



Source routine

An introduction to a new approach to source routines

Why do we need a source routine

- The source routine is used to define complex sources, when the options provided in the **BEAM**, **BEAMPOS** and **BEAMAXES** cards are not enough.
- Most common use cases:
 - Mixed field
 - Beam with an energy spectrum
 - Complex beam shape
 - Second step of a two-step simulation

The “old” source routine

- Scary for beginners, limited documentation
- Written according the FORTRAN 77 standard, prone to errors

```
1 *
2 *==== source =====
3 *
4 SUBROUTINE SOURCE ( NOMORE )
5
6 INCLUDE 'dblprc.inc'
7 INCLUDE 'dimpar.inc'
8 INCLUDE 'iouit.inc'
9
10 -----
11 *
12 * Copyright (C) 2003-2019: CERN & INFN
13 * All Rights Reserved.
14 *
15 * New source for FLUKA9x-FLUKA20xy:
16 *
17 * Created on 07 January 1990 by Alfredo Ferrari & Paola Sala
18 *                               Infn - Milan
19 *
20 * This is just an example of a possible user written source routine.
21 * note that the beam card still has some meaning - in the scoring the
22 * maximum momentum used in deciding the binning is taken from the
23 * beam momentum. Other beam card parameters are obsolete.
24 *
25 * Output variables:
26 *
27 *     Nomore = if > 0 the run will be terminated
28 *
29 *-----
30 *
31 INCLUDE 'beamcm.inc'
32 INCLUDE 'fheavy.inc'
33 INCLUDE 'flkstc.inc'
34 INCLUDE 'ioiocm.inc'
35 INCLUDE 'lctlcm.inc'
36 INCLUDE 'paprop.inc'
37 INCLUDE 'sourcm.inc'
38 INCLUDE 'sumcou.inc'
39 *
40 LOGICAL LFIRST, LISNUT
41 *
42 SAVE LFIRST
43 DATA LFIRST / .TRUE. /
44 *
45 * Statement function:
46 LISNUT (I) = INDEX ( PRNAME (I), 'NEUTRI' ) .GT. 0
47 *-----
48 *
49 *
50 *-----
51 *
52 * NOMORE = 0
53 *
54 * First call initializations:
55 IF ( LFIRST ) THEN
56 *
57 ** The following 3 cards are mandatory **
58 TKESUM = ZERZER
59 LFIRST = .FALSE.
60 LUSSRC = .TRUE.
61 *
62 ** User initialization **
63 END IF
64 *-----
65 *
66 * Push one source particle to the stack. Note that you could as well
67 * push many but this way we reserve a maximum amount of space in the
68 * stack for the secondaries to be generated
69 * Npflka is the stack counter: of course any time source is called it
70 * must be = 0
71 *
72 NPFLKA = NPFLKA + 1
73 *
74 * Wt is the weight of the particle
75 WTFLK ( NPFLKA ) = ONEONE
76 *
77 WEIPRI = WEIPRI + WTFLK ( NPFLKA )
78 *
79 * Particle type (=proton.....). Ijbeam is the type set by the BEAM
80 * card
81 IJBEAM = IJBEAM + 1
82 *
83 * (Radioactive) isotope:
84 IF ( IJBEAM .EQ. -2 .AND. LRDBEA ) THEN
85 IARES = IPROA
86 IZRES = IPROZ
87 IISRES = IPRON
88 CALL STISBM ( IARES, IZRES, IISRES )
89 IJHION = IPRON * 100000 + MOD ( IPROZ, 100 ) * 1000 + IPROA
90 IJHION = IJHION * 100 + KXHEAV
91 IONID = IJHION
92 CALL DCDION ( IONID )
93 CALL SETION ( IONID )
94 LFRPHN ( NPFLKA ) = .FALSE.
95 *
96 * Heavy ion:
97 ELSE IF ( IJBEAM .EQ. -2 ) THEN
98 IJHION = IPRON * 100000 + MOD ( IPROZ, 100 ) * 1000 + IPROA
