

Monte Carlo Simulation of a Uniform Response Silicon X-ray Detector



Sunil Chinnadurai, Poongundran Selvaprabhu, Vetriveeran Rajamani

Abstract: X-ray semiconductor detectors do not show an equal responsiveness for different incident photon energies. Detector response is required to be independent from the energy especially for dose measurements in medical or nuclear safety applications. So the target of the project is to achieve an energy independent response of the silicon x-ray detector. The active area of the silicon detector is partly covered with a brass plate featuring a round hole with a thin aluminum foil. The diameter has to be optimized to achieve an energy independent response of the detector. Monte Carlo simulation toolkit Geant4 is used to model the structure, matter and physical properties of the device. Silicon detector has a surface area of 10 mm x 10mm and about 500 um thick. Brass plate with thickness of 1.8 mm and round hole is mounted on top of it. X-ray photons with energies in different steps between 50 keV and 150 keV are used in the simulation. Monte Carlo simulation results presented in this report determines the best possible energy independent response of the silicon x-ray detector.

Keyword: Geant4, Monte Carlo simulation, Semiconductor detector, X-rays.

I. INTRODUCTION

X-rays are electromagnetic waves or mass less particles like any other kind of light. Light is a wave when it travels through space but it is a particle when we observe or measure it. The smallest unit of light or electromagnetic energy is called photons [1]. Photons are particles with zero mass and no electric charge. A Detector is any device that receives a signal and responds to it in a distinctive manner. X-ray detectors usually detect individual x-ray photons which react with the detector. X-ray detectors measure each individual photon and then accumulate enough measurements to make an exact picture of total source. X-ray detector is made up of silicon which is a semiconductor. Semiconductor detectors will be explained in theory part of the thesis. Some other types of x-ray detectors are Gas detectors, Scintillation counters, micro channel plates, etc. Monte Carlo simulation

is a method for continuously evaluating a deterministic model using sets of random numbers as inputs. Monte Carlo method is used when the model is complex and nonlinear [2,3]. Monte Carlo simulation toolkit Geant4 is used and it will be explained in theory part of the thesis. Now a day's X-rays are used in many fields. X-rays plays a major role especially in the field of medical applications such as radiography. The figure below explains the importance of the detector in the medical applications.

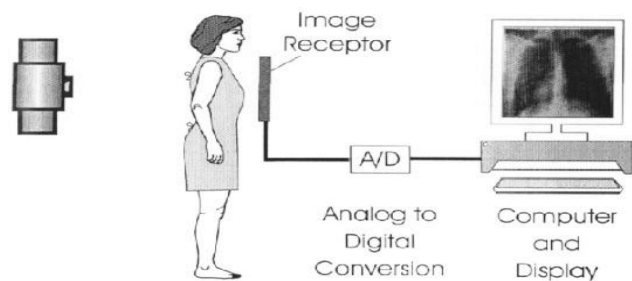


Figure 1: Digital Radiography System

In the above figure, X-rays are generated from the source (left most) which is radiated through human body and deposits the energy in the detector and the detector converts transmitted x-ray beam into an electrical signal which is then digitized and recorded in system and then the image will be processed using the system and digital communication methods. X-ray detector plays a very important role in collecting the needed information. So detector should provide uniform response which means sensitivity should be constant over the entire area of the image [4,5]. Sensitivity depends on the material of the detector which is defined as

$$\text{Sensitivity} = \frac{\text{Charges Produced by Detector}}{\text{Incident X-Ray Quantum of Specified Energy}}$$

We need to construct the detector in such a way that it should show uniform response for different incident photon energies. Gamma rays can easily pass through silicon detector because of its high energy. If high energy gamma rays penetrate through detector, then there is no use in placing the detector. Emitted gamma rays should be deposited in the silicon detector in order to find the response of the detector. So we need to construct the geometry in such a way that gamma rays are absorbed in the silicon detector [6,7]. So we are placing an aluminum foil before the silicon detector. Brass plate with hole is placed before the aluminum foil. Gamma rays generated from the source passes through the brass plate with hole, then through the aluminum foil and then hit the silicon detector. Some of the gamma rays will be absorbed in the silicon detector and others will be penetrated through the silicon detector.

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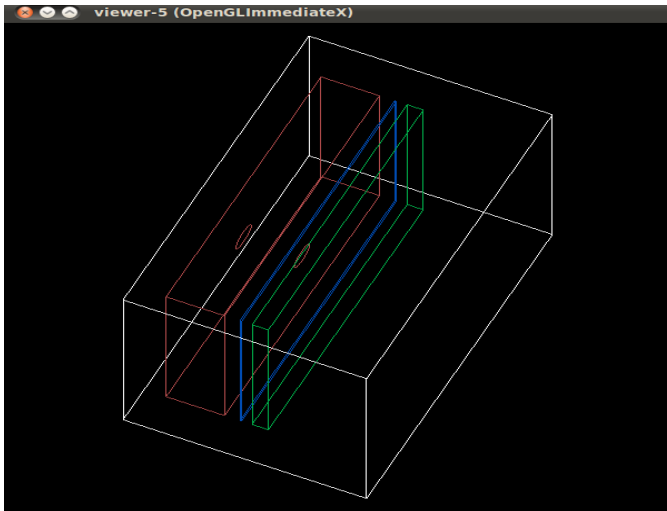


Figure 2: Constructed Detector Geometry

The above figure below shows the constructed detector geometry which consists of silicon detector, aluminum foil and brass plate with hole. Hole diameter of the brass plate can be varied. X-ray photons with energies in different steps between 50 keV and 150 keV should be used in the simulation to find the detector response of the silicon detector. The target of the thesis is to find the hole diameter of the brass plate that results in the best possible energy independent response of the silicon detector.

The remainder of the paper is organized as follows. Section II introduces generic system model. Section III presents the concept of windows cyclic prefix FBMC/COQAM and its application in massive MIMO networks. In section IV, we evaluate the efficient channel equalization techniques for WCP-COQAM scheme. Section V reports simulation results. Some conclusions are drawn in section VI.

