Available online at www.pelagiaresearchlibrary.com

Pelagia Research Library

Advances in Applied Science Research, 2014, 5(5):213-225

ISSN: 0976-8610
CODEN (USA): AASRFC

Simulation of a triple-photon decay in electron-positron pair annihilation

Ashraf Abdelrahman Assadig Elameen

Department of Physics, University of Medical Science and Technology (UMST), Khartoum-Sudan

---

ABSTRACT

Electron-positron annihilation is a fundamental process, when an electron and a positron collide in free space; the energy-momentum conservation requires that the annihilation takes place with the emission of at least two photons. Annihilation of electron-positron in more than two photons is less likely and (very) too sensitive to detect. In this work I created a simulation of the triple-photon decay in electron-positron pair annihilation, by using IPython program, and I compared the simulation results with actual data of the experiment that was performed by M. E. A. Elbasher et al in the Department of Physics, University of Stellenbosch.

Key words: Simulation, Annihilation, Positron.

INTRODUCTION

When a subatomic particles like electrons or protons collides with its respective anti-particles, it is annihilate into photons must have energy equivalent to the mass of particles and anti-particles pair before collision; based on law of conservation of energy, ‘energy can neither be created nor destroyed but can change from one form to another'. Anti-particles have exactly same mass, opposite electric charge and opposite additive quantum numbers from particles; so that the sums of all quantum numbers of the (particles and anti-particles) pair are zero and this require the momentum of photons production to be conserved.

Examples for the annihilation processes include electron- anti-electron (positron) pair annihilation, and the proton-anti-proton pair annihilation. In this project electron-positron pair annihilation at low energy, was studied to observe the decay of the triple-photon.

Positron can directly annihilates with an electron by emitting back-to-back two 511 keV (rest energy of the electron or positron)γ-rays, according to Einstein’s equation $E = mc^2$. γ-rays tell us that mass and energy are interchangeable [1]. This emerges when electron-positron pair has low energies.

If either the electron or positron, or both, have appreciable kinetic energies, other heavier particles can also be produced (such as D mesons) since there is enough kinetic energy in the relative velocities to provide the rest energies of those particles. It is still possible to produce photons and other light particles, but they will emerge with higher energies.

The energy of the emission should directly correlate with the mass of the positron. This is a unique process in electron-positron interaction. It is often employed to demonstrate the law of momentum conservation in subatomic processes; the reason for the fact that the annihilation radiation contains information on the electron momentum distribution at the annihilation site.

Sometimes the electron and positron creating bond through the electromagnetic force with binding energy 6.8 eV to form positronium atom [2]. There are two types of positronium atom, depending on spin aligned of electron and positron, if spins of electron and positron are parallel called orth-positronium, or spins anti-parallel called para-positronium.

When electron-positron pair first form positronium atom, the direction of the energy emitted from their annihilation will not be linear. i.e. more than two γ-rays were emitted in annihilation process. In this project, last case was studied 'positronium atom (Ps) was formed first'; to observe decay of triple γ-rays emitted, and this possible by simple triple coincidence measurements system.

The cross-section and the nature of annihilation depend on the mutual orientation of the spins of the particles participating in the annihilation process. For instance, para-positronium under goes two photons annihilation, while ortho-positronium undergoes three photons annihilation. The probabilities of the spontaneous annihilation of p-Ps and o-Ps atoms are also different. Ore and Powell in 1949 calculated that the ratio of the cross-section for the three and two γ-rays cases is approximately 1/370 [3]. The concept of cross-section in nuclear physics is the effective area which governs probability that nuclear reaction will take place.

Since both positronium formation and direct annihilation end in the same products (emittedγ-rays) they can be difficult to distinguish experimentally. Positronium formation cross-section are typically on the order of the cross sections for elastic and inelastic processes, while cross-section for direct annihilation are several orders of magnitude smaller. For example, for Argon the positronium formation cross-section is ~ $1a_0^2$, where a_0 is the bohr radius, while the direct annihilation cross-section is $\sim 10^{-5}\ a_0^2$. For this reason, above the positronium formation, it is difficult to measure direct annihilation [4].

In the absence of positronium formation, the relative probability of decay three photons in electron-positron pair annihilation is small. When positronium atom was formed, the relative probability of decay three photons in annihilation of the positron increases. Hence measurements of the relative probability of decay three photons annihilation of the positron after positronium atom was formed, provide a direct indication of positronium formation.

γ-rays can interact in matter, only three interaction mechanisms have any real significance in gamma ray spectroscopy: photoelectric absorption, Compton scattering, and pair production. Since photoelectric absorption predominates for low-energy γ-rays (up to several hundred keV), pair production predominates for high-energy gamma rays (above 5-10 MeV), then Compton scattering is the most probable process and only would take in account.

In this work IPython was used; it provides a rich toolkit to help make the most out of using 2Python, with support for interactive data visualization and web-based notebook with the same core features but support for code, text, mathematical expressions, and inline plots [5].

All possible probabilities to detect the triple-photon decay in the electron-positron pair annihilation, under triple coincidence measurement have been inserted and analyzed by IPython program and interpreted by using graph interpreter, the methods and all cases of the complete events are fully explained in appendix.

The triple-photon and the incomplete event were triggered by compton scatter. Thus,Python itself was sufficiently defined, I used Python because it represents a high-level language, and its an interpreter, interactive and object-oriented programming language is of high accuracy.

