

Status of the PMQ Magnet Development for PETRA IV

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Outline

High gradient PMQ design



01 Specification

02 Magnetic Design

- Geometry and materials
- Magnetic Force
- Gradient tuning
- Temperature Compensation
- Pole shape optimization
- Fringe field reduction

03 Magnetic Correction

- Harmonic shim

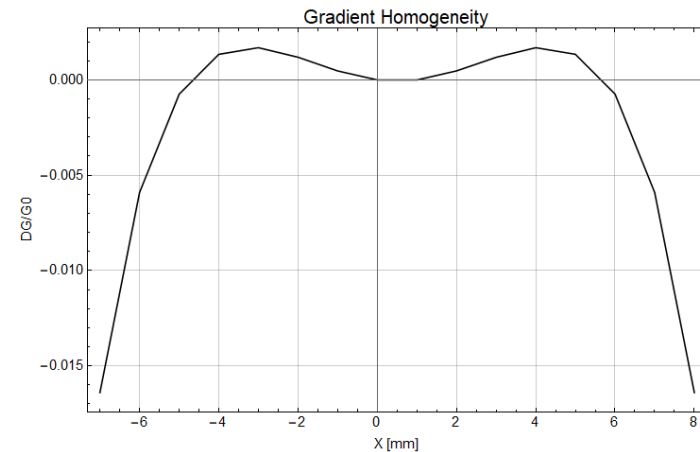
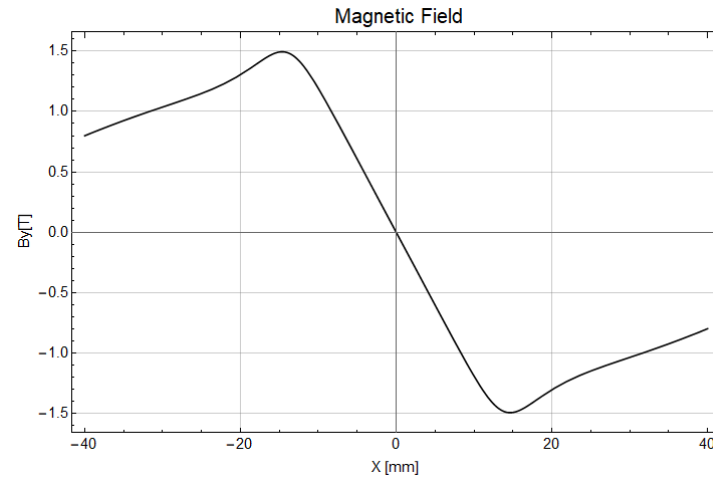
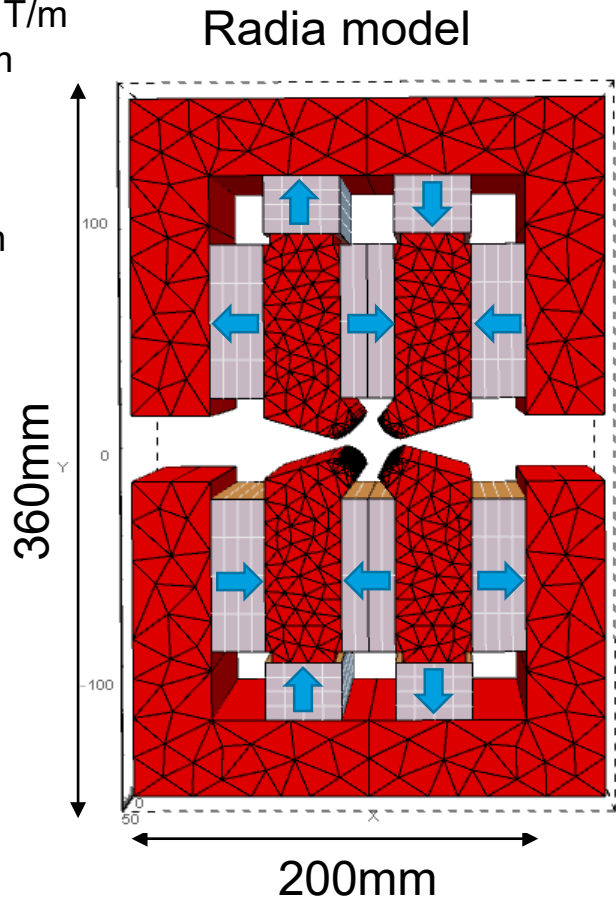
04 Perspective

- Design Finalization
- Mechanical design
- Prototype

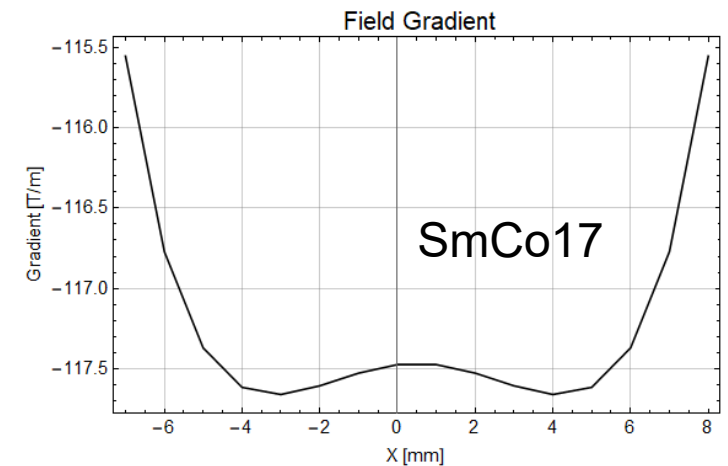
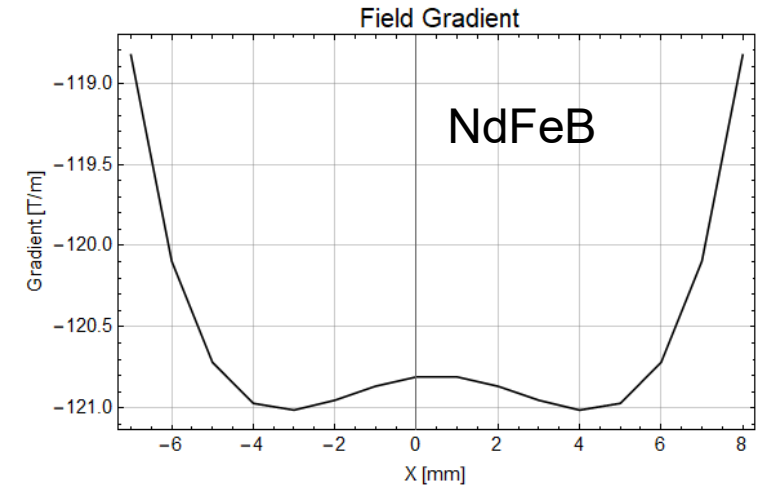
Specification and Preliminary Design

Specification for Petra IV PMQ

- Gradient: 120 T/m
- Gradient tuning: ~ 5 T/m
- Bore Radius: 11 mm
- GFR: ± 6.5 mm
- DG/G0: $5 \cdot 10^{-4}$
- Length: 0.169 m
- Vertical gap: 8.8mm

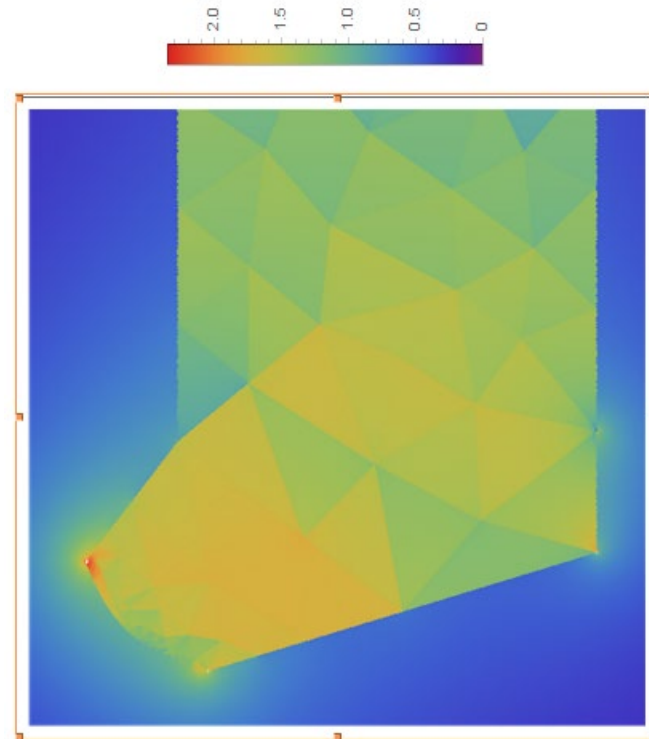
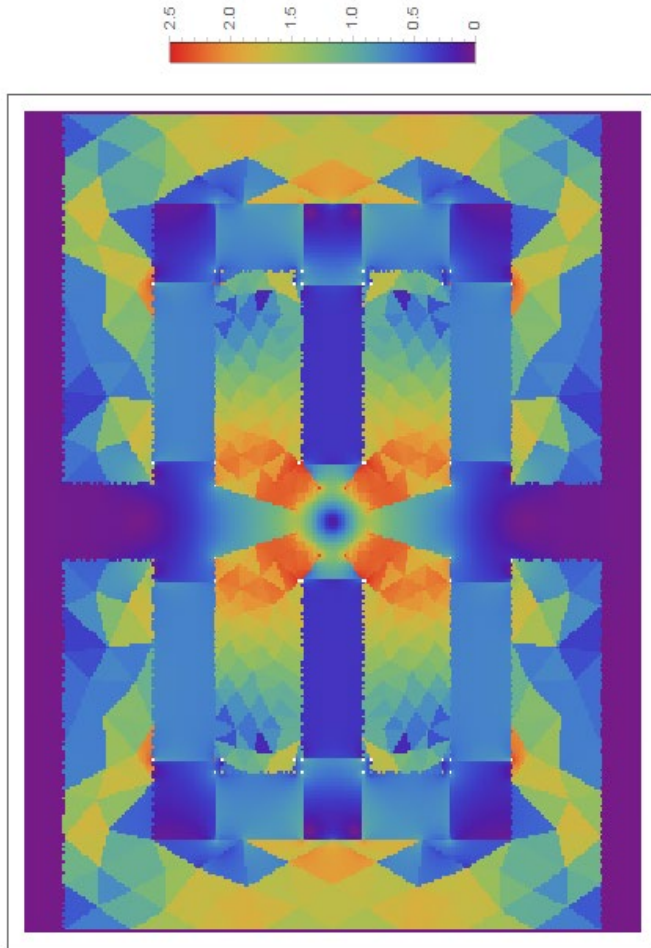


