Geant4: Electromagnetic Processes 3

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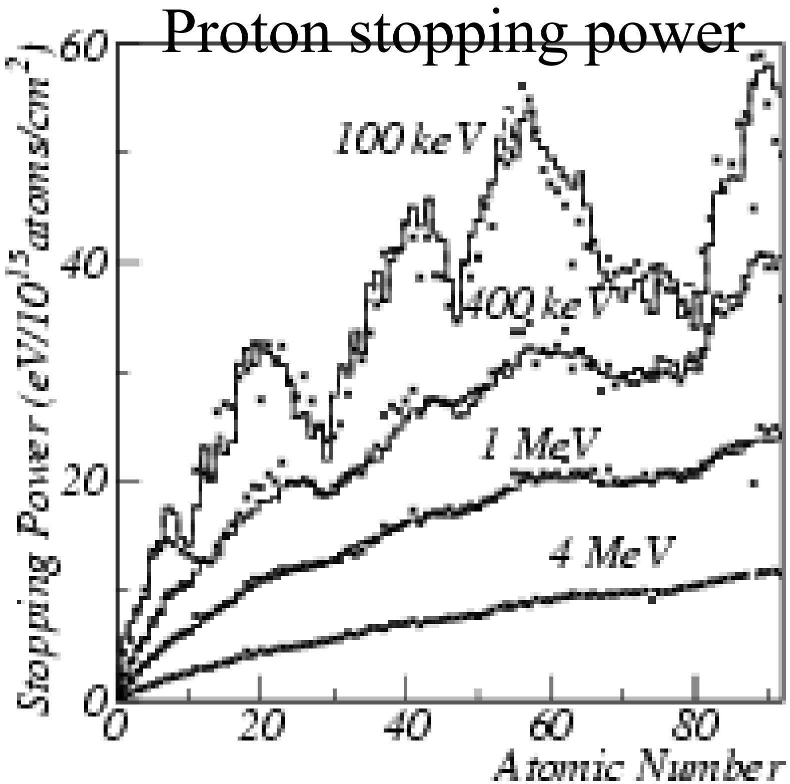
- Low energy package
- X-ray emission
- Optical processes

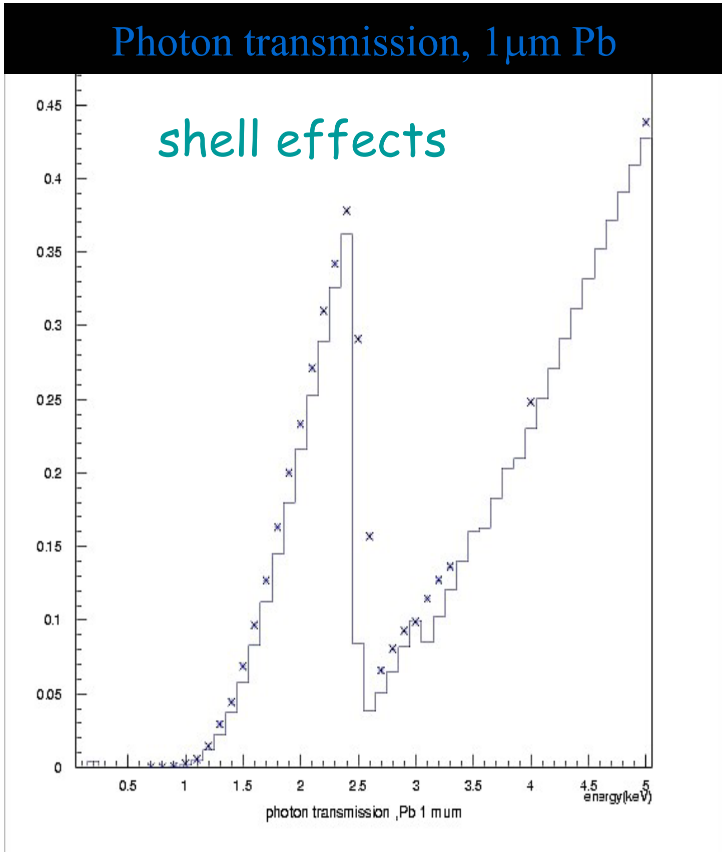
Geant4 low energy EM physics

- When energy transfer become close to energy of atomic electrons atomic shell structure should be taken into account
- Problems with theory, so phenomenology and experimental data are used



