EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CONVERSION EFFICIENCY OF LEAD FOR 30-200 MeV PHOTONS

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ABSTRACT

The conversion efficiency of lead has been measured as a function of thickness for 44 MeV, 94 MeV and 177 MeV photons, and as a function of energy between 29 MeV and 177 MeV for thickness of one and two radiation lengths. Some additional information on multiplicity of secondary tracks and on their angular distribution was obtained using a small streamer chamber. The results obtained confirm the shower calculations of Messel and Crawford.

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1. INTRODUCTION

A knowledge of the interactions of photons in various materials is frequently necessary for the design of experimental equipment and for the analysis of experimental data. For most design applications very general considerations such as those given by Rossi[1)] suffice. Sometimes it is possible to make direct calibration measurements for the analysis of data taken with specific equipment. More commonly, however, one has to rely on detailed shower calculations either used in an absolute fashion or used to extrapolate from established experimental results. One of the most detailed and best documented calculations is that of Messel and Crawford[2)]. However, published experimental data for testing the predictions are extremely few. It is in this context that we present some results that we have obtained in the course of developing the streamer chamber experiment at the CERN ISR[3)].

The measurements were designed to obtain data at photon energies below 200 MeV and for secondary electron energies down to zero, i.e. in circumstances where the shower calculations are expected to be least reliable. Nevertheless, it was found that the results of Messel and Crawford were very satisfactory, provided that reasonable extrapolations to extend the predictions down to zero energy secondaries were made.

2. PHOTON BEAM

A tagged photon beam developed at the CERN Synchro-cyclotron by the Lausanne-Munich group[4)] was used for the measurements. A sketch of the layout is shown in Fig. 1, where C_1, C_2, C_3, and C_4 are plastic scintillators typically 2 mm thick, while M_1 and M_2 are bending magnets. Positrons of momentum 240 MeV/c were selected by means of time of flight between C_1 and C_2 and by the magnet M_1, and allowed to produce photons by bremsstrahlung in a thin copper radiator (approximately 0.02 radiation lengths). The resulting photons were tagged and their energy defined by measuring the residual positron energy using the magnet M_2 and the trajectory C_2, C_3, C_4. A final identification of the positron was made using a gas Čerenkov detector; this was not essential, but it proved convenient in setting up the beam and in testing the system.

The size of the photon beam spot was determined using lead plates 5 mm thick with various size holes cut in them. These plates were placed in front of a large plastic scintillation detector and the counting rates determined. A typical measurement showed that 85% of the photons passed through a 10 cm × 10 cm area, while 99% passed through a 15 cm × 15 cm area.

The tagging efficiency was determined using a large NaI(Tl) detector 27 cm in diameter, 33 cm long. The efficiency of this detector was verified to be 100% for electrons and it was therefore assumed to be 100% for photons. By using this detector we found that a trigger was associated with a photon between 90% and 97% of the time, depending on the photon energy between 29 MeV and 198 MeV. The detector also provided a measure of the photon energy independent of that calculated from the magnet setting and a measure of the photon energy spread independent of that calculated from the sizes of the various scintillators and multiple scattering effects. The mean energy of the photon beam was determined to an accuracy of ±4 MeV at each energy and the energy spread was 19 MeV FWHM at all energies.

3. SCINTILLATION COUNTER MEASUREMENTS

Conversion efficiencies were measured using scintillation detectors in a "good geometry" arrangement. The photon beam, area less than 15 cm × 15 cm, struck a lead plate of the desired thickness and area 20 cm × 20 cm, immediately followed by a large plastic scintillation detector 28 cm × 40 cm and 5 mm thick. An event was counted as a conversion if more than 60 keV was deposited in the scintillator. The energy spectrum in the scintillator showed characteristic peaks corresponding to production of one, two, or three secondary electrons. Corrections were made for the measured conversion efficiency of the scintillator itself.

