Geant 4

User Application

http://cern.ch/geant4

Toolkit + User application

- Geant4 is a **toolkit**
  - i.e. you cannot "run" it out of the box
  - You must write an application, which uses Geant4 tools
- Consequences
  - There are no such concepts as "Geant4 defaults"
  - You must provide the necessary information to configure your simulation
  - You must deliberately choose which Geant4 tools to use
- Guidance: we provide many **examples**
  - **Novice Examples**: overview of Geant4 tools
  - **Advanced Examples**: Geant4 tools

Basic concepts

- What you **MUST** do:
  - Describe your **experimental set-up**
  - Provide the **primary particles** input to your simulation
  - Decide which **particles** and **physics models** you want to use out of those available in Geant4 and the precision of your simulation (cuts to produce and track secondary particles)

- You may also want
  - To interact with Geant4 kernel to **control** your simulation
  - To **visualise** your simulation configuration or results
  - To produce **histograms, tuples** etc. to be further analysed

Interaction with Geant4 kernel

- Geant4 design provides **tools** for a user application
  - To tell the kernel about your simulation configuration
  - To interact with Geant4 kernel itself

- Geant4 tools for user interaction are **base classes**
  - You create **your own concrete class** derived from the base classes
  - Geant4 kernel handles your own derived classes transparently through their base class interface (polymorphism)

- **Abstract base classes** for user interaction
  - User derived concrete classes are **mandatory**

- **Concrete base classes** (with virtual dummy methods) for user interaction
  - User derived classes are **optional**

User classes

Initialisation classes

- *G4VUserDetectorConstruction*
- *G4VUserPhysicsList*

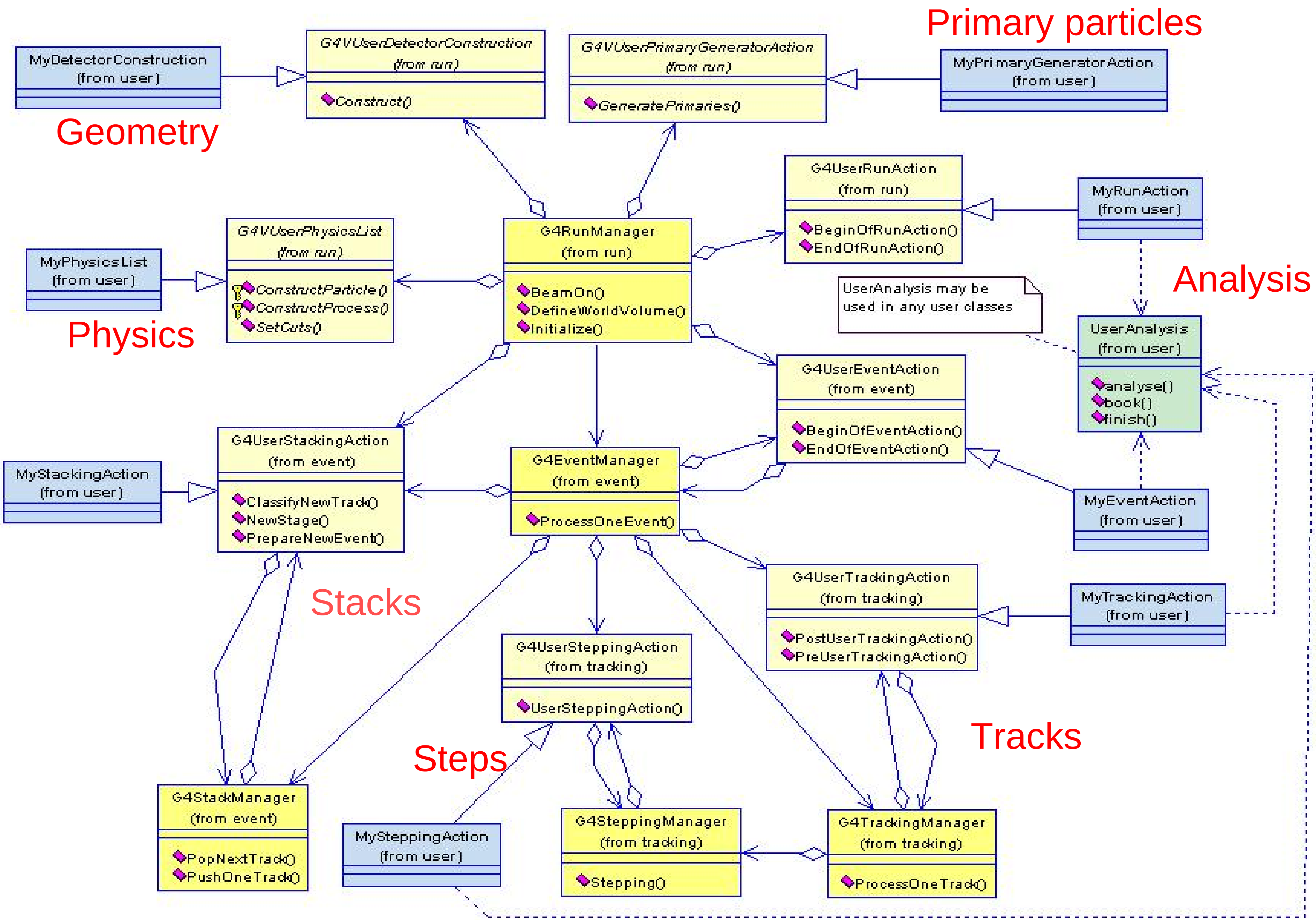
Action classes

- *G4VUserPrimaryGeneratorAction*
- G4UserRunAction
- G4UserEventAction
- G4UserTrackingAction
- G4UserStackingAction
- G4UserSteppingAction

Mandatory classes:

- *G4VUserDetectorConstruction*
  describe the experimental set-up
- *G4VUserPhysicsList*
  select the physics you want to activate
- *G4VUserPrimaryGeneratorAction*
  generate primary events

Overview of Geant4 advanced examples



The main program

- Geant4 does not provide the **main()**
  - Geant4 is a toolkit!
  - The main() is part of the user application

- In his/her main(), the user **must**
  - construct **G4RunManager** (or his/her own derived class)
  - notify the G4RunManager mandatory user classes derived from
    - ***G4VUserDetectorConstruction***
    - ***G4VUserPhysicsList***
    - ***G4VUserPrimaryGeneratorAction***

- The user may define in his/her main()
  - optional user action classes
  - VisManager, (G)UI session

main()

```
{
  …
  // Construct the default run manager
  G4RunManager* runManager = new G4RunManager;

  // Set mandatory user initialization classes
  MyDetectorConstruction* detector = new MyDetectorConstruction;
  runManager->SetUserInitialization(detector);
  runManager->SetUserInitialization(new MyPhysicsList);

  // Set mandatory user action classes
  runManager->SetUserAction(new MyPrimaryGeneratorAction);

  // Set optional user action classes
  MyEventAction* eventAction = new MyEventAction();
  runManager->SetUserAction(eventAction);
  MyRunAction* runAction = new MyRunAction();
  runManager->SetUserAction(runAction);
  …
}
```

Describe the experimental set-up

- Derive your own concrete class from the ***G4VUserDetectorConstruction*** abstract base class

- Implement the **Construct()** method
  - construct all necessary **materials**
  - define **shapes/solids** required to describe the geometry
  - **construct** and **place volumes** of your detector geometry
  - define **sensitive detectors** and identify detector volumes to associate them to
  - associate **magnetic field** to detector regions
  - define **visualisation** attributes for the detector elements

