(Hands-on) Primary Generator
- General Particle Source (GPS) -

T. Yamashita, Kobe Proton Center
T. Aso, NIT-Toyama

Outline

- This hands-on focuses on the General Particle Source (GPS) as the primary generator.

- You will do:
  - Check the GPS application implementation in the example application

  - Set primary particle parameters for
    - The medical beam lines:
      - Particle species, energy and momentum direction
      - Beam spot shape
      - Beam divergence
    - The branchy therapies such as:
      - Multiple volumetric sources

General Particle Source (GPS)

- GPS is one of build-in primary generators
  - It offers UI commands for the specifications of the spectral, spatial and angular distribution of the primary source particles.
  - The detail description can be found at:
    - **Book for Geant4 Application Developers**
      - ➢ Geant4 General Particle Source

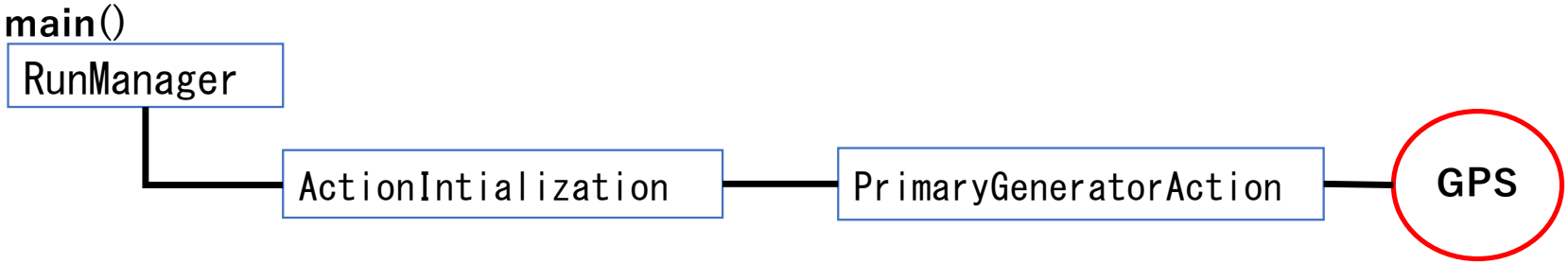
Download the Hands-on example code

- Download the Hands-on code if you have not done yet
  - See previous lecture

H02:Introduction of medical application example in Geant4 and the hands-on code

Checking the GPS implementation in the example application (1)

- G4GeneralParticleSource is a concrete class of primary generator.
- The following classes concern to the primary generator in the example code



- In the main program, ActionInitialization is registered to RunManager
- PrimaryGeneratorAction is registered in ActionInitialization
- G4GeneralParticleSource is instantiated in PrimaryGeneratorAction

Checking the GPS implementation in the example application (2) [Hands-on]

- In the example code:

```
$ cd ~/Galet-v11-MedEx

$ less  Galet.cc
$ less  src/ActionInitialization.cc
$ less  src/PrimaryGeneratorAction.cc
```

Galet.cc

```
//ActionInitializtion
auto actionInitialization = new Galet::ActionInitialization();
runManager->SetUserInitialization(actionInitialization);
```

src/ActionInitialization.cc

```
void ActionInitialization::Build() const
{
  SetUserAction(new PrimaryGeneratorAction);
  SetUserAction(new RunAction);
  SetUserAction(new EventAction);
  SetUserAction(new SteppingAction);
  SetUserAction(new TrackingAction);
}
```

src/PrimaryGeneratorAction.cc

```
PrimaryGeneratorAction::PrimaryGeneratorAction()
  :G4VUserPrimaryGeneratorAction(){
   fGPS = new G4GeneralParticleSource();
}
...
void PrimaryGeneratorAction::GeneratePrimaries(G4Event* anEvent){
  // This function is called at the beginning of event
  fGPS->GeneratePrimaryVertex(anEvent);
}
```

