esipap
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Detector Simulation Primary Particles

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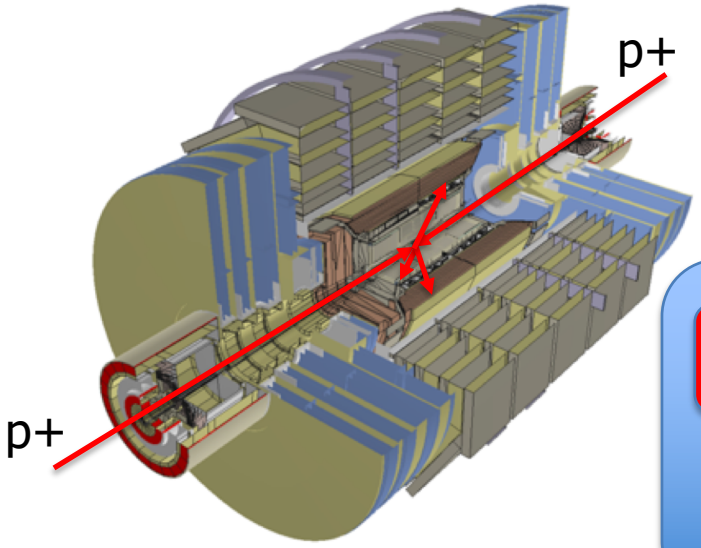
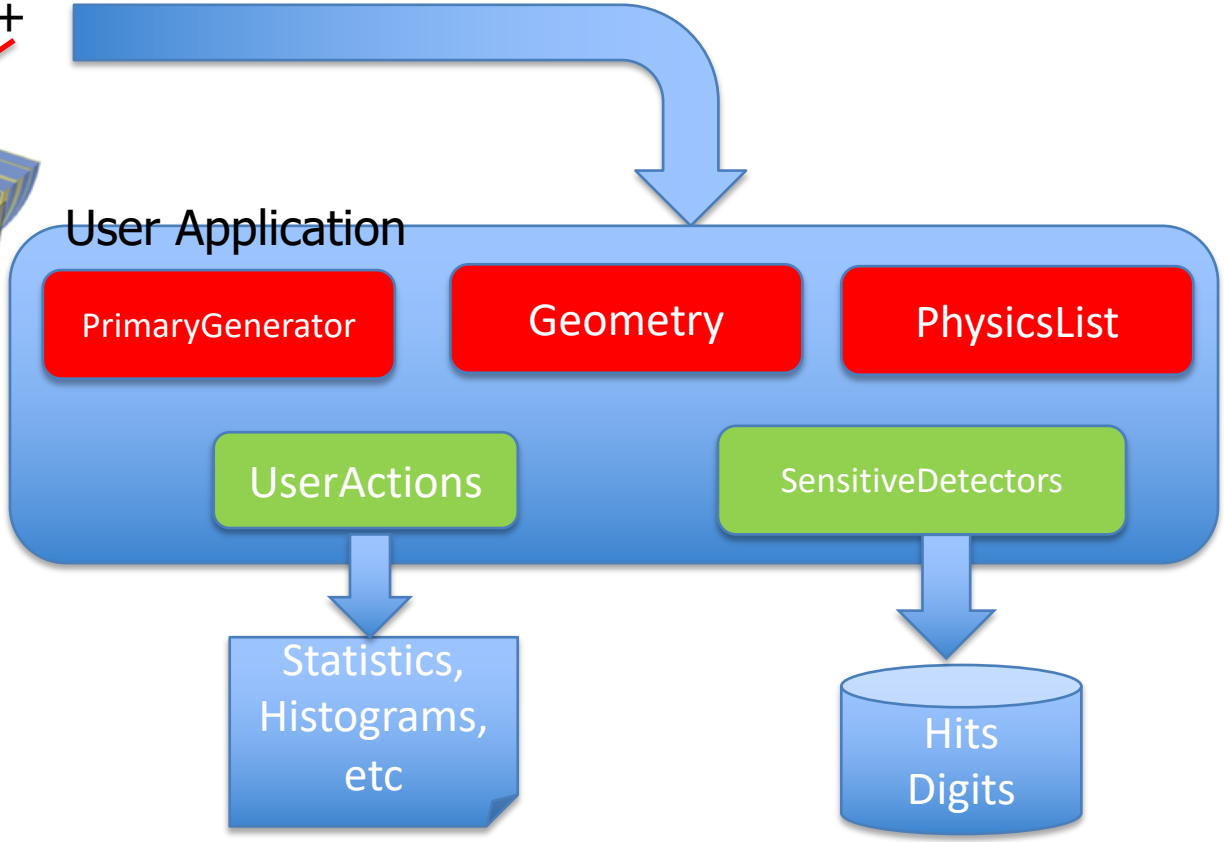
8-9.02.2021

What do we need to run simulation?



