Geant4 release 9.4

ELECTROMAGNETIC PHYSICS

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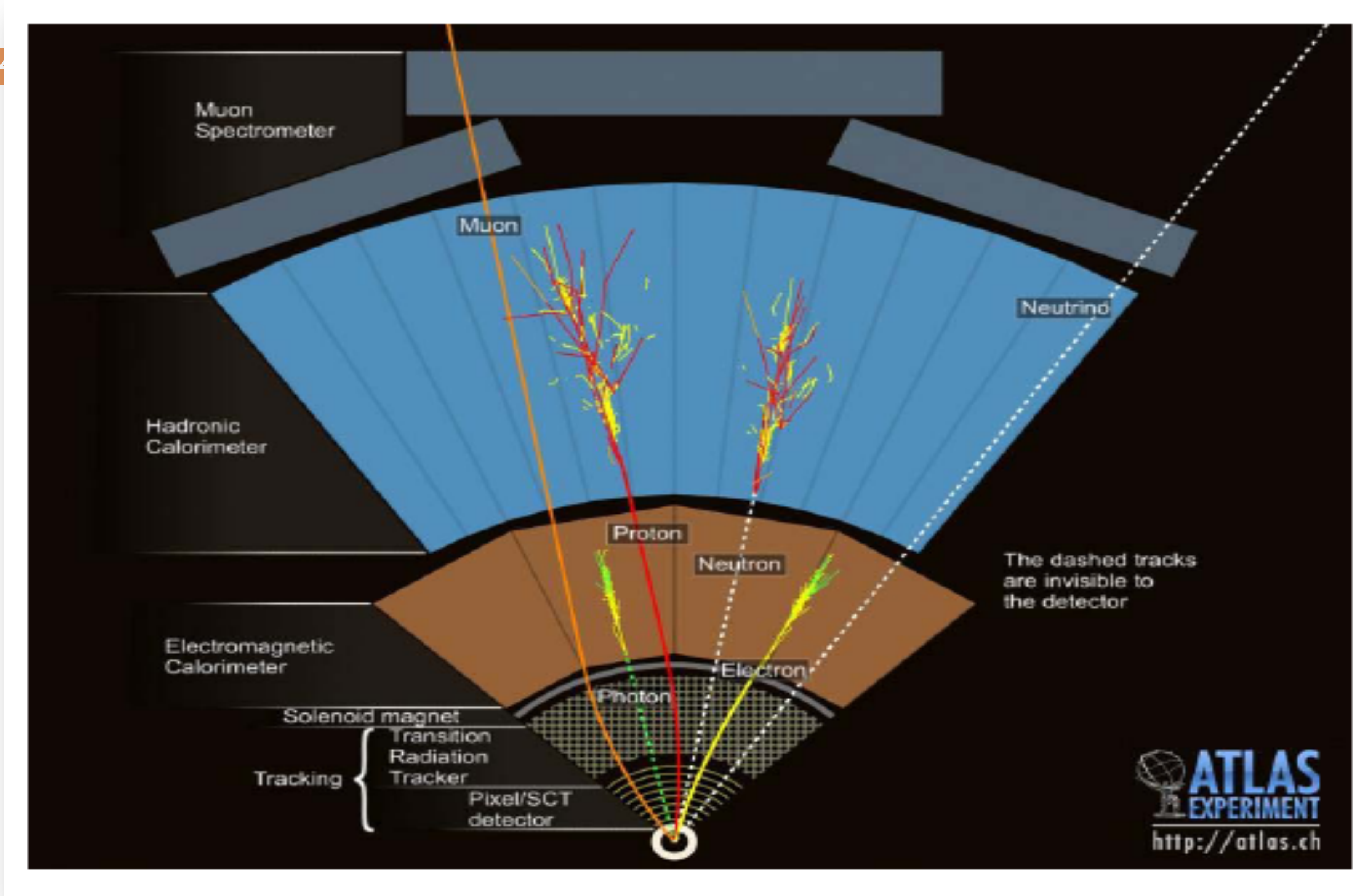
ELECTROMAGNETIC (EM) PHYSICS OVERVIEW

Geant4 Electromagnetic Physics

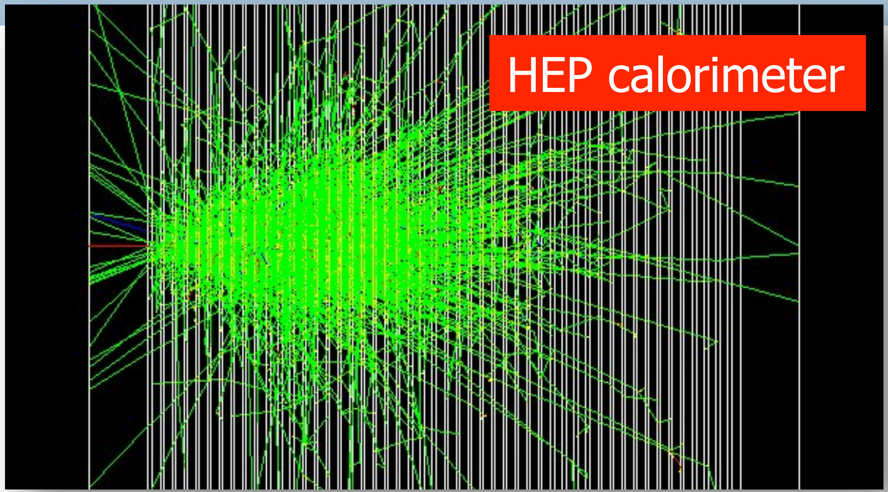
- Released with the 1st version of Geant4 with EM physics based on Geant3 experience (1998)
- Significant permanent development in many aspects of EM processes simulation since the beginning of Geant4 up to now
- Many years is used for large HEP experiments
  - BaBar, SLAC (since 2000)
  - LHC experiments: ATLAS, CMS and LHCb (since 2004)
- Many common requirements for HEP, space, medical and other applications
- A unique reference web page on Geant4 EM Physics
  - http://cern.ch/geant4/collaboration/working_groups/electromagnetic/index.shtml
  - Includes a Web interface to validation repository

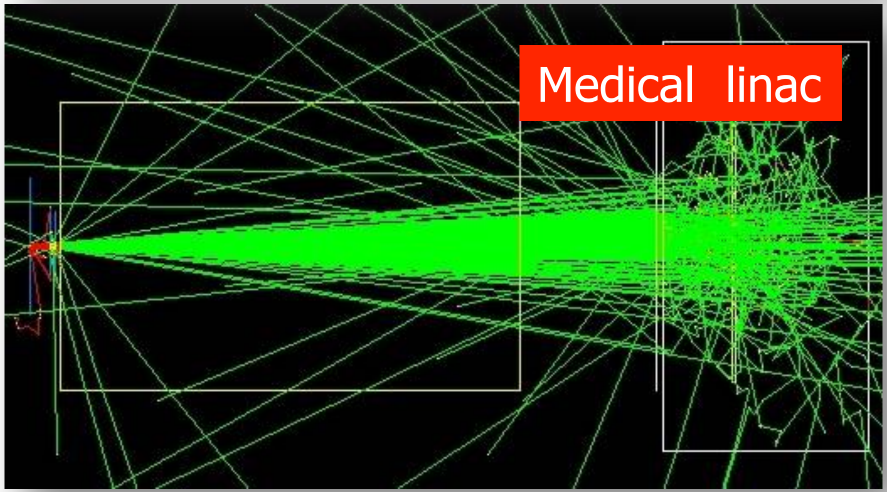
Geant4 simulation of ATLAS experiment at LHC, CERN



