High Resolution Mass Separator Dipole Design Studies for SPES Project

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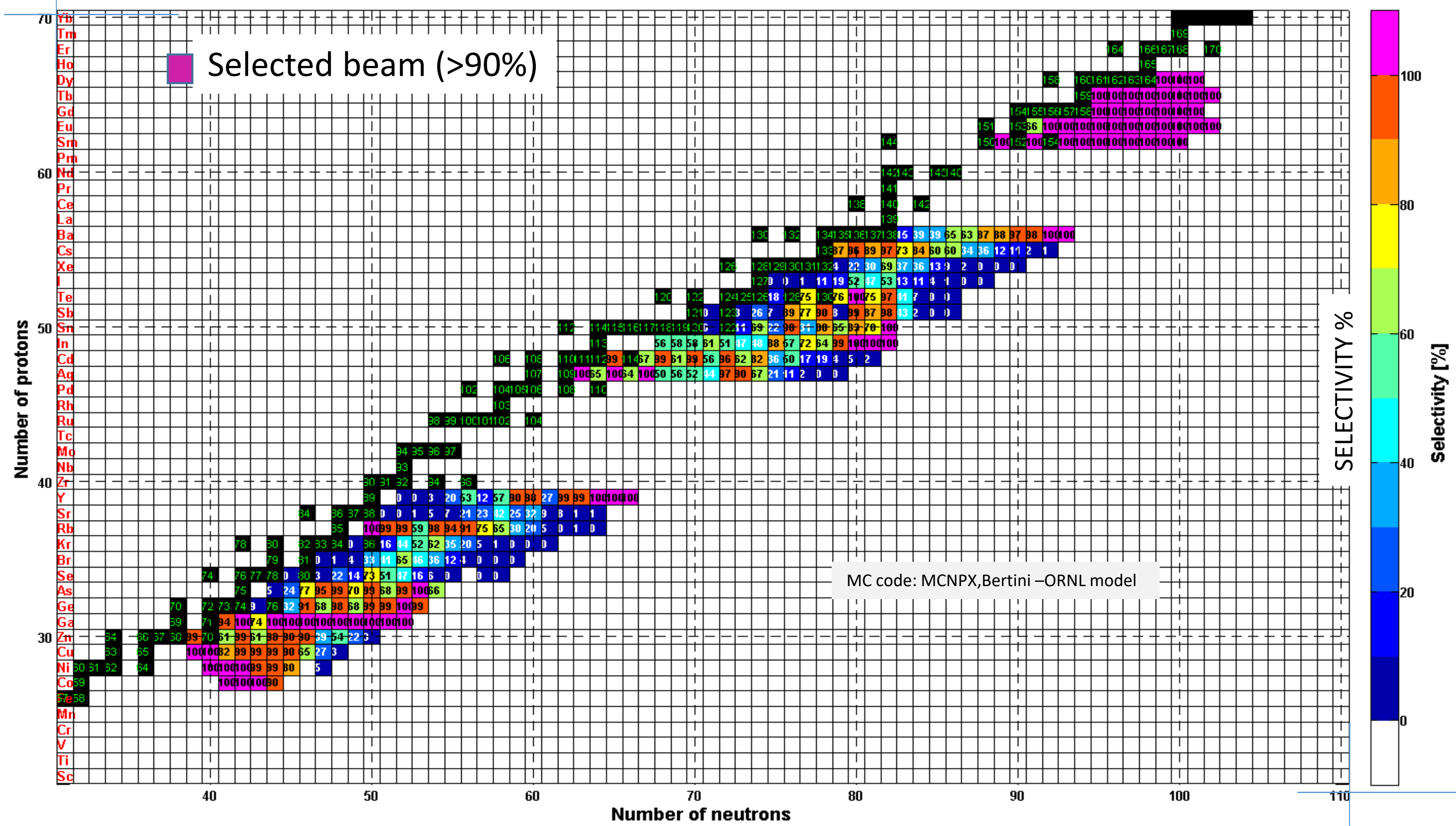
C. Baltador

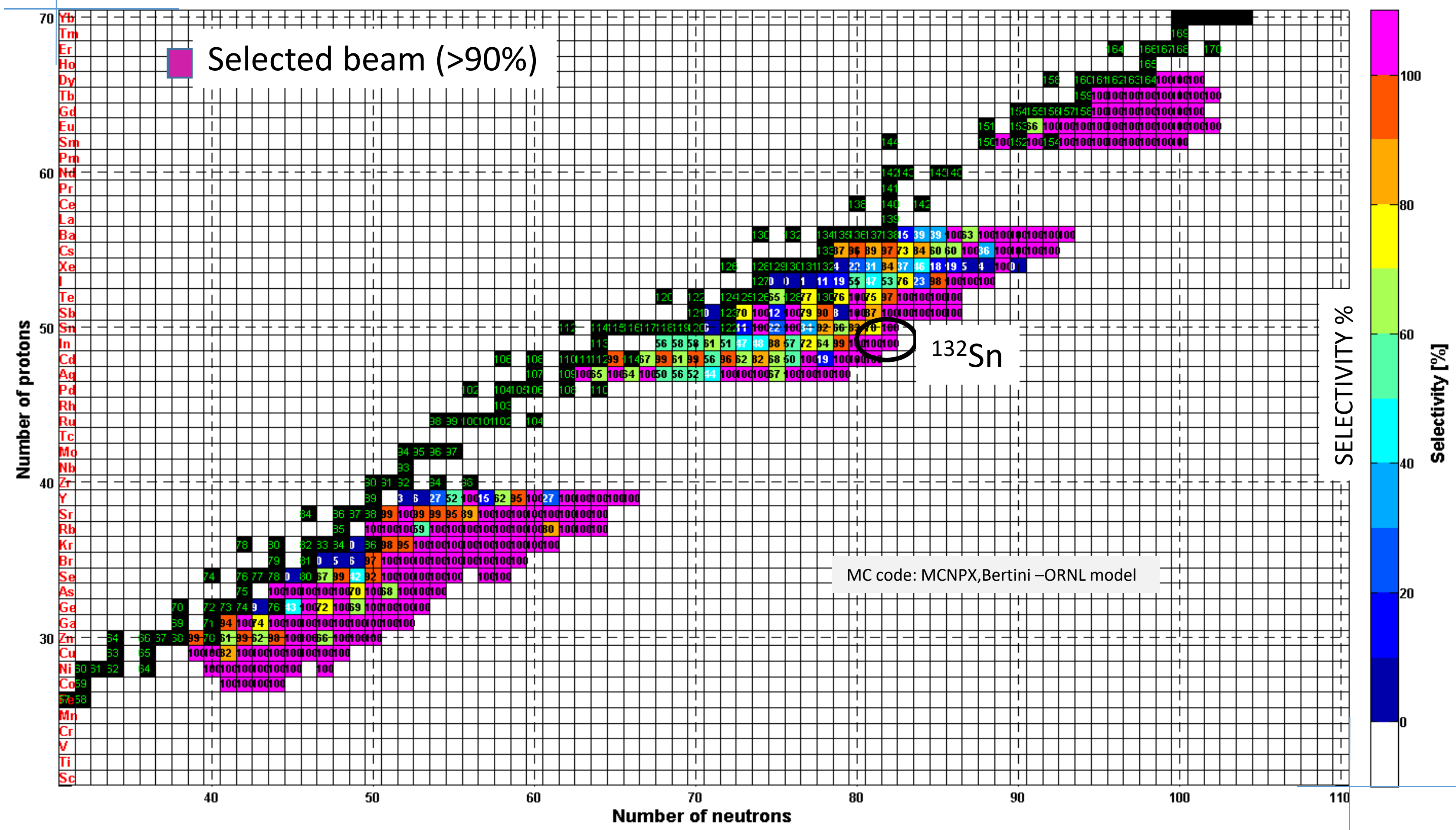
Why HRMS? SPES exotic beams production

Production & re-acceleration of **exotic beams (neutron rich nuclei) @ 1/200 mass purification**

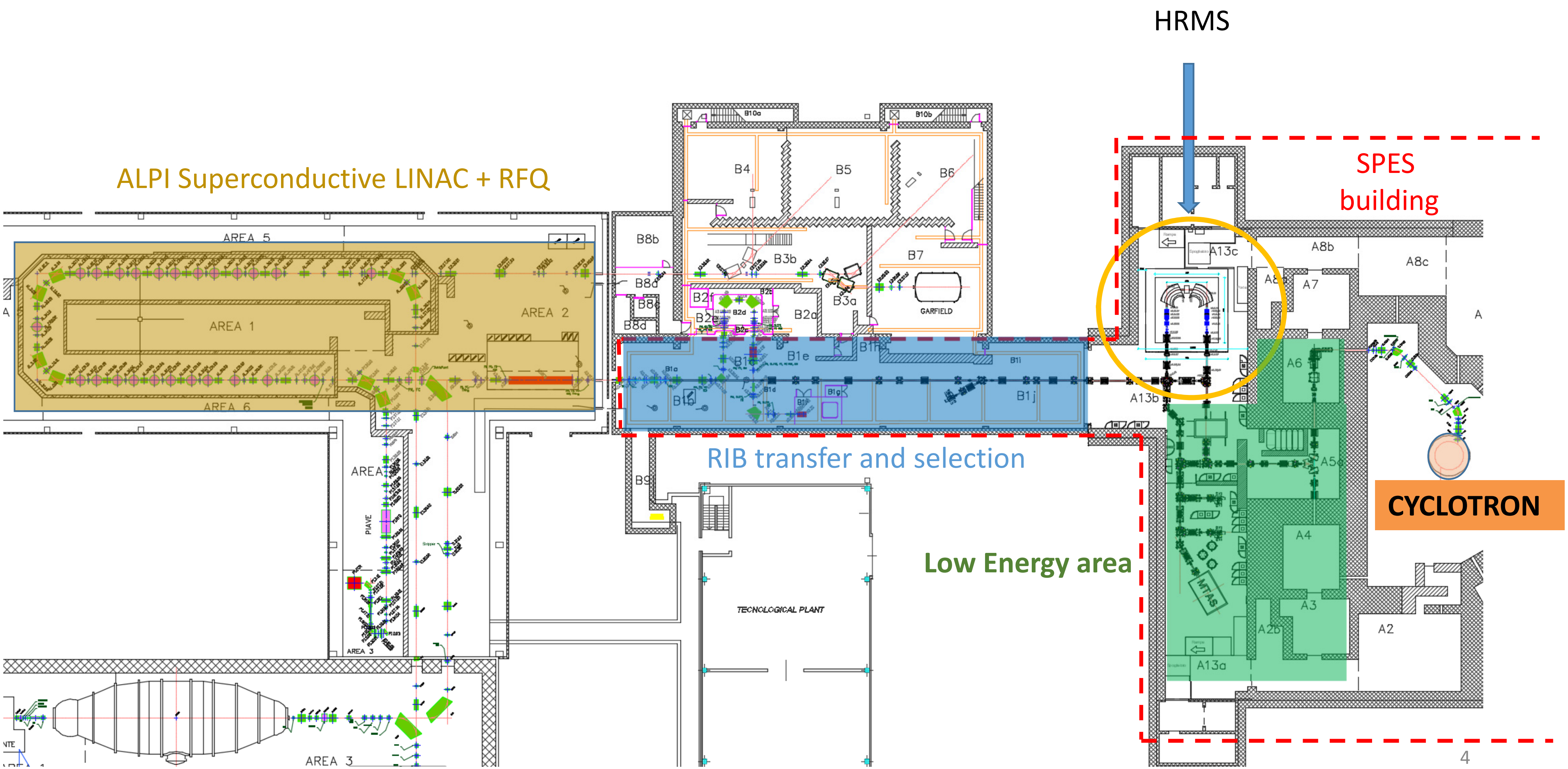


Why HRMS? SPES exotic beams production

Production & re-acceleration of **exotic beams (neutron rich nuclei) @ <u>1/20000 mass purification</u>**



