Experimental Techniques in Particle Physics

Geant4: A Toolkit for MC Simulation in Nuclear and Particle Physics. Overview and Applications.

Andreas Nowack

nowack@physik.rwth-aachen.de

RWTH Aachen University

WS 2020/21

Organisational Matters

- date and place
  - ZOOM:
    https://rwth.zoom.us/j/92810958987?pwd=cTF3bWpNS0lVMStpUGROaXZiaU5kUT09
  - Thursday
    - 14:30 – 16:00 obligatory
    - 16:00 – 17:30 optional

    in case of individual problems or questions, two tutors will help you

- general structure
  - recap
  - presentation of the topic of the day
  - hands-on tutorial, exercises, homework

- slides and program skeletons will be provided via Moodle before the tutorial

- requirements
  - CIP pool login (you can get it at the CIP pool helpdesk (edv-support@physik.rwth-aachen.de))

About Myself

- **Dr. Andreas Nowack**
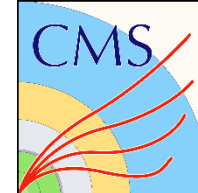 - e-mail: nowack@physik.rwth-aachen.de
  - phone: 0241 80-27282
  - office: 28 A 223 (currently

- **Duties**
  - CMS:
    - Grid Computing
    - operation and management of a computing cluster which is part of the Worldwide LHC Computing Grid
  - Institute:
    - part of the team managing CIP Pool and IT of 3rd institutes

Scope of the Tutorial

- building blocks of a Geant4 simulation
- modelling an experimental set-up
- simulation of different particle sources
- measurement of simulated interactions

Geant 4 Overview

What is Geant4?
A toolkit for the Passage of Particles through Matter

- Monte Carlo

- All Particle

- Complex Geometry

- Motion

- Fields

- Modern Programming (C++)
  - Hence FLEXIBLE

- Open and Free

I'm **version 4**

BRAVO!
BRAVO! BRAVO!

Geant 4 Overview

GEANT4 does not simulate beam-beam interactions.
One probably has to combine it with some beam-beam event generators
(pythia, sherpa…)

GEANT4 is not an executable program/file.
It is a collection of libraries organized in classes (C++ OOP)

GEANT4 is not an analysis program.
One probably has to combine it with other OOP analysis tools (ROOT)

Let us assume…

No doubt on that!

Don't give up !
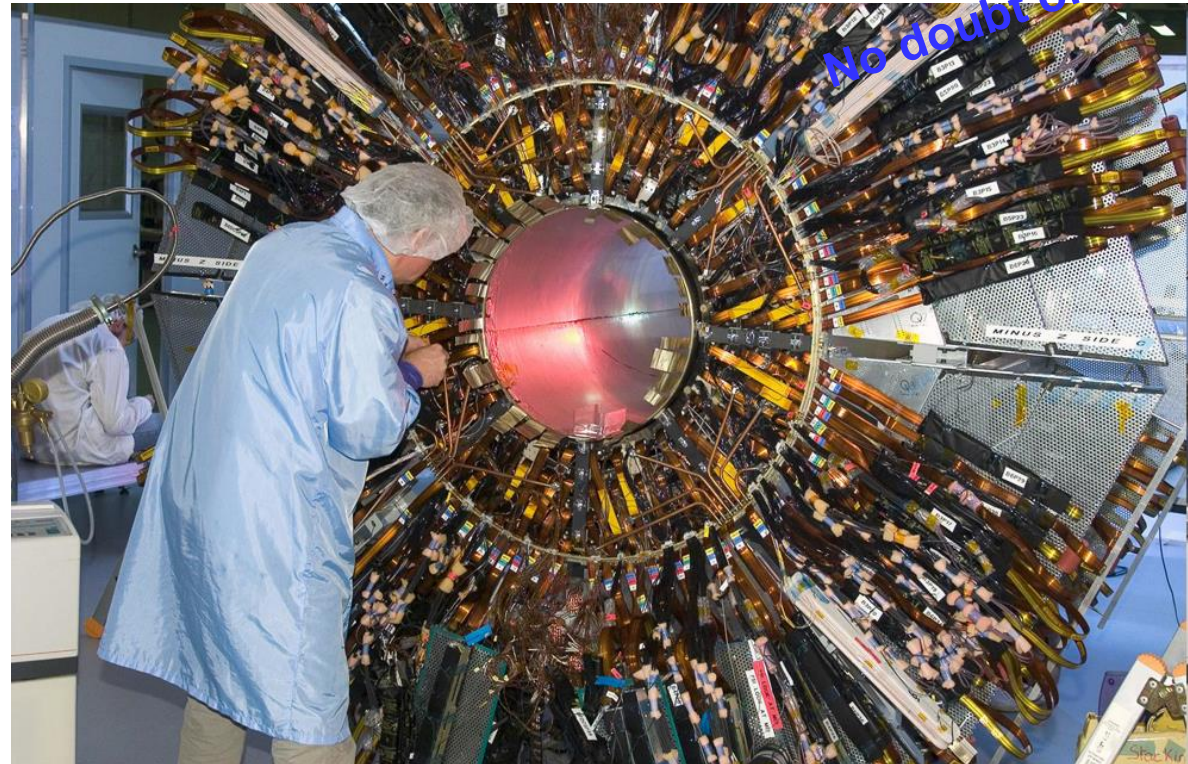
And you have to study this…

Plan of the Geant4 Tutorials

In total 13 tutorials organized in 5 topics

After an introduction on how to use the Geant4 installation in our environment.

- **Topic 1: Geant4 geometry (6)**
  - Basic Geometry
  - Advanced Geometry (detector modelling)
- **Topic 2: Materials in Geant4 (2)**
  - Basics: How to implement simple and complex Materials
  - Materials using NIST database
- **Topic 3: Particles and processes (2)**
  - Physics List
  - Primary particle generation
- **Topic 4: How to interact with your simulation (2)**
  - G4 user actions
- **Topic 5: How to do a simple analysis (1)**
  - (i.e. Link between G4 and Root)

Documentation (Today's topic after this overview)

50 GeV e⁻ → **E - 166** → 10 MeV γ⃗ → e⁺, e⁻

International Polarized Positron Collaboration
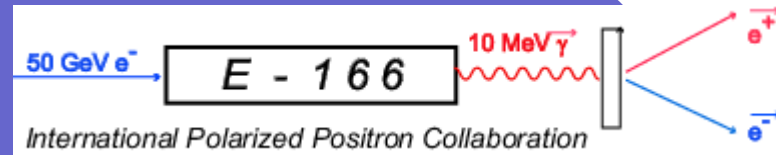
E166 Experimental setup
(Positron table at SLAC)

