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PEAK-SENSING DISCRIMINATOR FOR MULTICHANNEL DETECTORS WITH CROSS-TALK

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Abstract

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In view of handling the anode signals from the position-sensitive photomultiplier a new front-end electronic circuit has been designed and realized, which allows one to suppress annoying effects of the cross-talk between adjacent channels. The circuit was tested in association with a scintillating-fibre detector in a test beam at CERN. The basic performances, such as the detection efficiency and its uniformity, as well as the hit multiplicity for single tracks were compared to those of the conventional electronics based on the simple threshold discriminators. A great advantage of the peak-sensing circuit was experimentally demonstrated in particular in its real time digitization of the track position without significant ambiguity of the track position due to the cross-talk.

Аннотация

Горин А. и др. Пикочувствительный дискриминатор для многоканальных детекторов с кросс-током: Препринт ИФВЭ 98-39. – Протвино, 1998. – 12 с., 12 рис., библиогр.: 12.

Для обработки анодных сигналов позиционно-чувствительных ФЭУ предложена и реализована новая надетекторная электроника, позволяющая подавить нежелательные эффекты перекрестных наводок (кросс-токи) между соседними каналами. Электроника была испытана вместе с детектором на сцинтилляционных волокнах на пучке ускорителя ЦЕРН. Сравнивались основные характеристики детектора: эффективность регистрации и ее однородность, а также множественность для одиночных частиц, с аналогичными характеристиками обычного дискриминатора с фиксированным порогом. Было экспериментально показано преимущество пикочувствительной схемы при оцифровке в реальном времени положения трека частицы без заметной неопределенности трека из-за эффектов кросс-тока.

Introduction

A new trend in high luminosity experiments in Particle Physics is to integrate more precise information on the pattern of outgoing particles into the early stage of event selection. This trend requires a new type of detector that assures not only high space and time resolutions as *topological trigger* device, but also a simple and reliable operation in handling the position information in real time. To meet such a new demand a considerable progress has been achieved in the RD-17 experiment at CERN [1] which was dedicated to the fast readout of scintillating fibres (SciFi) using position-sensitive photomultipliers (PSPM). Among several papers devoted to tracking device using SciFi [2], the RD-17 program is particularly oriented toward the digitization of track position in real time, which is essential for topological trigger devices. For this purpose, a serial readout of the PSPM multianodes using a delay line method [3] has been extensively studied so far, not only to suppress annoying effects of the cross-talk between adjacent channels, but also for profiting from the cross-talk to obtain a better space resolution with respect to the anode size [4]. A successful application of this technique was found in a study of the local response of the electromagnetic calorimeter for the CHORUS experiment [5].

Recent progress in the PSPM technology allowed one to reduce the internal cross-talk due to the dispersion of secondary electrons to a few %, so that the main part comes from external sources like propagation of delta rays or UV light of primary scintillation from a hit fibre to neighbouring fibres. The present study concerns the design and the realization of a parallel readout electronics that allows one to suppress the annoying effects of such a short range cross-talk. The background idea is based on the centre-of-gravity method which is an essential tool for handling the position information from any type of multichannel detectors with cross-talk. The present circuit can be considered as a natural derivative of our previous study on a peak-sensing integrated circuit ORIGINE [6] in the case where the range of cross-talk is limited to the adjacent channels.

1. Principle of the Peak-Sensing circuit

The algorithm of the Peak-Sensing Circuit (PSC) is described as follows:

Denoting the signal amplitudes A_i for channels (i=1 to n), the track position is defined by the channel (i) if the slope change, $2A_i-(A_{i+1}+A_{i-1})$ is greater than the given threshold A". That is to say, after the subtraction of adjacent signals, an appropriate threshold A" is applied to pick up only the channel(s) giving the second-order derivative greater than the threshold. This means that the PSC algorithm supplies a dynamic cross-talk rejection.

As illustrated in Fig. 1, in comparison with the conventional discriminator, the PSC allows one to define the track position with a smaller amount of multi-hits without losing so much detection efficiency. The detection of double *adjacent* tracks is, however, limited by statistical fluctuations of signal amplitudes, for example, if the amplitude of the second signal $A_i + 1$ is smaller than $(A_i + A_{i+2})/2$, the track is ignored and the event is assigned as a single-track event. For this reason the threshold must be chosen as a compromise between this fluctuation and the cross-talk of the adjacent channels.