How to define materials

Different kinds of materials can be defined:
- Isotopes
- Elements
- Molecules
- Compounds and mixtures

```
PVPhysicalVolume*  MyDetectorConstruction::Construct()
  {
    …
    a = 207.19*g/mole;
    density = 11.35*g/cm3;
    G4Material* lead = new G4Material(name="Pb", z=82., a, density);

    density = 5.458*mg/cm3;
    pressure = 1*atmosphere;
    temperature = 293.15*kelvin;
    G4Material* xenon = new G4Material(name="XenonGas", z=54.,
                                   a=131.29*g/mole, density,
                                   kStateGas, temperature, pressure);
    ...
  }
```

Lead (annotates the first block: a, density, G4Material* lead)

Xenon gas (annotates the second block: density, pressure, temperature, G4Material* xenon)

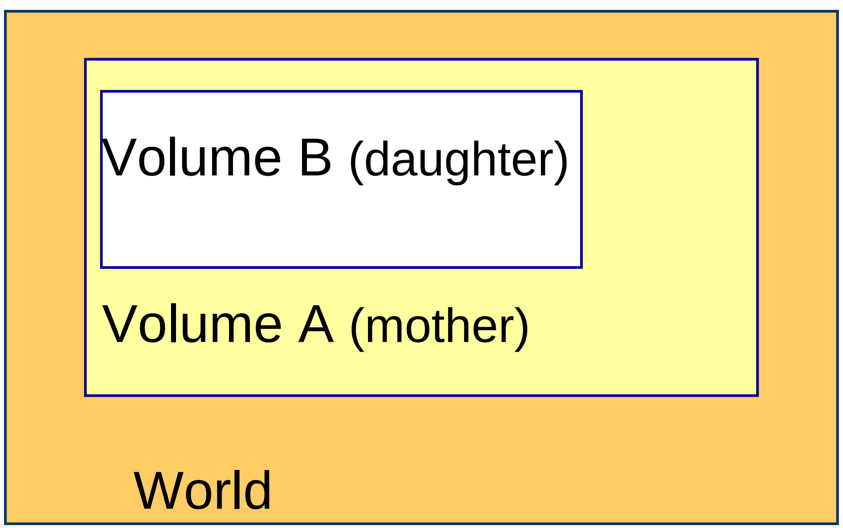
How to define a compound material

For example, a **scintillator** consisting of Hydrogen and Carbon:

```
G4double a = 1.01*g/mole;
G4Element* H  = new G4Element(name="Hydrogen", symbol="H", z=1., a);

a = 12.01*g/mole;
G4Element* C  = new G4Element(name="Carbon", symbol="C", z=6., a);

G4double density = 1.032*g/cm3;
G4Material* scintillator = new G4Material(name = "Scintillator", density,
numberOfComponents = 2);

scintillator -> AddElement(C, numberOfAtoms = 9);
scintillator -> AddElement(H, numberOfAtoms = 10);
```

Define detector geometry

- Three conceptual layers
  - G4VSolid — shape, size
  - G4LogicalVolume — material, sensitivity, magnetic field, etc.
  - G4VPhysicalVolume — position, rotation
- A unique physical volume (the world volume), which represents the experimental area, must exist and fully contain all other components



e.g.: Volume A is mother of Volume B

The mother must contain the daughter volume entirely

How to build the World

```
solidWorld = new G4Box(“World", halfWorldLength, halfWorldLength, halfWorldLength);
logicWorld = new G4LogicalVolume(solidWorld, air, "World", 0, 0, 0);
physicalWorld = new G4PVPlacement(0,                  //no rotation
                                  G4ThreeVector(),    // at (0,0,0)
                                  logicWorld,         // its logical volume
                                  "World",            // its name
                                  0,                  // its mother  volume
                                  false,              // no boolean operations
                                  0);                 // no magnetic field
```

How to build a volume inside the World

```
solidTarget = new G4Box(“Target", targetSize, targetSize, targetSize);
logicTarget = new G4LogicalVolume(solidTarget, targetMaterial, "Target",0,0,0);
physicalTarget = new G4PVPlacement(0,                 // no rotation
                                   positionTarget,    // at (x,y,z)
                                   logicTarget,       // its logical volume
                                   "Target",          // its name
                                   logicWorld,        // its mother  volume
                                   false,             // no boolean operations
                                   0);                // no particular field
```

Select physics processes

- Geant4 does not have any default particles or processes

- Derive your own concrete class from the ***G4VUserPhysicsList*** abstract base class
  – define all necessary particles
  – define all necessary processes and assign them to proper particles
  – define production thresholds (in terms of range)

- Pure virtual methods of G4VUserPhysicsList

ConstructParticles()
ConstructProcesses()
SetCuts()

→ to be implemented by the user in his/her concrete derived class

PhysicsList: particles and cuts

```
MyPhysicsList :: MyPhysicsList():  G4VUserPhysicsList()
{
   defaultCutValue = 1.0*cm;
}
```

Define **production thresholds** (the same for all particles)

```
void MyPhysicsList :: ConstructParticles()
{
   G4Electron::ElectronDefinition();
   G4Positron::PositronDefinition();
   G4Gamma::GammaDefinition();
}
```

Define the **particles** involved in the simulation

```
void MyPhysicsList :: SetCuts()
{
   SetCutsWithDefault();
}
```

Set the **production threshold**

PhysicsList: more about cuts

```
MyPhysicsList :: MyPhysicsList():  G4VUserPhysicsList()
{
    // Define production thresholds
    cutForGamma  = 1.0*cm;
    cutForElectron = 1.*mm;
    cutForPositron = 0.1*mm;
} ;
```

```
void MyPhysicsList :: SetCuts()
{
   // Assign production thresholds
   SetCutValue(cutForGamma, "gamma");
   SetCutValue(cutForElectron, "e-");
   SetCutValue(cutForPositron, "e+");
}
```

The user can define different cuts for different particles or different regions

Physics List: processes

Select physics processes to be activated for each particle type

```
void MyPhysicsList :: ConstructParticles()
 {
   if (particleName == "gamma")
     {
        pManager->AddDiscreteProcess(new G4PhotoElectricEffect());
        pManager->AddDiscreteProcess(new G4ComptonScattering());
        pManager->AddDiscreteProcess(new G4GammaConversion());
     }
   else if (particleName == "e-")
     {
        pManager->AddProcess(new G4MultipleScattering(), -1, 1,1);
        pManager->AddProcess(new G4eIonisation(), -1, 2,2);
        pManager->AddProcess(new G4eBremsstrahlung(), -1,-1,3);
     }
   else if (particleName == "e+")
     {
        pManager->AddProcess(new G4MultipleScattering(), -1, 1,1);
        pManager->AddProcess(new G4eIonisation(), -1, 2,2);
        pManager->AddProcess(new G4eBremsstrahlung(), -1,-1,3);
        pManager->AddProcess(new G4eplusAnnihilation(),  0,-1,4);
     }
}
```

The Geant4 *Standard* electromagnetic processes are selected in this example

Primary events

- Derive your own concrete class from the ***G4VUserPrimaryGeneratorAction*** abstract base class

- Define primary particles providing:
  - Particle type
  - Initial position
  - Initial direction
  - Initial energy

