Electron Beam Dump Simulation

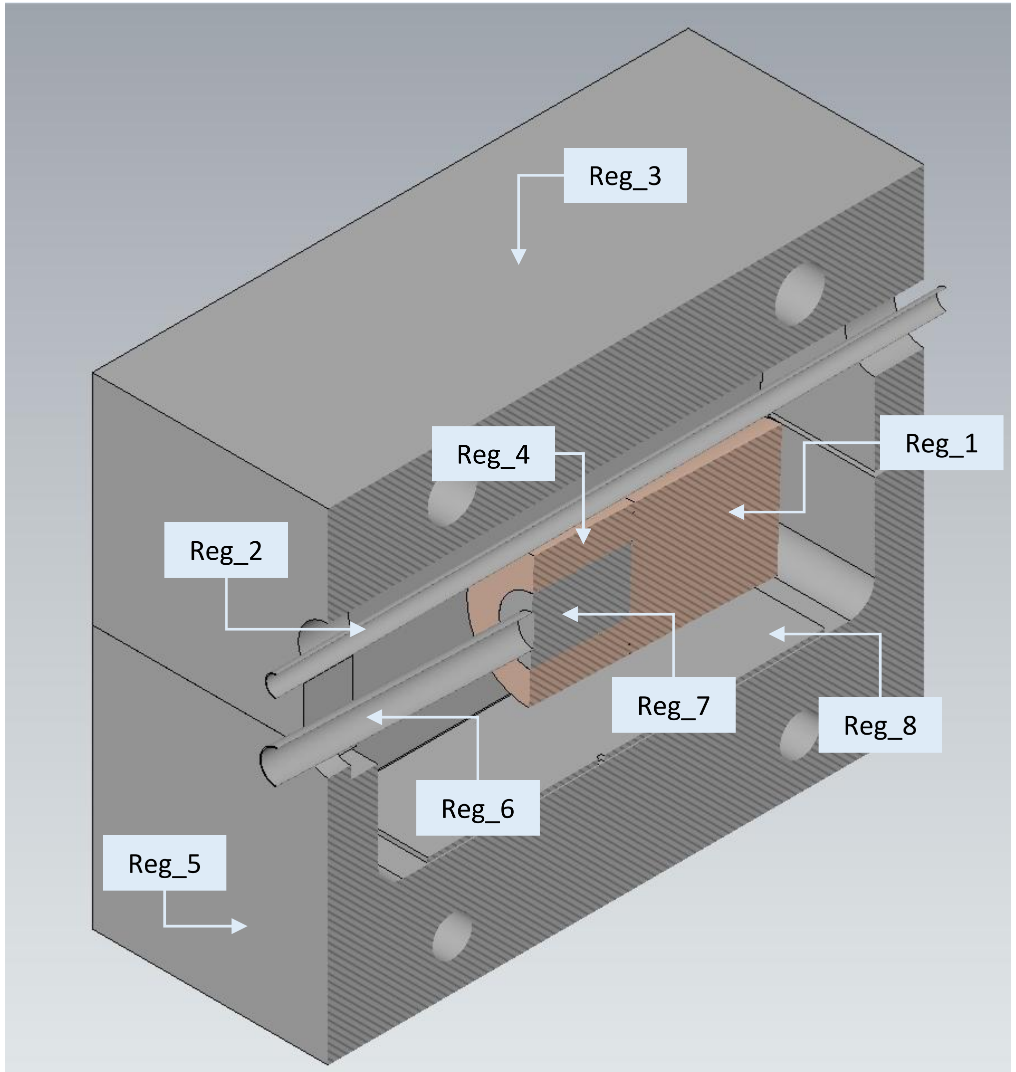
Report on: Dose rate at Q = 1 nC, Nuclei Charts

Sergii Vasiukov

ELBEX meeting
16.07.2025

https://indico.desy.de/event/50043/

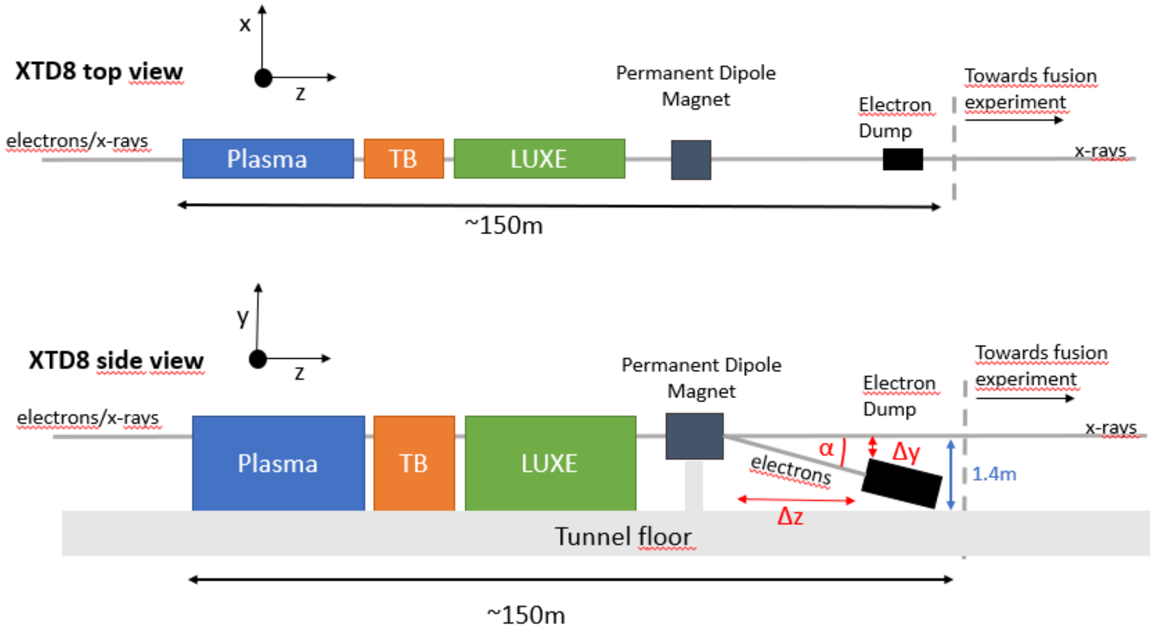
BEAM DUMP: Geometry and Model Components



Element	Dimensions, mm	Material	Model region
Top Concrete Shield (TCS)	950 x 1200 x h530	Concrete Portland	Reg_3
Bottom Concrete Shield (BCS)		Concrete Portland	Reg_5
Copper back	D260 x L300	Copper	Reg_1
Copper shield	D260, d130, L200	Copper	Reg_4
Beam Transport Pipe (BTP)	Di40, De43	Steel	Reg_2
Metal plate	W400, L800, t10	Steel	Reg_8
Beam Dump Core (BDC)	D130, L200	Aluminum	Reg_7
Beam Exit Pipe (BEP)	Di63, De67	Aluminum	Reg_6

Requirements for ELBEX main electron beam dump (14.05.2025)

The main electron dump is placed at the end of the ELBEX user beamline located in XTD8. The electron beam is bent downwards towards the dump with a permanent dipole magnet (see sketch). The dump is placed at an angle α and at a distance Δz from the permanent magnet such that sufficient space Δy remains between the dump and the X-ray beam pipe going at a height of 1.4m above the tunnel floor straight towards the fusion area and the Schenefeld hall.

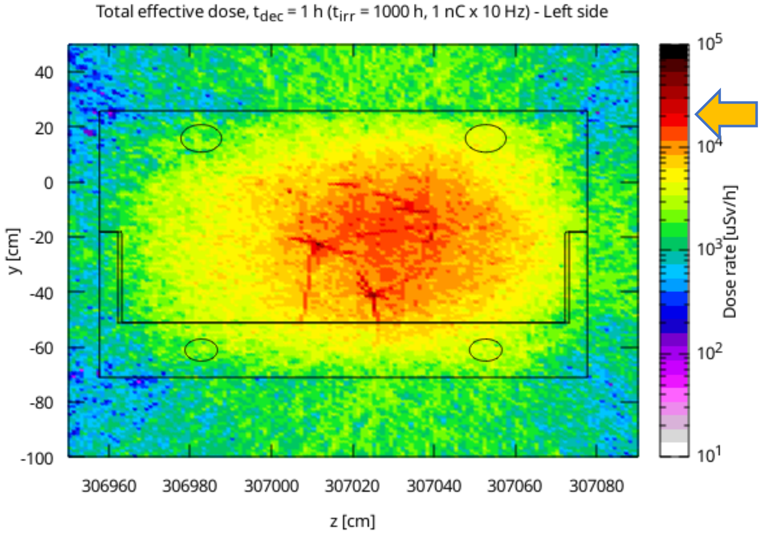


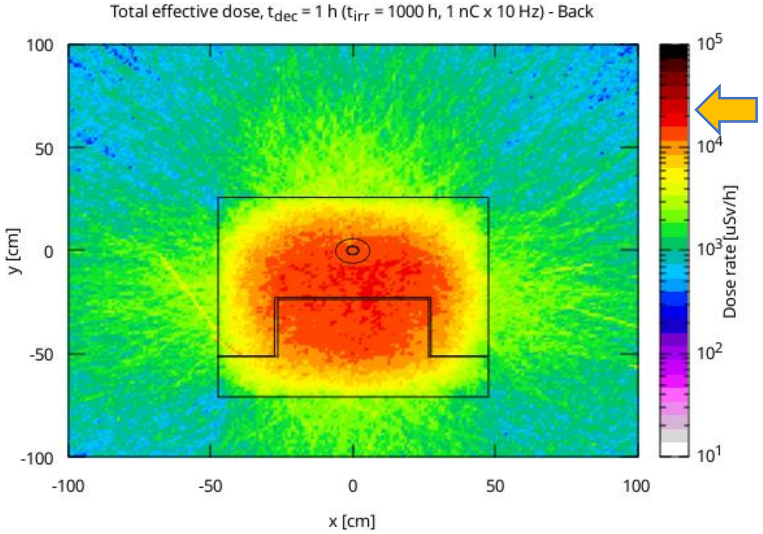
Parameter	Value
Maximum Beam Energy	40 GeV
Maximum number of bunches extracted per train to XTD8	50
Repetition rate	10 Hz
Maximum bunch charge	1 nC
Intra-train bunch spacing	220 ns

Beam intensity = $6.24 \times 10^{18} \times 10^{-9} \times 10 \times 50 = 3.12 \times 10^{12}$ e^- per sec → 6.24×10^{10} e^- per sec

