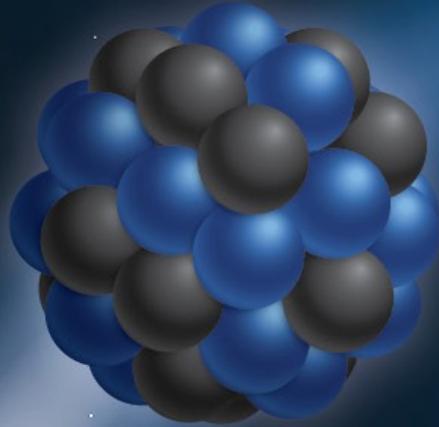


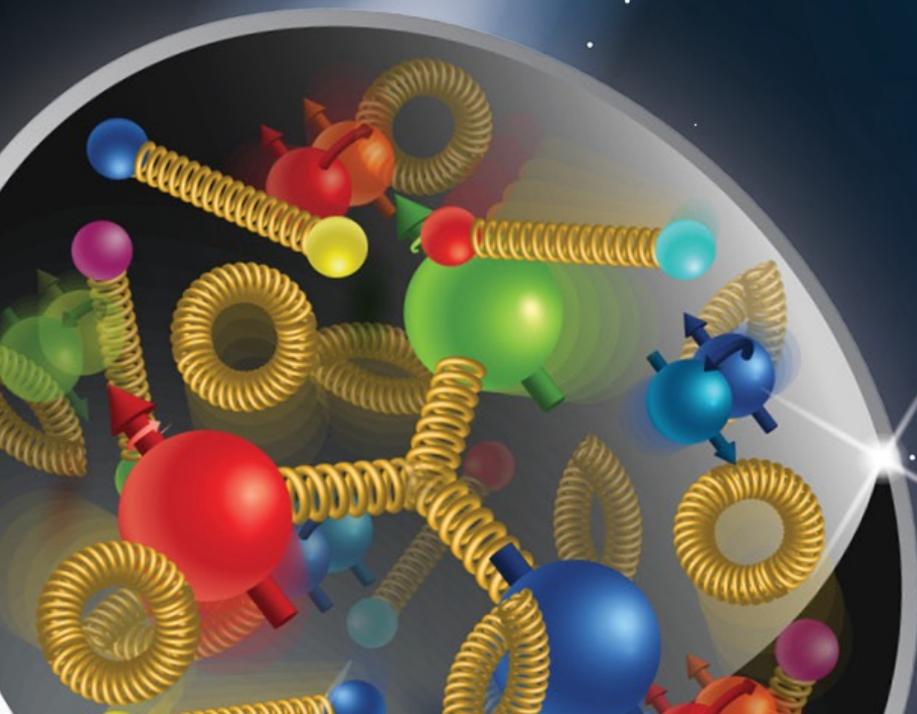
**GEANT4**  
A SIMULATION TOOLKIT

Version 11.1-p02



# 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



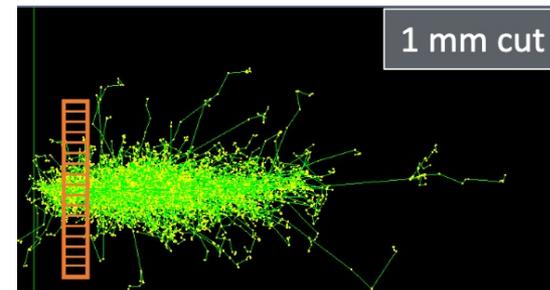
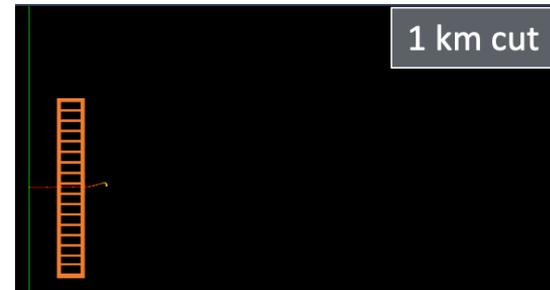
- Few secondaries produced by ionization or Bremsstrahlung
- Most energy are deposited along the parent track.
  - Continuous energy loss
- You will see higher total energy deposition along a step of the parent track.

