Geant 4

Example of User Application

http://cern.ch/geant4

The full set of lecture notes of this Geant4 Course is available at
http://www.ge.infn.it/geant4/events/nss2003/geant4course.html

Software process

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

User Requirements

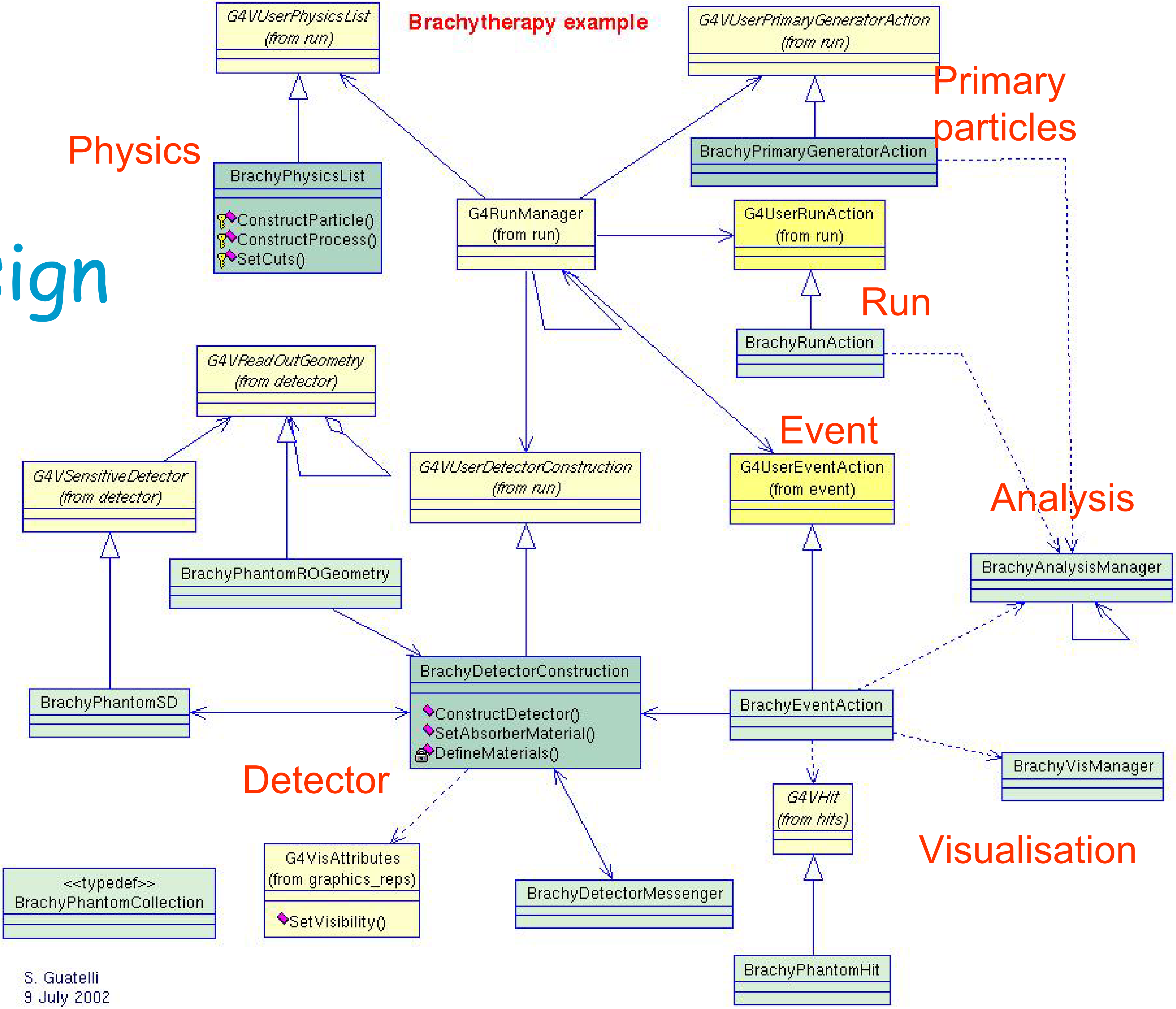
The application provides the simulation of energy deposit of a I-125 brachytherapic source in a phantom

- 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 voxels
- Physics
  1. Particles: e+,e-, gamma
  2. Low Energy 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

  1. The user shall be able to visualise the geometry involved and the trajectories of the particles
- Visualisation

OOAD

Design



Brachytherapy example

Physics

G4VUserPhysicsList
(from run)

BrachyPhysicsList
ConstructParticle()
ConstructProcess()
SetCuts()

G4RunManager
(from run)

G4VUserPrimaryGeneratorAction
(from run)

Primary particles

BrachyPrimaryGeneratorAction

G4UserRunAction
(from run)

Run

BrachyRunAction

G4VReadOutGeometry
(from detector)

G4VSensitiveDetector
(from detector)

BrachyPhantomROGeometry

G4VUserDetectorConstruction
(from run)

Event

G4UserEventAction
(from event)

Analysis

BrachyAnalysisManager

BrachyPhantomSD

BrachyDetectorConstruction
ConstructDetector()
SetAbsorberMaterial()
DefineMaterials()

BrachyEventAction

BrachyVisManager

Detector

G4VHit
(from hits)

Visualisation

<<typedef>>
BrachyPhantomCollection

G4VisAttributes
(from graphics_reps)
SetVisibility()

