PAUL SCHERRER INSTITUT

Swiss Accelerator Research and Technology

D. Araujo, B. Auchmann, A. Brem, T. Michlmayr, C. Müller, H. Rodrigues, D. Sotnikov and A. Milanese

Subscale Stress-Managed Common-coils Status and plans

November 2023

Work supported by the Swiss State Secretariat for Education, Research and Innovation SERI.
This work was performed under the auspices and with support from the Swiss Accelerator Research and Technology (CHART) program

PAUL SCHERRER INSTITUT

Swiss Accelerator Research and Technology

Agenda

- Concept and main parameters
- Engineering Design (T. Michlmayr)
- Needs to complete the engineering design
- Planning
- CERN/MPE collaboration on the protection
- 2^{nd} phase: hybrid LTS/HTS

Subscale Stress-managed Common-coils Goals and Parameters

- The subscale magnet serves as a platform for validating design and optimization tools, as well as manufacturing and assembly processes.

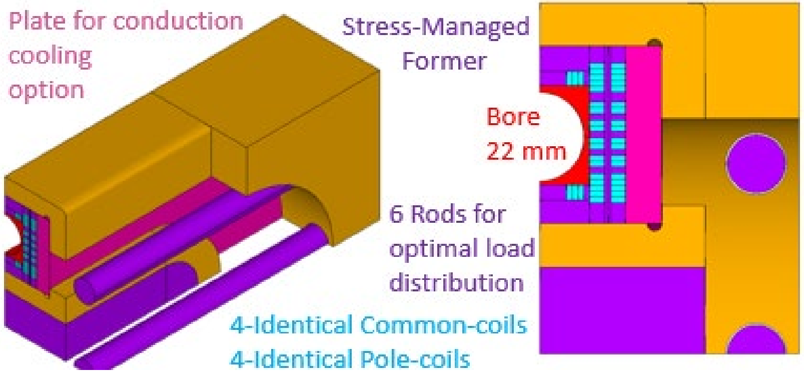
Cable & strand (LBNL Subscale CCT)		
Strand dia	0.6	mm
Number of strands	11	-
Bare dimensions	3.8 x 1.3	mm
Insulation thickness	0.15	mm
Cu/no-cu	1.17	

Goals		
Nominal Field B0	4 +	T
T operational	4.5	K
Max current	10.0	kA
Margin at Top and B_0	> 15	%

Dimensions		
Straight-Section	150	mm
Bore radius	22	
Intra-beam	120	
Total length	350	

Concept and main parameters 1/2

- Validating manufacturing process and introducing advanced concepts: coil pre-load free, at room temperature; stress-management structure and splicing on the low-field region.
- Fast turn-around platform for testing matrix systems; protection concepts and cooling options.
- Hybrid magnet with LTS Common-Coils and HTS racetracks
- LTS conductor manufactured by LBNL (cct subscale cable)

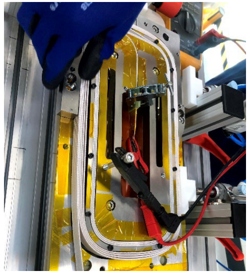


Magnet parameters for testing all coils or the common-coils. The coils straight section is 150 mm. The values refer to the fitted wire Ic curve at 4.2 K values (without self-field contribution).

Parameter	All coils	CCs
B_0 in T	5.15	5.1
B_{peak} in T	6.45	6.3
I_{op} in kA	8.25	9.2
E_{mag} in kJ	15.2	16.4

Concept and main parameters 2/2

- Progress on R&D and engineering design



Winding method validation

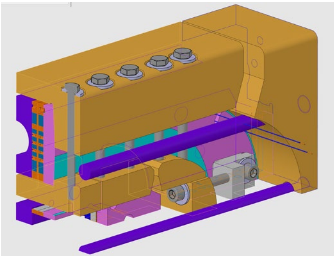
Instrumented mock-up for assembling validation

Pre-scaled paper after disassembling the Mock-up

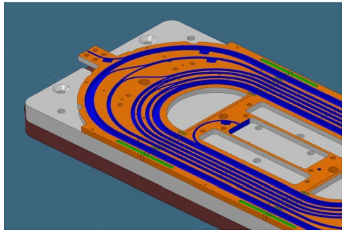
Mock-up for axial pre-load

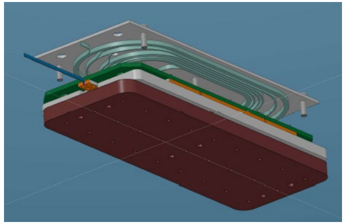
Low-temperature splicing process trials

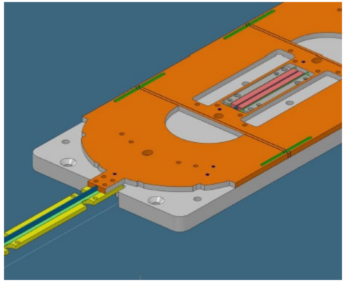
Completed engineering design

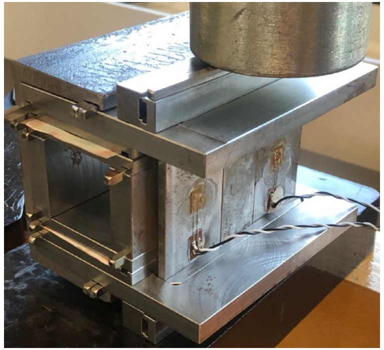


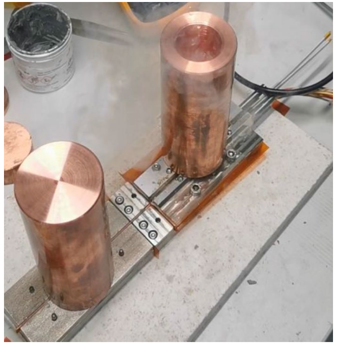
T. Michlmayr











D. Araujo, A. Brem, R. Felder, T. Michlmayr, C. Müller and H. Rodrigues

Agenda

- Concept and main parameters
- Engineering Design (T. Michlmayr)
- Needs to complete the engineering design
- Planning
- CERN/MPE collaboration on the protection
- 2nd phase: hybrid LTS/HTS

CHART
Swiss Accelerator Research and Technology

PAUL SCHERRER INSTITUT PSI

Needs to complete the engineering design

- Step file / details on the cryostat and on how the mechanical integration is to be done
  – Could we keep the possibility of testing it in both Diode and Siegtal?
  – Alignment of bore and rotating probe with compensation weights
  – NbTi – leads connections and routing

- Self supported rotating coil (22 mm bore) integration
  – Status of the probe development
  – What do we need to foresee in the structure of the magnet to use it?

