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A GRAY CODE HODOSCOPE AND FAST BUFFER FOR BEAM PARTICLE TAGGING[*]

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ABSTRACT

We have developed a scintillation counter hodoscope to measure the vertical position of a high energy charged particle with associated identity information. It may be used to tag beam tracks seen in detectors with poorer time resolution, such as bubble or spark chambers. The hodoscope consists of six overlapping planes of plastic scintillator strips 1/16 in. thick, 3 in. wide, and of varying height and vertical spacing. The vertical resolution is 3/32 in. over a 6 in. height. Each plane is connected to a single photomultiplier tube. The output from the six tubes forms the Gray code[‡] of the vertical position of a track passing perpendicularly through the planes. This and three bits of tagging information form a nine bit word associated with each track. Up to 16 such words are stored in an ECL buffer memory capable of accepting a new track every 20 ns. The buffer is interfaced to a DGC Supernova computer through CAMAC. The construction and performance of the device are discussed.

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[‡] This prevents ambiguity near strip edges.

I. INTRODUCTION

We have built a scintillation counter hodoscope to tag tracks in detectors with poorer time resolution, such as bubble or spark chambers, by encoding their vertical position along with up to three bits of tagging information. This device uses the Gray code to achieve 3/32 in. (2.4 mm) resolution over a 6 in. height with only six thin counters. The associated electronics have a time resolution of 10 ns and are capable of storing a new event every 20 ns, making the hodoscope suitable for use in beams with bad spill structure. The device has been successfully tested using the 30 in. bubble chamber at the National Accelerator Laboratory.

II. DESIGN OF THE HODOSCOPE

The hodoscope is made of six 1/16 in. thick plastic scintillator planes with an active area of 6 in. by 3 in. Each plane is divided into a number of horizontal strips of varying width separated by slots of equal width. A vertical cross section of the scintillator stack is shown in Fig. 1. All the strips in a given plane connect to a single photomultiplier tube. Beam particles travel perpendicularly through the stack. As can be seen from the diagram, the outputs from the six tubes form a six-bit number in Gray code representing the vertical position of each track. Each output represents one bit, and if a pulse is present, the bit is one. The 6 in. hodoscope is effectively divided into 64 3/32 in. high bins. The chief advantage of this coding scheme as compared with usual binary coding, for example, is that it is not discontinuous at a strip edge. If a particle grazes an edge and does not produce a count from the associated tube, the number which results is that of the adjacent bin. The position measurement is still good, since the particle was, in fact, at the edge of the bin. With ordinary binary coding, the resulting number would have corresponded to a bin far away from the actual track location. Another considerable advantage is that the bins are half as high as the finest scintillator strips. We developed this configuration of counters independently to achieve these objectives. Only later did we discover that we had essentially reinvented the Gray code.[1] Though a number of binary scintillation counter hodoscopes have been constructed,[2] we have not seen any reported in the literature with 64 cells using only six phototubes.

A typical scintillator plane (the one with eight 3/8 in. strips) is shown in Fig. 2. It was fabricated by milling slots in a rectangular piece of 1/16 in. thick Pilot B scintillator.[3] Light from the plane was transmitted to a vertically mounted RCA 8575 multiplier phototube by the 1/16 in. thick plastic lightpipe shown to the left of the scintillator.

In order to maintain the planes in alignment, two mounting holes were drilled in the edge of each scintillator away from the lightpipe and fitted with brass ferrules. The scintillators (including lightpipes and phototubes) were individually wrapped with aluminum foil and black tape. They were then stacked on a pair of accurately aligned dowel pins which fitted through the ferrules. The dowel pins and the phototube bases were attached to an aluminum plate which served as a support for the assembly. A cutout was provided behind the scintillators to reduce the amount of material in the beam. The completed hodoscope is shown in Fig. 3.

