

A few examples with FLUKA

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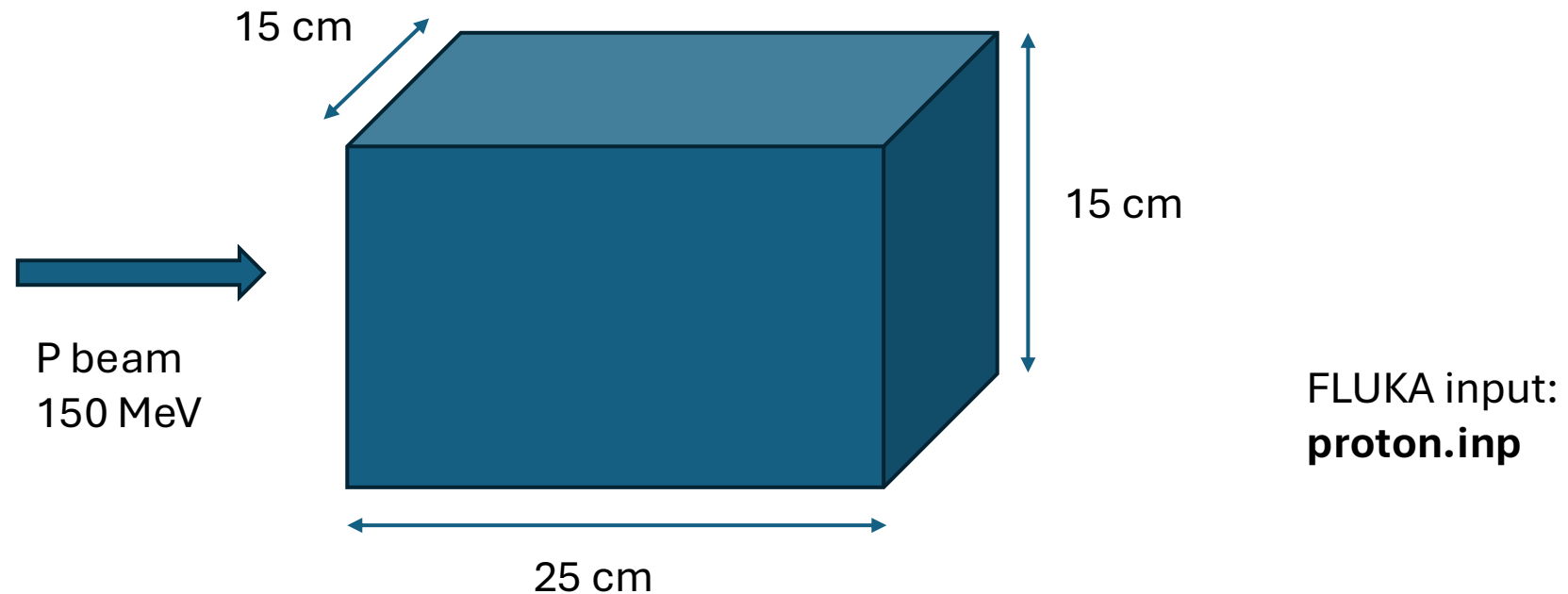
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Outline

- Simple radiotherapy exercises: simulated longitudinal Depth Dose Profiles in a water phantom using:
 - Photons
 - Protons
 - ^{12}C ions
- An advanced radiotherapy case: a proton beam on a real patient case
- Simple nuclear medicine example: a ^{18}F source in a water phantom

1) Predicting the Longitudinal Profile of Dose deposited by a proton beam in a water phantom

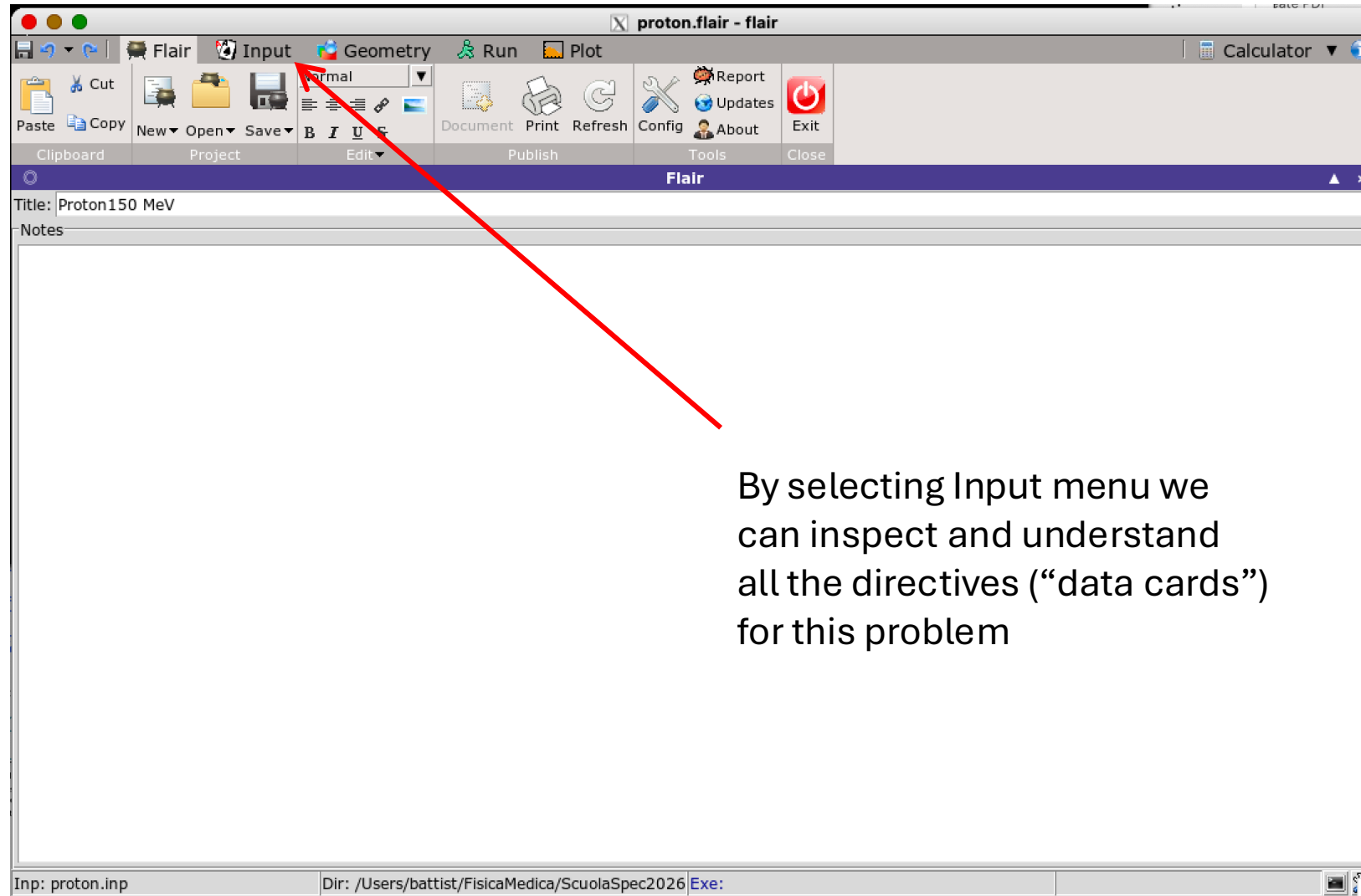


We can manage this simple problem by means of Flair, the graphical user interface of FLUKA

