Introduction to GEANT4

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material adapted from M. Asai / P. Gumplinger / G. Santin / J. McCormick

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Processes producing optical photons

- Optical Photon Production

- G4Cerenkov
- G4Scintillation
- G4TransitionRadiation

Warning: these processes generate optical photons without energy conservation

Cerenkov Process

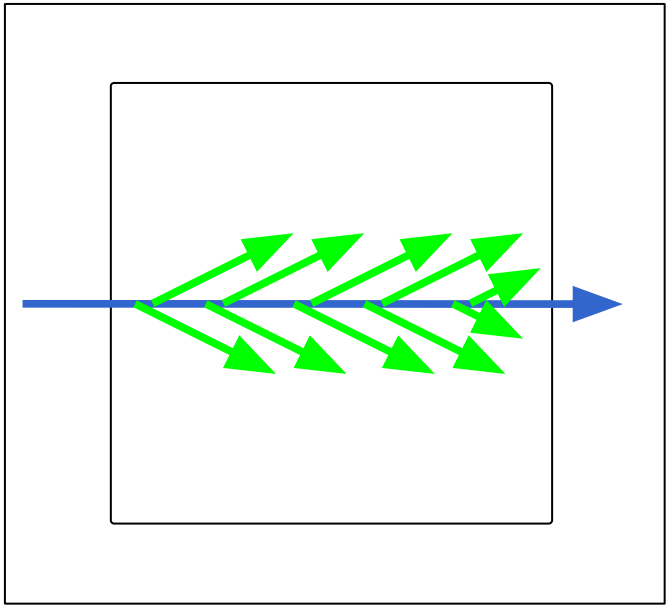
- Charged particle moving through a medium faster than the medium's group velocity of light

- Photons emitted on the surface of a cone. As the particle slows down:

a) the cone angle decreases
b) the emitted photon frequency increases
c) and their number decreases

- Cerenkov photons have inherent polarization perpendicular to the cone's surface

All described by the G4Cerenkov process



G4Cerenkov

- Cerenkov photon origins are distributed rectilinear over the step even in the presence of a magnetic field
  - Users must limit the max step size in order to accurately model the emission position

- Cerenkov photons are generated only in media where the user has provided an index of refraction

- An average number of photon is calculated for the wavelength interval in which the index of refraction is given
  - The actual number of emitted photons is then statistically sampled

- Cerenkov photon number varies linearly with velocity

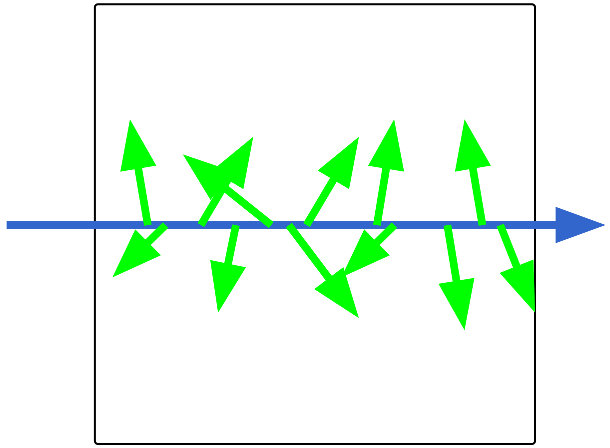
G4Cerenkov: Users options

- Suspend primary particle and track Cerenkov photons first
  - True: e.g. to avoid particle stack becoming too large with secondary photons
  - False: e.g. to avoid tracking all photons if the event is globally not interesting
- Set the (max) average number of Cerenkov photons per step
  - The actual number generated in any given step will be slightly different because of the statistical nature of the process
- G4Cerenkov can limit the Step by:
  - User defined average maximum number of photons to be generated during a step
  - User defined maximum allowed change in beta = v/c in % during the step.
  - A definite step limit when the track drops below the Cerenkov threshold

```
#include "G4Cerenkov.hh"
G4Cerenkov* theCkovProcess = new G4Cerenkov("Cerenkov");
theCkovProcess -> SetTrackSecondariesFirst(true);
G4int MaxNumPhotons = 300;
theCkovProcess->SetMaxNumPhotonsPerStep(MaxNumPhotons);
theCkovProcess->SetMaxBetaChangePerStep(10.0);
```

Scintillation Process

- number of photons generated is proportional to the energy lost during the step
- emission spectrum sampled from one (or two) empirical spectra
- Isotropic emission
- Uniform along the track segment
- With random linear polarization
- Emission time spectra with one (or two) exponential decay time constants (fast/slow)



