Impact on the IFMIF irradiation property from the beam profile

K. Kondo, U. Fischer, D. Große, A. Serikov

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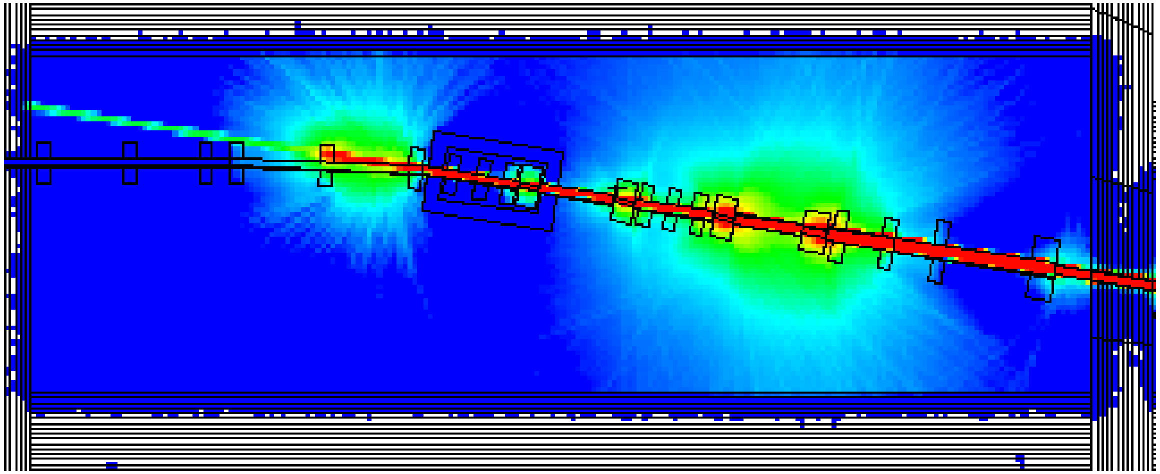
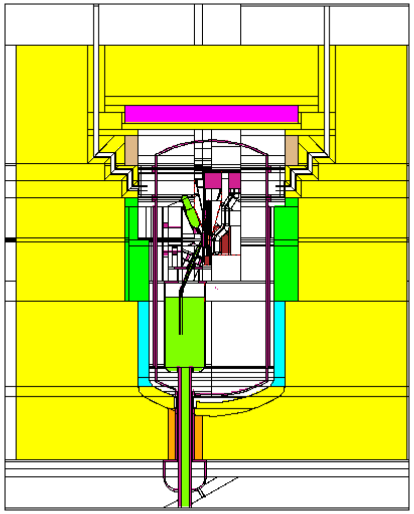
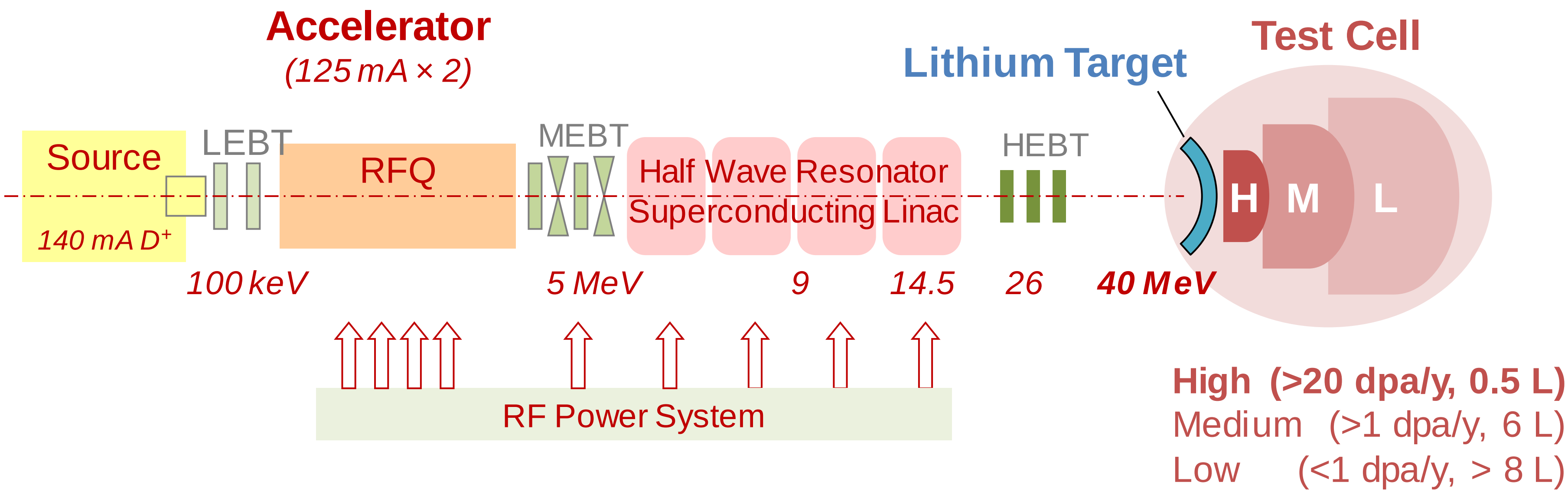




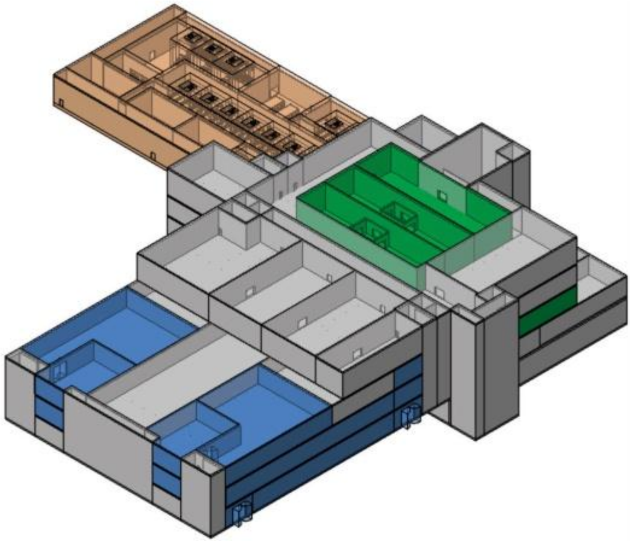
What is IFMIF?

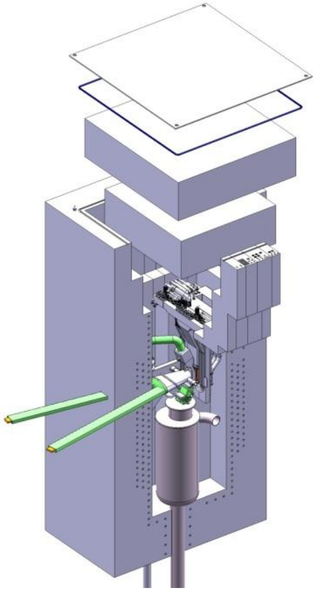
- IFMIF (International Fusion Materials Irradiation Facility)
  - Accelerator-based intense neutron source (D-Li, 40 MeV, 250 mA)
  - Subjecting candidate materials for fusion reactors to similar conditions expected to be experienced by a future power plant (DEMO)



What is IFMIF/EVEDA?

- IFMIF/EVEDA (The Engineering Validation and Engineering Design Activities)
  - Conducted in the framework of the Broader Approach (BA) Agreement between EU (F4E) and Japan (JAEA)
  - Validation Activities: **prototype accelerator (LIPAc)** in Rokkasho, EVEDA Lithium Test Loop (ELTL) in Oarai
  - **Engineering Design Activities** (EDA): Detailed, complete and fully integrated engineering design





What is LIPAc?

Karlsruhe Institute of Technology

High	>20 dpa/an,	0.5 L
Medium	> 1 dpa/an,	6 L
Low	< 1 dpa/an,	> 8 L

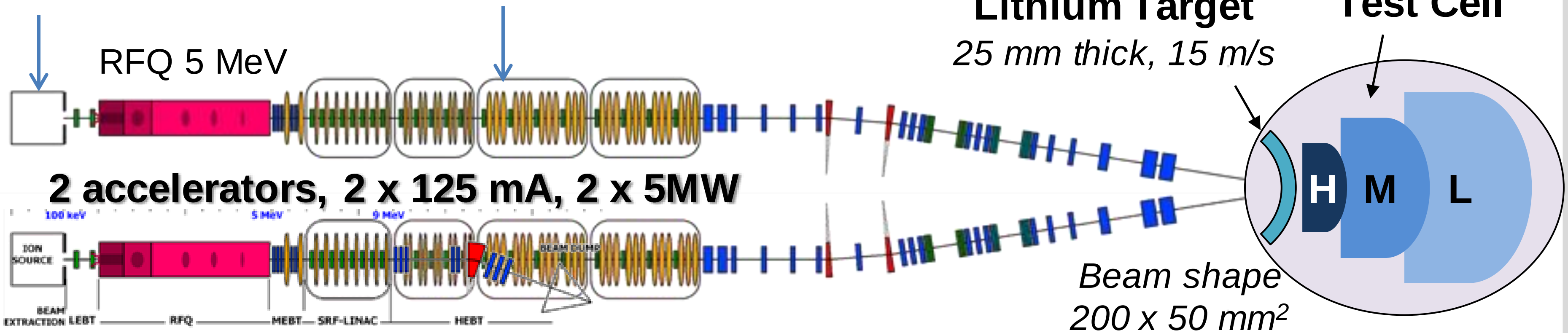
Deuteron source
140 mA, 100 keV

SRF Linac 40 MeV
(Half Wave Resonators)

Lithium Target
25 mm thick, 15 m/s

Test Cell

RFQ 5 MeV



2 accelerators, 2 x 125 mA, 2 x 5MW

Beam shape
200 x 50 mm²

Typical reactions
$^{7}Li(d,2n)^{7}Be$
$^{6}Li(d,n)^{7}Be$
$^{6}Li(n,T)^{4}He$

LIPAc = prototype for IFMIF
includes all critical accelerator components
to be tested at nominal beam current at BA site

Alban Mosnier, "LIPAc overview", IFMIF/EVEDA Workshop #4

IFMIF-related activities in KIT/INR/NK group

Karlsruhe Institute of Technology

- PA TF04 "*Other Engineering Validation Activities*", Sub-activity TF04.6 on "*Engineering Design and Validation Activities on Neutronics Simulation Tools, Models and Data*"
  - Development of **McDeLicious** Monte Carlo code to simulate d+Li nuclear reactions as the neutron and photon source.
  - Generation of the up-to-date **neutronics geometry model** by using **McCad** software and calculation of nuclear responses for the Test Facility, for which KIT is responsible.
  - Provision of nuclear data above 20 MeV neutron energy collaborating with FENDL-3 activities by IAEA.

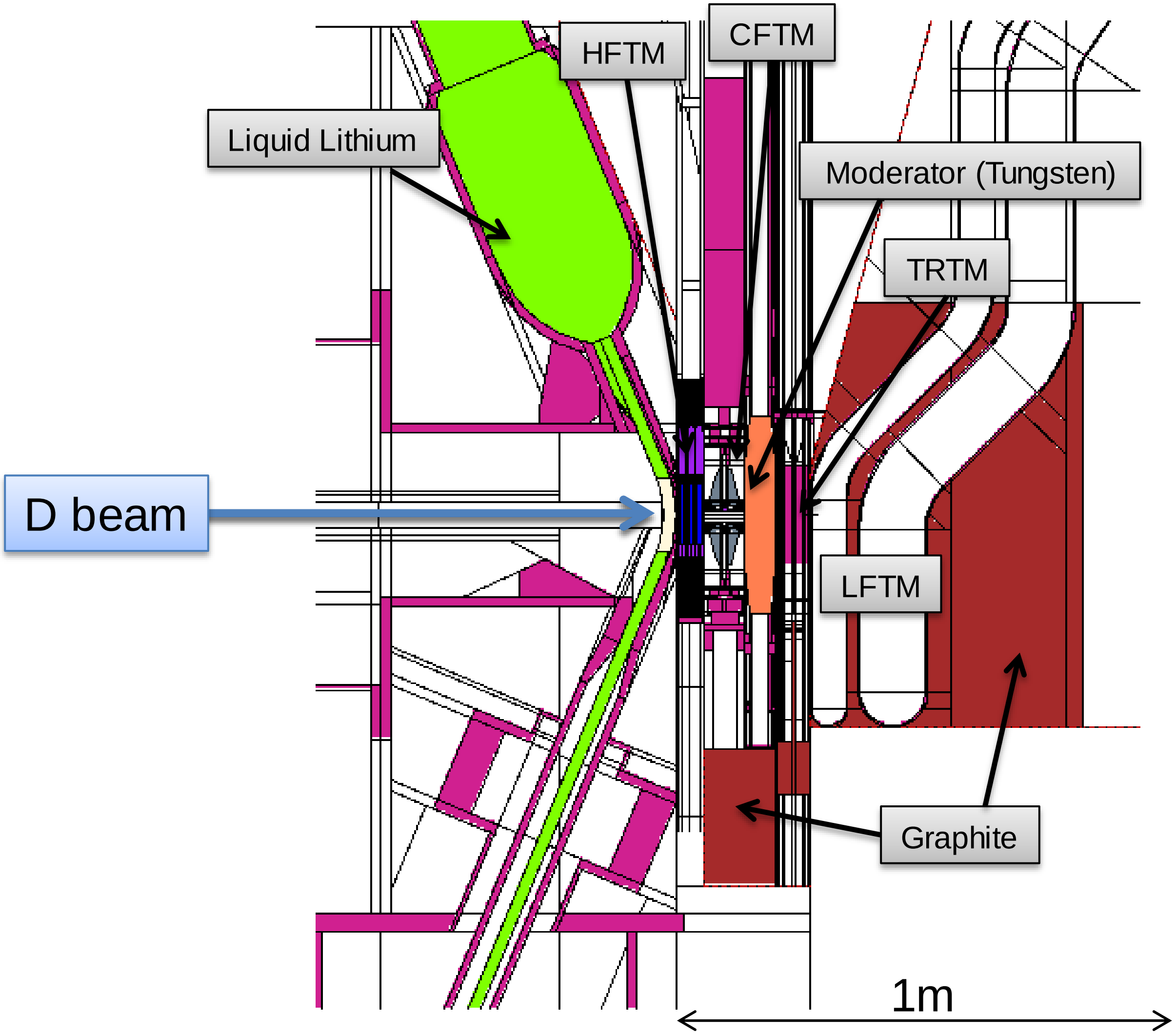
- PA ED04 "*Design Activity I*", Test Cell (TC), Access Cell (AC), and Test Module Handling Cells (TMHCs)
- **Neutronic analyses supports for the HEBT section layout design**

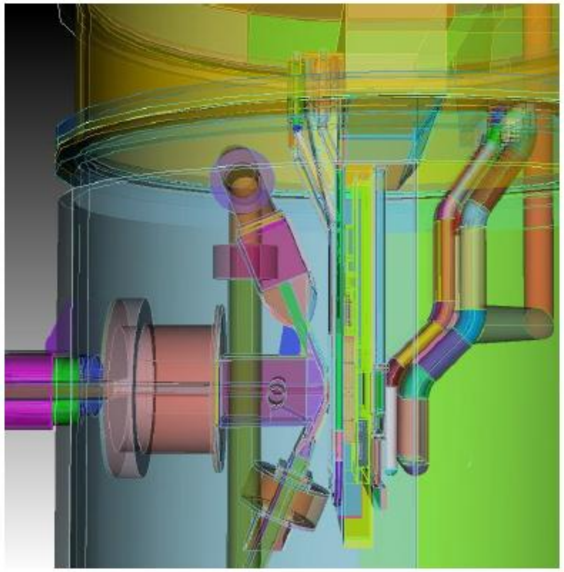
IFMIF users' requirements

- DPA
  - **0.1 L > 50 dpa/fpy**, **0.5 L > 20 dpa/fpy** in High Flux Test Module (**HFTM**)
    - *The highest-value regions can be characterized as providing a damage production rate of 50 dpa/y in an irradiation volume of 0.1 liter and 20 dpa/y in a volume of 0.5 liter.*
- Neutron flux gradients
  - **Less than 10%/cm**
    - *Neutron flux gradient no greater than 10% across the gage volume of specimens, since a high flux dependence is known (e.g., the fracture toughness in the low fluence range)*
- He-production/DPA, H-production/DPA
  - The ratios of the transmutation reaction H- and He-production rates to the displacement rate in the specimens are required to be similar to those for the materials in service in the blanket structure of the fusion reactor.
  - Affect swelling characteristics

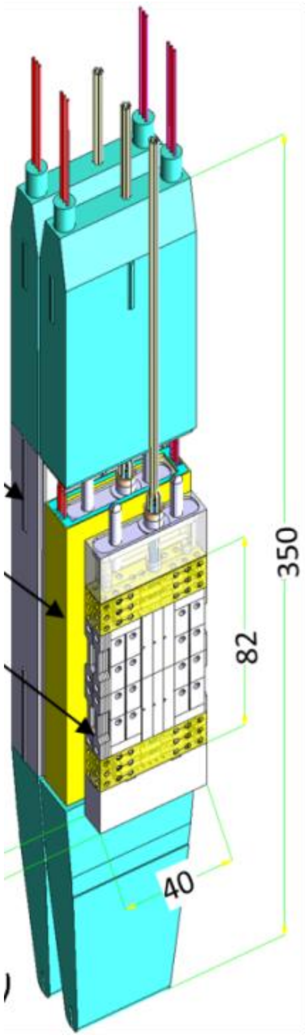
Ref: IFMIF Comprehensive Design Report (CDR), IFMIF International Team, Dec. 2003.

