Guide For Physics Lists

Release 10.4

Geant4 Collaboration

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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.

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PHYSICS LIST GUIDE

The Physics List is one of the three mandatory user classes of the GEANT4 toolkit. In this class all GEANT4 particles [refPart] and their interaction processes [refProc] 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 *[SA03]*, 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 *[JA09]*. Since the GEANT4 release 10.0 the default Physics List becomes FTFP_BERT *[JA16]*. 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 extention of the base class `G4VUserPhysicsList`. The advantages of the modular design are in maintenence 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 Physics List*
- `FTFP_BERT_ATL`
- `FTFP_BERT_HP`
- `FTFP_BERT_TRV`
- `FTFP_INCLXX`
- `FTFQGSP_BERT`
- `FTF_BIC`
- `QBBC` *QBBC Physics List [AVII11]*
- `QGSP_BERT` *QGSP_BERT Physics List*
- `QGSP_BERT_HP`
- `QGSP_BIC`
- `QGSP_BIC_AllHP`
- `QGSP_BIC_HP`
- `QGSP_FTFP_BERT`
- `QGSP_INCLXX`
- `QGS_BIC`
- `Shielding` *Shielding Physics List*
- `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 extention 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 extentions 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.
- `_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. A 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 Physics List

It is the current GEANT4 default *[JA16]*.

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 FTF, Bertini 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 12 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-^{3}He and anti-alphas 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 at 3 GeV to 0.0 and 12 GeV, 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, multi-fragmentation, neutron evaporation and photon evaporation models as needed. When the Bertini model is used, its own, simpler precompound and de-exciation models are invoked.

Inelastic nucleus-nucleus scattering for all incident A is handled by the Binary Light Ion Cascade (BIC) between 0 and 4 GeV/n, and by the FTF model between 2 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 3.5 GeV are interacted using the Bertini cascade, and above 3 GeV by the Quark-gluon String (QGS) model. Muons, electrons and positrons alos interact via transfer of virtual photons. These interactions are handled by G4MuonVDNuclearModel and G4ElectroVDNuclearModel which are applied at all energies.

Inelastic cross sections

The following cross section sets are used for pions and kaons below 91 GeV: G4PiNuclearCrossSection for π^+ and π^-, G4ChipsKaonPlusInelasticXS for K^+, G4ChipsKaonMinusInelasticXS for K^- and G4ChipsKaonZeroInelasticXS for K^0. For all these the Barashenkov-Glauber cross sections are used at 91 GeV and above.

G4BGGNucleonInelasticXS is used for protons and neutrons. Below 91 GeV, this class uses the Barashenkov parameterization and above 91 GeV it uses the Glauber-Gribov cross sections. For λ, Σ, Ξ and Ω^- hyperons the G4ChipsHyperonInelasticXS set 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-^{3}He 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, ^{3}He, alphas and anti-neutrons.

Elastic π^+ and π^- scattering is implemented by G4HadronElastic model from 0 1o 1 GeV and by the G4ElasticHadrNucleusHE coherent scattering model from 1 GeV and up.

For anti-protons, anti-deuterons, anti-tritons, anti-^{3}He 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

From 0 to 100 TeV ChipsProtonElasticXS provides the proton cross sections while G4NeutronElasticXS provides the neutron cross sections.

G4BGGPionElasticXS supplies the π^+ and π^- cross sections using the Barashenkov parameterization below 91 GeV and the Glauber-Gribov cross sections above 91 GeV. Kaons use the Glauber-Gribov cross sections at all energies.

Hyperons and anti-neutrons use the Gheisha elastic cross sections at all energies.

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

The Gheisha elastic cross sections are used for d,t and alpha at all energies while for ^{3}He the Glauber-Gribov elastic cross sections are used at all energies.

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

Capture and stopping

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-^{3}He, anti-alpha is handled by the FritiofCapture-AtRest model which uses the Fritiof string model.

Neutron capture uses the G4NeutronRadCapture model with the G4NeutronCaptureXS cross sections.

2.1.2 Electromagnetic Component

This physics list uses "standard" GEANT4 electromagnetic physics as built by the G4EmStandardPhysics constructor *EM physics constructors*. It is implemented for the following particles: γ, e^-, e^+, μ^-, μ^+, τ^-, τ^+, K^+, K^-, p, Σ^+, Σ^-, Ξ^-, Ω^-, anti(Σ^+, Σ^-, Ξ^-, Ω^-), d, t, ^3He, α, anti(d, t, ^3He, α), and `G4GenericIon`. Several charmed mesons are also treated, D^+, D^-, D_s^+, D_s^-, Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+, anti(Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+), as well as two bottom mesons, B^+ and B^-.

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 Standard EM models implement several processes.

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. 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 mu+ or mu-.

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. Mulitple Coulomb scattering in 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 and BetheBloch above.

There is no treatment of optical photons in this physics list.

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 decaied 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.

2.1.4 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 recomended 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.
- **FTFP_BERT_ATL**: identical to FTFP_BERT except that transition between the FTF model and the Bertini cascade is changed. 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 availble *EM physics constructors*), which may be used instead of the default electromagnetic physics.

2.2 QBBC Physics List

It is recommended for medical and space physics simulations *[AVII11]*.

2.2.1 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 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 12 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-^{3}He and anti-alphas 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 at 3 GeV to 0.0 and 5 GeV, and FTF is invoked with the complementary probability. The Binary cascade is used from 0 to 1.5 GeV for protons and neutrons.

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, 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 4 GeV/n, and by the FTF model between 2 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 3.5 GeV are interacted using the Bertini cascade, and above 3 GeV by the Quark-gluon String (QGS) model. Muons, electrons and positrons alos interact via transfer of virtual photons. These interactions are handled by G4MuonVDNuclearModel and G4ElectroVDNuclearModel which are applied at all energies.

Inelastic cross sections

The following cross section sets are used for pions and kaons below 91 GeV: G4PiNuclearCrossSection for π^+ and π^-, G4ChipsKaonPlusInelasticXS for K^+, G4ChipsKaonMinusInelasticXS for K^- and G4ChipsKaonZeroInelasticXS for K^0. For all these the Barashenkov-Glauber cross sections are used at 91 GeV and above.

G4BGGNucleonInelasticXS is used for protons and neutrons. Below 91 GeV, this class uses the Barashenkov parameterization and above 91 GeV it uses the Glauber-Gribov cross sections. For λ, Σ, Ξ and Ω^- hyperons the G4ChipsHyperonInelasticXS set 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-^{3}He 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, ^{3}He, alphas and anti-neutrons.

Elastic π^+ and π^- scattering is implemented by G4HadronElastic model from 0 1o 1 GeV and by the G4ElasticHadrNucleusHE coherent scattering model from 1 GeV and up.

For anti-protons, anti-deuterons, anti-tritons, anti-^{3}He 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

From 0 to 100 TeV ChipsProtonElasticXS provides the proton cross sections while G4NeutronElasticXS provides the neutron cross sections.

