



<https://fluka.cern>

An overview of the FLUKA particle transport code and its graphical user interface Flair

Academic training lecture
14.09.2022

Introduction

FLUKA.CERN distribution

<https://fluka.cern>



Release of FLUKA 4-0.1
2020-08-24 - [Release](#)

FLUKA online training for beginners (Sept/Oct 2020)
2020-08-01 - [Event](#)

Release of FLUKA 4.0 and Flair 3.1
2020-06-30 - [Release](#)

FLUKA online training in autumn 2020
2020-06-29 - [Event](#)

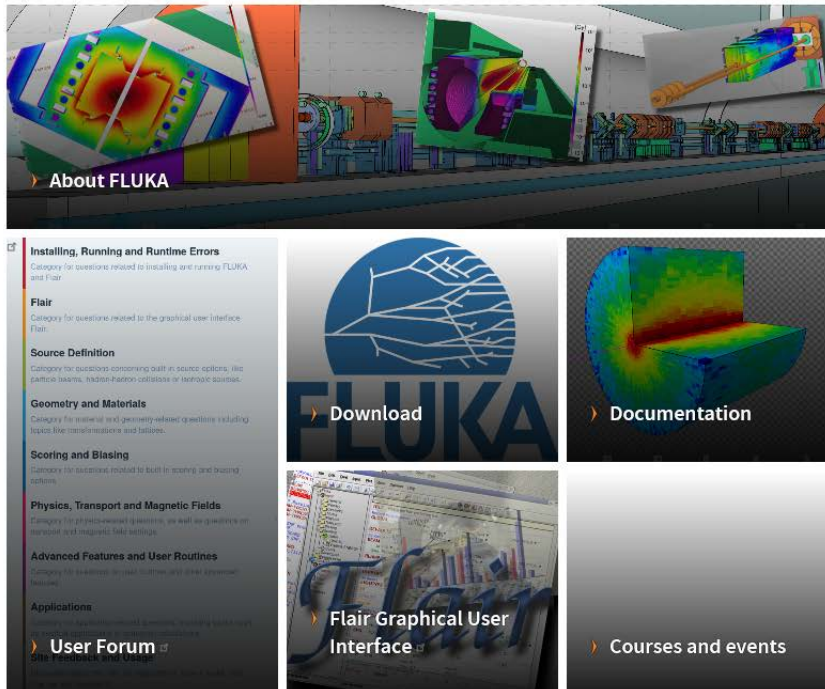
[more](#)

FLUKA 4-0.1, 2020-08-24

Flair 3.1-2nd, 2020-07-10

Registration problems? Enquiry about a commercial license? Enquiry about an institutional license for accessing the source code? Feedback to the website?

Use the [contact form](#).



Code history:

FLUKA was born in the 60's at CERN from Johannes Ranft

It's in active development since then, where several institutes and collaborators have contributed.

Currently the 4th generation of the code is distributed by CERN.

The next release **FLUKA 4-3.0** is scheduled for **September 15, 2022**

Licensing scheme

Registration options

FLUKA Single User License Agreement

Affiliates of institutes with a FLUKA Institutional License Agreement

CERN Staff members and Fellows

Affiliates of institutes which signed the FLUKA Memorandum of Understanding

Companies which purchased a FLUKA Commercial License Agreement

Includes access to the

source code

development version

- **Licenses are free** except for commercial use
- They are granted for **non-military use** only

User support

FLUKA User Forum

<https://cern.ch/fluka-forum>

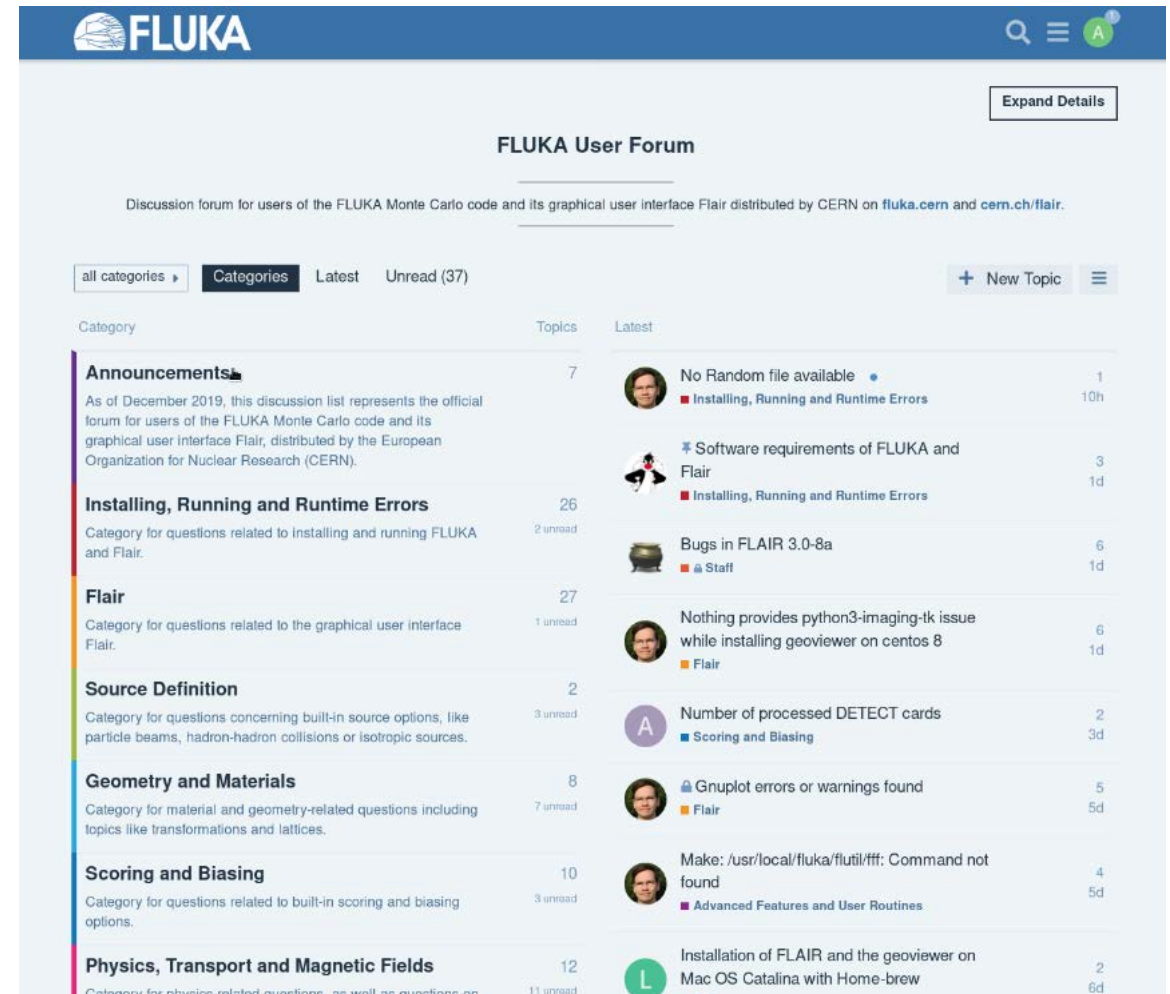
Note: an independent one time registration is required to be able to participate

FLUKA Training









Three Beginner Online Training courses were held 2020 and one in 2021.

One Beginner Training course was held at the University of Brussels in 2022

Advanced course planned for spring 2023 in the US.



The screenshot shows the FLUKA User Forum interface. At the top, there is a blue header with the FLUKA logo and navigation icons. Below the header, the forum title "FLUKA User Forum" is displayed, along with a description: "Discussion forum for users of the FLUKA Monte Carlo code and its graphical user interface Flair distributed by CERN on fluka.cern and cern.ch/flair." There are buttons for "Expand Details", "all categories", "Categories", "Latest", "Unread (37)", and "+ New Topic". The main content area is divided into two columns: "Category" and "Latest".

Category	Topics	Latest
Announcements As of December 2019, this discussion list represents the official forum for users of the FLUKA Monte Carlo code and its graphical user interface Flair, distributed by the European Organization for Nuclear Research (CERN).	7	
Installing, Running and Runtime Errors Category for questions related to installing and running FLUKA and Flair.	26 2 unread	 No Random file available ■ Installing, Running and Runtime Errors 10h
Flair Category for questions related to the graphical user interface Flair.	27 1 unread	 Software requirements of FLUKA and Flair ■ Installing, Running and Runtime Errors 3d
Source Definition Category for questions concerning built-in source options, like particle beams, hadron-hadron collisions or isotropic sources.	2 3 unread	 Bugs in FLAIR 3.0-8a ■ Staff 1d
Geometry and Materials Category for material and geometry-related questions including topics like transformations and lattices.	8 7 unread	 Nothing provides python3-imaging-tk issue while installing geoviewer on centos 8 ■ Flair 6d
Scoring and Biasing Category for questions related to built-in scoring and biasing options.	10 3 unread	 Number of processed DETECT cards ■ Scoring and Biasing 3d
Physics, Transport and Magnetic Fields Category for physics-related questions, as well as questions on	12 11 unread	 Gnuplot errors or warnings found ■ Flair 5d
		 Make: /usr/local/fluka/flutil/fff: Command not found ■ Advanced Features and User Routines 5d
		 Installation of FLAIR and the geoviewer on Mac OS Catalina with Home-brew ■ 2d

FLUKA capabilities

- hadron-hadron and hadron-nucleus interactions
- nucleus-nucleus interactions (including deuterons!)
- photon interactions (>100 eV)
- electron interactions (> 1 keV; including electronuclear)
- muon interactions (including photonuclear)
- neutrino interactions
- low energy (<20 MeV) neutron interactions and transport
- particle decay
- ionization and multiple (single) scattering (including all ions down to 250 eV/u)
- coherent effects in crystals (channelling)
- magnetic field, and electric field in vacuum
- combinatorial geometry and lattice capabilities
- voxel geometry and DICOM importing
- analogue or biased treatment
- on-line buildup and evolution of induced radioactivity and dose
- built-in scoring of several quantities (including DPA and dose equivalent)

In support of a
wide range of applications

- ✓ Accelerator design
- ✓ Particle physics
- ✓ Cosmic ray physics
- ✓ Neutrino physics
- ✓ Medical applications

- ✓ Radiation protection (shielding design, activation)
- ✓ Dosimetry
- ✓ Radiation damage
- ✓ Radiation to electronics effects
- ✓ ADS systems, waste transmutation
- ✓ Neutronics

Basic Input

Some history

- FLUKA's story begun a long time ago (1960s)...
 - ...no graphical interfaces, input and output via text file
- Inputfile can be very long > 50k lines
- Inputfile based on "cards": `.inp` file
- Each card has 1 name, 6 values (called WHATs), 1 string (called SDUM)
- Two examples of cards (the actual meaning is not relevant here):



BEAMPOS	4750.5	130.0	4866.5				NEGATIVE
BEAM	-0.4	0.2	5.0	1.E-4	1.E-4		ELECTRON
↑	↑	↑	↑	↑	↑	↑	↑
Card name	WHAT(1)	WHAT(2)	WHAT(3)	WHAT(4)	WHAT(5)	WHAT(6)	SDUM

FLAIR

- In 2006, Flair was born!



FLUKA advanced graphical user interface

Input file creation

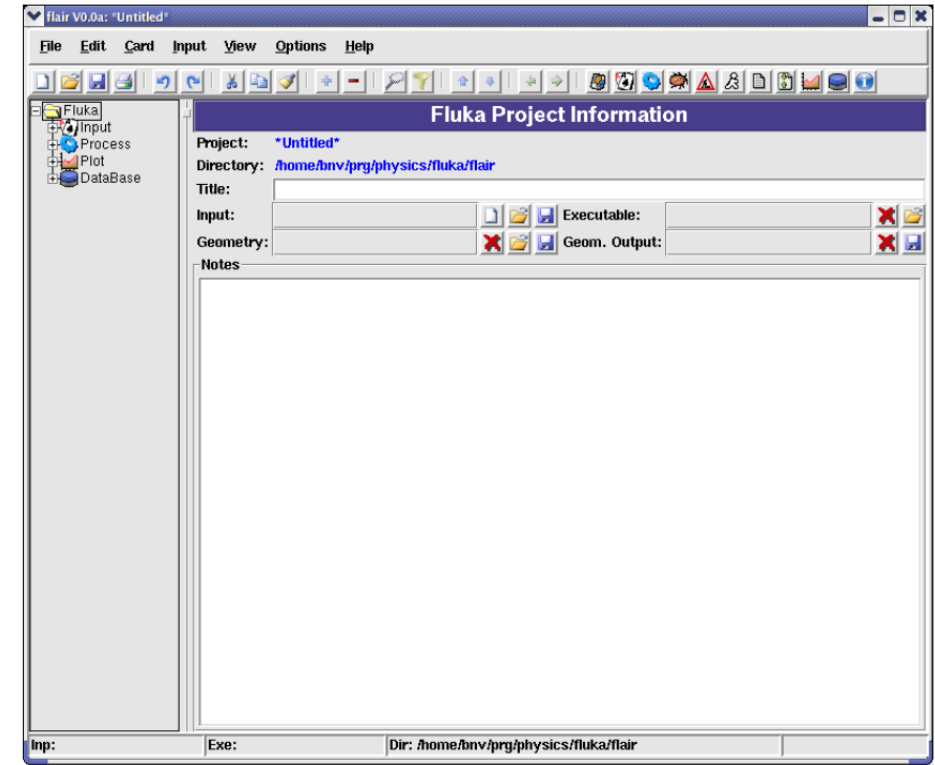
Geometry visualization and construction

Simulation execution

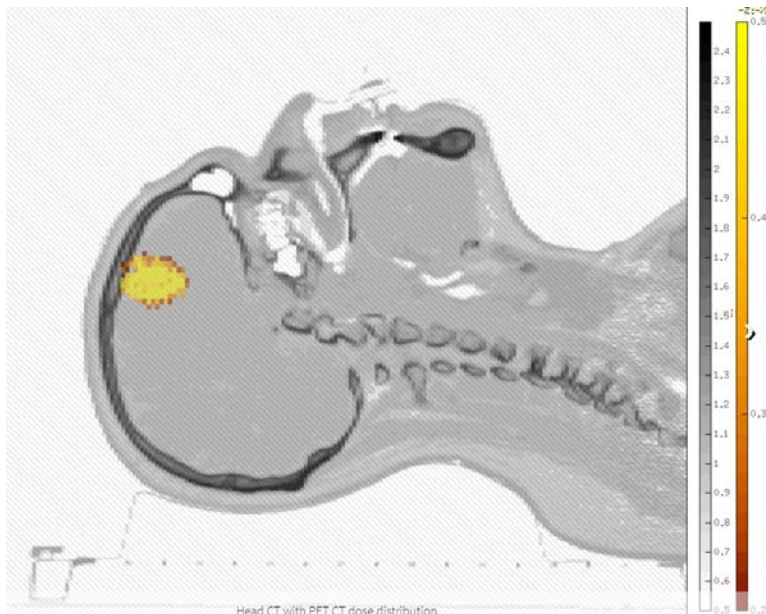
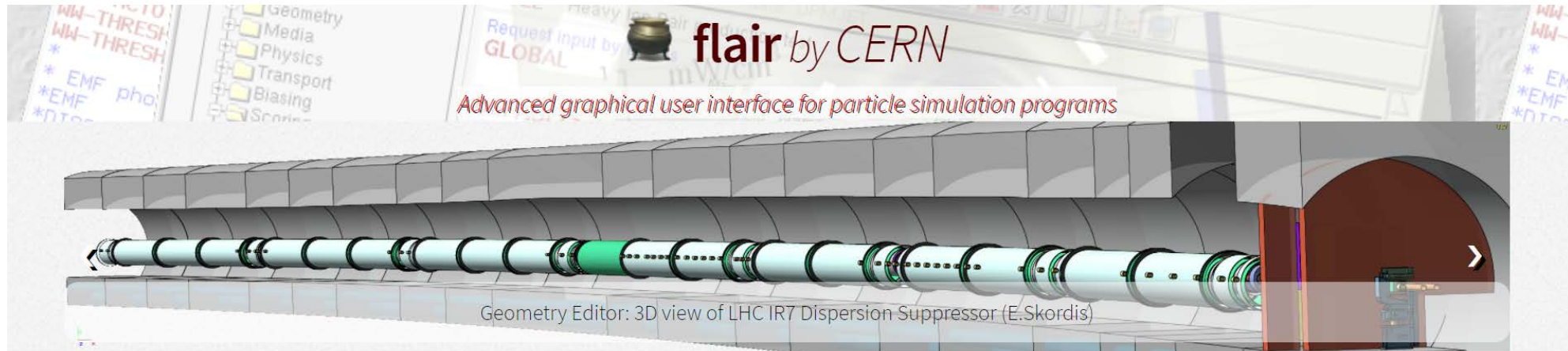
Results visualization

