



GEANT4
A SIMULATION TOOLKIT

Guide For Physics Lists

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Scope of this Manual

This guide is a description of the physics lists class which is one of the mandatory user classes for a GEANT4 application. For the most part the “reference” physic lists included in the source distribution are described here as well the modularity and electronic options. Some use cases and areas of application are also described.

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], 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]. In the beginning, the default GEANT4 Physics List was `QGSP_BERT` [eal09]. Since the GEANT4 release 10.0 the default Physics List becomes `FTFP_BERT` [eal16]. 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 applicable 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 neutron 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*
- FTFP_BERT_ATL
- FTFP_BERT_HP
- FTFP_BERT_TRV
- FTFP_INCLXX
- FTFQGSP_BERT
- FTF_BIC
- *QBBC*
- *QGSP_BERT*
- QGSP_BERT_HP
- *QGSP_BIC*
- QGSP_BIC_AllHP
- QGSP_BIC_HP
- QGSP_FTFP_BERT
- QGSP_INCLXX
- QGS_BIC
- *Shielding*
- 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 configuration 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*). Following extensions are available:

- EMV *EM Opt1* less precise, but faster set of electromagnetic physics is used. Otherwise known as electromagnetic option 1.
- EMX *EM Opt2* less precise, but faster set of electromagnetic physics is used. Otherwise known as electromagnetic option 2.
- EMY *EM Opt3* 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* the best set of electromagnetic physics models selected from the low energy and standard packages. With its concentration on the best possible physics, electromagnetic option 4 is slower than the standard EM package.
- LIV *EM Liv* 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* 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* 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* 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* 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` is made on top default electromagnetic configurations by substitution of all multiple scattering models by single scattering models.

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.

2.1 FTFP_BERT

It is the current GEANT4 default [eal16].

2.1.1 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 $p, n, \pi^+, \pi^-, K^+, K^-, K_L, K_S, \Lambda, \Sigma^+, \Sigma^-, \Sigma^0, \Xi^-, \Xi^0$ 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 parameterization. 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 parameterization.

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 parameterized 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 energies.

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 pions. 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 FritiofCaptureAtRest model which uses the Fritiof string model.

2.1.2 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 constructors*).

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.

2.1.3 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.

2.1.4 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.

2.1.5 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.

2.1.6 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++ cascade.
- **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 constructors*, which may be used instead of the default electromagnetic physics.

2.2 QBBC

It is recommended for medical and space physics simulations [eal11].

2.2.1 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^- , K_L , K_S , Λ , Σ^+ , Σ^- , Σ^0 , Ξ^- , Ξ^0 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 parameterization.

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 parameterization.

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 parameterized 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 energies.

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 pions. 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 FritiofCaptureAtRest model which uses the Fritiof string model.

2.2.2 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 constructors*).

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.

2.2.3 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.

2.2.4 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.

2.2.5 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*. It is recommended for medical and space applications [eal11].

2.2.6 Related Physics Lists

- **Electromagnetic options:** different configurations of electromagnetic physics are available (*EM physics constructors*), which may be used instead of the default electromagnetic physics.

2.3 QGSP_BERT

It is the former GEANT4 default [eal09].

2.3.1 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 parton model (FTF), Bertini and Precompound models. The Bertini intranuclear cascade is responsible for $p, n, \pi^+, \pi^-, K^+, K^-, K_L, K_S, \Lambda, \Sigma^+, \Sigma^-, \Sigma^0, \Xi^-, \Xi^0$ 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 parameterization. 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 parameterization.

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 parameterized 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 energies.

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 pions. 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 FritiofCaptureAtRest model which uses the Fritiof string model.

2.3.2 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 constructors*).

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.

2.3.3 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.

2.3.4 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.

2.3.5 Recommended Use Cases

QGSP_BERT can be used for collider physics applications, as an alternative to the recommended physics list FTFP_BERT.

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

2.3.6 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++ cascade.
- **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 constructors*), which may be used instead of the default electromagnetic physics.

2.4 QGSP_BIC

2.4.1 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 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^- , K_L , K_S , Λ , Σ^+ , Σ^- , Σ^0 , Ξ^- , Ξ^0 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 p , n , π^+ , π^- , K^+ , K^- , K_L , K_S , above 12 GeV. The FTF model handles these 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 parameterization. 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 parameterization.

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 parameterized 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 energies.

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 pions. 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 FritiofCaptureAtRest model which uses the Fritiof string model.

2.4.2 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 constructors*).

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.

2.4.3 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.

2.4.4 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.

2.4.5 Recommended Use Cases

QGSP_BIC can be used for collider physics applications, as an alternative to the recommended physics list FTFP_BERT.

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

2.4.6 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 constructors*), which may be used instead of the default electromagnetic physics.

2.5 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.

2.5.1 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 $p, n, \pi^+, \pi^-, K^+, K^-, K_L, K_S, \Lambda, \Sigma^+, \Sigma^-, \Sigma^0, \Xi^-, \Xi^0$ 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 parameterization. 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 parameterization.

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 parameterized 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 energies.

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 pions. 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 `FritiofCaptureAtRest` model which uses the Fritiof string model.

2.5.2 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 constructors*).

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.

2.5.3 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.

2.5.4 Recommended Use Cases

Shielding is recommended for applications for neutron transport.

2.5.5 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 constructors*), which may be used instead of the default electromagnetic physics.

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.

