Physics Particles and Physics lists

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XVI Seminar on Software for Nuclear, Sub-Nuclear and Applied Physics
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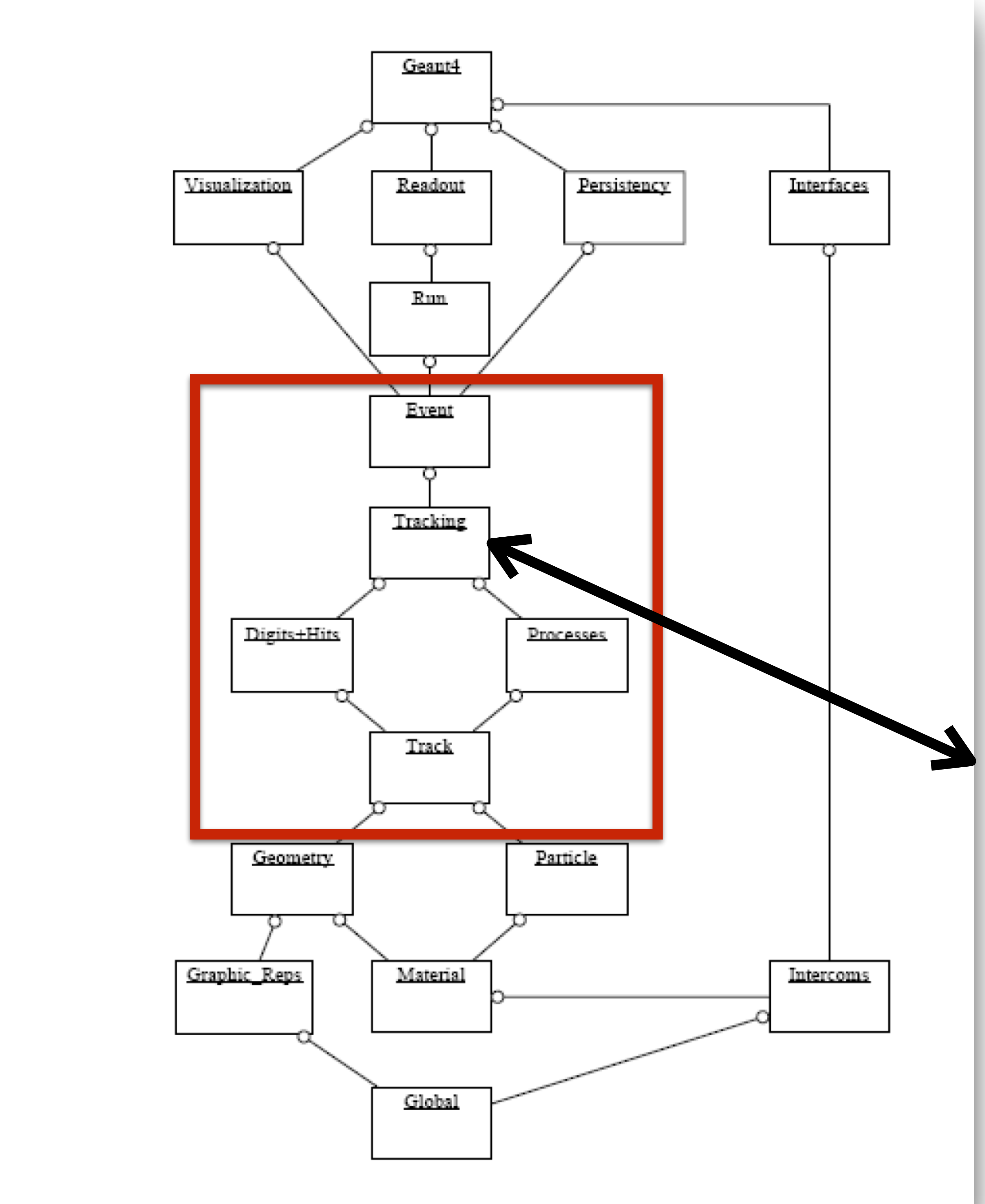


In spite of the name "track-ing", **particles are not transported in the tracking** category.

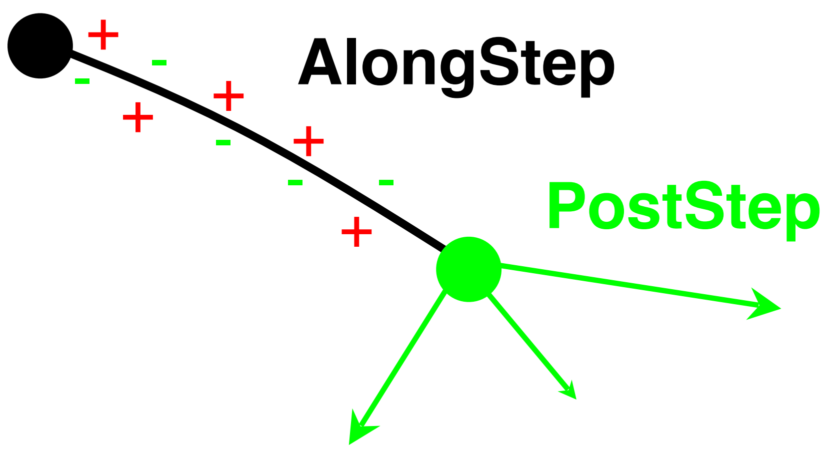
G4TrackingManager is an **interface class** which brokers transactions between the **event**, **track** and **tracking** categories.

