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24/07/25

3D modelling of FETS-FFA main magnet

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Geometry of doublet and coils

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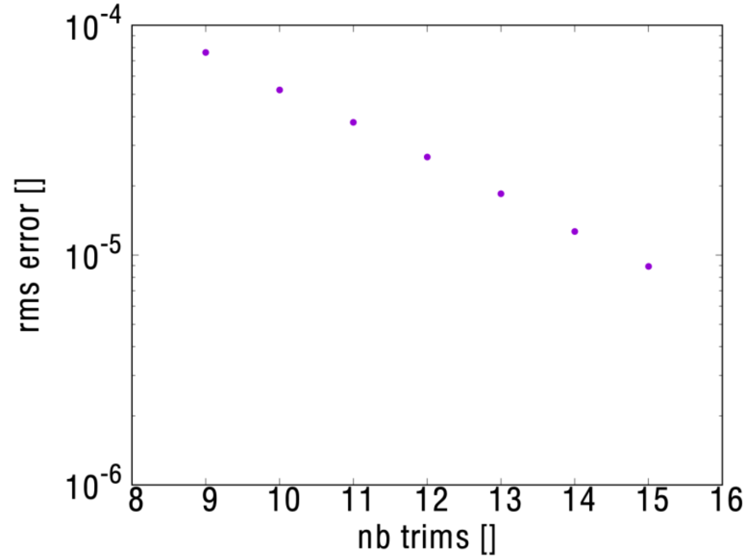
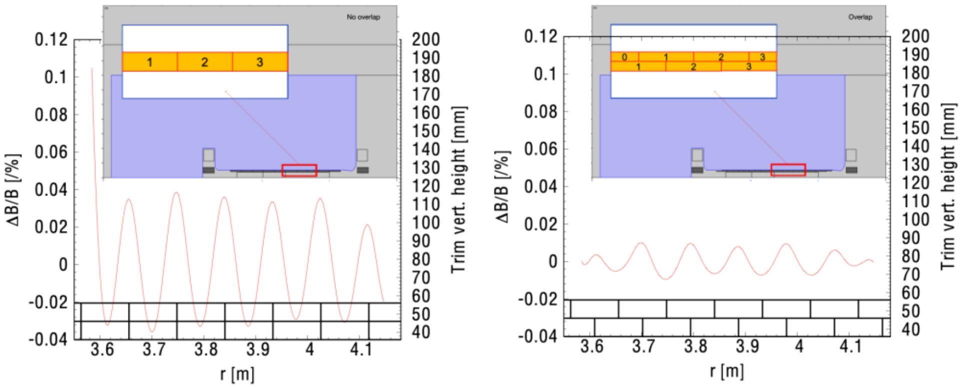
Number of trim coils





Chose 10 trim coils per layer as a balance
Between field error and number of power supplies

2 layers with an overlap from each other. Reduces the field error by a factor of about 5 for the same number of power supplies

2 layers with the same current settings for now

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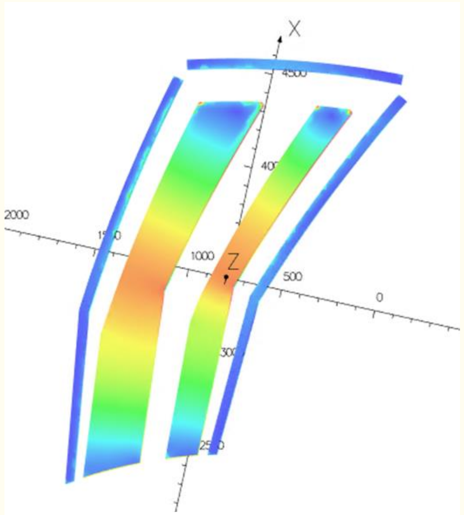
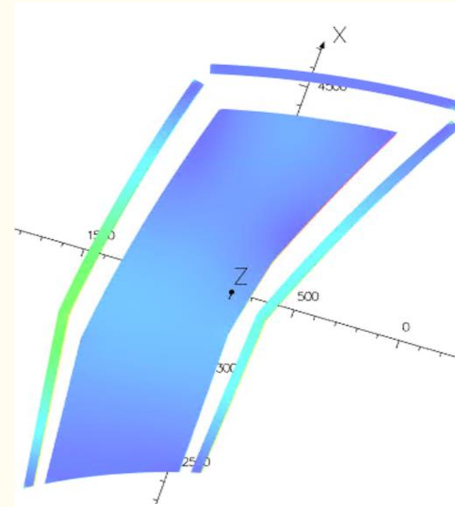
The initial design of the doublet had separate F/D magnets and clamps

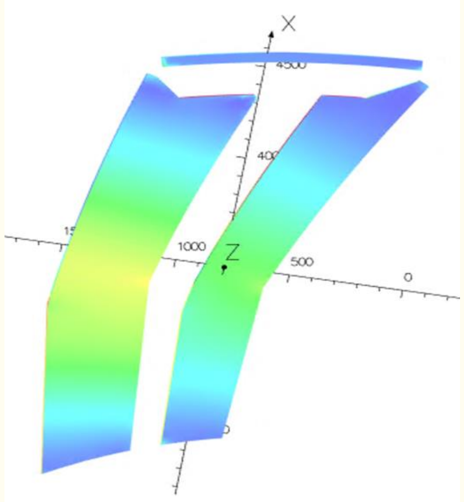
All separated



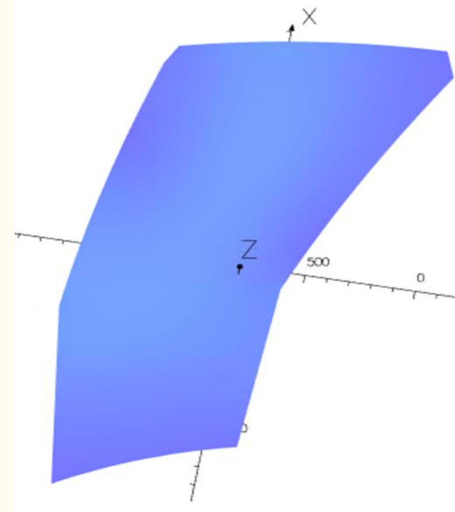
FD connected



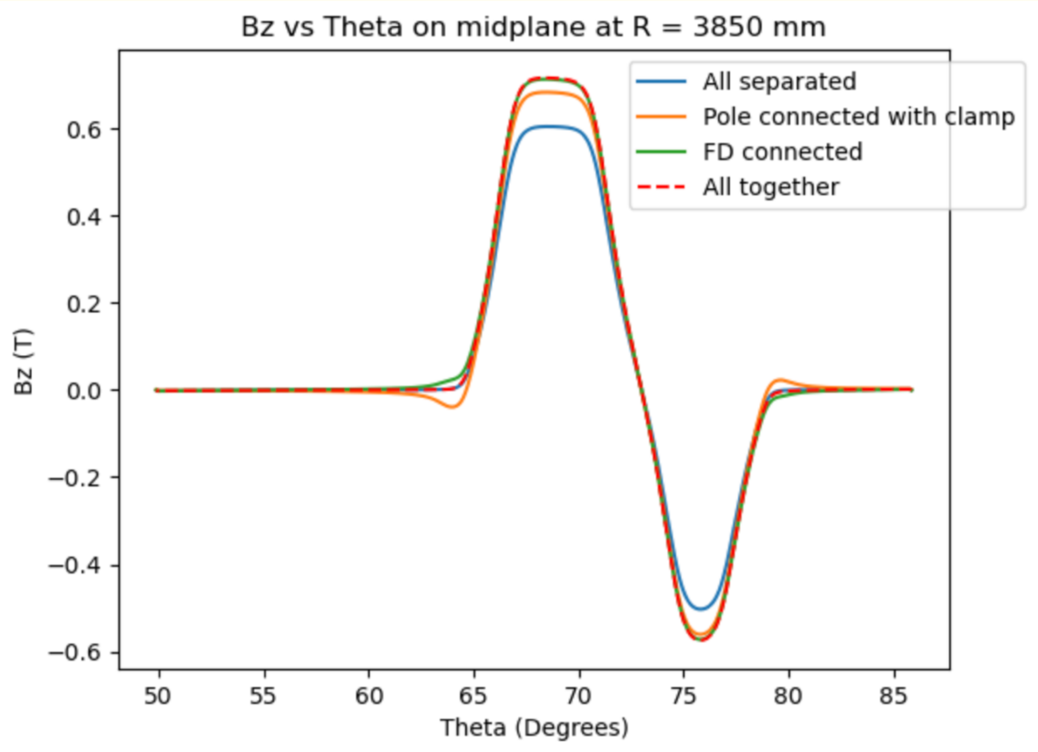
Pole connected with clamp



All connected



Effects of connecting the doublet magnetically
(All with the same current setting)



Reduced return yoke height: 700mm to 300mm

Reduced weight of doublet: 19 tonnes to 15 tonnes

Reduced power consumption of doublet: 39kW to 35 kW

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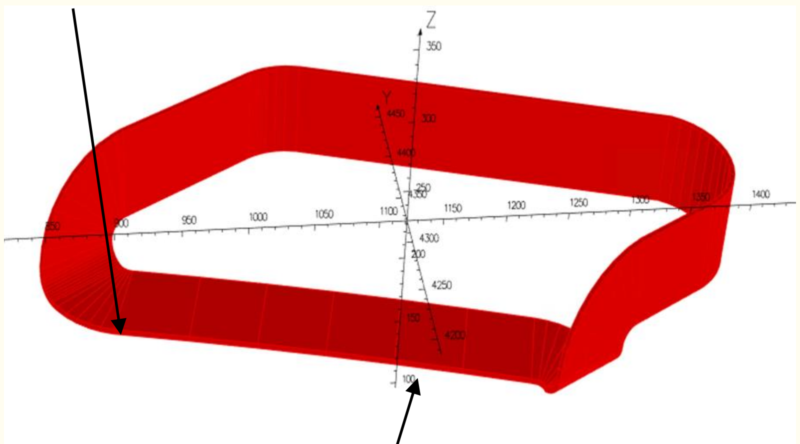
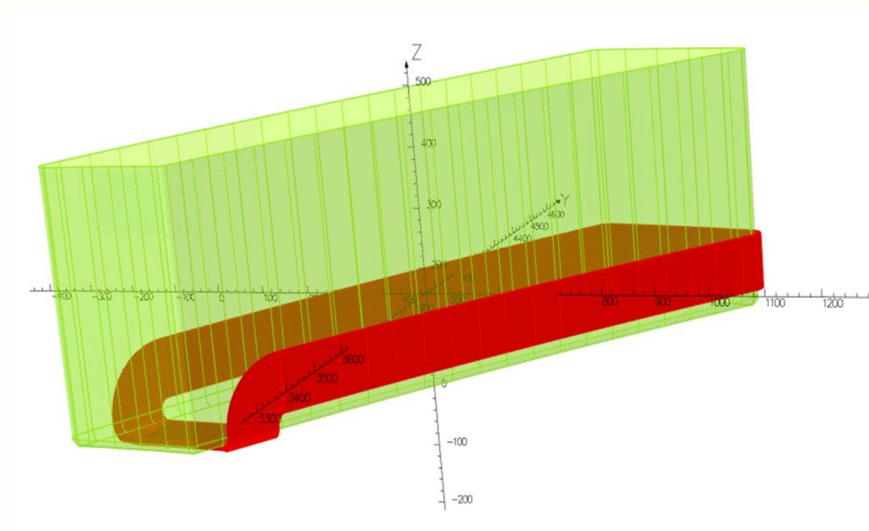
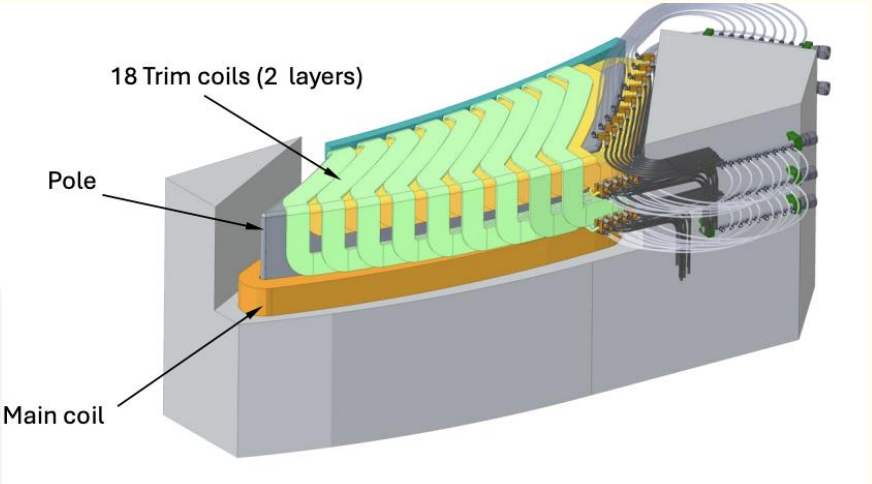
Geometry of trim coils

Horizontal bend to perpendicular of the spiral edge of the pole



Circular arc from the centre of the machine





(Design from LhARA, different from FETS-FFA but principle of trim coils is the same)

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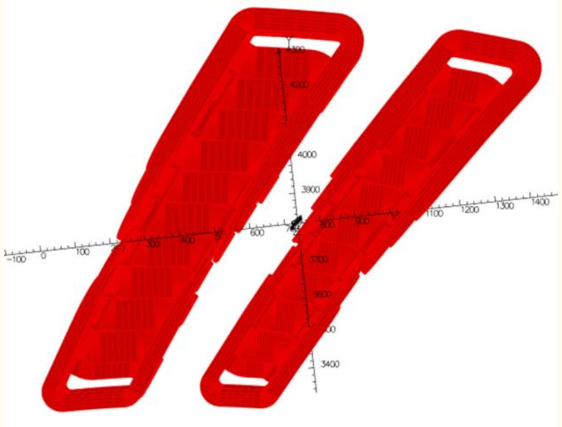
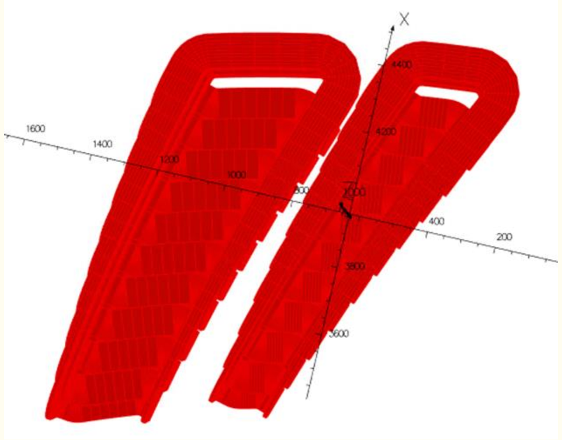
Different ways of wrapping the trim coils

Returning on the inside or outside of the pole, adds or subtracts to the main coil field respectively
Current values remains invariant apart from polarity