Run the Galet sample program

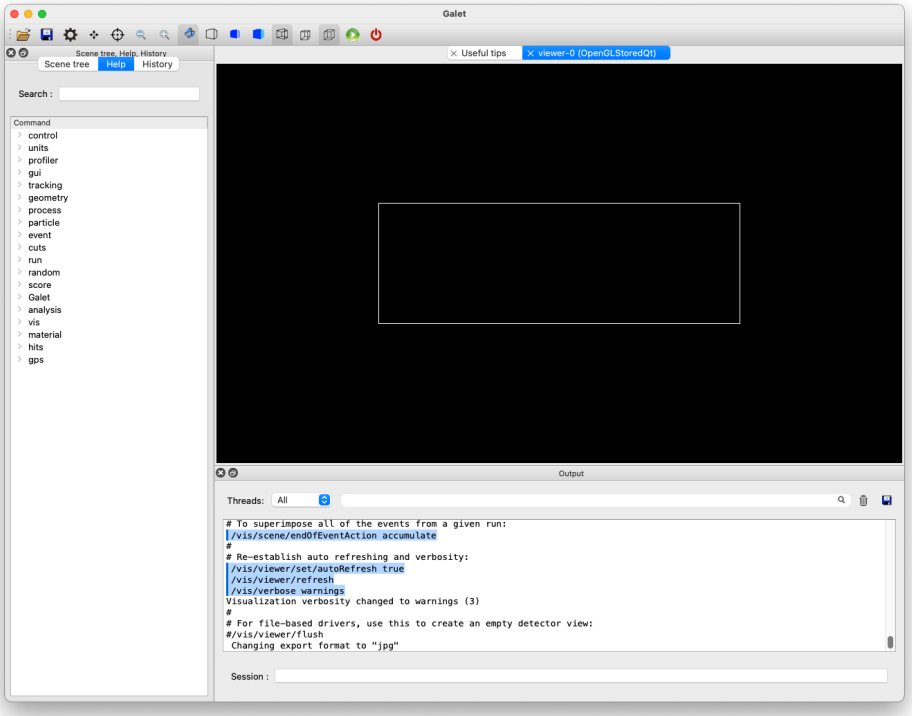
[Hands-on]

(Build the Galet application if you have not done yet.)

```
$ cd
$ mkdir Galet-v11-MedEx-build
$ cd Galet-v11-MedEx-build
$ cmake ../Galet-v11-MedEx
$ make
```

(Run the Galet application)

```
$ cd ~/Galet-v11-MedEx-build
$ ls
$ ./Galet
```



(Tips) Geant4 w/ visualization

- In several machine conditions, we may have problem of visualization such as very slow response, hang-up of application.

- If you have such problem, set the Geant4 RunManager type to serial by:

  ```
  $ export G4FORCE_RUN_MANAGER_TYPE=Serial
  ```

  - This command forces the Geant4 to run with a single thread mode.

- When you want to use the multithreading mode, remove this by:

  ```
  $ export  -n  G4FORCE_RUN_MANAGER_TYPE
  ```

Exercises

- Try series of example commands from Ex.1 to Ex.13 in the following slides. (Because of time limitation, you can choose only red examples.
  - Ex.1) Shooting gamma particles
  - Ex.2) Shooting carbon-ion particles
  - Ex.3) Place a Cs-137 nuclide
  - Ex.4) Beam spot (Square)
  - Ex.5) Beam spot (Circle)
  - Ex.6) Gaussian spot
  - Ex.7) Beam plane rotation
  - Ex.8) Beam angular biasing
  - Ex.9) Gaussian beam divergence
  - Ex.10) Focusing beam
  - Ex.11) Gaussian energy dist.
  - Ex.12) User-defined energy dist.
  - Ex.13) Two volumetric sources

Enter the commands in the session box.
Or
More easily, these commands are commented out in the gps.mac. Edit the gps.mac and activate the commands by deleting "#" while inserting "#" in the other needless commands.

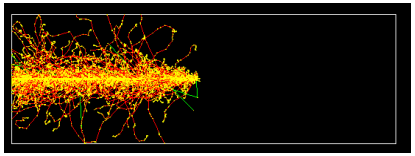
(Attention)
The GPS commands are sensitive to its command order. If you have problem, restart the Galet and then enter the commands with the order same as examples.

Setting primary particle parameters (1) [Hands-on]

- Try Ex1 to Ex3

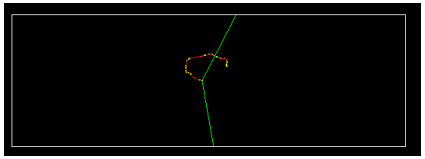
Ex. 1) Shooting gamma particles

```
/gps/particle gamma
/gps/energy    1.33 MeV
/gps/position  0. 0.  -5  cm
/gps/direction  0.  0.  -1.
/run/beamOn  50
```



