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SEARCH FOR MULTIPHOTON EVENTS PRODUCED IN PHOTON-BERYLLIUM INTERACTIONS

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The purpose of this experiment is to continue our search for multiphoton events at FNAL. Multiphoton events have been observed by several authors in cosmic ray exposures in the 1950's and have been associated by Ruderman and Zwanziger with bound magnetic monopole pairs. In our initial search, Multigamma #22, we sought to produce anomalous multiphoton events using 300 GeV/c protons on beryllium. In Multigamma #22, after subtracting the neutron background and accounting for the known sources of photons, there remains a residue of 11 multiphoton events whose cross section is most consistent with production by photons and whose characteristics are similar to the reported cosmic ray events. We find that each event has 5-7 converted photons immediately behind a 0.57 rl Pb converter, a projected production angle whose centroid is 0.1-2.4 mr, a production cone angle of 0.5-5.8 mr, and a total electromagnetic energy >100 GeV.

We propose to continue our search for anomalous multiphoton events in the tagged photon beam at FNAL because these events are most probably produced in photon interactions, and the tagged beam has the advantage of known photon intensity, angle and energy free of the troublesome neutron background. Thus the interpretation of the experimental results is less speculative. The experimental arrangement would optimize our search for these narrow, multiphoton showers and would benefit in its design from the experience gained in our previous search. The multiphotons would be produced in a Be target, travel ∿ 40 m. in vacuum, and form showers in a thick Pb converter. The shower cores would be recorded in desensitized multiwire proportional chambers (MWPC's) and their direction would be determined by conventional MWPC's. A lead glass counter array would be used to determine the total energy of the multiphotons. A candidate event would be required to have several shower cores and a total multiphoton energy nearly equal to the incident photon energy.

If we are scheduled to immediately follow E25A, and are able to use some of their existing apparatus (24" vacuum pipe, lead glass array, and information collection system), we would require only two weeks of testing and 100 hours of data-taking to complete the experiment. In order to be effective, each week of testing or data-taking should be preceded by a week with no beam usage. These estimates assume that 3×10^4 electrons/burst at 300 GeV/c are available in the tagged photon laboratory. With a two percent radiator in the tagging system, this intensity gives 400 photons/pulse with energies > 133 GeV. Using our estimated cross section for multiphoton production in γ-Be interactions [(0.2-10.8)mb], > 400 multiphoton events should be recorded, allowing cross sections as a function of energy, multiplicity, and production angle to be measured.

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I. MOTIVATION

We have recently completed a search for anomalous multiphoton events produced at small angles in 300 GeV/c proton-beryllium interactions. The results of this search, presented in Appendix A, are:

- Predicted and observed multiplicity distributions agree for multiplicities $\gtrsim 3$, as do the production cone angle and energy distributions where they are reliably known.
- No events with $\gtrsim 5$ showers were expected but 11 events were observed with 5-7 converted photon showers immediately behind a 0.57 rl converter, each with a total energy >100 GeV. Since the probability for shower production is ~0.36, these events would have a most probable photon multiplicity of ~17.
- The multiphoton events we observe are similar in character to anomalous multiphoton events observed in cosmic ray exposures[1].
- The cross section per nucleon of our multiphoton events, assuming they are produced in proton, neutron, and photon interactions, is (0.5-30) x 10^{-6}, (2-200) x 10^{-6}, and (0.02-1.2) mb respectively.
- The cross section per nucleon for production by cosmic ray neutrons and photons is 0.3 and 3 mb respectively. Thus, our results are most consistent with production by photons.

One of our multiphoton events is shown in Fig. 1.

Since the anomalous cosmic ray events and our multiphoton events appear to be produced at small angles in photon interactions, their production by tagged photons offers several distinct advantages over production by the real or virtual photons which are available in p-Be interactions:

- No neutron background. When present, this background requires complicated subtraction procedures which can mask the multiphoton signal.
- Fewer competing processes. Our multiphoton events occurred once in $\sim 5 \times 10^6$ proton interactions. They should occur, at a minimum, in 16% of the photoabsorption reactions[2]. The major competing process, however, is pair production whose cross section is 188 times larger[3] than the photoabsorption cross section. However, the signature for pair production, e^+e^- forward, will allow us to veto these events. If the e^+e^- pair fails to trigger the veto counter, the event will have a low apparent photon multiplicity and will not be a multiphoton candidate.
- Known photon intensity. This will allow us to obtain cross sections free of the uncertainties which were present in Multigamma #22.
- Known photon energy and angle on an event by event basis. This feature is indispensible for definitive identification of multiphoton events since these events should carry nearly the entire energy of the incident photon forward.

We therefore wish to press forward our search for multiphoton events in the tagged photon beam at FNAL.

II. EXPERIMENTAL ARRANGEMENT

The experimental arrangement which we propose to use will allow us to identify multiphoton events produced at less than 5 mr relative to the incident photon beam. Moving downstream, it would consist of (see Fig. 2) the photon tagging system (2% radiator), a ~ 0.04 rl Be target, lead covered veto counters, a 0.6m vacuum pipe $\sim$40m long, lead covered veto counters outside the acceptance aperature, a conventional MWPC covering the acceptance aperature, a $\sim$4 rl Pb converter, 2 desensitized MWPC's to record the core of each photon's shower, a conventional MWPC to measure the approximate angle of the showers, and a lead glass counter array to measure the total energy of the multiphoton event and the subenergies of closely spaced groups of photons.

We require a thin Be Target in order to minimize the probability for pair production by the multiple photons we expect to produce (a 20 photon event produced at the center of the Be target, would have a probability of generating no e^+e^- pairs = $[1- (0.04)\ (1/2)\ (7/9)]^{20}$ = 0.73, so 27% of our interesting events will be vetoed. The vacuum pipe end windows will increase somewhat the percentage vetoed.).

The lead covered veto counters will cause events with accompanying muons or wide angle ($>$5mr) charged or nuetral particles to be rejected.

The MWPC's we will employ were used in Multigamma #22. They measure 38 x 38 cm^2 and provide single coordinate readout. The chamber which precedes the Pb converter would be used as a veto counter. It has 99% efficiency for a minimum ionizing particle. The two chambers immediately behind the Pb converter would be desensitized so that they would respond only to the cores of the showers produced by the photons in the converter. The proper gas mixture which would simultaneously optimize our detection efficiency and resolution of adjacent cores must be determined. The two chambers would provide redundancy and give the projected production angle of the photons. The last chamber, located $\sim$2m downstream of the others has 99% efficiency and would allow us to estimate the production angle of the showers.

Since we will attempt to find an existing lead glass counter array to use in this experiment, details of this detector are not now available (For example, E25A presently has in the tagged photon beam an operational lead glass array composed of 6.3 x 6.3 x 61 cm^3 elements which would be well suited to our experimental needs).

Our trigger would consist of a signal from the photon tagging system, no signals in the veto counters or chamber preceding the lead converter, more than two shower cores behind the lead converter, and greater than 100 GeV total event energy deposited in the lead glass array.

Information from the MWPC's and the lead glass array will be stored on magnetic tape. System performance will be monitored on-line and final data analysis will be performed at VPI & SU.

III. PARTICIPANTS, SCHEDULING, COST

The three VPI & SU physicists authoring this proposal can devote nearly their entire research effort to this experiment as they now have no other commitments. A fourth faculty member is currently being sought by our group who, it is anticipated, will also participate in this effort. J. Fischer will generally participate in the experiment and in particular will assist in adapting the MWPC's to meet the requirements of shower core detection. We will request from the funding agencies support for a postdoctoral researcher whose sole responsibility will be this experiment. We would also expect to attract at least two collaborators, one of which is from FNAL, to participate in the testing and data-taking phase of this experiment.

If we are able to use equipment presently setup and working in the tagged photon laboratory (e.g. the 24" vacuum pipe, lead glass array, and information collection system of E25A) the time scale and cost of the experiment would be greatly reduced. If compatibility with the needs and interests of the E25A collaboration could be achieved, our multiphoton search could proceed as follows. VPI/BNL personnel would prepare and test the veto counters, the MWPC's, interfacing electronics, and on-line software during the spring and summer of 1976 so that in-beam testing could begin by September 1976. In the initial week of testing we would check the trigger logic and tune the MWPC's using single photons and electrons over a range of incident energy. The beam intensity required is 10% that needed for data taking. During the second and final test week we would evaluate the MWPC's using multiple photons and electrons and determine backgrounds. Here we would require the full beam intensity.

The 100 hours required for data-taking assumes, at 400 GeV/c, a proton intensity fo 2.5×10^{12} on target which yields a 300 GeV/c electron beam with an intensity of 3×10^{4} per sec. every 10 secs[4]. With a 2% radiator in the tagging system this would give approximately 400 photons/pulse above 133 GeV. At our minimum estimated cross section from Be of 0.18 mb, the 100 hours of running with a 0.04rl Be target should yield $[(\frac{0.18}{179})\ (0.04 \times 7/9)\ (\frac{400}{10})\ (100)\ (3600) = 450]$ at least 400 multiphoton events.

If the E25A equipment can be made available, few capital costs need be born by FNAL for our multiphoton search. FNAL would be asked to provide logic modules, scalers, and any additional 24" o.d. vacuum pipe that would be required. To effect this program, VPI & SU would request federal funds for summer faculty support, support for a postdoctoral fellow, travel and subsistence, and \$20K - \$30K for equipment purchases, interfacing electronics, and MWPC testing.

This experiment is exciting for the physics it may uncover, benefits from the experience gained in Multigamma #22, is relatively inexpensive, and is simple in design. Thus we request a prompt and favorable response to this proposal and early scheduling of the experiment.

FOOTNOTES & REFERENCES

1. G.B. Collins, et.al., Phys. Rev. D 8, 982 (1973)

2. We have used $\sigma_T(\gamma A) = [\, V(98.7 + 65.0\, \nu^{-1/2}) + (A-V)(103.4 + 33.1\, \nu^{-1/2})]$ ub; D.O. Caldwell, et.al., Phys Rev. D7, 1362 (1973); and therefore have assumed $A^{eff} = A$. At $\nu = 100$ GeV this gives $\sigma_T(\gamma\, Be) \approx .95$mb.

