

Physics in Geant4 : Particles and processes

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User classes (...continued)

At initialization

G4VUserDetectorConstruction

G4VUserPhysicsList

G4VUserActionInitialization

Global: only one instance exists in memory, shared by all threads.

At execution

G4VUserPrimaryGeneratorAction

G4UserRunAction

G4UserEventAction

G4UserStackingAction

G4UserTrackingAction

G4UserSteppingAction

Thread-local: an instance of each action class exists for each thread.

Contents

- Physics in Geant4 – motivation
- Particles
- Processes
- Physics lists

...Part 2:

- Production cuts
- Electromagnetic / hadronic physics
- Crystalline / optical physics

Physics – the challenge

- Huge amount of different processes for various purposes (only a handful relevant)
- Competing descriptions of the same physics phenomena (necessary to choose)
 - fundamentally different **approaches**
 - balance between **speed** and **precision**
 - different **parameterizations**
- Hypothetical processes & exotic physics

Solution: Atomistic approach with modular **physics lists**

Part I: **Particles**

Particles: basic concepts

There are three levels of class to describe particles in Geant4:

G4ParticleDefinition

Particle static properties: name, mass, spin, PDG number, etc.

G4DynamicParticle

Particle dynamic state: energy, momentum, polarization, etc.

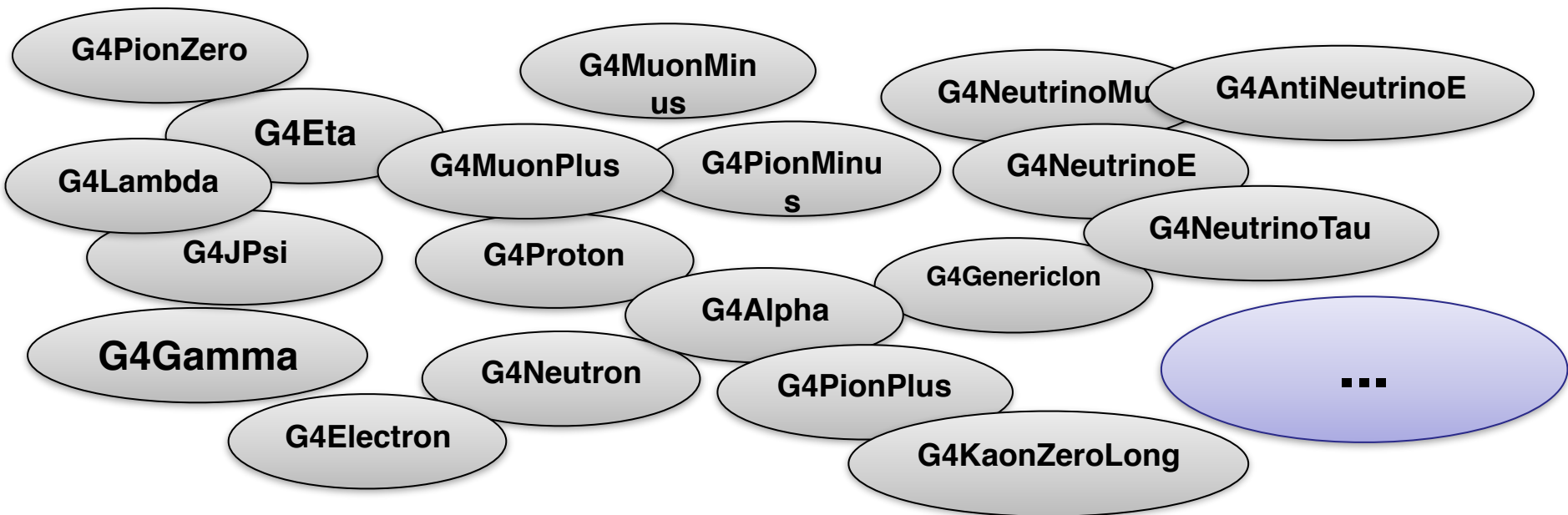
G4Track

Information for tracking in a detector simulation: position, step, current volume, track ID, parent ID, etc.

