Electromagnetic and Hadronic physics in Geant4

XI Seminar on software for Nuclear, Subnuclear and Applied physics,
May 25 - May 30, 2014 - Porto Conte, Italy

Outline

- The **philosophy** of the physics definition
- How to **define** and **activate** models
- **Electromagnetic** physics
- **Hadronic** physics
- Ongoing models for radiobiology

Philosophy

- Provide a **general model framework** that allows implementation of processes and models

- Separate models and cross sections implement processes

  - **MULTIPLE MODELS FOR THE SAME PROCESS**

- Provide processes containing

  - Many possible models and cross sections

  - Default cross sections for each model

Models under continuous development

G4VUserPhysicsList

- All physics lists **must** derive from this class
  - and then registered with the Run Manager

- Example

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

- User must implement the following methods:
  - ConstructParticle(), ConstructProces(), SetCuts()

ConstructParticle()

- Choose the **particles** you need in your simulation and define all of them here
  - G4Electron::ElectronDefinition()
  - G4Gamma::GammaDefinition()
  - .....
- Geant4 has classes that create **groups of particles**
  - G4BosonConstructor()
  - G4LeptonConstructor()
  - .....

ConstructProcess()

```
void MyPhysicsList::ConstructProcess()
 {
// provided by G4VUserPhysicsList, assign
transportation process to all particles defined in
ConstructParticle();
AddTransportation();
ConstructEM()  //Optional
ConstructGeneral() // Optional
.....
```

SetCuts()

Define all production cuts for **gamma**, **electrons** and **positrons**

- Recently also for protons

Notice: this is a **production cut,** not a tracking cut

All particle, once created, are **tracked** down to **zero** kinetic energy

The CUT is used to limit the **generation of secondaries** (i.e. delta from ionization, or gamma from bremsstrahlung)

The CUT is expressed in **equivalent range**

✓This is converted in energy for each material

Physics definition

- **Three different way to implement the physics models**

1. Explicitly associating a g **A GIVEN MODEL** to a **GIVEN PARTICLE** particle in (eventually) a **GIVEN ENERGY RANGE** energy range

✓ Error prone

✓ At code level

2. Use of **BUILDERS OR CONSTRUCTORS** and **REFERENCE PHYSICS LISTS**

✓ **THE CONSTRUCTORS**
are process related (Electromagnetic, Hadronic, Elastic, etc.)

✓ **THE REFERENCE PHYSICS LISTS** are complete physics lists

- Can be also called by the macro file

CASE 1: Use of the 'Constructors' and use a modular physics list

- Create a class derived by **`G4VModularPhysicsList`**
  - **`class myList : public G4VModularPhysicsList`**
- Implement the mandatory methods **`ConstructParticle()`** and **`ConstructProcess()`** and use the appropriate builders (or create your own)

```
void myList::ConstructProcess()
{
  AddTransportation();
  //Em physics
  G4VPhysicsConstructor* emList = new G4EmStandardPhysics();
  emList->ConstructProcess();
  //Inelastic physics for protons
  G4VPhysicsConstructor* pList = new G4QGSPProtonBuilder();
  pList->ConstructProcess();
```

These are 'Constructors'

CASE 2: use of the Reference Physics Lists (already prepared by the collaboration)

- In your main(), just register an instance of the physics list to the **G4RunManager**

```
#include "QGSP_BERT.hh"
int main()
{
  // Run manager
  G4RunManager * runManager = new G4RunManager();

  …
 G4VUserPhysicsList* physics = new QGSP_BERT();
  runManager-> SetUserInitialization(physics);
}
```

Where find the Reference Physics LIst ?

1. Where are the **builder** (or **constructors**)?

```
constructors Lavora! > pwd
/Users/cirrone/Geant4Dir/geant4-10-00-ref-03/source/physics_lists/constructors
```

Where find the Reference Physics LIst ?

1. Where are the **builder** (or **constructors**)?

```
constructors Lavora! > pwd
/Users/cirrone/Geant4Dir/geant4-10-00-ref-03/source/physics_lists/constructors
```

```
total 24
-rw-r--r--  1 cirrone  staff   708 Apr 19 00:12 CMakeLists.txt
-rw-r--r--  1 cirrone  staff   870 Apr 19 00:12 GNUmakefile
-rw-r--r--  1 cirrone  staff  1154 Apr 19 00:12 History
drwxr-xr-x  8 cirrone  staff   272 Apr 19 00:12 decay
drwxr-xr-x  8 cirrone  staff   272 Apr 19 00:12 electromagnetic
drwxr-xr-x  8 cirrone  staff   272 Apr 19 00:12 factory
drwxr-xr-x  8 cirrone  staff   272 Apr 19 00:12 gamma_lepto_nuclear
drwxr-xr-x  8 cirrone  staff   272 Apr 19 00:12 hadron_elastic
drwxr-xr-x  8 cirrone  staff   272 Apr 19 00:12 hadron_inelastic
drwxr-xr-x  8 cirrone  staff   272 Apr 19 00:12 ions
drwxr-xr-x  8 cirrone  staff   272 Apr 19 00:12 limiters
drwxr-xr-x  8 cirrone  staff   272 Apr 19 00:12 stopping
```

Where find the Reference Physics LIst ?

