INVESTIGATIONS OF ELECTROMAGNETIC CASCADES PRODUCED IN LEAD BY 2.5 GeV BREMSSTRAHLUNG

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ABSTRACT

Electromagnetic cascades produced in lead with 2.5 GeV bremsstrahlung were studied by using a lead glass shower counter with a help of Monte Carlo code. Measured pulse-height distributions that show the energy deposition in the counter caused with a single source photon are compared with calculated results. The energy spectra of transmitted particles obtained from the calculation are presented to show the behavior of the electromagnetic cascade development.

INTRODUCTION

Measurements of electromagnetic cascades have been made by various methods, using ionization chamber, scintillation counter, Cerenkov counter etc., concerning the absorbed dose or the number of charged particles inside a block of dense materials. The energy spectrum of particles transmitted a slab were not studied yet inspite of its importance for the radiation shielding and protection problems.

In this paper, the electromagnetic shower development with 2.5 GeV bremsstrahlung in lead were studied by using a lead glass shower counter together with the EGS4[1] Monte Carlo code. The pulse-height distributions obtained from measurements give the informations of the energy deposition inside the counter caused by a single source photon which produces many particles inside the slab. The detail study of particle spectrum both for photons and charged particles was performed with the calculated results of EGS4.

EXPERIMENT

The bremsstrahlung used in this experiment was produced by 2.5 GeV electrons circulating inside the storage ring of KEK Photon Factory striking the residual gas of the long straight section at the beam line 2. Total length of this straight section is about 12m but the thickness of target is very thin due to a high vacuum rate (e.g. $\sim 10^{-8}$ torr). Therefore the beam size of the bremsstrahlung is very nallow and the spectrum is almost the same with the bremsstrahlung reaction cross section of 2.5 GeV electrons. The experimental arrangement is shown in Fig. 1. The lead glass shower counter of 18 radiation length having the cross section of 9.0cm x 10cm at the beam entrance and 10.3cm x 10.3cm at the exit was positioned some 20m from the center of the straight section and the lead slab of 2-, 5- and 10-cm was inserted at 13.3cm from the counter surface. A lead colimator of 1cm diameter, which was positioned 5cm from the lead slab surface, was used to shield the gas bremsstrahlung produced at the bending region. The beam intensity during measurements were monitored with the storage current, which varies from 64mA to 84mA, and the vacuum rate at the both side of the straight section. The energy calibration of the pulse-height distribution was performed by the comparison with the lead glass counter response for the 2.5GeV bremsstrhlung calculated with EGS4 dscribed below.

MONTE CARLO CALCULATION

For the simulation of cascade showers in the lead slab and the counter, a general electromagnetic radiation transport code called EGS4 (Electron-Gamma Shower version 4) was used. Detailed of the simulation may be found elsewhere.[1,2] The Born approximation of complete screening is used as the spectrum of bremsstrahlung sampled. The probability for an electron of total energy E_0 to produce a photon of energy between k and k+dk when passing by an atom of atomic number Z is

$$\phi(k)dk=4\alpha r_e^2 Z(Z+1)dk/k\{[3/4(1.0-k/E_0)+k^2/E_0^2]\times \ln(183Z^{-1/3})+1/9(1.0-k/E_0)\} \quad (1)$$

where α =fine-structure constant=1/137

r_e=classical electron radius=2.82×10^{-13} cm.

Z=10 was used based on the fact that about 3/4 of the residual gas was H_2 and 1/4 was CO.[3] To get good statistics for high energy parts, an incident photon energy was sampled from the uniform distribution from 100MeV to the electron energy (E_0=2500MeV) and was assigned a weight that is carried along with each photon that is transported and scored. The weight is normalized to one incident photon from 100MeV to 2500MeV and expressed as follows;

$$WT(k)=\phi(k)/\int_{100}^{2500}\phi(k)dk \quad (2)$$

where k is the photon energy sampled.

Two different calculations were performed. One is the calculations of the energy deposition inside the lead glass counter by a single photon incident on the slab for the comparison with the experimental results. The other is those of the photon and charged particle spectrum transmitted the lead slab.

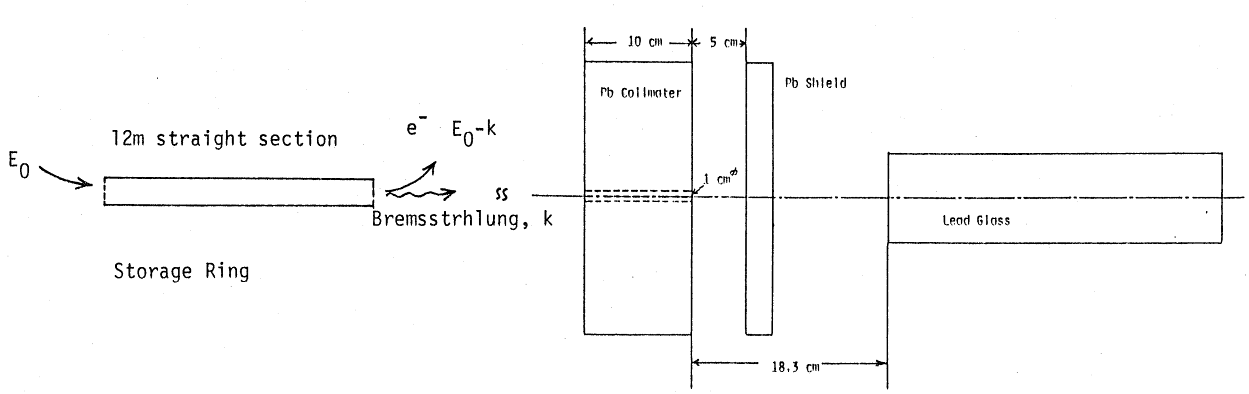

Fig.1 Experimental Arrangement.