Technical design
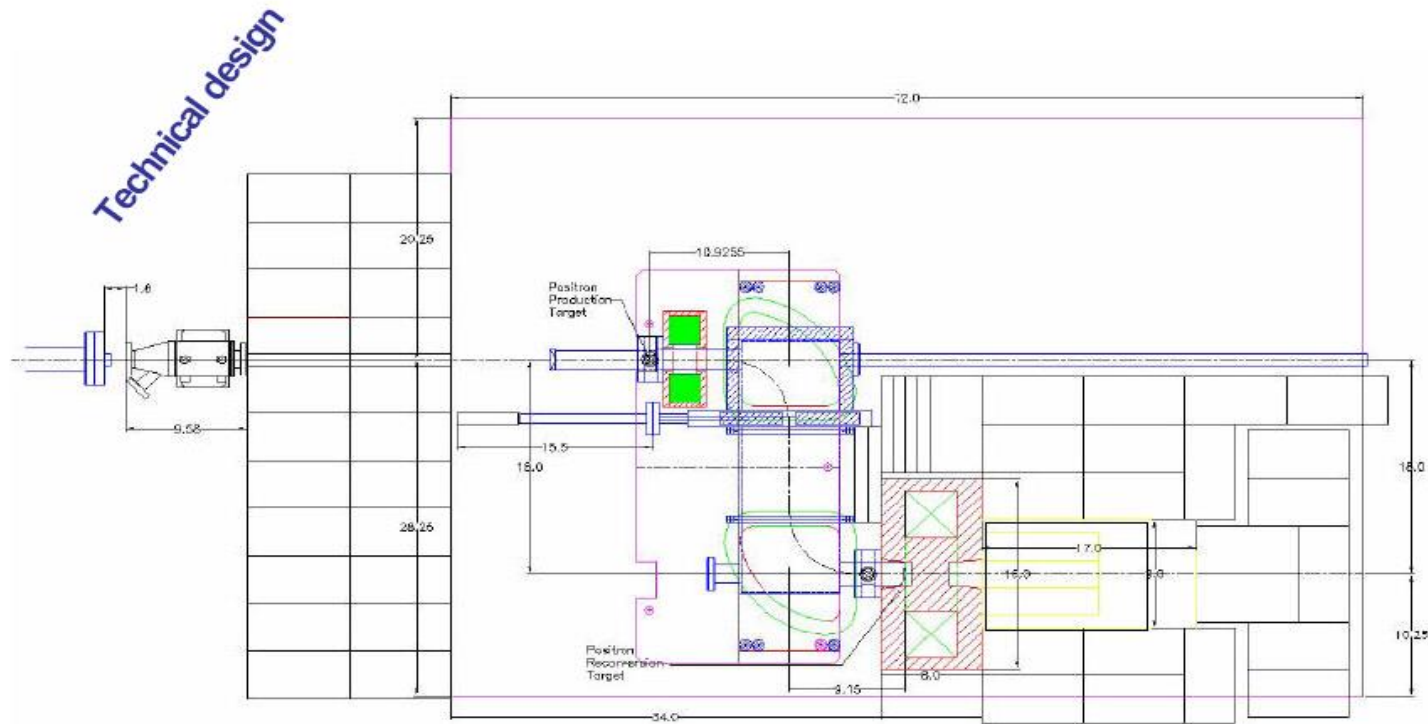
Example of an Experimental Setup. Spectrometer
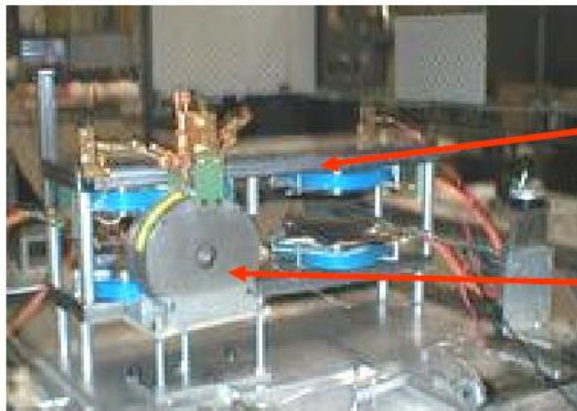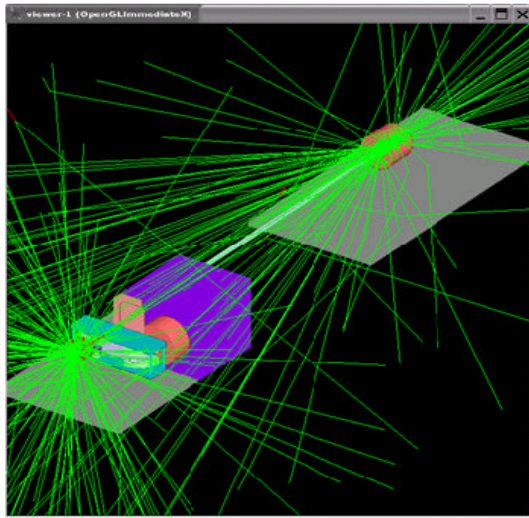
Bending Magnets

Solenoid
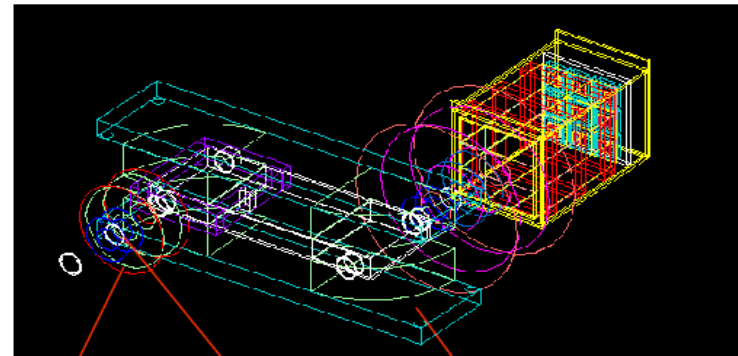
Solenoid

Conversion target

Spectrometer

Example of an Experimental Setup.

