the field line forces crossing the grid b_2 to those stopping at the grid. Our doubts led us to use the structure of fig. 4 to investigate the role of VUV photons in the transfer.

By replacing the grid b by a LiF window, as in the device shown in fig. 4, one eliminates any electron transfer. Using argon-acetone in A and in the MWPC we indeed observed pulses in the MWPC when A is amplifying X-ray photoelectrons. The pulse height, for a gain of 10^4 in A, is about the same in the MWPC for direct absorption of X-rays or for the VUV transmitted after multiplication in A. This pulse height indicates that the number of VUV photons per ionizing collision in A is at least 10%. In other words, the VUV photons do contribute to the extension of the avalanche, although they may not be the only source of propagation of the multiplication at the field strengths we apply in the gaseous mixtures we use.

2.2 The multistep gated structures in intense beams

The combination of a preamplifying gap A_1 , a transfer space, a gating grid, and a final amplifying stage A_2 , which was our original aim, has now been thoroughly investigated in an intense particle beam³⁾. Figure 9 shows the structure of the chamber.

Our recent studies clarified the advantages of a multistep structure compared to those of a single-gap structure, e.g. the rate limits, the gating properties, the multiparticle resolution, the time resolution, and these are described in full detail in ref. 3.

Figure 10 shows the variation of gain in a single gap of 5 mm as a function of the electric field, for 5.9 keV X-rays converted in the gas of the conversion gap.

The gating of the electrons in the drift space is done in the following way: the wires of G, spaced by 1 mm, are set alternately to a potential offset of ± 70 V. The amount of electrons amplified in PA_1 and crossing such a grid is then less than 1% (fig. 11). A pulse of variable width restores the equipotentiality of the wires in order to open the gate. We observe some parasitic pulses on the detecting electrodes at a level which is compatible with an efficient detection of the avalanches amplified in A_2 . The parasitic pulses arriving before the swarm of drifting electrons can also be easily gated off, provided they do not overload the amplifiers for a long time.

Each wire of the detecting electrode, 0.5 mm apart from each other, is equipped with an amplifier, and its pulse height can be measured in order to study the avalanche extension.

The detection threshold is close to 500 μ V. Figure 12 shows an efficiency curve, as a function of the voltage on the final state A_2 and as a function of gating width at low rates. Figure 13 shows the efficiency curves of A_2 together with the sparking points as a function of the incident particle rate and of the trigger rate. Figure 14 shows the efficiency curve with the gate open, and with the sparking points as a function of rate. Figure 15 shows the comparison of the sparking points with the gate open and with gating at different rates. We see that the gating considerably improves the rate capability before sparking.

This is just what can be expected, and it shows that the positive ions play a major role in the feedback mechanism leading to sparks.

This changes very little with the rate of gate triggering. Figure 16 shows the same efficiency curve as fig. 13 but with the conversion gap on. It leads to a wider plateau since more initial electrons are available for amplification. However, the memory time, because of conversion space length, is then of the order of 100 ns, and will add to the accidental rate in case of high fluxes. The situation is then similar to the one of MWPCs where the memory time is usually set by the gap width, in the absence of electronegative gases.

Also the total charge per particle at a given gain is increased and should lead to an earlier breakdown as a function of rate.

We observe that the limiting rate, for an acceptable efficiency of 95%, is of the order of $2 \times 10^5/\text{mm}^2$. This was tested in a beam of 20 mm^2 surface where the instant rate at the centre is higher than this average by a factor of 2 (ref. 3).

Under the same conditions, we compared a MWPC with 2.54 mm anode wire spacing, filled with argon-ethane (65/35), with a 500 μ V threshold in the wires. The flux limits are about 20 times smaller than in the multistep chamber. The results would indeed be better with a smaller wire spacing. However, the additional

advantage of the gated chamber in this intense beam is that the dead-time problems of the electronics at high rates are totally eliminated.

One important property of the chamber appears to be its good spatial resolution.

The first results had already shown that spatial resolutions of about 100 μm were possible²⁾.

We have equipped every detecting wire, over a length of 4 cm, with a pulse-height measuring circuit. One striking effect is that the influence of the positive pulses induced on the wires closest to the wire collecting the largest electron charge, reduces the lateral extension of the charges induced in the collecting wires. These tests were performed in a very high intensity beam, and an event with one accidental count detected in the 30 ns gate is visible: two particles, separated by 2 mm, are totally separated (fig. 17). In other words the resolution power is as good as with drift chambers, with the serious advantage of being true in two dimensions with a far smaller memory time.

