FERMILAB-PUB-75-128-E #118

Scintillation in Pilot 425 and UVT Lucite *

Peter H. Garbincius

Laboratory for Nuclear Science, Massachusetts Institute of Technology

Cambridge, Massachusetts 02139

July 3, 1975

(To be submitted to Nuclear Instruments and Methods)

Scintillation light was observed in Pilot 425 and UVT (ultra-violet transmitting) Lucite using slow protons below Cerenkov threshold. The light outputs relative to Pilot B scintillator were measured. Combined with high energy Cerenkov data, we find that the ratio of Cerenkov light to scintillation light is 11/1 for Pilot 425 and 80/1 for UVT Lucite for minimum ionizing particles.

* Work supported by the U.S. Energy Research and Development Administration.

I. Introduction

Acrylic lucite sheets have long been used as threshold Cerenkov counters. The high index of refraction, $n = 1.5$, implies thresholds of 124, 443, and 839 MeV/c for pions, kaons, and protons, respectively, leading to extensive use in the few GeV range. Recently, a technique has been developed [1] to use simple lucite radiators as multi-particle detectors by separating the various topologies by pulse height analysis. This is applicable in the high energy range where the Cerenkov light produced by each particle traversing the counter has reached its constant high energy limit.

A new product has recently been marketed, [2] Pilot 425, which is a lucite base in which a wavelength shifter absorbs the predominantly UV Cerenkov light and re-emits it in a spectrum peaking at 425 nm. This has two distinct advantages for counter physics. First, the blue fluorescent light is emitted in a spectral range more compatible with the frequency response of common photomultipliers. In tests using a prototype Cerenkov counter, a 67% increase in the photo-electron yield relative to UVT Lucite has been observed, [3] thus leading to better resolution and multi-particle separation. Second, the radiation is emitted more isotropically than the initial highly directional Cerenkov light. This also allows more flexible geometric designs for counters, while still collecting an appreciable number of photons onto the photocathode.[4]

The general properties of Pilot 425 relative to various lucites and a similar Nuclear Enterprise wavelength shifter have been studied by Sacharidis.[5] His results show the increased photo-electron yield for the Pilot and Nuclear Enterprises materials relative to Lucite. However, there remained a finite detection probability for particles even below Cerenkov threshold. This led to the discovery of scintillation light for the Nuclear Enterprises sample. No scintillation light was observed for the Pilot 425 or UVT Lucite samples down to 500 MeV/c incident proton momentum.

We intend to use lucite counters as part of a vertex detector to study the hadron multiplicities associated with a foward particle detected in a single arm spectrometer.[6] The counters will be placed downstream of a liquid hydrogen target and will cover a cone of 40 mrad half-angle about the beam. In addition to the fast produced secondaries, these counters will be subjected to slow recoil protons, delta rays, and even slow nuclear particles emanating from a nearby beam dump. Therefor, we proceeded with a set of measurements to ascertain the scintillation properties of Pilot 425 and UVT Lucite.

II. Tests at Low Energies

This part of the experiment was performed at the Harvard Cyclotron Medical Facility. The cyclotron produces beams of 160 MeV fixed energy protons. The protons are extracted using a magnetic dipole bump and are momentum analyzed by a bending magnet - slit combination. They are focused at our detector by a quadrupole pair. A 6 mm diameter collimator was placed 1 meter upstream of our counter. The kinetic energy of the protons could be varied by the introduction of calibrated polystyrene energy degraders just ahead of the collimator. This produced beams of energies of 20 $\pm$ 1 MeV to 157.5 $\pm$ 0.5 MeV. The incident energy spread, due mainly to straggling in the degrader, was neglected in our analysis. The rate was held to 500 - 1000 protons/second to limit pile-up and dead-time corrections for our electronics.

A test counter was prepared incorporating five different materials on a common UVT Lucite light pipe as in Figure 1. These included two sizes of scintillator, Pilot 425, UVT Lucite, and UVA Lucite. Using a diffuse green light-emitting diode, the light collection efficiency of this light guide was measure to vary by at most 12 % over the fase of the guide. The counter was coupled with optical grease to a 56 DVP phototube with a standard Amperex base. The operating voltage was 2400 volts.

Our trigger consisted of a single count in a 1/4" x 3/8" x 1/16" thick scintillator placed dirêctly before our test counter. The accidental rate in this counter was monitored over the course of the data run giving a background rate of 3.0 ± 0.5 %. This trigger was used to gate a linear stretcher. The gate width was 100 nsec. The anode output of the 56 DVP was amplified by a factor of 2.15 before integration by the stretcher. However, the input was attenuated by a factor of 0.14 for spectra using the scintillator. The stretcher output was stored by an ADC-multi-channel analyzer.