bending magnet

W and Pb bricks for shielding

solenoid

conversion target 0.5X_0 W

$conversion\ target\ 0.5X_0\ W$

Gamma table

Positron table

polarized γ beam from the Helical undulator

CsI calorimeter
inside the Lead block

analyzing magnet

reconversion target 0.5X_0 W
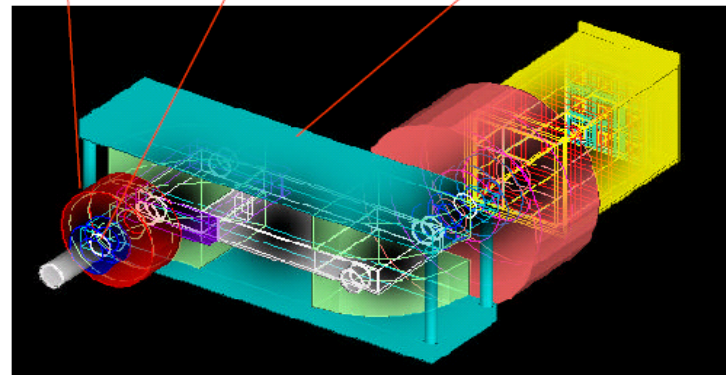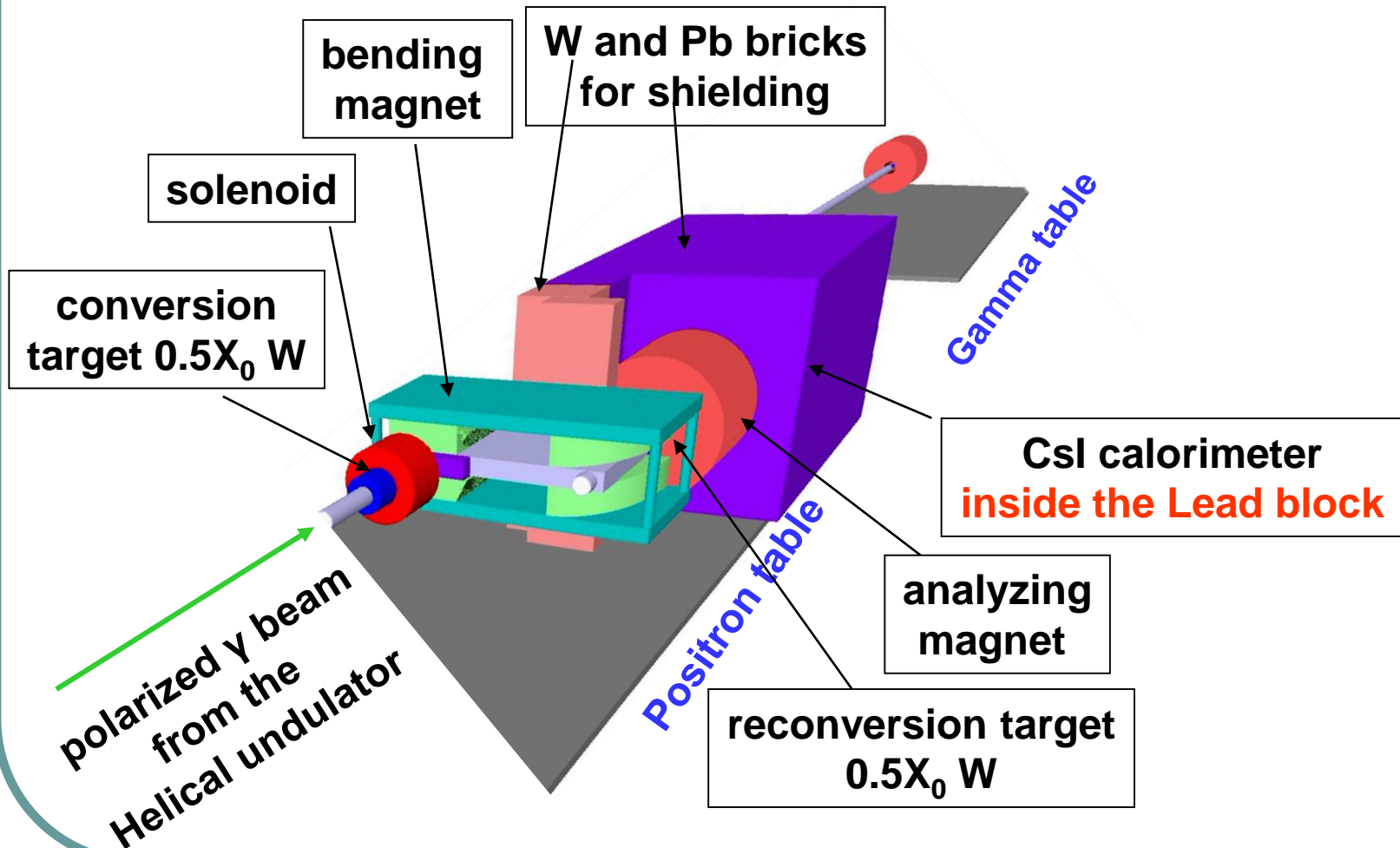
Example of an Experimental Setup. Test Run
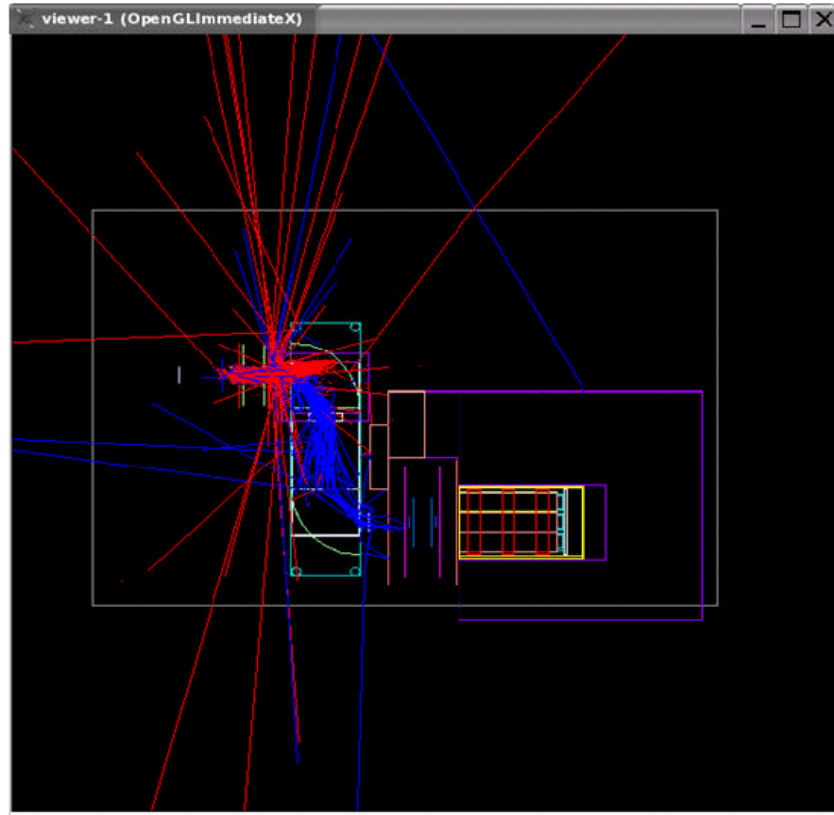
Example of an Experimental Setup.
Spectrometer E166 Experiment at SLAC
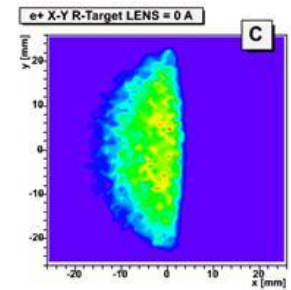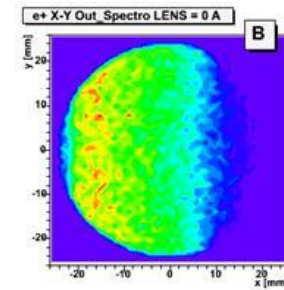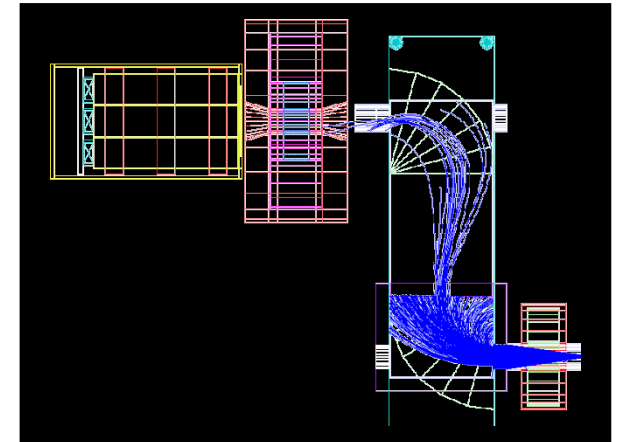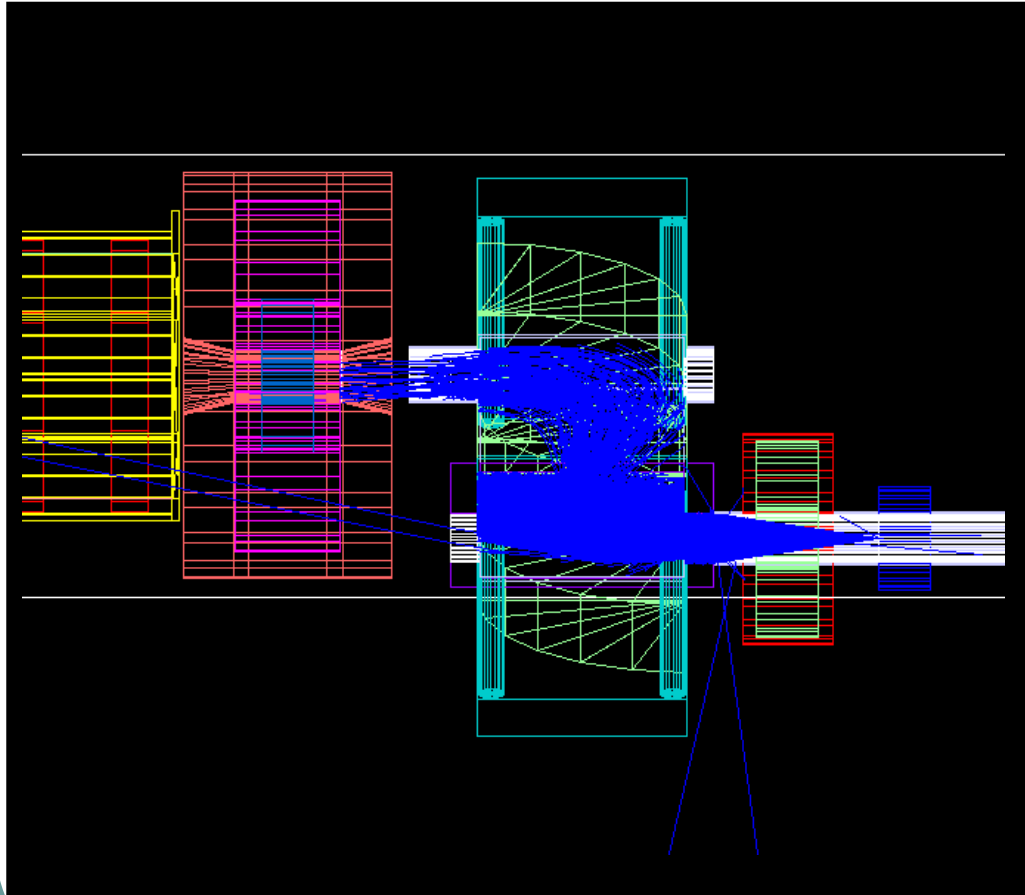
No!!!
It is not complicated.