Additionally Python has many advantages over other a high-level language like C, C^{++}, Perl and Java.

These advantages can be enumerated as follows:
- Python is easy to learn because of the very clean syntax.
- Extensive built-in run-time checks help to detect bugs and decrease development time.
- Programming with nested, heterogeneous data structures is easy.
- Object-oriented programming is convenient.
- There is support for efficient numerical computing.
- The integration of Python with C, C^{++}, Fortran, and Java is very well supported [6].

THEORIESOF POSITRON AND POSITRONIUM
The positron is anti-particle of electron, according to the CPT theorem, which states that the fundamental laws of physics are invariant under the combined actions of charge conjugation (C), parity (P) and time reversal (T), positron its has mass ($9.11\ 10^{31}$ kg) and lifetime are equal to those of the electron must be $4\ 10^{23}$ Year, also positron has an electric charge of positive electron (+e=$1.6\ 10^{\ 19}$ c) [7]. The positron eventually annihilates with an electron after a lifetime, which is inversely proportional to the local electron density [8].

Historical view

The anti-matter are not found in nature, except in cosmic ray interactions, and are therefore difficult to detect. The positron is an anti-electron, and it is first observation of anti-matter.

In 1930, P. A. M. Dirac was a predict of the existence of an anti-electron, when he applied relativistic quantum theory to an electron moving in an external magnetic field [9]. In 1933 Diracs anti-electron was first observed by C. D. Anderson in the cloud-chamber tracks of cosmic radiation. Anderson noticed a particle with charge opposite the electron, but lighter than either of the known positive particles at the time, the proton and the alpha particle [10].

Anderson who gave the positron its name, the discovery of Anderson was soon confirmed in December 1933 by Blackett and Occhialini, who also observed the phenomenon of pair production [11]. In 1934 Mohorovici proposed the existence of abound state of a positron and an electron [12]. Mohorovici ideas on the properties of this new atom were somewhat 3unconventional and the name electrum which he gave to it did not become widespread. Experimentally positronium atom was reported for the first time in 1951 by M. Deutsch [13].

Source of the positron

Positrons are emitted as a result of:

1. Decay of radioactive isotopes such as ^{22}Na,^{64}Cu and ^{58}Co within a unstable nucleus into neutron, positron and neutrino. This unstable nucleus emitted γ-rays to reach stable nucleus. These positron sources are used for laboratory applications.

$$p \rightarrow n + e^{+} + \nu \qquad (1)$$

2. Another way to produce high flux of positrons is to bombard electrons on an absorber of high atomic number creating bremsstrahlung rays, thereby generating electron-positron pairs.

For purpose research, always ^{22}Na isotope is used; because^{22}Na isotope give a relatively high positron field of 90.4 % and has several other advantages, first of all the appearance of a 1274 keV γ-rays almost simultaneously with the positron enables positron lifetime measurement by coincidence detectors. Moreover, the manufacture of laboratory source is simple; due to easy handling of different sodium salts in aqueous solution, such as sodium chloride or sodium acetate, finally reasonable price [14].

As shown in Fig. 1 ^{22}Na decays by positron emission or Electron Capture (EC) to 1274 KeV excited state of ^{22}Ne with a branching ratio of nearly 90% and 10% respectively and rather low component of 0.05% decay directly to the ground state, the half-life of ^{22}Na is 2.6 years.

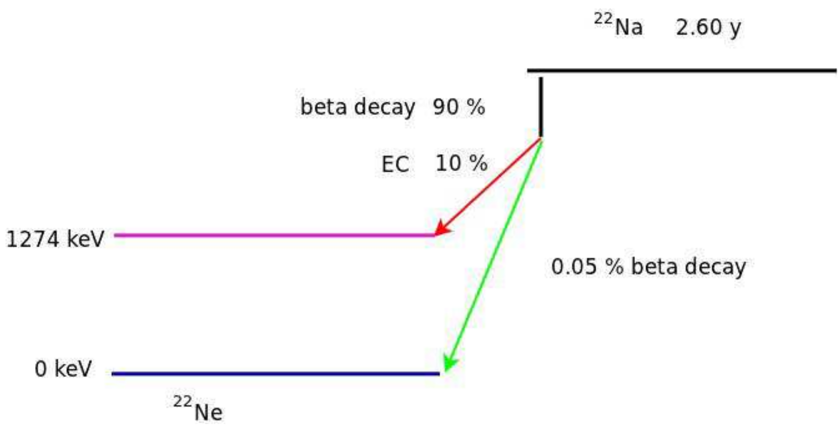

Figure 1: Decay scheme of ^{22}Na

Physics of positron and positronium

Positronium atom like hydrogen atom without nucleus which consists of one electron and one positron, positronium atom can not be found in nature. Positronium formed in a positron-electron atom collision can be in a state with principal quantum number up to n_{ps} provided that the kinetic energy of the incident positron, E, exceeds the difference between the ionization energy of the target, E_i, and the binding energy of the positronium in that state, i.e. $E \geq E_i - 6{:}8/n^2_{ps}$eV .