3.1 EM physics constructors

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

Electromagnetic physics in all physics constructors is implemented for the following particles: γ , e^- , e^+ , μ^- , μ^+ , τ^- , τ^+ , π^+ , π^- , K^+ , K^- , p , Σ^+ , Σ^- , Ξ^- , Ω^- , $\text{anti}(p, \Sigma^+, \Sigma^-, \Xi^-, \Omega^-)$, d , t , ${}^3\text{He}$, α , $\text{anti}(d, t, {}^3\text{He}, \alpha)$, and `G4GenericIon`.

Several charmed mesons are also treated, D^+ , D^- , D_s^+ , D_s^- , Λ_c^+ , Σ_c^+ , Σ_c^{++} , Ξ_c^+ , $\text{anti}(\Lambda_c^+, \Sigma_c^+, \Sigma_c^{++}, \Xi_c^+)$, as well as two bottom mesons, B^+ , B^- , B_c^+ , B_c^- , Ω_b^- , Σ_b^+ , Σ_b^- , Ξ_b^- , $\text{anti}(\Omega_b^-, \Sigma_b^+, \Sigma_b^-, \Xi_b^-)$.

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* - extension name EMV;
- `G4EmStandardPhysics_option2` *EM Opt2* - extension name EMX;
- `G4EmStandardPhysics_option3` *EM Opt3* - extension name EMY;
- `G4EmStandardPhysics_option4` *EM Opt4* - extension name EMZ;
- `G4EmLivermorePhysics` *EM Liv* - extension name LIV;
- `G4EmPenelopePhysics` *EM Pen* - extension name PEN;
- `G4EmStandardPhysicsGS` *EM GS* - extension name _GS;
- `G4EmLowEPPPhysics` *EM LE* - extension name _LE;
- `G4EmStandardPhysicsWVI` *EM WVI* - extension name WVI;
- `G4EmStandardPhysicsSS` *EM SS* - extension name _SS;
- `G4EmDNAPhysics` *EM DNA*.

3.2 EM Opt0

The default electromagnetic physics is built by the `G4EmStandardPhysics` constructor (see details in *EM Opt0*).

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. Ionization is modeled 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. Ionization 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 parameterization 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. Ionization is handled by several models depending on energy and particle type. For pions below 298 keV, Bragg model ionization is used for π^+ , and the ICRU73Q0 parameterization is used for π^- . Above this energy BetheBloch ionization is used. For kaons, the same ionization 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 is implemented by the Urban model at all energies. For alphas Bragg ionization is performed below 7.9 MeV and BetheBloch ionization above. For generic ions, Bragg is used below 2 MeV/u and BetheBloch above.

3.3 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 used 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. Ionization is modeled 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. Ionization 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 parameterization 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. Ionization is handled by several models depending on energy and particle type. For pions below 298 keV, Bragg model ionization is used for π^+ , and the ICRU73Q0 parameterization is used for π^- . Above this energy BetheBloch ionization is used. For kaons, the same ionization 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 is implemented by the Urban model at all energies. For alphas Bragg ionization is performed below 7.9 MeV and BetheBloch ionization above. For generic ions, Bragg is used below 2 MeV/u and BetheBloch above.

3.4 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. Ionization is modeled 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. Ionization 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 parameterization 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. Ionization is handled by several models depending on energy and particle type. For pions below 298 keV, Bragg model ionization is used for π^+ , and the ICRU73Q0 parameterization is used for π^- . Above this energy BetheBloch ionization is used. For kaons, the same ionization 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 is implemented by the Urban model at all energies. For alphas Bragg ionization is performed below 7.9 MeV and BetheBloch ionization above. For generic ions, Bragg is used below 2 MeV/u and BetheBloch above.

3.5 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. Ionization is modeled 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. Ionization 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 parameterization 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. Ionization is handled by several models depending on energy and particle type. For pions below 298 keV, Bragg model ionization is used for π^+ , and the ICRU73Q0 parameterization is used for π^- . Above this energy BetheBloch ionization is used. For kaons, the same ionization 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 is implemented by the Urban model at all energies. For alphas Bragg ionization is performed below 7.9 MeV and BetheBloch ionization above. For generic ions, Bragg is used below 2 MeV/u and BetheBloch above. Nuclear stopping model is used below 1 MeV.

3.6 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 Monarch 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 scattering 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. Ionization is modeled 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. Ionization 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 parameterization 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. Ionization is handled by several models depending on energy and particle type. For pions below 298 keV, Bragg model ionization is used for π^+ , and the ICRU73Q0 parameterization is used for π^- . Above this energy Bethe-Bloch ionization is used. For kaons, the same ionization 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 is implemented by the Urban model at all energies. For alphas Bragg ionization is performed below 7.9 MeV and Bethe-Bloch ionization 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.

3.7 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 scattering. Bremsstrahlung is implemented by the Seltzer-Berger model below 1 GeV and by the eBremsstrahlungRelModel model at high energies. Ionization is modeled by the Livermore model.

Other interactions are configured identically as in the G4EmStandardPhysics_option4 constructor.

3.8 EM Pen

This physics list uses “Penelope” GEANT4 electromagnetic physics as built by the G4EmPenelopePhysics constructor.

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.

3.9 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.

3.10 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 relativistic 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.

3.11 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`).

3.12 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.

3.13 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.

