Geant4 Physics List

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Thanks to P.Gumplinger, M.Maire, H.P.Wellisch

- General Physics
- Electromagnetic Physics
- Optical Photons
- Hadronic Physics

PhysicsList

- It is one of the « mandatory user classes »;
  - Defined in source/run
- Defines the three pure virtual methods:
  - ConstructParticle()
  - ConstructProcesse()
  - SetCuts()
- Concrete PhysicsList needs to inherit from G4VUserPhysicsList or G4VModularPhysicsList
- For interactivity G4UserPhysicsListMessenger can be used to handle PhysicsList parameters

General Physics

- The list of particles used in simulation needs to be registered
  - G4Gamma::Gamma()
  - G4Proton::Proton()
  - ……
- The list of physics processes per particle need to be registered before initialization of G4RunManager
  - /run/initialize

How to build PhysicsList?

- PhysicsList can be build by experience user
- Components are distributed inside subdirectory
  - $G4INSTALL/physics_list
- PhysicsList can be studied using G4 novice examples
  - **N02**: Simplified tracker geometry with uniform magnetic field
  - **N03**: Simplified calorimeter geometry
  - **N04**: Simplified collider detector with a readout geometry
- Copy PhysicsList from extended and advanced examples
  - **electromagnetic**: 13 examples for different aspects of EM physics
  - **N06 and extended/optical**: specifics of optical photons
  - **advanced**: different mini-applications of Geant4 based on real experimental setups
- Use predefined PhysicsList from
  - $G4INSTALL/physics_list/hadronic

Example: AddTransportation

```
void G4VUserPhysicsList::AddTransportation()  {
 G4Transportation* theTransportationProcess= new G4Transportation();
   // loop over all particles in G4ParticleTable
   theParticleIterator->reset();
   while( (*theParticleIterator)() ){
      G4ParticleDefinition* particle = theParticleIterator->value();
      G4ProcessManager* pmanager = particle->GetProcessManager();
      if (!particle->IsShortLived()) {
         if ( pmanager == 0)  {
            G4Exception("G4VUserPhysicsList::AddTransportation : no process manager!");
         } else {
           // add transportation with ordering = ( -1, "first", "first" )
           pmanager->AddProcess(theTransportationProcess);
           pmanager->SetProcessOrderingToFirst(theTransportationProcess,
   idxAlongStep);
           pmanager->SetProcessOrderingToFirst(theTransportationProcess,
   idxPostStep);
        }
    }
}
```

Example: Gamma processes

- Discrete processes - only PostStep actions;
  - Use function AddDiscreteProcess;
  - **pmanager** is the G4ProcessManager of the gamma;
  - Assume the transportation has been set by AddTransportation();
- The most simple code:

```
// Construct processes for gamma:
pmanager->AddDiscreteProcess(new G4GammaConversion());
pmanager->AddDiscreteProcess(new G4ComptonScattering());
pmanager->AddDiscreteProcess(new G4PhotoElectricEffect());
```

Example: electron and positron

Main interface with definition of the process order:

G4ProcessManager::AddProcess(G4VProcess*, int orderAtRest,
int orderAlongStep, int orderPostStep);

NOTE: if (order < 0) – process inactive; else – the order of DoIt method;
inverse order of GetInteractionLength

```
// add processes for e-
G4ProcessManager* pmanager = G4Electron::Electron()->GetProcessManager();
pmanager->AddProcess (new G4MultipleScattering,  -1,  1,  1 );
pmanager->AddProcess (new G4eIonisation,          -1,  2,  2 );
pmanager->AddProcess (new G4eBremsstrahlung,     -1,  3,  3 );
// add processes for e+
pmanager = G4Positron::Positron()->GetProcessManager();
pmanager->AddProcess (new G4MultipleScattering,  -1,  1,  1 );
pmanager->AddProcess (new G4eIonisation,          -1,  2,  2 );
pmanager->AddProcess (new G4eBremsstrahlung,     -1,  3,  3 );
pmanager->AddProcess (new G4eplusAnnihilation,    1, -1,  4 );
```

