

Guide For Physics Lists

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### i

**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 appli- cation. 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.

**CHAPTER**

# ONE

**PHYSICS LIST GUIDE**

The Physics List is one of the three mandatory user classes of the GEANT4 toolkit. In this class all GEANT4 particles and their interaction processes should be instantiated. This class should inherit from the base class G4VUserPhysicsList and should be given to G4RunManager:

G4MTRunManager\* runManager = **new** G4MTRunManager; runManager->SetUserInitialization(physicsList);

Here physicsList is a pointer to the user defined class. Initially [[eal03](#_bookmark26)], it was proposed for users to create custom class based on variants of PhysicsList in GEANT4 example applications. After first GEANT4 official releases, a conception of reference Physics Lists was introduced [[eal06](#_bookmark25)]. In the beginning, the default GEANT4 Physics List was QGSP\_BERT [[eal09](#_bookmark29)]. Since the GEANT4 release 10.0 the default Physics List becomes FTFP\_BERT [[eal16](#_bookmark27)]. The main advantage of working with the reference Physics List is in common method of instantiation of physics objects in GEANT4 tests, in GEANT4 examples, and in user applications. GEANT4 developers develop and validate these physics configurations and any user or group of users may reproduce the same physics in their GEANT4 applications. GEANT4 developers establish various tests and benchmarks, which are used for validation and verification of the GEANT4 toolkit before making a new public version. Users may compare results obtained in the same conditions in different setups.

Number of reference Physics Lists is not small, because there are many alternative physics models in the toolkit appli- cable for simulation of very different problems. Reference Physics Lists are available in GEANT4 physics\_list sub-library. All these classes inherit from virtual interface G4VModularPhysicsList (which is an extension of the base class G4VUserPhysicsList. The advantages of the modular design are in maintenance of modules by different GEANT4 working groups, independent development of particular modules, possibility for combining of various modules (following G4VPhysicsConstructor interface) in reference Physics Lists and in user custom Physics Lists. There are following types of modules:

* electromagnetic physics;
* extra physics processes for gamma and leptons;
* decay;
* hadron elastic;
* hadron inelastic;
* stopping particles capture processes;
* ion nuclear interactions;
* step limiters;
* others.

The last category may include any type of physics processes, for example, optical, exotic physics, thermal neu- tron transport model, and others. A user may customise reference Physics List using following interfaces of the G4VModularPhysicsList class:

* void RegisterPhysics(G4VPhysicsConstructor\* );
* void ReplacePhysics(G4VPhysicsConstructor\* );
* void RemovePhysics(G4VPhysicsConstructor\* );

The following reference Physics Lists are available in the physics\_lists sub-library:

* [*FTFP\_BERT*](#_bookmark2)
* FTFP\_BERT\_ATL
* FTFP\_BERT\_HP
* FTFP\_BERT\_TRV
* FTFP\_INCLXX
* FTFQGSP\_BERT
* FTF\_BIC
* [*QBBC*](#_bookmark3)
* [*QGSP\_BERT*](#_bookmark4)
* QGSP\_BERT\_HP
* [*QGSP\_BIC*](#_bookmark5)
* QGSP\_BIC\_AllHP
* QGSP\_BIC\_HP
* QGSP\_FTFP\_BERT
* QGSP\_INCLXX
* QGS\_BIC
* [*Shielding*](#_bookmark6)
* ShieldingLEND
* LBE
* NuBeam

These Physics List classes may be included directly to the user code. It is also possible instantiate reference Physics List by name using helper class G4PhysListFactory. Variants of usage of this helper class are demonstrated in GEANT4 extended examples:

* geant4/examples/extended/hadronic/Hadr00.cc - for multi-threaded mode;
* geant4/examples/extended/hadronic/Hadr01.cc - for sequential mode.

In the case of usage of this helper class, an additional possibility does exist to extend electromagnetic physics config- uration by simply adding an extension to a physics list name, for example FTFP\_BERT\_EMZ means , that the default electromagnetic physics is substituted by the configuration providing the most accurate simulation of electromagnetic physics (see details in [*EM physics constructors*](#_bookmark8)). Following extensions are available:

* EMV [*EM Opt1*](#_bookmark10) less precise, but faster set of electromagnetic physics is used. Otherwise known as electromag- netic option 1.
* EMX [*EM Opt2*](#_bookmark11) less precise, but faster set of electromagnetic physics is used. Otherwise known as electromag- netic option 2.
* EMY [*EM Opt3*](#_bookmark12) it uses a set of EM processes with accurate simulation of gamma and charged particle transport. Only the Urban multiple scattering model is used for all charged particles and all energies. Also known as electromagnetic option 3, the detailed physics causes longer execution times than the standard package.
* EMZ [*EM Opt4*](#_bookmark13) the best set of electromagnetic physics models selected from the low energy and standard pack- ages. With its concentration on the best possible physics, electromagnetic option 4 is slower than the standard EM package.
* LIV [*EM Liv*](#_bookmark14) is made on top of electromagnetic option 3 by substitution of standard models for gamma and electrons from Livermore set of models.
* PEN [*EM Pen*](#_bookmark15) is made on top of electromagnetic option 3 by substitution of standard models for gamma, electrons and positrons from Penelope-2008 set of models.
* \_GS [*EM GS*](#_bookmark16) is made on top of the default electromagnetic configurations by substitution of the Urban multiple scattering model for electrons and positrons by the Goudsmit-Saunderson model.
* \_LE [*EM LE*](#_bookmark17) is made on top of the default electromagnetic configurations by substitution of the Urban multiple scattering model for electrons and positrons by the LowEWentzelVI model. Also, using 5D gamma conversion model and Lindhard-Sorensent model for ion ionisation.
* WVI [*EM WVI*](#_bookmark18) is made on top of the default electromagnetic configurations by substitution of the Urban multiple scattering model for electrons and positrons by the WentzelVI model and ATIMA ion ionisation model.
* \_SS [*EM SS*](#_bookmark19) is made on top default electromagnetic configurations by substitution of all multiple scattering models by single scattering models.

**CHAPTER**

# TWO

**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.

# FTFP\_BERT

It is the current GEANT4 default [[eal16](#_bookmark27)].

* + 1. **Hadronic Component**

The purely hadronic part of this physics list consists of elastic, inelastic, capture and fission processes. Each process is built from a set of cross section sets and interaction models which provide the detailed physics implementation.

**Inelastic models**

The inelastic hadron-nucleus processes are implemented by the Fritiof parton model (FTF), Bertini and Precompound models. The Bertini intranuclear cascade is responsible for

*�, �, 𝜋*+*, 𝜋−, 𝐾*+*, 𝐾−, 𝐾𝐿, 𝐾𝑆,* Λ*,* Σ+*,* Σ*−,* Σ0*,* Ξ*−,* Ξ0 and Ω*−* interactions between 0 to 6 GeV. The

FTF model handles these same particles, but over the range 3 GeV to 100 TeV. It also handles anti-protons, anti-neutrons, anti-deuterons, anti-tritons, anti-3He, anti-alphas and anti-hyperons from 0 to 100 TeV/n.

Where Bertini and FTF overlap in particle type and energy range, Bertini is invoked with a probability that decreases linearly from 1.0 to 0.0, and FTF is invoked with the complementary probability.

When the FTF model is used, the Precompound model (P) is also invoked to de-excite the remnant nucleus after the initial high energy interaction. The precompound model in turn calls the Fermi breakup, neutron and light ion evaporation and photon evaporation models as needed. When the Bertini model is used, its own, simpler precompound and de-excitation models are invoked.

Inelastic nucleus-nucleus scattering for all incident A is handled by the Binary Light Ion Cascade (BIC) between 0 and 6 GeV/n, and by the FTF model between 3 GeV/n and 100 TeV/n. The scheme for choosing models in overlapping energy regions is the same as that for FTFP and BERT.

The hadronic interaction of gammas is handled by the photo-nuclear process in which gammas below 6 GeV are interacted using the Bertini cascade, and above 3 GeV by the Quark-gluon String (QGS) model. Muons, electrons and positrons also interact via transfer of virtual photons. These interactions are handled by G4MuonVDNuclearModel and G4ElectroVDNuclearModel which are applied at all energies.

**Inelastic cross sections**

G4BGGNucleonInelasticXS is used for protons, G4NeutronInelasticXS for neutrons, and G4BGGPionInelasticXS for pions. In these cross sections Barashenkov parameterisation is used below 91 GeV and Glauber-Gribov above.

For kaons, hyperons and anti-hyperons the Glauber-Gribov set (G4ComponentGGHadronNucleusXsc) is used at all energies.

All nucleus-nucleus cross sections are provided by G4ComponentGGNuclNuclXsc at all projectile energies. This class is the Glauber-Gribov nucleus-nucleus cross section parameterisation. When the projectile is an anti-proton, anti-neutron, anti-deuteron, anti-triton, anti-3He or anti-alpha, the G4ComponentAntiNuclNuclearXS class provides the cross sections using the Glauber-Gribov parameterisation.

Hadronic gamma interaction cross sections are supplied by G4PhotoNuclearCrossSection which is used at all gamma energies. G4ElectroNuclearCrossSection is used at all energies for *𝑒*+ and *𝑒−*, while G4KokoulinMuonNuclearXS is used for *𝜇*+ and *𝜇−* at all energies.

**Elastic models**

Elastic scattering of protons and neutrons use G4ChipsElasticModel from 0 to 100 TeV. This model uses the Kossov parameterised cross sections.

For almost all other hadrons the G4HadronElastic model is used for some or all of the energy range. This model is a two-exponential momentum transfer model updated from the old Gheisha code. It is used at all energies by kaons, hyperons, deuterons, tritons, 3He, alphas and anti-neutrons.

Elastic *𝜋*+ and *𝜋−* scattering is implemented by the G4ElasticHadrNucleusHE coherent scattering model for all ener- gies.

For anti-protons, anti-neutrons, anti-deuterons, anti-tritons, anti-3He and anti-alphas, G4HadronElastic is used from 0 to 100 MeV/n. Above 100 MeV/n these particles are handled by the G4AntiNuclElastic model.

There is currently no elastic scattering model for nuclear projectiles with *𝐴 >* 4.

**Elastic cross sections**

G4BGGNucleonElasticXS is used for protons, G4NeutronElasticXS for neutrons, and G4BGGPionElasticXS for pi- ons. In these cross sections Barashenkov parameterisation is used below 91 GeV and Glauber-Gribov above.

For kaons, hyperons, anti-hyperons and light ions the G4ComponentGGNuclNuclXsc elastic cross section is used.

anti-p, anti-d, anti-t, anti-3He and anti-alpha use the Glauber model cross section in G4ComponentAntiNuclNuclearXS at all energies.

No elastic cross sections are available for projectiles with *𝐴 >* 4.

**Capture and stopping**

Neutron capture uses the G4NeutronRadCapture model with the G4NeutronCaptureXS cross sections. Muon capture or decay at rest is handled by the G4MuonMinusCapture process.

The capture of negative pions and kaons once they have stopped is handled by the BertiniCaptureAtRest model which uses the Bertini cascade. The capture of anti-p, anti-d, anti-t, anti-3He, anti-alpha is handled by the FritiofCapture- AtRest model which uses the Fritiof string model.

## Electromagnetic Component

This physics list uses “standard” GEANT4 electromagnetic physics as built by the G4EmStandardPhysics constructor. It is implemented for *𝛾, 𝑒−, 𝑒*+*, 𝜇−, 𝜇*+*, 𝜏 −, 𝜏* +*,* and all stable charged hadrons/ion (see details in [*EM physics*](#_bookmark8)[*constructors*](#_bookmark8)).

There is no treatment of optical photons in this physics list, optical physics should be added on top of any reference or user custom physics.

## Decay Component

The decay of all long-lived hadrons and leptons is handled by the G4Decay process. It does not handle the decay of hadronic resonances like deltas, which should be decayed within hadronic models and heavy-flavor particles like D and B mesons or charmed hyperons.

## Neutron tracking cut

Neutrons may be killed if they fall below the energy cut (zero by default) or above the time cut (10 microsecond by default). These cuts may be modified via UI commands.

## Recommended Use Cases

FTFP\_BERT is recommended for collider physics applications. It usually produces the best agreement with test beam calorimeter data, including shower shape, energy response and resolution.

It is also recommended for cosmic ray applications where good treatment of very high energy particles is required. Note, however, that is not suited to very high energy collisions of order 10 TeV or more.

## Related Physics Lists

* + - * **FTFP\_BERT\_HP**: identical to FTFP\_BERT except that neutrons of 20 MeV and lower use the High Precision neutron models and cross sections to describe elastic and inelastic scattering, capture and fission. The G4NDL database is required for this physics list. Moreover, RadioactiveDecay is activated.
      * **FTFP\_BERT\_ATL**: identical to FTFP\_BERT except that transition between the FTF model and the Bertini cascade is changed: [9, 12] GeV. This was a requirement from the ATLAS experiment at LHC.
      * **FTFP\_BERT\_TRV**: identical to FTFP\_BERT except that several electromagnetic and hadronic models are substituted by their alternative.
      * **FTFP\_INCLXX**: identical to FTFP\_BERT except that the Bertini cascade is substituted by the INCL++ cas- cade.
      * **FTFQGS\_BERT**: identical to FTFP\_BERT except that QGS string model is used.
      * **FTF\_BIC**: identical to FTFP\_BERT except that the Binary cascade is used as by the FTF model instead of internal FTF cascade code for rescattering of secondary particles within nucleus.
      * **Electromagnetic options**: different configurations of electromagnetic physics are available [*EM physics con-*](#_bookmark8)[*structors*](#_bookmark8)), which may be used instead of the default electromagnetic physics.

# QBBC

It is recommended for medical and space physics simulations [[eal11](#_bookmark28)].

* + 1. **Hadronic Component**

The purely hadronic part of this physics list consists of elastic, inelastic, and capture processes. Each process is built from a set of cross section sets and interaction models which provide the detailed physics implementation.

**Inelastic models**

The inelastic hadron-nucleus processes are implemented by the FTF, Bertini, Binary and Precompound models. The Bertini intranuclear cascade is responsible for *𝜋*+*, 𝜋−, 𝐾*+*, 𝐾−, 𝐾𝐿, 𝐾𝑆,* Λ*,* Σ+*,* Σ*−,* Σ0*,* Ξ*−,* Ξ0 and Ω*−* interactions between 0 to 6 GeV. For protons and neutrons the Binary cascade is applied between 0 and 1.5 GeV, the Bertini cascade is applied from 1 to 6 GeV. The Fritiof parton model (FTF) handles these same particles, but over the range 3 GeV to 100 TeV. It also handles anti-protons, anti-neutrons, anti-deuterons, anti-tritons, anti-3He, anti-alphas and anti-hyperons from 0 to 100 TeV/n.

Where Bertini and FTF overlap in particle type and energy range, Bertini is invoked with a probability that decreases linearly from 1.0 to 0.0 and FTF is invoked with the complementary probability.

When the FTF model or the Binary cascade are used, the Precompound model (P) is also invoked to de-excite the remnant nucleus after the initial high energy interaction. The precompound model in turn calls the Fermi breakup, neutron and light ion evaporation and photon evaporation models as needed. When the Bertini model is used, its own, simpler precompound and de-excitation models are invoked.

Inelastic nucleus-nucleus scattering for all incident A is handled by the Binary Light Ion Cascade (BIC) between 0 and 6 GeV/n, and by the FTF model between 3 GeV/n and 100 TeV/n. The scheme for choosing models in overlapping energy regions is the same as that for FTFP and BERT.

The hadronic interaction of gammas is handled by the photo-nuclear process in which gammas below 6 GeV are interacted using the Bertini cascade, and above 3 GeV by the Quark-gluon String (QGS) model. Muons, electrons and positrons also interact via transfer of virtual photons. These interactions are handled by G4MuonVDNuclearModel and G4ElectroVDNuclearModel which are applied at all energies.

**Inelastic cross sections**

G4ParticleInelasticXS is used for protons, G4NeutronInelasticXS for neutrons, and G4BGGPionInelasticXS for pions. In these cross sections Barashenkov parameterisation is used below 91 GeV and Glauber-Gribov above.

For kaons, hyperons and anti-hyperons the Glauber-Gribov set (G4ComponentGGHadronNucleusXsc) is used at all energies.

Nucleus-nucleus cross sections for ions with *𝐴 >* 4 are provided by G4ComponentGGNuclNuclXsc at all projectile energies. This class is the Glauber-Gribov nucleus-nucleus cross section parameterisation.

