Progress on the Magnetic Design of Superconducting Dipoles in Acceleration Stage

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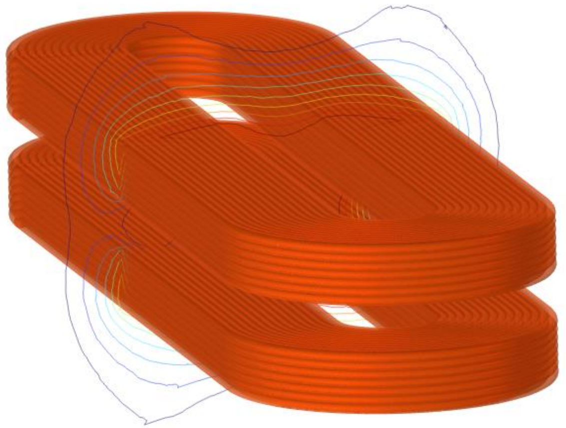
[1]CERN, [2]INFN – Genova

Accelerator Superconducting Magnets

Parameters

- **10 T** at the center
- Rectangular aperture **30 mm x 100 mm**
- Field quality in good field region TBD (ex. $b_n < 10$) units



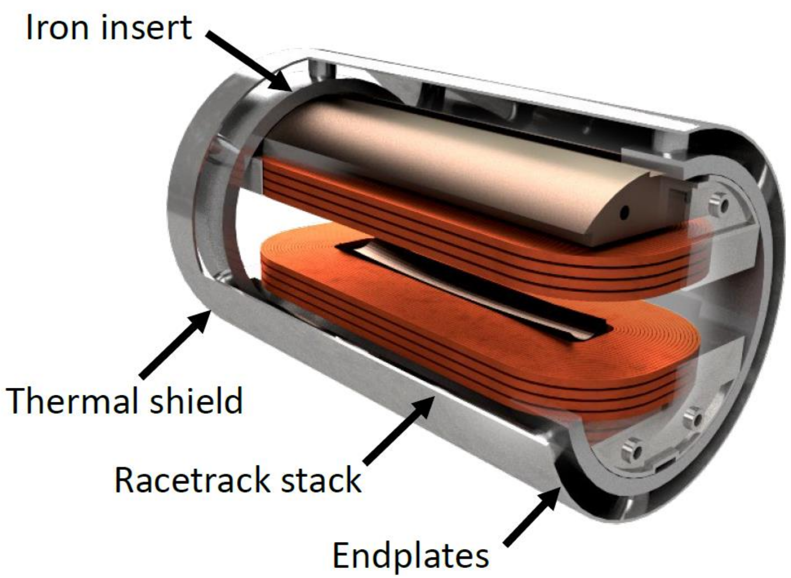
Considerations

- Attempt to use uniform technology throughout the collider complex
  - HTS windings (for robustness)
  - High current density (for cost reasons)
  - Operation at high temperature (for energy efficiency)

Parameter	Unit	
Minimum central field B_0	T	10
Free aperture (height x width)	mm2	30x100
Field Quality limits	units	10, 50 (to be iterated with beam physics)
Field quality homogeneity (B1 change)	%	
Good Field region (height x width)	mm2	10 mm x 20 mm
Operating temperature		TBD
HTS tape dimensions		12 mm x ** mm
Magnet length		

Overlap

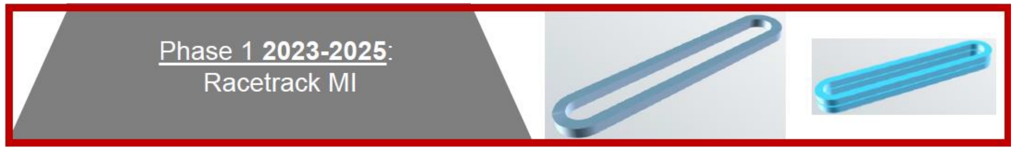
- **10 T** at 20 K, 10 K margin
- Rectangular aperture **50 mm x 80 mm**
- Field quality better than **1.5%**
- Straight section length: **550 mm**
- Conductor volume / m (straight sections): **0.0154** $\mathbf{m^3/m}$



[1] Design and Plan of a 10 T HTS Energy Saving Dipole Magnet for the Italian Facility IRIS, MT-28

