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Abstract:

From investigations based on the measurement of pictures from the Argonne 12-foot bubble chamber, we conclude that an HPD with a conventional mercury arc (BH6) illumination system will very probably be suitable for the measurement of BEBC pictures.

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Contents

1. Introduction

The new generation of big bubble chambers, e.g. BEBC (Big European Bubble Chamber) or the 12' Argonne HBC, will make novel requirements of film measurement devices. Apart from the design and development of new measuring systems[1] which are particularly conceived for the needs of such chambers, studies on some existing systems have been made to investigate their possibilities in handling these pictures.[2)3)4)] Besides software problems, especially the filtering and spatial reconstruction of events, hardware problems arise from the bright field illumination in these chambers and from the considerable variations in contrast of tracks and in the background transmission. Furthermore the diameter of the bubble images on the film will vary between 10 and 40 microns. This makes necessary careful consideration of the light intensity in the scanning spot and a new conception for a very dynamic track detection circuit.

The following investigations were made with the HPD of the Bonn-Hamburg-Collaboration[5) 6)] with a test sample of about 20 70mm-pictures from the 12' Argonne chamber. These pictures are likely to be representative of the film quality from future large bubble chambers, e.g. BEBC.

2. Illumination System

2.1 Quality of the Light Spot

Unlike most other HPD groups we use the illumination system first proposed by R.B. Palmer[7], which is based on the mercury arc lamp BH6 ($4,0 \cdot 10^4$ cdla/cm^2). The BH6 lamp, however, was replaced by the equivalent type SP900W ($2,2 \cdot 10^4$ cdla/cm^2) of Philips.

The spot diameter measured on our HPD is about 12 μ.[9] In the spot area the power available is 0.04 μW. This means approx. $6 \cdot 10^{10}$ photons/sec, which corresponds to about $3 \cdot 10^9$ electrons/sec[8] at the cathode of the photomultiplier 150 AVP. By optimizing the coating of the glassware for the strongest Hg line $\lambda_o \approx 440$ nm (our HPD had coatings for $\lambda_o \approx 580$ nm[8]) the effective power in the spot could probably be increased by a factor of 2.5 and the current at the output of the photomultiplier by a factor of 1.7. Fig. 1 shows the light spot power RL and the current RI_a in arbitrary units versus optimum wavelength λ_o of the coating (RL and RI_a are set equal to 1 at 580 nm).

2.2 The Signal/Noise Ratio

A very important property of a system for measuring weak signals is the Signal/ Noise Ratio S/N. For the HPD one can define S/N[8] by the expression[+)]:

$$S/N = \frac{M_\mu \cdot \left| \frac{T_{FT}}{T_{BG}} - 1 \right|}{\left(d^2 + b^2 + \frac{c}{I_a \cdot T_{BG}} \right)^{1/2}}$$

$T_{FT} \leq T_{BG}$	= dark field illumination
$T_{FT} \geq T_{BG}$	= bright field illumination
M_μ	= modulation of grid line of width μ (in microns)
I_a	= anode current of the photomultiplier (PM) without film
T_{FT}	= transmission of film track
T_{BG}	= transmission of background
b	= $\Delta T_{BG}/T_{BG}$
ΔT_{BG}	= fluctuation of film transmission by scanning the film with a light spot of given area
d	= influence of fiber quality in % of current I_a
c	= $m \cdot 2 \cdot e \cdot \Delta f \cdot \alpha^2$
m	= multiplication factor of the PM
e	= charge of electron
Δf	= band width of frequency of the connected circuit
α	= statistical factor describing the fluctuation of electronemission on the dynodes in the PM

+) The above expression is defined without influence of filter circuit (in contrast to Ref. 2).

Typical values for our installation are:

$M_2 \simeq 0.30$, ... $M_8 \simeq 0.65$, ... $M_{12} \simeq 0.90$, $M_{13} \simeq 0.90$

b	≈ 20 % (seems to be an upper limit)		for Argonne pictures
T_{BG}	≈ 10 to 30 %	see section 3	for Argonne pictures
T_{FT}	≃ 70 %	see section 3	
d	≈ 4 %		
I_a	≤ 2 mA		
m	$\approx 2 \cdot 10^6$		
Δf	≈ 4.1 MHz		
α^2	≈ 1.32		

Fig. 2 shows three curves of S/N versus width of grid line (resp. bubble diameter) for different values of T_{BG}. For comparison the dotted line shows the S/N-Ratio for 50 mm films(regular films from CERN 2m-HBC, $T_{FT} \simeq 10$ %, $T_{BG} \simeq 70$%, b ≃ 10 %).

