# Geant4: A Simulation toolkit

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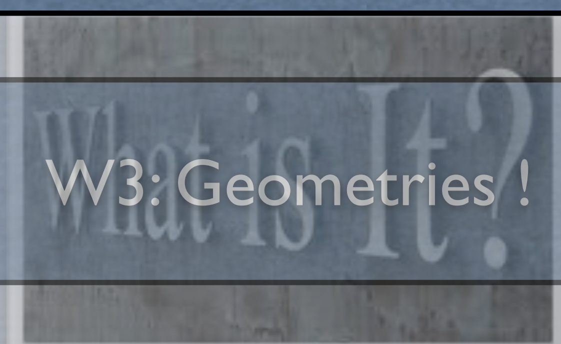
With many thanks to the Geant4 community !!!!

# The roadmap of the week

- W1: installation / running a G4 application
- **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;
};
```

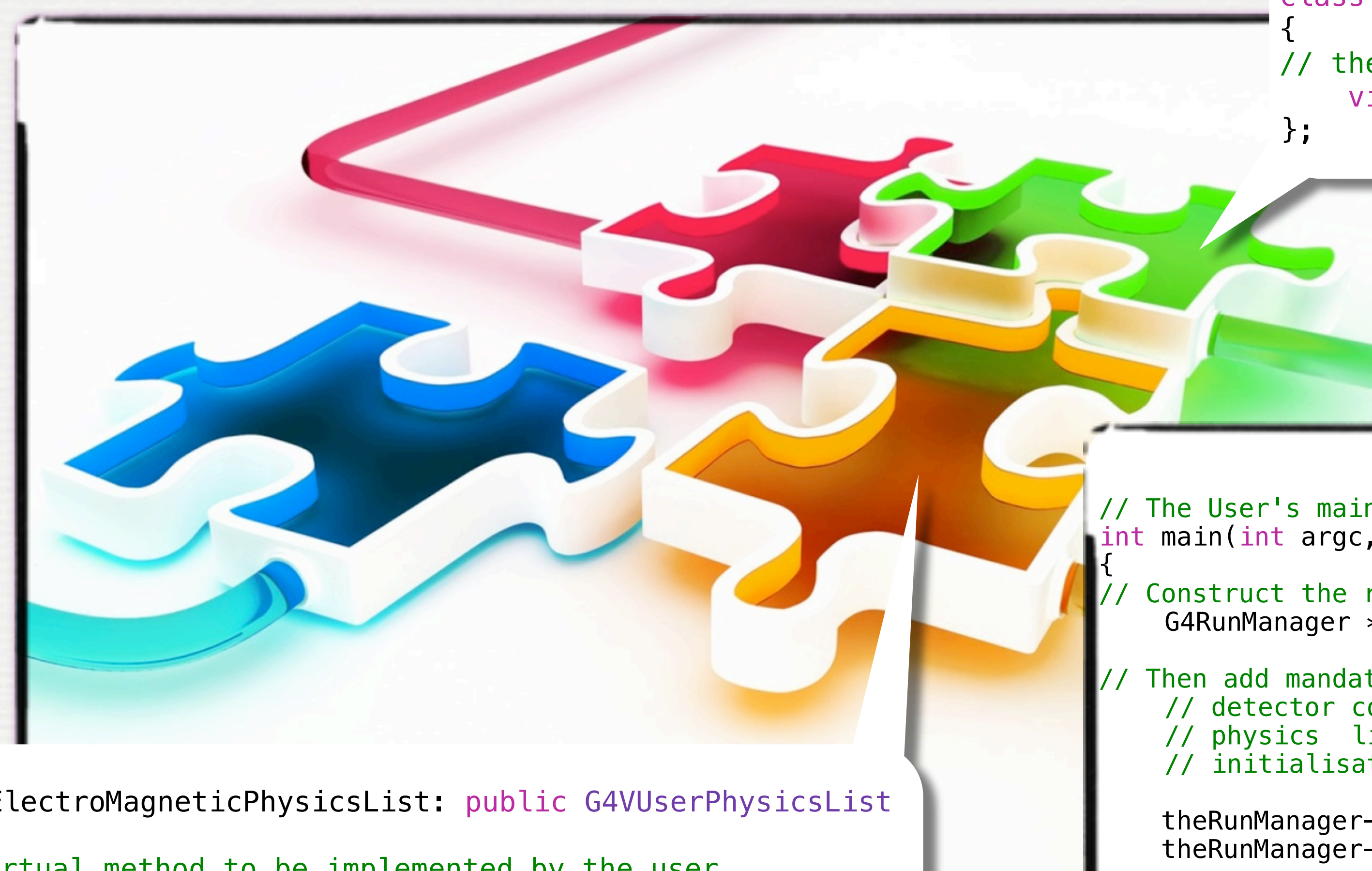
```
MyGeneratorMessenger::MyGeneratorMessenger(MyGenerator *agene):
     theGenerator(agene)
{
    theDirectory = new G4UIdirectory("/MyCommands/MyGenerator");
    theDirectory->SetGuidance("List of all my commands");

