Geant 4

Example of User Application

The Geant4 Brachytherapy Advanced Example

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http://cern.ch/geant4

Contents

- How to develop a Geant4 application
  - User Requirements
  - Design
  - Implementation

- Overview of the simplified version of Geant4 brachytherapy advanced example

Before starting

Documentation: **http://geant4.web.cern.ch/geant4**

click on documentation

click on User's Guide: For Application Developers

very useful !

Documentation about the Geant4 brachytherapy application:

www.ge.infn.it/geant4

Software process

How to develop a rigorous and reliable software!
Fundamental for Medical Physics Applications!

For example, a process model is the
Unified Software Development Process (USDP)

Iterative-incremental method

- Collection of the User Requirements

  - Study of the experimental set-up:
    - involved particles,
    - involved physics,
    - detectors
  - What is the scope of the simulation

- Design
  Project of the software structure
- Implementation
- Test

Capture User Requirements

Define the scope of the software system to be built ("what it should do")

How to collect User Requirements

- Study of the experimental set-up:
  - involved particles,
  - involved physics,
  - detectors
- What is the scope of the simulation

Example of User Requirement

UR1. The user shall be able to define electromagnetic processes for gamma
Need: Essential
Priority: High
Source: *who asks for the user requirement*

User Requirements

The application provides the simulation of energy deposit of a I-125 brachytherapic source in a phantom

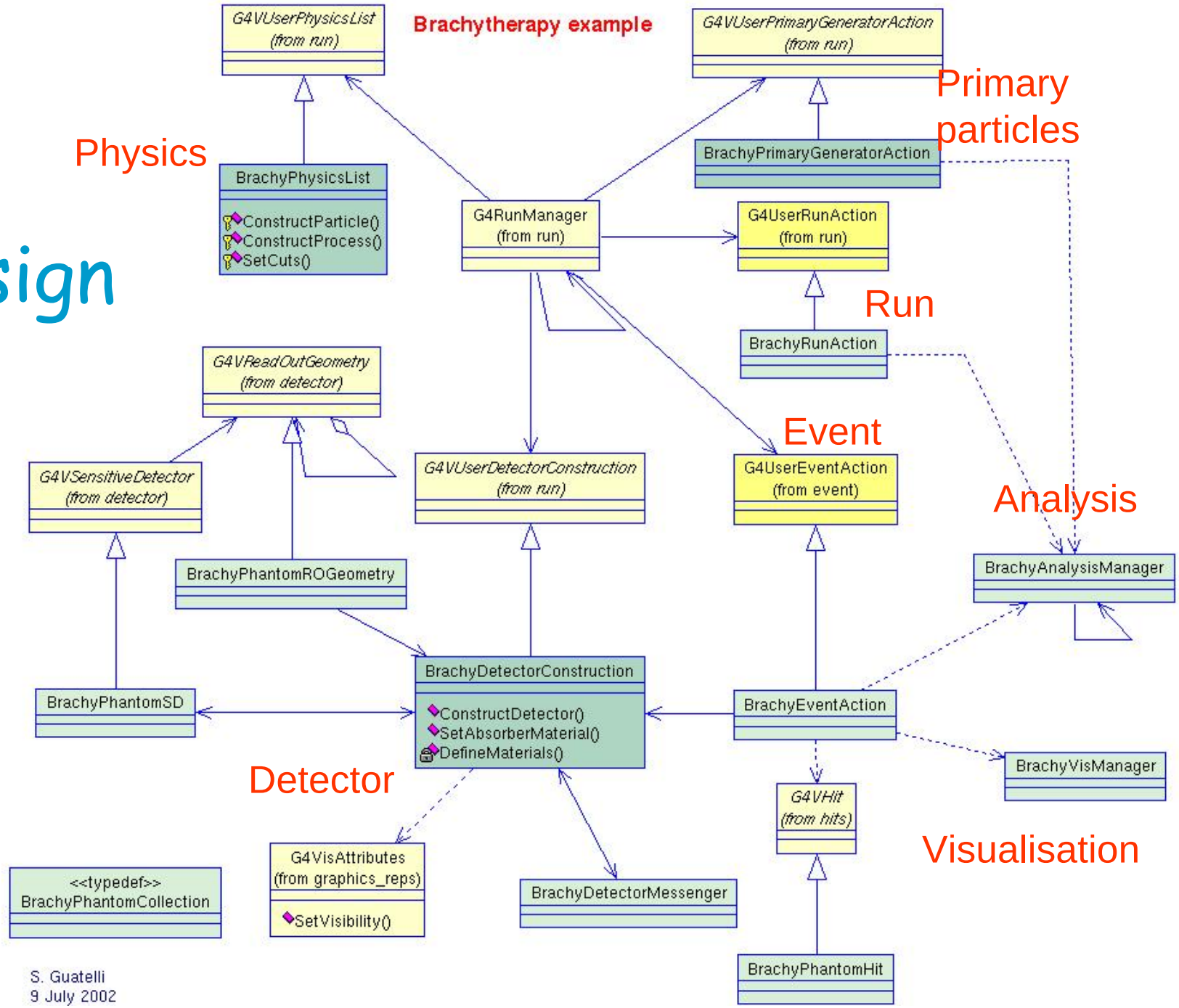
- **Geometry**
  1. The phantom is a box
  2. The radioactive source is in the center of the phantom
  3. The user shall be able to change the absorber material of the phantom
  4. The dose should be collected 1mm wide voxels
- **Physics**
  1. Defined particles: e+,e-, gamma
  2. Electromagnetic processes
- **Analysis**
  1. The user shall be able to calculate the total absorbed energy in the phantom:
     - 3D distribution in the volume
     - 2D distribution in the plain containing the source
- **Visualisation**
  1. The user shall be able to visualise the geometry involved and the trajectories of the particles

