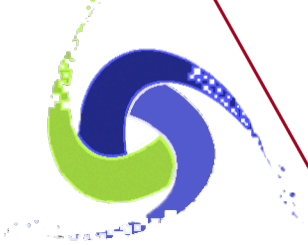


GEANT4
A SIMULATION TOOLKIT

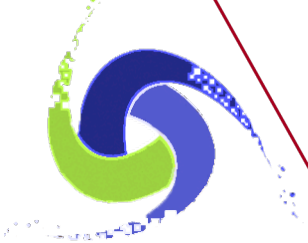
Version 10.4-p02

Kernel II

Makoto Asai (SLAC)
Geant4 Tutorial Course

Contents

- User limits
- Attaching user information to G4 classes
- Fast simulation (a.k.a. shower parameterization)
- Stacking mechanism



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User limits

G4UserLimits

- User limits are artificial limits affecting to the tracking.

```
G4UserLimits(G4double ustepMax = DBL_MAX,
             G4double utrakMax = DBL_MAX,
             G4double utimeMax = DBL_MAX,
             G4double uekinMin = 0.,
             G4double urangMin = 0. );
```

  - fMaxStep; // max allowed Step size in this volume
  - fMaxTrack; // max total track length
  - fMaxTime; // max global time
  - fMinEkine; // min kinetic energy remaining (only for charged particles)
  - fMinRange; // min remaining range (only for charged particles)

  Blue : affecting to step

  Red : affecting to track

- You can set user limits to logical volume and/or to a region.
  - User limits assigned to logical volume do not propagate to daughter volumes.
  - User limits assigned to region propagate to daughter volumes unless daughters belong to another region.
  - If both logical volume and associated region have user limits, those of logical volume win.

Processes co-working with G4UserLimits

- In addition to instantiating G4UserLimits and setting it to logical volume or region, you have to assign the following process(es) to particle types you want to affect.
- Limit to step

  fMaxStep : max allowed Step size in this volume

  – G4StepLimiter process must be defined to affected particle types.

  – This process limits a step, but it does not kill a track.
- Limits to track

  fMaxTrack : max total track length

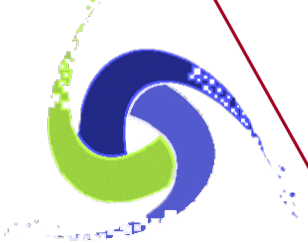
  fMaxTime : max global time

  fMinEkine : min kinetic energy (only for charged particles)

  fMinRange : min remaining range (only for charged particles)

  – G4UserSpecialCuts process must be defined to affected particle types.

  – This process limits a step and kills the track when the track comes to one of these limits. Step limitation occurs only for the final step.



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Version 10.4-p02

Attaching user information to some kernel classes

Attaching user information

- Abstract classes
  - You can use your own class derived from provided base class
  - G4Run, G4VHit, G4VDigit, G4VTrajectory, G4VTrajectoryPoint
- Concrete classes
  - You can attach a user information class object
    - G4Event - G4VUserEventInformation
    - G4Track - G4VUserTrackInformation
    - G4PrimaryVertex - G4VUserPrimaryVertexInformation
    - G4PrimaryParticle - G4VUserPrimaryParticleInformation
    - G4Region - G4VUserRegionInformation
  - User information class object is deleted when associated Geant4 class object is deleted.

Trajectory and trajectory point

- Trajectory and trajectory point class objects persist until the end of an event.
- G4VTrajectory is the abstract base class to represent a trajectory, and G4VTrajectoryPoint is the abstract base class to represent a point which makes up the trajectory.
  - In general, trajectory class is expected to have a vector of trajectory points.
- Geant4 provides G4Trajectoy and G4TrajectoryPoint concrete classes as defaults. These classes keep only the most common quantities.
  - If the you want to keep some additional information, you are encouraged to implement your own concrete classes deriving from G4VTrajectory and G4VTrajectoryPoint base classes.
  - Do not use G4Trajectory nor G4TrajectoryPoint concrete class as base classes unless you are sure not to add any additional data member.
    - Source of memory leak

Creation of trajectories

- Naïve creation of trajectories occasionally causes a memory consumption concern, especially for high energy EM showers.
- In UserTrackingAction, you can switch on/off the creation of a trajectory for the particular track.

```
void MyTrackingAction
           ::PreUserTrackingAction(const G4Track* aTrack)
{
  if(...)
  { fpTrackingManager->SetStoreTrajectory(true); }
  else
  { fpTrackingManager->SetStoreTrajectory(false); }
}
```

- If you want to use user-defined trajectory, object should be instantiated in this method and set to G4TrackingManager by SetTrajectory() method.

```
fpTrackingManager->SetTrajectory(new MyTrajectory(…));
```

Bookkeeping issues

- Connection from G4PrimaryParticle to G4Track

  G4int G4PrimaryParticle::GetTrackID()

  – Returns the track ID if this primary particle had been converted into G4Track, otherwise -1.