- Gradient: 117.5 T/m
- PM: SmCo17 Br=1.1T
- Iron ARMCO

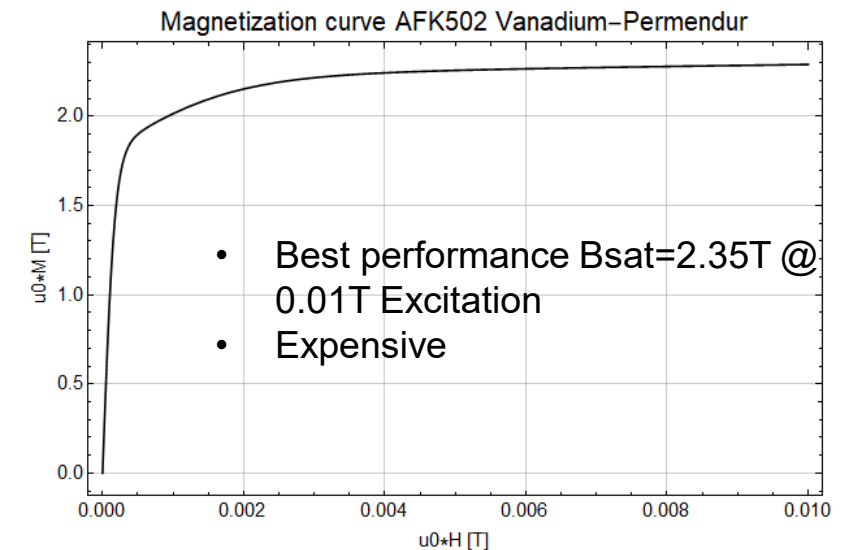
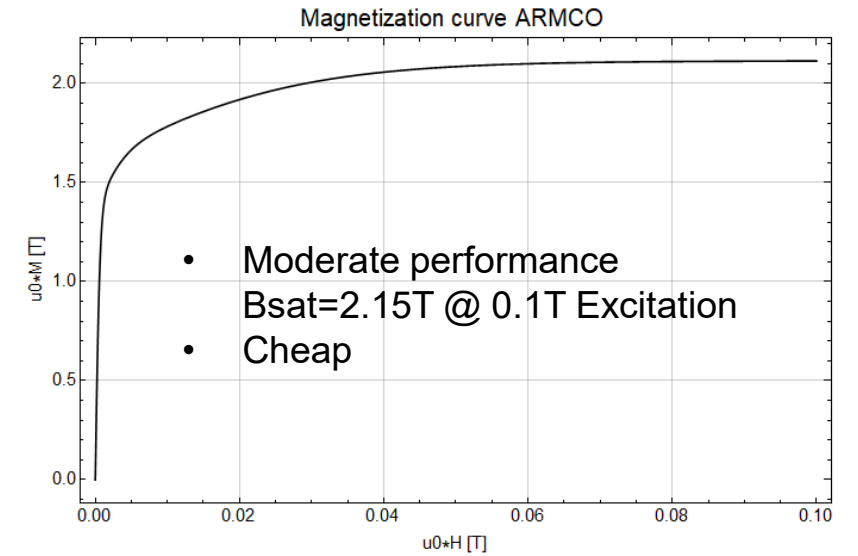