It is a tool based on Python3, Gnuplot and C++ programming languages which allows users to manage most of simulation cases without any need of code programming

FLAIR

In a terminal window we just give the line command:
`flair proton.inp`



By selecting Input menu we can inspect and understand all the directives (“data cards”) for this problem

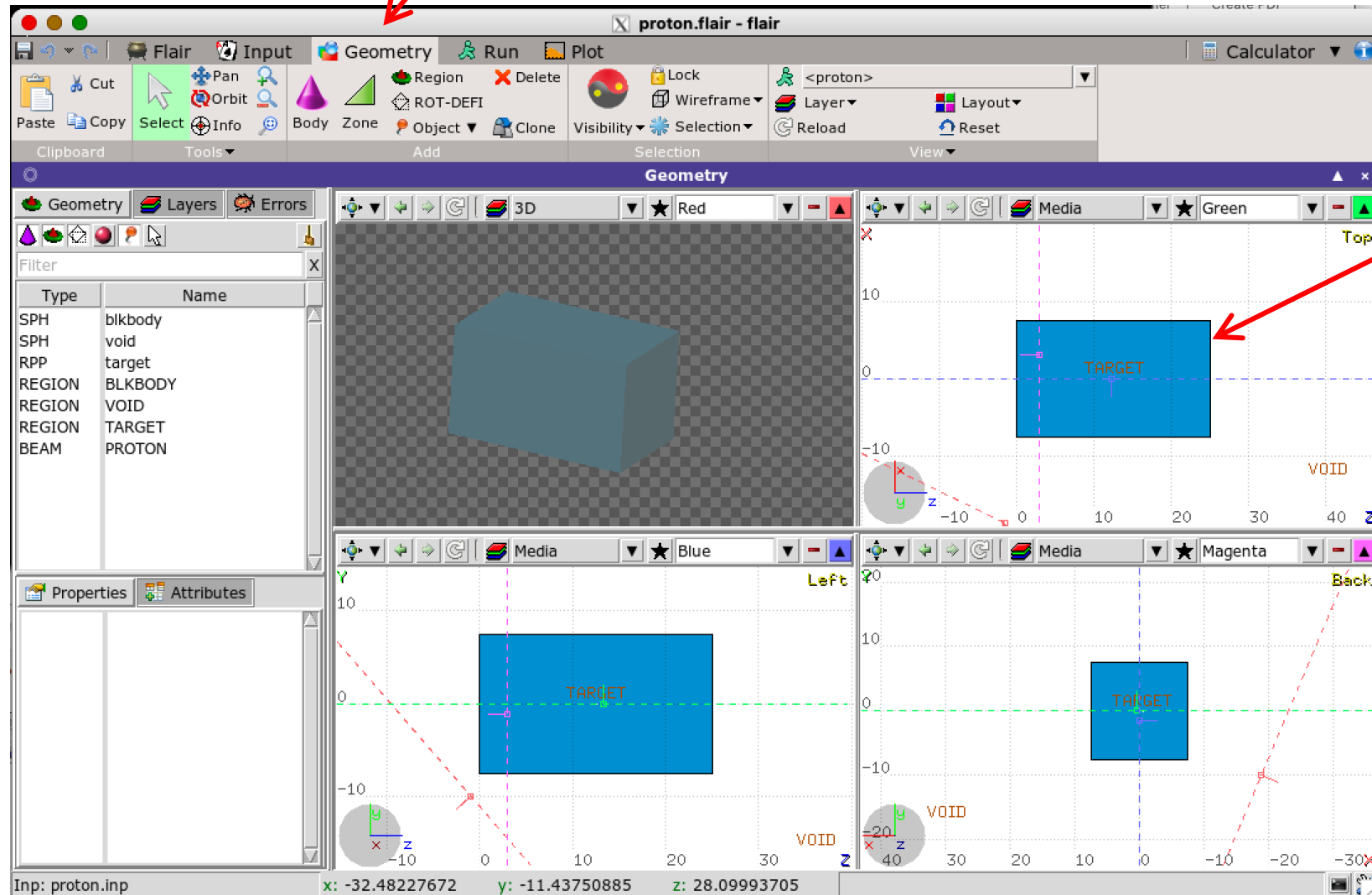
The input data cards

The screenshot displays the Flair software interface with the 'Input' window active. The window title is 'proton.flair - flair'. The interface includes a menu bar with options like 'Flair', 'Input', 'Geometry', 'Run', and 'Plot'. Below the menu bar is a toolbar with various icons for file operations and simulation controls. The main area shows a list of input cards for a simulation titled 'starting example'. The cards are as follows:

- TITLE**: starting example
- Set the defaults for precision simulations**
- DEFAULTS**: PRECISIO
- Define the beam characteristics**
- BEAM**: Beam: Energy, E: 0.15, Part: PROTON, Δp: Flat, Δφ: Flat, Shape(X): Rectangular, Δx, Shape(Y): Rectangular, Δy
- Define the beam position**
- BEAMPOS**: x: 0.0, y: 0.0, z: -0.5, cosx, cosy, Type: POSITIVE
- EMFCUT**: Type: transport, e-e+ Threshold: Kinetic, Reg, e-e+ Ekin: 0.0001, Y: 0.0001, to Reg: @LASTREG, Step
- EMFCUT**: Type: PROD-CUT, e-e+ Threshold: Kinetic, Fudgem: 1, Mat, e-e+ Ekin: 0.0001, Y: 0.0001, to Mat: @LASTMAT, Step
- GEOBEGIN**: Log, Acc, Opt, Geometry, Out, Fmt: COMBNAME
- Black body**
- SPH**: blkbody, x: 0.0, y: 0.0, z: 0.0, R: 10000.0
- Void sphere**
- SPH**: void, x: 0.0, y: -.4, z: 0.0, R: 1000.0
- Cylindrical target**
- RPP**: target, Xmin: -7.5, Xmax: 7.5, Ymin: -7.5, Ymax: 7.5, Zmin: 0.0, Zmax: 25.

At the bottom of the window, there is a status bar showing 'Inp: proton.inp' and 'Active:1 Total:23'.

