Universitatea Politehnica Bucureşti
Facultatea de Ştiinţe Aplicate
Proiect cercetare științifică 1

Geant4

Student: Geantă Andrei Alexandru

Main objective

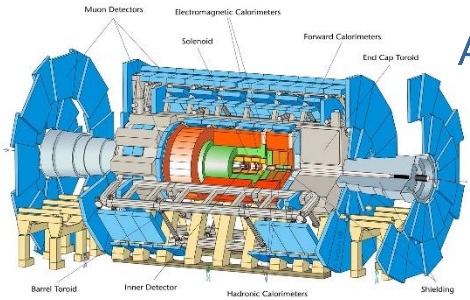
- Basic introduction to Geant4 software
- Installation of Geant4 software in LaMAR lab. of Department of Physics

Table of contents

What is Geant4?

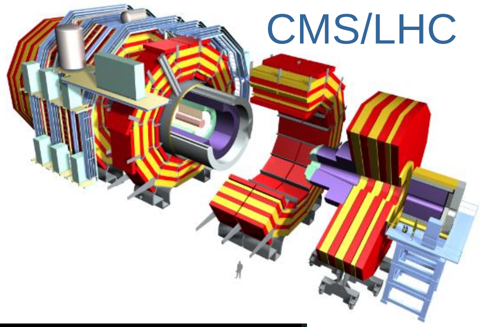
A Monte Carlo software toolkit to simulate the passage of particles through matter.

- It is for detector simulation of research in
  - **High energy physics**
  - **Nuclear physics**
  - **Cosmic ray physics**



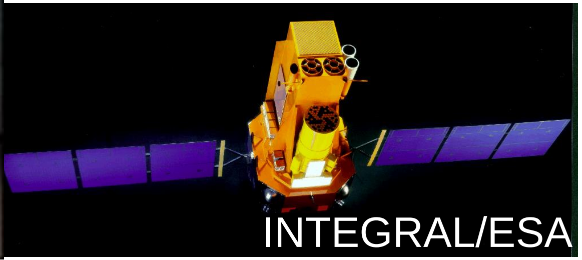
ATLAS/LHC

- It is also for application in
  - **Space science**
  - **Radiological science**
  - **Radiation background calculation**
  - **etc**



CMS/LHC

HIMAC/NIRS



INTEGRAL/ESA

Detector Simulation - General

- **General characteristics of a particle detector simulation program:**
  - ✓ **You specify the *geometry of a detector.***
  - ✓ **Then the program automatically *transports* the particle you injected to the detector by simulating the *particle interactions in matter* based on the Monte Carlo method.**

The heart of the simulation

➔ ***The Monte Carlo method to simulate the particle interactions in matter***

MC Simulation of Particle Interactions with Matter - 1

- **Basic concept : The exponential law**

$P(x)$ probability of not having an interaction after a distance *x*

wdx probability to having an interaction between *x* and *x+dx*

$$w = N \cdot \sigma$$

N: *Number of target particles per unit volume*

σ: *Interaction cross section*

$$P(x+dx) = \underline{P(x)}(1\underline{-wdx})$$

Probability of no-interaction in dx

Probability of no-interaction up to x

$$P(x) = \exp(-wx) \qquad P(0) = 1$$

← *Probability distribution function*

= *Exponential distribution*

MC Simulation of Particle Interactions with Matter - 2

- Generation of interactions

The probability of interaction between x ~ x+dx is:

$$P_{int}(x) = 1 - exp(-wx)$$

Then you can generate an interaction using the inverse method:

η: *Uniform random number of [0,1]*

$$\eta = 1 - exp(-wx)$$

$$x = -\frac{ln(1-\eta)}{w}$$

MC Simulation of Particle Interactions with Matter - 3

- Generation of interactions in heterogeneous matter

'*x*' has the dimension of 'length' and depends on material. Therefore the sampling depends on material.

