
# Scoring

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# Outline

- Extracting useful information
- Sensitive detectors, hits and hits collections
- Geant4 scorers
- Command-based scoring

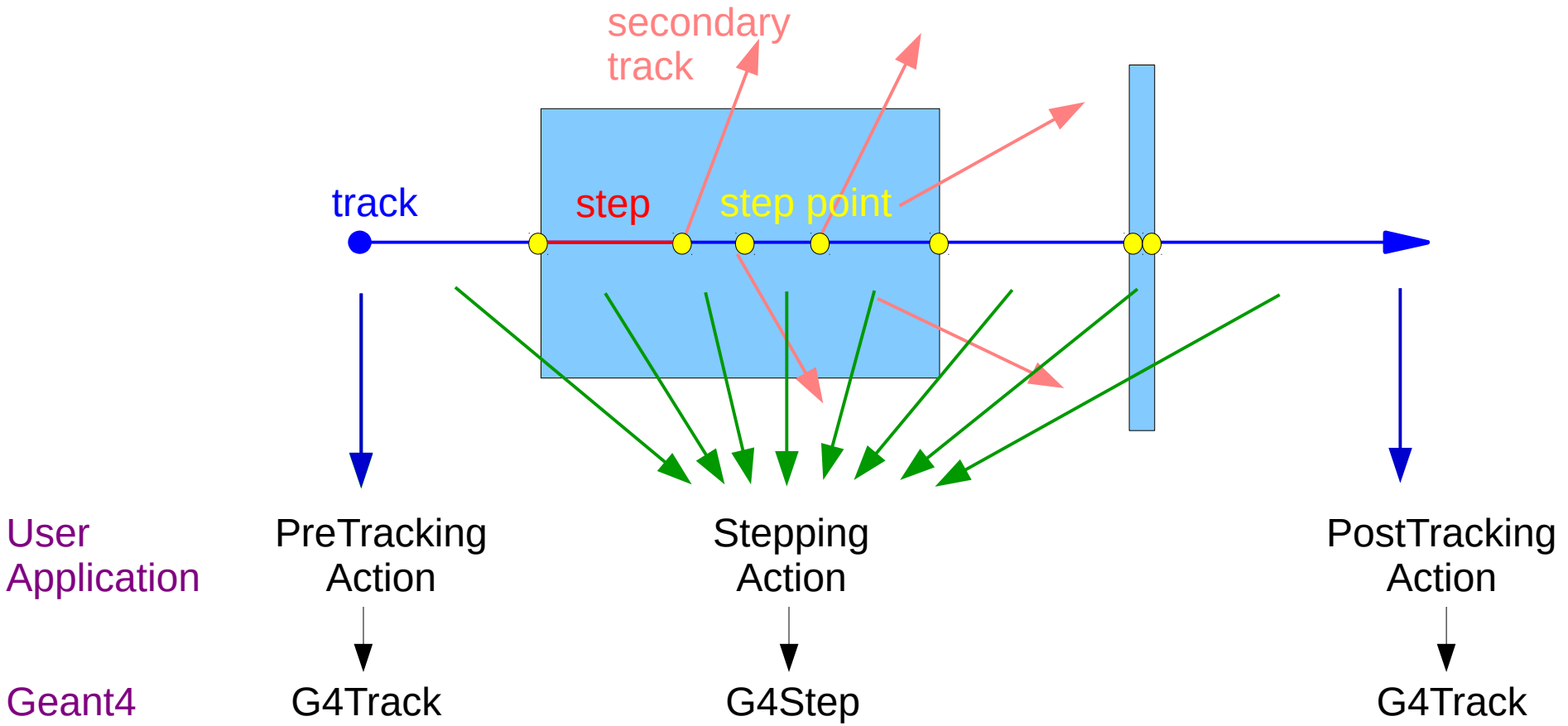
# Extracting Useful Information

- Given geometry, physics and primary track generation, Geant4 does proper physics simulation "silently".
  - You have to add a bit of code to extract information useful to you.
- The user action classes, if provided, are called by Geant4 kernel during all phases of tracking and have access to “theirs” Geant4 objects:
  - G4Run, G4Event, G4Track, G4Step