    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);
};
```



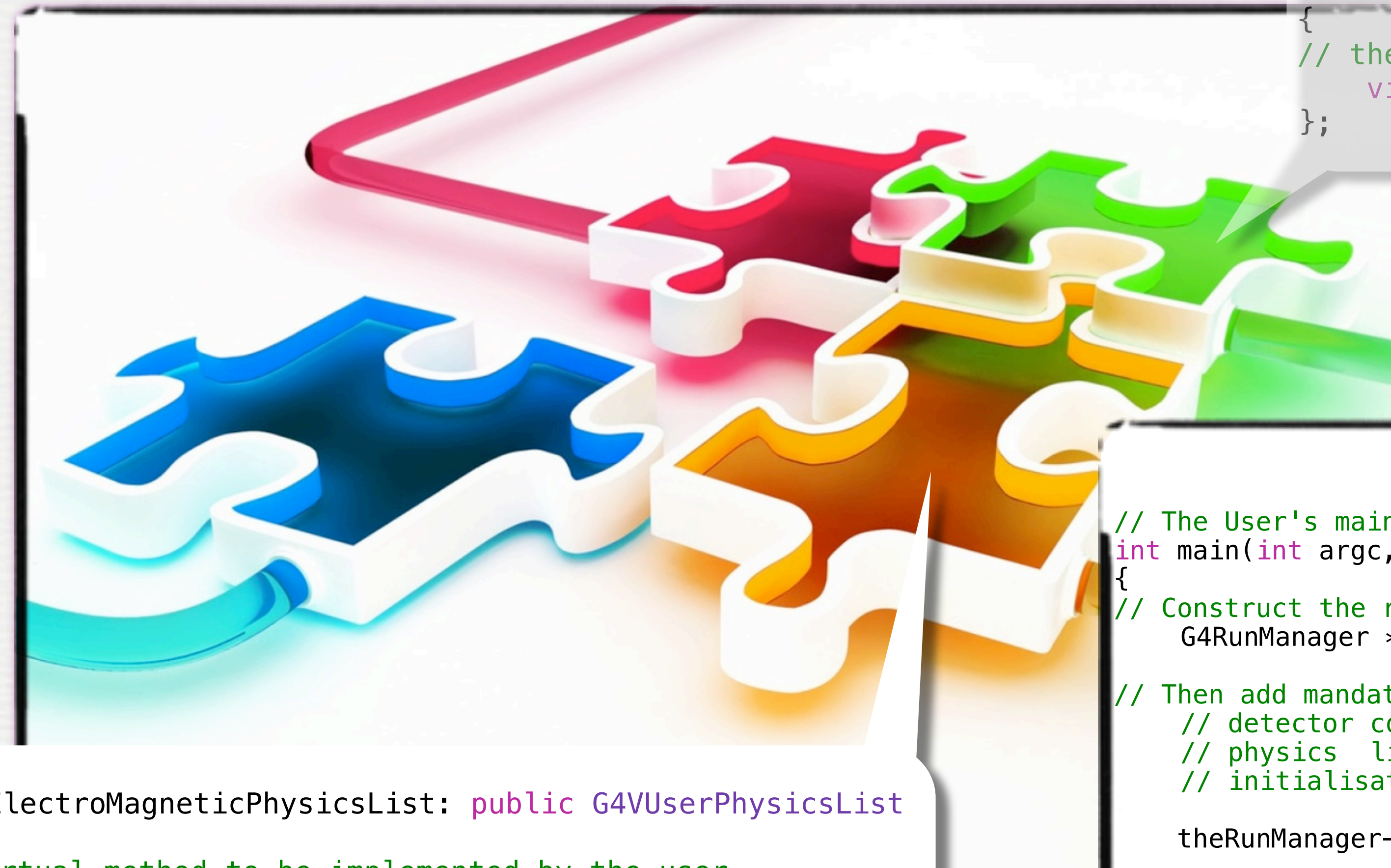
```
class AnElectroMagneticPhysicsList: public G4VUserPhysicsList
{
// the virtual method to be implemented by the user
      void ConstructParticle();
// the virtual method to be implemented by the user
      void ConstructProcess();
// the virtual method to be implemented by the user
      void SetCuts();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

```
// 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;
}
```

