“Construction and Simulation of an Ion Detector involving the DeltaE-E Technique using Geant4 Simulation Software ”

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In partial fulfillment of the requirements for the award of the degree of
B.Tech + M.Tech
By

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under the guidance of
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June 10, 2017

CERTIFICATE

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Whomsoever it May Concern,

This is to certify that Ms Nilormi Das, student of Integrated M.Tech (B.Tech + M.Tech) in Nuclear Science & Technology, 2012-2017 Batch from Amity university, Uttar Pradesh(UP) has completed internship project titled **"Construction and Simulation of an Ion Detector involving the ΔE - E Telescope using Geant4 Simulation Software"** at IUAC during the period January – June 2017 under my supervision.

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On the basis of declaration submitted by student Nilormi Das of B.Tech + M.tech Semester X hereby certify that the project titled "**Construction and Simulation of an Ion Detector involving the DeltaE-E Technique using Geant4 Simulation Software**" submitted to **Amity Institute of Nuclear Science and Technology**, Amity University, Uttar Pradesh, Noida, in partial fulfillment of the requirement for the award of the degree of (B.Tech + M.tech) in 2017, is an original contribution with existing knowledge and faithful record work carried out by him under my guidance and supervision. To the best of my knowledge this work has not been submitted in part or full for any degree or diploma to this university or elsewhere.

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Dr. Subhankar Paul
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DECLARATION BY THE STUDENT

I **Nilormi Das** student of B.Tech + M.Tech (Sem X) hereby declare that the project titled **"Construction and Simulation of an Ion Detector involving the DeltaE-E Technique using Geant4 Simulation Software."** which is submitted by me/us to Department of **Amity Institute of Nuclear Science and Technology**, Amity University, Uttar Pradesh, Noida, in partial fulfillment of requirement for the award of the degree of B.Tech + M.Tech has not been previously formed the basis for the award of any degree, diploma or other similar title or recognition.

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ABSTRACT

This project deals with the simulation of particle identification(PID)detector to distinguish between different ions emerging out from the same source. The technique used for identifying the ions is Delta E-E technique. The detector has been simulated using GEANT4 simulation software which has been described and discussed in this paper elaborately. The response of Si-Si and Gas-Si telescopes to heavy ions (C, N, O) produced as a result of nuclear interactions has been studied. The results obtained from GEANT4 has been compared with that of the results obtained from SRIM-TRIM simulation software.

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1. INTRODUCTION

In the world of Physics the most hottest topic of interest is the search of primary constituent of Matter. Since the days we had known about "Matter" we are in search of its origin which implies in understanding elementary particles which forms the building blocks of matter. Thus identification of particles becomes important. A variety of experimental techniques are used to identify these elementary particles. According to the principle of particle detection the particle must go some sort of interaction with the material of the detector. Interaction processes vary from particle to particle. The type of interaction depends on various factors of particles such as mass, charge, velocity, energy, momentum. The particles are boosted u to high energies before they are being injected to detector for collision with the detector material. Particle interaction results out in transfer of partial or full energy of incident radiation to the electrons or nuclei of the constituent atom or to charged particle products of nuclear interaction. Based on different types of particles and their various modes of interaction, different types of detectors have been designed. The detector mentioned in this paper is an ion detector.

2.1 Particles

In the field of high energy physics "**particles**" are referred to as the Elementary Particles or Fundamental Particles which form the building blocks of subatomic particles. For example, a neutron(subatomic particle) is composed of one Up and two Down Quarks (elementary particles) whereas an atom of Helium consists of two protons and two neutrons.

Elementary Particles have been classified on the basis of :

<u>(i)Mass</u>

Hadrons are the heaviest particles. This group is then split up into **baryons** and **mesons**. Baryons are the heaviest particles of all, followed by mesons. **Leptons** are the lightest particles.

<u>(ii) Their mode of interaction:</u>

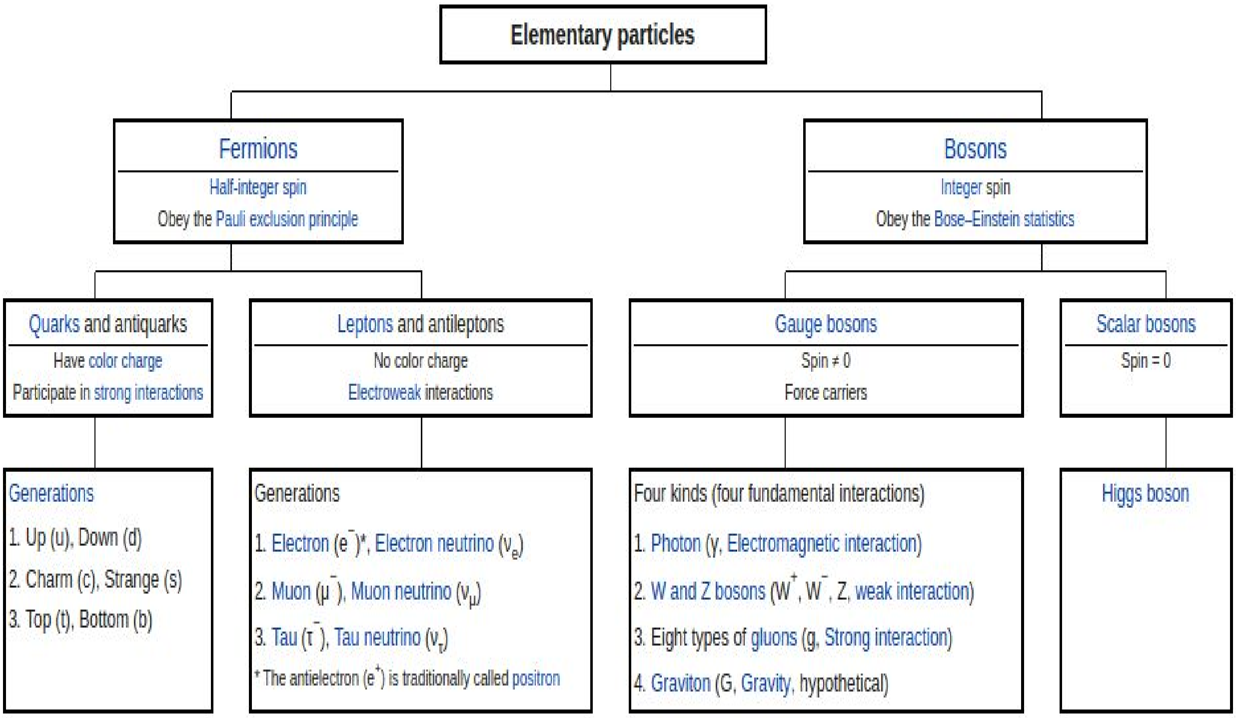
(a)Leptons- subatomic particle which do not participate in strong interaction

(b)Hadrons- subatomic particle which participate in strong interaction

<u>(iii) Spin:</u>

(a)Boson-subatomic particle with zero or integral spin(follows Bose-Einstein statistics)

(b)Fermions- subatomic particle with half-integral spin(follows Fermi-Dirac statistics)



<u>Fig 2.1: Flowchart showing Classification of elementary particles on the basis of spin, exchange force and interaction processes.</u>

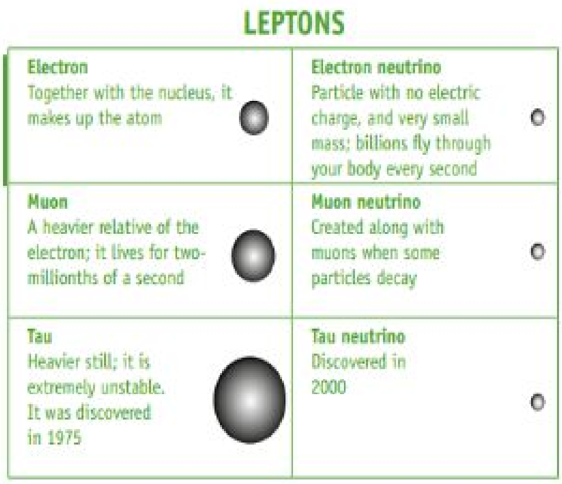


Fig 2.2 (a) Classification of Leptons

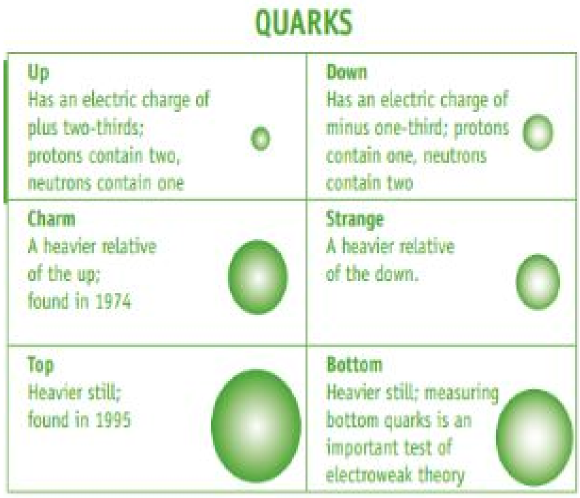


Fig 2.2 (b) Classification of Quarks

The four fundamental interactions or forces that govern the behavior of elementary particles are listed below:

- The gravitational force -The gravitational force is the weakest force among all the four forces (It causes interaction between states with energy). It is the only interaction that acts on all particles having mass, energy and/or momentum.This force has an infinite range, like electromagnetism but unlike strong and weak interaction. This force is attractive by nature, thus always attracts and never repels. It cannot be absorbed, transformed, or shielded against.
- The weak force - The weak force underlies natural radioactivity, for example in the Earth beneath our feet. It is also essential for the nuclear reactions in the centres of stars like the Sun, where hydrogen is converted into helium. It causes beta decay.
- The strong force - The strong force binds quarks together to make protons and neutrons (and other particles). It also binds protons and neutrons in nuclei, where it overcomes the enormous electrical repulsion between protons. Particles that interact via the strong force are also called ‘hadrons’.
- The electromagnetic force - It holds electrons to nuclei in atoms, binds atoms into molecules, and is responsible for the properties of solids, liquids and gases. (It causes interactions between charges).

Table 2.1 : Details of fundamental forces corresponding to the theory they obey, exchange particles, relative strength, variation in attractive property with distance and range

Interaction	Current theory	Mediators	Relative strength[4]	Long-distance behavior	Range (m)[citation needed]
Strong	Quantum chromodynamics (QCD)	gluons	10^{38}	1 (see discussion below)	10^{-15}
Electromagnetic	Quantum electrodynamics (QED)	photons	10^{36}	$\frac{1}{r^2}$	∞
Weak	Electroweak Theory (EWT)	W and Z bosons	10^{25}	$\frac{1}{r}\, e^{-m_{W,Z}\, r}$	10^{-18}
Gravitation	General relativity (GR)	gravitons (hypothetical)	1	$\frac{1}{r^2}$	∞

Table 2.2: The Properties of Four Fundamental Forces of Nature

Property/Interaction	Gravitation	Weak	Electromagnetic	Strong	
		(Electroweak)		Fundamental	Residual
Acts on:	Mass - Energy	Flavor	Electric charge	Color charge	Atomic nuclei
Particles experiencing:	All	Quarks, leptons	Electrically charged	Quarks, Gluons	Hadrons
Particles mediating:	Not yet observed (Graviton hypothesised)	W^+, W^- and Z^0	γ (photon)	Gluons	π, ρ and ω mesons
Strength at the scale of quarks:	10^{-41}	10^{-4}	1	60	Not applicable to quarks
Strength at the scale of protons/neutrons:	10^{-36}	10^{-7}	1	Not applicable to hadrons	20

2.2 Interaction of Particles with matter

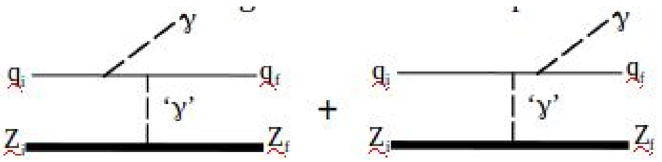
- **Charged Particles**

Charged particles continuously interact with electrons and protons of the absorber material primarily via the long-range Coulomb force. Modes of energy loss mechanism that charged particles undergo are:

(i) Ionisation- In this phenomenon charged particles can knock out outermost electrons from atoms of the medium while passing through matter. In this process, energy of a particle is lost due to ionisation. This process is seen in both heavy particles (like heavy ions), electrons and positrons

(ii)Bremsstrahlung : In this particle like electron and positron loses its energy due to photon emission. Classically, a charged particle radiates energy when it is accelerated: $dE/dt=(2/3)(e^2/c^3)a^2$

In QED we have to consider two diagrams where a real photon is radiated:



The cross section for a particle with mass mi to radiate a photon of E in a medium with Z electrons is:

$$\frac{d\sigma}{dE} \propto \frac{Z^2}{m_i^2}\frac{\ln E}{E}$$

m-2 behavior expected since classically radiation a2=(F/m)2 .

(iii) Multiple Scattering (Coulomb scattering): A charged particle traversing a medium is deflected by many small angle scatterings. These scattering are due to the coulomb field of atoms and are assumed to be elastic. In each scattering the energy of the particle is constant but the particle direction changes. In the simplest model of multiple scattering we ignore large angle scatters. In this approximation, the distribution of scattering angle plane after traveling a distance x through a material with radiation length = Lr is approximately gaussian:

$$\frac{dP(\theta_{plane})}{d\theta_{plane}} = \frac{1}{\theta_0\sqrt{2\pi}}\exp[-\frac{\theta_{plane}^2}{2\theta_0^2}]$$

$$\theta_0 = \frac{13.6\mathbf{MeV}}{\beta pc} z\sqrt{x/L_r}(1+0.038\ln\{x/L_r\})$$

- **Photon**

Photon being electromagnetic has zero mass, no charge or zero charge and a velocity equivalent to light. Unlike charged particles, photons do not undergo coulombic interaction with atomic electrons. They are far more penetrating in nature than charged particles. The three energy loss mechanisms that photons undergo are:

(i) Photoelectric Effect- In this process a photon undergoes interaction with an atom of the metal surface resulting into emission of an electron (photoelectron) by the atom of the material's(metal surface) most tightly bound shell or K-shell.

Energy of this photoelectron is given by:

$$\mathbf{E_{e-} = hv - E_b}$$

E_b = binding energy of the photoelectron in K-shell

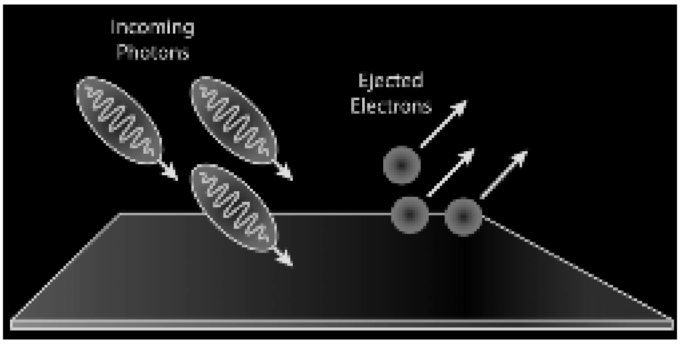


Fig 2.3 : The Photoelectric Effect

This process predominantly takes place when the photons are of relatively low energy(just greater than the binding energy of the electron with which it interacts) and the absorber material is made up of high atomic number (Z) element. This process has nothing to do with electrons, it is as a whole an atomic interaction process. It is one of the three processes through which gamma rays interact. This phenomenon ultimately leads to electromagnetic radiation. This process produces a scattered photon and an electron. The probability of photoelectric absorption varies as ~ Z^4 / E^3.

<u>(ii) Compton Effect</u>- Compton scattering takes place between the incident gamma-ray photon and an electron in the absorbing material.In this phenomenon, the incoming gamma-ray photon is deflected through an angle θ with respect to its original direction. The photon transfers a portion of its energy to the electron (assumed to be initially at rest), which is then known as a recoil electron, or a Compton electron. The Compton Scattering probability decreases with increase in photon energy and directly proportional to the number of electrons per gram, which only varies by 20% from the lightest to the heaviest elements (except for hydrogen). The scattering probability is almost independent of atomic number.

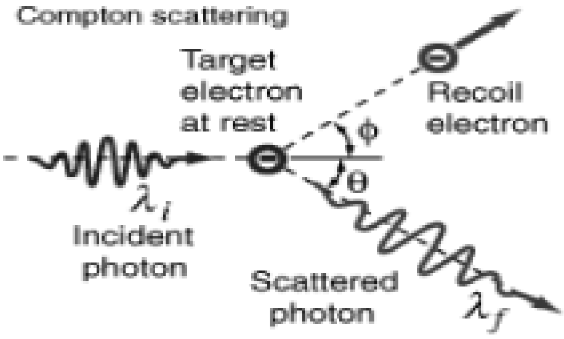


Fig 2.4: Compton Scattering

<u>(iii) Pair Production</u> - The term pair production refers to production of a pair of an elementary particle and its antiparticle. Thi phenomenon takes place when a photon of energy more than 1.022MeV interacts with a heavy nucleus to form electron-positron pair.