99 IJHION = IJHION * 100 + KXHEAV
100 IONID = IJHION
101 CALL DCDION ( IONID )
102 CALL SETION ( IONID )
103 ILOFLK ( NPFLKA ) = IJHION
104 *
105 * Flag this is prompt radiation
106 LRADDC ( NPFLKA ) = .FALSE.
107 *
108 * Group number for "low" energy neutrons, set to 0 anyway
109 IGROUP ( NPFLKA ) = 0
110 *
111 * Parent radioactive isotope:
112 IRDAZM ( NPFLKA ) = 0
113 *
114 * Particle age (s)
115 AGESTK ( NPFLKA ) = +ZERZER
116 *
117 * Kinetic energy of the particle (GeV)
118 TKEFLK ( NPFLKA ) = SQRT ( PBEAM**2 + AM ( IONID )**2 )
119 *
120 * Particle momentum
121 PMOFLK ( NPFLKA ) = PBEAM
122 PMOFLK ( NPFLKA ) = SQRT ( TKEFLK ( NPFLKA ) * ( TKEFLK ( NPFLKA )
123 * + TWOTWO * AM ( IONID ) ) )
124 *
125 * LFRPHN ( NPFLKA ) = .FALSE.
126 *
127 *
128 * AGESTK ( NPFLKA ) = +ZERZER
129 * Kinetic energy of the particle (GeV)
130 TKEFLK ( NPFLKA ) = SQRT ( PBEAM**2 + AM ( IONID )**2 )
131 *
132 * Particle momentum
133 PMOFLK ( NPFLKA ) = PBEAM
134 PMOFLK ( NPFLKA ) = SQRT ( TKEFLK ( NPFLKA ) * ( TKEFLK ( NPFLKA )
135 * + TWOTWO * AM ( IONID ) ) )
136 *
137 * Check if it is a neutrino, if so force the interaction
138 * (unless the relevant flag has been disabled)
139 IF ( LISNUT ( IJBEAM ) .AND. LNUFIN ) THEN
140 LFRPHN ( NPFLKA ) = .TRUE.
141 *
142 *
143 * Not a neutrino
144 ELSE
145 LFRPHN ( NPFLKA ) = .FALSE.
146 *
147 *
148 *
149 *
150 * From this point .....
151 * Particle generation (1 for primaries)
152 LOFLK ( NPFLKA ) = 1
153 *
154 * User dependent flag:
155 LOUSE ( NPFLKA ) = 0
156 *
157 * No channeling:
158 KCHFLK ( NPFLKA ) = 0
159 ECRFLK ( NPFLKA ) = ZERZER
160 *
161 * Extra infos:
162 INFSTK ( NPFLKA ) = 0
163 LNFSTK ( NPFLKA ) = 0
164 ANFSTK ( NPFLKA ) = ZERZER
165 *
166 * Parent variables:
167 IPRSTK ( NPFLKA ) = 0
168 EKPSK ( NPFLKA ) = ZERZER
169 *
170 * User dependent spare variables:
171 DO 100 ISPR = 1, MKBM1
172 SPAREK ( ISPR, NPFLKA ) = ZERZER
173 *
174 * User dependent spare flags:
175 DO 200 ISPR = 1, MKBM2
176 ISPAK ( ISPR, NPFLKA ) = 0
177 *
178 * Save the track number of the stack particle:
179 ISPAK ( MKBM2, NPFLKA ) = NPFLKA
180 NPARMA = NPARMA + 1
181 NUNPAR ( NPFLKA ) = NPARMA
182 NEVENT ( NPFLKA ) = 0
183 DFNEAR ( NPFLKA ) = +ZERZER
184 *
185 * ... to this point: don't change anything
186 AKNSHR ( NPFLKA ) = -TWOTWO
187 *
188 * Cosines (tx,ty,tz)
189 TXFLK ( NPFLKA ) = UBEAM
190 TYFLK ( NPFLKA ) = VBEAM
191 TZFLK ( NPFLKA ) = WBEAM
192 *
193 * Polarization cosines:
194 TXPOL ( NPFLKA ) = -TWOTWO
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```

The “new” source routine

- Simplified appearance
- Long & meaningful names for variables and routines
- Forced declaration of variables – Use of **implicit none**
- Documented by comments and in the manual
- Variables for user’s usage clearly indicated
- Lines not to be edited are “hidden” in routines
in the **source_library.inc** library file

- **Old source routines can still be used**

The “new” source routine

