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A TUNGSTEN PIN CUSHION PHOTON BEAM MONITOR*

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ABSTRACT

A simple high-energy photon beam monitor that produces a large signal comparable to that from a secondary emission quantameter was constructed. The device is a four quadrant beam position monitor that was used to precisely center a coherent bremsstrahlung beam on a small aperture collimator at the Stanford Linear Accelerator Center (SLAC). Each quadrant consists of an array of closely-spaced tungsten needles pointing in the downbeam direction from a tungsten base plate. This tungsten "pin-cushion" was mounted in air with no biasing potential. High-energy photons produced a positive charge on the pin-cushion by the shower emission effect.

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1. Introduction

A position monitor was required to center a coherent bremsstrahlung beam on the aperture of a collimator located upbeam of the spectrometer pivot in the SLAC end station A. The expected coherent current density in the annular area to be monitored ($1.75 \leq r \leq 4.5$ mm) was estimated to be approximately 6×10^7 equivalent quanta per cm^2 and pulse at energies $E_0 \geq 10$ GeV. This is more than two orders of magnitude below the sensitivity of secondary emission (SEM) foils and ZnS phosphor screens, and almost two orders of magnitude below YVO_4(Eu) and Al_2O_3(Cr) phosphor screens and Cerenkov cells.

Fortunately, for highly relativistic particles the electromagnetic shower emission effect yields net charge leakage signals in thick plates and targets which are comparable in magnitude to the intercepted beam current. The excess of electrons (over positrons) leaving the detector plate or target is a complicated function of target geometry, material (Z), incident beam energy and beam position on the target. The primary contributors to the signal are "knock-on" and Compton electrons. Secondary emission from the surface, photoabsorption and pair production followed by positron annihilation contribute to a lesser degree (a few percent).

The high sensitivity of shower emission monitors or thick SEM's has been recognized for some time and various models of such monitors were built and tested at SLAC. The most simple and also least efficient version is a flat plate with the beam impinging normally onto the plate and far away from the edges. The signal is then principally due to emission from the downbeam face of the plate. The magnitude of the signal is dependent on the thickness of the plate and the Z of the material. A maximum charge leakage can be expected from a high-Z material and a plate thickness equivalent to the depth to shower maximum for the incident beam energy. Unfortunately, in this geometry most of the laterally-generated knock-ons and Compton electrons never leave the target due to its large lateral extend. This is clearly demonstrated when the incident beam is steered close to the edge of the plate resulting in a great signal enhancement. This position sensitivity results in ambiguous signals and constrains the usefulness of plate-type thick SEM's, particularly as current limiters in the SLAC personnel and machine protection systems.

From the foregoing discussion it is evident that maximum signal intensity from a shower emission monitor can be expected for a detector geometry having small lateral extend, a length in beam direction equivalent to approximately the depth to shower maximum, and which consists of a high-Z material. The ideal geometry is then a circular cylinder with its axis of rotation parallel to the incident beam direction and with a radius small enough to allow the knock-ons to escape.

A beam intensity profile monitor consisting of an array of closely-spaced 0.025 mm thick, 2 radiation lengths (r.l.) long tungsten ribbons was described.[1] For an incident electron beam energy of 19 GeV and a peak current intercepted by one ribbon of 1.2 mA the signal was 3 mA. Thus the efficiency was 250%.

Since the magnitude of the shower emission effect under ideal conditions is expected to be proportional to the total number of electrons and positrons in the shower — which grows like the electron beam energy — we can also express this efficiency as 0.21×10^{-19} coulomb per GeV electron beam energy intercepted by the ribbon. Though not the most efficient, the ribbon geometry was selected as being the most suitable for this specific instrument.

2. Design and construction of monitor

From range-energy curves for electrons in high-Z materials such as tungsten, it is evident that the diameter of the emitting cylinder should not exceed approximately 1/2 mm in order to allow most of the knock-ons down to energies of about 1 MeV to escape. This diameter is substantially smaller than the beam cross sectional area to be monitored. Thus an array of tungsten cylinders or pins is required to cover the beam area of interest. The pins are brazed into a tungsten base plate. The latter fulfills two functions: (1) It serves as a mounting plate or "pin-cushion" to hold all the pins at a preselected proper spacing, and (2) it acts as a shower builder for the pins which extend from it in the downbeam direction. The thickness of the plate was selected to be about 2 r.l. ($\sim$8 mm in free machining tungsten with 90% W). The pins are 4 r.l. long resulting in an overall length of 6 r.l. which corresponds approximately to shower maximum in tungsten for the incident beam energies. They are approximately evenly spaced, $\sim$0.8 mm apart. Selection of this spacing was more the result of fabrication considerations rather than due to efforts to maximize the signal. It should be pointed out, however, that as the spacing is reduced, knock-ons leaving a pin encounter a greater likelihood of being absorbed by a neighboring pin, thus depositing their charge and reducing the net charge leakage signal.

