Monte Carlo Simulation of the Effective Solid Angle and the HPGe Response to Different Mono-Energetic Protons from Extended Source.

Alaa B. Kadhim
Department of Astronomy and Space, College of Science, University of Baghdad, Baghdad, Iraq.

Abstract
A program using Mont Carlo techniques has been written to calculate the effective solid angle of the detection system and simulate the response of the HPGe to mono-energetic protons from an extend source. It has been found that the fraction of the protons which leave through the cylindrical surface and deposit only part of their kinetic energy in the crystal increases with proton energy and the consequent increase in their range.

Keywords: Mon Carlo, Response, HPGe detector.

محاكاة مونت كارلو لحساب الزاوية الصلبة واستجابة كاشف الجرمانيوم عالي النقاوة لبروتونات احادية الطاقة من مصدر غير نقطي

علاء باقر كاظم
قسم الفلك والفضاء، كلية العلوم، جامعة بغداد، بغداد، العراق

الخلاصة:
استعملت تقنية مونت كارلو لحساب الزاوية الصلبة الفعالة ومحاكاة الاستجابة لكاشف الجرمانيوم عالي النقاوة لطاقات احادية للبروتونات من مصدر غير نقطي . وقد تم كتابة برنامج لهذا الغرض، حيث وجد ان جزء من البروتونات الساقطة تترك الكاشف بعد ان فقدت قسم من طاقتها في البلورة ويزداد هذا الفقدان للبروتونات مع زيادة الطاقة لها بسبب زيادة المدى لها.

Introduction:

To study any (γ, p) reaction with energy resolution to resolve low-lying states of the residual nucleus[1-5]. To a chieve this energy resolution a novel detection system was constructed. The detection system consisted of two silicon strip detectors (area 50 mm x 50 mm, thickness ~450 µm) and HPGe detector (had a diameter of 50 mm and thickness 25 mm)[6-8]. The detection system is schematically illustrated in figure-1. The Silicon Strip Detectors were used to determine the angle of emission of the high energy protons and to provide particle discrimination between electrons and protons. The HPGe was used to determine the energy of the protons. The angular range of the detection system was $\theta = 60^0 - 120^0$ and the angular resolution of the detector system was $5^0 \pm$.It should be noted that the target is parallel to the photon beam and that during experiment an area of ~ 10 cmx 4 cm area is illuminated by the photon beam. To obtain cross – section (absolute or relative) the effective solid angle of the detection system as a function of proton energy emission point and direction needs to be calculated.

*Email:baqer_alaa@yahoo.com

To achieve this , a program using Monto Carlo technique has been written to calculate the effective solid of the HPGe to different mono-energetic proton from an extended source.

The (γ, p) reactions provide a valuable opportunity to investigate the high momentum components of nucleon wave functions, and strong short range nucleon – nucleon correlations within nuclei[3-5]. Photons of the energy used as mention in the table-1 in some experiments have a significantly shorter wavelength, and are believed to interact with just a single nucleon or a small group of nucleons within the nucleus.