CEA-CERN HFM collaboration

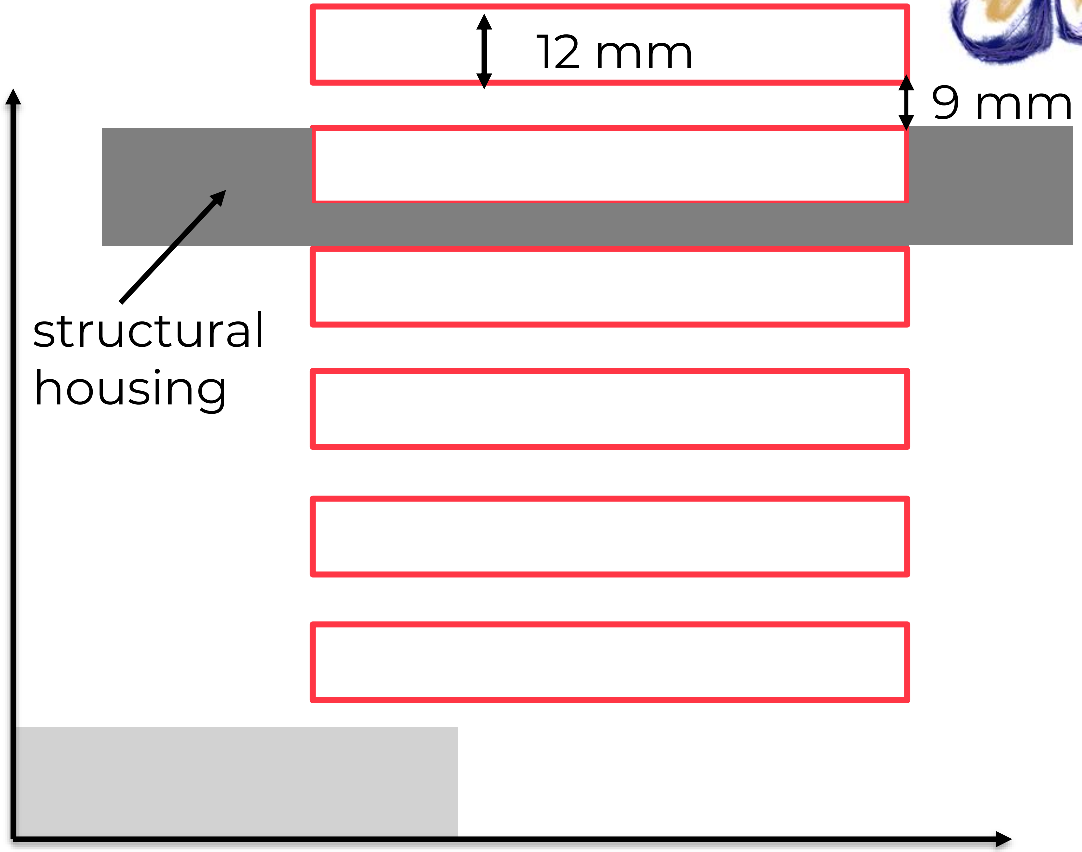
- Demonstrator of metal-insulated ReBCO high field magnet coils



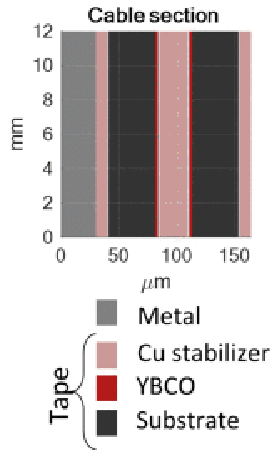
IRIS 10 T energy saving Dipole ESMA

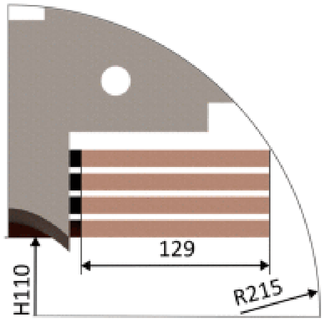
Thank you to discussions with those who designed the dipole magnet ESMA (Lorenzo B., Stefano S., etc.)

Innovative Research Infrastructure on applied Superconductivity IRIS



- **6 stacks** of 12 mm tape pancakes
- **9 mm gaps** for field quality
- **Metal insulated** (SS) (not NI because of long ramp up time)
- **1.5 % field quality** (150 units)
- **No Iron** because it limits the optimal field quality to one field value – this magnet must be used at range of field values