Design

Define the structure of the software by a software engineering point of view

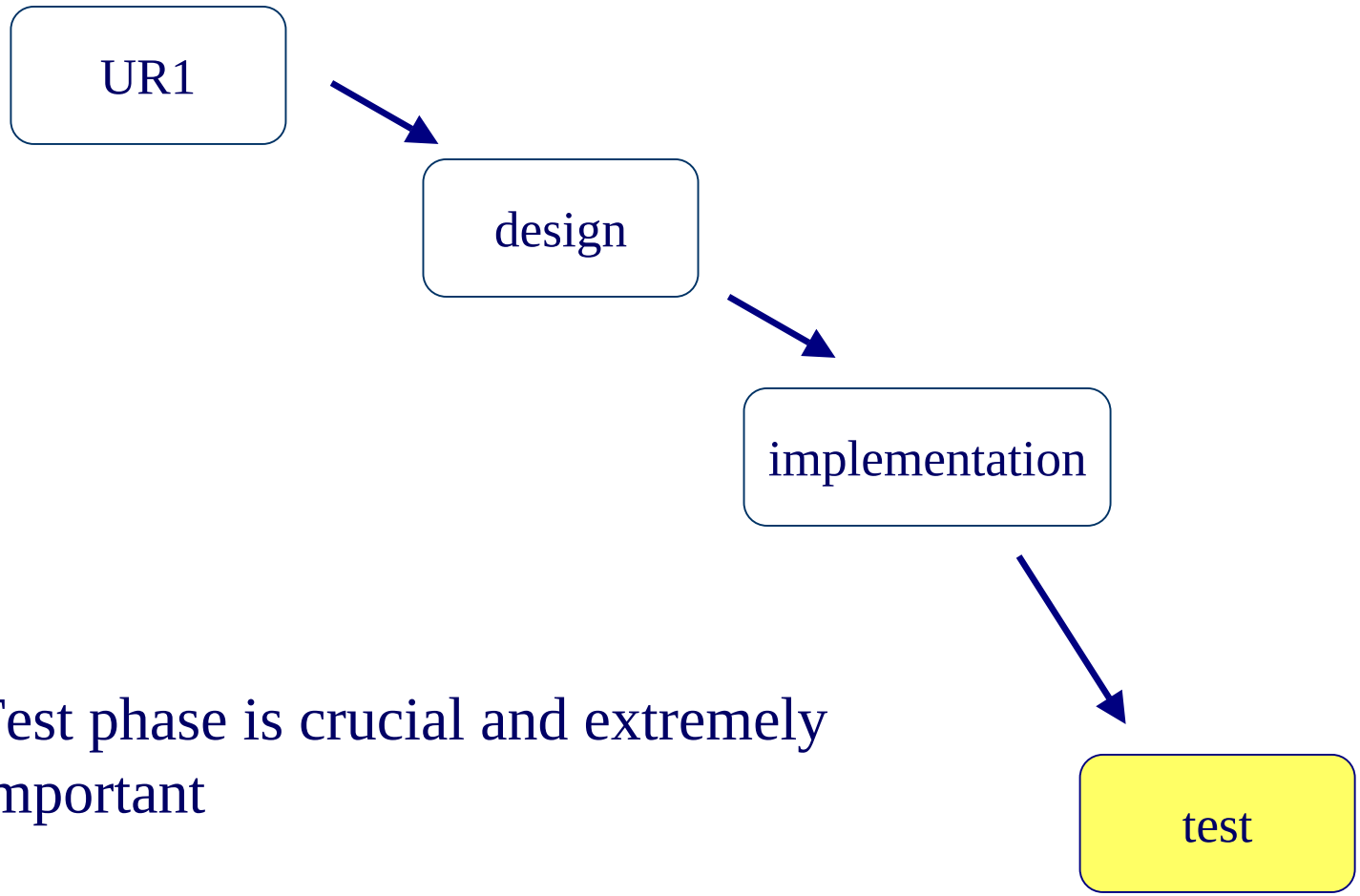
OOAD

Design



S. Guatelli
9 July 2002

Software development



Test phase is crucial and extremely important

Test

- Important and crucial issue
- Always in respect to experimental data
- Comparisons in respect to other MC toolkit are just curiosity

Levels of tests:

➢Microscopic test

Test on components of the application (i.e. Physics models adopted)

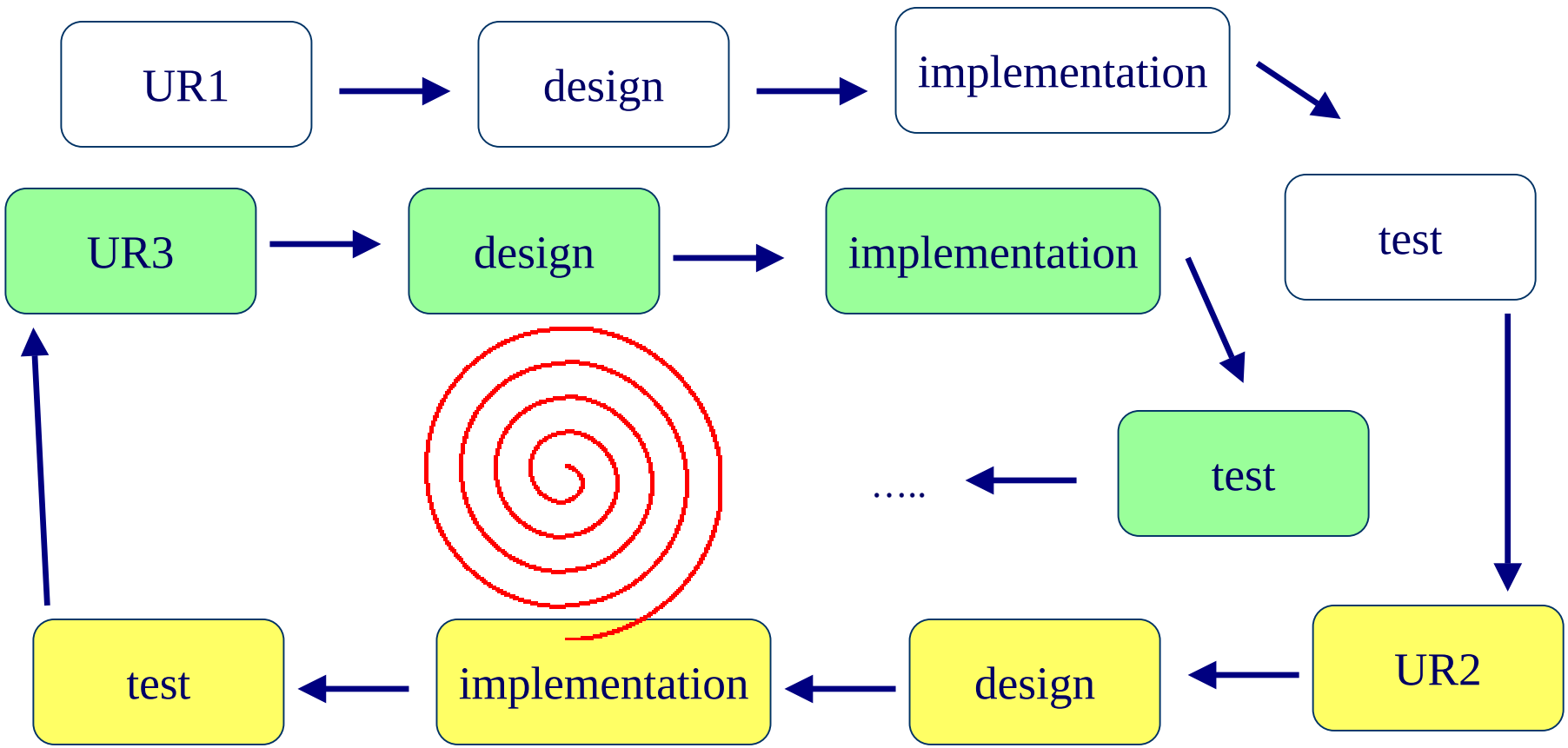
➢Macroscopic test

Test on the experimental set-up (physics, geometry, etc. together)

Iterative, incremental method

- UR1
- UR2
- UR3

Gain feedback on the developed software:
Examples: - Is the UR satisfied?
- Do we need new UR?
- How can we improve the software ?



Implementation

Implementation

Brachytherapy example

header files in include/*.hh, source code in src/ *.cc
main in Brachy.cc
macro: VisualisationMacro.mac

Classes

- BrachyAnalysisManager
- BrachyDetectorConstruction
- BrachyDetectorMessenger
- BrachyEventAction
- BrachyMaterial
- BrachyPhantomHit
- BrachyPhantomROGeometry
- BrachyPhantomSD
- BrachyPrimaryGeneratorAction
- BrachyPhysicsList
- BrachyRunAction
- BrachyEventAction
- BrachyVisManager

How to run

Define necessary environment variables

- source …

How to compile and link

- gmake

How to run

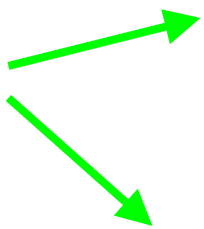
- $G4WORKDIR/bin/Linux/Brachy

Run Brachytherapy

1. It will appear: the visualization of the box
2. It will appear: |idle> (interactive mode)
3. Type */run/beamOn number of events*
4. The simulation is executed
5. Type *exit*