3. Quality of Film

As far as the film parameters are concerned, the 70 mm-Argonne-pictures and the future BEBC pictures differ very much from the pictures of smaller chambers, e.g. the 50 mm-pictures from the CERN 2m-HBC. Measurements with microscope and densitometer lead to the following results:

a) size of bubble images

50 mm-film (2m-CERN-HBC) :	25 μ (average diameter)
70 mm-Argonne 12' HBC-film:	10 to 30 μ (depending on position in the chamber)
BEBC-film [10]:	10 μ bottom plane
	12 to 15 μ beam plane
	20 to 40 μ top plane

The typical bubble structure of the tracks cannot be clearly identified on the Argonne pictures; instead one sees only a coherent and somewhat fuzzy track.

We have found that in general, in order to effect a registerable PM signal, at least 20% of the scanning spot has to be covered by a track. This leads to a lower limit of ~ 6μ [11] for the diameter of bubble images that can be digitized on our HPD.

b) photographic density

The photographic density D is defined by the well known equation

$$D = -\log_{10} T$$

where T is the unabsorbed fraction of light (transmission).

50mm-film (2m-CERN-HBC, average of 20 pictures 12 GeV/c pp)

background $D_{BG} = 0.14$

track $D_{FT} = 0.99 \div 0.95$

The variations in the background density were found negligible.

70mm-Argonne-film 12' HBC

background (average per frame) $\bar{D}_{BG} = 0.8 \div 1.0$ [10) 12)]

track $D_{FT} = 0.1 \div 0.2$

Variations in background density amount to ≤ 30% and are due to differences in transparency of the film in large areas which correspond to the different parts of the bubble chamber.

BEBC-film

Details have not yet been studied, but the average photographic density of the chamber image on the film will be between

$$\bar{D}_{BG} = 0.7 \div 1.2$$

In the case of full covered light spot we found that a minimum contrast $C = |D_{BG} - D_{FT}|$ of ~ 0.2 still leads to a PM signal which can be digitized.[11] For the 20 Argonne test pictures C was > 0.6.

In summary, we expect that the size of bubble images as well as the contrast of the BEBC pictures lie within the measurable range of an HPD with a suitable illumination system. However, the expected variation of the background density will be of decisive influence on the design of the track detection circuit.

4. Track Detection

A condition for the measurement of BEBC pictures on our HPD is the new design of the analogue part of the track detection circuit (TDC). The automatic gain control (AGC) and the threshold control are to be replaced by more complex systems, and as the light level and the track pulses are of the same polarity, a new method of generating a pedestal-free track signal must be employed. The idea is to design and develop a TDC compatible with both 2m-HBC and BEBC pictures (see Fig.3).

In the following the principle of TDC operation is outlined. As we prefer no gain control at the dynodes of the PMs, the PM-connected amplifier (PMA) has to serve as:

- Exclusive OR gate for the two scan modes of the HPD (0^o and 90^o),
- correcting element of the AGC,
- line driver between HPD and interface.

The output of the PMA is fed to the track amplifier and two circuits of the AGC: peak detector and lag amplifier; the AGC signal is the weighted sum of peak detector output and lag amplifier output with the weights depending on bright- or dark-field selection.

The track amplifier is part of the second control loop in the TDC. Its task is to amplify the track pulse and to subtract the level control signal from the PMA-output in order to generate a pedestal-free track signal (TS). The generation is performed in two steps. First the TS is controlled by a high-speed comparator. The two cases TS $\leq$ 0 and TS > 0 are represented by the digital levels 0 and L of the comparator's output and these levels are shifted to -L/2 and +L/2 (P to PN conversion). The result is a square wave with time-average zero, if the system has settled. In the second step this square wave is integrated; the integral is the level control signal mentioned above. Problems may arise by changing the integrator's time constant according to the expected width of the track pulses (for example, if the data box or the event area is scanned). When the dark field scan mode is selected, the settling time of the level control should be increased at the start of a scan line.

