Physics I : Physics Lists

Geant4 PHENIICS & IN2P3 Tutorial,
16 – 20 May 2022,
Orsay

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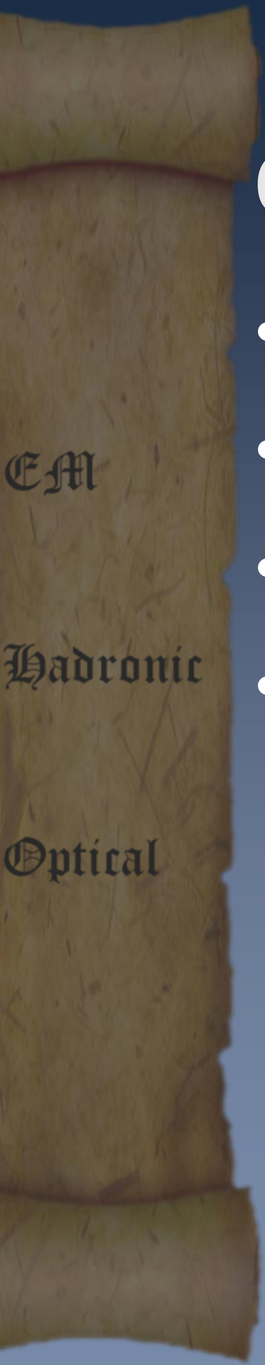
Credits…

- Daniel Brandt, Makoto Asai, Dennis Wright (SLAC),
- Gunter Folger (CERN), etc.



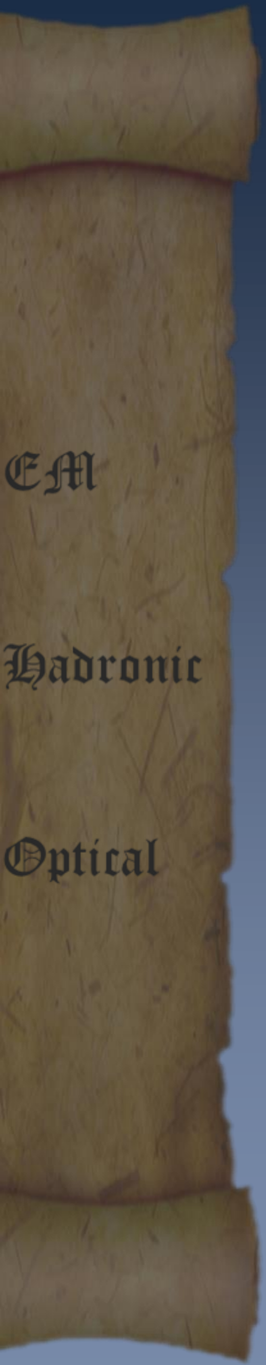
Outline

- Introduction
- The G4VUserPhysicsList class
- Modular physics lists
- Pre-packaged or reference physics lists

Introduction

What is a physics list and why do we need one?

What is a Physics List?



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  - physics processes,
  - and production thresholds,

  needed for your application.

What is a Physics List?

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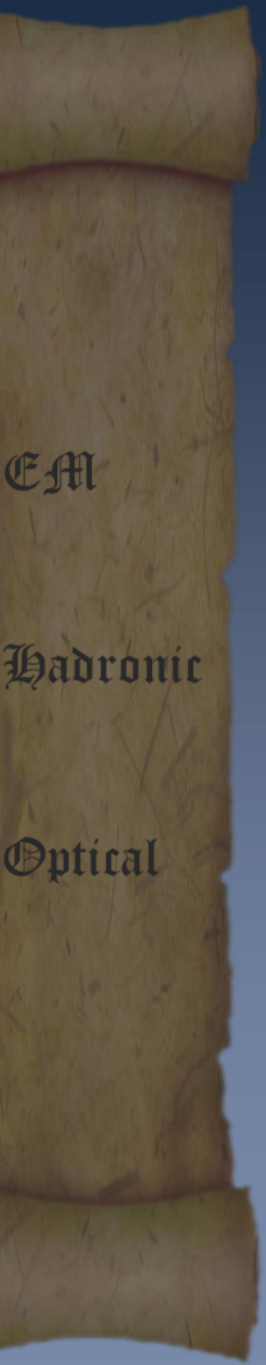
- It is passed to the run manager as the "physics configuration" of your application



What is a Physics List?

- A class which collects all
  - the particles,
  - physics processes,
  - and production thresholds,

  needed for your application.
- It is passed to the run manager as the “physics configuration” of your application
- It is one of the three mandatory classes that must exist in your simulation:
  - Remember, the two other ones are
    - detector construction and
    - primary generation action.

In many practical cases…

- You will not need the details in this presentation !

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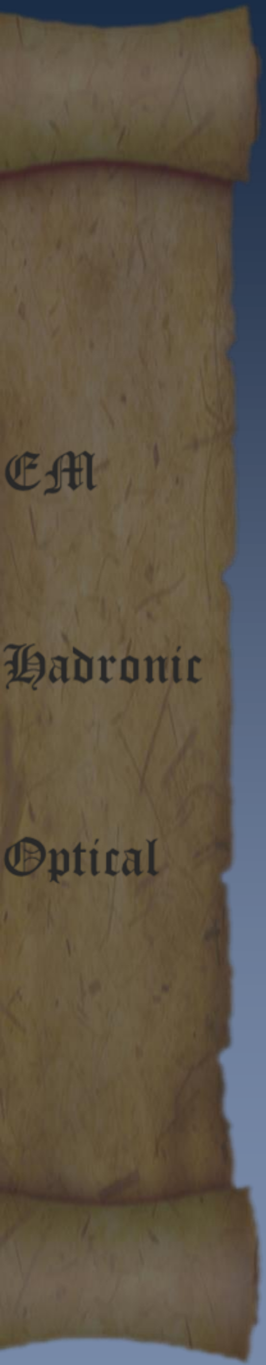