- Flair acts as an intermediate layer between the user and the input file
- It allows a user friendly editing of the FLUKA input
- Based on a `.flair` file and generates the `.inp` file that is run by FLUKA

Flair ≠ FLUKA



<https://flair.cern>



Authors

authors: Vasilis Vlachoudis (*lead author*)

Christian Theis

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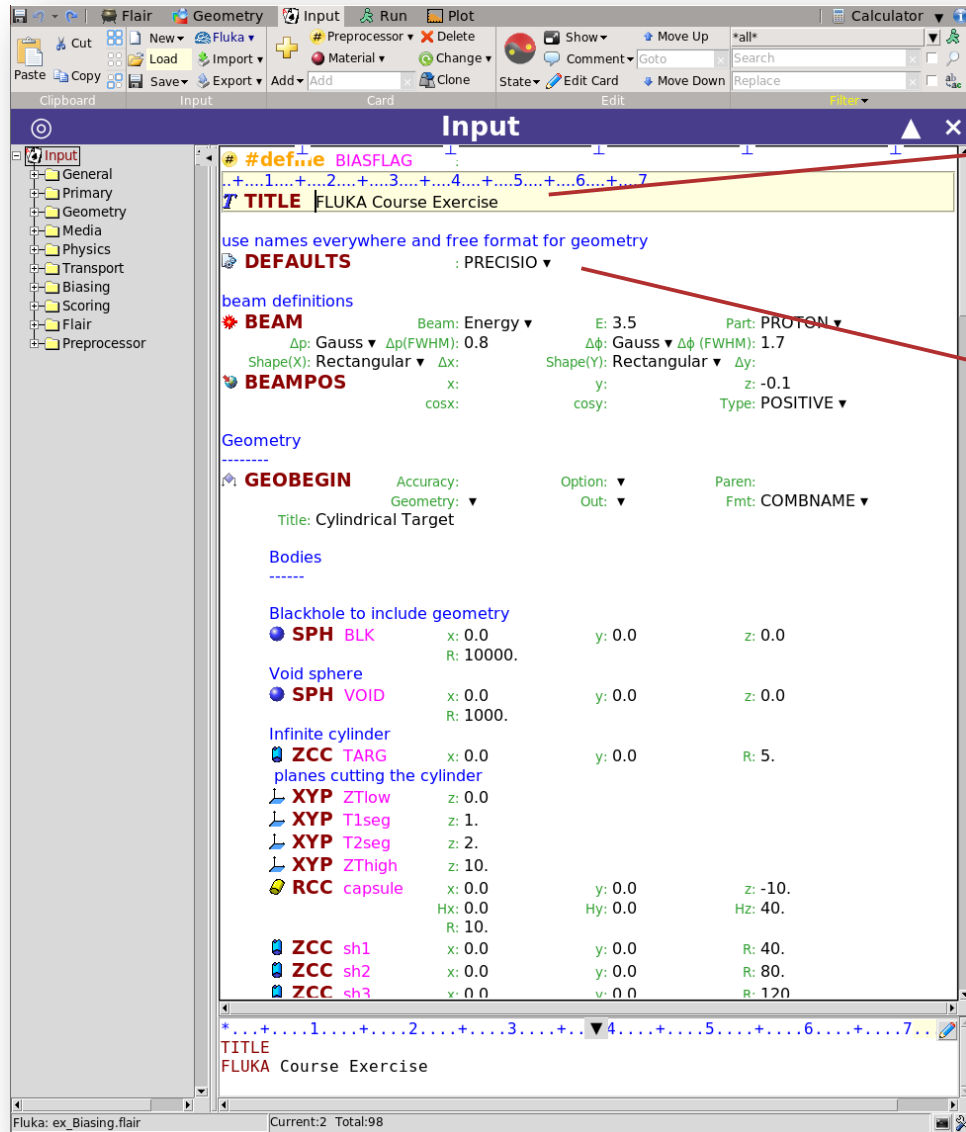
3.1-15.1

Fri 22-Oct-2021

Features

- modern and intuitive design
- Input editor for error free inputs
- Interactive geometry editor, photorealistic ray tracer and debugger
- run and monitor the simulation
- back-end for post-processing of results
- I/O of other simulation formats (MCNPX, GDML,...)
- Medical file importing, DICOM, RT-PLAN, DOSE,...
- extended material library

The input at a glance



```
#define BIASFLAG
*.....1.....2.....3.....4.....5.....6.....7
TITLE FLUKA Course Exercise

use names everywhere and free format for geometry
DEFAULTS : PRECISIO

beam definitions
BEAM      Beam: Energy  E: 3.5      Part: PROTON
          Δp: Gauss  Δp(FWHM): 0.8    Δφ: Gauss  Δφ (FWHM): 1.7
          Shape(X): Rectangular  Δx:      Shape(Y): Rectangular  Δy:
BEAMPOS   x:          y:          z: -0.1
          cosx:       cosy:       Type: POSITIVE

Geometry
GEOBEGIN  Accuracy:      Option:  Paren:
          Geometry:  Out:      Fmt: COMBNAME

Bodies
Blackhole to include geometry
SPH BLK   x: 0.0      y: 0.0      z: 0.0
          R: 10000.
Void sphere
SPH VOID  x: 0.0      y: 0.0      z: 0.0
          R: 1000.
Infinite cylinder
ZCC TARG  x: 0.0      y: 0.0      R: 5.
planes cutting the cylinder
XYP ZTlow z: 0.0
XYP T1seg z: 1.
XYP T2seg z: 2.
XYP ZThigh z: 10.
RCC capsule x: 0.0      y: 0.0      z: -10.
          Hx: 0.0      Hy: 0.0      Hz: 40.
          R: 10.
ZCC sh1   x: 0.0      y: 0.0      R: 40.
ZCC sh2   x: 0.0      y: 0.0      R: 80.
ZCC ch3   x: 0.0      y: 0.0      R: 120.

*.....1.....2.....3.....4.....5.....6.....7
TITLE
FLUKA Course Exercise
```

TITLE

Assign a title to the simulations

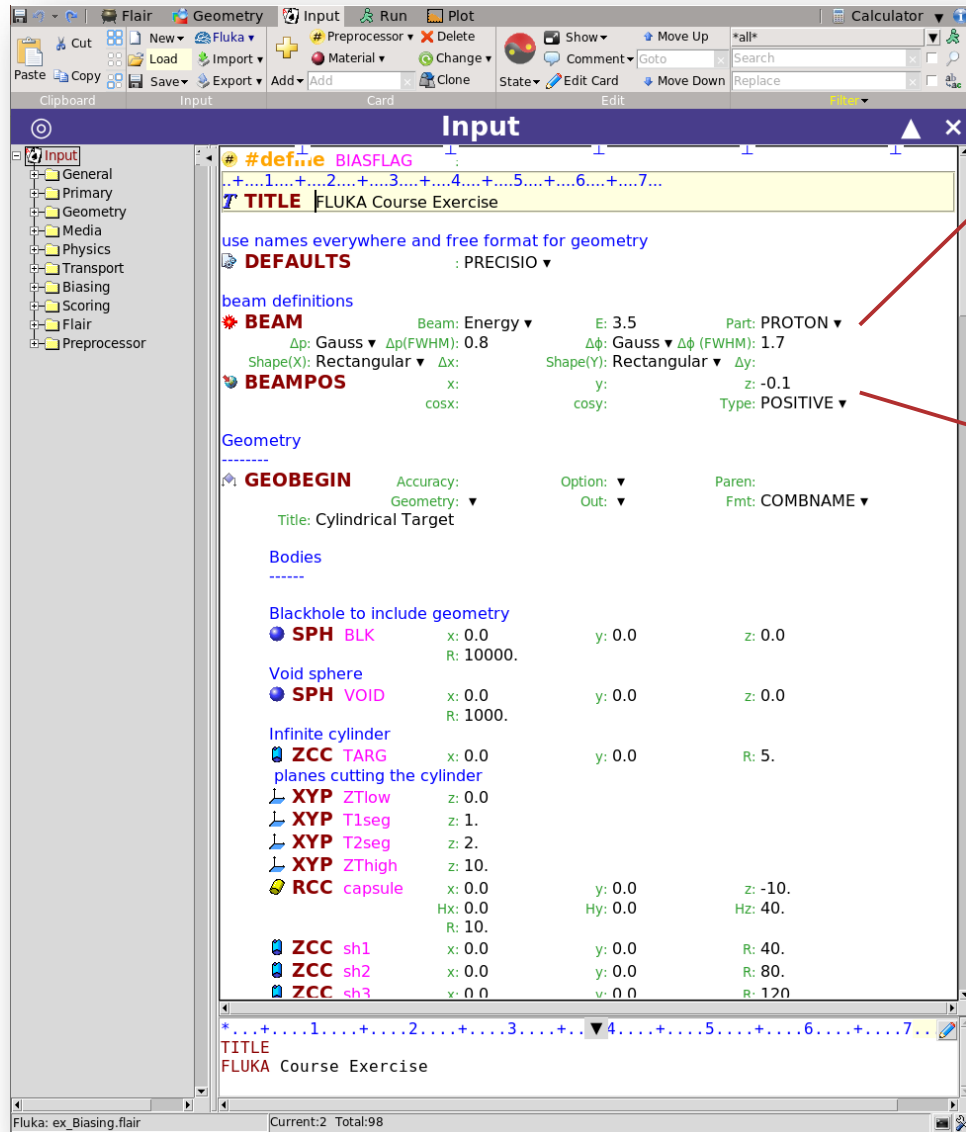
- The title is printed in the output files
- Not a mandatory card

DEFAULTS

Select one of the physics defaults settings

- To be defined at the very beginning of input, only preceded by the **TITLE** and **GLOBAL** cards
- Any of the physics defaults can be overridden later in the input with specific cards
- Given the progress over time in computer power, it is a reasonable approach to always select the most detailed physics defaults (**PRECISIO**) and override specific settings later depending on the needs of the problem

The input at a glance



```
#define BIASFLAG
+1...+2...+3...+4...+5...+6...+7...
TITLE FLUKA Course Exercise

use names everywhere and free format for geometry
DEFAULTS : PRECISIO

beam definitions
*BEAM      Beam: Energy  E: 3.5      Part: PROTON
           Δp: Gauss  Δp(FWHM): 0.8   Δφ: Gauss  Δφ(FWHM): 1.7
           Shape(X): Rectangular Δx:      Shape(Y): Rectangular Δy:
*BEAMPOS   x:          y:          z: -0.1
           cosx:       cosy:       Type: POSITIVE

Geometry
-----
*GEOBEGIN  Accuracy:      Option:      Paren:
           Geometry:     Out:          Fmt: COMBNAME
           Title: Cylindrical Target

Bodies
-----
Blackhole to include geometry
*SPH BLK   x: 0.0      y: 0.0      z: 0.0
           R: 10000.

Void sphere
*SPH VOID  x: 0.0      y: 0.0      z: 0.0
           R: 1000.

Infinite cylinder
*ZCC TARG  x: 0.0      y: 0.0      R: 5.
planes cutting the cylinder
*YYP ZTlow z: 0.0
*YYP T1seg z: 1.
*YYP T2seg z: 2.
*YYP ZThigh z: 10.
*RCC capsule x: 0.0      y: 0.0      z: -10.
           Hx: 0.0      Hy: 0.0      Hz: 40.
           R: 10.
*ZCC sh1   x: 0.0      y: 0.0      R: 40.
*ZCC sh2   x: 0.0      y: 0.0      R: 80.
*ZCC ch3   x: 0.0      y: 0.0      R: 120

+1...+2...+3...+4...+5...+6...+7...
TITLE
FLUKA Course Exercise
```

BEAM

Specify beam particle properties

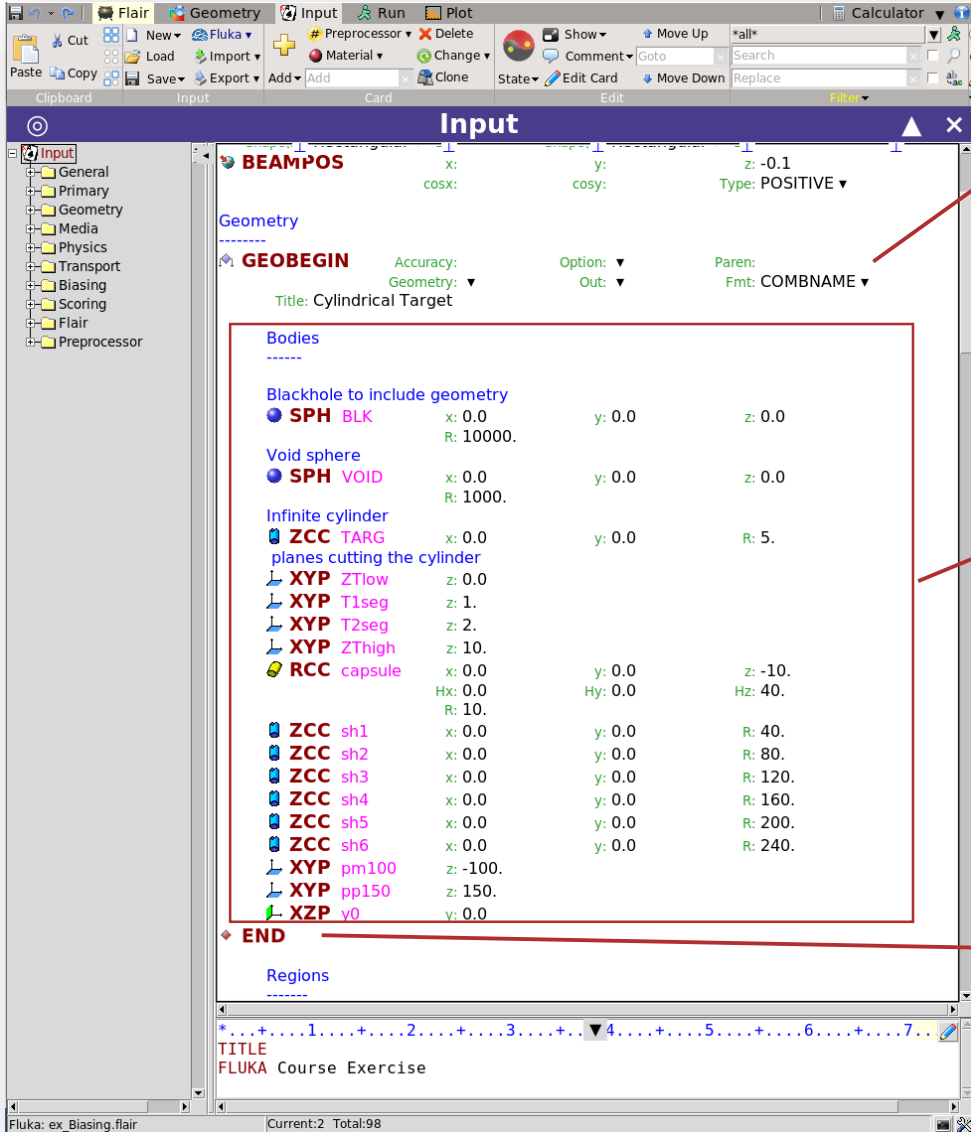
- Particle type
- Momentum or kinetic energy
- Momentum distribution
- Angular distribution
- Shape in the X-Y plane

BEAMPOS

Define beam spot and direction

- Beam spot is defined with its x, y and z coordinates [cm]
Default: Origin of the coordinate system
- 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, its sign to be provided via Type=POSITIVE/NEGATIVE

The input at a glance



GEOBEGIN

Start of input section that defines geometry

Body definitions

A body definition consists of:

- **3-letter code** indicating the **body type**
- **unique body name** (alphanumeric identifier, 8 character maximum, case sensitive)
- **set of geometrical quantities** defining the body, e.g. the body dimensions and the position in the coordinate system (all values in cm!)