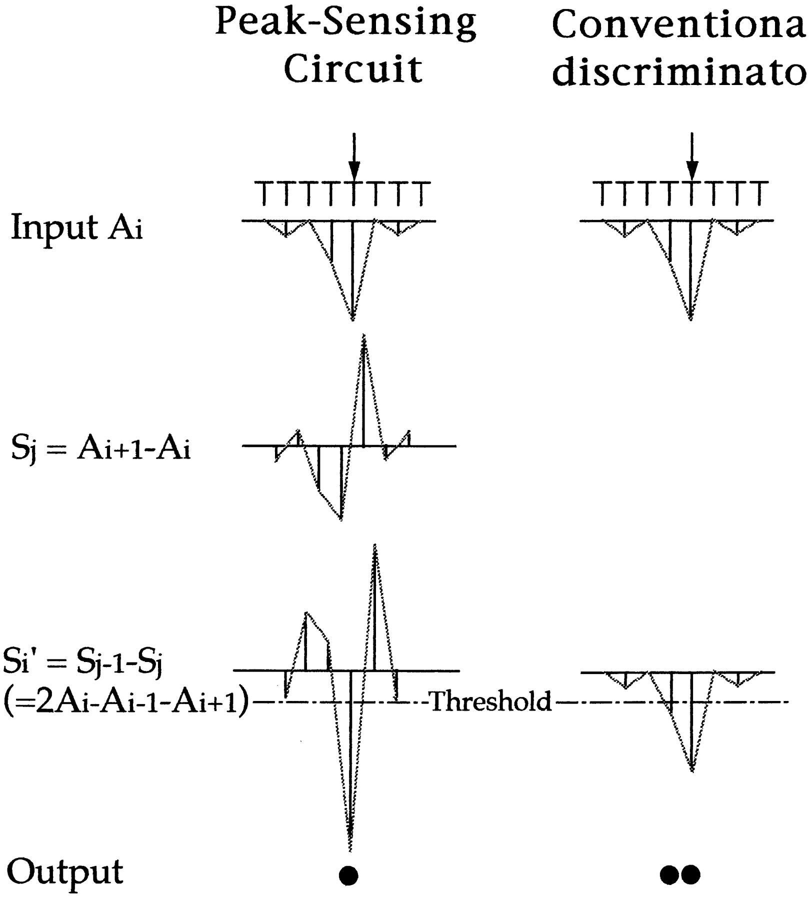


Fig. 1. Principle of the Peak-Sensing algorithm.

2. Description of the principal scheme

2.1. Design concept

The idea of the printed circuit board design is to combine the analogue electronics with the digital one inside the same module and to maximise the number of channels in one unit. Only conventional commercial IC's have been used to make modules simple and cheap. For the reason of simple operation and maintenance, we tolerated the edge effect which might arise at the extremity channels from the lack of connections between adjacent modules.

2.2. Specification of the module

The present module is featured by:

1. Number of channels per module: Input — 32 (analogue); output — 32 — Tracking and 16 — Triggering.

2. Input negative signal: amplitude range — $0 \div 1$ V ($R_l = 50\ \Omega$); pulse duration (FWHM) — $8 \div 10$ ns; input DC offset level ≤ 5 mV; input 50 Ω cable length ≤ 2 m.

3. Output ECL signal: pulse duration — 12 ns; load impedance — 100Ω; load capacity — 10 ECL inputs; output cable length ≤ 20 m.

4. PSC processing algorithm: $A_i \geq (A_{i-1} + A_{i+1})/2 + U_{thr}$; accuracy $\approx 5\%$.

5. Discriminator: tuning from 0 to 100 mV threshold simultaneously for all channels; individual channel adjustment from 10 to 40 mV threshold; threshold error $\leq 1.5\%$.

6. Timing specifications: propagation delay — 8.5 ns; delay difference between channels — 1 ns; after pulse dead time ≈ 30 ns (for an active channel and 2 adjacent ones).

7. Power consumption:
minus 6 V — 4.5 A, plus 6 V — 1.5 A, minus 12 V — 0.04 A, plus 12 V — 0.015 A.

8. Dimensions: standard NIM module of unit width.

2.3. Description of the circuit

The basic diagram of the module is schematically shown in Fig.2. An analogue input signal is applied to the resistor divider with 5/3 coefficient. Then, the signal is amplified by a wide bandwidth (200 MHz) amplifier AD9623 [7] with a gain of 6 (given by feedback resistors). The amplifier serves for the integrating of signal amplitude, as well as for providing the maximum amplitude to be sent to the comparator, so that the intrinsic bias shift of the integrator, ~ 3 mV, does not affect so much the result of amplitudes comparison. The gain is defined by the maximum admissible value of the output signal of the amplifier (3 V). The signal from the amplifier is fed to the comparator of the corresponding channel and to those of the adjacent ones. The signal is compared with a sum of signals from the adjacent channels according to the peak-sensing algorithm by the MAX9687 [8] comparator with 2 ns propagation delay. The sum of common bias (UREF1) and the individually adjustable threshold in each channel (UREF2) defines the true value of the threshold voltage.

