

Physics 2: Overview and Processes

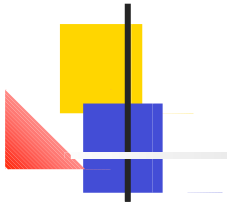


Shigeyuki Tajima

Duke/NCCU and TUNL

Slides courtesy of SLAC GEANT4 Team

Special thanks to Dennis Wright

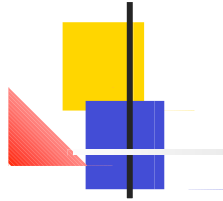


Outline

- 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)

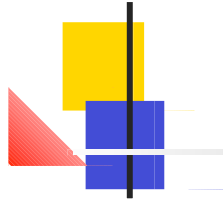


Geant4 Physics: Electromagnetic

- 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



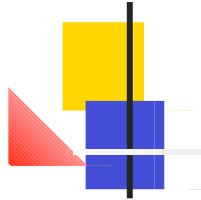
Geant4 Physics: Hadronic

- 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



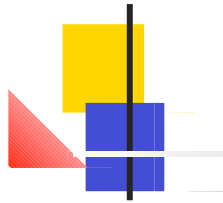
Geant4 Physics: Decay and Parameterized

- Decay processes include
 - weak decay (leptonic decays, semi-leptonic decays, radioactive decay of nuclei)
 - electromagnetic decay (π^0 , Σ^0 , 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: `Dolt()`
 - ♦ this requires a model of the physics

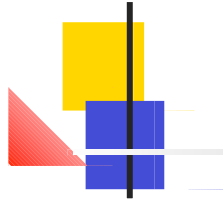


Physics Processes (2)

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

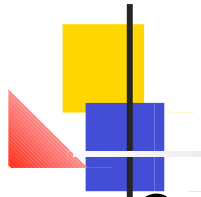
- A process may be a combination of all three of the above
 - in that case six methods must be implemented
(GetPhysicalInteractionLength() and Dolt() for each action)

- “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)



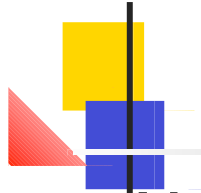
Example Processes (1)

- 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



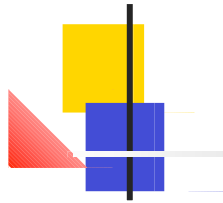
Example Processes (2)

- 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

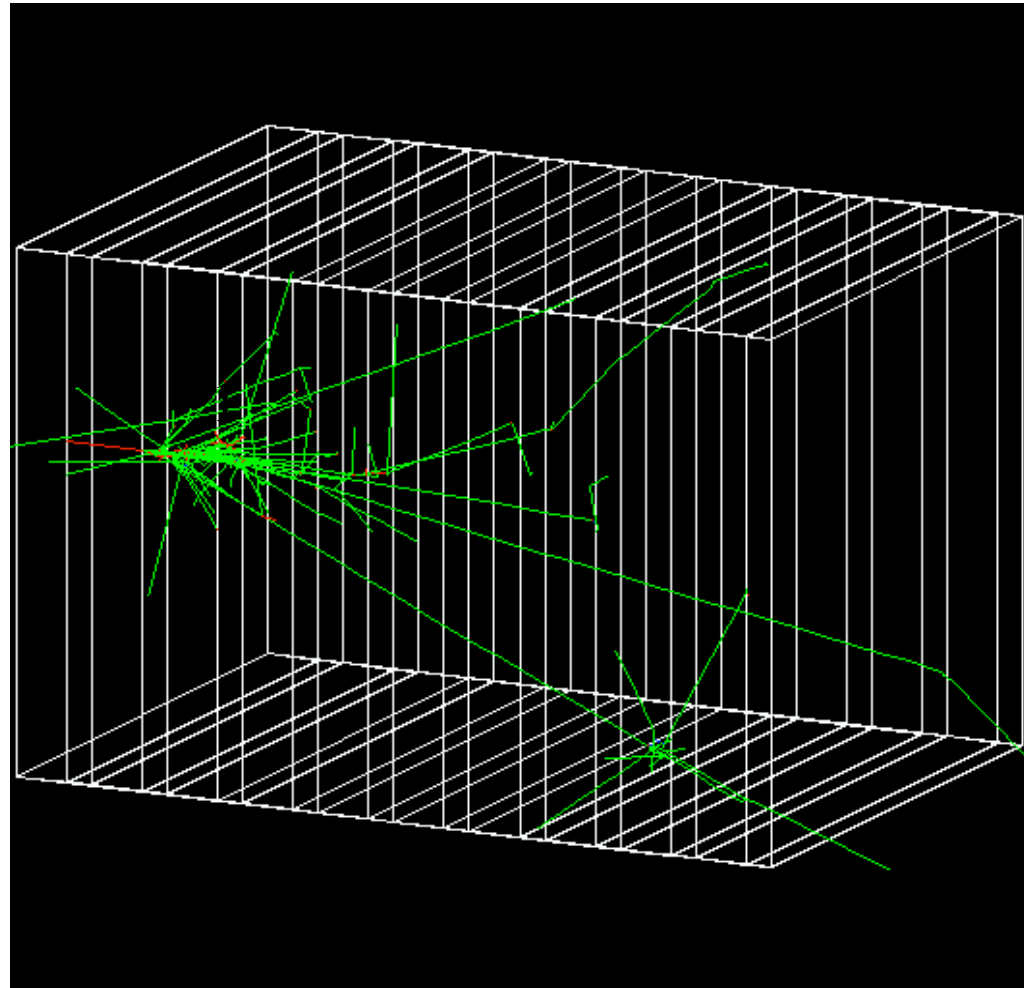
ionization

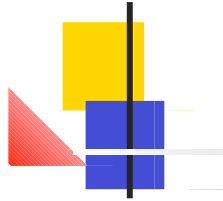
multiple scattering

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