For d, t, 3He, 4He G4ParticleInelasticXS is used.

When the projectile is an anti-proton, anti-neutron, anti-deuteron, anti-triton, anti-3He or anti-alpha, the G4ComponentAntiNuclNuclearXS class provides the cross sections using the Glauber-Gribov parameterisation.

Hadronic gamma interaction cross sections are supplied by G4PhotoNuclearCrossSection which is used at all gamma energies. G4ElectroNuclearCrossSection is used at all energies for *𝑒*+ and *𝑒−*, while G4KokoulinMuonNuclearXS is used for *𝜇*+ and *𝜇−* at all energies.

**Elastic models**

Elastic scattering of protons and neutrons use G4ChipsElasticModel from 0 to 100 TeV. This model uses the Kossov parameterised cross sections.

For almost all other hadrons the G4HadronElastic model is used for some or all of the energy range. This model is a two-exponential momentum transfer model updated from the old Gheisha code. It is used at all energies by kaons, hyperons, deuterons, tritons, 3He, alphas and anti-neutrons.

Elastic *𝜋*+ and *𝜋−* scattering is implemented by the G4ElasticHadrNucleusHE coherent scattering model for all ener- gies.

For anti-protons, anti-neutrons, anti-deuterons, anti-tritons, anti-3He and anti-alphas, G4HadronElastic is used from 0 to 100 MeV/u. Above 100 MeV/u these particles are handled by the G4AntiNuclElastic model.

There is currently no elastic scattering model for nuclear projectiles with *𝐴 >* 4.

**Elastic cross sections**

G4BGGNucleonElasticXS is used for protons, G4NeutronElasticXS for neutrons, and G4BGGPionElasticXS for pi- ons. In these cross sections Barashenkov parameterisation is used below 91 GeV and Glauber-Gribov above.

For kaons, hyperons, anti-hyperons and light ions the G4ComponentGGNuclNuclXsc elastic cross section is used.

anti-p, anti-d, anti-t, anti-3He and anti-alpha use the Glauber model cross section in G4ComponentAntiNuclNuclearXS at all energies.

No elastic cross sections are available for projectiles with *𝐴 >* 4.

**Capture and stopping**

Neutron capture uses the G4NeutronRadCapture model with the G4NeutronCaptureXS cross sections. Muon capture or decay at rest is handled by the G4MuonMinusCapture process.

The capture of negative pions and kaons once they have stopped is handled by the BertiniCaptureAtRest model which uses the Bertini cascade. The capture of anti-p, anti-d, anti-t, anti-3He, anti-alpha is handled by the FritiofCapture- AtRest model which uses the Fritiof string model.

## Electromagnetic Component

This physics list uses “standard” GEANT4 electromagnetic physics as built by the G4EmStandardPhysics constructor. It is implemented for *𝛾, 𝑒−, 𝑒*+*, 𝜇−, 𝜇*+*, 𝜏 −, 𝜏* +*,* and all stable charged hadrons/ion (see details in [*EM physics*](#_bookmark8)[*constructors*](#_bookmark8)).

There is no treatment of optical photons in this physics list, optical physics should be added on top of any reference or user custom physics.

## Decay Component

The decay of all long-lived hadrons and leptons is handled by the G4Decay process. It does not handle the decay of hadronic resonances like deltas, which should be decayed within hadronic models and heavy-flavor particles like D and B mesons or charmed hyperons.

Muon capture or decay at rest is handled by the G4MuonMinusCapture process.

## Neutron tracking cut

Neutrons may be killed if they fall below the energy cut (zero by default) or above the time cut (10 microsecond by default). These cuts may be modified via UI commands.

## Recommended Use Cases

QBBC is recommended for applications where accurate simulation for low-energy transport of protons and neutrons is needed. It usually produces the best agreement in the energy range below 1 GeV for thin target experiments. For higher energies it is the same as the default FTFP\_BERT physics [*FTFP\_BERT*](#_bookmark2). It is recommended for medical and space applications [[eal11](#_bookmark28)].

## Related Physics Lists

* + - * **Electromagnetic options**: different configurations of electromagnetic physics are available [*EM physics con-*](#_bookmark8)[*structors*](#_bookmark8)), which may be used instead of the default electromagnetic physics.

# QGSP\_BERT

It is the former GEANT4 default [[eal09](#_bookmark29)].

* + 1. **Hadronic Component**

The purely hadronic part of this physics list consists of elastic, inelastic, capture and fission processes. Each process is built from a set of cross section sets and interaction models which provide the detailed physics implementation.

**Inelastic models**

The inelastic hadron-nucleus processes are implemented by the quark-gluon model (QGS), the Fritiof par- ton model (FTF), Bertini and Precompound models. The Bertini intranuclear cascade is responsible for

*�, �, 𝜋*+*, 𝜋−, 𝐾*+*, 𝐾−, 𝐾𝐿, 𝐾𝑆,* Λ*,* Σ+*,* Σ*−,* Σ0*,* Ξ*−,* Ξ0 and Ω*−* interactions between 0 to 6 GeV. The QGS

model handles protons, neutrons, pions and kaons above 12 GeV. The FTF model handles these same particles, but over the range 3 GeV to 25 GeV, it also handles anti-protons, anti-neutrons, anti-deuterons, anti-tritons, anti-3He, anti-alphas and anti-hyperons from 0 to 100 TeV/n.

Where Bertini and FTF overlap in particle type and energy range, Bertini is invoked with a probability that decreases linearly from 1.0 to 0.0 and FTF is invoked with the complementary probability. Similar algorithm is applied in common energy area for FTF and QGS.

When the FTF and QGS models are used, the Precompound model (P) is also invoked to de-excite the remnant nucleus after the initial high energy interaction. The precompound model in turn calls the Fermi breakup, multi-fragmentation,

neutron evaporation and photon evaporation models as needed. When the Bertini model is used, its own, simpler precompound and de-excitation models are invoked.

Inelastic nucleus-nucleus scattering for all incident A is handled by the Binary Light Ion Cascade (BIC) between 0 and 6 GeV/n, and by the FTF model between 3 GeV/n and 100 TeV/n. The scheme for choosing models in overlapping energy regions is the same as that for FTFP and BERT.

The hadronic interaction of gammas is handled by the photo-nuclear process in which gammas below 6 GeV are interacted using the Bertini cascade, and above 3 GeV by the Quark-gluon String (QGS) model. Muons, electrons and positrons also interact via transfer of virtual photons. These interactions are handled by G4MuonVDNuclearModel and G4ElectroVDNuclearModel which are applied at all energies.

**Inelastic cross sections**

G4BGGNucleonInelasticXS is used for protons, G4NeutronInelasticXS for neutrons, and G4BGGPionInelasticXS for pions. In these cross sections Barashenkov parameterisation is used below 91 GeV and Glauber-Gribov above.

For kaons, hyperons and anti-hyperons the Glauber-Gribov set (G4ComponentGGHadronNucleusXsc) is used at all energies.

All nucleus-nucleus cross sections are provided by G4ComponentGGNuclNuclXsc at all projectile energies. This class is the Glauber-Gribov nucleus-nucleus cross section parameterisation. When the projectile is an anti-proton, anti-neutron, anti-deuteron, anti-triton, anti-3He or anti-alpha, the G4ComponentAntiNuclNuclearXS class provides the cross sections using the Glauber-Gribov parameterisation.

Hadronic gamma interaction cross sections are supplied by G4PhotoNuclearCrossSection which is used at all gamma energies. G4ElectroNuclearCrossSection is used at all energies for *𝑒*+ and *𝑒−*, while G4KokoulinMuonNuclearXS is used for *𝜇*+ and *𝜇−* at all energies.

**Elastic models**

Elastic scattering of protons and neutrons use G4ChipsElasticModel from 0 to 100 TeV. This model uses the Kossov parameterised cross sections.

For almost all other hadrons the G4HadronElastic model is used for some or all of the energy range. This model is a two-exponential momentum transfer model updated from the old Gheisha code. It is used at all energies by kaons, hyperons, deuterons, tritons, 3He, alphas and anti-neutrons.

Elastic *𝜋*+ and *𝜋−* scattering is implemented by the G4ElasticHadrNucleusHE coherent scattering model for all ener- gies.

For anti-protons, anti-neutrons, anti-deuterons, anti-tritons, anti-3He and anti-alphas, G4HadronElastic is used from 0 to 100 MeV/n. Above 100 MeV/n these particles are handled by the G4AntiNuclElastic model.

There is currently no elastic scattering model for nuclear projectiles with *𝐴 >* 4.

**Elastic cross sections**

G4BGGNucleonElasticXS is used for protons, G4NeutronElasticXS for neutrons, and G4BGGPionElasticXS for pi- ons. In these cross sections Barashenkov parameterisation is used below 91 GeV and Glauber-Gribov above.

For kaons, hyperons, anti-hyperons and light ions the G4ComponentGGNuclNuclXsc elastic cross section is used.

anti-p, anti-d, anti-t, anti-3He and anti-alpha use the Glauber model cross section in G4ComponentAntiNuclNuclearXS at all energies.

No elastic cross sections are available for projectiles with *𝐴 >* 4.

**Capture and stopping**

Neutron capture uses the G4NeutronRadCapture model with the G4NeutronCaptureXS cross sections. Muon capture or decay at rest is handled by the G4MuonMinusCapture process.

The capture of negative pions and kaons once they have stopped is handled by the BertiniCaptureAtRest model which uses the Bertini cascade. The capture of anti-p, anti-d, anti-t, anti-3He, anti-alpha is handled by the FritiofCapture- AtRest model which uses the Fritiof string model.

## Electromagnetic Component

This physics list uses “standard” GEANT4 electromagnetic physics as built by the G4EmStandardPhysics constructor. It is implemented for *𝛾, 𝑒−, 𝑒*+*, 𝜇−, 𝜇*+*, 𝜏 −, 𝜏* +*,* and all stable charged hadrons/ion (see details in [*EM physics*](#_bookmark8)[*constructors*](#_bookmark8)).

There is no treatment of optical photons in this physics list, optical physics should be added on top of any reference or user custom physics.

## Decay Component

The decay of all long-lived hadrons and leptons is handled by the G4Decay process. It does not handle the decay of hadronic resonances like deltas, which should be decayed within hadronic models and heavy-flavor particles like D and B mesons or charmed hyperons.

Muon capture or decay at rest is handled by the G4MuonMinusCapture process.

## Neutron tracking cut

Neutrons may be killed by energy cut (zero by default) or by time cut (10 microsecond by default). These cuts may be modified via UI commands.

## Recommended Use Cases

QGSP\_BERT can be used for collider physics applications, as an alternative to the recommended physics list FTFP\_BERT.

It is can also be used for cosmic ray applications where good treatment of very high energy particles is required. Note, however, that is not suited to very high energy collisions of order 10 TeV or more.

## Related Physics Lists

* + - * **QGSP\_BERT\_HP**: identical to QGSP\_BERT except that neutrons of 20 MeV and lower use the High Precision neutron models and cross sections to describe elastic and inelastic scattering, capture and fission. The G4NDL database is required for this physics list. Moreover, RadioactiveDecay is activated.
      * **QGSP\_FTFP\_BERT**: currently identical to QGSP\_BERT (it was different before and it might change in the future).
      * **QGSP\_INCLXX**: identical to QGSP\_BERT except that the Bertini cascade is substituted by the INCL++ cas- cade.
      * **QGSP\_INCLXX\_HP**: identical to QGSP\_BERT\_HP except that the Bertini cascade is substituted by the INCL++ cascade.
      * **Electromagnetic options**: different configurations of electromagnetic physics are available [*EM physics con-*](#_bookmark8)[*structors*](#_bookmark8)), which may be used instead of the default electromagnetic physics.

**14 Chapter 2. Reference Physics Lists**

# QGSP\_BIC

## Hadronic Component

The purely hadronic part of this physics list consists of elastic, inelastic, and capture processes. Each process is built from a set of cross section sets and interaction models which provide the detailed physics implementation.

**Inelastic models**

The inelastic hadron-nucleus processes are implemented by the Quark-gluon String (QGS), the Fritiof parton model (FTF), Bertini, Binary, and Precompound models. The Bertini intranuclear cascade is responsible for

*𝜋*+*, 𝜋−, 𝐾*+*, 𝐾−, 𝐾𝐿, 𝐾𝑆,* Λ*,* Σ+*,* Σ*−,* Σ0*,* Ξ*−,* Ξ0 and Ω*−* interactions between 0 to 6 GeV. The

Binary cascade is applied for neutrons and protons between 0 and 6 GeV. The QGS model is applied for

*�, �, 𝜋*+*, 𝜋−, 𝐾*+*, 𝐾−, 𝐾𝐿, 𝐾𝑆,* above 12 GeV. The FTF model handles the same particles, but over the range 3 GeV to 25 GeV. For hyperons, FTF is applied from 3 GeV to 100 TeV. FTF also handles anti-protons, anti-neutrons, anti-deuterons, anti-tritons, anti-3He, anti-alphas and anti-hyperons from 0 to 100 TeV/n.

When the QGS, FTF, and Binary models are used, the Precompound model (P) is also invoked to de-excite the remnant nucleus after the initial high energy interaction. The precompound model in turn calls the Fermi breakup, neutron and light ion evaporation and photon evaporation models as needed. When the Bertini model is used, its own, simpler precompound and de-excitation models are invoked.

Inelastic nucleus-nucleus scattering for all incident A is handled by the Binary Light Ion Cascade (BIC) between 0 and 6 GeV/n, and by the FTF model between 3 GeV/n and 100 TeV/n. The scheme for choosing models in overlapping energy regions is the same as that for FTFP and BERT.

The hadronic interaction of gammas is handled by the photo-nuclear process in which gammas below 6 GeV are interacted using the Bertini cascade, and above 3 GeV by the Quark-gluon String (QGS) model. Muons, electrons and positrons also interact via transfer of virtual photons. These interactions are handled by G4MuonVDNuclearModel and G4ElectroVDNuclearModel which are applied at all energies.

**Inelastic cross sections**

G4BGGNucleonInelasticXS is used for protons, G4NeutronInelasticXS for neutrons, and G4BGGPionInelasticXS for pions. In these cross sections Barashenkov parameterisation is used below 91 GeV and Glauber-Gribov above.

For kaons, hyperons and anti-hyperons the Glauber-Gribov set (G4ComponentGGHadronNucleusXsc) is used at all energies.

All nucleus-nucleus cross sections are provided by G4ComponentGGNuclNuclXsc at all projectile energies. This class is the Glauber-Gribov nucleus-nucleus cross section parameterisation. When the projectile is an anti-proton, anti-neutron, anti-deuteron, anti-triton, anti-3He or anti-alpha, the G4ComponentAntiNuclNuclearXS class provides the cross sections using the Glauber-Gribov parameterisation.

Hadronic gamma interaction cross sections are supplied by G4PhotoNuclearCrossSection which is used at all gamma energies. G4ElectroNuclearCrossSection is used at all energies for *𝑒*+ and *𝑒−*, while G4KokoulinMuonNuclearXS is used for *𝜇*+ and *𝜇−* at all energies.

**Elastic models**

Elastic scattering of protons and neutrons use G4ChipsElasticModel from 0 to 100 TeV. This model uses the Kossov parameterised cross sections.

For almost all other hadrons the G4HadronElastic model is used for some or all of the energy range. This model is a two-exponential momentum transfer model updated from the old Gheisha code. It is used at all energies by kaons, hyperons, deuterons, tritons, 3He, alphas and anti-neutrons.

Elastic *𝜋*+ and *𝜋−* scattering is implemented by the G4ElasticHadrNucleusHE coherent scattering model for all ener- gies.

For anti-protons, anti-neutrons, anti-deuterons, anti-tritons, anti-3He and anti-alphas, G4HadronElastic is used from 0 to 100 MeV/n. Above 100 MeV/n these particles are handled by the G4AntiNuclElastic model.

There is currently no elastic scattering model for nuclear projectiles with *𝐴 >* 4.

**Elastic cross sections**

G4BGGNucleonElasticXS is used for protons, G4NeutronElasticXS for neutrons, and G4BGGPionElasticXS for pi- ons. In these cross sections Barashenkov parameterisation is used below 91 GeV and Glauber-Gribov above.

For kaons, hyperons, anti-hyperons and light ions the G4ComponentGGNuclNuclXsc elastic cross section is used.

anti-p, anti-d, anti-t, anti-3He and anti-alpha use the Glauber model cross section in G4ComponentAntiNuclNuclearXS at all energies.

No elastic cross sections are available for projectiles with *𝐴 >* 4.