4 in 6 out

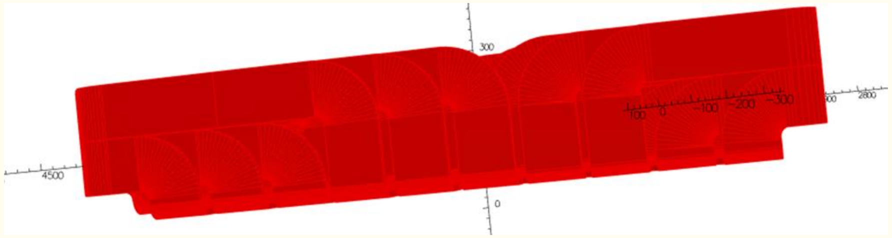


0 in 10 out

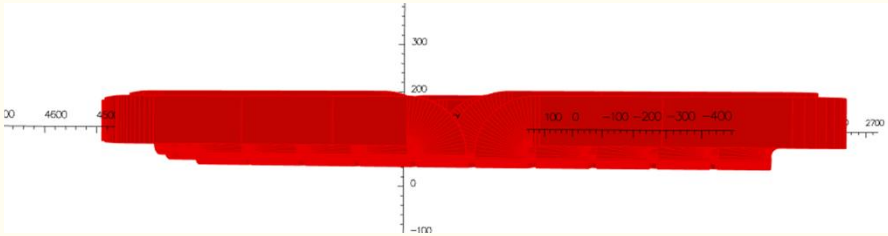


Returning on two height layers (Reduces thickness but increases pole height)

Two layers



One layer



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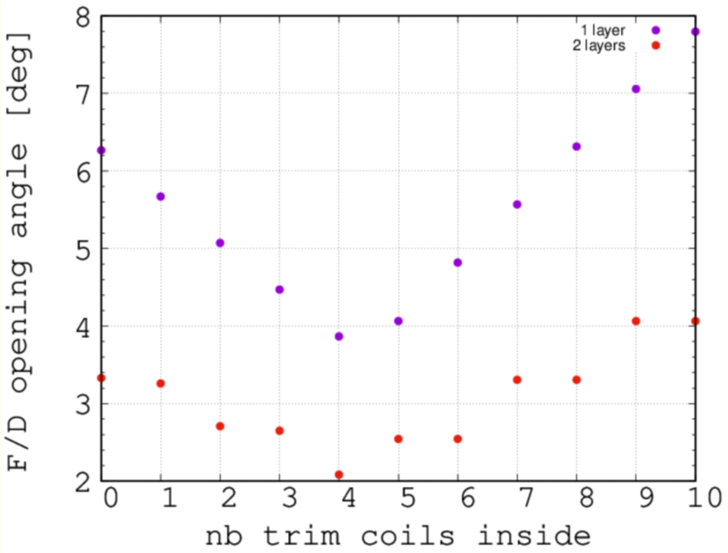
Opening angle between F and D magnet



	Initial lattice design (Degrees)	Magnet physical size (Degrees)
F	4.5	4.5
F/D	2.25	3.55
D	2.25	2.5
Between pole and clamp	N/A	1.92

4 in 6 out produces the smallest opening angle

0 in 10 out is the most efficient in terms of current, this is the chosen design

Opening angle between F/D increased to Accommodate thickness of coils

D pole opening angle increased to keep the constant radius part to half of the pole length

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4-fold symmetry

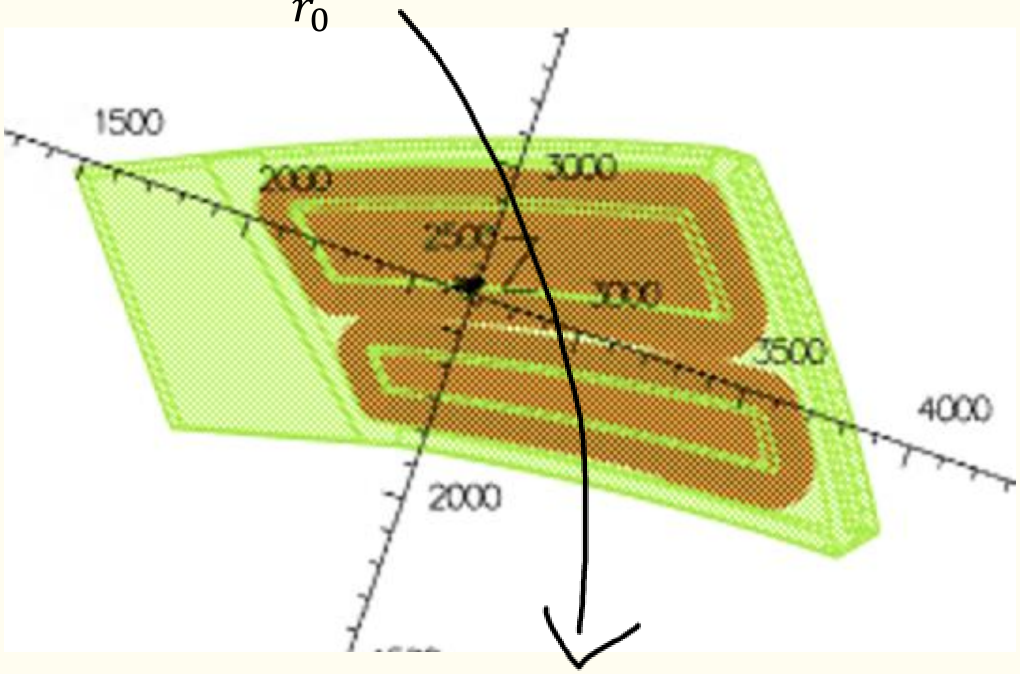
- Clamps between doublet 2 and 3 removed due to space constraint magnetic behavior needs to be studied
- Optimisation work was done on doublet 4 for different working points
- Tracking in a 16-fold symmetry lattice, will still give us an insight on the tune behaviour

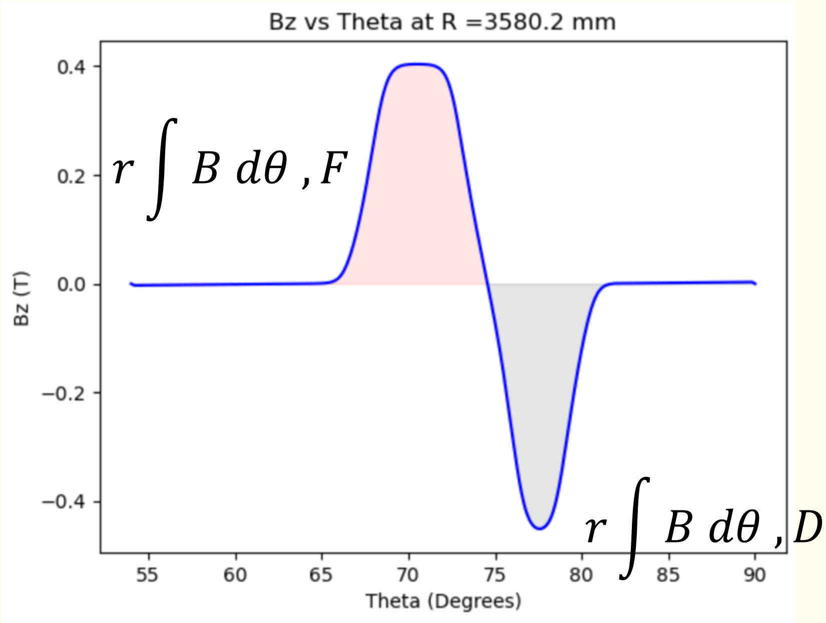
Optimisation of current

Integrated B field

Not enough parameters to make k constant everywhere on the azimuth, Instead make the integrated k constant.

$$BL = BL_0 \left(\frac{r}{r_0}\right)^{k+1} \qquad k = \frac{r}{BL}\frac{\partial BL}{\partial r} - 1 \qquad BL = r\int B\, d\theta$$





Using where the field crosses zero as a boundary, separate the integral into F and D sections

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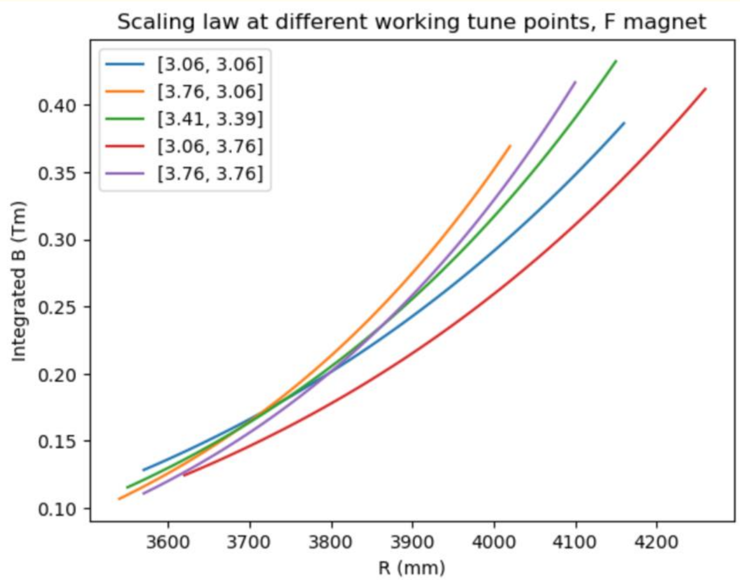

