Version 10.7

Primary Generators

Vladimir Ivanchenko (CERN, EP-SFT & Tomsk State University, Russia)

Geant4 Beginners Course

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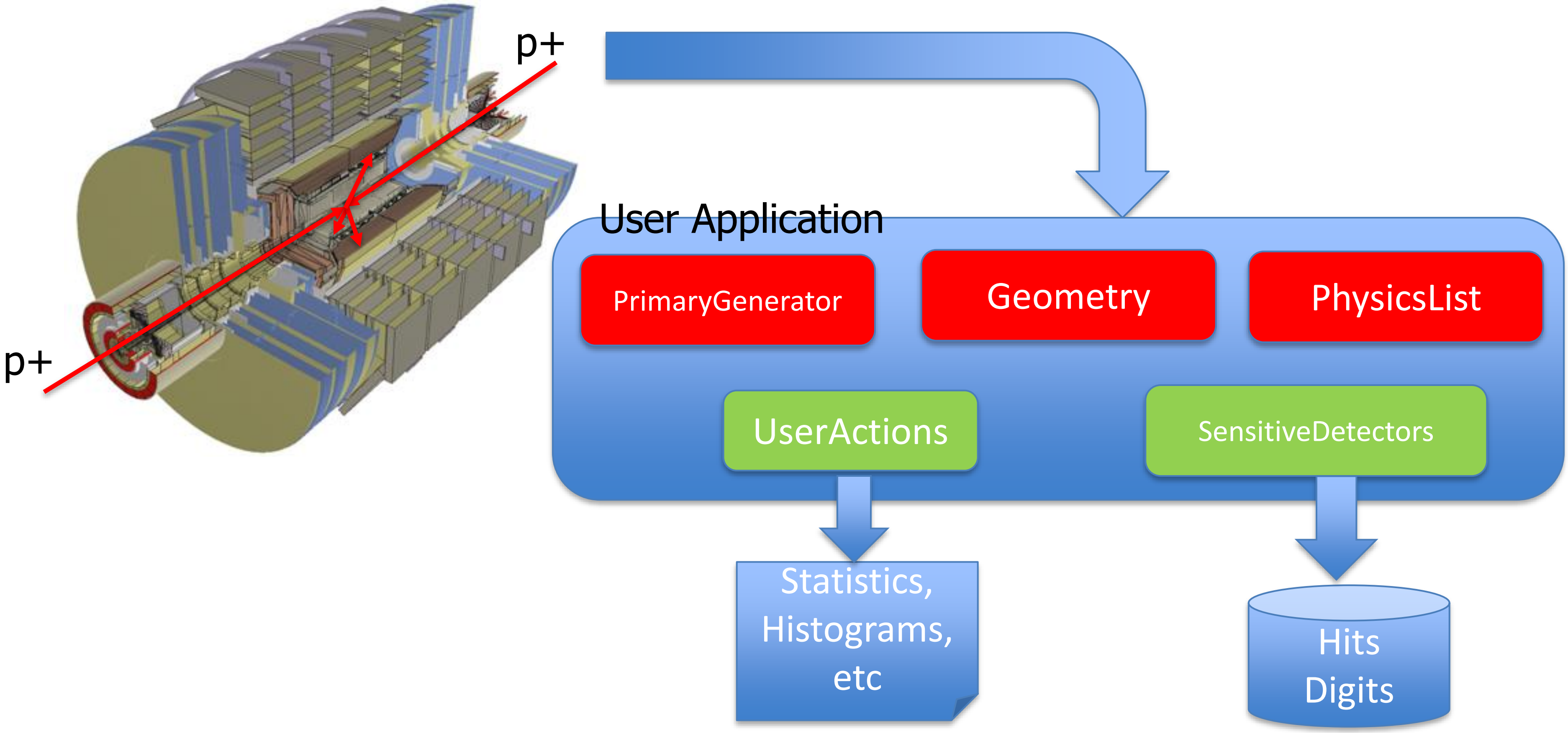
Based on material presented before by M. Asai (SLAC) and W. Pokorski (CERN)

What do we need to run simulation?



User Application

PrimaryGenerator

Geometry

PhysicsList

UserActions

SensitiveDetectors

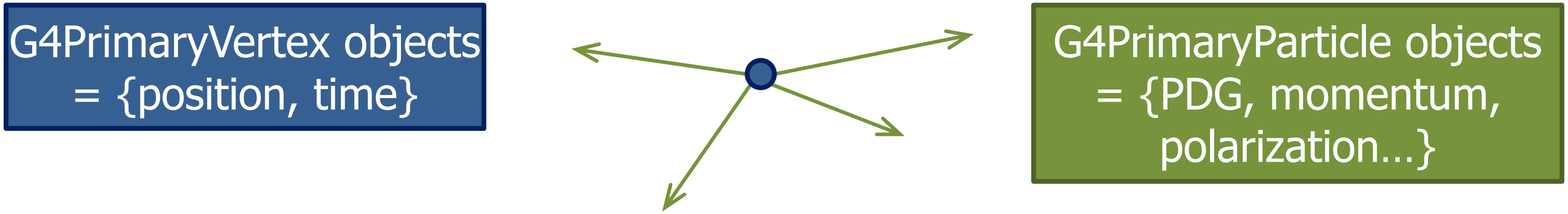
Statistics, Histograms, etc

Hits Digits

- User needs to provide ‘source’ of primary particles to Geant4
- Geant4 simulates the passages of those particles through the detector

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.