II. GENERIC SYSTEM MODEL

This part explains about the semiconductor detectors and the Monte Carlo simulation toolkit Geant4.

A. Semiconductor Detectors

Semiconductors are materials whose electrical properties lie between conductors and insulators. Semiconductors can be classified into p-type and n-type semiconductors. Holes are majority carriers in p-type and electrons are majority carriers in n-type. P-type semiconductors are called positive type semiconductors and n-type semiconductors are called negative type semiconductors. Silicon and Germanium are some basic examples of semiconductors. Band gap is the energy gap between the valence band and conduction band. Band gap is inversely proportional to the energy absorption of the material [8]. When the energy gap between the valence band and conduction band is more, then more excitation energy is required to move the electrons from valence band to conduction band. When the energy gap between the valence band and conduction band is less, then the excitation energy required to move the electrons from the valence band to the conduction band is also low. In a material, larger band gap will result in less energy absorption and smaller band gap will result in more energy absorption. So band gap plays a major role in energy absorption of the material [9]. Characteristics of semiconductor, insulator and conductor with respect to the band gap are shown in figure 3.

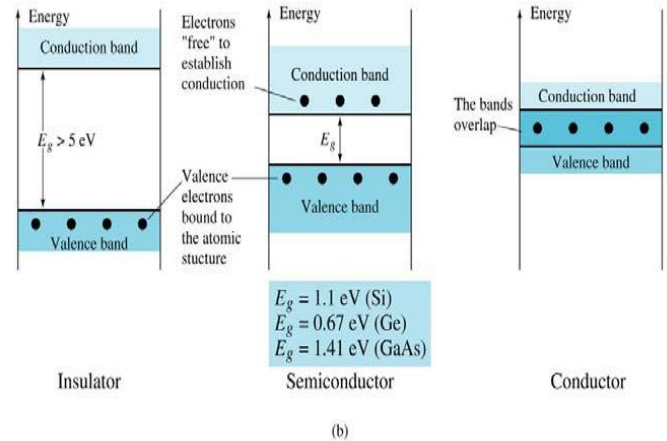


Figure 3: Characteristics of semiconductor, insulator and conductor

In figure 3, Insulators have larger band gap so it needs more energy to excite the valence electrons from valence band to conduction band. Diamond is a good example for insulators. But in the case of conductors the bands overlap so more current will flow. Band gap for the semiconductor materials like silicon, germanium and gallium arsenide are shown in figure 3. Semiconductor detectors are commonly used when best energy resolution is intended. In semiconductor detectors the fundamental information carriers are electron-hole pairs, which are produced along the path taken by the charged particles through the detector. By collecting electron hole pairs, the detection signal is formed.

B. Geant4

Geant4 is a Monte Carlo simulation toolkit for the simulation of passage of particles through matter. Geant4 is developed from geant3 which is written in FORTRAN and it is maintained by GEANT collaboration, CERN. Geant4 is a toolkit for high energy physics experiments using object oriented programming written in C++ language. In olden days, Geant4 stands for generation and tracking but in recent times it is called as geometry and tracking. Geant4 kernel provides frameworks of geometrical representation and physics processes. In Geant4 kernel, each class begins with the prefix G4 (for example: G4Generalparticlesource). G4 types are used only within the geant4 code. Geant4 is a state machine and it has six application states which are PreInit, Init, Idle, Geomclosed, EventProc and Quit. G4cout and G4cerr are same as the ordinary cout and cerr except that the output streams will be handled by the G4UImanager. Geant4 toolkit does not provide a main () method. G4Runmanager class is explicitly constructed in the users main (). G4Runmanager controls the flow of the program and manages the event loops within a run [10]. The run manager manages initialization procedures in the user initialization classes.

C. Geant4 Categories

Geant4 handles run, event, track, hits, trajectories, etc. Geant4 consists of 17 categories which are shown in the flowchart and each category is explained below.

In Geant4, global collects all classes, types, structures and constants which are considered of general use within the Geant4 toolkit. Global also defines the interface with third-party software libraries such as CLHEP (Class Library of High Energy Physics). Run is a collection of events. Run is represented by G4Run class and it is processed by G4Runmanager class. A run starts with Beam On () method of G4RunManager. The user cannot change the detector geometry and physics processes during the run. Event contains the primary particles. These primary particles are pushed into the stack. Processing of an event is completed when the primary particles in the stack becomes empty. Event is represented by G4Event class and it is processed by G4EventManager class. Hits collections, trajectory collections and digits collections are produced at the end of the event. In Geant4, Tracking is independent of particle type and physics process. Calculating the path of the particle is called tracking which is the basic part in the detector simulation. Track is a snapshot of the particle which has the position and physical quantities of current instance. Trajectories are the path of the particles moving through space. Trajectory class objects are used to record the track. Geant4 geometry has three layers such as G4Vsolids, G4Logicalvolume and G4Vphysicalvolume. The main function of Geant4 geometry is that the volume definitions are independent of the solid representation. Examples of ageant4 geometry are CSG (Constructed Solid Geometries), BREPS (Boundary Represented Solids), etc. CSG are simple solids and BREPS are solids whose volumes are defined by boundary surfaces. In Geant4, Materials and Particles have to be defined before they are used in the program. Materials are defined in detector construction class and particles are defined in physics list class. Interaction of particles with the material is observed in Geant4. Examples of materials are silicon, germanium, copper, etc. Examples of particles are electron, gamma, etc. Geant4 provides a wide variety of physics processes. Physics processes describe the particle interaction with matter. Processes can be selected by energy range, particle type, material, etc. Examples of physics processes are Electromagnetic, hadronic, decay, etc. Hit is a snapshot of the physical interaction of the track. Hit is a user defined class derived from G4VHit. Hit collections are accessible through G4Event at the end of the event. Digit is created with one or more hits. Digit is a user defined class derived from G4VDigitizerModule. Digits must be accessed by the user explicitly. Intercoms handle the framework mechanism of defining and delivering commands. Commands in Geant4 can be hard-coded or it can be given by user interface. Commands can also be given from macro file. Macro files are ASCII files that contain user interface commands. Interface handles the graphical user interface (GUI) and their interactions with the external software. Geant4 visualization system has the following functions such as its fast response to study detector geometries, particle trajectories and hits in the detectors. Geant4 has many visualization drivers which have flexible camera control to debug complex geometries and has the tools to produce high quality output. Visualization system in Geant4 can also show volume overlap errors in detector geometries. A set of visualizable 3D data is called scene. Computer Graphics modeler which uses raw data in a scene called scene handler. Visualization driver can be defined as the combination of scene handler and viewer where viewer is called as image