Geometry in Geant4
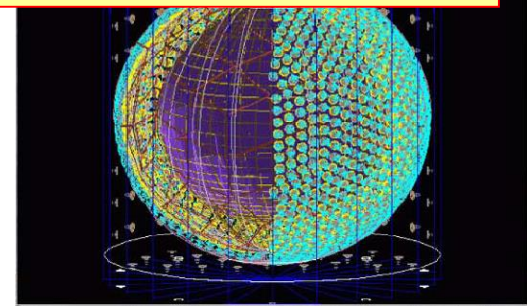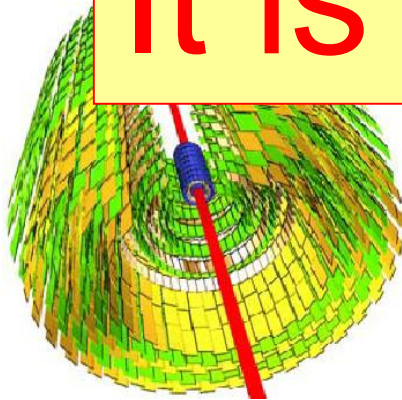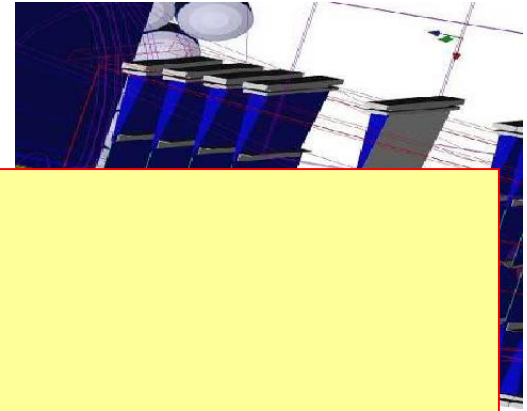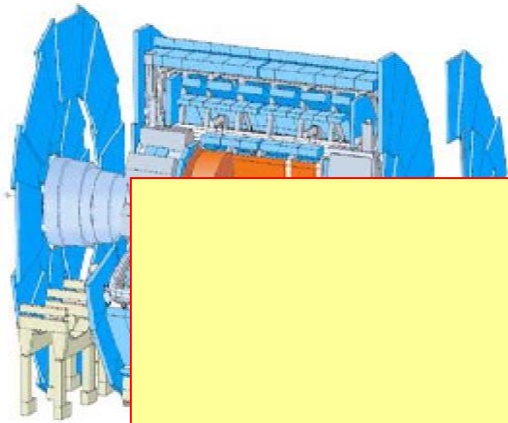
How to Start with the Geometry?

We are lucky: We have already

predefined
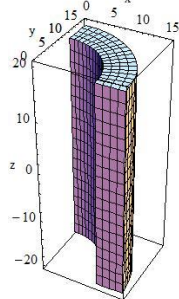
CSG Solids (geometries)
(Constructed Solid Geometry)
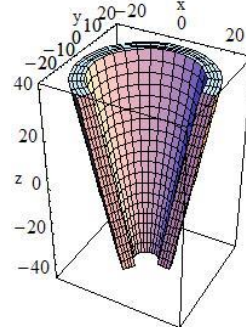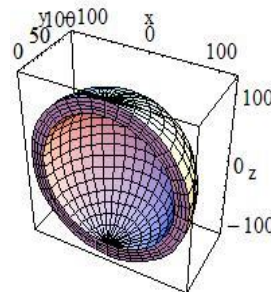
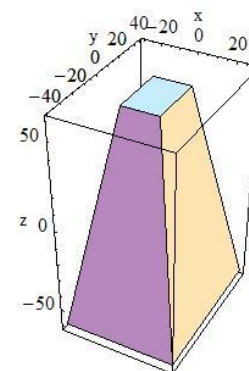**You just need to get used to its concept and syntax!**
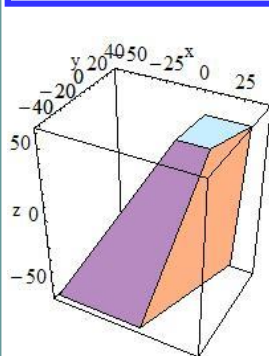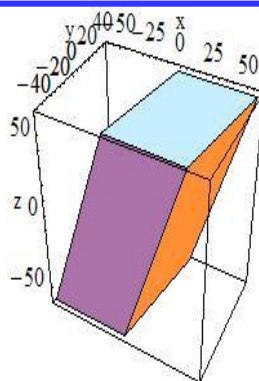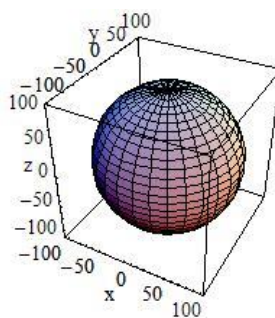**Then it's easy!**
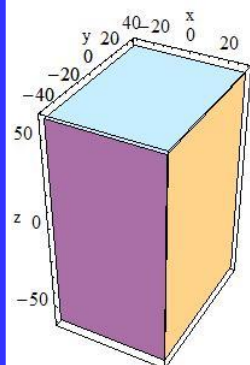
Box

