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1 Introduction

Different techniques are under development to realize detectors with a short readout time of some ten nanoseconds, to measure a small number of photons produced by charged particles crossing scintillating fibers [1-9]. Many of these studies are aimed at applications in experiments at large hadron colliders, with hundreds of thousands of channels to be handled. Large scale development programmes are dealing with this problem. Our own investigations were initiated by the plan to employ high resolution fiber detectors in building a forward proton spectrometer of the H1 experiment at the HERA ep-collider within the next two years [3]. For this application we have to read out a moderate number of a few thousand channels, to observe a signal of about 20 photons every 96 nanoseconds. We decided to use position sensitive photomultipliers (PSPM) for this purpose. They are available since some years and used or proposed for different types of fiber detectors [2-6].

2 Devices investigated

Various types of PSPM are extensively studied by several groups. They differ mainly by the principles used for electron amplification, like mesh dynodes, electron focussing or multichannel plates. We describe in the following tests of the Hamamatsu tubes H4140 and H4139-20 [3] and the Philips tube XP1724A[4]. Important parameters of these devices as given by the producers are shown in table 1.

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Table 1: Technical parameters of considered position sensitive photomultipliers as published by the producers

	XP 1724A	H 4140	H 4139–20
producer	Philips	Hamamatsu	
Nr. of Pixel	96	256	64
pixel size	2.54 mm	2.54 mm	4.0 ∅ pitch 5.08 mm
cross talk	5 %	≥ 50 %	< 2 %
pulse rise time	5 nsec	2.7 nsec	2.7 nsec
dynode stages	10	16	16
gain	10^6 at 1150 V	10^6 at 2500 V	10^6 at 2500 V
qu. eff. 420 nm	~ 20 %	~ 20 %	~ 20 %

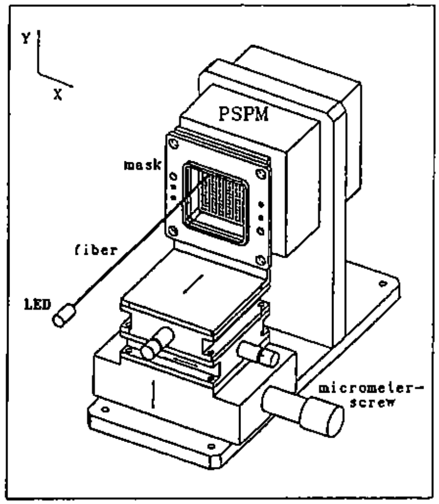

Figure 1: Mechanical support for the fiber arrangement on the PSPM photocathode

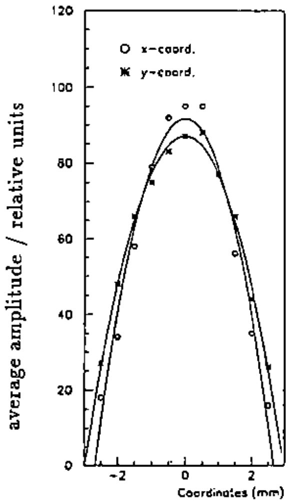

Figure 2: Relative amplitude response across a single pixel of the H4139-20

As can be seen the H4140 is expected to show a rather large electrical cross talk, in contrast to the other tubes. The XP1724A has a fiber optical entrance window in front of its photocathode to reduce optical cross talk.

The studies described in the following have been made with 1 mm scintillating fibers illuminated by light emitting diodes, ^{90}Sr and ^{106}Ru β–sources, cosmic particles and a 5 GeV electron test beam. Further results, in particular on 500 μm single fibers and fiber detector measurements have been published elsewhere [10,11].

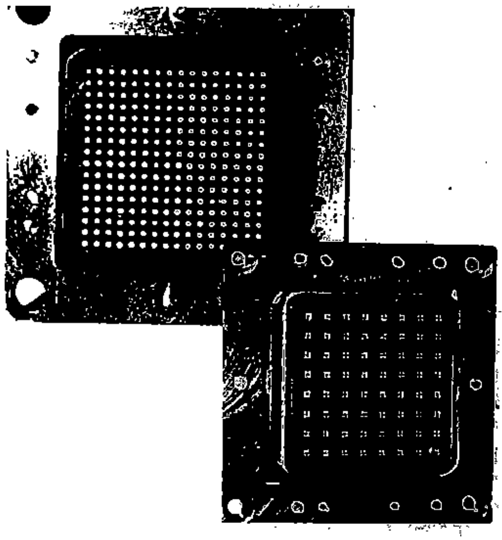

Figure 3: Masks for fiber positioning at the H4140 and H4139–20 photocathode

3 Mechanics and data acquisition

To allow precise adjustment of the fibers in correspondence to the PSPM anode pixels, we used specially designed masks which are installed in front of the photocathodes of the devices (see fig.1). A support with three micrometer screws allows shifts in x and y direction and rotations to find the best possible general alignment with respect to all anode pixels. A single pixel sensitivity distribution measured across the pixels x and y extensions in steps of 500 μm is given in fig. 2 for the H4139-20. Fig. 3 shows masks for the H4140 with 256 holes and for the H4139–20 with 4x64 holes used in this case for 4–fold multiplexing.

