PS activation and collimation studies

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PS – status and outlook

- PS has recently been refurbished: new coils installed into dipoles (CF magnets).
- Insulation in the old coils had received 10-40 MGy*
- Ineffective area of insulator need only be small (~1mm^2)*
- Lamination in the yoke is also a concern.
- Losses during beta-beam operation will be considerable!
- Physics years: neutrinos and anti-neutrinos, 5 years each.

* Private communication, Karl Hubert Mess, CERN

Radiation dose - simulation

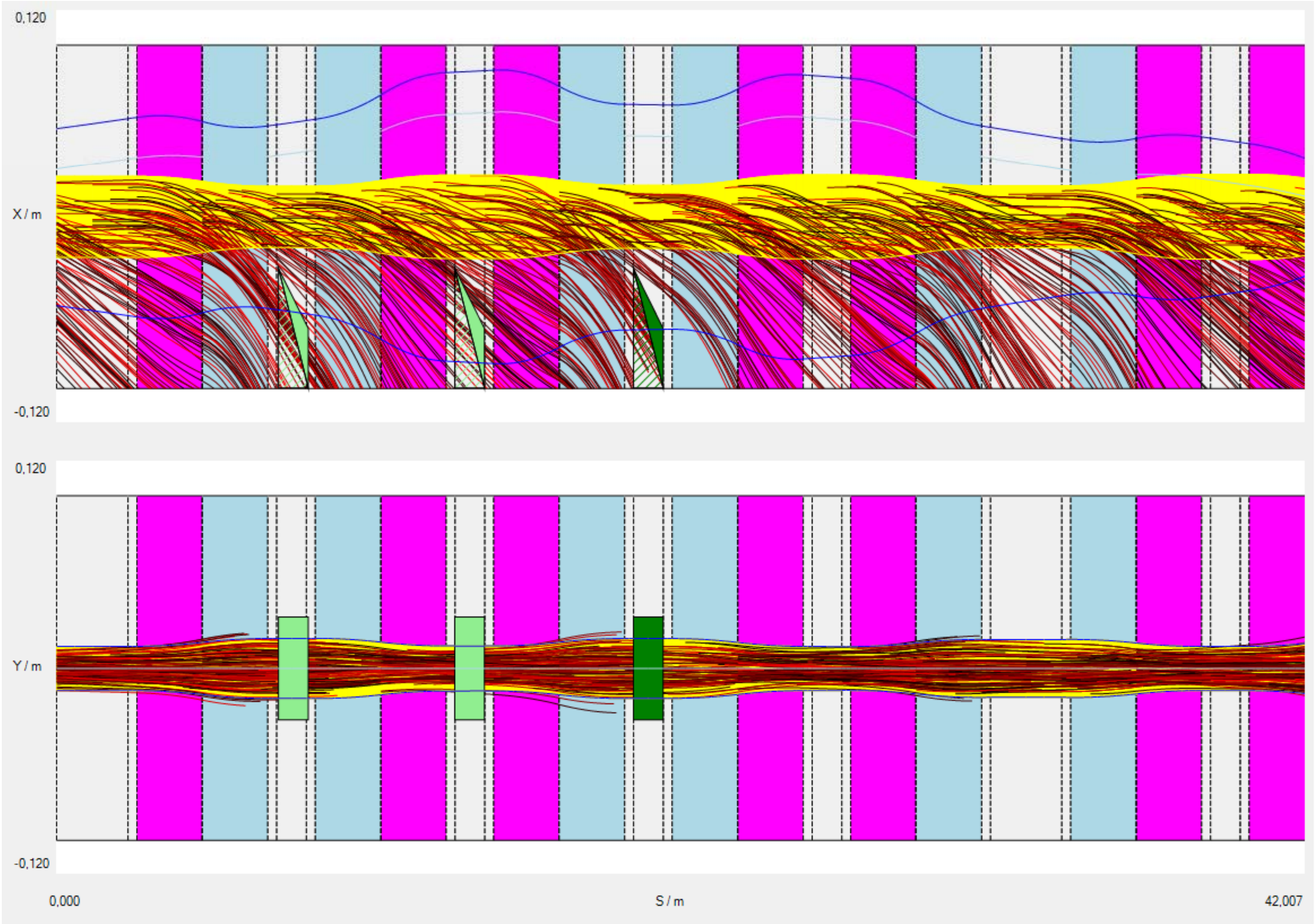
- Require simulation on the most expensive components: magnets.
- Nuclear transport code FLUKA employed.
- Nearly all losses are from beta decay. Approximated to 100%
- Detailed description of geometry: magnet yoke, coil, beampipe and collimators.
- Loss maps of the beta decay daughter nuclei taken from the accelerator tracking code StrahlSim (C. Omet, GSI).

StrahlSim: Losses

He-beam. Decay products tracked to the collimator and beampipe (red & black curves).

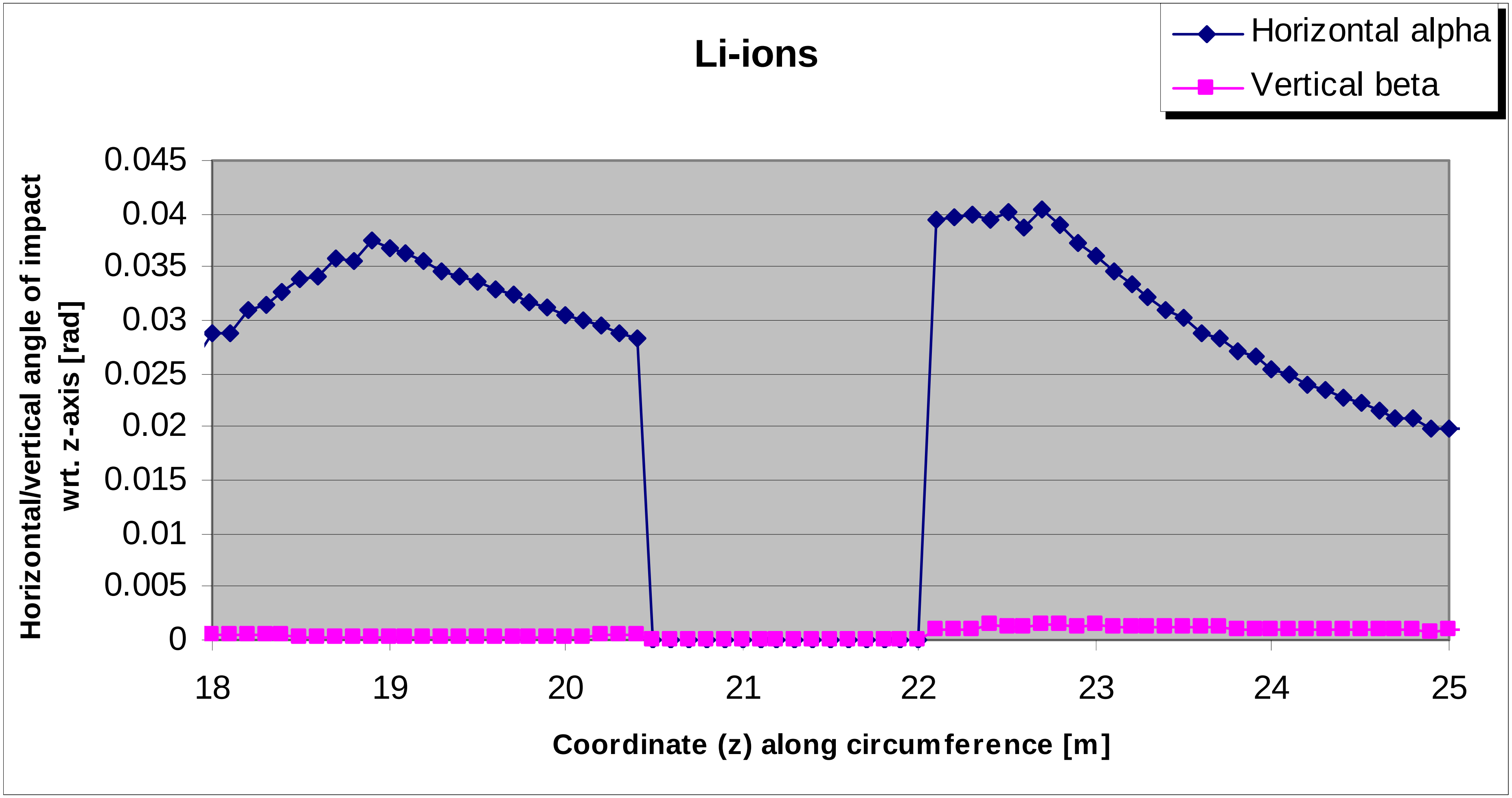
Horizontal

Vertical



StrahlSim: Loss map

He-beam. Angles of incidence (wrt. z axis) along the beamline.



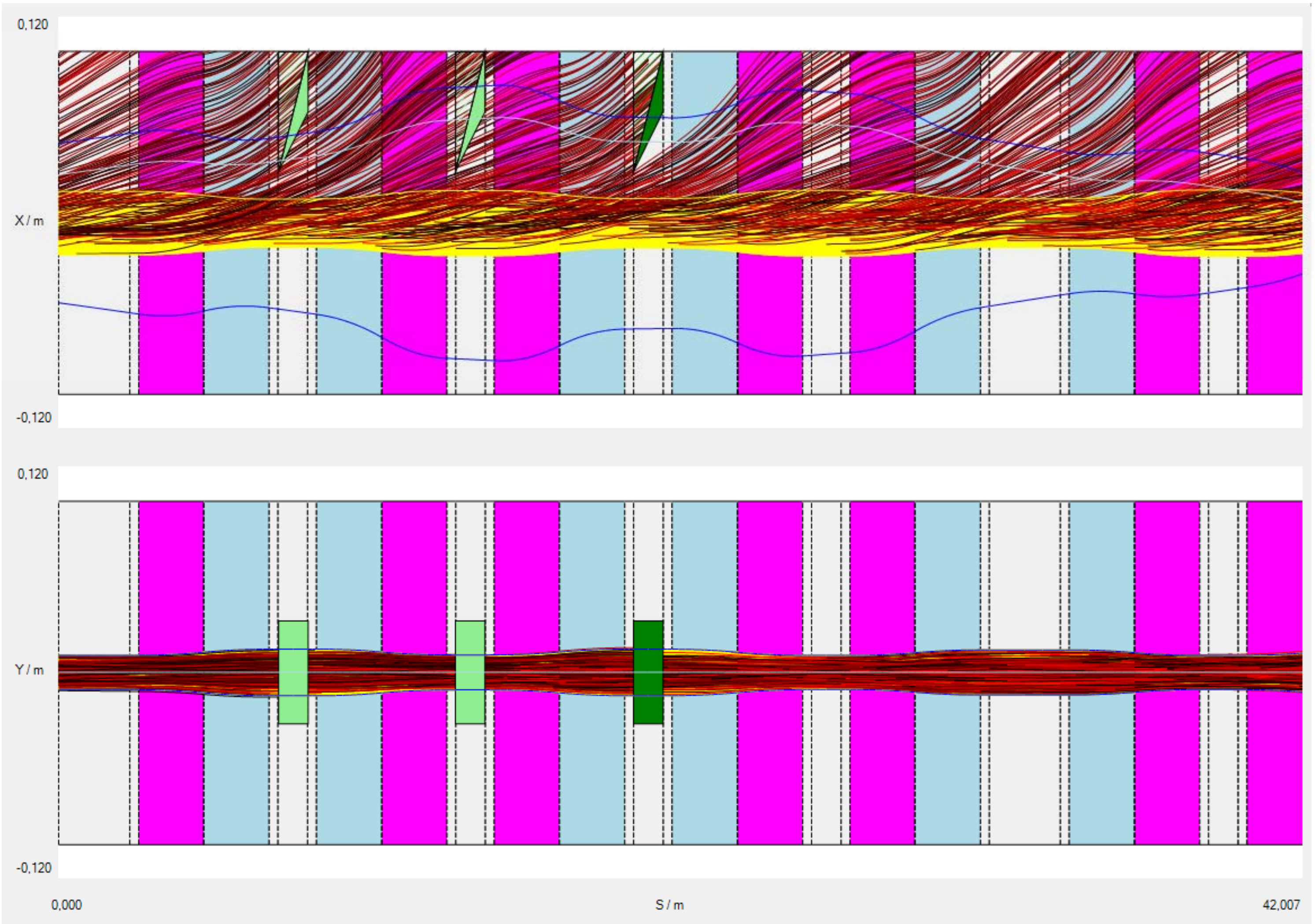
StrahlSim: Losses

Beta Beams in EURISOL

Ne-beam. Decay products tracked to the collimator and beampipe (red curves).

