Initial Evaluations of Demonstrator Geometry, 2024

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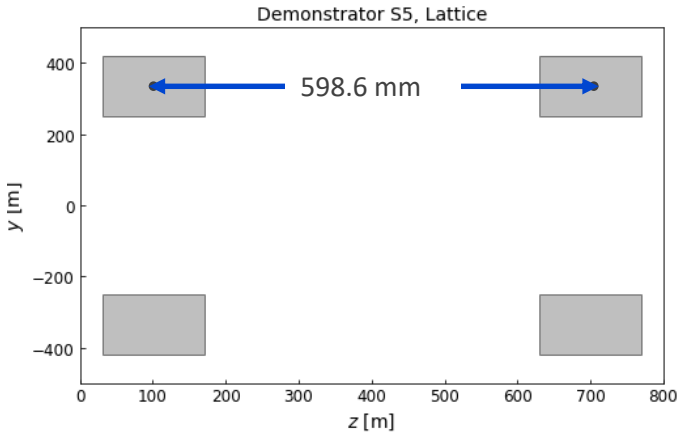
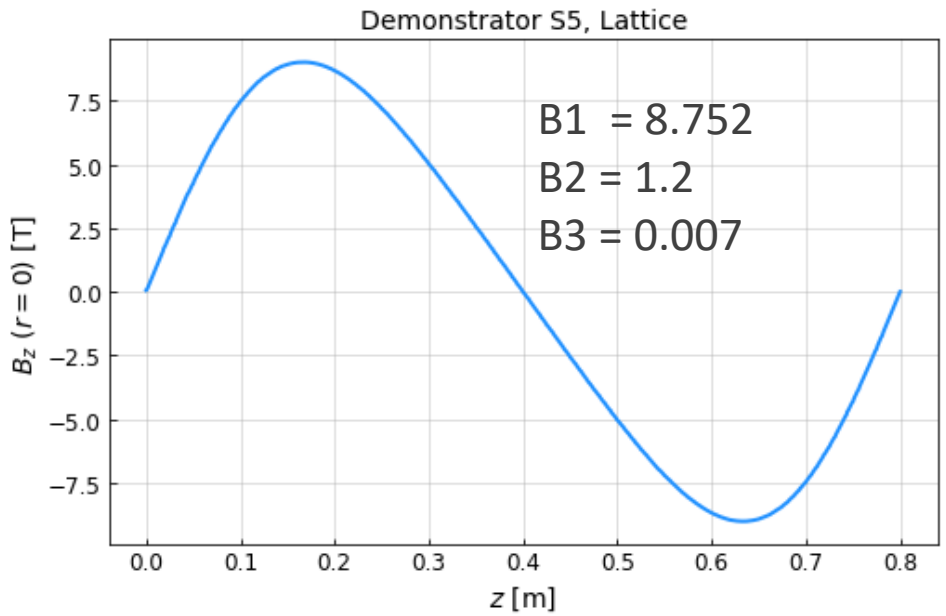
Analysis of Desired Configuration (June 2024)

Demonstrator – Details and Results from COMSOL

Details

	Demo
Bore Radius	250.0
Thickness	169.3
Length	140.0
J [A/mm2]	500.0
Cell Length	0.800





Values in PDF
B1 = 8.75
B2 = 1.25
B3 = 0.00

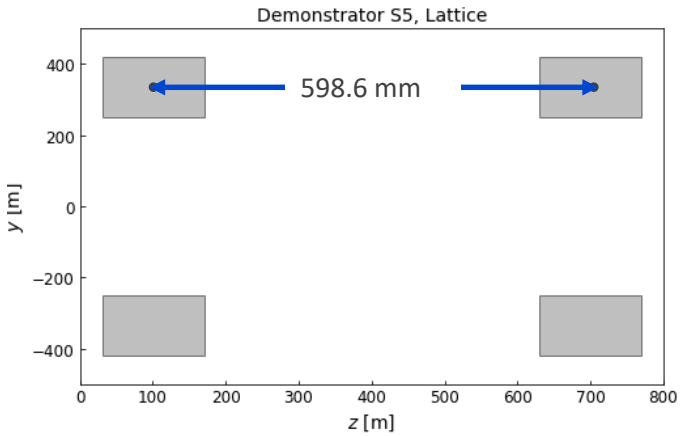
COMSOL Results (Lattice)

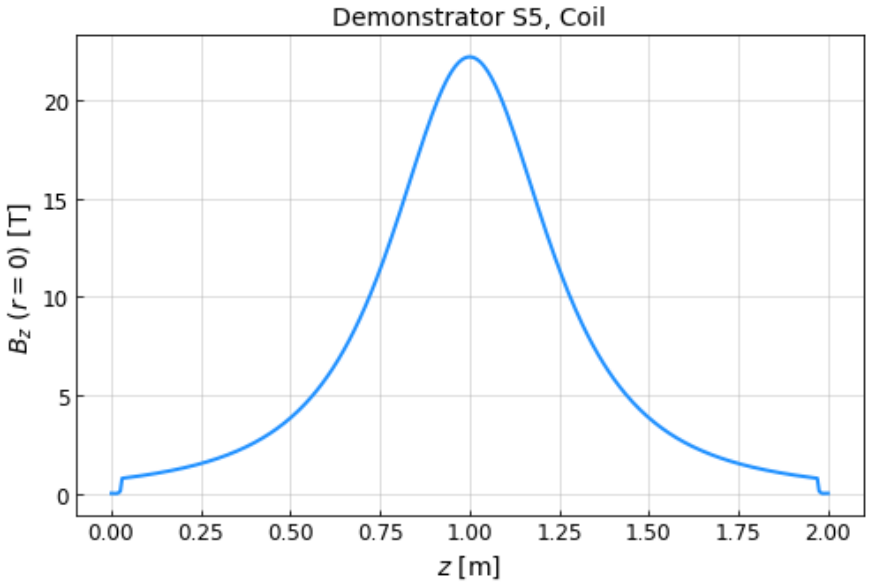
	Demo
Peak Bz On Axis [T]	9.0
E_m [MJ]	54.2
Current[A] [12 mm x 0.11 mm]	660.0
Peak B_r in Coil [T]	20.4
Peak B_{norm} in Coil [T]	39.162
F_z [MN]	192.9
Max σ_{hoop} [MPa]	1219.6
Max σ_r [MPa]	0.0
Min σ_r [MPa]	-418.1
Min σ_z [MPa]	-866.4

Demonstrator – Details and Results from COMSOL

Details

	Demo
Bore Radius	250.0
Thickness	169.3
Length	140.0
J [A/mm2]	500.0
Cell Length	0.800



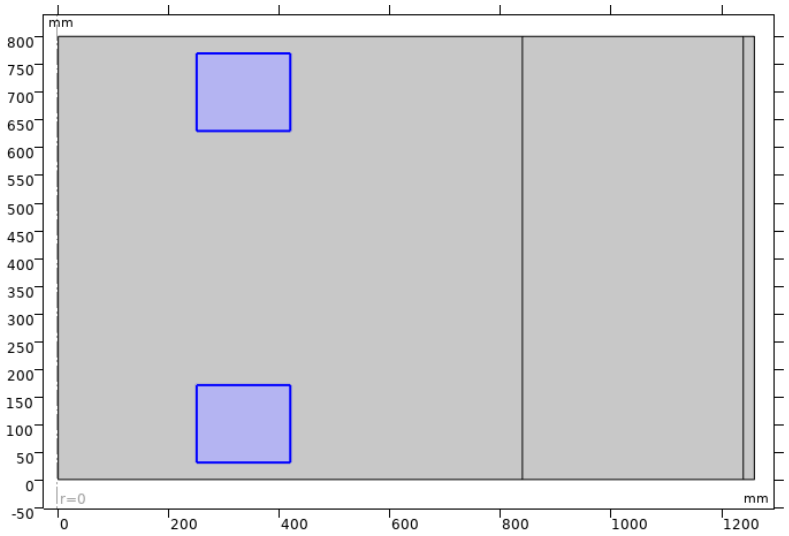


COMSOL Results (Single Coil)