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- You will not need the details in this presentation !
- Because Geant4 provides “pre-packaged physics lists”
  - Also called “reference physics lists”
- These have nicknames like:

FTFP_BERT_HP

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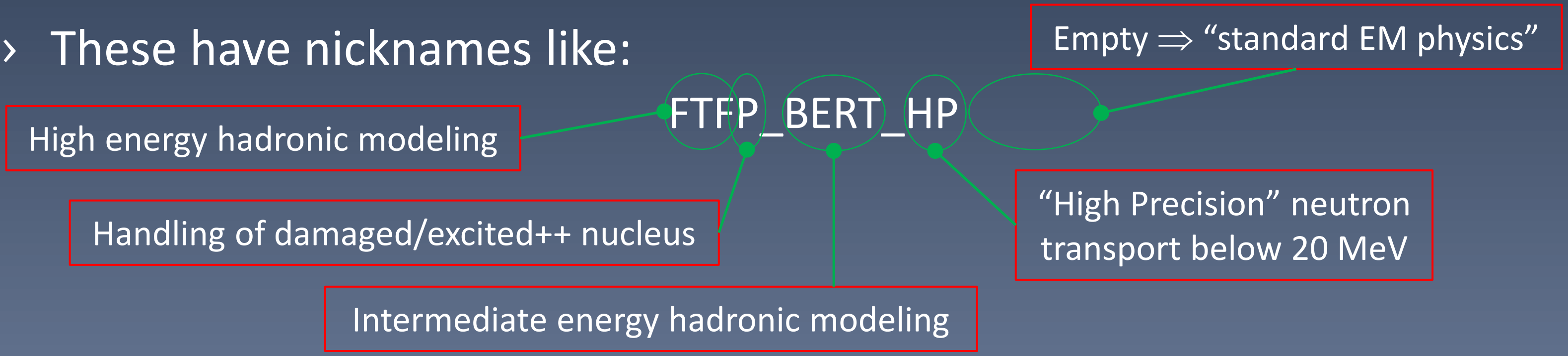

FTFP_BERT_HP

Empty ⇒ “standard EM physics”

High energy hadronic modeling

Handling of damaged/excited++ nucleus

“High Precision” neutron transport below 20 MeV

Intermediate energy hadronic modeling

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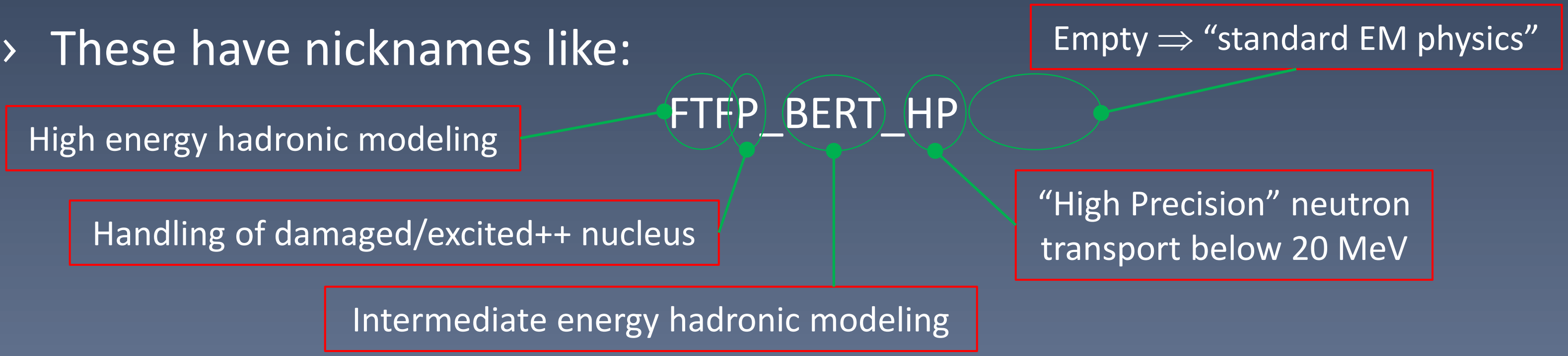

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Intermediate energy hadronic modeling

- They cover most of the “use cases”, and are part of the routine testing and validation of Geant4
  - Reference physics lists are the most tested
  - Several of them are used in (heavy) production by experiments
- But sometimes users (you) want to customize their physics lists
  - This is possible in Geant4
  - At various levels of granularity
  - And for this, you need to know about “physics list”.

The G4VUserPhysicsList class

The fundamental class

G4VUserPhysicsList

- **G4VUserPhysicsList** is the base class for physics list
- It defines three mandatory (pure virtual) methods:
  - **ConstructParticle() :**
    - choose all the particles you need in your simulation
  - **ConstructProcess() :**
    - for each particle, assign all the physics processes needed in your simulation
    - ***What's a process ?***
      - a class that implements how a particle interacts with matter
      - more on this later
  - **SetCuts() :**
    - set the range cuts for secondary production
    - ***What's a range cut ?***
      - a production threshold for secondary particles
      - more on this later
- These methods are called by the "run manager".

G4VUserPhysicsList : an example

- Your physics list header hence looks like:

```
#include “G4VUserPhysicsList.hh”

class MyPhysicsList: public G4VUserPhysicsList
 {
     public:
          MyPhysicsList();
          ~MyPhysicsList();
          void ConstructParticle();
          void ConstructProcess();
          void SetCuts();
  };
```

G4VUserPhysicsList : an example

- Your physics list header hence looks like:

```
#include “G4VUserPhysicsList.hh”

class MyPhysicsList: public G4VUserPhysicsList
 {
     public:
          MyPhysicsList();
          ~MyPhysicsList();
          void ConstructParticle();
          void ConstructProcess();
          void SetCuts();
  };
```

- Let’s look at these method implementations
  - and possible variations on these.

