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Silicon multilayer target for a high intensity charm photoproduction experiment

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Abstract: The silicon active target for the high intensity heavy flavour photoproduction experiment NA14 has been tested satisfactorally. The standard deviation of the gaussian noise distribution of the associated electronics was, on average, 17kev. The stability of the energy-scale calibration was better than about 1% in a month. However it can be improved to 0.5% by monitoring the system over shorter periods.

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1. Introduction

For many years silicon devices have been used in high-energy physics, particularly in the study of coherent interactions on Si nuclei[1],[2].

The possibility of making thin detector slices (≈300μm) and of arranging them into a multilayer target with small inter-layer space made them appear well-suited for the study of short-lived particles photoproduced coherently off the Si nucleus[3].

The main difficulty is that a multiplicity step, which might be the signature of a particle decay, can also be simulated by an e^+e^- pair coming from a γ conversion. This background is usually not negligible in this type of experiment. Furthermore the coherent cross-section is only a fraction of the overall charm production cross-section[4].

The use of silicon chips as microstrip detectors connected to fast electronics of 20-40ns pulse duration, can produce a detector with a spacial resolution $\sigma \approx 12\mu m$ capable of operating in a very high incident flux.

The use of a multilayer telescope associated with a microstrip detector affords very precise vertex determination even in high-energy physics incoherent reactions where a high secondary multiplicity is expected. Therefore, this detector looks promising in the field of incoherent production of charm particles off Si nuclei[4].

In the NA14 experiment installed in the high-intensity hall of the CERN-SPS, the silicon detectors will constitute an active target which will enable a high event collection rate of photoproduced charmed states to be obtained. The multilayer target and the microstrip detectors are associated in order to localize the charmed particles decay vertices in both coherent and incoherent reactions and will hopefully untangle the problem related to the multiplicity step generated by the γ's produced in the target.

A series of tests has been carried out to determine the feasibility of such a complex detector configuration and its behaviour in high fluxes. This paper deals with the performance of the silicon multilayer target.

2. Active target characteristics

2.1. Target lay-out

In the NA14 experiment, the primary electron beam of about $10^8 e^-$/burst generates a bremssthralung photon beam of 175GeV of maximum energy. These energetic photons are accompanied by a number of synchrotron radiated soft photons and photons whose energy is in the range 1-10MeV. The electromagnetic background is such that a very high rate of emitted soft electrons is induced in the target.

The NA14 multilayer silicon target (fig 1) consists of 30 silicon detectors (1) spaced by 200µm each, divided in 24 two mm wide vertical strips. This is followed by a 31st detector with 20 two mm wide horizontal strips. All the detectors have 20cm^2 active area and are 300µm thick. The longitudinal granularity allows the reconstruction of the primary and secondary (due to a heavy flavour decay) vertices with an accuracy of 200µm. The transverse granularity permits very high fluxes without degrading the electronic processing of the signals. The 31st detector provides bidimensional information about both the interaction and e^+e^- background pairs generated in the target.

Downstream of the target are located 4 doublets of microstrip detectors. Each doublet consits of two detectors, whose strips are oriented horizontally and vertically. In the forth doublet, the strips are inclined at ±30° to the vertical. The spacing between the doublets is of 1.5cm and the first one is located at 2.5cm from the target. Each microstrip detector has 25cm^2 active area and a strip pitch of 50µm (fig 2) and is 350µm thick. (2

To select a heavy flavour candidate, it is required that a track, offset from the event vertex by more than 80µm, is reconstructed using the informations coming from the microstrip set, and is associated with a step in the charged multiplicity detected by the active target.