There are two types of positronium depend on spin alignment of the electron and positron: para-positronium (system of an electron and a positron with anti-parallel spins) and ortho-positronium (system of an electron and a positron with parallel spins). According to quantum mechanics (using tensor product), there are two spins for two types of positronium singlet state with total spin$S = \frac{1}{2} - \frac{1}{2} = 0$, for para-positronium and triplet state with total$S = \frac{1}{2} + \frac{1}{2} = 1$, for orth-positronium.

Ortho-positronium has three sub states, which differ in the value of the magnetic quantum number m = 1; 0; 1, and para-positronium has m = 0. In vacuum positronium atom are formed of approximately 75 % ortho-positronium and 25 % para-positronium. If electron and positron annihilate directly or after formed positronium atom must be satisfy conservation of electric charge formulated at the same time by American scientists Benjamin Franklin and William Watson, in 1747, which provides electric charge can neither be created nor destroyed. i.e. the net electric charge of an isolated system remains constant (the total charge is always the same) and momentum conservation: the total momentum of the system is the same after the collision as before. The most common applications of the conservation of momentum is to problems involve collisions for isolated systems, thus it is applied in the annihilation of positron (collision of positron and electron) [15].

Mathematically

F = -F (third law of newton)

F = dp/dt = 0

where F is the external force, it is equal zero for isolated systems. Thus, P=constant , the total momentum of an isolated systems remains constant. Two types of positronium atom (para and ortho-positronium) can be found in excited state called rydberg positronium. The annihilation modes of positronium governed by selection rule derived by wolfenstein and ravenhall [16]. To conclude that positronium in state with spin S and orbital angular momentum L can only annihilates into n gamma rays where

$$(-1)^{n\gamma} = (-1)^{l+s} \tag{2}$$

where n number of photons emitted in annihilation process.

For ground state positronium with L= 0, for example, to para-positronium atom (S=0) and (L=0), the left side of above equation becomes $(1)^0 = 1$, so that; the number of photons must be equal even number (2, 4,...), for ortho-positronium (S=1) and (L=0), the left side of above equation becomes $1^1 = 1$, so that; the number of photons must be equal odd number (3, 5,...).

Note that ortho-positronium annihilation is accompanied by emission of odd number of photons, at least three photons; because one photon cannot be emitted (in one pair of positron-electron); applying energy and momentum conservation, the photon would have an energy equal to thetotal energy of the incoming electron-positron pair and a momentum of zero. This is impossible because a photons energy and momentum are related by E = pc.

The para-positronium has a shorter lifetime than ortho-positronium, and it is annihilates in two photons, while ortho-positronium annihilates in three photons. The intrinsic lifetime for para-positronium is 0.125 ns and for ortho-positronium is 142 ns. In ordinary molecular media, the electron density is low enough; so that para-positronium can pick o electrons from the media that have anti-parallel spin to that of the positron, and under two photons annihilation this called pick-o annihilation of positronium [17].

Para-positronium and ortho-positronium atoms can be found in excited state Ps* other than ground state, it is called reydberg positronium. One quantity that can be measured is the annihilation rates of positrons for molecules; the annihilation rate for a molecule is proportional to the overlap of the wave functions of the positron with the molecular electrons. Therefore, the measurements of annihilation rates gives information about the close-range interaction of the positron with the molecular electrons, to measure annihilation rates uses a ^{22}Na radioactive source, which emits a 1274 keV γ-rays with a negligible delay after the emission of a positron.

EXPERIMENTAL DESIGN

For -particles emitted from radioactive decays or charge particles emitted from nuclear reactions at low energies (MeV), very thin detector is sufficient. While for γ-rays the range of thickness is large; thus a germanium detector is used.

Detecting X-rays and γ-rays is not a direct process. X-rays and γ-rays photons do not have an intrinsic charge and therefore do not create ionization or excitation of the medium it is passing through directly. Thus, the measurement of these photons is dependent on their interaction with the electrons of the medium. The incident photons will create fast electrons which we look at; to understand the nature of the photon itself. These electrons will have a maximum energy that is equal to the energy of the incident γ-rays on that electron. There are three manners in which the photon will interact with the medium that, which is of concern for γ-rays spectroscopy: Photoelectric absorption, Compton scattering, and Pair production. Because of the fact that the photons themselves are invisible to the detector, a detector needs to have a couple of specific functions. The first is to act as a medium that will have a high probability that an incident γ-rays will interact within that medium. The second function of the detector is to accurately detect the fast electrons that are created [18].

The setup of the experiment, which was conducted in the Physics Laboratory of Department of Physics, University of Stellenbosch, was shown in Fig. 2, and the components of the experimental setup are illustrated below as:

- **HPGe and NaI detectors**

High Purity Germanium detectors (HPGe) have been widely used in the nuclear and industrial sectors for many applications. HPGe detectors must be operating at low temperature, namely 90-120 K. The great advantage to using a High Purity Germanium detector is the fact that they have excellent energy resolution for γ-rays spectroscopy, a high energy resolution means that the detector can discriminate between γ-rays with similar energies. The more resolution a detector has, the more defined a gamma spectrum becomes.

The γ-rays absorption efficiency for Ge (Z=32) is much less than that for the iodine (Z=53) in NaI(TI); due to the higher atomic number and generally larger size.