## Geant4 and User Application

# Event Processing

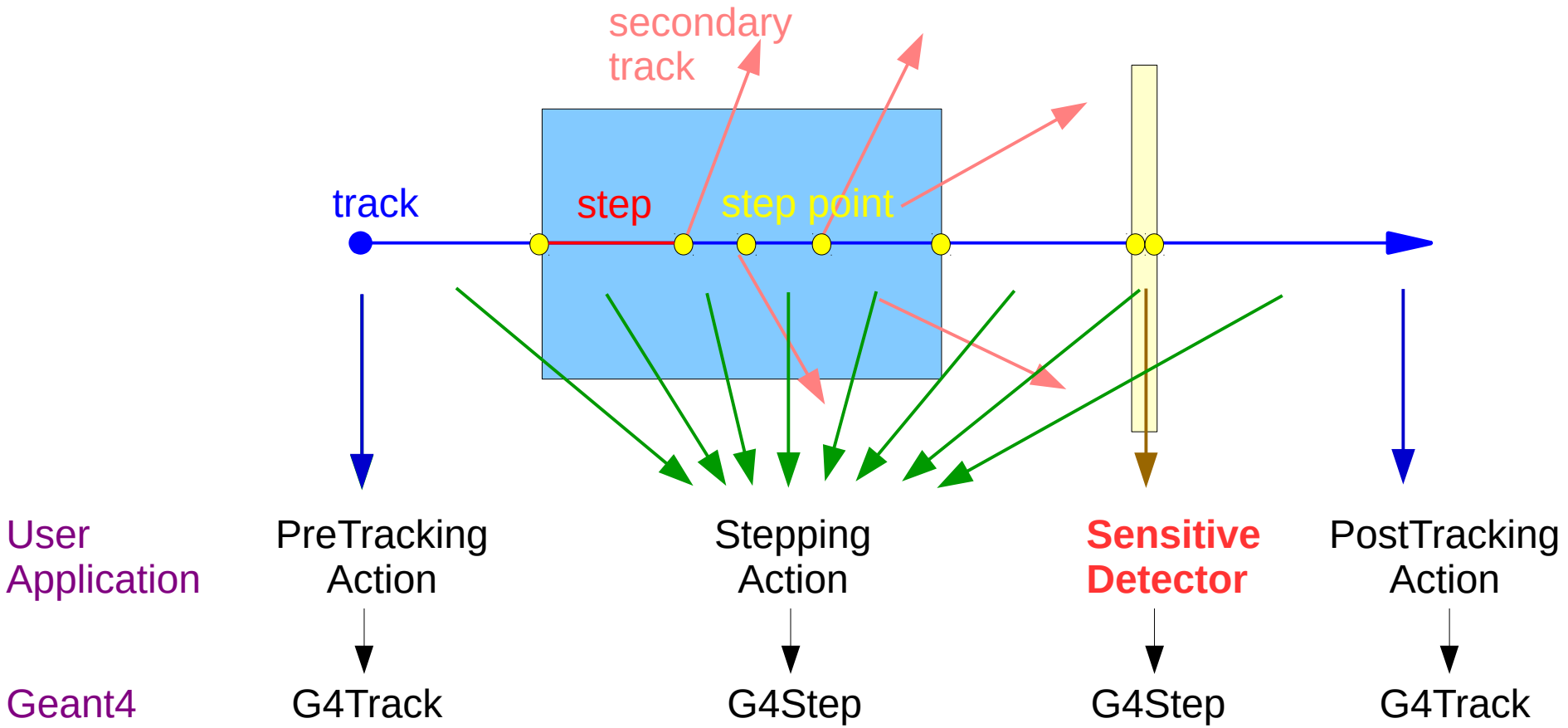
*User classes are called during event processing and can collect the information about tracked particles from Geant4 objects*



## Geant4 and User Application

# Event Processing (2)

*A special user class, sensitive detector, can be attached to (a) selected volume(s) and then called during event processing*