Ex. 2) Shooting carbon-ion particles

```
/gps/particle ion
/gps/ion  6  12  6
/gps/energy   2400.0 MeV
/gps/position 0. 0.  -5  cm
/gps/direction  0.  0.  -1.
/run/beamOn  50
```



Ex. 3) Place a Cs-137 nuclide

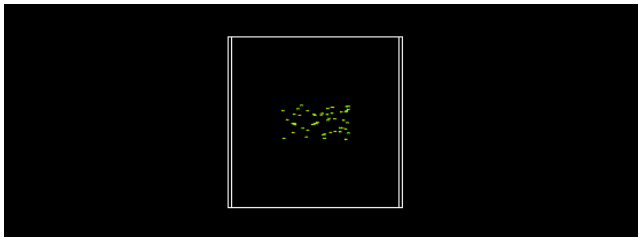
```
/gps/particle ion
/gps/ion  55  137  0
/gps/energy   0.0 MeV
/gps/position    0. 0.  -5  cm
/run/beamOn  1
```

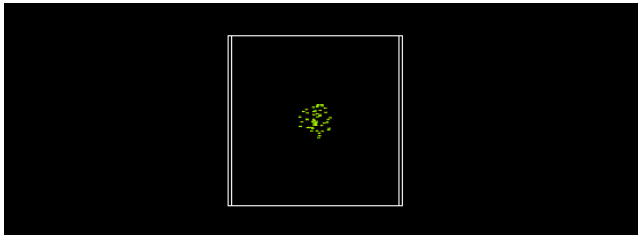
Snippet from G4 manual

Command	Arguments	Description and restrictions
/gps/List		List available incident particles
/gps/particle	name	Defines the particle type [default *geantino*], using GEANT4 naming convention.
/gps/direction	Px Py Pz	Set the momentum direction [default (1,0,0)] of generated particles using (1)
/gps/energy	E unit	Sets the energy [default 1 MeV] for mono-energetic sources. The units can be eV, keV, MeV, GeV, TeV or PeV. (NB: it is recommended to use /gps/ene/mono instead.)
/gps/position	X Y Z unit	Sets the centre co-ordinates (X,Y,Z) of the source [default (0,0,0) cm]. The units can be micron, mm, cm, m or km. (NB: it is recommended to use /gps/pos/centre instead.)
/gps/ion	Z A Q E	After `/gps/particle ion`, sets the properties (atomic number Z, atomic mass A, ionic charge Q, excitation energy E in keV) of the ion.
/gps/ionLvl	Z A Q lvl	After `/gps/particle ion`, sets the properties (atomic number Z, atomic mass A, ionic charge Q, Number of metastable state excitation level (0-9) of the ion.
/gps/time	t0 unit	Sets the primary particle (event) time [default 0 ns]. The units can be ps, ns, us, ms, or s.
/gps/polarization	Px Py Pz	Sets the polarization vector of the source, which does not need to be a unit vector.
/gps/number	N	Sets the number of particles [default 1] to simulate on each event.
/gps/verbose	level	Control the amount of information printed out by the GPS code. Larger values produce more detailed output.

Setting the complex beam position parameters (1) [Hands-on]

- Try Ex.4 to Ex 5





Ex.4) Beam spot (Square)

```
/gps/particle geantino
/gps/pos/type Plane
/gps/pos/shape Square
/gps/pos/halfx  20. cm
/gps/pos/halfy  10. cm
/gps/pos/centre 0. 0. 0. cm
/gps/direction  0  0   -1
/gps/energy   200 MeV
/run/beamOn  50
```

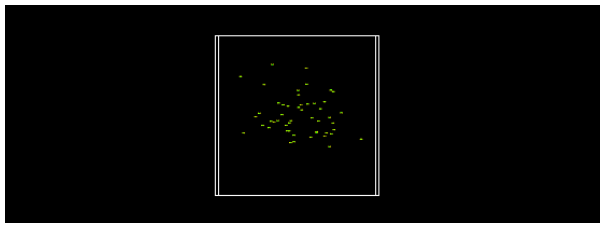
Ex.5) Beam spot (Circle)

```
/gps/particle      geantino
/gps/pos/type    Plane
/gps/pos/shape Circle
/gps/pos/radius  10. cm
/gps/pos/centre  0.  0.  0. cm
/gps/direction     0  0   -1
/gps/energy        200. MeV
/run/beamOn 50
```