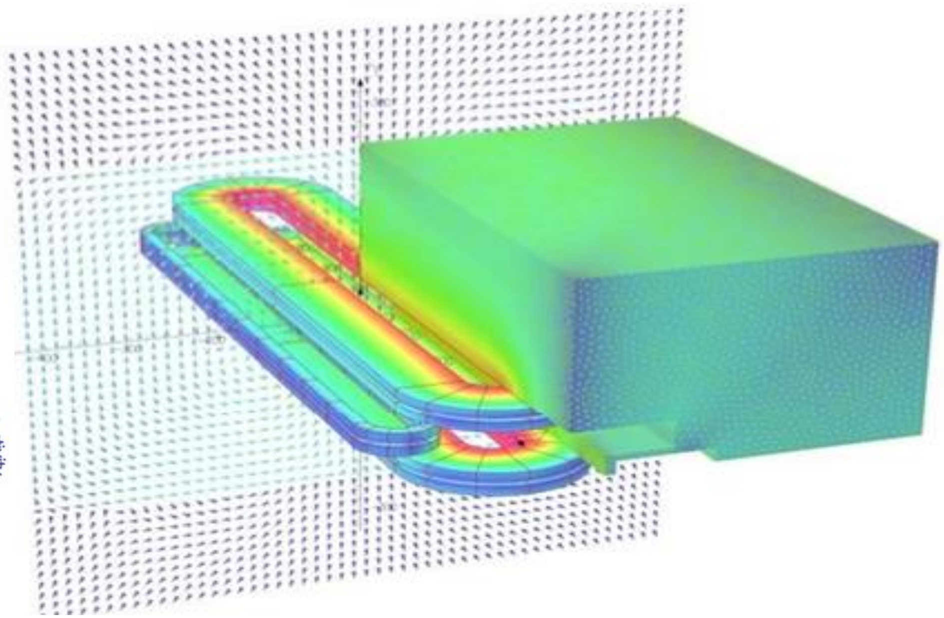


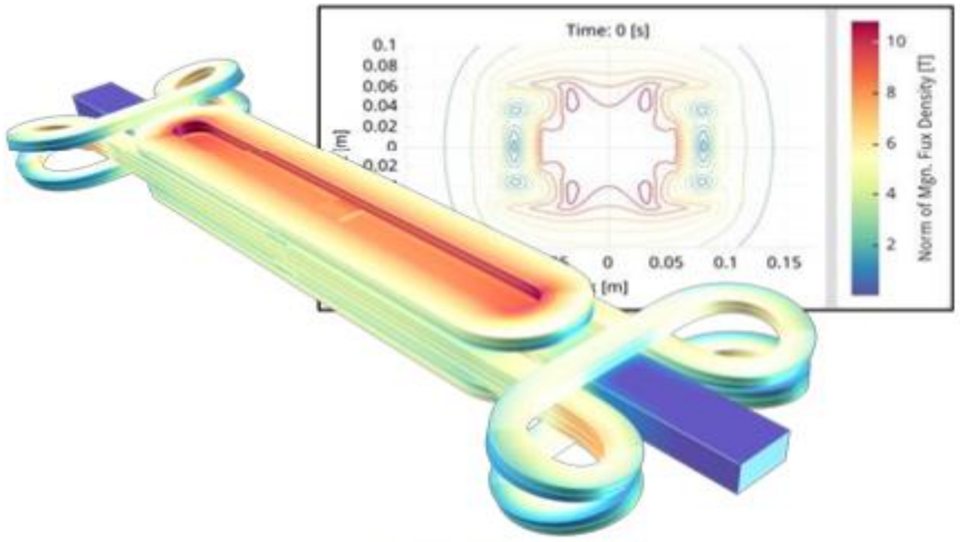
[1] L. Rossi and others, "Design and Plan of a 10 T HTS Energy Saving Dipole Magnet for the Italian Facility IRIS," in IEEE Transactions on Applied Superconductivity, vol. 34, no. 5, pp. 1-6, Aug. 2024, Art no. 4602406, doi: 10.1109/TASC.2024.3355357

Conceptual Design (**Reminder:** previously ruled out more complex geometries)

2.1 Flat RT coils in midplane, with return leg on external part

2.2 Cloverleaf winding (novel)





Reference: IRIS - https://indico.cern.ch/event/1220254/contributions/5270734/attachments/2607808/4507319/REBCO%20I.FAST%20CCT%20&%20IRIS%2010%20T%20HTS%20dipole%20at%20INFN.pdf

Add construction complexity

Limited advantages (see [1])

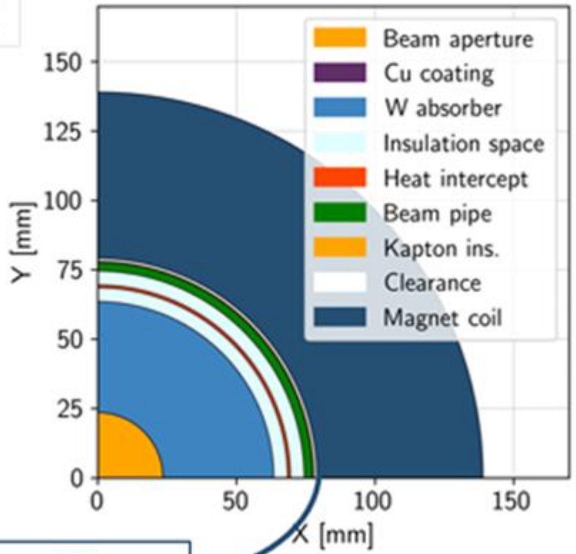
Radial Build

- Important for defining space for magnets

Assuming 10 TeV machine and coil at 4.5 K

Beam aperture (5σ)	23.5 mm radius
Cu layer beam screen	0.01 mm thick
Tungsten absorber	40 mm thick
Insulation space	5 mm thick
Heat intercept	1 mm thick
Insulation space	5 mm thick
Beam pipe	3 mm thick
Kapton insulation	0.5 mm thick
Clearance	1 mm thick
Coil pack*	(60 mm thick)