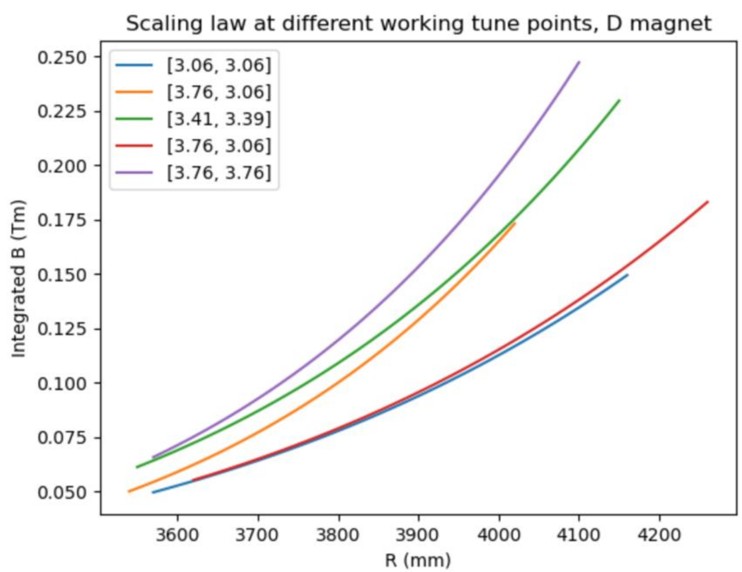

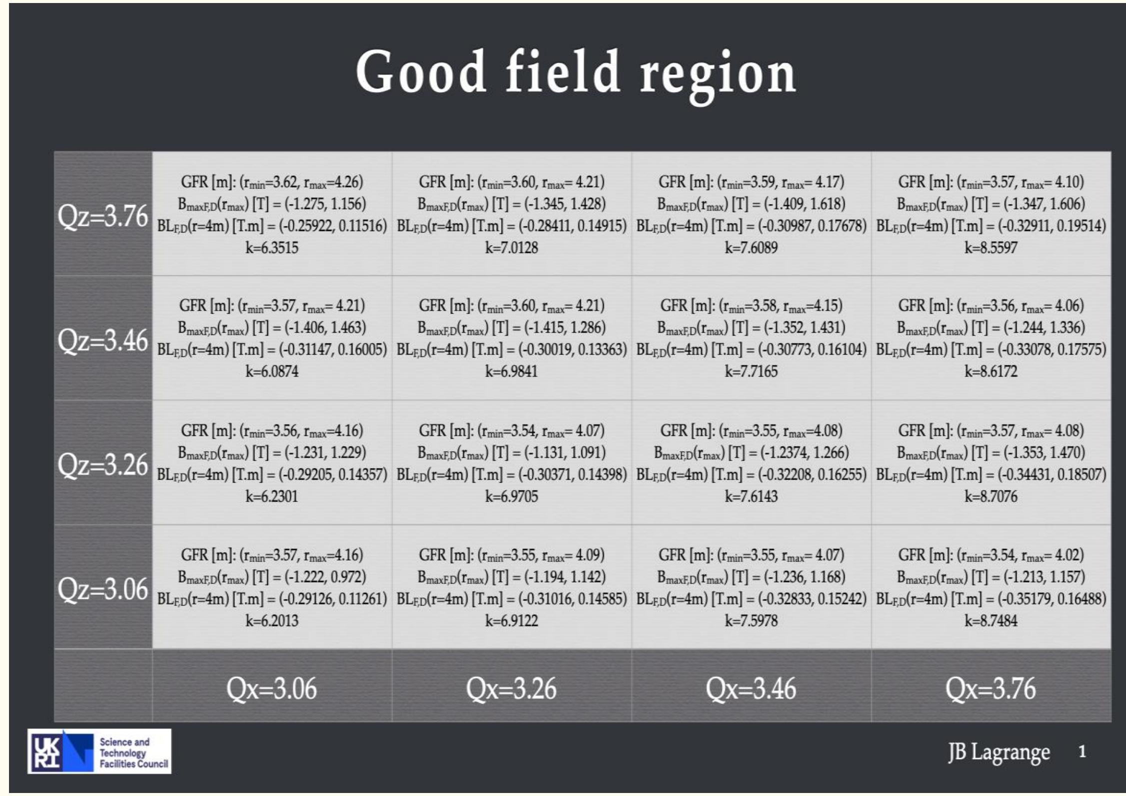

Good field region

Qz=3.76	GFR [m]: (r_{min}=3.62, r_{max}=4.26) $B_{maxF,D}(r_{max})$ [T] = (-1.275, 1.156) $BL_{F,D}$(r=4m) [T.m] = (-0.25922, 0.11516) k=6.3515	GFR [m]: (r_{min}=3.60, r_{max}= 4.21) $B_{maxF,D}(r_{max})$ [T] = (-1.345, 1.428) $BL_{F,D}$(r=4m) [T.m] = (-0.28411, 0.14915) k=7.0128	GFR [m]: (r_{min}=3.59, r_{max}= 4.17) $B_{maxF,D}(r_{max})$ [T] = (-1.409, 1.618) $BL_{F,D}$(r=4m) [T.m] = (-0.30987, 0.17678) k=7.6089	GFR [m]: (r_{min}=3.57, r_{max}= 4.10) $B_{maxF,D}(r_{max})$ [T] = (-1.347, 1.606) $BL_{F,D}$(r=4m) [T.m] = (-0.32911, 0.19514) k=8.5597
Qz=3.46	GFR [m]: (r_{min}=3.57, r_{max}= 4.21) $B_{maxF,D}(r_{max})$ [T] = (-1.406, 1.463) $BL_{F,D}$(r=4m) [T.m] = (-0.31147, 0.16005) k=6.0874	GFR [m]: (r_{min}=3.60, r_{max}= 4.21) $B_{maxF,D}(r_{max})$ [T] = (-1.415, 1.286) $BL_{F,D}$(r=4m) [T.m] = (-0.30019, 0.13363) k=6.9841	GFR [m]: (r_{min}=3.58, r_{max}=4.15) $B_{maxF,D}(r_{max})$ [T] = (-1.352, 1.431) $BL_{F,D}$(r=4m) [T.m] = (-0.30773, 0.16104) k=7.7165	GFR [m]: (r_{min}=3.56, r_{max}= 4.06) $B_{maxF,D}(r_{max})$ [T] = (-1.244, 1.336) $BL_{F,D}$(r=4m) [T.m] = (-0.33078, 0.17575) k=8.6172
Qz=3.26	GFR [m]: (r_{min}=3.56, r_{max}=4.16) $B_{maxF,D}(r_{max})$ [T] = (-1.231, 1.229) $BL_{F,D}$(r=4m) [T.m] = (-0.29205, 0.14357) k=6.2301	GFR [m]: (r_{min}=3.54, r_{max}= 4.07) $B_{maxF,D}(r_{max})$ [T] = (-1.131, 1.091) $BL_{F,D}$(r=4m) [T.m] = (-0.30371, 0.14398) k=6.9705	GFR [m]: (r_{min}=3.55, r_{max}=4.08) $B_{maxF,D}(r_{max})$ [T] = (-1.2374, 1.266) $BL_{F,D}$(r=4m) [T.m] = (-0.32208, 0.16255) k=7.6143	GFR [m]: (r_{min}=3.57, r_{max}= 4.08) $B_{maxF,D}(r_{max})$ [T] = (-1.353, 1.470) $BL_{F,D}$(r=4m) [T.m] = (-0.34431, 0.18507) k=8.7076
Qz=3.06	GFR [m]: (r_{min}=3.57, r_{max}=4.16) $B_{maxF,D}(r_{max})$ [T] = (-1.222, 0.972) $BL_{F,D}$(r=4m) [T.m] = (-0.29126, 0.11261) k=6.2013	GFR [m]: (r_{min}=3.55, r_{max}= 4.09) $B_{maxF,D}(r_{max})$ [T] = (-1.194, 1.142) $BL_{F,D}$(r=4m) [T.m] = (-0.31016, 0.14585) k=6.9122	GFR [m]: (r_{min}=3.55, r_{max}= 4.07) $B_{maxF,D}(r_{max})$ [T] = (-1.236, 1.168) $BL_{F,D}$(r=4m) [T.m] = (-0.32833, 0.15242) k=7.5978	GFR [m]: (r_{min}=3.54, r_{max}= 4.02) $B_{maxF,D}(r_{max})$ [T] = (-1.213, 1.157) $BL_{F,D}$(r=4m) [T.m] = (-0.35179, 0.16488) k=8.7484
	Qx=3.06	Qx=3.26	Qx=3.46	Qx=3.76

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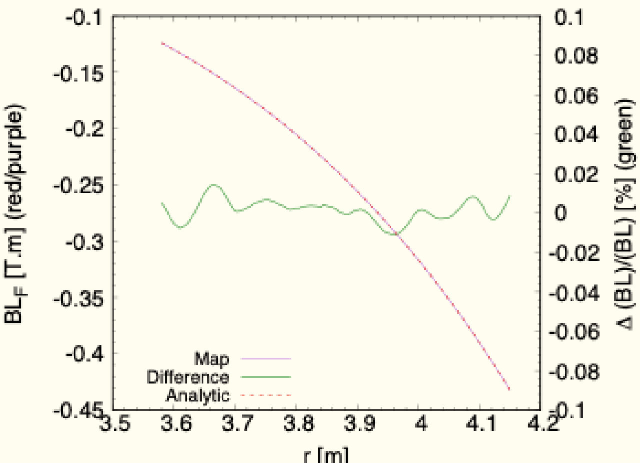
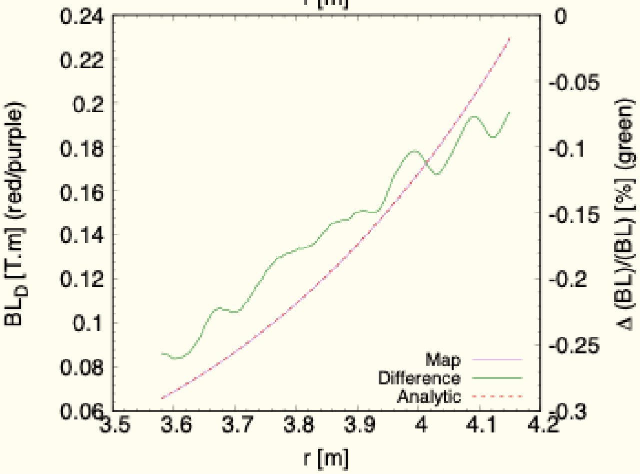
JB Lagrange 1

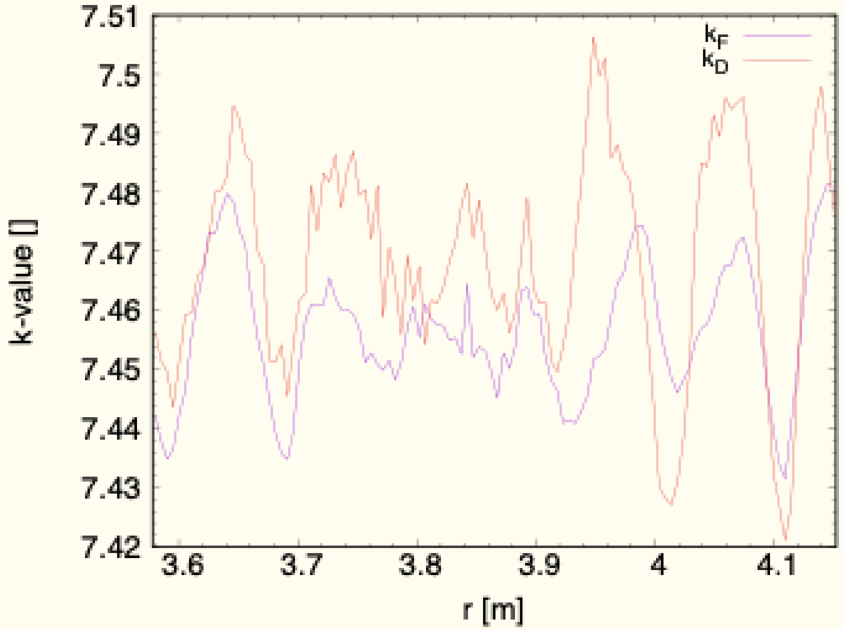
Central tune point [3.39,3.41] and the four working tune points at the Corners of this table was investigated

Field quality and k value after currents optimised





Wasn't interpolating fine enough the the previous code,
Which leads to a systematic growing trend.



Target k value: 7.46 +/- 0.04

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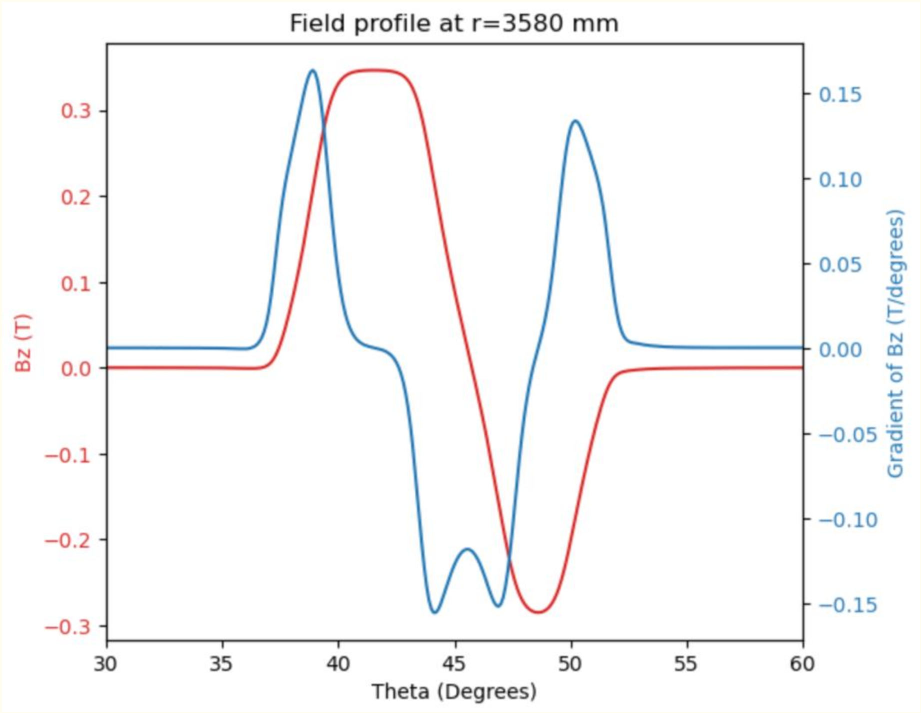
Spiral angle

Using the angle of the centre of moment θ_{COM} on the longitudinal gradient G of the field along a constant radius

$\theta_{COM} = \frac{\int G\,\theta\,d\theta}{\int G\,d\theta}$, where $G = \frac{\partial B_z}{\partial \theta}$, the gradient of the field with respect to theta.