Figure 2 shows the conversion efficiency measured as a function of the thickness of lead, for three different photon energies. This is the most important result to be presented in this paper. The systematic errors in the measurement are believed to be less than ±0.025 in conversion efficiency. The lines shown in the figure are smooth curves drawn through the data, and are not theoretical.

Figure 3 shows the conversion efficiency measured as a function of energy for thicknesses of 5 mm and 10 mm of lead. These thicknesses correspond to 1 radiation length and 2 radiation lengths, according to the definition of Messel and Crawford2). It should be noted that according to them 1 radiation length of lead is 5.82 g cm^{-2} or 5.13 mm, which is different from the value of 6.4 g cm^{-2} or 5.6 mm given in the Particle Properties pocket-book5). The cross-hatched zones in Fig. 3 represent the results of Messel and Crawford2) extrapolated from the calculated values for secondary electrons above 10 MeV down to the experimental threshold which is effectively zero. The width of the zones represents the uncertainty in the extrapolation which is as large as 0.10 in conversion efficiency and is greatest at low photon energies and for larger thicknesses of lead.

It is concluded from these comparisons that the calculations of Messel and Crawford predict the experimental results within the measurement error and the extrapolation uncertainty.

4. STREAMER CHAMBER MEASUREMENTS

In order to obtain additional information on the secondary electrons from converted photons, a limited number of photographs was taken using a small streamer chamber. The photographs were obtained in two-dimensional stereo, viewed perpendicular and parallel to the photon direction. No ambiguities of significance were encountered in interpreting the photographs.

Most of the photographs were of conversions in slabs of lead-oxide-araldite mixture used in the ISR streamer chamber³⁾. However, a few measurements were made with 10 mm Pb. The conclusions from the streamer chamber photographs, all of which were triggered by the signal from a 2 mm plastic scintillation detector directly before the chamber, are:

i) A small proportion of the photographs was blank. This effect is certainly not due to lack of efficiency of the streamer chamber, and it is attributed tentatively to back scattering in the trigger scintillator. The effect was about 1% at 177 MeV and about 10% at 44 MeV, greater for thicker converters.

ii) The multiplicity of secondary tracks was counted, excluding obvious δ-rays, for 44 MeV, 94 MeV and 177 MeV photons converted in 1 radiation length and 2 radiation lengths of the lead-oxide-araldite mixture. The results are generally consistent, *mutatis mutandis*, with the predictions of Messel and Crawford for Pb at 50, 100 and 200 MeV.

iii) Some features of the angular distributions of tracks were studied. At 44 MeV, for 2 radiation lengths of lead-oxide-araldite the angle of the smallest-angle secondary was measured, regardless of multiplicity. It was found to be distributed with an r.m.s. angle of 25°. At 177 MeV, similar measurements were made for 2 radiation lengths of lead. Here the r.m.s. value of the angle of the smallest-angle secondary was approximately 15°, while the r.m.s. angle of all tracks was approximately 25°. All these values are consistent within statistical uncertainty with the predictions of Messel and Crawford.

To summarize, we have presented careful measurements of conversion efficiency in lead for photons between 30 and 200 MeV. The results confirm, after suitable extrapolation, the shower calculations of Messel and Crawford²⁾ which can therefore be relied upon with increased confidence.

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REFERENCES

1) B. Rossi, High energy particles (Prentice-Hall, New York, 1952).

2) H. Messel and D.F. Crawford, Electron-photon shower distribution function tables for lead, copper and air absorbers (Pergamon Press, New York, 1970).

3) K. Eggert, W. Thomé, B. Betev, G. Bohm, P. Darriulat, P. Dittmann, E. Gygi, M. Holder, K.T. McDonald, T. Modis, H.G. Pugh, F. Schneider, H. Albrecht, K. Tittel, I. Derado, V. Eckardt, H.J. Gebauer, R. Meinke, O.R. Sander and P. Seyboth, A streamer chamber detector at the CERN Intersecting Storage Rings, MPI-PAE/Exp. El. 45, February 1975, to be published in Nuclear Instrum. Methods.

