Sources

Advanced FLUKA Course
Overview

1. Built-in sources
   - Beam definition
   - Extended sources
   - Sources for collider experiments

2. User-defined sources
   - User routine SOURCE
   - Useful auxiliary routines
   - Sampling techniques
   - Two-step methods

3. Example: point vs. extended source
Built-in sources
**Beam definition - 1**

**Input card:** BEAM

defines several *beam characteristics:*

type of particle, energy, divergence, profile

**Example**

```
*...+.....1....+....2....+....3....+....4....+....5....+....6....+....7....+...
BEAM 3.5  -0.082425   -1.7    0.0    0.0    0.0    PROTON
```

- 3.5 GeV/c [*WHAT (1)*] proton beam [*SDUM*] with weight 1 [*WHAT (6)*]
- Gaussian momentum distribution: 0.082425 GeV/c FWHM [*WHAT (2)*]
- Gaussian angular distribution: 1.7 mrad FWHM [*WHAT (3)*]
- no beam width along x (point-like source) [*WHAT (4)*]
- no beam width along y (point-like source) [*WHAT (5)*]
Beam definition - 2

Input card: BEAMPOS

If SDUM = blank:
defines the coordinates of the centre of the beam spot (i.e., the point from which transport starts) and the beam direction

*...+...1...+...2...+...3...+...4...+...5...+...6...+...7...+
BEAMPOS 0.0       0.0       -0.1       0.0       0.0       0.0       0.0

• x-coordinate: 0.0  [WHAT(1)]
• y-coordinate: 0.0  [WHAT(2)]
• z-coordinate: -0.1 cm [WHAT(3)]
• direction cosine with respect to the x-axis: 0.0  [WHAT(4)]
• direction cosine with respect to the y-axis: 0.0  [WHAT(5)]
• WHAT(6) is not used!
→ beam points in the positive z-direction starting at (0., 0., -0.1)
Beam definition - 3

Input card: **BEAMAXES**

defines the **beam reference frame** which all parameters defined with BEAM and BEAMPOS refer to (angular divergence, transverse profile, polarization, extended sources)

**Example**

```
*...+...1...+...2...+...3...+...4...+...5...+...6...+...7...+
BEAMAXES  1.0   0.0   0.0   0.0  0.0  0.7071068  0.7071068
```

- cosine of angle between x-axis of beam and x-axis of geometry frame  
[WHAT (1)]
- cosine of angle between x-axis of beam and y-axis of geometry frame  
[WHAT (2)]
- cosine of angle between x-axis of beam and z-axis of geometry frame  
[WHAT (3)]
  
  (1,0,0) \rightarrow x-axes of beam and geometry frames are parallel

- cosine of angle between z-axis of beam and x-axis of geometry frame  
[WHAT (4)]
- cosine of angle between z-axis of beam and y-axis of geometry frame  
[WHAT (5)]
- cosine of angle between z-axis of beam and z-axis of geometry frame  
[WHAT (6)]
  
  (0,0.7071068,0.7071068) \rightarrow z-axes of beam frame is at 45deg to both y- and z-axes of geometry frame
Extended sources - *Spherical shell source*

Input card: **BEAMPOS**

If $SDUM = SPHE-VOL$:
defines a spatially extended source in a *spherical shell*

**Example**

```plaintext
*...+....1...+....2...+....3...+....4...+....5...+....6...+....7...+
BEAMPOS 0.0 0.0 0.0 0.0 0.0 0.0 0.0
BEAMPOS 0.0 1.0 0.0 0.0 0.0 0.0 0.0SPHE-VOL
```

- radius (in cm) of the inner sphere shell: 0.0 cm  [WHAT (1)]
- radius (in cm) of the outer sphere shell: 1.0 cm  [WHAT (2)]
- WHAT (3) - WHAT (6) are not used!