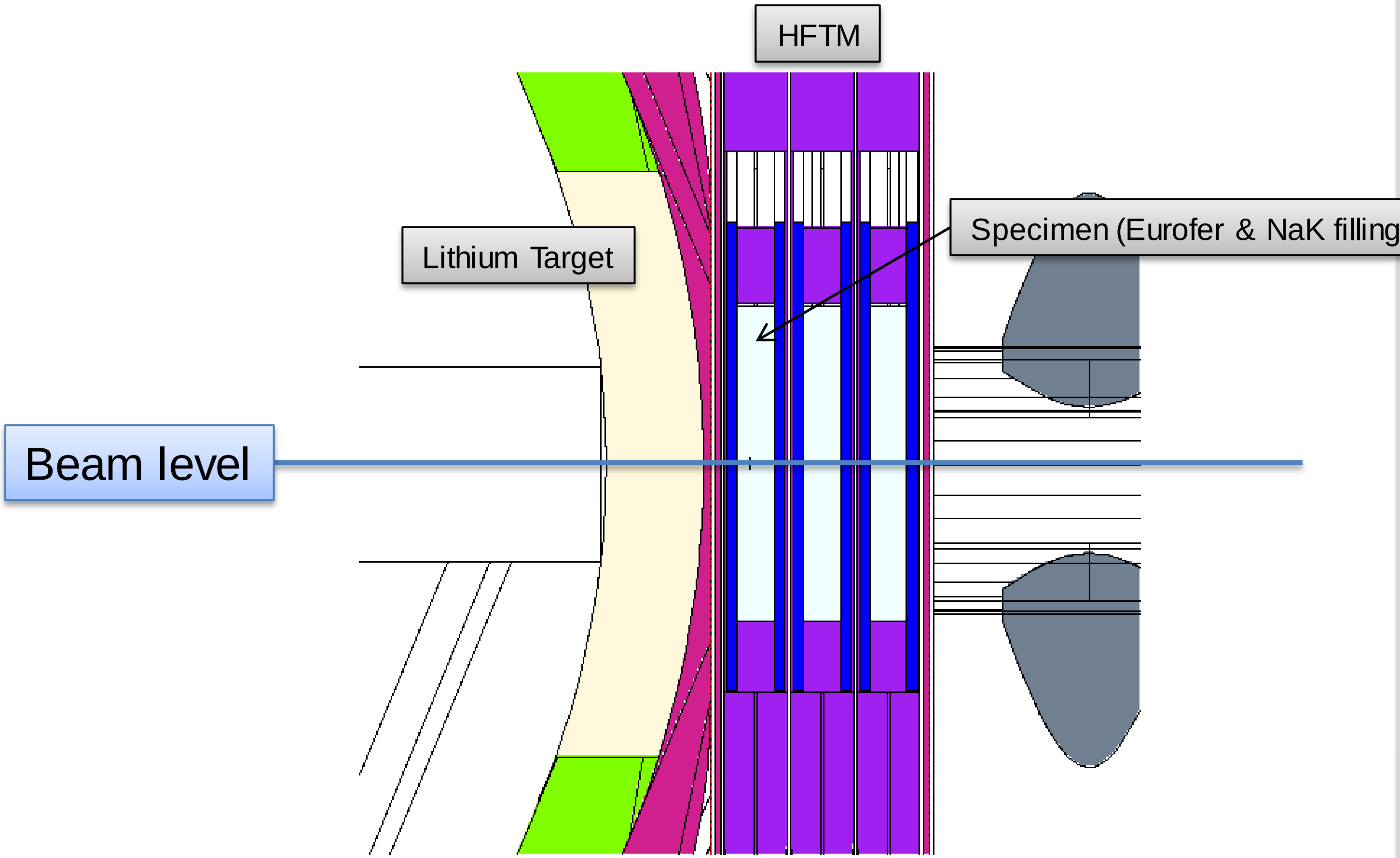
Calculation model (Test Modules)





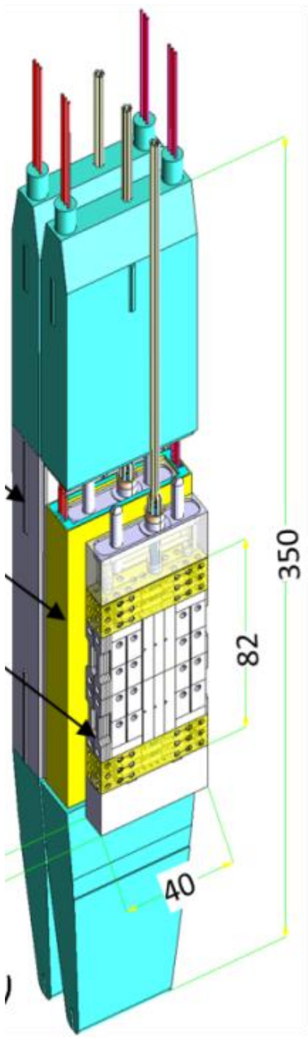
Calculation model for HFTM-V (vertical cut)

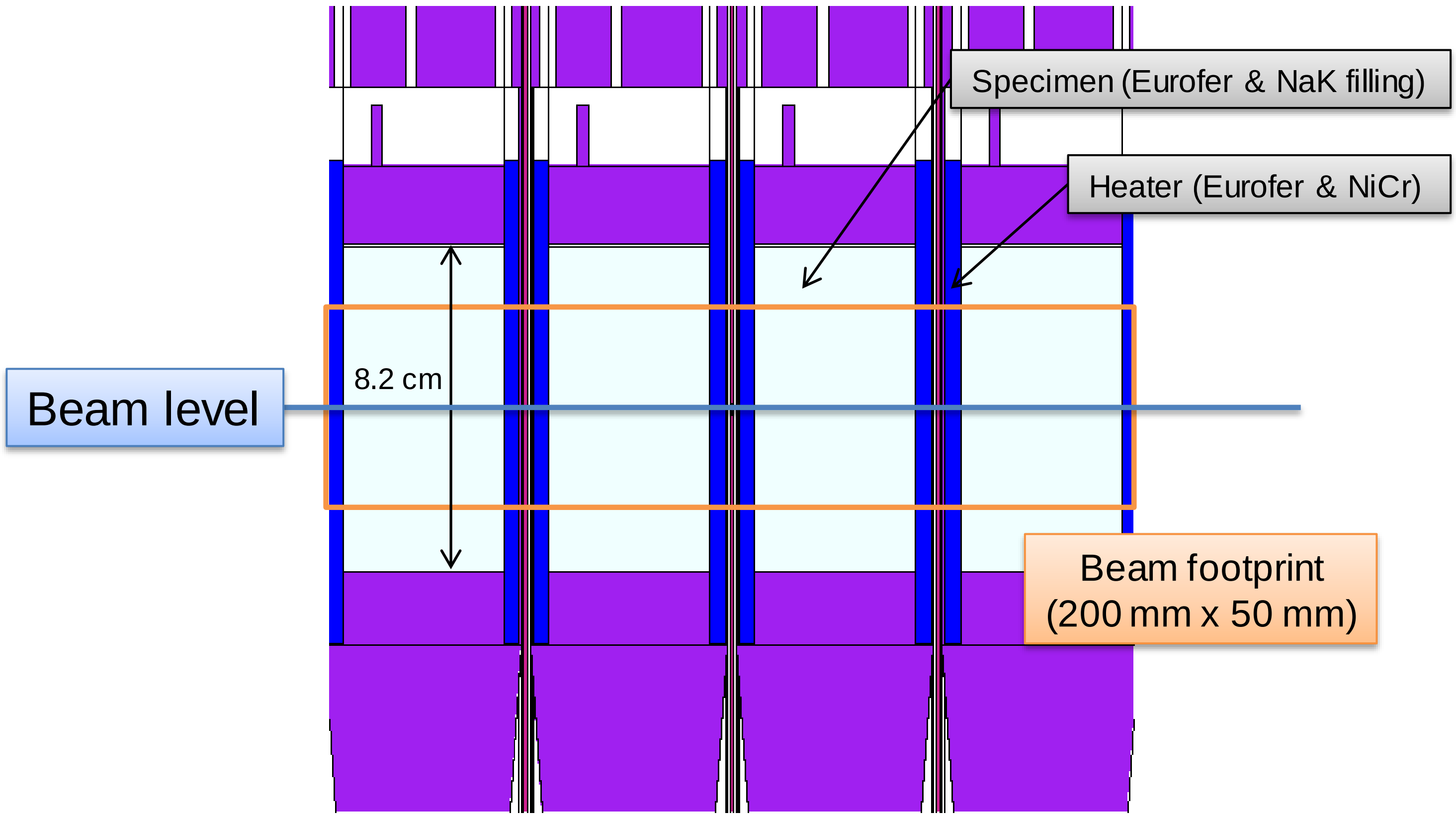




Eurofer: NaK = 74:26 (volume ratio)
Na:K = 22:78 (wt ratio)

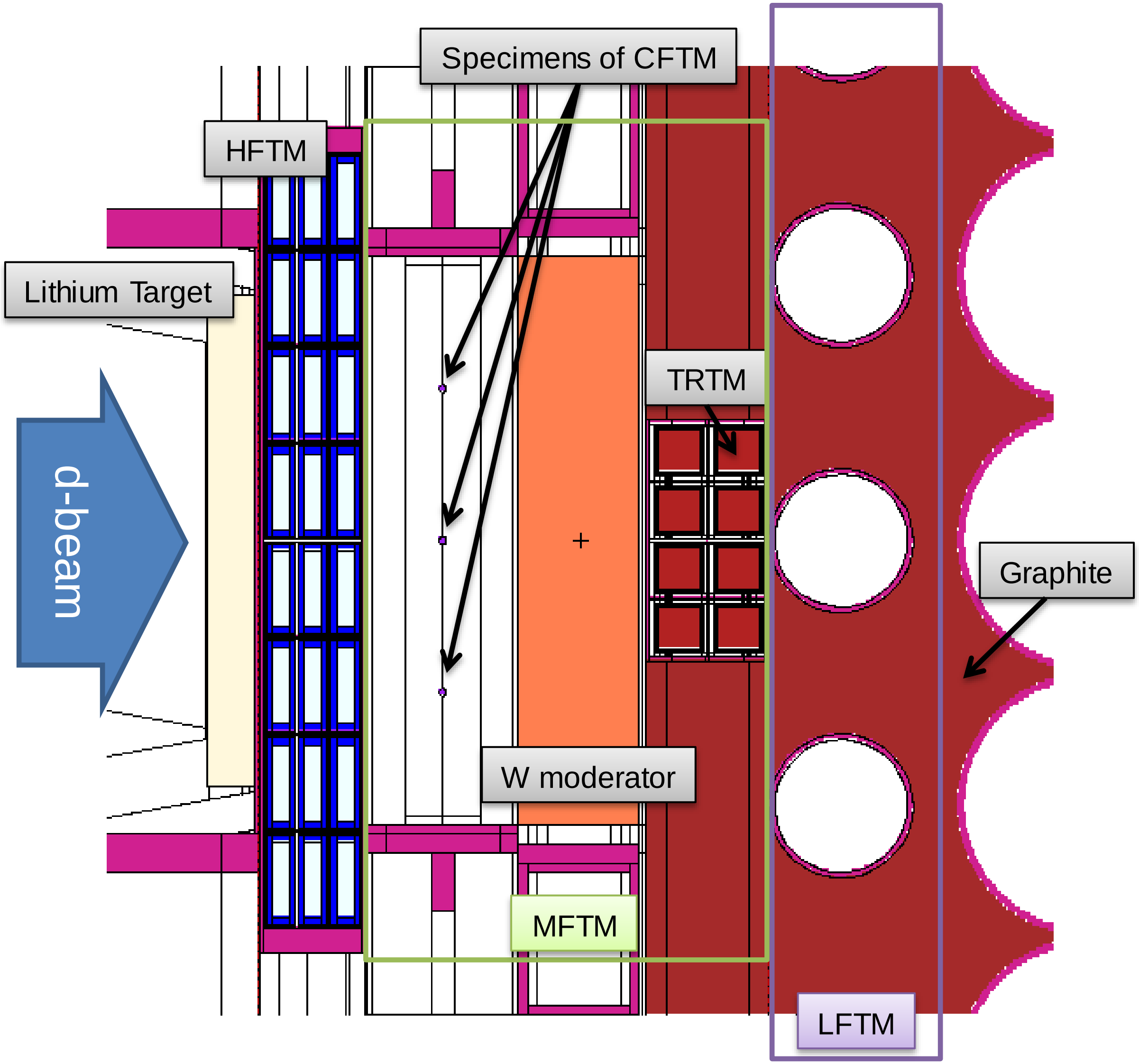
Calculation model for HFTM-V (from front)

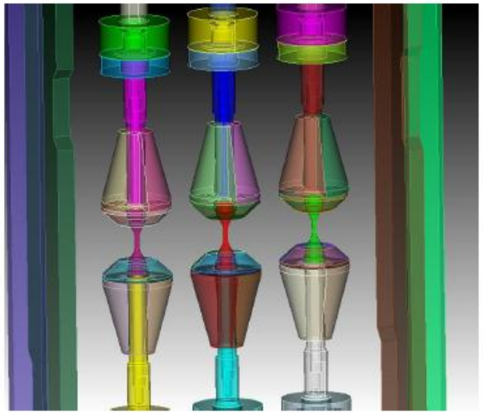


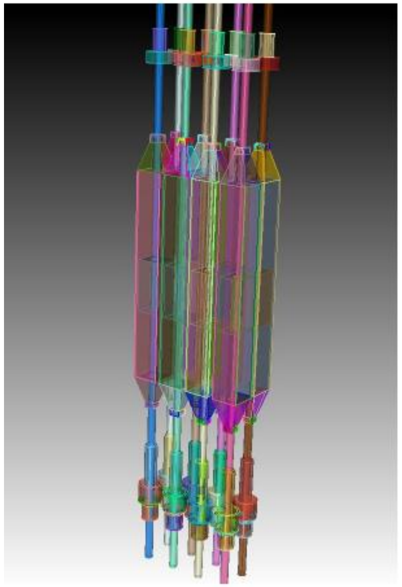


Eurofer: NaK = 74:26 (volume ratio)
Na:K = 22:78 (wt ratio)

Calculation model for MFTM and LFTM (horizontal cut)