- Gradient: 120.8 T/m
- PM: NdFeB Br=1.25T
- Iron ARMCO

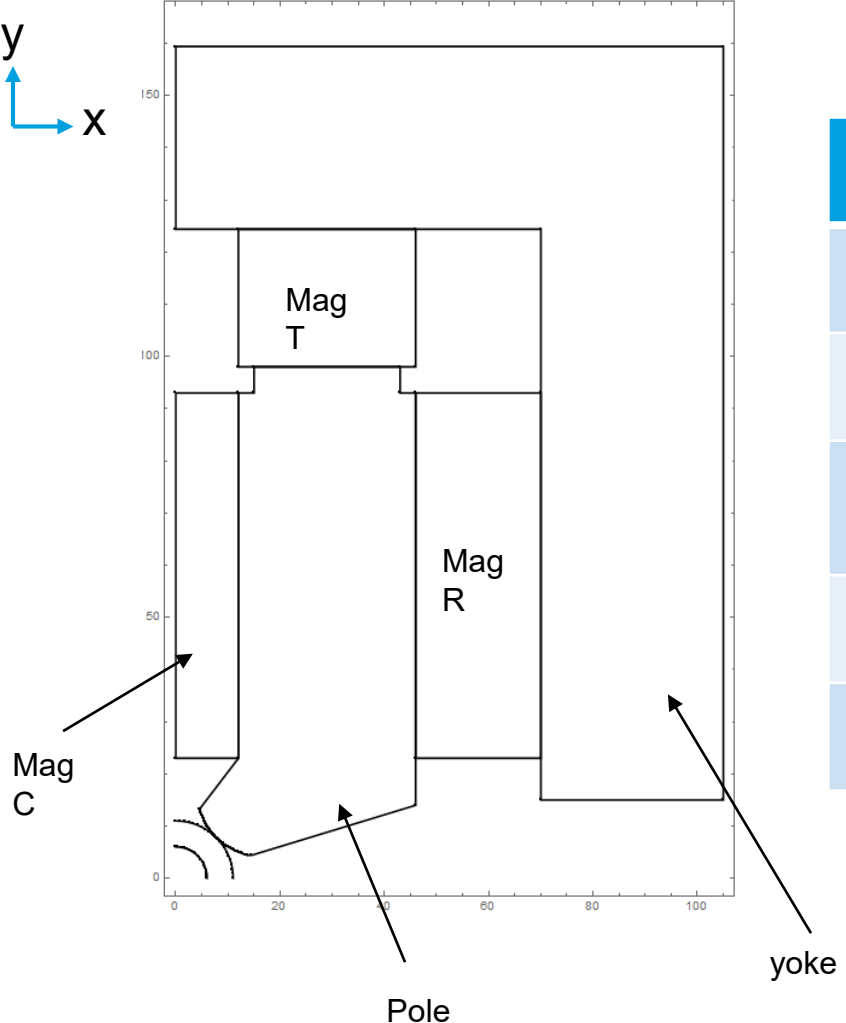
Specification and Preliminary Design



10 T/m Gradient gain using Vanadium Permendur Pole material (Vacoflux)

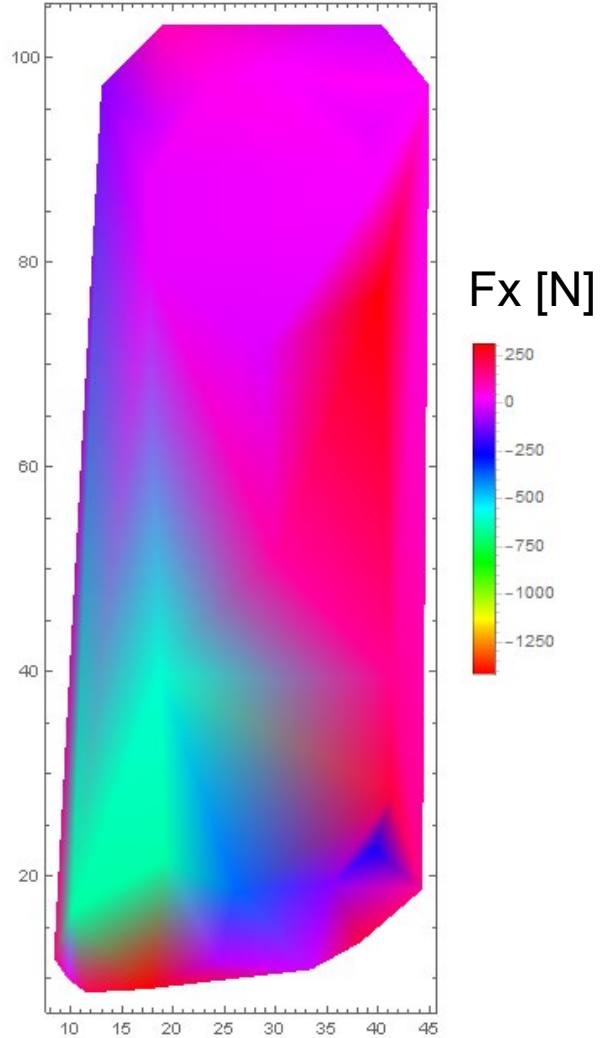


Magnetic Force



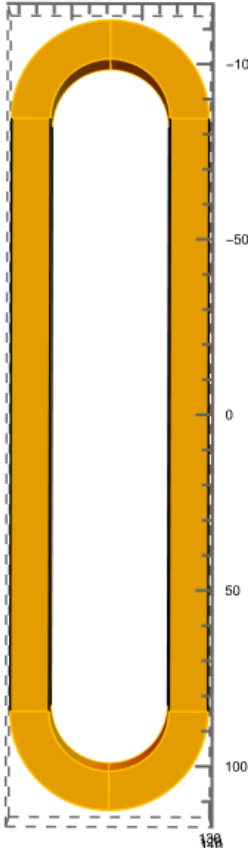
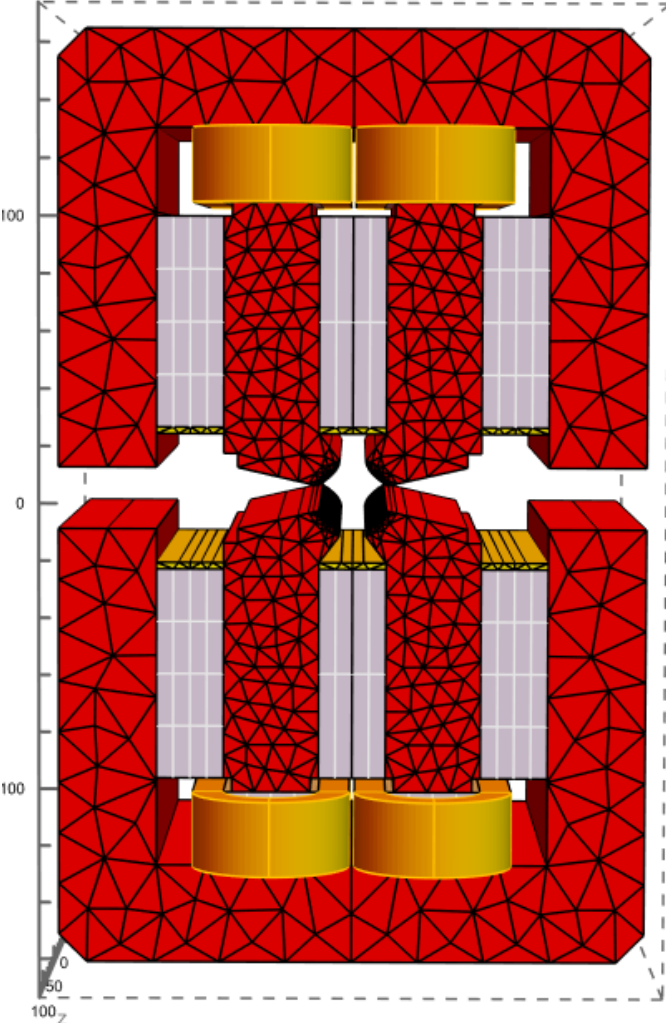
Name	Fx [N]	Fy [N]
Mag C	-594	-91
Mag R	551	59
Mag T	35	1240
Yoke	-300	-602
Pole	-1505	675

