Simple sources and preprocessor

Outline

1. Simple source definition

- Definition of simple beams
  - Beam parameters
  - Beam visualisation
  - Beam rotation
- Volumetric sources
- Multiple Beam Spots
- Further possibilities

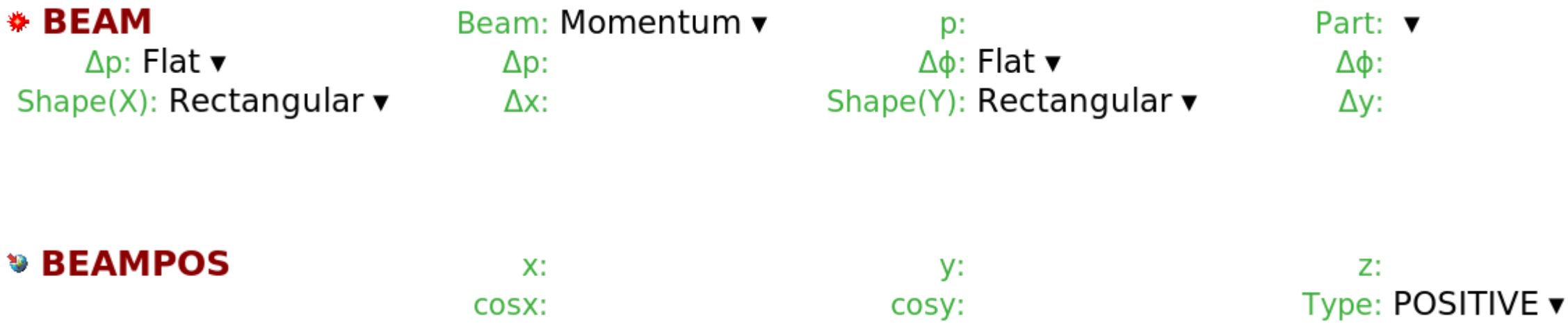
2. The FLUKA preprocessor

1. Simple sources

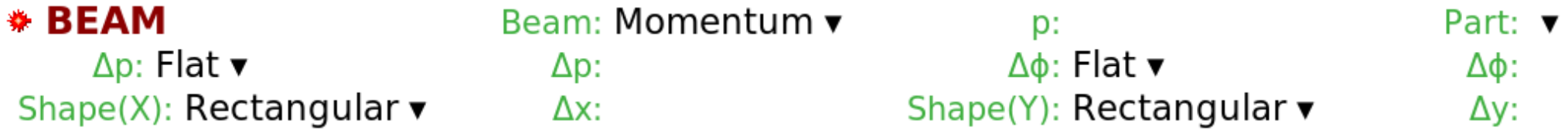
BEAM & **BEAMPOS** cards | Visualisation | Volumetric sources | Multiple Beam Spots

Required cards

- In the *Basic input & Flair introduction* lecture we already saw two cards related to defining a beam in FLUKA, namely the **BEAM** and **BEAMPOS** cards:



The BEAM card



- The BEAM card allows to specify the following parameters:
  - Particle type
  - Momentum or kinetic energy
  - Momentum distribution
  - Angular distribution
  - Shape in the X-Y plane

The BEAM card: particle type

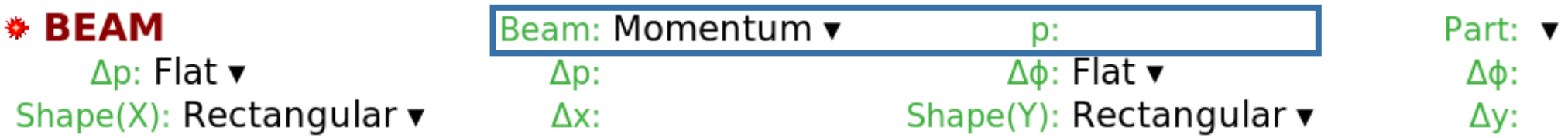
Select particle type from the dropdown menu

Default particle: **PROTON**

Non-standard particles:

- **HEAVYION**: Ion beams heavier than ^{4}He – Requires a **HI-PROPE** card.
- **ISOTOPE**: Radioactive isotope sources – Requires the **HI-PROPE** and **RADDECAY** cards. See the *Radiation Protection calculations* lecture

The BEAM card: momentum/energy definition



Select **Momentum** or **Energy** from the dropdown menu

Enter the **value** in the input field next to it

Default value: **200 [GeV/c]**

Note: In the case of advanced sources, setting the momentum slightly higher than the maximum momentum used in those sources is **crucial**, since this value is used to initialise the cross section data tables.

(See the *Advanced topics* lecture and FLUKA Advanced Course)

The BEAM card: momentum and angular distributions

Momentum distribution types:

- **Flat**: Full width of a rectangular **momentum** distribution centred at beam momentum [GeV/c]
- **Gaussian**: FWHM of a Gaussian **momentum** distribution [GeV/c]

IMPORTANT: This is always momentum distribution, even if **Energy** was selected

Angular distribution types:

- **Flat**: Full width of a rectangular angular distribution centred at the beam axis [mrad]
- **Isotropic**: Isotropic distribution
- **Gaussian**: FWHM of a Gaussian angular distribution centred at the beam axis [mrad]

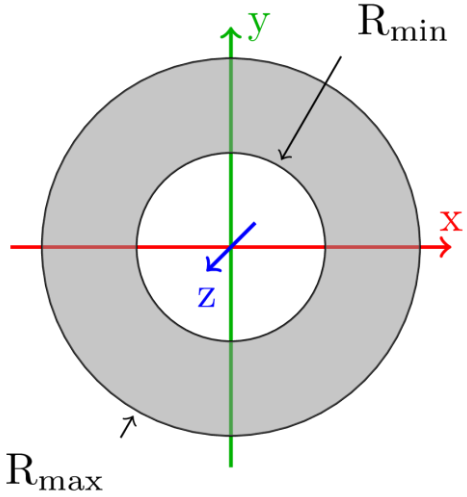
The BEAM card: beam shape in the X-Y plane

BEAM	Beam: Momentum ▾	p:		Part: ▾
Δp: Flat ▾	Δp:	Δϕ: Flat ▾		Δϕ:
Shape(X): Rectangular ▾	Δx:	Shape(Y): Rectangular ▾		Δy:

Distribution type:

- **Rectangular**: Full beam width in **x/y** direction centred at the beam axis [cm]
- **Gaussian**: FWHM of a Gaussian distribution in **x/y** direction centred at the beam axis [cm]