Example: hadrons and ions

- Hadrons (pions, kaons, proton,…)
- Light ions (deuteron, triton, alpha)
- Heavy ions (GenericIon)
- Example loop over list of particles:

```
G4ProcessManager* pmanager = particle->GetProcessManager();
G4String pName = particle->GetParticleName();
// Ions
If ( pName == "GenericIon" || pName == "alpha" || pName == "He3") {
  pmanager->AddProcess (new G4MultipleScattering,  -1,  1,  1 );
  pmanager->AddProcess (new G4ionIonisation,        -1,  2,  2 );

// Hadrons
}  else if (particle->GetPDGCharge() != 0 && particle->GetPDGMass() > 130.*MeV) {
  pmanager->AddProcess (new G4MultipleScattering,  -1,  1,  1 );
  pmanager->AddProcess (new G4hIonisation,          -1,  2,  2 );
}
```

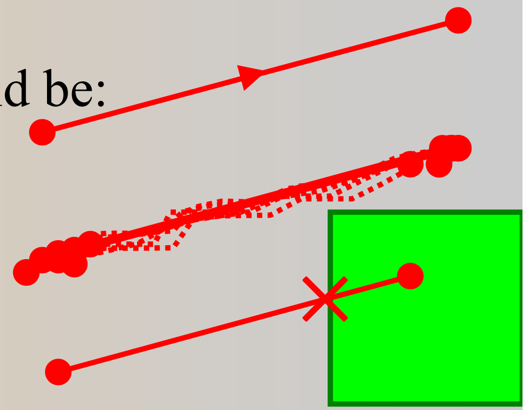
Processes ordering

- Ordering of following processes is critical:
  - Assuming n processes, the ordering of the AlongGetPhysicalInteractionLength should be:

    [n-2] …

    [n-1] multiple scattering

    [n] transportation



- Why ?
  - Processes return a « true path length »;
  - The multiple scattering convers it into into a ***shorter*** « geometrical » path length;
  - Based on this new length, the transportation can geometrically limits the step.
- Other processes ordering usually do not matter

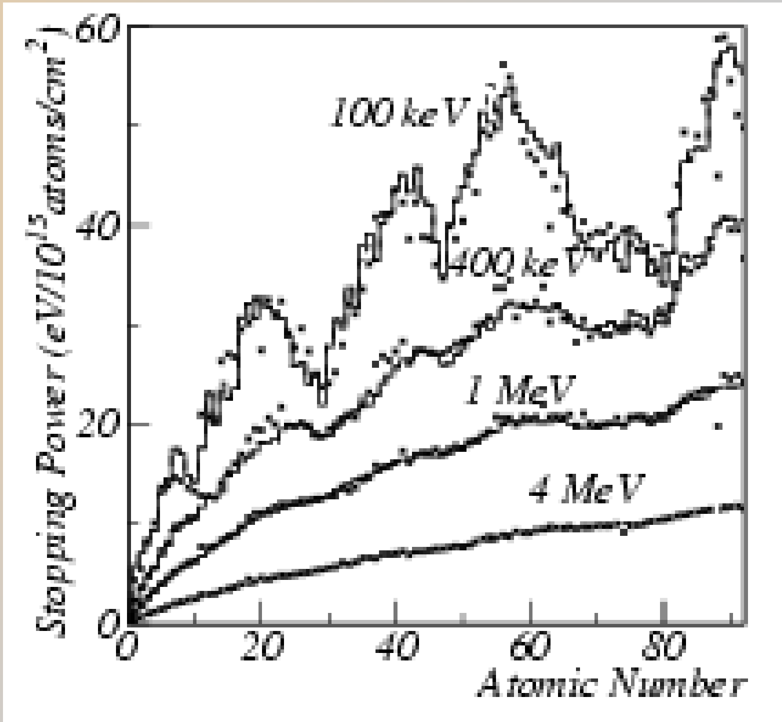
Standard EM PhysicsList

- Standard EM PhysicsList:
  - $G4INSTALL/physics_lists/electromagnetic/standard
- Different aspects of EM physics are demonstrating in examples:
  - $G4INSTALL/examples/electromagnetic/extended
- There are UI commands for defining cuts and to choose options for the EM physics
  - /testem/phys/setCuts 0.01 mm
  - /testem/phys/addPhysics standard
  - ….
- Steering is also provided via
  - G4EmProcessOptions::SetMaxEnergy(10.0*GeV);
  - G4EmProcessOptions::SetVerbose(2);
- Components of this PhysicsList are provided as physics_list subdirectory and in different extended examples