As the output of the track amplifier (pedestal-free) is bi-directional (the direction depends on whether a bright or dark field signal is supplied), an absolute generator has to be inserted between the track amplifier and a threshold control which consists of two active elements, a high-speed comparator and an analogue gate with subsequent amplifier. The further elements for signal handling are described elsewhere.[13) 14) 15)]

Not all of the described TDC components have yet been operated. The marked blocks in Fig.3 show those elements that we actually used in a test assembly to digitize the pictures from the ANL 12' HBC. As the absolute generator was absent it was not possible to digitize the databox information, because the databox is dark field illuminated. Furthermore the AGC was not provided, so that the problems in our method or level control became more obvious. With the integrator's time constant adjusted for small track width (10 μ) the level control had the characteristics as shown in Fig.4a-c. The upper line always represents the signal at point (1) in Fig.3 and the lower one the signal at point (2) . Fig.4a shows a typical bright field signal, Fig.4b a detail of it, and Fig.4c the response of the level control on a typical dark field signal.

The electronic components used were relatively slow (band-width 20 MHz) and had a low-limited voltage range, so considerable improvements are possible.

In Fig.5-7 one can see the results obtained with our test-TDC, digitizing a sample of Argonne 12' HBC pictures. Fig.5 shows HPD-digitizations, Fig.6 presents HPD-digitizations in comparison with the original photographs, and in Fig.7 the influence of a threshold control is visible.

Apart from a final version of a TDC, along the line which has been discussed, the entire circuit has to be completed by an efficient filter to reduce digitizations coming from track and background sources smaller than 10 μ on film. We do not believe that the $\sin^2$-filter, used in Fig.3, is an optimal solution because we do not yet know which form and shape the pulses generated by most of the BEBC tracks will have. But nevertheless the $\sin^2$-filter, designed for typical bubble tracks (2m-HBC) of about 10 μ and disc rotation in the HPD of 3000 rpm, reduced the number of digitizations for the Argonne test sample by more than a factor of 2. This means that mainly sources on film smaller than 10 μ have been suppressed.

5. Conclusion

Our illumination system is based on the mercury arc lamp SP 900 W. The power in the light spot ($\emptyset \simeq 12$ μ) is about 0.04 μW. This system effects measurable signals with S/N > 1 for 'black' bubbles ≥ 6 μ diameter and for contrast > 0.2. The corresponding parameters of the future BEBC pictures should be larger than the mentioned values for contrast and bubble diameter. But as we know from the Argonne 12'-HBC the BEBC pictures will have a great variation of track contrast and background transmission. Furthermore the lower limit of bubble images on the film will be about 10μ. In considering this specifications we developed a TDC, to meet these more difficult conditions in measuring the future BEBC pictures. With essential parts of this TDC about 20 pictures of the 12' Argonne bubble chamber have been digitized. As for the digitizing procedure on the HPD the very promising results demonstrated by the figures suggest that the HPD can successfully measure BEBC pictures.

6. Acknowledgements

We are grateful to Prof. M. Derrick from the Argonne National Laboratory for sending us a sample of film from the 12' ANL chamber. In particular we thank H. J. Mück, H.-H. Nagel, E. Raubold and P. Söding for critical remarks and discussions.

With pleasure we take the occasion of this report to refer to H.-H. Nagel, who has been responsible not only for the development of our HPD installation but also for the concept of the current measuring system, which has effectively supported most of our investigations.

7. Figure Captions

Fig. 1: Relative light spot power RL and relative current RI_a versus optimum wavelength λ_o of the coating.

Fig. 2: Signal/Noise Ratio.

Fig. 3: Principle of Track Detection.

Fig. 4: Operation of Ligh-level Control.

Fig. 5: HPD - Digitizations of Argonne Pictures.

Fig. 6: HPD - Digitizations of Argonne Pictures in comparison to the original photographs.

Fig. 7: Influence of the Threshold.

