Geant4: A Simulation toolkit

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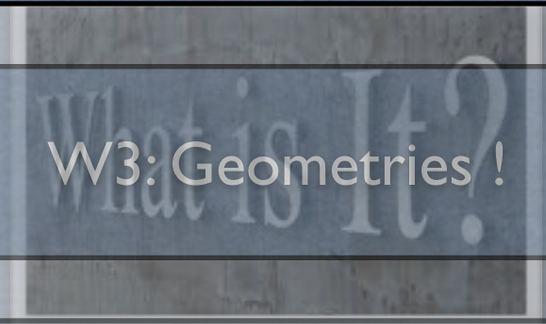
With many thanks to the Geant4 community !!!!

The roadmap of the week

W1: installation / running a G4 application

Why?

W2: Primary generator, GPS, physics list



W3: Geometries !

W4: Sensitive detectors / user's actions

w1: 3:00, Monday
w2: 3:00, Tuesday
w3: 4:30, Wednesday
w4: 3:00, Thursday

NOW, HOW does it really work ?

W2: Primary generator, GPS, physics list

Some general Geant4 aspects

Physics Lists tour

Definition of the Primary generator

G4ParticleGUN

G4GeneralParticleSource

System of units in Geant4

Geant4 has no default unit imposed to the user but all available

- To give a number, unit must be “multiplied” to the number. For example :

```
G4double width = 12.5*m;
G4double density = 2.7*g/cm3;
```

  - If no unit is specified, the internal G4 unit will be used, but **this is discouraged** !
  - Almost all commonly used units are available.
  - See: `G4SystemOfUnits.hh`

- Divide a variable by a unit you want to get.

```
G4cout << dE / MeV << “(MeV)”<< G4endl;
```

- To print the list of units:
  - From the code

```
G4UnitDefinition::PrintUnitsTable();
```

  - At run-time, as UI command:

```
Idle> /units/list
```

System of units in Geant4

- G4 internal system of units :

  millimetre (mm), nanosecond (ns), Mega eV (MeV), positron charge (eplus) degree Kelvin (kelvin), the amount of substance (mole), luminous intensity (candela), radian (radian), steradian (steradian)

- All other units are computed from the basic ones.
- In output, Geant4 can choose the most appropriate unit to use.
  Just specify the ***category*** for the data (Length, Time, Energy, etc…):

```
G4cout << G4BestUnit(StepSize, "Length");
```

  ➥ StepSize will be printed in km, m, mm or … fermi, depending on its value

- New units can be defined using `G4UnitDefinition`

How to write your command

We have seen one can interact with the simulation using UI commands
The technic in play is available for users using **Messengers**

In fact, it helps to modify selected parameters of a given C++ class:

- ➥ No need to re-compile
- ➥ Convenient, to chain simulations in one session

```
# run 1
/myparameter/set value1
/run/beamOn 1000
# run 2
/myparamteter/set value2
/run/beamOn 1000
...
```

- ➥ **It has a cost** ! some C++ code to be written by the user
- ➥ Do it if the parameter is modified often in your simulation

Ex: we would like to change MyParameter in the class MyGenerator

How to write your command

```
class MyGenerator: public G4VUserPrimaryGeneratorAction
{
private:
    G4int MyParameter;

...
public:
    void SetMyParameter(G4int new_parameter)
    {
      MyParameter = new_parameter;
    }
...
};
```

```
MyGenerator::MyGenerator()
{
      MyParameter = 0;
}
MyGenerator::MyGenerator()
{
}
```

This is the starting point to have a
MyGenerator class
with a parameter called
MyParameter ...

How to write your command

... and the requirements for a messenger:

/MyCommands/MyGenerator/MyParameter 10

```
class MyGeneratorMessenger;

class MyGenerator: public G4VUserPrimaryGeneratorAction
{
private:
    G4int MyParameter;
    MyGeneratorMessenger *theMessenger;
...
public:
    void SetMyParameter(G4int new_parameter)
    {
      MyParameter = new_parameter;
    }
...
};
```

```
MyGenerator::MyGenerator()
{
      MyParameter = 0;
      theMessenger = new MyGeneratorMessenger(this);
}
MyGenerator::MyGenerator()
{
    delete theMessenger;
}
```

```
#include "G4UImessenger.hh"

class G4UIdirectory;
class G4UIcmdWithAString;
class G4UIcmdWithAnInteger;

//! Messenger class for MyGenerator
class MyGeneratorMessanger: public G4UImessenger
{
public:
    MyGeneratorMessanger(MyGenerator *);
    ~ MyGeneratorMessanger();

    void SetNewValue(G4UIcommand*, G4String);

private:
    MyGenerator *theGenerator;

    G4UIdirectory *theDirectory;
    G4UIcmdWithAnInteger *Cmd;
};
```

```
MyGeneratorMessenger::MyGeneratorMessenger(MyGenerator *agene):
     theGenerator(agene)
{
    theDirectory = new G4UIdirectory("/MyCommands/MyGenerator");
    theDirectory->SetGuidance("List of all my commands");

    Cmd = new G4UIcmdWithAnInteger("/MyCommands/MyGenerator/MyParameter", this);
    Cmd->SetGuidance("To change the value of MyParameter");
    Cmd->SetGuidance("Required parameters: an integer");
    Cmd->AvailableForStates(G4State_PreInit,G4State_Idle);
}

MyGeneratorMessenger::~ MyGeneratorMessenger()
{
    delete theDirectory; delete Cmd;
}

void MyGeneratorMessenger::SetNewValue(G4UIcommand* command, G4String newValue)
{
    if( command == Cmd )
          theGenerator->SetMyParameter( Cmd->GetNewIntValue(newValue) );
}
```

The user's application

This is what we are going to see in the next slides

the primary generator - **the description of the physics**

```
class AGammaGun : public G4VUserPrimaryGeneratorAction
{
// the virtual method to be implemented by the user
    virtual void GeneratePrimaries(G4Event* anEvent);
};
```

```
class AnElectroMagneticPhysicsList: public G4VUserPhysicsList
{
// the virtual method to be implemented by the user
      void ConstructParticle();
// the virtual method to be implemented by the user
      void ConstructProcess();
// the virtual method to be implemented by the user
      void SetCuts();
};
```

```
// The User's main program to control / run simulations
int main(int argc, char** argv)
{
// Construct the run manager, necessary for G4 kernel to control everything
    G4RunManager *theRunManager = new G4RunManager();

// Then add mandatory initialization G4 classes provided by the USER
    // detector construction
    // physics  list
    // initialisation of the generator

    theRunManager->SetUserInitialization( new ARedSphereConstuction() );
    theRunManager->SetUserAction( new AGammaGun() );
      .
      .
    return 0;
}
```

