Interaction with the Geant4 kernel – part 1

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… User classes (cont'ed)

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 **`G4RunManager`** 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)

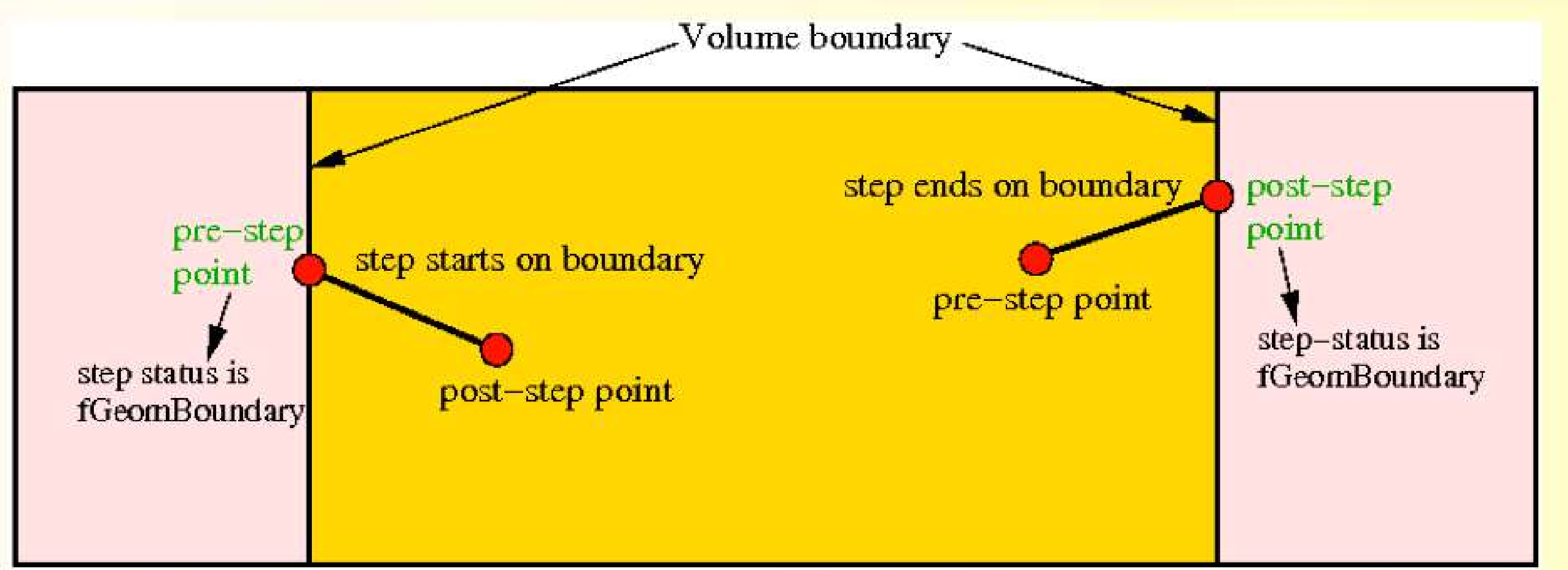
- `G4Step` represents a step in the particle propagation, i.e. the "flight" of the particle between two subsequent interactions
- A G4Step object stores transient information of the step
  - Has the information about the **two points** (pre-step and post-step) and the **'delta'** information of a particle (energy loss on the step, ...)
  - It is updated each time a process is invoked
- A step **can never cross a boundary**
  - Steps can be limited by geometry
- You can extract information from a step after the step is completed, in the **`UserSteppingAction()`** of your step action class file
  - User class derived by **`G4UserSteppingAction`**

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(), ...**

Step concept and boundaries

- In case a step is limited by a volume boundary, the end point physically stands on the boundary and it belongs to the next volume [this is a convention]
- 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** → **`fGeometryBoundary`** when the step ends on a volume boundary (does not apply to world volume)