generator. Solids, trajectories and hits can be visualized by interacting with graphical libraries. Visualization system in Geant4 helps to develop several drivers independently because of its object oriented design.

III. METHODOLOGY

Monte Carlo simulation tool kit Geant4 is used to model the structure, matter and physical properties of the device. Detector geometry which consists of silicon detector, aluminum foil and brass plate with hole is constructed using geant4. X-ray photons (Gamma particles) with energies in different steps between 50 and 150 Kev is used in the simulation. Interaction of particles with the silicon detector (energy absorbed in the silicon detector) is observed in the simulation by varying the hole diameter of the brass plate. Detector geometry and particles interactions with the detector can be visualized with the help of the visualization driver called open GL. Geant4 simulation results can be viewed in the output command window (terminal). Simulation results are plotted to find the hole diameter that results in best possible energy independent response of the silicon detector. Steps to achieve the desired results in Geant4 are shown in figure 5. These steps are explained in the implementation part of the thesis.

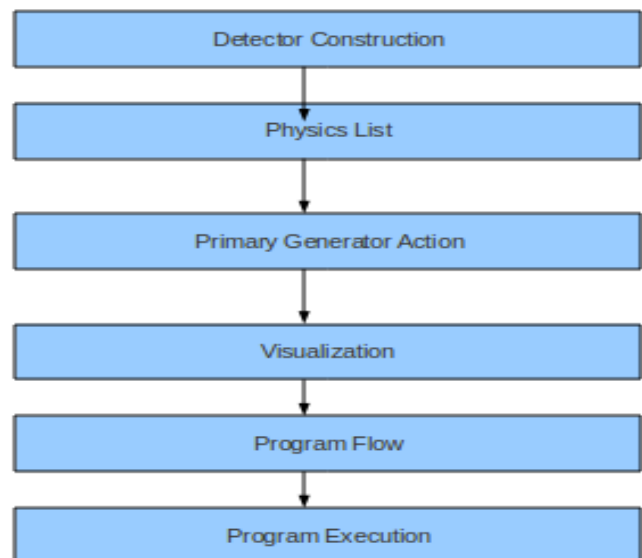
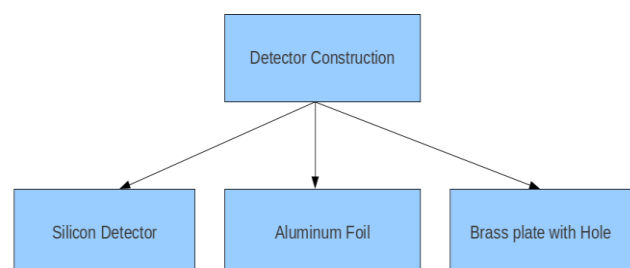


Figure 4: Steps involved in Implementation

IV. IMPLEMENTATION

A. Detector Construction:



The above tree diagram shows that silicon detector, aluminum foil, brass plate with hole has to be constructed in the detector geometry. In order to construct the detector geometry we need to define the materials which will be used in the detector geometry. Materials used in the simulation are Galactic, Silicon, Aluminum, brass, copper, zinc and lead. Materials should be defined in Geant4 as shown below.

```
new G4Material("Silicon" , z=14, a=28.09*g/mole, density= 2.330*g/cm3);
```

In the same way, other materials used in the simulation are defined and which is shown in the Appendix part of the paper. Materials are defined in the detector construction class which is one of the mandatory user initialization classes in Geant4. Geant4 detector geometry consists of volumes like world volume and logical volumes. World volume is the largest volume and all other volumes will be placed inside this volume. There should not be any overlapping between the volumes which is placed inside the world volume and also there should not be any overlapping between the world volume and the daughter volumes. The shape of the world volume is a box. World volume is created by three important steps which are as follows

Create a solid, logical volume, placements:

A box with a name World has been created and its extent along each of the Cartesian axis. Size of the world volume can be varied so that it accommodates all other volumes inside it. I have described about the solid, the name of the solid I.e. World and the material of the solid I.e. Galactic. Placement is the positioning of the logical volume into the mother volume. Here I am placing my world logical volume at the vertex (0, 0, and 0). World volume is constructed in Geant4 and which can be seen in any of the Geant4 visualization drivers.

Silicon detector is also created as described above by the following three steps as creating a box with a name Absorber and with dimensions of about 500 um thickness and size of about 10x10 mm and have described about the solid, the name of the solid I.e. Absorber and the material of the solid I.e. Silicon and placing my logical volume inside the world volume at the vertex (0, 0, 0). World volume acts as mother volume for the Absorber. Absorber acts as a daughter volume for the World. Figure 6 below shows the silicon detector in surface (style) with thickness of about 500 um and a size of about 10 x 10 mm which is seen in the visualization driver called open GL.