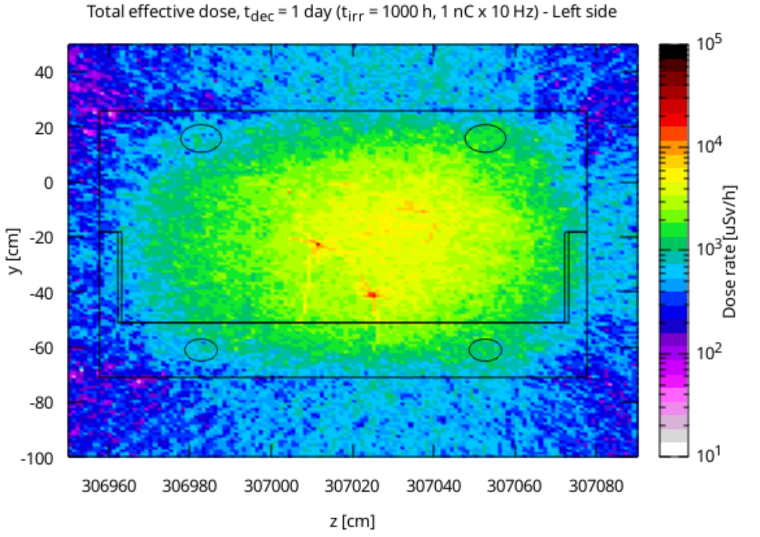
Residual Decay

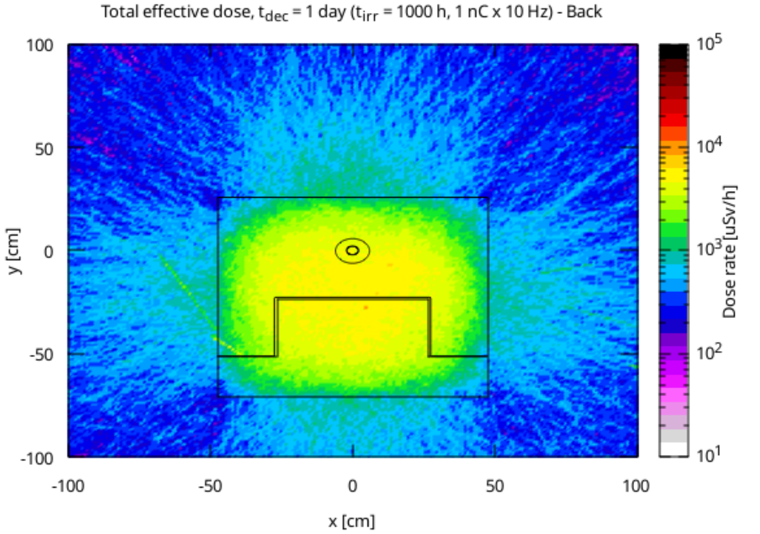
1 hour



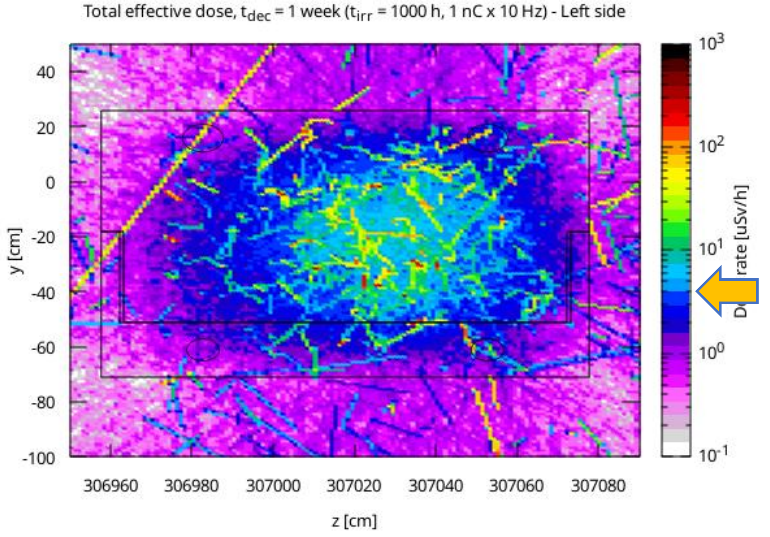


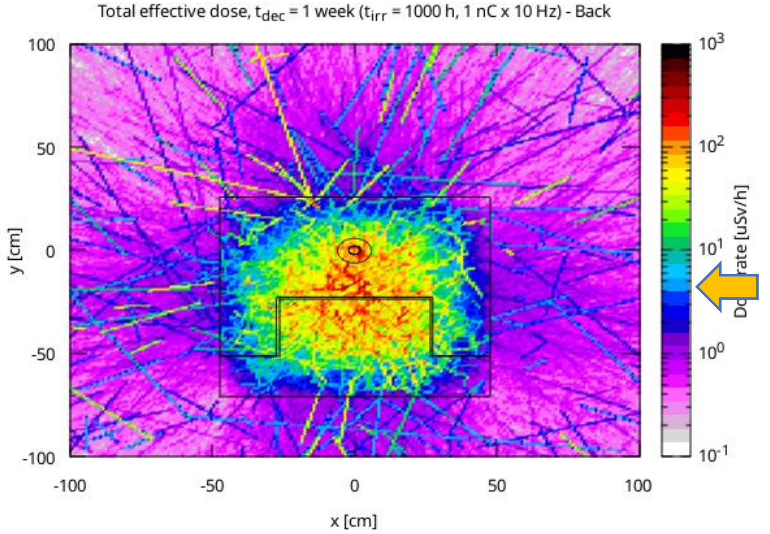
1 day





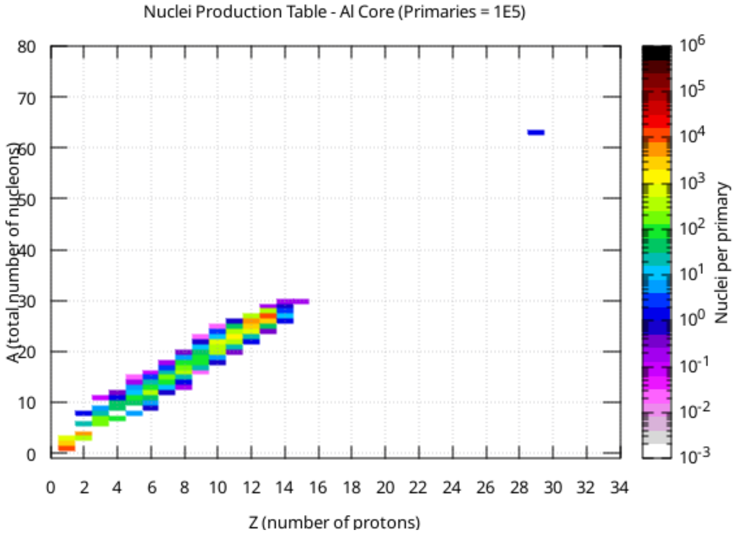
1 week

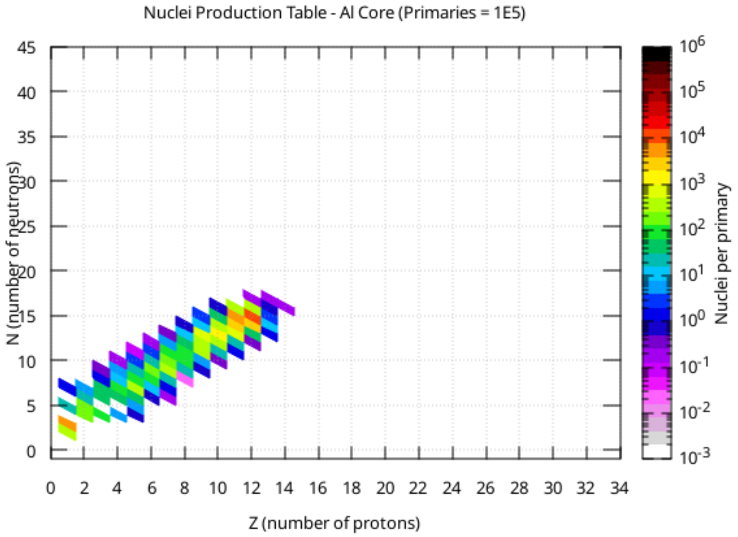




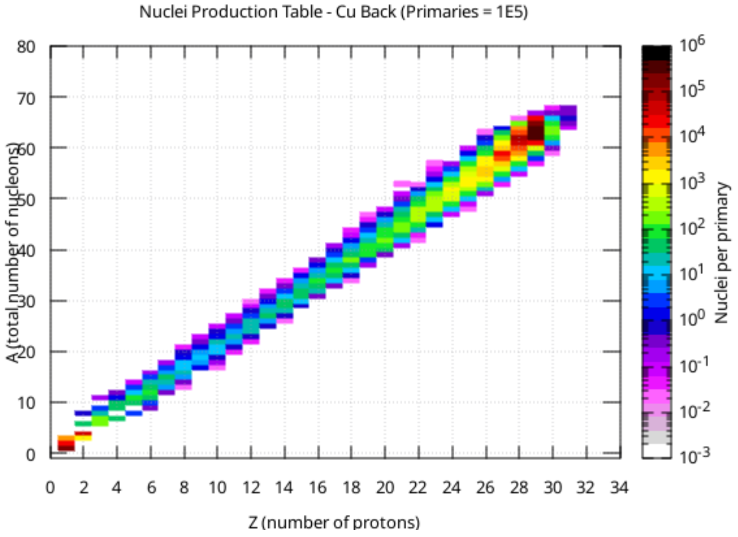
Nuclei Production: Nuclide Charts

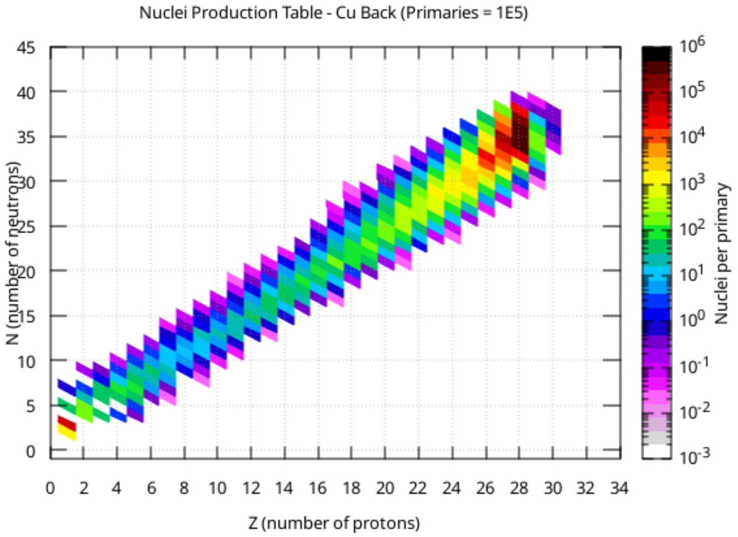
Al core



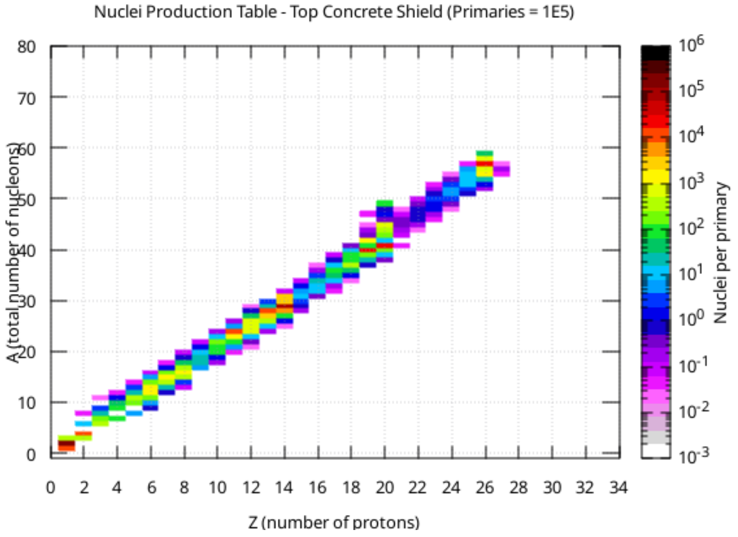


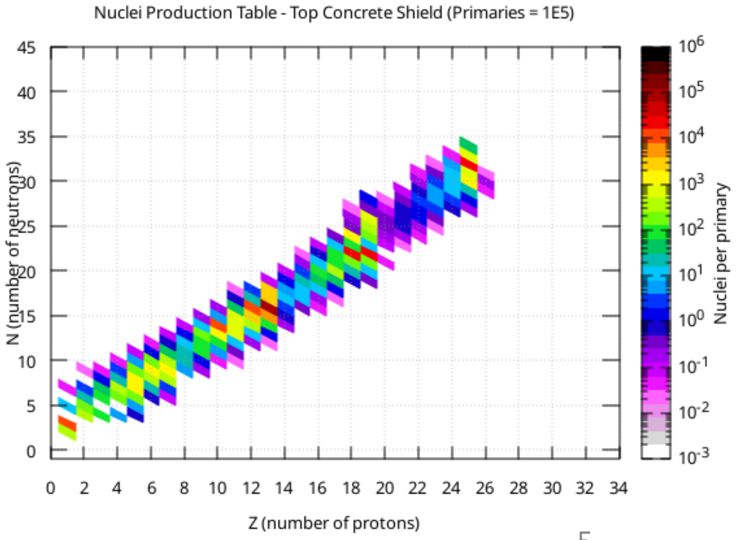
Cu back



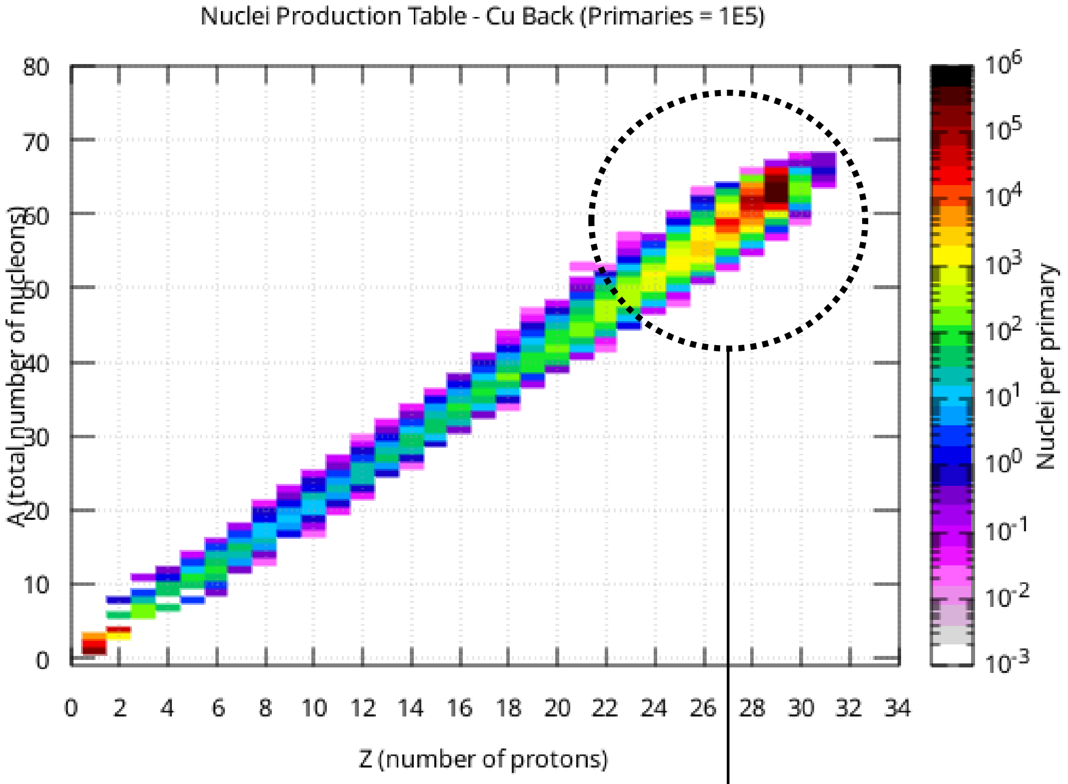


Concrete shield





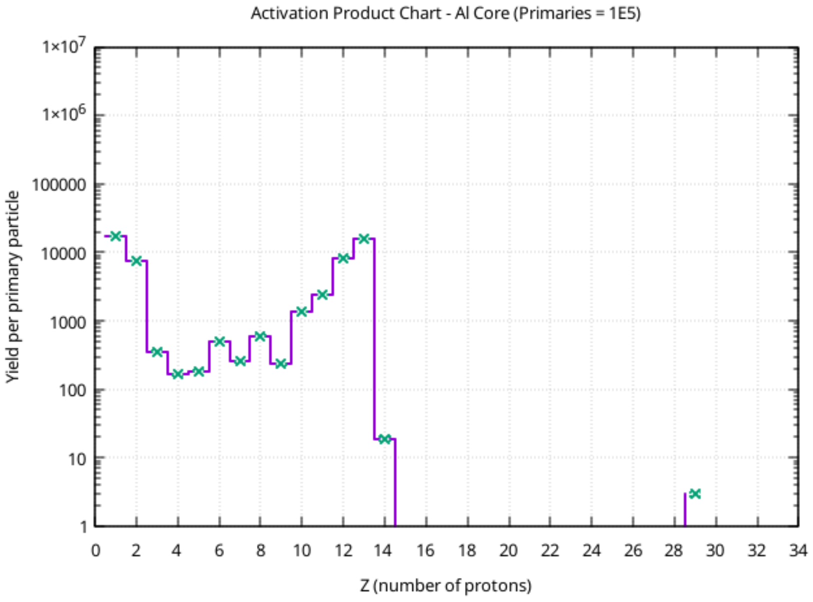
Hazardous Isotopes: Z = 1–30

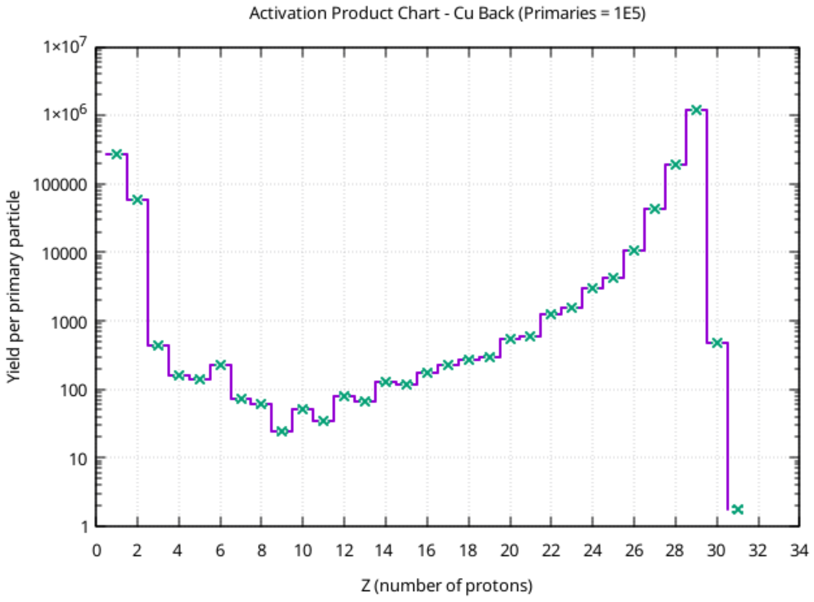


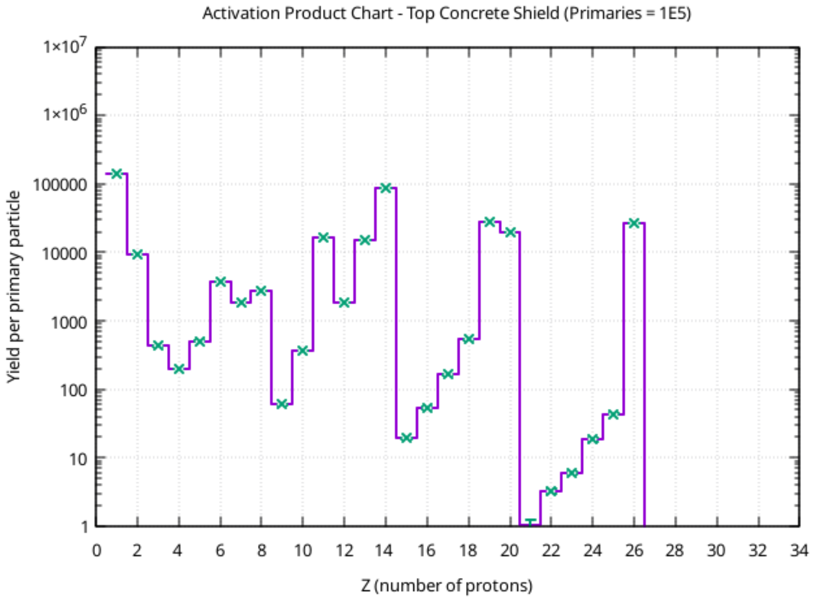
Z	A	N	Element	Isotope	Notes
1	3	2	Hydrogen	H-3	Tritium, β-emitter, long-lived (12.3 y)
3	6	3	Lithium	Li-6	Used in fusion, neutron absorber
4	10	6	Beryllium	Be-10	Long-lived, α-emitter
11	22	11	Sodium	Na-22	γ-emitter, $T_{1/2}$ = 2.6 y
13	28	15	Aluminium	Al-28	Short-lived β^- emitter
17	36	19	Chlorine	Cl-36	Very long-lived, β^- emitter
18	41	23	Argon	Ar-41	γ-emitter, short-lived (1.8 h)
19	40	21	Potassium	K-40	β and γ-emitter
23	48	25	Vanadium	V-48	β^+ and γ-emitter, $T_{1/2}$ = 16 days
24	51	27	Chromium	Cr-51	γ-emitter
25	**54**	**29**	**Manganese**	**Mn-54**	**Strong γ-emitter, $T_{1/2}$ = 312 days**
26	**55**	**29**	**Iron**	**Fe-55**	**X-ray emitter, long-lived**
27	**60**	**33**	**Cobalt**	**Co-60**	**High γ emitter**
28	**63**	**35**	**Nickel**	**Ni-63**	**β-emitter**
30	**65**	**35**	**Zinc**	**Zn-65**	**High γ emitter**

Nuclei Production

- Cu Back (Region 7) shows higher residual nuclei production, including Zn-65 and Co-60, which are long-lived gamma emitters with significant radiological impact.
- Top Concrete Shield (Region 3) shows a consistent reduction (~55–65%) in yield for all relevant isotopes.
- Co-60 and Zn-65 are the most concerning due to their half-lives and gamma emission — more shielding is needed. Stainless steel is one of the options.







Energy Deposited for ANSYS simulation

IN PROGRESS…

https://gitlab.cern.ch/SY_STI_TCD/Fluka-to-ansys-tables

Fluka To Ansys Tables

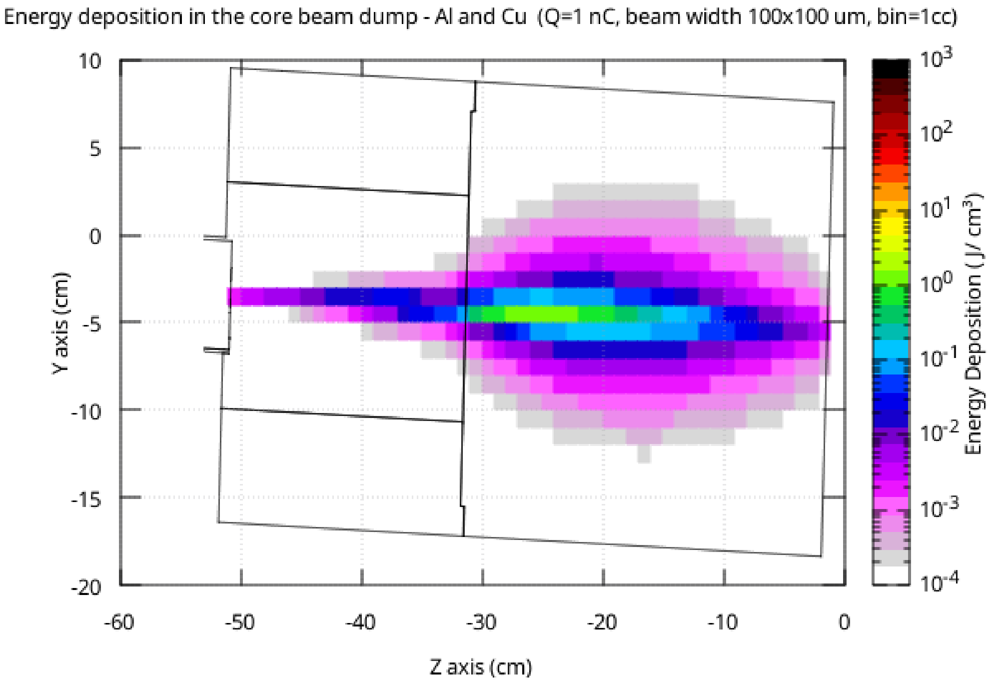
Script to convert Fluka energy deposition files to a loadable power table by Ansys Mechanical, CFX and Fluent tools of Ansys. The script allows scaling based on beam intensity and pulse length, coordinate transformation and total power calculation.