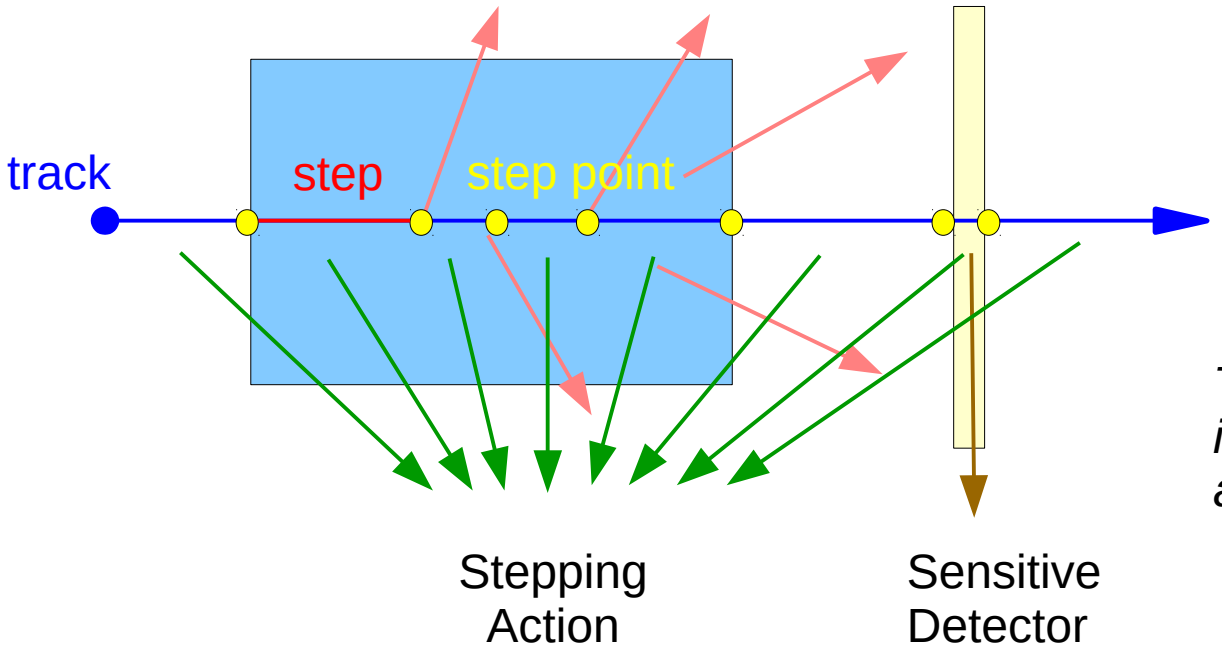
# Extracting Useful Information (2)

- During stepping, two user classes can be called
  - User stepping action – called in each step
  - User sensitive detector – called only when track passes a "sensitive" volume
  - Both have access to G4Step

# Sensitive Detectors

# Sensitive Detector

- A sensitive detector is assigned to a logical volume
- The sensitive detectors are invoked when a step takes place in the logical volume that they are assigned to




*The sensitive detector will be invoked all in the steps inside a sensitive volume*

# Defining a Sensitive Detector

- Sensitive detector objects are created and assigned to logical volumes in a user detector construction class in ConstructSDandField() function
- Creating SD object:

MyDetectorConstruction.cc

```
G4VSensitiveDetector* mySD
  = new MySD("MySD", “MyHitsCollection”);
```

  - Each sensitive detector object must have a unique name.
  - More than one sensitive detector instances (objects) of the same type (class) can be defined with different detector name

- Assigning to a logical volume via the volume name

```
// defined previously
// G4VSensitiveDetector* mySD = ...
SetSensitiveDetector(“MyLVName”, mySD);
```

  - The SetSensitiveDetector function is defined in G4VUserDetectorConstruction base class (only since Geant4 10.x)

# Sensitive Detector Class

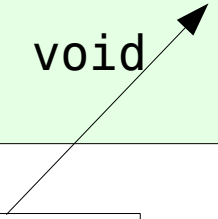
- A sensitive detector is defined in a user class, MySD, derived from G4VSensitiveDetector base class
  - It defines the following user functions which are invoked by Geant4 kernel during event processing:
  - At **begin of event**: Initialize()
  - In **a step** (if in the associated volume): ProcessHits(..)
  - At **end of event**: EndOfEvent(..)

- Note that User stepping action defines only a function invoked when processing a step

# Sensitive Detector Class (2)

```
#include "G4VSensitiveDetector.hh"
...
class MySD : public G4VSensitiveDetector {
public:
  MySD(const G4String& name
       const G4String& hitsCollectionName););
  virtual ~MySD();

  virtual void   Initialize(G4HCofThisEvent* hce);
  virtual G4bool ProcessHits(G4Step* step,
                             G4TouchableHistory* history);
  virtual void   EndOfEvent(G4HCofThisEvent* hce);
};
```