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: step "deltas"

```
UserSteppingAction::UserSteppingAction(const G4Step* step) {
  // Total energy deposition on the step (= energy deposited by energy loss
  // process and energy of secondaries that were not created since their
  // process and energy of secondaries that were not created since their
  // energy was < Cut):
  G4double energyDeposit = step -> GetTotalEnergyDeposit();

  // Difference of energy, position and momentum of particle between pre-
  // and post-step point
  G4double deltaEnergy = step -> GetDeltaEnergy();
  G4ThreeVector deltaPosition = step -> GetDeltaPosition();
  G4double deltaMomentum = step -> GetDeltaMomentum();

  // Step length
  G4double stepLength = step -> GetStepLength();
}
```

Example: particle info

```
// Retrieve from the current step the track (after PostStepDolt 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

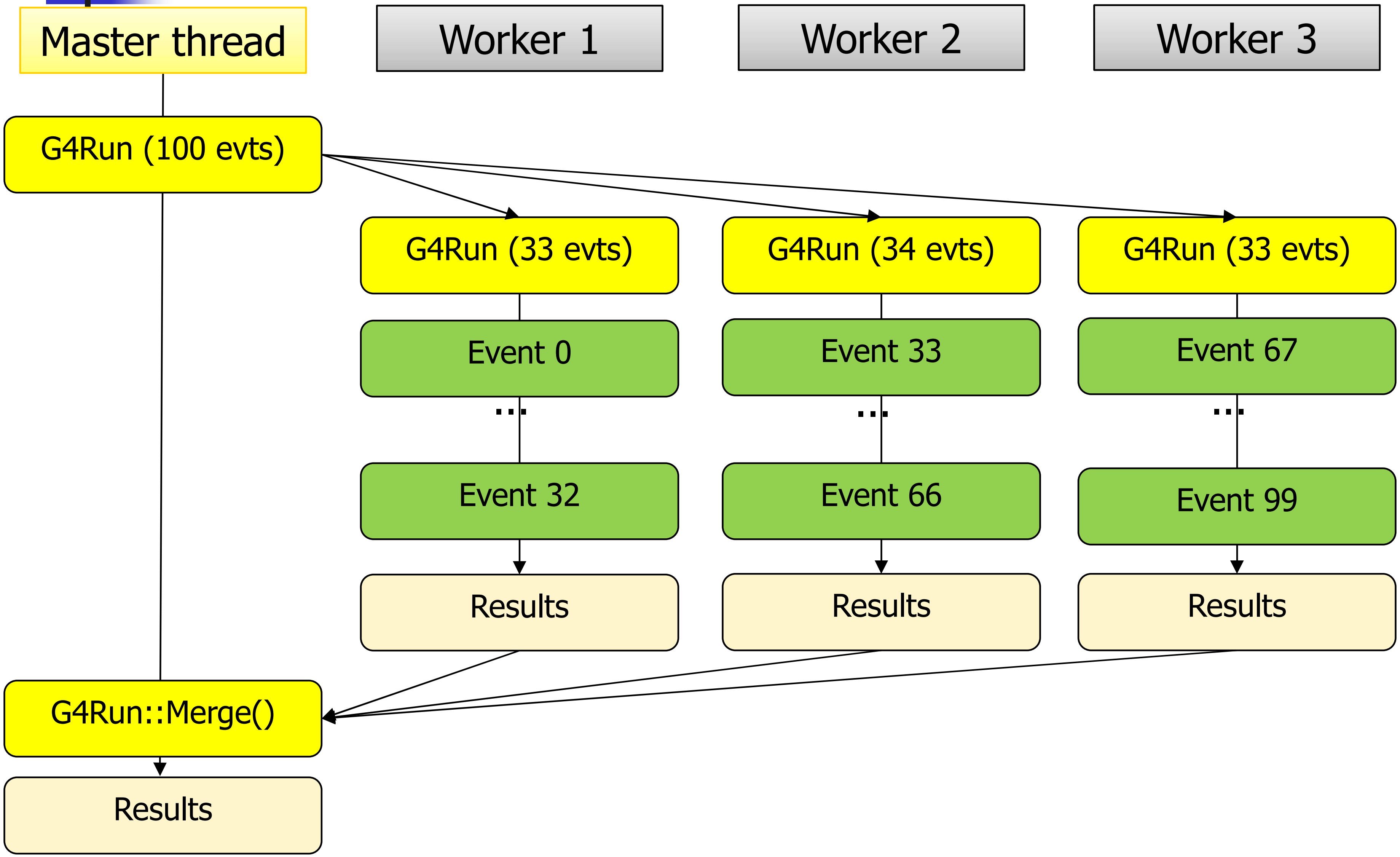
Optional user classes

- 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

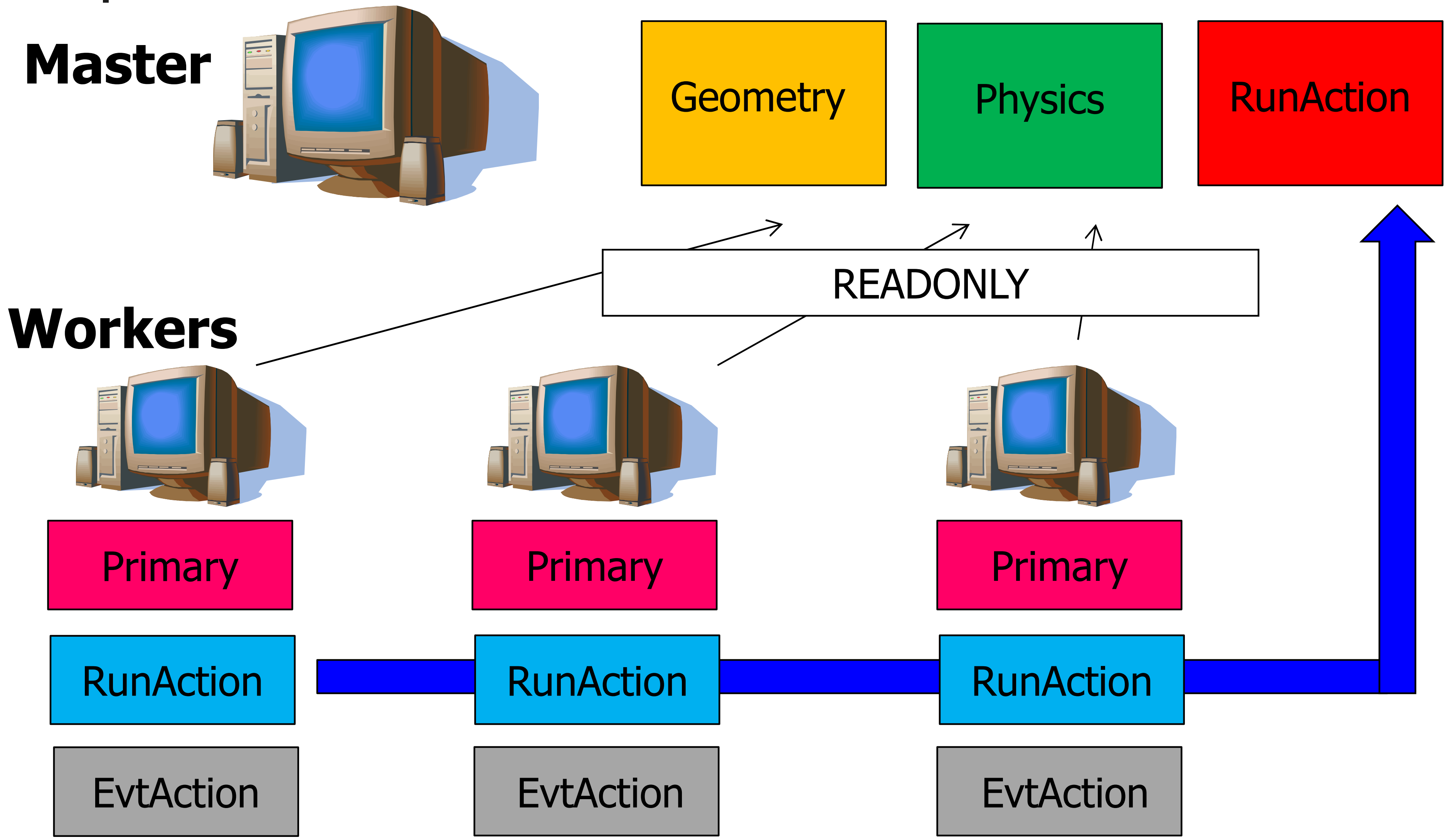
e.g. actions to be done at the beginning and end of each event

- 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

- The instances of the user action classes (all of them, some of them, …) must be **registered** to the **`G4RunManager`** via a user-defined action initialization class

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

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());
}
```

