Getting started with simulations in Geant4

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Schedule

DAY1	Mandatory and optional classes in Geant4	Defining a simple geometry	Simulating Rutherford's alpha scattering experiment and additional assignments
DAY 2	Particle Gun, User actions and Scoring volumes	Simulating muon lifetime measurement	Simulating proton energy loss and bethe-bloch equation based particle identification

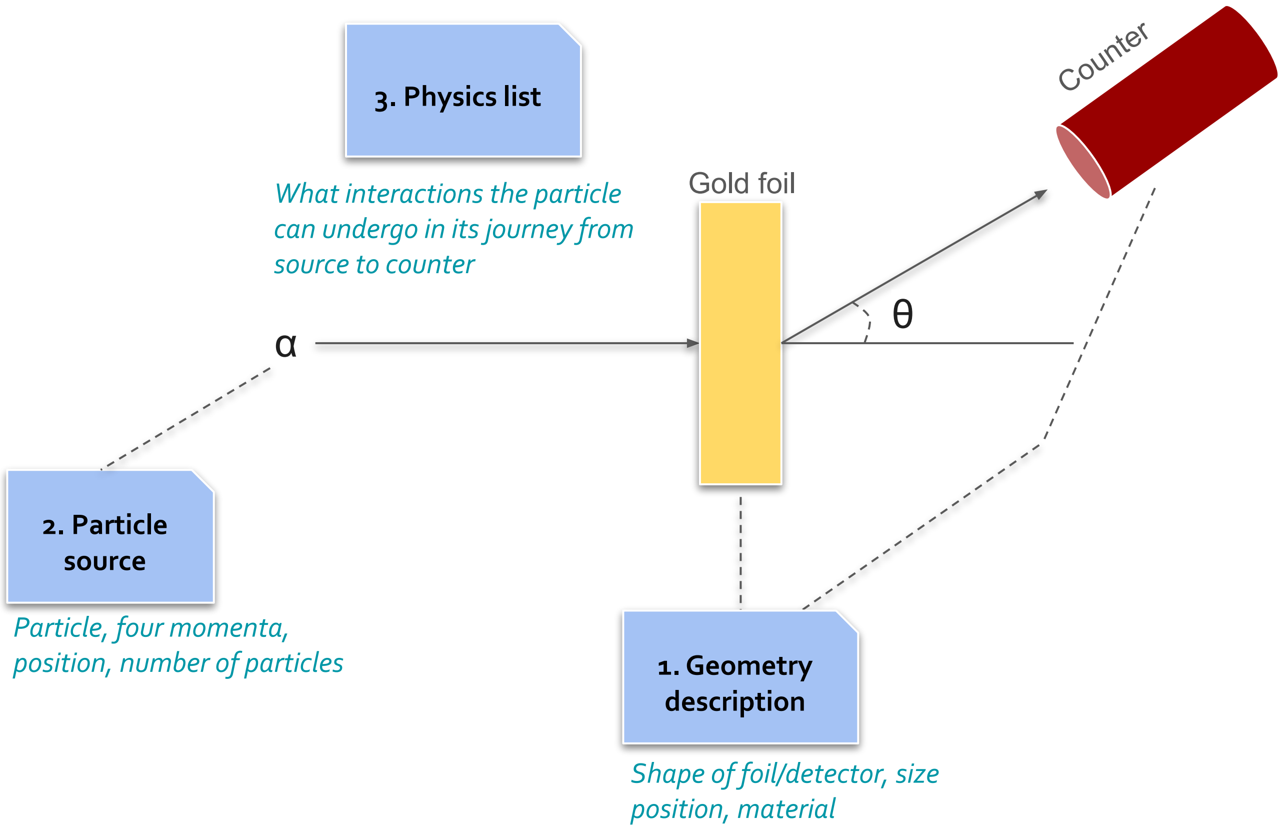
Links and other information (posted on slack)

