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PHYSICS I
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A PROPOSAL TO BUILD A PLUMBICON CAMERA SYSTEM FOR OMEGA

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1. INTRODUCTION

We propose to build a filmless data acquisiton system for Omega. This will be based on the plumbicon television camera tube, and will consist of a set of cameras, a control system and a digitising system interfaced to the EMR computer.

The need for an automatic data taking system, with its obvious advantages of giving immediate on-line information and avoiding film processing and measurement, is well recognised. Wire chambers and proportional chambers are in a state of development which does not allow a decision to build them to be made in time for the first Omega experiments.

Though a vidicon system has been operated successfully for several years at the Rutherford Laboratory(1) the long recovery time of the vidicon tube (~100 msec) makes it unsuitable for general use on Omega. The recently introduced plumbicon tube, however, does not have this disadvantage and in all other respects appears to be as good as the vidicon (see appendix 2). Thus one can expect a spatial accuracy of 0.5mm or better combined with a dead time of less than 10 msec. The accuracy is comparable to that of a wire chamber and the data taking capability several times faster than that of a film camera allowing 30 events per burst to be recorded.

A realistic specification for the proposed system is given below, and also a detailed description of how we propose to organise the manufacture, testing and installation of component parts.

2. SPECIFICATION

The operating principle of our T.V. system is to scan the camera tube with a conventional raster, and adjust the raster to give a one to one correspondence between scan lines and spark chamber gaps (one scan line per gap). This requires a certain level of raster stability and adjustment, which is well within the capabilities of present electronic techniques. At present plumbicons have rather small photo sensitive surfaces (12mm x 9mm), but by using several cameras to cover a given area an adequate accuracy is possible. It is proposed to scan the 3m x 1½m area presented by the Omega spark chambers with three cameras (per stereo view), so that the 150 cm dimension, along the spark chamber gap, will map into a 12mm image length on the plumbicon surface; a demagnification of approximately 120.

Two sets of fiducials per ten gap chamber module are needed for calibration purposes giving a total of 120 lines to be scanned for the ten modules. It would be an advantage if equi-spaced scan lines could be used and this would require the chambers to be positioned accordingly. A 'blank' line between modules would then exist giving a total of 129 lines or 43 per camera. Increasing this to 45 would give some overlap.

Two additional cameras viewing a set of downstream chambers, outside the main field volume, could be added, to increase momentum accuracy for high momentum particles, making a total of eight cameras.

It is proposed that each of the eight cameras will have its own digitising electronics so that all eight cameras will be scanned and digitised in parallel, in order to keep readout time to a minimum. Eight scalers per camera allow up to eight sparks per gap to be recorded. The 64 scalers will be transferred serially to the EMR computer, and reset, during the 'fly back time'. The EMR has a cycle time of 1.6μs, so that it will take 102μs to transfer the 64 scalers. During this rather long data transfer interval it is proposed to make a slow repeat scan, with increased plumbicon beam current, to erase any remaining image.

The digitising accuracy is proportional to the clock frequency. With a clock frequency of 120 MHz a line scan time of 68.3μsec gives a complete line count of 8191, that is a thirteen bit binary word. The EMR computer has a sixteen bit word length and so we are left with three bits for additional information, if required. The total readout time will be 7.7 msec, so that event rates as high as 30 per burst (at 50% dead time loss) could be considered.

The following table summarizes the basic specification of the system:-

No of cameras	8
No of line scans per camera	45
Maximum no of sparks per line	8
Clock frequency	120 MHz /sec
Scan time per line	68.3μsec
Erase time per line	102 μ secs
Readout time of cameras (system dead time)	7.7 ms

3. OPERATING CHARACTERISTICS

We give below the expected operating characteristics for the plumbicon system which we have deduced from experience with our present vidicon system, and from investigations carried out using a prototype plumbicon camera.

3.1 ACCURACY

The measurements described in Appendix 2 indicate that the positional accuracy which can be extracted from the pulses in our plumbicon camera is about ± 0.3mm for a 150 cm line scan and a dynamic range of 50. The process of extracting this information will itself introduce an error, but we are confident of obtaining an accuracy of ± 0.5mm or better. The present vidicon system with a 150cm line scan is giving an accuracy of between 0.5mm and 0.6mm.

3.2 TWO SPARK RESOLUTION

This is limited by the size of the scanning electron spot and the dimensions of the photosensitive surface. For the tubes we intend to use these are 50µm and 12mm respectively giving an optimum two spark resoultion of 1/240 or 0.6cm in a 150 cm line scan.

3.3 DYNAMIC RANGE

We have shown that dynamic ranges of spark intensities of 50:1 can be handled by the plumbicon tube without affecting its accuracy.

3.4 RECOVERY TIME

For the specification set out in section 2 this will be 7.7 ms.

3.5 SENSITIVITY

Our tests show that at a working aperture of f16 pulses of 100 mv are obtained for a beam current of 200nA (see figure 1). The amplifier noise level is ± 1 mv, so that a working discriminator level would be 2 mv. This means that there would be 100% detection efficiency over a dynamic range of 50:1 at f16.

4. ORGANISATION AND TIMESCALE

4.1 ORGANISATION

The organisation of the project has been divided up into three sections which can be pursued concurrently. A description ofeach of these sections together with the names of the groups who are willing to be responsible for carrying them out are given below.

a) Dr Briandet and his group from Ecole Polytechnique are considering untertaking the design, development and building of the digital system right through to the computer interface.

b) Mr Peter Wilde and the electronics group from RHEL will do the full design and engineering of the plumbicon cameras, their analogue circuits, and the control system.

c) RHEL Group A/Birmingham/Westfield have an assessment group of physicists and technicians who will evaluate the characteristics of the various prototype systems, as supplied by Peter Wilde.

