



<https://fluka.cern>

Presentation of the FLUKA particle transport code and tutorial with its graphical user interface Flair

Material prepared by the FLUKA collaboration

RADMEP workshop 2023

04.12.2023

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](#)

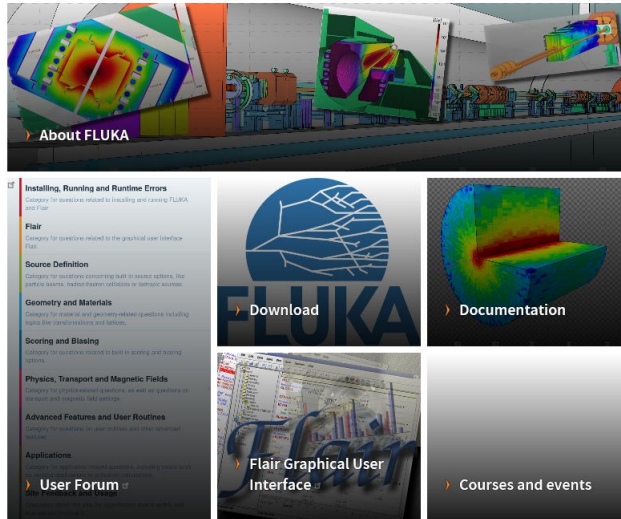
[more](#)

FLUKA 4-0.1, 2020-08-24

Flair 3.1-2st, 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 4-4.0** is scheduled for **early 2024**

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

Binary version only

- **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 held in 2020 and one in 2021.

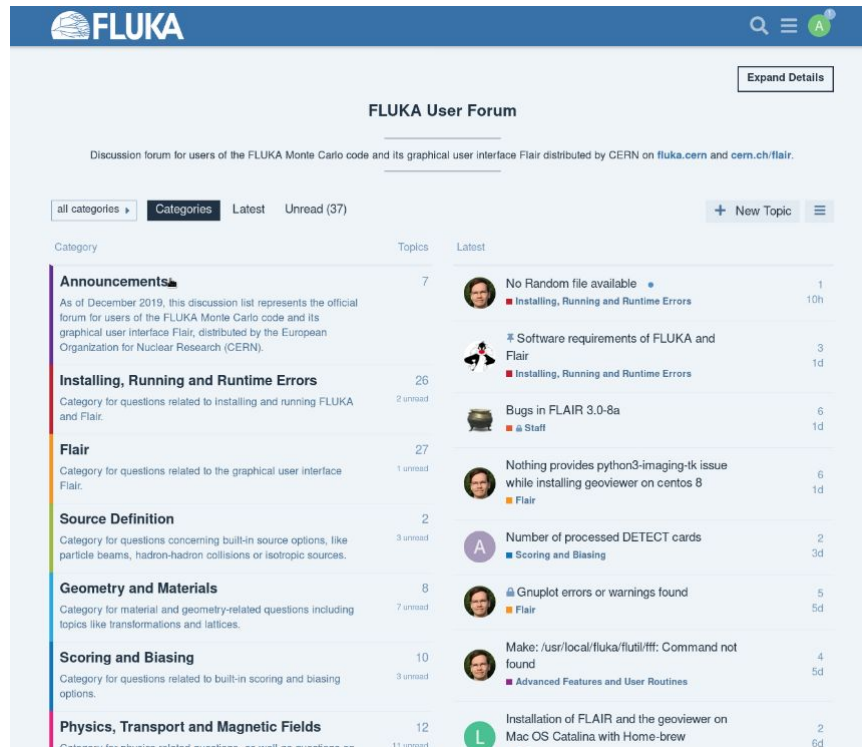
Two Beginner Training courses:

- University of Brussels in 2022
- NEA, Paris in 2023

and one Advance course held:

- Argonne NL, Chicago in 2023

The next beginner's course is planned for 15-19 April 2024 in Madrid



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." A search bar and "Expand Details" button are also visible. The main content area features a list of categories and topics. The categories are: "Announcements" (7 topics), "Installing, Running and Runtime Errors" (26 topics), "Flair" (27 topics), "Source Definition" (2 topics), "Geometry and Materials" (8 topics), "Scoring and Biasing" (10 topics), and "Physics, Transport and Magnetic Fields" (12 topics). Each category has a brief description. To the right, a list of recent topics is shown, including "No Random file available", "Software requirements of FLUKA and Flair", "Bugs in FLAIR 3.0-8a", "Nothing provides python3-imaging-tk issue while installing geoviewer on centos 8", "Number of processed DETECT cards", "Gnuplot errors or warnings found", "Make: /usr/local/fluka/flutil/fft: Command not found", and "Installation of FLAIR and the geoviewer on Mac OS Catalina with Home-brew".

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

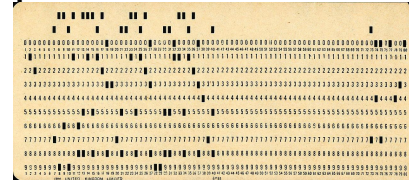
- ✓ Accelerator design
- ✓ Particle physics
- ✓ Cosmic ray physics
- ✓ Neutrino physics
- ✓ Medical applications

- ✓ 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

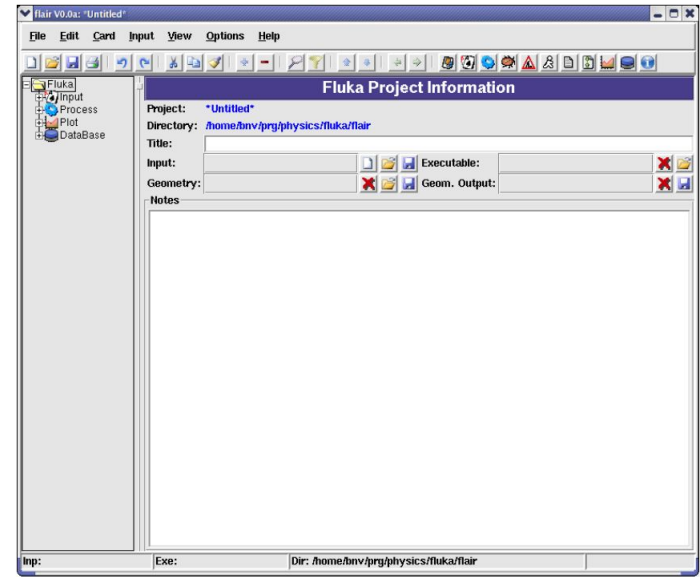
Input file creation

Geometry visualization and construction

Simulation execution

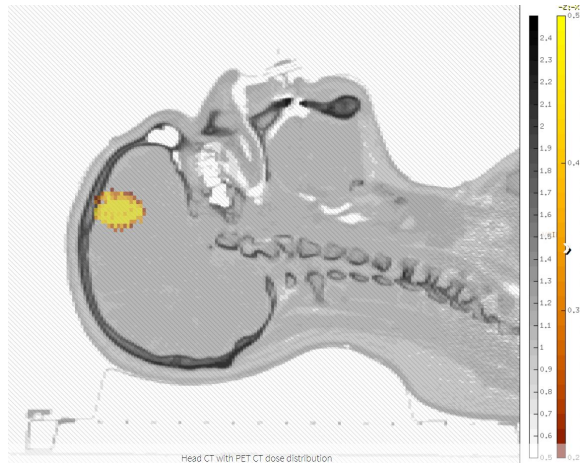
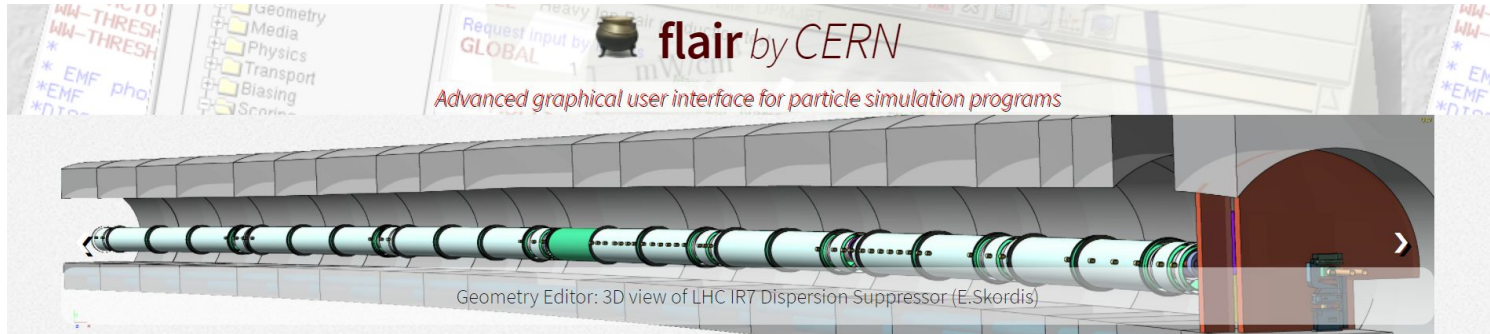
Results visualization

- 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 \neq FLUKA

<https://flair.cern>



Current Version

- Latest version: **3.3-0.2**
- Released on: **Fri 24-Nov-2023**
- Powered by python3, tkinter, gnuplot, pydicom