- Github page:
  - https://github.com/deepaksamuel/neus-exercises
- Material database
  - https://www.fe.infn.it/u/paterno/Geant4_tutorial/slides_further/Geometry/G4_Nist_Materials.pdf
- PDG codes:
  - https://pdg.lbl.gov/2007/reviews/montecarlorpp.pdf
- If you have not installed Geant4 yet, you can install it quickly using:
  - sudo snap install gate
- VSCode for coding
  - https://code.visualstudio.com/download

About Geant4

- C++ toolkit to simulate particle interactions with matter
- Not a programme, helps you build one using its classes and libraries
- Prerequisites to learn Geant4:
  - C++
  - Physics of particle interactions with matter
  - Physics of detectors
  - Data analysis

Mandatory classes in Geant4: Gold foil experiment



Geiger and Marsden’s paper

Geiger H, Marsden E. On a diffuse reflection of the α-particles. Proceedings of the Royal Society of London. Series A, Containing Papers of a Mathematical and Physical Character. 1909 Jul 31;82(557):495-500.

https://royalsocietypublishing.org/doi/pdf/10.1098/rspa.1909.0054

Read the paper and note down the following:

a. What were the primary investigations undertaken in this work?
b. How big was the entire setup?
c. What was the source used in the experiment?
d. What is the typical energy and activity of the source used?
e. Is the source monoenergetic or has a spectrum?
f. What was the detector used in the experiment?
g. What physical quantities does the detector measure?
h. What targets were used and what was the thickness of the foils?
i. How far was the detector from the foil and how far was foil from the source
j. Approximately how many alphas were reflected back

Running our first code

- Open VSCode and from the menu, open a new terminal

- On the terminal, issue the following commands
  - `git clone http://github.com/deepaksamuel/neus-exercises.git`
- Once cloned, go to File -> Open Folder and open *neus-exercises*
  - Expand the *alpha-scattering* folder and view its contents

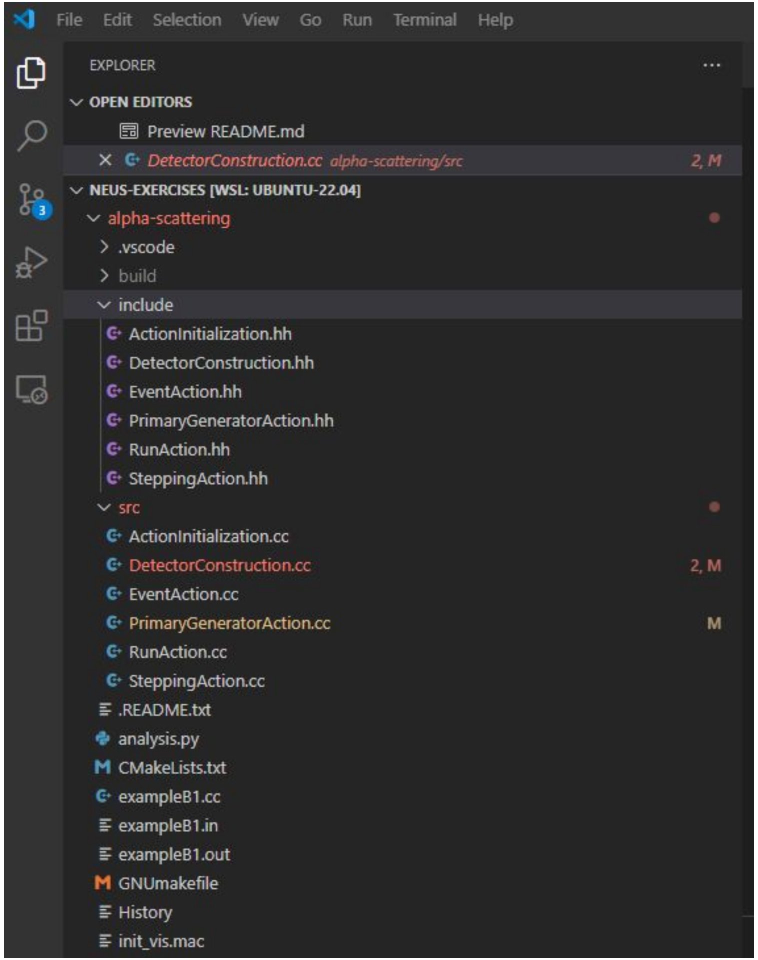
Code structure

a. **`include`**
   i. All header files (.hh extension)

b. **`src`** folder
   i. All source files (.cc extension)