3. The cross section for pair production from Be is 179 mb; Y.S. Tsai , SLAC - PUB - 1365 (January 1974).

4. P. Davis, et.al., NAL TM - 535, (December 1974)

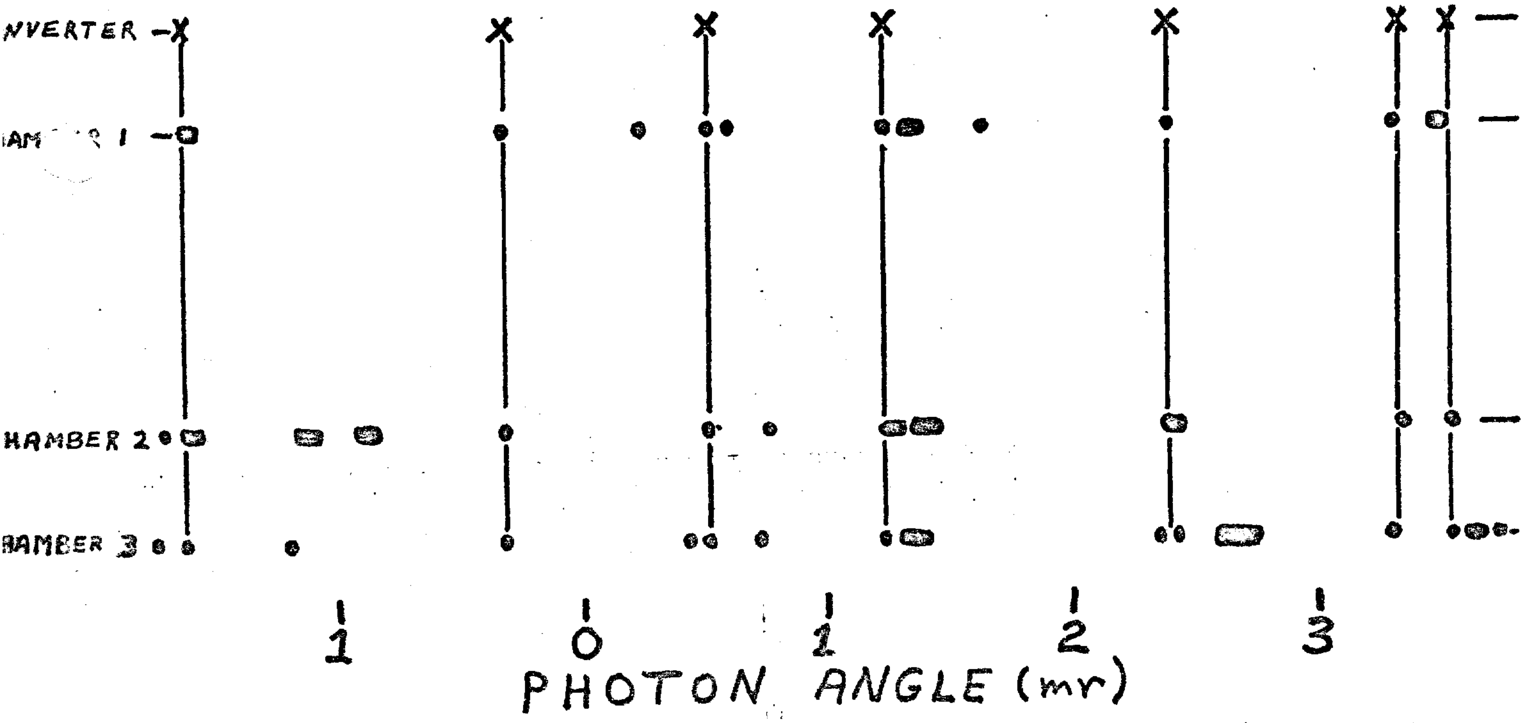

Fig. 1: This multiphoton event, seen in Multigamma #22, has seven photon showers and a total event energy of 150-200 GeV. The photons are incident from the top.

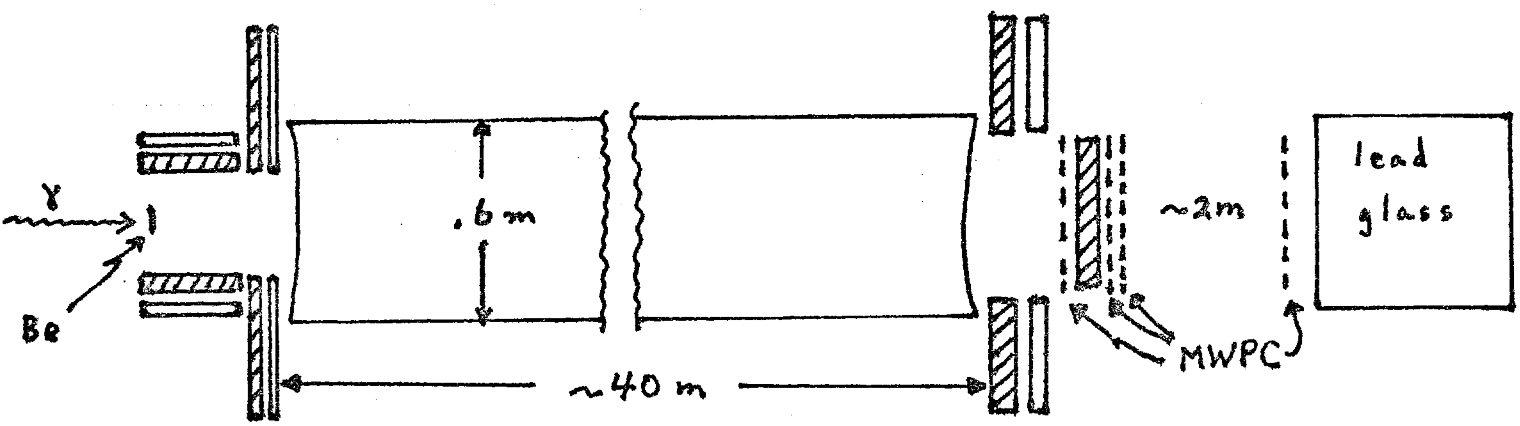

Fig. 2: Schematic of the experimental arrangement.

~4 rl Pb converter

veto scintillators

Appendix A

Search for Multi-photon Events From Proton Nuclei Interactions at 300 GeV/c[+]

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We have recorded the multiplicity, energy and angular distributions of 340,000 multi-photon events produced in proton nuclei interactions at 300 GeV/c. Of the 80,000 events analyzed the dominant behavior of the above quantities is consistent with that expected from known processes. However a few high multi-photon events inconsistent with known processes were found at a level of $\sim 10^{-7}$ per photon interaction.

I. Introduction

Since Dirac in 1931 predicted the existence of magnetic molopoles[1], many fruitless experimental searches for free monopoles have been made[2]. Ruderman and Zwanziger[3] explain these negative results by pointing out that the forces between monopoles are ultra strong ($\alpha^{-1} = 137$) and long ranged ($\sim r^{-2}$). Thus molopole pairs must be produced with relativistic velocities in their own center-of-mass system in order to escape their own self-attraction. However, bremsstrahlung processes associated with their production may greatly exceed the molopole's rest energy. Thus, except for very high energy interactions, these molopole pairs would annihilate producing more radiation. The authors estimate that at energies of 10^{13}eV $\sim$ 100 photons with laboratory energies of a few hundred to thousands of MeV would result.

In support of their model, Ruderman and Zwanziger point to the observation of anomalous energetic narrow pure photon cosmic ray showers[4]. A review of five of these events[5] shows that each contained 10-30 electron-positron pairs confined within a cone of 10^{-3} - 10^{-4} r with a total energy of $>$ 50GeV. The possible explanation of these multi-photon events is indeed attractive, however, other processes could be evoked.[6] Independent of interpretation we have attempted to rediscover these events at FNAL.

The cosmic ray events were apparently all produced by uncharged particles but circumstances at FNAL made it necessary to use 300GeV/c protons on a beryllium target as a source. The resulting photons were detected through the electromagnetic showers they produced in a lead converter placed before a set of three multi-proportional wire chambers. Since the angular separation of the individual photons was expected to be small, the detector system was located at a distance of 39 meters from the beryllium target. A larger distance was not possible but would have been preferable, since the linear separation of 10^{-4} showers at that distance is only about 4 mm or less than the separation of two wires in our MWPC's. Thus only photons with angular separations greater than 10^{-4} radians could be resolved.

The detector system used was composed of trigger and veto counters, lead an plexiglass photon converters, multi-wire proportional chambers, air and lead glass Cherenkov counters. The trigger and subsequent tracking criteria when combined with appropriately subtracted converter runs enhanced the photon signal in the presence of the more intense neutron background. Comparison with Monte-Carlo-gnerated, known photon sources allows extraction of the anamolous photon events we are searching for.

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app.

II. Experimental Details

A. Beam and Targets

The experiment was performed in the M-2 beam line of the Meson Detector Building using a 300 GeV/c diffracted proton beam. This beam was produced at the completion of each main ring acceleration period by extracting a fraction of the circulating protons and focusing them on the meson target, 0.1 x 0.1 x 20 cm^3 Be. The resulting diffractively scattered protons then entered the M-2 beam line where they were transported 366m and focused on our target. Here the beam area was 0.25 x 0.25cm^2, had horizontal and vertical angular divergences of 0.1 mr, and had intensity variable from 10^5 to 10^7 protons per acceleration period. Our target, 1.3 x 2.0 x 20 cm^3 Be, was rotated with respect to the incident beam to obtain target thicknesses from 0.025 to 0.073 interaction lengths with corresponding radiation lengths from 0.033 to 0.098.

As seen in Fig. 1, three bending magnets downstream of the target swept the unscattered proton beam and all produced charged particles clear of the detector. Between the last bending magnet and the detector, the charged beam wascontained in a 7.6 cm o. d. vacuum pipe located at 17.5 mr. with respect to the incident beam direction. The unbent neutral secondaries were contained in a 36cm o. d. vacuum pipe.

A 9 x 9 cm^2 scintillation counter placed at the downstream end of the 7.6 cm vacuum pipe monitored the beam at low intensities while a small counter telescope of two 5 x 2.5 x 1.3 cm^3 scintillation counters located next to the detector monitored back-scattered particles from the beam dump at high intensities.

The beam spot and position was monitored with survey-located horizontal and vertical Single Wire Ionization Chambers, SWIC's, read by a CAMAC system and displayed on a television monitor. The display was refreshed after each main ring cycle.

B. Multi-Photon Detector

The multi-photon detector (see Fig. 2) converted individual photons into electron pairs, recorded the tracks of the pairs, estimated the number of tracks, and measured the total energy of each multi-photon event. The detector consisted of three 248 wire proportional chambers, an air and a lead glass Cherenkov counter, and trigger and veto scintillation counter arrays.

Each multi-wire proportional chamber,[7] MWPC, contained a vertical plane of 25 cm stainless steel readout wires spaced 1.6 mm apart. The total average interaction and radiation length for each chamber was 6×10^{-4} and 9×10^{-4} respectively. The chambers had a 55 n sec time resolution using a gas mixture of 1% freon 13B1, 82% ultra pure Argon, and 18% methylal. Between data-taking runs the chambers were scanned by using a motor-driven, highly collimated, remotely controlled source-scintillation counter and the restulting wire maps were evaluated for mal-functions. The efficiency of the chambers (99%) and spark size (97% single wire) remained unchanged over the period of the experiment, 8 months elapsed time and 800 hours of operation.

