Interaction with kernel - part 1

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(A lot of material by L. Pandola)

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… User classes (cont'd)

At initialization

G4VUserDetectorConstruction

G4VUserPhysicsList

G4VUserActionInitialization

Global: only one instance exists in memory, shared by all threads.

At execution

G4VUserPrimaryGeneratorAction

G4UserRunAction*

G4UserEventAction

G4UserStackingAction

G4UserTrackingAction

G4UserSteppingAction

Local: an instance of each action class exists for each thread.

(*) Two RunAction's allowed: one for master and one for threads

Outlook

- Run, Event, Track, ...
  - a word about multi-threading
- Optional user action classes
- Command-based scoring
- Analysis tools *(detached slides)*

Part I: The main ingredients

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)
  - Worker/master thread (for MT)

Run, Event and Tracks

The Event (G4Event)

- An Event is the basic unit of simulation in Geant4
- At the beginning of processing, primary tracks are generated and they are pushed into a stack
- A track is 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)
- **`G4EventManager`** class manages the event
- **`G4UserEventAction`** is the optional User hook

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
- At the beginning of a Run, geometry is optimised for navigation and cross section tables are (re)calculated
- The **`G4(MT)RunManager`** class manages the processing of each Run, represented by:
  - **G4Run** class
  - **G4UserRunAction** for an optional User hook

The Track (G4Track)

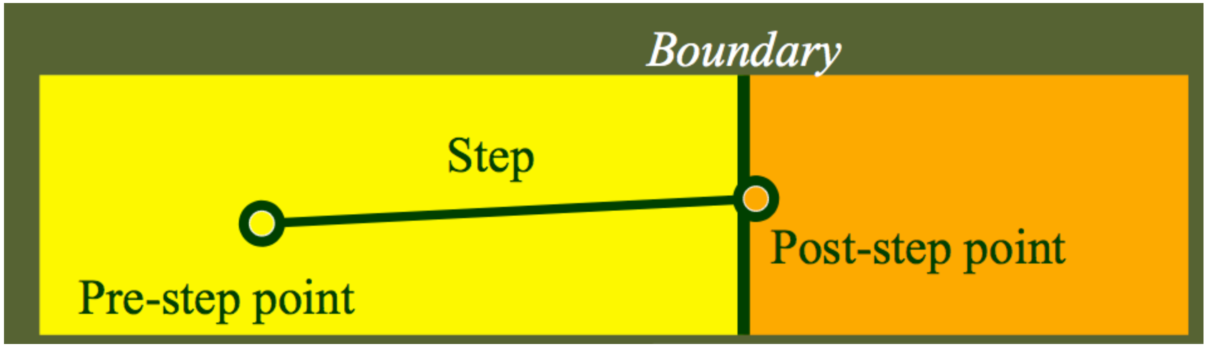
- The Track is a **snapshot of a particle** and it is represented by the **`G4Track`** class
  - It keeps ‘current’ information of the particle (i.e. energy, momentum, position, polarization, ..)
  - It is updated after every step
- The track object is **deleted** when
  - It goes outside the world volume
  - 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

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 (*see later*)
  - **`UserSteppingAction()`** of your step action class file (*see 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



