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Section IX. Silicon detectors

POSITION SENSITIVE SILICON DETECTORS INSIDE THE TEVATRON COLLIDER *

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Four position sensitive silicon detectors have been tested inside the Tevatron beam pipe at Fermilab. The system is the prototype of the small angle silicon spectrometer designed to study primarily $p-\bar{p}$ elastic and diffractive cross-sections at the Collider of Fermilab (CDF).

Particles in the beam halo during $p-\bar{p}$ storage tests were used to study the performance of the detectors. Efficiency, linearity of response and spatial resolution are shown. Measurements performed at different distances from the beam axis have shown that the detectors could be operated at 8.5 mm from the beam with low rates and no disturbance to the circulating beams. This distance corresponds to about 11 times the standard half-width of the local beam envelope.

The behaviour of the detectors with the radiation dose has also been investigated.

1. Introduction

The Collider Detector of Fermilab (CDF) will include two spectrometers at extremely small angles (down to $\theta \sim 0.2$ mr) around the beam axis on the left and right side of the intersection. These spectrometers will exploit the machine dipoles and quadrupoles for bending and will employ seven detector stations at various distances from the beam–beam crossing, ranging from ~ 5 to ~ 55 m. The detectors will be multistrip silicon diodes.

The physics addressed is small angle elastic scattering, total $p-\bar{p}$ cross section and inelastic diffraction, and, in general all interesting diffractive-like processes [1,2].

The CDF spectrometers represent a step forward compared to the "roman pot" system developed at CERN and based on conventional detectors in mobile frames outside the beam pipe [3]. Our silicon detectors operate under vacuum and can therefore reach smaller distances from the beams. Moreover, due to specially designed mechanical supports, systems with complete azimuthal coverage can be implemented where useful for physics.

2. The prototype telescope

During the Tevatron 1 test period (September–October '85) a prototype telescope of four silicon detectors was installed on the machine and tested for a number of important features. These detectors, with an active area of 13 cm^2, were ~ 900 μm thick and had a petal-like shape as illustrated in fig. 1. 100 μm wide aluminum electrodes were obtained by means of a lithographic process on the surface of the detectors. The strips run along approximately constant polar or azimuthal angle, 1 mm apart from each other.

The system was designed for operation in the high vacuum of the Tevatron and the detectors were mounted on a supporting rod held on a movable flange-bellow system which was remotely operated via the standard accelerator network. Depending on the beam conditions in the various runs (position of the beam axis and beam

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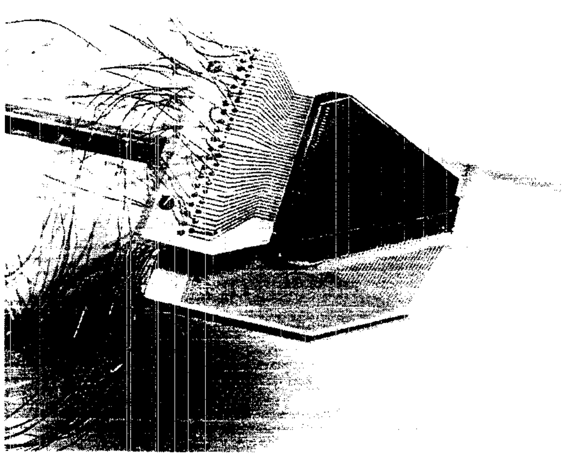

Fig. 1. The prototype telescope mounted on the supporting rod.

size), the distance of the detectors from the beam could be accordingly varied with great accuracy. The detectors were connected to the outside world through multipin high vacuum feedthroughs.

Besides the detectors themselves, all materials operating in vacuum, including signal cables, were carefully selected in order to avoid any virtual leakage which could cause a local vacuum deterioration. The preamplifiers were located just outside the flange, on the feedthroughs pins themselves. The signals were transferred through the CDF "rabbit" system and then processed on an IBM-PC. A sketch of the test set-up is shown in fig. 2.

3. Test results

As it was shown elsewhere [4], by exploiting the resistive layer of undepleted silicon at the ohmic contact it is possible to use the charge division between adjacent strips to determine the position of a crossing particle with an accuracy much better than the strip pitch; in principle, the accuracy is limited only by the signal-to-noise ratio and, in our case, should amount to less than 100 μm.

