Physics Lists

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Outline

- Introduction
- The G4VUserPhysicsList class
- Modular physics lists
- Packaged physics lists
- Choosing the appropriate physics list
- Validating your physics list

What is a Physics List?

- A class which collects all the particles, physics processes and production thresholds needed for your application
- It tells the run manager how and when to invoke physics
- It is a very flexible way to build a physics environment
  - user can pick the particles he wants
  - user can pick the physics to assign to each particle
- But, user must have a good understanding of the physics required
  - omission of particles or physics could cause errors or poor simulation

Why Do We Need a Physics List?

- Physics is physics – shouldn't Geant4 provide, as a default, a complete set of physics processes that everyone can use?
- No:
  - there are many different physics models and approximations
    - very much the case for hadronic physics
    - but also true for electromagnetic physics
  - computation speed is an issue
    - a user may want a less-detailed, but faster approximation
  - no application requires all the physics and particles that Geant4 has to offer
    - e.g., most medical applications do not want multi-GeV physics

Why Do We Need a Physics List?

- For this reason Geant4 takes an atomistic, rather than an integral approach to physics
  - provide many physics components (processes) which are decoupled from one another (for the most part)
  - user selects these components in custom-designed physics lists in much the same way as a detector geometry is built
- Exceptions
  - a few electromagnetic processes must be used together
  - future processes involving interference of electromagnetic and strong interactions may require coupling as well

Physics Processes Provided by Geant4

- EM physics
  - "standard" processes valid from ~1 keV to ~PeV
  - "low energy" valid from 250 eV to ~PeV
  - optical photons
- Weak interaction physics
  - decay of subatomic particles
  - radioactive decay of nuclei
- Hadronic physics
  - pure strong interaction physics valid from 0 to ~TeV
  - electro- and gamma-nuclear valid from 10 MeV to ~TeV
- Parameterized or "fast simulation" physics

G4VUserPhysicsList

- All physics lists must derive from this class
  - and then be registered with the run manager
- Example:

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

- User must implement the methods ConstructParticle, ConstructProcess and SetCuts

G4VUserPhysicsList: Required Methods

- ConstructParticle() – choose the particles you need in your simulation and define them all here
- ConstructProcess() – for each particle, assign all the physics processes important in your simulation
  - What's a process?
  - → a class that defines how a particle should interact with matter (it's where the physics is!)
  - more on this later
- SetCuts() – set the range cuts for secondary production
  - What's a range cut?
  - → essentially a low energy limit on particle production
  - more on this later

ConstructParticle()

```
void MyPhysicsList::ConstructParticle()  {
    G4BaryonConstructor* baryonConstructor =
                                        new G4BaryonConstructor();
    baryonConstructor->ConstructParticle();
    delete baryonConstructor;
    G4BosonConstructor* bosonConstructor =
                                        new G4BosonConstructor();
    bosonConstructor->ConstructParticle();
    delete bosonConstructor;
    …
    …
}
```

ConstructParticle() (alternate)

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

ConstructProcess()

```
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
}
```

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.
  }
```

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
```

SetCuts()

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

G4VModularPhysicsList

- The physics list in our example is quite simple
- A realistic physics list is likely to have many more physics processes
  - such a list can become quite long, complicated and hard to maintain
  - try a modular physics list instead
- Features of G4VModularPhysicsList
  - derived from G4VUserPhysicsList
  - AddTransportation() automatically called for all registered particles
  - allows you to define “physics modules”: EM physics, hadronic physics, optical physics, etc.

A Simple G4VModularPhysicsList

- Constructor:

```
MyModPhysList::MyModPhysList(): G4VModularPhysicsList() {
    defaultCutValue = 0.7*mm;
    RegisterPhysics(new ProtonPhysics() );
    // all physics processes having to do with protons
    RegisterPhysics(new ElectronPhysics() );
    // all physics processes having to do with electrons
    RegisterPhysics(new DecayPhysics() );
    // physics of unstable particles
}
```

- SetCuts:

```
void MyModPhysList::SetCuts() { SetCutsWithDefault(); }
```

Physics Constructors

- Allows you to group particle and process construction according to physics domains
- class ProtonPhysics : public G4VPhysicsConstructor

```
{
  public:
     ProtonPhysics(const G4String& name = "proton");
     virtual ~ProtonPhysics();
     virtual void ConstructParticle()
     // easy – only one particle to build in this case
     virtual void ConstructProcess();
     // put here all the processes a proton can have
}
```