G4BGGPionElasticXS supplies the π^+ and π^- cross sections using the Barashenkov parameterization below 91 GeV and the Glauber-Gribov cross sections above 91 GeV. Kaons use the Glauber-Gribov cross sections at all energies.

Hyperons and anti-neutrons use the Gheisha elastic cross sections at all energies.

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

The Gheisha elastic cross sections are used for d,t and alpha at all energies while for ^{3}He the Glauber-Gribov elastic cross sections are used at all energies.

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

Capture and stopping

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-^{3}He, anti-alpha is handled by the FritiofCapture-AtRest model which uses the Fritiof string model.

Neutron capture uses the G4NeutronRadCapture model with the G4NeutronCaptureXS cross sections.

2.2.2 Electromagnetic Component

This physics list uses "standard" GEANT4 electromagnetic physics as built by the G4EmStandardPhysics constructor *EM physics constructors*. It is implemented for the following particles: γ, e^-, e^+, μ^-, μ^+, τ^-, τ^+, K^+, K^-, p, Σ^+, Σ^-, Ξ^-, Ω^-, anti(Σ^+, Σ^-, Ξ^-, Ω^-), d, t, ^3He, α, anti(d, t, ^3He, α), and `G4GenericIon`.

Several charmed mesons are also treated, D^+, D^-, D_s^+, D_s^-, Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+, anti(Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+), as well as two bottom mesons, B^+ and B^-.

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 Standard EM models implement several processes.

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. 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. Mulitple Coulomb scattering in 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 and BetheBloch above.

There is no treatment of optical photons in this physics list.

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 decaied 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 recomended 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 Physics List*. It is recommended for medical and space applications *[AVII11]*.

2.2.6 Related Physics Lists

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

2.3 QGSP_BERT Physics List

It is the former GEANT4 default *[JA09]*.

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 FTF, Bertini 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 12 GeV. The quark-gluon model (QGS) handles protons, neutrons, pions and kaions above 12 GeV. The Fritiof parton model (FTF) handles these same particles, but over the range 9.5 GeV to 25 GeV, it also handles anti-protons, anti-neutrons, anti-deuterons, anti-tritons, anti-^{3}He and anti-alphas 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 at 9.5 GeV to 0.0 and 9.9 GeV, 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-exciation models are invoked.

Inelastic nucleus-nucleus scattering for all incident A is handled by the Binary Light Ion Cascade (BIC) between 0 and 4 GeV/n, and by the FTF model between 2 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 3.5 GeV are interacted using the Bertini cascade, and above 3 GeV by the Quark-gluon String (QGS) model. Muons, electrons and positrons alos interact via transfer of virtual photons. These interactions are handled by G4MuonVDNuclearModel and G4ElectroVDNuclearModel which are applied at all energies.

Inelastic cross sections

The following cross section sets are used for pions and kaons below 91 GeV: G4PiNuclearCrossSection for π^+ and π^-, G4ChipsKaonPlusInelasticXS for K^+, G4ChipsKaonMinusInelasticXS for K^- and G4ChipsKaonZeroInelasticXS for K^0. For all these the Barashenkov-Glauber cross sections are used at 91 GeV and above.

G4BGGNucleonInelasticXS is used for protons and neutrons. Below 91 GeV, this class uses the Barashenkov parameterization and above 91 GeV it uses the Glauber-Gribov cross sections. For λ, Σ, Ξ and Ω^- hyperons the G4ChipsHyperonInelasticXS set 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-^{3}He 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, ^{3}He, alphas and anti-neutrons.

Elastic π^+ and π^- scattering is implemented by G4HadronElastic model from 0 1o 1 GeV and by the G4ElasticHadrNucleusHE coherent scattering model from 1 GeV and up.

For anti-protons, anti-deuterons, anti-tritons, anti-^{3}He 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

From 0 to 100 TeV ChipsProtonElasticXS provides the proton cross sections while G4NeutronElasticXS provides the neutron cross sections.

G4BGGPionElasticXS supplies the π^+ and π^- cross sections using the Barashenkov parameterization below 91 GeV and the Glauber-Gribov cross sections above 91 GeV. Kaons use the Glauber-Gribov cross sections at all energies.

Hyperons and anti-neutrons use the Gheisha elastic cross sections at all energies.

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

The Gheisha elastic cross sections are used for d,t and alpha at all energies while for ^{3}He the Glauber-Gribov elastic cross sections are used at all energies.

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

Capture and stopping

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-^{3}He, anti-alpha is handled by the FritiofCapture-AtRest model which uses the Fritiof string model.

Neutron capture uses the G4NeutronRadCapture model with the G4NeutronCaptureXS cross sections.

2.3.2 Electromagnetic Component

This physics list uses "standard" GEANT4 electromagnetic physics as built by the G4EmStandardPhysics constructor *EM physics constructors*. It is implemented for the following particles: γ, e^-, e^+, μ^-, μ^+, τ^-, τ^+, K^+, K^-, p, Σ^+, Σ^-, Ξ^-, Ω^-, anti(Σ^+, Σ^-, Ξ^-, Ω^-), d, t, ^3He, α, anti(d, t, ^3He, α), and G4GenericIon.

Several charmed mesons are also treated, D^+, D^-, D_s^+, D_s^-, Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+, anti(Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+), as well as two bottom mesons, B^+ and B^-.

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 Standard EM models implement several processes.

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. 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 in 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 and BetheBloch above.

There is no treatment of optical photons in this physics list.

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 decaied 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 is recomended 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 traetment of very high energy particles is required. Note, however, that is not suited to very high energy collisions of order 10 TeV or more.

2.3.6 Related Physics Lists

- **QGSP_BERT_BERT**: identical to QGSP_BERT except transition regions between models.
- **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.

- **QGSP_BIC**: identical to QGSP_BERT except that the Binary cascade is used instead of the Bertini cascade.
- **QGSP_BIC_HP**: identical to QGSP_BIC except that 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.
- **QGSP_BIC_AllHP**: identical to QGSP_BIC except that 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. For protons, deuterons and alpha particles below 100 MeV the High Precision cross sections for elastic and inelastic scattering are used. The G4NDL database is required for this physics list.
- **QGSP_INCLXX**: identical to QGSP_BERT except that the Bertini cascade is substituted by the INCL++ cascade.
- **QGSQGS_BERT**: identical to QGSP_BERT except that QGS string model is used.
- **QGS_BIC**: identical to QGSP_BERT except that the Binary cascade is used as by the QGS model instead of internal QGS 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.

2.4 Shielding Physics List

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.

2.4.1 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 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 12 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-^{3}He and anti-alphas 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 at 3 GeV to 0.0 and 5 GeV, and FTF is invoked with the complementary probability. The Binary cascade is used from 0 to 1.5 GeV for protons and neutrons.

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

Inelastic nucleus-nucleus scattering for all incident A is handled by the Binary Light Ion Cascade (BIC) between 0 and 4 GeV/n, and by the FTF model between 2 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 3.5 GeV are interacted using the Bertini cascade, and above 3 GeV by the Quark-gluon String (QGS) model. Muons, electrons and positrons alos interact via transfer of virtual photons. These interactions are handled by G4MuonVDNuclearModel and G4ElectroVDNuclearModel which are applied at all energies.