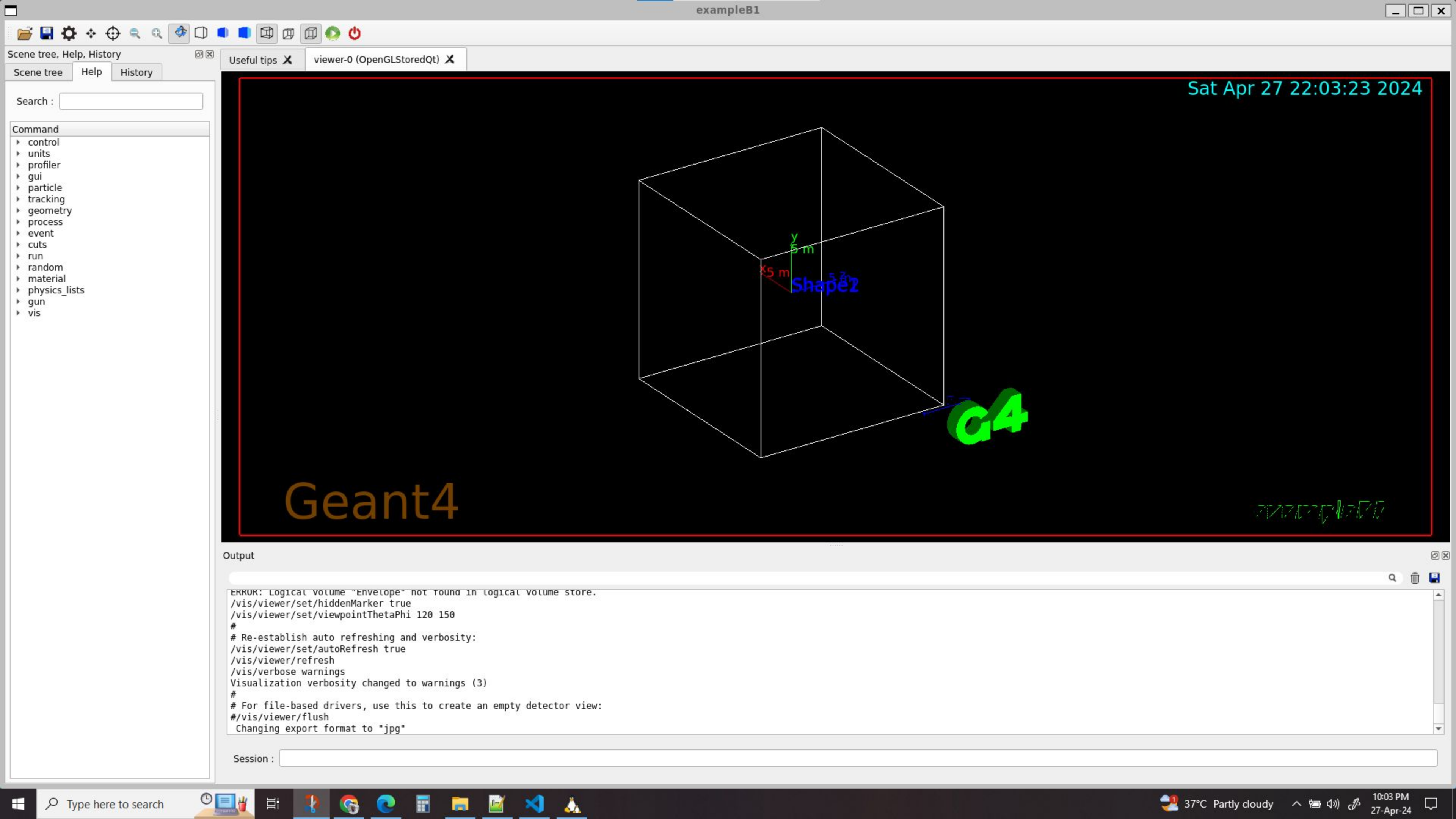
c. **`exampleB1.cc`**
   i. main file

d. **`build`** folder:
   i. You should create this folder inside the `alpha-scattering` folder
   ii. Use *`mkdir build`* to create one