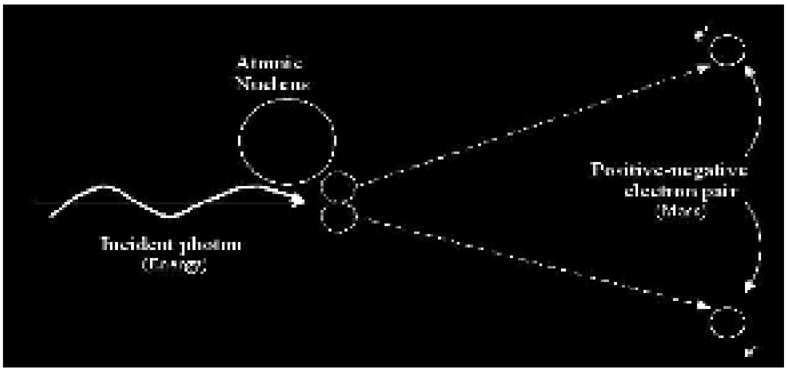


Fig 2.5: Pair-Production Process showing energy-mass conversion

Pair production probability increases with increase in photon energy and with atomic number approximately as Z^2.

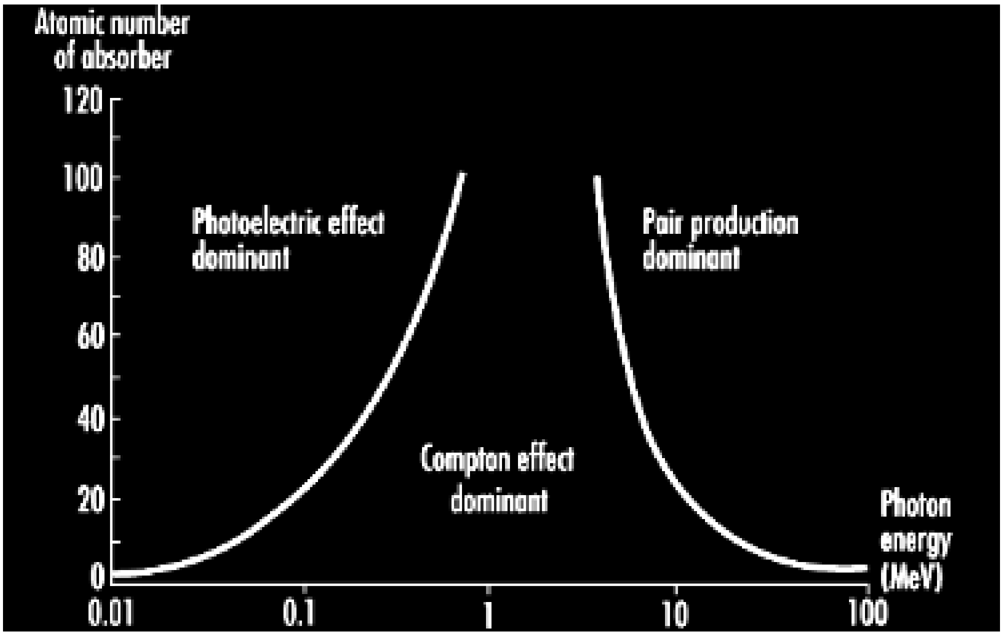


Fig 2.6 : Relative importance of the three principal interactions of photons in matter

- **Neutron**

The most common neutron interactions with matter are inelastic collisions, neutron capture (or activation) and fission. All of these are interactions with nuclei. A nucleus colliding inelastically with a neutron is left at a higher energy level. It can release this energy in the form of a gamma ray or by emitting a beta particle, or both. In neutron capture, an affected nucleus may absorb the neutron and eject energy as gamma or x rays or beta particles, or both. The secondary particles then cause ionization as discussed above. In fission, a heavy nucleus absorbs the neutron and splits into two lighter nuclei that are almost always radioactive.

2.3 Particle Detector

Particle detector is also known as a radiation detector which is used to detect, track, and/or identify ionizing particles, such as those produced by nuclear decay, cosmic radiation, or reactions due to interaction of the particles while travelling through the volume of the particle detector with the detector material. The main objectives of radiation detectors are to measure energy deposited by the particles while it passes through the detector volume and other attributes such as momentum, spin, charge of the particles which traverses through the detector due to interaction with the detector material. Detectors are operated either in current mode or pulse mode. In pulse mode the detector records the interaction of each individual quantum of radiation i.e. information on the energy of each radiation is obtained. In the current mode, the detector measures the average current produced in the interaction of radiation.

2.3.1 General Properties of a Detector

(i) Sensitivity- sensitivity of a detector implies the capability of a detector to generate usable signals corresponding to certain kind of radiation and amount of energy which is dependent on cross-section of the ionizing reaction, detector mass, inherent noise, etc.
(ii)Response- The ionization produced inside a detector is proportional to the loss of energy of radiation in the sensitive volume. The radiation energy and the total charge or pulse height of the output signal define the response of the detector.
(iii)Resolution
(iv)Efficiency- Efficiency of detector is defined as the ratio of the number of events registered by the detector to the number of events produced by the source. It is denoted by Ɛ. Efficiency depends on the detector geometry and on the probability of interaction in the detector. It also depends on the interaction cross section of the incident radiation on the detector medium. Thus, it depends on the type of radiation, its energy and the detector material.
(v)Dead Time- The minimum time difference between the two successive events in a counting system or detector is termed as dead time. During this time interval, the detector is insensitive and no event is recorded during this time interval.The minimum possible dead time is a desirable characteristic for a good detector.

2.3.2 Objectives of a particle detector

(i) To localize the particle trajectory in space-.
(ii) To measure the particle energy.

(iii) To localize the particle in time
(iv) To identify the particle

2.4 Detectors used for Particle Detection

Detectors can be classified based on the detector material used and/or type of measurement that can be made. e.g., gas filled detectors in which ionisation produced is measured. Some materials absorb energetic radiations and produce scintillation that can be measured.

2.4.1 Gas Filled Detectors

Most widely used radiation detectors are based on measuring the effects produced when ionising radiation passes through a gas filled chamber. While passing through the gas, radiation produces ionisation or excitations along its path.
A typical gas filled detector consists of a metallic enclosure that is either sealed or fabricated in such a way to permit a continuous flow of the fill gas. The outer wall serves as a cathode where as a thin wire, a plate or a rod, that is centrally placed and insulated from the cathode, serves as an anode.

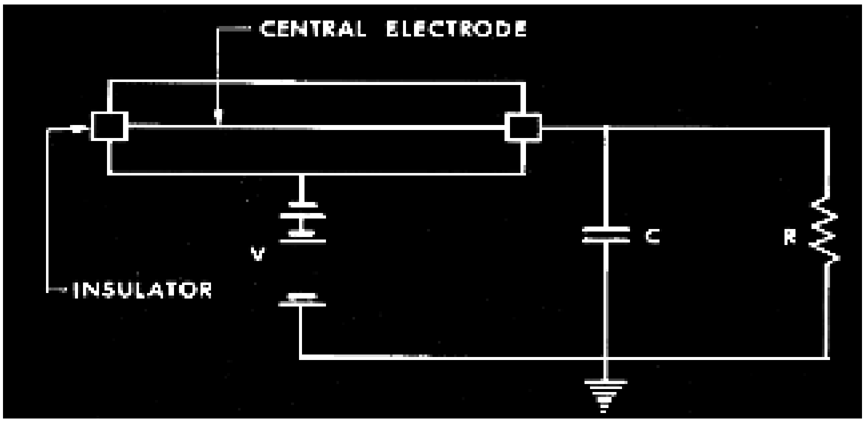


Fig 2.7 : Diagram of a gas filled detector for Pulse operation, V: applied voltage, C: capacitor and R: resistance

The positive ions and electrons that are produced may recombine. But if an electric field is applied, positive ions start migrating to the cathode and electrons towards anode. If the field strength (applied voltage per unit length), is high enough to prevent recombination during migration, then all the charge reaches the respective electrodes. Measurement of this charge gives an indication of the presence of ionising radiations. Quantitative information can easily be obtained from the measured charge which is related to the strength of the ionising radiation.