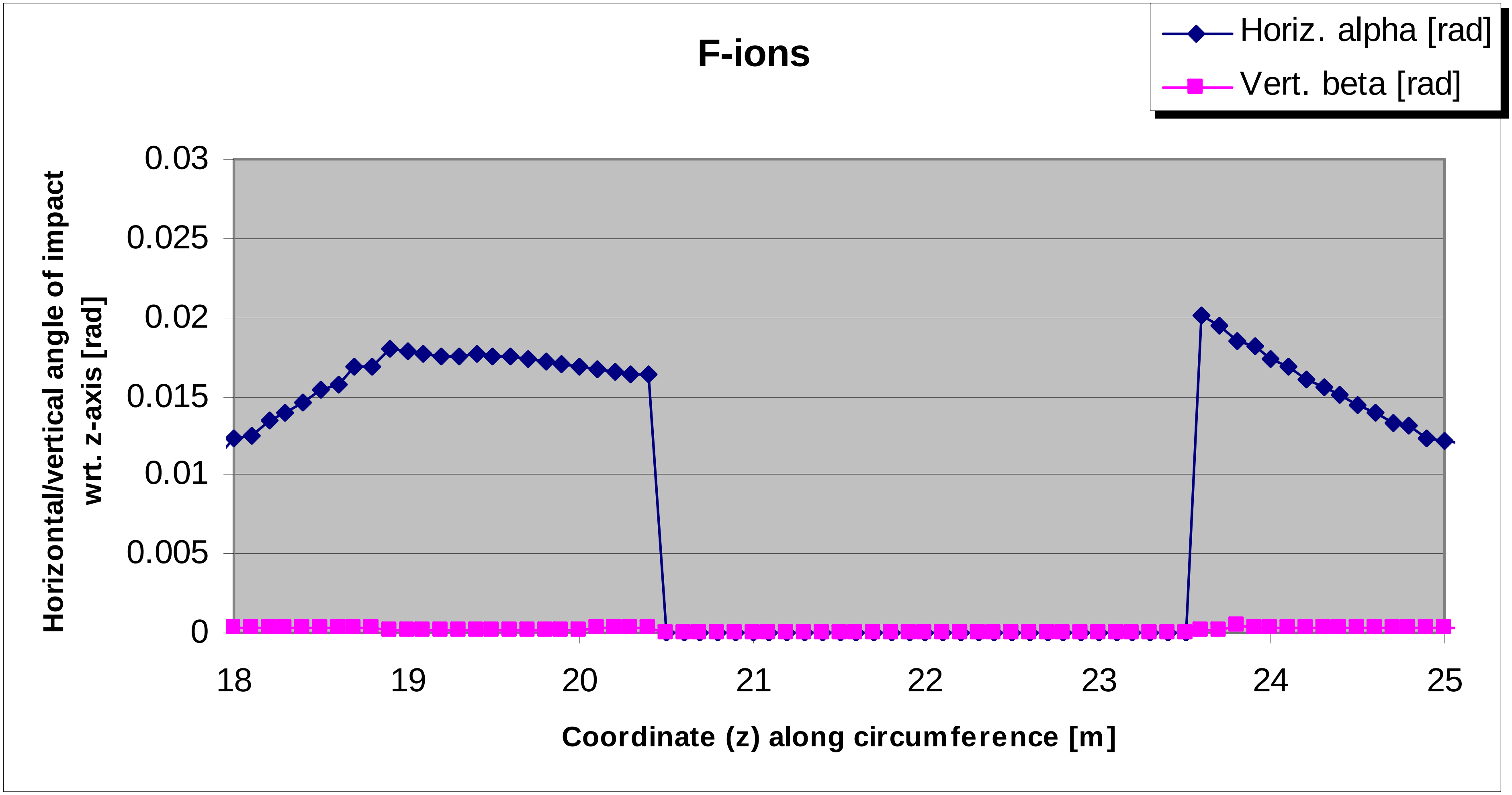
Horizontal

Vertical



StrahlSim: Loss map

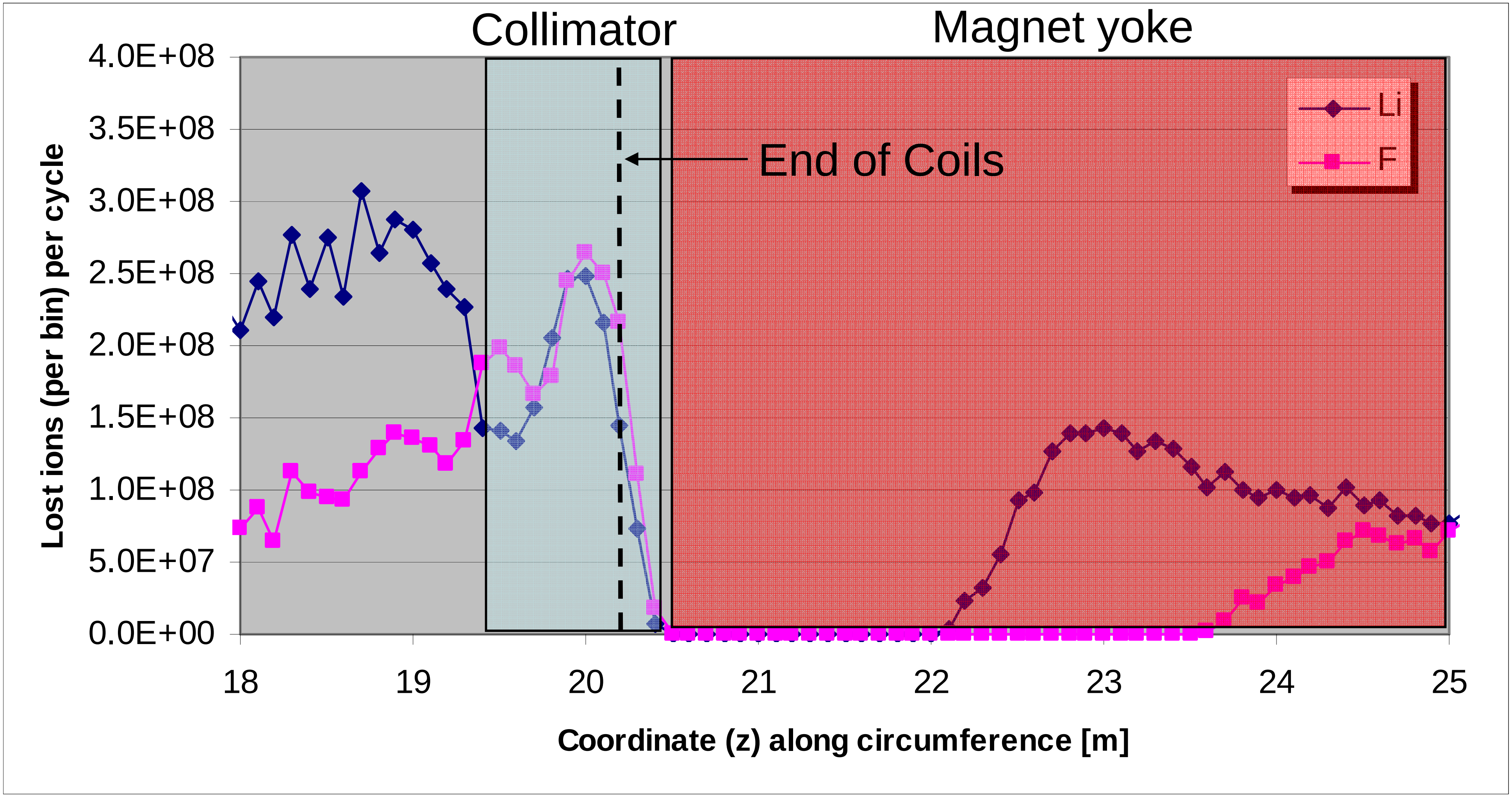
Ne-beam. Angles of incidence (wrt. z axis) along the beamline.



StrahlSim: Loss maps

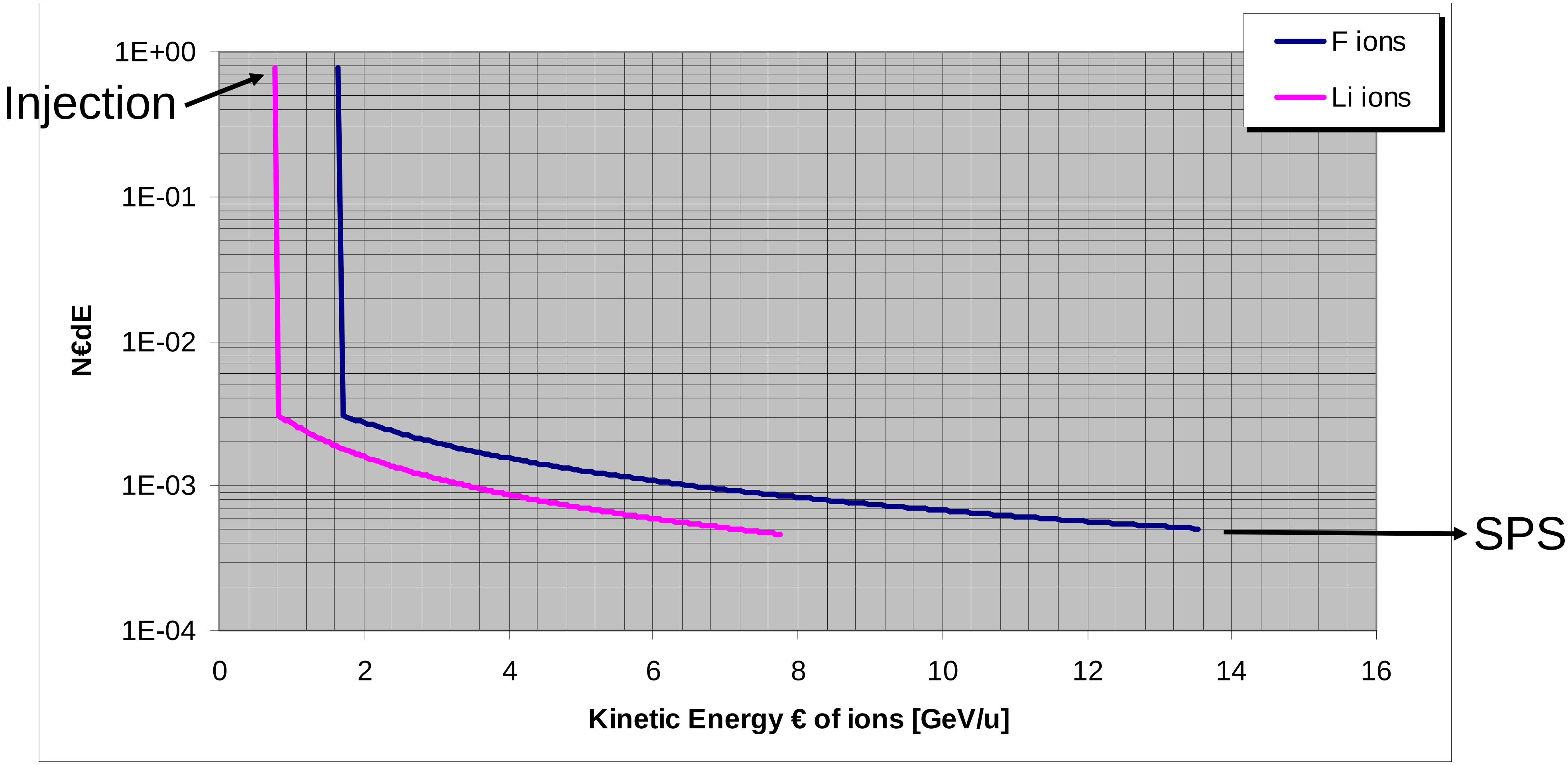
Beta Beams in EURISOL

He- and Ne beams. Loss distribution along the machine.



StrahlSim: Losses

He- and Ne beams. Energy distributions of the daughter nuclei over the complete cycle.



Transverse beam profiles

He- and Ne beams in the FLUKA model.

Approximation 1. effect of adiabatic damping represented as an average:

$$\langle \beta\gamma \rangle_t = \frac{\beta\gamma_{inj}(t_1+t_2)+\frac{1}{2}t_2\left(\beta\gamma_{ext}-\beta\gamma_{inj}\right)}{t_1+t_2} \qquad \langle \varepsilon_y \rangle_t = \varepsilon_{inj,y}\frac{\beta\gamma_{inj}}{\langle \beta\gamma \rangle_t}$$

Linear dipole field ramp: Flat bottom time t_1, acceleration time t_2.

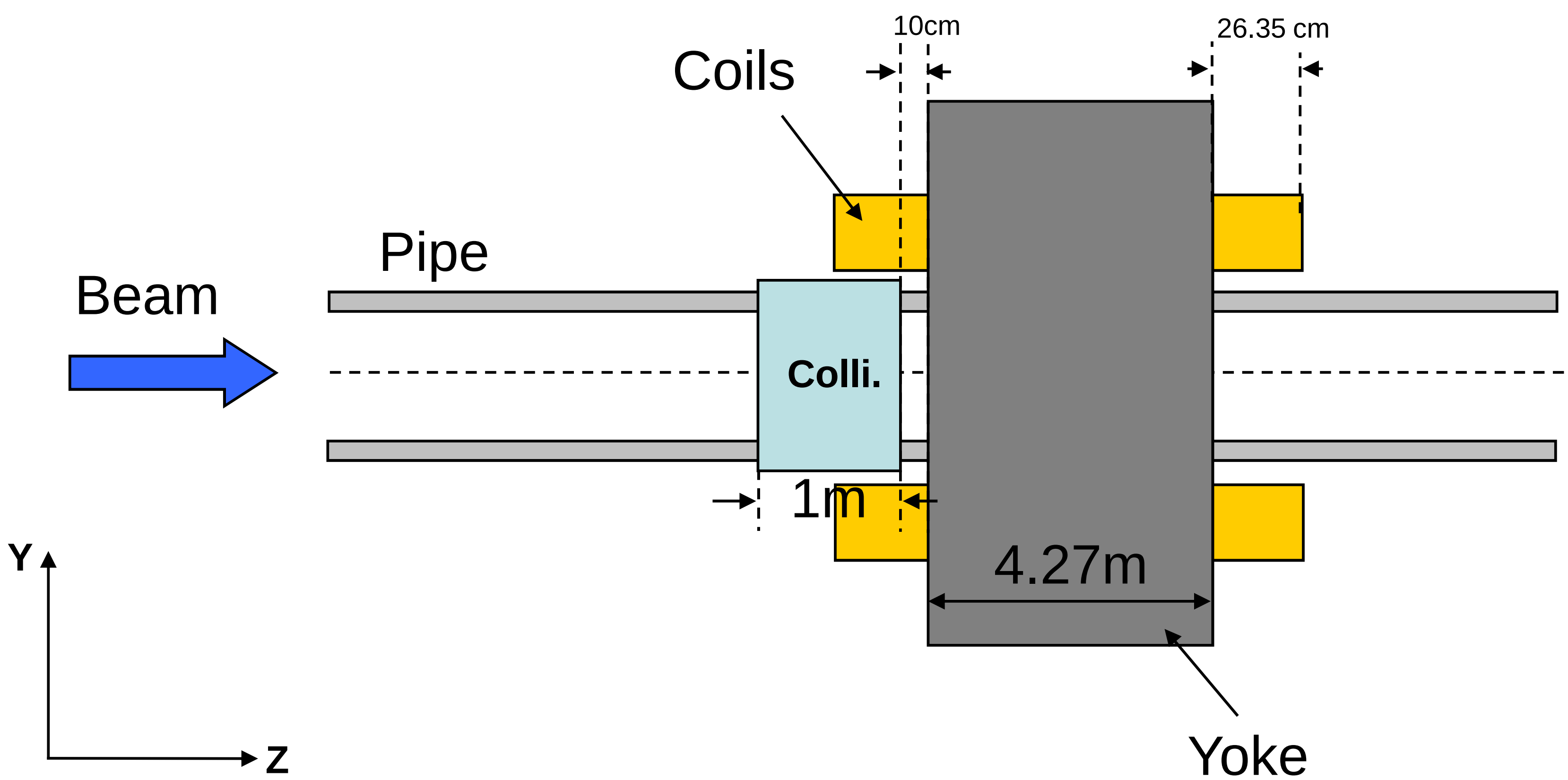
Approximation 2. Transverse <u>vertical</u> primary beam profile is

static and Gaussian with the width given by

$$\Delta Y_{FWHM} = 2\sqrt{\ln(4)\langle \varepsilon_{rms,y}\rangle_t \langle \beta_y \rangle}$$