Energy Deposited for ANSYS simulation

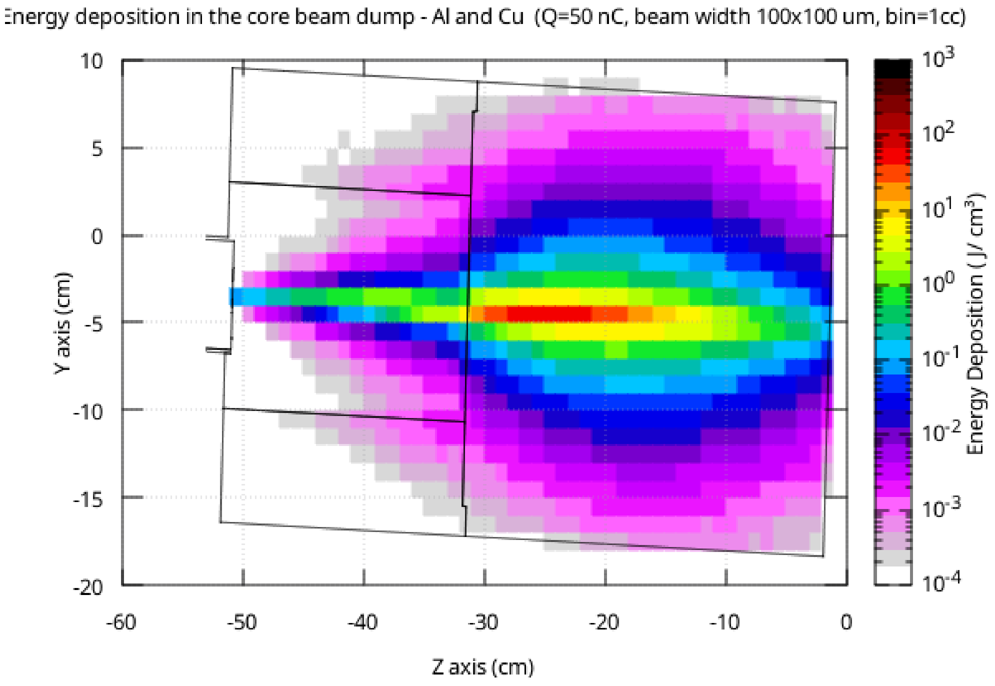
1 GeV = 1.602e-10 J
1 C = 6.24 x 1e18 e-

IN PROGRESS…

Norm factor = 1.602 x 1e-10 x 6.24 x 1e9



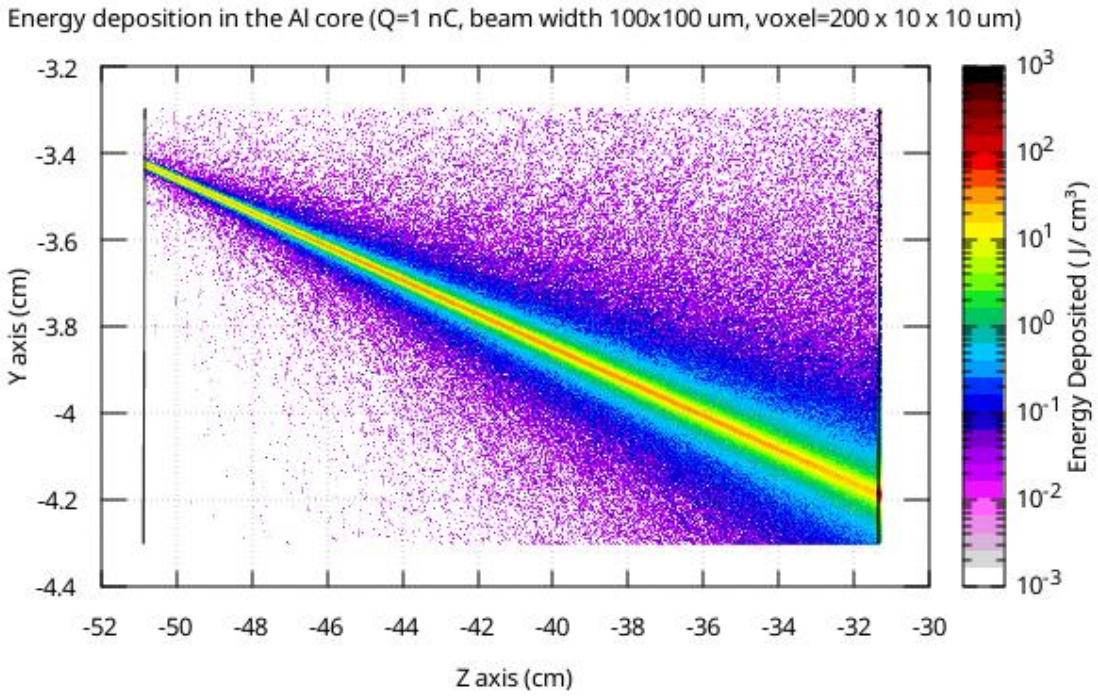
Norm factor = 1.602 x 1e-10 x 6.2 x 1e9 x 50



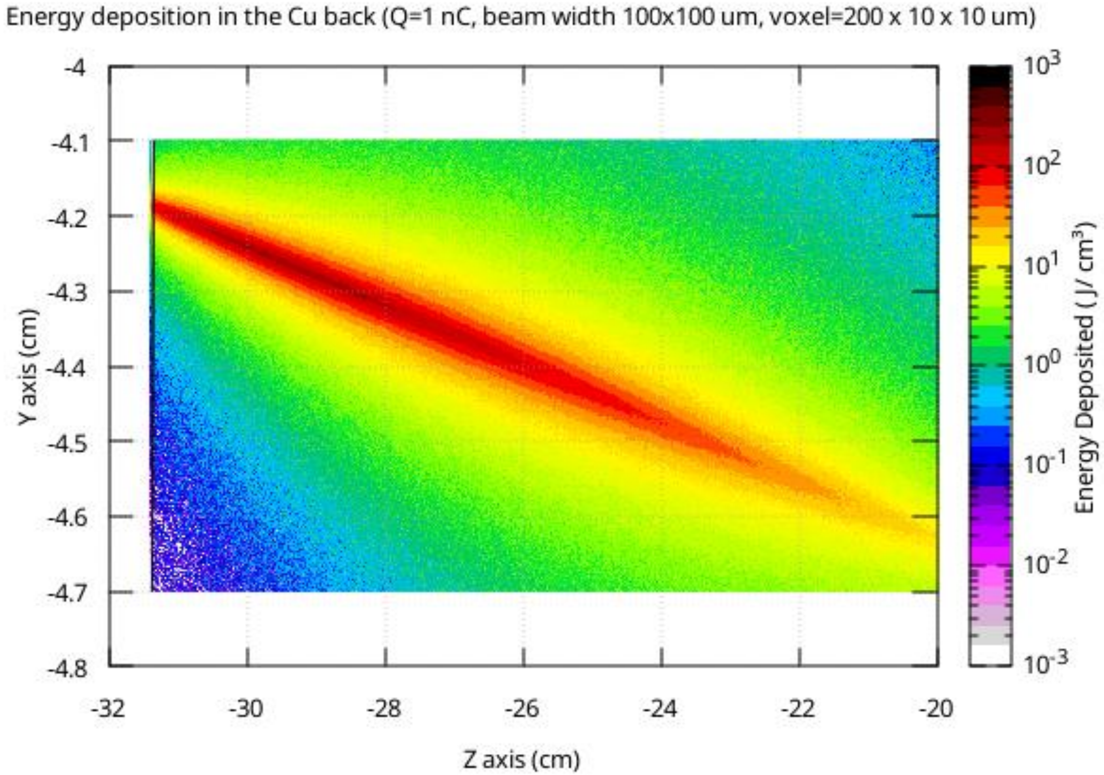
Radiation Resistance of materials

IN PROGRESS…

Al core



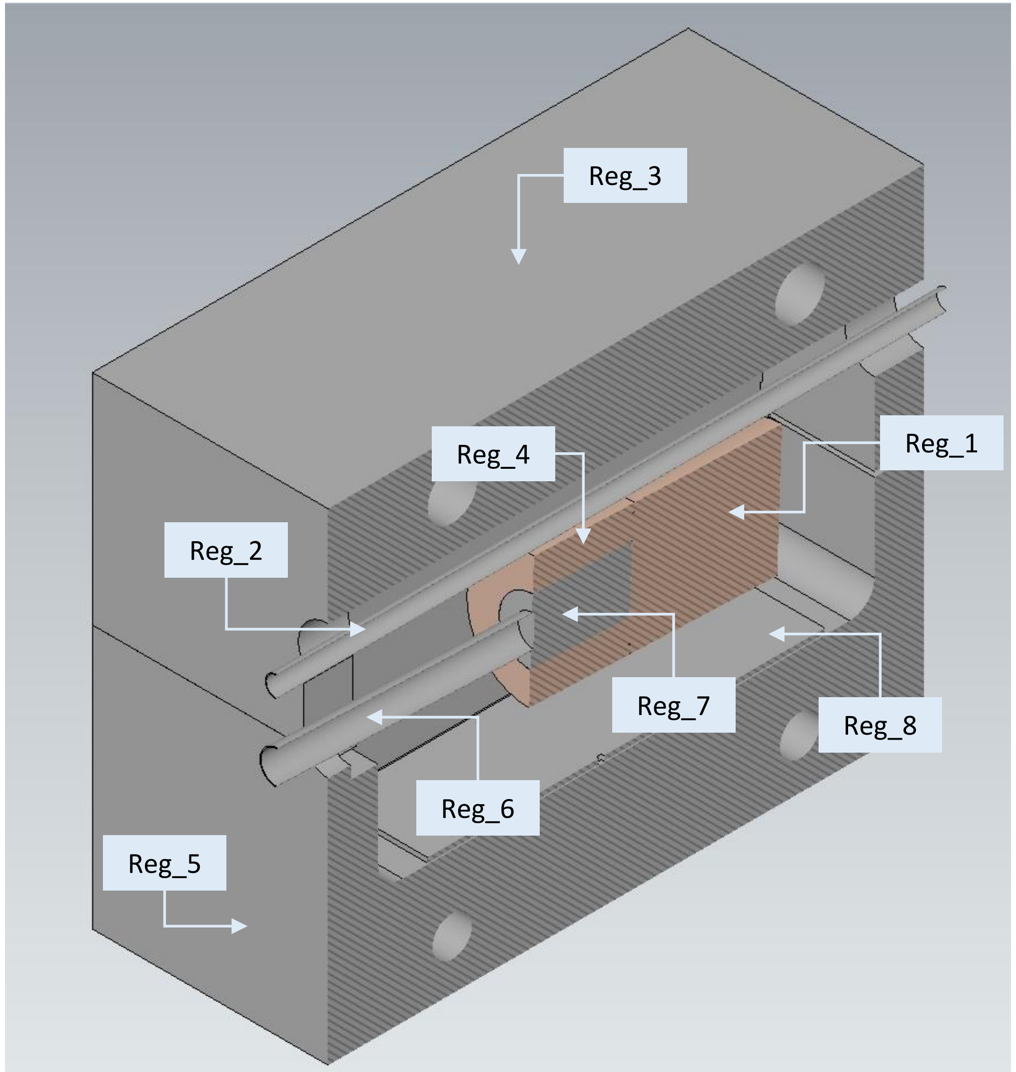
Cu back



Thank you for attention

BACK UP

BEAM DUMP: Geometry and Model Components



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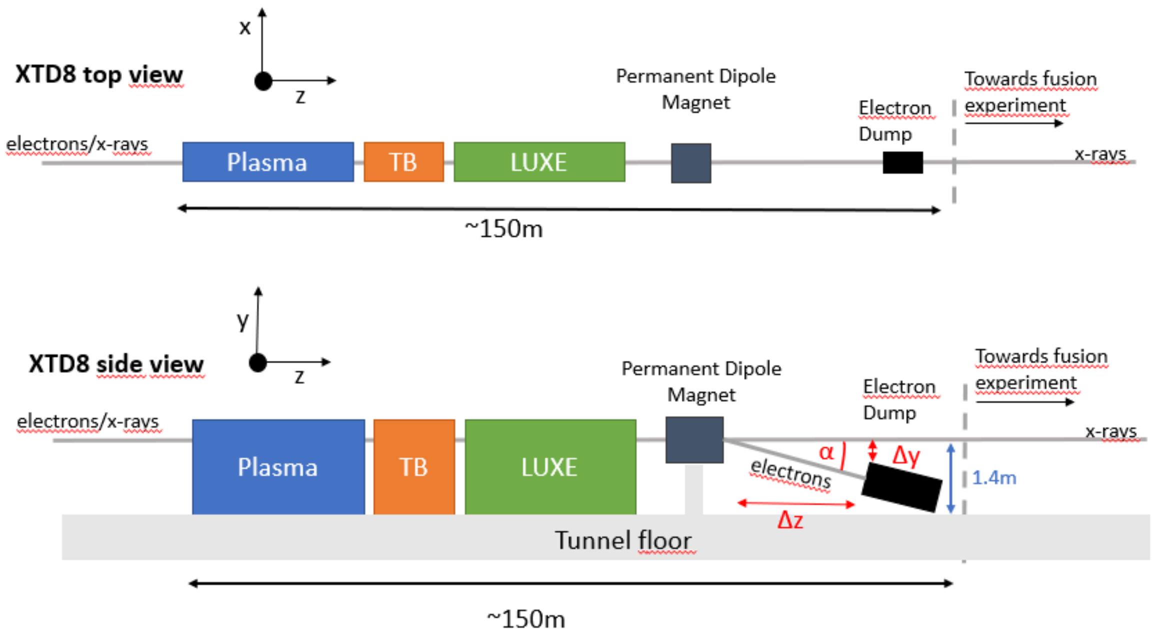
Requirements for ELBEX main electron beam dump (14.05.2025)

The main electron dump is placed at the end of the ELBEX user beamline located in XTD8. The electron beam is bent downwards towards the dump with a permanent dipole magnet (see sketch). The dump is placed at an angle α and at a distance Δz from the permanent magnet such that sufficient space Δy remains between the dump and the X-ray beam pipe going at a height of 1.4m above the tunnel floor straight towards the fusion area and the Schenefeld hall.