# The user's application

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

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



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

```
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 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

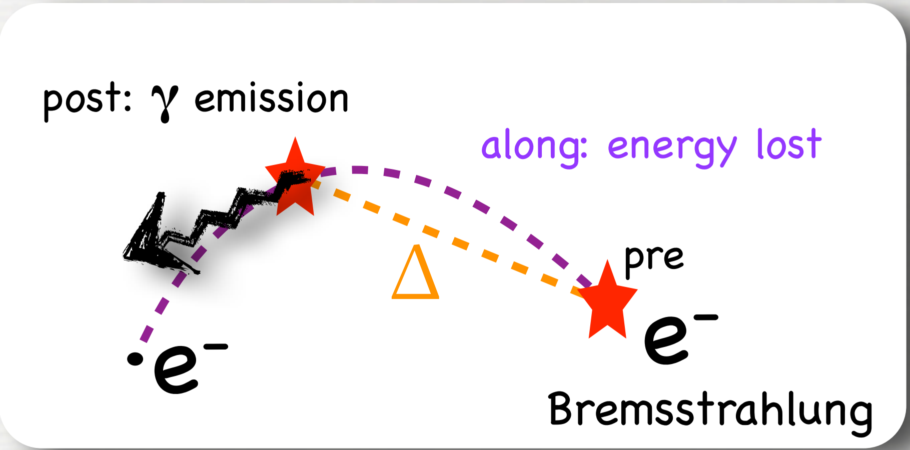
➥ **atomistic approach**: not all the physics into the box!

➥ 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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  - optical photons
- 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();
}
```