The shell is centred at the \((x,y,z)\) point defined by another BEAMPOS card with $SDUM = \text{blank (or = NEGATIVE)}$. The particle direction or angular distribution are those defined by BEAM, BEAMAXES and another BEAMPOS cards.
Extended sources - Cylindrical shell source

Input card: BEAMPOS

If \textbf{SDUM} = \textit{CYLI-VOL}:
defines a spatially extended source in a \textit{cylindrical shell}
with the height parallel to the \textit{z}-axis of the beam frame

\textbf{Example}

\begin{verbatim}
*....+.....1.....+.....2.....+.....3.....+.....4.....+.....5.....+.....6.....+.....7.....+
BEAMPOS 0.0 0.0 0.0 0.0 0.0 0.0 0.0
BEAMPOS 0.0 1.0 0.0 1.0 0.0 0.0 0.0 CYLI-VOL
\end{verbatim}

- radius (in cm) of the inner cylinder defining the shell: 0.0 cm \[\text{WHAT (1)}\]
- radius (in cm) of the outer cylinder defining the shell: 1.0 cm \[\text{WHAT (2)}\]
- height (in cm) of the inner cylinder defining the shell: 0.0 cm \[\text{WHAT (3)}\]
- height (in cm) of the outer cylinder defining the shell: 1.0 cm \[\text{WHAT (4)}\]
- \text{WHAT (5)} - \text{WHAT (6)} are not used!

The shell is centred at the \((x,y,z)\) point defined by another BEAMPOS card with \textbf{SDUM} = blank (or \textbf{NEGATIVE}). The particle direction or angular distribution are those defined by \textit{BEAM}, \textit{BEAMAXES} and another \textit{BEAMPOS} cards.
Extended sources - *Cartesian shell source*

Input card: **BEAMPOS**

If **SDUM = CART-VOL**: defines a spatially extended source in a *Cartesian shell* with the sides parallel to the beam frame axes

**Example**

```
*...+...1...+...2...+...3...+...4...+...5...+...6...+...7...+
BEAMPOS  0.0  0.0  0.0  0.0  0.0  0.0  0.0
BEAMPOS  0.0  1.0  0.0  1.0  0.0  0.0  1.0CART-VOL
```

- length (in cm) of the x-side of the inner parallelepiped defining the shell: 0.0 cm [WHAT (1)]
- length (in cm) of the x-side of the outer parallelepiped defining the shell: 1.0 cm [WHAT (2)]
- length (in cm) of the y-side of the inner parallelepiped defining the shell: 0.0 cm [WHAT (3)]
- length (in cm) of the y-side of the outer parallelepiped defining the shell: 1.0 cm [WHAT (4)]
- length (in cm) of the z-side of the inner parallelepiped defining the shell: 0.0 cm [WHAT (5)]
- length (in cm) of the z-side of the outer parallelepiped defining the shell: 1.0 cm [WHAT (6)]

The shell is centred at the (x,y,z) point defined by another BEAMPOS card with **SDUM = blank** (or = **NEGATIVE**). The particle direction or angular distribution are those defined by BEAM, BEAMAXES and another BEAMPOS cards.
Extended sources - *Spherical surface source*

Input card: **BEAMPOS**

If **SDUM = FLOOD:**

defines a source distribution on a *spherical surface*

**Example**

```
* ...+...1 ...+...2 ...+...3 ...+...4 ...+...5 ...+...6 ...+...7 ...+...
BEAMPOS  0.0  0.0  0.0  0.0  0.0  0.0  0.0
BEAMPOS  0.0  1.0  0.0  0.0  0.0  0.0  0.0FLOOD
```

- radius (in cm) of the sphere: 1.0 cm  [WHAT (1) ]
- **WHAT (2) - WHAT (6)** are not used!