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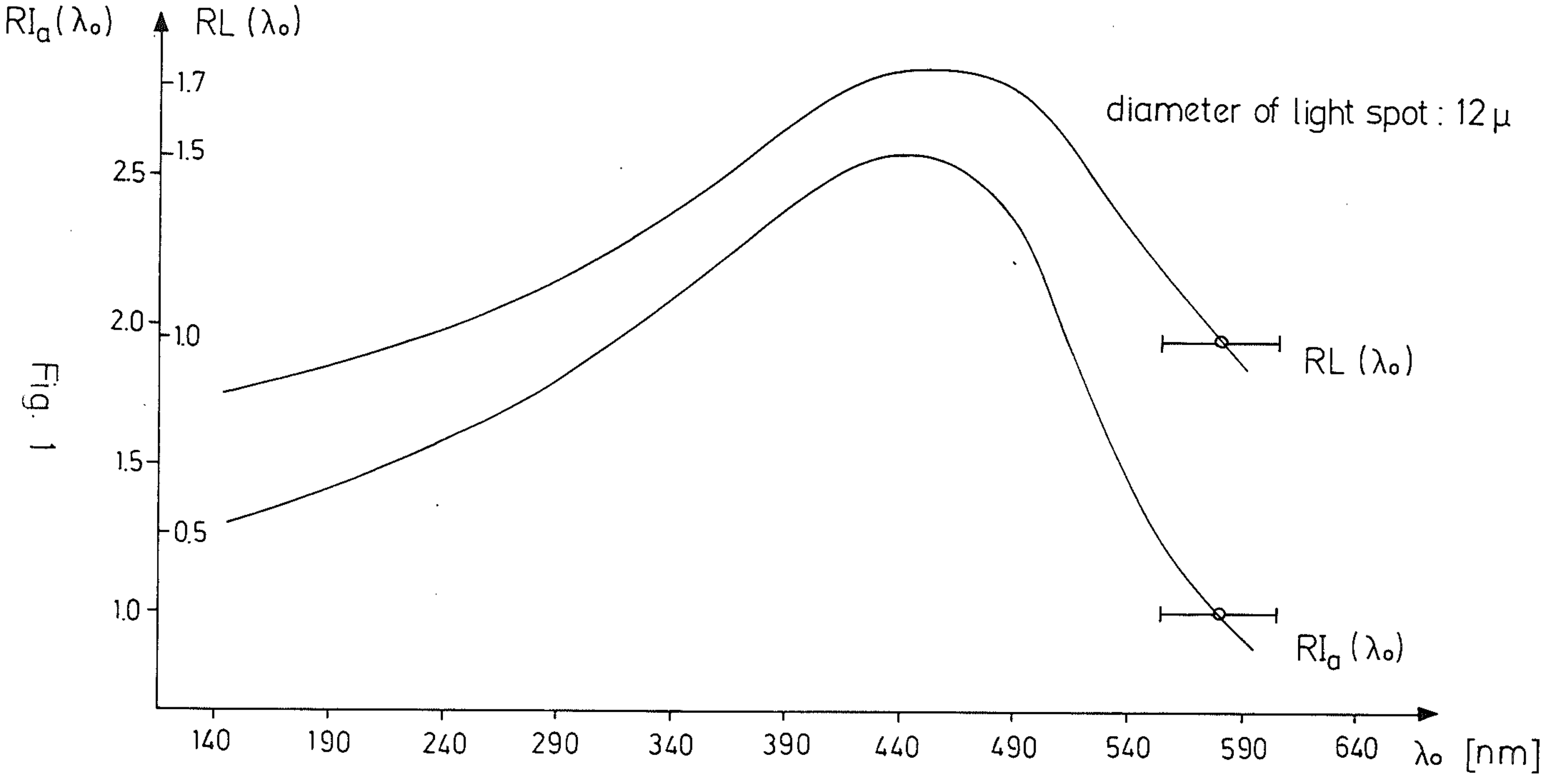
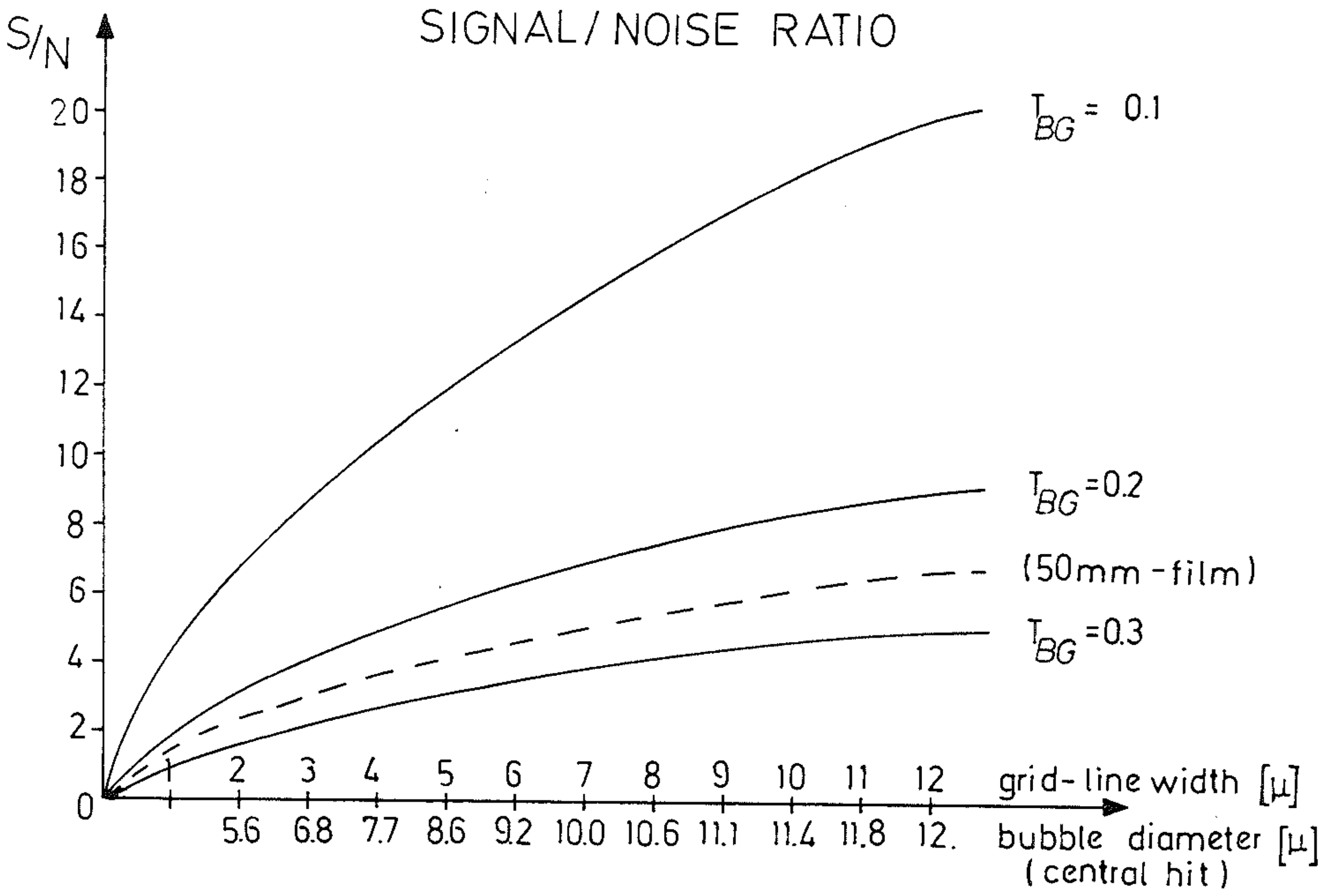
Fig. 1