The geometry viewer



You can have different cartesian projections, 3D views, and other options

Different colors represent different materials

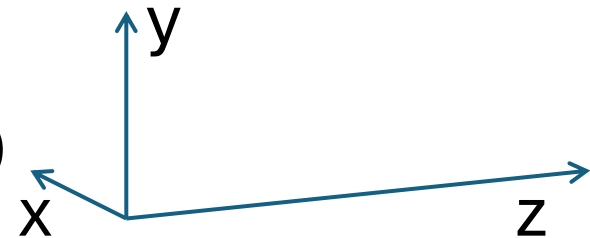
Important to know in advance

FLUKA units

- ⊛ time → s
- ⊛ length → cm
- ⊛ energy → GeV
- ⊛ masses → GeV/c^2
- ⊛ B → Tesla

Reference frame (cartesian, right-handed)

- ⊛ z is the default primary beam direction (can be changed)
- ⊛ y is pointing upwards



Analyzing input - 1

Primary energy

Select particle (menu)

The screenshot shows the Flair software interface with the following configuration:

- TITLE**: starting example
- DEFAULTS**: PRECISIO
- BEAM** (Define the beam characteristics):
 - Beam: Energy \cdot E: 0.15
 - Δp : Flat \cdot $\Delta \phi$: Flat \cdot
 - Shape(X): Rectangular \cdot Δx : Shape(Y): Rectangular \cdot Δy :
- BEAMPOS** (Define the beam position):
 - x: 0.0 y: 0.0 z: -0.5
 - cosx: cosy: Type: POSITIVE \cdot
- EMFCUT** (Type: transport \cdot):
 - e-e+ Threshold: Kinetic \cdot e-e+ Ekin: 0.0001 γ : 0.0001
 - Reg: \cdot to Reg: @LASTREG \cdot Step:
- EMFCUT** (Type: PROD-CUT \cdot):
 - e-e+ Threshold: Kinetic \cdot e-e+ Ekin: 0.0001 γ : 0.0001
 - Mat: \cdot to Mat: @LASTMAT \cdot Step:
- Fudgem: 1.

Primary coordinates, angle and direction

Analyzing input - 2

Body of Phantom (Rectangular Parallelepiped) and we call it **phant**

The screenshot shows a software interface with a menu bar (Flair, Input, Geometry, Run, Plot) and a toolbar. The main window displays a code editor with the following content:

```
GEOBEGIN
Title:
Black body
SPH blkbody x: 0.0 y: 0.0 z: 0.0
R: 10000.0
Void sphere
SPH void x: 0.0 y: -4 z: 0.0
R: 1000.0
Cylindrical target
RPP phant Xmin: -7.5 Xmax: 7.5
Ymin: -7.5 Ymax: 7.5
Zmin: 0.0 Zmax: 25.
END
Black hole
REGION BLKBODY Neigh: 5
expr: +blkbody -void
Void around
REGION VOID Neigh: 5
expr: +void -phant
Target
REGION PHANTOM Neigh: 5
expr: +phant
END
GEOEND
```

Annotations in the image:

- A red box highlights the top portion of the code editor, containing the text: "Body of Phantom (Rectangular Parallelepiped) and we call it **phant**".
- A red box highlights the "Coordinates of vertices" for the "Void sphere" entry, containing the text: "Coordinates of vertices".
- A red box highlights the "Defining the Body **phant** as a Region called **PHANTOM**" section, containing the text: "Defining the Body **phant** as a Region called **PHANTOM**".

Analyzing input - 3

The screenshot shows the 'proton.flair - flair' application window. The main workspace displays the 'Input' configuration table. The table has columns for region names, materials, and various simulation parameters. Red annotations highlight specific settings:

- Assigning material WATER to region PHANTOM:** A red box highlights the 'ASSIGNMA' row where 'Mat: WATER' is assigned to 'Reg: PHANTOM'. An arrow points from the text box to this row.
- Setting the seed of Random numbers:** A red box highlights the 'RANDOMIZ' row with 'Unit 01' and 'Seed:' set. An arrow points from the text box to the 'Seed:' field.
- Setting the number of primaries:** A red box highlights the 'START' row with 'No.: 10000.'. An arrow points from the text box to the 'No.' field.

The configuration table content is as follows:

Region	Material	Expression	Neigh
Black hole	BLKBODY	expr: +blkbody -void	
Void around	VOID	expr: +void -phant	Neigh: 5
Target	PHANTOM	expr: +phant	Neigh: 5
END			
GEOEND			
ASSIGNMA	Mat: BLCKHOLE	Step:	Reg: BLKBODY
ASSIGNMA	Mat: VACUUM	Step:	Reg: VOID
ASSIGNMA	Mat: WATER	Step:	Reg: PHANTOM
USRBIN	Type: X-Y-Z	Part: DOSE	Ymin: -6, Ymax: 6, Zmin: 0.0, Zmax: 11, NY: 1200, NZ: 1200
RANDOMIZ	Unit 01	Seed:	
START	No.: 10000	Time:	Core: , Report: default
STOP			

Analyzing input - 4

proton.flair - flair

Flair Input Geometry Run Plot

Clipboard Input Card Edit Filter View

Input

Black hole
REGION BLKBODY
expr: +blkbody -void

Void around
REGION VOID
expr: +void -phant

Target
REGION PHANTOM
expr: +phant

END
GEOEND

...+...1...+...2...+...3...+...4...+...5...+...6...+...7...

ASSIGNMA Mat: BLCKHOLE Reg: BLKBODY to Reg: Synchrontron rad:
Mat(Decay): Step: Field: Synchrontron rad:

ASSIGNMA Mat: VACUUM Reg: VOID to Reg: Synchrontron rad:
Mat(Decay): Step: Field: Synchrontron rad:

ASSIGNMA Mat: WATER Reg: PHANTOM to Reg: Synchrontron rad:
Mat(Decay): Step: Field: Synchrontron rad:

**** Scoring ****

USRBIN Unit: 21 BIN Name: Edep
Type: X-Y-Z Xmin: -10 Xmax: 10 NX: 200.
Part: DOSE Ymin: -10 Ymax: 10 NY: 1
Zmin: 0.0 Zmax: 25. NZ: 250

Set the random number seed
RANDOMIZ Unit 01

Set the number of primary histories to be simulated in the run
START No.: 10000.

STOP Time:

Setting the scoring of Dose, using the USRBIN option: here a X-Y-Z grid superimposed to a region of space (in out case over the Phantom)

Will write output on "Logical Unit" no. 21 as a binary file

Analyzing input - 5

The screenshot shows the Flair software interface with the following components:

- Menu Bar:** Flair, Input, Geometry, Run, Plot, Calculator.
- Toolbar:** Cut, Copy, Paste, New, Load, Save, Export, Import, Preprocessor, Material, Add, Change, Delete, Show, Comment, Refresh, Move Up, Move Down, Search, Filter, Viewer, Editor, Print.
- Left Sidebar:** Input (selected), General, Primary, Geometry, Media, Physics, Transport, Biasing, Scoring, Flair, Preprocessor.
- Main Text Area:** Contains the input script for a simulation.