Inelastic cross sections

The following cross section sets are used for pions and kaons below 91 GeV: G4PiNuclearCrossSection for π^+ and π^-, G4ChipsKaonPlusInelasticXS for K^+, G4ChipsKaonMinusInelasticXS for K^- and G4ChipsKaonZeroInelasticXS for K^0. For all these the Barashenkov-Glauber cross sections are used at 91 GeV and above.

G4BGGNucleonInelasticXS is used for protons and neutrons. Below 91 GeV, this class uses the Barashenkov parameterization and above 91 GeV it uses the Glauber-Gribov cross sections. For λ, Σ, Ξ and Ω^- hyperons the G4ChipsHyperonInelasticXS set 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-^{3}He 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, ^{3}He, alphas and anti-neutrons.

Elastic π^+ and π^- scattering is implemented by G4HadronElastic model from 0 1o 1 GeV and by the G4ElasticHadrNucleusHE coherent scattering model from 1 GeV and up.

For anti-protons, anti-deuterons, anti-tritons, anti-^{3}He 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

From 0 to 100 TeV ChipsProtonElasticXS provides the proton cross sections while G4NeutronElasticXS provides the neutron cross sections.

G4BGGPionElasticXS supplies the π^+ and π^- cross sections using the Barashenkov parameterization below 91 GeV and the Glauber-Gribov cross sections above 91 GeV. Kaons use the Glauber-Gribov cross sections at all energies.

Hyperons and anti-neutrons use the Gheisha elastic cross sections at all energies.

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

The Gheisha elastic cross sections are used for d,t and alpha at all energies while for ^{3}He the Glauber-Gribov elastic cross sections are used at all energies.

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

Capture and stopping

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-^{3}He, anti-alpha is handled by the FritiofCapture-AtRest model which uses the Fritiof string model.

Neutron capture uses the G4NeutronRadCapture model with the G4NeutronCaptureXS cross sections.

2.4.2 Electromagnetic Component

This physics list uses "standard" GEANT4 electromagnetic physics as built by the G4EmStandardPhysics constructor *EM physics constructors*. It is implemented for the following particles: γ, e^-, e^+, μ^-, μ^+, τ^-, τ^+, K^+, K^-, p, Σ^+, Σ^-, Ξ^-, Ω^-, anti(Σ^+, Σ^-, Ξ^-, Ω^-), d, t, ^3He, α, anti(d, t, ^3He, α), and `G4GenericIon`.

Several charmed mesons are also treated, D^+, D^-, D_s^+, D_s^-, Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+, anti(Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+), as well as two bottom mesons, B^+ and B^-.

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 Standard EM models implement several processes.

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. 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 in 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 and BetheBloch above.

There is no treatment of optical photons in this physics list.

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, 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.

2.4.4 Recommended Use Cases

Shielding is recomended for applications for neutron transport.

2.4.5 Related Physics Lists

- **ShieldingLEND**: different configurations of low-energy neutron transport with LEND option.
- **Electromagnetic options**: different configurations of electromagnetic physics are availble *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 *[JA09]*, were extended in *[VI11]* and become stable in recent releases of GEANT4 *[JA16]*.

The default electromagnetic physics is built by the `G4EmStandardPhysics` constructor (see details in *EM Opt0*). It is implemented for the following particles: γ, e^-, e^+, μ^-, μ^+, τ^-, τ^+, K^+, K^-, p, Σ^+, Σ^-, Ξ^-, Ω^-, anti(Σ^+, Σ^-, Ξ^-, Ω^-), d, t, ^3He, α, anti(d, t, ^3He, α), and `G4GenericIon`.

Several charmed mesons are also treated, D^+, D^-, D_s^+, D_s^-, Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+, anti(Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+), as well as two bottom mesons, B^+ and 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* - extention name EMV;
- `G4EmStandardPhysics_option2` *EM Opt2* - extention name EMX;
- `G4EmStandardPhysics_option3` *EM Opt3* - extention name EMY;
- `G4EmStandardPhysics_option4` *EM Opt4* - extention name EMZ;
- `G4EmLivermorePhysics` *EM Liv* - extention name LIV;
- `G4EmPenelopePhysics` *EM Pen* - extention name PEN;
- `G4EmStandardPhysics_GS` *EM GS* - extention name _GS;
- `G4EmStandardPhysics_SS` *EM SS* - extention name _SS;
- `G4EmStandardPhysics` *EM DNA*.

3.2 EM Opt0

This physics list uses "standard" GEANT4 electromagnetic physics as built by the `G4EmStandardPhysics` constructor. It is implemented for the following particles: γ, e^-, e^+, μ^-, μ^+, τ^-, τ^+, K^+, K^-, p, Σ^+, Σ^-, Ξ^-, Ω^-, anti(Σ^+, Σ^-, Ξ^-, Ω^-), d, t, ^3He, α, anti(d, t, ^3He, α), and G4GenericIon.

Several charmed mesons are also treated, D^+, D^-, D_s^+, D_s^-, Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+, anti(Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+), as well as two bottom mesons, B^+ and B^-.

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 Standard EM models implement several processes.

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. 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 mu+ and mu-, and from 1 GeV to 100 TeV, the MuBetheBloch model is used for both mu+ and mu-. The muPairProduction model handles e+/e- pair production caused by either mu+ or mu-.

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 in 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 and BetheBloch above.

3.3 EM Opt1

This physics list uses "standard" GEANT4 electromagnetic physics as built by the `G4EmStandardPhysics_option1` constructor. It is implemented for the following particles: γ, e^-, e^+, μ^-, μ^+, τ^-, τ^+, K^+, K^-, p, Σ^+, Σ^-, Ξ^-, Ω^-, anti(Σ^+, Σ^-, Ξ^-, Ω^-), d, t, ^3He, α, anti(d, t, ^3He, α), and G4GenericIon.

Several charmed mesons are also treated, D^+, D^-, D_s^+, D_s^-, Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+, anti(Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+), as well as two bottom mesons, B^+ and B^-.

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 Standard EM models implement several processes.

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. 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 mu+ and mu-, and from 1 GeV to 100 TeV, the MuBetheBloch model is used for both mu+ and mu-. The muPairProduction model handles e+/e- pair production caused by either mu+ or mu-.

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 in 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 and BetheBloch above.

3.4 EM Opt2

This physics list uses "standard" GEANT4 electromagnetic physics as built by the `G4EmStandardPhysics_option2` constructor. It is implemented for the following particles: γ, e^-, e^+, μ^-, μ^+, τ^-, τ^+, K^+, K^-, p, Σ^+, Σ^-, Ξ^-, Ω^-, anti(Σ^+, Σ^-, Ξ^-, Ω^-), d, t, ^3He, α, anti(d, t, ^3He, α), and G4GenericIon.

Several charmed mesons are also treated, D^+, D^-, D_s^+, D_s^-, Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+, anti(Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+), as well as two bottom mesons, B^+ and B^-.

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 Standard EM models implement several processes.