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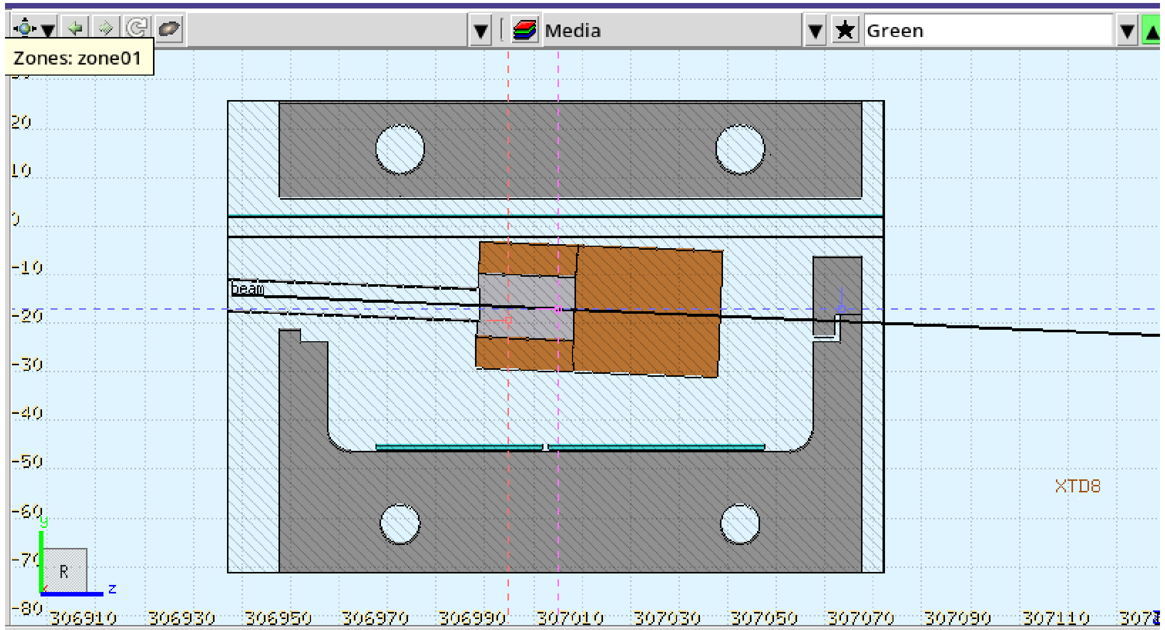
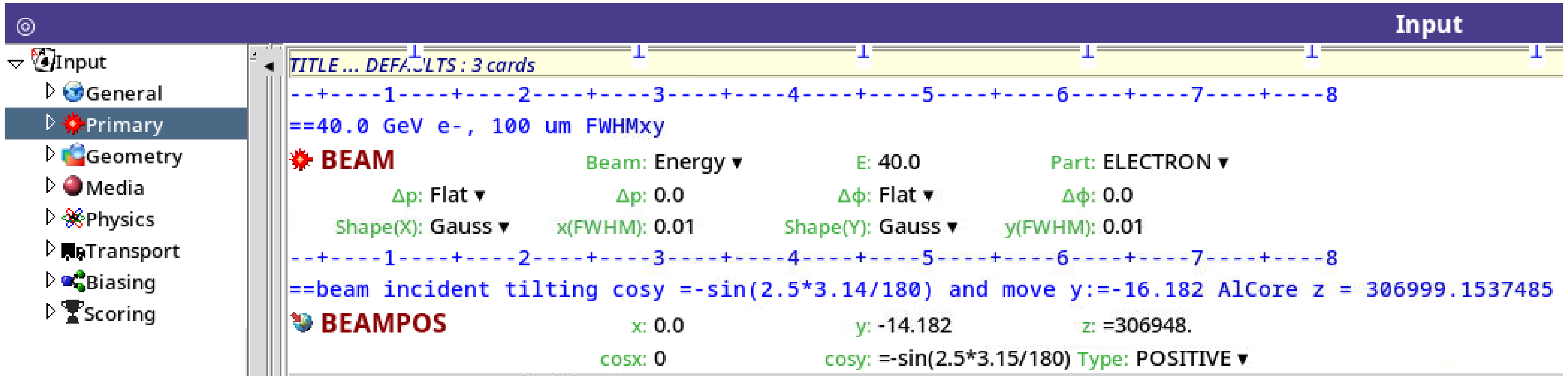
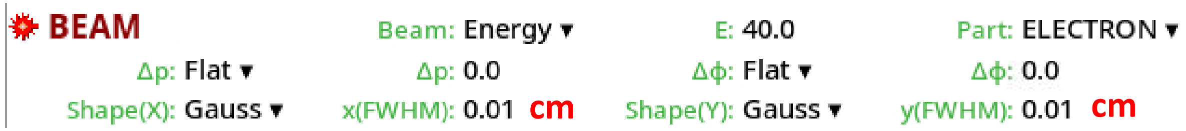
Beam Parameters

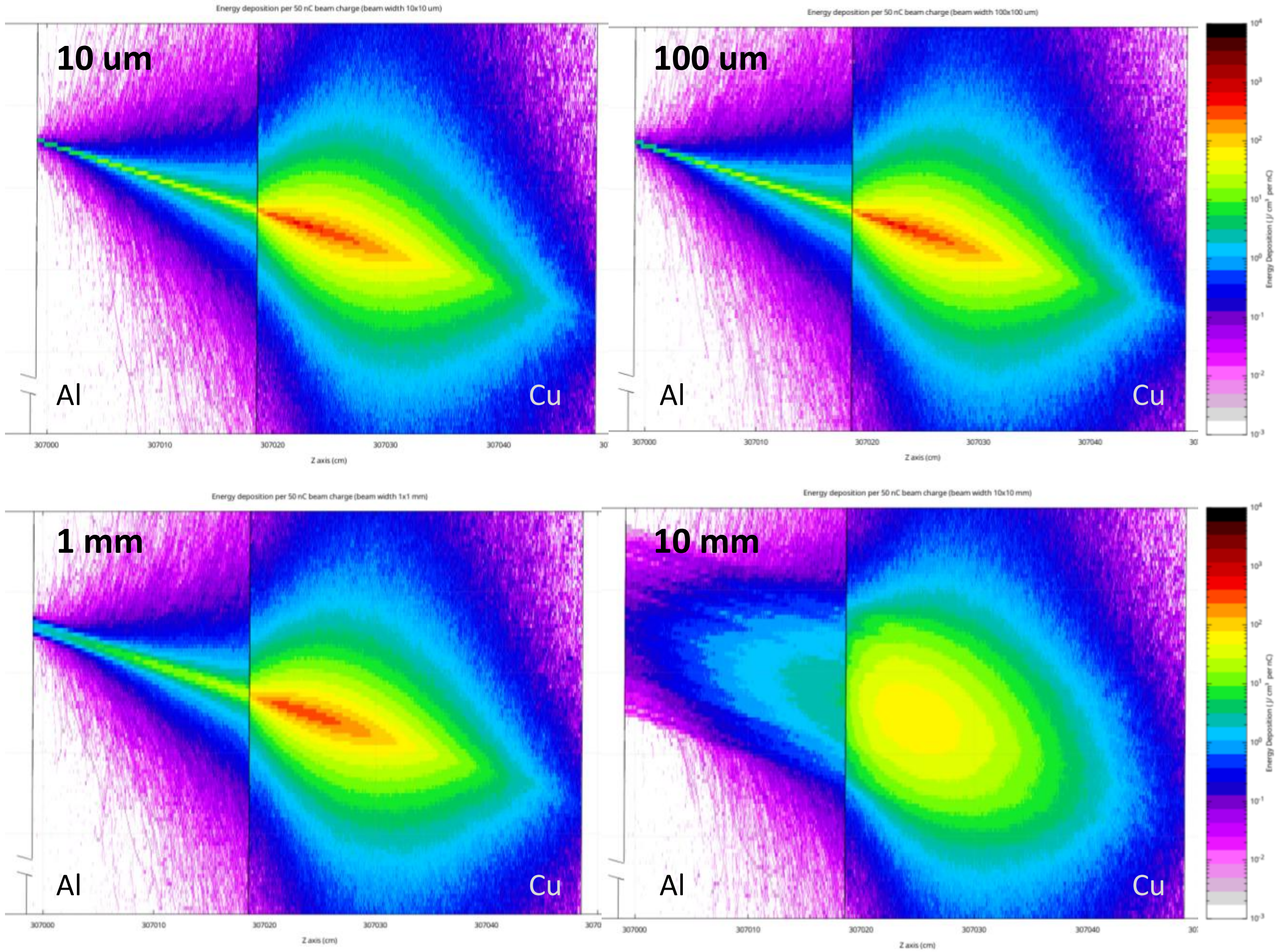
Parameter	Value
Particle	Electron
Energy	40.0 GeV
Type	Gauss
FWHM	0.1 mm (0.01 cm)
Initial position	X = 0 cm Y = -141.82 mm Z = 3069480.0 mm
beam incident tilting	Cos Y ~ 2.235 degrees



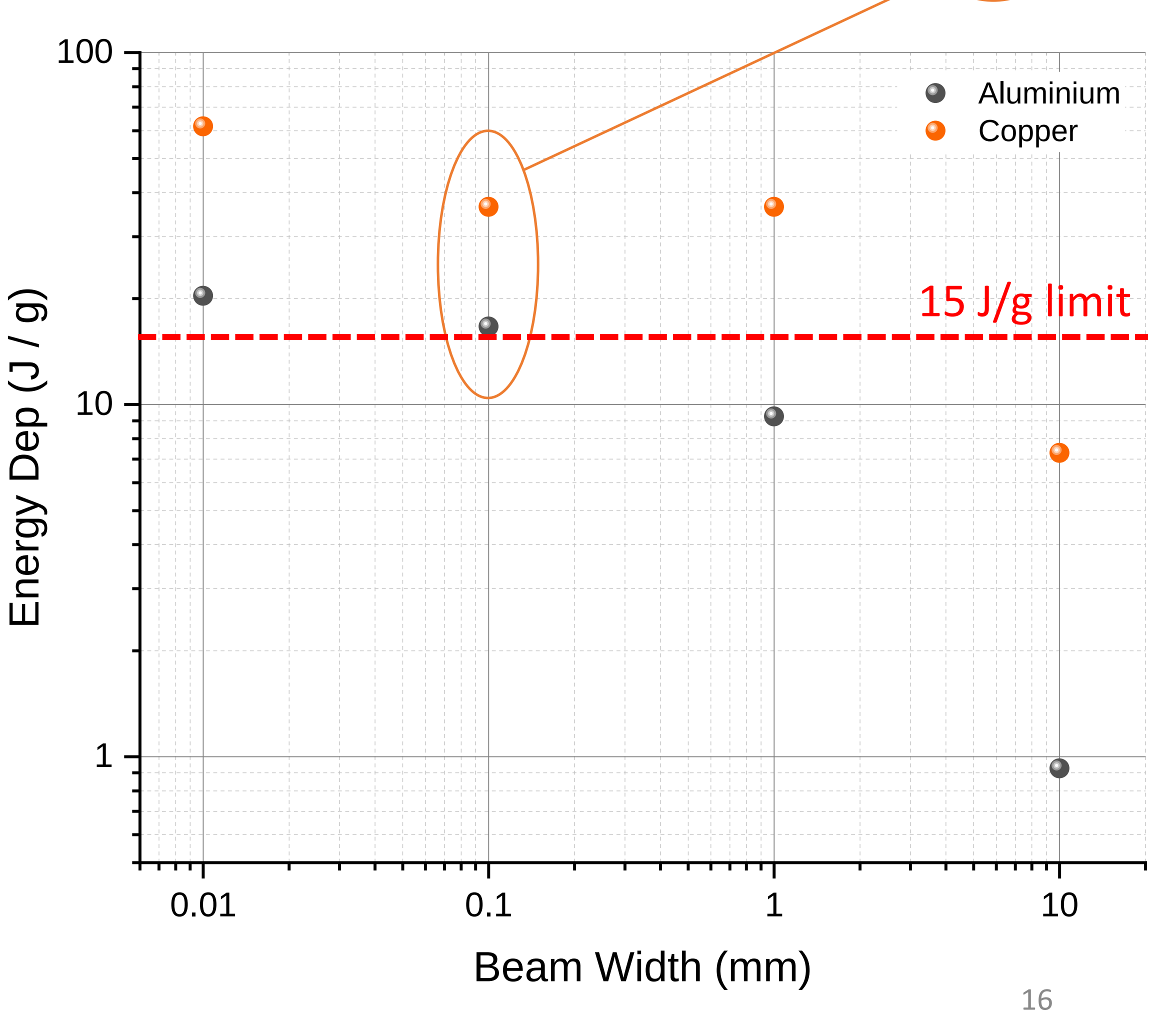


Radiation Resistance of materials



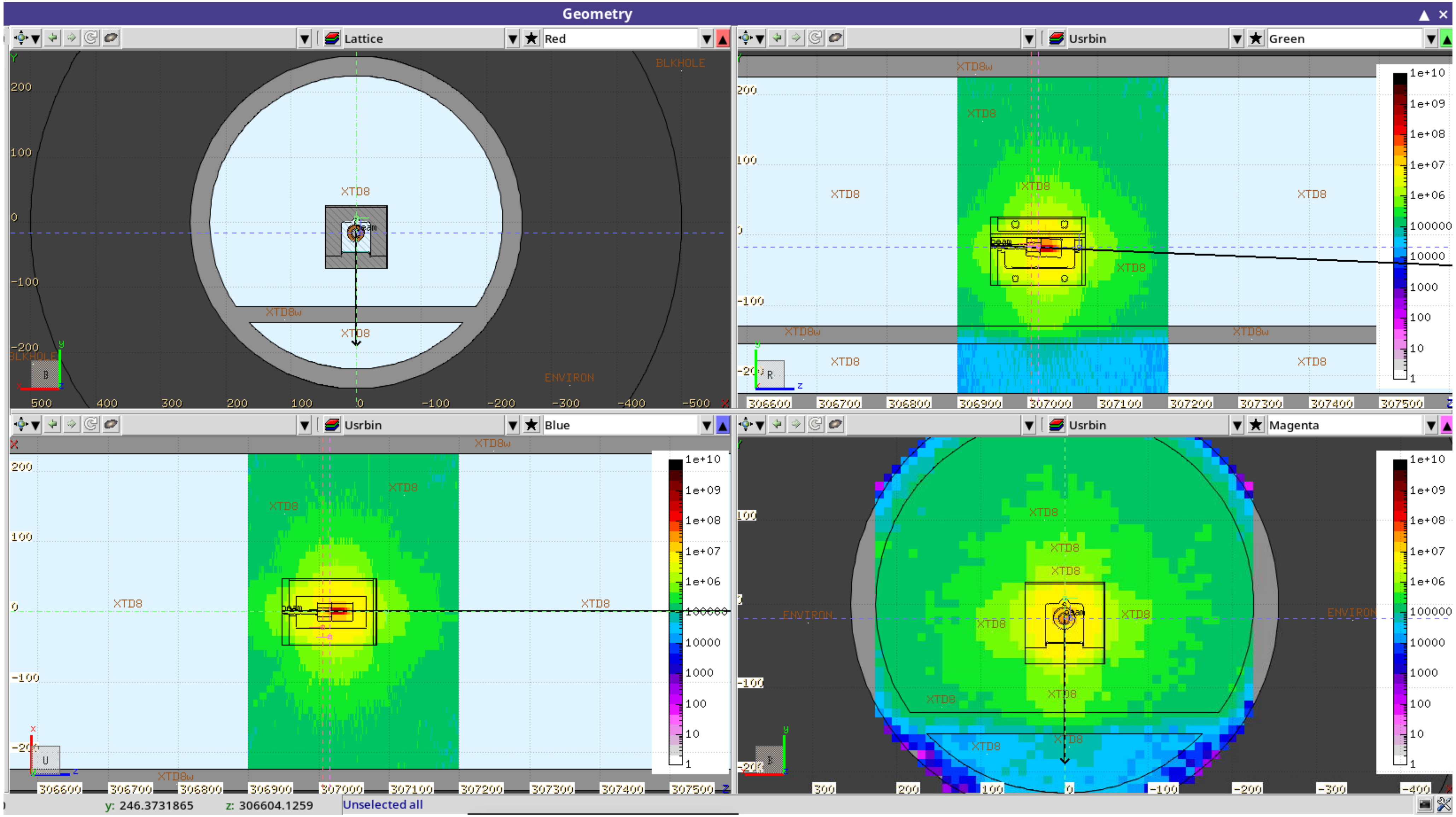


Material	Energy deposition limit (theor.)	Energy deposition (sim.)
Al (ρ=2.7 g/cm^3)	100 – 200 J/g	**17 J/g**
Cu (ρ=8.96 g/cm^3)	500 – 1000 J/g	**36 J/g**

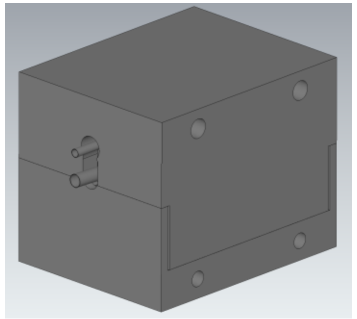


Simulation results: heat maps dose rate in the tunnel

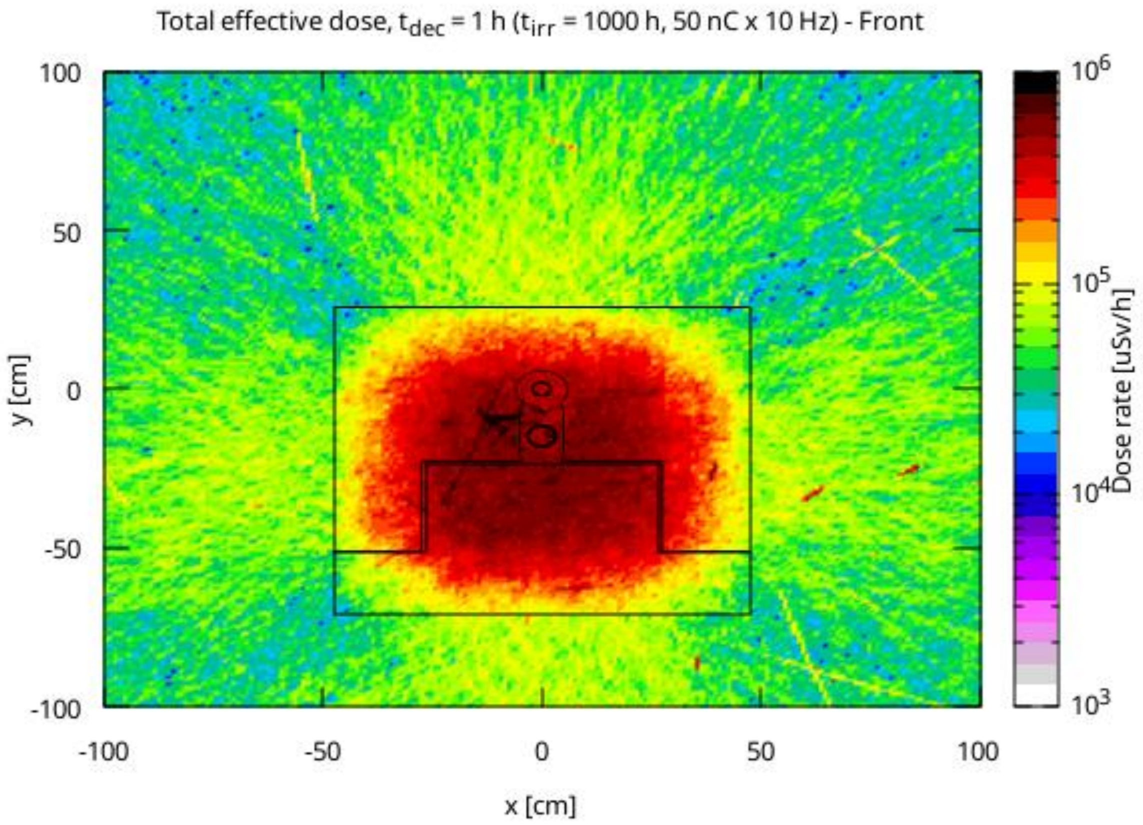
Thanks to Ted Liang for his help with the model and advice.