Some representative spectra are presented in Figures 2 through 4. The general features of these spectra are a pedestal peak in channel 10 followed by the actural spectra. Figure 2 shows the typical pedestal peak formed by accidental coincidences followed by a Landau energy loss spectrum for 90 MeV protons incident upon our 3/16" scintillator. Compare this to the Pilot 425 and UVT Lucite spectra in

Figures 3 and 4. The spectra are not resolved from the pedestals in these cases. The pedestals consist mainly of light levels below the minimum sensitivity of our stretcher. The data are presented in Table 1. The channel of the peak of the Pilot 425 spectrum is seen to rise as our beam energy decreases, typical of a scintillation or a dE/dx process. This rise is plotted for the Pilot 425 and scintillator samples, corrected for attenuation or amplification in Figure 5a. Also plotted is a theoretical curve for the most probable energy loss in Pilot B scintillator.[9] Only our lowest energy protons are completely stopped in the Pilot 425 and Lucite samples, thereby giving at most 40 MeV ionization and causing the curves in Figure 5 to turn over.

The pulse height spectrum of UVT Lucite at 90 MeV is presented in Figure 4. It consists mostly of pedestal, indicating very little scintillation light is produced. The fraction of events falling in the pedestal, corrected for accidentals, is also presented in Table 1. This fraction is used to estimate the photo-electron yield in our photomultiplier.[8] The photo-electron yield in Figure 5b is seen to rise with decreasing energy, again indicating a scintillation effect. However, the amount of scintillation light from UVT Lucite is, on the average, a factor of 8.9 ± 0.8 below that of a comparable thickness of Pilot 425. The UVA Lucite sample also exhibits scintillation effects at the same level as the UVT Lucite.

III. Tests at High Energies

To check the relative light outputs at high energies, another study was undertaken using a 100 GeV negative beam at Fermilab. The typical beam composition was 92% pions, 4% kaons, 2% anti-protons, and 2% electrons and muons. No study was made of the dependence of the response on incident particle species. Our trigger consisted of a coincidence between a 1/2"x1/2"x1/16" counter located directly ahead of our sample and a larger beam defining counter located 10 meters upstream. The upstream counter was also used to veto events with extra beam particles incident within an interval of 150 nsec before or after a trigger candidate. This employed both pile-up veto logic and a dE/dx window to insure freedom from pile-up effects. Additionally, our trigger logic was inhibited for 6 μ sec following a valid trigger to allow resettling of our stretcher. The gate to the stretcher was set at 80 nsec. Typical trigger rates were 100-300 per pulse. The spectra for the 1/16 and 3/16 scintillators employed 2X and 5X attenuators to avoid saturation of the stretcher. The scintillator spectra were appropriately averaged in the analysis. The results are presented in Table 2. Typical spectra for Pilot 425 and UVT Lucite samples are given in Figure 6. The complete set of ratios of light outputs for various materials at both high and low energies is presented in Table 3. From these data we may find the ratio

$$\left.\frac{\text{Pilot 425}}{\text{Pilot B}}\right|_{100\text{ GeV}} = \frac{1}{27.6 \pm 0.7} .$$

Using the ratio

$$\left.\frac{\text{Pilot 425}}{\text{Pilot B}}\right|_{40\text{-}160\ \text{MeV}} = \frac{1}{330 \pm 22},$$

and assuming that the scintillation light yields follow the ionization loss theory, we find a scintillation light to Cerenkov light ratio for Pilot 425 at 100 GeV to be

$$\left.\frac{\text{Scintillation}}{\text{Cerenkov}}\right|_{\substack{\text{Pilot 425} \\ @\ 100\ \text{GeV}}} = 0.090 \pm 0.007 .$$

This is to be compared with the manufacturer's quoted value of[2] 10 % at high energies.

IV. Conclusions

We may conclude that the Pilot 425 does indeed scintillate with a scintillation to Cerenkov ratio of about 1/11 for high energy particles. However, this indicates that the response to a 50 MeV proton will be about half that of a high energy pion and care must be taken if such backgrounds are possible. The UVT Lucite, however, shows much smaller relative scintillation properties with a comparable ratio of about 1/80, and should therefore produce a cleaner threshold effect.

Acknowledgements

I would like to extend my thanks to the staff of the Harvard Cyclotron Lab, and to W. Aitkenhead, G. Brandenburg, W. Busza, M. Jacobs, C.R. Smith, and C. Young of LNS-MIT, and to C.J. Garbincius for their help in various phases of this project.

Footnotes

1. W. Busza, J.E. Elias, D.F. Jacobs, P.A. Swartz, C.C. Young and M.R. Sogard, Phys. Rev. Letters 34, 836 (1975).

2. Pilot 425 specifications sheet, Nuclear Enterprises, Inc., San Carlos, California 94070. I would like to acknowledge informative discussions with R.J. Wyman.