The tracking manager **receives a track from the event** manager and takes the actions required to finish tracking

G4TrackingManager aggregates the pointers to **G4SteppingManager**, **G4Trajectory** and **G4UserTrackingAction** (it also uses **G4Track and G4Step)**

G4VProcess class

- Abstract class as a base for all processes in Geant4
  - Used by all physics processes (also by the transportation, etc…
  - Defined in **source/processes/management**
- Define three kinds of actions:



  - **AtRest** actions:
    - Decay, e^+ annihilation …
  - **AlongStep** actions:
    - To describe continuous (inter)actions, occurring along the path of the particle, like ionisation;
  - **PostStep** actions:
    - For describing point-like (inter)actions, like decay in flight, hadronic interactions …

A process can implement a combination of them (decay = AtRest + PostStep)

Example processes

- Discrete process: Compton Scattering, hadronic inelastic, ...
  - step determined by cross section, interaction at end of step
    - PostStepGPIL(), PostStepDoIt()
- Continuous process: Čerenkov effect
  - photons created along step, roughly proportional to step length
    - AlongStepGPIL(), AlongStepDoIt()
- At rest process: muon capture at rest
  - interaction at rest
    - AtRestGPIL(), AtRestDoIt()

pure

- Rest + discrete: positron annihilation, decay, ...
  - both in flight and at rest
- Continuous + discrete: ionization
  - energy loss is continuous
  - knock-on electrons (δ-ray) are discrete

combined

Handling multiple processes

1 a particle is shot and “transported”

2 all processes associated to the particle propose a geometrical step length (depends on process cross-section)

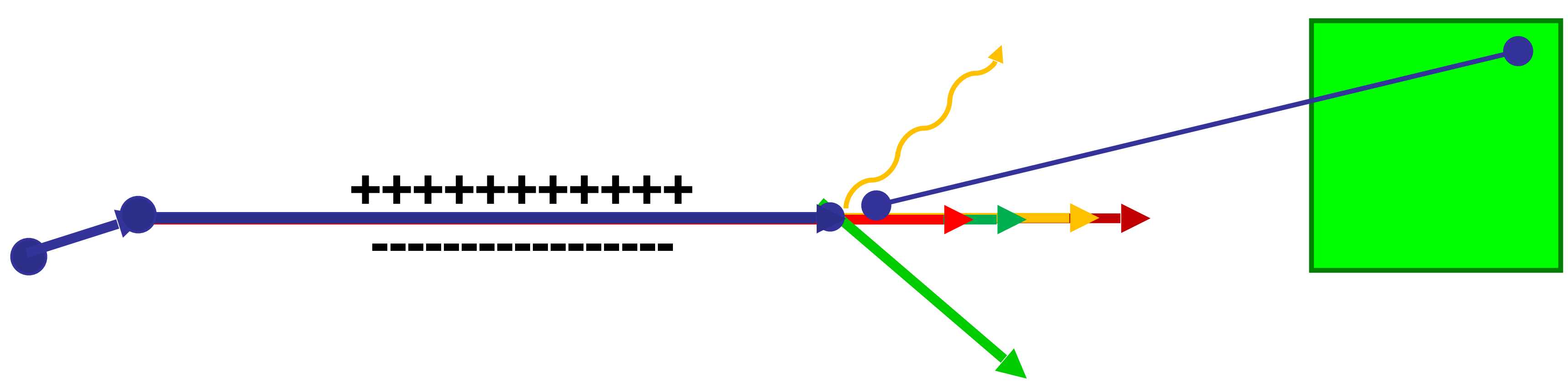
3 The process proposing the shortest step “wins” and the particle is moved to destination (if shorter than “Safety”)

4 All processes along the step are executed (e.g. ionization)

5 post step phase of the process that limited the step is executed.
New tracks are “pushed” to the stack

6 If E_{kin}=0 all at rest processes are executed; if particle is stable the track is killed. Else:

7 New step starts and sequence repeats...



Contents

User classes

At initialization

G4VUserDetectorConstruction

G4VUserPhysicsList

G4VUserActionInitialization

Global: only one instance exists in memory, shared by all threads.

At execution

G4VUserPrimaryGeneratorAction

G4UserRunAction

G4UserEventAction

G4UserStackingAction

G4UserTrackingAction

G4UserSteppingAction

Thread-local: an instance of each action class exists for each thread.

Particles and Processes

Particles: basic concepts

There are three levels of class to describe particles in Geant4:

G4ParticleDefinition

Particle static properties: name, mass, spin, PDG number, etc.

G4DynamicParticle

Particle dynamic state: energy, momentum, polarization, etc.

G4Track

Information for tracking in a detector simulation: position, step, current volume, track ID, parent ID, etc.

Particles: common hadrons & ions table

Particle name	Class name	Name (in GPS...)	PDG
(anti)proton	G4Proton G4AnitProton	proton anti_proton	2212 -2212
(anti)neutron	G4Neutron G4AntiNeutron	neutron anti_neutron	2112 -2112
(anti)lambda	G4Lambda G4AntiLambda	lambda anti_lambda	3122 -3122
pion	G4PionMinus G4PionPlus G4PionZero	pi- pi+ pi0	-211 211 111
kaon	G4KaonMinus G4KaonPlus G4KaonZero G4KaonZeroLong G4KaonZeroShort	kaon- kaon+ kaon0 kaon0L kaon0S	-321 321 311 130 310
(anti)alpha	G4Alpha G4AntiAlpha	alpha anti_alpha	1000020040 -1000020040
(anti)deuteron	G4Deteuron G4AntiDeuteron	deuteron anti_deuteron	1000010020 -1000010020
Heavier ions	G4Ions	ion	100ZZZAAAI*

*ZZZ=proton number, AAA=nucleon number, I=excitation level

Processes: basic concepts

How do particles interact with materials?

G4VProcess

Responsibilities:

1. *decide* ***when*** *and* ***where*** *an interaction occurs*
   - **GetPhysicalInteractionLength...()**

     → *limit the step*
   - this requires a cross section
   - for the **transportation** process, the distance to the nearest object

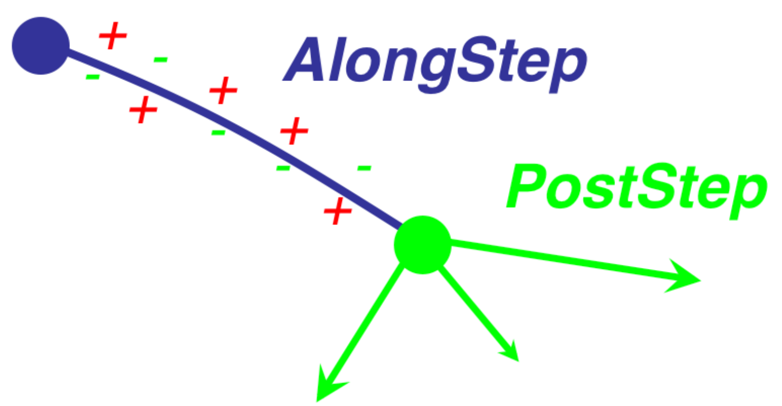
2. *generate the* ***final state*** *of the interaction*
   - changes momentum, generates secondaries, etc.)
   - method: **DoIt...()**
   - this requires a model of the physics