Gamma and electron transport

- Photon processes
  - γ conversion into e+e- pair
  - Compton scattering
  - Photoelectric effect
  - Rayleigh scattering
  - *Gamma-nuclear interaction in hadronic sub-package CHIPS*
- Electron and positron processes
  - Ionization
  - Coulomb scattering
  - Bremsstrahlung
  - *Nuclear interaction in hadronic sub-package CHIPS*
  - Positron annihilation
- Suitable for HEP & many other Geant4 applications with electron and gamma beams





Located in $G4INSTALL/sources/processes/electromagnetic

Geant4 EM packages

- Standard
  - gammas, e+- up to 100 TeV
  - hadrons up to 100 TeV
  - ions up to 100 TeV
- Muons
  - up to 1 PeV
  - energy loss propagator
- X-rays
  - X-ray and optical photon production processes
- High-energy
  - processes at high energy (E>10GeV)
  - physics for exotic particles
- Polarisation
  - simulation of polarised beams
- Optical
  - optical photon interactions
- Low-energy
  - Livermore library g, e- from 250 eV up to 1 GeV
  - Livermore library based polarized processes
  - PENELOPE code rewrite , g, e- , e+ from 250 eV up to 1 GeV (2001 version & 2008 version as beta)
  - hadrons and ions up to 1 GeV
  - microdosimetry models for radiobiology (Geant4-DNA project) from 4 eV to 10 MeV
  - atomic de-excitation (fluorescence + Auger)
- Adjoint
  - New sub-library for reverse Monte Carlo simulation from the detector of interest back to source of radiation
- Utils : general EM interfaces

Software design

- Since Geant4 9.3beta (June, 2009) the design is uniform for all EM packages
  - Allowing a coherent approach for high-energy and low-energy applications

- A physical interaction or process is described by a process class
  - Naming scheme : « G4ProcessName »
  - For example: G4Compton for photon Compton scattering
  - Assigned to Geant4 particle types
  - Inherit from G4VEmProcess base class

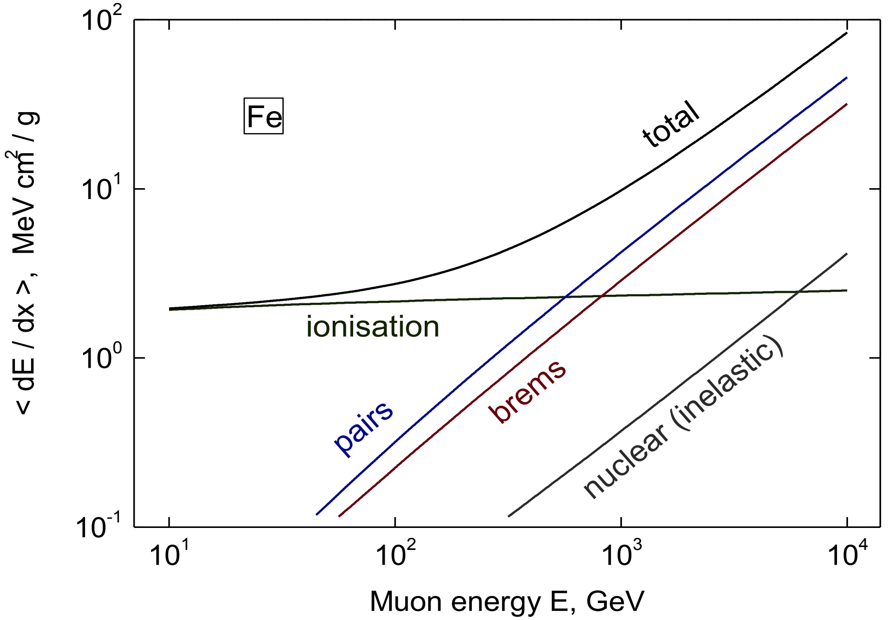
- A physical process can be simulated according to several models, each model being described by a model class
  - Naming scheme : « G4ModelNameProcessNameModel »
  - For example: G4LivermoreComptonModel
  - Models can be assigned to certain energy ranges and G4Regions
  - Inherit from G4VEmModel base class

- Model classes provide the computation of
  - Cross section and stopping power
  - Sample selection of atom in compound
  - Final state (kinematics, production of secondaries…)

Example : muon energy loss

$$\frac{dE(E,T_{cut})}{dx} = n_{at}\int_0^{T_{cut}} T \frac{d\sigma(Z,E,T)}{dT}\,dT$$

- Continuous energy loss from processes
  - Ionisation
  - Production of e+e-
  - Bremsstrahlung
- Ionisation and delta-electron production
  - G4BetheBlochModel
- Below 200 keV – ICRU'49 parameterization of dE/dx
  - G4BraggIonModel
- Radiative corrections to ionization at E > 1 GeV
  - G4MuBetheBlochModel

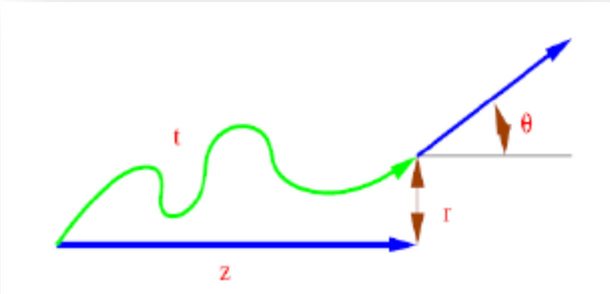


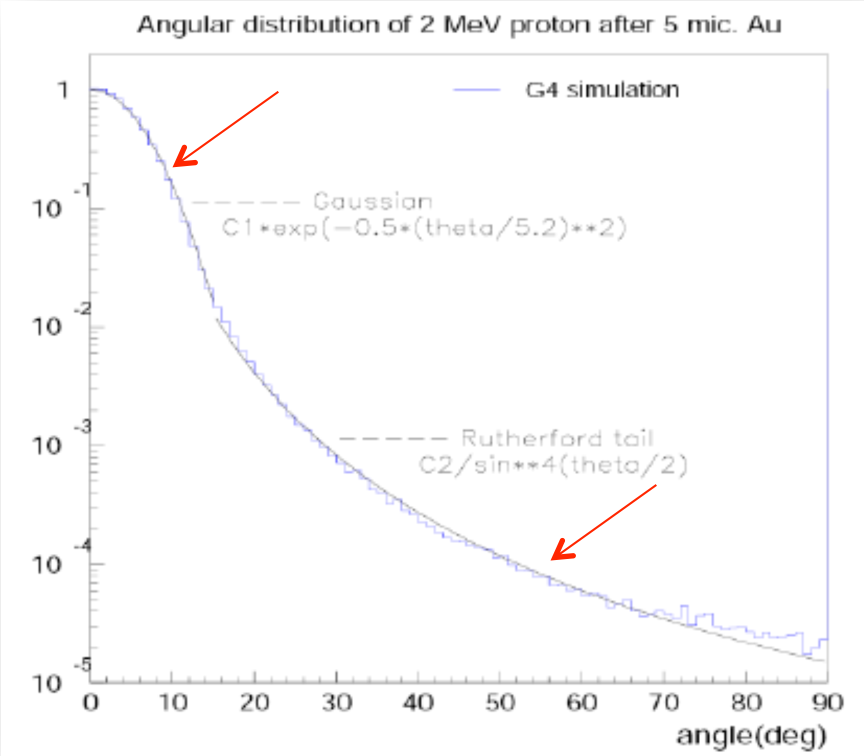
Muon stopping power precision ~2%

Multiple Coulomb Scattering (MSC)

- Charged particles traversing a finite thickness of matter suffer elastic Coulomb scattering.