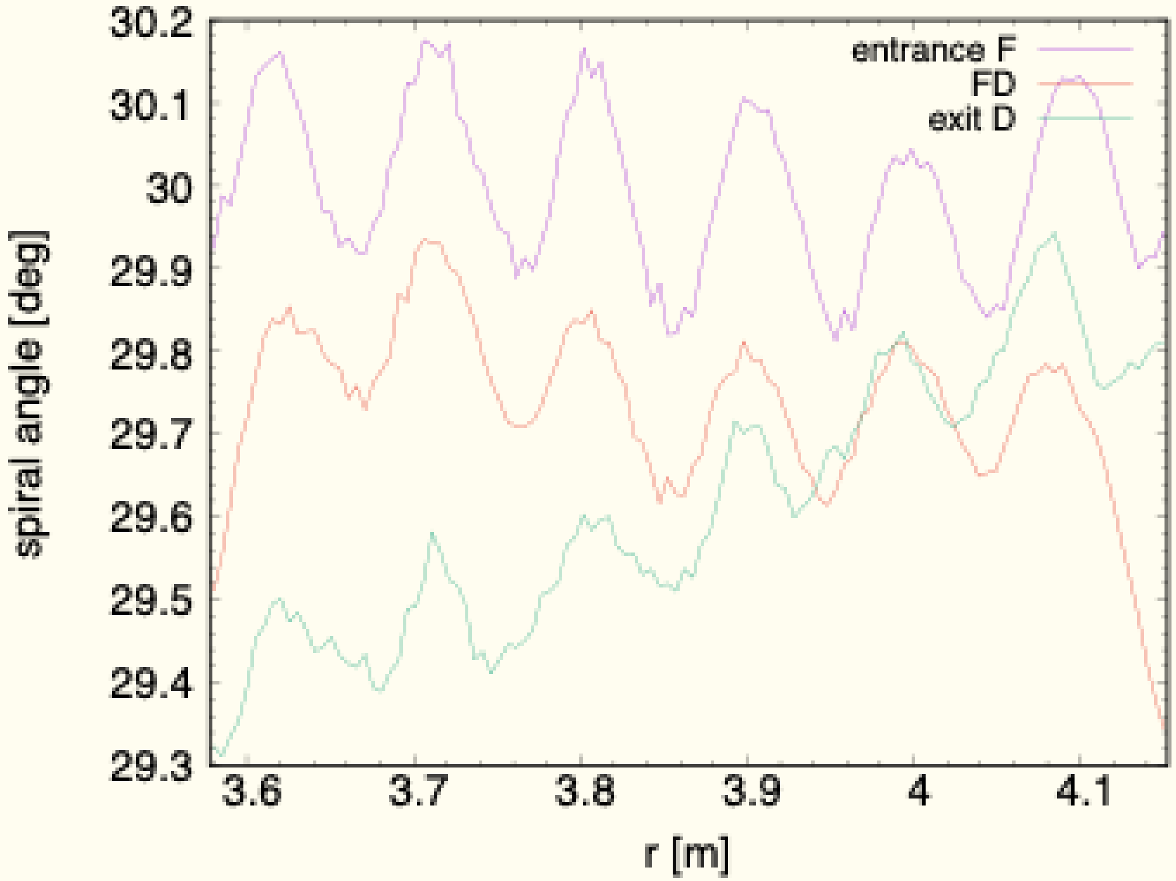


$$r\frac{d\theta_{Com}}{dr} = \tan(z)$$

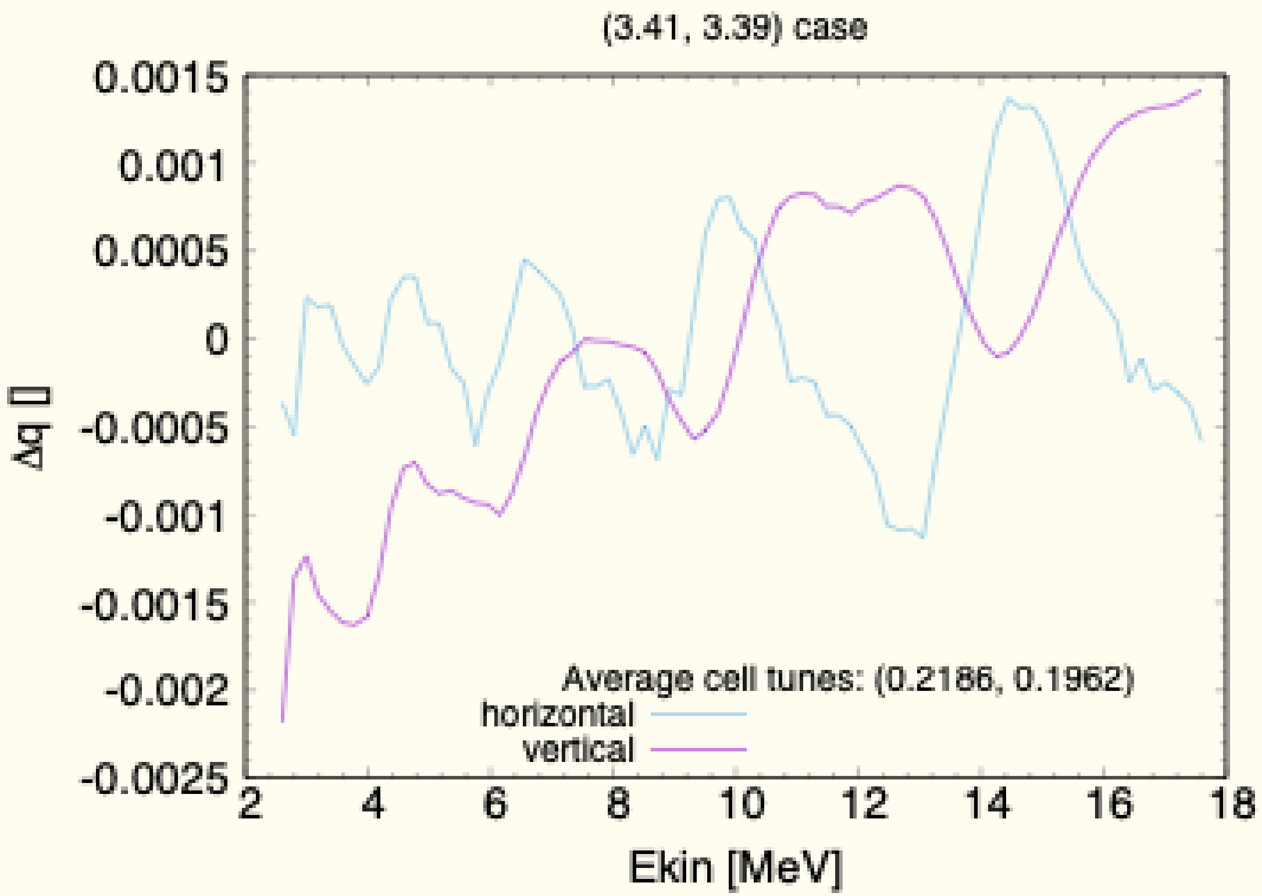
Introduce spiral angles for

- entrance F
- between F and D
- exit D

Spiral angle
Target +/- 0.2 degrees



Variation in cell tune



Target cell tune variation: +/- 0.000625

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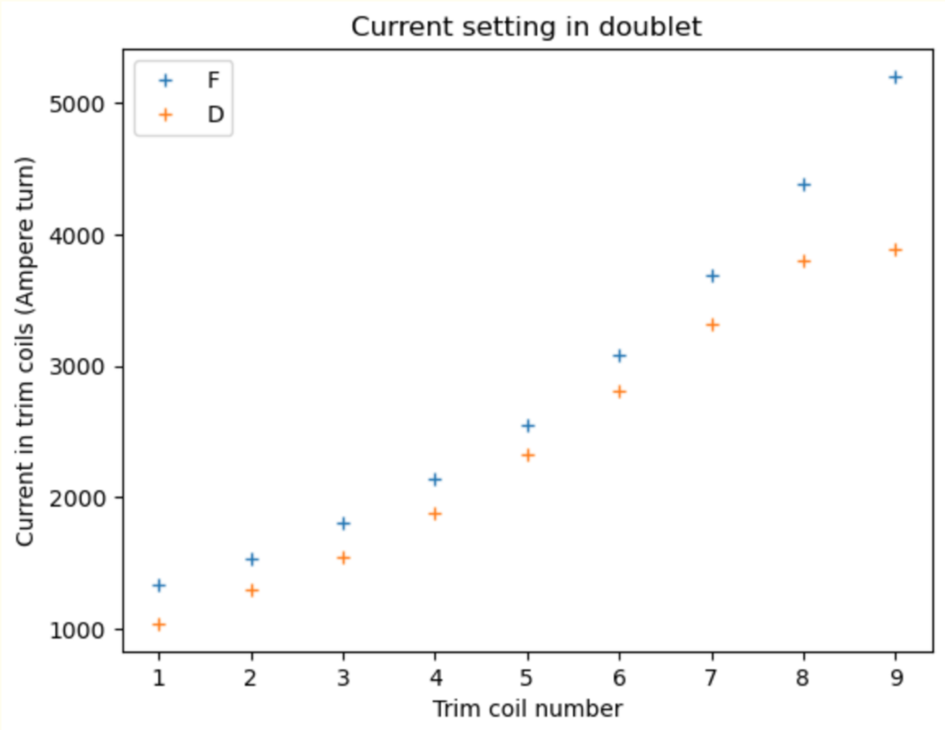
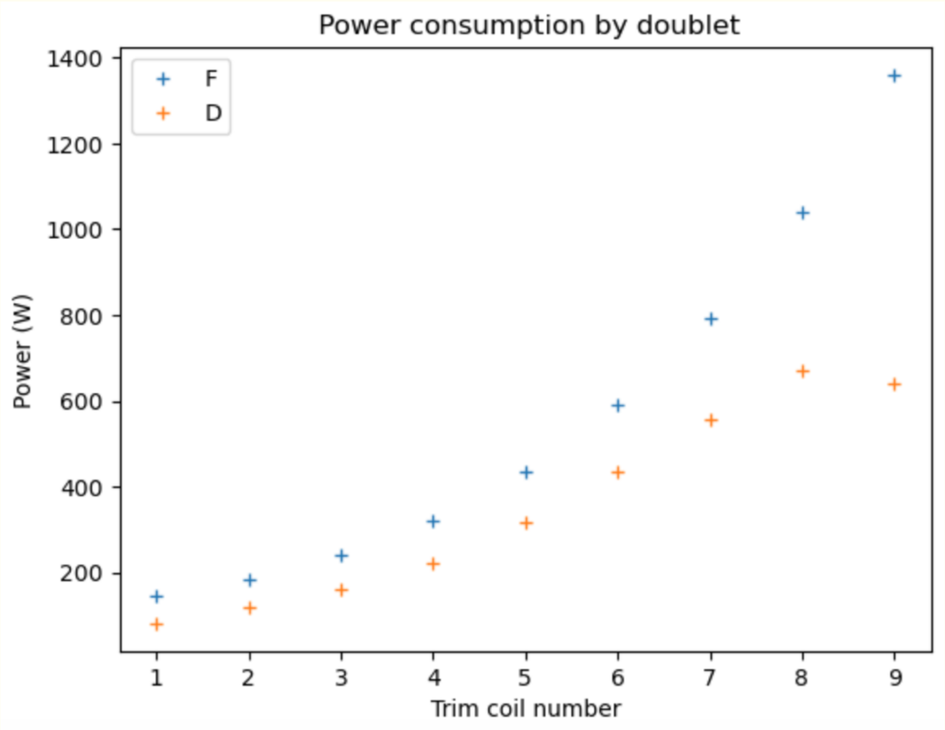
Power estimation





Main coil F: 11695 Ampere turn, 1060W
Main coil D: 10517 Ampere turn, 780W

Two layers of trim coils have same current settings but different lengths
Showing here the layer with longer length.

34 kW per doublet, 550kW for all the doublets (assuming all doublets are the same)

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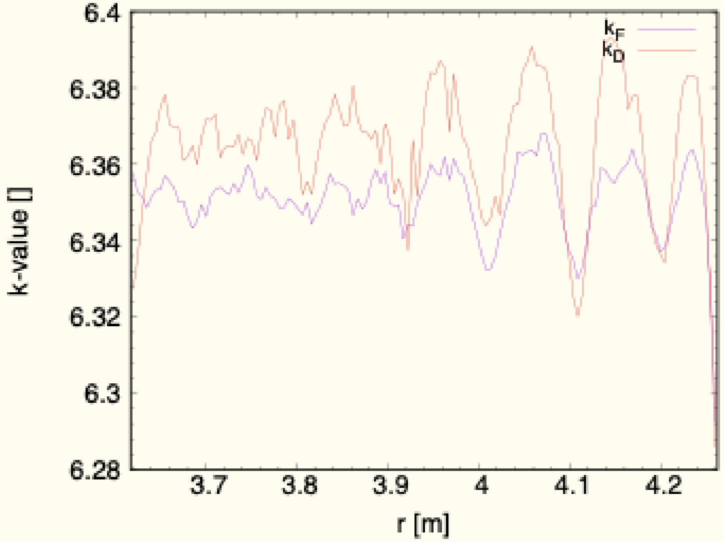
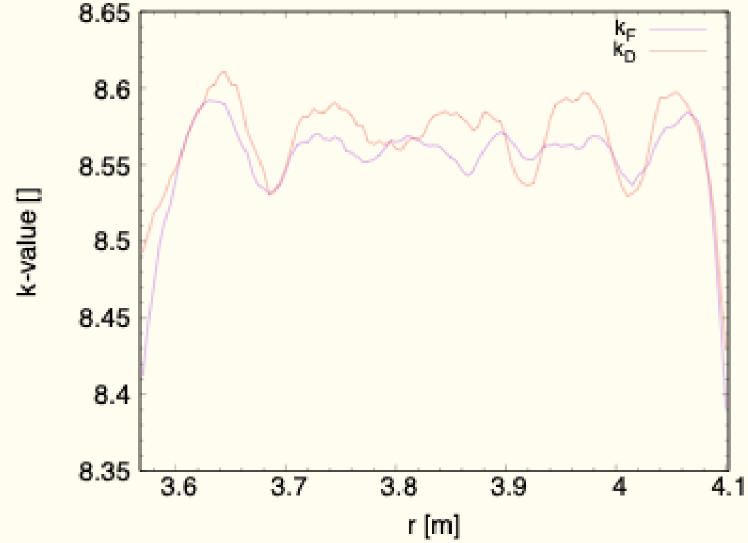
k value

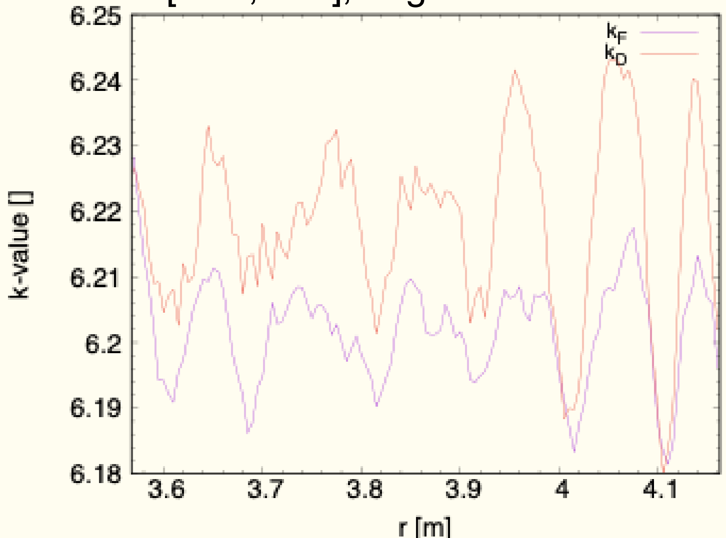
[3.06,3.76] , target k=6.35 +/ 0.04



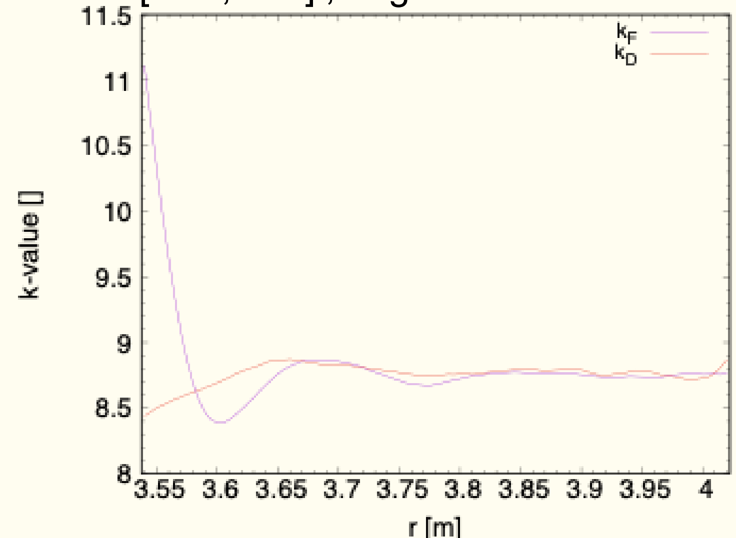
[3.76,3.76], target k=8.56 +/ 0.04



[3.06,3.06], target k=6.20 +/ 0.04

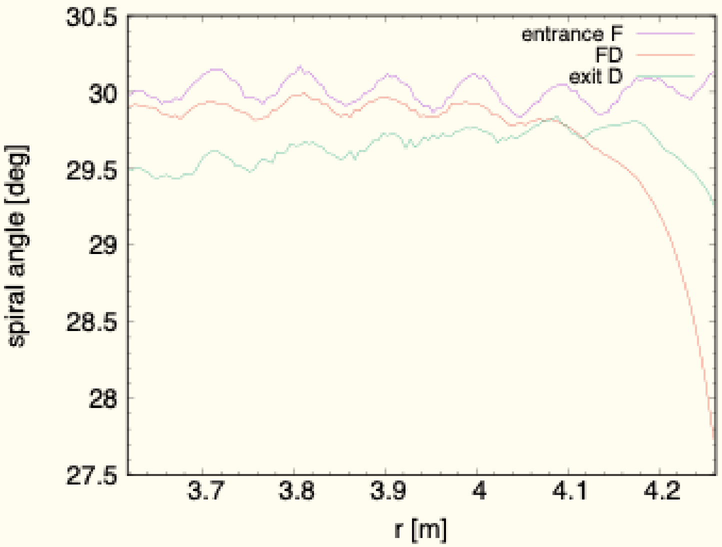


[3.76,3.06] , target k=8.75 +/ 0.04

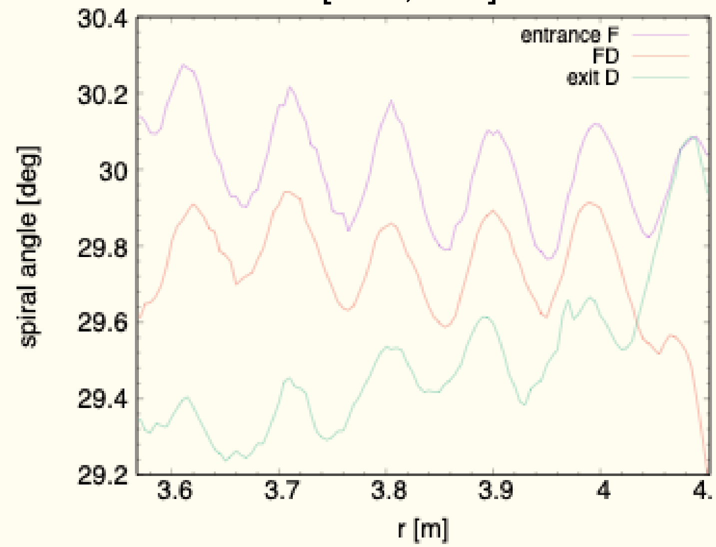


Spiral angle, target 30.0 +/- 0.2

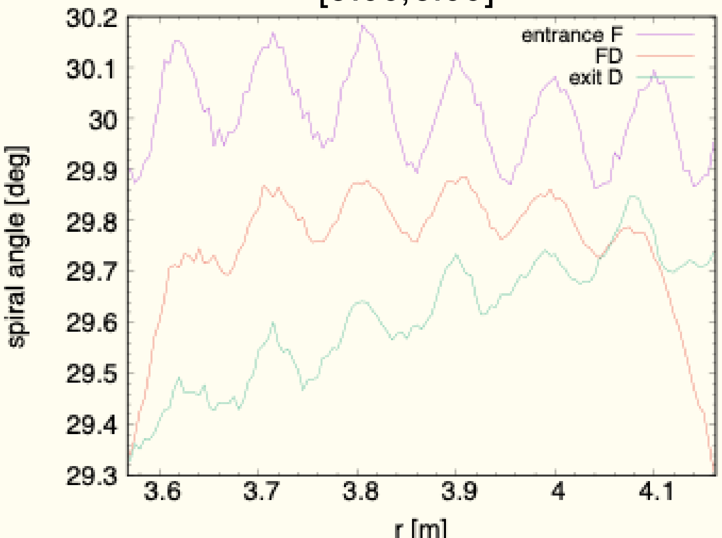
[3.06,3.76]



