

Interaction with the Geant4 Kernel-I

Davide Chiappara
University of Padova (UNIPD)
Istituto Nazionale di Fisica Nucleare (INFN)

Kernel Interaction lectures

Kernel I (Wednesday)

Notations, user actions, command-based scoring

Kernel II (Thursday)

Sensitive detector, native scoring

Kernel III (Friday)

custom hits

Initialisation classes

Invoked at the initialisation

G4VUserDetectorConstruction
G4VUserPhysicsList

Action classes

Invoked during the execution loop

G4VUserPrimaryGeneratorAction

G4UserRunAction
G4UserEventAction
G4UserTrackingAction
G4UserStackingAction
G4UserSteppingAction

Contents

- Run, Event, Track, ...
- Optional user action classes
- Command-based scoring
- Accumulables
- Analysis tools

Part I: Run, Track, Event, ...

Geant4 terminology: an overview

The following **keywords** are often used in Geant4

Run, Event, Track, Step

Processes: At Rest, Along Step, Post Step

Cut (or production threshold)

Run, Event and Track

Run

Event 0

track 1

track 2

track 3

track 4

Event 1

track 1

track 2

track 3

Event 2

track 1

Event 3

track 1

track 2

track 3

track 4

The Run (G4Run)

As an analogy with a real experiment, a run of Geant4 starts with 'Beam On'

Within a run, the user **cannot change**

- The detector setup

- The physics setting (processes, models)

A run is a collection of events with the same detector and physics conditions

The **G4(MT)RunManager** class manages the processing of each run, represented by:

- G4Run** class

- G4UserRunAction** for an optional user hook

The Event (G4Event)

An Event is the **basic unit** of simulation

At the beginning of event, **primary tracks** are **generated** and they are pushed into a stack

Tracks are popped up from the stack one-by-one **and 'tracked'**

Secondary tracks are also pushed into the stack

When the **stack gets empty**, the processing of the event is **completed**

G4Event class **represents an event**. At the end of a successful event it has:

List of **primary** vertices and particles (as input)

Hits and **Trajectory** collections (as outputs)

The Track (G4Track)

The Track is a **snapshot of a particle** and it is represented by the **G4Track** class
It **keeps 'current' information** of the particle (i.e. energy, momentum, position, polarization, ..)

It is **updated** after every step

The track object is **deleted** when:

It goes outside the world volume

It disappears in an interaction (decay, inelastic scattering)

It is slowed down to zero kinetic energy and there are no '*AtRest*' processes

It is manually killed by the user

No track object **persists** at the end of the event

G4TrackingManager class manages the tracking

G4UserTrackingAction is the optional User hook

G4Track status

After each step the track can change its state

The status can be (red can only be set by the User)

Track Status	Description
fAlive	The particle is continued to be tracked
fStopButAlive	Kin. Energy = 0, but AtRest process will occur
fStopAndKill	Track has lost identity (has reached world boundary, decayed, ...), Secondaries will be tracked
fKillTrackAndSecondaries	Track and its secondary tracks are killed
fSuspend	Track and its secondary tracks are suspended (pushed to stack)
fPostponeToNextEvent	Track but NOT secondary tracks are postponed to the next event (secondaries are tracked in current event)

The Step (G4Step)

G4Step represents a step in the particle propagation

A G4Step object stores **transient information** of the step

In the tracking algorithm, G4Step is **updated** each time a **process** is invoked (e.g. multiple scattering)

You can **extract information** from a step after the step is completed, e.g.

in **ProcessHits()** method of your sensitive detector
(later)

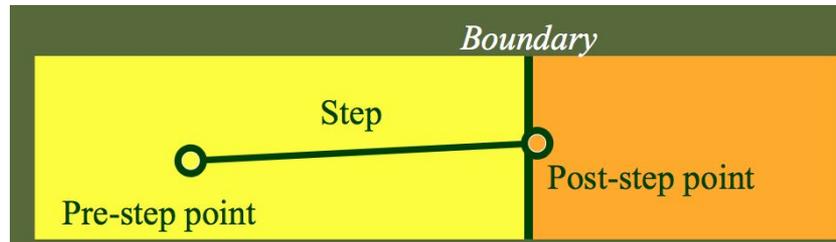
in **UserSteppingAction()** of your step action class
(later)

The Step in Geant4

The **G4Step** has the information about the **two points** (pre-step and post-step) and the **'delta'** information of a particle (energy loss on the step,

Each point knows the **volume** (and the material)

In case a step is limited by a volume boundary, the **end point** physically stands on the **boundary** and it **logically belongs to the next volume**



G4Step object

A **G4Step** object contains

The **two endpoints** (pre and post step) so one has access to the **volumes** containing these endpoints

Changes in **particle properties** between the points

Difference of particle energy, momentum,

Energy deposition on step, step length, time-of-flight, ...

