GPS
General Particle Source

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Geant 4

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Ecole Geant4
Annecy, 18-21 and 25-28 Nov 2008

Outline

- Introduction
- Basic functioning
- Position, angular & energy distributions
- Examples

Motivation

- After first simple tutorial trials, modelling sources in realistic set-up soon requires relatively more complex sources
- G4ParticleGun can be used in most cases

  (as in the series of examples during this tutorial), but
  - users still needs to code (C++) almost every change and
  - add related UI commands for interactive control
- Requirements for advanced primary particle modelling are often common to many users in different communities
  - E.g. uniform vertex distribution on a surface, isotropic generation, energy spectrum,…

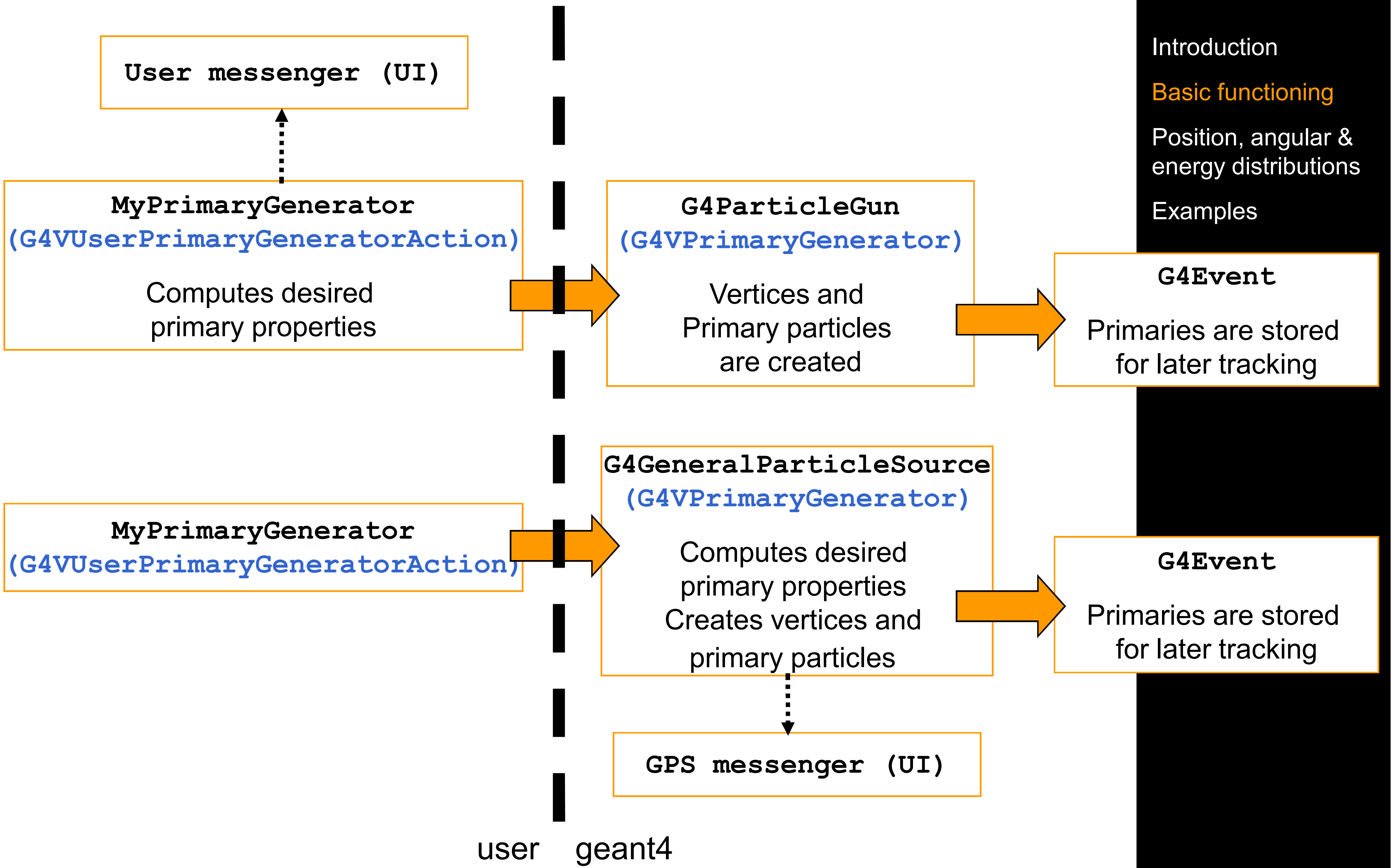
What is GPS?