Definition of a particle

Geant4 provides **G4ParticleDefinition** daughter classes to represent a large number of elementary particles and nuclei, organized in six major categories:

leptons, mesons, baryons, bosons, short-lived and ions



User must define **all particle** types which might be used in the application: not only **primary particles** but also all other particles which may appear as **secondaries** generated by the used physics processes

Particles in Geant4

- **Particle Data Group (PDG) particles**
- **Optical photons** (different from gammas!)
- Special particles: **geantino** and **charged geantino**
 - Only transported in the geometry (**no interactions**)
 - Charged geantino also feels the **EM fields**
- **Short-lived** particles ($\tau < 10^{-14}$ s) are **not transported** by Geant4 (decay applied)
- **Light ions** (as deuterons, tritons, alphas)
- **Heavier ions** represented by a single class: **G4Ions**

Leptons & bosons table

Particle name	Class name	Name (in GPS...)	PDG
electron	G4Electron	e-	11
positron	G4Positron	e+	-11
muon +/-	G4MuonPlus G4MuonMinus	mu+ mu-	-13 13
tauon +/-	G4TauPlus G4TauMinus	tau+ tau-	-15 15
electron (anti)neutrino	G4NeutrinoE G4AntiNeutrinoE	nu_e anti_nu_e	12 -12
muon (anti)neutrino	G4NeutrinoMu G4AntiNeutrinoMu	nu_mu anti_nu_mu	14 -14
tau (anti)neutrino	G4NeutrinoTau G4AntiNeutrinoTau	nu_tau anti_nu_tau	16 -16
photon (γ , X)	G4Gamma	gamma	22
photon (optical)	G4OpticalPhoton	opticalphoton	(0)
geantino	G4Geantino	geantino	(0)
charged geantino	G4ChargedGeantino	chargedgeantino	(0)

Common hadrons & ions table

Particle name	Class name	Name (in GPS...)	PDG
(anti)proton	G4Proton G4AnitProton	proton anti_proton	2212 -2212
(anti)neutron	G4Neutron G4AntiNeutron	neutron anti_neutron	2112 -2112
(anti)lambda	G4Lambda G4AntiLambda	lambda anti_lambda	3122 -3122
pion	G4PionMinus G4PionPlus G4PionZero	pi- pi+ pi0	-211 211 111
kaon	G4KaonMinus G4KaonPlus G4KaonZero G4KaonZeroLong G4KaonZeroShort	kaon- kaon+ kaon0 kaon0L kaon0S	-321 321 311 130 310
(anti)alpha	G4Alpha G4AntiAlpha	alpha anti_alpha	1000020040 -1000020040
(anti)deuteron	G4Deteuron G4AntiDeuteron	deuteron anti_deuteron	1000010020 -1000010020
Heavier ions	G4Ions	ion	100ZZZAAAI*

*ZZZ=proton number, AAA=nucleon number, l=excitation level

Part II: **Processes**

Processes

How do particles interact with materials?

Responsibilities:

1. *decide **when** and **where** an interaction occurs*

- **GetPhysicalInteractionLength...()**

→ *limit the step*

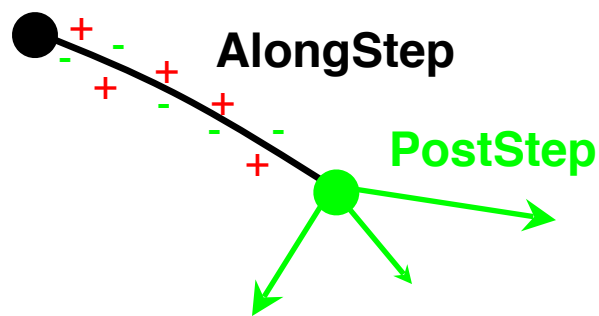
- this requires a cross section
- for the **transportation** process, the distance to the nearest object

2. *generate the **final state** of the interaction*

- changes momentum, generates secondaries, etc.)
- method: **DoIt...()**
- this requires a model of the physics

G4VProcess class

- Abstract class as a base for all **processes** in Geant4
 - Used by all physics processes (also by the transportation, etc...)
 - Defined in **source/processes/management**
- Define **three kinds of actions**:
 - **AtRest** actions:
 - Decay, e⁺ annihilation ...
 - **AlongStep** actions:
 - To describe continuous (inter)actions, occurring along the path of the particle, like ionisation;
 - **PostStep** actions:
 - For describing point-like (inter)actions, like decay in flight, hadronic interactions ...