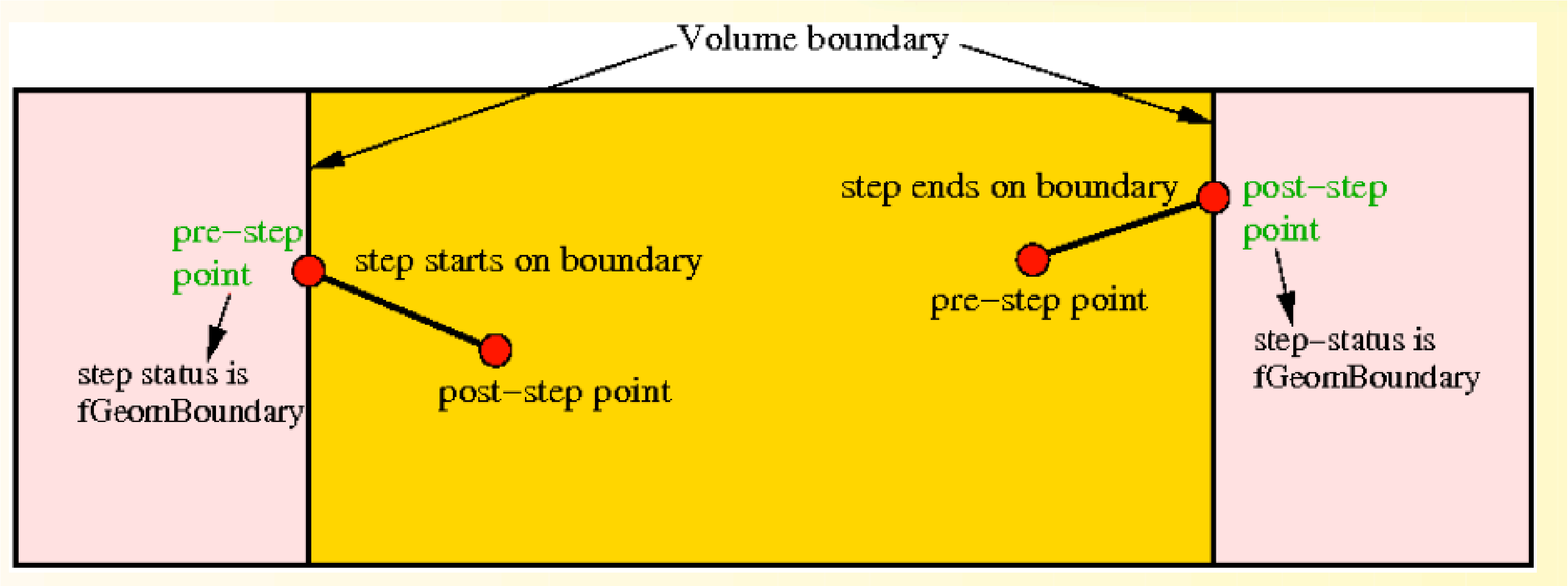
- **`G4UserSteppingAction`** is the optional User hook

The 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 information or object istances
  - **`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



Example: parent track and process

```
if (track->GetTrackID() != 1)
{
    G4cout << "Particle is a secondary" << G4endl;

    if (track->GetParentID() == 1)
    {
        G4cout << "But parent was a primary" << G4endl;
    }

    // Get process information
    G4VProcess* creatorProcess = track->GetCreatorProcess();
    G4String processName = creatorProcess->GetProcessName();
    G4cout << "Particle was created by " << processName << G4endl;
    }
}
```

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();
```

Example: particle info

```
// Retrieve from the current step the track (after PostStepDoIt of
// step is completed):
G4Track* track = step -> GetTrack();

// From the track you can obtain the pointer to the dynamic particle:
const G4DynamicParticle* dynParticle = track -> GetDynamicParticle();

// From the dynamic particle, retrieve the particle definition:
G4ParticleDefinition* particle = dynParticle -> GetDefinition();

// The dynamic particle class contains e.g. the kinetic energy after the step:
G4double kinEnergy = dynParticle -> GetKineticEnergy();

// From the particle definition class you can retrieve static
// information like the particle name:
G4String particleName = particle -> GetParticleName();

