Voxels and Medical Applications

21st FLUKA Beginner's Course

ALBA – Barcelona, Spain

08 – 12 April 2019

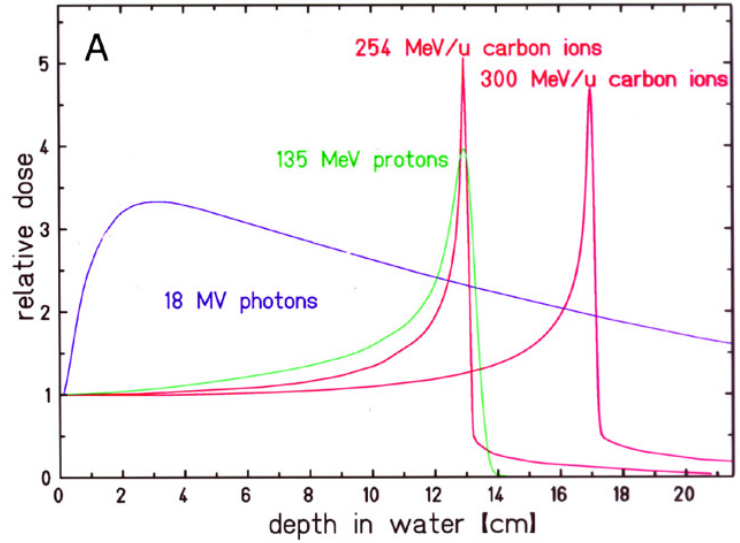
Medical Physics and related disciplines applications

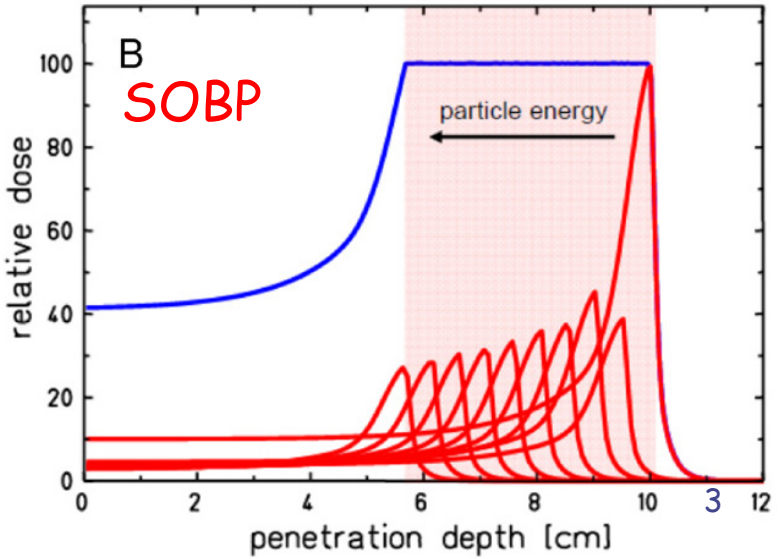
- Nuclear Medicine
  - Dosimetry
- Radiotherapy
  - Simulation of therapy devices
  - Simulations of treatments / treatment assessment
- Particle Therapy
  - Shielding
  - Facility commissioning
  - Treatment planning and forward checks
  - Predictions and data processing for monitoring applications (imaging for hadrontherapy)
  - Design of instruments, dosimetry
  - Calculation for shielding and rad. protection in facilities

Medical applications: Particle Therapy

One of the powerful application of FLUKA & FLAIR is related to Particle Therapy.

- Particle Therapy is a radiation therapy to treat tumors (deep seated, resistant to conventional RT with photons…)
- Exploits "heavy" charged particle beams (p, 12C…) typical energy loss in matter, characterized by the Bragg peak (BP)
- The more the beam kinetic energy the deeper the BP position
- Several BPs are summed up to cover the tumor volume (SOBP)

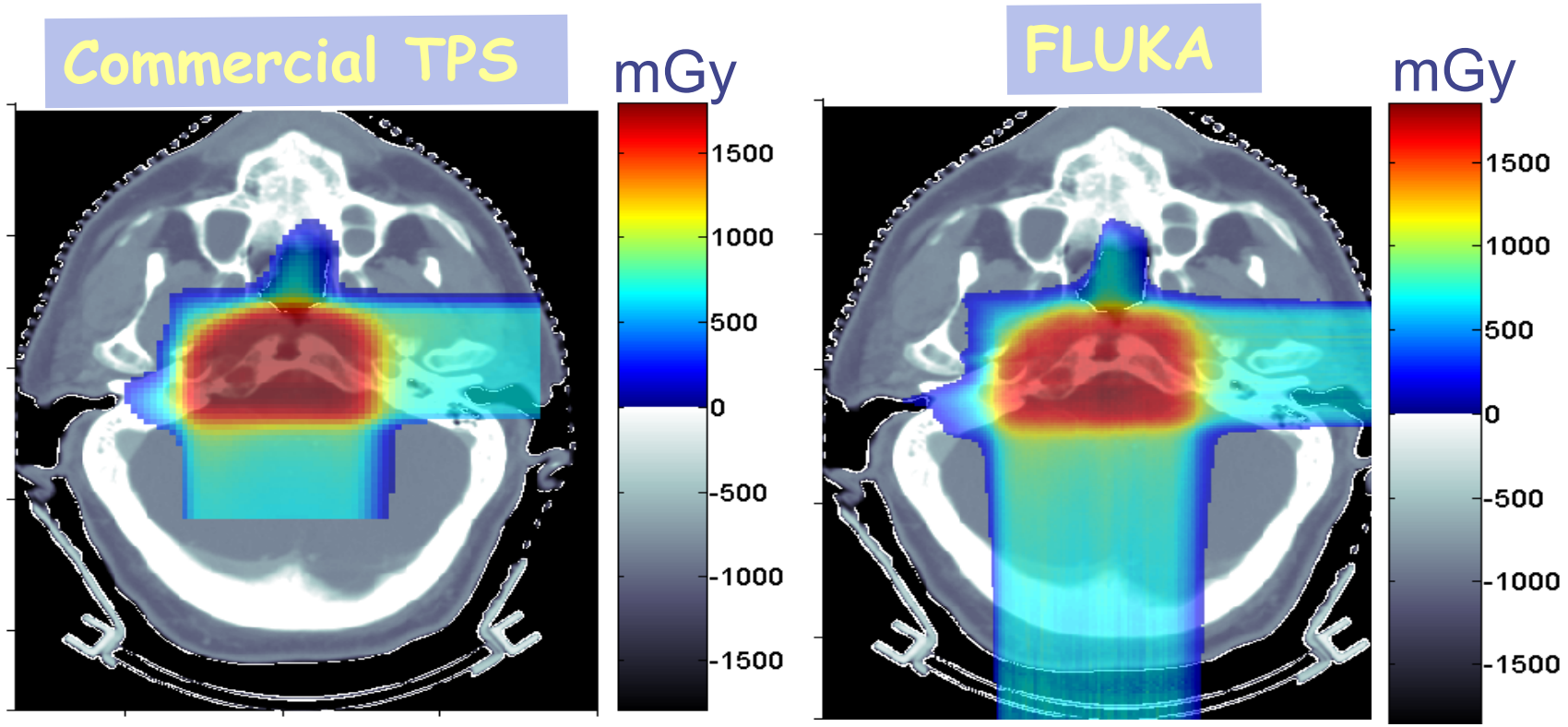




The issue of complex geometries: patient cases

In clinics, treatment plans are needed. The medical physicist have to decide in advance how to target the tumor based on patient CT.

CT scans of a human body are important also for dosimetric calculations of the planned treatment in radiotherapy.

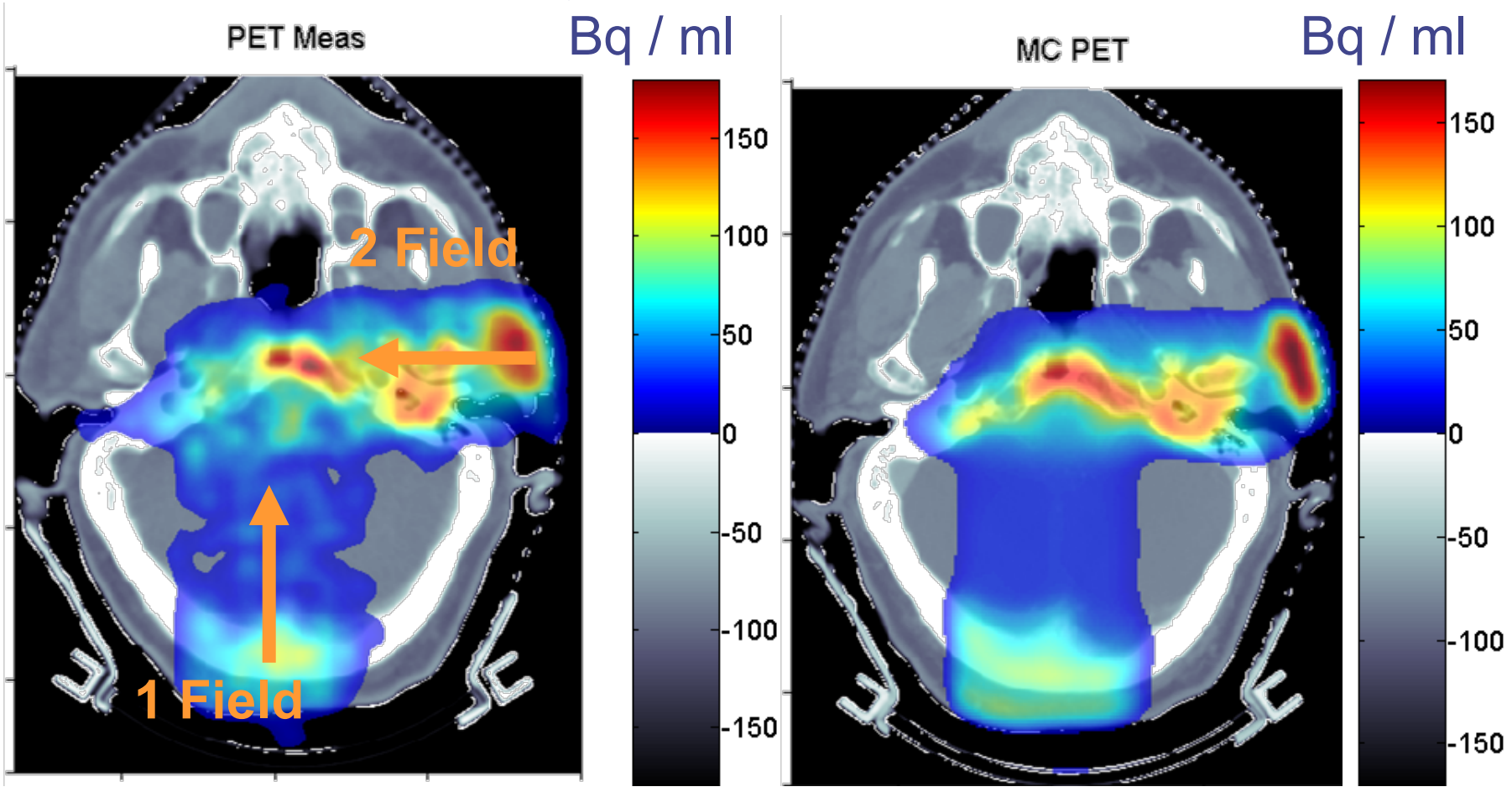


Parodi et al., 2007

Post-radiation PET/CT @ MGH

Average Activity

Clival Chordoma, 0.96 GyE / field, ΔT1 ~ 26 min, ΔT2 ~ 16 min



K. Parodi et al, IJROBP 2007

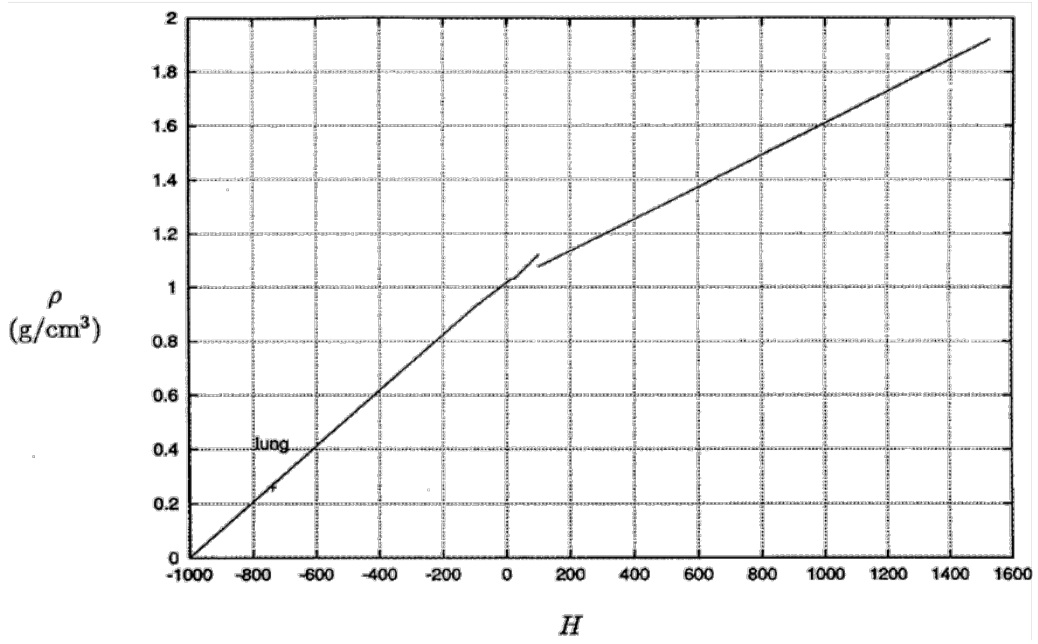
… and FLUKA-voxel functionalities being also used at CNAO …

CT stoichiometric calibration

- The CT scan contains integer values “Hounsfield Unit” reflecting the X-ray attenuation coefficient μ_x

$HU_x = 1000\ (\mu_x - \mu_{H20}) / \mu_{H20}$, typically $-1000 \leq HU \leq 3500$

Assign to each material a “nominal mean density”, e.g. using the density at the center of each HU interval **(Jiang et al, MP 2004)**



Schneider et al PMB 45, 2000

But “real density” (and related physical quantities) varies continuously with HU value !!!

Practical issues for Medical Applications: assigning a material to an *organ*

- How to assign realistic human tissue parameters (= materials) for MC Calculation ?
- How to find a good compromise between the number of different HU values (~ 3000-5000) and the materials to be considered in the MC ?
  (issues on memory and computation speed when attempting to treat each HU number as a different material !!!)
- How to preserve continuous, HU-dependent information when segmenting the HU numbers into intervals sharing the same “tissue” material ?
  (critical for ion range calculation in PT!!!)