3.14 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
```

3.14.1 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  ↵
↪AngularGenSauterGavrila FluoActive

Compton scattering
compt:     SubType= 13  BuildTable= 1
          Lambda table from 100 eV to 1 MeV, 7 bins per 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 per decade, spline: 1
          ===== EM models for the G4Region DefaultRegionForTheWorld =====
          BetheHeitler : Emin=      0 eV   Emax=    80 GeV  AngularGenUrban
          BetheHeitlerLPM : Emin=    80 GeV  Emax=    100 TeV  AngularGenUrban

Rayleigh scattering
Rayl:      SubType= 11  BuildTable= 1
          Lambda table from 100 eV to 100 keV, 7 bins per 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 per 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, stepLimitType: 1, latDisplacement: 1
      ===== EM models for the G4Region  DefaultRegionForTheWorld =====
      UrbanMsc : Emin=      0 eV      Emax=      100 MeV  Table with 42 bins
↔Emin=      100 eV      Emax=      100 MeV
      WentzelVIUni : Emin=      100 MeV  Emax=      100 TeV  Table with 42 bins
↔Emin=      100 MeV      Emax=      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 per decade, spline: 1
      finalRange(mm)= 1, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 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 per 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  AngularGenUrban
      eBremLPM : Emin=      1 GeV      Emax=      100 TeV  AngularGenUrban
    
```

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 per 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, stepLimitType: 1, latDisplacement: 1
      ===== EM models for the G4Region  DefaultRegionForTheWorld =====
      UrbanMsc : Emin=      0 eV      Emax=      100 MeV  Table with 42 bins
↔Emin=      100 eV      Emax=      100 MeV
    
```

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```
WentzelVIUni : Emin=      100 MeV  Emax=      100 TeV  Table with 42 bins_
↔Emin=      100 MeV  Emax=      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 per decade, spline: 1
finalRange(mm)= 1, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 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 per 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  AngularGenUrban
eBremLPM : Emin=      1 GeV   Emax=     100 TeV  AngularGenUrban
```

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 per 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, stepLimitType: 0, latDisplacement: 0
===== EM models for the G4Region  DefaultRegionForTheWorld =====
WentzelVIUni : Emin=      0 eV    Emax=     100 TeV  Table with 84 bins_
↔Emin=     100 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 per 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 per 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
```

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 per decade, spline: 1
finalRange(mm)= 0.1, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 0.01
===== EM models for the G4Region  DefaultRegionForTheWorld =====
Bragg : Emin=      0 eV    Emax=      2 MeV
BetheBloch : Emin=      2 MeV  Emax=     100 TeV
```

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CSDA range table up to 1 GeV in 49 bins

mu+

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 per 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, step limit type: 0, lateralDisplacement: 0,
 ↪polarAngleLimit(deg)= 180
 ===== EM models for the G4Region DefaultRegionForTheWorld =====
 WentzelVIUni : Emin= 0 eV Emax= 100 TeV Table with 84 bins
 ↪Emin= 100 eV Emax= 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 per 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 per 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 per decade, spline: 1
 finalRange(mm)= 0.1, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 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

mu-

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 per 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.

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```

msc:      SubType= 10
         RangeFactor= 0.2, step limit type: 0, lateralDisplacement: 0,
↳polarAngleLimit(deg)= 180
         ===== EM models for the G4Region DefaultRegionForTheWorld =====
         WentzelVIUni : Emin=      0 eV   Emax=     100 TeV Table with 84 bins
↳Emin=    100 eV   Emax=     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 per 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 per 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 per decade, spline: 1
         finalRange(mm)= 0.1, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 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

```

3.14.2 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
↳AngularGenSauterGavrila FluoActive

Compton scattering
compt: , applyCuts: 1      SubType= 13 BuildTable= 1
         Lambda table from 100 eV to 1 MeV, 7 bins per 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 per decade, spline: 1
         ===== EM models for the G4Region DefaultRegionForTheWorld =====
         BetheHeitler : Emin=      0 eV   Emax=     80 GeV AngularGenUrban
         BetheHeitlerLPM : Emin=    80 GeV Emax=    100 TeV AngularGenUrban

```

e-

```

Coulomb scattering. Simulation of elastic scattering
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 per 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, stepLimitType: 0, latDisplacement: 1
  ===== EM models for the G4Region  DefaultRegionForTheWorld =====
    UrbanMsc : Emin=      0 eV    Emax=      100 MeV  Table with 42 bins_
↪Emin=      100 eV    Emax=      100 MeV
    WentzelVIUni : Emin=      100 MeV  Emax=      100 TeV  Table with 42 bins_
↪Emin=      100 MeV  Emax=      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 per decade, spline: 1
  finalRange(mm)= 1, dRoverRange= 0.8, integral: 1, fluct: 1, linLossLimit= 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 per 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  AngularGenUrban
    eBremLPM : Emin=      1 GeV  Emax=      100 TeV  AngularGenUrban

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 per 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, stepLimitType: 0, latDisplacement: 1
  ===== EM models for the G4Region  DefaultRegionForTheWorld =====
    UrbanMsc : Emin=      0 eV    Emax=      100 MeV  Table with 42 bins_
↪Emin=      100 eV    Emax=      100 MeV
    WentzelVIUni : Emin=      100 MeV  Emax=      100 TeV  Table with 42 bins_
↪Emin=      100 MeV  Emax=      100 TeV