ConstructParticle() (1/2)

- You have several ways to implement this method.
- The most granular approach:

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

Eg : mandatory call to make the « gamma » particle type existing in memory

ConstructParticle() (2/2)

- A more global approach, using “constructors”
  - Utility classes that gather the proper G4XXX::XXXDefinition() calls

```
void MyPhysicsList::ConstructParticle()
{
       G4BaryonConstructor* baryonConstructor =
                                 new G4BaryonConstructor();
       baryonConstructor->ConstructParticle();
       delete baryonConstructor;

       G4BosonConstructor* bosonConstructor =
                                 new G4BosonConstructor();
       bosonConstructor->ConstructParticle();
       delete bosonConstructor;
       …
       …
}
```

ConstructParticle() (2/2)

- A more global approach, using “constructors”
  - Utility classes that gather the proper G4XXX::XXXDefinition() calls

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void MyPhysicsList::ConstructParticle()
{
       G4BaryonConstructor* baryonConstructor =
                                  new G4BaryonConstructor();
       baryonConstructor->ConstructParticle();
       delete baryonConstructor;

       G4BosonConstructor* bosonConstructor =
                                  new G4BosonConstructor();
       bosonConstructor->ConstructParticle();
       delete bosonConstructor;
       …
       …
}
```

G4XXX::XXXDefinition() calls happen here

ConstructProcess()

- Process construction can also be made in several ways
  - Not showing everything here
- For convenience here, we split ConstructProcess() as:

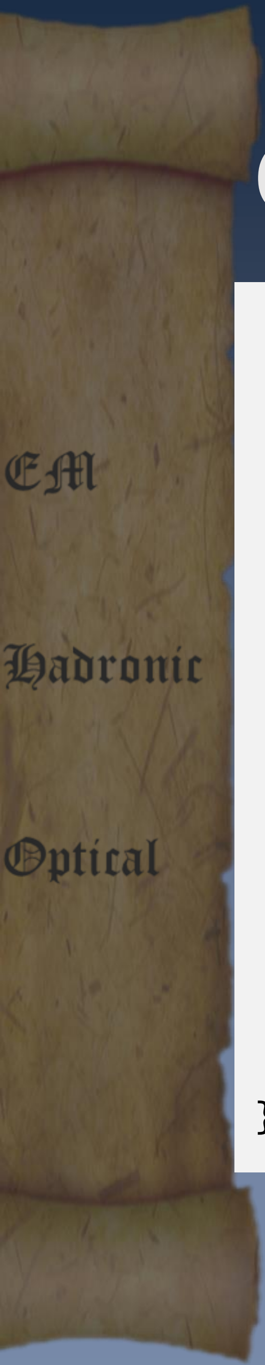
```
void MyPhysicsList::ConstructProcess()
{
       AddTransportation();
       // method provided by G4VUserPhysicsList : assigns transportation
       // process to all particles defined in ConstructParticle()

        ConstructEM();
        // method may be defined by user (for convenience)
        // put electromagnetic physics here

        ConstructGeneral();
        // method may be defined by user to hold all other processes
}
```

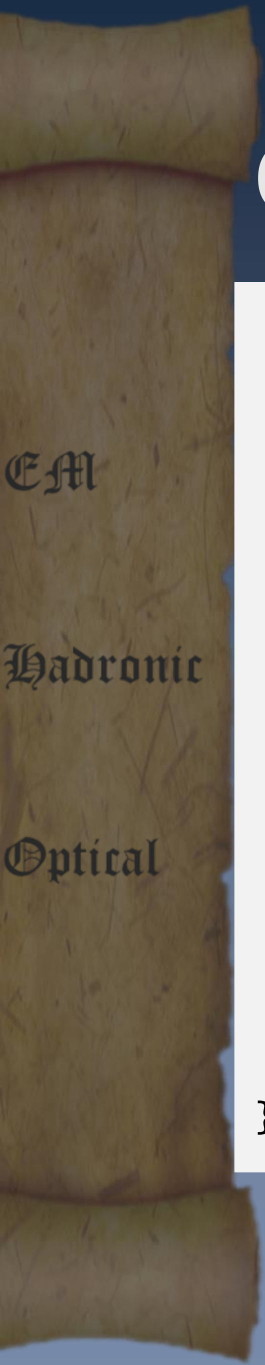
Transportation "process" cares about geometry and fields, and updates coordinates of particles

ConstructProcess() : ConstructEM()