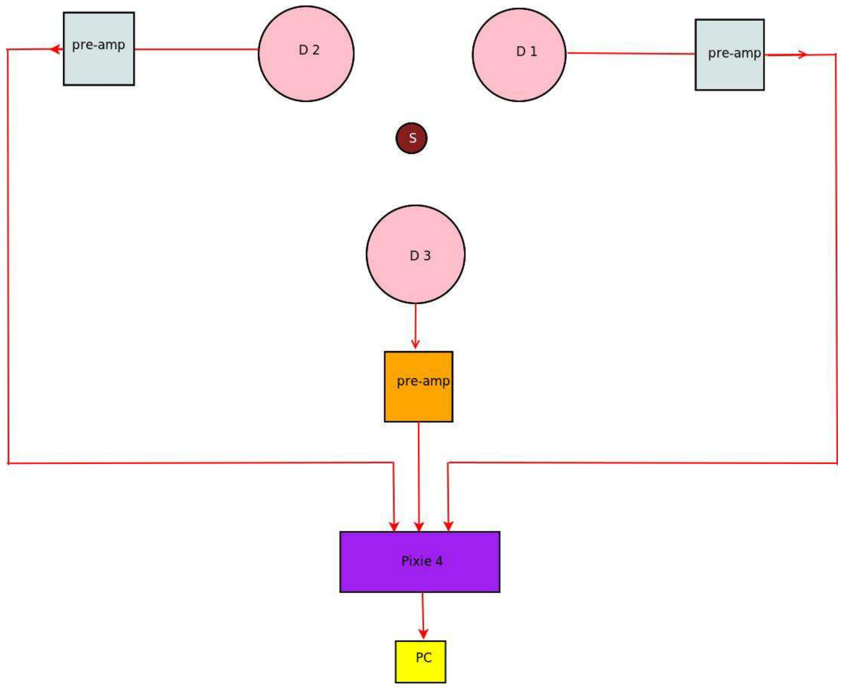

Figure 2: Block diagram of electronic and detectors used in the experiment

Although of advantages of HPGe detectors, NaI(TI) are used because it is has higher detection efficiency for higher energy γ-rays than do HPGe detectors (but much poorer energy resolution), also NaI(TI) detectors offer long time for timing measurements.

- **Pre-amplifier**

The primary function of a pre-amplifier is to extract the signal from the detector without significantly degrading the intrinsic signal-to-noise ratio. Therefore, the pre-amplifier is located as close as possible to the detector, and the input circuits are designed to match the characteristics of the detector. Different pulse processing techniques are typically employed, depending on whether the arrival time or the amplitude (energy) of the detected event must be measured. There are two types of signal pulses in radiation measurements: linear and logic pulses. A linear pulse is signal pulse carrying information through its amplitude and shape. A logic pulse is a signal pulse of standard size and shape that carries information only by its presence or absence. Generally, linear pulses are produced by radiation interactions and then converted to logic pulses [19].

- **Pixie-4**

The DGF Pixie-4 is a multichannel data acquisition system for nuclear physics and other applications requiring coincident radiation detection. It provides digital spectrometry and waveform acquisition for four input signals per module; several modules can be combined into a larger system. The DGF Pixie-4 is based on the CompactPCI/PXI standard which allows data transfer rates from Pixie-4 memory to the host computer of up to 109 MB/s [20].

METHOD OF SIMULATION

The experimental setup are simulated as shown in Fig. 3 to obtain the same results. In this setup the detectors are not shielded against Compton scattering and a γ-rays is likely to deposit its energy in two individual detectors through Compton scattering, thus Compton scattering was take in account; because the range of γ-rays emitted from source is large.

^{22}Na was used in an experiment of the project, three detectors (two HPGe detectors and one NaI(TI) detector) are placed in one plane at an angle of 120^0 to each other at equal distances from the sample with the source. Such an arrangement of the detectors permits the detection of the three photons from a single act of decay three photons in electron-positron pair annihilation with the same energy.

The distance between the source and the detectors is chosen such that no straight line could pass through the source or through more than one detector, thus none of detectors pairs are aligned, such that it is impossible to detect the back-to-back photons in coincidence measurement, when the annihilation takes place in the vicinity of the source.

If three photons are emitted in three different directions with approximately equal energy, the photons must be emitted on a plane with relatively similar angles between every direction; due to momentum conservation.

The scientific importance of this simulation is the ability to study the annihilation of triple-photon as shown in Fig. 3, in which the three individual photons are characterized by continuous energy spectrum with total energy equal to 1022 keV (each photon have energy equal to 1022/3 keV), and direction verifying the momentum conservation with respect to center of annihilation. Three detectors that not only able to detect triple-photon emitted in electron-positron pair, but also able to detect the energy of one back-to-back and -rays transition with fraction of Compton scattered from each of any one (511 or 1274 keV), in coincidence measurement as illustrated in Fig. 5 and Fig. 4 are employed.

All the possible cases for detection γ-rays emitted from electron-positron pair annihilation in coincidence measurements are precisely summarized in table 1.