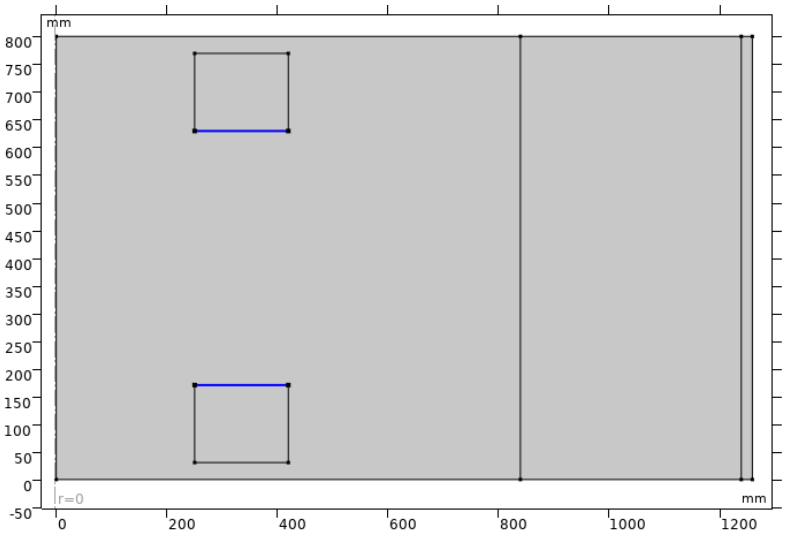
	Demo
Peak Bz On Axis [T]	22.2
E_m [MJ]	49.9
Peak B_r in Coil [T]	25.0
Peak B_{norm} in Coil [T]	40.0
Max σ_{hoop} [MPa]	2493.090
Max σ_r [MPa]	0.0
Min σ_r [MPa]	-444.1
Min σ_z [MPa]	-463.1