- 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()`

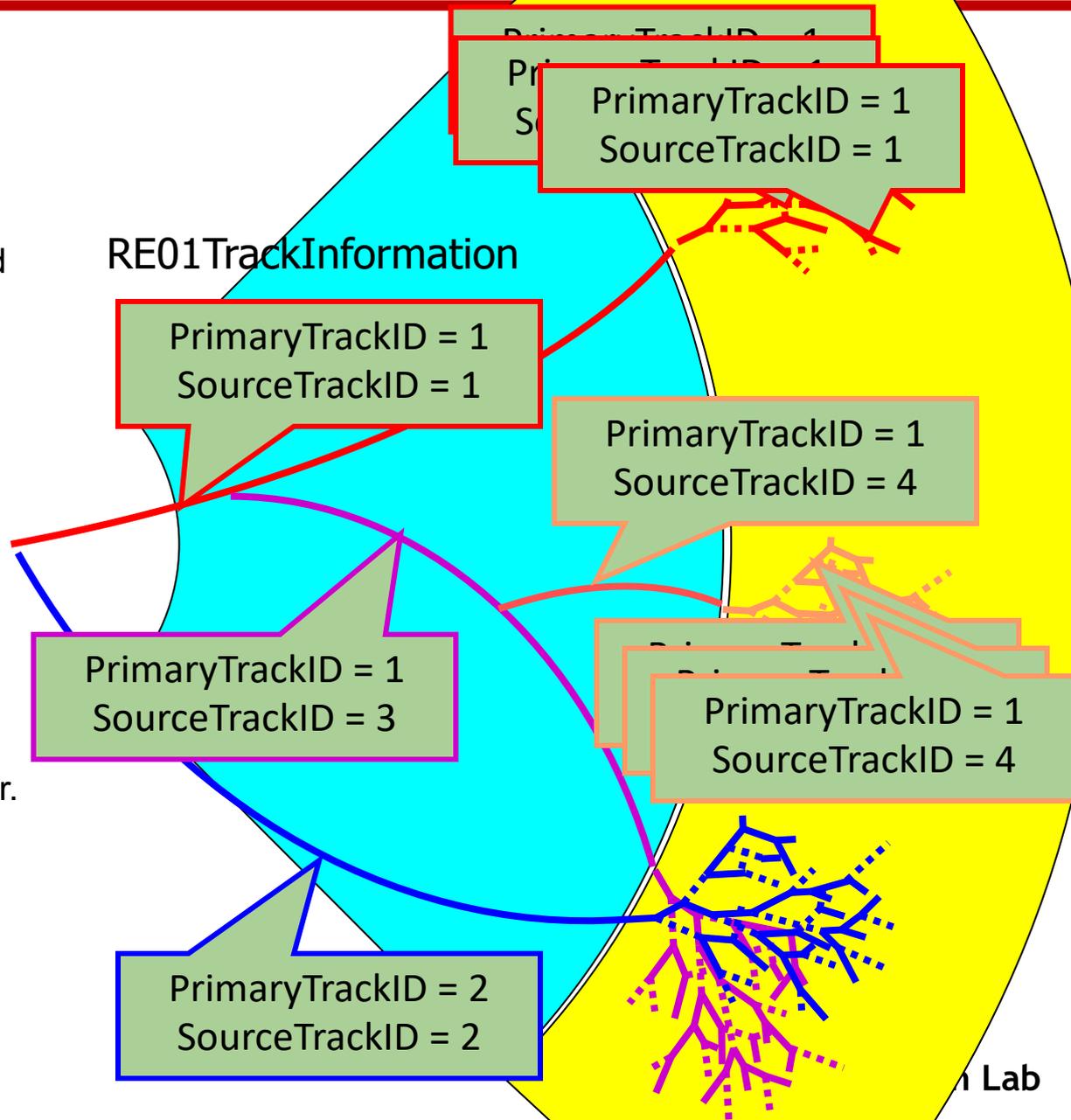
– Returns the pointer of G4PrimaryParticle object if this track was defined as a primary or a pre-assigned decay product, otherwise null.