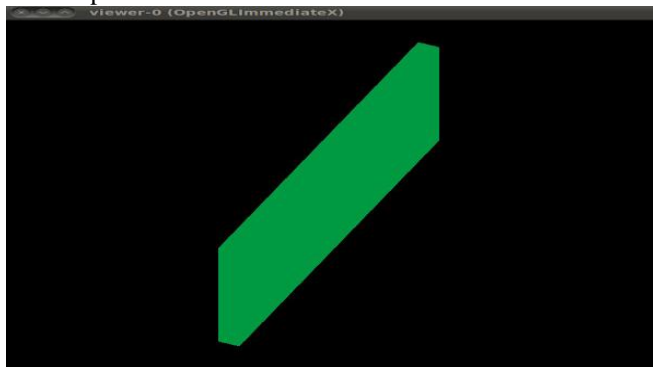


Figure 6: Silicon detector in surface

Aluminum filter has to be placed before the Silicon detector in the world volume. Aluminum foil is created as follows by creating a box with a name Foil and with dimensions of about 0.05 mm thickness and size of about 10x10 mm and described about the solid, the name of the solid I.e. Foil and

the material of the solid I.e. Aluminum. Logical volume has been placed inside the world volume at the vertex (-0.6 mm, 0, 0). No overlapping should be there between one material and other material when it is placed inside the world volume. World volume acts as mother volume for the Foil. Foil acts as a daughter volume for the World. Figure 7 shows Aluminum foil in surface with a thickness of about 0.05 mm and a size of about 10 x 10 mm which is seen in the open GL visualization driver.

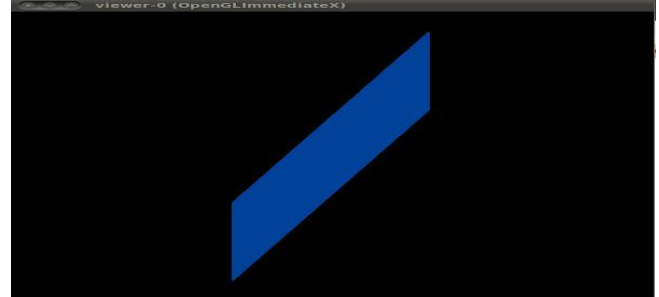


Figure 7: Aluminum Foil in surface

Brass plate with hole has been placed before the Aluminum foil in the world volume. Brass plate can be created easily as the aluminum foil and the silicon detector. But we need a hole in the brass plate. In order to get a hole, we need to create a Box and Tubs I.e. cylinder by creating a box with a name Box and with dimensions of about 1.8 mm thickness and size of about 10x10 mm. Tubs with a name Cylinder is created and it is shown below. Value of External radius has to be changed to vary the hole diameter of the brass plate.

```
G4Tubs* cyl = new G4Tubs ("Cylinder", internal radius, external radius, height, 0, twopi);
```

In order to get the hole we need to use the Boolean operations for the above two solids such as box and tubs. Before applying the Boolean operations we need to rotate the cylinder in such a way that cylinder should be placed exactly in the box. When we subtract box with the cylinder we created, then box with hole will be produced as the result which is shown in figure 8. Code for rotating the cylinder by 90 degrees and subtracting the two solids are given below respectively.

```
yRot->rotateY(M_PI/2.*rad);
```

```
G4SubtractionSolid*subtractionmoved=new G4SubtractionSolid("plateWithHole", box, cyl,yRot, zTrans);
```

Subtracted solid is named as the plate with hole which is made up of the material called brass. Brass plate with hole is created with dimensions of about 1.8 mm thickness and size of 10 x 10 mm. Logical volume is placed inside the world volume at the vertex (-2 mm, 0, 0). No overlapping should be there between one material and other material when it is placed inside the world volume. World volume acts as mother volume for the plate with hole. Plate with hole acts as a daughter volume for the World. Brass plate with hole in surfaces is shown in the figure 8 and figure 9.

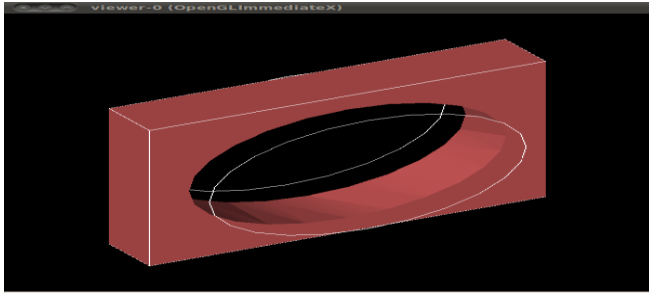


Figure 8: Brass plate with hole (Hole diameter = 4 mm)
When we change the external radius in the below code to 0.5 mm then the brass plate with hole diameter = 0.5 mm will be created as shown in the figure 10.
G4Tubs cyl = new G4Tubs ("Cylinder", internal radius, external radius, height, 0, twopi);*

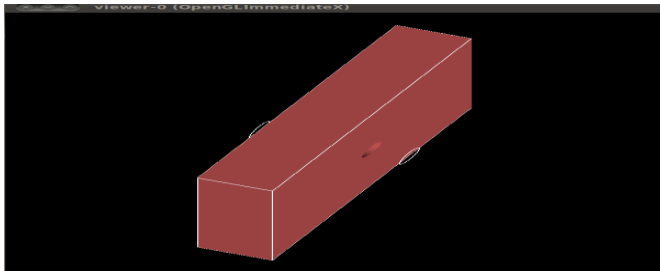


Figure 9: Brass plate with hole (Hole diameter = 0.5 mm)
Figure 10 shows the brass plate with hole in wire frame (style). Figure on the left shows brass plate with hole diameter= 4mm. Figure on the right shows the brass plate with hole diameter= 0.5 mm

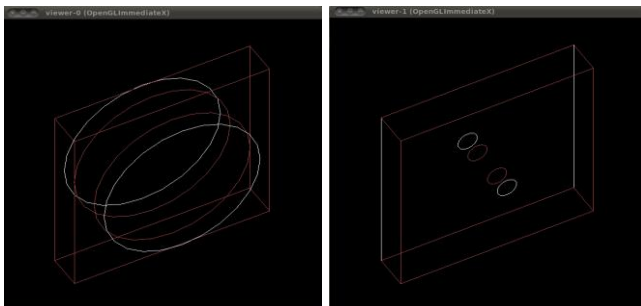


Figure 10: Brass plate with hole in wire frame (4 mm (left) and 0.5 mm (right))

Colors for logical volumes:

In order to highlight or differentiate easily we can give separate colors for the logical volumes which are placed inside the mother volume. I have represented Silicon detector in green, Aluminum foil in blue and brass plate with hole in red. Figure 11 shows silicon detector, Aluminum foil and Brass plate with hole in different colors in wire frame placed inside the world volume in two dimensions.