Command	Arguments	Description and restrictions
/gps/pos/type	dist	Sets the source positional distribution type: *Point* [default], *Plane, Beam, Surface, Volume.*
/gps/pos/shape	shape	Sets the source shape type, after `/gps/pos/type` has been used. For a Plane this can be *Circle, Annulus, Ellipse, Square, Rectangle.* For both Surface or Volume sources this can be *Sphere, Ellipsoid, Cylinder, Para* (parallelepiped).
/gps/pos/centre	X Y Z unit	Sets the centre co-ordinates (X,Y,Z) of the source [default (0,0,0) cm]. The units can only be micron, mm, cm, m or km.
/gps/pos/rot1	$R1_x$ $R1_y$ $R1_z$	Defines the first (x' direction) vector R1 [default (1,0,0)], which does not need to be a unit vector, and is used together with `/gps/pos/rot2` to create the rotation matrix of the shape defined with `/gps/shape`.
/gps/pos/rot2	$R2_x$ $R2_y$ $R2_z$	Defines the second vector R2 in the xy plane [default (0,1,0)], which does not need to be a unit vector, and is used together with `/gps/pos/rot1` to create the rotation matrix of the shape defined with `/gps/shape`.
/gps/pos/halfx	len unit	Sets the half-length in x [default 0 cm] of the source. The units can only be micron, mm, cm, m or km.
/gps/pos/halfy	len unit	Sets the half-length in y [default 0 cm] of the source. The units can only be micron, mm, cm, m or km.
/gps/pos/halfz	len unit	Sets the half-length in z [default 0 cm] of the source. The units can only be micron, mm, cm, m or km.
/gps/pos/radius	len unit	Sets the radius [default 0 cm] of the source or the outer radius for annuli. The units can only be micron, mm, cm, m or km.
/gps/pos/inner_radius	len unit	Sets the inner radius [default 0 cm] for annuli. The units can only be micron, mm, cm, m or km.

Setting the complex beam position parameters (2) [Hands-on]

- Try Ex.6



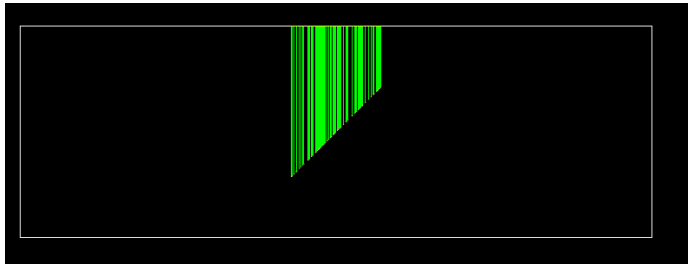
Ex.6) Gaussian spot

```
/vis/viewer/set/viewpointThetaPhi 0. 180.
/gps/particle   geantino
/gps/pos/type    Beam
/gps/pos/sigma_r   10.0 cm
/gps/pos/centre  0.   0.   0. cm
/gps/direction  0  0   -1
/gps/energy 200. MeV
/run/beamOn 50
```

/gps/pos/radius	len unit	Sets the radius [default 0 cm] of the source or the outer radius for annuli. The units can only be micron, mm, cm, m or km.
/gps/pos/inner_radius	len unit	Sets the inner radius [default 0 cm] for annuli. The units can only be micron, mm, cm, m or km.
/gps/pos/sigma_r	sigma unit	Sets the transverse (radial) standard deviation [default 0 cm] of beam position profile. The units can only be micron, mm, cm, m or km.
/gps/pos/sigma_x	sigma unit	Sets the standard deviation [default 0 cm] of beam position profile in x-direction. The units can only be micron, mm, cm, m or km.
/gps/pos/sigma_y	sigma unit	Sets the standard deviation [default 0 cm] of beam position profile in y-direction. The units can only be micron, mm, cm, m or km.
/gps/pos/paralp	alpha unit	Used with a Parallelepiped. The angle [default 0 rad] α formed by the y-axis and the plane joining the centre of the faces parallel to the zx plane at y and +y. The units can only be deg or rad.
/gps/pos/parthe	theta unit	Used with a Parallelepiped. Polar angle [default 0 rad] θ of the line connecting the centre of the face at z to the centre of the face at +z. The units can only be deg or rad.
/gps/pos/parphi	phi unit	Used with a Parallelepiped. The azimuth angle [default 0 rad] ϕ of the line connecting the centre of the face at z with the centre of the face at +z. The units can only be deg or rad.
/gps/pos/confine	name	Allows the user to confine the source to the physical volume *name* [default NULL].