- The General Particle Source (GPS) offers as pre-defined many common options for particle generation (energy, angular and spatial distributions)
  - GPS is a concrete implementation of G4VPrimaryGenerator (as G4ParticleGun but more advanced)
  - G4 class name: G4GeneralParticleSource (in the event category)
- User cases: space radiation environment, medical physics, accelerator (fixed target)
- First development (2000) University of Southampton (ESA contract), maintained and upgraded now mainly by QinetiQ and ESA
- Extensive up-to-date documentation at http://reat.space.qinetiq.com/gps

Summary of GPS features

- Primary vertex can be randomly positioned with several options
  - Emission from point, plane,…
- Angular emission
  - Several distributions; isotropic, cosine-law, focused, …
  - With some additional parameters (min/max-theta, min/max-phi,…)
- Kinetic energy of the primary particle can also be randomized.
  - Common options (e.g. mono-energetic, power-law), some extra shapes (e.g. black-body) or user defined
- 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

GPS vs G4ParticleGun



GPS control: scripting UI

- All features can be used via C++ or command line (or macro) UI
- Example of isotropic emission in UserPrimaryGenerator C++ code:

examples/advanced/human_phantom/src/G4HumanPhantomPrimaryGeneratorAction.cc

```
G4double a,b,c;
G4double n;
do {
  a = (G4UniformRand()-0.5)/0.5;
  b = (G4UniformRand()-0.5)/0.5;
  c = (G4UniformRand()-0.5)/0.5;
  n = a*a+b*b+c*c;
} while (n > 1 || n == 0.0);
n = std::sqrt(n);
a /= n;
b /= n;
c /= n;
G4ThreeVector direction(a,b,c);
particleGun->SetParticleMomentumDirection(direction);
```

