

Physics 3: Cuts, Decay, and Optical Physics

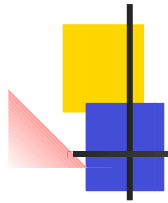


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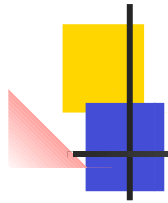
Slides courtesy of SLAC GEANT4 Team

Special thanks to Dennis Wright



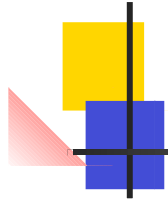
Outline

- Production Thresholds
- Cuts per Region
- The Decay Process
 - applicability
 - available decay modes
- Optical Photons
 - available processes



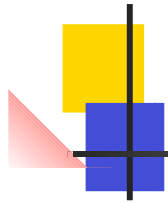
Threshold for Secondary Production (1)

- Every simulation developer must answer the question: **how low can you go?**
 - at what energy do I stop tracking particles?
- This is a balancing act
 - need to go low enough to get the physics you're interested in
 - can't go too low because some processes have infrared divergence causing CPU time to skyrocket
- The traditional Monte Carlo solution is to impose an absolute cutoff in energy
 - particles are stopped when this energy is reached
 - remaining energy is dumped at that point



Threshold for Secondary Production (2)

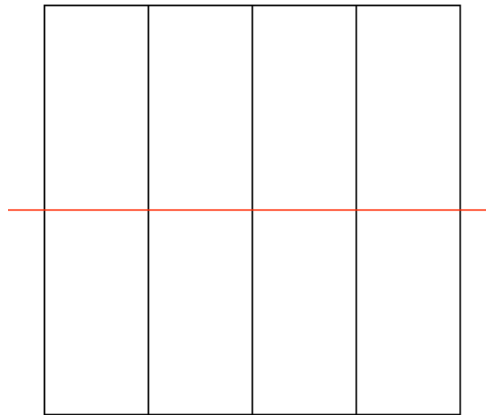
- But, such a cut may cause imprecise stopping location and deposition of energy
- There is also a particle dependence
 - range of 10 keV γ in Si is a few cm
 - range of 10 keV e^- in Si is a few microns
- And a material dependence
 - suppose you have a detector made of alternating sheets of Pb and plastic scintillator
 - if the cutoff is OK for Pb, it will likely be wrong for the scintillator which does the actual energy deposition measurement



Threshold for Secondary Production (3)

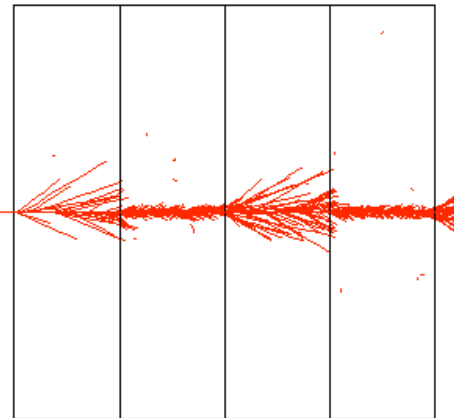
- Geant4 solution: impose a **production threshold**
 - this threshold is a **distance**, not an energy
 - default = 1 mm
 - the primary particle loses energy by producing secondary electrons or gammas
 - if primary no longer has enough energy to produce secondaries which travel at least 1mm, two things happen:
 - discrete energy loss ceases (no more secondaries produced)
 - the primary is tracked down to zero energy using continuous energy loss
- Stopping location is therefore correct
- Only one value of production threshold distance is needed for all materials because it corresponds to different energies depending on material.

Production Threshold vs. Energy Cut

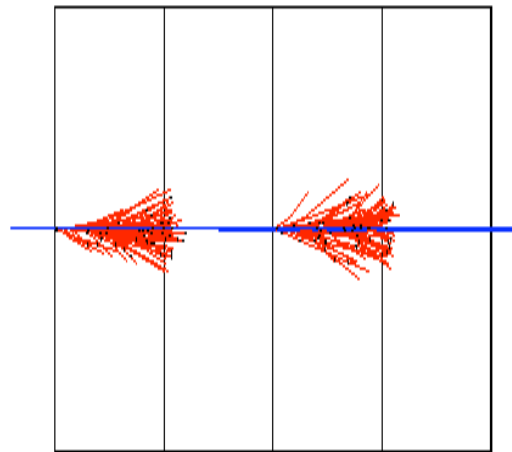


Cut = 2 MeV

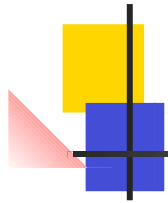
500 MeV p in
LAr-Pb sampling
calorimeter



Cut = 450 keV



Production range = 1.5 mm



Threshold for Secondary Production (4)

- Geant4 recommends the default value of 1mm
 - user needs to decide the best value
 - this will depend on the size of sensitive elements within the simulated detector, and on available CPU
- This value is set in the SetCuts() method of your physics list.
- Instead of “secondary production threshold distance” it is more convenient to simply say “cuts”
 - but please remember that this does not mean that any particle is actually stopped before it runs out of energy