COMSOL Analysis – Reminder of Setup

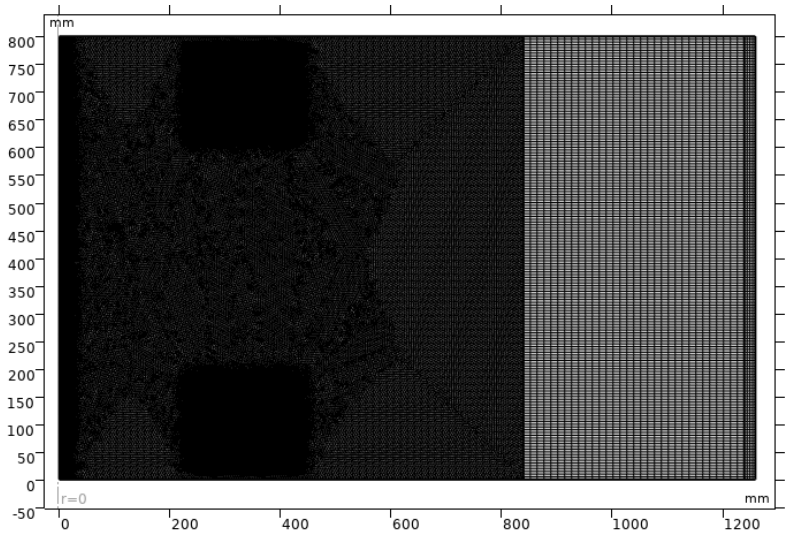
Material: Copper



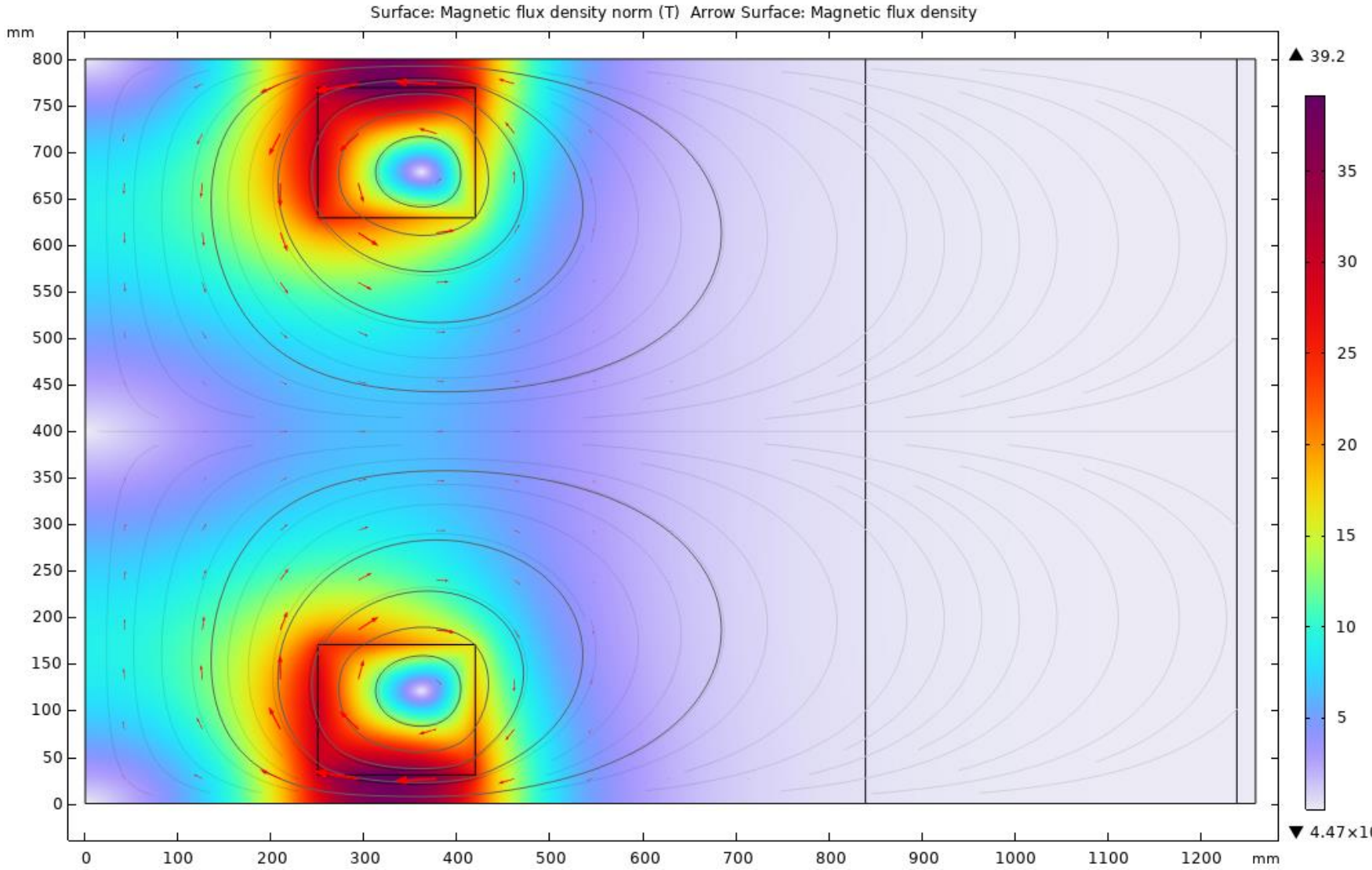
Roller Placement



Mesh



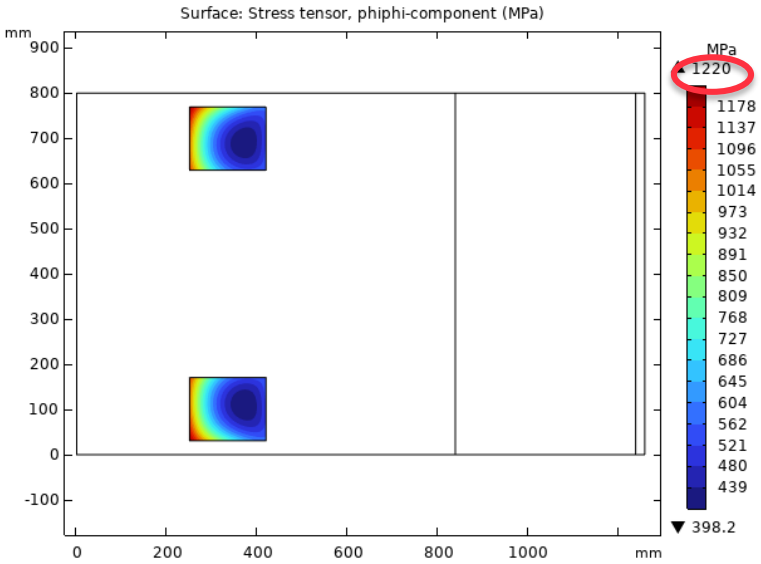
COMSOL Analysis – **2D Field**



COMSOL Analysis – **Mechanics**

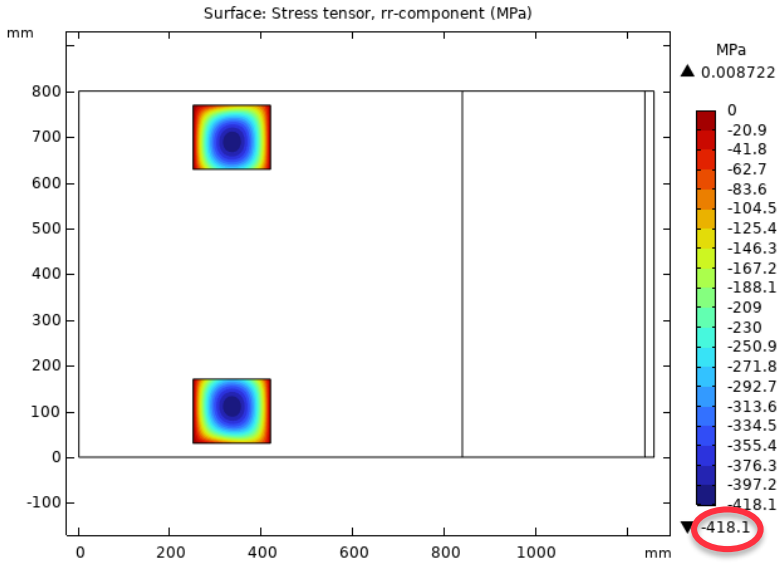
Hoop Stress

398 to 1220 Mpa



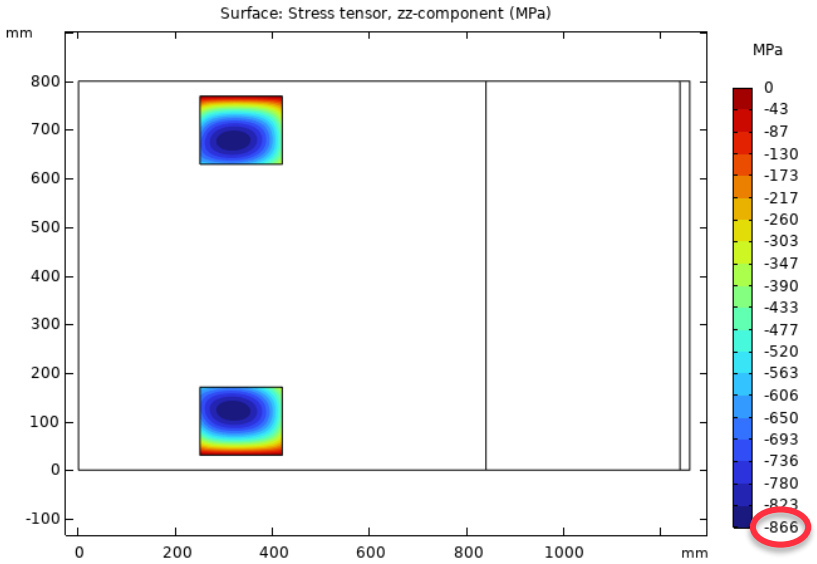
Radial Stress

0 to -418 MPa



Longitudinal Stress

0 to -866 MPa



Analysis of Desired Configuration (June 2024)

Guiding Design Parameters

- σ_θ: hoop stress
- σ_r: radial stress
- e_m: magnetic energy density
- J_c: critical current density

Example limits

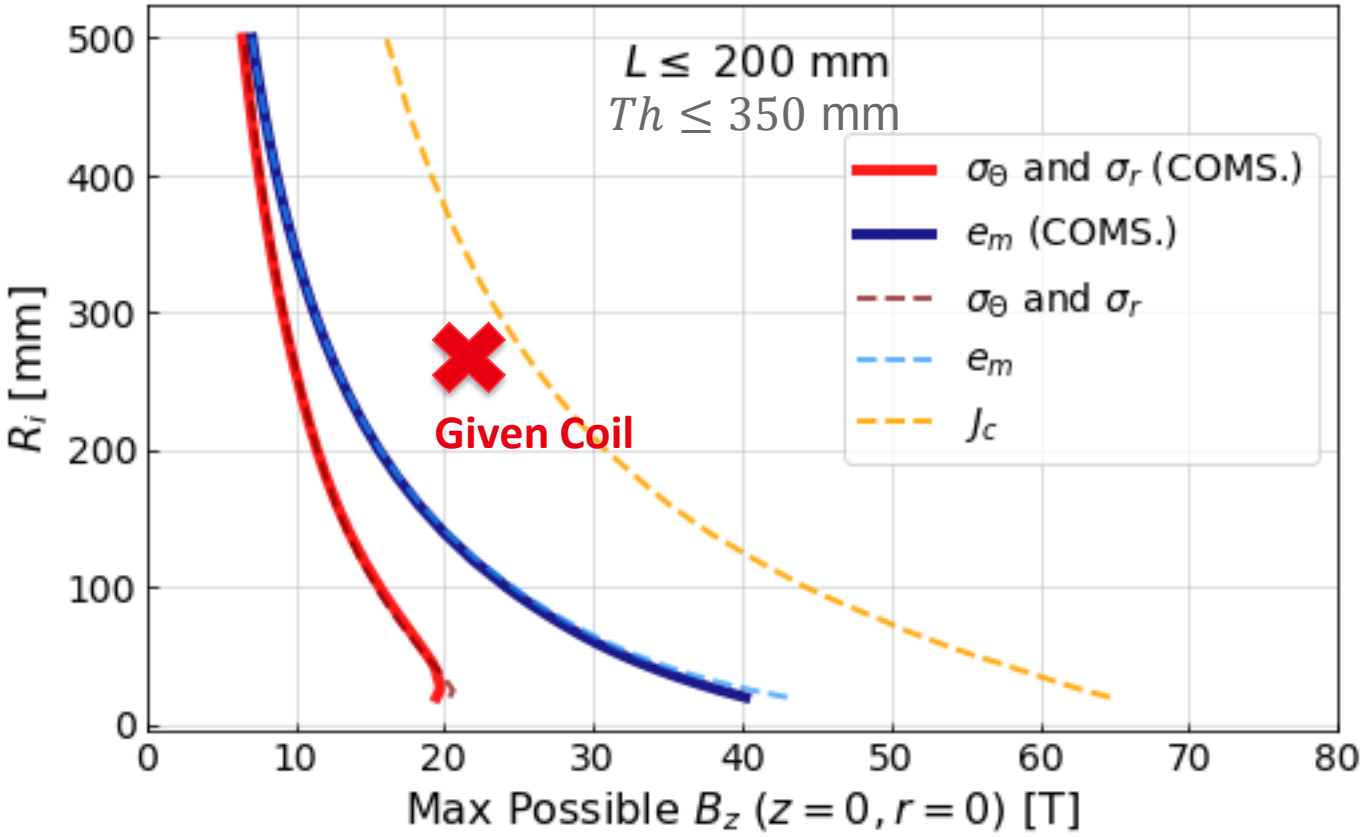
- $\sigma_\theta \leq 300$ MPa
- $\sigma_r \leq 20$ MPa (Tensile)
- $e_m \leq 150$ MJ/m3
- J_c : HTS at $T_{op} = 20$ K and 2.5 K margin (Fujikura FESC-SCH tape)

Other considerations (numerical)

- Forces

A-B Plot, Single Solenoid

1. Over a fine interval of bore radius, scan solenoids of different length and thickness and compute
   - σ_θ, σ_r: hoop stress, radial stress
   - e_m: magnetic energy density
   - J_c: critical current density
2. At each bore radius, find the maximum achievable peak field on axis ($B_z(z = 0, r = 0)$), for
   - $\sigma_\theta \leq 300$ MPa
   - $\sigma_r \leq 20$ MPa (Tensile)
   - $e_m \leq 150$ MJ/m3
   - J_c : HTS at $T_{op} = 20$ K and 2.5 K margin (Fujikura FESC-SCH tape)