Geant4 low energy EM physics

- When energy transfer become close to energy of atomic electrons atomic shell structure should be taken into account
- Problems with theory, so phenomenology and experimental data are used

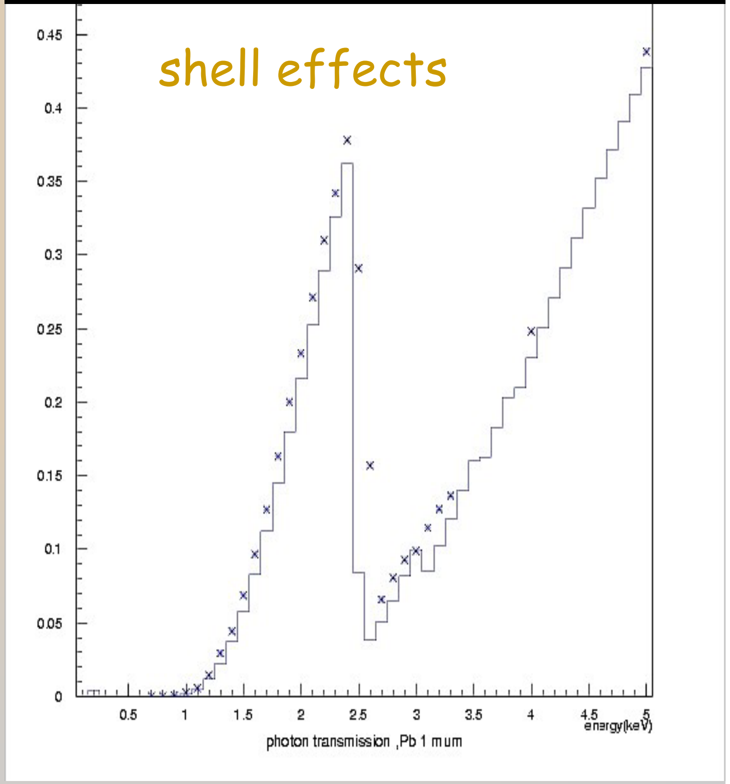
Proton stopping power



Geant4 low energy EM physics

- Validity down to **250 eV**
  - 250 eV is a “suggested” lower limit
  - data libraries down to 10 eV
  - 1 < Z < 100
- Exploit **evaluated data libraries** (from LLNL):
  - EADL (Evaluated Atomic Data Library)
  - EEDL (Evaluated Electron Data Library)
  - EPDL97 (Evaluated Photon Data Library)

Photon transmission, 1µm Pb



Geant4 low energy EM physics

- Compton scattering
- Polarised Compton
- Rayleigh scattering
- Photoelectric effect
- Pair production
- Bremsstrahlung
- Electron ionisation
- Hadron ionisation
- Atomic relaxation
- Set of Penelope models (new)

- It is relatively new package
- Development is driven by requirements which come from medicine and space research
- There are also users in HEP instrumentation

Geant4 low energy EM physics

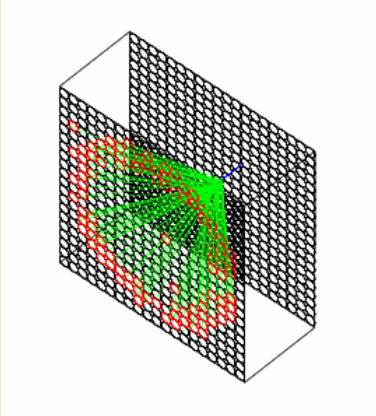
- To use G4 lowenergy package user has to substitute a standard process in the PhysicsList by the corresponding lowenergy process:
  - G4hIonisation → G4hLowEnergyIonisation
  - G4eIonisation → G4LowEnergyIonisation
  - ……
- The environment variable G4LEDATA should be defined
  - setenv G4LEDATA $G4INSTALL/data/G4EMLOW3.0