Authors

authors: Vasilis Vlachoudis (*lead author*)
Christian Theis
Wioletta Kozłowska

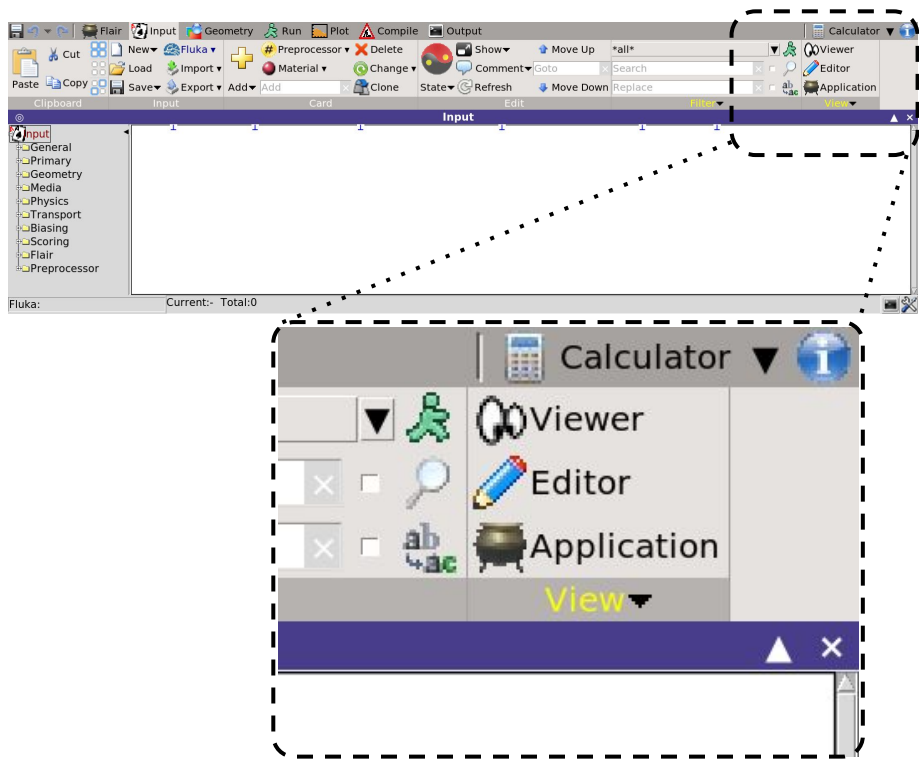


Features

- 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 FLUKA manual

Available in Flair clicking on the “info” button



...or via the FLUKA Web-site



The input at a glance

```
#define BIASFLAG
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
        cosy: Type: POSITIVE

Geometry
-----
GEOBEGIN Accuracy: Option: Parent:
         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 z: 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 z: 0.0 R: 40.
ZCC sh2 x: 0.0 y: 0.0 z: 0.0 R: 80.
ZCC sh3 x: 0.0 y: 0.0 z: 0.0 R: 120.

TITLE
FLUKA Course Exercise
```

TITLE

Assign a title to the simulations

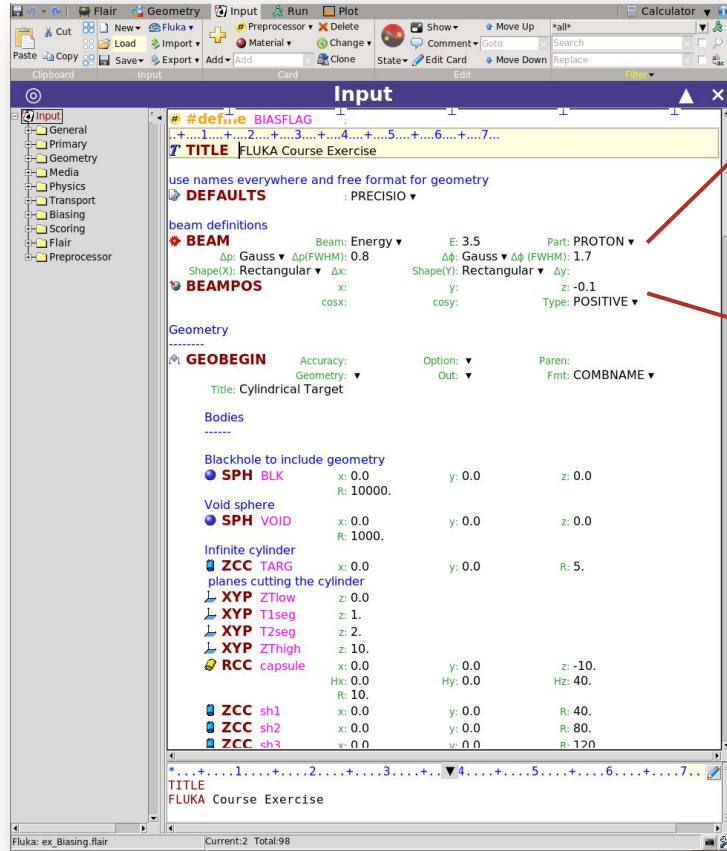
- The title is printed in the output files
- Not a mandatory card

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:      Parent:
          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 sh3   x: 0.0          y: 0.0          R: 120.

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

BEAM

Specify beam particle properties

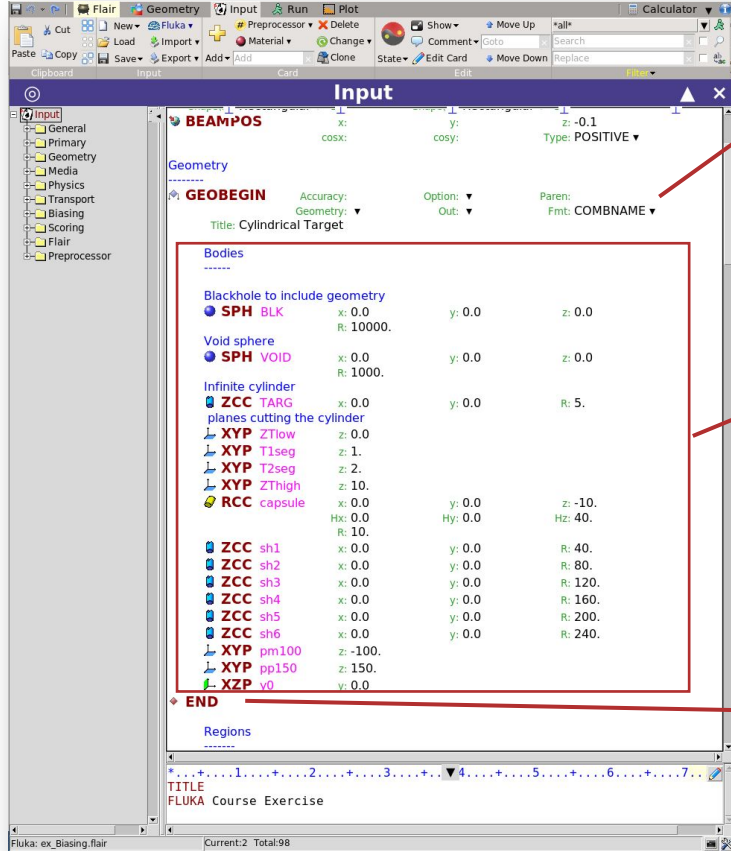
- Particle type
- Momentum or kinetic energy
- Momentum distribution
- Angular distribution
- Shape in the X-Y plane

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

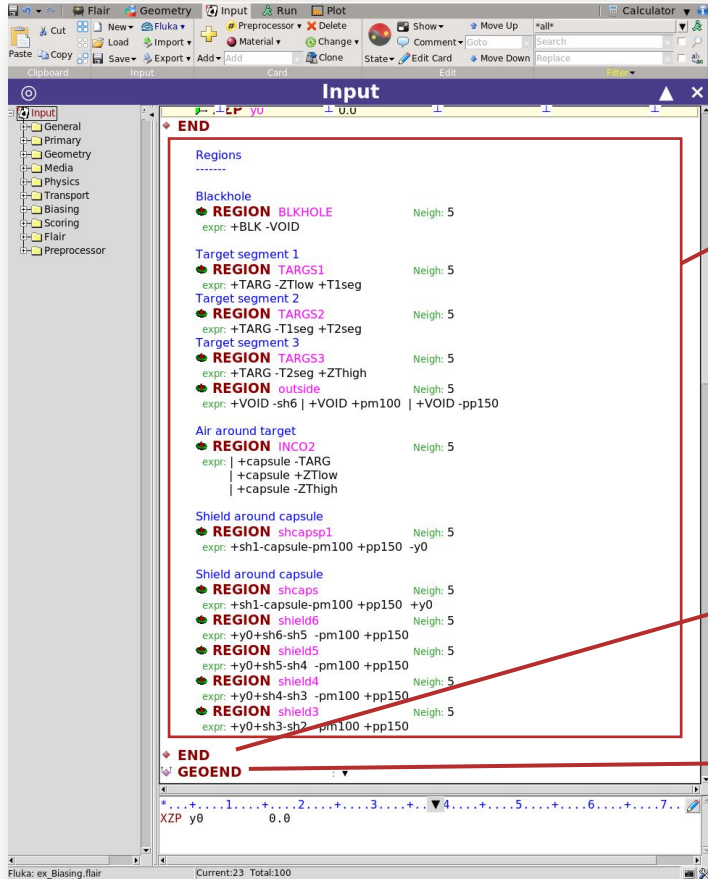
A body definition consists of:

- **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



The screenshot shows the FLUKA Input window with the following content:

```
Input
-----
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 shcaps1     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
```