- Equivalent GPS (script)

```
/gps/ang/type iso
```

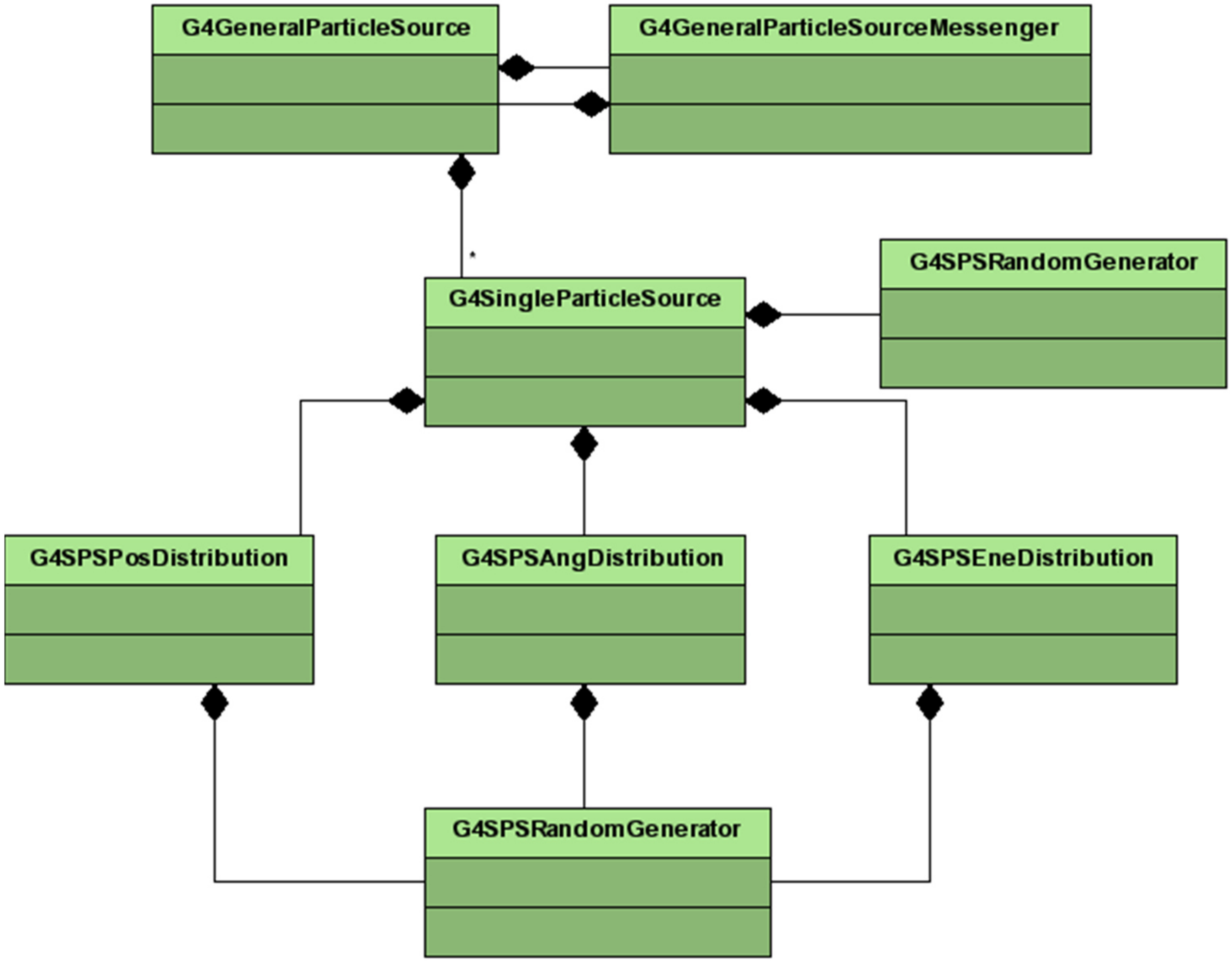
UserPrimaryGeneratorAction class

- Can be extremely simple:

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

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

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

- All user instructions given via macro UI commands

Class diagram



Multiple sources

- Definition of multiple "parallel" sources
- One source per event is used
- Sampling according to relative intensity

First source is always already present (implicitly created)

one can add intensity information

```
/gps/source/intensity 5.
```

Additional sources must be added explicitly

```
/gps/source/add 10.
```

Biasing

- Users can bias distributions by entering a histogram
- It is the random numbers from which the quantities are picked that are biased

  → so one needs a histogram only from 0 to 1
- Great care must be taken when using this option
- Bias histograms are entered in the same way as other user-defined histograms

```
/gps/hist/type biasx
      | biasy | biasz | biast | biasp | biaspt | biaspp | biase
```

Position distributions /gps/pos/…

- Point

  E.g.
  ```
  /gps/pos/type Point
  /gps/pos/centre 0. 0. 0. cm
  ```

- Beam

  E.g.
  ```
  /gps/pos/type Beam
  /gps/pos/shape Circle
  /gps/pos/radius 1. mm
  /gps/pos/sigma_r 2. mm
  ```

- Plane
  - Shape: Circle, Annulus, Ellipsoid, Square or Rectangle

  E.g.
  ```
  /gps/pos/type Plane
  /gps/pos/shape Rectangle
  /gps/pos/halfx 50 cm
  /gps/pos/halfy 70 cm
  ```

- Surface or Volume
  - Shape: Sphere, Ellipsoid, Cylinder or Para
  - Surface: zenith automatically oriented as normal to surface at point

  E.g.
  ```
  /gps/pos/type Surface
  /gps/pos/shape Sphere
  /gps/pos/radius 1. m
  ```

Position distributions
/gps/pos/… (2)

- Some shared UI commands

- **/gps/pos/centre**
- **/gps/pos/halfx | y | z**
- **/gps/pos/radius**
- **/gps/pos/inner_radius**
- **/gps/pos/sigmar**
- **/gps/pos/sigmax | y**
- **/gps/pos/rot1**
- **/gps/pos/rot2**

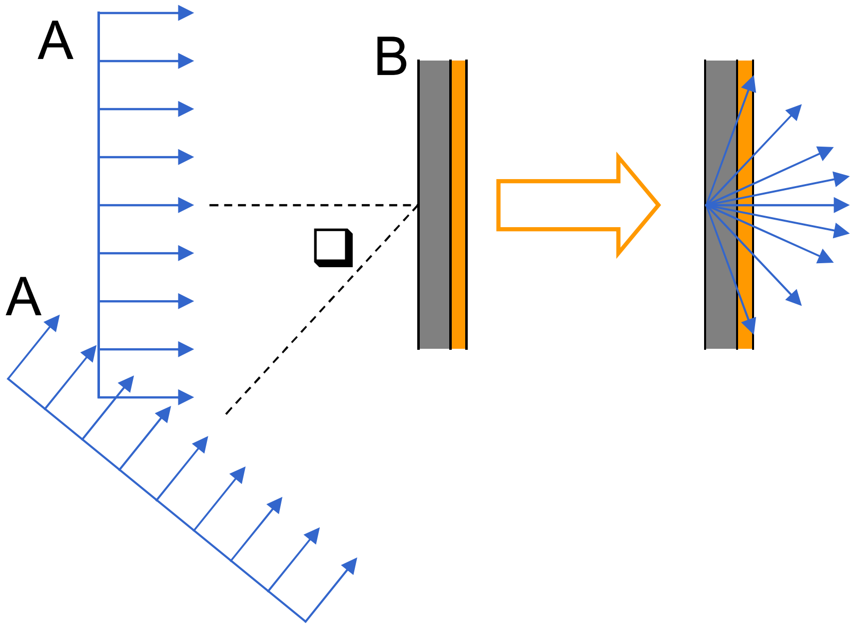
- When usinig Volume type, one can limit the emission from within a certain volume in the “mass” geometry