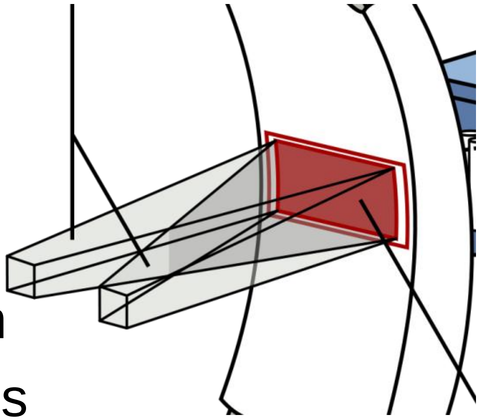






McDeLicious Monte Carlo Code

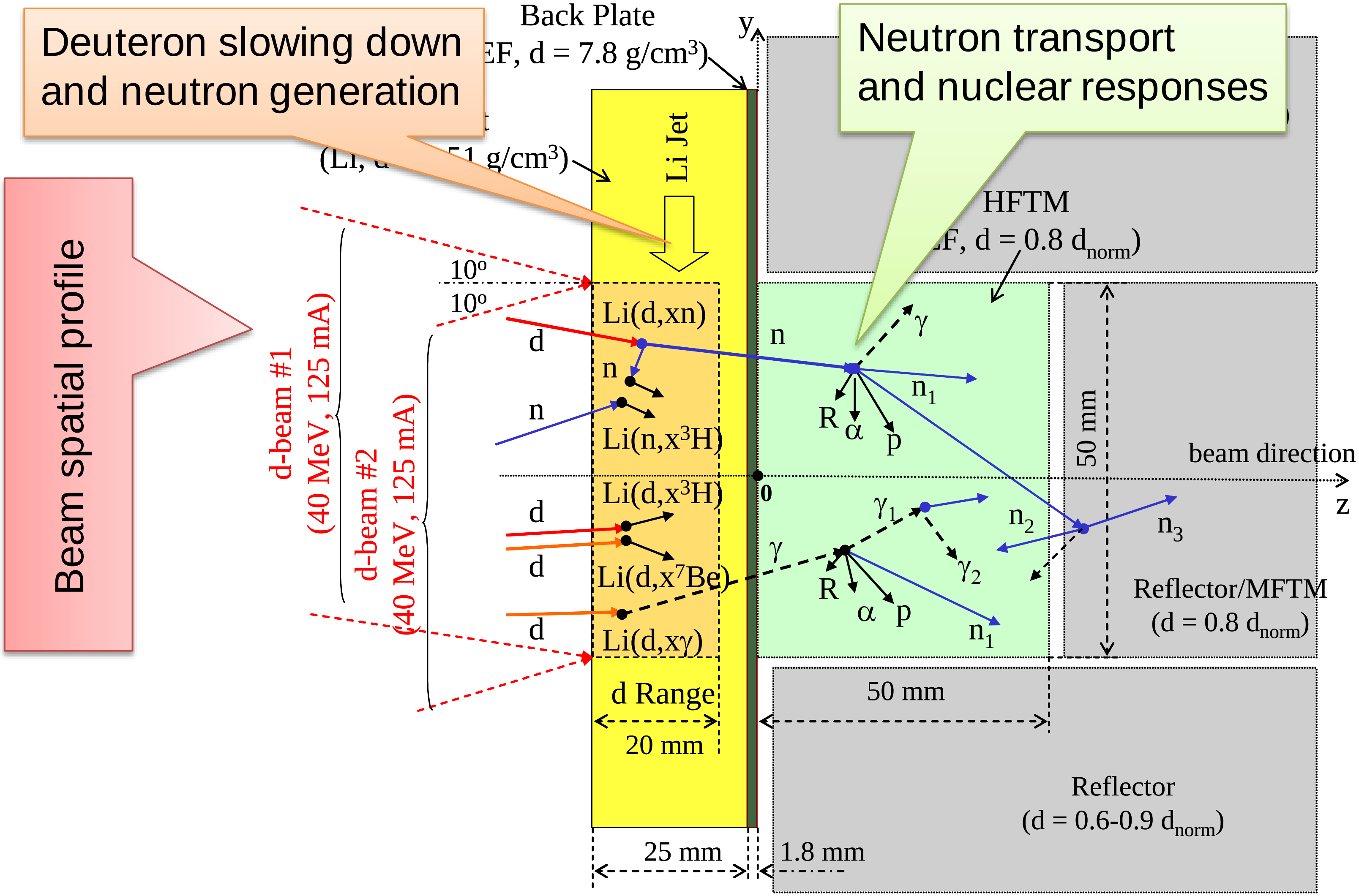
- Developed at FZK/KIT to enable a proper representation of the d-Li neutron and gamma source term in Monte Carlo transport calculations for IFMIF
- Enhancement to MCNP5 with tabulated double-differential d + ^{6,7}Li cross-section data up to 50 MeV
- Modeling of deuteron beam configuration, orientation and profile, Simulation of deuteron slowing down in Lithium
- MPI parallel calculation is available



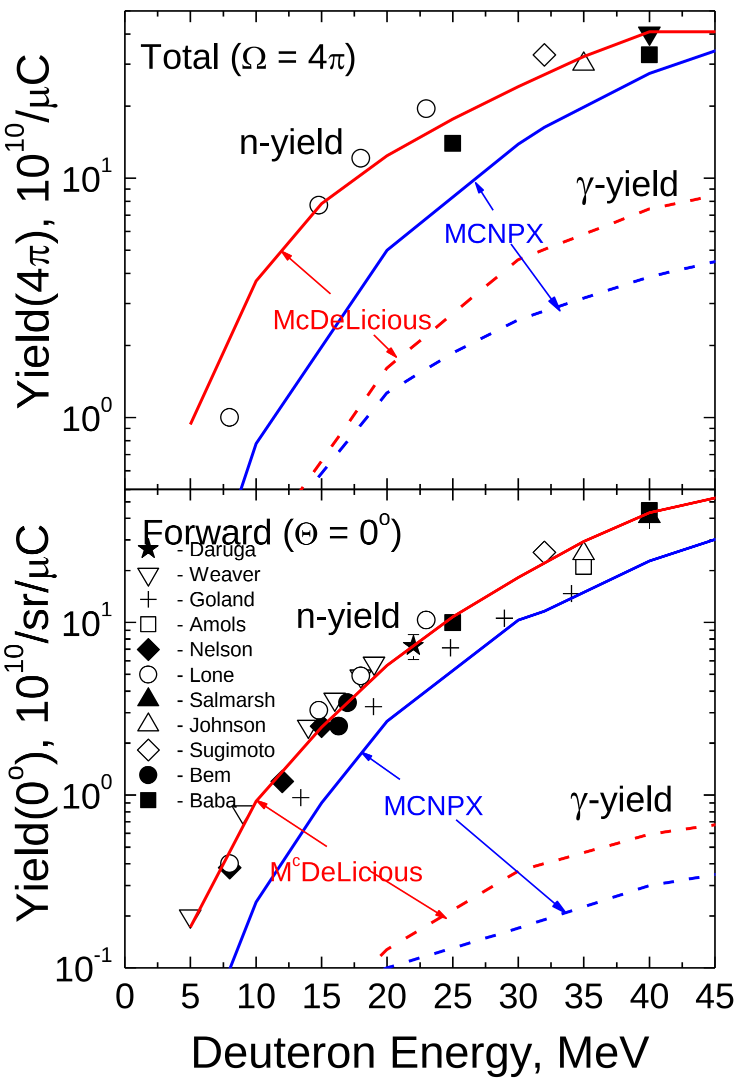
- McDeLicious-05 (2005) : updated d + ^{6,7}Li evaluation
- McDeLicious-10 (2010) : Inclusion of primary photons
- **McDeLicious-11 (2011) : New beam footprint implementation**

(with MCNP5-1.60)

Nuclear interaction simulated by *McDeLicious*

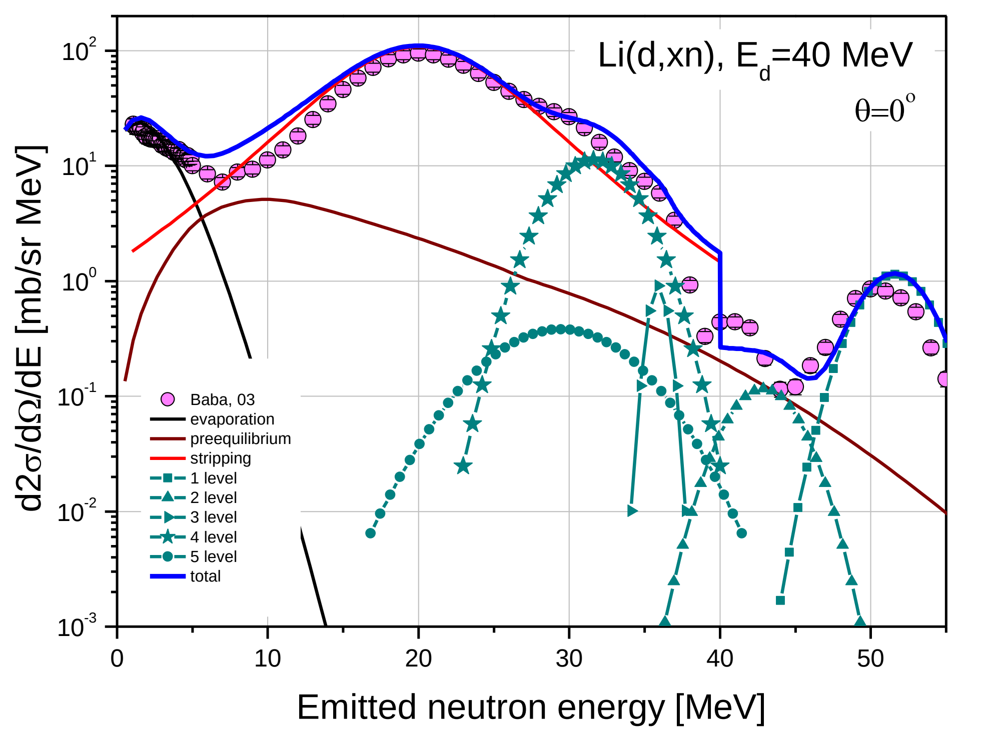


McDeLicious Monte Carlo Code



Ed = 40 MeV

Exp.: M.Hagiwara et al. Fus.Sci.Tech.48(2005)1320



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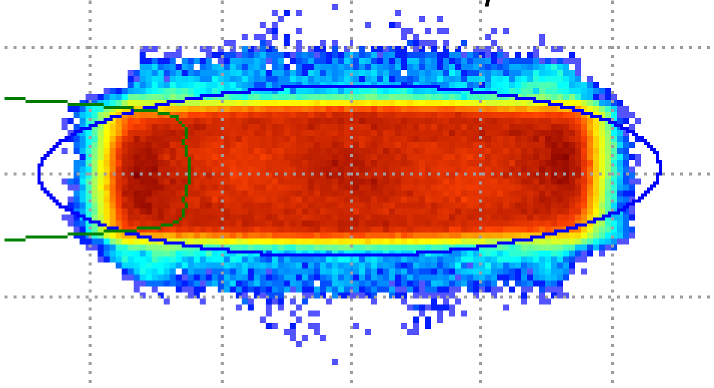
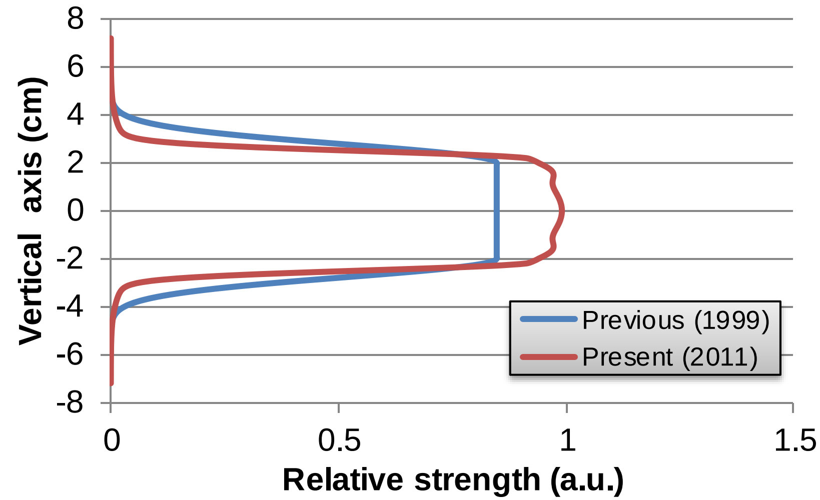
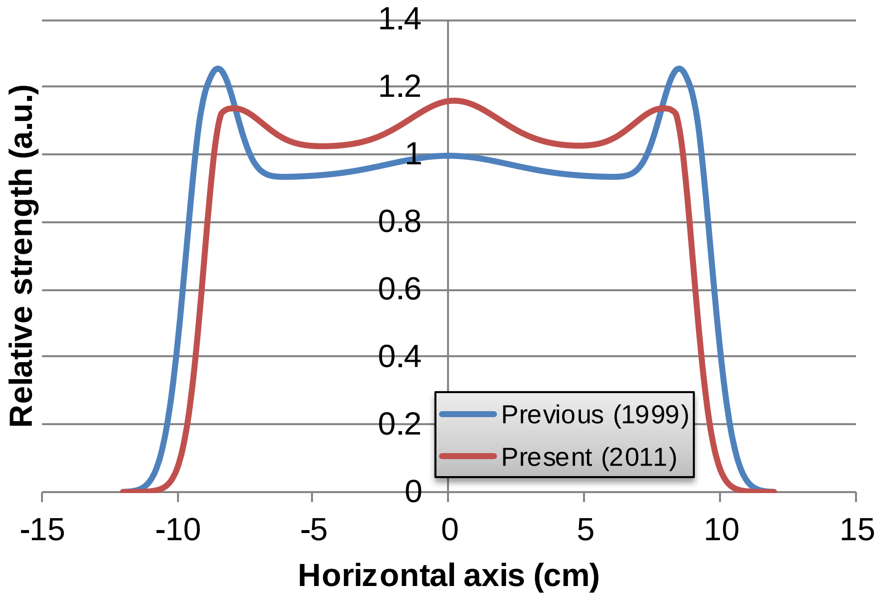
Implementation of footprint data

P.A.Phi Nghiem,
“HEBT-IFMIF-v01-2008-06-10-output”







- The beam distribution has been expressed by the sum of three Gaussian distribution functions in each direction.
- A new feature is implemented to sample the beam entry position according to a probability table

Beam dynamics calculation result

x(mm)	x'(mrad)	y(mm)	y'(mrad)	z(mm)	z'(mrad)	Phase(deg)	Time(s)	Energy(MeV)	Pow er(W,q=1)
-5.033922e+001	-3.466687e+000	+1.342971e+001	+6.917757e-001	+1.009663e+002	+2.455768e+000	-1.040205e+002	-1.651119e-009	+4.027858e+001	+4.986867e+000
+1.924875e+001	+8.122830e-001	+8.151876e+000	+2.879899e-001	+1.276540e+002	+3.046610e+000	-1.314375e+002	-2.086310e-009	+4.032749e+001	+4.992922e+000
+2.397694e+001	+1.179464e+000	+2.876207e+001	+1.268685e+000	-1.685598e+002	-4.031562e+000	+1.747900e+002	+2.774444e-009	+3.974190e+001	+4.920422e+000
+8.572998e+001	+4.198617e+000	+2.126040e+001	+2.139889e-001	-4.320354e+001	-1.018891e+000	+4.466528e+001	+7.089727e-010	+3.999106e+001	+4.951269e+000
-2.239956e+001	-1.060340e+000	-1.631003e+001	-2.101870e-001	-2.288212e+001	-5.387720e-001	+2.364474e+001	+3.753134e-010	+4.003078e+001	+4.956187e+000
-8.372669e+001	-4.238910e+000	+8.800046e+000	+3.636840e-001	-5.721191e+001	-1.406860e+000	+5.917059e+001	+9.392157e-010	+3.995896e+001	+4.947296e+000
-6.119351e+001	-3.011660e+000	-1.930296e+001	-5.750334e-001	-5.379786e+001	-1.295489e+000	+5.563322e+001	+8.830669e-010	+3.996818e+001	+4.948436e+000
-8.080709e+001	-3.990666e+000	+1.746579e+001	+5.051837e-001	+1.310792e+002	+3.176789e+000	-1.349478e+002	-2.142029e-009	+4.033826e+001	+4.994257e+000
-2.512994e+001	-1.324263e+000	+9.551404e+000	+5.163551e-001	+2.170674e+002	+5.210381e+000	-2.230220e+002	-3.540031e-009	+4.050664e+001	+5.015103e+000
-2.796636e+001	-1.388738e+000	+5.667024e+000	+2.391316e-001	-1.742003e+002	-4.226037e+000	+1.806742e+002	+2.867844e-009	+3.972583e+001	+4.918431e+000
-5.179573									47e+000
+7.75250									33e+000
-8.415894									94e+000
+9.06251									67e+000
-6.093936									15e+000
-8.558279									55e+000
+7.94037									31e+000
+7.46751									25e+000
-1.127094									66e+000
+8.39010									05e+000
+8.24356									51e+000
-5.778491									61e+000
+5.99537									37e+000
-7.239197									30e+000
+7.47176									21e+000
-6.038778									37e+000
-1.529847									57e+000
+1.132792e+001	+5.429207e-001	+1.924750e+000	+5.043385e-002	+1.507332e+002	+3.542519e+000	-1.551243e+002	-2.462291e-009	+4.036854e+001	+4.998005e+000
+2.137146e+001	+9.777400e-001	-1.217444e+001	-5.718694e-001	-2.191127e+002	-5.144470e+000	+2.274665e+002	+3.610580e-009	+3.964990e+001	+4.909030e+000
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-1.775213e+001	-8.827991e-001	+1.624627e+001	+5.295887e-001	-8.077196e+001	-1.939445e+000	+8.358120e+001	+1.326686e-009	+3.991491e+001	+4.941842e+000
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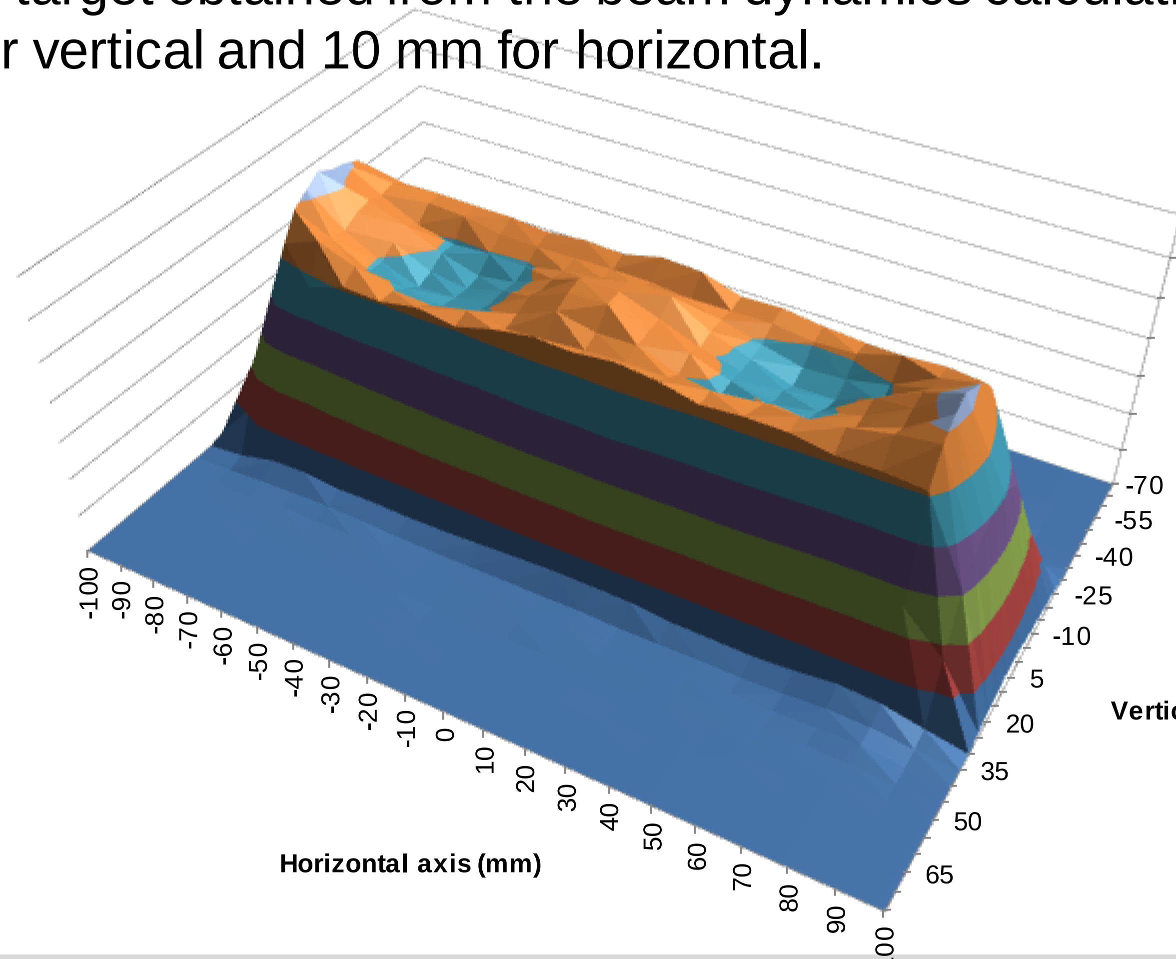
-6.561793e+001	-3.171219e+000	-9.388203e+000	-2.302062e-001	+7.263609e+001	+1.745904e+000	-7.488617e+001	-1.188669e-009	+4.021982e+001	+4.979593e+000
+2.068040e+001	+9.771223e-001	-1.351297e+001	+3.376777e-002	-7.690773e+001	-1.866481e+000	+7.957673e+001	+1.263123e-009	+3.992095e+001	+4.942589e+000
-3.061314e+001	-1.491824e+000	-1.538677e+001	-5.590240e-001	-7.209775e+001	-1.772442e+000	+7.459283e+001	+1.184013e-009	+3.992872e+001	+4.943552e+000
+3.606850e+001	+1.698205e+000	+6.224806e-001	+1.360474e-001	-5.501771e+001	-1.369875e+000	+5.689872e+001	+9.031542e-010	+3.996202e+001	+4.947675e+000
-6.477752e+001	-3.056436e+000	-1.121079e+001	-4.169387e-001	-1.802905e+002	-4.353521e+000	+1.870155e+002	+2.968500e-009	+3.971529e+001	+4.917126e+000
-8.305449e+001	-4.498132e+000	+7.968576e+000	+1.013775e-001	-9.676082e+000	-2.232488e-001	+9.995506e+000	+1.586588e-010	+4.005688e+001	+4.959419e+000