SPES - ALPI Layout



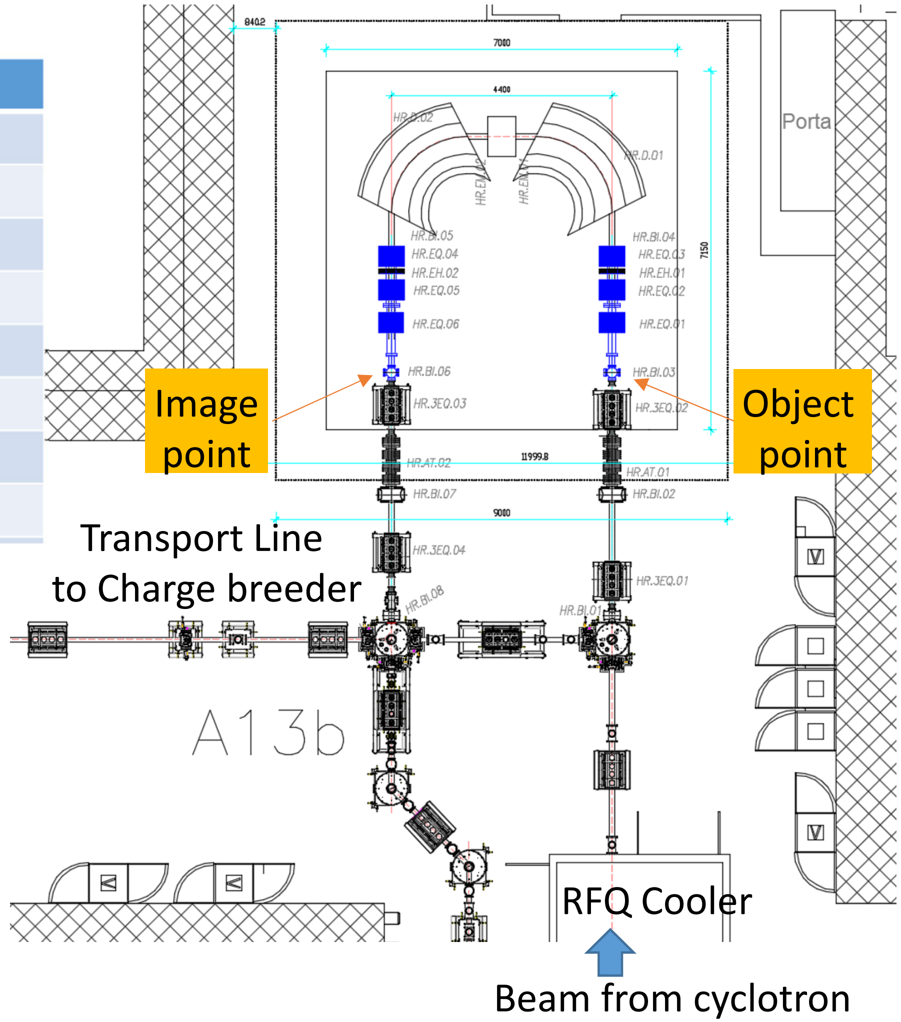
HRMS Layout

Beam parameters

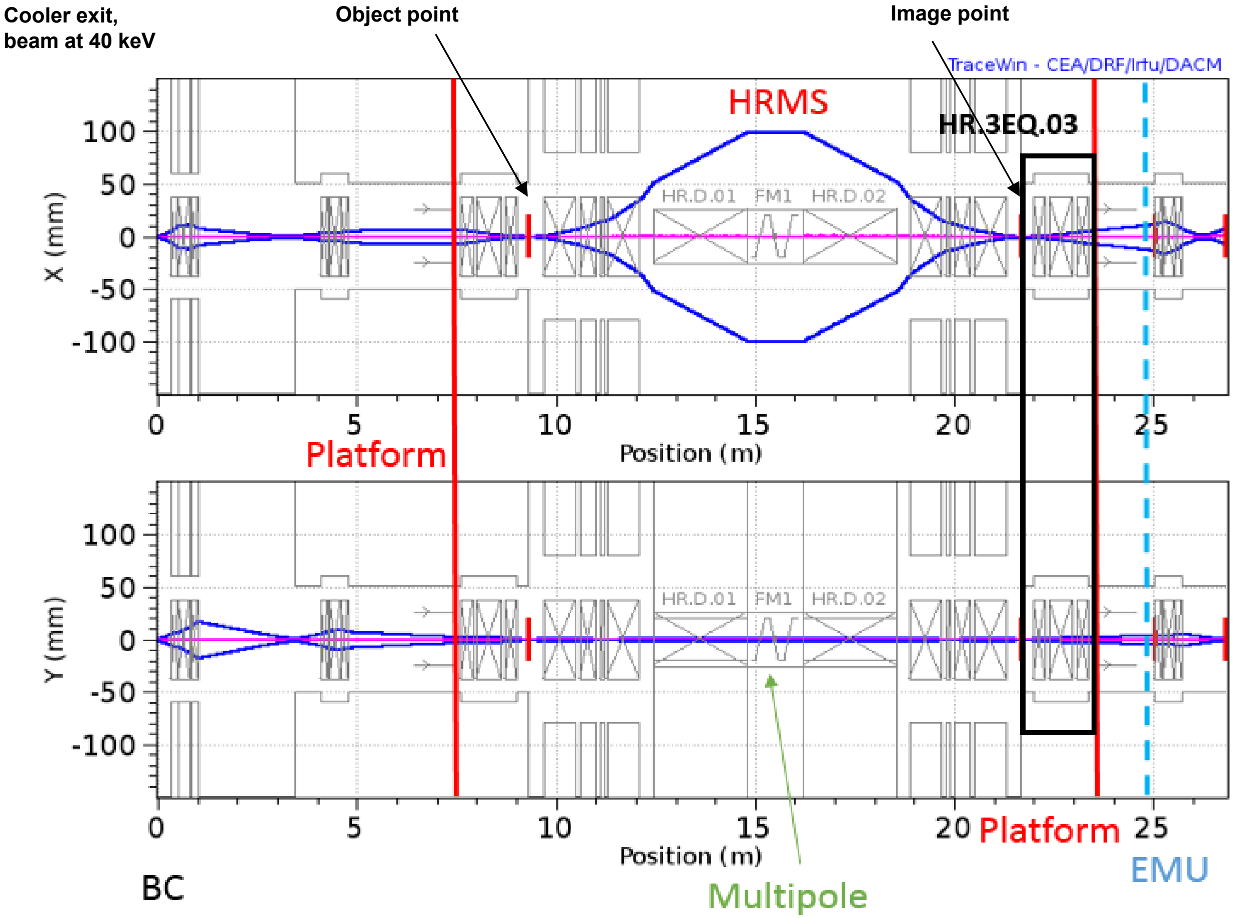
Parameter	Value	unit
Ref. Ion (1+)	132	A
Energy (β)	0.26 (0.00206)	MeV
Bρ (Eρ)	0.843 (0.52)	T*m (MV)
Norm. RMS Emittance	0.0014	mm*mrad
RMS energy Spread	+/- 1	eV
Geom. TOT Emittance	7	mm*mrad (3σ cut Gaussian dist.)
Geom. 90% Emittance	3.2	mm*mrad (3σ cut Gaussian dist.)
RMS spot size at image	0.3	mm

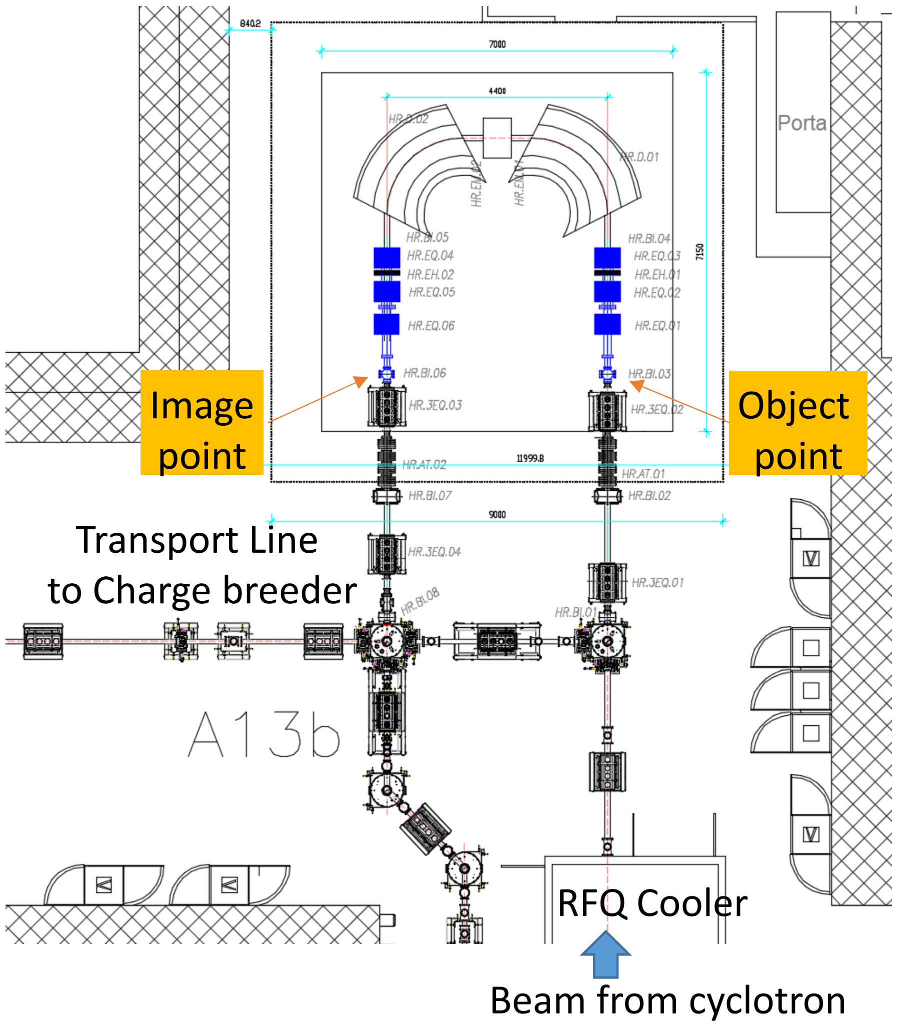
Components specifications

Element	Nom. Value	Units
Triplets	-7 / +6 / -7	kV
Slits (obj-im)	1.1	mm
Quadrupoles 1-6	-9.6	kV
Quadrupoles 2-5	+4	kV
Hexapole	< 1	kV
Quadrupoles 3-4	-6	kV
Dipole	0.5623	T
Multipole	< 1	kV



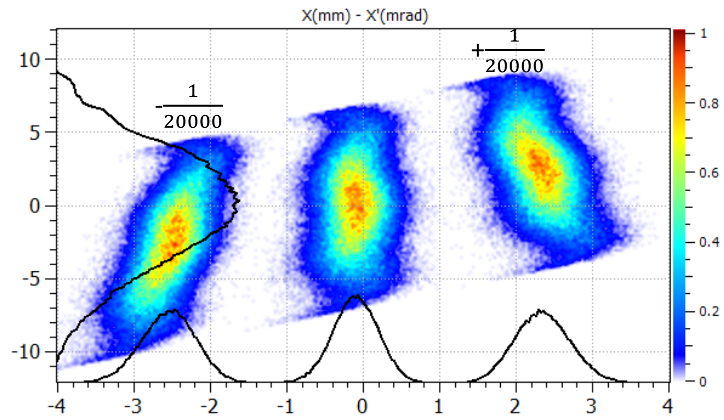
HRMS Layout


Cooler exit,
beam at 40 keV
Object point
Image point
TraceWin - CEA/DRF/Irfu/DACM
HRMS
HR.3EQ.03
HR.D.01
FM1
HR.D.02
X (mm)
Y (mm)
Position (m)
Platform
Platform
EMU
BC
Multipole


Porta
Image point
Object point
Transport Line
to Charge breeder
A13b
RFQ Cooler
Beam from cyclotron

HRMS challenges

Reference beam for beam optics simulations: $^{132}\mathrm{Sn}$ @ 260 keV
(40 kV from source extraction + 220 kV HV platform)



Objectives

- Effective mass separation of 1/20000 to reduce isobar contaminants
- Distribution peaks of the separated in beams dist > 1 mm at image point

Issues (sources of resolutive power degradation)

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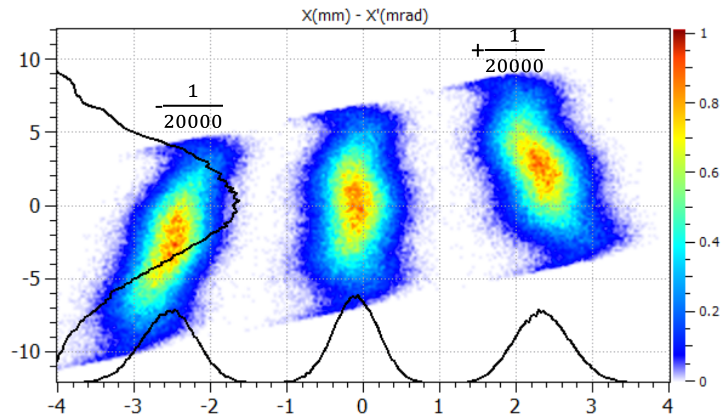

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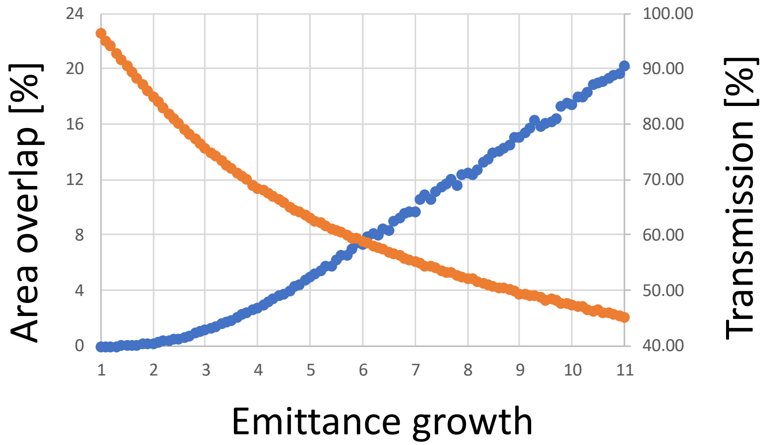
Emittance $$\frac{dm}{m} = \frac{2\varepsilon_{geom}}{D\, x'}$$



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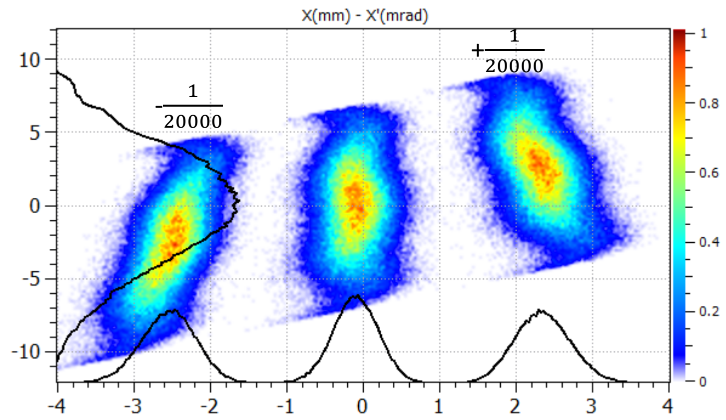