- Implement the virtual member function **GeneratePrimaries()**

Generate primary particles

```
MyPrimaryGeneratorAction:: My PrimaryGeneratorAction()
{
  G4int numberOfParticles = 1;
  particleGun = new G4ParticleGun (numberOfParticles);
  G4ParticleTable* particleTable = G4ParticleTable::GetParticleTable();
  G4ParticleDefinition* particle = particleTable->FindParticle(“e-“);
  particleGun->SetParticleDefinition(particle);
  particleGun->SetParticlePosition(G4ThreeVector(x,y,z));
  particleGun->SetParticleMomentumDirection(G4ThreeVector(x,y,z));
  particleGun->SetParticleEnergy(energy);
}

void MyPrimaryGeneratorAction::GeneratePrimaries(G4Event* anEvent)
{
  particleGun->GeneratePrimaryVertex(anEvent);
}
```

Optional User Action classes

- Five concrete base classes whose virtual member functions the user may override to gain control of the simulation at various stages
  - G4User**Run**Action
  - G4User**Event**Action
  - G4User**Tracking**Action
  - G4User**Stacking**Action
  - G4User**Stepping**Action

- Each member function of the base classes has a dummy implementation
  - Empty implementation: does nothing
- The user may implement the member functions he desires in his/her derived classes

- Objects of user action classes must be registered with G4RunManager

Optional User Action classes

G4UserRunAction

- BeginOfRunAction(const G4Run*)
  - For example: book histograms
- EndOfRunAction(const G4Run*)
  - For example: store histograms

G4UserEventAction

- BeginOfEventAction(const G4Event*)
  - For example: perform and event selection
- EndOfEventAction(const G4Event*)
  - For example: analyse the event

G4UserTrackingAction

- PreUserTrackingAction(const G4Track*)
  - For example: decide whether a trajectory should be stored or not
- PostUserTrackingAction(const G4Track*)

Optional User Action classes

G4UserSteppingAction

- UserSteppingAction(const G4Step*)
  - For example: kill, suspend, postpone the track
  - For example: draw the step

G4UserStackingAction

- PrepareNewEvent()
  - For example: reset priority control
- ClassifyNewTrack(const G4Track*)
  - Invoked every time a new track is pushed
  - For example: classify a new track (priority control)
    - Urgent, Waiting, PostponeToNextEvent, Kill
- NewStage()
  - Invoked when the Urgent stack becomes empty
  - For example: change the classification criteria
  - For example: event filtering (event abortion)

Select (G)UI and visualisation

- In your **main()**, taking into account your computer environment, instantiate a **G4UIsession** concrete class provided by Geant4 and invoke its **sessionStart()** method
- Geant4 provides:
  - G4UIterminal
  - csh or tcsh like character terminal
  - G4GAG
  - tcl/tk or Java PVM based GUI
  - G4Wo
  - Opacs
  - G4UIBatch
  - batch job with macro file
  - …

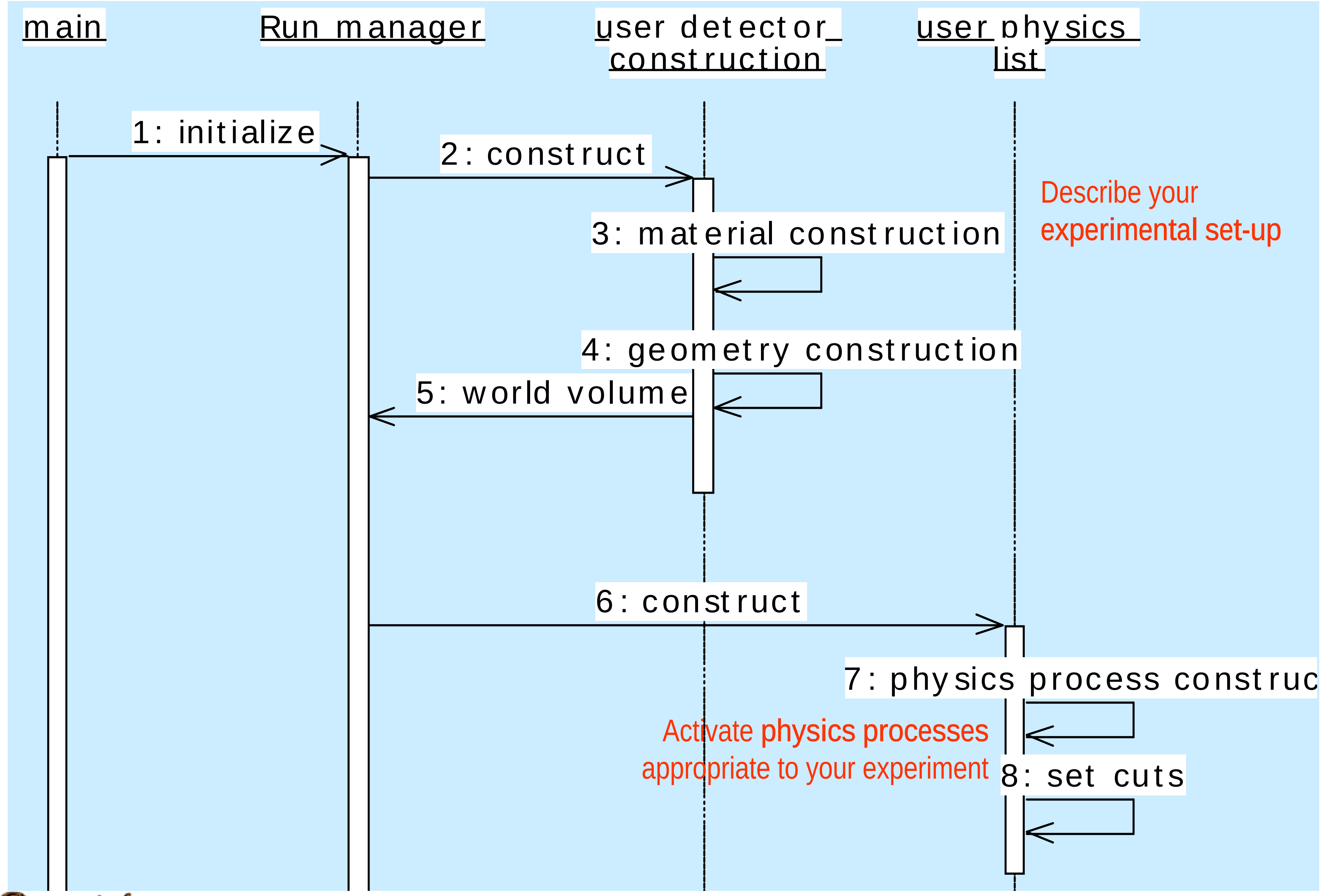
- In your **main()**, taking into account your computer environment, instantiate a **G4VisExecutive** and invoke its **initialize()** method
- Geant4 provides interfaces to various graphics drivers:
  - DAWN *(Fukui renderer)*
  - WIRED
  - RayTracer *(ray tracing by Geant4 tracking)*
  - OPACS
  - OpenGL
  - OpenInventor
  - VRML
  - …

Recipe for novice users

Experienced users may do much more, but the conceptual process is still the same…

