Physics II – Overview and Processes

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based on Geant4 v9.5-p01

Outline

- Physics Overview
  - Electromagnetic processes
  - Hadronic Processes
  - Decay and parametrized processes

- Processes
  - Types of processes
  - Example processes
  - Defining your own process
  - Multiple processes

- Summary

Geant4 Physics

- Gean4 provides a wide variety of physics components, coded as processes

- Processes are organized into three main categories: “Electromagnetic“, “Hadronic“ and “Decay & Parametrized“

- Each process provides methods to determine...
  - ...at what point a particle interacts
  - ...what happens to the particle when it interacts

- In most cases a user will not worry about the structure of the process class and merely choose which processes to apply

Electromagnetic Processes

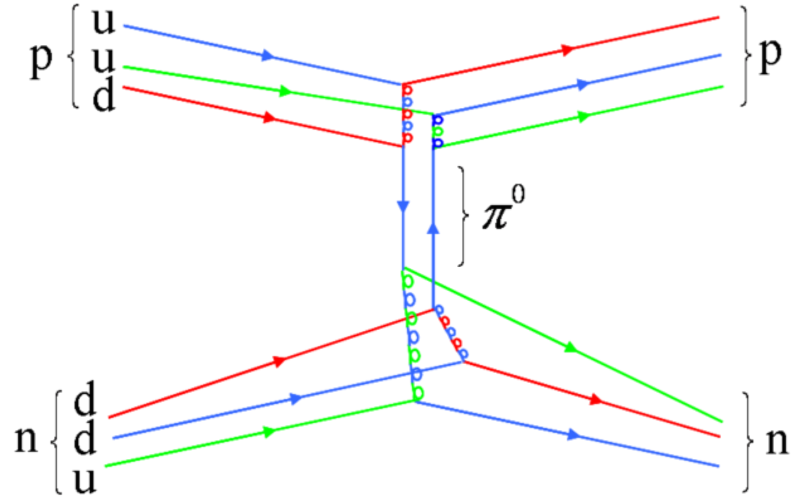
- Standard - complete set of processes covering charged particles and gammas.
  - Energy range 1 keV - ~PeV

- Low energy –Special routines for e+,e-,γ, charged hadrons.
  - More atomic shell structure detail
  - Some processes valid down to hundreds of eV
  - Some processes not valid above 1 GeV

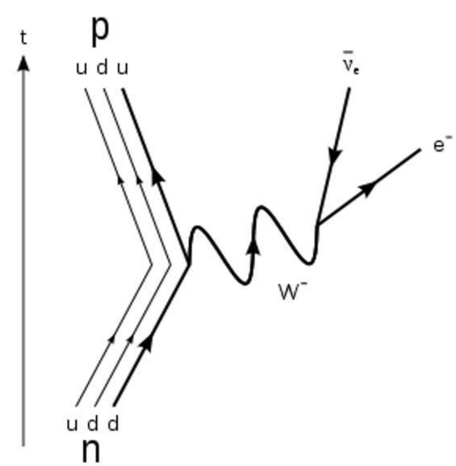
- Optical photon – Long wavelength γ (x-ray, UV, visible)
  - Reflection, refraction, absorption, wavelength shifts, Rayleigh scattering

Hadronic Processes

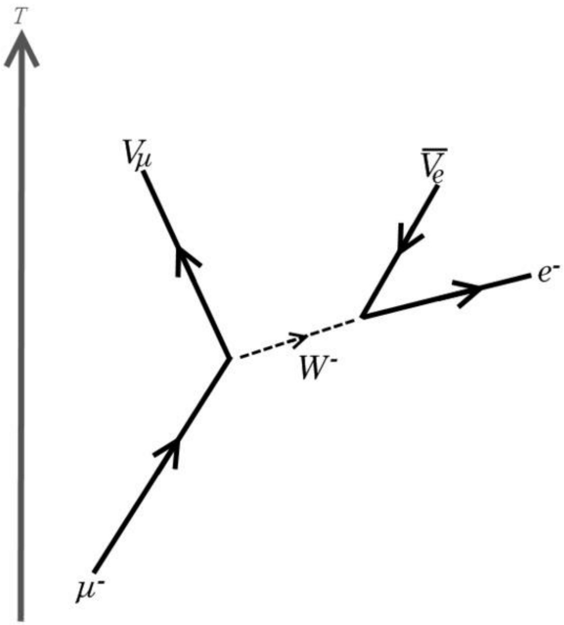
- Pure Hadronic Processes (0 - ~TeV)
  - elastic
  - inelastic
  - capture
  - fission
- Strong Radioactive Decay
  - at rest
  - In flight
- Photo-Nuclear (~10 MeV - ~TeV)
- Lepto-Nuclear (~10 MeV - ~TeV)
  - e+, e- nuclear reactions
  - muon nuclear reactions