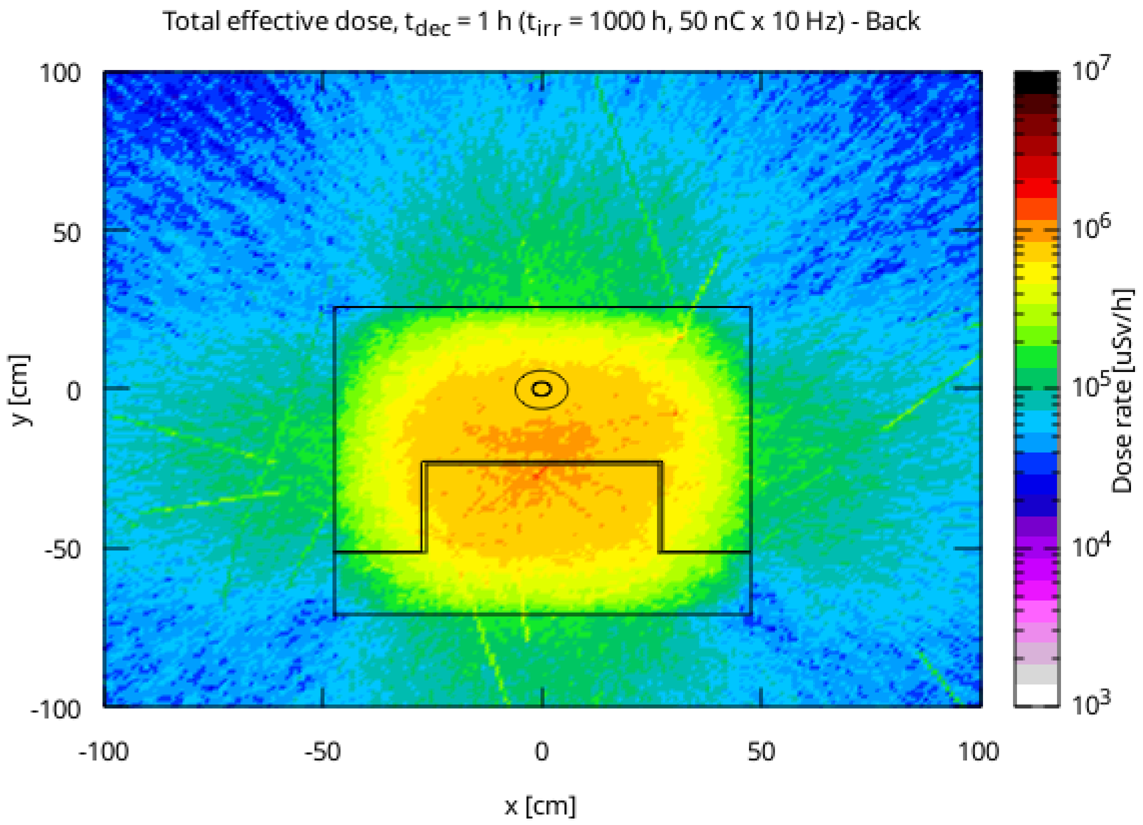
Residual Decay: 1 hour



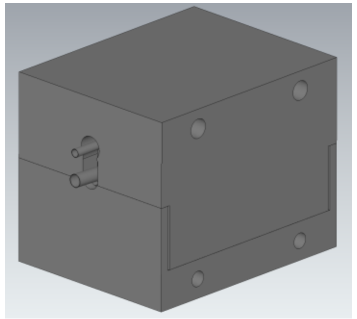
Front side



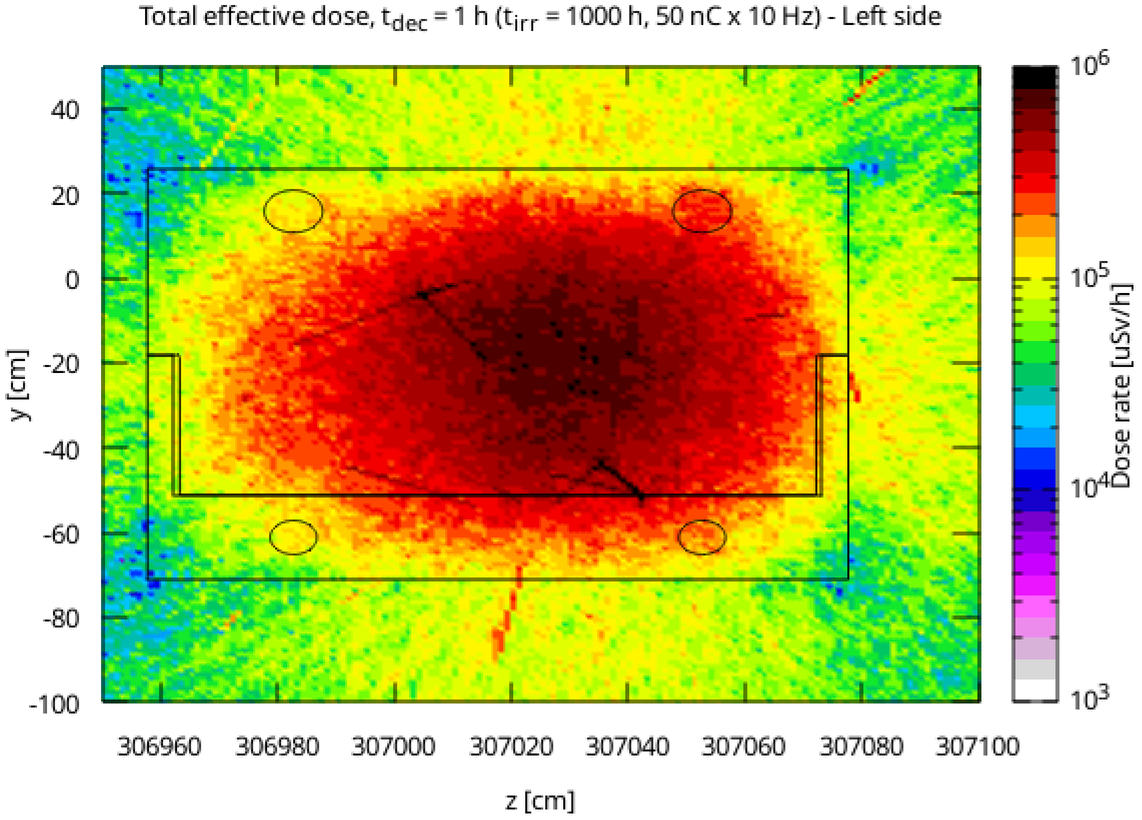
Back side



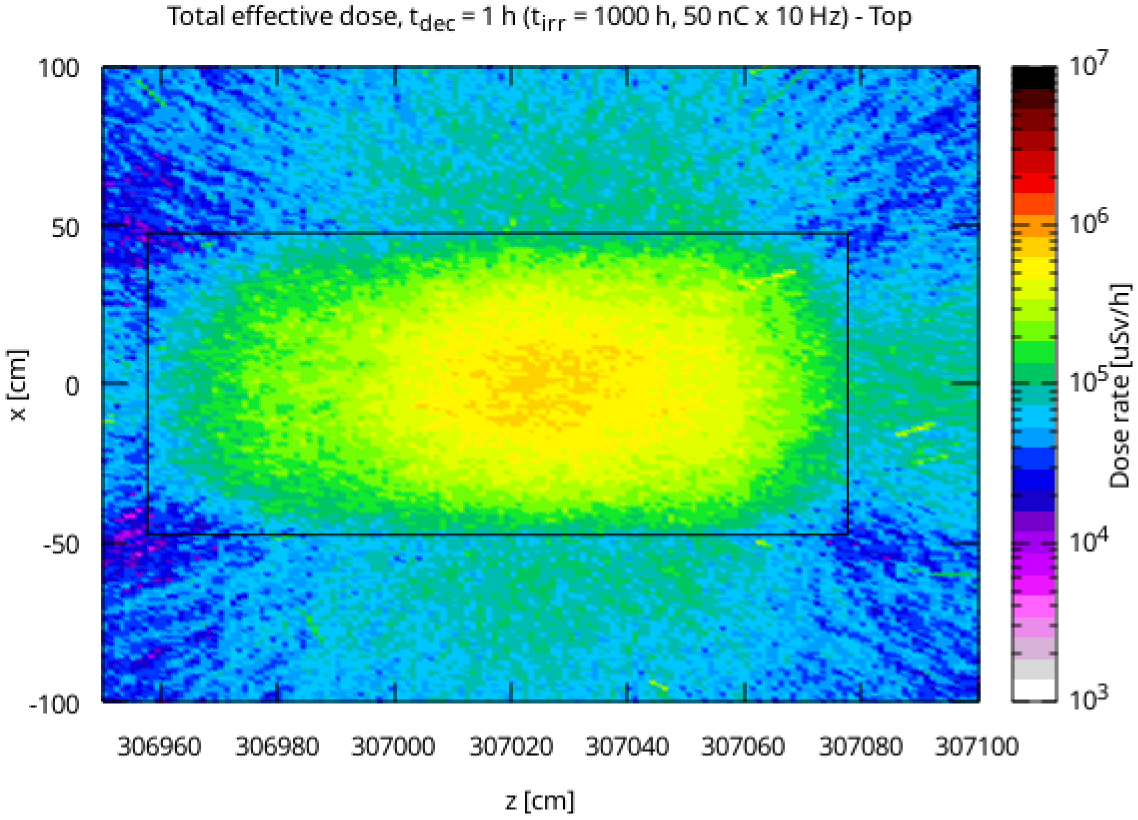
Residual Decay: 1 hour



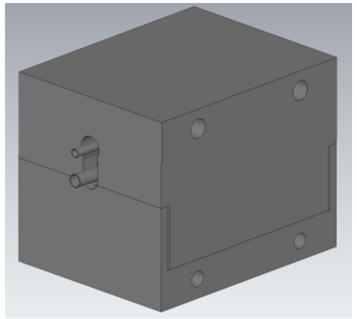
Left side



Top side

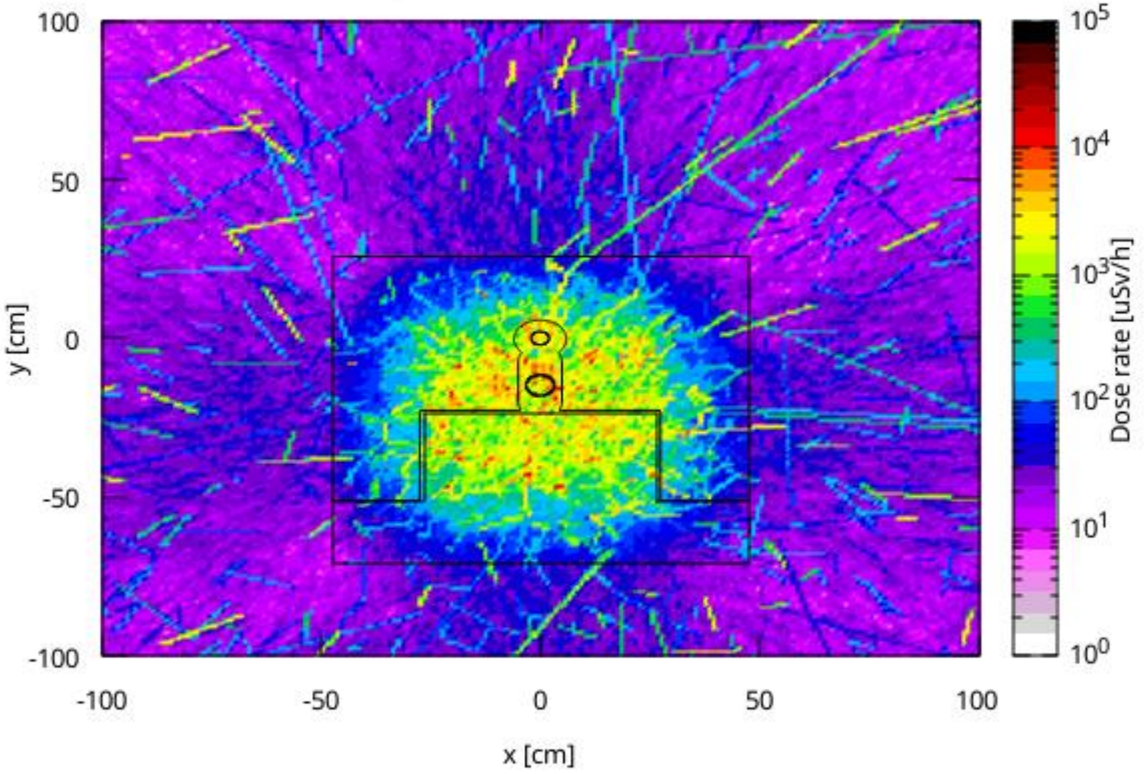


Residual Decay: 1 week



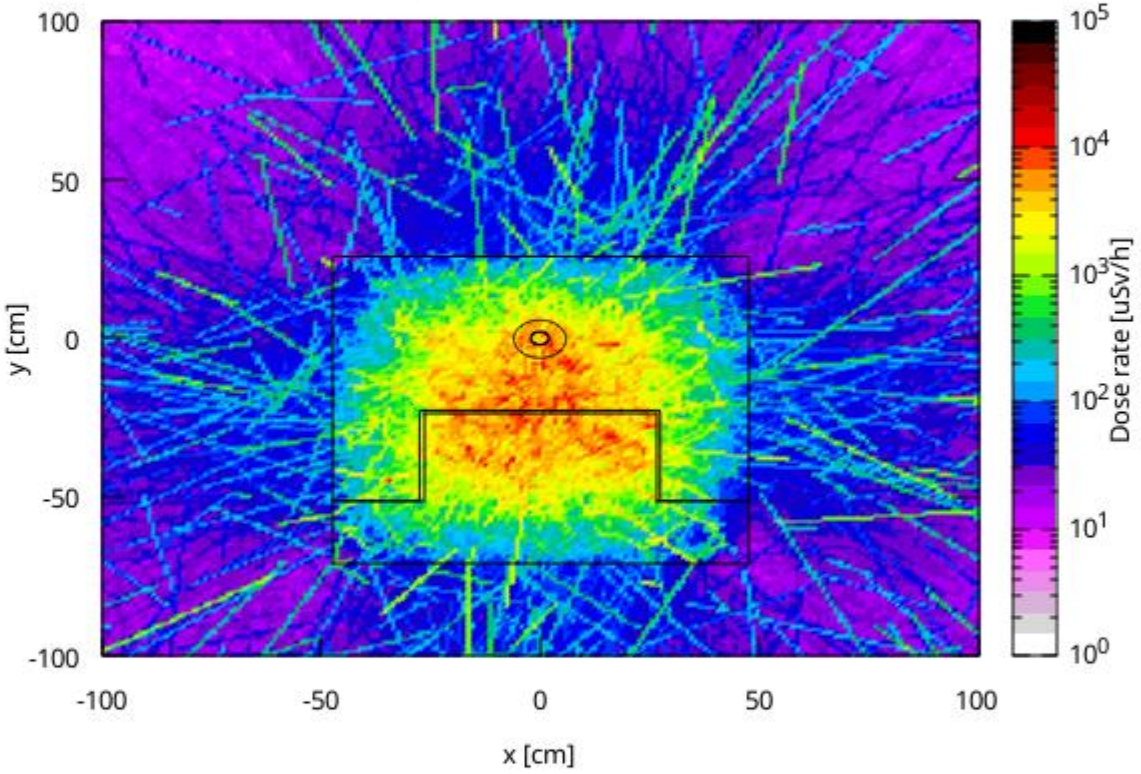
Front side

Total effective dose, t_{dec} = 1 week (t_{irr} = 1000 h, 50 nC x 10 Hz) - Front

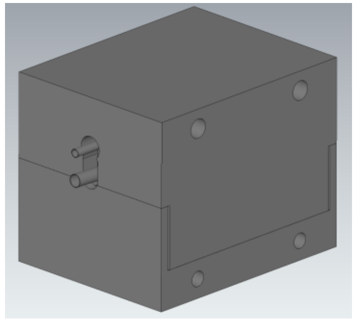


Back side

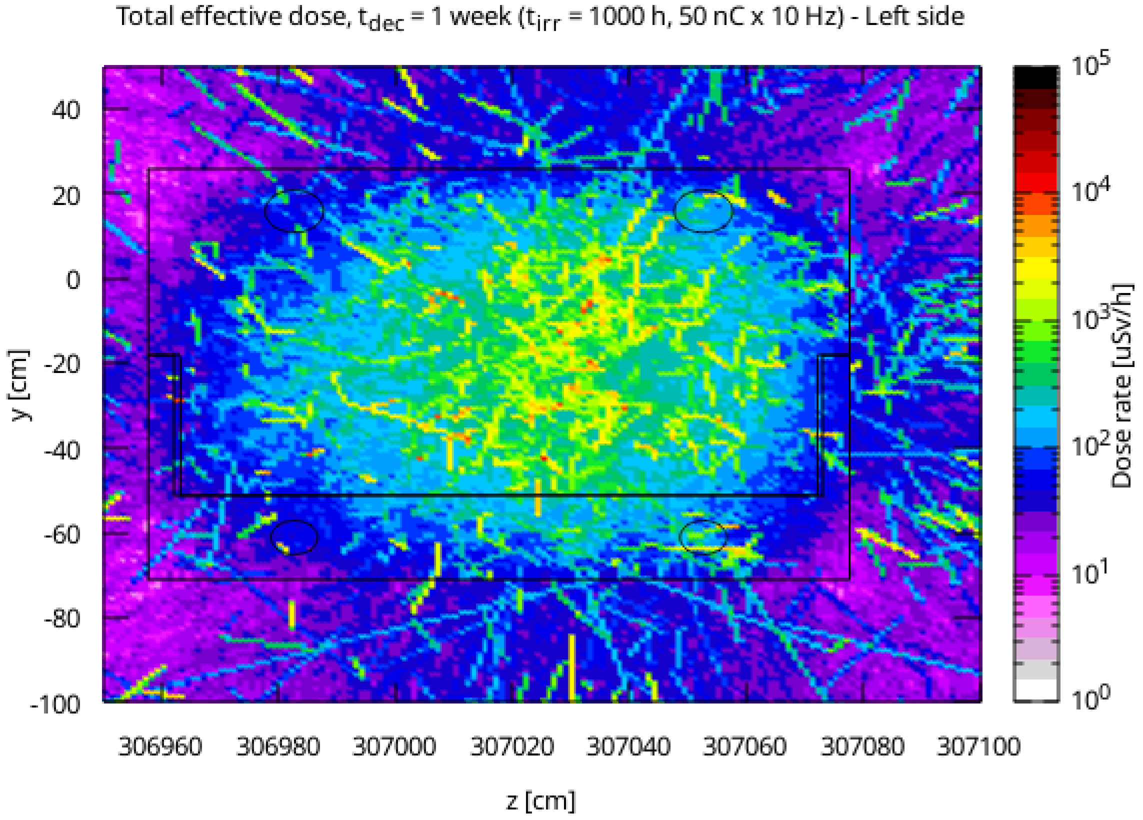
Total effective dose, t_{dec} = 1 week (t_{irr} = 1000 h, 50 nC x 10 Hz) - Back