1. Where are the **builder** (or **constructors**)?

```
constructors Lavora! > pwd
/Users/cirrone/Geant4Dir/geant4-10-00-ref-03/source/physics_lists/constructors
```

```
total 24
-rw-r--r--  1 cirrone  staff   708 Apr 19 00:12 CMakeLists.txt
-rw-r--r--  1 cirrone  staff   870 Apr 19 00:12 GNUmakefile
-rw-r--r--  1 cirrone  staff  1154 Apr 19 00:12 History
drwxr-xr-x  8 cirrone  staff   272 Apr 19 00:12 [illegible]
drwxr-xr-x  8 cirrone  staff   272 Apr 19 00:12 electromagnetic
drwxr-xr-x  8 cirrone  staff   272 Apr 19 00:12 [illegible]
drwxr-xr-x  8 cirrone  staff   272 Apr 19 00:12 gamma_lepto_nuclear
drwxr-xr-x  8 cirrone  staff   272 Apr 19 00:12 hadron_elastic
drwxr-xr-x  8 cirrone  staff   272 Apr 19 00:12 hadron_inelastic
drwxr-xr-x  8 cirrone  staff   272 Apr 19 00:12 ions
drwxr-xr-x  8 cirrone  staff   272 Apr 19 00:12 limiters
drwxr-xr-x  8 cirrone  staff   272 Apr 19 00:12 stopping
```

Where find the Reference Physics LIst ?

1. Where are the **builder** (or **constructors**)?

```
constructors Lavora! > pwd
/Users/cirrone/Geant4Dir/geant4-10-00-ref-03/source/physics_lists/constructors
```

```
total 24
-rw-r--r--  1 cirrone  staff   708 Apr 19 00:12 CMakeLists.txt
-rw-r--r--  1 cirrone  staff   870 Apr 19 00:12 GNUmakefile
-rw-r--r--  1 cirrone  staff  1154 Apr 19 00:12 History
drwxr-xr-x  8 cirrone  staff   272 Apr 19 00:12 doxy
drwxr-xr-x  8 cirrone  staff   272 Apr 19 00:12 electromagnetic
drwxr-xr-x  8 cirrone  staff   272 Apr 19 00:12 factory
drwxr-xr-x  8 cirrone  staff   272 Apr 19 00:12 gamma_lepto_nuclear
drwxr-xr-x  8 cirrone  staff   272 Apr 19 00:12 hadron_elastic
drwxr-xr-x  8 cirrone  staff   272 Apr 19 00:12 hadron_inelastic
drwxr-xr-x  8 cirrone  staff   272 Apr 19 00:12 ions
drwxr-xr-x  8 cirrone  staff   272 Apr 19 00:12 limiters
drwxr-xr-x  8 cirrone  staff   272 Apr 19 00:12 stopping
```

```
19 00:12 G4EmDNAPhysics.hh
19 00:12 G4EmDNAPhysics_option1.hh
19 00:12 G4EmLivermorePhysics.hh
19 00:12 G4EmLivermorePolarizedPhysics.hh
19 00:12 G4EmLowEPPhysics.hh
19 00:12 G4EmPenelopePhysics.hh
19 00:12 G4EmStandardPhysics.hh
19 00:12 G4EmStandardPhysics_option1.hh
19 00:12 G4EmStandardPhysics_option2.hh
19 00:12 G4EmStandardPhysics_option3.hh
19 00:12 G4EmStandardPhysics_option4.hh
19 00:12 G4OpticalPhysics.hh
19 00:12 G4OpticalPhysicsMessenger.hh
19 00:12 G4OpticalProcessIndex.hh
```

1. Where are the **Reference Physics List** ?

```
lists Lavora! > pwd
/Users/cirrone/Geant4Dir/geant4-10-00-ref-03/source/physics_lists/lists
```

