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accuracy with which the ε_i values are determined in both cases is given by the number of events in the η meson peak or, more precisely, by the number of triggerings of each of the elements of the avalanche hodoscope detector. Let us note that the angular dependence of the amplitude is automatically taken into account in this calibration method with an accuracy of the angular size of the element, i.e., with $\Delta\theta \sim 20/L$, where L (cm) denotes the distance from the target to the spectrometer; in other words, corrections for the angular dependence are implicitly contained in the coefficients ε_i obtained.

In the proposed calibration with resonances, the coefficients ε_i are directly related to the tabulated masses of the neutral mesons, whereas after a calibration on an electron beam, certain differences of the e and gamma avalanches, incomplete absorption, etc. must be taken into account. Similar algorithms can be developed for resonances in a system with more than two gamma quanta.

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COORDINATE-SENSITIVE DETECTOR ON THE BASIS OF MICROCHANNEL PLATES

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A coordinate-sensitive detector built on the basis of microchannel plates and a multianode collector is being described. The sensitive surface of the detector has a diameter of 24 mm; the spatial resolution is better than 75 μm; and the dead time is 10 μsec. The coordinates of each particle recorded are determined from the ratio of the charges which are incident on 19 collector elements. The electronics comprises an analog part and a digital part, both controlled by a microcomputer.

Coordinate-sensitive detectors on the basis of microchannel plates can record particle coordinates in the plane of a field of vision with a diameter of a few centimeters. The recordings are possible with an accuracy of the order of several dozen microns and with a time resolution of up to 1 nsec. The recordings are characterized by a low intrinsic noise level of $\sim 1\ \mathrm{cm}^{-2}\cdot\mathrm{sec}^{-1}$ [1-4]. Since their applicability range is very broad, coordinate-sensitive detectors have been successfully used to record electrons, ions, and neutral particles, and ultraviolet radiation, x rays, visible, and infrared radiation. The present paper describes a two-dimensional coordinate sensitive detector with analog retrieval of the coordinate in-

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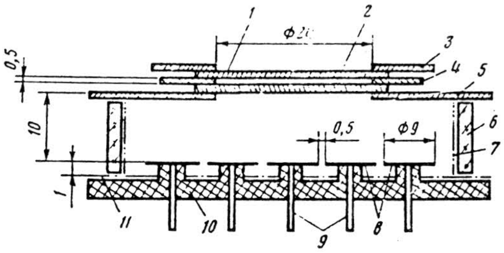

Fig. 1. Design scheme of the coordinate-sensitive detector: 1) first microchannel plate; 2) second microchannel plate; 3, 5) metal rings; 4) ceramic ring; 6) shielding cylinder; 7) semiconducting layer; 8) anode disks; 9) anode output leads; 10) ceramic plate; 11) conductive layer.

formation. Certain detector characteristics are reported (preliminary results have been published earlier in [5]).

In the coordinate-sensitive detector under consideration, the coordinates of a recorded particle are determined from the center of gravity of the electron avalanche when the charge is subdivided between insulated collector elements, i.e., the anodes. Such a collector is relatively simple to produce; when compared with resistive anodes, the noise currents, which limit the spatial resolution, are small in the collector and the nonlinearity in the coordinate determination can be easily eliminated.

The sensitive element of the coordinate-sensitive detector is formed by a block of two consecutively arranged microchannel plates with a sensitive field of 24 mm, a channel diameter of 12 μm, and an angle of 6° of channel inclination relative to the normal to the surface of the microchannel plates (Fig. 1). The characteristics of a block of microchannel plates in particle recording are well known [2]. The arrival of a particle at the detector causes an electron avalanche (containing 10^7 electrons) at the output of the second microchannel plate. The avalanche is incident on a collector consisting of 19 metal anode-disks with a diameter $d = 9$ mm; the disks form a hexagonal structure (Fig. 2) which resembles that used in gamma cameras [3]. The microchannel plates and the collector are assembled with the aid of four ceramic tubes running through openings in the collector and with metal rings fixing the positions of the microchannel plates. The gap between the microchannel plates is defined by a ceramic ring. The anodes are soldered to pins which are attached to 19 protrusions on a ceramic plate (Fig. 1). The surface of the ceramic plate between the protrusions is silver-coated, is on the potential of the collector, and collects the electrons which were flying between the anodes. The nonsensitive zone between the individual anodes and the collectors is relatively large but nonconductive surfaces are missing on the path of the electron avalanche, and it is therefore not possible that distorting electrostatic fields develop.