However, the following sampling is independent of material:

$$xw = -ln(1-\eta)$$

Therefore we introduce the 'mean free path' λ as

$$\lambda = \frac{\int xP(x)dx}{\int P(x)dx} = \frac{1}{w}$$

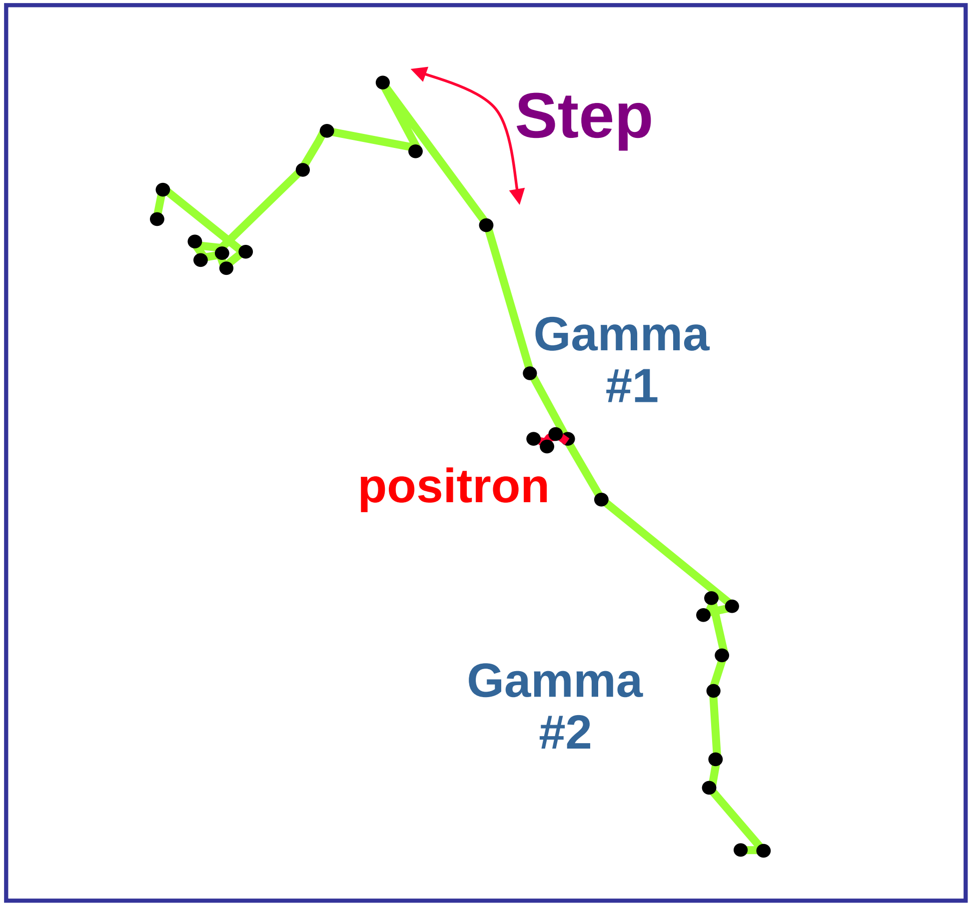
Then we can sample *in the material independent way* by measuring the length in the unit of λ.

$$\frac{x}{\lambda} = -ln(1-\eta)$$

Number of Mean Free Path (NMFP)

Particle Transportation - Introduction

- A particle is transported in the *stepwise* manner.



Example:

Annihilation of the 8MeV positron in water

Particle Transportation: How to Determine a Step - 1

➊ At the beginning of a step, the NMFP (Number of Mean Free Path) for each physics process, which is associated to the particle, is sampled by the *material independent way.*

Example

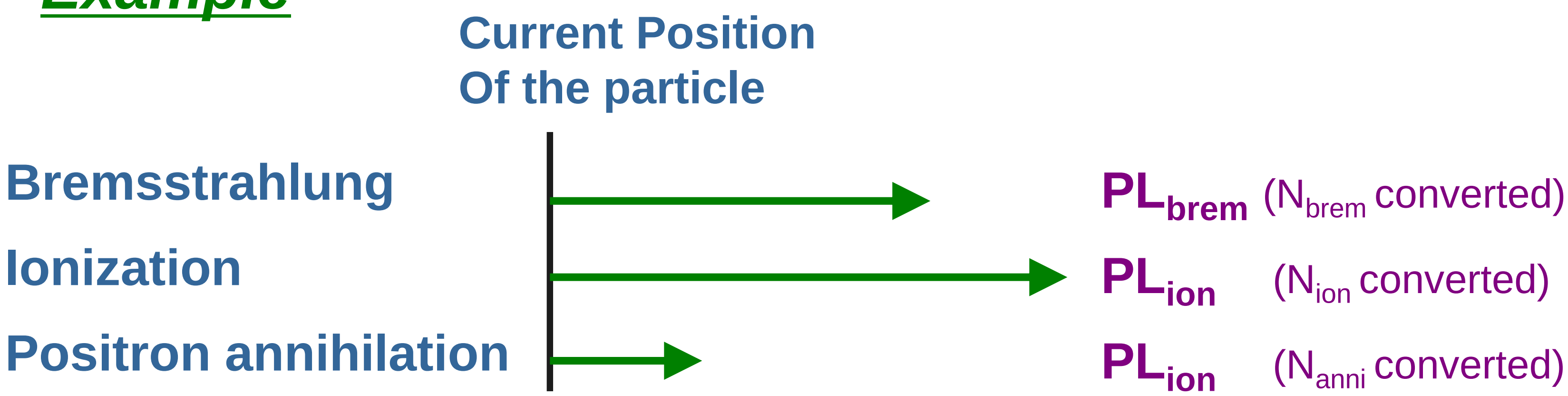
The positron has the following physics processes. For each of these processes, assigns NMFP by the exponential law of interactions.

