Physics 2: Overview and Processes

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Outline

- Physics Overview
  - the physics Geant4 has to offer

- Processes
  - how they work
  - example processes
Geant4 Physics

• A wide variety of “physics components” is available in Geant4.

➡ Physics components are “processes” in Geant4.

• A process is a class which tells a particle how to interact

• Categories:
  1. Electromagnetic
  2. Hadronic
  3. Decay

• User-defined processes can be written (derived from Geant4 process)
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-, gamma, 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 - ~100 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
Geant4 Physics:
Decay and Parameterized

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

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

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

- 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 Coulomb 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 traveled in the previous step
  - repeat the procedure
Example Event with Standard EM Processes Turned On

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