In order to create a plane-parallel electric field in the gap between the second microchannel plate and the collector and in order to reduce the influence of edge effects, charging of the insulators, and external electric fields, a resistive layer (resistance 10^6-10^7 Ω) was applied to the inner surface of the glass ring. The resistive layer was produced by annealing chromium oxide applied as a paste to the surface. One face of the ring was connected with the output of the second microchannel plate, whereas the second face was on collector potential.

The characteristics of the coordinate-sensitive detector were investigated in a vacuum chamber under a pressure of $(1\text{-}3)\cdot 10^{-6}$ torr. The turbomolecular pumps used for evacuation and a fluid trap almost fully precluded contamination of the coordinate-sensitive detector by oil vapors. The chamber had provisions for irradiating the coordinate-sensitive detector with beams of ions and neutral atoms of various elements with energies of 500-3000 eV or with ultraviolet light ($\lambda = 147$ nm) from a source with a diaphragm (diameter of the diaphragm 10-300 μm) mounted at a distance of 50 cm from the coordinate-sensitive detector. The counting rate of the coordinate-sensitive detector and the pulse-amplitude distribution in coordinate determinations were controlled through pulses derived from the output of the second micro-

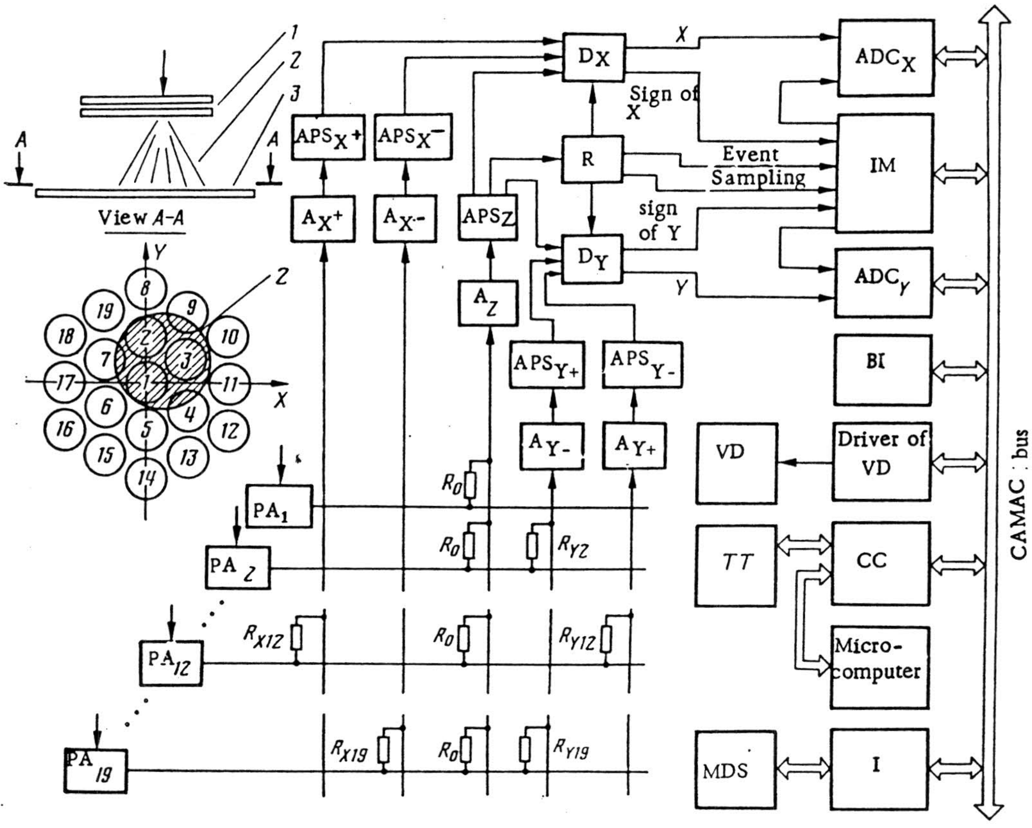

Fig. 2. Circuitry of the electronics and system for the retrieval and processing of the signals from the coordinate-sensitive detector: 1) block of microchannel plates; 2) electronic avalanche; 3) collector; A) amplifier; APS) pulse shaping amplifier; D) dividing stage; R) rejecting stage; BI) bus indicator; IM) interface module; VD) video display; TT) teletype; CC) crate controlling stage; MDS) magnetic disk storage; I) interface.