Schematic: Magnet Geometry

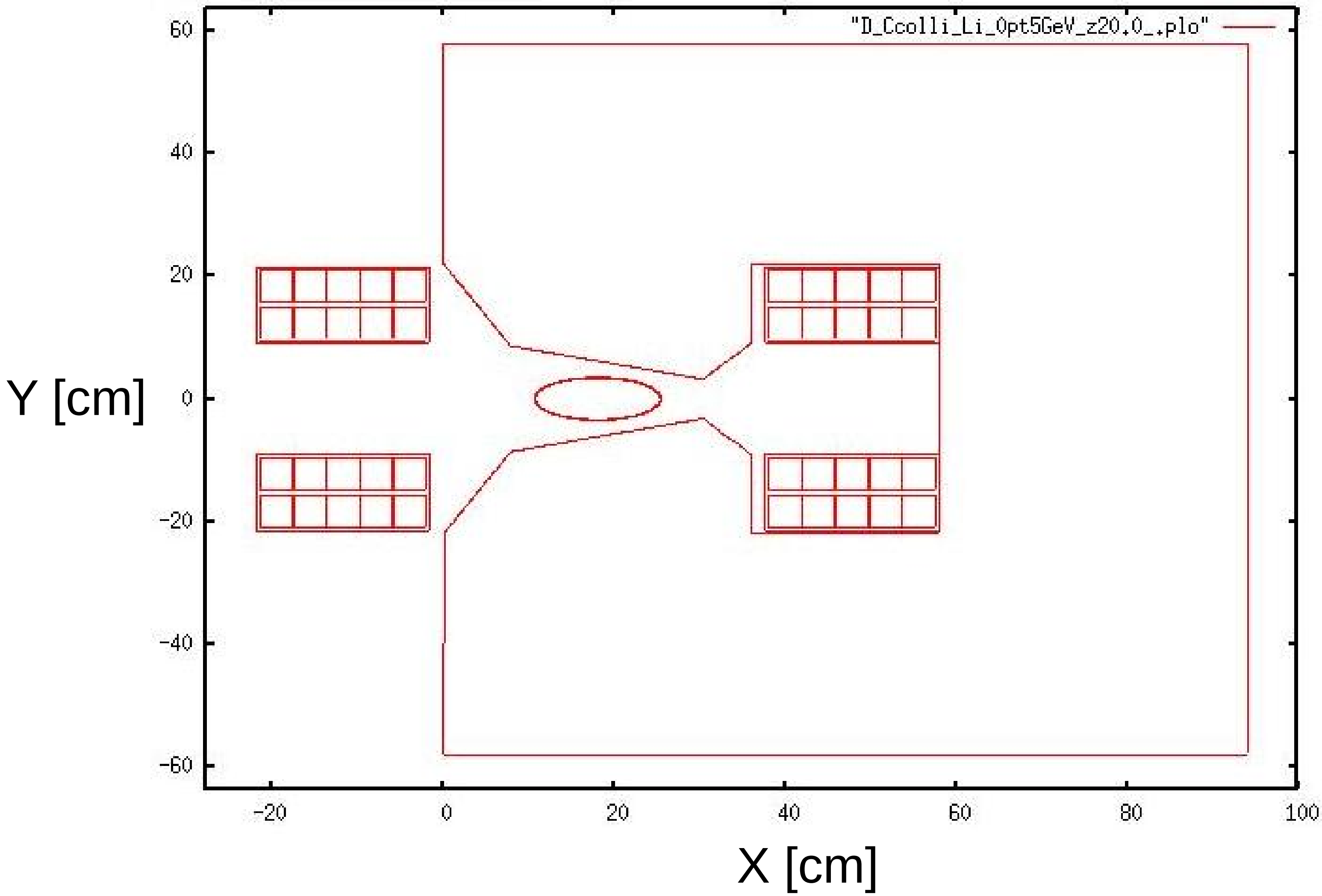
Side view of beamline section including a combined function magnet.



FLUKA: Magnet geometry

PS combined function D-magnet. Beam into page.

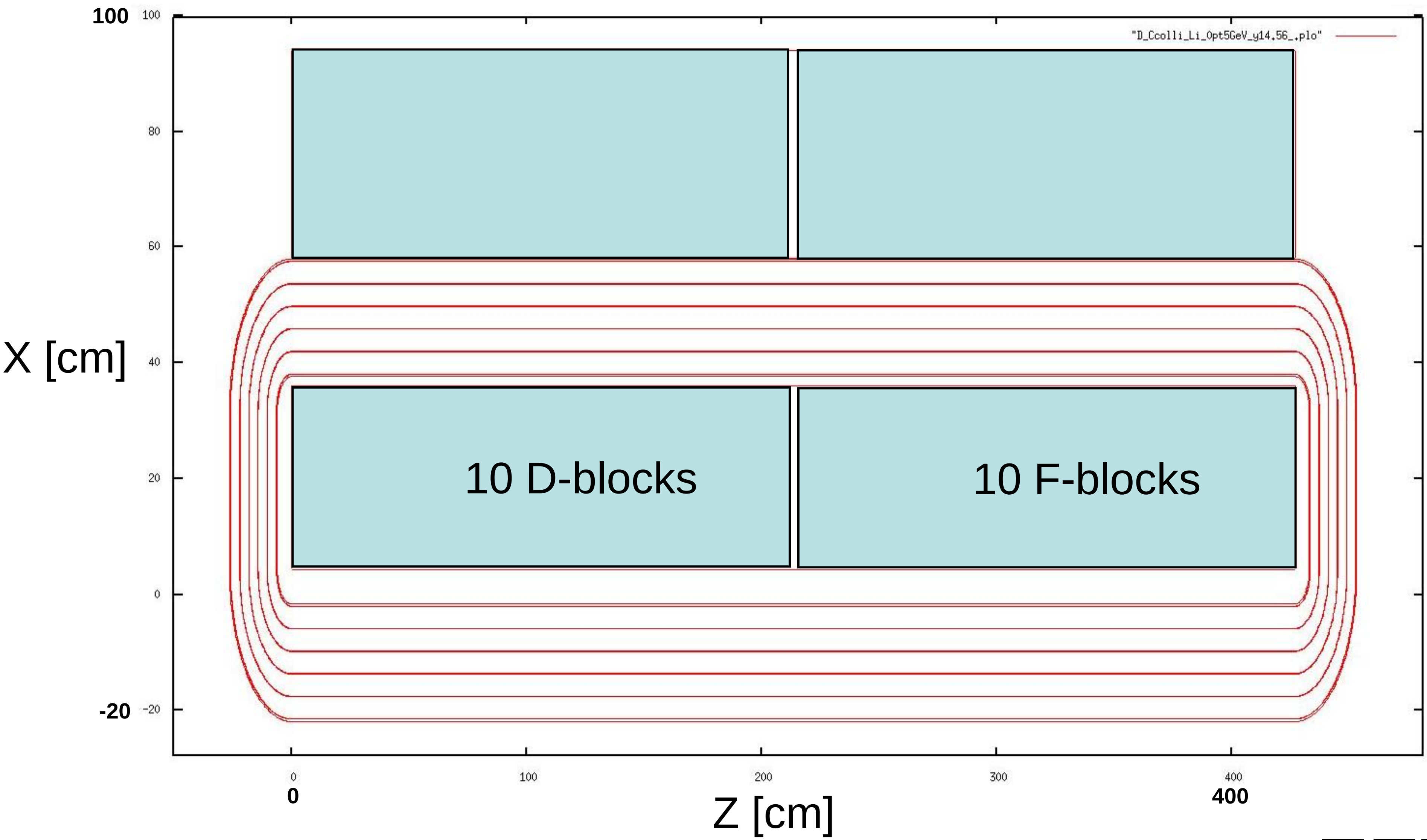
Vertical cross section through middle of magnet.



Magnet geometry

PS combined function D-magnet. Beam from left to right.

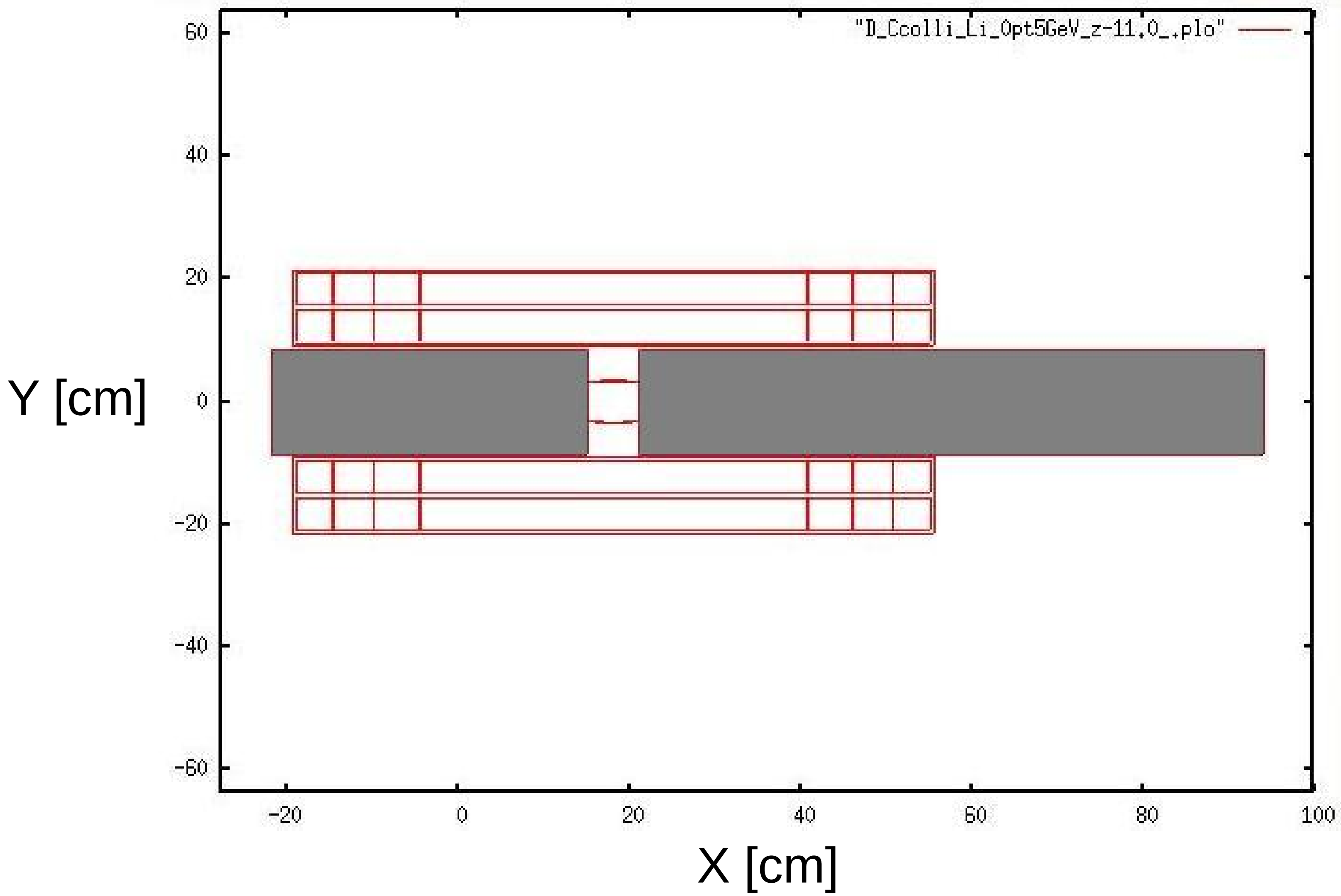
Horizontal cross section through magnet and top/bottom pancake coil.