- Range of dump resistance for protection studies

- …

Planning

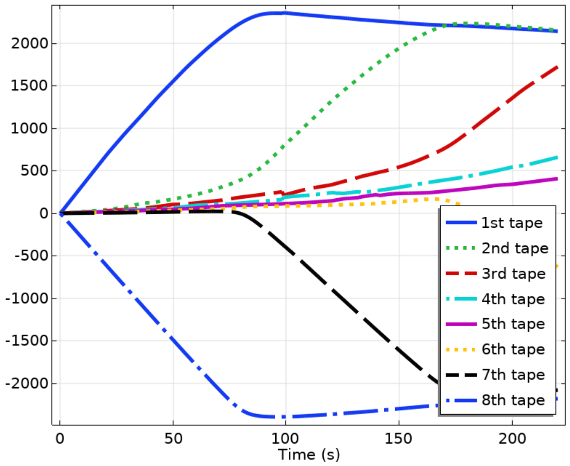
Task	November				December				January					February				March					April			
	45	46	47	48	49	50	51	52	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Engineering Design																										
Procurement of Coil Components																										
1st Coil Ceramic coating and winding																										
1st Coil HT																										
1st Coil Intrumentation																										
1st Coil Impregnation																										
2nd Coil Ceramic coating and winding																										
2nd Coil HT																										
2nd Coil Intrumentation																										
2nd Coil impregnation																										
1st and 2nd Coils splice																										
3rd Coil Ceramic coating and winding																										
3rd Coil HT																										
3rd Coil Intrumentation																										
3rd Coil Impregnation																										
4th Coil Ceramic coating and winding																										
4th Coil HT																										
4th Coil Intrumentation																										
4th Coil impregnation																										
3rd and 4th Coils splice																										
Coils Outer Splices																										
Magnet Structure: assembly with dummy Coils and instrumentation																										
Magnet Assembly and Final Checks																										
Shipment																										
Nov-23			CAS					Break																		

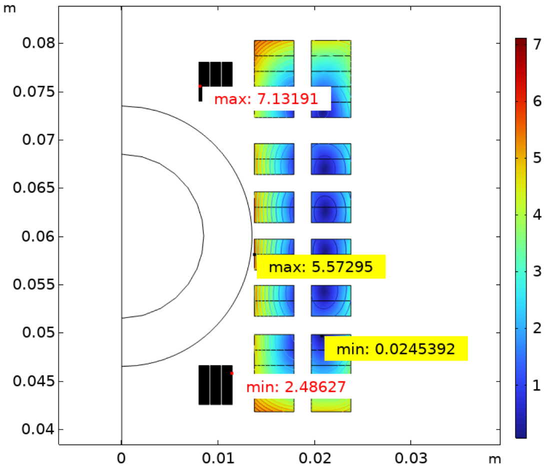
Agenda

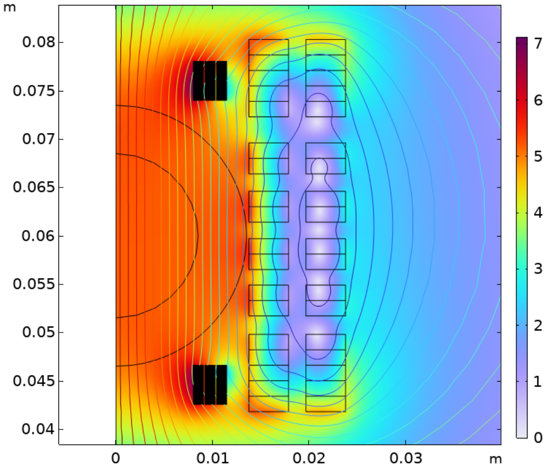
- Concept and main parameters
- Engineering Design (T. Michlmayr)
- Needs to complete the integration
- Planning
- CERN/MPE collaboration on the protection
- 2nd phase: hybrid LTS/HTS

Agenda 2nd phase: hybrid LTS/HTS

- First PSI step towards the development of hybrid magnets
- Modelling validation via magnetic field measurements (LTS vs Hybrid version)
- CERN/MPE collaboration on the protection and advanced modelling
- 2nd pair of leads for independently powering LTS and HTS coils?







Computations from D. Sotnikov

Agenda

- Concept and main parameters
- Engineering Design (T. Michlmayr)
- Needs to complete the engineering design
- Planning
- CERN/MPE collaboration on the protection
- 2nd phase: hybrid LTS/HTS
- Conduction cooled subscale with forced flow cooling circuit?

Backup slides

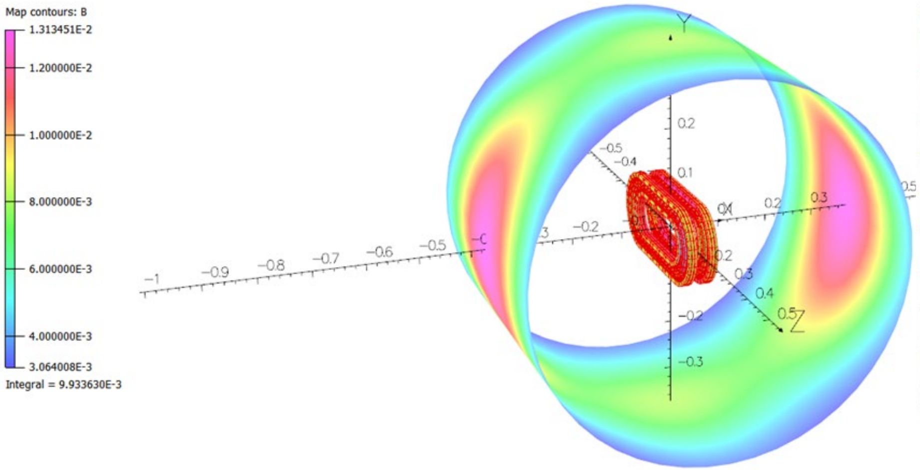
- Stray field estimation
- 3D field quality optimization

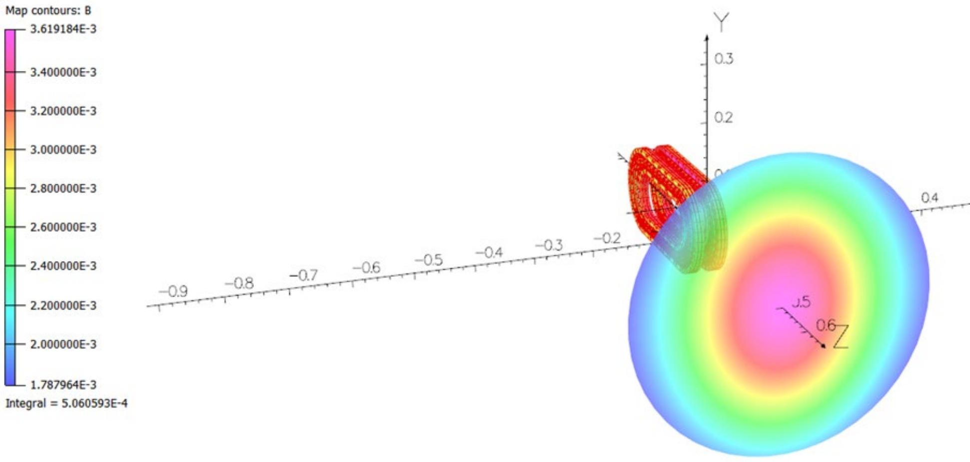
Stray-field computation (CERN safety regulation)

- With the 6 coils solution

The plot shows the stray field on the cylinder with R = 0.375 m and H = 0.6 m (from -0.3 to +0.3 in respect to the magnet barycenter).