At the |idle> prompt,
type *help*,
information
about interactive commands

About Visualization

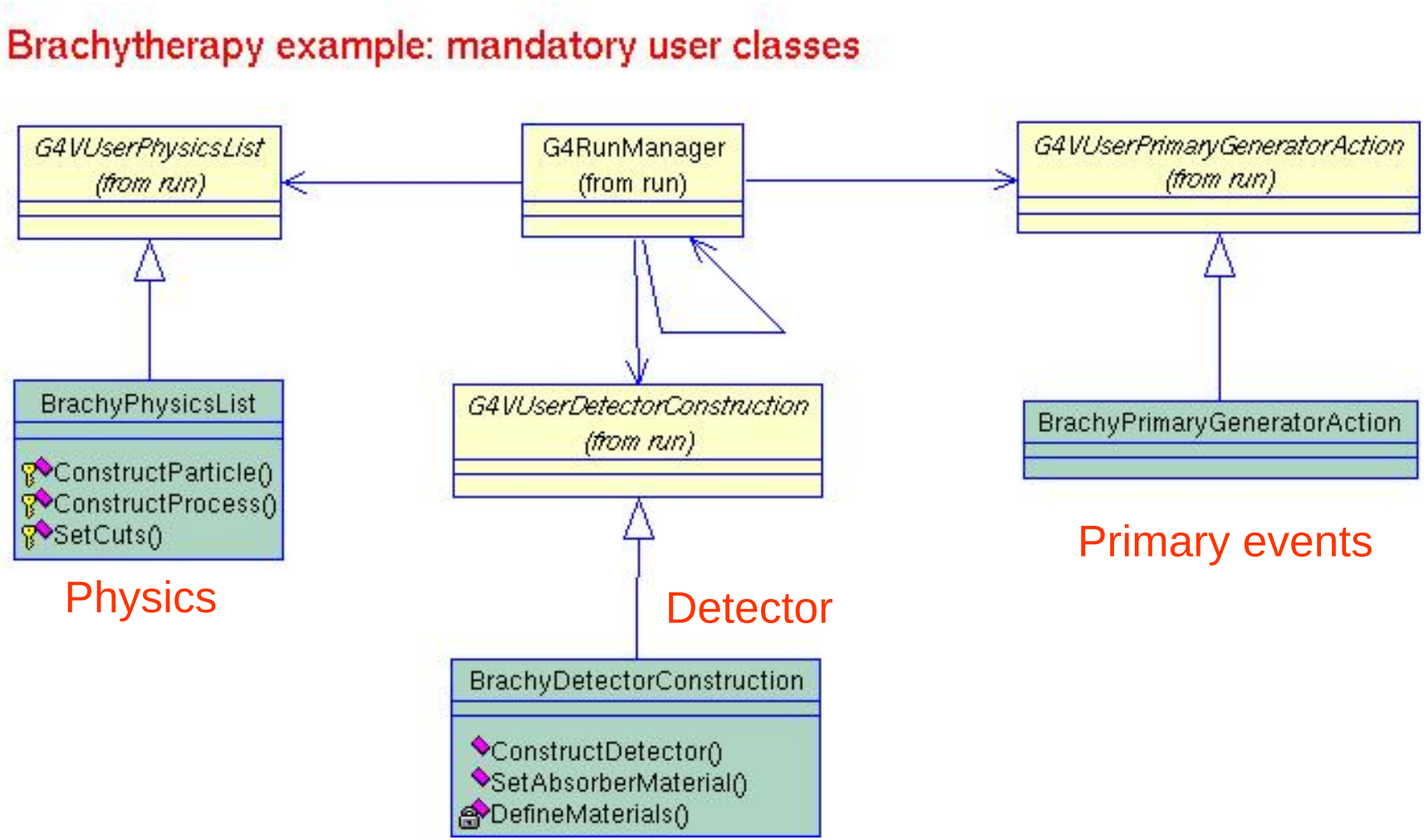


OGLIX : Immediate visualization
No images saved!

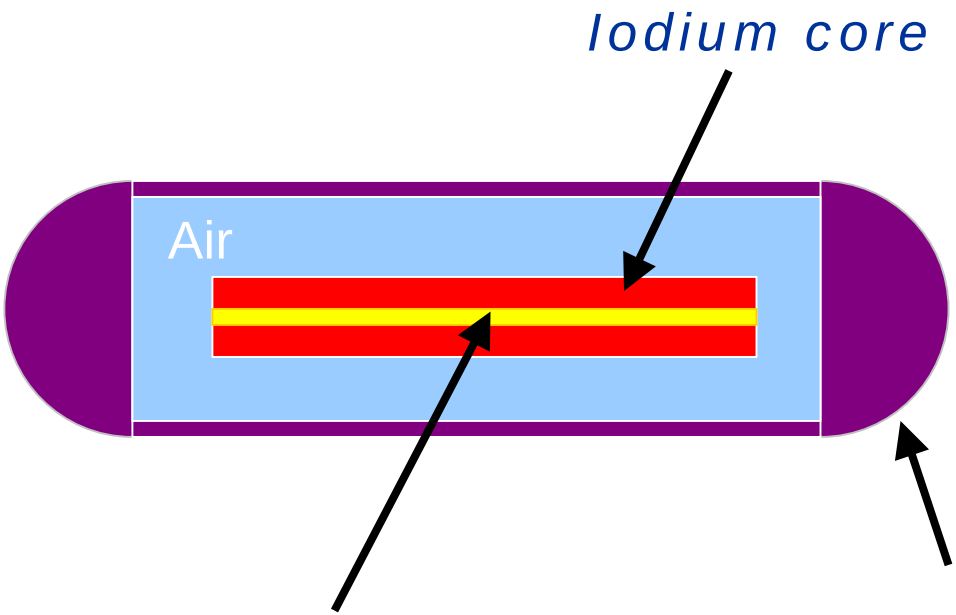
DAWN : Interactive panel
images saved

Default visualization driver
OGLIX
defined in VisualisationMacro.mac

Mandatory user classes



BrachyDetectorConstruction



Model of a I-125 brachytherapic source geometry and materials

Titanium capsule tip:
Semisphere
radius:0.40mm

Titanium tube:
Outer radius:0.40mm
Half length:1.84mm

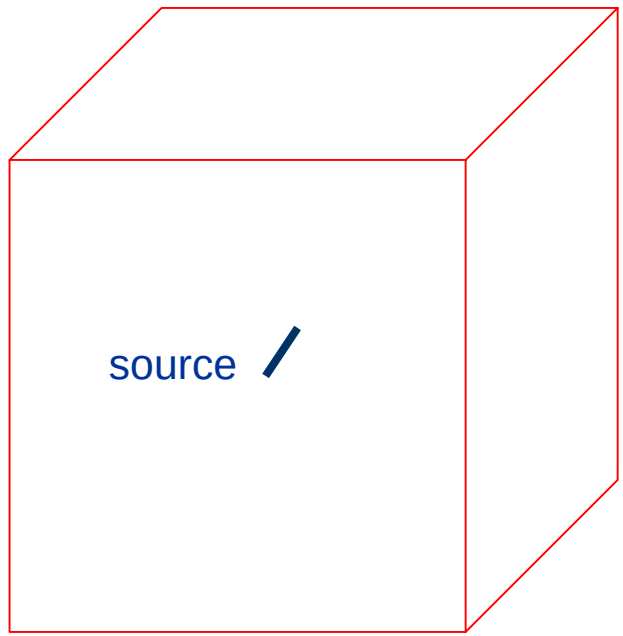
Iodium core:
Inner radius :0
Outer radius: 0.30mm
Half length:1.75mm

Golden marker:
Inner radius :0
Outer radius: 0.085 mm
Half length:1.75mm

Air:
Outer radius:0.35mm
half length:1.84mm

BrachyDetectorConstruction

```
BrachyDetectorConstruction::BrachyDetectorConstruction{}
 BrachyDetectorConstruction::~BrachyDetectorConstruction{}
 G4VPhysicalVolume* BrachyDetectorConstruction::Construct()
 {
   pMaterial-> DefineMaterials();
   ConstructSource();
   ConstructPhantom();
   ConstructSensitiveDetector();
   return WorldPhys;
 }
```



ConstructSource()

// source Bebig Isoseed I-125 ...

…. construct iodium core and golden marker…

the mother volume is an air tube

```
// Iodium core
 iodiumCore = new G4Tubs("ICore",0.085*mm,0.35*mm,1.75*mm,0.*deg,360.*deg);
  iodiumCoreLog = new G4LogicalVolume(iodiumCore,iodium,"iodiumCoreLog");
  iodiumCorePhys = new G4PVPlacement(0,  G4ThreeVector(0.,0.,0.), "iodiumCorePhys",
  iodiumCoreLog,  defaultTubPhys, false,  0);
// Golden marker
  marker = new G4Tubs("GoldenMarker",0.*mm,0.085*mm,1.75*mm,0.*deg,360.*deg);
  markerLog = new G4LogicalVolume(marker,gold,"MarkerLog");
  markerPhys = new G4PVPlacement(0, G4ThreeVector(0.,0.,0.), "MarkerPhys", markerLog,
                                 defaultTubPhys, false, 0);
```

BrachyPhysicsList

```
BrachyPhysicsList::BrachyPhysicsList():
G4VUserPhysicsList()
{
defaultCutValue = 0.1*mm;
.....}
BrachyPhysicsList::~BrachyPhysicsList(){}
void BrachyPhysicsList::ConstructParticle()
{
  ConstructBosons();
  ConstructLeptons();
}
void BrachyPhysicsList::ConstructBosons()
{
  G4Gamma::GammaDefinition();
}
void BrachyPhysicsList::ConstructLeptons()
{
  G4Electron::ElectronDefinition();
  G4Positron::PositronDefinition();
}
```

```
void
BrachyPhysicsList::ConstructProcess()
{
  AddTransportation();
  ConstructEM();
}
```