SetCut() method in ExampleN03

Source code from N03/src/ExN03PhysicsList.cc

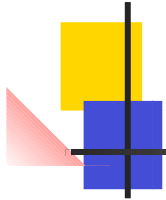
defaultCutValue = 1.0*mm

```
247 void ExN03PhysicsList::SetCuts()  
248 {  
  
254 // set cut values for gamma at first and for e- second and next for e+,  
255 // because some processes for e+/e- need cut values for gamma  
256 //  
257     SetCutValue(defaultCutValue, "gamma");  
258     SetCutValue(defaultCutValue, "e-");  
259     SetCutValue(defaultCutValue, "e+");  
  
262 }
```



Cuts per Region (1)

- In a complex detector there may be many different types of sub-detectors involving
 - finely segmented volumes
 - very sensitive materials
 - large, undivided volumes
 - inert materials
- The same value of the secondary production threshold may not be appropriate for all of these
 - user must define regions of similar sensitivity and granularity and assign a different set of production thresholds (cuts) for each
- **Warning: this feature is for users who are**
 - **simulating the most complex detectors**
 - **experienced at simulating EM showers in matter**



Cuts per Region (2)

- A default region is created automatically for the world volume
 - it has the cuts which you set in `SetCuts()` in your physics list
 - these will be used everywhere except for user-defined regions
- To define a special region with different cuts, user must
 - create a `G4ProductionCuts` object
 - initialize it with the new cuts
 - assign it to a region which has already been created

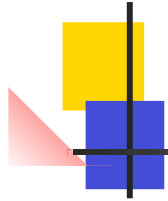


Cuts per Region (3)

- ```
void BeamTestPhysicsList::SetCuts()
{
 SetCutValue(defaultCutValue, "gamma");
 SetCutValue(defaultCutValue, "e-");
 SetCutValue(defaultCutValue, "e+");
 // Get the region
 G4Region* aRegion =
 G4RegionStore::GetInstance()->GetRegion("NewRegion");

 // Define cuts object for the new region and set values
 G4ProductionCuts* cuts = new G4ProductionCuts;
 cuts->SetProductionCut(0.01*mm); // same cut for gamma, e+, e-

 // Assign cuts to region
 aRegion->SetProductionCuts(cuts);
}
```



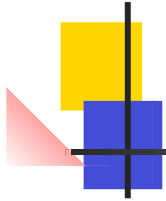
# The Decay Process

- Derived from G4VRestDiscreteProcess
  - decay can happen in-flight or at rest
- Should be applied to all unstable, long-lived particles
- Different from other physical processes:
  - mean free path for most processes:  $\lambda = N\rho\sigma / A$
  - for decay in-flight:  $\lambda = \gamma\beta c\tau$
- Same decay process for all eligible particles
  - decay process retrieves BR and decay modes from decay table stored in each particle type



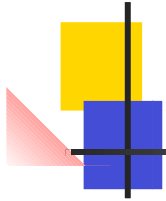
# Available Decay Modes

- Phase space:
  - 2-body e.g.  $\pi^0 \rightarrow \gamma\gamma$ ,  $\Lambda \rightarrow p \pi^-$
  - 3-body e.g.  $K_L^0 \rightarrow \pi^0 \pi^+ \pi^-$
  - many body
- Dalitz:  $\pi^0 \rightarrow e^+ e^- \gamma$
- Muon decay
  - V – A, no radiative corrections, mono-energetic neutrinos
- Leptonic tau decay
  - like muon decay
- Semi-leptonic K decay:  $K \rightarrow \pi l \nu$



# Optical Photons (1)

- Technically, should belong to electromagnetic category, but:
  - optical photon wavelength is  $\gg$  atomic spacing
  - treated as waves  $\rightarrow$  no smooth transition between optical and gamma particle classes
- Optical photons are produced by the following Geant4 processes:
  - G4Cerenkov
  - G4Scintillation
  - G4TransitionRadiation
- **Warning: these processes generate optical photons without energy conservation**

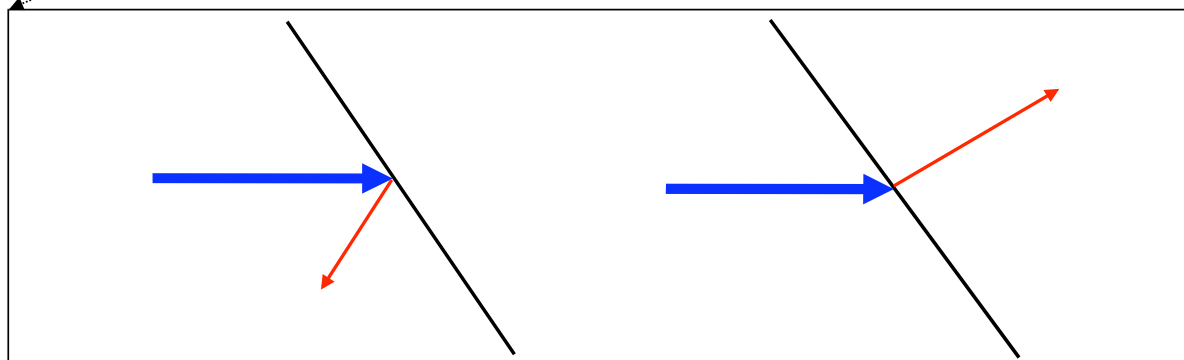
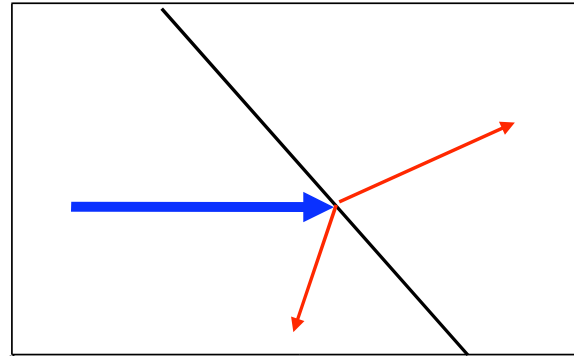