G4cout << particleName << ": kinetic energy of "
    << (kinEnergy / MeV) << " MeV" << G4endl;
```

Part II: Optional User Action classes

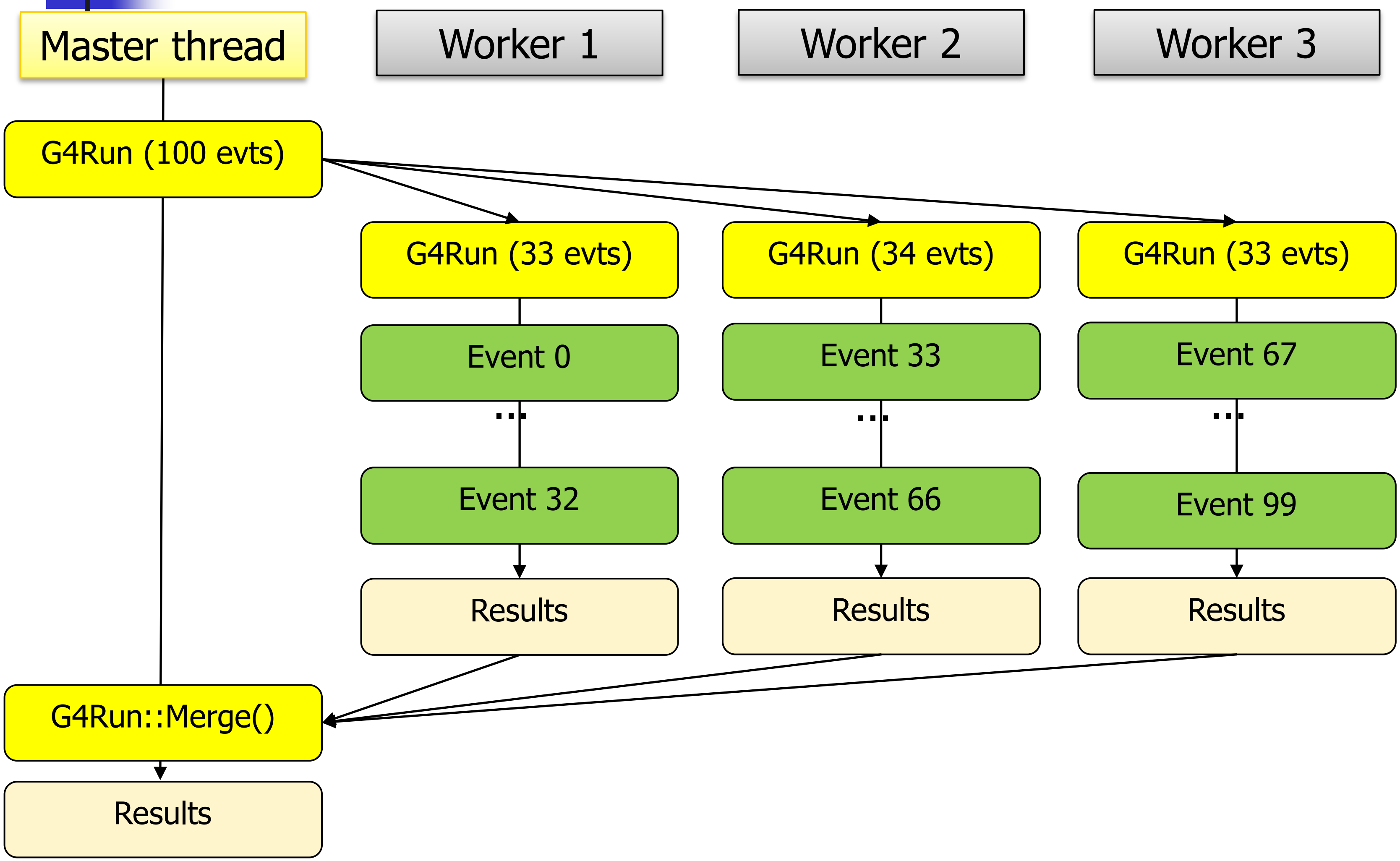
Optional user classes

- Five base classes with virtual methods the user may override to step during the execution of the application ("user hooks")
  - G4User**Run**Action
  - G4User**Event**Action
  - G4User**Tracking**Action
  - G4User**Stacking**Action
  - G4User**Stepping**Action

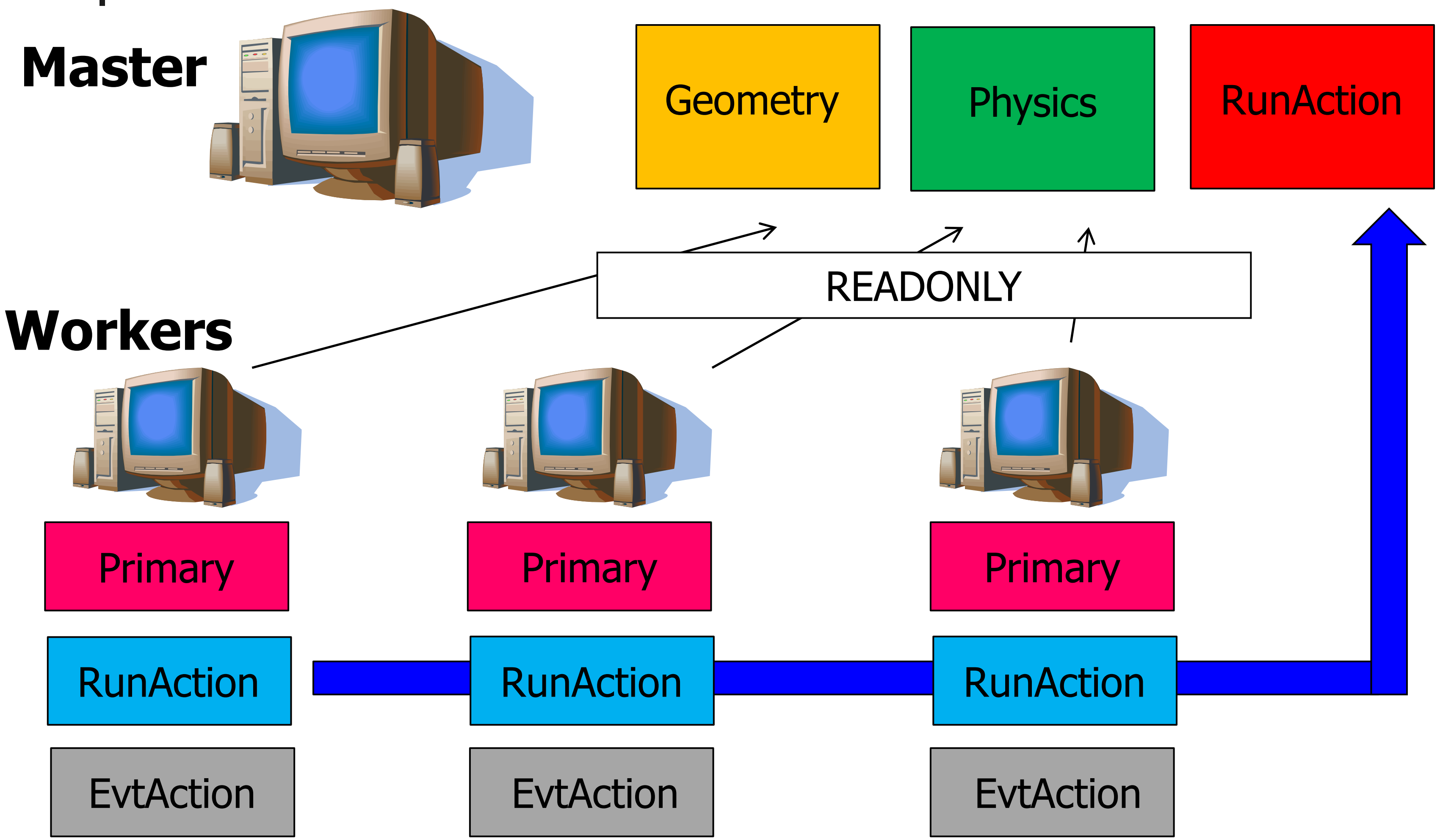
e.g. actions to be done at the beginning and end of each event

- Default implementation (**not** purely virtual): **do nothing**
- Therefore, **override** only the methods you need.

Multi-threaded processing of events



User actions in MT mode



G4UserRunAction