Relative light spot power RL and relative current RI_a versus optimum wavelength λ_0 of the coating

Fig. 2



$T_{FT} = 0.7, \quad d = 0.04, \; b = 0.2$

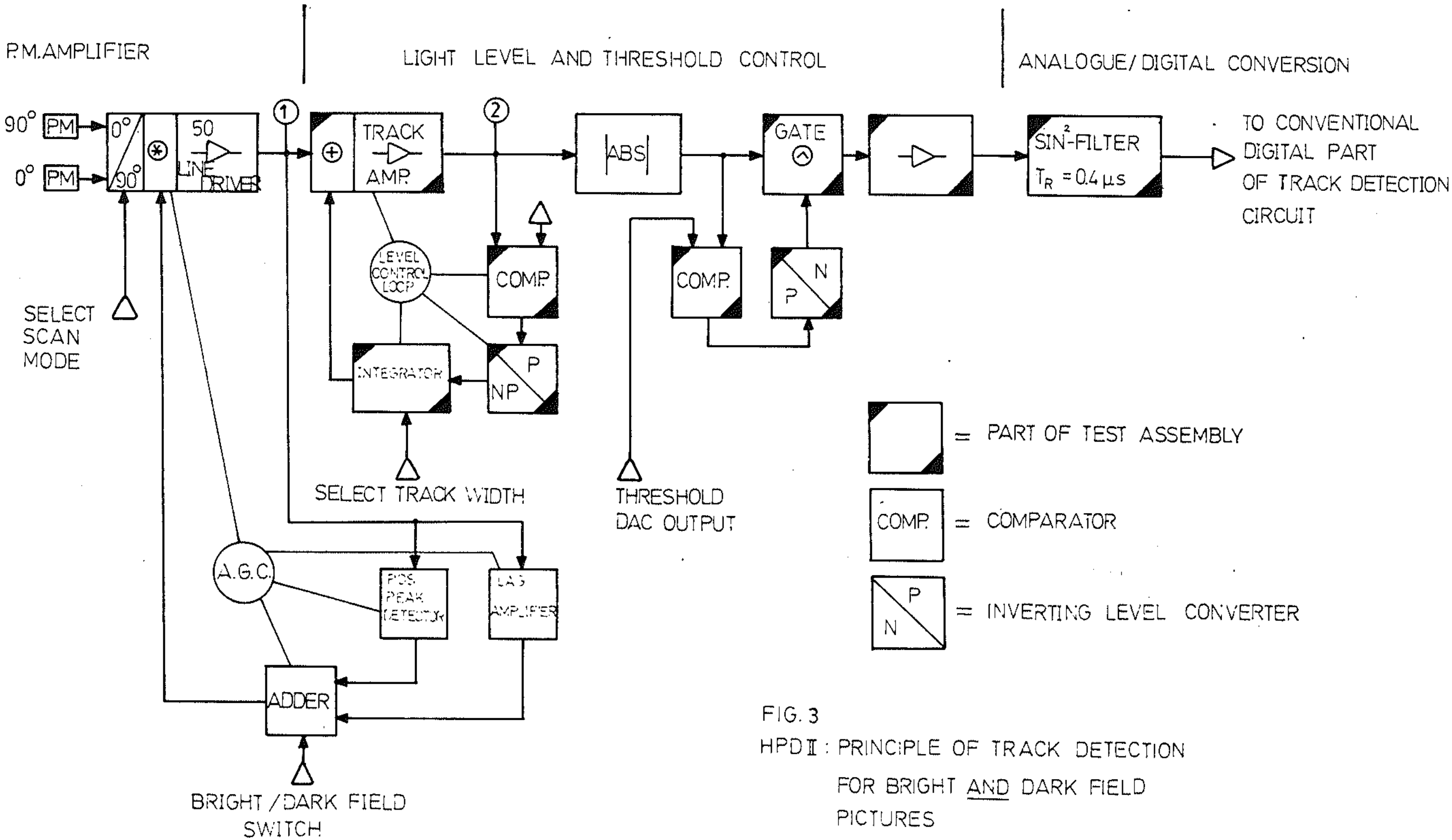


FIG. 3
HPD II : PRINCIPLE OF TRACK DETECTION
FOR BRIGHT AND DARK FIELD
PICTURES

Operation of Light-level Control

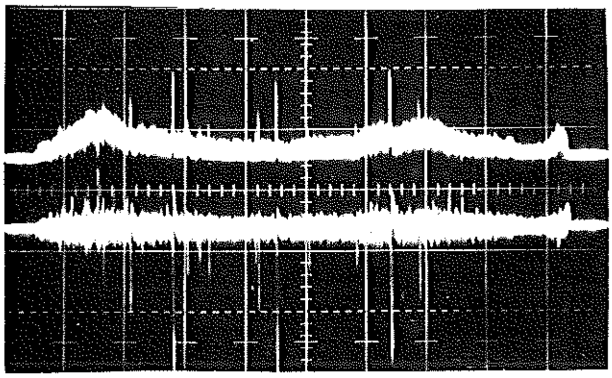


Fig.4a Bright-field signal

hor.: 200 μsec/div
vert.: 1 V/div