Pole Force (Fx) distribution

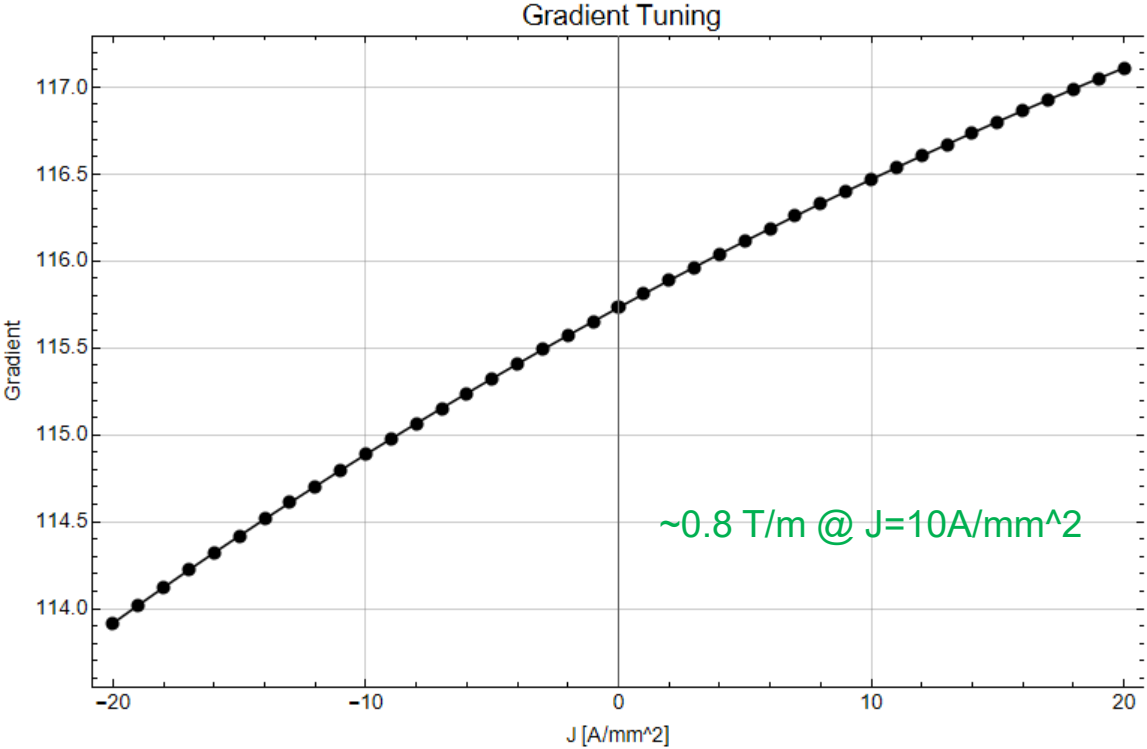


Gradient Tuning

Gradient Tuning with coils



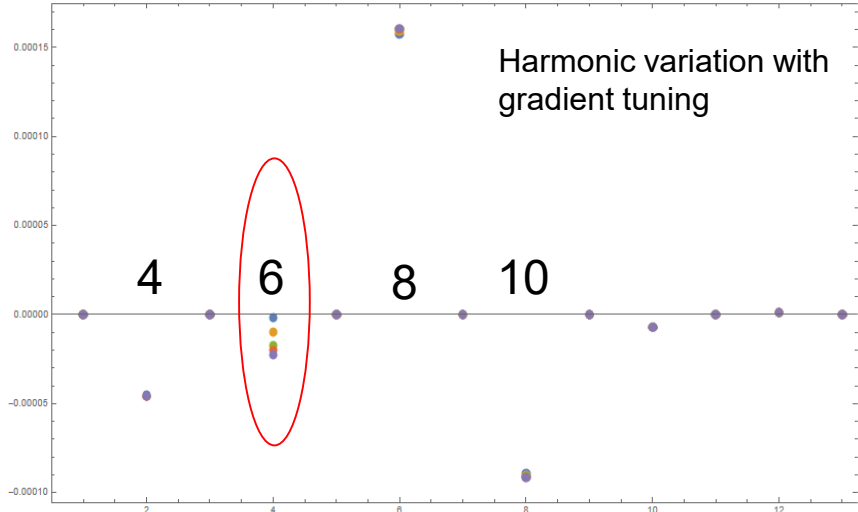
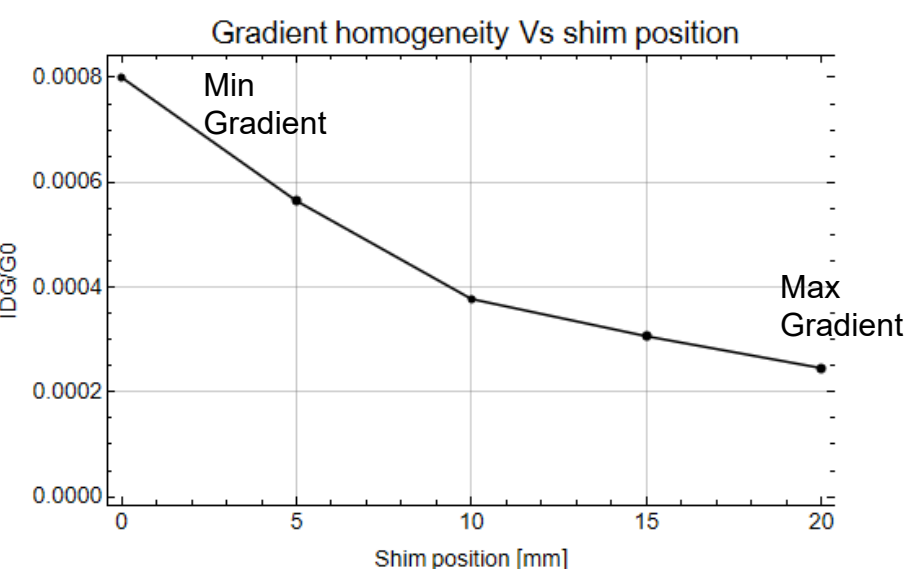
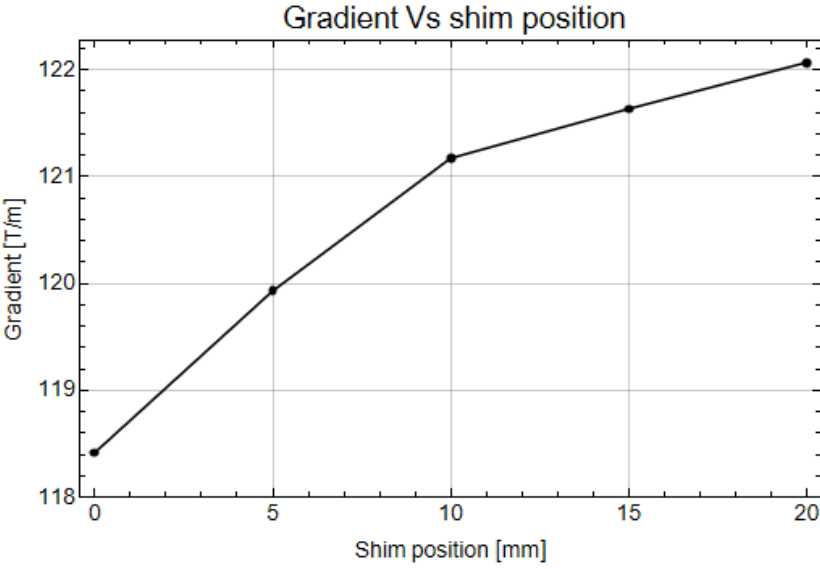
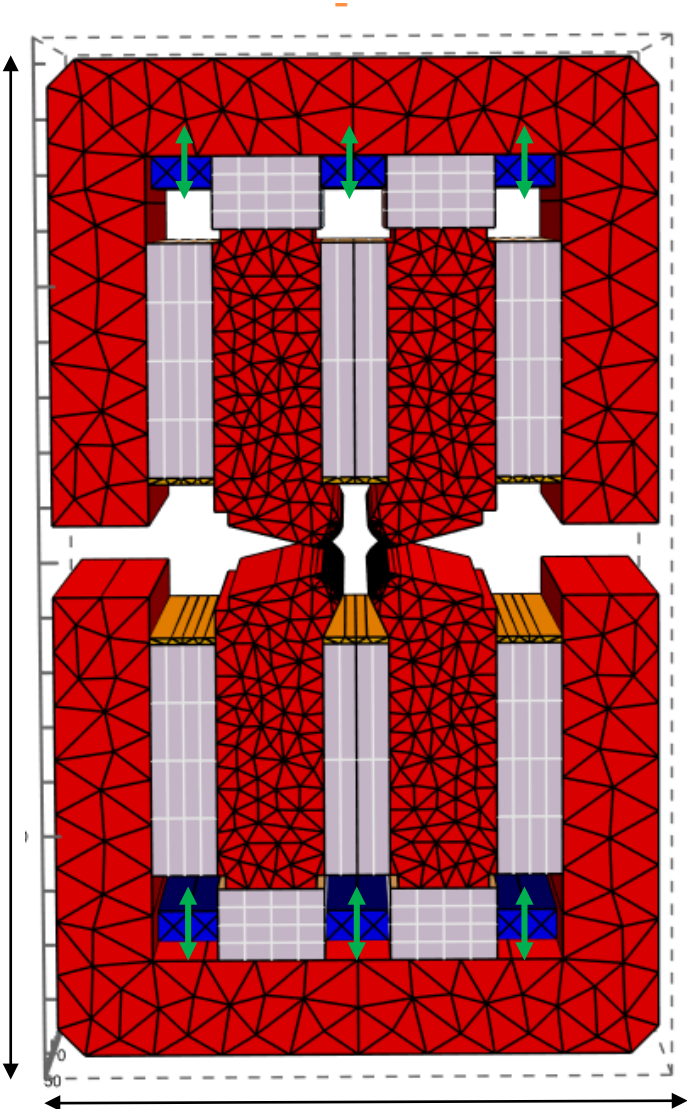
Tuning Coil



➡ No efficient solution

Gradient Tuning

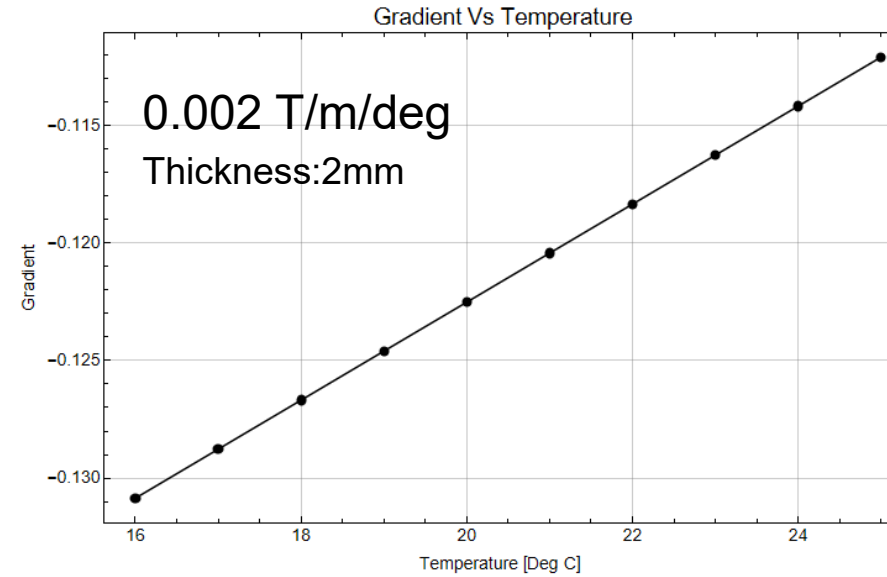
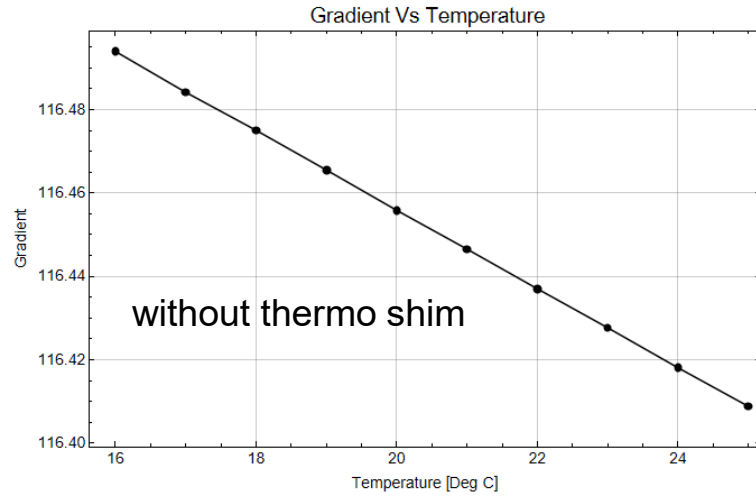
Gradient Tuning with Shunt



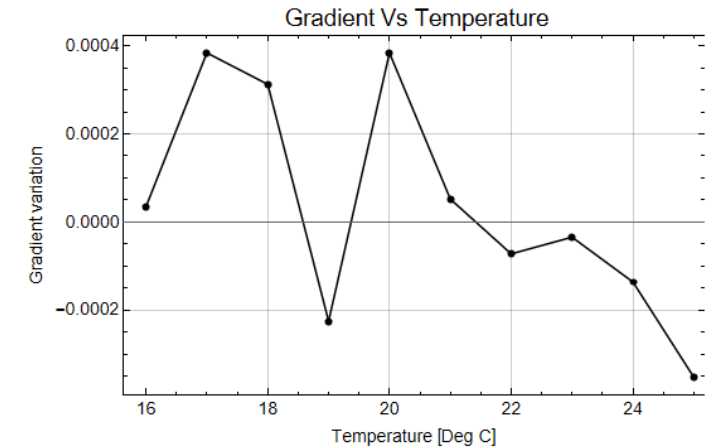
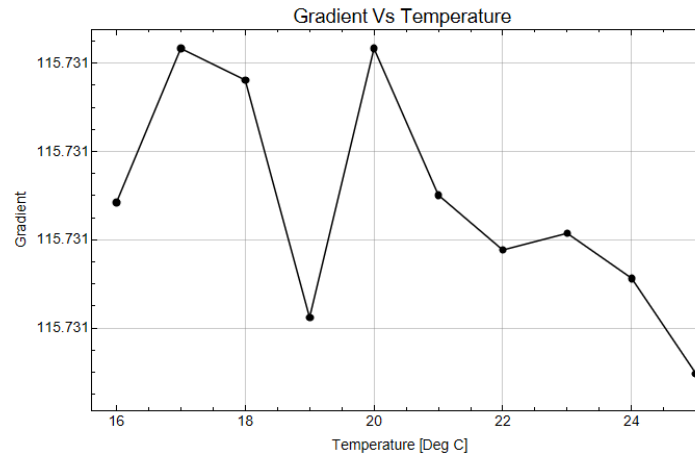
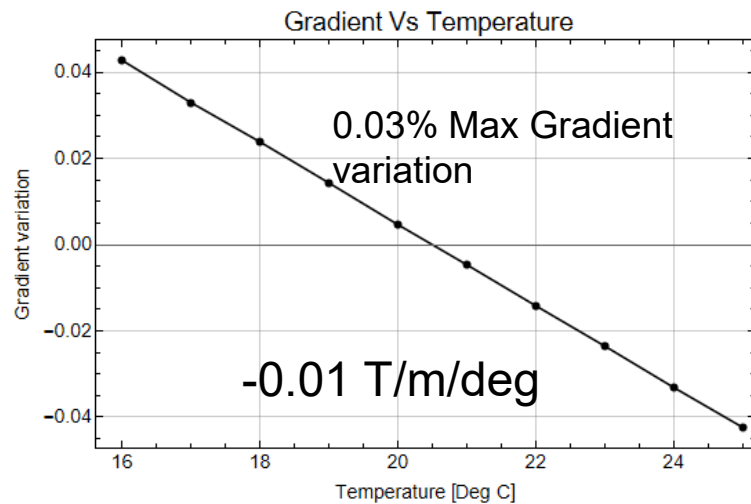
- Movable Iron shunt
- 5T/m gradient tuning range achievable
- Gradient homogeneity impact
- Required Correction of harmonic