```

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```

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 per decade, spline: 1
            finalRange(mm)= 1, dRoverRange= 0.8, integral: 1, fluct: 1, linLossLimit= 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 per 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   AngularGenUrban
            eBremLPM : Emin=     1 GeV   Emax=     100 TeV  AngularGenUrban

```

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 per 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, stepLimitType: 0, latDisplacement: 0
            ===== EM models for the G4Region DefaultRegionForTheWorld =====
            WentzelVIUni : Emin=      0 eV   Emax=     100 TeV  Table with 84 bins
            ↪Emin=     100 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 per 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 per 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

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 per decade, spline: 1
            finalRange(mm)= 0.1, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 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

```

mu+

```

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 per 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, step limit type: 0, lateralDisplacement: 0,
↳polarAngleLimit(deg)= 180
      ===== EM models for the G4Region  DefaultRegionForTheWorld =====
      WentzelVIUni : Emin=      0 eV      Emax=      100 TeV Table with 84 bins
↳Emin=      100 eV      Emax=      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 per 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 per 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 per decade, spline: 1
      finalRange(mm)= 0.1, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 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

```

mu-

```

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 per 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, step limit type: 0, lateralDisplacement: 0,
↳polarAngleLimit(deg)= 180
      ===== EM models for the G4Region  DefaultRegionForTheWorld =====
      WentzelVIUni : Emin=      0 eV      Emax=      100 TeV Table with 84 bins
↳Emin=      100 eV      Emax=      100 TeV

```

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```

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 per 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 per 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 per decade, spline: 1
              finalRange(mm)= 0.1, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 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
    
```

3.14.3 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
              ↪AngularGenSauterGavrila FluoActive

Compton scattering
compt:       SubType= 13 BuildTable= 1
              Lambda table from 100 eV to 1 MeV, 7 bins per 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 per decade, spline: 1
              ===== EM models for the G4Region DefaultRegionForTheWorld =====
                  BetheHeitler : Emin=      0 eV   Emax=     80 GeV   AngularGenUrban
                  BetheHeitlerLPM : Emin=    80 GeV Emax=    100 TeV   AngularGenUrban
    
```

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 per decade, spline: 1
              ThetaMin(p) < Theta(degree) < 180; pLimit(GeV^1)= 0.139531
              ===== EM models for the G4Region DefaultRegionForTheWorld =====
    
```

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```
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, stepLimitType: 0, latDisplacement: 0
          ===== EM models for the G4Region DefaultRegionForTheWorld =====
                UrbanMsc : Emin=      0 eV    Emax=      100 MeV  Table with 42 bins
↪Emin=      100 eV    Emax=      100 MeV
                WentzelVIUni : Emin=      100 MeV  Emax=      100 TeV  Table with 42 bins
↪Emin=      100 MeV  Emax=      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 per decade, spline: 1
           finalRange(mm)= 1, dRoverRange= 0.8, integral: 1, fluct: 1, linLossLimit= 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 per 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  AngularGenUrban
                 eBremLPM : Emin=      1 GeV  Emax=      100 TeV  AngularGenUrban
```

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 per 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= 0.2, stepLimitType: 0, latDisplacement: 0
          ===== EM models for the G4Region DefaultRegionForTheWorld =====
                UrbanMsc : Emin=      0 eV    Emax=      100 MeV  Table with 42 bins
↪Emin=      100 eV    Emax=      100 MeV
                WentzelVIUni : Emin=      100 MeV  Emax=      100 TeV  Table with 42 bins
↪Emin=      100 MeV  Emax=      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 per decade, spline: 1
           finalRange(mm)= 1, dRoverRange= 0.8, integral: 1, fluct: 1, linLossLimit= 0.01
           ===== EM models for the G4Region DefaultRegionForTheWorld =====
```

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```

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 per 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   AngularGenUrban
eBremLPM : Emin=     1 GeV   Emax=    100 TeV   AngularGenUrban

```

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 per 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 per 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 per 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

```

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 per decade, spline: 1
finalRange(mm)= 0.1, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 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

```

mu+

```

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 per 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

```

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```

RangeFactor= 0.2, step limit type: 0, lateralDisplacement: 0,
↪polarAngleLimit(deg)= 180
===== EM models for the G4Region DefaultRegionForTheWorld =====
WentzelVIUni : Emin=      0 eV   Emax=     100 TeV Table with 84 bins
↪Emin=     100 eV   Emax=     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 per 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 per 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 per decade, spline: 1
finalRange(mm)= 0.1, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 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

```

mu-

```

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 per 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, step limit type: 0, lateralDisplacement: 0,
↪polarAngleLimit(deg)= 180
===== EM models for the G4Region DefaultRegionForTheWorld =====
WentzelVIUni : Emin=      0 eV   Emax=     100 TeV Table with 84 bins
↪Emin=     100 eV   Emax=     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 per 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 per decade, spline: 1

```

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```

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 per decade, spline: 1
finalRange(mm)= 0.1, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 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
    
```

3.14.4 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  ↵
↵AngularGenSauterGavrila FluoActive

Compton scattering
compt:      SubType= 13 BuildTable= 1
      Lambda table from 10 eV to 1 MeV, 20 bins per 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 FluoActive

Gamma conversion
conv:      SubType= 14 BuildTable= 1
      Lambda table from 1.022 MeV to 100 TeV, 20 bins per decade, spline: 1
      ===== EM models for the G4Region DefaultRegionForTheWorld =====
      BetheHeitler : Emin=      0 eV   Emax=      80 GeV AngularGenUrban
      BetheHeitlerLPM : Emin=      80 GeV Emax=    100 TeV AngularGenUrban