- The cumulative effect of these small angle scatterings is a net deflection from the original particle direction.

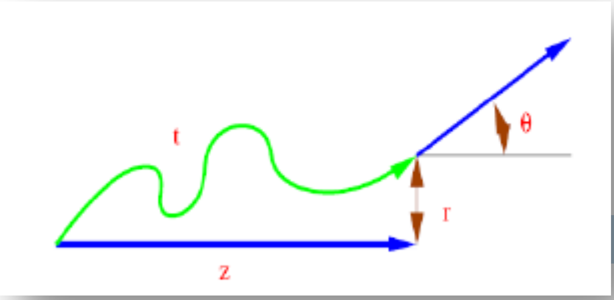




MSC models

Model	Particle type	Energy limit	Specifics and applicability
Urban (Urban 2006)	Any	-	Default model, (Lewis 1950) approach, tuned to data, used for LHC production.
Screened Nuclear Recoil (Mendenhall and Weller 2005)	p, ions	< 100 MeV/A	Theory based process, providing simulation of nuclear recoil for sampling of radiation damage, focused on precise simulation of effects for space app.
Goudsmit-Saunderson (Kadri 2009)	e^+, e^-	< 1 GeV	Theory based cross sections (Goudsmit and Saunderson 1950). EPSEPA code developed by Penelope group, final state using EGSnrc method (Kawrakov et al. 1998), precise electron transport
Coulomb scattering (2008)	any	-	Theory based (Wentzel 1927) single scattering model, uses nuclear form-factors (Butkevich et al. 2002), focused on muons and hadrons
WentzelVI (2009)	any	-	MSC for small angles, Coulomb Scattering (Wentzel 1927) for large angles, focused on simulation for muons and hadrons.
Ion Coulomb scattering (2010)	ions	-	Model based on Wentzel formula + relativistic effects + screening effects for projectile & target. From the work of P. G. Rancoita, C. Consolandi and V. Ivantchenko.

MSC algorithm



- Legend
  - True path length : t
  - Longitudinal or geometrical displacement : z
  - Lateral displacement : r
  - Angular deflection : (θ, f)

- The algorithm performs several steps for the simulation of MSC which are essentially the same for many « condensed » simulations
  - The physics processes and the geometry select the step length; MSC performs the t ↔ z transformation only
  - The transport along the initial direction is not MSC's business
  - Sampling of scattering angle (θ, ϕ)
  - Computing of lateral displacement and relocation of particle

Geant4 Urban MSC model

- The MSC model used in Geant4 is based on Lewis' MSC theory of transport of charged particles (1950)

- It uses phenomenological functions to determine the angular and spatial distributions after a simulation step

- The functions have been chosen in such a way as to give the same moments of the angular and spatial distributions as the Lewis theory

MSC classes

- Processes per particle type are available
  - G4eMultipleScattering for e+/e-
  - G4MuMultipleScattering for μ+/μ-
  - G4hMultipleScattering for hadrons and ions

- L. Urban models
  - G4UrbanMscModel93 : used by default in G4eMultipleScattering
  - G4UrbanMscModel90 : used for muons in G4MuMultipleScattering, and for hadrons & ions in G4hMultipleScattering

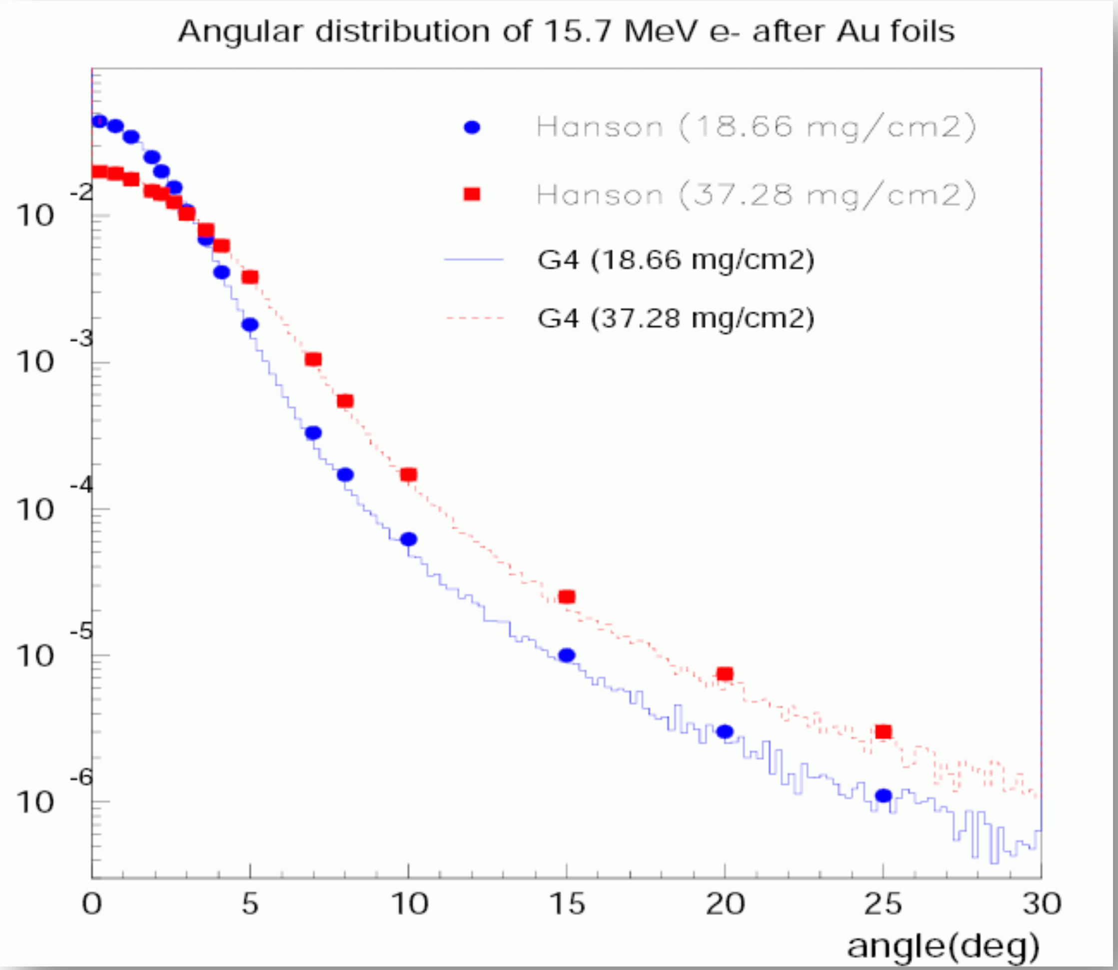
- Alternative single and multiple scattering models are available to users
  - see extended examples…