Temperature compensation

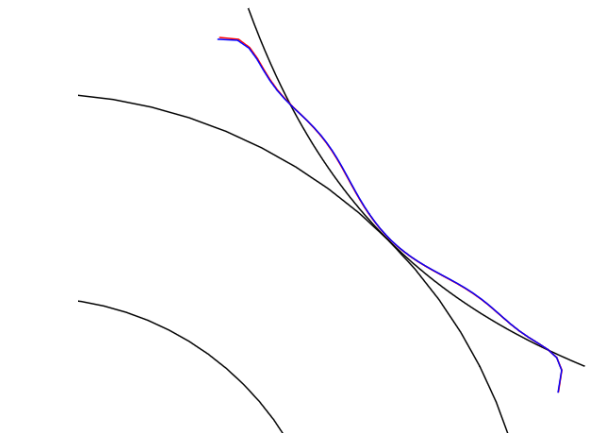
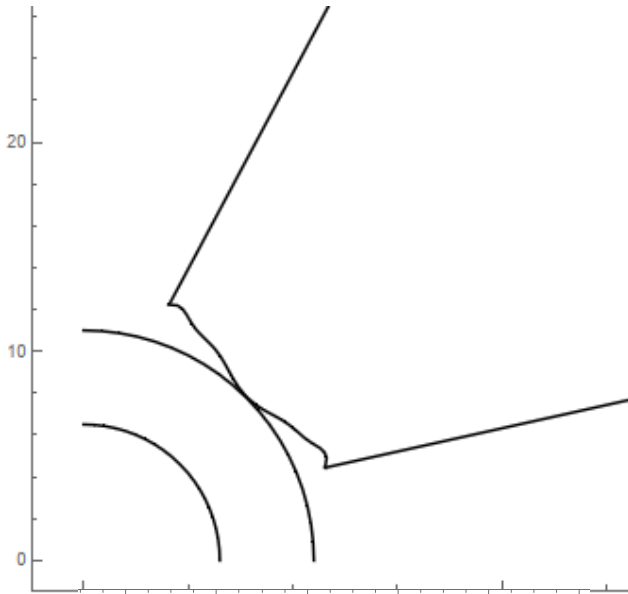
- Temperature coefficient PM SmCo17: -0.033% /deg
- Temperature coefficient thermo shim(FeNi): -1.7% /deg
- Thermal shim Thickness: 2mm



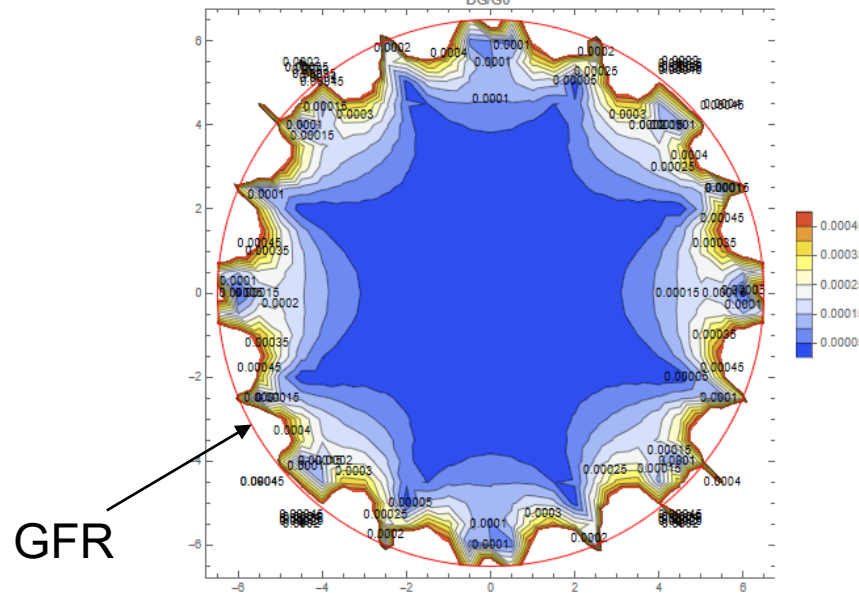
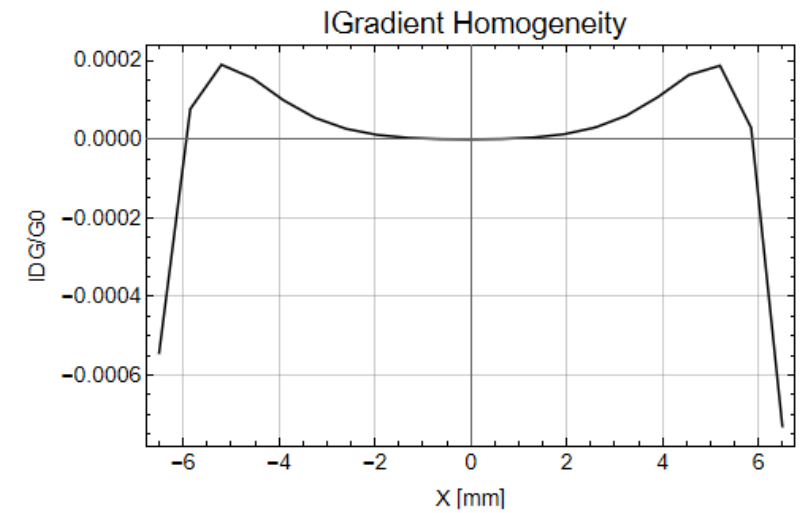
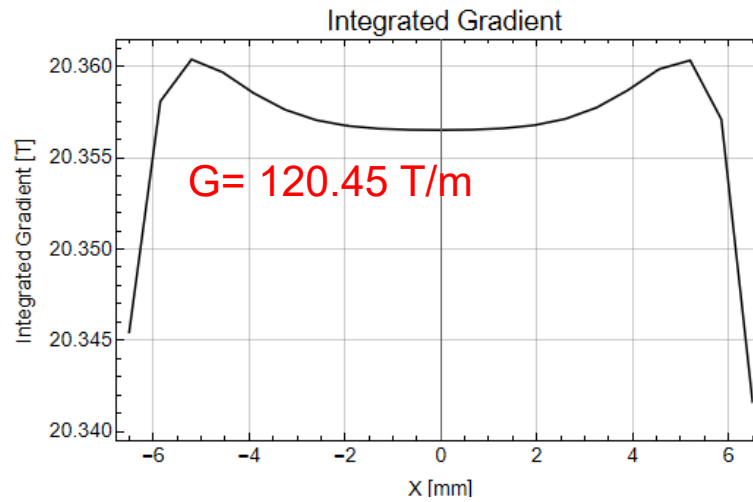
Correction (2.36mm thickness)



Pole Shape optimization (2D&3D)