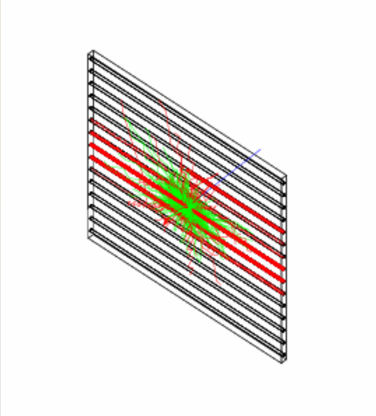
OPTICAL PHOTON PROCESSES IN GEANT4

- Optical photons generated by following processes (processes/electromagnetic/xrays):
  - Scintillation
  - Cherenkov
  - Transition radiation
- Optical photons have following physics processes (processes/optical/):
  - Refraction and Reflection at medium boundaries
  - Bulk Absorption
  - Rayleigh scattering
- ExampleN06 at /examples/novice/N06

OPTICAL PHOTON PROCESSES IN GEANT4

- Material properties should be defined for G4Scintillation process, so only inside the scintillator the process is active
- G4Scintillation should be ordered after all energy loss processes
- G4Cerenkov is active only if for the given material an index of refraction is provided
- For simulation of optical photons propagation G4OpticalSurface should be defined for a given optical system





G4Cerenkov: User Options

- Suspend primary particle and track Cherenkov photons first
- Set the max number of Cherenkov photons per step

in ExptPhysicsList:

```
#include "G4Cerenkov.hh"

G4Cerenkov* theCerenkovProcess = new G4Cerenkov("Cerenkov");
theCerenkovProcess -> SetTrackSecondariesFirst(true);
G4int MaxNumPhotons = 300;
theCerenkovProcess->SetMaxNumPhotonsPerStep(MaxNumPhotons);
```

Boundary Processes

- G4OpticalSurface needs to be defined
- Dielectric - Dielectric

  Depending on the photon's wave length, angle of incidence, (linear) polarization, and refractive index on both sides of the boundary:

  (a) total internal reflected

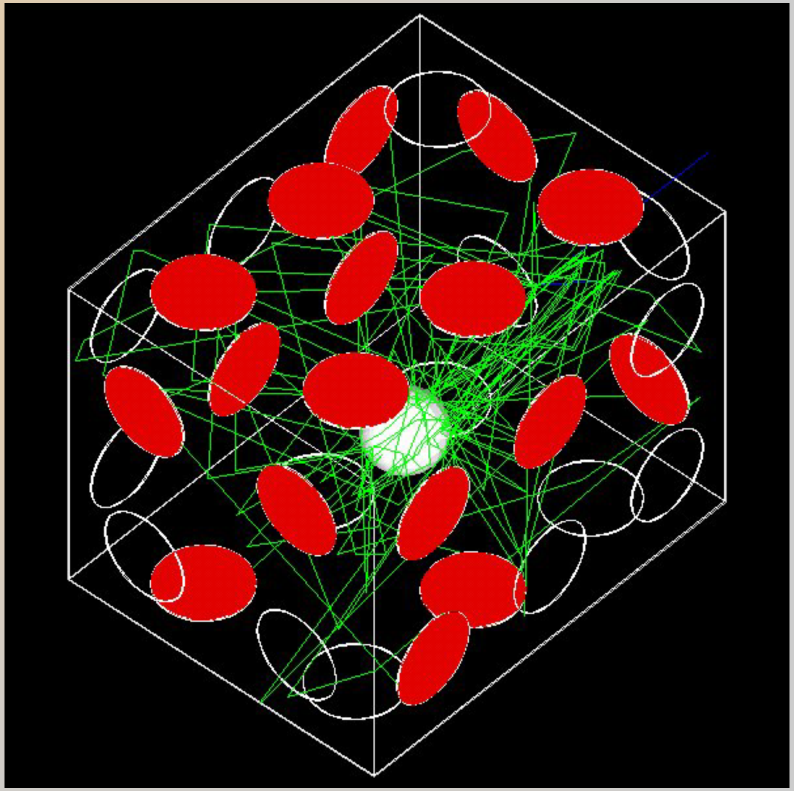
  (b) Fresnel refracted

  (c) Fresnel reflected

- Dielectric - Metal

  (a) absorbed (detected)