4.2 TIMESCALE

January-March 1971	Design of camera shell. Design and production of first prototype camera and control system to be evaluated by the assessment group.
April-June 1971	Production of two advanced prototype cameras and an additional control system
July-August 1971	a) testing of 1 advanced camera at RHEL to determine remaining bugs b) 1 camera and 1 control unit taken to CERN to be operated in conjunction with the digital system which should be ready by this time.

September-October 1971	Further electronics design effort to iron out remaining bugs in camera design prior to starting full production
November-December 1971	Full production of 10 operational cameras of final design (the 2 advanced cameras would be modified to the final design as part of the 10)
January-June 1972	Installation of 8 cameras into Omega system, and final debugging alignment and on line connection.

4.3 MANPOWER REQUIREMENTS

4.3.1 Digital system

Numbers have not yet been defined, but it appears that Dr Briandet has a strong group supported by Ecole Polytechnique that he would like to bring into the project

4.3.2 Design and production

Peter Wilde has two members of the electronics group who are already full time in the project. In addition he would like to fill a vacancy to bring a further man into the project. The assistance of a good mechanical designer for a period of six months from Mid January is also required.

4.3.3. Physics Assessment

Group A have 1 physicist and 1 technician who have been working for some months on evaluating plumbicon characteristics, and who would be strongly committed to assessment tests during 1971. Birmingham group are willing to supply two technicians to take part in this work. The Westfield college group will supply effort and expert advice at all stages.

4.3.4 Long term Manpower Commitment

At least two men would be needed during 1972 to 'run in' the system on Omega. These would very likely be 1 physicist and 1 technician from Rutherford Laboratory. We would expect that after the first year CERN would provide staff, as part of Omega project, to maintain the plumbicon system.

REFERENCES

J Crawford, P Osmon, J Strong, Nuclear Instruments and Methods 52 (1969) p 213-222

N H Lipman, Dubna Conference on Filmless Spark Chambers (1969) p 93-112

P Osmon, Joint Conference on Digital Methods of Measurement (July 1969) - IERE report

APPENDIX 1

A NOTE ON RECORDING OF SPARK CHAMBER INFORMATION USING TELEVISION CAMERA TUBES

1. The Principles of the Method

2. The Present Vidicon System

    2.1 Description
    2.2 Accuracy
    2.3 Two Spark Resolution
    2.4 Dynamic Range
    2.5 Recovery Time

1. The Principles of the Method

In a television camera the image of the object being recorded is focussed on a transparent photosensitive layer of low electrical conductivity. The outer surface of this layer is in contact with a transparent conductor which is held at a positive potential of about 50V. The inner surface is held at approximately zero potential by a scanning electron beam. The effect of light is to increase the conductivity of the photosensitive layer and as a result an electrostatic image of the object is produced on the inner surface. The scanning electron beam discharges this image and charge also flows from the 50V supply to maintain the voltage across the layer at 50V. The current supplied from the 50V supply is the video signal and contains in analogue form the complete picture information. The photo-induced conductivity decays away in a characteristic time. The decay appears to be exponential, and clearly the time constant gives some measure of the memory time of the camera tube. More details can be found in reference 1.

2. The Present Vidicon System

2.1 Description

The present system operating at the RHEL employs vidicon camera tubes. The deflection of the electron beam is controlled in such a way that one line scan reads out the spark information in one spark chamber gap. The time which elapses between the beginning of the line scan and the spark positions in the gap is digitised by an 80 mc/s clock and a fast scaling system. A complete spark chamber is read out sequentially gap by gap. Fiducials which are recorded in a similar way to the sparks can be positioned at the ends of the gaps, or in a dead space between active gaps of the chamber.

Operating parameters of the present camera are given below:

Useful area of photosensitive surface	12mm x 9mm
Time for one line scan of electron beam	50µs
Time for flyback of electrom beam	12µs
No of line scans	20
Read out time for camera	1.24ms

/continued...

With such a camera the following parameters were measured

2.2 Accuracy

The accuracy of the camera is expressed as a fraction of the line scan length. Limitations on the accuracy of the system come about in the following way

The size of the electron beam spot scanning the back of the photosensitive surface is easy to measure and is 60μm FWHM. The length of the line scan is 12mm and the time for one line scan is 50μs. The time taken for a 60μm spot to pass a point on the surface is then 250 ns. Under normal operating conditions the electron beam current is not sufficient to discharge the image of a spark at one pass. This means that current is flowing during the complete traversal of the image by the spot, and that the video signal is a pulse of 250 ns FWHM. This signal is typically 100 nA and subsequent amplification which is necesary for further processing has the effect of widening this pulse. To obtain timing information we are required to produce a pulse at the centroid of this pulse and this is done by a zero-crossing technique. For pulses whose shape is independent of amplitude, this can be done very precisely. However this is not the case, due to a constant noise level in the amplifier and effects caused by the intensity of the scanning electron beam.

The accuracy of the present system has been extracted by studying three stereo views of two sparks. In table 1 we present the result of four of our cameras, and also the expected accuracy in an Omega chamber of 150cm scan.

	Accuracy	Spatial Accuracy in Omega
Camera 1	± 1/2730	± 0.55 mm
2	± 1/2730	± 0.55 mm
3	± 1/2000	± 0.75 mm
4	± 1/2310	± 0.65 mm

/continued ...