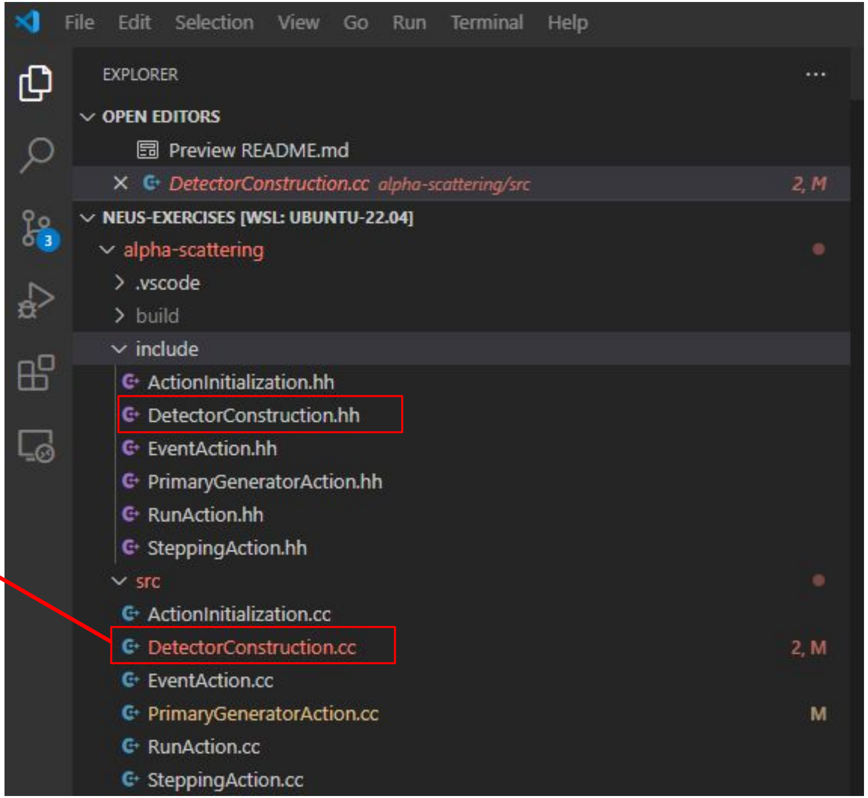
Compiling our code

a. For the compilation to succeed, you must set the G4 environment variables. This is typically done by sourcing a script, in the **terminal** where you compile the code.
   i. For snap installations: `source /snap/gate/45/usr/local/bin/geant4.sh`
   ii. If compiled from source: `YOUR_G4_INSTALL_FOLDER/install/bin/geant4.sh`
b. For compiling the alpha-scattering code:
   i. `cd alpha-scattering`
   ii. `mkdir build`
   iii. `cd build`
   iv. `cmake ../`
   v. `make`
   vi. `./exampleB1`
c. Note:
   i. everytime you open a new terminal the `geant4.sh` file should be sourced
   ii. everytime you make a change to your code, only the last two commands should be issued:
      1. `make`
      2. `./exampleB1`
d. You should see a box on your screen!

