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ABSTRACT

A total absorption scintillation counter for high-energy photons has been developed with $\pm 7\%$ energy resolution for 130-Mev photons. The counter was built of enough plastic scintillator to contain most of the energy and maintain a high detection efficiency. We employed the technique of observing a statistical sampling of light from an integrating volume. The integrating volume was obtained by painting the surface of the counter with a diffuse reflector and detecting the light with a large number of photomultiplier tubes placed symmetrically about the counter. Use of a scintillator enabled us to work with a light source of high intensity, thus assuring optimum photon statistics.

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INTRODUCTION AND PHYSICAL PRINCIPLES

We desired to build a total absorption scintillation counter of high efficiency which could be used to determine high photon energies with good resolution. Examination of the absorption cross sections for gamma rays in lead and carbon¹ (Fig. 1) shows the pair-production cross section increasing with energy and the Compton-scattering cross section decreasing with energy.² This conflict in energy dependence leads to a minimum in the total-absorption cross section, which for high-Z material is more pronounced and appears at lower energies than for low-Z materials.

An electron produced by either process may lose its energy either through radiation or through ionizing collisions. From the relationship between the two modes of energy loss,

$$\frac{(dE/dx)_{\text{radiation}}}{(dE/dx)_{\text{ionizing collisions}}} \approx EZ/800 \text{ Mev.}$$

(where E is the energy of the particle in question, and Z is the atomic number of the material the particle traverses) one can see that the critical energy, at which radiative loss equals ionizing loss, is inversely related to Z . In high- Z materials there is a strong probability of reradiation bremsstrahlung in the region of the minimum in the absorption cross section; therefore in high- Z materials where the critical energy is low there may be large

fluctuations in the energy containment, and thus poor energy resolution, unless the counter is large enough to contain nearly all the energy.

When the energy of the photon is near the critical energy, the volume of the energy containment is elongated in the direction of the incoming photon. When the energy is much greater than the critical energy, the volume is more nearly spherical and less sensitive to the direction of the incoming photon.

The problem of containment is further complicated by the interaction of the photon at various depths in the counter in the usual exponential fashion (Fig. 2). This results in fluctuations in the energy contained in the counter. The effect of the variation in the photon interaction position is more apparent in low-Z materials which require fewer radiation lengths to contain the energy.

The energy contained by an absorption counter is usually detected by converting a fraction of it to visible light, either by Cerenkov radiation or a scintillation process. The light is then detected by a photomultiplier-tube arrangement, and for a given event the energy contained in the counter is determined to an accuracy within the variance of the number of detected photons. The variance is due to the statistical nature of the light-producing process and to variations in light collection efficiency. The statistical fluctuations are related to the square roots of the numbers of photons detected. The variations in light-collection efficiency are mainly due to variations in the solid angle subtended by the phototubes at different positions in the counter, and to the different effects of reflection and absorption in collecting the light from different positions. Fluctuations in the position of the generated light are due to variations in the position and direction of the incident photon and the fact that successive showers are not contained in the same elements of volume. Variations in light-collection efficiency are more pronounced in large-volume counters such as are required to contain 185-Mev photons.

The probability of collecting light from all volume elements in the counter can be made approximately independent of position by coating the counter with a diffuse reflector. The diffuse reflector is useful only to the extent that the light is reflected before detection and not detected directly. If there were no self-absorption and perfect reflectivity, all the light could be collected by this method, but in practice only a small fraction of the light is collected.

THE APPARATUS

A. Kantz and R. Hofstadter measured the shower containment of 185-Mev electrons in C, Al, Cu, Sn, and Pb.² The behavior of the plastic scintillator (Table I) can be approximated by their carbon data. Based on these data, a counter was constructed from a plastic-scintillator cylinder five radiation lengths long and one radiation length in diameter, which will contain about 94% of the energy of an axially incident high-energy photon. In comparison, for the same situation in lead, their data indicate that the cylinder would need to be 14 radiation lengths long and 20 radiation lengths in diameter. The plastic-scintillator cylinder was 80 in. long and 16 in. in diameter; a lead-glass cylinder to provide the same containment would be 15.4 in. long and 22 in. in diameter, if we assume a density of 3.89 g/cm^3 and a typical composition for such glass.