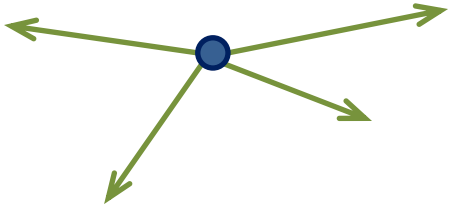


- User needs to provide 'source' of primary particles to Geant4
- Geant4 simulates the passages of those particles through the detector

Primary vertex and primary particle

- Primary particle(s) means particle(s) 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}

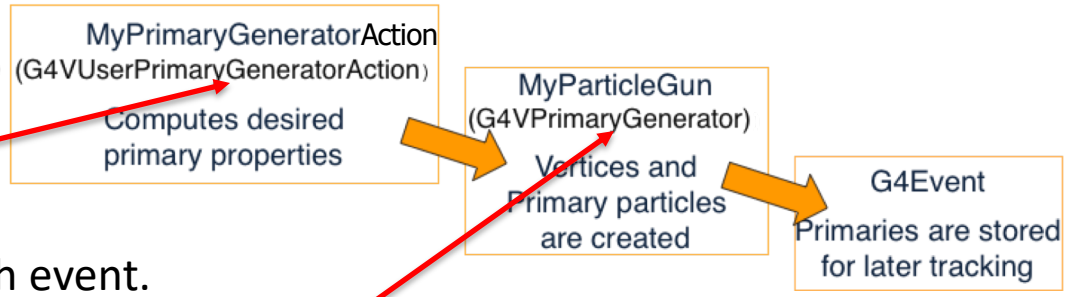


G4PrimaryParticle objects = {PDG, momentum, polarization…}

- 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.
  - Can randomize particle-by-particle value(s)
  - Can set these values to primary generator(s)
  - Invokes **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);
}
```

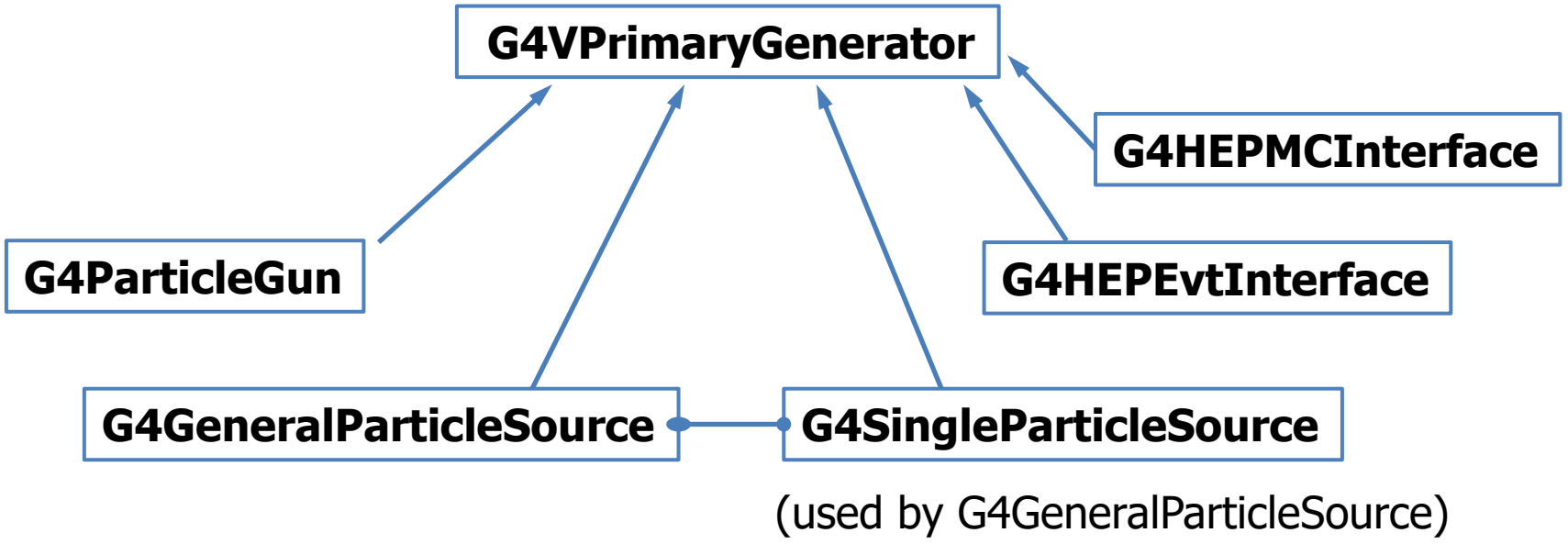
GEANT4

A SIMULATION TOOLKIT

Version 10.5

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
  - For example, 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);
}
```

