VEKSTER AND BALDIN LABORATORY OF HIGH ENERGY PHYSICS

FINAL REPORT ON THE INTEREST PROGRAMME

Research in: Soft photon study in hadron and nuclear interaction

Student:
Tambani Melton Musekwa
University of Johannesburg
South Africa

Supervisor:
Prof Elena Kokoulina

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Wave 5

Introduction

Soft photons are the product of high energy interactions, having energy smaller than 50 MeV. Experiments of such phenomenon was done years ago and still there is not a clear explanation or information to explain them.

A way to detect soft photons is through electromagnetic calorimeters. The study of soft photon (SPh) was confirmed that is valid in hadron and nuclear interaction between low and high energies. Using the application of electromagnetic theory to the interaction particles to describe electromagnetic shower. As the energy is higher than the spread of electromagnetic shower is higher. Photons with high energy soft photons are able to interact with the nucleic and positron electron pairs and can scatter from electrons.

Aim (goal of the project)

The study of theoretical basis of particle detection by electromagnetic. Calorimetry then simulate both two types of calorimeters for soft photon detector using monte-Carlo method in GEANT 4, and the use of codding language to run and get information. This can be done as of example 4 of GEANT 4. Then lastly compare the energy resolution and price of the detectors.

Background and theory

A combination of various detector methods helps to identify elementary particles and nuclei. The shower phenomenon and the simplified cascade model gives a brief mathematical outline of shower, and at high energies absorption techniques in calorimeters provide an additional particle identification and an accurate energy measurement.

The concept of a particle an abstraction of our everyday observation of matter. The interest in soft photon is that it is very fascinating since the nature and sph is not clear enough to everyone. In this experiment two types of samples calorimeter were taken and compared, shaslik and spaghetti. With the different types and thickness of absorption of their material. The structure is conducted using the monte-Carlo method based on example 4 in GEANT 4, using CERN ROOT and LINEX to get the fitting curves and all figures.

Particle detection

Particle behave in a wave form and they interact depending off what type of a particle or matter then the interactions are different. With changed particles the main interaction is when the particles are ionization and excitation and bremsstrahlung. For relativistic particle. When the particle interacts, they can be detected based on their characteristic interaction process.

The detection of soft photons using electromagnetic calorimeters. Then the focus is on bremsstrahlung for electrons and positrons, and pair production for photons since they are the most dominant in electron-photon cascades at high energies, the energy greater than 1 MeV.

In Bremsstrahlung

The equation for the energy loss by bremsstrahlung for high energies:

Eq.1

$$-\frac{dE}{dx} \approx 4\alpha\, N_a \frac{Z^2}{A} Z^2 \left(\frac{R^2}{4\pi\varepsilon_0 mc^2}\right)^2 \times E ln\left(\frac{183}{Z^{\frac{1}{3}}}\right)$$

With Z, a being atomic number, and weight of the medium and Z, m and E are angle number, mass and energy of the incident particle.

For electron, the Radiation length X_0 for specific material:

Eq.2

$$-\frac{dE}{dx} = \frac{E}{X_0}$$

Then for material made up of one element the Radiation length is:

Eq.3

$$X_0 = 716.\frac{A}{Z(Z+1)\ln\left(\frac{287}{\sqrt{Z}}\right)} \; \{g/cm^2\}$$

Then when a material is made up of mixture of elements, then the Radiation length becomes:

Eq.4

$$X_0 = \frac{1}{\sum_{i=1}^{N} \frac{f_i}{X_0^i}}$$

Where f_i is the mass fraction of the components with the radiation length X_0 and so then

Eq.5

$$f_i = \frac{A_i V_i}{\sum A_i V_i}$$

The critical energy the energy loss for bremsstrahlung and it is given by:

Eq.6

$$E_c = \frac{550MeV}{Z_{eff}}$$

Where Z_{eff} is an effective atomic number for a material of mixture of elements and is given by:

Eq.7

$$Z_{eff} = \frac{\sum Z_i f_i}{\sum f_i}$$

The equation to describe the cross section of the pair production is given by:

Eq.8

$$\sigma_{pair} \approx \frac{7}{9} 4\alpha r_e^2 Z^2 \ln\left(\frac{183}{Z^{\frac{1}{3}}}\right)$$
$$\approx \frac{7}{9}\left(\frac{A}{N_A}\right)\left(\frac{1}{X_0}\right)$$

In the electron photon cascade the energy loss of an electron and or that of positron its average is around 62.9% per radiation length.