END

Ends the body definition

The input at a glance

```
END
Regions
-----
Blackhole
● REGION BLKHOLE           Neigh: 5
  expr: +BLK -VOID

Target segment 1
● REGION TARGS1           Neigh: 5
  expr: +TARG -ZTlow +T1seg
Target segment 2
● REGION TARGS2           Neigh: 5
  expr: +TARG -T1seg +T2seg
Target segment 3
● REGION TARGS3           Neigh: 5
  expr: +TARG -T2seg +ZThigh
● REGION outside         Neigh: 5
  expr: +VOID -sh6 | +VOID +pm100 | +VOID -pp150

Air around target
● REGION INCO2           Neigh: 5
  expr: | +capsule -TARG
        | +capsule +ZTlow
        | +capsule -ZThigh

Shield around capsule
● REGION shcapsp1        Neigh: 5
  expr: +sh1-capsule-pm100 +pp150 -y0

Shield around capsule
● REGION shcaps          Neigh: 5
  expr: +sh1-capsule-pm100 +pp150 +y0
● REGION shield6         Neigh: 5
  expr: +y0+sh6-sh5 -pm100 +pp150
● REGION shield5         Neigh: 5
  expr: +y0+sh5-sh4 -pm100 +pp150
● REGION shield4         Neigh: 5
  expr: +y0+sh4-sh3 -pm100 +pp150
● REGION shield3         Neigh: 5
  expr: +y0+sh3-sh2 -pm100 +pp150

END
GEOEND

*...+...1...+...2...+...3...+...4...+...5...+...6...+...7...
XZP y0      0.0
```

Region definitions

A region definition consists of:

- **Unique region name** (alphanumeric identifier, 8 character maximum, case sensitive, must start with an alphabetical character)
- Estimate of the **number of neighboring zones**
- A single **Boolean zone expression** or a series of **Boolean zone expressions** combined via the **union operator**

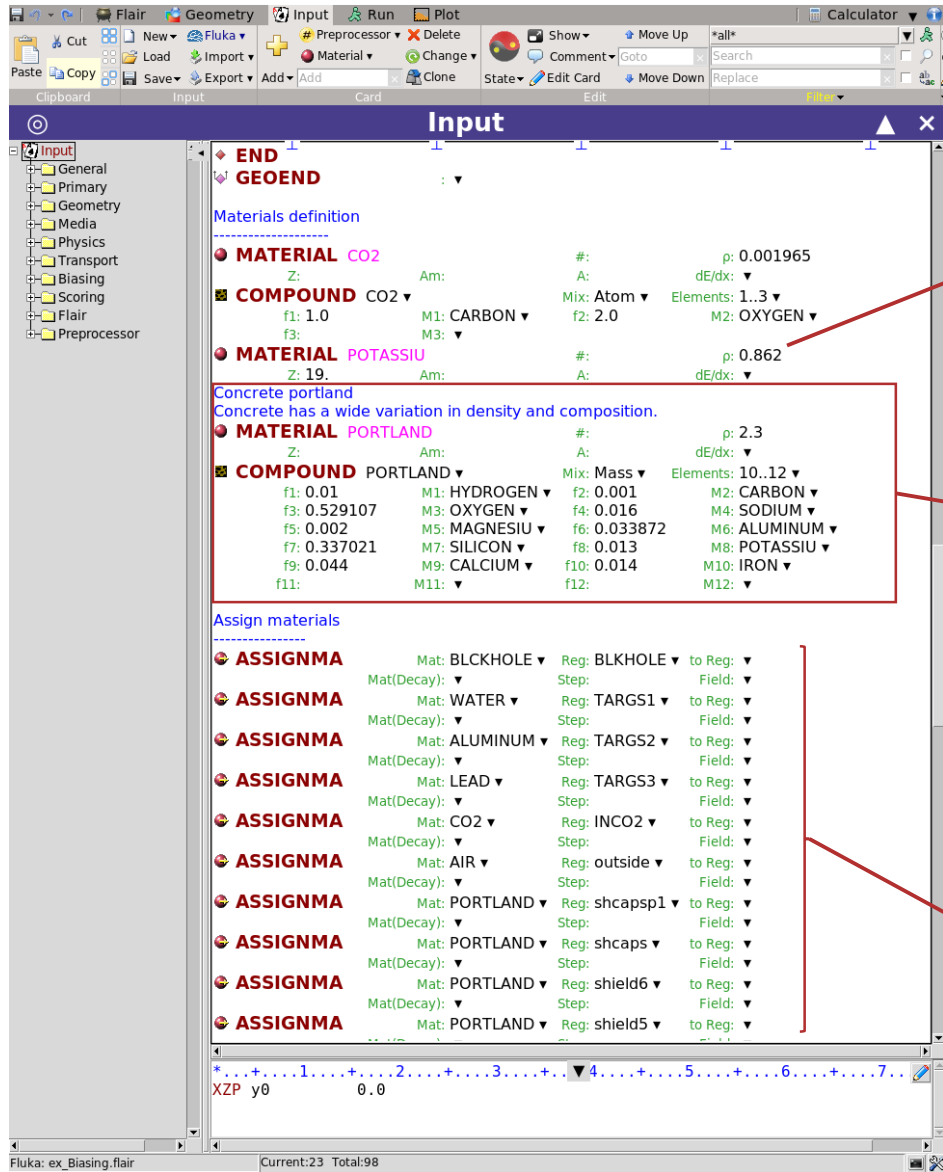
END

Ends the region definition

GEOEND

End of input section that defines geometry

The input at a glance



MATERIAL

Definition of a non-predefined single element

- Each material must have a **unique name**
- Definition of charge, mass number and density in g/cm^3

MATERIAL / COMPOUND

Definition of composite materials

- Each composite material must have a **unique name**
- Definition of components and their abundances in terms of either atom content, mass fraction or volume fraction
- Definition of density in g/cm^3

ASSIGNMA

Assignment of material to a region

Pre-defined materials

- A number of common materials (23 elements and 12 compounds) are pre-defined in FLUKA and can be assigned to a region without the corresponding material declaration.
- 2 special materials are also included:
 - **VACUUM**: obvious definition. Static electrical fields can be defined only in vacuum.
 - **BLACKHOLE**: Ideal absorber, must be assigned to the “black body” region surrounding your geometry but can also be used elsewhere in the geometry, e.g. for perfect shielding/collimation, to reduce CPU-time by killing tracking in certain regions etc.
- In addition, Flair comes with an extensive library of materials (elemental and compounds) that can be imported into the input

5.2.1. List of pre-defined single-element FLUKA materials

Fluka name	Fluka number	Common name	A	Z	Density [g/cm ³]
BLACKHOLE	1	Blackhole or External Vacuum	0	0	0
VACUUM	2	Vacuum or Internal Vacuum	0	0	0
HYDROGEN	3	Hydrogen	1	1	0.00012051
HELIUM	4	Helium	2	2	0.00017861
BERYLLIU	5	Beryllium	4	4	1.8184
CARBON	6	Carbon	12	6	2.267
NITROGEN	7	Nitrogen	14	7	1.2017
OXYGEN	8	Oxygen	16	8	1.429
MAGNESIU	9	Magnesium	24	12	1.738
ALUMINUM	10	Aluminium	27	13	2.70
IRON	11	Iron	56	26	7.874
COPPER	12	Copper	64	29	8.96
SILVER	13	Silver	108	47	10.49
SILICON	14	Silicon	28	14	2.329
GOLD	15	Gold	197	79	19.30
MERCURY	16	Mercury	201	80	13.55
LEAD	17	Lead	208	82	11.35
TANTALUM	18	Tantalum	182	73	16.69
SODIUM	19	Sodium	23	11	0.971
ARGON	20	Argon	40	18	1.781
CALCIUM	21	Calcium	40.078	20	1.550

5.2.2. List of pre-defined ICRU compounds

Fluka name	Common name	Density [g/cm ³]
WATER	Water	1.0
POLYSTYR	Polystyrene	1.06
PLASCINT	Plastic scintillator	1.032
PMMA	Polymethyl methacrylate, Plexiglas, Lucite, Perspex	1.19
BONECOMP	Compact bone	1.85
BONECORT	Cortical bone	1.85
MUSCLESK	Skeletal muscle	1.04
MUSCLEST	Striated muscle	1.04
ADTISSUE	Adipose tissue	0.92
KAPTON	Kapton polyimide film	1.42
POLYETHY	Polyethylene	0.94
AIR	Dry air at NTP conditions	0.00120479

The screenshot shows the 'Materials' dialog box in FLUKA. It features a search bar, a 'Material List' table, and a 'Material Properties' section. The 'Material List' table includes columns for Material, Density, and Stoichiometry. The 'Material Properties' section shows the title 'Polypropylene' and a chemical structure diagram.

Material	Density	Stoichiometry
Epoxy (molded)	1.85	H-19, C-18, O-3
Polyethylene Marlex	0.93	H-4, C-2
Polypropylene	1.43	H-10, C-22, N-2, O-5
Polychloro-p-xylylene Paralene-C	1.289	H-7, C-8, Cl-1
760 Formvar PMMA	1.31	H-8, C-5, O-2
Bakelite	1.45	H-9, C-9, O-1
Epoxy (cast)	1.18	H-19, C-18, O-3
Polyvinylchloride Rigid PVC	1.68	H-3, C-2, Cl-1
Polycarbonate Lexan, Makrofol	1.2	H-14, C-16, O-3
Polypropylene	0.9	H-6, C-3

Material Properties section:
Title: Polypropylene
Notes: Stoichiometry Properties
Chemical Formula: C3H6
Names: Polyimide

The input at a glance

```
Input
# BIASING
Type: Low neutrons
Reg: shield2 to Reg:
Step:
Imp: 0.125
# BIASING
Type: Low neutrons
Reg: shield3 to Reg:
Step:
Imp: 0.0625
# BIASING
Type: Low neutrons
Reg: shield4 to Reg:
Step:
Imp: 0.03125
# BIASING
Type: Low neutrons
Reg: shield5 to Reg:
Step:
Imp: 0.015625
# BIASING
Type: Hadrons & Muons
Reg: shield6 to Reg:
Step:
Imp: 2.
# BIASING
Type: Hadrons & Muons
Reg: shcasp1 to Reg:
Step:
Imp: 4.
# BIASING
Type: Hadrons & Muons
Reg: shieldp2 to Reg:
Step:
Imp: 8.
# BIASING
Type: Hadrons & Muons
Reg: shieldp3 to Reg:
Step:
Imp: 16.
# BIASING
Type: Hadrons & Muons
Reg: shieldp4 to Reg:
Step:
Imp: 32.
# BIASING
Type: Hadrons & Muons
Reg: shieldp5 to Reg:
Step:
Imp: 64.
# BIASING
Type: Hadrons & Muons
Reg: shieldp6 to Reg:
Step:
Imp: 0.5
# BIASING
Type: Hadrons & Muons
Reg: shcaps to Reg:
Step:
Imp: 0.25
# BIASING
Type: Hadrons & Muons
Reg: shield2 to Reg:
Step:
Imp: 0.125
# BIASING
Type: Hadrons & Muons
Reg: shield3 to Reg:
Step:
Imp: 0.0625
# BIASING
Type: Hadrons & Muons
Reg: shield4 to Reg:
Step:
Imp: 0.03125
# BIASING
Type: Hadrons & Muons
Reg: shield5 to Reg:
Step:
Imp: 0.015625
#endif
USRBIN
Type: R-Phi-Z
Part: NEUTRON
Rmin: 0.0 Rmax: 240. NR: 50.
X: Y: NPhi: 120.
Zmin: -100. Zmax: 150. NZ: 50.
RANDOMIZ
Unit: 01 Seed:
No.: 5000. Core:
Time: Report: default
STOP
```

RANDOMIZ

Initialization of random number sequence (“seed”)

- Allows using different random sequences as needed when several simulations are run on several CPU in parallel
- Flair takes care of the using different “random seeds” when spawning runs

START

Definition of number of primary particles

- Starts the simulation
- Results returned as average over the cascades induced by the given number of primary particles

STOP

Stop the execution of the program

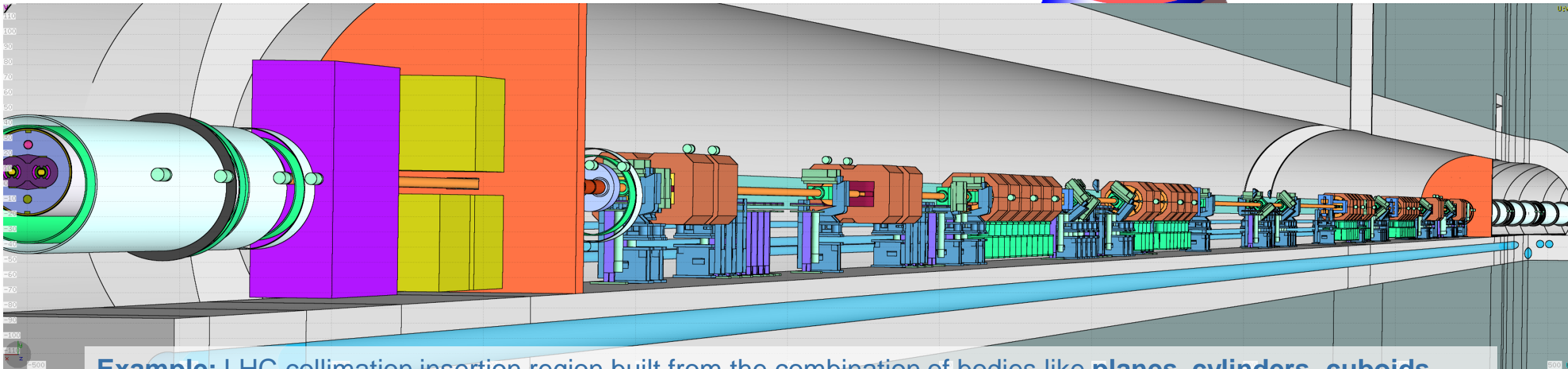
- Not really mandatory (program stops at the end of the input)
- Can become handy for debugging purposes

Combinatorial Geometry

Principle of combinatorial geometry

- Basic objects called **bodies** (such as cylinders, spheres, parallelepipeds, etc.) are combined to form more complex objects called **regions**
- This combination is done using **Boolean operations**

Resulting region



Example: LHC collimation insertion region built from the combination of bodies like **planes, cylinders, cuboids, ...**

Image from Wikipedia (CC BY-SA 3.0)

body

body

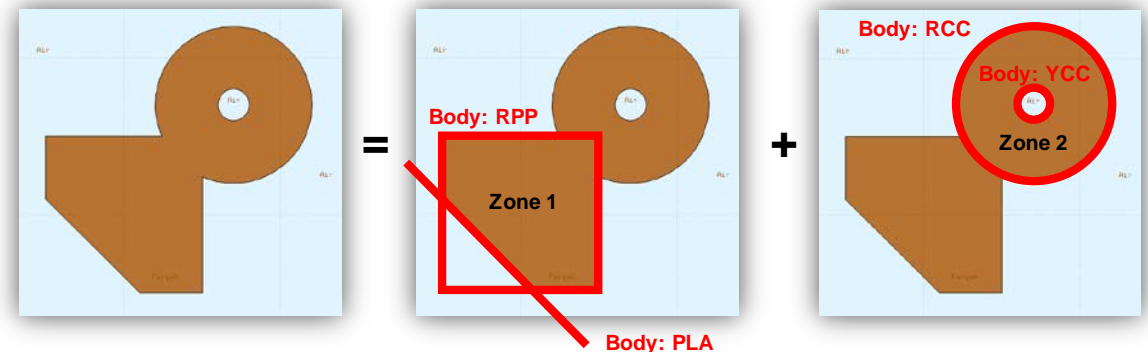
Bodies and regions

Following *bodies* are available in FLUKA:

- **Planes**
 - XYP, XZP, YZP: Infinite half space delimited by a coordinate plane
 - PLA: Generic infinite half-space, delimited by a **PLA**ne
- **Boxes**
 - RPP: **R**ectangular **P**arallele**P**iped
- **Sphere and spheroid**
 - SPH: **SPH**ere
 - ELL: **ELL**ipsoid of revolution
- **Cylinders and cones**
 - XCC, YCC, ZCC: Infinite **C**ircular **C**ylinder, parallel to coordinate axis
 - RCC: **R**ight **C**ircular **C**ylinder
 - XEC, YEC, ZEC: Infinite **E**lliptical **C**ylinder, parallel to coordinate axis
 - REC: **R**ight **E**lliptical **C**ylinder
 - TRC: **T**runcated **R**ight angle **C**one
- **Other**
 - QUA: **QUA**dric

Regions are defined by combining FLUKA bodies using Boolean operations:

- Regions are obtained by the **union of sub-regions** (called zones); in the simplest case a region consists of a single zone
- Zones are defined by **intersections and/or subtractions of bodies** (Boolean zone expressions)

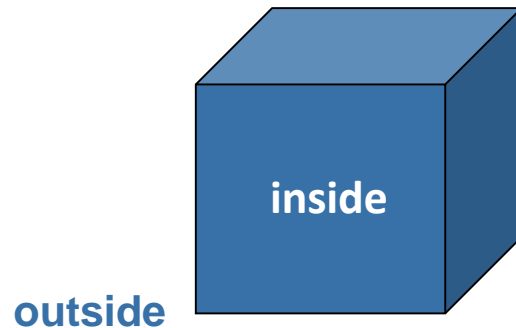


- Zones / regions must be finite
- Each point in space must belong to one (and only one) region
- Regions are of **homogeneous material composition** (i.e. only one material can be assigned to a region)