  Default: **Δx** = 0.0, **Δy** = **Δx**
- **Annular** distribution can be selected in the dropdown menu of **Shape(X)**
  - **Rmin** and **Rmax** are the radii of the distribution
  - The beam particle position is uniformly sampled on the **x**-**y** plane between **Rmin** and **Rmax**
  - For circular beam use **Rmin = 0.0**



The BEAMPOS card: beam position and direction

Position:

The beam position is defined with its **x**, **y** and **z** coordinates [cm]

Default: Origin of the coordinate system

Direction:

The beam axis is defined via direction cosines with respect to the x and y axes

The third direction cosine (**cosz**) is automatically calculated by FLUKA

Note that this is not enough for an unequivocal direction definition; the sign of **cosz** has to be provided as well. Select **POSITIVE** or **NEGATIVE** from the *Type* dropdown

Default: Positive z direction

Default beam

- What happens if the **BEAM** and **BEAMPOS** cards are not filled in or are missing?
- FLUKA will use the built-in default (***note**: may change in the future*):
  - Protons at 200 GeV/c momentum
  - Pencil beam: No divergence, zero radius
  - Starting from the origin of the coordinate system
  - Directed along the positive z axis

- This is almost never what you want!
- Always complete the relevant information in the **BEAM** and **BEAMPOS** card
- It is good practice to confirm what source you have defined by checking the FLUKA output (see the *Standard output* lecture)

Beam visualisation

- The easiest way to check whether the beam parameters are set correctly is to visualise the beam

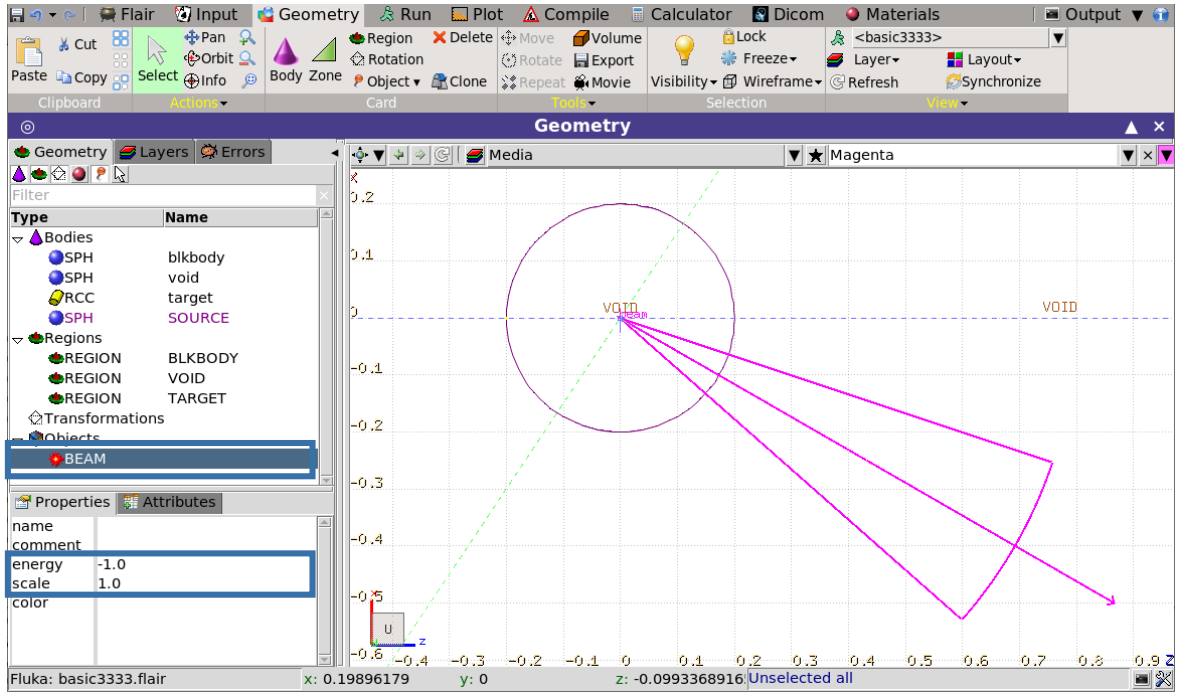
- There are two ways to do this:
  - Use the Geoviewer's BEAM object
  - Use standard FLUKA scorings (See the *Scoring* lectures) with **BEAMPART** as particle type
    - USRBIN for particle location and direction
    - USRBDX for energy spectrum (with a closed surface surrounding the source location)

Beam visualisation

- **Example 1:** 1 GeV Gaussian beam | 0.1 GeV/c FWHM momentum distribution | 0.4 rad flat angular distribution | rotated around the y axis by -30°

