Geant 4

Version 10.3-p03

Primary Particle

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Geant4 Tutorial Course

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- Built-in primary particle generators
  - Particle gun
  - Interfaces to HEPEVT and HEPMC
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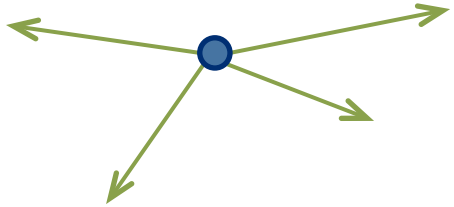
Primary vertex and primary particle

- Primary particle means particle with which you start an event.
  - E.g. particles made by the primary p-p collision, an alpha particle emitted from radioactive material, a gamma-ray from treatment head, etc.
  - Then Geant4 tracks these primary particles in your geometry with physics interactions and generates secondaries, detector responses and/or scores.
- Primary vertex has position and time. Primary particle has a particle ID, momentum and optionally polarization. One or more primary particles may be associated with a primary vertex. One event may have one or more primary vertices.

G4PrimaryVertex objects = {position, time}



G4PrimaryParticle objects = {PDG, momentum, polarization…}

- Generation of primary vertex/particle is one of the user-mandatory tasks. G4VUserPrimaryGeneratorAction is the abstract base class to control the generation.
  - Actual generation should be delegated to G4VPrimaryGenerator class. Several concrete implementations, e.g. G4ParticleGun, G4GeneralParticleSource, are provided.

G4VUserPrimaryGeneratorAction

- This class is one of mandatory user classes to control the generation of primaries.
  - This class itself should NOT generate primaries but invoke **GeneratePrimaryVertex()** method of primary generator(s) to make primaries.
- Constructor
  - Instantiate primary generator(s)
  - Set default values to it(them)
- GeneratePrimaries() method
  - Invoked at the beginning of each event.
  - Randomize particle-by-particle value(s)
  - Set these values to primary generator(s)
    - Never use hard-coded UI commands
  - Invoke **GeneratePrimaryVertex()** method of primary generator(s)
- Your concrete class of G4VUserPrimaryGeneratorAction must be instantiated in the Build() method of your G4VUserActionInitialization

G4VUserPrimaryGeneratorAction

Constructor : Invoked only once

```
MyPrimaryGeneratorAction::MyPrimaryGeneratorAction()
{
    G4int n_particle = 1;
    fparticleGun  = new G4ParticleGun(n_particle);

    // default particle kinematic
    G4ParticleTable* particleTable = G4ParticleTable::GetParticleTable();
    G4ParticleDefinition* particle = particleTable->FindParticle("gamma");
    fparticleGun->SetParticleDefinition(particle);
    fparticleGun->SetParticleMomentumDirection(G4ThreeVector(0.,0.,1.));
    fparticleGun->SetParticleEnergy(100.*MeV);
    fparticleGun->SetParticlePosition(G4ThreeVector(0.,0.,-50*cm));
}
```

Invoked once per each event

```
void MyPrimaryGeneratorAction::GeneratePrimaries(G4Event* anEvent)
{
    fparticleGun->SetParticleMomentum(G4RandomDirection());
    fparticleGun->GeneratePrimaryVertex(anEvent);
}
```

