Sensitive Detector in Geant4

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How to retrieve information

There are 3 ways

- Use the sensitive detector(**G4VSensitiveDetector**)

A specific feature to Geant4 is that a user can provide his/her own implementation of the detector and **its response customized**

- Create User scores attaching them to a given volume

- Built-in scoring command

What is a sensitive detector (SD)?

A logical volume becomes sensitive if it has a pointer to a sensitive detector (G4VSensitiveDetector)

- A sensitive detector can be instantiated several times, where the instances are assigned to different logical volumes
- Note that SD objects must have unique detector names
- A logical volume can only have one SD object attached

Two possibilities to make use of the SD functionality:

- Create your own sensitive detector (using class inheritance)
  - Highly customizable
- Use Geant4 built-in tools: Primitive scorers

Adding sensitivity to a logical volume

Modify the ConstructSDandField() method of the user Detector Construction

- Create an instance of a sensitive detector
- Assign the pointer of your SD to the logical volume of your detector geometry

```
G4VSensitiveDetector* mySensitive
   = new MySensitiveDetector(SDname="/MyDetector");   } create instance

boxLogical->SetSensitiveDetector(mySensitive);   } assign to logical volume
(or)
SetSensitiveDetector("LVname",mySensitive);   } assign to logical volume (alternative)
```

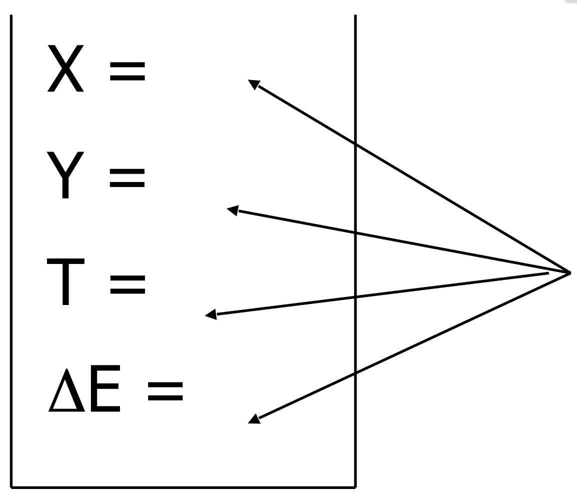
The ingredients of user SD

- A powerful and flexible way of extracting information from the physics simulation is to **define your own SD**
- Derive **your own concrete classes** from the base classes and customize them according to your needs

	Concrete class	**Base class**
Sensitive Detector	MySensitiveDetector	G4VSensitiveDetector
Hit	MyHit	G4VHit
		Template class
Hits collection		G4THitsCollection<MyHit*>

What is the Hit?

A "Hit" is like a "container", a **empty box** which will store the information retrieved step by step



The Hit **concrete class** (derived by **G4VHit**) must be written by the user: the user must decide **which variables** and/or information the hit should store and **when** store them

The Hit objects are **created** and **filled** by the **SensitiveDetector** class (invoked at each step in detectors defined as sensitive). **Stored** in the "**HitCollection**", attached to the **G4Event**: can be retrieved at the EndOfEvent

Hit class

- Hit is a user-defined class which derives from the base class **G4VHit**. Two virtual methods
  - Draw()
  - Print()
- You can store various types of information by implementing your own concrete Hit class
- Typically, one may want to record information like
  - Position, time and ΔE of a step
  - Momentum, energy, position, volume, particle type of a given track
  - Etc.

