A CCD Beam Profile Monitor for 14.6 GeV/amu ^{16}O Ions

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Introduction

A solid state image sensor called a charge coupled device, or CCD, was evaluated as a beam profile monitor for 14 GeV/amu ^{16}O ions and 14 GeV protons accelerated by the Alternating Gradient Synchrotron (AGS) at Brookhaven National Laboratory. The relativistic heavy ion experiment, E-802, requires tightly focussed relativistic heavy ion and proton beams from the AGS. The beam transport system designed for E-802 should provide a focal spot of 1-2 mm in size which is difficult to measure quantitatively with conventional beam diagnostic wire chambers that have 2 mm wire spacings. Since the ionization level is high because of the high Z of heavy ions, a charge coupled device (CCD) should be very responsive to minimum ionizing heavy ions and possibly to protons as well.

Experimental Procedure

The small CCD camera and power unit, 4.5 x 3.0 x 11.8 cm, shown in Fig. 1, was mounted with the beam axis on the lens axis approximately 2 meters downstream from the target. The light sensitive CCD unit is shown in Fig. 2 with the lens removed from the camera. The sensing area as shown is 8.8 mm horizontal x 6.6 mm vertical, consisting of 384 x 491 (h/v) picture elements or a total of 188,544 pixels. The pixel or cell size is 23 μm x 13.4 μm (h/v). The chip size as shown in Fig. 2 is 10.7 mm x 9.3 mm (h/v). When operated as a black and white TV camera the resolution is 280 x 350 lines (h/v).

Since the ^{16}O ion energy is 14 GeV/amu the lens structure has little or no effect on the beam profile (lens in or lens out showed the same display). The ions pass through the lens structure, then the CCD, and on through the electronic circuit cards of the camera and power supply, out the back, and finally into the concrete beam stop several meters downstream. The camera with lens in place is most convenient for alignment since the TV monitor provides a visual reference to the target.

Experimental Results with 14 GeV/amu ^{16}O Ions

One complete television frame (1/30 sec integration time) during the middle of a 1/4 second beam spill is shown in Fig. 3. The horizontal line structure is an artifact of the television "freeze frame" unit, however the multiple pixel structure of many single events is real and evident. Each heavy ion penetrating the CCD appears to saturate one or more pixels and ~300 ions are shown in this frame.

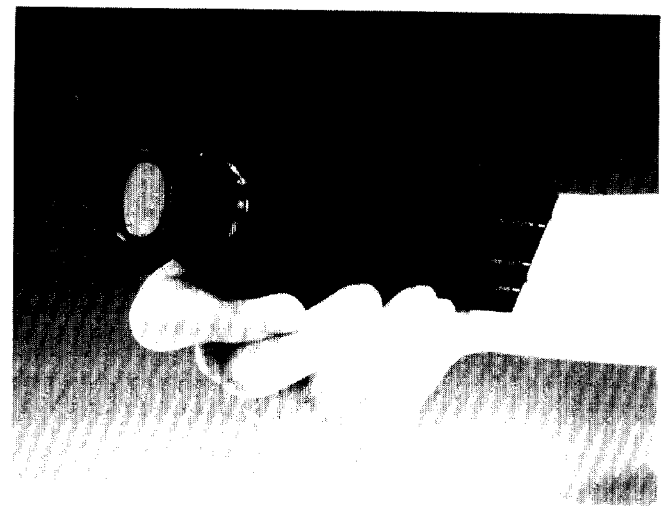

Fig. 1 Miniature CCD black and white TV camera.

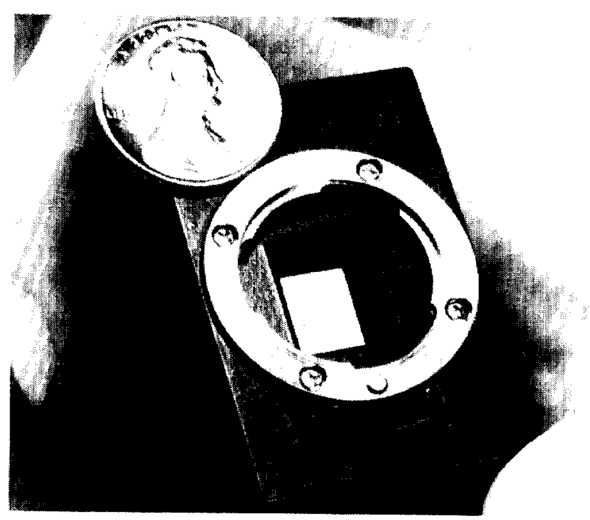

Fig. 2 Television camera with lens removed to show the CCD microchip that actually profiles the beam. The minimum ionizing particles pass through the CCD perpendicularly and the rest of the camera as well.