  (b) reflected

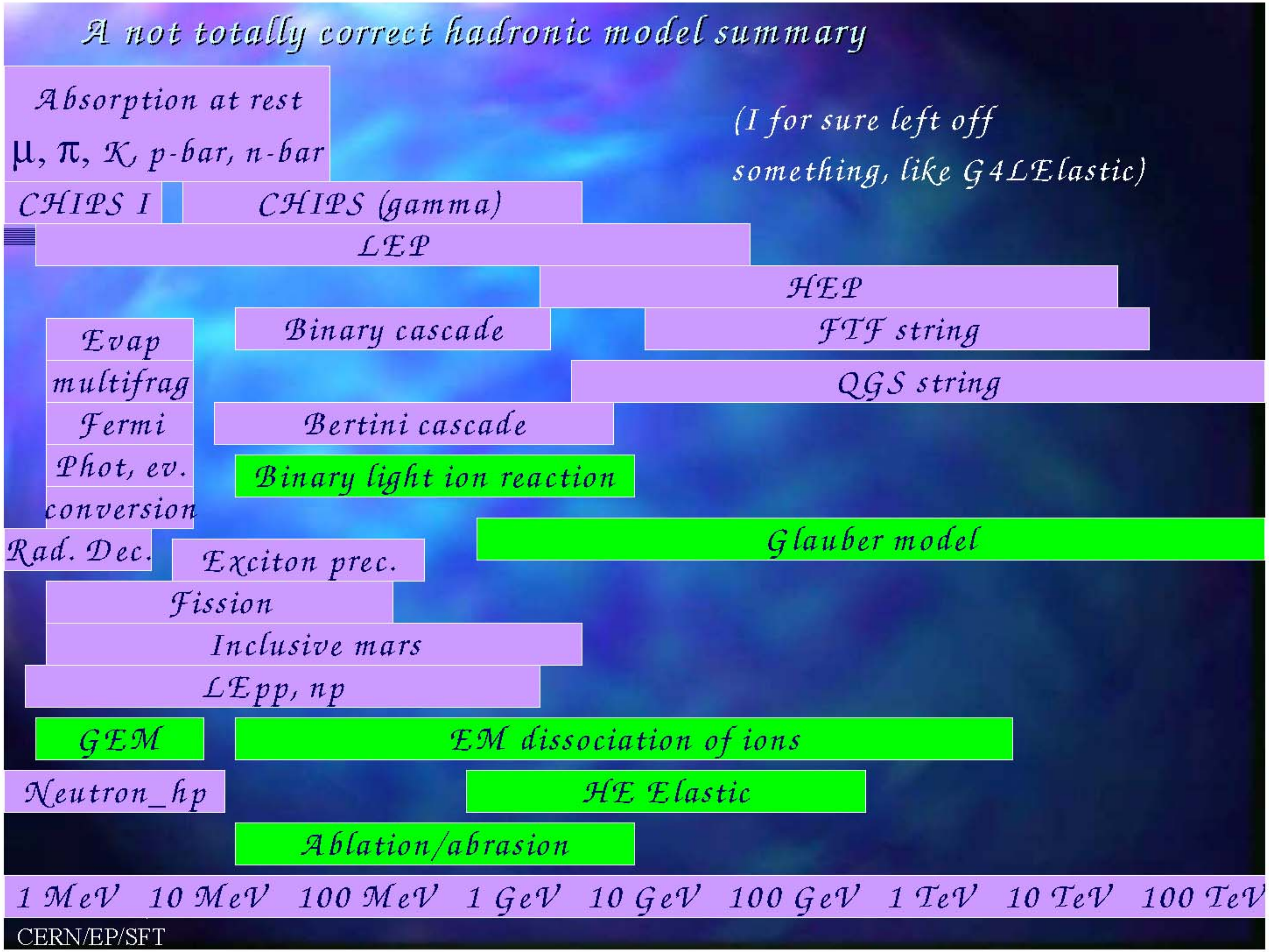


Some remarks

- Geant4 Standard EM package the optimal for most part of HEP applications
- Geant4 Lowenergy package provide a possibility to apply toolkit to variety of applications for which atomic shell structure is essential
- Optical photons generation and tracking can be simulated inside the same geometry