3. Test performed with W. Aitkenhead and W. Busza of MIT at the Brookhaven AGS using 4-6 GeV pions and electrons. Further details will be presented in forthcoming publications.

4. B. Brown, Fermilab, and W. Selove, U. of Pennsylvania, are using Pilot 425 as novel light pipes to redirect Cerenkov and scintillation light from large calorimeters to their phototubes. These techniques were discussed at the Calorimetry Workshop, Fermilab, May, 1975.

5. E.J. Sacharidis, Nucl. Instr. and Meth. 101 (1972) 327.

6. Proposal for Fermilab Experiment 118A, J.I. Friedman, spokesman. Bari-Brown-Fermilab-MIT Collaboration.

7. The amplitudes have been normalized to a common scale by the removal of amplification or attenuation factors. The absolute normalization of this scale is 0.047 pC/channel.

8. For Pilot 425, the photo-electron yield was calibrated as a function of the pulse height peak position. For UVT Lucite, it was calculated using an inefficiency method discussed by P. Baillon, et al., Nucl. Instr. and Meth. 126 (1975) 13. Both techniques give equivalent results for the Pilot 425 data. The photo-electron yields have been normalized to a common sample thickness of 0.489 inch.

9. J.M. Paul, Nucl. Instr. and Meth. 96 (1971) 51.

10. Light outputs have been normalized to 0.5 inch thickness. The 3/16" and 1/16" scintillator data are likewise averaged.

11. Notice that an upper limit for variations due to light collection efficiency has been measured to be 12 % and has not been included in the error estimates for the ratios.

Table 1. Low Energy Data.

Proton Energy		Scintillator	Pilot 425		UVT Lucite		UVA Lucite	
		0.209 inch	0.489 inch		0.455 inch		0.502 inch	
Incident	Corrected for dE/dx	Peak[7]	Peak[7]	P.E. yield[8]	Fraction pedestal	P.E. yield[8]	Fraction pedestal	P.E. yield[8]
157.5 MeV	156.0 MeV	371±10	2.3±0.2	1.2±0.1	0.83±0.01	0.13±0.01		
90.3	87.8	513±5	3.3±0.2	1.6±0.1	0.72±0.01	0.27±0.02		
64.2	60.9	584±6	6.5±0.5	3.3±0.3	0.70±0.01	0.30±0.02		
49.7	45.7	691±9	9.3±0.5	4.6±0.2	0.63±0.01	0.42±0.02		
40.6	35.8	805±15	7.0±0.4	3.5±0.2	0.65±0.01	0.41±0.02	0.64±0.01	0.44±0.02

Table 2. High Energy Data.[10]

Energy	100 GeV
Material	**Channel of Spectrum Peak**
Scintillator	5456 ± 44
Pilot 425	198 ± 6
UVT Lucite	154 ± 4
UVA Lucite	124 ± 4

Table 3. Light Output Ratios.[10,11]

Ratio = Light (a) / Light (b)

b\a	UVT	Pilot 425	Scintillator
High Energy - 100 GeV			
UVA	1.24±0.05	1.60±0.07	44.0±1.5
UVT		1.29±0.05	35.4±1.0
Pilot 425			27.6±0.7
Low Energy - 40 - 160 MeV			
UVT		8.9±0.8	2900±400
Pilot 425			330±22

Figure captions

Figure 1. Test counter incorporating five samples on a common light pipe coupled to a 56 DVP photomultiplier.

Figure 2. Pulse height spectrum for 0.209 inch scintillator for 90 MeV incident protons. Calibration is 6.7 pC/channel.

Figure 3. Pulse height spectrum for Pilot 425 at 90 MeV. Calibration is 0.022 pC/channel.

Figure 4. Pulse height spectrum for UVT Lucite at 90 MeV. Calibration is 0.022 pC/channel.

Figure 5 a. Energy dependence of most probable energy loss for Pilot 425 and scintillator samples. Solid curve is the calculated energy loss neglecting shell corrections.[9] Proton energy scale includes energy losses in traversing trigger counter.

Figure 5 b. Photo-electron yield[8] in 56 DVP for Pilot 425 and UVT Lucite samples.

Figure 6. Cerenkov pulse height spectra for Pilot 425 and UVT Lucite samples at 100 GeV.