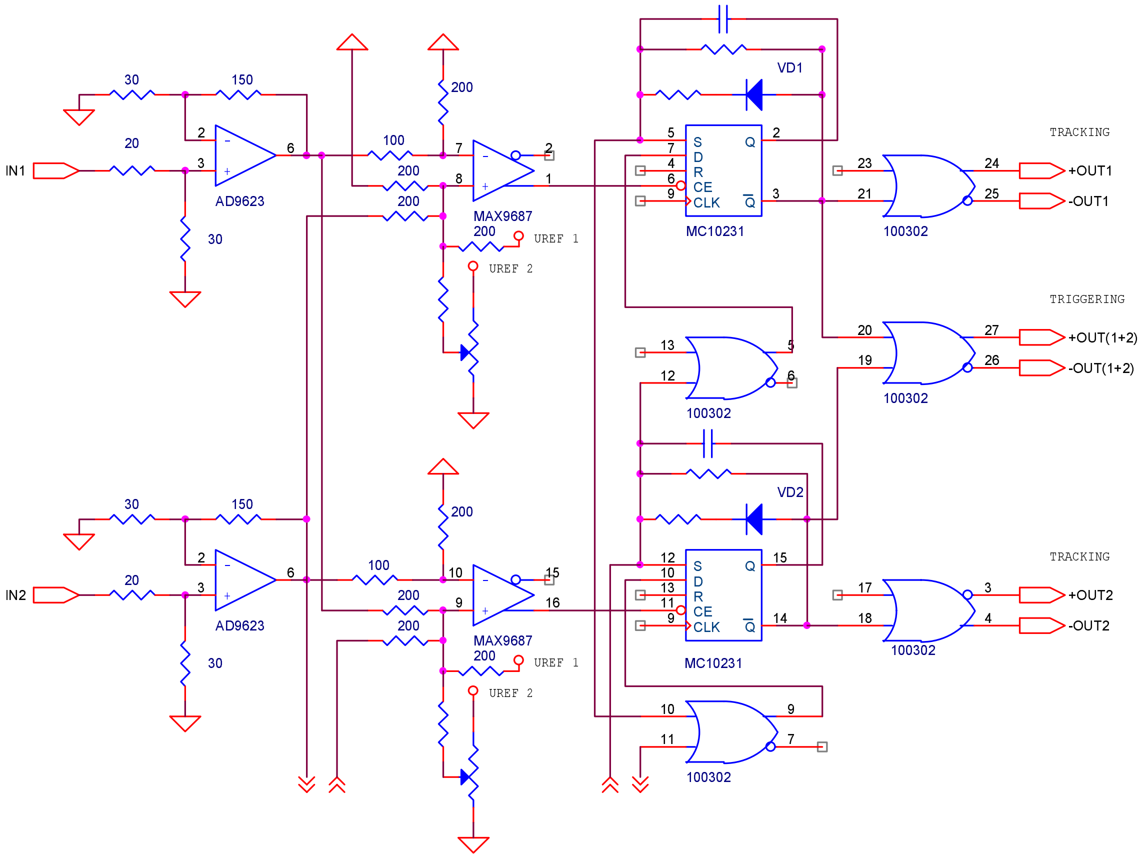


Fig. 2. Principal circuit diagram of 2 first channels.

The comparator signal passes to the trigger MC10231 [9] used as a one-shot generator. To eliminate false triggering of the adjacent channels from the positive afterpulses a circuit to suppress the start of the one-shot generators has been inserted. For this special diodes (VD1, VD2) to make different output and reset pulse duration of the trigger were introduced in RC-chain of the trigger. A trigger reset pulse is also fed to the data inputs of the triggers of the adjacent channels, thus, impeding their triggering after the output pulse shaping during "dead time" of order 30 ns. To sum up the reset pulses coming from the adjacent channels, 100302 [9] gates have been used. The same elements are employed to sum up over 2 adjacent output pulses to create Triggering output and buffer the main outputs for Tracking. The ECL outputs are assigned to operate on 100 Ω matching line (twisted pair).

A 6-layer printed board has been designed for the PSC module. The number of layers is defined by the number of output conductors and the number and geometry of the input signal lines. To apply the input signal, a symmetric strip line with screening conductors at each side has been utilized (Fig.3). Wave impedance of such line with an accuracy of around 5% is derived by the following formula [10]:

$$Z = (60/\sqrt{\varepsilon_r})ln4b/[0.67\pi w(0.8 + t/w)]$$

where ε_r — relative dielectric constant of the board material, w, b, t — dimensions, indicated in Fig.3.

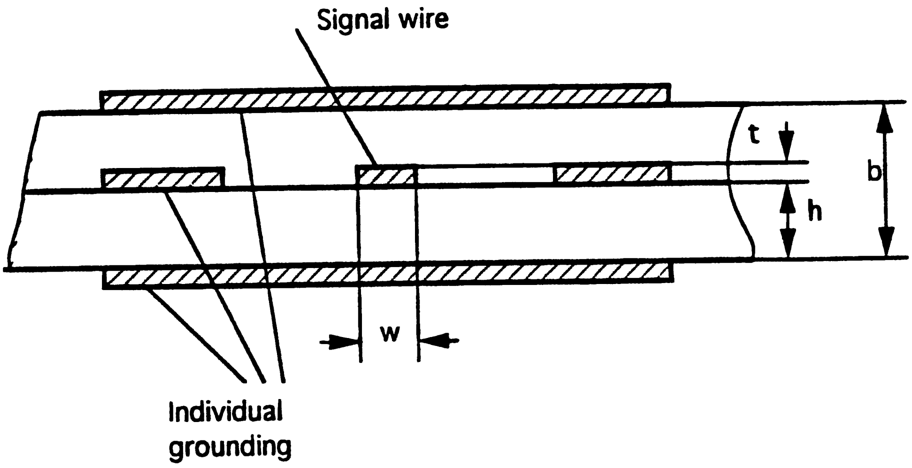


Fig. 3. Input signal symmetric strip line layout geometry.