```
void BeginOfRunAction(const G4Run*)
void EndOfRunAction(const G4Run*)
G4Run* GenerateRun()
```

Uses:

- Book/output histograms and other analysis tools
- Custom G4Run with additional information
- Define parameters

MT

G4UserEventAction

```
void BeginOfEventAction(const G4Event*)
void EndOfEventAction(const G4Event*)
```

Uses:

- Hit collection and event analysis
- Event selection
- Logging (e.g. output event number)

G4UserStackingAction

```
G4ClassificationOfNewTrack
      ClassifyNewTrack(const G4Track*)
void NewStage()
void PrepareNewEvent()
```

Uses:

- Pre-selection of tracks (~manual cuts)
- Optimization of the order of track execution

G4UserTrackingAction

```
void PreUserTrackingAction(const
    G4Track*)
void PostUserTrackingAction(const
    G4Track*)
```

Uses:

- Track pre-selection
- Store trajectories

G4UserSteppingAction

```
void UserSteppingAction(const G4Step*)
```

Uses:

- Get information about particles
- Kill tracks under specific circumstances

Registration of user actions

- In multi-threading mode (and sequential), objects of user action classes must be **registered** to the `G4(MT)RunManager` via a user-defined action initialization class

```
runManager->SetUserInitialization(
      new MyActionInitialization);
```

- In sequential mode, the actions can *also* be registered to the run manager directly (not recommended)

```
runManager->SetUserAction(new MyRunAction);
```

MyActionInitialization

- Register thread-local user actions

```
void MyActionInitialization::Build() const
{
  //Set mandatory classes
  SetUserAction(new MyPrimaryGeneratorAction());
  // Set optional user action classes
  SetUserAction(new MyEventAction());
  SetUserAction(new MyRunAction());
}
```

Also the primary generator

- Register RunAction for the master (optional)

MT