Solid Curves: COMSOL (COMSOL)
Dashed curves: Semi-analytic

A-B Plot, 2-4 Solenoids in a Lattice

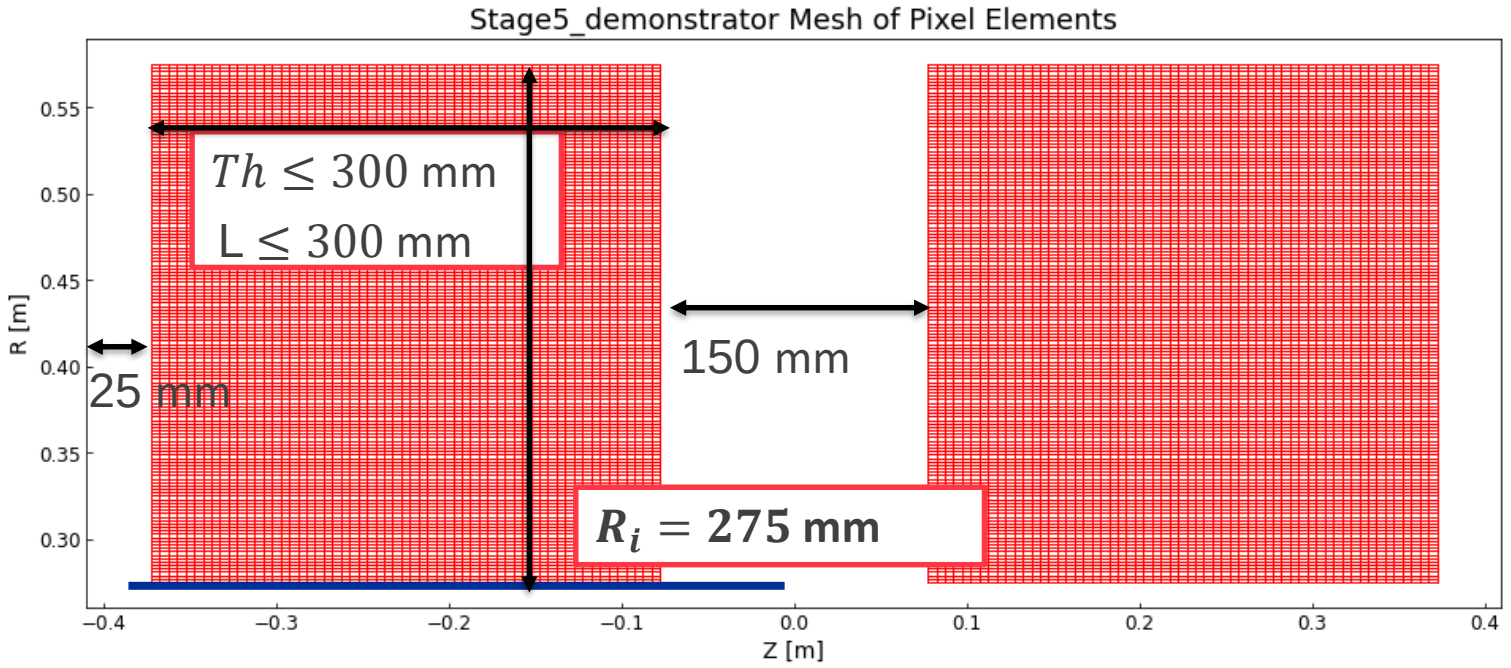
COMING

1. For the desired peak field, what harmonics are possible ($R_i = 275$ mm, $L_{cell} = 0.8$ m)

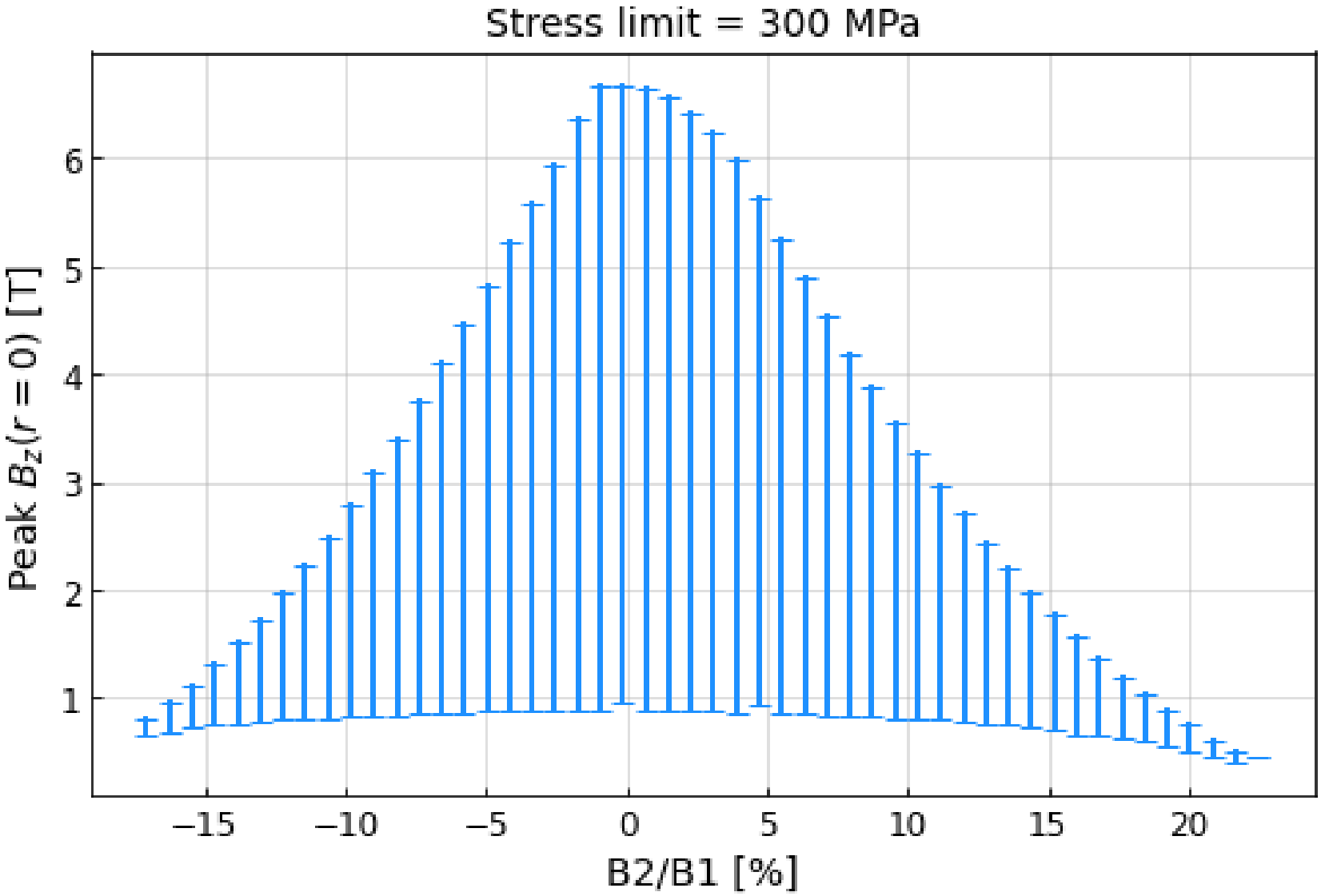
Scan space:

- 50 mm gap between coils sides
- 150 mm gap in center **
- $R_i = 275$ mm

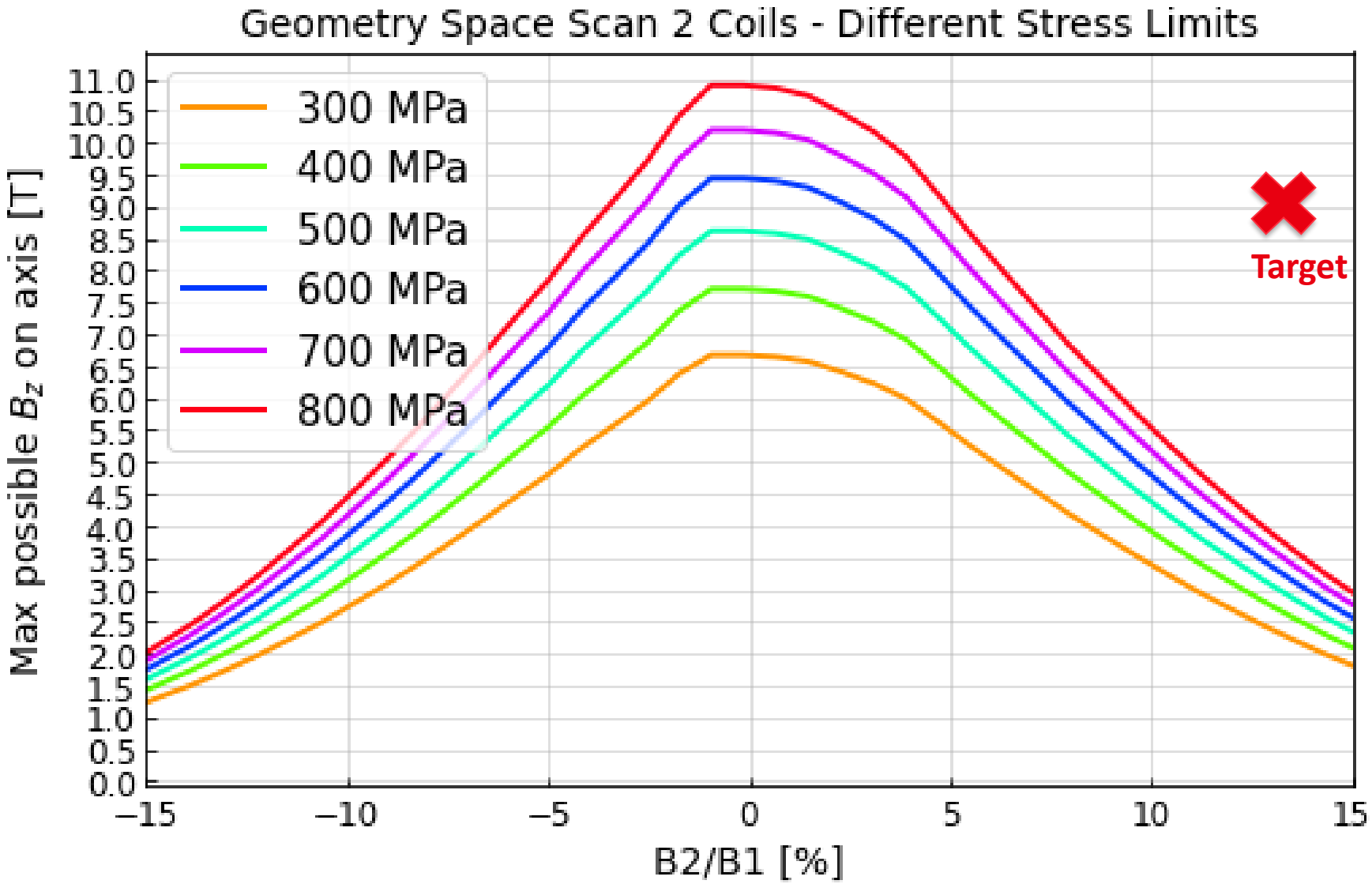
→ **144k** geometries (dr = 2 mm, dz = 5 mm)