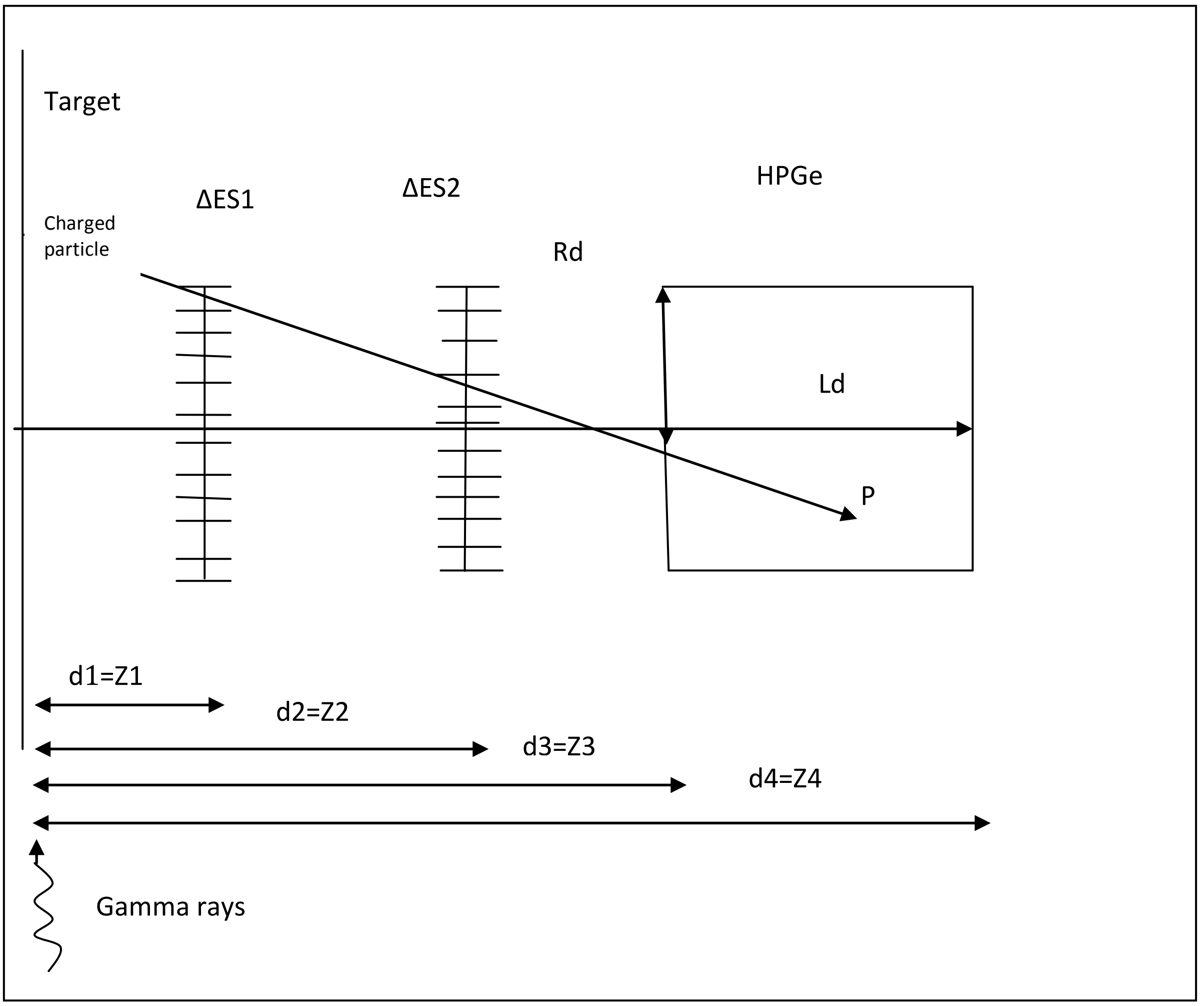

Figure .1- Schematic diagram of the high resolution proton detection system developed for the(γ, p) reaction.

Table 1- TheNo.of particles left the surface of the (HPGe) crystal increase with increase their energies.

Ep (MeV)	No. of initial particles (N_{tot})	No. of particles hits	No. of particles absorbed (N_{det})		No. of particles left		Solid angle of system Ω_{eff}	The statistical uncertainty σ
20	10^7	189982	184637	97.2%	5345	2.8%	0.1160	0.000274
30	10^7	189982	180812	95.2%	9170	4.8%	0.1136	0.000269
40	10^7	189982	174944	92.1%	15038	7.9%	0.1099	0.000264
50	10^7	189982	168243	88.6%	21739	11.4%	0.1055	0.000259
60	10^7	189982	162111	85.3%	27871	14.7%	0.1018	0.000254
70	10^7	189982	154005	81.1%	35977	18.9%	0.0967	0.000248
80	10^7	189982	146664	77.2%	43318	22.8%	0.0921	0.000242
90	10^7	189982	133397	70.2%	56585	29.8%	0.0838	0.000230
100	10^7	189982	120057	63.2%	69925	36.8%	0.0754	0.000218