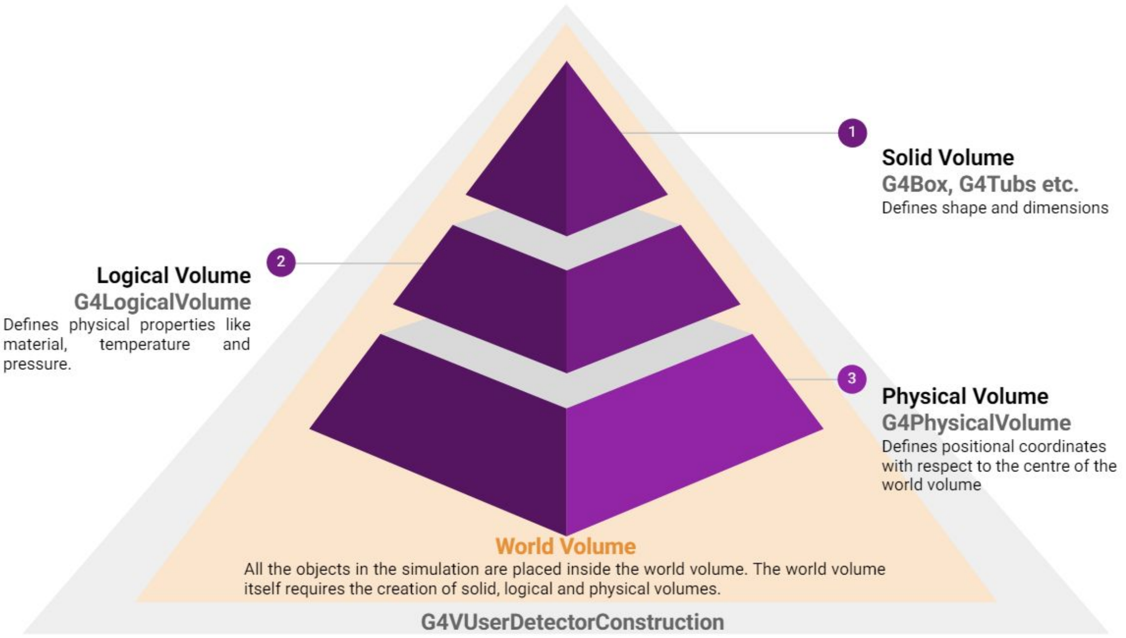

exampleB1
Scene tree, Help, History
Scene tree
Help
History
Search :
Command
control
units
profiler
gui
particle
tracking
geometry
process
event
cuts
run
random
material
physics_lists
gun
vis
Useful tips
viewer-0 (OpenGLStoredQt)
Sat Apr 27 22:03:23 2024
y
5 m
5 m
Shape2
G4
Geant4
Output
/vis/viewer/set/hiddenMarker true
/vis/viewer/set/viewpointThetaPhi 120 150
#
Re-establish auto refreshing and verbosity:
/vis/viewer/set/autoRefresh true
/vis/viewer/refresh
/vis/verbose warnings
Visualization verbosity changed to warnings (3)
#
For file-based drivers, use this to create an empty detector view:
#/vis/viewer/flush
Changing export format to "jpg"
Session :
Type here to search
37°C Partly cloudy
10:03 PM
27-Apr-24

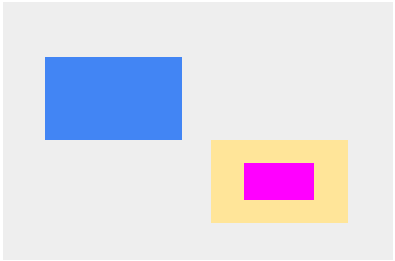
Mandatory class 1: Detector Construction (geometry)

```
G4Material* world_mat = nist->FindOrBuildMaterial("G4_Galactic");//Vaccum

 // define sizes
 G4double world_sizeXYZ = 2000*cm; // 2cm cube

// create world volume

//solid volume
 G4Box* solidWorld =
   new G4Box("World",                       //its name
      0.5*world_sizeXYZ, 0.5*world_sizeXYZ, 0.5*world_sizeXYZ);     //its size

// logical volume
  G4LogicalVolume* logicWorld =
    new G4LogicalVolume(solidWorld,          //its solid
                        world_mat,           //its material
                        "World");            //its name
// physical volume
  G4VPhysicalVolume* physWorld =
    new G4PVPlacement(0,                     //no rotation
                      G4ThreeVector(),       //at (0,0,0) // world usually placed at 0,0,0
                      logicWorld,            //its logical volume
                      "World",               //its name
                      0,                     //its mother  volume - world mother volume is 0
                      false,                 //no boolean operation
                      0,                     //copy number
                      checkOverlaps);        //overlaps checking
```