Geant4 Hits

Since in the simulation one may have different sensitive detectors in the same setup (e.g. a calorimeter and a Si detector),

it is possible to define many Hit classes (all derived by G4VHit) storing different information

X =
Y =
T =
ΔE =

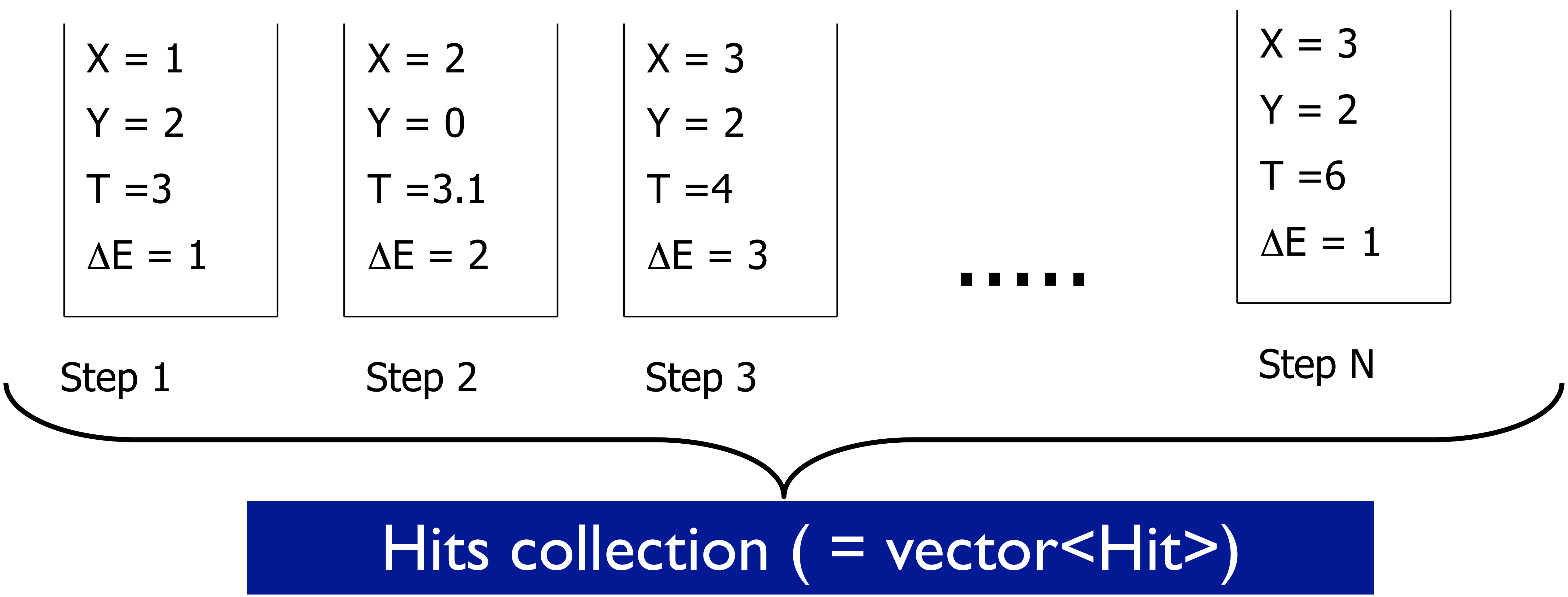
Class Hit1 : public G4VHit

Z =
Pos =
Dir =

Class Hit2 : public G4VHit

Hits Collection

At each step in a detector defined as sensitive, the method **ProcessHit()** of the user SensitiveDetector class is inkoved: it must **create**, **fill** and **store** the Hit objects