```
1 *
2 *
3 * Copyright (C) 2020: CLM
4 * All Rights Reserved.
5 * Source routine of FLUKA
6 *
7 * Created on 26 September 2020 by David Stratakis & Roberto Versari
8 *
9 *
10 *
11 * Modified on 17 November 2020 by David Stratakis & Roberto Versari
12 *
13 *
14 * This is a simplified user-written source routine utilizing a
15 * separate source routine library.
16 *
17 * It is intended as an alternative non-user-friendly version of the
18 * source.f routine. Existing FLUKA & source routines remain
19 * compatible.
20 *
21 * Note that the beam card still has some meaning - in the morning the
22 * main momentum used in deciding the binning is taken from the
23 * beam momentum. Other beam card parameters are obsolete.
24 *
25 *
26 * Output variables:
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```

• Note: the snapshot is not meant to be read – Detailed view will follow

User declaration

```
! =====  
! BEGINNING of user declared variables  
! =====
```

```
! =====  
! END of user declared variables  
! =====
```

- Dedicated space for the declaration of additional variables (and functions)

User declaration (example)

```
! =====  
! BEGINNING of user declared variables  
! =====
```

```
integer :: counter  
double precision :: energy  
logical :: flag
```

```
! =====  
! END of user declared variables  
! =====
```

Initialization

- Initialization of internal variables
Runs every time, resetting their values to the defaults

```
call initialization()
```

```
if ( first_run ) then
```

```
! =====  
! BEGINNING of custom initialization  
! =====
```

```
! =====  
! END of custom initialization  
! =====
```

```
first_run = .false.
```

```
end if
```

- Custom initialization block

Runs only the first time the source routine is used

Main section

- For setting the internal variables directly, or using one of the sampling routines
- To enable a line, remove the `*`
(The command should start on the 7th column)
- The variables with `[` `]` brackets and ... are placeholders, they need to be replaced with values or user variables
(Brackets should be deleted)
- Always use double precision format for floating point numbers (1.0d0)

```
! =====  
! BEGINNING of customizable code  
! =====  
  
* particle_code = ...  
  
* heavyion_atomic_number = ...  
* heavyion_mass_number = ...  
* heavyion_isomer = ...  
  
* momentum_energy = ...  
  
* energy_logical_flag = .true.  
  
* particle_weight = ...  
  
* momentum_energy = sample_flat_momentum_energy( [min], [max] )  
* momentum_energy = sample_gaussian_momentum_energy( [mean], [fwhm] )  
* momentum_energy = sample_maxwell_boltzmann_energy( [temperature] )  
* momentum_energy = sample_histogram_momentum_energy( [filename], [unit] )  
* momentum_energy = sample_spectrum_momentum_energy( [filename], [unit] )  
  
* call sample_exponential_energy_weight( [e_min], [e_max], [intensity_ratio], momentum_energy, particle_weight )  
  
* divergence_x = ...  
* divergence_y = ...  
  
* gaussian_divergence_logical_flag = .true.  
  
* coordinate_x = ...  
* coordinate_y = ...  
* coordinate_z = ...  
  
* coordinate_[a] = sample_flat_distribution( [min], [max] )  
* coordinate_[a] = sample_gaussian_distribution( [mean], [fwhm] )  
* call sample_annular_distribution( [rmin], [rmax], coordinate_[a], coordinate_[b] )  
  
* direction_cosx = ...  
* direction_cosy = ...  
* direction_cosz = ...  
  
* direction_flag = ...  
  
* call sample_isotropic_direction( direction_cosx, direction_cosy, direction_cosz )  
  
* polarization_cosx = ...  
* polarization_cosy = ...  
* polarization_cosz = ...  
  
* particle_age = ...  
* kshort_component = ...  
* delayed_radioactive_decay = ...  
  
* call read_phase_space_file( [filename], [energy_unit], [length_unit], phase_space_entry, [sequential_logical_flag], nomore )  
  
* particle_code = phase_space_entry%pc  
* momentum_energy = phase_space_entry%me  
  
* energy_logical_flag = .true.  
  
* coordinate_x = phase_space_entry%x  
* coordinate_y = phase_space_entry%y  
* coordinate_z = phase_space_entry%z  
  
* direction_cosx = phase_space_entry%u  
* direction_cosy = phase_space_entry%v  
* direction_cosz = phase_space_entry%w  
  
* particle_weight = phase_space_entry%wei  
  
* debug_logical_flag = .true.  
* debug_lines = ...
```