In order to use the instrument as a beam position monitor, the emitter is divided into 4 evenly-spaced segments, each of which covers an angular range of 60°. Adjacent emitter segments are separated from each other by radially-oriented, 1/2 mm thick aluminum plates. They were installed to reduce cross-talk between neighboring emitters, particularly shielding against low-energy electrons emitted from the surface of the pins and low-energy knock-ons.

The 4 emitter segments are mounted in an insulating cylinder. Boron nitride was used for ease of fabrication, good electrical resistivity and reasonable thermal conductivity to dissipate the heat generated by the beam in the tungsten. The signals are brought out from each emitter segment via a minature 50Ω coax cable (RG-174U). The latter is terminated with a BNC connector (Kings KC-59-281). Figure 1 shows a schematic of the pin-cushion monitor and Figure 2 depicts two photographs of the vital parts of the instrument.

3. Experimental setup

The four-quadrant pin-cushion monitor was used in an inclusive photoproduction experiment at SLAC to center the coherent photon beam produced by a thin diamond radiator on a 2 mm diameter collimator hole. The photons that passed through the aperture eventually were absorbed in a secondary emission quantameter[2] (SEQ). This device is well understood and its calibration constant of 3.2×10^{-19} coulomb/GeV is independent of the incident energy for the SLAC range of energies.

Each quadrant of the pin-cushion monitor, as well as the SEQ, were connected to charge sensitive amplifiers (ORTEC 109A, with modifications). These produced a 400 μsec time constant output pulse with voltage proportional to the input charge. Figure 3 is an oscilloscope photograph of two typical output pulses, corresponding to two accelerator pulses at a pulse repetition rate of 180 pps. A 1000 channel analog to digital converter (ADC) was used to convert the voltage level 20 μsec after the peak of the pulse into digital information. For the runs under consideration the sensitivity of the system was 9 channels/pico-coulomb for the SEQ and 11 channels/pico-coulomb for the quadrant monitor.

The various runs involved different incident photon energy spectra which were related to different orientations of the diamond radiator. The spectrum was basically characterized by a broad (3 GeV at the base) spike on top of a normal bremsstrahlung background. Additionally, the spike for different runs was linearly polarized in the vertical (V) or horizontal (H) planes, which caused the photon intensity distribution at the collimator to elongate horizontally or vertically for the two cases respectively. Sums of the digital pulse height information for the four quadrants and the SEQ were accumulated during a run for all pulses that were sufficiently well centered.

4. Experimental Results

Table I gives a set of representative ratios of the output of one quadrant (L) of the pin-cushion monitor to that of the SEQ. This depended on the incident photon beam energy spectrum for the run. The quantity k refers to the high-energy edge of the main spike in the coherent part of the spectrum. If the diamond was oriented to produce no coherent effects, then the remaining incoherent spectrum (INC) was very similar to ordinary bremsstrahlung with an end point energy in this case of 19.7 GeV.

It is possible to calculate the ratios in Table I by assuming the quadrant monitor gives a signal proportional to the total energy per pulse of the incident photon beam. This was done for a 60° quadrant extending over the radial interval $1.75 \leq r \leq 4.5$ mm. In addition, the average $\bar{k}_L$ of the photons incident on the L quadrant was calculated, arbitrarily defining the number of photons to be all those with energy greater than 30 MeV. The results are given in Table II.

The final result in the comparison of the pin-cushion monitor to the SEQ is obtained by normalizing the observed signals by the calculated incident intensities. Figure 4 is a plot of 9/11 (L/SEQ) (I_{ESQ}/I_L) versus the average photon beam energy. Using the value of 3.2×10^{-19} coulomb/GeV as the calibration constant of the SEQ, a constant is obtained for the pin-cushion monitor which varies from 1.3×10^{-19} to 10^{-19} coulomb/GeV; a remarkable result for such a simple and inexpensive device.