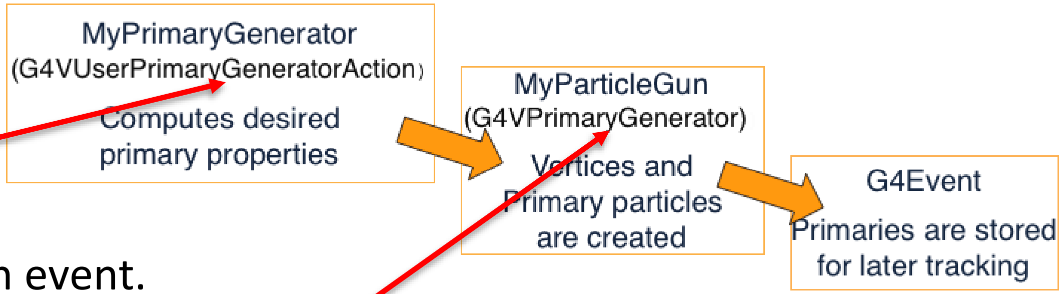
G4PrimaryVertex objects = {position, time}

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)



MyPrimaryGenerator
(G4VUserPrimaryGeneratorAction)
Computes desired primary properties

MyParticleGun
(G4VPrimaryGenerator)
Vertices and Primary particles are created

G4Event
Primaries are stored for later tracking

- Your concrete class of G4VUserPrimaryGeneratorAction must be instantiated in the Build() method of your G4VUserActionInitialization

G4VUserPrimaryGeneratorAction

Constructor :
Invoked only once

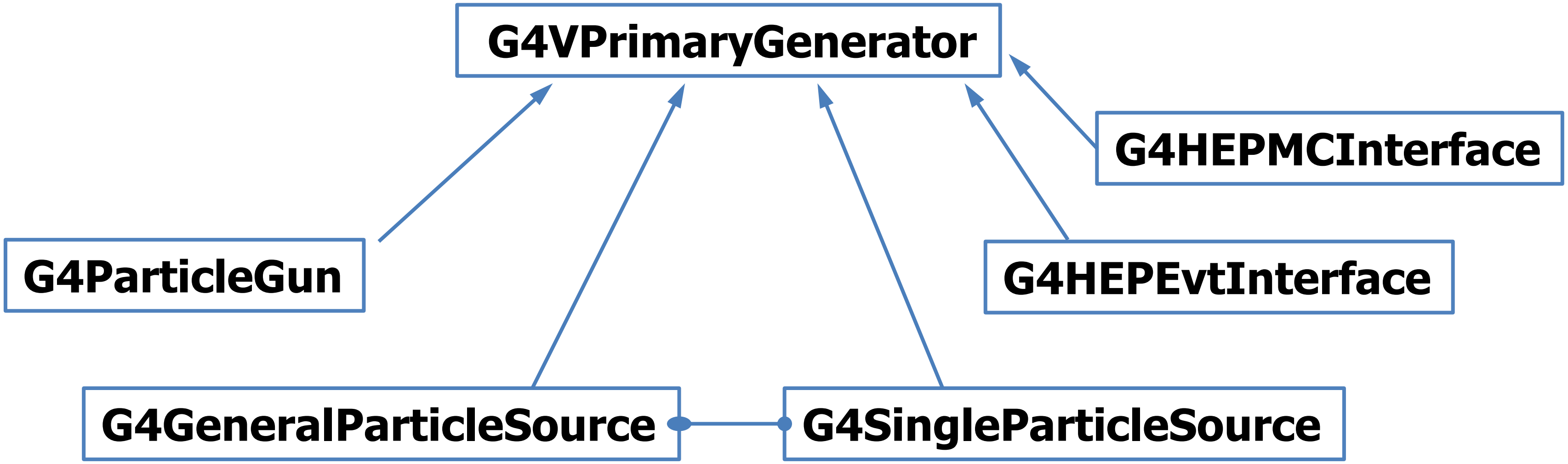
```
MyPrimaryGeneratorAction::MyPrimaryGeneratorAction()
{
     G4int n_particle = 1;
     fparticleGun  = new G4ParticleGun(n_particle);

     // 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);
}
```

BUILT-IN PRIMARY PARTICLE GENERATORS

Built-in concrete classes of G4VPrimaryGenerator



G4VPrimaryGenerator

G4HEPMCInterface

G4ParticleGun

G4HEPEvtInterface

G4GeneralParticleSource

G4SingleParticleSource

(used by G4GeneralParticleSource)

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
- 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
- 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.