Magnet geometry

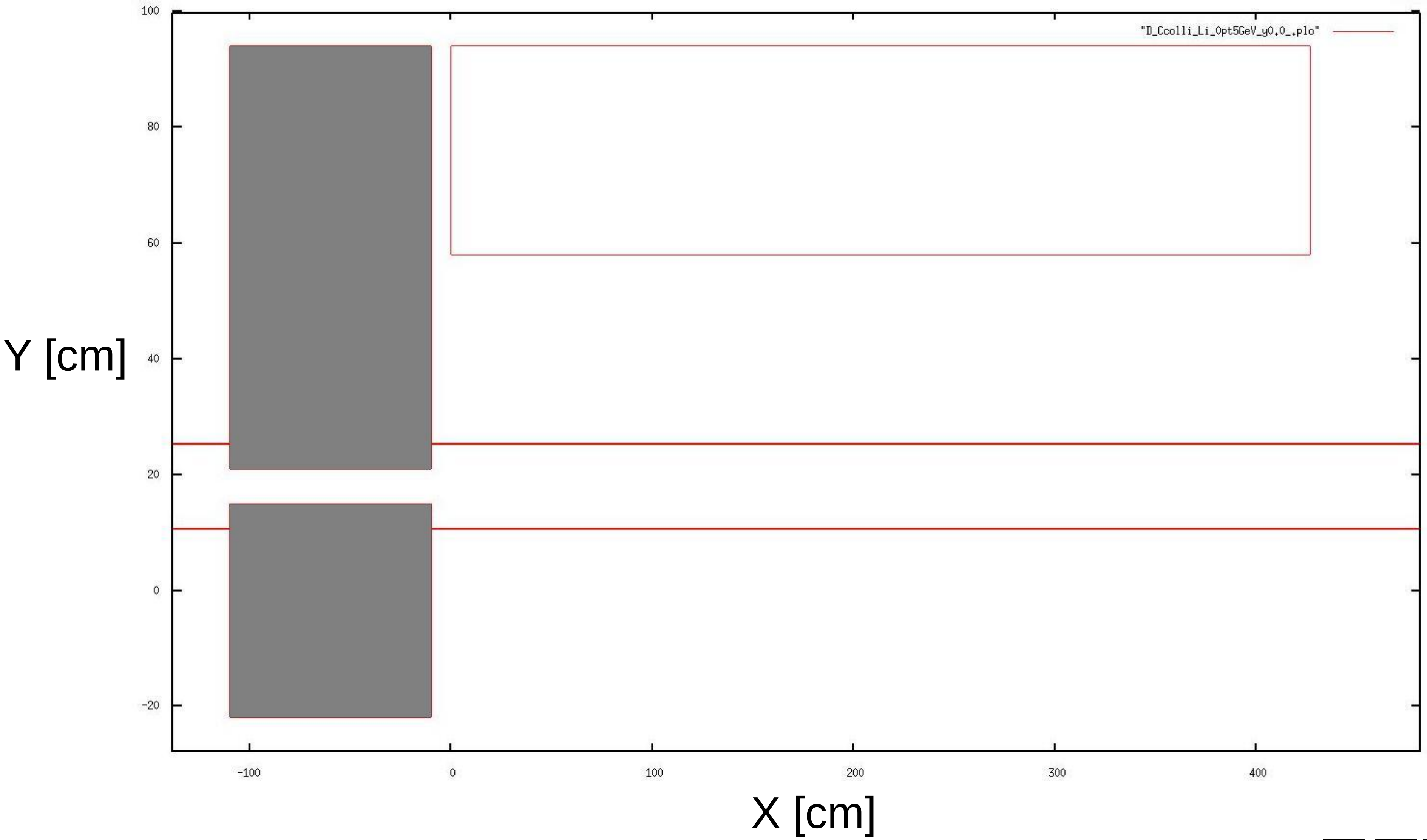
PS combined function D-magnet. Beam into page.

Vertical cross section through collimators and coils at the front of the magnet.



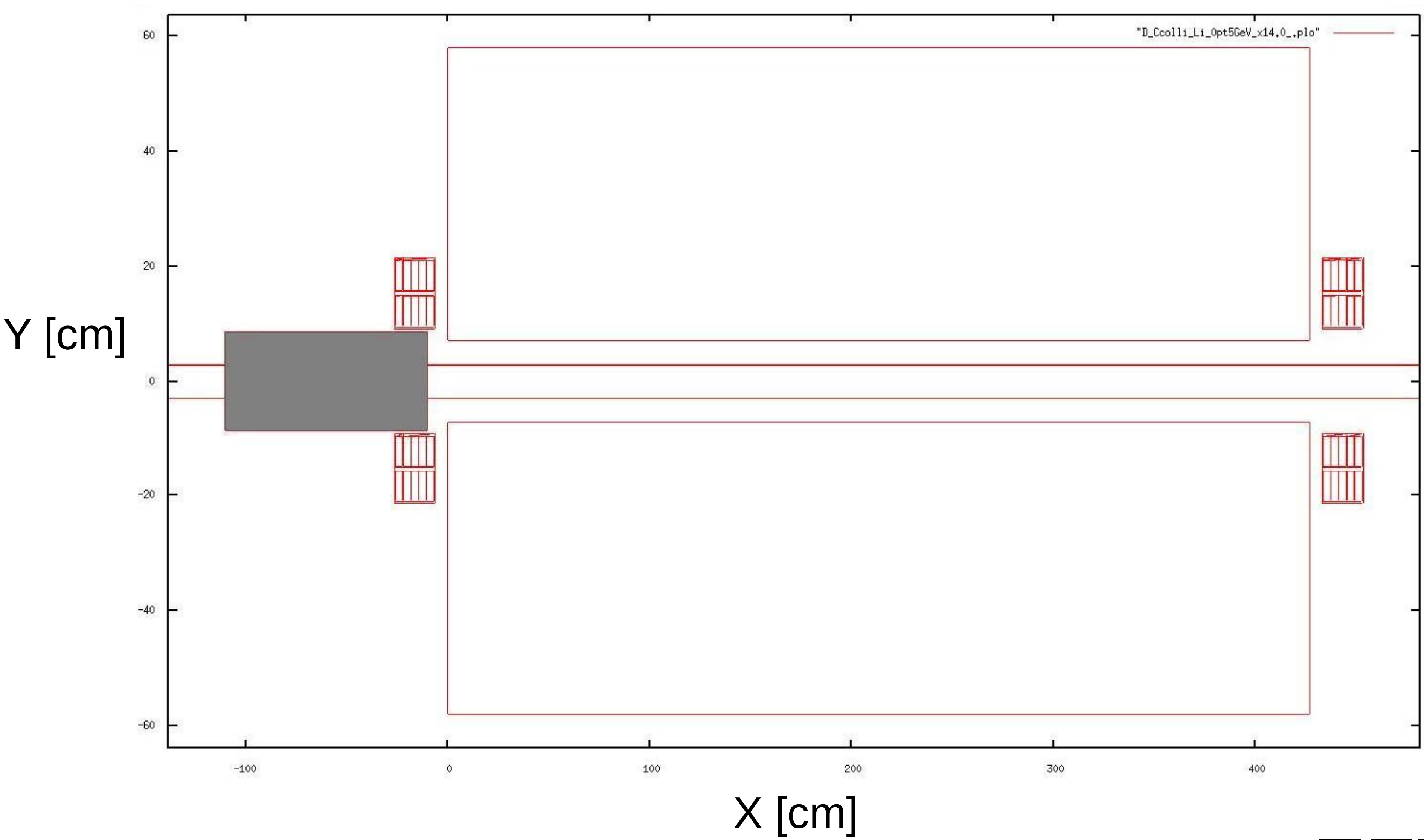
Magnet geometry

PS combined function D-magnet. Beam from left to right.



Magnet geometry

PS combined function D-magnet. Beam from left to right.



Insulation around the coils

FLUKA materials

Coil insulation: Epoxy fibre glass resin (4mm thick)

Mainly consists of glass type E (80%). 100% assumed in model.

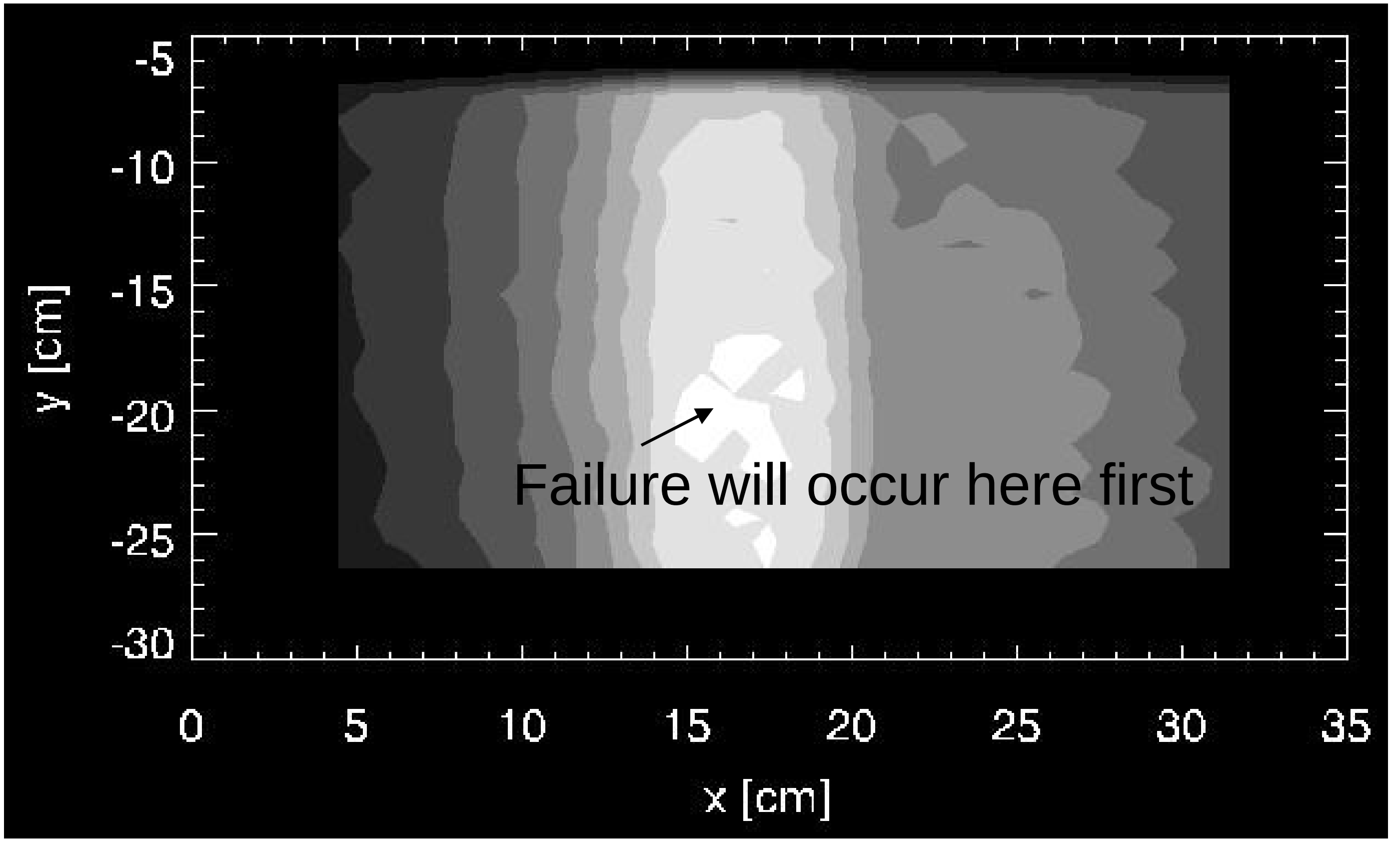
	Fraction of mass
SiO_2	**52-56 %**
Alkaline Oxides	0-2 %
CaO	**16-25 %**
MgO	**0-5%**
B_2O_3	**5-10%**
Al_2O3	**12-16%**
TiO_2	0-0.8%
Fe_2O_3	0.05-0.4%
F_2	0-1%

Dose rate distribution in the coils

Insulation: bottom horizontal sheet of the top front straight.

$^{18}F^{9+}$ 1.1 GeV/u → C collimator.

Ilustration only!



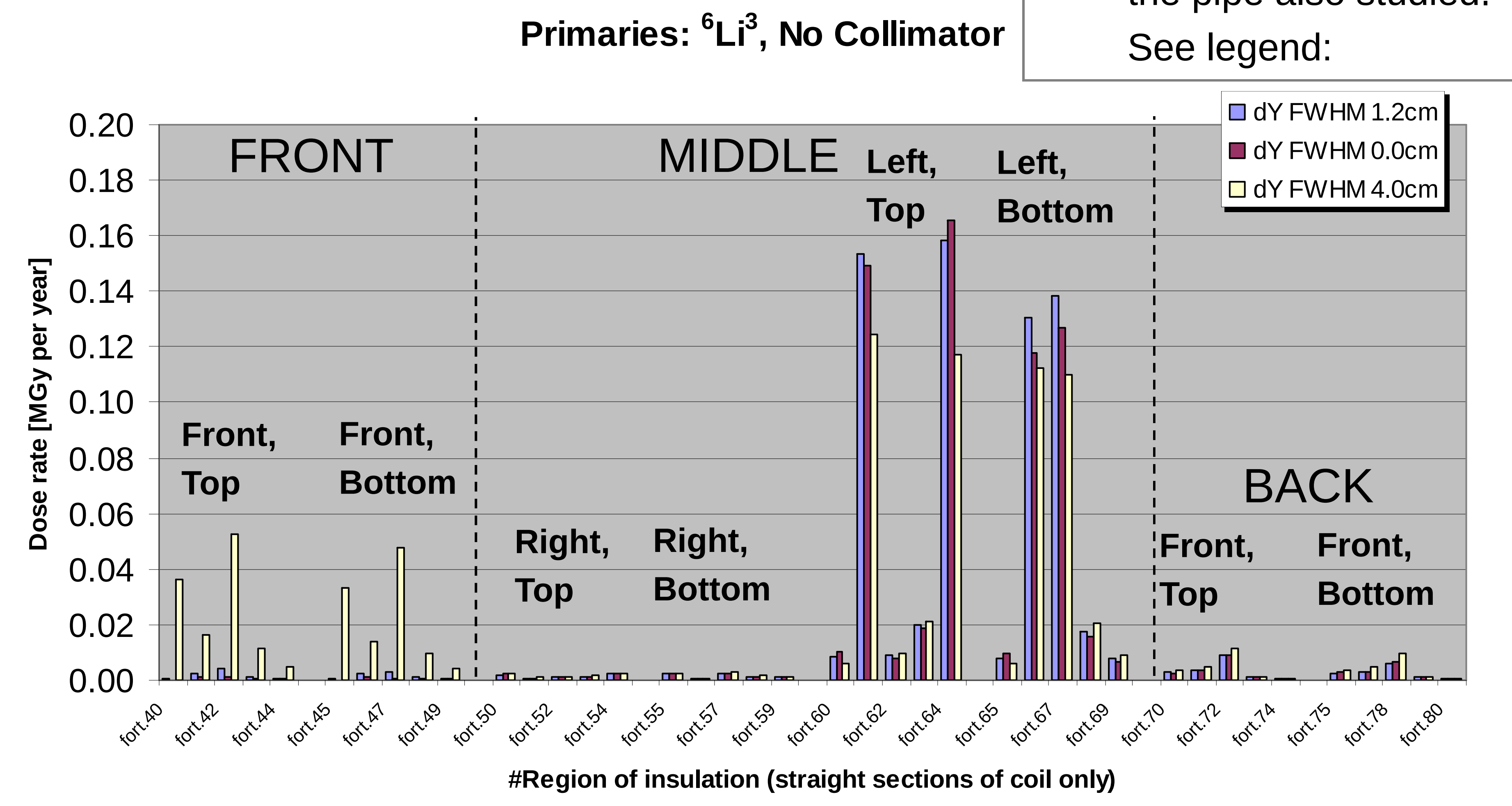
Dose rates and lifetimes (1)

Beta Beams in EURISOL

He-beam pattern: Angular and energy distributions given by StrahlSim.