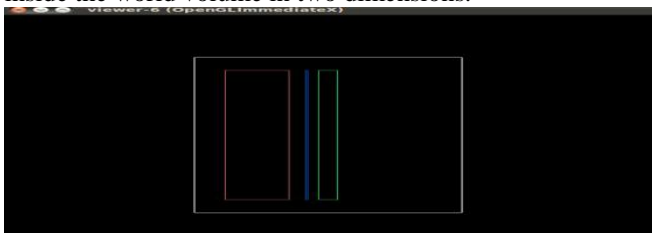


Figure 11: Detector Geometry in 2 Dimensions (Wire frame)

Figure 12 shows the detector geometry in different angles in three Dimensions. Figure shown on the left is viewed from the camera angle with theta=70 and phi=80. Figure shown on the right is viewed from the camera angle with theta=70 and phi=50.

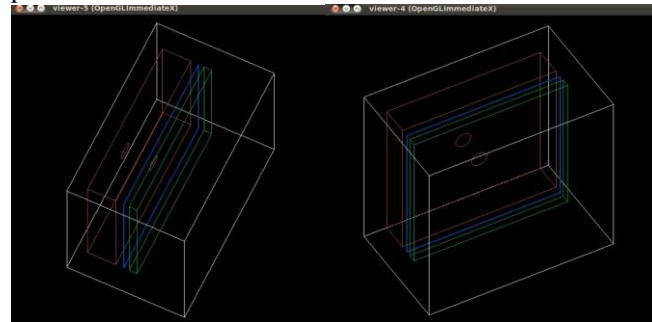


Figure 12: Detector Geometry in 3 Dimensions (Wire frame)

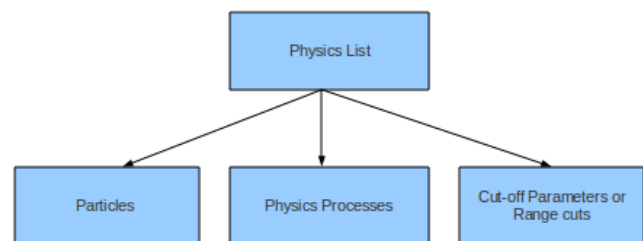
The image shown below is taken from the command window summarizes the materials and their parameters used in the detector geometry.

```
Material: Galactic density: 0.000 kg/m3 RadL: 204727512.315 pc Nucl.In
t.Length: 114561548.020 pc Imean: 19.200 eV temperature: 2.73 K pressure
: 0.00 atm
---> Element: Galactic ( ) Z = 1.0 N = 1.0 A = 1.01 g/mole ElmMa
ssFraction: 100.00 % ElmAbundance 100.00 %

Material: Silicon density: 2.330 g/cm3 RadL: 9.368 cm Nucl.Int.Leng
th: 45.761 cm Imean: 173.000 eV
---> Element: Silicon ( ) Z = 14.0 N = 28.1 A = 28.09 g/mole ElmMas
sFraction: 100.00 % ElmAbundance 100.00 %

The WORLD is made of 7.5 mm of Galactic. The transverse size (YZ) of the wo
rld is 1.2 cm
The ABSORBER is made of 500 um of Silicon. The transverse size (YZ) is 1 cm
X position of the middle of the absorber 0 fm The Foil is made of 50 um of Al
uminium. The size is 1 cm
The PLATE with hole is made of 1.8 mm of Brass. The size is 1 cm
```

B. Physics List:



Gamma particles are used in the simulation. Photons which have less energy are called gamma rays. Gamma particle in geant4 is defined as follows

G4Gamma::GammaDefinition();

A class that defines how a particle should interact with matter is called process. Physics process used in the Geant4 simulation is Standard Electromagnetic process in which Gamma particles can undergo three kinds of process when it is interacting with the material. The three kinds of processes are Photoelectric effect, Compton scattering and Gamma conversion. Since incident photon energies used in the simulation range between 50 and 150 keV, there will be more Compton scattering process than the photoelectric effect. Some other physics lists available in geant4 are low energy physics, hadronic physics, etc. The three processes involved with gamma particles are explained below.

Photoelectric effect:

During the interaction of photons with the absorber atom, photon loses its whole energy during the process of knocking an electron out of orbit. This ejected electron is called photo electron and this effect is called photo electric effect. This process occurs with low energy photons having energy between 10 and 500 keV.

Compton scattering:

During the interaction of photons with the absorber atom, part of the photon energy is lost to the electron and photons with less energy have been ejected and travel in different direction. This process is called Compton scattering. This process occurs with photons having energy between 100 and 150 keV.

Gamma conversion:

Photons with energy greater than 1.02 meV interact with the absorber atom can produce an electron-positron pair. This process is called pair production or gamma conversion. Since the incident photon energy used in the simulation is between 50 and 150 keV there will not be any gamma conversion process taking place in the simulation.

Cut-off Parameters:

Range Cut values for the secondary particle production such as electron, positron and gamma are defined in the physics list class which is one of the mandatory user initialization classes in Geant4. Particles unable to travel at least the range cut values are not produced. When photons with energy range between 50 and 150 keV interacts with matter, there is a possibility for the production of electron and gamma. Range cut values for gamma and electron are defined in the Geant4 as shown below.