The input script content is as follows:

```
END
Black hole
REGION BLKBODY Neigh: 5
  expr: +blkbody -void
Void around
REGION VOID Neigh: 5
  expr: +void -phant
Target
REGION PHANTOM Neigh: 5
  expr: +phant
END
GEOEND
...+...1...+...2...+...3...+...4...+...5...+...6...+...7...
ASSIGNMA Mat: BLCKHOLE Reg: BLKBODY to Reg:
  Mat(Decay): Step: Field: Synchrotron rad:
ASSIGNMA Mat: VACUUM Reg: VOID to Reg:
  Mat(Decay): Step: Field: Synchrotron rad:
ASSIGNMA Mat: WATER Reg: PHANTOM to Reg:
  Mat(Decay): Step: Field: Synchrotron rad:
**** Scoring ****
USBIN 1 BIN
  Type: X-Y-Z
  Part: DOSE
  Ymin: -6. Ymax: 6.
  Zmin: 0.0 Zmax: 11.
let the random number seed
RANDOMIZ Unit 01 Seed:
let the number of primary histories to be simulated in the run
START No.: 10000. Core:
  Time: Report: default
STOP
```

Annotations in the image:

- A red box highlights the `RANDOMIZ` card. A red arrow points from the text "Setting the seed of Random numbers" to the `Unit 01` parameter.
- A red box highlights the `START` card. A red arrow points from the text "Setting the number of primaries (take 20000)" to the `No.: 10000.` parameter.

Managing the simulation run

The screenshot shows the FLAIR software interface with the 'Run' panel active. The 'Run' panel has a title 'Proton150 MeV' and several fields: 'Primaries' (0), 'Time' (0), 'Rnd' (0), and 'Exe' (flukadpm3). The 'No' field is set to 3 and the 'To' field is set to 3. A 'Start' button is located in the top right of the Run panel. The 'Progress' section at the bottom shows 'Status: Finished OK' and 'Input: proton'. The status bar at the bottom indicates 'Inp: proton.inp' and 'Running 0 out of 1'.

Name	Value
Primaries	0
Time	0
Rnd	0
Exe	flukadpm3

Progress

Status:	Finished OK	Input:	proton	Dir:	
Started:		ETA:		Time/prim:	
Elapsed:		Cycle:		Run:	
Cycles:					
Primaries:					

Inp: proton.inp Running 0 out of 1

Start button

Set the number of statistically independent runs (cycles, alias "batches")
Let's take 3

Select the FLUKA standard executable.
Use **flukadpm3**, which is present in the FLUKA installation directory

Managing the simulation run

The screenshot displays the FLAIR software interface with the 'Run' panel active. The top toolbar includes buttons for 'Run', 'Plot', 'Cycle', 'Run', 'Kill', 'Refresh', and 'Start'. The 'Run' panel shows a table with columns 'Run' and 'Spawn', and a 'Title' field set to 'Proton150 MeV'. Below this, there are fields for 'Primaries', 'Time', 'Rnd', and 'Exe'. A 'Progress' section at the bottom provides detailed simulation status:

Name	Value
Input	proton
Dir	fluka_13525
Status	Running
Started	2026.02.23 13:30:52
ETA	2026.02.23 13:31:03
Elapsed	354.422 ms
Time/prim	0.295352 ms
Cycle	2.59909 s
Run	10.7061 s
Cycles	Current: 1 [3] Completed: 0%
Primaries	Current: 1201 [10000] Completed: 12%

At the bottom of the interface, it shows 'Inp: proton.inp' and 'Running 0 out of 1'.

Here you can check the progress of simulation run

Post-processing of results when the run is finished

1) Select Data button

2) Select Process button

Run	Command	Output	Unit
<proton>	usrbin	proton_21.bnn	21
<proton>	usrbin	proton_22.bnn	22

File	Type	Size	Date
proton001_fort.21	21	200238	2026.02.23 13:30:57
proton002_fort.21	21	200238	2026.02.23 13:31:01
proton003_fort.21	21	200238	2026.02.23 13:31:06

It will merge the output files from the n independent cycles and will produce the output USRBIN file (*.bnn)