Preferred dose rate <0.2 MGy/year

Pencil beam and 2σ filling the pipe also studied. See legend:

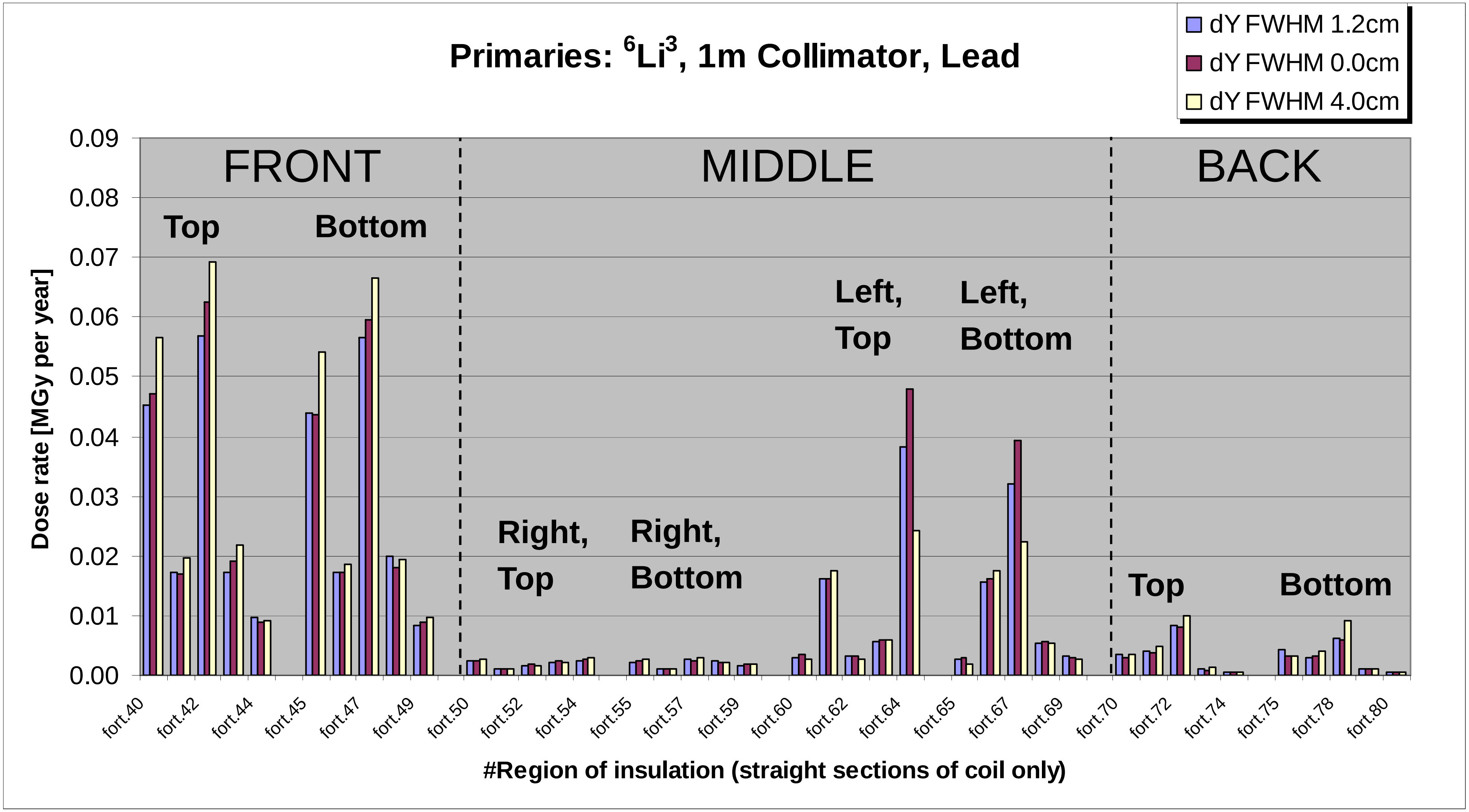


Bends in the coils and straights at the back not included.

Dose rates and lifetimes (2)

Beta Beams in EURISOL

He-beam pattern: Angular and energy distributions given by Strahlsim.



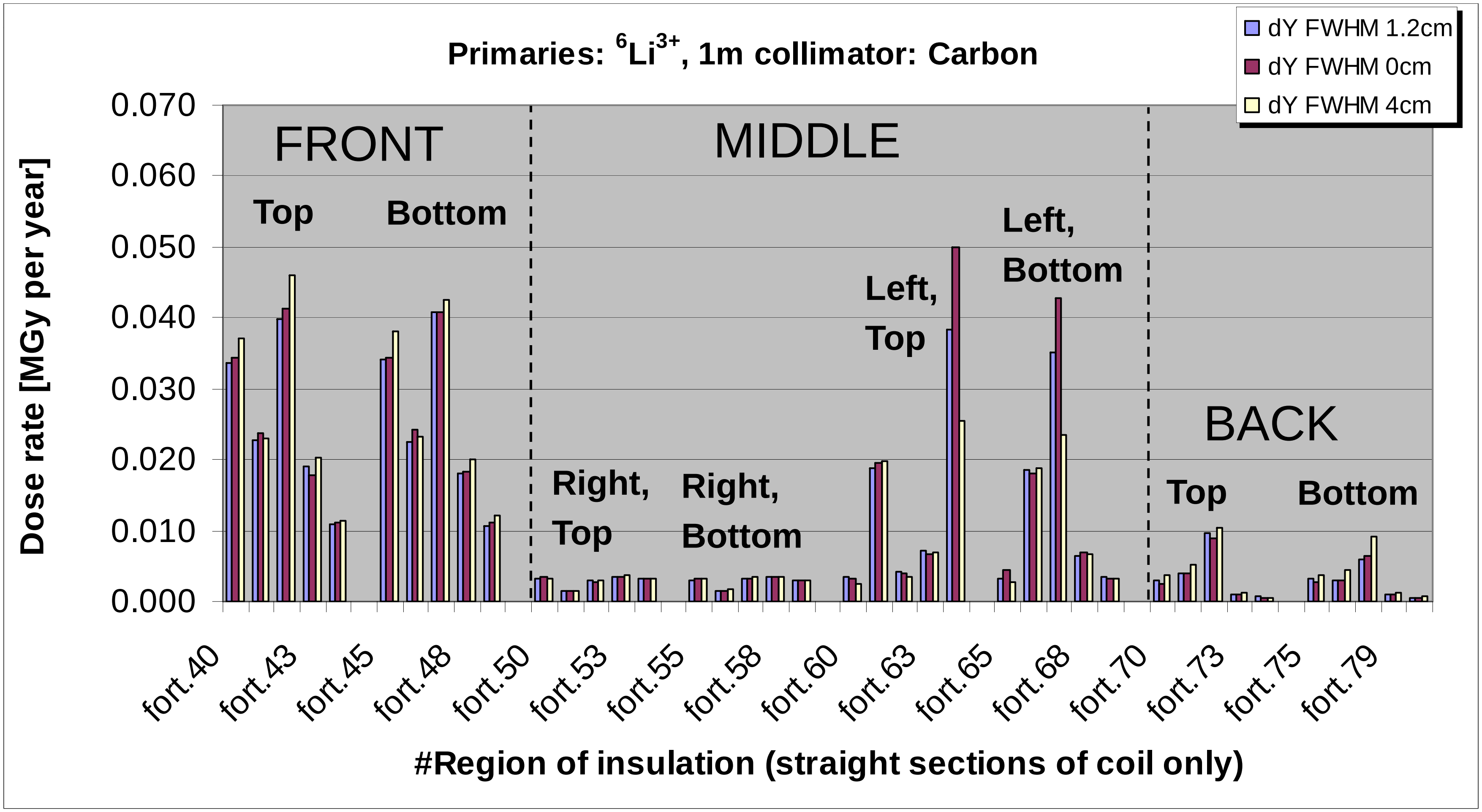
Bends in the coils and straights at the back not included.

GSI

Dose rates and lifetimes (3)

Beta Beams in EURISOL

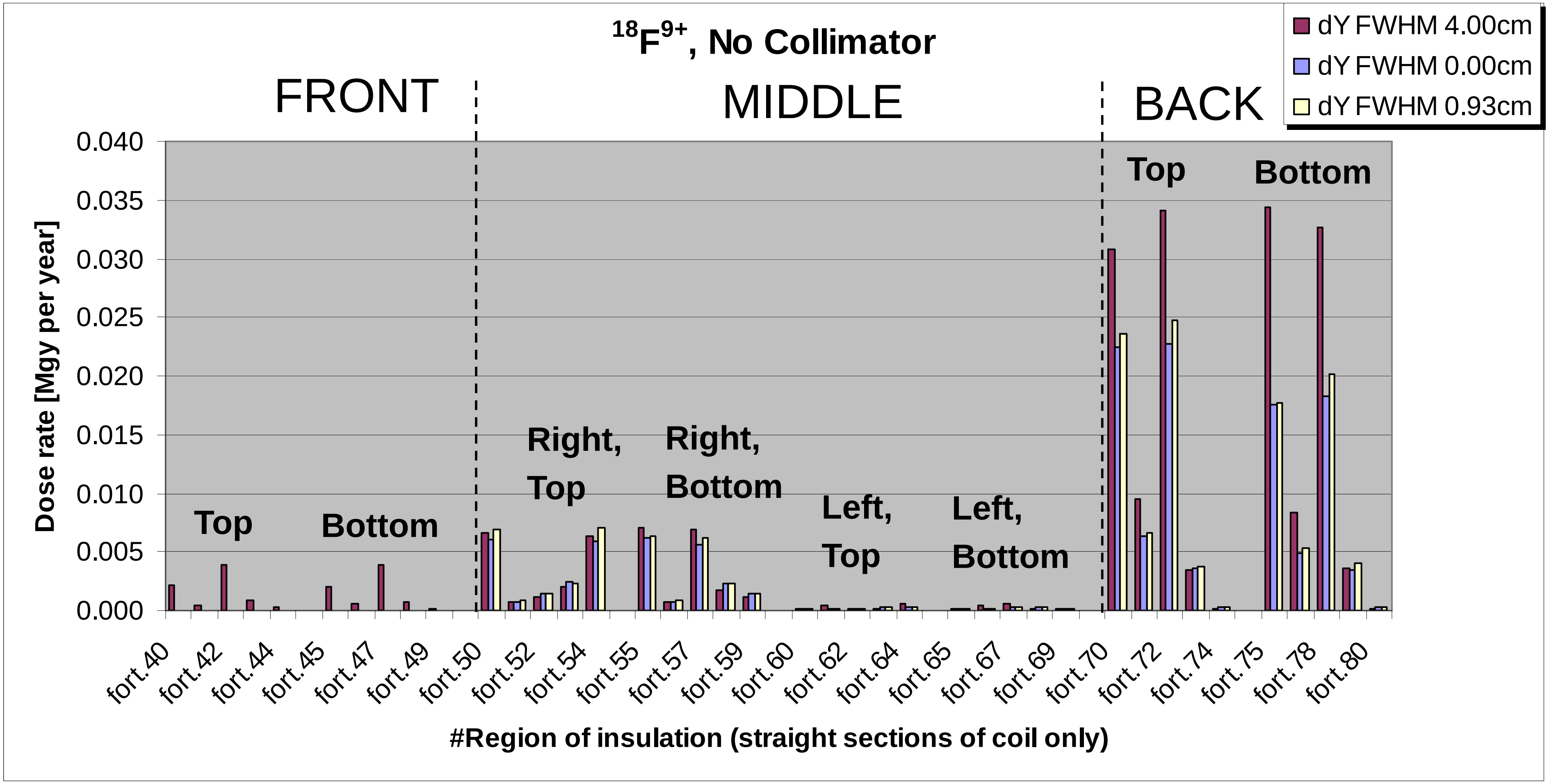
He-beam pattern: Angular and energy distributions given by Strahlsim.



Bends in the coils and straights at the back not included.