2.3 Two Spark Resolution

This quantity is a measure of the separation between two sparks such that they would be resolved by the camera and is expressed as a fraction of line scan length.

We have shown in the preceding section that the typical pulse width obtained from a point source is a little bigger than 250 ns. After amplification in our system it is 300 ns. If we take as our criterion for resolving two pulses that they should be separated by more than their width then we obtain for the best possible resolution of our cameras a value of 1/167. For 150 cm line scan as required for Omega this gives a two spark resolution of 9mm.

2.4 Dynamic Range

We consider the concept of dynamic range in the following way. For any spark chamber experiment we will have a range of vidicon pulse heights going from zero up to some maximum value. For the largest pulses the electron beam intensity can be adjusted to maximise pulse height ~~ie~~ ensure that the charge image is being removed in one scan. The amplifier following the camera tube will generate a certain noise level. Signal pulses of this amplitude are clearly inaccessible and so the noise level represents the lowest useful pulse height. The dynamic range of pulse heights is then the ratio of the largest pulse to the noise level. For a given aperture, dictated by depth of focus considerations, and a given spark chamber, the largest pulse height is fixed. This means the dynamic range of pulse heights can only be improved by decreasing the amplifier noise.

In our present experiment the largest pulses obtained are 150 mV. Because of noise in the amplifier the threshold for acceptable pulses is set at 20 mV. This gives a dynamic range capability of 7.5:1. In fact the camera is looking at predominantly one spark events and there are extremely few events below 50 mV. That is the dynamic range of pulse heights we are seeing is only 3:1 for one spark events.

/continued ...

For the vidicon, the relationship between the signal current (I_s) and the illumination (E) is given by

$$I_s = E^{\gamma} ,$$

where γ is 0.6. Using this we extract a dynamic range capability for spark intensities of 29:1.

2.5 Recovery Time

Due to the finite decay time of the conductivity of the photosensitive surface the vidicon tube has a memory. The typical time for the induced conductivity to fall to 5% of its initial value is 120 ms. We define recovery time by the time which must be allowed to elapse for the conductivity produced by our brightest spark to decay below the threshold of our detection system. It is then obvious that the recovery time of the camera is determined by the dynamic range of spark intensities that have to be covered. For example, our dynamic range capability of 29:1 in spark intensities discussed in 2.4, gave us a dynamic range capability in pulse height of 7.5:1, and, assuming an exponential decay for the conductivity of 40 ms, a compulsory recovery time of 80 ms.

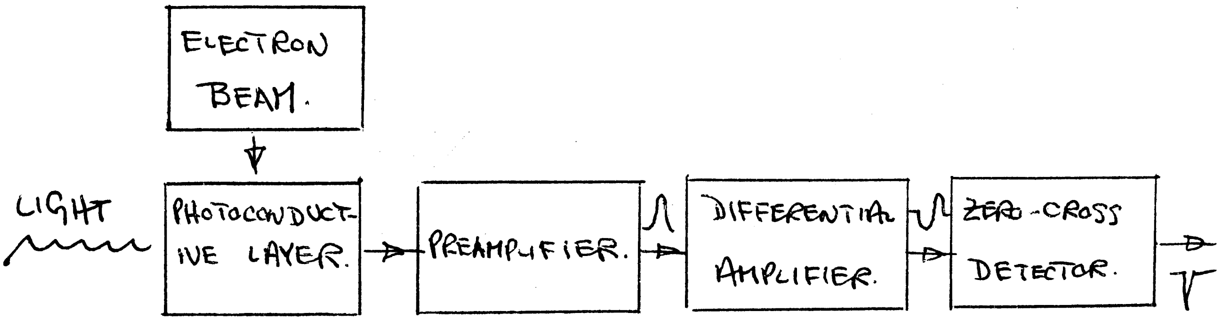
APPENDIX 2

PRELIMINARY RESULTS OF AN INVESTIGATION OF PLUMBICON TELEVISION CAMERA TUBE

1. Introduction
2. Dynamic Range and Sensitivity
3. Recovery time and build up time
4. Accuracy

INTRODUCTION

The following measurements have been made at RHEL by counter group A, using a plumbicon television camera tube, in order to decide whether a camera based on such a tube would be suitable for data acquisition in OMEGA. In parallel to this investigation similar measurements have been made by the electronics group. Two cameras were used in our measurements, one of which was standard and the other had incorporated in it an improved preamplifier. A block diagram of the camera is given below.



2. DYNAMIC RANGE AND SENSITIVITY

The following measurements were made using an improved version of the preamplifier. A spark chamber consisting of two gaps was triggered by a source. Figure 1 shows the maximum pulse height obtained at the output from the preamplifier as a function of aperture, for various values of the electron beam current. The curves exhibit the phenomenon of "beam saturation" that is for intense sources there is insufficient beam current to discharge the photo-induced electrostatic image on the photo-conductive surface. For the plumbicon the relationship between signal current (I_s) and the energy deposited on the photo-conductive surface (E) is given by:

$$I_s = E^{\gamma}$$

where γ is 0.9. The lines through the points in figure 1 are eye fits assuming the curves go through the origin.