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. 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 mu+ and mu-, and from 1 GeV to 100 TeV, the MuBetheBloch model is used for both mu+ and mu-. The muPairProduction model handles e+/e- pair production caused by either mu+ or mu-.

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 in 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 and BetheBloch above.

3.5 EM Opt3

This physics list uses "standard" GEANT4 electromagnetic physics as built by the `G4EmStandardPhysics_option3` constructor. It is implemented for the following particles: γ, e^-, e^+, μ^-, μ^+, τ^-, τ^+, K^+, K^-, p, Σ^+, Σ^-, Ξ^-, Ω^-, anti(Σ^+, Σ^-, Ξ^-, Ω^-), d, t, ^3He, α, anti(d, t, ^3He, α), and G4GenericIon.

Several charmed mesons are also treated, D^+, D^-, D_s^+, D_s^-, Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+, anti(Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+), as well as two bottom mesons, B^+ and B^-.

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 Standard EM models implement several processes.

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. 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 mu+ and mu-, and from 1 GeV to 100 TeV, the MuBetheBloch model is used for both mu+ and mu-. The muPairProduction model handles e+/e- pair production caused by either mu+ or mu-.

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 in 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 and BetheBloch above.

3.6 EM Opt4

This physics list uses "standard" GEANT4 electromagnetic physics as built by the `G4EmStandardPhysics_option4` constructor. It is implemented for the following particles: γ, e^-, e^+, μ^-, μ^+, τ^-, τ^+, K^+, K^-, p, Σ^+, Σ^-, Ξ^-, Ω^-, anti(Σ^+, Σ^-, Ξ^-, Ω^-), d, t, ^3He, α, anti(d, t, ^3He, α), and G4GenericIon.

Several charmed mesons are also treated, D^+, D^-, D_s^+, D_s^-, Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+, anti(Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+), as well as two bottom mesons, B^+ and B^-.

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 Standard EM models implement several processes.

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. 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 mu+ and mu-, and from 1 GeV to 100 TeV, the MuBetheBloch model is used for both mu+ and mu-. The muPairProduction model handles e+/e- pair production caused by either mu+ or mu-.

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 in 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 and BetheBloch above.

3.7 EM Liv

This physics list uses "Livermore" GEANT4 electromagnetic physics as built by the `G4EmLivermorePhysics` constructor. It is implemented for the following particles: γ, e^-, e^+, μ^-, μ^+, τ^-, τ^+, K^+, K^-, p, Σ^+, Σ^-, Ξ^-, Ω^-, anti(Σ^+, Σ^-, Ξ^-, Ω^-), d, t, ^3He, α, anti(d, t, ^3He, α), and G4GenericIon.

Several charmed mesons are also treated, D^+, D^-, D_s^+, D_s^-, Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+, anti(Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+), as well as two bottom mesons, B^+ and B^-.

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 Standard EM models implement several processes.

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. 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 mu+ and mu-, and from 1 GeV to 100 TeV, the MuBetheBloch model is used for both mu+ and mu-. The muPairProduction model handles e+/e- pair production caused by either mu+ or mu-.

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 in 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 and BetheBloch above.

3.8 EM Pen

This physics list uses "Penelope" GEANT4 electromagnetic physics as built by the `G4EmPenelopePhysics` constructor. It is implemented for the following particles: γ, e^-, e^+, μ^-, μ^+, τ^-, τ^+, K^+, K^-, p, Σ^+, Σ^-, Ξ^-, Ω^-, anti(Σ^+, Σ^-, Ξ^-, Ω^-), d, t, ^3He, α, anti(d, t, ^3He, α), and G4GenericIon.

Several charmed mesons are also treated, D^+, D^-, D_s^+, D_s^-, Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+, anti(Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+), as well as two bottom mesons, B^+ and B^-.

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 Standard EM models implement several processes.

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. 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 mu+ and mu-, and from 1 GeV to 100 TeV, the MuBetheBloch model is used for both mu+ and mu-. The muPairProduction model handles e+/e- pair production caused by either mu+ or mu-.

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 in 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 and BetheBloch above.

3.9 EM GS

This physics list uses "standard" GEANT4 electromagnetic physics as built by the `G4EmStandardPhysicsGS` constructor. It is implemented for the following particles: γ, e^-, e^+, μ^-, μ^+, τ^-, τ^+, K^+, K^-, p, Σ^+, Σ^-, Ξ^-, Ω^-, anti(Σ^+, Σ^-, Ξ^-, Ω^-), d, t, ^3He, α, anti(d, t, ^3He, α), and G4GenericIon.

Several charmed mesons are also treated, D^+, D^-, D_s^+, D_s^-, Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+, anti(Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+), as well as two bottom mesons, B^+ and B^-.

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 Standard EM models implement several processes.

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. 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 mu+ and mu-, and from 1 GeV to 100 TeV, the MuBetheBloch model is used for both mu+ and mu-. The muPairProduction model handles e+/e- pair production caused by either mu+ or mu-.

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 in 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 and BetheBloch above.

3.10 EM SS

This physics list uses "standard" GEANT4 electromagnetic physics as built by the `G4EmStandardPhysicsSS` constructor. It is implemented for the following particles: γ, e^-, e^+, μ^-, μ^+, τ^-, τ^+, K^+, K^-, p, Σ^+, Σ^-, Ξ^-, Ω^-, anti(Σ^+, Σ^-, Ξ^-, Ω^-), d, t, ^3He, α, anti(d, t, ^3He, α), and G4GenericIon.

Several charmed mesons are also treated, D^+, D^-, D_s^+, D_s^-, Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+, anti(Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+), as well as two bottom mesons, B^+ and B^-.

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 Standard EM models implement several processes.

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. 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 mu+ and mu-, and from 1 GeV to 100 TeV, the MuBetheBloch model is used for both mu+ and mu-. The muPairProduction model handles e+/e- pair production caused by either mu+ or mu-.

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 in 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 and BetheBloch above.

3.11 EM DNA

This physics list uses "DNA" GEANT4 electromagnetic physics as built by the `G4EmDNAPhysics` constructor. It is implemented for the following particles: γ, e^-, e^+, μ^-, μ^+, τ^-, τ^+, K^+, K^-, p, Σ^+, Σ^-, Ξ^-, Ω^-, anti(Σ^+, Σ^-, Ξ^-, Ω^-), d, t, ^3He, α, anti(d, t, ^3He, α), and G4GenericIon.

Several charmed mesons are also treated, D^+, D^-, D_s^+, D_s^-, Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+, anti(Λ_c^+, Σ_c^+, Σ_c^{++}, Ξ_c^+), as well as two bottom mesons, B^+ and B^-.

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 Standard EM models implement several processes.

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. 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 mu+ and mu-, and from 1 GeV to 100 TeV, the MuBetheBloch model is used for both mu+ and mu-. The muPairProduction model handles e+/e- pair production caused by either mu+ or mu-.

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 in 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 and BetheBloch above.