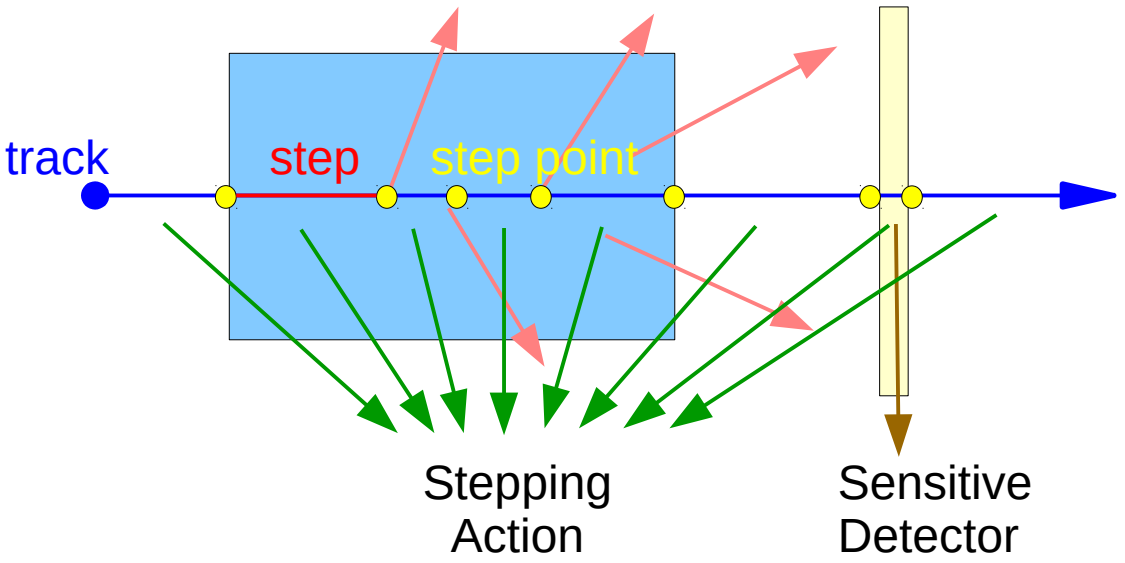


*The user functions called by Geant4 kernel*

# Hits and Hits Collections

# A Hit

- Hit is a snapshot of the physical interaction of a track or an accumulation of interactions of tracks in the sensitive region of your detector
- Depending on your application you may be interested in various types information:
  - position and time of the step, momentum and energy of the track, energy deposition of the step, geometrical information, …



# User Hit Class

MyHit.hh

- You can store various types information by implementing your own concrete Hit class.
  - In this example we store the energy deposition of the step

```
class MyHit
{
public:
  MyHit();
  // set/get methods; eg.
  void     SetEdep (G4double edep);
  G4double GetEdep() const;
private:
  // some data members; eg.
  G4double fEdep;  // energy deposit
};
```

- Typically for each information to be stored in a hit we add:

| | | |
|---|---|---|
| Data member | G4type fData; | G4double fEdep; |
| Set function | void SetData(G4type data); | void SetEdep(G4double edep): |
| Get function | G4type GetData() const; | G4double GetEdep() const; |

# Create a Hit

- A hit can be created when a step takes place in a sensitive logical volume, in a user sensitive detector function ProcessHits(..)

```
G4bool MySD::ProcessHits(G4Step* step,
                         G4TouchableHistory* /*history*/)
{
  MyHit* newHit = new MyHit();
  // Get some properties from G4Step and set them to the hit
  // newHit->SetXYZ();
  G4double edep = step->GetTotalEnergyDeposit();
  newHit->SetEdep(edep);
  // ...
  return true;
}
```

  - Currently, returning boolean value is not used.
  - The “history” will be given only if a Readout geometry is defined to this sensitive detector (the readout geometry is not presented in this course)

# Hits Collections

- Many hits can be created during one event
- Hit objects must be stored in a dedicated collection
- Geant4 provides a dedicated class, G4THitsCollection, which allows to associate the hits collections with G4Event object and can be then accessed
  - through G4Event at the end of event, to be used for analyzing an event
  - through G4SDManager during processing an event, to be used for event filtering.
- When using Geant4 hits collections, the user hit class must derive from G4VHit base class
- Users may also define their own hits collections, eg.
  - Using STL library: std::vector<MyHit>
  - Using their application framework, eg. in the context of ROOT, it can be a ROOT collection (TObjArray, TClonesArray)

