Physics II: Overview and Processes

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Outline

• Physics Overview
  ▪ the physics Geant4 has to offer

• Processes
  ▪ how they work
  ▪ example processes
Geant4 provides a wide variety of physics components for use in simulation

Physics components are coded as processes
- a process is a class which tells a particle how to interact
- user may write his own processes (derived from Geant4 process)

Processes are grouped into
- electromagnetic, hadronic, and decay categories
Geant4 Physics: Electromagnetic

- standard – complete set of processes covering charged particles and gammas
  - energy range 1 keV to ~PeV
- low energy – specialized routines for e+, e-, γ, charged hadrons
  - more atomic shell structure details
  - some processes valid down to 250 eV or below
  - others not valid above a few GeV
- optical photon – only for long wavelength photons (x-rays, UV, visible)
  - processes for reflection/refraction, absorption, wavelength shifting, Rayleigh scattering
Geant4 Physics: Hadronic

- Pure hadronic (0 - ~TeV)
  - elastic
  - inelastic
  - capture
  - fission
- radioactive decay
  - at-rest and in-flight
- photo-nuclear (~10 MeV - ~Tev)
- lepto-nuclear (~10 MeV - ~Tev)
  - e+, e- nuclear reactions
  - muon-nuclear reactions
Decay processes include

- weak decay (leptonic decays, semi-leptonic decays, radioactive decay of nuclei)
- electromagnetic decay ($\pi^0$, $\Sigma^0$, etc. decay)
- strong decays not included here (they are part of hadronic models)

Parameterized processes

- electromagnetic showers propagated according to parameters averaged over many events
- faster than detailed shower simulation
Physics Processes (1)

- All the work of particle decays and interactions is done by processes
  - transportation is also handled by a process

- A process does two things:
  - decides when and where an interaction will occur
    - method: GetPhysicalInteractionLength()
    - this requires a cross section, decay lifetime
    - for the transportation process, the distance to the nearest object along the track is required
  - generates the final state of the interaction (changes momentum, generates secondaries, etc.)
    - method: DoIt()
    - this requires a model of the physics
Physics Processes (2)

- There are three flavors of processes:
  - well-located in space -> PostStep
  - distributed in space -> AlongStep
  - well-located in time -> AtRest

- A process may be a combination of all three of the above
  - in that case six methods must be implemented
    (GetPhysicalInteractionLength() and DoIt() for each action)

- “Shortcut” processes are defined which invoke only one
  - Discrete process (has only PostStep physics)
  - Continuous process (has only AlongStep physics)
  - AtRest process (has only AtRest physics)
Example Processes (1)

- **Discrete process:** Compton Scattering
  - step determined by cross section, interaction at end of step
    - PostStepGPIL()
    - PostStepDoIt()

- **Continuous process:** Cerenkov effect
  - photons created along step, # roughly proportional to step length
    - AlongStepGPIL()
    - AlongStepDoIt()

- **At rest process:** positron annihilation at rest
  - no displacement, time is the relevant variable
    - AtRestGPIL()
    - AtRestDoIt()

- These are examples of so-called “pure” processes
Example Processes (2)

- 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 process
  - more on this later

- Multiple scattering is also continuous + discrete
Handling Multiple Processes

• Many processes (and therefore many interactions) can be assigned to the same particle
• How does Geant4 decide which interaction happens at any one time?
  ▪ interaction length or decay length is sampled from each process
  ▪ shortest one happens, unless
    ▪ a volume boundary is encountered in less than the sampled length. Then no physics interaction occurs (just simple transport).
  ▪ the processes that were not chosen have their interaction lengths shortened by the distance travelled in the previous step
  ▪ repeat the procedure
  ▪ detailed discussion of this in next talk
Particle

1. At rest
   - Process 1
2. In-flight
   - Process 2
3. Process
   - Process 3
   - Process n

- Energy range manager
  - Model 1
  - Model 2
  - Model n

- Cross section data store
  - C.S. set 1
  - C.S. set 2
  - C.S. set n

Total: 12
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 one occurs first depends on cross sections, lifetimes, and distances to volume boundaries.
How Geant4 Handles Competing Processes
(addendum to Process Overview talk)
Interaction Length Sampling

- At the beginning of the first step, the interaction length is found from the cross section and target number density:
  - sampling is done from the distribution $e^{-\sigma_p L}$

this is done for each process assigned to the particle, so we now have several different lengths, plus the distance to the next volume boundary
Which Process Occurs?

• For the simple case of a gamma with Compton scattering and pair production assigned, the sampled lengths will be:
  – typically short for Compton scattering (large cross section)
  – typically long for pair production (small cross section)

• The process with the shortest sampled length is always chosen to occur
  – this process defines the length of the first step

• After the process occurs, we're ready for the next step
  – the process which has just occurred must be re-sampled
  – the processes which did not occur (pair production) are not re-sampled and must have the previous step length subtracted from their originally sampled lengths
Reducing the Interaction Lengths

- **Step 1:**
  - all lengths sampled
  - Compton occurs

- **Step 2:**
  - Compton re-sampled
  - boundary is crossed

- **Step 3:**
  - Compton occurs again
  - new boundary found

- **Step 4:**
  - Compton re-sampled
  - pair production occurs