2.2. Associated electronics

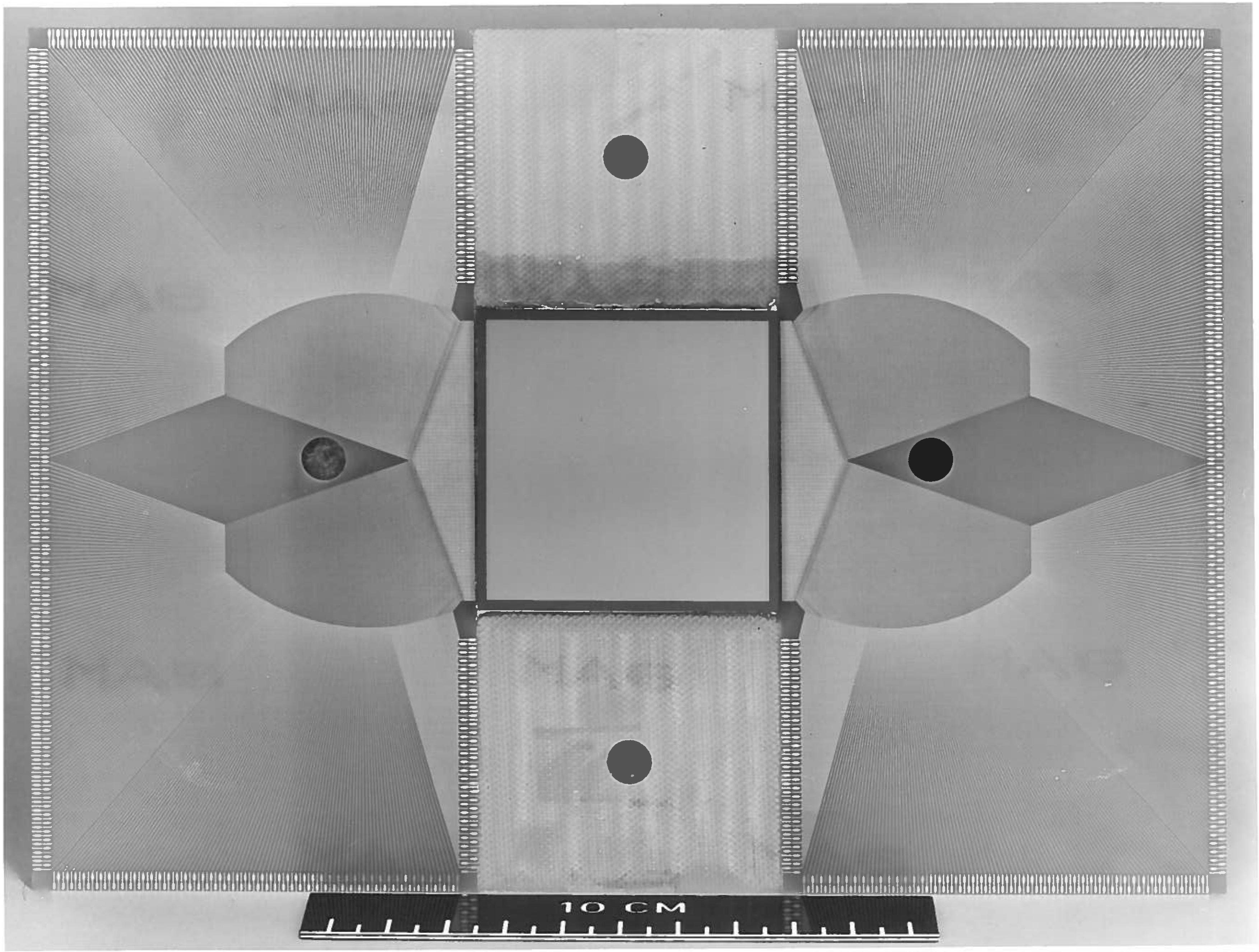
The associated electronics[5], which provides a base-time of the outgoing signal of about 60ns, is able to limit the pile-up effects. It can be operated either as AC or periodically stabilized DC coupled (fig 3), in (3) which the feedback loop is closed in order to update the quiescent condition in the processor during the inter-burst time. The electronics scheme

Fig. 1

Fig. 1 - Side view of the NA14 multilayer silicon target. The beam is coming from the right.

Fig. 2

Fig. 2 - Microstrip detector with an active area of 25 cm^2 and a strip pitch of 50 m.