Setting the complex beam position parameters(3) [Hands-on]

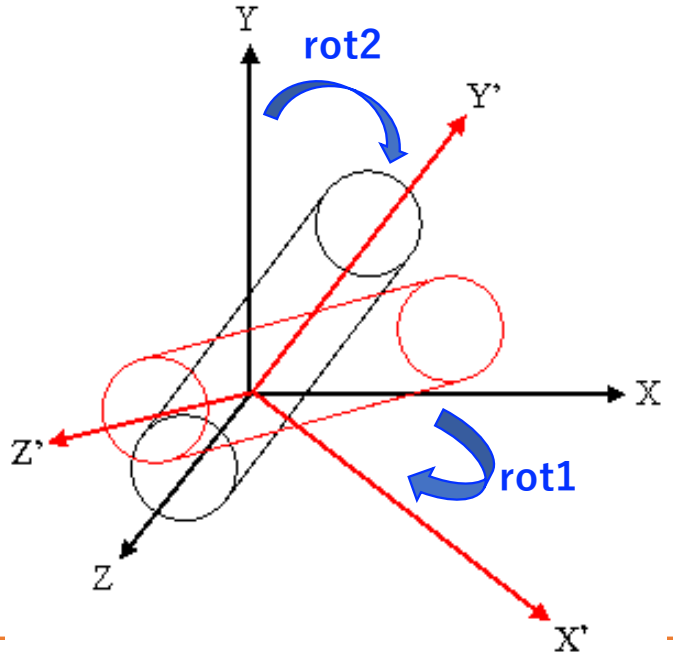
- Try Ex.7



Ex.7) Beam plane rotation

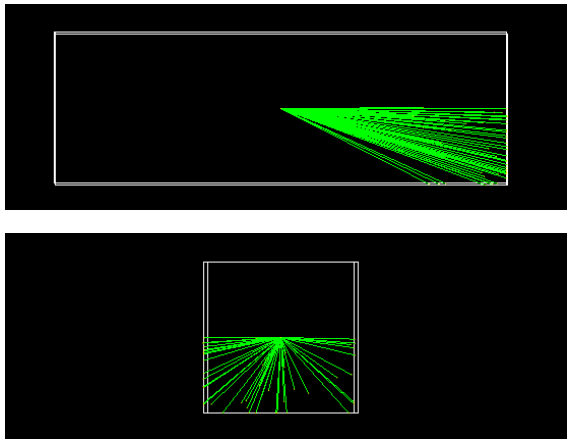
```
/gps/particle geantino
/gps/pos/type Plane
/gps/pos/shape Square
/gps/pos/centre 0. 0. 0. cm
/gps/pos/halfx  30. cm
/gps/pos/halfy  30. cm
/gps/pos/rot1  1 0 0
/gps/pos/rot2  0 1 1
/gps/direction  0  1   0
/gps/energy 200. MeV
```

/gps/pos/rot1	$R1_x$ $R1_y$ $R1_z$	Defines the first (x' direction) vector R1 [default (1,0,0)], which does not need to be a unit vector, and is used together with `/gps/pos/rot2` to create the rotation matrix of the shape defined with `/gps/shape`.
/gps/pos/rot2	$R2_x$ $R2_y$ $R2_z$	Defines the second vector R2 in the xy plane [default (0,1,0)], which does not need to be a unit vector, and is used together with `/gps/pos/rot1` to create the rotation matrix of the shape defined with `/gps/shape`.



Setting the complex beam angular parameters (1) [Hands-on]

- Try Ex.8



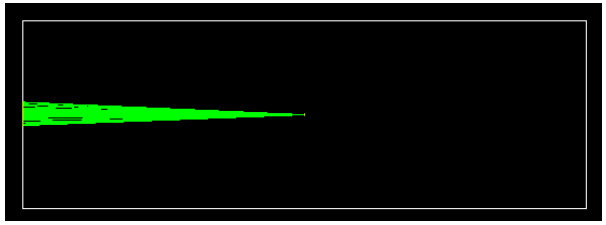
Ex.8) Beam angular biasing

```
/gps/particle geantino
/gps/pos/type  Point
/gps/pos/centre 0. 0. 0. cm
/gps/ang/type iso
/gps/ang/mintheta  0. deg
/gps/ang/maxtheta  30. deg
/gps/ang/minphi  0. deg
/gps/ang/maxphi  180. deg
/gps/energy 200. MeV
```