G4VProcess class

- Physics processes describe HOW particles interact with material
- Are derived from G4VProcess base class
- Abstract class defining the common interface of all processes in Geant4, used by all physics processes

Three kinds of "actions":

- AtRest actions
  - Decays, e^+ annihilation
- AlongStep actions
  - To describe continuous (inter)actions, occurring along the path of the particle, i.e. **"soft" interactions**
- PostStep actions
  - To describe the point-like (inter)actions, like decay in flight, hadronic interactions, i.e. **"hard" interactions**



Tracking and Cuts

Tracking: basic concepts

- G4Track keeps current information of the particle and has static information

- G4Track keeps information at the beginning of the step. After finishing all AlongStepDoIts, G4Track is updated. It is updated after each invocation of a PostStepDoIt.

- All Geant4 processes, including the transportation of particles, are treated generically. In spite of the name "*tracking*", particles are not *transported* in the tracking category.

Tracking Verbosity

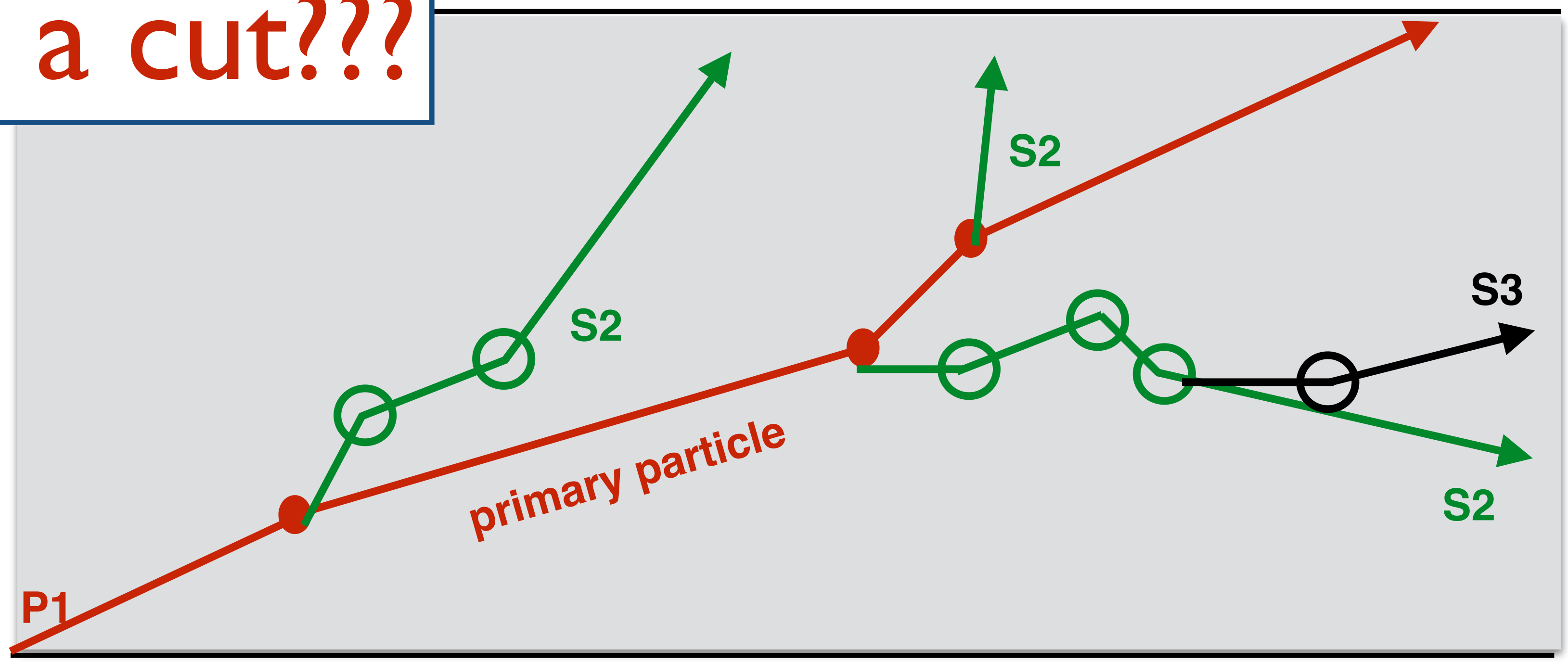
UI command: **`/tracking/verbose 1`**

```
*******************************************************************************
* G4Track Information:   Particle = gamma,   Track ID = 1,   Parent ID = 0
*******************************************************************************

Step#     X(mm)     Y(mm)     Z(mm)  KinE(MeV)   dE(MeV)  StepLeng TrackLeng   NextVolume ProcName
    0      47.4       -53      -150          6         0         0         0     Envelope initStep
    1      47.4       -53       -58      0.844         0        92        92     Envelope compt
    2       -46      15.9      5.55       0.47         0       132       224     Envelope compt
    3      -100      6.37     -3.62       0.47         0      55.6       280        World
Transportation
    4      -120      2.84     -7.02       0.47         0      20.6       301   OutOfWorld
Transportation
*******************************************************************************
* G4Track Information:   Particle = e-,   Track ID = 3,   Parent ID = 1
*******************************************************************************
Step#     X(mm)     Y(mm)     Z(mm)  KinE(MeV)   dE(MeV)  StepLeng TrackLeng   NextVolume ProcName
    0       -46      15.9      5.55      0.375         0         0         0     Envelope initStep
    1     -46.1      16.4      5.98     0.0482     0.327      1.16      1.16     Envelope eIoni
    2     -46.1      16.3      5.98          0    0.0482    0.0408       1.2     Envelope eIoni
```

Production cuts: basic concepts

What is a cut???