In figure 2 we plot the values of pulse height at f1.4 for various beam currents. For such intense sources we are presumably working in the plateau region of the curves in figure 1 and these pulses represent the maximum amplitude for the beam used. Also in figure 2 we have plotted the estimated positions ofthe knees of the curves in figure 1, and this line defines one limit of the region in which we can use the plumbicon camera. The working region lies between this line and the beam current axis, because only here is the tube in the non "beam saturated" condition and only here are the pulses from the preamplifier of constant shape. For example for our spark chamber,an aperture of f16 at a beam current of 200μA would ensure we were working in the linear region. Under such conditions the maximum pulse height from the preamplifier is 118mV. The noise level, which decides the height of the smallest pulses which can be accepted, is ± 1mV. Setting the threshold for pulses at 2mV gives us a dynamic range capability of 59:1. If this is insufficient for the experiment in question, then it is evident from figure 2 that increasing the beam current also increases the dynamic range capability.

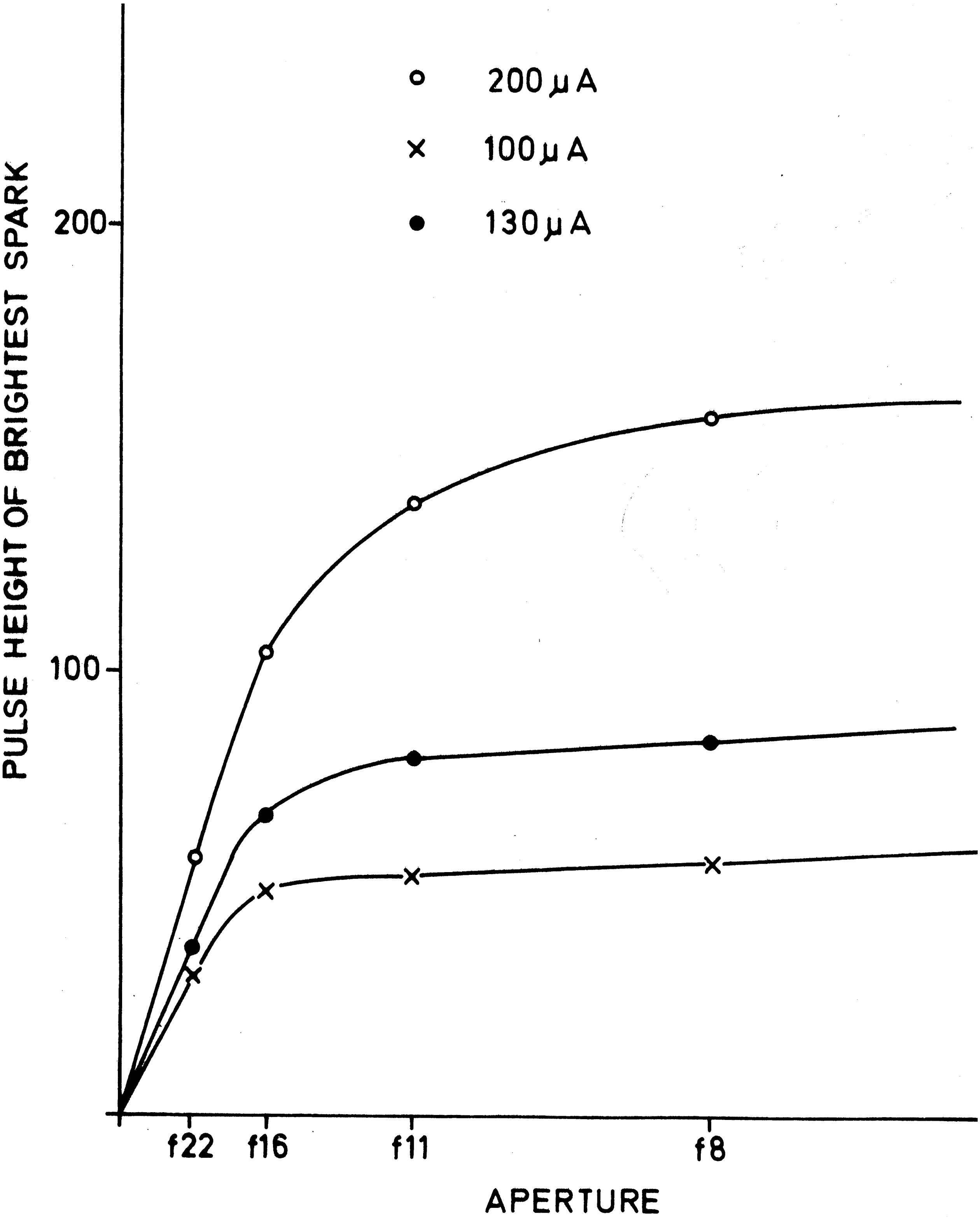
3. RECOVERY TIME AND BUILD UP TIME

The recovery time and image build up time for the plumbicon were measured in the following way. The camera was set up producing a line scan of 52μsecs every 64μsec, and focussed on a triggered spark gap, the electron beam being blanked for a variable time, during and after the spark discharge. By studying the pulse heights of the pulses obtained in the subsequent unblanked line scans, the build up time and removal time for the charge image were measured The pulse trains were photographed and the pulse heights measured. For the image build up time we can quote a figure of less than 0.2ms. With beam currents below 100μA several scans were required to remove the image; the number required being essentially independent of the spark intensity. Sufficiently high currents (200μA) will remove the image in a single scan. Such currents may be undesirable on the digitising scan as they slightly worsen the resolution. A further erase scan at high beam current is therefore preferred.