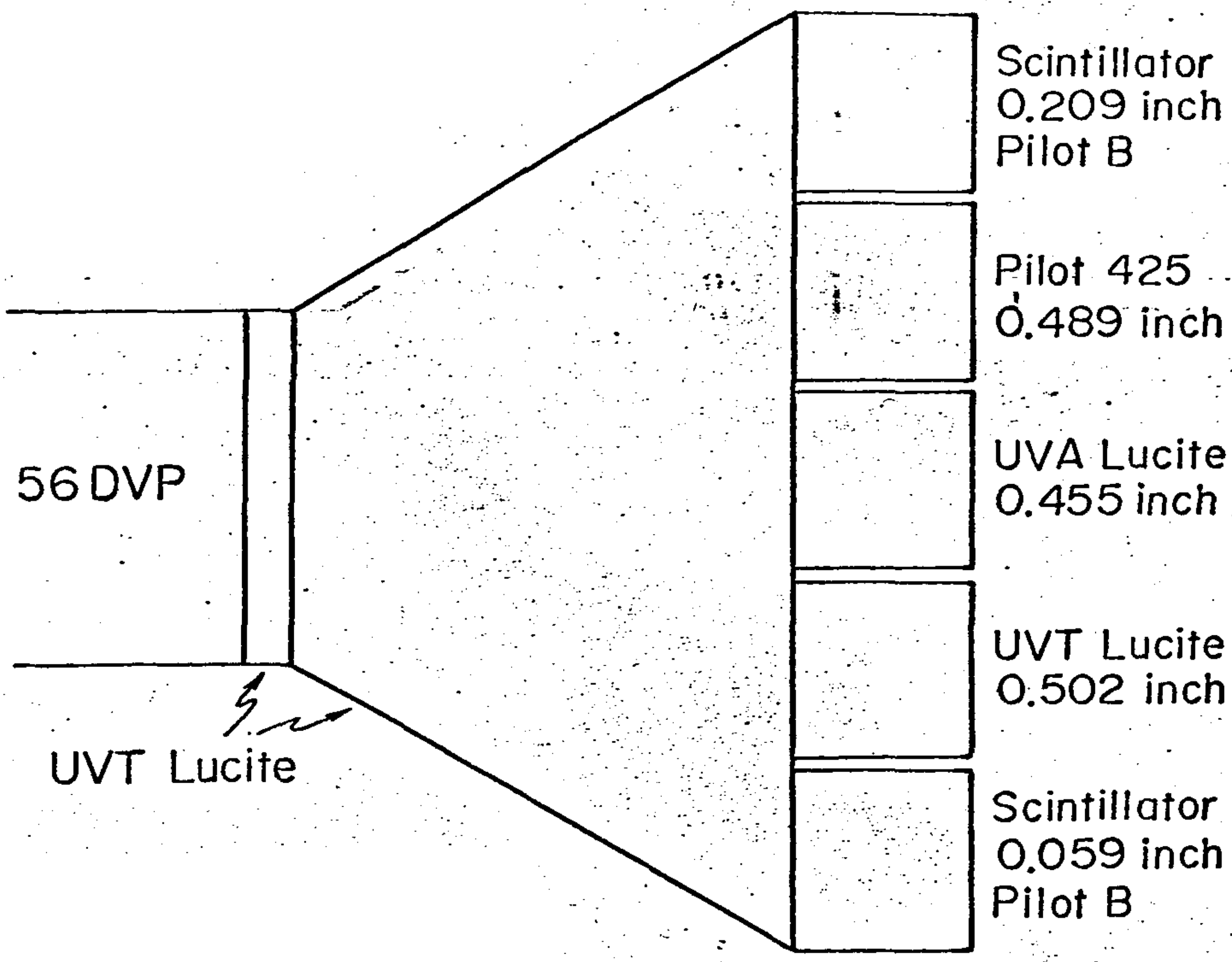