III. THE FAST BUFFER

The hodoscope is used in conjunction with a fast buffer capable of storing one 10-bit word every 20 ns. This allows data to be stored at a

50 MHz instantaneous rate during an accelerator burst and to be read out between bursts. A block diagram of the buffer and its related electronics is shown in Fig. 4. The buffer has a total capacity of 16 words. Six bits of each word are used for the hodoscope output. One bit is turned on whenever data is stored, allowing the unambiguous recognition of an input pattern of all zeros. The remaining three bits are available for tagging information.

The fast buffer consists of 10 16-bit shift registers operating in parallel. These are constructed of Fairchild 9500 series emitter coupled logic (ECL) integrated circuits.[4] The entire buffer is constructed on a single high-density wire-wrap panel.[5] The power supply for the integrated circuits is offset by + 0.8 V from ground potential to allow the use of standard fast NIM logic levels at the inputs to the buffer. Data present at the inputs is stored in the buffer when accompanied by a "strobe" pulse generated by event-defining scintillation counters. Data is read out from the buffer to a DGC Supernova[6] computer by way of CAMAC modules. Using the "test" input, the computer can set all input data lines to one. A simultaneous "advance" pulse from the computer stores this pattern in the registers. This permits on-line checking of the buffer electronics.

IV. PERFORMANCE

The feasibility of the hodoscope design with narrow strips of thin scintillator attached to a thin lightpipe was first tested in a beam at the LBL Bevatron using a prototype 6 in. x 3 in. x 1/16 in. counter divided into 16 strips 3/16 in. wide. It was found to be at least 98.5% efficient. The efficiency was uniform from strip to strip as well as along the length of a given strip. We felt sufficiently encouraged by this result to go ahead with the construction of the entire system.

The fast buffer was constructed. Each channel was tested and found to be capable of operating with 10 ns time resolution at a 50 MHz repetition rate. Individual channels could be made to run at 100 MHz using selected integrated circuits.

An on-line computer program was written for use with the hodoscope and its associated electronics. This program reads out the fast buffer, eight 100 MHz scalers, an ADC, and a frame number register between accelerator bursts and records the data on magnetic tape or punched paper tape. In addition, the program monitors all of the apparatus for proper operation and prints a diagnostic error message on the teletype if a fault is discovered. Histograms are collected of the scaler and ADC contents per accelerator burst, the accumulated number of counts in each fast buffer channel, and the decoded beam particle positions from the hodoscope. Any histogram may be printed on the teletype or line printer without interrupting data collection. The beam profile, distribution of number of tracks per burst, and percentage of particles of a given type in the beam may thus be conveniently monitored during a run.

The test of the completed system was done in the beam line of the NAL 30 in. bubble chamber where we were awaiting an exposure and participating in beam tuning. The hodoscope was set up on an instrument stand upstream from the bubble chamber. Signals from the counters, the frame number readout from the bubble chamber, and synchronization pulses from the accelerator were sent to the fast electronics and computer with its line printer and tape drive, which were set up in a small van parked next to the bubble chamber building. A block diagram of the elctronics for the system is shown in Fig. 4. The hodoscope and tagging signals were strobed into the fast buffer by a twofold coincidence from a beam telescope consisting of scintillators immediately in front of and behind the hodoscope.

Beam profiles, such as the one shown in Fig. 5, were obtained with the hodoscope during the tuning of a 200 GeV/c π^- beam. A brief run was then made with the bubble chamber to test the hodoscope on a track-by-track basis. The counting efficiency was determined by comparing the vertical position of tracks seen in the hodoscope with their position in the bubble chamber. In a sample of 122 unambiguous beam tracks used in this test, 119 had codes corresponding to the correct position to within the accuracy of the bubble chamber measurements. The remaining three had codes differing from the correct one by a single missing bit, indicating failure of one of the counters to detect a particle. The counting efficiency of the hodoscope was thus $97.6^{+0.7}_{-2.4}\%$. This could be improved by running the tubes at higher voltages to insure counting of single photoelectrons. The present efficiency would, however, be adequate for most tagging applications.