4) L.H. Guex, C. Joseph, M.T. Tran, B. Vaucher, E. Winkelmann, W. Bayer, H. Hilscher and H. Schmitt, Phys. Letters 55B, 101 (1975).

5) Particle Data Group, Review of particle properties, Phys. Letters 50B, 74 (1974).

Figure captions

Fig. 1	:	Layout of the tagged photon beam.
Fig. 2	:	Conversion efficiency of lead for 44 MeV, 94 MeV and 177 MeV photons, as a function of the converter thickness. The lines are drawn to connect the points.
Fig. 3	:	Conversion efficiency of 5 mm and 10 mm thicknesses of lead, for several energies between 29 MeV and 177 MeV. The cross-hatched areas represent predictions made using Ref. 2, with uncertainties due to extrapolation of the predictions to zero energy for the secondary electrons.

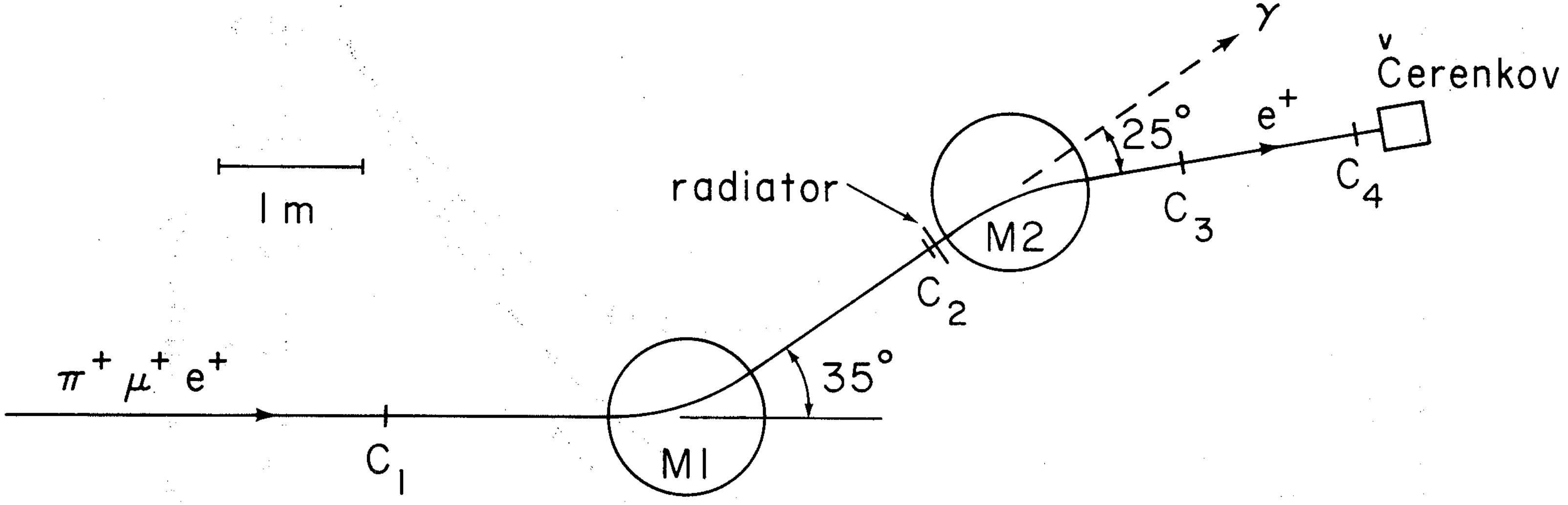

Fig. 1

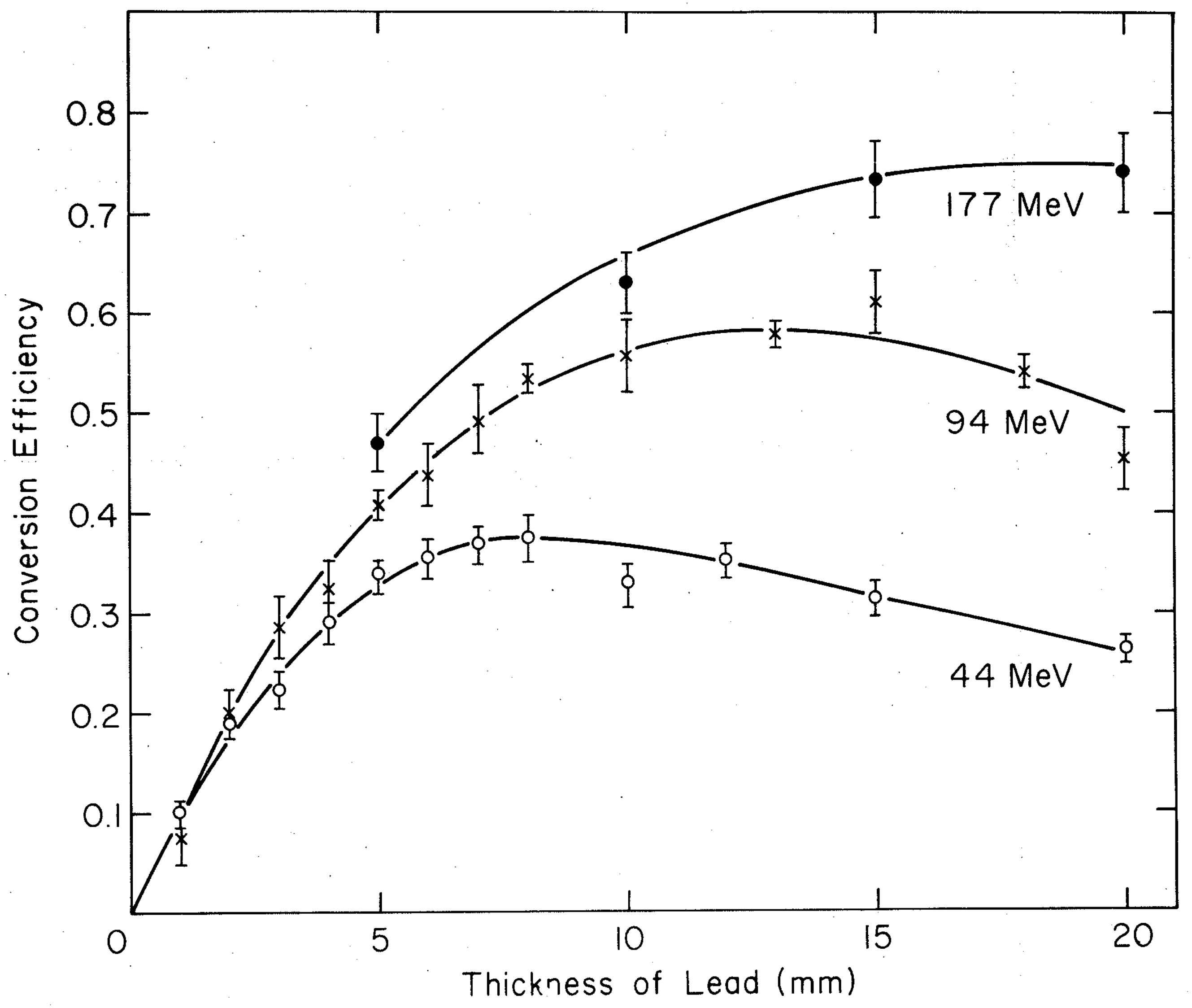
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Conversion Efficiency
0
5
10
15
20
Thickness of Lead (mm)
177 MeV
94 MeV
44 MeV