G4Scintillation

G4Scintillation Process may use

- SCINTILLATION
- FASTCOMPONENT
- SLOWCOMPONENT
- SCINTILLATIONYIELD
- RESOLUTIONSCALE
- FASTTIMECONSTANT
- SLOWTIMECONSTANT
- YIELDRATIO

G4Scintillation

- Scintillation material has a characteristic light yield
- Option: suspend primary particle and track scintillation photons first

Physics List

```
#include “G4Scintillation.hh”

G4Scintillation* theScintProcess =
   new G4Scintillation(“Scintillation”);
theScintProcess -> SetTrackSecondariesFirst(true);
theScintProcess -> SetScintillationYieldFactor(0.2);
theScintProcess -> SetScintillationExcitationRatio(1.0);
```

Note:

- The ‘YieldFactor’ allows for different scintillation yields depending on the particle type
- In such case, separate scintillation processes must be attached to the various particles. Same for the ratio between fast and slow components

LAr Scintillation

Let's include a model for LAr Scintillation

1. Include LAr properties:

```
const G4int nEntries = 5;
G4double LAr_PhE[nEntries] =  { 2.0*eV, 2.341*eV,
2.757*eV, 3.353*eV, 4.136*eV };

G4double Rind_LAr[nEntries] =  { 1.35, 1.35, 1.35, 1.35,
1.35};
G4double Absl_LAr[nEntries] =  {3448*m,  4082*m,
6329*m,  9174*m, 12346*m };

// distribution of produced optical photons
G4double LAr_SCINT[NUMENTRIES] =
   {0.000134, 0.053991, 0.398942, 0.004432,0.241971};
```

LAr Scintillation

2. Define a properties table and attach to it LAr characteristics:

```
G4MaterialPropertiesTable* LAr_MPT = new
   G4MaterialPropertiesTable();

LAr_MPT ->
   AddProperty("FASTCOMPONENT",LAr_PhE,LAr_SCINT,NUMENTRIES);
LAr_MPT -> AddProperty("RINDEX", LAr_PhE,Rind_LAr,NUMENTRIES);
LAr_MPT -> AddProperty("ABSLENGTH",LAr_PhE,
   Absl_LAr,NUMENTRIES);
LAr_MPT -> AddConstProperty ("SCINTILLATIONYIELD", 100./MeV);
LAr_MPT -> AddConstProperty("RESOLUTIONSCALE",1.0)
LAr_MPT -> AddConstProperty("FASTTIMECONSTANT",45.*ns);
LAr_MPT -> AddConstProperty("YIELDRATIO",1.0);

LAr -> SetMaterialPropertiesTable(LAr_MPT);
```

Summary

- Optical processes handle
  - the productions of photons by scintillation, Cerenkov and transition radiation and
  - the reflection, refraction, absorption, wavelength shifting and scattering of long-wavelength photons

- Examples
  - **`examples/novice/N06`**
  - **`examples/extended/optical/LXe`**
  - **`examples/extended/optical/OpNovice`**

Summary

- **Documentation**
  http://cern.ch/geant4 → User support
  → Application Developers Guide → Optical photon processes
  http://cern.ch/geant4 → User support
  → Physics reference manual → Optical photons

- **Forum**
  http://cern.ch/geant4 → User support
  → User forum → Processes Involving Optical Photons

References:

G. Santini, Geant4 optics [https://slideplayer.com/slide/10598502]

P. Gumplinger, Optical Photon Processes in Geant4.
[http://geant4.slac.stanford.edu/UsersWorkshop/PDF/Peter/OpticalPhoton.pdf]

J. McCormick, Simulating Optical Processes Using Geant4: Scintillating Cells and WLS Fibers [https://slideplayer.com/slide/5114623]

Optical Parameters Summary

General
PP (emission mom.)
RINDEX
ABSLENGTH

Scintillation
SCINTILLATION
FASTCOMPONENT
SLOWCOMPONENT
SCINTILLATIONYIELD
RESOLUTIONSCALE
FASTTIMECONSTANT
SLOWTIMECONSTANT
YIELDRATIO

WLS
WLSABSLENGTH
WLSCOMPONENT
WLSTIME

Boundary
Finish
Model
Type
RINDEX
SPECULARLOBECONSTANT
BACKSCATTERCONSTANT
REFLECTIVITY
EFFICIENCY