Detector Construction: Three volumes





World volume (also mother volume of all inside)

daughter volume

daughter volume (also mother volume of the one inside)

daughter volume

Exercise 1a: Place a gold target in the world volume

```
// G4Material* target_mat = nist->FindOrBuildMaterial("??"); // Gold target

// G4double target_sizeXY = ??; // set lateral dimensions
// G4double target_sizeZ  = ??; // set thickness

// G4Box* solidTar =                        // create solid volume
//   new G4Box("Target",                    //its name
//       0.5*target_sizeXY, 0.5*target_sizeXY, 0.5*target_sizeZ); //its size

// G4LogicalVolume* logicTar =               // create logic volume
//   new G4LogicalVolume(solidTar,           //its solid
//                       target_mat,            //its material
//                       "Target");          //its name

// // create physical volume
// new G4PVPlacement(0,                      //no rotation
//                   G4ThreeVector(),        //at (0,0,0)
//                   logicTar,               //its logical volume
//                   "Target",              //its name
//                   logicWorld,             //its mother  volume
//                   false,                  //no boolean operation
//                   0,                      //copy number
//                   checkOverlaps);         //overlaps checking
```

- Change the material to the Gold
  - https://www.fe.infn.it/u/paterno/Geant4_tutorial/slides_further/Geometry/G4_Nist_Materials.pdf
- Set the size to one similar to the one used in the experiment
- Where would you place it?
  - We will place it at the origin
  - Origin is the centre of the World volume
- Uncomment the code !
  - Lines 108-130 of DetectorConstruction.cc
- Compile the code and see how the geometry looks like

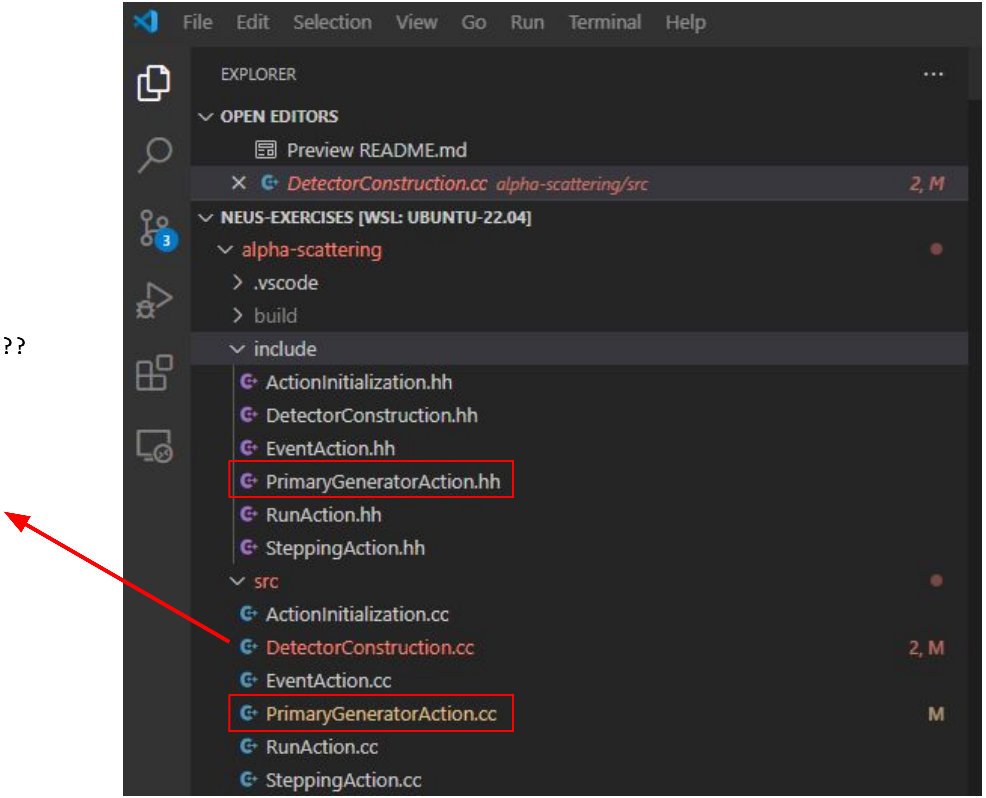
Exercise 1b: Place a detector in the world volume

```
`// G4Material* detector_mat =
nist->FindOrBuildMaterial("??"); // use simple material like
air

  // G4double detecter_inner_radius = 0.999*cm;
  // G4double detecter_outer_radius = 1.000*cm;

  // G4Sphere* solidDet =
  //   new G4Sphere("Detector",                    //its
name
  //       detecter_inner_radius, detecter_outer_radius,
0.*degree, 360*degree, 0*degree, 180*degree);`
```