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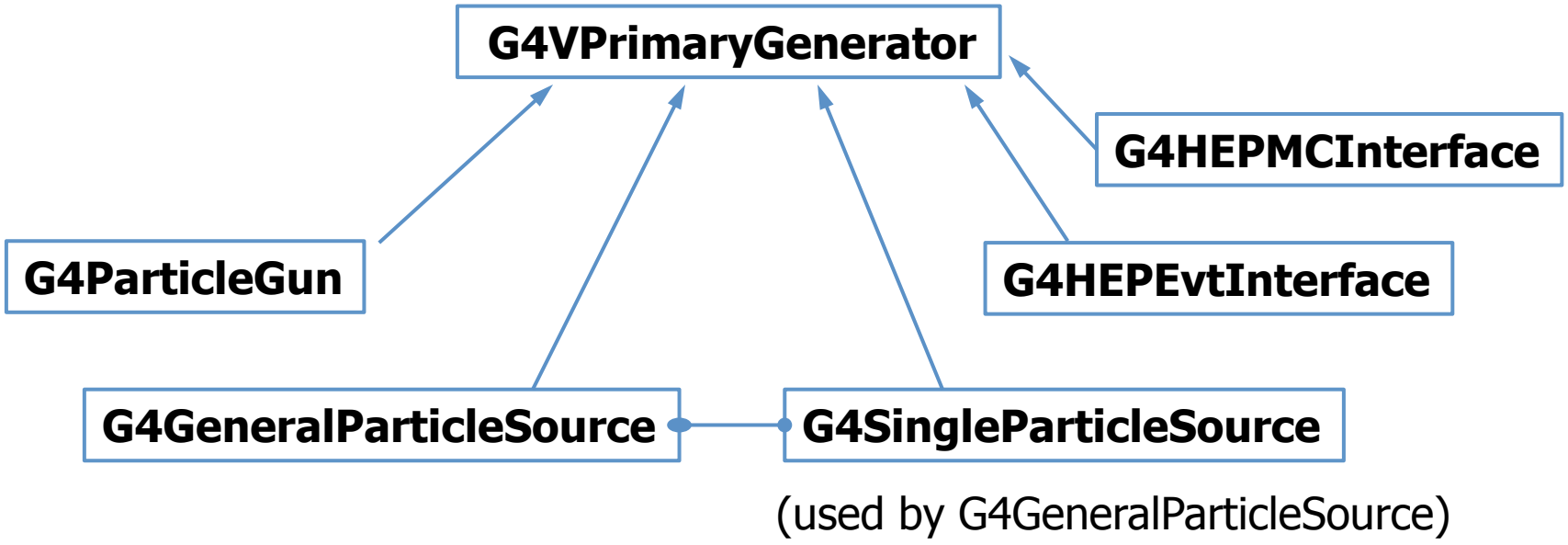
Built-in primary particle generators

Built-in concrete classes of G4VPrimaryGenerator



G4ParticleGun

- 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
- One of most frequently asked questions is :

  I want “particle shotgun”, “particle machinegun”, etc.
- Instead of implementing such a fancy weapon, in your implementation of UserPrimaryGeneratorAction, you can
  - Shoot random numbers in arbitrary distribution
  - Use set methods of G4ParticleGun
  - Use G4ParticleGun as many times as you want
  - Use any other primary generators as many times as you want to make overlapping events

What to do and where to do

- In the constructor of your UserPrimaryGeneratorAction
  - Instantiate G4ParticleGun
  - Set default values by set methods of G4ParticleGun
    - Particle type, kinetic energy, position and direction
- In your macro file or from your interactive terminal session
  - Set values for a run
    - Particle type, kinetic energy, position and direction
- In the GeneratePrimaries() method of your UserPrimaryGeneratorAction
  - Shoot random number(s) and prepare track-by-track or event-by-event values
    - Kinetic energy, position and direction
  - Use set methods of G4ParticleGun to set such values
  - Then invoke GeneratePrimaryVertex() method of G4ParticleGun
  - If you need more than one primary tracks per event, loop over randomization and GeneratePrimaryVertex().

- examples/basic/B5/src/B5PrimaryGeneratorAction.cc is a good example to start with.