1. Where are the **Reference Physics List** ?

```
lists Lavora! > pwd
/Users/cirrone/Geant4Dir/geant4-10-00-ref-03/source/physics_lists/lists
```

```
-rw-r--r--  1 cirrone  staff  38580 Apr 19 00:12 LBE.icc
-rw-r--r--  1 cirrone  staff   2382 Apr 19 00:12 QBBC.hh
-rw-r--r--  1 cirrone  staff   2509 Apr 19 00:12 QGSP_BERT.hh
-rw-r--r--  1 cirrone  staff   4514 Apr 19 00:12 QGSP_BERT.icc
-rw-r--r--  1 cirrone  staff   2536 Apr 19 00:12 QGSP_BERT_HP.hh
-rw-r--r--  1 cirrone  staff   4332 Apr 19 00:12 QGSP_BERT_HP.icc
-rw-r--r--  1 cirrone  staff   2490 Apr 19 00:12 QGSP_BIC.hh
-rw-r--r--  1 cirrone  staff   4584 Apr 19 00:12 QGSP_BIC.icc
-rw-r--r--  1 cirrone  staff   2544 Apr 19 00:12 QGSP_BIC_HP.hh
-rw-r--r--  1 cirrone  staff   4156 Apr 19 00:12 QGSP_BIC_HP.icc
-rw-r--r--  1 cirrone  staff   2576 Apr 19 00:12 QGSP_FTFP_BERT.hh
-rw-r--r--  1 cirrone  staff   4196 Apr 19 00:12 QGSP_FTFP_BERT.ic
-rw-r--r--  1 cirrone  staff   2186 Apr 19 00:12 QGSP_INCLXX.hh
-rw-r--r--  1 cirrone  staff   2189 Apr 19 00:12 QGSP_INCLXX_HP.hh
-rw-r--r--  1 cirrone  staff   2501 Apr 19 00:12 QGS_BIC.hh
-rw-r--r--  1 cirrone  staff   4353 Apr 19 00:12 QGS_BIC.icc
-rw-r--r--  1 cirrone  staff   2662 Apr 19 00:12 Shielding.hh
-rw-r--r--  1 cirrone  staff   6522 Apr 19 00:12 Shielding.icc
```

1. Where are the **Reference Physics List** ?

```
lists Lavora! > pwd
/Users/cirrone/Geant4Dir/geant4-10-00-ref-03/source/physics_lists/lists
```

```
-rw-r--r--  1 cirrone  staff  38580 Apr 19 00:12 LBE.icc
-rw-r--r--  1 cirrone  staff   2382 Apr 19 00:12 QBBC.hh
-rw-r--r--  1 cirrone  staff   2509 Apr 19 00:12 QGSP_BERT.hh
-rw-r--r--  1 cirrone  staff   4514 Apr 19 00:12 QGSP_BERT.icc
-rw-r--r--  1 cirrone  staff   2536 Apr 19 00:12 QGSP_BERT_HP.hh
-rw-r--r--  1 cirrone  staff   4332 Apr 19 00:12 [illegible]c
-rw-r--r--  1 cirrone  staff   2490 Apr 19 00:12 QGSP_BIC.hh
-rw-r--r--  1 cirrone  staff   4584 Apr 19 00:12 [illegible]
-rw-r--r--  1 cirrone  staff   2544 Apr 19 00:12 QGSP_BIC_HP.hh
-rw-r--r--  1 cirrone  staff   4156 Apr 19 00:12 QGSP_BIC_HP.icc
-rw-r--r--  1 cirrone  staff   2576 Apr 19 00:12 QGSP_FTFP_BERT.hh
-rw-r--r--  1 cirrone  staff   4196 Apr 19 00:12 QGSP_FTFP_BERT.ic
-rw-r--r--  1 cirrone  staff   2186 Apr 19 00:12 QGSP_INCLXX.hh
-rw-r--r--  1 cirrone  staff   2189 Apr 19 00:12 QGSP_INCLXX_HP.hh
-rw-r--r--  1 cirrone  staff   2501 Apr 19 00:12 QGS_BIC.hh
-rw-r--r--  1 cirrone  staff   4353 Apr 19 00:12 QGS_BIC.icc
-rw-r--r--  1 cirrone  staff   2662 Apr 19 00:12 Shielding.hh
-rw-r--r--  1 cirrone  staff   6522 Apr 19 00:12 Shielding.icc
```