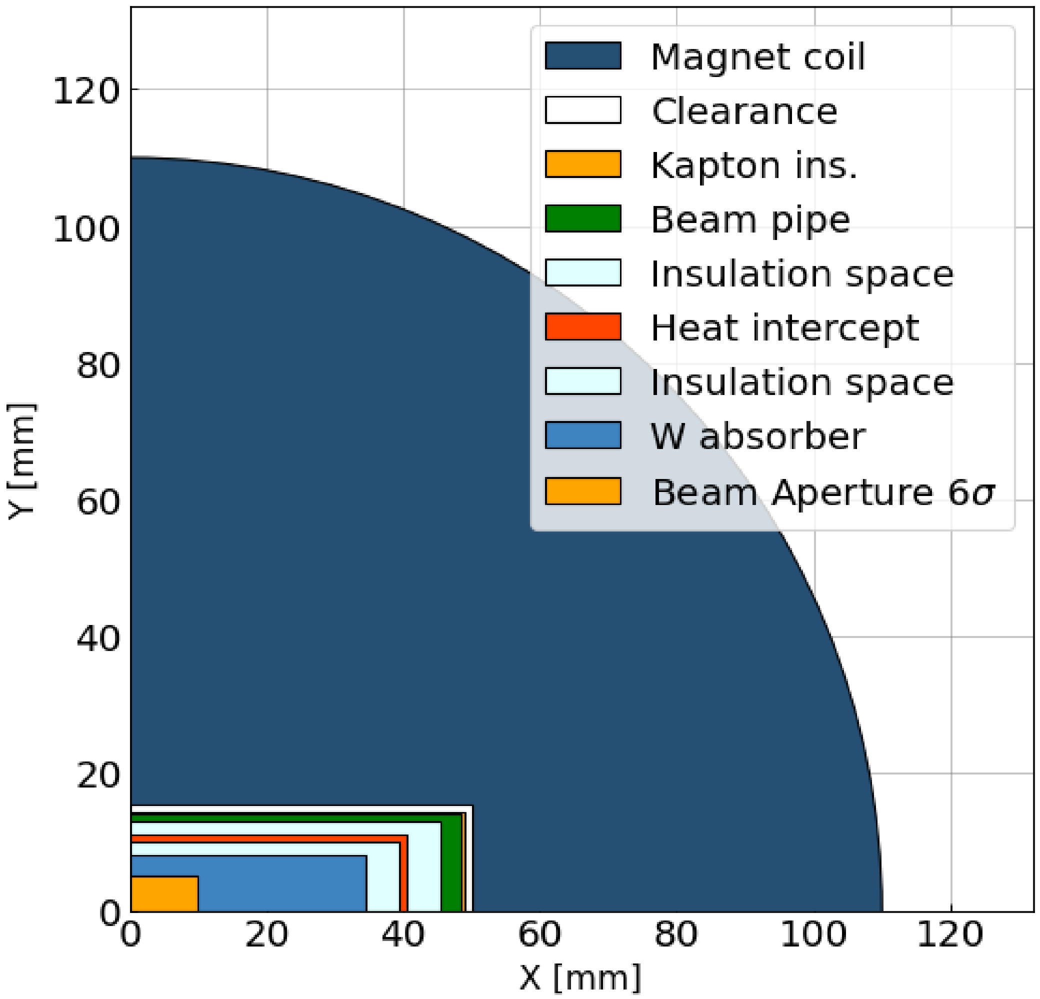
*thickness TBD, placeholder



Courtesy of Patricia Borges de Sousa
https://indico.cern.ch/event/1250075/contributions/5357594/

Coil aperture 158 mm

Novelli, Daniel, et al.

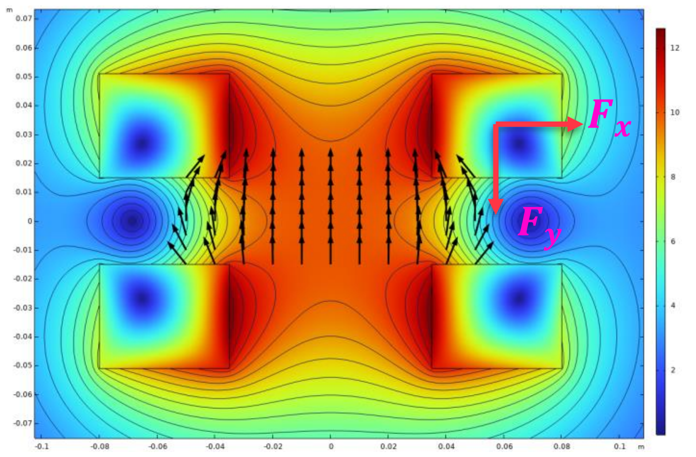


Magnet Design Status

Previously, single stacks of conductor were investigated in terms of cost, with some mechanical analysis (Annual Meeting)