/gps/pos/confine your_physical_volume_name

Angular distributions
/gps/ang/…

- Isotropic (**`iso`**)
- Cosine-law (**`cos`**)
  - See next slides for more information
- Planar wave (**`planar`**)
  - Standard emission in one direction
    (it's also implicitly set by **`/gps/direction x y z`**)
- Accelerator beam
  - 1-d or 2-d gaussian emission, **`beam1d`** or **`beam2d`**
- Focusing to a point (**`focused`**)
- User-defined (**`user`**)

Isotropic radiation in space: Cos VS Iso ?
I. Slab source



- Objective:

  model an isotropic flux in space, shooting from a planar surface (assuming flux from right is stopped)

- By definition of isotropic flux:

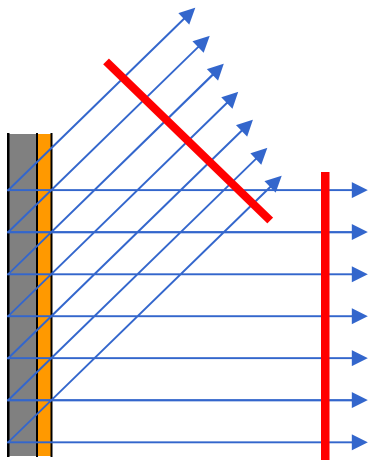
  → The flux passing through a surface (such as A) is not dependent on the direction

- The slab B sees
  - Full flux for a direction normal to its surface
  - reduced by a factor cos(❑) for tilted directions (/cm^2 !)

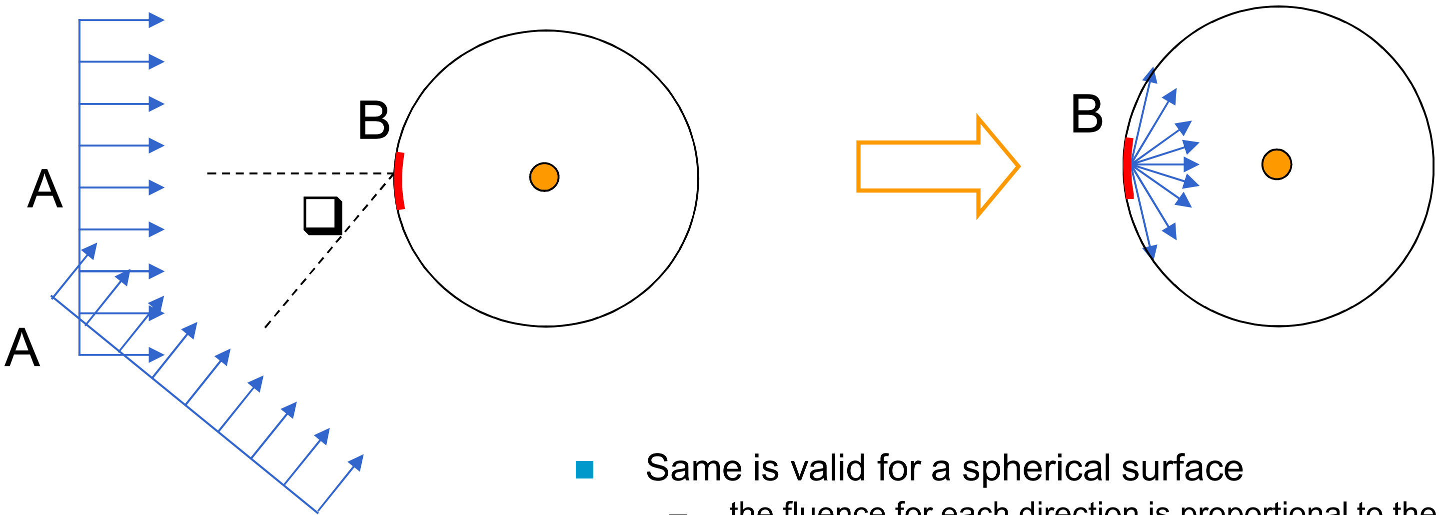
→ We must use “cosine-law” angular distribution when shooting primaries from the slab

If one shoots an isotropic flux from a slab the final distribution in space is not isotropic !