Tube

Cone

Sphere

Trapezoid
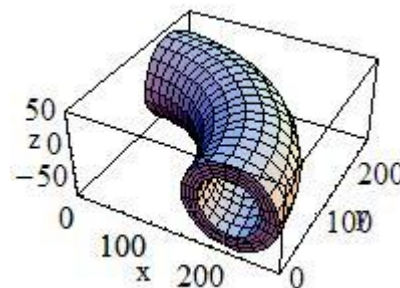
My preferred ones… very basic and simple… see exercise

Generic
trapezoid
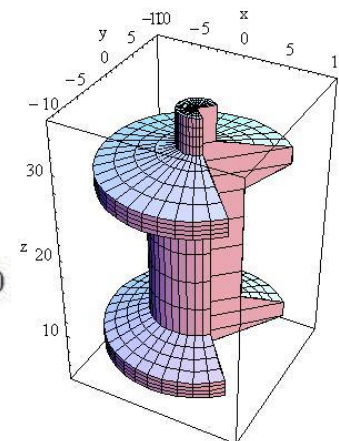
Parallelepiped

Solid
Sphere

Torus

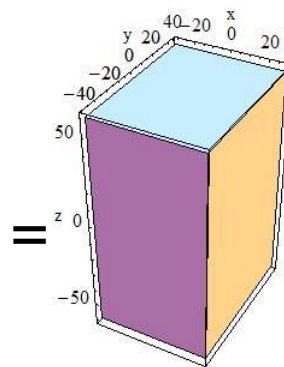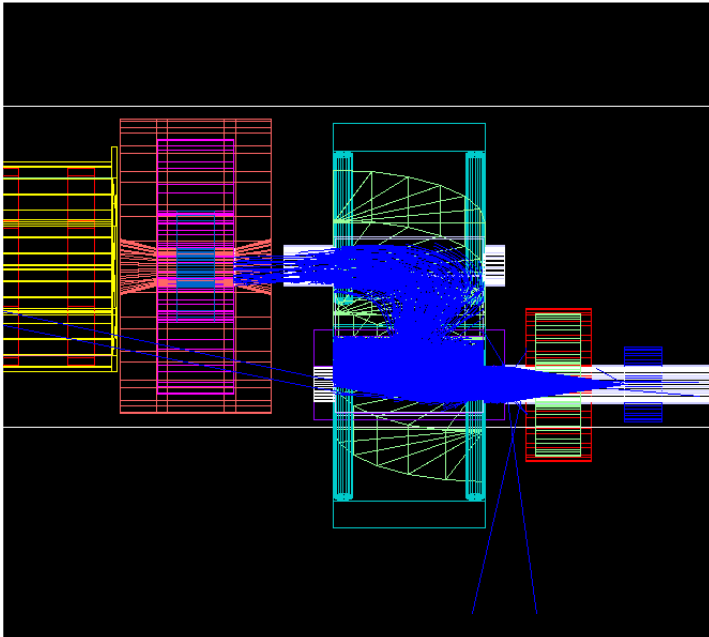Polycons

Is It Enough to Have Only 22 CSG?

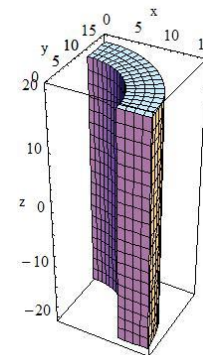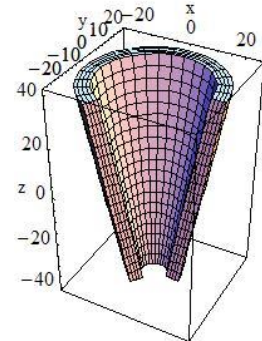Yes, 22 predefined CSG are more than enough…

= **a few boxes** & **a few tubes** & **one (1) cone**

What About a Special Geometry?
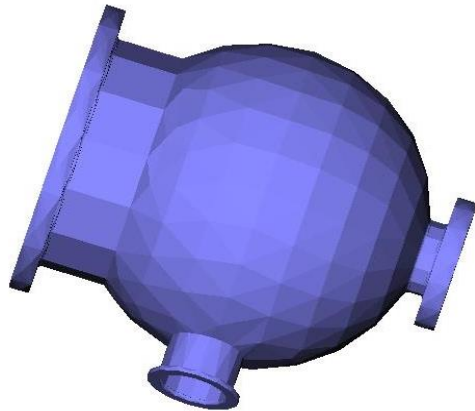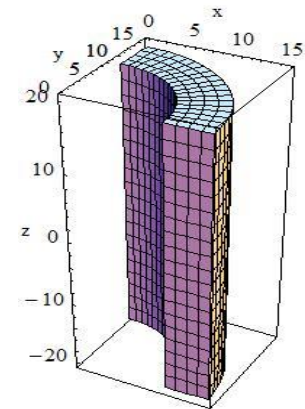
This is a result of Boolean operations on CSGs.