With a ^{plastic} counter of this size, we decided to detect the light by taking a statistical sample of light from an integrating "sphere." To approximate a sphere, the 80-by 16-in. cylinder was divided into four 20-by 16-in. sections. The machine-finished surface of the scintillator was coated with a diffuse reflector consisting of α -alumina in an acryloid resin which has an index of refraction of approximately 1.5.³ It was hoped that the coefficient of reflectivity of the diffuse surface and the self-absorption of the scintillation light by the counter would be such as to allow the light to make a number of reflections

on the average before being detected. This would insure that a large percentage of the detected photons would be position-insensitive. The light was detected by six RCA 6655A photomultiplier tubes arranged in a symmetrical fashion on each of the four sections), as shown in Fig. 3.

The large volume of scintillator in the counter makes it very sensitive to background. For example, cosmic rays alone give 7000 counts/min above 56 Mev. The amount of shielding required for various backgrounds is sufficient to warrant every attempt to keep the size of the counter and its phototubes to a minimum. The counter sections were contained in a steel box with thin aluminum end walls. The steel box served as a magnetic shield as well as a structural support and a light-tight container.

In order to maintain the counter's energy resolution, the projected path of a detected photon must fall within the defining cylinder of the counter for its entire length. Hence, the detected photons must be collimated appropriately.

Having divided the counter into four sections, one must take care to ensure that the electronic gain of each section is the same. We first set the gain of all the phototubes, using collimated minimum-ionizing cosmic rays as a primary standard. A secondary standard, a dc light source (1B59), was used to set the high voltage of the phototube thereafter. The resultant pulse from the counter was taken to be the sum of the pulses from the four sections.

DATA

The pulse from the counter was observed to have a rise time of approximately 20 nsec by use of a Tektronix 517A oscilloscope. The length of the rise time indicates that most of the scintillation light is randomly reflected before being detected.

The resolution of the counter was measured by observing the 129.4-Mev monoenergetic photon produced by the radiative capture of stopping pions in hydrogen in the reaction $\pi^- + p \rightarrow \gamma + n$.

In addition to the monoenergetic photon peak, there is a distribution of photons from the decay of the neutral pion produced in the accompanying reaction, $\pi^- + p \rightarrow \pi^0 + n$ (Fig. 4). If the linearly extrapolated tail of the neutral-pion distribution is subtracted from the monoenergetic photon peak data, a Gaussian curve can be fitted to the data. This Gaussian has a resolution of 7% half-width at half maximum (Fig. 5).