Inp: proton.inp Files: 0

Plotting results

1) Add a plot of USRBIN type

2) Load the *.bnn output file

3) Select 1D Projection

4) Select Z projection

5) Produce plot by pressing Plot button

Flair Input Geometry Run Plot Output

Clipboard Plot List Action

proton_plot01
Red
Green
Blue
Magenta

Title: Plot #1

Display: 0

Log Min Max

File: proton_21.bnn Title: starting example

Cycles: 3 Primaries: 30000 Weight: 30000.0 Time: ***** Sum file ***

Binning Info

Det: 1 Edep X: [-10 .. 10] x 200 (0.1) Min: 2.87381585E-08

Type: 10: X-Y-Z Y: [-10 .. 10] x 1 (20) Max: 1.27492545E-04

Score: DOSE Z: [0 .. 25] x 250 (0.1) Int: 0.14412678821831093

Projection & Limits

Type: 1D Projection

Options

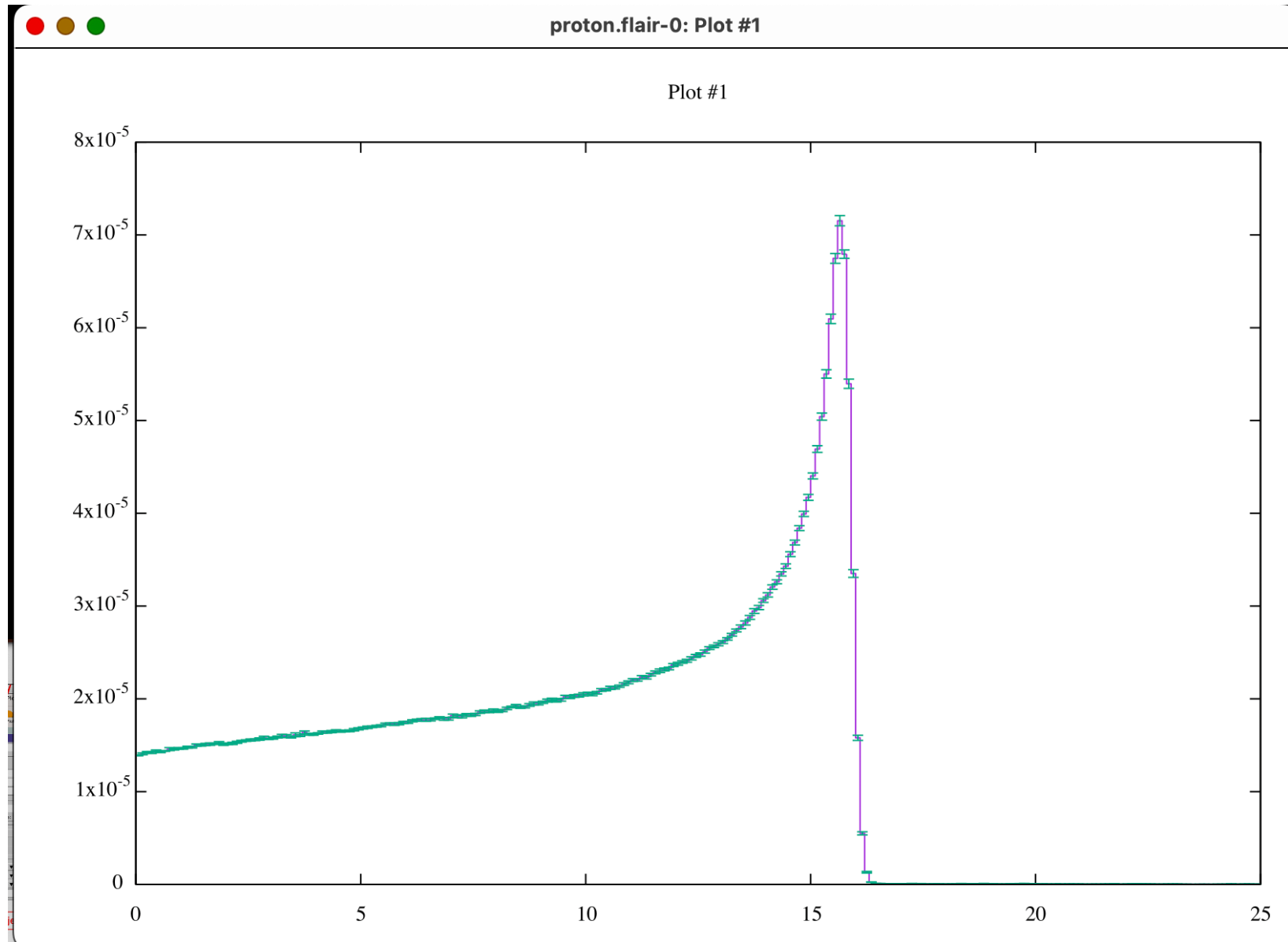
Type: histerror

Color: Line width: 0

Point type: dot Point size: 0

Inp: proton.inp Plot completed

Plotting results



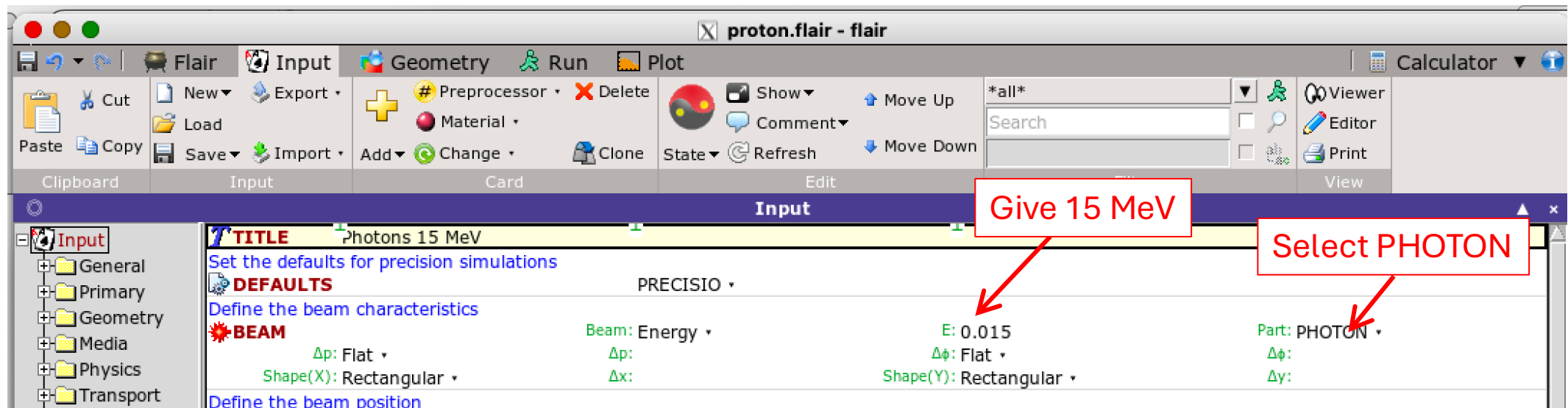
Plotting results

Plot can be saved in different formats

An ascii files with the tabulation of numbers will be also available (*.dat)

Inp: proton.inp Plot completed

Same exercise for photons



In case of photons use at least 50000 primaries/cycle

Same exercise for ^{12}C ions

The screenshot shows the Flair software interface for configuring a simulation. The main workspace displays the 'Input' card with the following settings:

- TITLE:** ^{12}C ions 300 MeV
- DEFAULTS:** PRECISIO
- BEAM:** Beam: Energy $E: 0.3$, $\Delta p: \text{Flat}$, $\Delta \phi: \text{Flat}$, Shape(X): Rectangular, Shape(Y): Rectangular
- HI-PROPE:** Z: 6, A: 12
- BEAMPOS:** z: -0.5, Type: POSITIVE

Red annotations highlight specific settings:

- An arrow points to the 'Beam: Energy' field with the text "Give 300 MeV/u".
- An arrow points to the 'Part: HEAVYION' field with the text "Select HEAVYION".
- A red box surrounds the 'HI-PROPE' card with the text "Addition card HI-PROPE to specify Z and A of ion".

In case of carbon ions use ~ 5000 primaries/cycle
(longer CPU time/primary is needed for Nucleus-Nucleus interactions)