ACCURACY

Because of the ease with which the charged image can be removed from the plumbicon photo-conductive surface it was anticipated that there might be an accuracy problem due to the pulse shape being a function of spark intensity ie the image of low intensity sparks would require only the leading edge of the scanning electron beam to be discharged, and would therefore give narrow pulses. Measurements were made using 2 DC light sources, a fixed distance apart, scanned by one line scan. In the direction of the scanning electron beam the images of these sources on the photo-conductive surface had a dimension of ∿30 μm. An oscilloscope was triggered by the first of the pulses from the preamplifier and the behaviour of the second pulse as a function of light intensity was studied by interposing neutral density filters between the second light and the camera. The camera was operated at f1.4 and a beam current of 200μA. In figure 3 we give a plot of pulse height from the preamplifier against attenuation of the light source, showing that we are working almost completely in the linear region, although "beam saturation" is occurring at zero attentuation. In figure 4 there is a plot of the timing of the cross-over point of the amplified pulses: for a dynamic range of pulse intensities of 50:1 the time slewing is ± 10ns. Also there is a plot of pulse width against intensity and it is evident that there is a dependence of some kind. The surprising thing then is that the cross-over point seems to be relatively independent of pulse width. For a line scan time of 52μ sec the potential accuracy is ± 1/5200, and for an Omega chamber of 150 cm, ± 0.3mm in space.

Measurements on pulse shape as a function of intensity were also made for sparks. We have no quantitative analysis of these results but the indications are that there is no difference between a DC source and a spark from this view point. We do not anticipate any problem here, as the mechanisms involved are the same, but we do intend to do more precise measurements on sparks. Also we have as yet notinvestigated the problems of generating a pulse on the cross-over point for very small pulses, but again do not anticipate any problems.



○ 200 µA
× 100 µA
● 130 µA
PULSE HEIGHT OF BRIGHTEST SPARK
200
100
f22
f16
f11
f8
APERTURE

Fig. 1.

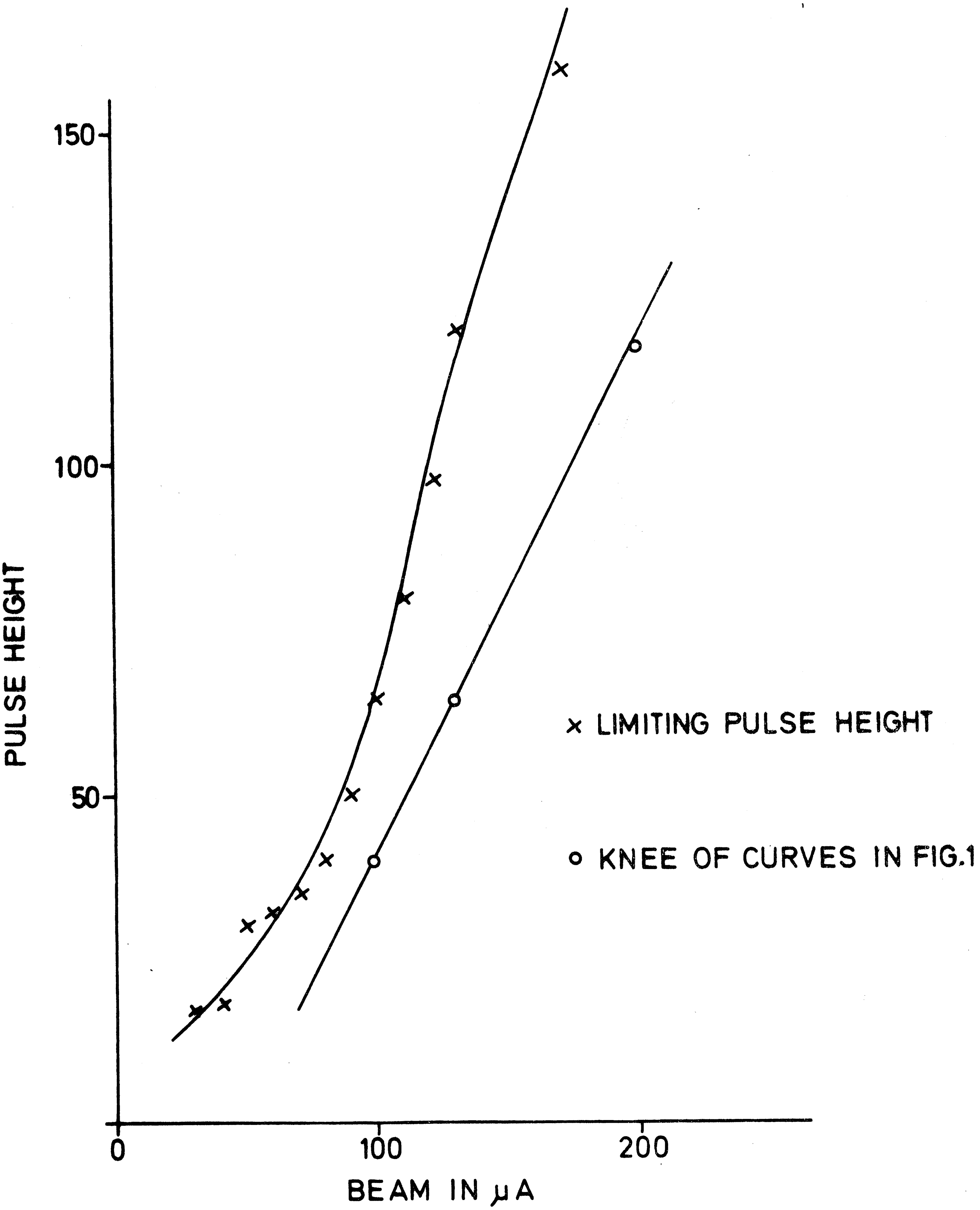

150
100
50
0
100
200
PULSE HEIGHT
BEAM IN μA
× LIMITING PULSE HEIGHT
○ KNEE OF CURVES IN FIG.1

Fig. 2.

