Introduction

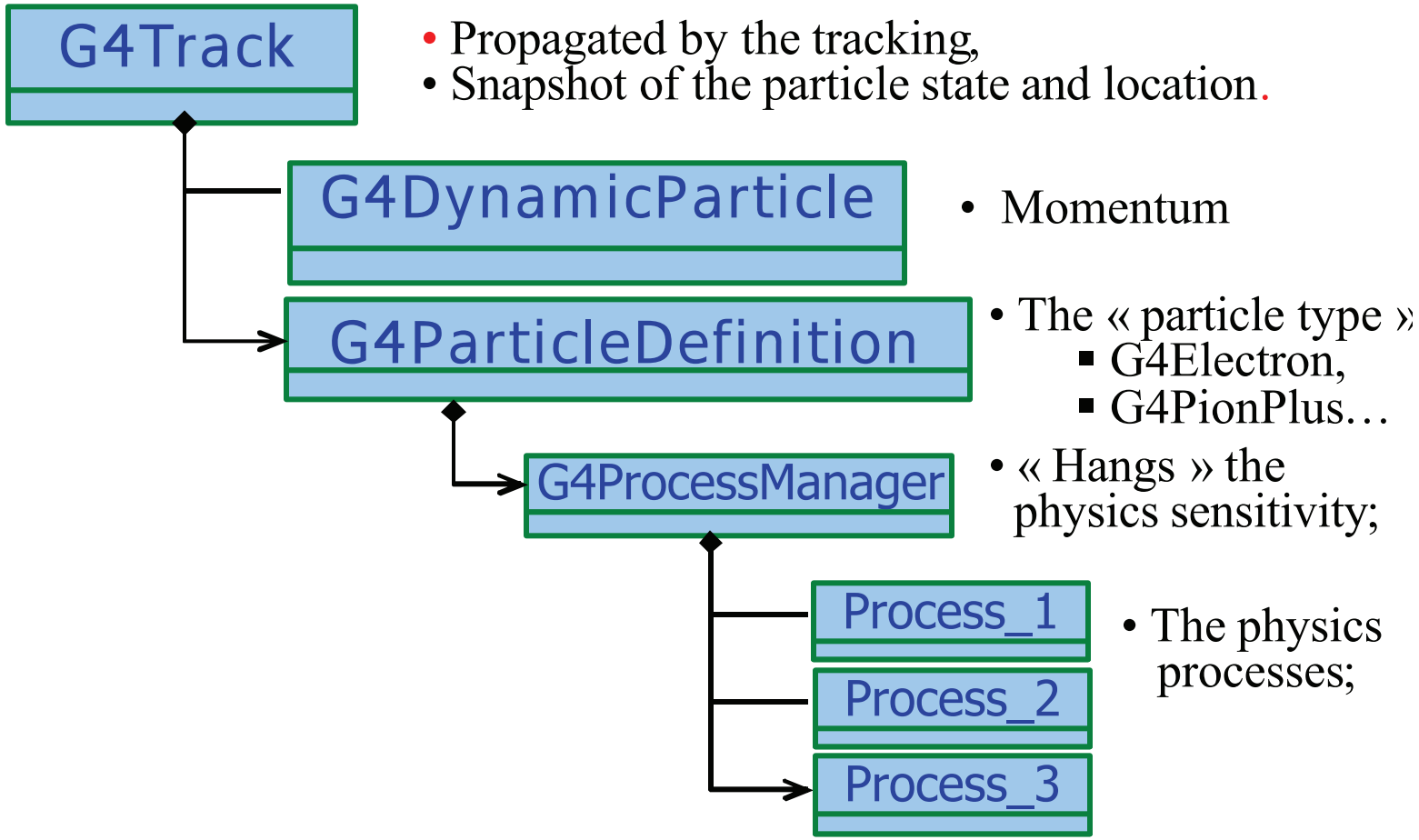
In Geant4, the user has to specify which particles, processes, and production cuts.