2D & 3D shape -> tiny difference

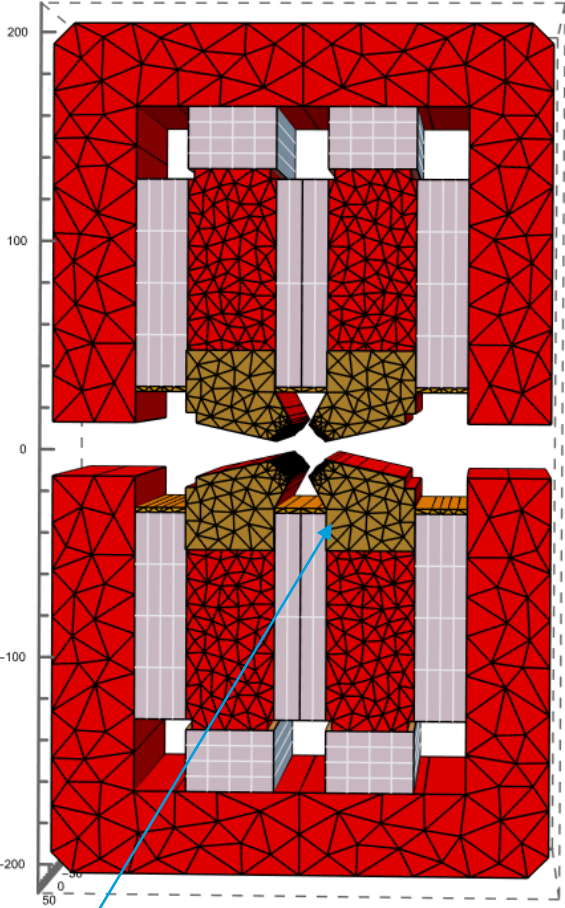


Integrated Harmonics

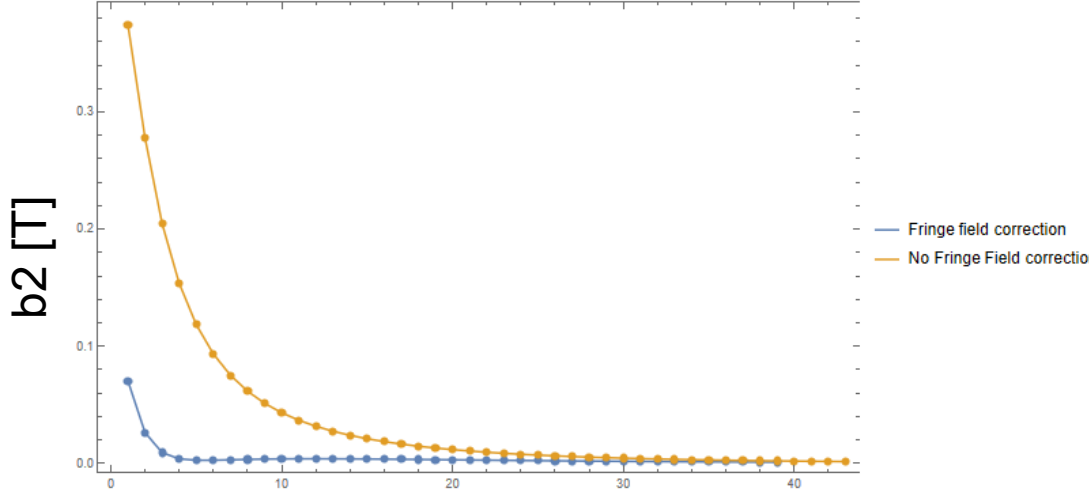
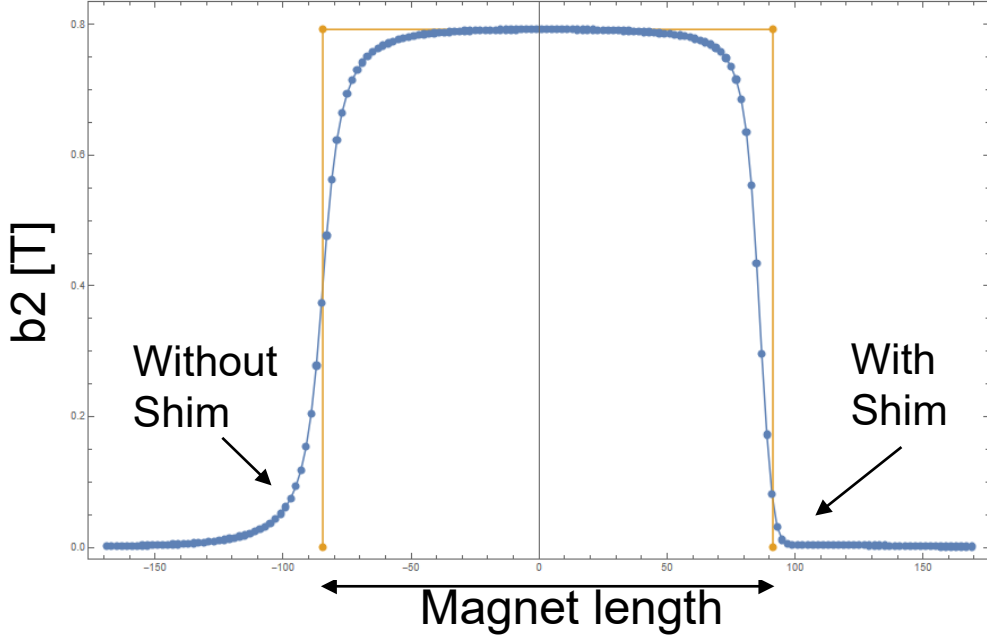
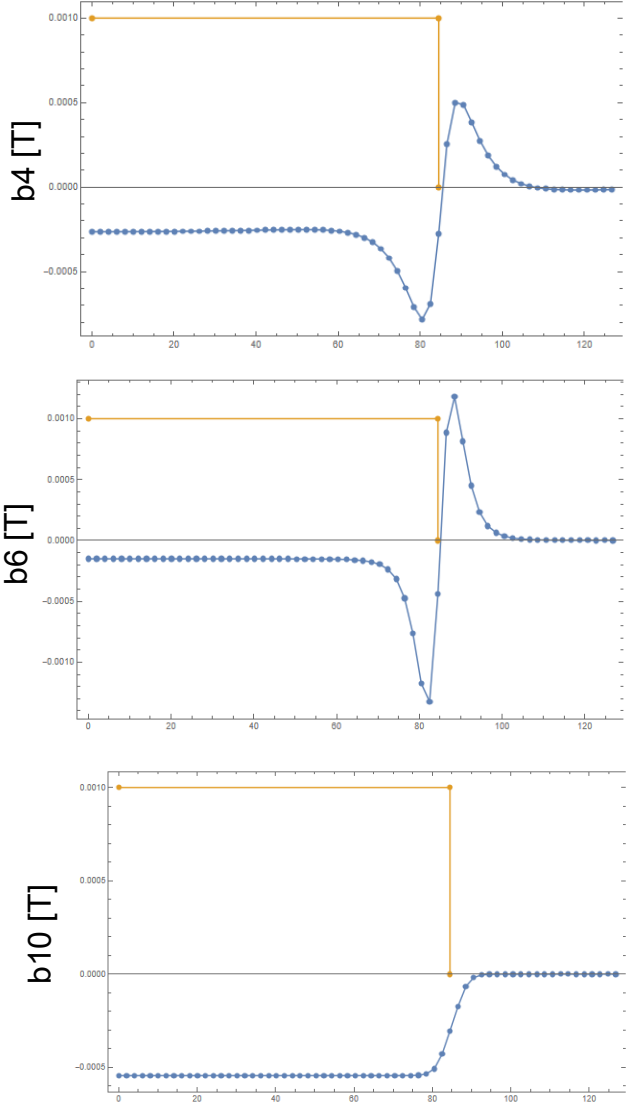
1	0	0
2	0.132317	10000.
3	0	0
4	3.3517×10^{-6}	0.253307
5	0	0
6	0.0000170568	1.28908
7	0	0
8	-1.11112×10^{-6}	-0.0839738
9	0	0
10	-2.14325×10^{-6}	-0.161978
11	0	0
12	1.67678×10^{-7}	0.0126723
13	0	0
14	-0.0000131667	-0.995089
15	0	0