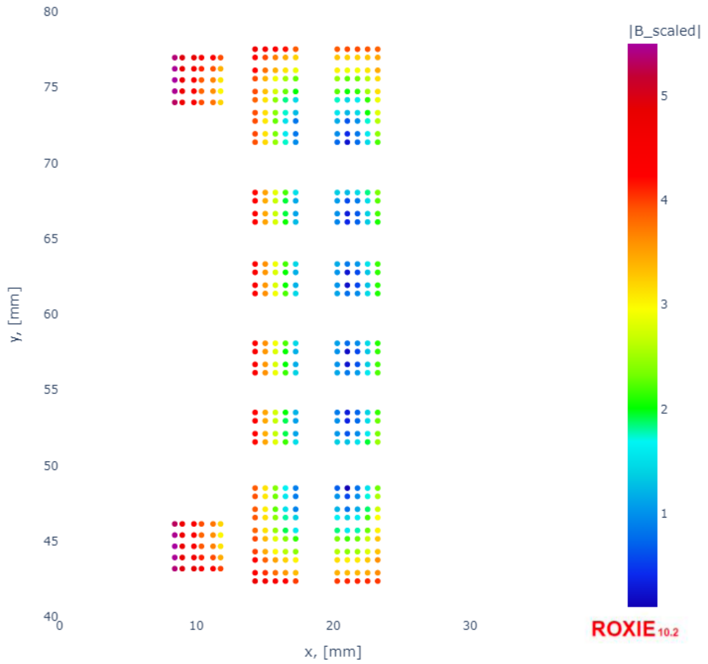
The plot shows the stray field on the disk with R = 0.375 m and H position = 0.5 m.