This is a ***mandatory*** and ***critical*** user's task.

This allows customization and performance.

Transparency and modularity: e.g. the user can define and use new processes, without knowing the kernel of Geant4.

What is tracked in GEANT4 ?



G4Track

- It is created by a process
- It is tracked from its birth until either it exits the world volume or it is killed:
  - by an interaction,
  - or because it comes to rest, and is stable
  - or by a user's action;
- It is not persistent: hits are usually saved.

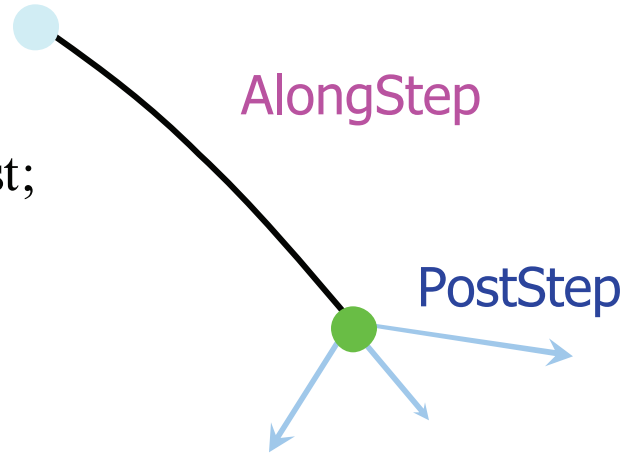
Processes in Geant4

- Processes describe how particles interact with a material or a volume;
- G4VProcess : abstract interface to the physics processes;
- processes are associated to particles;
- transportation treated as a process;
- tracking of particles is done in steps:
  an unbiased procedure must decide the step length and what happens;
- in Geant4, processes and tracking/geometry are well separated and decoupled.

Process actions

There are three situations, where <tracking> may want to ask information from <process>:

- AtRest:
  - Decay, e^+ annihilation, absorption at rest;
- AlongStep
  - To describe 'continuous' interactions, occuring along the path of the particle, like ionization and bremsstrahlung;
- PostStep
  - To describe 'discrete' interactions, in practice **most of the processes**.



The 6 main methods of G4Vprocess

- A process will implement any combination of the 3 actions: AtRest, AlongStep and PostStep;

  Eg: decay = AtRest + PostStep
- Each action defines 2 methods:
  - GetPhysicalInteractionLength():

    Used to ***limit the step size***:
    - because the process « triggers » an interaction, a decay, geometry boundary, a user's limit …
  - DoIt():
    - Implements the ***actual action*** to be applied on the track;
    - Typically final state generation.

G4VProcess & G4ProcessManager

- In practice, the G4ProcessManager has 3 lists of actions:
  - One for the AtRest methods of the particle;
  - One for the AlongStep ones;
  - And one for the PostStep actions.
- Those lists are set up in the Physics List and then used by the Tracking.

Stepping algorithm

Processes have to cooperate in their AlongStep actions; compete for PostStep and AtRest actions.

1. Determine the step length, as the smallest proposed length of all GPILs of all processes associated with the G4Track;
2. Apply all AlongStepDoIt() actions;
3. Apply PostStepDoIt() of the process who won the race for the step length (and also of special “forced” actions);

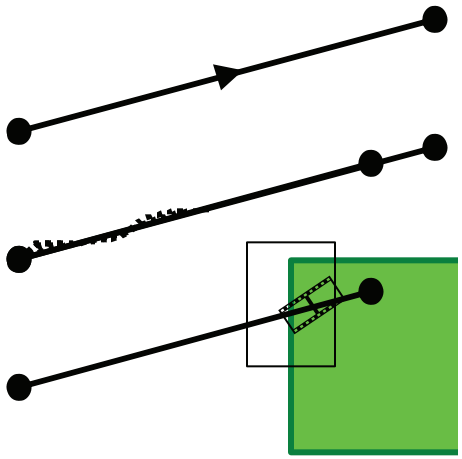
NB) For AtRest the step length is actually a time.