10 CM

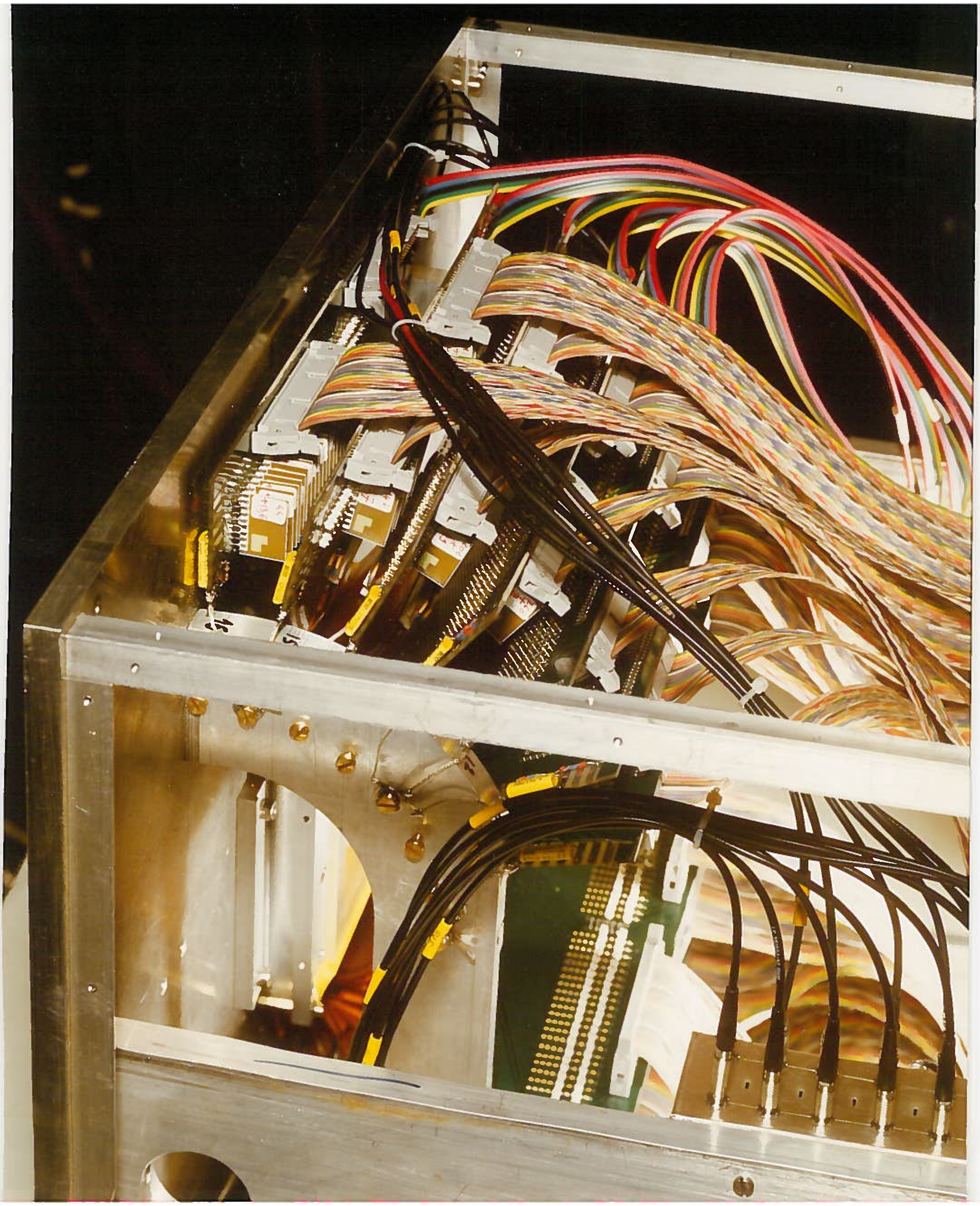
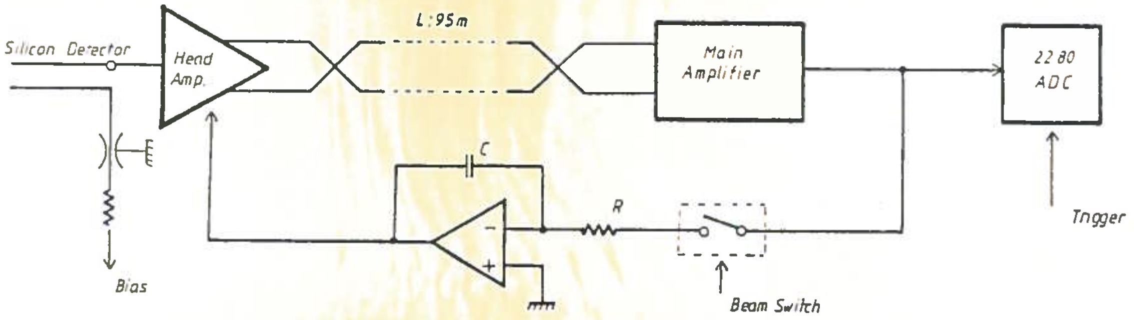
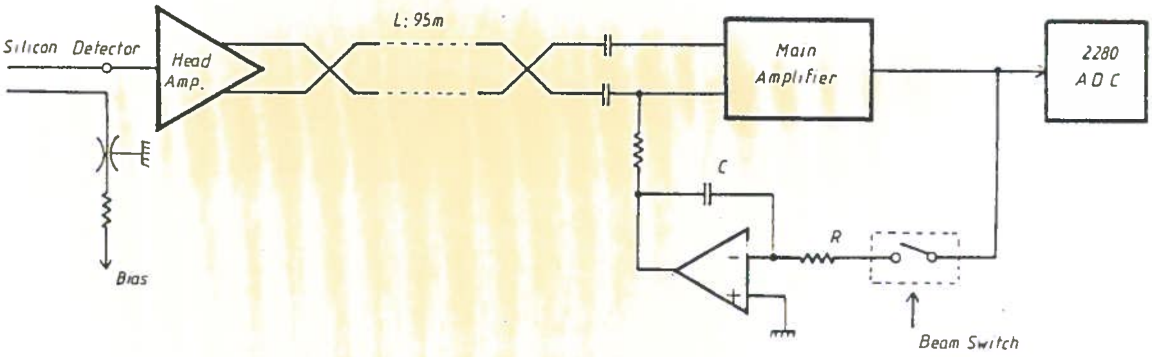