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// Then add mandatory initialization G4 classes provided by the USER
    // detector construction
    // physics  list
    // initialisation of the generator

    theRunManager->SetUserInitialization( new AnElectroMagneticPhysicsList() );
.
.
    return 0;
}
```

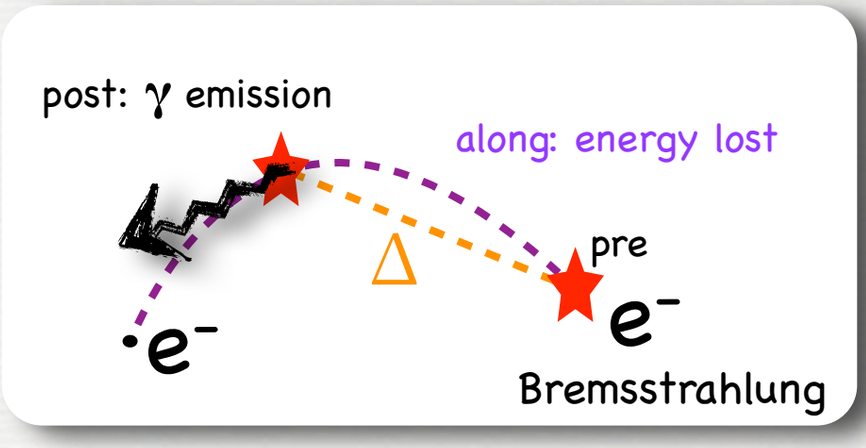
The Physics Lists

The user's class defines **all the particles** and **all the physics** they can see

It includes **Primaries** and **Secondaries**

To each kind of particle a list of processes is attached

- ➥ **atomistic approach**: not all the physics into the box!
- ➥ models in physics are always evolving
- ➥ medical physics not the same that HEP physics !
- ➥ for a given interaction, **it allows several models for different energy ranges**
- ➥ computation speed is an issue



Process description in Geant4 based on Along, Post and At Rest actions.
Some process belongs to one category while others belong to more. Ex:

- Discrete process: **Compton Scattering, hadronic inelastic, ...**
  - ➥ step determined by cross section, interaction at end of step
- Continuous process: **Cerenkov effect**
  - ➥ photons created along step, roughly proportional to step length
- At rest process: **radioactive decay of nuclei**
  - ➥ interaction at rest

these processes belong to one category

- Rest + discrete: **positron annihilation, decay**, ...
  - ➥ both in flight and at rest
- Continuous + discrete: **ionization**
  - ➥ energy loss is continuous
  - ➥ knock-on electrons (δ-ray) are discrete

these processes belong to two categories

Overview of processes provided

- EM physics
  - "standard" processes valid from ~ 1 keV to ~PeV
  - "low energy" valid from 250 eV to ~PeV
  - optical photons ⚠
- Weak interaction physics
  - decay of subatomic particles
  - radioactive decay of nuclei
- Hadronic physics
  - pure strong interaction physics valid from 0 to ~TeV
  - electro- and gamma-nuclear valid from 10 MeV to ~TeV
- Parameterized or "fast simulation" physics

What is to be used for your physics is out of this lecture!

Overview of processes provided

- EM physics
  - "standard" proces
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- Weak interaction phy
  - decay of subatomi
  - radioactive decay
- Hadronic physics
  - pure strong intera
  - electro- and gamm
- Parameterized or "fa

Two possible approaches

- The **G4VUserPhysicsList** class
  historically, available from the beginning
  to do the definition at a fine level (per particle) ...
  could be long, hard to maintain ...

- Using **G4VModularPhysicsList***
  physics organized in modules (EM, optical physics...)
  A convenient way to go !

There are pre-packaged physics lists provided:

➥ based on modular physics lists

➥ ***This is not the truth !!!***

* **G4VModularPhysicsLists itself inherits from G4VUserPhysicsList ...**

What is to be used for your physics is out of this lecture!

The user's Physics List