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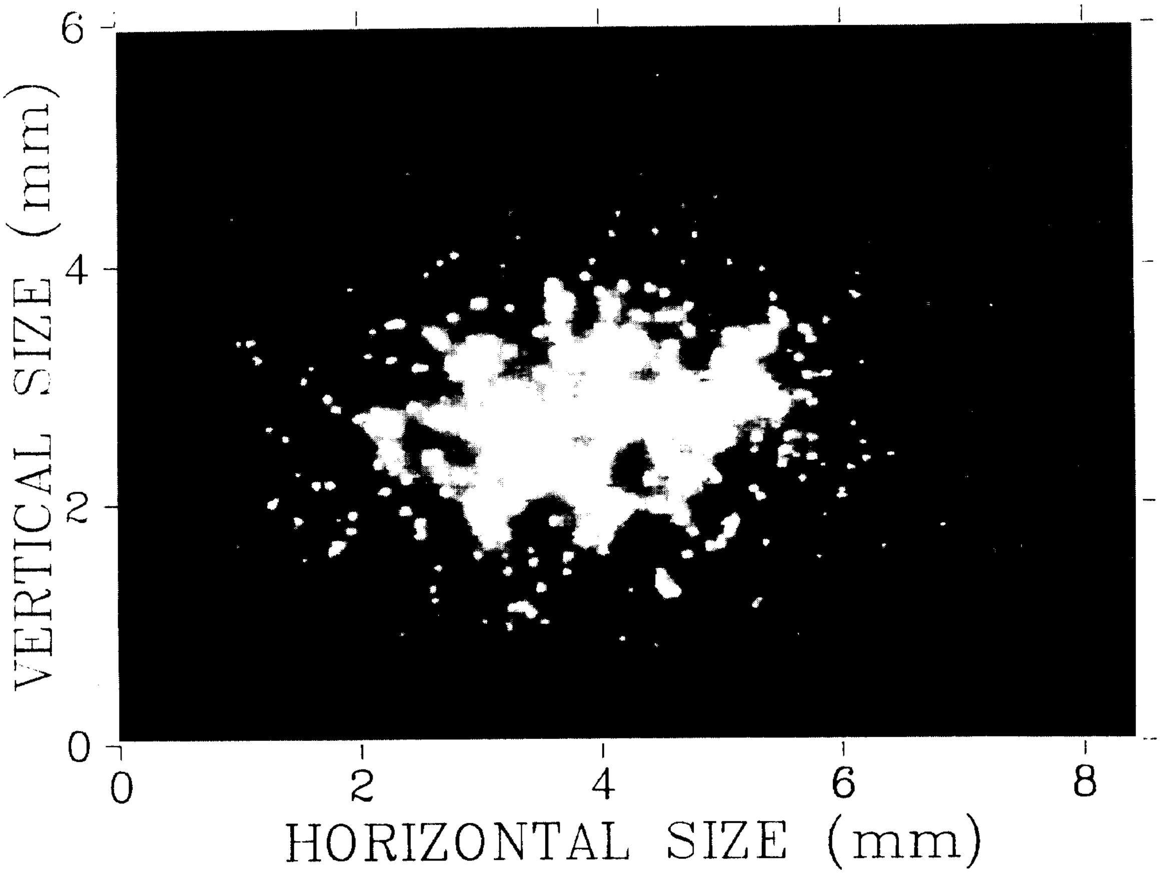

Fig. 3 Focussed beam profile of 14 GeV/amu ^{16}O ions integrated for 1/30 sec (one tv frame) during a 1/4 sec beam spill (see text).

Frame-by-frame comparison showed that the beam was unstable horizontally during the spill time of up to 1/2 sec, moving horizontally 3-5 mm from the beginning to the end of the spill, and distorting the visually observed circular beam spot to the horizontal ellipse distribution shown in Fig. 3.

Various beam focus and steering conditions could easily be studied in detail with the CCD camera, and the data was easily recorded on a VHS recorder and studied live with instant replay or freeze frame playback from the tape. Various digital "frame grabber" computer methods could also be used to study beam profiles from pulse to pulse and, with appropriate digital processing, be used to control the beam transport and tuning system.

Relativistic heavy ion intensities of 10^2 to 10^3/sec were used for these measurements and a total exposure of 10^7 heavy ions over the study period resulted in the failure of ~20 pixels randomly located on the screen. (The damaged pixels stay in the light or full on condition at all times.)

Experimental Results with 14 GeV Protons

Secondary protons of 14 GeV were extracted from a primary target and focussed onto the E-802 target. The minimum ionizing protons were unable to saturate the CCD pixels as did the 8+ charged ^{16}O ions: at beam spill levels of 10^3/sec the proton beam profile was barely observable; however, at 10^5/sec the pixels receive multiple proton hits within the 1/30 second integration period and the beam spot is easily observable as shown in Fig. 4. The best focus of the secondary proton beam was 4-5 mm diameter while the direct ^{16}O beam was 2-3 mm. However, the horizontal position stability was 0-1 mm rather than the 3-5 mm observed for the ^{16}O beam. After exposure to 10^8-10^9 protons, several hundred pixels were destroyed and the central region of the CCD showed a definite degradation of its gray scale (with no beam the black screen has a gray central region).