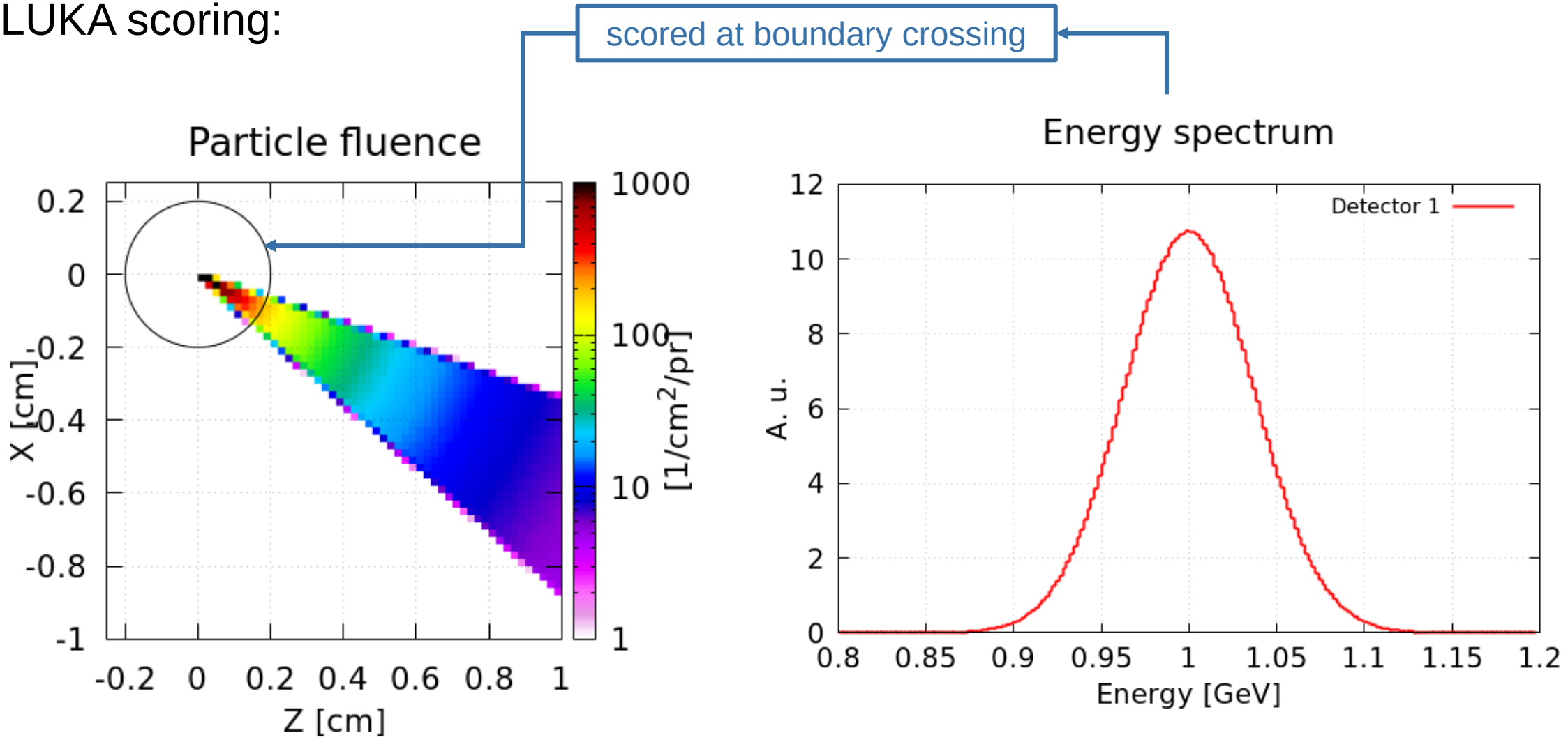
BEAM Beam: Energy ▾ E: 1.0 Part: ▾
Δp: Gauss ▾ Δp(FWHM): 0.1 Δϕ: Flat ▾ Δϕ: 400.0
Shape(X): Rectangular ▾ Δx: Shape(Y): Rectangular ▾ Δy:
BEAMPOS x: 0.0 y: 0.0 z: 0.0
cosx: -0.5 cosy: 0.0 Type: POSITIVE ▾

- Geoviewer BEAM object:
  - Starting point
  - Direction
  - Angular distribution
  - Beam mean energy
  - Default scale: 1 GeV(/c) = 1 cm
    Can be changed with the scale parameter



Beam visualisation

- FLUKA scoring:

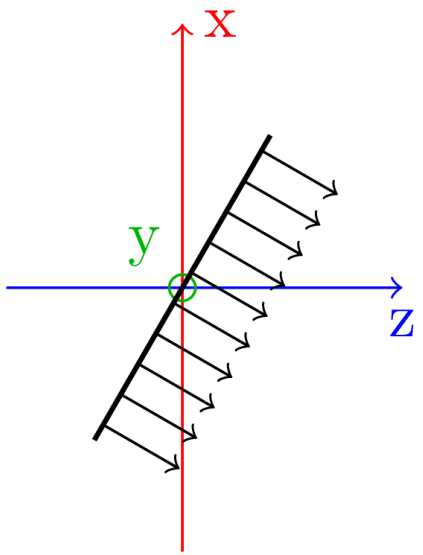


Beam rotation

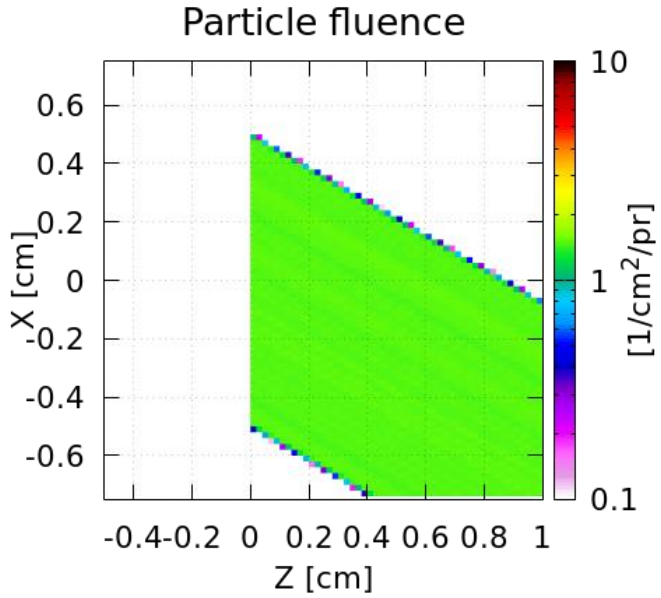
- **Example 2:** R = 0.5 cm cylindrical beam | zero divergence | rotated around y axis by -30°

```
BEAM          Beam: Momentum ▾        p:              Part: ▾
   Δp: Flat ▾      Δp:                Δϕ: Flat ▾      Δϕ:
Shape(X): Annular ▾  Rmin: 0.0        Rmax: 0.5
BEAMPOS          x: 0.0               y: 0.0          z: 0.0
                 cosx: -0.5           cosy: 0.0       Type: POSITIVE ▾
```

Expectation:



Reality:



- *Remember:* the **BEAM** card sets the X-Y shape of the beam, which is not influenced by the beam direction set in the **BEAMPOS** card... so how can we rotate the beam?