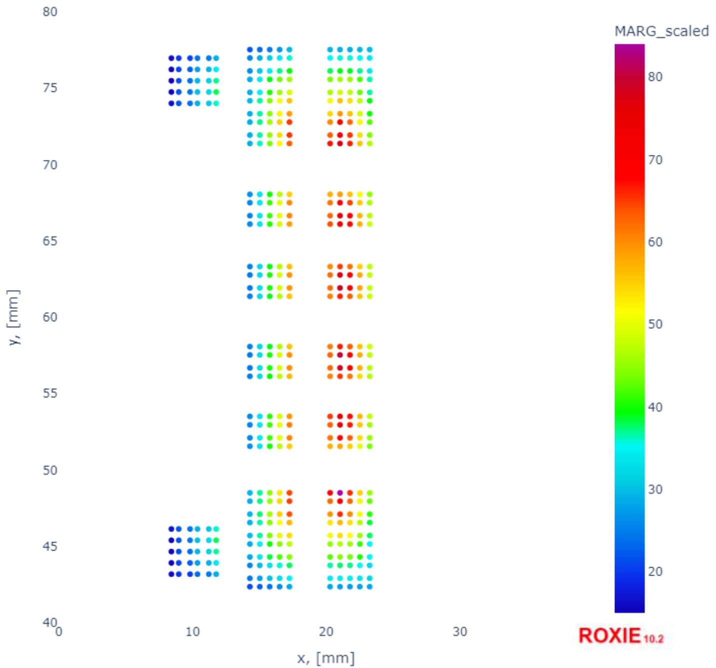




2D Magnetostatics: $B_0 = 4.5$ T, I = 7.1 kA

- Peak field on conductor: 5.49 T
- Margin at 4.5 K: 15 %
- Field Quality

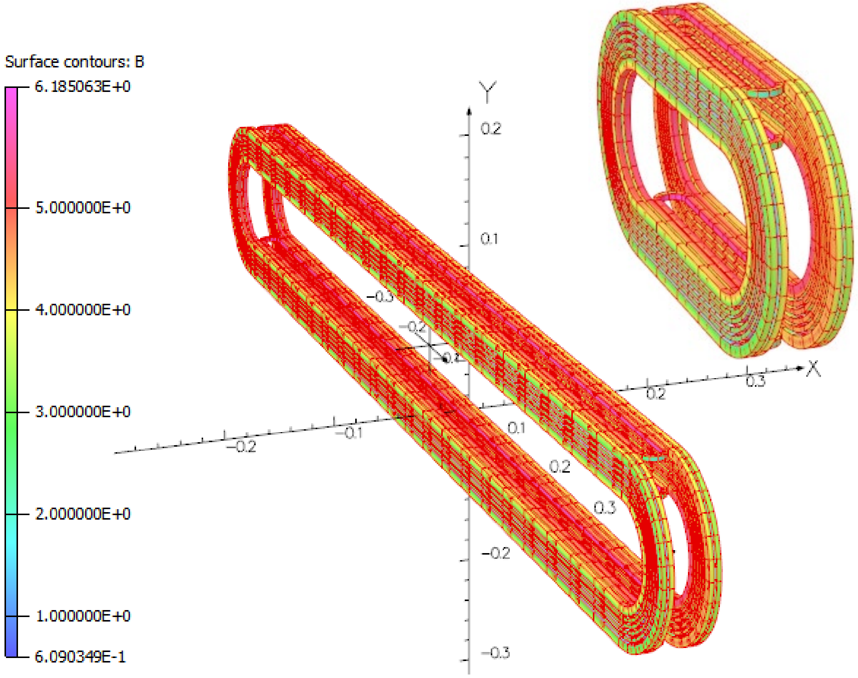




Multi pole	Units
b3	-0.2
b5	-3.1
b7	3.8
b9	-1.
a2	0.9
a4	3.7
a6	-0.2
a8	0.0

3D Field Quality Computation

- 1 m and 150 mm long straight section

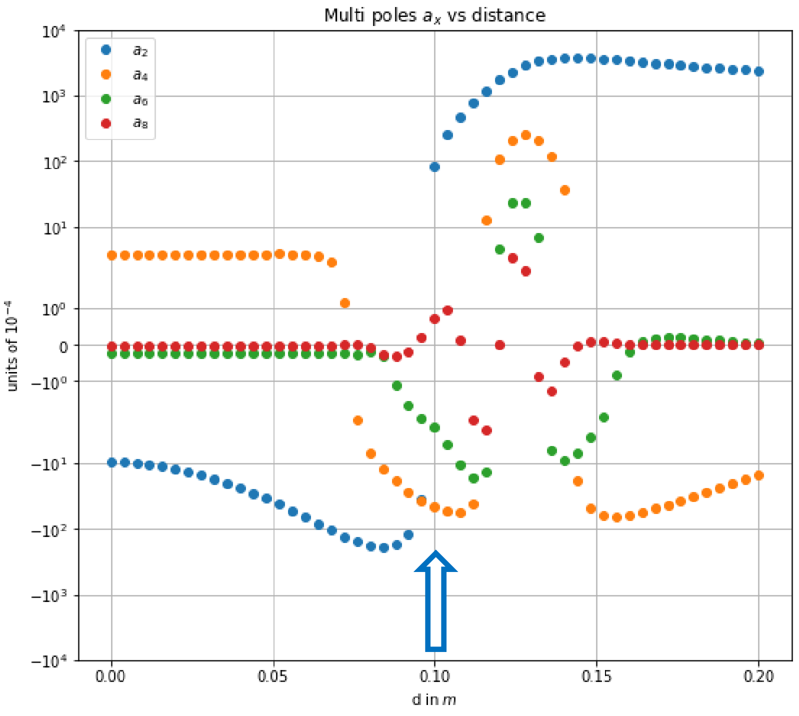


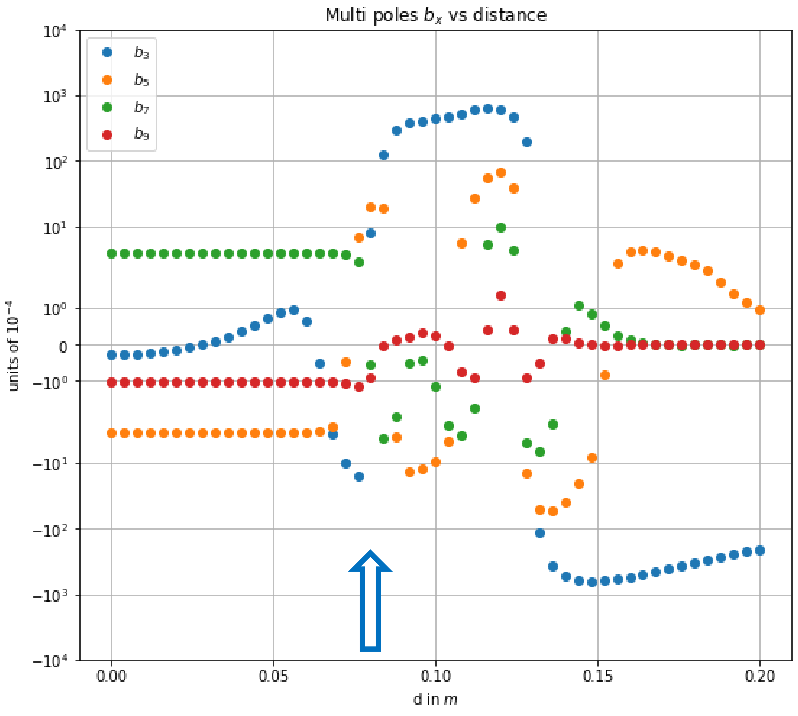
Multi-poles	Units			
-	2D	3D 1 m	3D 0.15 m	Integral
b3	-0.2	-0.62	-0.26	87.8
b5	-3.1	-3.34	-3.35	-1.2
b7	3.8	3.81	3.82	2.0
b9	-1.	-1.00	-1.00	-0.7
a2	0.9	0.89	-9.54	315.1
a4	3.7	3.71	3.72	5.67
a6	-0.2	-0.23	0.23	-0.8
a8	0.0	-0.01	-0.01	-0.1

