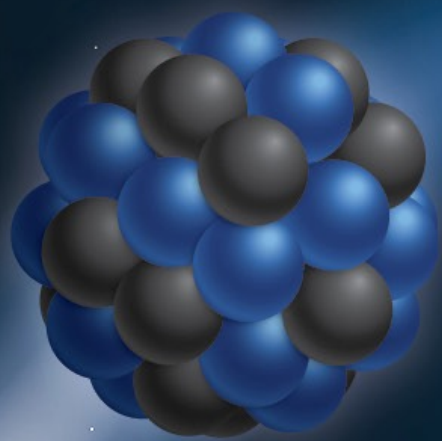




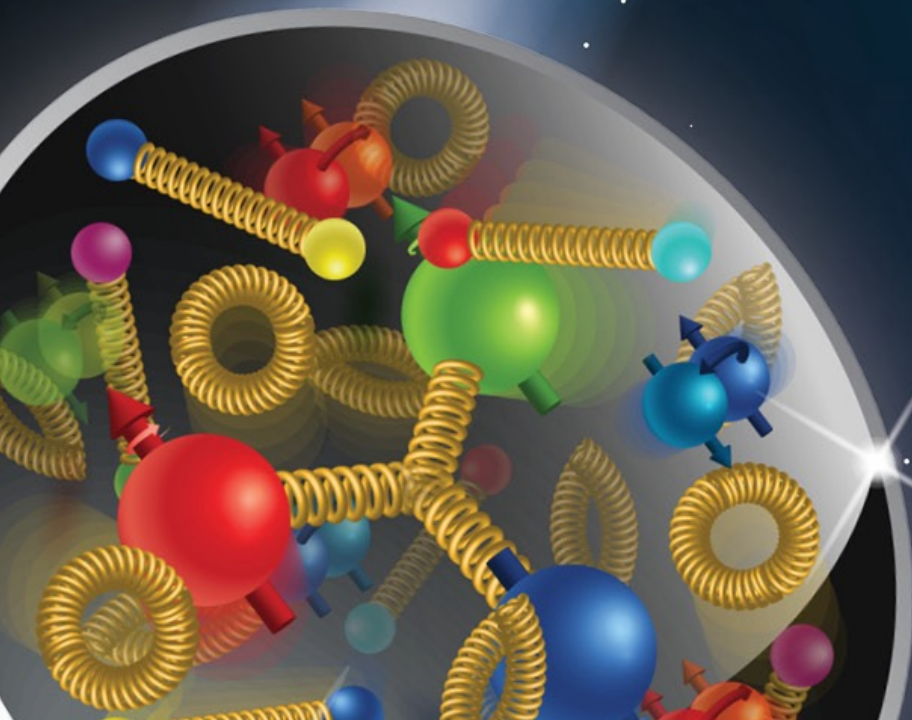
GEANT4
A SIMULATION TOOLKIT

Version 11.0-p03



Kernel II

Makoto Asai (Jefferson Lab)
Geant4 Tutorial Course



 **Jefferson Lab**



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Contents



- User limits
- Attaching user information to G4 classes
- Stacking mechanism



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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. );
```

- **ustepMax**; // max allowed step size in this volume
- **utrakMax**; // max total track length
- **utimeMax**; // max global time
- **uekinMin**; // min kinetic energy remaining (only for charged particles)
- **urangMin**; // 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

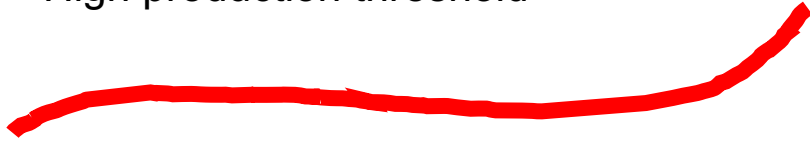
- In addition to instantiating G4UserLimits and setting it to logical volume or region, you have to assign the following process(es) to particle types you want to affect.
- Limit to step
 - `ustepMax` : max allowed Step size in this volume
 - `G4StepLimiter` process must be defined to affected particle types.
 - This process limits a step, but it does not kill a track.
- Limits to track
 - `utrakMax` : max total track length
 - `utimeMax` : max global time
 - `uekinMin` : min kinetic energy (only for charged particles)
 - `urangMin` : 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.

Production thresholds (a.k.a. cuts)

- Geant4 **does not have** any tracking cut. It always tracks a particle down to zero kinetic energy.