Table 1: All possible cases of triple coincidence measurements on three detectors

Detector 1 (keV)	Detector 2(keV)	Detector 3(keV)
1022/3	1022/3	1022/3
γ	511-b	b
γ	b	511-b
γ -a	a	511
γ -a	511	a
511	a	γ -a
511	γ -a	a
511-b	b	γ
511-b	γ	b
a	511	γ -a
a	γ -a	511
b	γ	511-b
b	511-b	γ

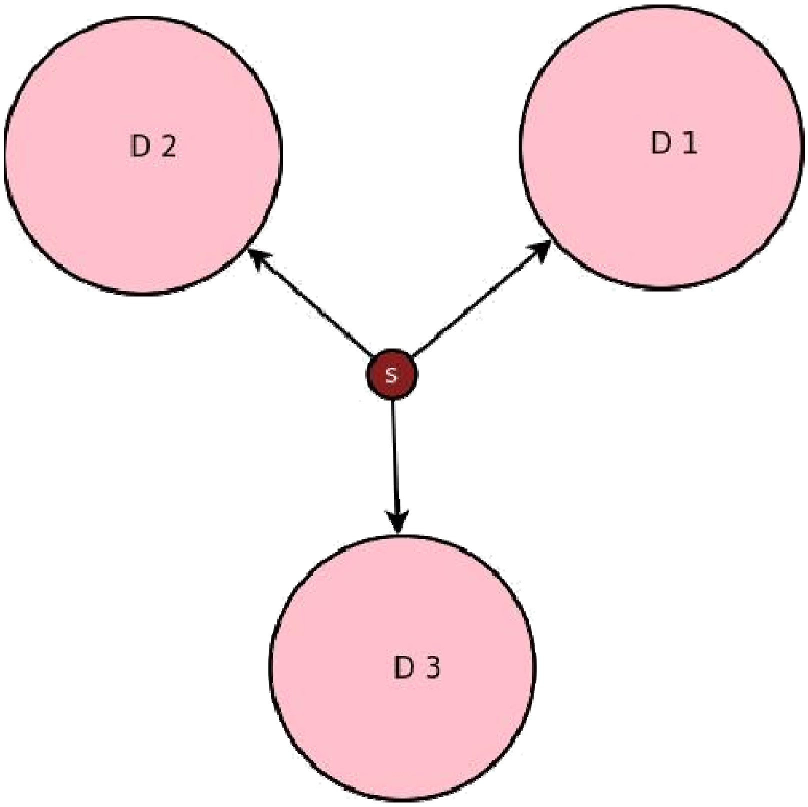

Figure 3: Three Germanium detectors at equally-spaced angles pointing at a ^{22}Na source detect triple photons emission from ortho-positronium annihilation with the 1274 keV γ-rays transition are emitted

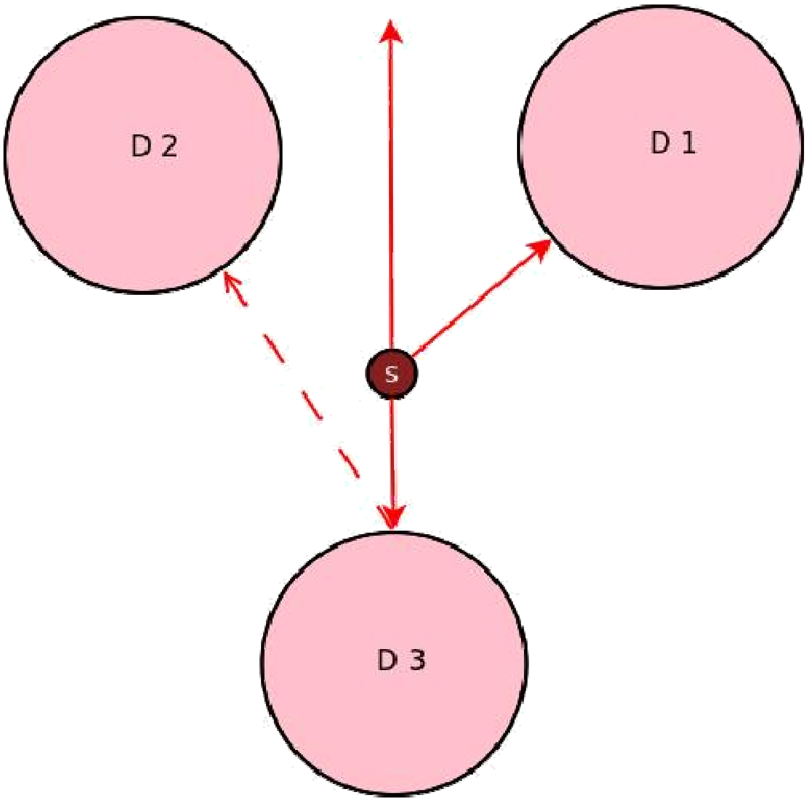

Figure 4: Three Germanium detectors at equally-spaced angles pointing at a ^{22}Na source detect 1274 keV γ-rays transition, one of back-to-back annihilation (511 keV) and fraction scattered from 511 keV