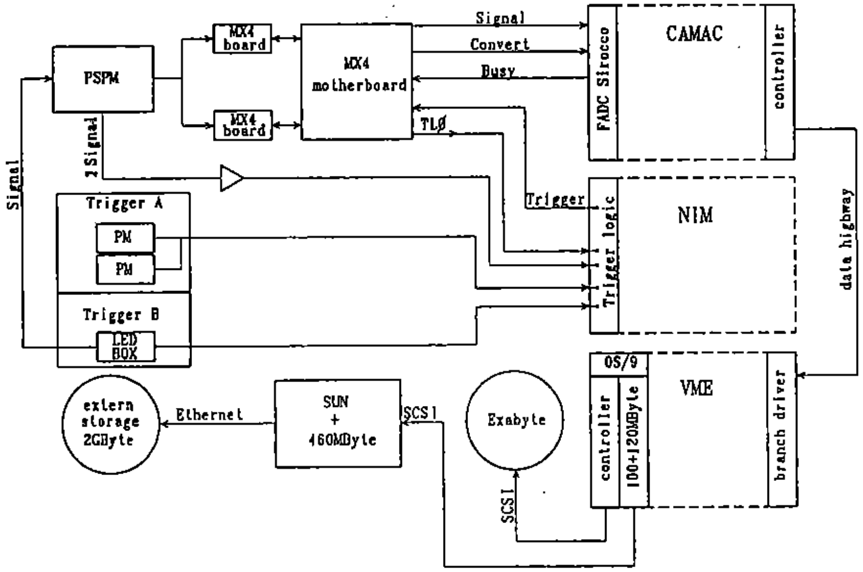

Figure 4: Scheme of DAQ–System used for PSPM readout

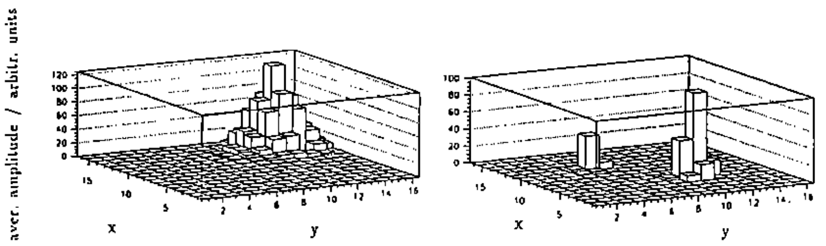

Figure 5: Average signal amplitudes for single fibers illuminated by LED's a.) H4140, b.) XP1724A (coordinates in relative anode pixel numbers).

The pulse rise time of the PSPM's under study is a few nanoseconds (see table 1). Therefore the time behaviour of a future fiber detector will be mainly restricted by the read out electronics. For collider applications signals have to be digitised and pipelined in an early stage. We will not treat this problem here; instead we measure the total light amplitude as seen by the PSPM. For this purpose we borrowed the complete readout boards developed for the L3-fiber detector [12]. The serial output of these boards was digitised by a SIROCCO II flash ADC using a VME-OS9 online data taking system with a CAMAC interface. The trigger was provided by the steering signal for a light emitting diode or by an outer scintillator trigger system. The data could be stored on disk and tape. The whole readout scheme is sketched in fig. 4.

4 Results for H4140 and XP1724A

The average signal amplitudes for single fibers illuminated by a LED producing light corresponding to minimum ionizing particles are shown in figs 5a and b for the H4140 and XP1724 respectively. They show the expected cross talk behaviour and confirm the producers data. However the main problem of these devices is not cross talk but the low position recognition efficiency at low light levels. Defining ε^{pos} to be the ratio of the number of triggers found at the expected position, to that of all triggers we observe the dependence on the maximum light amplitude as shown in fig. 6. It is surprizing that the curves for both devices agree rather well.