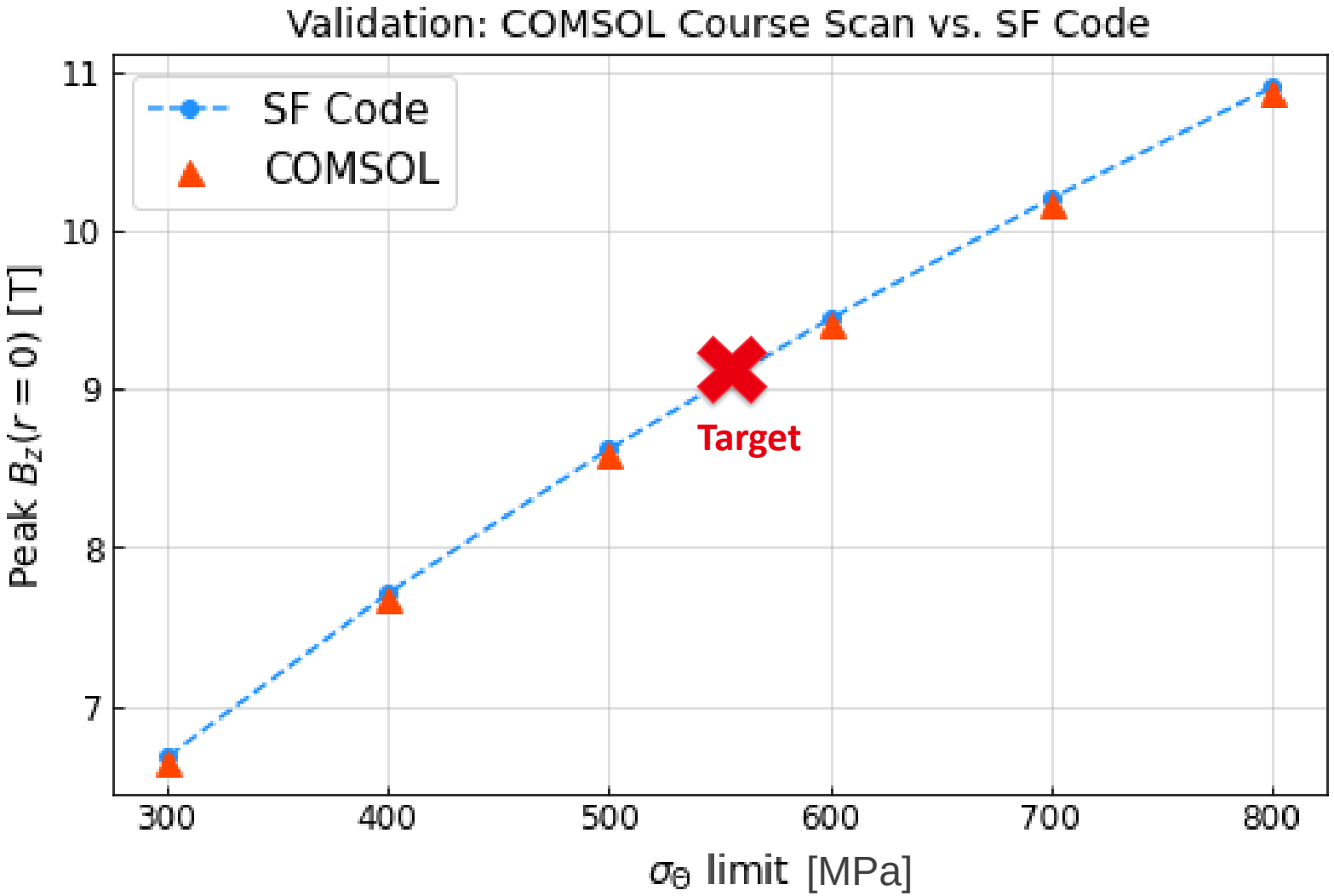
Numerical Scan of 2 Coils



Numerical Scan of 2 Coils



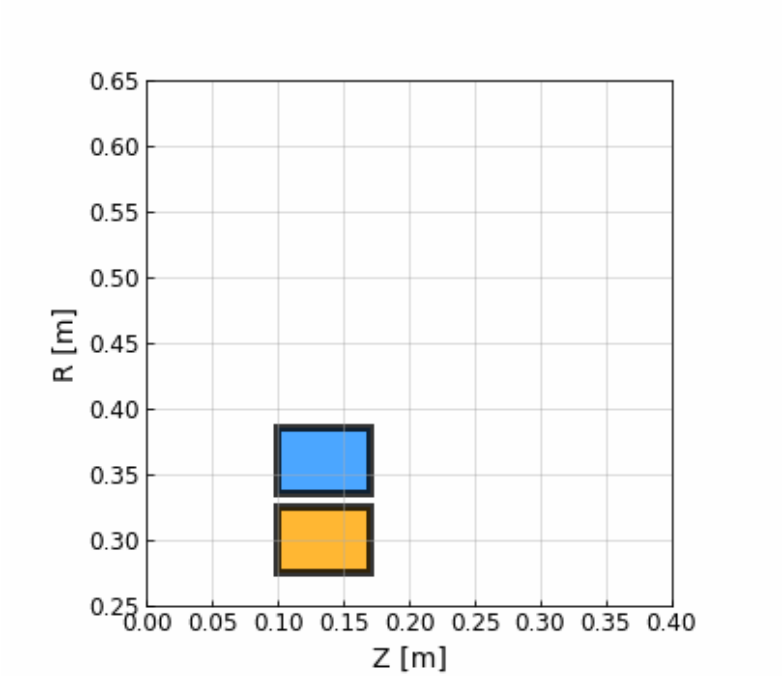
Numerical Scan of 2 Coils (peak possible field)