Then from this it implies that the mean free path of radiation length will be $\frac{9}{7}$ per pair production.by

Assuming the energy is symmetrically shared between particles then this leads to plotting the curves as represented below, in taking t as the distance from the incident particle entering point normalized in radiation length and $t = \frac{X}{X_0}$

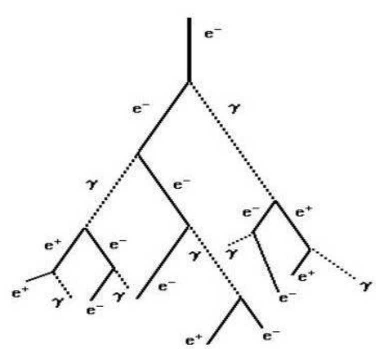


Fig.(a) diagram of an electron initiated electromagnetic shower

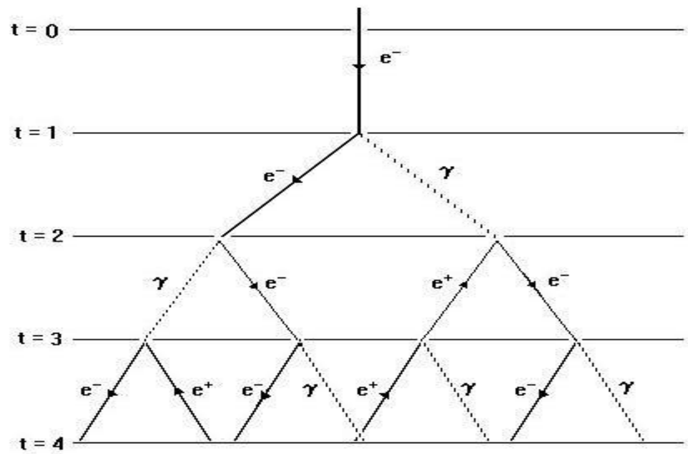


Fig.(b) Schematic diagram of Cascade model.

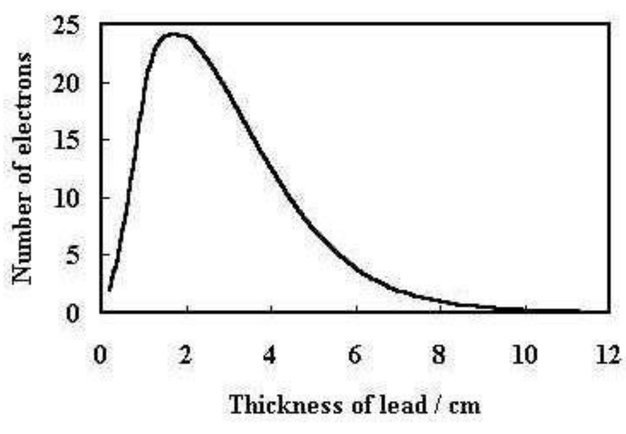


Fig.(C) Number of Shower Particles Vs Thickness of the lead absorber

Calorimeters

The simulation and testing of “Spaghetti” and “Shashlik” was done using two types of calorimeters:

Homogeneous Calorimeters

Heterogeneous Calorimeters

Where Homogeneous calorimeters are for electromagnetic calorimeters and Heterogeneous Calorimeters can be of Hadron or electromagnetic.

In electromagnetic calorimeter, the main parameter is the energy resolution. From this experiment to estimate the energy resolution, can be done in the following way:

$$\frac{\sigma(E)}{E} = \frac{\sigma_{gauss}}{E_0}$$

Where σ_{gauss} is the standard deviation from the normal distribution

Results : Homogeneous Calorimeter

The material used was LU_2SiO_5

Using the equations listed above to calculate or estimate the results in the table below.

Table.1: Parameters of elements found in LYSO crystal

Elements	Atomic Number	Atomic Weight	Density	Mass fraction	Radiation length {g/cm^2}	Radiation Length {cm}	Valence
Lu	71	174.98	9.85	0..64	6.79	0.7	2
Si	14	28.06	2.4	0.06	22	9.35	1
O	8	16	1.48	0.18	34.5	24.13	5

In longitudinal the electromagnetic shower for maximum for electrons is $t_{max} = 1.05\, X_0$ and then the radius of the shower is $R_{max} = 2.16X_0$