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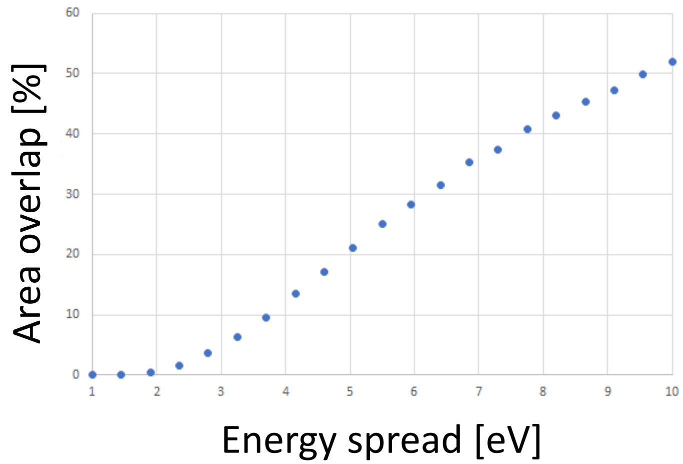
- $\varepsilon_{geom} = 3.2\ mm\ mrad$

Energy spread: $2\frac{dp}{p} = \frac{dm}{m} + \frac{dE}{E}$



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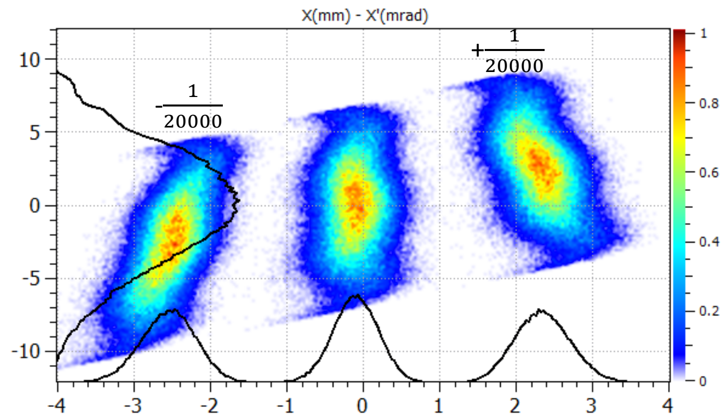
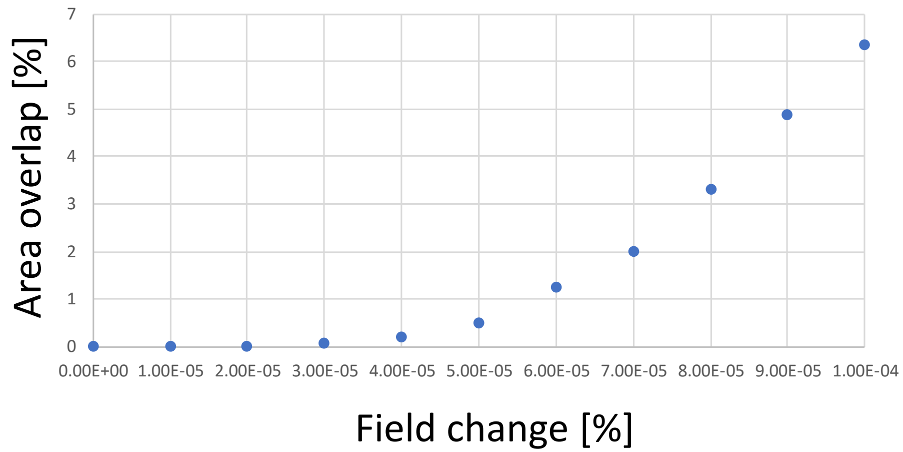


Issues (sources of resolutive power degradation)

- $\varepsilon_{geom} = 3.2\ mm\ mrad$
- $\frac{dE}{E} = \pm 1\ eV\ @\ 260\ keV$

Field homogineity $\frac{dB}{B} = \frac{1}{2}\frac{dm}{m}$



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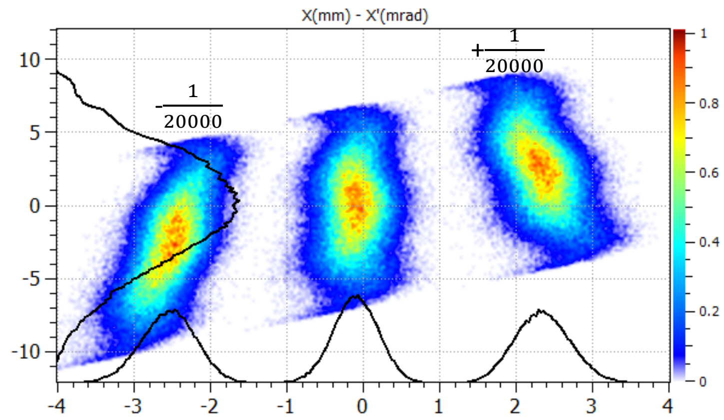

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- $\frac{dB}{B} = \pm 5\ 10^{-5}$ within beam occupancy

RFQ cooler + HV platform

Dipole mechanical design

HRMS challenges

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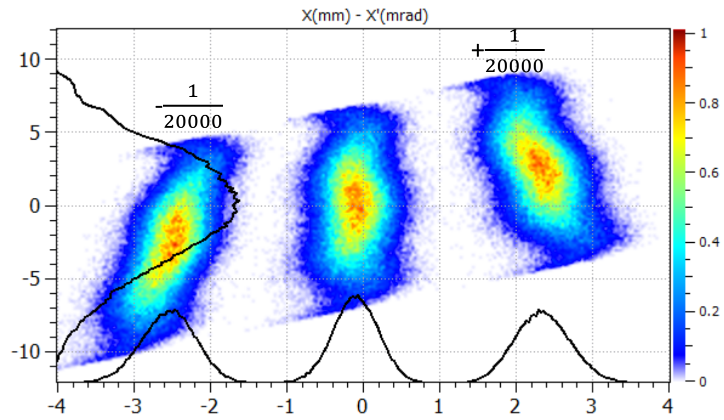

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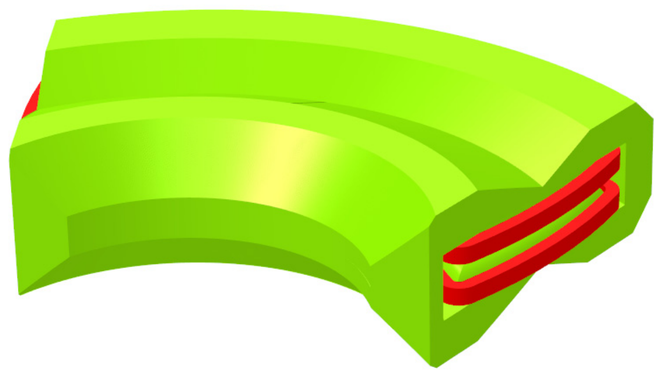
Dipole mechanical design

High field homogeneity dipole design

Dipole parameters (^{132}Sn optics)	Value	Units
Nominal Magnetic Field	0.562	T
Bending angle (ϕ)	90	deg
Curvature radius (ρ)	1500	mm
Bρ (@260 keV)	0.8434	Tm
Entrance&Exit edges angle (α)	27.16	deg
Edge Hexapole radius ($r_{hexapole}$)	2220	mm
Vertical Gap (wrt optical axis)	± 30	mm
Pole length (wrt optical axis)	± 430	mm



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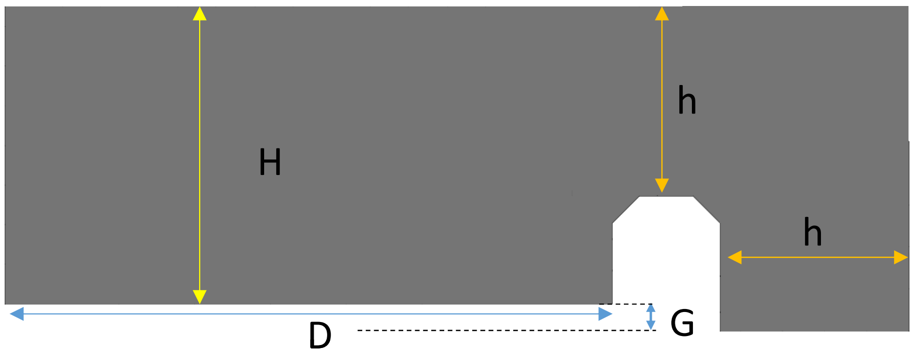
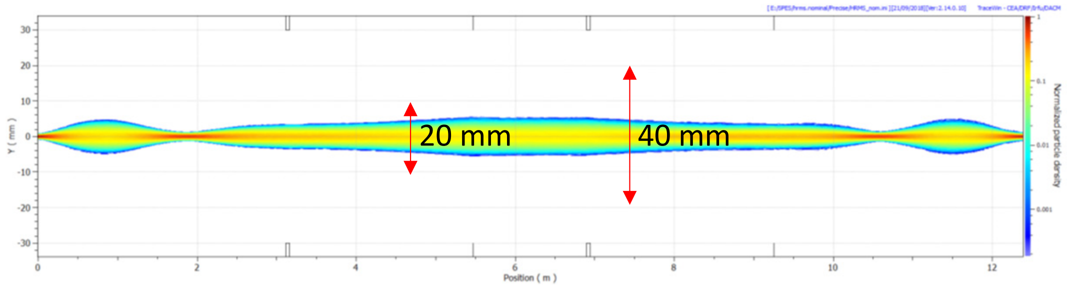
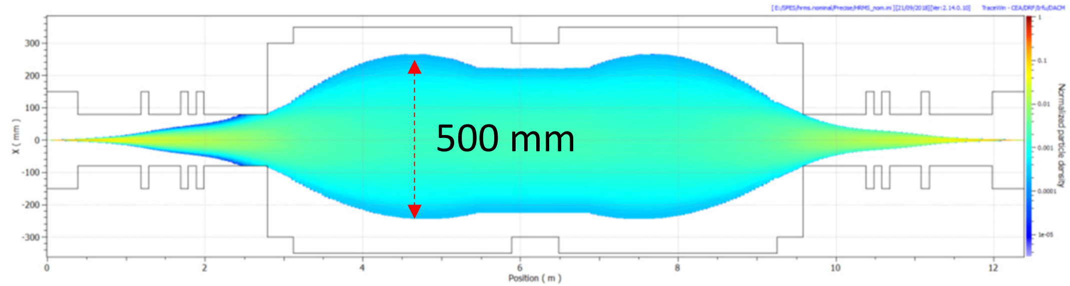


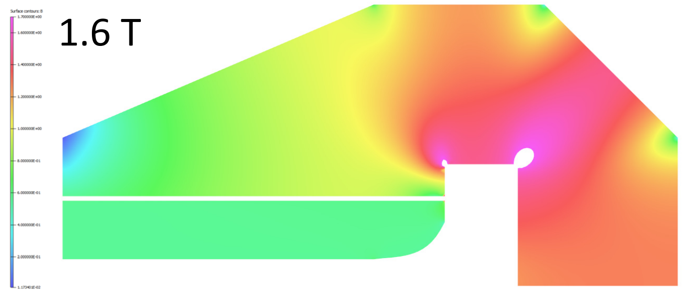
Dipole gap: vertical beam extension



Pole length: horizontal beam extension



Return yoke: coil size + iron magnetization



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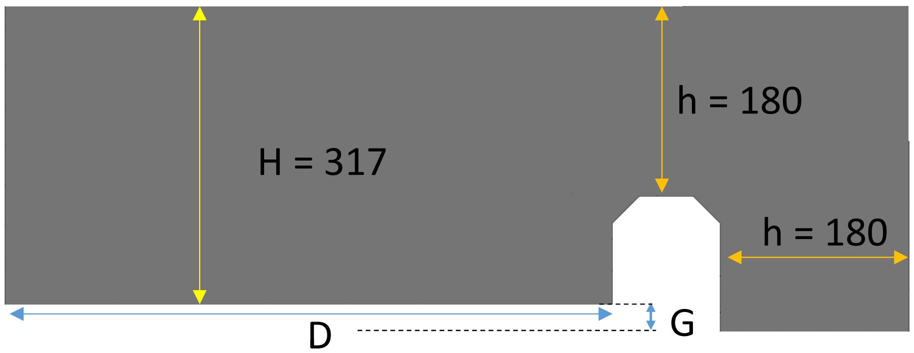
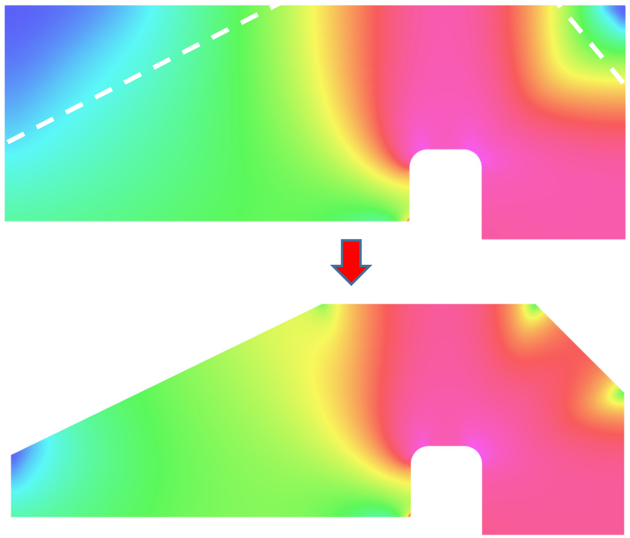


Weigth optimization:

HRMS will be installed on a HV platform: dipole weigth < 15 Tons

The constraint on the magnetization level of the iron goes against this constraint. The idea was to cut the iron where magnetization level is poor.