The chamber signals were amplified, shaped, and output in a 1V, 100 ns signal with a -1.75 V. d.c. offset. Shielded 61m coaxial cables carried these signals to the interface located in the experimental trailer. A 70 ns gate generated by the fast logic allowed latches to be set by the shaped in-time signals from the individual wires. The interface scanned all of these latches. If a set latch was encountered the memory buffer of the PDP-8/I stored the corresponding wire number. The interface scalers provided visual readouts of logic triggers, the number of times at least one latch was set, and the total number of latches set.

The air Cherenkov counter (C) detected only electrons produced by high energy photons. The counter was a 90 x 90 x 90 cm^3 box with sides of 0.6 cm Al and ends of 0.16 cm Al. A spherical mirror of radius 1.6 m collected Cherenkov light and focused it on a 12.7 cm photo tube. Electrons with energy greater than ∼21 MeV and angle less than 35 mr with respect to the mirror's symmetry axis, the neutral beam line, produced detectable Cherenkov light. The counter detection efficiency for single particles was about 58% for an electron-positron pair from a converted photon. Since the output pulse height of the photo tube was correlated with the multiplicity of traversing charged particles it was fanned into five threshold discriminators, the lowest set at the 1-2 converted photon level and used in the trigger logic while the others tagged higher multiplicity events.

The lead glass Cherenkov counter[8] (G) consisted of a single piece of glass 45 x 20 x 30 cm^3 viewed by two 12.7 cm photo tubes located in a light-tight wooden box along the 30cm dimension. The beam traversed the 30 cm while the vertical and horizontal acceptances were 20cm and 45cm respectively. The counter was calibrated with 40-200 GeV/c electrons and pions. Since the lead glass was 12 radiation and 2 collision lengths thick, electromagnetic showers developed completely while hadronic showers were only partially developed. Figure 3 shows this effect in the pulse height spectrum from the summed photo tube outputs. The summed photo tube output was fanned into five threshold discriminators, the lowest set for 100 GeV total shower energy and used in the trigger logic while the others tagged events of progressively higher energies.

The detector system, located 39m downstream of the Be target, had a horizontal (vertical) acceptance of ± 4 (± 1.6) mr defined by lead-covered (2rl) scintillation counters preceding the detector which rejected events with charged particles or photons, outside the solid angle. Events with charged particles in the acceptance region were vetoed by a scintillation counter (1.27cm) preceding the detector. Electromagnetic showers were produced by photons in a converter preceding the first MWPC. The system provided a high degree of selectivity toward high multiplicity, high energy, small production angle, low cross section, time resolved individual events. At 40m the MWPC's provided a projected angular resolution of 0.04 mr. We thus attempted to optimize the system capability for detecting energetic, narrow, photon showers.

C. Event Selection and Acquisition

The fast logic, seen in Fig. 4, selected and recorded events with the required number of converted neutrals and minimum total energy. A trigger resulted when no veto counter signal (S3) was present and a signal was obtained from both Cherenkov counters and their bracketing counters (S1 & S2). Thus our trigger (S1 . S2 . C . G. $\overline{S3}$), which required that an event contain ~ 3 forward, charged particles in the air counter and deposit at least 100 GeV in the lead glass counter, generated a gate signal for the interface. If the signals were in the gate and if there was at least one hit on the third chamber, all chambers were scanned by the interface and the numbers of the hit wires were read through a data break into a PDP-8/I memory buffer. During the scanning, the interface was in the busy mode so that no additional gate signals could be generated.

The interface accepted eight additional bits of data from the air and the lead glass counter discriminators. Since high discriminator levels indicated a large number of electrons and high total photon energy respectively, we could trigger on a low air and glass level to optimize the data acquisiton rate while tagging events with high multiplicity and/or high energy.

The wire identification codes for hits on proportional chamber wires were read serially into separate 12-bit words of the memory buffer, as were the Cherenkov level codes. A typical event would have codes which corresponded to hits on the first, second, and third chambers, an air Cherenkov level, a lead glass Cherenkov level, and an event separation word of zeroes. When the 1024 word data buffer was filled, an interrupt signal was generated by the interface placing it in the busy mode and signaling the computer to service the buffer. The computer then copied the data buffer onto a 7-track 556 BPI magnetic tape and incremented the on-line analysis arrays. This action completed, the data were cleared, the interface was placed in acquisiton mode, and more data were accepted.

D. Monitoring

On-line data were logged through the computer's data break. Thus while data were being taken diagnostic displays were viewed on a storage scope; they included: wire maps (frequency of hits on each MWPC), chamber multiplicity distributions (frequency of single, double, triple, etc., hits), and individual events. Wire maps and multicplicity distributions were updated after every full data buffer. A telepype provided, upon request, a hard copy of the distributions. These displays allowed a check on the detector performance and an overview of the data being acquired. Problems with the chambers or their readout were thus quickly detected.

After each data tape had been filled, ~12 hrs., it was transported to the CDC-6600 at FNAL for analysis. Using the large sample of data, wire maps and multiplicity distributions as a function of the Cherenkov counters' levels could be obtained with good statistics. In addition typically a hundred events were displayed on hard copy providing a highly visible sample of data, and allowing us to examine in detail preselected categories of events. We thus were able to optimize the experimental arrangement for our search.

III. Data Analysis

This experiment is basically a search for events consisting of 10-30 photons with angular divergences of 10^{-3} to 10^{-4} radians. The central experimental problem is to identify such events in the presence of multi-photon events whose origins are known multimeson production processes, spurious events resulting from misinterpreted neutron interactions and malfunctioning of the apparatus. The apparatus was designed to eliminate as far as possible these types of background; but, for additional assurance, runs were made with both lead and plexiglass converters in front of MWPC's. These converters had approximately the same collision lengths but very different radiation lengths so that, after proper normalization, the background of spurious events produced in the lead converter could be eliminated by subtracting the plexiglass converter events. This subtraction was always performed after the event selection criteria had been applied equally to both lead and plexiglass converter runs.

The complexity of the production processes being viewed by the apparatus and the untested performance of our method for detecting photons made some verification of the overall performance of the apparatus desirable. Accordingly a Monte Carlo program generated events from all known production processes which, when combined with the physical characteristics of the apparatus, provided an estimate of absolute counting rates for a wide range of responses of the system. Thus the estimated rates for shower multiplicities of one through four were compared with the corresponding multiplicities obtained from the actual data. Multiplicities of three or below were too low to be of primary interest but the good agreement between the Monte Carlo and the actual data at these multiplicities provided assurance that the experimental conditions were understood and added conficence to the interpretation of high multiplicity events where the Monte Carlo program provides little information.

Approximately 340,000 events were recorded and available for analysis using the VPI-IBM 370/165 computer. These events were produced in a variety of ways, some expected and some spurious, but most may be considered as a background to the searched for multiphoton events. Thus the residue of events after accounting for these various background events could contain the narrow photon showers seen in cosmic rays, i.e. events with a large number of photon conversions having an opening angle of one milliradian or less. The most important sources of the background are now discussed.

Neutrons[9] interacting in the converter are the souce of the most serious background. Since the number of them incident on our detector exceed the photon events[10] by a factor of sixty, the detector trigger and subsequent track identification should suppress the neutron initiated events by a large factor. The lead glass counter reduces the neutron trigger by a factor of ten because in this unit hadronic showers are inefficient in producing Cherenkov radiation. Futhermore the probability for one or more photon conversions in the lead converter exceeds the neutron interaction probability by a factor of thirty. These two factors result in a ratio of neutron induced triggers to total triggers of less than 1 in 5. Table 1 summarizes our estimate of the relative fraction of triggers with lead and plexiglass converters. Since the interaction probability in the lead and plexiglass are nearly the same, the plexiglass subtraction should eliminate most remaining neutron events. However, since the neutrons which interact in the converter contain multiple π^0's ($\langle n_{\pi^0}\rangle \approx 4$ at 300 GeV), the lead will convert the π^0 photons more effectively than the plexiglass and therefore the lead converter runs will contain relatively more neutron events. This effect is strongly topology dependent, fortunately, the differences are the smallest at large multiplicities.[11]

A computer program selected from the data store events with different shower multiplicity as indicated by the number and location of hits on the three MWPC's. The number of events of each multiplicity was found to be sensitive to the criteria written into the program; and several versions were tried, two of which are reported here. The objective was a selection criteria which made valid the procedure of subtracting the plexiglass events from the lead events, thereby eliminating secondary sources. Fig. 5 shows a number of computer reconstructed events which serve to illustrate the selection criteria adopted. The hits on three chambers were considered to form an acceptable track if the projected angular divergence relative to the neutral beam axis was less than 10 mr. This represents a 1 wire separation on adjacent chambers and therefore is the most stringent requirement we could make given our chamber resolution and separation. Two distinct tracks were required to be separated in the first chamber by at least two wires with no hits.

Photons, which are our principle interest, upon interacting in the converter, will usually create a small shower since the converter is only 0.57 rl. Since the photon energy is in the GeV range the angular separation of the e^+e^- pairs will usually be less than a milleradian and the shower will usually be recorded in the chambers as a single hit. Some low energy electrons are occasionally emitted by the shower at large angles, but usually do not complicate the interpretation of the event. Fig. 5 (a) shows a clearcut three track event selected by the above criteria. The requirement that the track be within $\pm$10 mr of the neutral beam axis eliminated most photons not coming directly from the target.

There was the question whether particles resulting from scattering from various parts of our apparatus were affecting the results. Triggers from sources other than p-Be interactions were investigated by examining the production angle (determined by the average position of the extremum tracks) for various apparent multiplicities. These distributions as displayed in Fig. 6 are approximately Gaussian and symmetric about 0 mr except for multiplicity one. The swept charge beam is to the left of 0 mr in the figure and we attribute the large assymmetry in the multiplicity one distribution to background events and have eliminated these events by folding the distribution on the right of 0 mr. The effectiveness of our veto counters is strikingly apparent in this distribution. We conclude that for $n \gtrsim 2$ scattering plays little or no role in the accepted events.

A veto counter was placed 56 cm in front of the first MWPC to eliminate stray charged particles. This veto counter unfortunately could, by having neutrons interact in it near the downstream side, produce charged secondaries which were not vetoed out. The result was a source of secondaries, close to the MWPC which for angles less than 10 mr produced acceptable tracks simulating photon events from the much more distant Be target at an apparent cone angle (distance between extreme tracks/distance to Be target) less than 0.36 mr. The average plexiglass subtraction will not adequately eliminate the subsample of these events having low charge multiplicity because of the difference in the conversion probabilities of the lead and plexiglass. Corrections for this effect were applied from runs where the veto counter was not in the acceptance aperature. The distribution of cone angles for various multiplicities is displayed in Fig. 7. The effects of the veto counter are apparent in the n = 2 distribution.