CutForGamma = 1.0 mm;

CutForElectron = 1.0 mm;

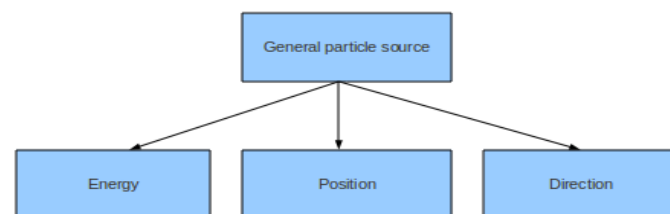
Secondary particles unable to travel at least the range cut value of 1 mm are not produced.

C. Primary Generator action:

Primary generator action class is one of the mandatory user action classes in Geant4. Particles used in the Geant4 simulation are gamma and it can be found in geant4 by the following source code.

```
G4ParticleDefinition* particle =  
particleTable->FindParticle("gamma");
```

Now we need a source which generates those gamma particles. There are two kinds of sources which are particle gun and general particle source.



Particle gun:

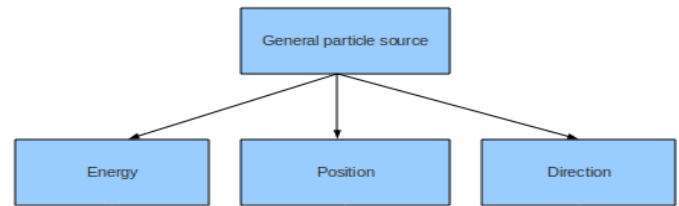
Particle gun generates single particle at a time. Particle gun is time consuming when generating huge number of particles.

General particle source (gps):

General particle source generates multiple particles at a time. General particle source is largely useful to generate more number of particles. General particle source is used in the geant4 simulation in order to generate more particles at short time. General particle source can be initialized in Geant4 as shown below.

```
particleGun = new G4GeneralParticleSource();
```

We need to define the position, direction and energy for the general particle source after choosing general particle source as the source for generating the gamma particles



Incident gamma energy is set in geant4 as shown below and it has to be varied from 50 keV to 150 keV to observe the response of the silicon x-ray detector.

```
particleGun->GetCurrentSource()->GetEneDist()->SetMonoEnergy(50.0*keV);
```

In the above code, gamma energy is set to 50 keV and it can be varied before building the application in Geant4. Placement of the general particle source is essential since it should be placed where the generated particles from the general particle source should hit the detector. Particle position of gps is defined in Geant4 as shown below.

```
particleGun->SetParticlePosition(G4ThreeVector(x0,y0,z0));
```

Where (x0, y0, z0) will vary according to the detector construction. Particles generated should hit the detector geometry to observe the response of the detector. Particles direction can be set for general particle source as shown below.

```
ParticleGun->GetAngDist()->SetParticleMomentumDirection(G4ThreeVector(1.,0.,0.));
```

The above code shows that the particles are moving in the positive x direction. Particle direction can be changed according to the detector geometry. The shape of the general particle source used in the simulation is square source and some other shapes available in Geant4 are circle, ellipsoid, rectangle, cylinder, sphere, etc. General particle source type is planar. Other types of sources available are beam, point, surface and volume.

D. Visualization:

Visualization in Geant4 is performed either with commands or writing C++ source codes of user action classes. After constructing the detector geometry, defining particles and physics process for each particle it is essential to visualize the detector geometry and the particles interaction with the detector geometry. The objects such as detector components, physical volumes, logical volumes, solids, particle trajectories and their tracking steps, dose, hits in detector components, etc. can be visualized in Geant4 with the help of the visualization driver. Visualization driver can also visualize the source of the gamma particles generated I.e. general particle source.

E. Program flow and Program Execution:

In figure 13, Detector construction class and Physics list (standard Electromagnetic physics) class are assigned to G4 Run manager which controls the flow of the program in any Geant4 simulation. Detector construction and physics list classes are derived from the G4Vuserdetectorconstruction and G4VuserphysicsList.

G4Vuserdetectorconstruction and G4VuserphysicsList classes are the two mandatory user initialization classes in Geant4. Silicon detector, Aluminum foil and Brass plate with a hole are defined and constructed in the detector construction class of Geant4. Gamma Particles, and their physics processes such as photo electric effect, Compton scattering and gamma conversion are registered in Geant4. Range cut values (production cuts) for the secondary particles are also defined in the Physics list class of Geant4. G4Runmanager gets all the necessary information from the detector construction and physics list in order to initialize the run. Binary executable file will be created for all the applications which are built in Geant4. After executing the binary file, Geant4 will enter into the pre initialization mode where Visualization drivers will be registered to the Geant4. Geant4 will enter into the initialization mode with the following command which is shown below

/run/initialize

Geant4 user mandatory user initialization classes such as detector construction class and physics list class will be registered to the Geant4 in the initialization mode.