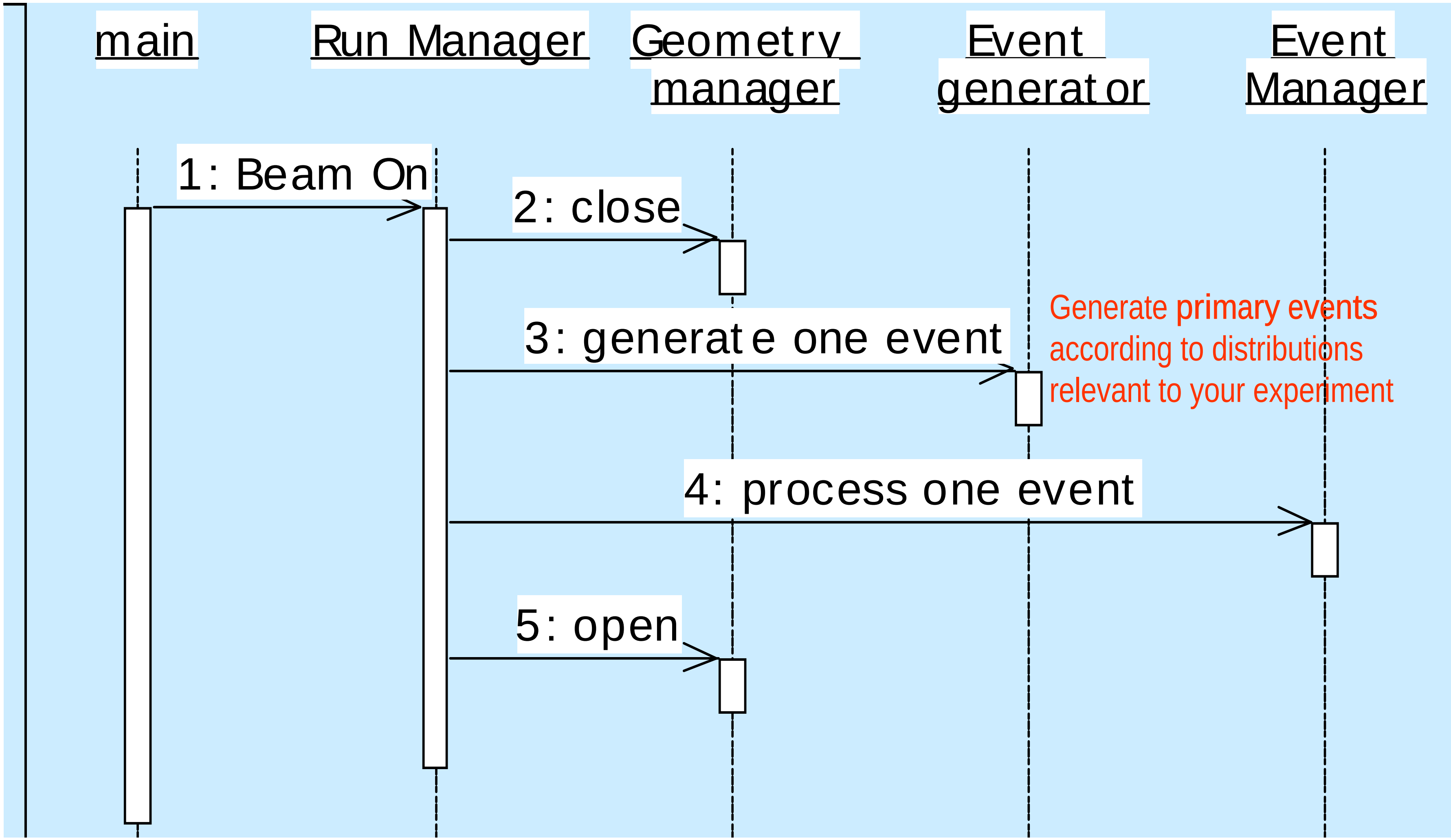
- Design diagram as in generic Geant4 Advanced Example
- Create your derived mandatory user classes
  - My**DetectorConstruction**
  - My**PhysicsList**
  - My**PrimaryGeneratorAction**
- Optionally create your derived user action classes
  - MyUser**Run**Action
  - MyUser**Event**Action
  - MyUser**Tracking**Action
  - MyUser**Stacking**Action
  - MyUser**Stepping**Action
- Create your main()
  - Instantiate G4RunManager or your own derived MyRunManager
  - Notify the RunManager of your mandatory and optional user classes
  - Optionally initialize your favourite User Interface and Visualization
- That’s all!