V. CONCLUSION

The hodoscope described in this paper offers a means of tagging particle beams with good spatial resolution using only a small number of scintillation counters, devices which have proved themselves capable of reliable operation over long periods of time with no expert attention. Compared with alternate schemes, such as proportional wire chambers,[8] the hodoscope has the advantages of better time resolution and shorter dead time. In addition, since it uses less complex electronic circuitry and needs no gas supply, it is simpler to operate.

VI. ACKNOWLEDGEMENTS

We would like to thank K. Hayes and R. Smith for their help in constructing the hodoscope, and I. Drahun for machining the scintillators. We thank W.D. Hartsough and the Bevatron personnel for providing us with a beam to test the prototype scintillator. We are especially grateful to L. Voyvodic and the crew of the NAL 30 in. bubble chamber for their assistance in the test of the completed system.

FOOTNOTES AND REFERENCES

1. It appears that Gray was not the first person to invent the Gray code, either. For an interesting discussion of these matters, see F.G. Heath, Scientific American 227, No. 2 (1972) 76.

2. L. Alvarez, Rev. Sci. Instr. 31 (1960) 76; E.F. Beall, IEEE Trans. Nucl. Sci. NS-13, no. 1 (1966) 297.

3. Manufactured by Pilot Chemical Div., New England Nuclear Corp., Watertown, Mass. 02172.

4. Manufactured by Fairchild Semiconductor, Mountain View, Calif. 94040.

5. The wirewrap panel had dimensions 7 3/8 in. x 7 in. and held up to 60 integrated circuits. It was manufactured by Augat, Inc. Attleboro, Mass. 02703.

6. Manufactured by Data General Corporation, Southboro, Mass. 01772.

7. Channel 52_8 ($=42_{10}$) is incremented when all planes have a signal, a condition which occurs frequently when an interaction upstream produces a shower of particles that passes through the hodoscope. This feature is useful in beam tuning, since the relative number of showers increases if the beam is misaligned and is scraping a magnet or beam pipe. The relative excess in this channel is thus a measure of misalignment.

8. M. Davier, et al., "Design, Construction, and Operational Characteristics of a Proportional Beam Hodoscope System," Report No. SLAC-PUB-1164, Stanford Linear Accelerator Center (1972)(presented at the IEEE 1972 Nuclear Science Symposium, Miami Beach, Florida, December 6-8, 1972).

FIGURE CAPTIONS

1. Vertical cross-section of the hodoscope scintillators showing the Gray code arrangement. The active areas of the scintillator planes are shown shaded. A track passing through the stack along the dashed line, (a), would produce an output Gray code of 110010 (decoded as 35), giving the vertical position of the track to an accuracy of 3/32 in.

2. A scintillator plane (lower right) with its lightpipe, showing method of construction.

3. The completed hodoscope on its mounting plate.

4. Block diagram of the hodoscope trigger and readout electronics for bubble chamber tagging.

5. A typical vertical beam profile obtained with the hodoscope during the tuning of a 200 GeV/c π^- beam at NAL. All numbers are octal. The excess number of counts in channel 52_8 is an artifact.[7]