Add electromagnetic processes

BrachyPhysicsList

```
void BrachyPhysicsList::ConstructEM()
{ theParticleIterator->reset();
  while( (*theParticleIterator)() ){
    G4ParticleDefinition* particle = theParticleIterator->value();
    G4ProcessManager* pmanager = particle->GetProcessManager();
    G4String particleName = particle->GetParticleName();
if (particleName == "gamma") {
      lowePhot = new  G4LowEnergyPhotoElectric("LowEnPhotoElec");
      pmanager->AddDiscreteProcess(new G4LowEnergyRayleigh);
      pmanager->AddDiscreteProcess(lowePhot);
      pmanager->AddDiscreteProcess(new G4LowEnergyCompton);
      pmanager->AddDiscreteProcess(new G4LowEnergyGammaConversion);
    } else if (particleName == "e-") {
      loweIon  = new G4LowEnergyIonisation("LowEnergyIoni");
      loweBrem = new G4LowEnergyBremsstrahlung("LowEnBrem");
      pmanager->AddProcess(new G4MultipleScattering, -1, 1,1);
      pmanager->AddProcess(loweIon,     -1, 2,2);
      pmanager->AddProcess(loweBrem,    -1,-1,3);
} else if (particleName == "e+"){…}
…
}
```

Set EM processes for e-, e+, gamma

BrachyPrimaryGeneratorAction

- I-125 delivers gamma
- Gamma Energy Spectrum
- Random direction
- Random position inside the iodium core

Energy(keV)	Probability
27.4	0.783913
31.4	0.170416
35.5	0.045671

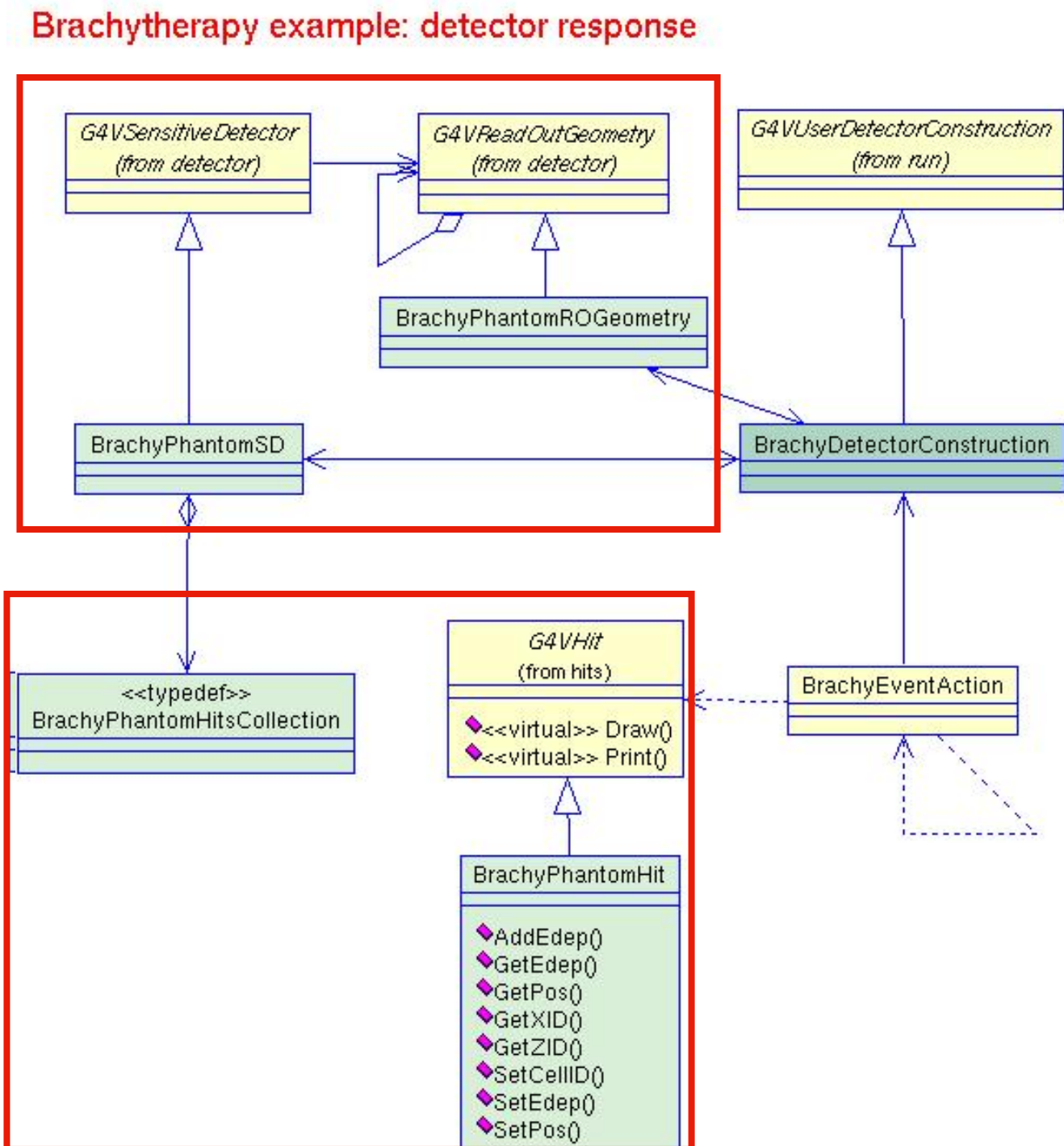
```
void BrachyPrimaryGeneratorAction::GeneratePrimaries(G4Event* anEvent)
  {
  …..
  particleGun->SetParticlePosition(position);
  particleGun -> SetParticleDirection(direction);
  particleGun -> SetParticleEnergy(energy);
  particleGun->GeneratePrimaryVertex(anEvent);
  }
```

Energy deposit

How to retrieve the energy deposit in the phantom

Concepts:

- Hits
- Sensitive Detector
- Readout Geometry



Set Sensitive Detector and RO Geometry

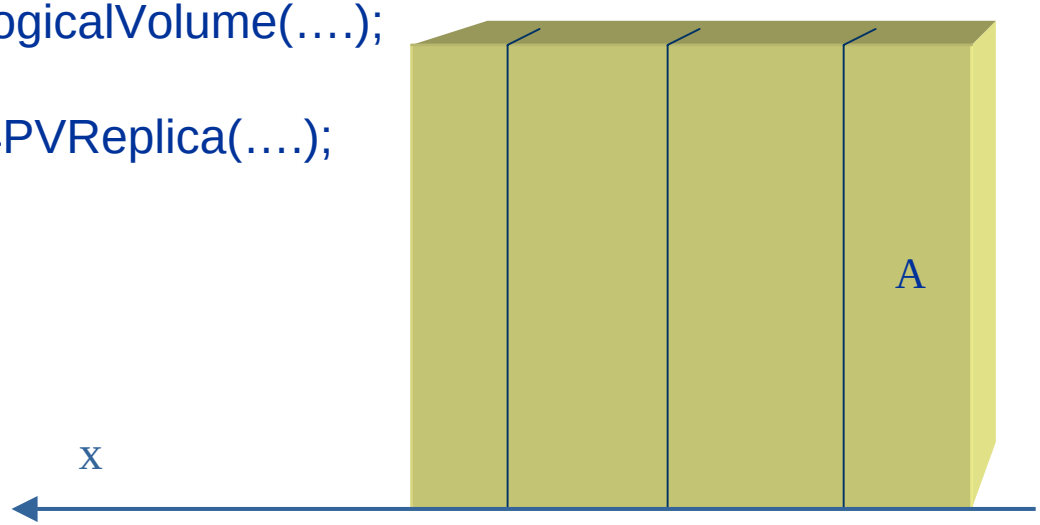
```
void  BrachyDetectorConstruction::ConstructSensitiveDetector()
{
  G4SDManager* pSDManager = G4SDManager::GetSDMpointer();
  if(!phantomSD){
    phantomSD = new BrachyPhantomSD(sensitiveDetectorName,numberOfVoxelsAlongX,
                                                    numberOfVoxelsAlongZ);
    G4String ROGeometryName = "PhantomROGeometry";
    phantomROGeometry = newBrachyPhantomROGeometry(ROGeometryName,
      phantomDimensionX,phantomDimensionZ,numberOfVoxelsAlongX,numberOfVoxelsAlongZ);
    phantomROGeometry->BuildROGeometry();
    phantomSD->SetROgeometry(phantomROGeometry);
    pSDManager->AddNewDetector(phantomSD);
    PhantomLog->SetSensitiveDetector(phantomSD);
  }
}
```