Initialisation

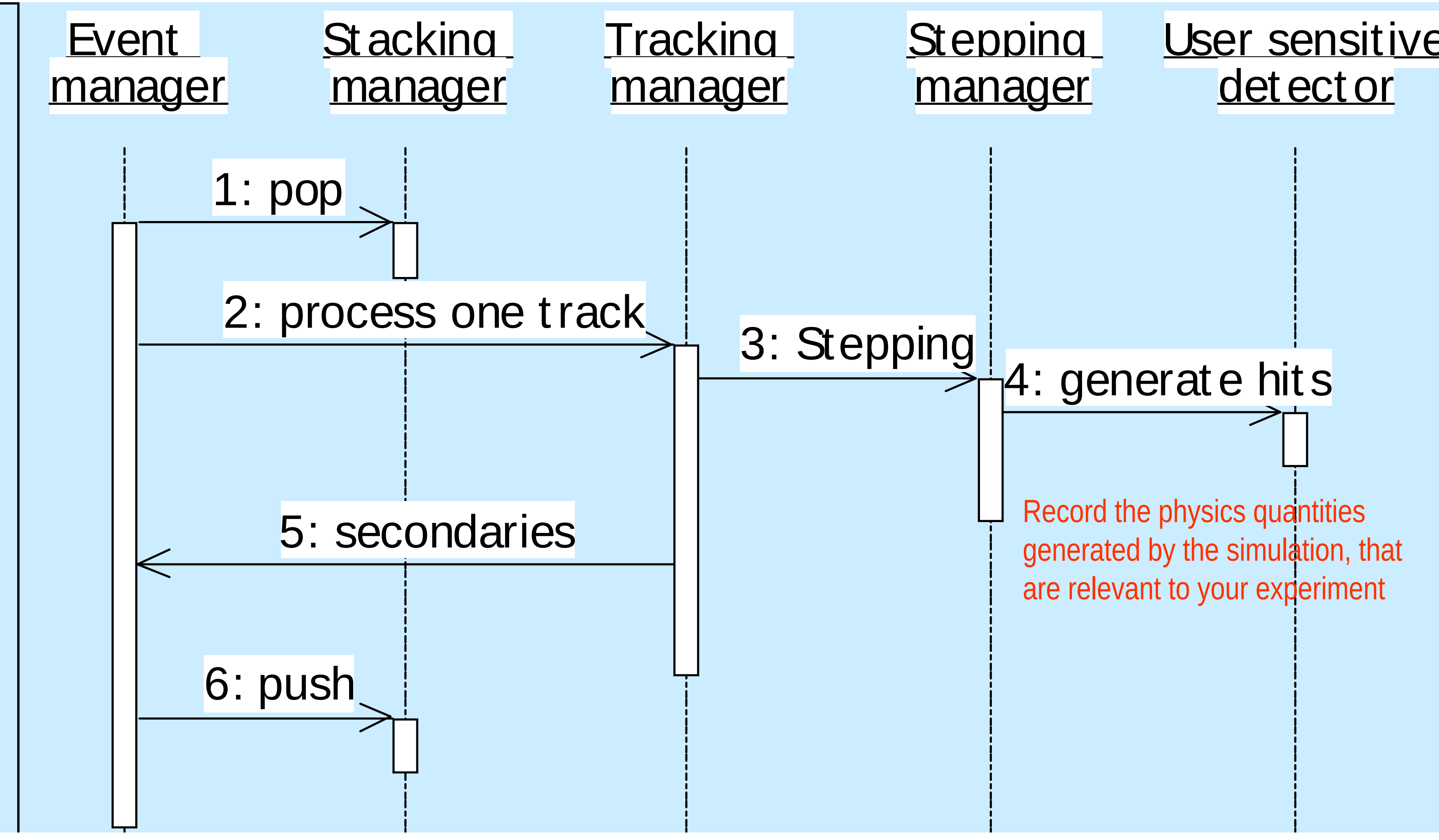


Geant 4

Beam On

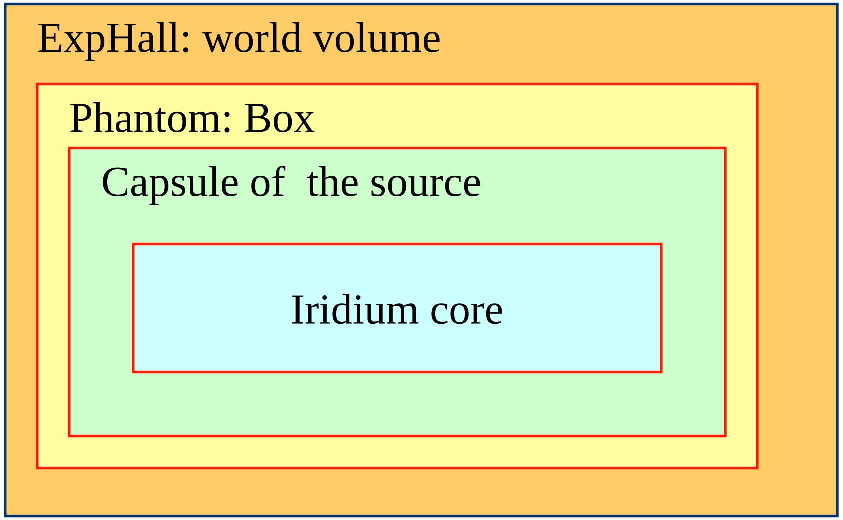

main
Run Manager
Geometry manager
Event generator
Event Manager
1: Beam On
2: close
3: generate one event
Generate primary events according to distributions relevant to your experiment
4: process one event
5: open

Event processing

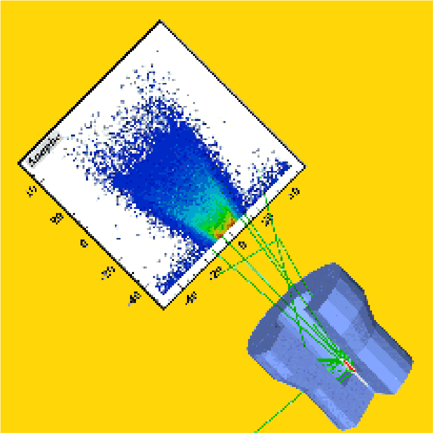


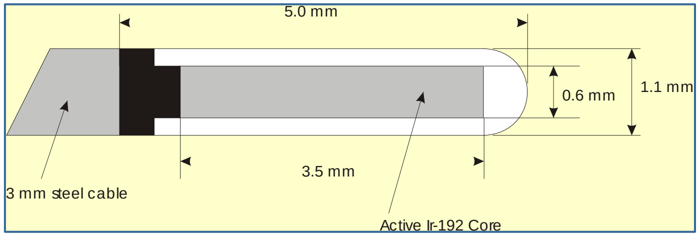
Brachytherapy Advanced Example

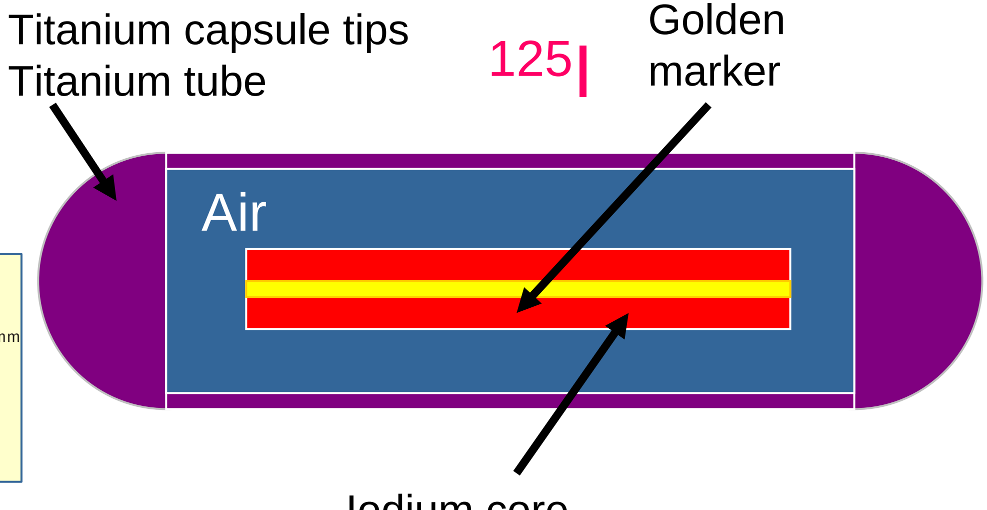
- geant4/source/examples/advanced/brachytherapy/
- Model brachytherapy sources: Ir, I, Leipzig applicator