Cross-section

Needs optimization

Why does the sign of the integral change? 1/2

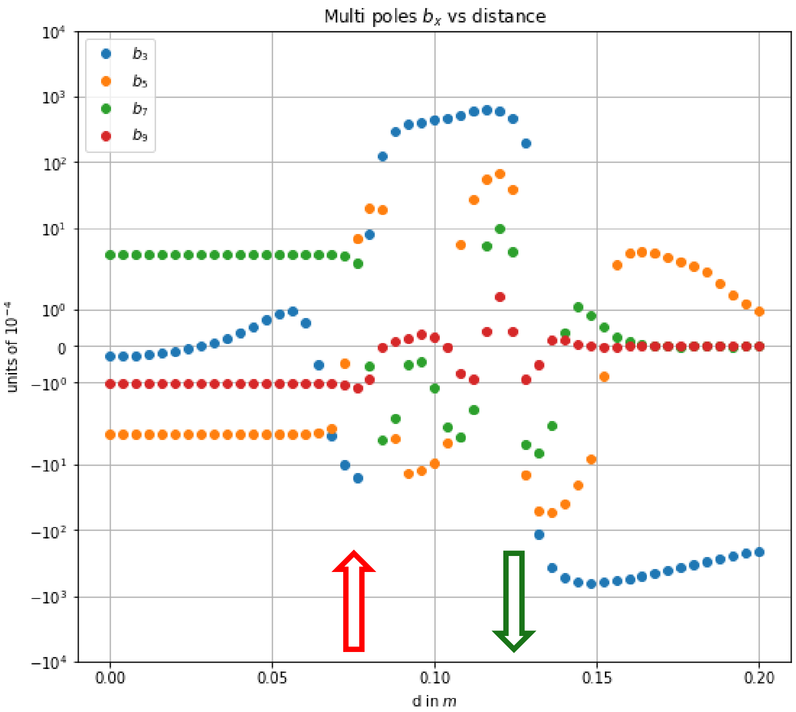


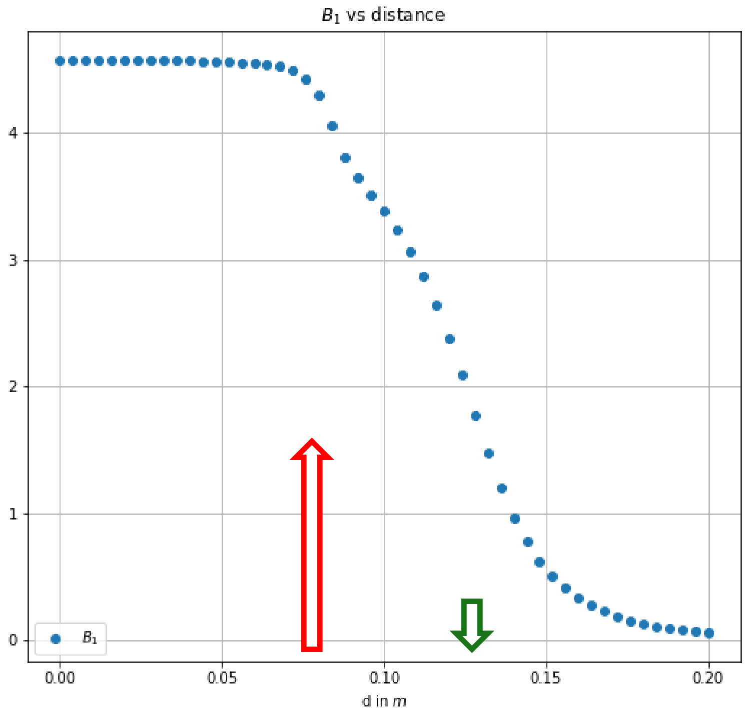


Integral a2 >> 0

Integral b3 >> 0

Why does the sign of the integral change? 2/2

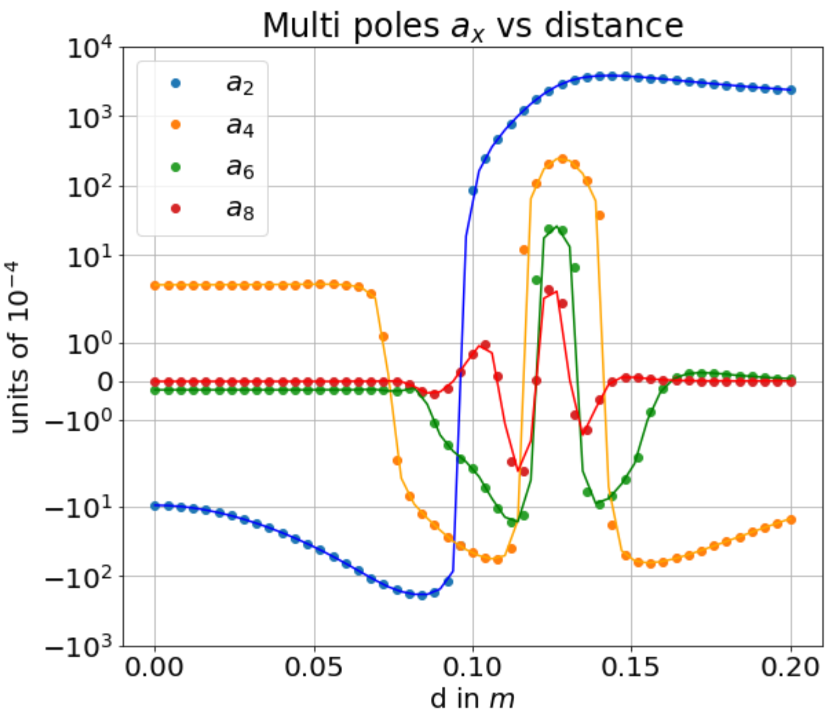


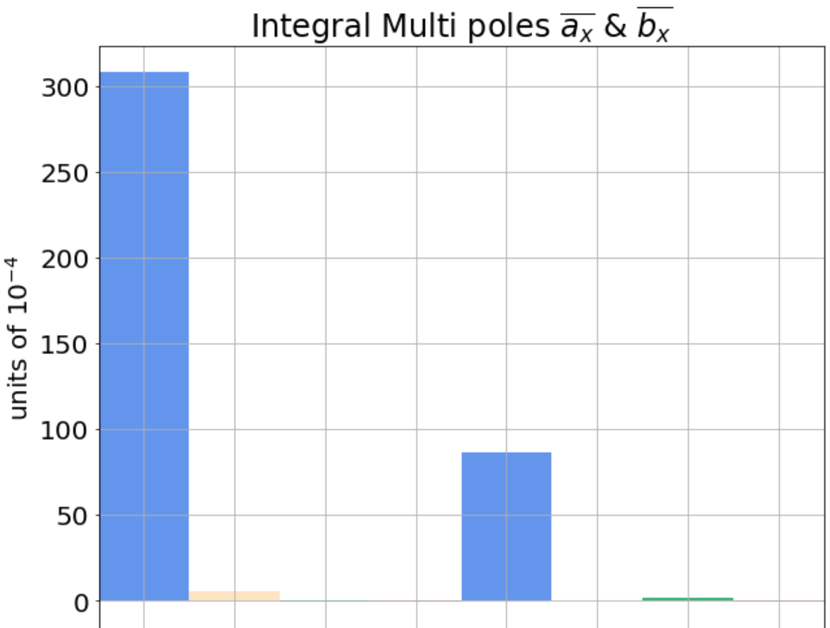


Integral b3 >> 0

big contribution vs small contribution

In order to optimize, how can we quickly calculate the integral?