```
void MyPhysicsList::ConstructEM()
{
  G4PhysicsListHelper* ph = G4PhysicsListHelper::GetPhysicsListHelper();
  theParticleIterator->reset();
  while( (*theParticleIterator)() )
   {
     G4ParticleDefinition* particle = theParticleIterator->value();
     if  (particle == G4Gamma::Gamma() )
        {
          ph->RegisterProcess(new G4GammaConversion(),  particle);
          ….  // add more processes
        }
     …  // do electrons, positrons, etc.
   }
}
```

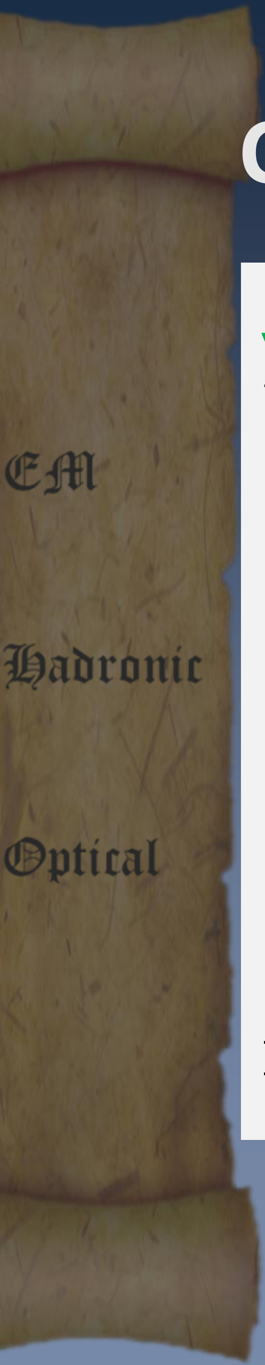
ConstructProcess() : ConstructEM()



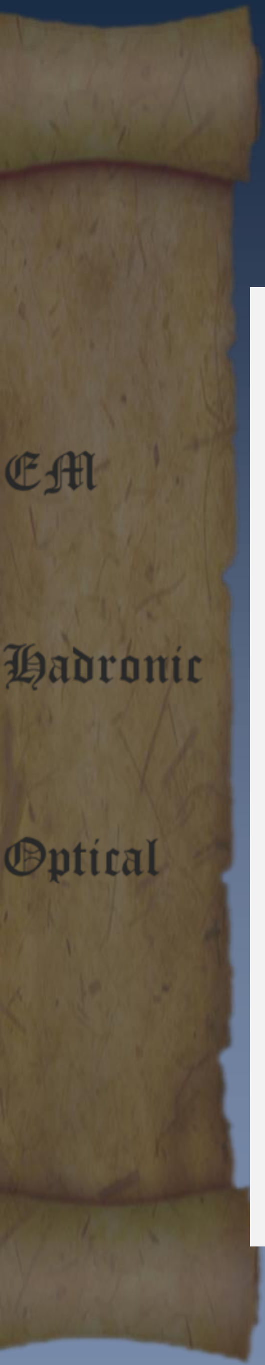
```
void MyPhysicsList::ConstructEM()
{
  G4PhysicsListHelper* ph = G4PhysicsListHelper::GetPhysicsListHelper();
  theParticleIterator->reset();
  while( (*theParticleIterator)() )
   {
     G4ParticleDefinition* particle = theParticleIterator->value();
     if  (particle == G4Gamma::Gamma() )
        {
          ph->RegisterProcess(new G4GammaConversion(),  particle);
          ….  // add more processes
        }
     …  // do electrons, positrons, etc.
   }
}
```

This is an helper tool : you can go even more granular, specifying the ordering execution of process methods.

ConstructProcess() : ConstructGeneral()



```
void MyPhysicsList::ConstructGeneral()
{
  G4PhysicsListHelper* ph = G4PhysicsListHelper::GetPhysicsListHelper();
  // Add decay process
  G4Decay* theDecayProcess = new G4Decay();
  theParticleIterator->reset();
  while( (*theParticleIterator)() )
    {
      G4ParticleDefinition* particle = theParticleIterator->value();
      if  (theDecayProcess->IsApplicable(*particle) )
         {
           ph->RegisterProcess(theDecayProcess, particle);
         }
    }
  // Add other physics
  ...
}
```



ConstructProcess() : SetCuts()

```
void MyPhysicsList::SetCuts()
{
  defaultCutValue = 0.7*mm;
  SetCutValue(defaultCutValue, “gamma”);
  SetCutValue(defaultCutValue, “e-”);
  SetCutValue(defaultCutValue, “e+”);
  SetCutValue(defaultCutValue, “proton”);
  //
  // These are the production cuts you need to set
  // - not required for any other particle
}
```

Modular physics lists

Building physics lists by “physics modules”

From flat list to “physics blocks”

- A realistic physics list has many particles and physics processes
  - Writing such a physics list as a “flat list” makes it long,
  - Complicated, hard to read,
  - And hard to maintain !
- Geant4 adopted a “modular physics list” approach:
  - Physics is organized by “physics modules”
    - EM physics, hadronic physics, optical physics, etc.
  - And you register the physics modules your are interested in in your “modular physics list”
- Still :
  - Starting from the base class G4VUserPhysicsList remains possible
  - You are free to use or not these functionalities
  - Again: this is a “toolkit” approach

G4VModularPhysicsList

- Derived from G4VUserPhysicsList
  - It is a G4VUserPhysicsList in the C++ sense
  - Ie, in header file of this class you find:
    - class G4VModularPhysicsList : public G4VUserPhysicsList {…};
- A G4VModularPhysicsList object registers “physics modules”, eg:

  someModularPhysicsList->Register(new DecayPhysics());

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- A G4VModularPhysicsList object registers "physics modules", eg:

  someModularPhysicsList->Register(new DecayPhysics());

- The "physics module" class itself is:

  G4VPhysicsConstructor

- Which defines two methods:
  - **virtual void ConstructParticle();**
    - As with G4VUserPhysicsList : it is to declare the particle types used
  - **virtual void ConstructProcess();**
    - As with G4VUserPhysicsList : it is to associate processes to above particles
- AddTransportation() automatically called for all registered particles

Example : FTFP_BERT_HP constructor

```
 G4DataQuestionaire it(photon, neutron);
 G4cout << "<<< Geant4 Physics List simulation engine: FTFP_BERT_HP 2.0"<<G4endl;
 G4cout <<G4endl;
 this->defaultCutValue = 0.7*CLHEP::mm;
 this->SetVerboseLevel(ver);
// EM Physics
 this->RegisterPhysics( new G4EmStandardPhysics(ver) );
 // Synchroton Radiation & Gamma/lepto-Nuclear Physics
 this->RegisterPhysics( new G4EmExtraPhysics(ver) );
 // Decays
 this->RegisterPhysics( new G4DecayPhysics(ver) );
  // Hadron Elastic scattering
 this->RegisterPhysics( new G4HadronElasticPhysicsHP(ver) );
  // Hadron Physics
 this->RegisterPhysics( new G4HadronPhysicsFTFP_BERT_HP(ver) );
 // Stopping Physics
 this->RegisterPhysics( new G4StoppingPhysics(ver) );
 // Ion Physics
 this->RegisterPhysics( new G4IonPhysics(ver) );
```

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These derive from G4VPhysicsConstructor

Example : FTFP_BERT_HP constructor

EM

Hadron

Optical