**Capture and stopping**

Neutron capture uses the G4NeutronRadCapture model with the G4NeutronCaptureXS cross sections. Muon capture or decay at rest is handled by the G4MuonMinusCapture process.

The capture of negative pions and kaons once they have stopped is handled by the BertiniCaptureAtRest model which uses the Bertini cascade. The capture of anti-p, anti-d, anti-t, anti-3He, anti-alpha is handled by the FritiofCapture- AtRest model which uses the Fritiof string model.

## Electromagnetic Component

This physics list uses “standard” GEANT4 electromagnetic physics as built by the G4EmStandardPhysics constructor. It is implemented for *𝛾, 𝑒−, 𝑒*+*, 𝜇−, 𝜇*+*, 𝜏 −, 𝜏* +*,* and all stable charged hadrons/ion (see details in [*EM physics*](#_bookmark8)[*constructors*](#_bookmark8)).

There is no treatment of optical photons in this physics list, optical physics should be added on top of any reference or user custom physics.

## Decay Component

The decay of all long-lived hadrons and leptons is handled by the G4Decay process. It does not handle the decay of hadronic resonances like deltas, which should be decayed within hadronic models and heavy-flavor particles like D and B mesons or charmed hyperons.

## Neutron tracking cut

Neutrons may be killed if they fall below the energy cut (zero by default) or above the time cut (10 microsecond by default). These cuts may be modified via UI commands.

## Recommended Use Cases

QGSP\_BIC can be used for collider physics applications, as an alternative to the recommended physics list FTFP\_BERT.

It is can also be used for cosmic ray applications where good treatment of very high energy particles is required. Note, however, that is not suited to very high energy collisions of order 10 TeV or more.

## Related Physics Lists

* + - * **QGSP\_BIC\_HP**: identical to QGSP\_BIC except that neutrons of 20 MeV and lower use the High Precision neutron models and cross sections to describe elastic and inelastic scattering, capture and fission. The G4NDL database is required for this physics list. Moreover, RadioactiveDecay is activated.
      * **QGSP\_BIC\_AllHP**: identical to QGSP\_BIC\_HP except that for protons and light ions (d, t, He3, and alpha), ParticleHP is used below 200 MeV.
      * **Electromagnetic options**: different configurations of electromagnetic physics are available [*EM physics con-*](#_bookmark8)[*structors*](#_bookmark8)), which may be used instead of the default electromagnetic physics.

# Shielding

It is recommended for simulation of deep shielding. Neutrons of 20 MeV and lower use the High Precision neutron models and cross sections to describe elastic and inelastic scattering, capture and fission. The G4NDL database is required for this physics list.

* + 1. **Hadronic Component**

The purely hadronic part of this physics list consists of elastic, inelastic, capture and fission processes. Each process is built from a set of cross section sets and interaction models which provide the detailed physics implementation.

**Inelastic models**

The inelastic hadron-nucleus processes are implemented by the Fritiof parton model (FTF), Bertini and Precompound models. The Bertini intranuclear cascade is responsible for

*�, �, 𝜋*+*, 𝜋−, 𝐾*+*, 𝐾−, 𝐾𝐿, 𝐾𝑆,* Λ*,* Σ+*,* Σ*−,* Σ0*,* Ξ*−,* Ξ0 and Ω*−* interactions between 0 to 6 GeV. The

FTF model handles these same particles, but over the range 3 GeV to 100 TeV. It also handles anti-protons, anti-neutrons, anti-deuterons, anti-tritons, anti-3He, anti-alphas and anti-hyperons from 0 to 100 TeV/n.

Where Bertini and FTF overlap in particle type and energy range, Bertini is invoked with a probability that decreases linearly from 1.0 to 0.0, and FTF is invoked with the complementary probability.

When the FTF model is used, the Precompound model (P) is also invoked to de-excite the remnant nucleus after the initial high energy interaction. The precompound model in turn calls the Fermi breakup, neutron and light ion evaporation and photon evaporation models as needed. When the Bertini model is used, its own, simpler precompound and de-excitation models are invoked.

Inelastic nucleus-nucleus scattering for all incident A is handled by the Binary Light Ion Cascade (BIC) between 0 and 6 GeV/n, and by the FTF model between 3 GeV/n and 100 TeV/n. The scheme for choosing models in overlapping energy regions is the same as that for FTFP and BERT.

The hadronic interaction of gammas is handled by the photo-nuclear process in which gammas below 6 GeV are interacted using the Bertini cascade, and above 3 GeV by the Quark-gluon String (QGS) model. Muons, electrons and positrons also interact via transfer of virtual photons. These interactions are handled by G4MuonVDNuclearModel and G4ElectroVDNuclearModel which are applied at all energies.

**Inelastic cross sections**

G4BGGNucleonInelasticXS is used for protons, G4NeutronInelasticXS for neutrons, and G4BGGPionInelasticXS for pions. In these cross sections Barashenkov parameterisation is used below 91 GeV and Glauber-Gribov above.

For kaons, hyperons and anti-hyperons the Glauber-Gribov set (G4ComponentGGHadronNucleusXsc) is used at all energies.

All nucleus-nucleus cross sections are provided by G4ComponentGGNuclNuclXsc at all projectile energies. This class is the Glauber-Gribov nucleus-nucleus cross section parameterisation. When the projectile is an anti-proton, anti-neutron, anti-deuteron, anti-triton, anti-3He or anti-alpha, the G4ComponentAntiNuclNuclearXS class provides the cross sections using the Glauber-Gribov parameterisation.

Hadronic gamma interaction cross sections are supplied by G4PhotoNuclearCrossSection which is used at all gamma energies. G4ElectroNuclearCrossSection is used at all energies for *𝑒*+ and *𝑒−*, while G4KokoulinMuonNuclearXS is used for *𝜇*+ and *𝜇−* at all energies.

**Elastic models**

Elastic scattering of protons and neutrons use G4ChipsElasticModel from 0 to 100 TeV. This model uses the Kossov parameterised cross sections.

For almost all other hadrons the G4HadronElastic model is used for some or all of the energy range. This model is a two-exponential momentum transfer model updated from the old Gheisha code. It is used at all energies by kaons, hyperons, deuterons, tritons, 3He, alphas and anti-neutrons.

Elastic *𝜋*+ and *𝜋−* scattering is implemented by the G4ElasticHadrNucleusHE coherent scattering model for all ener- gies.

For anti-protons, anti-neutrons, anti-deuterons, anti-tritons, anti-3He and anti-alphas, G4HadronElastic is used from 0 to 100 MeV/n. Above 100 MeV/n these particles are handled by the G4AntiNuclElastic model.

There is currently no elastic scattering model for nuclear projectiles with *𝐴 >* 4.

**Elastic cross sections**

G4BGGNucleonElasticXS is used for protons, G4NeutronElasticXS for neutrons, and G4BGGPionElasticXS for pi- ons. In these cross sections Barashenkov parameterisation is used below 91 GeV and Glauber-Gribov above.

For kaons, hyperons, anti-hyperons and light ions the G4ComponentGGNuclNuclXsc elastic cross section is used.

For all ions the G4ComponentGGNuclNuclXsc elastic cross section is used. anti-p, anti-d, anti-t, anti-3He and anti- alpha use the Glauber model cross section in G4ComponentAntiNuclNuclearXS at all energies.

**Capture and stopping**

Neutron capture uses the G4NeutronRadCapture model with the G4NeutronCaptureXS cross sections. Muon capture or decay at rest is handled by the G4MuonMinusCapture process.

The capture of negative pions and kaons once they have stopped is handled by the BertiniCaptureAtRest model which uses the Bertini cascade. The capture of anti-p, anti-d, anti-t, anti-3He, anti-alpha is handled by the FritiofCapture- AtRest model which uses the Fritiof string model.

## Electromagnetic Component

This physics list uses “standard” GEANT4 electromagnetic physics as built by the G4EmStandardPhysics constructor. It is implemented for *𝛾, 𝑒−, 𝑒*+*, 𝜇−, 𝜇*+*, 𝜏 −, 𝜏* +*,* and all stable charged hadrons/ion (see details in [*EM physics*](#_bookmark8)[*constructors*](#_bookmark8)).

There is no treatment of optical photons in this physics list, optical physics should be added on top of any reference or user custom physics.

## Decay Component

The decay of all long-lived hadrons and leptons is handled by the G4Decay process. It does not handle the decay of hadronic resonances like deltas, heavy-flavor particles like D and B mesons or charmed hyperons.

This physics list does invoke the G4RadioactiveDecay process, so unstable ions will be decayed. Muon capture is handled by the G4MuonMinusCapture process.

## Recommended Use Cases

Shielding is recommended for applications for neutron transport.

## Related Physics Lists

* + - * **ShieldingM**: different transition from the Bertini model to the FTF model: from 9.5 to 9.9 GeV.
      * **ShieldingLEND**: different configurations of low-energy neutron transport with LEND option.
      * **Electromagnetic options**: different configurations of electromagnetic physics are available [*EM physics con-*](#_bookmark8)[*structors*](#_bookmark8)), which may be used instead of the default electromagnetic physics.

**CHAPTER**

# THREE

**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.

# EM physics constructors

Electromagnetic physics constructors were first published in [[eal09](#_bookmark29)], were extended in [[eal11](#_bookmark30)] and become stable in recent releases of GEANT4 [[eal16](#_bookmark27)]. The default electromagnetic physics is built by the G4EmStandardPhysics constructor (see details in [*EM Opt0*](#_bookmark9)).

Electromagnetic physics in all physics constructors is implemented for the following particles:

*𝛾, 𝑒−, 𝑒*+*, 𝜇−, 𝜇*+*, 𝜏 −, 𝜏* +*, 𝜋*+*, 𝜋−, 𝐾*+*, 𝐾−, �,* Σ+*,* Σ*−,* Ξ*−,* Ω*−,* anti( *�,* Σ+*,* Σ*−,* Ξ*−,* Ω*−* ),

*𝑑, �,* 3*𝐻𝑒, 𝛼,* anti( *𝑑, �,* 3*𝐻𝑒, 𝛼*), and G4GenericIon.

Several charmed mesons are also treated, *𝐷*+*, 𝐷−, 𝐷*+*, 𝐷−,* Λ+*,* Σ+*,* Σ++*,* Ξ+*,* anti(Λ+*,* Σ+*,* Σ++*,* Ξ+), as

*� � 𝑐 𝑐 𝑐 𝑐 𝑐 𝑐 𝑐 𝑐*

well as two bottom mesons, *𝐵*+*, 𝐵−, 𝐵*+*, 𝐵−,* Ω*−,* Σ+*,* Σ*−,* Ξ*−* anti( Ω*−,* Σ+*,* Σ*−,* Ξ*−*).

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Internal tables for energy loss, range and cross sections are built from 100 eV to 100 TeV. These limits are defined based on LHC experiments requirements. Upper limits of applicability of various electromagnetic processes are larger and are process dependent. For example, muon models are valid up to 1 PeV. In order to provide particle transport for all use-cases, the operational energy range goes down to zero but below 1 keV the accuracy of the default set of models is degraded substantially.

The GEANT4 toolkit includes many alternative physics models, especially, for electromagnetic physics. There are several well established configurations recommended for different applications:

* G4EmStandardPhysics\_option1 [*EM Opt1*](#_bookmark10) - extension name EMV;
* G4EmStandardPhysics\_option2 [*EM Opt2*](#_bookmark11) - extension name EMX;
* G4EmStandardPhysics\_option3 [*EM Opt3*](#_bookmark12) - extension name EMY;
* G4EmStandardPhysics\_option4 [*EM Opt4*](#_bookmark13) - extension name EMZ;
* G4EmLivermorePhysics [*EM Liv*](#_bookmark14) - extension name LIV;
* G4EmPenelopePhysics [*EM Pen*](#_bookmark15) - extension name PEN;
* G4EmStandardPhysicsGS [*EM GS*](#_bookmark16) - extension name \_GS;
* G4EmLowEPPhysics [*EM LE*](#_bookmark17) - extension name \_LE;
* G4EmStandardPhysicsWVI [*EM WVI*](#_bookmark18) - extension name WVI;
* G4EmStandardPhysicsSS [*EM SS*](#_bookmark19) - extension name \_SS;
* G4EmDNAPhysics [*EM DNA*](#_bookmark20).

# EM Opt0

The default electromagnetic physics is built by the G4EmStandardPhysics constructor (see details in [*EM Opt0*](#_bookmark9)).

For each particle type Standard EM models implement several processes. Processes cover physics from 0 to 100 TeV for gamma, *𝑒−* and *𝑒*+ and up to 1 PeV for muons. EM interactions of charged hadrons and ions cover the range 0 to 100 TeV. Though the operational energy range goes down to zero, below 1 keV accuracy of these models is substantially lower.

Photons: *𝑒−/𝑒*+ pair production is implemented by the BetheHeitler model with the LPM effect at high energies and Compton scattering is implemented by the Klein-Nishina model. Photo-electric effect and Rayleigh scattering are both handled by the Livermore models.

Electrons and positrons: multiple Coulomb scattering is handled by the Urban model from 0 to 100 MeV and by the WentzelVI model from 100 MeV to 100 TeV, which is combined with the single Coulomb scattering model, which is applied for large angle scattering. *UseSafety* step limitation is used for multiple scattering. Bremsstrahlung is implemented by the eBremSB model and the eBremLPM model which takes into account the LPM effect at high energies. Ionisation is modelled by the Moller-Bhabha formulation, and positron annihilation is implemented by the eplus2gg model.

Muons: multiple Coulomb scattering is handled by the WentzelVI model combined with the single scattering model at all energies, and by the eCoulombScattering model at all energies. Bremsstrahlung is handled by the MuBrem model. Ionisation is implemented by several models depending on energy and particle type. From 0 to 200 keV, the Bragg model is used for *𝜇*+ and the ICRU73Q0 parameterisation is used for *𝜇−*. Between 200 keV and 1 GeV the BetheBloch model is used for both *𝜇*+ and *𝜇−*, and from 1 GeV to 100 TeV, the MuBetheBloch model is used for both

*𝜇*+ and *𝜇−*. The muPairProduction model handles e+/e- pair production caused by either *𝜇*+ or *𝜇−*.

Pions, kaons, protons and anti-protons: multiple Coulomb scattering is performed by the WentzelVI model and Coulomb scattering by the eCoulombScattering model. Bremsstrahlung is handled by hBrem model. *𝑒−/𝑒*+ pair production by hadrons is implemented by the hPairProduction model. Ionisation is handled by several models depend- ing on energy and particle type. For pions below 298 keV, Bragg model ionisation is used for *𝜋*+, and the ICRU73Q0 parameterisation is used for *𝜋−*. Above this energy BetheBloch ionisation is used. For kaons, the same ionisation mod- els are used, but the change from low energy to high energy models occurs at 1.05 MeV. For protons, the Bragg model is used below 2 MeV and the BetheBloch above. For anti-protons ICRU73Q0 is used below 2 MeV and BetheBloch above.

alpha and G4GenericIon: only two EM processes are applied. Multiple Coulomb scattering in implemented by the Urban model at all energies. For alphas Bragg ionisation is performed below 7.9 MeV and BetheBloch ionisation above. For generic ions, Bragg is used below 2 MeV/u and BetheBloch above.

# EM Opt1

This physics list uses “standard” GEANT4 electromagnetic physics as built by the

G4EmStandardPhysics\_option1 constructor.

For each particle type several processes are implemented. Processes cover physics from 0 to 100 TeV for gamma, *𝑒−* and *𝑒*+ and up to 1 PeV for muons. EM interactions of charged hadrons and ions cover the range 0 to 100 TeV. Though the operational energy range goes down to zero, below 1 keV accuracy of these models is substantially lower.

Photons: *𝑒−/𝑒*+ pair production is implemented by the BetheHeitler model with the LPM effect at high energies and Compton scattering is implemented by the Klein-Nishina model. Photo-electric effect and Rayleigh scattering are both handled by the Livermore models. *ApplyCuts* option is use to cut out low-energy *𝑒−*, produced by gamma processes.

Electrons and positrons: multiple Coulomb scattering is handled by the Urban model from 0 to 100 MeV and by the WentzelVI model from 100 MeV to 100 TeV, which is combined with the single Coulomb scattering model, which is applied for large angle scattering. *Minimal* step limitation is used for multiple scattering. Bremsstrahlung

is implemented by the eBremSB model and the eBremLPM model which takes into account the LPM effect at high energies. Ionisation is modelled by the Moller-Bhabha formulation, and positron annihilation is implemented by the eplus2gg model.