    - Both for primaries and pre-assigned decay products

- Connection from G4Track to G4PrimaryParticle

  G4PrimaryParticle* G4DynamicParticle::GetPrimaryParticle()

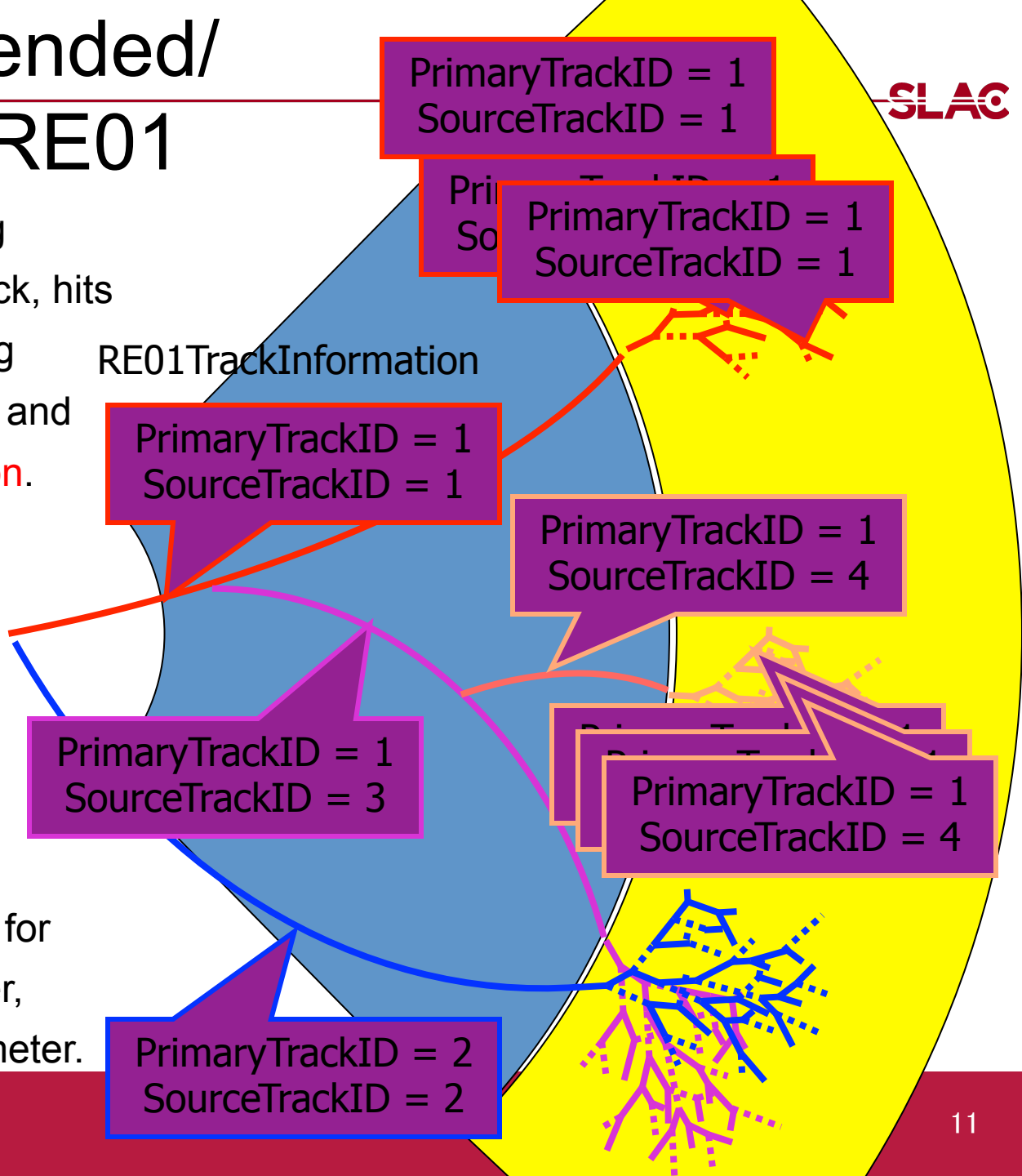
  – Returns the pointer of G4PrimaryParticle object if this track was defined as a primary or a pre-assigned decay product, otherwise null.

- G4VUserPrimaryVertexInformation, G4VUserPrimaryParticleInformation and G4VUserTrackInformation may be used for storing additional information.

  – Information in UserTrackInformation should be then copied to user-defined trajectory class, so that such information is kept until the end of the event.