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**

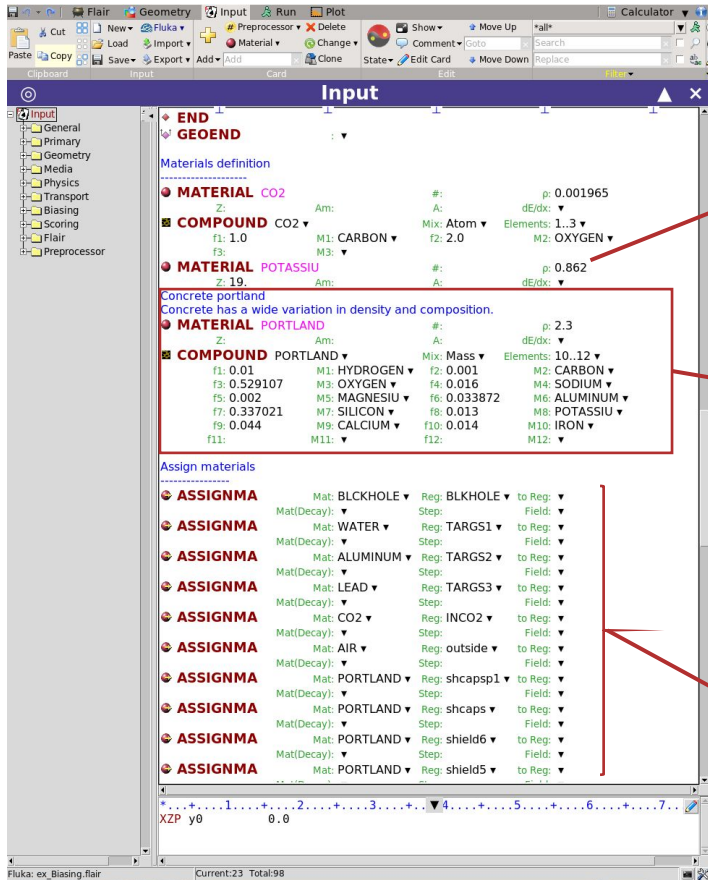
END

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.
 - **BLCKHOLE**: 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]
BLCKHOLE	1	Blackhole or External Vacuum	0	0	0
VACUUM	2	Vacuum or Internal Vacuum	0	0	0
HYDROGEN	3	Hydrogen	1	1	0.0703
HELIUM	4	Helium	2	2	0.1785
BERYLLIU	5	Beryllium	9	4	1.848
CARBON	6	Carbon	12	6	2.267
NITROGEN	7	Nitrogen	14	7	1.2047
OXYGEN	8	Oxygen	16	8	1.429
MAGNESIU	9	Magnesium	24	12	1.738
ALUMINIUM	10	Aluminium	27	13	2.701
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	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 list of material groups (Biological, Elements, General, ICRU, Implantation, Liquids / Gases, Metal Alloys, Plastics / Polymers, Targets, User), and a 'Material List' table. The 'Material List' table has columns for Material, Density, and Stoichiometry. The 'Plastics / Polymers' group is selected, showing materials like Epoxy (molded), Polyethylene Marlex, Polypropromellitimide Polyimide, Kapton, Polychloro-p-xylylene Paralene-C, 760 Formvar PMMA, Bakelite, Epoxy (cast), Polyvinylchloride Rigid PVC, Polycarbonate Lexan, Makrofol, and Polypropylene. Below the table, the 'Material Properties' section is visible, showing the title 'Title: Polypropromellitimide Polyimide, Kapton' and the 'Notes' section with a chemical structure diagram of a polyimide ring.

The input at a glance

```

#endef
USRBIN
Type: R-Phi-Z
Part: NEUTRON
Unit: 35 BIN
Rmin: 0.0
Rmax: 240.
X:
Y:
Zmin: -100.
Zmax: 150.
Name: det
NR: 50.
NPhi: 120.
Nz: 30.

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

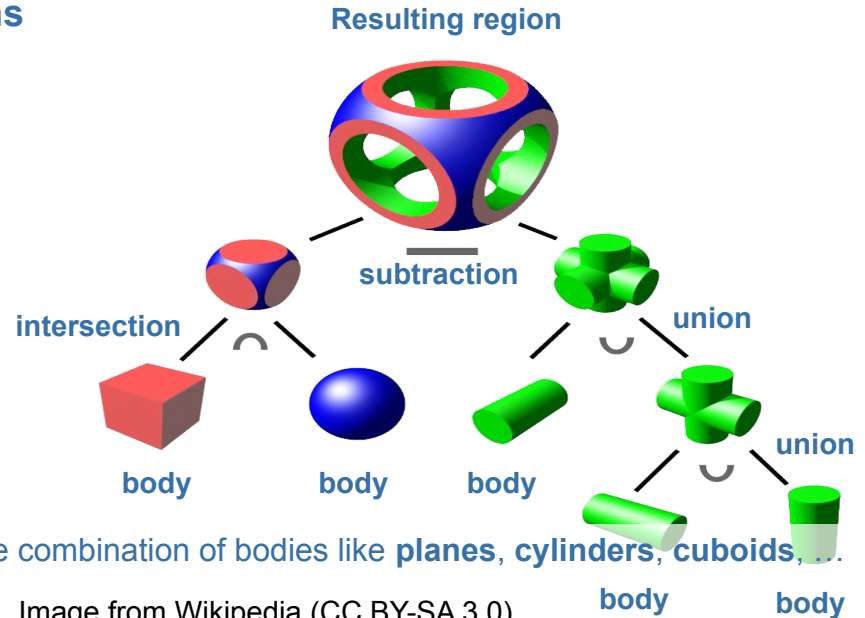
- Not really mandatory (program stops at the end of the input)
- Can become handy for debugging purposes

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**

Operation	Math	FLUKA
Union	\cup	
Intersection	\cap	+
Subtraction	$\cap ^$	-



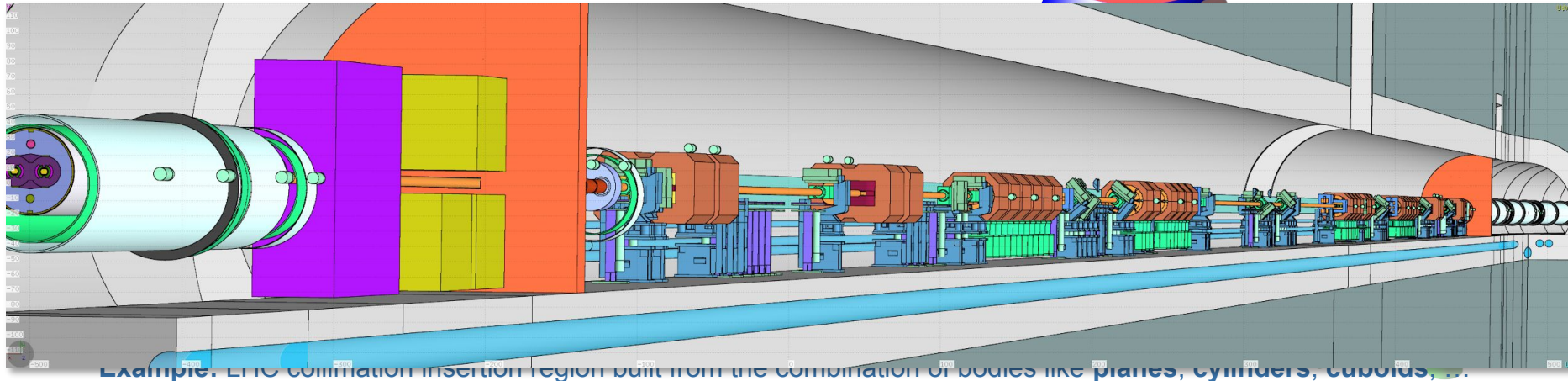
Example: LHC collimation insertion region built from the combination of bodies like **planes, cylinders, cuboids, ...**

Image from Wikipedia (CC BY-SA 3.0)

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

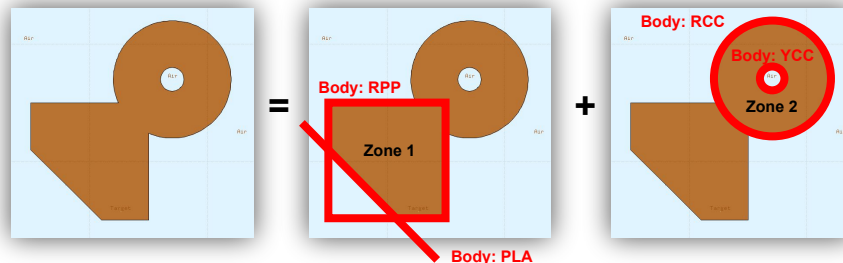
Bodies and regions

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**: Rectangular **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)

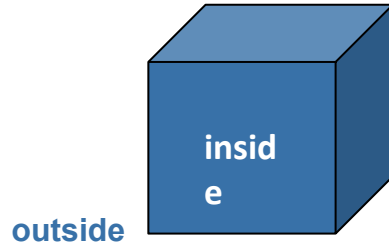


- Zones / regions must be finite
- Each point in space must belong to one (and only one) region
- Regions are of **homogeneous material composition** (i.e. only one material can be assigned to a region)

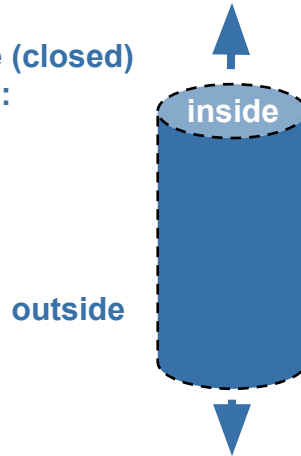
Inside and outside a body

- 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

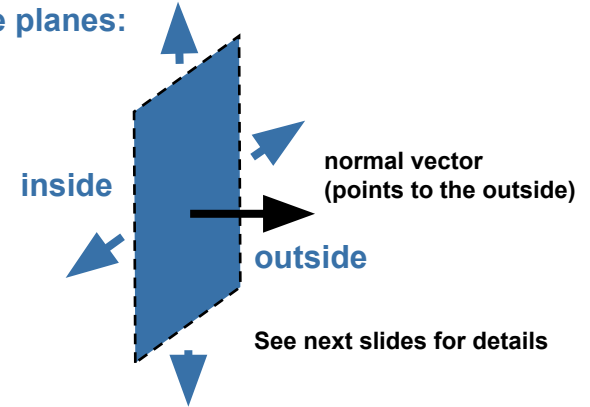
Finite bodies:



Infinite (closed) bodies:

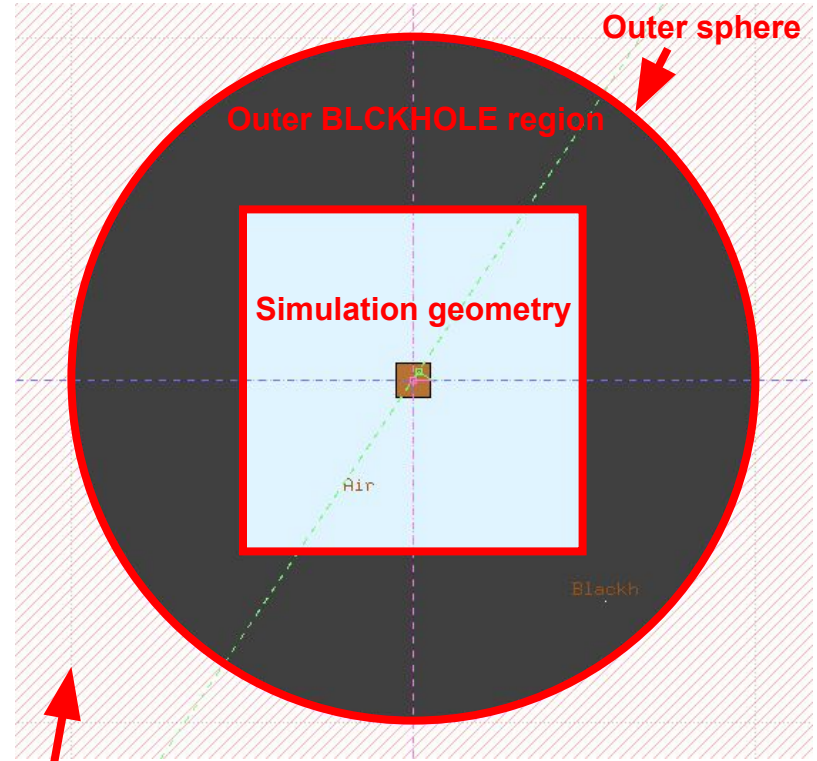


Infinite planes:



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