A pointer to the associated **G4Track** object

Volume hierarchy information

G4Step provides many **Get...** methods to access these information or objects

G4StepPoint* `GetPreStepPoint()`,

The Geometry Boundary

To check, if a step **ends on a boundary**, one may compare if the **physical volume** of **pre** and **post-step** points are **equal**

One can also use the **step status**

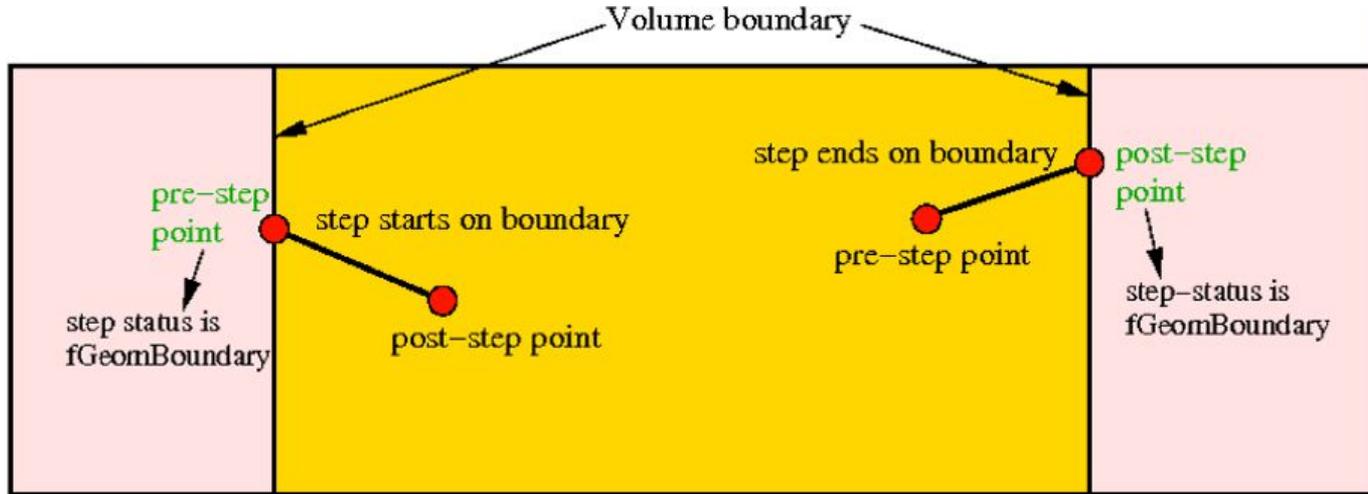
Step Status provides information about the **process** that **restricted** the **step length**

It is attached to the **step points**: the pre has the status of the previous step, the post of the current step

If the status of POST is **fGeometryBoundary**, the step **ends on a volume boundary** (does not apply to world volume)

To check if a step **starts** on a volume boundary you can also use the step status of the PRE-step point

Step Concept and Boundaries



Example: boundaries

```
G4StepPoint* preStepPoint = step -> GetPreStepPoint();
G4StepPoint* postStepPoint = step -> GetPostStepPoint();

// Use the GetStepStatus() method of G4StepPoint to get the status of the
// current step (contained in post-step point) or the previous step
// (contained in pre-step point):
if(preStepPoint -> GetStepStatus() == fGeomBoundary) {
    G4cout << "Step starts on geometry boundary" << G4endl;
}
if(postStepPoint -> GetStepStatus() == fGeomBoundary) {
    G4cout << "Step ends on geometry boundary" << G4endl;
}

// You can retrieve the material of the next volume through the
// post-step point:
G4Material* nextMaterial = step->GetPostStepPoint()->GetMaterial();
```

Geant4 terminology: an overview

Run: is a collection of events with the same detector and physics conditions;

Event: is a collection of primary and secondary particles in a stack

Track: is a snapshot of a particle

Step: represents a step in the particle propagation

Processes: ...