```
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this->RegisterPhysics( new G4StoppingPhysics(ver) );
// Ion Physics
this->RegisterPhysics( new G4IonPhysics(ver) );
```

```
void G4EmExtraPhysics::ConstructParticle()
{
  G4Gamma::Gamma();
  G4Electron::Electron();
  G4Positron::Positron();
  G4MuonPlus::MuonPlus();
  G4MuonMinus::MuonMinus();
}
```

```
void G4EmExtraPhysics::ConstructProcess()
{
 …
 …
  if (synchOn)        BuildSynch();
  if (gammNucOn) BuildGammaNuclear();
  if (muNucOn)      BuildMuonNuclear();
}
```

```
this->RegisterPhysics( new G4EmStandardPhysics(ver) );
// Synchroton Radiation & Gamma/lepto-Nuclear Physics
this->RegisterPhysics( new G4EmExtraPhysics(ver) );
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this->RegisterPhysics( new G4DecayPhysics(ver) );
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this->RegisterPhysics( new G4StoppingPhysics(ver) );
// Ion Physics
this->RegisterPhysics( new G4IonPhysics(ver) );
```

```
void G4EmExtraPhysics::ConstructParticle()
{
  G4Gamma::Gamma();
  G4Electron::Electron();
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  G4MuonPlus::MuonPlus();
  G4MuonMinus::MuonMinus();
}
```

```
void G4EmExtraPhysics::ConstructProcess()
{
 …
 …
  if (synchOn)        BuildSynch();
  if (gammNucOn) BuildGammaNuclear();
  if (muNucOn)      BuildMuonNuclear();
}
```