```
class AnElectroMagneticPhysicsList: public G4VUserPhysicsList
{
// the virtual method to be implemented by the user
   void ConstructParticle();
// the virtual method to be implemented by the user
   void ConstructProcess();
// the virtual method to be implemented by the user
   void SetCuts();
};
```

Note - In Geant4, different objects for 'particles'

G4VDynamicParticle: to describe a particle interacting with materials
aggregates information to describe the dynamic of particles (energy, momentum, polarization, etc…)

G4ParticleDefinition: to define a particle
aggregates information to characterize a particle's properties (name, mass, spin, etc…) ☛ singleton in C++

```
void AnElectroMagneticPhysicsList::SetCuts()
{
  defaultCutValue = 0.1 * mm;
  // set cut values for gamma at first and for e- second and next for e+,
  // because some processes for e+/e- need cut values for gamma
  //
  SetCutValue(defaultCutValue, "gamma");
  SetCutValue(defaultCutValue, "e-");
  SetCutValue(defaultCutValue, "e+");
  SetCutValue(defaultCutValue, "proton");

  if (verboseLevel>0) DumpCutValuesTable();
}
```

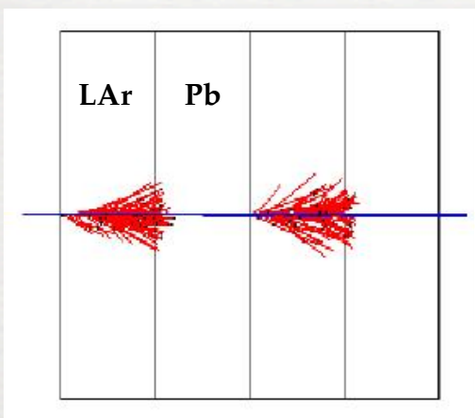
```
void AnElectroMagneticPhysicsList::ConstructParticle()
{
  // This ensures that objects of these particle types will be
  // created in the program.
  G4Gamma::GammaDefinition();
  G4Electron::ElectronDefinition();
  G4Positron::PositronDefinition();
  G4MuonPlus::MuonPlusDefinition();
  G4MuonMinus::MuonMinusDefinition();
  ...
}
```

or

```
void AnElectroMagneticPhysicsList::ConstructParticle()
{
  // construction per type of particles
  G4BosonConstructor  pBosonConstructor;
  pBosonConstructor.ConstructParticle();

  G4LeptonConstructor pLeptonConstructor;
  pLeptonConstructor.ConstructParticle();