Examples/extended/runAndEvent/RE01

- An example for connecting G4PrimaryParticle, G4Track, hits and trajectories, by utilizing G4VUserTrackInformation and G4VUserRegionInformation.
- SourceTrackID means the ID of a track which gets into calorimeter.
- PrimaryTrackID is copied UserTrackInformation daughter tracks.
- SourceTrackID is updated for secondaries born in tracker, while just copied in calorimeter.



Examples/extended/runAndEvent/RE01

```
Primary particles -----------------------------------------------------

Primary vertex (0,0,0)   at t = 0 [ns]
  ==PDGcode 25 is not defined in G4 (19.53824,24.846369,-6.0465937) [GeV] >>> G4Track ID 1
    ==PDGcode 23 is not defined in G4 (1.1302123,-23.156443,114.16953) [GeV] >>> G4Track ID 6780
      ==PDGcode 13 (mu-) (-22.464989,-38.451706,20.864853) [GeV] >>> G4Track ID 6782
      ==PDGcode -13 (mu+) (23.595201,15.29526,93.304688) [GeV] >>> G4Track ID 6781
```

Trajectory of track6782

```
TrackID =6782 : ParentID=6780 : TrackStatus=1
Particle name : mu-  PDG code : 13  Charge : -1
Original momentum : -22.464989 -38.451706 20.864853 GeV
Vertex : 4.11461
  Current traject
Point[0] Positio
Point[1] Positio
Point[2] Positio
Point[3] Positio
Point[4] Positio
Point[5] Positio
Poin
...
Point[24] Position= (-233.79372,-400.12944,217.10408)
```

Tracker hits of track6782

```
TrackID 6782   Position (-126.11431,-215.85917,117.12988)     : 1878.8831 [keV]
TrackID 6782   Position (-127.89383,
TrackID 6782   Position (-151.33864,
TrackID 6782   Position (-176.56317,-302.20101,163.96689)     : 1776.6378 [keV]
TrackID 6782   Position (-201.7911,-345.36988,187.38871)     : 2413.8986 [keV]
TrackID 6782   Position (-227.01961,-388.53841,210.81469)     : 550.67792 [keV]
TrackID 6782   Position (-227.70865,-389.71739,211.45445)     : 638.57593 [keV]
TrackID 6782   Position (-228.6702,-391.36253,212.34721)     : 778.03992 [keV]
```

Calorimeter hits of track6782

```
Source track ID 6782 (mu-,49.162515[GeV]) at (-252.24762,-431.70723,234.23766)
Original primary track ID 1 (unknown,335.96305[GeV])
Cell[11,31]    0.028283647 [GeV]
Cell[12,31]    0.039822296 [GeV]
Cell[13,31]    0.050185748 [GeV]
Cell[14,31]    0.049883344 [GeV]
Cell[15,31]    0.041446764 [GeV]
Cell[16,31]    0.06386168 [GeV]
Cell[16,32]    0.0036926015 [GeV]
Cell[17,32]    7.2955385e-05 [GeV]
Cell[17,31]    0.0043463898 [GeV]
Cell[15,32]    0.010138473 [GeV]
Cell[14,32]    0.0018386352 [GeV]
Cell[13,32]    0.0018836759 [GeV]
Cell[12,32]    0.00036846059 [GeV]
### Total energy deposition in calorimeter by a source track in 13 cells : 0.29582467 (GeV)
```

Energy deposition includes not only muon itself but also all secondary EM showers started inside the calorimeter.

RE01RegionInformation

- RE01 example has three regions, i.e. default world region, tracker region and calorimeter region.
  - Each region has its unique object of RE01RegionInformation class.

```
class RE01RegionInformation : public G4VUserRegionInformation
{
  …
  public:
   G4bool IsWorld() const;
   G4bool IsTracker() const;
   G4bool IsCalorimeter() const;
  …
};
```

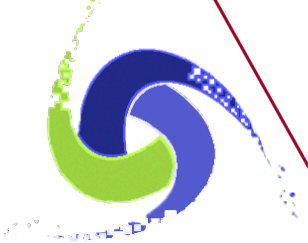
- Through step->preStepPoint->physicalVolume->logicalVolume->region->regionInformation, you can easily identify in which region the current step belongs.
  - Don’t use volume name to identify.