G4VUserPrimaryGeneratorAction

```
void T01PrimaryGeneratorAction::
          GeneratePrimaries(G4Event* anEvent)
{ G4ParticleDefinition* particle;
  G4int i = (int)(5.*G4UniformRand());
  switch(i)
  { case 0: particle = positron; break; ... }
  particleGun->SetParticleDefinition(particle);
  G4double pp =
    momentum+(G4UniformRand()-0.5)*sigmaMomentum;
  G4double mass = particle->GetPDGMass();
  G4double Ekin = sqrt(pp*pp+mass*mass)-mass;
  particleGun->SetParticleEnergy(Ekin);
  G4double angle = (G4UniformRand()-0.5)*sigmaAngle;
  particleGun->SetParticleMomentumDirection
           (G4ThreeVector(sin(angle),0.,cos(angle)));
  particleGun->GeneratePrimaryVertex(anEvent);
}
```

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

Interfaces to HEPEvt and HepMC

- Concrete implementations of G4VPrimaryGenerator
  - A good example for experiment-specific primary generator implementation
- G4HEPEvtInterface
  - Suitable to /HEPEVT/ common block, which many of (FORTRAN) HEP physics generators are compliant to.
  - ASCII file input
- G4HepMCInterface
  - An interface to HepMC class, which a few new (C++) HEP physics generators are compliant to.
  - ASCII file input or direct linking to a generator through HepMC.

G4GeneralParticleSource

- A concrete implementation of G4VPrimaryGenerator
  - Suitable especially to space applications

```
MyPrimaryGeneratorAction::
          MyPrimaryGeneratorAction()
{ generator = new G4GeneralParticleSource; }
void MyPrimaryGeneratorAction::
          GeneratePrimaries(G4Event* anEvent)
{ generator->GeneratePrimaryVertex(anEvent); }
```

- Detailed description

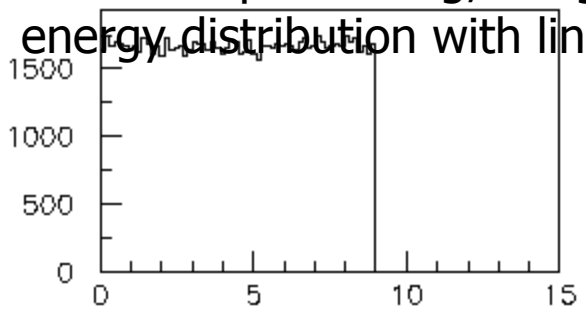
  Section 2.7 of Application Developer's Guide

Square

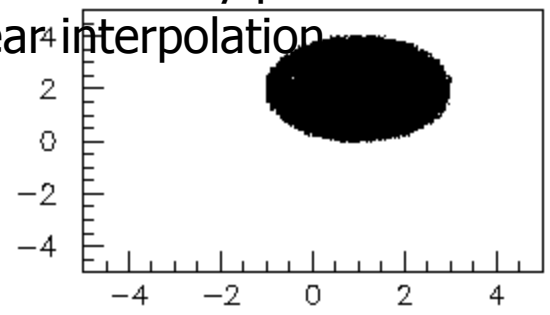
Spheri

Cylindri
energy

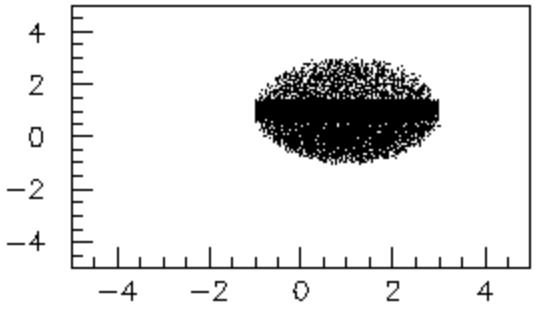
Spherical volume with z biasing, isotropic radiation with theta and phi biasing, integral arbitrary point-wise energy distribution with linear interpolation