$$\sqrt{\sum bn^2} = 2 \cdot 10^{-5}$$

Fringe Field Reduction

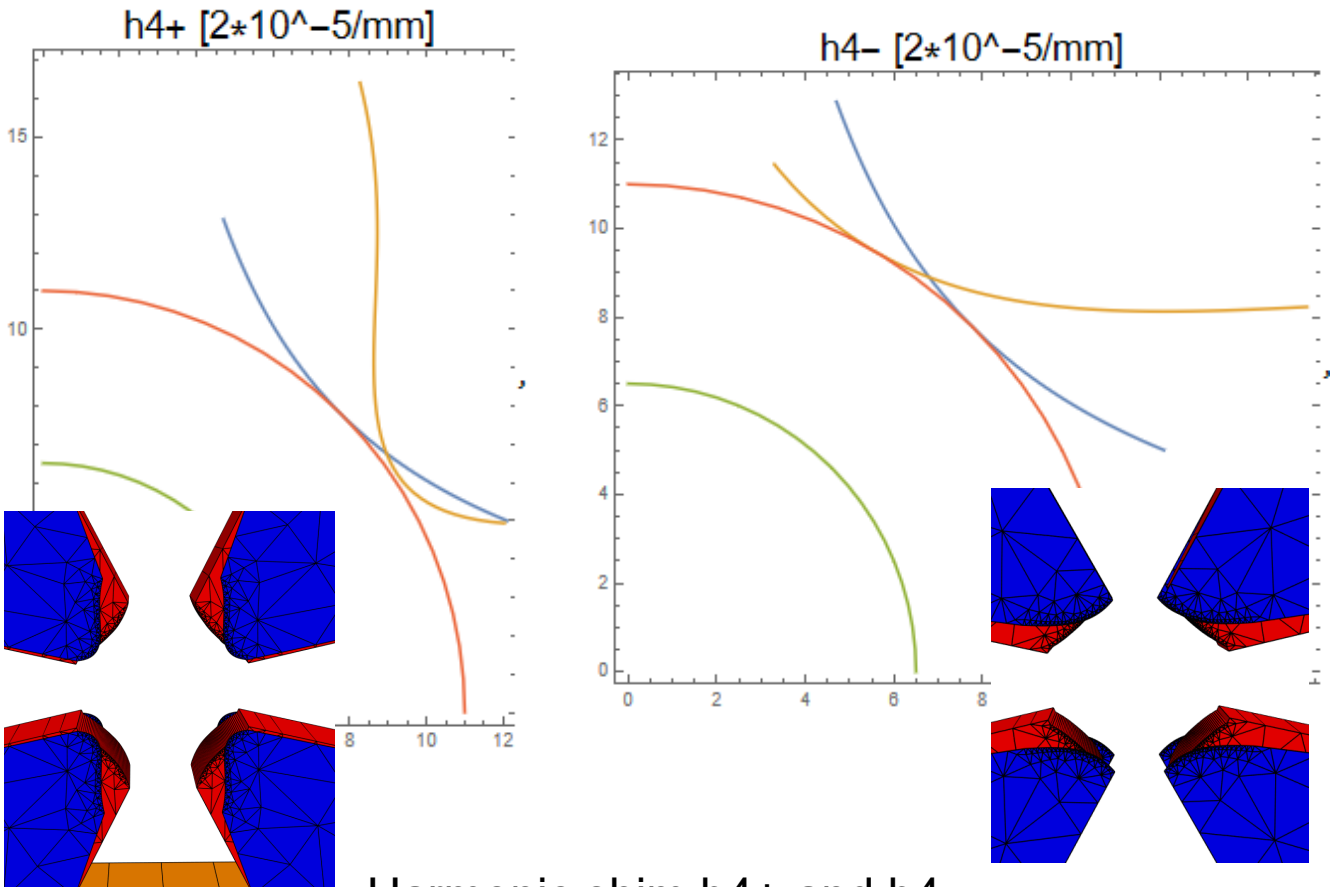


PM shim
6.85mm Thickness



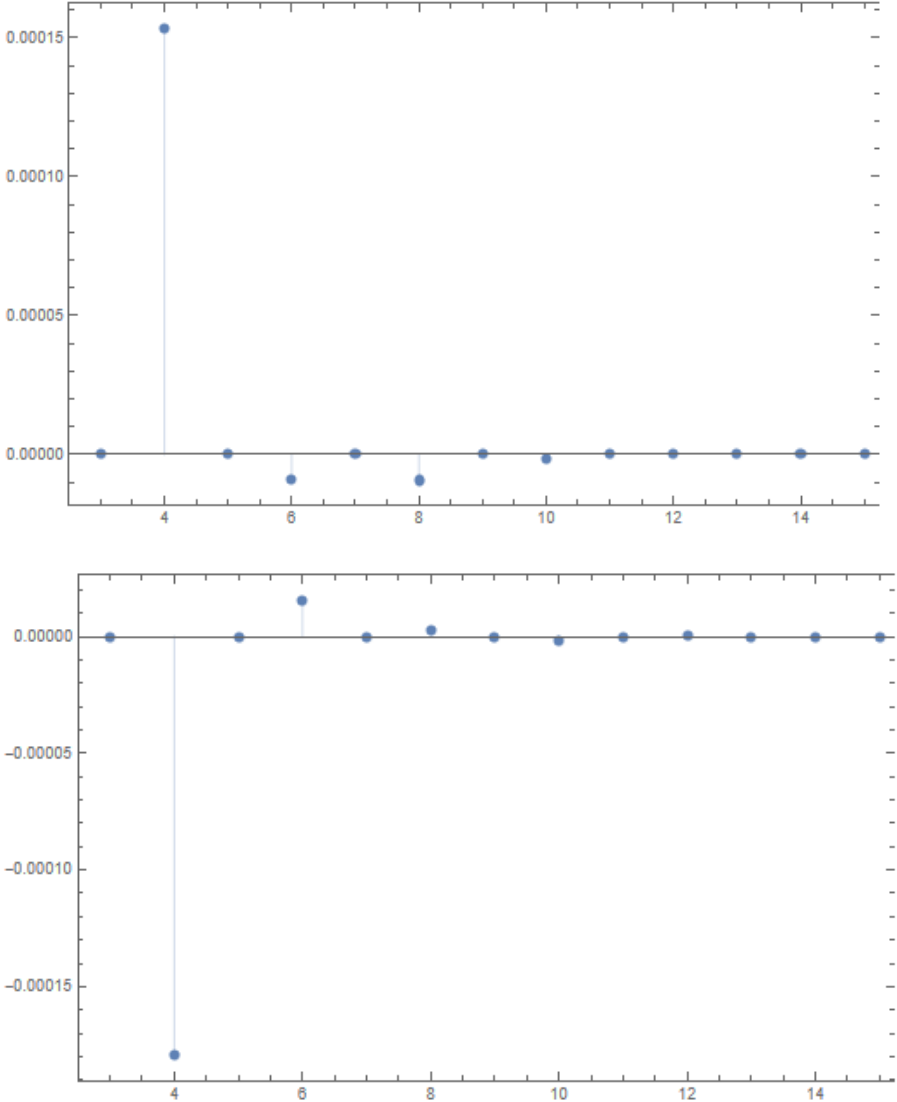
Magnetic Correction

Harmonic Shim



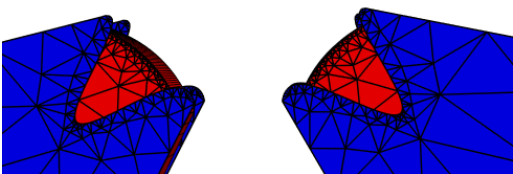
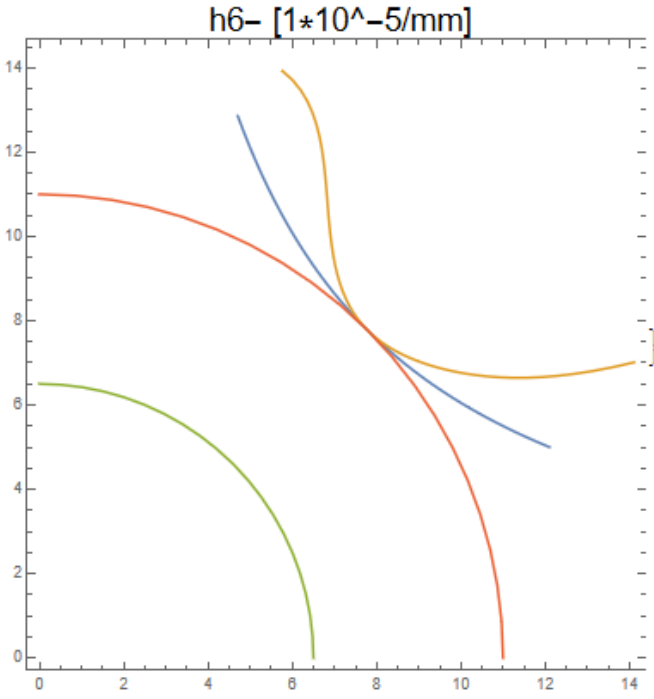
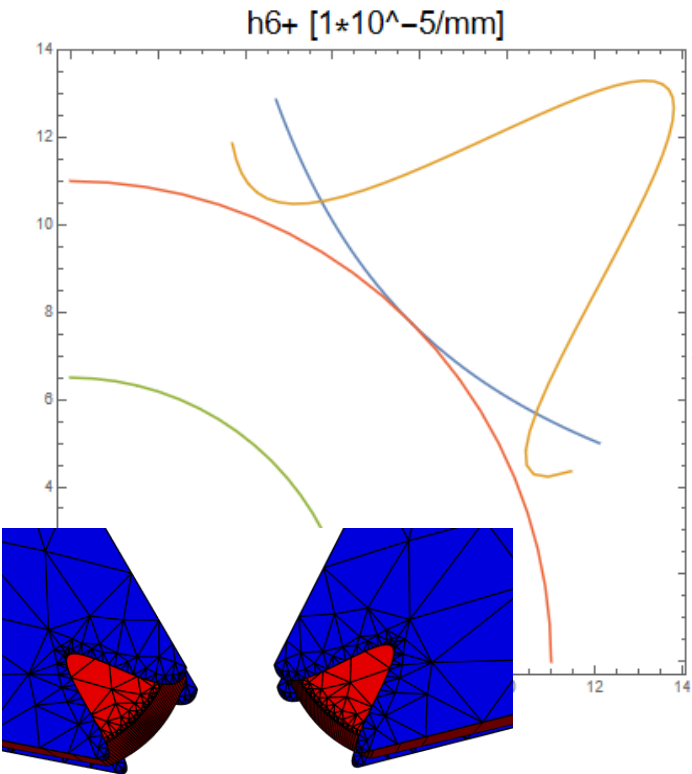
Harmonic shim b4+ and b4-