  G4MesonConstructor pMesonConstructor;
  pMesonConstructor.ConstructParticle();
}
```



500 MeV proton in LAr/Pb calo.

- 1.5*mm global cut
  ☛ 455 keV in LAr / 2MeV in Pb
- cuts per region is also possible
  ☛ see lecture on geometry

The user's Physics List

```
void AnElectroMagneticPhysicsList::ConstructProcess()
{
  // ############## TRANSPORTATION ###############
  AddTransportation();

  // ########## ELECTROMAGNETIC PROCESSES ##########
  G4PhysicsListHelper *ph =
      G4PhysicsListHelper::GetPhysicsListHelper();
  theParticleIterator->reset();
  while( (*theParticleIterator)() ){
    G4ParticleDefinition* particle = theParticleIterator->value();
    G4String particleName = particle->GetParticleName();

    // define EM physics for gamma
    if (particleName == "gamma") {
      // activate photoelectric effect
      ph->RegisterProcess(new G4PhotoElectricEffect, particle);
      // activate Compton scattering
      G4ComptonScattering* cs   = new G4ComptonScattering;
      cs->SetEmModel(new G4KleinNishinaModel());
      ph->RegisterProcess(cs, particle);
      // activate gamma conversion
      ph->RegisterProcess(new G4GammaConversion, particle);
    }
    ...
}
...
```

or

```
AModularElectroMagneticPhysicsList::AModularElectroMagneticPhysicsList()
      : G4VModularPhysicsList()
{
     // default cut value  (1.0mm)
     defaultCutValue = 1.0*mm;
     RegisterPhysics( new G4EmStandardPhysics(1) );
     // Muon Physics ( Apply related processes to mu and tau
     RegisterPhysics( new MyNeutronPhysics("neutron") );
}

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

```
class MyNeutronPhysics : public G4VPhysicsConstructor
{
    MyNeutronPhysics(const G4String& name="neutron");
    // This method will be invoked in the Construct() method.
    virtual void ConstructProcess();
};
```

here ConstructProcess() contains something similar to the left window !!!!

Whatever the method

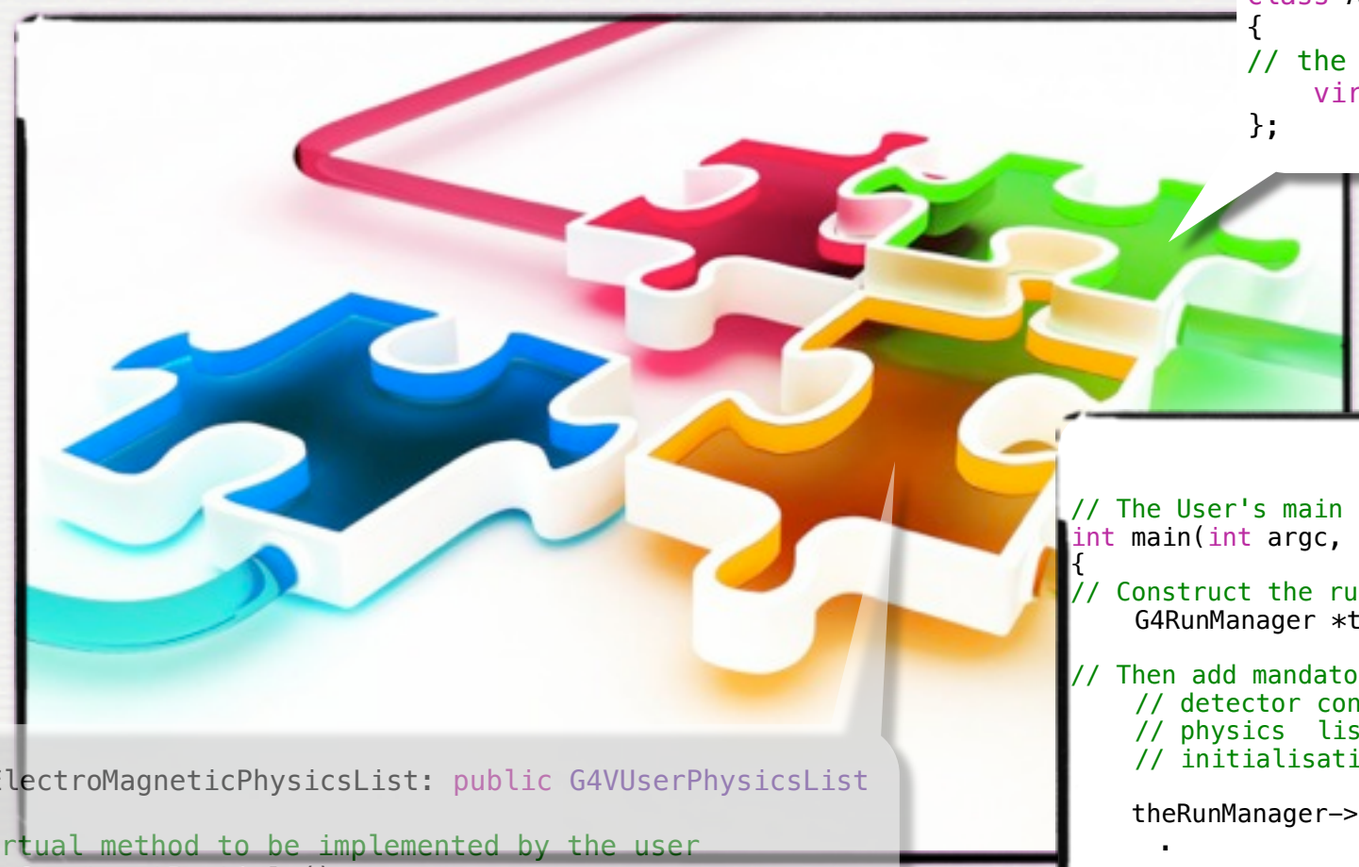
```
// The User's main program to control / run simulations
int main(int argc, char** argv)
{
// Construct the run manager, necessary for G4 kernel to control everything
    G4RunManager *theRunManager = new G4RunManager();
// Then add mandatory initialization G4 classes provided by the USER
  // First method
  theRunManager->SetUserInitialization(new AnElectroMagneticPhysicsList());
  // OR second method
  theRunManager->SetUserInitialization(new AModularElectroMagneticPhysicsList());
  // OR directly a pre-packaged physics list ...
  G4VModularPhysicsList * aphysicsList = new FTFP_BERT();
  theRunManager->SetUserInitialization( aphysicsList );
 .
}
```