Cut: ...

Worker / Master threads: ...

Part II: Optional user action classes

Optional User Action classes

Five **base classes** with virtual methods the user may override to step during the execution of the application

G4UserRunAction

G4UserEventAction

G4UserTrackingAction

G4UserStackingAction

G4UserSteppingAction

Default implementation (**not** purely virtual): **Do nothing** ☺

Therefore, **override** only the methods you need.

G4UserRunAction

This class has three virtual methods which are invoked by G4RunManager for each run:

GenerateRun() ==> **G4Run*** **GenerateRun()**

This method is invoked at the beginning of BeamOn. Because the user can inherit the class G4Run and create his/her own concrete class to store some information about the run, the GenerateRun() method is the place to instantiate such an object

BeginOfRunAction() ==> **void** **BeginOfRunAction(const G4Run*)**

This method is invoked before entering the event loop. This method is invoked after the calculation of the physics tables.

EndOfRunAction() ==> **void** **EndOfRunAction(const G4Run*)**

This method is invoked at the very end of the run processing. It is typically used for a simple analysis of the processed run.

G4UserEventAction

This class has two virtual methods which are invoked by G4EventManager for each event:

beginOfEventAction() ==> void **BeginOfEventAction**(const **G4Event***)

This method is invoked before converting the primary particles to G4Track objects. A typical use of this method would be to initialize and/or book histograms for a particular event.

endOfEventAction() ==> void **EndOfEventAction**(const **G4Event***)

This method is invoked at the very end of event processing. It is typically used for a simple analysis of the processed event.

G4UserStackingAction

This class has three virtual methods, **ClassifyNewTrack**, **NewStage** and **PrepareNewEvent** which the user may override in order to control the various track stacking mechanisms.

ClassifyNewTrack() ==>

G4ClassificationOfNewTrack **ClassifyNewTrack**(const G4Track*)

is invoked by G4StackManager whenever a new G4Track object is "pushed" onto a stack by G4EventManager.

G4ClassificationOfNewTrack has four possible values:

fUrgent - track is placed in the *urgent* stack (*default*)

fWaiting - track is placed in the waiting stack, and will not be simulated until the urgent stack is empty

fPostpone - track is postponed to the next event

fKill - the track is deleted immediately and not stored in any stack.

These assignments may be made based on the origin of the track which is obtained as follows:

```
G4int parent_ID = aTrack->get_parentID( );
```

where

parent_ID = 0 indicates a primary particle

parent_ID > 0 indicates a secondary particle

parent_ID < 0 indicates postponed particle from previous event.

G4UserStackingAction

NewStage() ==> void NewStage()

is invoked when the *urgent* stack is empty and the *waiting* stack contains at least one G4Track object.

PrepareNewEvent() ==> void PrepareNewEvent()

is invoked at the beginning of each event. At this point no primary particles have been converted to tracks, so the *urgent* and *waiting* stacks are empty.

G4UserSteppingAction

UserSteppingAction() ==> void **UserSteppingAction**(const g4Step*)