You can set a **"range" production threshold**

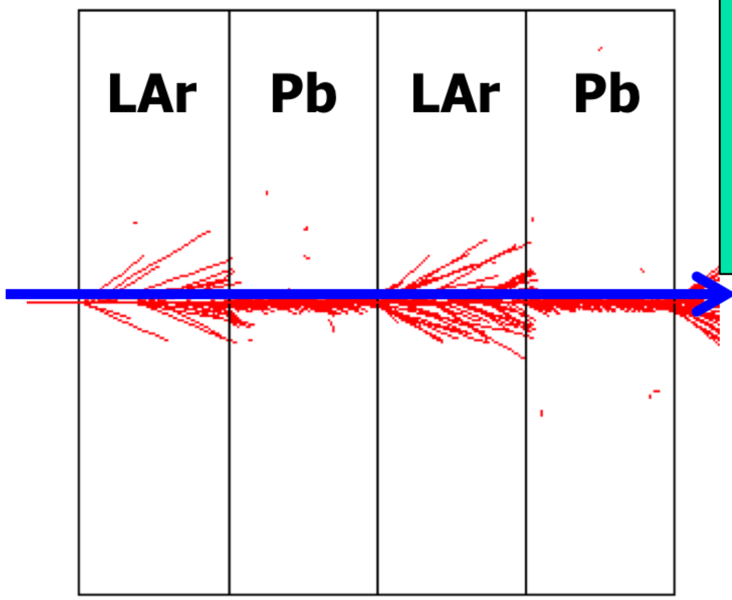
- this threshold is a distance, not an energy
- default = 1 mm
- Particles unable to travel at least the range cut are not produced
- Energy is conserved !!!

Production threshold is internally converted to the energy threshold W_0, depending on particle type and material

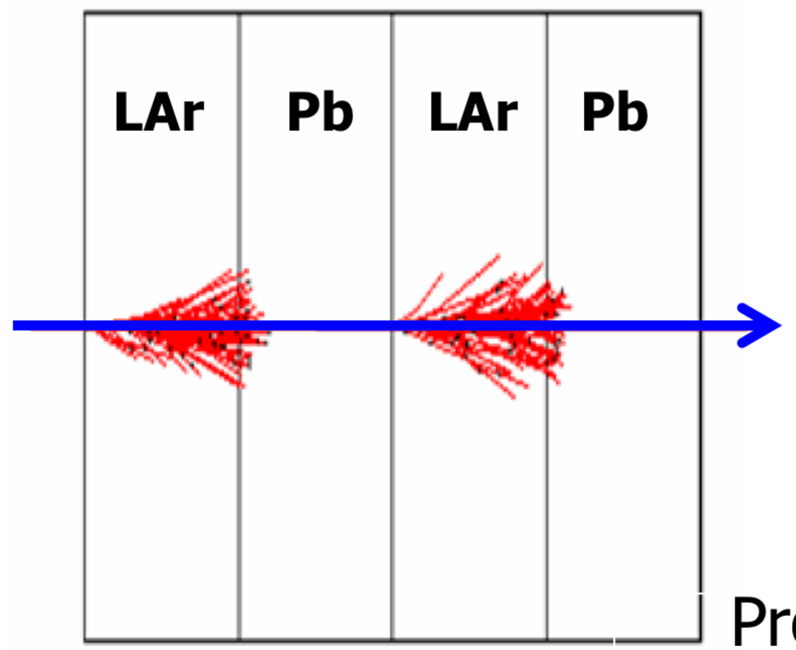
Effective energy threshold is different in each material

Cut in range: an example

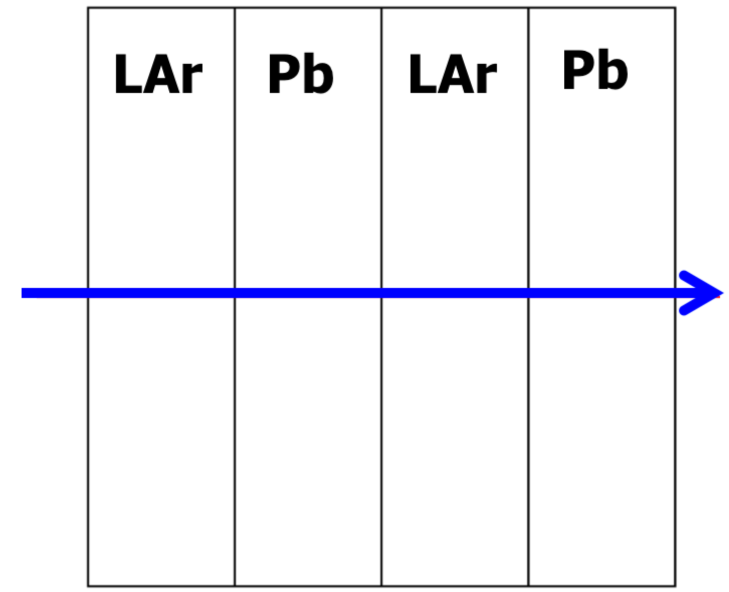
500 MeV p in LAr-Pb sampling calorimeter



Cut = 455 keV
(range in LAr = 1.5 mm)



Production range =1.5 mm



Cut = 2 MeV

Threshold in range: 1.5 mm

455 keV electron energy in liquid Ar

2 MeV electron energy in Pb

Cuts: UI Commands


```
# Universal cut (whole world, all particles)
/run/setCut 10 mm

# Override low-energy limit
/cuts/setLowEdge 100 eV

# Set cut for a specific particle (whole world)
/run/setCutForAGivenParticle gamma 0.1 mm

# Set cut for a region (all particles)
/run/setCutForARegion myRegion 0.01 mm

# Print a summary of particles/regions/cuts
/run/dumpCouples
```

Physics in Geant4

Physics - the challenge

- Huge amount of different processes for various purposes (only a handful relevant)
- Competing descriptions of the same physics phenomena (necessary to choose)
  - fundamentally different **approaches**
  - balance between **speed** and **precision**
  - different **parameterizations**
- Hypothetical processes & exotic physics

Solution: Atomistic approach with modular **physics lists**

Physics models: basic concepts

There are currently 28 "packaged" physics lists available

- but you will likely interested in only a few, namely the "reference physics lists"
- many physics lists are either developmental or cutomized in some way, and so not very useful to new users

Reference physics lists

- QGSP_BERT, QGSP_BERT_EMV, QGSP_BERT_HP, QGSP_BIC, FTFP_BERT, LBE, LHEP
- plus a few more

Conventional Physics List

- Two families of builders for the high-energy part
- **QGS**, or list based on a model that use the Quark Gluon String model for high energy hadronic interactions of protons, neutrons, pions and kaons
- **FTF**, based on the FTF (FRITIOF like string model) for protons, neutrons, pions and kaons
- Three families for the cascade energy range
- **BIC**, binary cascade
- **BERT**, Bertini cascade
- **INCLXX**, Liege Intranuclear cascade model

- New Model: ParticleHP

Data based on TENDL-2014 (charged particles) and ENDFVII.r1 (neutrons).