CT stoichiometric calibration

CT segmentation into 27 materials of defined elemental composition (from analysis of 71 human CT scans)

Air, Lung, Adipose tissue

Soft tissue

Skeletal tissue

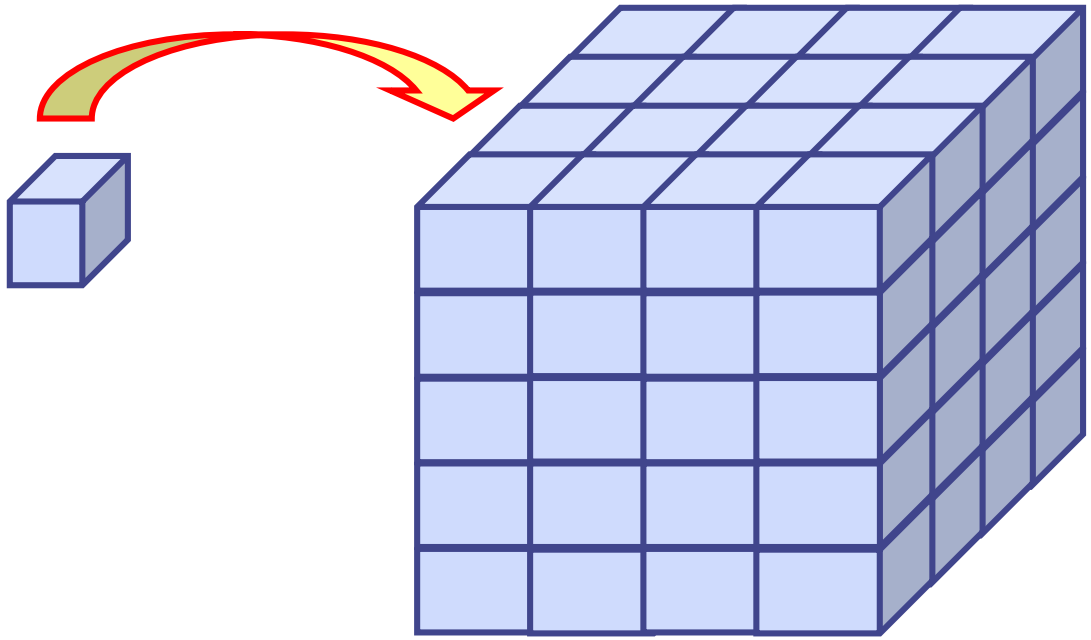
	w_i(pp)											
H	H	C	N	O	Na	Mg	P	S	Cl	Ar	K	Ca
−1000–−950			75.5	23.2						1.3		
−950–−120	10.3	10.5	3.1	74.9	0.2		0.2	0.3	0.3		0.2	
−120–−83	11.6	68.1	0.2	19.8	0.1			0.1	0.1			
−82–−53	11.3	56.7	0.9	30.8	0.1			0.1	0.1			
−52–−23	11.0	45.8	1.5	41.1	0.1		0.1	0.2	0.2			
−22–7	10.8	35.6	2.2	50.9			0.1	0.2	0.2			
8–18	10.6	28.4	2.6	57.8			0.1	0.2	0.2		0.1	
19–80	10.3	13.4	3.0	72.3	0.2		0.2	0.2	0.2		0.2	
80–120	9.4	20.7	6.2	62.2	0.6			0.6	0.3			
120–200	9.5	45.5	2.5	35.5	0.1		2.1	0.1	0.1		0.1	4.5
200–300	8.9	42.3	2.7	36.3	0.1		3.0	0.1	0.1		0.1	6.4
300–400	8.2	39.1	2.9	37.2	0.1		3.9	0.1	0.1		0.1	8.3
400–500	7.6	36.1	3.0	38.0	0.1	0.1	4.7	0.2	0.1			10.1
500–600	7.1	33.5	3.2	38.7	0.1	0.1	5.4	0.2				11.7
600–700	6.6	31.0	3.3	39.4	0.1	0.1	6.1	0.2				13.2
700–800	6.1	28.7	3.5	40.0	0.1	0.1	6.7	0.2				14.6
800–900	5.6	26.5	3.6	40.5	0.1	0.2	7.3	0.3				15.9
900–1000	5.2	24.6	3.7	41.1	0.1	0.2	7.8	0.3				17.0
1000–1100	4.9	22.7	3.8	41.6	0.1	0.2	8.3	0.3				18.1
1100–1200	4.5	21.0	3.9	42.0	0.1	0.2	8.8	0.3				19.2
1200–1300	4.2	19.4	4.0	42.5	0.1	0.2	9.2	0.3				20.1
1300–1400	3.9	17.9	4.1	42.9	0.1	0.2	9.6	0.3				21.0
1400–1500	3.6	16.5	4.2	43.2	0.1	0.2	10.0	0.3				21.9
1500–1600	3.4	15.5	4.2	43.5	0.1	0.2	10.3	0.3				22.5

Schneider et al PMB 45, 2000

From CT to FLUKA voxel geometry

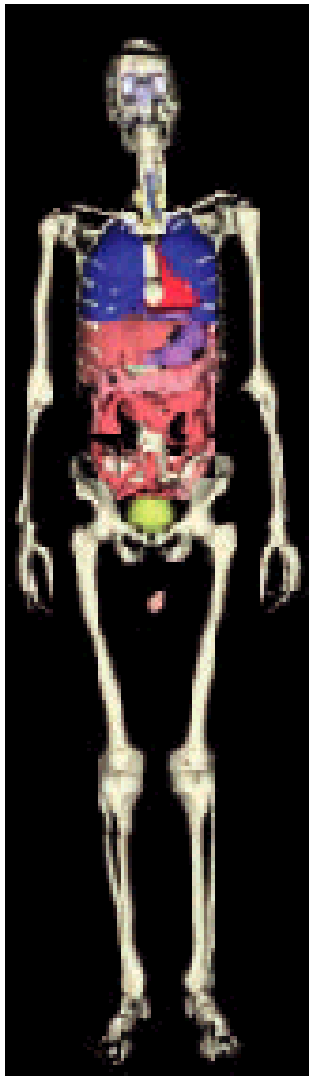
- The user must convert his CT scan or equivalent data to a format understood by FLUKA: VOXEL geometry. (Starting from DICOM images, this is performed directly by FLAIR - see next slides).

- It is possible to describe a geometry in terms of “voxels”, i.e., tiny parallelepipeds (all of equal size) forming a 3-dimensional grid

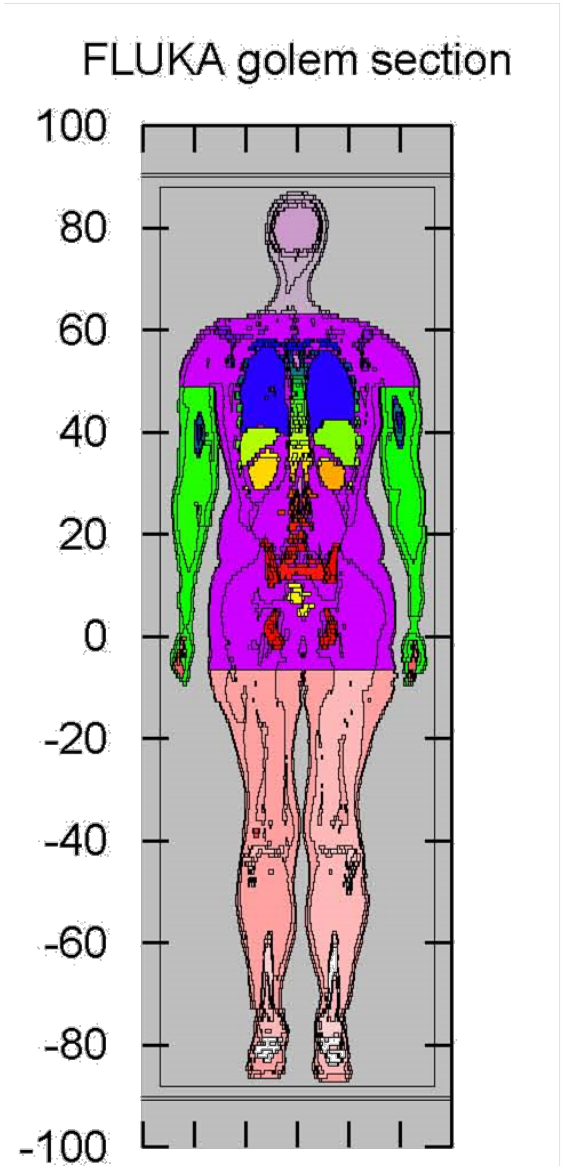


Voxel geometry - Example

The anthropomorphic
GOLEM phantom



Implementation in FLUKA (radioprotection applications)



Petoussi-Henss et al, 2002

From CT to FLUKA voxel geometry

- We will use loosely the word “organ” to indicate a group of voxels (or even more than one group) made of the same “tissue” material (same HU value or in a given HU interval)
- Assign an organ index to each voxel. In many practical cases, the user will have a continuum of CT values (HU), and may have to group these values in intervals
- Each organ is identified by a unique integer ≤32767. The organ numbering does not need to be contiguous i.e. “holes” in the numbering sequence are allowed.
- One of the organs must have number **0** and plays the role of the medium surrounding the voxels (usually vacuum or air).
- Assign to each NONZERO organ a voxel-region number. The voxel-region numbering has to be contiguous and starts from 1.

The FLUKA voxel geometry

- All CT information can be given as input to FLUKA through a special file *vxl containing:
  - The number of voxels in each coordinate
  - The number of voxel-regions, and the maximum organ number
  - The voxel dimension in each coordinate
  - A list of the organ corresponding to each voxel
  - A list of the voxel-region number corresponding to each organ
  - Definition of Regions of Interests (ROI)
    - A list of the ROIs for each voxel

- The code handles each organ as a Comb Geo region, possibly in addition to other conventional "non-voxel" regions defined by the user
- The voxel structure can be complemented by parts written in the standard Combinatorial geometry
- The code assumes that the voxel structure is contained in a parallelepiped. This RPP is automatically generated from the voxel information.

Example – Medical application

FLAIR has a capability to process the DICOM* files using the pydicom module and convert them to FLUKA VOXELS, USRBIN compatible files as well as providing input for Treatment Plan simulations

Needed softwares: http://www.fluka.org/flair/download.html

- Flair and Flair-geoviewer
- Python2 and Python2-scipy
- Tkinter toolkit
- Python imaging library
- Pydicom
- Numpy

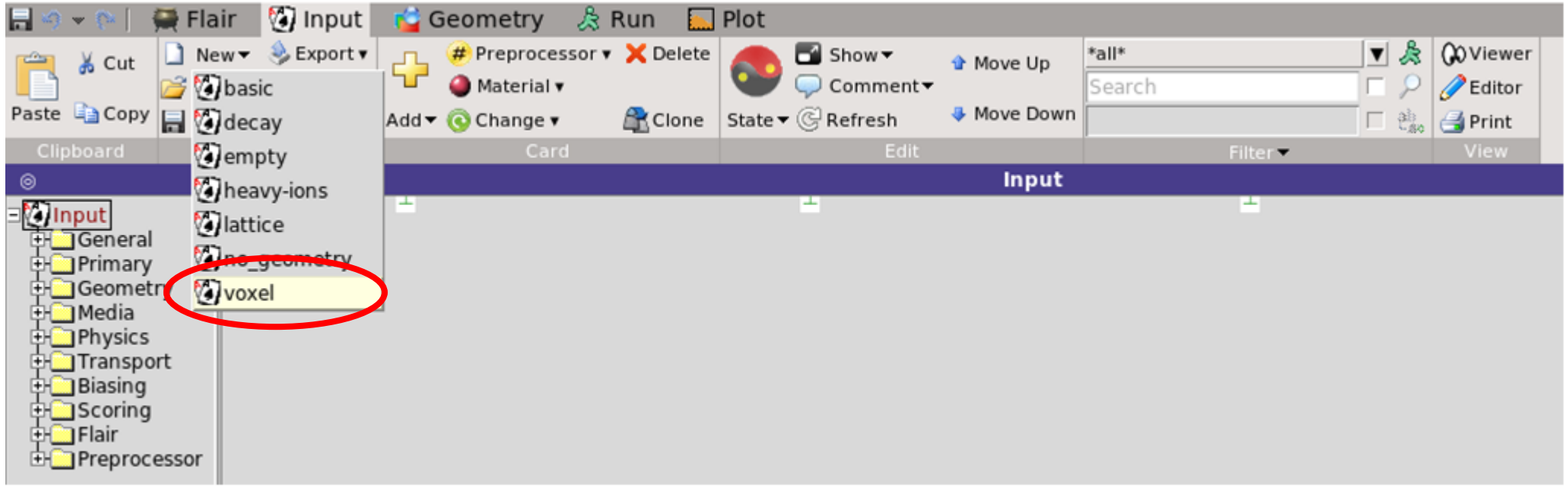
If some python package is missing, you will read a message like:

```
pydicom library is not installed

                Website: http://code.google.com/p/pydicom/

                Install:
                        Fedora    # dnf install python2-pydicom
                        Ubuntu    # apt-get install python-dicom python-scipy
                        all       # easy_install pydicom
                                  (Requires the python-setuptools),
                Extra requirements:
                        python-numeric, python-imaging or python-pillow,
                python-imaging-tk or python-pillow-tk
```

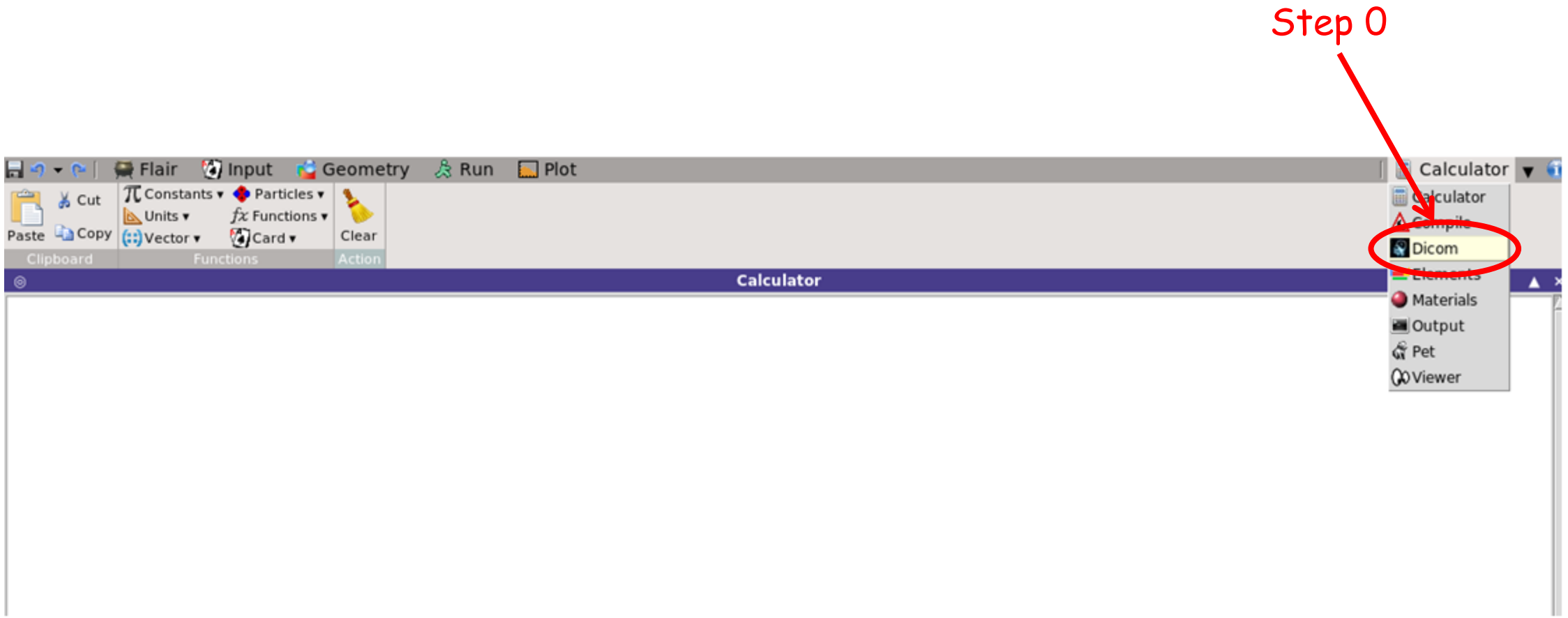
*DICOM=Digital Imaging and Communications in Medicine. It is a medical standard for distributing any kind of medical image

Prepare the input file:

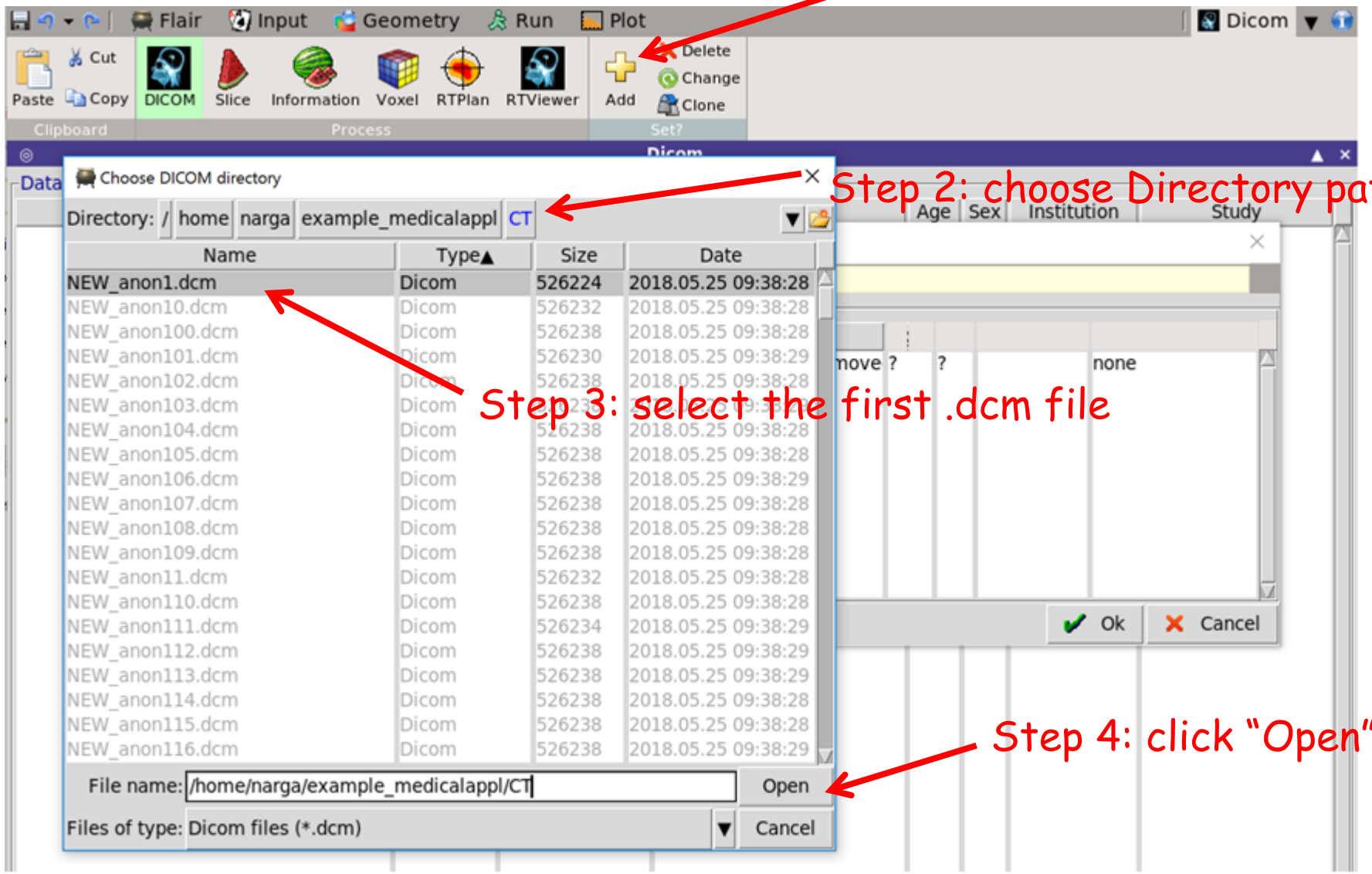
- Create the default input file for voxel using Flair