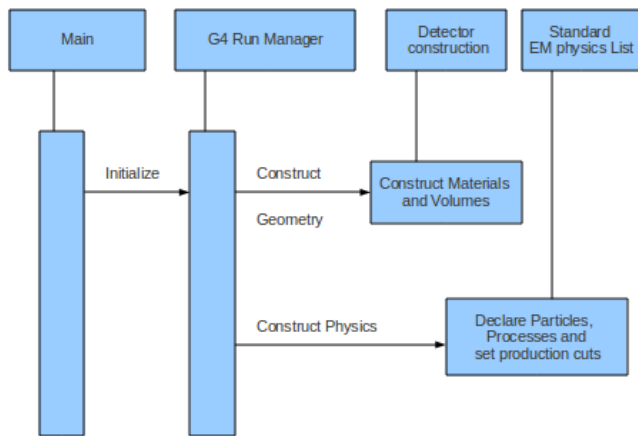


Figure 13: Run Initialization in Geant4

Figure 14 shows the output from the command window for initializing the run. In Figure 14 all the materials used in the detector geometry are shown and the range cut values for secondary particles such as electron, positron and gamma are also shown in the figure 14.

```

===== Table of registered couples =====
Index : 0 used in the geometry : Yes recalculation needed : No
Material : Galactic
Range cuts : gamma 1 mm e- 1 mm e+ 1 mm proton 0 fm
Energy thresholds : gamma 990 eV e- 990 eV e+ 990 eV proton 0 eV
Region(s) which use this couple :
DefaultRegionForTheWorld

Index : 1 used in the geometry : Yes recalculation needed : No
Material : Silicon
Range cuts : gamma 1 mm e- 1 mm e+ 1 mm proton 0 fm
Energy thresholds : gamma 6.95018 keV e- 548.291 keV e+ 526.624 keV p
Region(s) which use this couple :
DefaultRegionForTheWorld

Index : 2 used in the geometry : Yes recalculation needed : No
Material : Aluminium
Range cuts : gamma 1 mm e- 1 mm e+ 1 mm proton 0 fm
Energy thresholds : gamma 6.90363 keV e- 598.345 keV e+ 570.85 keV p
Region(s) which use this couple :
DefaultRegionForTheWorld

Index : 3 used in the geometry : Yes recalculation needed : No
Material : Brass
Range cuts : gamma 1 mm e- 1 mm e+ 1 mm proton 0 fm
Energy thresholds : gamma 24.5851 keV e- 1.34924 MeV e+ 1.27005 MeV p
Region(s) which use this couple :
DefaultRegionForTheWorld
  
```

Figure 14: Output for initializing the run in Geant4

In figure 15, Primary Generator Action is assigned to Geant4 Run Manager. Primary Generator Action is a mandatory user action class in geant4. Primary Generator Action is derived from the G4VPrimaryGeneratorAction class. General particle source which is defined in the primary generator action class can generate gamma particles with the incident energy of 50 keV by the following commands which are shown below.

/gps/particle gamma
/gps/energy 50 keV

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Incident gamma energy can be varied by replacing the 50 keV with the desired energy value. In Geant4, simulation can be started with the Beam On command which creates events as shown below.

/run/beamOn 10000

The above command generates 10000 events of gamma particle with energy of about 50 keV. G4 Run manager controls the program flow and manages the event loops within a run as shown in the figure 15. Interaction of particles with the material is processed by G4 Event manager. When gamma particles enters the world volume, some of the gamma particles will be absorbed by the logical volumes present in the detector geometry and loses their energy and undergoes physics processes such as Compton scattering and photoelectric effect. Geant4 simulation tracks the particles only inside the world volume. Particle interactions with silicon detector are only needed to find the energy absorbed in the silicon detector. Energy absorbed in the silicon detector is measured by the electron hole pairs created in the silicon detector. Geant4 simulation tracks the particles which are absorbed by the silicon detector with the help of the G4 Tracking manager. Gamma particles which are not absorbed by the logical volumes present in the detector geometry are gone out of the world volume and the Geant4 simulation stops tracking those particles.

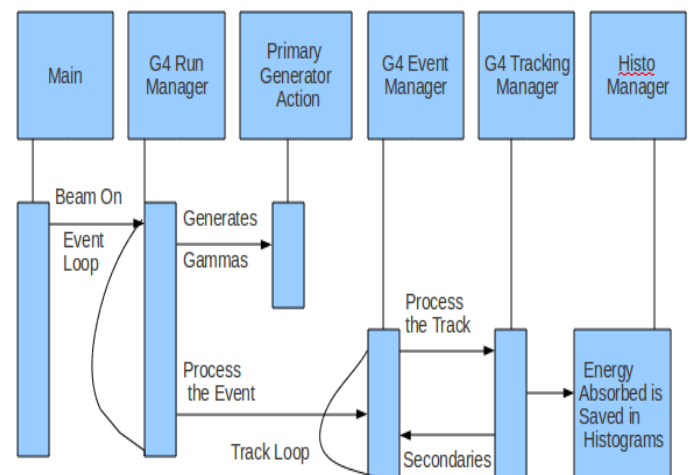


Figure 15: Processing the run in Geant4 simulation

Energy absorbed in the silicon detector (absorber) is printed in the output command window for the incident photon energy of 50 keV is shown below.

```

===== run summary =====

The run was 10000 gamma of 50 keV through 500 um of Silicon (density: 2.33 g/cm3 )

Total energy deposit in absorber per event = 1.017 keV +- 68.91 eV

-----> Mean dE/dx = 0.02035 MeV/cm (0.008734 MeV*cm2/g)

From formulas :
  restricted dEdx = 0 MeV/cm (0 MeV*cm2/g)
  full dEdx      = 0 MeV/cm (0 MeV*cm2/g)

Leakage : primary = 36.67 keV +- 220.7 eV secondaries = 27.97 eV +- 9.992 eV
Energy balance : edep + eLeak = 37.72 keV
  
```

Incident photon energy is varied from 50 keV to 150 keV in the interval of 25 keV. Energy absorbed in the silicon detector is observed for all the incident photon energies. Now vary the hole diameter of the brass plate and observe the energy absorbed in the silicon detector for incident photon energies from 50 keV to 150 keV.

The same procedure must be repeated for the various hole diameters and results are compared to find the hole diameter that results in the best possible energy independent response of the silicon detector. Macro files are created so that we do not need to type the commands every time to run the simulation with different incident photon energies. The file which consists of series of commands which will be executed sequentially is called as macro file. Macro file will be called at the pre initialization mode of Geant4. Example for the Macro file is given in the Appendix part of the paper. Energy absorbed in the silicon detector is saved as histograms to analyze the Geant4 simulation results with the help of the analysis tool called ROOT. Histograms are managed by Histo manager class of Geant4.

V. SIMULATION RESULTS

Geant4 simulation results for the incident photon energy of 50 keV when the hole diameter of the brass plate is 4mm is shown in the Figure 16. Ten thousand (10000) gamma particles are incident through the whole area of the detector geometry. Simulation results are shown in wire frame (style) in two dimensions. The yellow dots are step points. Incident gamma particles are shown in green color. Geant4 simulation results are shown in the open GL visualization driver.