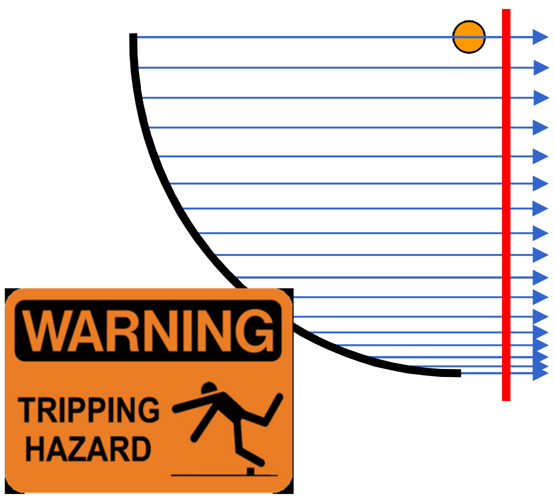
Different fluences through surfaces at different angles



Isotropic radiation in space: Cos VS Iso ?
II. Sphere source



- Same is valid for a spherical surface
  - the fluence for each direction is proportional to the cosine of the angle between the source direction and the local normal to the sphere surface



- Cosine-law angular emission actually works not only for the sphere, but for generic surfaces (e.g. shooting from a box)
- Isotropic angular emission from the surface leads to non isotropic fluence in the volume
  - E.g. for each emission direction the final distribution is not flat on a plane normal to the emission direction
- One can verify the various options by placing an oriented detector in different positions/orientations in the volume

Energy distributions
/gps/ene/…

Kinetic energy of the primary particle can also be randomized, with several predefined options:

- Common options (e.g. mono-energetic, power-law, exponential, gaussian, etc)
  - mono-energetic (`Mono`)
  - linear (`Lin`)
  - power-law (`Pow`)
  - exponential (`Exp`)
  - gaussian (`Gauss`)

- Some extra predefined spectral shapes (bremsstrahlung, black-body, cosmic diffuse gamma ray,…)
  - bremsstrahlung (`Brem`)
  - black-body (`Bbody`)
  - cosmic diffuse gamma ray (`Cdg`)

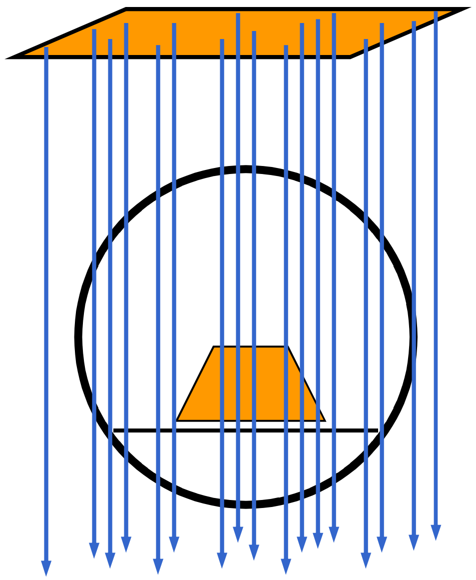
- User defined
  - user-defined histogram (`User`)
  - arbitrary point-wise spectrum (`Arb`) and
  - user-defined energy per nucleon histogram (`Epn`)

Example:
proton source of exercises jour 2a 2b 2c

- Vertices on rectangle along **`xz`** at edge of World
- Parallel emission along **`-y`**
- Monoenergetic: **`500 MeV`**

Macro

```
/gps/particle proton

/gps/ene/type Mono
/gps/ene/mono 500 MeV

/gps/pos/type Plane
/gps/pos/shape Rectangle
/gps/pos/rot1 0 0 1
/gps/pos/rot2 1 0 0
/gps/pos/halfx 46.2 cm
/gps/pos/halfy 57.2 cm
/gps/pos/centre 0. 57.2 0. cm

/gps/direction 0 -1 0
```