Beam rotation

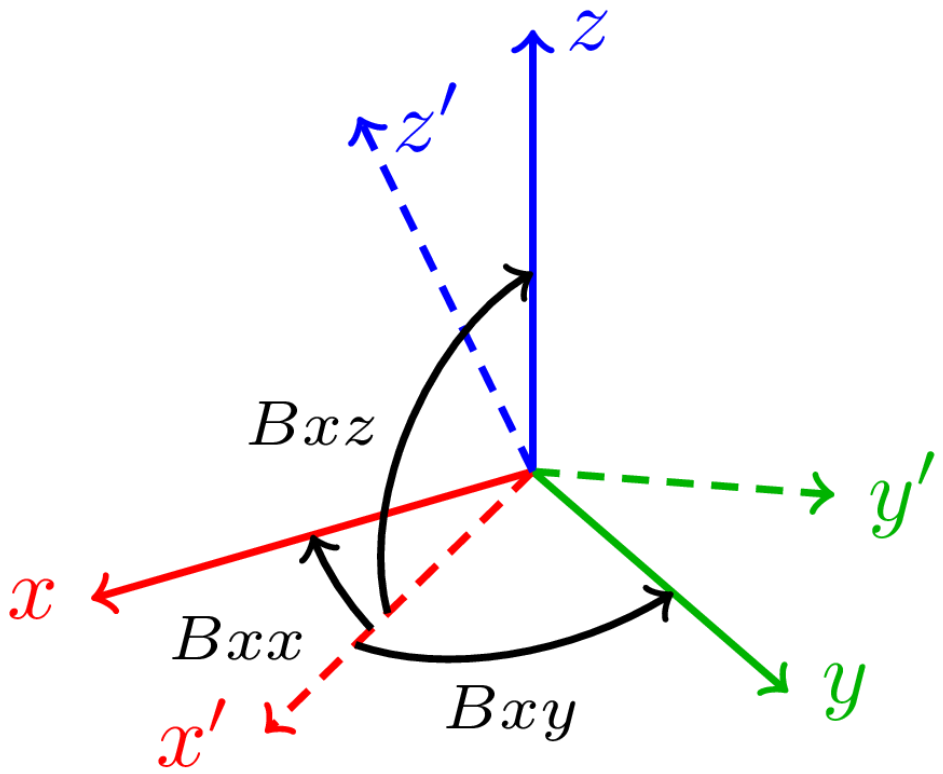
- Input card: **BEAMAXES**

BEAMAXES cosBxx: cosBxy: cosBxz: cosBzx: cosBzy: cosBzz:

Defines the beam coordinate system (**x′, y′, z′**) with respect to the geometry one (**x, y, z**)

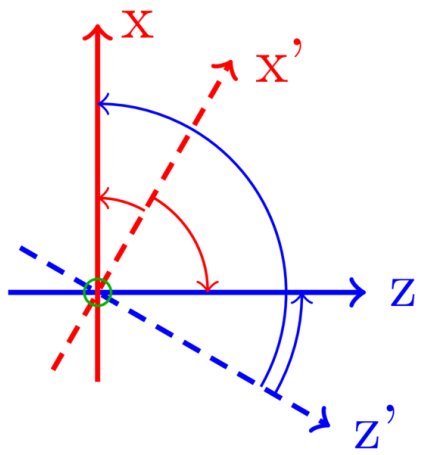
Input fields:

- **cosBxx**: cosine of the angle between **x′** and **x**
- **cosBxy**: cosine of the angle between **x′** and **y**
- **cosBxz**: cosine of the angle between **x′** and **z**
- **cosBzx**: cosine of the angle between **z′** and **x**
- **cosBzy**: cosine of the angle between **z′** and **y**
- **cosBzz**: cosine of the angle between **z′** and **z**

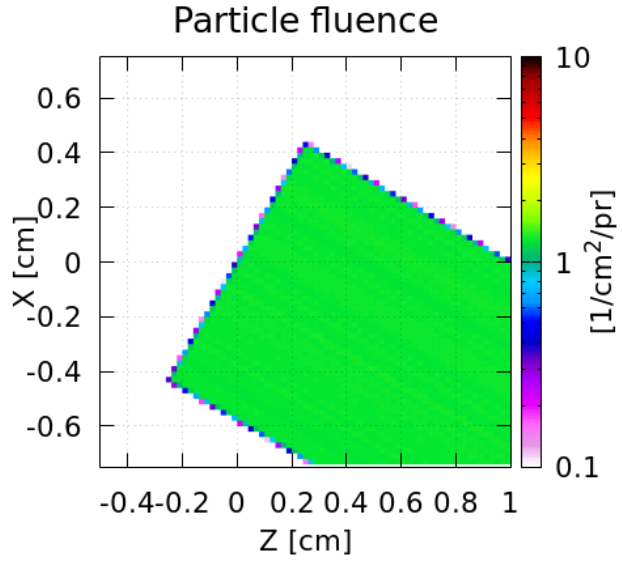


Beam rotation

- **Example 2:** R = 0.5 cm cylindrical beam | zero divergence | rotated around y axis by -30°



WHAT	Beam axis	Geo axis	Angle [°]	Cos(Angle)
cosBxx	x'	x	30	~0.866
cosBxy	x'	y	90	0
cosBxz	x'	z	-60	0.5
cosBzx	z'	x	120	-0.5
cosBzy	z'	y	90	0
cosBzz	z'	z	30	~0.866



BEAMAXES cosBxx: 0.86602540378 cosBxy: 0.0 cosBxz: 0.5
cosBzx: -0.5 cosBzy: 0.0 cosBzz: 0.86602540378

Volumetric sources

Volumetric sources can be defined with a second **BEAMPOS** card:

- Available types:
  - Spherical shell (**SPHE-VOL**)
  - Cylindrical shell (**CYLI-VOL**)
  - Cartesian shell (**CART-VOL**)
  - Spherical surface (**FLOOD**)

- Volumetric sources are centred around the position defined in the first **BEAMPOS** card
- The location inside the volume is sampled uniformly
- The particle direction and angular distribution set in the first **BEAMPOS** card and the **BEAM** card are still applied
- **Warning:** The spatial distributions specified in the **BEAM** card will be disregarded

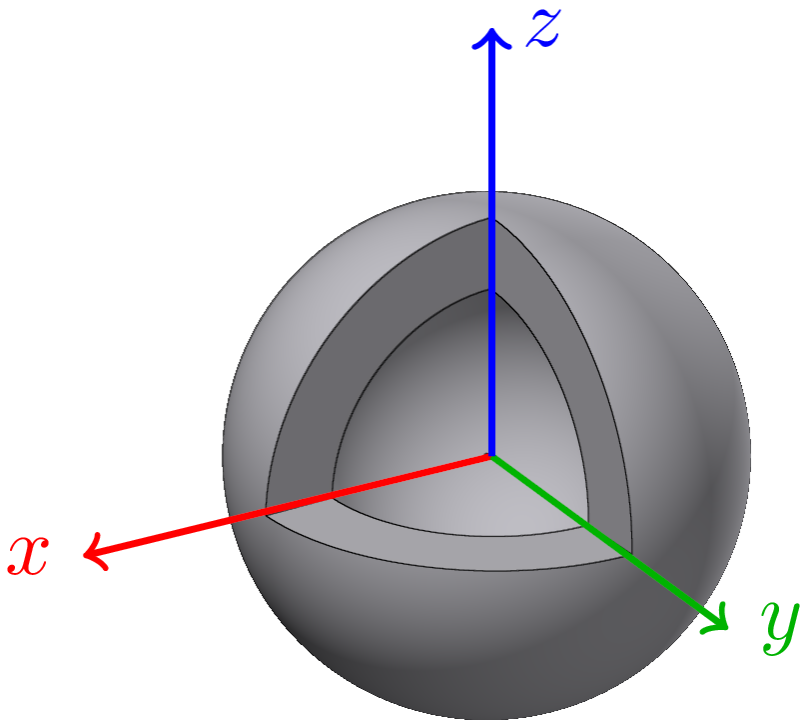
Volumetric sources – *Spherical shell*

BEAMPOS Rin: Rout: Type: SPHE-VOL ▾

Specifies a spherical shell shaped source

Input fields:

- **Rin**: Inner radius [cm]
- **Rout**: Outer radius [cm]



Volumetric sources – *Cylindrical shell*

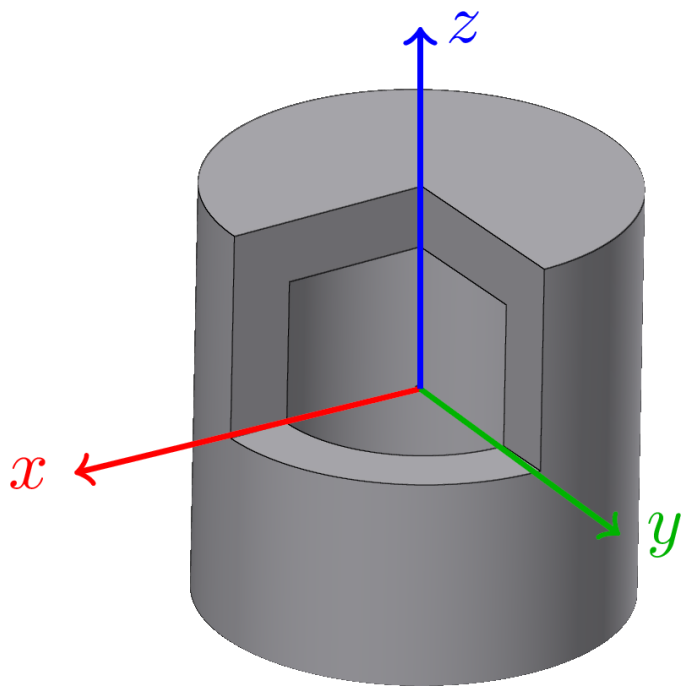
BEAMPOS Rin: Rout: Type: CYLI-VOL ▾
Hin: Hout:

Specifies a cylindrical shell shaped source around the **z** axis of the geometry

Input fields:

- **Rin**: Inner radius [cm]
- **Rout**: Outer radius [cm]
- **Hin**: Inner height [cm]
- **Hout**: Outer height [cm]

Note: The reference coordinate system can be changed with the **BEAMAXES** card



Volumetric sources – *Cartesian shell*

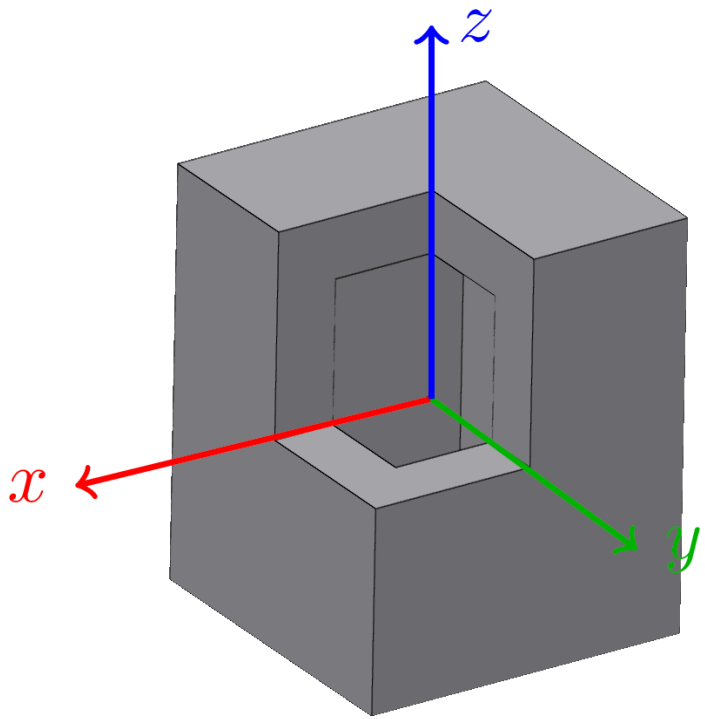
BEAMPOS Xin: Xout: Type: CART-VOL ▾
Yin: Yout:
Zin: Zout:

Specifies a Cartesian shell shaped source along the axes of the geometry

Input fields:

- **Xin & Xout**: Inner & outer length of the **x**-sides
- **Yin & Yout**: Inner & outer length of the **y**-sides
- **Zin & Zout**: Inner & outer length of the **z**-sides

Note: The reference coordinate system can be changed with the **BEAMAXES** card



Volumetric sources – *Spherical surface source*

BEAMPOS R: Type: FLOOD ▾

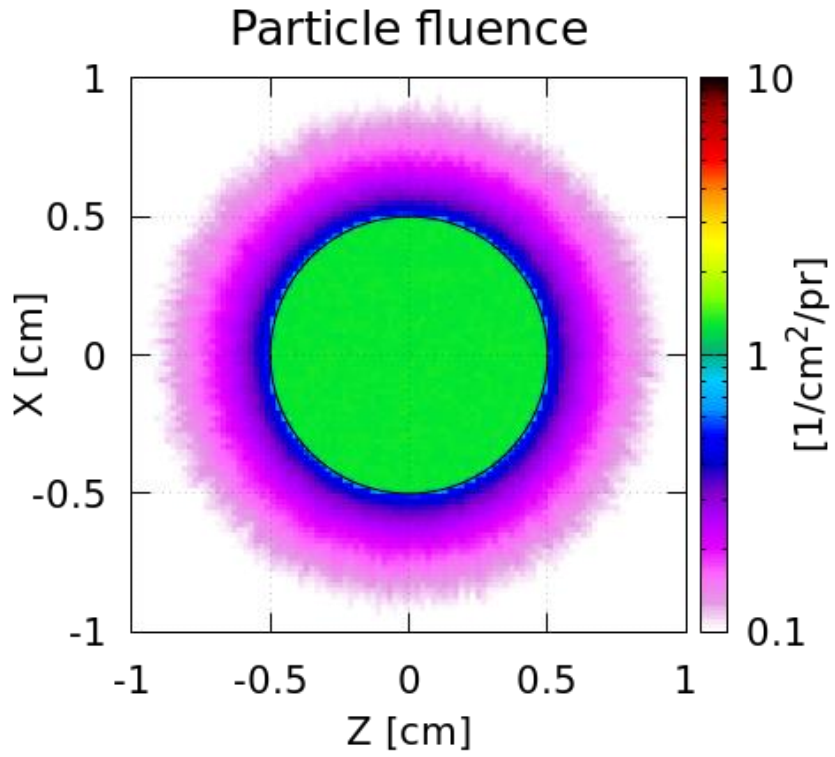
Specifies a spherical surface source in a way that the fluence inside the sphere is **uniform** and **isotropic**