Primary particle

```
*      particle_code = ...
```

- By default, the particle type given in the **BEAM** card is taken
- Particle codes explained in FLUKA manual section 5.1
- Possible application: beam made of more than one type of particles

```
*      heavyion_atomic_number = ...  
*      heavyion_mass_number = ...  
*      heavyion_isomer = ...
```

- Only used if primary particle is set to HEAVYION or ISOTOPE on the **BEAM** card
- Default values are set on the **HI-PROPE** card, or for ^{12}C if the card is missing

Energy / momentum

```
*      momentum_energy = ...
```

- By default, the particle momentum is expected
- The default value is based on the **BEAM** card
(Automatically converted into momentum if energy is given in the **BEAM** card)
- If energy is specified in the source routine, the following logical value must be set **.true.**

```
*      energy_logical_flag = .true.
```

Energy / momentum

- The momentum divergence set on the **BEAM** card is not retained
- It is necessary to specify it in the source routine
- It is easy with the supplied functions / subroutine

Sampling functions:

Analytical

- Flat (Uniform)
- Gaussian
- Maxwell-Boltzmann
- Exponential

From an external file

- Histogram
- Continuous spectrum
- Discrete spectrum

Energy / Momentum – Analytical samplings

- Flat / uniform:

- Samples uniformly between two momentum [GeV/c] or, energy [GeV] values

* `momentum_energy = sample_flat_momentum_energy([min], [max])`

- Gaussian:

- Samples from a Gaussian distribution with a given mean and FWHM value ([GeV/c] or [GeV])

* `momentum_energy = sample_gaussian_momentum_energy([mean], [fwhm])`

- Maxwell-Boltzmann:

- Samples from a Maxwell-Boltzmann energy distribution with a given temperature [GeV]
- It is only meaningful if the `energy_logical_flag` is set to `.true.`

* `momentum_energy = sample_maxwell_boltzmann_energy([temperature])`

Energy / Momentum – Analytical samplings

- Exponential:

- Samples according the exponential distribution between two energies [GeV], with a given intensity ration at the specified energies

```
*      call sample_exponential_energy_weight(  
          [e_min], [e_max], [intensity_ratio],  
          momentum_energy, particle_weight  
      )
```

- It is only meaningful if the **energy_logical_flag** is set to **.true.**
- Note 1: Different syntax used (function vs. subroutine)
- Note 2: The return values **momentum_energy** and **particle_weight** are among the arguments
- Note 3: **This is a biased sampling!** It is not suitable for cases where fully analogue simulation is required (E.g. scoring with **DETECT** card)

Energy / Momentum – Sampling from file

- Histogram:

- Samples from a histogram specified in an external file

```
*      momentum_energy = sample_histogram_momentum_energy (  
          [filename], [unit]  
      )
```

- The external file needs to have 3 columns:
 - Lower energy boundary of the histogram's bins
 - Upper energy boundary of the histogram's bins
 - Intensity per energy unit (dN/dp or dN/dE)
- The particle momentum / energy is sampled uniformly within a bin
- **[unit]** variable is the unit used in the external file. Possible values:
 - TeV/c, GeV/c, MeV/c, keV/c, J
 - TeV, GeV, MeV, keV, eV, J

Energy / Momentum – Sampling from file

- Continuous spectrum:

- Samples from a continuous spectrum specified in an external file

```
*      momentum_energy = sample_spectrum_momentum_energy (  
          [filename], [unit]  
      )
```

- Samples from a discrete (line) spectrum specified in an external file

```
*      momentum_energy = sample_discrete_momentum_energy (  
          [filename], [unit]  
      )
```

- The external file needs to have 2 columns:

- Energy
- Intensity at the specified energy
- With the continuous spectrum, the intensity is linearly interpolated