For example this one…

We have only three Boolean operations

1. Subtractions
2. Unions
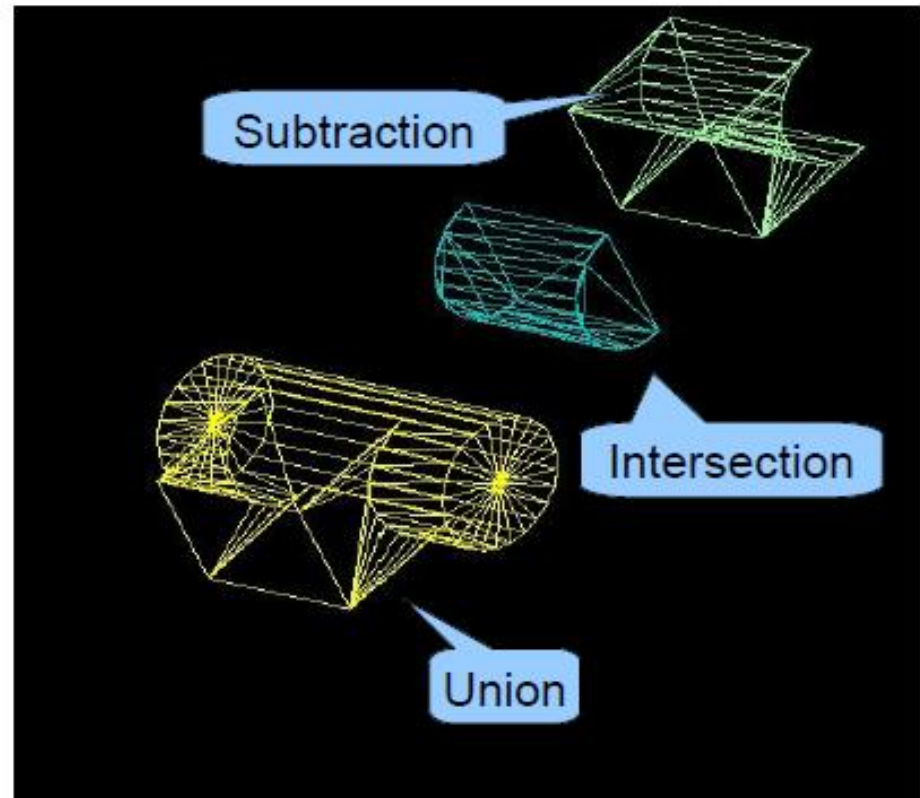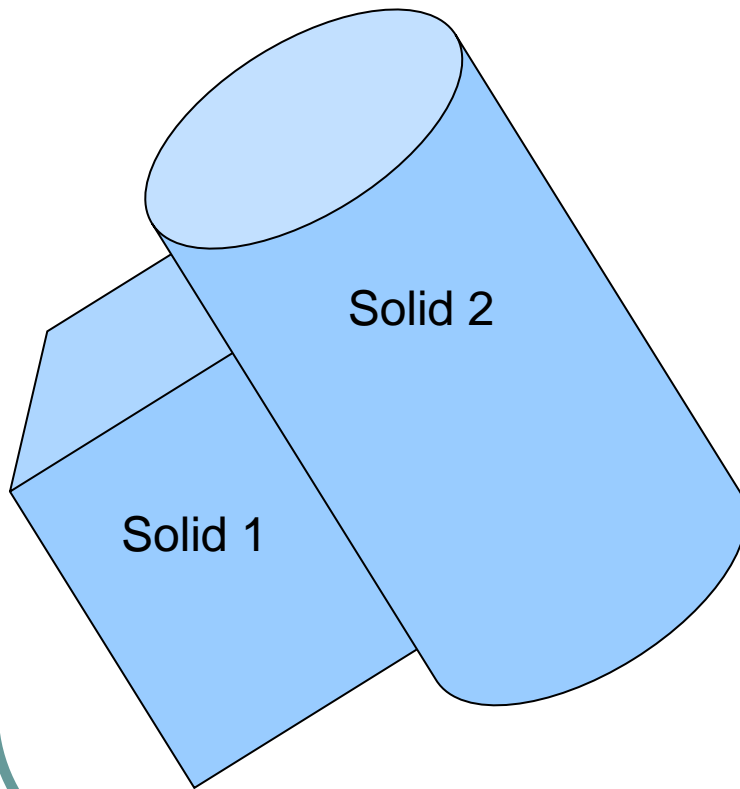3. Intersections
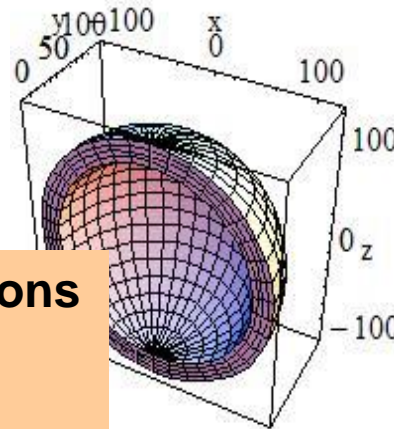
Sphere

Tube

Solids Made by Boolean Operations

Solid 2

Solid 1

Subtraction

Intersection

Union

Keep in mind that…

The world volume is your experimental hall.
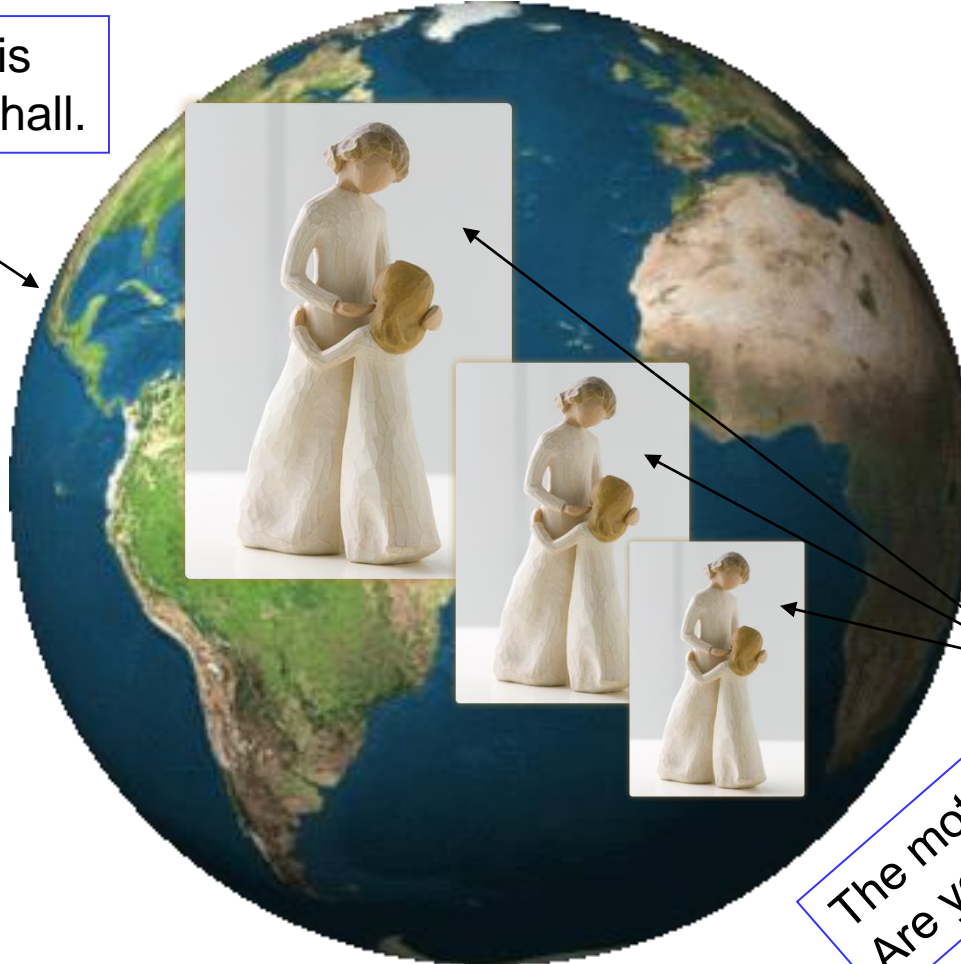
The mother/daughter volumes
Are your setup/experiment.

World volume (mandatory)