BrachyDetectorMessenger

BrachyPhantomHit

Geant 4

S. Guatelli
9 July 2002

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 …

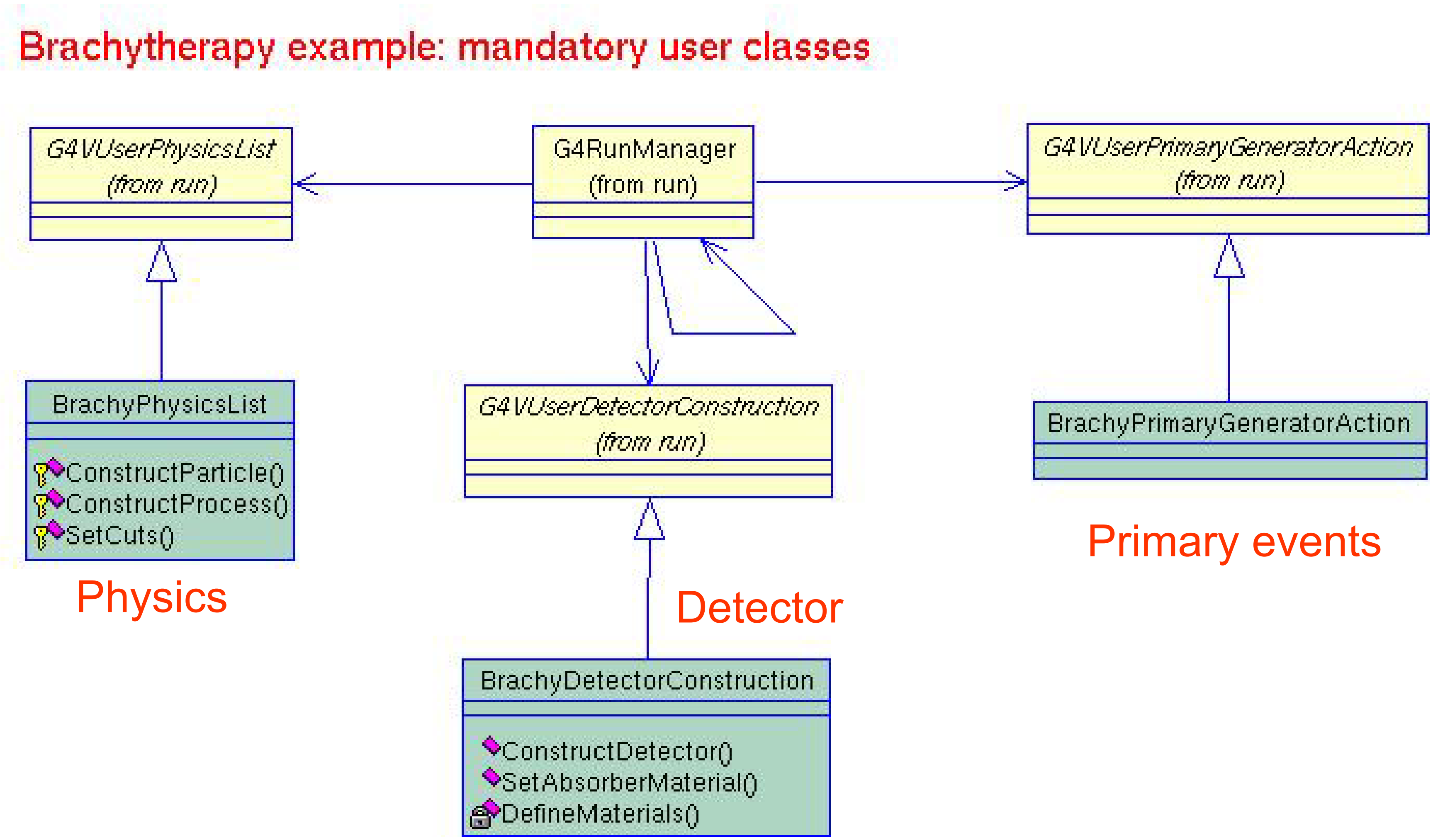
How to compile and link

gmake

How to run

$G4WORKDIR/bin/Linux/Brachy

Mandatory user classes

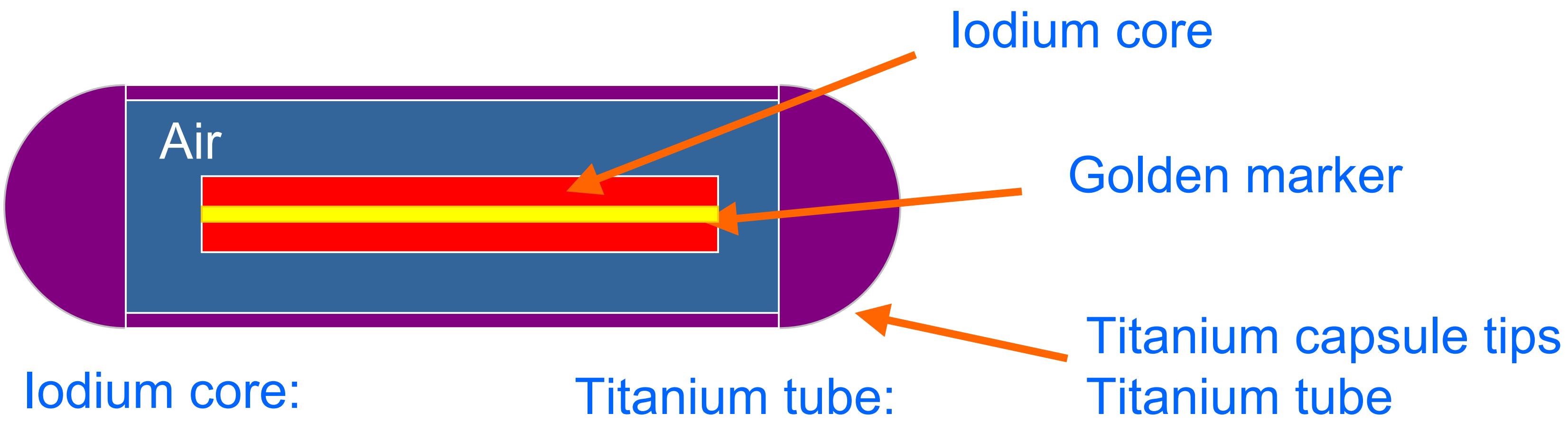


Physics

Detector

Primary events

BrachyDetectorConstruction



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

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

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

Titanium capsule tip:
Semisphere
radius:0.40mm

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