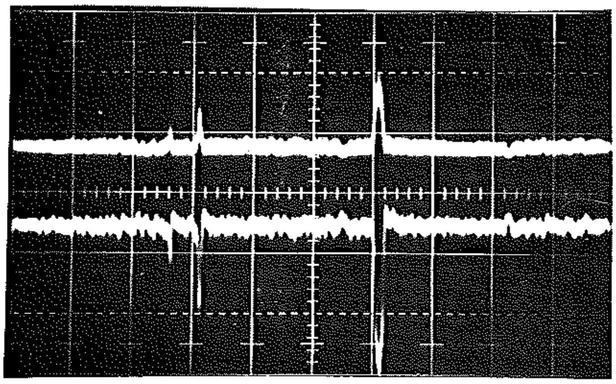


Fig.4b Detail of Fig.4a

hor.: 20 μsec/div
vert.: 1 V/div

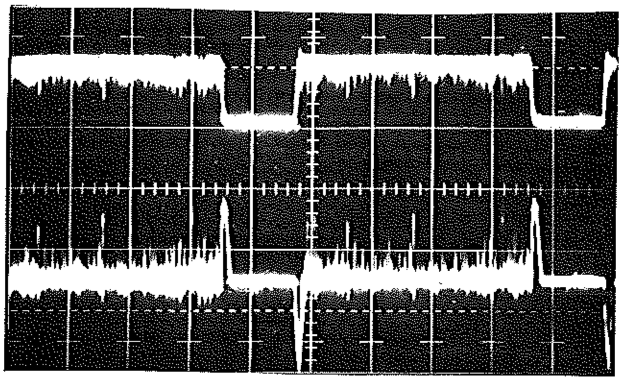


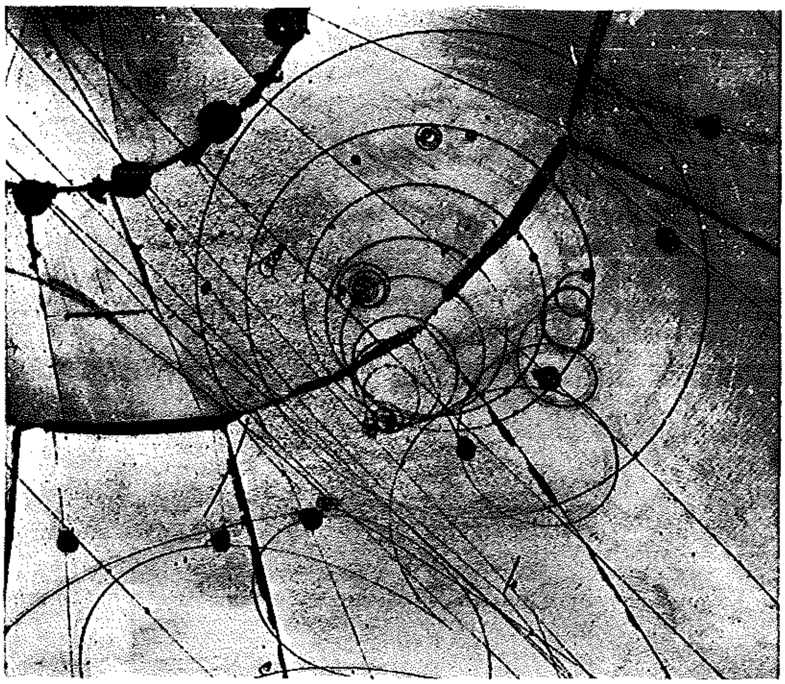
Fig.4c Dark-field signal

hor.: 500 μsec/div
vert.: 2 V/div

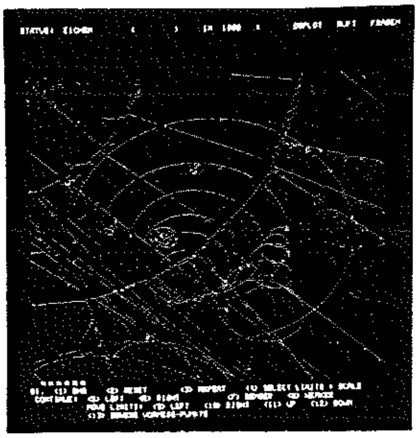
HPD-Digitizations of Argonne Pictures

Fig.5

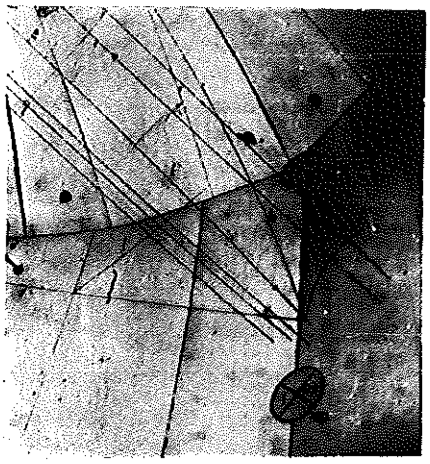
HPD-Digitizations of Argonne Pictures in Comparison to the Original Photographs