➡ **world volume is the mother volume of Volume 1 and 2**

Volume 1 and 2 are daughters of world volume

Volume 1 is mother of volume 3

Etc…

Important rules !
1. **No overlap….**
2. **Fully contained**

Volume 1

Volume 2

Volume 3

z

y

x

z

y

x

Materials in G4

Materials, Elements, and Isotopes

Nature

General Considerations

different materials
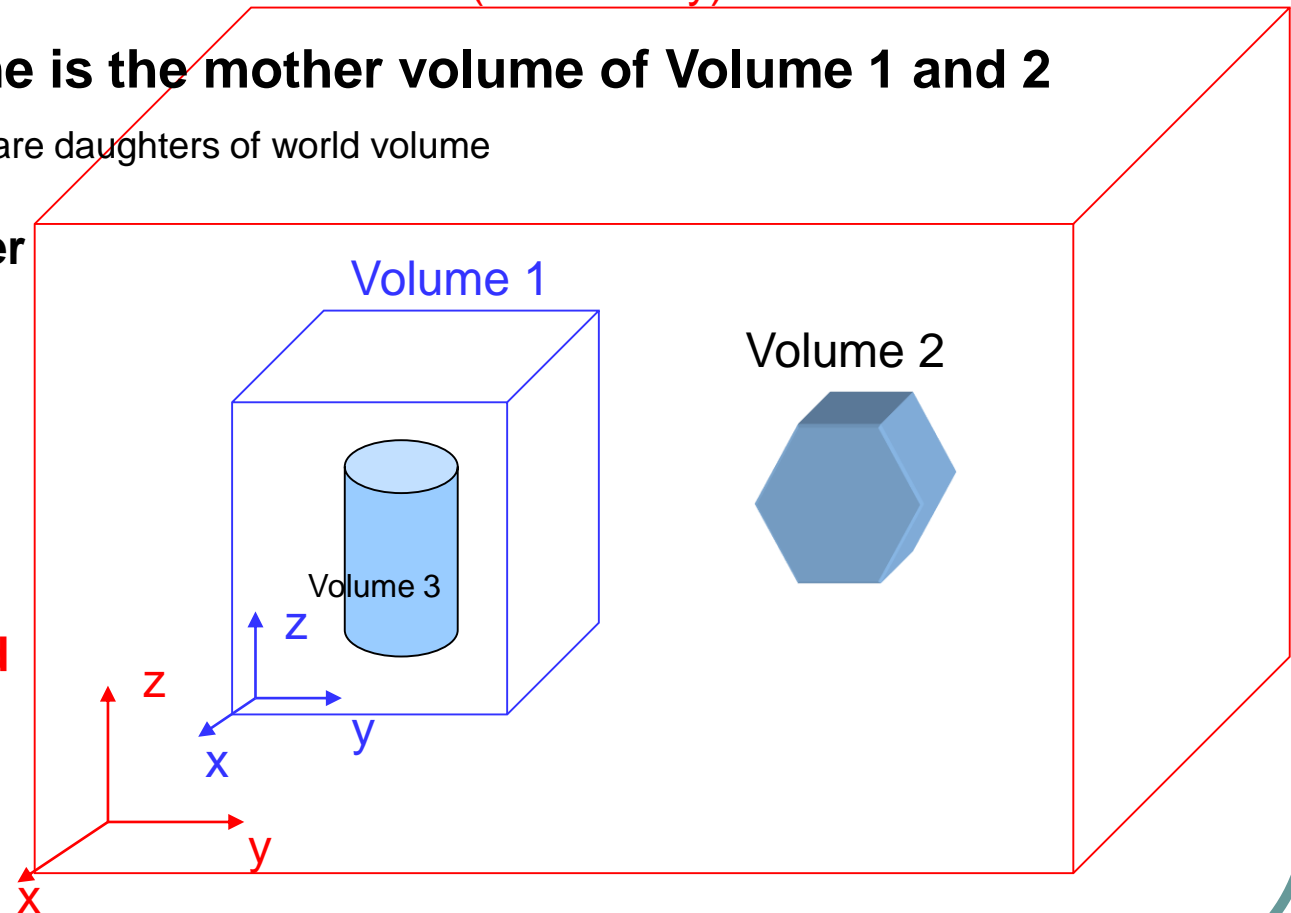
Geant4

different states (Solid, Liquid or Gas)

Geant4

Geant4

G4Material

different chemical compounds, mixtures, alloys

Geant4

G4Element

different elements

Geant4

different isotopes

G4Isotope
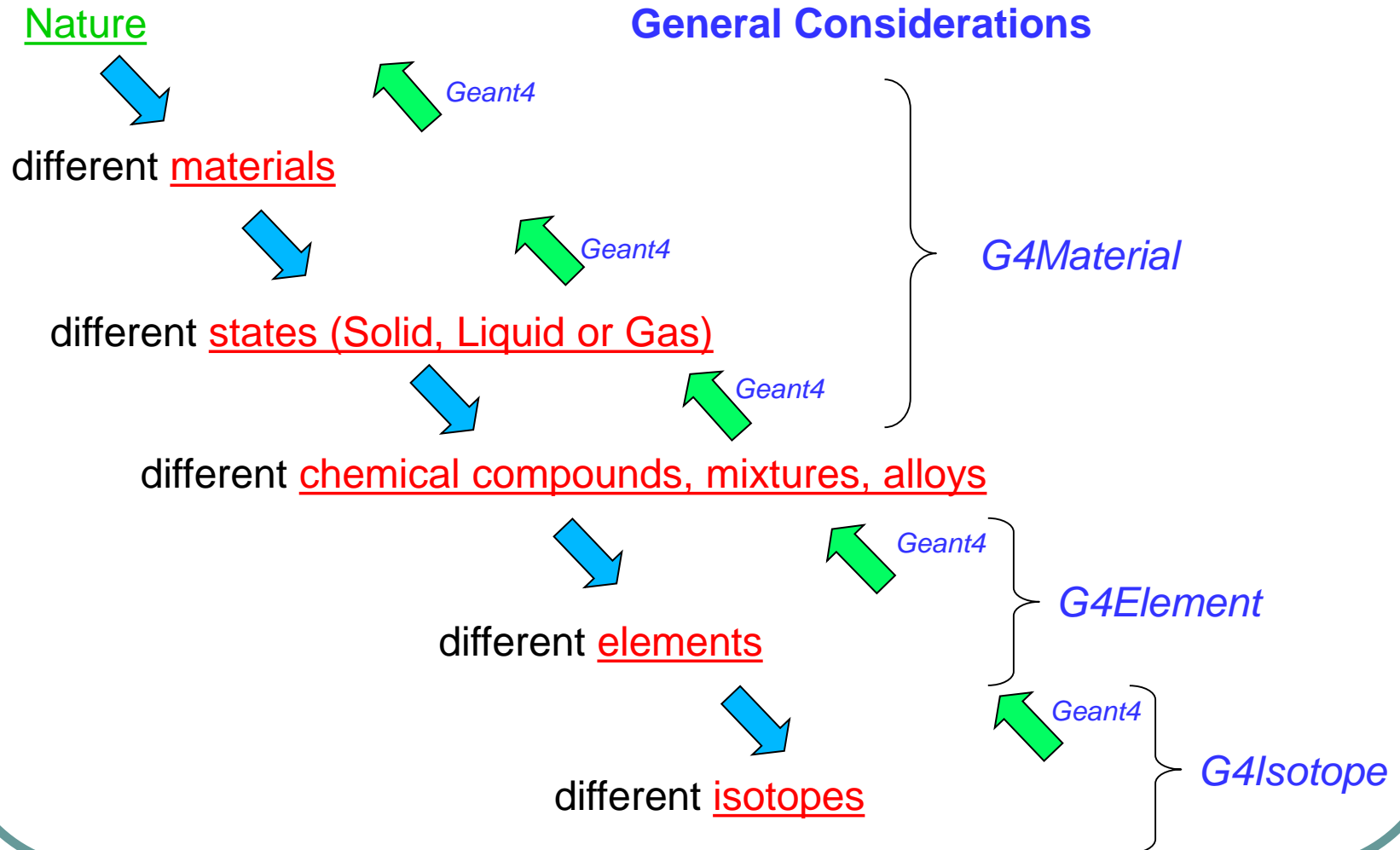
Particles and Processes in G4
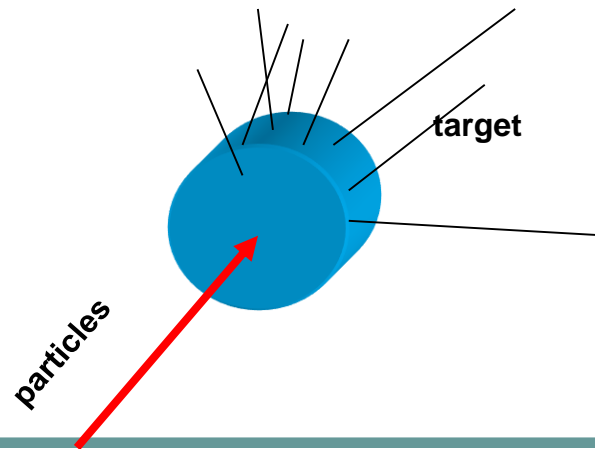
Particles and Processes

In the Physics List

How to Define Particles in G4?