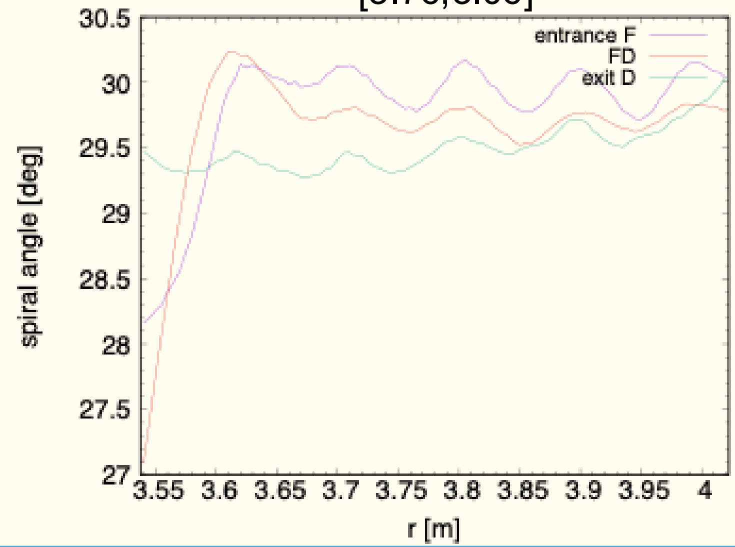
[3.76,3.76]



[3.06,3.06]



[3.76,3.06]



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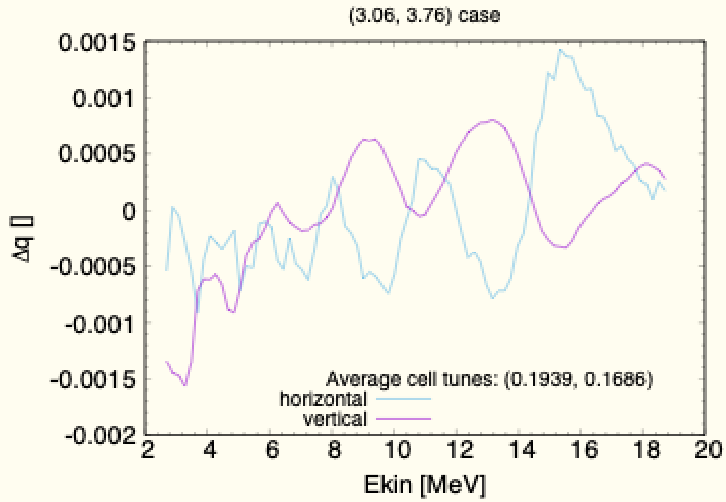
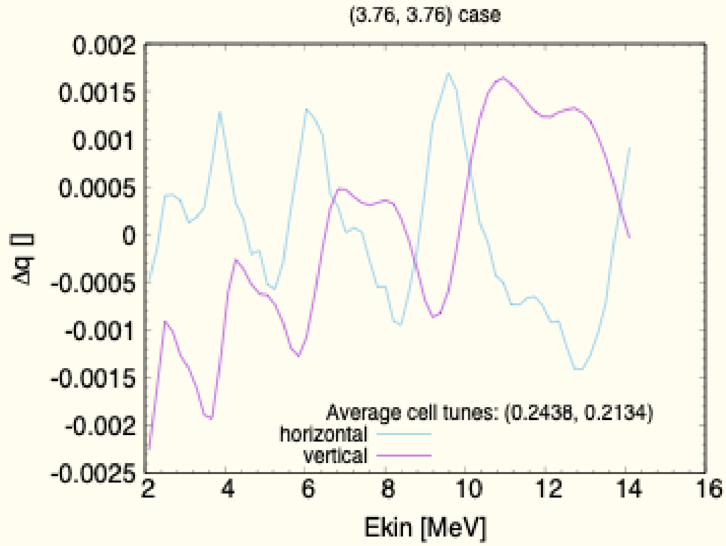
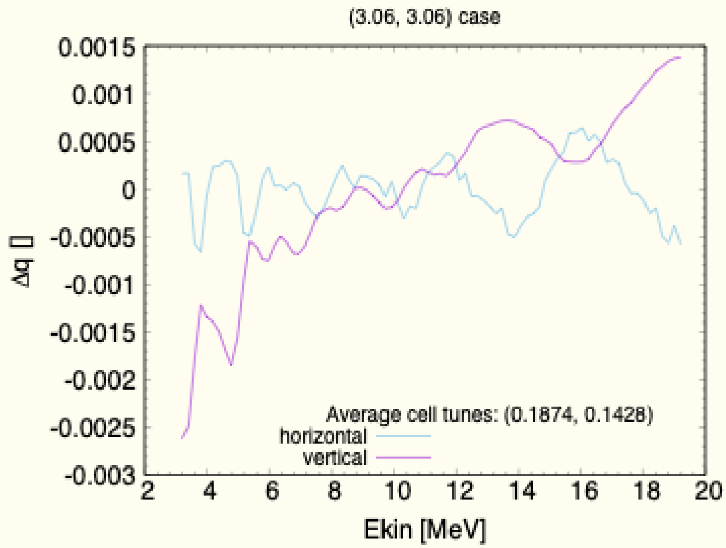
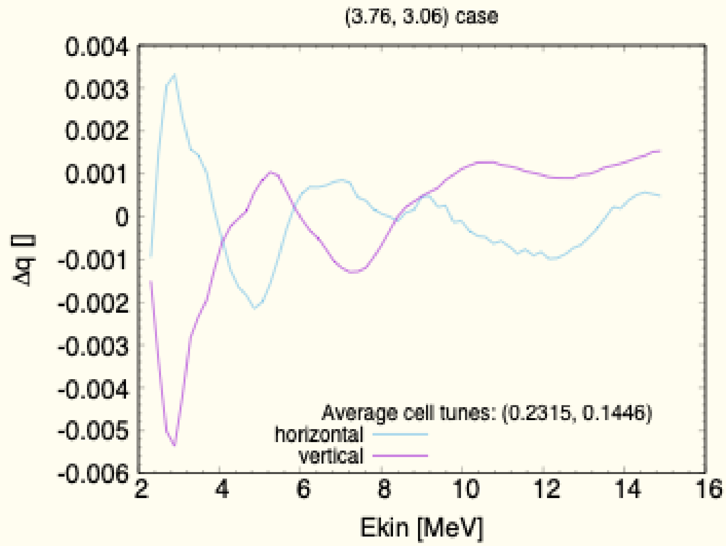
Variation in cell tune, target +/- 0.000625

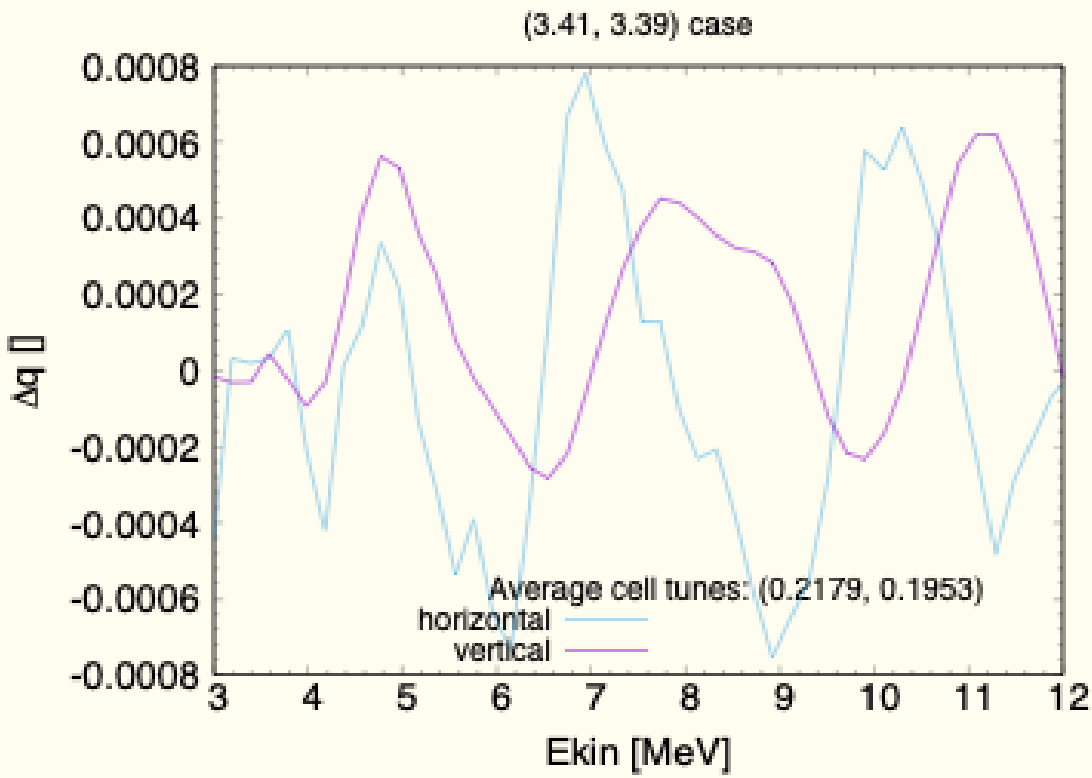






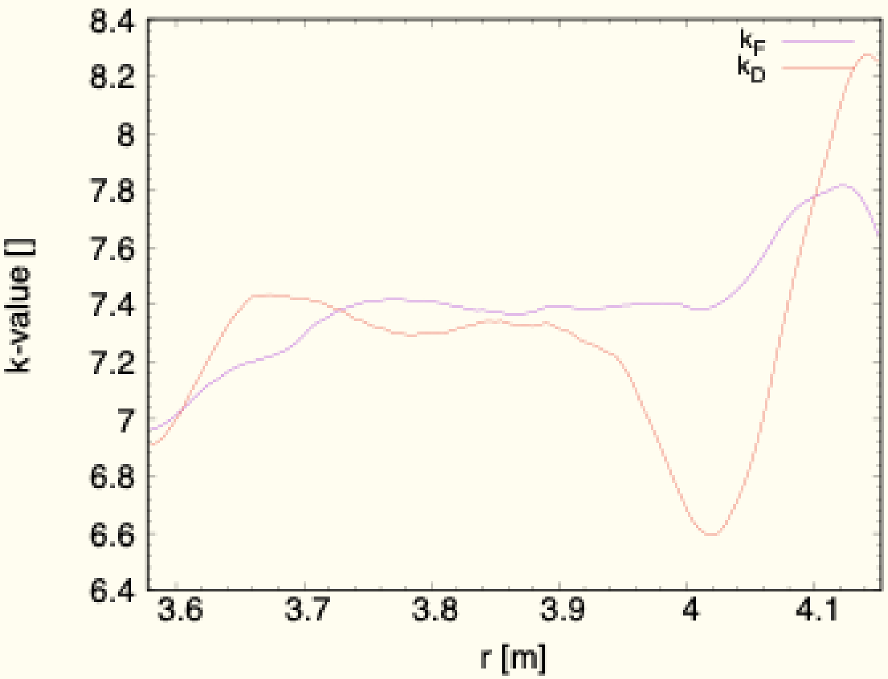


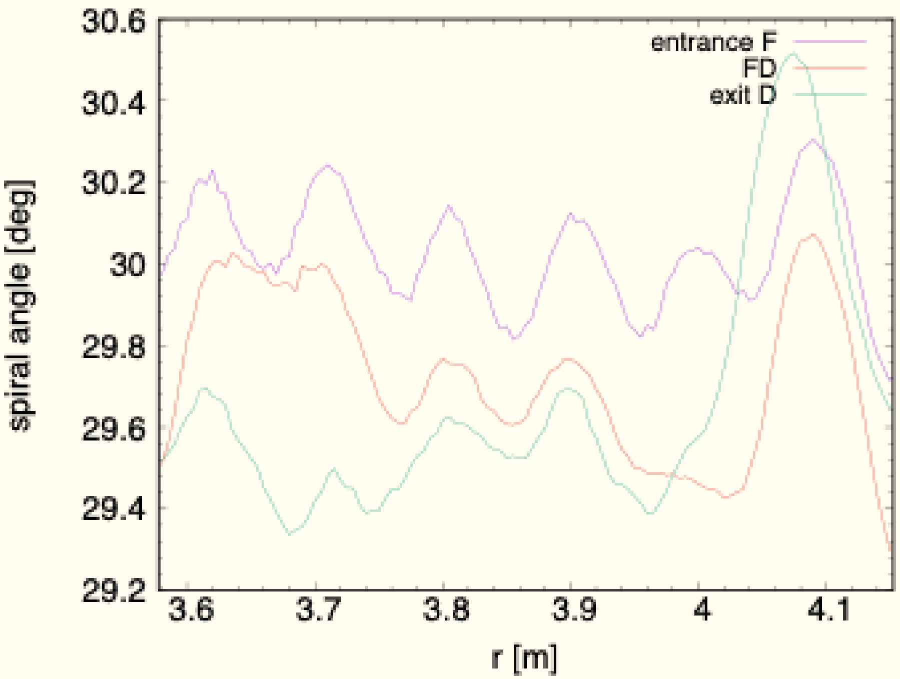
Using tune as target function for optimisation



Cell tune variation closer to the target of +/- 0.000625, violates scaling law (next slide)

Using tune as target function for optimisation





Significantly deviates from the scaling law, could have a big impact on the dynamic aperture that needs to be studied