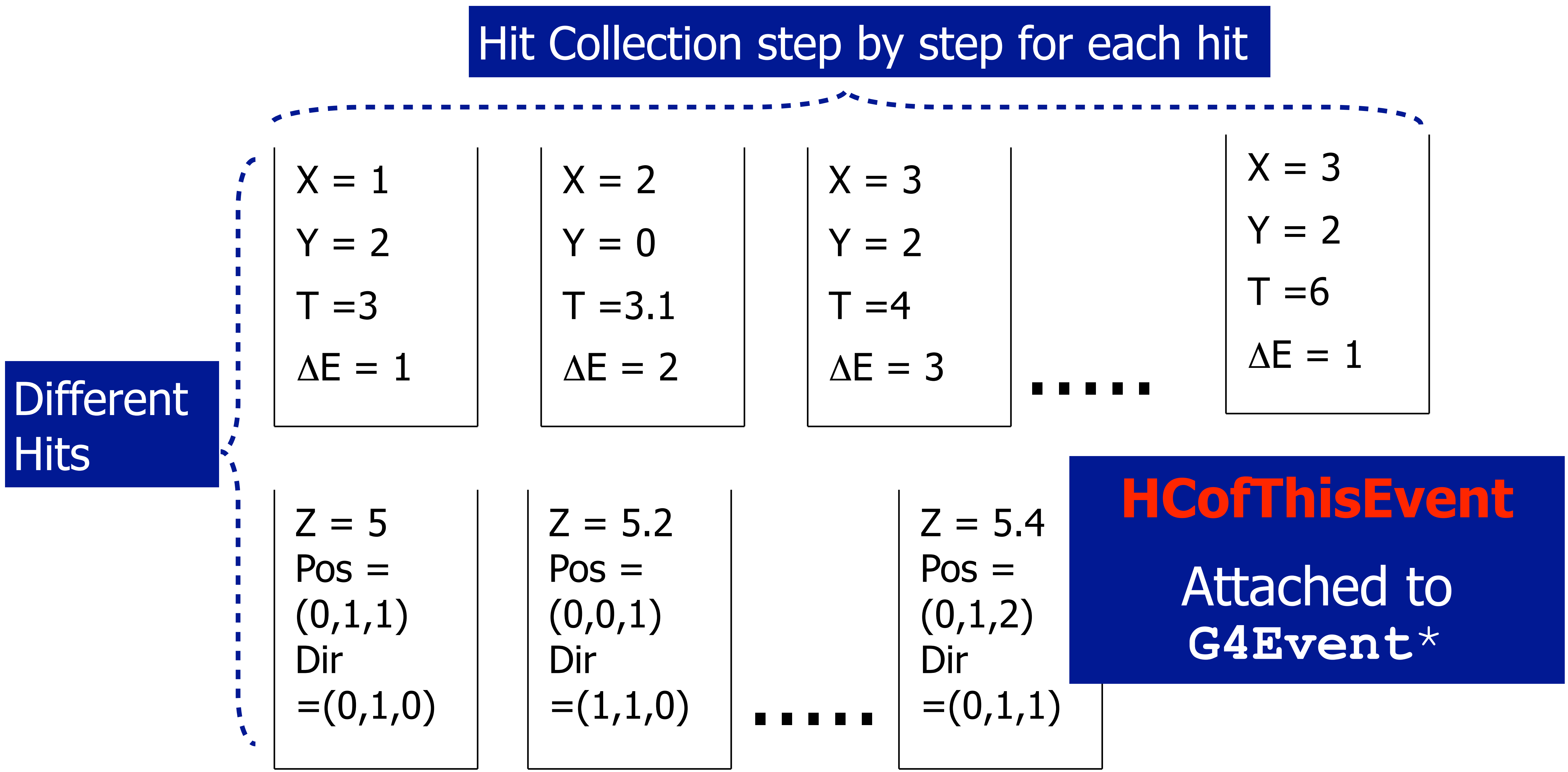


Hits Collection - 2

- Once created in the sensitive detectors, objects of the concrete hit class **must be stored** in a **dedicated collection**
  - Template class **G4THitsCollection<MyHit>**, which is actually an array of **MyHit***
- The hits collections can be accesses in different phases of tracking
  - At the end of each event, through the **G4Event** (a-posteriori event analysis)
  - During event processing, through the Sensitive Detector Manager G4SDManager (event filtering)

The HCofThisEvent

Remember that you may have **many kinds of Hits**
(and Hits Collections)



Hits Collections of an event

- A **G4Event** object has a **G4HCofThisEvent** object at the end of the event processing (if it was successful)
  - The pointer to the G4HCofThisEvent object can be retrieved using the **G4Event::GetHCofThisEvent()** method
- The G4HCofThisEvent stores all hits collections created within the event
  - Hits collections are accessible and can be processed e.g. in the EndOfEventAction() method of the User Event Action class