channel plate. These pulses also allowed the determination of the time of particle arrival at the detector with an accuracy of up to 1 nsec. The collector of the coordinate-sensitive detector was on ground potential; the input surface of the first microchannel plate was on a potential of ∿−2 kV. The conditions of operation of the microchannel plate block were initially selected by varying the high voltage. The high-voltage divider was mounted outside the vacuum chamber so that the conditions of operation of the plates could be changed during operation of the detector.

Depending upon the point at which the particles are incident on the detector, the electron avalanche is split between the elements forming the collector. The X and Y coordinates of the particle recorded can be determined [3] with the formulas

$$\begin{aligned} X &= K\Sigma f_{Xi}q_i/q_0, \\ Y &= K\Sigma f_{Yi}q_i/q_0, \\ q_0 &= \Sigma q_i, \end{aligned} \qquad (1)$$

where q_i denotes the charge which is in incident on the i-th anode; f_{X_i} and f_{Y_i} denote weight coefficients corresponding to the coordinates of the center of the i-th anode in the corresponding axes; and K denotes a proportionality coefficient; the summation is extended over all the anodes. It is assumed in this determination of the coordinates that q_i depends linearly upon the particle coordinates; the relation is really nonlinear. Therefore the formulas (1) distort the image obtained with the coordinate-sensitive detector, and the magnitude of the distortion depends upon the ratio of the anode-disk diameter to the transverse dimensions of the electron avalanche at the collector. Computer calculations have shown that the optimum value of the ratio is 0.4-0.5.

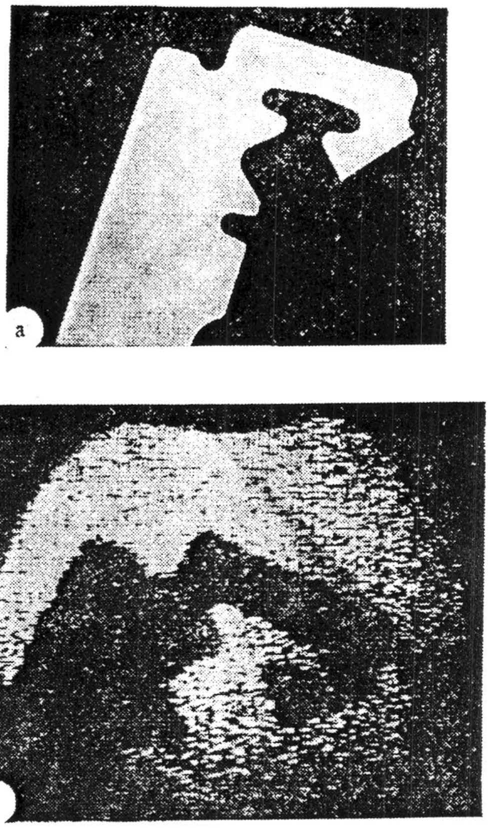

Fig. 3. a) Photograph of a piece of a razor plate; b) video screen image of the razor blade shadow in an ion beam; image obtained with the aid of the coordinate-sensitive detector.