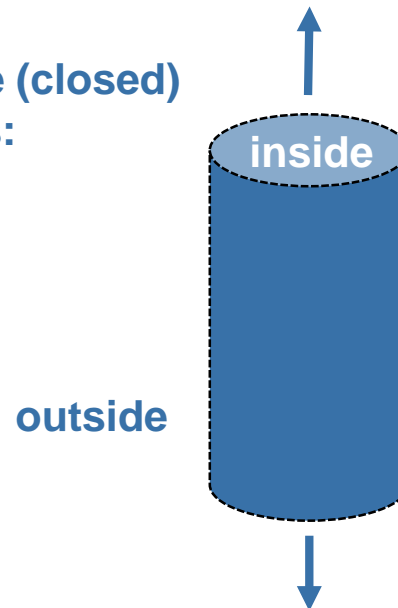
Inside and outside a body

- Each body splits the space into two domains: **inside** and **outside**
 - This concept will be later used when defining zones and regions
 - **+body** refers to the volume **inside** of the body
 - **-body** refers to the volume **outside** of the body
 - The concept of inside and outside is applied to all bodies including infinite planes

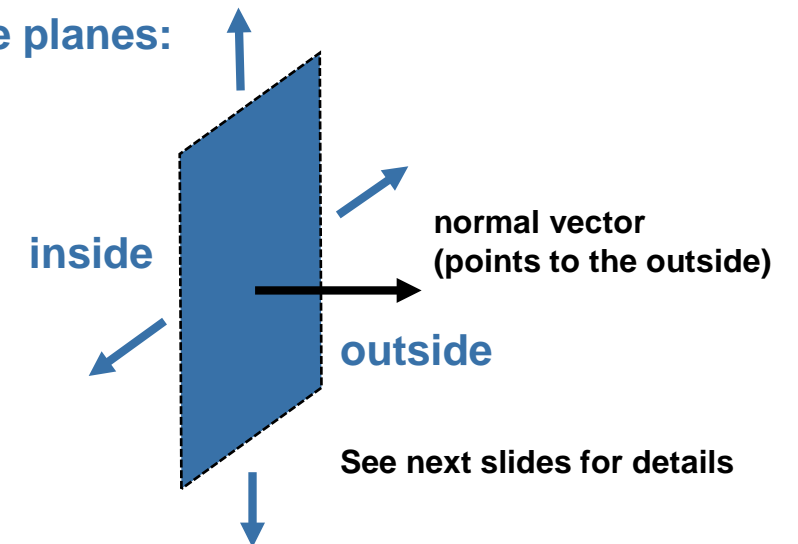
Finite bodies:



Infinite (closed) bodies:

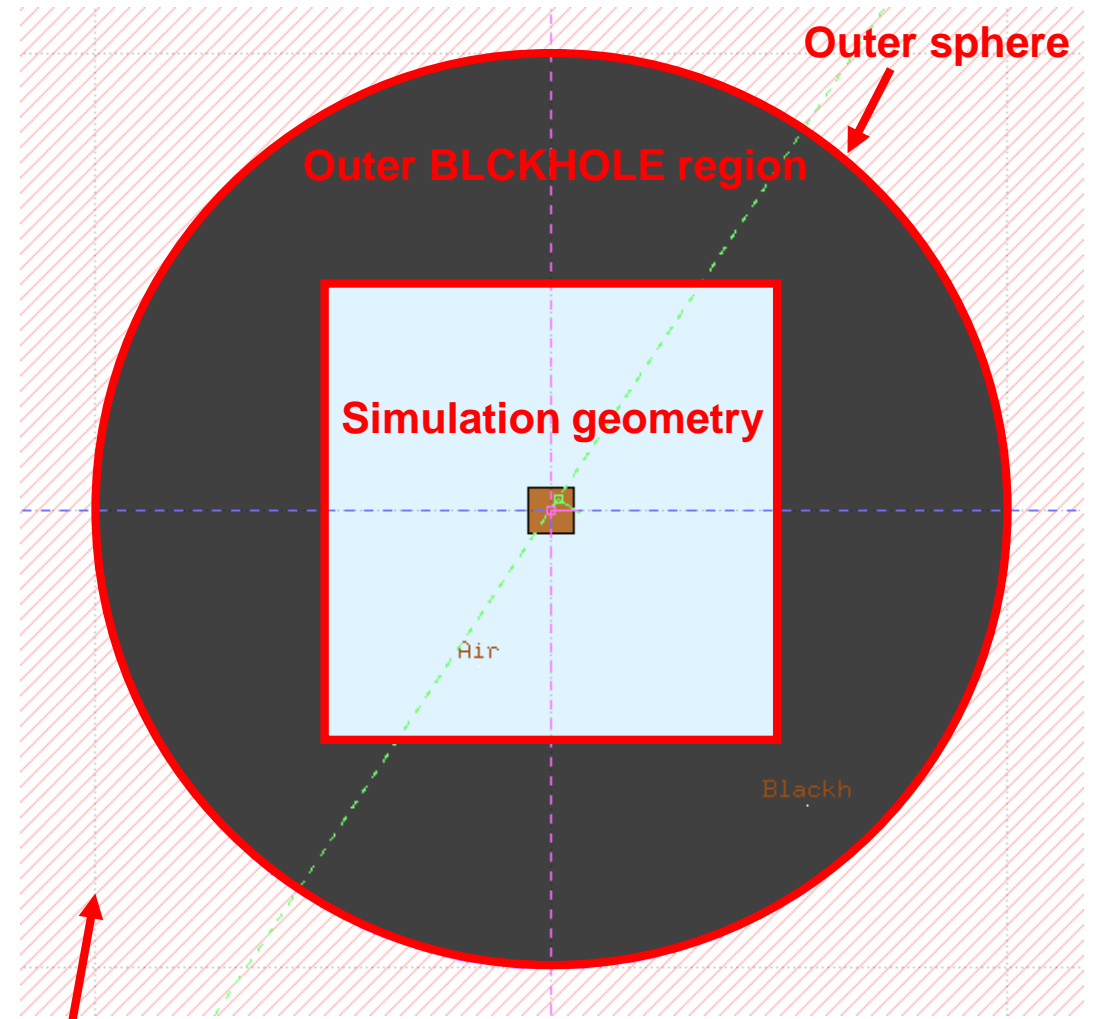


Infinite planes:



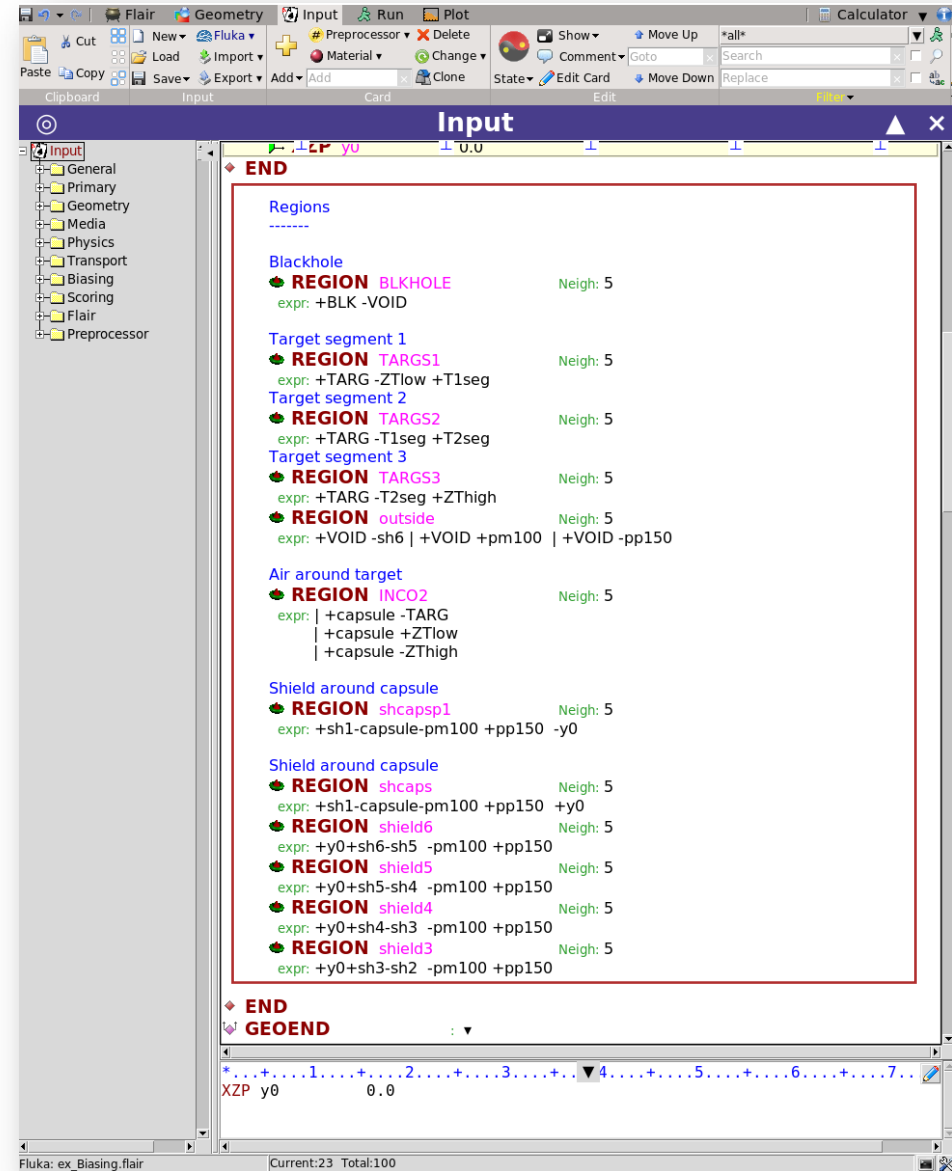
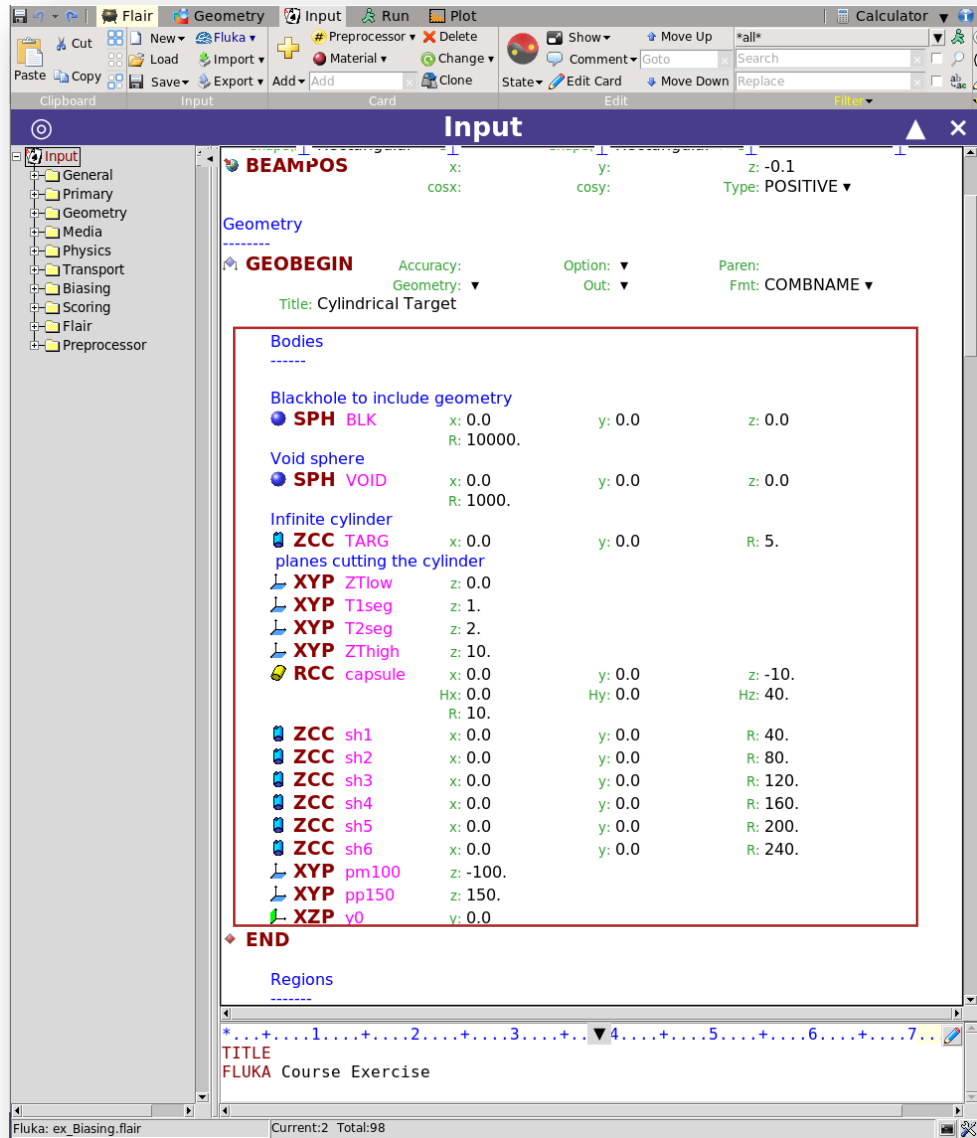
The outer “black hole” confinement

- FLUKA defines a special material called BLCKHOLE:
 - BLCKHOLE is an **all-absorbing material**
 - Particles vanish when entering a region filled with BLCKHOLE
- The entire geometry must be embedded in a region filled with BLCKHOLE
 - This avoids tracking particles to infinity
 - The outer surface of this BLCKHOLE region must be a single closed body (e.g. a sphere)



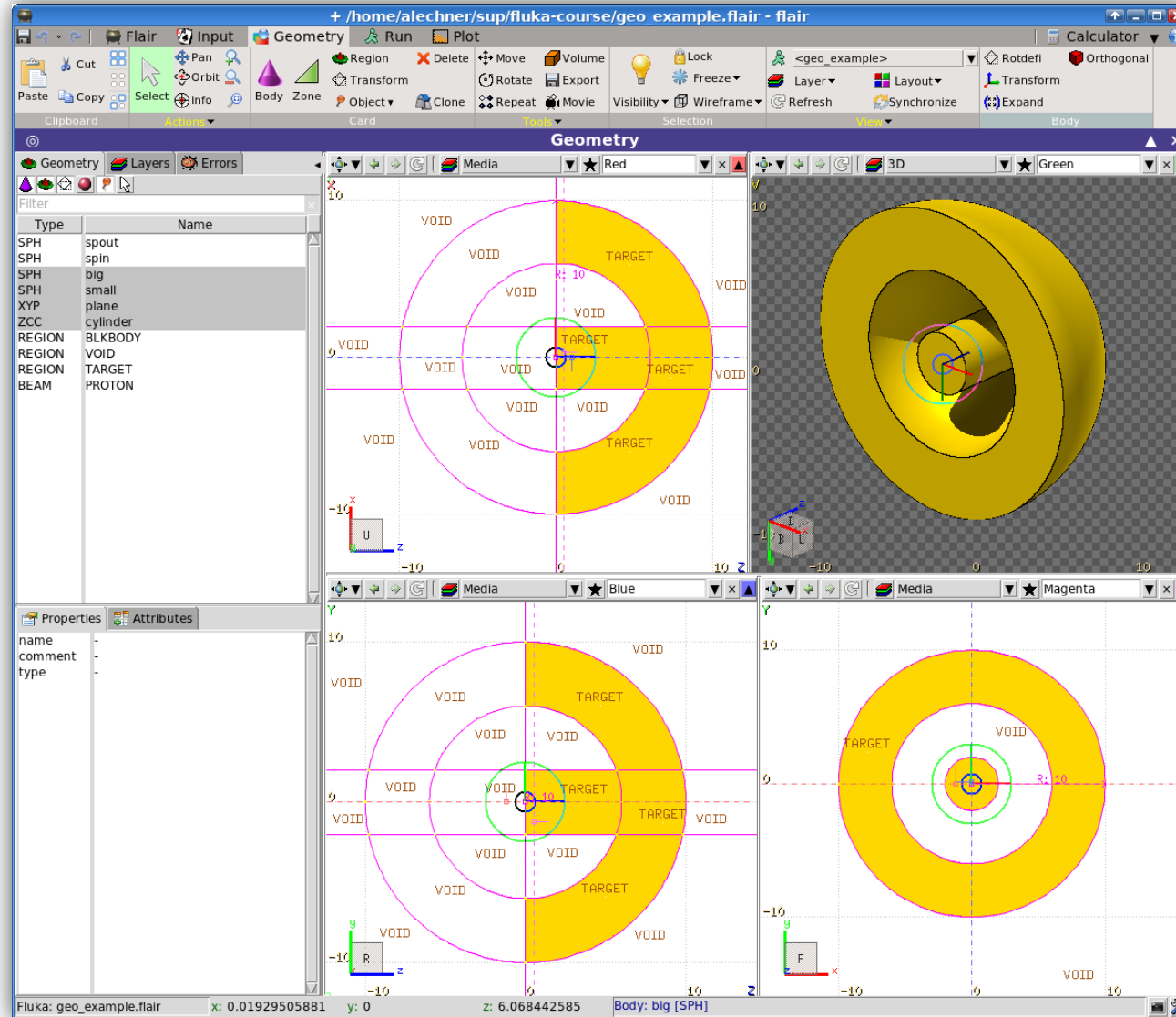
Outside of the BLCKHOLE enclosure,
the region can remain undefined!