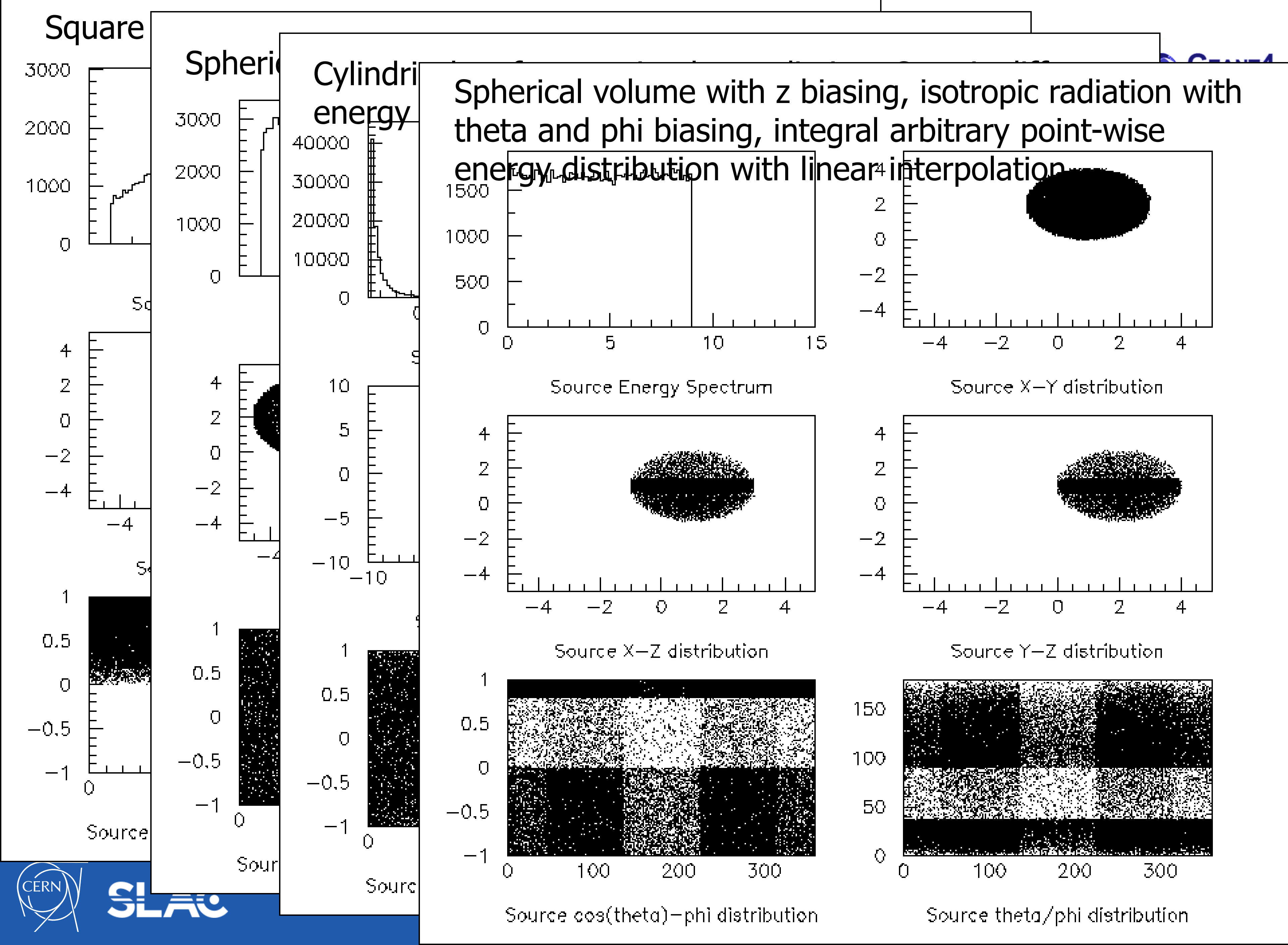
G4GeneralParticleSource

- 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:
- https://geant4-userdoc.web.cern.ch/UsersGuides/ForApplicationDeveloper/html/GettingStarted/generalParticleSource.html