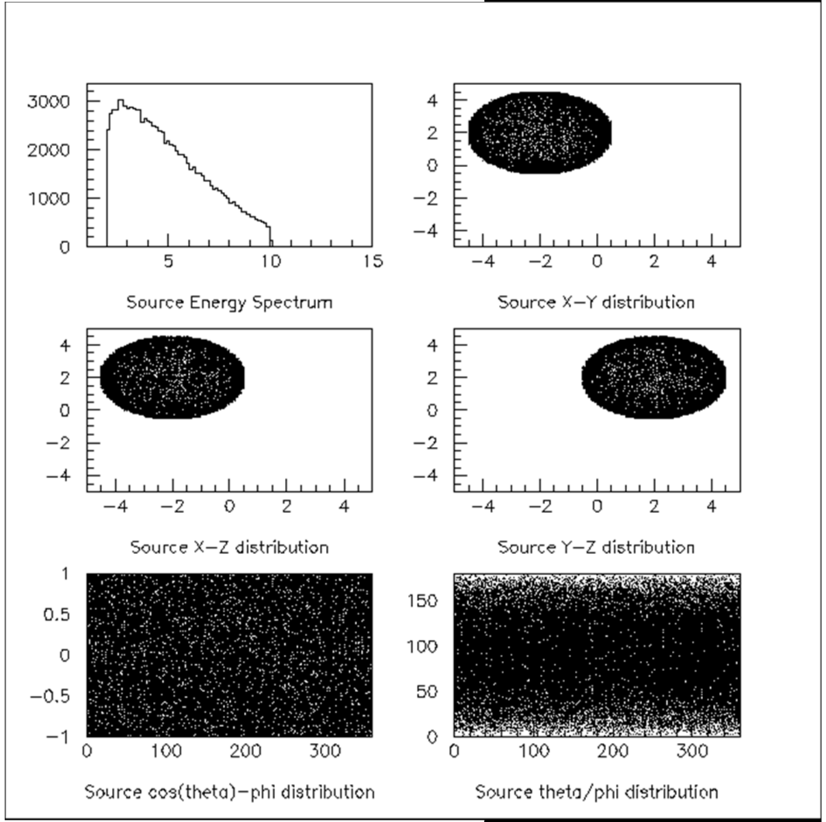


GPS
Example 6

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

Macro

```
/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
```

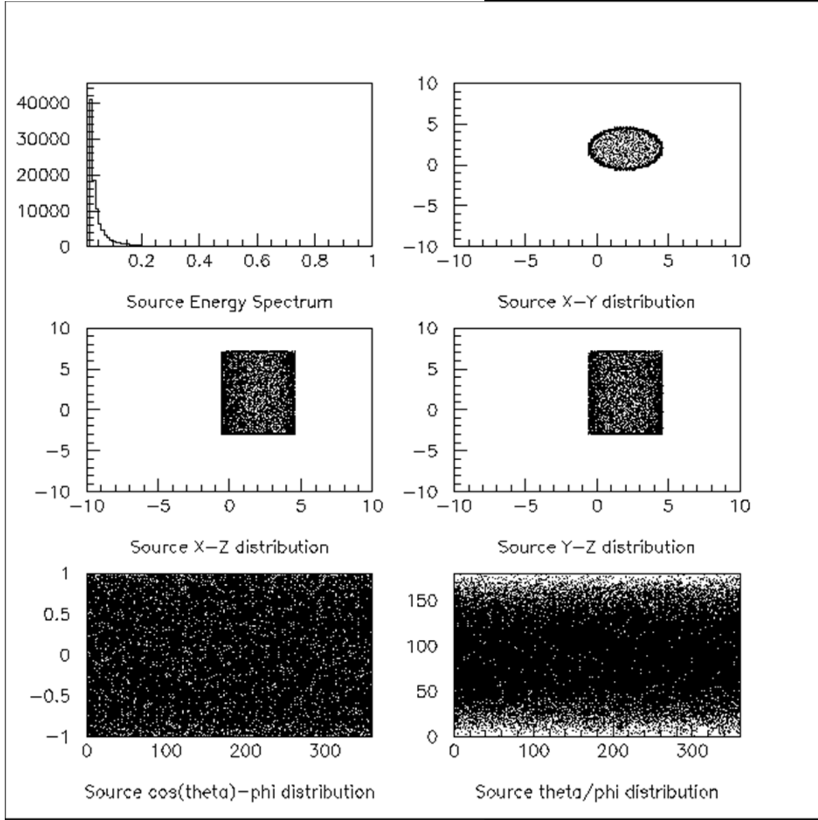


GPS
Example 7

- Vertex on cylinder surface
- Cosine-law emission
  (to mimic isotropic source in space)
- Pre-defined spectrum
  (Cosmic Diffuse Gamma)

Macro

```
/gps/particle gamma

/gps/pos/type Surface
/gps/pos/shape Cylinder
/gps/pos/centre 2. 2. 2. cm
/gps/pos/radius 2.5 cm
/gps/pos/halfz 5. cm

/gps/ang/type cos

/gps/ene/type Cdg
/gps/ene/min 20. keV
/gps/ene/max 1. MeV
/gps/ene/calculate
```