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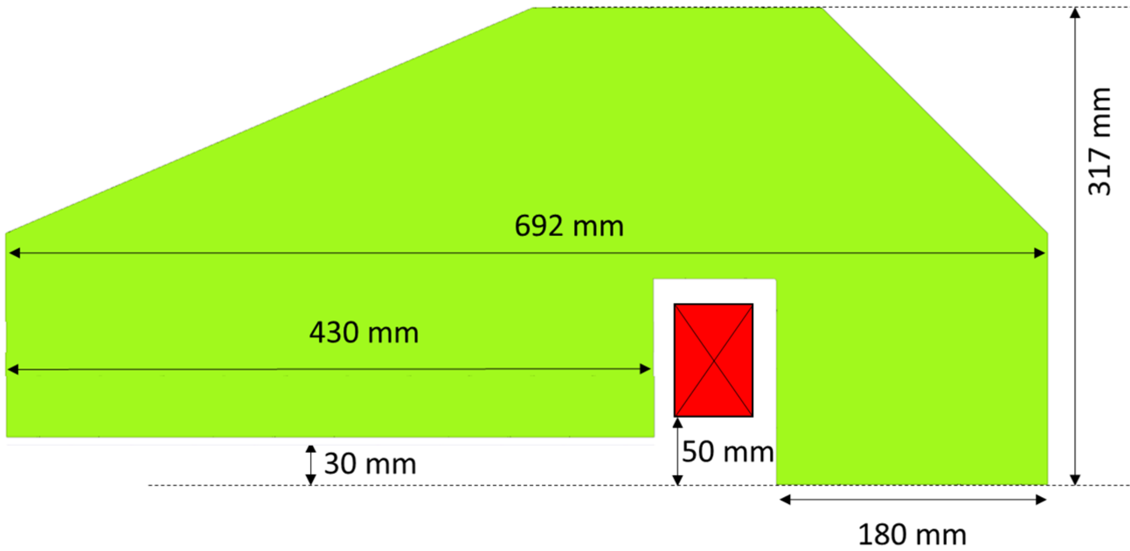
Cross section view



Iron yoke weight (single dipole)

V = 1,51 m^3 -> P = 12.0 Tons

Power Supply (single dipole)

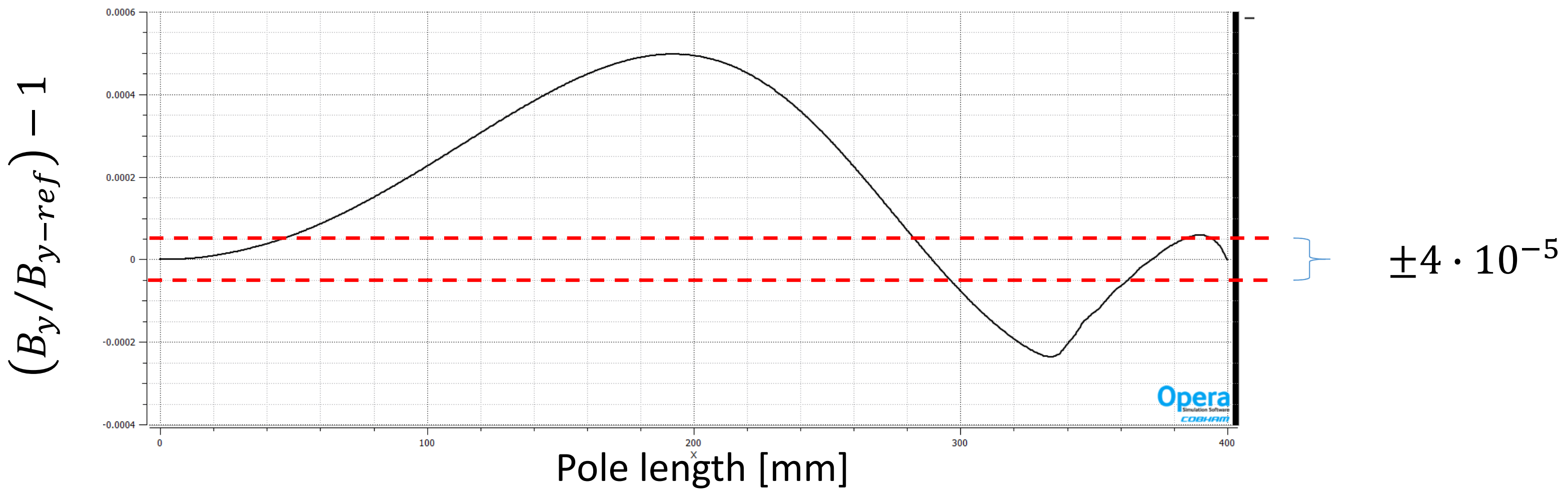
Power: 28 kW

Field homogeneity optimization

Procedure:

- Optimization of field homogineity in the transversal direction by 2D simulations
- Transposition to third dimension of the optimized 2D design
- New optimization both in transversal and longitudinal direction by considering 3D asimmetry

The observable: field flatness, defined as $(B_y/B_{y-ref}) - 1$, which has to be zeo within the target range 4 10^{-5}.



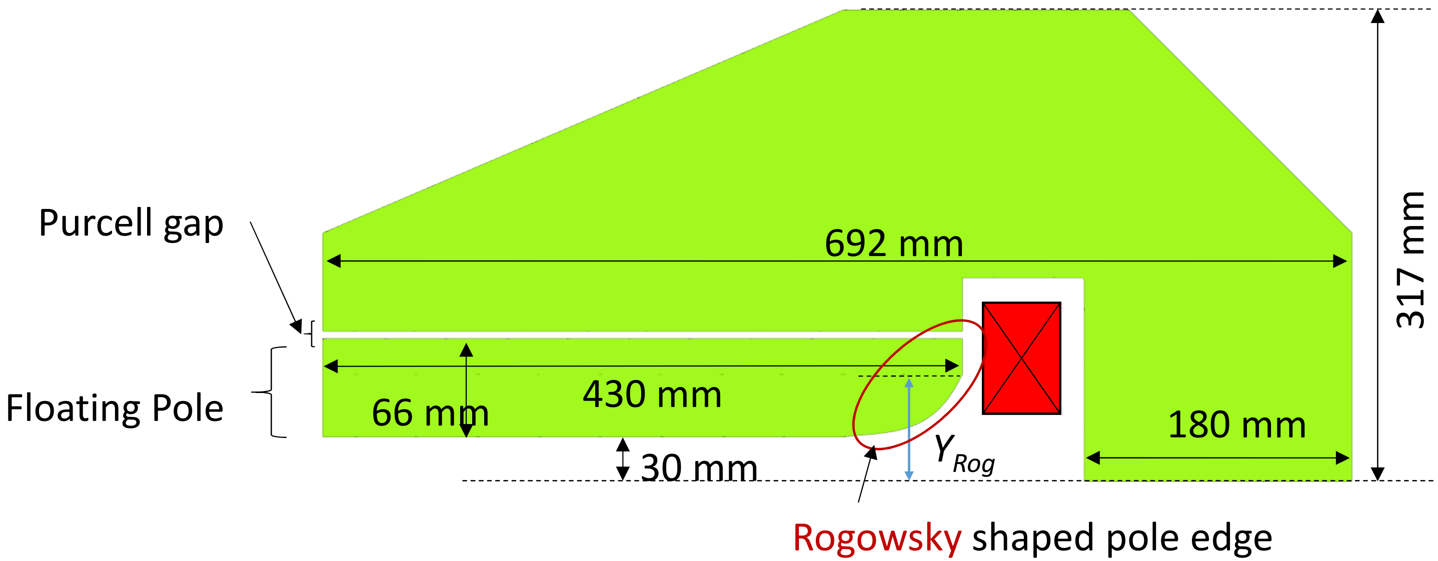
2D optimization: Purcell cell + Rogowsky edge

Purcell cell: pole magnetically detached from the yoke. This lead to the floating pole design

Purcell geometry

thickness: 5 mm

vertical position: 96 mm



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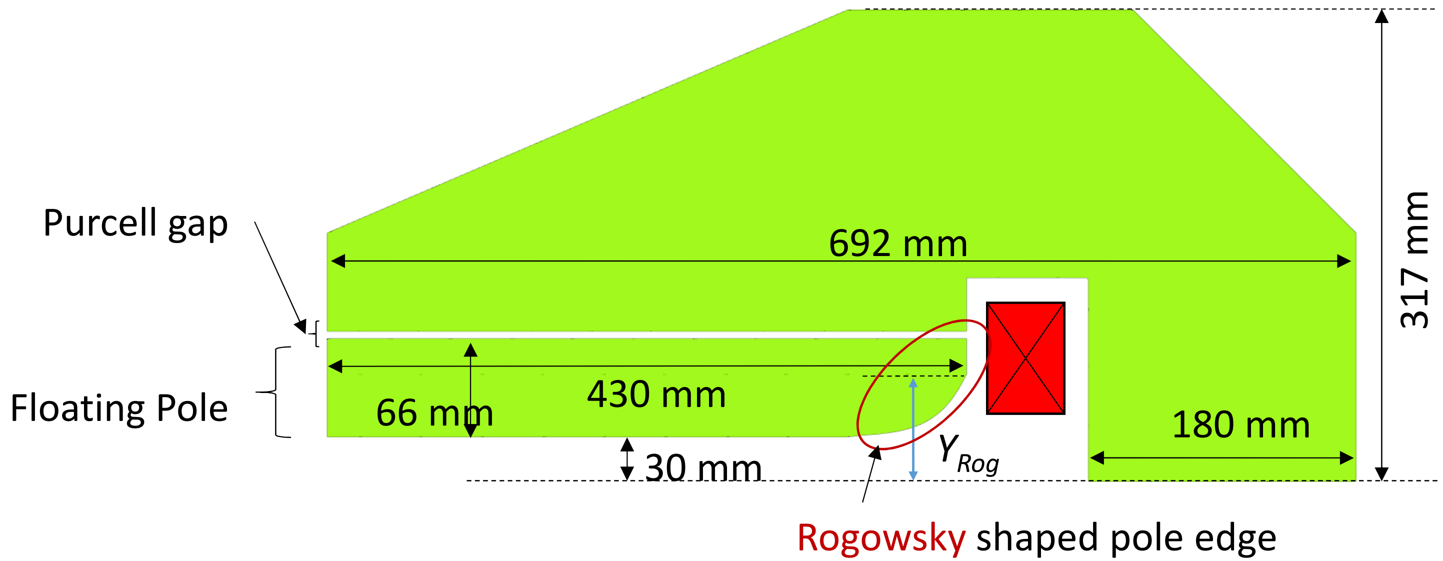
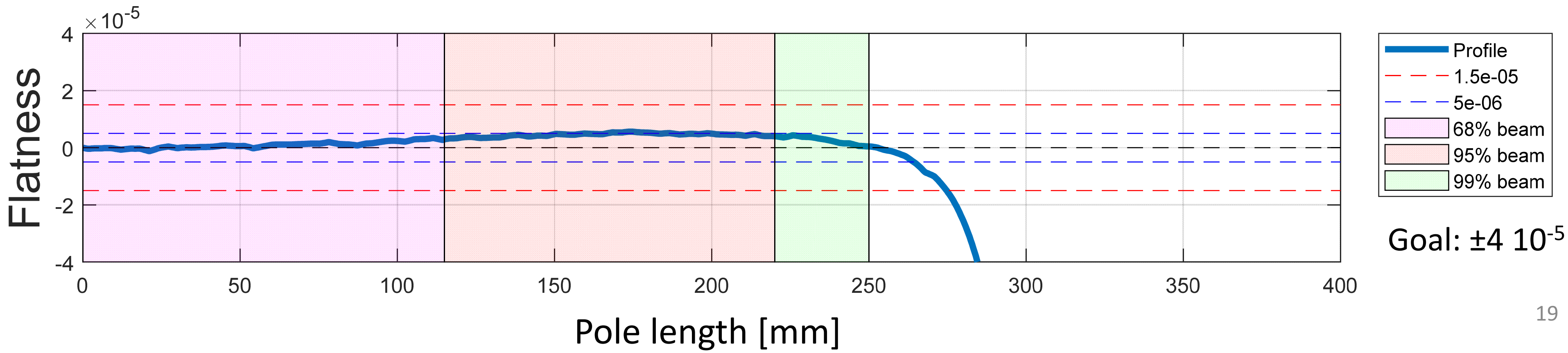
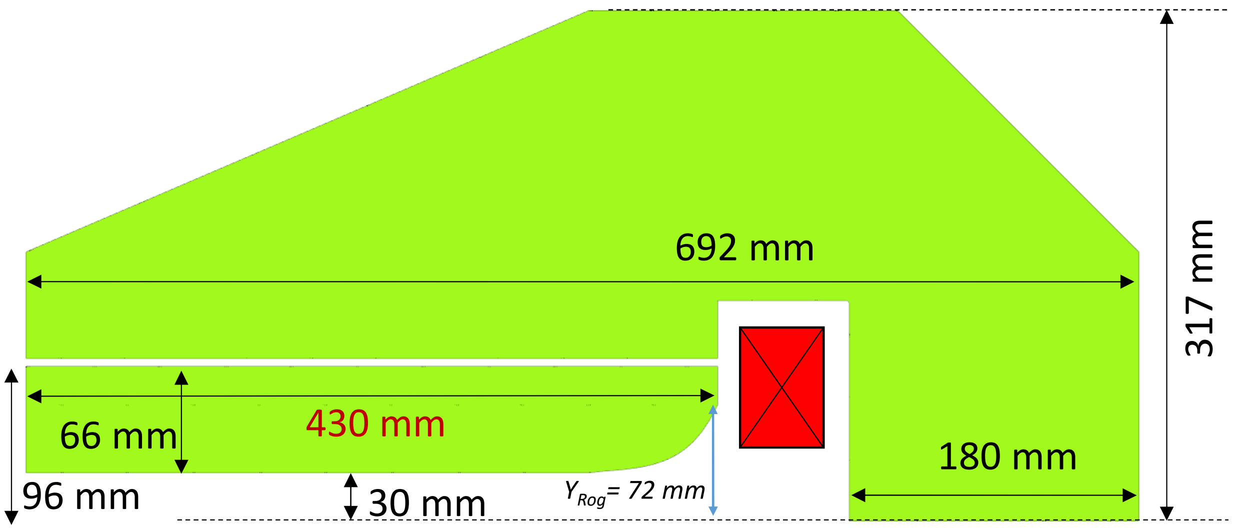