```
void MyActionInitialization::BuildForMaster() const
{
  // Set optional user action classes
SetUserAction(new MyMasterRunAction());
}
```

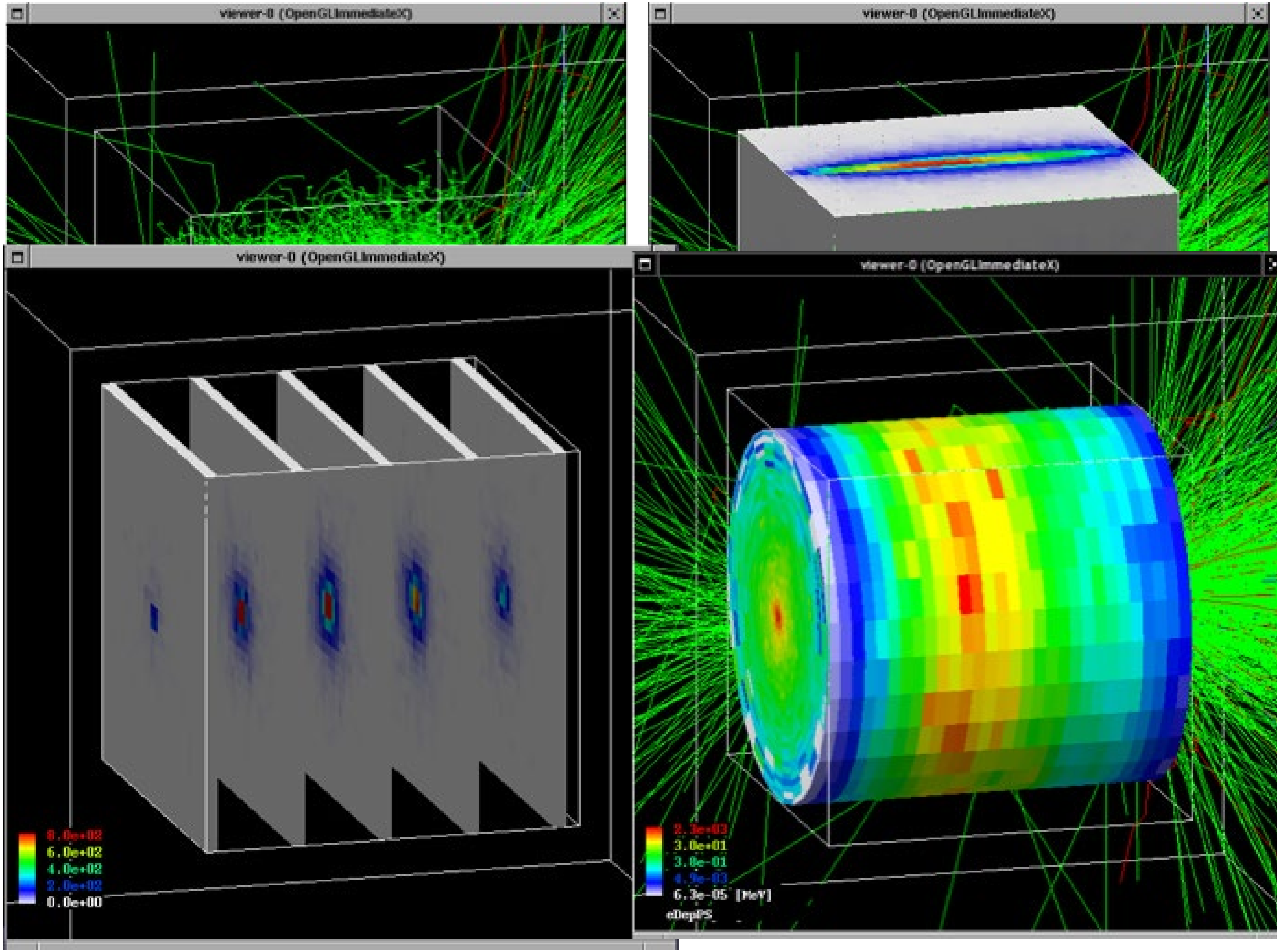
Part III: Command-based scoring

Command-based scoring

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

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

- 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

G4analysis tools

(detached session)

Geant4 analysis classes

- A basic analysis interface is available in Geant4 for histograms (1D and 2D) and ntuples
  - Make life easier because they are thread-safe