3.12 Tables by constructor

3.12.1 emstandard

```
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 ======
        KleinNishina : 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
     BetheHeitlerLPM : Emin=       80 GeV   Emax=       100 TeV

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-

Multiple scattering. Simulates combined effects of elastic scattering at the end of the
step, to save computing time. Maybe 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 TeV  Table with 84 bins Emin=    100
→eV    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)= 0.1, dRoverRange= 0.1, integral: 1, fluct: 1, linLossLimit= 0.01
      ===== EM models for the G4Region  DefaultRegionForTheWorld ======
        MollerBhabha : Emin=        0 eV    Emax=       100 TeV

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  DipBustGen
            eBremLPM : Emin=        1 GeV   Emax=       100 TeV  DipBustGen

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. Maybe 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 TeV  Table with 84 bins Emin=    100
→eV    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)= 0.1, dRoverRange= 0.1, integral: 1, fluct: 1, linLossLimit= 0.01
      ===== EM models for the G4Region  DefaultRegionForTheWorld ======
        MollerBhabha : Emin=        0 eV    Emax=        100 TeV

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   DipBustGen
            eBremLPM : Emin=        1 GeV   Emax=        100 TeV  DipBustGen

proton

Hadron multiple scattering. Simulates combined effects of elastic scattering at the end of the
step, to save computing time. Maybe 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 TeV  Table with 84 bins Emin=    100
→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)= 0.02, dRoverRange= 0.1, 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

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

mu+

Muon multiple scattering. Simulates combined effects of elastic scattering at the end of the
step, to save computing time. Maybe 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 ======
            UrbanMsc : Emin=        0 eV    Emax=        100 TeV  Table with 84 bins Emin=    100
→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)= 0.05, dRoverRange= 0.1, 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

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

mu-

Muon multiple scattering. Simulates combined effects of elastic scattering at the end of the
step, to save computing time. Maybe 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 ======
           UrbanMsc :  Emin=         0 eV    Emax=      100 TeV  Table with 84 bins Emin=    100␣
↪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)= 0.05, dRoverRange= 0.1, 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

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
```

3.12.2 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 ======
```

```
         PhotoElectric :  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
      BetheHeitlerLPM :  Emin=       80 GeV   Emax=      100 TeV

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

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

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   DipBustGen
           eBremLPM :  Emin=        1 GeV   Emax=      100 TeV   DipBustGen

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


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


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   DipBustGen
            eBremLPM : Emin=        1 GeV   Emax=       100 TeV   DipBustGen


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

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

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 =====
          ICRU73QO : Emin=        0 eV    Emax=      200 keV
         BetheBloch : Emin=      200 keV  Emax=        1 GeV
       MuBetheBloch : Emin=        1 GeV  Emax=      100 TeV
```

3.12.3 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
     BetheHeitlerLPM : Emin=       80 GeV  Emax=      100 TeV


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= 0.2, 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

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  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, 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: 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

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   AngularGen2BS
            eBremLPM : Emin=        1 GeV   Emax=       100 TeV   AngularGen2BS

proton

Coulomb scattering. Simulation of elastic scattering events individually. May be used in
combination with multiple scattering, where Coulomb scattering is used for hard (large
angle) collisions and multiple scattering for soft collisions.
CoulombScat: integral: 1     SubType= 1 BuildTable= 1
      Lambda table from threshold  to 100 TeV, 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

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

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 ======
             ICRU73QO : Emin=         0 eV    Emax=       200 keV
           BetheBloch : Emin=       200 keV   Emax=         1 GeV
         MuBetheBloch : Emin=         1 GeV   Emax=       100 TeV
```

3.12.4 emstandard_opt3

```
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

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

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
       BetheHeitlerLPM : Emin=        80 GeV   Emax=       100 TeV

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
        Sampling table 25x1001; from 0.1 GeV to 100 TeV
        ===== EM models for the G4Region  DefaultRegionForTheWorld ======
           muPairProd : 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
```

```
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 ======
         muPairProd : 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

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
        BetheBloch : Emin=        2 MeV   Emax=      100 TeV

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

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

3.12.5 emstandard_opt4

```
gamma


Photoelectric effect
phot:     SubType= 12  BuildTable= 0
      LambdaPrime table from 200 keV to 10 TeV in 154 bins
      ===== EM models for the G4Region  DefaultRegionForTheWorld ======
 LivermorePhElectric : Emin=        0 eV    Emax=        10 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 10 TeV in 140 bins
      ===== EM models for the G4Region  DefaultRegionForTheWorld ======
   LowEPComptonModel : Emin=        0 eV    Emax=        20 MeV  FluoActive
       KleinNishina : Emin=       20 MeV    Emax=        10 TeV  FluoActive


Gamma conversion
conv:     SubType= 14  BuildTable= 1
      Lambda table from 1.022 MeV to 10 TeV, 20 bins per decade, spline: 1
      ===== EM models for the G4Region  DefaultRegionForTheWorld ======
       PenConversion : Emin=        0 eV    Emax=        80 GeV
     BetheHeitlerLPM : Emin=       80 GeV    Emax=        10 TeV


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 10 TeV in 160 bins
      ===== EM models for the G4Region  DefaultRegionForTheWorld ======
   LivermoreRayleigh : Emin=        0 eV    Emax=        10 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 10 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=        10 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=        10 TeV  Table with 100 bins Emin=   ␣
→100 MeV   Emax=     10 TeV
```

Pair production
```
ePairProd:     SubType= 4
      dE/dx and range tables from 100 eV  to 10 TeV in 220 bins
      Lambda tables from threshold to 10 TeV, 20 bins per decade, spline: 1
      Sampling table 21x1001; from 0.1 GeV to 10 TeV
      ===== EM models for the G4Region  DefaultRegionForTheWorld ======
        muPairProd :  Emin=        0 eV    Emax=        10 TeV
```

Ionisation
```
eIoni:     SubType= 2
      dE/dx and range tables from 100 eV  to 10 TeV in 220 bins
      Lambda tables from threshold to 10 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 MeV
     MollerBhabha :  Emin=        1 MeV   Emax=        10 TeV   deltaVI
```

Bremsstrahlung
```
eBrem:     SubType= 3
      dE/dx and range tables from 100 eV  to 10 TeV in 220 bins
      Lambda tables from threshold to 10 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=        10 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 10 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=        10 TeV
```

Positron annihilation
```
annihil:  integral: 1     SubType= 5  BuildTable= 0
      ===== EM models for the G4Region  DefaultRegionForTheWorld ======
          eplus2gg :  Emin=        0 eV    Emax=        10 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=       10 TeV  Table with 100 bins Emin=
→100 MeV    Emax=    10 TeV

Pair production
ePairProd:      SubType= 4
      dE/dx and range tables from 100 eV  to 10 TeV in 220 bins
      Lambda tables from threshold to 10 TeV, 20 bins per decade, spline: 1
      Sampling table 21x1001; from 0.1 GeV to 10 TeV
      ===== EM models for the G4Region  DefaultRegionForTheWorld ======
        muPairProd : Emin=        0 eV    Emax=       10 TeV