Use of RE01RegionInformation

```
void RE01SteppingAction::UserSteppingAction(const G4Step * theStep)
{ // Suspend a track if it is entering into the calorimeter

  // get region information
  G4StepPoint* thePrePoint = theStep->GetPreStepPoint();
  G4LogicalVolume* thePreLV = thePrePoint->GetPhysicalVolume()->GetLogicalVolume();
  RE01RegionInformation* thePreRInfo
   = (RE01RegionInformation*)(thePreLV->GetRegion()->GetUserInformation());
  G4StepPoint* thePostPoint = theStep->GetPostStepPoint();
  G4LogicalVolume* thePostLV = thePostPoint->GetPhysicalVolume()->GetLogicalVolume();
  RE01RegionInformation* thePostRInfo
   = (RE01RegionInformation*)(thePostLV->GetRegion()->GetUserInformation());

  // check if it is entering to the calorimeter volume
  if( !(thePreRInfo->IsCalorimeter()) && (thePostRInfo->IsCalorimeter()) )
  { theTrack->SetTrackStatus(fSuspend); }
}
```



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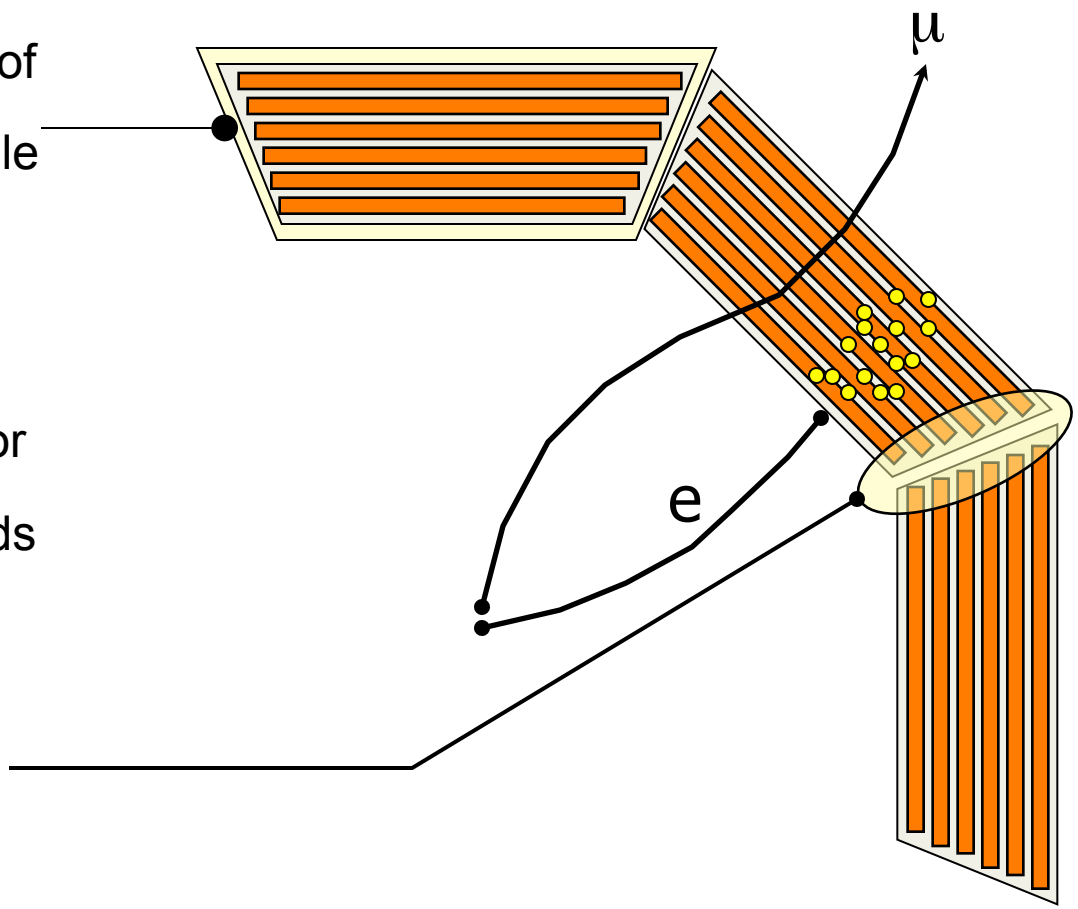
Fast simulation
(a.k.a. Shower parameterization)

Fast simulation - Generalities

- Fast Simulation, also called as shower parameterization, is a shortcut to the "ordinary" tracking.
- Fast Simulation allows you to take over the tracking and implement your own "fast" physics and detector response.
- The classical use case of fast simulation is the shower parameterization where the typical several thousand steps per GeV computed by the tracking are replaced by a few ten of energy deposits per GeV.
- Parameterizations are generally experiment dependent. Geant4 provides a convenient framework and also one concrete parameterization G4Flash.