Packaged Physics Lists

- Our example dealt mainly with electromagnetic physics
- A realistic physics list can be found in basic example B3
  - uses "standard" EM physics and decay physics
  - a good starting point
  - add to it according to your needs
- Adding hadronic physics is more involved
  - for any one hadronic process, user may choose from several hadronic models
  - choosing the right models for your application requires care
  - to make things easier, pre-packaged physics lists are provided according to some reference use cases

Packaged Physics Lists

- Each pre-packaged physics list includes different choices of EM and hadronic physics
- A list of these can be found in your copy of the toolkit at
  geant4/source/physics_lists/lists/include
- Caveats
  - these lists are provided as a “best guess” of the physics needed in a given use case
  - the user is responsible for validating the physics for his own application and adding (or subtracting) the appropriate physics
  - they are intended as starting points or templates

Production Physics Lists

- Among the pre-packaged physics lists are the "Production" physics lists
  - a small number of well-maintained and tested physics lists
  - also the most used (ATLAS, CMS, etc.) and most recommended
- These are updated less frequently
  - more stable
- More on these, and which ones we recommend, later

A Short Guide to Choosing a Physics List

Choosing a Physics List

- Which physics list you use is highly dependent on your use case
- Before choosing, or building your own, familiarize yourself with the major physics processes available
  - the process-model catalog is useful for this
  - see Geant4 web page under User Support, item 11b

- Geant4 provides several "production physics lists" which are routinely validated and updated with each release
  - these should be considered only as starting points which you may need to validate or modify for your application
- There are also many physics lists in the examples which you can copy
  - these are often very specific to a given use case

Choosing a Physics List

- There are currently 19 packaged physics lists available
  - but you will likely be interested in only a few, namely the “production” physics lists
  - many physics lists are either developmental or customized in some way, and so not very useful to new users

- All of the packaged physics lists use templates

- 6 reference physics lists:
  - FTFP_BERT, FTFP_BERT_HP
  - QGSP_BERT, QGSP_BERT_HP, QGSP_BIC
  - QGSP_FTFP_BERT

Physics List Naming Convention

- The following acronyms refer to various hadronic options
  - QGS -> Quark Gluon String model (>~20 GeV)
  - FTF -> Fritiof string model (>~5 GeV)
  - BIC -> Binary Cascade (<~ 10 GeV)
  - BERT -> Bertini-style cascade (<~ 10 GeV)
  - HP -> High Precision neutron model (< 20 MeV)
  - P -> G4Precompund model used for de-excitation

- EM options designated by
  - no suffix : standard EM physics
  - EMV suffix : older but faster EM processes
  - other suffixes for other EM options

Production Physics Lists

- FTFP_BERT
  - recommended by Geant4 for HEP
  - contains all standard EM processes
  - uses Bertini-style cascade for hadrons < 5 GeV
  - uses FTF (Fritiof) model for high energies (> 4 GeV)

- QGSP_BERT
  - all standard EM processes
  - Bertini-style cascade up to 9.9 GeV
  - QGS model for high energies (> ~18 GeV)
  - FTF in between

Production Physics Lists

- QGSP_BIC
  - same as QGSP_BERT, but replaces Bertini cascade with Binary cascade and G4Precompound model
  - recommended for use at energies below 200 MeV (many medical applications)

- FTFP_BERT_HP
  - same as FTFP_BERT, but with high precision neutron model used for neutrons below 20 MeV
  - significantly slower than FTFP_BERT when full thermal cross sections used
    - there's an option to turn this off
  - for radiation protection and shielding applications

Other Physics Lists

- Shielding
  - based on FTFP_BERT_HP with improved neutron cross sections from JENDL
  - better ion interactions using QMD model
  - currently used by SuperCDMS dark matter search
  - recommended for:
    - shielding applications
    - space physics
    - HEP

Other Physics Lists

- FTFP_INCLXX, FTFP_INCLXX_HP
  - like FTFP_BERT, but with BERT replaced by INCL++ cascade model
- QBBC
  - uses both BERT and BIC cascade models
  - latest coherent elastic scattering
  - neutronXS models (faster CPU-wise)
- QGSP_BIC_HP
  - same as QGSP_BIC, but with high precision neutron model used for neutrons below 20 MeV
  - recommended for radiation protection, shielding and medical applications

Other Physics Lists (based on use case)

- If primary particle energy in your application is < 5 GeV (for example, clinical proton beam of 150 MeV)
  - start with a physics list which includes BIC or BERT
  - e.g. QGSP_BIC, QGSP_BERT, FTFP_BERT, etc.
- If neutron transport is important
  - start with physics list containing “HP”
  - e.g. QGSP_BIC_HP, FTFP_BERT_HP, etc.
- If you’re interested in Bragg curve physics
  - use a physics list ending in “EMV” or “EMX”
  - e.g. QGSP_BERT_EMV