In PhantomDetectorConstruction

RO Geometry

The phantom is devided in voxels

```
BrachyPhantomROGeometry::BrachyPhantomROGeometry() {}

BrachyROGeometry::~BrachyROGeometry() {}

G4VPhysicalVolume*  BrachyPhantomROGeometry :: Build()
{
 // example : X division
 ROPhantomXDivision = new G4Box( ….);

 ROPhantomXDivisionLog = newG4LogicalVolume(….);

 ROPhantomXDivisionPhys = new G4PVReplica(….);
……..
}
```



Sensitive Detector

```
G4bool BrachyPhantomSD::ProcessHits
(G4Step* aStep, G4TouchableHistory* ROhist)
{....

 G4double energyDeposit = aStep->GetTotalEnergyDeposit();

....
G4VPhysicalVolume* physVol = ROhist->GetVolume();
  // Read Voxel indexes: i is the x index, k is the z index
  G4int k = ROhist->GetReplicaNumber(1);
  G4int i = ROhist->GetReplicaNumber(2);
  G4int j= ROhist->GetReplicaNumber();
.....
  BrachyPhantomHit* PhantomHit = new BrachyPhantomHit(
                                    physVol ->GetLogicalVolume(), i,j,k)

     PhantomHit->SetEdep(energyDeposit);
     PhantomHit->SetPos(physVol->GetTranslation());
...  }
```

Store the energy deposit in one hit

In PhantomSensitiveDetector

Hits

- Hit is a user-defined class derived from G4VHit
- You can store various types information by implementing your own concrete Hit class:
  - position and time of the step
  - momentum and energy of the track
  - energy deposit of the step
  - geometrical information
  - etc.
- Hit objects of a concrete hit class must be stored in a dedicated collection, which is instantiated from G4THitsCollection template class

BrachyPhantomHit (header file)

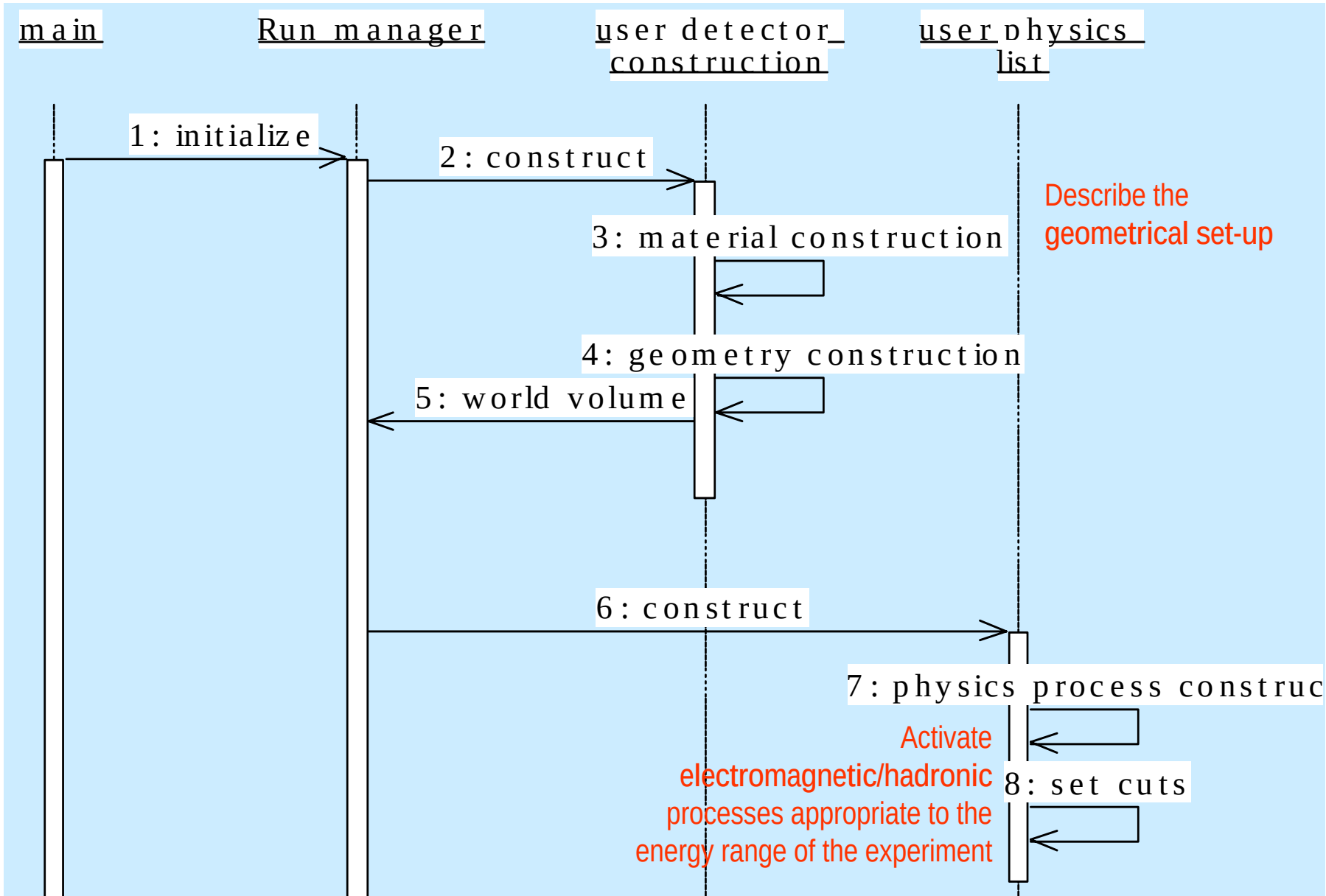
```
class BrachyPhantomHit : public G4VHit
{
public:
  BrachyPhantomHit(G4LogicalVolume* ,G4int ,G4int ,G4int );
  ~BrachyPhantomHit();
.....

  inline G4int GetXID() {return xHitPosition;} //Get hit x coordinate
  inline G4int GetZID() {return zHitPosition;} // Get hit z coordinate
  inline G4int GetYID() {return yHitPosition;} // Get hit y coordinate
  inline  G4double GetEdep() {return energyDeposit;}  // Get energy deposit
….}
```

BrachyEventAction

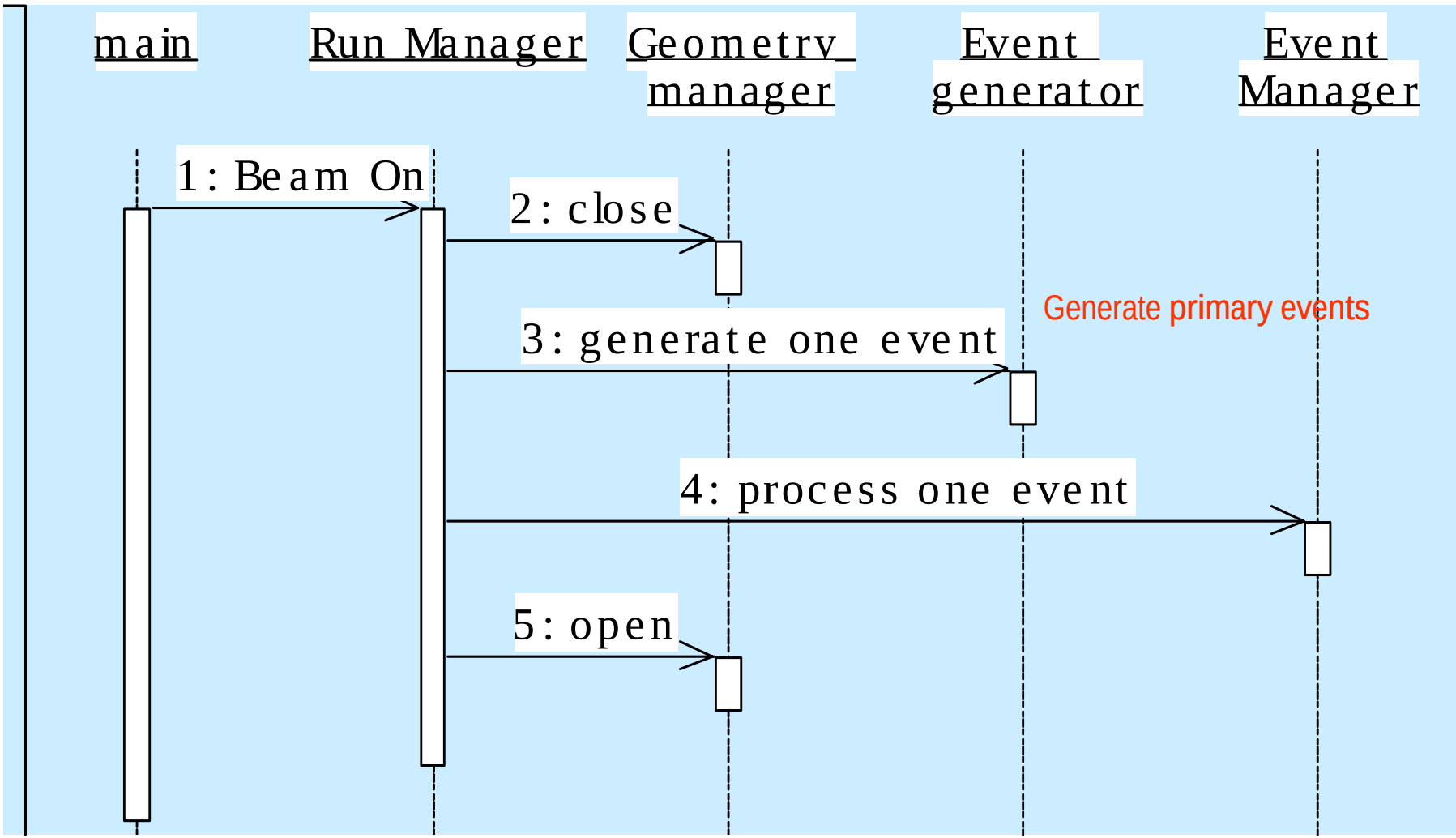
```
void BrachyEventAction::EndOfEventAction(const G4Event* evt)
{....
 G4HCofThisEvent* HCE = evt->GetHCofThisEvent();
  BrachyPhantomHitsCollection* CHC = NULL;
  if(HCE)
     CHC = (BrachyPhantomHitsCollection*)(HCE->GetHC(hitsCollectionID));
 if(CHC)
   {
      G4int hitCount = CHC->entries();
       for (G4int h = 0; h < hitCount; h++)
       {
        G4int i=((*CHC)[h])->GetZID();
         G4int k=((*CHC)[h])->GetXID();
         G4int j=((*CHC)[h])->GetYID();
         G4double EnergyDep=((*CHC)[h]->GetEdep());
       ...}
...}
...}
```