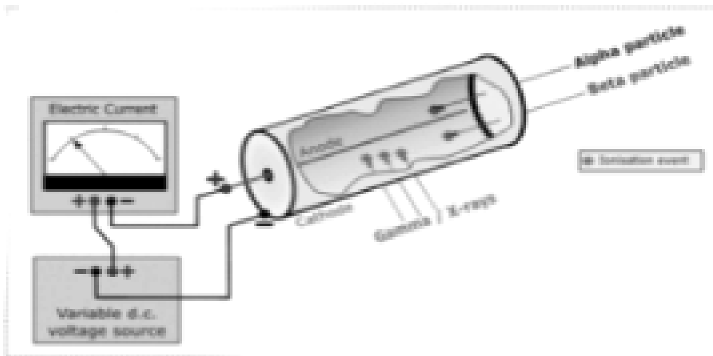


Fig 2.8 : Experimental Setup of a Cylindrical chamber. The cylindrical chamber of a gas-filled detector with end window subjected to ionising radiation. Low penetrating radiation enters via an end window but high penetrating radiation can also enter via the cylinder side wall.

2.4.1.1 Different regions of operation of gas-filled detectors

The diagram shows the relationship of the gaseous detection regions using an experimental concept of applying a varying voltage to a cylindrical chamber which is subjected to ionisation radiation. Alpha and Beta particles are plotted to demonstrate the effect of the different ionizing energies but the same principle extends to all forms of ionizing radiation. The ion chambers and and proportional regions can operate at atmospheric pressure and their output varies with radiation energy. However in practice Geiger region is operated at a reduced pressure (1/10th of an atmosphere) to allow operation at much lower voltages;

otherwise impractically high voltages would be required. The Geiger region output does not differentiate between radiation energies.

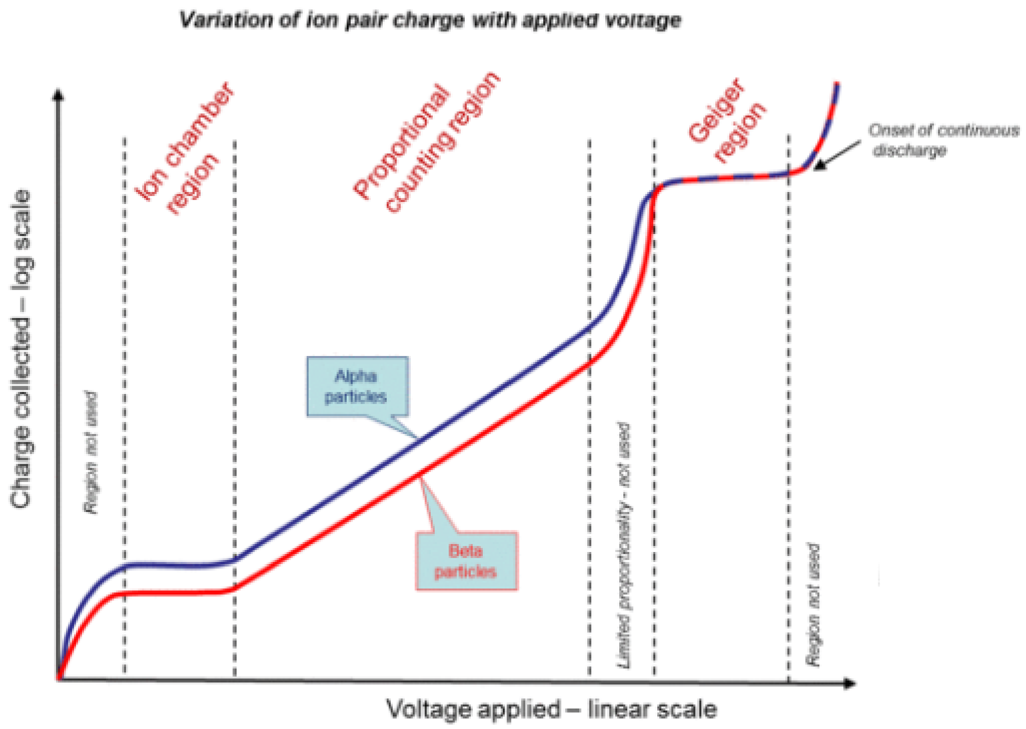


Fig 2.9 : Plot of variation of ion pair current against applied voltage for a wire cylinder gaseous radiation detector

The three types of detectors that work on the basis of measurement of ionisation produced in a gas are: Ion chambers, proportional counters and Geiger Müller (GM) counters. These detectors differ mainly in the strength of the electric field applied. Ion-pair formation, multiplication and discharge processes that take place in a gas filled detector under the influence of applied electric field are described below.

(i) Ion Chambers

Ion chambers are the simplest of all the gas filled detectors. All the charge produced by interaction of radiation with the fill gas in the detector volume is collected through the application of electric field . Ion chambers can be operated both in pulse and current modes. Argon, He, H_2 N_2, air and CH_4 (methane) are a few fill gases that are used in ion chambers. Energy required for producing an effective ion pair, on an average, is about 30-35 eV although ionization potentials range between 10-20 eV.

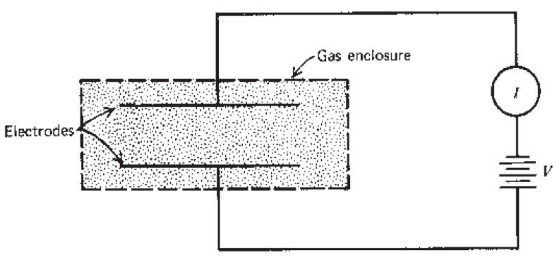


Fig 2.10: Illustration of the basic elements of a rudimentary ion chamber

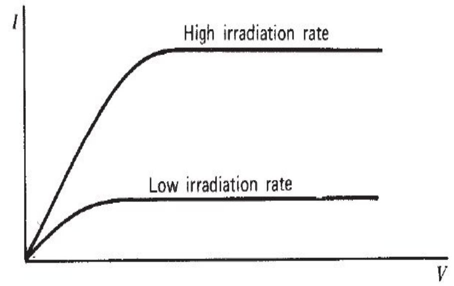


Fig 2.11 : Current -Voltage characteristion obtained from Ionisation Chamber Detector corresponding to high and low irradiation rate

Some of the applications of ion chambers are:

- Calibration of radioactive sources,.
- Radioactivity dose monitors.
- Radiation survey instruments and measurement of radioactive gases.
- Ionisation chambers are also useful in charged particle spectroscopy, e.g., measurement of α-particles and fission fragments.
- Due to significant differences in their mass and energy, pulse heights for α-particles and fission fragments are different.
- Individual pulses corresponding to α particle and fission fragments are measured, taking care that dimensions of the detector are larger than the ranges of these charged particles.
- These detectors are used to measure low α active samples in presence of large amount of β radiation and low fission rates in presence of large α fluxes taking advantages of pulse height discrimination.

(ii) Proportional Counters

Proportional gas ionization detectors (proportional counters) operate at a higher voltage gradient than ion chambers (Region III, Fig.) and are always operated in pulse mode. They rely on the gas multiplication to amplify the charge created by interaction of radiation with the fill gas.

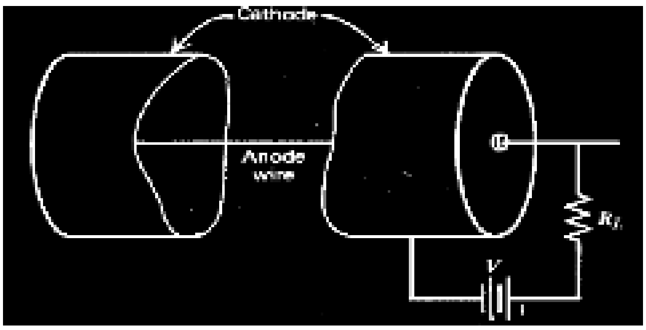


Fig 2.12 : Basic elements of a proportional counter. The outer cathode must also provide a vacuum-tight enclosure for the fill gas. The output pulse is developed across the load resistance R_L

(iii) Geiger-Muller Counter/Detector

This detector is detecting and measuring all three kinds of radiation (alpha, beta and gamma) using the ionization effect produced in the Geiger Tube. The geometry of this detector consists of a Geiger

Muller(GM) Tube which is filled with inert gases such as Neon, Argon and Helium at a low pressure at which high voltage is applied. The two walls of the GM Tube acts as electrodes. There is a central electrode inside the **GM tube**. A voltage supply is connected across the casing of the **tube** and the central electrode. The fill gas inside the GM Tube becomes conductive of electricity due to impact of high energy particles. When particles from a ionizing radiation is allowed to pass through the GM Detector, the particles penetrate the GM tube and collide with the inert fill gas resulting in release of more electrons. It has larger dead-time as compared to the ones discussed above and and low counting rates too.