Geant4 low energy EM physics

- Validity down to **250 eV**
  - 250 eV is a “suggested” lower limit
  - data libraries down to 10 eV
  - 1 < Z < 100
- Exploit **evaluated data libraries** (from LLNL):
  - EADL (Evaluated Atomic Data Library)
  - EEDL (Evaluated Electron Data Library)
  - EPDL97 (Evaluated Photon Data Library)



Geant4 low energy EM physics

- Compton scattering
- Polarised Compton
- Rayleigh scattering
- Photoelectric effect
- Pair production
- Bremsstrahlung
- Electron ionisation
- Hadron ionisation
- Atomic relaxation
- Set of Penelope models (new)

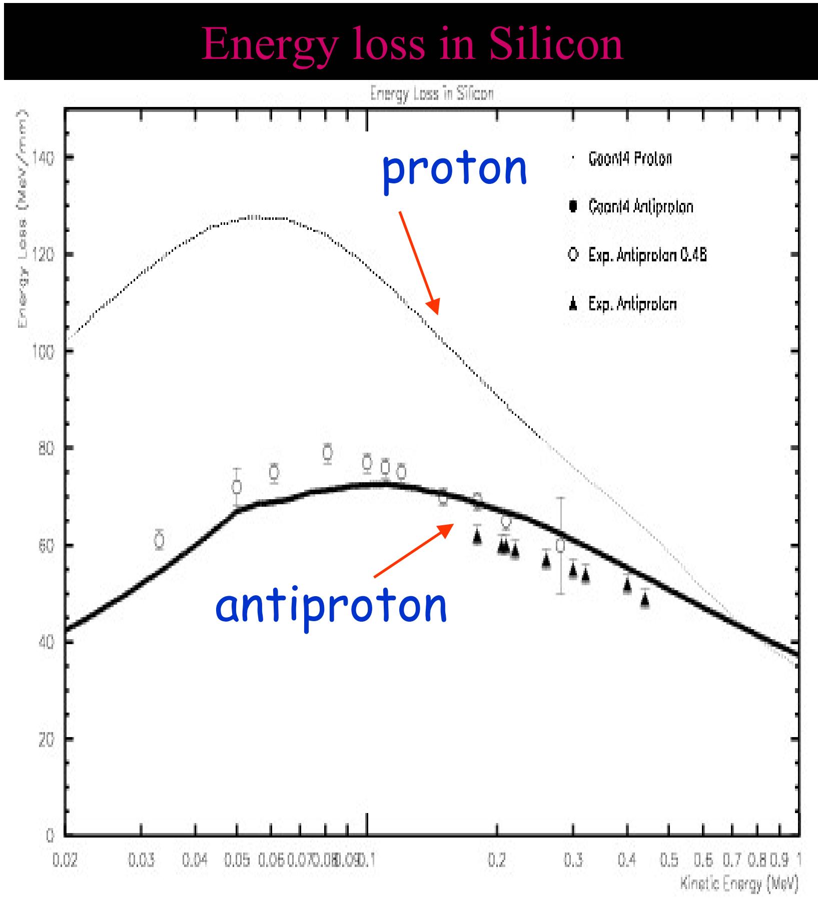
- It is relatively new package
- Development is driven by requirements which come from medicine and space research
- There are also users in HEP instrumentation