To summarize the presently clear advantages of the multistep gated chamber as compared to most MWPCs or drift chambers:

- an intrinsic rate density limitation 5 to 10 times higher than in MPWCs;
- a time jitter of the order of 10 to 15 ns FWHM at atmospheric pressure;
- a memory time below 100 ns;
- an intrinsic adjustable delay, free of dead-time;
- a strong decrease in the dead-time problem in the electronic circuits;
- an intrinsic accuracy of about 100 μm (r.m.s.);
- a double particle separation of about 1.5 mm, bidimensional;
- a gain that is easily compatible with the detection of single electrons released at the cathode;
- by combining these chambers with a coarse scintillation hodoscope limiting the surface of the triggered grid to narrow strips, it is possible to bring the accidentals to much lower rates than those corresponding to a memory of 100 ns, thus reducing the problems of ambiguities.

These studies have also revealed that single-step chambers with parallel plate amplification offer interesting prospects for low-rate localization of minimum ionization particles. Among many applications which can be foreseen in fields far remote from high-energy physics, I would like to quote a few examples.

2.3 Localization of ionization produced at the surface of an electrode

2.3.1 Paper chromatography

In some cases gaseous detectors are used to localize the position of the β -emitting radioactive nuclei. They offer the advantage over photographic film of having a much greater sensitivity and, over scanning counters, of a faster response. Their main drawback often comes from the range of the β -rays inside the gas of the counter.

The property of a parallel-plate gap to multiply free electrons at a rate varying exponentially with its distance to the anode, favours those electrons liberated at the cathode entrance window of the chamber.

Two groups have shown the advantages of the addition of a parallel-grid amplifying gap to a proportional counter: Nguyen et al.²⁰⁾ for a one-dimensional counter; and G. Petersen et al.⁴⁾, who are presenting the results of a two-dimensional chromatography chamber at this conference.

2.3.2 Slow neutron detection

Another possible application of the multistep chamber to a new field is the localization of slow neutrons.

With thin foils of gadolinium it is possible to efficiently absorb slow neutrons with the emission of low-energy electrons. The range of those electrons is still so large in a gas at atmospheric pressure that it leads to large errors.

One way that has recently been investigated is to limit the range of the electron by solid channels²¹⁾. Another way is to use a preamplifying gap, as in the chromatography, since this will favour the localization of the exit points from the gadolinium foils. The advantage should lie in a serious reduction of the γ background. Experiments are under way at the Laue Langevin Institute in Grenoble.

2.4 New types of visible photon detector

An interesting application of the properties of a combination of scintillation gaseous detectors and MWPCs would be the development of new light-amplifiers which we want to undertake at Orsay.

Numerous attempts have been and are still being made to use gaseous amplification in order to obtain pulses from single electrons extracted in photocathodes by visible light. One successful step in this direction is reported at this conference by J. Huffman and C. Rubbia. Our approach is different. We want to have the photocathode in a pure noble gas such as Kr, in a sealed container. We know from industrial experience with gaseous photocells that, if properly done, this permits an unlimited life for the photocathode. We then produce VUV light in the krypton by drifting the electrons between two grids. This has the advantage of avoiding any ion bombardment of the photocathode, although our work in multistep chambers has shown that these ions can be easily gated away. We then transfer and localize the photons in a photo-ionization multiwire chamber.

The attractive advantage of such a device is the separation of the fragile photocathode from the localization chamber, the built-in memory, the operation at atmospheric pressure, the gating possibility, and the potential accuracy of 100 μm . Its possible development in co-operation with industries specialized in photocells is under discussion.

3. CONCLUSIONS

I have limited this paper to some new prospects opened up by the development and understanding of parallel-plate amplifying structures.

They have gone surprisingly further than our initial goal when we first started to study multistep gated chambers, and we clearly see interesting fields of developments in subjects such as

- high-rate counters;
- low-cost parallel-plate detectors;
- localization detectors for X-rays, VUV light, visible light;
- neutron detectors;
- β -chromatography illustrating the fertility of research in gaseous detectors.