- Uncomment the code
  - Lines 134 - 143 of DetectorConstruction.cc
- Create a sphere that:
  - Surrounds the target
  - Not extending out of the World Volume
  - Thin
- A sample `Solid Volume` is created for you
- You should create the
  - `logical volume`
  - `physical volume`
- Compile the code and see how the geometry looks like

Mandatory class 2: Primary generator action (Particle source)

```
G4ParticleTable* particleTable =
G4ParticleTable::GetParticleTable();
    G4String particleName;
    G4ParticleDefinition* particle
      = particleTable->FindParticle(particleName="alpha");
    fParticleGun->SetParticleDefinition(particle);
    //
fParticleGun->SetParticleMomentumDirection(G4ThreeVector(??,??,??
));
    // fParticleGun->SetParticleEnergy(??.*MeV);
```



Exercise 1c: Setting particle properties

```
G4ParticleTable* particleTable =
G4ParticleTable::GetParticleTable();
    G4String particleName;
    G4ParticleDefinition* particle
      = particleTable->FindParticle(particleName="alpha");
    fParticleGun->SetParticleDefinition(particle);
    //
fParticleGun->SetParticleMomentumDirection(G4ThreeVector(??,
??,??));
    // fParticleGun->SetParticleEnergy(??.*MeV);
```

- The particle is already set to `alpha`
- Uncomment the code
  - Lines 58 - 59 of PrimaryGeneratorAction.cc
- Set the
  - Momentum direction
  - Energy as specified in the paper
- Uncomment line 77 and set the
  - `Particle position`
- Compile the code and on the window the pops up, type the command in the text field at the bottom (session):
  - `\run\beamOn 100`

Exercise 1c: Setting particle properties

```
G4ParticleTable* particleTable =
G4ParticleTable::GetParticleTable();
    G4String particleName;
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      = particleTable->FindParticle(particleName="alpha");
    fParticleGun->SetParticleDefinition(particle);
    //
fParticleGun->SetParticleMomentumDirection(G4ThreeVector(??,
??,??));
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```

- The particle is already set to `alpha`
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Exercise 1d: More details on tracks