The surface is centred at the (x,y,z) point defined by another **BEAMPOS** card with **SDUM = blank** (or = **NEGATIVE**). The particle direction or is distributed according to a diffusive distribution, so that to generate a uniform and isotropic fluence equal to $1/\pi R^2$ everywhere in the sphere (in absence of materials)
Extended sources - Example

Radioactive source of $^{60}\text{Co}$ (two main $\gamma$-emissions: 1332.5 keV and 1173.2 keV)
cylindrical shape, 2cm diameter, 2mm height along $z$, centre of base of cylinder at origin

*...+...1...+...2...+...3...+...4...+...5...+...6...+...7...+...
BEAM          0.0
HI-PROPE      27.0    60.0
BEAMPOS       0.0     0.0     0.1     0.0     0.0     0.0
BEAMPOS       0.0     1.0     0.0     0.2     0.0     0.0

or

*...+...1...+...2...+...3...+...4...+...5...+...6...+...7...+...
BEAM       1252.8E-6  10000.
BEAMPOS 0.0     0.0     0.1     0.0     0.0     0.0
BEAMPOS 0.0     1.0     0.0     0.2     0.0     0.0

If height along $x$ (instead of $z$) add

*...+...1...+...2...+...3...+...4...+...5...+...6...+...7...+...
BEAMAXES 0.0     0.0     -1.0    1.0     0.0     0.0

or

BEAMAXES 0.0     0.0     -1.0    1.0     0.0     0.0

...+...1...+...2...+...3...+...4...+...5...+...6...+...7...+...
Special sources - *pp collisions*

Input card: **SPECSOUR**

**Example:** LHC
7 TeV/c, full crossing angle of 285 μrad in yz-plane

**Momentum vectors of colliding proton beams:** *three possibilities*

1) **If** SDUM = **PPSOURCE**:

<table>
<thead>
<tr>
<th>SPECSOUR</th>
<th>0.0</th>
<th>0.9975</th>
<th>6999.9999</th>
<th>0.0</th>
<th>0.9975-6999.9999PPSOURCE</th>
</tr>
</thead>
</table>

- *x, y, z-components of lab momentum for proton beam 1* [WHAT(1-3)]
- *x, y, z-components of lab momentum for proton beam 2* [WHAT(4-6)]

2) **If** SDUM = **CROSSASY**:

<table>
<thead>
<tr>
<th>SPECSOUR</th>
<th>7000.0</th>
<th>142.5E-6</th>
<th>90.0</th>
<th>7000.0</th>
<th>142.5E-6</th>
<th>0.0CROSSASY</th>
</tr>
</thead>
</table>

- *lab momentum for proton beam 1* [WHAT(1)]
- *polar angle (rad) between proton beam 1 and positive z-direction* [WHAT(2)]
- *azimuth angle (deg!) defining crossing plane* [WHAT(3)]
- *lab momentum for proton beam 2* [WHAT(4)]
- *polar angle (rad) between proton beam 2 and positive z-direction* [WHAT(5)]
Special sources - pp collisions

3) If $\text{SDUM} = \text{CROSSSYM}$:

$\ldots + \ldots 1 \ldots + \ldots 2 \ldots + \ldots 3 \ldots + \ldots 4 \ldots + \ldots 5 \ldots + \ldots 6 \ldots + \ldots 7 \ldots + \ldots$

<table>
<thead>
<tr>
<th>SPECSOUR</th>
<th>7000.</th>
<th>142.5E-6</th>
<th>90.0</th>
<th>0.0</th>
<th>0.0</th>
<th>0.0</th>
<th>0.0CROSSSYM</th>
</tr>
</thead>
</table>

- lab momentum for proton beams 1 and 2 $[\text{WHAT}(1)]$
- half crossing angle (rad) $[\text{WHAT}(2)]$
- azimuth angle (deg!) defining crossing plane $[\text{WHAT}(3)]$
- $\text{WHAT}(4)$ - $\text{WHAT}(6)$ are not used!