Ionisation
eIoni:     SubType= 2
      dE/dx and range tables from 100 eV  to 10 TeV in 220 bins
      Lambda tables from threshold to 10 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 MeV
      MollerBhabha : Emin=        1 MeV    Emax=       10 TeV   deltaVI

Bremsstrahlung
eBrem:     SubType= 3
      dE/dx and range tables from 100 eV  to 10 TeV in 220 bins
      Lambda tables from threshold to 10 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=       10 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 10 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=       10 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=       10 TeV  Table with 220 bins Emin=
→100 eV    Emax=    10 TeV

Hadron bremsstrahlung
hBrems:     SubType= 3
      dE/dx and range tables from 100 eV  to 10 TeV in 220 bins
      Lambda tables from threshold to 10 TeV, 20 bins per decade, spline: 1
      ===== EM models for the G4Region  DefaultRegionForTheWorld ======
             hBrem : Emin=        0 eV    Emax=       10 TeV

Hadron pair production
hPairProd:     SubType= 4
      dE/dx and range tables from 100 eV  to 10 TeV in 220 bins
```

```
       Lambda tables from threshold to 10 TeV, 20 bins per decade, spline: 1
       Sampling table 13x1001; from 7.50618 GeV to 10 TeV
       ===== EM models for the G4Region  DefaultRegionForTheWorld ======
            hPairProd : Emin=        0 eV    Emax=      10 TeV


Ionisation
hIoni:      SubType= 2
       dE/dx and range tables from 100 eV  to 10 TeV in 220 bins
       Lambda tables from threshold to 10 TeV, 20 bins per decade, spline: 1
       finalRange(mm)= 0.01, 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=      10 TeV   deltaVI


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 10 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=      10 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=      10 TeV  Table with 220 bins Emin=    ␣
↪100 eV    Emax=      10 TeV


Muon bremsstrahlung
muBrems:      SubType= 3
       dE/dx and range tables from 100 eV  to 10 TeV in 220 bins
       Lambda tables from threshold to 10 TeV, 20 bins per decade, spline: 1
       ===== EM models for the G4Region  DefaultRegionForTheWorld ======
              MuBrem : Emin=        0 eV    Emax=      10 TeV


Pair production
muPairProd:      SubType= 4
       dE/dx and range tables from 100 eV  to 10 TeV in 220 bins
       Lambda tables from threshold to 10 TeV, 20 bins per decade, spline: 1
       Sampling table 17x1001; from 1 GeV to 10 TeV
       ===== EM models for the G4Region  DefaultRegionForTheWorld ======
          muPairProd : Emin=        0 eV    Emax=      10 TeV


Muon ionisation
muIoni:      SubType= 2
       dE/dx and range tables from 100 eV  to 10 TeV in 220 bins
       Lambda tables from threshold to 10 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 ======
              Bragg : Emin=        0 eV    Emax=     200 keV   deltaVI
          BetheBloch : Emin=      200 keV   Emax=       1 GeV   deltaVI
        MuBetheBloch : Emin=        1 GeV   Emax=      10 TeV


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 10 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=        10 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=        10 TeV  Table with 220 bins Emin=   ␣
→100 eV    Emax=    10 TeV
```

Muon bremsstrahlung
```
muBrems:      SubType= 3
       dE/dx and range tables from 100 eV  to 10 TeV in 220 bins
       Lambda tables from threshold to 10 TeV, 20 bins per decade, spline: 1
        ===== EM models for the G4Region  DefaultRegionForTheWorld ======
               MuBrem : Emin=         0 eV    Emax=        10 TeV
```

Pair production
```
muPairProd:      SubType= 4
       dE/dx and range tables from 100 eV  to 10 TeV in 220 bins
       Lambda tables from threshold to 10 TeV, 20 bins per decade, spline: 1
       Sampling table 17x1001; from 1 GeV to 10 TeV
        ===== EM models for the G4Region  DefaultRegionForTheWorld ======
           muPairProd : Emin=         0 eV    Emax=        10 TeV
```

Muon ionisation
```
muIoni:      SubType= 2
       dE/dx and range tables from 100 eV  to 10 TeV in 220 bins
       Lambda tables from threshold to 10 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 ======
             ICRU73QO : Emin=         0 eV    Emax=       200 keV   deltaVI
            BetheBloch : Emin=       200 keV   Emax=         1 GeV   deltaVI
          MuBetheBloch : Emin=         1 GeV   Emax=        10 TeV
```

3.12.6 emlivermore

gamma

Photoelectric effect
```
phot:      SubType= 12  BuildTable= 0
       LambdaPrime table from 200 keV to 1 TeV in 134 bins
        ===== EM models for the G4Region  DefaultRegionForTheWorld ======
 LivermorePhElectric : Emin=         0 eV    Emax=         1 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 1 TeV in 120 bins
        ===== EM models for the G4Region  DefaultRegionForTheWorld ======
    LivermoreCompton : Emin=         0 eV    Emax=         1 TeV  FluoActive
```

Gamma conversion
```
conv:      SubType= 14  BuildTable= 1
       Lambda table from 1.022 MeV to 1 TeV, 22 bins per decade, spline: 1
        ===== EM models for the G4Region  DefaultRegionForTheWorld ======
 LivermoreConversion : Emin=         0 eV    Emax=        80 GeV
      BetheHeitlerLPM : Emin=        80 GeV   Emax=         1 TeV
```

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 1 TeV in 140 bins
    ===== EM models for the G4Region  DefaultRegionForTheWorld ======
  LivermoreRayleigh : Emin=        0 eV    Emax=        1 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 1 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=        1 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= 0.02, stepLimitType: 3, latDisplacement: 1, skin= 1, geomFactor= 2.5
    ===== EM models for the G4Region  DefaultRegionForTheWorld ======
        UrbanMsc : Emin=        0 eV    Emax=      100 MeV  Table with 120 bins Emin=    ␣
↪100 eV    Emax=     100 MeV
      WentzelVIUni : Emin=      100 MeV    Emax=        1 TeV  Table with 80 bins Emin=    100␣
↪MeV   Emax=       1 TeV


Ionisation
eIoni:      SubType= 2
    dE/dx and range tables from 100 eV  to 1 TeV in 200 bins
    Lambda tables from threshold to 1 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 ======
    LowEnergyIoni : Emin=        0 eV    Emax=      100 keV   deltaVI
      MollerBhabha : Emin=      100 keV    Emax=        1 TeV   deltaVI


Bremsstrahlung
eBrem:      SubType= 3
    dE/dx and range tables from 100 eV  to 1 TeV in 200 bins
    Lambda tables from threshold to 1 TeV, 20 bins per decade, spline: 1
    LPM flag: 1 for E > 1 GeV,  VertexHighEnergyTh(GeV)= 100000
    ===== EM models for the G4Region  DefaultRegionForTheWorld ======
        LowEnBrem : Emin=        0 eV    Emax=        1 GeV   AngularGen2BS
          eBremLPM : Emin=        1 GeV    Emax=        1 TeV   DipBustGen


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 1 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=        1 TeV


Positron annihilation
annihil:  integral: 1      SubType= 5  BuildTable= 0
    ===== EM models for the G4Region  DefaultRegionForTheWorld ======
        eplus2gg : Emin=        0 eV    Emax=        1 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= 0.02, stepLimitType: 3, latDisplacement: 1, skin= 1, geomFactor= 2.5
    ===== EM models for the G4Region  DefaultRegionForTheWorld ======
```

```
        UrbanMsc :  Emin=        0 eV    Emax=      100 MeV  Table with 120 bins Emin=    ␣
→100 eV    Emax=    100 MeV
       WentzelVIUni :  Emin=      100 MeV   Emax=        1 TeV  Table with 80 bins Emin=    100␣
→MeV   Emax=      1 TeV

Ionisation
eIoni:     SubType= 2
      dE/dx and range tables from 100 eV  to 1 TeV in 200 bins
      Lambda tables from threshold to 1 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=        1 TeV   deltaVI

Bremsstrahlung
eBrem:     SubType= 3
      dE/dx and range tables from 100 eV  to 1 TeV in 200 bins
      Lambda tables from threshold to 1 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=        1 TeV   DipBustGen

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 ======
       WentzelVIUni :  Emin=        0 eV    Emax=        1 TeV  Table with 200 bins Emin=    ␣
→100 eV    Emax=      1 TeV

Hadron bremsstrahlung
hBrems:     SubType= 3
      dE/dx and range tables from 100 eV  to 1 TeV in 200 bins
      Lambda tables from threshold to 1 TeV, 20 bins per decade, spline: 1
      ===== EM models for the G4Region  DefaultRegionForTheWorld ======
            hBrem :  Emin=        0 eV    Emax=        1 TeV

Hadron pair production
hPairProd:     SubType= 4
      dE/dx and range tables from 100 eV  to 1 TeV in 200 bins
      Lambda tables from threshold to 1 TeV, 20 bins per decade, spline: 1
      Sampling table 9x1001; from 7.50618 GeV to 1 TeV
      ===== EM models for the G4Region  DefaultRegionForTheWorld ======
        hPairProd :  Emin=        0 eV    Emax=        1 TeV

Ionisation
hIoni:     SubType= 2
      dE/dx and range tables from 100 eV  to 1 TeV in 200 bins
      Lambda tables from threshold to 1 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=        1 TeV   deltaVI

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 1 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=        1 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=        1 TeV  Table with 200 bins Emin=   ␣
↪100 eV    Emax=      1 TeV
```