Command	Arguments	Description and restrictions
/gps/ang/type	AngDis	Sets the angular distribution type (*iso* [default], *cos, planar, beam1d, beam2d, focused, user*) to either isotropic, cosine-law or user-defined.
/gps/ang/rot1	$AR1_x$ $AR1_y$ $AR1_z$	Defines the first (x' direction) rotation vector AR1 [default (1,0,0)] for the angular distribution and is not necessarily a unit vector. Used with `/gps/ang/rot2` to compute the angular distribution rotation matrix.
/gps/ang/rot2	$AR2_x$ $AR2_y$ $AR2_z$	Defines the second rotation vector AR2 in the xy plane [default (0,1,0)] for the angular distribution, which does not necessarily have to be a unit vector. Used with `/gps/ang/rot2` to compute the angular distribution rotation matrix.
/gps/ang/mintheta	MinTheta unit	Sets a minimum value [default 0 rad] for the θ distribution. Units can be deg or rad.
/gps/ang/maxtheta	MaxTheta unit	Sets a maximum value [default π rad] for the θ distribution. Units can be deg or rad.
/gps/ang/minphi	MinPhi unit	Sets a minimum value [default 0 rad] for the ϕ distribution. Units can be deg or rad.
/gps/ang/maxphi	MaxPhi unit	Sets a maximum value [default 2π rad] for the ϕ distribution. Units can be deg or rad.

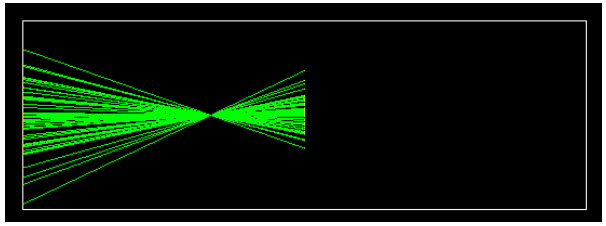
Setting the complex beam angular parameters (2) [Hands-on]

- Restart Galet, then try Ex.9 to Ex.10



Ex.9) Gaussian beam divergence

```
/gps/particle  geantino
/gps/pos/type  Beam
/gps/pos/sigma_r 0.2 mm
/gps/pos/centre  0.  0.  0. cm
/gps/direction 0 0 -1
/gps/ang/type beam2d
/gps/ang/sigma_x  10. mrad
/gps/ang/sigma_y  20. mrad
/gps/energy   200 MeV
/run/beamOn  50
```



Ex.10)Focusing beam

```
/gps/particle  geantino
/gps/pos/type  Beam
/gps/pos/sigma_r 100. mm
/gps/pos/centre  0.  0.  0. cm
/gps/direction 0 0 -1
/gps/ang/type  focused
/gps/ang/focuspoint  0.  0.  -50.  cm
/gps/energy   200 MeV
/run/beamOn  50
```

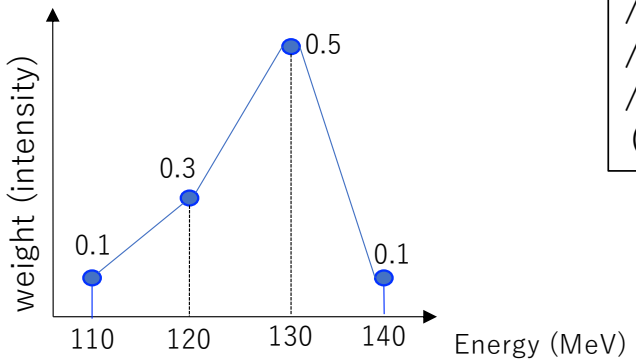
Command	Arguments	Description and restrictions
/gps/ang/type	AngDis	Sets the angular distribution type (*iso* [default], *cos, planar, beam1d, beam2d, focused, user*) to either isotropic, cosine-law or user-defined.
/gps/ang/rot1	$AR1_x$ $AR1_y$ $AR1_z$	Defines the first (x' direction) rotation vector AR1 [default (1,0,0)] for the angular distribution and is not necessarily a unit vector. Used with `/gps/ang/rot2` to compute the angular distribution rotation matrix.
/gps/ang/rot2	$AR2_x$ $AR2_y$ $AR2_z$	Defines the second rotation vector AR2 in the xy plane [default (0,1,0)] for the angular distribution, which does not necessarily have to be a unit vector. Used with `/gps/ang/rot2` to compute the angular distribution rotation matrix.
/gps/ang/mintheta	MinTheta unit	Sets a minimum value [default 0 rad] for the θ distribution. Units can be deg or rad.
/gps/ang/maxtheta	MaxTheta unit	Sets a maximum value [default π rad] for the θ distribution. Units can be deg or rad.
/gps/ang/minphi	MinPhi unit	Sets a minimum value [default 0 rad] for the ϕ distribution. Units can be deg or rad.
/gps/ang/maxphi	MaxPhi unit	Sets a maximum value [default 2π rad] for the ϕ distribution. Units can be deg or rad.
/gps/ang/sigma_r	sigma unit	Sets the standard deviation [default 0 rad] of beam directional profile in radial. The units can only be deg or rad.
/gps/ang/sigma_x	sigma unit	Sets the standard deviation [default 0 rad] of beam directional profile in x-direction. The units can only be deg or rad.
/gps/ang/sigma_y	sigma unit	Sets the standard deviation [default 0 rad] of beam directional profile in y-direction. The units can only be deg or rad.
/gps/ang/focuspoint	X Y Z unit	Set the focusing point (X,Y,Z) for the beam [default (0,0,0) cm]. The units can only be micron, mm, cm, m or km.
/gps/ang/user_coor	bool	Calculate the angular distribution with respect to the user defined co-ordinate system (*true*), or with respect to the global co-ordinate system (*false*, default).
/gps/ang/surfnorm	bool	Allows user to choose whether angular distributions are with respect to the co-ordinate system (*false*, default) or surface normals (*true*) for user-defined distributions.