REFERENCES

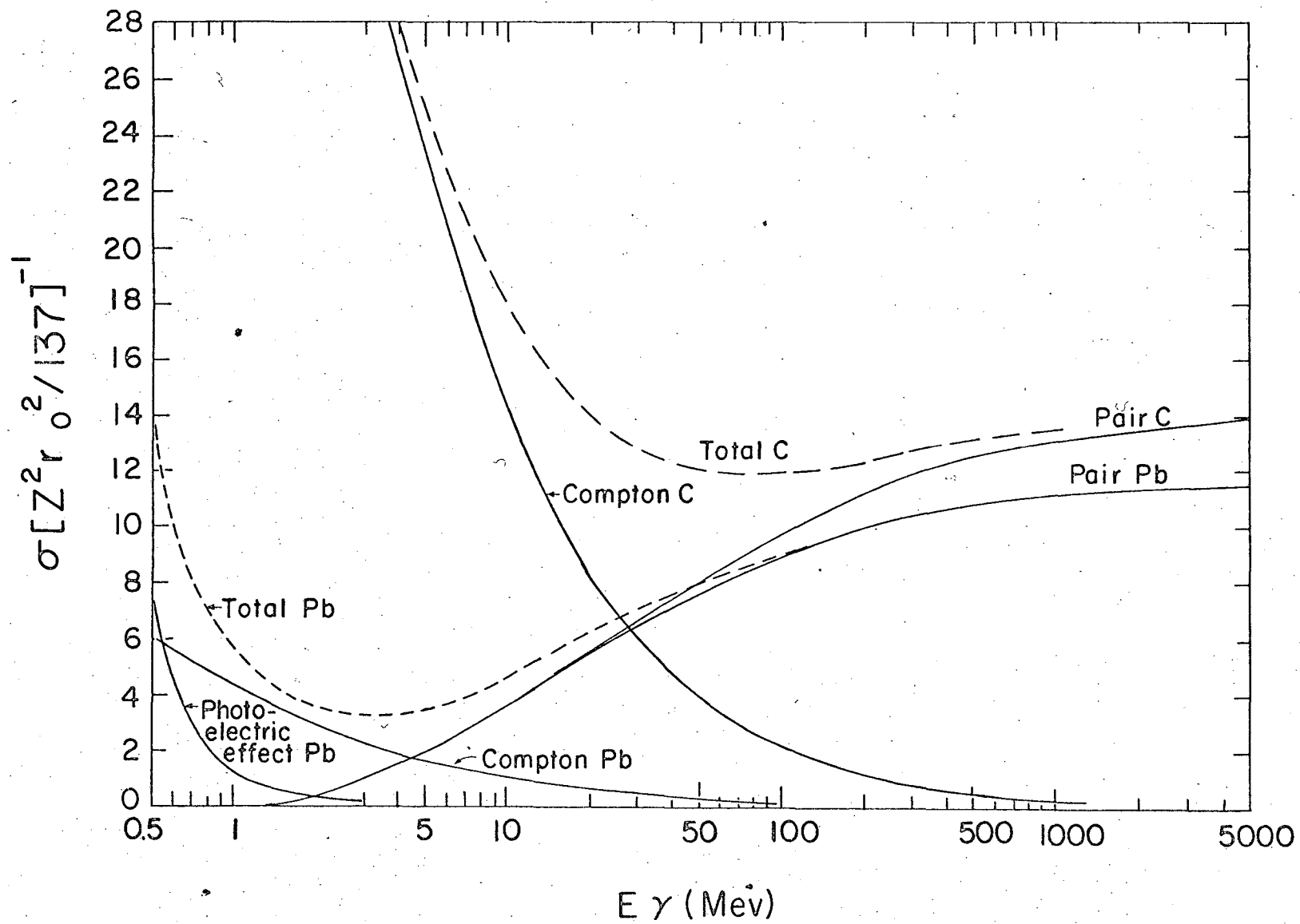
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