# User Geant4 Hit Class

- Hits collection of a concrete hit class is defined as a specialization of the G4THitsCollection template class
  - Note the analogy of G4THitsCollection<MyHit> with std::vector<MyHit>
  - To avoid long names we define a name shortcut using **typedef**

MyHit.hh

```
#include "G4VHit.hh"
class MyHit : public G4VHit
{
  // the class definition as before
  // utility functions (called by Geant4)
  virtual void Draw();
  virtual void Print();
};
#include "G4THitsCollection.hh"
typedef G4THitsCollection<MyHit> MyHitsCollection;
```

*When using Geant4 hits collections, the user hit class must derive from G4VHit*

# G4Allocator

- Creation / deletion of an object is a heavy operation.
  - It may cause a performance concern, in particular for objects that are frequently instantiated / deleted like hits.
- Geant4 provides G4Allocator class which provides functions for efficient memory allocation and de-allocation
  - It allocates a chunk of memory space for objects of a certain class.
- The same pattern can be used in all user classes, its is sufficient just to put the relevant user class name

# G4Allocator (2)

MyHit.hh

```
#include "G4Allocator.hh"
class MyHit : public G4VHit {
    // ...
    inline void* operator new(size_t);
    inline void  operator delete(void* hit);
    // ...
};
extern G4Allocator<MyHit>* MyHitAllocator;
inline void* MyHit::operator new(size_t) {
  return (void*)MyHitAllocator->MallocSingle();
}
inline void MyHit::operator delete(void* hit) {
  MyHitAllocator->FreeSingle((MyHit*)hit);
}
```

MyHit.cc

```
// ...
G4Allocator<MyHit>* MyHitAllocator;
// ..
```

- The pattern (in green) can be cut & pasted in your hit (and other) classes
- Then you need just to replace MyHit with your class name

# Define Hits Collection (1)

```
void MySD::MySD(const G4String& name,
                const G4String& hitsCollectionName)
 : G4VSensitiveDetector(name),
   fHitsCollection(0)
{
  collectionName.insert(hitsCollectionName);
}
```

- The name(s) of the hits collection(s) which is (are) handled by this sensitive detector is defined in the constructor
  - It is saved in the collectionName data member of the G4VSensitiveDetector base class
- In case your sensitive detector generates more than one kinds of hits (e.g. anode and cathode hits separately), define all collection names.

# Define Hits Collection (2)

```
void MySD::Initialize(G4HCofThisEvent* hce)
{
  fHitsCollection
    = new MyHitsCollection (SensitiveDetectorName, collectionName[0]);
  G4int hcID
    = G4SDManager::GetSDMpointer()->GetCollectionID(collectionName[0]);
  hce->AddHitsCollection(hcID, hitsCollection);
}
```

- The hits collection object is created in Initialize()
  - This method is invoked at the beginning of each event
- The collectionID, hcID, is available after this sensitive detector object is constructed and registered to G4SDManager.
  - Thus, GetCollectionID() method cannot be invoked in the constructor of this detector class.
- It can be then attached to G4HCofThisEvent object given in the argument.
  - This object is then available via G4Event object

# Filling A Hits Collection

- The hits are usually inserted in the hits collection when they are created

MySD.cc

```
void MySD::SomeFunction(...)
{
  // Create a hit
  MyHit* newHit = new MyHit();
  // Set some properties to the hit
  // newHit->SetXYZ();
  // Add the hit in the SD hits collection
  fHitsCollection->insert(newHit);
}
```

- Depending on the detector type SomeFunction() can be either Initialize() or ProcessHits()

# Filling A Hits Collection (2)

- The way how the hits collections are filled depends on a detector type
- *A tracker detector* typically generates a hit for every single step of every single (charged) track
  - Hits are created in MySD::ProcessHits()
  - They typically contain
    - Position and time, energy deposition of the step, track ID
- *A calorimeter detector* typically generates a hit for every cell, and accumulates energy deposition in each cell for all steps of all tracks
  - Hits are created in MySD::Initialize()
  - They typically contain:
    - Sum of deposited energy, Cell ID

# Iterate over A Hits Collection

```
void MySD::EndOfEvent(G4HCofThisEvent* /*hce*/)
{
  G4int nofHits = fHitsCollection->entries();
  G4cout << "Hits Collection: in this event there are "
         << nofHits << " hits " << G4endl;
  for ( G4int i=0; i<nofHits; ++i ) (*fHitsCollection)[i]->Print();
}
```