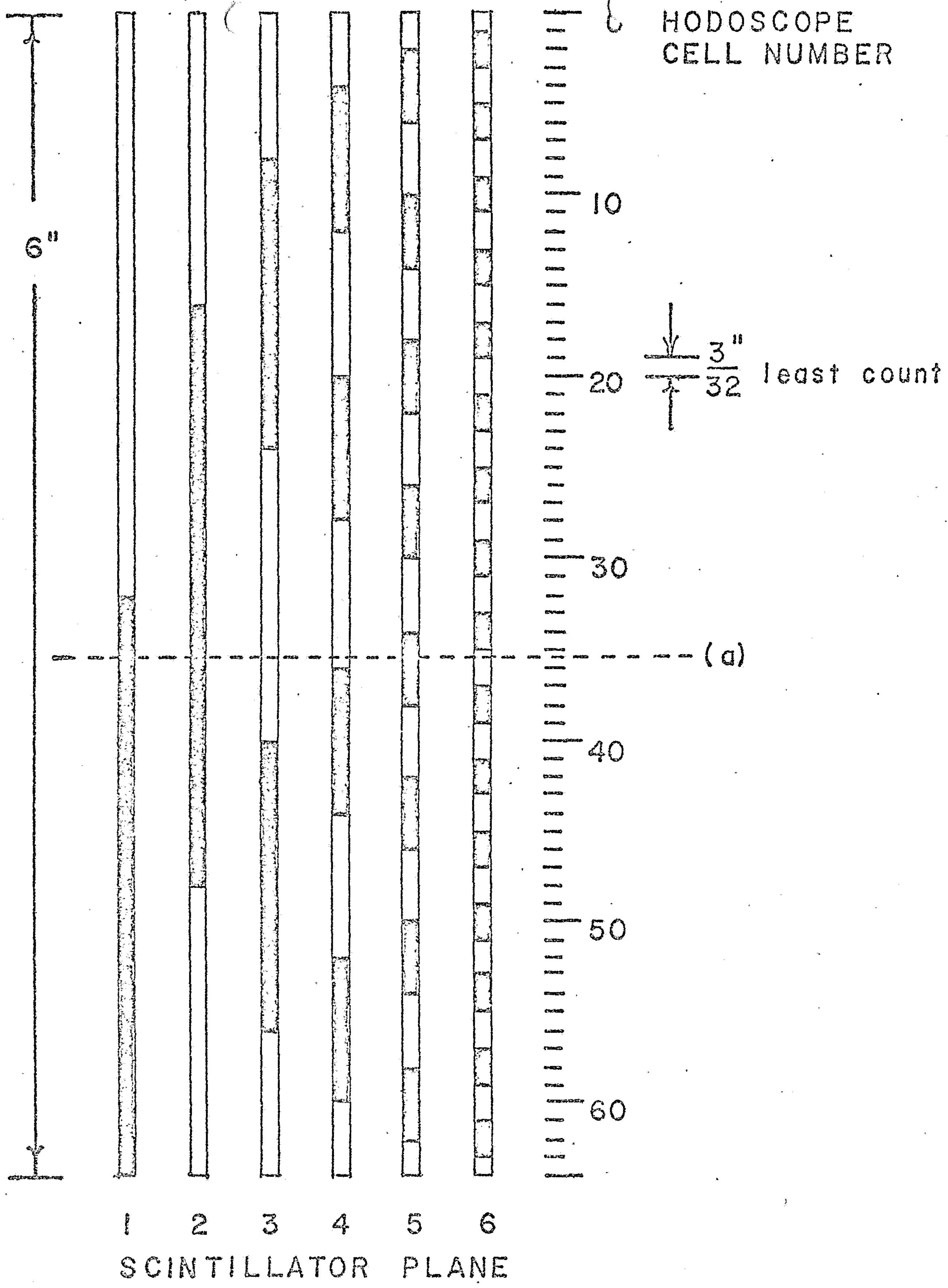

HODOSCOPE
CELL NUMBER
6"
3"/32 least count
10
20
30
40
50
60
(a)
1
2
3
4
5
6
SCINTILLATOR PLANE

Fig. 1.