Setting the beam energy parameters (1) [Hands-on]

- Try Ex.11 to Ex.12

Ex.11) Gaussian energy dist.

```
/gps/particle  proton
/gps/pos/centre 0. 0. 0. cm
/gps/direction 0  0  1
/gps/ene/type Gauss
/gps/ene/mono  100 MeV
/gps/ene/sigma  50. MeV
/tracking/verbose 1
/run/beamOn 1
/run/beamOn 1
```



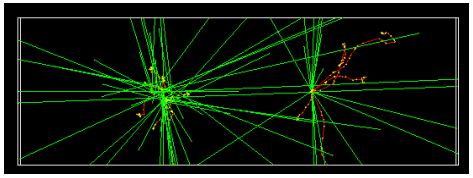
Ex.12) User-defined energy dist.

```
/gps/particle geantino
/gps/position  0. 0.  0.  cm
/gps/direction  0.  0.  1.
/gps/ene/type  User
/gps/hist/type  energy
/gps/hist/point  110.  0.1
/gps/hist/point  120.  0.3
/gps/hist/point  130.  0.5
/gps/hist/point  140.  0.1
/tracking/verbose 1
/run/beamOn  1
/run/beamOn  1
(Check its initial energy)
```

/gps/ene/type	EnergyDis	Sets the energy distribution type to one of (see Table 1): *Mono* (mono-energetic, default), *Lin* (linear), *Pow* (power-law), Exp (exponential), *Gauss* (Gaussian), *Brem* (bremsstrahlung), *Bbody* (black-body), *Cdg* (cosmic diffuse gamma-ray), *User* (user-defined histogram), *Arb* (point-wise spectrum), *Epn* (energy-per-nucleon histogram)
/gps/ene/min	Emin unit	Sets the minimum [default 0 keV] for the energy distribution. The units can be eV, keV, MeV, GeV, TeV or PeV.
/gps/ene/max	Emax unit	Sets the maximum [default 0 keV] for the energy distribution. The units can be eV, keV, MeV, GeV, TeV or PeV.
/gps/ene/mono	E unit	Sets the energy [default 1 MeV] for mono-energetic sources. The units can be eV, keV, MeV, GeV, TeV or PeV.
/gps/ene/sigma	sigma unit	Sets the standard deviation [default 0 keV] in energy for Gaussian or Mono energy distributions. The units can be eV, keV, MeV, GeV, TeV or PeV.
/gps/hist/type	type	Set the histogram type: predefined *biasx* [default], *biasy, biasz, biast* (angle θ, *biasp* (angle ϕ), *biaspt* (position θ, *biaspp* (position ϕ), *biase*; user-defined histograms *theta, phi, energy, arb* (point-wise), *epn* (energy per nucleon).
/gps/hist/reset	type	Re-set the specified histogram: *biasx* [default], , *biasy, biasz, biast, biasp, biaspt, biaspp, biase, theta, phi, energy, arb, epn.*
/gps/hist/point	E_{hi} Weight	Specify one entry (with contents *Weight*) in a histogram (where E_{hi} is the bin upper edge) or point-wise distribution (where E_{hi} is the abscissa). The abscissa E_{hi} must be in GEANT4 default units (MeV for energy, rad for angle).