Alternate EM Physics Lists

- Up to now, most physics lists mentioned have used the "standard" EM processes, but "low energy" EM physics is also available
  - G4EmLivermorePhysics (physics list suffix = LIV)
  - G4EmLivermorePolarizedPhysics
  - G4EmPenelopePhysics (suffix = PEN)
  - G4EmDNAPhysics

- Physics lists containing these are recommended for micro-dosimetry applications

- For examples using a DNA physics list, go to
  - geant4/source/examples/advanced

Using Alternate EM Physics Lists

- These physics list classes derive from the G4VPhysicsConstructor abstract base class
- A good implementation example that uses these already available physics lists can be found in
  - examples/extended/electromagnetic/TestEm2

- Once you know the desired hadronic part of the physics list name (e.g. FTFP_BERT) an easy way to keep straight the various EM options is to use the G4PhysListFactory class:
  - G4PhysListFactory factory;

```
G4VModularPhysicsList* physList =
        factory.GetReferencePhysList("FTFP_BERT_ XXX");
// where XXX = EMV or EMX or LIV or PEN
```

Using Geant4 Validation to Choose Physics Lists

- Ultimately you must choose a physics list based on how well its component processes and models perform
  - physics performance
  - CPU performance
- Geant4 provides validation (comparison to data) for most of its physics codes
  - validation is a continuing task, performed at least as often as each release
  - more validation tests added as time goes on
- To access these comparisons, go to Geant4 website
  - follow the chain: click on “Validation of Geant4” -> “Validation and testing” -> Validation Database: “FNAL_DB”

New Hadronic Validation Framework

Geant 4

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Testing and Validation

This webpage is under redesign. Some links are old and may be removed. Please be patient.

Physics Validation

This collection of links and resources covers the aspects of general interest for Geant4 physics validation.
The activities of this area are coordinated by the Physics Validation Task Force in the Testing and Quality Assurance Working Group.

Results and documents

- Validation DataBase: FNAL DB, or access to previous, no longer supported version of FNAL DB
- Electromagnetic physics: Results, publications, validation; HEP journals publications ; HEP conference proceedings ; HEP presentations
- Electromagnetic Validation repository
- Hadronic Validation Web Pages
- HEP experiments related notes documents and notes (in collaboration with LCG Physics Validation Project)

Technical documentation and resources

- The Geant4 testing system
- The Geant4 GRID-based testing system
- Validation Framework Design Proposal
- LCG Physics Validation Project (focus on LHC experiments)
- The task force twiki contains information on the current activities.

Computing Performance

This collection of links and resources covers the aspects of the monitoring of performances of the Geant4 code.
The activities of this area are coordinated by the Monitoring computing performance and benchmarking Task Force in the Testing and Quality Assurance Working Group.

Geant 4 validation web application

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- Test result browser
- Display test
- Database Statistics
- Display references

Welcome to the GEANT4 validation web application the current time is: Fri Apr 10 16:43:59 CDT 2015"

Introduction

The Geant4 collaboration regularly performs validation and regression tests where results obtained with a new Geant4 version are compared to data obtained by various HEP experiments or the results of previous releases. We have organized the materials in one central repository make this data available with this web application. It allows to interactively select and overlay compatible data, e.g. to compare the results of different releases, different physics models or target materials in one plot.

Please make your selection from the menu on the left. To get more information hover the pointer over the menu item.

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Name	Description	Working Group
ATLAS	shower characteristics of ATLAS Calorimeters	LHC-feedback
CMS	shower characteristics of CMS Calorimeters	LHC-feedback
atlasbar	Test of ALTAS barrel type em calorimeter, determines response, resolution, and CPU performance	electromagnetic
test37	Test against Sandia data, electron beam in semi-infinite media.	electromagnetic
test41	Comparison with MUSCAT experiment for multiple scattering validation	electromagnetic
Franz	Neutron-induced production of protons, deuterons and tritons by neutrons between 300-580 MeV	hadronic
Hadrlon	Test of Physics Lists (thick targets, ion beams)	hadronic
IAEA	IAEA Benchmark of Nuclear Spallation Models	hadronic
Testfragm	Test of hadronic generators (thin targets, ion beams)	hadronic
simplifiedCalo	Test of Shower shapes using selected simplified calorimeter setups.	hadronic
test19	High energy test, provides comparison with NA61 (31 GeV/c proton beam) and NA49 (158 GeV/c proton beam) data sets.	hadronic
test22	Testing of the FTF model and comparison with experimental data for a wide energy region	hadronic
test23	Physicslist label test	hadronic
[illegible]	Test of hadronic generators of inelastic processes	hadronic
test35	Test of hadronic generators of inelastic processes, based on results of HARP collaboration, Experiment PS214 at CERN.	hadronic
[illegible]	Test of hadronic generators of inelastic processes on thick targets.	hadronic
test47	Intermediate energy validation is done by comparing Monte Carlo predictions vs experimental data.	hadronic
test48	Stopping particle test Monte Carlo predictions are compared to experimental data.	hadronic
test75	Test of gamma-nuclear interactions	hadronic