1. Where are the **Reference Physics List** ?

```
lists Lavora! > pwd
/Users/cirrone/Geant4Dir/geant4-10-00-ref-03/source/physics_lists/lists
```

```
-rw-r--r--  1 cirrone  staff  38580 Apr 19 00:12 LBE.icc
-rw-r--r--  1 cirrone  staff   2382 Apr 19 00:12 QBBC.hh
-rw-r--r--  1 cirrone  staff   2509 Apr 19 00:12 QGSP_BERT.hh
-rw-r--r--  1 cirrone  staff   4514 Apr 19 00:12 QGSP_BERT.icc
-rw-r--r--  1 cirrone  staff   2536 Apr 19 00:12 QGSP_BERT_HP.hh
-rw-r--r--  1 cirrone  staff   4332 Apr 19 00:12 [illegible]c
-rw-r--r--  1 cirrone  staff   2490 Apr 19 00:12 QGSP_BIC.hh
-rw-r--r--  1 cirrone  staff   4584 Apr 19 00:12 [illegible]
-rw-r--r--  1 cirrone  staff   2544 Apr 19 00:12 QGSP_BIC_HP.hh
-rw-r--r--  1 cirrone  staff   4156 Apr 19 00:12 QGSP_BIC_HP.icc
-rw-r--r--  1 cirrone  staff   2576 Apr 19 00:12 QGSP_FTFP_BERT.hh
-rw-r--r--  1 cirrone  staff   4196 Apr 19 00:12 QGSP_FTFP_BERT.ic
-rw-r--r--  1 cirrone  staff   2186 Apr 19 00:12 QGSP_INCLXX.hh
-rw-r--r--  1 cirrone  staff   2189 Apr 19 00:12 QGSP_INCLXX_HP.hh
-rw-r--r--  1 cirrone  staff   2501 Apr 19 00:12 QGS_BIC.hh
-rw-r--r--  1 cirrone  staff   4353 Apr 19 00:12 QGS_BIC.icc
-rw-r--r--  1 cirrone  staff   2662 Apr 19 00:12 Shielding.hh
-rw-r--r--  1 cirrone  staff   6522 Apr 19 00:12 Shielding.icc
```

```
// EM Physics
this->RegisterPhysics( new G4EmStandardPhysics(ver) );

// Synchroton Radiation & GN Physics
this->RegisterPhysics( new G4EmExtraPhysics(ver) );

// Decays
this->RegisterPhysics( new G4DecayPhysics(ver) );

 // Hadron Elastic scattering
this->RegisterPhysics( new G4HadronElasticPhysics(ver) );

 // Hadron Physics
this->RegisterPhysics(  new G4HadronPhysicsQGSP_BIC(ver));

// Stopping Physics
this->RegisterPhysics( new G4StoppingPhysics(ver) );

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

// Neutron tracking cut
this->RegisterPhysics( new G4NeutronTrackingCut(ver));
```

1. Where are the **Reference Physics List** ?

```
lists Lavora! > pwd
/Users/cirrone/Geant4Dir/geant4-10-00-ref-03/source/physics_lists/lists
```

```
-rw-r--r--  1 cirrone  staff  38580 Apr 19 00:12 LBE.icc
-rw-r--r--  1 cirrone  staff   2382 Apr 19 00:12 QBBC.hh
-rw-r--r--  1 cirrone  staff   2509 Apr 19 00:12 QGSP_BERT.hh
-rw-r--r--  1 cirrone  staff   4514 Apr 19 00:12 QGSP_BERT.icc
-rw-r--r--  1 cirrone  staff   2536 Apr 19 00:12 QGSP_BERT_HP.hh
-rw-r--r--  1 cirrone  staff   4332 Apr 19 00:12 QGSP_BERT_HP.icc
-rw-r--r--  1 cirrone  staff   2490 Apr 19 00:12 QGSP_BIC.hh
-rw-r--r--  1 cirrone  staff   4584 Apr 19 00:12 QGSP_BIC.icc
-rw-r--r--  1 cirrone  staff   2544 Apr 19 00:12 QGSP_BIC_HP.hh
-rw-r--r--  1 cirrone  staff   4156 Apr 19 00:12 QGSP_BIC_HP.icc
-rw-r--r--  1 cirrone  staff   2576 Apr 19 00:12 QGSP_FTFP_BERT.hh
-rw-r--r--  1 cirrone  staff   4196 Apr 19 00:12 QGSP_FTFP_BERT.icc
-rw-r--r--  1 cirrone  staff   2186 Apr 19 00:12 QGSP_INCLXX.hh
-rw-r--r--  1 cirrone  staff   2189 Apr 19 00:12 QGSP_INCLXX_HP.hh
-rw-r--r--  1 cirrone  staff   2501 Apr 19 00:12 QGS_BIC.hh
-rw-r--r--  1 cirrone  staff   4353 Apr 19 00:12 QGS_BIC.icc
-rw-r--r--  1 cirrone  staff   2662 Apr 19 00:12 Shielding.hh
-rw-r--r--  1 cirrone  staff   6522 Apr 19 00:12 Shielding.icc
```

```
// EM Physics
this->RegisterPhysics( new G4EmStandardPhysics(ver) );

// Synchroton Radiation & GN Physics
this->RegisterPhysics( new G4EmExtraPhysics(ver) );

// Decays
this->RegisterPhysics( new G4DecayPhysics(ver) );

 // Hadron Elastic scattering
this->RegisterPhysics( new G4HadronElasticPhysics(ver) );

 // Hadron Physics
this->RegisterPhysics(  new G4HadronPhysicsQGSP_BIC(ver));

// Stopping Physics
this->RegisterPhysics( new G4StoppingPhysics(ver) );

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

// Neutron tracking cut
this->RegisterPhysics( new G4NeutronTrackingCut(ver));
```

Reference physics lists

- Provide a complete and realistic physics with ALL models of interest
- Provided according to some Use-cases
- Few choices are available for EM physics
- Several possibilities for hadronic
- They are intended as starting point and their builder can be reused
  - They are made up of builders, so easy to change/replace each given block