Physics lists

Physics List

- One instance per application
  - registered to run manager in main()
  - inheriting from G4VUserPhysicsList
- Responsibilities
  - all particle types (electron, proton, gamma, ...)
  - all processes (photoeffect, bremsstrahlung, ...)
  - all process parameters (...)
  - production cuts (e.g. 1 mm for electrons, ...)

Physics List

3 ways to get a **physics list**

1) Manual: Specify all particles & processes that may occur in the simulation. (difficult)

2) Physics constructors: Combine your physics from pre-defined sets of particles and processes. Still you define your own class – modular physics list (easier)

3) Reference physics lists: Take one of the pre-defined physics lists. You don't create any class (easy)

Physics List

Way 1

G4VUserPhysicsList class

Implement 3 methods:

```
class MyPhysicsList : public G4VUserPhysicsList {
public:
    // ...
    void ConstructParticle();  // pure virtual
    void ConstructProcess();   // pure virtual
    void SetCuts();
    // ...
}
```

Advantage: most flexible

Disadvantages:

- most verbose
- most difficult to get right

Physics List

G4VUserPhysicsList: implementation

ConstructParticle():

– choose the particles you need in your simulation, define all of them here

ConstructProcess() :

– for each particle, assign all the physics processes relevant to your simulation

SetCuts() :

– set the range cuts for secondary production for processes with infrared divergence

Physics List

Way 2

G4VModularPhysicsList

- Similar structure as G4VUserPhysicsList (same methods to override – though not necessary):

```
class MyPhysicsList : public G4VModularPhysicsList {
public:
    MyPhysicsList();             // define physics constructors
    void ConstructParticle();   // optional
    void ConstructProcess();    // optional
    void SetCuts();             // optional
}
```

Differences to "manual" way:

- Particles and processes typically handled by **physics constructors** (still customizable)
- **Transportation** automatically included

Physics List

Physics constructor

= "**module**" of the **modular physics list**

- Inherits from **G4VPhysicsConstructor**
- Defines **ConstructParticle**() and **ConstructProcess**()
  - to be fully imported in modular list (behaving in the same way)
- **GetPhysicsType**()
  - enables switching physics of the same type, if possible (see next slide)

Physics List

Physics constructors

- Huge set of pre-defined ones
  - **EM**: Standard, Livermore, Penelope
  - **Hadronic inelastic:** QGSP_BIC, FTFP_Bert, ...
  - **Hadronic elastic:** G4HadronElasticPhysics, ...
  - ... (decay, optical physics, EM extras, ...)
- You can implement your own (of course) by inheriting from the G4VPhysicsConstructor class

Physics List

Replace physics constructors

You can **add** or **remove** the physics constructors after the list instance is created:

- e.g. in response to **UI command**
- only **before initialization**
- physics of the same type can be **replaced**

```
void MyModularList::SelectAlternativePhysics() {
    AddPhysics(new G4OpticalPhysics);
    RemovePhysics(fDecayPhysics);
    ReplacePhysics(new G4EmLivermorePhysics);
}
```

Physics List

SetCuts()

- Define all **production** cuts for gamma, electrons and positrons
  - Recently also for protons
- Notice: this is a **production cut**, not a tracking cut

Physics List

Way 3

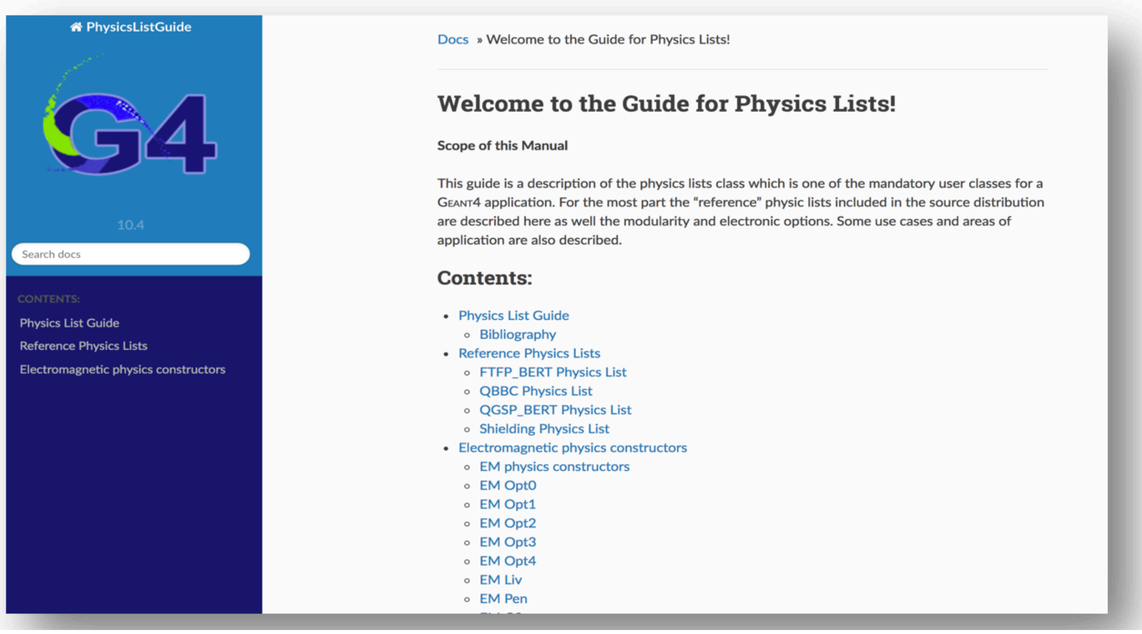
Reference physics lists

- Pre-defined physics lists
  - already containing a complete set of particles & processes (that work together)
  - targeted at specific area of interest (HEP, medical physics, ...)
  - constructed as **modular physics lists**, built on top of **physics constructors**
  - customizable (by calling appropriate methods before initialization)