 - Unless the particle interacts or goes away.
 - A particle may decay or be captured even after it stops.
- Of course each physics model has its limited applicability.
 - For example Standard EM has lower limit of 990 eV.
 - It means we can calculate the range of a particle at $E_k = 990$ eV.
 - So, when a particle comes down to $E_k = 990$ eV, instead of killing it at that point, Geant4 makes one more step to push the particle to its final stopping point.
- Geant4 **does have** production thresholds applied to secondary particle production.
 - To address the infrared divergence of some physics processes
 - e.g. ultra-soft forward gamma production in Bremsstrahlung
 - To also address the limited computing resources
 - e.g. too many soft delta-rays
- Geant4 requires production thresholds to be specified **in length**.
 - Secondaries that won't travel more than the threshold won't be generated but their kinetic energies are deposited along the trajectory of their parent particle.

Production thresholds (a.k.a. cuts)

- High production threshold



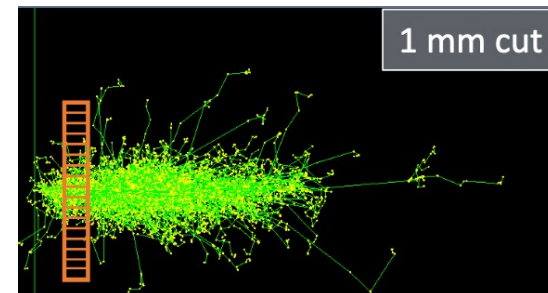
- Few secondaries produced by ionization or Bremsstrahlung
- Most energy are deposited along the parent track.
 - Continuous energy loss
- You will see higher total energy deposition along a step of the parent track.

- If energy deposition is scored in a large bulk volume, you won't see difference in high and low thresholds.
 - Except for the difference in computing time
- If energy deposition is scored in granular scoring cells, you will see large difference.