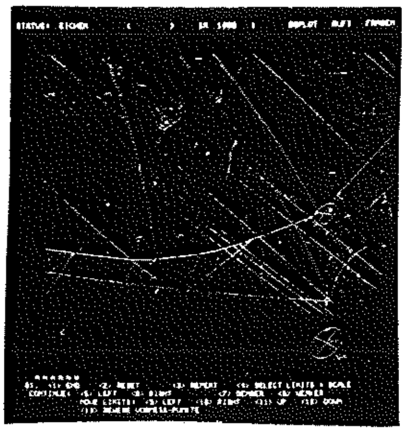
Original

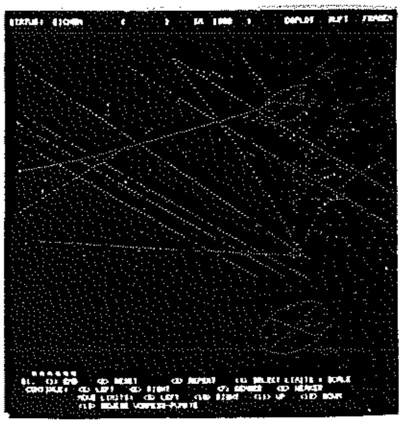


HPD-Digitization



Original
(bubble diameter ~15μ)

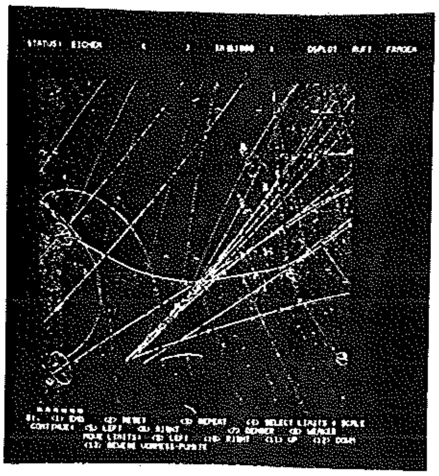




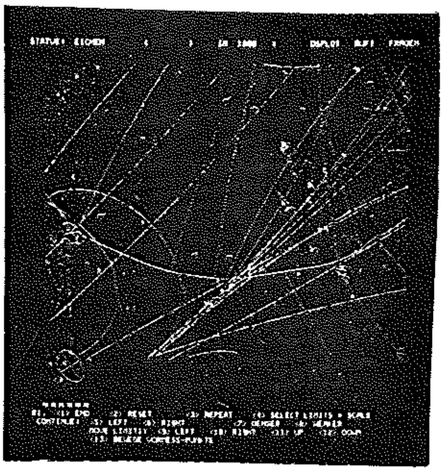
HPD-Digitization

Fig.6

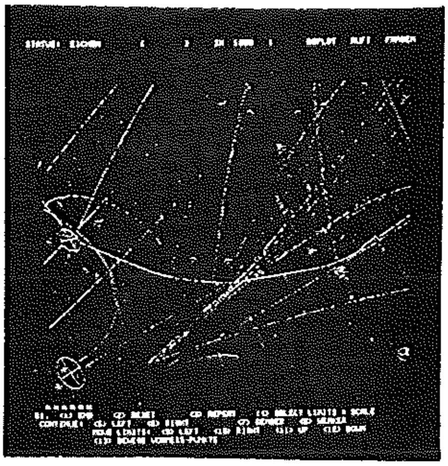
Influence of Threshold



a



b



c

a < b < c (a ≙ without threshold)

Fig.7