Muon bremsstrahlung
```
muBrems:     SubType= 3
      dE/dx and range tables from 100 eV  to 1 TeV in 200 bins
      Lambda tables from threshold to 1 TeV, 20 bins per decade, spline: 1
      ===== EM models for the G4Region  DefaultRegionForTheWorld ======
            MuBrem : Emin=        0 eV    Emax=        1 TeV
```

Pair production
```
muPairProd:     SubType= 4
      dE/dx and range tables from 100 eV  to 1 TeV in 200 bins
      Lambda tables from threshold to 1 TeV, 20 bins per decade, spline: 1
      Sampling table 13x1001; from 1 GeV to 1 TeV
      ===== EM models for the G4Region  DefaultRegionForTheWorld ======
        muPairProd : Emin=        0 eV    Emax=        1 TeV
```

Muon ionisation
```
muIoni:     SubType= 2
      dE/dx and range tables from 100 eV  to 1 TeV in 200 bins
      Lambda tables from threshold to 1 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=        1 TeV
```

```
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 1 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=        1 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=        1 TeV  Table with 200 bins Emin=   ␣
↪100 eV    Emax=      1 TeV
```

Muon bremsstrahlung
```
muBrems:     SubType= 3
      dE/dx and range tables from 100 eV  to 1 TeV in 200 bins
      Lambda tables from threshold to 1 TeV, 20 bins per decade, spline: 1
      ===== EM models for the G4Region  DefaultRegionForTheWorld ======
            MuBrem : Emin=        0 eV    Emax=        1 TeV
```

```
Pair production
muPairProd:     SubType= 4
    dE/dx and range tables from 100 eV  to 1 TeV in 200 bins
    Lambda tables from threshold to 1 TeV, 20 bins per decade, spline: 1
    Sampling table 13x1001; from 1 GeV to 1 TeV
    ===== EM models for the G4Region  DefaultRegionForTheWorld ======
        muPairProd : Emin=        0 eV    Emax=        1 TeV

Muon ionisation
muIoni:     SubType= 2
    dE/dx and range tables from 100 eV  to 1 TeV in 200 bins
    Lambda tables from threshold to 1 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=        1 TeV
```