- `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
```

Trajectory of track6782

```
Vertex : 4.11461
Current trajectory : TrackID 6782 Position (-126.11431,-215.85917,117.12988) : 1878.8831 [keV]
Point[0] Position : TrackID 6782 Position (-127.89383, 4.56017 [keV]
Point[1] Position : TrackID 6782 Position (-151.33864, 83.9962 [keV]
Point[2] Position : TrackID 6782 Position (-176.56317,-302.20101,163.96689) : 1776.6378 [keV]
Point[3] Position : TrackID 6782 Position (-201.7911,-345.36988,187.38871) : 2413.8986 [keV]
Point[4] Position : TrackID 6782 Position (-227.01961,-388.53841,210.81469) : 550.67792 [keV]
Point[5] Position : TrackID 6782 Position (-227.70865,-389.71739,211.45445) : 638.57593 [keV]
Point[6] Position : TrackID 6782 Position (-228.6702,-391.36253,212.34721) : 778.03992 [keV]
```

Tracker hits of track6782

```
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])
```

Calorimeter hits of track6782

```
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]
```

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

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

# 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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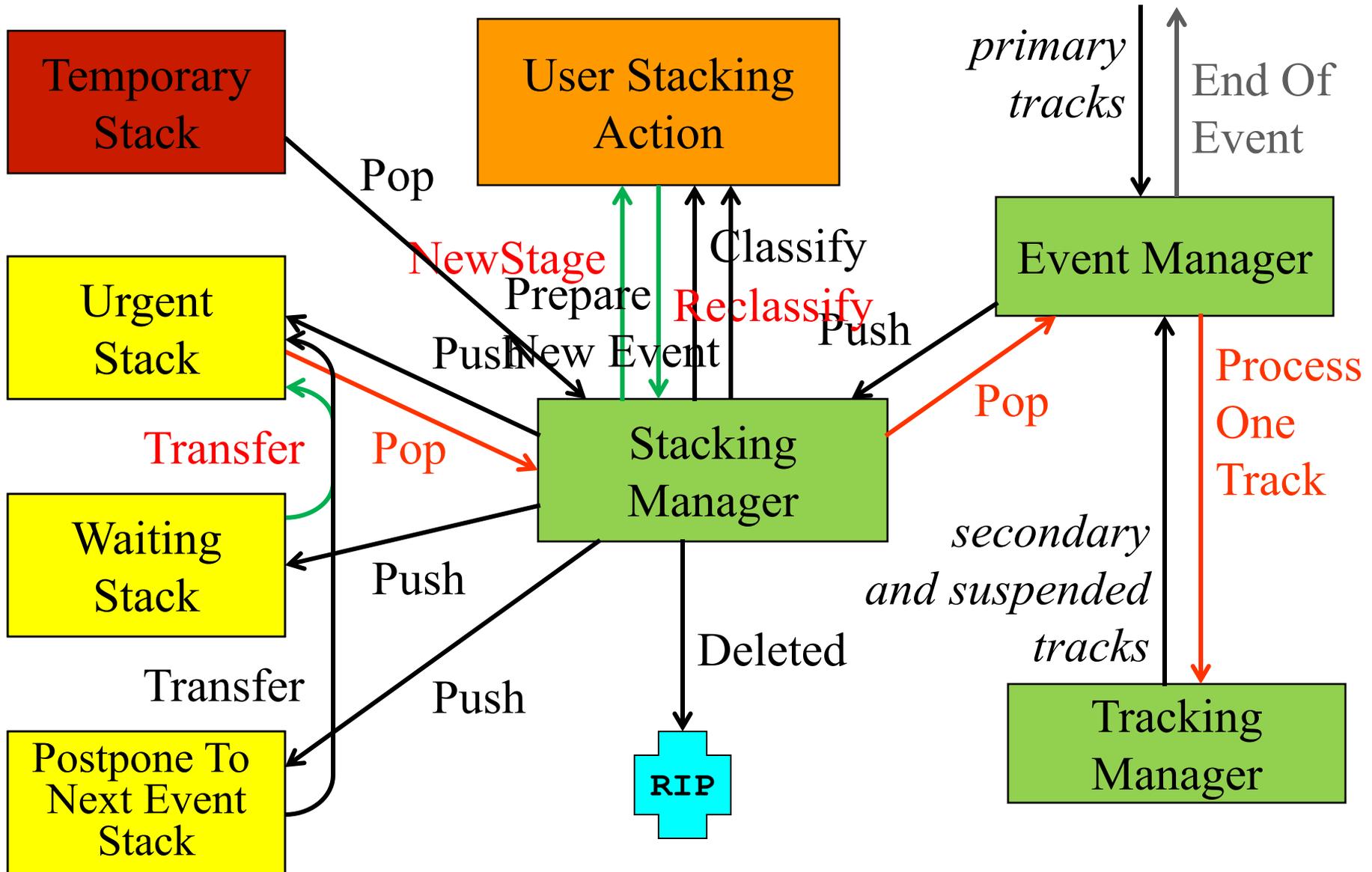
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# Track stacks in Geant4

- 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

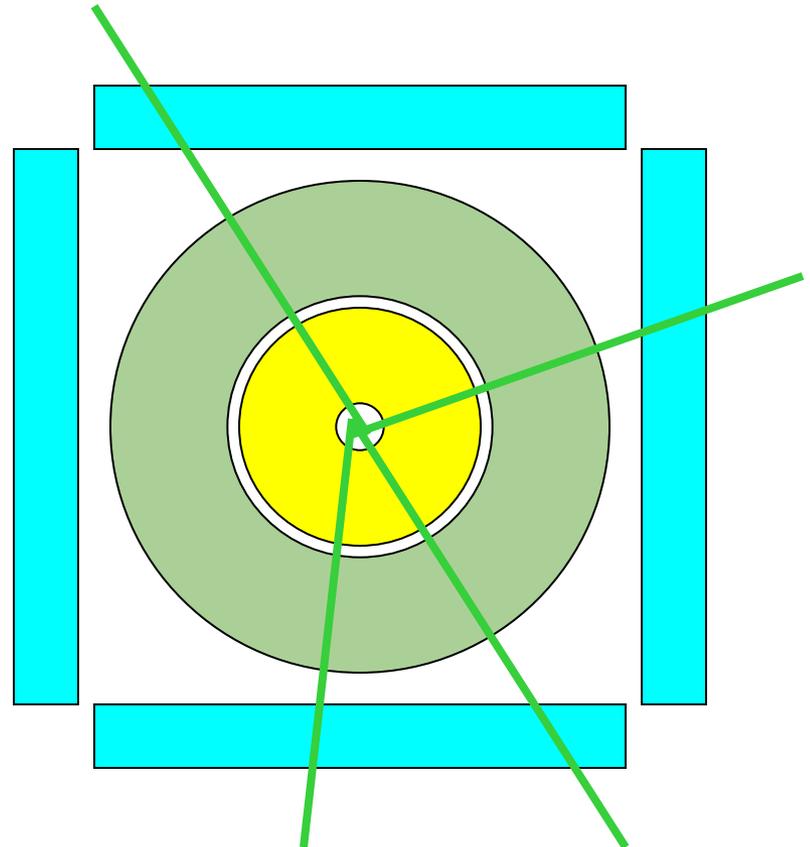
- In UserSteppingAction, user can change the status of a track.

```
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.