ACKNOWLEDGMENT

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REFERENCES

1. D. R. Walz and E. J. Seppi, "A High-Resolution Beam Intensity Profile Monitor," IEEE Trans. on Nuclear Science, NS-16, 926 (1971), also Report No. SLAC-PUB-882.

2. R. Anderson, Nucl. Inst. and Meth. 65, 195 (1968).

TABLE I

Experimental ratios of pin-cushion monitor to SEQ

k_{POL}	L/SEQ
15_H	.40
15_V	.47
11_H	.28
11_V	.42
INC	.51

TABLE II

Calculated incident intensity ratios and average photon energy

k_{POL}	I_L/I_{SEQ}	k_L(GeV)
15_H	.88	3.4
15_V	1.1	4.0
11_H	.64	4.0
11_V	1.1	4.9
INC	1.0	2.6

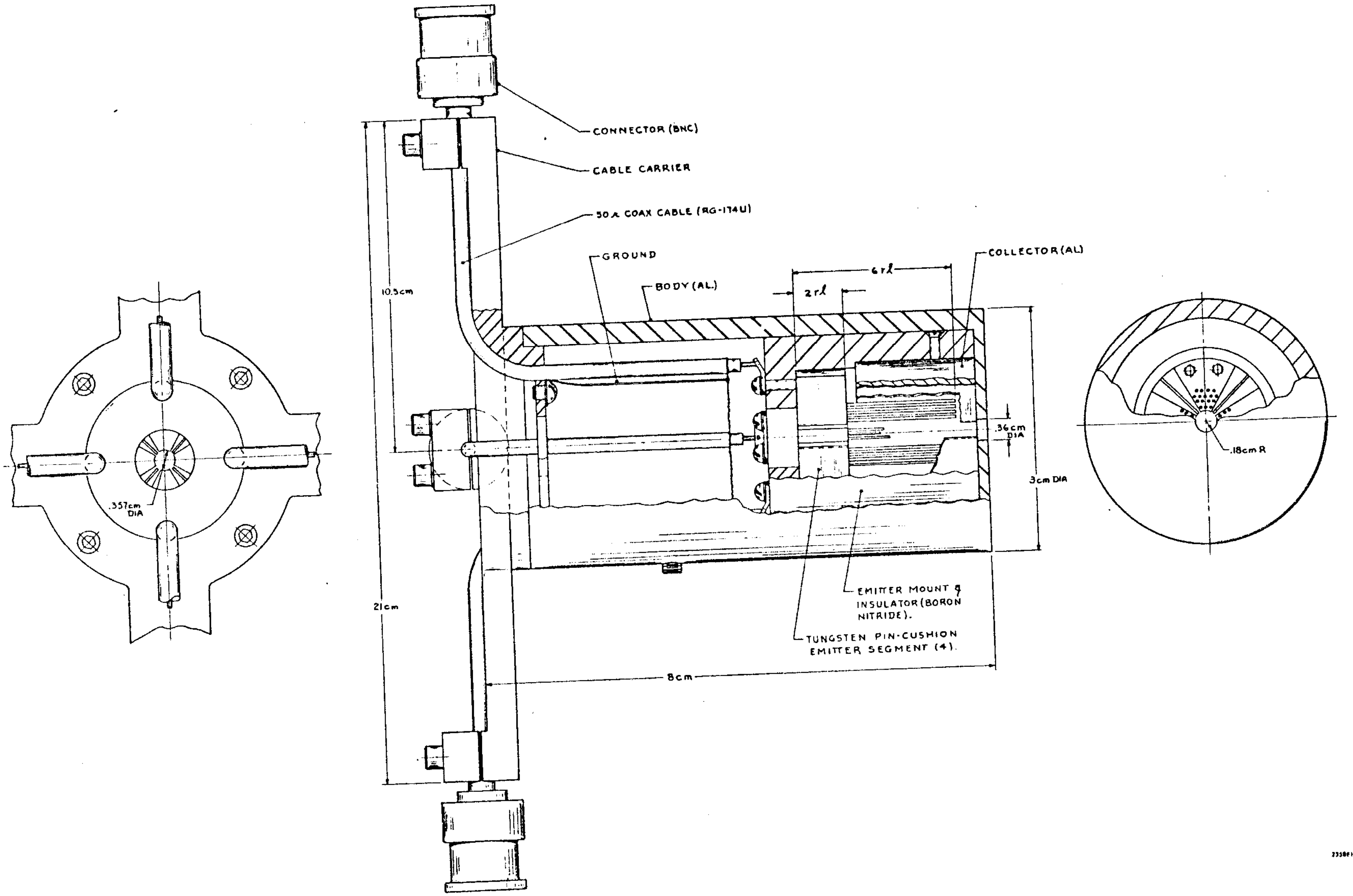
FIGURE CAPTIONS

1. Schematic of pin cushion monitor.

2. Pin-cushion monitor parts and downbeam view of pin-cushion monitor assembly.

3. Pin-cushion monitor output signal for two successive pulses. Oscilloscope setting: 1 msec/division horizontal, 0.2 volts/division vertical.

4. Pin-cushion/SEQ signal ratio versus average photon beam energy.



CONNECTOR (BNC)
CABLE CARRIER
50 Ω COAX CABLE (RG-174U)
GROUND
BODY (AL.)
COLLECTOR (AL)
6 rl
2 rl
10.5cm
.36cm DIA
3cm DIA
.18cm R
.357cm DIA
21cm
EMITTER MOUNT & INSULATOR (BORON NITRIDE).
TUNGSTEN PIN-CUSHION EMITTER SEGMENT (4).
8cm