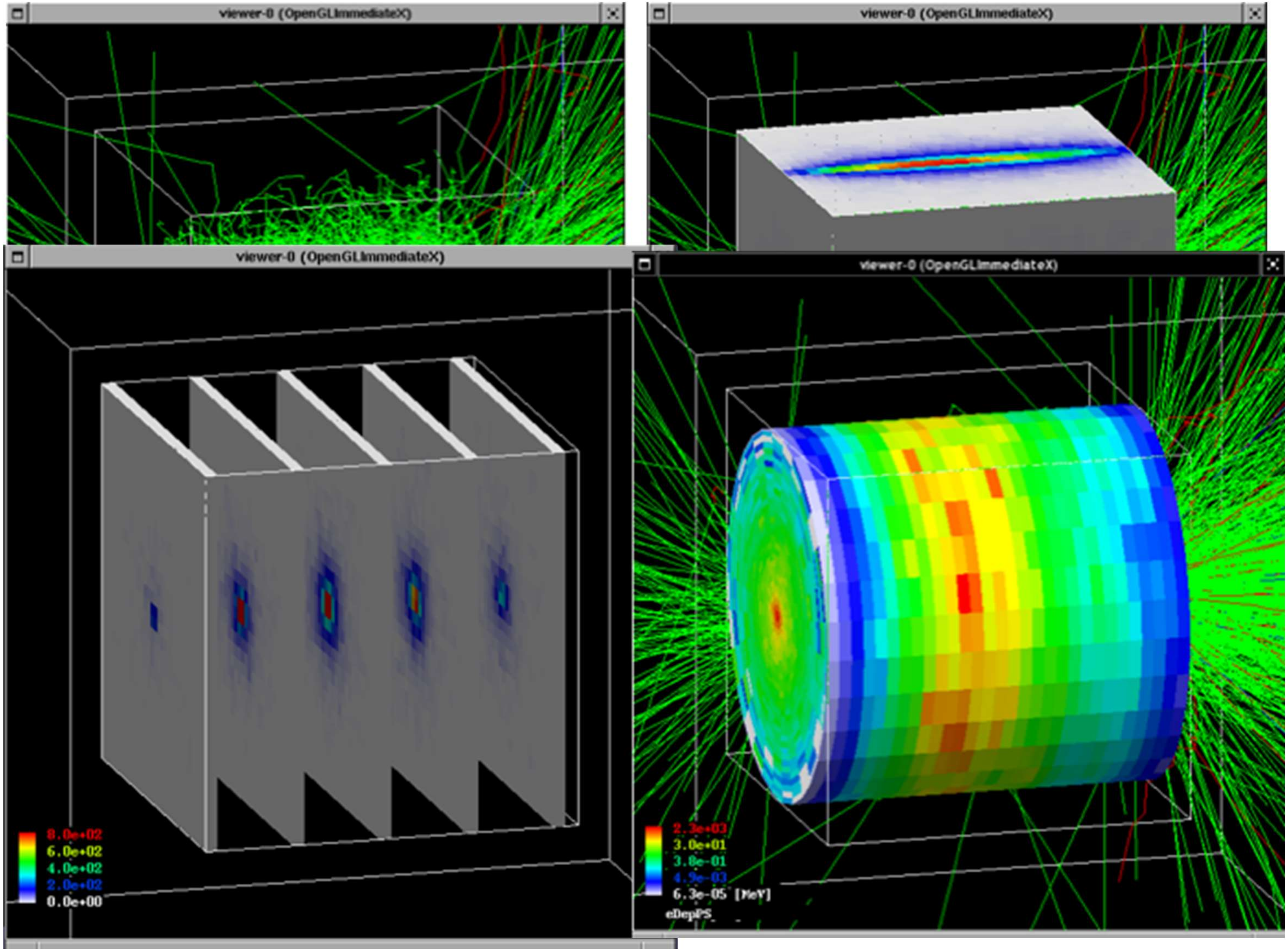
Part III: Command-based scoring

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)
8.0e+02
6.0e+02
4.0e+02
2.0e+02
0.0e+00
viewer-0 (OpenGLImmediateX)
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