→ **Get information about particles** ←

kill tracks under specific circumstances

Part III: Command-based scoring

Command-based Scoring

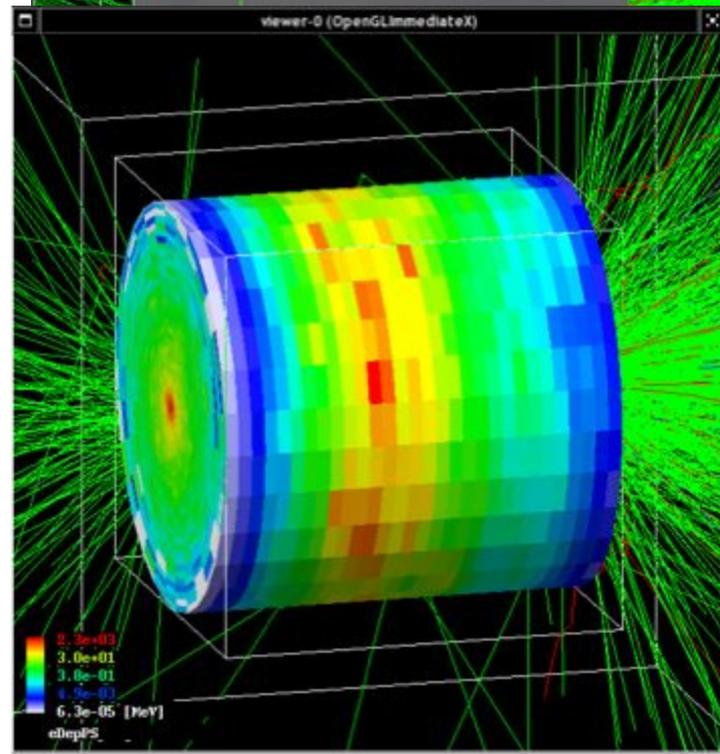
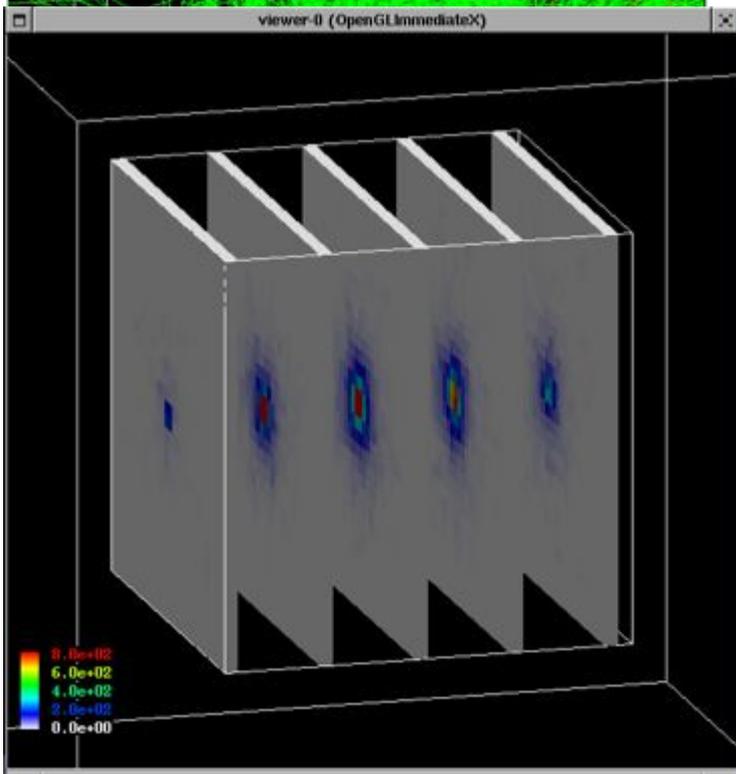
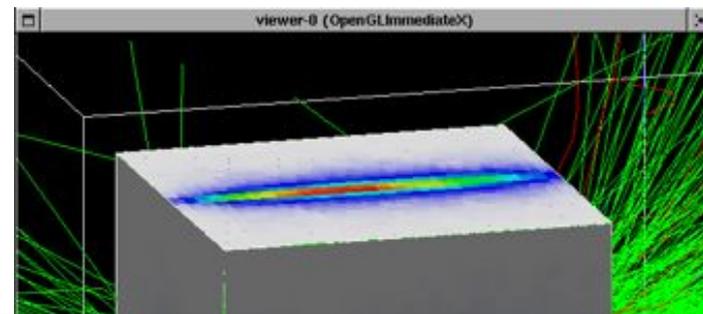
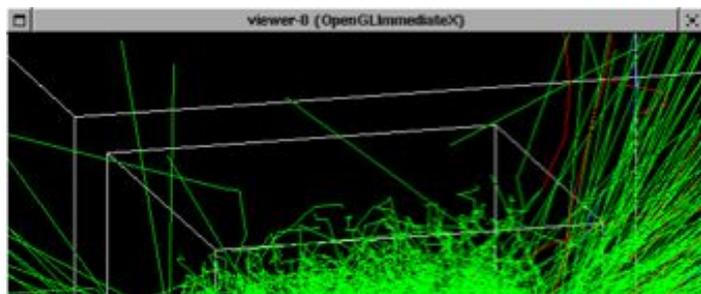
UI **commands** for scoring → no C++ required, apart from accessing
G4ScoringManager

```
int main() {  
    ...  
    G4ScoringManager::GetScoringManager();  
    ...  
}
```