Hadronic Physics

- Interaction of particles with atomic nuclei
- Interactions on-fly are simulated by discrete processes - only PostStep actions
  - Cross section calculation and secondary generators are separated
  - Different secondary generators should be applied for different energy ranges and particle type
- Capture of stopping particles: only AtRest actions


A not totally correct hadronic model summary
(I for sure left off
something, like G4LElastic)
Absorption at rest
μ, π, K, p-bar, n-bar
CHIPS I
CHIPS (gamma)
LEP
HEP
Evap
Binary cascade
FTF string
multifrag
QGS string
Fermi
Bertini cascade
Phot, ev.
Binary light ion reaction
conversion
Glauber model
Rad. Dec.
Exciton prec.
Fission
Inclusive mars
LEpp, np
GEM
EM dissociation of ions
Neutron_hp
HE Elastic
Ablation/abrasion
1 MeV
10 MeV
100 MeV
1 GeV
10 GeV
100 GeV
1 TeV
10 TeV
100 TeV
CERN/EP/SFT

Hadronic Physics: proton

- Cross section data set and list of models need to be defined
- Example:

```
// proton inelastic by Binary Cascade and LHEP
particle = G4Proton::Proton();
pmanager = particle->GetProcessManager();
G4ProtonInelasticProcess* p = G4ProtonInelasticProcess);
p->RegisterMe(new G4LEProtonInelastic );
p->RegisterMe(new G4BinaryCascade );
p->AddDataSet(new G4ProtonInelasticCrossSection );
pmanager->AddDiscreteProcess(p);
```

Hadronic Physics: neutron

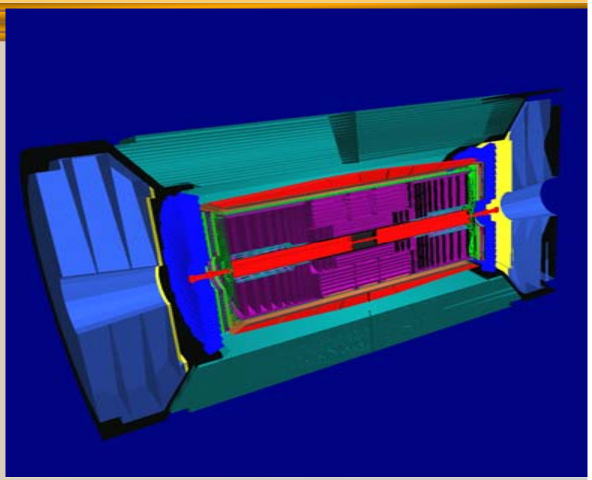
```
// neutron inelastic by Binary Cascade and LHEP, fission, and capture
particle = G4Neutron::Neutron();
pmanager = particle->GetProcessManager();
G4NeutronInelasticProcess* p = G4NeutronInelasticProcess);
// Default energy ranges for models
p->RegisterMe(new G4LENeutronInelastic );
p->RegisterMe(new G4BinaryCascade );
p->AddDataSet(new G4NeutronInelasticCrossSection );
pmanager->AddDiscreteProcess(p);
// fission
G4HadronFissionProcess* theFissionProcess = new G4HadronFissionProcess;
theFissionProcess->RegisterMe(new G4LFission );
pmanager->AddDiscreteProcess(theFissionProcess);
// capture
G4HadronCaptureProcess* theCaptureProcess = new G4HadronCaptureProcess;
theCaptureProcess->RegisterMe(new G4LCapture );
pmanager->AddDiscreteProcess(theCaptureProcess );
```