    - ROOT is not! Manual text output usually not!
    - No need to worry about the interference of threads
- Unique interface to support different output formats
  - ROOT, AIDA XML, CSV and HBOOK
  - Code is the same, just change one line to switch from one to an other
- Everything done via **`G4AnalysisManager`**
  - Singleton class → use Instance()
  - **UI commands** available

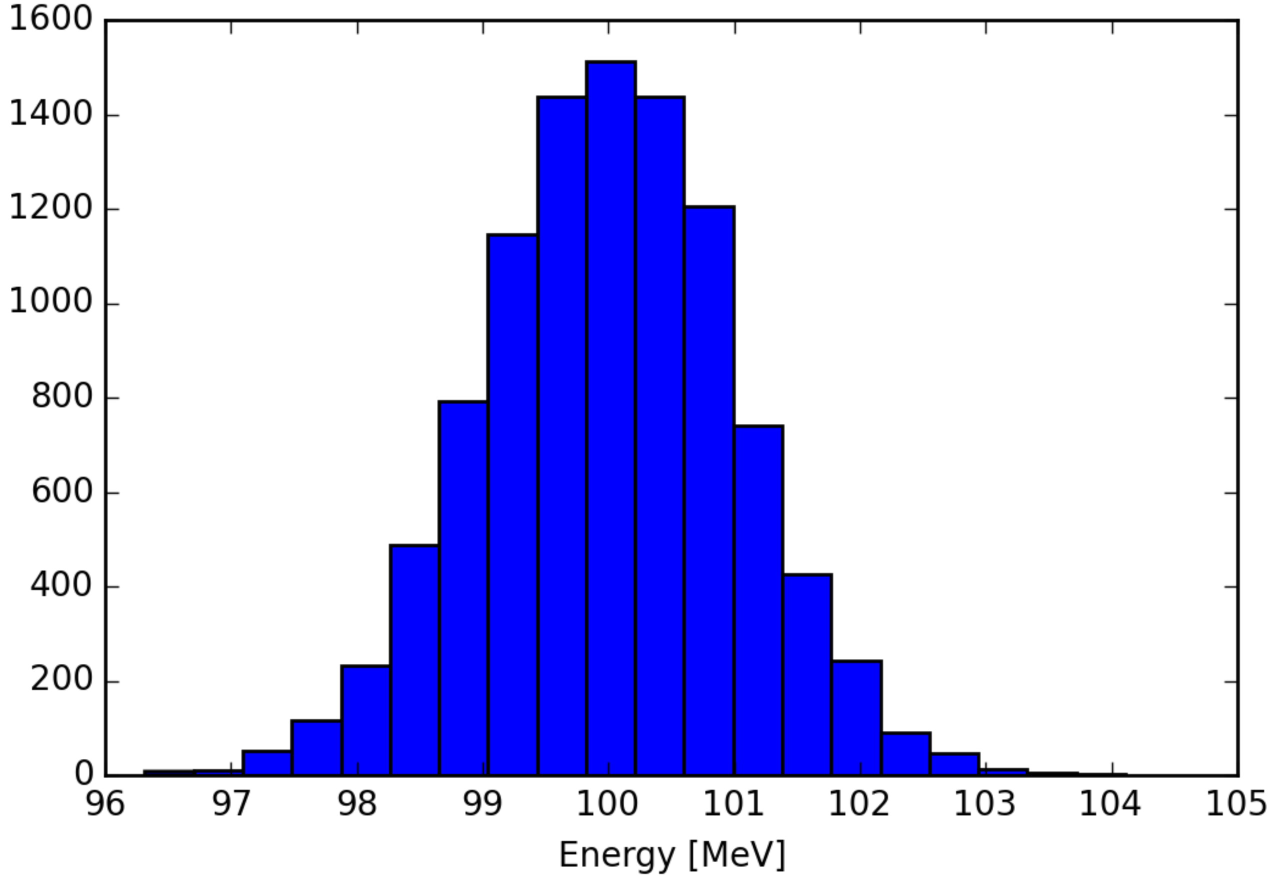
g4analysis

- Selection of output format is performed by including a proper header file
- **All** the rest of the code **unchanged**
  - Unique interface