Ordering of the processes

- Ordering of following processes is critical:
  - Assuming n processes, the ordering of the AlongStepGetPhysicalInteractionLength of the last processes should be:

    [n-2] …
    [n-1] multiple scattering
    [n] transportation

- Why ?
  - Processes return a « true path length »;
  - The multiple scattering « virtually folds up » this true path length into a ***shorter*** « geometrical » path length;
  - Based on this new length, the transportation can geometrically limits the step.



- For other processes ordering does not matter.

How to create a new process?

- Inherit from one of the following 7 classes:

  ContinuousProcess, ContinuousDiscreteProcess, DiscreteProcess, RestContinuousDiscreteProcess, RestContinuousProcess, RestDiscreteProcess, RestProcess

- Implement the cross-section of the process

  in: GetPhysicalInteractionLength

- Implement the final-state of the process

  in: DoIt . Get familiar with classes:

  G4Step and G4VParticleChange.

- Learn by looking at some of Geant4 processes (but **not G4MultipleScattering** and **G4Transportation**: they are special!).

The Production Cuts

- In Geant4 there is no tracking cut: particles are tracked down to a zero range/Ekin.
- Only production cuts exist, i.e. cuts allowing a particle to be born or not.
- Why are production cuts needed?

  Two electromagnetic processes, δ-rays production and bremsstrahlung, have an infrared divergence; in practice, below the production cut, these processes are treated as continuous effect (AlongStep action).
- For other processes (and particles), production cuts can be an option to speed-up the simulation.

Range vs. Energy production cuts

- In Geant4, users specify production cuts

  in range, and then internally this is converted into kinetic energy.
- The production of a secondary particle is relevant if it can be "visible" in the detector: range cut allows to easily define such visibility.
- A cut of the same energy would lead to very different ranges: for the same particle type, depending on the material; for the same material, depending on particle type.
- Different range cuts can be chosen per region.

G4UserLimit

This class allows to define the following limits (in a given G4LogicalVolume):

- Maximum step size;
- Maximum track length;
- Maximum track time;
- Minimum kinetic energy (tracking cut).

The user can inherit from G4UserLimit, or can instantiate the default implementation.

These limits are unphysical “tricks” that can improve either the CPU performance of the simulation, or (in the case of the maximum step only) the precision of the simulation.

Electromagnetic Physics

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Electromagnetic Physics in G4

- The projectile is assumed to have a kinetic energy between 1 keV and 100 GeV

  (this is the Standard EM: there is a low-energy extension, down to 250 eV, and a high-energy ones, especially for muons, up to several hundred GeV);
- The atomic electrons are quasi-free: their binding energy is neglected (except for the photoelectric effect);
- The atomic nucleus is fixed: the recoil momentum is neglected;
- The matter is described as homogeneous, isotropic, amorphous.
- Single interactions are precisely described by QED, but there are medium-effects that complicate things…
- It must be very CPU performant!

EM processes

Common to all charged particles:

- Ionization
- Coulomb scattering from nuclei
- Scintillation
- Cerenkov effect
- Transition radiation

Electrons and Positrons:

- Bremsstrahlung
- e+ annihilation

Muons

- e+/e- pair production
- Bremsstrahlung
- Nuclear interaction

EM processes (cont.)

Photons:

- ■ conversion
- Compton (incoherent) scattering
- Photo-electric effect

Optical photons:

- Rayleigh (coherent) scattering
- Reflection and refraction
- Absorption

NB) Clear distinction between **G4Gamma** and **G4OpticalPhoton** (✦ >> atomic scale) for CPU performance reasons.

There are also other processes:

- Synchrotron radiation
- Fluorescence
- Auger effect
- Gamma-nuclear, electron-nuclear

And also weak physics processes: ▮- capture