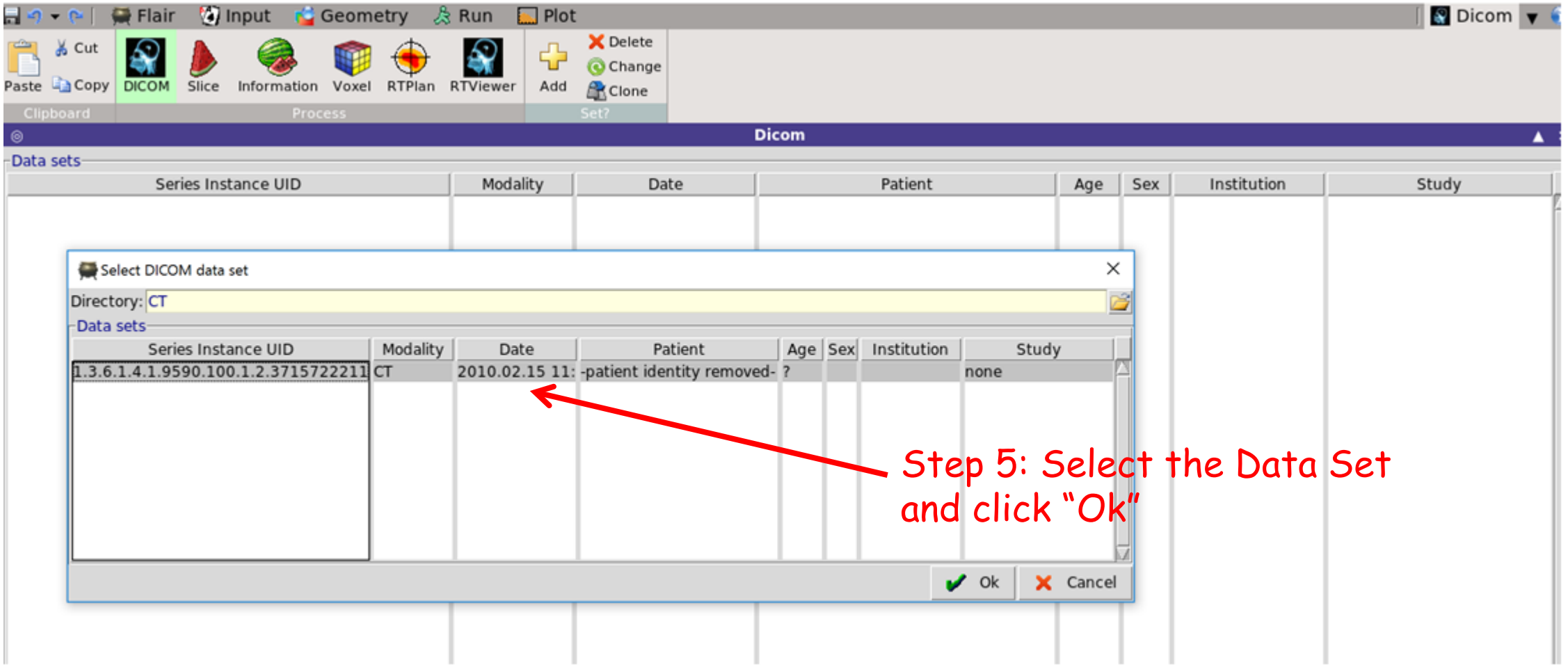
Import the DICOM



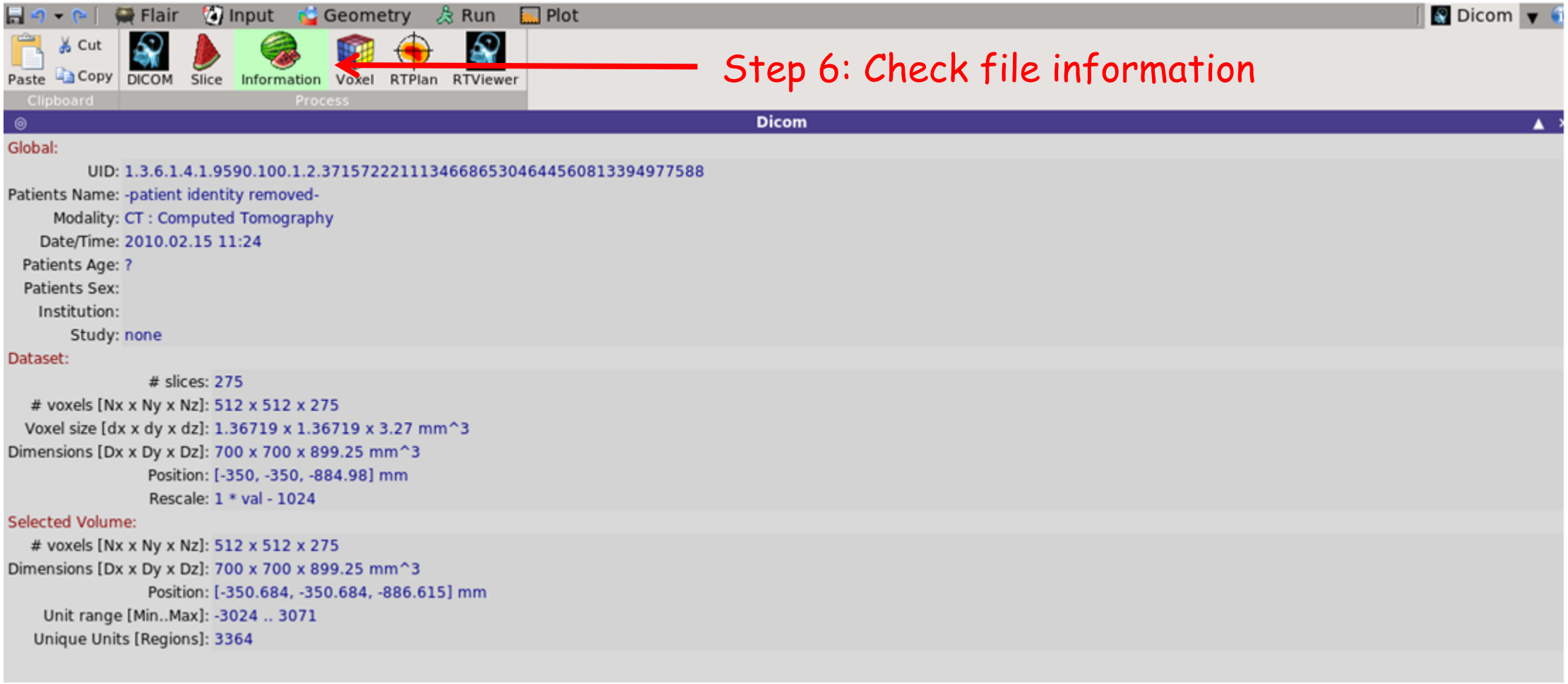
Choose **DICOM**



Open **DICOM**

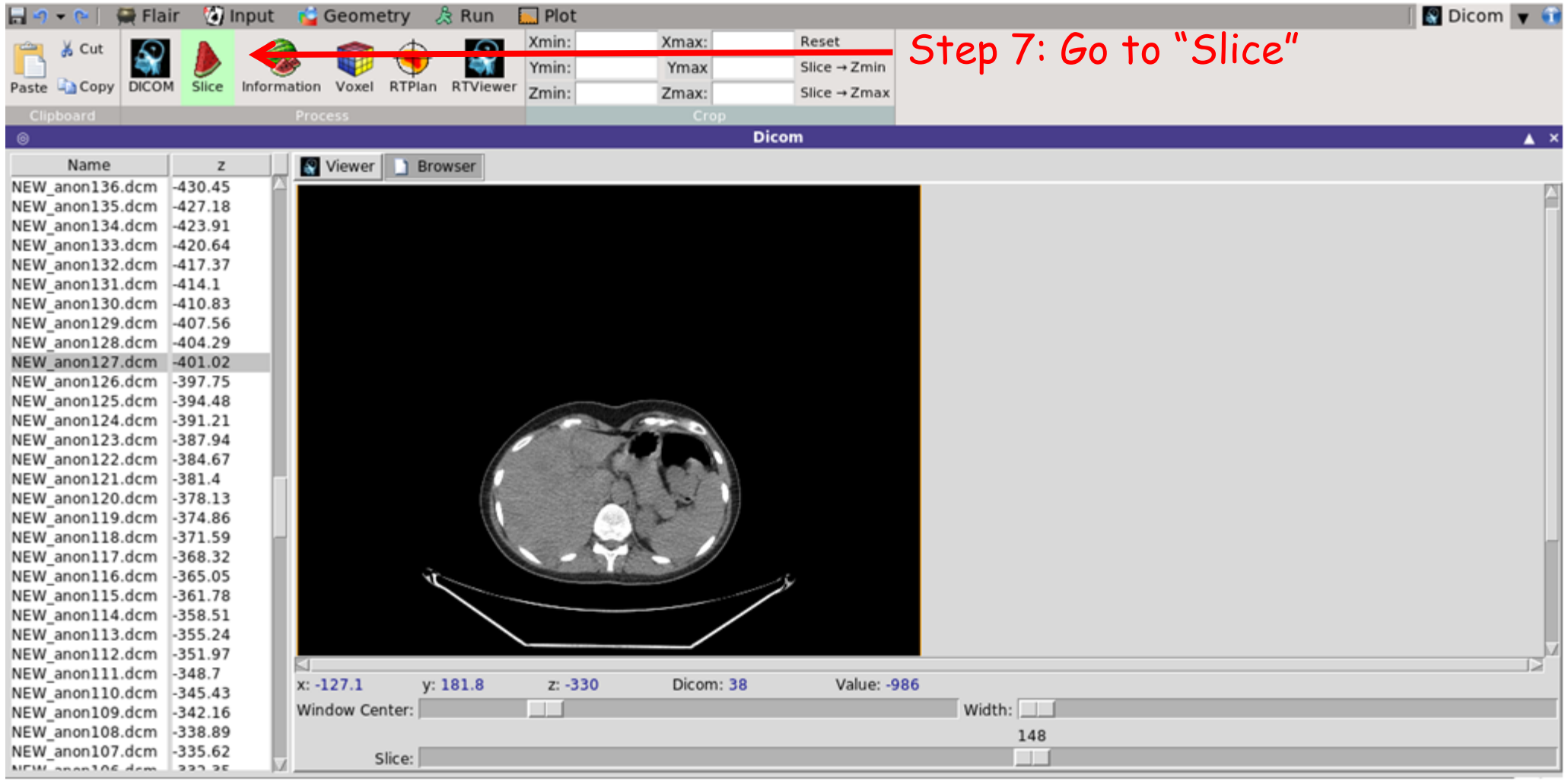

Flair
Input
Geometry
Run
Plot
Dicom
Cut
Copy
Paste
DICOM
Slice
Information
Voxel
RTPlan
RTViewer
Add
Delete
Change
Clone
Clipboard
Process
Set?
Dicom
Data sets
Series Instance UID
Modality
Date
Patient
Age
Sex
Institution
Study
Select DICOM data set
Directory: CT
Data sets
Series Instance UID
Modality
Date
Patient
Age
Sex
Institution
Study
1.3.6.1.4.1.9590.100.1.2.3715722211
CT
2010.02.15 11:
-patient identity removed-
?
none
Ok
Cancel
Step 5: Select the Data Set and click "Ok"

Infos about CT just loaded

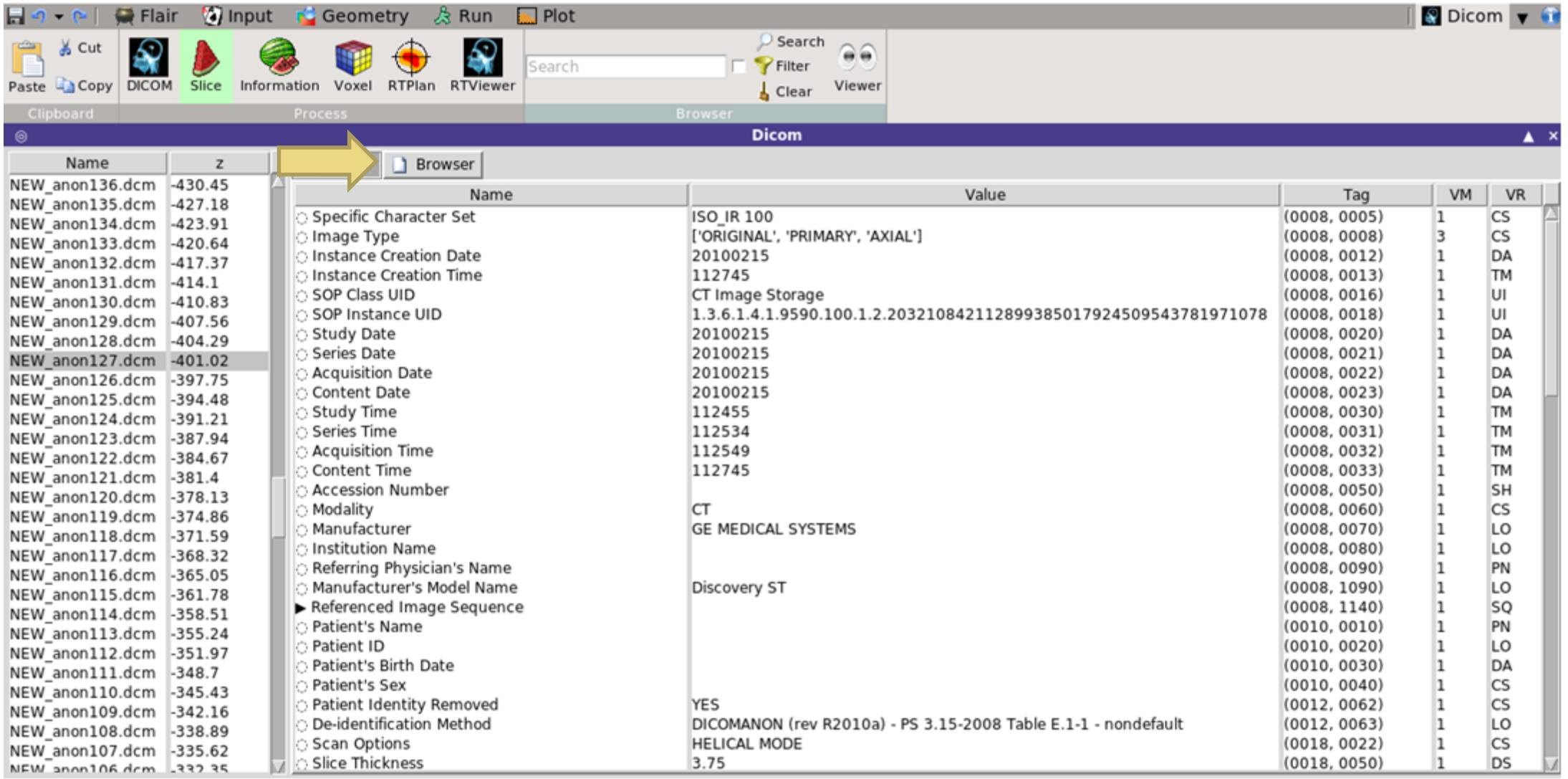


Inspecting the Images (1/2)

Each .dcm file represents a CT slice.