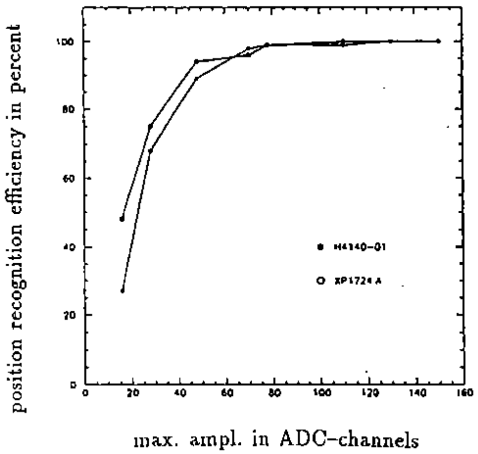

Figure 6: Position recognition efficiency in dependence of maximum amplitude per trigger

Table 2: Relative sensitivity of H4140 anode pixels measured differentially at a high voltage of 2700 V.

4	2	9	6	7	7	7	7	1	7	9	4	7	6	6	6
6	16	15	15	17	15	18	14	16	14	14	9	12	10	10	8
16	18	21	21	20	23	25	28	26	24	26	25	26	15	26	9
18	21	23	23	23	29	28	31	33	37	37	39	20	18	21	29
45	43	60	64	69	60	75	79	32	75	44	75	42	77	14	52
25	48	34	55	37	69	33	72	45	83	48	80	39	77	37	34
23	31	29	59	37	72	37	71	48	77	44	77	43	79	40	70
31	72	37	87	44	71	51	75	69	68	58	80	57	74	45	71
34	75	45	100	83	93	60	82	57	90	83	92	49	78	75	59
58	67	77	72	88	78	91	84	90	91	90	77	72	73	68	61
67	58	83	69	82	77	86	82	87	75	66	68	67	61	66	60
71	63	66	66	87	69	91	74	81	69	68	53	53	55	63	56
63	61	66	80	78	90	79	79	88	81	73	77	69	72	75	64
50	71	58	80	66	77	70	74	72	72	73	57	69	69	67	56
52	67	66	66	66	77	74	83	61	67	67	63	44	64	58	53
53	61	62	67	70	69	71	63	57	67	52	49	52	52	46	40

Different methods have been applied to identify the fiber position. The simplest one is to search for relative amplitude maxima in the PSPM anode pixel array. Another method which we also applied was cluster search with following center of gravity calculation and digitization. The results differ only marginally.

A serious problem in all cases is the varying PSPM pixel sensitivity. In particular for devices with large cross talk all neighbouring pixels influence each other if sensitivity measurements are performed. We made such measurements under working conditions for all tubes under study, illuminating each pixel separately. The result for the H4140 is shown in table 2. A sensitivity variation of 100:1 is visible with even local minima. It is clear that good position recognition can not be achieved in this case. From fig. 7 one observes that the results do not improve in presence of a magnetic field. Although as proposed by the producer the cross talk becomes considerably smaller, this does not lead to a better position recognition efficiency.

To get improved results for ε^{pos} a uniform anode sensitivity has to be achieved. In this case even high cross talk devices could have interesting applications. Putting a dense target of 500 μm fibers to a "uniform part" of the H4140 photocathode a track resolution of 150 μm was found for crossing cosmic particles. This precision was reached by searching for the amplitude center of gravity transverse to the particle track.

We got also a rather promising result for the preshower detection capability of the H4140. We inserted a 1 cm thick lead plate (1.8 X_0) between two fiber double layers. This configuration was exposed to 5 GeV electrons. Comparing light amplitudes from fibers behind and in front of the lead plate we found a ratio greater than one in 99% of all events allowing to identify the start of an electromagnetic shower from electrons or photon conversions.

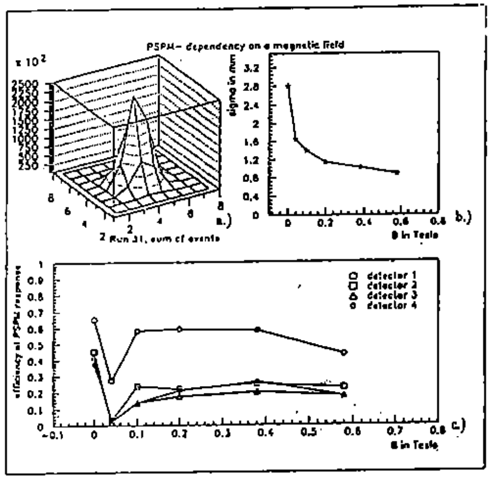

Figure 7: Magnetic field dependence of H4140 parameters a.) average amplitude for B = 0.1T, b.) half width of event amplitude, c.) hit detection efficiency, (from ref. 4)

5 Results for the H4139–20

In fig. 8 we show a typical signal of a "dark current electron" measured with a 10 kΩ resistor and no further amplification. For our normally used high voltage of 2100 V we observe an average amplitude of 50 mV with a rise time of 3 nsec and a signal width of 10 nsec.