```
#ifndef MyAnalysis_h
#define MyAnalysis_h 1
#include <G4RootAnalysisManager.hh>
#include <G4CsvAnalysisManager.hh>

// Use ROOT as output format for Geant4 analysis tools
using G4AnalysisManager = G4RootAnalysisManager;
// using G4AnalysisManager = G4CsvAnalysisManager;
#endif
```

Histograms


1600
1400
1200
1000
800
600
400
200
0
96
97
98
99
100
101
102
103
104
105
Energy [MeV]

Open file and book histograms

```
#include "MyAnalysis.hh"

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);
  man->CreateH1("hh","Title",100,0.,10);

 // Open an output file
  man->OpenFile("myoutput");
}
```

Start numbering of histograms from ID=1

ID=1

ID=2

Open output file

Fill histograms and write on file

```
#include "MyAnalysis.hh"
void MyEventAction::EndOfEventAction(const G4Run* aRun)
{
  auto man = G4AnalysisManager::Instance();
  man->FillH1(1, fEnergyAbs/MeV);   } ID=1
  man->FillH1(2, fEnergyGap/MeV);     ID=2
}

void MyRunAction::EndOfRunAction(const G4Run* aRun)
{
  G4AnalysisManager::Instance()->Write();
}

int main()
{
  ...
  G4AnalysisManager::Instance()->CloseFile();
}
```

Ntuples

EventID	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

- g4tool supports ntuples
  - Any number of ntuples
  - Any number of columns per ntuple
  - Supported types are **int/float/double**
- For more complex tasks (e.g. full functionality of ROOT TTrees) have to link ROOT directly
  - And take care of thread-safety

Book ntuples

```
#include "MyAnalysis.hh"
void MyRunAction::BeginOfRunAction(const G4Run* run)
{
  // Get analysis manager
  auto man = G4AnalysisManager::Instance();
  man-> SetFirstNtupleId(1);