Reference physics lists

- **Electromagnetic interactions** for all particles. Different settings are offered
  - Default transport parameters (best performance)
  - Some optimised choice (_EMV extension)
  - Some high precision choice (_EMY extension)
- **Inelastic** interactions
- **Elastic scattering**
- **Capture**
- **Decay** of unstable particles
- Specialized treatment of **low energy neutrons** (< 20 MeV)

Electromagnetic Physics

EM concepts I

- The same physics processes (e.g. Compton scattering) can be described by different models, that can be **alternative** or **complementary** in a given energy range

- For instance: Compton scattering can be described by

  - **G4KleinNishinaCompton**

  - **G4LivermoreComptonModel** (specialized low-energy, based on the Livermore database)

  - **G4PenelopeComptonModel** (specialized low-energy, based on the Penelope analytical model)

  - **G4LivermorePolarizedComptonModel** (specialized low-energy, Livermore database with polarization)

  - **G4PolarizedComptonModel** (Klein-Nishina with polarization)

- Different models can be combined, so that the appropriate one is used in each given energy range (␣ performance optimization)

EM concepts II

- A physical interaction or process is described by a process class
  - Naming scheme : « G4ProcessName »
  - Eg. : « G4Compton » for photon Compton scattering
- A physical process can be simulated according to several models, each model being described by a model class
  - The usual naming scheme is: « G4ModelNameProcessNameModel »
  - Eg. : « G4LivermoreComptonModel » for the Livermore Compton model
  - Models can be alternative and/or complementary on certain energy ranges
  - Refer to the Geant4 manual for the full list of available models

EM physics models

- Models and processes for the description of the EM interactions in Geant4 have been grouped in several packages

Package	Description
Standard	γ-rays, $e^{\pm}$ up to 100 TeV, Hadrons, ions up to 100 TeV
Muons	Muons up to 1 PeV
X-rays	X-rays and optical photon production
Optical	Optical photons interactions
High-Energy	Processes at high energy (> 10 GeV). Physics for exotic particles
Low-Energy	Specialized processes for low-energy (down to 250 eV), including atomic effects
Polarization	Simulation of polarized beams

EM processes for gamma and e+/-

Particle	Process	G4Process
Photons	Gamma Conversion in $e^{\pm}$	`G4GammaConversion`
	Compton scattering	`G4ComptonScattering`
	Photoelectric effect	`G4PhotoElectricEffect`
	Rayleigh scattering	`G4RayleighScattering`
$e^{\pm}$	Ionisation	`G4eIonisation`
	Bremsstrahlung	`G4eBremsstrahlung`
	Multiple scattering	`G4eMultipleScattering`
e^{+}	Annihilation	`G4eplusAnnihilation`

When/why to use Low Energy models

- **Use** Low-Energy models (Livermore or Penelope), as an alternative to Standard models, when you:
  - need precise treatment of EM showers and interactions at low-energy (keV scale)
  - are interested in atomic effects, as fluorescence x-rays, Doppler broadening, etc.
  - can afford a more CPU-intensive simulation
  - want to cross-check an other simulation (e.g. with a different model)
- Do **not** use when you are interested in EM physics at the MeV region
  - same results as Standard EM models, performance penalty

Example: physics list for gamma

```
G4ProcessManager* pmanager
if ( particleName == "gamma"   )
{
   pmanager->AddDiscreteProcess(new G4PhotoElectricEffect);
   pmanager->AddDiscreteProcess(new G4ComptonScattering);
   pmanager->AddDiscreteProcess(new G4GammaConversion);
   pmanager->AddDiscreteProcess(new G4RayleighScattering);
 }
```

- For each process a default model is used among all the available ones:
  e.g. the **G4KleinNishinaCompton** for the **G4ComptonStcattering**)

- This default can be changed (e.g. **G4PenelopeComptonModel**)

Ready-to-use Physics Constructors

G4EmStandardPhysics – default
G4EmStandardPhysics_option1 – HEP fast but not precise
G4EmStandardPhysics_option2 – Experimental
G4EmStandardPhysics_option3 – medical, space

G4EmLivermorePhysics
G4EmLivermorePolarizedPhysics
G4EmPenelopePhysics
G4EmDNAPhysics

Combined Physics
Standard > 1 GeV
LowEnergy < 1 GeV

- **`$G4INSTALL/source/physics_list/builders`**
- Advantage of using of these classes – they are tested on regular basis and are used for regular validation

How to extract physics

- Possible to retrieve physics quantities via the G4EmCalculator class file

- Example for retrieving total cross section of a process with name procName, for particle partName and for the material matName

```
G4EmCalculator emCalculator;
G4Material* material =
  G4NistManager::Instance()->FindOrBuildMaterial("matName);
G4double massSigma = emCalculator.ComputeCrossSectionPerVolume
   (energy,particle,procName,material);
G4cout << G4BestUnit(massSigma, "Surface/Volume") << G4endl;
```