- The MySD::EndOfEvent() method is invoked at the end of processing an event.
  - It is invoked even if the event is aborted
  - It is invoked before UserEventAction::EndOfEventAction

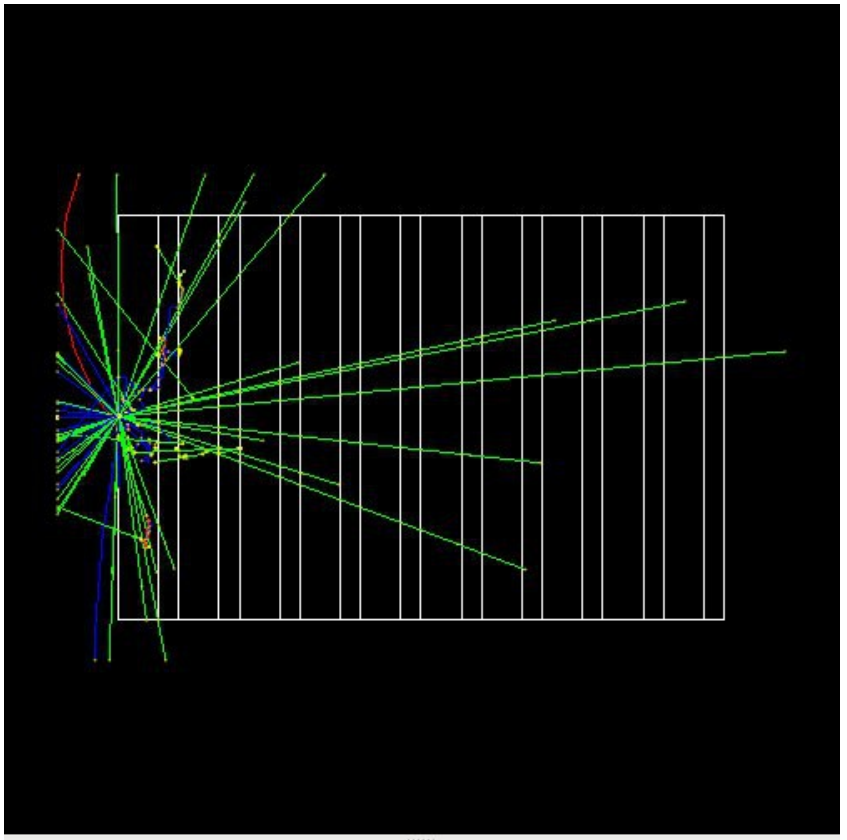
# Geant4 Scorers

# Ready to Use Scoring Classes

- A typical quantities, such as energy deposit, track length etc. can be accounted using the classes already available in Geant4:
  - G4MultiFunctionalDetector – a sensitive detector which can be associated with scorers to account physical quantities
  - **Various scorer classes** are available:
    - G4PSTrackLength, G4PSEnergyDepsit, G4PSDoseDeposit, G4PSChargeDeposit, G4PSFlatSurfaceCurrent, G4PSNofSecondary, G4PSNofStep, …
    - All scorer classes are derived from G4VPrimitiveScorer base class
    - See Application Developers Guide 4.4.5 for the complete list
  - **Filter classes** can be used to apply a selection on the quantities to be accounted:
    - G4SDCharged[Neutral]Filter, G4SDParticleFilter, G4SDKineticEnergyFilter, …
    - The filter classes are derived from G4VSDFilter base class
    - See Application Developers Guide 4.4.6 for the complete list

# Example B4d

- An example of use of Geant4 scorers is provided in basic example B4d
- G4MultiFunctionalDetector
- Scorers accounting energy deposit and track length: G4PSEnergyDeposit, G4PSTrackLength
- Filter to select charged particles: G4SDCharchedFilter



# Command-based scoring

# Command-based scoring

- Command-based scoring functionality offers the built-in scoring mesh and various scorers for commonly-used physics quantities such as dose, flux, etc.
  - Due to small performance overhead, it does not come by default.
- To use this functionality, activate the G4ScoringManager after the instantiation of G4RunManager in your main()
- This will create the UI commands of this functionality in /score directory.

```
#include "G4ScoringManager.hh"
int main()
{
   // ...
   G4RunManager* runManager = new G4RunManager;
   G4ScoringManager::GetScoringManager();
   // ...
}
```