Dose rates and lifetimes (4)

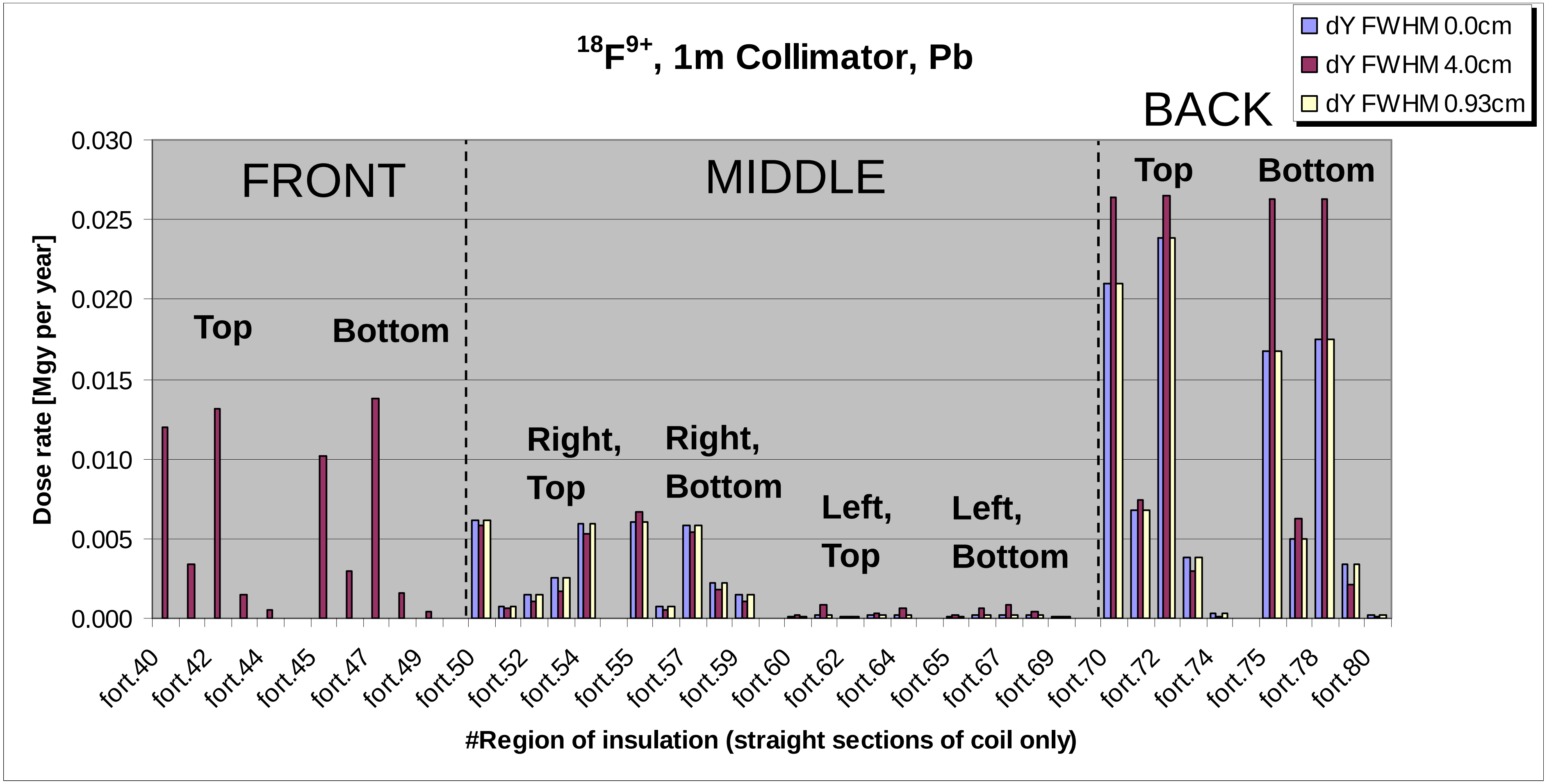
F-beam pattern: Angular and energy distributions given by Strahlsim code. Mean vertical FWHM of beam during machine cycle is dY.



Bends in the coils and straights at the back: not included.

Dose rates and lifetimes (5)

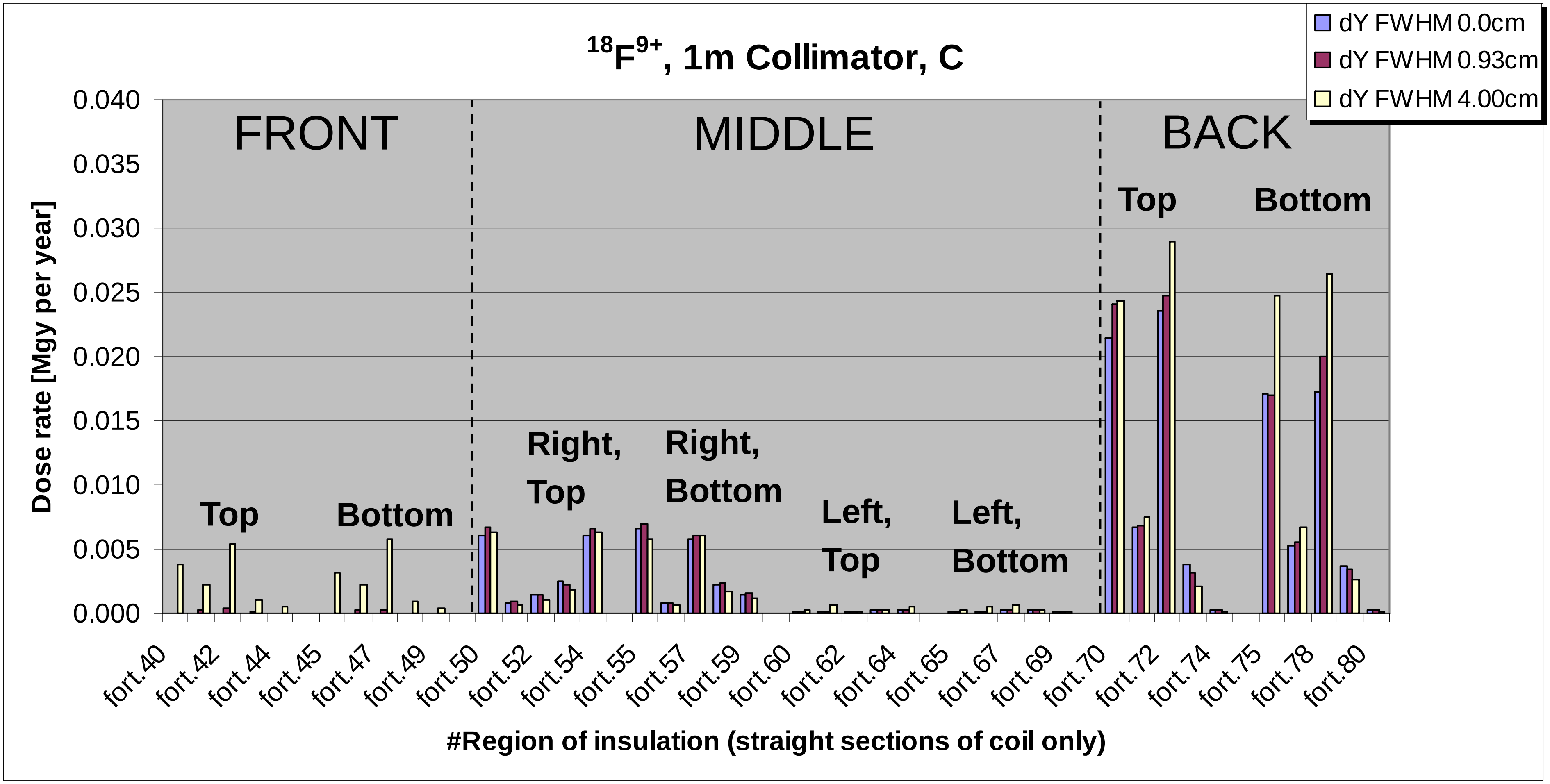
F-beam pattern: Angular and energy distributions given by Strahlsim code. Mean vertical FWHM of beam during machine cycle is dY.



Bends in the coils and straights at the back: not included.

Dose rates and lifetimes (6)

F-beam pattern: Angular and energy distributions given by Strahlsim code. Mean vertical FWHM of beam during machine cycle is dY.



Bends in the coils and straights at the back: not included.

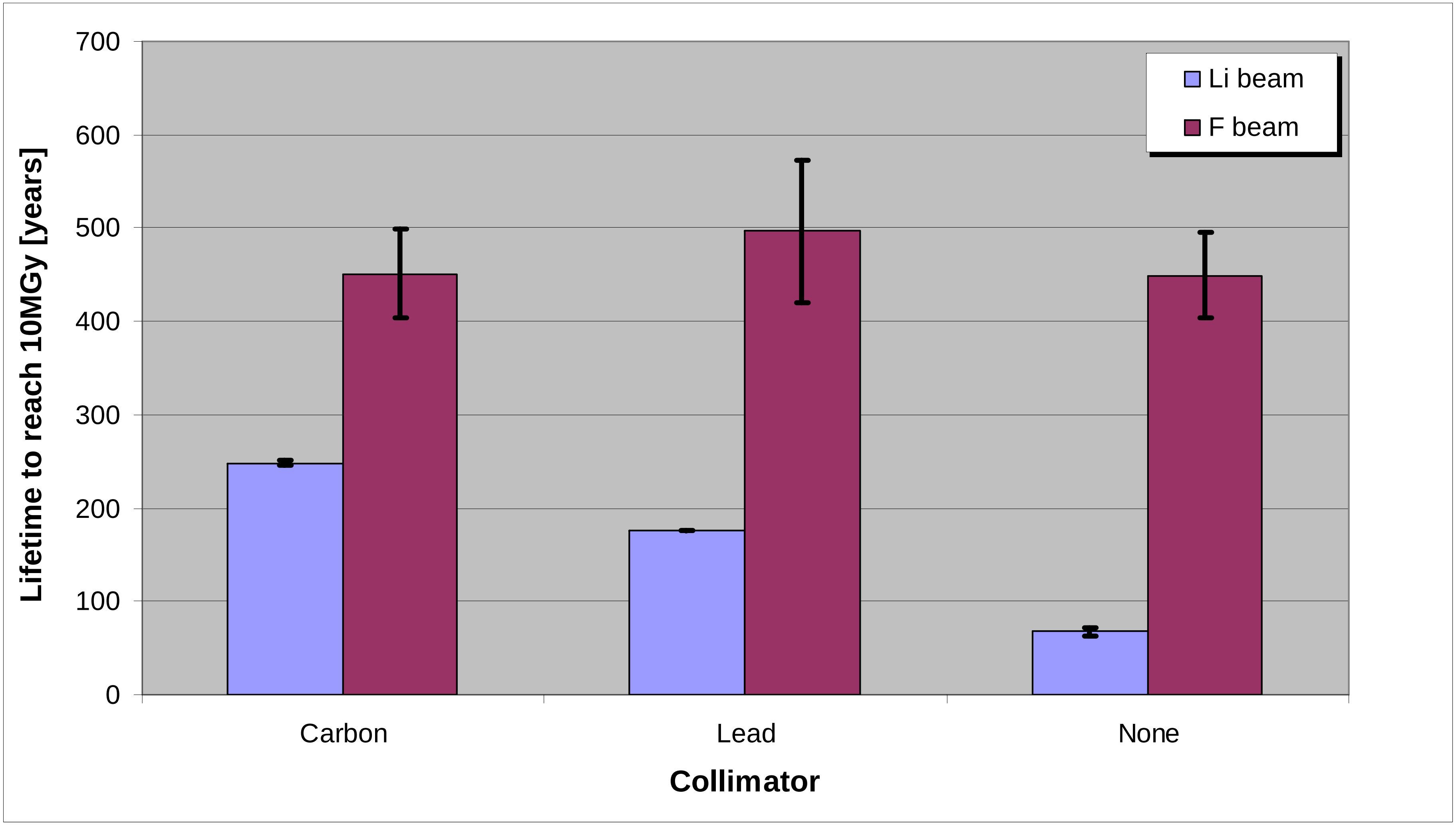
Lifetimes

Beta Beams in EURISOL

Losses on target geometry (z=18-25m):

8.2×10^9 Li-ions/s 1.2×10^9 F-ions/s

Error bars due to statistical error; differences taken in reflection asymmetry.