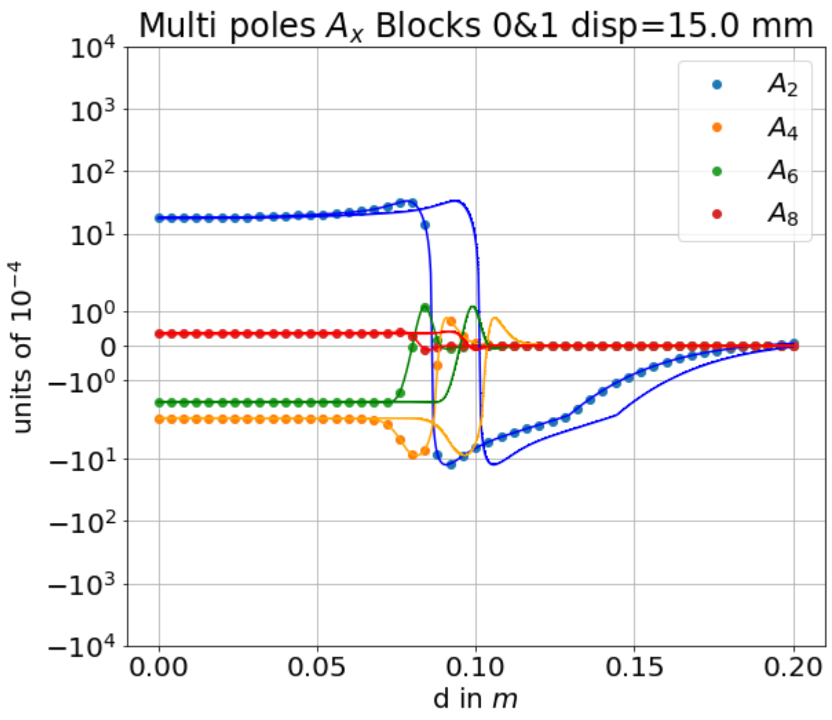


a2	a4	a6	a8	b3	b5	b7	b9
308.17	5.57	-0.69	-0.03	86.83	0.27	2.21	-0.68

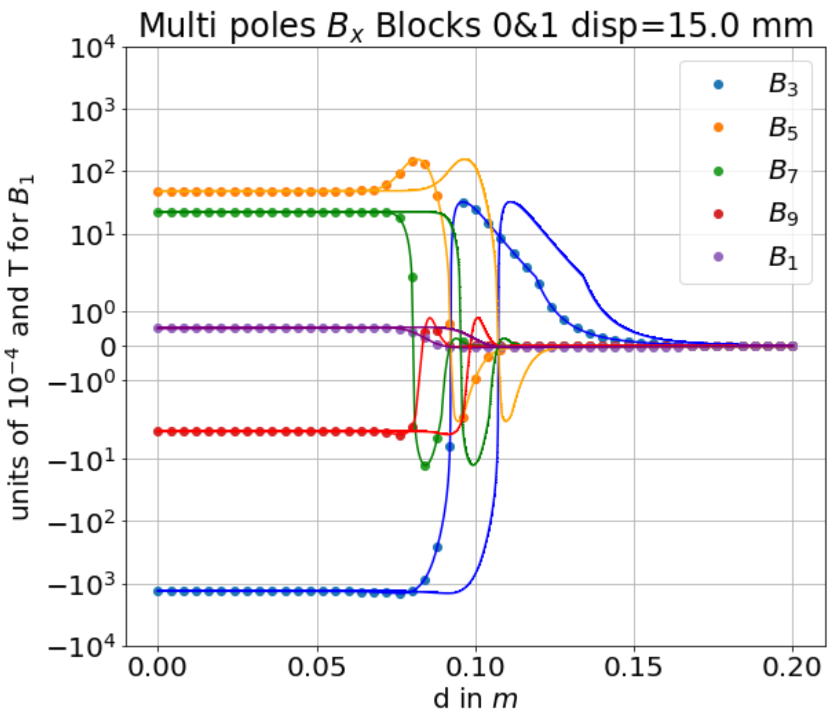
Cubic-spline interpolation

Integration over the interpolated function

Blocks' contribution and displacement

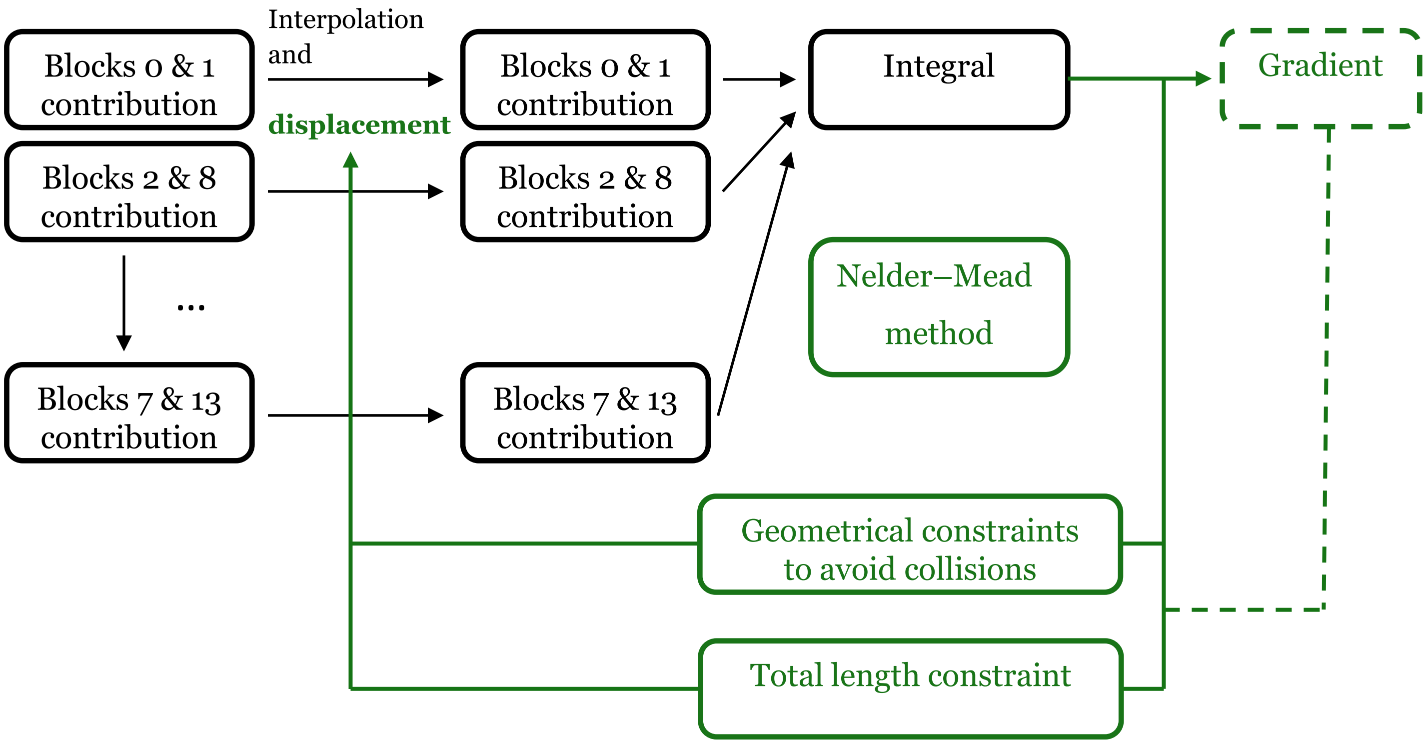


Cubic-spline interpolation and shift on the axial direction

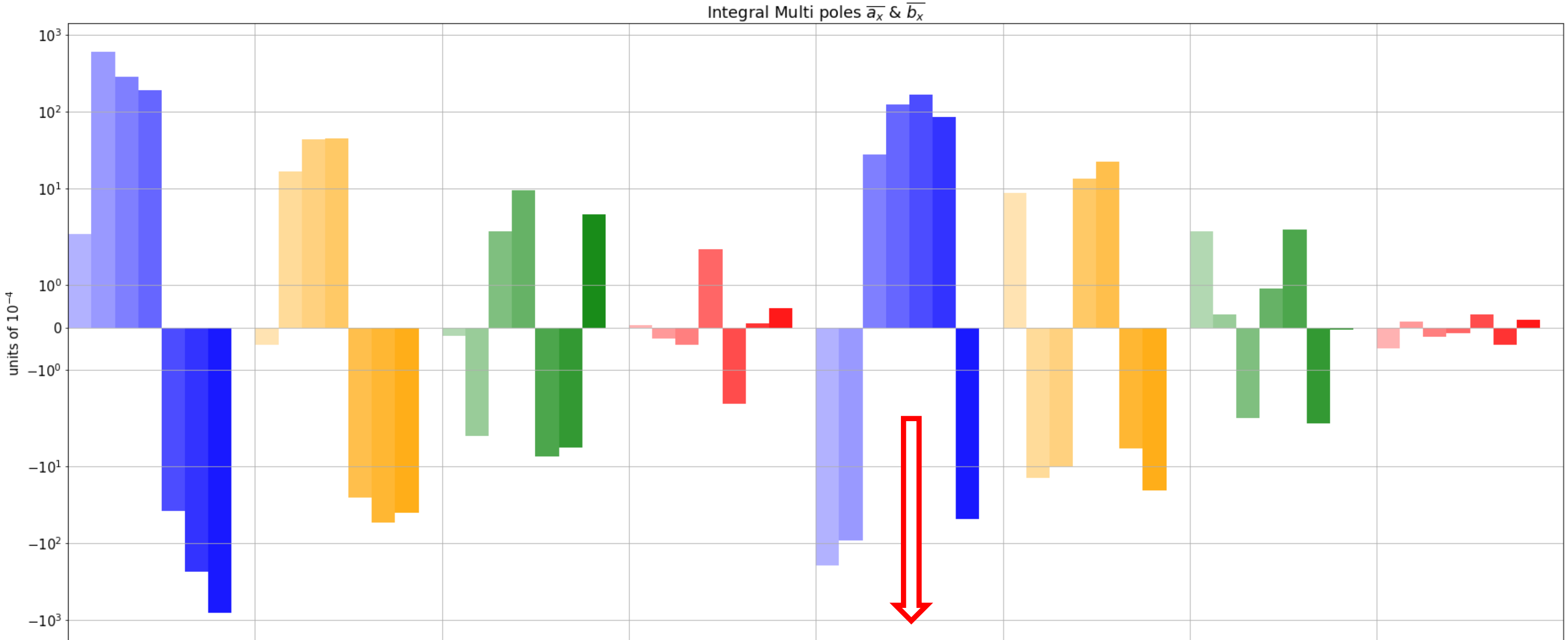


B1 is also displaced to allow the integral computation

Optimization scheme

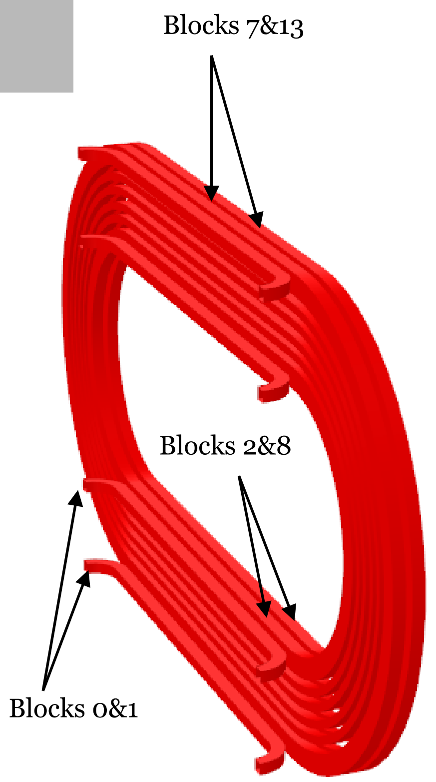


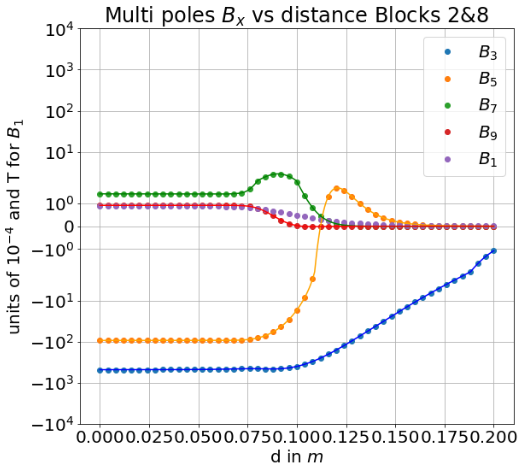
Result: sum of multi poles = 101.18

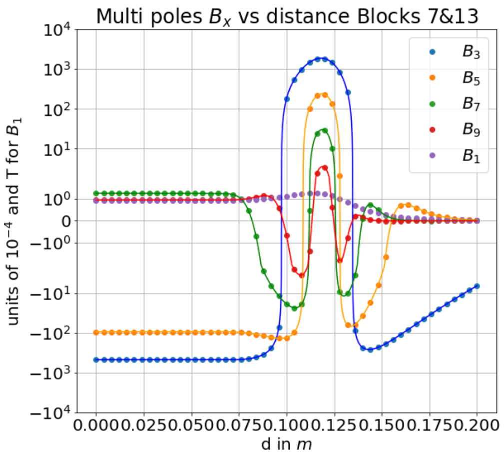