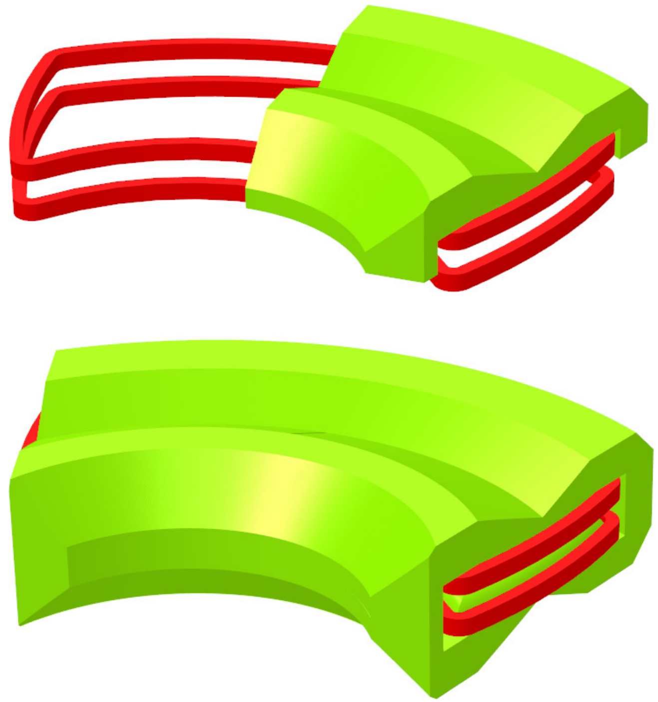


Goal: $\pm 4\ 10^{-5}$

3D design v0

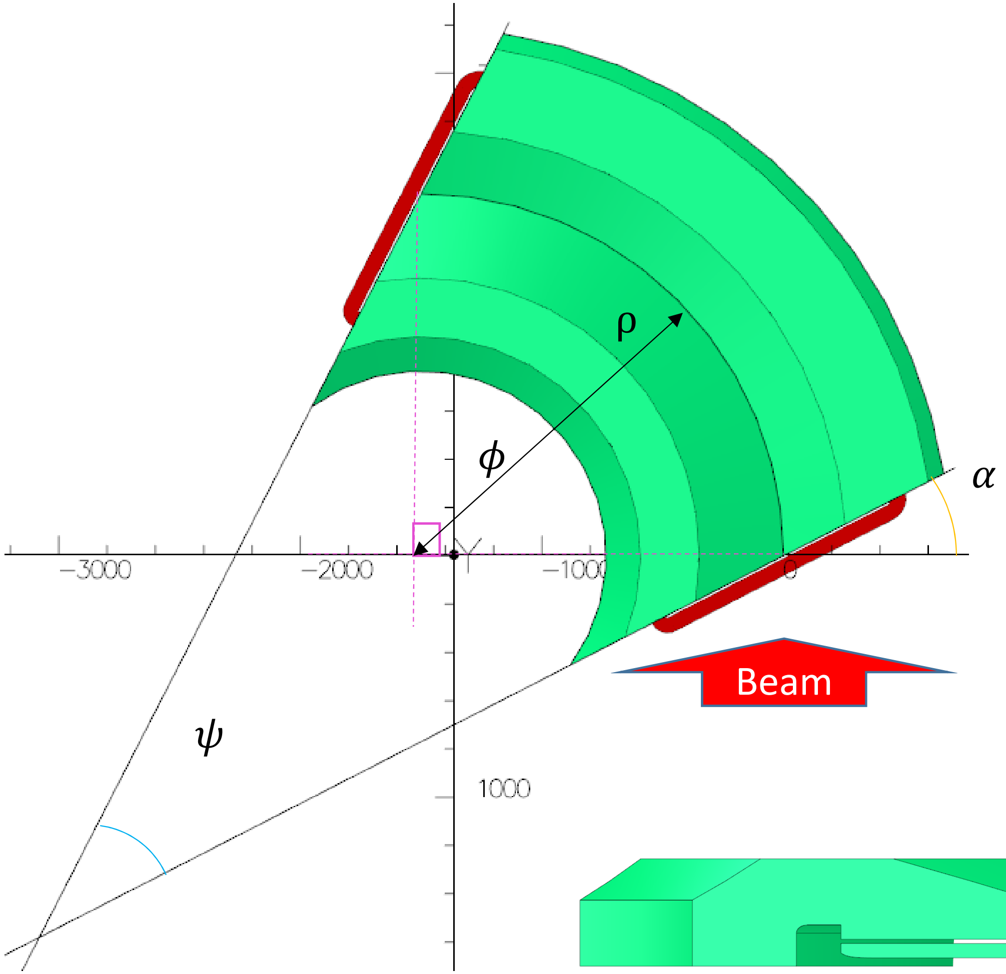
3D transposition of the optimized 2D model





3D model

Estrusion from 2D to a 3D, by 90° rotation and curvature radius of 1500 mm



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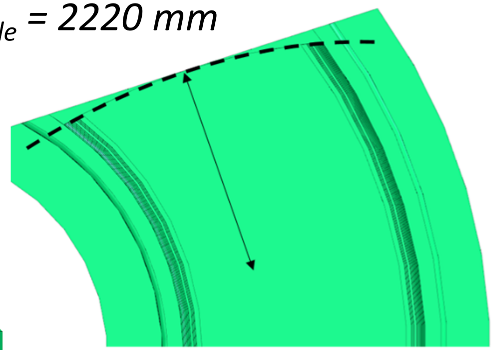
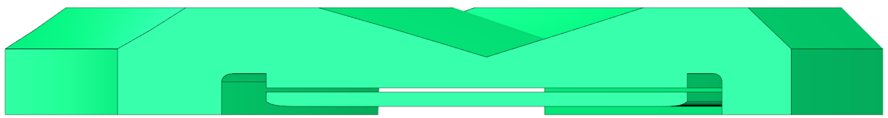
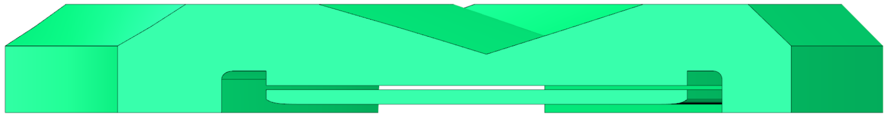
$r_{Hexapole}$ = 2220 mm



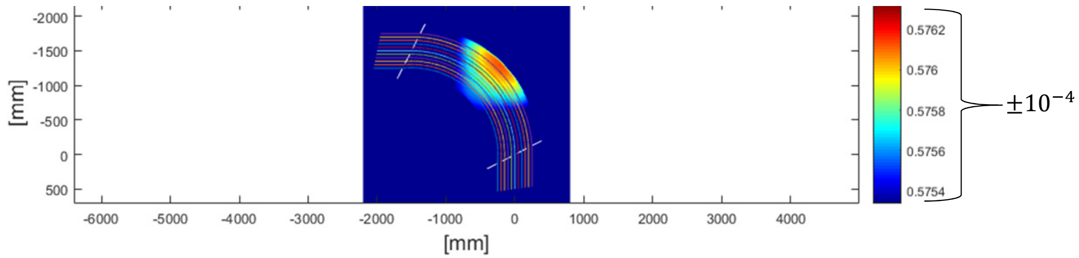


3D design optimization

Simple extrusion



No Rogowsky edge shaped at entrance and exit faces



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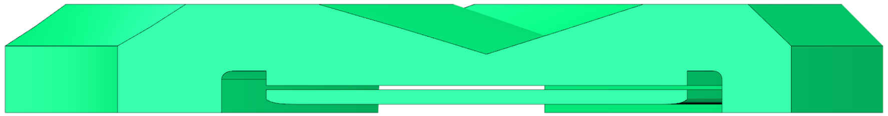

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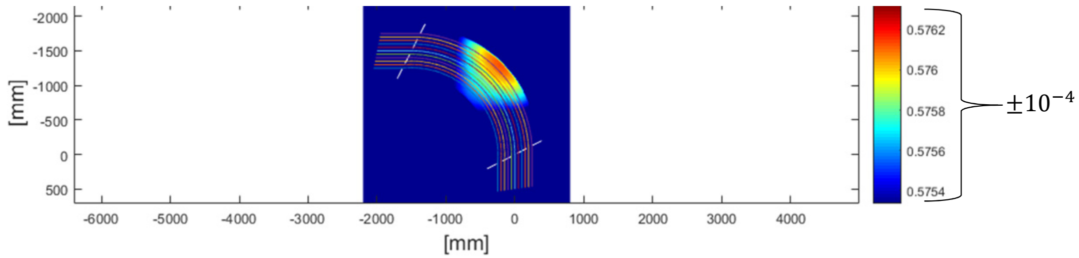
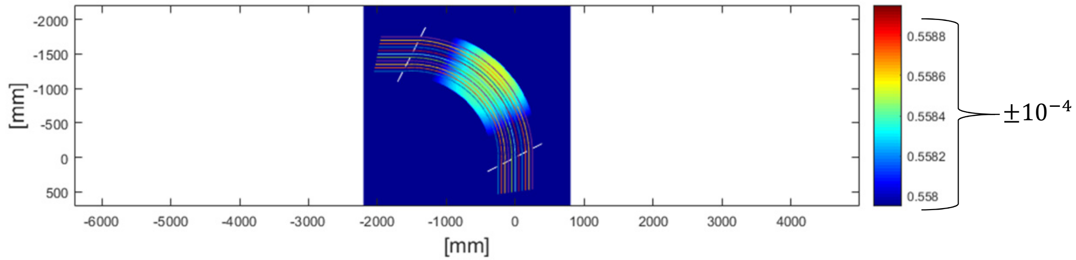


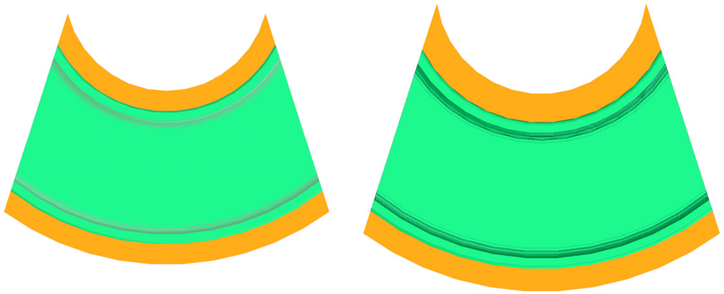
Balance of the magnetic flux in the return yoke

The intrinsic asymmetry of a bended dipole results in asymmetric magnetic fluxes between the internal end the external return yoke.

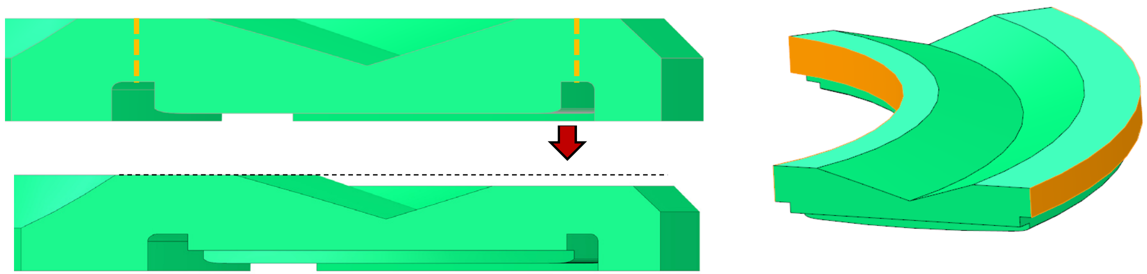


Flux equalization is achieved by equalizing the return yoke surface areas both in the horizontal and in the vertical plane where the return yoke is connected to the central pole.