Geometry input in Flair



Flair geometry editor

Allows creating geometries at a (few) mouse click(s)...



Scoring of physical quantities

FLUKA scoring

- It is said that Monte Carlo (MC) is a “**mathematical experiment**”; the MC equivalent of the result of a real experiment (*i.e.*, of a **measurement**) is called an **estimator**
- Just as a real measurement, an estimator is obtained by sampling from a statistical distribution and has a **statistical error** (and in general also a **systematic** one)
- There are often several different techniques to measure the same physical quantity: in the same way, **the same quantity can also be calculated using different kinds of estimators**
- FLUKA offers **numerous different estimators**, *i.e.* **scoring** for various quantities of interest can be requested directly from the input file

FLUKA scoring

What?

Energy deposition and derivatives (dose), fluence or current versus energy, angle or other kinematic variables, time, DPA, residual activity...

Where?

In regions, across boundaries, on region-independent grids

When?

At the end of each cycle or at each event

Output?

Saved in `[inputname]nnn_fort.##` files, where `nnn` is the cycle number & `##` is the logical unit number chosen by the user

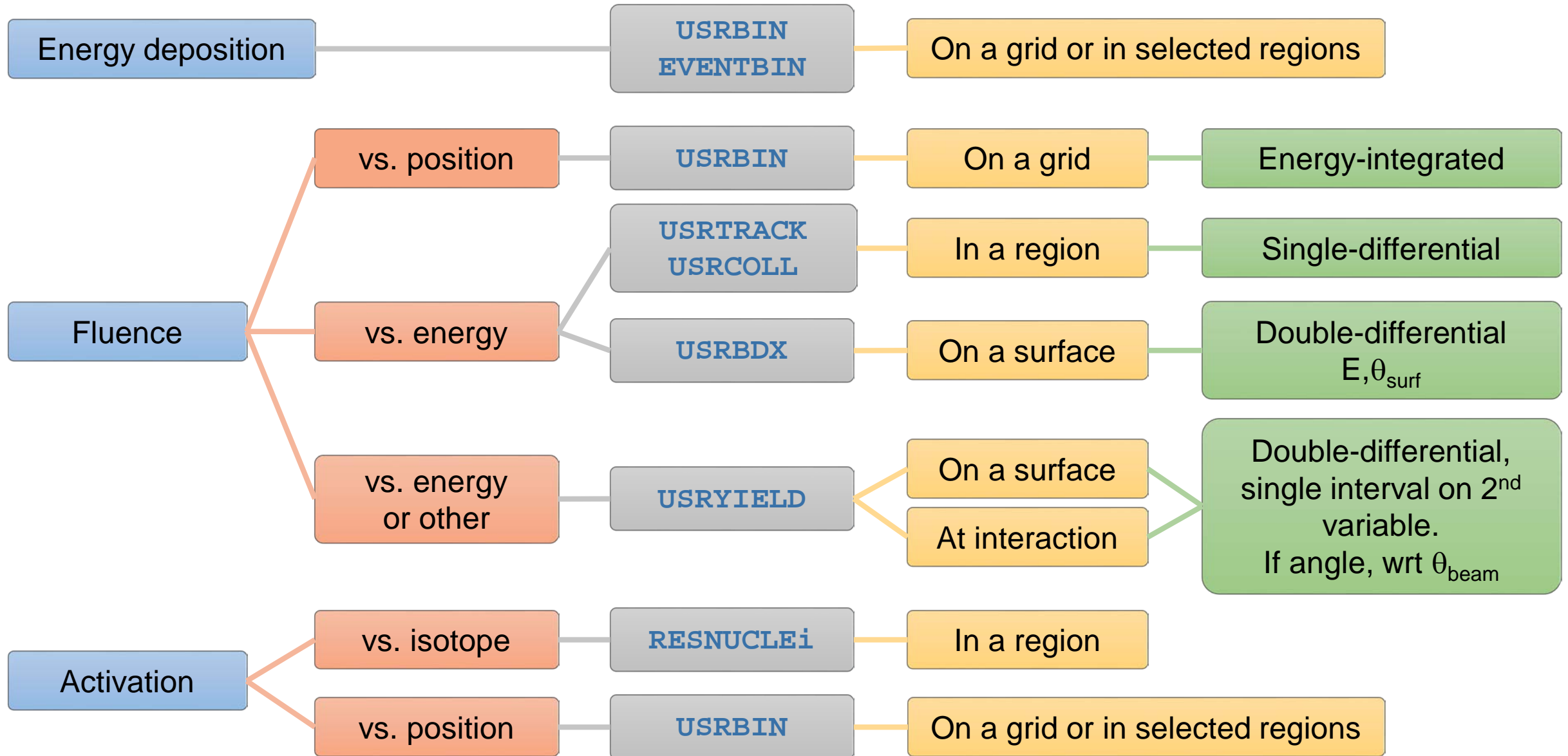
Results?

Post-processing utilities merge cycles, calculate average and rms, provide data files for plotting. Available via **Flair**

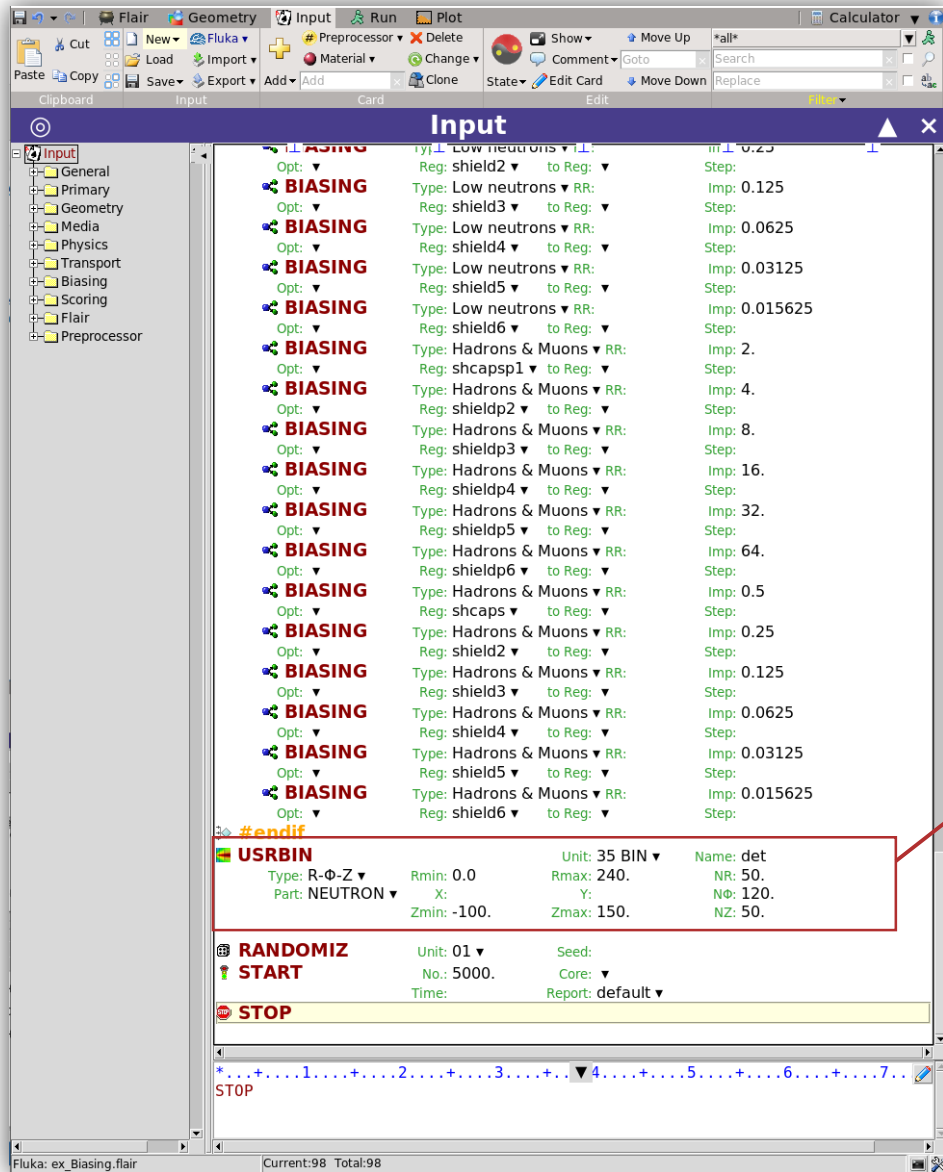
Results normalised **per primary**

User code needed for processing of custom scoring!

The FLUKA estimator zoo



A scoring example



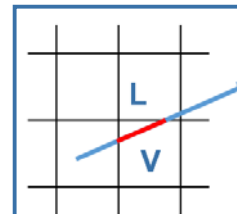
USRBIN

Scores distributions of one of several quantities in a regular spatial structure (mesh) independent from the geometry or on a region basis.

Here: neutron fluence in a cylindrical mesh around beam axis

- R: 0 - 240cm in 50 bins
- z: -100cm to 150cm in 50 bins
- Phi: 120 bins

Results in units of $1/\text{cm}^2$ per primary particle

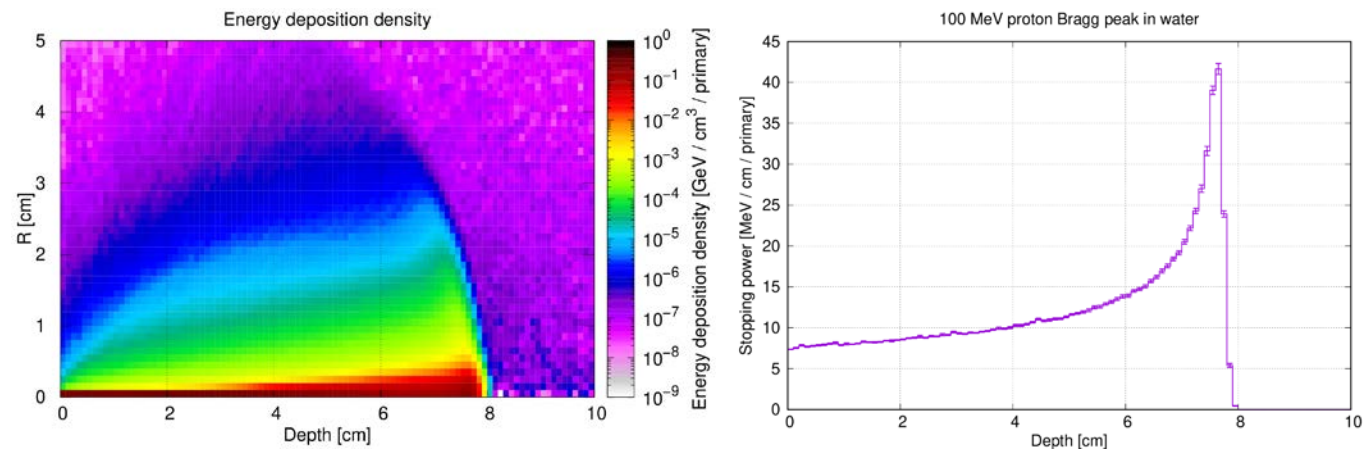
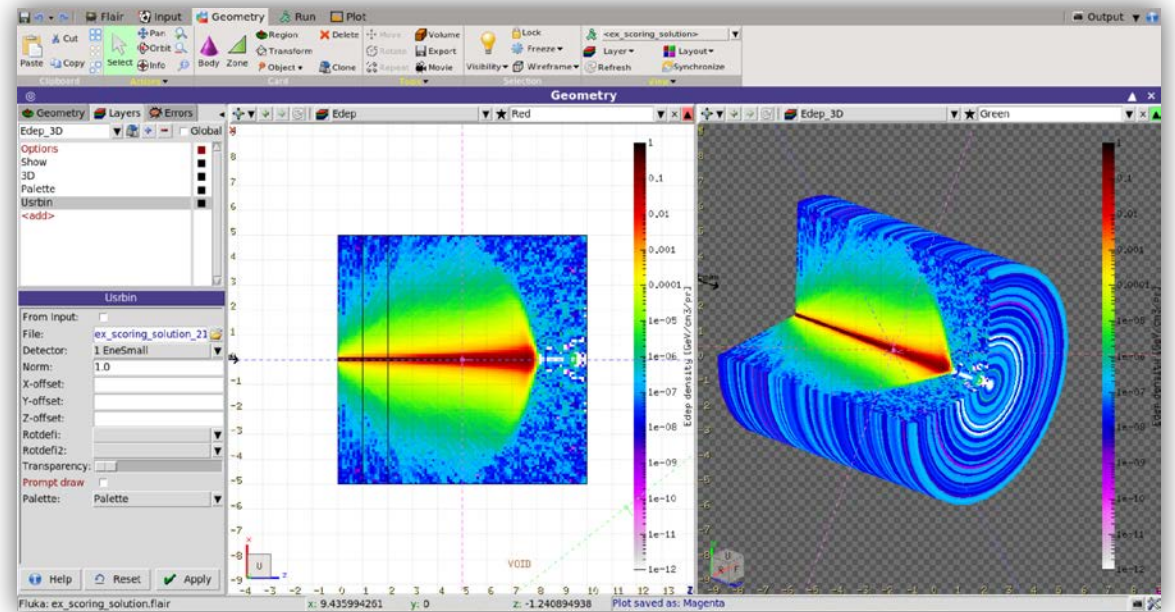
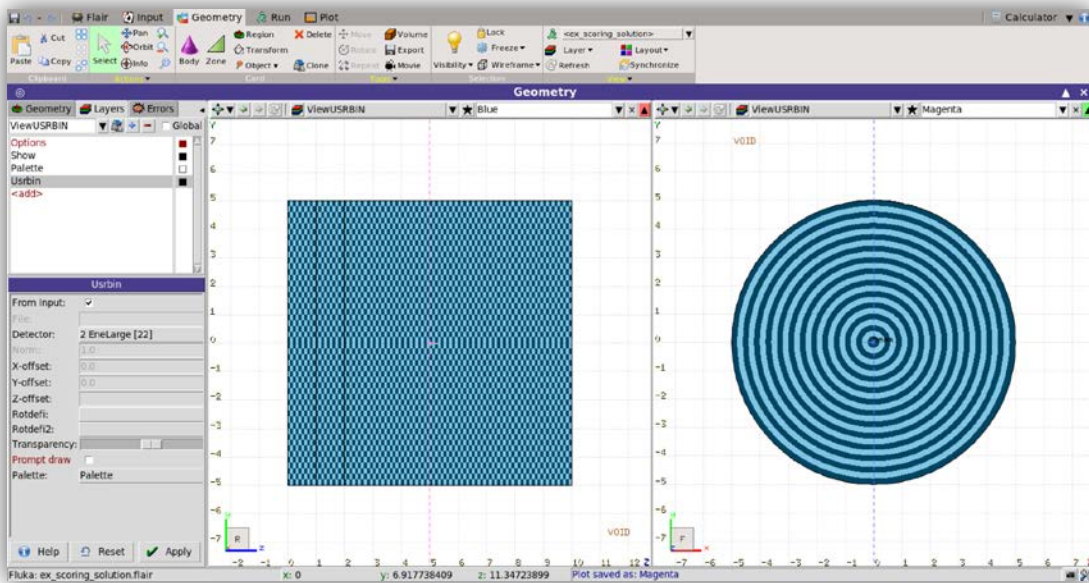


Path length L [cm] inside the bin divided by the bin volume V [cm^3] $\rightarrow \text{cm} / \text{cm}^3 = 1/\text{cm}^2$

Visualization with Flair

and the final results (examples)

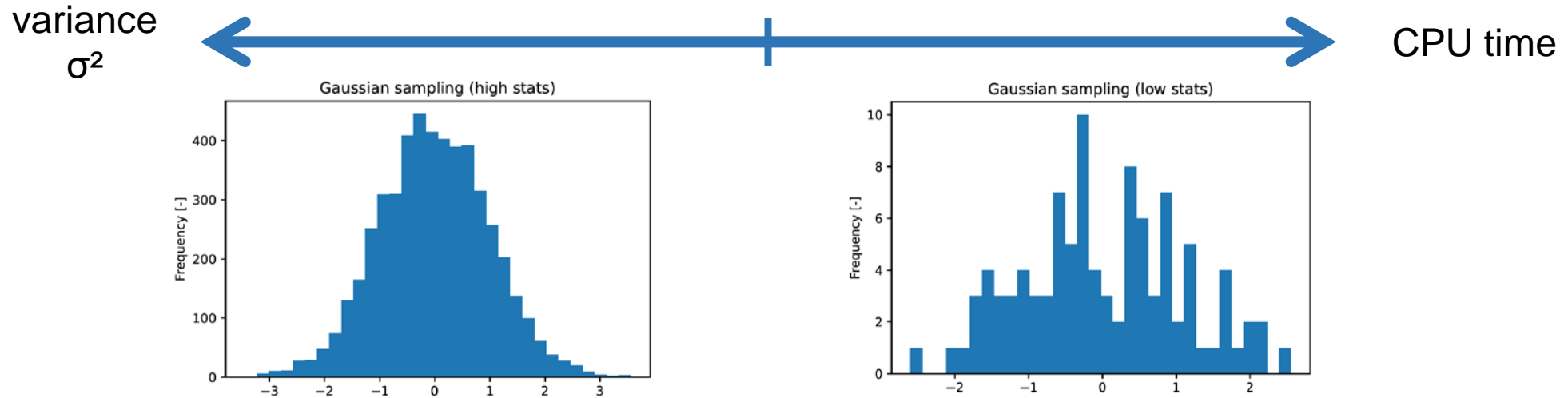
...of the scoring mesh



Biasing techniques

Introduction to biasing

- Statistical bias: tendency causing a result to differ from the underlying fact
- In the context of FLUKA
 - Deliberately altering simulation parameters to improve variance or CPU time
 - This bias is countered by changing weights of particles