See $G4INSTALL/examples/extended/electromagnetic/TestEm14

Hadronic Physics

- Data-driven models
- Parametrisation models
- Theory driven models

Hadronic physics challenge

- Three energy regimes
  - < 100 MeV
  - resonance and cascade region (100 MeV - 10 GeV)
  - > 20 GeV (QCD strings)
- Within each regime there are several models
- Many of these are phenomenological

Reference physics lists for Hadronic interaction

- Are part of the Geant4 code

- Three family of lists

  - QGS, or list based on a model that use the Quark Gluon String model for high energy hadronic interactions of protons, neutrons, pions and kaons

  - FTF, based on the FTF (FRITIOF like string model) for protons, neutrons, pions and kaons

  - Other specialized physics lists

Cross sections

- **Default Cross sections but also specific databases:**
  - Low energy neutrons
    - ✓ G4NDL available as external data files
    - ✓ Available with or without thermal cross section
  - Neutron and proton reaction cross section
    - ✓ 20 MeV < E < 20 GeV
  - Ion-nucleus reaction cross sections
    - ✓ E/A < 1 GeV
  - Isotope production data

G4NDL (G4 Neutron Data Library)

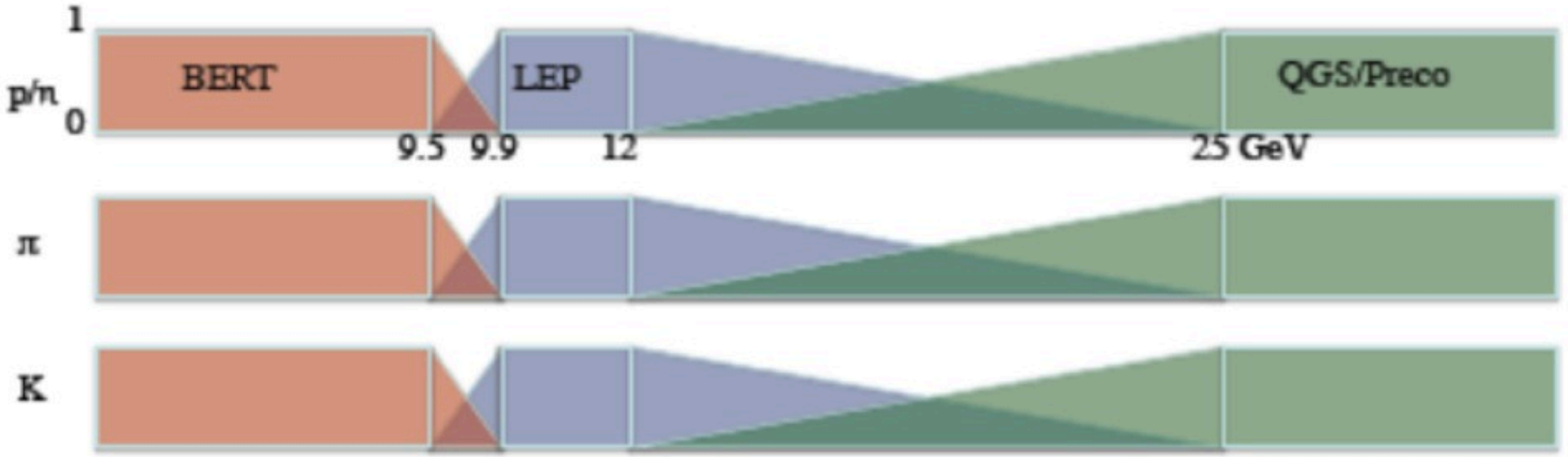
- **Neutron data files for High precision models**
- These data include both cross sections and final states
- These data derived by the following evaluated data libraries
  - Brond-2.1
  - CENDL2.2
  - EFF-3
  - ENDF/B
  - FENDL/E
  - JEF2.2
  - JENDL-FF
  - MENDL

Physics lists for NeutronHPThermalScattering

```
// The process
G4HadronElasticProcess*    theNeutronElasticProcess   = new G4HadronElasticProcess();

// Cross Section Data set
G4NeutronHPElasticData* theHPElasticData = new G4NeutronHPElasticData();
theNeutronElasticProcess->AddDataSet( theHPElasticData );
G4NeutronHPThermalScatteringData* theHPThermalScatteringData = new G4NeutronHPThermalScatteringData();
theNeutronElasticProcess->AddDataSet( theHPThermalScatteringData );

// The model
G4NeutronHPElastic* theNeutronElasticModel = new G4NeutronHPElastic();
theNeutronElasticModel->SetMinEnergy ( 4.0*eV );
theNeutronElasticProcess->RegisterMe(theNeutronElasticModel);
G4NeutronHPThermalScattering* theNeutronThermalElasticModel = new
```

```
G4NeutronHPThermalScattering();
theNeutronThermalElasticModel->SetMaxEnergy ( 4.0*eV );
theNeutronElasticProcess->RegisterMe(theNeutronThermalElasticModel);

// Apply Processes to Process Manager of Neutron
G4ProcessManager* pmanager = G4Neutron::Neutron()-> GetProcessManager();
pmanager->AddDiscreteProcess( theNeutronElasticProcess );
```