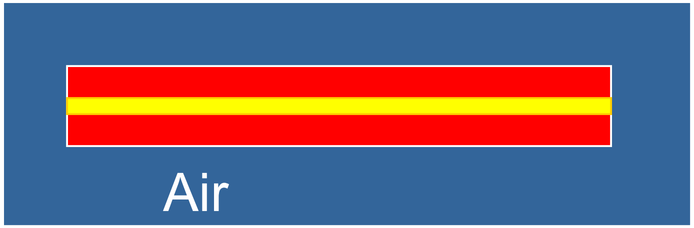
Model of a I-125 brachytherapic source geometry and materials

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();

}
```

BrachyPhysicsList
Set the EM processes

```
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);
  }
```

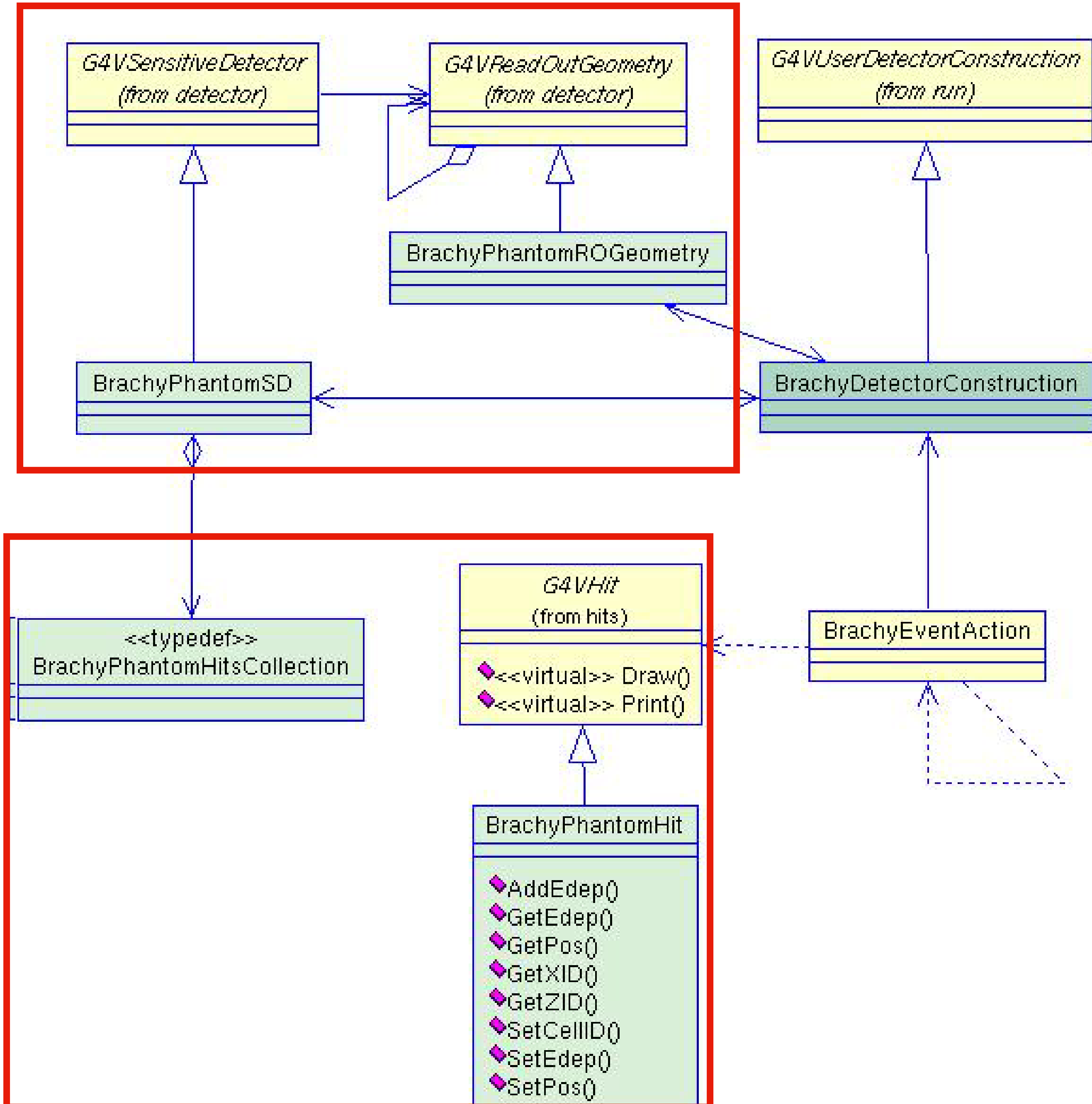
Brachytherapy example: detector response

Energy deposit

How to retrieve the energy deposit in the phantom

Concepts:

- Sensitive Detector
- Readout Geometry
- Hits



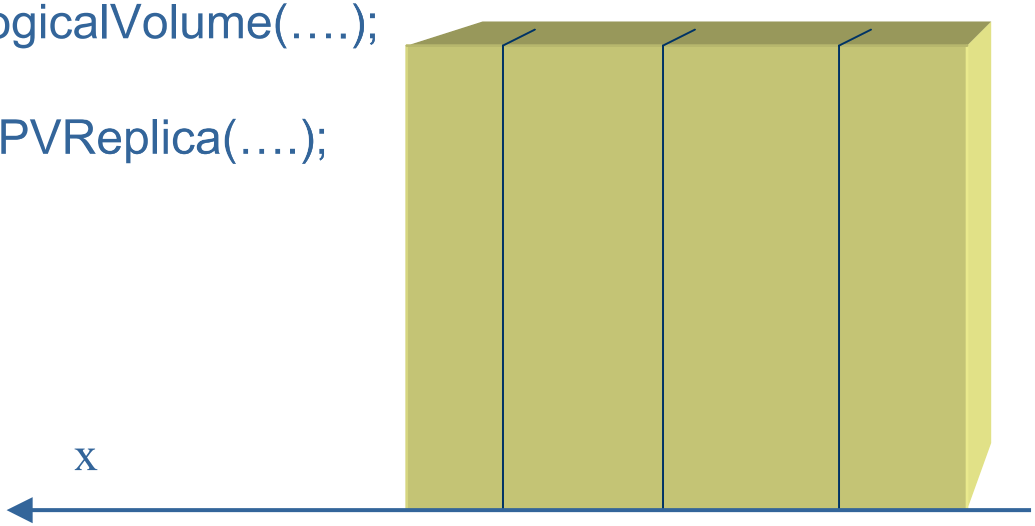
Geant 4

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);
 }
}
```