- Goodness of simulations : Figure of Merit = $\frac{1}{\sigma^2 t}$
 - The larger the better

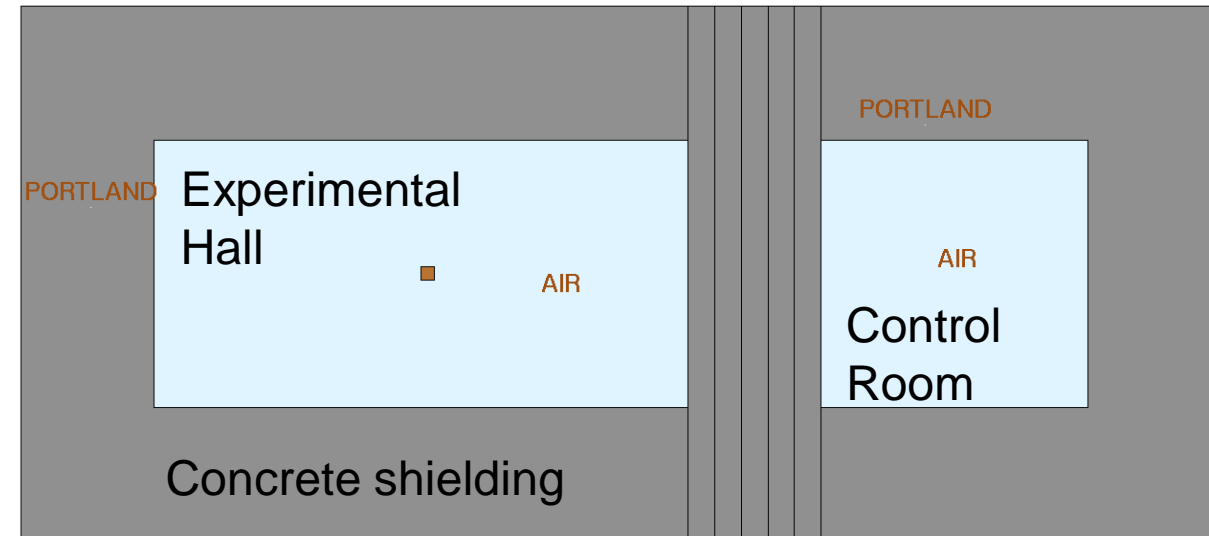
Non-biased Monte Carlo simulations

Characteristics

- Samples from
 actual phase-space distributions
- Preserves correlations
- Reproduces fluctuations

Drawbacks

- Converges slowly
- Rare events are... “rare”



Non-biased Monte Carlo simulations

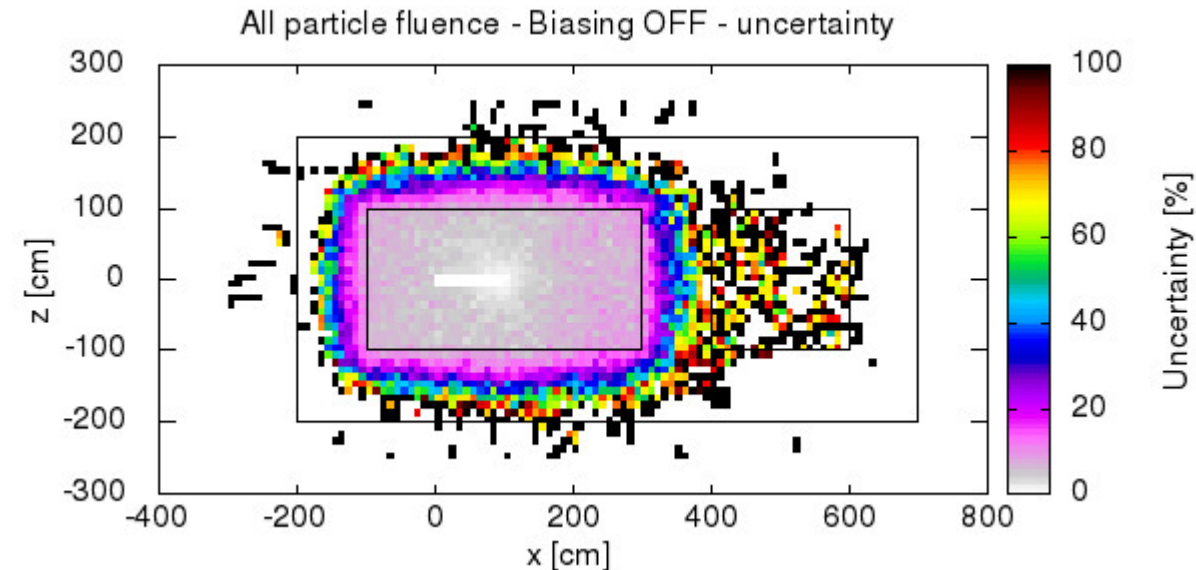
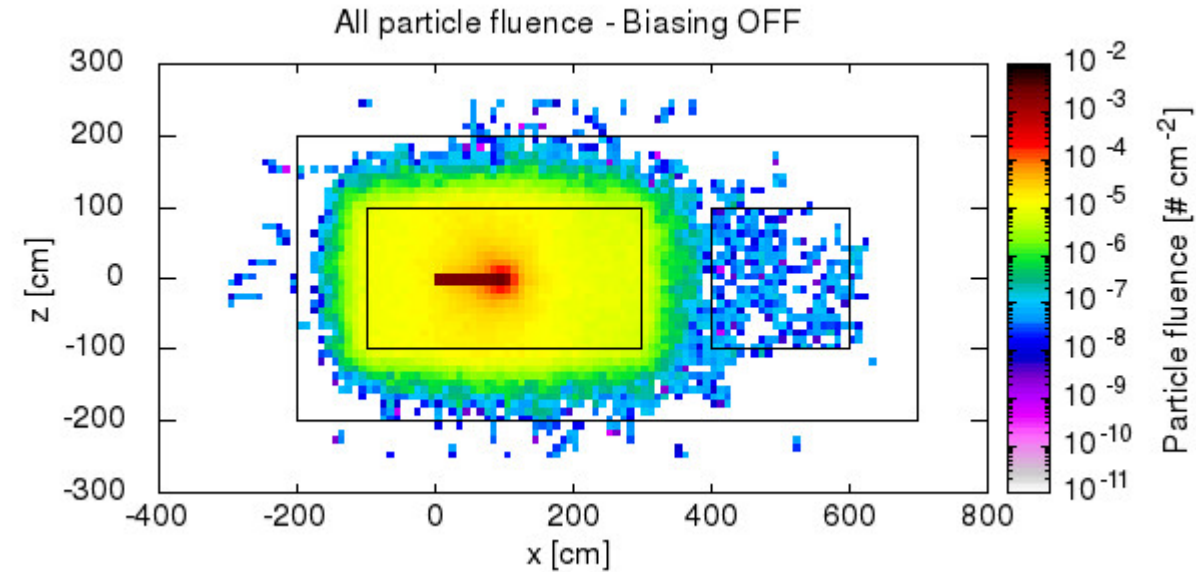
200000 primaries

Characteristics

- Samples uniformly from the phase-space distribution
- Preserves correlations
- Reproduces fluctuations

Drawbacks

- Converges slowly
- Rare events are... “rare”



Biased Monte Carlo simulations

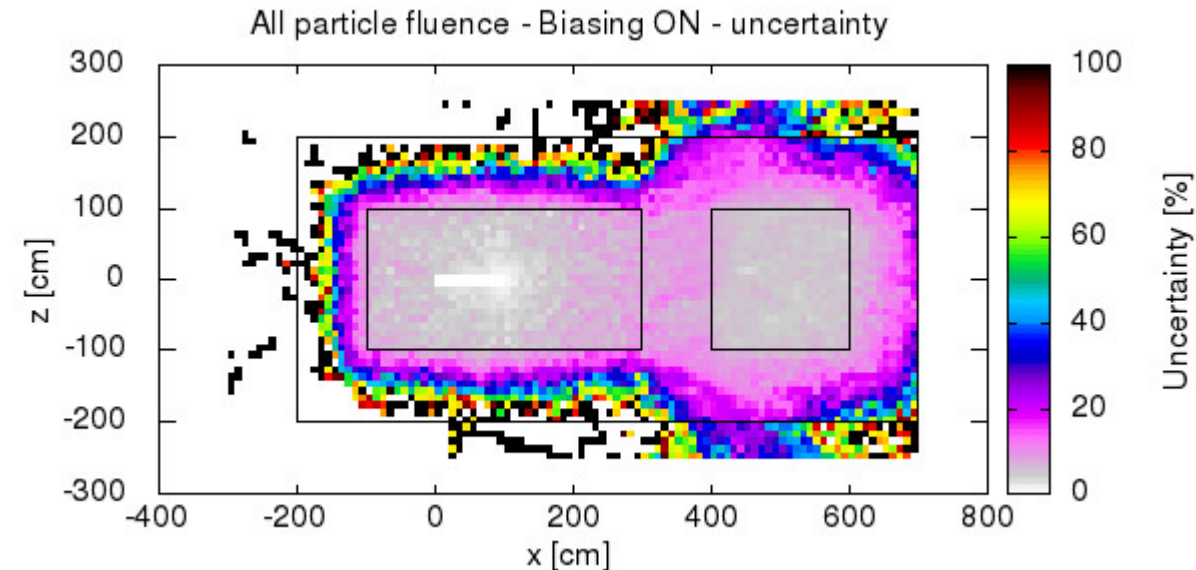
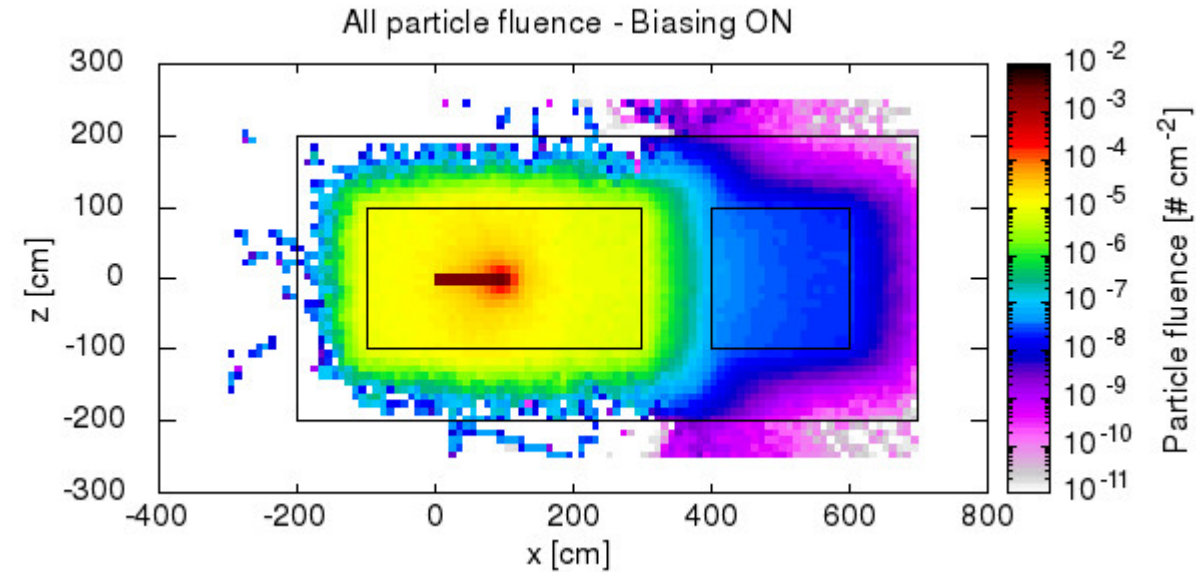
200000 primaries

Characteristics

- Samples from distorted distributions
- Converges “quickly”

Drawbacks

- Cannot reproduce fluctuations and correlations
- Requires active reasoning and experience
- Requires user’s time to be implemented



Biassing techniques in FLUKA

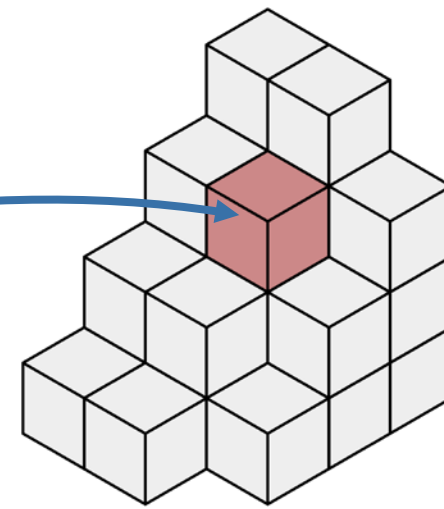
- *Region Importance Biassing* (**BIASING**)
- *Mean Free Path Biassing* (**LAM-BIAS**)
- Leading Particle Biassing (**EMF-BIAS**)
- Multiplicity Tuning (**BIASING**)
- Lifetime / Decay-length Biassing (**LAM-BIAS**)
- Weight Windows (**WW-FACTO**, **WW-THRES**, **WW-PROFI**)
- Low-energy neutrons non-analogue absorption (**LOW-BIAS**)
- Low-energy neutrons downscattering (**LOW-DOWN**)
- User defined biassing (usbset.f , usimbs.f)

} During this lessons we will only look at these 2 types

Medical applications

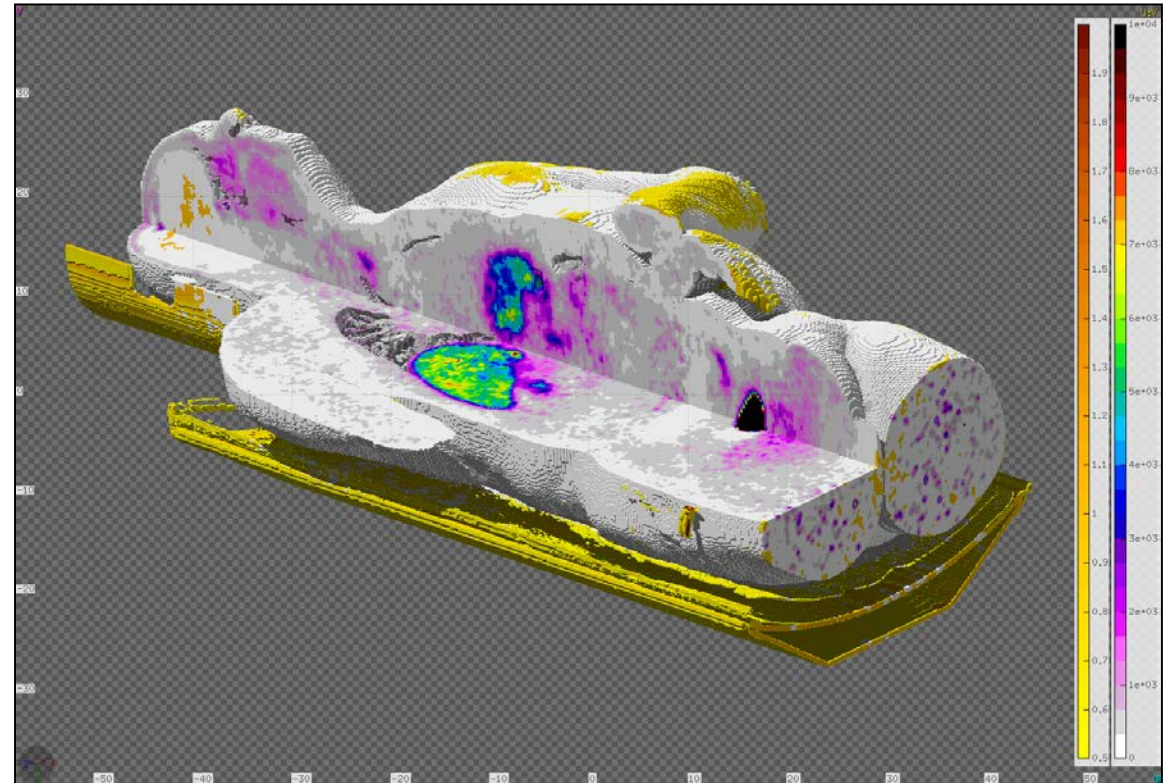
(...a short “teaser”)