#include "G4ParticleTypes.hh"

void ……..PhysicsList::ConstructParticle() { …. }

How to Define Processes in G4?

#include "G4ProcessManager.hh"
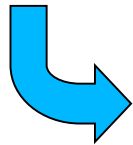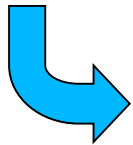
void …….PhysicsList::ConstructProcess() { …. }

Particles

Electrons

Positrons

Gamma

→ **Which processes are needed?**

target
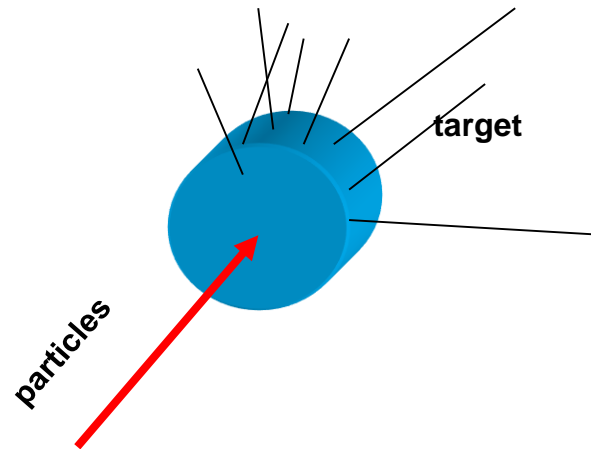
particles

Particles and Processes

If particle is a
Gamma ▨➡

Photo Electric Effect → G4PhotoElectricEffect.hh

Compton Scattering → G4ComptonScattering.hh

Gamma Conversion → G4GammaConversion.hh

If particle is an
Electrons ▨➡

Multiple Scattering → G4eMultipleScattering.hh

Ionisation → G4eIonisation.hh

Bremsstrahlung → G4eBremsstrahlung.hh

If particle is a
Positrons ▨➡

Multiple Scattering → G4eMultipleScattering.hh

Ionisation → G4eIonisation.hh

Bremsstrahlung → G4eBremsstrahlung.hh

Annihilation → G4eplusAnnihilation.hh

User Actions in G4

Where can I get ………..?
Where can I set ……………….?

Geant4

Actions in Geant4

User classes

Initialization classes

Invoked at the initialization

G4VUserDetectorConstruction
G4VUserPhysicsList

Action classes

Invoked during an event loop

G4VUserPrimaryGeneratorAction
G4UserRunAction
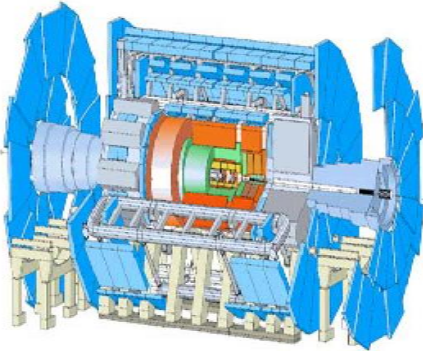G4UserEventAction
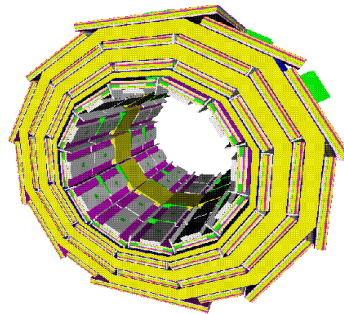G4UserSteppingAction

Note: classes written in red are mandatory.

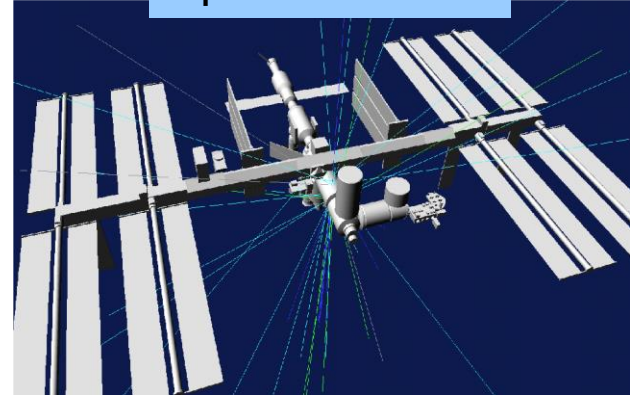**main()**
Geant4 does not provide main().

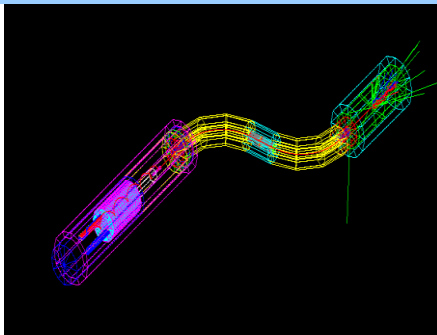# Where is Geant4 used? (Applications)
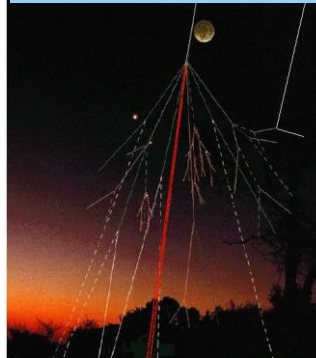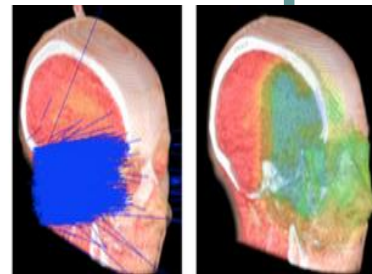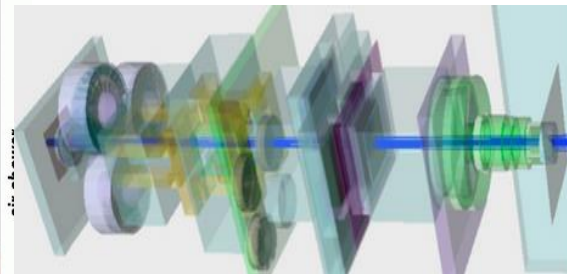
LHC - ATLAS

LHC - CMS

Space Science

Accelerator Physics

Astrophysics

Medical Physics

At the end of the semester you will be convinced that

- **Geant4 is a powerful toolkit for MC simulation.**
  - Maintained by more than 100 scientist
  - Open, for developers with a huge validation program
  - Free to all scientist.

- **Geometry, Materials, particles and processes**
  - Very flexible geometry… simple and complex
  - Materials using NIST database, or own implementation
  - Predefined particles and processes. Predefined physics list

- **Wide range of application**
  - Nuclear and high energy physics, astrophysics, space science, medical physics

- **OOP C++ programming language**
  - One should not be scarred to jump into this field.
  - Learning-by-doing method works well.
  - One has to invest time to master this toolkit… big satisfaction at the end

- Thanks a lot!

Now: Your Questions?