Ongoing conceptual design: two **approaches** taking place:

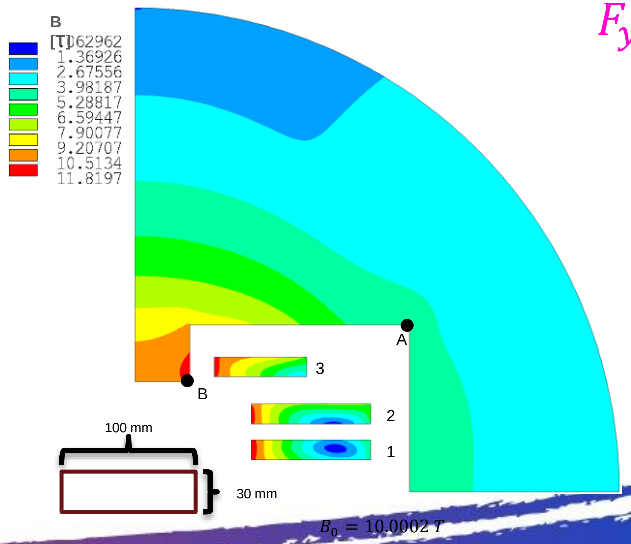
1. **Numerical optimization routine** looking at conductor volume, field quality (w/o iron) and critical current density limit
2. **Optimization in ROXIE** including Iron



$F_x = 2.8$ MN
$F_y = 3.8$ MN

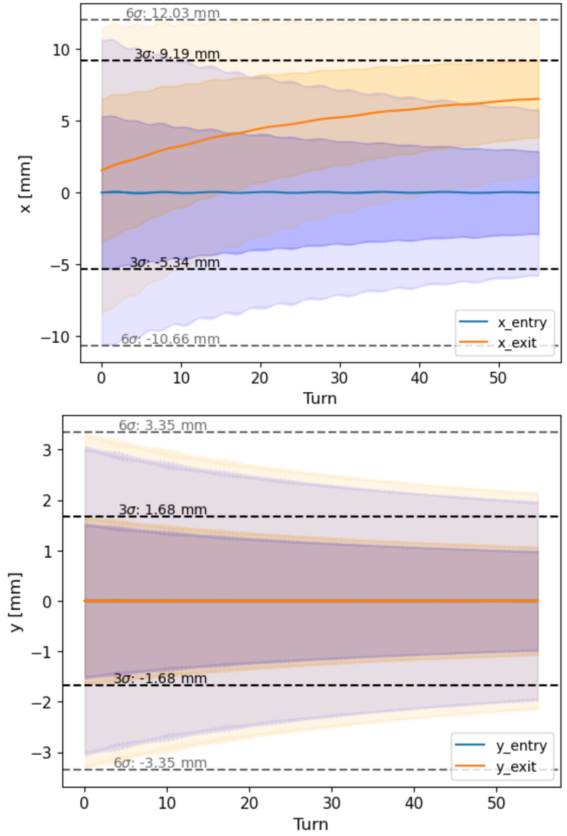
First Goals:

- Optimization study on possible configurations as a function of cost, field quality, and complexity (number of racetracks, uniformity..)
- Mechanical analysis



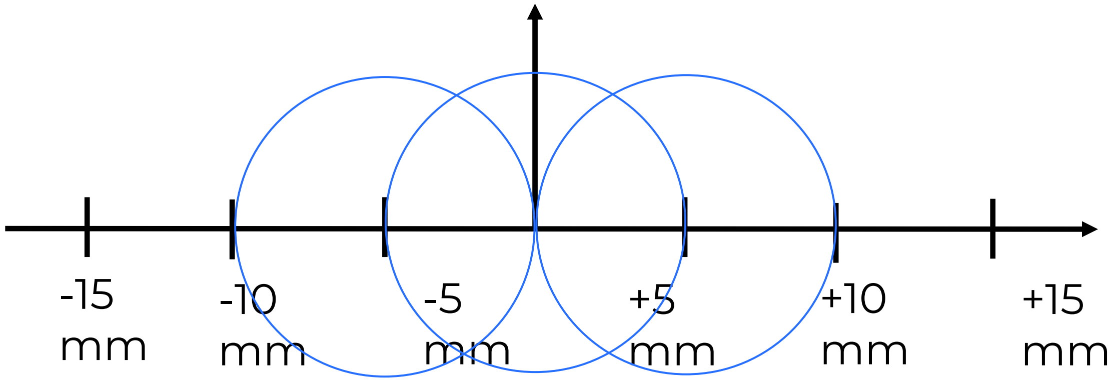
Field Quality Calculation (Updated Values)