x, *x*‘, *y*, *y*‘, *z*, *z*‘, Phase, Time, Energy, Power for 1e6 particles

Only *x* and *y* were used in our calculation.

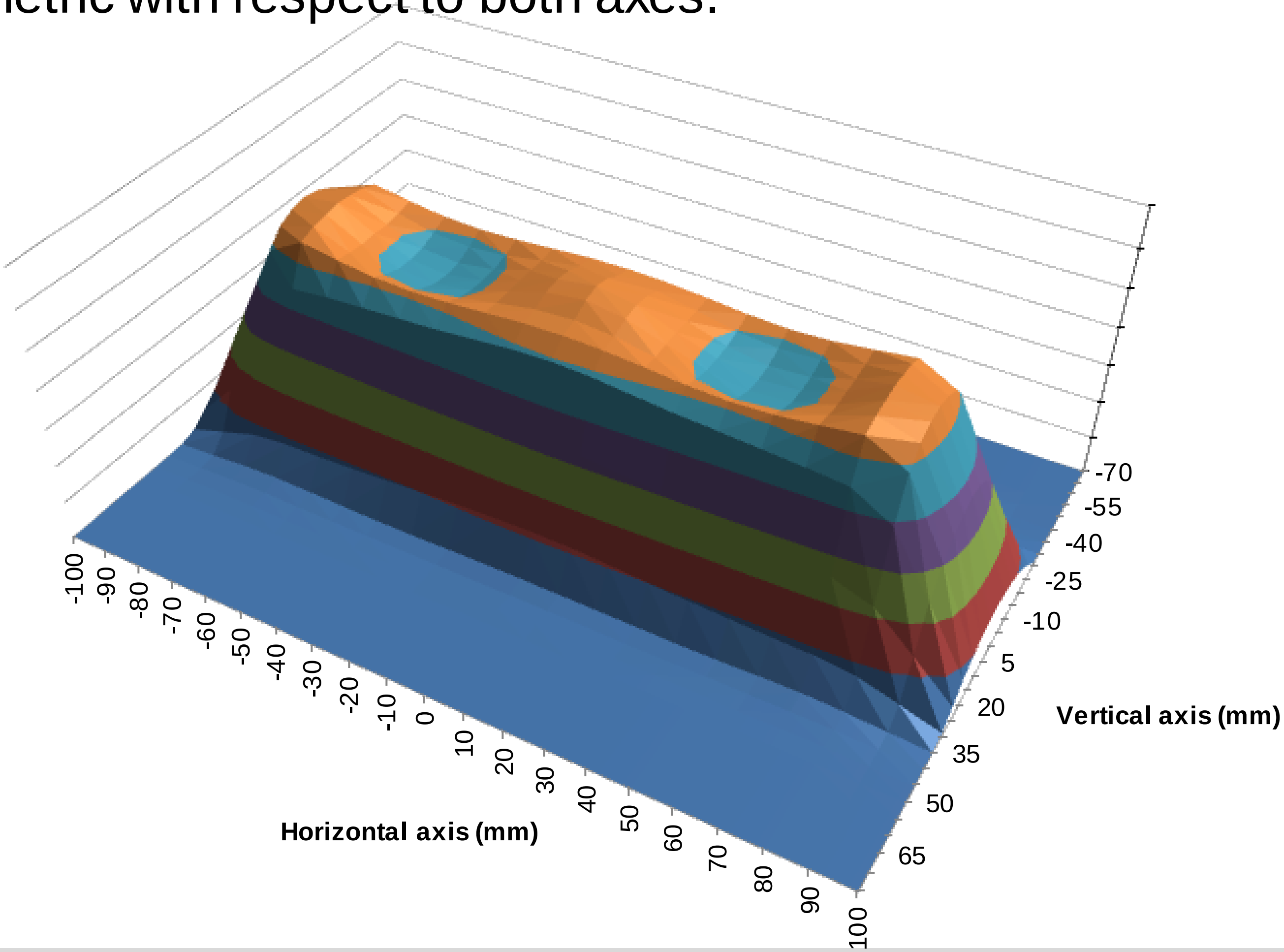
New footprint (probability table)

- The probability table was directly prepared by binning the distribution on the target obtained from the beam dynamics calculation in step of 5 mm for vertical and 10 mm for horizontal.



New footprint (probability table, smoothed and symmetrized)

- The table was smoothed with a Gaussian filter and averaged as it is symmetric with respect to both axes.



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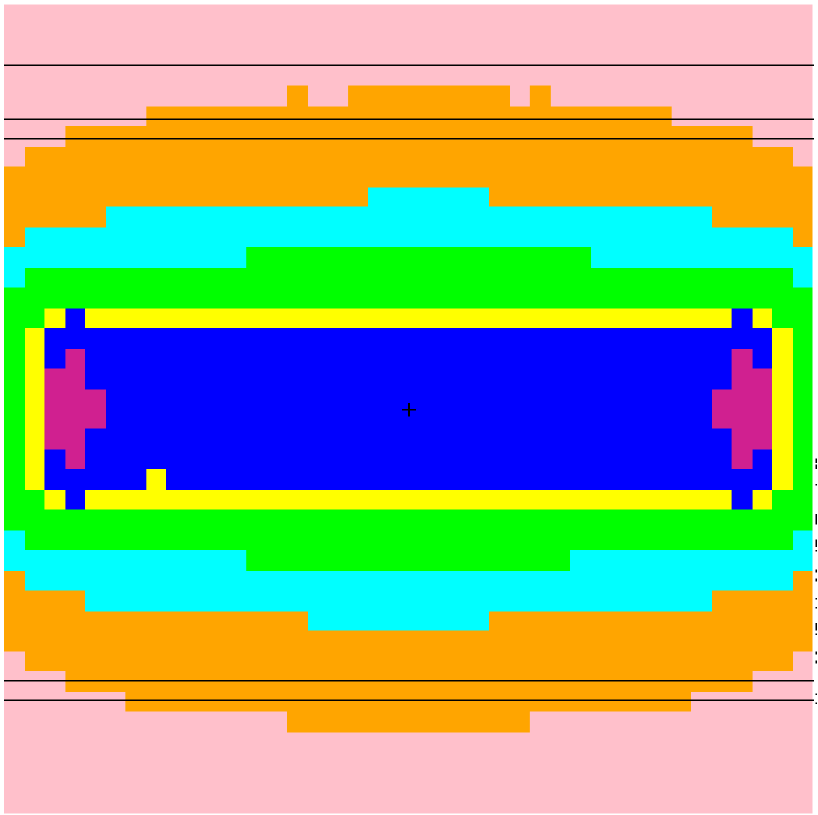
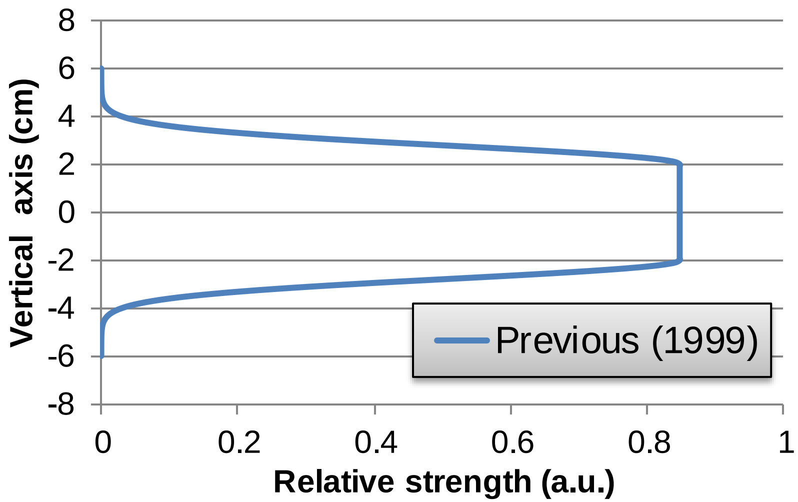
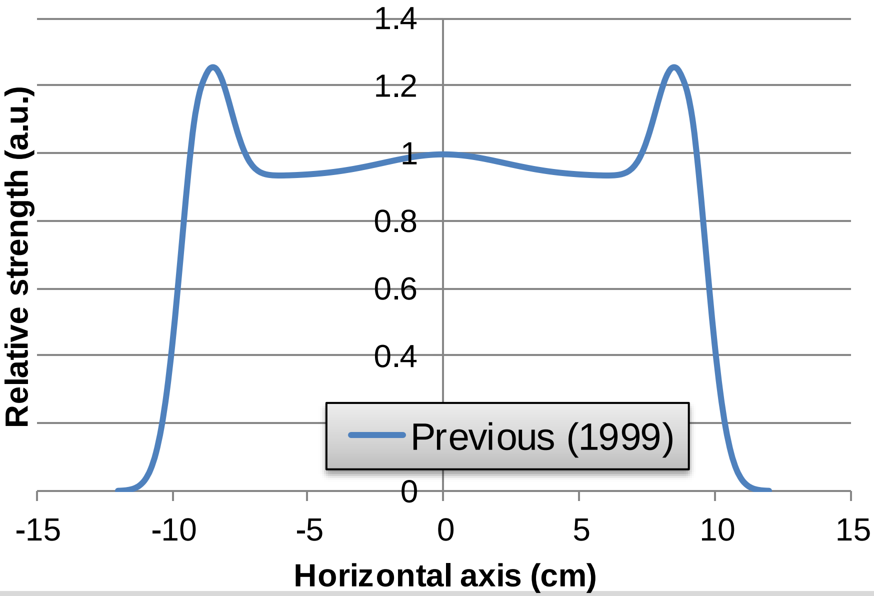
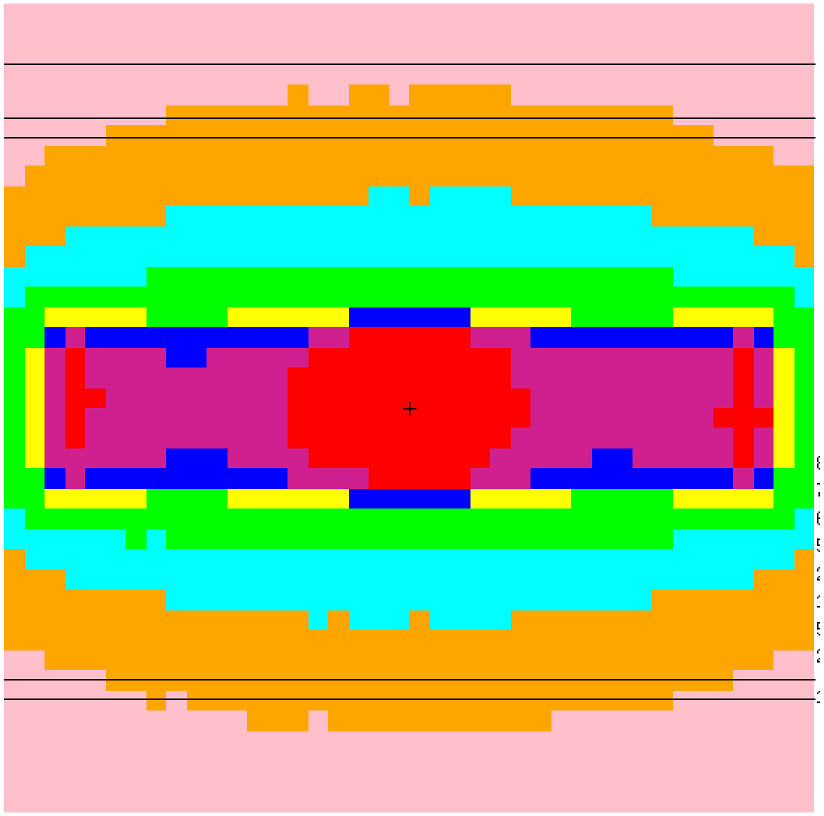
Previous footprint