A process can implement a combination of them (decay = AtRest + PostStep)

Example processes

- Discrete process: **Compton Scattering, hadronic inelastic, ...**
 - step determined by cross section, interaction at end of step
 - PostStepGPIL(), PostStepDolt()
- Continuous process: **Čerenkov effect**
 - photons created along step, roughly proportional to step length
 - AlongStepGPIL(), AlongStepDolt()
- At rest process: **muon capture at rest**
 - interaction at rest
 - AtRestGPIL(), AtRestDolt()

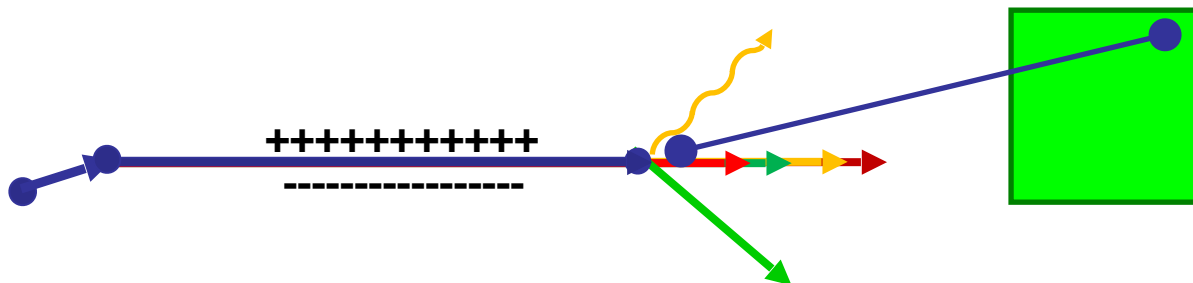
pure

- Rest + discrete: **positron annihilation, decay, ...**
 - both in flight and at rest
- Continuous + discrete: **ionization**
 - energy loss is continuous
 - knock-on electrons (δ -ray) are discrete

combined

Handling multiple processes

- 1 a particle is shot and “transported”
- 2 all processes associated to the particle propose a geometrical step length (depends on process cross-section)
- 3 The process proposing the shortest step “wins” and the particle is moved to destination (if shorter than “Safety”)
- 4 All processes along the step are executed (e.g. ionization)
- 5 post step phase of the process that limited the step is executed.
New tracks are “pushed” to the stack
- 6 If $E_{\text{kin}}=0$ all at rest processes are executed; if particle is stable the track is killed. Else:
- 7 New step starts and sequence repeats...



Part III:
Physics lists

Physics list

- One instance per application
 - registered to run manager in **main()**
 - inheriting from **G4VUserPhysicsList**
- Responsibilities
 - all particle types (electron, proton, gamma, ...)
 - all processes (photoeffect, bremsstrahlung, ...)
 - all process parameters (...)
 - production cuts (e.g. 1 mm for electrons, ...)

3 ways to get a physics list

- 1) Manual: Specify all particles & processes that may occur in the simulation. (difficult)
- 2) Physics constructors: Combine your physics from pre-defined sets of particles and processes. Still you define your own class – modular physics list (easier)
- 3) Reference physics lists: Take one of the pre-defined physics lists. You don't create any class (easy)

G4VUserPhysicsList class

Implement 3 methods:

```
class MyPhysicsList : public G4VUserPhysicsList {
public:
    // ...
    void ConstructParticle(); // pure virtual
    void ConstructProcess(); // pure virtual
    void SetCuts();
    // ...
}
```

Advantage: most flexible

Disadvantages:

- most verbose
- most difficult to get right

G4VUserPhysicsList: implementation

ConstructParticle():