fig. 3



Fully stabilised D.C. coupled chain



AC coupled chain

Fig. 3 - Silicon active target electronics for high fluxes.

is given in[5].

The DC coupling mode has been tested for a 10GeV pion flux between $3x10^5$ and 10^6 π/s, at the CERN-PS. Neither a shift in the pulse-height, corresponding to the most probable energy-loss of the relativistic pion, nor a broadening of the spectrum have been observed. In figs 4a and 4b, the energy-loss spectrum of relativistic muons traversing a 300µm thick strip detector of the active target is given, for an associated electronics AC and DC coupled respectively. (4)

The extended bandwidth of the DC coupled mode, in particular for low frequencies, makes its energy resolution somewhat worse than the one of the AC version. The degradation of the energy resolution is mainly due to 50Hz line parasitic pick-up and to low frequency components of the noise generated by a thick film carbon resistor used in the hybrid circuit (1/F noise). The standard deviation of the Gaussian noise distribution is, on average, 17.7keV and 20.7keV for AC and DC coupled mode respectively.

The measured counting rate in the more exposed target strip detector was $\approx 6x10^5$ counts/burst. Thus in order to have the best signal-to-noise ratio the AC coupling mode has been introduced in the electronics associated to the active target.

The preamplifiers were located near the target (fig 1) and the line receivers about 90m away. The readout was provided by 2282 LeCroy charge sensing ADC's. The gate was 70ns long.

3. Performance of the Silicon target

3.1. Features of silicon detectors and associated electronics

The target has been exposed in the NA14 beam to test its behaviour under running conditions.

The leakage current was, on average, 1.3µA per detector plane. There was no indication of degraded energy resolution due to the leakage current.

It was periodically calibrated with a muon beam. The pedestal position (namely the ADC channel value corresponding to no charge collected) was