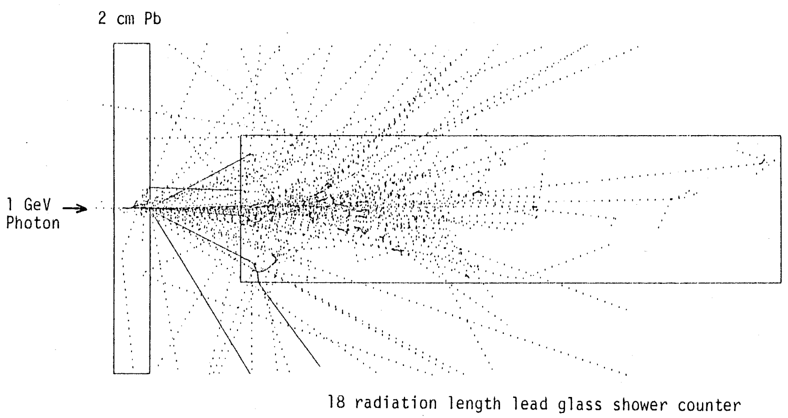

Fig.2 EGS4 generated shower event in the lead slab and the lead glass shower counter. Charged particle and photon tracks are depicted as solid and dotted lines, respectively.

RESULTS AND DISCUSSION

Fig.2 shows tracks of charged particles (solid lines) and photons (dots) for a cascade initiated by a single 1GeV photon for a 2cm lead slab. It is clearly seen that a single incident photon produces many photons and charged particles which enter on the counter. It is almost impossible to measure the energy deposition due to each produced particle in separate. Therfore, the experimental results give only the energy deposition with all particles produced by the source photon and enter on the counter. The comparisons of the pulse height distributions with the calculated energy depositions are shown in Fig.3. Agreements between experiments and calculations are excellent. This shows that EGS4 can simulates the electromagnetic cascade in good accuracy. The transmiited spectra of photons and charged particles for 0.56-, 2.0-, 5.0- and 10-cm lead slab are shown in Fig.4 and Fig.5, respectively. In Fig.3, the bremsstrahlung spectrum given in Eq.(1) is also shown. The errors on each result were obtained by dividing the EGS4 runs, for each lead thickness, into 5 runs of 500 to 1000 incident showers each. Each data point and error bar corresponds to the mean and standard deviation of the mean for the 5 runs. The average number of photons and charged particles transmitted the lead slab are shown in Fig.6 together with thier average energy. These figures well show the tendency of the electromagnetic cascade that the high energy particles were converted to the many lower energy particles via the reaction of the pair production or the bremsstrahlug. The contribution of the charged particles in the escape energy fractions drops rapidly beyond 5-cm. This means that the energy is carried away in the form of photons at this region.

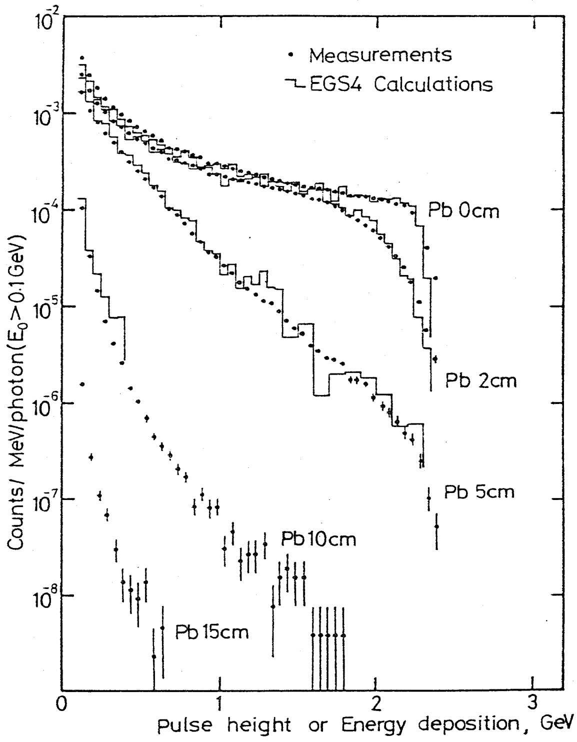

Fig.3 Comparison of measured and calculated energy deposition in the lead glass shower counter caused with a source photon.

REFERENCES

(1) W.R. Nelson, H. Hirayama and D.W.O. Rogers, Stanford Linear Accelerator Report No. SLAC-265 (in preparation).