- Current assumption before update: 50 mm in x, 20 mm in y



Credit and thanks to Lisa Soubirou

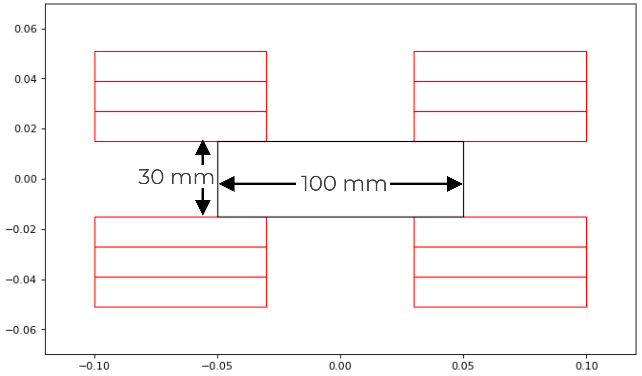
- **Update**: good field region 20 mm in x, 10 mm in y (roughly 6σ beam)

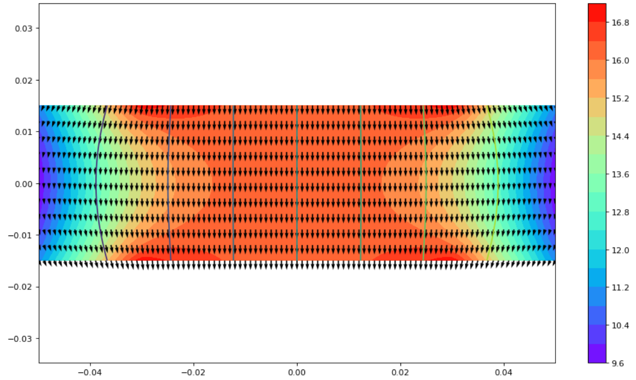


Numerical Optimization Routine

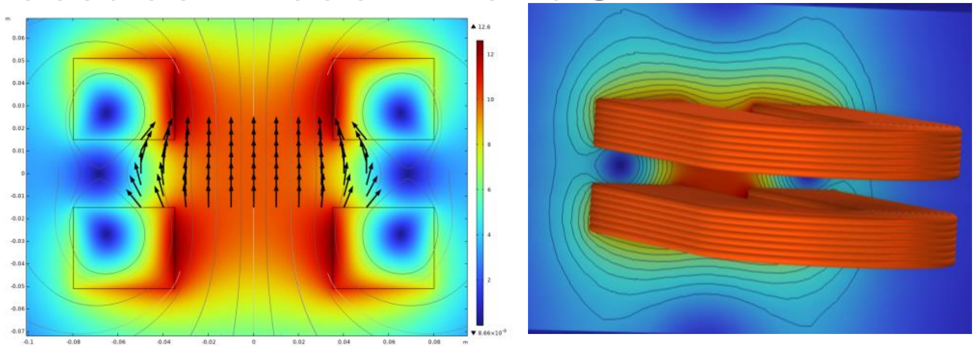
An approach to best optimize **field quality** and **cost**

- **Input constraints**:
  - Search resolution
  - Space the RTs can exist in
  - RT constraints (minimum length in x, thickness in y (12 mm))
  - Current Density (<700 A/mm2)
- **Limitations**: does not include Iron