- **Bremsstrahlung** — **NMFP = N_{brem}**
- **Ionization** — **NMFP = N_{ion}**
- **Positron annihilation** — **NMFP = N_{anni}**

Particle Transportation: How to Determine a Step - 2

❷ Using the cross-section in the material where the particle is currently in, converts the each NMFP to the physical length (PL):

Example



❸ The process which has the minimum PL determines the step length.

➔ **'Positron annihilation' in the above example.**

Particle Transportation - continued

❹ Transports the particle for the determined step.

❺ If the particle is still alive after the interaction, do the sampling again for all NMFPs, and continue the transportation.

❻ If the particle disappears after the interaction, then the transportation is terminated.

What Geant4 Can Do for You?

- Transports a particle step-by-step by taking into account the interactions with materials and external electro-magnetic field until the particle
  - **loses its kinetic energy to zero,**
  - **disappears by an interaction,**
  - **comes to the end of the simulation volume (end of the world).**
- Provides a way the user intervenes the transportation process and grabs the simulation results
  - **at the beginning and end of transportation,**
  - **at the end of each stepping in a transportation,**
  - **at the time when the particle going into the sensitive volume of the detector,**
  - **etc.**

What You Have to Do for Geant4?

- Three indispensable information you have to prepare:
  - **Geometrical information of the detector**
  - **Choice of physics processes**
  - **Kinematical information of particles which go into the detector**

- Auxiliary you have to prepare:
  - **Magnetic and electric field**
  - **Actions you want to take when you intervene the particle transportation**
  - **Actions you want to take when a particle goes into a sensitive volume of the detector**
  - **etc.**

Tools for Input Preparation

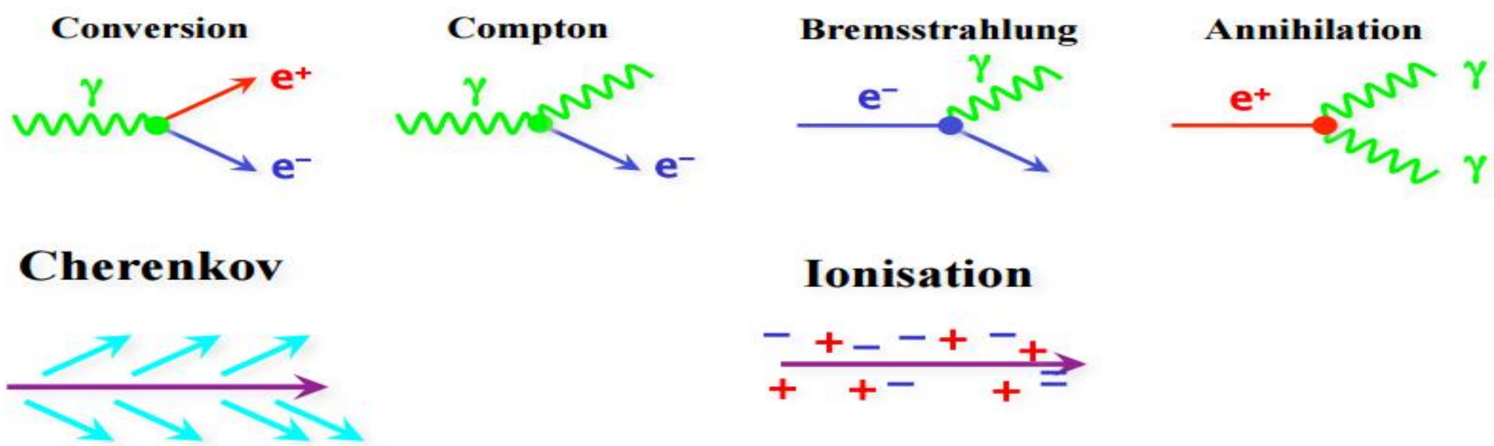
Geant4 provides standard tools to help you to prepare input information.