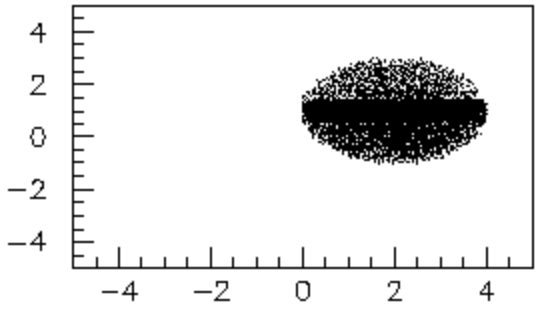
Source Energy Spectrum



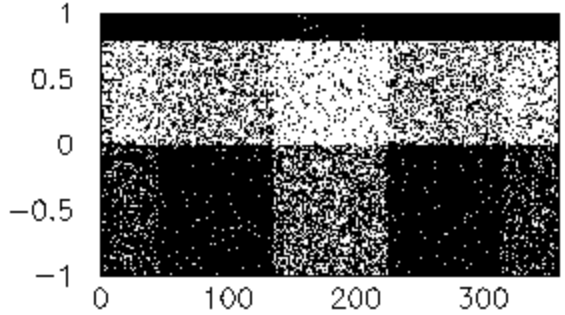
Source X–Y distribution



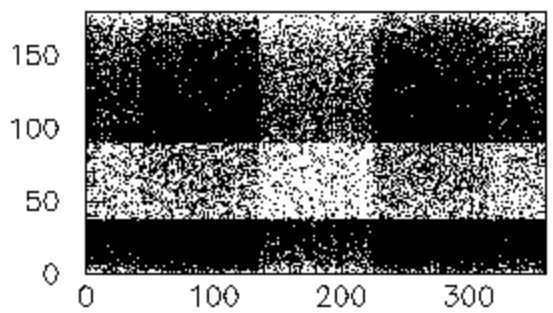
Source X–Z distribution



Source Y–Z distribution



Source cos(theta)–phi distribution



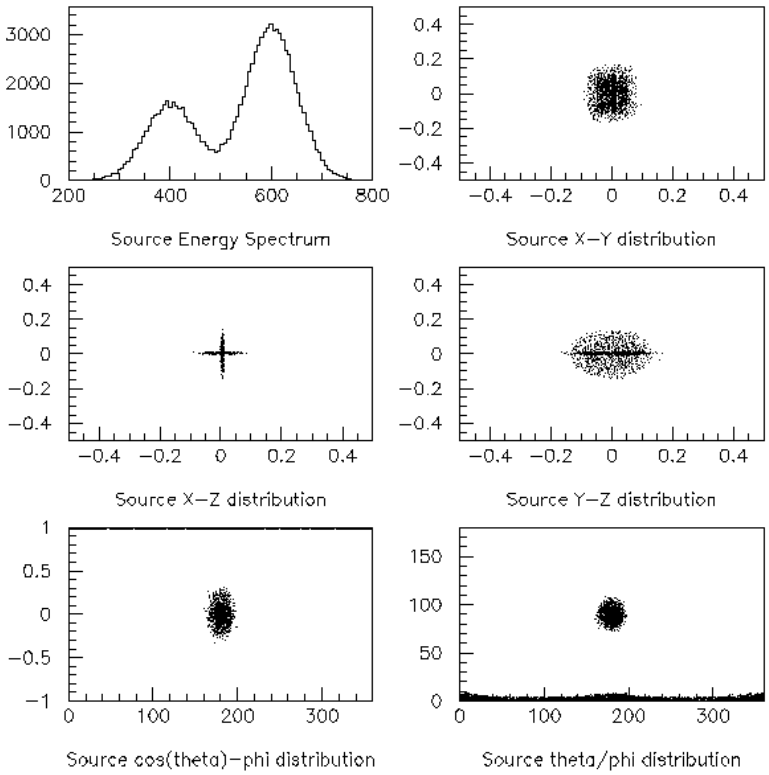
Source theta/phi distribution

Example commands of General Particle Source

```
# two beams in a generator
#
# 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
```