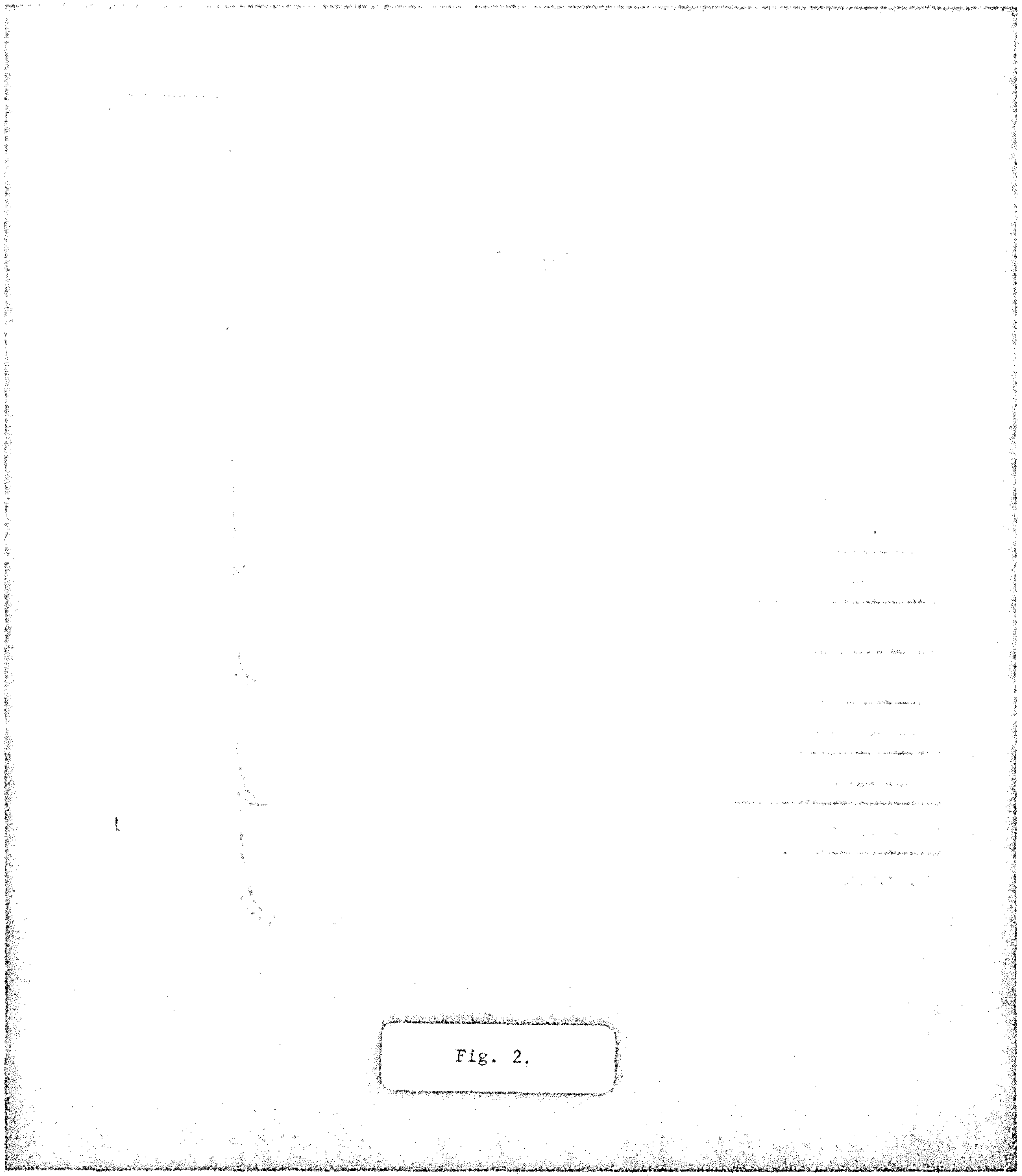


Fig. 2.