- Multiple choices to describe the detector geometry
  - **Combining basic geometry elements (box, cylinder, trapezoid, etc)**
  - **Representation by surface planes**
  - **Representation by boolean operation, etc**
- Standard way to define materials in the detector
  - **A large collection of examples to define various materials**
- A set of wide variety of particles
  - **Standard elementary particles (electron, muon, proton,….)**
  - **Unstable particles (resonances, quarks, …)**
  - **Ions**
  - **Exotic particles (geantino, charged geantino)**

Choice of Physics Processes

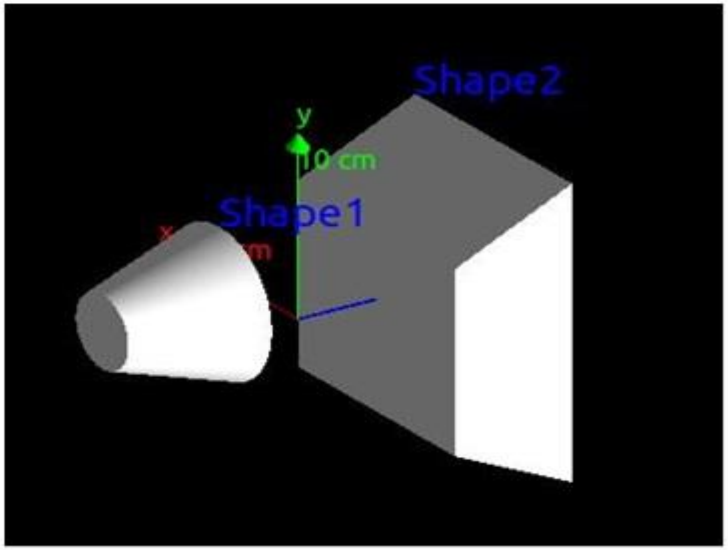
Geant4 provides a wide variety of physics models of particle interactions with matter you can select.

- Category of physics processes
  - **Standard electromagnetic processes**
  - **Low energy electromagnetic processes**
  - **Hadronic processes**



Example 1

- Particle interaction with matter
- Two volumes: tissue and bone materials
- Nr of events: 1000
- Particle energy: 100 MeV



  - γ
    - Dose in scoring volume : 554.131 picoGy $\pm$ 32.934 picoGy
  - p^+
    - Dose in scoring volume : 1.01163 picoGy $\pm$ 1.01113 picoGy
  - n^0
    - Dose in scoring volume : 317.497 picoGy $\pm$ 36.0848 picoGy