Voxel geometries



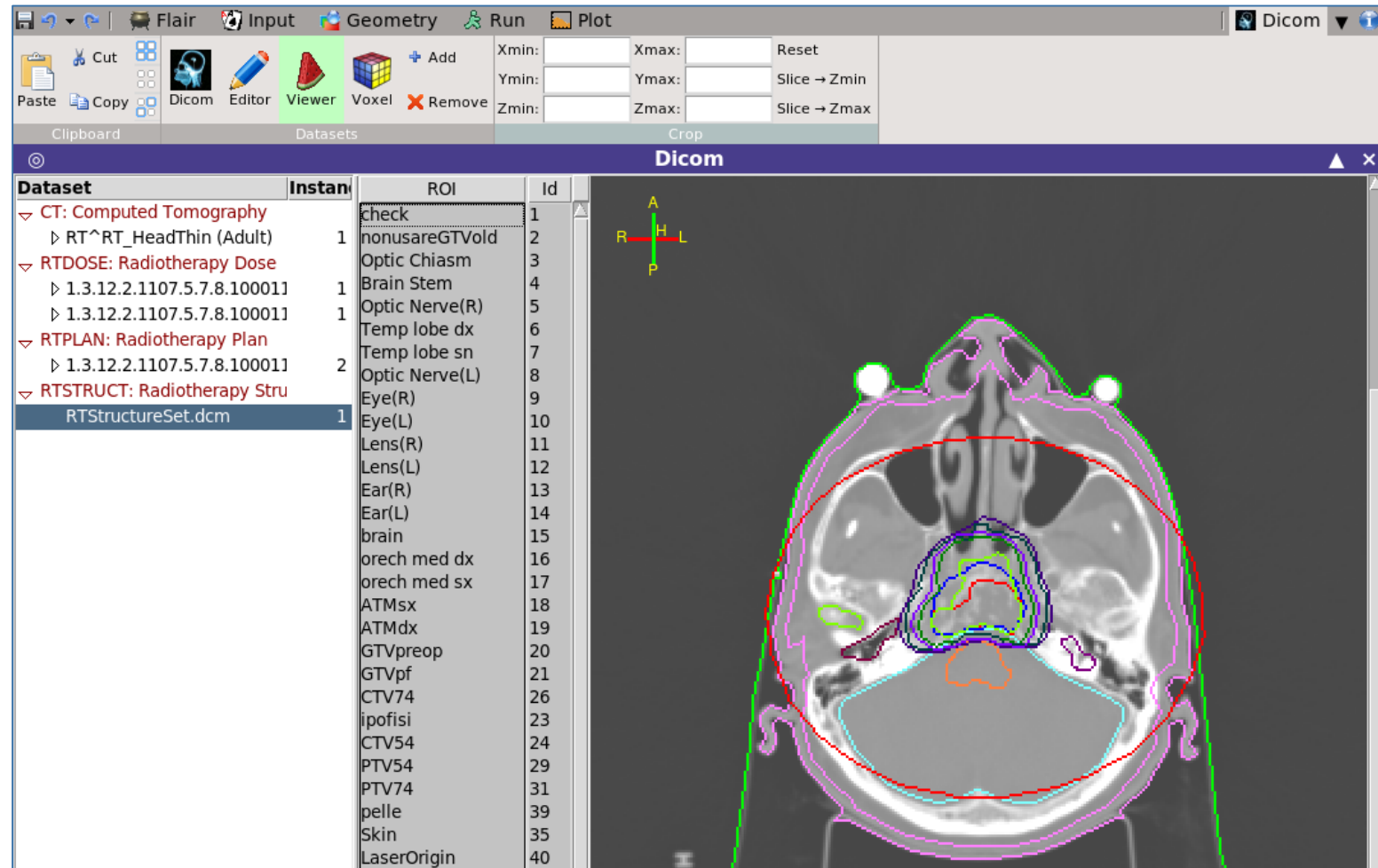
- A geometry can be described in terms of **voxels**, tiny parallelepipeds of equal size forming a 3-dimensional grid
- Voxel geometries are especially useful for importing CT scans, e.g. for dosimetric calculations of radiotherapy treatments
- Flair can process CT scans in the DICOM(*) format using the **pydicom** module and convert them to FLUKA voxel geometries or USRBIN-compatible files

(*) DICOM (Digital Imaging and Communications in Medicine) is a medical standard for distributing any kind of medical image.



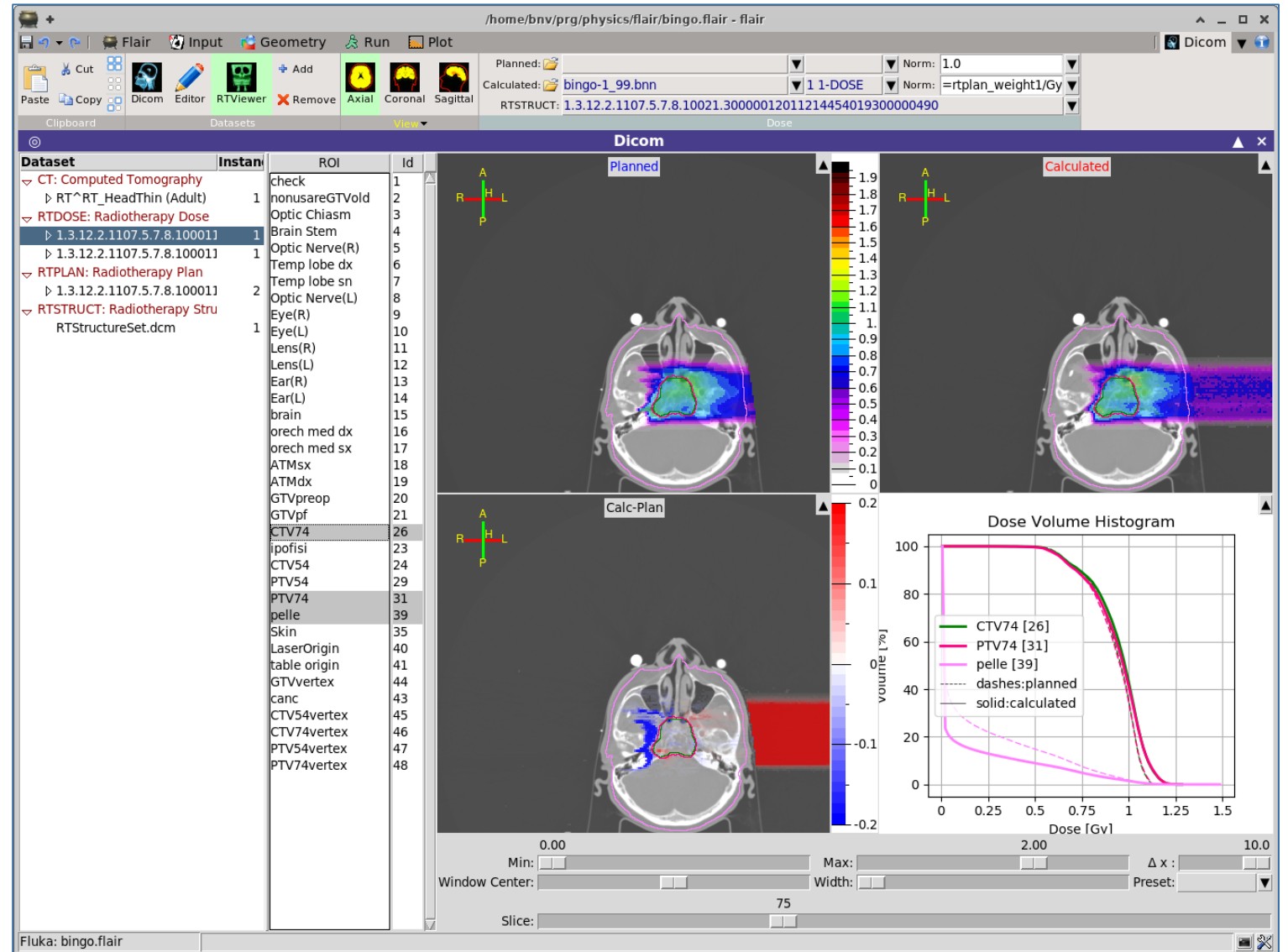
Defining organs

- DICOM files can be browsed, visualised and edited (e.g. anonymised)
- Voxels can be grouped into “organs”
- ROIs (Regions Of Interest) can be defined
- The voxel geometry is contained in an RPP and can be placed within a larger combinatorial FLUKA geometry



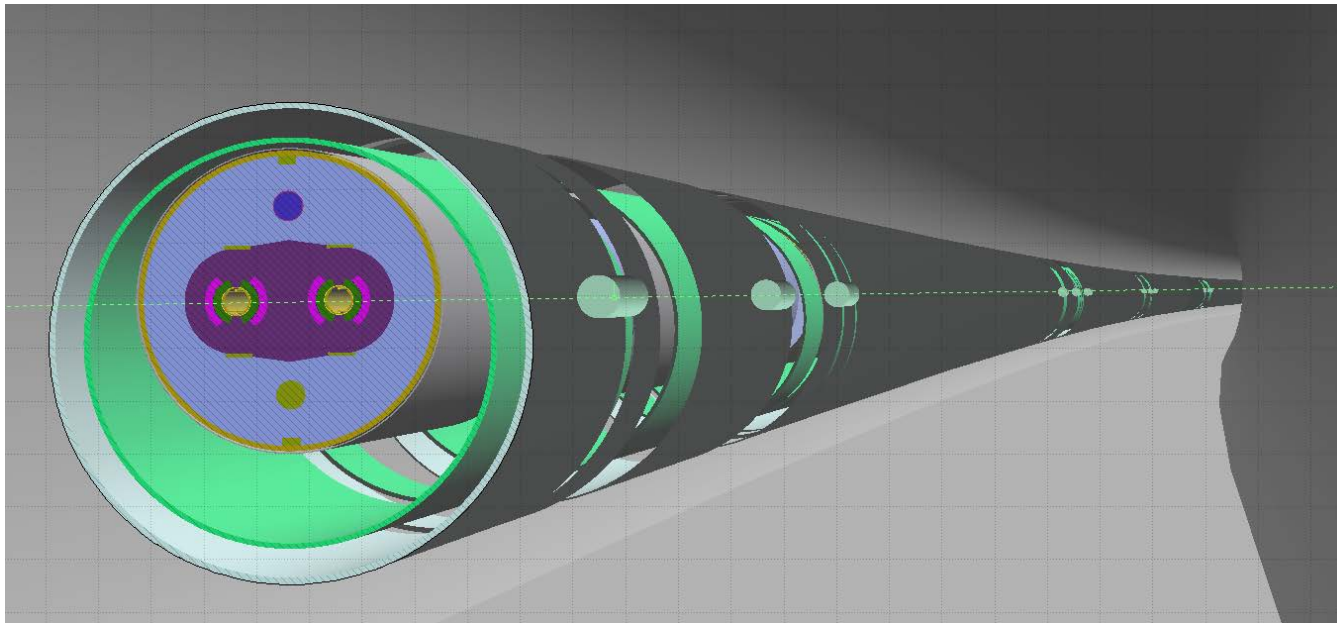
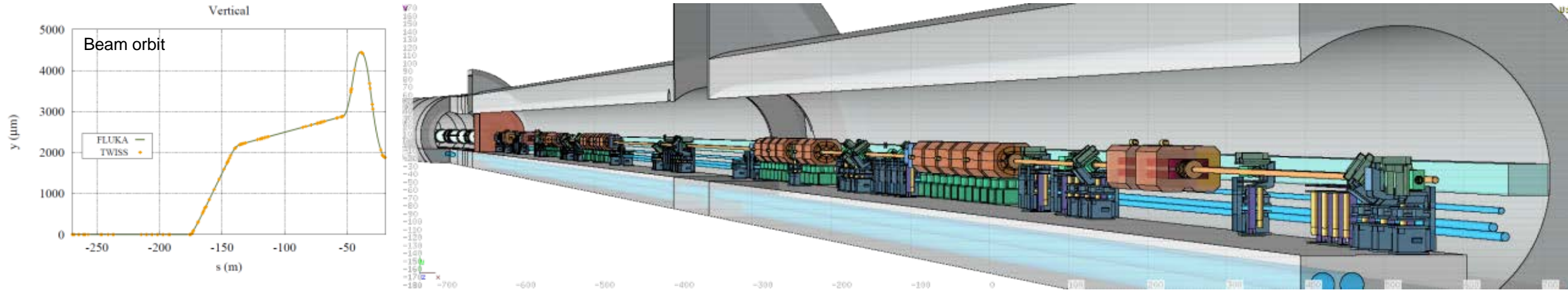
Calculating dose to organs

- Correction factors for the density and dE/dx can be specified
- The RTPLAN can be converted to a FLUKA input
- RTDOSE: the calculated data can be compared to the planned dose
- Automatic generation of DVH (Dose Volume Histogram)
- Relevant cards: **VOXELS**, **CORRFAC**, **RAD-BIOL**, **TPSSCORE**