The value of the generated fluence is: $\frac{1}{\pi R^2}$ cm^{-2}

Input fields:

- **R**: Radius of the sphere [cm]

Warning: The particle direction and angular distribution set on the first **BEAMPOS** and the **BEAM** card are disregarded



Multiple beam spots – SPECSOUR

Input card: SPECSOUR – BEAMSPOT

Allows to define multiple beam spots

Can be used where the capabilities of the **BEAM**, **BEAMPOS**, and **BEAMAXES** are not sufficient, but more than one beam is required, like for radiotherapy.

- # spots: Number of defined beam spots, up to 15000
- Sampling: How primaries sampled between the individual beam spots
  - **Random**: The beam spots are sampled randomly, according to their weights
  - **Sequentially weighted**: The beam spots are sampled sequentially each with a number of primaries proportional to its weight
  - **Sequentially equal**: The beam spots are sampled sequentially, all with the same number of primaries, ignoring their weights

Beam spots are defined with **SPOTBEAM**, **SPOTPOS** and **SPOTDIR** cards

Multiple beam spots – SPOTBEAM

Spot definition:

- **spot_id**: ID number of the beam spot. Numbering has to be continuous, starting from 1
  Note the unusual location of the input field
- **Spot weight**: Relative intensity of the beam spot

Particle type:

- **Part**: Spot's particle type. If not selected, a heavy ion can be specified with:
- **Z** (atomic), **A** (mass number), **Isomer**: Specify a heavy ion

Default: Particle defined on the **BEAM** card (if no **Part** selected and no heavy ion specified)

Multiple beam spots – SPOTBEAM

Momentum / energy:

- **Beam**: Defines the **Momentum** [GeV/c] or **Energy** [GeV] or the emitting particle

Default: Momentum / energy defined on the **BEAM** card

Momentum distribution:

- **Δp**: Defines the beam's momentum distribution as:
  - **Flat**: Full width of a rectangular **momentum** distribution centred at beam momentum [GeV/c]
  - **Gaussian**: FWHM of a Gaussian **momentum** distribution [GeV/c]

Default: 0.0 **(!)**

Multiple beam spots – SPOTBEAM

Angular distribution:

- **ΔΦx, ΔΦy**: Defines the beam's angular distribution in the **x/y** plane, as:
  - **Flat**: Full width of a rectangular angular distribution centred around the beam axis [mrad]
  - **Isotropic**: Isotropic distribution (Input as **Flat** distribution with angle larger than 2π [rad])
  - **Gaussian**: FWHM of a Gaussian angular distribution [mrad]

Default: **ΔΦx** = 0.0, **ΔΦy = ΔΦx**

BEAMSPOT - Visualisation

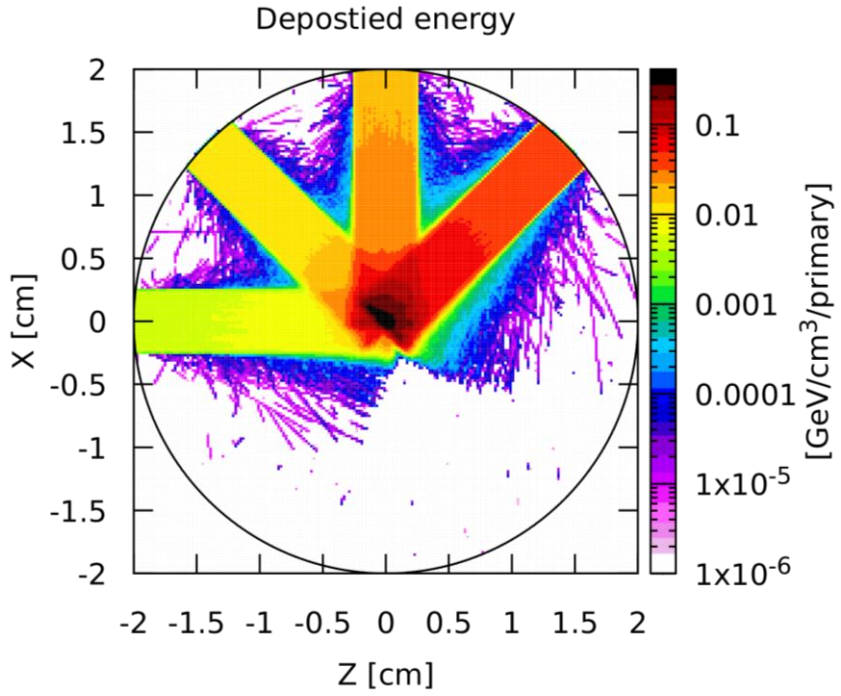
Input card: **SPECSOUR – BEAMSPOT**

Example:

R = 2 cm water sphere

47.5 MeV, 2.5 mm cylindrical, proton beams

4 spots, in 45° steps, with 2^n weight



BEAM		Beam:	Energy	E:	0.0475	Part:	PROTON
	Δp: Flat	Δp:		Δϕ:	Flat	Δϕ:	
	Shape(X): Rectangular	Δx:		Shape(Y):	Rectangular	Δy:	
SPECSOUR		Type:	BEAMSPOT	# spots:	4	Sampling:	Random
SPOTBEAM 1		Beam:	Momentum	p:		Part:	
		Z:	0	A:	0	Isomer:	0
	Δp: Flat	Δp:		Spot Weight:	1		
	Δϕx: Flat	Δϕx:		Δϕy:	Flat	Δϕy:	
SPOTPOS 1		x:		y:		z:	-5
	Shape(X): Annular	Rmin:		Rmax:	0.25		
SPOTDIR 1		cosx:		cosy:		cosz:	
		cosBxx:		cosBxy:		cosBxz:	
SPOTBEAM 2		Beam:	Momentum	p:		Part:	
		Z:	0	A:	0	Isomer:	0
	Δp: Flat	Δp:		Spot Weight:	2		
	Δϕx: Flat	Δϕx:		Δϕy:	Flat	Δϕy:	
SPOTPOS 2		x:	5	y:		z:	-5
	Shape(X): Annular	Rmin:		Rmax:	0.25		
#define	angle2	:	-45				
SPOTDIR 2		cosx:	=sind(angle2)	cosy:	0	cosz:	=cosd(angle2)
		cosBxx:	=cosd(angle2)	cosBxy:	0	cosBxz:	=-sind(angle2)
SPOTBEAM 3		Beam:	Momentum	p:		Part:	
		Z:	0	A:	0	Isomer:	0
	Δp: Flat	Δp:		Spot Weight:	4		
	Δϕx: Flat	Δϕx:		Δϕy:	Flat	Δϕy:	
SPOTPOS 3		x:	5	y:		z:	
	Shape(X): Annular	Rmin:		Rmax:	0.25		
#define	angle3	:	-90				
SPOTDIR 3		cosx:	=sind(angle3)	cosy:	0	cosz:	=cosd(angle3)
		cosBxx:	=cosd(angle3)	cosBxy:	0	cosBxz:	=-sind(angle3)
SPOTBEAM 4		Beam:	Momentum	p:		Part:	
		Z:	0	A:	0	Isomer:	0
	Δp: Flat	Δp:		Spot Weight:	8		
	Δϕx: Flat	Δϕx:		Δϕy:	Flat	Δϕy:	
SPOTPOS 4		x:	5	y:		z:	5
	Shape(X): Annular	Rmin:		Rmax:	0.25		
#define	angle4	:	-135				
SPOTDIR 4		cosx:	=sind(angle4)	cosy:	0	cosz:	=cosd(angle4)
		cosBxx:	=cosd(angle4)	cosBxy:	0	cosBxz:	=-sind(angle4)

Further possibilities

Sometimes the **BEAM**, **BEAMPOS**, and **BEAMAXES** cards are not enough

- Special sources available in FLUKA
  - Colliding beams
  - Synchrotron radiation
  - Cosmic rays
  - USRBIN source

- Program your own custom sources (Source routine – FLUKA Advanced Course)

2. The FLUKA preprocessor

The FLUKA preprocessor

- A limited, “C”-like preprocessor
- Manipulates the input before execution using directives

- 3 type of directives (starting with: **#**):
  - Definition:
    `#define, #undef`
  - Conditional:
    `#if, #elif, #else, #endif`
  - Include:
    `#include`

FLUKA preprocessor - *Definition*

Directive: `#define`

- Identifiers without numerical or character value:

  `#define identifier_name :`

  - Used in conjunction with conditional directives (**`#if identifier_name ... #endif`**)
  - ***identifier_name*** can be up to 40 character long

- Identifiers with numerical or character value:

  `#define identifier_name : value`

  - The ***value*** can be used in any other input card by referencing **$identifier_name** and can be up to 40 characters long
  - Can also be used in conjunction with conditional directives

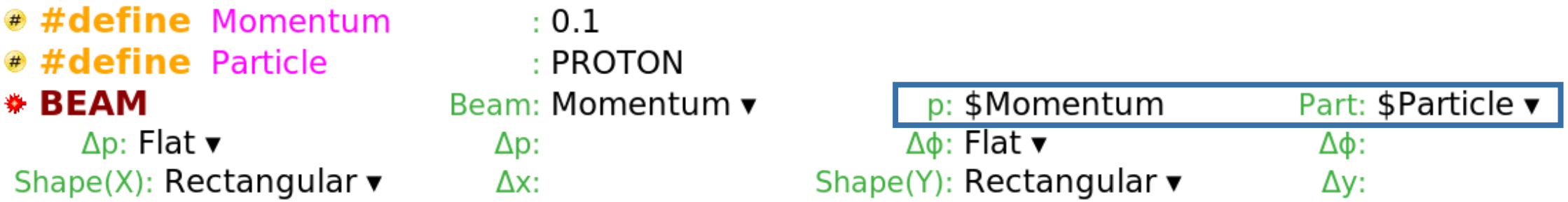
Directive: `#undef`

`#undef identifier_name ▾`

- Deletes a previously defined identifier

FLUKA preprocessor - *Definition*

- Identifiers can be *defined* and *referenced* anywhere in the input file
- Example:

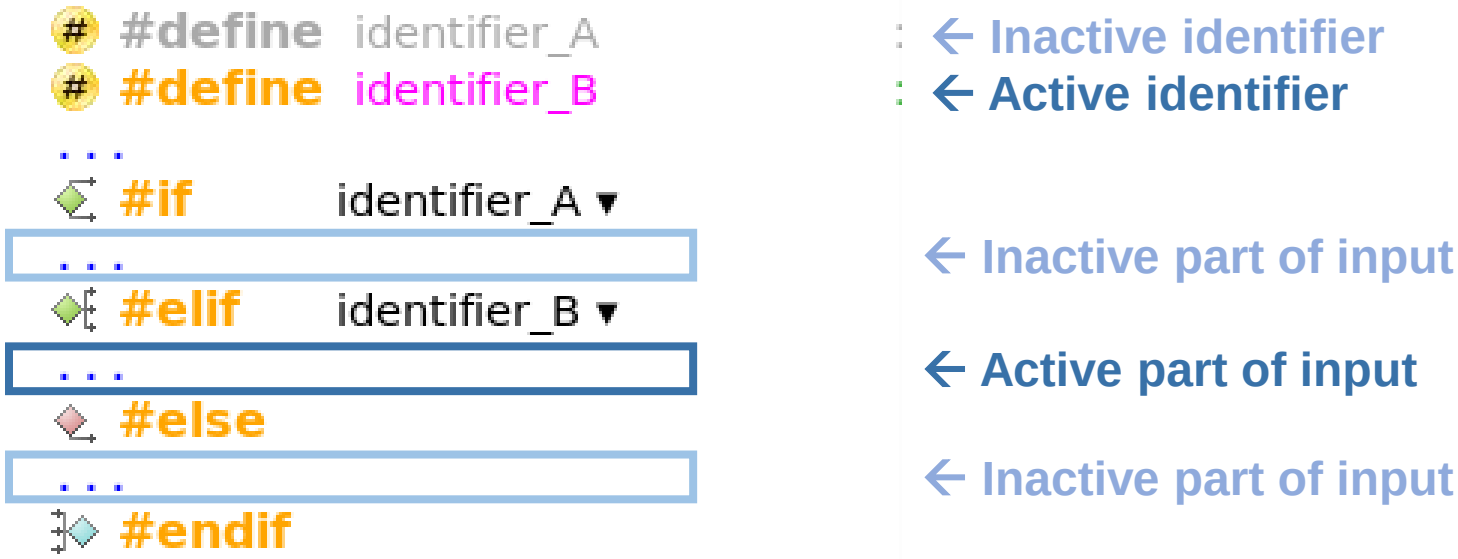


- **Note:** It is possible to redefine an identifier with a second `#define` directive
  - This is **NOT RECOMMENDED**
  - If an identifier is redefined, the new value is only applied to cards below
  - The output and error files will contain warning messages

FLUKA preprocessor - *Conditional*

Directives: `#if, #elif, #else, #endif`

- To include or exclude parts of the input in conjunction with the `#define` directives



- They work similarly to any programming language

  Limitation: Cannot compare values, only test if an identifier is defined or not

- Can be nested

  Limitation: Maximum of 10 nesting levels can be used

FLUKA preprocessor - *Conditional*

```
#define NeutronBeam :
...
#if NeutronBeam ▾
  BEAM          Beam: Energy ▾      E: 0.1          Part: NEUTRON ▾
   Δp: Flat ▾      Δp:             Δϕ: Flat ▾        Δϕ:
   Shape(X): Rectangular ▾  Δx:  Shape(Y): Rectangular ▾  Δy:
#else
  BEAM          Beam: Energy ▾      E: 0.05         Part: PHOTON ▾
   Δp: Flat ▾      Δp:             Δϕ: Flat ▾        Δϕ:
   Shape(X): Rectangular ▾  Δx:  Shape(Y): Rectangular ▾  Δy:
#endif
...
#if NeutronBeam ▾
  ASSIGNMA      Mat: CONCRETE ▾     Reg: SHIELD ▾     to Reg: ▾
              Mat(Decay): ▾       Step:             Field: ▾
#else
  ASSIGNMA      Mat: LEAD ▾         Reg: SHIELD ▾     to Reg: ▾
              Mat(Decay): ▾       Step:             Field: ▾
#endif
```

FLUKA preprocessor - *Conditional*

```
#define  NeutronBeam      :
...
#if    NeutronBeam ▾
   #define  Energy         : -0.1
   #define  Particle       : NEUTRON
   #define  ShieldMa       : CONCRETE
#else
   #define  Energy         : -0.05
   #define  Particle       : PHOTON
   #define  ShieldMa       : LEAD
#endif
...
BEAM          Beam: Energy ▾          E: $Energy          Part: $Particle ▾
   Δp: Flat ▾          Δp:          Δϕ: Flat ▾          Δϕ:
Shape(X): Rectangular ▾   Δx:   Shape(Y): Rectangular ▾   Δy:
...
ASSIGNMA      Mat: $ShieldMa ▾      Reg: SHIELD ▾      to Reg: ▾
              Mat(Decay): ▾         Step:              Field: ▾
```

FLUKA preprocessor - *Include*

Directive: `#include`

`#include` <path>/filename.inp ▾

- Includes the specified file to the input
- Can be nested at multiple levels

- The path can be:
  - Relative to the **main input** file
  - Absolute

- Use cases:
  - Split large input files into multiple smaller ones
  - Reuse same input section (beam definition, scoring, etc.) in multiple input files


FLUKA

Back-up slides

Multiple beam spots – SPOTPOS

SPOTPOS (optional)

Spot definition:

- **spot_id**: ID number of the beam spot, which this card applies to
  Note the unusual location of the input field

Beam spot position:

- **x**, **y**, **z**: Position of the beam spot along the **x**, **y**, and **z** axes [cm]

Beam spot shape:

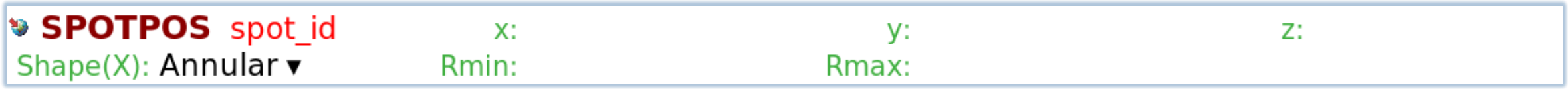
Shape(X), **Shape(Y)**: Defines the spatial distribution of the beam spot, as:

- **Rectangular**: Full beam width in **x/y** direction centred at the beam axis [cm]
- **Gaussian**: FWHM of a Gaussian distribution in x/y direction centred at the beam axis [cm]

Default: **Δx** = 0.0, **Δy** = **Δx**

Multiple beam spots – SPOTPOS

SPOTPOS (optional)



Beam spot shape (cont.):

Shape(X): Defines the spatial distribution of the beam spot, as:

- **Annular**: Defines a cylindrical beam shape in the **x-y** plane

  Rmin and **Rmax** are the radii of the distribution

  For circular beam use **Rmin = 0**

Defaults:

If no values or **SPOTPOS** card provided, then the position and shape is taken from the **BEAM** and **BEAMPOS** cards

Multiple beam spots – SPOTDIR

SPOTDIR (optional)

SPOTDIR	spot_id	cosx:	cosy:	cosz:
		cosBxx:	cosBxy:	cosBxz:

Spot definition:

- **spot_id**: ID number of the beam spot, which this card applies to
  Note the unusual location of the input field

Beam spot direction:

- **cosx**, **cosy**, **cosz**: Defines the direction cosines of the beam

Default: Beam direction specified on the **BEAMPOS** card is used

Multiple beam spots – SPOTDIR

SPOTDIR (optional)

SPOTDIR	spot_id	cosx:	cosy:	cosz:
		cosBxx:	cosBxy:	cosBxz:

Beam spot coordinate system:

- **cosBxx**, **cosBxy**, **cosBxz**: Defines the direction cosines of the x axis of the beam coordinate system

Default: Beam coordinate system defined on the **BEAMAXES** card is used

If the x axis of the beam spot coordinate system is specified, the z axis will be the beam spot direction, and the y axis will be automatically computed