- choose the particles you need in your simulation, define all of them here

ConstructProcess() :

- for each particle, assign all the physics processes relevant to your simulation

SetCuts() :

- set the range cuts for secondary production for processes with infrared divergence

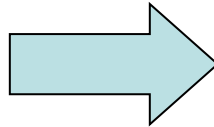
i) ConstructParticle()

Due to the large number of particles can be necessary to instantiate, this method sometimes can be not so comfortable



It is possible to define **all** the particles belonging to a **Geant4** category:

- **G4LeptonConstructor**
- **G4MesonConstructor**
- **G4BaryonConstructor**
- **G4BosonConstructor**
- **G4ShortlivedConstructor**
- **G4IonConstructor**



```
void MyPhysicsList::ConstructParticle() {
    G4Electron::ElectronDefinition();
    G4Proton::ProtonDefinition();
    G4Neutron::NeutronDefinition();
    G4Gamma::GammaDefinition();
    ....
}
```

```
void MyPhysicsList::ConstructParticle() {
    // Construct all baryons
    G4BaryonConstructor bConstructor;
    bConstructor.ConstructParticle();
    // Construct all leptons
    G4LeptonConstructor lConstructor;
    lConstructor.ConstructParticle();
    // ...
}
```

ii) ConstructProcess()

1. For each particle, get its **process manager**.

```
G4ProcessManager *e1Manager = G4Electron::ElectronDefinition()->GetProcessManager();
```

2. Construct all **processes** and **register** them.

```
e1Manager->AddProcess(new G4eMultipleScattering, -1, 1, 1);  
e1Manager->AddProcess(new G4eIonisation, -1, 2, 2);  
e1Manager->AddProcess(new G4eBremsstrahlung, -1, -1, 3);  
e1Manager->AddDiscreteProcess(new G4StepLimiter);
```

```
AddTransportation();
```

iii) SetCuts()

- Define all **production** cuts for **gamma**, **electrons** and **positrons**
 - Recently also for **protons**
- Notice: this is a **production cut**, not a tracking cut

MORE ON THIS LATER

```
void StandardPhysics::ConstructParticle()
```

```
{
```

```
    // We are interested in gamma, electrons and possibly positrons
```

```
    G4Electron::ElectronDefinition();
```

```
    G4Positron::PositronDefinition();
```

```
    G4Gamma::GammaDefinition();
```

```
}
```

```
void StandardPhysics::ConstructProcess()
```

```
{
```

```
    // Transportation is necessary
```

```
    AddTransportation();
```

```
    // Electrons
```

```
    G4ProcessManager *elManager = G4Electron::ElectronDefinition()->GetProcessManager();
```

```
    elManager->AddProcess(new G4eMultipleScattering, -1, 1, 1);
```

```
    elManager->AddProcess(new G4eIonisation, -1, 2, 2);
```

```
    elManager->AddProcess(new G4eBremsstrahlung, -1, -1, 3);
```

```
    elManager->AddDiscreteProcess(new G4StepLimiter);
```

```
    // Positrons
```

```
    G4ProcessManager *posManager = G4Positron::PositronDefinition()->GetProcessManager();
```

```
    posManager->AddProcess(new G4eMultipleScattering, -1, 1, 1);
```

```
    posManager->AddProcess(new G4eIonisation, -1, 2, 2);
```

```
    posManager->AddProcess(new G4eBremsstrahlung, -1, -1, 3);
```

```
    posManager->AddProcess(new G4eplusAnnihilation, 0, -1, 4);
```

```
    posManager->AddDiscreteProcess(new G4StepLimiter);
```

```
    // Gamma
```

```
    G4ProcessManager *phManager = G4Gamma::GammaDefinition()->GetProcessManager();
```

```
    phManager->AddDiscreteProcess(new G4ComptonScattering);
```

```
    phManager->AddDiscreteProcess(new G4PhotoElectricEffect);
```

```
    phManager->AddDiscreteProcess(new G4GammaConversion);
```

```
    // TODO: Introduce Rayleigh scattering. It has large cross-section than Pair production
```

```
}
```

```
void StandardPhysics::SetCuts()
```

```
{
```

```
    // TODO: Create a messenger for this
```

```
    defaultCutValue = 0.03 * mm;
```

```
    SetCutsWithDefault();
```

```
}
```