Geant4 low energy EM physics

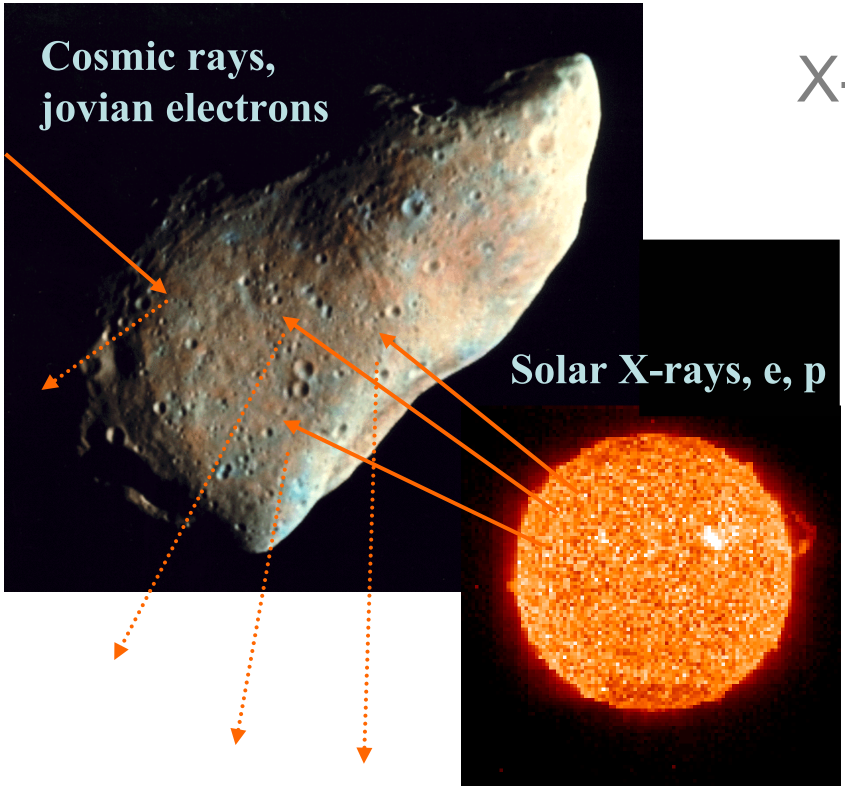
- To use G4 lowenergy package user has to substitute standard process in the PhysicsList by corresponding lowenergy:
  - G4hIonisation → G4hLowEnergyIonisation
  - G4eIonisation → G4LowEnergyIonisation
  - ……
- The environment variable G4LEDATA should be defined

Geant4 low energy EM physics

- Ionization is different for particles and antiparticles (Barkas effect)
- Ionization at low energy depends on molecular shell structure
- Chemical formula can be assign to the material – will be effective for heights of the Bragg peak of ionization