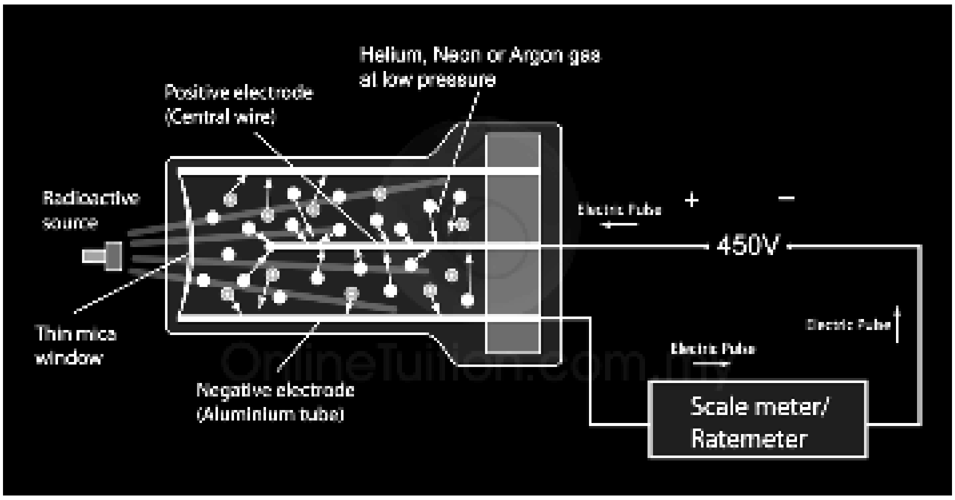


Fig 2.13: Schematic of Geiger-Muller Detector

Another class of gas filled detectors like BF_3, ^3He and ^4He are exclusively used for neutron detection.

2.4.2 Solid-State Detector

Solid-state detectors are also called semi-conductor detectors. This is a class of radiation detectors in which the detection medium constitutes semiconductor materials like silicon and germanium. This type of detector measure ionising radiation by number of electron-hole produced in the semiconductor set between two electrodes.

2.4.3 Scintillation Detector

The detection of ionizing radiation by the scintillation light produced in certain materials is one of the oldest techniques on record. It is desirable that the scintillation material should convert the kinetic energy of charged particles into detectable light with a high scintillation efficiency and this conversion plot is desired to be linear. Scintillation materials which are commonly used are broadly categorized as organic and inorganic. Organic scintillators use organic-based liquids and plastics (such as anthracene) whereas inorganic scintillators use alkali halide crystals such a NaI(Tl)[Sodium Iodide Thallium activated]. Inorganic scintillators gives out the yield high light output and linearity but they respond slowly whereas response time of organic scintillators is faster but yield less light output. Organic scintillators are a favourable choice for beta spectroscopy and fast neutron detection(because of their hydrogen content) whereas inorganic scintillators are favourably used for gamma spectroscopy. The fluorescence process in organics arises due to transitions in the energy level structure of a single molecule.

3. Objective

The target is to simulate the expected spectra obtained from delta E-E telescope which identify particle fragments.
The apparatus is somewhat like :
(i) A beam of any element such as Carbon is made to fall on a relatively thin film of Silicon to mainly measure the energy.
(ii) The beam coming out from the silicon film is made to pass through a much relatively thick film as compared to that of the silicon, where the beam is expected to deposit most of its energy.

3.1 Delta(Δ) E - E Telescope Particle Identification Detector

One of the most crucial and important aspect of high energy physics is particle identification. As different particles interact via different interaction processes, the method of detection also varies with type of particles, thus the type of detectors vary too. In this project, an Ion Detector has been simulated using the Delta E - E technique. The ΔE - E technique is based on the measurement of the energies deposited in two detectors. In this project, the ΔE- E detector has the first layer is usually much thinner as compared to that of the second layer. The materials for both the layers may be same or different. In a Si-Si Delta E- E detector both the layers are of same material i.e. of Silicon whereas in case of Gas-Si detector, first layer is made of gas and the second layer is made of Silicon.

4.1 Simulation Software Used(GEANT4)

The simulation software that has been used to simulate the DeltaE-E Particle Identification Detector is GEANT4 version 10.4.3. The series of simulation software designed to describe the passage of elementary particles through matter, using Monte Carlo methods is named as GEANT by CERN, the developer of this simulation software. GEANT stands for Geometry and Tracking. It has been developed to simulate high energy physics experiments. **Geant4** stands for GEometry ANd Tracking. It is a platform for "the simulation of the passage of particles through matter," using Monte Carlo methods. GEANT4 is the successor of the GEANT series of software toolkits developed by CERN, and the first to use object oriented programming (in C++). Its development, maintenance and user support are taken care by the international Geant4 Collaboration. Application areas include high energy physics and nuclear experiments, medical, accelerator and space physics studies.[2] The software is used by a number of research projects around the world. The Geant4 is an open source software which is freely available from the project web site; until version 10.3

(released 9th December 2016 (patch-01, released 24 February 2017), no specific software license for its use existed; Geant4 is now provided under the Geant4 Software License.

The various facilities included in GEANT4 are :

- **Geometry Handling** - It includes the physical layout of the experiment such as geometry of detector calorimeter, absorbers, etc. It also mentions how the particle trajectory will be affected due to the dimension of the layout in the experiment.
- **Tracking**- It simulates the path of the particle while traversing through matter considering all the possible kind of interactions and decay processes.
- **Response of Detector**- It keeps a track record of how a detector would respond when a particle travels through the detector.
- **Run Management**- It records the details of each run (a set of events), as well as set up the experiment in different configurations between runs.
- **Visualization**- Geant4 offers a number of options for visualization, including OpenGL(very responsive photorealistic graphics), Qt(the User Interface and all Visualization windows in the same window,GUI control, very responsive photorealistic graphics plus more interactivity), OpenInventor(very responsive photorealistic graphics plus more interactivity), HepRep(GUI control, want to be able to pick on items to inquire about them), DAWN(to render highest quality photorealistic images for use in a poster or a technical design report, and one can live without quick rotate and zoom), VRML(to render to a 3D format that others can view in a variety of commodity browsers (including some web browser plug-ins), RayTracer(to visualize a geometry that the other visualization drivers can't handle, or you need transparency or mirrors, and you don't need to visualize trajectories), gMocren(to visualization volume data, such as radiation therapy dose distribution), ASCIITree(to quickly check the geometry hierarchy, or if you want to calculate the volume or mass of any geometry hierarchy),Wt(to interact with your application with a Web BroswserUser Interface, *WARNING:* this driver is experimental and should be used with caution). One can also add one's own visualization driver. Geant4's visualization system is modular. By creating just three new classes, one can direct Geant4 information to one's own visualization system.
- **User Interface**- familiar user interface based on Tcsh.

Geant4 can also perform basic histogramming; it requires external analysis tools or software that implements the AIDA framework for exploiting advanced histogramming features.