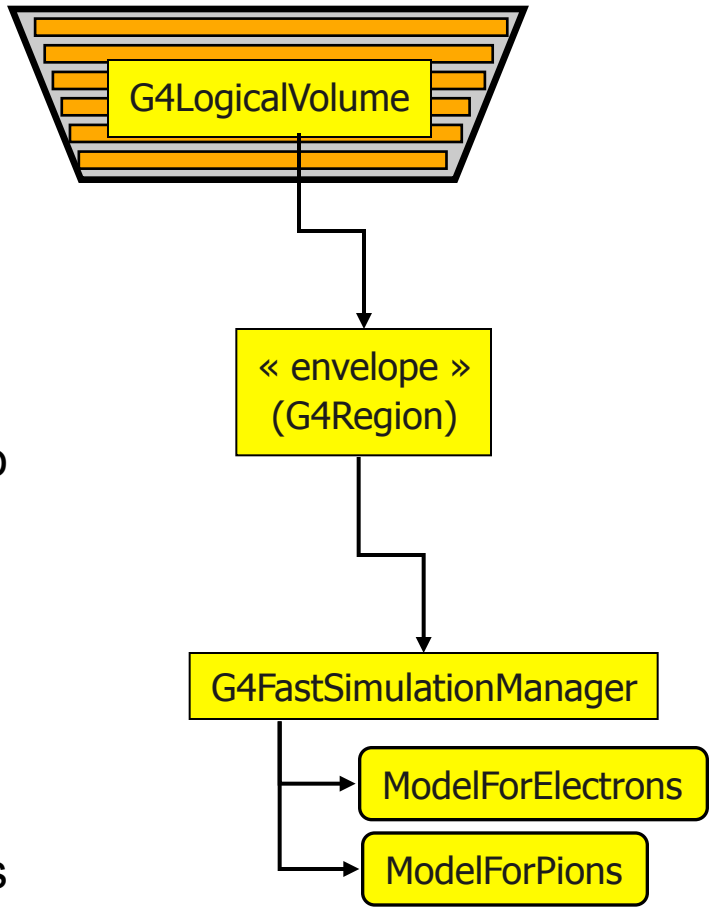
Parameterization features

- Parameterizations take place in an *envelope*. An envelope is a region, that is typically a mother volume of a sub-system or of a major module of such a sub-system.
- Parameterizations are often dependent to particle types and/or may be applied only to some kinds of particles.
- They are often not applied in complicated regions.