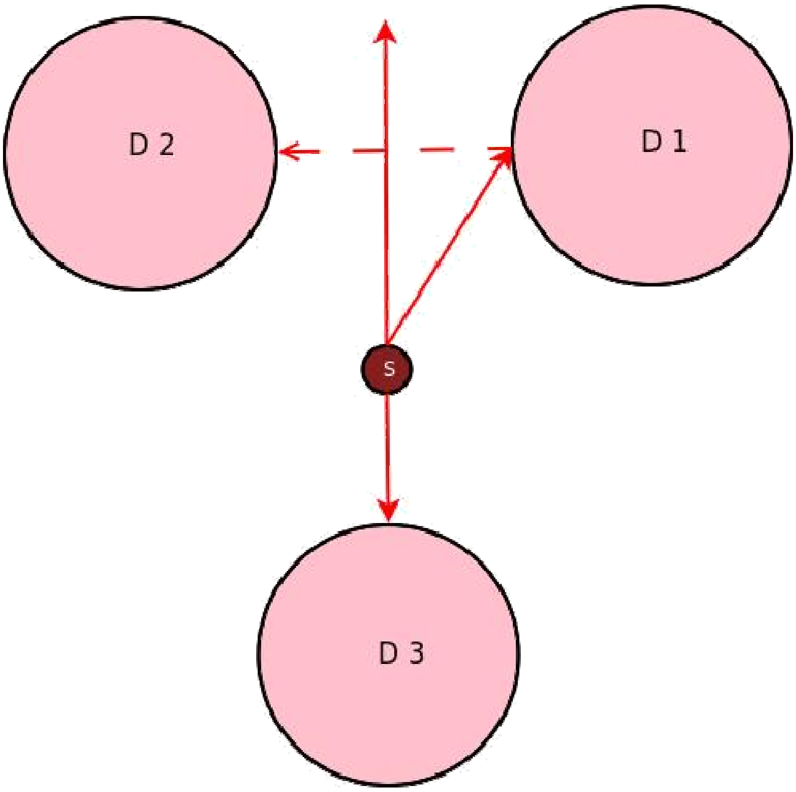

Figure 5: Three Germanium detectors at equally-spaced angles pointing at a ^{22}Na source detect 1274 keV γ-rays transition, one of back-to-back (511 keV) and fraction scattered from 1274 keV

RESULTS AND DISCUSSION

The results of the simulation that were obtained by using Python programming language (IPython) are discussed to illustrate the triple-photon decay in electron-positron pair annihilation.

Simulation results

As shown in Table 1 all the possible cases of triple coincidence measurements on the three detectors are simulated using IPython. The results of the simulated cases of triple coincidence measurements are described as follow:

The energy of emitted photons can be detected by any one of the three detectors used in this project are obviously presented in Fig. 6, in which the energy E_i of one detector (i=1, 2 or 3) can be any value of (511, 1274, 340.66, 511-b, 1274-a, a or b) keV, where

511 keV one photon of back-to-back emitted in annihilation. 1274 keV γ-rays transition energy emitted from the ^{22}Na source.

a and b fraction of the energy scattered (Compton scattering)from 1274 keV and 511 keV respectively.

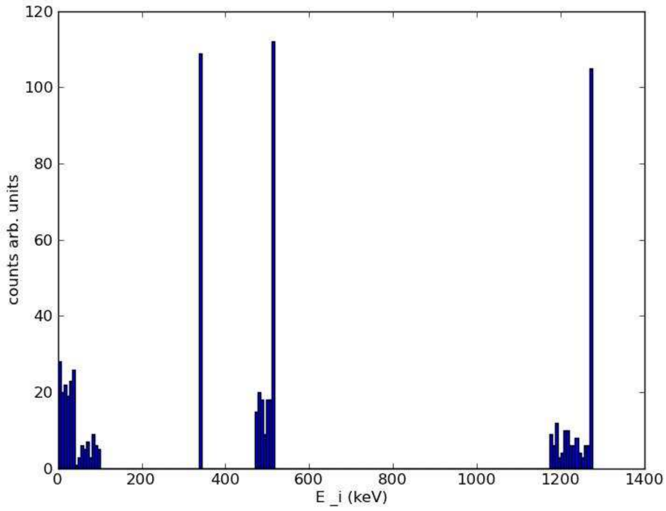

Figure 6: Simulation of emitted photons measured in one detector

The three big peaks appear from left to right on the interpreter can be explained as follow:

- The first peak indicates one of triple-photon (340 keV) decayed in the annihilation.
- The second peak indicates one of back-to-back (511 keV) photon decayed in the annihilation.
- The third peak indicates γ-rays transition energy emitted from the ^{22}Na source.

Note that the peak of case of triple annihilation (340.66 keV) appears without small peaks beside it; because it is happened without any compton scattering.

The two peaks at E_{sum} = 1022 and 1274 keV in Fig. 7 can be interpreted as follow, 1022 keV represents the event, when the total energy is the energy of triple photon deposited in three detectors corresponding to Fig. 3. The E_{sum} = 1785 keV peak is the energy sum of the 1274 keV plus one of back-to-back annihilation of photons corresponding to Fig. 4, and represent incomplete events.

Note that 1785 keV peak is very long compared with 1022 keV peak; this because the ratio of event of triple photons (1022 keV) to the incomplete events involve scatter photons (1785 keV) is very small.