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

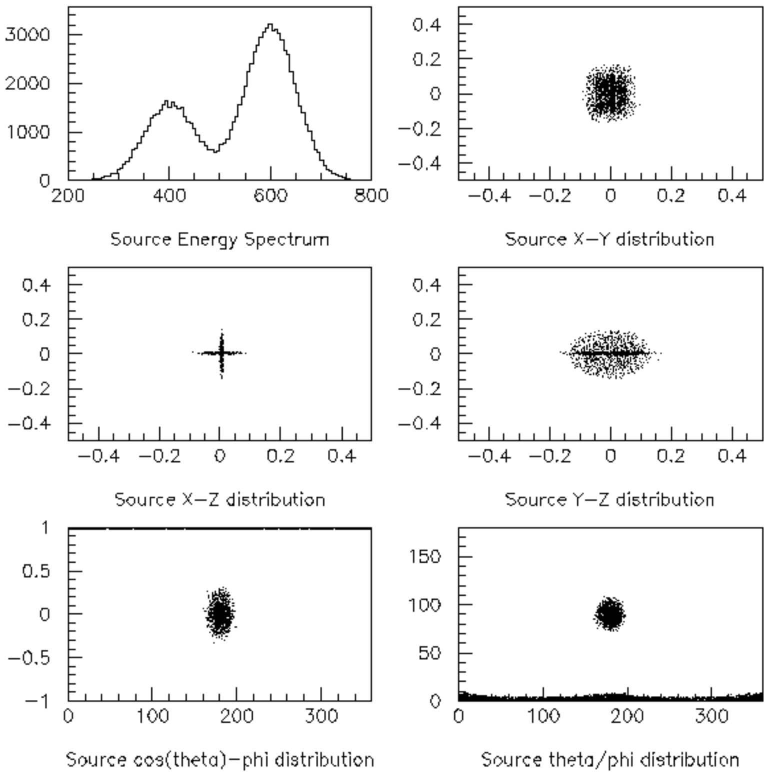


Example commands of General Particle Source

```
# 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
```



Source Energy Spectrum

Source X−Y distribution

Source X−Z distribution

Source Y−Z distribution

Source cos(theta)−phi distribution

Source theta/phi distribution

Particle Gun vs. General Particle Source

- Particle Gun
  - Simple and naïve
  - 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.

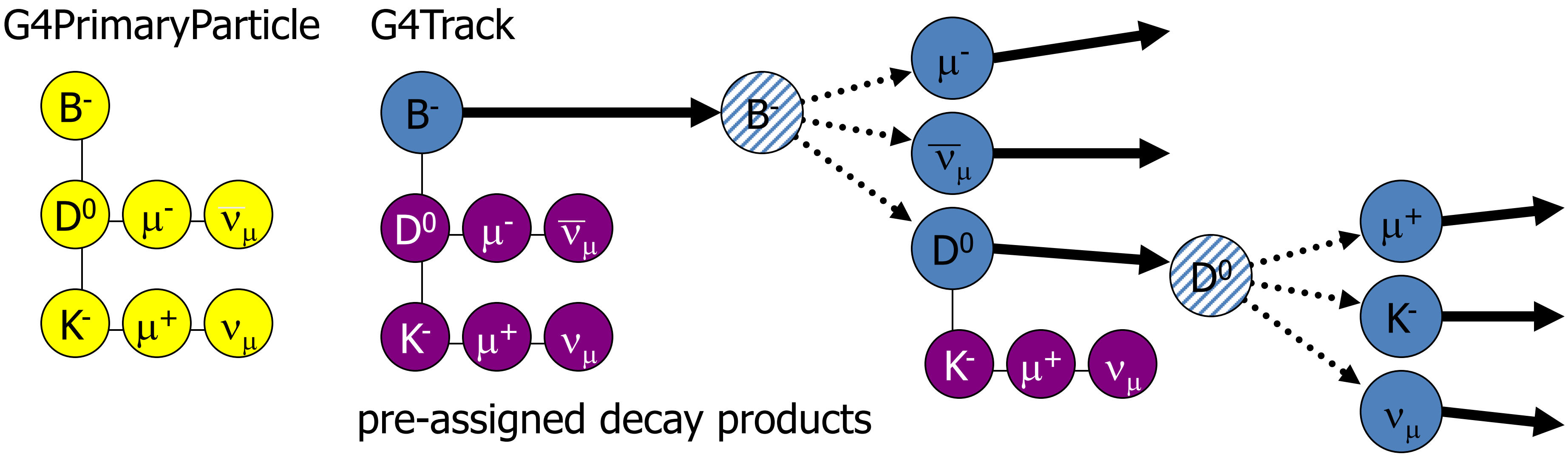
PRE-ASSIGNED DECAY

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.



Conclusions

- User primary generator action is a mandatory class that user must implement
  - this class can re-use existing primary generators
  - it plays the role of providing ‘primary particles’ that Geant4 transports through the detector
- ‘particle guns’ used for test-beam or fixed target simulations
- interface to HepMC event record used for MC event generators