3.12.7 empenelope

```
gamma

Photoelectric effect
phot:     SubType= 12  BuildTable= 0
    LambdaPrime table from 200 keV to 10 TeV in 154 bins
    ===== EM models for the G4Region  DefaultRegionForTheWorld ======
      PenPhotoElec : Emin=        0 eV    Emax=       10 TeV  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 10 TeV in 140 bins
    ===== EM models for the G4Region  DefaultRegionForTheWorld ======
        PenCompton : Emin=        0 eV    Emax=       10 TeV  FluoActive

Gamma conversion
conv:     SubType= 14  BuildTable= 1
    Lambda table from 1.022 MeV to 10 TeV, 20 bins per decade, spline: 1
    ===== EM models for the G4Region  DefaultRegionForTheWorld ======
      PenConversion : Emin=        0 eV    Emax=       80 GeV
    BetheHeitlerLPM : Emin=       80 GeV   Emax=       10 TeV

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 10 TeV in 160 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 10 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=       10 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= 0.02, stepLimitType: 3, latDisplacement: 1, skin= 1, geomFactor= 2.5
      ===== EM models for the G4Region  DefaultRegionForTheWorld ======
            UrbanMsc : Emin=        0 eV    Emax=      100 MeV  Table with 120 bins Emin=    ␣
↪100 eV    Emax=    100 MeV
        WentzelVIUni : Emin=      100 MeV   Emax=       10 TeV  Table with 100 bins Emin=    ␣
↪100 MeV   Emax=     10 TeV

Ionisation
eIoni:      SubType= 2
      dE/dx and range tables from 100 eV  to 10 TeV in 220 bins
      Lambda tables from threshold to 10 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 ======
            PenIoni : Emin=        0 eV    Emax=        1 GeV
      MollerBhabha : Emin=        1 GeV    Emax=       10 TeV

Bremsstrahlung
eBrem:      SubType= 3
      dE/dx and range tables from 100 eV  to 10 TeV in 220 bins
      Lambda tables from threshold to 10 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=       10 TeV   DipBustGen

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 10 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=       10 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=       10 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= 0.02, stepLimitType: 3, latDisplacement: 1, skin= 1, geomFactor= 2.5
      ===== EM models for the G4Region  DefaultRegionForTheWorld ======
            UrbanMsc : Emin=        0 eV    Emax=      100 MeV  Table with 120 bins Emin=    ␣
↪100 eV    Emax=    100 MeV
        WentzelVIUni : Emin=      100 MeV   Emax=       10 TeV  Table with 100 bins Emin=    ␣
↪100 MeV   Emax=     10 TeV

Ionisation
eIoni:      SubType= 2
      dE/dx and range tables from 100 eV  to 10 TeV in 220 bins
      Lambda tables from threshold to 10 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 ======
            PenIoni : Emin=        0 eV    Emax=        1 GeV
      MollerBhabha : Emin=        1 GeV    Emax=       10 TeV

Bremsstrahlung
eBrem:      SubType= 3
      dE/dx and range tables from 100 eV  to 10 TeV in 220 bins
      Lambda tables from threshold to 10 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=       10 TeV   DipBustGen

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=       10 TeV  Table with 220 bins Emin=    ␣
↪100 eV    Emax=    10 TeV

Hadron bremsstrahlung
hBrems:     SubType= 3
      dE/dx and range tables from 100 eV  to 10 TeV in 220 bins
      Lambda tables from threshold to 10 TeV, 20 bins per decade, spline: 1
          ===== EM models for the G4Region  DefaultRegionForTheWorld ======
               hBrem : Emin=        0 eV    Emax=       10 TeV

Hadron pair production
hPairProd:      SubType= 4
      dE/dx and range tables from 100 eV  to 10 TeV in 220 bins
      Lambda tables from threshold to 10 TeV, 20 bins per decade, spline: 1
      Sampling table 13x1001; from 7.50618 GeV to 10 TeV
          ===== EM models for the G4Region  DefaultRegionForTheWorld ======
           hPairProd : Emin=        0 eV    Emax=       10 TeV

Ionisation
hIoni:      SubType= 2
      dE/dx and range tables from 100 eV  to 10 TeV in 220 bins
      Lambda tables from threshold to 10 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=       10 TeV

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 10 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=       10 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=       10 TeV  Table with 220 bins Emin=    ␣
↪100 eV    Emax=    10 TeV

Muon bremsstrahlung
muBrems:     SubType= 3
      dE/dx and range tables from 100 eV  to 10 TeV in 220 bins
```

```
        Lambda tables from threshold to 10 TeV, 20 bins per decade, spline: 1
        ===== EM models for the G4Region  DefaultRegionForTheWorld ======
              MuBrem : Emin=        0 eV    Emax=       10 TeV


Pair production
muPairProd:      SubType= 4
      dE/dx and range tables from 100 eV  to 10 TeV in 220 bins
      Lambda tables from threshold to 10 TeV, 20 bins per decade, spline: 1
      Sampling table 17x1001; from 1 GeV to 10 TeV
      ===== EM models for the G4Region  DefaultRegionForTheWorld ======
          muPairProd : Emin=        0 eV    Emax=       10 TeV


Muon ionisation
muIoni:      SubType= 2
      dE/dx and range tables from 100 eV  to 10 TeV in 220 bins
      Lambda tables from threshold to 10 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=       10 TeV


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 10 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=       10 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=       10 TeV  Table with 220 bins Emin=   ␣
↪100 eV    Emax=       10 TeV


Muon bremsstrahlung
muBrems:      SubType= 3
      dE/dx and range tables from 100 eV  to 10 TeV in 220 bins
      Lambda tables from threshold to 10 TeV, 20 bins per decade, spline: 1
      ===== EM models for the G4Region  DefaultRegionForTheWorld ======
              MuBrem : Emin=        0 eV    Emax=       10 TeV


Pair production
muPairProd:      SubType= 4
      dE/dx and range tables from 100 eV  to 10 TeV in 220 bins
      Lambda tables from threshold to 10 TeV, 20 bins per decade, spline: 1
      Sampling table 17x1001; from 1 GeV to 10 TeV
      ===== EM models for the G4Region  DefaultRegionForTheWorld ======
          muPairProd : Emin=        0 eV    Emax=       10 TeV


Muon ionisation
muIoni:      SubType= 2
      dE/dx and range tables from 100 eV  to 10 TeV in 220 bins
      Lambda tables from threshold to 10 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=       10 TeV
```

3.13 Tables by particle

3.13.1 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	Photoelectric 0-100 TeV	KleinNishina 0-100 TeV	BetheHeitler 0-80 GeV BetheHeitlerLPM 80 GeV-100 TeV
Opt2	Livermore-Rayleigh 0-100 TeV	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-10 TeV	PenConversion 0-80 GeV BetheHeitlerLPM 80 GeV-100 TeV
Livermore	Livermore-Rayleigh 0-100 TeV	Livermore-PhElectric 0-1 TeV	LivermoreCompton 0-1 TeV	LivermoreConversion 0-80 GeV BetheHeitlerLPM 80 GeV-100 TeV
Penelope	PenRayleigh 0-100 GeV	PenPhotoElec 0-10 TeV	PenCompton 0-10 TeV	PenConversion 0-80 GeV BetheHeitlerLPM 80 GeV-100 TeV

3.13.2 Electron

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

	Coulomb scattering	Multiple scattering	Pair production	Ionisation	Bremsstrahlung
Opt0	none	UrbanMsc 0-100 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	muPairProd 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-10 TeV	muPairProd 0-10 TeV	PenIoni 0-1 MeV MollerBhabha 1 MeV-100 TeV	eBremSB 0-1 GeV eBremLPM 1 GeV-100 TeV
Livermore	eCoulombScattering 100 MeV-10 TeV	UrbanMsc 0-100 MeV; WentzelVIUni 100 MeV-1 TeV	none	LowEnergyIoni 0-100 keV MollerBhabha 100 keV-1 TeV	LowEnBrem 0-1 GeV eBremLPM 1 GeV-100 TeV
Penelope	eCoulombScattering 100 MeV-10 TeV	UrbanMsc 0-100 MeV WentzelVIUni 100 MeV-10 TeV	none	PenIoni 0-1 GeV MollerBhabha 1 GeV-10 TeV	PenBrem 0-1 GeV eBremLPM 1 GeV-100 TeV

3.13.3 Positron

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

	Coulomb scattering	Multiple scattering	Pair production	Ionisation	Annihilation	Bremsstrahlung
Opt0	none	UrbanMsc 0-100 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	mu-Pair-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-10 TeV	Goudsmit-Saunderson 0-100 MeV; WentzelVIUni 100 MeV-10 TeV	mu-Pair-Prod 0-10 TeV	PenIoni 0-1 MeV MollerBhabha 1 MeV-10 TeV	eplus2gg 0-100 TeV	eBremSB 0-1 GeV eBremLPM 1 GeV-100 TeV
Livermore	eCoulomb-Scattering 100 MeV-10 TeV	UrbanMsc 0-100 MeV; WentzelVIUni 100 MeV-1 TeV	none	MollerBhabha 0-1 TeV	eplus2gg 0-100 TeV	eBremSB 0-1 GeV eBremLPM 1 GeV-100 TeV
Penelope	eCoulomb-Scattering 100 MeV-10 TeV	UrbanMsc 0-100 MeV WentzelVIUni 100 MeV-10 TeV	none	PenIoni 0-1 GeV MollerBhabha 1 GeV-10 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

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