Figure 2 shows the circuitry of the electronics and the system of retrieval and processing of the coordinate information obtained with the coordinate detector described. The analog portion, the detailed circuits of which have been presented in [5], delivers two pulses with amplitudes proportional to the values of X and Y coordinates, respectively. The subsequent signal processing is digital. The coordinate origin is assumed at the center of the central collector element. This makes it necessary to generate separate signals for the positive and negative values of the X and Y coordinates but the coordinate errors are uniformly distributed over the sensitive detector surface. The signals from each of the collector elements are amplified by the stages of a preamplifier PA_i which is built in the form of charge-sensitive sections with a signal-decay time constant of $\sim$200 μsec. The capacity of the feedback circuit of PA_i is 2.2 pF. The output signals of PA_i are added through resistors R_i in four circuits corresponding to the positve and negative coordinates (X_+, X_- and Y_+, Y_-). The ratio of the resistor values R_{X_i} and R_{Y_i} determines the weight coefficients f_{X_i} and f_{Y_i} of the summation in Eq. (1) for developing the coordinate signals.

The signals which were collected through the resistors are applied to amplifiers and corresponding pulse-shaping amplifiers APS. The output signals of APS are almost rectangular with a length of $\sim$2 μsec. Resistors R_0 are used to pick up a certain fraction of the signals from all preamplifiers (i.e., from all the collector elements). The resulting signal is amplified by amplifier A_Z and pulse-shaping amplifier APS_Z. The amplitude U_Z of the output signal of this stage is proportional to the total charge q_0 of the avalanche at the output of the microchannel plate block. The stages D_X and D_Y for signal dividing, which are multiplying stages of the four-quadrant type [6], derive the amplitude difference of the pulses obtained from stages APS_{X+} and APS_{X-} and APS_{Y+} and APS_{Y-}. The amplitude differences $|U_{X+} - U_{X-}|$ and $|U_{Y+} - U_{Y-}|$ are normalized to the amplitude U_Z. Thus, signals with an amplitude proportional to the Cartesian coordinates X and Y are generated in the output stages D_X and D_Y, respectively. These signals have trapezoidal shape with a rise and decay time of $\sim$0.5

μsec and a flat 1-μsec-long top section. Stages D_X and D_Y develop additional logic signals indicating the sign of the respective coordinate.

In order to preclude the recording of events in which two particles arriving in the coordinate-sensitive detector with a delay $\lesssim 2$ μsec cause signal overlapping, the rejecting stage R was introduced. R receives pulses from pulse-shaping amplifier APS_Z and generates strobing signals and signals prohibiting the data processing. No processing takes place and no events are recorded if the amplitude-sampling requirement $0.67\bar{q} < q_0 < 1.33\bar{q}$ is not satisfied, where $\bar{q}$ denotes the average charge in an avalanche; the charge of 10^7 electrons was assumed to be equal to the average charge.

The result of the analog processing of the collector signals in the charge-sensitive detector is obtained in the form of two signals with an amplitude corresponding to the X and Y coordinates of the particle recorded; in addition four logic signals are obtained: the EVENT signal indicates that a particle was recorded and that conversion has taken place; the SAMPLING signal indicates that the conditions for sampling are being satisfied; SIGN X and SIGN Y signals refer to the signs. The dead time is $\lesssim 10$ μsec.