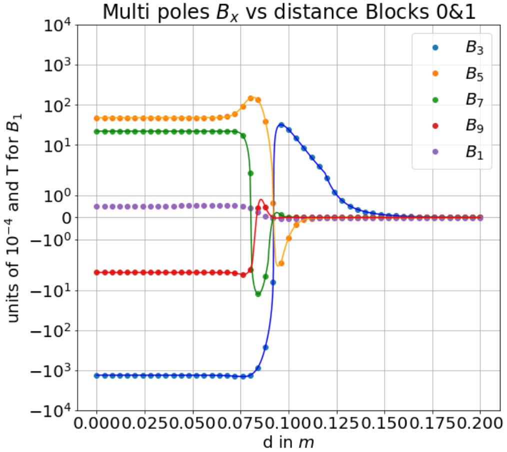
	$\overline{a_2} = -0.0$	$\overline{a_4} = -14.2$	$\overline{a_6} = -0.6$	$\overline{a_8} = -0.0$	$\overline{b_3} = 72.7$	$\overline{b_5} = -5.6$	$\overline{b_7} = 1.8$	$\overline{b_9} = -0.6$
Blocks 0 & 1	2.53	-0.42	-0.2	0.05	-193.56	8.88	2.78	-0.5
Blocks 2 & 8	609.39	16.65	-4.06	-0.26	-92.28	-14.25	0.31	0.14
Blocks 3 & 9	286.71	43.86	2.79	-0.4	28.09	-9.97	-2.36	-0.22
Blocks 4 & 10	193.77	45.2	9.45	1.84	125.53	13.39	0.91	-0.12
Blocks 5 & 11	-38.14	-25.53	-7.52	-1.79	166.16	22.74	2.96	0.3
Blocks 6 & 12	-237.78	-53.48	-5.63	0.1	86.82	-5.83	-2.77	-0.4
Blocks 7 & 13	-816.48	-40.49	4.6	0.46	-48.04	-20.61	-0.04	0.19