To preserve the accuracy of the calculation, the following requirements should be fulfilled: $w/(b-t)$ <0.35 and t/b <0.25. For the printed board of PSC, a fabric cloth-based laminate was used with ε_r=5.5, the width of the signal wire was w=0.4 mm. The thickness of metallization t was about 0.01 mm. Hence, the thickness of a layer h was chosen to be 0.5 mm, the thickness of the whole board was 2.5 mm. Calculated wave impedance of such a strip line was 45.6Ω.

When testing the board prototype, substantial interference pulses (~10-20 mV) at the input analogue chains arose from the input connector. Therefore, ground and signal lines were joined to the connector contacts by the "chess order" (Fig.4). As a result, the interference to the adjacent channels went down to 3-5 mV.

Adjustment of the common threshold was carried out with the aid of a potentiometer accessible from the faceplate; the monitoring pin of the common threshold with a factor of 10 is also installed in this plate.

To read out the output signals from each channel (Tracking) and the sum of the adjacent channels (Triggering), two multi-pin connectors of the 3M type were mounted into the faceplate.

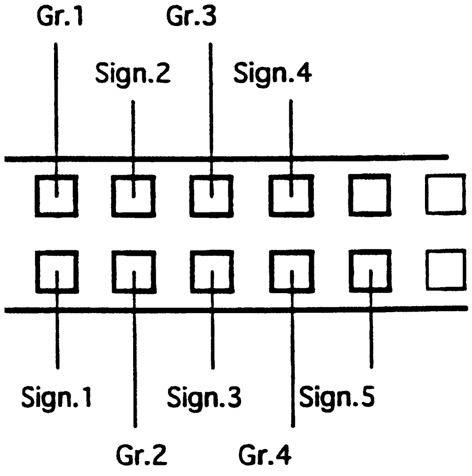


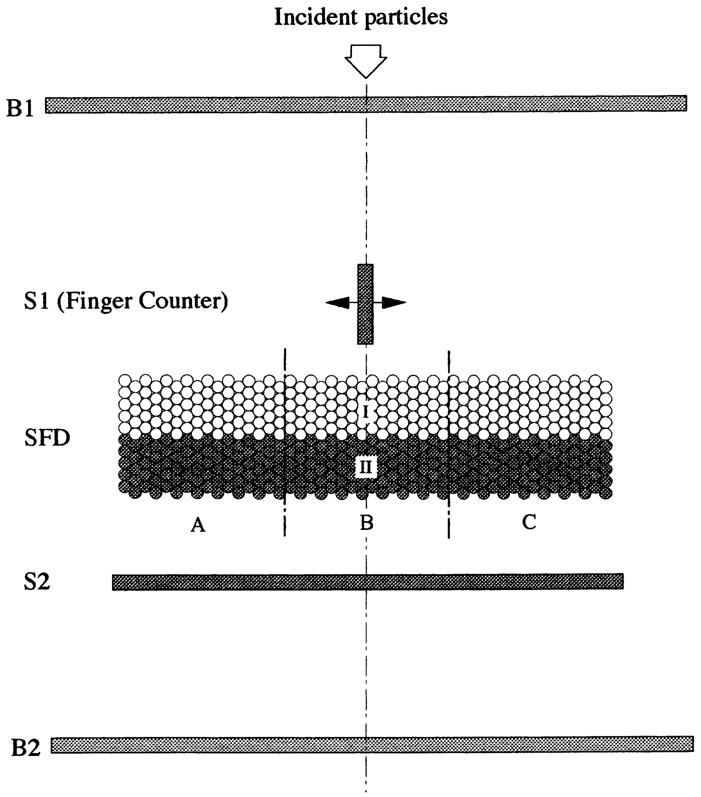
Fig. 4. Input connector pin layout (Gr. — ground and Sign. — signal pins).

Analogue signals were connected through 64-pin connector of the Burndy type from the rear side of the crate. It is worthwhile noting that such a position of input and output connectors allows one to obtain almost the same signal delay for all the channels.

3. Experimental results

In our previous paper [11] some different algorithms for handling multianode signals were described and compared experimentally and by simulation as well. The study has revealed an advantage of PSC to the conventional discriminator in an excellent agreement between the simulation and the experimental results.