MSC in Physics Lists from G4 9.4

- Situation is changed significantly

EM Reference Physics list	e- / e+ G4eMultipleScattering	mu+ / mu- G4MuMultipleScattering	Hadrons, ions G4hMultipleScattering
G4EmStandardPhysics	G4UrbanMscModel93	G4WentelVIModel + G4CoulombScattering	G4UrbanMscModel90
G4EmStandardPhysics_option1	G4UrbanMscModel93	G4WentelVIModel+ G4CoulombScattering	G4UrbanMscModel90
G4EmStandardPhysics_option2	G4UrbanMscModel93	G4WentelVIModel+ G4CoulombScattering	G4WentelVIModel for pions, kaons, protons
G4EmStandardPhysics_option3	G4UrbanMscModel93	G4WentelVIModel+ G4CoulombScattering	G4UrbanMscModel90
G4EmLivermorePhysics	G4GoudsmithSaundersonMscModel	G4WentelVIModel+ G4CoulombScattering	G4UrbanMscModel90
G4EmLivermorePolarizedPhysics	G4GoudsmithSaundersonMscModel	G4WentelVIModel+ G4CoulombScattering	G4UrbanMscModel90
G4EmPenelopePhysics	G4GoudsmithSaundersonMscModel	G4WentelVIModel+ G4CoulombScattering	G4UrbanMscModel90

Example of MSC validation



HOW TO INVOKE EM PHYSICS IN GEANT4 ?

Physics lists

- A Physics list is the mandatory user class making the general interface between the physics the user needs and the Geant4 kernel
  - It should include the list of particles
  - The G4ProcessManager of each particle maintains a list of processes

- There are 3 ordered types of processes per particle which are active at different stages of the Geant4 tracking:
  - AtRest (annihilation, …)
  - AlongStep (ionisation, Bremsstrahlung, …)
  - PostStep (photo-electric, Compton, Cerenkov,….)

- Geant4 provides several configurations of EM physics lists called constructors (G4VPhysicsConstructor) in the physics_list library of Geant4

- These constructors can be included into a modular Physics list in a user application (G4VModularPhysicsList)

EM Physics constructors

- G4EmStandardPhysics – default
- G4EmStandardPhysics_option1 – HEP, fast but not precise
- G4EmStandardPhysics_option2 – experimental
- G4EmStandardPhysics_option3 – medical, space
- G4EmLivermorePhysics
- G4EmLivermorePolarizedPhysics
- G4EmPenelopePhysics
- G4EmDNAPhysics

Combined Physics:
- Standard > 1 GeV
- Low Energy < 1 GeV

- Located in $G4INSTALL/source/physics_list/builders
- Advantage of using of these classes
  - they are tested on a regular basis and are used for regular validation

Example: G4EmStandard Physics


```
G4ProcessManager* pmanager

  if ( particleName == "gamma"  ) {
    pmanager->AddDiscreteProcess(new G4PhotoElectricEffect);
    pmanager->AddDiscreteProcess(new G4ComptonScattering);
    pmanager->AddDiscreteProcess(new G4GammaConversion);

  } else if ( particleName == "e+" ) {
    pmanager->AddProcess(new G4eMultipleScattering, -1,  1, 1);
    pmanager->AddProcess(new G4eIonisation,         -1,  2, 2);
    pmanager->AddProcess(new G4eBremsstrahlung,     -1,  3, 3);
    pmanager->AddProcess(new G4eplusAnnihilation,    0, -1, 4);
```

Only PostStep

AlongStep

AtRest PostStep

3 stages

- Numbers are process order
  - G4Transportation is the 1st (order = 0) for AlongStep and PostStep
- "-1" means that the process is not active

Example: Penelope Physics

- Process class G4PhotoElectricEffect
- The default model is G4PEEffectModel
- There are alternative Livermore and Penelope models
- Example of combined EM Physics Lists
  - Penelope photo-electric below 1 GeV

```
…
G4double limit = 1.0*GeV;
If ( particleName == "gamma"  )
{
   G4PhotoElectricEffect* pef= new G4PhotoElectricEffect();
   G4PenelopePhotoElectricModel* aModel = new G4PenelopePhotoElectricModel();
   aModel->SetHighEnergyLimit(limit);
   pef->AddEmModel(0, aModel);               // 1st parameter - order
   pmanager->AddDiscreteProcess(pef);
…
```

How to extract Physics ?

- Possible to retrieve Physics quantities using a G4EmCalculator object

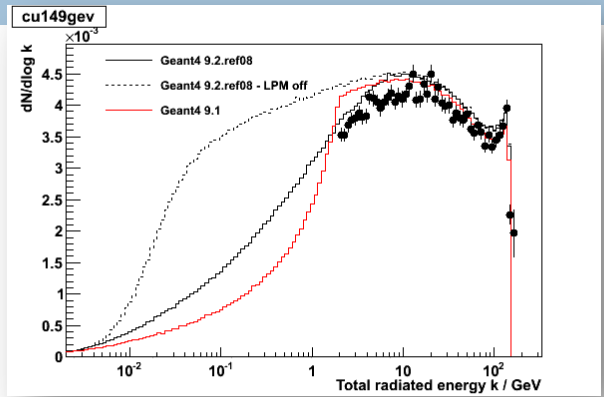
- Physics List should be initialized

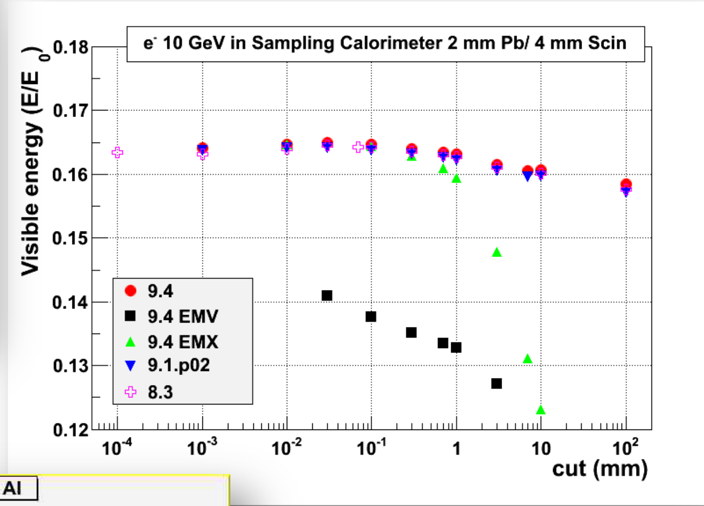
- Example for retrieving the total cross section of a process with name procName, for particle and material matName

```
#include "G4EmCalculator.hh"
...
G4EmCalculator emCalculator;

G4Material* material =
  G4NistManager::Instance()->FindOrBuildMaterial(matName);

G4double density = material->GetDensity();

G4double massSigma = emCalculator.ComputeCrossSectionPerVolume
    (energy,particle,procName,material)/density;

G4cout << G4BestUnit(massSigma, "Surface/Mass") << G4endl;
```