Sensitive Detector (SD) implementation

- To create a sensitive detector, **derive** your own concrete class from the **G4VSensitiveDetector** abstract base class
  - The principal purpose of the sensitive detector is to create hit objects
  - Overload the following methods (see also next slide):

Initialize()
ProcessHits() (Invoked for each step if step starts in logical volume having the SD attached)
EndOfEvent()

SD implementation: constructor

- Specify a hits collection (by its unique name) for each type of hits considered in the sensitive detector:
  - Insert the name(s) in the collectionName vector

```
MySensitiveDetector::MySensitiveDetector(G4String detectorUniqueName)
                          : G4VSensitiveDetector(detectorUniquename),
                           collectionID(-1)  {

  collectionName.insert(“collection_name");
}
```

Base class

```
class G4VSensitiveDetector {
 ...
 protected:
    G4CollectionNameVector collectionName;
    // This protected name vector must be filled in
    // the  constructor of the concrete class for
    // registering names of hits collections
 ...
};
```

SD implementation: Initialize()

- The Initialize() method is invoked at the beginning of each event
- Construct all hits collections and insert them in the G4HCofThisEvent object, which is passed as argument to Initialize()
  - The **AddHitsCollection()** method of G4HCofThisEvent requires the collection ID
- The unique collection ID can be obtained with GetCollectionID():
  - GetCollectionID() cannot be invoked in the constructor of this SD class (It is required that the SD is instantiated and registered to the SD manager first).
  - Hence, we defined a private data member (collectionID), which is set at the first call of the Initialize() function

```
void MySensitiveDetector::Initialize(G4HCofThisEvent*HCE) {
  if(collectionID < 0)
        collectionID = GetCollectionID(0); // Argument : order of collect.
                                           // as stored in the collectionName
  hitsCollection = new MyHitsCollection
                     (SensitiveDetectorName, collectionName[0]);

  HCE -> AddHitsCollection(collectionID, hitsCollection);
}
```

SD implementation: ProcessHits()

- This **ProcessHits()** method is invoked for every step in the volume(s) which hold a pointer to this SD (= each volume defined as "sensitive")
- The main mandate of this method is to generate hit(s) or to accumulate data to existing hit objects, by using information from the current step
  - Note: Geometry information must be derived from the "PreStepPoint"

```
G4bool MySensitiveDetector::ProcessHits(G4Step* step,
                                        G4TouchableHistory*ROhist) {
  MyHit* hit = new MyHit();          // 1) create hit
...
  // some set methods, e.g. for a tracking detector:
  G4double energyDeposit = step -> GetTotalEnergyDeposit();
  hit -> SetEnergyDeposit(energyDeposit); // See implement. of our Hit class   // 2) fill hit
...
  hitsCollection -> insert(aHit);    // 3) insert in the collection
  return true;
}
```

SD implementation: EndOfEvent()

- This EndOfEvent() method is invoked at the end of each event.
  - Note is invoked before the EndOfEvent function of the G4UserEventAction class

```
void MySensitiveDetector::EndOfEvent(G4HCofThisEvent* HCE) {
}
```

Process hit: example

```
void MyEventAction::EndOfEventAction(const G4Event* event) {

 // index is a data member, representing the hits collection index of the
 // considered collection. It was initialized to -1 in the class constructor
 if(index < 0)   index =
   G4SDManager::GetSDMpointer() -> GetCollectionID("myDet/myColl");

 G4HCofThisEvent* HCE = event-> GetHCofThisEvent();

 MyHitsCollection* hitsColl = 0;
 if(HCE)  hitsColl = (MyHitsCollection*)(HCE->GetHC(index));

 if(hitsColl)  {
   int numberHits = hitsColl->entries();

   for(int i1= 0; i1 < numberHits ; i1++) {
     MyHit* hit = (*hitsColl)[i1];
     // Retrieve information from hit object, e.g.
     G4double energy = hit -> GetEnergyDeposit;
     ... // Further process and store information
   }
 }
}
```

retrieve index

retrieve all hits collections

retrieve hits collection by index

cast

loop over individual hits, retrieve the data

Recipe and strategy - 1

- Create your detector geometry
  - Solids, logical volumes, physical volumes
- Implement a sensitive detector and assign an instance of it to the **logical volume** of your geometry set-up
  - Then this volume becomes "sensitive"
  - Sensitive detectors are active for each particle steps, if the step starts in this volume