Lists of reference physics lists

Source code: `$G4INSTALL/source/physics_lists/lists`

```
FTF_BIC.hh                  G4PhysListRegistry.hh         QGSP_BIC_AllHP.hh
FTFP_BERT.hh                G4PhysListStamper.hh          QGSP_BIC.hh
FTFP_BERT_HP.hh             INCLXXPhysicsListHelper.hh    QGSP_BIC_HP.hh
FTFP_BERT_TRV.hh            LBE.hh                        QGSP_FTFP_BERT.hh
FTFP_INCLXX.hh              NuBeam.hh                     QGSP_INCLXX.hh
FTFP_INCLXX_HP.hh           QBBC.hh                       QGSP_INCLXX_HP.hh
G4GenericPhysicsList.hh     QGS_BIC.hh                    Shielding.hh
G4PhysListFactoryAlt.hh     QGSP_BERT.hh
G4PhysListFactory.hh        QGSP_BERT_HP.hh
```

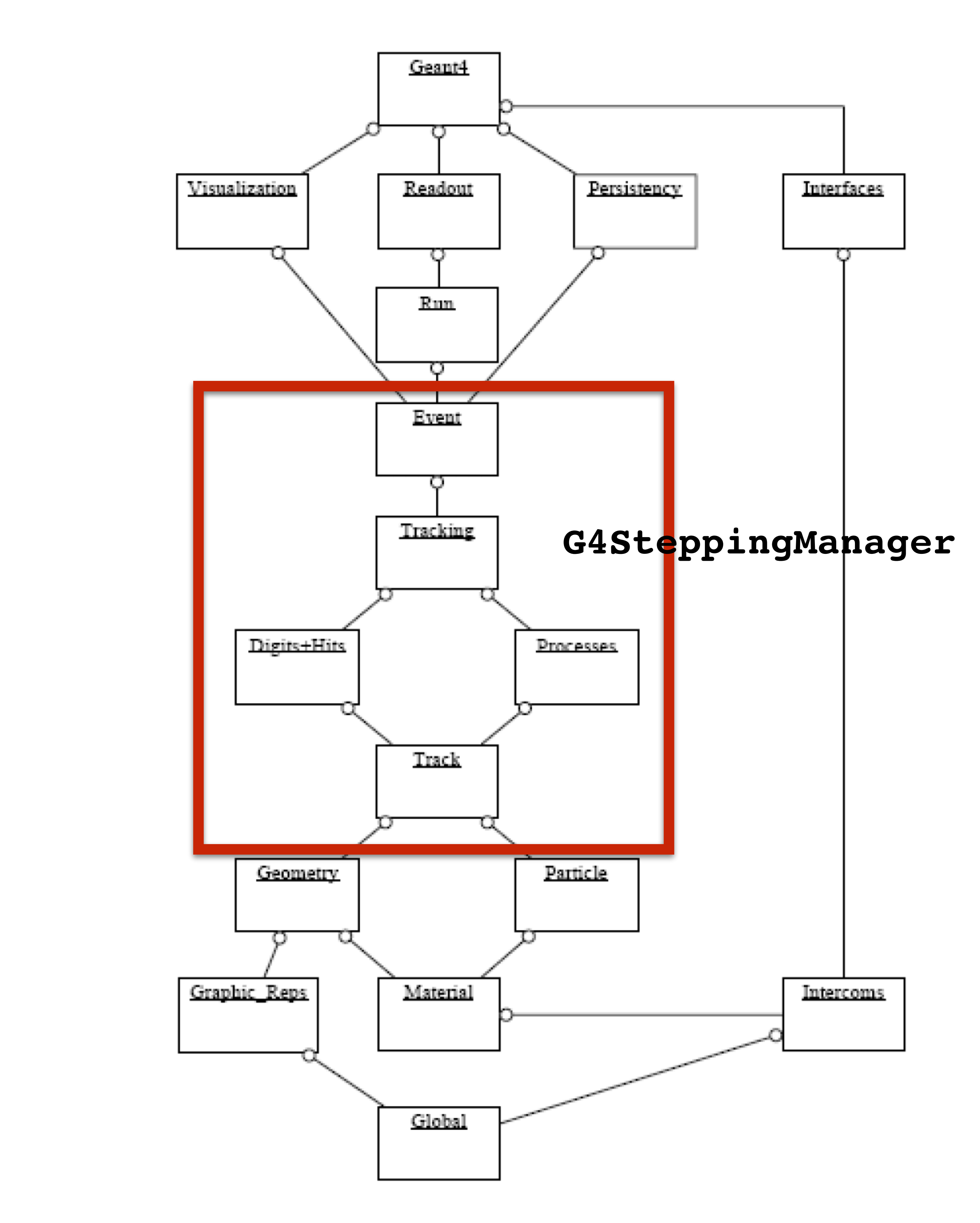


====> Task 3

link to the task: http://geant4.lngs.infn.it/alghero2019/task3/index.html

Task 3 - Physics and Physics Lists

- Processes and particles
- Physics constructors
- Physics lists
- Production and cuts