In this paper we present some experimental results directly related to the specific function of the PSC. The PSC module was tested in association with a SciFi detector (SFD) prototype dedicated to DIRAC experiment [12]. The prototype consists of a 0.5 mm diameter SciFi array (SCSF38, Kuraray) coupled to a PSPM (H5828 or H6568 from Hamamatsu Photonics). Each 5-fibre column of 100 mm active length is optically connected to the corresponding channel of the PSPM. A beam experimental set-up using 3 (A, B, C) H6568 16-channel tubes in each layer is schematically shown in Fig.5. The double superlayers (overlapped with a high precision) allowed one to make a tagging of incident particles with one (I) of them to tune PSPM's and PSC's, connected to the other one (II) by measuring the basic characteristics of the detector such as detection efficiency, multiplicity distribution and track definition.



TRIGGER = B1*B2*S2 (or S1)

Fig. 5. Beam experimental set-up for testing the PSC. B1, B2, S1 and S2 — trigger counters. A, B, C — Scintillating fibre regions (16 columns), corresponding to separate PSPM's.

The detector tuning consists of two steps:

1. Due to the difference in gain of each PSPM it was necessary to tune the power supply high voltage for every tube to get the same mean value of the detection efficiency. For this purpose the tuning was done at a low level of efficiency of the order of $80 \div 90\%$. The result of gain normalisation is shown in Fig.6.

2. The optimal threshold was then determined by scanning the detection efficiency in a wide range of high voltages at different thresholds. Typical results for H6568 are presented in Fig.7. Together with the detection efficiency we checked also the multiplicity distribution in layer II for single tracks defined by layer I. An example of such a histogram is shown in Fig.8. It is evident that the multiplicity becomes larger for higher efficiency due to the decrease of the effective threshold. The sources of the multiplicity can be any type of cross-talk as well as accidental or noise pulses producing fake hits. The relative efficiency to detect only a single hit event has been calculated (extracted from the experimental data illustrated in Fig.7) and shown in Fig. 9. The curves show clearly the maximum value of $90 \div 91\%$, corresponding to the optimal operation conditions.

Under these conditions the total detection efficiency is $96 \div 98\%$ with $5 \div 7\%$ contamination of multiple hit events. Neither significant dependence on the threshold value was found, but for this tube (H6568) operation at higher threshold (and higher voltage consequently) looks preferable.

To check the boundary effect due to the lack of adjacent signals at the extremities of the PSC as well as of the PSPM's, two couples of track distributions across these boundaries are presented in Fig.10. In both cases the effect is considered to be negligible compared with a slight asymmetry of the left and right tails, which comes from a small inclination of the fibre array to the beam direction — as it was observed with central channels too.

As one can see from Fig.6 the uniformity of the detection efficiency is not very high due to the dispersion of the PM gain. To decrease this fluctuation the individual threshold tuning for selected channels (13, 15, 22, 26, and 42) has been done. The result is shown in Fig.11.

We studied also the performance of the PSC at high beam rates. Any anomaly had not been revealed up to $\sim 10^4$/s per channel, the maximum intensity available with the T10 (CERN PS) beam.

The essential feature of the PSC is in fact the possibility of implementing a clear definition of track position in spite of the cross-talk between adjacent channels. This merit can be confirmed by comparing the probability of single-hit detection with the PSC to that with a conventional threshold discriminator. Fig.12 presents results of such comparison obtained with a PSPM H5828 provided with fine-mesh type dynodes. Compared to the above results, the ratio of single-hit events is slightly lower, $\sim 85\%$ at the maximum, due to the higher cross-talk and noise of H5828. However, the advantage of the PSC to the conventional discriminator is clearly shown, in particular, by the lower ratio of double-hit events.

The time resolution of the whole system, SciFi+PSPM+PSC was also studied and a resolution of ≈ 0.6 ns r.m.s. was obtained for the typical SciFi light yield ≈ 10 photoelectrons.