Some HEP experiments that have used GEANT4 are:

- BaBar and GLAST at SLAC
- ATLAS, CMS and LHCb at LHC, CERN
- Borexino at Gran Sasso Laboratory
- DUNE and MINOS at Fermilab
- Enriched Xenon Observatory (EXO)
- T2K
- CUORE
- Dark Matter Detectors: LUX, XENON

4.1.1 C++ files used to simulate Delta E- E Telescope

PID.cc

The contents of main() will vary according to the needs of a given simulation application and therefore must be supplied by the user. The main() method is implemented by two toolkit classes, G4RunManager and G4UImanager, and three classes, ExG4DetectorConstruction01, ExG4PhysicsList00 and ExG4ActionInitialization01, which are derived from toolkit classes. The first thing main() must do is create an instance of the G4RunManager class. This is the only manager
class in the Geant4 kernel which should be explicitly constructed in the user's main(). It controls the flow of the program and manages the event loop(s) within a run. If the user wants to make the simulation code multi-threaded, G4MTRunManager should be instantiated instead of G4RunManager.
When G4RunManager is created, the other major manager classes are also created. They are deleted automatically when G4RunManager is deleted. The run manager is also responsible for managing initialization procedures, including methods in the user initialization classes. Through these the run manager must be given all the information necessary to build and run the simulation, including:

- how the detector should be constructed,
- all the particles and all the physics processes to be simulated,
- how the primary p
- article(s) in an event should be produced, and
- any additional requirements of the simulation.any additional requirements of the simulation

PrimaryGeneratorAction.cc

This is one of the mandatory classes. In this concrete class, how a primary event should be generated needs to be specified. Actual generation of primary particles will be done by concrete classes of G4VPrimaryGenerator. This concrete class just arranges the way primary particles are generated. In the constructor of G4VPrimaryGeneratorAction, the primary generator(s) should be instantiated. If necessary, some initial conditions needs to be set for the generator(s). More than one generator can be invoked and/or one generator can be invoked more than once. Mixing up several generators can produce a more complicated primary event.Geant4 provides three G4VPrimaryGenerator concrete classes: G4ParticleGun, G4GeneralParticleSource and G4HEPEvtInterface. G4ParticleGun is a generator provided by Geant4. This class generates primary particle(s) with a given momentum and position. It does not provide any sort of randomizing. The constructor of G4ParticleGun takes an integer which causes the generation of one or more primaries of exactly same kinematics. It is a rather frequent user requirement to generate a primary with randomized energy, momentum, and/or position. Such randomization can be achieved by invoking various set methods provided by G4ParticleGun. The invocation of these methods should be implemented in the generatePrimaries() method of one’s concrete G4VPrimaryGeneratorAction class before invoking generatePrimaryVertex() of G4ParticleGun.

DetectorConstruction.cc

It describes the entire detector setup, including:- its geometry, the materials used in its construction, a definition of its sensitive regions and the readout schemes of the sensitive regions.

Particles.cc

Geant4 provides various types of particles for use in simulations: ordinary particles, such as electrons, protons, and gammas resonant particles with very short lifetimes, such as vector mesons and delta baryons nuclei, such as deuteron, alpha, and heavy ions (including hyper-nuclei) quarks, di-quarks, and gluon. Each particle is represented by its own class, which is derived from G4ParticleDefinition.

PhysicsList.cc

It defines:

- the particles to be used in the simulation,
- all the physics processes to be simulated.

ActionInitialization.cc

It defines:

- so-called user action classes (see next section) that are invoked during the simulation,
- which includes one mandatory user action to define the primary particles.\

RunAction.cc

This method is invoked at the beginning of BeamOn or before entering the event loop. A typical use of this method would be to initialize and/ or book histograms for a particular run. This method is invoked after the calculation of the physics tables.

EventAction.cc
This method is invoked before converting the primary particles to G4Track objects. A typical use of this method would be to initialize and/or book histograms for a particular event.

SteppingAction.cc
This is used to visualize tracking steps at each step with various visualization attributes, e.g., color, at each step, automatically.

4.2 Types of detector simulated

4.2.1 Si-Si Delta E - E Detector

In this detector, both the layers of the detector are made of Silicon(Si)and are cuboid in shape. The first layer of Si is of 30 micron depth and the second layer is of 3mm depth.

4.2.2 Gas-Si Δ E - E Detector

This detector is also composed of two layers like Si-Si detector but the first layer of this detector is made of gas unlike Si-Si detector and the second layer is of Si. The gaseous layer is a mixture of Argon(97%) and Methane (CH4, 2.9%). The compound gasous mixture Ar_7CH_4 has a density of 1.709mg/cc. All the C++ files used for this program are same as that of Si-Si Delta E - E detector except the Detector Construction file.

5 OBSERVATIONS & RESULTS

The following section includes the results obtained from GEANT4 simulation software for Gas-Si and SI-Si ΔE- E PID Detector. Three beams of Carbon(^{12}C) , Nitrogen(^{14}N) and Oxygen(^{16}O) which is made to accelerate through the detector have energies in the MeV range.

5.1 Observations for Si-Si ΔE-E PID Detector

The table below mentions the results of deposition Carbon(^{12}C) ions of 60 MeV energy for 100 events in the first and second layer of Si-Si detector respectively.

Table 5.1: Data for ^{12}C beam deposition after passing through Si-Si detector

Ion Number	Δ E	E
1	7.01	53
2	7.27	52.7
3	7.36	52.6
4	7.34	52.7

5	7.28	52.7
6	7.22	52.8
7	7.21	52.8
8	7.32	52.7
9	7.18	52.8
10	7.16	52.8
11	6.99	53
12	7.33	52.7
13	7.13	52.9
14	6.99	53
15	7.05	52.9
16	7.1	52.9
17	7.1	52.9
18	7.2	52.8
19	7.26	52.7
20	7.29	52.7
21	7.15	15.2
22	7.29	52.7
23	7.23	52.8
24	7.04	53
25	7.33	52.7
26	7.25	52.7
27	7.09	52.9
28	7.93	52.6
29	7.32	52.7
30	7.05	53
31	7.28	52.7
32	719	52.8
33	7.29	52.7
34	7.23	52.8
35	7.13	52.9
36	7.04	53

37	7.28	52.7
38	7.38	52.6
39	7.1	52.9
40	7.1	52.9
41	7.38	52.6
42	7.1	52.9
43	6.95	53
44	7.34	52.7
45	7.16	52.8
46	7.36	52.6
47	7.19	52.8
48	7.1	52.9
49	7.12	52.9
50	7.21	52.8
51	7.14	52.9
52	6.91	53.1
53	7.06	52.9
54	7.26	52.7
55	7.15	52.9
56	7.22	52.8
57	7.18	52.8
58	7.05	53
59	7.19	52.8
60	7.15	52.9
61	7.31	52.7
62	7.07	52.9
63	7.35	52.7
64	7.21	52.8
65	7.07	52.9
66	7.31	52.7
67	7.35	52.7
68	7.28	52.7

69	7.27	52.7
70	7.18	52.8
71	7.28	52.7
72	7.18	52.8
73	7.25	52.8
74	7.43	52.6
75	7.26	52.7
76	6.95	53
77	7.11	52.9
78	7.25	52.8
79	7.03	53
80	7.28	52.8
81	7.12	52.9
82	7.38	52.7
83	7.2	52.8
84	7.19	52.8
85	7.31	52.7
86	7.3	52.7
87	6.98	53
88	7.31	52.7
89	7.14	52.9
90	7.32	52.7
91	7.13	52.9
92	7.13	52.9
93	7.08	52.9
94	7.27	52.7
95	7.42	52.6
96	7.09	52.9
97	7.14	52.9
98	7.27	52.7
99	7.3	52.7
100	7.23	52.8

The table below mentions the results of deposition Nitrogen(^{14}N) ions of 60 MeV energy for 100 events in the first and second layer of Si-Si detector respectively.

Table 5.2: Data for ^{14}N beam deposition after passing through Si-Si detector

Ion Number	ΔE	E
1	10.5	49.5
2	10.8	49.2
3	11	49
4	10.9	49.1
5	10.9	49.1
6	10.8	49.2
7	10.8	49.2
8	10.9	49.1
9	10.7	49.3
10	10.7	49.3
11	10.5	49.5
12	10.9	49.1
13	10.7	49.3
14	10.5	49.5
15	10.6	49.4
16	10.6	49.4
17	10.6	49.4
18	10.8	49.2
19	10.8	49.2
20	10.9	49.1
21	10.7	49.3
22	10.9	49.1
23	10.8	49.2
24	10.5	49.5
25	10.8	49.2
26	10.9	49.1

27	10.8	49.2
28	10.6	49.4
29	11	49
30	10.9	49.1
31	10.6	49.4
32	10.9	49.1
33	10.7	49.3
34	10.9	49.1
35	10.8	49.2
36	10.7	49.3
37	10.6	49.4
38	10.9	49.1
39	11	49
40	10.6	49.4
41	10.6	49.4
42	11	49
43	10.6	49.4
44	10.4	49.6
45	10.9	49.1
46	10.7	49.3
47	11	49
48	10.7	49.3
49	10.6	49.4
50	10.7	49.3
51	10.8	49.2
52	10.7	49.3
53	10.4	49.6
54	10.6	49.4
55	10.8	49.2
56	10.7	49.3
57	10.8	49.2
58	10.7	49.3

59	10.6	49.4
60	10.7	49.3
61	10.7	49.3
62	10.9	49.1
63	10.6	49.4
64	10.9	49.1
65	10.8	49.2
66	10.6	49.4
67	10.9	49.1
68	10.9	49.1
69	10.9	49.1
70	10.8	49.2
71	10.7	49.3
72	10.9	49.1
73	10.7	49.3
74	10.8	49.2
75	11.1	48.9
76	10.8	49.2
77	10.4	49.6
78	10.6	49.4
79	10.8	49.2
80	10.5	49.5
81	10.9	49.1
82	10.8	49.2
83	10.6	49.4
84	11	49
85	10.9	49.1
86	10.6	49.4
87	10.9	49.1
88	10.7	49.3
89	10.9	49.1
90	10.8	49.2

91	10.7	49.3
92	10.6	49.4
93	10.9	49.1
94	11	49
95	10.6	49.4
96	10.6	49.4
97	11	49
98	10.6	49.4
99	10.4	49.4
100	10.9	49.1

The table below mentions the results of deposition Oxygen(^{16}O) ions of 60 MeV energy for 100 events in the first and second layer of Si-Si detector respectively.