```
BEAMPOS
cosx:          cosy:          Type: POSITIVE
z: -0.1

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: 1000.0

Void sphere
SPH VOID     x: 0.0          y: 0.0          z: 0.0
              R: 1000.0

Infinite cylinder
ZCC TARG     x: 0.0          y: 0.0          R: 5.0
planes cutting the cylinder
XYP ZTlow    z: 0.0
XYP T1seg    z: 1.0
XYP T2seg    z: 2.0
XYP ZThigh   z: 10.0
RCC capsule  x: 0.0          y: 0.0          z: -10.0
              Hx: 0.0          Hy: 0.0          Hz: 40.0
              R: 10.0

ZCC sh1      x: 0.0          y: 0.0          R: 40.0
ZCC sh2      x: 0.0          y: 0.0          R: 80.0
ZCC sh3      x: 0.0          y: 0.0          R: 120.0
ZCC sh4      x: 0.0          y: 0.0          R: 160.0
ZCC sh5      x: 0.0          y: 0.0          R: 200.0
ZCC sh6      x: 0.0          y: 0.0          R: 240.0
XYP pm100    z: -100.0
XYP pp150    z: 150.0
XZP y0       y: 0.0

END

Regions
-----
TITLE
FLUKA Course Exercise
```

```
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 shcaps1      Neigh: 5
expr: +sh1-capsule-pm100 +pp150 -y0

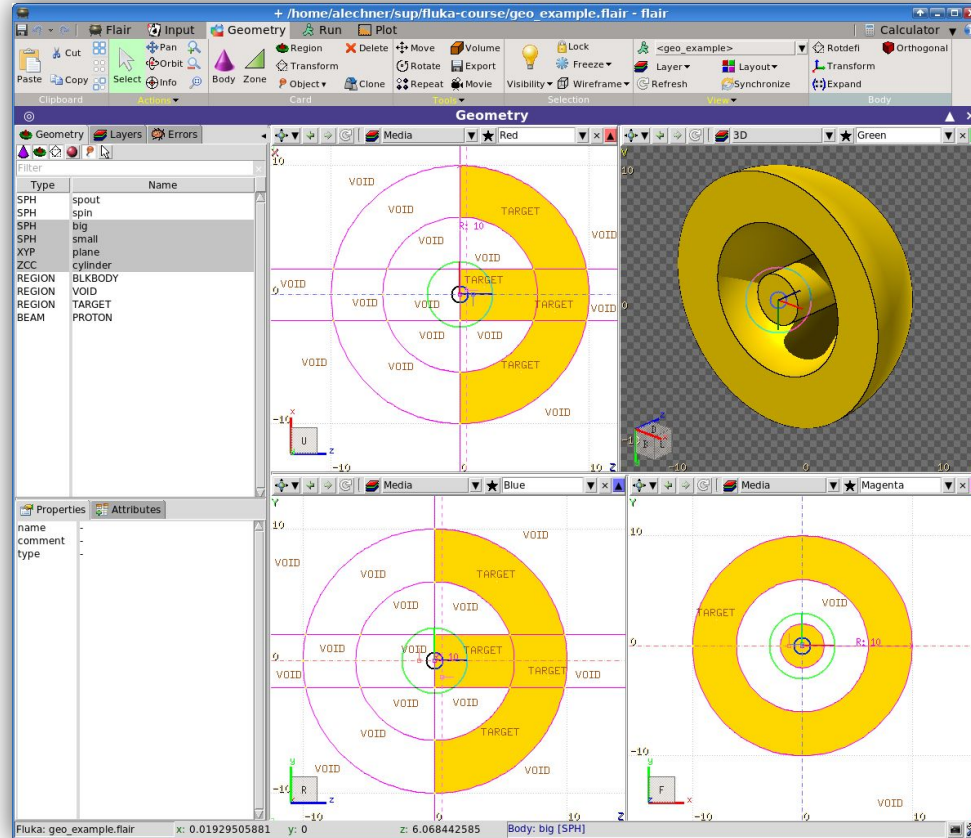
Shield around capsule
REGION shcaps       Neigh: 5
expr: +sh1-capsule-pm100 +pp150 +y0
REGION shield6      Neigh: 5
expr: +y0+sh6-sh5 -pm100 +pp150
REGION shield5      Neigh: 5
expr: +y0+sh5-sh4 -pm100 +pp150
REGION shield4      Neigh: 5
expr: +y0+sh4-sh3 -pm100 +pp150
REGION shield3      Neigh: 5
expr: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