Rayleigh scattering
Rayl:      SubType= 11 BuildTable= 1
      Lambda table from 10 eV to 100 keV, 20 bins per 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, stepLimitType: 3, latDisplacement: 1, skin= 1, geomFactor= 2.5
      ===== EM models for the G4Region DefaultRegionForTheWorld =====
      UrbanMsc : Emin=      0 eV   Emax=    100 TeV Table with 240 bins ↵
↵Emin=    100 eV   Emax=    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 per decade, spline: 1
    
```

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```
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 per decade, spline: 1
finalRange(mm)= 0.1, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 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 per 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, stepLimitType: 3, latDisplacement: 1, skin= 1, geomFactor= 2.5
===== EM models for the G4Region DefaultRegionForTheWorld =====
UrbanMsc : Emin=      0 eV   Emax=     100 TeV   Table with 240 bins
↪Emin=    100 eV   Emax=     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 per 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 per decade, spline: 1
finalRange(mm)= 0.1, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 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 per 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

```

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, stepLimitType: 0, latDisplacement: 1
          ===== EM models for the G4Region  DefaultRegionForTheWorld =====
          UrbanMsc :  Emin=          0 eV   Emax=          100 TeV  Table with 240 bins
↔Emin=     100 eV   Emax=          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 per 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 per 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

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 per decade, spline: 1
          finalRange(mm)= 0.05, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 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

```

mu+

```

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, step limit type: 0, lateralDisplacement: 1,
↔polarAngleLimit(deg)= 180
          ===== EM models for the G4Region  DefaultRegionForTheWorld =====
          UrbanMsc :  Emin=          0 eV   Emax=          100 TeV  Table with 240 bins
↔Emin=     100 eV   Emax=          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 per 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 per 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

```

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```

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 per decade, spline: 1
             finalRange(mm)= 0.05, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 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
    
```

mu-

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, step limit type: 0, lateralDisplacement: 1,
          ↪polarAngleLimit(deg)= 180
          ===== EM models for the G4Region DefaultRegionForTheWorld =====
          UrbanMsc : Emin=      0 eV   Emax=    100 TeV  Table with 240 bins,
          ↪Emin=    100 eV   Emax=    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 per 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 per 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 per decade, spline: 1
             finalRange(mm)= 0.05, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 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
    
```

3.14.5 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
           ↪AngularGenSauterGavrila FluoActive
    
```

Compton scattering

```

compt:     SubType= 13  BuildTable= 1
    
```

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```

Lambda table from 100 eV to 1 MeV, 20 bins per 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  FluoActive
  KleinNishina : Emin=      20 MeV  Emax=      100 TeV  FluoActive

Gamma conversion
conv:      SubType= 14  BuildTable= 1
  Lambda table from 1.022 MeV to 100 TeV, 20 bins per decade, spline: 1
  ===== EM models for the G4Region DefaultRegionForTheWorld =====
  PenConversion : Emin=      0 eV   Emax=      20 MeV
  BetheHeitler : Emin=      20 MeV  Emax=      80 GeV  AngularGenUrban
  BetheHeitlerLPM : Emin=      80 GeV  Emax=      100 TeV  AngularGenUrban

Rayleigh scattering
Rayl:      SubType= 11  BuildTable= 1
  Lambda table from 100 eV to 100 keV, 20 bins per 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 per 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, stepLimitType: 2, latDisplacement: 1
  ===== EM models for the G4Region DefaultRegionForTheWorld =====
GoudsmitSaunderson : Emin=      0 eV   Emax=      100 MeV  Table with 120 bins_
↔Emin=      100 eV   Emax=      100 MeV
  WentzelVIUni : Emin=      100 MeV  Emax=      100 TeV  Table with 120 bins_
↔Emin=      100 MeV  Emax=      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 per 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 per decade, spline: 1
  finalRange(mm)= 0.01, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 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

```

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```

Lambda tables from threshold to 100 TeV, 20 bins per 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 per 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= 0.2, stepLimitType: 2, latDisplacement: 1
===== EM models for the G4Region DefaultRegionForTheWorld =====
GoudsmitSaunderson : Emin=      0 eV   Emax=    100 MeV   Table with 120 bins_
↔Emin=    100 eV   Emax=    100 MeV
WentzelVIUni : Emin=    100 MeV   Emax=    100 TeV   Table with 120 bins_
↔Emin=    100 MeV   Emax=    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 per 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 per decade, spline: 1
finalRange(mm)= 0.01, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 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 per 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
    
```

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```

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 per 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, stepLimitType: 0, latDisplacement: 1
  ===== EM models for the G4Region  DefaultRegionForTheWorld =====
  WentzelVIUni : Emin=      0 eV    Emax=     100 TeV Table with 240 bins_
↪Emin=     100 eV    Emax=     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 per 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 per 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

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 per decade, spline: 1
  finalRange(mm)= 0.02, dRoverRange= 0.1, integral: 1, fluct: 1, linLossLimit= 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

```

mu+

```

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 per 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, step limit type: 0, lateralDisplacement: 1, _
↪polarAngleLimit(deg)= 180
  ===== EM models for the G4Region  DefaultRegionForTheWorld =====
  WentzelVIUni : Emin=      0 eV    Emax=     100 TeV Table with 240 bins_
↪Emin=     100 eV    Emax=     100 TeV