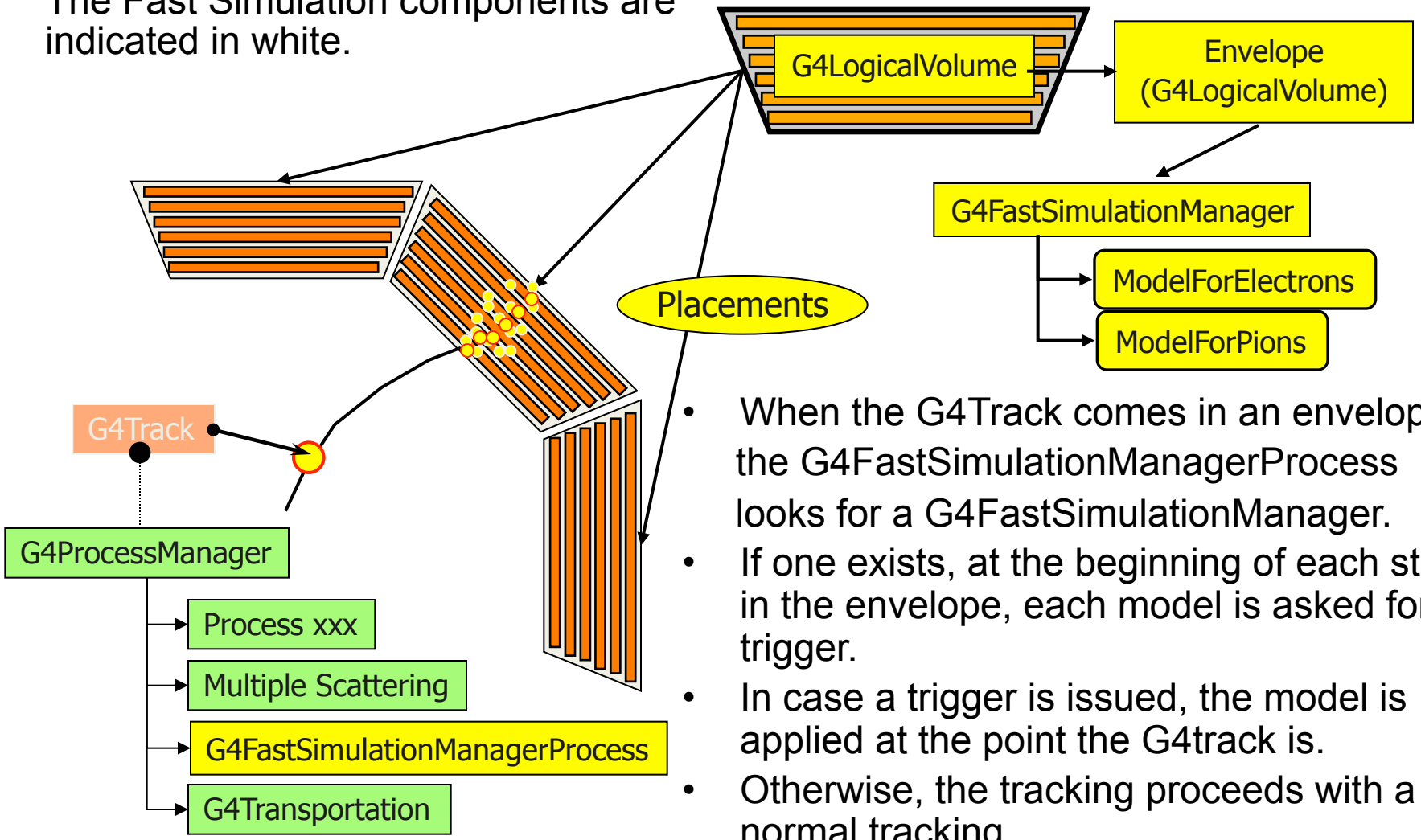
Models and envelope

- Concrete models are bound to the envelope through a G4FastSimulationManager object.
- This allows several models to be bound to one envelope.
- The envelope is simply a G4Region which has G4FastSimulationManager.
- All [grand[…]]daughter volumes will be sensitive to the parameterizations.
- A model may returns back to the "ordinary" tracking the new state of G4Track after parameterization (alive/killed, new position, new momentum, etc.) and eventually adds secondaries (e.g. punch-through) created by the parameterization.

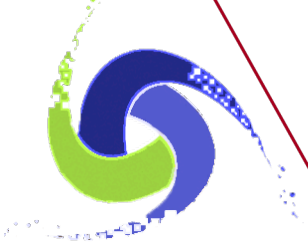


Fast Simulation

- The Fast Simulation components are indicated in white.



- When the G4Track comes in an envelope, the G4FastSimulationManagerProcess looks for a G4FastSimulationManager.
- If one exists, at the beginning of each step in the envelope, each model is asked for a trigger.
- In case a trigger is issued, the model is applied at the point the G4track is.
- Otherwise, the tracking proceeds with a normal tracking.



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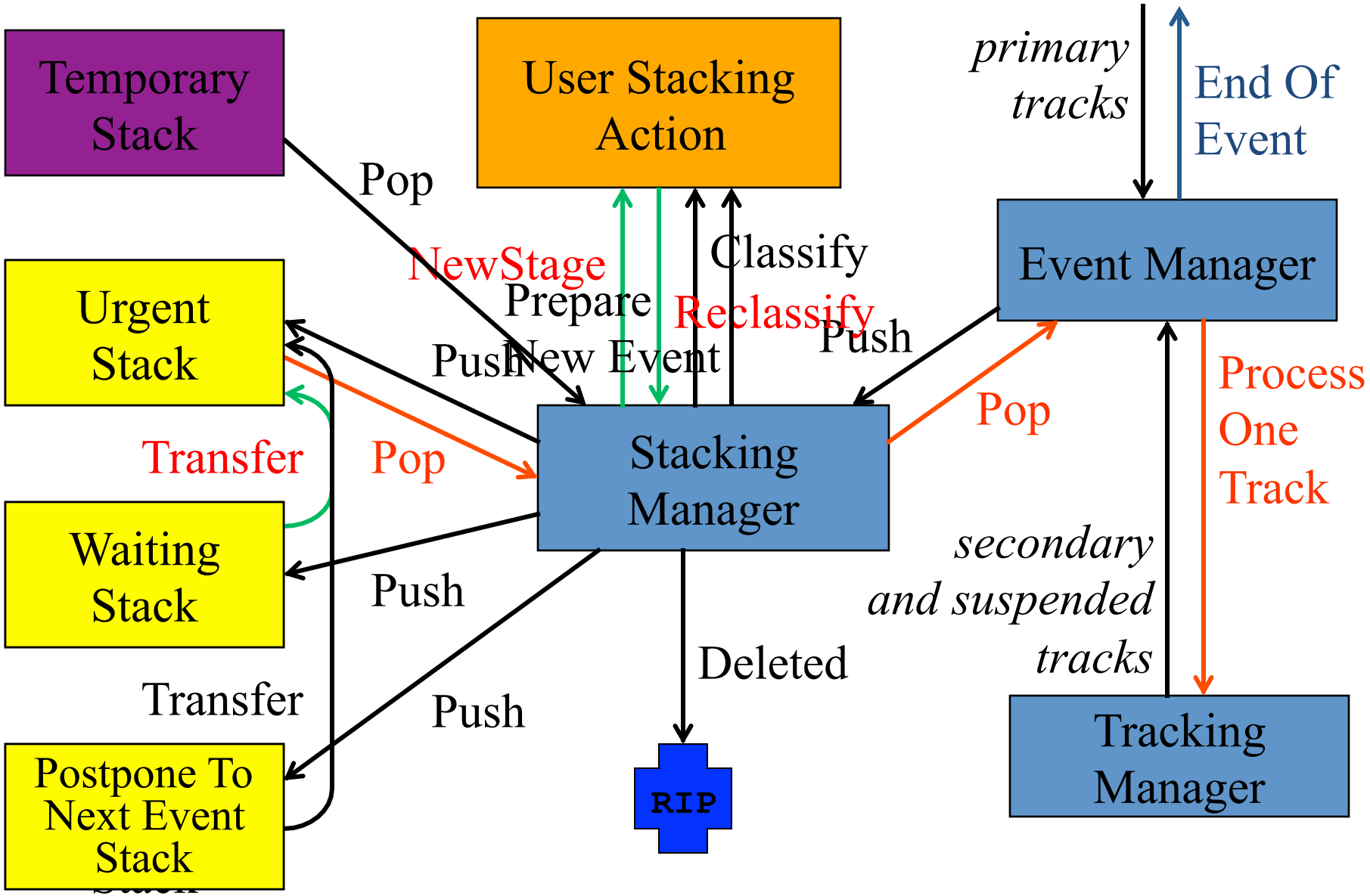
Version 10.4-p02