Above: p-n scattering by pion exchange
Below: beta decay



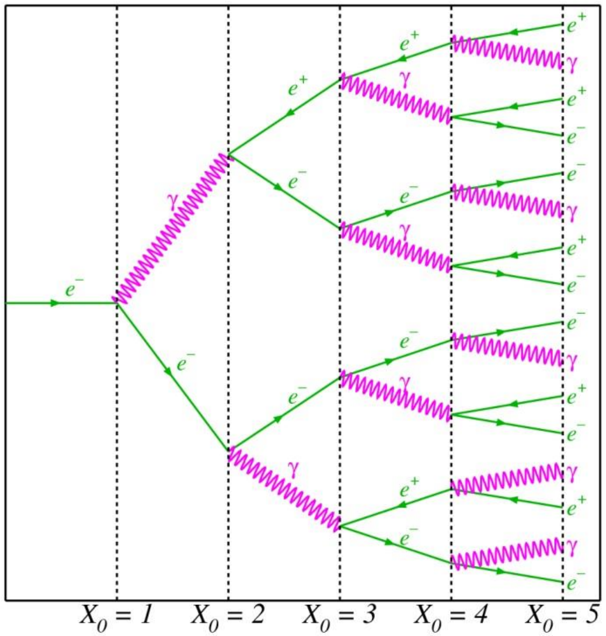
Decay and Parametrized



- Decay processes
  - weak decay (leptonic decays, semi-leptonic decays, radioactive decay of nuclei)
  - electromagnetic decay (π0, Σ0 , etc. decay)

  Strong decays not included here (they are part of hadronic models).

- Parametrized processes
  - electromagnetic showers propagated according to parameters averaged over many events
  - faster than detailed shower simulation



Geant4 Processes

- All particle interactions/decays are simulated as processes

Note:transportation is also handled by a process

- A process does two things:
  - Decide when and where an interaction will occur

    method: GetPhysicalInteractionLength()

    this requires a mean free path, decay lifetime

    transportation process: find distance to the nearest object along track

  - Generate the final state of the interaction (change momentum, generate secondaries, etc.)

    method: DoIt()

    this requires a model of the physics

Example Processes - Pure

Discrete process: Compton Scattering

step determined by mean free path, interaction at end of step

PostStepGPIL(), PostStepDoIt()

Continuous process: Cerenkov effect

photons created along step, # ~proportional to step length

AlongStepGPIL(), AlongStepDoIt()

At rest process: positron annihilation at rest

no displacement, time is the relevant variable

AtRestGPIL(), AtRestDoIt()

All of the above are “pure” processes.

Example Processes - Mixed

Continuous + discrete: ionization

energy loss is continuous

Moller/Bhabha scattering and knock-on electrons are discrete

Continuous + discrete: bremsstrahlung

energy loss due to soft photons is continuous

hard photon emission is discrete

- In both cases, the production threshold separates the continuous and discrete parts of the processmore on this later

- Multiple scattering is also continuous + discrete

Defining a Process - I

•Defining a discrete process:

```
class exampleProcess: public G4VDiscreteProcess
```

•Apart from constructors, the entire functionality is contained in two methods

•Provide physical interaction length:

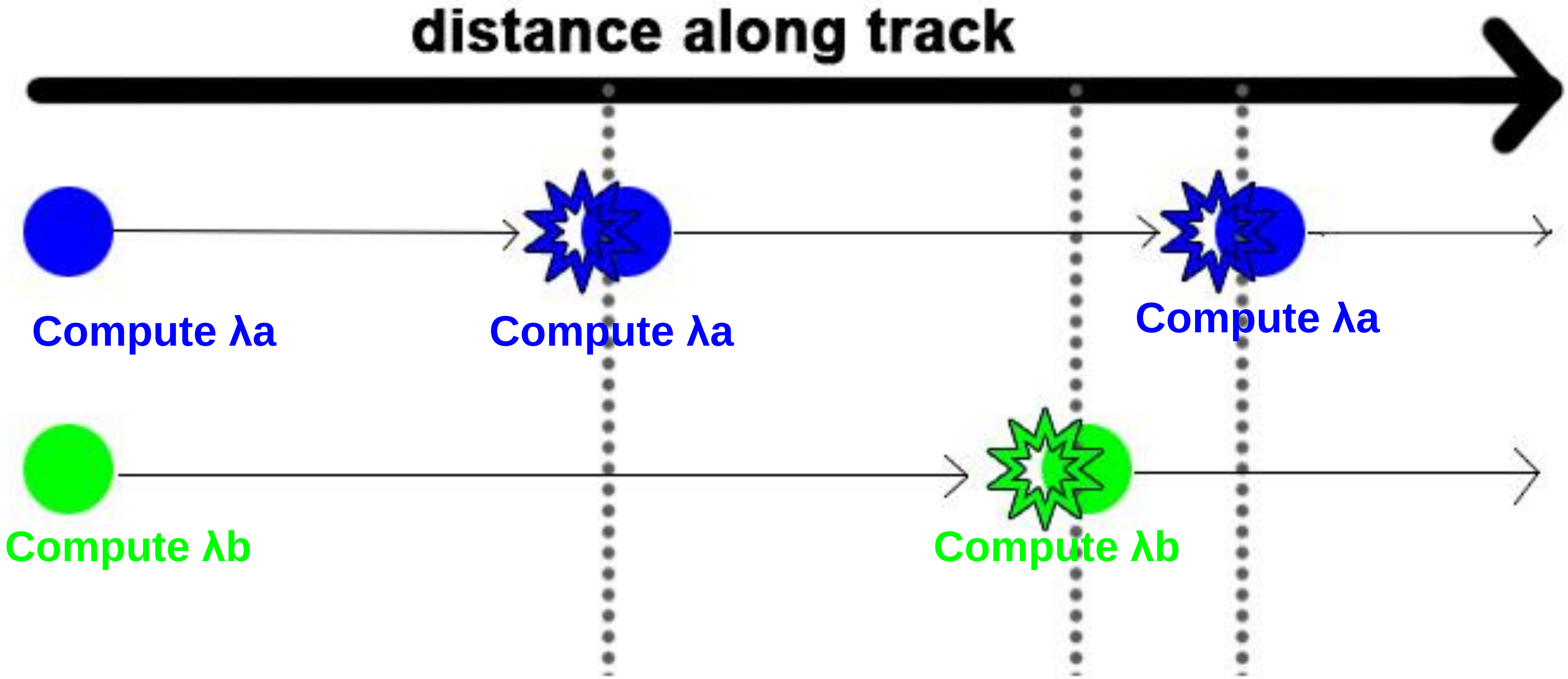
```
virtual G4double GetMeanFreePath(const G4Track&, G4double,
G4ForceCondition*);
```

•Provide physical interaction length:

```
Virtual G4VParticleChange PostStepDoIt(const G4Track&,
G4Step&);
```

```
#include "LukeScatteringProcess.hh"
#include "DriftingElectron.hh"
#include "DriftingHole.hh"

//define constructor, destructor and copy operator
LukeScatteringProcess::LukeScatteringProcess(const G4String& aName):
                 G4VDiscreteProcess(aName) { . . . }
LukeScatteringProcess::~LukeScatteringProcess(){ ; }
LukeScatteringProcess::LukeScatteringProcess(LukeScatteringProcess& right):
                 G4VDiscreteProcess(right){ ; }

G4double LukeScatteringProcess::GetMeanFreePath
                 (const G4Track& aTrack, G4double, G4ForceCondition* condition) {
        *condition = NotForced;
        //[do whatever math is necessary to compute G4double mfp]
        return mfp;
}

G4VParticleChange* LukeScatteringProcess::PostStepDoIt
                 (const G4Track&  aTrack, const G4Step& aStep){

        aParticleChange.Initialize(aTrack);
        //[do whatever math is necessary to compute changes to particle]
        aParticleChange.ProposeEnergy(aTrack.GetKineticEnergy()-daughterEnergy);
        aParticleChange.ProposeMomentumDirection(scatterDirection);
        return &aParticleChange;
}

G4bool LukeScatteringProcess::IsApplicable(const G4ParticleDefinition& aPD)
{ return(&aPD==DriftingElectron::Definition() );}
```