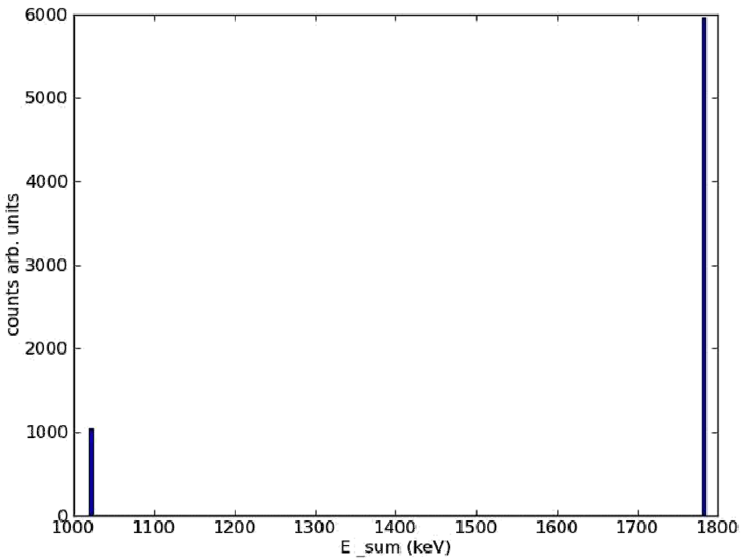

Figure 7: Simulation of energy deposited in three detectors

Experimental results

The tool used for analyzing the data of experiment was ROOT, which is an object oriented data analysis framework initiated at CERN by Ren Brun and Fons Rademakers. It contains a large number of packages concerning different parts of data analysis, for example histogramming handling, curve fitting, ministration and statistics tools [21]. The data of experiment analyzed by ROOT to get on following graphs.

Fig. 8 shows, the energy of emitted photons measured in one detector, obviously, it is in agreement with result obtained by IPython, except 1022 peak which represent as repeat of two back-to-back decay see Fig. 6. Note that the graph obtained by experimental results, associated with noise at whole graph, which represent background. Thus the only difference to experimental considerations.

Fig. 9 shows sum of energy deposited in three detectors, obviously, it is in agreement with result obtained by the simulations, see Fig. 7. But, the graph obtained by the actual experimental results differs from the graph of simulation, by 2296 keV peak which represent combination of two events for two back-to-back (1022) keV plus 1274 keV γ-rays transition, this occurs when positron annihilate away from the ^{22}Na source between a pair of detectors with transition energy deposited in three detectors. Obviously, this is the only difference between the actual experiment and the simulation