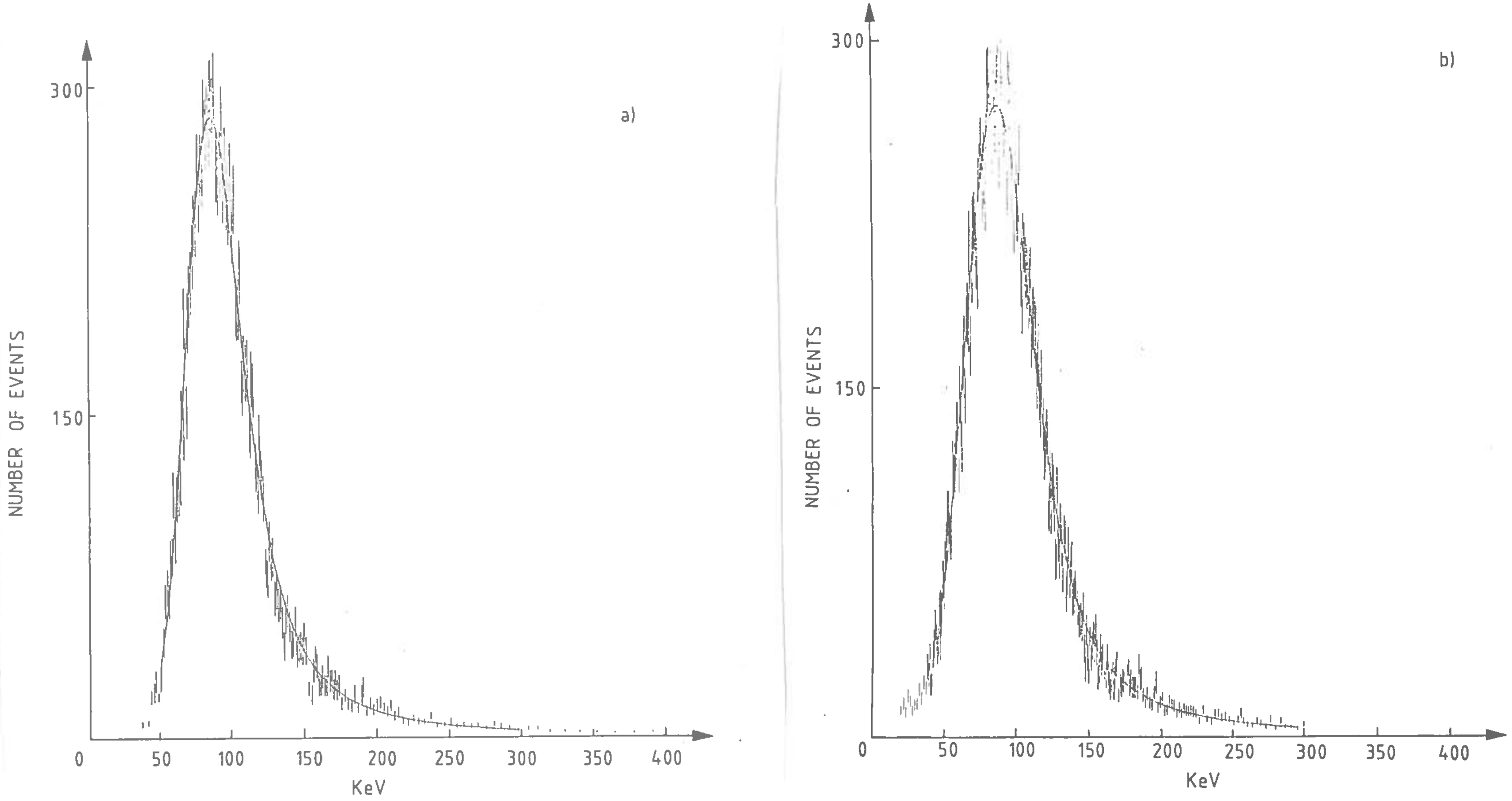


Fig. 4 - Energy-loss spectra sensed by a strip detector in the active target ; a) the electronics is AC coupled, b) is DC coupled. The standard deviation of the Gaussian noise contribution is 25.6 keV and 25.2 keV respectively. The data have been fitted to a Landau distribution convolved by Gaussian (continuous lines).

shifted by about two ADC channels in a month. The most probable energy-loss was about 150 ADC channels (that is about 85keV). Thus the pedestal variation affects the energy-scale calibration by 1%.