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Figure captions

- Fig. 1 : Spectral distribution of the secondary light-emission of pure noble gases, in moderate electric fields, together with the ionization potentials of some vapours, acetone, benzene, and triethylamine (ref. 15).
- Fig. 2 : Energy spectra from a pressurized xenon scintillation proportional chamber: 5 atm Xe; 10 cm absorption depth; 0.7 cm light-generating gap at $3.3 \text{ kV cm}^{-1} \text{ atm}^{-1}$. VUV converted by p-terphenyl. The sources are ^{241}Am (a) and ^{57}Co (b). The photons are localized to 0.3 cm FWHM. (ref. 16.)
- Fig. 3 : Compilation of quantum efficiencies of benzene and TEA and of the transparency of several fluoride windows for 5 mm thick crystals as a function of photon wavelength (ref. 5). Recent evidence suggests that the TEA quantum efficiency shown is peaked at 37%. (ref. 19.)
- Fig. 4 : The photo-ionization proportional scintillation detector (PIPS). Dashed lines represent crossed wire meshes, having wires 50 μm in diameter and 450 μm apart. Grid 4 is laminated. Larger dots represent cathode wires ($\phi = 100 \mu\text{m}$) and the smaller dots anode wires ($\phi = 50 \mu\text{m}$).
- Fig. 5 : Energy resolution of a PIPS. The ^{55}Fe X-rays are filtered by chromium to eliminate the K_{β} line 9.5% FWHM at 5.9 keV. Transfer efficiency: 10 VUV detected photons per ionization electron in direct irradiation of the wire chamber.
- Fig. 6 : Schematics of parallel-plate amplifying elements. A region A of high electric field is followed by a lower field region T. The electrode b can be either a parallel-wire grid or a crossed-wire mesh. Charge multiplication may take place in the upper region with a constant transfer of electrons independent of lateral position. The maximum gain is dependent on the initial ionization transferred from the conversion gap D.

- Fig. 7 : Pulses from a single-gap amplifying element. Gap width 3 mm; gas filling argon + 3% acetone under normal conditions; 5.9 keV X-rays; HV = 3300 V; pulses on electrode b (see fig. 6). a) No transfer to T. b) Transfer to T.
- Fig. 8 : Measured transverse avalanche width in the preamplification gap (standard deviation) in argon-acetone, as a function of the inverse acetone content (in percent). Gain of 10^4 .
- Fig. 9 : Schematics of the gated multistep avalanche chamber (GMSC). Electrodes identified by the potentials HV2, HV3, and GND are crossed wire meshes, having 50 μm wire diameter and 500 μm pitch. Electrodes HV4 - HV5 and HV6 are planes of parallel wires, with diameter and pitch as before, perpendicular to each other; the particular layout of the gate electrode allows to d.c. or pulse offset pairs of adjacent wires. Electrode HV1 is a 10 μm thick aluminium foil. By a proper choice of potentials, charges liberated in the conversion region are preamplified and transferred to drift region 1; if the gate electrode is equipotential at the time the electron cloud approaches, the charge is transferred to the second element of amplification equipped with read-out electronics.
- Fig. 10 : The absolute gain in a 5 mm thick parallel-plate chamber, operated at atmospheric pressure in a 98-2 mixture of argon-acetone, is a function of the applied field.
- Fig. 11 : Transparency for electrons of the gate electrode, as a function of the difference of potential $V_G = (HV4 - HV5)$ between adjacent pairs of wires (500 μm pitch). The voltage difference for blocking, about 180 V, depends of course on the existing drift field, 1.4 kV/cm as can be deduced from the values indicated in the inset.

- Fig. 12 : Efficiency plateaux for the detection of minimum ionizing particles, as a function of the voltage in the second amplification element, for several operating conditions. The conversion on mode corresponds to detection of the ionization produced in the conversion space, while in the conversion off only the charge produced within the preamplification element is multiplied. The two modes can be simply selected by a proper adjustment of HV1 (see fig. 1).
- Fig. 13 : Efficiency for detection of minimum ionizing particles for a gated, conversion-off operation.
- Fig. 14 : Efficiency for detection of minimum ionizing particles, measured at small rates and for two values of preamplification (full lines and left vertical side), and breakdown voltage as a function of particles' rate (broken lines and right vertical scales). Operating conditions for the GMSC: conversion off and gate d.c. open.
- Fig. 15 : The spark breakdown voltage in the second amplification element, for a fixed preamplification, as a function of the detected 8 keV X-ray flux. Measurements are shown both for the d.c. gate condition, and for the pulsed-gate operation; in the last case, the small figures on the two sides of the measurement bars indicate the gate opening frequency (as a percentage of the total flux detected on the preamplification element). The gated operation allows the attainment of chamber gains larger by almost two orders of magnitude (see fig. 10), also for the opening frequencies approaching 100%, thus indicating that breakdown is caused by positive ions' feedback.
- Fig. 16 : Same as for fig. 14, for the conversion on and 30 ns gate operation. The sparking point bars represent the measurement of breakdown, for a given flux, at two extremes of gate-opening frequencies (10 kHz and zero). The value of the preamplification voltage for each measurement is also shown, and the reading has to be combined with the corresponding efficiency plateau for a given flux.

Fig. 17 : Double-track event; the distance between the two centres of gravity corresponds to about 2 mm.

Fig. 1

Fig. 2a

Fig. 2b

Fig. 3

Fig. 4

Fig. 5

Fig. 6

$a)$

$b)$

Fig. 7

Fig. 8

Fig. 9

Fig. 10

Fig. 11

Fig. 12

Fig. 13

Fig. 14

Fig. 15