```
-   Blue:      Positive charge
-   Red:       Negative
-   Green:     Neutral
```

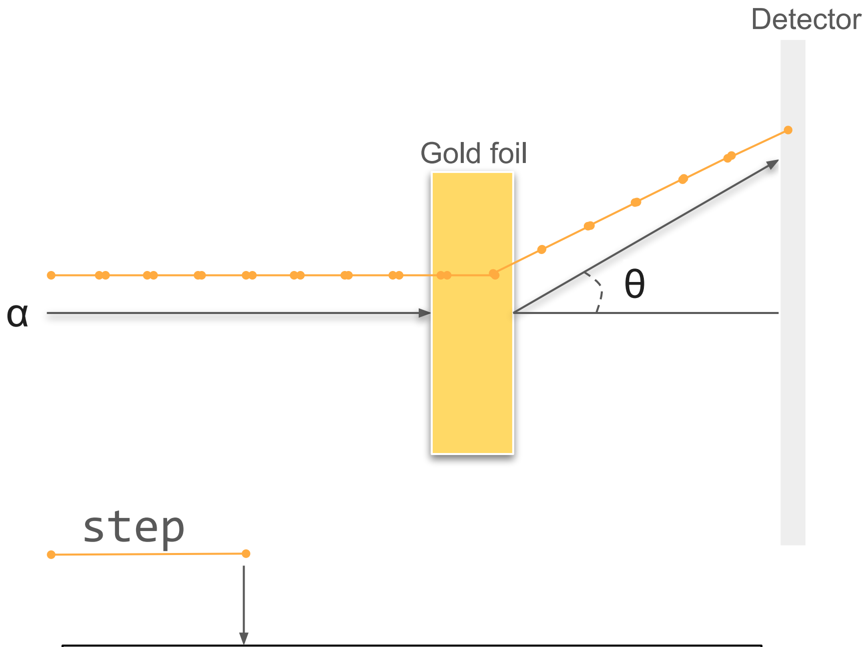
- Change the world material to G4_AIR
    - Zoom into the tracks and see if you can observe any other colours
- Guess which particles these colours represent

Mandatory class 3: Physics list

```
// Physics list
G4VModularPhysicsList* physicsList = new QBBC;
physicsList->SetVerboseLevel(1);
runManager->SetUserInitialization(physicsList);
```

- Check exampleB1.cc
  - Line 71
- A `physics list` is responsible for:
  - specifying all the particles that will be used in the simulation application
  - list of physics processes assigned to each individual particles
- 28 packaged reference list provided by Geant4
  - QGSP_BERT, QGSP_BERT_EMV, QGSP_BERT_HP, QGSP_BIC, FTFP_BERT, LBE, LHEP …
- For some experiments you may have to write your own physics list

Reading out data




```
UserSteppingAction(const G4Step* step)
in SteppingAction.cc.
The step pointer contains information about the
particles properties at that step
```

Reading out data

a. File is created in RunAction.cc
    i. Line 63: BeginOfRunAction

b. File is closed in RunAction.cc
    i. Line 131: EndOfRunAction

c. File is filled in SteppingAction.cc
    i. Line 56: UserSteppingAction

Exercise 1d

a. Inside the `build` folder, you will find a file name `output.csv`
b. Check how the file looks like and what it contains
c. Use the analysis.py file to perform some simple analysis
   i. Check the particle ids of particles that hit the detector
      1. Use the PDG to verify the numbers
   ii. Check the energy of the alpha particle that hits the detector
   iii. Plot the angular distribution of the particles
   iv. Change the thickness of the foil to 5 different values and plot the variation of transmission as a function of thickness
   v. Check at what thickness the alpha particle stop penetrating the gold foil
   vi. Change the foil material and plot the angular distributions

Exercise 1d

a. Inside the `build` folder, you will find a file name `output.csv`
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Exercise 1f-Neutrino generation

a. In this assignment, you will demonstrate the production of neu
b. Read the paper at:
   i. The NuMI Beam at FNAL and its Use for Neutrino Cross Section Measurements: https://arxiv.org/pdf/0709.2737
c. Use the neutrino-production project for this purpose
d. Create a:
   i. A target as mentioned in the paper
   ii. A beam at the end of the target with energy as mentioned in the paper
   iii. A detector (thin) at the other end of the detector
   iv. World volume encompassing the target, detector and beam
e. Shoot 1 proton and list down the particles you see in the detector
f. What would you do in order to see neutrinos?

Exercise 1f-Neutrino generation

a. Increase the world volume to add a decay volume
b. Place a detector at the end of the decay volume:
    i. List down the particles you see
    ii. The energy spectrum of all the particles