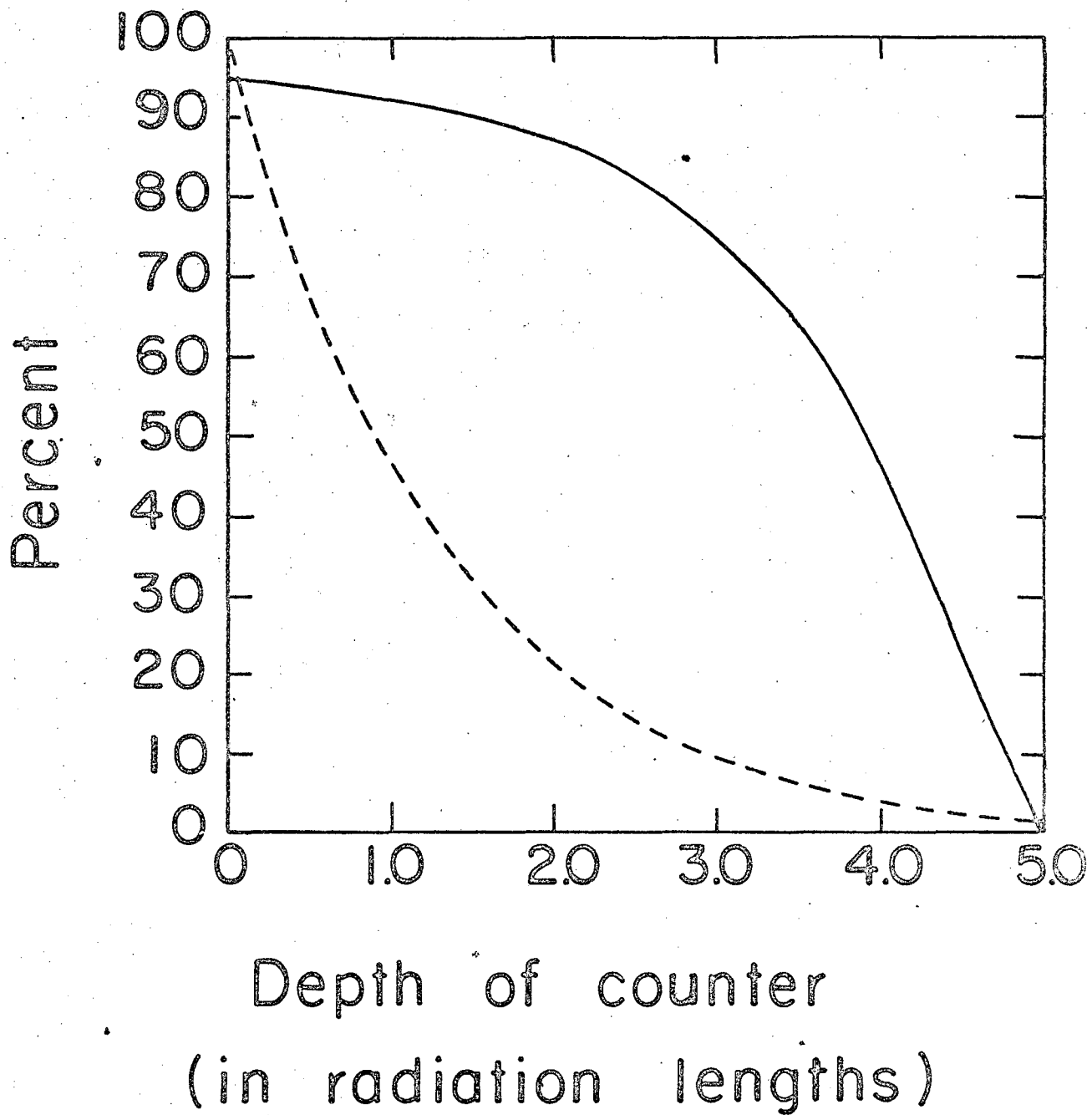
Table I. Composition of the plastic scintillator used.