Energy / Momentum – Examples

- Setting energy flag to true:

```
energy_logical_flag = .true.
```

- Monoenergetic beam:

```
momentum_energy = 1.0d-1
```

- Gaussian beam:

```
momentum_energy = sample_gaussian_momentum_energy(1.0d-1, 1.0d-2)
```

Energy / Momentum – Examples

- Sampling from an exponential distribution:

```
call sample_exponential_energy_weight(1.0d-6, 1.0d-3, 0.01d0,  
& momentum_energy, particle_weight)
```

- Sampling from an external spectrum:

```
momentum_energy = sample_spectrum_momentum_energy(  
& 'spectrum.txt', 'MeV')
```

Note: The & character is for the line continuations, it should be always in column 6.

Source routine – Particle weight

```
*      particle_weight = ...
```

- To create biased sources (see Monte Carlo lecture)
- Usually needed only for complex source definitions
- Note: The exponential spectrum sampling subroutine uses variable particle weight, but in that case, it is automatically set

Source routine – Beam divergence

```
*      divergence_x = ...  
*      divergence_y = ...
```

- By default:
 - values are taken from the **BEAM** card
 - It is assumed to be a flat angular distribution
- For Gaussian divergence the following logical value must be set *.true.*

```
*      gaussian_divergence_logical_flag = .true.
```

Source routine – Beam starting position

```
*      coordinate_x = ...  
*      coordinate_y = ...  
*      coordinate_z = ...
```

- By default, values are taken from the **BEAMPOS** card
- Beam shape set in the **BEAM** card, and
- extended sources specified in additional **BEAMPOS** cards are not implemented

Source routine – Beam starting position

- Some predefined routines (2 functions and 1 subroutine) are already available:

Flat distribution:

```
*      coordinate_[a] = sample_flat_distribution( [min], [max] )
```

Gaussian distribution:

```
*      coordinate_[a] = sample_gaussian_distribution( [mean], [fwhm] )
```

Annular distribution:

```
*      call sample_annular_distribution( [rmin], [rmax], coordinate_[a],
```

Remember the values must be in double precision (**1.0d0**).

Note: If annular sampling is used, the coordinates have to be selected as well.

Source routine – Beam direction

```
*      direction_cosx = ...  
*      direction_cosy = ...  
*      direction_cosz = ...
```

- By default, values are taken from the **BEAMPOS** card

- If the **direction_flag** is set to:




```
*      direction_flag = ...
```

- 0 : All three values are considered and they are normalized automatically (Default)
 - 1 : The manually set value of the z direction is disregarded. Instead, it is calculated from the x and y direction cosines with a positive sign.
 - 2 : As with option 1, but negative sign is used.
- A predefined subroutine is already available for isotropic direction sampling

```
*      call sample_isotropic_direction( direction_cosx, direction_cosy, direction_cosz )
```

Source routine – Unused values

- It is important to remember, not all values used in the FLUKA input are used in the source routine:
 - The beam momentum distribution
 - The shape of the extended beam / volumetric sources
 - The separate coordinate system set up for the beam

 BEAM	Beam: Momentum ▼	p:	Part: ▼
Δp: Flat ▼	Δp:	Δφ: Flat ▼	Δφ:
Shape(X): Rectangular ▼	Δx:	Shape(Y): Rectangular ▼	Δy:
 BEAMPOS	x:	y:	z:
	cosX:	cosy:	Type: POSITIVE ▼
 BEAMAXES	cosBxx:	cosBxy:	cosBxz:
	cosBzx:	cosBzy:	cosBzz:

- If one of these features is required, it needs to be programmed in the source routine as well by using the available sampling procedures or by custom code.