Many pre-packaged **PhysicsLists** available:
http://geant4.cern.ch/support/proc_mod_catalog/physics_lists/physicsLists.shtml

The user's application

This is what we are going to see in the next slides

the primary generator - **the description of the physics**



```
class AGammaGun : public G4VUserPrimaryGeneratorAction
{
// the virtual method to be implemented by the user
    virtual void GeneratePrimaries(G4Event* anEvent);
};
```

```
class AnElectroMagneticPhysicsList: public G4VUserPhysicsList
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// The User's main program to control / run simulations
int main(int argc, char** argv)
{
// Construct the run manager, necessary for G4 kernel to control everything
     G4RunManager *theRunManager = new G4RunManager();

// Then add mandatory initialization G4 classes provided by the USER
     // detector construction
     // physics  list
     // initialisation of the generator

     theRunManager->SetUserAction( new AGammaGun() );
       .
       .
     return 0;
}
```

G4 Primary Generators

- To **provide primary events to the simulation**, the user should provide a class which inherits from G4VUserPrimaryGeneratorAction
- This class **controls the generation of primaries**
  What kind of particle (how many) what energy, position, direction, polarisation, etc
- This class itself **should NOT generate primaries but invoke `GeneratePrimaryVertex()`** method of primary generator(s) to make primaries (G4VPrimaryGenerator)
- Thus, in principle, the constructor is used to
  Instantiate primary generator(s)
  Set default values to it (them)
- In the **`GeneratePrimaries()`** method
  Randomize particle-by-particle value(s)
  Set these values to primary generator(s)
  Invoke **`GeneratePrimaryVertex()`** method of primary generator(s)

The G4ParticleGun

- G4ParticleGun is one Concrete implementations of G4VPrimaryGenerator
  A good example for experiment-specific primary generator implementation

- It shoots
  one primary particle of a certain energy from a certain point at a certain time
  to a certain direction.
  - Various set methods are available
  - Intercoms commands* are also available for setting initial values

- G4ParticleGun is basic, but it can be used from inside UserPrimaryGeneratorAction to model complex source types / distributions:
  - Generate the desired distributions (by shooting random numbers)
  - Use set methods of G4ParticleGun
  - Use G4ParticleGun as many times as you want
  - Use other primary generators as many times as you want to make overlapping events

The G4ParticleGun

Example of usage of **G4ParticleGun**

In MyPrimaryGeneratorAction.cc

```
MyPrimaryGeneratorAction::MyPrimaryGeneratorAction()
{
      particleGun = new G4ParticleGun();
}


void MyPrimaryGeneratorAction::GeneratePrimaries(G4Event* anEvent)
{
    particleGun->SetParticleDefinition(G4Electron::Definition());
    particleGun->SetParticleMomentum(G4ThreeVector(1.0,0,0));
    particleGun->SetParticleEnergy(100.0*keV);
    particleGun->GeneratePrimaryVertex(anEvent);
}
```

You can repeat this for generating more than one primary particles.