Implementing the above tracking, subtraction and correction procedures leaves a sample of events which come from photons produced in p-Be collisions. These photons result from known hadron processes and other processes which we wish to investigate. To extract the anamolous photon events we compared the corrected data with that expected from photons which decay from mesons produced in the p-Be interactions. The expected distributions were generated by:

1) Using a "ρ-meson model" to generate the number of π^o pairs and proportionally adding single π^o's to obtain agreement with the bubble chamber[12] numbers for the average π^o multiplicity for each topology:

2) Parameterizing the momentum distribution by the scalling function of Dao et. al.[13];

3) Including diffractively produced π^o's through the decays $N^*(1238) \rightarrow N\pi^o$, $N^*(1760) \rightarrow N^*(1238)\pi^o \rightarrow N\pi^o\pi^o$, and $N^*(1760) \rightarrow N\rho \rightarrow N\pi^o\pi^o$; and

4) Using the bubble chamber momentum distributions[13] for K_s^o to generate K_s^o and K_L^o decays into π^o's.

The multiplicity, angle and energy distributions thus generated are compared with those same distributions resulting from the subtracted data corrected for counter efficiency (4-45% correction depending on multiplicity), trigger and data collection efficiency (4% correction), and veto counter effects (15% correction). These comparisons without arbitrary normalization are shown in Figs. 8-10. The multiplicity distributions are strikingly similar for apparent multiplicities (n) of three or less. At a multiplicity of four and above there is some difference between the data and generated events. The selection program does encounter difficulty with events of great complexity. When a large number of secondaries occur which traverse the MWPC's at large angles the hits may be so numerous that their accidental arrangement satisfies the selection criteria to the extent that the program records a falsely high multiplicity. Neutron interactions in lead and plexiglass can result in very large multiplicities ($\sim$20). The frequency of these events differ in the two converters because of their different conversions and nuclear properties. This difficulty is illustrated in Fig. 5(b). The event shown here is most probably due to a single neutron interaction but was recorded by the program as an event of multiplicity 6.

To reduce these effects an additional selection criteria was established which rejected very complex events by requiring for acceptance that the total number of hits on the first chamber be less than four times the number of different tracks (This criteria is referred to as the "hit requirement".). The multiplicity distributions for both the lead and plexiglass converters for the two selection criteria are shown in Fig. 11. One notes that the hit requirement has eliminated all evidence for events with $n \geq 5$ and the agreement with the generated data (see Fig. 8) is excellent.

The comparison between data and generated events made above concerns multiplicity distributions. Corresponding differences could also be expected to occur in the cone angle distribution and energy distributions if a source of multiphotons similar to those found in cosmic rays existed. Fig. 9 shows the normalized cone angle distributions obtained from the simulated events (crosses) and the data (dots). There are no differences suggestive of these multiphoton effects. Fig. 10 shows the comparison for the energy distributions. The difference at high energy and low multiplicity cannot be taken too seriously since there are no measured spectra of π^0;s of K^0;s at these high energies and small angles. Therefore the generating functions may be totally inapplicable in this energy range. Although there are no compelling discrepencies between the generated events and the data we collected, especially for the more conservative reconstruction criteria, we could very well be eliminating the multiphoton events we seek by applying them.

Since the simulated distributions yielded essentially no events with apparent multiplicity $(n) \geq 5$, we visually examined all computer selected events with $n \geq 5$, with and without the hit requirement, in the belief that true high multiplicity events may have escaped detection by the selection process. The criteria for accepting an event as a genuine $n \geq 5$ was the presence of five or more separate showers whose axes, as determined by hits in the three MWPC's, were parallel to one another and directed toward the beryllium target 40 m upstream. This selection eliminated near at hand sources which give high multiplicity divergent showers and therefore allow fictitious parallel tracks. Of the 588 events examined from the lead converter runs, 7 events passed this criteria. In the plexiglass runs, 334 events were examined with 2 passing the same criteria.

It is also possible that the multiphoton events we are searching for would be overlooked if their angular spread were of the order of 0.5 mr. Under these condtions the photon produced showers would overlap to some extent and the tracking criteria would record an apparent multiplicity lower than the correct one. For example, if a typical multiphoton event contains 20 photons within a cone angle of 0.5 mr, we would record an $n \geq 5$ less than 1% of the time using the tracking criteria; although 90% of the events would have 5 or more photon conversions. To investigate these effects we examined individually all events, independent of multiplicity, which had numerous hits within a small region of the first chamber. These events were then assigned a multiplicity on the basis of hit distribution in all three chambers. Those with an assigned multiplicity of five or greater were recorded. Of the 2646 events scanned from the lead converter, 4 had an assigned $n \geq 5$ while none of the 991 events scanned from the plexiglass converter had an assigned $n \geq 5$.

The multiplicity, energy, production angle and cone angle of the events selected by these two additional criteria are given in Table II. Fig. 5 (c) shows one of these events. We note that all but one event has an energy greater than 150 GeV. The cone angle on the other hand appears to be on the high side of the 1 mr we expect from typical cosmic ray multiphoton events. After normalization and correction for trigger inefficiencies the 9 (11-2) events correspond to a cross section for production by protons on a nucleon of $(6.5 \pm 2.4) \times 10^{-33}$ cm^2. This number has not been corrected for effects of the veto counter, aperature, tracking criteria or conversion efficiency. The size of these corrections depends critically on the number of photons in a multiphoton event and their angular spread. Since the residue of events we see have lateral extents of several milleradians these correction factors can increase the above cross section estimate by a factor of four or more. Therefore the cross section per nucleon for this residue is estimated to be (0.5-30) $\times 10^{-33}$ cm^2 if it is produced by proton interactions. Since the multiphoton events seen in cosmic rays were apparently produced by an uncharged particle, we assume this residue is produced by either secondary neutrons or secondary photons. Accordingly we calculate the corresponding cross sections. If the residue is produced by neutrons interacting in the beryllium, assuming that the neutrons originate from proton collisions and are produced on the average at the center of the target, we find a cross section per nucleon of (2-200) $\times$ 10^{-33} cm^2. If the residue is produced by γ-Be collisions where the photons are produced in p-Be collisions in the same target, we estimate a cross section for the residue of (0.02-1.2) $\times 10^{-27}$ cm^2. This latter number is to be compared with the estimated cross section per nucleon for multiphoton cosmic ray showers[5] of 3×10^{-27} cm^2 assuming A = 100 for emulsions. If the cosmic ray multiphoton events were produced by cosmic ray neutrons a production cross section per nucleon of about 3×10^{-28} cm^2 would be required, three order of magnitude above ours. Therefore the most likely source of these events is photon-nucleon interactions.

The validity of these few high multiplicity events must, however, remain in doubt since they represent processes occurring only about seventeen times in 10^8 p-Be interactions.

IV. Conclusion

This experiment suggests the possible existence of multiphoton events which are inconsistent with known production processes. Further experimental investigation in a known photon beam will be required to clarify the nature and source of these events.

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Acknowledgements

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Footnotes & References

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+ This work presented in partial fulfillment of the requirements for the Doctor of Philosophy degree at Virginia Polytechnic Institute and State University. Present address: Babcock and Wilcox, Lynchburg, Virginia.

* Work supported in part by grants from the Research Corporation of New York and the National Science Foundation.

** Work supported by the U.S. Atomic Energy Commission.

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6. For example, cascade decay by photon emission of closely spaced nucleon resonances: V.L. Teplitz and K. Johnson, private communication; F.von Hippel and C. Quigg, Phys. Rev. D5, 624 (1972).
7. Details of the chambers' construction and operation appear in Appendix A.
8. Graciously loaned on short notice by Dr. DeWire of Cornell University.
9. In all discussions in this paper hadronic cross sections are taken to be 39 $A^{2/3}$ mb, where A is the mass number of the target. We assume that the forward charged and neutral secondary spectrum is

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app.

References continued

the same for p-A as pp and that np and nn interaction are the same as pp except for one and two less charges respectively. We also assume, as an upper limit, that 40% of all p-Be interactions produce a neutron in our detector.

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app.

TABLE I: Estimated Fraction of Triggers

Source	Converter:	
	Lead	Plexiglass
n-Veto	.018	.062
n-Converter	.165	.550
γ-Converter	.817	.388

TABLE II: Characteristics of Individually Scanned Events (Pb Converter)

Event	n	E_{TOT}(GeV)	θ_p(mr)	θ_C(mr)
1	7	150-200	0.92	5.16
2	6	150-200	1.04	2.12
3	6	100-150	0.52	5.76
4	7	150-200	0.72	4.00
5	6	200-250	1.12	3.72
7	6	250-300	1.24	4.92
8	5	150-200	2.36	3.08
9	6	200-250	2.40	1.04
10	6	150-200	3.36	0.72
11	6	200-250	0.10	0.52

Figure Captions

Fig. 1.

Schematic of Experimental Set up.

Fig. 2.

Schematic of Multiphoton Detector.

Fig. 3.

Pulse height distributions in thė lead glass counter.

a) 40 GeV/c negative beam.

b) 65,100 and 200 GeV/c negative beams.

Fig. 4.

Schematic of fast trigger logic, data acquisition and on-line monitoring.

Fig. 5.

Examples of events selected by the computer program. n = number of showers (≡ photon multiplicity) as indicated by the computer; θ_p = production angle: θ_c = cone angle of photon shower. Dots (.) represent hits in the MWPC's. Solid lines have been added to show shower axis. Dashed lines suggest trajectories of particles emitted at large angles from a single source.

a) A clearcut three photon shower.

b) A complex event which was erroneously identified as n = 6.

c) A high multiplicity event (n = 7) which was verified by inspection.

Fig. 6.

Production angle distributions for various photon multiplicities. The distorted n = 1 distribution is attributed to single particles scattered from the deflected proton beam.

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app.

Figure Captions Continued

Fig. 7.

Cone angle distributions for various photon multiplicities.

The small angle shaded peak in the n = 2 curve is believed due to neutrons interacting in the nearby veto Scintillator.

Fig. 8.

Comparison between the fraction of observed photon multiplicities per interaction and the same for the generated data. All events have a total energy $>$100 GeV.

Solid line is generated data.

○ = absolute cross sections resulting from lead plexiglass subtraction.

● = cross sections resulting from lead plexiglass subtractions, with the hit requirement, and adjusted by a factor of 1.24.

Shows good agreement at lower multiplicities.

Fig. 9.