Muons: multiple Coulomb scattering is handled by the WentzelVI model combined with the single scattering model at all energies, and by the eCoulombScattering model at all energies. Bremsstrahlung is handled by the MuBrem model. Ionisation is implemented by several models depending on energy and particle type. From 0 to 200 keV, the Bragg model is used for mu+ and the ICRU73Q0 parameterisation is used for mu-. Between 200 keV and 1 GeV the BetheBloch model is used for both *𝜇*+ and *𝜇−*, and from 1 GeV to 100 TeV, the MuBetheBloch model is used for both

*𝜇*+ and *𝜇−*. The muPairProduction model handles e+/e- pair production caused by either *𝜇*+ or *𝜇−*.

Pions, kaons, protons and anti-protons: multiple Coulomb scattering is performed by the WentzelVI model and Coulomb scattering by the eCoulombScattering model. Bremsstrahlung is handled by hBrem model. *𝑒−/𝑒*+ pair production by hadrons is implemented by the hPairProduction model. Ionisation is handled by several models depend- ing on energy and particle type. For pions below 298 keV, Bragg model ionisation is used for *𝜋*+, and the ICRU73Q0 parameterisation is used for *𝜋−*. Above this energy BetheBloch ionisation is used. For kaons, the same ionisation mod- els are used, but the change from low energy to high energy models occurs at 1.05 MeV. For protons, the Bragg model is used below 2 MeV and the BetheBloch above. For anti-protons ICRU73Q0 is used below 2 MeV and BetheBloch above.

Alpha and G4GenericIon: only two EM processes are applied. Multiple Coulomb scattering in implemented by the Urban model at all energies. For alphas Bragg ionisation is performed below 7.9 MeV and BetheBloch ionisation above. For generic ions, Bragg is used below 2 MeV/u and BetheBloch above.

# EM Opt2

This physics list uses “standard” GEANT4 electromagnetic physics as built by the

G4EmStandardPhysics\_option2 constructor.

For each particle type several processes are implemented. Processes cover physics from 0 to 100 TeV for gamma, *𝑒−* and *𝑒*+ and up to 1 PeV for muons. EM interactions of charged hadrons and ions cover the range 0 to 100 TeV. Though the operational energy range goes down to zero, below 1 keV accuracy of these models is substantially lower.

Photons: *𝑒−/𝑒*+ pair production is implemented by the BetheHeitler model with the LPM effect at high energies and Compton scattering is implemented by the Klein-Nishina model. Photo-electric effect and Rayleigh scattering are both handled by the Livermore models.

Electrons and positrons: multiple Coulomb scattering is handled by the Urban model from 0 to 100 MeV and by the WentzelVI model from 100 MeV to 100 TeV, which is combined with the single Coulomb scattering model, which is applied for large angle scattering. *Simple* step limitation is used for multiple scattering. Bremsstrahlung is implemented by the eBremSB model and the eBremLPM model which takes into account the LPM effect at high energies. Ionisation is modelled by the Moller-Bhabha formulation, and positron annihilation is implemented by the eplus2gg model.

Muons: multiple Coulomb scattering is handled by the WentzelVI model combined with the single scattering model at all energies, and by the eCoulombScattering model at all energies. Bremsstrahlung is handled by the MuBrem model. Ionisation is implemented by several models depending on energy and particle type. From 0 to 200 keV, the Bragg model is used for mu+ and the ICRU73Q0 parameterisation is used for mu-. Between 200 keV and 1 GeV the BetheBloch model is used for both *𝜇*+ and *𝜇−*, and from 1 GeV to 100 TeV, the MuBetheBloch model is used for both

*𝜇*+ and *𝜇−*. The muPairProduction model handles e+/e- pair production caused by either *𝜇*+ or *𝜇−*.

Pions, kaons, protons and anti-protons: multiple Coulomb scattering is performed by the WentzelVI model and Coulomb scattering by the eCoulombScattering model. Bremsstrahlung is handled by hBrem model. *𝑒−/𝑒*+ pair production by hadrons is implemented by the hPairProduction model. Ionisation is handled by several models depend- ing on energy and particle type. For pions below 298 keV, Bragg model ionisation is used for *𝜋*+, and the ICRU73Q0

parameterisation is used for *𝜋−*. Above this energy BetheBloch ionisation is used. For kaons, the same ionisation mod- els are used, but the change from low energy to high energy models occurs at 1.05 MeV. For protons, the Bragg model is used below 2 MeV and the BetheBloch above. For anti-protons ICRU73Q0 is used below 2 MeV and BetheBloch above.

Alpha and G4GenericIon: only two EM processes are applied. Multiple Coulomb scattering in implemented by the Urban model at all energies. For alphas Bragg ionisation is performed below 7.9 MeV and BetheBloch ionisation above. For generic ions, Bragg is used below 2 MeV/u and BetheBloch above.

# EM Opt3

This physics list uses “standard” GEANT4 electromagnetic physics as built by the

G4EmStandardPhysics\_option3 constructor.

Processes cover physics from 0 to 100 TeV for gamma, *𝑒−* and *𝑒*+ and up to 1 PeV for muons. EM interactions of charged hadrons and ions cover the range 0 to 100 TeV. Though the operational energy range goes down to zero, below 1 keV accuracy of these models is substantially lower.

For each particle type several processes are implemented. Photons: *𝑒−/𝑒*+ pair production is implemented by the BetheHeitler model with the LPM effect at high energies and Compton scattering is implemented by the Klein-Nishina model. Photo-electric effect and Rayleigh scattering are both handled by the Livermore models.

Electrons and positrons: multiple Coulomb scattering is handled by the Urban model from 0 to 100 TeV. *UseDistance- ToBoundary* step limitation is used for multiple scattering. Bremsstrahlung is implemented by the eBremSB model and the eBremLPM model which takes into account the LPM effect at high energies. Ionisation is modelled by the Moller-Bhabha formulation, and positron annihilation is implemented by the eplus2gg model.

Muons: multiple Coulomb scattering is handled by the the Urban model from 0 to 100 TeV. Bremsstrahlung is handled by the MuBrem model. Ionisation is implemented by several models depending on energy and particle type. From 0 to 200 keV, the Bragg model is used for *𝜇*+ and the ICRU73Q0 parameterisation is used for *𝜇−*. Between 200 keV and 1 GeV the BetheBloch model is used for both *𝜇*+ and *𝜇−*, and from 1 GeV to 100 TeV, the MuBetheBloch model is used for both *𝜇*+ and *𝜇−*. The muPairProduction model handles e+/e- pair production caused by either *𝜇*+ or *𝜇−*.

Pions, kaons, protons and anti-protons: multiple Coulomb scattering is performed by the Urban model and Coulomb scattering by the eCoulombScattering model. Bremsstrahlung is handled by hBrem model. *𝑒−/𝑒*+ pair production by hadrons is implemented by the hPairProduction model. Ionisation is handled by several models depending on energy and particle type. For pions below 298 keV, Bragg model ionisation is used for *𝜋*+, and the ICRU73Q0 parameterisation is used for *𝜋−*. Above this energy BetheBloch ionisation is used. For kaons, the same ionisation models are used, but the change from low energy to high energy models occurs at 1.05 MeV. For protons, the Bragg model is used below 2 MeV and the BetheBloch above. For anti-protons ICRU73Q0 is used below 2 MeV and BetheBloch above.

alpha and G4GenericIon: only two EM processes are applied. Multiple Coulomb scattering in implemented by the Urban model at all energies. For alphas Bragg ionisation is performed below 7.9 MeV and BetheBloch ionisation above. For generic ions, Bragg is used below 2 MeV/u and BetheBloch above. Nuclear stopping model is used below 1 MeV.

# EM Opt4

This physics list uses “standard” GEANT4 electromagnetic physics as built by the

G4EmStandardPhysics\_option4 constructor.

Photons: *𝑒−/𝑒*+ pair production is implemented by the BetheHeitler model with the LPM effect at high energies and Compton scattering is implemented by the Klein-Nishina model above 20 MeV. Below 20 MeV the Monarsh University model (*G4LowEPComptonModel*) for Compton scattering and Penelope pair production models are used. Photo-electric effect and Rayleigh scattering are both handled by the Livermore models.

Electrons and positrons: multiple Coulomb scattering is handled by the Goudsmit-Sounderson model from 0 to 100 MeV and by the WentzelVI model from 100 MeV to 100 TeV, which is combined with the single Coulomb scatter- ing model, which is applied for large angle scattering. *UseSafetyPlus* step limitation with *error free* approach near geometry boundaries is used for multiple scattering. Bremsstrahlung is implemented by the eBremSB model and the eBremLPM model which takes into account the LPM effect at high energies. Ionisation is modelled by the Moller- Bhabha formulation, and positron annihilation is implemented by the eplus2gg model. The process of *𝑒−/𝑒*+ pair production by electrons and positrons is also used.

Muons: multiple Coulomb scattering is handled by the WentzelVI model combined with the single scattering model at all energies, and by the eCoulombScattering model at all energies. Bremsstrahlung is handled by the MuBrem model. Ionisation is implemented by several models depending on energy and particle type. From 0 to 200 keV, the Bragg model is used for *𝜇*+ and the ICRU73Q0 parameterisation is used for *𝜇−*.

Between 200 keV and 1 GeV the Bethe-Bloch model is used for both *𝜇*+ and *𝜇−*, and from 1 GeV to 100 TeV, the MuBetheBloch model is used for both *𝜇*+ and *𝜇−*. The muPairProduction model handles e+/e- pair production caused by either *𝜇*+ or *𝜇−*.

Pions, kaons, protons and anti-protons: multiple Coulomb scattering is performed by the WentzelVI model and Coulomb scattering by the eCoulombScattering model. Bremsstrahlung is handled by hBrem model. *𝑒−/𝑒*+ pair production by hadrons is implemented by the hPairProduction model. Ionisation is handled by several models depend- ing on energy and particle type. For pions below 298 keV, Bragg model ionisation is used for *𝜋*+, and the ICRU73Q0 parameterisation is used for *𝜋−*. Above this energy Bethe-Bloch ionisation is used. For kaons, the same ionisa- tion models are used, but the change from low energy to high energy models occurs at 1.05 MeV. For protons, the Bragg model is used below 2 MeV and the BetheBloch above. For anti-protons ICRU73Q0 is used below 2 MeV and BetheBloch above.

alpha and G4GenericIon: only two EM processes are applied. Multiple Coulomb scattering in implemented by the Ur- ban model at all energies. For alphas Bragg ionisation is performed below 7.9 MeV and Bethe-Bloch ionisation above. For generic ions, For ion ionisation of ions below 1 GeV/u ICRU73 model (G4IonParametrisedLossModel) is used, above 1 GeV/u the Bethe-Bloch model is applied. Nuclear stopping model is used below 1 MeV.

# EM Liv

This physics list uses “Livermore” GEANT4 electromagnetic physics as built by the G4EmLivermorePhysics

constructor.

For each particle type, EM models implement several processes. Photons: *𝑒−/𝑒*+ pair production is implemented by the Bethe-Heitler 5D model below 80 GeV and relativistic Bethe-Heitler model above. The Compton scattering are implemented by the Livermore models up to 1 GeV and at high energies by the Klein-Nishina models, respectively. Photo-electric effect and Rayleigh scattering are both handled by Livermore models.

Electrons: multiple Coulomb scattering is handled by the GS model at low energy and by the WentzelVI model at higher energies, which is combined with the single Coulomb scattering model, which is applied for large angle scatter- ing. Bremsstrahlung is implemented by the Seltzer-Berger model below 1 GeV and by the eBremsstrahlungRelModel model at high energies. Ionisation is modelled by the Livermore model.

Other interactions are configured identically as in the G4EmStandardPhysics\_option4 constructor.

# EM Pen

This physics list uses “Penelope” GEANT4 electromagnetic physics as built by the G4EmPenelopePhysics con- structor.

Specific low-energy Penelope models are used for gamma, *𝑒−*, and *𝑒*+ below 1 GeV. Above 1 GeV and for all other charged particles the configuration is the same as in the G4EmStandardPhysics\_option4 constructor.

# EM GS

This physics list uses “standard” GEANT4 electromagnetic physics as built by the G4EmStandardPhysicsGS constructor. This configuration is same as in the default G4EmStandardPhysics constructor, except multiple scattering of *𝑒−* and *𝑒*+, which is handled by the Goudsmit-Sounderson model from 0 to 100 MeV.

# EM LE

This physics list uses “standard” GEANT4 electromagnetic physics as built by the G4EmLowEPPhysics constructor. This configuration is same as in the default G4EmStandardPhysics constructor, except several additions.

Photons: *𝑒−/𝑒*+ pair production is implemented by the Bethe-Heitler 5D model below 80 GeV and relativis- tic Bethe-Heitler model above. The Compton scattering are implemented by the Monarsh University model (G4LowEPComptonModel) up to 20 MeV and by the Klein-Nishina model above 20 MeV.

For all charged particle and energies G4LowEWentzelVIModel is used for simulation of multiple scattering. The BS generator is used for simulation of bremsstrahlung angular distribution.

For protons and alpha ICRU90 data for 3 materials is used.

For ion ionisation of ions below 10 MeV/u ICRU73 model (G4IonParametrisedLossModel) is used, above 10 MeV/u the Lindhard-Sorensen model is applied (G4LindhardSorensenIonModel). Additionally, bremsstrahlung and *𝑒−/𝑒*+ pair production are implemented for ions.

# EM WVI

This physics list uses “standard” GEANT4 electromagnetic physics as built by the G4EmStandardPhysicsWVI constructor. This configuration is same as in the default G4EmStandardPhysics constructor, except multiple scattering

For *𝑒−* and *𝑒*+ at all energies G4WentzelVIModel is used for simulation of multiple scattering combined with single elastic at large angles.

For ion ionisation of ions below 2 MeV/u the Bragg model is used, above 2 MeV/u the ATIMA model is applied (G4AtimaEnergyLossModel) with ATIMA fluctuation model (G4AtimaFluctuations).

# EM SS

This physics list uses “standard” GEANT4 electromagnetic physics as built by the G4EmStandardPhysicsSS constructor. This configuration is same as in the default G4EmStandardPhysics constructor, except multiple scattering is not used and only elastic scattering process is applied for all changed particles.

# EM DNA

The currently recommended Geant4-DNA physics lists are assembled in three constructors,

G4EmDNAPhysics\_option2, G4EmDNAPhysics\_option4 and G4EmDNAPhysics\_option6.

These physics lists handle the discrete electromagnetic interactions of: photons, electrons, protons, neutral hydrogen, alpha particles and their charged states and a few ions : Li (3,7), Be (4,9), B (5,11), C (6,12), N (7,14), O (8,16), Si (14,28), Fe (26,56).

Physical interactions for electrons are: ionisation, electronic excitation, elastic scattering, and, for G4EmDNAPhysics\_option2, vibrational excitation and attachment. Different models are adopted in the three recommended constructors. For example, inelastic interactions are described by the dielectric function theory or by alternative semi-empirical approaches.

Physical interactions of protons, neutral hydrogen, alpha particles and their charged states, heavier ions, and photons are handled identically by all three constructors. They are nuclear scattering, electronic excitation, ionisation, electron capture and electron loss. For ions heavier than alpha particles, only the ionisation process is available.

All details including energy ranges of applicability and performance comparison are presented in the Geant4-DNA web site (<http://geant4-dna.in2p3.fr/styled-3/styled-8/index.html>) or in this publication: Med. Phys. 45 (2018) e722-e739 (<https://doi.org/10.1002/mp.13048>)

Other alternative constructors are available but we currently recommend the usage of the above constructors.