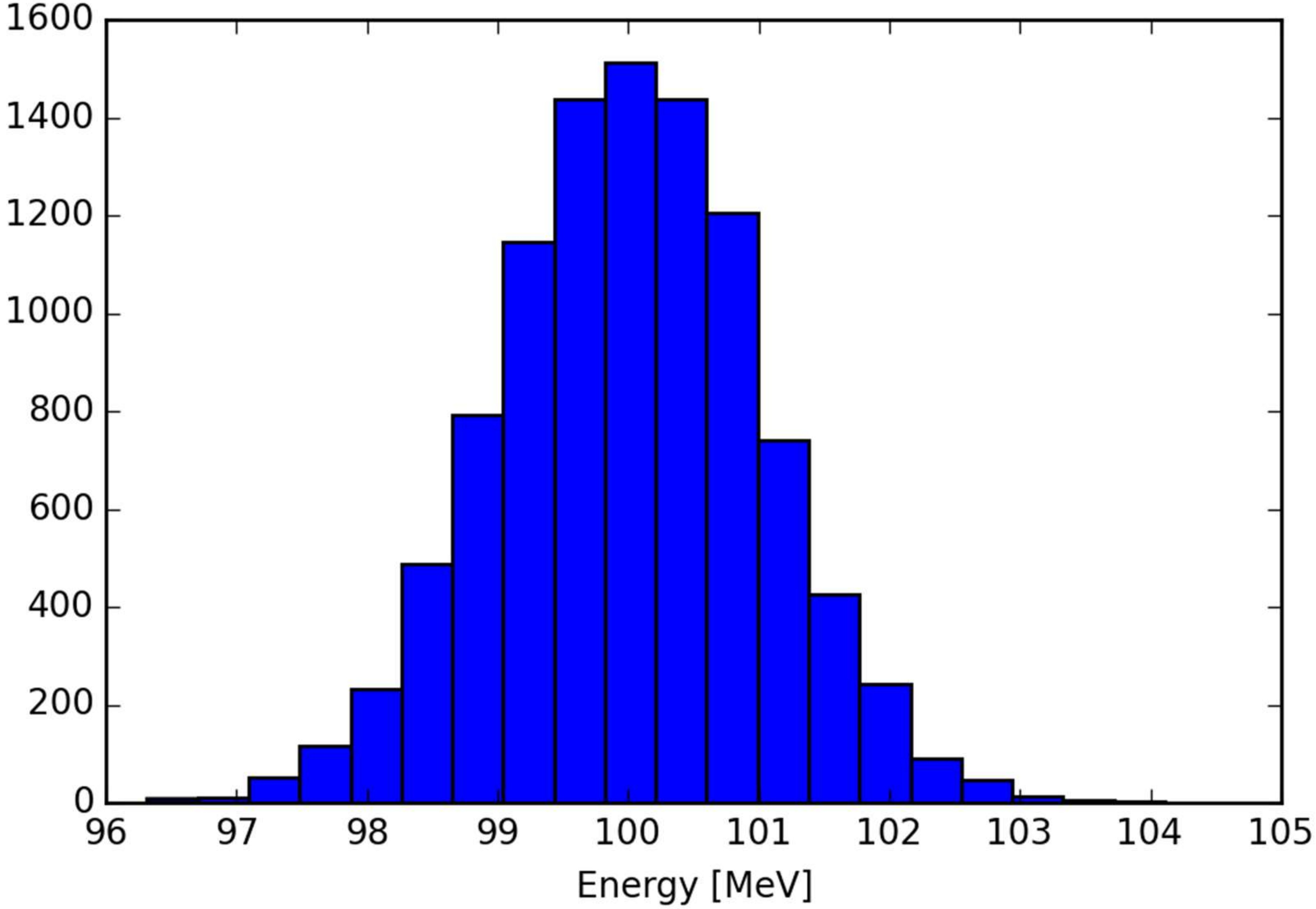
```
#ifndef ANALYSIS_HH
#define ANALYSIS_HH

// Use ROOT as output format for all 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);
  man->FillH1(2, fEnergyGap/MeV);
}
```