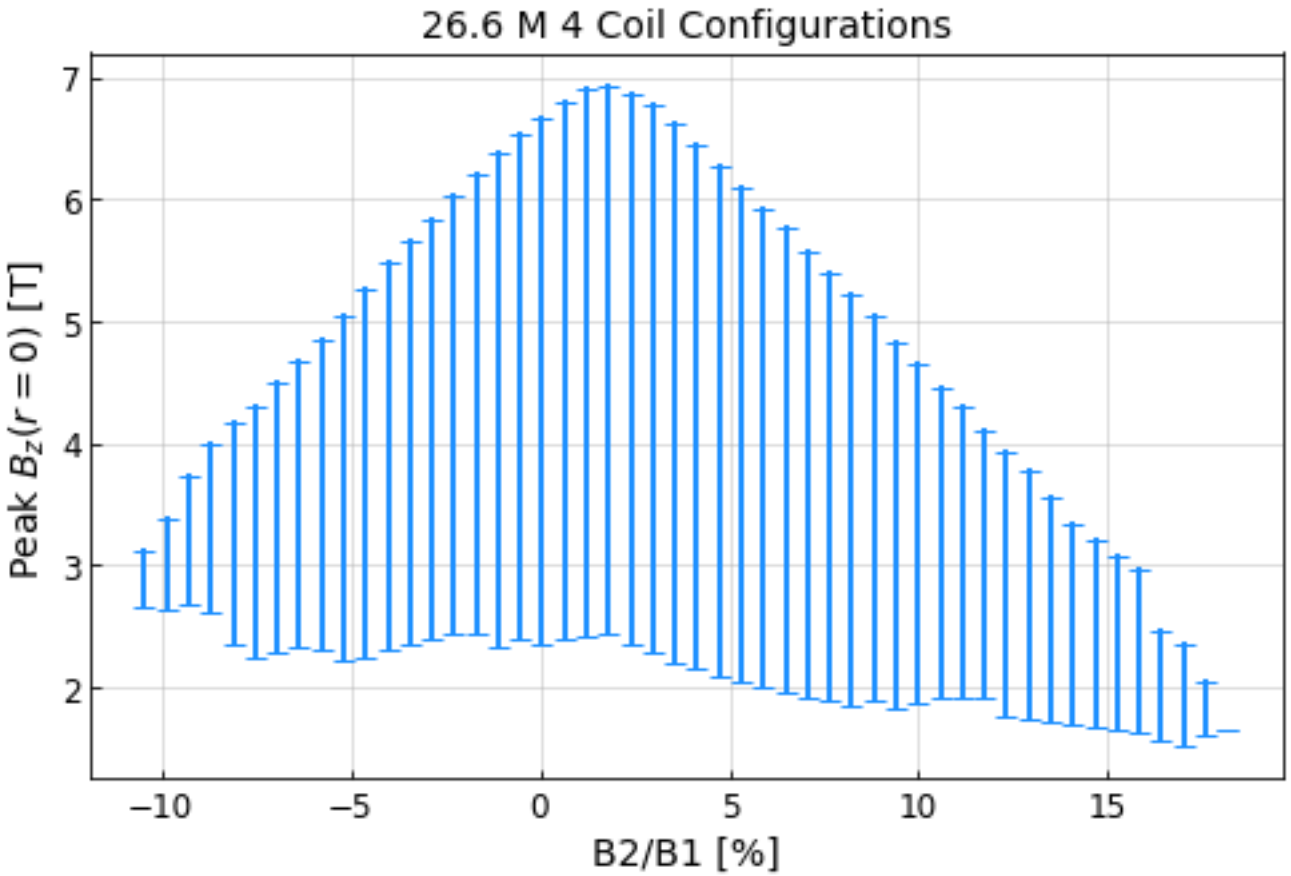


Analysis – 4 Coils

4 Coil Scan (gap between is 200 mm)

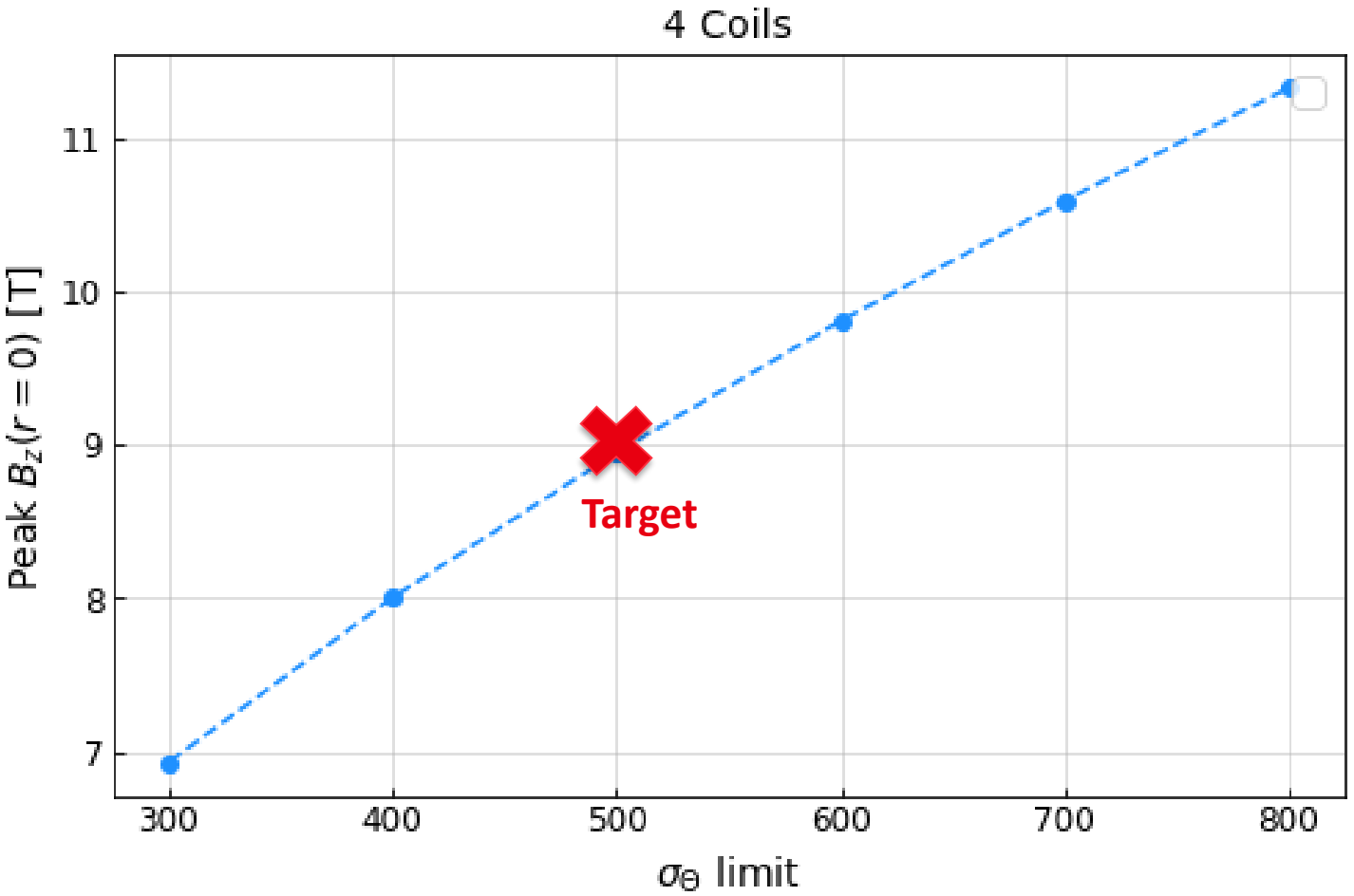
- $Gap\ Waveguide = 200\ mm$
- $60\ mm \leq L \leq 250\ mm$
- $50\ mm \leq Th \leq 200\ mm$
- Coil 2: $275\ mm \leq R_i \leq 375\ mm$
- Coil 1: $\mathrm{R}_i = 275\ mm$

