Süleyman Demirel Üniversitesi
Fen Bilimleri Enstitüsü Dergisi
Cilt 21, Sayı 2, 296-298, 2017

Süleyman Demirel University
Journal of Natural and Applied Sciences
Volume 21, Issue 2, 296-298, 2017

DOI: 10.19113/sdufbed.25872

A Monte Carlo Study on Position Resolution of PWO Crystal

Fatma KOCAK[*1]

[1]Uludag University, Department of Physics, 16059, Bursa

(Alınış / Received: 28.12.2016, Kabul / Accepted: 15.03.2017, Online Yayınlanma / Published Online: 10.04.2017)

Keywords
PWO crystal,
Position resolution,
GEANT4

Abstract: An electron produces an electromagnetic shower in a crystal calorimeter and the deposited electron energy generally extends over several crystals. PWO crystal is proposed to use for the electromagnetic calorimeter part of the Turkish Accelerator Center Particle Factory detector. In this study, the center of gravity method was used to determine the position of the centroid of the electromagnetic shower initiated by an electron in a 3×3 PWO-matrix and the position resolution of the electromagnetic calorimeter of the Turkish Accelerator Center Particle Factory detector was calculated using the Monte Carlo simulation based on GEANT4.

PWO Kristalinin Konum Çözünürlüğü Üzerine Bir Monte Carlo Çalışması

Anahtar Kelimeler
PWO kristali,
Konum çözünürlüğü,
GEANT4

Özet: Bir elektron, bir kristal kalorimetre içerisinde elektromanyetik bir sağanak üretir ve depolanan elektron enerjisi genellikle birkaç kristalin üzerine yayılır. PWO kristalinin Türk Hızlandırıcı Merkezi Parçacık Fabrikası detektörünün elektromanyetik kalorimetresinde kullanılması önerilmektedir. Bu çalışmada, 3×3' lük bir PWO matrisinde bir elektron tarafından başlatılan elektromanyetik sağanağın merkezinin konumunu belirlemek için ağırlık merkezi metodu kullanıldı ve Türk Hızlandırıcı Merkezi Parçacık Fabrikası detektörünün elektromanyetik kalorimetresinin konum çözünürlüğü GEANT4' e dayanan Monte Carlo benzetişimi kullanılarak hesaplandı.

1. Introduction

The Turkish Accelerator Center (TAC) [1] project was planned as a regional facility for accelerator based research in Turkey. The TAC will include an IR FEL facility based on SC linac with 15-40 MeV energy, a third generation synchrotron radiation facility based on 3 GeV electron synchrotron, a fourth generation SASE FEL facility based on 3 GeV electron linac, a multi-purpose proton accelerator facility with 3 MeV-2 GeV beam energy and a super charm factory based on a linac ring type electron-positron collider at center of mass energy 3.77 GeV [2,3]. Good energy and position resolution of the electromagnetic calorimeter (ECAL) of the TAC Particle Factory (TAC-PF) detector is important for both neutral and charged particles. $PbWO_4$ (PWO) is one of the crystals proposed as the active medium for the TAC-PF ECAL, because of its high density (ρ=8.28 g/cm^3), short radiation length (X_0=0.89 cm) and fast decay time (about 80% of light is emitted in 25 ns) [4,5].

Electromagnetic calorimeters made of crystals are widely used to determine position and energy of the electron or photon in high energy physics experiments. While the total deposited energy in the calorimeter is used to measure the energy of incident particle, the deposited energies in several crystals is used to determine the position of particle. The aim of the study is to calculate position resolution of PWO crystal for incident electrons at energy range from 100 MeV to 2 GeV.