The occasional random lines and comet-like events observed in Fig. 4 are probably due to heavy fragments from nuclear reactions in the silicon or CCD structure near or in the plane of the sensing units. The high energy reactions fragment the nucleus and the resulting low to medium energy heavy ions are easily observed. Similar events were observed with the heavy ion beam but with lower frequency because of the lower intensity (1/100) used for the study.

A simple modification of the camera structure allows the CCD unit to be swung 90° so that its plane is parallel to the long axis of the camera which would then allow the CCD itself to be moved in and out of the beam with the camera axis perpendicular to the beam axis. In this way a simple mechanical control could then insert the CCD into the beam for diagnostic tuning and inspection when needed (without exposing the camera electronics) and out of the beam most of the time in order to extend the useful life of the device as much as possible.

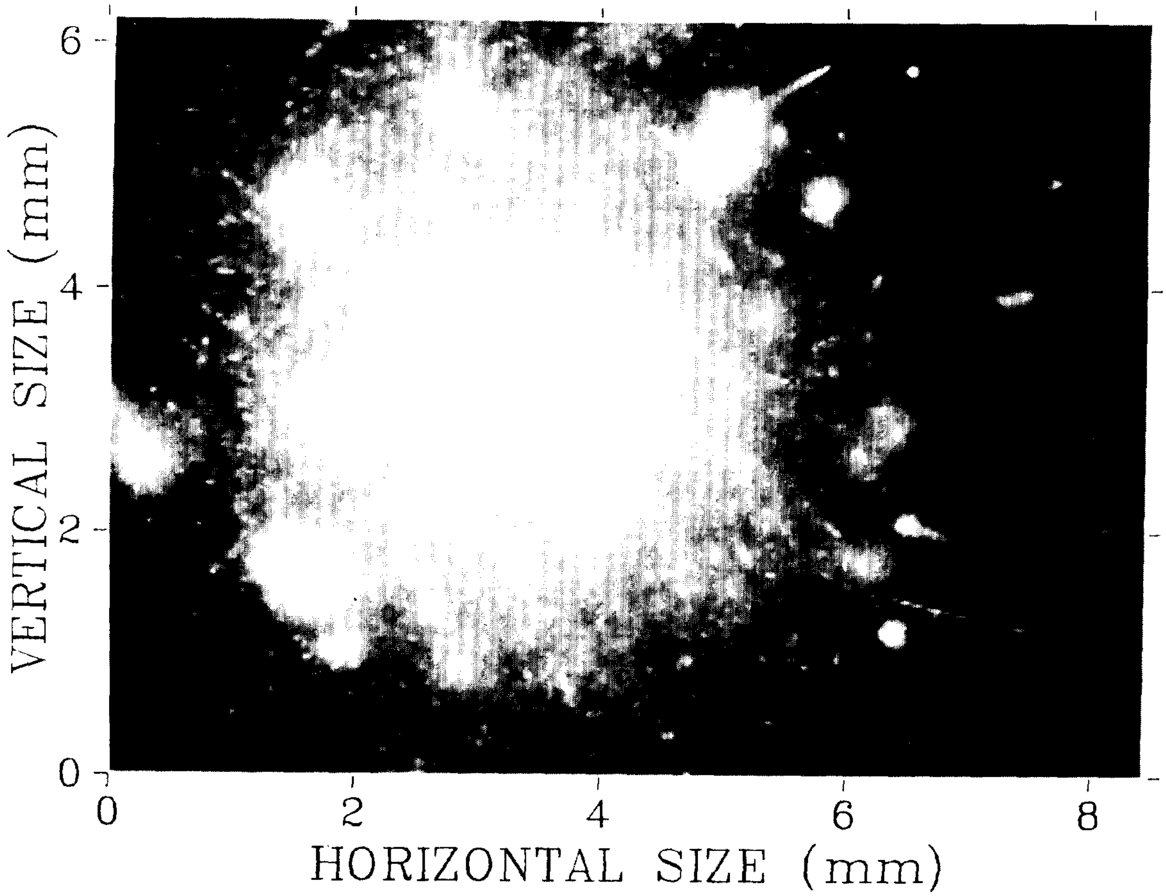

Fig. 4 Focussed beam profile of 14 GeV protons integrated for 1/30 sec during a 1/2 sec beam spill. Note the low to medium energy heavy ion tracks from nuclear fragmentation that are due to proton induced nuclear reactions.

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REFERENCES

1. CCD Video Camera Module, Model XC-37, Mfd by the Sony Corp., Japan.