Hadronic models match

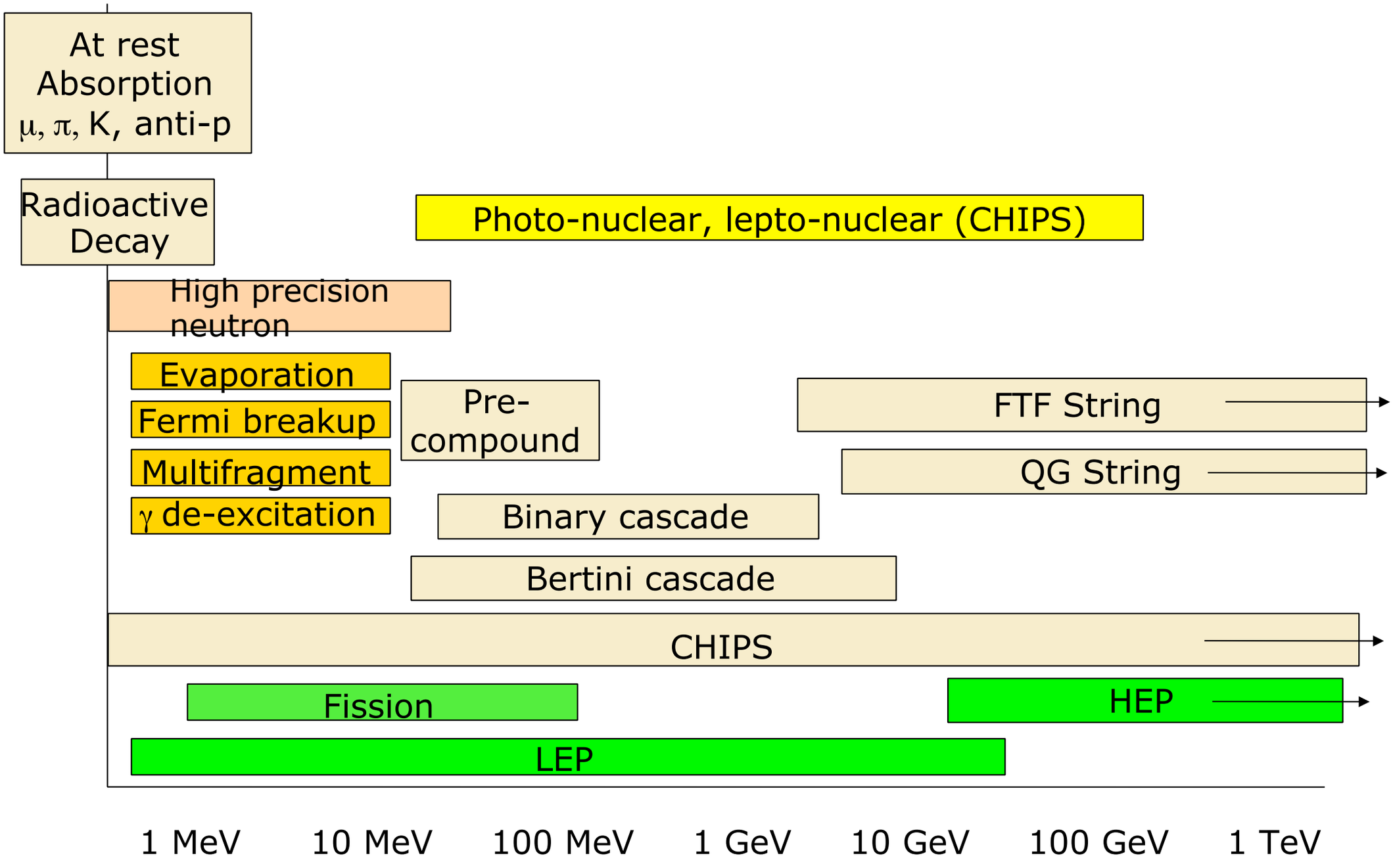


Recommended reference physics lists

- A dedicated web page
- Application fields are identified
  - High energy physics
  - LHC neutron fluxes
  - Shielding
  - Medical
  - .....

Hadronic process/Model Inventory

http://geant4.cern.ch/support/proc_mod_catalog/models



Where to find information?

- Process/model catalog

  - Home/User Support --> Geant4 web site

Where to find information?