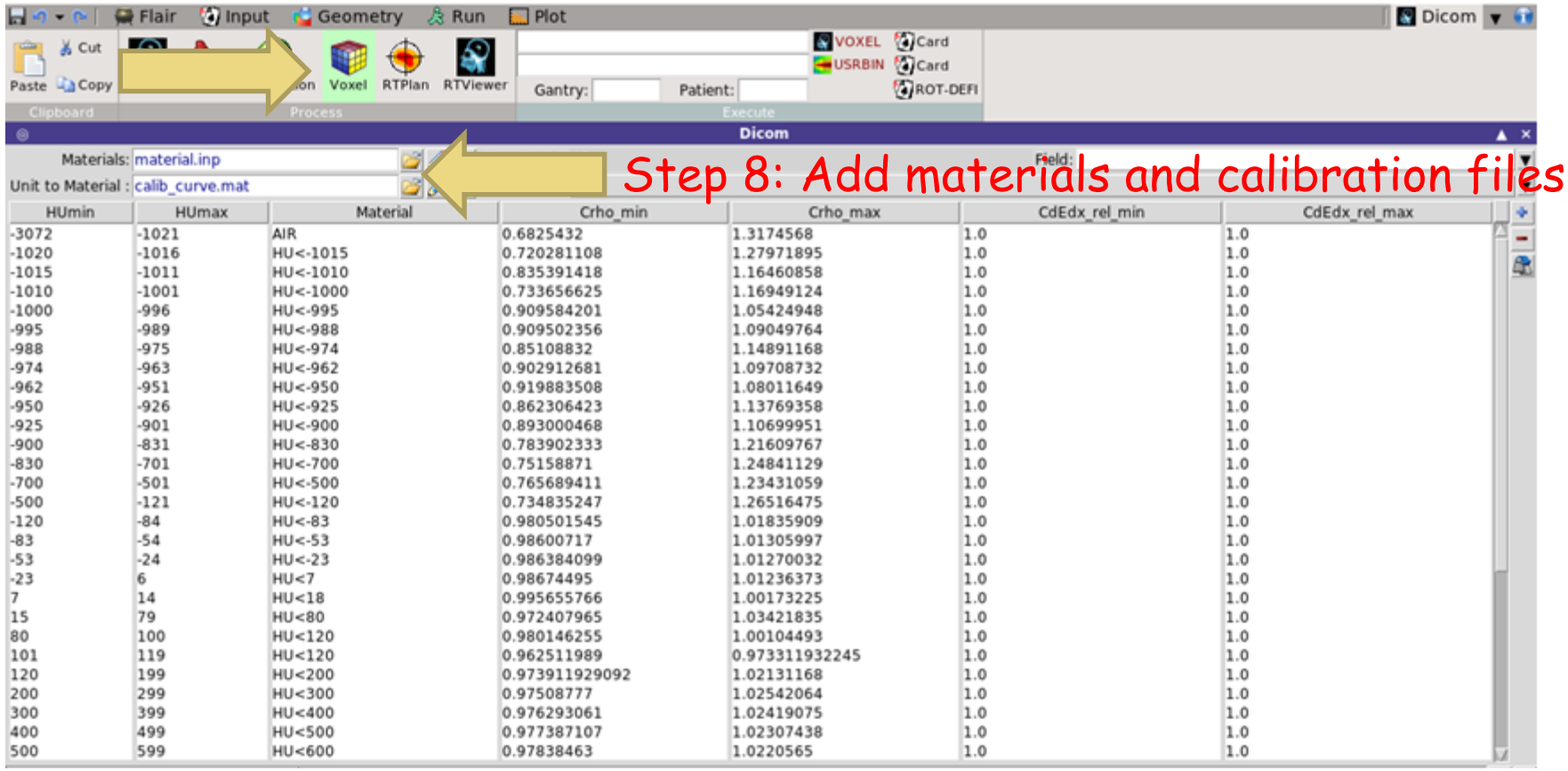


Inspecting the Images (2/2)



Creating the VOXEL file

The "Voxel" tab is used in order to convert the CT dataset to VOXELS. For the VOXEL geometry two additional files are needed (material.inp and calib_curve.mat).



HUmin	HUmax	Material	Crho_min	Crho_max	CdEdx_rel_min	CdEdx_rel_max
-3072	-1021	AIR	0.6825432	1.3174568	1.0	1.0
-1020	-1016	HU<-1015	0.720281108	1.27971895	1.0	1.0
-1015	-1011	HU<-1010	0.835391418	1.16460858	1.0	1.0
-1010	-1001	HU<-1000	0.733656625	1.16949124	1.0	1.0
-1000	-996	HU<-995	0.909584201	1.05424948	1.0	1.0
-995	-989	HU<-988	0.909502356	1.09049764	1.0	1.0
-988	-975	HU<-974	0.85108832	1.14891168	1.0	1.0
-974	-963	HU<-962	0.902912681	1.09708732	1.0	1.0
-962	-951	HU<-950	0.919883508	1.08011649	1.0	1.0
-950	-926	HU<-925	0.862306423	1.13769358	1.0	1.0
-925	-901	HU<-900	0.893000468	1.10699951	1.0	1.0
-900	-831	HU<-830	0.783902333	1.21609767	1.0	1.0
-830	-701	HU<-700	0.75158871	1.24841129	1.0	1.0
-700	-501	HU<-500	0.765689411	1.23431059	1.0	1.0
-500	-121	HU<-120	0.734835247	1.26516475	1.0	1.0
-120	-84	HU<-83	0.980501545	1.01835909	1.0	1.0
-83	-54	HU<-53	0.98600717	1.01305997	1.0	1.0
-53	-24	HU<-23	0.986384099	1.01270032	1.0	1.0
-23	6	HU<7	0.98674495	1.01236373	1.0	1.0
7	14	HU<18	0.995655766	1.00173225	1.0	1.0
15	79	HU<80	0.972407965	1.03421835	1.0	1.0
80	100	HU<120	0.980146255	1.00104493	1.0	1.0
101	119	HU<120	0.962511989	0.973311932245	1.0	1.0
120	199	HU<200	0.973911929092	1.02131168	1.0	1.0
200	299	HU<300	0.97508777	1.02542064	1.0	1.0
300	399	HU<400	0.976293061	1.02419075	1.0	1.0
400	499	HU<500	0.977387107	1.02307438	1.0	1.0
500	599	HU<600	0.97838463	1.0220565	1.0	1.0

- material.inp: file with conversion of HU to materials nominal density and composition
- calib_curve.mat: file with density correction factors to be applied to the lower/upper limit of the HU range

Creating the VOXEL file: the .mat file

- <= Unit: specify the upper limit of the range. Every entry will correspond to a range from the previous upper limit+1 until the current upper limit.
- Material: select any of the predefined FLUKA materials defined previously.

  Optionally you can specify correction factors for the density and dE/dx
- Crho_min/Chro_max: density correction factors to be applied on the lower/upper limit of the unit range.
- CdEdx_rel_min/CdEdx_rel_max: relative correction factors on dE/dx for minimum/maximum unit in the range.

HUmin	HUmax	Material	Crho_min	Crho_max	CdEdx_rel_min	CdEdx_rel_max
-3072	-1021	AIR	0.6825432	1.3174568	1.0	1.0
-1020	-1016	HU<-1015	0.720281108	1.27971895	1.0	1.0
-1015	-1011	HU<-1010	0.835391418	1.16460858	1.0	1.0
-1010	-1001	HU<-1000	0.733656625	1.16949124	1.0	1.0
-1000	-996	HU<-995	0.909584201	1.05424948	1.0	1.0
-995	-989	HU<-988	0.909502356	1.09049764	1.0	1.0
-988	-975	HU<-974	0.85108832	1.14891168	1.0	1.0
-974	-963	HU<-962	0.902912681	1.09708732	1.0	1.0
-962	-951	HU<-950	0.919883508	1.08011649	1.0	1.0
-950	-926	HU<-925	0.862306423	1.13769358	1.0	1.0
-925	-901	HU<-900	0.893000468	1.10699951	1.0	1.0
-900	-831	HU<-830	0.783902333	1.21609767	1.0	1.0
-830	-701	HU<-700	0.75158871	1.24841129	1.0	1.0
-700	-501	HU<-500	0.765689411	1.23431059	1.0	1.0
-500	-121	HU<-120	0.734835247	1.26516475	1.0	1.0
-120	-84	HU<-83	0.980501545	1.01835909	1.0	1.0
-83	-54	HU<-53	0.98600717	1.01305997	1.0	1.0
-53	-24	HU<-23	0.986384099	1.01270032	1.0	1.0
-23	6	HU<7	0.98674495	1.01236373	1.0	1.0
7	14	HU<18	0.995655766	1.00173225	1.0	1.0
15	79	HU<80	0.972407965	1.03421835	1.0	1.0
80	100	HU<120	0.980146255	1.00104493	1.0	1.0
101	119	HU<120	0.962511989	0.973311932245	1.0	1.0

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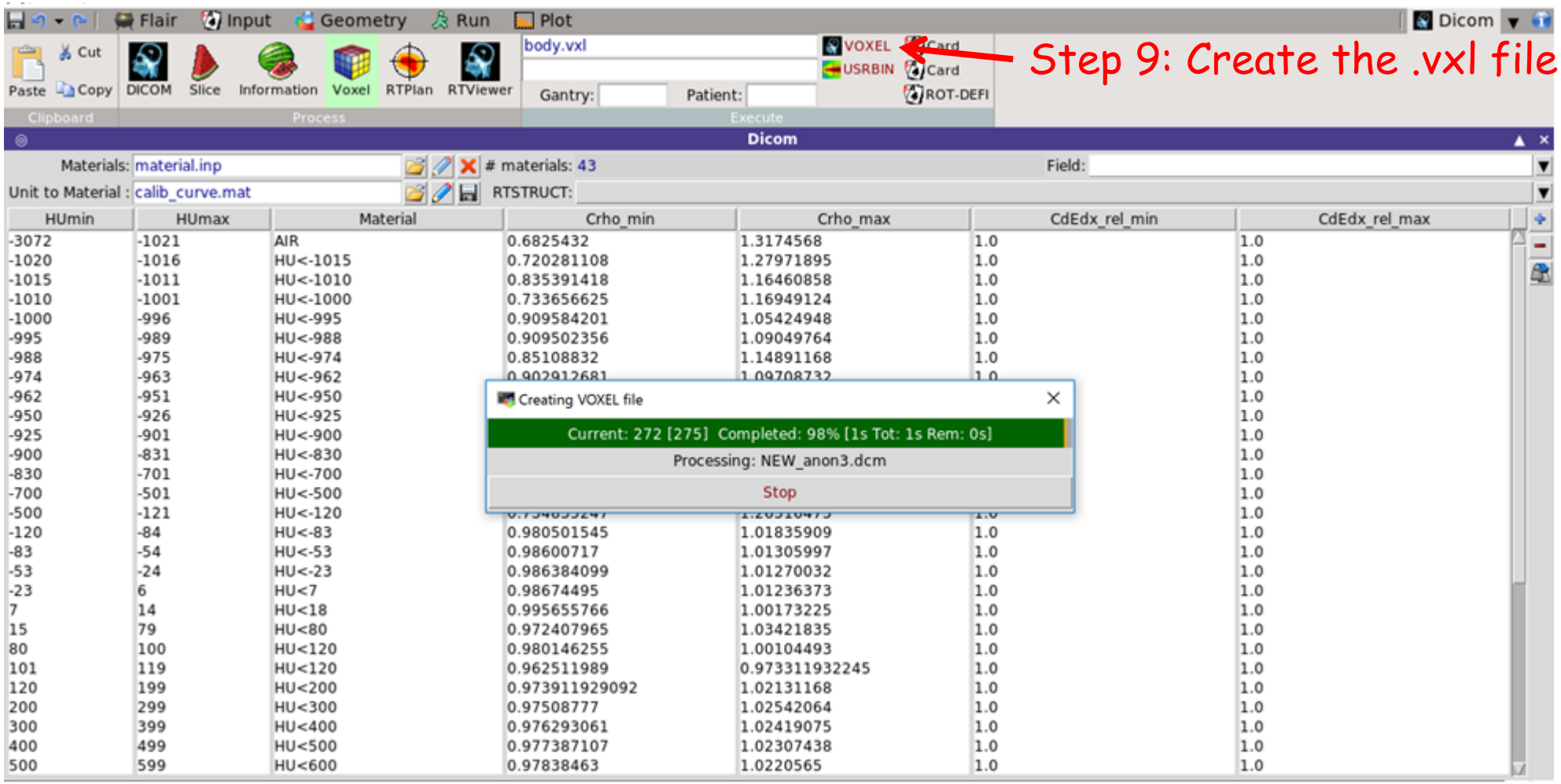

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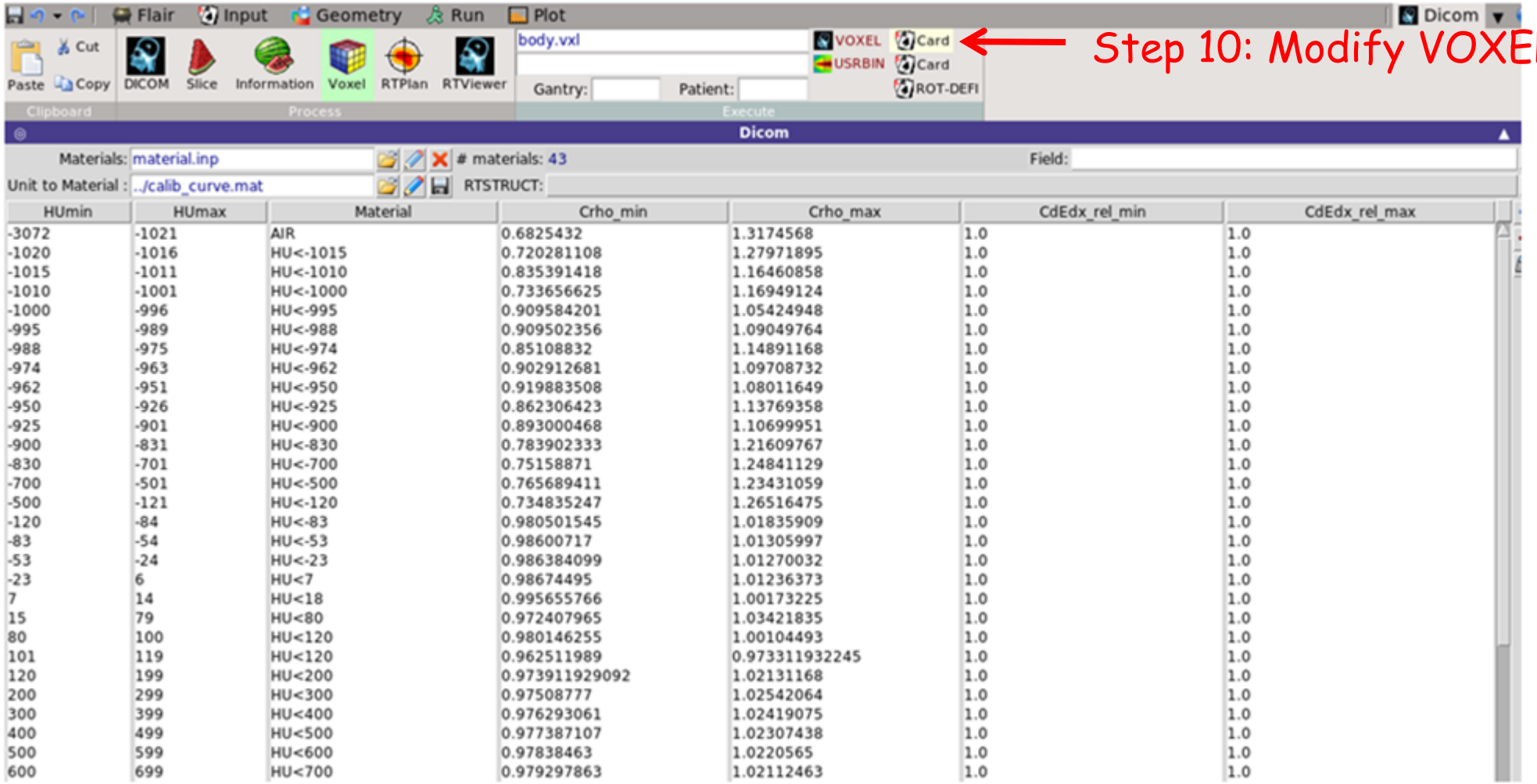
-1015	-1011	HU<-1010	0.835391418	1.16460858	1.0	1.0
-1010	-1001	HU<-1000	0.733656625	1.16949124	1.0	1.0
-1000	-996	HU<-995	0.909584201	1.05424948	1.0	1.0
-995	-989	HU<-988	0.909502356	1.09049764	1.0	1.0
-988	-975	HU<-974	0.85108832	1.14891168	1.0	1.0
-974	-963	HU<-962	0.902912681	1.09708732	1.0	1.0
-962	-951	HU<-950				1.0
-950	-926	HU<-925				1.0
-925	-901	HU<-900				1.0
-900	-831	HU<-830				1.0
-830	-701	HU<-700				1.0
-700	-501	HU<-500				1.0
-500	-121	HU<-120				1.0
-120	-84	HU<-83	0.980501545	1.01835909	1.0	1.0
-83	-54	HU<-53	0.98600717	1.01305997	1.0	1.0
-53	-24	HU<-23	0.986384099	1.01270032	1.0	1.0
-23	6	HU<7	0.98674495	1.01236373	1.0	1.0
7	14	HU<18	0.995655766	1.00173225	1.0	1.0
15	79	HU<80	0.972407965	1.03421835	1.0	1.0
80	100	HU<120	0.980146255	1.00104493	1.0	1.0
101	119	HU<120	0.962511989	0.973311932245	1.0	1.0
120	199	HU<200	0.973911929092	1.02131168	1.0	1.0
200	299	HU<300	0.97508777	1.02542064	1.0	1.0
300	399	HU<400	0.976293061	1.02419075	1.0	1.0
400	499	HU<500	0.977387107	1.02307438	1.0	1.0
500	599	HU<600	0.97838463	1.0220565	1.0	1.0

Modifying the VOXEL card

The "Voxel" tab is used in order to convert the CT dataset to VOXELS. For the VOXEL geometry two additional files are needed (material.inp and calib_curve.mat).