Retrieve energy deposit in the phantom

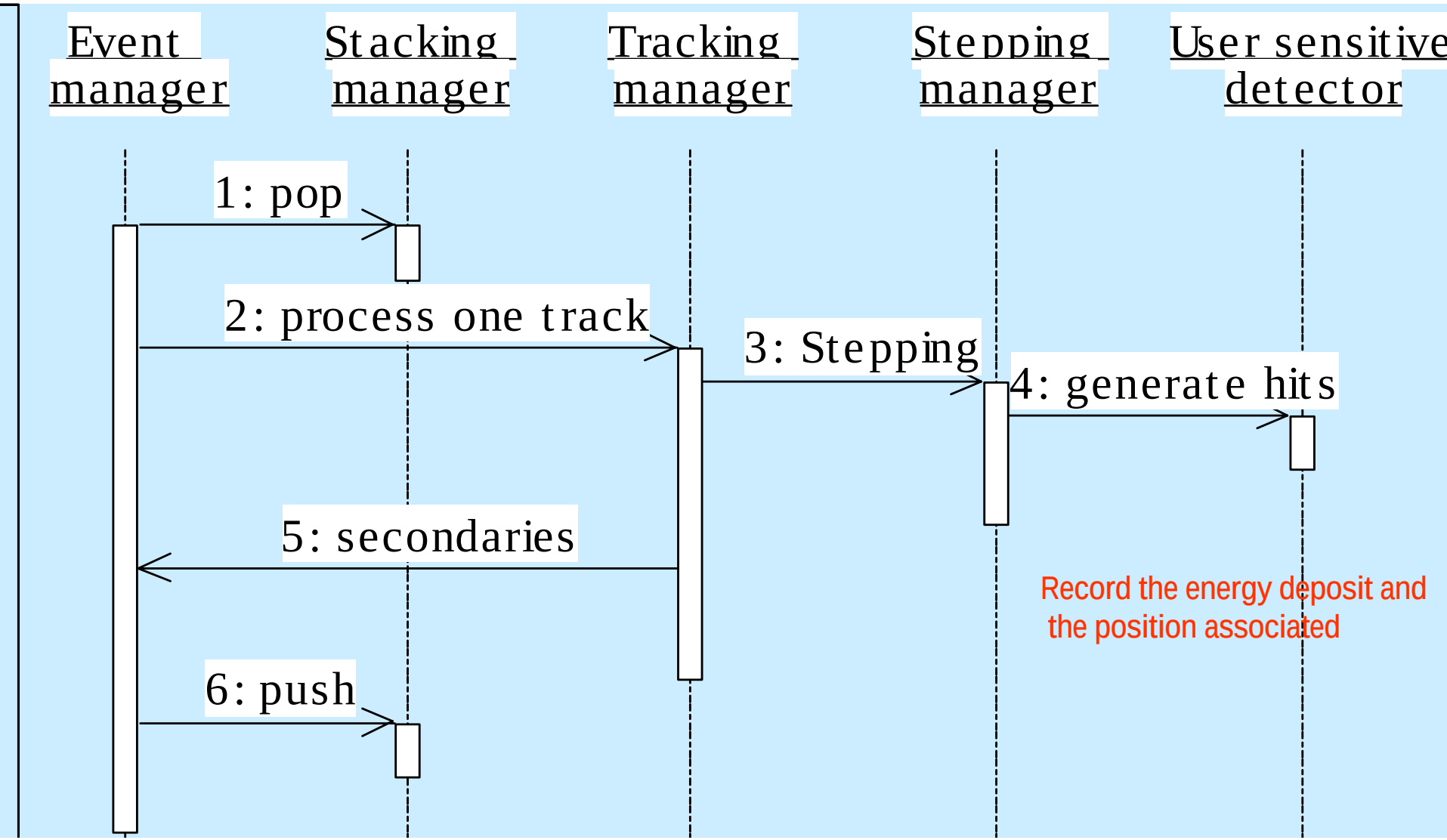
Initialisation



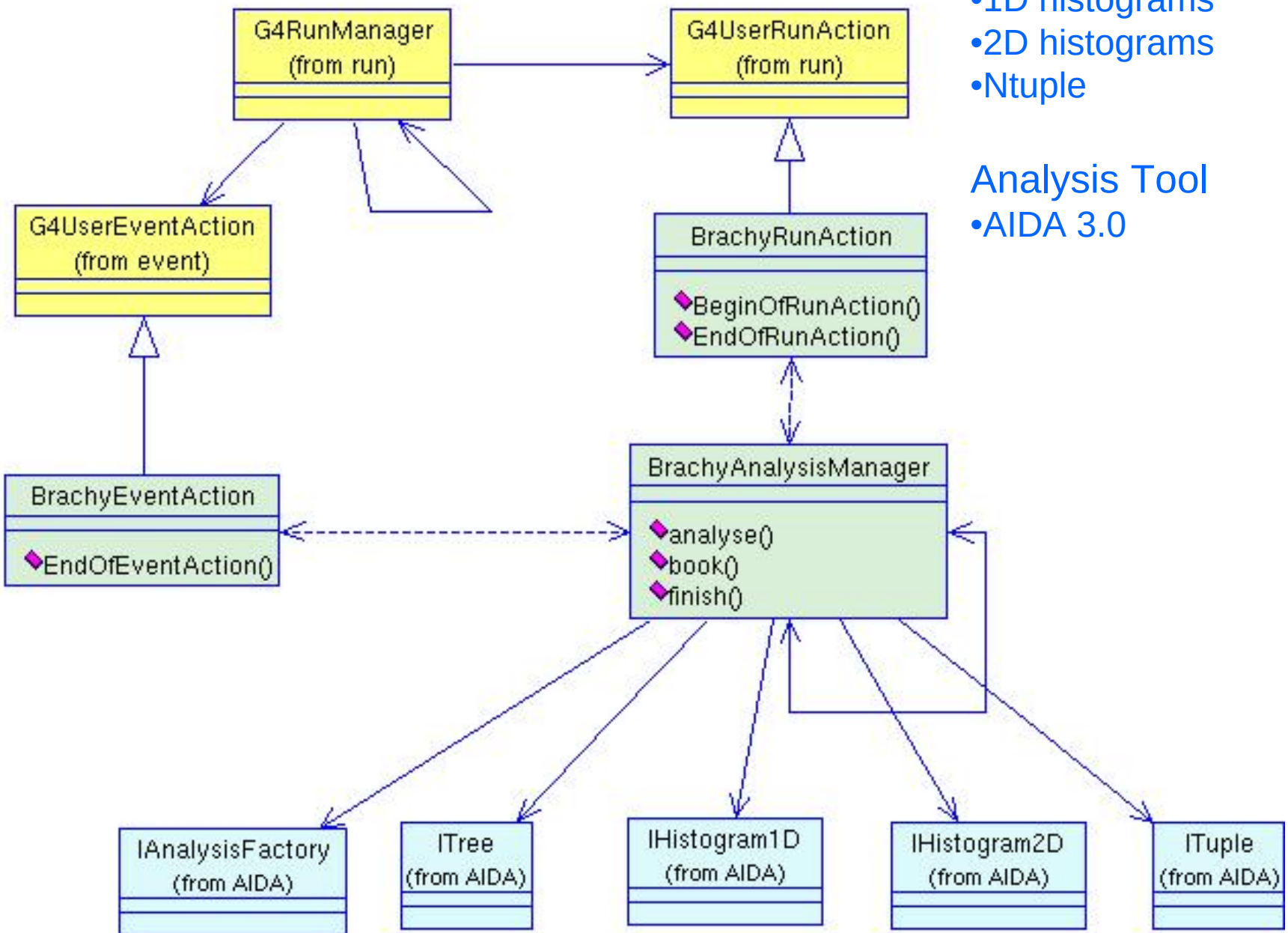
Beam On


main
Run Manager
Geometry_ manager
Event generator
Event Manager
1: Beam On
2: close
Generate primary events
3: generate one event
4: process one event
5: open

Event processing



Brachytherapy example: analysis



How to produce
- 1D histograms
- 2D histograms
- Ntuple

Analysis Tool
- AIDA 3.0

BrachyAnalysisManager

```
BrachyAnalysisManager::BrachyAnalysisManager() :
 ....
{
  //build up  the  factories
aFact = AIDA_createAnalysisFactory();
 AIDA::ITreeFactory *treeFact = aFact->createTreeFactory();
theTree = treeFact->create(fileName,"hbook",false, true);
....
  histFact = aFact->createHistogramFactory( *theTree );
  tupFact  = aFact->createTupleFactory    ( *theTree );
}
void BrachyAnalysisManager::finish()
{
theTree->commit(); // write all histograms to file ...
theTree->close(); // close (will again commit) ...
}
```

Create the .hbk file…

Close the .hbk file

BrachyAnalysisManager

```
void BrachyAnalysisManager::book()
{
  //creating a 2D histogram ...
  h1 = histFact->createHistogram2D("10","Energy, pos",
                                   300 ,-150.,150.,   //bins'number,xmin,xmax
                                   300,-150.,150.    );//bins'number,ymin,ymax

//creating a 1D histogram ...
  h2 = histFact->createHistogram1D("20","Initial Energy",  500,0.,50.);
//creating a ntuple ...
 if (tupFact) ntuple = tupFact->create("1","1",columnNames, options);
....}
```

BrachyAnalysisManager

How to fill histograms….

```
void BrachyAnalysisManager::FillHistogramWithEnergy (G4double x, G4double z,
G4float energyDeposit)
{
  //2DHistogram: energy deposit in a voxel which center is fixed in position (x,z)
  h1->fill(x,z,energyDeposit);
}