Stack management

Track stacks in Geant4

- By default, Geant4 has three track stacks.
  - "Urgent", "Waiting" and "PostponeToNextEvent"
  - Each stack is a simple "last-in-first-out" stack.
  - User can arbitrary increase the number of stacks.
- ClassifyNewTrack() method of UserStackingAction decides which stack each newly storing track to be stacked (or to be killed).
  - By default, all tracks go to Urgent stack.
- A Track is popped up only from Urgent stack.
- Once Urgent stack becomes empty, all tracks in Waiting stack are transferred to Urgent stack.
  - And NewStage() method of UsetStackingAction is invoked.
- Utilizing more than one stacks, user can control the priorities of processing tracks without paying the overhead of "scanning the highest priority track".
  - Proper selection/abortion of tracks/events with well designed stack management provides significant efficiency increase of the entire simulation.

Stacking mechanism



G4UserStackingAction

- User has to implement three methods.
- G4ClassificationOfNewTrack ClassifyNewTrack(const G4Track*)
  - Invoked every time a new track is pushed to G4StackManager.
  - Classification
    - fUrgent - pushed into Urgent stack
    - fWaiting - pushed into Waiting stack
    - fPostpone - pushed into PostponeToNextEvent stack
    - fKill - killed
- void NewStage()
  - Invoked when Urgent stack becomes empty and all tracks in Waiting stack are transferred to Urgent stack.
  - All tracks which have been transferred from Waiting stack to Urgent stack can be reclassified by invoking stackManager->ReClassify()
- void PrepareNewEvent()
  - Invoked at the beginning of each event for resetting the classification scheme.

Tips of stacking manipulations

- Classify all secondaries as fWaiting until Reclassify() method is invoked.
  - You can simulate all primaries before any secondaries.
- Classify secondary tracks below a certain energy as fWaiting until Reclassify() method is invoked.
  - You can roughly simulate the event before being bothered by low energy EM showers.
- Suspend a track on its fly. Then this track and all of already generated secondaries are pushed to the stack.
  - Given a stack is "last-in-first-out", secondaries are popped out prior to the original suspended track.
  - Quite effective for Cherenkov lights
- Suspend all tracks that are leaving from a region, and classify these suspended tracks as fWaiting until Reclassify() method is invoked.
  - You can simulate all tracks in this region prior to other regions.
  - Note that some back splash tracks may come back into this region later.

Set the track status

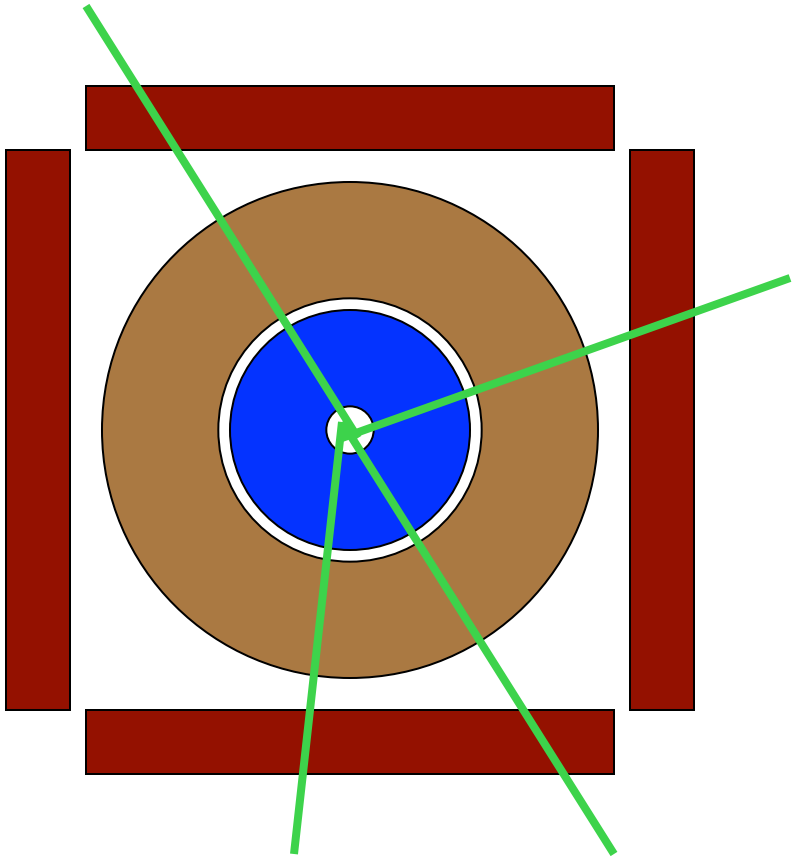
- In UserSteppingAction, user can change the status of a track.

```
void MySteppingAction::UserSteppingAction
                              (const G4Step * theStep)
{
  G4Track* theTrack = theStep->GetTrack();
  if(…) theTrack->SetTrackStatus(fSuspend);
}
```