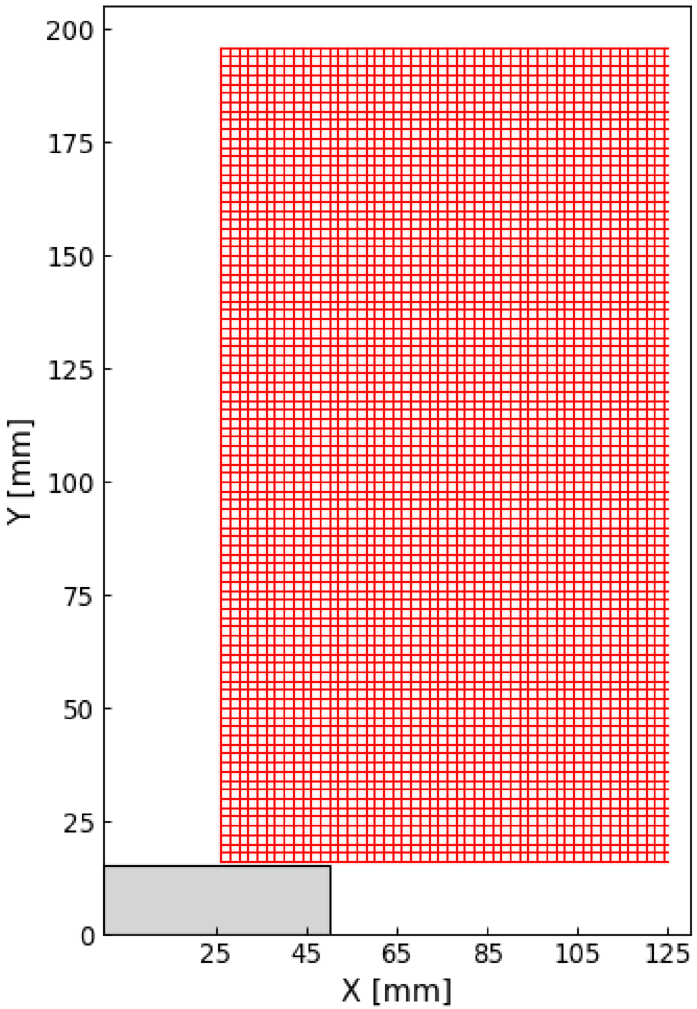


Racetrack Model **2D** and **3D**

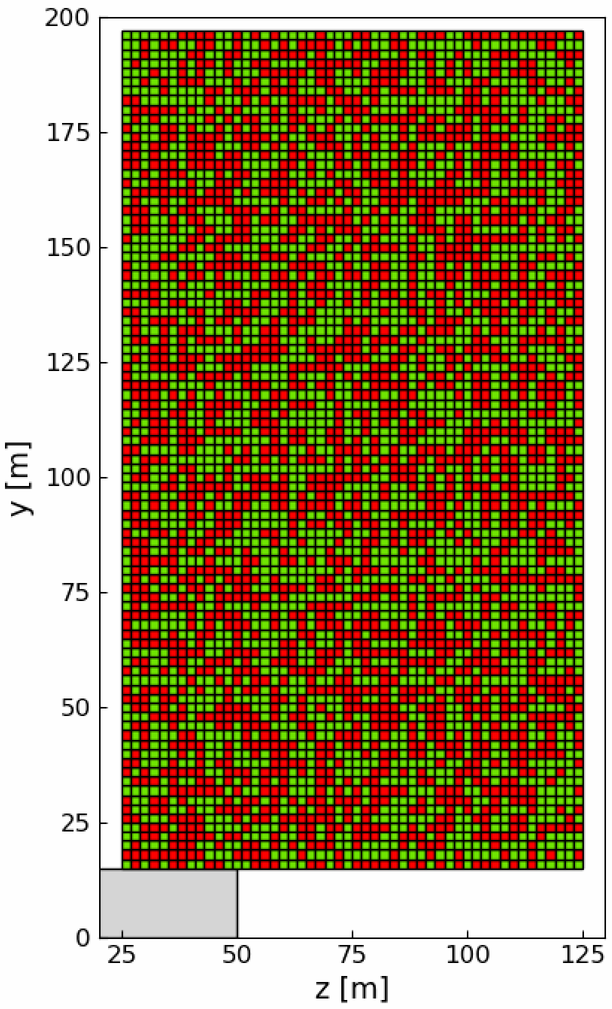


Numerical Optimization Routine - **Method**

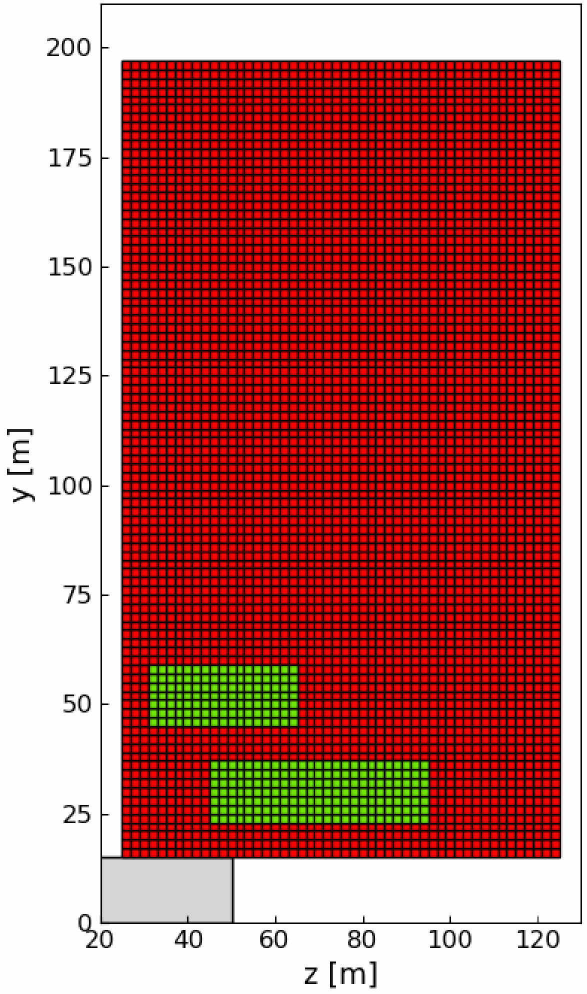
I. Establish grid where RT pancakes are allowed to exist (Ex. 2 mm dx dy)