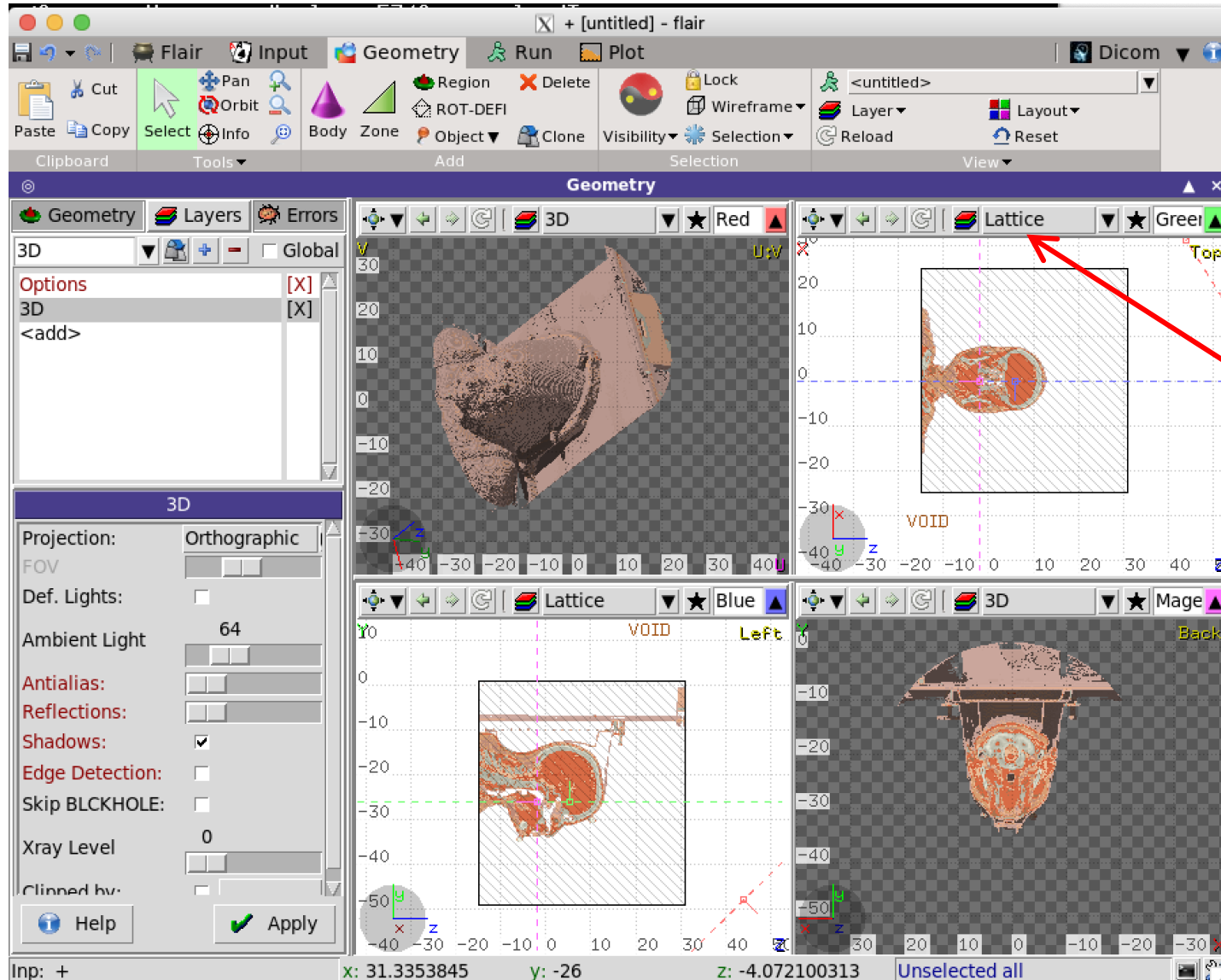
In the case of nuclei like Deuterium, Tritium, ^3He and ^4He , specific particles exist, and energy has to be given as total kinetic energy

For all other nuclei, HEAVYION + HI-PROPE have to be used, and kin. energy has to be given as energy/nucleon

2) A patient case example

flair dicom.inp

Or even better: flair dicom.flair



Use 3D or Lattice visualization layers

This is a voxel geometry obtained from a CT dicom file

3) Simulating a radionuclide: ^{18}F Fluorine source

flair 18Fluorine.inp

Or even better: flair 18Fluorine.flair

Select particle ISOTOPE

Set Z and A of isotope

The screenshot shows the Flair software interface with the following input configuration:

Section	Parameter	Value
TITLE	18Fluorine source	
GLOBAL	Max #reg:	9999
DEFAULTS	PRECISIO	
BEAM	Beam:	Momentum
BEAM	Shape(X):	Rectangular
BEAM	Shape(Y):	Rectangular
BEAM	Part:	ISOTOPE
BEAM	Type:	CART-VOL
BEAM	x:	0.0
BEAM	y:	0.0
BEAM	z:	0.0
BEAM	Z:	9
BEAM	A:	18
HI-PROPE	Decays:	Semi-Analogue
HI-PROPE	h/μ Int:	ignore
HI-PROPE	h/μ LPB:	ignore
HI-PROPE	h/μ WW:	ignore
HI-PROPE	Low-n Bias:	ignore
HI-PROPE	Low-n WW:	ignore
HI-PROPE	decay cut:	0.0
HI-PROPE	prompt cut:	0.0
EMFCUT	Type:	transport
EMFCUT	e-e+ Threshold:	Kinetic
EMFCUT	Reg:	@LASTREG
EMFCUT	e-e+ Ekin:	1e-05
EMFCUT	Y:	0.00001
EMFCUT	to Mat:	@LASTMAT
EMFCUT	Step:	
EMFCUT	Fudgem:	1

The command defines a spatially extended source shaped as a Cartesian shell with the edges parallel to the axes of the reference.

The outer and the inner parallelepiped are centred at a x,y,z point defined by another BEAMPOSit command, which also sets the particle direction by means of a SDUM blank or = NEGATIVE.

The particle angular distribution, or lack of it, is defined by the BEAM card.

Different options: Cartesian, Cylindrical or Spherical shell

Cartesian volume

The screenshot shows the Flair software interface with the following input deck:

TITLE	18Fluorine source		
GLOBAL	Max #reg: 9999,	Analogue: ▾	DNear: ▾
	Input: ▾	Geometry: ▾	
DEFAULTS	PRECISIO ▾		
BEAM	Beam: Momentum ▾	p:	Part: ISOTOPE ▾
	Δp: Flat ▾	Δφ: Flat ▾	Δφ:
	Shape(X): Rectangular ▾	Shape(Y): Rectangular ▾	Δx:
BEAMPOS	Xin: 0.0	Xout: 5,	Type: CART-VOL ▾
	Yin: 0.0	Yout: 5,	
	Zin: 0.0	Zout: 5,	
BEAMPOS	x: 0.0	y: 0.0	z: 0.0
	cosx:	cosy:	Type: NEGATIVE ▾
HI-PROPE	Z: 9,	A: 18,	Isom:
RADDECAY	Decays: Semi-Analogue ▾	Patch Isom: ▾	Replicas:
	h/μ Int: ignore ▾	h/μ WW: ignore ▾	e-e+ Int: ignore ▾
	e-e+ LPB: ignore ▾	Low-n Bias: ignore ▾	Low-n WW: ignore ▾
	e-e+ WW: ignore ▾	prompt cut: 0.0	Coulomb corr: ▾
	decay cut: 0.0		
EMFCUT	Type: transport ▾	e-e+ Ekin: 1e-05	Y: 0.00001
	e-e+ Threshold: Kinetic ▾	to Reg: @LASTREG ▾	Step:
	Reg: ▾		
EMFCUT	Type: PROD-CUT ▾	e-e+ Ekin: 1e-05	Y: 0.00001
	e-e+ Threshold: Kinetic ▾	to Mat: @LASTMAT ▾	Step:
	Mat: ▾		
	Fudgem: 1,		

In the semi-analogue mode, each single radioactive nucleus is treated in a Monte Carlo way like all other unstable particles: a random decay time, random daughters, random radiation are selected and tracked.