Source routine – Phase-space sampling

- Used for the second step in a two-step simulation

- It reads a file containing information on individual particles:

- Particle code
- Momentum / energy
- Starting coordinate
- Starting direction
- Weight

- Can replay the particles sequentially, or select from them randomly

```
*      call read_phase_space_file( [filename], [en
*
*      particle_code   = phase_space_entry%pc
*      momentum_energy = phase_space_entry%m_e
*
*      energy_logical_flag = .true.
*
*      coordinate_x = phase_space_entry%x
*      coordinate_y = phase_space_entry%y
*      coordinate_z = phase_space_entry%z
*
*      direction_cosx = phase_space_entry%u
*      direction_cosy = phase_space_entry%v
*      direction_cosz = phase_space_entry%w
*
*      particle_weight = phase_space_entry%wei
```

Source routine – Debugging

- To help debug the source routine, the major particle parameters can be printed
- To enable this feature, set

```
*      debug_logical_flag = .true.
```

- The printed parameters:

- Energy / momentum
- Coordinates
- Direction
- Weight

- The number of primaries printed can be set with:

```
*      debug_lines = 100
```

SOURCE card and passing parameters

- To invoke a source routine, it is necessary to add a **SOURCE** card
- A **SOURCE** card can be empty or can be used to pass parameters to the routine
 - Max. 18 numerical values (**WHASOU (ii)**) and 1 string (max. 8 characters) (**SDUSOU**)

```
# SOURCE          #1: 7.          #2: 250.         #3: 12.5
sdum: linksour   #4: 3.75        #5:              #6:
                 #7:              #8:              #9:
                 #10:             #11:            #12:
                 #13:             #14:            #15:
                 #16:             #17:            #18:
```

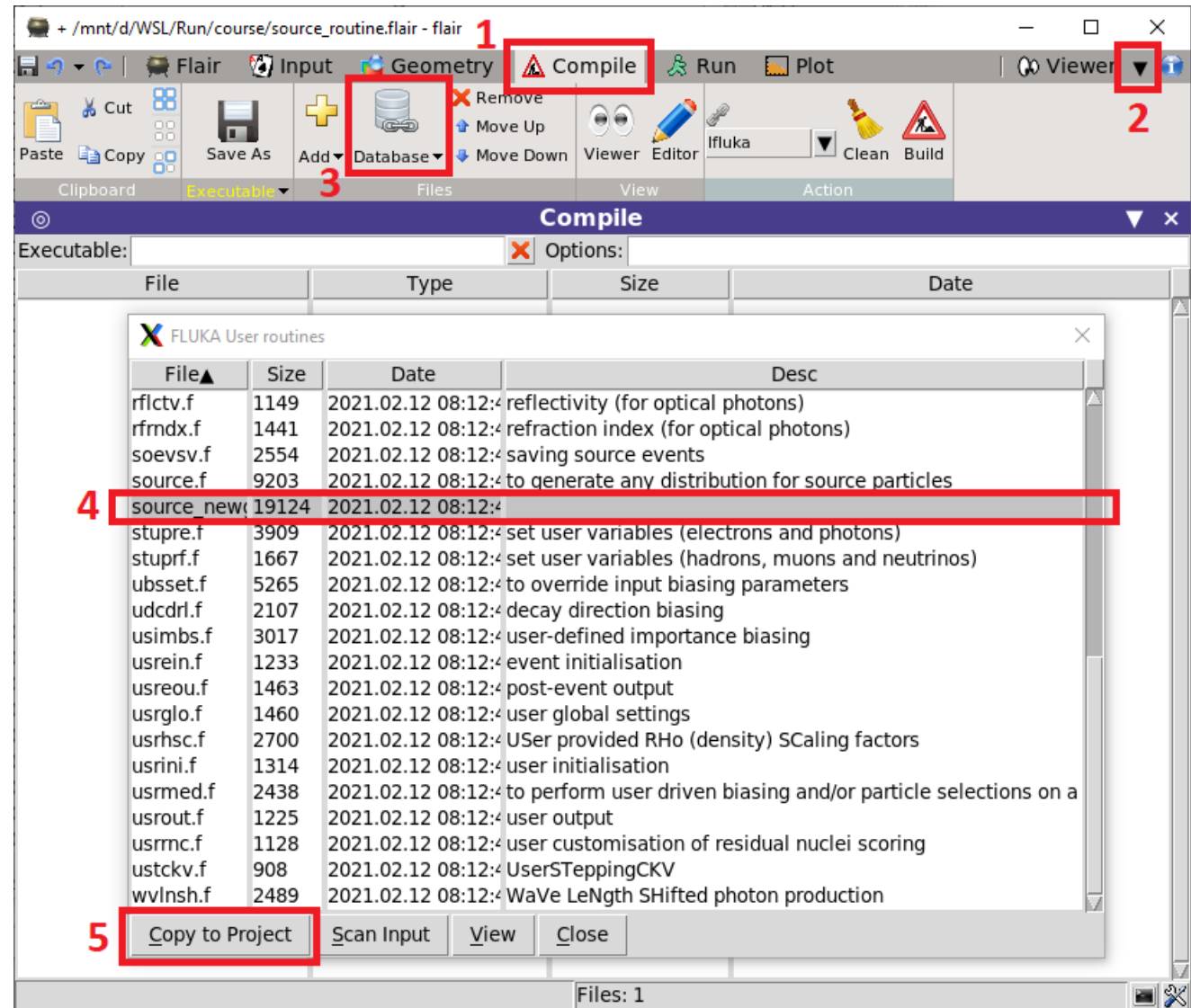
- Good practice:

Even if the beam energy / momentum is defined in the source routine, specify it in the **BEAM** card as it is used for internal initialization. Set a momentum value higher than the maximum possible one.

Adding the user routine to the project folder

1. Open [Compile] tab
2. It is maybe hidden in the dropdown menu
3. Click the [Database] button (Use [Add] for an existing file)
4. Select the user routine you want to use
5. Click [Copy to Project]

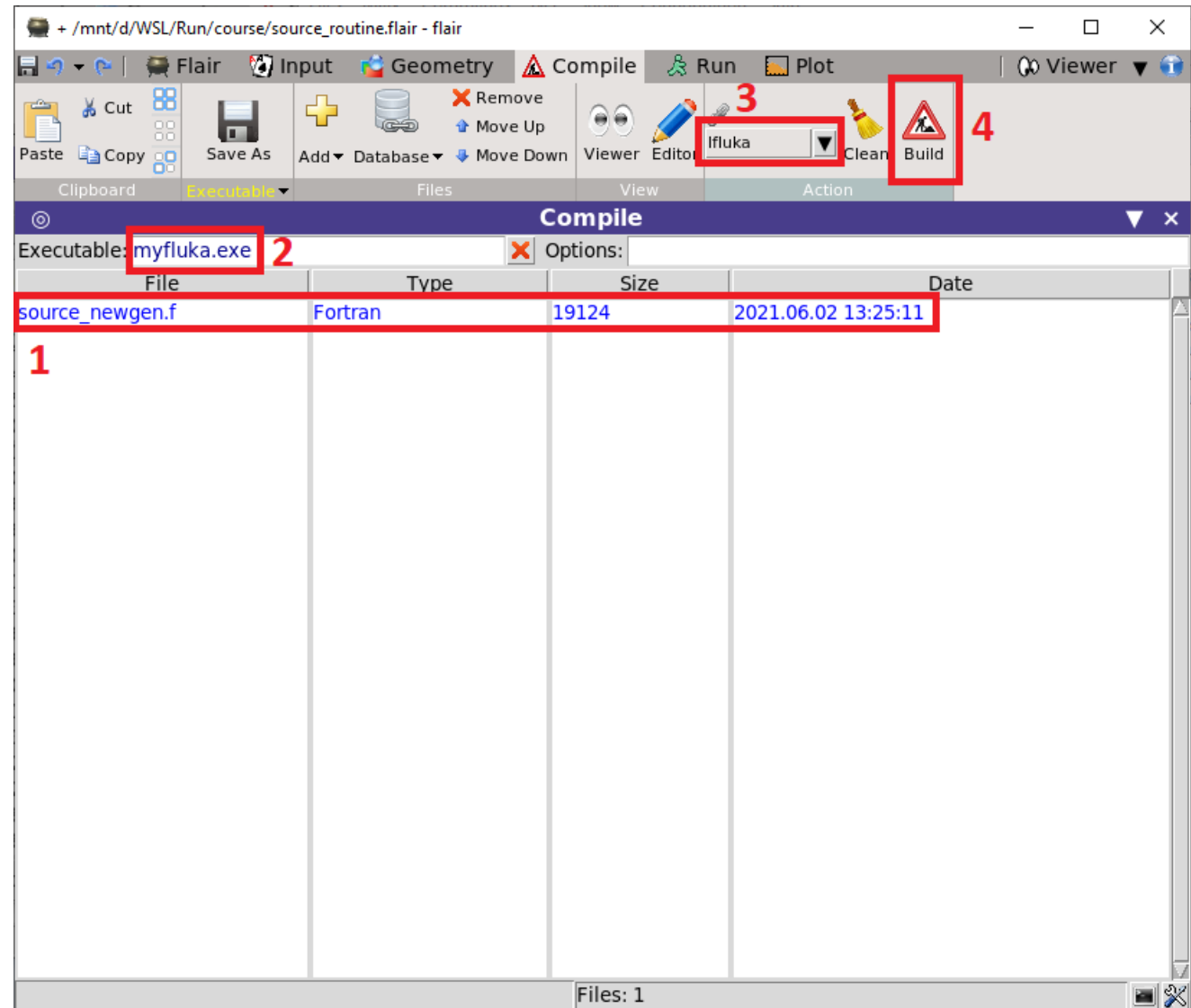
The copied user routine will be in the Flair projects directory