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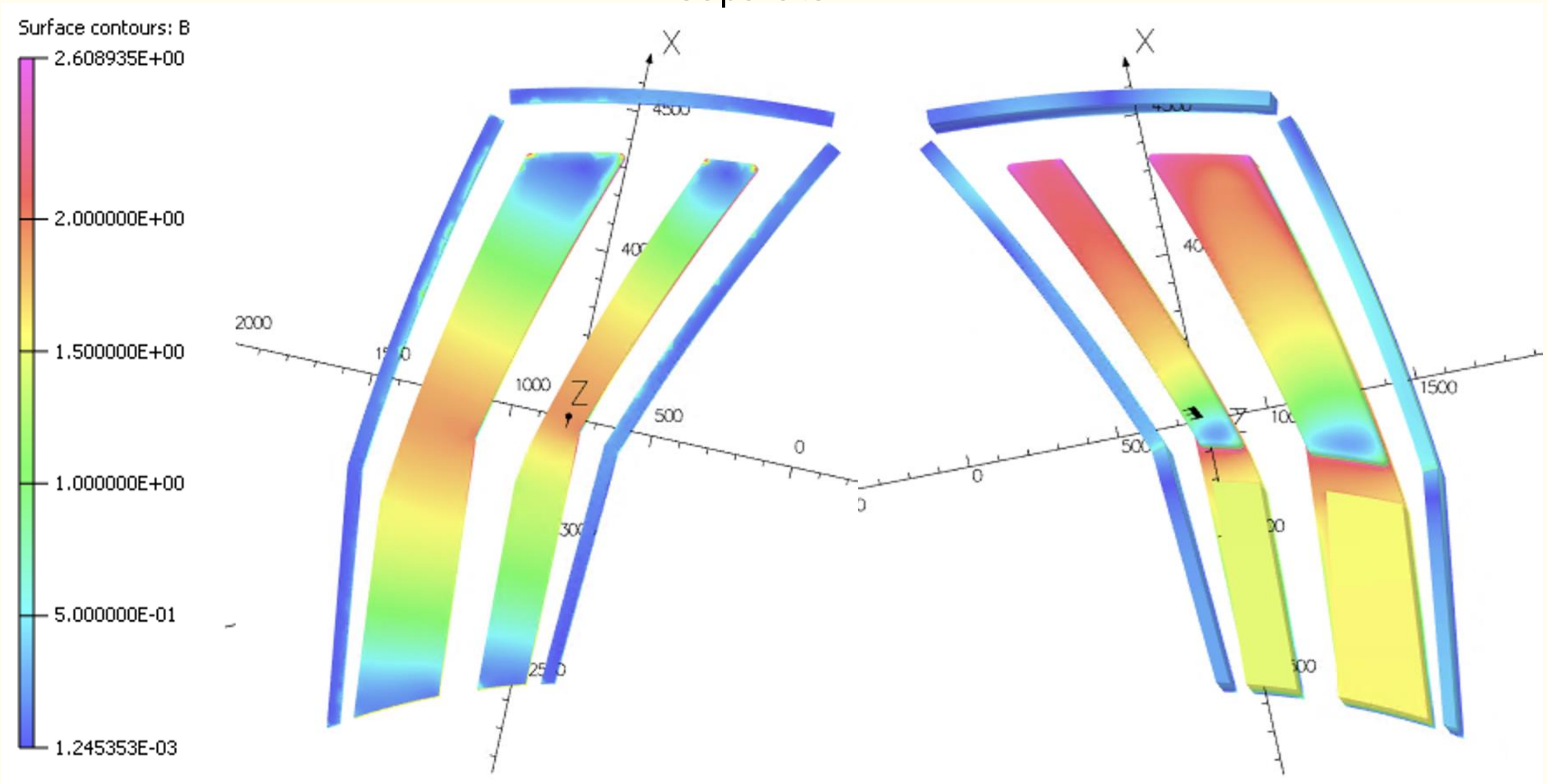
Conclusion

- Variation in horizontal tune close to the target requirement
- Increasing trend in the vertical tune can be flattened by optimizing the clamps and/or pole shape. The amplitude of oscillation will be similar to that of the horizontal tune and fulfill the specification.
- Variation in vertical tune can also be flattened by using the tune as the target when optimising the currents. A Careful dynamic aperture study will be required at all energies

Extra slides

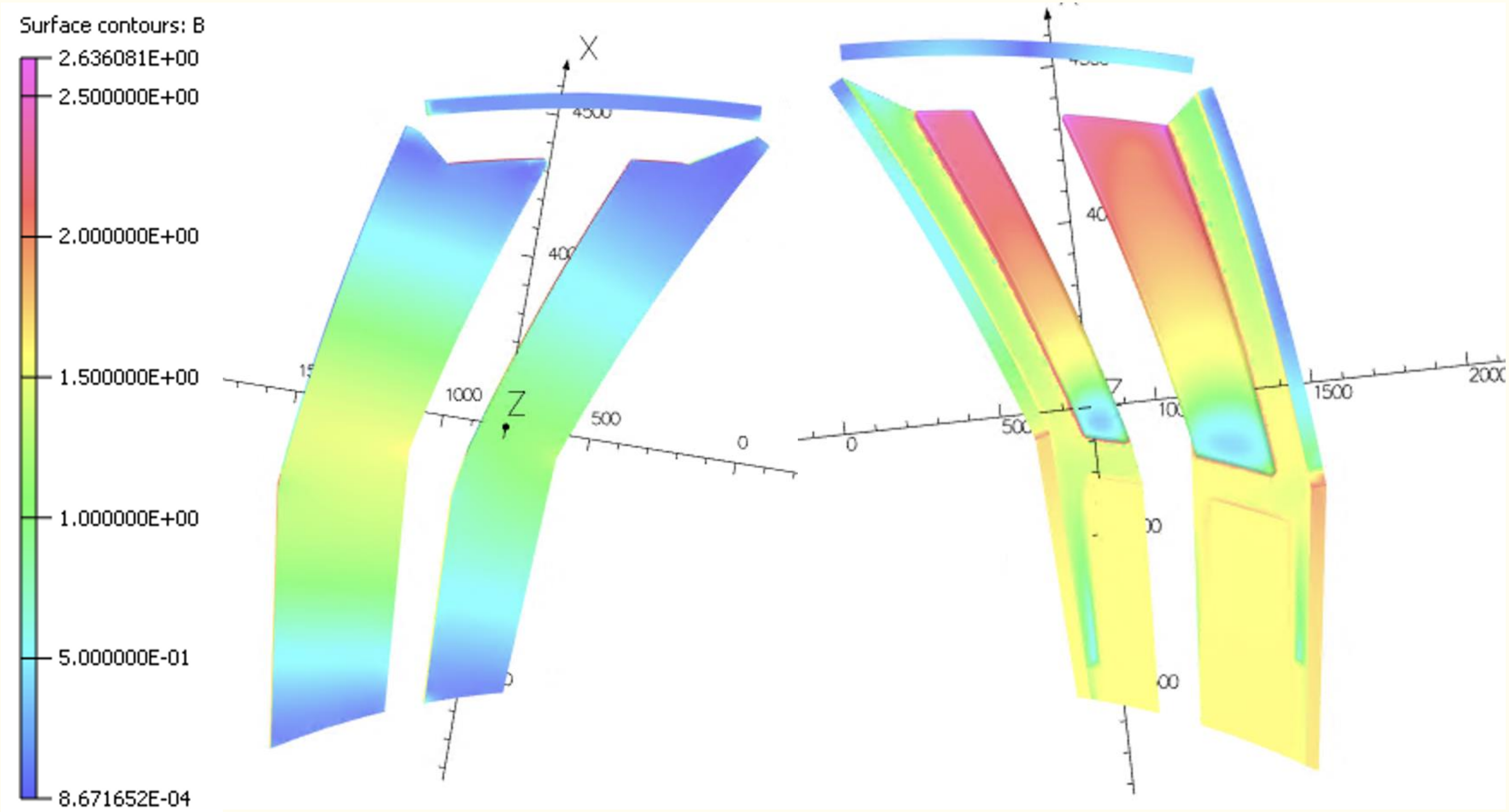
The initial design of the doublet had separate F/D magnets and clamps