HUmin	HUmax	Material	Crho_min	Crho_max	CdEdx_rel_min	CdEdx_rel_max
-3072	-1021	AIR	0.6825432	1.3174568	1.0	1.0
-1020	-1016	HU<-1015	0.720281108	1.27971895	1.0	1.0
-1015	-1011	HU<-1010	0.835391418	1.16460858	1.0	1.0
-1010	-1001	HU<-1000	0.733656625	1.16949124	1.0	1.0
-1000	-996	HU<-995	0.909584201	1.05424948	1.0	1.0
-995	-989	HU<-988	0.909502356	1.09049764	1.0	1.0
-988	-975	HU<-974	0.85108832	1.14891168	1.0	1.0
-974	-963	HU<-962	0.902912681	1.09708732	1.0	1.0
-962	-951	HU<-950	0.919883508	1.08011649	1.0	1.0
-950	-926	HU<-925	0.862306423	1.13769358	1.0	1.0
-925	-901	HU<-900	0.893000468	1.10699951	1.0	1.0
-900	-831	HU<-830	0.783902333	1.21609767	1.0	1.0
-830	-701	HU<-700	0.75158871	1.24841129	1.0	1.0
-700	-501	HU<-500	0.765689411	1.23431059	1.0	1.0
-500	-121	HU<-120	0.734835247	1.26516475	1.0	1.0
-120	-84	HU<-83	0.980501545	1.01835909	1.0	1.0
-83	-54	HU<-53	0.98600717	1.01305997	1.0	1.0
-53	-24	HU<-23	0.986384099	1.01270032	1.0	1.0
-23	6	HU<7	0.98674495	1.01236373	1.0	1.0
7	14	HU<18	0.995655766	1.00173225	1.0	1.0
15	79	HU<80	0.972407965	1.03421835	1.0	1.0
80	100	HU<120	0.980146255	1.00104493	1.0	1.0
101	119	HU<120	0.962511989	0.973311932245	1.0	1.0
120	199	HU<200	0.973911929092	1.02131168	1.0	1.0
200	299	HU<300	0.97508777	1.02542064	1.0	1.0
300	399	HU<400	0.976293061	1.02419075	1.0	1.0
400	499	HU<500	0.977387107	1.02307438	1.0	1.0
500	599	HU<600	0.97838463	1.0220565	1.0	1.0
600	699	HU<700	0.979297863	1.02112463	1.0	1.0

The voxels card

The geometry is written like a normal Combinatorial Geometry input, but in addition a VOXELS card is inserted right after the GEOBEGIN card and before the Geometry title card

- WHAT(1), WHAT(2), WHAT(3) = x, y, z coordinates chosen as the origin of the "voxel volume", (i.e. of a region made of a single RPP body extending from WHAT(1) to WHAT(1) + NX*DX, …) which contains all the voxels
- WHAT(4) ROT-DEFI transformation applied to the whole voxel
- WHAT(5), WHAT(6): not used
- SDUM = name of the voxel file
  extension will be assumed to be .vxl)

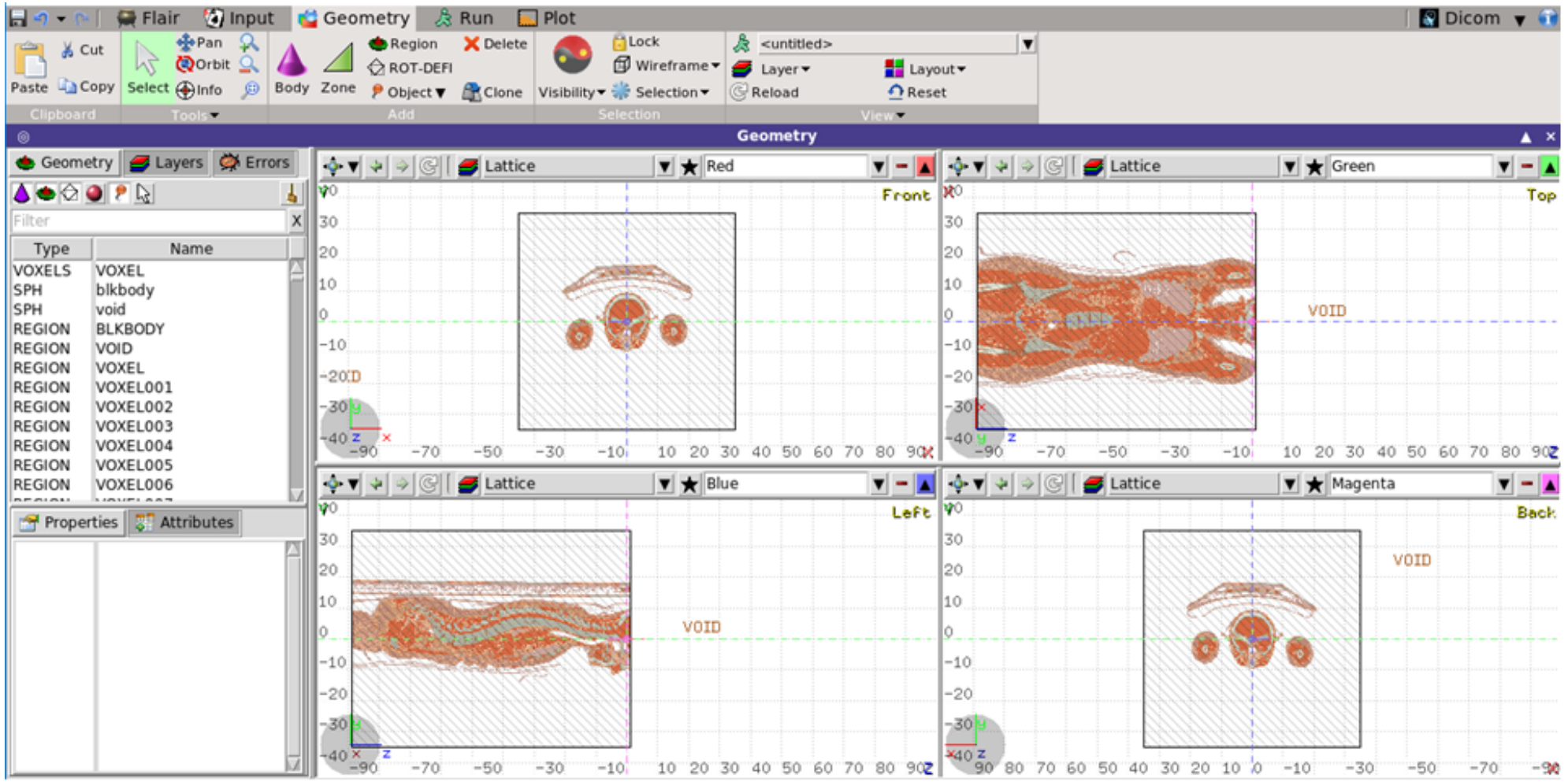
Voxel Body

- The usual list of NB bodies, not including the RPP corresponding to the “voxel volume” (see VOXELS card above). This RPP will be generated and added automatically by the code as the (NB+1)th body, with one corner in the point indicated in the VOXELS card, and dimensions NX*DX, NY*DY and NZ*DZ as read from the voxel file.
- The usual region list of NR regions, with the space occupied by body named VOXEL or numbered NB+1 (the “voxel volume”) subtracted. In other words, the NR regions listed must cover the whole available space, excepted the space corresponding to the “voxel volume”. This is easily obtained by subtracting body VOXEL or NB+1 in the relevant region definitions, even though this body is not explicitly input at the end of the body list.

GEOBEGIN		Log: ▾ Geometry: ▾	Acc: Out: ▾	Opt: ▾ Fmt: COMBNAME ▾
	Title:			
VOXELS		x: -35.0683594 Trans: ▾	y: -35.0683594 Filename: body ▾	z: -88.6615
Black body SPH	blkbody	x: 0 R: 100000	y: 0	z: 0
Void sphere SPH	void	x: 0 R: 10000	y: 0	z: 0
END				
Black hole REGION	BLKBODY		Neigh: 5	
	expr: +blkbody -void			
Void around REGION	VOID		Neigh: 5	
	expr: +void -VOXEL			
END				
GEOEND		▾		

Voxel Regions (1/2)

The code will automatically generate and add several regions



Voxel Regions

The code will automatically generate and add several regions.

- NM additional regions, where NM = number of non-zero organs:

Name	Number	Description
VOXEL	NR+1	sort of a "cage" for all voxels. Nothing should ever be deposited in it. The user shall assign vacuum to it.
VOXEL001	NR+2	containing all voxels belonging to organ number 0. There must be at least 2 of such voxels, but in general they should be many more. Typical material assignment to this region is air
VOXEL002	NR+3	corresponding to organ 1
VOXEL003	NR+4	corresponding to organ 2
VOXEL###	NR+2+NM	corresponding to organ NM

Run the example and check the output

Run a simulation using 400 MeV/n primary carbon ions at (0.0, 0.0, -200.0) cm.

In the output file check:

- RPP bodies
- Voxel regions
- Range of HUs and corresponding density and dE/dx
- Composition of materials with HUs<-1015
- CORRFACTors

The region-dependent CORRFACT card

- "CORRFACT" card allows to alter material density for dE/dx and nuclear processes
- First two WHATs specify a density scaling factor (restricted to the interval [2/3,3/2]) for charged particle ionization processes (WHAT(1)) and for all other processes (WHAT(2)) to the region(s) specified by the WHAT(4-6) *[cf. manual]*
- Especially important in PT to force the MC to follow the same semi-empirical HU-range calibration curve as the Treatment Planning System (TPS) for dosimetric comparisons
- At the end of the .vxl file FLAIR automatically appends the CORRFACT cards, calculated taking into account the calibration curves provided by the user.

How to account for HU-dependent dEdx

- In the INPUT
  - Let several regions share the same material composition and mean density according to CT segmentation (reduced number of materials to save memory / initialization time)

```
ASSIGNMA    BONE  VOXEL005          (region number 25)
ASSIGNMA    BONE  VOXEL016          (region number 31)
```

  - Use CORRFACT to impose the desired correction for stopping power (⇒ ion range!) in the regions KREG corresponding to different organs IO (i.e., different HU values) sharing the same MATERIAL assignment

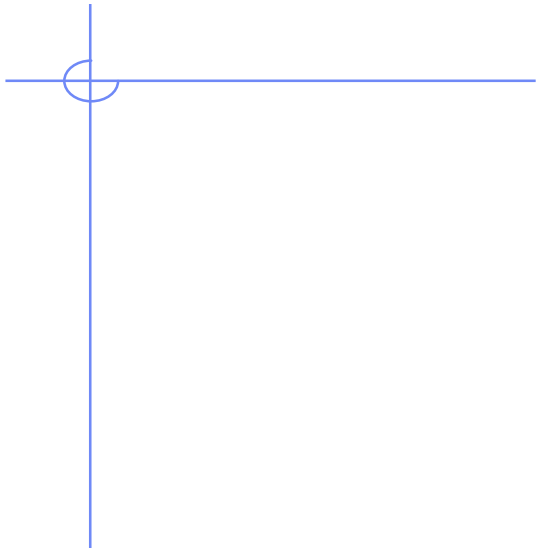
```
CORRFACT      0.85      0.0      0.0      25
CORRFACT      1.3       0.0      0.0      31
```

Region #25 corresponds to "softer" bone than #31

Few remarks

- The assignment of materials to organ regions is made directly by FLAIR. The user has to assign the materials to the remaining regions defined by standard combinatorial geometry.

- The “calib_curve.mat” and “material.inp” files are examples, the users should update these files taking into account the calibration curves for their treatment planning systems (calibration curve depends on the calculation method, used phantom and (only slightly) scanner.



Additional Info

FLUKA PET TOOLS (1/2)

The FLUKA PET TOOLS package* consists of:

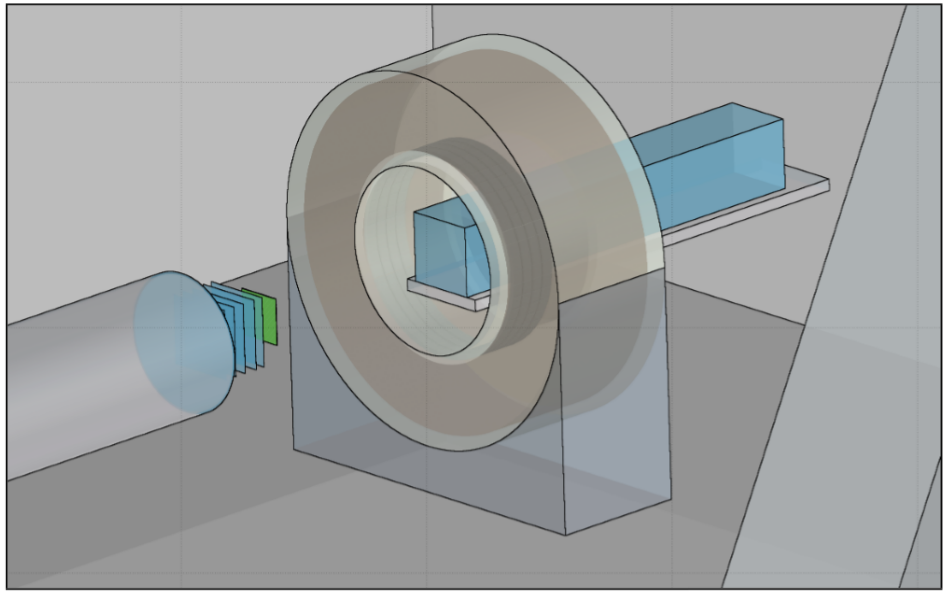
- **PET geometry tools**: to replicate the PET scanner
  existing commercial models or a customized model
- **Scoring routines**: to collect the relevant simulated data (e.g. coincidence γ)
- **Post-processing routines**: to generate both sinogram and coincidence lists output
- **Imaging tools**: by means of a filtered-back-projection algorithm, or an embedded maximum-likelihood-estimation-method**, the output is converted into images.

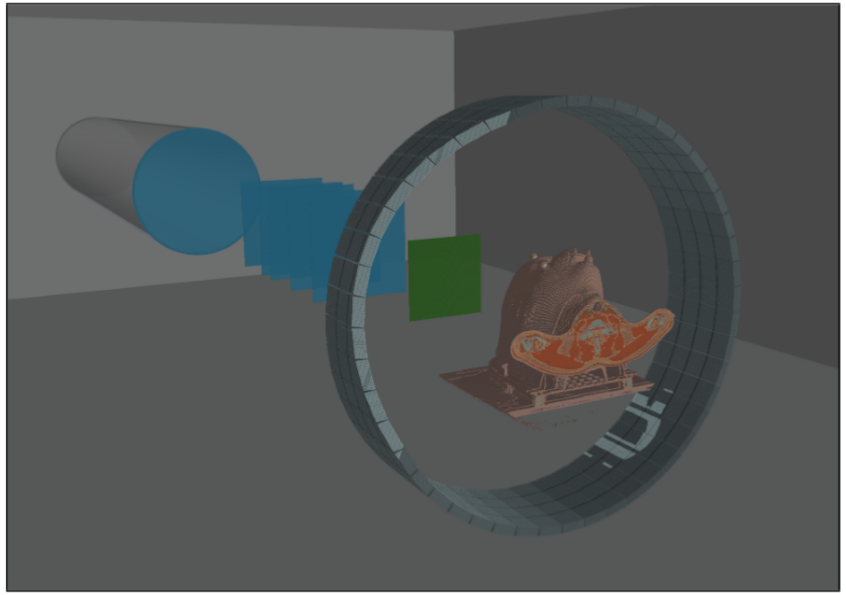
*Ortega P-PG *et al* 2014 Radiother Oncol, 110
**MLEM implementation code written by Toufique Y

FLUKA PET TOOLS (2/2)

The FLUKA PET TOOLS package allows:

- to model a realistic PET scanner in Flair
- image acquisition a in a patient VOXEL phantom
- integration of beam time structure and event filtering
- scanner design and image optimization