(macro continuation…)

```
# beam #2
# 2x the instensity of beam #1
/gps/source/add 10.
#
# this is a electron beam
/gps/particle e-
/gps/pos/type Beam
# it beam spot is of 2d gaussian profile
# with a 1x2 mm2 central plateau
# it is in the x-y plane centred at the orgin
/gps/pos/centre  0. 0. 0. mm
/gps/pos/halfx 0.5 mm
/gps/pos/halfy 1. mm
/gps/pos/sigma_x 0.1 mm
# the spread in y direction is stronger
/gps/pos/sigma_y 0.2 mm
#
#the beam is travelling along -Z_axis
/gps/ang/type beam2d
/gps/ang/sigma_x 2. deg
/gps/ang/sigma_y 1. deg
# gaussian energy profile
/gps/ene/type Gauss
/gps/ene/mono 600 MeV
/gps/ene/sigma 50. MeV
```



Particle Gun vs. General Particle Source

- Particle Gun
  - Simple and naïve
  - Shoot one track at a time
  - Easy to handle.
    - Use set methods to alternate track-by-track or event-by-event values.
- General Particle Source
  - Powerful
  - Controlled by UI commands.
    - Almost impossible to control through set methods
  - Capability of shooting particles from a surface of a volume.
  - Capability of randomizing kinetic energy, position and/or direction following a user-specified distribution (histogram).

- If you need to shoot primary particles from a surface of a volume, either outward or inward, GPS is the choice.
- If you need a complicated distribution, not flat or simple Gaussian, GPS is the choice.
- Otherwise, use Particle Gun.

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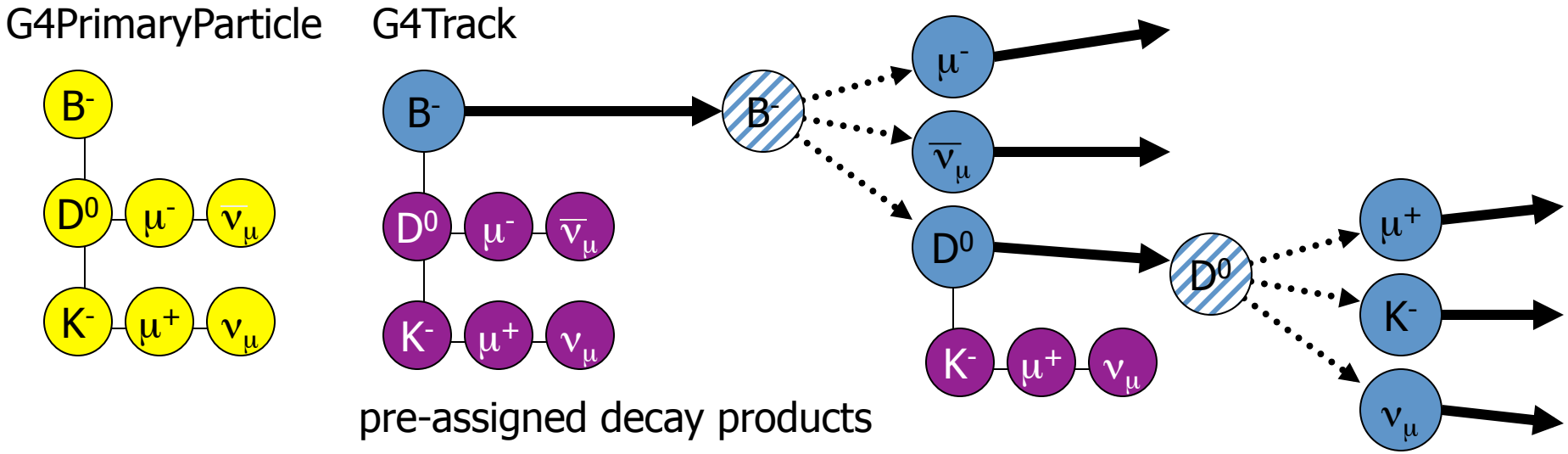
Pre-assigned decay

Pre-assigned decay

- By default, when an unstable particle comes to its decay point, G4DecayProcess looks up the decay table defined in the G4ParticleDefinition of this particle type and randomly selects a decay channel.
- Alternatively, you may define a particular decay channel to G4PrimaryParticle.
  - Then, G4DecayProcess takes that channel without looking up the decay table and Lorentz-boost.
- Two major use cases.
  - Shooting exotic primary particle, e.g. Higgs. Geant4 does not know how to decay Higgs, thus you have to define the decay daughters.
  - Forcing decay channel for each particle, e.g. forcing a rare channel

