OPERATING CHARACTERISTICS OF A PROTOTYPE HIGH ENERGY GAMMA-RAY TELESCOPE

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1. Introduction. The field of gamma-ray astronomy in the energy range from ten to several hundred MeV is severely limited by the angular resolution that can be achieved by present instruments. The identification of some of the point sources found by the COS-B mission and the resolution of detailed structure existing in those sources may depend on the development of a new class of instrument (1). The coded aperture mask telescope, used successfully at X-ray energies (2), holds the promise of being such an instrument. We have operated a prototype coded aperture telescope in a tagged photon beam ranging in energy from 23 to 123 MeV. The purpose of the experiment was to demonstrate the feasibility of operating a coded aperture mask telescope in this energy region. This paper reports some preliminary results and conclusions drawn from some of the data resulting from this experiment.

2. Apparatus and Procedure. The apparatus is illustrated in figure 1. The incident beam passed through a mask, an anticoincidence counter, a position sensitive gamma-ray detector, a time-of-flight (TOF) counter, and a scintillation calorimeter. For the runs reported here, the mask consisted of an array of tungsten blocks, 6.3 millimeters square, arranged in a checkerboard pattern. The blocks were 2.7 radiation lengths thick and produced a spatial modulation of the beam that passed through the mask. The position-sensitive detector consisted of a stack of three drift-chamber modules.

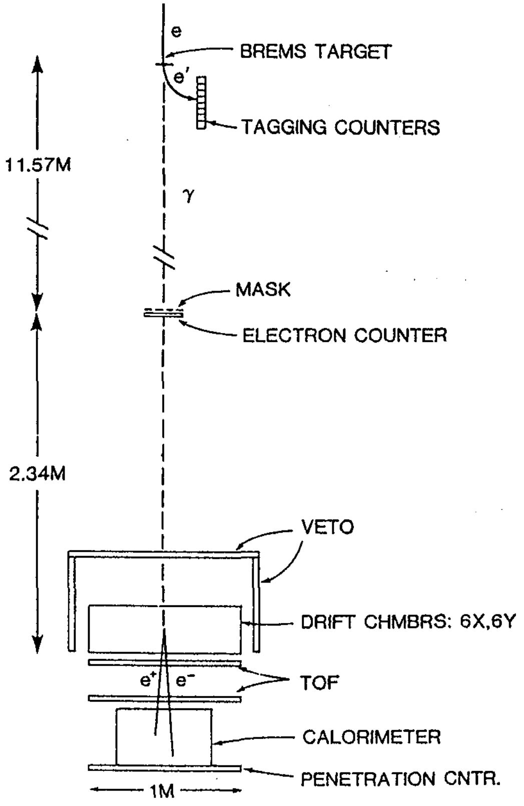

Fig. 1. Diagram of the apparatus.

Each module contained four drift chambers, two for measuring each of the two coordinates orthogonal to the beam. Photons converting in the drift-chamber array produced electron-positron pairs which passed through the remainder of the chambers and into the time-of-flight detector and the calorimeter. Readout of the chambers and calorimeter was initiated by a coincidence of a tagging count and the time-of-flight counters in the absence of a signal from the anticoincidence counter.

The experiment was operated in the low energy hall of the electron linac of the C.E.N. Saclay laboratory. A tagged bremsstrahlung beam was used as the source of photons. Eight tagging channels provided energy identification of individual photons from 52% to 68% of the full electron energy. A signal from one of these tagging channels was required for readout of the experiment. Photon energy bands of 94-119, 78-99, 42-53, and 23-30 MeV were used. The assembly of chambers and associated scintillation counters and calorimeters could be rotated to permit data-taking at angles of incidence up to 40 degrees from the normal. The mask was rotated by the same amount during these runs.

The chambers had active areas of 85 by 85 centimeters. They had 9 millimeter gaps and 4 centimeter drift distances. No provision was made within the individual chambers to resolve the left-right ambiguity but chambers within one module were arranged in a staggered pattern so that the ambiguity could be resolved when observing reasonably straight tracks. The drift field was established by field planes which consisted of printed circuit boards each 1% of a radiation length in thickness on which the field-shaping electrodes had been etched. They were operated on an argon-isobutane mixture with a drift field of 1 kilovolt per centimeter. Pulses from groups of chamber sense wires were discriminated and sent to a set of fast flip-flops which routed the logic pulses alternately to two time-to-digital converter (TDC) channels for each group. This permitted the recording of double hits on a sense wire as might be caused by the passage of a pair of tracks through the chambers. Pulse pair resolution was about 1 millimeter. The TDC′s were operated in a CAMAC system which was controlled by a PDP-11/24 computer. TDC data for each reporting sense wire were recorded on magnetic tape along with the tagging channel, and pulse heights from the TOF scintillators and calorimeter.

Prior to the operation of the experiment at the electron linac it was determined that the chambers suffered from a loss of efficiency in the 25% of the drift space farthest from the sense wires. Using cosmic ray muons, it was found that individual track positions had a root-mean-square uncertainty of approximately 1 millimeter.

Following the data taking runs, the TDC data from the events were processed by a pattern recognition and track fitting program. From this came a list of positions of the conversion vertices of individual gamma rays. Approximately 25% of the triggers resulted in a conversion vertex appearing in the fiducial volume of the chamber array. The two-dimensional distribution of vertices could be matched to the checkerboard pattern of the mask. Vertex positions relative to the mask pattern were determined and aggregated to produce a plot of vertex density as a function of distance across the shadows of the opaque and transmitting mask elements. Figure 2 shows such a plot.