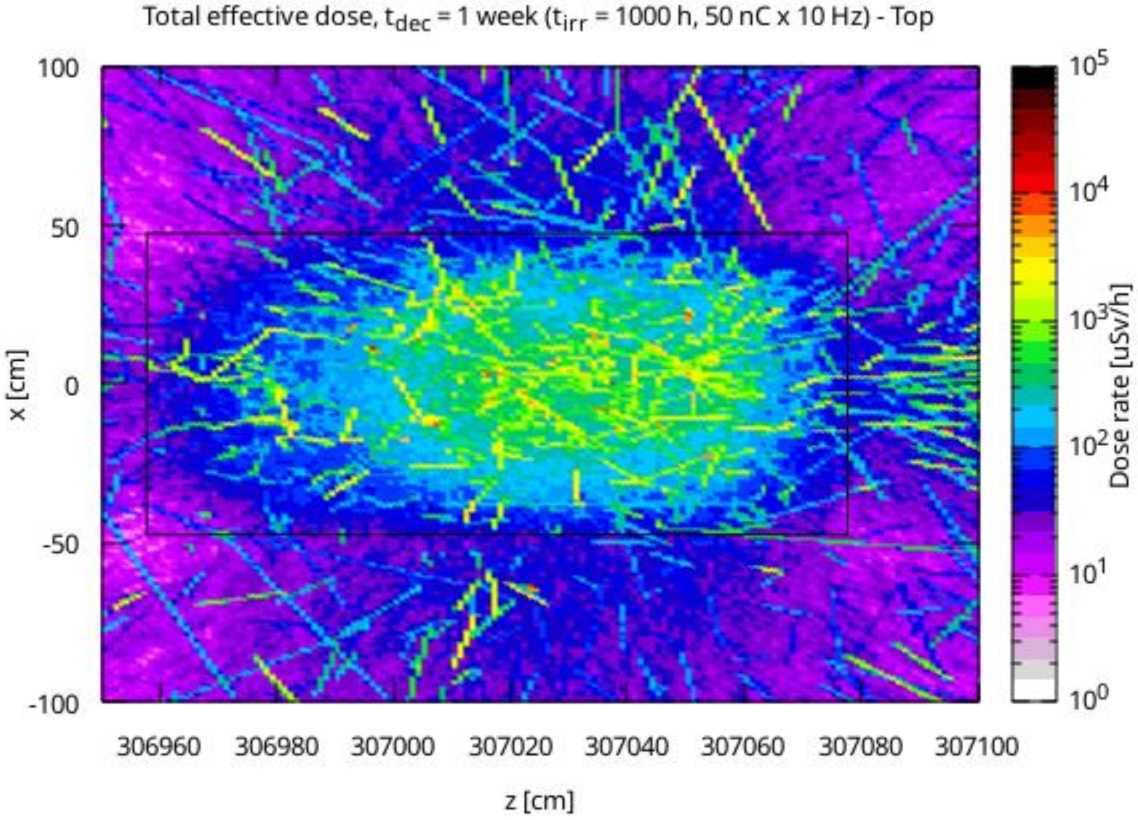
Residual Decay: 1 week



Left side



Top side



What the Model Allows You to Observe

The model makes it possible to

- Dose rate heat map and profiles;
- Assess dose outside shielding (important for personnel and electronics);
- Evaluate shielding efficiency.

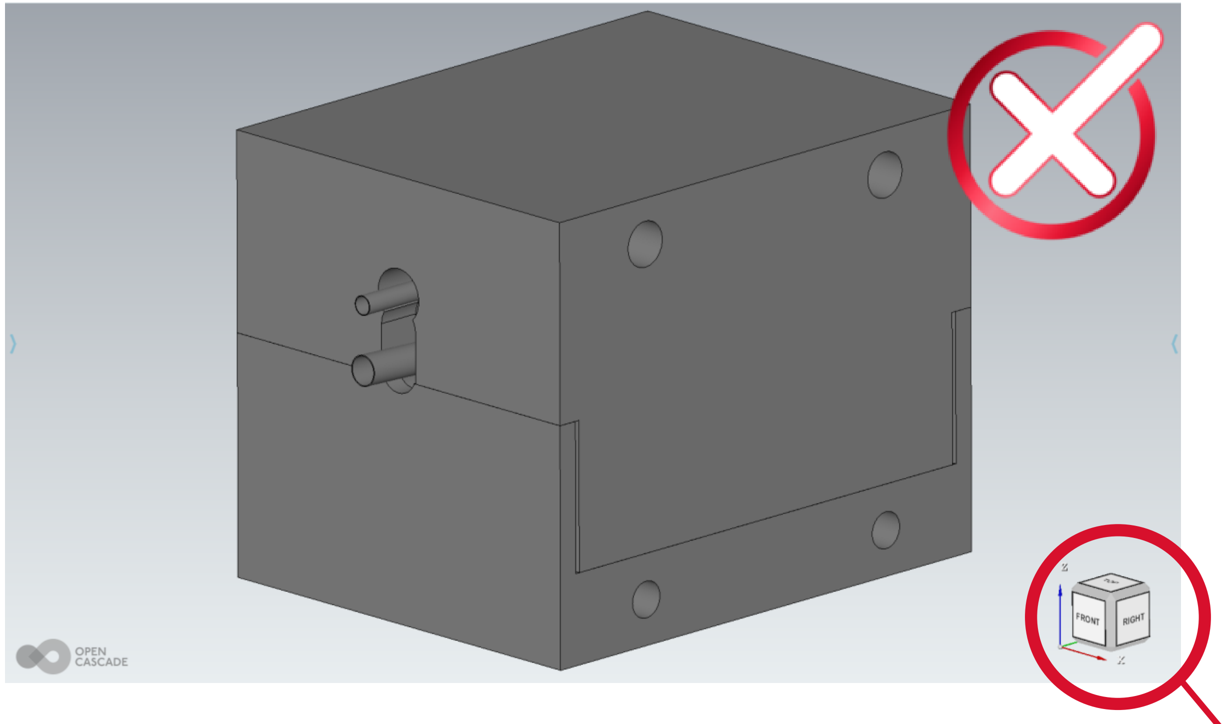
Arguments demonstrating the model's suitability for an electron beam dump

- The 40 GeV electron beam energy corresponds to new realistic accelerator conditions.
- Main physical processes relevant to a high-energy beam dump are activated and explicitly treated.
- The complex beam dump geometry is imported from detailed CAD (ABAQUS) data, ensuring geometric fidelity.
- Energy-loss and fluence scorers quantify heating and material damage inside the dump.
- Dose-equivalent scoring in surrounding regions addresses radiation-protection requirements.
- Residual-dose calculations provide cooldown estimates for safe human access and maintenance.

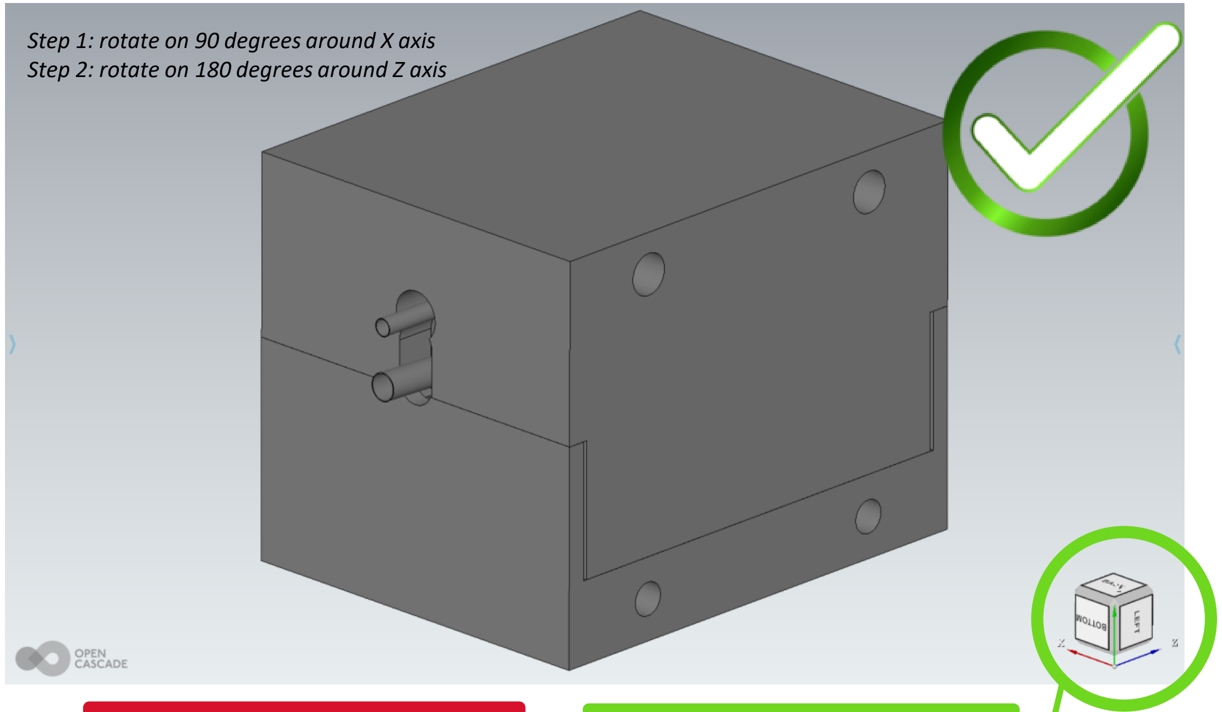
Supplementary Materials

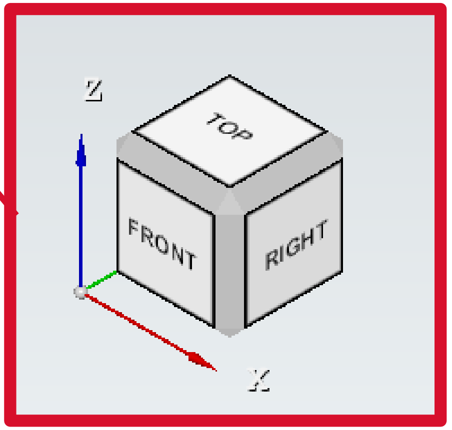
BEAM DUMP: Model Orientation

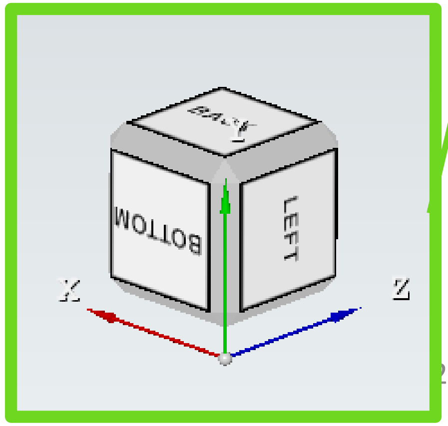
Initial Model XYZ (CAD)



Rotated Model XZY (FLUKA)







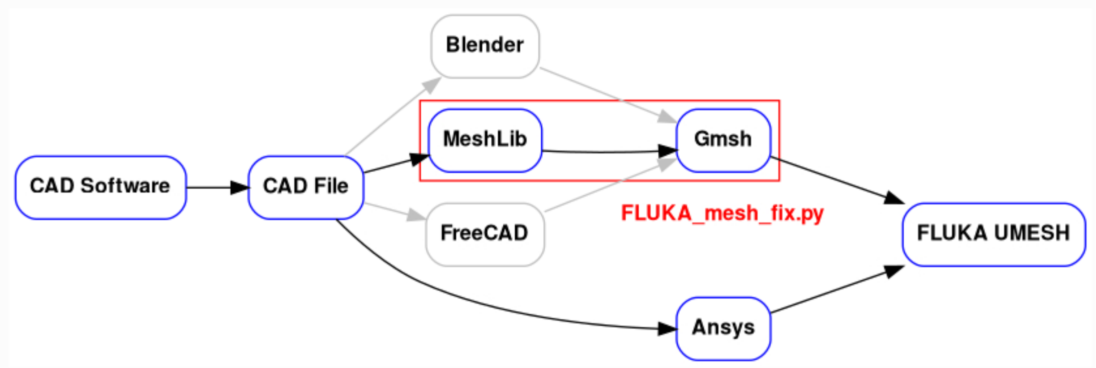
The correct orientation of the model must be done before importing it into FLUKA. Minimizing rotation and positioning operations ensures fewer bugs during simulation and data post-processing.

Advice: perform all work with the model in a CAD file, convert and import the finished model into FLUKA!

Complex Model Import to FLUKA

Unstructured meshes mini guide has been used to convert CAD file of the complex model to FLUKA UNMESH card (ABAQUS file)

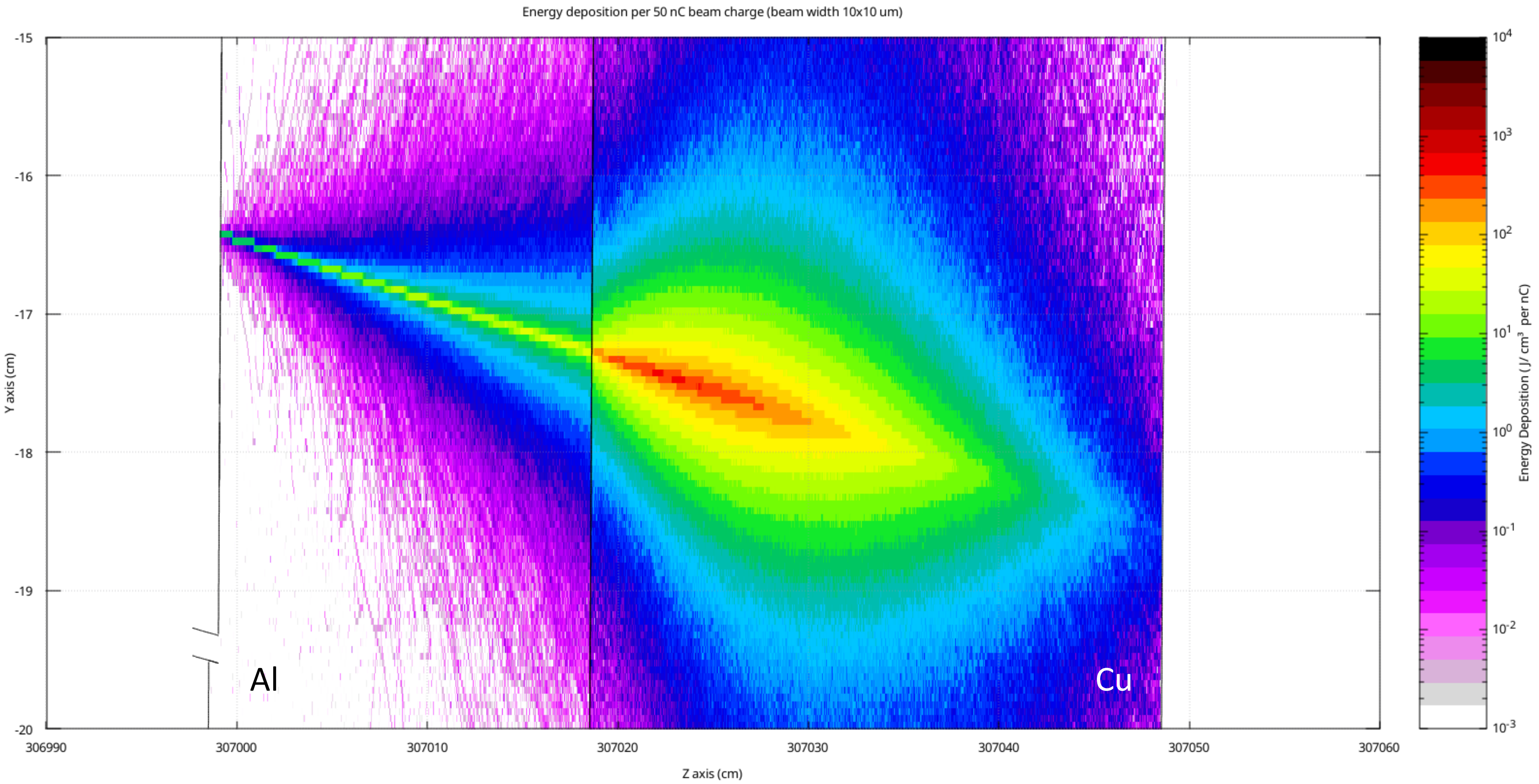
Starting with FLUKA version 4-5.0, the support of multiple types of the first order polyhedral meshes, the Unstructured Meshes (UM), has been included in the code. This document has the scope to guide in the use of UM as geometry of FLUKA simulations.