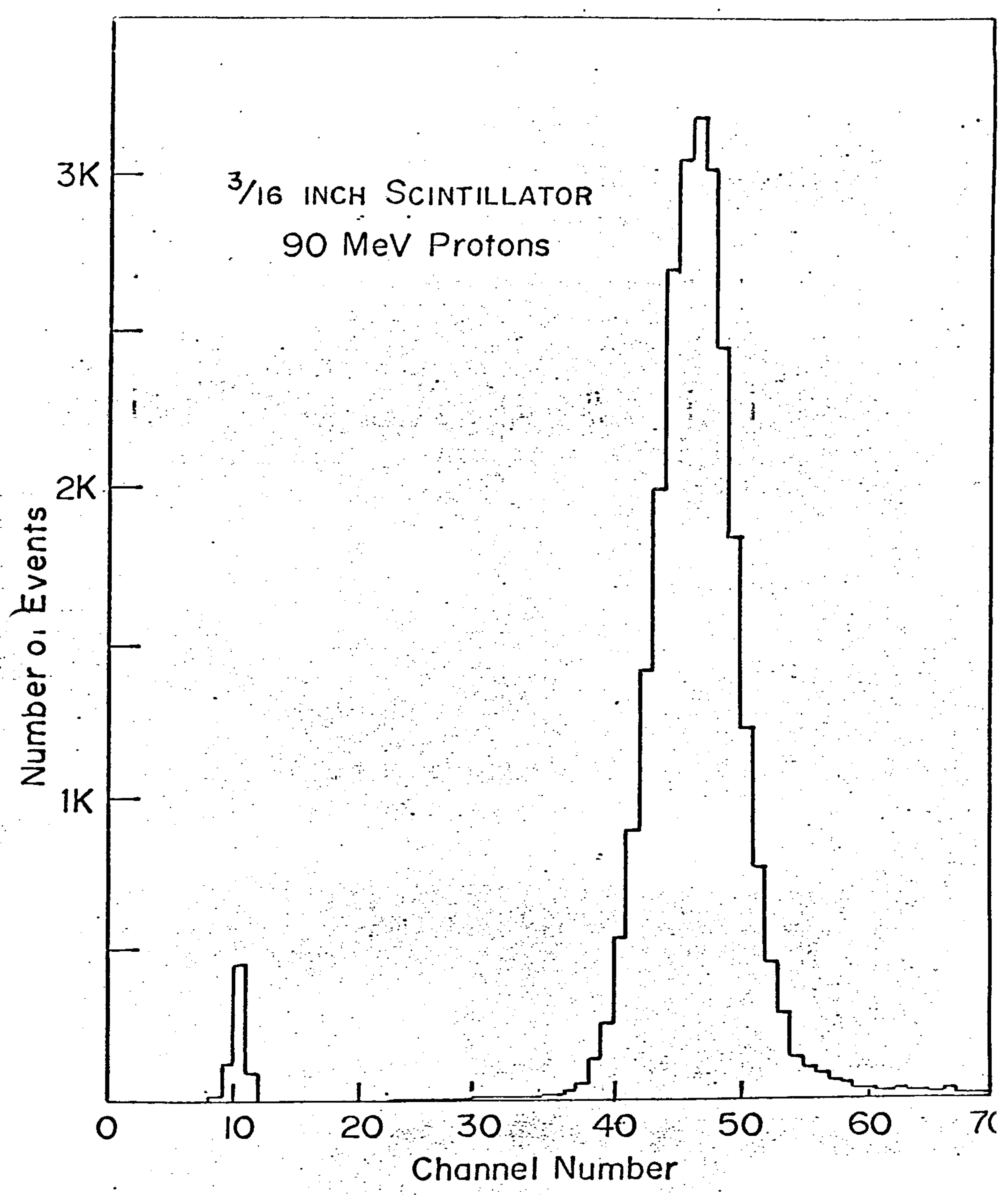

