Geant4 11.1-p02

Production Thresholds
Decay Processes

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Outline

- Production thresholds
  - How they work, how to set them
  - Cuts per region
- Geant4 decay process
  - Available decay channels
  - Defining decay channels
  - Specialized decays

Threshold for Secondary Production

- 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 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

- But such a cut may cause imprecise stopping location and deposition of energy

- There is also a particle dependence
  - range of a 10 keV γ in Si is a few cm
  - range of a 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 measurement

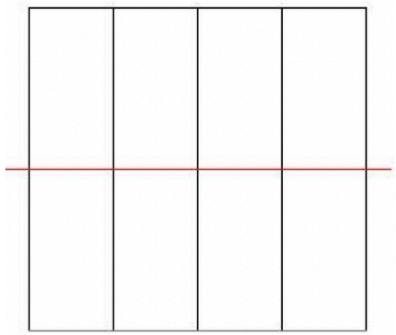
Threshold for Secondary Production

- Geant4 solution: impose a production threshold
  - this threshold is a distance, not an energy
  - default = 0.7 mm
  - the primary particle loses energy by producing secondary electrons and gammas
  - if primary no longer has enough energy to produce secondaries which can travel at least 0.7 mm, 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 threshold distance is needed for all materials because it corresponds to different energies depending on the material

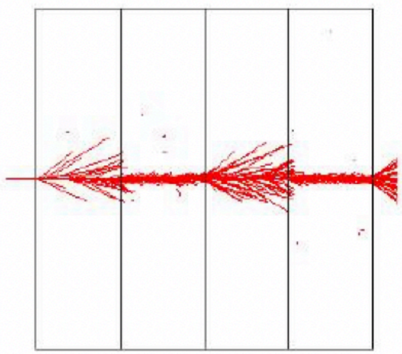
Production Threshold vs. Energy Cut

- Example: 500 MeV p in LAr-Pb Sampling Calorimeter

Geant3 (and others)

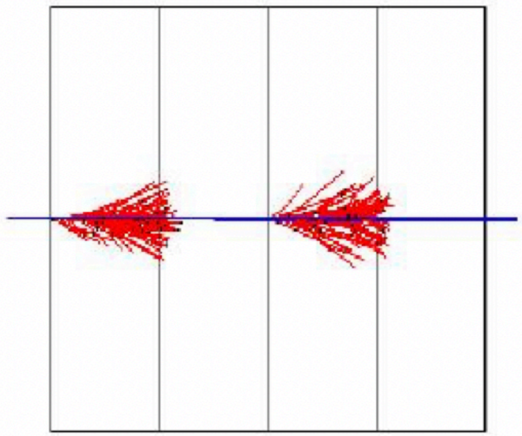


Cut = 2 MeV



Cut = 450 keV

Geant4

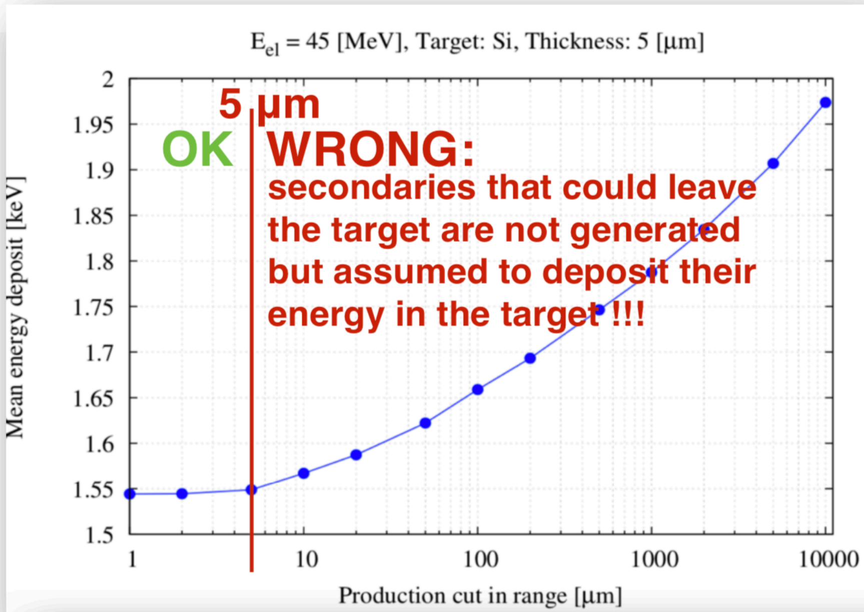


Production range = 1.5 mm

Threshold for Secondary Production

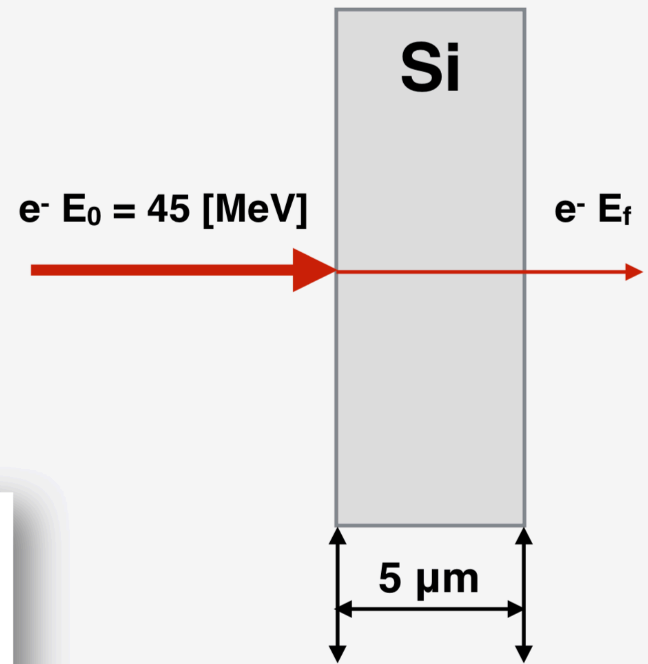
- Geant4 recommends the default value of 0.7 mm
  - user needs to decide the best value
  - will depend on size and sensitive elements within the simulated detector, and on available CPU
- This value is set in the SetCuts() method of your physics list
  - defined for γ, e^-, e^+, proton secondaries
  - UI commands
    - /run/setCut 0.1 mm
    - /run/setCutForAGivenParticle e- 0.1 mm
- 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 stopped before it runs out of energy