Interaction point of colliding proton beams (continuation card):

<table>
<thead>
<tr>
<th>SPECSOUR</th>
<th>12.E-5</th>
<th>12.E-5</th>
<th>5.0</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>SPECSOUR</th>
<th>7000.</th>
<th>142.5E-6</th>
<th>90.0</th>
<th>0.0</th>
<th>0.0</th>
<th>0.0</th>
<th>0.0CROSSSYM</th>
</tr>
</thead>
</table>

- $\sigma_x$ in cm for Gaussian sampling around XBEAM: 12 mm $[\text{WHAT}(7)]$
- $\sigma_y$ in cm for Gaussian sampling around YBEAM: 12 mm $[\text{WHAT}(8)]$
- $\sigma_z$ in cm for Gaussian sampling around ZBEAM: 5 cm $[\text{WHAT}(9)]$

(XBEAM,YBEAM,ZBEAM) defined with BEAMPOS card
### Special sources - Heavy ion collisions

<table>
<thead>
<tr>
<th>BEAM</th>
<th>7000.0</th>
<th>HEAVYION</th>
</tr>
</thead>
<tbody>
<tr>
<td>HI-PROPE</td>
<td>82.0</td>
<td>208.0</td>
</tr>
<tr>
<td>SPECSOUR</td>
<td>7000.0</td>
<td>142.5E-6</td>
</tr>
<tr>
<td>SPECSOUR</td>
<td>12.E-5</td>
<td>12.E-5</td>
</tr>
</tbody>
</table>

- id of beam particle 1 (default the one of BEAM) \[\text{WHAT}(10)\]
- mass of beam particle 2 (default 1) \[\text{WHAT}(11)\]
- charge of beam particle 2 (default 1) \[\text{WHAT}(12)\]

For collisions in the DPMJET energy range, don't forget the following cards:

<table>
<thead>
<tr>
<th>EVENTYPE</th>
<th>2.0</th>
<th>DPMJET</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYSICS</td>
<td>8000.0</td>
<td>LIMITS</td>
</tr>
</tbody>
</table>

Where “8000.0” should be larger than \(\frac{1}{2}\) of the centre-of-mass energy (the energy of whichever beam for a head-on collision in a symmetric collider)
User-defined sources
Source routine - 1

- Allows the definition of primary particle properties (in space, energy, time, direction or mixture of particles) which cannot be described with built-in sources.

- Activated with input card SOURCE. The parameter list of that card (two continuation cards possible!) allows the user to pass on up to 18 numerical values WHASOU(1–18) and one 8-character string SDUSOU via COMMON/SOURCM/.

- At each call, one (or more) particle(s) must be loaded onto COMMON/FLKSTK/ (particle bank) before returning control. These values can be read from a file, generated by some sampling algorithm, or just assigned.

- Argument list: if NOMORE=1 (output variable) the run will be terminated after exhausting the primary particles loaded onto the stack in the present call. The history number limit set with card START will be overridden.
Source routine - 2

... LOGICAL LFIRST
*
SAVE LFIRST
DATA LFIRST / .TRUE. /
...
NOMORE = 0
*
* | First call initializations:
  IF ( LFIRST ) THEN
* | *** The following 3 cards are mandatory ***
    TKESUM = ZERZER
    LFIRST = .FALSE.
    LUSSRC = .TRUE.
* | *** User initialization ***

Any first-time initialization can be inserted here, for example
- setting up parameters passed on via SOURCE card
- reading spectra from data files