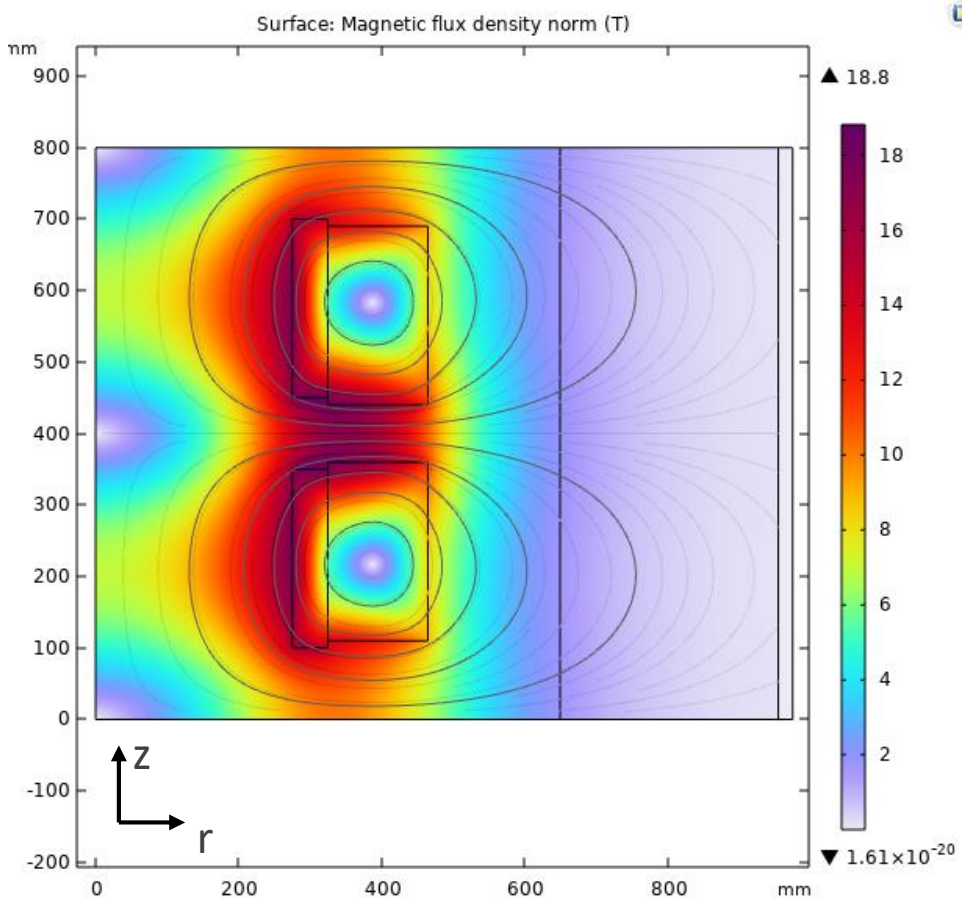




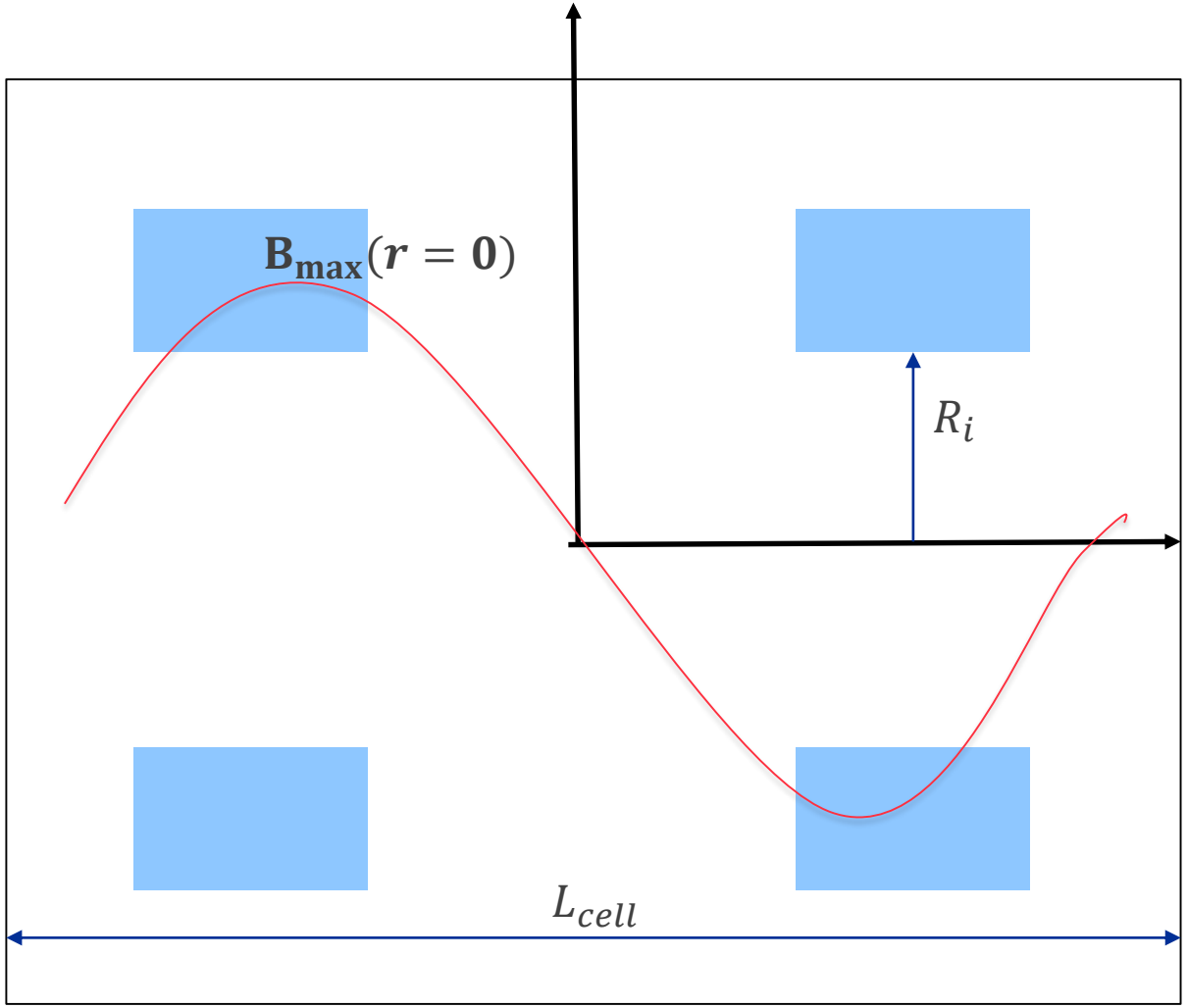
4 Coil Scan Conclusions (geometry creating highest field on axis)

$\sigma_\theta = 300$ MPa in each coil





Next Steps



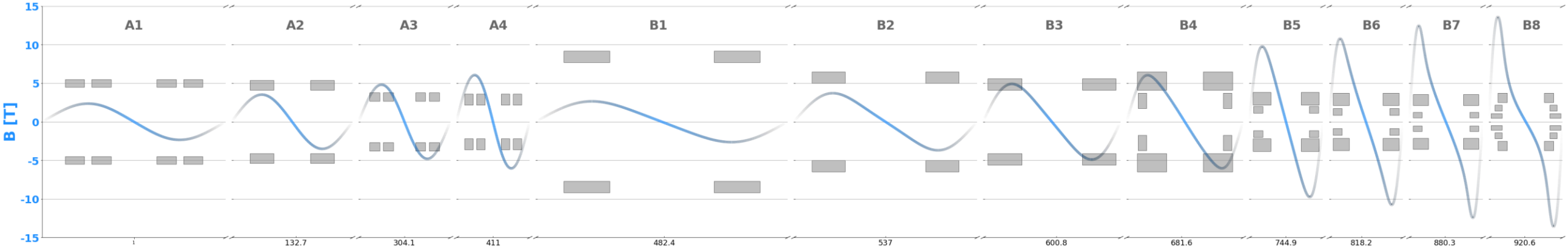
To get towards desired $\mathbf{B_{max}}(\boldsymbol{r}=\mathbf{0})$

1. Reduce R_i (design change)
2. Increase the cell length ?
3. … consider pre-stress compression, coils treated as system (lower stresses) …Break coils into 2 ? (same radii, diff radii

Or

- reduce $\mathbf{B_{max}}(\boldsymbol{r}=\mathbf{0})$ …..

US-MAP Optics



	A1-1	A2-1	A3-1	A4-1	B1-1	B2-1	B3-1	B4-1	B4-2	B5-1	B5-2	B6-1	B6-2	B7-1	B7-2	B8-1	B8-2	B8-3
Bore Radius [mm]	450	410	270	220	770	500	410	175	410	113	217	84	215	50	210	45	140	250
Thickness [mm]	100	130	110	140	150	150	150	200	240	88	165	92	160	74	145	65	80	120
Length [mm]	210	260	110	90	500	360	370	92	320	100	196	100	177	100	170	120	80	100
J [A/mm2]	63.2	126.6	165.0	195.0	69.8	90.0	123.0	94.0	70.3	157.0	168.0	185.0	155.1	198.0	155.0	220.0	135.0	153.0
Cell Length [m]	2.0	1.3	1.0	0.8	2.8	2.0	1.5	1.270		0.806		0.806		0.806		0.806		
N Cells	66	130	107	88	20	32	54	50		91		77		50		61		

US MAP parameters

	A1-1	A2-1	A3-1	A4-1	B1-1	B2-1	B3-1	B4-1	B4-2	B5-1	B5-2	B6-1	B6-2	B7-1	B7-2	B8-1	B8-2	B8-3
Bore Radius [mm]	450	410	270	220	770	500	410	175	410	113	217	84	215	50	210	45	140	250
Thickness [mm]	100	130	110	140	150	150	150	200	240	88	165	92	160	74	145	65	80	120
Length [mm]	210	260	110	90	500	360	370	92	320	100	196	100	177	100	170	120	80	100
J [A/mm2]	63.2	126.6	165.0	195.0	69.8	90.0	123.0	94.0	70.3	157.0	168.0	185.0	155.1	198.0	155.0	220.0	135.0	153.0
Cell Length [m]	2.0	1.3	1.0	0.8	2.8	2.0	1.5	1.270		0.806		0.806		0.806		0.806		
N Cells	66	130	107	88	20	32	54	50		91		77		50		61		

	A1	A2	A3	A4	B1	B2	B3	B4	B5	B6	B7	B8
B1	-2.323	-3.480	-4.792	-6.056	-2.565	-3.537	-4.736	-5.650	-9.058	-9.034	-8.960	-8.658
B2/B1	-0.001	-0.001	-0.001	-0.002	0.096	0.136	0.142	0.216	0.240	0.370	0.505	0.648
B3/B1	-0.014	-0.011	-0.005	-0.002	-0.014	-0.013	0.002	0.036	0.041	0.101	0.192	0.292
B4/B1	-0.000	-0.000	-0.001	-0.001	-0.002	-0.004	-0.000	-0.006	0.001	0.010	0.025	0.071
B5/B1	-0.002	-0.000	-0.001	-0.001	-0.000	-0.000	0.000	-0.008	-0.003	-0.008	-0.027	-0.008

IMCC New Optics Version 2.0 June 2024

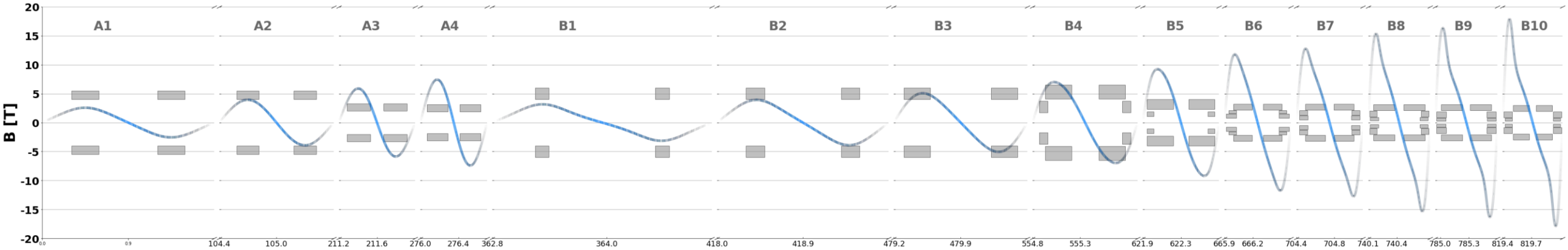
Total Number of Solenoids in 1 chain: 3054 | **Total Length**: 850.3 m
On axis field from 2.6 T to 17.9 T (in Lattice)