Fig. 2

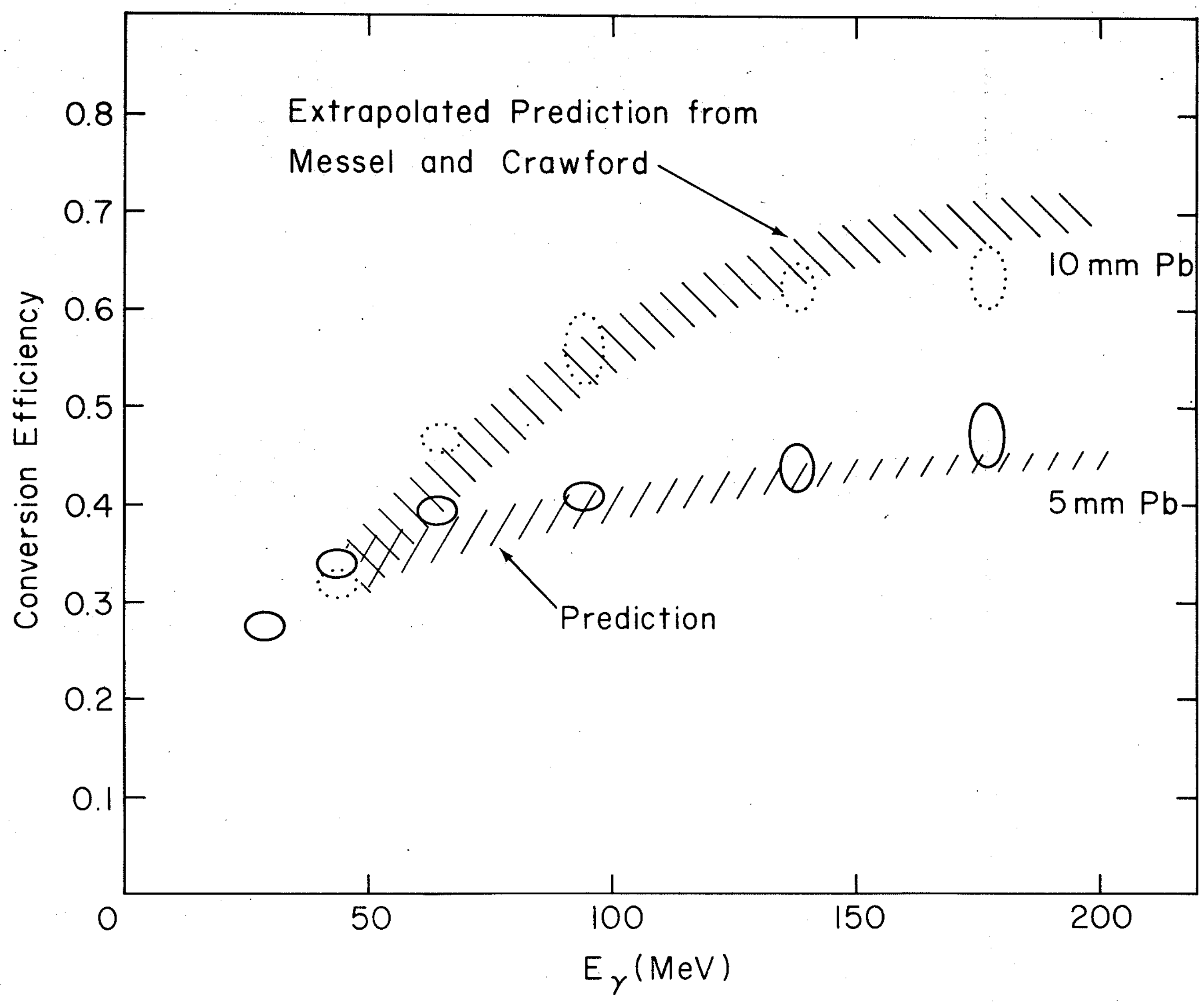
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Conversion Efficiency
0
50
100
150
200
E_γ (MeV)
Extrapolated Prediction from
Messel and Crawford
10 mm Pb
5 mm Pb
Prediction

Fig. 3