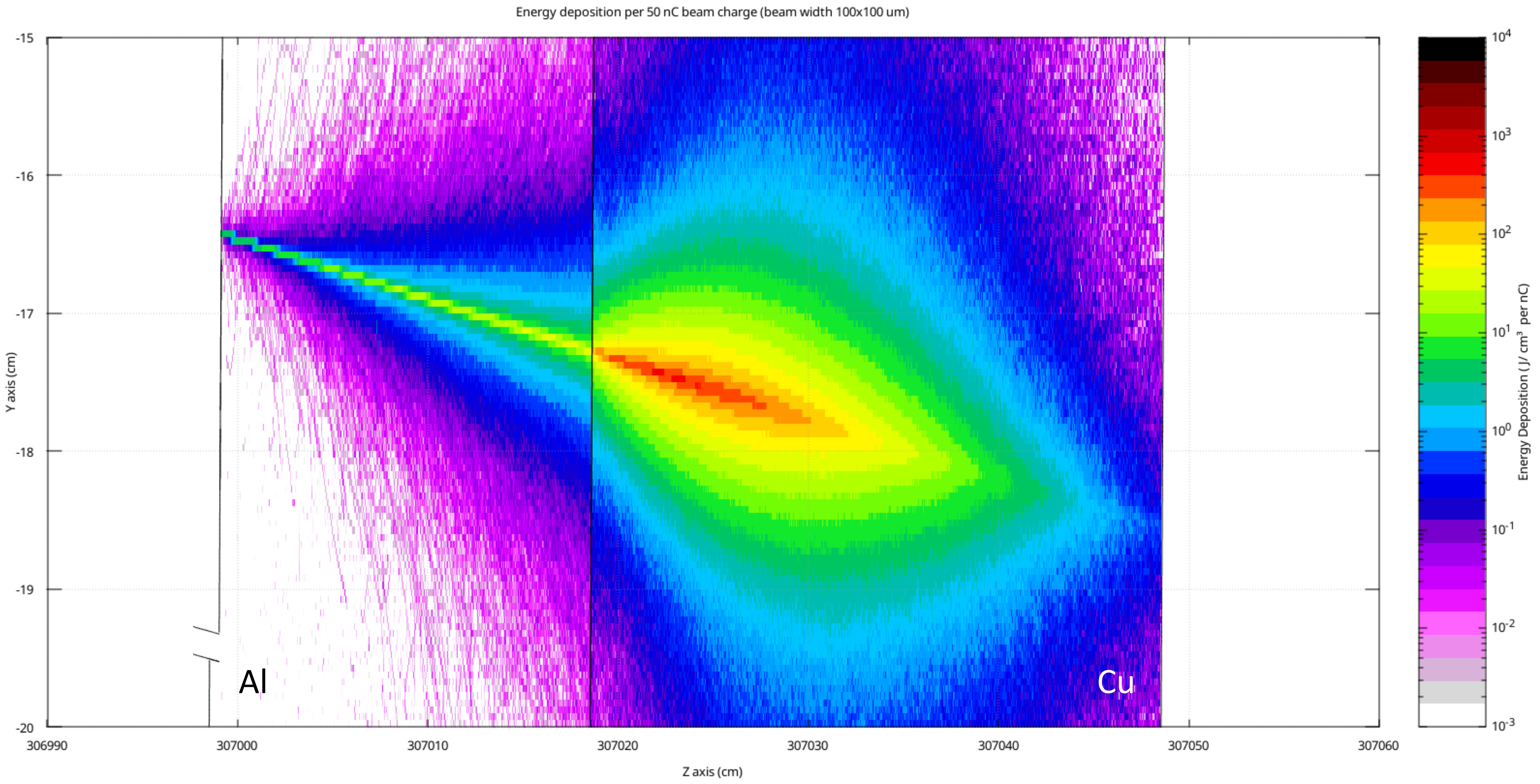
CAD file → STEP file → ABAQUS file

A specific tool, FLUKA_mesh_fix.py has been developed for this purpose. It is a Python script, located in the geom_mesh_utils package, which utilizes Voxel remeshing, similar to the one in Blender. The script employs a comparable functionality from the Meshlib library, which is more flexible in terms of supported systems and Python versions (more details and guide for the meshing script).

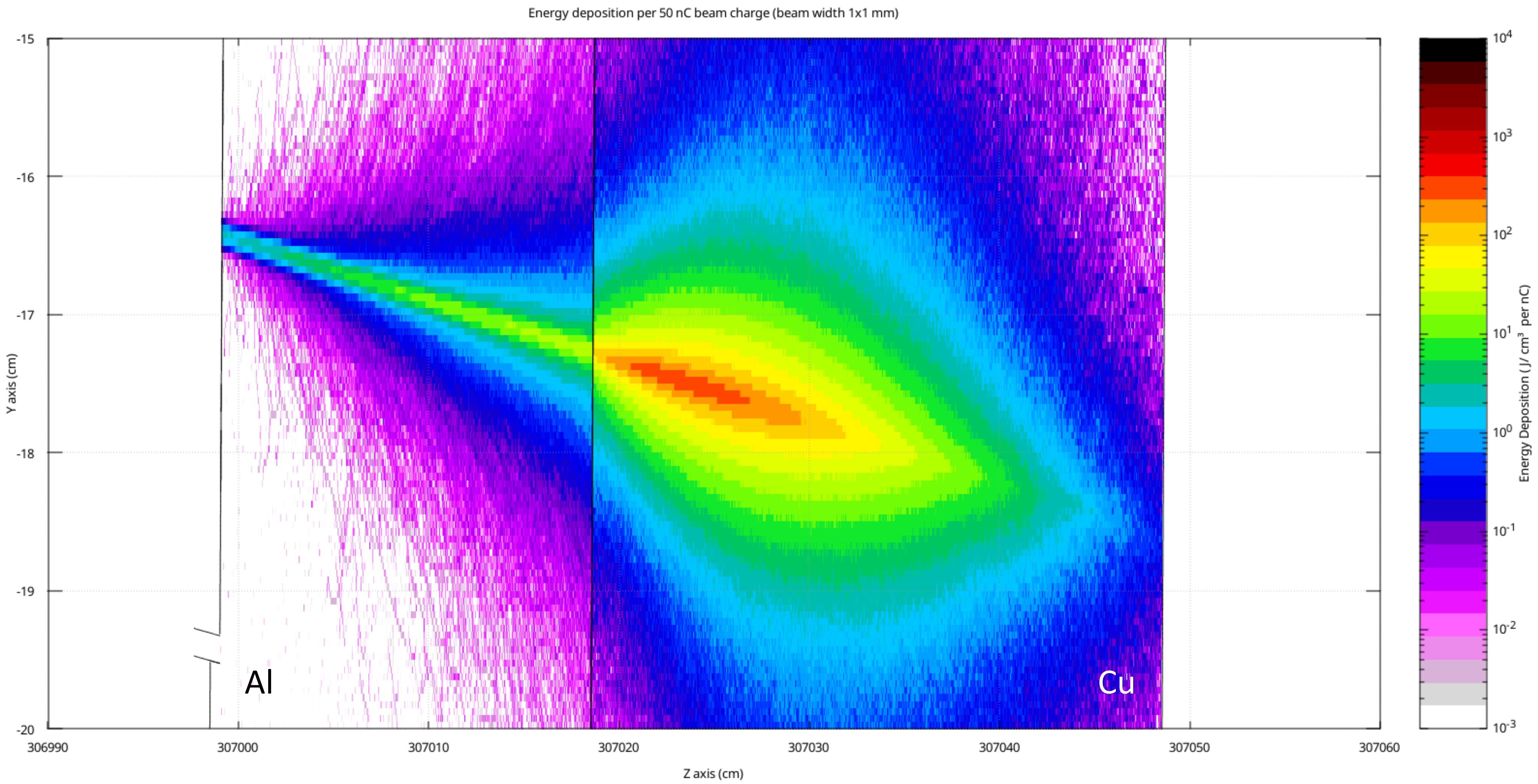
Radiation Hardness: beam width 10 x 10 um



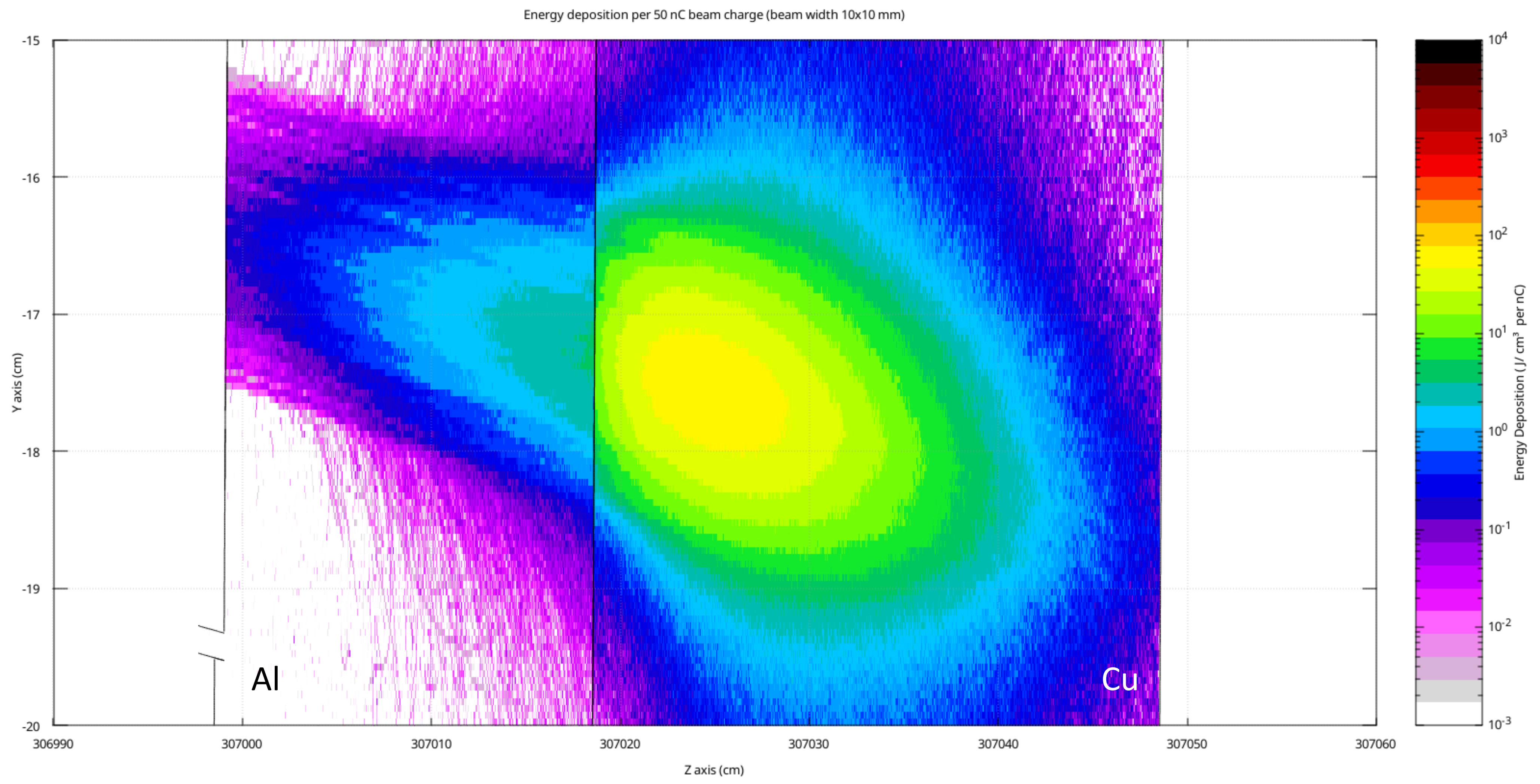
Radiation Hardness: beam width 100 x 100 um