void BrachyAnalysisManager::PrimaryParticleEnergySpectrum
(G4double primaryParticleEnergy)
{
  //1DHisotgram: energy spectrum of primary particles
  h2->fill(primaryParticleEnergy);
}
```

BrachyAnalysisManager

How to fill Ntuples….

```
void BrachyAnalysisManager::FillNtupleWithEnergy(G4double xx,G4double yy,
G4double zz, G4float en)
{.....
  G4int indexX = ntuple->findColumn( "x" );
  G4int indexY = ntuple->findColumn( "y" );
  G4int indexZ = ntuple->findColumn( "z" );
  G4int indexEnergy = ntuple->findColumn( "energy" );
  ntuple->fill(indexEnergy, en);
  ntuple->fill(indexX, xx);
  ntuple->fill(indexY, yy);
  ntuple->fill(indexZ, zz);
  ntuple ->addRow();
}
```

Analysis management

```
void BrachyRunAction::BeginOfRunAction(const G4Run*)
{
....
  BrachyAnalysisManager* analysis = BrachyAnalysisManager::getInstance();
  analysis->book();
....
}
```

Booking histograms and ntuple …

```
void BrachyRunAction::EndOfRunAction(const G4Run* aRun)
{
.....
  BrachyAnalysisManager* analysis = BrachyAnalysisManager::getInstance()
 .....
  analysis->finish();
....
}
```

…Closing the hbook file

In BrachyRunAction

Energy deposit

```
void BrachyEventAction::EndOfEventAction(const G4Event* evt)
{
…. // here the energy deposit information is retrieved
//Store information about energy deposit in a 2DHistogram and in a ntuple ...
 BrachyAnalysisManager* analysis =  BrachyAnalysisManager::getInstance
 analysis->FillHistogramWithEnergy(x,z,EnergyDep/MeV);}}
 analysis->FillNtupleWithEnergy(x,y,z,EnergyDep/MeV);
...
}
```

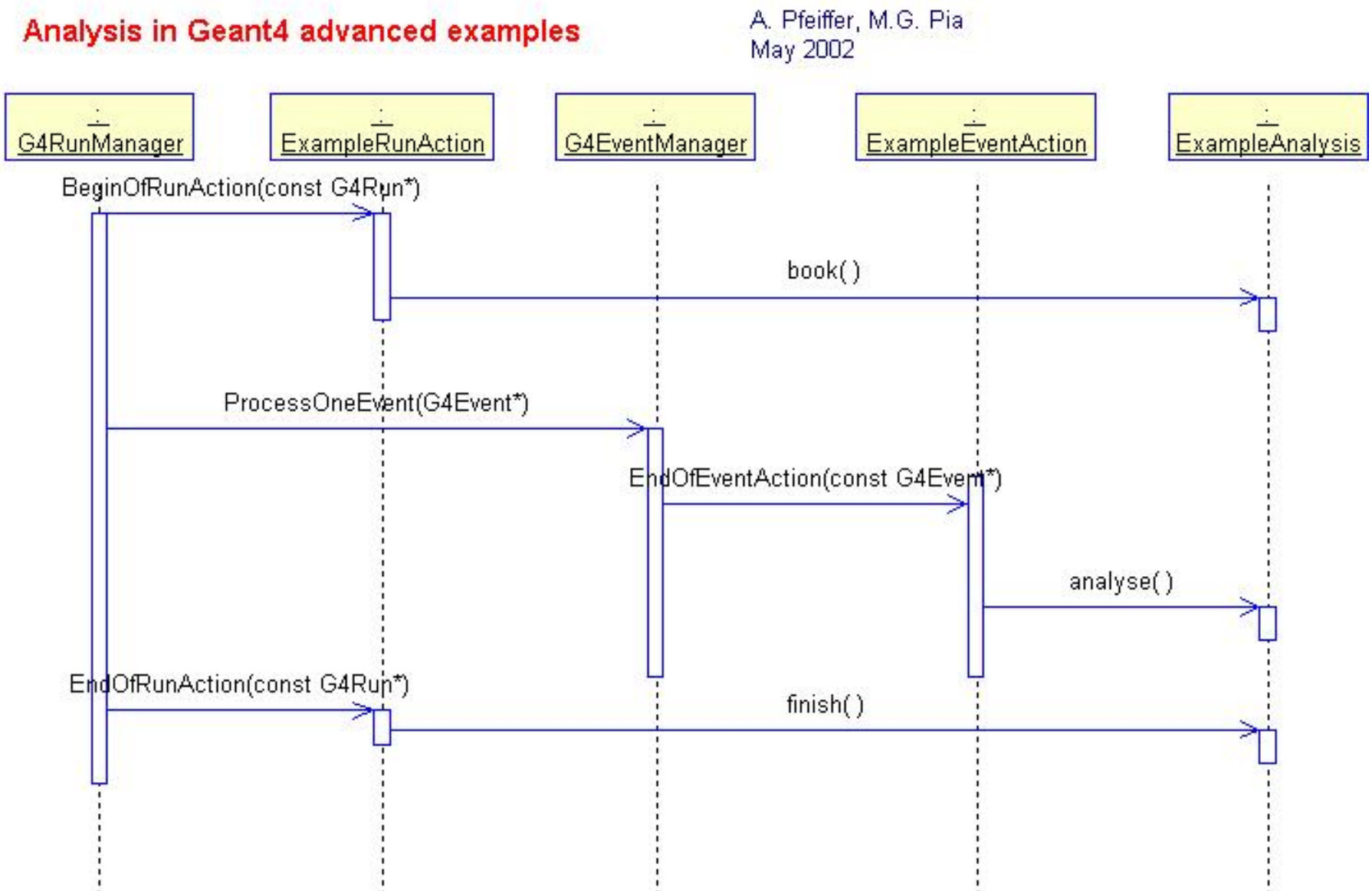
In the BrachyEventAction

Gamma energy spectrum

```
BrachyPrimaryGeneratorAction:: GeneratePrimaries(G4Event* anEvent)
{
  //Store the initial energy in a 1D histogram
  analysis-> PrimaryParticleEnergySpectrum(primaryParticleEnergy/keV);
  // generate primary particle
  …
}
```