Example: Put it together

G4VModularPhysicsList

- Similar structure as **G4VUserPhysicsList** (same methods to override – though not necessary):

```
class MyPhysicsList : public G4VModularPhysicsList {
public:
    MyPhysicsList();           // define physics constructors
    void ConstructParticle();  // optional
    void ConstructProcess();   // optional
    void SetCuts();           // optional
}
```

Differences to “manual” way:

- Particles and processes typically handled by **physics constructors** (still customizable)
- **Transportation** automatically included

Physics constructor

= “module” of the modular physics list

- Inherits from **G4VPhysicsConstructor**
- Defines **ConstructParticle()** and **ConstructProcess()**
 - to be fully imported in modular list (behaving in the same way)
- **GetPhysicsType()**
 - enables switching physics of the same type, if possible (see next slide)

Physics constructors

- Huge set of pre-defined ones
 - **EM:** Standard, Livermore, Penelope
 - **Hadronic inelastic:** QGSP_BIC, FTFP_Bert, ...
 - **Hadronic elastic:** G4HadronElasticPhysics, ...
 - ... (decay, optical physics, EM extras, ...)
- You can implement your own (of course) by inheriting from the G4VPhysicsConstructor class

Using physics constructors

Add **physics constructor** in the **constructor**:

```
MyModularList::MyModularList() {  
    // Hadronic physics  
    RegisterPhysics(new G4HadronElasticPhysics());  
    RegisterPhysics(new G4HadronPhysicsFTFP_BERT_TRV());  
    // EM physics  
    RegisterPhysics(new G4EmStandardPhysics());  
}
```

This already works and no further method overriding is necessary 😊.

Replace physics constructors

You can **add** or **remove** the physics constructors after the list instance is created:

- e.g. in response to **UI command**
- only **before initialization**
- physics of the same type can be **replaced**

```
void MyModularList::SelectAlternativePhysics() {  
    AddPhysics(new G4OpticalPhysics);  
    RemovePhysics(fDecayPhysics);  
    ReplacePhysics(new G4EmLivermorePhysics);  
}
```

Reference physics lists

- Pre-defined physics lists
 - already containing a complete set of particles & processes (that work together)
 - targeted at specific area of interest (HEP, medical physics, ...)
 - constructed as **modular physics lists**, built on top of **physics constructors**
 - customizable (by calling appropriate methods before initialization)

Alternative: Reference list by name

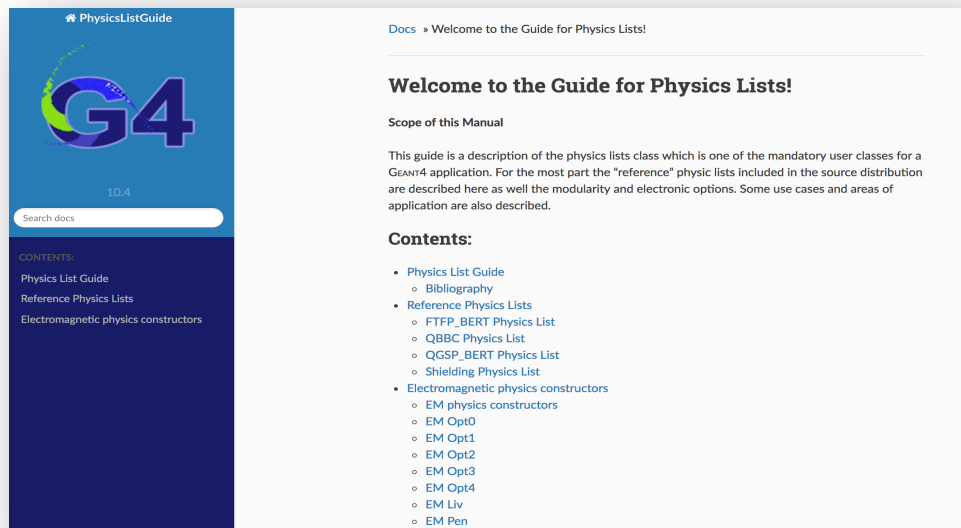
- If you want to get reference physics lists by **name** (e.g. from environment variable), you can use the **G4PhysListFactory** class:

```
#include "G4PhysListFactory.hh"
int main() {
    // Run manager
    G4RunManager* runManager = new G4RunManager();
    // E.g. get the list name from environment variable
    G4String listName{ getenv("PHYSICS_LIST") };
    auto factory = new G4PhysListFactory();
    auto physics = factory->GetReferencePhysList(listName);
    runManager->SetUserInitialization(physics);
    // ...
}
```