Solvent:	97.46% polystyrene (C_8H_8)
Activator:	2.5% p-terphenyl
Shifter:	0.03% tetraphenyl-butadiene
Release agent	0.01% zinc stearate
Tolerance:	$\pm 1\%$ of each ingredient by weight
Radiation length:	43.4 g/cm ² or 41.3 cm
Index of refraction:	1.595

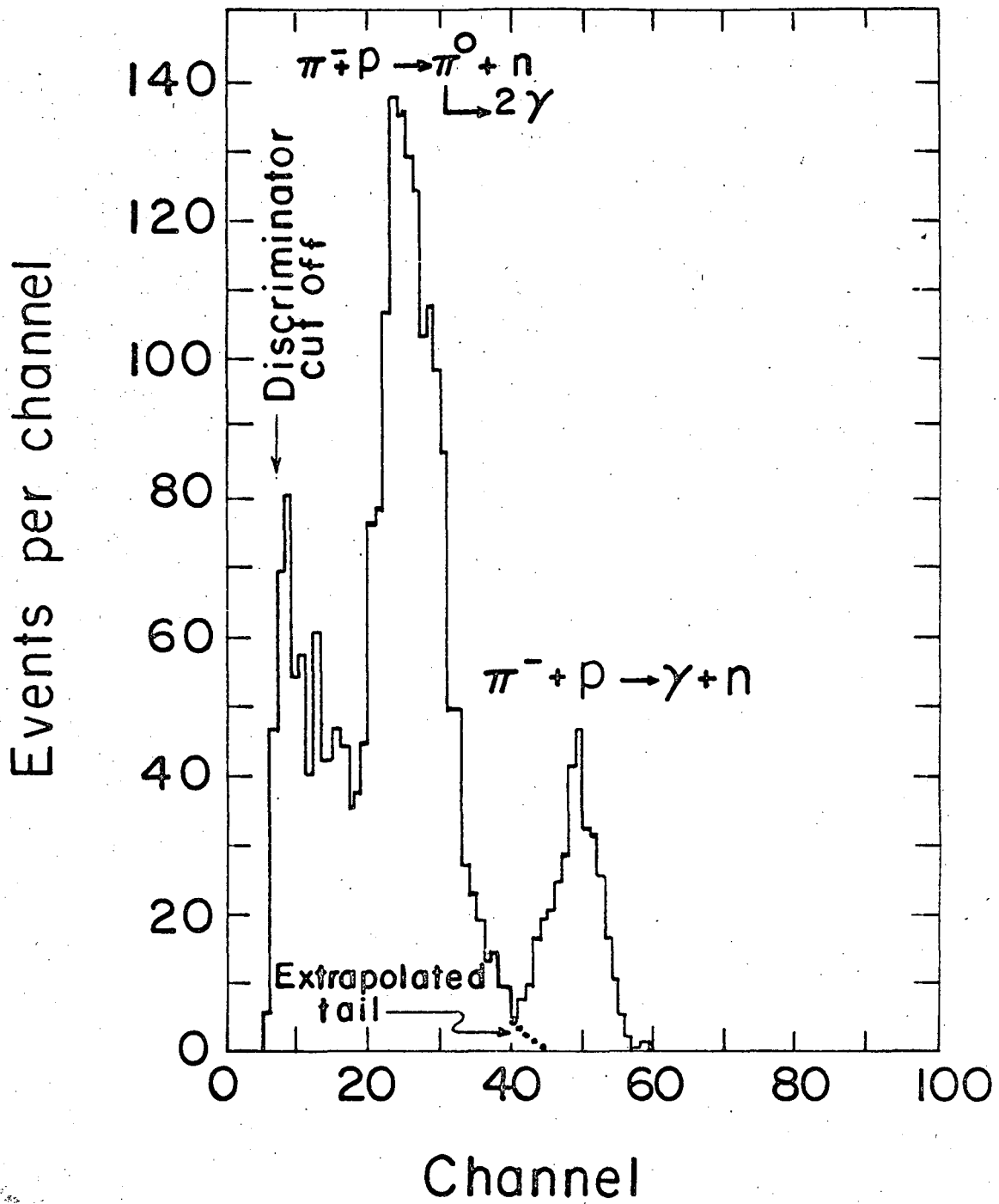
FIGURE LEGENDS

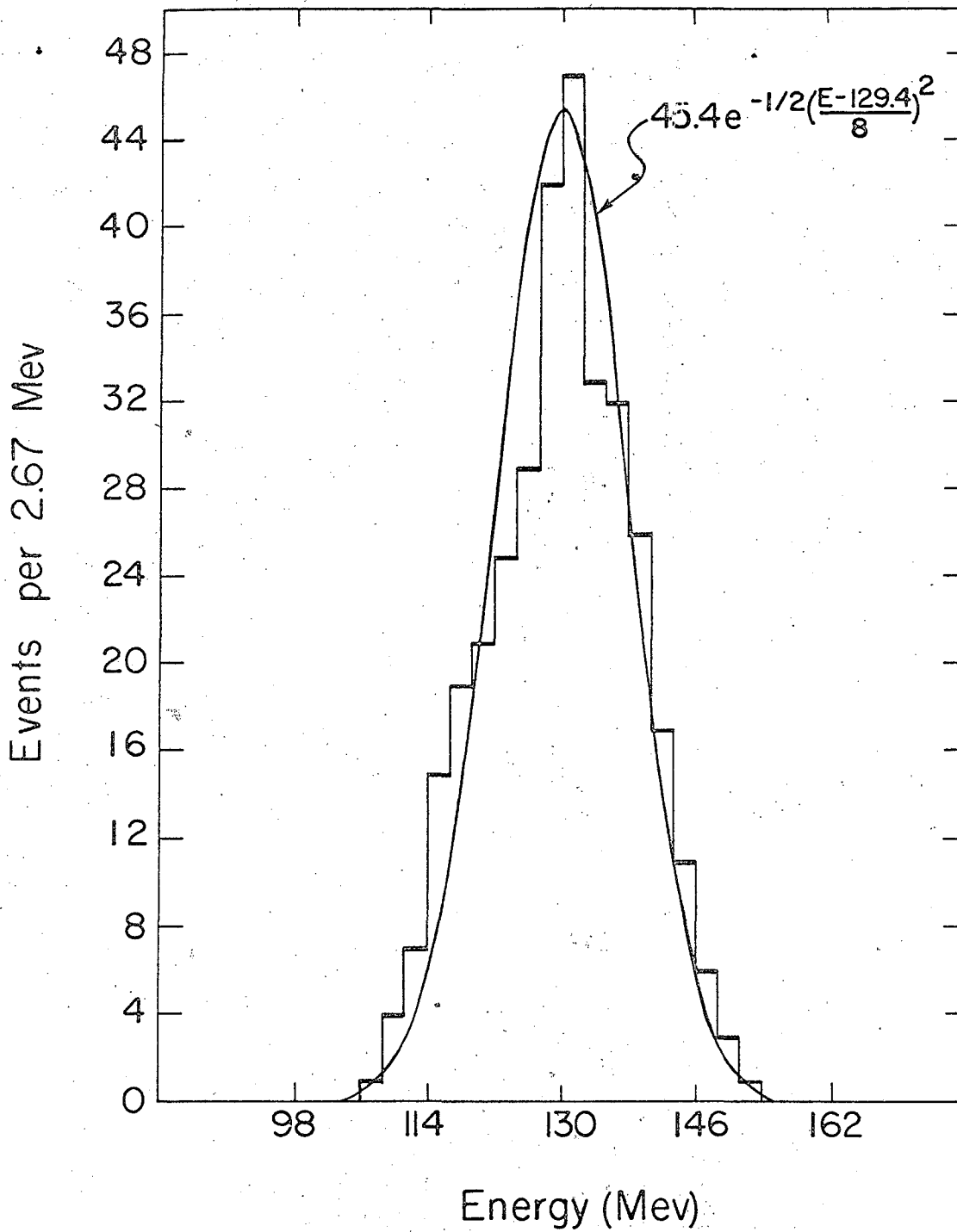
1. Total absorption cross sections for gamma rays in carbon and lead. Here the cross section in units of $Z^2 r_0^2 / 137$ is plotted versus the energy in Mev. This figure is derived from curves given by Bethe and Ashkin.¹
2. Energy containment versus interaction depth. The solid line represents the average energy contained in the counter as a function of the point of production of a 185-Mev electron. The curve is derived from the data of Kantz and Hofstadter.² The dashed line represents the probability that an incident 185-Mev photon penetrates a given distance into the counter.
3. Diagram of one of the four identical sections of the counter, showing the mounting of the photomultiplier tube.
4. Photon spectrum obtained by the counter for stopping negative pions in hydrogen. The number of events per channel is plotted against the channel number of the pulse-height analyzer.
5. Gaussian curve through the data of the 129.4-Mev monoenergetic photon peak after the linearly extrapolated tail of the neighboring photon distribution has been subtracted. The probability of a greater deviation from this curve by a subsequent set of data is 0.45, as determined by a χ^2 analysis.





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