Using a random trigger and our usual DAQ system we find a small pedestal width of $< \sigma > = 2.5$ ADC channels. The pedestal peak is overlayed with a trigger signal from dark current electrons in fig. 9 using minimum possible trigger threshold. A clear separation of both peaks is visible.

Applying a LED signal corresponding to about five photoelectrons to the PSPM(this is what we expect for minimum ionizing particles in our detector application) we get the average signal amplitude shown in fig. 10. Very low cross talk is observed. Together with a rather good anode uniformity (2.5:1) this leads to the good position recognition of about 99% measured for 10^4 triggers in fig. 11. A 6σ cut is applied to remove random noise.

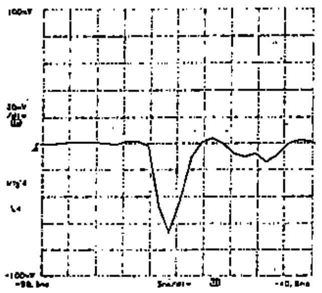

Figure 8: Typical anode signal of a H4139-20 pixel for a dark current electron

Looking however in more detail at single events one observes rather often the "split "of signals, i. e. two large maxima appear at separate positions. This effect is particularly dangerous if the PSPM "surface" has to be subdivided into several regions attributed later to e. g. different layers of a fiber detector. Using quadrants and searching for local amplitude maxima separately for each region, the same data as before give now the result shown in fig. 12. A large number of "induced noise" signals is seen in empty layers. In a real four layer fiber detector the situation would not be as bad because hopefully every layer will produce its own large signals.

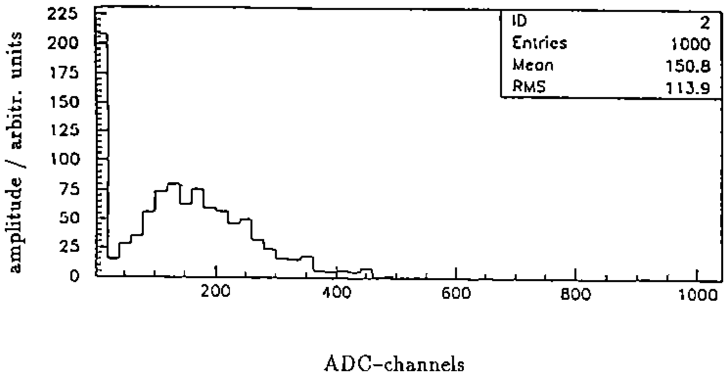

Figure 9: Overlay of amplitude distributions of random noise and trigger signals from dark current electrons

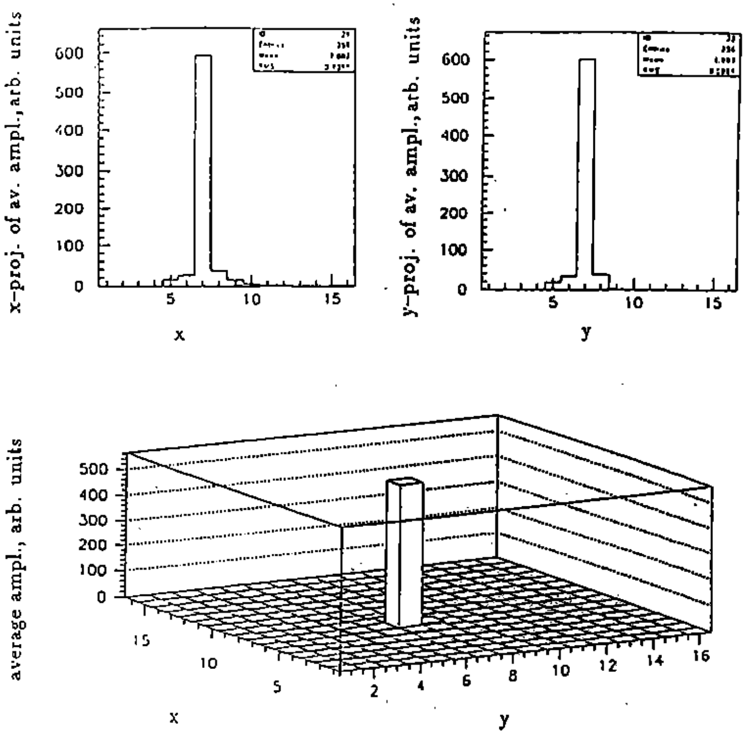

Figure 10: Average amplitude for a single fiber illuminated by a LED. (coordinates in relative anode pixel numbers)