END
GEOEND

TITLE
XZP y0             0.0
```

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

Built-in and user scoring

- Several **pre-defined estimators** can be activated in FLUKA; one usually refers to these estimators as **built-in scoring** capabilities
- Users may build their own custom scoring through **user routines**
- However, **built-in scoring**:
 - covers most **common needs**
 - has been **extensively tested**
 - takes **biasing automatically into account**
 - has **refined algorithms** for track subdivision (apportioning)
 - comes with **utility programs** that allow to evaluate statistical errors
- Therefore users are strongly encouraged to **prefer built-in scorings** wherever possible
- Standard scoring can be adapted by means of simple user routines (**fluscw.f**, **comscw.f**), activated via **USERWEIG** card

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

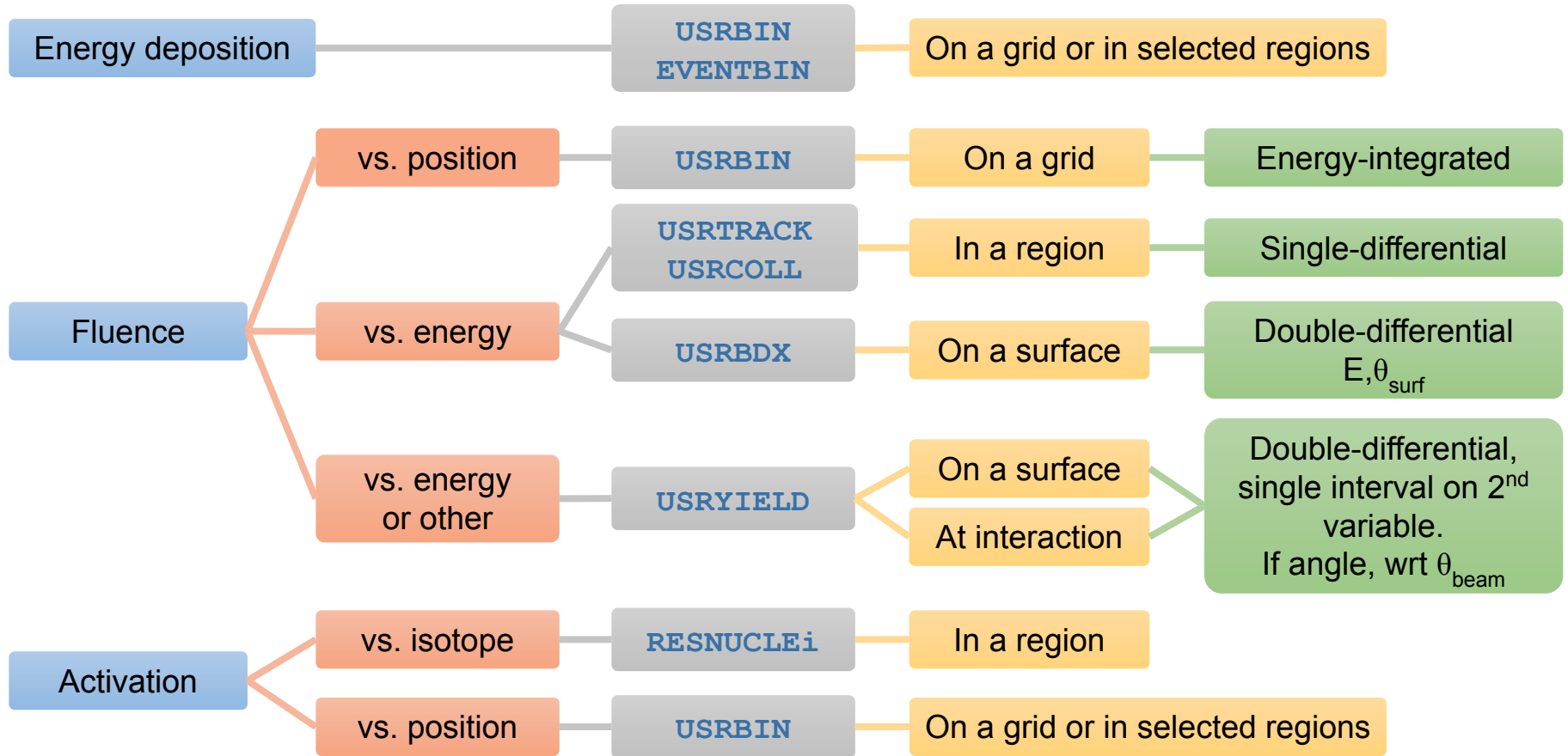
Results?

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

The screenshot shows the FLUKA Input window with a list of cards. The USRBIN card is highlighted with a red box. The parameters for the USRBIN card are:

Parameter	Value
Type	R-Phi-Z
Part	NEUTRON
Unit	01
Seed	5000
Rmin	0.0