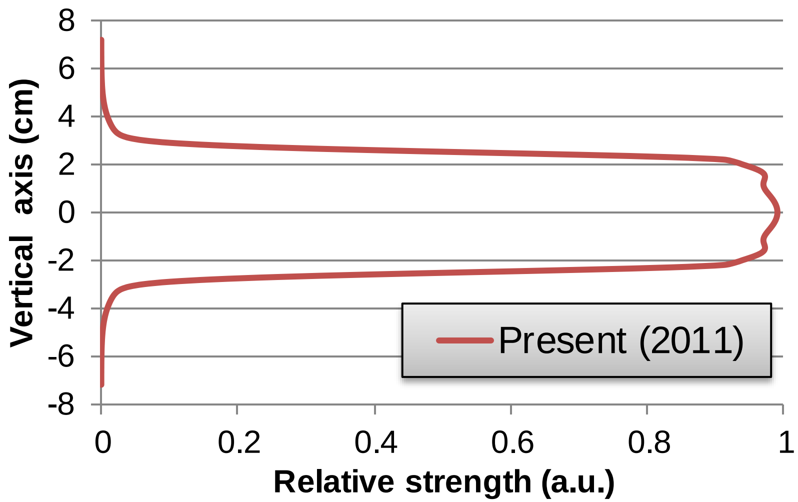


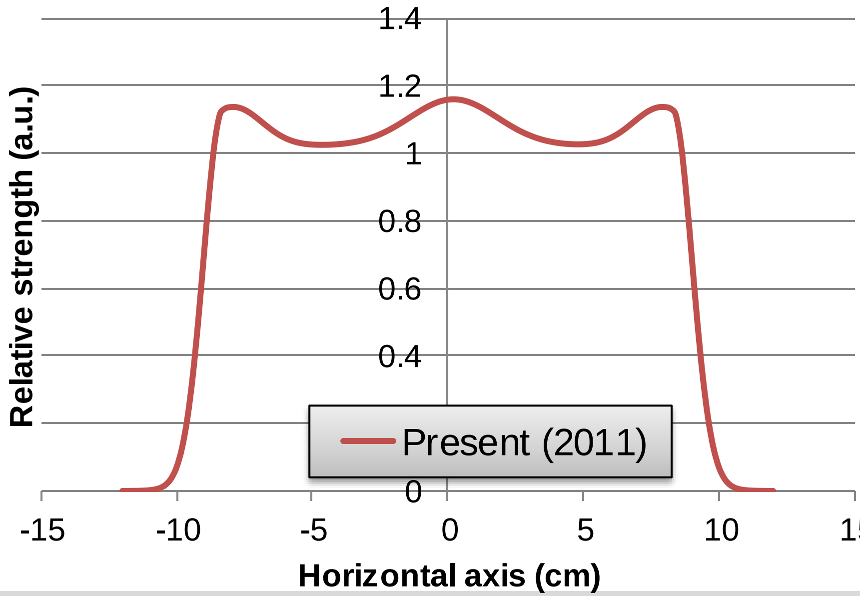




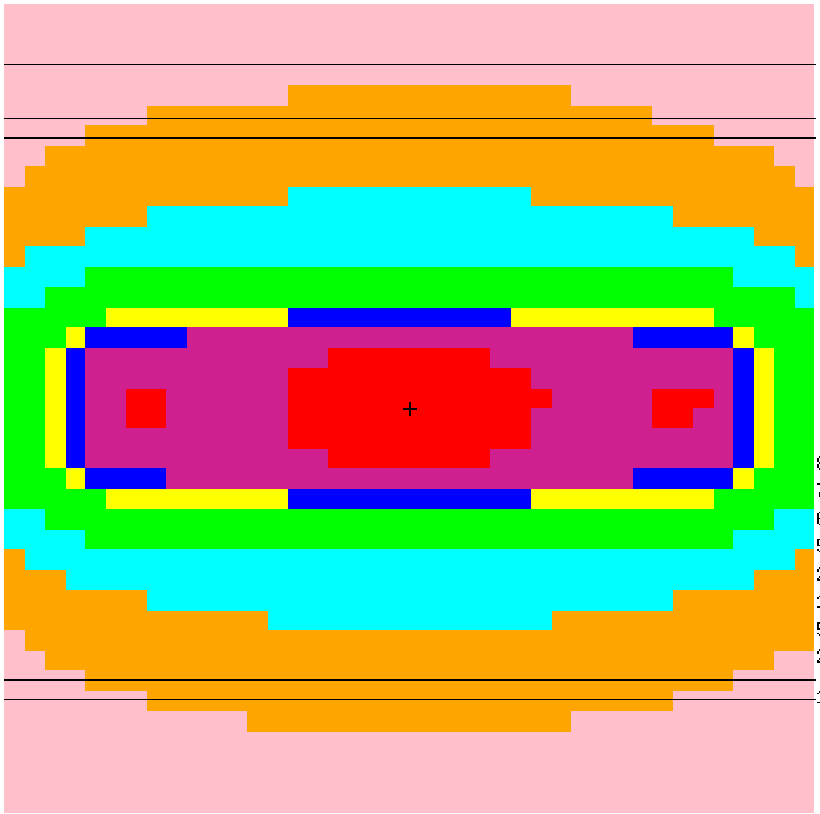
New footprint (fitting function sampling)

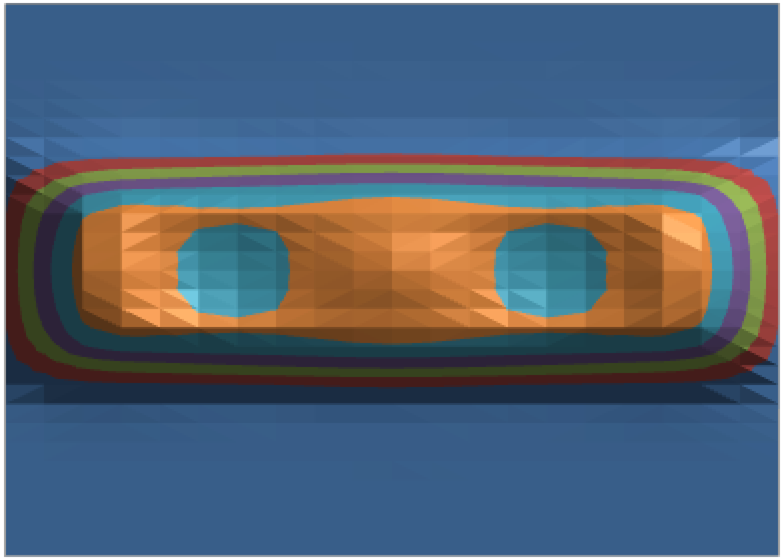




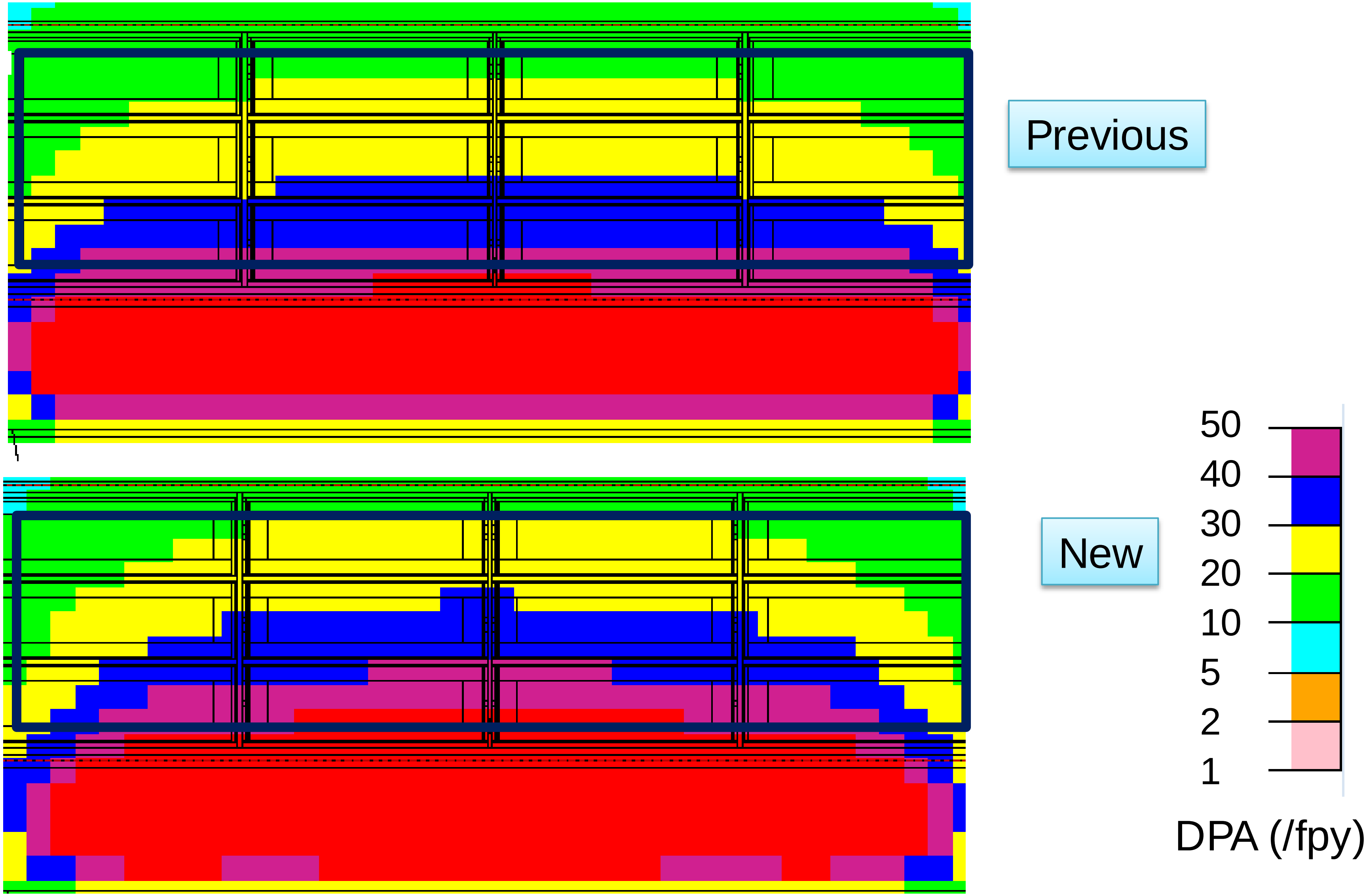


New footprint (table sampling)

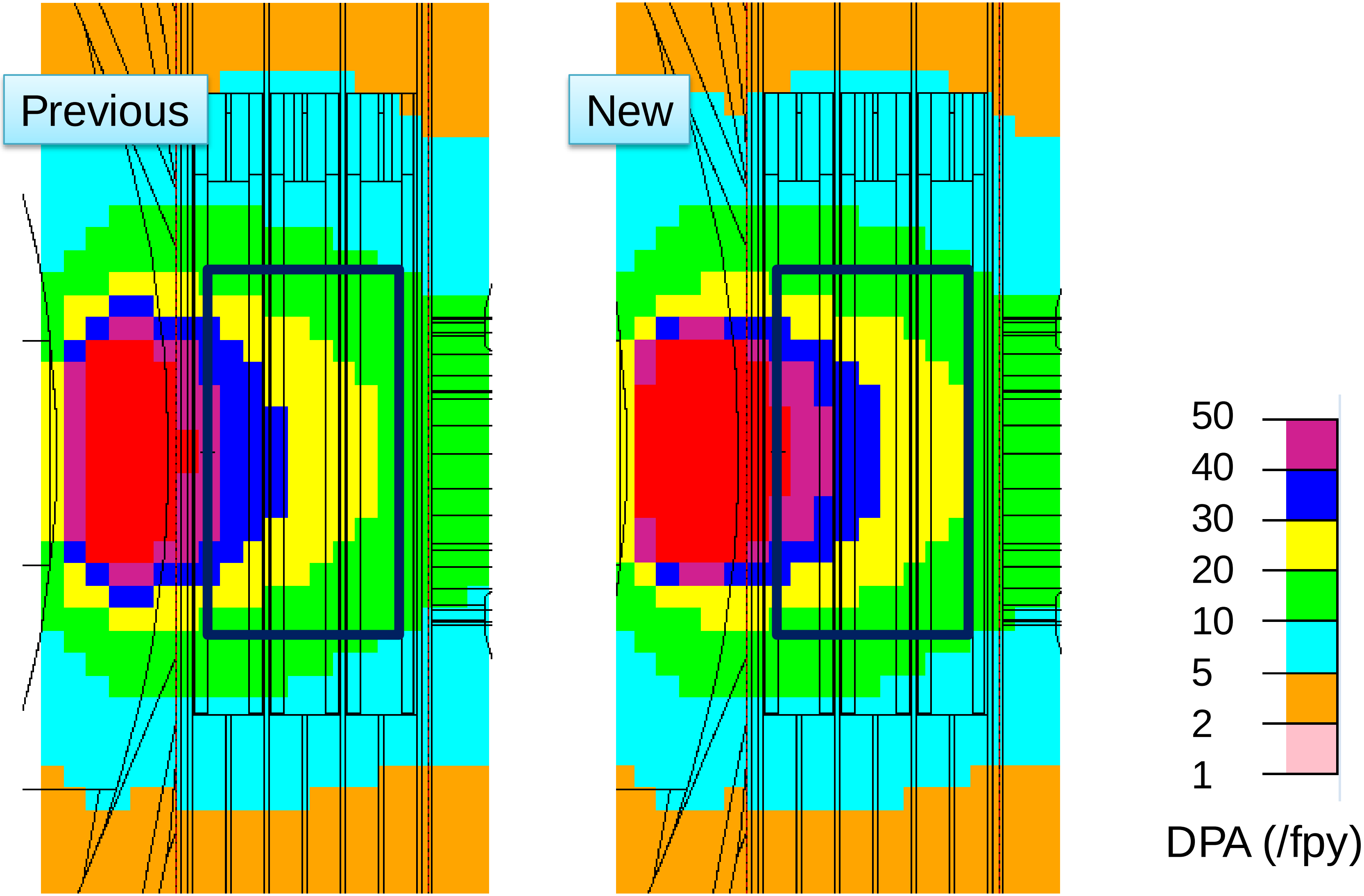




DPA distribution inside HFTM (horizontal cut)

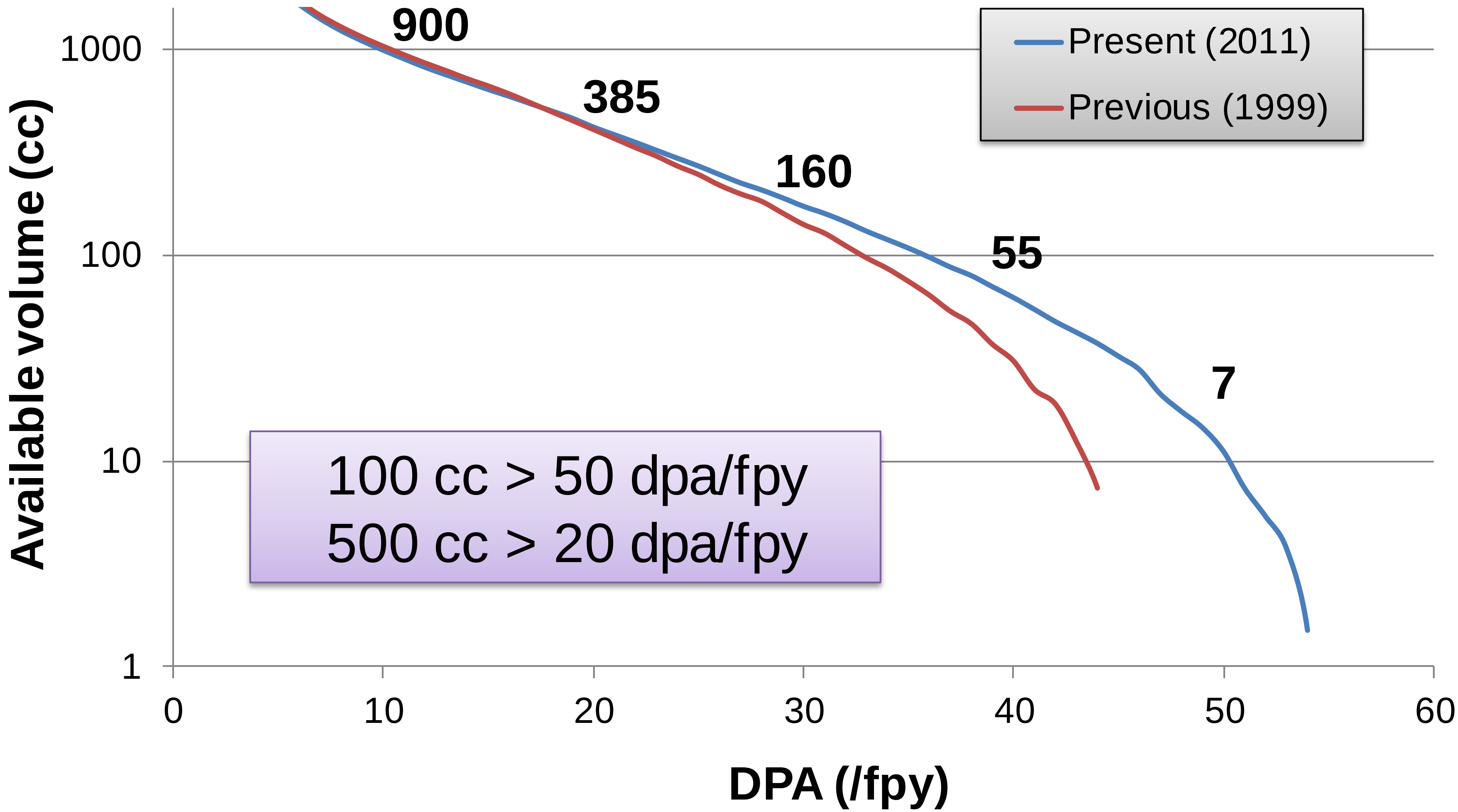


DPA distribution inside HFTM (vertical cut)