Lifetimes

Losses on target geometry (z=18-25m):

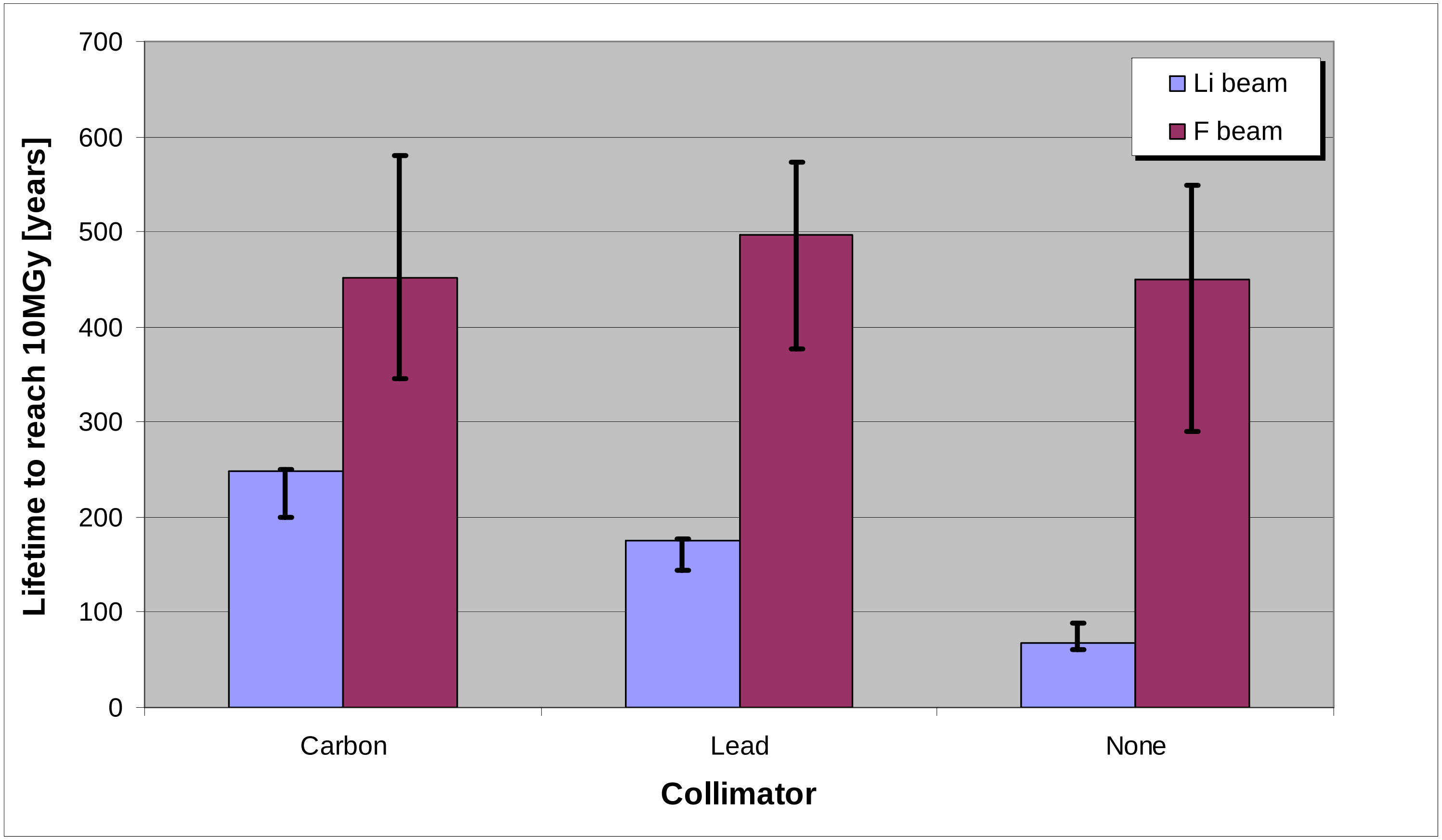
8.2×10^9 Li-ions/s 1.2×10^9 F-ions/s

Error bars show effect of changing the vertical beam width, incl. statistical error.

Max. and Min. taken from min. dose rate for vertical dY_{FWHM}:

Li: 0, 1.2, 4 cm

F: 0, 0.93, 4 cm

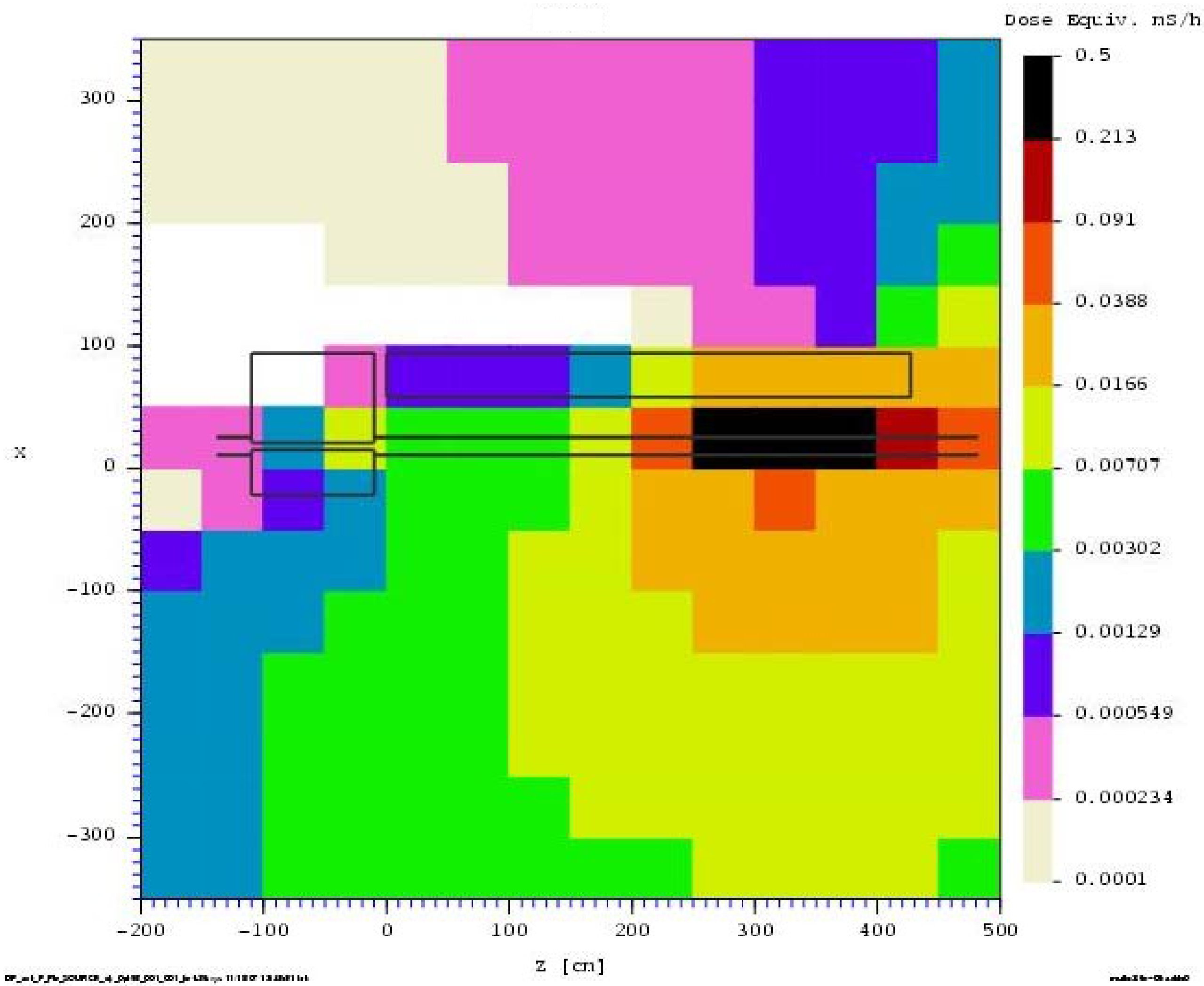


Activation – ^{18}F, Pb collimator

Continuous irradiation at 1.2×10^{9} Ptcls/s (over z=18-25m) for 5 years.

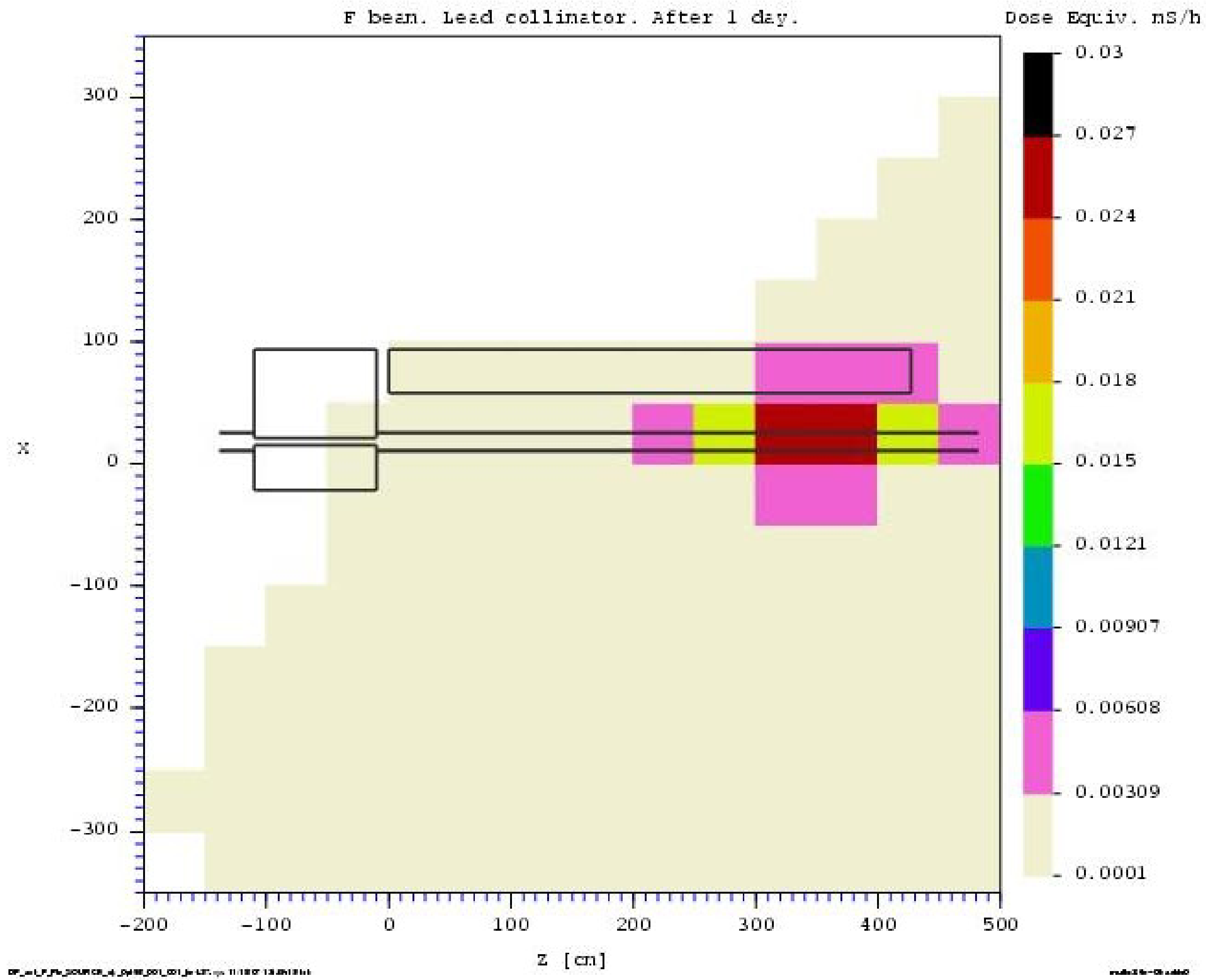
Residual equivalent dose rate map (mSv/hour) 1 hour after shut down.

Horizontal slice through beampipe. Dimensions in cm.



Activation – ^{18}F, Pb collimator

Equivalent dose rate 1 day after shut down.



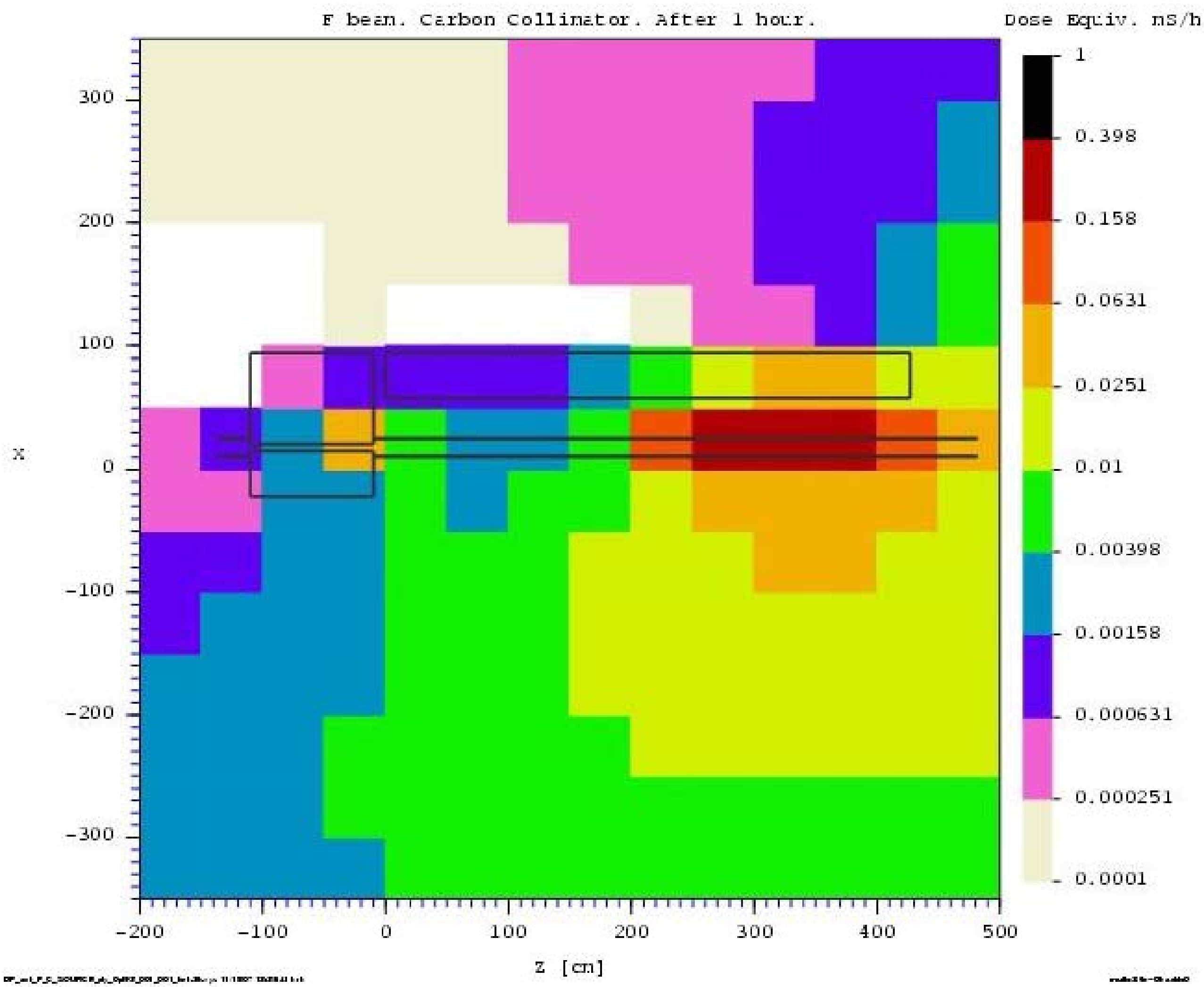
Activation – ^{18}F, C collimator

Continuous irradiation at 1.2x109 Ptcls/s (over z=18-25m) for 5 years.