Rmax	240
X	Y
Zmin	-100
Zmax	150
Name	det
NR	50
NPhi	120
NZ	50

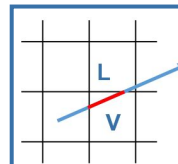
USRBIN

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

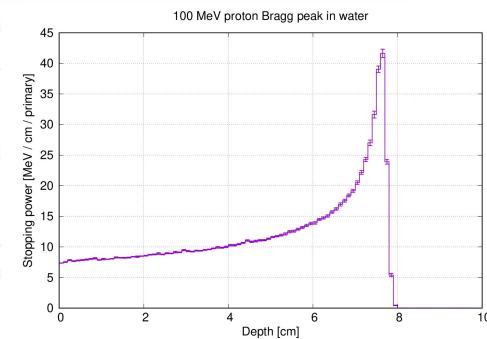
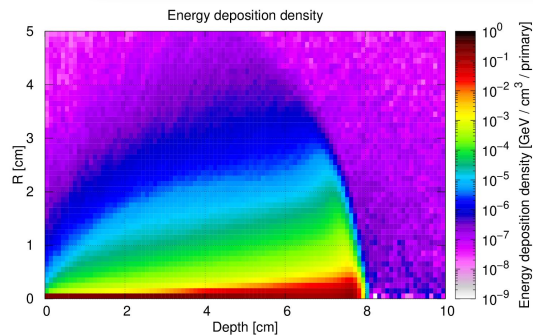
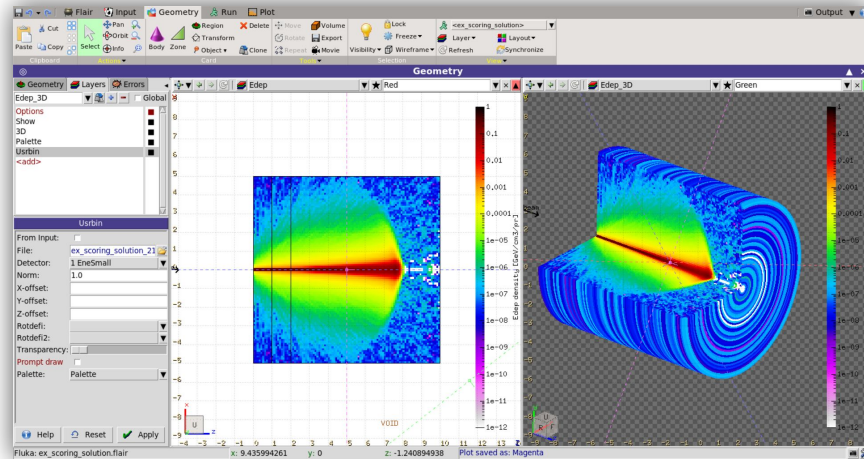
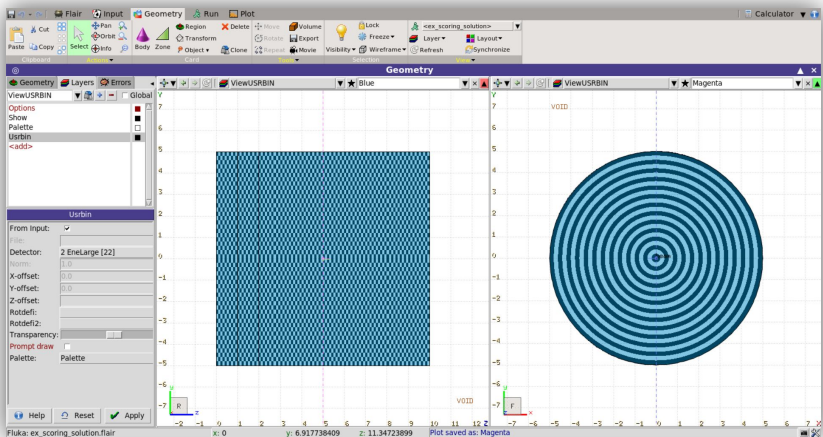


Path length L [cm] inside the bin divided by the bin volume V [cm^3] $\rightarrow \text{cm} / \text{cm}^3 = 1/\text{cm}^2$

Visualization with Flair

and the final results (examples)

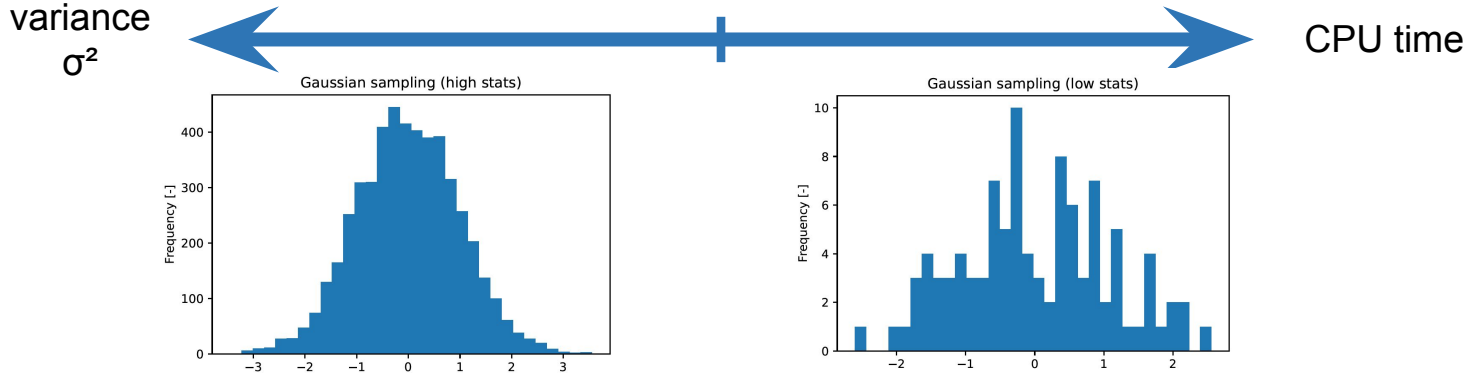
...of the scoring mesh



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

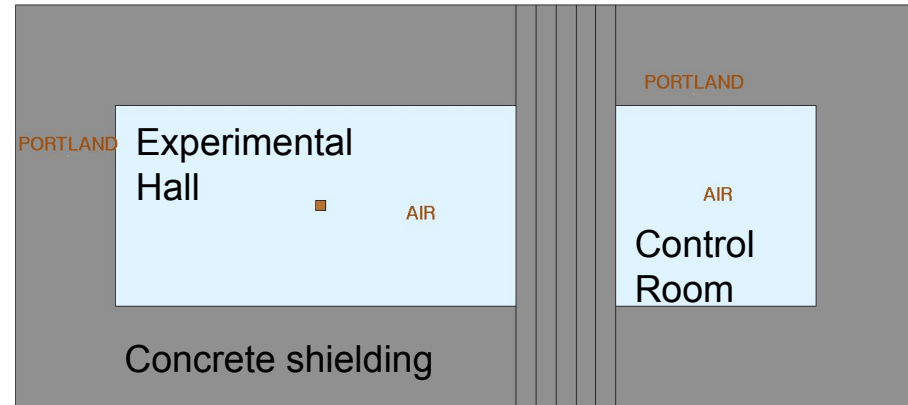
Non-biased Monte Carlo simulations

Characteristics

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

Drawbacks

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



Non-biased Monte Carlo simulations

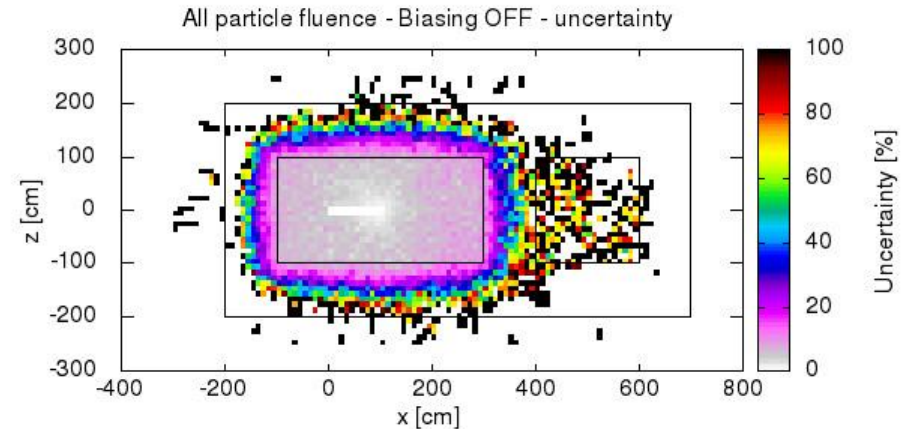
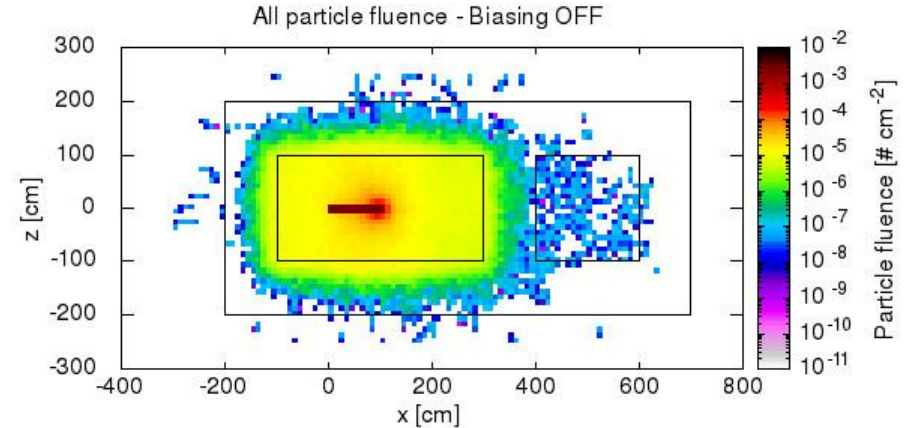
200000

Characteristics

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

Drawbacks

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



Biased Monte Carlo simulations

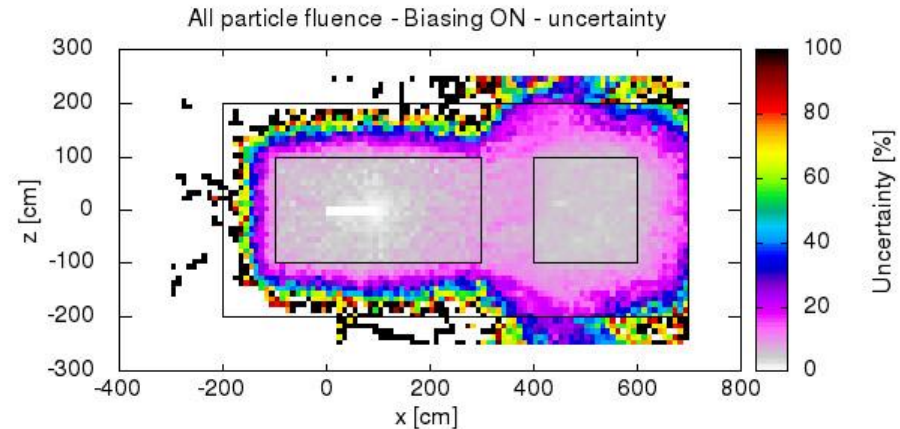
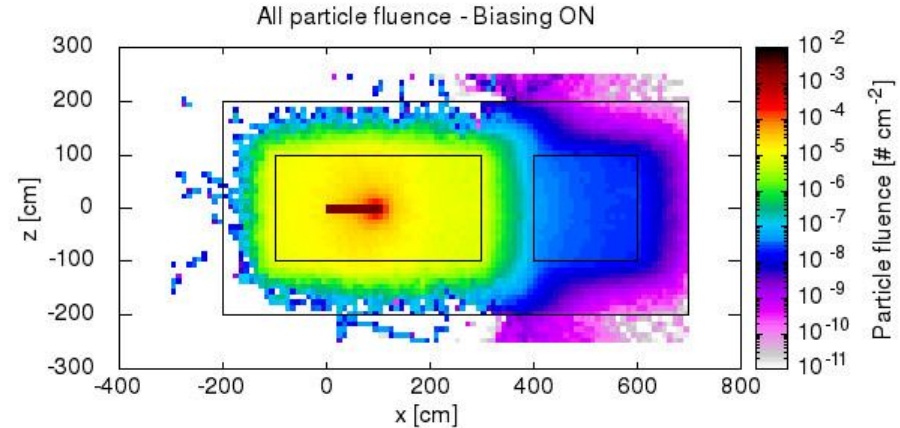