Recipe and strategy - 2

- Create hits objects in your sensitive detector using information from the particle step
  - You need to create the hit class(es) according to **your requirements**
- **Store** hits in hits collections (automatically associated to the **G4Event** object)
- Finally, process the information contained in the hit in user action classes (e.g. **G4UserEventAction**) to obtain results to be stored in the analysis object

Native Geant4 scoring

Extract useful information

- Geant4 provides a number of **primitive scorers**, each one accumulating one physics quantity (e.g. total dose) for an event
- This is alternative to the **customized** sensitive detectors, which can be used with full flexibility to gain complete control
- It is convenient to use primitive scorers instead of user-defined sensitive detectors when

you are not interested in recording each individual step, but accumulating physical quantities for an event or a run and you have not too many scorers

G4MultiFunctionalDetector

G4MultiFunctionalDetector is a concrete class derived from **G4VSensitiveDetector**

- It should be **assigned to a logical volume** as a **kind of** (ready-for-the-use) **sensitive detector**
- It takes an arbitrary number of **G4VPrimitiveSensitivity** classes, to define the scoring quantities that you need
  - Each **G4VPrimitiveSensitivity** accumulates one physics quantity for each physical volume
  - E.g. **G4PSDoseScorer** (a concrete class of **G4VPrimitiveSensitivity** provided by Geant4) accumulates dose for each cell

By using this approach, **no need to implement sensitive detector** and **hit classes**!

G4VPrimitiveSensitivity

- Primitive scorers (classes derived from **G4VPrimitiveSensitivity**) have to be registered to the **G4MultiFunctionalDetector**
  - **->RegisterPrimitive(), ->RemovePrimitive()**
- They are designed to **score one kind of quantity** (surface flux, total dose) and to **generate one hit collection** per event
  - automatically named as

<MultiFunctionalDetectorName>/<PrimitiveScorerName>

  - hit collections can be retrieved in the EventAction or RunAction (as those generated by sensitive detectors)
  - do not share the same primitive score object among multiple G4MultiFunctionalDetector objects (results may mix up!)

For example ...

```
MyDetectorConstruction::ConstructSDandField()
{
   G4MultiFunctionalDetector* myScorer = new
  G4MultiFunctionalDetector("myCellScorer");

   myCellLog->SetSensitiveDetector(myScorer);

   G4VPrimitiveSensitivity* totalSurfFlux = new
     G4PSFlatSurfaceFlux("TotalSurfFlux");
   myScorer->RegisterPrimitive(totalSurfFlux);
   G4VPrimitiveSensitivity* totalDose = new G4PSDoseDeposit("TotalDose");
   myScorer->RegisterPrimitive(totalDose);
}
```

instantiate multi-functional detector

attach to volume

create a primitive scorer (surface flux) and register it

create a primitive scorer (total dose) and register it

Some primitive scorers that you may find useful

- Concrete Primitive Scorers ([?] Application Developers Guide)
  - Track length
    - G4PSTrackLength, G4PSPassageTrackLength
  - Deposited energy
    - G4PSEnergyDeposit, G4PSDoseDeposit
  - Current/Flux
    - G4PSFlatSurfaceCurrent, G4PSSphereSurfaceCurrent,G4PSPassageCurrent, G4PSFlatSurfaceFlux, G4PSCellFlux, G4PSPassageCellFlux
  - Others
    - G4PSMinKinEAtGeneration, G4PSNofSecondary, G4PSNofStep, G4PSCellCharge