Lists of reference physics lists

Source code: `$G4INSTALL/source/physics_lists/lists`

```
FTF_BIC.hh  
FTFP_BERT.hh  
FTFP_BERT_HP.hh  
FTFP_BERT_TRV.hh  
FTFP_INCLXX.hh  
FTFP_INCLXX_HP.hh  
G4GenericPhysicsList.hh  
G4PhysListFactoryAlt.hh  
G4PhysListFactory.hh  
G4PhysListRegistry.hh  
G4PhysListStamper.hh  
INCLXXPhysicsListHelper.hh  
LBE.hh  
NuBeam.hh  
QBBC.hh  
QGS_BIC.hh  
QGSP_BERT.hh  
QGSP_BERT_HP.hh  
QGSP_BIC_AllHP.hh  
QGSP_BIC.hh  
QGSP_BIC_HP.hh  
QGSP_FTFP_BERT.hh  
QGSP_INCLXX.hh  
QGSP_INCLXX_HP.hh  
Shielding.hh
```



PhysicsListGuide

10.4

Search docs

CONTENTS:

- Physics List Guide
- Reference Physics Lists
- Electromagnetic physics constructors

Docs » Welcome to the Guide for Physics Lists!

Welcome to the Guide for Physics Lists!

Scope of this Manual

This guide is a description of the physics lists class which is one of the mandatory user classes for a `Geant4` application. For the most part the "reference" physics lists included in the source distribution are described here as well the modularity and electronic options. Some use cases and areas of application are also described.

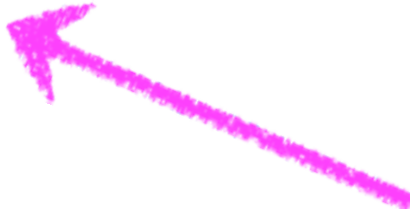
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 - EM Liv
 - EM Pen

Where to find information?

User Support

1. [Getting started](#)
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 - b. [LXR code browser -or- draft doxygen documentation](#)
4. [Frequently Asked Questions \(FAQ\)](#)
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7. [User Forum](#)
8. [Documentation](#)
 - a. [Introduction to Geant4](#)
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 - d. [Toolkit Developers Guide](#)
 - e. [Physics Reference Manual](#)
 - f. [Software Reference Manual](#)
9. Physics lists
 - a. [Electromagnetic](#)
 - b. [Hadronic](#)



3 ways to get a physics list (summary)

1) Manual:

`G4VUserPhysicsList`

2) Physics constructors:

`G4VModularPhysicsList`

3) Reference physics lists:

no class 😊

Conclusion

- Geant4 description of physics is very flexible
 - many particles
 - many processes
 - many models
 - many physics lists

...End of process

Task 3

- **Task 3a** Learn about processes and particles
- **Task 3b** Physics constructors and physics lists
- **Task 3c** Geant4 production cuts

Exercise 3a.1: Particle list and particle properties

Exercise 3a.2: Processes attached to a particle

Exercise 3a.3: Activate/inactivate processes

Task 3

- Task 3a Learn about processes and particles
- **Task 3b** Physics constructors and physics lists
- Task 3c Geant4 production cuts

Exercise 3b.1: Change EM physics using Geant4 constructors

Exercise 3b.2: Add an additional EM constructor

Exercise 3b.3: Add hadronic physics