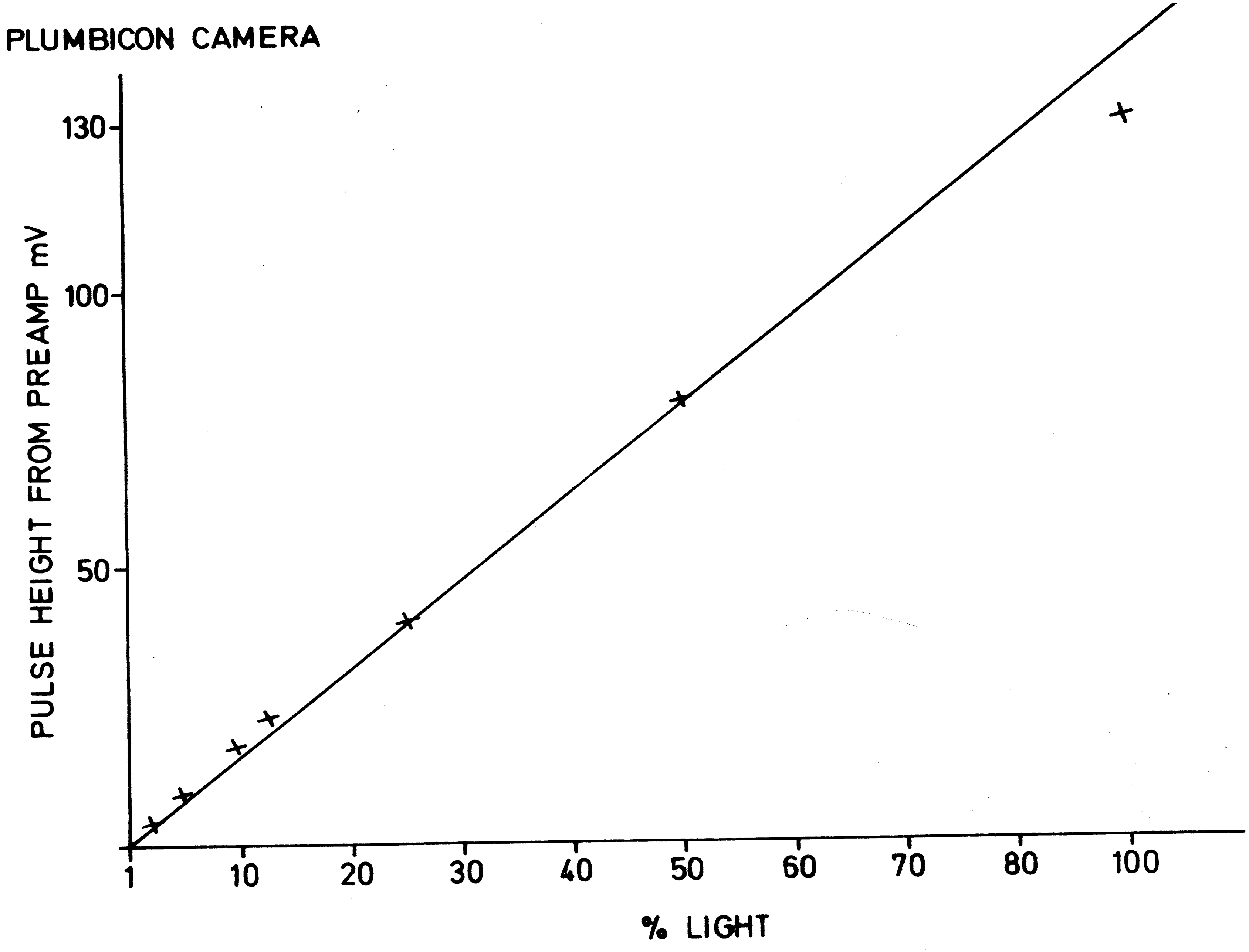

PLUMBICON CAMERA
PULSE HEIGHT FROM PREAMP mV
130
100
50
1
10
20
30
40