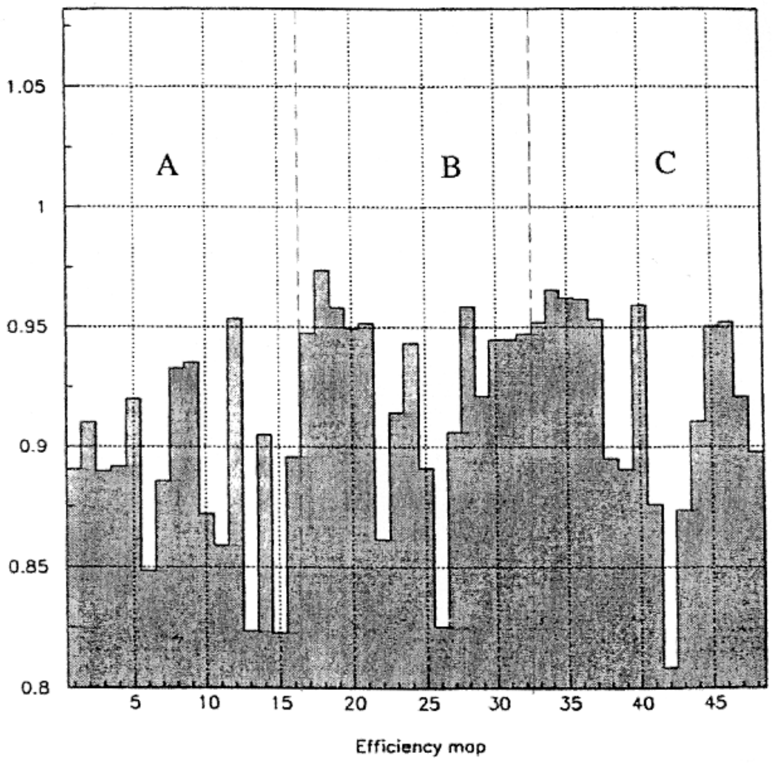


Fig. 6. Uniformity of the detection efficiency for 3 tubes (U_A=780 V, U_B=800 V, U_C=780 V).

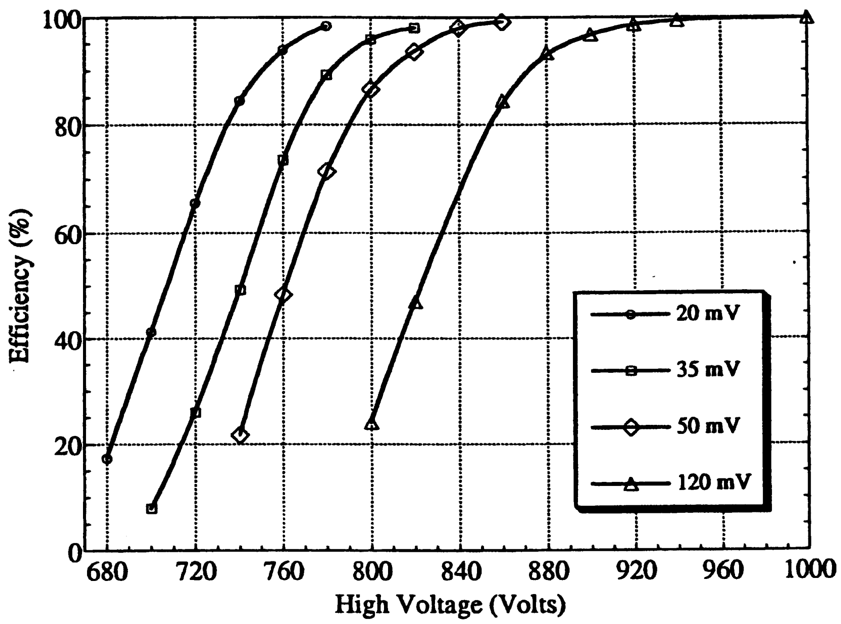


Fig. 7. Scan of the detection efficiency as a function of operation voltage. The threshold values are indicated.