Monte-Carlo simulation:

The calculation data have been analyzed, the results of Monto-Carlo simulations were used. These simulations were undertaken to determine properties of the detection system such as the effective solid angle and angular resolution. It was necessary to use the Monto-Carlo simulation technique because of the complexity of the detection system. The experimental geometry consisted of a target, two strip detectors, and a (HPGe) detector as shown in figure-1. The major stages of the program are described below:

- Select the angle of proton emission isotropically.
- Select the point of the reaction in the target randomly.
- Determine whether the emitted proton hits the front face of the HPGe detector.
- Determine whether the proton is fully stopped in the HPGe detector.
- If it is stopped in the HPGedetector calculate how much of its energy is deposited in the detector.
- Calculation of the effective solid angle covered by the charged particles telescope is given by[5]:

$$\Omega_{eff} = \frac{N_{det}}{N_{tot}} \times 2 \times \pi$$

where

N_{det} is the number of particles absorbed in the detector.

N_{tot} is the total number of initial particles.

- The statistical uncertainty in the solid angle was estimated by:

$$\sigma = \Omega_{eff}\sqrt{\frac{1}{N_{tot}} + \frac{1}{N_{det}}}$$

- Determination of the charged particles tracks through the charged particles telescopes and calculation of all energy losses of the particles is given by:

$$E_{kp} = E_{HPGe} + E_{s1}^{Front} + E_{s2}^{Back} + E_t + E_b$$

where :

E_{kp} is the total kinetic energy of the detected proton.

E_{HPGe} is the deposited energy in the HPGe crystal.

E_{s1}^{Front} is the deposited energy in front strip detector.

E_{s2}^{Back} is the deposited energy in back strip detector.

E_t is the deposited energy in the target.

E_b is the deposited in the berillium window.

The equation of the line defined by the proton path is given by:

$$\vec{r} = \vec{r}_0 + t \times \vec{n} \quad \text{……………………….(1)}$$

where n is a vector along the direction of the proton path and t is a variable parameter and the parametric equation are:

$$x = x_0 + t \times n_x \quad \text{………………………(2)}$$

$$y = y_0 + t \times n_y \quad \text{……………………….(3)}$$

$$z = z_0 + t \times n_z \quad \text{………………………..(4)}$$

where x_0, y_0, and z_0 are the coordinates of the emitter point in the target and n_x,n_y, n_z are the components of the vector n.

we choose n_x,n_y, and n_z to be:

$$n_x = \cos\theta \quad \text{……………………..(5)}$$

$$n_y = \sin\theta\cos\varphi \quad \text{……..……………….(6)}$$

$$n_z = \sin\theta\sin\varphi \quad \text{……..……………..(7)}$$

The coordinates x_0 and y_0 can be obtained from the equations:

$$x_0 = R_1 \times A - \frac{A}{2} \quad \text{……..……………….(8)}$$

$$y_0 = R_2 \times B - \frac{B}{2} \quad \text{……………………(9)}$$

In this case we have taken the origin of our reference coordinate system to be the center of the target, where A and B are the dimensions of the target and R_1 and R_2 are random numbers in range 0 to 1:

For given θ and φ we can calculate n_x, n_y and n_z thus obtain x_1 and y_1 for the front strip:

$x_1 = x_0 + t_1 \times n_x$ ……..……………(10)

$y_1 = y_0 + t_1 \times n_y$ …..…..…………(11)

where $t_1 = \frac{d_1}{n_z}$, $z_1 = d_1$, and d_1 is the distance between the target and the front strip detector.