G4VSDFilter

- A **`G4VSDFilter`** can be attached to `G4VPrimitiveSensitivity` to define **which kind of tracks** have to be scored (e.g. one wants to know surface flux of protons only)
  - `G4SDChargeFilter` (accepts only charged particles)
  - `G4SDNeutralFilter` (accepts only neutral particles)
  - `G4SDKineticEnergyFilter` (accepts tracks in a defined range of kinetic energy)
  - `G4SDParticleFilter` (accepts tracks of a given particle type)
  - `G4VSDFilter` (base class to create user-customized filters)

For example ...

```
MyDetectorConstruction::ConstructSDandField()
{
  G4VPrimitiveSensitivity* protonSurfFlux
  = new G4PSFlatSurfaceFlux("pSurfFlux");
   G4VSDFilter* protonFilter = new
      G4SDParticleFilter("protonFilter");
   protonFilter->Add("proton");

   protonSurfFlux->SetFilter(protonFilter);

   myScorer->RegisterPrimitive(protonSurfFlux);
}
```

create a primitive scorer (surface flux), as before

create a particle filter and add protons to it

register the filter to the primitive scorer

register the scorer to the multifunc detector (as shown before)

How to retrieve information - part 1

- At the end of the day, one wants to retrieve the information from the scorers
  - True also for the customized hits collection
- Each scorer creates a hit collection, which is attached to the G4Event object
  - Can be retrieved and read at the end of the event, using an integer ID
  - Hits collections mapped as **G4THitsMap<G4double>*** so can loop on the individual entries
  - Operator += provided which automatically sums up hits (no need to loop)

How to retrieve information – part 2

```
//needed only once
G4int collID = G4SDManager::GetSDMpointer()
  ->GetCollectionID("myCellScorer/TotalSurfFlux");
```

Get **ID** for the collection (given the name)

```
G4HCofThisEvent* HCE = event->GetHCofThisEvent();
```

Get **all HC** available in this event

```
G4THitsMap<G4double>* evtMap =
    static_cast<G4THitsMap<G4double>*>
    (HCE->GetHC(collID));
```

Get the HC with the **given ID** (need a cast)

```
 std::map<G4int,G4double*>::iterator itr;
 for (itr = evtMap->GetMap()->begin(); itr !=
     evtMap->GetMap()->end(); itr++) {
    G4double flux = *(itr->second);
    G4int copyNb  = *(itr->first);
}
```