Scintillator
0.209 inch
Pilot B
Pilot 425
0.489 inch
UVA Lucite
0.455 inch
UVT Lucite
0.502 inch
Scintillator
0.059 inch
Pilot B
56 DVP
UVT Lucite

fig 1


3/16 INCH SCINTILLATOR
90 MeV Protons
3K
2K
1K
Number of Events
0
10
20
30
40
50
60
70
Channel Number
Fig 2

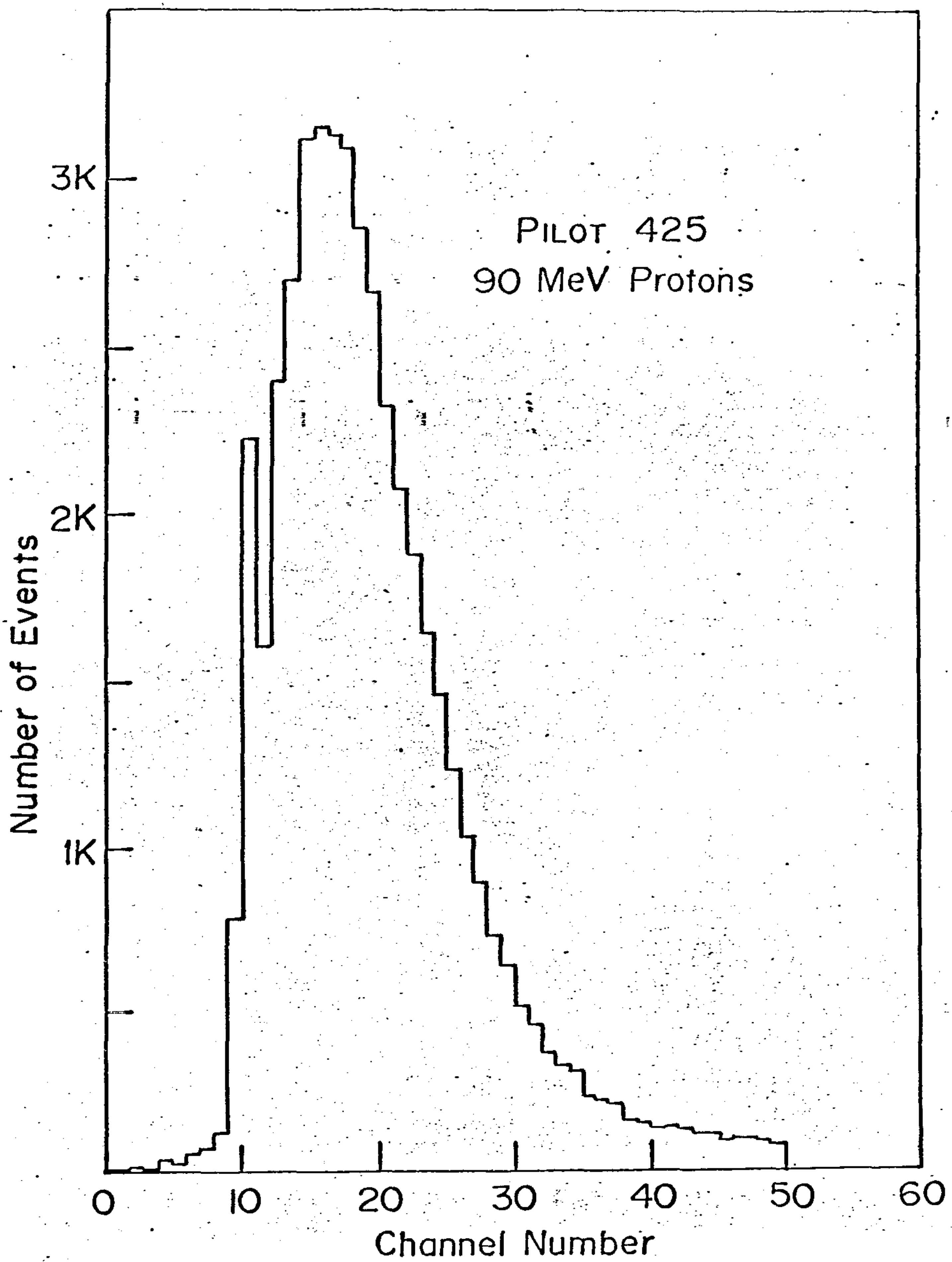

PILOT 425
90 MeV Protons
Number of Events
3K
2K
1K
0
10
20
30
40
50
60
Channel Number