This allows for event-by-event analysis, with the time structure recorded in the particles age variable.

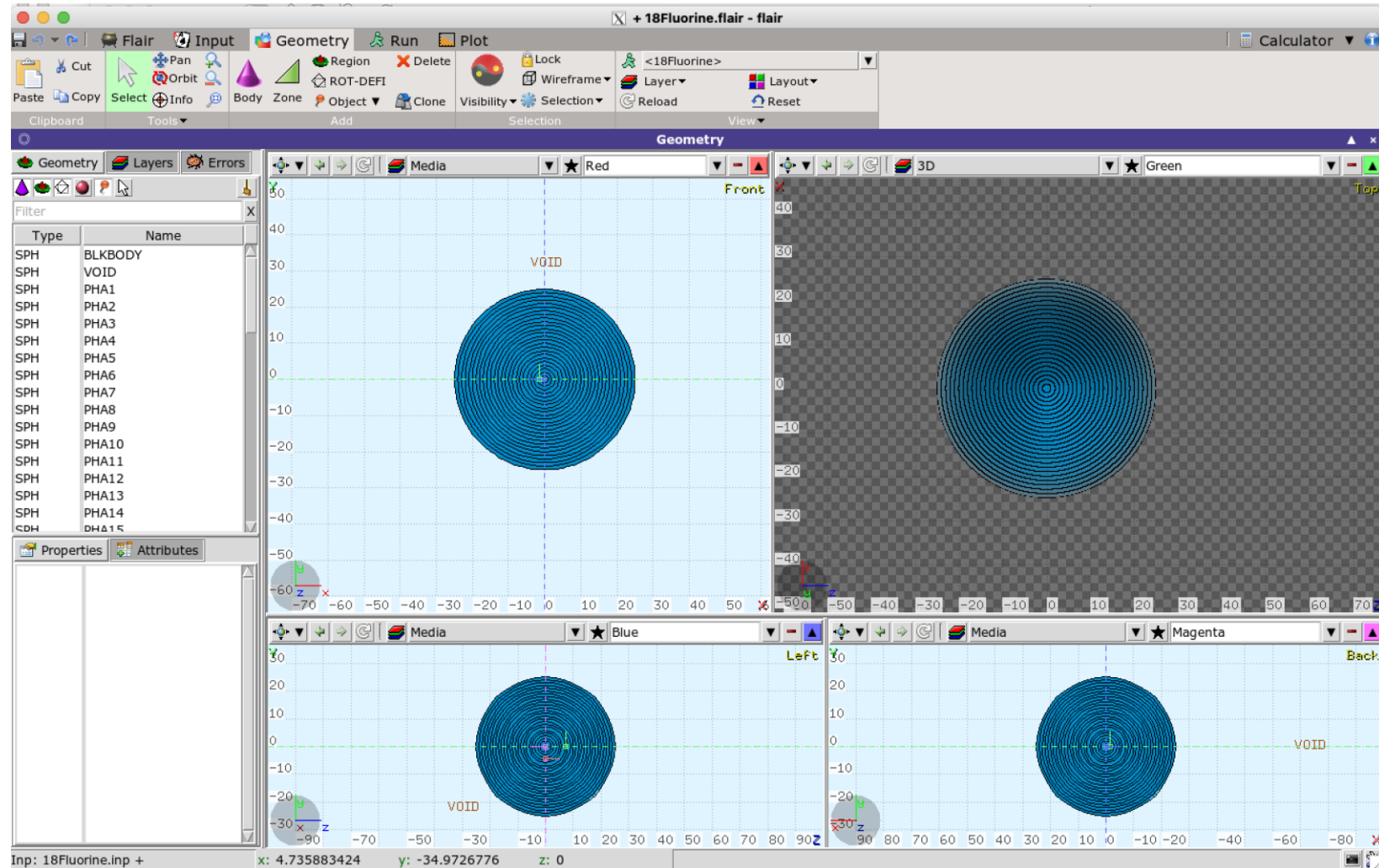
Radioactive decay in semi-analogue mode

The screenshot shows the Flair software interface for a simulation titled '+ 18Fluorine.flair - flair'. The 'Input' section is expanded, showing various configuration options. The 'RADDECAY' section is highlighted with a red box, and a red arrow points from the text 'Radioactive decay in semi-analogue mode' to the 'Decays: Semi-Analogue' option.

Section	Parameter	Value
TITLE	18Fluorine source	
GLOBAL	Max #reg:	9999
GLOBAL	Analogue:	▼
GLOBAL	Geometry:	▼
GLOBAL	DNear:	▼
DEFAULTS	PRECISIO	▼
BEAM	Beam:	Momentum
BEAM	p:	▼
BEAM	Part:	ISOTOPE
BEAM	Δp:	Flat
BEAM	Δφ:	Flat
BEAM	Δx:	▼
BEAM	Shape(Y):	Rectangular
BEAM	Δy:	▼
BEAMPOS	Xin:	0.0
BEAMPOS	Xout:	5
BEAMPOS	Yin:	0.0
BEAMPOS	Yout:	5
BEAMPOS	Zin:	0.0
BEAMPOS	Zout:	5
BEAMPOS	Type:	CART-VOL
BEAMPOS	x:	0.0
BEAMPOS	y:	0.0
BEAMPOS	z:	0.0
BEAMPOS	cosx:	▼
BEAMPOS	cosy:	▼
BEAMPOS	Type:	NEGATIVE
HI-PROPE	Z:	0
HI-PROPE	A:	18
HI-PROPE	Isom:	▼
RADDECAY	Decays:	Semi-Analogue
RADDECAY	h/μ Int:	ignore
RADDECAY	h/μ LPB:	ignore
RADDECAY	h/μ WW:	ignore
RADDECAY	Replicas:	▼
RADDECAY	e-e+ LPB:	ignore
RADDECAY	e-e+ WW:	ignore
RADDECAY	Low-n Bias:	ignore
RADDECAY	Low-n WW:	ignore
RADDECAY	decay cut:	0.0
RADDECAY	prompt cut:	0.0
RADDECAY	Coulomb corr:	▼
EMFCUT	Type:	transport
EMFCUT	e-e+ Threshold:	Kinetic
EMFCUT	e-e+ Ekin:	1e-05
EMFCUT	Y:	0.00001
EMFCUT	Reg:	▼
EMFCUT	to Reg:	@LASTREG
EMFCUT	Step:	▼
EMFCUT	Type:	PROD-CUT
EMFCUT	e-e+ Threshold:	Kinetic
EMFCUT	e-e+ Ekin:	1e-05
EMFCUT	Y:	0.00001
EMFCUT	to Mat:	@LASTMAT
EMFCUT	Step:	▼
EMFCUT	Fudgem:	1
EMFCUT	Mat:	▼