The charge partition mechanism was accurately monitored using crossing particles from the beam halo. Minimum ionizing particles were selected by requesting a double coincidence between two out of four detectors. Under these conditions the collected events were subdivided in two main categories, single and double hit events, depending on the number of strips fired per event. The single hit events, corresponding to particles that hit directly the strips, were a small fraction of the total. Their pulse height distribution (fig. 3) shows a clear Landau peak.

The pulse height distribution of the double hit events, corresponding to particles crossing the interstrip region,

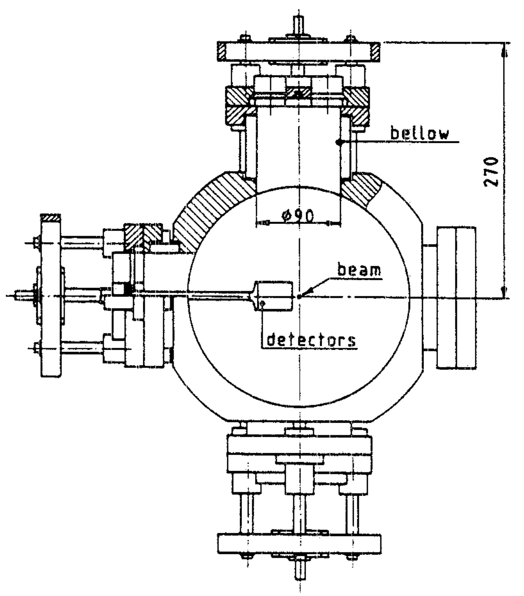

Fig. 2. The mechanical assembly of the detectors inside the Tevatron beam pipe.

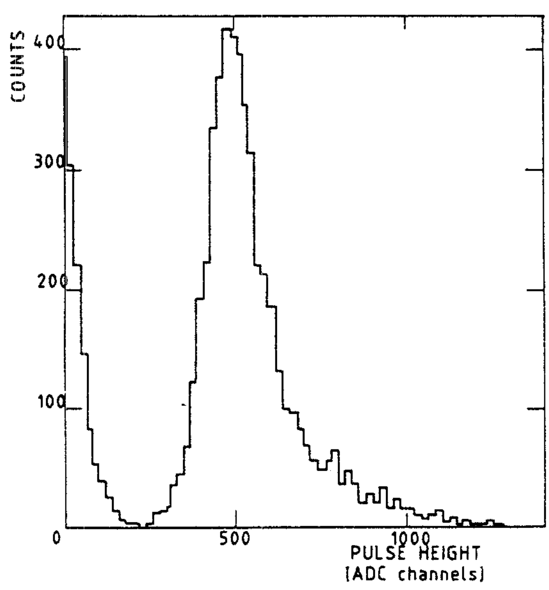

Fig. 3. Pulse height distribution for "single hit" events.

is a flat distribution with a tail (fig. 4a), but a simple sum of the pulse heights collected by two adjacent strips shows the minimum ionizing peak (fig. 4b.). The signal to noise ratio in this case was 13 to 1.

Due to the large angular divergence of the particles in the beam halo and to the small number of measurements (two points per coordinate), we can give only some indications on the detector resolution. In fig. 5a we show a number of impact points reconstructed on detector 3. The corresponding positions as reconstructed on detector 1 are shown in fig. 5b, where the influence of the large angular spread of the particles is quite clear (consider that the two detectors are only 7 mm apart). The plot of the difference pos_3-pos_1 is shown in fig. 6. Again the angular spread overcomes the spread due to the finite detector resolution, so, unfolding the particles divergence, we can only conclude that our data are consistent with the expected resolution of 80 μm.