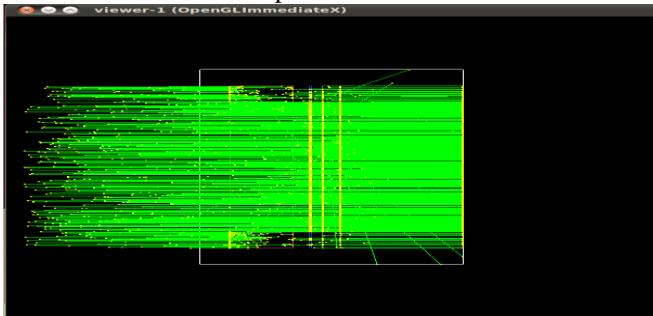


Figure 16: Geant4 simulation output in two dimensions

Geant4 simulation results for the incident photon energy of 50 keV when the hole diameter of the brass plate is 4mm is shown in the Figure 17. Ten thousand (10000) gamma particles are incident through the whole area of the detector geometry. Simulation results are shown in wire frame (style) in three dimensions. The yellow dots are step points. Incident gamma particles are shown in green color. Geant4 simulation results are shown in the open GL visualization driver.

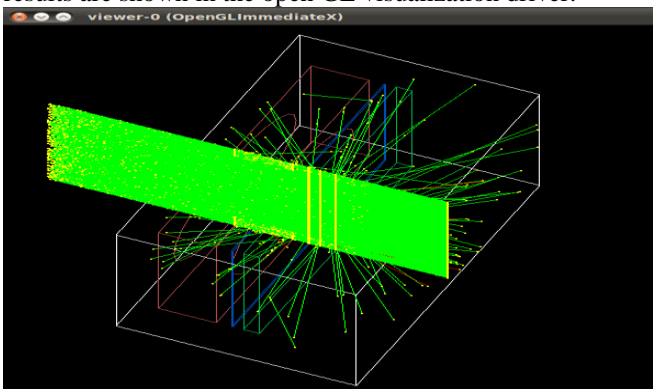


Figure 17: Geant4 simulation output in three dimensions

Geant4 simulation results for the incident photon energy of 50 keV when the hole diameter of the brass plate is 4mm is shown in the Figure 18. Ten thousand (10000) gamma particles are incident through the whole area of the detector geometry. Geant4 simulation results are shown in the output command window.

The observed results in the Geant4 simulation is plotted as a bar diagram for the various hole diameters. Figure 19 shows the energy absorbed in the silicon detector when the hole diameter of the brass plate is 0.75 mm. Bar chart is drawn between the Radiated energy (keV) and energy absorbed in silicon detector (eV). Energy absorbed in the silicon detector is almost uniform for different incident or radiated photon energies.

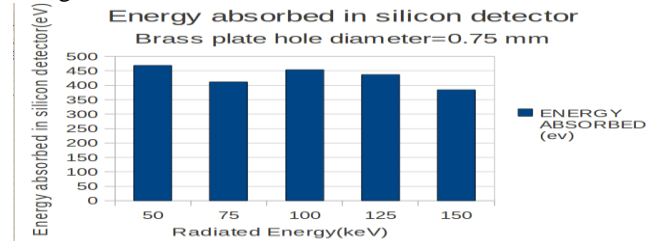


Figure 18: Energy Absorbed in silicon Detector with hole diameter = 0.75 mm.

Energy absorbed in the silicon detector when the hole diameter of the brass plate is 0.75 mm is shown in Figure 20. Bar chart is drawn between the Radiated energy (keV) and energy absorbed in silicon detector (eV). Energy absorbed in the silicon detector is not uniform for different incident or radiated photon energies.

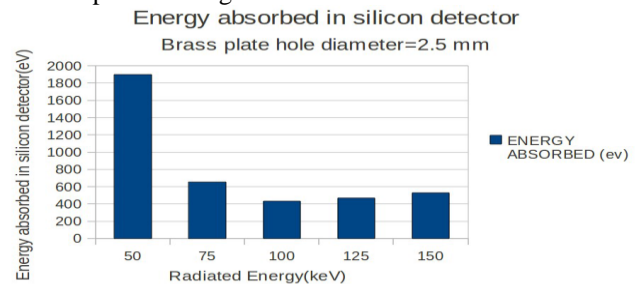


Figure 19: Energy Absorbed in silicon Detector with hole diameter = 2.5 mm

Energy absorbed in the silicon detector when the hole diameter of the brass plate is 0.75 mm is shown in Figure 21. Bar chart is drawn between the Radiated energy (keV) and energy absorbed in silicon detector (eV). Energy absorbed in the silicon detector is not uniform for different incident or radiated photon energies from 50 keV to 150 keV.

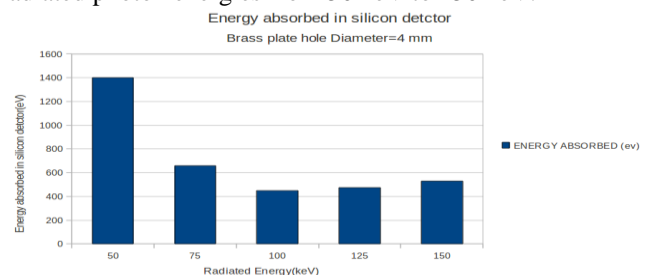


Figure 20: Energy Absorbed in silicon Detector with hole diameter = 4 mm

VI. CONCLUSION

From the Geant4 simulation results we can conclude that X-ray silicon detector shows best possible uniform response for the different photon energies from 50 to 150 keV. We can also able to conclude that the best possible energy independent response of the silicon detector is produced when the hole diameter of the brass plate is 0.75 mm.

In future different detector geometries can be constructed by changing the thickness of the silicon detector, placing the additional filters before the detector, changing the materials which are used in constructing the detector, etc. In future one can also find the energy deposited in the specific volumes present in the detector geometry.

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