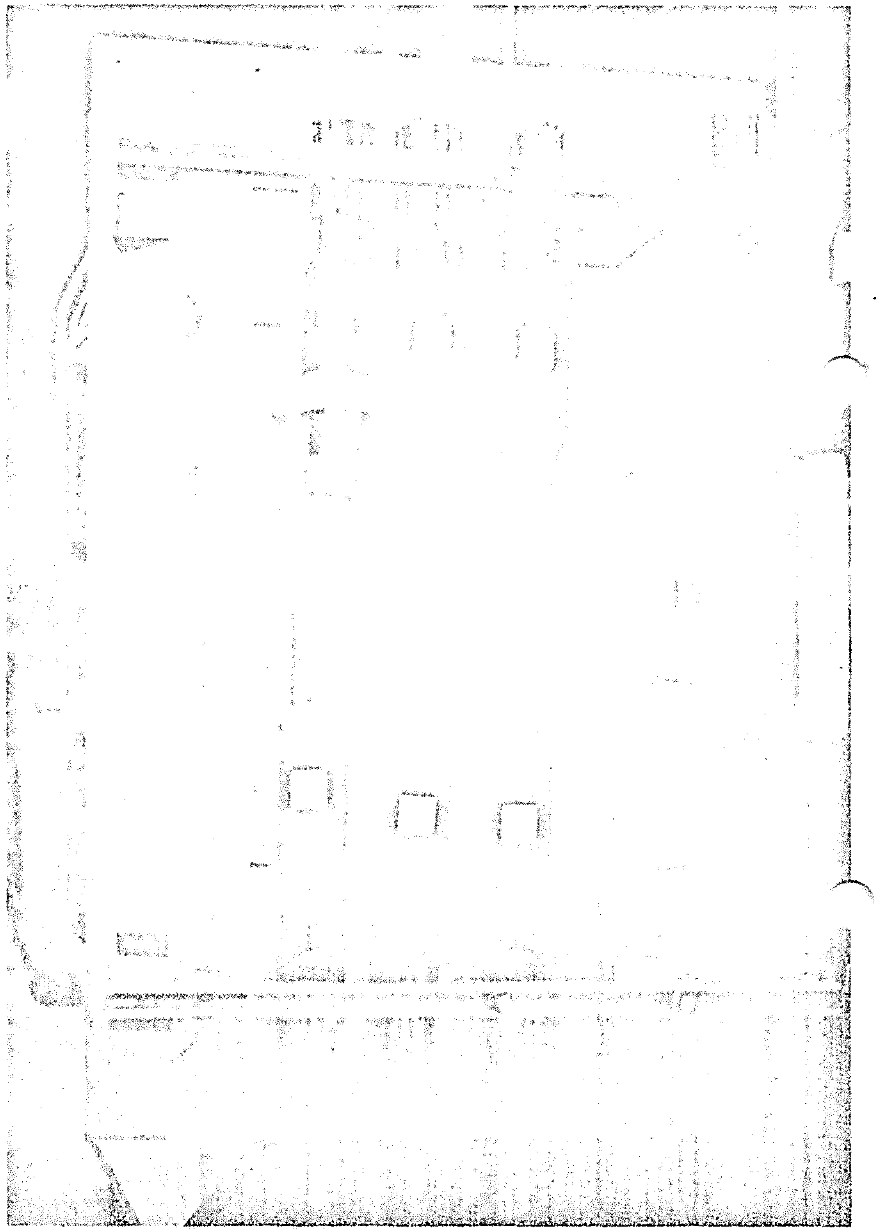


Fig. 3.