15*10^-5 → ~15 units/mm shim thickness



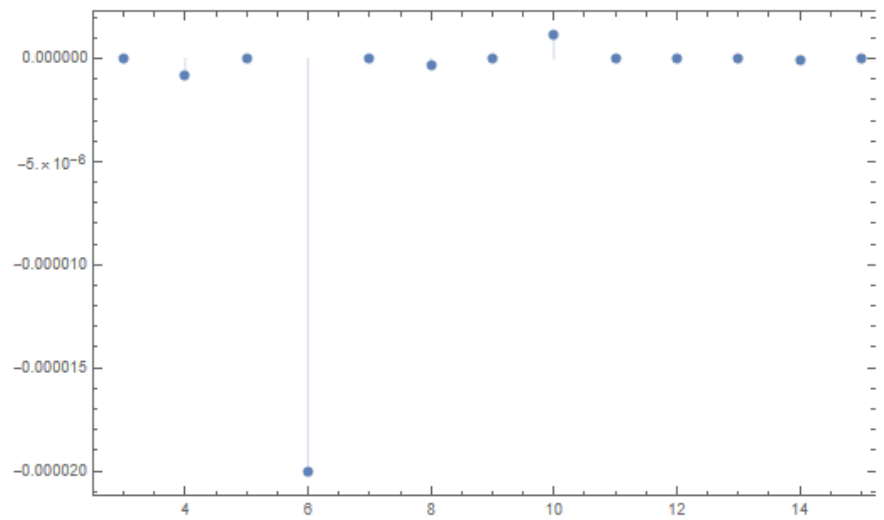
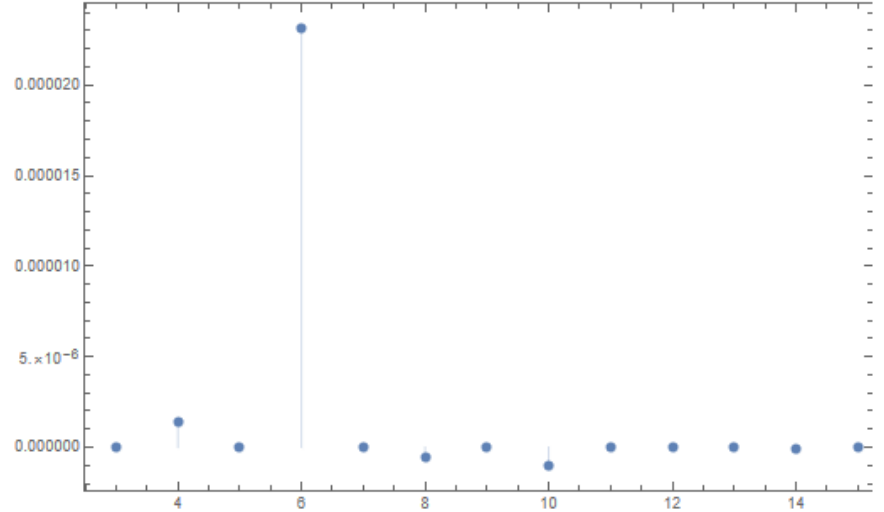
Magnetic Correction

Harmonic Shim

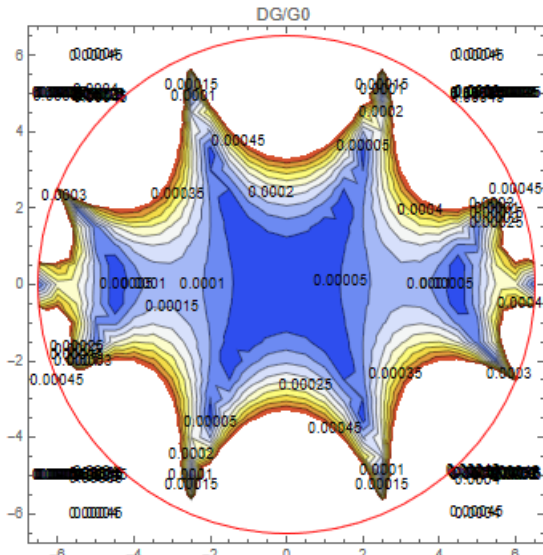
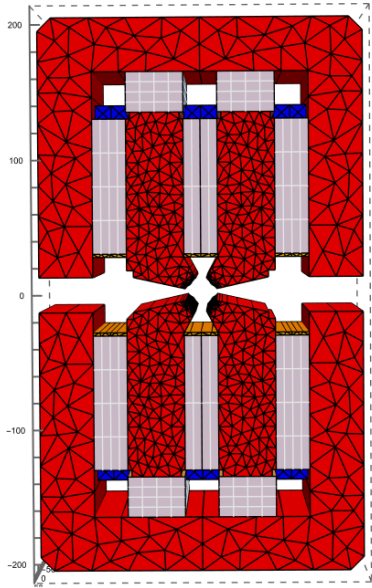


Harmonic shim b6+ and b6-

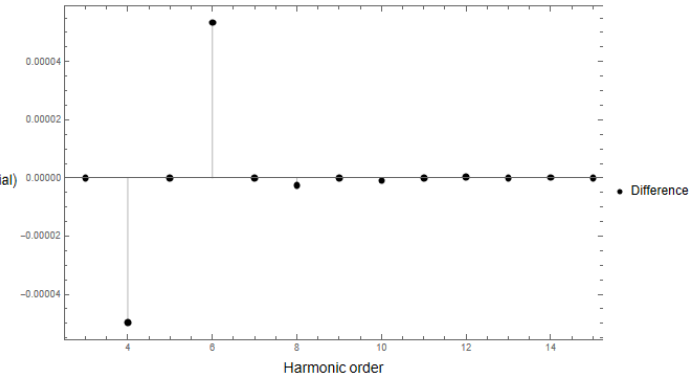
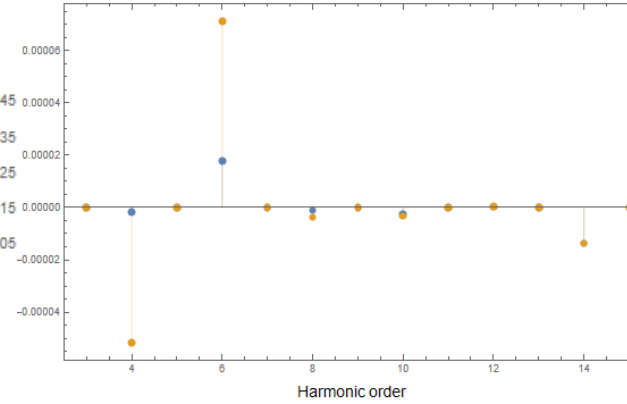
$2 \cdot 10^{-5} \rightarrow \sim 2$ units/mm shim thickness



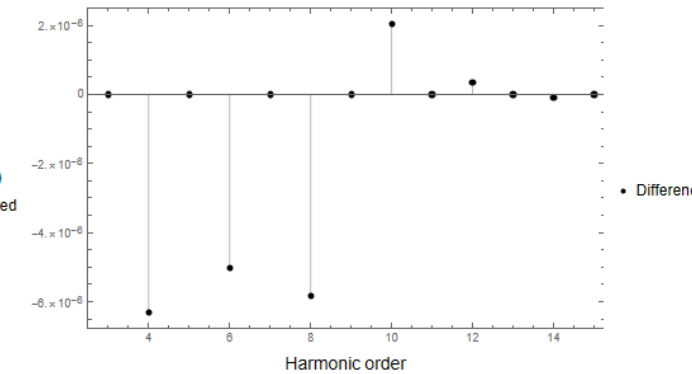
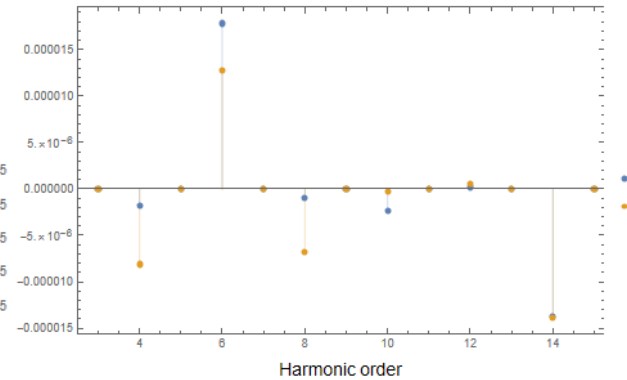
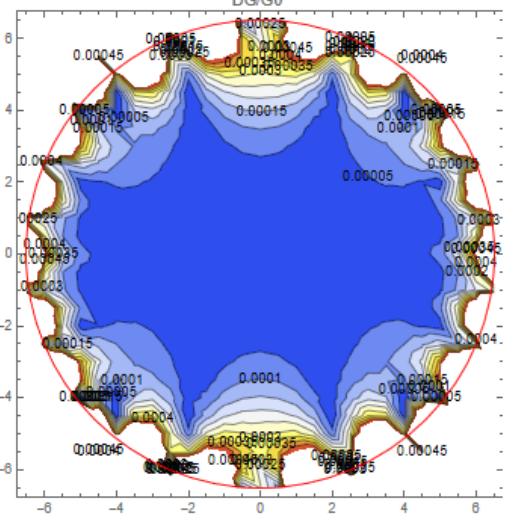
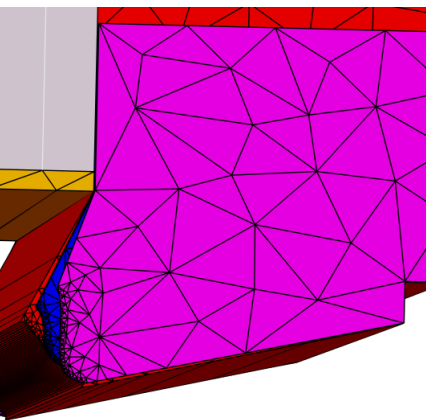
Magnetic correction test



Field perturbation at minimum gradient with tuning shunt (negligible perturbation at max gradient with shunt on the top)



Field correction



Stack of two shim
 b6- ; 2.5mm thickness
 b4+ ; 0.35mm thickness

Field error correction with "harmonic shim"

- Generation of a specific harmonic order (b4+, b4-, b6+, b6-)
- Correction of gradient tuning error (b6 harmonic variation)
- Correction of possible mechanical error
- Flexible correction: stack of correction shim

Perspective

- > Magnetic design finalization
 - Parameter update, model improvement
 - Study of the final magnet model

- > Mechanical design
 - On progress, first CAD model
 - Prototype afterwards

Thank you