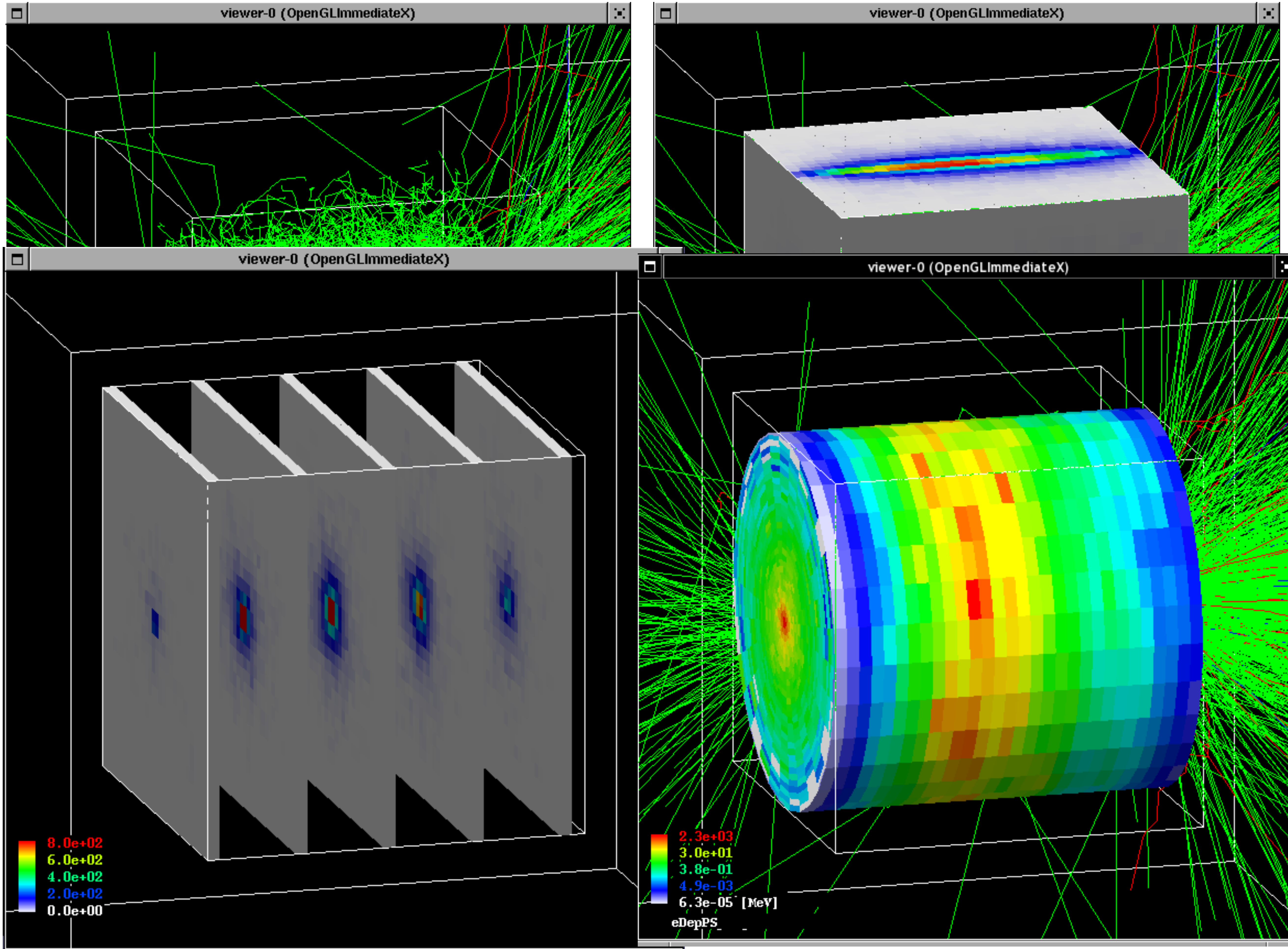
Loop over the **individual entries** of the HC: the key of the map is the copyNb, the other field is the real content

Command-based scoring

Thanks to the newly developed parallel navigation, an **arbitrary scoring mesh geometry** can be defined which is independent to the volumes in the mass geometry.
Also, G4MultiFunctionalDetector and primitive scorer classes now offer the built-in scoring of most-common quantities

UI commands for scoring → no C++ required, apart from instantiating `G4ScoringManager` in `main()`

- Define a scoring mesh
  /score/create/boxMesh <mesh_name>
  /score/open, /score/close
- Define mesh parameters
  /score/mesh/boxsize <dx> <dy> <dz>
  /score/mesh/nbin <nx> <ny> <nz>
  /score/mesh/translate,
- Define primitive scorers
  /score/quantity/eDep <scorer_name>
  /score/quantity/cellFlux <scorer_name>
  currently **20 scorers** are available
- Define filters
  /score/filter/particle <filter_name> <particle_list>
  /score/filter/kinE <filter_name> <Emin> <Emax> <unit>
  currently **5 filters** are available
- Output
  /score/draw <mesh_name> <scorer_name>
  /score/dump, /score/list


viewer-0 (OpenGLImmediateX)
viewer-0 (OpenGLImmediateX)
viewer-0 (OpenGLImmediateX)
viewer-0 (OpenGLImmediateX)
8.0e+02
6.0e+02
4.0e+02
2.0e+02
0.0e+00
2.3e+03
3.0e+01
3.8e-01
4.9e-03
6.3e-05 [MeV]
eDepPS

How to learn more about built-in scoring

Have a look at the **dedicated extended examples** released with Geant4:

examples/extended/runAndEvent/RE02

(use of primitive scorers)

examples/extended/runAndEvent/RE03

(use of UI-based scoring)

Thank you

Exercises

Task5b: Command-based scoring
Task5c: Primitive scorer
Task5d: Customized sensitive detector