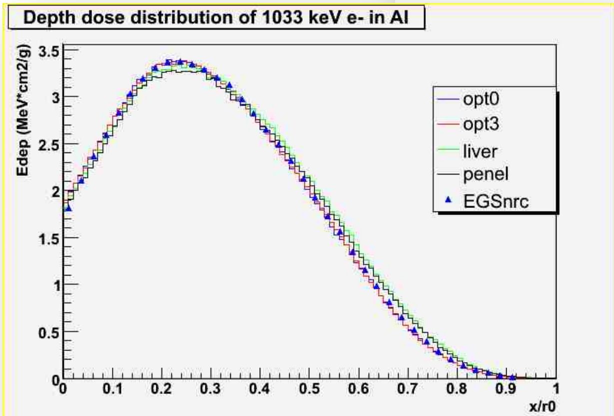
- A good example: $G4INSTALL/examples/extended/electromagnetic/TestEm14. Look in particular at the RunAction.cc class

Validation repository





- A web-based verification tool has been developed for easy comparison of EM physics results obtained with different Geant4 version, and with measurements



http://www-zeuthen.desy.de/geant4/web/

To learn more:
$G4INSTALL/examples/extended/electromagnetic

Check basic quantities	
Total cross sections, mean free paths ...	TestEm0, Em13, Em14
Stopping power, particle range ...	Em0, Em1, Em5, Em11, Em12
Final state : energy spectra, angular distributions	Em14
Energy loss fluctuations, fluorescence	Em18
Multiple Coulomb scattering	
as an isolated mechanism	Em15
as a result of particle transport	Em5
More global verifications	
Single layer: transmission, absorption, reflexion	Em5
Bragg curve, tallies	Em7
Depth dose distribution	Em11, Em12
Shower shapes, Moliere radius	Em2
Sampling calorimeters, energy flow	Em3
Crystal calorimeters	Em9
Other specialized programs	
High energy muon physics	Em17
Other rare, high energy processes	Em6
Synchrotron radiation	Em16
Transition radiation	Em8
Photo-absorption-ionization model	Em10

Refer to section on extended examples in App. User Guide.

Suggestions

- The list of available EM processes and models is maintained by EM working groups in EM web pages
  - http://cern.ch/geant4/collaboration/working_groups/electromagnetic/index.shtml
- Geant4 extended and advanced examples show how to use EM processes and models
  - In $G4INSTALL/examples
- User feedback is always welcome

LOW ENERGY ELECTROMEGENTIC PHYSICS

Content

- Context
- Physics models
  - Livermore, including polarized photon models
  - Penelope
  - Ion ICRU'73 model
  - Geant4-DNA
  - Atomic de-excitation
- How to implement a Physics list ?
- Documentation

CONTEXT

Purpose

- Extend the coverage of Geant4 electromagnetic interactions with matter
  - for photons, electrons, hadrons and ions
  - down to very low energies (sub-keV scale)

- Possible domains of applications
  - space science
  - medical physics
  - microdosimetry for radiobiology
  - …

- Choices of Physics models include
  - Livermore library: electrons and photons [250 eV – 1 GeV]
  - Penelope (Monte Carlo): electrons, positrons and photons [250 eV – 1 GeV]
  - Microdosimetry models (Geant4-DNA project): [eV – ~100 MeV]

Recent software design

- Identical to the one proposed by the Standard EM working group
  - Applicable to all low energy electromagnetic software classes
  - Allows a coherent approach to the modelling of all electromagnetic interactions
  - No more artificial separation between the 2 EM categories
  - Many bugs & flaws accumulated over past years have been solved
  - Please use Geant4 9.4 release and above !

- A physical interaction or process is described by a process class
  - Naming scheme : « G4ProcessName »
  - Eg. : « G4ComptonScattering » for photon Compton scattering

- A physical process can be simulated according to several models, each model being described by a model class
  - Naming scheme : « G4ModelNameProcessNameModel »
  - Eg. : « G4LivermoreComptonModel » for the Livermore Compton model
  - Models can be alternative and/or complementary in certain energy ranges

- According to the selected model, model classes provide the computation of
  - the process total cross section & the stopping power
  - the process final state (kinematics, production of secondaries…)

PHYSICS MODELS

Livermore models

Livermore models

- Full set of models for electrons and gammas

- Based on publicly available evaluated data tables from the Livemore data library
  - EADL : Evaluated Atomic Data Library
  - EEDL : Evaluated Electrons Data Library
  - EPDL97 : Evaluated Photons Data Library
  - Mixture of experiments and theories
  - Binding energies: Scofield

- Data tables are interpolated by Livermore model classes to compute
  - Total cross sections: photoelectric, Compton, Rayleigh, pair production, Bremsstrahlung
  - Sub-levels integrated cross sections: photo-electric, ionization
  - Energy spectra: secondary e- processes

- Validity range : 250 eV - 100 GeV
  - Processes can be used down to 100 eV, with a reduced accuracy
  - In principle, validity range down to ~10 eV

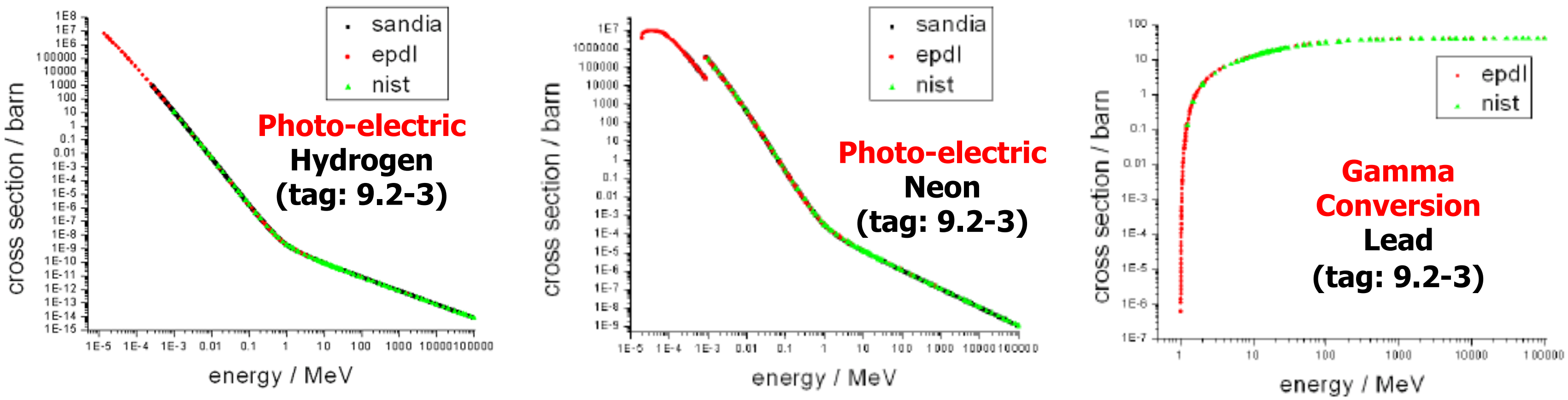
- Included elements from Z=1 to Z=100
  - Include atomic effects (fluorescence, Auger)
  - Atomic relaxation : Z > 5 (EADL transition data)