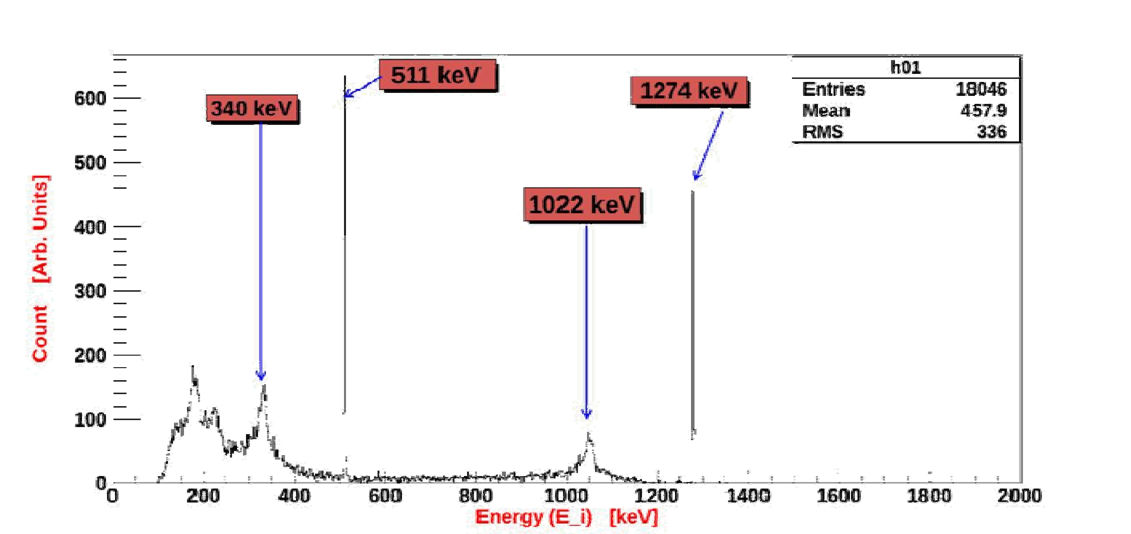

Figure 8: Energy of emitted photons measured in one detector

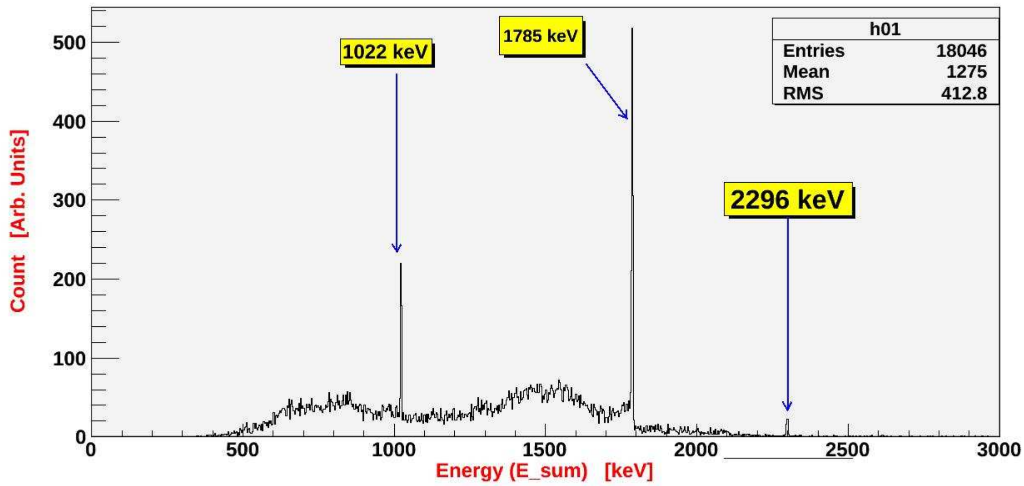

Figure 9: Sum of the energy deposited in the three detectors

CONCLUSION

The results of the simulation of the triple-photon decay in the electron-positron pair annihilation which obtained by using IPython program are in adequate agreement with the actual experimental results which performed in the Physics Laboratory of Department of Physics, University ofStellenbosch [22]. Interestingly, the simulation interpreter has very precisely illustrated all aspects of the triple-photon decay in a very high precession and was able to avoid the researcher burden of a conducting the experiments by using the sensitive reactions at standard laboratory conditions. The result of this simulation strongly suggest that the simulation is very robust to study the electron-positron pair annihilation and it also can yield more accurate results that are comparable with a similar experiment run at the lab.

Appendix

```
"""

This program simulates triple-photon decay in positron-electron pair annihilation.

"""

import sys import doctest import math import random

from pylab import *

y=[]

y1=[]

y2=[]

y3=[]

y0=[]

n=10000 import random

for i in range(n):

g=1022

a=random.randint(1,100)

b=random.randint(1,40) d1=random.choice([g/3,1274,g/2,1274-a,g/2-b,a,b]) d2=random.choice([g/3,1274,g/2,1274-a,g/2-b,a,b]) d3=random.choice([g/3,1274,g/2,1274-a,g/2-b,a,b])

########################################

if d1==g/2: d2=a d3=1274-a

elif d1==g/2: d2=1274-a d3=a

########################################

if d1==g/2-b: d2=b

d3=1274

elif d1==g/2-b: d2=1274

d3=b
```

```
#########################################
if d1==a: d2=g/2 d3=1274-a
elif d1==a: d2=1274-a d3=g/2
#########################################
if d1==b: d2=1274 d3=g/2-b elif d1==b: d2=g/2-b d3=1274
########################################
if d1==1274: d2=b d3=g/2-d2
elif d1==1274: d2=g/2-b
d3=b
########################################
if d1==1274-g/2: d2=a
d3=g/2
elif d1==1274-g/2: d2=g/2 d3=a
########################################
if d1==g/3: # 340.66666 d2=d1
d3=d1
POS=d1+d2+d3
y.append(POS)
y1.append(d1)
y2.append(d2)
y3.append(d3)
hist(y1,bins=190) xlabel('E _sum (keV)') ylabel('counts arb. units') show()
```

Acknowledgments
I would like to express my special gratitude and thanks to Mr. M. E. A. Elbasher for the thoughtful discussions and for his full support for this work, my thanks go also to Dr. Paul Papka who providing me with the experimental data. It is also a pleasure to thank Dr. Mohamed A. Osman for reading the draft of this paper and providing comments.

REFERENCES

[1] A. Einstein. Does the inertia of a body depend upon its energy-content? *Annalen Der Physik*, 18:639641, **1905**.
[2] A. Gordon Emslie and Einar Tandberg-Hanssen, editors. The physics of Solar Flares. Cam-bridge University Press, **2009**.
[3] A. Ore and J. L. Powell. Three-photon annihilation of an electron-positron pair. Prccedings of The Royal Society of London, 75:1696, **1949**.
[4] Levi Daniel Barnes, editor. Energy-resolved Positron-Molecule Annihilation: Vibrational Feshbach Resonances and Bound States. Chairman, **2005**.
[5] http://www.ipython.org.
[6] Hans Petter Langtangen, editor. Ython Scriptingfor Computational Science. Simula Research Laboratory and

University of Oslo, **2004**.
[7] M. Charlton and J. W. Humberston, editors. Positron Physics. Cambridge University Press, **2001**.
[8] Dieter K. Schroder, editor. Semiconductor Material And Device Characterization. John Wely and Sons, **2006**.
[9] P. A. M Dirac. Theory of electrons and proton. Prccedings of The Royal Society of London, 126:360365, **1930**.
[10] Carl D. Anderson. *Physical Review*, 43:491494, **1933**.
[11] P. M. S Blakett. *Nature*, 132:917{919, **1933**.
[12] Mohorovicic. S. Possibility of new element and their importance for astrophsics. Stronomisch Nachrichten, 253:94, **1934**.
[13] M. Deutsch. *Physical Review*, 83:455456, **1933**.
[14] Reinhard Krause-Rehberg, editor. Positron Annihilation in Semiconductors. Hartmut S. Leipner, **1999**.
[15] LEO Sartori, editor. A simpli ed Approoach to Einstein Theories. University of Califoria Press, **1996**.
[16] Wolfenstein and D.G.ravenhall. *Stronomisch Nachrichten*, 88:279282, **1954**.
[17] Y. C. Jean et al, editor. *World Scientic*, **2003**.
[18] Glenn F. Knoll, editor. Radiation Detection and Measurements. John Wely and Sons, **1992**.
[19] http://www.ortec-online.com.
[20] http://www.xia.com.
[21] http://root.cern/ch.
[22] M. E. A. Elbasher et al. Obsevation of triple-photon decay in positron-electron pair annihi-lation: a triple coincidence setup for undergraduate laboratory. arXiv, **2011**.