The system for the retrieval and processing of the information arriving from the analog part of the coordinate-sensitive detector was built with an "Élektronika-60" microcomputer and CAMAC modules. A special interface module IM was used in addition to standard modules. The pulses with amplitudes proportional to the X and Y coordinates were applied to ten-bit analog-digital converters with a conversion time $\leqslant 24$ μsec; the four logic signals were applied to the interface module which records two "coordinate" (X and Y) pulses corresponding to the same particle. Since only the interface module received a logic signal indicating that an event has taken place whereas "coordinate" pulses are fed into the analog-digital converters, the interface module disables the inputs of the analog-digital converters and its own input and stores in a special register the state of the logic levels while the microprocessor proceeds to processing of the event's information. The readings of the analog-digital converter and of the interface register are read out. Furthermore, the program determines the reliability of an event (check whether the sampling condition is satisfied), performs the required transformations on the particle coordinates, can write out these coordinates on, say, a magnetic disk, or can display them on a video screen or teletype, and can determine certain characteristics. Once the processing has been terminated, the interface upon a computer command enables the inputs of the analog-digital converters and enables the input of the interface proper, and the system is then ready for receiving and processing the next event. Since the digital processing is made with standard equipment and since the computer program was written in a high-level language, the time required for the processing of one event is relatively long, namely ∿1 msec. When a specialized digital part is built and inserted, the processing time can be reduced to 10-20 μsec.

A 10-20-μm-wide straight slit, which was illuminated with, say, ultraviolet radiation, was placed directly before the coordinate sensitive detector to determine its characteristics. The slit width was chosen much smaller than the spatial resolution of the coordinate-sensitive detector, and the width of the resulting image of the slit is therefore the response to a practically pointlike perturbation and can be assumed as indicative of the resolution of the setup. It was found that the spatial resolution ξ (total width on half the height) depends upon the potential difference ΔU between the output of the second microchannel plate and the collector. For $10 < \Delta U < 30$ V the ξ value did not exceed 75 μm. The deviations from the straight line of the slit image characterize the nonlinearity of the coordinate-sensitive detector. In the case of a 10-mm-long slit, the mean-square deviation of the image from a straight line amounted to 120 μm.

Figure 3 demonstrates the capabilities of the coordinate-sensitive detector which we built. Figure 3b shows the image of the shadow portion of a razor blade piece in a flux of He^+ ions; the image is displayed on a video screen. Twelve-thousand ions were recorded. Figure 3a is for comparison a photograph of the razor blade. The nonuniformity of the bias illumination was caused by the inhomogeneity of the ion beam. The bright dots on the background of the shadow are caused by the intrinsic noise of the microchannel plate block. The noise is rather uniformly distributed over the input surface of the coordinate-sensitive detector. A certain lack of sharpness and distortions in the image are caused by poor performance of the display.

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WIDE-APERTURE TRANSITION RADIATION DETECTOR FOR SEPARATING ELECTRONS FROM HADRONS

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The characteristics of a multichannel detector of transition radiation were investigated; cluster counting is the principle of operation of the detector which consists of three modules, each containing a radiation emitter and a proportional chamber. A 10-μm-thick Lavsan film was used as the radiation emitter. At a momentum of 26 GeV/c, the efficiency of recording electrons is 77% and the coefficient of π meson suppression reaches 10. The possible use of the detector for separating electron-positron pairs in hadron-nuclear interactions was studied.

It was shown in [1, 2] that the recording of x-ray transition radiation by cluster counting is characterized by several advantages over measurements of the total ionization, namely because the coefficient of separating electrons from hadrons is increased, the response becomes faster, the recording is simplified because pulse counters are used in place of amplitude-digital converters, and the requirements to the stability of gas amplification and the stability of the electronics can be reduced. But the authors of [1, 2] used radiation emitters of lithium foils or carbon fibers which are technologically hard to employ in wide-aperture detectors. The goal of the present work was to develop a large-diameter x-ray transition radiation detector for recording electron-positron pairs with an effective mass of ~ 3 GeV/c^2 which are generated in interactions of hadrons with nuclei. Such a detector must have the smallest possible amount of material along the beam, must efficiently separate electrons and pions, must be short, and must work efficiently under high loads ($\sim 5 \cdot 10^6$ particle/sec).

Calculations which were made with the program described in [3] have shown that for Lavsan-film radiation emitters (which are very simple from the technological viewpoint) the optimum film thickness is 10 μm and the optimum gap width is 1 mm in the problem which we consider. Such radiation emitters have been prepared by cementing Lavsan film to duraluminum rings and subsequent heating by hot air to obtain stretching. The detector consists of three

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