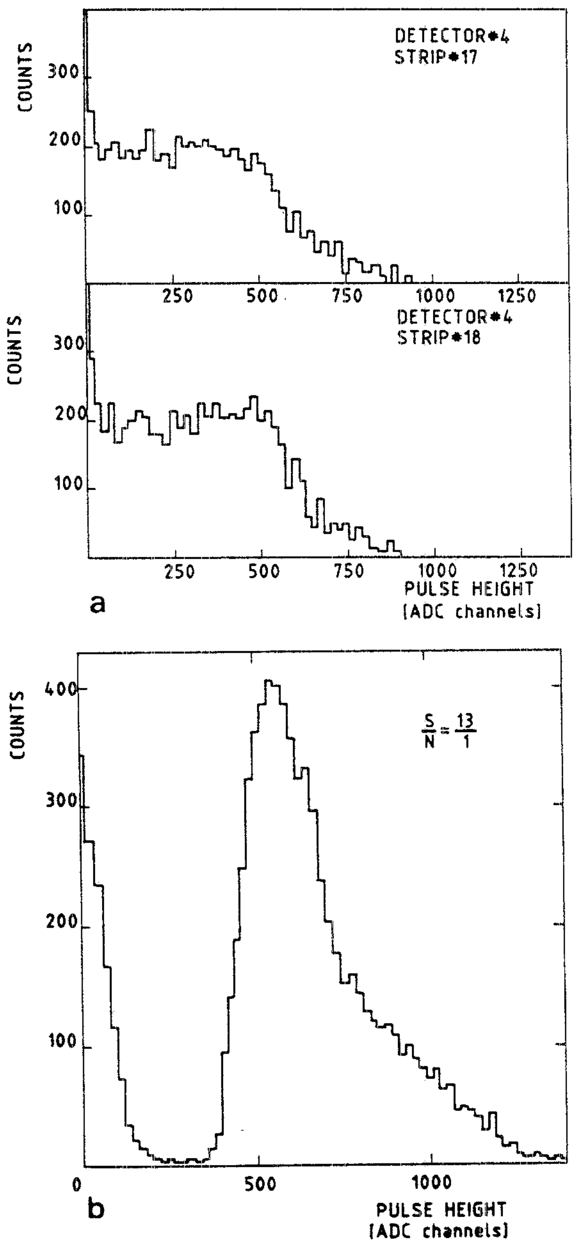

Fig. 4. (a) Pulse height distribution for "double hit" events. (b) Sum of the pulse heights collected by two adjacent strips.

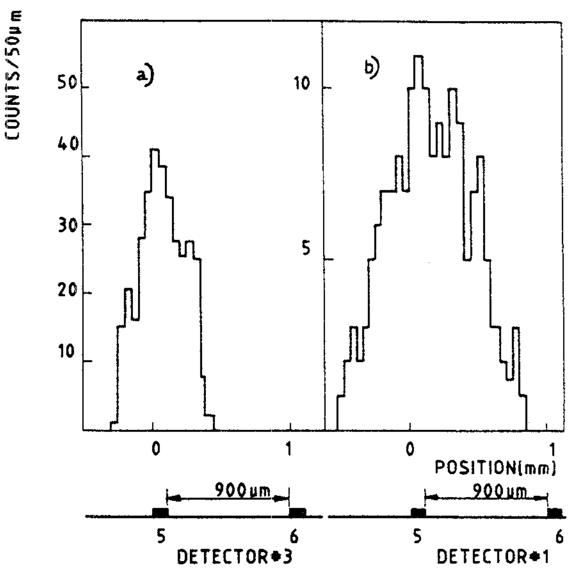

Fig. 5. (a) Reconstructed impact points on strip 5 of detector 3. (b) Corresponding impact points as reconstructed on detector number 1.

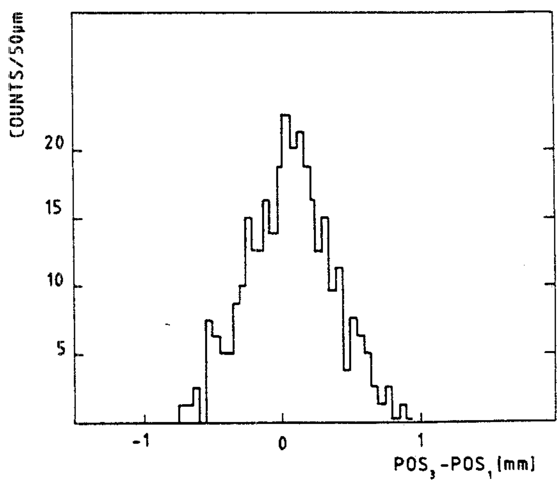

Fig. 6. Distribution of the difference pos_3-pos_1.