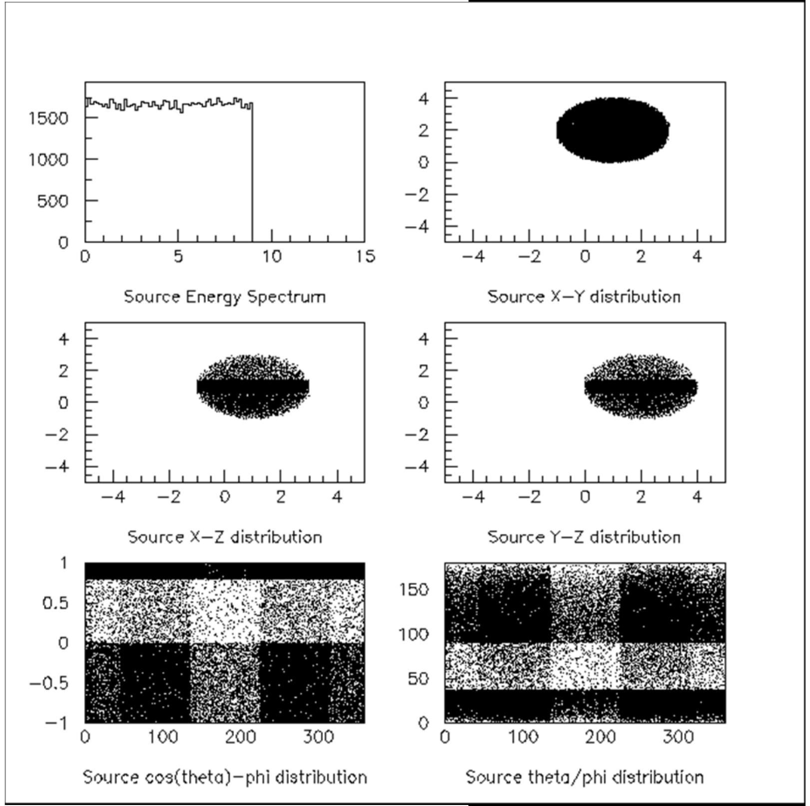



GPS
Example 24

- Vertex in sphere volume
  with z biasing
- Isotropic radiation
  with theta and phi biasing
- Integral arbitrary point-wise energy
  distribution with linear interpolation.

Macro

```
/gps/particle geantino
/gps/pos/type Volume
/gps/pos/shape Sphere
/gps/pos/centre 1. 2. 1. cm
/gps/pos/radius 2. Cm

/gps/ang/type iso

/gps/ene/type Arb
/gps/ene/diffspec 0
/gps/hist/type arb
/gps/hist/point 0.0 11.
/gps/hist/point 1.0 10.
/gps/hist/point 2.0 9.
/gps/hist/point 3.0 8.
/gps/hist/point 4.0 7.
/gps/hist/point 7.0 4.
/gps/hist/point 8.0 3.
/gps/hist/point 9.0 2.
/gps/hist/point 10.0 1.
/gps/hist/point 11.0 0.
/gps/hist/inter Lin

/gps/hist/type biasz
/gps/hist/point 0. 0.
/gps/hist/point 0.4 0.5
/gps/hist/point 0.6 1.
/gps/hist/point 1. 0.2

/gps/hist/type biast
/gps/hist/point 0. 0.
/gps/hist/point 0.1 1.
/gps/hist/point 0.5 0.1
/gps/hist/point 1. 1.

/gps/hist/type biasp
/gps/hist/point 0. 0.
/gps/hist/point 0.125 1.
/gps/hist/point 0.375 4.
/gps/hist/point 0.625 1.
/gps/hist/point 0.875 4.
/gps/hist/point 1. 1.
```