RS Augusto, PhD thesis, Univ of Munich LMU

FLUKA PET TOOLS : Example of application

Mouse Geometry in Flair

Radioisotope density map in Flair

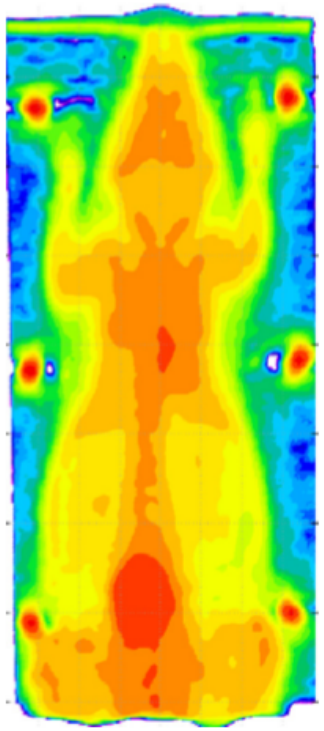


Image reconstructed with FBP

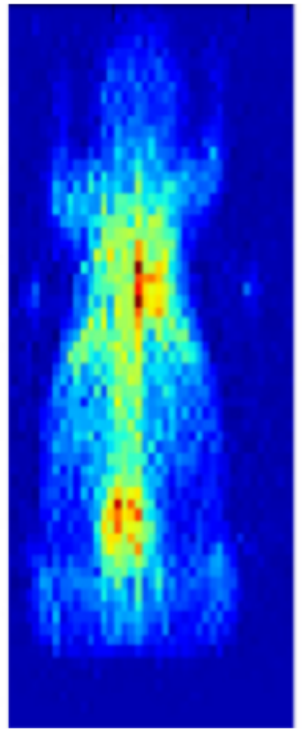
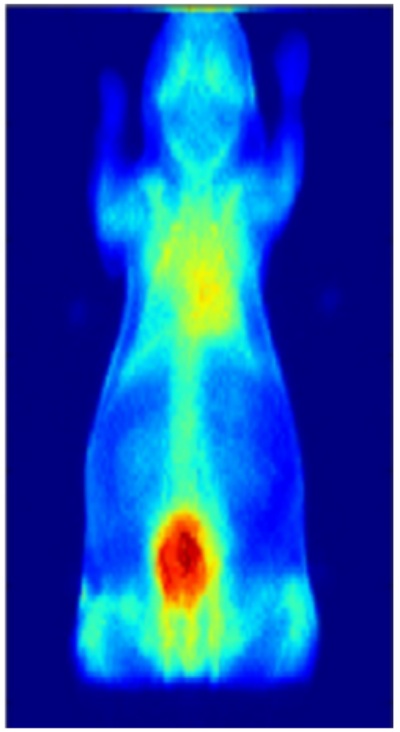


Image reconstructed with MLEM



RS Augusto *et al.* Physica Medica 54 (2018) 189–199

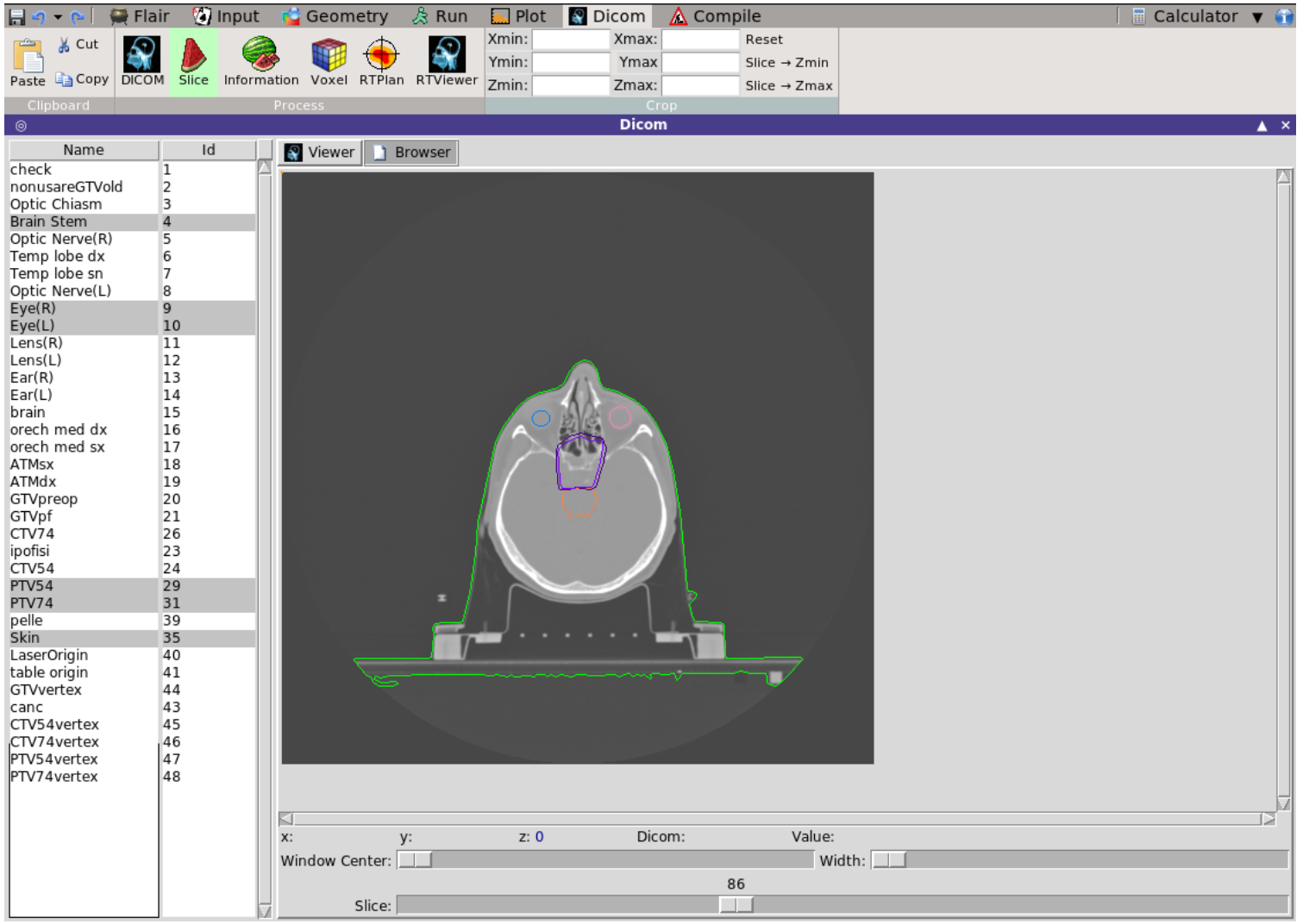
Spare

The FLUKA voxel with ROI

- The information for regions of interest (ROIs) and points of interests (eg. dose reference points) are included in RTSTRUCT file
- ROIs are represented as the points belonging to a closed polygon using 2D coordinates (not rounded to the pixel size of the corresponding CT image).
- User can embedded RTSTRUCT file into the VOXEL
  - For each voxel Flair identifies list of ROIs and creates ROI to voxel correspondence matrix
  - Voxel **with RT STRUCT** information can be currently used as an input for DVH calculations, however **simulations will be available with the next FLUKA release**
  - Flair provides some checks on the structures, like calculating volumes using the true polygonal information or the discretiza- tion to voxels. Differences up to few percent can be visible due to quantification process

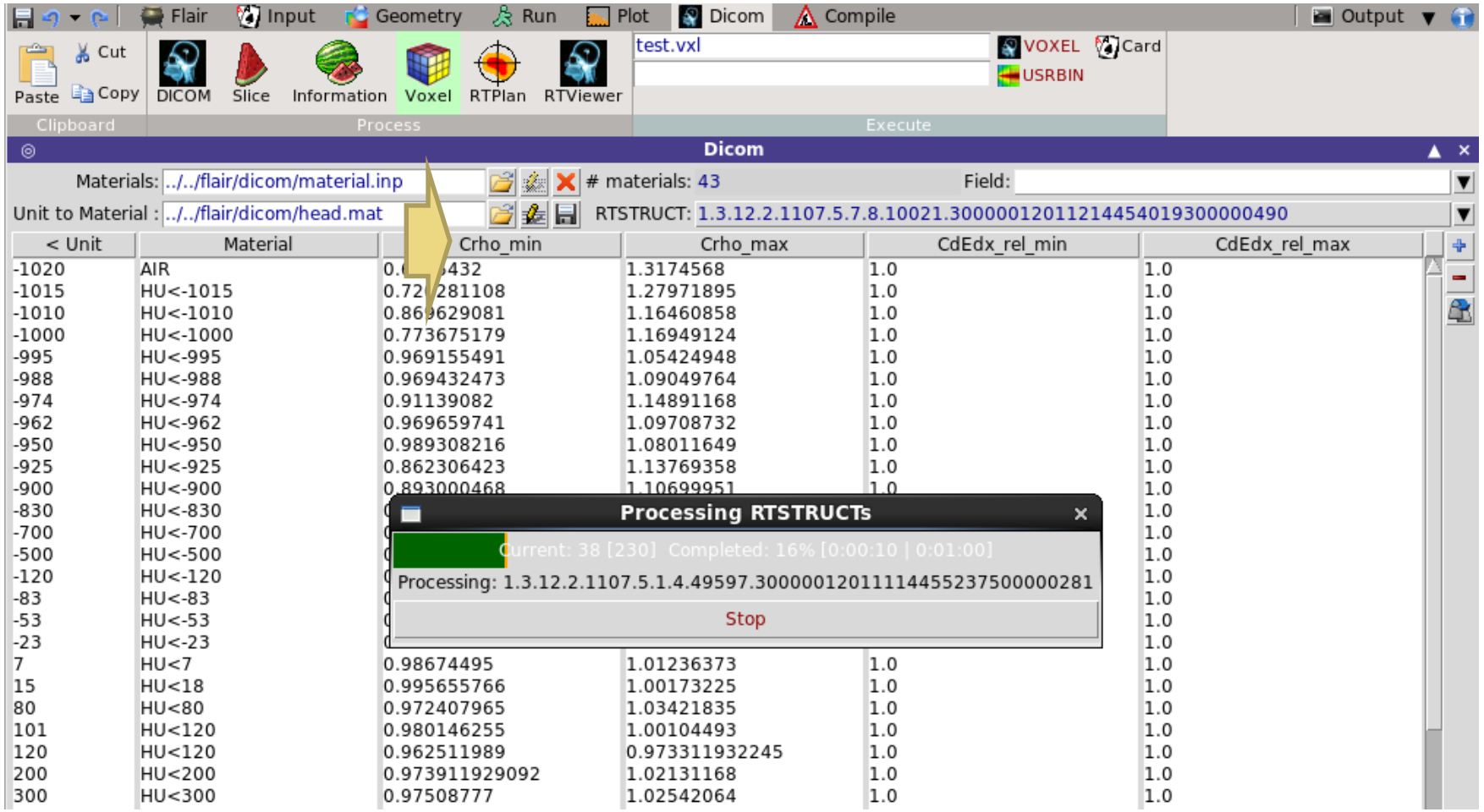
Processing the **DICOM** files with FLAIR VII

Select RTSTRUCT "Data sets" and inspect the ROI's



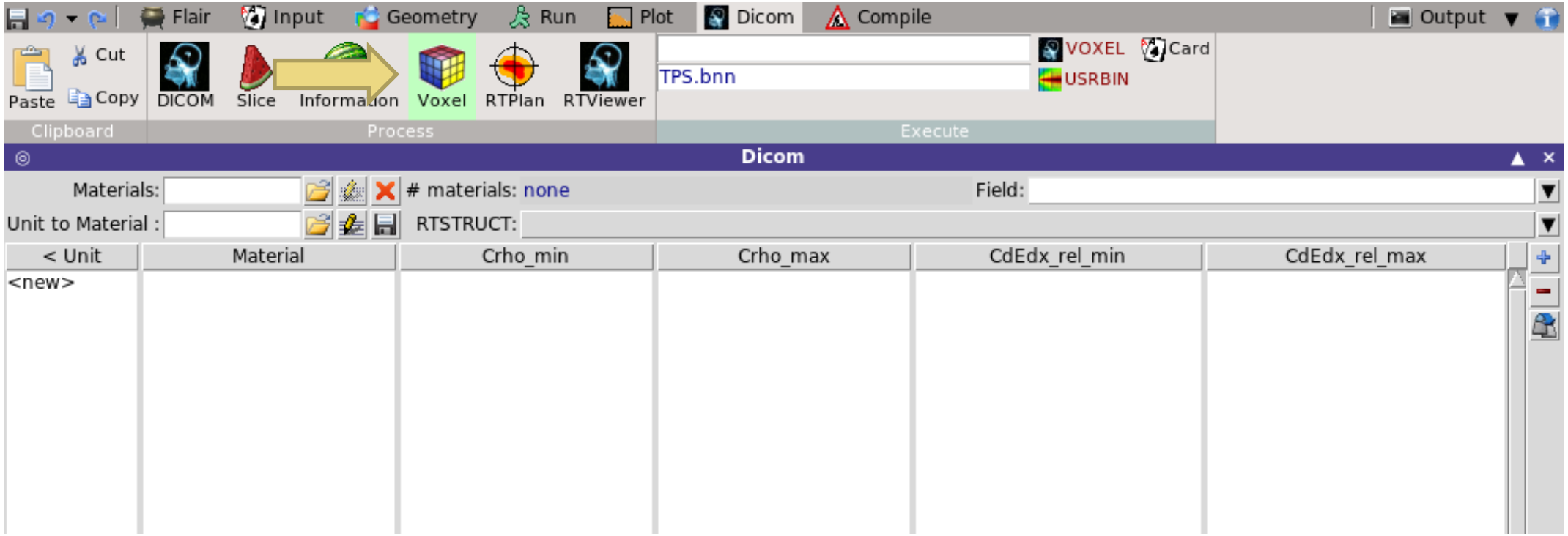
Processing the **DICOM** files with FLAIR VIII

User can include ROIs imported from RTSTRUCT. Selection of corresponding file is done in VoxelTab.



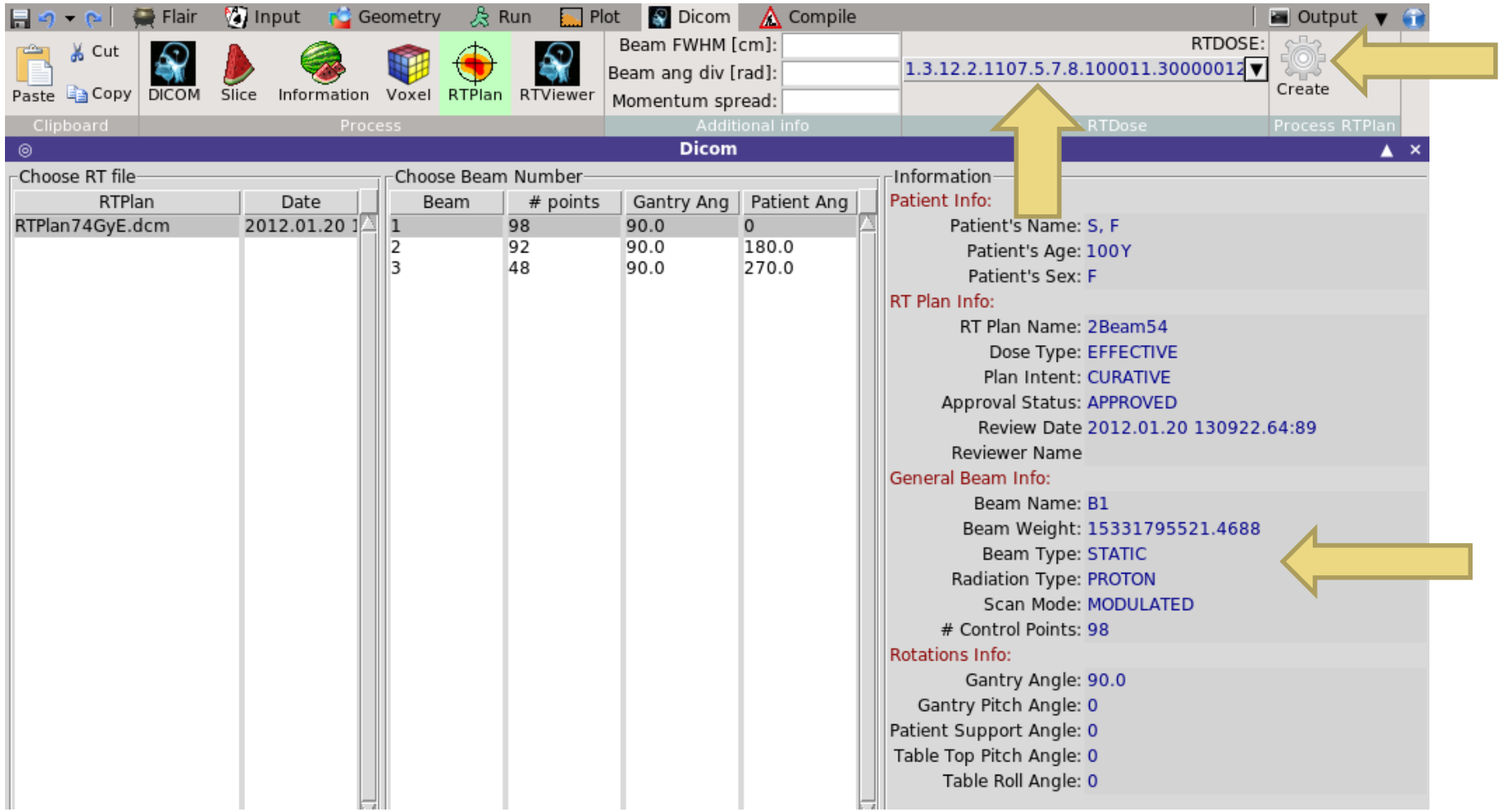
Processing the **DICOM** files with FLAIR IX

The "VoxelTab" is also for converting the RTDOSE dataset to FLUKA understandable format – USRBIN.
This can be further used for postprocessing and plotting purposes.