2. Position Resolution

The position of the particle can be described by the center of gravity of the electromagnetic shower. The center of gravity, $x_{gravity}$ and $y_{gravity}$ are calculated from the following formulas:

$$x_{gravity} = \frac{\sum_i E_i x_i}{\sum_i E_i}, y_{gravity} = \frac{\sum_i E_i y_i}{\sum_i E_i} \quad (1)$$

where E_i is the deposited energy in the i^{th} crystal and (x_i, y_i) is the position of its center, taking as (0.,0.) for the central crystal [6-8]. The sum is generally taken over 9 to 25 crystals belonging to a matrix. As an example, Figure 1 shows the correlation between the $x_{gravity}$ and $y_{gravity}$ coordinates in a 3×3 PWO matrix at the electron energy of 250 MeV.

*İlgili yazar: fkocak@uludag.edu.tr

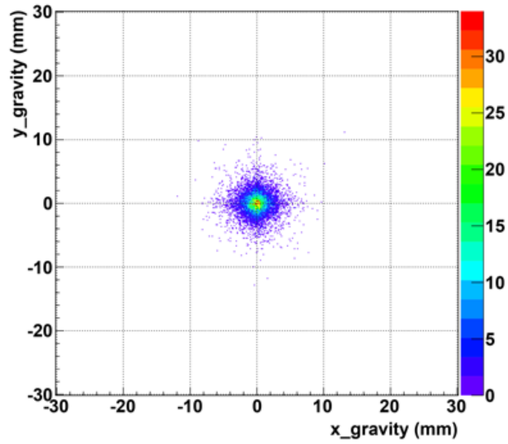

Figure 1. $x_{gravity}$-$y_{gravity}$ position of electrons on the front face of the 3×3 PWO matrix at 250 MeV.

3. GEANT4 Simulations and Results

Geant4 simulation code [9] has been used to simulate electrons passing through the calorimeter prototype consisted of nine PWO blocks of a 3×3 matrix in the energy region from 100 MeV to 2 GeV. The PWO crystals have a 200 mm length with cross section 20×20 mm^2 (22X_0). In order to obtain distributions of the center of gravity of the deposited energy in the crystals, the electrons were injected into eleven different points on the central crystal of the matrix. The relation between the positions determined by center of gravity method ($x_{gravity}$) and the impact positions (x) for 1 GeV electrons is shown in Figure 2. The center of gravity method results in an *S*-shape curve instead of a linear variation for the determination of the true impact position as can be seen in Figures 2 and 3.

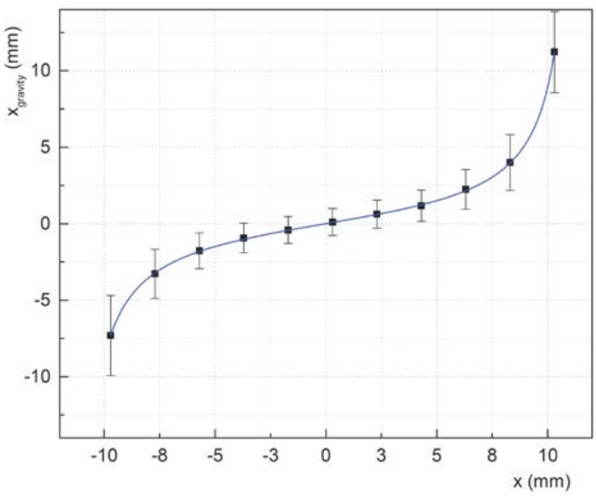

Figure 2. Positions obtained by the center of gravity technique versus the impact position of the electrons (S-curve).

The correction curves are nearly independent from the energies of incident electrons, since the lateral electromagnetic shower profile almost never changes with the energy. To remove the non-linearity between the x and $x_{gravity}$, these correction curves were fitted with an empirical function given by:

$$x_{gravity} = c \tan d(x - e) \qquad (2)$$

where c, d and e are the fit parameters. For example, as a result of this fit, c, d and e values were obtained as 1.866, 0.136 and -0.013 at 1 GeV, respectively.