50
60
70
80
100
% LIGHT

Fig.3

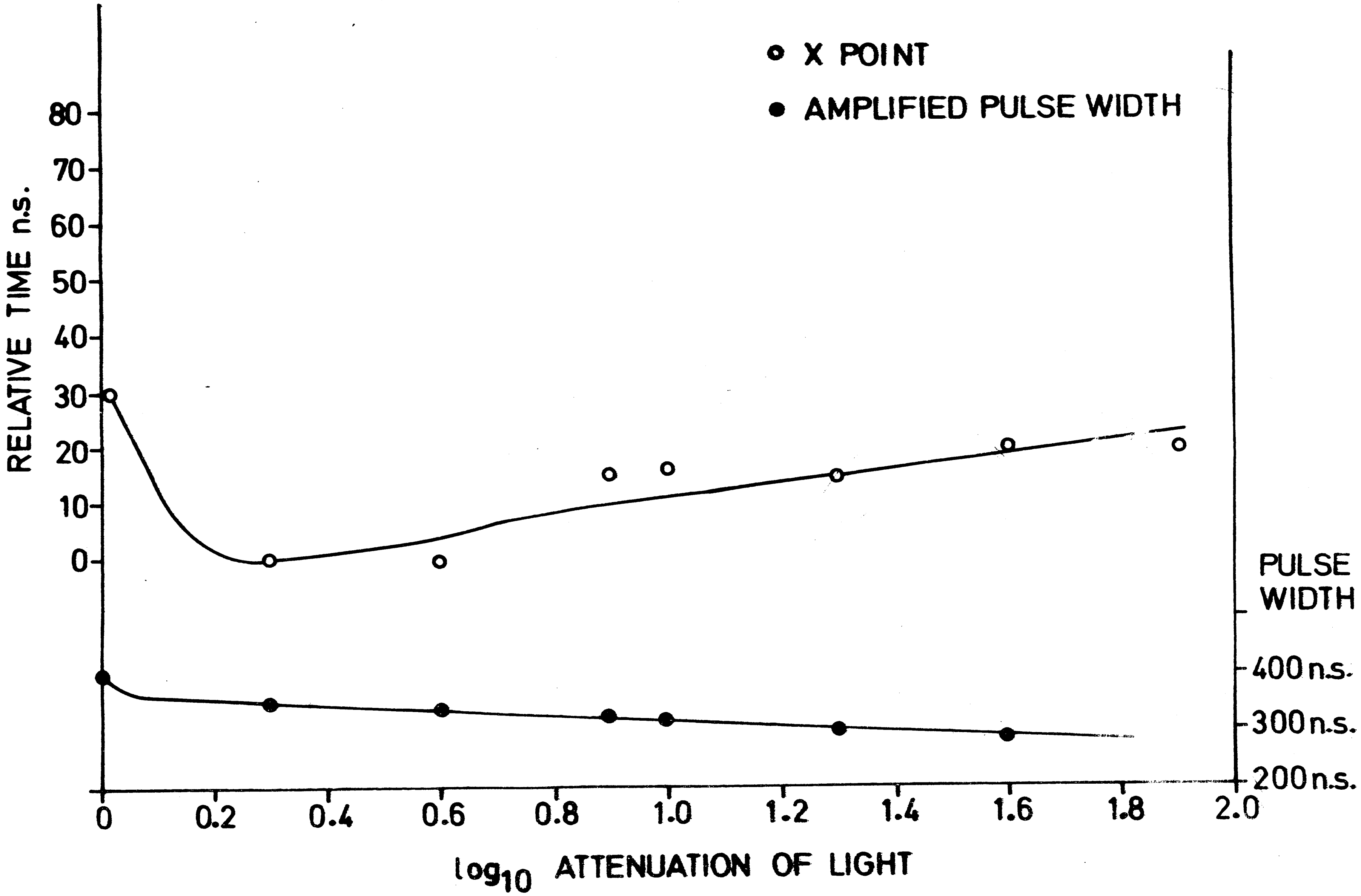
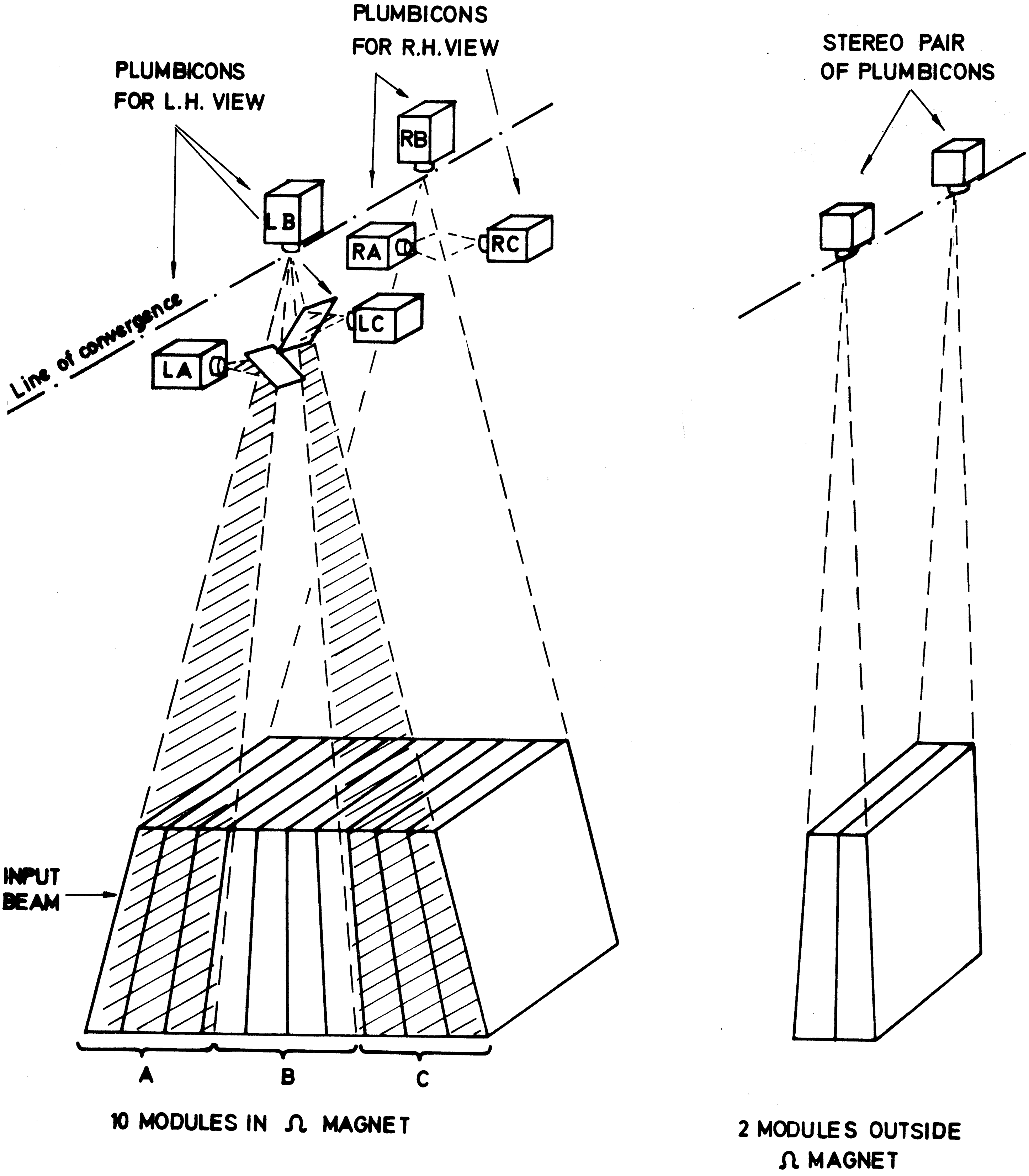