## Optical Photons (2)

- Optical photons undergo:
  - Rayleigh scattering
  - refraction and reflection at medium boundaries
  - bulk absorption
  - wavelength shifting
- Geant4 keeps track of polarization
  - but not overall phase -> no interference
- Optical properties can be specified in `G4Material`
  - reflectivity, transmission efficiency, dielectric constants, surface properties  
--> [G4MaterialPropertiesTable](#)
- Photon spectrum properties also defined in `G4Material`
  - scintillation yield, time structure (fast, slow components)

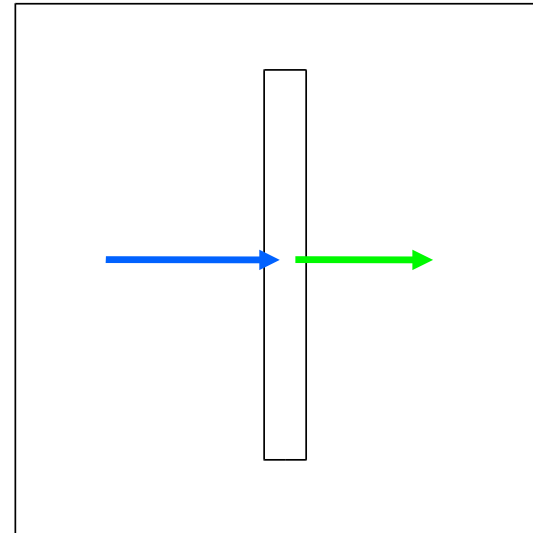
## Optical Photons (3)

- Geant4 demands particle-like behavior for tracking:
  - thus, no “splitting”
  - event with both refraction and reflection must be simulated by at least two events



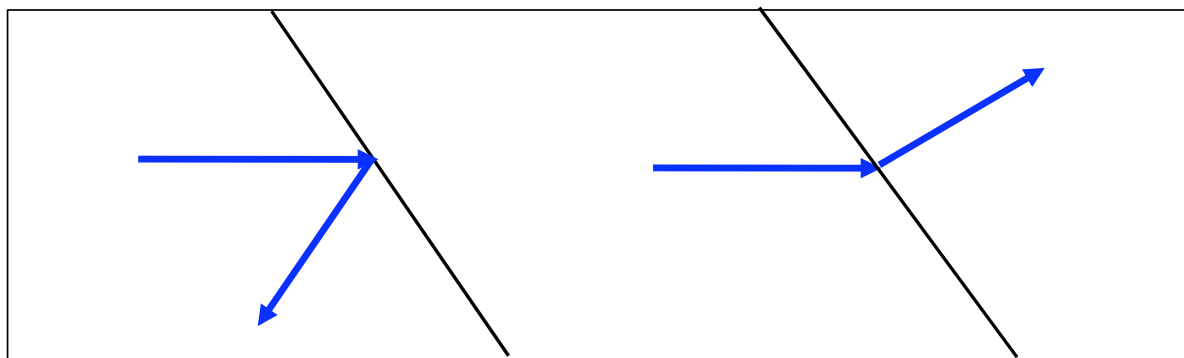
# Wavelength Shifting

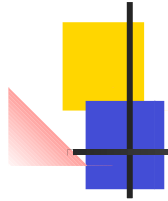
- Handled by G4OpWLS
  - initial photon is killed, one with new wavelength is created
  - builds its own physics table for mean free path
- User must supply:
  - absorption length as function of photon energy
  - emission spectra parameters as function of energy
  - time delay between absorption and re-emission



# Boundary Interactions

- Handled by `G4OpBoundaryProcess`
  - refraction
  - reflection
- User must supply surface properties using `G4OpticalSurfaceModel`
- Boundary properties
  - dielectric-dielectric
  - dielectric-metal
  - dielectric-black material
- Surface properties:
  - polished
  - ground
  - front- or back-painted, ...





## Summary

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- The precision of particle stopping and the production of secondary particles are determined by a **secondary production threshold**
- For complex detectors with different types of sensitive volumes, **different production** thresholds may be defined for **different regions** within the detector
- There is one **decay process** for all long-lived, unstable particles
- **Optical processes** handle the reflection, refraction, absorption, wavelength shifting and scattering of **long-wavelength** photons