```
this->RegisterPhysics( new G4EmStandardPhysics(ver) );
// Synchroton Radiation & Gamma/lepto-Nuclear Physics
this->RegisterPhysics( new G4EmExtraPhysics(ver) );
// Decays
```

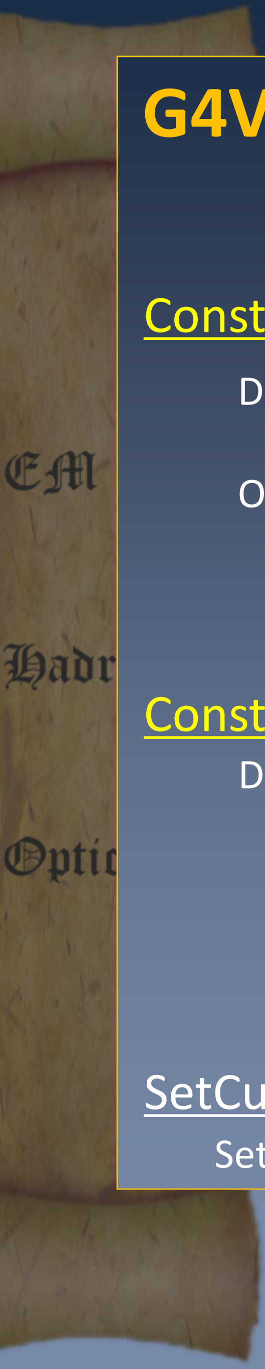
```
void G4EmExtraPhysics::BuildSynch()
{
…
…
  pManager = G4Electron::Electron()->GetProcessManager();
  G4SynchrotronRadiation* theElectronSynch = new G4SynchrotronRadiation();
  pManager->AddDiscreteProcess(theElectronSynch);
…
…
}
```

Physics Constructors Catalogue Overview

Defined in geant4/source/physics_lists/constructors

- **Physics constructors directories:**
  - decay
    - Decay physics, radioactive decay
  - electromagnetic
    - « standard » & low energy EM, optical, DNA
  - gamma_lepto_nuclear
    - Gamma and lepto-nuclear + synchrotron
  - hadron_elastic
    - Elastic hadronic physics, includes ions
  - hadron_inelastic
    - Inelastics hadronic physics options
  - ions
    - Inelastic hadronic physics for ions
  - stopping
    - At rest absorption physics

- **« Technical » constructors directory:**
  - limiters
    - Constructors to add special functionalities to physics lists
    - Special cuts:
      - Add process to kill tracks by max time, min E kin, with a dedicated constructor for neutrons
    - Biasing:
      - Options to add biasing processes or to bias physics processes
    - Parallel world:
      - Activate simultaneous navigation in different & parallel geometries
    - Fast simulation:
      - Activate shortcut to standard tracking for fast simulation



G4VUserPhysicsList

Mandatory methods (you must provide)

Methods provided (not to implement)

Optional methods

ConstructParticles()

Direct calls to particle construction methods:

eg: G4Electron::ElectronDefinition();

Or using particle constructors:

eg: G4BaryonConstructor

ConstructProcesses()

Direct assignement of processes to particles:

eg: ph->RegisterProcess(new G4GammaConversion(), particle);

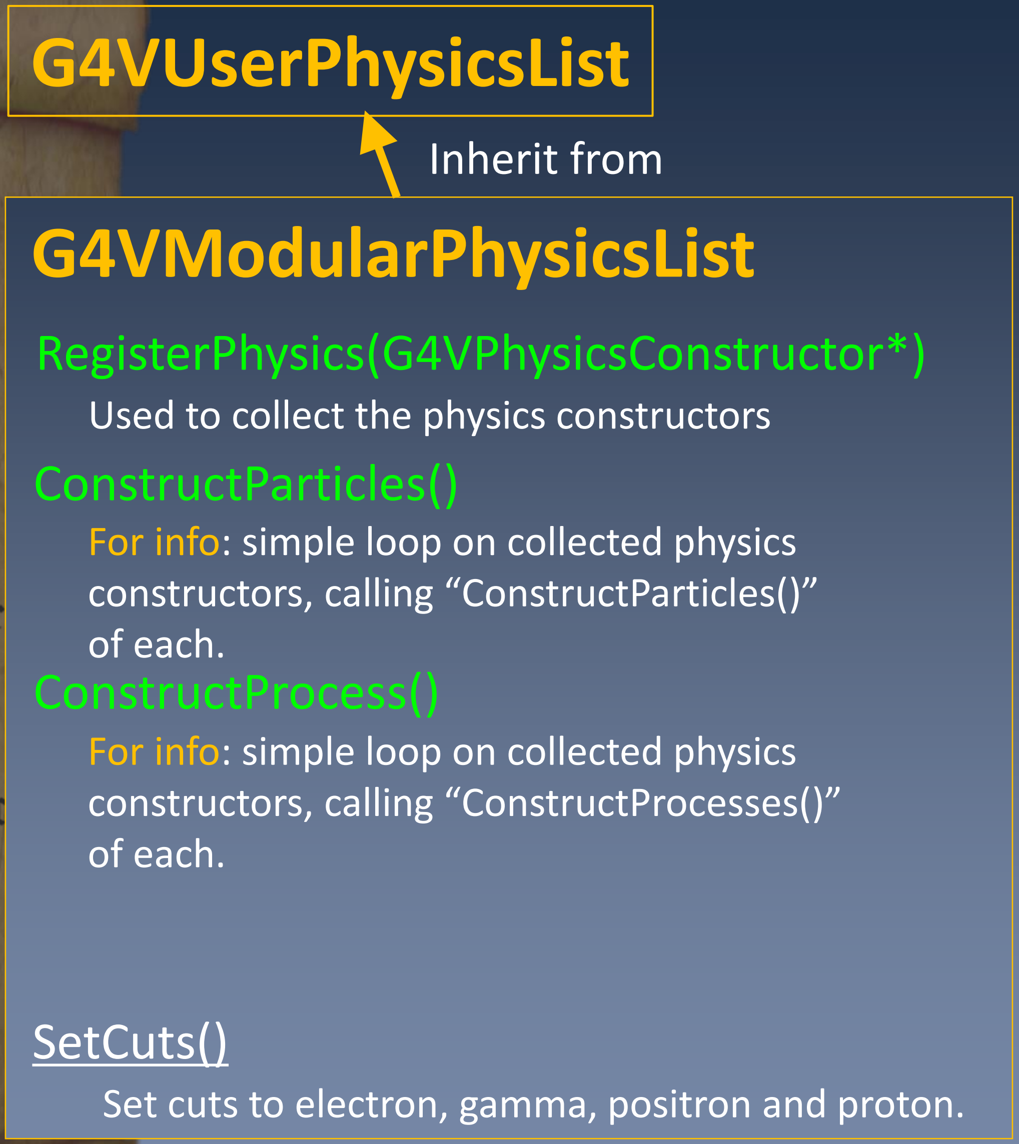
SetCuts()

Set cuts to electron, gamma, positron and proton.

Mandatory methods (you must provide)

Methods provided (not to implement)

Optional methods



G4VUserPhysicsList

Inherit from

G4VModularPhysicsList

RegisterPhysics(G4VPhysicsConstructor*)

Used to collect the physics constructors

ConstructParticles()

For info: simple loop on collected physics constructors, calling “ConstructParticles()” of each.

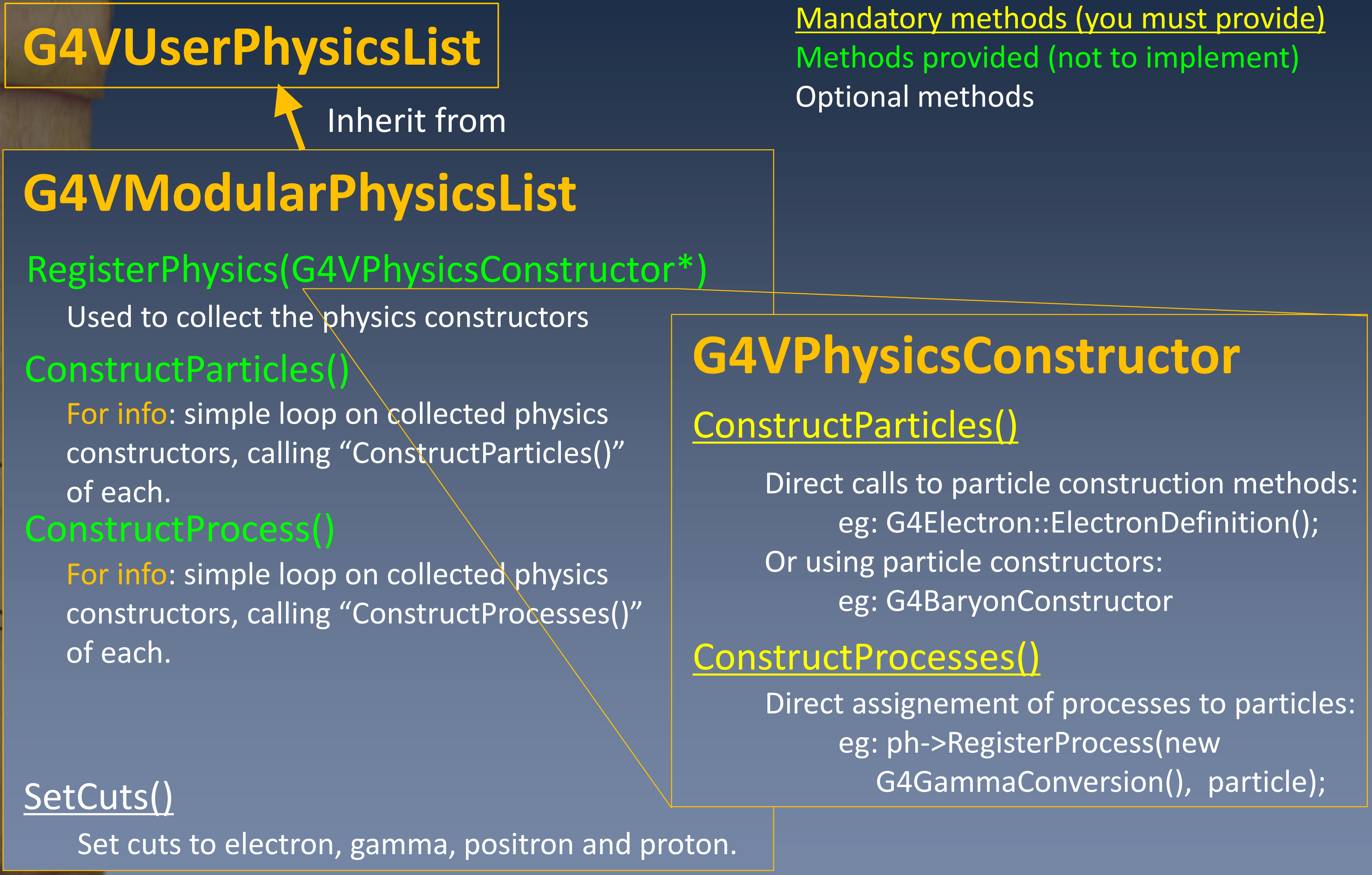
ConstructProcess()

For info: simple loop on collected physics constructors, calling “ConstructProcesses()” of each.

SetCuts()

Set cuts to electron, gamma, positron and proton.

Mandatory methods (you must provide)
Methods provided (not to implement)
Optional methods



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SetCuts()

Set cuts to electron, gamma, positron and proton.

G4VPhysicsConstructor

ConstructParticles()

Direct calls to particle construction methods:
eg: G4Electron::ElectronDefinition();
Or using particle constructors:
eg: G4BaryonConstructor

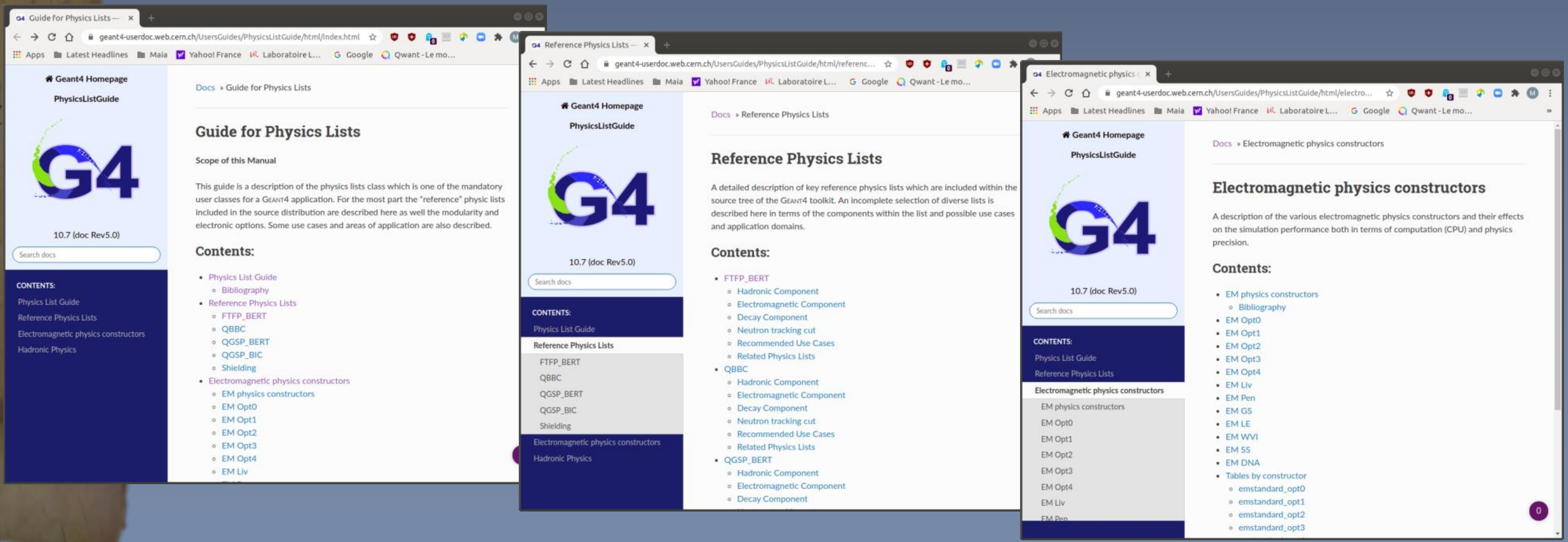
ConstructProcesses()

Direct assignement of processes to particles:
eg: ph->RegisterProcess(new G4GammaConversion(), particle);

Reference Physics Lists

Pre-packaged or Reference Physics Lists

- The pre-packaged physics list are a set of physics lists based on G4VModularPhysicsList and which respond to frequent use-cases.
  - HEP, medical, shielding, etc…
- Each pre-packaged physics list includes different choices of EM and hadronic physics
  - These choices are embodied in “physics constructors”
- These physics lists can be found on the Geant4 web page at