User Support

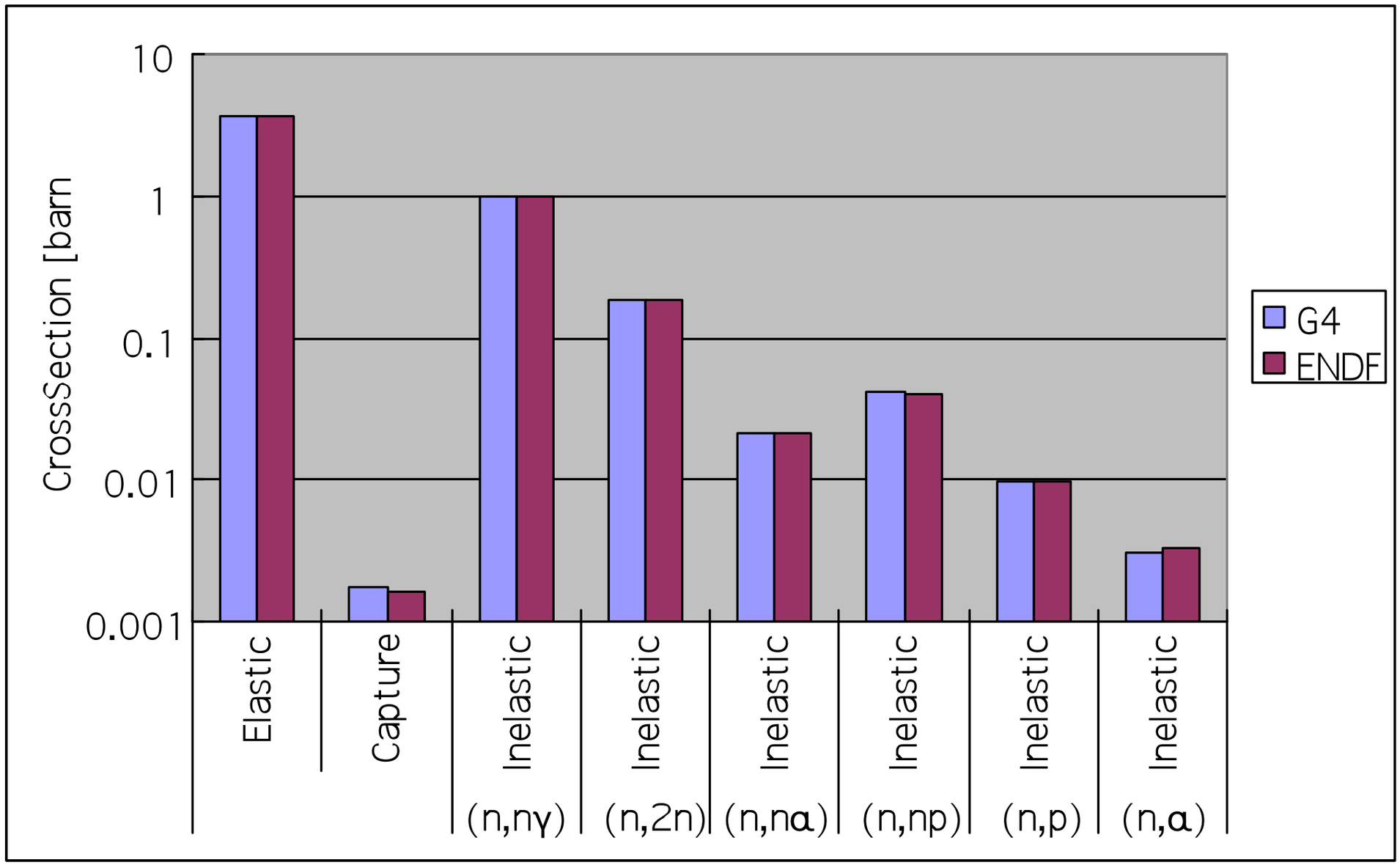
1. Getting started
2. Training courses and materials
3. Source code
    a. Download page
    b. LXR code browser -or- draft doxygen documentation
4. Frequently Asked Questions (FAQ)
5. Bug reports and fixes
6. User requirements tracker
7. User Forum
8. Documentation
    a. Introduction to Geant4
    b. Installation Guide
    c. Application Developers Guide
    d. Toolkit Developers Guide
    e. Physics Reference Manual
    f. Software Reference Manual
9. Physics lists
    a. Electromagnetic
    b. Hadronic

Thank you

Thermal neutron scattering

- At thermal neutron energies, atomic translational motion as well as vibration and rotation of the chemically bound atoms affect the neutron scattering cross section and the energy and angular distribution of secondary neutrons.
- The energy loss or gain of incident neutrons can be different from interactions with nuclei in unbound atoms.
- Only individual Maxwellian motion of the target nucleus (Free Gas Model) was taken into account in the default NeutronHP models.

Some verification: channel cross section



Some verification: secondary energy spectrum