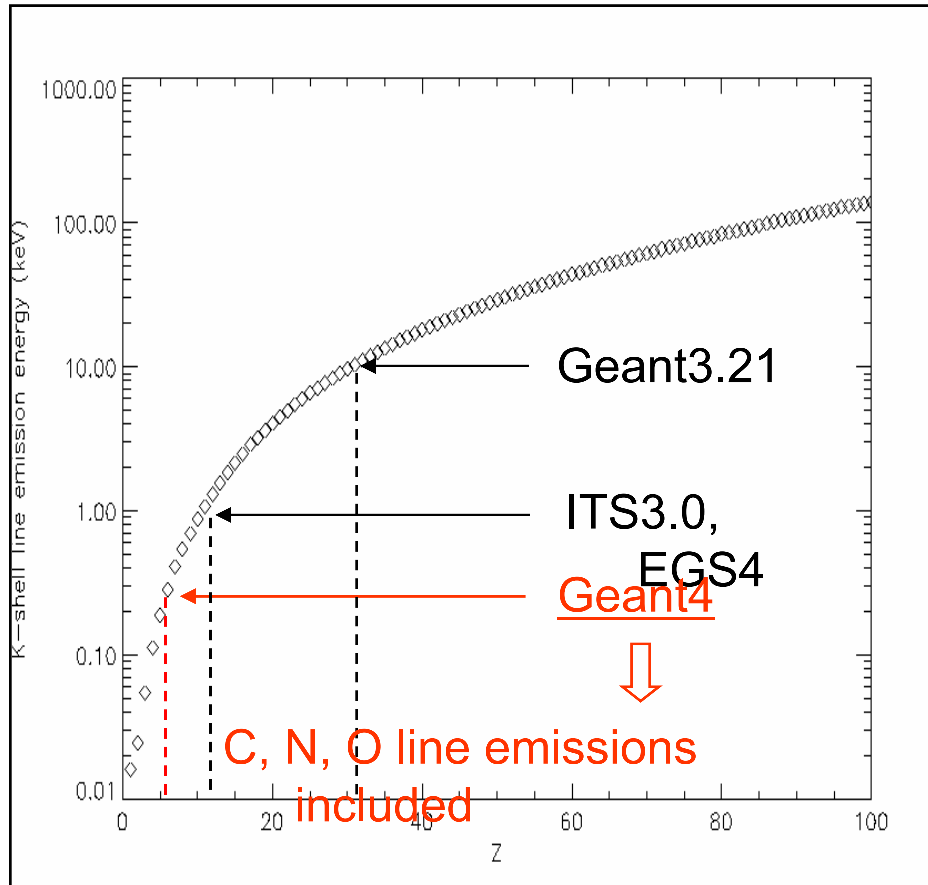


Geant4 space applications



Courtesy SOHO EIT

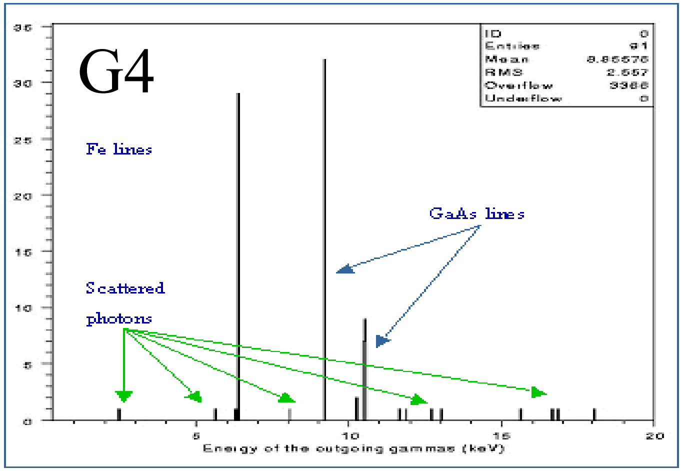
X-Ray Surveys of Solar System Bodies

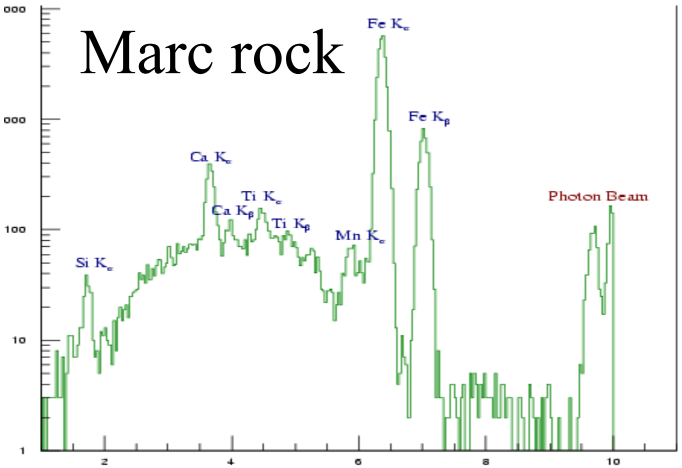


Induced X-ray line emission: indicator of target composition (~100 μm surface layer)

Geant4 low energy EM physics

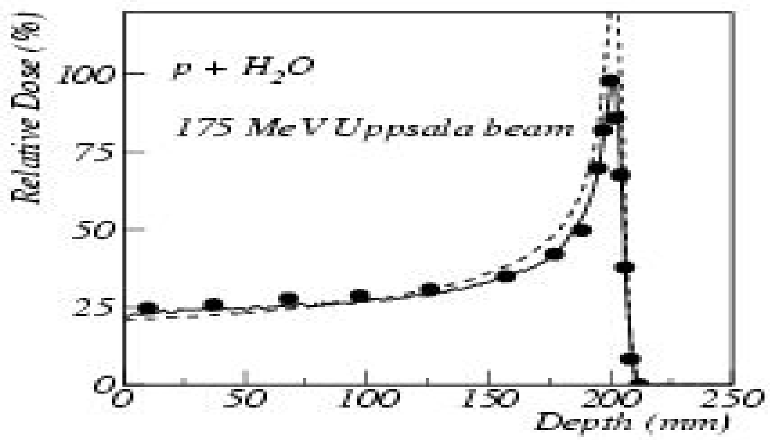
- Atomic relaxations are implement for ionization processes and photoelectric effect
- Cross sections of shell ionization are used
- Fluorescence and Auger electrons are produced