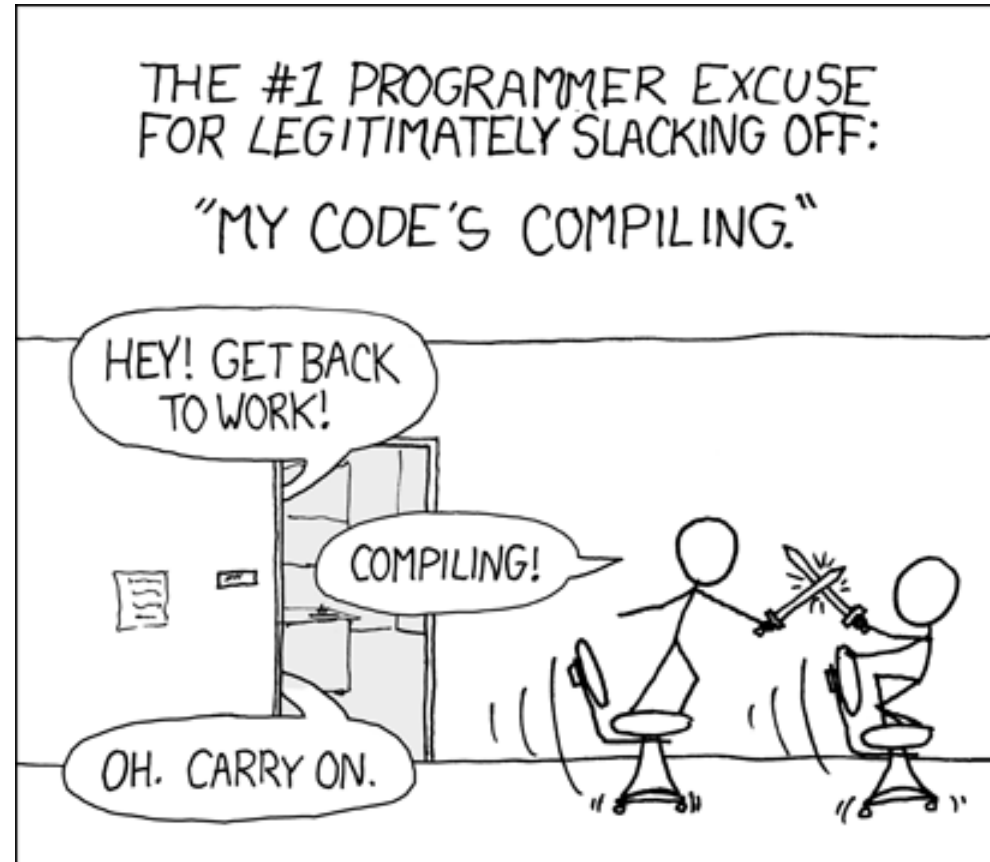
Compiling a custom FLUKA executable

1. Verify that the user routine is in the list
2. Name your custom executable
3. Select the appropriate linker:
 - a. Use *lfluka* by default
 - b. Use *ldpmqmd* if DPMJET or RQMD models are needed
4. Compile the executable

The custom executable should be set default on the [Run] tab automatically



Time for an exercise!



xkcd.com/303