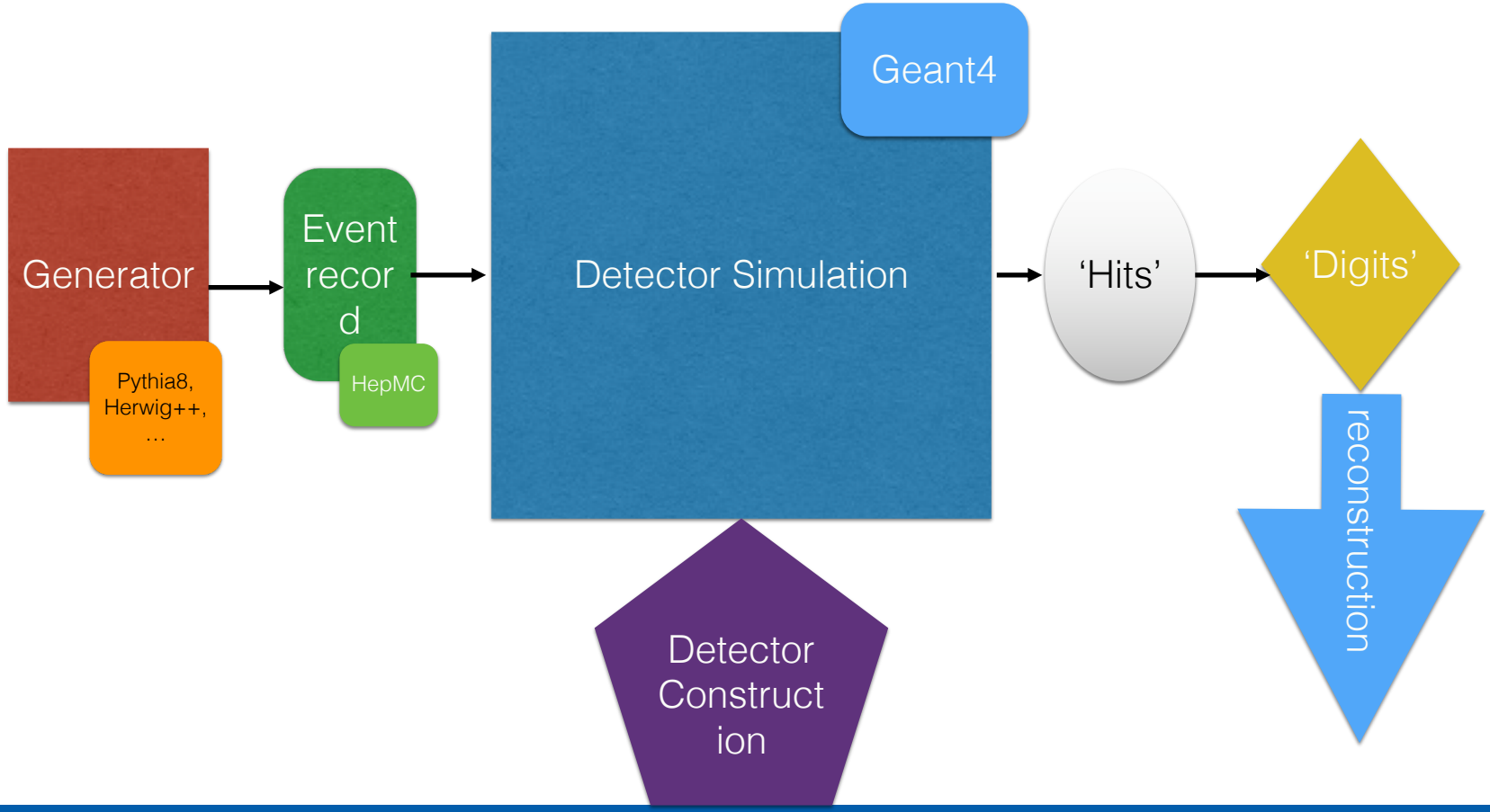
- You can repeat this for generating more than one primary particles.