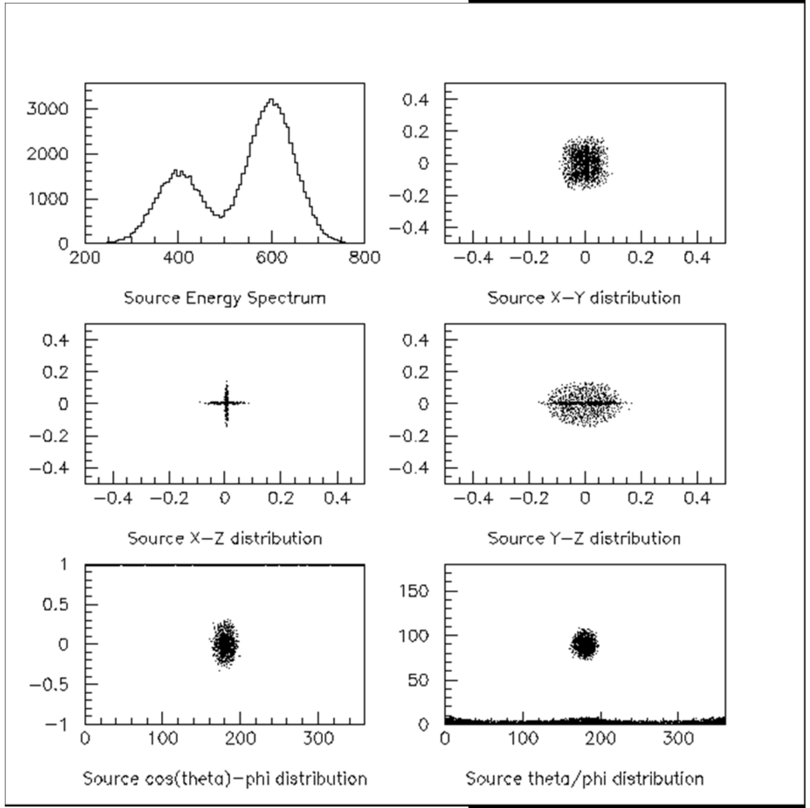



GPS
Example 31

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

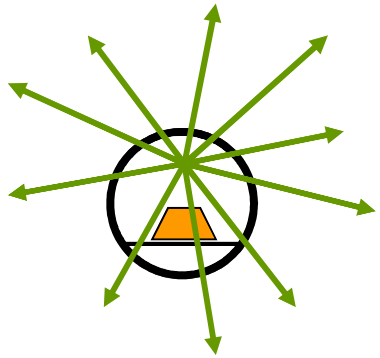
Macro

```
# 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
    /source/add 10.

    # this is a electron beam
    ...
```

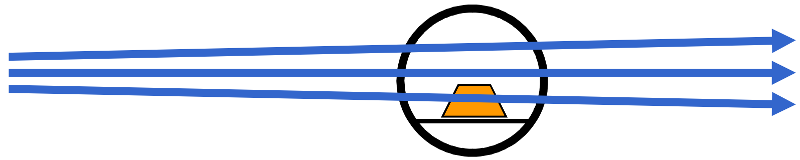


Exercises

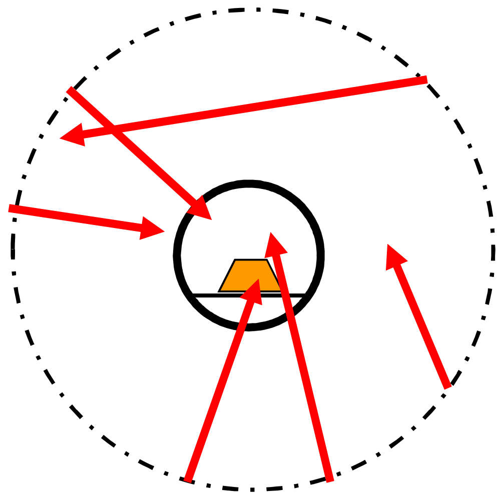
1. Cobalt-60 gamma source



1. Proton accelerator source



1. Space electron environment



Introduction

Basic functioning

Position, angular & energy distributions

Examples

Documentation and support

Primary Generation in Geant4

- Lecture 4 : Generation of primary particles

GPS

- Website: http://reat.space.qinetiq.com/gps/

Support from users and developers

- Geant4 HyperNews – Particles
  questions, proposal of new capabilities
  http://hypernews.slac.stanford.edu/HyperNews/geant4/get/particles.html

Normalisation for Isotropic radiation in space, Sphere surface

- N_r is the number of particles traversing my source volume in the real world
- N_r depends on the external flux, integrated on relevant source surface and solid angle
  - Only the source geometry is relevant for source normalisation, no detector parameter

- Φ → external flux (energy integrated) [/ cm^2 s sr]

Two possible approaches

- Method 1
  - Integrate over the 2 π emission angle, with cosine-law biasing → $$\int_0^{2\pi} d\phi \int_0^{\pi/2} d\theta \cos\theta \sin\theta = \pi$$
  - Then integrate over the source sphere surface: $S = 4\pi R^2$

- Method 2 (euristic)
  - Assume isotropic source in space (no cosine-law) → $$\int_0^{2\pi} d\phi \int_0^{\pi} d\theta \sin\theta = 4\pi$$
  - Take only sphere equatorial surface as effective geometrical cross section: $S = \pi R^2$

$$\boxed{N_r = \Phi\, 4\pi^2 R^2}$$