Fig. 1

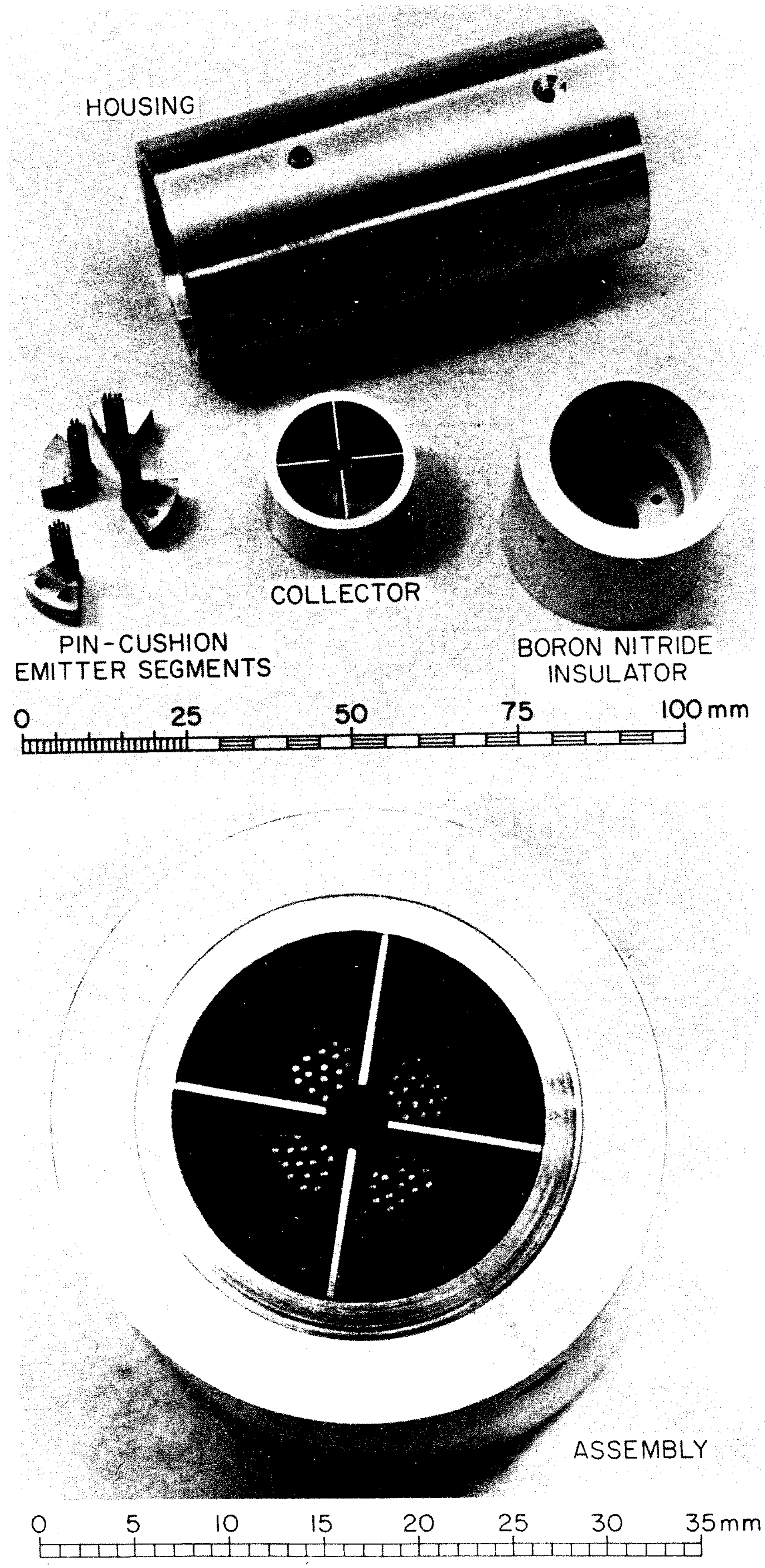

HOUSING
COLLECTOR
PIN-CUSHION
EMITTER SEGMENTS
BORON NITRIDE
INSULATOR
0
25
50
75
100 mm
ASSEMBLY
0
5
10
15
20
25
30
35 mm

Fig. 2

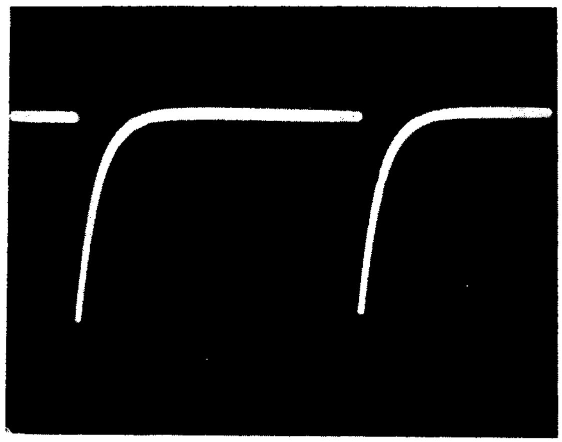