END IF
...
Source routine - 3

... NPFLKA = NPFLKA + 1
* Wt is the weight of the particle
WTFKL (NPFLKA) = ONEONE
WEIPRI = WEIPRI + WTFKL (NPFLKA)
* Particle type (1=proton.....). Ijbeam is the type set by the BEAM
card 
* +-----------------------------------------------*
* | (Radioactive) isotope:
| IF ( IJBEAM .EQ. -2 .AND. LRDBEA ) THEN 
| IARES = IPROA
| IZRES = IPROZ
| IISRES = IPROM
| CALL STISBM ( IARES, IZRES, IISRES )
| IJHION = IPROZ * 1000 + IPROA
| IJHION = IJHION * 100 + KKHEAV
| IONID = IJHION
| CALL DCDION ( IONID )
| CALL SETION ( IONID )
* |
* +-----------------------------------------------*
* | Heavy ion:
| ELSE IF ( IJBEAM .EQ. -2 ) THEN
| IJHION = IPROZ * 1000 + IPROA
| IJHION = IJHION * 100 + KKHEAV
| IONID = IJHION
| CALL DCDION ( IONID )
| CALL SETION ( IONID )
| ILOFLK (NPFLKA) = IJHION
* | Flag this is prompt radiation
| LRADD (NPFLKA) = .FALSE.
* | Group number for "low" energy neutrons, set to 0 anyway
| IGROUP (NPFLKA) = 0
* |
* +-----------------------------------------------*
* | Normal hadron:
| ELSE
| IONID = IJBEAM
| ILOFLK (NPFLKA) = IJBEAM
* | Flag this is prompt radiation
| LRADD (NPFLKA) = .FALSE.
* | Group number for "low" energy neutrons, set to 0 anyway
| IGROUP (NPFLKA) = 0
| END IF
* |
* +-----------------------------------------------*

increase pointer in FLKSTK
weight of particle (if ≠ 1 biased source)
total weight of primaries (don’t change)

Definition of particle type

- The template sets the type of particle equal to the one defined by the BEAM card (and HI-PROPE, if used).

- Whichever valid particle type can be set inside the source (may be different event by event)
Source routine - 4

... * Particle age (s)
    AGESTK (NPFLKA) = +ZERZER
    AKNSHR (NPFLKA) = -TWOTWO
* Kinetic energy of the particle (GeV)
    TKEFLK (NPFLKA) = SQRT ( PBEAM**2 + AM (IONID)**2 )
* Particle momentum
    PMOFLK (NPFLKA) = PBEAM
* Cosines (tx,ty,tz)
    TXFLK (NPFLKA) = UBEAM
    TYFLK (NPFLKA) = VBEAM
    TZFLK (NPFLKA) = WBEAM
* TZFLK (NPFLKA) = SQRT ( ONEONE - TXFLK (NPFLKA)**2 &
                         - TYFLK (NPFLKA)**2 )
* Particle coordinates
    XFLK (NPFLKA) = XBEAM
    YFLK (NPFLKA) = YBEAM
    ZFLK (NPFLKA) = ZBEAM
* Polarization cosines:
    TXPOL (NPFLKA) = -TWOTWO
    TYPOL (NPFLKA) = +ZERZER
    TZPOL (NPFLKA) = +ZERZER

...
* User dependent flag:
  LOUSE (NPFLKA) = 0
* User dependent spare variables:
  DO 100 ISPR = 1, MKBMX1
    SPAREK (ISPR,NPFLKA) = ZERZER
  100 CONTINUE
* User dependent spare flags:
  DO 200 ISPR = 1, MKBMX2
    ISPARK (ISPR,NPFLKA) = 0
  200 CONTINUE

Variables that allow to store additional information in COMMON /FLKSTK/, such as information on ancestors of a certain particle
Auxiliary routines - Random numbers

... = FLRNDM (XDUMMY)
returns a 64-bit random number [0-1]
NOTE: Fundamental for SOURCE! No other external random generators must be used, otherwise the history reproducibility will be lost.

CALL FLNRRN (RGAUSS)
returns a normally distributed random number RGAUSS

CALL FLNRR2 (RGAUS1,RGAUS2)
returns an uncorrelated pair of normally distributed random numbers RGAUS1 and RGAUS2

CALL SFECFE (SINT,COST)
returns SINT and COST, sine and cosine of a random azimuth angle SINT**2 + COST**2 = 1.D+00

CALL RACO (TXX, TYY, TZZ)
returns a random 3D direction (TXX, TYY, TZZ) such that: TXX**2 + TYY**2 + TZZ**2 = 1.D+00
Auxiliary routines - Name/number conv.