Predefined Physics Lists

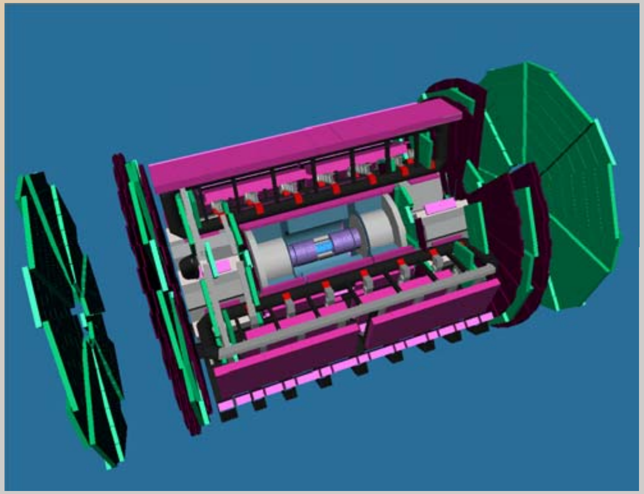
- Hadronic physics is complex
- Different experiments/groups need to coordinate simulation efforts
- Predefined Physics Lists were designed
  - $G4INSTALL/physics_lists/hadronic
- Both hadronic and EM physics are included, method of compilation and linking is provided
- Different use-cases
  - Geant4 web

LHC Physics

CMS



ATLAS

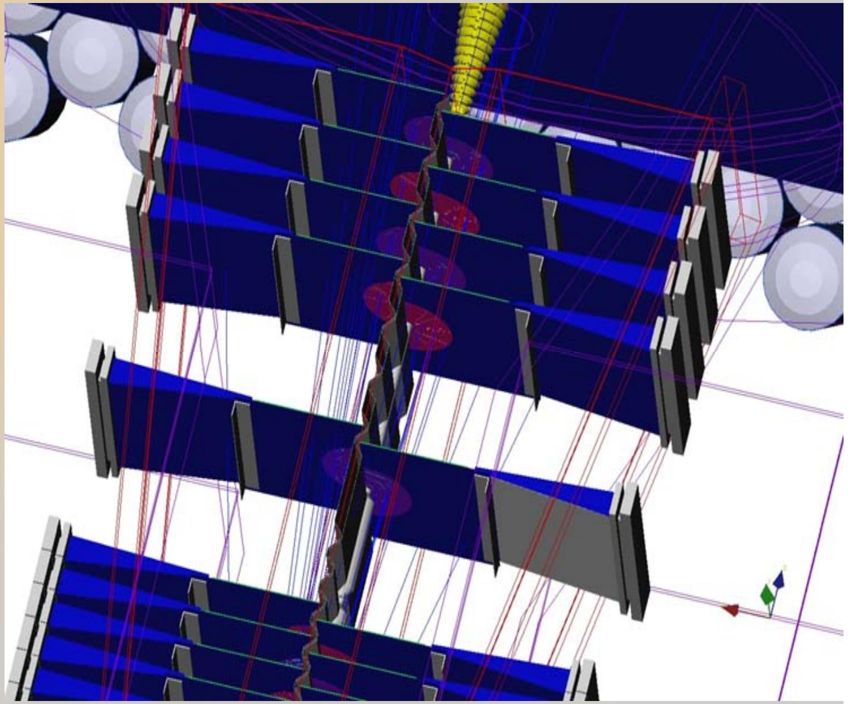


- From TeV down to MeV energy scale for precise simulation of detector response
- Following lists are recommended for Geant4 version 7.0p01:
  - QGSP_GN (Quark Gluon String + PreCompound + Gamma-Nuclear)
  - QGSP_BERT (Quark Gluon String + PreCompound + Bertini Cascade)
  - QGSC (Quark Gluon String + CHIPS)
  - LHEP_BERT (Low-energy Parameterized + Bertini cascade)

Extensions of Hadronic Physics

- For neutron penetration High Precision model of neutron transport down to very low energies
  - NeutronHPCrossSections
- For radioactive decays of nuclei:
  - G4RADIOACTIVEDATA
- Gamma and electro – nuclear interaction by the CHIPS package

LHCb



Conclusion remarks

- Using Geant4 examples and physics_lists package novice user can take existing PhysicsList without detailed studying of interaction of particles with matter
- Default values of internal model parameters are reasonably defined
- To estimate the accuracy of simulation results indeed one have to study Geant4 and physics in more details
- It is true for any simulation software!