Similarity x_2, y_2 can be found for the back strip:

$x_2 = x_0 + t_2 \times n_x$ ……..……………(12)

$y_2 = y_0 + t_2 \times n_y$ ……..……………(13)

where $t_2 = \frac{d_2}{n_x}$, $z_2 = d_2$, and d_2 is the distance between the target and the back detector.

we calculate x_{HPGe}^{face} and y_{HPGe}^{face} for the face of the (HPGe) detector by the equation:

$x_{HPGe}^{face} = x_0 + t_{HPGe}^{face} \times n_x$ ………..…………(14)

$y_{HPGe}^{face} = y_0 + t_{HPGe}^{face} \times n_y$ ……….…………..(15)

Where $t_{HPGe}^{face} = \frac{d_{HPGe}^{face}}{n_z}$, $z_3 = d_3$ and $d3$ is the distance between the target and the face of the (HPGe) crystal.

Thus, the radius of the (HPGe) crystal is given by:

$R_{HPGe}^{face} = \left[(x_{HPGe}^{face})^2 + (y_{HPGe}^{face})^2\right]^{\frac{1}{2}}$ …..………………..(16)

we check whether the proton hits the face of the (HPGe) crystal or not by comparing R_{HPGe}^{face} with R_{HPGe} . If R_{HPGe}^{face} is greater than R_{HPGe} , then the proton does not hit the face of the (HPGe) crystal.

In the case the proton hits the face of the (HPGe) crystal then we ask that 'Does the proton leaves the crystal?'. If it does, we have to calculate the point at which the proton is stopped.

Let R_P be the energy range of a proton in the HPGe crystal. Then

$R_P = \left|\left[\vec{r_s} - r_{HPGe}^{face}\right]\right|$ ……………….(17)

$R_P = \left|\left[\vec{r_0} + t_s \times \vec{n} - (\vec{r_0} + t_{HPGe}^{face} \times \vec{n}\right]\right|$ ……………..(18)

$R_P = \left(t_s - t_{HPGe}^{face}\right)|\vec{n}|$, where $|\vec{n}| = 1$ ……………..(19)

$R_P = t_s - t_{HPGe}^{face}$ ……………..(20)

$t_s = t_{HPGe}^{face} + R_P$ …………….(21)

where t_{HPGe}^{face} is the distance along the trajectory of the proton from the emitter point to the face of the HPGe crystal, and t_s is the distance along the trajectory from the emitter point to the point at which the proton is stopped.

Since we now know t_s , we can easily calculate (x_s , y_s , z_s) from:

$x_s = x_0 + t_s \times n_x$ ……………….(22)

$y_s = y_0 + t_s \times n_y$ ..……………..(23)

$z_s = z_0 + t_s \times n_z$ ………………..(24)

If z_s is greater than z_{HPGe}^{back} or $\left[(x_s)^2 + (y_s)^2\right]^{\frac{1}{2}}$ is greater than R_{HPGe}^{face} then the proton is not stopped in the HPGe crystal.

For the case where the proton is not stopped in the crystal but goes out from any side the crystal surface we need to know how far it travels through the crystal before leaving it (at point x_l , y_l , z_l) we have:

$x_l^2 + y_l^2 = R_{HPGe}^2$ ………………..(25)

$(x_0 + t_l \times n_x)^2 + (y_0 + t_l \times n_y)^2 = R_{HPGe}^2$ ……………..….(26)

$a \times t_l^2 + b \times t_l + c = 0$ ……………….(27)

Solving for t_l gives:

$t_l = \frac{-b \pm (b^2 - 4ac)^{1/2}}{2a}$ ……………….(28)

Once we have t_l ,we can determine x_l ,y_l and z_l by:

$$x_l = x_0 + t_l \times n_x \qquad \text{.................(29)}$$

$$y_l = y_0 + t_l \times n_y \qquad \text{.................(30)}$$

$$z_l = z_0 + t_l \times n_z \qquad \text{................(31)}$$

wheret_l is the distance along the trajectory of the proton from the target to the point which the proton is stopped out the crystal. Let d_{tr} be the distance travelled through the crystal. If z_l is less than z_{HPGe}^{face} then:

$$d_{tr} = |(\vec{\gamma} - \gamma_{HPGe}^{face})| \qquad \text{.............(32)}$$

$$d_{tr} = t_1 - t_{HPGe}^{face} \qquad \text{.............(33)}$$

Once d_{tr} is known then the energy lost E_{lost} can be found by:

$$E_{lost} = E_P\,(range = R_p\,) - E_P\,[(range = (R_p - d_{tr}))] \qquad \text{.............(34)}$$