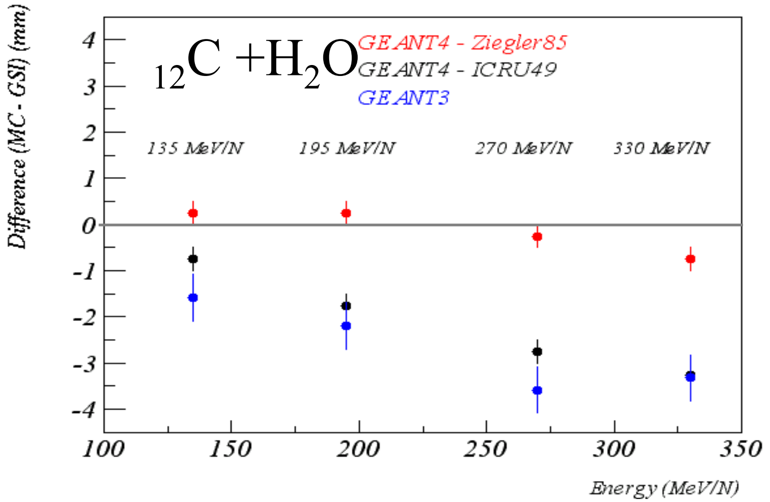




Radiation dose distribution

- The simulation of radiation dose distribution is required for medical, space, and other applications
- If hadronic processes are ignored in simulation, then the width of the Bragg peak of ionization cannot be reproduced by Geant4
- Taking into account hadronic processes the experimental data can reasonably reproduced





Optical Photon Processes in GEANT4

- Concept of "optical Photon" in G4

  λ >> atomic spacing

- G4OpticalPhoton: wave like nature of EM radiation
- G4OpticalPhoton <=|=> G4Gamma

  (no smooth transition)

- When generated polarisation should be set:

```
aphoton->SetPolarization(ux,uy,uz); // unit vector!!!
```

Optical Photon Processes in GEANT4

- Optical photons generated by following processes (processes/electromagnetic/xrays):
  - Scintillation
  - Cherenkov
  - Transition radiation
- Optical photons have following physics processes (processes/optical/):
  - Refraction and Reflection at medium boundaries
  - Bulk Absorption
  - Rayleigh scattering
- ExampleN06 at /examples/novice/N06

Optical Photon Processes in GEANT4

- Material properties should be defined for G4Scintillation process, so only inside the scintillator the process is active
- G4Cerenkov is active only if for the given material an index of refraction is provided
- For simulation of optical photons propagation G4OpticalSurface should be defined for a given optical system

Cherenkov Process

- Cherenkov light occurs when a charged particle moves through a medium faster than the medium’s group velocity of light.
- Photons are emitted on the surface of a cone, and as the particle slows down:

  (a) the cone angle decreases

  (b) the emitted photon frequency increases

  (c) and their number decreases
- Cherenkov photons have inherent polarization perpendicular to the cone’s surface.

G4Cerenkov: User Options

- Suspend primary particle and track Cherenkov photons first
- Set the max number of Cherenkov photons per step

in ExptPhysicsList:

```
#include "G4Cerenkov.hh"

G4Cerenkov* theCerenkovProcess = new G4Cerenkov("Cerenkov");
theCerenkovProcess -> SetTrackSecondariesFirst(true);
G4int MaxNumPhotons = 300;
theCerenkovProcess->SetMaxNumPhotonsPerStep(MaxNumPhotons);
```

G4Scintillation

- Number of photons generated proportional to the energy lost during the step
- Emission spectrum sampled from empirical spectra
- Isotropic emission
- Uniform along the track segment
- With random linear polarization
- Emission time spectra with one exponential decay time constant.

Rayleigh Scattering

- The cross section is proportional to cos2(α), where α is the angle between the initial and final photon polarization.
- The scattered photon direction is perpendicular to the new photon’s polarization in such a way that the final direction, initial and final polarization are all in one plane.
- Rayleigh scattering attenuation coefficient is calculated for water but in all other cases it must be provided by the user:

Boundary processes

- Dielectric - Dielectric

  Depending on the photon's wave length, angle of incidence, (linear) polarization, and refractive index on both sides of the boundary:

  (a) total internal reflected

  (b) Fresnel refracted

  (c) Fresnel reflected

- Dielectric - Metal

  (a) absorbed (detected)

  (b) reflected

Boundary Process

- A ‘discrete process’, called at the end of every step
- never limits the step (done by the transportation)
- sets the ‘Forced’ condition.
- preStepPoint: is still in the old volume
- postStepPoint: is already in the new volume
- Conceptual class: G4LogicalSurface (in the geometry category) holds:

    (i) pointers to the relevant physical or logical volumes

    (ii) pointer to a G4OpticalSurface

Conclusion remarks

- Geant4 standard package the optimal for most part of HEP applications
- Geant4 lowenergy package provide a possibility to apply toolkit to variety of applications for which atomic shell structure is essential
- Nuclear interactions of hadrons should be taken into account even at low energies for precise dosimetry
- Optical photons generation and tracking can be simulated inside the same geometry