Comparison between the cone angle distributions of the data (.) and generated events (x).

Fig. 10.

Comparison between the energy distribution of data for various values of n and the corresponding distributions for generated events. A factor of 1.24 has been used throughout to raise the level of the data. No significant discrepancies are apparent.

Fig. 11.

Comparison of multiplicity distributions with lead and plexiglass converters. Results with and without the hit requirement are included. All events have a total energy $>$100 GeV.

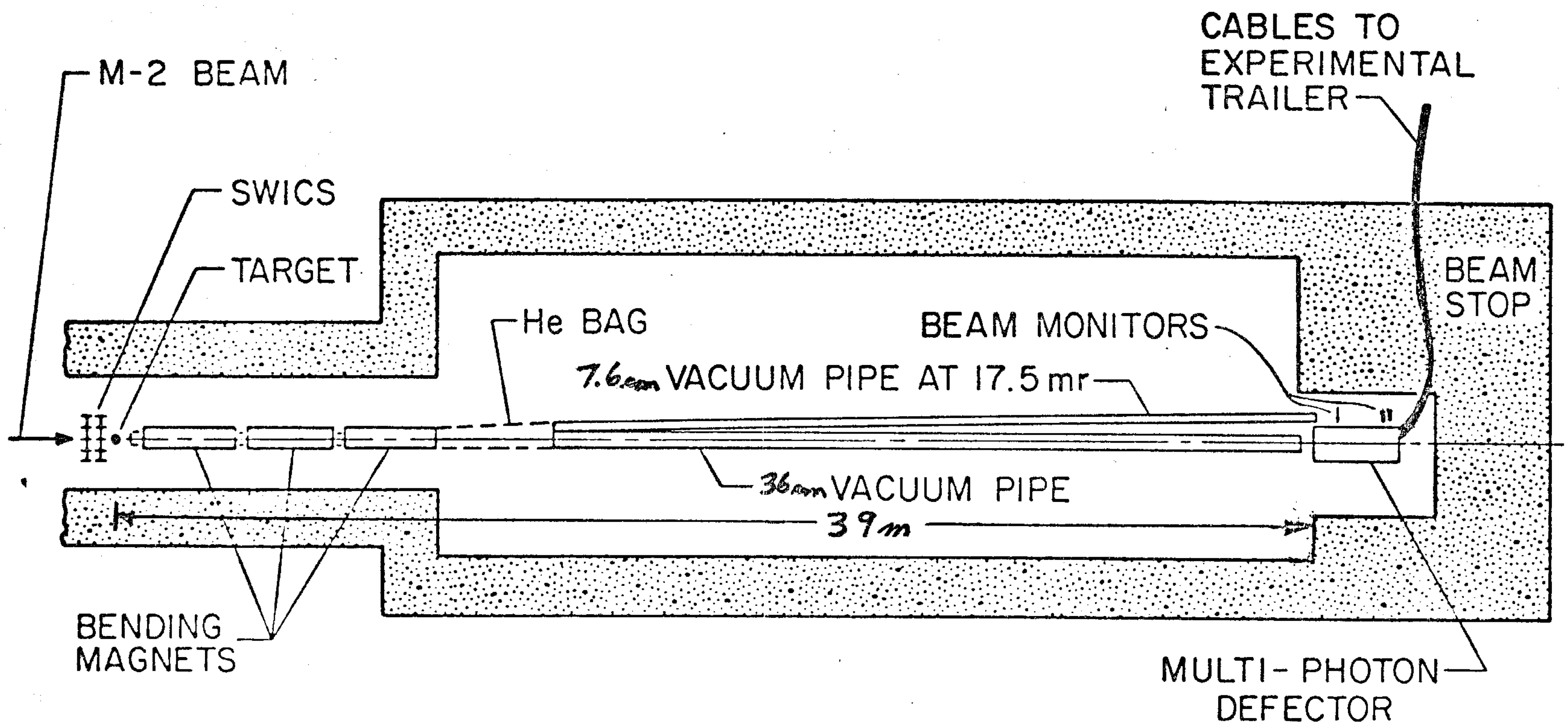

Fig. 1.

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app.

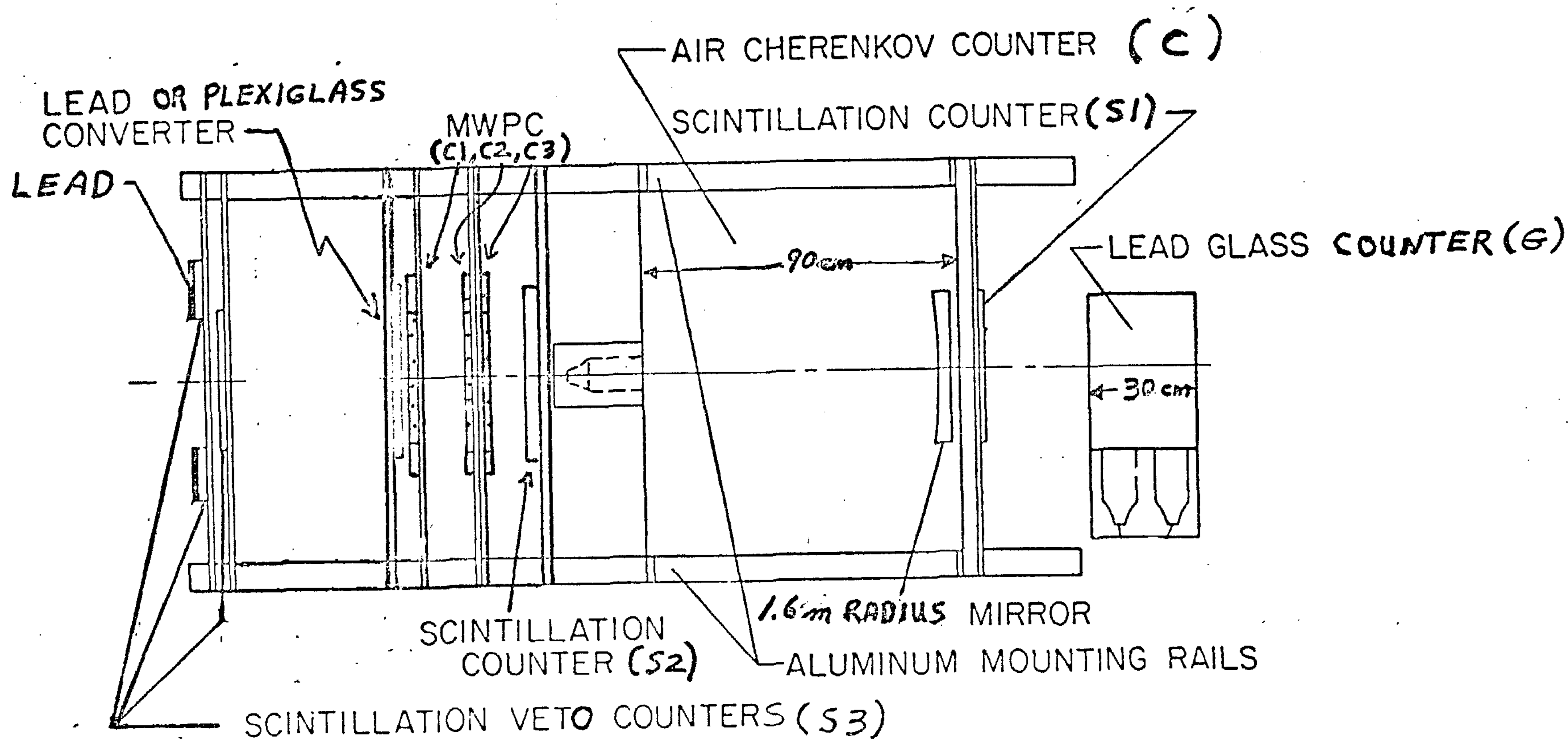

Fig. 2.

475-24 app.

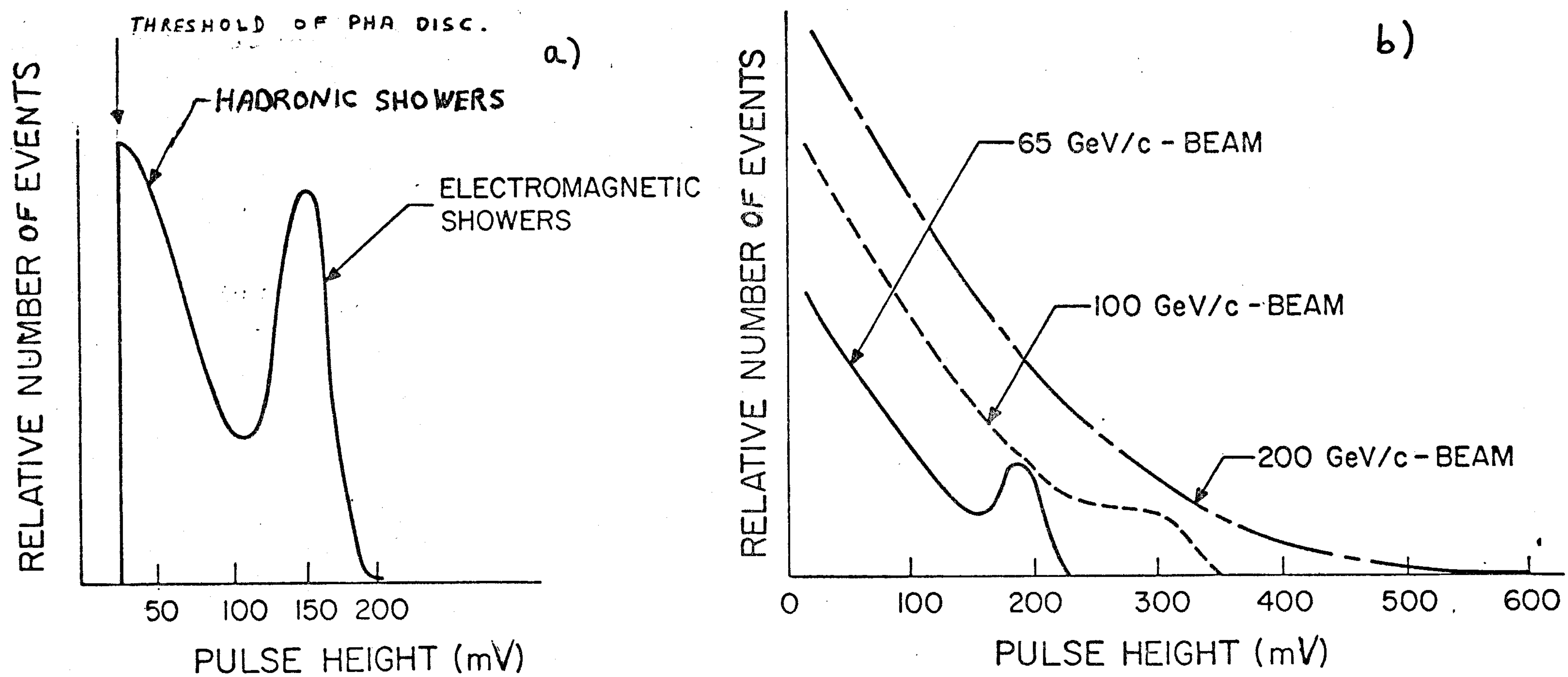

Fig. 3.