Horizontal plane



Vertical plane



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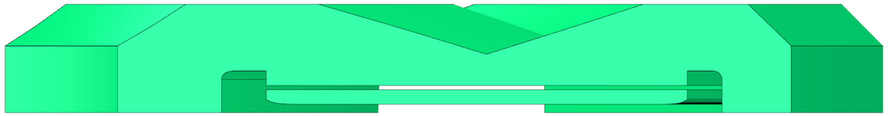

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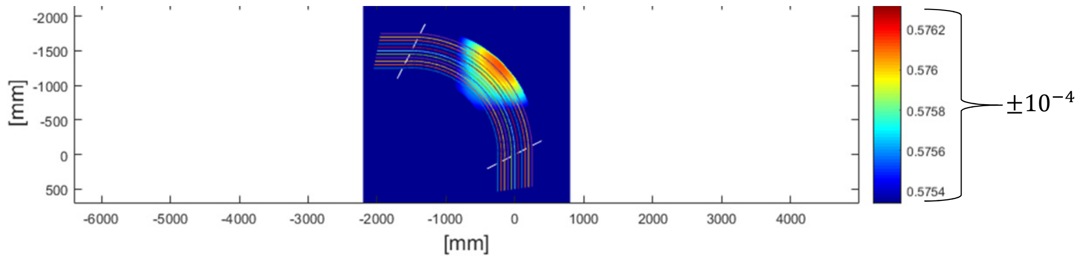

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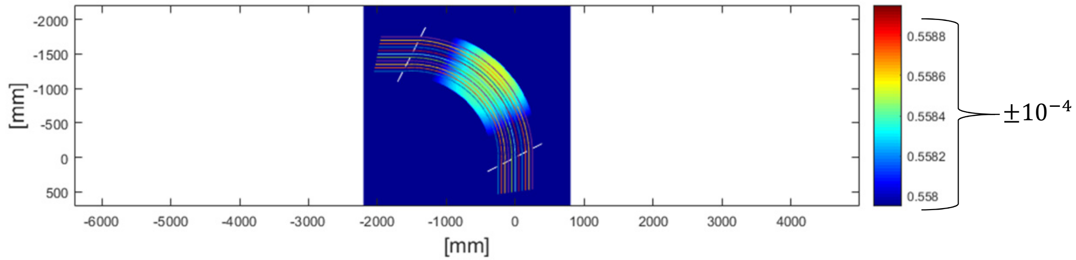
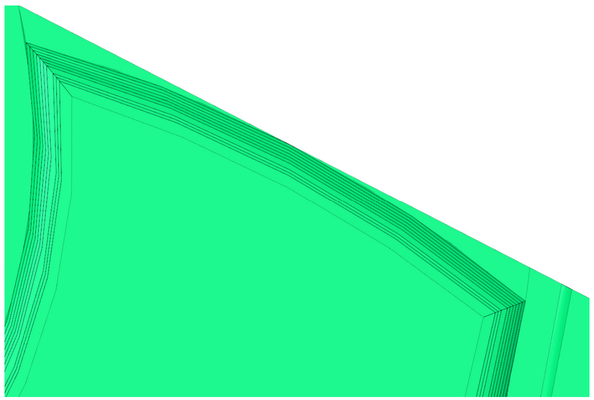
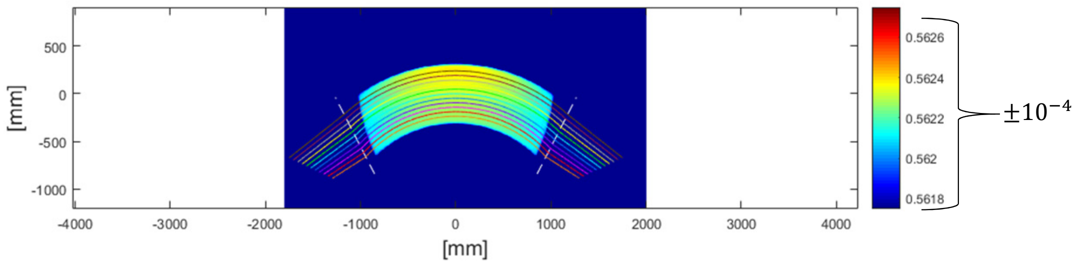


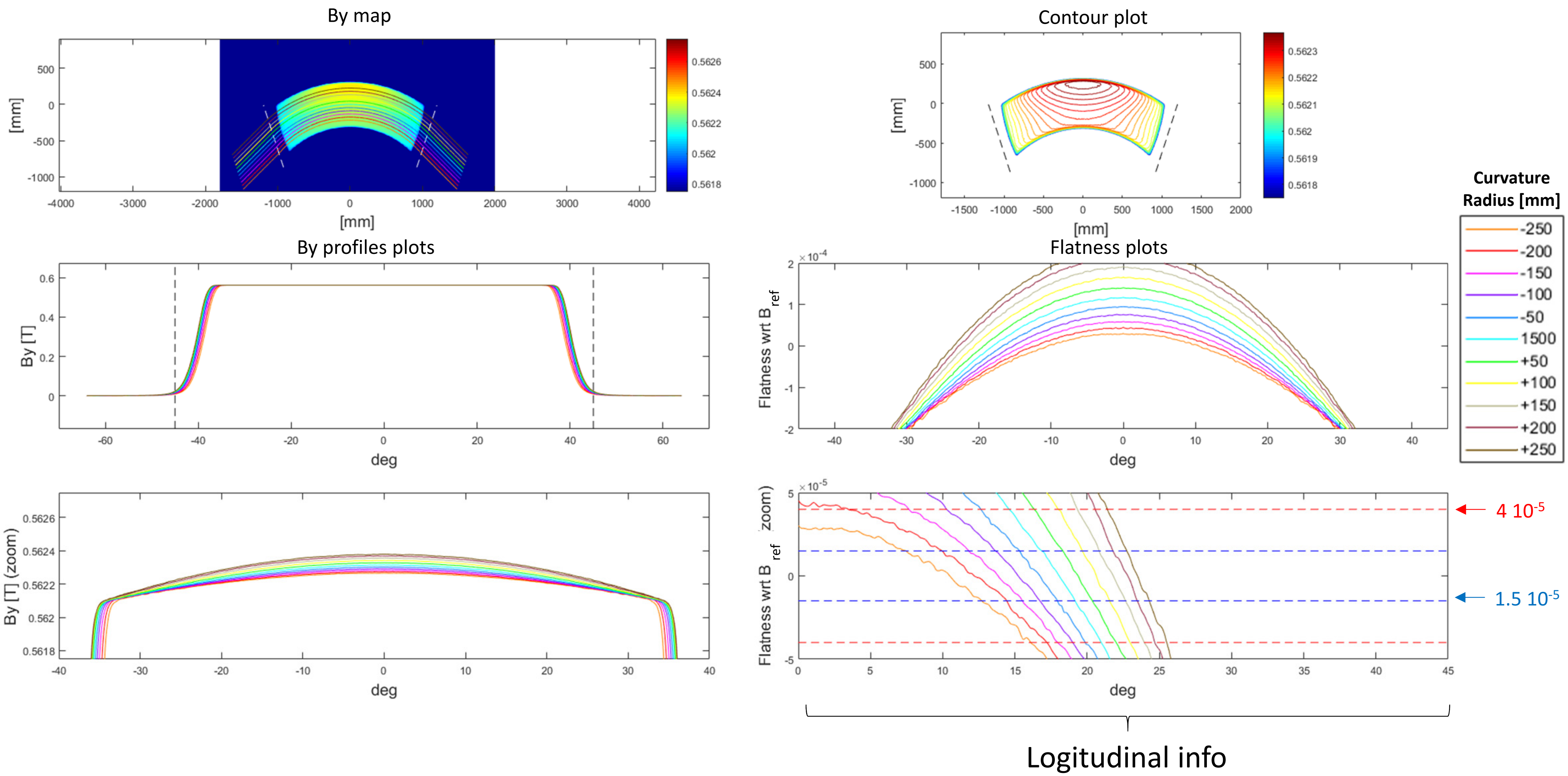
Rogowsky shaped edge at entrance and exit faces



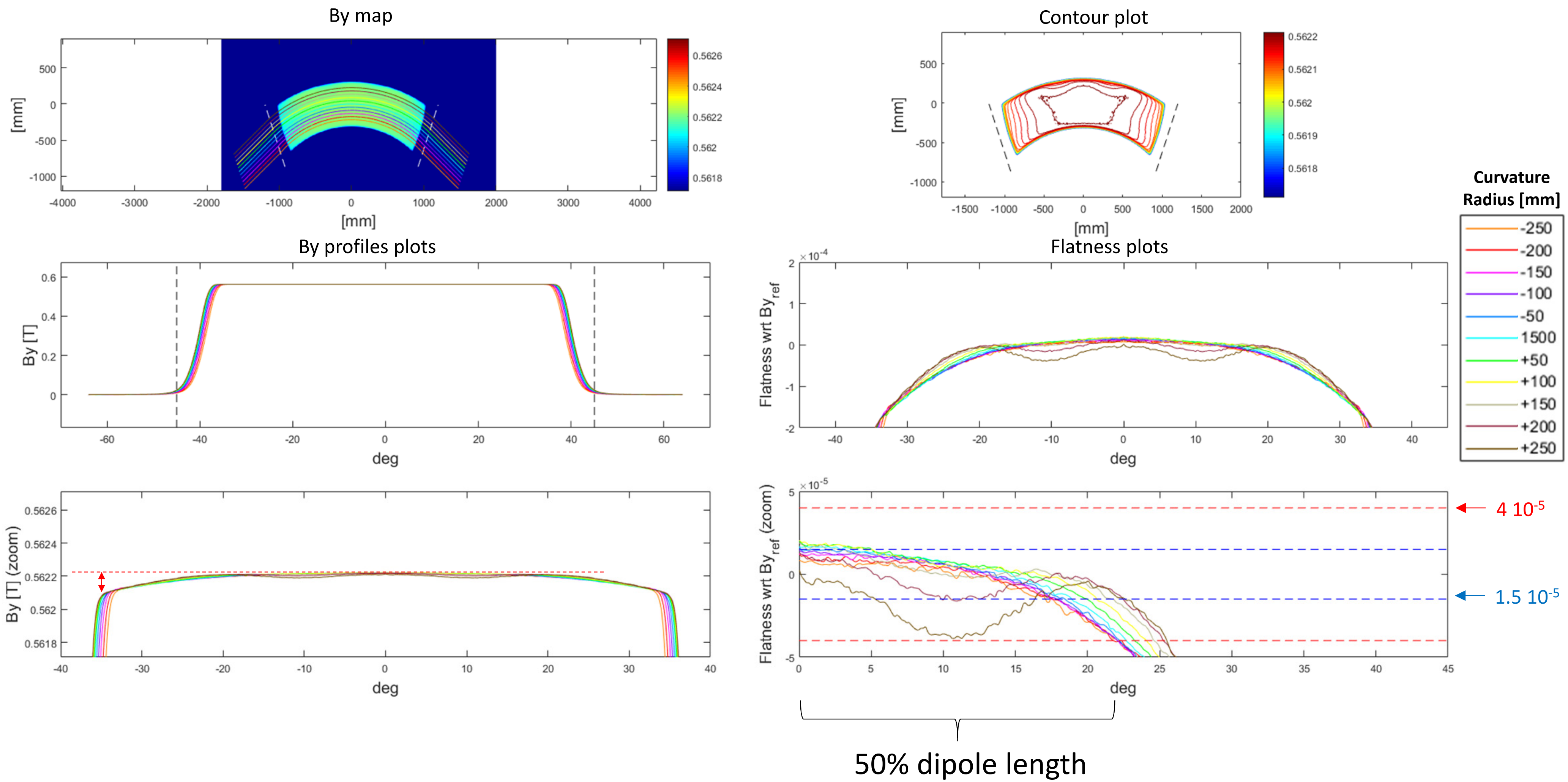


Strong Enhancement of the field homogineity when Rogowsky edge shaping is extended to the entrance and exit faces.