Pre-assigned decay products

- Physics generator can assign a decay channel for each individual particle separately.
  - Decay chain can be “pre-assigned”.
- A parent particle in the form of G4Track object travels in the detector, bringing “pre-assigned” decay daughters as objects of G4DynamicParticle.
  - When the parent track comes to the decay point, pre-assigned daughters become to secondary tracks, instead of randomly selecting a decay channel defined to the particle type. Decay time of the parent can be pre-assigned as well.



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Reading input file for primary particles in MT mode (including Connecting to Fortran event generator)

Input data file for PrimaryGeneratorAction

- PrimaryGeneratorAction is a thread-local class. Thus, special attention is required if the user needs an input file to read primary particles.
  - If thread-local objects of PrimaryGeneratorAction naively open a file and read it, they all read the file from the beginning and they all read exactly the same input.
- The appropriate implementation of reading an input file for PrimaryGeneratorAction depends on the use-case, more precisely, on the ratio of the cost of accessing to the data file to the total execution time of one event on one thread.
  - If this ratio is low, i.e. execution time dominates (typically the case of high-energy physics experiment where the energy of primary particles are high), the file access can be shared with Mutex locking mechanism.
  - If this ratio is high, i.e. file access is a significant fraction of the execution time (typically the case of medical and space applications where the energy of primary particles are rather low), the input data should be cached in addition to the Mutex locking.
- To use Mutex locking mechanism, include G4AutoLock.hh header file.

high-energy physics sample code with G4HEPEvtInterface

- Here is a high-energy physics sample code with G4HEPEvtInterface that reads a Pythia input file. G4HEPEvtInterface has to be a single object shared by all the PrimaryGeneratorAction objects, and the access to G4HEPEvtInterface::GeneratePrimaryVertex() should be protected by Mutex.

MyHepPrimaryGenAction.hh

```
#include "G4VUserPrimaryGeneratorAction.hh"
class G4HEPEvtInterface;
class MyHepPrimaryGenAction
 : public G4VUserPrimaryGeneratorAction
{
 public:
   MyHepPrimaryGenAction(G4String fileName);
   ~MyHepPrimaryGenAction();
   . . .
   virtual void GeneratePrimaries(G4Event* anEvent);
 private:
   static G4HEPEvtInterface* hepEvt;
};
```

Detailed example of reading Pythia output file is found in examples/extended/runandEvent/RE05

MyHepPrimaryGenAction.cc

```
#include "MyHepPrimaryGenAction.hh"
#include "G4HEPEvtInterface.hh"
#include "G4AutoLock.hh"
namespace { G4Mutex myHEPPrimGenMutex = G4MUTEX_INITIALIZER; }
G4HEPEvtInterface* MyHepPrimaryGenAction::hepEvt = 0;

MyHepPrimaryGenAction::MyHepPrimaryGenAction(G4String fileName)
{
 G4AutoLock lock(&myHEPPrimGenMutex);
 if( !hepEvt ) hepEvt = new G4HEPEvtInterface( fileName );
}

MyHepPrimaryGenAction::~MyHepPrimaryGenAction()
{
 G4AutoLock lock(&myHEPPrimGenMutex);
 if( hepEvt ) { delete hepEvt; hepEvt = 0; }
}

void MyHepPrimaryGenAction::GeneratePrimaries(G4Event* anEvent)
{
 G4AutoLock lock(&myHEPPrimGenMutex);
 hepEvt->GeneratePrimaryVertex(anEvent);
}
```

lower-energy sample code with G4ParticleGun

- Here is a lower-energy sample code with G4ParticleGun to shoot 10 MeV electrons. The input file contains list of G4ThreeVector of the momentum direction (ex, ey, ez) and it is read by a dedicated file reader class MyFileReader. MyFileReader is shared by all threads, and reads 100 events at a time and buffers them. Primary vertex position is randomized.
- Please note that, for the simplicity of this sample code, it does not consider the end-of-file.