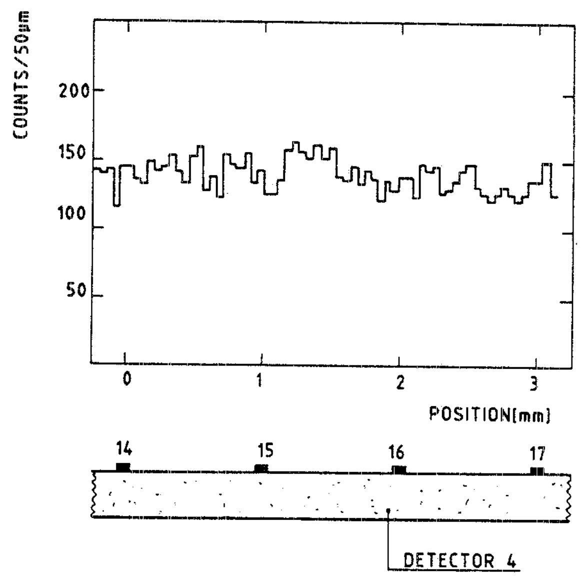

Fig. 7. The response of detector 4 to a uniform flux of particles.

The relative detection efficiency for the four detectors was found to be greater than 99%.

The linearity of response in the interstrip region has been checked plotting the impact positions, as reconstructed by the detectors, when the telescope was positioned at a distance from the beam at which the illumination was approximately uniform (fig. 7). All in all we conclude that the detectors behave according to expectations.

A number of scans of the beam halo was done both in high and low beta optics, by measuring the rate of minimum ionizing particles crossing the telescope when the detectors were moved toward the beam (in steps of 100 μm).

The results are summarized in fig. 8. In both cases a distance smaller than 10 mm from the beam axis was easily reached without affecting the performance of the detectors or disturbing the stored beam. This distance corresponds to 11 times the standard beam half-width and this would indicate that $\theta \leq 0.2$ mr will be reachable in the actual experiment.

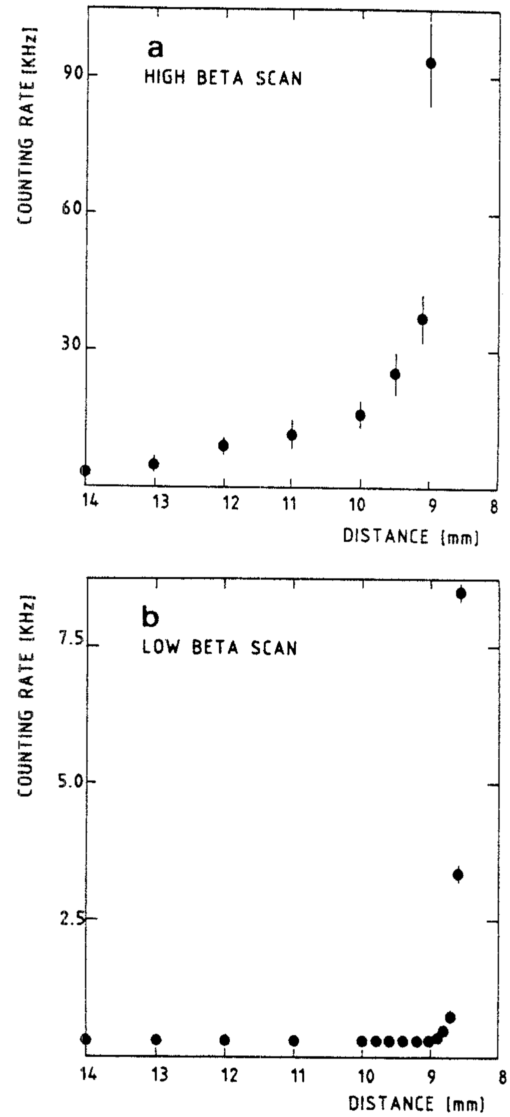

Fig. 8. (a) Beam halo scan for high β optics. (b) Beam halo scan for low β optics.

4. Radiation resistance and conclusions

The radiation intensity on the detectors was continously monitored during the test. Measurements performed with thermoluminescence dosimeters positioned on the flange and all around the beam pipe showed an overall integrated dose of about 500 rad after more than one month of operation.

Since previously performed tests with a high intensity beta source had shown, that for an irradiation up to 10^4 rad there was no practical effect on the electrode response, we conclude that the planned cross-section measurements are feasible, since in similar future running conditions the detectors will be able to stand one full year of operation.

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