Interfaces to HEPEvt and HepMC

- Other concrete implementations of G4VPrimaryGenerator ready to use
  - 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.

Simulation chain for HEP experiment

(slide from Introduction)



G4GeneralParticleSource

- Yet another concrete implementation of G4VPrimaryGenerator
  - Suitable especially to space applications

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

- Detailed description

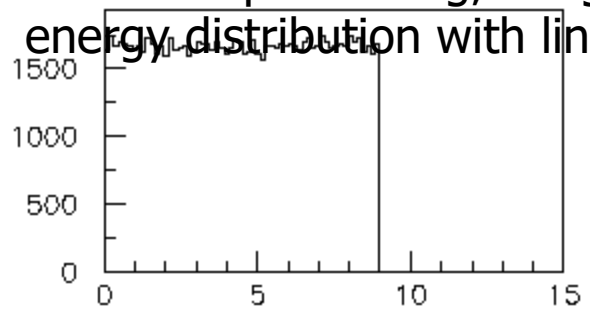
  Section 2.7 of Application Developer's Guide

Square

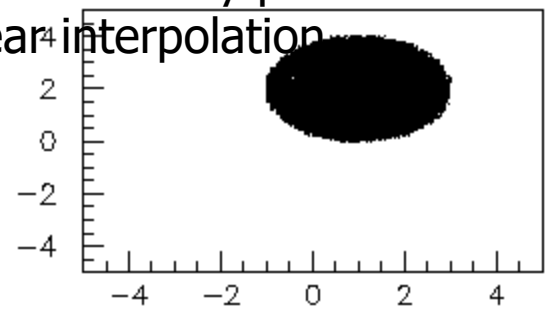
Spheri

Cylindri
energy

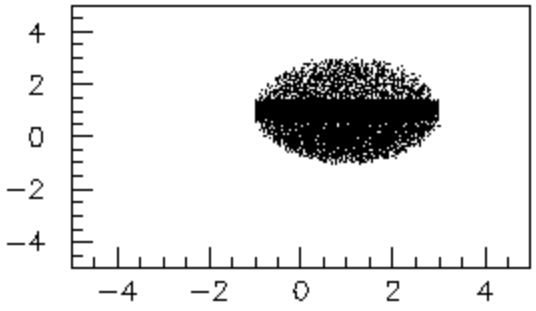
Spherical volume with z biasing, isotropic radiation with theta and phi biasing, integral arbitrary point-wise energy distribution with linear interpolation