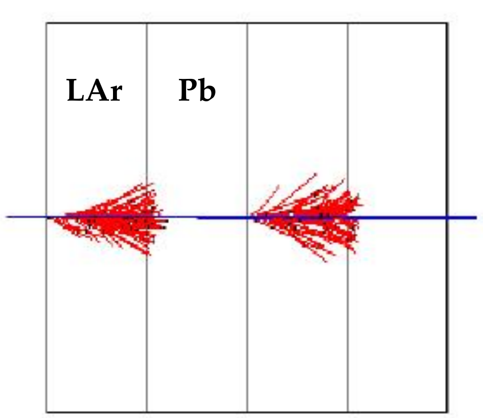
```
void AnElectroMagneticPhysicsList::ConstructParticle()
{
  // This ensures that objects of these particle types will be
  // created in the program.
  G4Gamma::GammaDefinition();
  G4Electron::ElectronDefinition();
  G4Positron::PositronDefinition();
  G4MuonPlus::MuonPlusDefinition();
  G4MuonMinus::MuonMinusDefinition();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

**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 ➾

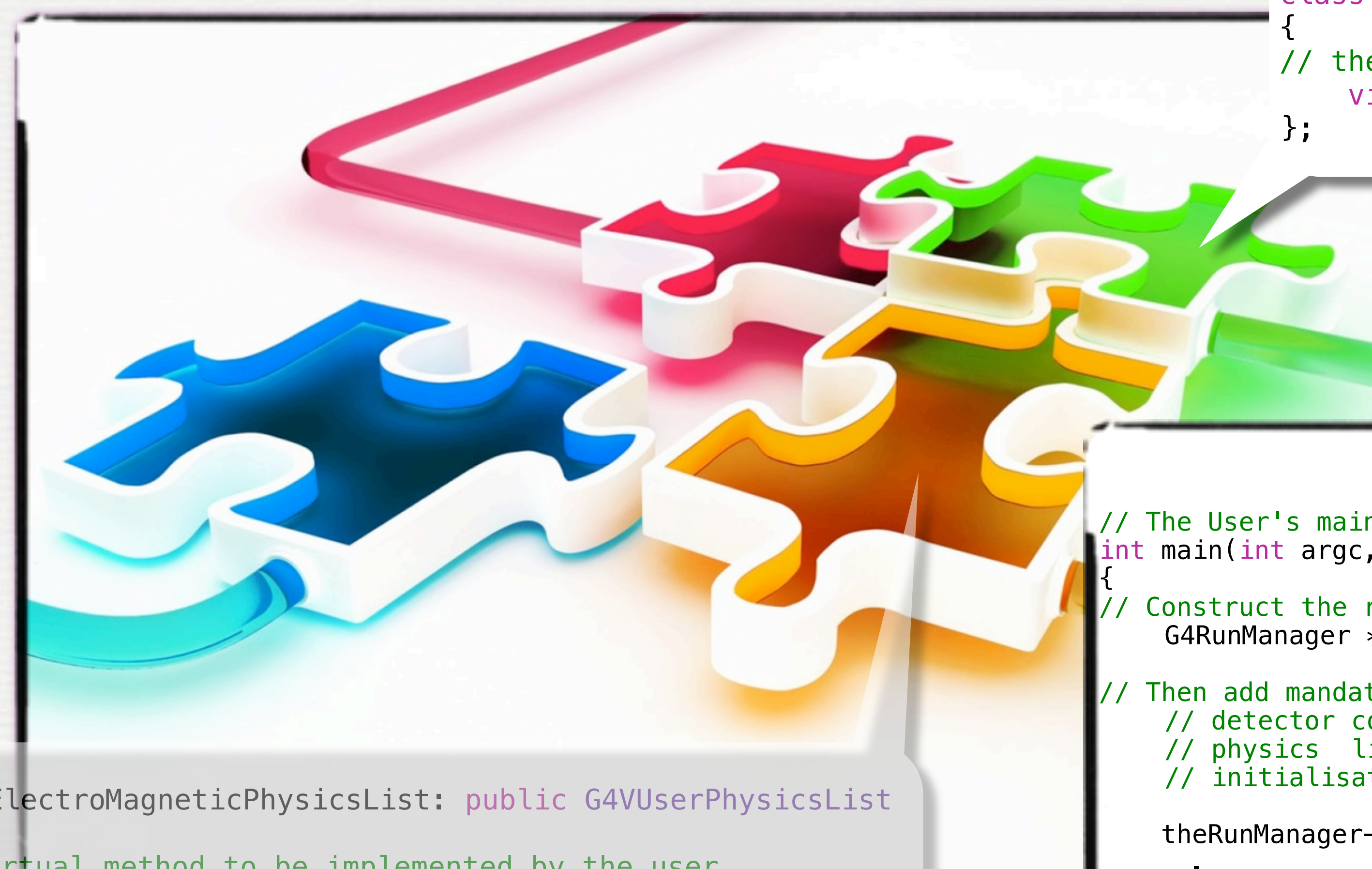
```
// The User's main program to control / run simulations
int main(int argc, char** argv)
{
// Construct the run manager, necessary for G4 kernel to control everything
      G4RunManager *theRunManager = new G4RunManager();
// Then add mandatory initialization G4 classes provided by the USER
   // 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
{
// the virtual method to be implemented by the user
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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