  - https://geant4-userdoc.web.cern.ch/UsersGuides/PhysicsListGuide /html/index.html
  - And subsequent “Reference Physics Lists” link.
- Please be critical:
  - When choosing a physics list : does it cover your needs ?
  - Of course you are invited anyway to perform relevant validations.



Docs » Guide for Physics Lists

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” physic 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.

Contents:

- Physics List Guide
  - Bibliography
- Reference Physics Lists
  - FTFP_BERT
  - QBBC
  - QGSP_BERT
  - QGSP_BIC
  - Shielding
- Electromagnetic physics constructors
  - EM physics constructors
  - EM Opt0
  - EM Opt1
  - EM Opt2
  - EM Opt3
  - EM Opt4
  - EM Liv

Docs » Reference Physics Lists

Reference Physics Lists

A detailed description of key reference physics lists which are included within the source tree of the GEANT4 toolkit. An incomplete selection of diverse lists is described here in terms of the components within the list and possible use cases and application domains.

Contents:

- FTFP_BERT
  - Hadronic Component
  - Electromagnetic Component
  - Decay Component
  - Neutron tracking cut
  - Recommended Use Cases
  - Related Physics Lists
- QBBC
  - Hadronic Component
  - Electromagnetic Component
  - Decay Component
  - Neutron tracking cut
  - Recommended Use Cases
  - Related Physics Lists
- QGSP_BERT
  - Hadronic Component
  - Electromagnetic Component
  - Decay Component

Docs » Electromagnetic physics constructors

Electromagnetic physics constructors

A description of the various electromagnetic physics constructors and their effects on the simulation performance both in terms of computation (CPU) and physics precision.

Contents:

- EM physics constructors
  - Bibliography
- EM Opt0
- EM Opt1
- EM Opt2
- EM Opt3
- EM Opt4
- EM Liv
- EM Pen
- EM GS
- EM LE
- EM WVI
- EM SS
- EM DNA
- Tables by constructor
  - emstandard_opt0
  - emstandard_opt1
  - emstandard_opt2
  - emstandard_opt3

Pre-packaged Physics Lists

- Hadronic parts:
  - FTFP_BERT, FTFP_BERT_HP, FTFP_BERT_TRV, FTFP_BERT_ATL
  - FTFP_INCLXX, FTFP_INCLXX_HP
  - FTF_BIC, LBE, QBBC
  - QGSP_BERT, QGSP_BERT_HP
  - QGSP_BIC, QGSP_BIC_HP, QGSP_BIC_AllHP
  - QGSP_FTFP_BERT
  - QGSP_INCLXX, QGSP_INCLXX_HP
  - QGS_BIC
  - Shielding, ShieldingLEND, ShieldingM
  - NuBeam
- EM suffix options:
  - “” : Standard (in HEP measure…) EM physics
  - _EMV, _EMX : fast options for high-energy physics
  - _EMY, _EMZ, _LIV, _PEN : more precise options (medical & space applications)
  - __GS : option using new Goudsmit-Saunderson multiple scattering model

Pre-packaged Physics Lists

- Hadronic parts:
  - FTFP_BERT, FTFP_BERT_HP, FTFP_BERT_TRV, FTFP_BERT_ATL
  - FTFP_INCLXX, FTFP_INCLXX_HP
  - FTF_BIC, LBE, QBBC
  - QGSP_BERT, QGSP_BERT_HP
  - QGSP_BIC, QGSP_BIC_HP, QGSP_BIC_AllHP
  - QGSP_FTFP_BERT
  - QGSP_INCLXX, QGSP_INCLXX_HP
  - QGS_BIC
  - Shielding, ShieldingLEND, ShieldingM
  - NuBeam

Since :
- 10.0
- 10.1
- 10.2

- Used++ in production
- "Experimental"

- EM suffix options:
  - "" : Standard (in HEP measure…) EM physics
  - _EMV, _EMX : fast options for high-energy physics
  - _EMY, _EMZ, _LIV, _PEN : more precise options (medical & space applications)
  - __GS : option using new Goudsmit-Saunderson multiple scattering model

EM

Hadronic

Optical

Physics list factory

Shielding

QGSP _INCLXX

QGSP _BIC_HP

QGSP _BERT

FTFP _BER

Physics lists and the physics list factory

- To make use of existing physics lists, you have two choices
- You can instantiate the physics list, and set it to the run manager:

```
       #include "FTFP_BERT.hh”
       …
         G4VModularPhysicsList* physicsList = new FTFP_BERT;
         runManager->SetUserInitialization(physicsList);
```

- Or you can use the “physics list factory” utility either:
  - Getting the physics list by name:

```
#include "G4PhysListFactory.hh“
…
 G4PhysListFactory physListFactory;
 G4VModularPhysicsList* physicsList
    = physListFactory.GetReferencePhysList("FTFP_BERT");
 runManager->SetUserInitialization(physicsList);
```

    - You can (and should) check before if this physics list name exists, with:

```
        physListFactory.IsReferencePhysList("FTFP_BERT");
```

  - Or getting the physics from the environment variable PHYSLIST:

```
        physicsList = physListFactory.ReferencePhysList();
```

Summary

- All the particles, physics processes and production cuts needed for an application must go into a physics list
  - And you pass this physics list to the run manager
- Two kinds of physics list classes are available for users to derive from
  - G4VUserPhysicsList – for relatively simple physics lists
  - G4VModularPhysicsList – for advanced physics lists
- Pre-packaged physics lists are provided by Geant4
  - Electromagnetic physics lists
  - Electromagnetic + hadronic physics lists
  - … and other options
  - These can be used as starting point in dedicated cases
- You must be critical in choosing the physics to use