b3 example: blocks able to decrease it







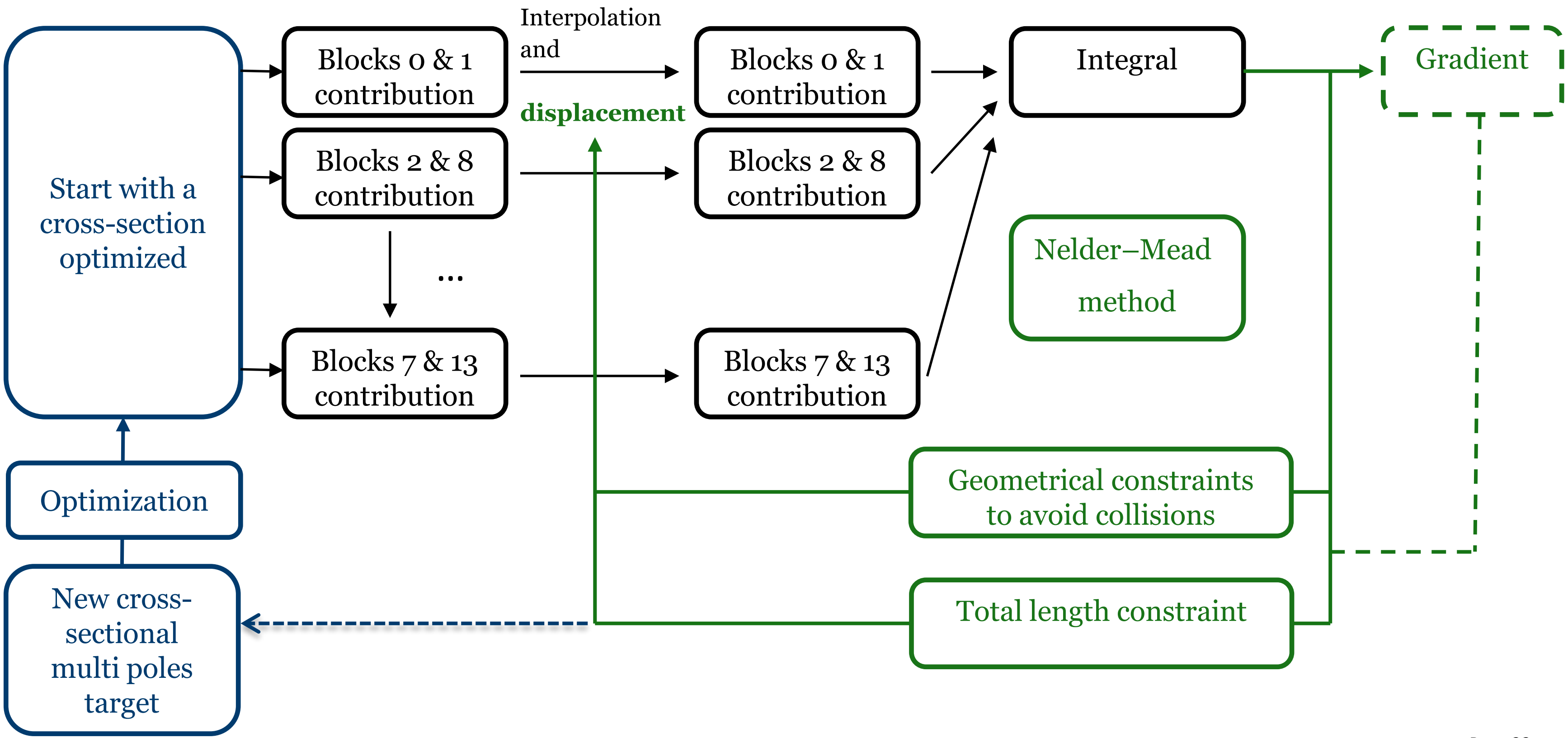


Blocks 2&8: increasing their length would shift the entirely coil pack

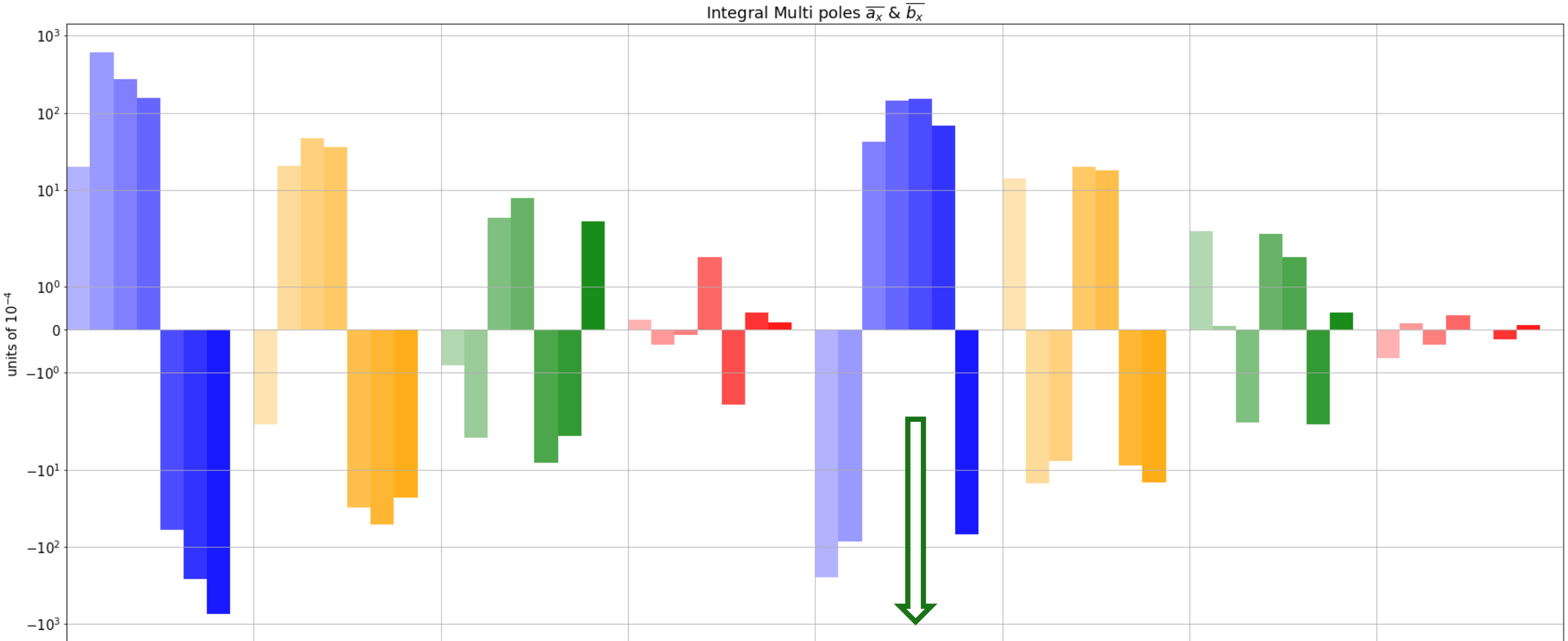
Blocks 0&1: increasing their length helps but they contribute little to B1

Blocks 7&13: increasing their length increases this block length but not the whole magnet

Optimization scheme 2



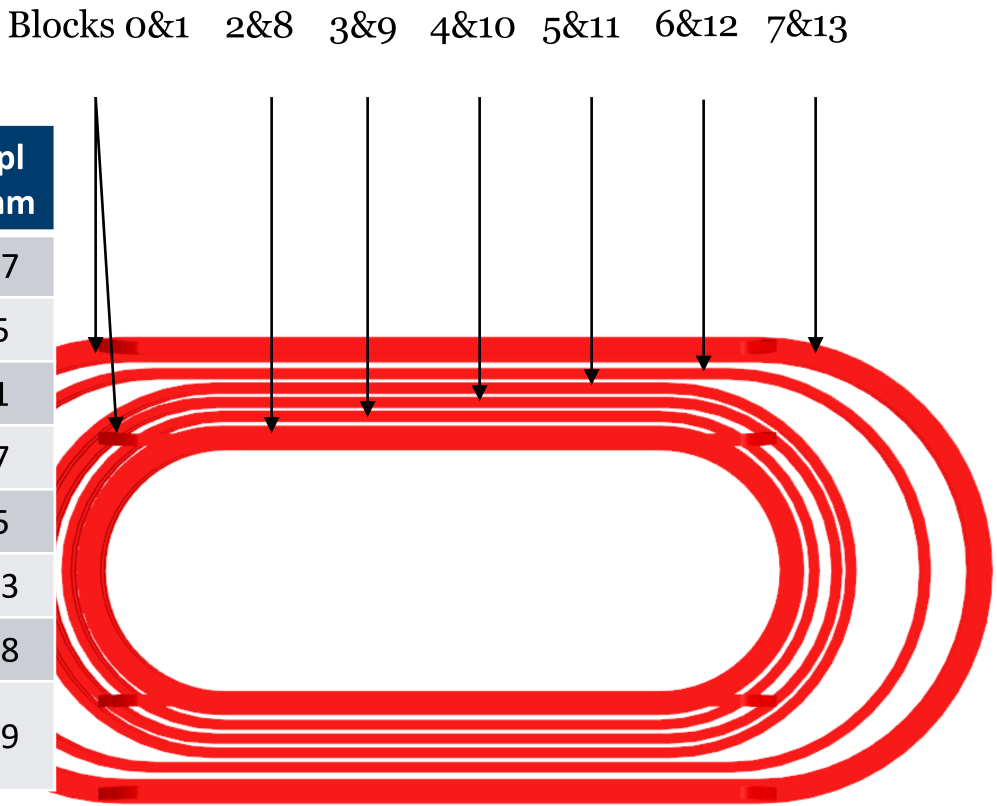
Result 2: sum of multi poles = 15.76



	$\overline{a_2}$ = -4.4	$\overline{a_4}$ = -3.7	$\overline{a_6}$ = -0.3	$\overline{a_8}$ = 0.3	$\overline{b_3}$ = 4.4	$\overline{b_5}$ = 5.3	$\overline{b_7}$ = 2.8	$\overline{b_9}$ = -0.6
Blocks 0 & 1	20.05	-2.58	-0.82	0.24	-244.76	13.95	2.96	-0.65
Blocks 2 & 8	607.79	20.41	-3.91	-0.34	-85.83	-15.15	0.1	0.14
Blocks 3 & 9	275.31	46.86	4.35	-0.12	42.38	-7.74	-2.49	-0.35
Blocks 4 & 10	157.47	35.97	7.88	1.7	144.6	19.78	2.72	0.33
Blocks 5 & 11	-60.04	-30.77	-8.15	-1.74	150.2	17.99	1.69	0.01
Blocks 6 & 12	-262.31	-50.69	-3.65	0.41	67.21	-8.95	-2.56	-0.23
Blocks 7 & 13	-742.69	-22.9	3.98	0.18	-69.4	-14.58	0.4	0.11

Optimized geometry

Blocks	Displ in mm
0 & 1	27.7
2 & 8	0.5
3 & 9	0.1
4 & 10	3.7
5 & 11	0.5
6 & 12	24.3
7 & 13	34.8
Total 2-13	63.9



Multi-poles	Units	
-	Cross-section	Integral
b3	0.6	4.3
b5	8.6	5.3
b7	4.2	2.8
b9	- 0.8	-0.6
a2	- 35.4	-3.2
a4	11.3	-3.7
a6	-1.0	-0.3
a8	0.2	-0.3

Optim 2