MyLowEPrimaryGenAction.hh

```
#include "G4VUserPrimaryGeneratorAction.hh"
class G4ParticleGun;
class MyFileReader;
class MyLowEPrimaryGenAction
 : public G4VUserPrimaryGeneratorAction
{
 public:
   MyLowEPrimaryGenAction(G4String fileName);
   virtual ~MyLowEPrimaryGenAction();
   . . .
   virtual void GeneratePrimaries(G4Event* anEvent);
 private:
   static MyFileReader* fileReader;
   G4ParticleGun* particleGun;
};
```

MyLowEPrimaryGenAction.cc – part 1/2

```
#include "G4ParticleTable.hh"
#include "G4ParticleDefinition.hh"
#include "Randomize.hh"
#include "G4AutoLock.hh"
namespace { G4Mutex myLowEPrimGenMutex = G4MUTEX_INITIALIZER; }
MyFileReader* MyLowEPrimaryGenAction::fileReader = 0;

MyLowEPrimaryGenAction::MyLowEPrimaryGenAction(G4String fileName)
{
 G4AutoLock lock(&myLowEPrimGenMutex);
 if( !fileReader ) fileReader = new MyFileReader( fileName );
 particleGun = new G4ParticleGun(1);
 G4ParticleTable* particleTable = G4ParticleTable::GetParticleTable();
 G4ParticleDefinition* particle = particleTable->FindParticle("e-");
 particleGun->SetParticleDefinition(particle);
 particleGun->SetParticleEnergy(10.*MeV);
}

MyLowEPrimaryGenAction::~MyLowEPrimaryGenAction()
{
 G4AutoLock lock(&myLowEPrimGenMutex);
 if( fileReader ) { delete fileReader; fileReader = 0; }
}
```

MyLowEPrimaryGenAction.cc – part 2/2

```
void MyLowEPrimaryGenAction::GeneratePrimaries(G4Event* anEvent)
{
  G4ThreeVector momDirction(0.,0.,0.);
  if(fileReader)
  {
    G4AutoLock lock(&myLowEPrimGenMutex);
    momDirection = fileReader->GetAnEvent();
  }
  particleGun->SetParticleMomentumDirection(momDirction);
  G4double x0 = 2.* Xmax * (G4UniformRand()-0.5);
  G4double y0 = 2.* Ymax * (G4UniformRand()-0.5);
  particleGun->SetParticlePosition(G4ThreeVector(x0,y0,0.));
  particleGun->GeneratePrimaryVertex(anEvent);
}
```

MyFileReader.hh and .cc

```
#include <list>
#include <fstream>
class MyFileReader
{
 public:
  MyFileReader(G4String fileName);
  ~MyFileReader();
  . . .
  G4ThreeVector GetAnEvent();
 private
  std::ifstream inputFile;
  std::list<G4ThreeVector> evList;
};
```

```
MyFileReader::MyFileReader(G4String fileName)
{ inputFile.open(filename.data()); }

MyFileReader::~MyFileReader()
{ inputFile.close(); }

G4ThreeVector MyFileReader::GetAnEvent()
{
 if( evList.size() == 0 )
 {
  for(int i=0;i<100;i++)
  {
   G4double ex, ey, ez;
   inputFile >> ex >> ey >> ez;
   evList.push_back( G4ThreeVector(ex,ey,ez) );
  }
 }
 G4ThreeVector ev = evList.pop_front();
 return ev;
}
```

Additional note for low-energy case

- Please note that Mutex has a performance penalty.
- Thus, in case the user uses many threads and the execution time of one event is very short, the most efficient way is splitting the input file to the number of threads so that each thread reads its own dedicated input file without Mutex lock.
- In this case, the buffering shown in above-mentioned MyFileReader class should be still used to reduce the file I/O overhead.