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app.

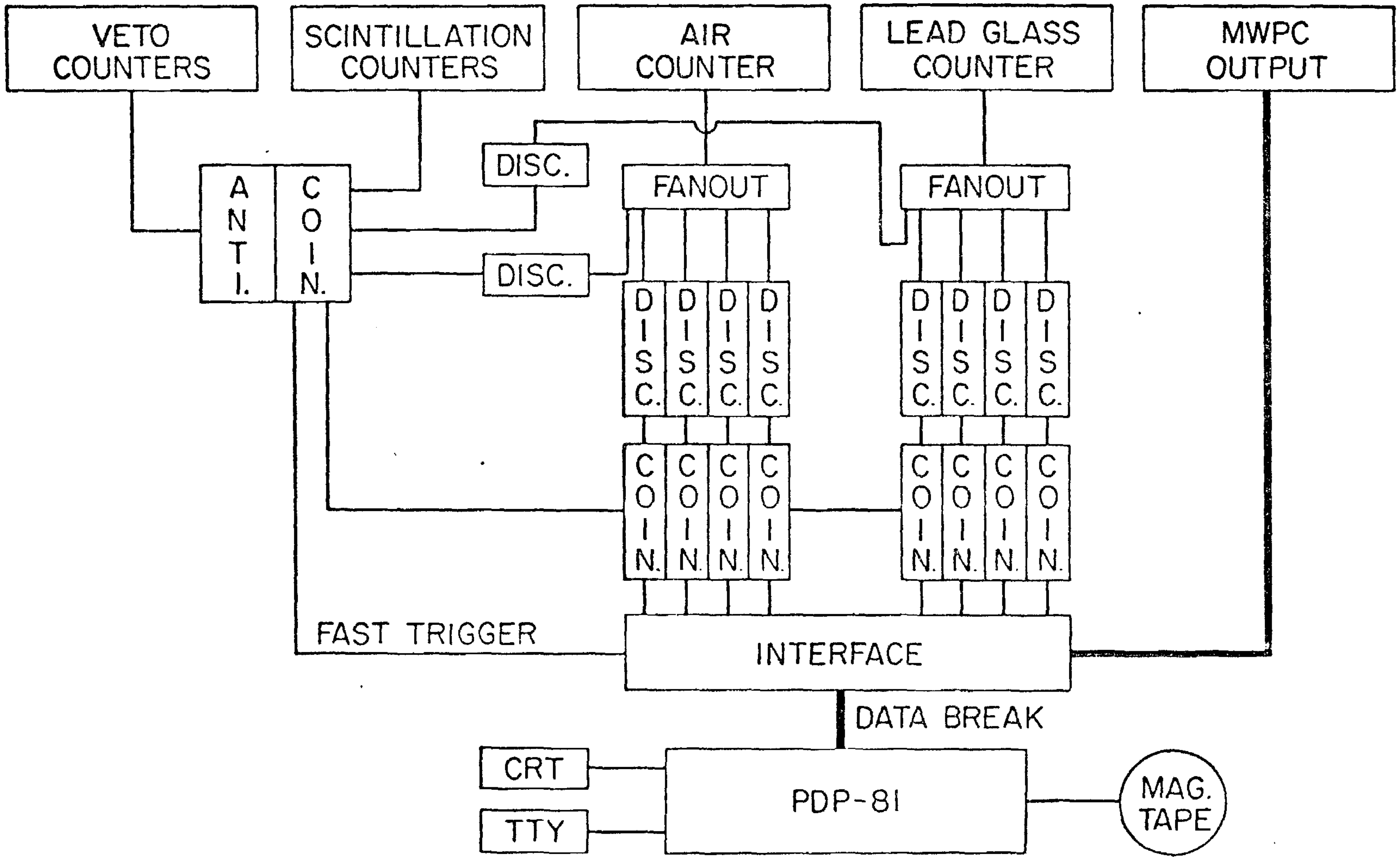
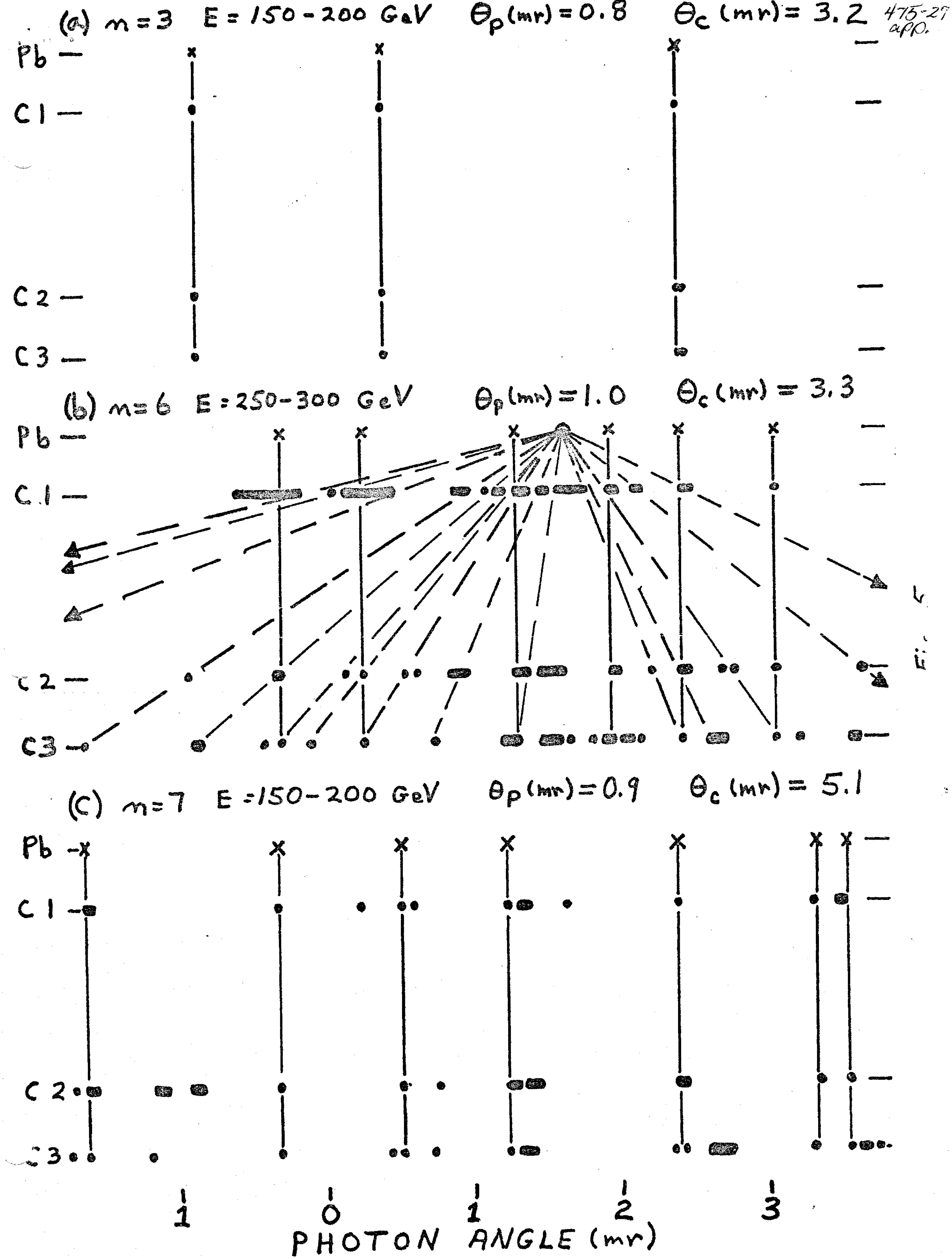


Fig. 4.



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(a) n=3 E=150-200 GeV θp(mr)=0.8 θc(mr)=3.2
Pb
C1
C2
C3
(b) n=6 E=250-300 GeV θp(mr)=1.0 θc(mr)=3.3
Pb
C1
C2
C3
(c) n=7 E=150-200 GeV θp(mr)=0.9 θc(mr)=5.1
Pb
C1
C2
C3
1
0
1
2
3
PHOTON ANGLE (mr)

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app.