- Define a scoring mesh
 /score/create/boxMesh <mesh_name>
- Define mesh parameters
 /score/mesh/boxsize <dx> <dy> <dz>
 /score/mesh/nbin <nx> <ny> <nz>
- Define primitive scorers
 /score/quantity/energyDeposit <scorer_name>
 /score/quantity/cellFlux <scorer_name>
 currently **20 scorers** are available

- Define filters and close
 /score/filter/particle <filter_name> <particle_list>
 /score/filter/kineticEnergy <filter_name> <Emin> <Emax> <unit>
 currently **5 filters** are available
 /score/close
- Output
 /score/drawProjection <mesh_name> <scorer_name>
 /score/dump, /score/list

<https://geant4-userdoc.web.cern.ch/UsersGuides/ForApplicationDeveloper/html/Detector/commandScore.html>



Detached session: Geant4 analysis

G4Accumulable<T>

Templated class can be used to facilitate merging of the values accumulated on workers to the master thread

Accumulable during Run

Value merge at the end (explicit)

Scalar variables only (otherwise, expert)

Alternative to ntuples/histograms *(later)*

Managed by **G4AccumulableManager**

<=10.2: Previously named G4Parameter!

Geant4 Analysis

A **basic analysis interface** is available in Geant4 for **histograms** (1D and 2D) and **ntuples**

Unified interface to support different output formats

ROOT, CSV, XML, and HDF5

Code is the same, just change one line to switch from one to another

Everything is done using **G4AnalysisManager**

UI commands available

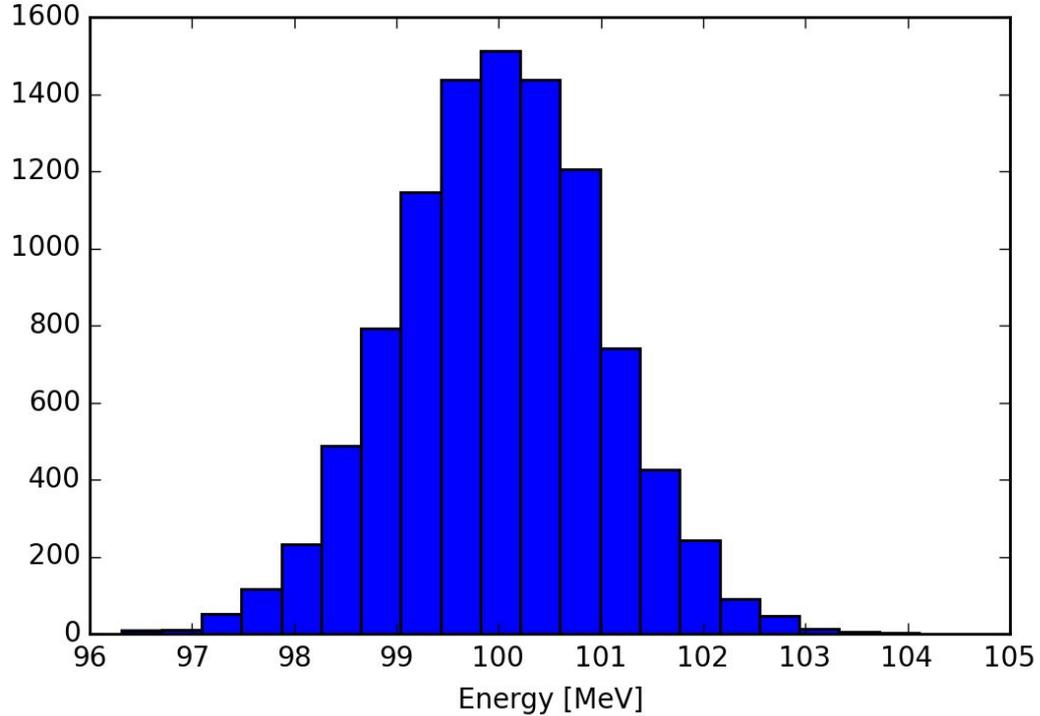
Geant4 analysis

Selection of output format is performed by setting the proper file extension in `RunAction::BeginOfRunAction()`

```
// Get analysis manager
auto analysisManager = G4AnalysisManager::Instance();

// Open an output file
//
G4String fileName = "B4.root";
// Other supported output types:
// G4String fileName = "B4.csv";
// G4String fileName = "B4.hdf5";
// G4String fileName = "B4.xml";
analysisManager->OpenFile(fileName);
G4cout << "Using " << analysisManager->GetType() << G4endl;
```