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

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

Start numbering of ntuples from ID=1

ID=1

ID=2

Fill ntuples

- File handling and general clean-up as shown for histograms

```
#include "MyAnalysis.hh"
void MyEventAction::EndOfEventAction(const G4Run* aRun)
{
  auto 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

More slides…

Output stream (`G4cout`)

- `G4cout` is a `iostream` object defined by Geant4.
  - Used in the same way as standard `std::cout`
  - Output streams handled by `G4UImanager`
  - `G4endl` is the equivalent of `std::endl` to end a line
- MT-handling: will display also the threadID

```
WT1> I am here
WT5> I am here
```

- Output strings may be displayed in another window (Qt GUI) or redirected to a file

Example: output on screen

```
void SteppingAction::UserSteppingAction(const G4Step* aStep)
{
    // Collect data
    G4Track* theTrack = aStep->GetTrack();
    G4DynamicParticle* particle = theTrack->GetDynamicParticle();
    G4ParticleDefinition* parDef = particle->GetDefinition();

    G4double edep = aStep->GetTotalEnergyDeposit();
    G4double particleCharge = particle->GetCharge();
    G4double kineticEnergy = theTrack->GetKineticEnergy();

    // The output
    G4cout
      << "Energy deposited--->" <<  " " <<  edep << "
      << "Charge--->" <<  " " << particleCharge << " "
      << "Kinetic Energy --->" << "  " << kineticEnergy << " " <<
G4endl;
}
```

Output on screen: an example

```
Begin of Event: 0

Energy deposited---> 9.85941e-22 Charge---> 6 Kinetic energy---> 160
Energy deposited---> 8.36876     Charge---> 6 Kinetic energy---> 151.631
Energy deposited---> 8.63368     Charge---> 6 Kinetic energy---> 142.998
Energy deposited---> 5.98509     Charge---> 6 Kinetic energy---> 137.012
Energy deposited---> 4.73055     Charge---> 6 Kinetic energy---> 132.282
Energy deposited---> 0.0225575   Charge---> 6 Kinetic energy---> 132.254
Energy deposited---> 1.47468     Charge---> 6 Kinetic energy---> 130.785
Energy deposited---> 0.0218983   Charge---> 6 Kinetic energy---> 130.76
Energy deposited---> 5.22223     Charge---> 6 Kinetic energy---> 125.541
Energy deposited---> 7.10685     Charge---> 6 Kinetic energy---> 118.434
Energy deposited---> 6.62999     Charge---> 6 Kinetic energy---> 111.804
Energy deposited---> 6.50997     Charge---> 6 Kinetic energy---> 105.294
Energy deposited---> 6.28403     Charge---> 6 Kinetic energy---> 99.0097
Energy deposited---> 5.77231     Charge---> 6 Kinetic energy---> 93.2374
Energy deposited---> 5.2333      Charge---> 6 Kinetic energy---> 88.0041
Energy deposited---> 3.9153      Charge---> 6 Kinetic energy---> 84.0888
Energy deposited---> 14.3767     Charge---> 6 Kinetic energy---> 69.7121
Energy deposited---> 14.3352     Charge---> 6 Kinetic energy---> 55.3769
```

Example: output to an ASCII file

MT

```
#include <fstream>

class SteppingAction{
    // ...
    std::ofstream fout;
};

SteppingAction::SteppingAction() : fout("outfile.txt") { }

void SteppingAction::UserSteppingAction(const G4Step* aStep)
{
    G4Track* theTrack = aStep->GetTrack();
    G4double edep = aStep->GetTotalEnergyDeposit();
    G4double kineticEnergy = theTrack->GetKineticEnergy();

    // The output
    fout
      << "Energy deposited--->" <<  " " <<  edep << " "
      << "Kinetic Energy -->" << "  " << kineticEnergy << G4endl;
}
```

Hands-on session

- Task4
  - Task4a: User Actions
  - Task4b: Command-based scoring

- **`http://geant4.lns.infn.it/alghero2023/task4`**