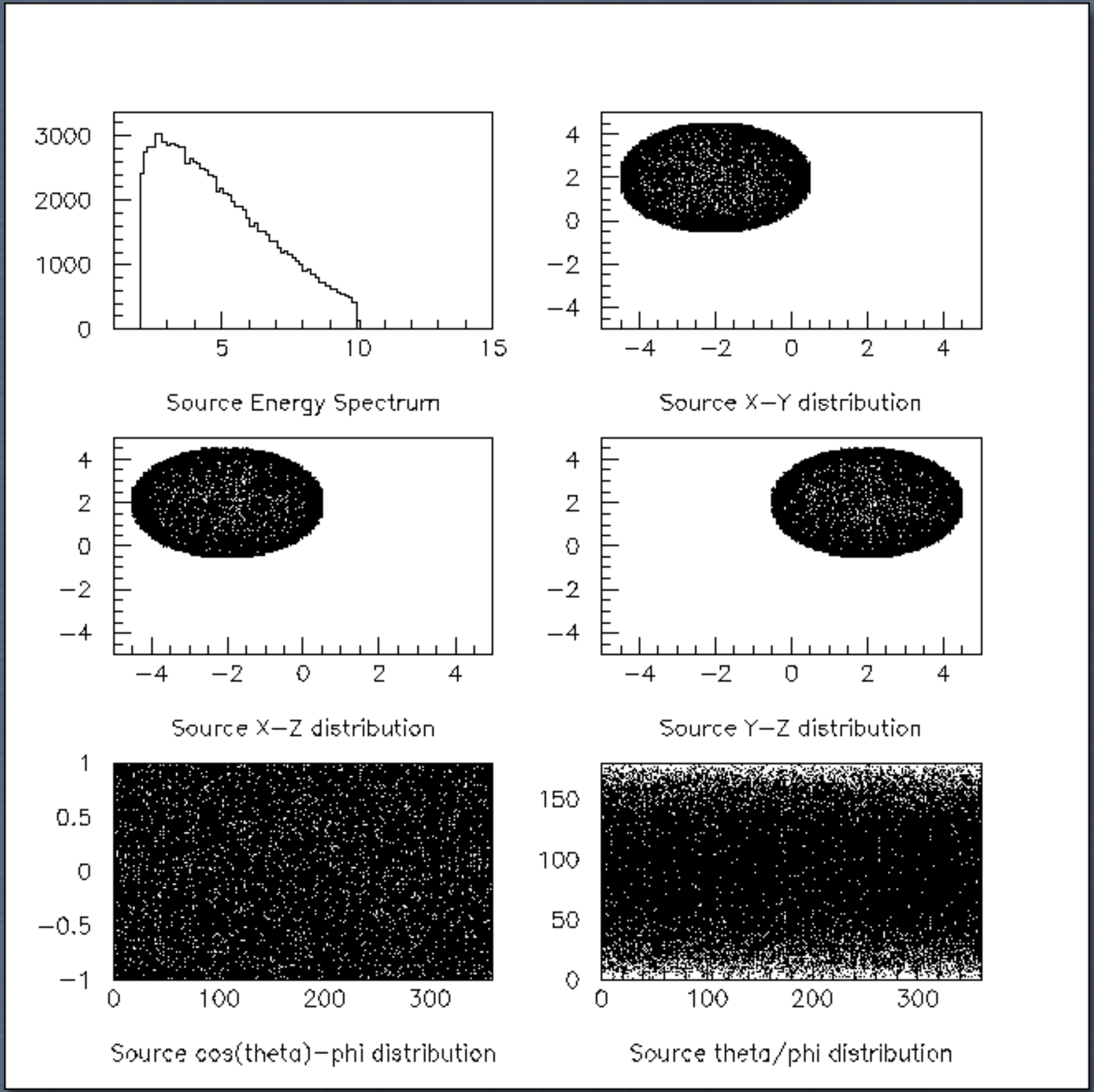
```
MyGPSPrimaryGeneratorAction::MyGPSPrimaryGeneratorAction()
{
        m_particleGun = new G4GeneralParticleSource();
}

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)

G4 macro to do that