For case where the proton is not stopped in the crystal but goes out the back of the crystal, we need to know again how far it travels through the crystal before leaving it.

$$d_{tr} = t_{HPGe}^{back} - t_{HPGe}^{face} \qquad \text{...........(35)}$$

wheret_{HPGe}^{back} the distance along the trajectory of the proton from the target to the back of the (HPGe) crystal.

Results and Discussions

The result of simulation to determine the response of (HPGe) to different mono-energetic protons shows that protons which are stopped within the active volume of the (HPGe) produce the full energy as shown in figure-2. Protons which are not completely stopped within the active volume of the (HPGe) produce the low energy continuum. The events arise from protons passing through the (HPGe) at extreme angles where there is insufficient thickness to stop the proton. This simulation include all events for which the protons pass through any pair of strips and enter the (HPGe) crystal. The fraction of the protons which leave through the cylindrical surface and deposit only part of their kinetic energy in the crystal is 7.9% (EP= 40 MeV). The probability of this happening increases with proton energy and the consequent increase in their range as shown in table 1.

The overall results of the test were that the nominal depth of 25 mm is sufficient to stop ~ 100 MeV protons at (2.49 cm).

One can conclude that the active depth is quite sufficient for detection of protons over the energy range of interest in the present geometry set.

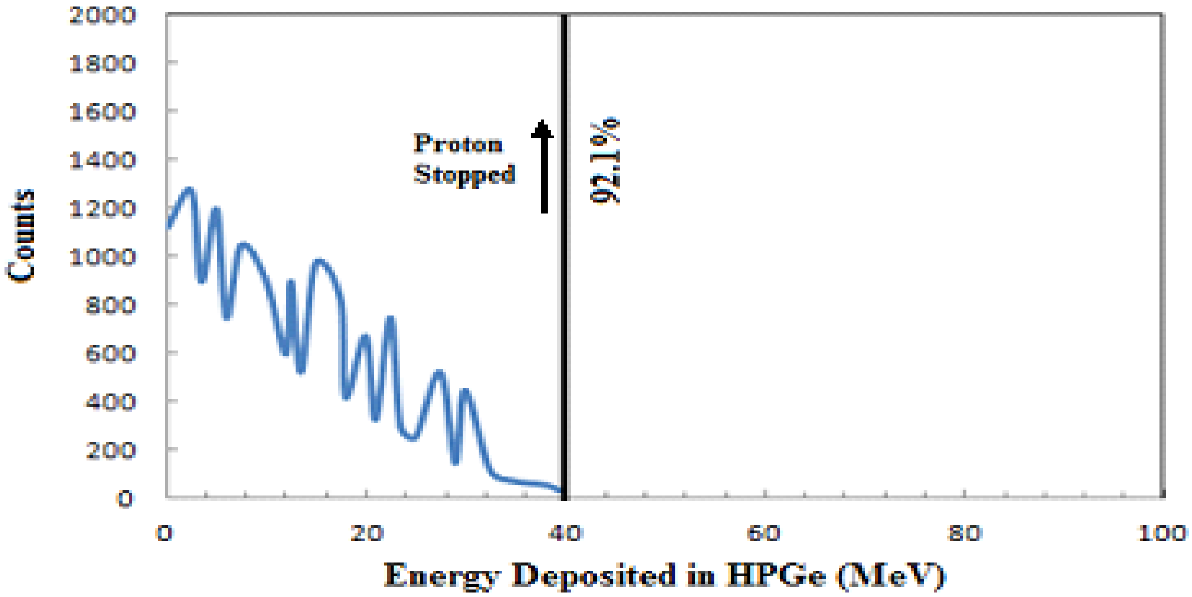

Figure 2- Simulation of the (HPGe) response to 40 MeV protons for typical experimental geometry.

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