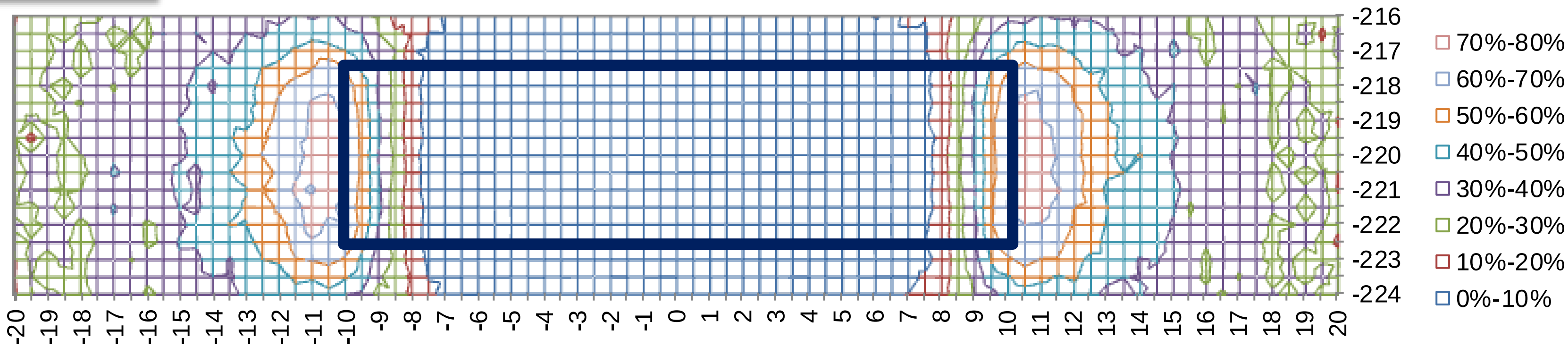
Available Volume in HFTM vs DPA

Max. 1600 cc = 40 × 5 × 8 cm^3

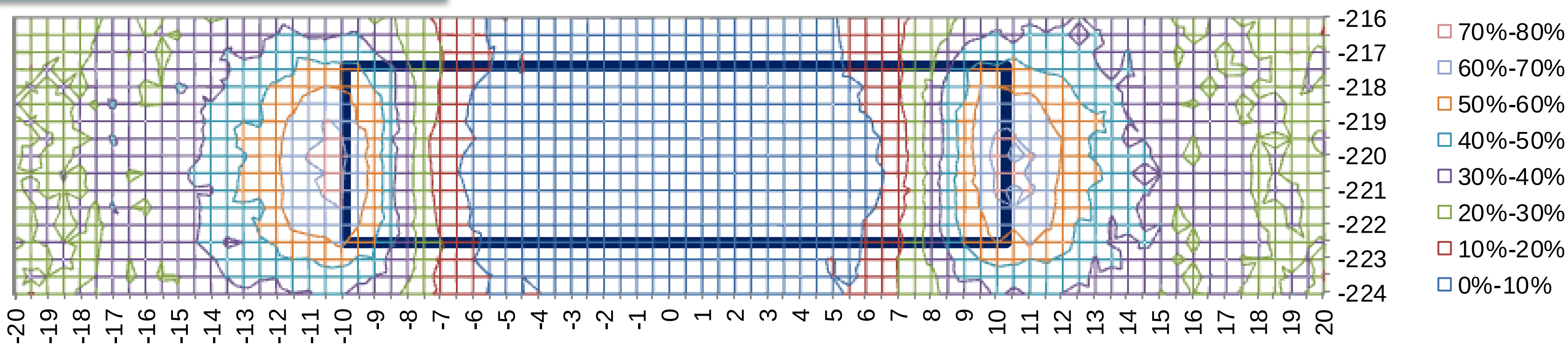


Neutron flux gradient inside HFTM

Previous

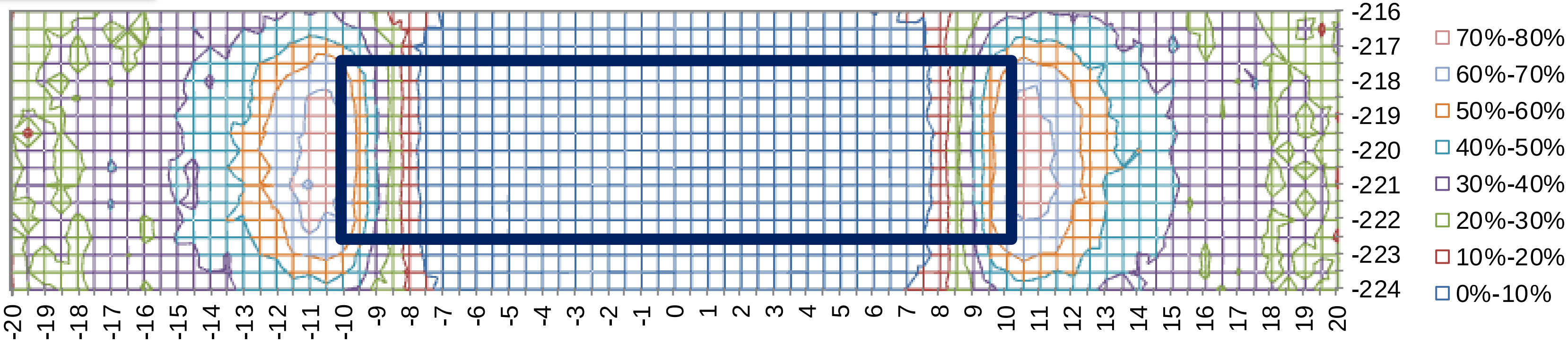


New (Table sampling)

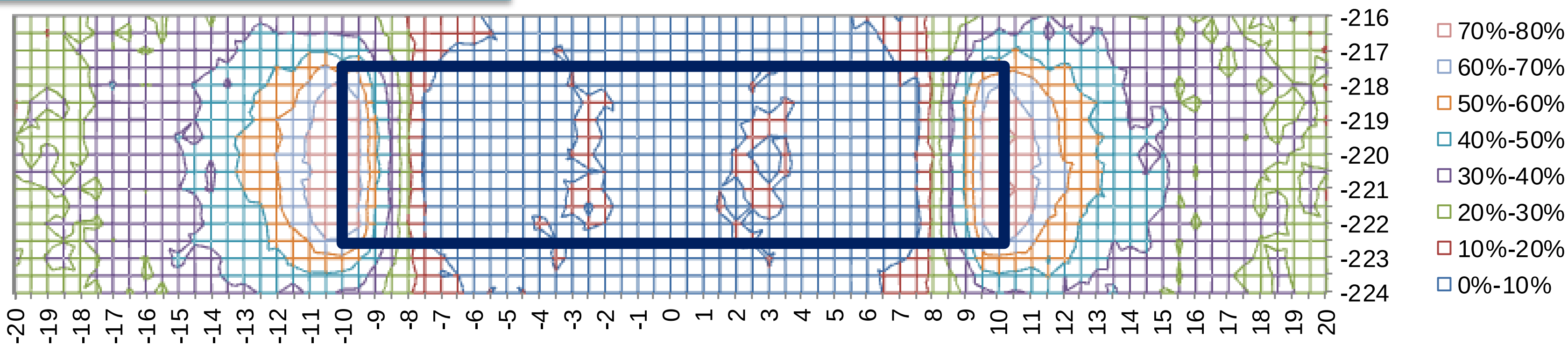


Neutron flux gradient inside HFTM

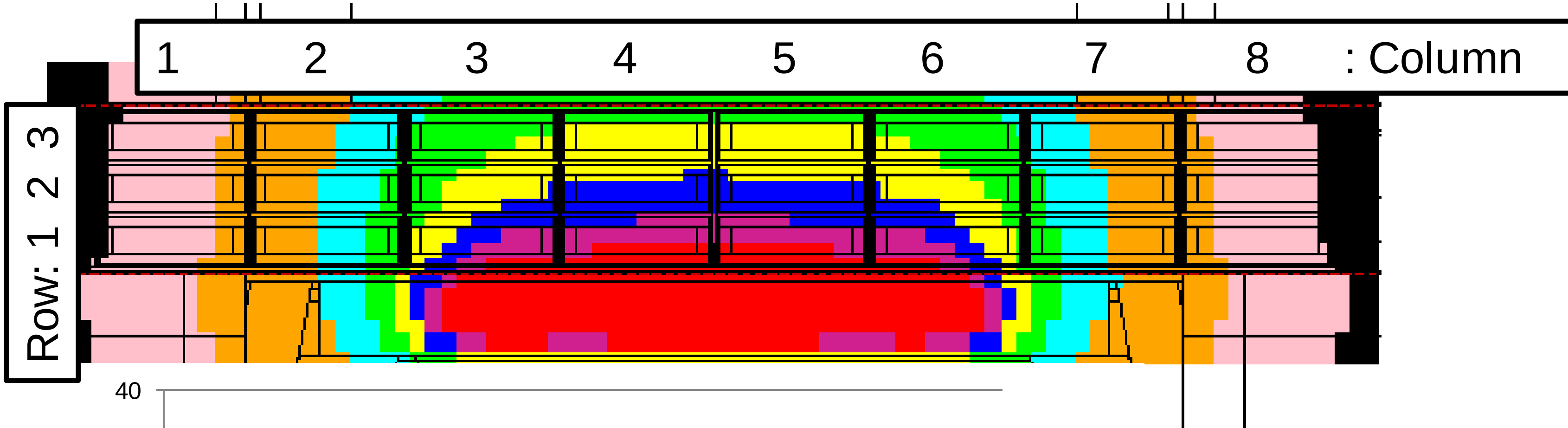
Previous

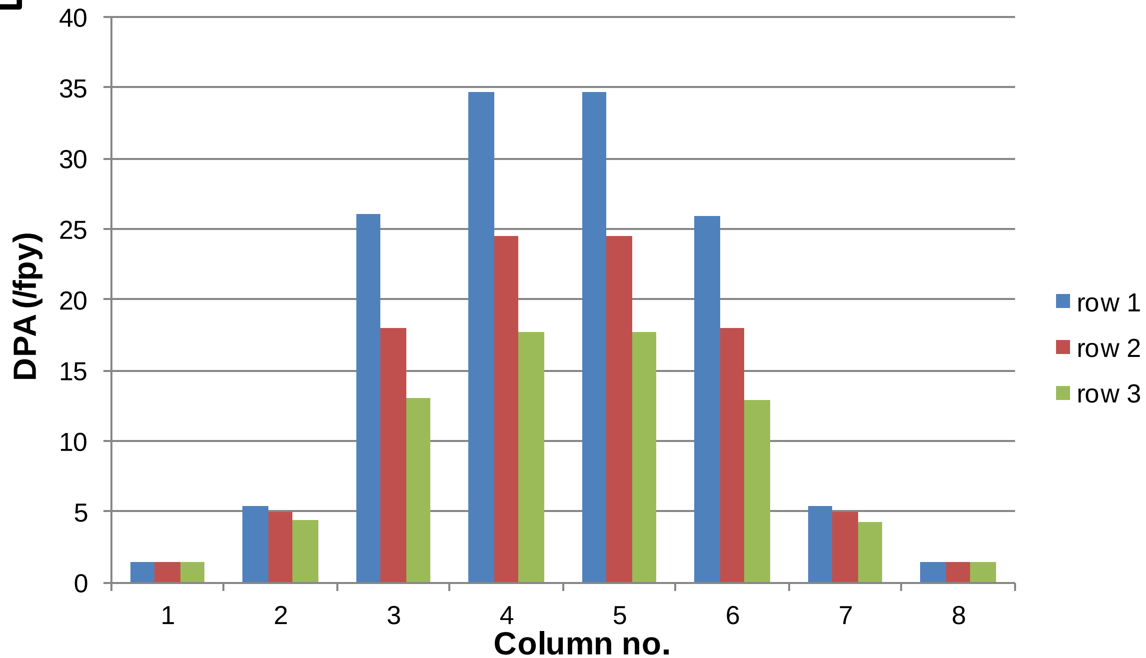


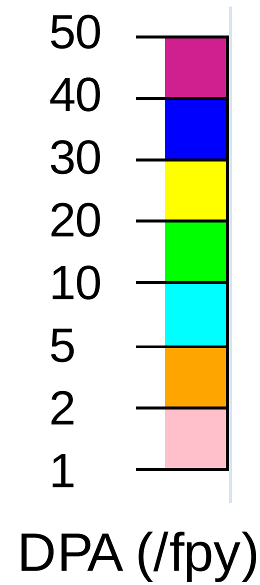
New (Gaussian function)