Example 2

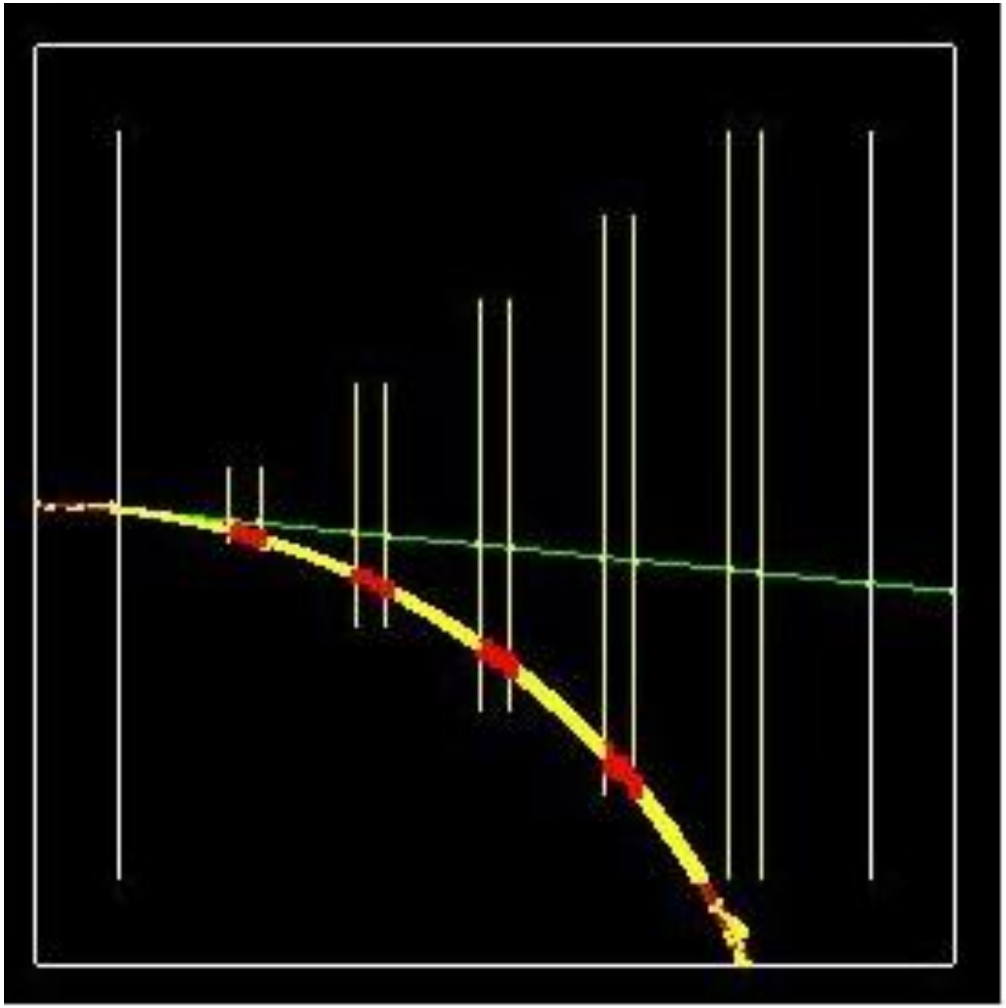
- **Fixed target experiment.**
- **Target followed by six chambers of increasing transverse size at defined instances from the target.**
- **In addition, a global, uniform, and transverse magnetic field can be applied.**
- **Run:**