RO Geometry

```
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

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)

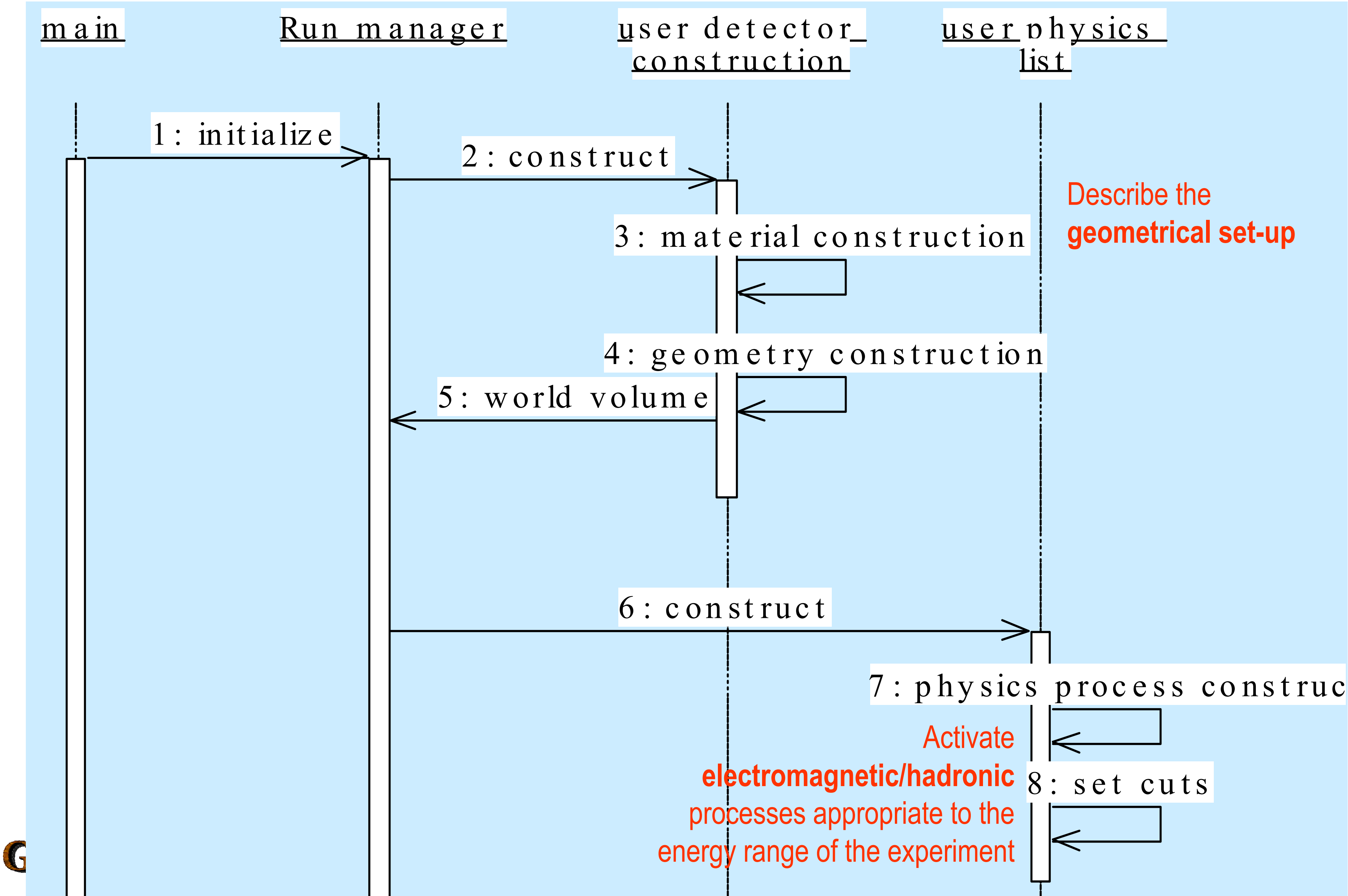
```
class BrachyPhantomHit : public G4VHit
{
public:
  BrachyPhantomHit(G4LogicalVolume* ,G4int ,G4int ,G4int );
  ~BrachyPhantomHit();
.....
 inline void SetCellID(G4int XID,G4int YID,G4int ZID) // Set Hit position
 {xHitPosition = XID; zHitPosition = ZID;  yHitPosition = YID;  }
 inline void SetEdep(G4double edep) {energyDeposit = edep;} //Set hit energy deposit
 inline void SetPos(G4ThreeVector xyz) {hitPosition = xyz;} // Set hit position