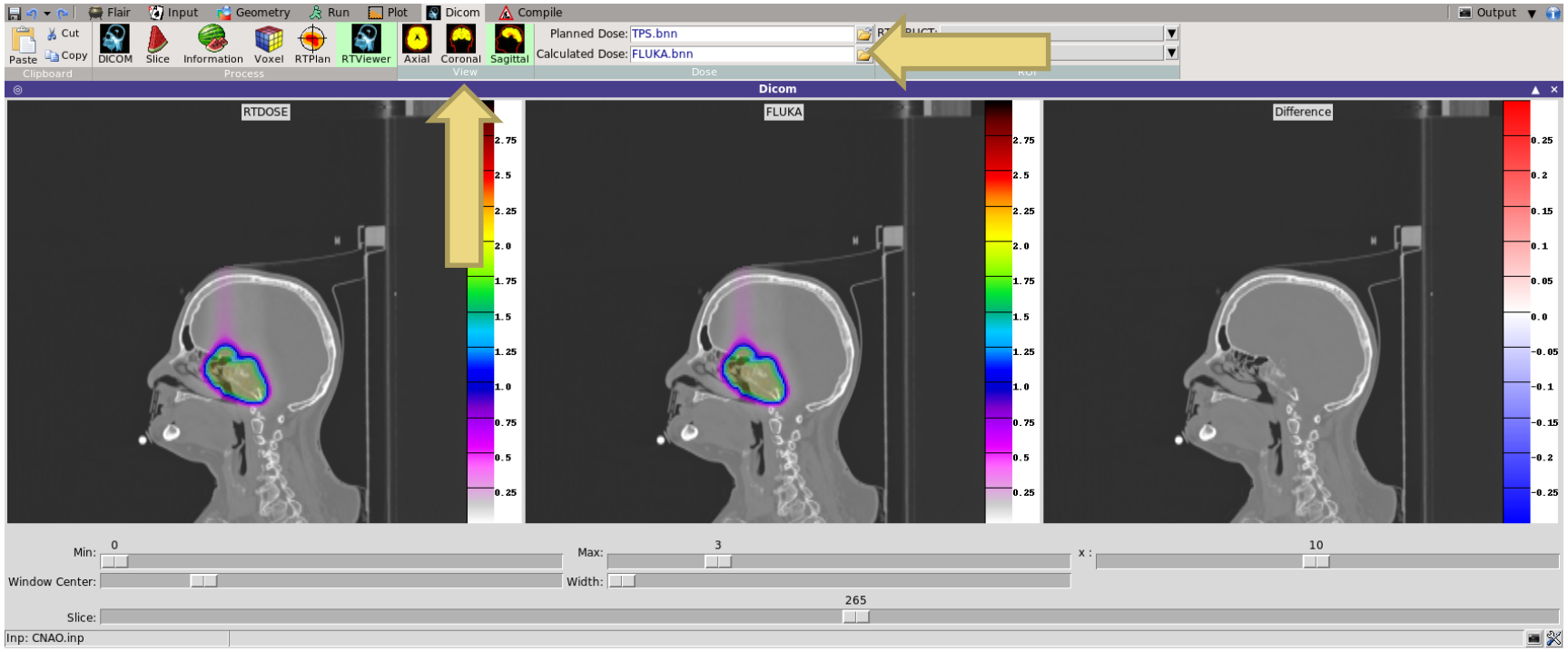
Processing the **DICOM** files with FLAIR X

The "RTPlan" tab is used to modify input file for Treatment Plan Simulations using data from RTPLAN and RTDOSE



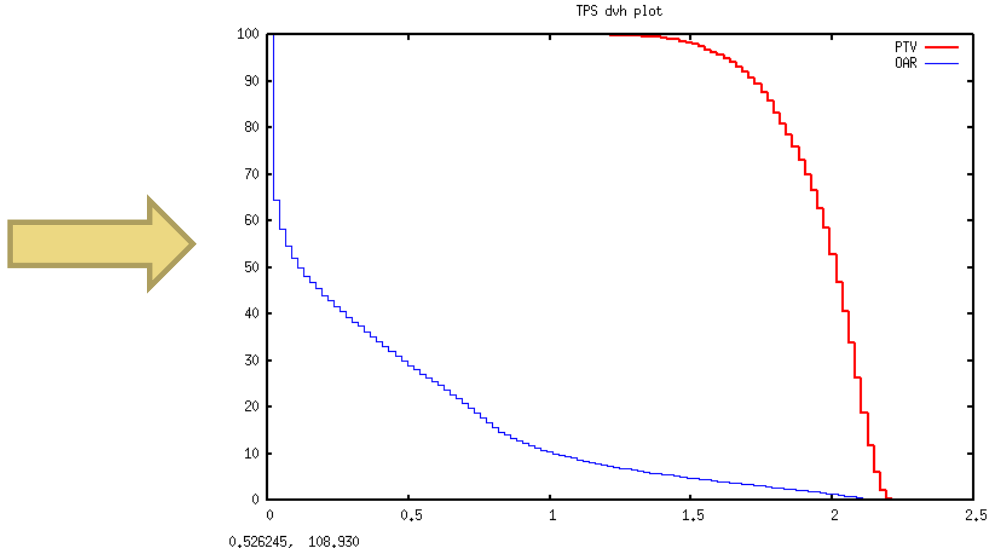
Processing the **DICOM** files with FLAIR XI

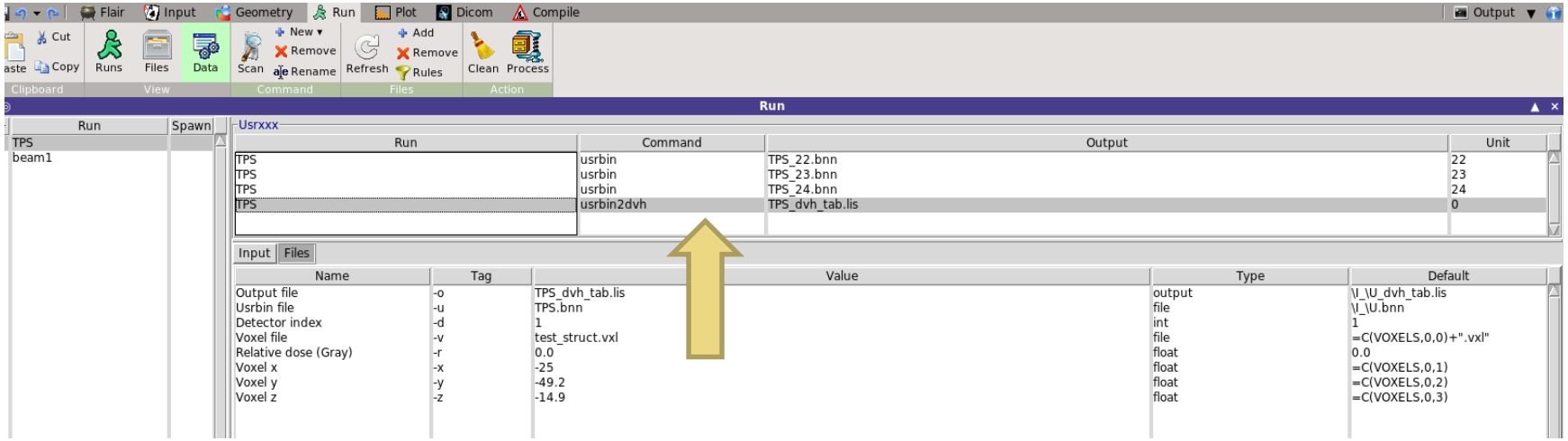
- The "RTViewer" tab provides graphical comparison of TPS and FLUKA calculations using USRBIN files
- Available views for Axial, Coronal and Sagittal planes



Processing the **DICOM** files with FLAIR XII

FLAIR postprocessing routine allows to create data for Dose-Volume Histograms (DVH) plots





Few remarks

- Updated input file from RTPlan Tab uses #include cards in order to import pencil beam parameters.
  Due to typical vast number of described beams user needs to **activate/deactivate** these cards .

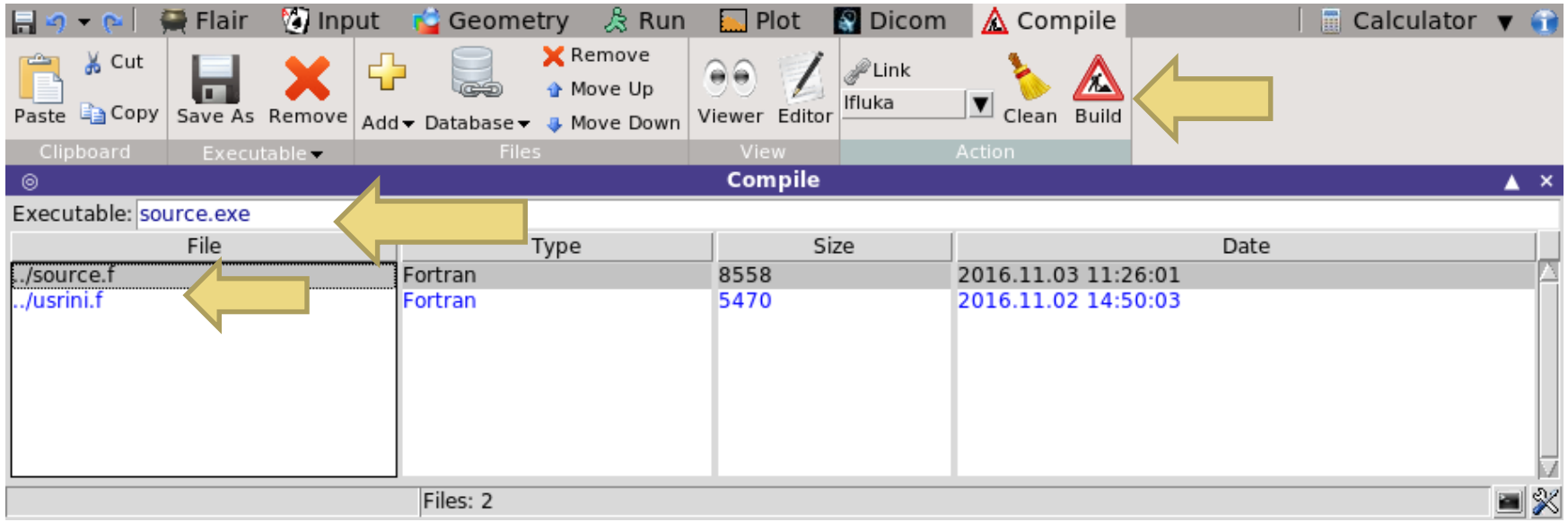
- Simulated and processed FLUKA files have to be **weighted** according to the information from RTPlan – usrwei routine available in FLAIR.

- DVH plots requires *.vxl file **with RTSTRUCT** information.

- In RTViewer graphical comparison is available only for the *.bnn files with the **same binnings and positions**.
  Editing input file by RTPlan Tab allows to provide correct parameters – user chooses corresponding RTDOSE file.

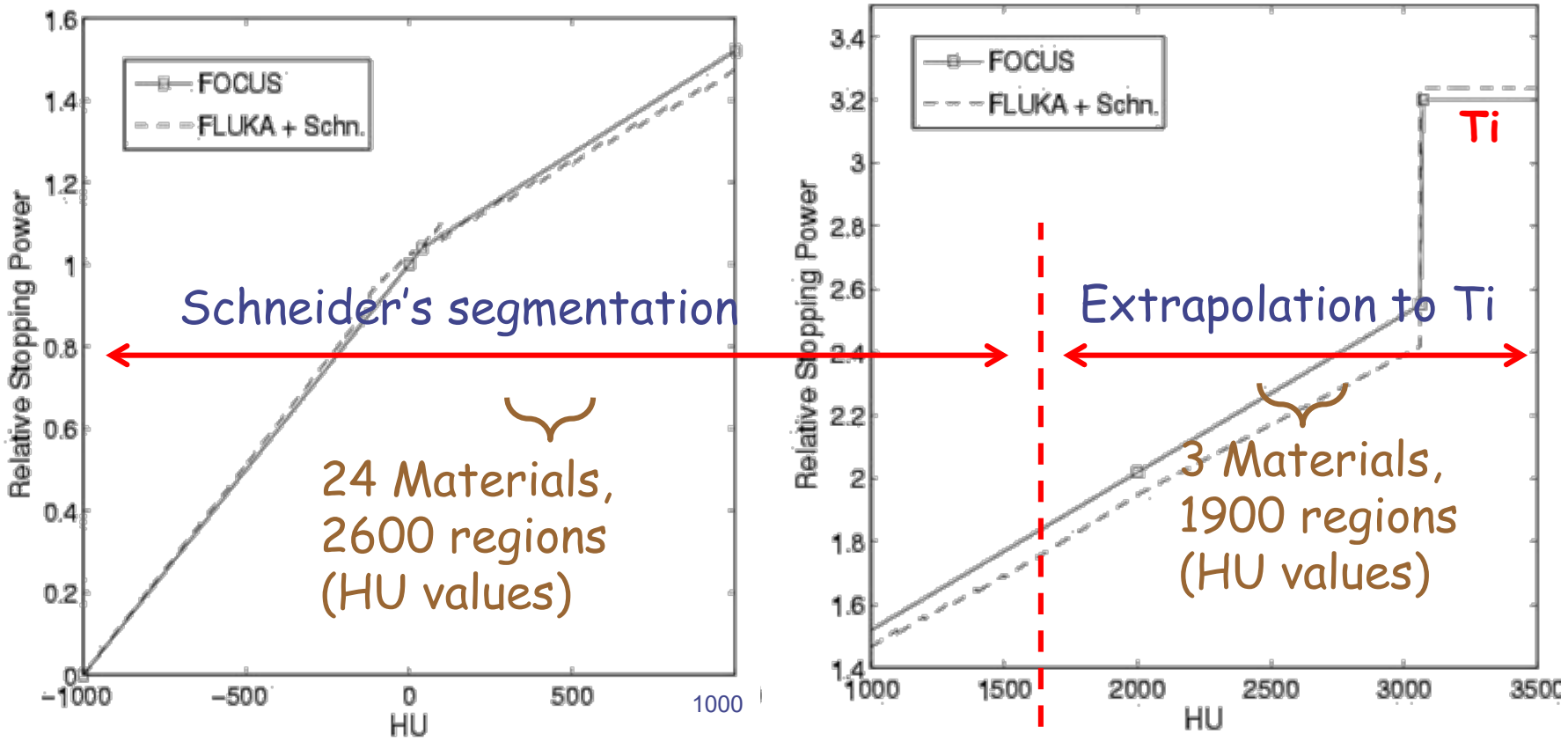
Additional material – user routine

- In current version user needs to compile special routine for defining pencil beam source parameters.
- In the next FLUKA release new cards will allow user to simulate RTPLAN without external routines.



Forcing FLUKA to follow the same range calibration curve as TPS for p @ MGH Boston

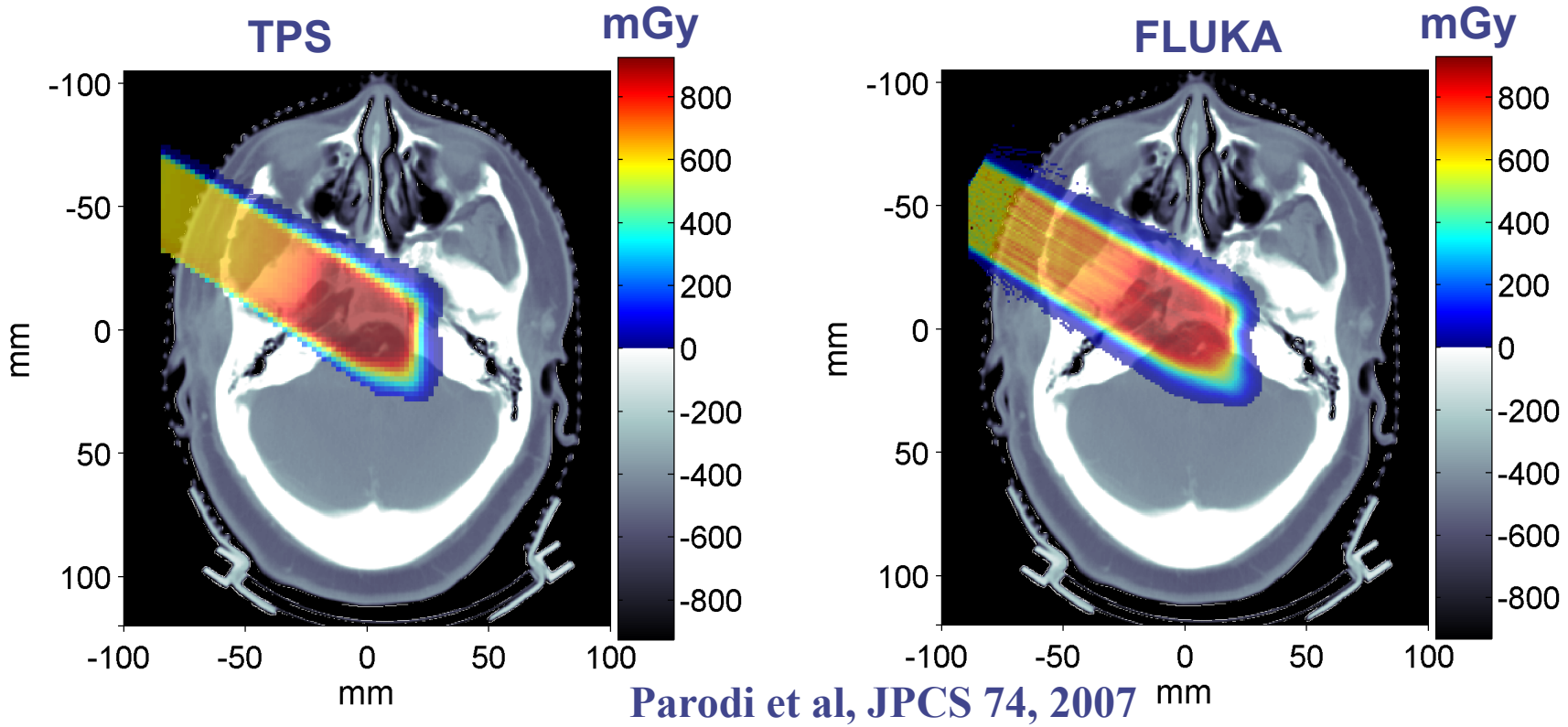
The CORRFACT ionization scaling factors were obtained from the dEdx ratio between TPS and FLUKA (+ Schneider "mass density") -> The user should update a file with his own calibration for CdEdX_rel taking into account his TPS.