Muon bremsstrahlung

```

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```

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 per 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 per 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 per decade, spline: 1
  finalRange(mm)= 0.02, dRoverRange= 0.1, integral: 1, fluct: 1, linLossLimit= 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

```

mu-

```

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 per 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, step limit type: 0, lateralDisplacement: 1,
  ↪polarAngleLimit(deg)= 180
  ===== EM models for the G4Region DefaultRegionForTheWorld =====
    WentzelVIUni : Emin=      0 eV   Emax=    100 TeV  Table with 240 bins
  ↪Emin=    100 eV   Emax=    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 per 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 per 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

```

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```

Lambda tables from threshold to 100 TeV, 20 bins per decade, spline: 1
finalRange(mm)= 0.02, dRoverRange= 0.1, integral: 1, fluct: 1, linLossLimit= 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
    
```

3.14.6 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
↔AngularGenSauterGavrila FluoActive

Compton scattering
compt: SubType= 13 BuildTable= 1
Lambda table from 100 eV to 1 MeV, 20 bins per 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 FluoActive
KleinNishina : Emin= 1 GeV Emax= 100 TeV FluoActive

Gamma conversion
conv: SubType= 14 BuildTable= 1
Lambda table from 1.022 MeV to 100 TeV, 20 bins per decade, spline: 1
===== EM models for the G4Region DefaultRegionForTheWorld =====
BetheHeitler5D : Emin= 0 eV Emax= 1 GeV AngularGenUrban
BetheHeitlerLPM : Emin= 1 GeV Emax= 100 TeV AngularGenUrban

Rayleigh scattering
Rayl: SubType= 11 BuildTable= 1
Lambda table from 100 eV to 100 keV, 20 bins per 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 per 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, stepLimitType: 2, latDisplacement: 1
===== EM models for the G4Region DefaultRegionForTheWorld =====
GoudsmitSaunderson : Emin= 0 eV Emax= 100 MeV Table with 120 bins
↔Emin= 100 eV Emax= 100 MeV
WentzelVIUni : Emin= 100 MeV Emax= 100 TeV Table with 120 bins
↔Emin= 100 MeV Emax= 100 TeV
    
```

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```

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 per 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 per decade, spline: 1
  finalRange(mm)= 0.01, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 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 per 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 per 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= 0.2, stepLimitType: 2, latDisplacement: 1
  ===== EM models for the G4Region DefaultRegionForTheWorld =====
GoudsmitSaunderson : Emin=      0 eV   Emax=     100 MeV Table with 120 bins_
↔Emin=     100 eV   Emax=     100 MeV
  WentzelVIUni : Emin=     100 MeV Emax=     100 TeV Table with 120 bins_
↔Emin=     100 MeV Emax=     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 per 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

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```
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 per decade, spline: 1
            finalRange(mm)= 0.01, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 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 per 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

```
Nuclear stopping
nuclearStopping:  SubType= 8 BuildTable= 0
            ===== EM models for the G4Region DefaultRegionForTheWorld =====
            ICRU49NucStopping : Emin=      0 eV      Emax=      1 MeV
```

```
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 per 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, stepLimitType: 0, latDisplacement: 1
            ===== EM models for the G4Region DefaultRegionForTheWorld =====
            WentzelVIUni : Emin=      0 eV      Emax=      100 TeV Table with 240 bins
            ↵Emin=      100 eV      Emax=      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 per 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 per 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
```

```
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 per decade, spline: 1
            finalRange(mm)= 0.05, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 0.01
            ===== EM models for the G4Region DefaultRegionForTheWorld =====
            Bragg : Emin=      0 eV      Emax=      2 MeV  deltaVI
```

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

mu+

```
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 per 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, step limit type: 0, lateralDisplacement: 1,
↳polarAngleLimit(deg)= 180
      ===== EM models for the G4Region  DefaultRegionForTheWorld =====
      WentzelVIUni : Emin=      0 eV  Emax=      100 TeV  Table with 240 bins
↳Emin=      100 eV  Emax=      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 per 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 per 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 per decade, spline: 1
      finalRange(mm)= 0.05, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 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
```

mu-

```
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 per 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
```

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```

combined with Coulomb scattering in a 'mixed' scattering algorithm.
msc:      SubType= 10
         RangeFactor= 0.2, step limit type: 0, lateralDisplacement: 1,
↔polarAngleLimit(deg)= 180
===== EM models for the G4Region DefaultRegionForTheWorld =====
         WentzelVIUni : Emin=      0 eV   Emax=     100 TeV Table with 240 bins
↔Emin=    100 eV   Emax=     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 per 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 per 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 per decade, spline: 1
         finalRange(mm)= 0.05, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 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
    
```

3.14.7 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 FluoActive
         PhotoElectric : Emin=    1 GeV   Emax=    100 TeV
↔AngularGenSauterGavrila FluoActive

Compton scattering
compt:    SubType= 13 BuildTable= 1
         Lambda table from 100 eV to 1 MeV, 20 bins per 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 FluoActive
         KleinNishina : Emin=    1 GeV   Emax=    100 TeV FluoActive

Gamma conversion
conv:     SubType= 14 BuildTable= 1
         Lambda table from 1.022 MeV to 100 TeV, 20 bins per decade, spline: 1
         ===== EM models for the G4Region DefaultRegionForTheWorld =====
         PenConversion : Emin=      0 eV   Emax=      1 GeV
         BetheHeitler : Emin=    1 GeV   Emax=    80 GeV AngularGenUrban
         BetheHeitlerLPM : Emin=   80 GeV Emax=   100 TeV AngularGenUrban

Rayleigh scattering
    
```