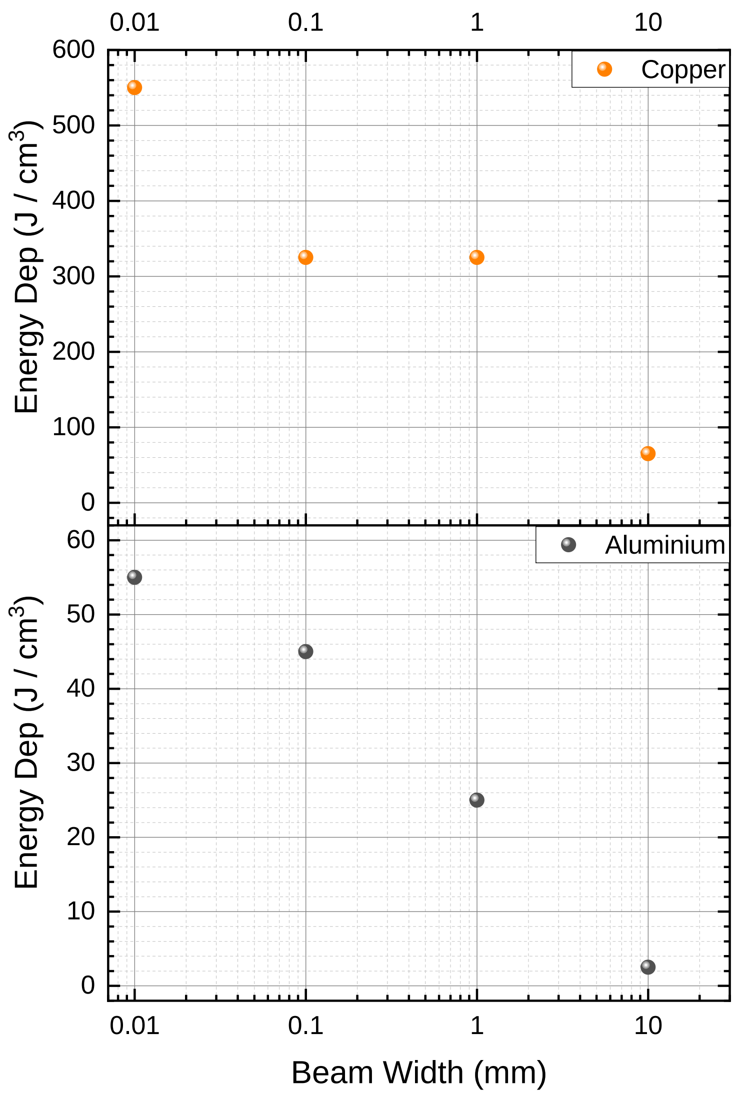
Radiation Hardness: beam width 1 x 1 mm

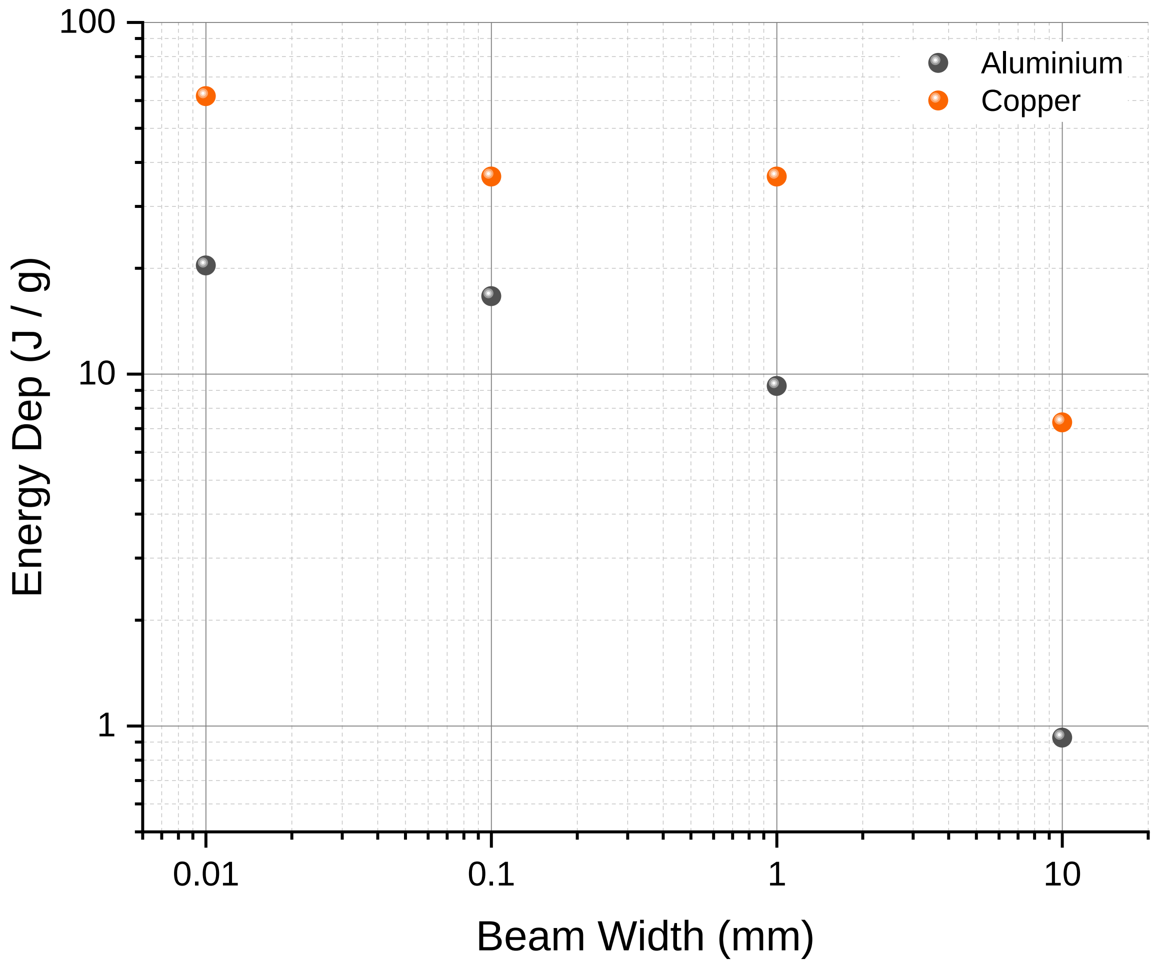


Radiation Hardness: beam width 10 x 10 mm

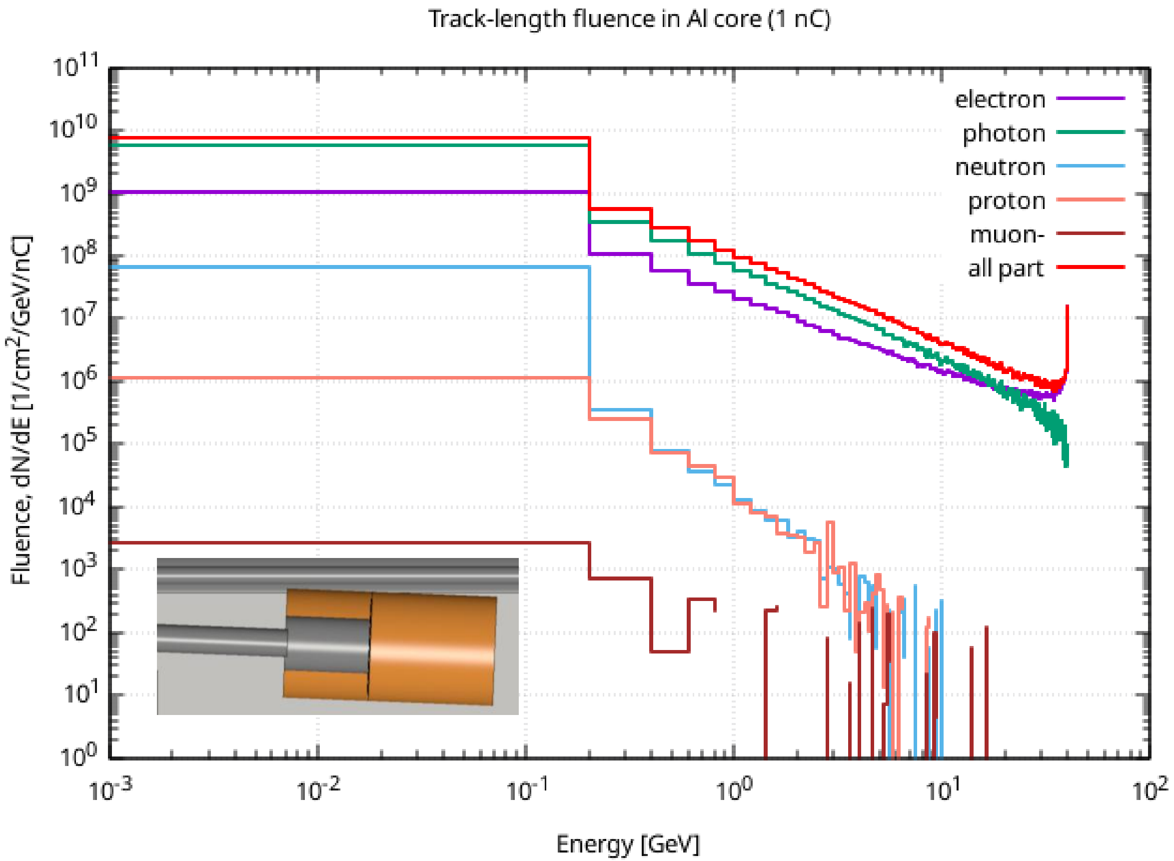


Radiation Resistance: limits check





Simulation results: Track-length fluence



Normalization

To compare results and interpret the data quantitatively, the track-length fluence was normalized using the formula:

$$Norm\ Factor = \frac{1}{\pi \cdot L \cdot R^2} \cdot N_A$$

where: L=20 cm — radius of the cylindrical aluminum core, R=6.5 cm —the core radius, $N_A=6.24\times10^9$ — conversion factor from nC to the number of primary particles.

This normalization allows expressing the fluence per unit volume per unit energy per unit charge, yielding values in: [1/(cm²·GeV·nC)]

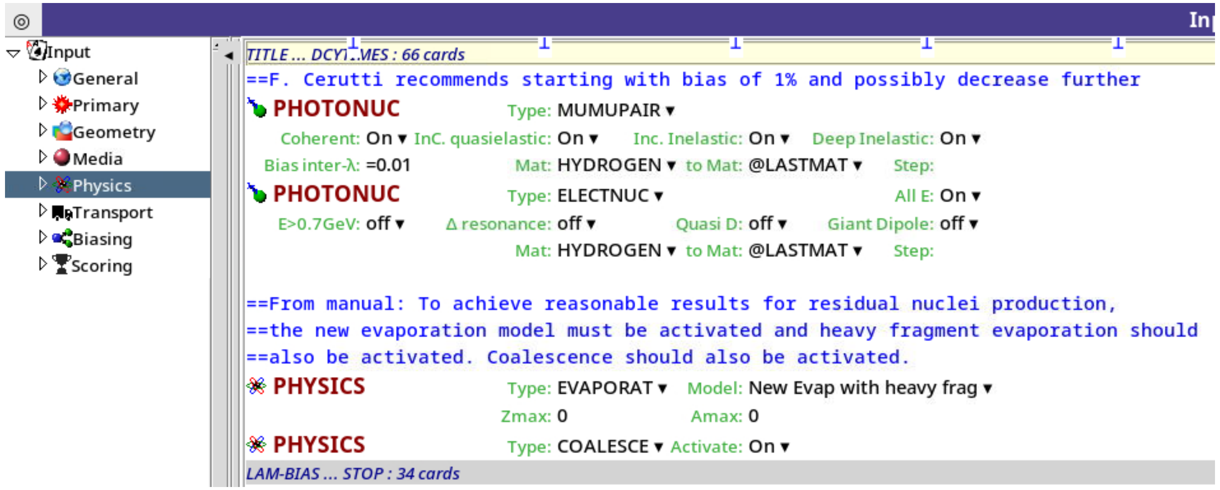
Such normalization makes the results applicable for evaluating radiation effects per unit incident charge, facilitating comparisons across different experimental setups or beam intensities.

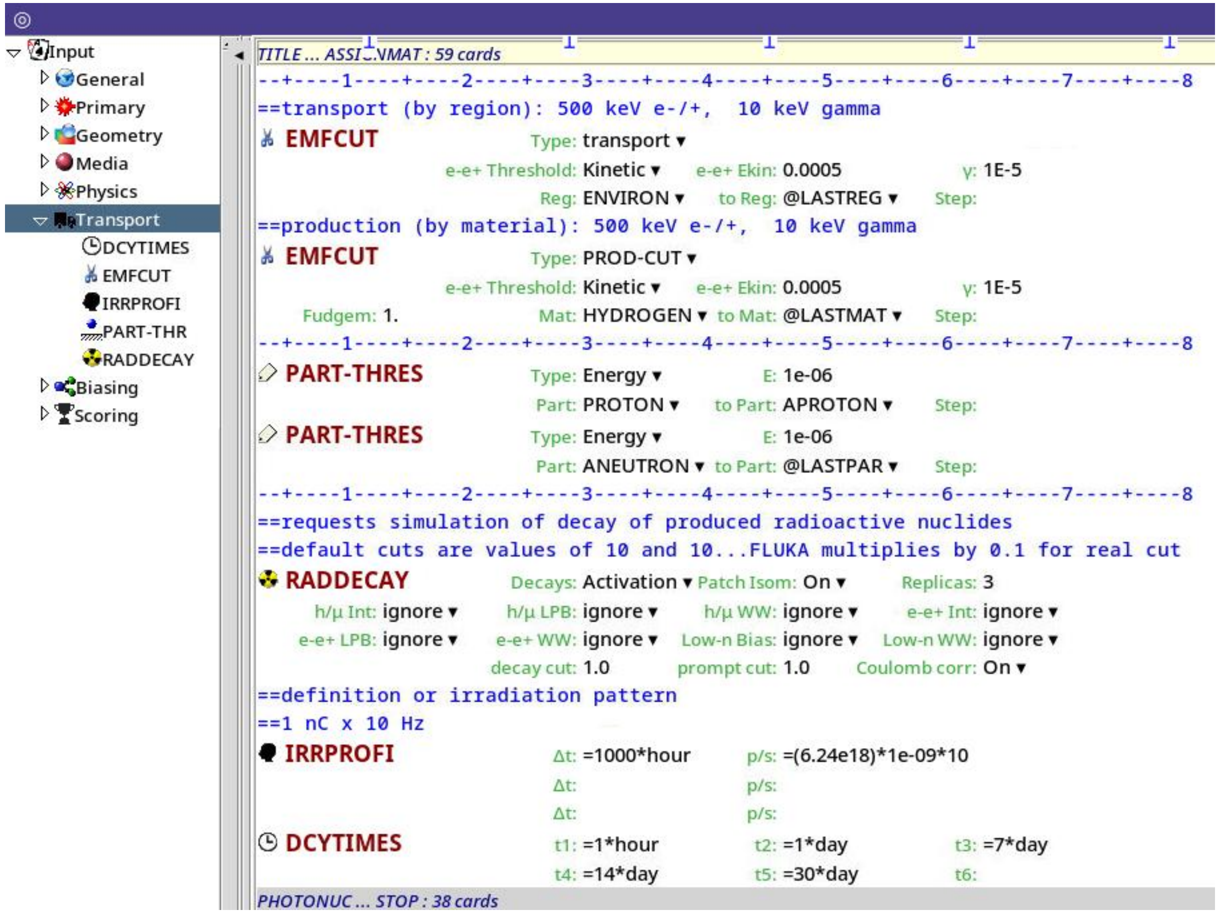
- The aluminum cylindrical core is exposed to a significant flux of secondary particles, especially electrons and photons at low energies, and protons and neutrons at higher energies.
- The maximum track-length fluence reaches approximately 10^{10}–10^{11} [1/(cm²·GeV·nC)] around 1–10 MeV, which is critical for assessing radiation hardness.
- The spectrum is characteristic of hadronic and electromagnetic cascades generated by primary particle interactions with the target.
- The fluence distribution highlights the dominant particle types and energy ranges that contribute most to radiation dose and particle flux, which is essential for shielding design, material selection, and electronic damage evaluation.

Physics and Transport Cards

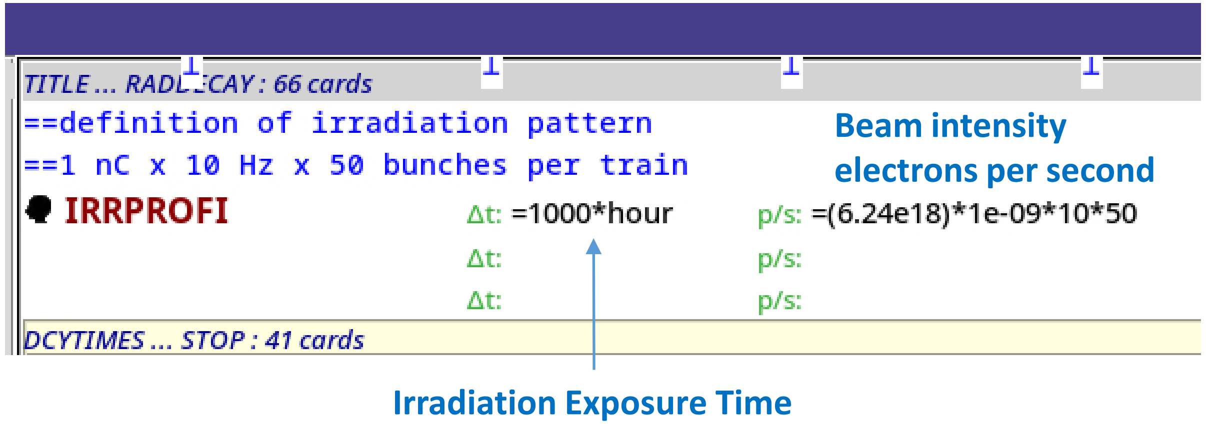
Physics included in the calculation

- Electromagnetic transport of electrons and photons — included; lower transport thresholds set to 500 keV for e⁻ and 10 keV for γ.
- Residual-nuclei production — included via the RADDECAY and DCYSCORE cards.
- Nuclear evaporation — enabled through PHYSICS EVAPORAT, allowing the de-excitation of highly excited nuclei.
- Coalescence of light fragments — enabled through PHYSICS COALESCE.
- Photo-nuclear reactions — included and accelerated with a mean-free-path bias (LAM-BIAS).
- Muon, photon and neutron interactions — fully enabled by the corresponding PHYSICS, PHOTONUC and scoring cards.
- Secondary (bremsstrahlung) radiation — handled by FLUKA's built-in electromagnetic model.

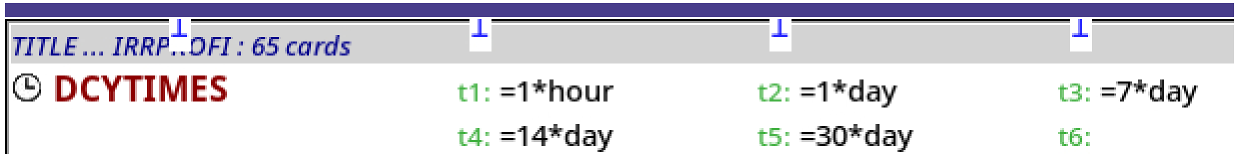




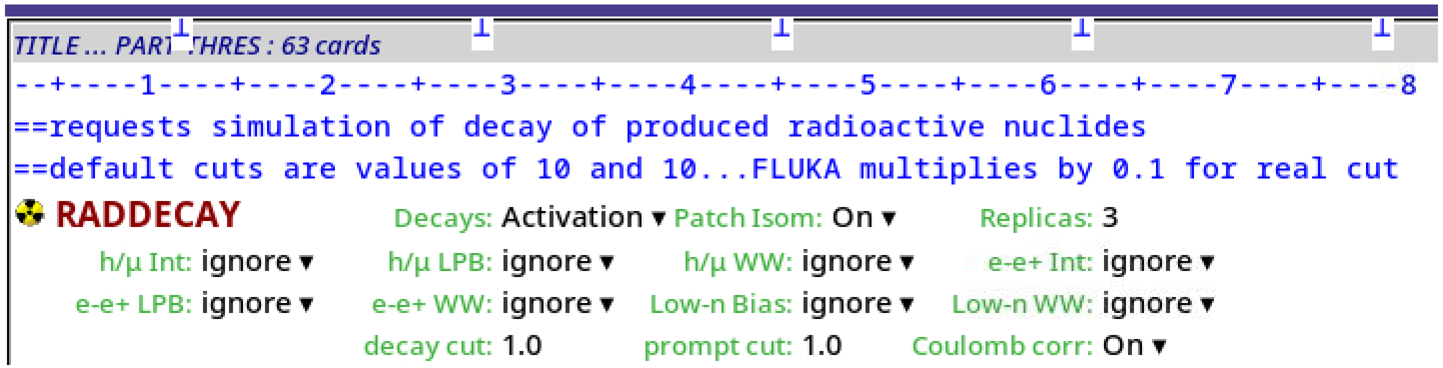
Residual Decay Settings



Defines how long and with what intensity the system is irradiated (e.g. 10 sec, 10 h). Irradiation profile (IRRPROFI): 1 nC per pulse at 10 Hz with 50 bunches per train, giving 3.12×10^{12} primary particles per hour.



Specifies moments after shutdown for dose evaluation. Decay times (DCYTIMES): residual-dose evaluations scheduled at 1 h, 1 d, 7 d, 14 d and 30 d after beam shutdown.



With RADDECAY, FLUKA simulates the entire chain of residual radiation, including β-decay, γ-emission, and neutron emission from unstable nuclei.