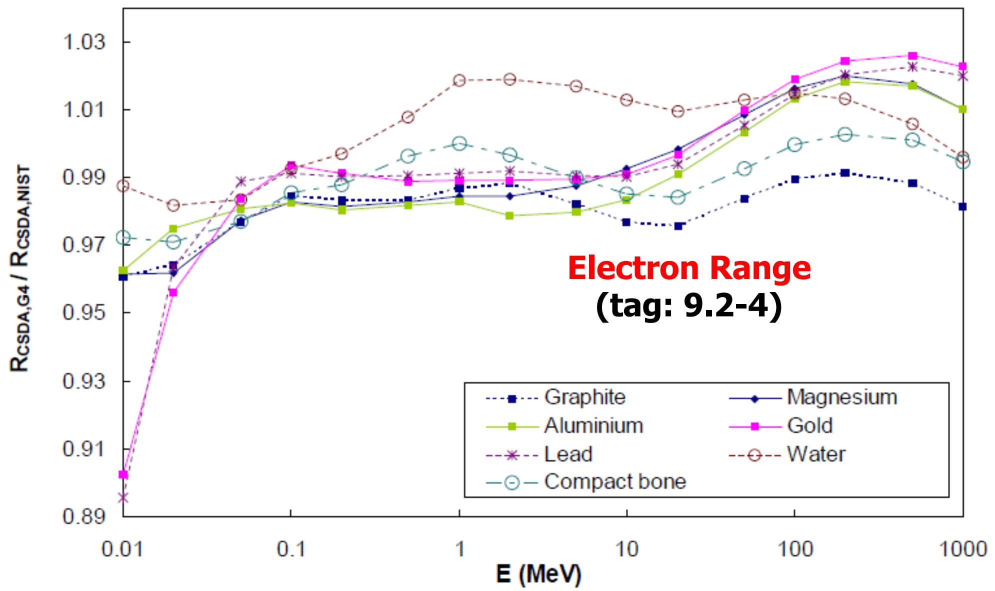
- Naming scheme: G4LivermoreXXXModel (eg. G4LivermoreComptonModel)

Livermore models

Physics Process	Process Class	Model Class	Low Energy Limit	High Energy Limit
Gammas				
Compton	G4ComptonScattering	G4LivermoreComptonModel	250 eV	100 GeV
Polarized Compton	G4ComptonScattering	G4LivermorePolarizedComptonModel	250 eV	100 GeV
Rayleigh	G4RayleighScattering	G4LivermoreRayleighModel	250 eV	100 GeV
Polarized Rayleigh	G4RayleighScattering	G4LivermorePolarizedRayleighModel	250 eV	100 GeV
Conversion	G4GammaConversion	G4LivermoreGammaConversionModel	1.022 MeV	100 GeV
Polarized Conversion	G4GammaConversion	G4LivermorePolarizedGammaConversionModel	1.022 MeV	100 GeV
Photo-electric	G4PhotoElectricEffect	G4LivermorePhotoElectricModel	250 eV	100 GeV
Polarized Photo-electric	G4PhotoElectricEffect	G4LivermorePolarizedPhotoElectricModel	250 eV	100 GeV
Electrons				
Ionization	G4eIonisation	G4LivermoreIonisationModel	250 eV	100 GeV
Bremsstrahlung	G4eBremsstrahlung	G4LivermoreBremsstrahlungModel	250 eV	100 GeV

Eg. of validation of Livermore models





Polarized Livermore processes

- Describe in detail the kinematics of polarized photon interactions
- Based on the Livermore database
- Possible applications of such developments
  - design of space missions for the detection of polarized photons
- Documentation
  - Nucl. Instrum.Meth. **A566**: 590-597, 2006 (Photoelectric)
  - Nucl. Instrum.Meth. **A512**: 619-630, 2003 (Compton and Rayleigh)
  - Nucl.Instrum.Meth. **A452**:298-305,2000 (Pair production)
- Naming scheme: G4LivermorePolarizedXXXModel
  - eg. G4LivermorePolarizedComptonModel

PHYSICS MODELS

Penelope models

Penelope physics

- Geant4 includes the low-energy models for $e^{\pm}$ and **gamma-rays** from the Monte Carlo code PENELOPE (PENetration and Energy LOss of Positrons and Electrons) version 2001 (and 2008 as beta)
  - Nucl. Instrum. Meth. **B 207** (2003) 107

- Physics models
  - Specifically developed by the Barcelona group (F. Salvat *et al.*)
  - Great care was dedicated to the low-energy description
    - atomic effects, fluorescence, Doppler broadening, etc.

- Mixed approach: analytical, parametrized & database-driven
  - applicability energy range: 250 eV - 1 GeV

- Includes also positrons (not described by Livermore models)

- G4PenelopeXXXModel (e.g. G4PenelopeComptonModel)

Penelope models

Physics Process	Process Class	Model Class	Low Energy Limit	High Energy Limit
Gammas				
Compton	G4ComptonScattering	G4PenelopeComptonModel	250 eV	1 GeV
Rayleigh	G4RayleighScattering	G4PenelopeRayleighModel	250 eV	1 GeV
Conversion	G4GammaConversion	G4PenelopeGammaConversionModel	1.022 MeV	1 GeV
Photo-electric	G4PhotoElectricEffect	G4PenelopePhotoElectricModel	250 eV	1 GeV
Electrons/Positrons				
Ionization	G4eIonisation	G4PenelopeIonisationModel	250 eV	1 GeV
Bremsstrahlung	G4eBremsstrahlung	G4PenelopeBremsstrahlungModel	250 eV	1 GeV
Positrons				
Annihilation	G4eplusAnnihilation	G4PenelopeAnnihilationModel	250 eV	1 GeV

PHYSICS MODELS

Ions

Ion energy loss model

- Describes the energy loss of ions heavier than Helium
  due to interaction with the atomic shells of target atoms

- The model computes
  - Restricted stopping powers: continuous energy loss of ions as they slow down in an absorber
  - Cross sections for the production of δ-rays
    - δ-rays are only produced above a given threshold, which inherently also governs
      the discrete energy loss of ions

- Primarily of interest for
  - Medical applications
  - Space applications

Ion stopping powers (1/2)

- Electronic stopping powers are an important ingredient to determine the mean energy loss of ions along simulation steps
  - Impacts the ion range (for example)

- Restricted stopping powers: account for the fact that the continuous energy loss description is restricted to energies below T_{cut} (where T_{cut} denotes the lower production threshold of δ-rays)

- Restricted stopping powers are calculated according to (T = kinetic energy per nucleon)
  - $T < T_L$: Free electron gas model
  - $T_L \leq T \leq T_H$: Interpolation of tables or parameterization approach
  - $T > T_H$: Bethe formula (using an effect. charge) + high order corr.