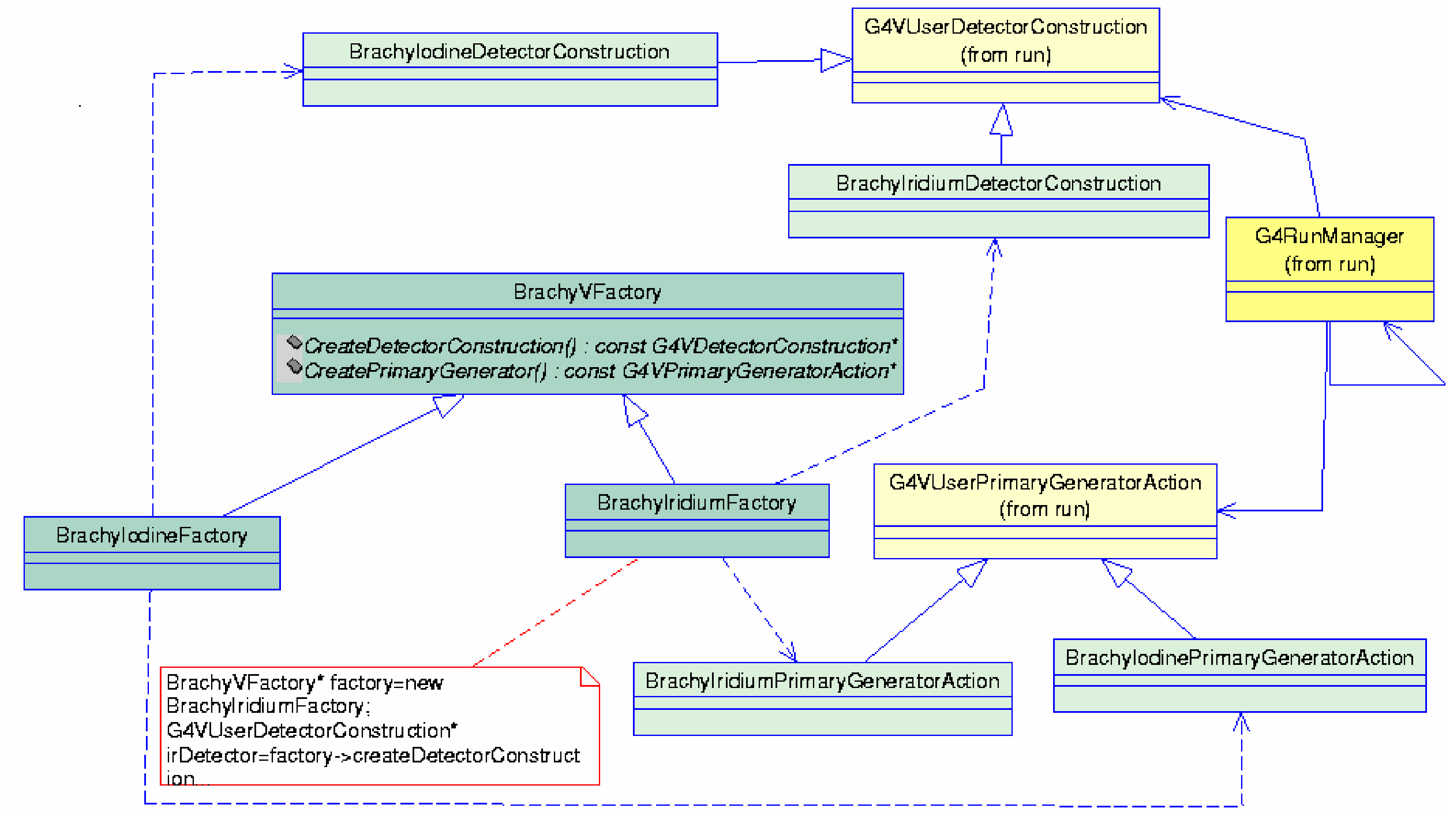
^{192}Ir







Geant 4

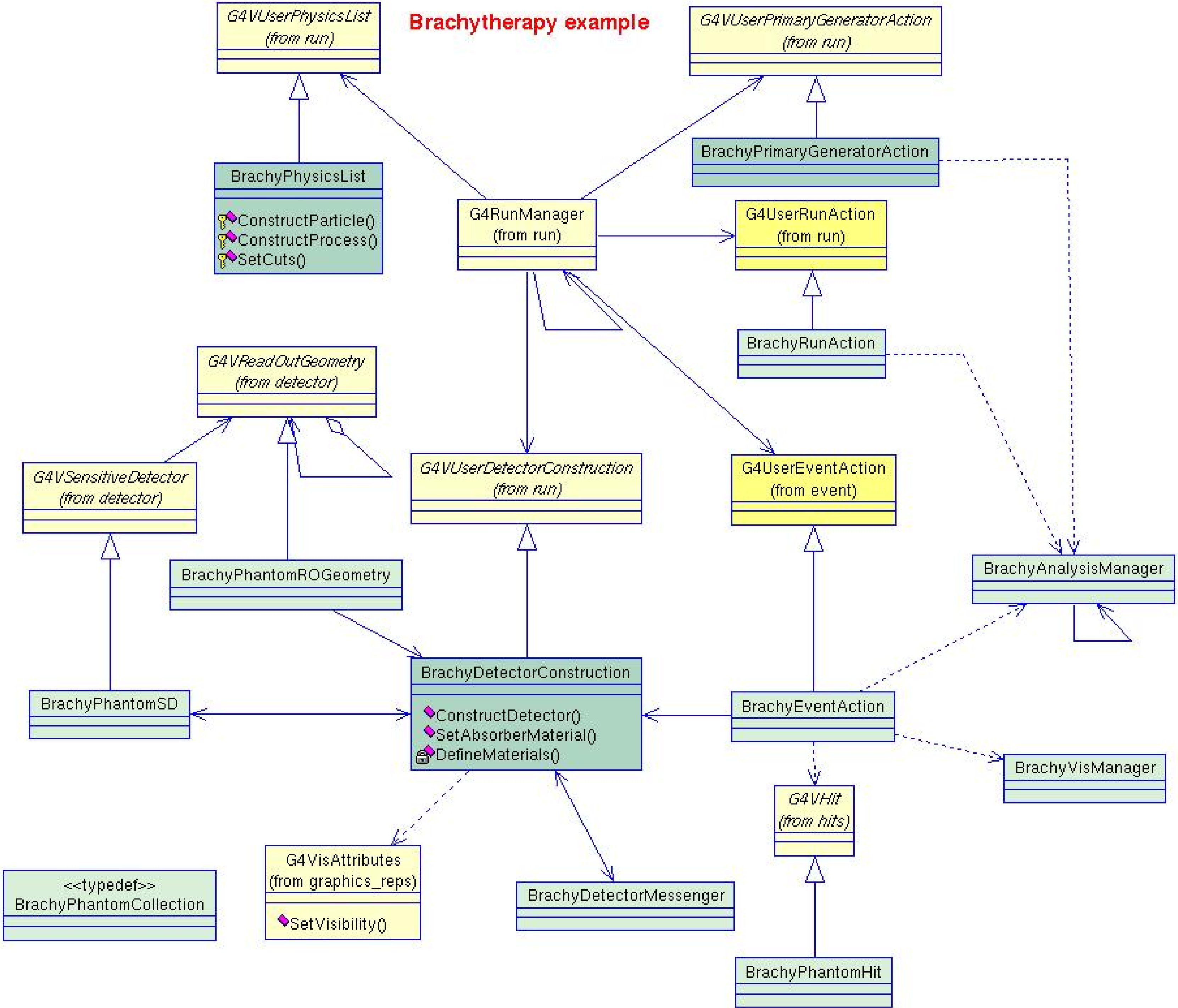


Configuration of

- any brachytherapy technique
- any source type

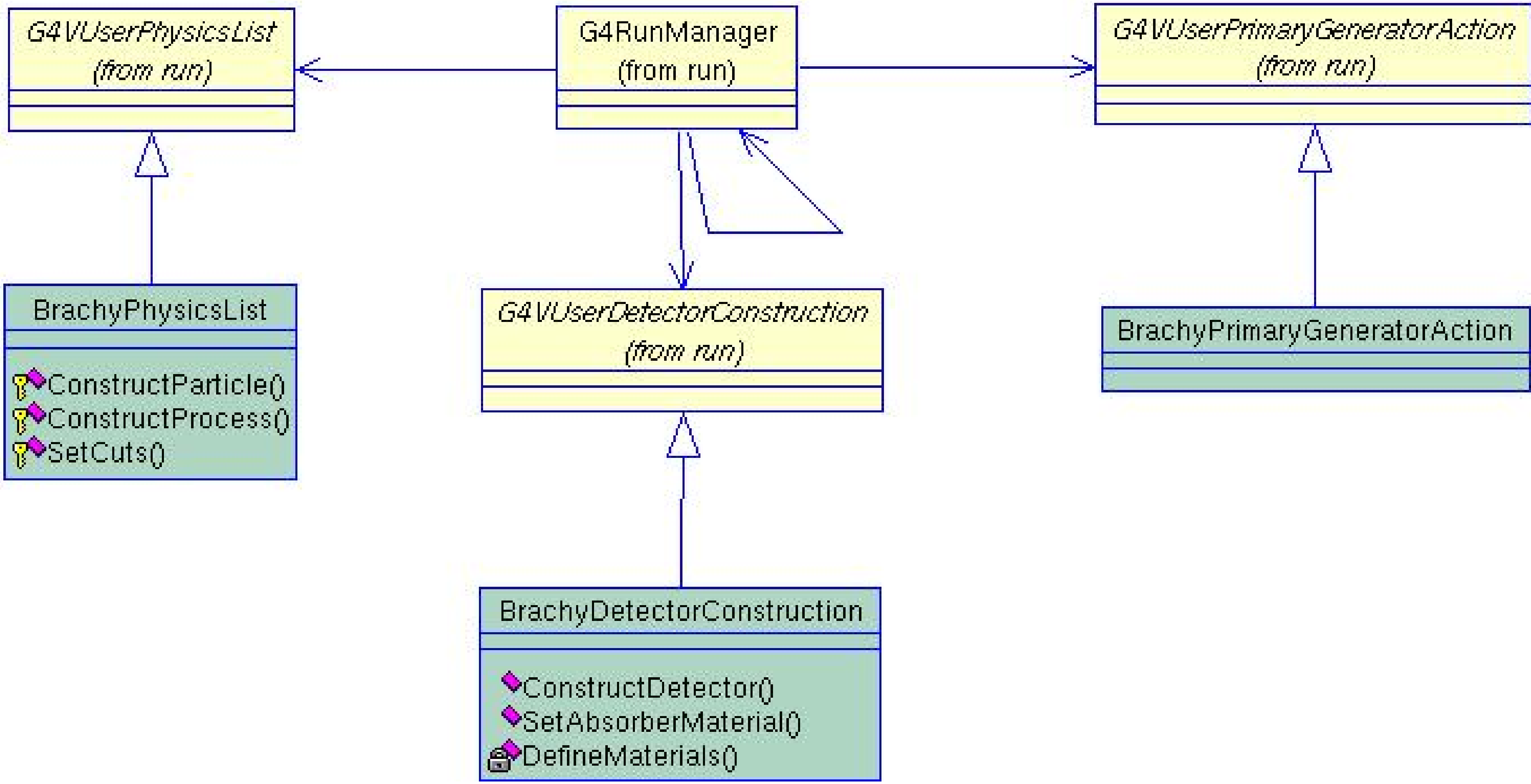
through an Abstract Factory
to define
geometry, primary spectrum