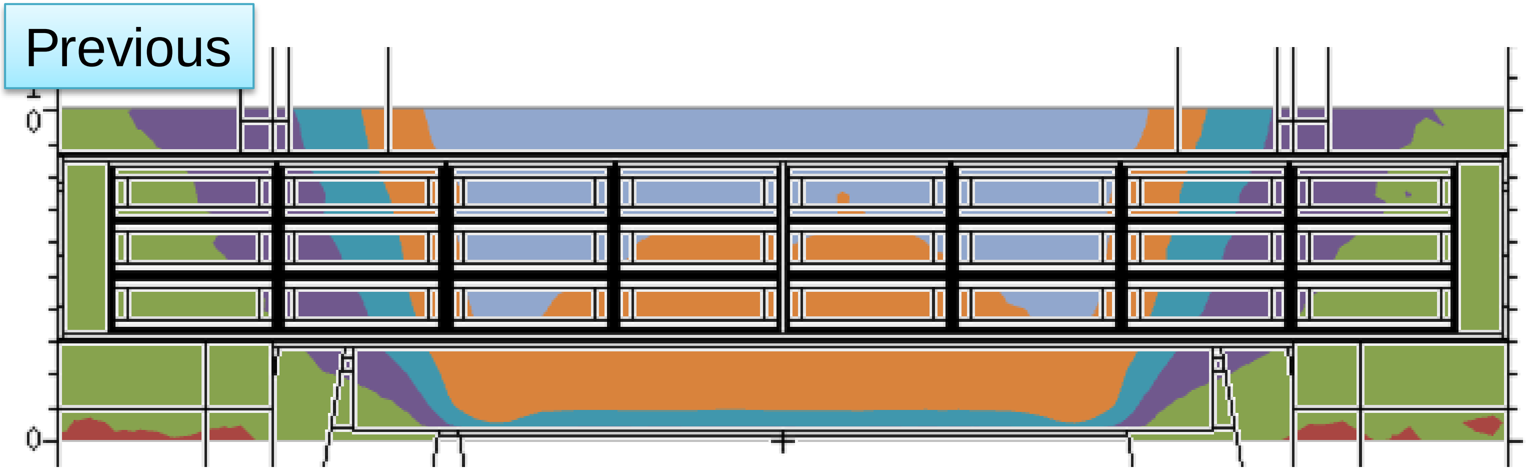
DPA in each specimen stack of HFTM

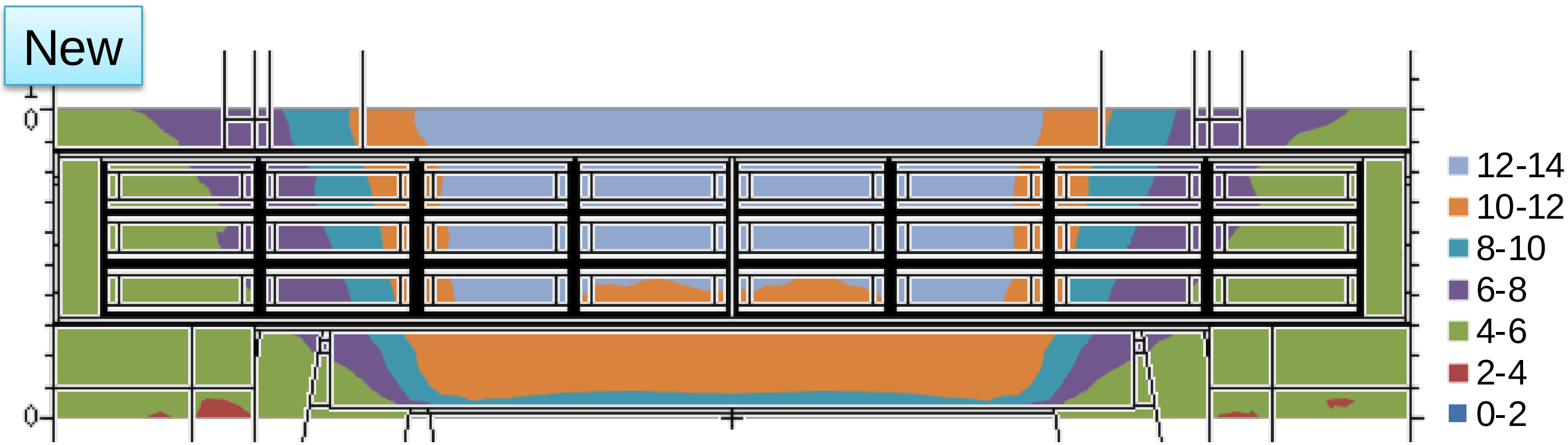




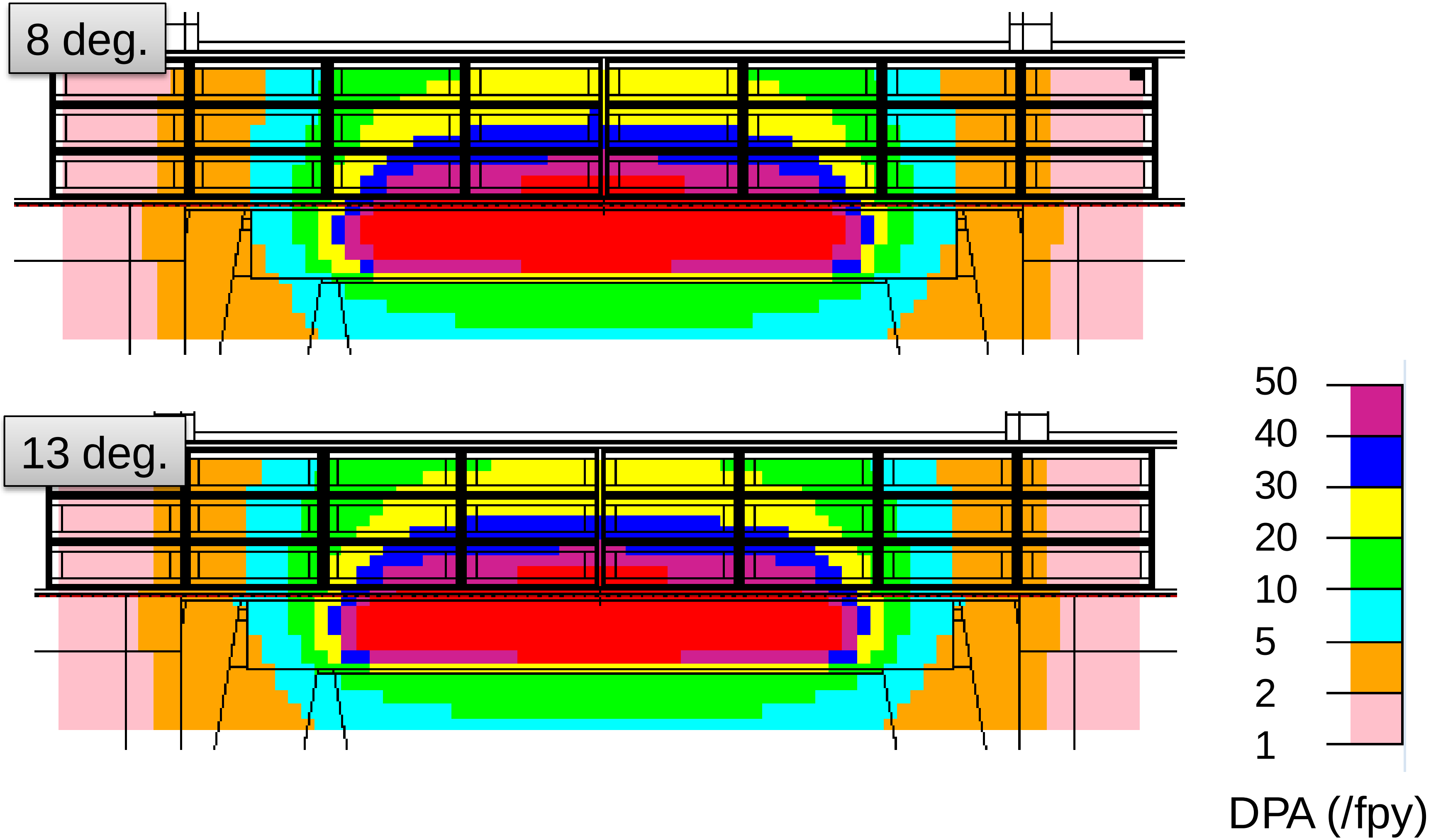


He/dpa in each specimen stack of HFTM





Effect from beam incident angle



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Summary

- **McDeLicious** was updated to simulate the beam footprint according to a probability table.
- The impact on the nuclear responses from the difference of the beam footprint has been examined.
  - DPA
  - Neutron flux gradient
  - He/DPA, H/DPA
- The previous manner in McDeLicious to describe the beam footprint using by combination of Gaussian functions would be not sufficient to asses above parameters.
- The impact on the nuclear responses from the difference of the beam incident angle is not signifficant.

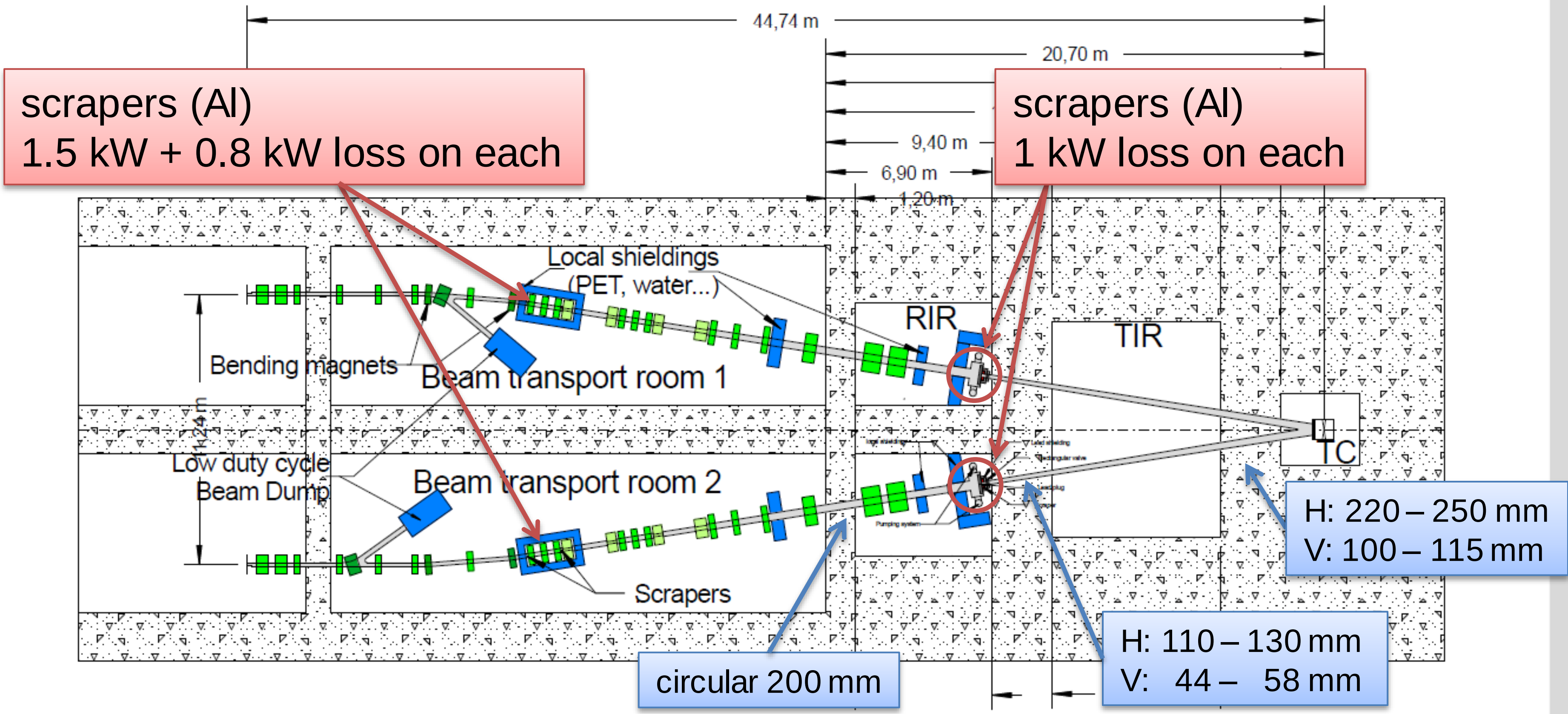
Vielen Dank für Ihre Aufmerksamkeit!

Thank you for your attention.

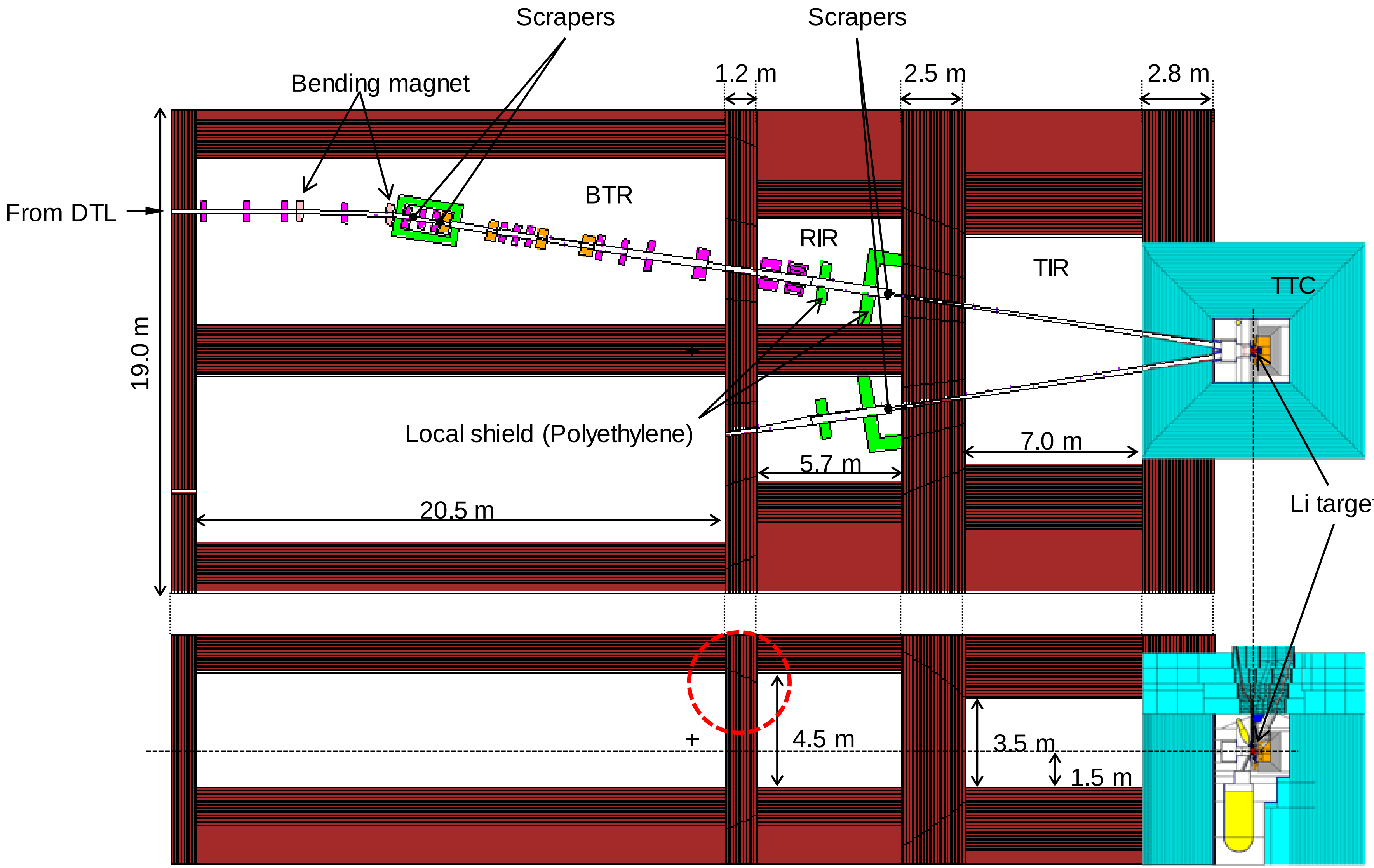
ご静聴ありがとうございました。

“4th proposal for HEBT section”

- Now we assume the “4th proposal” (July 2011)
  - 1 kW loss on each Al scraper in RIR is assumed, where around 1e13 neutron production per sec. takes place.



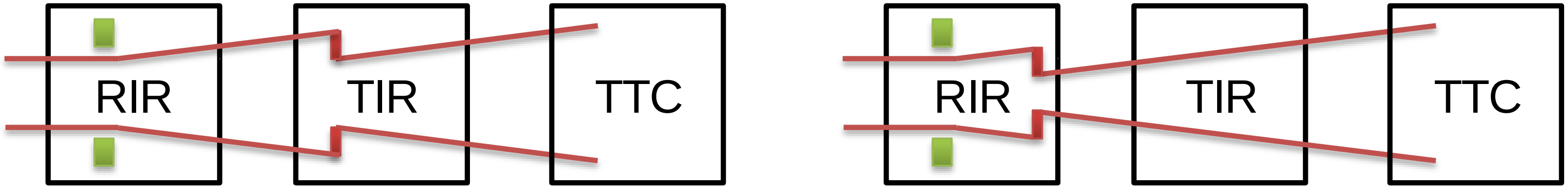
Calculation model for building



Layout of HEBT section (1)

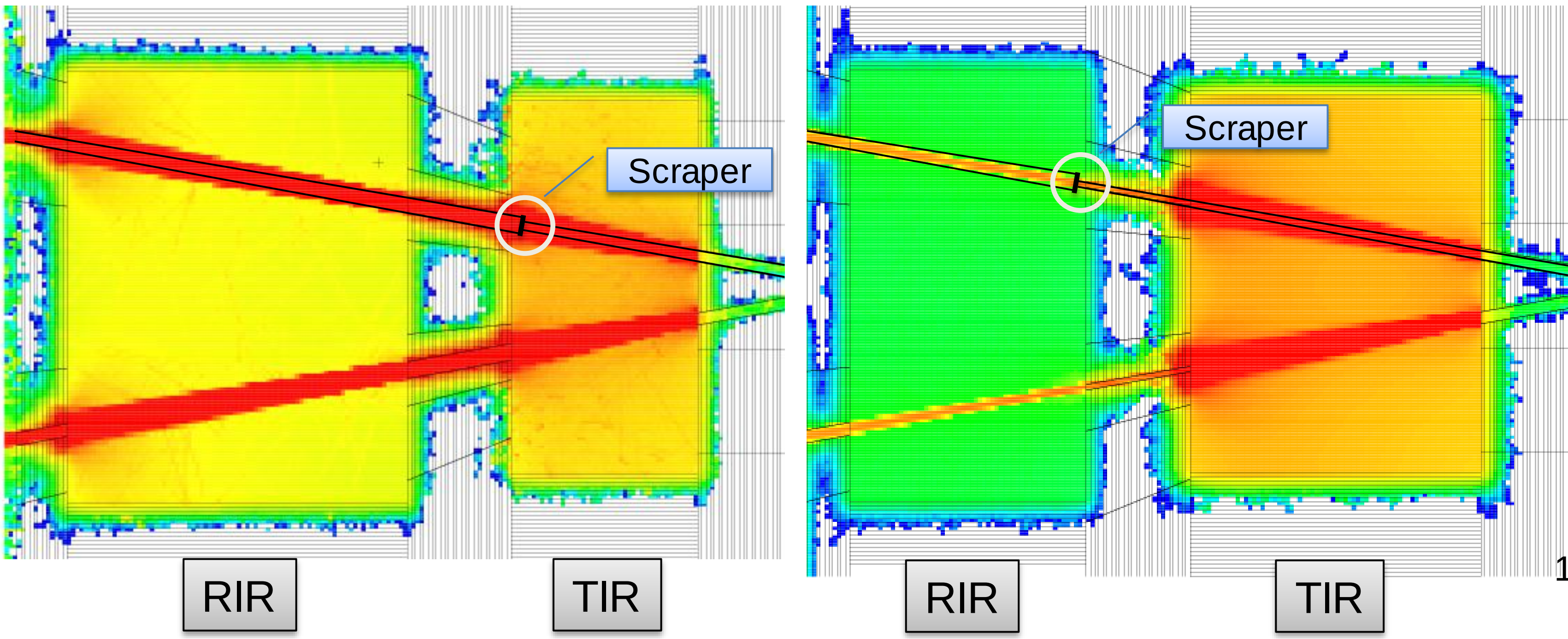
- A beam scraper is needed to be installed in TIR or RIR.
- There has been iterative examination of the window size in the walls and the place of the beam scraper.