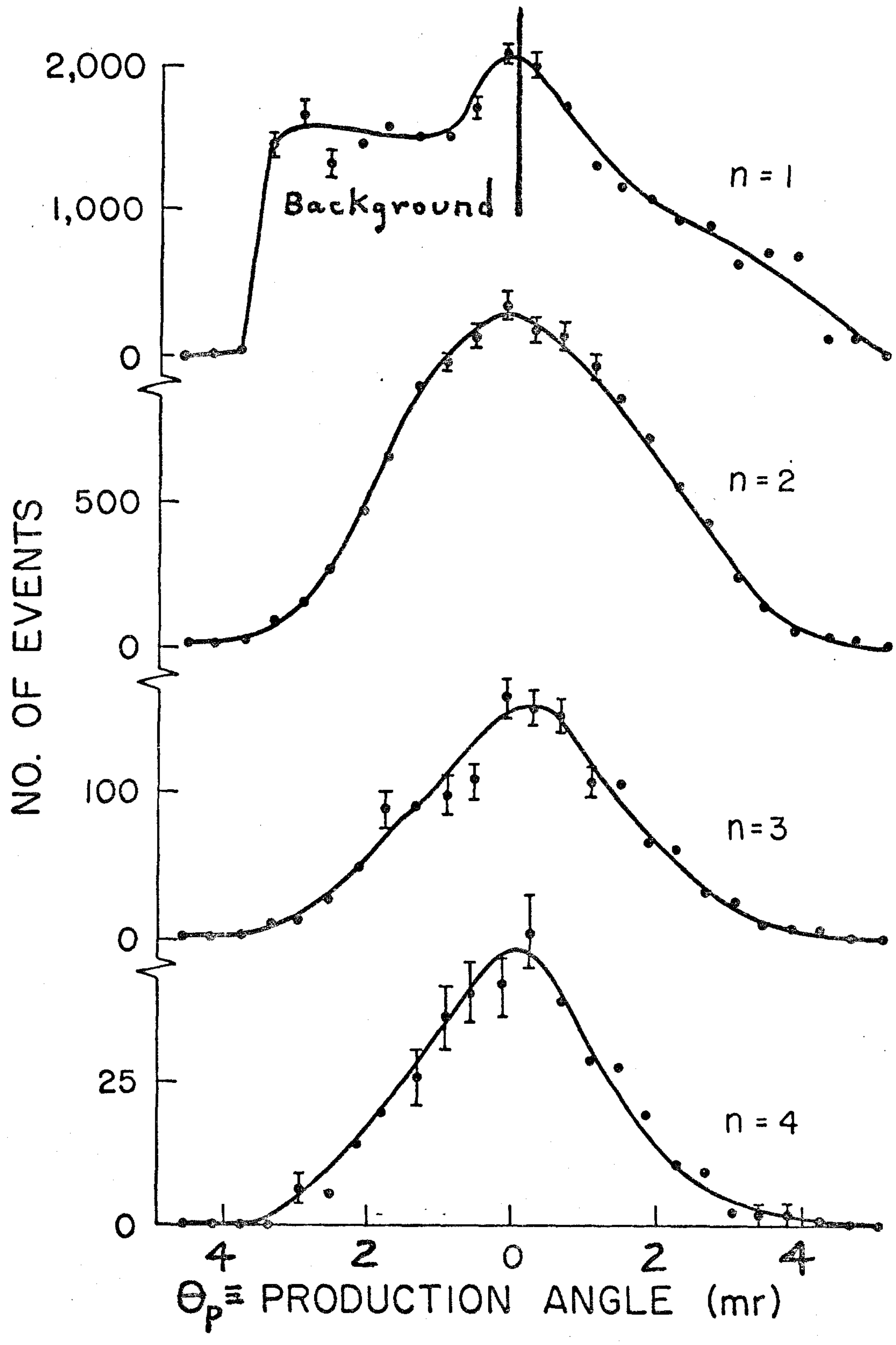

Fig. 6.

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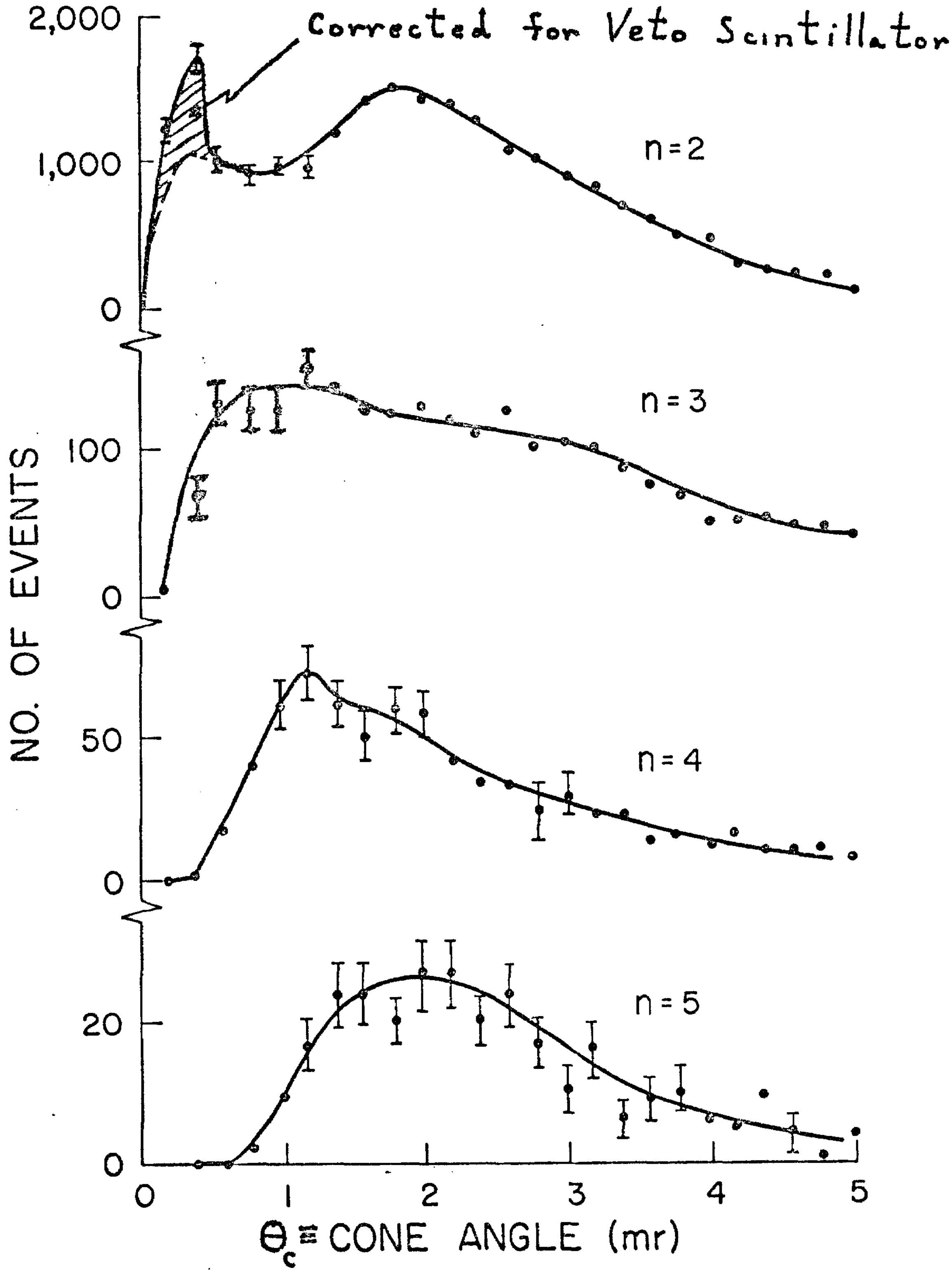
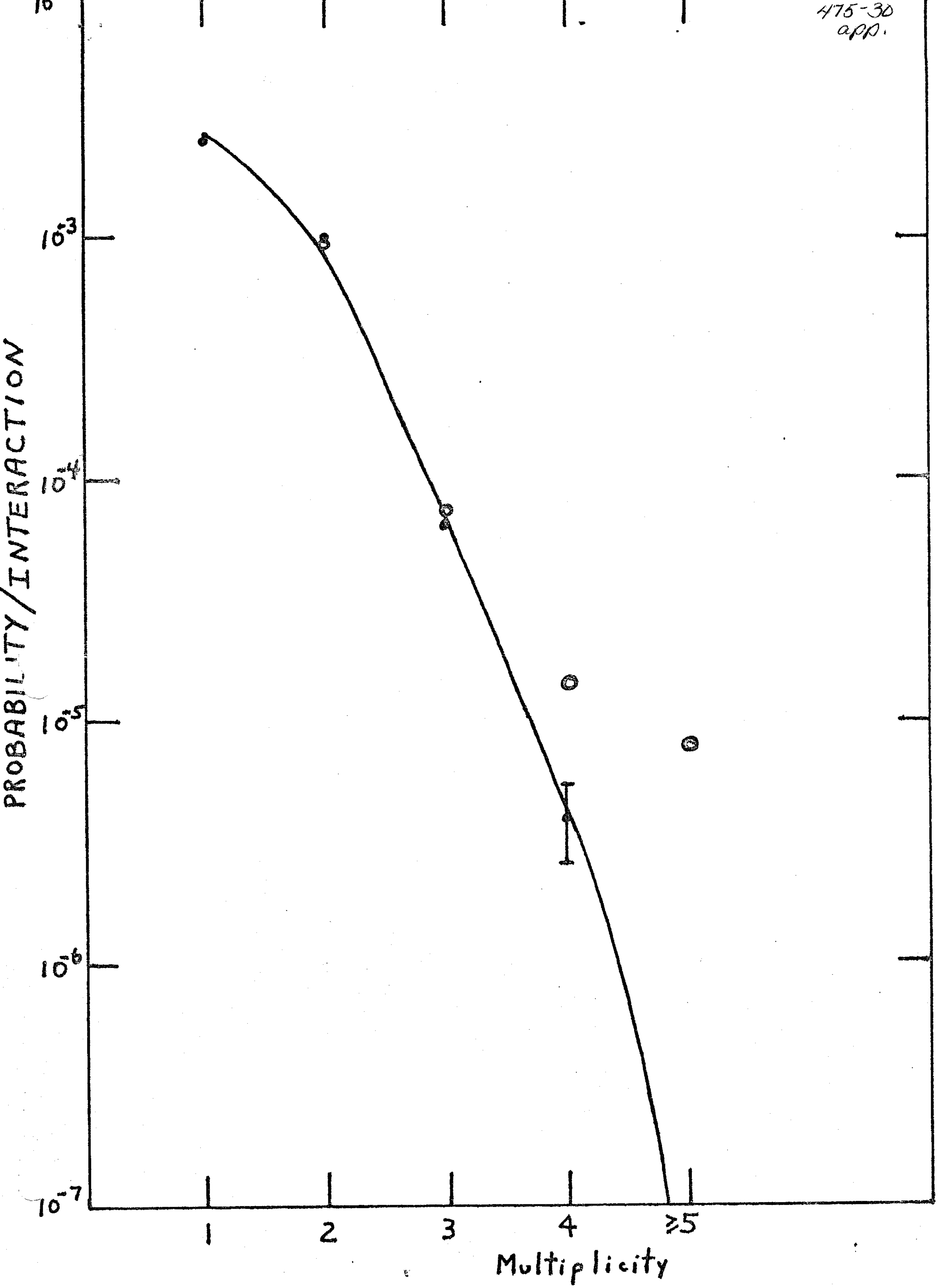


Fig. 7.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app.
PROBABILITY/INTERACTION
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
1
2
3
4
≥5
Multiplicity

Fig. 8.