fig 3

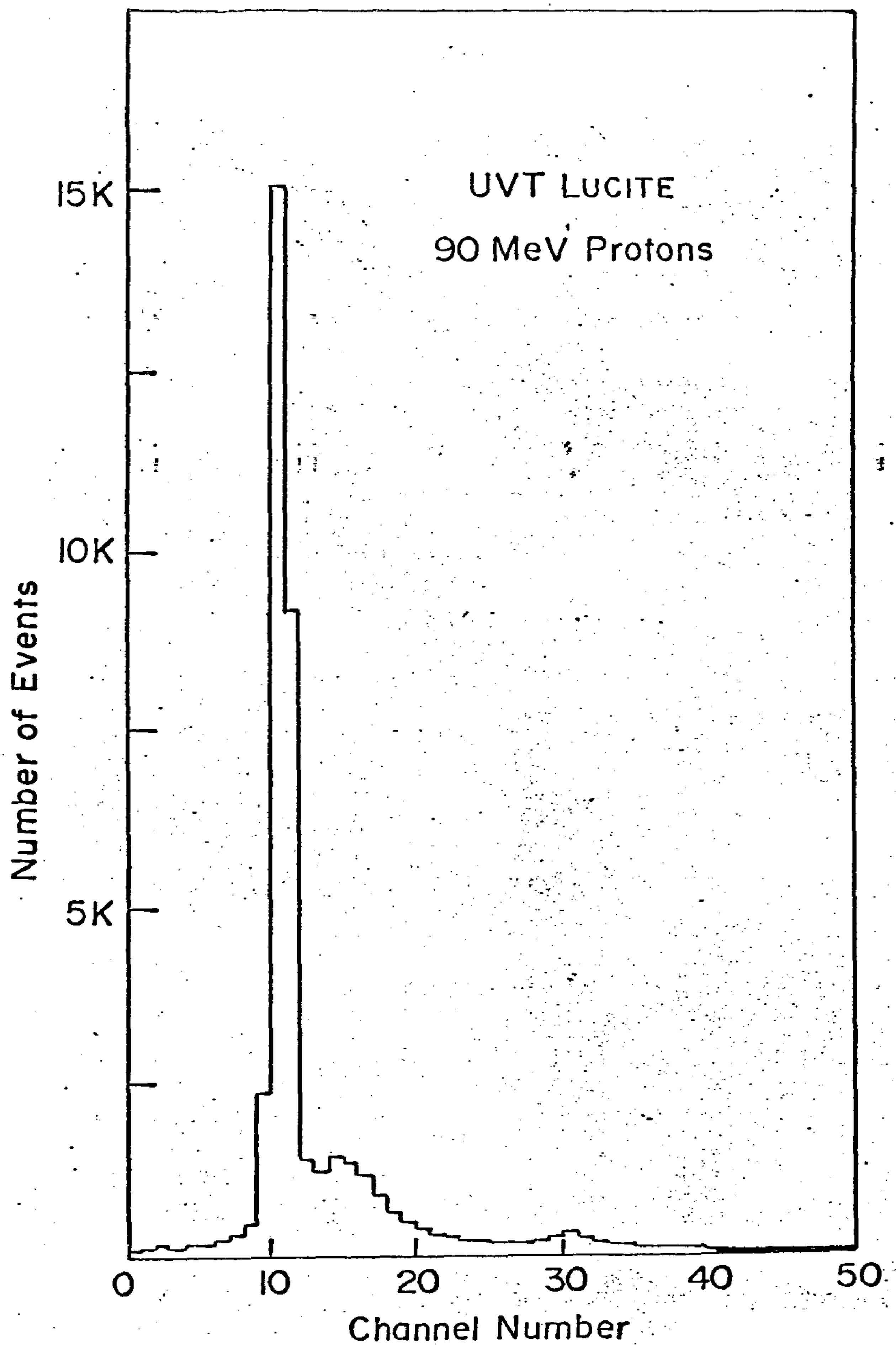
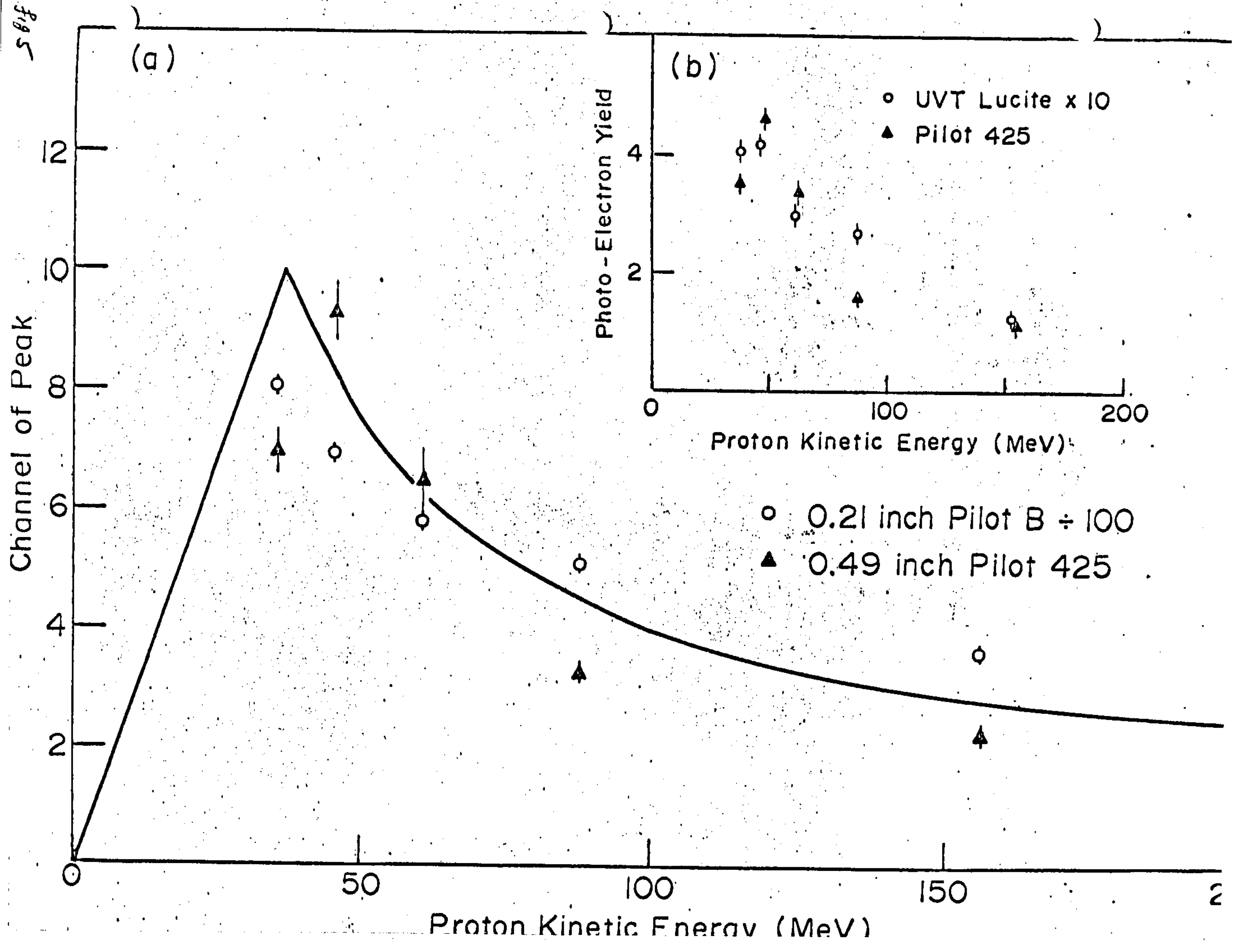
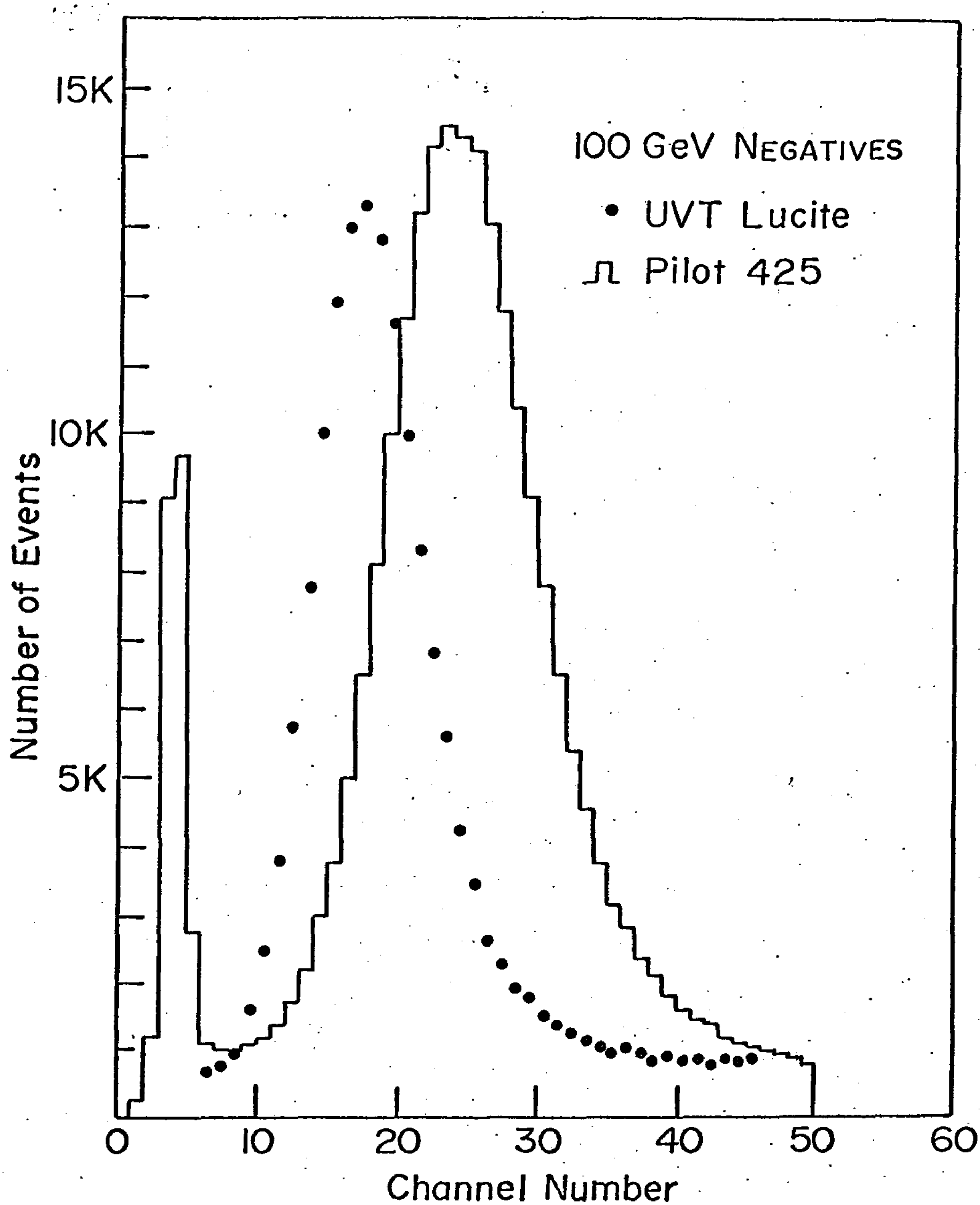

UVT LUCITE
90 MeV Protons
15K
10K
5K
Number of Events
0
10
20
30
40
50
Channel Number

fig 4

fig 5


(a)
Channel of Peak
12
10
8
6
4
2
0
50
100
150
2
Proton Kinetic Energy (MeV)
0.21 inch Pilot B ÷ 100
0.49 inch Pilot 425
(b)
Photo-Electron Yield
4
2
0
100
200
Proton Kinetic Energy (MeV)
UVT Lucite x 10
Pilot 425


100 GeV NEGATIVES
• UVT Lucite
Pilot 425
15K
10K
5K
Number of Events
0
10
20
30
40
50
60
Channel Number
Fig 6