All separate

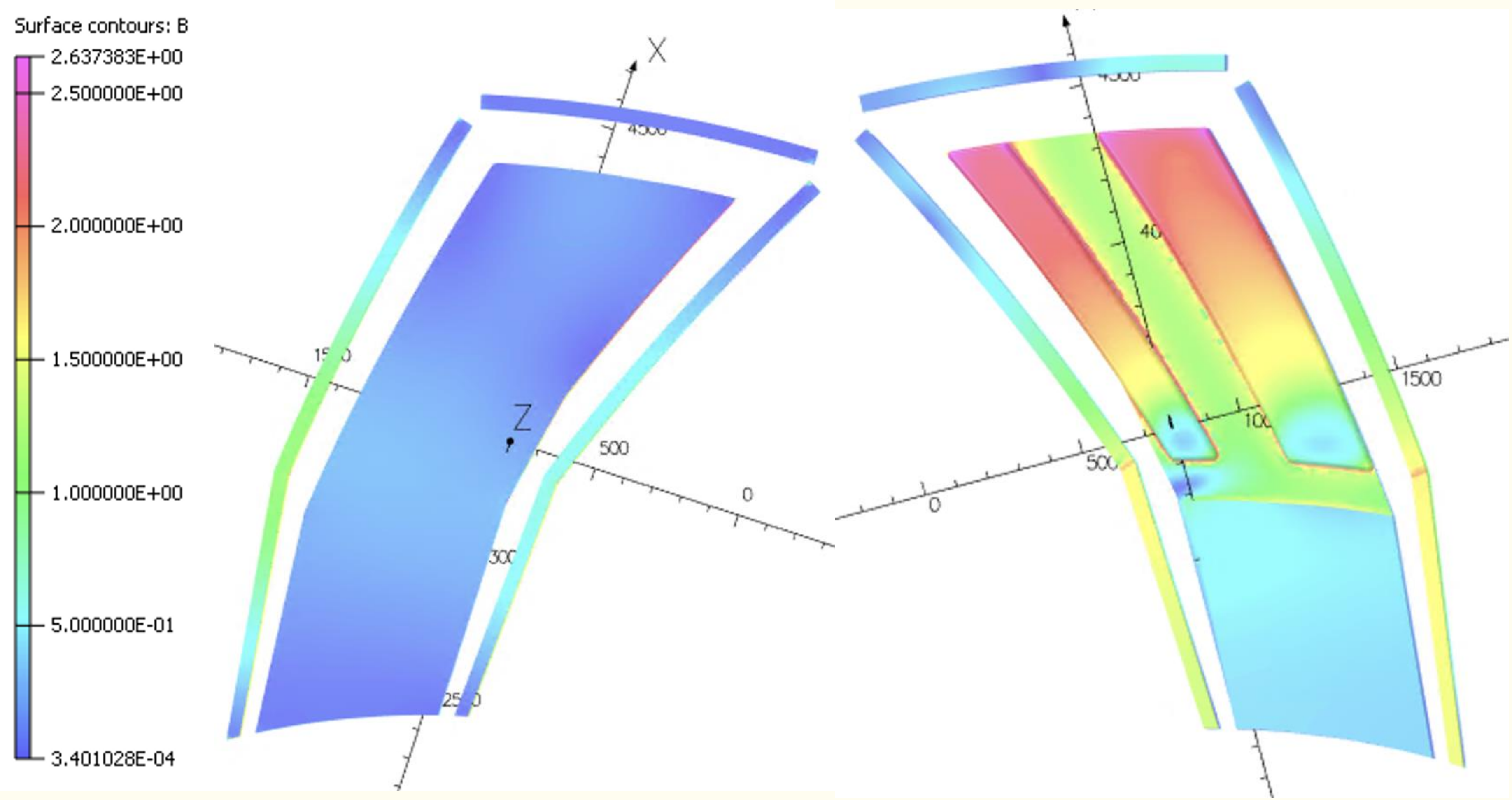


Several other designs were explored with the same current settings

Pole connected with clamps

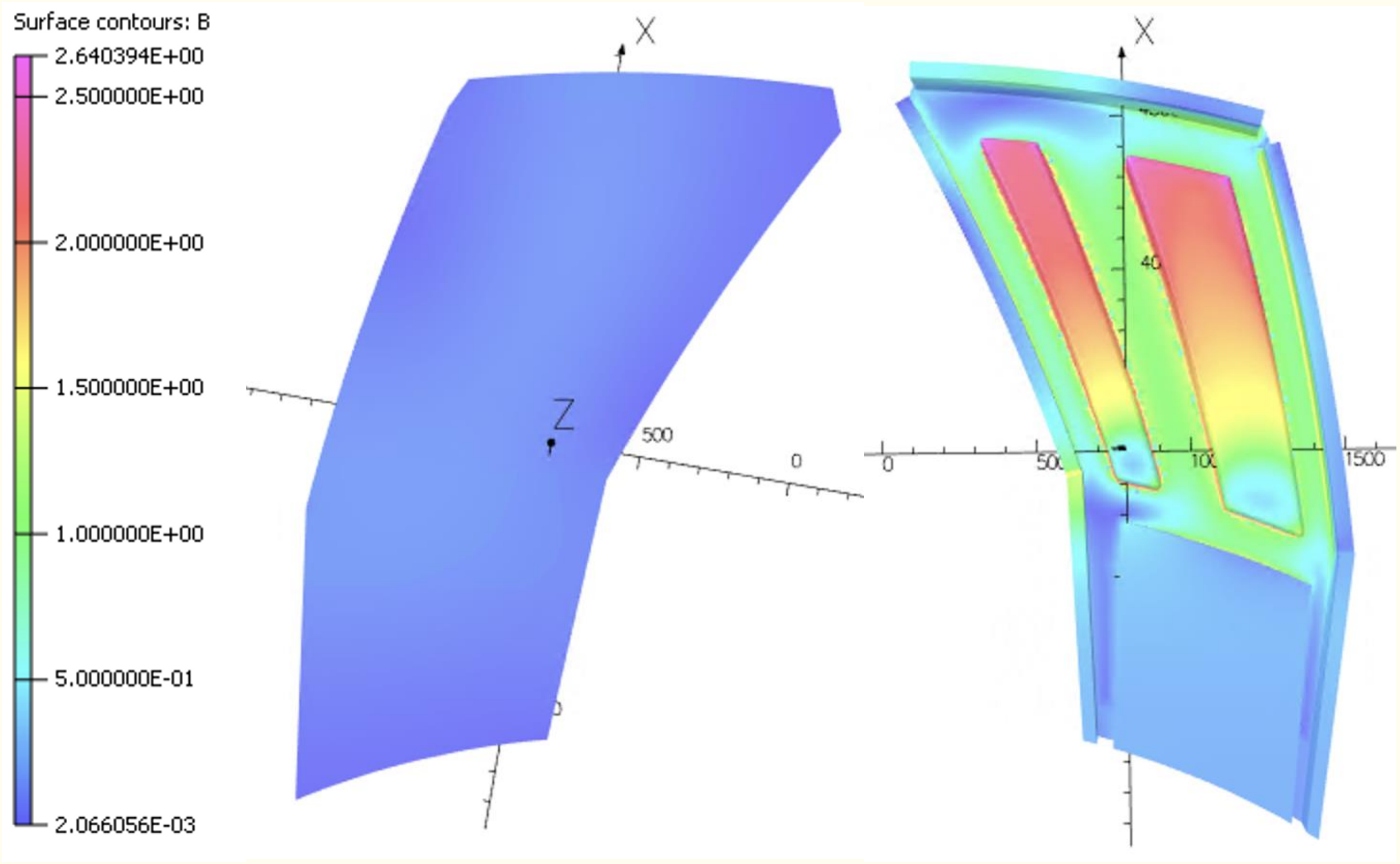


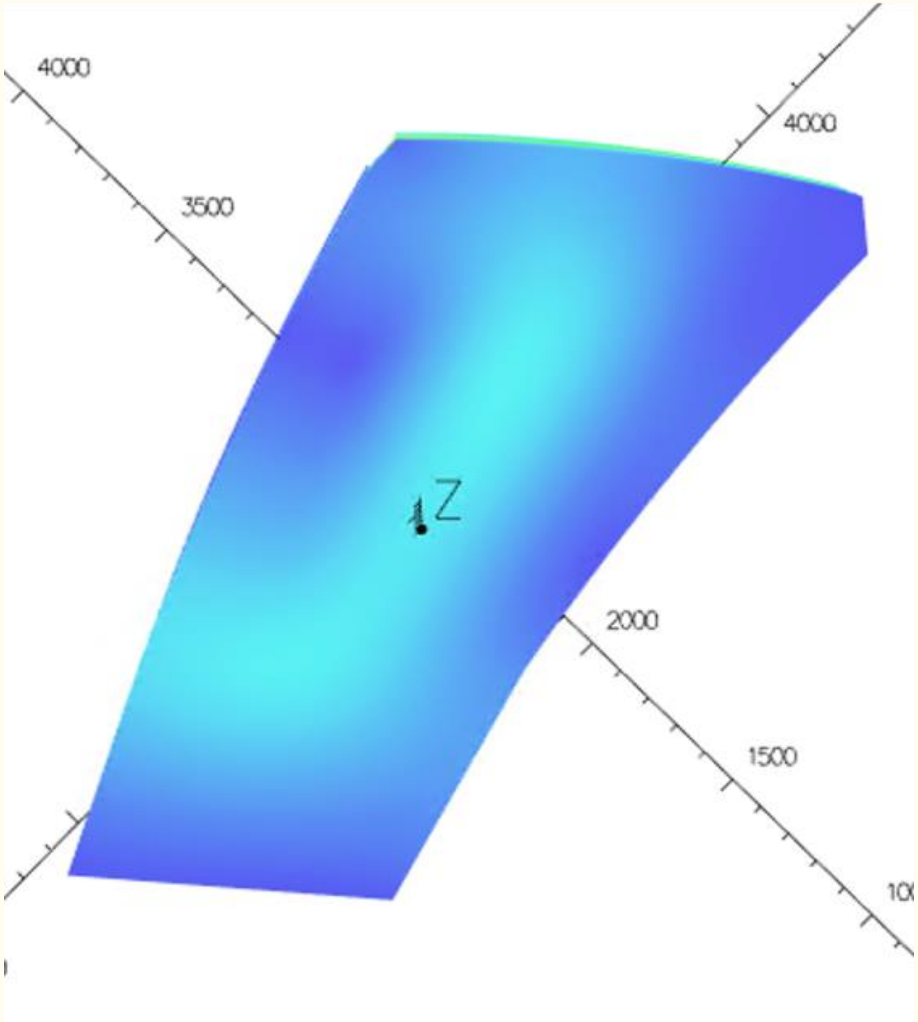
FD connected



Instead connect everything together with iron

All together

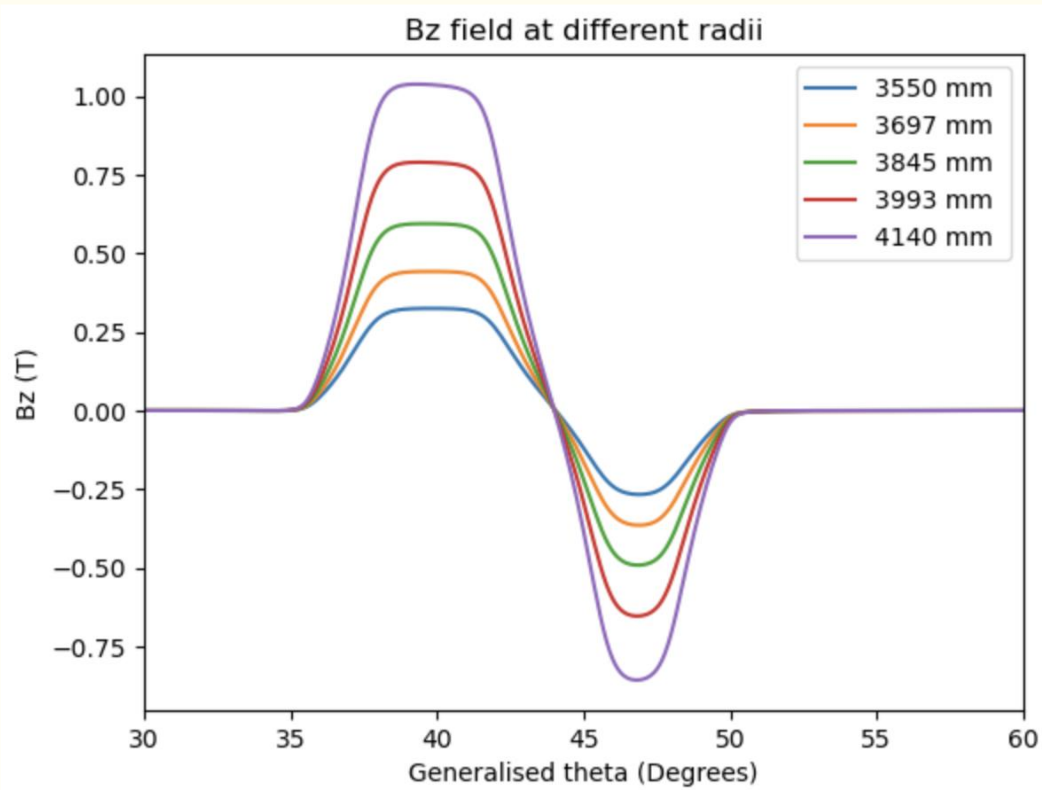


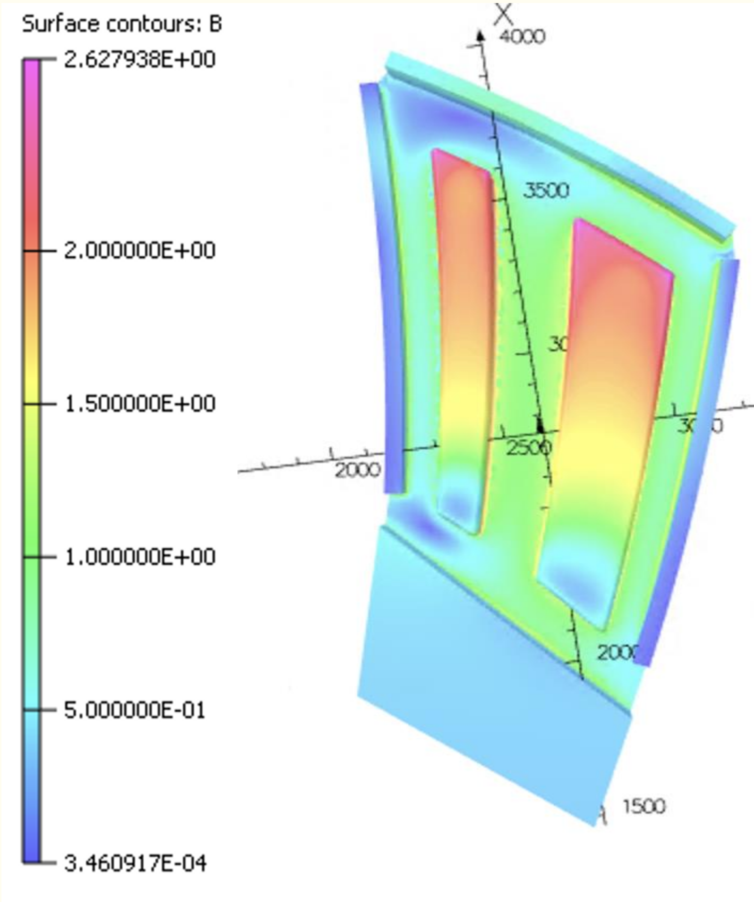


By reducing the yoke height further, we can See the flux returning between F and D Pole making it more current efficient.

Saturation level and Bz field profiles on midplane

Pole reaching 2.6T
Short D magnet, flat top never reached





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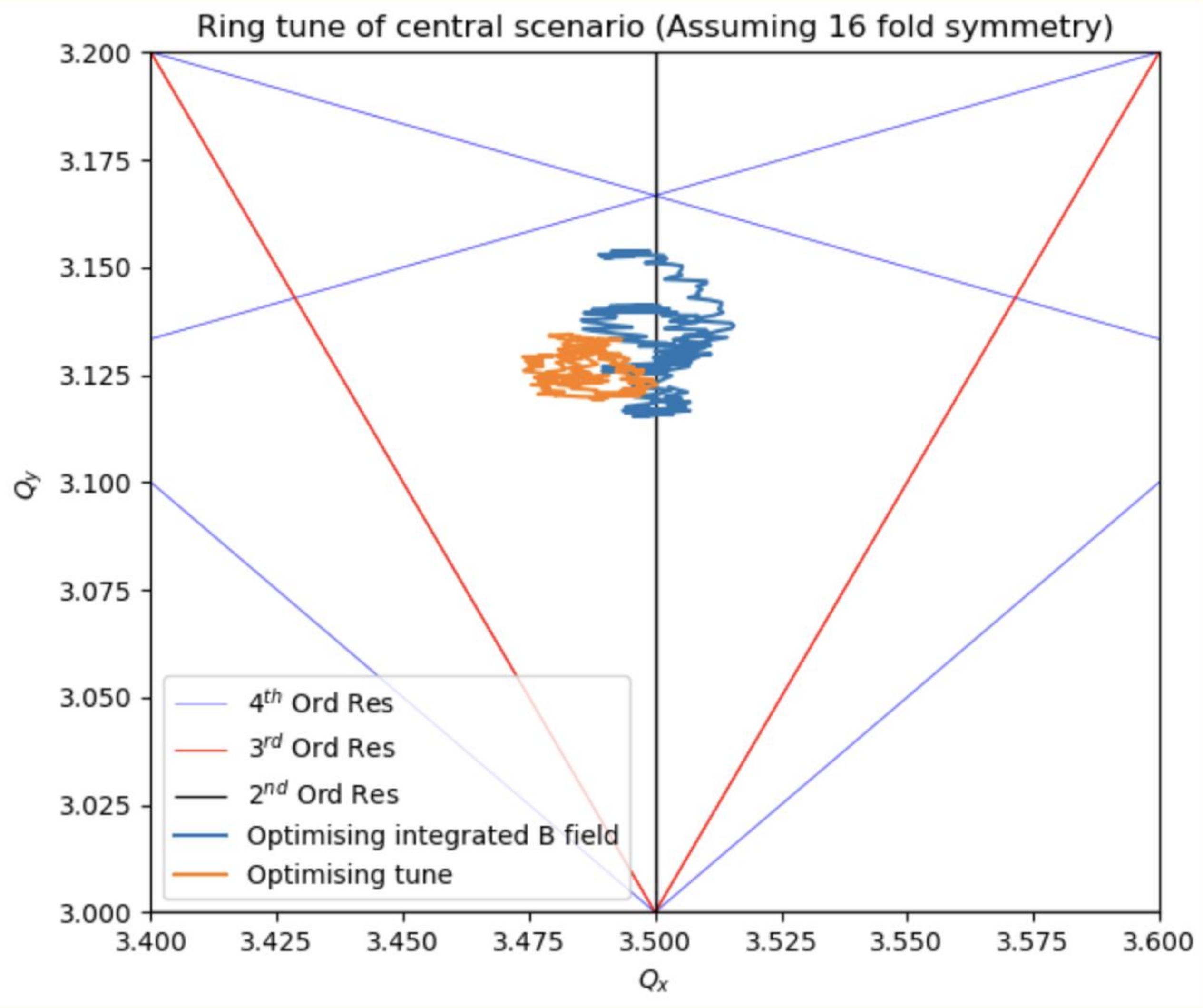
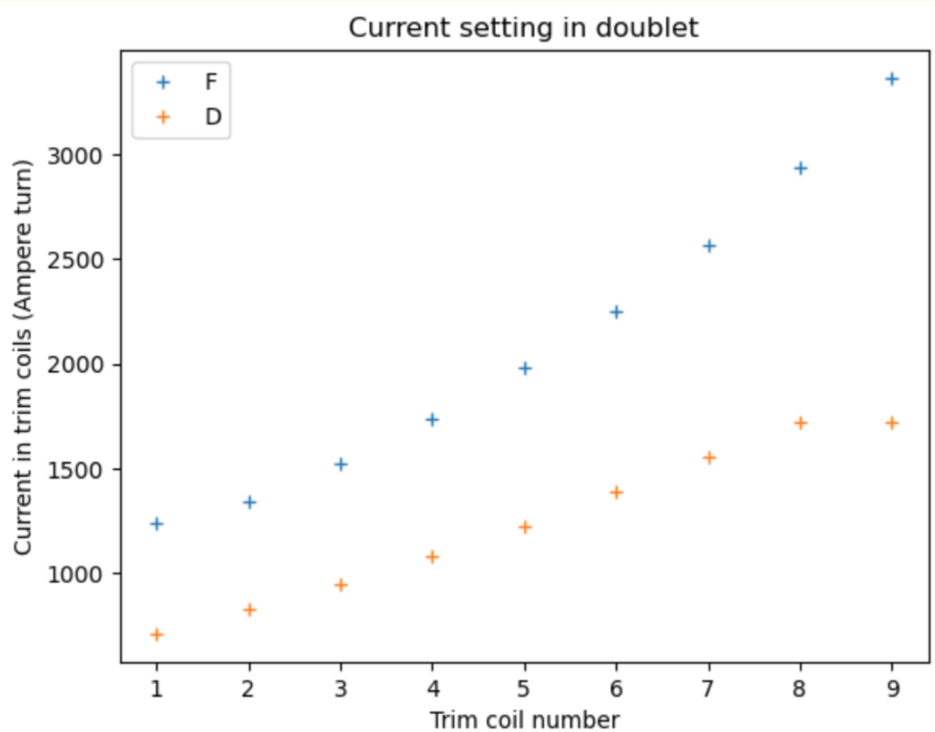
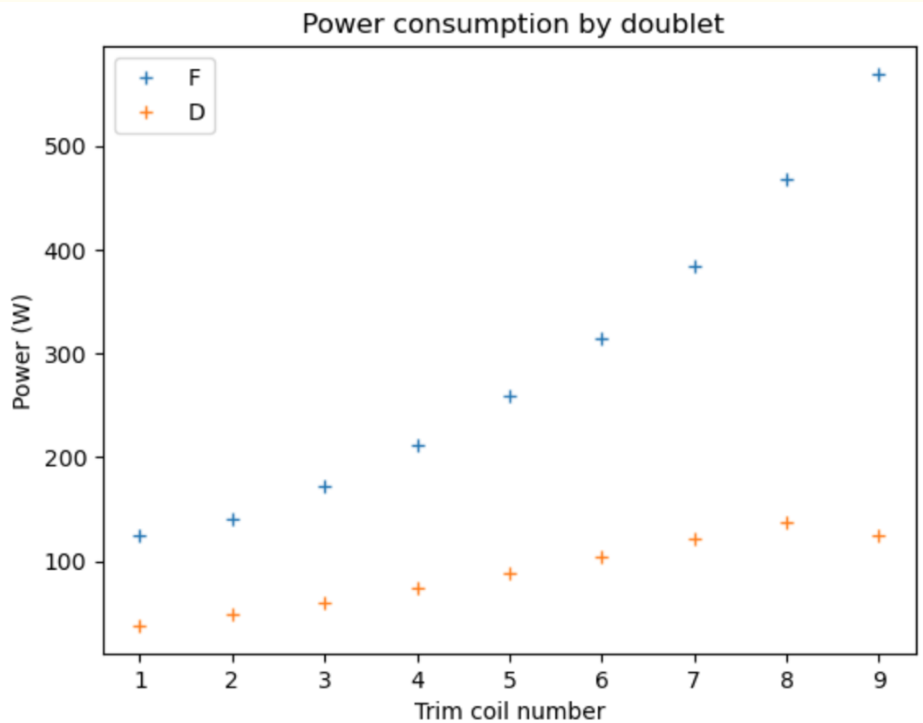