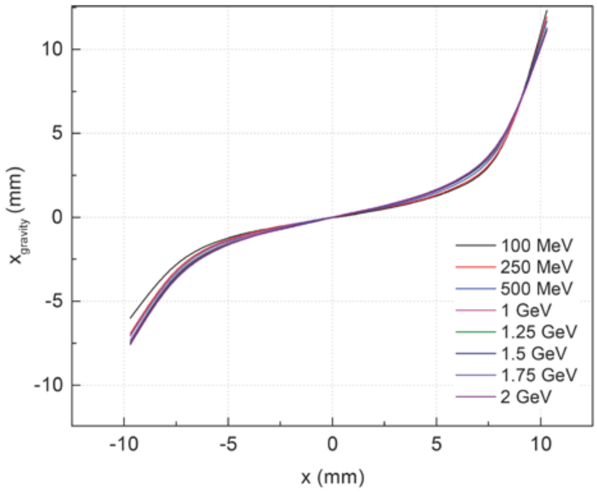

Figure 3. S-curves for 0.1, 0.25, 0.50, 1, 1.25, 1.5, 1.75 and 2 GeV.

Using the fitted values of c, d and e, the corrected position x_{corr} was determined by inverted Eq. 2,

$$x_{corr} = \frac{1}{d}\tan^{-1}\frac{x_{gravity}}{c} + e. \qquad (3)$$

The corrected position distributions were fitted with a Gaussian function to obtain the position resolutions (see for example Figure 4). Figure 5 shows the position resolutions for several electron energies at the center of the PWO crystal. These values are compatible with the experimental results given in Ref [6].

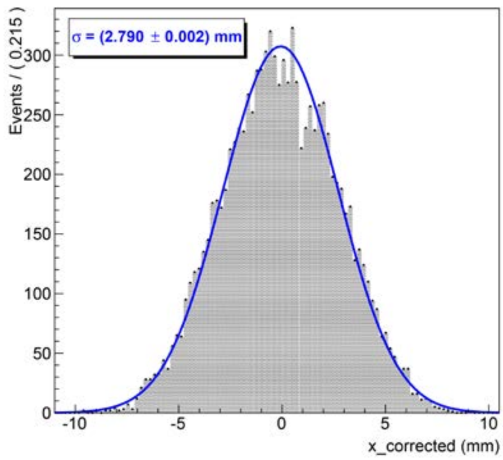

Figure 4. The position distribution after the correction for electron energy of 1 GeV.

Monte Carlo simulation shows that the position resolution gets better with the increasing incident electron energy at the center of the PWO crystal. The energy dependence of the position resolution can be represented as:

$$\sigma_x(mm) = \frac{(2.62 \pm 0.11)}{\sqrt{E(GeV)}} \oplus (0.86 \pm 0.19) \qquad (4)$$

The position resolution is non-constant on the whole surface of the crystal and changes depending on the impact position. As shown in Figure 6, the resolution gets better towards the edges of the crystal and the smallest resolutions are obtained in the edges. This can be explained by the fact that the electromagnetic shower sharing starts to become important in that region.

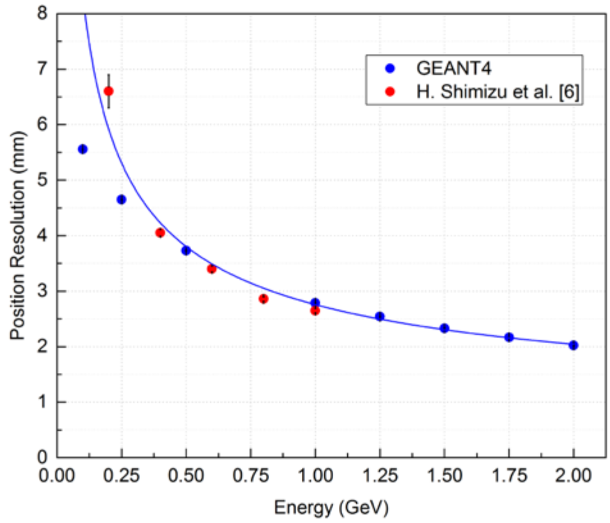

Figure 5. Position resolutions versus incident electron energy at the center of the PWO crystal.