Ion stopping powers (2/2)

- Parameterization approach
  - Model incorporates ICRU 73 stopping powers into Geant4

- ICRU73 model
  - Covers a large range of ion-material combinations: Li to Ar, and Fe
  - Stopping powers: based on binary theory
  - Special case: water
    - Revised ICRU 73 tables of P. Sigmund are used (since Geant4 9.3.b01)
    - Mean ionization potential of water of 78 eV
  - Current model parameters (Geant4 9.3.b01):
    - T_{High} = 10 MeV/nucleon (except Fe ions: T_H = 1 GeV/nucleon)
    - T_{Low} = 0.025 MeV/nucleon (lower boundary of ICRU 73 tables)
  - For ions heavier than Ar
    - Scaling of Fe ions based on effective charge approach

How to use the new model ?

- Model name: G4IonParametrisedLossModel

- Applicable from Z>2

- Already included in G4EmStandardPhysics_option3, G4EmLivermorePhysics and G4EmPenelopePhysics physics builders

- Designed to be used with the G4ionIonisation process (in standard EM category)
  - Not activated by default when using G4ionIonisation
  - Users can employ this model by using the SetEmModel method of the G4ionIonisation process

- Restricted to one Geant4 particle type: G4GenericIon
  - the process G4ionIonisation is also applicable to alpha particles (G4Alpha) and He3 ions (G4He3), however the G4IonParametrisedLossModel model must not be activated for these light ions
  - Below Z<2, we use G4BraggModel, G4BraggIonModel, and G4BetheBlochModel with the G4ionIonisation process

Using ICRU 73 data tables

- The ion model
  - uses ICRU 73 stopping powers, if corresponding ion-material combinations are covered by the ICRU 73 report
  - otherwise applies a Bethe-Bloch based formalism
- For compounds, ICRU 73 stopping powers are used if the material name coincides with the name of Geant4 NIST materials
  - e.g. G4_WATER
- Elemental materials are matched to the corresponding ICRU 73 stopping powers by means of the atomic number of the material. The material name may be arbitrary in this case.
- For a list of applicable materials, the user is referred to the ICRU 73 report.
- All data files are in the G4LEDATA set of data.

PHYSICS MODELS

Geant4-DNA

Geant4 for microdosimetry

- History : initiated in 2001 by Petteri Nieminen (European Space Agency / ESTEC) in the framework of the « Geant4-DNA » project

- Objective : adapt the general purpose Geant4 Monte Carlo toolkit for the simulation of interactions of radiation with biological systems at the cellular and DNA level (« microdosimetry »)

- A full multidisciplinary activity of the Geant4 low energy electromagnetic Physics working group, involving physicists, theoreticians, biophysicsts…

- Applications :
  - Radiobiology, radiotherapy and hadrontherapy
    (eg. early prediction of direct & non-direct DNA strand breaks from ionising radiation)
  - Radioprotection for human exploration of Solar system
  - Not limited to biological materials (ex. DNA bases)

Geant4 for microdosimetry

- Several models are available for the description of physical processes involving

  e^-, p, H, He, He^+, He^{2+}, C^{6+}, N^{7+}, O^{8+}, Fe^{28+}

- Include elastic scattering, excitation (electronic + vibrations), ionisation and charge change

- For now, these models are valid for liquid water medium only

- Models available in Geant4-DNA
  - are published in the literature
  - may be purely analytical or use interpolated cross section data

- They are all discrete processes
  - See $G4INSTALL/examples/advanced/dnaphysics

- Can be combined with other EM categories (Standard, LowE)
  - See $G4INSTALL/examples/advanced/microdosimetry

Physics stage :

status of Physics models in Geant4 9.4

	e	**p**	**H**	**a, He+, He**	**C, O, Fe,...**
Elastic scattering	> 9 eV – 1 MeV Screened Rutherford **>4 eV – 1 MeV** Champion	-	-	-	-
Excitation A_1B_1, B_1A_1, Ryd A+B, Ryd C +D, diffuse bands	9 eV – 1 MeV Born	10 eV – 500 keV Miller Green 500 keV – 100 MeV Born	10 eV – 500 keV Miller Green	Effective charge scaling from same models as for proton 1 keV – 400 MeV	-
Charge Change	-	100 eV – 10 MeV Dingfelder	100 eV – 10 MeV Dingfelder		-
Ionisation $1b_1$, $3a_1$, $1b_2$, $2a_1$ + $1a_1$	11 eV – 1 MeV Born	100 eV – 500 keV Rudd 500 keV – 100 MeV Born	100 eV – 100 MeV Rudd		Effective charge scaling **0.5 MeV*u – 10^6 MeV*u**
Vibrational excitation	**2 – 100 eV** Sanche	-			
Attachment	**4 – 13 eV** Melton				

PHYSICS MODELS

Atomic de-excitation

Atomic effects

- Atomic de-excitation initiated by other EM processes
  - Examples: photo-electric effect, ionisation by e- and ions (eg. PIXE)
  - Leave the atom in an excited state

- EADL data contain transition probabilities
  - radiative: fluorescence
  - non-radiative:
    - Auger e-: inital and final vacancies in different sub-shells
    - Coster-Kronig e-: identical sub-shells

- Atomic de-excitation simulation is now compatible with both Standard & LowE EM categories

Including atomic effects

- How to use fluorescence in Livermore & Penelope Physics ?
  - Fluorescence is automatically activated for gamma photo electric effect and for electron ionisation.
  - If a user wants to deactivate fluorescence, he/she needs to apply the SetUseAtomicDeexcitation(false) method to the corresponding model.

- How to include Auger emission in Livermore & Penelope Physics ?
  - The user must apply the method ActivateAuger(true) to the corresponding model.
  - For example, for gammas and electrons with Penelope:

```
thePenelopePhotoElectricModel->ActivateAuger(true);
thePenelopeIonisationModel->ActivateAuger(true);
```

- How to include fluorescence, Auger emission in Standard EM (options 2 & 3) ?
  - Some UI commands are available (no more code edition necessary !)

```
/run/initialize
/process/em/fluo true
/process/em/auger true
/process/em/pixe true
```

  - The same approach will be proposed for Livermore & Penelope

- Example to start from
  - See $G4INSTALL/examples/extended/electromagnetic/TestEm18

HOW TO IMPLEMENT A EM PHYSICS LIST ?

Physics lists

- A user can
  - use reference Physics lists provided with Geant4 (QBBC, ….)
  - build his/her own Physics list in his/her application
  - or use already available EM constructors

1. If you choose to build your own Physics list
   - Refer to the Geant4 Low Energy EM working group website, look at the Processes and Physics lists sections
   - Also you may refer to Geant4 examples
     - $G4INSTALL/examples/extended/electromagnetic/TestEm14

2. More safe: if you prefer to use the available constructors, these are named as:
   - G4EmLivermorePhysics
   - G4EmLivermorePolarizedPhysics
   - G4EmPenelopePhysics
   - G4EmDNAPhysics

How to use the already available Physics lists constructors?