200000

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



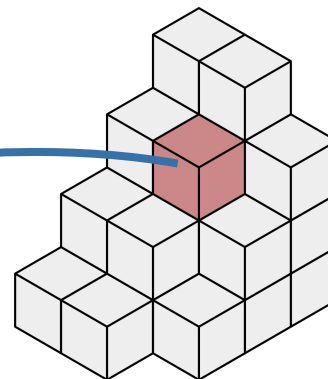
Biasing techniques in FLUKA

- *Region Importance Biasing* (**BIASING**)
- *Mean Free Path Biasing* (**LAM-BIAS**)
- *Leading Particle Biasing* (**EMF-BIAS**)
- *Multiplicity Tuning* (**BIASING**)
- *Lifetime / Decay-length Biasing* (**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 biasing* (`usbset.f` , `usimbs.f`)

Medical applications

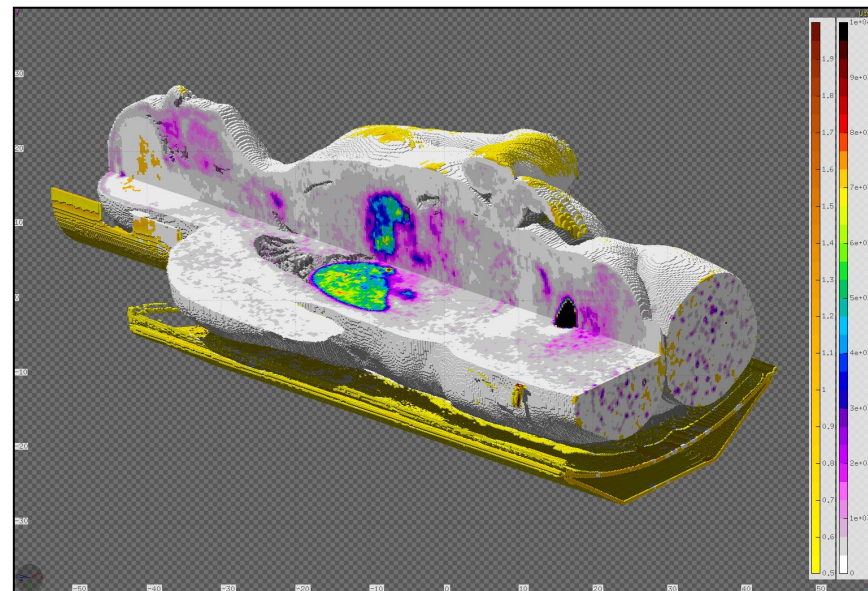
(...a short
“teaser”)

Voxel geometries



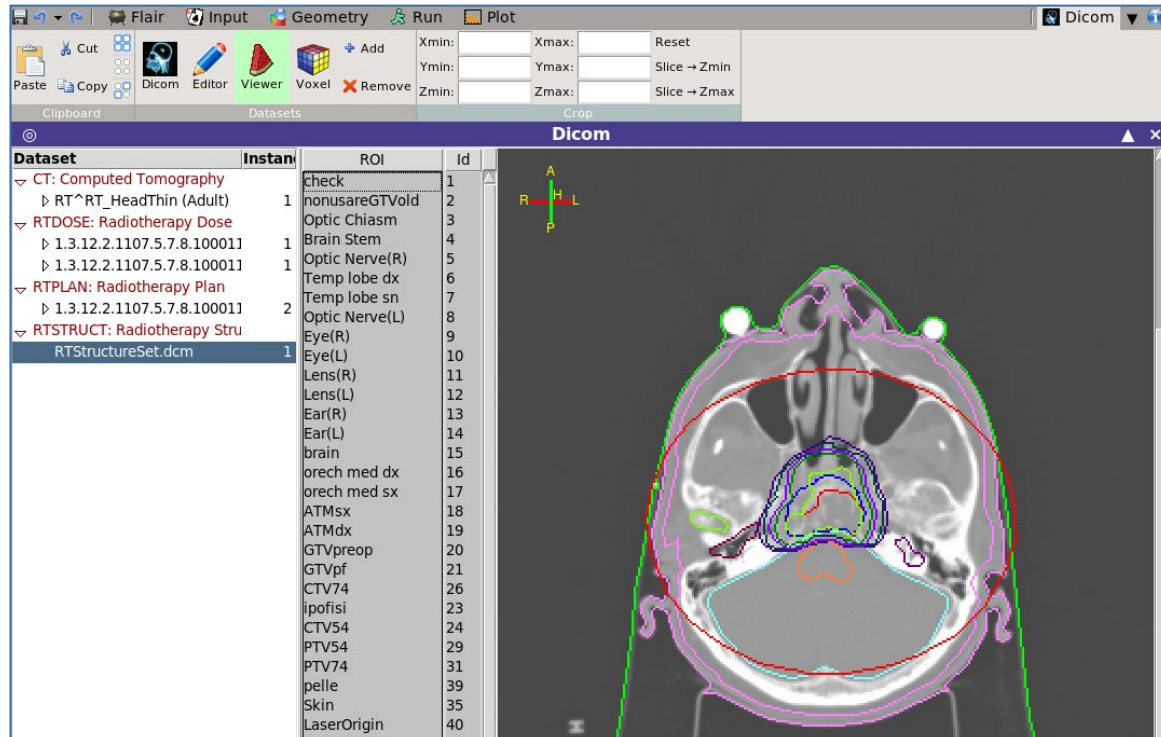
- A geometry can be described in terms of **voxels**, tiny parallelepipeds of equal size forming a 3-dimensional grid
- Voxel geometries are especially useful for importing CT scans, e.g. for dosimetric calculations of radiotherapy treatments
- Flair can process CT scans in the DICOM(*) format using 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.



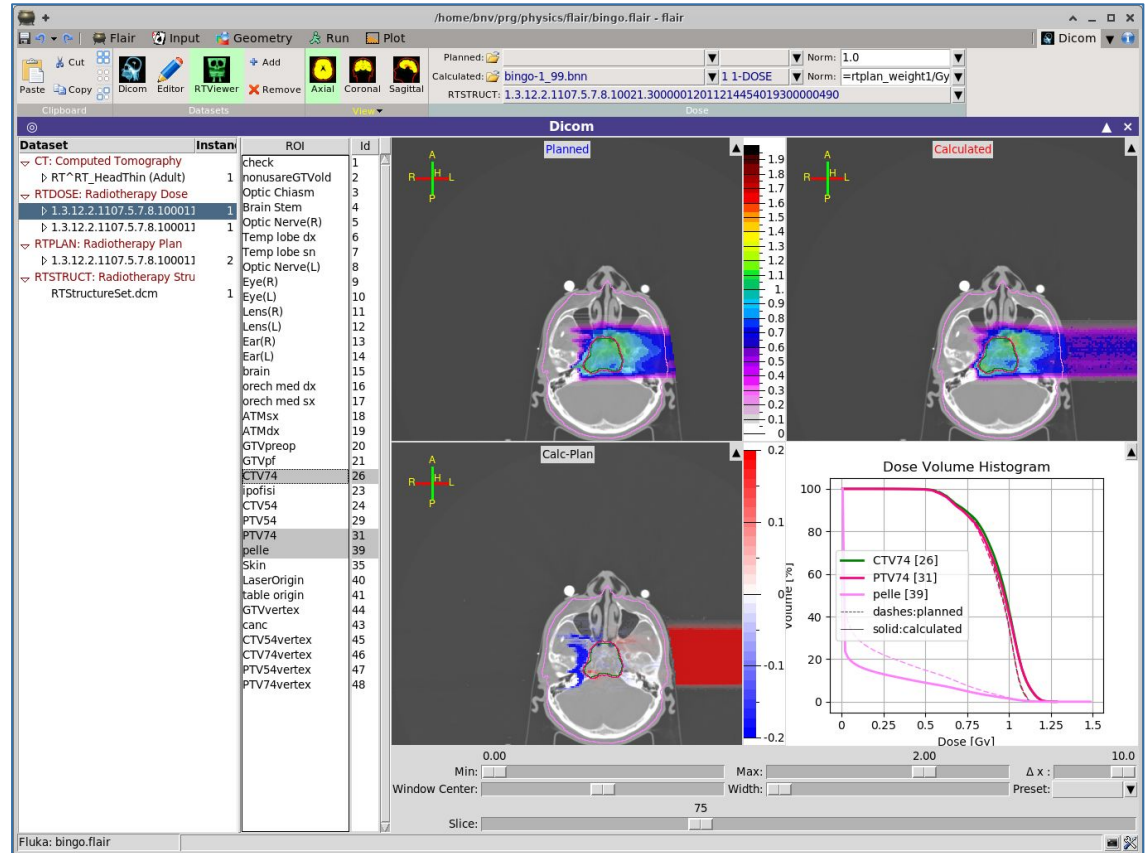
Defining organs

- 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



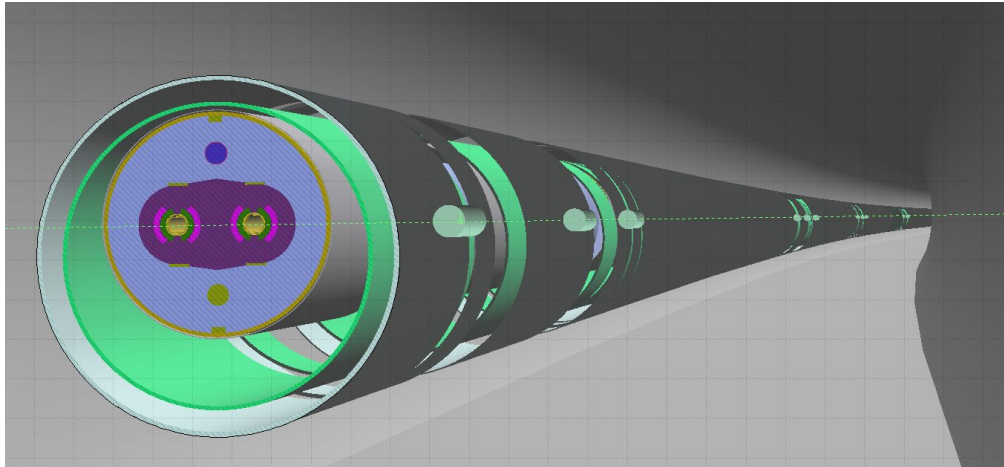
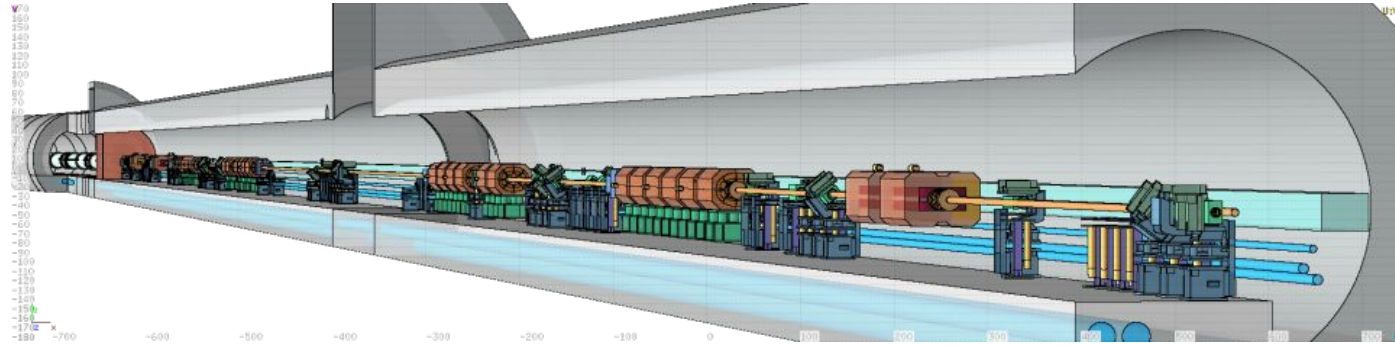
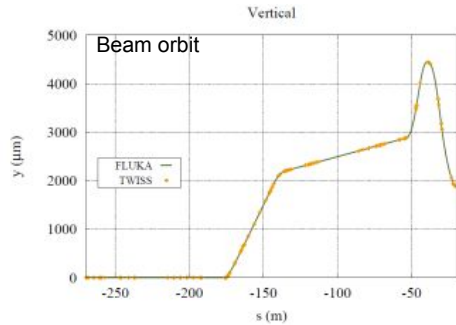
Calculating dose to organs