Geometry

Spherical Phantom: water
25 spherical shells



Scoring

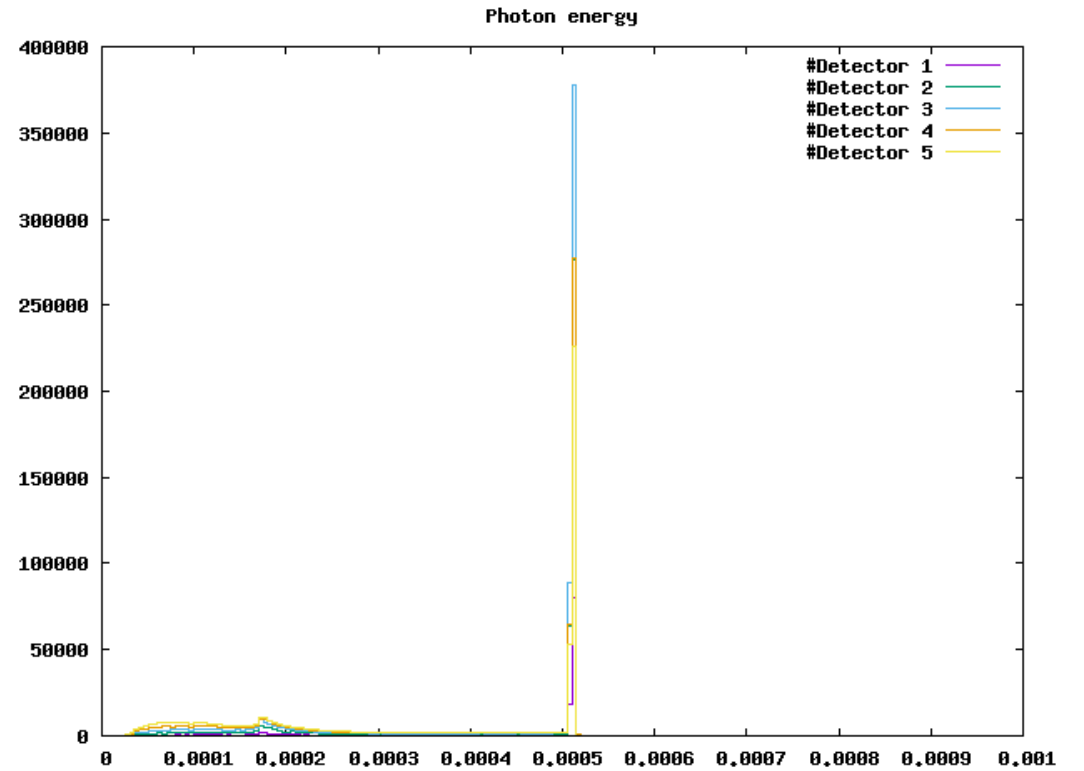
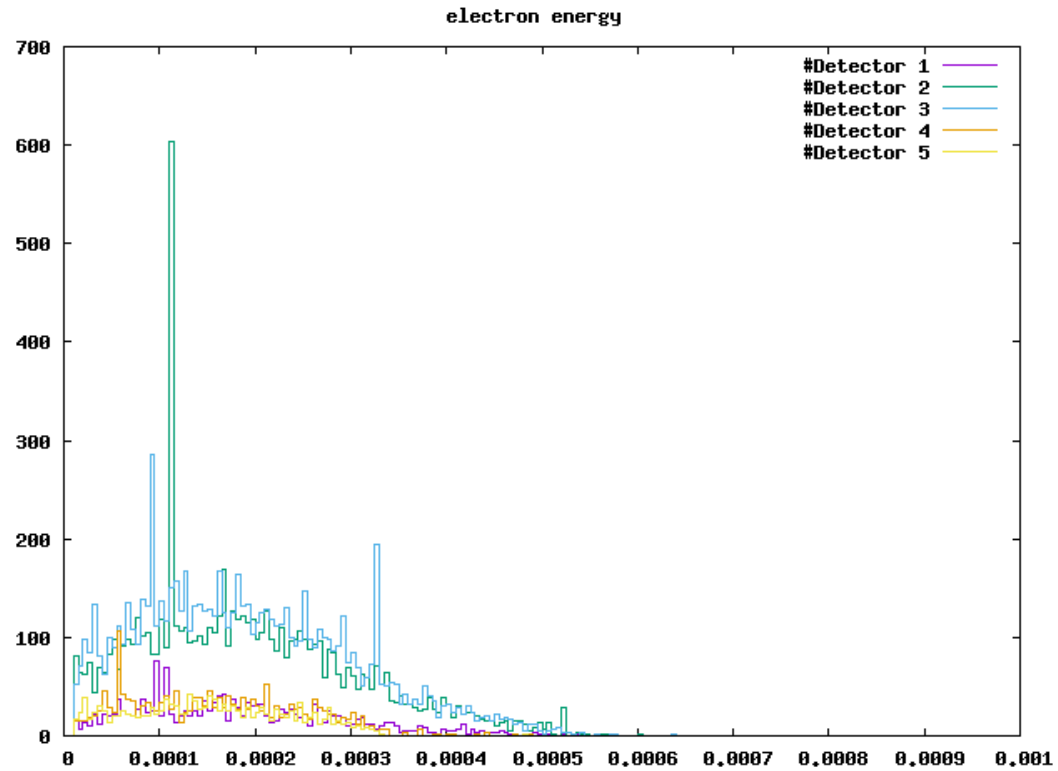
At the boundary of the phantom shells: electrons-positrons (unit 26) and photons (unit 27) two-way fluence scoring (linear binning in energy and solid angle)

Unit	Type	Part	Reg	Emin	Emax	Ωmin	Ωmax	Name
26	USRBDX	PHOTON	PHANT21	0.0	0.001			Eph21
27	USRBDX	PHOTON	PHANT22	0.0	0.001			Eph22
28	USRBDX	PHOTON	PHANT23	0.0	0.001			Eph23
29	USRBDX	PHOTON	PHANT24	0.0	0.001			Eph24
22	USRBIN	DOSE						Dose
23	USRBIN	PHOTON						GamFl
24	USRBIN	E+&E-						EleFl
25	USRBIN	ACTIVITY						Activity
26	DCYSCORE	Semi-Analogue						
27	DCYSCORE	Semi-Analogue						

On the source volume:
Dose (unit 22),
photon fluence (unit 23),
electron-positron fluence (unit 24),
activity (unit 28)

DCYSCORE:
Necessary to bound decay products to the scoring

Boundary fluence plots



2-D Dose and fluence plots