○ X POINT
● AMPLIFIED PULSE WIDTH
RELATIVE TIME n.s.
80
70
60
50
40
30
20
10
0
PULSE WIDTH
400 n.s.
300 n.s.
200 n.s.
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
$\log_{10}$ ATTENUATION OF LIGHT

Fig. 4



OPTICAL ARRANGEMENT FOR 8 PLUMBICONS USED WITH Ω

FIG. 5

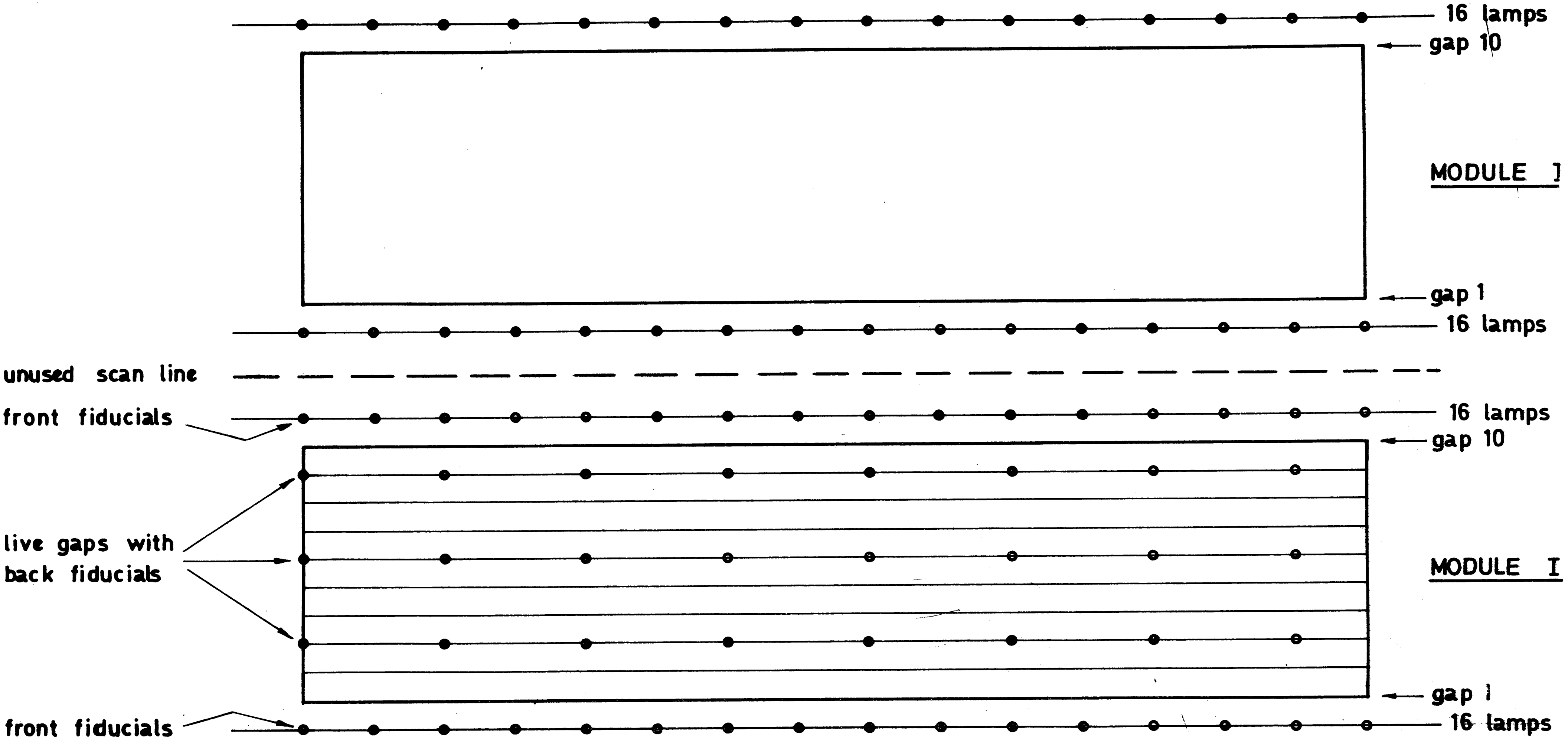


DIAGRAM SHOWING FIDUCIAL ARRANGEMENT AND RELATION TO SCAN LINES

FIG. 6