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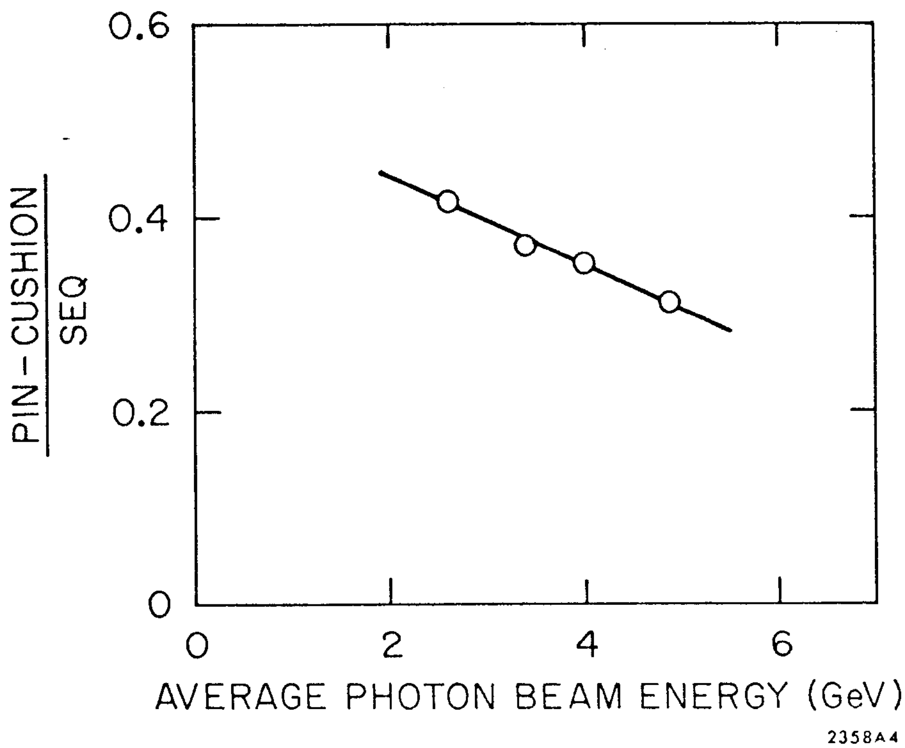
Fig. 3



0.6
0.4
0.2
0
PIN-CUSHION / SEQ
0
2
4
6
AVERAGE PHOTON BEAM ENERGY (GeV)
2358A4

Fig. 4