Parodi et al MP 34, 2007, Parodi et PMB 52, 2007

Applications of FLUKA to p therapy @ MGH

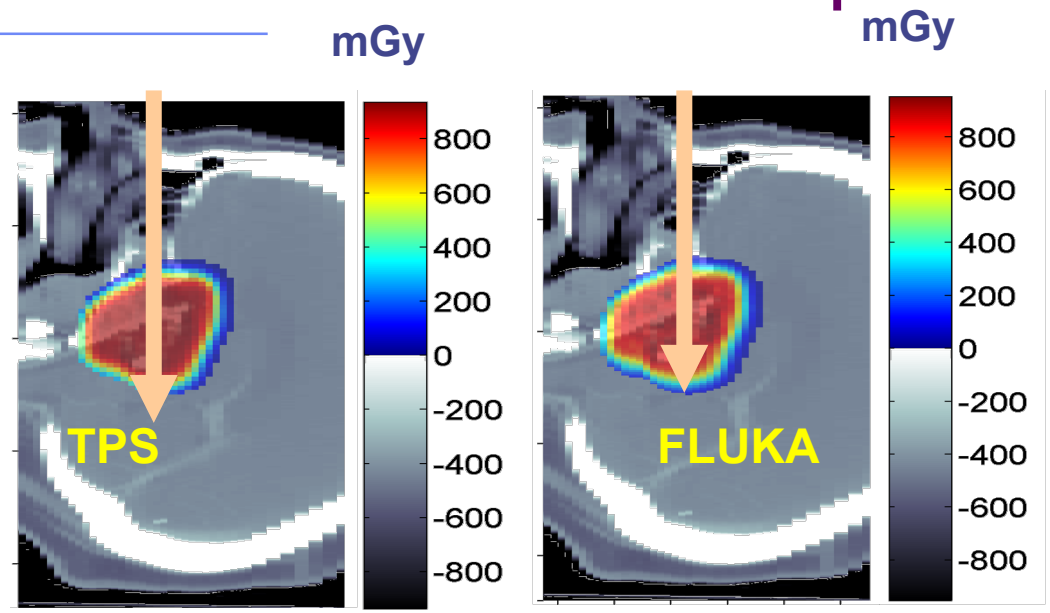
Input phase-space provided by H. Paganetti, MGH Boston



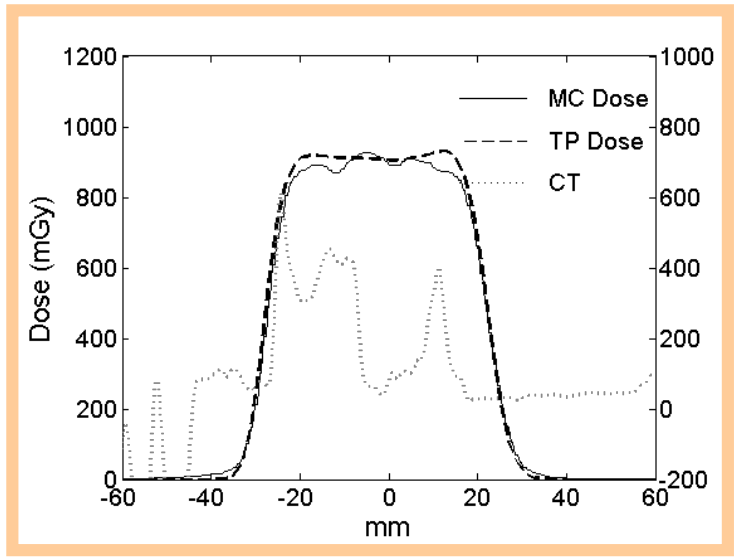
Parodi et al, JPCS 74, 2007

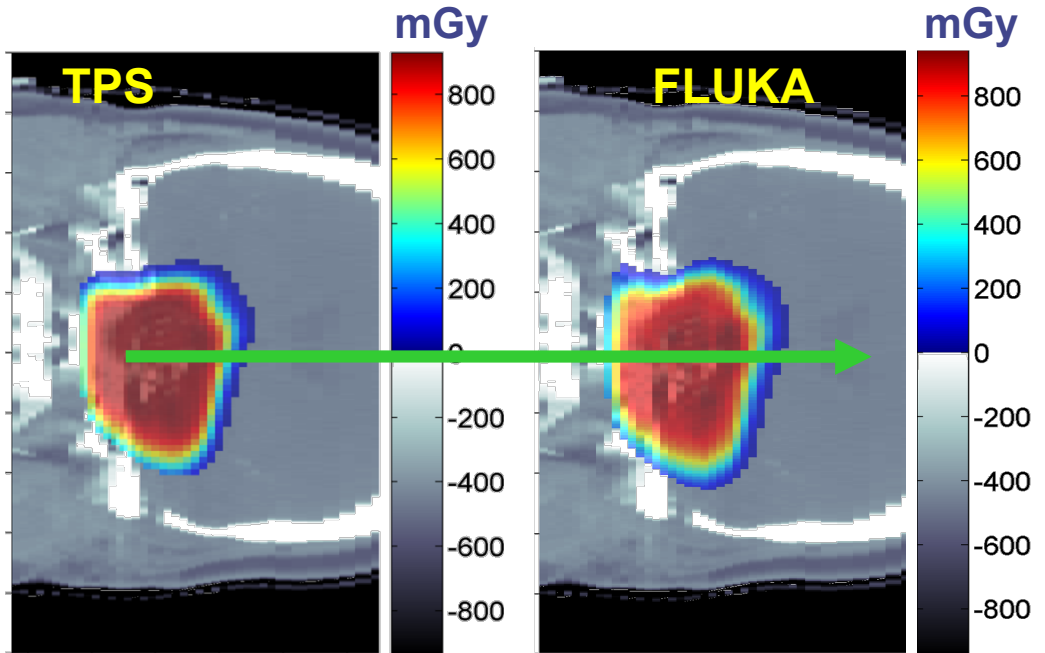
Prescribed dose: 1 GyE
MC : ~ 5.5 10^6 protons in 10 independent runs
(11h each on Linux Cluster mostly using 2.2GHz Athlon processors)

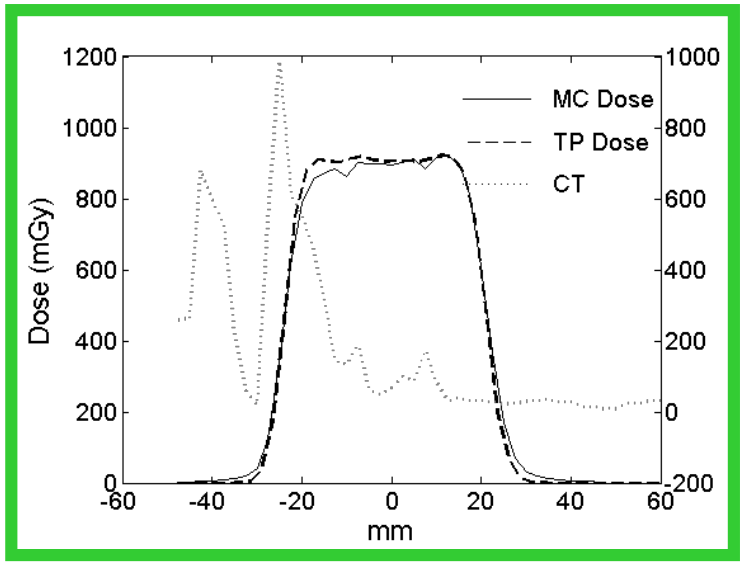
Applications of FLUKA to p therapy @ MGH



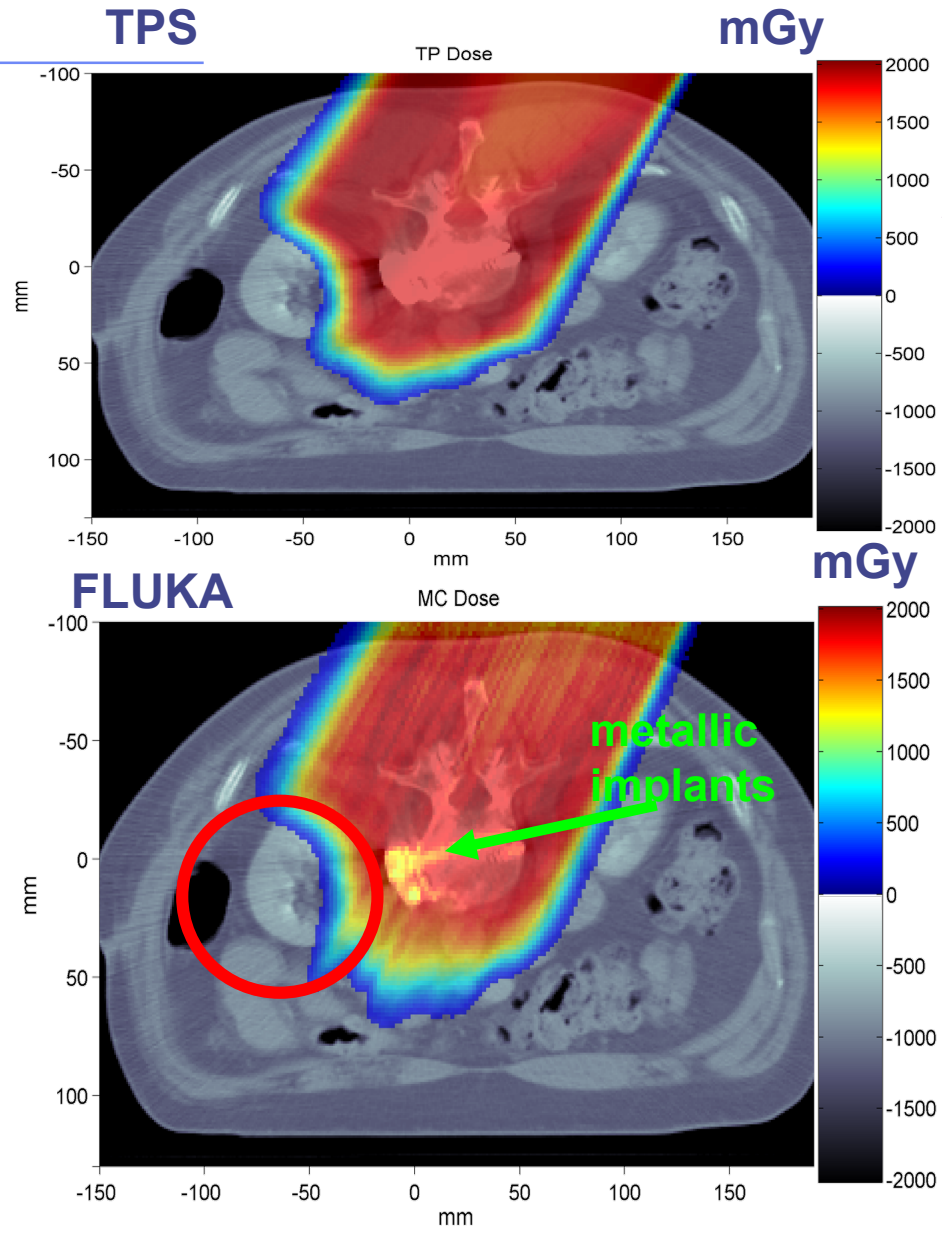
Parodi et PMB 52, 2007







Applications of FLUKA to p therapy @ MGH



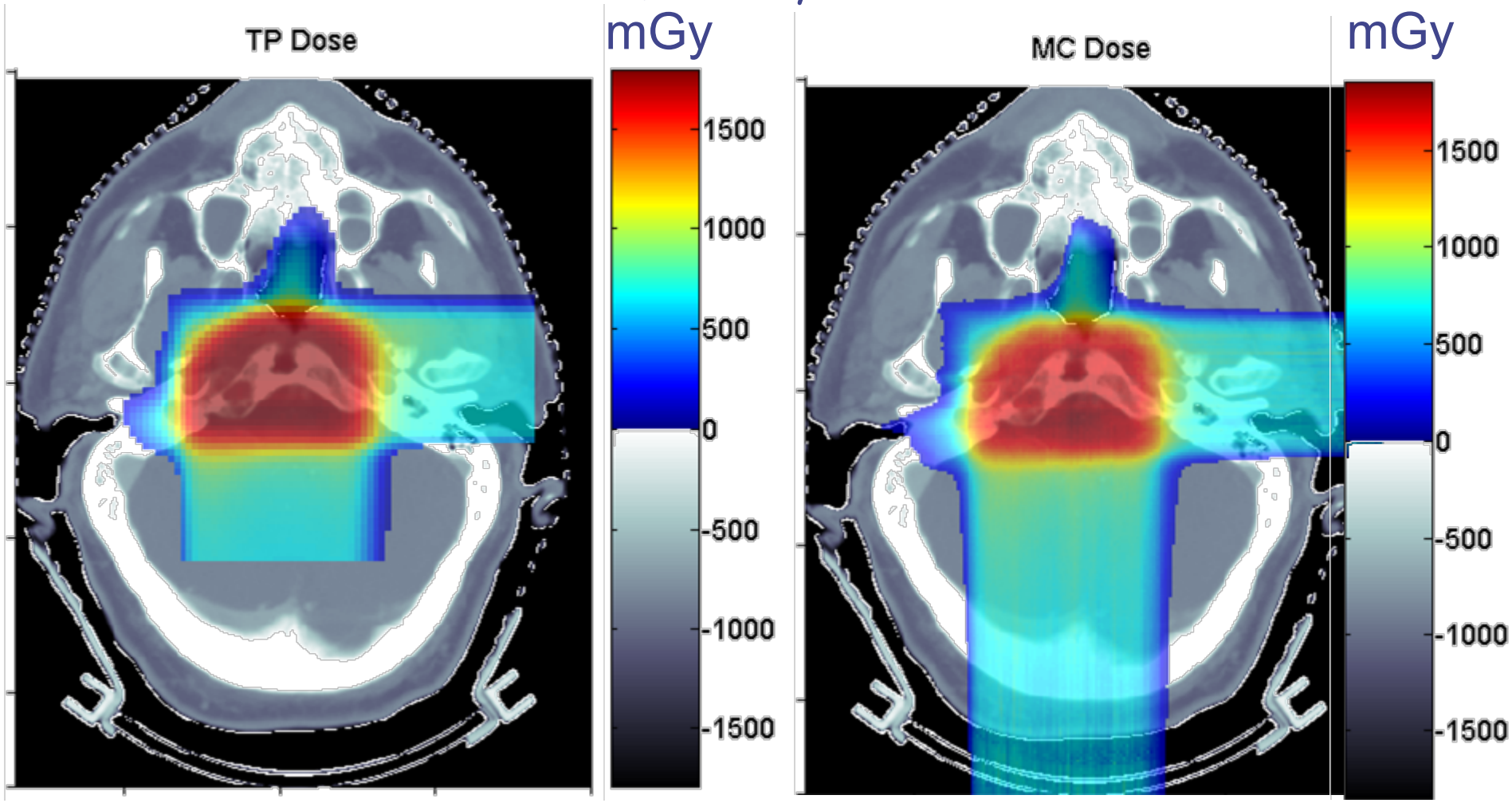
Prescribed dose: 2 GyE
MC : ~ 7.4 10^7p in 12 independent runs (~ 130h each on 2.2 GHz Linux cluster)

K. Parodi et al, IJROBP 2007

Applications of FLUKA to p therapy @ MGH

Clival Chordoma, 0.96 GyE / field

Planned dose



K. Parodi et al, IJROBP 2007