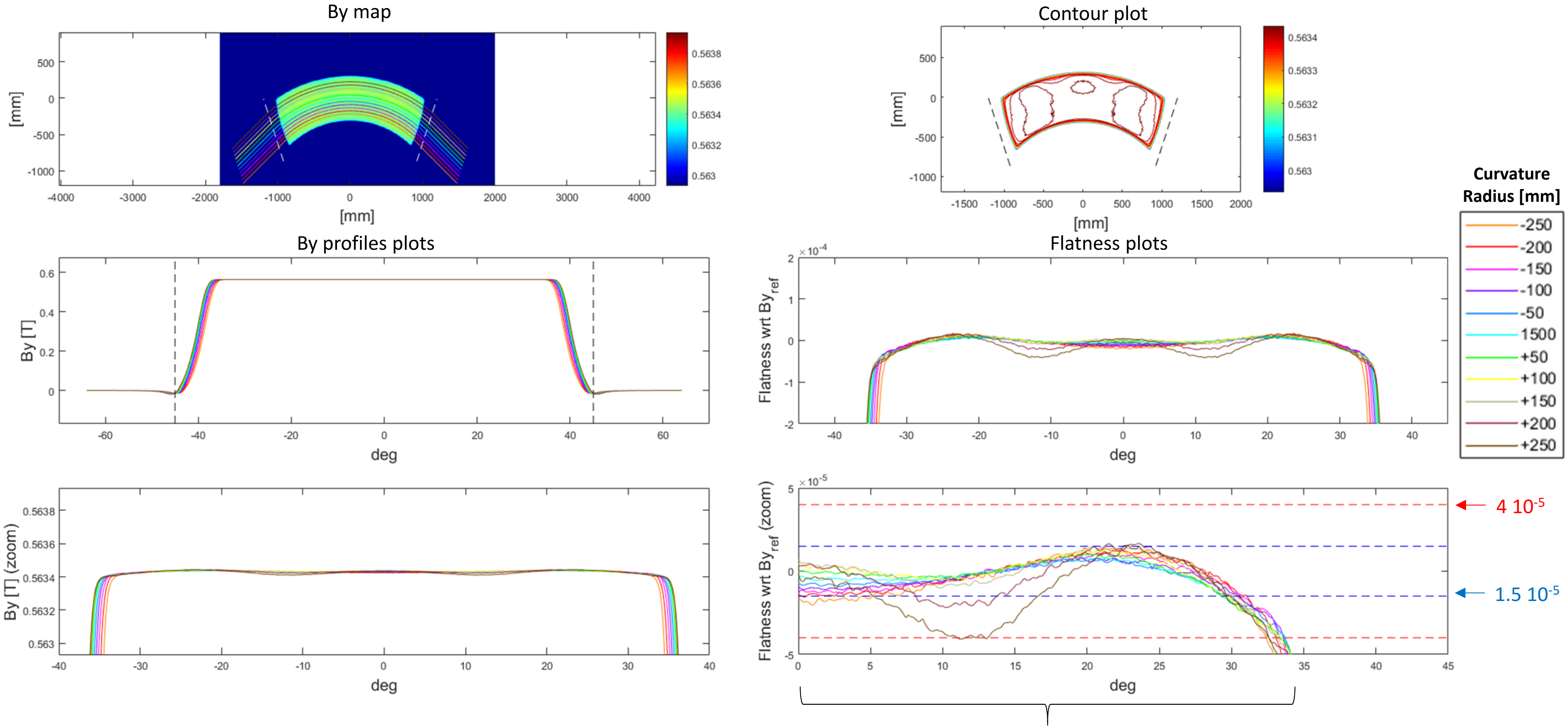
3D design optimization v0



3D design optimization v1: pole "elbow" cut



3D design optimization v2: field reinforcements



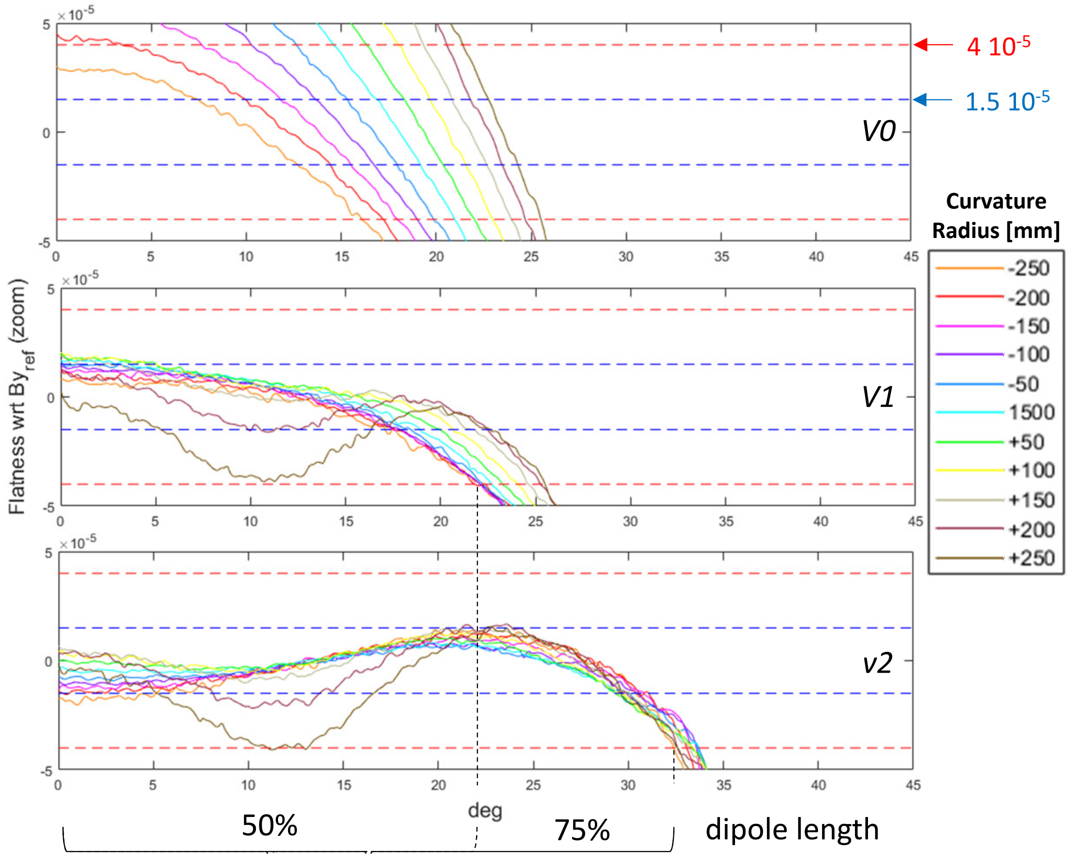
75% dipole length

3D design: flatness optimization summary

v0

v1

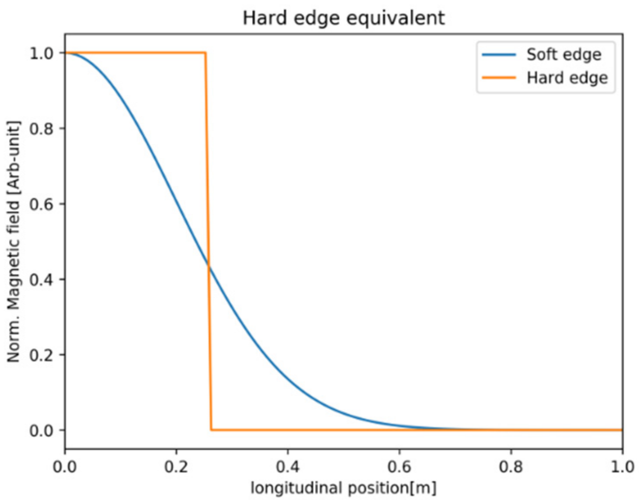
v2



Elbow cut

Edge reinforcements

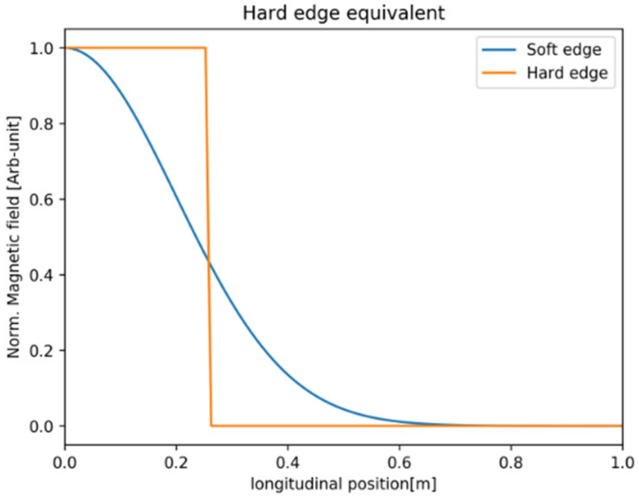
Fringe Field effect



$$L_{eff} = \frac{\int_{-\infty}^{\infty} B_y(s)ds}{B_y(0)} \qquad \left(L_{equ\_hard} = \frac{\pi}{2}\rho = 2356\ mm\right)$$

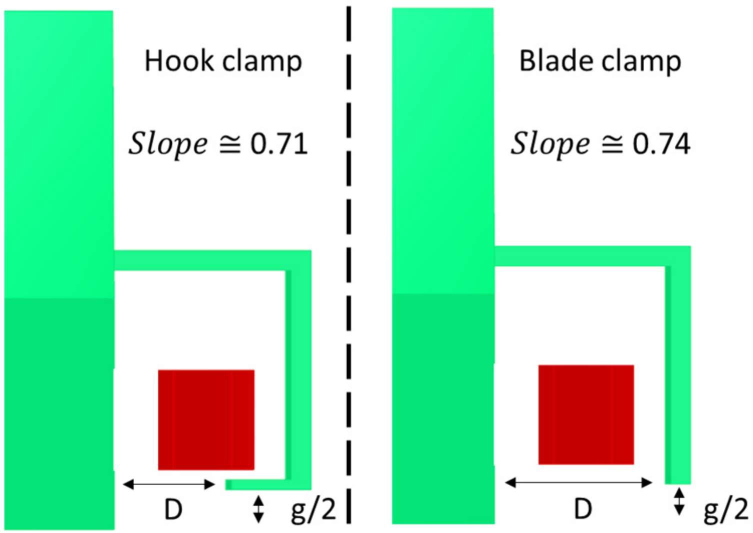
$$Slope = \frac{\int_{-\infty}^{\infty} B_y(s)\left(B_y(0) - B_y(s)\right)ds}{gB_y(0)^2}$$

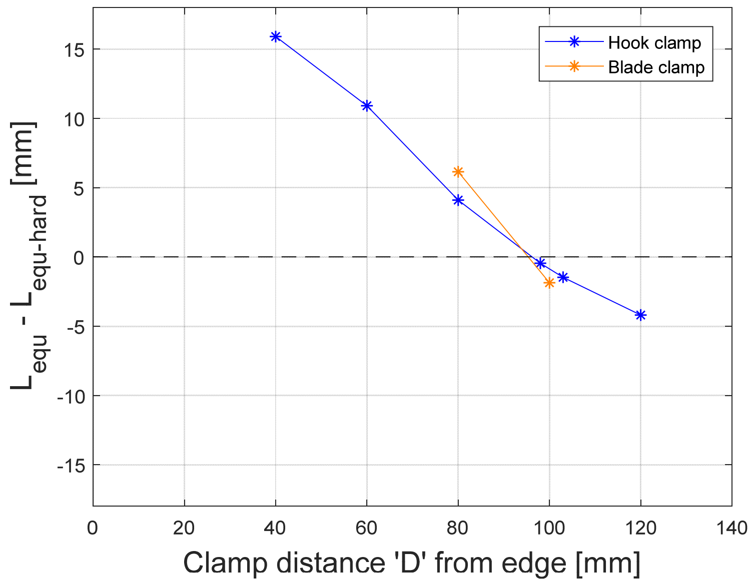
Fringe Field effect



$$L_{eff} = \frac{\int_{-\infty}^{\infty} B_y(s)ds}{B_y(0)} \qquad \left(L_{equ\_hard} = \frac{\pi}{2}\rho = 2356\ mm\right)$$

$$Slope = \frac{\int_{-\infty}^{\infty} B_y(s)\left(B_y(0) - B_y(s)\right)ds}{gB_y(0)^2}$$