Histograms



Open file and book histograms

```
void MyRunAction::BeginOfRunAction(const G4Run* run)
{
    // Get analysis manager
    G4AnalysisManager* man = G4AnalysisManager::Instance();
    man->SetVerboseLevel(1);
    man->SetFirstHistoId(1);
    // Creating histograms
    man->CreateH1("h", "Title", 100, 0., 800*MeV);
    man->CreateH1("hh", "Title", 100, 0., 10*MeV);
    // Open an output file
    man->OpenFile("myoutput.root");
}
```

Start numbering of histograms from ID=1

ID=1

ID=2

Open output file

Fill histograms and write the file

```
void MyEventAction::EndOfEventAction(const G4Run* aRun)
```

```
{  
    auto man = G4AnalysisManager::Instance();  
    man->FillH1(1, fEnergyAbs);  
    man->FillH1(2, fEnergyGap);  
}
```



```
MyRunAction::~~MyRunAction()
```

```
{  
    auto man = G4AnalysisManager::Instance();  
    man->Write();  
}
```

```
MyRunAction::EndOfRunAction(const G4Run* aRun)
```

```
{  
    ...  
    auto man = G4AnalysisManager::Instance();  
    man->CloseFile();  
}
```

Ntuples

ParticleID	Energy	x	y
0	99.5161753	-0.739157031	-0.014213165
1	98.0020355	1.852812521	1.128640204
2	100.0734469	0.863203688	-0.277949199
3	99.3508677	-2.063452685	-0.898594988
4	101.2505954	1.030581054	0.736468229
5	98.9849841	-1.464509417	-1.065372115
6	101.1547644	1.121931704	-0.203319254
7	100.8876748	0.012068917	-1.283410959
8	100.3013861	1.852532119	-0.520615895
9	100.6295882	1.084122362	0.556967258
10	100.4887681	-1.021971662	1.317380892
11	101.6716567	0.614222096	-0.483530242
12	99.1083093	-0.776034456	0.203524549
13	97.3595776	0.814378204	-0.690615126
14	100.7264612	-0.408732803	-1.278746667

Ntuples Support

g4tools support ntuples

- **any** number of ntuples
- **any** number of columns
- supported types: int/float/double

For more complex tasks (other functionality of ROOT TTrees) have to link ROOT directly

Book Ntuples

```
void MyRunAction::BeginOfRunAction(const G4Run* run)
{
  // Get analysis manager
  G4AnalysisManager* man = G4AnalysisManager::Instance();
  man->SetFirstNtupleId(1); 

  // Creating ntuples
  man->CreateNtuple("name", "Title");
  man->CreateNtupleDColumn("Eabs");
  man->CreateNtupleDColumn("Egap");
  man->FinishNtuple(); 

  man->CreateNtuple("name2", "title2");
  man->CreateNtupleIColumn("ID");
  man->FinishNtuple(); 
}

```

Fill Ntuples

File handling and general clean-up as shown for histograms

```
void MyEventAction::EndOfEventAction(const G4Run* aRun)
{
    G4AnalysisManager* man = G4AnalysisManager::Instance();
    man->FillNtupleDColumn(1, 0, fEnergyAbs);
    man->FillNtupleDColumn(1, 1, fEnergyGap);
    man->AddNtupleRow(1);

    man->FillNtupleIColumn(2, 0, fID);
    man->AddNtupleRow(2);
}
```

ID=1,
columns 0, 1

ID=2,
column 0

Conclusion

Concepts of run, event, step, track, particle

User action classes

Data output – g4tools

Task4

- Task 4a User actions
- Task 4b Command-based scoring
- Task 4c Geant4 native scoring (multi-functional detectors)



Exercise 4a.1: Kill a particle
Exercise 4a.2: Calculate total track length



Exercise 4b.2: Create a scoring mesh
Exercise 4b.1: Enable the scoring manager
Exercise 4b.3: Visualize the mesh
Exercise 4b.4: Dump results