  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

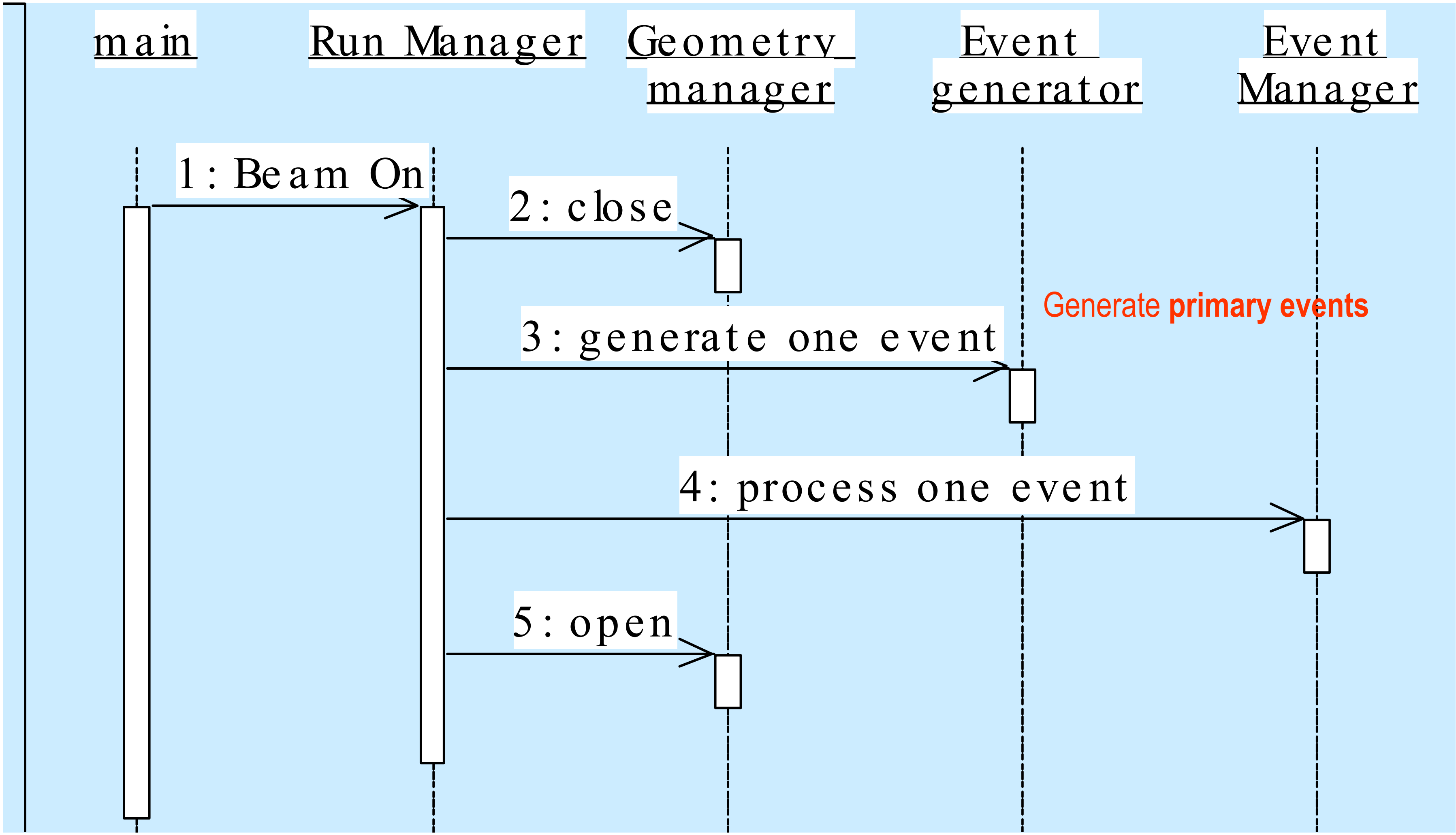
Initialisation


main
Run manager
user detector_ construction
user physics_ list
1 : initialize
2 : construct
3 : material construction
4 : geometry construction
5 : world volume
6 : construct
7 : physics process construc
8 : set cuts