# Tables by constructor

Tables of electromagnetic processes for several common constructors. To generate these tables (in reStructuredText format), call:

G4LossTableManager::Instance()->DumpHtml()

For example, use example extended/electromagnetic/TestEm0, and set the environment variables G4PhysListName to be the name of the file to write (extension .rst will be added), and G4PhysListDocDir to be the name of the directory to write the file. Set the physics list in the macro file. Also set:

/process/em/verbose 1

* + 1. **emstandard\_opt0**

### gamma

Photoelectric effect

phot: SubType=12 BuildTable=0

LambdaPrime table from 200 keV to 100 TeV in 61 bins

===== EM models for the G4Region DefaultRegionForTheWorld ====== LivermorePhElectric : Emin= 0 eV Emax= 100 TeV SauterGavrila Fluo

Compton scattering

compt: SubType=13 BuildTable=1

Lambda table from 100 eV to 1 MeV, 7 bins/decade, spline: 1 LambdaPrime table from 1 MeV to 100 TeV in 56 bins

===== EM models for the G4Region DefaultRegionForTheWorld ====== Klein-Nishina : Emin= 0 eV Emax= 100 TeV

Gamma conversion

conv: SubType=14 BuildTable=1

Lambda table from 1.022 MeV to 100 TeV, 18 bins/decade, spline: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== BetheHeitlerLPM : Emin= 0 eV Emax= 100 TeV ModifiedTsai

Rayleigh scattering

Rayl: SubType=11 BuildTable=1

Lambda table from 100 eV to 100 keV, 7 bins/decade, spline: 0 LambdaPrime table from 100 keV to 100 TeV in 63 bins

===== EM models for the G4Region DefaultRegionForTheWorld ======

LivermoreRayleigh : Emin= 0 eV Emax= 100 TeV CullenGenerator

### e-

Coulomb scattering. Simulation of elastic scattering

events individually. May be used in combination with multiple scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 SubType=1 BuildTable=1

Lambda table from 100 MeV to 100 TeV, 7 bins/decade, spline: 1 ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 100 MeV Emax= 100 TeV

Multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May be combined with Coulomb scattering in a 'mixed' scattering algorithm.

msc: SubType= 10

RangeFactor= 0.04, stepLimType: 1, latDisp: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== UrbanMsc : Emin= 0 eV Emax= 100 MeV Nbins=42 100 eV - 100 MeV

WentzelVIUni : Emin= 100 MeV Emax= 100 TeV Nbins=42 100 MeV - 100 TeV

Ionisation

eIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 StepFunction=(0.2, 1 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== MollerBhabha : Emin= 0 eV Emax= 100 TeV

CSDA range table up to 1 GeV in 49 bins

Bremsstrahlung eBrem: SubType=3

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 LPM flag: 1 for E > 1 GeV, VertexHighEnergyTh(GeV)= 100000

===== EM models for the G4Region DefaultRegionForTheWorld ======

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eBremSB : Emin= 0 eV Emax= 1 GeV ModifiedTsai eBremLPM : Emin= 1 GeV Emax= 100 TeV ModifiedTsai

### e+

Coulomb scattering. Simulation of elastic scattering

events individually. May be used in combination with multiple

scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 SubType=1 BuildTable=1

Lambda table from 100 MeV to 100 TeV, 7 bins/decade, spline: 1 ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 100 MeV Emax= 100 TeV

Positron annihilation

annihil: integral:1 SubType=5 BuildTable=0

===== EM models for the G4Region DefaultRegionForTheWorld ====== eplus2gg : Emin= 0 eV Emax= 100 TeV

Multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May be combined with Coulomb scattering in a 'mixed' scattering algorithm.

msc: SubType= 10

RangeFactor= 0.04, stepLimType: 1, latDisp: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== UrbanMsc : Emin= 0 eV Emax= 100 MeV Nbins=42 100 eV - 100 MeV

WentzelVIUni : Emin= 100 MeV Emax= 100 TeV Nbins=42 100 MeV - 100 TeV

Ionisation

eIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 StepFunction=(0.2, 1 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== MollerBhabha : Emin= 0 eV Emax= 100 TeV

CSDA range table up to 1 GeV in 49 bins

Bremsstrahlung eBrem: SubType=3

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 LPM flag: 1 for E > 1 GeV, VertexHighEnergyTh(GeV)= 100000

===== EM models for the G4Region DefaultRegionForTheWorld ====== eBremSB : Emin= 0 eV Emax= 1 GeV ModifiedTsai

eBremLPM : Emin= 1 GeV Emax= 100 TeV ModifiedTsai

### proton

Coulomb scattering. Simulation of elastic scattering

events individually. May be used in combination with multiple scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 SubType=1 BuildTable=1

Lambda table from threshold to 100 TeV, 7 bins/decade, spline: 1 ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 0 eV Emax= 100 TeV

Hadron multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May

be combined with Coulomb scattering in a 'mixed' scattering algorithm. msc: SubType= 10

RangeFactor= 0.2, stepLimType: 0, latDisp: 0

===== EM models for the G4Region DefaultRegionForTheWorld ======

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WentzelVIUni : Emin= 0 eV Emax= 100 TeV Nbins=84 100 eV - 100 TeV

Hadron bremsstrahlung hBrems: SubType=3

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== hBrem : Emin= 0 eV Emax= 100 TeV

Hadron pair production hPairProd: SubType=4

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 Sampling table 17x1001; from 7.50618 GeV to 100 TeV

===== EM models for the G4Region DefaultRegionForTheWorld ====== hPairProd : Emin= 0 eV Emax= 100 TeV

### mu+

Ionisation

hIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 StepFunction=(0.2, 0.1 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== Bragg : Emin= 0 eV Emax= 2 MeV

BetheBloch : Emin= 2 MeV Emax= 100 TeV CSDA range table up to 1 GeV in 49 bins

Coulomb scattering. Simulation of elastic scattering

events individually. May be used in combination with multiple scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 SubType=1 BuildTable=1

Lambda table from threshold to 100 TeV, 7 bins/decade, spline: 1 ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 0 eV Emax= 100 TeV

Muon multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May be combined with Coulomb scattering in a 'mixed' scattering algorithm.

msc: SubType= 10

RangeFactor= 0.2, stepLimType: 0, latDisp: 0, polarAngLim(deg)= 180

===== EM models for the G4Region DefaultRegionForTheWorld ====== WentzelVIUni : Emin= 0 eV Emax= 100 TeV Nbins=84 100 eV - 100 TeV

Muon bremsstrahlung muBrems: SubType=3

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== MuBrem : Emin= 0 eV Emax= 100 TeV

Pair production muPairProd: SubType=4

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 Sampling table 21x1001; from 1 GeV to 100 TeV

===== EM models for the G4Region DefaultRegionForTheWorld ====== muPairProd : Emin= 0 eV Emax= 100 TeV

Muon ionisation muIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

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### mu-

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Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 StepFunction=(0.2, 0.1 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== Bragg : Emin= 0 eV Emax= 200 keV

BetheBloch : Emin= 200 keV Emax= 1 GeV MuBetheBloch : Emin= 1 GeV Emax= 100 TeV

CSDA range table up to 1 GeV in 49 bins

Coulomb scattering. Simulation of elastic scattering

events individually. May be used in combination with multiple scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 SubType=1 BuildTable=1

Lambda table from threshold to 100 TeV, 7 bins/decade, spline: 1 ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 0 eV Emax= 100 TeV

Muon multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May be combined with Coulomb scattering in a 'mixed' scattering algorithm.

msc: SubType= 10

RangeFactor= 0.2, stepLimType: 0, latDisp: 0, polarAngLim(deg)= 180

===== EM models for the G4Region DefaultRegionForTheWorld ====== WentzelVIUni : Emin= 0 eV Emax= 100 TeV Nbins=84 100 eV - 100 TeV

Muon bremsstrahlung muBrems: SubType=3

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== MuBrem : Emin= 0 eV Emax= 100 TeV

Pair production muPairProd: SubType=4

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 Sampling table 21x1001; from 1 GeV to 100 TeV

===== EM models for the G4Region DefaultRegionForTheWorld ====== muPairProd : Emin= 0 eV Emax= 100 TeV

Muon ionisation muIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 StepFunction=(0.2, 0.1 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== ICRU73QO : Emin= 0 eV Emax= 200 keV

BetheBloch : Emin= 200 keV Emax= 1 GeV MuBetheBloch : Emin= 1 GeV Emax= 100 TeV

CSDA range table up to 1 GeV in 49 bins

## emstandard\_opt1

### gamma

Photoelectric effect

phot: applyCuts:1 SubType=12 BuildTable=0

LambdaPrime table from 200 keV to 100 TeV in 61 bins

===== EM models for the G4Region DefaultRegionForTheWorld ====== LivermorePhElectric : Emin= 0 eV Emax= 100 TeV SauterGavrila Fluo

Compton scattering

compt: applyCuts:1 SubType=13 BuildTable=1

Lambda table from 100 eV to 1 MeV, 7 bins/decade, spline: 1 LambdaPrime table from 1 MeV to 100 TeV in 56 bins

===== EM models for the G4Region DefaultRegionForTheWorld ====== Klein-Nishina : Emin= 0 eV Emax= 100 TeV

Gamma conversion

conv: applyCuts:1 SubType=14 BuildTable=1

Lambda table from 1.022 MeV to 100 TeV, 18 bins/decade, spline: 1

===== EM models for the G4Region DefaultRegionForTheWorld ======

BetheHeitlerLPM : Emin= 0 eV Emax= 100 TeV ModifiedTsai

### e-

Coulomb scattering. Simulation of elastic scattering

events individually. May be used in combination with multiple scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 applyCuts:1 SubType=1 BuildTable=1 Lambda table from 100 MeV to 100 TeV, 7 bins/decade, spline: 1 ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 100 MeV Emax= 100 TeV

Multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May be combined with Coulomb scattering in a 'mixed' scattering algorithm.

msc: SubType= 10

RangeFactor= 0.2, stepLimType: 0, latDisp: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== UrbanMsc : Emin= 0 eV Emax= 100 MeV Nbins=42 100 eV - 100 MeV

WentzelVIUni : Emin= 100 MeV Emax= 100 TeV Nbins=42 100 MeV - 100 TeV

Ionisation

eIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 StepFunction=(0.8, 1 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== MollerBhabha : Emin= 0 eV Emax= 100 TeV

CSDA range table up to 1 GeV in 49 bins

Bremsstrahlung eBrem: SubType=3

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 LPM flag: 1 for E > 1 GeV, VertexHighEnergyTh(GeV)= 100000

===== EM models for the G4Region DefaultRegionForTheWorld ====== eBremSB : Emin= 0 eV Emax= 1 GeV ModifiedTsai

eBremLPM : Emin= 1 GeV Emax= 100 TeV ModifiedTsai

### e+

Coulomb scattering. Simulation of elastic scattering

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events individually. May be used in combination with multiple

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scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 applyCuts:1 SubType=1 BuildTable=1 Lambda table from 100 MeV to 100 TeV, 7 bins/decade, spline: 1 ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 100 MeV Emax= 100 TeV

Positron annihilation

annihil: integral:1 applyCuts:1 SubType=5 BuildTable=0

===== EM models for the G4Region DefaultRegionForTheWorld ====== eplus2gg : Emin= 0 eV Emax= 100 TeV

Multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May be combined with Coulomb scattering in a 'mixed' scattering algorithm.

msc: SubType= 10

RangeFactor= 0.2, stepLimType: 0, latDisp: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== UrbanMsc : Emin= 0 eV Emax= 100 MeV Nbins=42 100 eV - 100 MeV

WentzelVIUni : Emin= 100 MeV Emax= 100 TeV Nbins=42 100 MeV - 100 TeV

Ionisation

eIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 StepFunction=(0.8, 1 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== MollerBhabha : Emin= 0 eV Emax= 100 TeV

CSDA range table up to 1 GeV in 49 bins

Bremsstrahlung eBrem: SubType=3

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 LPM flag: 1 for E > 1 GeV, VertexHighEnergyTh(GeV)= 100000

===== EM models for the G4Region DefaultRegionForTheWorld ====== eBremSB : Emin= 0 eV Emax= 1 GeV ModifiedTsai

eBremLPM : Emin= 1 GeV Emax= 100 TeV ModifiedTsai

### proton

Coulomb scattering. Simulation of elastic scattering

events individually. May be used in combination with multiple scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 applyCuts:1 SubType=1 BuildTable=1

Lambda table from threshold to 100 TeV, 7 bins/decade, spline: 1 ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 0 eV Emax= 100 TeV

Hadron multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May

be combined with Coulomb scattering in a 'mixed' scattering algorithm. msc: SubType= 10

RangeFactor= 0.2, stepLimType: 0, latDisp: 0

===== EM models for the G4Region DefaultRegionForTheWorld ====== WentzelVIUni : Emin= 0 eV Emax= 100 TeV Nbins=84 100 eV - 100 TeV

Hadron bremsstrahlung hBrems: SubType=3

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1

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===== EM models for the G4Region DefaultRegionForTheWorld ====== hBrem : Emin= 0 eV Emax= 100 TeV

Hadron pair production hPairProd: SubType=4

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 Sampling table 17x1001; from 7.50618 GeV to 100 TeV

===== EM models for the G4Region DefaultRegionForTheWorld ====== hPairProd : Emin= 0 eV Emax= 100 TeV

### mu+

Ionisation

hIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 StepFunction=(0.2, 0.1 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== Bragg : Emin= 0 eV Emax= 2 MeV

BetheBloch : Emin= 2 MeV Emax= 100 TeV CSDA range table up to 1 GeV in 49 bins

Coulomb scattering. Simulation of elastic scattering

events individually. May be used in combination with multiple scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 applyCuts:1 SubType=1 BuildTable=1

Lambda table from threshold to 100 TeV, 7 bins/decade, spline: 1 ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 0 eV Emax= 100 TeV

Muon multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May be combined with Coulomb scattering in a 'mixed' scattering algorithm.

msc: SubType= 10

RangeFactor= 0.2, stepLimType: 0, latDisp: 0, polarAngLim(deg)= 180

===== EM models for the G4Region DefaultRegionForTheWorld ====== WentzelVIUni : Emin= 0 eV Emax= 100 TeV Nbins=84 100 eV - 100 TeV

Muon bremsstrahlung muBrems: SubType=3

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== MuBrem : Emin= 0 eV Emax= 100 TeV

Pair production muPairProd: SubType=4

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 Sampling table 21x1001; from 1 GeV to 100 TeV

===== EM models for the G4Region DefaultRegionForTheWorld ====== muPairProd : Emin= 0 eV Emax= 100 TeV

Muon ionisation muIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 StepFunction=(0.2, 0.1 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ======

|  |  |  |
| --- | --- | --- |
| Bragg : Emin= | 0 eV Emax= | 200 keV |
| BetheBloch : Emin= | 200 keV Emax= | 1 GeV |
| MuBetheBloch : Emin= | 1 GeV Emax= | 100 TeV |

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### mu-

CSDA range table up to 1 GeV in 49 bins

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Coulomb scattering. Simulation of elastic scattering

events individually. May be used in combination with multiple scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 applyCuts:1 SubType=1 BuildTable=1

Lambda table from threshold to 100 TeV, 7 bins/decade, spline: 1 ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 0 eV Emax= 100 TeV

Muon multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May be combined with Coulomb scattering in a 'mixed' scattering algorithm.

msc: SubType= 10

RangeFactor= 0.2, stepLimType: 0, latDisp: 0, polarAngLim(deg)= 180

===== EM models for the G4Region DefaultRegionForTheWorld ====== WentzelVIUni : Emin= 0 eV Emax= 100 TeV Nbins=84 100 eV - 100 TeV

Muon bremsstrahlung muBrems: SubType=3

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== MuBrem : Emin= 0 eV Emax= 100 TeV

Pair production muPairProd: SubType=4

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 Sampling table 21x1001; from 1 GeV to 100 TeV

===== EM models for the G4Region DefaultRegionForTheWorld ====== muPairProd : Emin= 0 eV Emax= 100 TeV

Muon ionisation muIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 StepFunction=(0.2, 0.1 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== ICRU73QO : Emin= 0 eV Emax= 200 keV

BetheBloch : Emin= 200 keV Emax= 1 GeV MuBetheBloch : Emin= 1 GeV Emax= 100 TeV

CSDA range table up to 1 GeV in 49 bins

## emstandard\_opt2

### gamma

Photoelectric effect

phot: SubType=12 BuildTable=0

LambdaPrime table from 200 keV to 100 TeV in 61 bins

===== EM models for the G4Region DefaultRegionForTheWorld ====== PhotoElectric : Emin= 0 eV Emax= 100 TeV SauterGavrila Fluo

Compton scattering

compt: SubType=13 BuildTable=1

Lambda table from 100 eV to 1 MeV, 7 bins/decade, spline: 1 LambdaPrime table from 1 MeV to 100 TeV in 56 bins

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===== EM models for the G4Region DefaultRegionForTheWorld ====== Klein-Nishina : Emin= 0 eV Emax= 100 TeV

Gamma conversion

conv: SubType=14 BuildTable=1

Lambda table from 1.022 MeV to 100 TeV, 18 bins/decade, spline: 1

===== EM models for the G4Region DefaultRegionForTheWorld ======

BetheHeitlerLPM : Emin= 0 eV Emax= 100 TeV ModifiedTsai

### e-

Coulomb scattering. Simulation of elastic scattering

events individually. May be used in combination with multiple scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 SubType=1 BuildTable=1