- If a track is killed in UserSteppingAction, physics quantities of the track (energy, charge, etc.) are not conserved but completely lost.

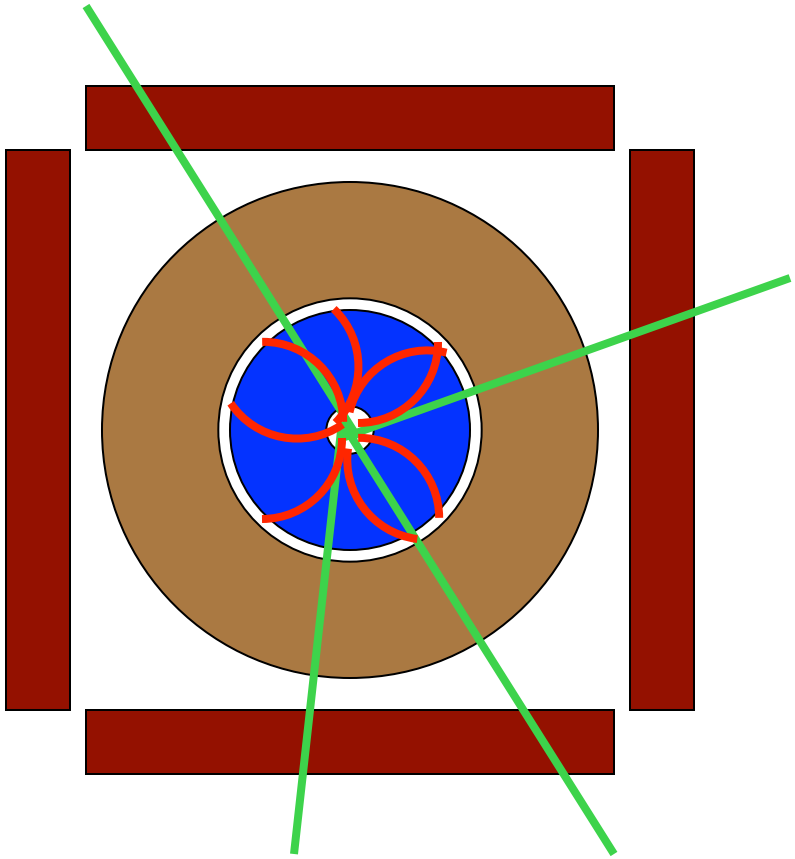
RE05StackingAction

- RE05 has simplified collider detector geometry and event samples of Higgs decays into four muons.
- Stage 0
  - Only primary muons are pushed into Urgent stack and all other primaries and secondaries are pushed into Waiting stack.
  - All of four muons are tracked without being bothered by EM showers caused by delta-rays.
  - Once Urgent stack becomes empty (i.e. end of stage 0), number of hits in muon counters are examined.
  - Proceed to next stage only if sufficient number of muons passed through muon counters. Otherwise the event is aborted.



RE05StackingAction

- Stage 1
  - Only primary charged particles are pushed into Urgent stack and all other primaries and secondaries are pushed into Waiting stack.
  - All of primary charged particles are tracked until they reach to the surface of calorimeter. Tracks reached to the calorimeter surface are suspended and pushed back to Waiting stack.
  - All charged primaries are tracked in the tracking region without being bothered by the showers in calorimeter.
  - At the end of stage 1, isolation of muon tracks is examined.



RE05StackingAction

- Stage 2
  - Only tracks in "region of interest" are pushed into Urgent stack and all other tracks are killed.
  - Showers are calculated only inside of "region of interest".