➥ several **G4ParticleGun** in action

The G4GeneralParticleSource GPS*

GPS is an advanced concrete implementation of G4VPrimaryGenerator
It offers as pre-defined many common (and not so common) options for particle generation

- Primary vertex can be randomly positioned with options
  Point, *Beam, Plane (Circle, Annulus, Ellipsoid, Square or Rectangle)*
  Surface or *Volume (Sphere, Ellipsoid, Cylinder or Para)*
- Angular emission can be
  isotropic (iso), cosine-law (cos), planar wave (planar), 1-d accelerator beam (beam1d),
  2-d accelerator beam (beam2d), focusing to a point (focused) or user-defined (user)
- Kinetic energy of the primary particle can also be randomized.
  mono-energetic (Mono), linear (Lin), power-law (Pow), exponential (Exp), Gaussian (Gauss),
  bremsstrahlung (Brem), black-body (Bbody), cosmic diffuse gamma ray (Cdg), user-defined histogram (User),
  arbitrary point-wise spectrum (Arb) and user-defined energy per nucleon histogram (Epn)
- Multiple sources
  With user defined relative intensity
- Capability of event biasing (variance reduction).
  By enhancing particle type, distribution of vertex point, energy and/or direction
- All features can be used via C++ or command line (or macro) UI

* **http://reat.space.qinetiq.com/gps/**

The G4GeneralParticleSource GPS

On the user's side, the G4VUserPrimaryGeneratorAction is very simple to implement

In MyGPSPrimaryGeneratorAction.cc

```
MyGPSPrimaryGeneratorAction::MyGPSPrimaryGeneratorAction()
{
        m_particleGun = new G4GeneralParticleSource();
}

MyGPSPrimaryGeneratorAction::~MyGPSPrimaryGeneratorAction()
{
        delete m_particleGun;
}

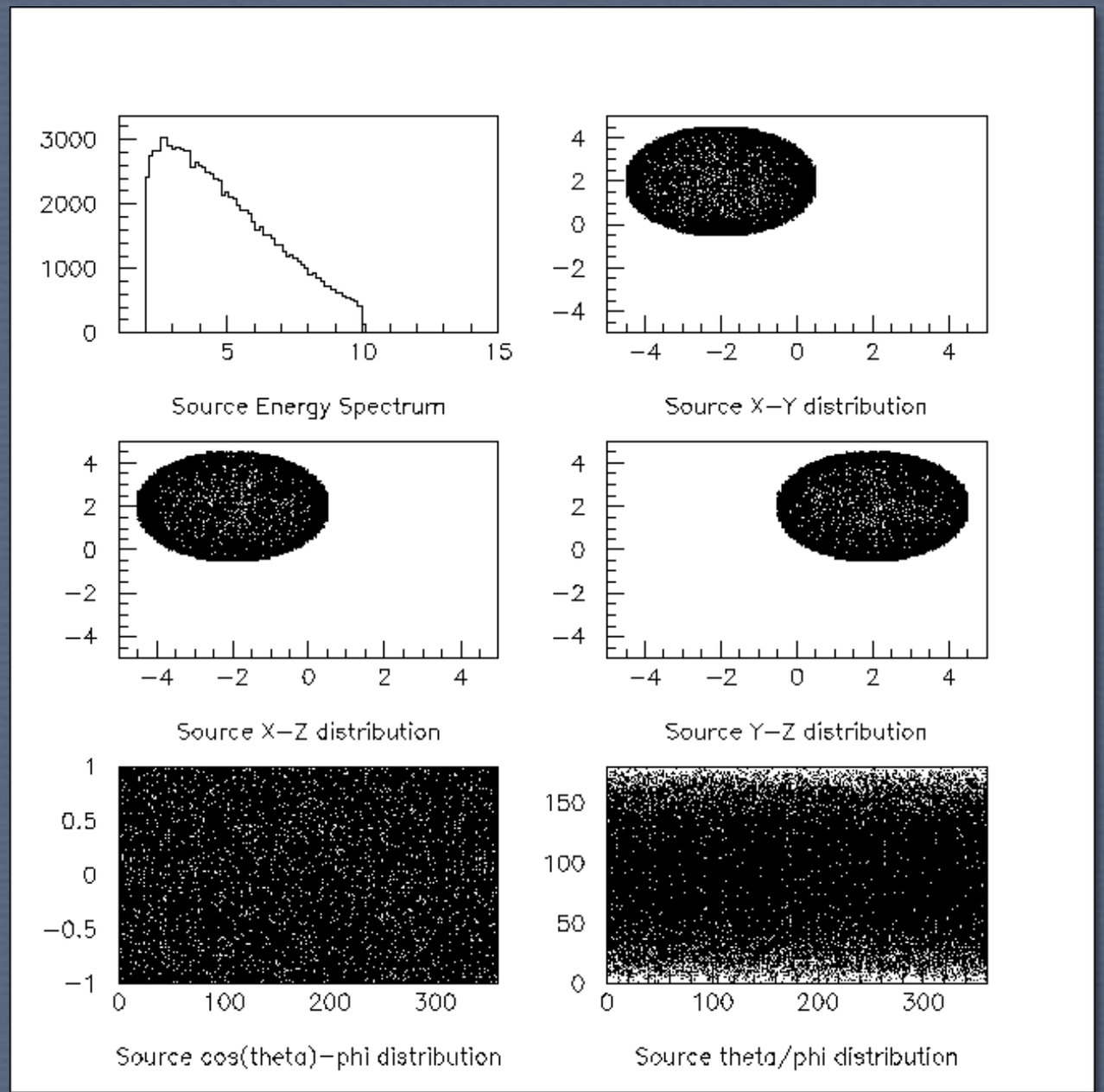
void MyGPSPrimaryGeneratorAction::GeneratePrimaries(G4Event* anEvent)
{
        m_particleGun->GeneratePrimaryVertex(anEvent);
}
```