- We recommend the production thresholds being comparable to volume dimensions.
 - Default length : 0.7 mm

- Low production threshold



- Lots of secondaries produced by ionization or Bremsstrahlung
- Energy deposition is shared by local deposition along the parent and secondaries.
- You will see lower total energy deposition along a step of the parent track.



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Attaching user information

- Class extension
 - You can create your own class derived from provided base class
 - **G4Run, G4VHit, G4VDigit, G4VTrajectory, G4VTrajectoryPoint**
- Aggregation
 - 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 **G4Trajectory** and **G4TrajectoryPoint** concrete classes as defaults. These classes keep only the most commonly-used quantities.
 - G4RichTrajectory and G4SmoothTrajectory are also available.
 - If the you want to keep some additional information, you are encouraged to implement your own concrete trajectory and trajectory point 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()`

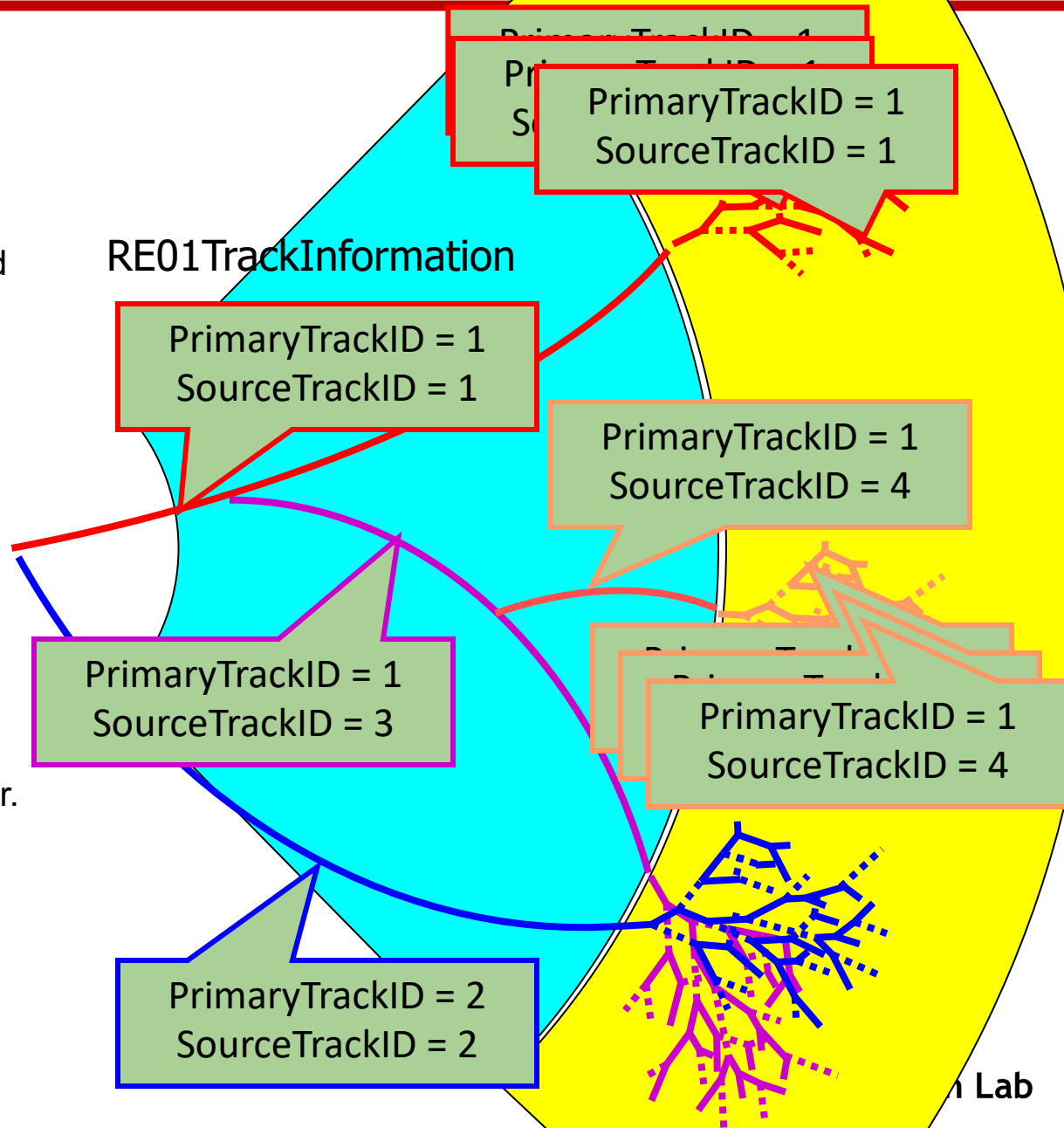
– Returns the pointer of G4PrimaryParticle object if this track was defined as a primary or a pre-assigned decay product, otherwise null.

- `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**.
- PrimaryTrackID is copied to UserTrackInformation of daughter tracks.
- SourceTrackID means the ID of a track which gets into calorimeter.
- 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
```