Computing interaction length and *DoIt*

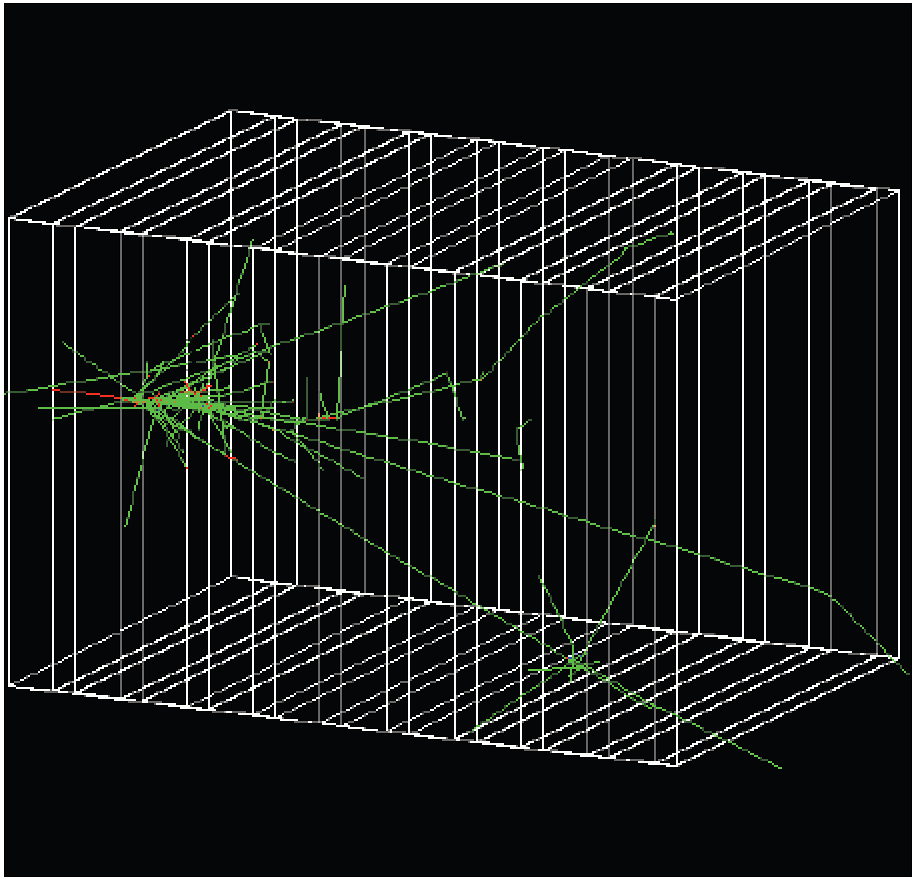


1. Compute interaction lengths A and B
2. Propagate particle until A or B occurs or geometry boundary encountered
3. If process occurred, re-compute that processes interaction length only

Example Event Using EM Processes

•50 MeV e- entering LAr-Pb calorimeter

Processes used:
- bremsstrahlung
- Ionization
- Multiple scattering
- Positron annihilation
- pair production
- Compton scattering



Summary

•Geant4 supplies many physics processes which cover electromagnetic, hadronic and decay physics

•Processes are organized according to when they are used during the tracking of a particle (discrete, continuous, at-rest, etc.)

•Many processes may be assigned to one particle

which processes occurs first depends on mean free paths, lifetimes and distances to volume boundaries