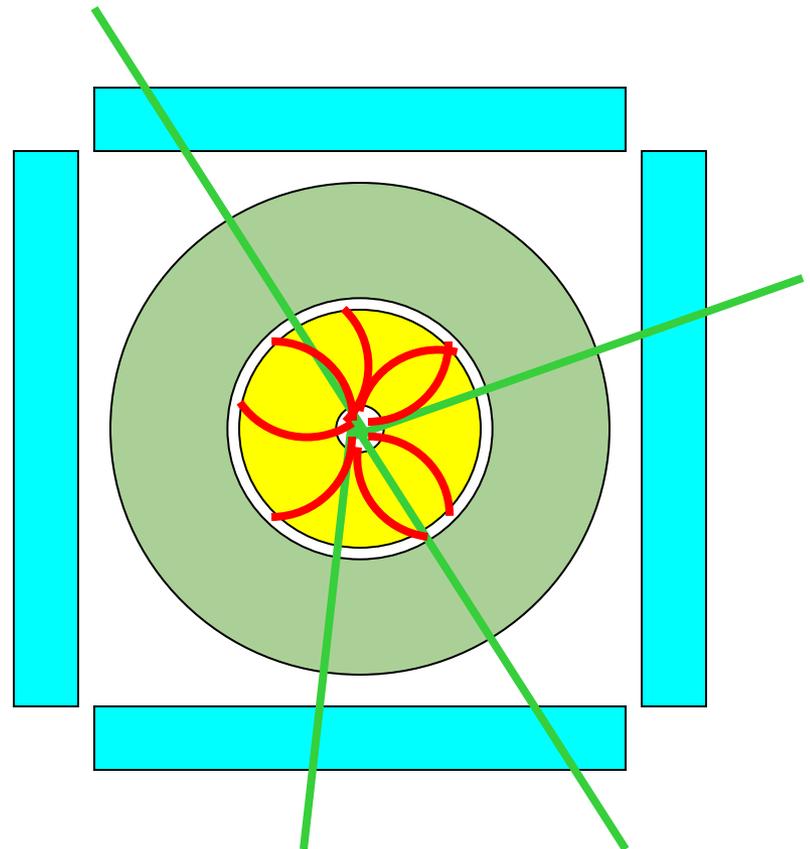
# RE05StackingAction

- 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.



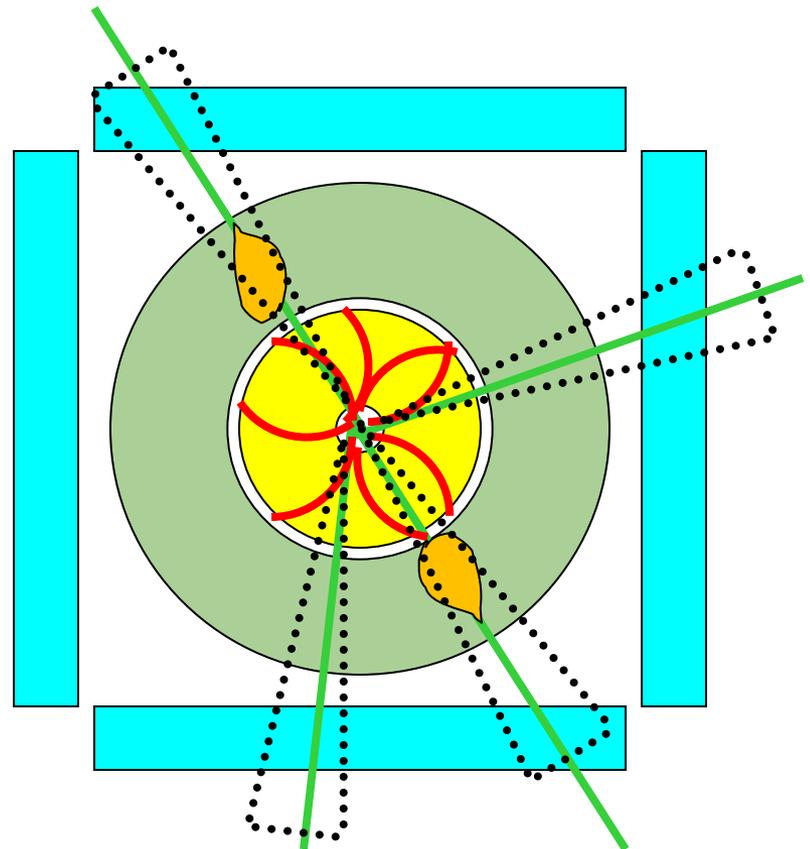
# RE05StackingAction

- 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"**.



# Tips of stacking manipulations

- Classify all secondaries as **fWaiting** until **Reclassify()** method is invoked.
  - You can simulate all primaries before any secondaries.
- Classify 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 / scintillation 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.