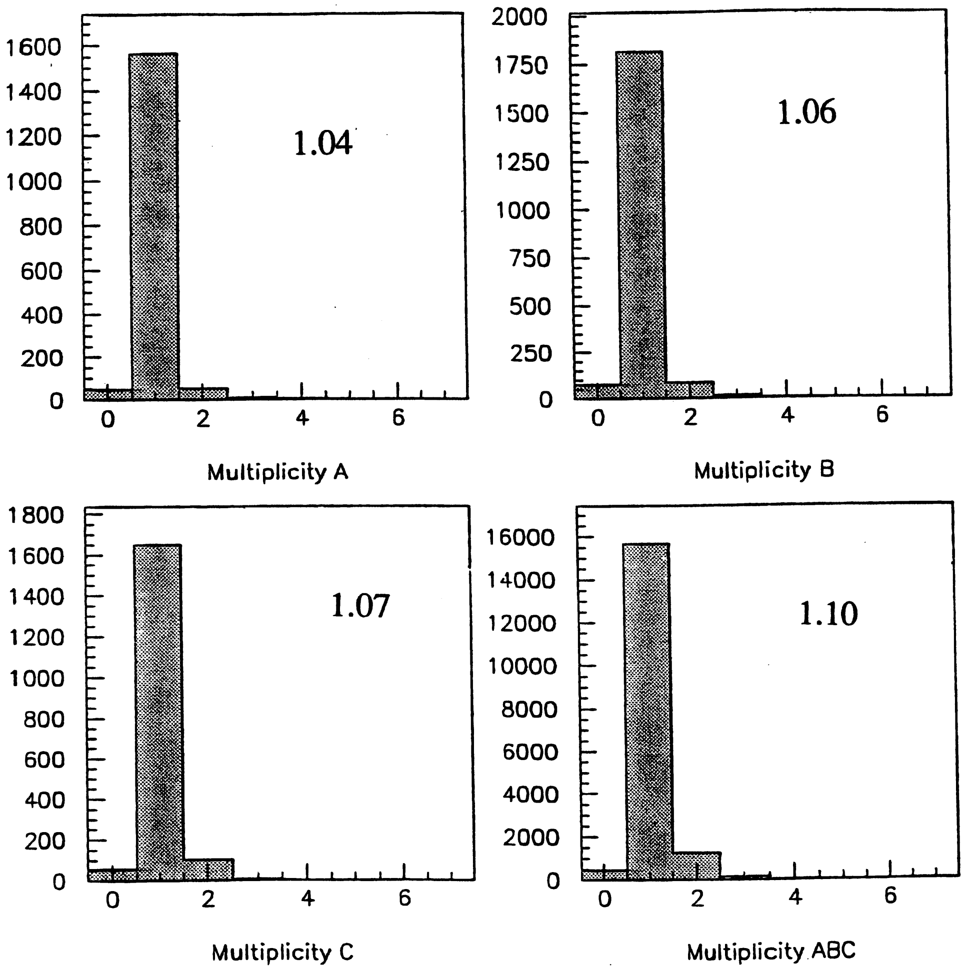


Fig. 8. Multiplicity histograms (U_A=800 V, U_B=820 V, U_C=785 V, U_{thr}=35 mV). The multiplicity values for each tube and total are shown.

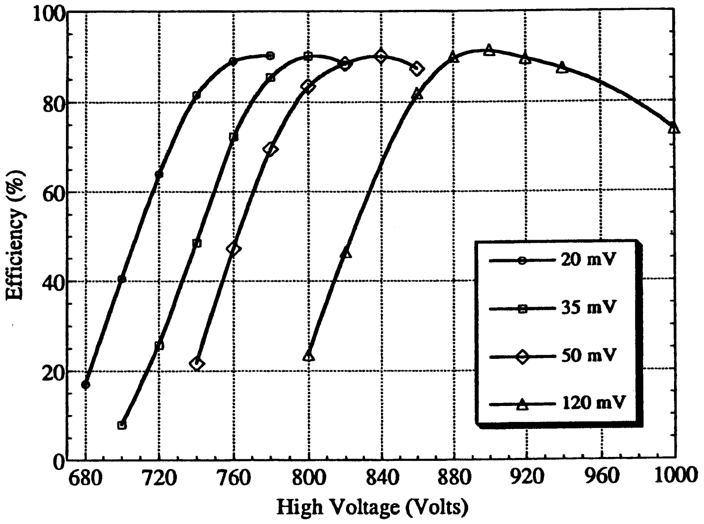


Fig. 9. Relative efficiency for multiplicity equal to 1 (single hit events).

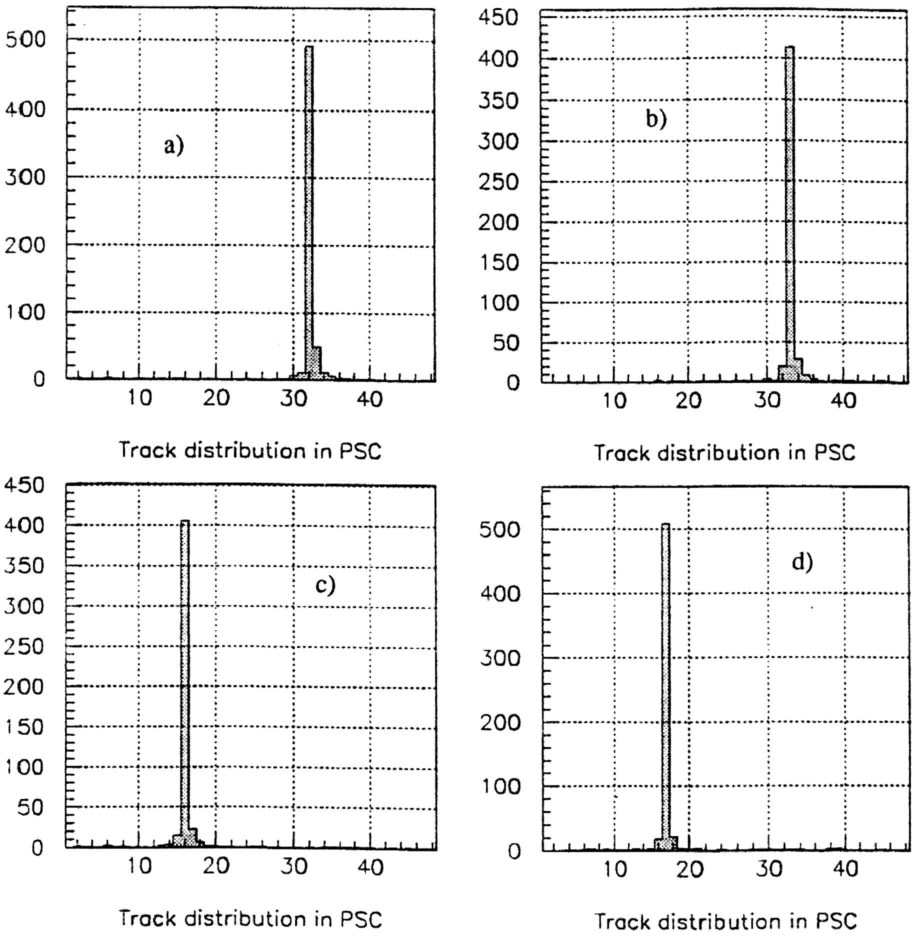


Fig. 10. Track distributions for channels: 32 (a) and 33(b) — PSC boundary effect, 16(c) and 17(d) — boundary effect between different tubes.