Equivalent dose rate (mSv/hour) 1 hour after shut down.

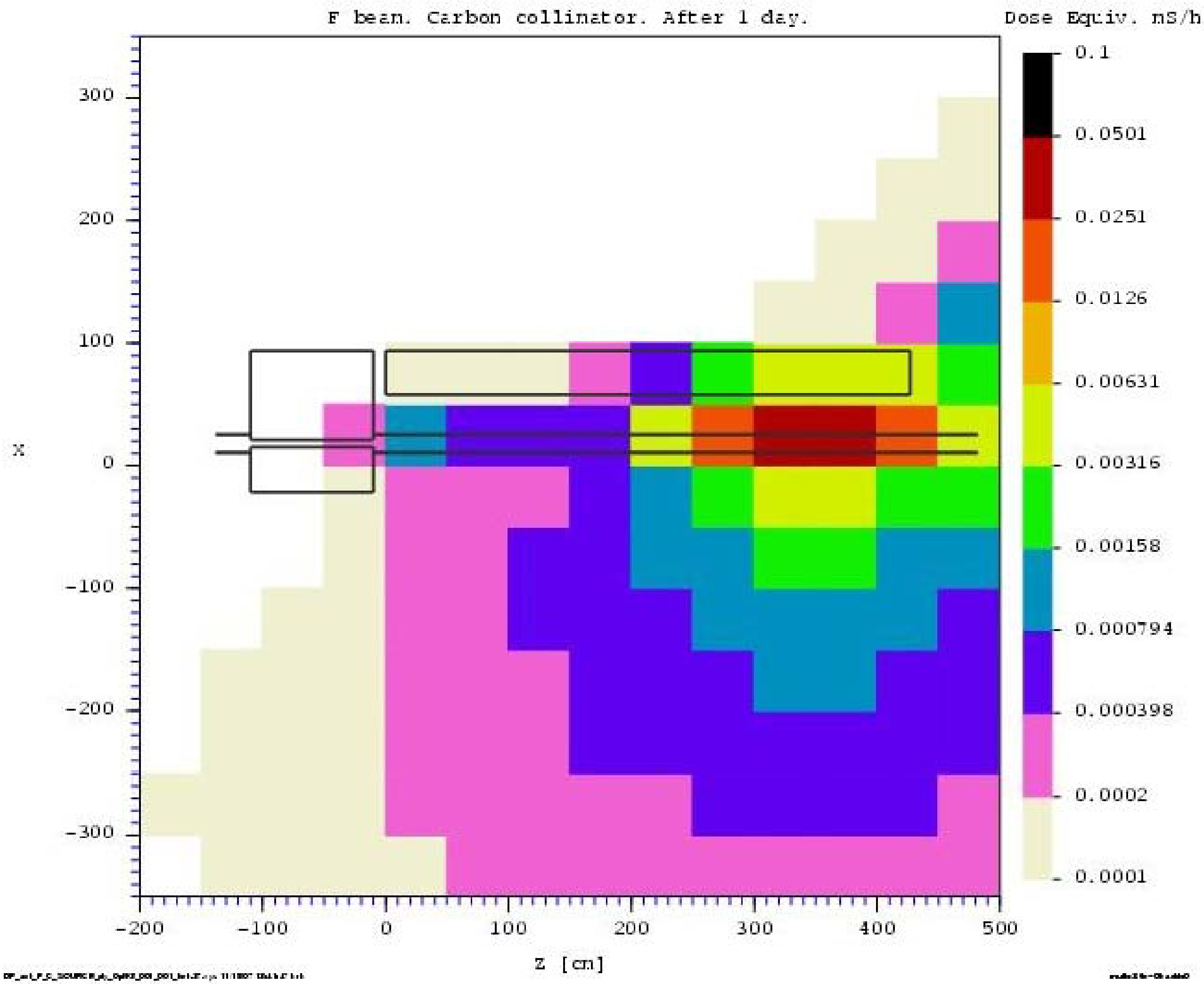
Horizontal slice through beampipe.

Dimensions in cm.



Activation – ^{18}F, C collimator

Equivalent dose 1 day after shut down.



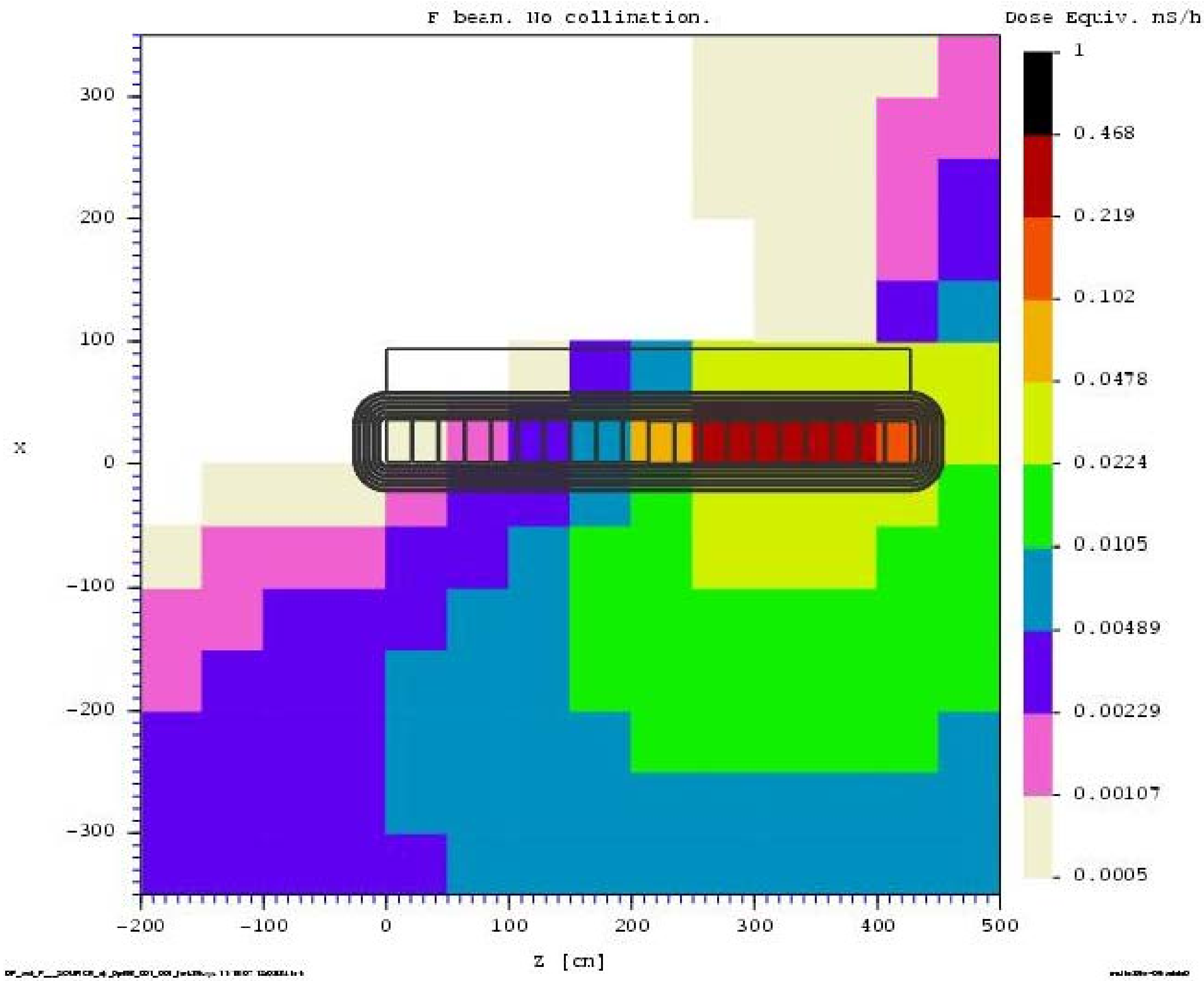
Activation – ^{18}F, no collimator

Beta Beams in EURISOL

Continuous irradiation at 1.2x109 Ptcls/s (over z=18-25m) for 5 years.

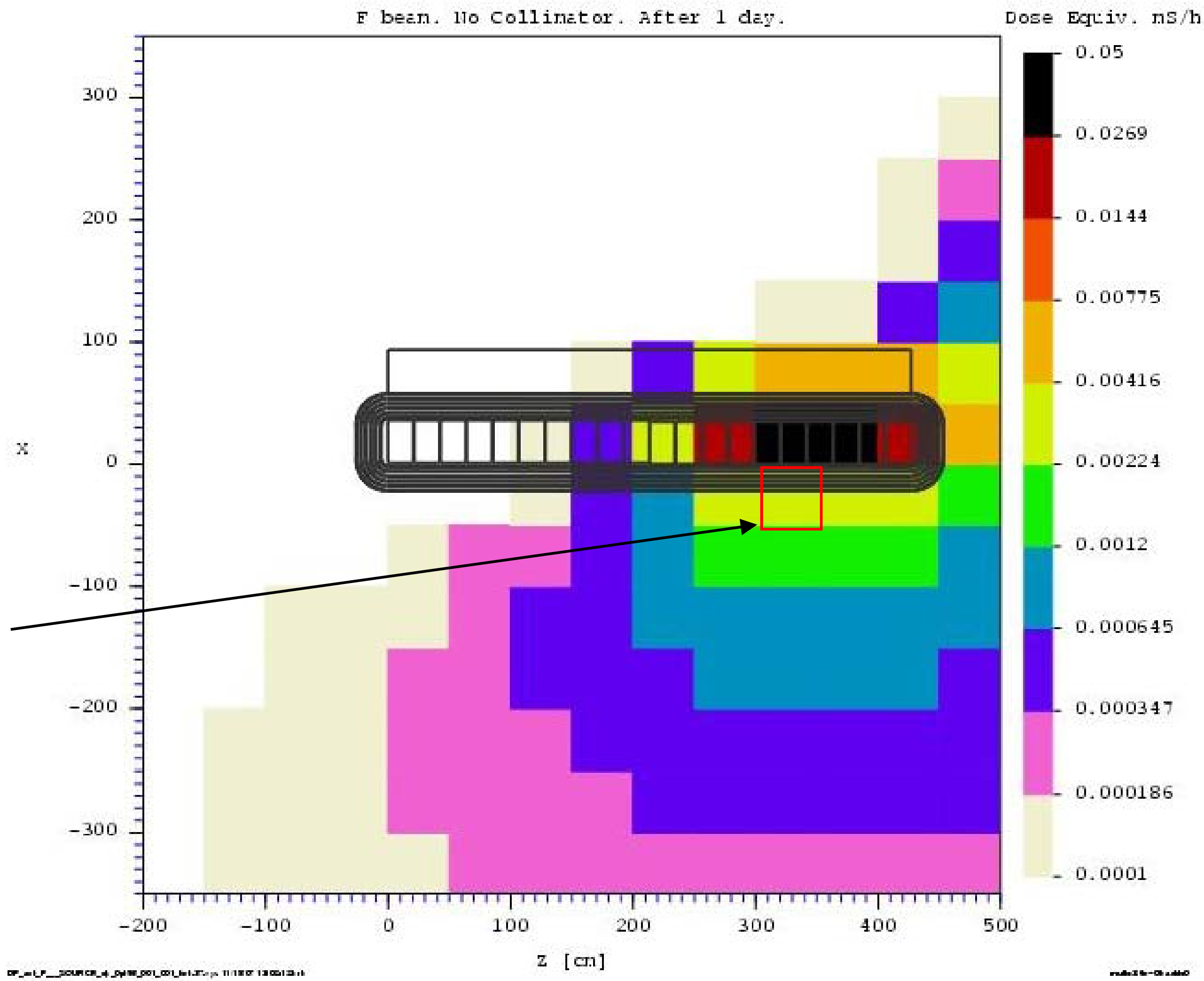
Equivalent dose (mSv/hour) 1 hour after shut down.

Horizontal slice
through middle of geometry
(i.e. beampipe).
Dimensions in cm.
Coils and yoke overlaid
for clarity.



Activation – ^{18}F, no collimator

Equivalent dose 1 day after shut down.



Dose rates for table in the next slide are taken from here!

Residual dose rates

Reduction of equivalent dose rate over time for ^{18}F-beam on D-magnet and beampipe w/o collimation.

Dose rates in table below are those at the cubic volume:

Z: 300-350cm, X: 0-50cm, Y: 0-50cm

(i.e. towards the back of the magnet where the dose is highest, and close to pipe, in between coils).

	Equivalent dose [μSv/hour] after…			
Collimator	1 hour	1 day	1 week	30 days
None	47.8	4.16	4.16	2.09
Carbon	63.1	6.31		
Lead	91	12.1		

Values are upper level estimates read from the colour scale in the previous dose rate maps and are therefore rough estimates!

Summary

- Physical prompt dose rates and therefore operational lifetimes of the coils in the PS (D-dipole) have been estimated using the FLUKA transport code.
- The functional lifetimes of coil insulation for all cases studied appear to be long enough. Minimum of 60 years with no collimation.
- Residual equivalent dose rates have also been calculated for Ne operation after 5 years of continuous operation. Cooling times required to reach safe radiation levels for maintenance appear to be reasonable.
- Carbon is the most suitable for collimation of the materials considered since it results in the lowest dose rates in the coil insulation and has the least activation.

Outlook

- The lamination in the magnet needs to be investigated, particularly for ^{18}F hitting the right side of the D-magnet, likewise for ^{6}Li hitting left side of F-magnet.
- More realistic shape for the collimators.
- The activation of the water used for cooling magnet and collimators?