Describe the **geometrical set-up**

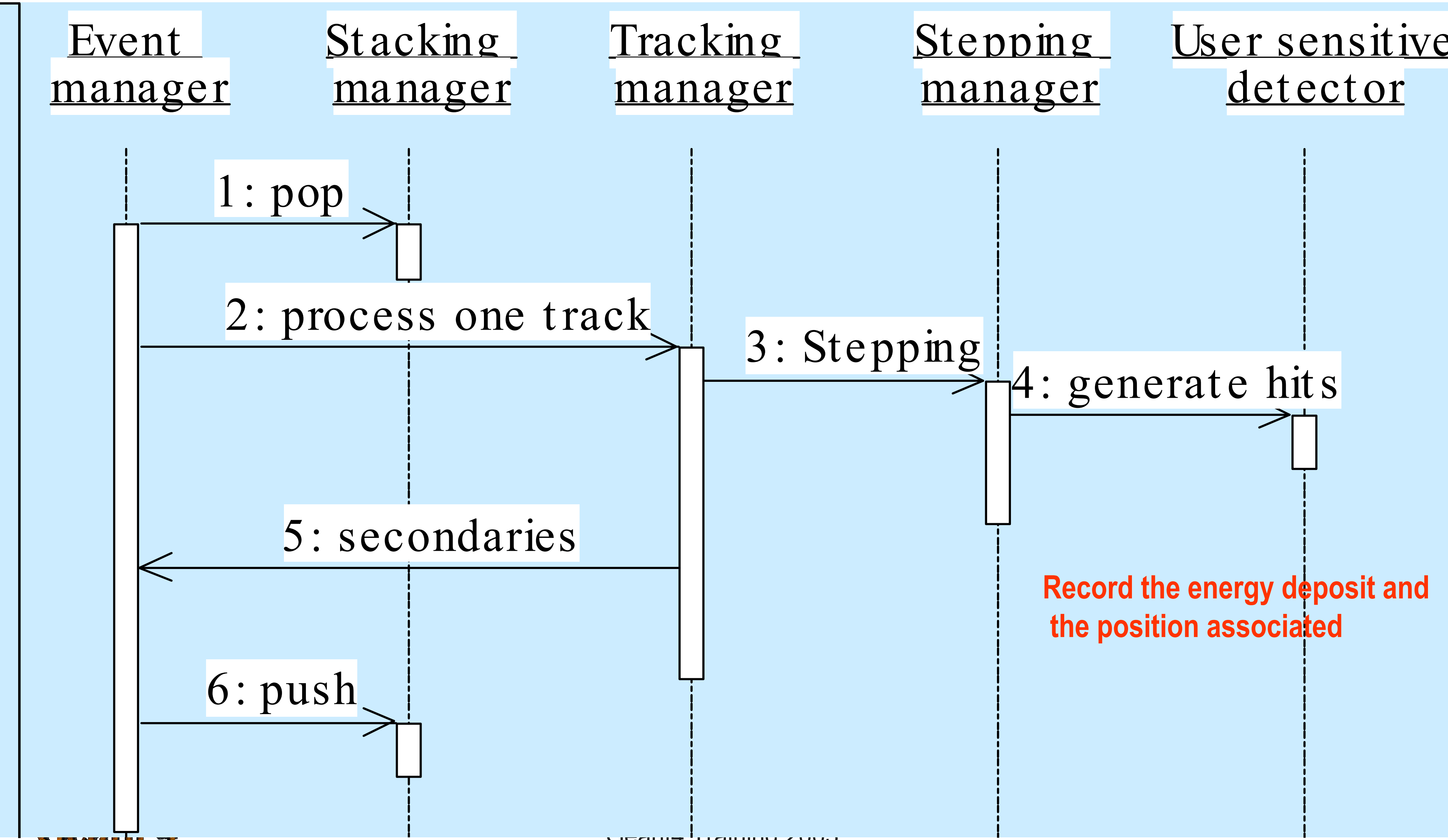
Activate **electromagnetic/hadronic** processes appropriate to the energy range of the experiment