Table 5.3: Data for ^{16}O beam deposition after passing through Si-Si detector

Ion Number	ΔE	E
1	14.6	45.4
2	15.1	44.9
3	15.3	44.7
4	15.3	44.7
5	15.2	44.8
6	15	45
7	15	45
8	15.2	44.8
9	14.9	45.1
10	14.9	45.1
11	14.5	45.5
12	14.3	44.7
13	14.8	45.2
14	14.6	45.4

15	14.7	45.4
16	14.7	45.3
17	14.8	45.2
18	14.8	45.2
19	15	45
20	15.1	44.9
21	15.2	44.8
22	14.9	45.1
23	15.2	44.8
24	15.1	44.9
25	14.7	45.3
26	15.3	44.7
27	15.1	44.9
28	14.8	45.2
29	15.4	44.6
30	15.2	44.8
31	14.7	45.3
32	15.2	44.8
33	15	45
34	15.2	44.8
35	15.1	44.9
36	14.8	45.2
37	14.7	45.3
38	15.2	44.8
39	15.4	44.6
40	14.8	45.2
41	15.4	44.6
42	14.8	45.2
43	14.5	45.5
44	15.3	44.7
45	14.9	45.1
46	15.3	44.7

47	15	45
48	14.8	45.2
49	14.8	45.2
50	15	45
51	14.9	45.1
52	14.4	45.6
53	14.7	45.3
54	15.1	44.9
55	14.9	45.1
56	15	45
57	14.9	45.1
58	14.7	45.3
59	15	45
60	14.9	45.1
61	15.2	44.8
62	14.7	45.3
63	15.3	44.7
64	15	45
65	14.7	45.3
66	15.2	44.8
67	15.3	44.7
68	15.1	44.9
69	15.1	44.9
70	14.9	45.1
71	15.1	44.9
72	15	45
73	15.1	44.9
74	15.5	44.5
75	15.1	44.9
76	15.5	45.5
77	14.8	45.2
78	15.1	44.9

79	14.6	45.4
80	14.9	45.1
81	14.8	45.2
82	15.3	44.7
83	15	45
84	15	45
85	15.2	44.8
86	15.2	44.8
87	14.5	45.5
88	15.2	44.8
89	14.9	45.1
90	15.2	44.8
91	14.8	45.2
92	14.8	45.2
93	14.7	45.3
94	15.1	44.9
95	15.4	44.6
96	14.7	45.3
97	14.9	45.1
98	15.1	44.9
99	15.2	44.8
100	15.1	44.9

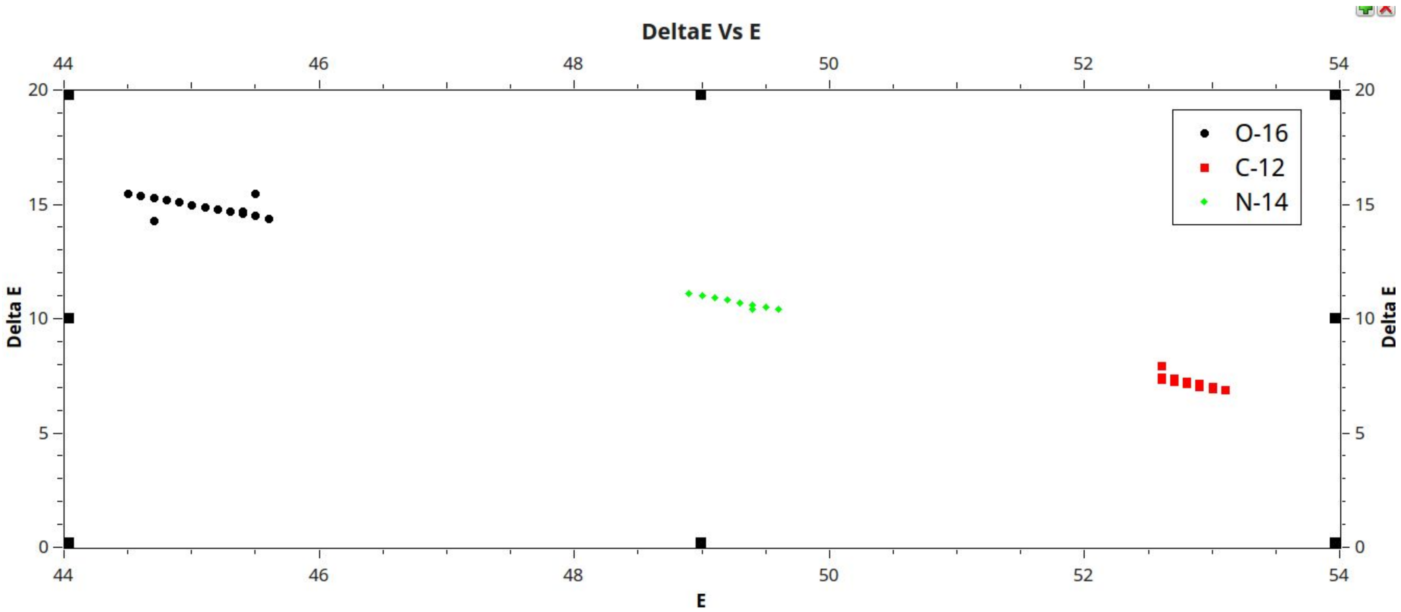


Fig 5.1: Plot of Delta E vs E for O, N , and C ions of Si-Si PID detector from the data obtained from GEANT4 software and graph has been plotted using QtiPlot software.

5.2 Observations for Gas-Si ΔE-E PID Detector

The table below mentions the results of deposition Carbon(^{12}C) ions of 60 MeV energy for 50 events in the first and second layer of Gas-Si detector respectively.

Table 5.4: Data for ^{12}C beam deposition after passing through Gas-Si detector

Ion Number	Δ E	E
1	51.8	8.2
2	52	8
3	51.8	8.2
4	51.3	8.7
5	51.8	8.2
6	52	8
7	51.6	8.4
8	51.8	8.2
9	51.5	8.5
10	51.5	8.5
11	51.8	8.2

12	52	8
13	51.8	8.2
14	51.3	8.7
15	51.8	8.2
16	52	8
17	51.6	8.4
18	51.8	8.2
19	51.5	8.5
20	51.5	8.5
21	51.8	8.2
22	52	8
23	51.8	8.2
24	51.3	8.7
25	51.8	8.2
26	51.9	8.1
27	51.6	8.4
28	51.8	8.2
29	51.7	8.3
30	51.5	8.5
31	51.8	8.2
32	51.3	8.7
33	51.8	8.2
34	51.9	8.1
35	51.6	8.4
36	51.8	8.2
37	51.7	8.3
38	51.5	8.5
39	51.8	8.2
40	52	8
41	51.6	8.4
42	51.8	8.2
43	51.8	8.2

44	51.5	8.5
45	51.5	8.5
46	51.7	8.3
47	51.5	8.5
48	51.8	8.2
49	51.3	8.7
50	51.8	8.2

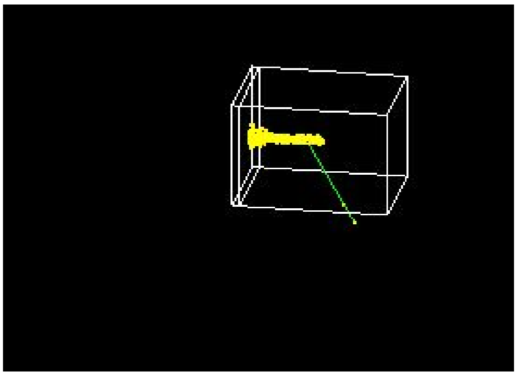


Fig 5.2: Path of 60 MeV C^{12} ions for a run of 100 events through 4cm layer of Gas (mixture of Argon and Methane) followed by a 0.1cm layer of Si.