Conversion of region name to number

CALL GEON2R ( REGNAM, NREG, IERR )

Input variable:
  Regnam  = region name (CHAR*8)

Output variables:
  Nreg    = region number
  Ierr    = error code (0 on success, 1 on failure)

Conversion of region number to name

CALL GEOR2N ( NREG, REGNAM, IERR )

Input variable:
  Nreg    = region number

Output variables:
  Regname = region name (CHAR*8)
  Ierr    = error code (0 on success, 1 on failure)
CALL OAUXFI (‘file’, LUN, ‘CHOPT’, IERR)

to open an auxiliary file (to read data or parameters) looking automatically for the file in some default locations (temporary directory, working directory)

CALL FLABRT (‘name’,’message’)

this allows to force a FLUKA abort on user request: it might be useful to perform a debugging (using gdb for instance)

CALL SFLOOD ( XXX, YYY, ZZZ, UXXX, VYYY, WZZZ )

returns in XXX, YYY, ZZZ a random position ON the surface of a sphere of radius 1 and centre 0 (multiply XXX, YYY, ZZZ by the actual radius and add the centre coordinates) and UXXX, VYYY, WZZZ are random cosines distributed so as to generate a uniform and isotropic fluence inside the sphere numerically given by $1/(\pi R^2)$, $R$ being the sphere radius.
Sampling from a distribution - Discrete

1) From the cumulative distribution

- Suppose to have a *discrete* random variable $x$, that can assume values $x_1, x_2, ..., x_n, ...$ with probability $p_1, p_2, ..., p_n, ...$
- Assume $\sum_i p_i = 1$, or normalize it
- Divide the interval $[0,1)$ in $n$ subintervals, with limits
  
  $y_0 = 0, \ y_1 = p_1, \ y_2 = p_1 + p_2, ...$

- Generate a uniform pseudo-random number $\xi$
- Find the interval $i^{th}$ $y$-interval such that $y_{i-1} \leq \xi < y_i$
- Select $X = x_i$ as the sampled value

Since $\xi$ is uniformly random:

$$P(x_i) = P(y_{i-1} \leq \xi < y_i) = y_i - y_{i-1} = p_i$$
Sampling from a distribution - \textit{Discrete}

2) By adjusting weights

- Suppose to have an fluence energy spectrum $\Phi$ given in $N$ discrete energy bins between $E_0$ and $E_N$: $\Phi_1, \ldots, \Phi_N$
- Generate a uniform pseudo-random number $\xi$
- Find the interval $i^{\text{th}}$ energy bin such that 
  $$E_{i-1} \leq \xi (E_N - E_0) < E_i$$
- Generate another uniform pseudo-random number $\xi \in [0,1)$ and sample an energy uniformly within the $i^{\text{th}}$ energy bin
- assign a weight $\Phi_i$ to that primary particle

\textbf{Note:} This method is often used for spectra steeply decreasing with energy (e.g., $\Phi \sim 1/E$), where the result depends significantly on the particle cascades cause by high energy primaries, as it ensures faster convergence to the mean value.
Sampling from a distribution - Continuous

1) By integration

• Integrate the distribution function $f(x)$, analytically or numerically, and normalize to 1 to obtain the normalized cumulative distribution

$$F(\xi) = \frac{\int_{x_{\min}}^{\xi} f(x)dx}{\int_{x_{\min}}^{x_{\max}} f(x)dx}$$

• Generate a uniform pseudo-random number $\xi \in [0,1)$

• Get the desired result by finding the inverse value $X = F^{-1}(\xi)$, analytically or most often numerically, i.e. by interpolation (table look-up)

Since $\xi$ is uniformly random:

$$P(a < x < b) = P(F(a) \leq \xi < F(b)) = F(b) - F(a) = \int_{a}^{b} f(x)dx$$
Sampling from a distribution - Continuous