Brachytherapy example

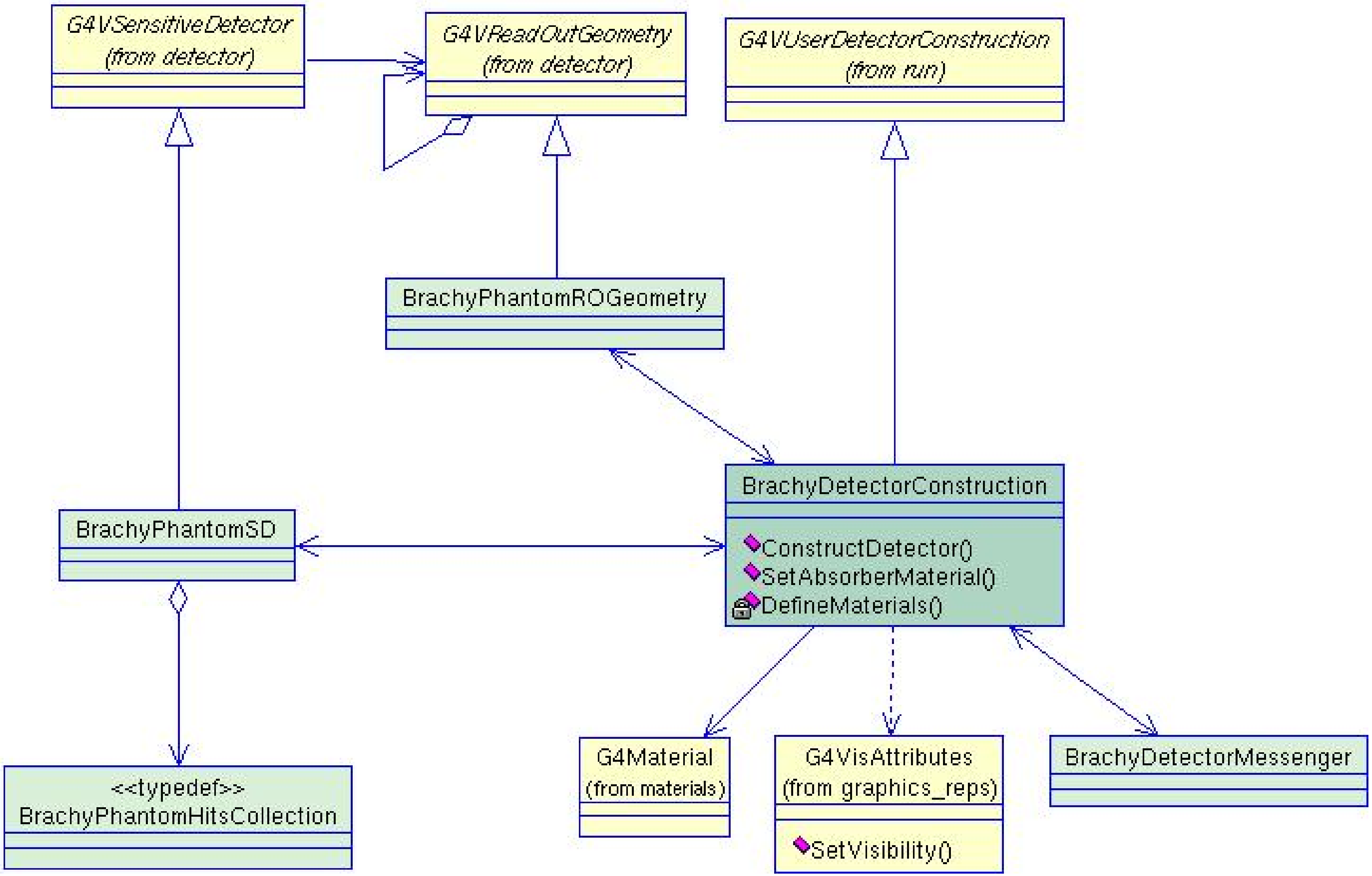


Geant 4

Brachytherapy example: mandatory user classes



Brachytherapy example: detector description



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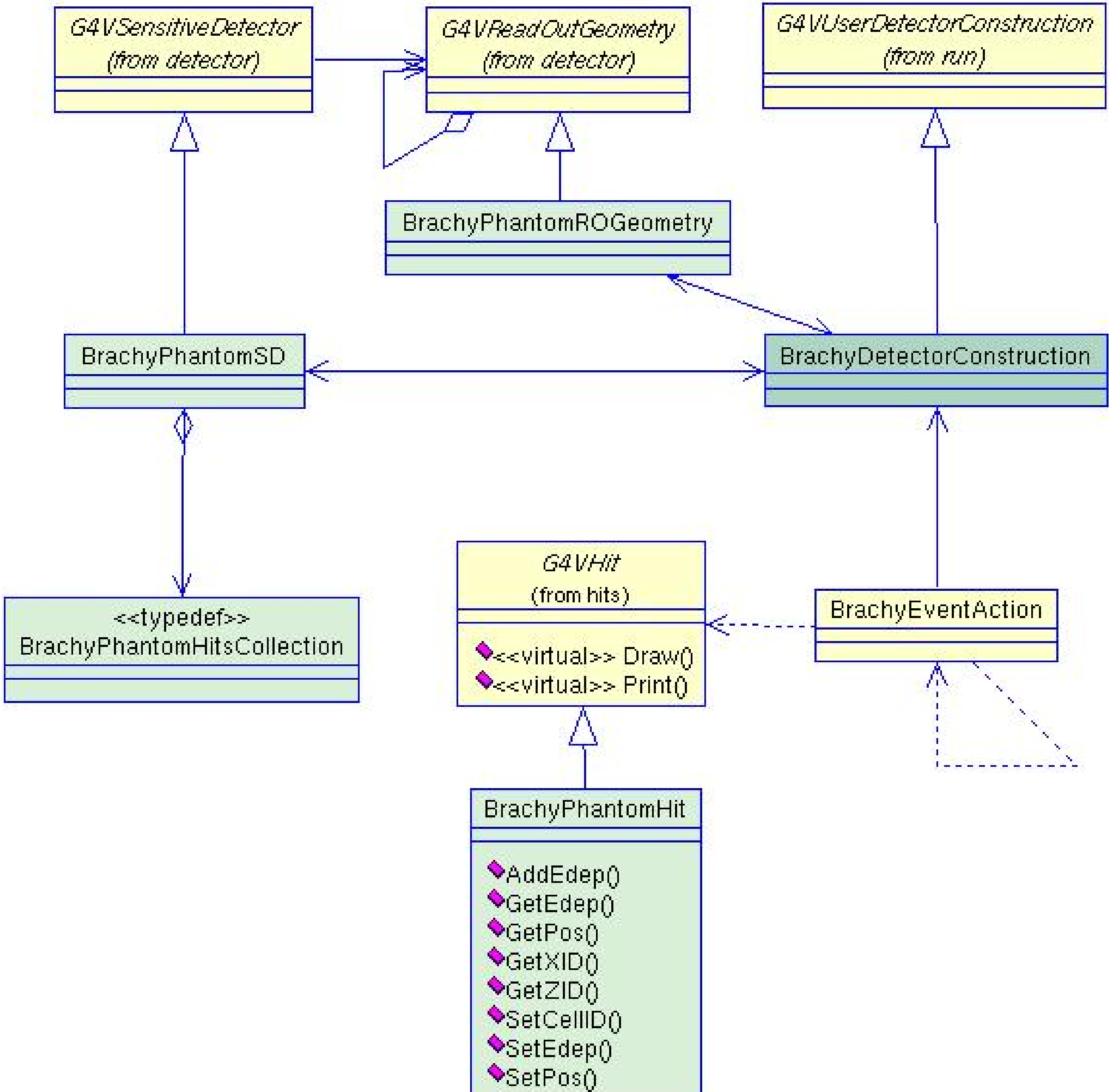
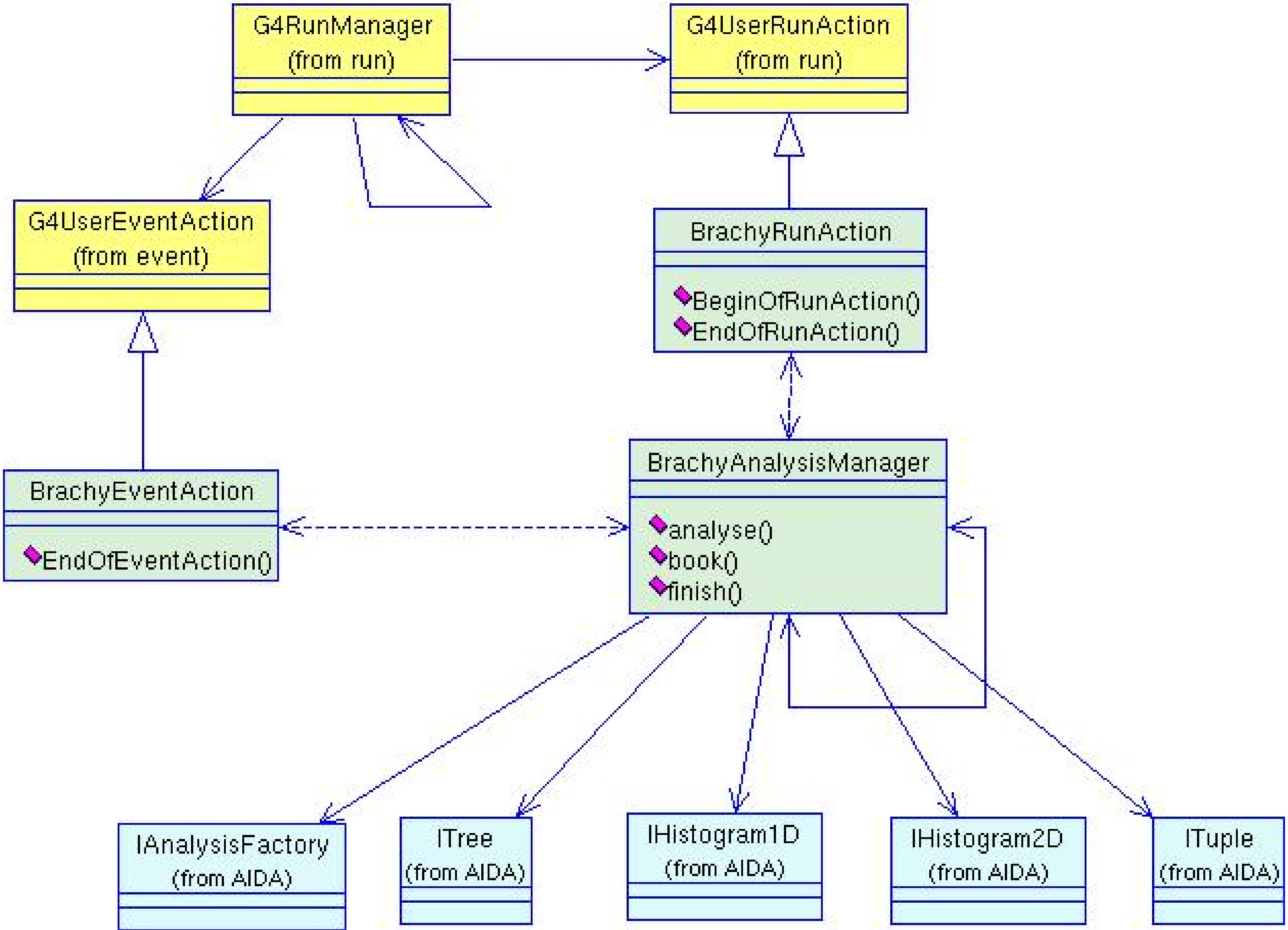
Brachytherapy example: detector response



Brachytherapy example: analysis



How to run Brachytherapy

- Define the necessary environment variables
  - source setup.csh
- Compile and build your executable
  - gmake
- Run
  - $G4WORKDIR/bin/Linux/Brachy
  - Default macro :VisualisationMacro.mac
- geant4/source/examples/advanced/brachytherapy/**README**