Setting the multiple volumetric sources (1)

- Try Ex.13



Ex.13) Two volumetric sources

```
/gps/source/add  0.5
/gps/particle ion
/gps/ion  27  60  0
/gps/energy   0.0 MeV
/gps/pos/type Volume
/gps/pos/shape Sphere
/gps/pos/radius  10. cm
/gps/pos/centre  0.  0.  -50. cm
#
/gps/source/add  0.5
/gps/particle ion
/gps/ion  55  137  0
/gps/energy   0.0 MeV
/gps/pos/type Volume
/gps/pos/shape Sphere
/gps/pos/radius  1. cm
/gps/pos/centre   0. 0.  +50.  cm
#
/run/beamOn  50
```

/gps/source/add	intensity	Add a new particle source with the specified intensity
/gps/source/list		List the particle sources defined.
/gps/source/clear		Remove all defined particle sources.
/gps/source/show		Display the current particle source
/gps/source/set	index	Select the specified particle source as the current one.
/gps/source/delete	index	Remove the specified particle source.
/gps/source/multiplevertex	flag	Specify *true* for simultaneous generation of multiple vertices, one from each specified source. False [default] generates a single vertex, choosing one source randomly.

/gps/pos/type	dist	Sets the source positional distribution type: *Point* [default], *Plane, Beam, Surface, Volume.*
/gps/pos/shape	shape	Sets the source shape type, after `/gps/pos/type` has been used. For a Plane this can be *Circle, Annulus, Ellipse, Square, Rectangle*. For both Surface or Volume sources this can be *Sphere, Ellipsoid, Cylinder, Para* (parallelepiped).
/gps/pos/centre	X Y Z unit	Sets the centre co-ordinates (X,Y,Z) of the source [default (0,0,0) cm]. The units can only be micron, mm, cm, m or km.

Practice [Hands-on]

- Consider the GPS commands for following parameters.
  - Particle　　Proton
  - Position Profile
    - Type　　Beam
    - Center coordinate　　(0,　0,　1500) mm
    - Radial standard deviation　5 mm
  - Angular Profile
    - Type　　Beam2d
    - Standard deviation in X 10 mrad
    - Standard deviation in Y 20 mrad
  - Energy Profile
    - Type　　Gauss
    - Energy　　150 MeV
    - Standard deviation　0.127 MeV

Enter the commands in session box and check the consequence.

Answer of practice 1 [Hands-on]

```
/gps/particle    proton
/gps/position    0. 0. 1500 mm
/gps/pos/type    Beam
/gps/pos/sigma_r  5.0 mm
/gps/ang/type    beam2d
/gps/ang/sigma_x  10 mrad
/gps/ang/sigma_y  20 mrad
/gps/ene/type    Gauss
/gps/ene/mono  150.0  MeV
/gps/ene/sigma  0.127 MeV
```

These commands are also written in gps.mac.

Edit gps.mac
- **inactivate the default setting**
- **activate these lines**
- **check the consequence**
- **Try to modify these parameters and check the consequence**

Answer of practice 1 [Hands-on]

These commands are also written in gps.mac.

Quit the Galet and Edit gps.mac
- **inactivate the default setting**
- **activate these lines**
- **check the consequence**
- **Try to modify these parameters and check the consequence**

***After you check the gps.mac, please take it back to default parameters.**

gps.mac

```
#-----
# Proton pencil beam
#-----
#/gps/position 0. 0.  150. cm
#/gps/direction 0. 0. -1.
#/gps/energy   200. MeV
#/gps/particle  proton
#-----
# Proton beam
#-----
/gps/particle    proton
/gps/position    0. 0. 1500 mm
/gps/pos/type    Beam
/gps/pos/sigma_r  5.0 mm
/gps/ang/type    beam2d
/gps/ang/sigma_x  10 mrad
/gps/ang/sigma_y  20 mrad
/gps/ene/type    Gauss
/gps/ene/mono  150.0  MeV
/gps/ene/sigma  0.127 MeV
#-----
# RI Co-60
#-----
#/gps/position 0. 0.  3. cm
#/gps/energy   0. MeV
#/gps/particle  ion
#/gps/ion      27 60
#
```

Default parameters

Answer of practice 1