Power estimation [3.06, 3.06]



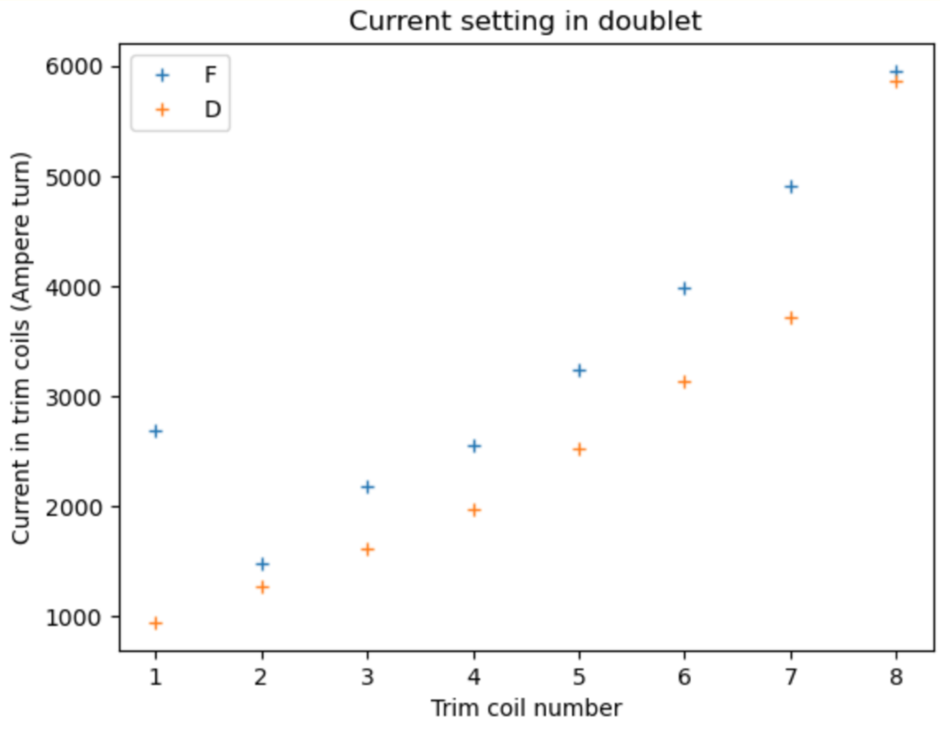


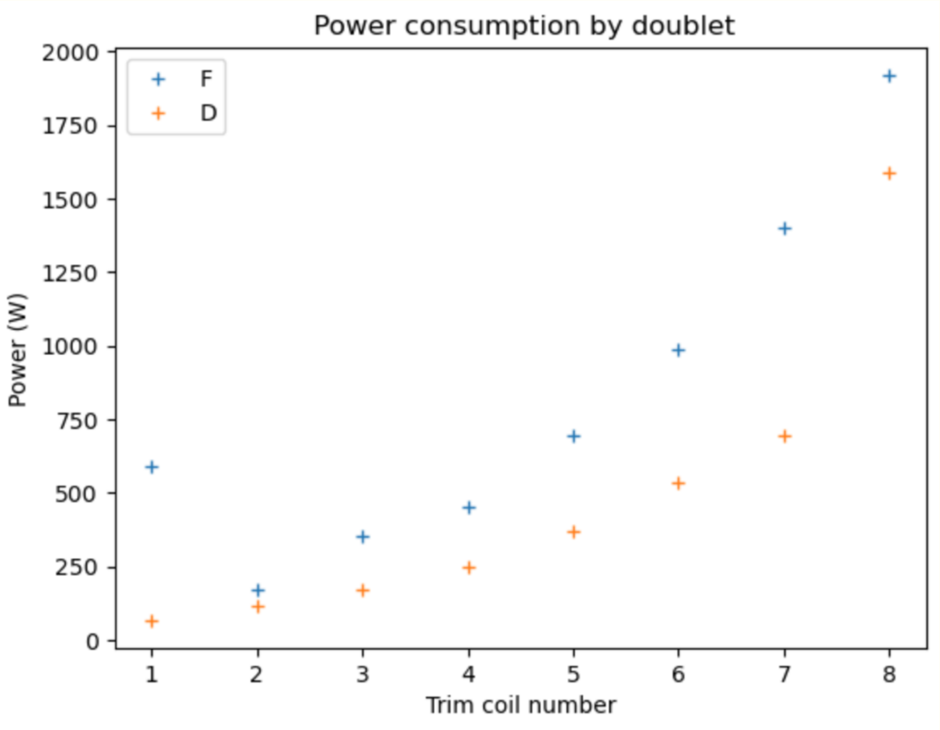
Main coil F: 12794 Ampere turn, 1260W
Main coil D: 7964 Ampere turn, 447W

Two layers of trim coils have same current settings but different lengths
Showing here the layer with longer length.

16 kW per doublet, 256 kW for all the doublets (assuming all doublets are the same)

Power estimation [3.76, 3.06]





Main coil F: 8522 Ampere turn, 560W
Main coil D: 8299 Ampere turn, 486W

Two layers of trim coils have same current settings but different lengths
Showing here the layer with longer length.

40 kW per doublet, 640 kW for all the doublets (assuming all doublets are the same)

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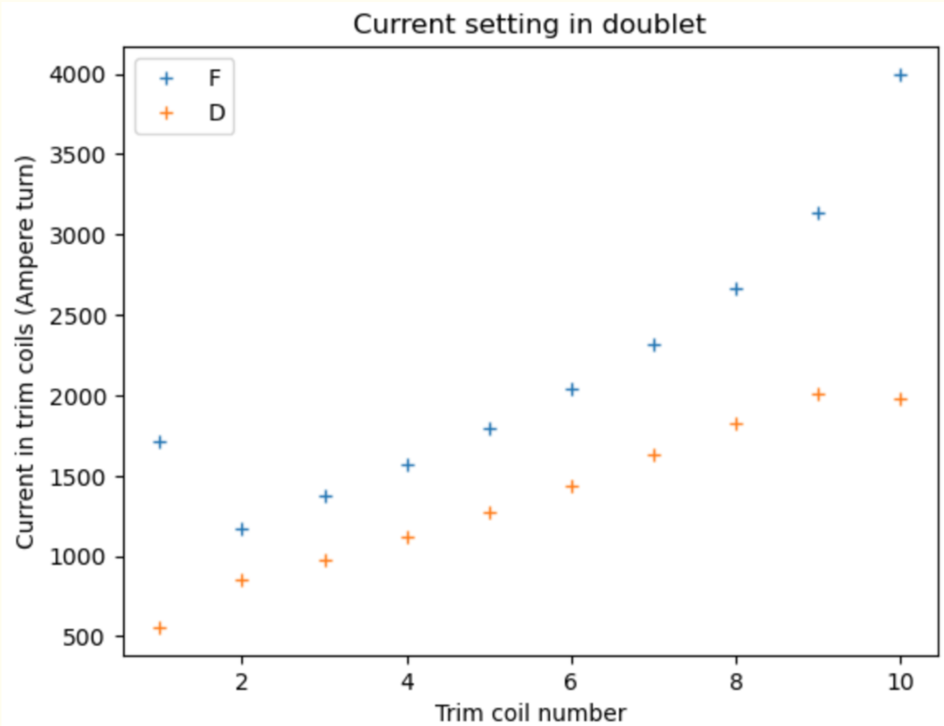
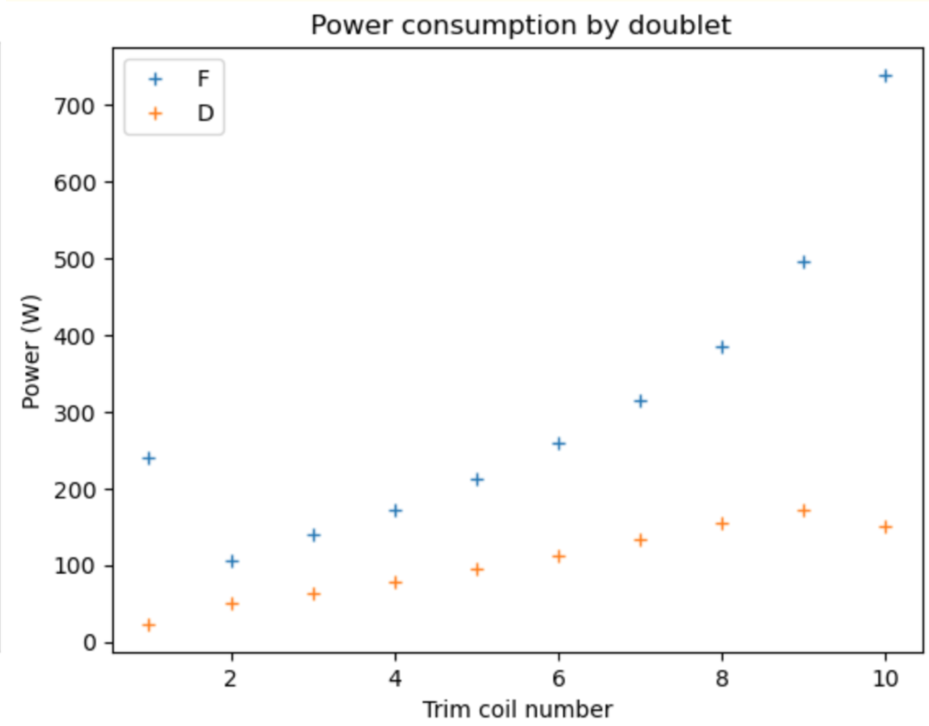
Power estimation [3.06, 3.76]



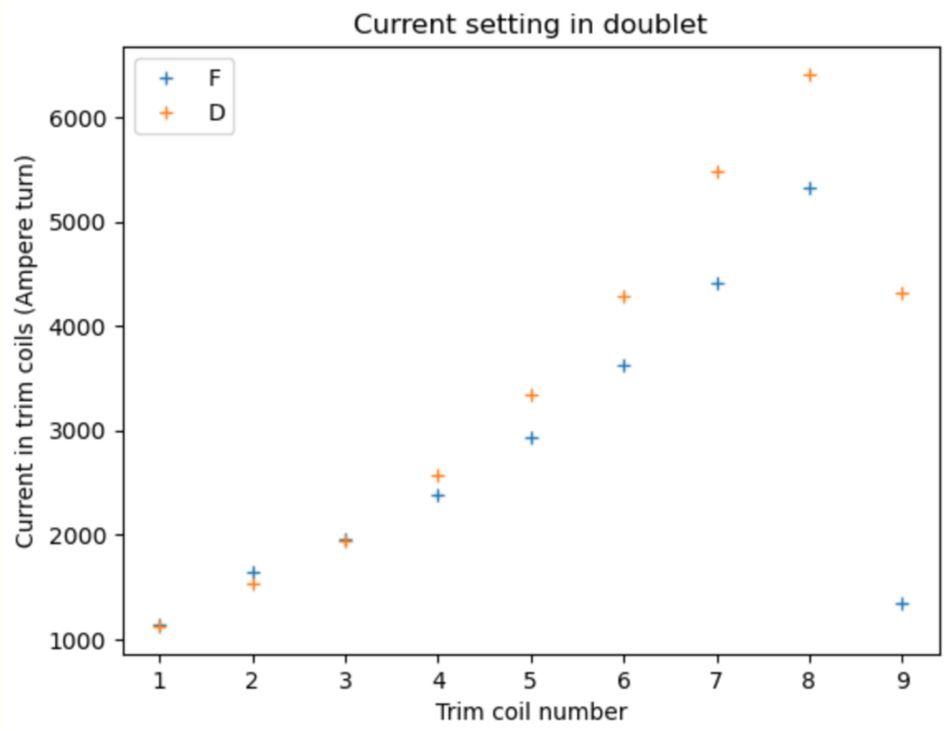


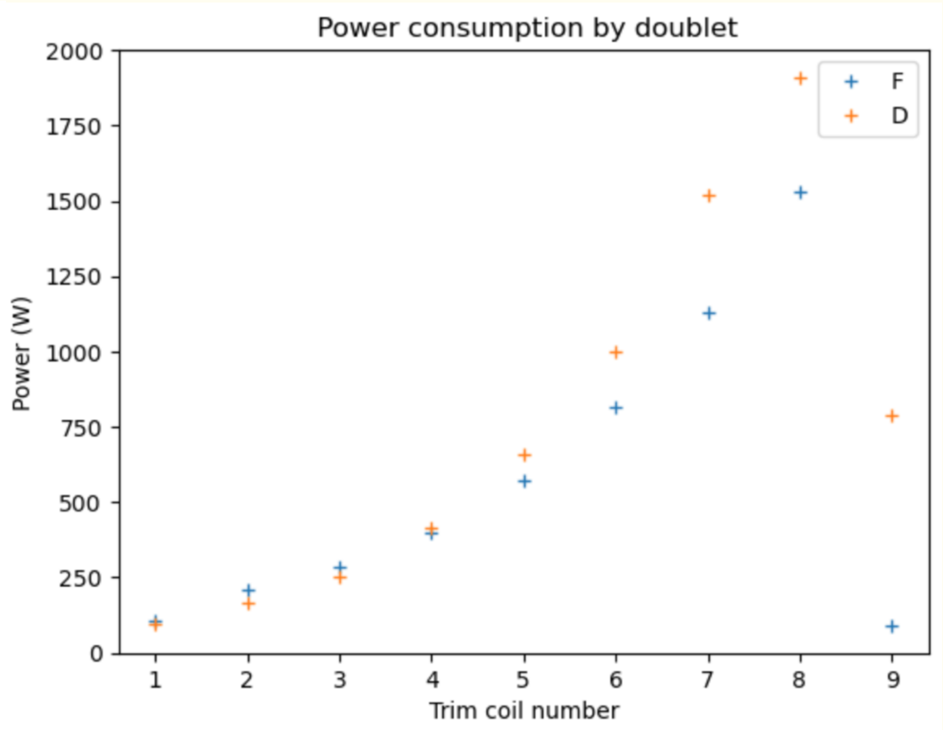
Main coil F: 10020 Ampere turn, 774W
Main coil D: 8246 Ampere turn, 480W

Two layers of trim coils have same current settings but different lengths
Showing here the layer with longer length.

17.5 kW per doublet, 280 kW for all the doublets (assuming all doublets are the same)

Power estimation [3.76, 3.76]





Main coil F: 10703Ampere turn, 884W
Main coil D: 11175 Ampere turn, 881W

Two layers of trim coils have same current settings but different lengths
Showing here the layer with longer length.

47 kW per doublet, 752kW for all the doublets (assuming all doublets are the same)