Some examples

Accelerator geometries



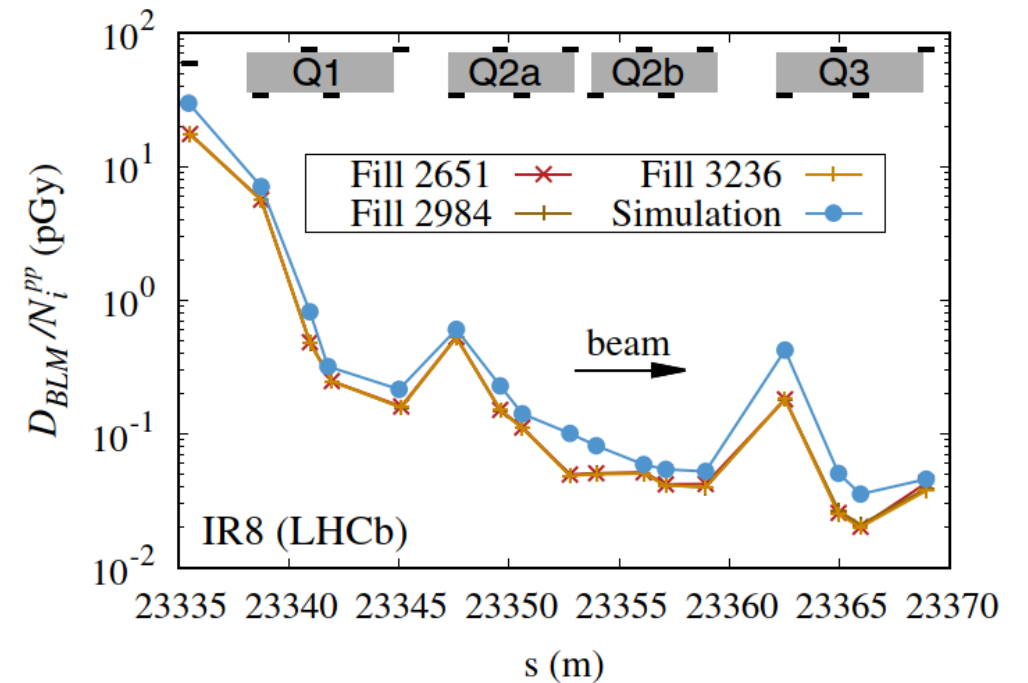
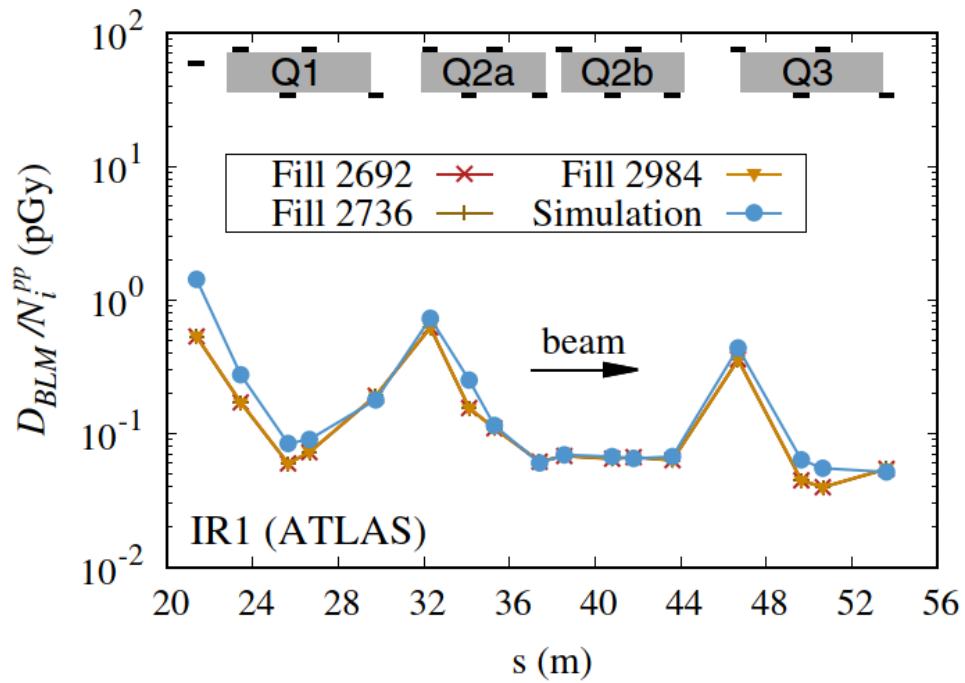
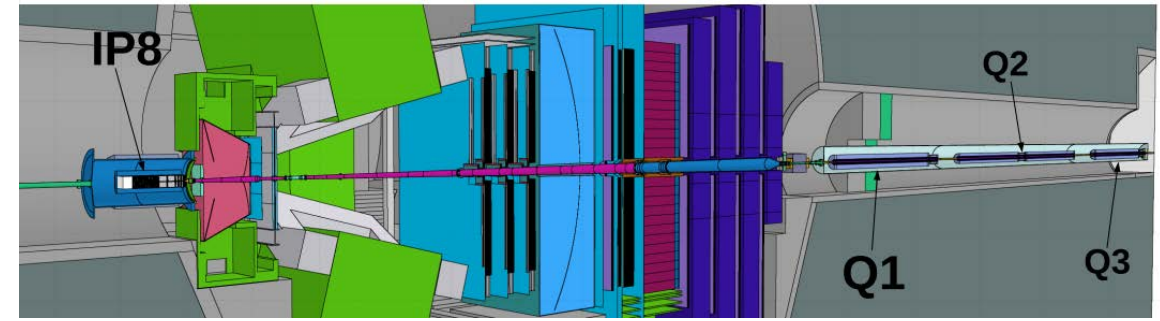
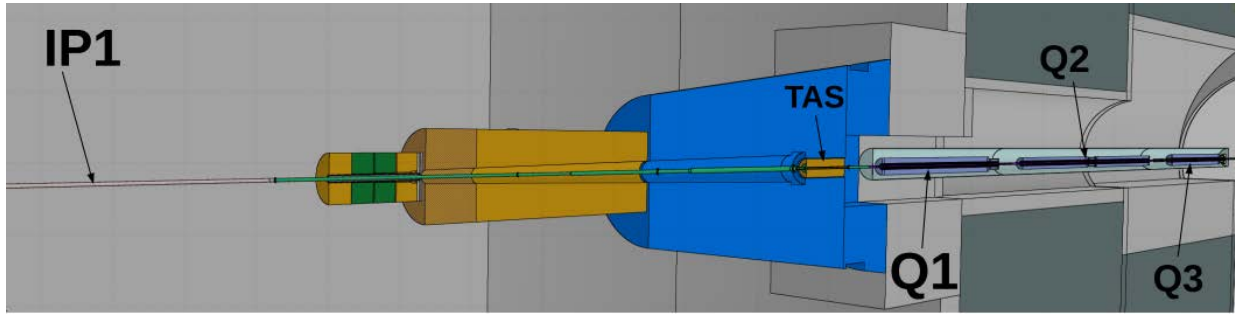
From DETAILED MODELS OF ACCELERATOR COMPONENTS WITH ASSOCIATED SCORING and the ELEMENT SEQUENCE AND RESPECTIVE MAGNETIC STRENGTHS, as given IN THE MACHINE OPTICS (TWISS) FILES, the **AUTOMATIC CONSTRUCTION OF COMPLEX BEAM LINES**, including collimator settings and element displacement (BLMs), is achievable, profiting from roto-translation directives and replication (lattice) capabilities.

LINE BUILDER

[A. Mereghetti et al.,
IPAC2012, WEPPD071, 2687]

Beam loss description at the LHC

[A. Lechner et al.,
Phys. Rev. AB 22 (2019) 071003]



Activation benchmarking

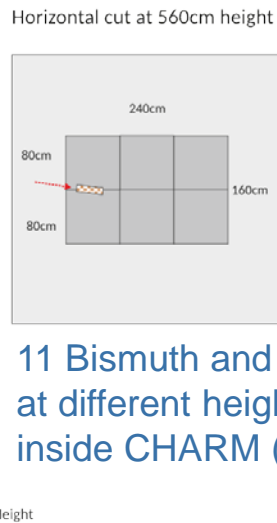
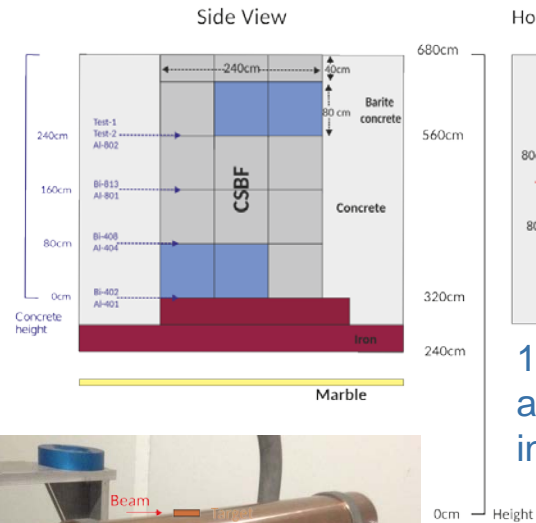
@ CERN SHIELDING BENCHMARK FACILITY (24 GeV/c p)

[E. Iliopoulou and R. Froeschl]

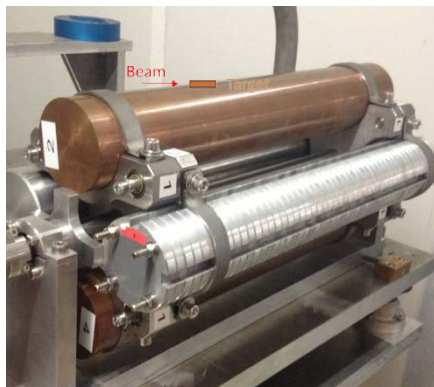
Situated laterally above the CHARM target

for deep shielding penetration studies (Detector calibration, Detector inter-comparison, Activation)

360cm of concrete and barite concrete
plus 80cm of cast iron



11 Bismuth and Aluminum samples
at different heights in CSBF and also
inside CHARM (@ -80cm)

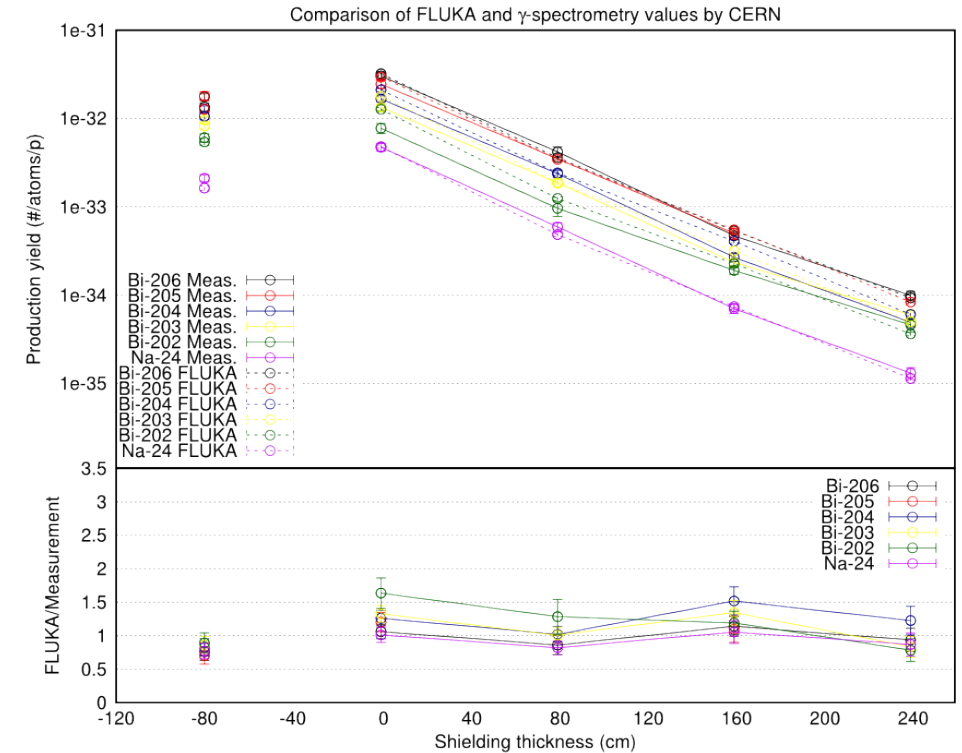


@ CHARM (CERN High energy AcceleRator Mixed field facility,

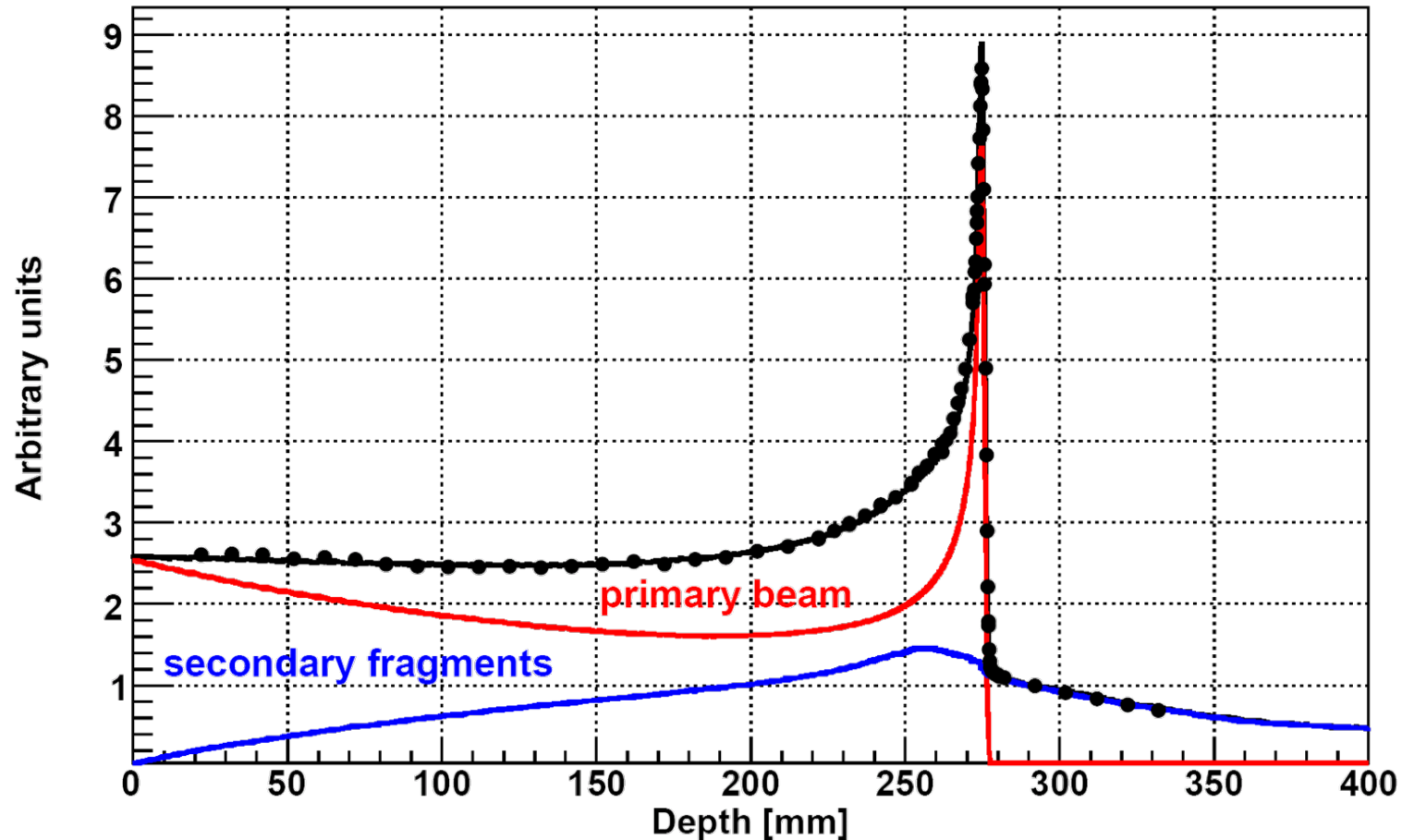
to study radiation effects on electronic components)

5×10^{11} protons/pulse, 350ms pulse length, max. average beam intensity 6.6×10^{10} p/s

three 50cm long 8cm diameter targets: Copper, Aluminum, Aluminum with holes



Medical physics: radiotherapy



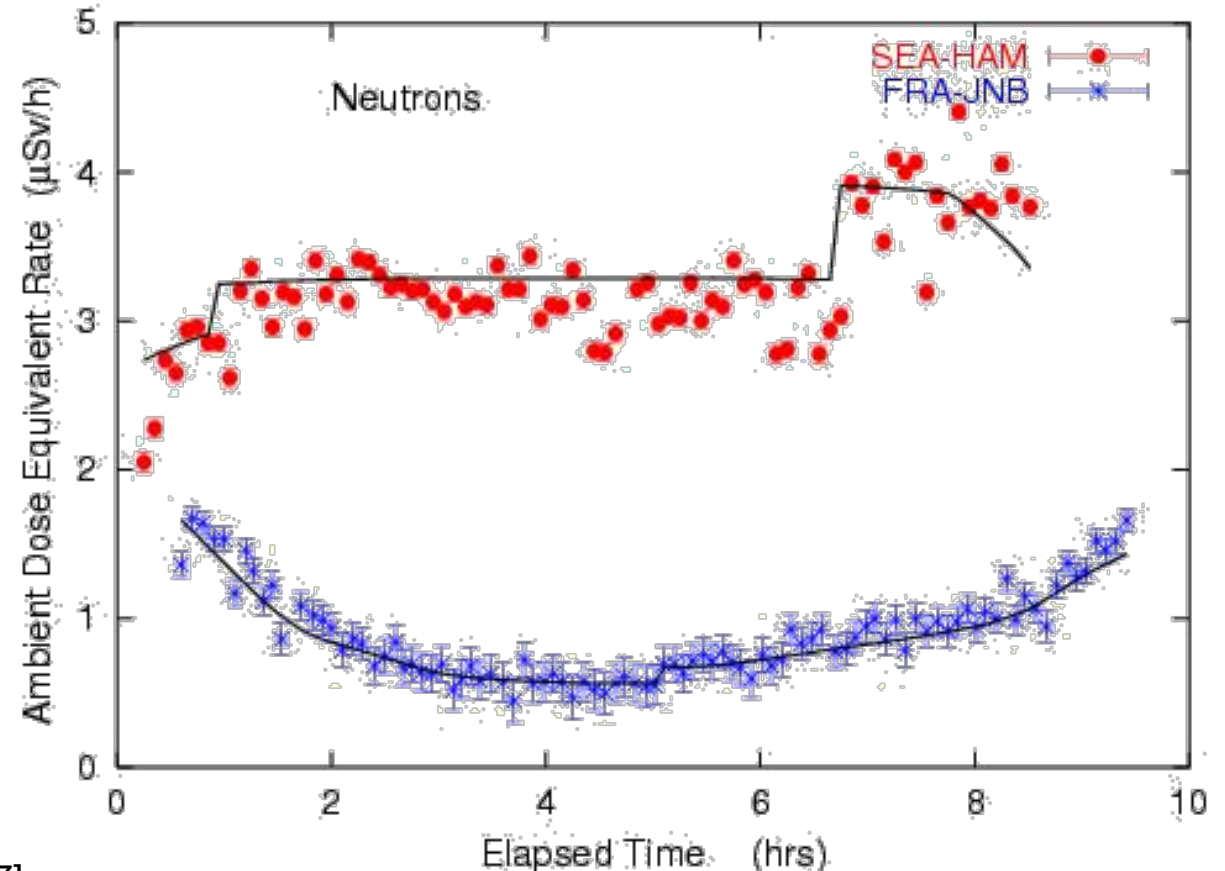
Bragg peak in a water phantom
400 MeV/A C beam:
The importance of fragmentation

[Exp. Data (points) from Haettner et al, Rad. Prot. Dos. 2006
Simulation: A. Mairani PhD Thesis, 2007, Nuovo Cimento C, 31, 2008]

Dosimetry and cosmic rays

- Complete simulation of cosmic rays interactions in the atmosphere, by means of a dedicated CR package available to users
- Model of airplane geometry
- Response of dosimeters

Ambient dose equivalent from neutrons at solar maximum on commercial flights from Seattle to Hamburg and from Frankfurt to Johannesburg



[Solid lines: FLUKA simulation
S. Roesler et al.,
Rad. Prot. Dosim. 98 (2002) 367]