This seems to be realistic as demonstrated for a fiber detector designed for efficiency tests of spliced fibers traversed by cosmic particles (see fig. 13). Four layers of 16 fibers are arranged in quadrants at the PSPM. The upper and lower layer consist of scintillating BCF-12 fibers[1] which in addition are coupled to two XP2020 photomultipliers. A coincidence of signals from these two photomultipliers together with T1 starts the PSPM readout. Layers 2 and 3 of the detector consist of 6 cm BCF-12 scintillating fibers spliced to ~ 25 cm light guides. The efficiency of all four layers is shown for 2000 cosmic triggers in fig. 14. For layers included in the trigger it is 99%, for the other layers it is still 93%. Using a track fit procedure to remove background we observe real tracks (with ≥ 3 points) for 66% of all crossing particles.

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	1			2			
	1						1
			1	1	2	1	
6	3	12	9	3	3	2	1
7	4	9860	9	6	1	1	1
2	8		6	7	1	1	1
6	12	2	6	2	2	2	

Figure 11: Position recognition pattern for 10^4 triggers of the H4139-20. Fiber position is pixel (3.3).

26	20	18	31	13	19	10	14
16	14	21	26	28	24	16	11
23	26	26		17	19	5	9
25	27	79	44	29	19	11	11
6	3	12	9	282	110	44	40
7	5	9897	9	341	134	64	44
2	9		7	297	100	57	32
7	12	2	6	174	99	32	39

Figure 12: Position recognition pattern for the same data as in fig. 11 but PSPM now subdivided into four sections

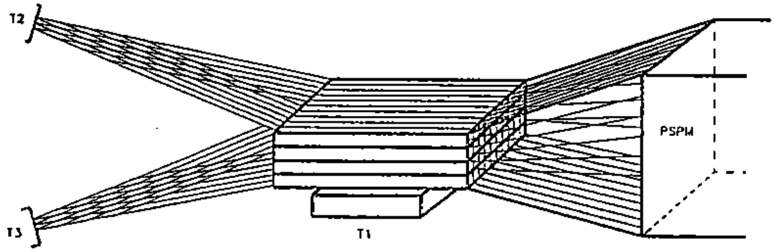

Figure 13: Principle scheme of a "self-triggering" fiber detector

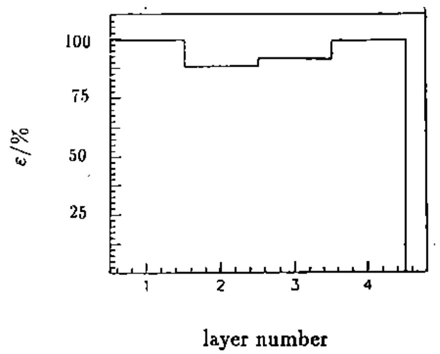

Figure 14: Efficiency of four fiber layers with respect to 2000 cosmic particle crossings

6 Summary

Investigating three different types of position sensitive photomultipliers, the H4140 and H4139-20 of Hamamatsu and the XP1724A of Philips, we confirm the producers parameters for all devices. However both the H4140 and XP1724A have been found to have problems to detect the right fiber position at low light levels. The main difficulty for large cross talk devices is the non-uniform response of anode pixels.

For the H4139-20 very low cross talk and high sensitivity even for low light levels were found. Responding to light signals the device produces additional noise with amplitudes considerably above the normal random noise. Nevertheless, using the H4139-20 for reading out 1 mm diameter fibers illuminated by traversing cosmic particles we measure efficiencies near to the theoretical maximum.

Acknowledgement

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References

1. D. Bernard, *NIM* A **315** (1992) 43.
2. K. Kuroda et al., *NIM* A **300** (1991) 259.
3. J. Bähr et al., *NIM* A **324** (1993) 145.
4. J. Bähr et al., *NIM* A **330** (1993) 103.
5. J. Hauser et al., *NIM* A **321** (1992) 497.
6. B. Abbot et al., *NIM* A **327** (1993) 319.
   M. Atac et al., *NIM* A **330** (1992) 155.
7. R. De Salvo et al., *NIM* A **315** (1992) 375.
   S. Basen et al., *NIM* A **330** (1993) 93.
8. C. d'Ambrosio et al., *NIM* A **322** (1992) 20.
9. P. Cushman, R. Rusack, *NIM* A **333** (1993) 381.
10. J. Bähr et al., proceedings of the "International workshop on position sensitive detectors", London 1993.
11. R. Völkert, Diploma work, Universität Münster, 1993.
12. H. Akbari et al., *NIM* A **302** (1991) 415.