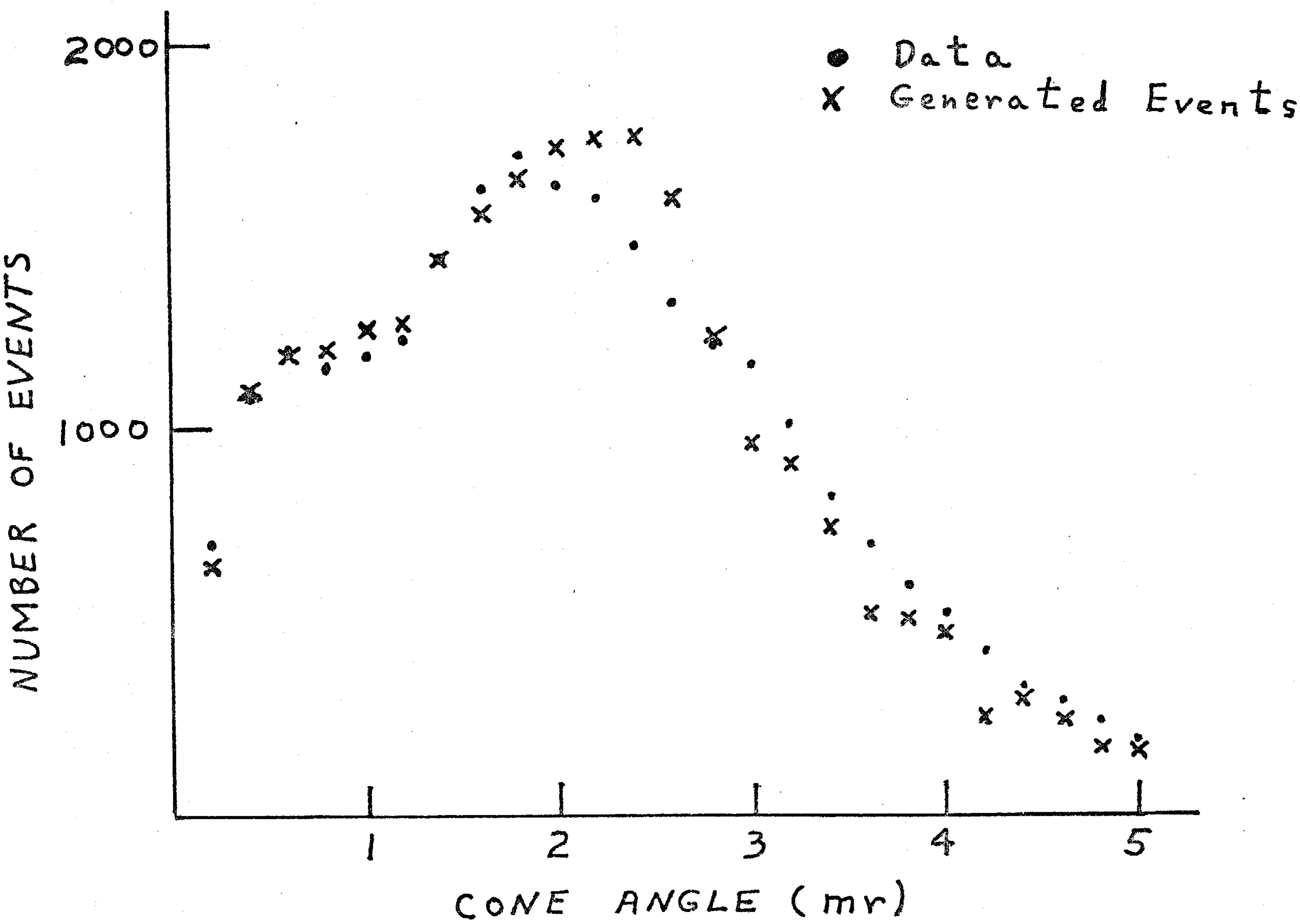

Fig. 7.

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app.

475-32 app.

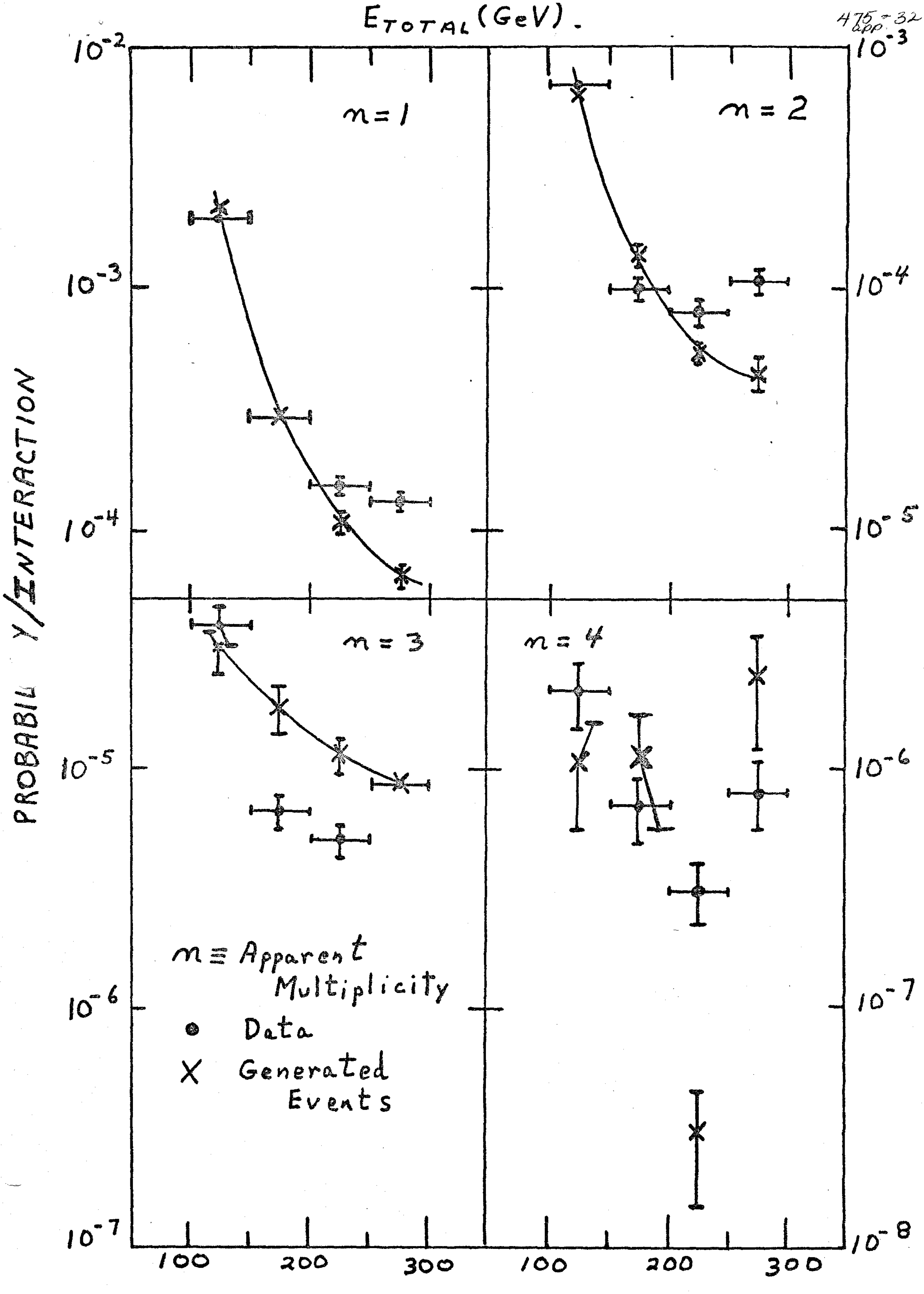
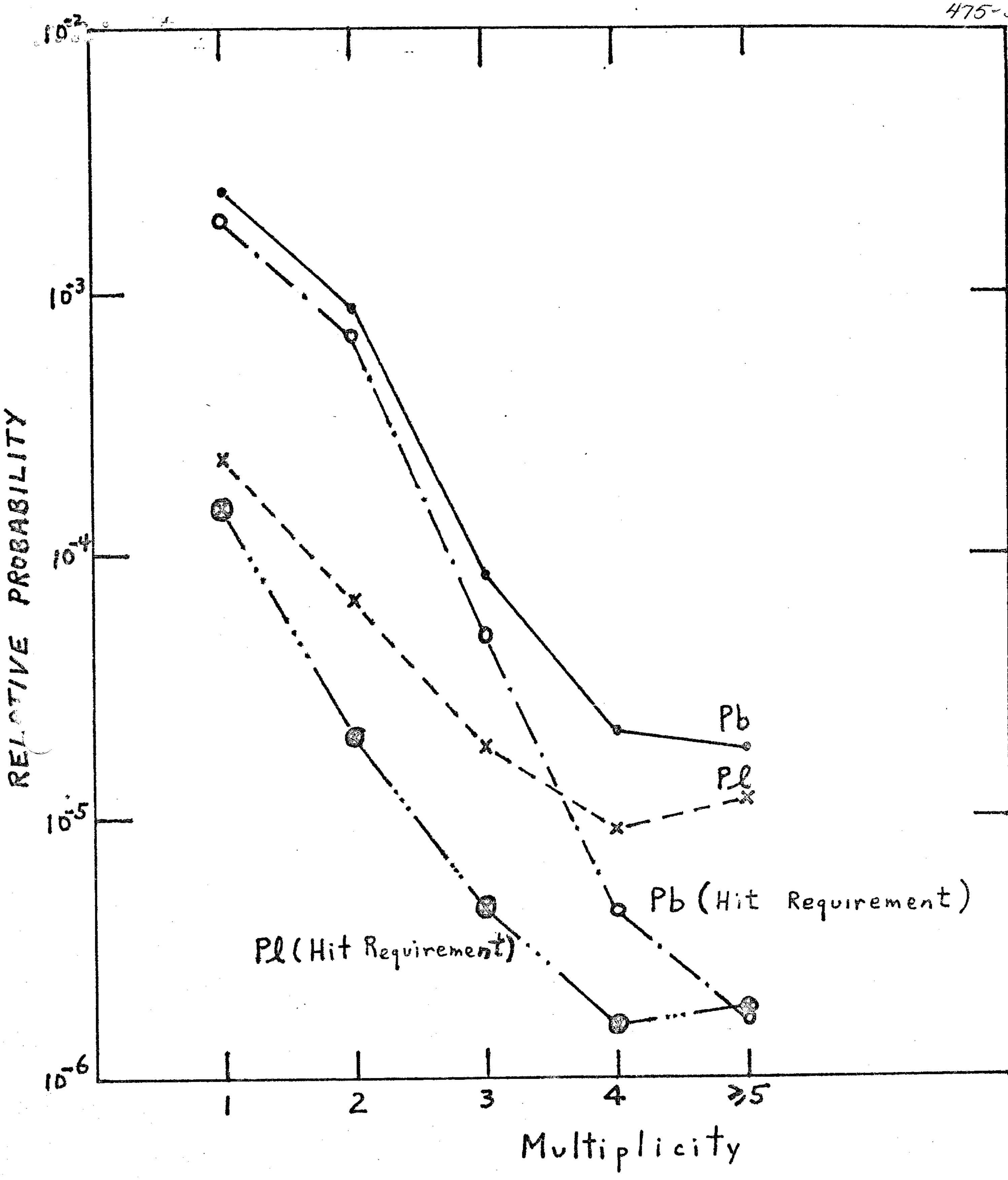


Fig. 10.



RELATIVE PROBABILITY
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
Pb
Pl
Pb (Hit Requirement)
Pl (Hit Requirement)
1
2
3
4
≥5
Multiplicity

Fig. 11.