Beam On



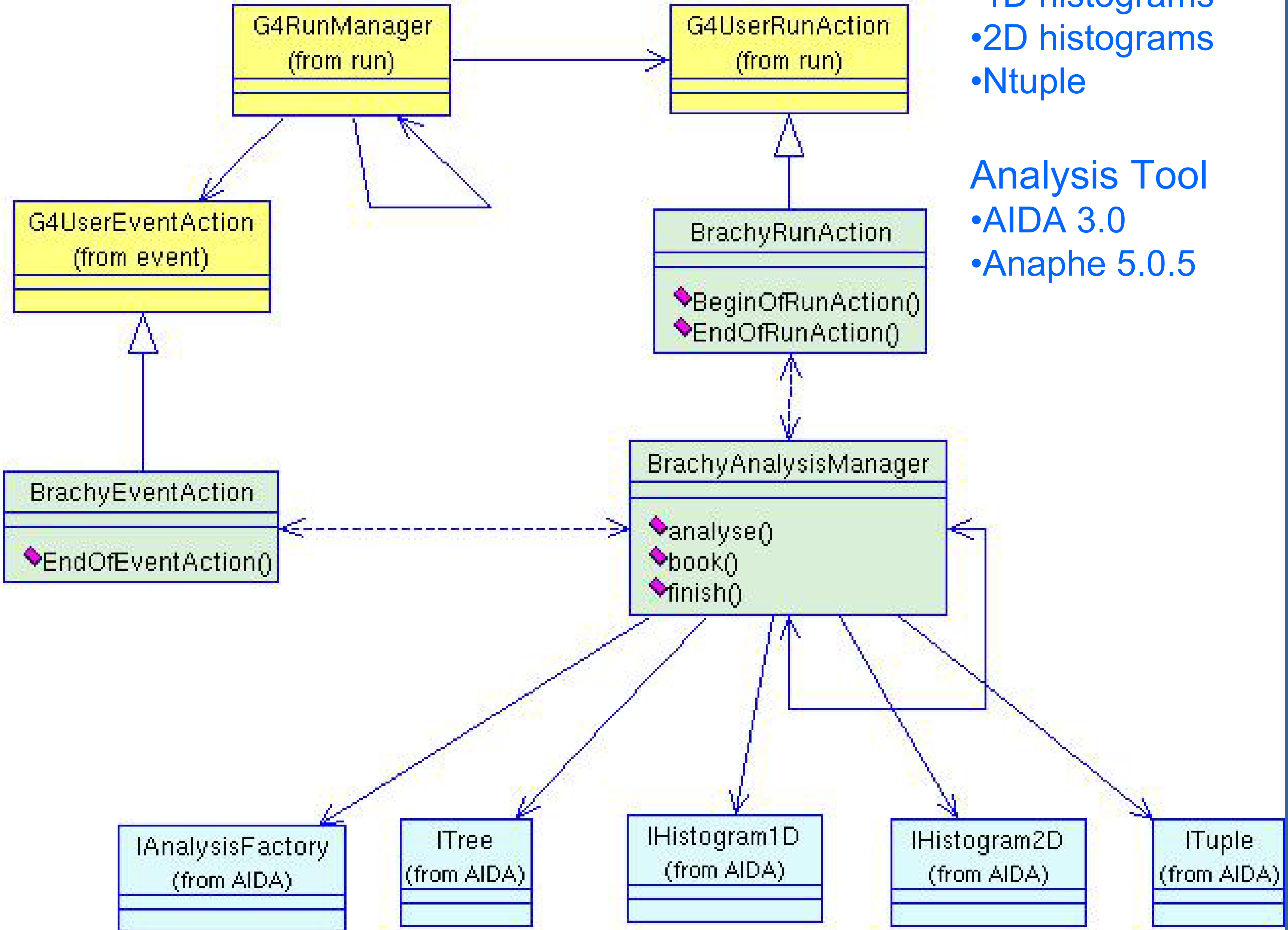
Generate **primary events**

Event processing



Record the energy deposit and the position associated

Brachytherapy example: analysis



How to produce

- 1D histograms
- 2D histograms
- Ntuple

Analysis Tool

- AIDA 3.0
- Anaphe 5.0.5

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 );
}
```

Create the .hbk file…