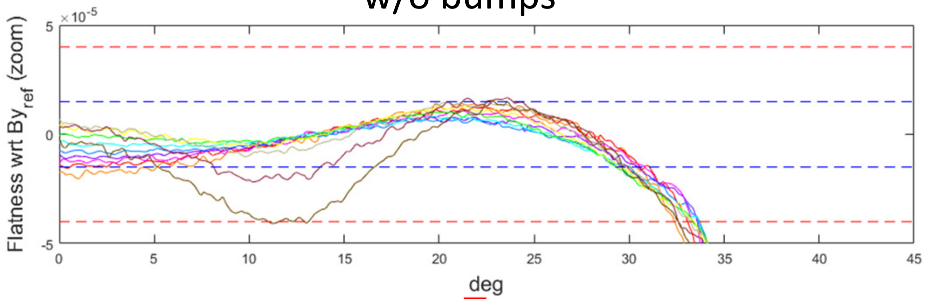




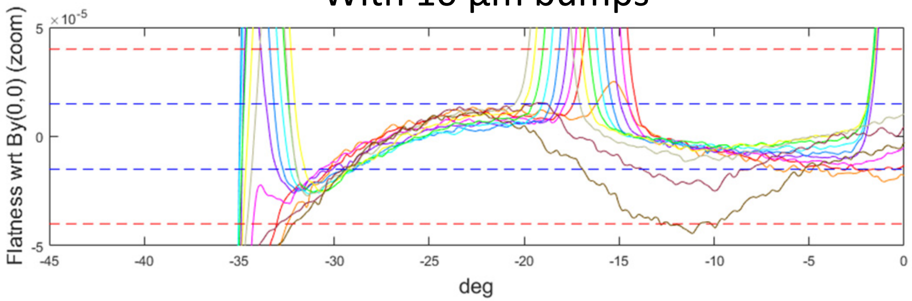
Errors study: Surface roughness

- Pole face: < 10^{-6} m = 1 µm

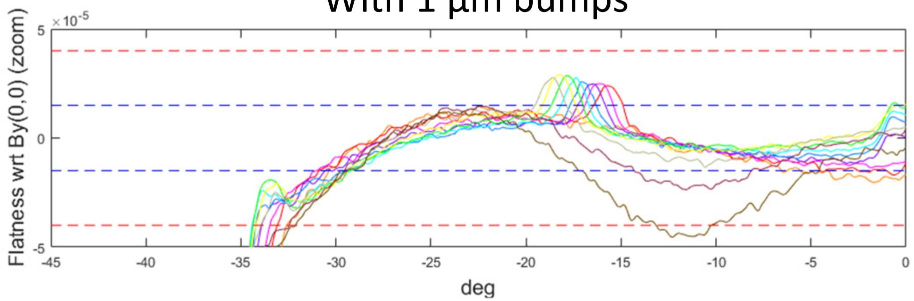
w/o bumps

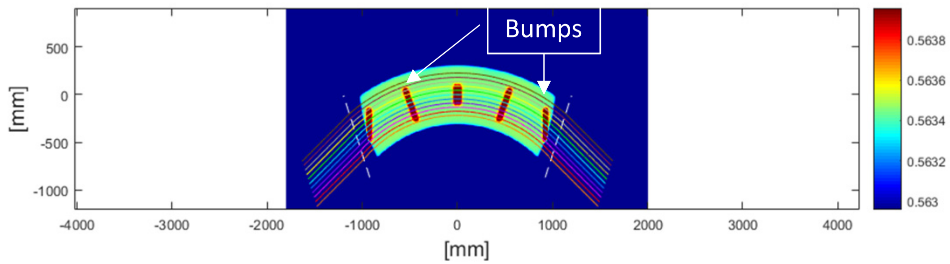


With 10 µm bumps

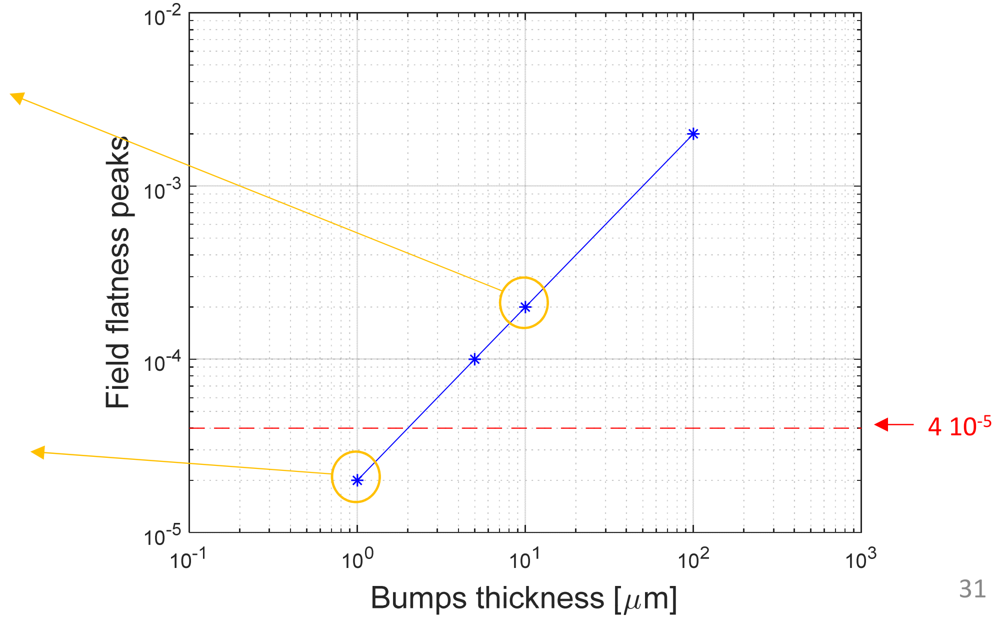


With 1 µm bumps

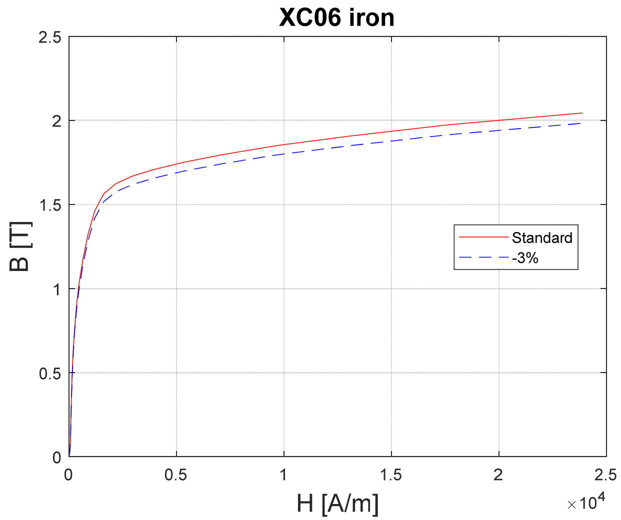


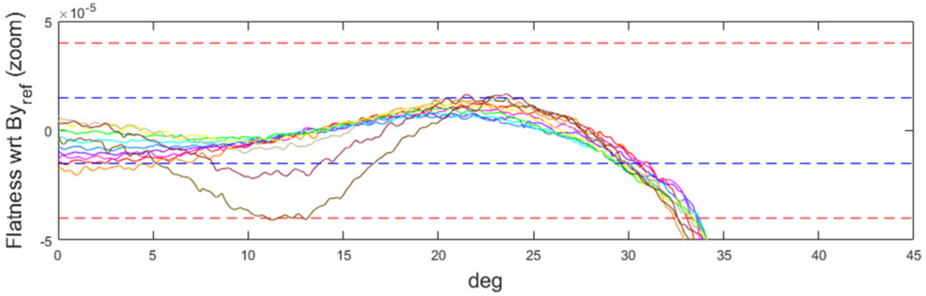


By adding artificial bumps to the pole surface it was possible to appreciate field flatness dependance to surface roughness

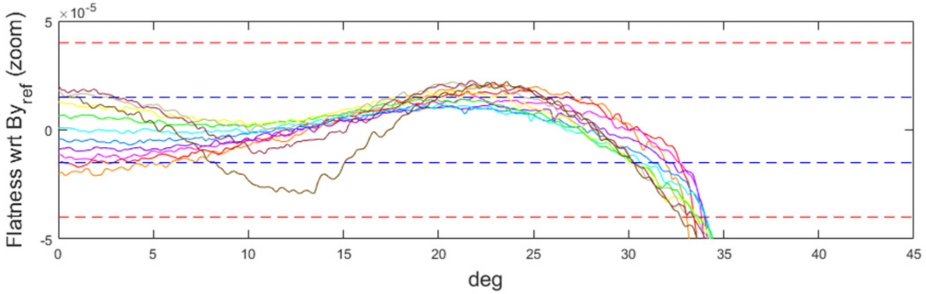


Errors study: Permeability

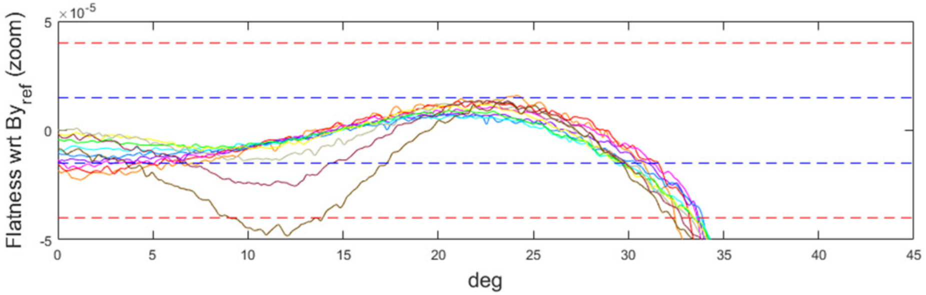




B-H reference



B-H -3% (bubbles in pole)



B-H -3% (whole pole)

Errors study: Current variation

+10% current increase

Current (I): 357.5 A

Curr. Dens: 4.6 A/mm²

Power: 14 kW

$By_{ref} = 0.62\ T$

Nominal case

Current (I): 325 A

Curr. Dens: 4.2 A/mm²

Power: 14 kW

$By_{ref} = 0.562\ T$

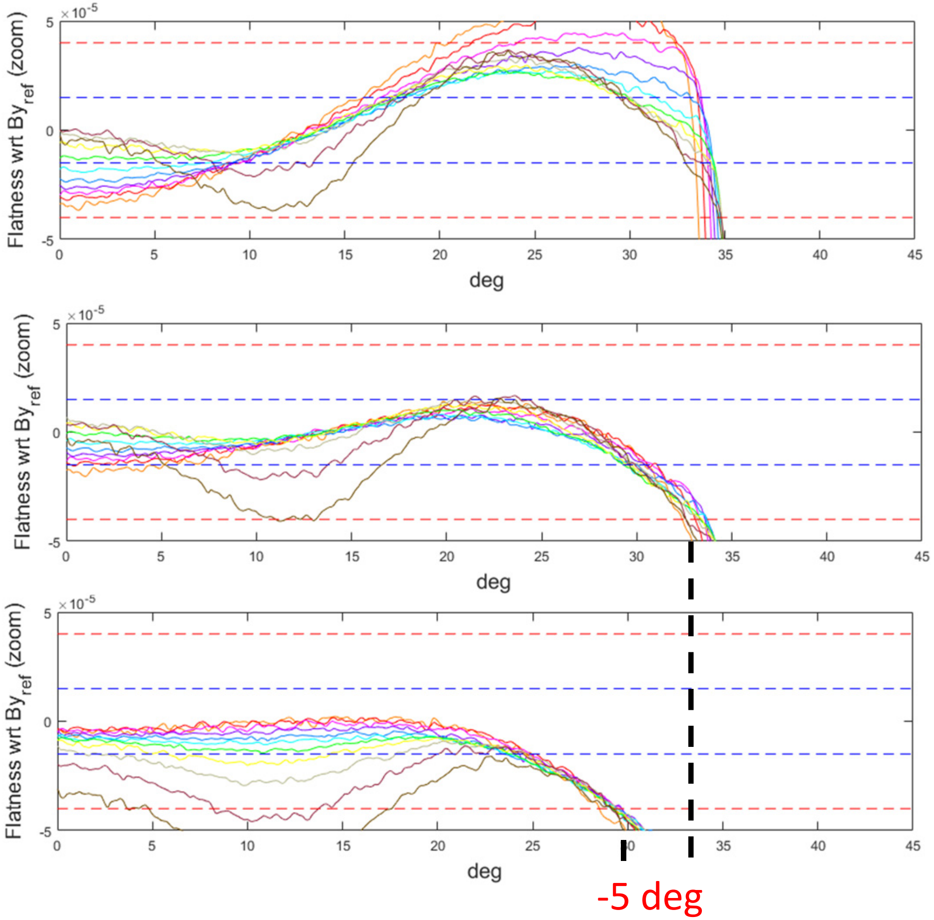
-20% current decrease

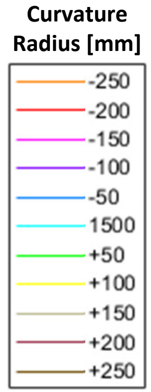
Current (I): 256 A

Curr. Dens: 3.3 A/mm²

Power: 8.5 kW

$By_{ref} = 0.441\ T$



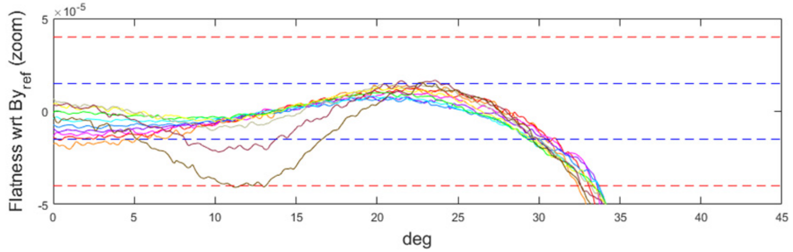


Conclusions

1/20000 mass purification is needed -> very high field homogeneity throughout entire beam occupancy

Studies presented so far demonstrate that a field flatness suitable for a separator with a resolution of 1/20000 is feasible:

Field homogenity well beyond target goal of 4 10^{-5} around reference field By = 0.562 T, covering 99% of beam horizontal extension and 75% of dipole length



Mechanical and alignment tolerances studies are currently ongoing: preliminary studies are giving encouraging results with very strict tolerances, but anyhow reasonable

Since the engineering of the design here presented was not done yet, this can't be considered the final design

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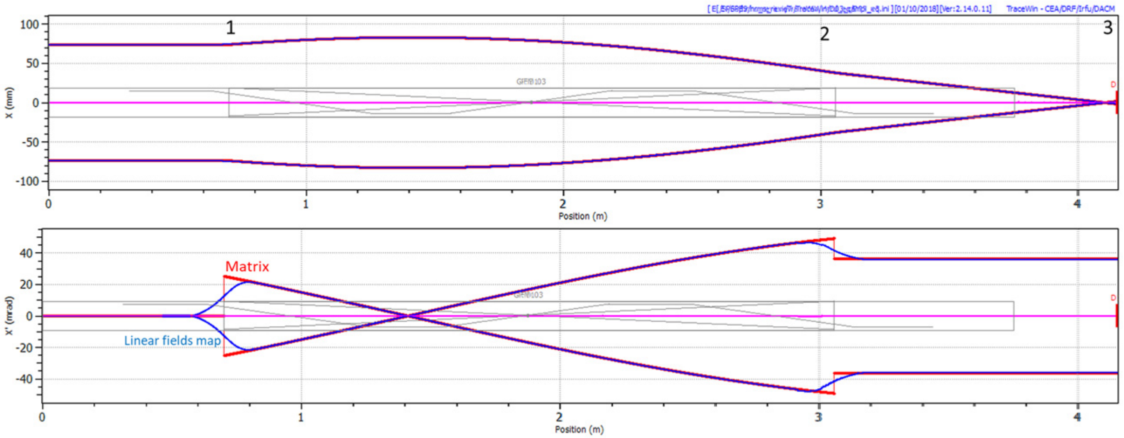
Design validation

Beam envelope within dipole



Beam emittance within dipole