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

TrackID	6782	Position	(-126.11431, -215.85917, 117.12988)	Energy	1878.8831 [keV]
Current trajectory	TrackID 6782	Position	(-127.89383, -215.85917, 117.12988)	Energy	4.56017 [keV]
Point[0] Position	TrackID 6782	Position	(-151.33864, -215.85917, 117.12988)	Energy	83.9962 [keV]
Point[1] Position	TrackID 6782	Position	(-176.56317, -302.20101, 163.96689)	Energy	1776.6378 [keV]
Point[2] Position	TrackID 6782	Position	(-201.7911, -345.36988, 187.38871)	Energy	2413.8986 [keV]
Point[3] Position	TrackID 6782	Position	(-227.01961, -388.53841, 210.81469)	Energy	550.67792 [keV]
Point[4] Position	TrackID 6782	Position	(-227.70865, -389.71739, 211.45445)	Energy	638.57593 [keV]
Point[5] Position	TrackID 6782	Position	(-228.6702, -391.36253, 212.34721)	Energy	778.03992 [keV]

Poin

Poin Source track ID 6782 (mu-,49.162515[GeV]) at (-252.24762,-431.70723,234.23766)

Poin Original primary track ID 1 (unknown,335.96305[GeV])

Poin Cell[11,31] 0.028283647 [GeV]

Poin Cell[12,31] 0.039822296 [GeV]

Poin Cell[13,31] 0.050185748 [GeV]

Poin Cell[14,31] 0.049883344 [GeV]

Poin Cell[15,31] 0.041446764 [GeV]

Poin Cell[16,31] 0.06386168 [GeV]

Poin Cell[16,32] 0.0036926015 [GeV]

Poin Cell[17,32] 7.2955385e-05 [GeV]

Poin Cell[17,31] 0.0043463898 [GeV]

Poin Cell[15,32] 0.010138473 [GeV]

Poin Cell[14,32] 0.0018386352 [GeV]

Poin Cell[13,32] 0.0018836759 [GeV]

Poin Cell[12,32] 0.00036846059 [GeV]

Total energy deposition in calorimeter by a source track in 13 cells : 0.29582467 (GeV)

Poin Cell[12,31] 0.00036846059 [GeV]

Point[24] Position= (-233.79372, -400.12944, 217.10408)

Trajectory of track6782

Tracker hits of track6782

Calorimeter hits of track6782

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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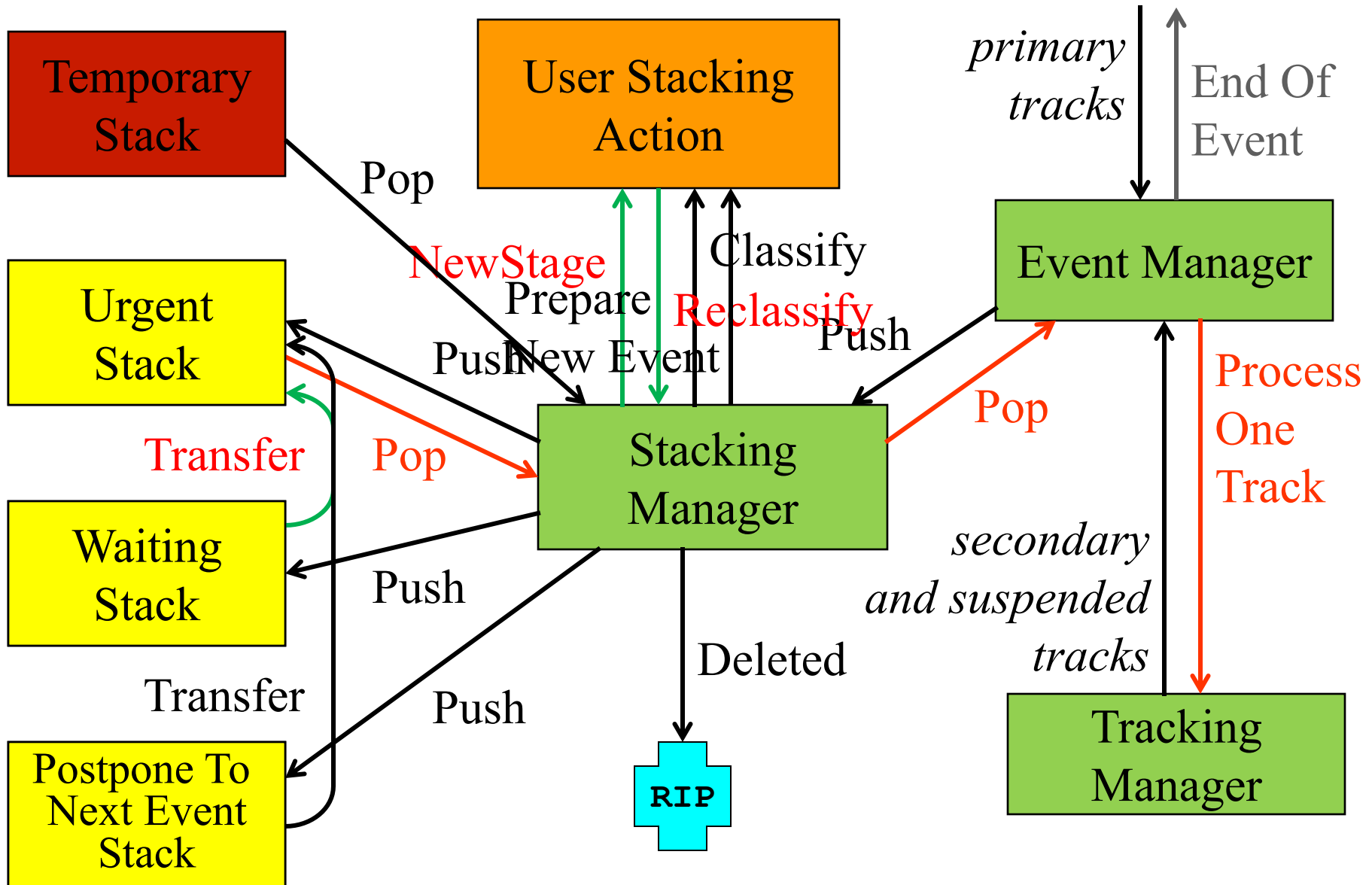
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Track stacks in Geant4