```
/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
```

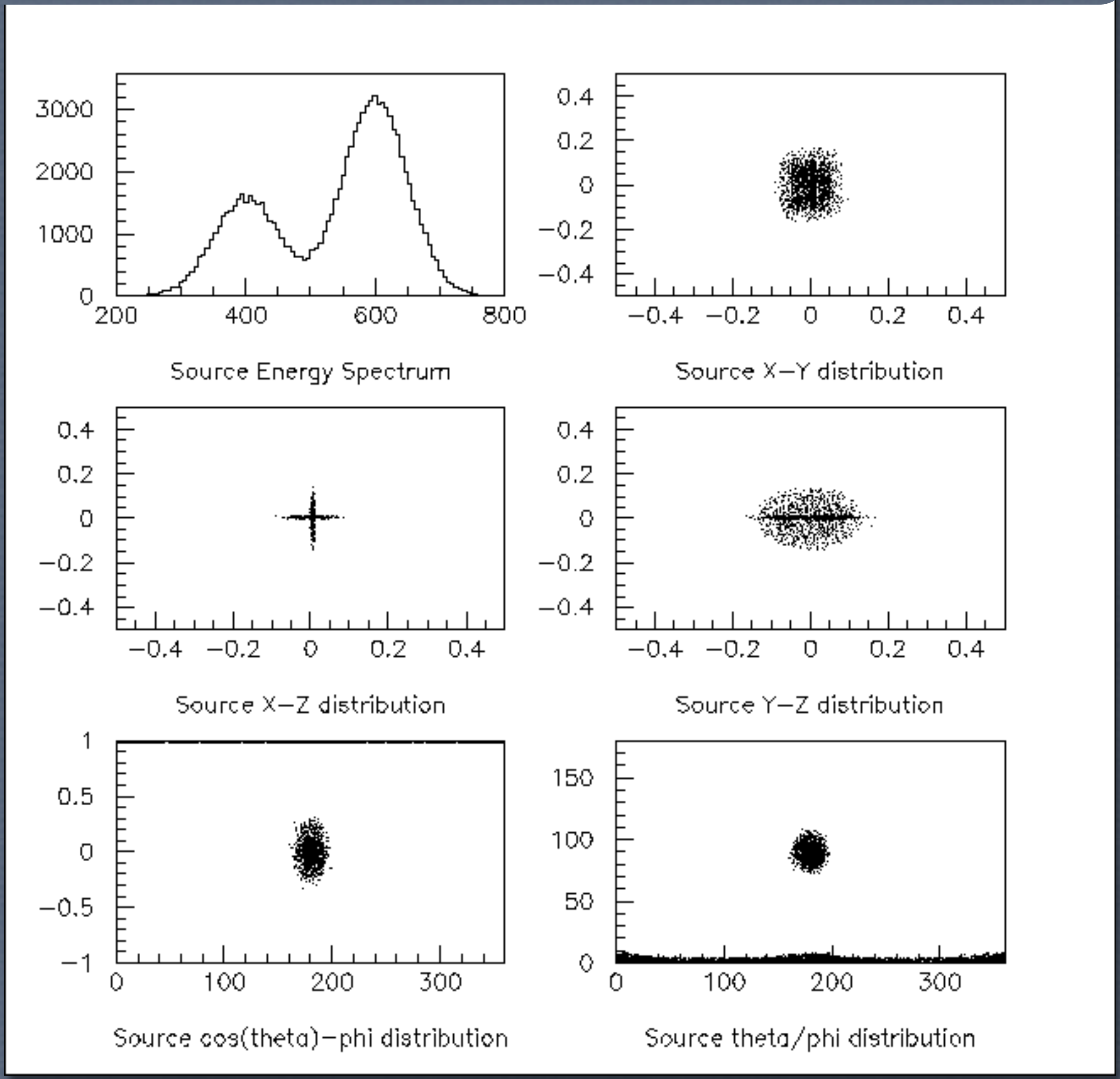


# The G4GeneralParticleSource GPS

## 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**