		Case 1 (11/2010)	Case 2 (03/2011)	Case 3 (06/2011)	Case 4 (07/2011)	
		Dia (mm)	Dia (mm)	Dia (mm)	Dia (mm)	
					Start	End
BTR-RIR	(circular)	300	300	200	200	
RIR-TIR	H	400	130	200	110	130
	V	300	60	60	44	58
TIR-TTC	H	285	250	360	220	250
	V	100	100	115	100	115
Scraper		TIR (1e-3)	RIR (1e-3)	RIR (1e-4)	RIR (1e-3/1e-4)	

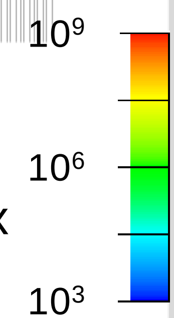


Example of neutron flux distribution

Case 1 Case 2



Only streaming neutron (no scraper contribution)

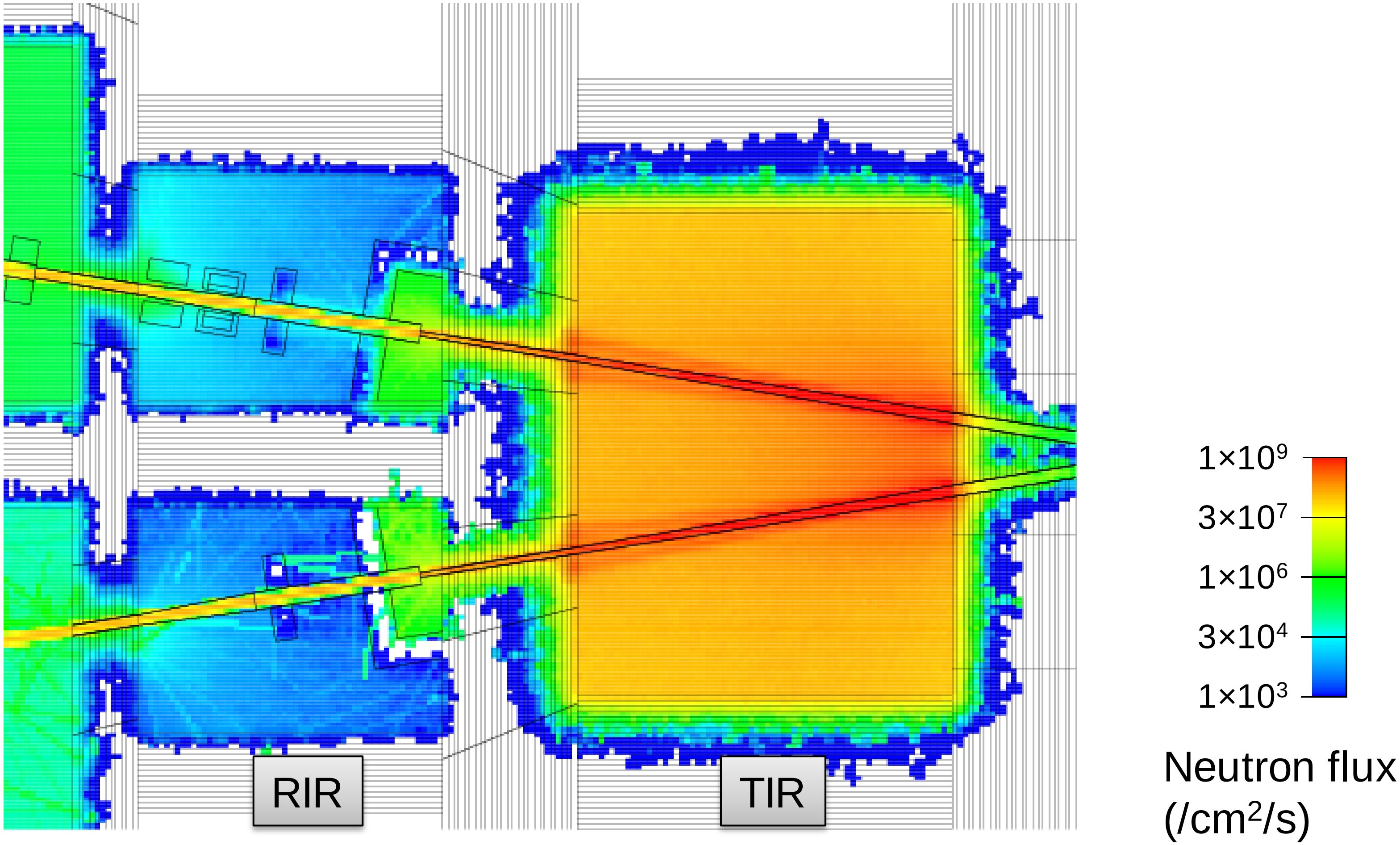


Neutron flux ($/cm^2/s$)

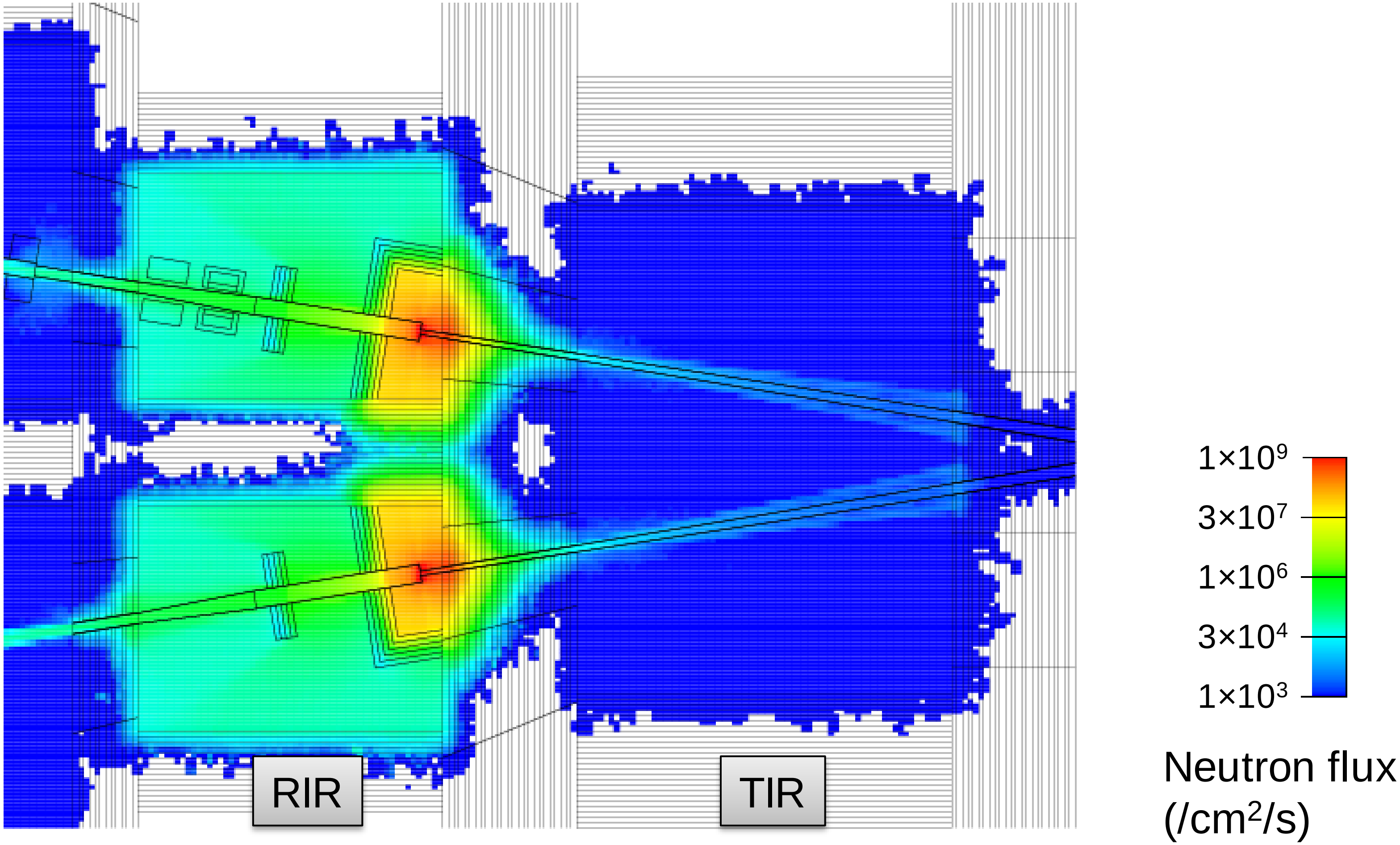
Scraper contribution

- Neutron / photon production due to the d-Al reaction
  - 1 kW loss leads to around 1e13 (/s) neutron production !
  - Physical models implemented in MCNPX
    - INCL4/ABLA, ISABEL/ABLA
    - The limit of these models has been pointed out by F. Ogando (UNED). (*See his presentation*)
  - Neutron source term based on Hagiwara's experimental data
    - Total neutron yield was multiplied by a factor of 2 considering "*ambiguity about the absolute values*".
    - Photon data is not available.
- Local shielding structure made of low density polyethylene (50 cm-t) is utilized around the scrappers.

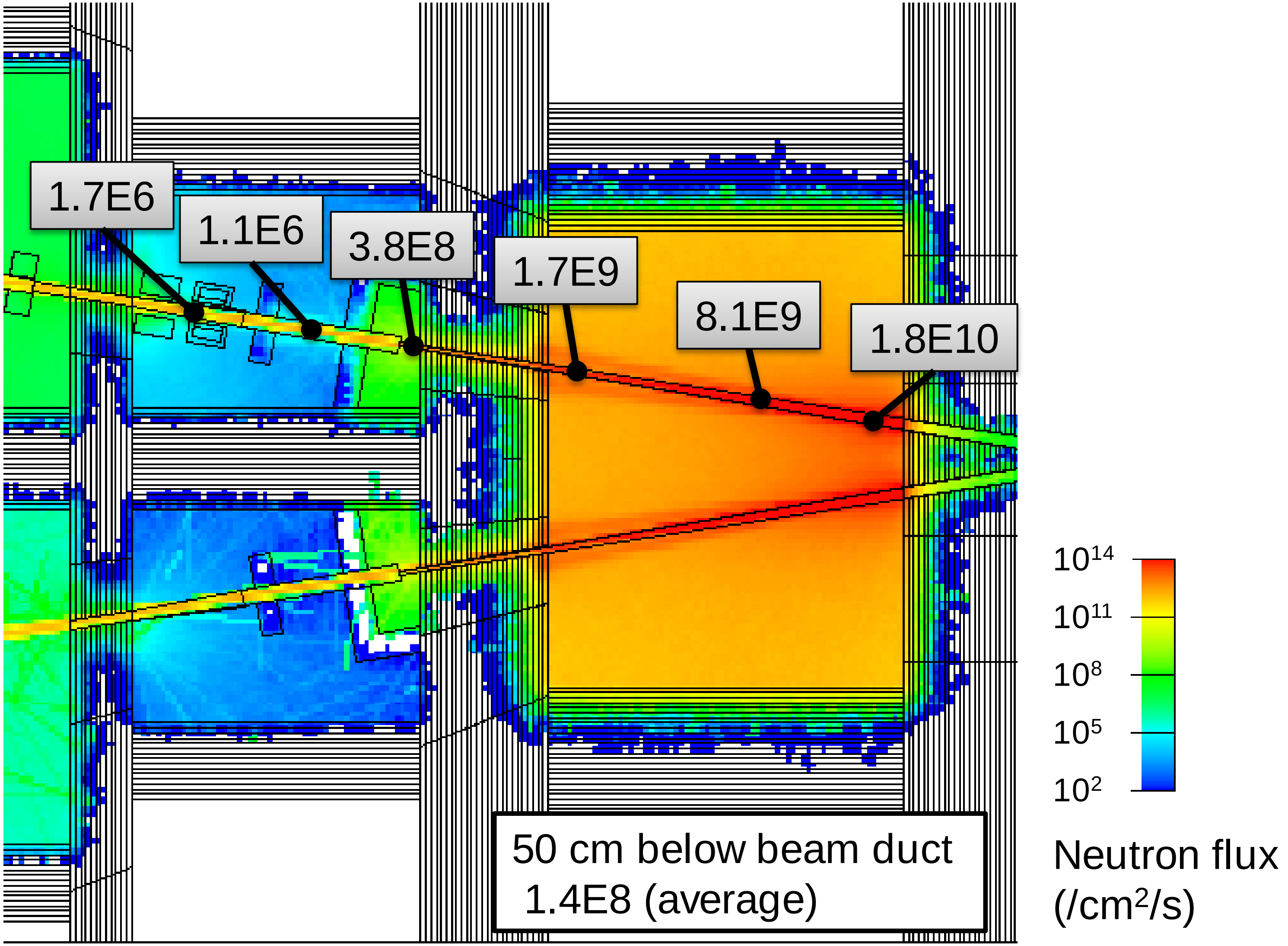
Neutron flux due to streaming



Neutron flux due to RIR scraper



Averaged neutron flux for beam ducts due to streaming

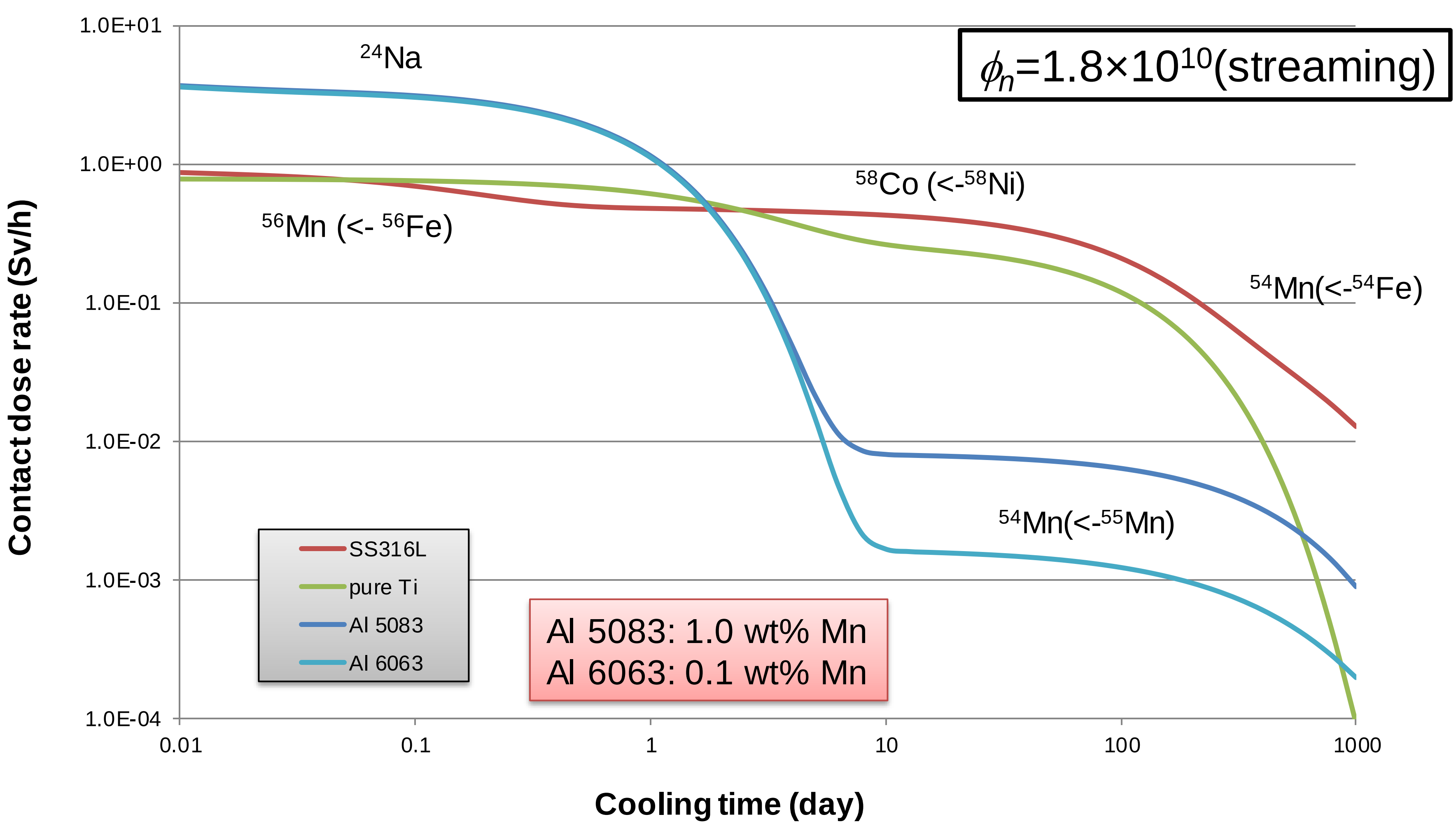


Shutdown calculation condition

- Shutdown dose rate calculation
  - FISPACT-2007 + EAF-2007
  - 11 months continuous operation in full power
  - Contact dose rate at the surface of a semi-infinite slab (*except d-Scraper*)
  - Focusing on maintenance period (i.e. up to 10^3 days cooling)

- Beam ducts
  - **Al 5083 with the thickness of 5mm** for all ducts
  - 5 mm gap between the window in the concrete wall

Shutdown dose for beam duct in TIR (most downstream point, cell20003 seg1)



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Shutdown dose for TIR (outside beam duct, averaged over r>50)