  Magnetic Field: 0.2 Tesla

  TargetMaterial: Water

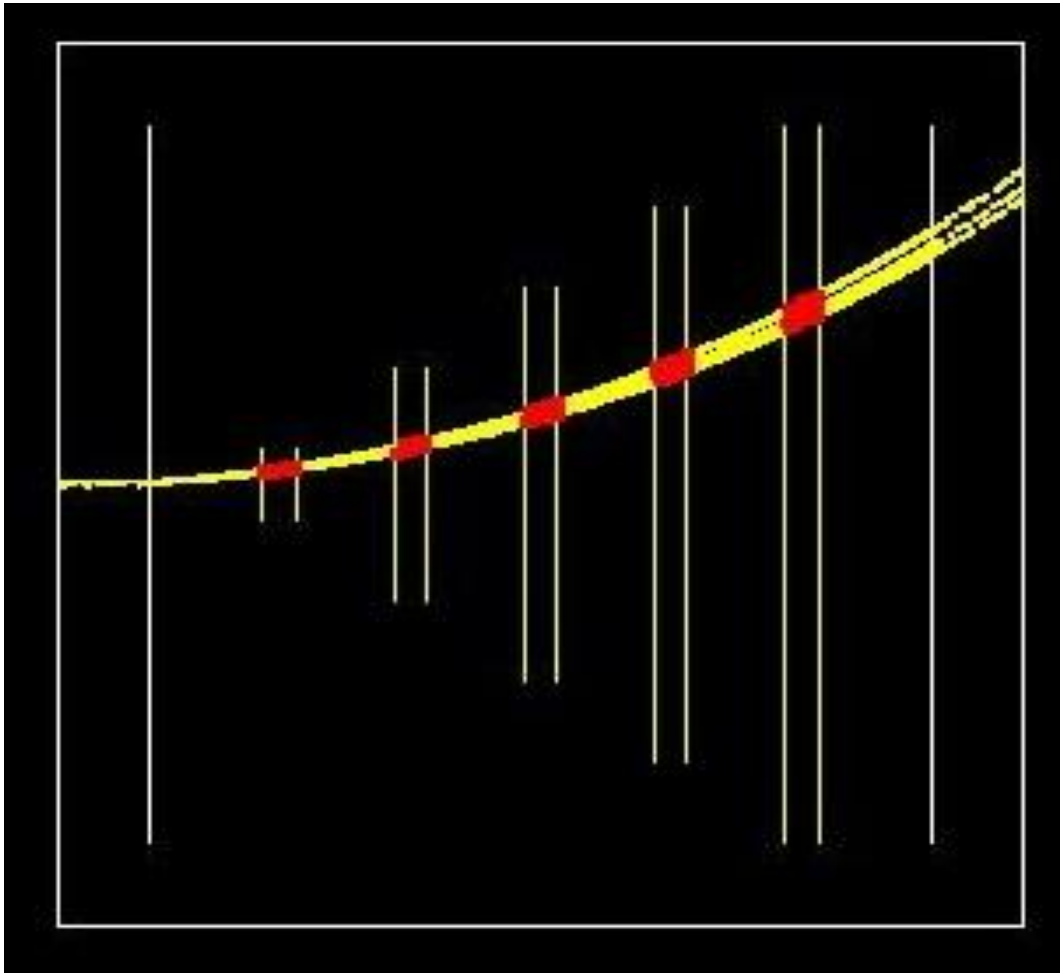
  ChamberMaterial: Ar

Example 2



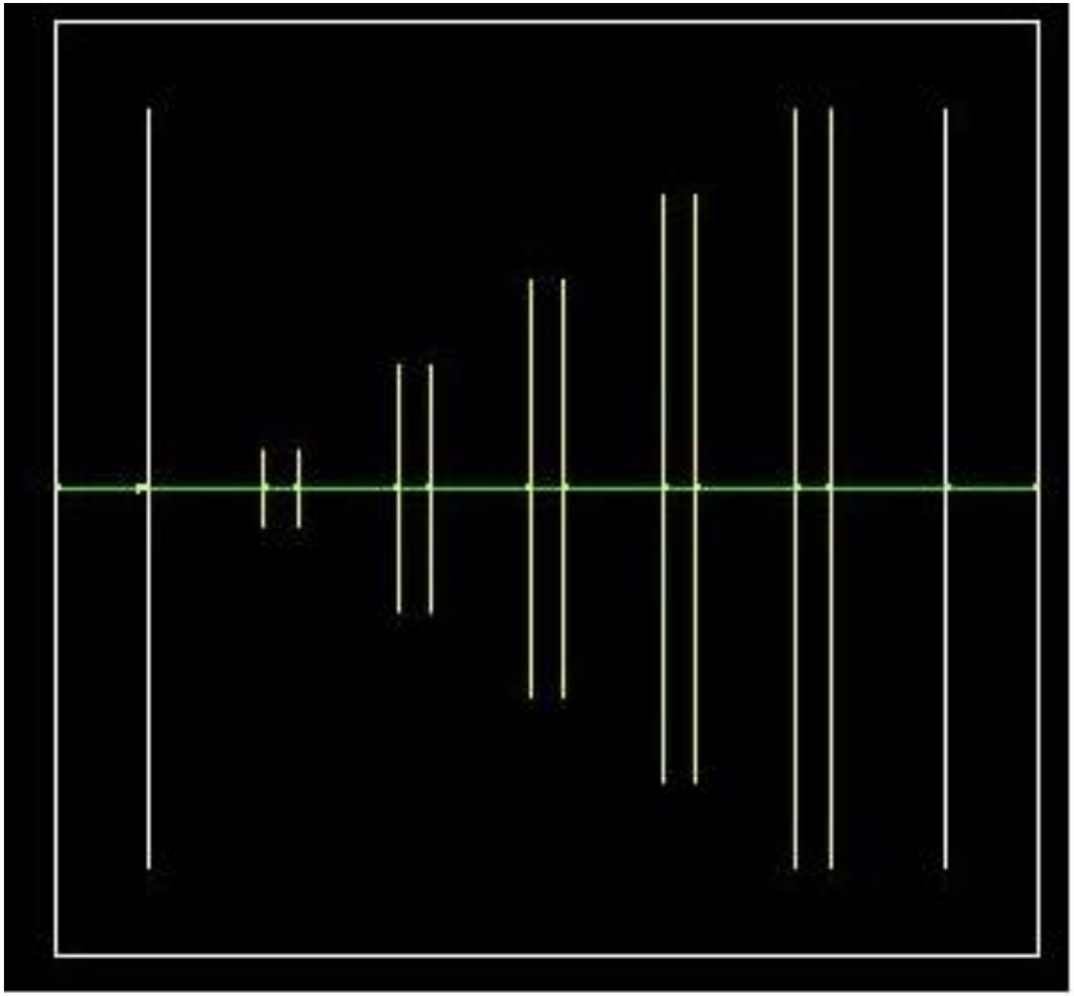
Interaction between an e- and the detector material placed in a magnetic field.