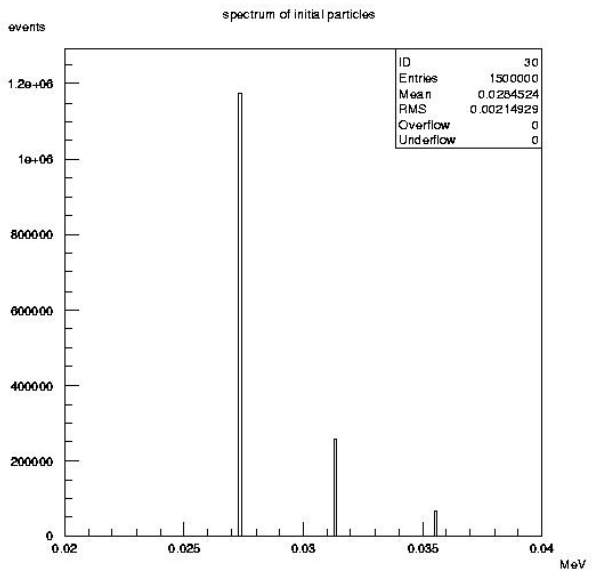
In the BrachyPrimaryGeneratorAction

Analysis dynamic flow

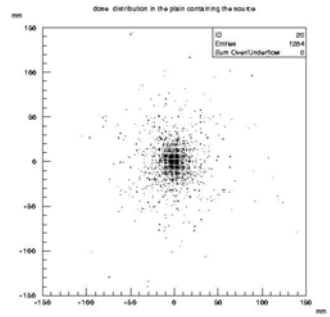


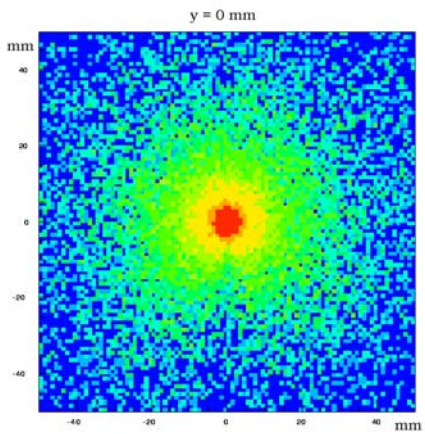
Some Results

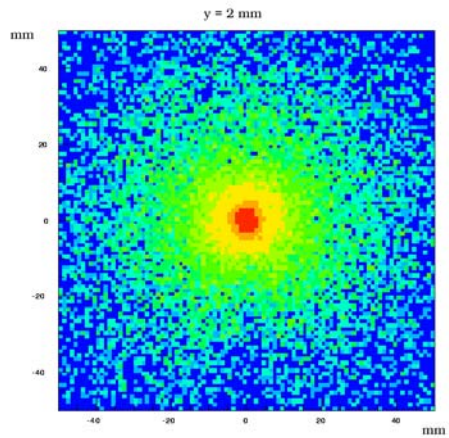
Primary particles
Energy Spectrum
(1D histogram)



Energy deposit
(2D histogram)







Control, monitor the simulation

BrachyDetectorMessenger

```
BrachyDetectorMessenger::BrachyDetectorMessenger( BrachyDetectorConstruction* Det):
detector(Det)

{   detectorDir = new G4UIdirectory("/phantom/");
  detectorDir->SetGuidance(" phantom control.");
  phantomMaterialCmd = new G4UIcmdWithAString("/phantom/selectMaterial",this);
  phantomMaterialCmd->SetGuidance("Select Material of the detector.");
  phantomMaterialCmd->SetParameterName("choice",false);
  phantomMaterialCmd->AvailableForStates(G4State_Idle);
 }

void BrachyDetectorMessenger::SetNewValue(G4UIcommand* command,G4String newValue)
{
  if( command == phantomMaterialCmd )
   { detector->SetPhantomMaterial(newValue);}
}
```

How to change phantom absorber material

(G)UI

How to change the phantom absorber material

- Run $G4WORKDIR/bin/Linux-g++/Brachy
- (G)UI session : interactive session
- Type /phantom/selectMaterial Lead

The phantom absorber material now is lead

Macro

- A macro is an ASCII file containing UI commands
- All commands must be given with their full-path directories

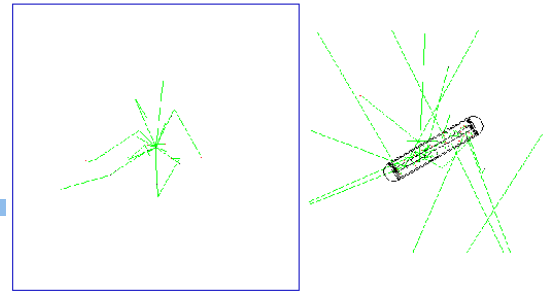
```
/control/verbose 1
/run/verbose 1
/event /verbose 1
/phantom/selectMaterial Lead

# run 10 events
/run/beamOn 10
```

A macro can be executed by
- `/control/execute`
- `/control/loop`
- `/control/foreach`

in UI session

A macro can be executed also typing:
$G4WORKDIR/bin/Linux-g++/Brachy macro.mac

Visualisation



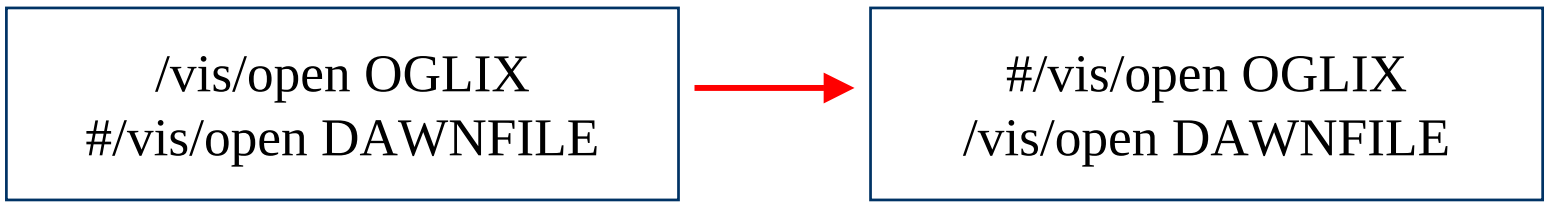
- Control of several kinds of visualisation
  - detector geometry
  - particle trajectories
  - hits in the detectors
- You can interface your Geant4 application with different visualisation packages
- VisualisationMacro.mac

```
# Macro file for the visualisation
# create empty scene
#
/vis/scene/create
vis/open OGLIX
/vis/viewer/flush
# for drawing the tracks
/tracking/storeTrajectory 1
/vis/scene/endOfEventAction accumulate
/vis/viewer/update
/run/initialize
/run/beamOn 10
```

More about visualisation

How to change driver:

in VisualisationMacro.mac



How to work with OGLIX:

At the |idle> prompt

- Type help
- Type the number corresponding to /vis/
- Information about visualization commands

Eg. rotation of the geometry
magnification…

How to work with DAWN:

The interactive panel appears:

- devices: choose the format of the image
- camera: choose the geometry parameters (rotation, magnification...)

Conclusions

In this tutorial it is shown

- How to develop a Geant4 application
  - UserRequirements
  - Design
  - Implementation
- How to run it
- How to define primary particles
- How to define experimental set-up
- How to build a sensitive detector
- How to produce histograms and ntuples
- How to control the simulation
- How to visualise the experimental set-up