The G4GeneralParticleSource GPS

- Vertex on sphere surface
- Isotropic emission
- Pre-defined spectrum (black-body)

<u>G4 macro to do that</u>

```
/gps/particle geantino
/gps/pos/type Surface
/gps/pos/shape Sphere
/gps/pos/centre -2. 2. 2. cm
/gps/pos/radius 2.5 cm
/gps/ang/type iso
/gps/ene/type Bbody
/gps/ene/min 2. MeV
/gps/ene/max 10. MeV
/gps/ene/temp 2e10
/gps/ene/calculate
```



The G4GeneralParticleSource GPS

G4 macro to do that

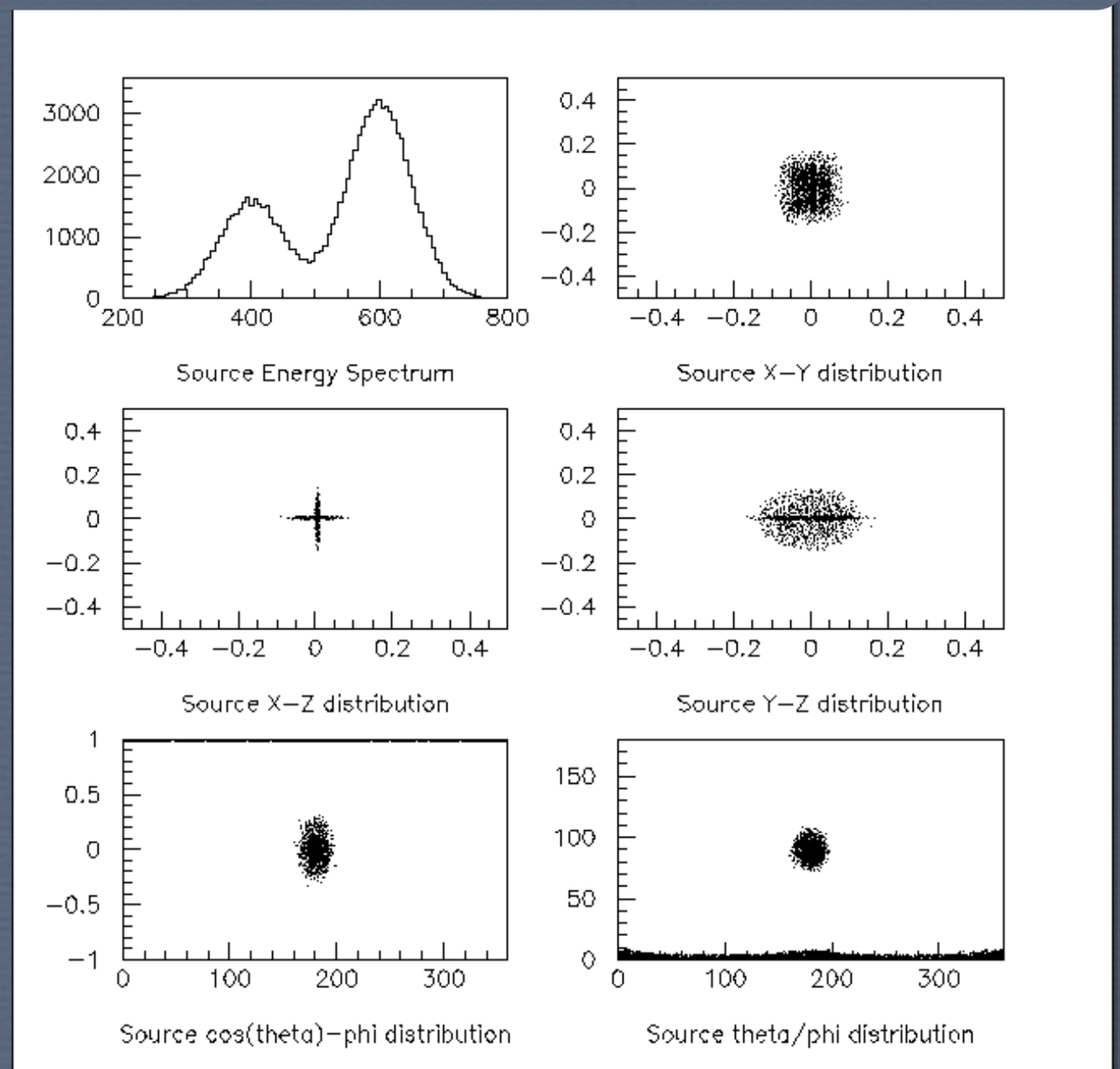
```
# beam #1
      # default intensity is 1 now change to 5.
      /gps/source/intensity 5.

      /gps/particle proton
      /gps/pos/type Beam

      # the incident surface is in the y-z plane
      /gps/pos/rot1 0 1 0
      /gps/pos/rot2 0 0 1

      # the beam spot is centered at the origin and is
      # of 1d gaussian shape with a 1 mm central plateau
      /gps/pos/shape Circle
      /gps/pos/centre 0. 0. 0. mm
      /gps/pos/radius 1. mm
      /gps/pos/sigma_r .2 mm
      #
      # the beam is travelling along the X_axis with 5 degrees dispersion
      /gps/ang/rot1 0 0 1
      /gps/ang/rot2 0 1 0
      /gps/ang/type beam1d
      /gps/ang/sigma_r 5. deg
      #
      # the beam energy is in gaussian profile centered at 400 MeV
      /gps/ene/type Gauss
      /gps/ene/mono 400 MeV
      /gps/ene/sigma 50. MeV
# beam #2
      # 2x the instensity of beam #1
      /gps/source/add 10.
      #
      # this is a electron beam
      ...
```

- Two-beam source definition (multiple sources)
- Gaussian profile
- Can be focused / defocused



The user's application

TODO List

- Go and see the available physics lists.
  Load them in the simulation and check the content with UI commands

- Write your own generator using G4ParticleGun
  isotropic gamma or neutron or proton depending of one parameter
  change the parameter using messengers

- Write an interface to G4GeneralParticleSource. Run with:
  - ➥ a spherical surface source, isotropic radiation, black-body energy
  - ➥ a rotated parallelepiped volume source, isotropic radiation, bremsstrahlung energy

- The file XXX contains geantino. The format is X Y Z Dx Dy Dz
  ➥ Write a generator reading the file, characterize the sources

Conclusions of w2

We have seen:

- how to write messengers
- an overview of the G4 physics list
  - ➥ customize if it is required
  - ➥ **use pre-defined ones**
- how to write different **generators of primaries**
  - ➥ there are also 2 primary generators dedicated to HEP
  - ➥ **G4HEPEvtInterface, G4HEPMCInterface**