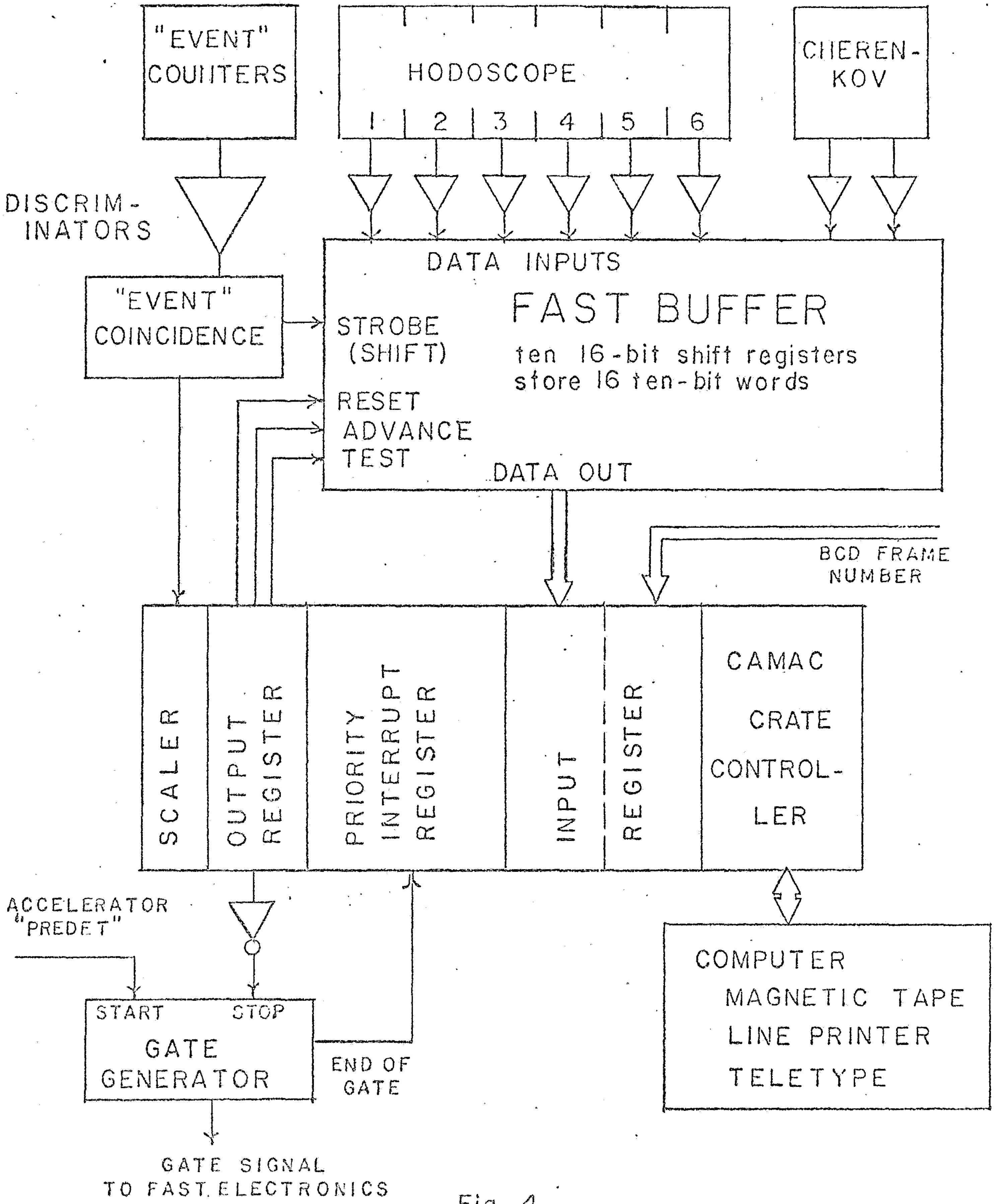
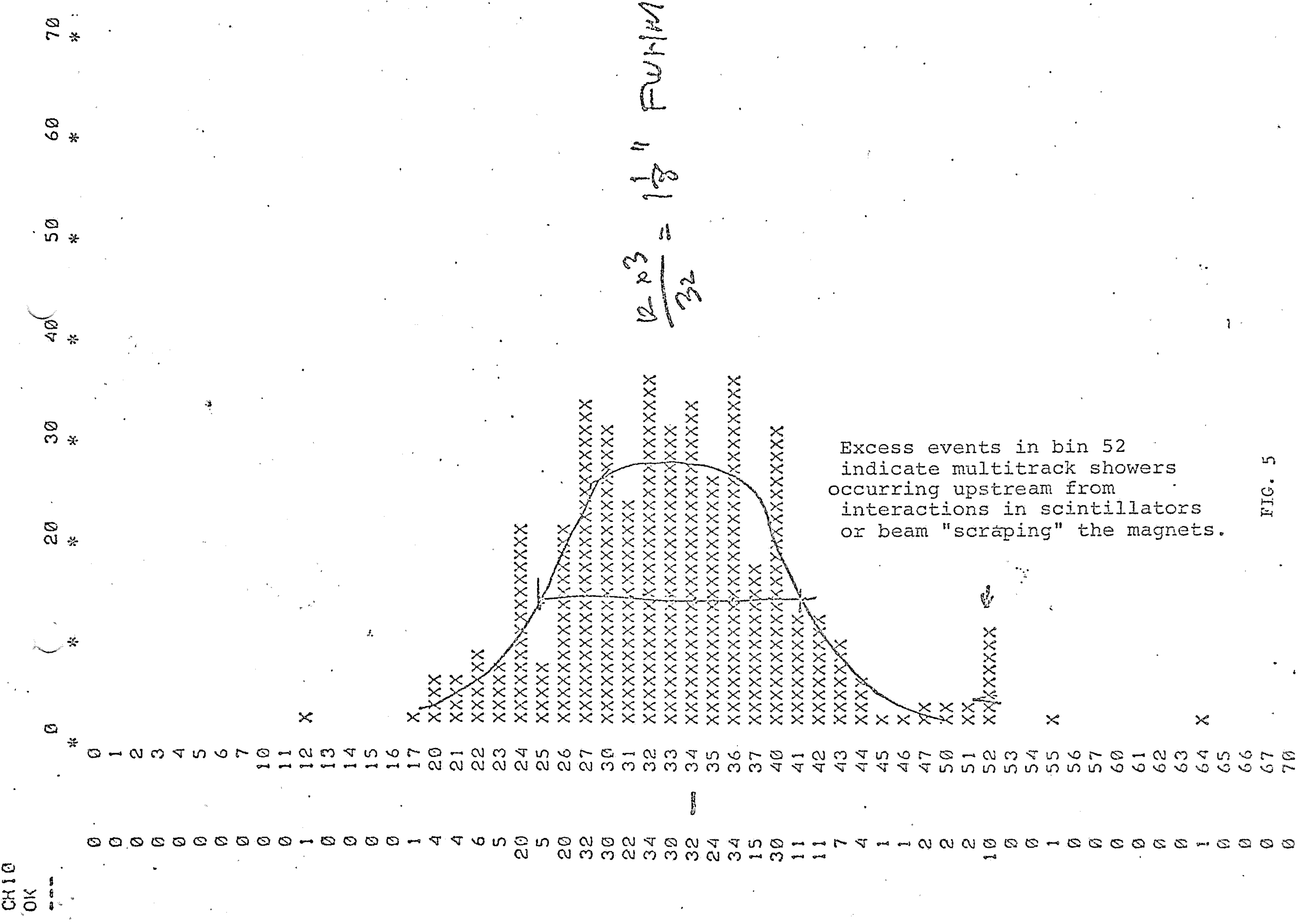

"EVENT" COUNTERS
HODOSCOPE
1
2
3
4
5
6
CHEREN-KOV
DISCRIM-INATORS
"EVENT" COINCIDENCE
DATA INPUTS
FAST BUFFER
STROBE (SHIFT)
ten 16-bit shift registers store 16 ten-bit words
RESET
ADVANCE
TEST
DATA OUT
BCD FRAME NUMBER
SCALER
OUTPUT REGISTER
PRIORITY INTERRUPT REGISTER
INPUT
REGISTER
CAMAC CRATE CONTROL-LER
ACCELERATOR "PREDET"
START
STOP
GATE GENERATOR
END OF GATE
COMPUTER
MAGNETIC TAPE
LINE PRINTER
TELETYPE
GATE SIGNAL TO FAST ELECTRONICS

Fig. 4.



Excess events in bin 52
indicate multitrack showers
occurring upstream from
interactions in scintillators
or beam "scraping" the magnets.

FIG. 5