## Command-based Scoring

# Example Macro

```
# Define scoring mesh
/score/create/boxMesh boxMesh_1
/score/mesh/boxSize 100. 100. 100. cm
/score/mesh/nBin 30 30 30

# Define scoring quantity
/score/quantity/energyDeposit boxMash
keV

# Define a filter
/score/filter/charged

# Close mesh
/score/close
```

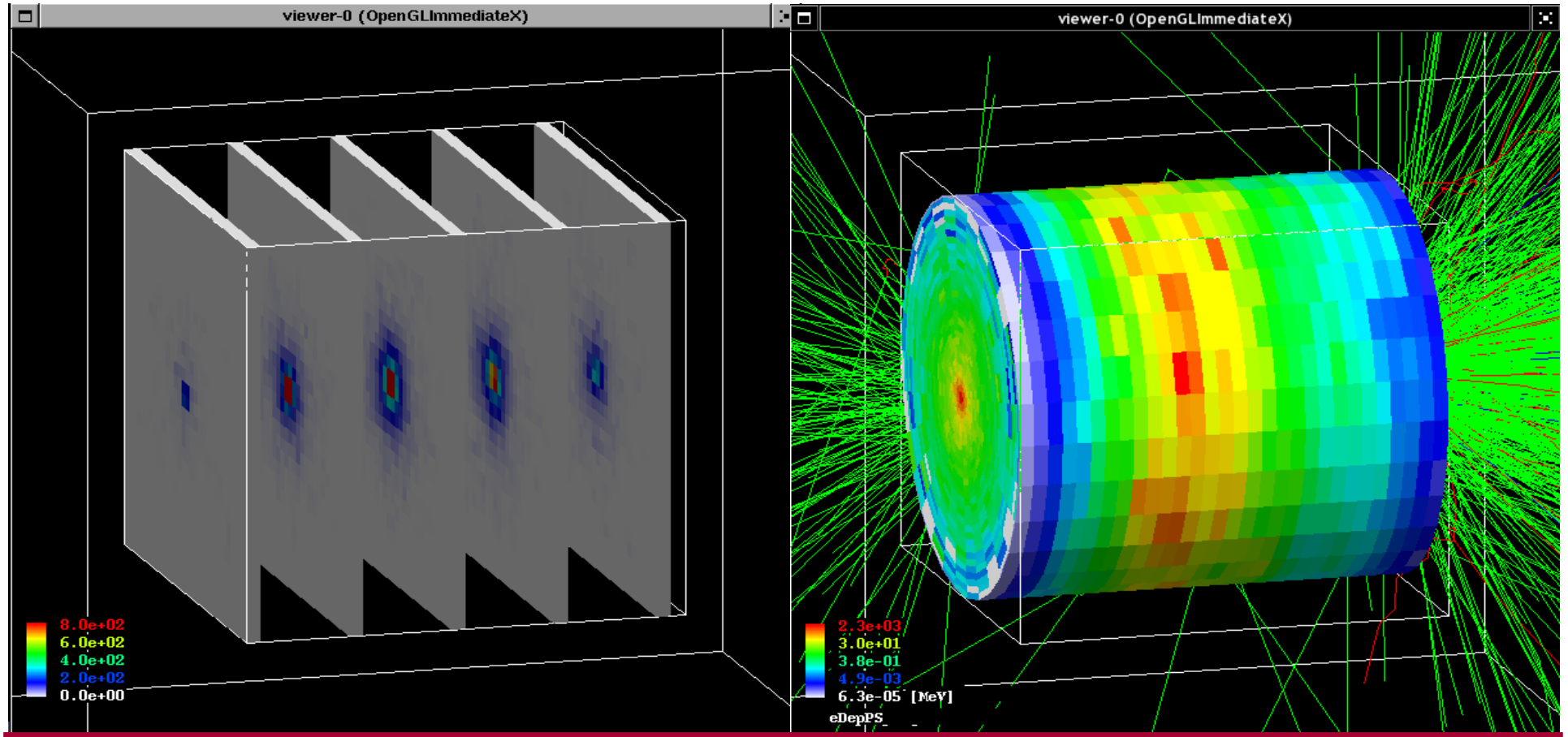
3D scoring mash:
name, shape&size, number of bins

Scoring quantity:
energyDeposit

Filter:
charged particles only

Close mash

# Command-based Scoring Examples (2)




From M.Asai

# Summary

- The Geant4 toolkit provides dedicated classes/tools for user scoring:
  - Sensitive detectors
  - Geant4 scorers
  - Command-based scoring