Lambda table from 100 MeV to 100 TeV, 7 bins/decade, spline: 1 ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 100 MeV Emax= 100 TeV

Multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May be combined with Coulomb scattering in a 'mixed' scattering algorithm.

msc: SubType= 10

RangeFactor= 0.2, stepLimType: 0, latDisp: 0

===== EM models for the G4Region DefaultRegionForTheWorld ====== UrbanMsc : Emin= 0 eV Emax= 100 MeV Nbins=42 100 eV - 100 MeV

WentzelVIUni : Emin= 100 MeV Emax= 100 TeV Nbins=42 100 MeV - 100 TeV

Ionisation

eIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 StepFunction=(0.8, 1 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== MollerBhabha : Emin= 0 eV Emax= 100 TeV

CSDA range table up to 1 GeV in 49 bins

Bremsstrahlung eBrem: SubType=3

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 LPM flag: 1 for E > 1 GeV, VertexHighEnergyTh(GeV)= 100000

===== EM models for the G4Region DefaultRegionForTheWorld ====== eBremSB : Emin= 0 eV Emax= 1 GeV ModifiedTsai

eBremLPM : Emin= 1 GeV Emax= 100 TeV ModifiedTsai

### e+

Coulomb scattering. Simulation of elastic scattering

events individually. May be used in combination with multiple scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 SubType=1 BuildTable=1

Lambda table from 100 MeV to 100 TeV, 7 bins/decade, spline: 1 ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 100 MeV Emax= 100 TeV

Positron annihilation

annihil: integral:1 SubType=5 BuildTable=0

===== EM models for the G4Region DefaultRegionForTheWorld ====== eplus2gg : Emin= 0 eV Emax= 100 TeV

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Multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May be combined with Coulomb scattering in a 'mixed' scattering algorithm.

msc: SubType= 10

RangeFactor= 0.2, stepLimType: 0, latDisp: 0

===== EM models for the G4Region DefaultRegionForTheWorld ====== UrbanMsc : Emin= 0 eV Emax= 100 MeV Nbins=42 100 eV - 100 MeV

WentzelVIUni : Emin= 100 MeV Emax= 100 TeV Nbins=42 100 MeV - 100 TeV

Ionisation

eIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 StepFunction=(0.8, 1 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== MollerBhabha : Emin= 0 eV Emax= 100 TeV

CSDA range table up to 1 GeV in 49 bins

Bremsstrahlung eBrem: SubType=3

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 LPM flag: 1 for E > 1 GeV, VertexHighEnergyTh(GeV)= 100000

===== EM models for the G4Region DefaultRegionForTheWorld ====== eBremSB : Emin= 0 eV Emax= 1 GeV ModifiedTsai

eBremLPM : Emin= 1 GeV Emax= 100 TeV ModifiedTsai

### proton

Coulomb scattering. Simulation of elastic scattering

events individually. May be used in combination with multiple scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 SubType=1 BuildTable=1

Lambda table from threshold to 100 TeV, 7 bins/decade, spline: 1 ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 0 eV Emax= 100 TeV

Hadron bremsstrahlung hBrems: SubType=3

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== hBrem : Emin= 0 eV Emax= 100 TeV

Hadron pair production hPairProd: SubType=4

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 Sampling table 17x1001; from 7.50618 GeV to 100 TeV

===== EM models for the G4Region DefaultRegionForTheWorld ====== hPairProd : Emin= 0 eV Emax= 100 TeV

### mu+

Ionisation

hIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 StepFunction=(0.2, 0.1 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== Bragg : Emin= 0 eV Emax= 2 MeV

BetheBloch : Emin= 2 MeV Emax= 100 TeV CSDA range table up to 1 GeV in 49 bins

Coulomb scattering. Simulation of elastic scattering

events individually. May be used in combination with multiple scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 SubType=1 BuildTable=1

Lambda table from threshold to 100 TeV, 7 bins/decade, spline: 1 ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 0 eV Emax= 100 TeV

Muon multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May be combined with Coulomb scattering in a 'mixed' scattering algorithm.

msc: SubType= 10

RangeFactor= 0.2, stepLimType: 0, latDisp: 0, polarAngLim(deg)= 180

===== EM models for the G4Region DefaultRegionForTheWorld ====== WentzelVIUni : Emin= 0 eV Emax= 100 TeV Nbins=84 100 eV - 100 TeV

Muon bremsstrahlung muBrems: SubType=3

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== MuBrem : Emin= 0 eV Emax= 100 TeV

Pair production muPairProd: SubType=4

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 Sampling table 21x1001; from 1 GeV to 100 TeV

===== EM models for the G4Region DefaultRegionForTheWorld ====== muPairProd : Emin= 0 eV Emax= 100 TeV

### mu-

Muon ionisation muIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 StepFunction=(0.2, 0.1 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== Bragg : Emin= 0 eV Emax= 200 keV

BetheBloch : Emin= 200 keV Emax= 1 GeV MuBetheBloch : Emin= 1 GeV Emax= 100 TeV

CSDA range table up to 1 GeV in 49 bins

Coulomb scattering. Simulation of elastic scattering

events individually. May be used in combination with multiple scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 SubType=1 BuildTable=1

Lambda table from threshold to 100 TeV, 7 bins/decade, spline: 1 ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 0 eV Emax= 100 TeV

Muon multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May be combined with Coulomb scattering in a 'mixed' scattering algorithm.

msc: SubType= 10

RangeFactor= 0.2, stepLimType: 0, latDisp: 0, polarAngLim(deg)= 180

===== EM models for the G4Region DefaultRegionForTheWorld ====== WentzelVIUni : Emin= 0 eV Emax= 100 TeV Nbins=84 100 eV - 100 TeV

Muon bremsstrahlung muBrems: SubType=3

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dE/dx and range tables from 100 eV to 100 TeV in 84 bins

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Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== MuBrem : Emin= 0 eV Emax= 100 TeV

Pair production muPairProd: SubType=4

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 Sampling table 21x1001; from 1 GeV to 100 TeV

===== EM models for the G4Region DefaultRegionForTheWorld ====== muPairProd : Emin= 0 eV Emax= 100 TeV

Muon ionisation muIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 84 bins

Lambda tables from threshold to 100 TeV, 7 bins/decade, spline: 1 StepFunction=(0.2, 0.1 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== ICRU73QO : Emin= 0 eV Emax= 200 keV

BetheBloch : Emin= 200 keV Emax= 1 GeV MuBetheBloch : Emin= 1 GeV Emax= 100 TeV

CSDA range table up to 1 GeV in 49 bins

## emstandard\_opt3

### gamma

Photoelectric effect

phot: SubType=12 BuildTable=0

LambdaPrime table from 200 keV to 100 TeV in 174 bins

===== EM models for the G4Region DefaultRegionForTheWorld ====== LivermorePhElectric : Emin= 0 eV Emax= 100 TeV SauterGavrila Fluo

Compton scattering

compt: SubType=13 BuildTable=1

Lambda table from 10 eV to 1 MeV, 20 bins/decade, spline: 1 LambdaPrime table from 1 MeV to 100 TeV in 160 bins

===== EM models for the G4Region DefaultRegionForTheWorld ====== KleinNishina : Emin= 0 eV Emax= 100 TeV Fluo

Gamma conversion

conv: SubType=14 BuildTable=1

Lambda table from 1.022 MeV to 100 TeV, 20 bins/decade, spline: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== BetheHeitlerLPM : Emin= 0 eV Emax= 100 TeV ModifiedTsai

Rayleigh scattering

Rayl: SubType=11 BuildTable=1

Lambda table from 10 eV to 100 keV, 20 bins/decade, spline: 0 LambdaPrime table from 100 keV to 100 TeV in 180 bins

===== EM models for the G4Region DefaultRegionForTheWorld ======

LivermoreRayleigh : Emin= 0 eV Emax= 100 TeV CullenGenerator

### e-

Multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May be combined with Coulomb scattering in a 'mixed' scattering algorithm.

msc: SubType= 10

RangeFactor= 0.04, stepLimType: 3, latDisp: 1, skin= 1, geomFactor= 2.5

===== EM models for the G4Region DefaultRegionForTheWorld ======

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UrbanMsc : Emin= 0 eV Emax= 100 TeV Nbins=240 100 eV - 100 TeV

Pair production ePairProd: SubType=4

dE/dx and range tables from 10 eV to 100 TeV in 260 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 Sampling table 25x1001; from 0.1 GeV to 100 TeV

===== EM models for the G4Region DefaultRegionForTheWorld ====== ePairProd : Emin= 0 eV Emax= 100 TeV

Ionisation

eIoni: SubType=2

dE/dx and range tables from 10 eV to 100 TeV in 260 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 StepFunction=(0.2, 0.1 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== MollerBhabha : Emin= 0 eV Emax= 100 TeV deltaVI

CSDA range table up to 1 GeV in 160 bins

Bremsstrahlung eBrem: SubType=3

dE/dx and range tables from 10 eV to 100 TeV in 260 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 LPM flag: 1 for E > 1 GeV, VertexHighEnergyTh(GeV)= 100000

===== EM models for the G4Region DefaultRegionForTheWorld ====== eBremSB : Emin= 0 eV Emax= 1 GeV AngularGen2BS

eBremLPM : Emin= 1 GeV Emax= 100 TeV AngularGen2BS

### e+

Positron annihilation

annihil: integral:1 SubType=5 BuildTable=0

===== EM models for the G4Region DefaultRegionForTheWorld ====== eplus2gg : Emin= 0 eV Emax= 100 TeV

Multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May be combined with Coulomb scattering in a 'mixed' scattering algorithm.

msc: SubType= 10

RangeFactor= 0.04, stepLimType: 3, latDisp: 1, skin= 1, geomFactor= 2.5

===== EM models for the G4Region DefaultRegionForTheWorld ====== UrbanMsc : Emin= 0 eV Emax= 100 TeV Nbins=240 100 eV - 100 TeV

Pair production ePairProd: SubType=4

dE/dx and range tables from 10 eV to 100 TeV in 260 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 Sampling table 25x1001; from 0.1 GeV to 100 TeV

===== EM models for the G4Region DefaultRegionForTheWorld ====== ePairProd : Emin= 0 eV Emax= 100 TeV

Ionisation

eIoni: SubType=2

dE/dx and range tables from 10 eV to 100 TeV in 260 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 StepFunction=(0.2, 0.1 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== MollerBhabha : Emin= 0 eV Emax= 100 TeV deltaVI

CSDA range table up to 1 GeV in 160 bins

Bremsstrahlung eBrem: SubType=3

dE/dx and range tables from 10 eV to 100 TeV in 260 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 LPM flag: 1 for E > 1 GeV, VertexHighEnergyTh(GeV)= 100000

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### proton

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===== EM models for the G4Region DefaultRegionForTheWorld ====== eBremSB : Emin= 0 eV Emax= 1 GeV AngularGen2BS

eBremLPM : Emin= 1 GeV Emax= 100 TeV AngularGen2BS

Nuclear stopping

nuclearStopping: SubType=8 BuildTable=0

===== EM models for the G4Region DefaultRegionForTheWorld ====== ICRU49NucStopping : Emin= 0 eV Emax= 1 MeV

Hadron multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May

be combined with Coulomb scattering in a 'mixed' scattering algorithm. msc: SubType= 10

RangeFactor= 0.2, stepLimType: 0, latDisp: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== UrbanMsc : Emin= 0 eV Emax= 100 TeV Nbins=240 100 eV - 100 TeV

Hadron bremsstrahlung hBrems: SubType=3

dE/dx and range tables from 10 eV to 100 TeV in 260 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== hBrem : Emin= 0 eV Emax= 100 TeV

Hadron pair production hPairProd: SubType=4

dE/dx and range tables from 10 eV to 100 TeV in 260 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 Sampling table 17x1001; from 7.50618 GeV to 100 TeV

===== EM models for the G4Region DefaultRegionForTheWorld ====== hPairProd : Emin= 0 eV Emax= 100 TeV

### mu+

Ionisation

hIoni: SubType=2

dE/dx and range tables from 10 eV to 100 TeV in 260 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 StepFunction=(0.2, 0.05 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== Bragg : Emin= 0 eV Emax= 2 MeV deltaVI

BetheBloch : Emin= 2 MeV Emax= 100 TeV deltaVI CSDA range table up to 1 GeV in 160 bins

Muon multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May be combined with Coulomb scattering in a 'mixed' scattering algorithm.

msc: SubType= 10

RangeFactor= 0.2, stepLimType: 0, latDisp: 1, polarAngLim(deg)= 180

===== EM models for the G4Region DefaultRegionForTheWorld ====== UrbanMsc : Emin= 0 eV Emax= 100 TeV Nbins=240 100 eV - 100 TeV

Muon bremsstrahlung muBrems: SubType=3

dE/dx and range tables from 10 eV to 100 TeV in 260 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== MuBrem : Emin= 0 eV Emax= 100 TeV

Pair production muPairProd: SubType=4

dE/dx and range tables from 10 eV to 100 TeV in 260 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1

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### 3.14. Tables by constructor 41

Sampling table 21x1001; from 1 GeV to 100 TeV

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===== EM models for the G4Region DefaultRegionForTheWorld ====== muPairProd : Emin= 0 eV Emax= 100 TeV

### mu-

Muon ionisation muIoni: SubType=2

dE/dx and range tables from 10 eV to 100 TeV in 260 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 StepFunction=(0.2, 0.05 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== Bragg : Emin= 0 eV Emax= 200 keV deltaVI

BetheBloch : Emin= 200 keV Emax= 1 GeV deltaVI MuBetheBloch : Emin= 1 GeV Emax= 100 TeV

CSDA range table up to 1 GeV in 160 bins

Muon multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May be combined with Coulomb scattering in a 'mixed' scattering algorithm.

msc: SubType= 10

RangeFactor= 0.2, stepLimType: 0, latDisp: 1, polarAngLim(deg)= 180

===== EM models for the G4Region DefaultRegionForTheWorld ====== UrbanMsc : Emin= 0 eV Emax= 100 TeV Nbins=240 100 eV - 100 TeV

Muon bremsstrahlung muBrems: SubType=3

dE/dx and range tables from 10 eV to 100 TeV in 260 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== MuBrem : Emin= 0 eV Emax= 100 TeV

Pair production muPairProd: SubType=4

dE/dx and range tables from 10 eV to 100 TeV in 260 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 Sampling table 21x1001; from 1 GeV to 100 TeV

===== EM models for the G4Region DefaultRegionForTheWorld ====== muPairProd : Emin= 0 eV Emax= 100 TeV

Muon ionisation muIoni: SubType=2

dE/dx and range tables from 10 eV to 100 TeV in 260 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 StepFunction=(0.2, 0.05 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== ICRU73QO : Emin= 0 eV Emax= 200 keV deltaVI

BetheBloch : Emin= 200 keV Emax= 1 GeV deltaVI MuBetheBloch : Emin= 1 GeV Emax= 100 TeV

CSDA range table up to 1 GeV in 160 bins

## emstandard\_opt4

### gamma

Photoelectric effect

phot: SubType=12 BuildTable=0

LambdaPrime table from 200 keV to 100 TeV in 174 bins

===== EM models for the G4Region DefaultRegionForTheWorld ====== LivermorePhElectric : Emin= 0 eV Emax= 100 TeV SauterGavrila Fluo

Compton scattering

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compt: SubType=13 BuildTable=1

Lambda table from 100 eV to 1 MeV, 20 bins/decade, spline: 1 LambdaPrime table from 1 MeV to 100 TeV in 160 bins

===== EM models for the G4Region DefaultRegionForTheWorld ====== LowEPComptonModel : Emin= 0 eV Emax= 20 MeV Fluo

KleinNishina : Emin= 20 MeV Emax= 100 TeV Fluo

Gamma conversion

conv: SubType=14 BuildTable=1

Lambda table from 1.022 MeV to 100 TeV, 20 bins/decade, spline: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== BetheHeitler5D : Emin= 0 eV Emax= 100 TeV ModifiedTsai

Rayleigh scattering

Rayl: SubType=11 BuildTable=1

Lambda table from 100 eV to 100 keV, 20 bins/decade, spline: 0 LambdaPrime table from 100 keV to 100 TeV in 180 bins

===== EM models for the G4Region DefaultRegionForTheWorld ======

LivermoreRayleigh : Emin= 0 eV Emax= 100 TeV CullenGenerator

### e-

Coulomb scattering. Simulation of elastic scattering

events individually. May be used in combination with multiple scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 SubType=1 BuildTable=1