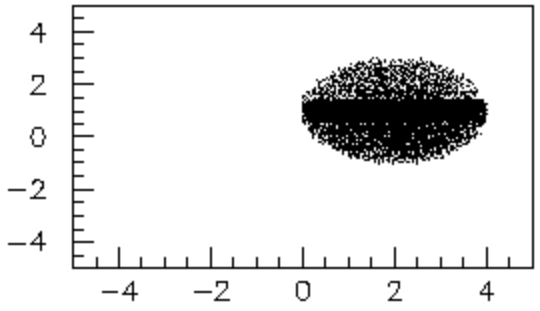
Source Energy Spectrum



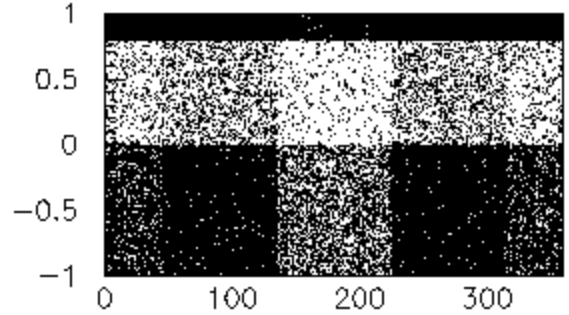
Source X–Y distribution



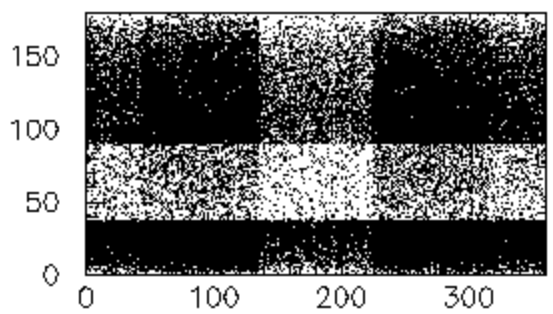
Source X–Z distribution



Source Y–Z distribution



Source cos(theta)–phi distribution



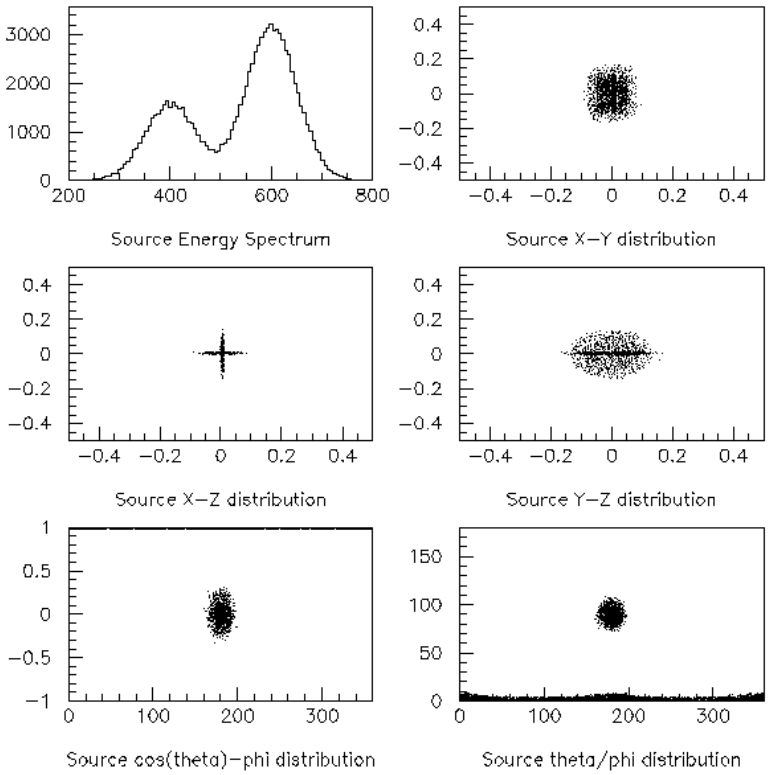
Source theta/phi distribution

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.

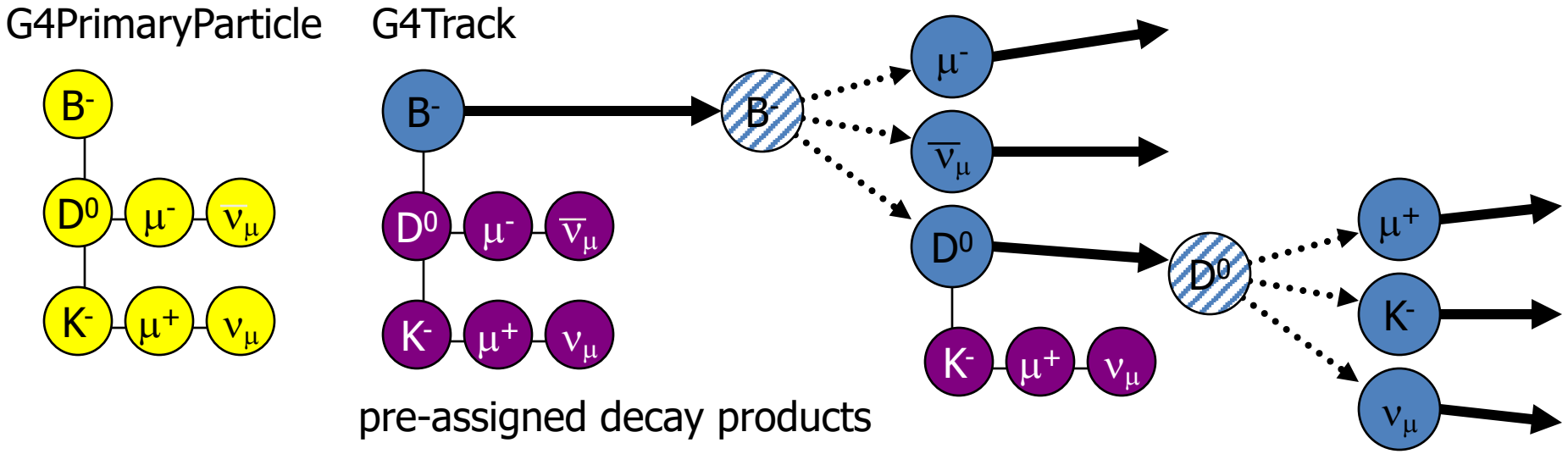
Pre-assigned decay

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
- General Particle Source capable of shooting particles from a surface of a volume
  - useful for space applications, medical applications, etc
- interface to HepMC event record used for MC event generators