The standard deviation of the noise gaussian distribution varied, on average, by about 7.5% (after a month). The energy-loss of n-relativistic particles traversing a detector of thickness x is [6]

$$f(\Delta,x)=1/(\sigma\sqrt{2\pi})\ {}_{-\infty}\int^{+\infty} f_L(\Delta,x)\exp[-(\Delta-\varepsilon)^2/2\sigma^2]d\varepsilon$$

where $f_L(\Delta,x)$ is the Landau distribution for n relativistic particles whose full width at half maximum is $\approx 4\xi$, $\xi=n\xi_1$, $\sigma^2=n\sigma_1{}^2+\sigma^2{}_{noise}$; ξ_1=5.35keV and σ_1=5.5keV for relativistic particles traversing a 300µm thick silicon detector. Thus the variation of σ_{noise} of about 7-10% does not affect the energy-loss reconstruction procedure for n>2 relativistic particles.

In order to have an energy-scale calibration defined at better than 1% it is possible to calibrate the electronics periodically, i.e. every 8-10 hours, by using a test capacitance located at the input of the preamplifier. In this way the energy-scale calibration can be known at about 0.5% and the variation of the standard deviation of the noise gaussian distribution is about 3.5%.

3.2. Beam dump test of the active target

A tungsten dump with a length of 86cm was located downstream of the multilayer target and exposed to the full intensity of the NA14 photon beam. The trigger was formed by requiring that the incident photon interacts in the target and that one or two muons are observed emerging from the dump. In this way an enriched charm sample, with semi leptonic decays, was expected.

The target worked satisfactorally, except for four unbiased layers. In fig 5, an event with a multiplicity step is shown. The interaction layer has sensed an energy-loss compatible with that expected for the coherent recoil of the silicon nucleus. The following layers detect two and others four relativistic particles. On the left side the height corresponding to the most probable energy-loss of the 10 relativistic particles is given. The spurious hits around the interaction are due to the electromagnetic background.

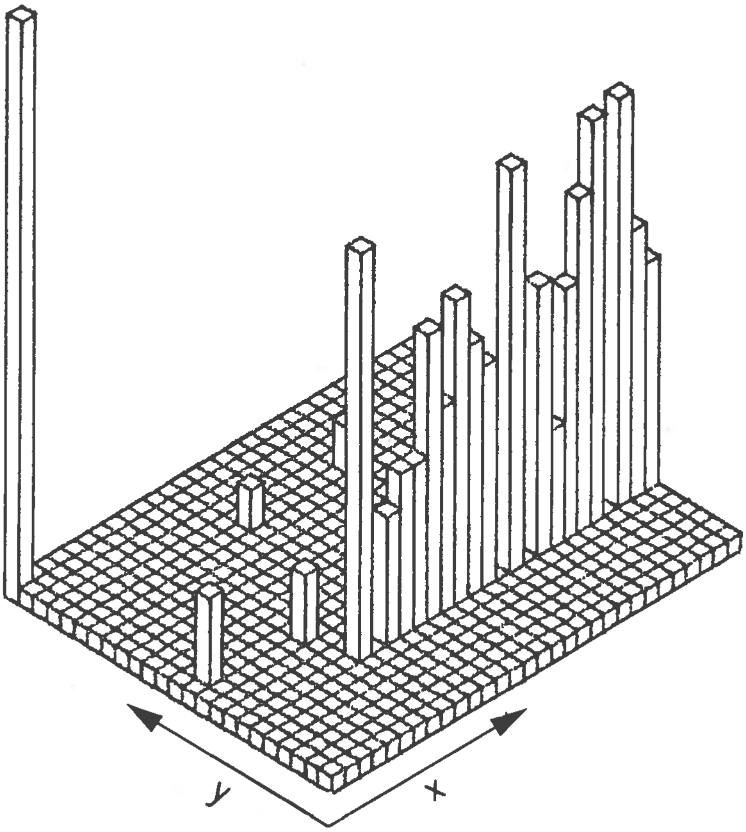


Fig. 5 - Multiplicity step sensed by the NA14 multilayer target. The y-axis is 4 cm long and the x-axis is 1.5 cm long. At left, the energy-loss corresponding to 10 relativistic particles is given.

4. Conclusion

The silicon active target has been shown to work satisfactorally at the full intensity of the NA14 photon beam.

The energy-scale calibration of the detectors and the associated electronics varied by about 1% over a month. However it is possible to improve it to about 0.5% by monitoring the system every 8-10 hours.

The noise contribution to the measured energy-loss distribution does not impair the reconstruction procedure for n>2 relativistic particles traversing the detector.

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