Choosing the Correct Production Threshold



cut [μm]	mean E_{dep}	rms E_{dep}	prod. thres. [keV]		mean num. sec.	
			γ	e^-	γ	e^-
1	1.54423	0.000573911	0.99	0.99	0.0006811	0.1018230
2	1.54443	0.000583879	0.99	2.9547	0.0006843	0.0316897
5	1.54882	0.000605834	0.99	13.1884	0.0006857	0.0068261
10	1.56717	0.000665733	0.99	31.9516	0.0006730	0.0028232
20	1.58734	0.000743473	1.08038	47.8191	0.0006651	0.0018811
50	1.62223	0.000912408	1.67216	80.7687	0.0006557	0.0011304
100	1.65893	0.001108240	2.32425	121.694	0.0006518	0.0007536
200	1.69338	0.001342180	3.2198	187.091	0.0006465	0.000477
500	1.74642	0.001774670	5.00023	337.972	0.0006184	0.0002617
1000	1.78751	0.002219870	6.95018	548.291	0.0006054	0.0001622
2000	1.83440	0.002861020	9.66055	926.09	0.0005786	9.3e-05
5000	1.90700	0.004243030	14.9521	2074.3	0.0005427	4.07e-05
10000	1.97378	0.006036600	20.6438	4007.59	0.000521	2.22e-05

Compute the mean of the energy deposit (E_f-E_0) in the target



Cuts per Region

- In a complex detector there may be many different types of sub-detector 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

- A default region is created automatically for the world volume
  - it uses the cut values which you set in SetCuts() in your physics list
  - these will be used everywhere except for user-defined regions

- In the geometry an instance of G4Region must be created which corresponds to the volume where the cuts are to be changed

- To define different cuts for this special region, user must
  - create a G4ProductionCuts object
  - initialize it with the new cuts
  - assign it to a new region which has already been created

Cuts per Region

- void MyPhysicsList::SetCuts() {

```
SetCutValue(defaultCutValue, “gamma”);   // same for e-, e+, p

// Get the region
G4Region* aRegion =
    G4RegionStore::GetInstance()->GetRegion(“RegionA”);
// Define cuts object for the new region and set values
G4ProductionCuts* cuts = new G4ProductionCuts();
cuts->SetProductionCut(0.01*mm);   // here, same for all

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

}

Particle Decays

- For all unstable, long-lived particles
  - not used for radioisotopes (G4RadioactiveDecay)
- Decay can happen in flight or at rest
  - decay process is discrete + at-rest (G4VRestDiscreteProcess)
- Different from other physical processes
  - mean free path (λ) for most processes: $1/\lambda = \Sigma = N\rho\sigma/A$
  - for decay in flight (mean free path): $\lambda = \gamma\beta c\tau$
  - for decay at rest (mean life time): $\lambda \rightarrow \tau$
  - at rest processes like decay and capture compete in time
- Same process used for all eligible particles
  - retrieves branching ratios and decay modes from decay table stored for each particle type

Particle Decay Modes Available

- Phase space
  - two-body: $\pi^0 \rightarrow \gamma\gamma$ (~98.8%)
  - three-body: $K_L^0 \rightarrow \pi^+\pi^-\pi^0$
- Dalitz
  - $\pi^0 \rightarrow l^+l^-\gamma$
- Muon and tau decay
  - $\mu^- \rightarrow e^- \overline{\nu_e} \nu_\mu$
  - no radiative corrections , mono-energetic neutrinos
- Semi-leptonic K decay
  - $K \rightarrow \pi \, l \, \nu$

Defining Decay Channels

- Geant4 provides decay modes for long-lived particles
  - user can re-define decay channels if necessary
- But decay modes for short-lived (e.g. heavy flavor) particles not provided by Geant4
  - user must "pre-assign" to particle
    - proper lifetime
    - decay modes
    - decay products
  - process can invoke decay handler from external generator
    - must use G4ExtDecayer interface
- Take care that the pre-assigned decays from generators do not overlap with those defined by Geant4 (e.g. K^0_S , τ)

Specialized Particle Decays

- G4DecayWithSpin
  - produces Michel electron/positron spectrum with first order radiative corrections
  - initial muon spin is required
  - propagates spin in magnetic field (precession) over remainder of muon lifetime

- G4UnknownDecay
  - only for not-yet-discovered particles (e.g. SUSY)
  - discrete process – only in-flight decays allowed
  - pre-assigned decay channels must be supplied by user or generator

Summary

- The precision of particle stopping and the production of secondary particles are determined by a secondary production threshold
  - which is a length
- For complex detectors with varying types of sensitive volumes, different production thresholds may be defined for different regions within the detector
- A single process handles the decay of many long-lived particles
- Decay modes available for special circumstances
  - Muon decay
  - Unknown decay