- 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 UserStackingAction 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

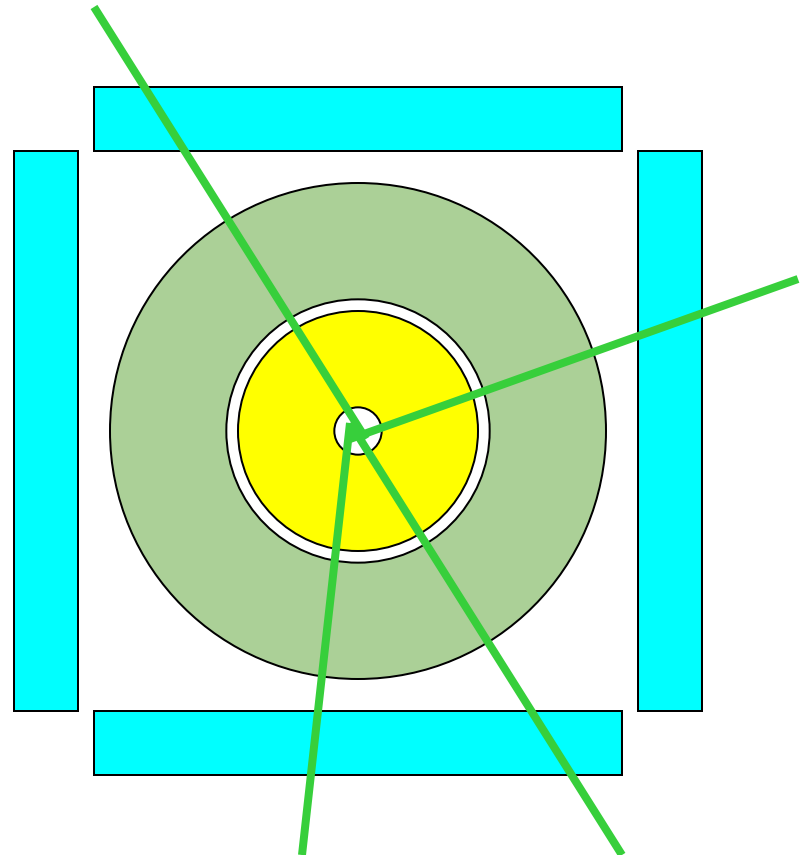
- In UserSteppingAction, user can change the status of a track.

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

- If a track is killed in UserSteppingAction or in the UserStackingAction, 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"**.