- 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

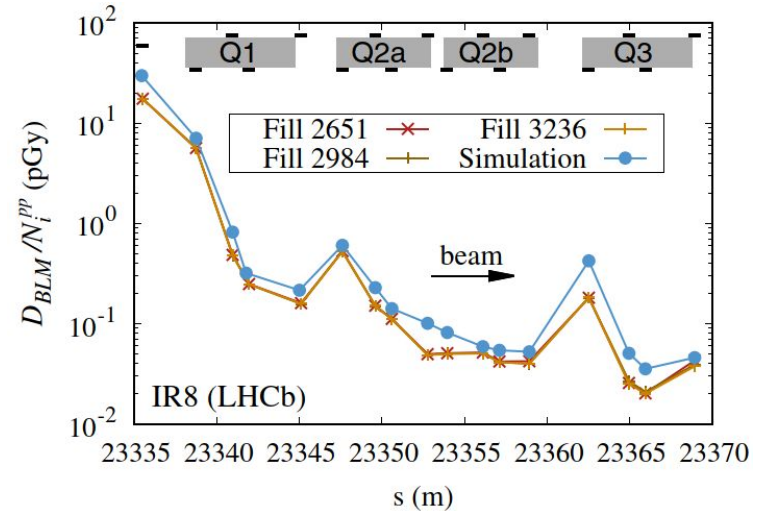
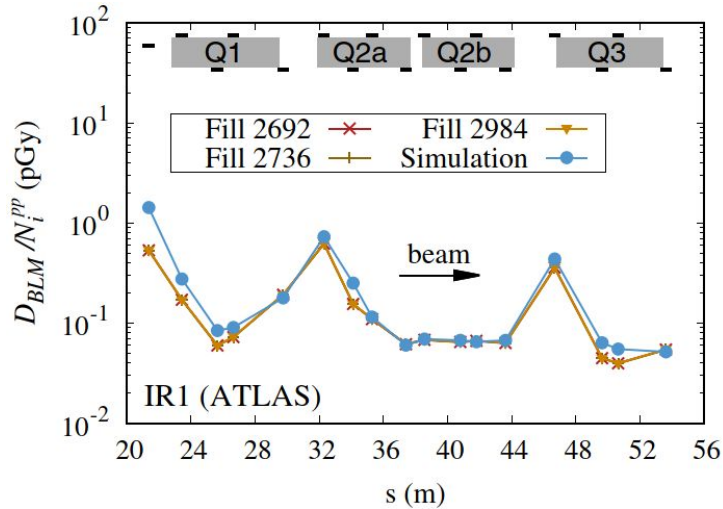
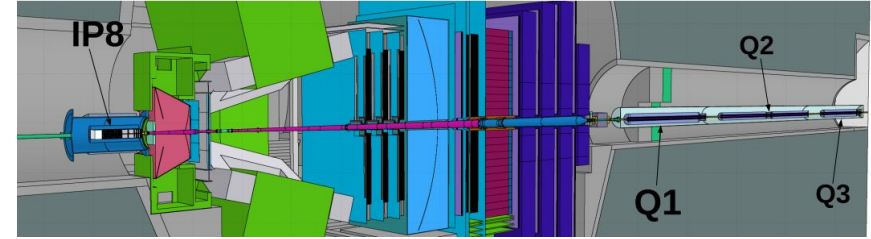
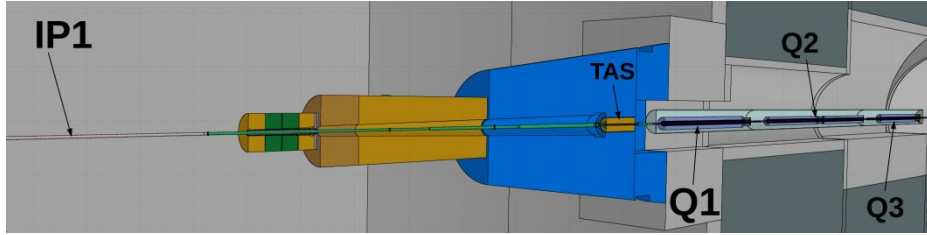


From DETAILED MODELS OF ACCELERATOR COMPONENTS WITH ASSOCIATED SCORING and the ELEMENT SEQUENCE AND RESPECTIVE MAGNETIC STRENGTHS, as given IN THE MACHINE OPTICS (TWISS) FILES, the **AUTOMATIC CONSTRUCTION OF COMPLEX BEAM LINES**, including collimator settings and element displacement (BLMs), is achievable,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

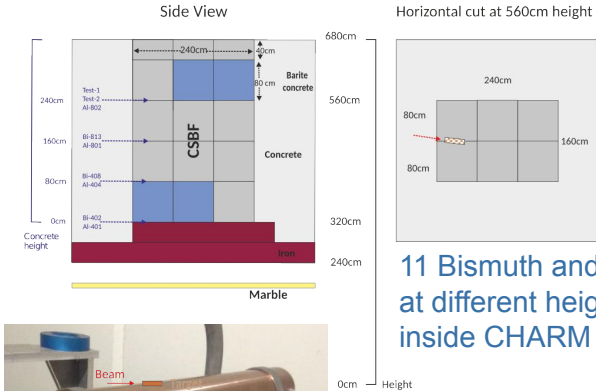
@ CERN SHIELDING BENCHMARK FACILITY (24 GeV/c p)

Situated laterally above the CHARM target

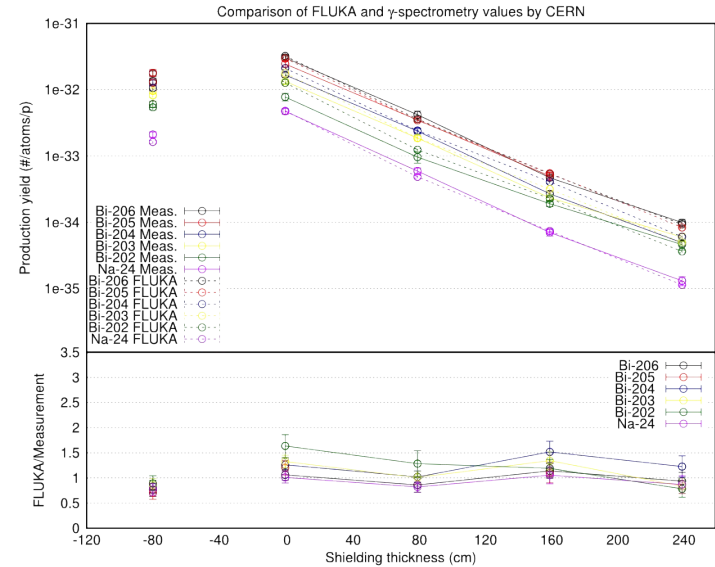
for deep shielding penetration studies (Detector calibration, Detector inter-comparison, Activation)

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

[E. Iliopoulou and R. Froeschl]



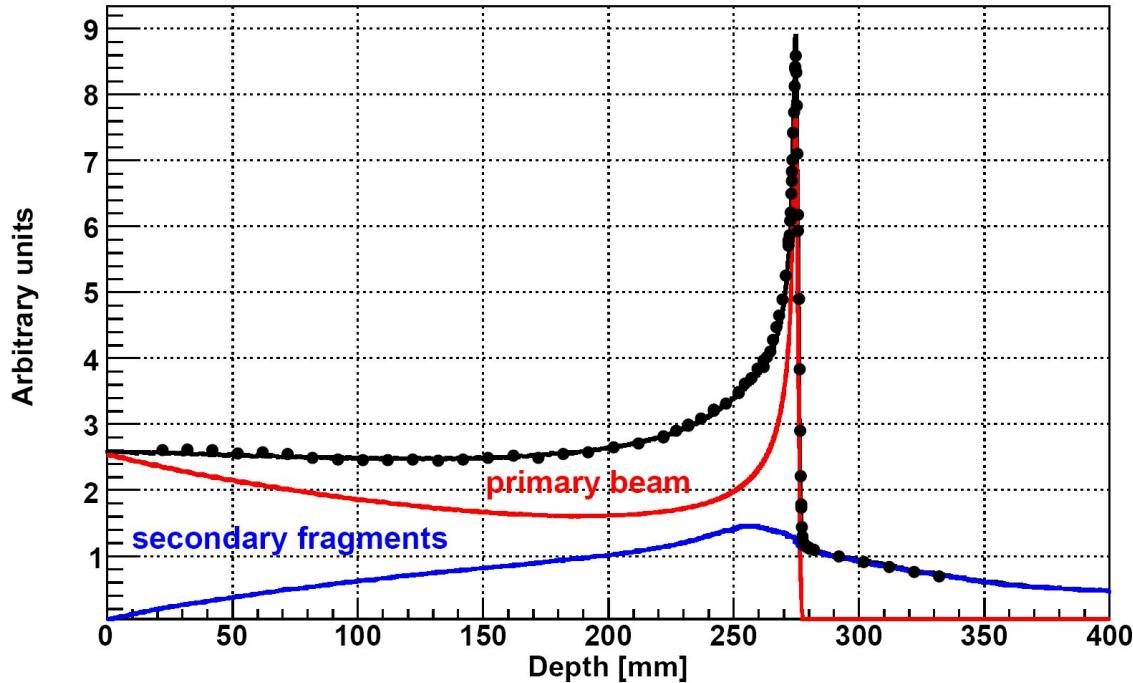
11 Bismuth and Aluminum samples
at different heights in CSBF and also
inside CHARM (@ -80cm)



@ 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

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

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