```
void BrachyAnalysisManager::finish()
{
theTree->commit(); // write all histograms to file ...
theTree->close(); // close (will again commit) ...
```

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 the 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

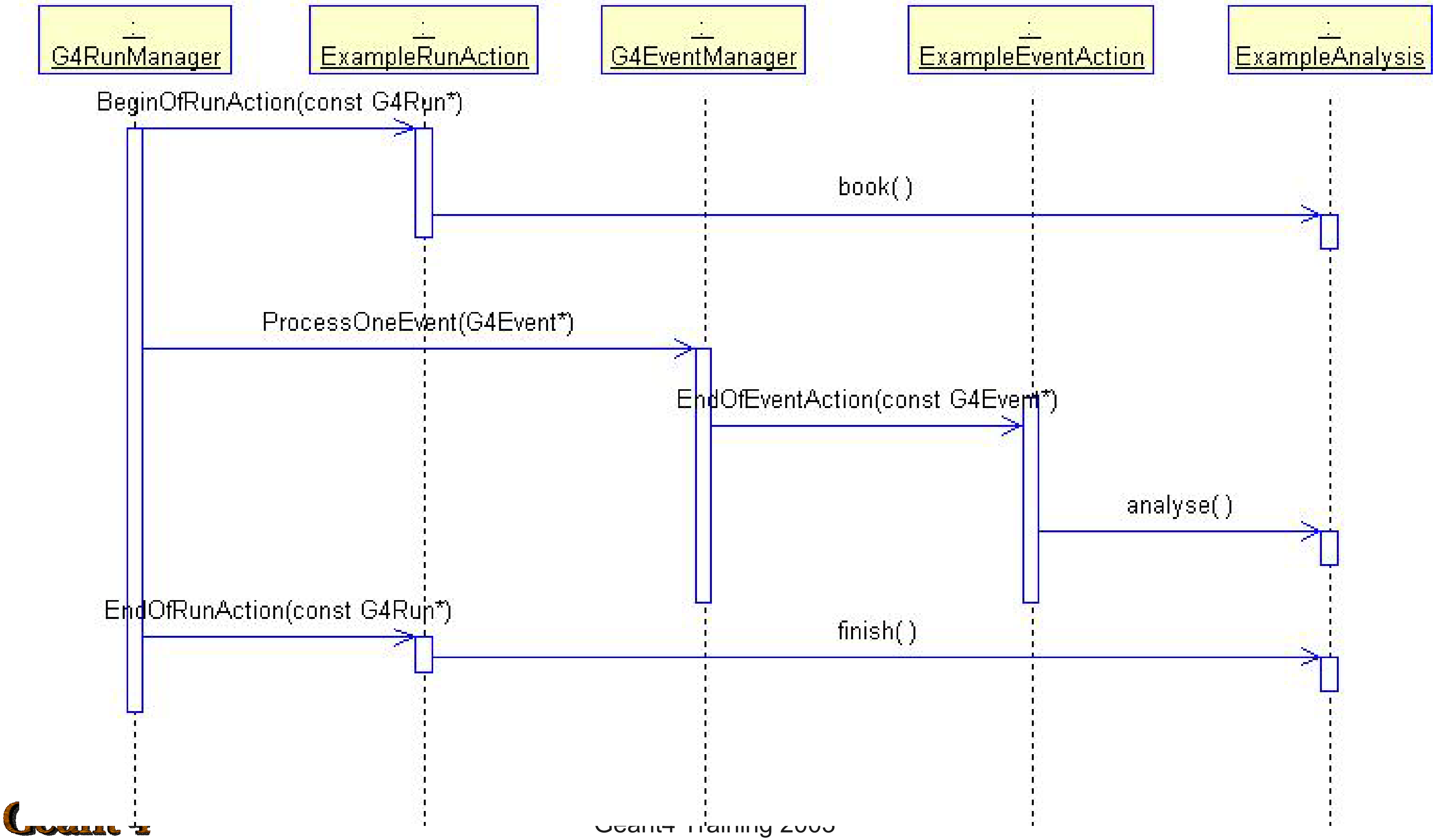
```
BrachyPrimaryGeneratorAction:: GeneratePrimaries(G4Event* anEvent)
{
  //Store the initial energy in a 1D histogram
  analysis-> PrimaryParticleEnergySpectrum(primaryParticleEnergy/keV);
  // generate primary particle
  …
}
```

In the BrachyPrimaryGeneratorAction

Analysis dynamic flow

Analysis in Geant4 advanced examples

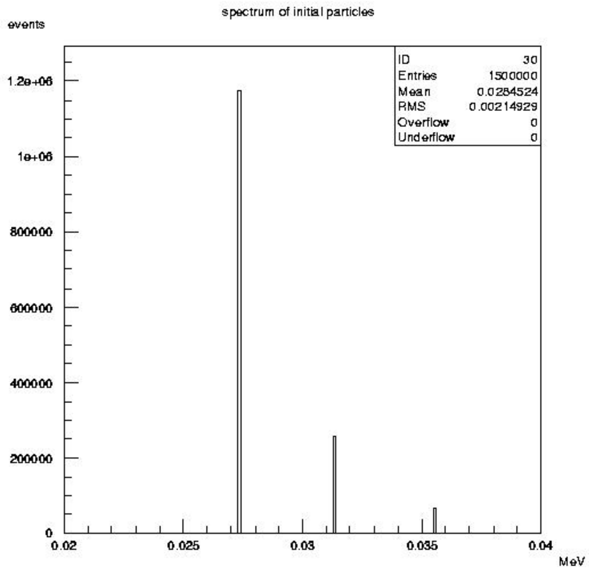
A. Pfeiffer, M.G. Pia
May 2002



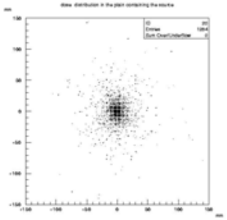
: G4RunManager
: ExampleRunAction
: G4EventManager
: ExampleEventAction
: ExampleAnalysis
BeginOfRunAction(const G4Run*)
book( )
ProcessOneEvent(G4Event*)
EndOfEventAction(const G4Event*)
analyse( )
EndOfRunAction(const G4Run*)
finish( )

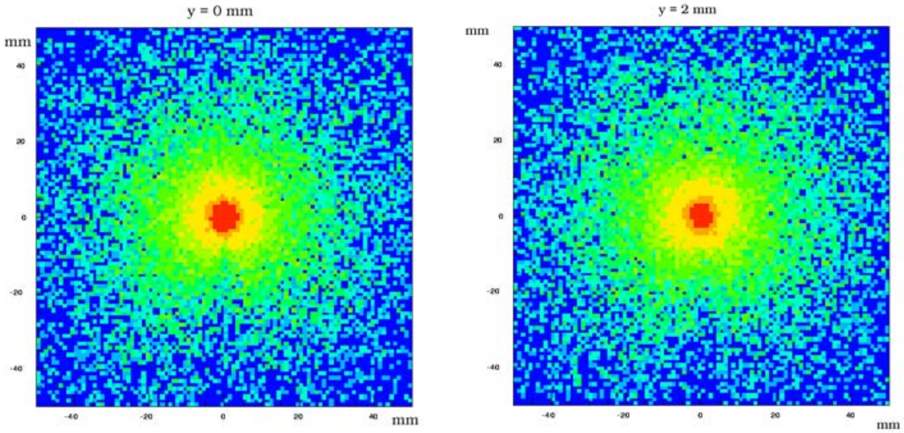
Some Results

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);}
}
```

(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

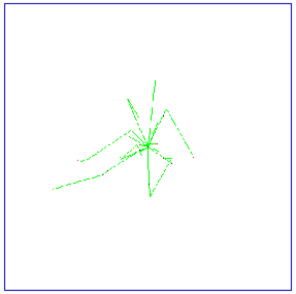
- `/control/execute`
- `/control/loop`
- `/control/foreach`

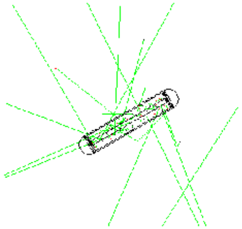
in UI session

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

- In the Brachytherapy Example OGLIX, DAWN

- VisualisationMacro.mac

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

Conclusions

- How to build up a Geant4 application
  - UserRequirements
  - Design
  - Implementation
- How to run it
- How to produce histograms and ntuples
- How to control the simulation
- Ho to visualise the experimental set-up