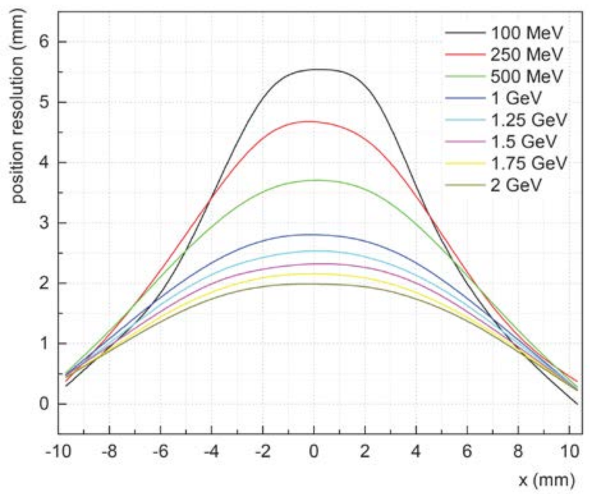

Figure 6. Position resolutions versus the impact position of the electrons inside the PWO crystal.

4. Conclusion

Position resolution for a matrix consisting of 3×3 PWO crystals has been studied by using the center of gravity method for the ECAL of the TAC-PF detector. Simulations were performed in the incident electron energies between 100 MeV and 2 GeV. For 1 GeV electrons, position resolution is 2.79 mm in the center of the crystal, and is 0.245 mm at the edge of the crystal. The stochastic term of the position resolution is also found about 2.62 mm. In determination of the final design of the TAC-PF ECAL, other important requirements such as energy resolution, non-uniformity of light yield, ageing, radiation hardness, and choice of photo-sensors should be taken into account in addition to the position resolution.

Acknowledgment

The numerical calculations reported in this study were partially performed at TUBITAK ULAKBIM, High Performance and Grid Computing Center (TRUBA resources).

References

[1] http://thm.ankara.edu.tr

[2] Recepoglu, E., Sultansoy, S. 2011. A high luminosity ERL on ring e^-e^+ collider for a super charm factory. Turk. J. Phys., 35(2011), 257-263.

[3] Aksoy, A., Cakır, O., Duran Yıldız, H., Yavas, O. et al. 2014. Turkish Accelerator Center: The Status and Road Map. Proceedings of the 5th International Particle Accelerator Conference (IPAC2014), June, Dresden, Germany, 2921-2923.

[4] Kocak, F. 2015. Simulation studies of crystal-photodetector assemblies for the Turkish accelerator center particle factory electromagnetic calorimeter. Nucl. Instrum. Meth. A, 787(2015), 144-147.

[5] Diemoz, M. 2007. The electromagnetic calorimeter of the CMS experiment. Nucl. Instrum. Meth. A, 581(2007), 380-383.

[6] Shimizu, H., Sakamoto, Y., Hashimoto, T., Abe, K., Asano, Y., Kinashi, T., Matsumoto, T., Matsumura, T., Okuno, H., Yoshida, H.Y. 2000. Performance of a $PbWO_4$ crystal calorimeter for 0.2-1.0 GeV electrons. Nucl. Instrum. Meth. A, 447(2000), 467-475.

[7] Daskalakis, G., Markou, C. 1998. Monte Carlo studies on Position Resolution for the CMS ECAL calorimeter. CMS Note 1998/053.

[8] Batarin, V.A., Brennan, T., Butler, J., Cheung, H., Derevschikov, A.A., Fomin, Y.V., Frolov, V., Goncharenko, Y.M., Grishin, V.N., Kachanov, V.A. et al. 2003. Precision measurement of energy and position resolutions of the BTeV electromagnetic calorimeter prototype. Nucl. Instrum. Meth. A, 510 (2003), 248-261.

[9] Agostinelli, S., Allison, J., Amako, K., Apostolakis, J., Araujo, H., Arce, P., Asai, M., Axen, D., Banerjee, S., Barrand, G. et al. 2003. Geant4-a simulation toolkit. Nucl. Instrum. Meth. A, 506(2003), 250-303.