Example

Take \( f(x) = e^{-\frac{x}{\lambda}}, \ x \in [0, \infty) \)

Cumulative distribution:

\[
F(t) = \int_{0}^{t} e^{-\frac{x}{\lambda}} dx = \lambda \times \left(1 - e^{-\frac{t}{\lambda}}\right)
\]

Normalized:

\[
F'(t) = \int_{0}^{t} e^{-\frac{x}{\lambda}} dx = 1 - e^{-\frac{t}{\lambda}}
\]

Generate a uniform pseudo-random number \( \xi \in [0,1) \)

\[
1 - e^{-\frac{t}{\lambda}} = \xi
\]

Sample \( t \) by inverting

\[
t = -\lambda \ln(1 - \xi)
\]

Repeat N times
Sampling from a distribution – Continuous

2) By rejection

• Let be \( f'(x) \), a normalized distribution function, which cannot be sampled by integration and inversion
• Let be \( g'(x) \), a normalized distribution function, which can be sampled, and such that \( C g'(x) \geq f'(x), \ \forall \ x \in [x_{\text{min}}, x_{\text{max}}] \)
• Sample \( X \) from \( g'(x) \), and generate a uniform pseudo-random number \( \xi \in [0,1) \)
• Accept \( X \) if \( \xi < f'(X)/C g'(X) \), if not repeat the previous step
• The overall efficiency (accepted/rejected) is given by:

\[
R = \int \frac{f'(x)}{C g'(x)} g'(x) \, dx = \frac{1}{C}
\]

• and the probability that \( X \) is accepted is unbiased:

\[
P(X) \, dX = \frac{1}{R} g'(X) \, dX \times \frac{f'(X)}{C g'(X)} = f'(X) \, dX
\]
**Example**

- Let be \( f'(x) = \frac{(1+3x^2)}{4}, \ x \in [-1,1], \)
- Take \( g'(x) = \frac{1}{2}, \ C = 2 \)
- Generate two uniform pseudo-random numbers \( \xi_1, \xi_2 \in [0,1) \)
- Accept \( X = 2 \xi_1 - 1 \) if \( \xi_2 < \frac{(1+3X^2)}{4} \), if not repeat
Sampling from a distribution - Continuous

3) By adjusting weights

- Suppose to have a fluence energy spectrum $\Phi(E)$ given in between $E_0$ and $E_1$
- Generate a uniform pseudo-random number $\xi \in [0,1)$ and calculate the sampled energy $E = E_0 + \xi (E_1 - E_0)$
- Assign a weight $\Phi(E)$ to that primary particle
Two-step methods

Example:
predict reading of a (small) radiation detector at a remote location in a huge geometry, *e.g.*, LHCb experiment at CERN

Problem: direct calculation in one step highly inefficient due to the small affected phase-space
Two-step methods

Solution: split simulation into two steps
1) Calculation of radiation field at detector location
2) Simulation of detector reading

Two options:

Directional dependence of detector reading is negligible
- calculate average fluence energy spectra, separately for different particle types, at the detector location
- simulate reading of detector with user-defined source which reads in the calculated spectra and samples particle type, energy and direction (e.g., isotropic incidence)
- important: results of the second step have to be normalized to the integrated particle fluence obtained in the first step

Directional dependence of detector reading is important
- replace detector by ‘blackhole’ and write all information on particles entering it (type, energy, position, direction) into an external file
- simulate reading of detector (if possible with the original geometry now containing the detector) with user-defined source which reads in the particles from the external file
- important: pick entries randomly from external file to avoid going through identical sequence of particles if several runs are performed
Example: point vs. extended source
Example - *Cs* irradiator

- Iron encapsulation
- Reference disc
- Tungsten collimator
- Aluminium part of source
- CsCl source
- Lead container

© H. Vincke, CERN
Extended source

Point source

pGy/primary
Example - Cs irradiator