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```
Rayl:      SubType= 11  BuildTable= 1
          Lambda table from 100 eV to 100 keV, 20 bins per 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 per 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, stepLimitType: 2, latDisplacement: 1
          ===== EM models for the G4Region DefaultRegionForTheWorld =====
GoudsmitSaunderson : Emin=      0 eV      Emax=     100 MeV  Table with 120 bins_
↪Emin=     100 eV      Emax=     100 MeV
  WentzelVIUni : Emin=     100 MeV  Emax=     100 TeV  Table with 120 bins_
↪Emin=     100 MeV  Emax=     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 per 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 per decade, spline: 1
            finalRange(mm)= 0.01, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 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 per 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  AngularGenUrban
```

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 per 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=      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= 0.2, stepLimitType: 2, latDisplacement: 1
===== EM models for the G4Region DefaultRegionForTheWorld =====
GoudsmitSaunderson : Emin=       0 eV   Emax=      100 MeV  Table with 120 bins_
↔Emin=      100 eV   Emax=      100 MeV
  WentzelVIUni : Emin=      100 MeV  Emax=      100 TeV  Table with 120 bins_
↔Emin=      100 MeV  Emax=      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 per 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 per decade, spline: 1
  finalRange(mm)= 0.01, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 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 per 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  AngularGenUrban

```

proton

```

Nuclear stopping
nuclearStopping:      SubType= 8  BuildTable= 0
===== EM models for the G4Region DefaultRegionForTheWorld =====
ICRU49NucStopping : Emin=       0 eV   Emax=       1 MeV

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 per 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

```

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```

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, stepLimitType: 0, latDisplacement: 1
         ===== EM models for the G4Region DefaultRegionForTheWorld =====
           UrbanMsc : Emin=      0 eV   Emax=    100 TeV Table with 240 bins
         ↪Emin=    100 eV   Emax=    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 per 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 per 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

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 per decade, spline: 1
         finalRange(mm)= 0.05, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 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
    
```

mu+

```

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 per 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, step limit type: 0, lateralDisplacement: 1,
         ↪polarAngleLimit(deg)= 180
         ===== EM models for the G4Region DefaultRegionForTheWorld =====
           WentzelVIUni : Emin=      0 eV   Emax=    100 TeV Table with 240 bins
         ↪Emin=    100 eV   Emax=    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 per 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
    
```

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```

Lambda tables from threshold to 100 TeV, 20 bins per 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 per decade, spline: 1
finalRange(mm)= 0.05, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 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

```

mu-

```

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 per 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, step limit type: 0, lateralDisplacement: 1,
↳polarAngleLimit(deg)= 180
===== EM models for the G4Region DefaultRegionForTheWorld =====
    WentzelVIUni : Emin=      0 eV    Emax=    100 TeV Table with 240 bins
↳Emin=    100 eV    Emax=    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 per 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 per 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 per decade, spline: 1
finalRange(mm)= 0.05, dRoverRange= 0.2, integral: 1, fluct: 1, linLossLimit= 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

```

3.15 Tables by particle

3.15.1 Gamma

Table 3.1: Models used for gamma processes for different EM physics constructors.

title	Rayleigh	Photoelectric	Compton	Gamma conversion
Opt0	Livermore-Rayleigh 0-100 TeV	Livermore-PhElectric 0-100 TeV	KleinNishina 0-100 TeV	BetheHeitler 0-80 GeV; BetheHeitlerLPM 80 GeV-100 TeV
Opt1	none	Livermore-PhElectric 0-100 TeV	KleinNishina 0-100 TeV	BetheHeitler 0-80 GeV; BetheHeitlerLPM 80 GeV-100 TeV
Opt2	none	PhotoElectric 0-100 TeV	KleinNishina 0-100 TeV	BetheHeitler 0-80 GeV; BetheHeitlerLPM 80 GeV-100 TeV
Opt3	Livermore-Rayleigh 0-100 TeV	Livermore-PhElectric 0-100 TeV	KleinNishina 0-100 TeV	BetheHeitler 0-80 GeV; BetheHeitlerLPM 80 GeV-100 TeV
Opt4	Livermore-Rayleigh 0-100 TeV	Livermore-PhElectric 0-100 TeV	LowEPComptonModel 0-20 MeV; KleinNishina 20 MeV-100 TeV	PenConversion 0-20 MeV; BetheHeitler 20 MeV-80 GeV; BetheHeitlerLPM 80 GeV-100 TeV
Livermore	Livermore-Rayleigh 0-100 TeV	Livermore-PhElectric 0-100 TeV	LivermoreCompton 0-1 GeV; KleinNishina 1 GeV-100 TeV	BetheHeitler5D 0-1 GeV; BetheHeitlerLPM 1 GeV-100 TeV
Penelope	Pen-Rayleigh 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; BetheHeitler 1 GeV-80 GeV; BetheHeitlerLPM 80 GeV-100 TeV

3.15.2 Electron

Table 3.2: Models used for electron processes for different EM physics constructors.