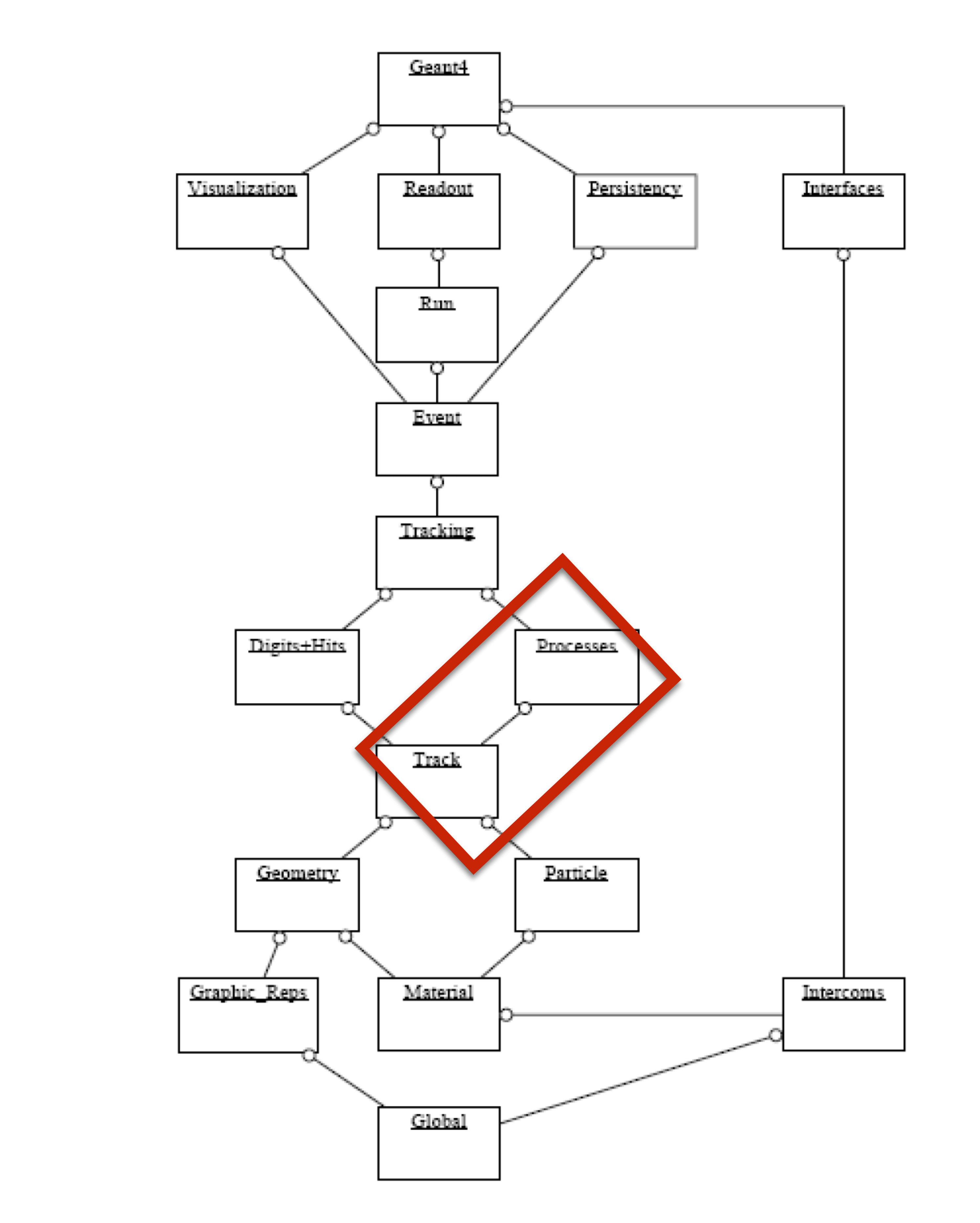


`G4SteppingManager` plays an essential role in **tracking the particle.**

It takes care of all **message passing between objects in the different categories relevant to transporting** a particle (for example, geometry and interactions in matter).

Its public method **`Stepping()`** steers the stepping of the particle.