Example 2



Interaction between a proton and the detector material placed in a magnetic field.

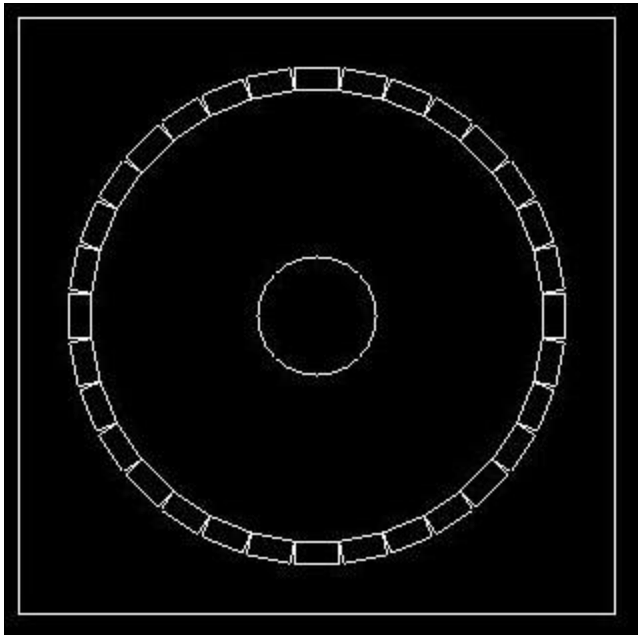
Example 2



Interaction between a neutron and the detector material placed in a magnetic field.

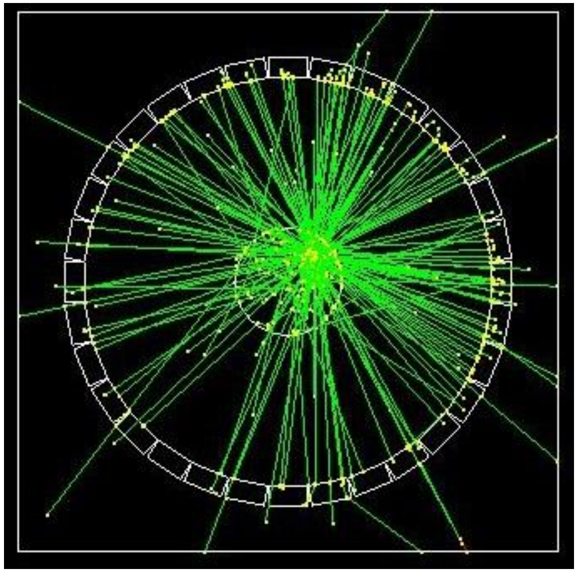
Example 3

- **This example simulates schematically a Positron Emitted Tomography system.**
- **The support of gamma detection are scintillating crystals.**
- **The head of a patient is schematised as a homogeneous cylinder of brain tissue, placed at the center of full detector.**
- **“Good” event is an event in which an identical energy of 511 keV is deposited in two separate Crystals.**
- **The total dose deposited in a patient during a run is also computed.**



Example 3

- **Particle beam: F18 ion**
- **The run was 40000 events ; Nb of 'good' e+ annihilations: 5228**
- **Total dose in patient : 1.22886 nanoGy**



- **Particle beam: C11 ion**
- **The run was 40000 events ; Nb of 'good' e+ annihilations: 5226**
- **Total dose in patient : 1.67531 nanoGy**

- **Particle beam: O15 ion**
- **The run was 40000 events ; Nb of 'good' e+ annihilations: 5283**
- **Total dose in patient : 2.71752 nanoGy**

Conclusions & Perspectives

- **GEANT4 is a toolkit for detector simulations.**
- **It allows the description of the geometry and material of the detector elements.**
- **The kinematics of the primary physics events is used to generate particles which are then tracked through the detector, simulating their physics interactions in matter and the effect of fields and boundaries on their trajectories.**
- **Detector simulations in LaMAR.**
- **Detector simulations in HEP.**