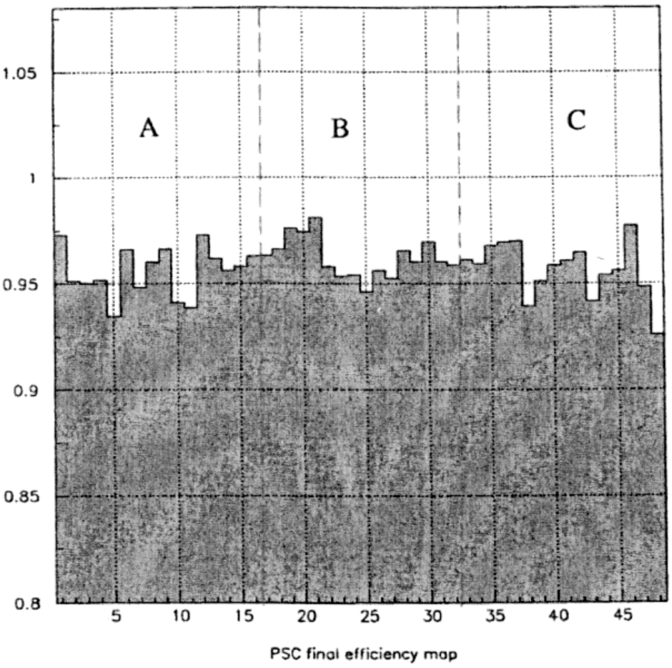


Fig. 11. Uniformity of the detection efficiency after individual channel threshold adjustment (U_A=800 V, U_B=820 V, U_C=790 V, U_{thr}=35 mV).

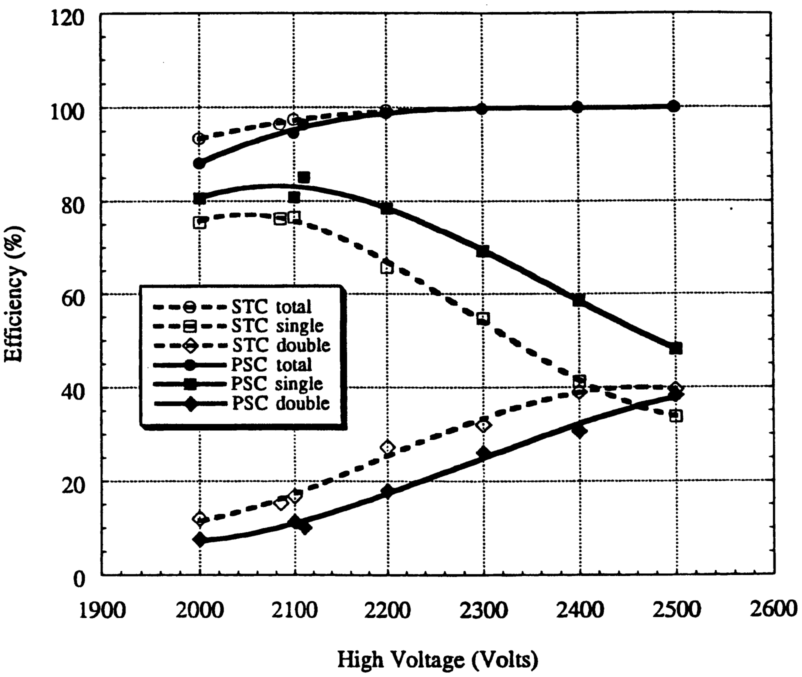


Fig. 12. Comparison of detection efficiencies experimentally obtained with the PSC and with a conventional discriminator (STC).

Conclusions

A new type of front-end circuits has been conceived and realized in view of handling the signals from position-sensitive photomultipliers. The prototypes based on the peak-sensing algorithm were tested in association with a SciFi detector under realistic conditions. Experimental results confirmed an important advantage of the PSC to the conventional threshold discriminator with a clear definition of the track position suppressing the annoying effects of the cross-talk between adjacent channels. It is worthwhile mentioning that the possibility of digitizing the track position in real time with the minimum hit-multiplicity is a crucial condition to pull more precise information on the pattern of produced particles early in the event selection process.

The PSC presented above potentially has a wide range of application, not only for tracking, but also for topological triggering in high luminosity experiments.

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