Results: Heterogeneous Calorimeters

The results of this type is represented down by means of figures,

Figure.1. calorimeter Spaghetti type

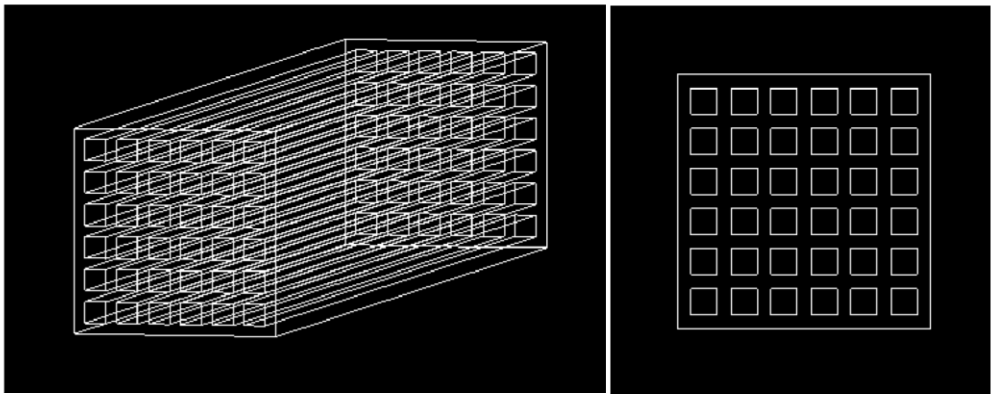


Figure.2. Calorimeter Shashlik type

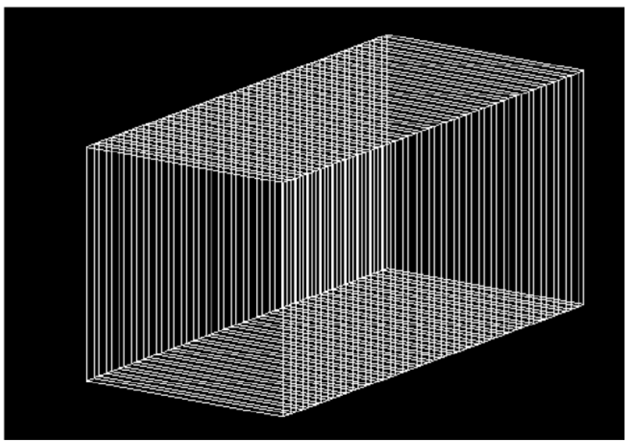


Table.2.

Elements	Density	Radiation Length
Cu	8	1.43
w	15	0.4
5% Cu 95% W	14.6	0.37
50% Cu 50% W	11.6	0.6
95% Cu 5% W	8.2	1.34

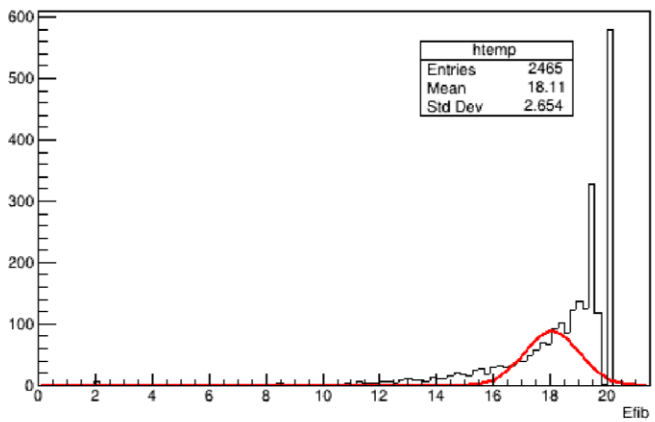
All of the simulations were based on Example 4 in GEANT4, and all analysis, plotting and curve fitting were done using CERN Root.

Homogeneous calorimeter

The homogeneous calorimeter simulated consists of LYSO crystal only, which was described in Table

For larger energies, the figure shows only the beginning part of the fitted Gaussian distribution. The reason for this is the thickness of the calorimeter, which makes it unusable for larger energies. A way to resolve this problem is to enlarge the calorimeter thickness. As mentioned before, this solution is very cost-inefficient and that is why heterogeneous calorimeters are introduced.

Energy for homogeneous



Discussion and conclusion

Five different types of calorimeters were proposed: homogeneous calorimeter with LYSO scintillator crystal, spaghetti type heterogeneous calorimeter with Cu with W compound absorber and LYSO scintillator rods and three different heterogeneous shashlik types of the same materials, with different thicknesses Depending on the thickness and type of the calorimeter the effects was found to be different for all of them. The electromagnetic shower depend of the amount of energy deposited. The (SPh) interact as normal photons although they are of higher energy than normal photon. The energy resolution was found to be for incident particle energy of 20, 30, 40, 50, and 100 MeV for all of the heterogeneous calorimeters.

The goal of this report was simulate and consider different models of electromagnetic calorimeters for soft photon detection. The ratio of caparison was found around 1:3 which is acceptable based on the difference between the types of calorimeter and how they behave as crystal structures and gives the best compromise between performances on low and high energies as well as the amount of crystal used, and therefore the price

Reference:

[1] ew York, 2011C. Grupen and B. Shwartz. Particle detectors (Cambridge University Press, N)

[2] S. Masciocchi. Electromagnetic calorimeters (GSI and University of Heidelberg). Heidelberg, 28 June 2017.

[3] Richard C. Fernow *Introduction to Experimental Particle Physics,* Cambridge University Press.

[4] Rossi B 1964, *Cosmic Rays* (London: George Allen and Unwin)

[5] Particle Data Group, Review of particle properties, Rev.Mod.Phys. 56:S1-S304.1984