Lambda table from 100 MeV to 100 TeV, 20 bins/decade, spline: 1 ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 100 MeV Emax= 100 TeV

Multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May be combined with Coulomb scattering in a 'mixed' scattering algorithm.

msc: SubType= 10

RangeFactor= 0.08, stepLimType: 2, latDisp: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== GoudsmitSaunderson : Emin= 0 eV Emax= 100 MeV Nbins=120 100 eV - 100 MeV

WentzelVIUni : Emin= 100 MeV Emax= 100 TeV Nbins=120 100 MeV - 100 TeV

Pair production ePairProd: SubType=4

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 Sampling table 25x1001; from 0.1 GeV to 100 TeV

===== EM models for the G4Region DefaultRegionForTheWorld ====== ePairProd : Emin= 0 eV Emax= 100 TeV

Ionisation

eIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 StepFunction=(0.2, 0.01 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== LowEnergyIoni : Emin= 0 eV Emax= 100 keV deltaVI

MollerBhabha : Emin= 100 keV Emax= 100 TeV deltaVI CSDA range table up to 1 GeV in 140 bins

Bremsstrahlung eBrem: SubType=3

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 LPM flag: 1 for E > 1 GeV, VertexHighEnergyTh(GeV)= 100000

===== EM models for the G4Region DefaultRegionForTheWorld ======

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eBremSB : Emin= 0 eV Emax= 1 GeV AngularGen2BS eBremLPM : Emin= 1 GeV Emax= 100 TeV AngularGen2BS

### e+

Coulomb scattering. Simulation of elastic scattering

events individually. May be used in combination with multiple

scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 SubType=1 BuildTable=1

Lambda table from 100 MeV to 100 TeV, 20 bins/decade, spline: 1 ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 100 MeV Emax= 100 TeV

Positron annihilation

annihil: integral:1 SubType=5 BuildTable=0

===== EM models for the G4Region DefaultRegionForTheWorld ====== eplus2gg : Emin= 0 eV Emax= 100 TeV

Multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May be combined with Coulomb scattering in a 'mixed' scattering algorithm.

msc: SubType= 10

RangeFactor= 0.08, stepLimType: 2, latDisp: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== GoudsmitSaunderson : Emin= 0 eV Emax= 100 MeV Nbins=120 100 eV - 100 MeV

WentzelVIUni : Emin= 100 MeV Emax= 100 TeV Nbins=120 100 MeV - 100 TeV

Pair production ePairProd: SubType=4

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 Sampling table 25x1001; from 0.1 GeV to 100 TeV

===== EM models for the G4Region DefaultRegionForTheWorld ====== ePairProd : Emin= 0 eV Emax= 100 TeV

Ionisation

eIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 StepFunction=(0.2, 0.01 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== PenIoni : Emin= 0 eV Emax= 100 keV

MollerBhabha : Emin= 100 keV Emax= 100 TeV deltaVI CSDA range table up to 1 GeV in 140 bins

Bremsstrahlung eBrem: SubType=3

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 LPM flag: 1 for E > 1 GeV, VertexHighEnergyTh(GeV)= 100000

===== EM models for the G4Region DefaultRegionForTheWorld ====== eBremSB : Emin= 0 eV Emax= 1 GeV AngularGen2BS

eBremLPM : Emin= 1 GeV Emax= 100 TeV AngularGen2BS

### proton

Coulomb scattering. Simulation of elastic scattering

events individually. May be used in combination with multiple scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 SubType=1 BuildTable=1

Lambda table from threshold to 100 TeV, 20 bins/decade, spline: 1 ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

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===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 0 eV Emax= 100 TeV

Hadron multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May

be combined with Coulomb scattering in a 'mixed' scattering algorithm. msc: SubType= 10

RangeFactor= 0.2, stepLimType: 0, latDisp: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== WentzelVIUni : Emin= 0 eV Emax= 100 TeV Nbins=240 100 eV - 100 TeV

Hadron bremsstrahlung hBrems: SubType=3

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== hBrem : Emin= 0 eV Emax= 100 TeV

Hadron pair production hPairProd: SubType=4

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 Sampling table 17x1001; from 7.50618 GeV to 100 TeV

===== EM models for the G4Region DefaultRegionForTheWorld ====== hPairProd : Emin= 0 eV Emax= 100 TeV

### mu+

Ionisation

hIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 StepFunction=(0.1, 0.02 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== Bragg : Emin= 0 eV Emax= 2 MeV deltaVI

BetheBloch : Emin= 2 MeV Emax= 100 TeV deltaVI CSDA range table up to 1 GeV in 140 bins

Coulomb scattering. Simulation of elastic scattering

events individually. May be used in combination with multiple scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 SubType=1 BuildTable=1

Lambda table from threshold to 100 TeV, 20 bins/decade, spline: 1 ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 0 eV Emax= 100 TeV

Muon multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May be combined with Coulomb scattering in a 'mixed' scattering algorithm.

msc: SubType= 10

RangeFactor= 0.2, stepLimType: 0, latDisp: 1, polarAngLim(deg)= 180

===== EM models for the G4Region DefaultRegionForTheWorld ====== WentzelVIUni : Emin= 0 eV Emax= 100 TeV Nbins=240 100 eV - 100 TeV

Muon bremsstrahlung muBrems: SubType=3

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== MuBrem : Emin= 0 eV Emax= 100 TeV

Pair production muPairProd: SubType=4

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dE/dx and range tables from 100 eV to 100 TeV in 240 bins

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Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 Sampling table 21x1001; from 1 GeV to 100 TeV

===== EM models for the G4Region DefaultRegionForTheWorld ====== muPairProd : Emin= 0 eV Emax= 100 TeV

### mu-

Muon ionisation muIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 StepFunction=(0.1, 0.02 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== Bragg : Emin= 0 eV Emax= 200 keV deltaVI

BetheBloch : Emin= 200 keV Emax= 1 GeV deltaVI MuBetheBloch : Emin= 1 GeV Emax= 100 TeV

CSDA range table up to 1 GeV in 140 bins

Coulomb scattering. Simulation of elastic scattering

events individually. May be used in combination with multiple scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 SubType=1 BuildTable=1

Lambda table from threshold to 100 TeV, 20 bins/decade, spline: 1 ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 0 eV Emax= 100 TeV

Muon multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May be combined with Coulomb scattering in a 'mixed' scattering algorithm.

msc: SubType= 10

RangeFactor= 0.2, stepLimType: 0, latDisp: 1, polarAngLim(deg)= 180

===== EM models for the G4Region DefaultRegionForTheWorld ====== WentzelVIUni : Emin= 0 eV Emax= 100 TeV Nbins=240 100 eV - 100 TeV

Muon bremsstrahlung muBrems: SubType=3

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== MuBrem : Emin= 0 eV Emax= 100 TeV

Pair production muPairProd: SubType=4

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 Sampling table 21x1001; from 1 GeV to 100 TeV

===== EM models for the G4Region DefaultRegionForTheWorld ====== muPairProd : Emin= 0 eV Emax= 100 TeV

Muon ionisation muIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 StepFunction=(0.1, 0.02 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== ICRU73QO : Emin= 0 eV Emax= 200 keV deltaVI

BetheBloch : Emin= 200 keV Emax= 1 GeV deltaVI MuBetheBloch : Emin= 1 GeV Emax= 100 TeV

CSDA range table up to 1 GeV in 140 bins

## Livermore

### gamma

Photoelectric effect

phot: SubType=12 BuildTable=0

LambdaPrime table from 200 keV to 100 TeV in 174 bins

===== EM models for the G4Region DefaultRegionForTheWorld ====== LivermorePhElectric : Emin= 0 eV Emax= 100 TeV SauterGavrila Fluo

Compton scattering

compt: SubType=13 BuildTable=1

Lambda table from 100 eV to 1 MeV, 20 bins/decade, spline: 1 LambdaPrime table from 1 MeV to 100 TeV in 160 bins

===== EM models for the G4Region DefaultRegionForTheWorld ====== LivermoreCompton : Emin= 0 eV Emax= 1 GeV Fluo

KleinNishina : Emin= 1 GeV Emax= 100 TeV Fluo

Gamma conversion

conv: SubType=14 BuildTable=1

Lambda table from 1.022 MeV to 100 TeV, 20 bins/decade, spline: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== BetheHeitler5D : Emin= 0 eV Emax= 100 TeV ModifiedTsai

Rayleigh scattering

Rayl: SubType=11 BuildTable=1

Lambda table from 100 eV to 100 keV, 20 bins/decade, spline: 0 LambdaPrime table from 100 keV to 100 TeV in 180 bins

===== EM models for the G4Region DefaultRegionForTheWorld ======

LivermoreRayleigh : Emin= 0 eV Emax= 100 TeV CullenGenerator

### e-

Coulomb scattering. Simulation of elastic scattering

events individually. May be used in combination with multiple scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 SubType=1 BuildTable=1

Lambda table from 100 MeV to 100 TeV, 20 bins/decade, spline: 1 ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 100 MeV Emax= 100 TeV

Multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May be combined with Coulomb scattering in a 'mixed' scattering algorithm.

msc: SubType= 10

RangeFactor= 0.08, stepLimType: 2, latDisp: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== GoudsmitSaunderson : Emin= 0 eV Emax= 100 MeV Nbins=120 100 eV - 100 MeV

WentzelVIUni : Emin= 100 MeV Emax= 100 TeV Nbins=120 100 MeV - 100 TeV

Pair production ePairProd: SubType=4

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 Sampling table 25x1001; from 0.1 GeV to 100 TeV

===== EM models for the G4Region DefaultRegionForTheWorld ====== ePairProd : Emin= 0 eV Emax= 100 TeV

Ionisation

eIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 StepFunction=(0.2, 0.01 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ======

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LowEnergyIoni : Emin= 0 eV Emax= 100 keV deltaVI MollerBhabha : Emin= 100 keV Emax= 100 TeV deltaVI

CSDA range table up to 1 GeV in 140 bins

Bremsstrahlung eBrem: SubType=3

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 LPM flag: 1 for E > 1 GeV, VertexHighEnergyTh(GeV)= 100000

===== EM models for the G4Region DefaultRegionForTheWorld ====== eBremSB : Emin= 0 eV Emax= 1 GeV AngularGen2BS

eBremLPM : Emin= 1 GeV Emax= 100 TeV AngularGen2BS

### e+

Coulomb scattering. Simulation of elastic scattering

events individually. May be used in combination with multiple scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 SubType=1 BuildTable=1

Lambda table from 100 MeV to 100 TeV, 20 bins/decade, spline: 1 ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 100 MeV Emax= 100 TeV

Positron annihilation

annihil: integral:1 SubType=5 BuildTable=0

===== EM models for the G4Region DefaultRegionForTheWorld ====== eplus2gg : Emin= 0 eV Emax= 100 TeV

Multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May be combined with Coulomb scattering in a 'mixed' scattering algorithm.

msc: SubType= 10

RangeFactor= 0.08, stepLimType: 2, latDisp: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== GoudsmitSaunderson : Emin= 0 eV Emax= 100 MeV Nbins=120 100 eV - 100 MeV

WentzelVIUni : Emin= 100 MeV Emax= 100 TeV Nbins=120 100 MeV - 100 TeV

Pair production ePairProd: SubType=4

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 Sampling table 25x1001; from 0.1 GeV to 100 TeV

===== EM models for the G4Region DefaultRegionForTheWorld ====== ePairProd : Emin= 0 eV Emax= 100 TeV

Ionisation

eIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 StepFunction=(0.2, 0.01 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== MollerBhabha : Emin= 0 eV Emax= 100 TeV deltaVI

CSDA range table up to 1 GeV in 140 bins

Bremsstrahlung eBrem: SubType=3

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 LPM flag: 1 for E > 1 GeV, VertexHighEnergyTh(GeV)= 100000

===== EM models for the G4Region DefaultRegionForTheWorld ====== eBremSB : Emin= 0 eV Emax= 1 GeV AngularGen2BS

eBremLPM : Emin= 1 GeV Emax= 100 TeV AngularGen2BS

### proton

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Coulomb scattering. Simulation of elastic scattering

events individually. May be used in combination with multiple scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 SubType=1 BuildTable=1

Lambda table from threshold to 100 TeV, 20 bins/decade, spline: 1 ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 0 eV Emax= 100 TeV

Hadron multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May

be combined with Coulomb scattering in a 'mixed' scattering algorithm. msc: SubType= 10

RangeFactor= 0.2, stepLimType: 0, latDisp: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== WentzelVIUni : Emin= 0 eV Emax= 100 TeV Nbins=240 100 eV - 100 TeV

Hadron bremsstrahlung hBrems: SubType=3

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== hBrem : Emin= 0 eV Emax= 100 TeV

Hadron pair production hPairProd: SubType=4

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 Sampling table 17x1001; from 7.50618 GeV to 100 TeV

===== EM models for the G4Region DefaultRegionForTheWorld ====== hPairProd : Emin= 0 eV Emax= 100 TeV

### mu+

Ionisation

hIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 StepFunction=(0.2, 0.05 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== Bragg : Emin= 0 eV Emax= 2 MeV deltaVI

BetheBloch : Emin= 2 MeV Emax= 100 TeV deltaVI CSDA range table up to 1 GeV in 140 bins

Coulomb scattering. Simulation of elastic scattering

events individually. May be used in combination with multiple scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 SubType=1 BuildTable=1

Lambda table from threshold to 100 TeV, 20 bins/decade, spline: 1 ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 0 eV Emax= 100 TeV

Muon multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May be combined with Coulomb scattering in a 'mixed' scattering algorithm.

msc: SubType= 10

RangeFactor= 0.2, stepLimType: 0, latDisp: 1, polarAngLim(deg)= 180

===== EM models for the G4Region DefaultRegionForTheWorld ====== WentzelVIUni : Emin= 0 eV Emax= 100 TeV Nbins=240 100 eV - 100 TeV

Muon bremsstrahlung muBrems: SubType=3

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

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Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== MuBrem : Emin= 0 eV Emax= 100 TeV

Pair production muPairProd: SubType=4

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 Sampling table 21x1001; from 1 GeV to 100 TeV

===== EM models for the G4Region DefaultRegionForTheWorld ====== muPairProd : Emin= 0 eV Emax= 100 TeV

### mu-

Muon ionisation muIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 StepFunction=(0.2, 0.05 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== Bragg : Emin= 0 eV Emax= 200 keV deltaVI

BetheBloch : Emin= 200 keV Emax= 1 GeV deltaVI MuBetheBloch : Emin= 1 GeV Emax= 100 TeV

CSDA range table up to 1 GeV in 140 bins

Coulomb scattering. Simulation of elastic scattering

events individually. May be used in combination with multiple scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 SubType=1 BuildTable=1

Lambda table from threshold to 100 TeV, 20 bins/decade, spline: 1 ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 0 eV Emax= 100 TeV

Muon multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May be combined with Coulomb scattering in a 'mixed' scattering algorithm.

msc: SubType= 10

RangeFactor= 0.2, stepLimType: 0, latDisp: 1, polarAngLim(deg)= 180

===== EM models for the G4Region DefaultRegionForTheWorld ====== WentzelVIUni : Emin= 0 eV Emax= 100 TeV Nbins=240 100 eV - 100 TeV

Muon bremsstrahlung muBrems: SubType=3

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== MuBrem : Emin= 0 eV Emax= 100 TeV

Pair production muPairProd: SubType=4

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 Sampling table 21x1001; from 1 GeV to 100 TeV

===== EM models for the G4Region DefaultRegionForTheWorld ====== muPairProd : Emin= 0 eV Emax= 100 TeV

Muon ionisation muIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 StepFunction=(0.2, 0.05 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ======

ICRU73QO : Emin= 0 eV Emax= 200 keV deltaVI

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BetheBloch : Emin= 200 keV Emax= 1 GeV deltaVI MuBetheBloch : Emin= 1 GeV Emax= 100 TeV

CSDA range table up to 1 GeV in 140 bins

## Penelope

### gamma

Photoelectric effect

phot: SubType=12 BuildTable=0

LambdaPrime table from 200 keV to 100 TeV in 174 bins

===== EM models for the G4Region DefaultRegionForTheWorld ====== PenPhotoElec : Emin= 0 eV Emax= 1 GeV Fluo

PhotoElectric : Emin= 1 GeV Emax= 100 TeV SauterGavrila Fluo

Compton scattering

compt: SubType=13 BuildTable=1

Lambda table from 100 eV to 1 MeV, 20 bins/decade, spline: 1 LambdaPrime table from 1 MeV to 100 TeV in 160 bins