	Coulomb scattering	Multiple scattering	Pair production	Ionisation	Bremsstrahlung
Opt0	eCoulombScattering 100 MeV-100 TeV	UrbanMsc 0-100 MeV; WentzelVUni 100 MeV-100 TeV	none	MollerBhabha 0-100 TeV	eBremSB 0-1 GeV; eBremLPM 1 GeV-100 TeV
Opt1	eCoulombScattering 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	eCoulombScattering 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	eCoulombScattering 100 MeV-10 TeV	Goudsmit-Saunderson 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	eCoulombScattering 100 MeV-100 TeV	Goudsmit-Saunderson 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	eCoulombScattering 100 MeV-100 TeV	Goudsmit-Saunderson 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

3.15.3 Positron

Table 3.3: Models used for positron processes for different EM physics constructors.

	Coulomb scattering	Multiple scattering	Pair production	Ionisation	Annihilation	Bremsstrahlung
Opt0	eCoulomb-Scattering 100 MeV-100 TeV	UrbanMsc 0-100 TeV; WentzelVIUni 100 MeV-100 TeV	none	MollerBhabha 0-100 TeV	eplus2gg 0-100 TeV	eBremSB 0-1 GeV; eBremLPM 1 GeV-100 TeV
Opt1	eCoulomb-Scattering 100 MeV-100 TeV	UrbanMsc 0-100 MeV; WentzelVIUni 100 MeV-100 TeV	none	MollerBhabha 0-100 TeV	eplus2gg 0-100 TeV	eBremSB 0-1 GeV; eBremLPM 1 GeV-100 TeV
Opt2	eCoulomb-Scattering 100 MeV-100 TeV	UrbanMsc 0-100 MeV; WentzelVIUni 100 MeV-100 TeV	none	MollerBhabha 0-100 TeV	eplus2gg 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	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-Prod 0-100 TeV	PenIoni 0-100 keV; MollerBhabha 100 keV-100 TeV	eplus2gg 0-100 TeV	eBremSB 0-1 GeV; eBremLPM 1 GeV-100 TeV
Livermore	eCoulomb-Scattering 100 MeV-100 TeV	GoudsmitSaunderson 0-100 MeV; WentzelVIUni 100 MeV-100 TeV	ePair-Prod 0-100 TeV	MollerBhabha 0-100 TeV	eplus2gg 0-100 TeV	eBremSB 0-1 GeV; eBremLPM 1 GeV-100 TeV
Penelope	eCoulomb-Scattering 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	PenAnnih 0-1 GeV; eplus2gg 1 GeV-100 TeV	PenBrem 0-1 GeV; eBremLPM 1 GeV-100 TeV

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

BIBLIOGRAPHY

- [eal06] J. Allison et al. Geant4 developments and applications. *IEEE Transactions on Nuclear Science*, 53:270–278, feb 2006. URL: <http://ieeexplore.ieee.org/document/1610988?reload=true>, doi:10.1109/TNS.2006.869826.
- [eal16] J. Allison et al. Recent developments in geant4. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 835:186–225, nov 2016. URL: <https://doi.org/10.1016/j.nima.2016.06.125>, doi:10.1016/j.nima.2016.06.125.
- [eal09] J. Apostolakis et al. Geometry and physics of the geant4 toolkit for high and medium energy applications. *Radiation Physics and Chemistry*, 78(10):859–873, oct 2009. URL: <https://doi.org/10.1016/j.radphyschem.2009.04.026>, doi:10.1016/j.radphyschem.2009.04.026.
- [eal03] S. Agostinelli et al. Geant4—a simulation toolkit. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 506(3):250–303, jul 2003. URL: [https://doi.org/10.1016/S0168-9002\(03\)01368-8](https://doi.org/10.1016/S0168-9002(03)01368-8), doi:10.1016/s0168-9002(03)01368-8.
- [eal16] J. Allison et al. Recent developments in geant4. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 835:186–225, nov 2016. URL: <https://doi.org/10.1016/j.nima.2016.06.125>, doi:10.1016/j.nima.2016.06.125.
- [eal11] A.V. Ivantchenko et al. Geant4 hadronic physics for space radiation environment. *International Journal of Radiation Biology*, 88(1-2):171–175, sep 2011. URL: <https://doi.org/10.3109/09553002.2011.610865>, doi:10.3109/09553002.2011.610865.
- [eal09] J. Apostolakis et al. Geometry and physics of the geant4 toolkit for high and medium energy applications. *Radiation Physics and Chemistry*, 78(10):859–873, oct 2009. URL: <https://doi.org/10.1016/j.radphyschem.2009.04.026>, doi:10.1016/j.radphyschem.2009.04.026.
- [eal16] J. Allison et al. Recent developments in geant4. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 835:186–225, nov 2016. URL: <https://doi.org/10.1016/j.nima.2016.06.125>, doi:10.1016/j.nima.2016.06.125.
- [eal09] J. Apostolakis et al. Geometry and physics of the geant4 toolkit for high and medium energy applications. *Radiation Physics and Chemistry*, 78(10):859–873, oct 2009. URL: <https://doi.org/10.1016/j.radphyschem.2009.04.026>, doi:10.1016/j.radphyschem.2009.04.026.
- [eal11] V. Ivanchenko et al. Recent improvements in geant4 electromagnetic physics models and interfaces. *Progress in NUCLEAR SCIENCE and TECHNOLOGY*, 2:898–903, oct 2011. URL: <http://www.aesj.or.jp/publication/pnst002/data/898-903.pdf>.