ID=1
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

G4Accumulable<T>

- Templated class to **collect** simple information
  - Thread-safe
  - Accumulable during Run
  - Value merge at the end (explicit)
  - Scalar variables only (otherwise, expert)
- Alternative to ntuples/histograms
- Managed by `G4AccumulableManager`

► G4Accumulable.hh

G4Accumulable – C++ (1)

1) Declare (instance) variables (of RunAction)

```
G4Accumulable<G4int>    fNElectrons;
G4Accumulable<G4double> fAverageElectronEnergy;
```

2) Register to accumulable manager (in RunAction constructor)

```
G4AccumulableManager* accManager = G4AccumulableManager::Instance();
accManager->RegisterAccumulable(fNElectrons);
accManager->RegisterAccumulable(fAverageElectronEnergy);
```

3) Reset to zero values (in **RunAction::BeginOfRunAction**)

```
G4AccumulableManager* accManager = G4AccumulableManager::Instance();
accManager->Reset();
```

4) Update during run (e.g. in Stacking action)

```
fNElectrons += 1;      // Normal arithmetics
```

G4Accumulable – C++ (2)

MT

5) Merge after run (in **RunAction::EndOfRunAction**)

```
G4AccumulableManager* accManager = G4AccumulableManager::Instance();
accManager->Merge();
```

6) Report after run (in **RunAction::EndOfRunAction**)

```
G4AccumulableManager* accManager = G4AccumulableManager::Instance();
if (IsMaster())
{
    if (fNElectrons.GetValue())
    {
        G4cout << " * Produced " << fNElectrons.GetValue();
        G4cout << " secondary electrons/event. Average energy: ";
        G4cout << fAverageElectronEnergy.GetValue()/keV/fNElectrons.GetValue();
        G4cout << " keV" << G4endl;
    }
    else
        G4cout << " * No secondary electrons produced" << G4endl;
}
```

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


```
#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/vienna2024/task4`**

G4TrackStatus

- 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)

MT

User-defined run class

```
class MyRun : public G4Run
{ ... };
```

Virtual methods

- RecordEvent()
  - called at the end of each event
  - **alternative to EndOfEventAction()** of the EventAction class
- Merge()
  - Called at the end of each worker run by the **master**

When/why to use it?

- Convenient in **MT-mode**, because it allows the **merging** of information (global quantities) from **thread-local runs** into the master
  - UserEventAction is thread-local

Multiple user actions

- G4MultiRunAction
- G4MultiEventAction
- G4MultiTrackingAction
- G4MultiSteppingAction
- no G4MultiStackingAction

```
auto multiAction = new G4MultiEventAction{ new MyEventAction1,
        new MyEventAction2 };
//...
multiAction->push_back(new MyEventAction3);
SetUserAction(multiAction);
```

Containers enabling to have **multiple user actions** of the same "kind", implemented as customized std::vector's.

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