===== EM models for the G4Region DefaultRegionForTheWorld ====== PenCompton : Emin= 0 eV Emax= 1 GeV Fluo

KleinNishina : Emin= 1 GeV Emax= 100 TeV Fluo

Gamma conversion

conv: SubType=14 BuildTable=1

Lambda table from 1.022 MeV to 100 TeV, 20 bins/decade, spline: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== PenConversion : Emin= 0 eV Emax= 1 GeV

BetheHeitlerLPM : Emin= 1 GeV Emax= 100 TeV ModifiedTsai

Rayleigh scattering

Rayl: SubType=11 BuildTable=1

Lambda table from 100 eV to 100 keV, 20 bins/decade, spline: 0 LambdaPrime table from 100 keV to 100 TeV in 180 bins

===== EM models for the G4Region DefaultRegionForTheWorld ======

PenRayleigh : Emin= 0 eV Emax= 100 GeV

### e-

Coulomb scattering. Simulation of elastic scattering

events individually. May be used in combination with multiple scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 SubType=1 BuildTable=1

Lambda table from 100 MeV to 100 TeV, 20 bins/decade, spline: 1 ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 100 MeV Emax= 100 TeV

Multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May be combined with Coulomb scattering in a 'mixed' scattering algorithm.

msc: SubType= 10

RangeFactor= 0.08, stepLimType: 2, latDisp: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== GoudsmitSaunderson : Emin= 0 eV Emax= 100 MeV Nbins=120 100 eV - 100 MeV

WentzelVIUni : Emin= 100 MeV Emax= 100 TeV Nbins=120 100 MeV - 100 TeV

Pair production ePairProd: SubType=4

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1

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Sampling table 25x1001; from 0.1 GeV to 100 TeV

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===== EM models for the G4Region DefaultRegionForTheWorld ====== ePairProd : Emin= 0 eV Emax= 100 TeV

Ionisation

eIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 StepFunction=(0.2, 0.01 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== PenIoni : Emin= 0 eV Emax= 1 GeV

MollerBhabha : Emin= 1 GeV Emax= 100 TeV CSDA range table up to 1 GeV in 140 bins

Bremsstrahlung eBrem: SubType=3

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 LPM flag: 1 for E > 1 GeV, VertexHighEnergyTh(GeV)= 100000

===== EM models for the G4Region DefaultRegionForTheWorld ======

PenBrem : Emin= 0 eV Emax= 1 GeV

eBremLPM : Emin= 1 GeV Emax= 100 TeV ModifiedTsai

### e+

Coulomb scattering. Simulation of elastic scattering

events individually. May be used in combination with multiple scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 SubType=1 BuildTable=1

Lambda table from 100 MeV to 100 TeV, 20 bins/decade, spline: 1 ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 100 MeV Emax= 100 TeV

Positron annihilation

annihil: integral:1 SubType=5 BuildTable=0

===== EM models for the G4Region DefaultRegionForTheWorld ======

PenAnnih : Emin= 0 eV Emax= 1 GeV eplus2gg : Emin= 1 GeV Emax= 100 TeV

Multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May be combined with Coulomb scattering in a 'mixed' scattering algorithm.

msc: SubType= 10

RangeFactor= 0.08, stepLimType: 2, latDisp: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== GoudsmitSaunderson : Emin= 0 eV Emax= 100 MeV Nbins=120 100 eV - 100 MeV

WentzelVIUni : Emin= 100 MeV Emax= 100 TeV Nbins=120 100 MeV - 100 TeV

Pair production ePairProd: SubType=4

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 Sampling table 25x1001; from 0.1 GeV to 100 TeV

===== EM models for the G4Region DefaultRegionForTheWorld ====== ePairProd : Emin= 0 eV Emax= 100 TeV

Ionisation

eIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 StepFunction=(0.2, 0.01 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ======

PenIoni : Emin= 0 eV Emax= 1 GeV

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MollerBhabha : Emin= 1 GeV Emax= 100 TeV CSDA range table up to 1 GeV in 140 bins

Bremsstrahlung eBrem: SubType=3

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 LPM flag: 1 for E > 1 GeV, VertexHighEnergyTh(GeV)= 100000

===== EM models for the G4Region DefaultRegionForTheWorld ======

PenBrem : Emin= 0 eV Emax= 1 GeV

eBremLPM : Emin= 1 GeV Emax= 100 TeV ModifiedTsai

### proton

Coulomb scattering. Simulation of elastic scattering

events individually. May be used in combination with multiple scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 SubType=1 BuildTable=1

Lambda table from threshold to 100 TeV, 20 bins/decade, spline: 1 ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 0 eV Emax= 100 TeV

Hadron multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May

be combined with Coulomb scattering in a 'mixed' scattering algorithm. msc: SubType= 10

RangeFactor= 0.2, stepLimType: 0, latDisp: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== WentzelVIUni : Emin= 0 eV Emax= 100 TeV Nbins=240 100 eV - 100 TeV

Hadron bremsstrahlung hBrems: SubType=3

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== hBrem : Emin= 0 eV Emax= 100 TeV

Hadron pair production hPairProd: SubType=4

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 Sampling table 17x1001; from 7.50618 GeV to 100 TeV

===== EM models for the G4Region DefaultRegionForTheWorld ====== hPairProd : Emin= 0 eV Emax= 100 TeV

### mu+

Ionisation

hIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 StepFunction=(0.2, 0.05 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== Bragg : Emin= 0 eV Emax= 2 MeV

BetheBloch : Emin= 2 MeV Emax= 100 TeV CSDA range table up to 1 GeV in 140 bins

Coulomb scattering. Simulation of elastic scattering

events individually. May be used in combination with multiple scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 SubType=1 BuildTable=1

Lambda table from threshold to 100 TeV, 20 bins/decade, spline: 1

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### 3.14. Tables by constructor 53

ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

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===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 0 eV Emax= 100 TeV

Muon multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May be combined with Coulomb scattering in a 'mixed' scattering algorithm.

msc: SubType= 10

RangeFactor= 0.2, stepLimType: 0, latDisp: 1, polarAngLim(deg)= 180

===== EM models for the G4Region DefaultRegionForTheWorld ====== WentzelVIUni : Emin= 0 eV Emax= 100 TeV Nbins=240 100 eV - 100 TeV

Muon bremsstrahlung muBrems: SubType=3

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1

===== EM models for the G4Region DefaultRegionForTheWorld ====== MuBrem : Emin= 0 eV Emax= 100 TeV

Pair production muPairProd: SubType=4

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 Sampling table 21x1001; from 1 GeV to 100 TeV

===== EM models for the G4Region DefaultRegionForTheWorld ====== muPairProd : Emin= 0 eV Emax= 100 TeV

### mu-

Muon ionisation muIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 StepFunction=(0.2, 0.05 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== Bragg : Emin= 0 eV Emax= 200 keV

BetheBloch : Emin= 200 keV Emax= 1 GeV MuBetheBloch : Emin= 1 GeV Emax= 100 TeV

CSDA range table up to 1 GeV in 140 bins

Coulomb scattering. Simulation of elastic scattering

events individually. May be used in combination with multiple scattering, where Coulomb scattering is used for hard (large angle) collisions and multiple scattering for soft collisions.

CoulombScat: integral:1 SubType=1 BuildTable=1

Lambda table from threshold to 100 TeV, 20 bins/decade, spline: 1 ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531

===== EM models for the G4Region DefaultRegionForTheWorld ====== eCoulombScattering : Emin= 0 eV Emax= 100 TeV

Muon multiple scattering. Simulates combined effects of elastic scattering at the end of the step, to save computing time. May be combined with Coulomb scattering in a 'mixed' scattering algorithm.

msc: SubType= 10

RangeFactor= 0.2, stepLimType: 0, latDisp: 1, polarAngLim(deg)= 180

===== EM models for the G4Region DefaultRegionForTheWorld ====== WentzelVIUni : Emin= 0 eV Emax= 100 TeV Nbins=240 100 eV - 100 TeV

Muon bremsstrahlung muBrems: SubType=3

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1

===== EM models for the G4Region DefaultRegionForTheWorld ======

MuBrem : Emin= 0 eV Emax= 100 TeV

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Pair production muPairProd: SubType=4

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 Sampling table 21x1001; from 1 GeV to 100 TeV

===== EM models for the G4Region DefaultRegionForTheWorld ====== muPairProd : Emin= 0 eV Emax= 100 TeV

Muon ionisation muIoni: SubType=2

dE/dx and range tables from 100 eV to 100 TeV in 240 bins

Lambda tables from threshold to 100 TeV, 20 bins/decade, spline: 1 StepFunction=(0.2, 0.05 mm), integ: 1, fluct: 1, linLossLim= 0.01

===== EM models for the G4Region DefaultRegionForTheWorld ====== ICRU73QO : Emin= 0 eV Emax= 200 keV

BetheBloch : Emin= 200 keV Emax= 1 GeV MuBetheBloch : Emin= 1 GeV Emax= 100 TeV

CSDA range table up to 1 GeV in 140 bins

# Tables by particle

## Gamma

Table 3.1: Models used for gamma processes for different EM physics constructors.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| title | Rayleigh | Photoelectric | Compton | Gamma conversion |
| Opt0 | Livermor-  eRayleigh 0-100 TeV | LivermorePhElectric  0-100 TeV | KleinNishina 0-100 TeV | BetheHeitlerLPM 0-100  TeV |
| Opt1 | none | LivermorePhElectric  0-100 TeV | KleinNishina 0-100 TeV | BetheHeitlerLPM 0-100  TeV |
| Opt2 | none | PhotoElectric 0-100 TeV | KleinNishina 0-100 TeV | BetheHeitlerLPM 0-100  TeV |
| Opt3 | Livermor-  eRayleigh 0-100 TeV | LivermorePhElectric  0-100 TeV | KleinNishina 0-100 TeV | BetheHeitlerLPM 0-100  TeV |
| Opt4 | Livermor-  eRayleigh 0-100 TeV | LivermorePhElectric  0-100 TeV | LowEPComptonModel 0-20  MeV KleinNishina 20 MeV-100 TeV | BetheHeitler5D 0-100 TeV |
| Livermore | Livermor-  eRayleigh 0-100 TeV | LivermorePhElectric  0-100 TeV | LivermoreCompton 0-1 GeV  KleinNishina 1 GeV-100 TeV | BetheHeitler5D 0-100 TeV |
| Penelope | PenRayleigh  0-100 GeV | PenPhotoElec 0-1 GeV  PhotoElectric 1 GeV-100 TeV | PenCompton 0-1 GeV  KleinNishina 1 GeV-100 TeV | PenConversion 0-1 GeV  BetheHeitlerLPM 1 GeV-100 TeV |

## Electron

Table 3.2: Models used for electron processes for different EM physics constructors.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Coulomb  scattering | Multiple scattering | Pair  pro- duction | Ionisation | Bremsstrahlung |
| Opt0 | eCoulombScat-  tering 100 MeV-100 TeV | UrbanMsc 0-100 MeV  WentzelVIUni 100 MeV-100 TeV | none | MollerBhabha 0-100  TeV | eBremSB 0-1 GeV  eBremLPM 1 GeV-100 TeV |
| Opt1 | eCoulombScat-  tering 100 MeV-100 TeV | UrbanMsc 0-100 MeV;  WentzelVIUni 100 MeV-100 TeV | none | MollerBhabha 0-100  TeV | eBremSB 0-1 GeV  eBremLPM 1 GeV-100 TeV |
| Opt2 | eCoulombScat-  tering 100 MeV-100 TeV | UrbanMsc 0-100 MeV  WentzelVIUni 100 MeV-100 TeV | none | MollerBhabha 0-100  TeV | eBremSB 0-1 GeV  eBremLPM 1 GeV-100 TeV |
| Opt3 | none | UrbanMsc 0-100 TeV | ePair-  Prod 0-100  TeV | MollerBhabha 0-100  TeV | eBremSB 0-1 GeV  eBremLPM 1 GeV-100 TeV |
| Opt4 | eCoulombScat-  tering 100 MeV-10 TeV | GoudsmitSaunderson  0-100 MeV WentzelVIUni  100 MeV-100 TeV | ePair-  Prod 0-100  TeV | LowEnergyIoni 0-100  keV MollerBhabha 100 keV-100 TeV | eBremSB 0-1 GeV  eBremLPM 1 GeV-100 TeV |
| Livermore | eCoulombScat-  tering 100 MeV-100 TeV | GoudsmitSaunderson  0-100 MeV WentzelVIUni  100 MeV-100 TeV | ePair-  Prod 0-100  TeV | LowEnergyIoni 0-100  keV MollerBhabha 100 keV-100 TeV | eBremSB 0-1 GeV  eBremLPM 1 GeV-100 TeV |
| Penelope | eCoulombScat-  tering 100 MeV-100 TeV | GoudsmitSaunderson  0-100 MeV WentzelVIUni  100 MeV-100 TeV | ePair-  Prod 0-100  TeV | PenIoni 0-1 GeV  MollerBhabha 1 GeV-100 TeV | PenBrem 0-1 GeV  eBremLPM 1 GeV-100 TeV |

## Positron

Table 3.3: Models used for positron processes for different EM physics constructors.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Coulomb  scattering | Multiple scattering | Pair  pro- duc- tion | Ionisation | Annihilation | Bremsstrahlung |
| Opt0 | eCoulomb-  Scattering 100  MeV-100  TeV | UrbanMsc 0-100 MeV  WentzelVIUni 100 MeV-100 TeV | none | MollerBhabha  0-100 TeV | eplus2gg | eBremSB 0-1  GeV eBremLPM 1 GeV-100 TeV |
| 0-100 TeV |
|  |
|  |
| Opt1 | eCoulomb-  Scattering 100  MeV-100  TeV | UrbanMsc 0-100 MeV  WentzelVIUni 100 MeV-100 TeV | none | MollerBhabha  0-100 TeV | eplus2gg | eBremSB 0-1  GeV eBremLPM 1 GeV-100 TeV |
| 0-100 TeV |
|  |
|  |
| Opt2 | eCoulomb-  Scattering 100  MeV-100  TeV | UrbanMsc 0-100 MeV  WentzelVIUni 100 MeV-100 TeV | none | MollerBhabha  0-100 TeV | eplus2gg | eBremSB 0-1  GeV eBremLPM 1 GeV-100 TeV |
| 0-100 TeV |
|  |
|  |
| Opt3 | none | UrbanMsc 0-100 TeV | ePair-  Prod 0-100  TeV | MollerBhabha  0-100 TeV | eplus2gg  0-100 TeV | eBremSB 0-1  GeV eBremLPM 1 GeV-100 TeV |
| Opt4 | eCoulomb-  Scattering 100  MeV-100  TeV | GoudsmitSaunderson  0-100 MeV  WentzelVIUni 100 MeV-100 TeV | ePair- | PenIoni 0-100 | eplus2gg | eBremSB 0-1  GeV eBremLPM 1 GeV-100 TeV |
| Prod | keV | 0-100 TeV |
| 0-100 | MollerBhabha |  |
| TeV | 100 keV-100  TeV |  |
| Livermore | eCoulomb-  Scattering 100  MeV-100  TeV | GoudsmitSaunderson  0-100 MeV  WentzelVIUni 100 MeV-100 TeV | ePair- | MollerBhabha  0-100 TeV | eplus2gg | eBremSB 0-1  GeV eBremLPM 1 GeV-100 TeV |
| Prod | 0-100 TeV |
| 0-100 |  |
| TeV |  |
| Penelope | eCoulomb-  Scattering 100  MeV-100  TeV | GoudsmitSaunderson  0-100 MeV  WentzelVIUni 100 MeV-100 TeV | ePair- | PenIoni 0-1 GeV  MollerBhabha 1 GeV-100 TeV | PenAnnih 0-1  GeV eplus2gg 1 GeV-100  TeV | PenBrem 0-1  GeV eBremLPM 1 GeV-100 TeV |
| Prod |
| 0-100  TeV |

**CHAPTER**

# FOUR

**STATUS OF THIS DOCUMENT**

Guide describing Physics Lists and their possible application in more detail.

* + - * Rev 1.0: First sphinx version implemented for GEANT4 Release 10.4, 8th Dec 2017
      * Rev 2.0: Updates and fixes in documentatio for GEANT4 Release 10.4, 15th May 2018
      * Rev 3.0: GEANT4 Release 10.5, 11th December 2018
      * Rev 3.1: GEANT4 Updates and fixes - especially to search functionality, 5th March 2019
      * Rev 4.0: GEANT4 Release 10.6, 6th December 2019

**Guide For Physics Lists, Release 10.6**

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