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- Exp. data browser
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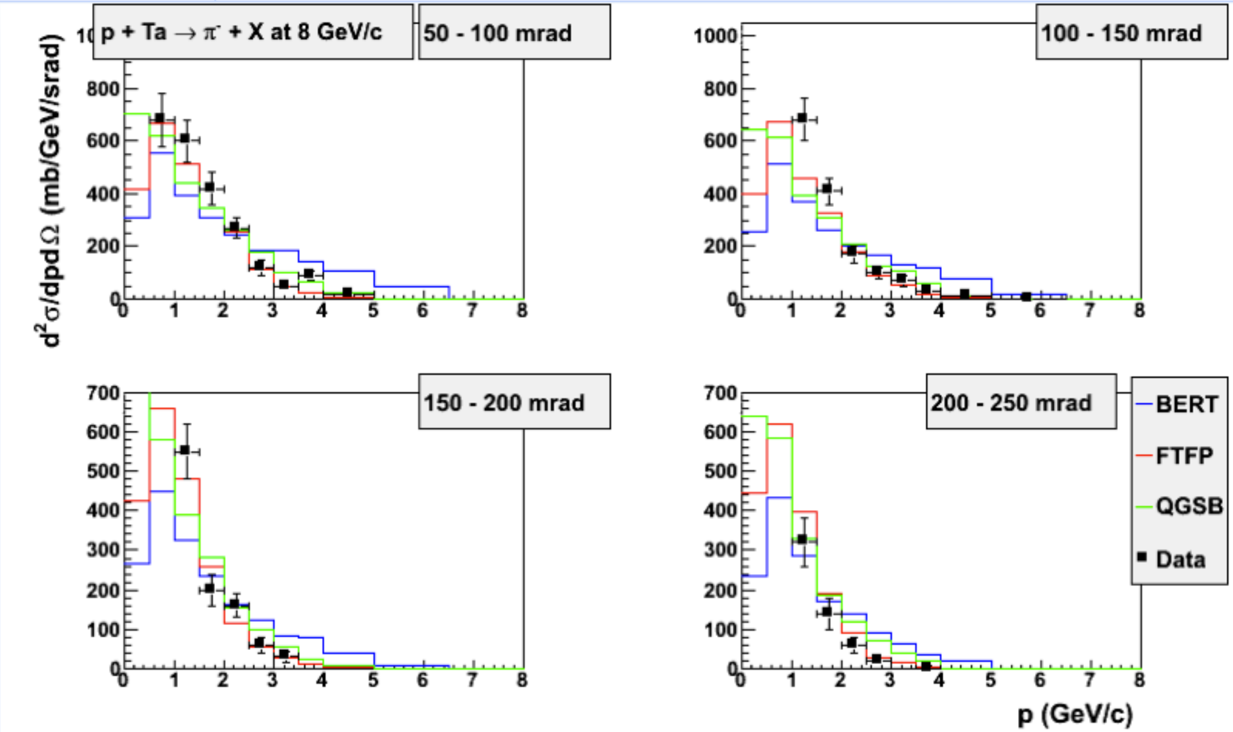
Name of the Test:	test35
Responsible:	V. Ivanchenko
Description:	Test of hadronic generators of inelastic processes, based on results of HARP collaboration, Experiment PS214 at CERN.



Required information specific to the selected test:	
Geant4 Version:	geant4-09-06-ref-00

Summary

- All the particles, physics processes and production cuts needed for an application must go into a physics list
- Two kinds of physics list classes are available for users to derive from
  - G4VUserPhysicsList – for relatively simple physics lists
  - G4VModularPhysicsList – for detailed physics lists
- Some physics lists are provided by Geant4 as a starting point for users
- Care is required by user in choosing the right physics
  - use the validation