- These classes derive from the G4VPhysicsConstructor abstract base class; they are added to the reference Physics lists via the method RegisterPhysics (G4VPhysicsConstructor*)
  - see $G4INSTALL/source/physics_lists/lists subdirectory

- A good alternative implementation example of Physics list that uses EM physics constructors is available in $G4INSTALL/examples/extended/electromagnetic/TestEm2

- If some hadronic physics is needed additionally to EM Physics: $G4INSTALL/examples/extended/electromagnetic/TestEm7

- The source code for Physics list constructors is available in the following directory $G4INSTALL/source/physics_list/builders

DOCUMENTATION

Web sites

- A unique reference web page on Geant4 EM Physics
  - http://geant4.cern.ch/collaboration/EMindex.shtml

- From there, links to :
  - Geant4 Standard Electromagnetic Physics working group pages
  - Geant4 Low Energy Electromagnetic Physics working group pages

- Also from Geant4 web site:
  - http://cern.ch/geant4
    - Who we are
      - Low energy Electromagnetic Physics

EM Physics CERN TWiki

https://twiki.cern.ch/twiki/bin/view/Geant4/ElectromagneticPhysics

Electromagnetic Physics

- Introduction
- Working Group pages
- Validation and verification
- Publications and presentations
- Examples
- Physics Lists
- Models and Processes
- Milestones
- Release notes
- Manuals
- Getting help
- Related links

Introduction

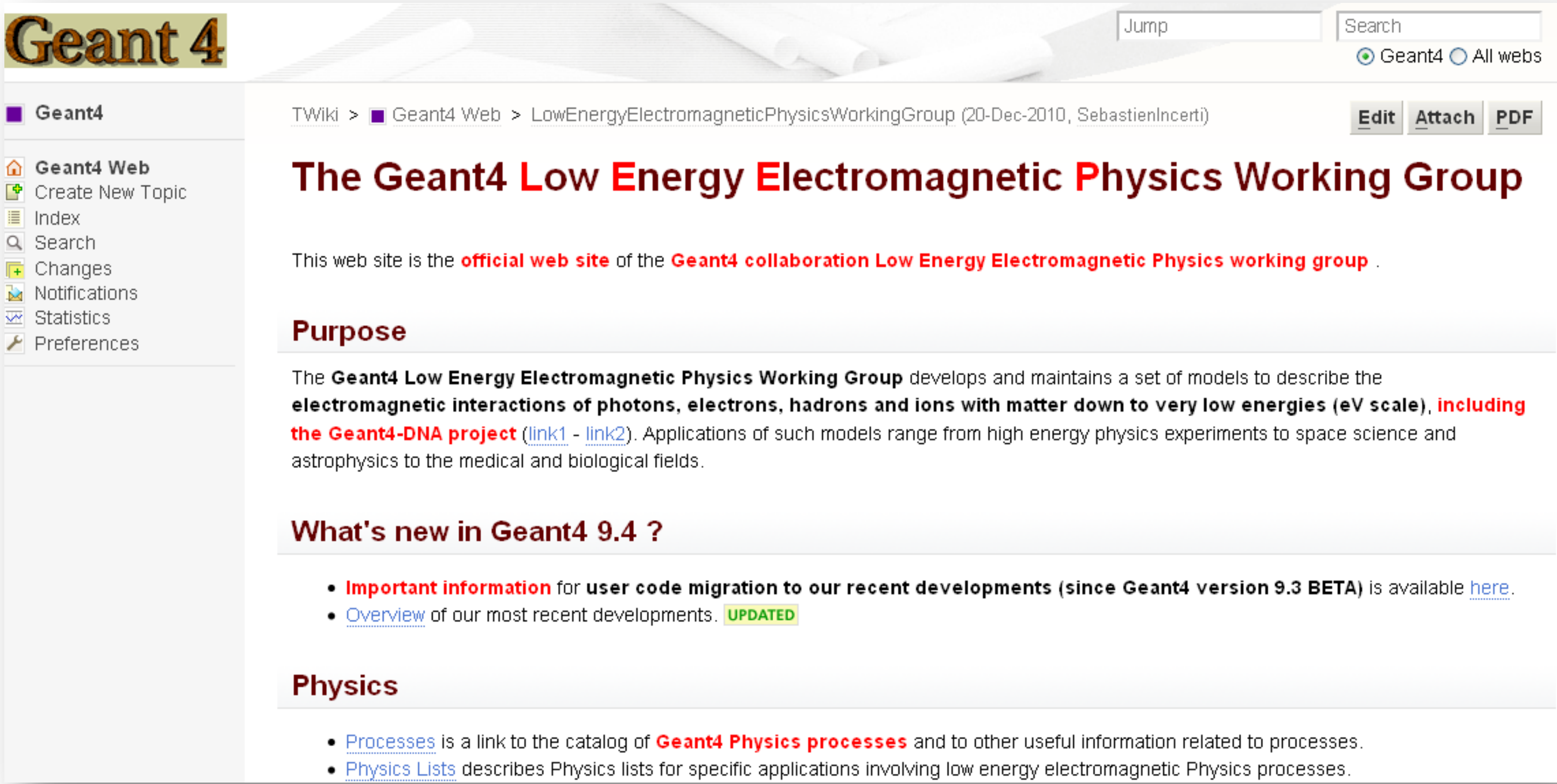
The electromagnetic physics domain includes Geant4 sub-packages for simulation of electromagnetic interactions of charged particles, gammas and optical photons. This is central TWiki page for Geant4 EM physics maintained by common efforts of the EM Standard and EM Low-energy working groups.

Working Group pages

- Electromagnetic Physics Home
- Electromagnetic Standard working group page
- Electromagnetic Standard working group coordination TWiki
- Low Energy Electromagnetic working group page
- Low Energy Electromagnetic working group TWiki

Low Energy WG CERN TWiki

https://twiki.cern.ch/twiki/bin/view/Geant4/LowEnergyElectromagneticPhysicsWorkingGroup



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TWiki > Geant4 Web > LowEnergyElectromagneticPhysicsWorkingGroup (20-Dec-2010, SebastienIncerti)

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The Geant4 Low Energy Electromagnetic Physics Working Group

This web site is the **official web site** of the **Geant4 collaboration Low Energy Electromagnetic Physics working group** .

Purpose

The **Geant4 Low Energy Electromagnetic Physics Working Group** develops and maintains a set of models to describe the **electromagnetic interactions of photons, electrons, hadrons and ions with matter down to very low energies (eV scale)**, **including the Geant4-DNA project** (link1 - link2). Applications of such models range from high energy physics experiments to space science and astrophysics to the medical and biological fields.

What's new in Geant4 9.4 ?

- **Important information** for **user code migration to our recent developments (since Geant4 version 9.3 BETA)** is available here.
- Overview of our most recent developments. UPDATED

Physics

- Processes is a link to the catalog of **Geant4 Physics processes** and to other useful information related to processes.
- Physics Lists describes Physics lists for specific applications involving low energy electromagnetic Physics processes.

Summary:
when/why to use Low Energy Models

- Use Low-Energy models (Livermore or Penelope), as an alternative to Standard models, when you:
  - need precise treatment of EM showers and interactions at low-energy (keV scale)
  - are interested in atomic effects, as fluorescence x-rays, Doppler broadening, etc.
  - can afford a more CPU-intensive simulation
  - want to cross-check another simulation (e.g. with a different model)

- Do not use when you are interested in EM physics > MeV
  - same results as Standard EM models, strong performance penalty

THANK YOU