	A1-1	A2-1	A3-1	A4-1	B1-1	B2-1	B3-1	B4-1	B4-2	B5-1	B5-2	B6-1	B6-2	B6-3	B7-1	B7-2	B7-3	B8-1	B8-2	B8-3	B9-1	B9-2	B9-3	B10-1	B10-2	B10-3
Bore Radius	400	400	200	190	400	400	400	175	410	110	230	80	160	220	50	130	220	30	100	210	25	85	210	25	85	195
Thickness	150	150	125	125	200	200	200	200	240	80	170	70	50	100	70	80	100	60	100	105	50	100	105	50	100	105
Length	287	233	245	217	146	194	277	91	277	70	274	105	81	196	89	84	213	87	78	223	96	100	225	75	89	168
J [A/mm2]	57.6	149.5	131.5	193.2	96.9	102.1	127.9	88.5	153.6	179.6	154.0	214.4	211.5	212.7	183.3	153.9	210.3	193.7	202.1	212.8	256.4	88.5	204.9	326.8	146.1	207.8
Cell Length	1.8	1.2	0.8	0.7	2.3	1.8	1.4	1.100		0.800		0.700			0.700			0.650			0.650			0.630		
N Cells	58	89	81	124	24	34	54	61		55		55			51			69			53			49		

	A1	A2	A3	A4	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
B1	-2.45	-3.90	-5.86	-7.41	-2.82	-3.71	-4.93	-6.99	-9.22	-10.72	-10.89	-11.97	-11.72	-11.92
B2/B1 [%]	-0.22	-0.12	-1.50	-0.71	9.85	7.43	11.49	12.14	14.73	27.67	33.48	41.68	48.53	52.72
B3/B1 [%]	-4.30	-0.81	-0.43	-0.31	-9.32	-4.22	-0.23	3.04	4.72	8.69	13.78	20.86	27.75	30.87
B4/B1 [%]	-0.04	-0.04	-0.09	-0.08	-1.74	-0.62	-0.14	0.43	0.89	1.19	2.37	6.11	9.53	10.30
B5/B1 [%]	0.04	-0.03	-0.08	-0.07	0.64	0.07	-0.04	-0.10	-0.13	-0.28	-1.00	-0.16	0.76	-0.33

IMCC New Optics Version 2.0 June 2024

Total Number of Solenoids in 1 chain: 3054 | **Total Length**: 850.3 m
On axis field from 2.6 T to 17.9 T (in Lattice)



	A1-1	A2-1	A3-1	A4-1	B1-1	B2-1	B3-1	B4-1	B4-2	B5-1	B5-2	B6-1	B6-2	B6-3	B7-1	B7-2	B7-3	B8-1	B8-2	B8-3	B9-1	B9-2	B9-3	B10-1	B10-2	B10-3
Bore Radius	400	400	200	190	400	400	400	175	410	110	230	80	160	220	50	130	220	30	100	210	25	85	210	25	85	195
Thickness	150	150	125	125	200	200	200	200	240	80	170	70	50	100	70	80	100	60	100	105	50	100	105	50	100	105
Length	287	233	245	217	146	194	277	91	277	70	274	105	81	196	89	84	213	87	78	223	96	100	225	75	89	168
J [A/mm2]	57.6	149.5	131.5	193.2	96.9	102.1	127.9	88.5	153.6	179.6	154.0	214.4	211.5	212.7	183.3	153.9	210.3	193.7	202.1	212.8	256.4	88.5	204.9	326.8	146.1	207.8
Cell Length	1.8	1.2	0.8	0.7	2.3	1.8	1.4	1.100		0.800		0.700			0.700			0.650			0.650			0.630		
N Cells	58	89	81	124	24	34	54	61		55		55			51			69			53			49		

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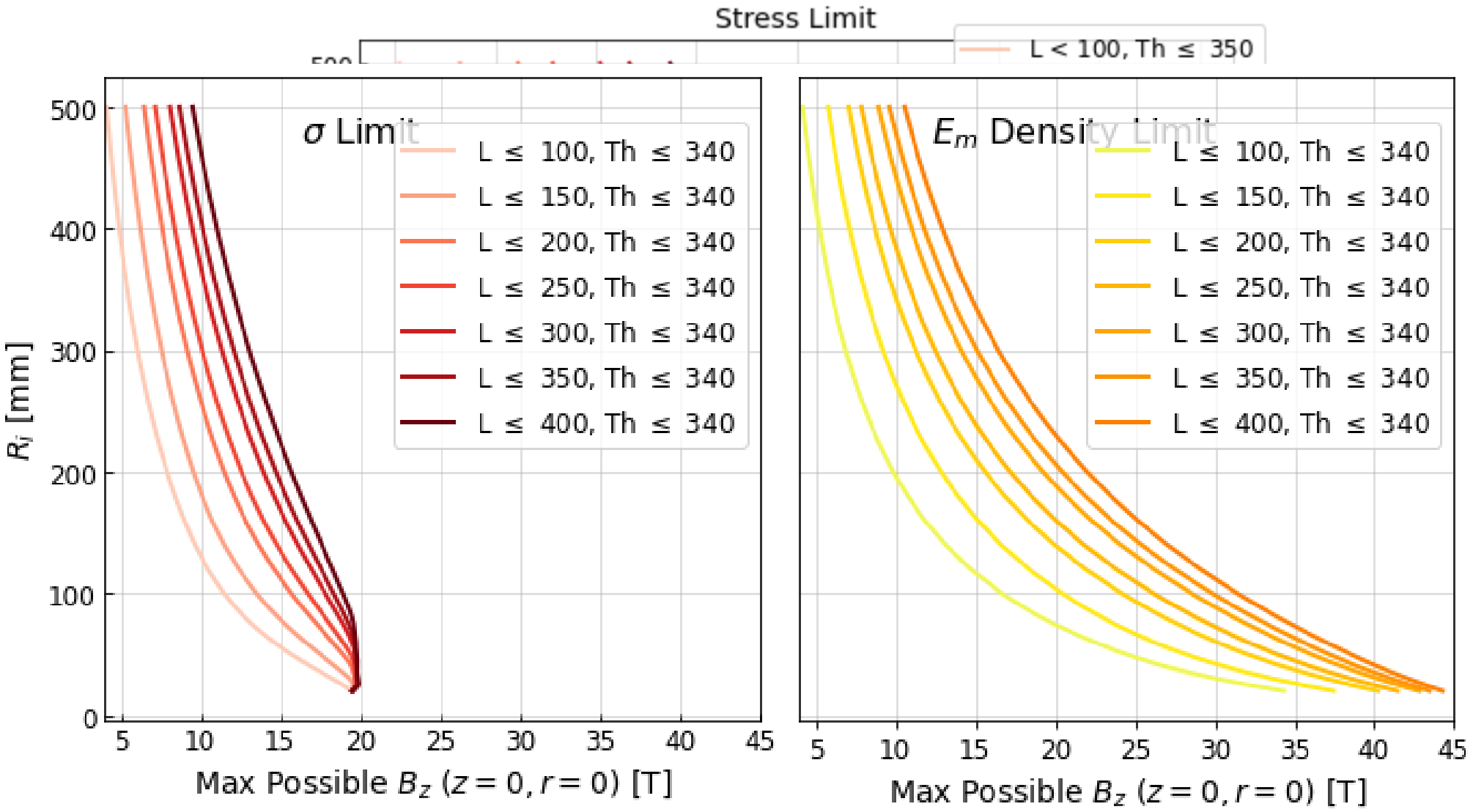
Stress Limit
L < 100, Th ≤ 350
σ Limit
L ≤ 100, Th ≤ 340
L ≤ 150, Th ≤ 340
L ≤ 200, Th ≤ 340
L ≤ 250, Th ≤ 340
L ≤ 300, Th ≤ 340
L ≤ 350, Th ≤ 340
L ≤ 400, Th ≤ 340
R_i [mm]
0
100
200
300
400
500
5
10
15
20
25
30
35
40
45
Max Possible B_z $(z = 0, r = 0)$ [T]
E_m Density Limit
L ≤ 100, Th ≤ 340
L ≤ 150, Th ≤ 340
L ≤ 200, Th ≤ 340
L ≤ 250, Th ≤ 340
L ≤ 300, Th ≤ 340
L ≤ 350, Th ≤ 340
L ≤ 400, Th ≤ 340
5
10
15
20
25
30
35
40
45
Max Possible B_z $(z = 0, r = 0)$ [T]