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(3) H. Kitamura, private comunication.

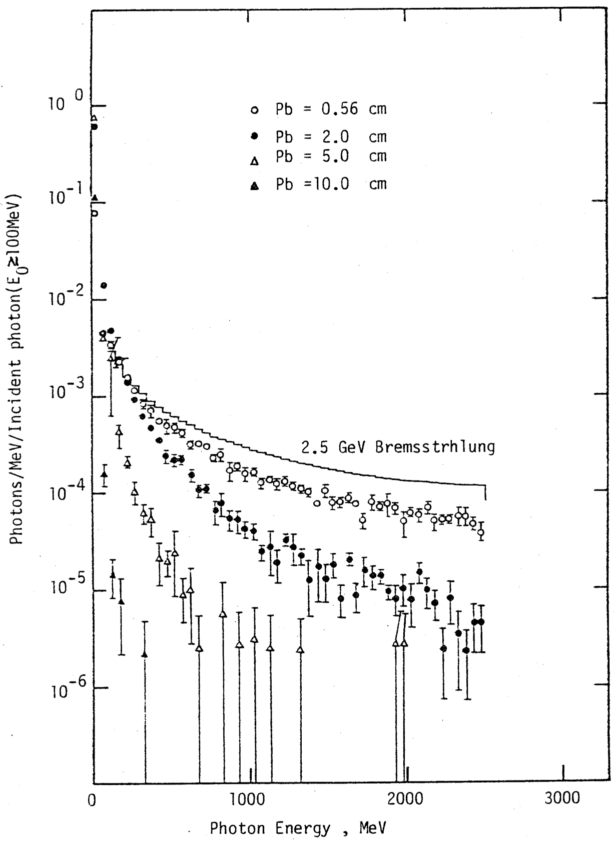

Fig.4 Calculted photon energy spectra transmitted through 0.56-, 2.0-, 5.0- and 10-cm thick lead.

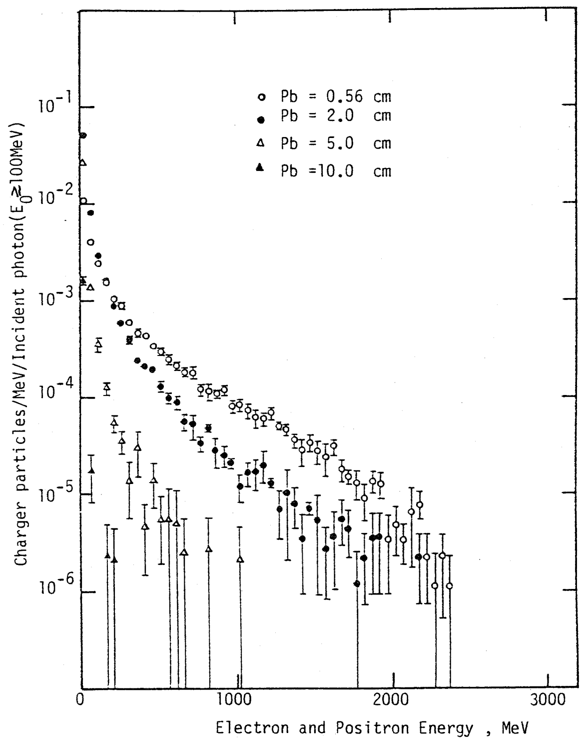

Fig.5 Calculated charged particle energy spectra transmitted through 0.56-, 2.0-, 5.0- and 10-cm thick lead.

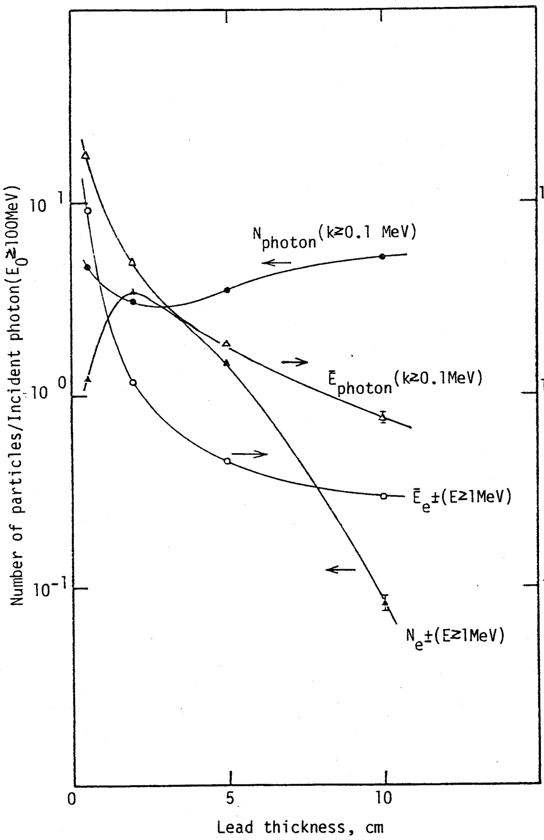

Fig.6 Number of photons and charged particles transmitted lead slab and thier average energy obtained from calculated results.