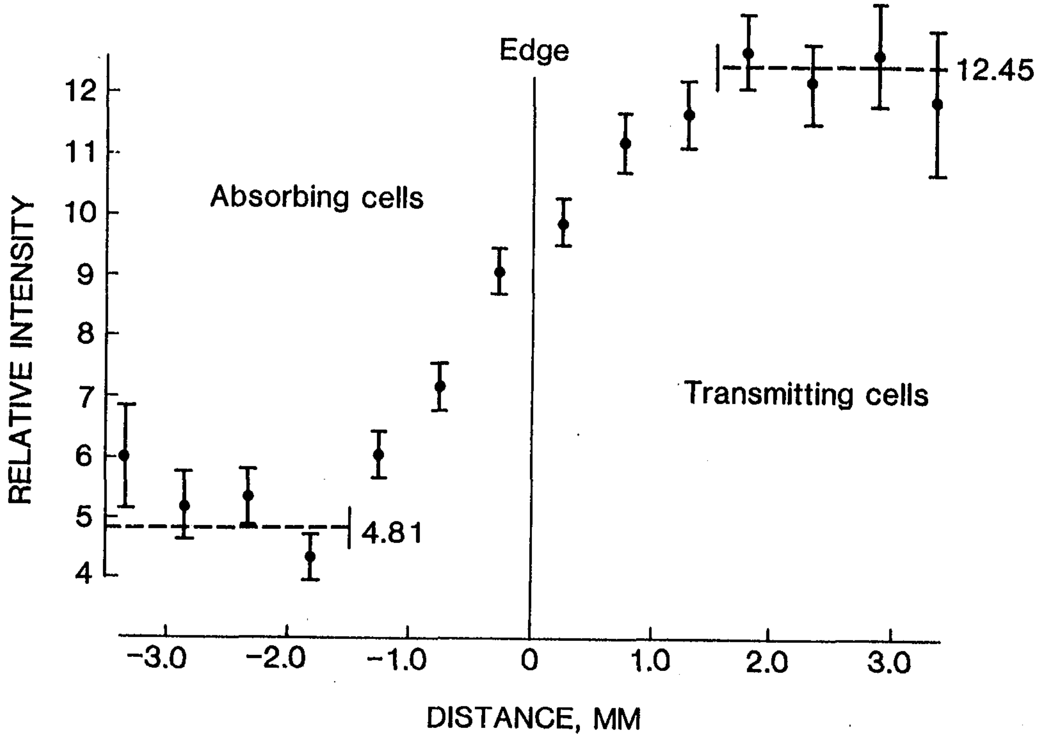

Fig. 2 Vertex density as a function of position within the shadows of opaque (left) and transparent (right) mask elements. The case shown is for 106 MeV photons at normal incidence.

3. Results. We refer to the ratio of vertex density behind the opaque mask elements to that behind the transmitting elements as the modulation ratio. This ratio should be simply the known transmission of the tungsten elements at the photon energy in question. Except under the most favorable conditions, this did not turn out to be the case. The table below shows the modulation ratio for several of the runs and the theoretical ratio.

The increase of the modulation ratio above the theoretical value could be viewed as the result of the addition of a uniform background of events which are not modulated by the mask. We attribute this uniform background predominantly to a population of events that failed to be properly recognized and fitted by the reconstruction program. The unexpectedly low efficiency of the chambers and track error made it difficult, even with manual scanning, to identify the track origins and trajectories with certainty. This problem was exacerbated at low energies where scattering of the tracks was greater. Supporting this supposition, a calculation in which the chamber data were simulated by Monte Carlo methods shows that, as chamber efficiency is diminished and track accuracy decreased, the track recognition and fitting program fails to calculate the vertex positions to about the degree observed. Furthermore, placing more stringent requirements on the quality of the fit to the experimental data produced a smaller sample of vertex positions but one which showed considerably less of this uniform background. In the table, cases marked with * were those to which this more stringent requirement was applied. Approximately half the events met the requirement.

PHOTON ENERGY (MeV)	INCIDENT ANGLE (Degrees)	MEASURED RATIO	THEORET. RATIO
106	* 0	.287	.225
106	0	.405	.225
106	13	.557	.231
106	* 26	.536	.251
106	26	.653	.251
88	0	.474	.229
88	10	.614	.233
88	20	.632	.244
47	0	.598	.276
47	10	.718	.280
47	20	.751	.293
26	0	.737	.333
26	10	.669	.338

The error in vertex location for events that were properly recognized can be estimated from the width of the transition region between the shadows of the opaque and transmitting regions. In the case shown in figure 2, the vertex density makes the transition from 25% to 75% of full height over a distance of 1.5 millimeters. If one were to model the vertex position point spread function by a gaussian, this would imply an r.m.s. uncertainty in vertex location of 1.1 millimeters. The table below shows the vertex location accuracy and modulation ratio other energies and angles.

4. Conclusions. We have demonstrated the feasibility of using a coded aperture mask telescope at photon energies higher than used heretofore. In this experiment, the reliability and accuracy of recognizing and fitting tracks was not as great as would be needed for an astronomical instrument. This condition could be improved by increasing the number of chambers used and by improving the efficiency of the chambers.

5. Acknowledgements. We wish to thank A. Veyssiere and the staff of the A.L.S. low energy beam facility for their assistance and cooperation in making these measurements. This work was supported by grant NAGW-451 from the U.S. National Aeronautics and Space Administration and grants from the U.K. Science and Engineering Research Council.

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