The table below mentions the results of deposition Nitrogen(^{14}N) ions of 60 MeV energy for 50 events in the first and second layer of Gas-Si detector respectively.

Table 5.5 : Data for ^{14}N beam deposition after passing through Gas-Si detector

Ion Number	Δ E	E
1	47.9	12.1
2	48.1	11.9
3	47.5	12.5
4	48	12
5	47.6	12.4
6	47.9	12.1
7	47.7	12.3
8	47.6	12.4
9	48	12

10	47.7	12.3
11	48.1	11.9
12	47.5	12.5
13	48	12
14	48.1	11.9
15	47.5	12.5
16	48	12
17	47.6	12.4
18	47.9	12.1
19	47.5	12.5
20	48	12
21	47.9	12.1
22	48.1	11.9
23	47.5	12.5
24	48	12
25	47.6	12.4
26	47.9	12.1
27	48.1	11.9
28	47.5	12.5
29	48	12
30	47.6	12.4
31	47.9	12.1
32	47.7	12.3
33	47.6	12.4
34	47.9	12.1
35	48.1	11.9
36	47.5	12.5
37	48	12
38	47.6	12.4
39	47.9	12.1
40	47.5	12.5
41	48	12

42	47.6	12.4
43	47.9	12.1
44	47.7	12.3
45	47.6	12.4
46	48	12
47	47.7	12.3
48	47.9	12.1
49	47.7	12.3
50	47.6	12.4

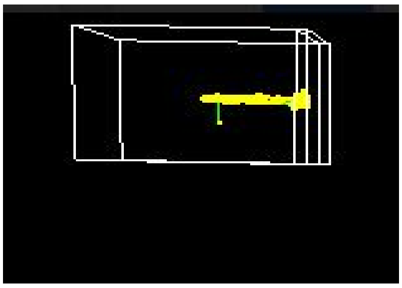


Fig 5.3: Path of 60 MeV N^{14} ions for a run of 100 events through 4cm layer of Gas (mixture of Argon and Methane) followed by a 0.1cm layer of Si.

The table below mentions the results of deposition Oxygen(^{16}O) ions of 60 MeV energy for 50 events in the first and second layer of Gas-Si detector respectively.

Table 5.6: Data for ^{16}O beam deposition after passing through Gas-Si detector

Ion Number	**Δ** E	E
1	43	17
2	43.1	16.9
3	43.5	16.5
4	43.2	16.8
5	43.7	16.3
6	43.2	16.8
7	43.3	16.7
8	43.5	16.5
9	43.3	16.7

10	43.7	16.3
11	43.2	16.8
12	43.7	16.3
13	43.2	16.8
14	43.3	16.7
15	43.5	16.5
16	43.3	16.7
1 7	43.7	16.3
18	43.2	16.8
19	43.7	16.3
20	43.2	16.8
21	43	17
22	43.1	16.9
23	43.5	16.5
24	43.2	16.8
25	43.7	16.3
26	43.2	16.8
27	43.3	16.7
28	43.5	16.5
29	43.3	16.7
30	43.7	16.3
31	43	17
32	43.1	16.9
33	43.5	16.5
34	43.2	16.8
35	43.7	16.3
36	43.2	16.8
37	43.3	16.7
38	43.5	16.5
39	43.3	16.7
40	43.7	16.3

41	43.5	16.5
42	43.2	16.8
43	43.7	16.3
44	43.2	16.8
45	43.3	16.7
46	43.7	16.3
47	43	17
48	43.1	16.9
49	43.5	16.5
50	43.2	16.8

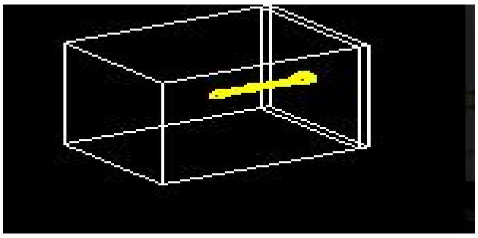


Fig 5.4: Path of 60 MeV O^{16} ions for a run of 100 events through 4cm layer of Gas (mixture of Argon and Methane) followed by a 0.1cm layer of Si.

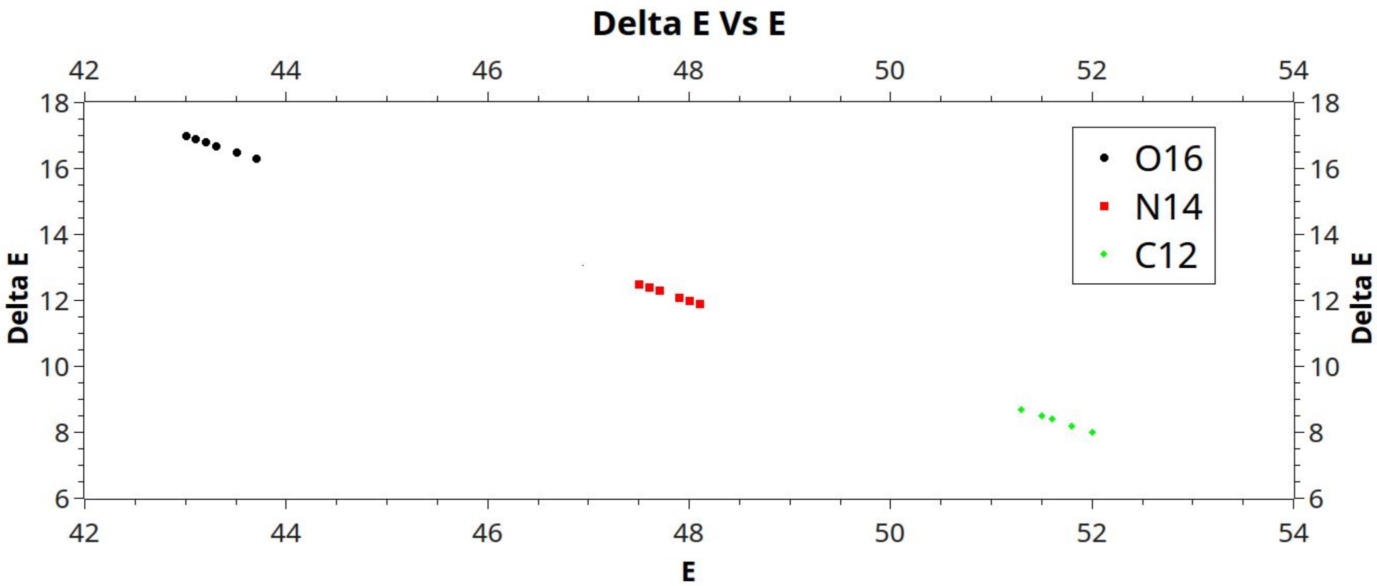


Fig 5.5: Plot of Delta E vs E for O, N , and C ions of Gas-Si PID detector from the data obtained from GEANT4 software and graph has been plotted using QtiPlot software.

5.3 RESULTS DISCUSSION

The data obtained from both Si-Si and Gas-Si PID Detector have plotted in terms of of Delta E vs E. In the fig(si-Si), the plot shows three bands (shown in three different colours) for three different ions have been obtained from the data obtained from GEANT4. In the fig (gas-si), the plots shows

6. CONCLUSION

The graphs obtained from the simulation are similar as expected. So this simulation can help to verify and debugging the experimental data obtained from DeltaE-E detectors during experiments.
Prediction and verification of an ion can be easily done as separate bands can be seen in the graphs. The amount of energy deposition in both of the layer by an incident ion can help us to identify it. This we can conclude saying that Delta E-E PID detector will be useful in detecting and identifying more than one heavy ion beams when made pass through simultaneously distinctly.

8. FUTURE SCOPE

As this project was just a step to learn the software GEANT4 and make use of it to simulate a detector. During Summer Internship 2016 me and my project partner had dealt with a 14 MeV Neutron Generator at Institute for Plasma Research, Gandhinagar. The problem aroused in the facility was production of neutrons from the copper beam dump of the neutron generator due to interaction between deuteron beam with was asked to calculate neutron yield from the copper beam dump of that neutron generator. In the future we (me and my project partner) are planning to simulate a 14 MeV Neutron Generator (the one at IPR) and calculate neutron yield from the copper beam dump of that neutron generator.

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