Processes

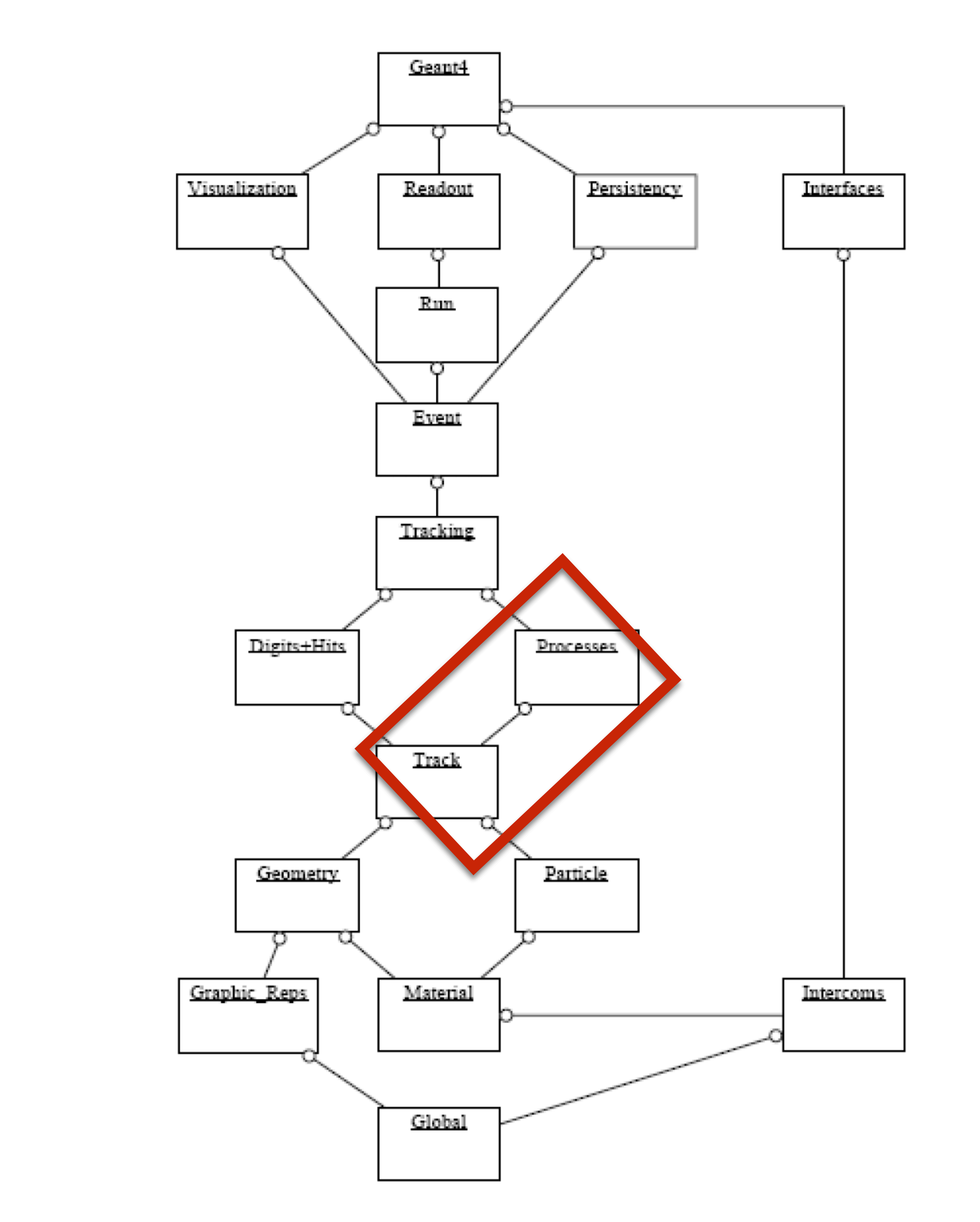


G4VProcess is a base class of all processes

Only `processes` **can change information** of **G4Track** and add secondary tracks via **ParticleChange**.

If a user want to modify information of **G4Track**, he SHOULD create a special process for the purpose and **register the process to the particle.**

G4VProcess is a **base class** of all processes and it has 3 kinds of **DoIt** and **GetPhysicalInteraction**



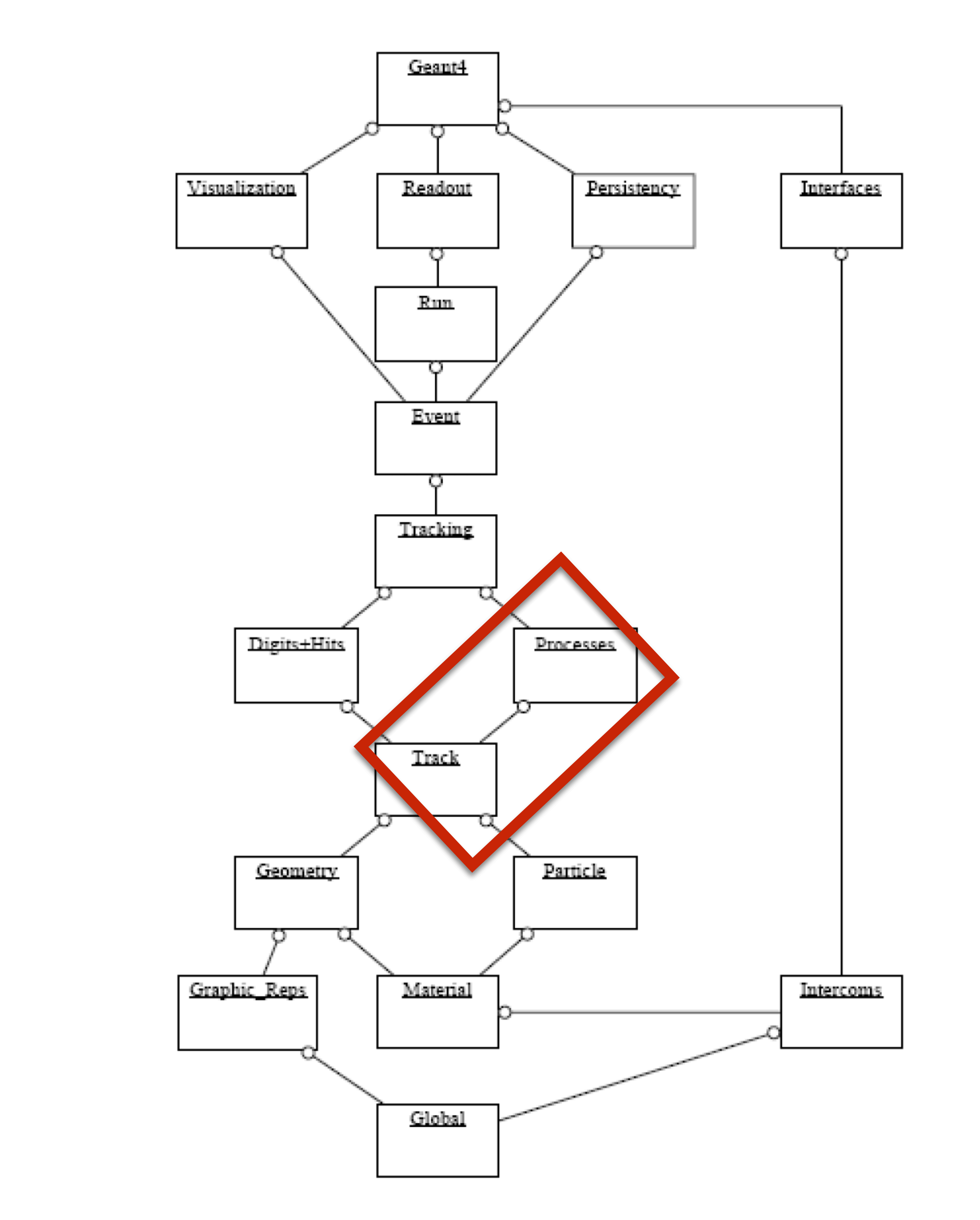
Track

G4Track keeps **'current' information of the particle.** (i.e. energy,momentum, position, time and so on) and **has 'static'** information (i.e. mass, charge, life and so on)

Step

G4Step stores the transient information of a step.
This includes the **two endpoints** of the step, `PreStepPoint` and `PostStepPoint`, which contain the **points' coordinates and the volumes containing the points**. `G4Step` also stores the change in track properties between the two points (such as energy and momentum), are updated as the various active processes are invoked.

Particle Change



Processes do NOT change any information of **`G4Track`** directly in their DoIt.

Instead, **they proposes changes** as a result of interactions by using **`ParticleChange`**.

After each `DoIt`, `ParticleChange` updates `PostStepPoint` based on proposed changes.

Then, `G4Track` is updated after finishing all `AlongStepDoIts` and after each `PostStepDoIt`.