II. Calculate field contribution from all grid elements



III. Create all unique configurations of 2, 3, 4, 5, and 6 pancakes



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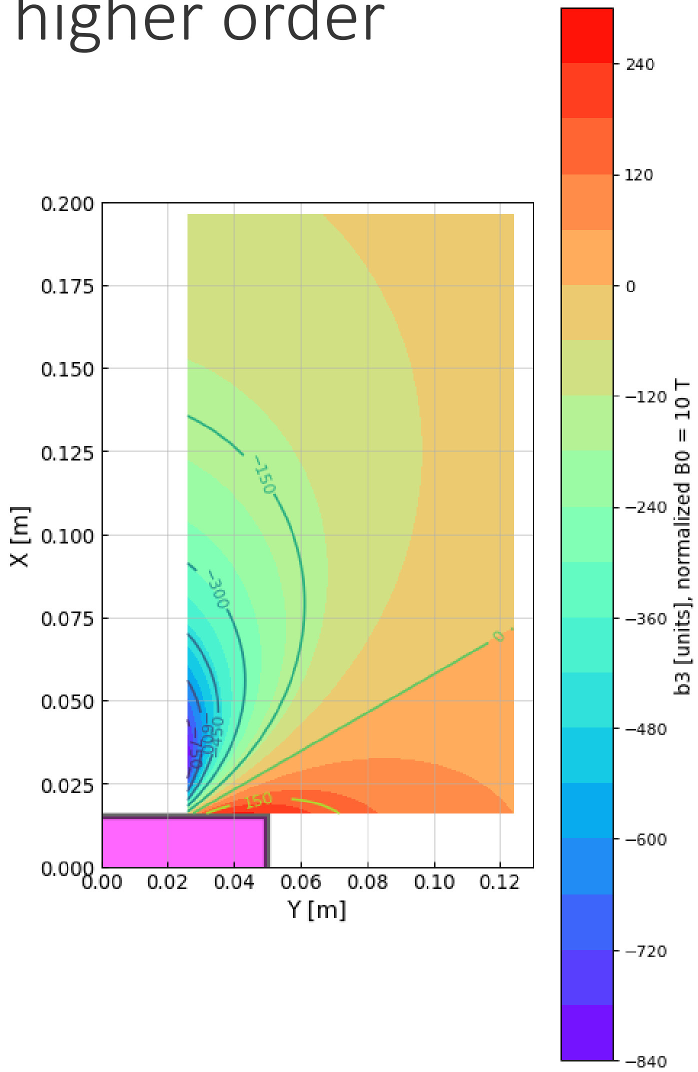
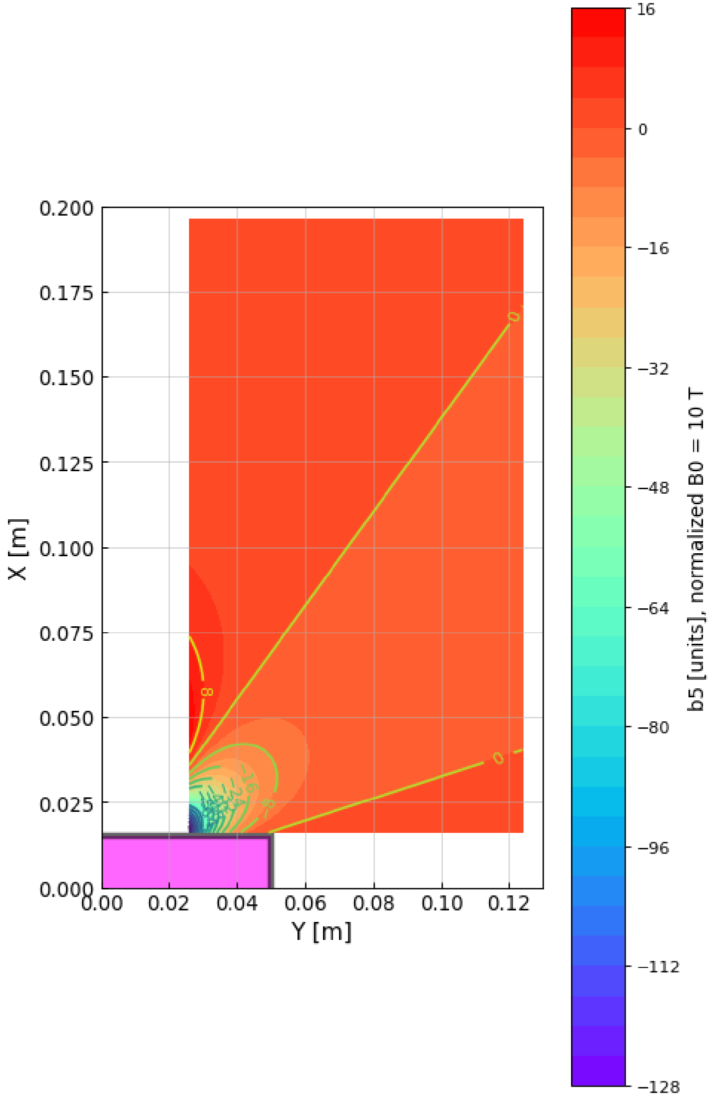
Numerical Optimization Routine - **Method**

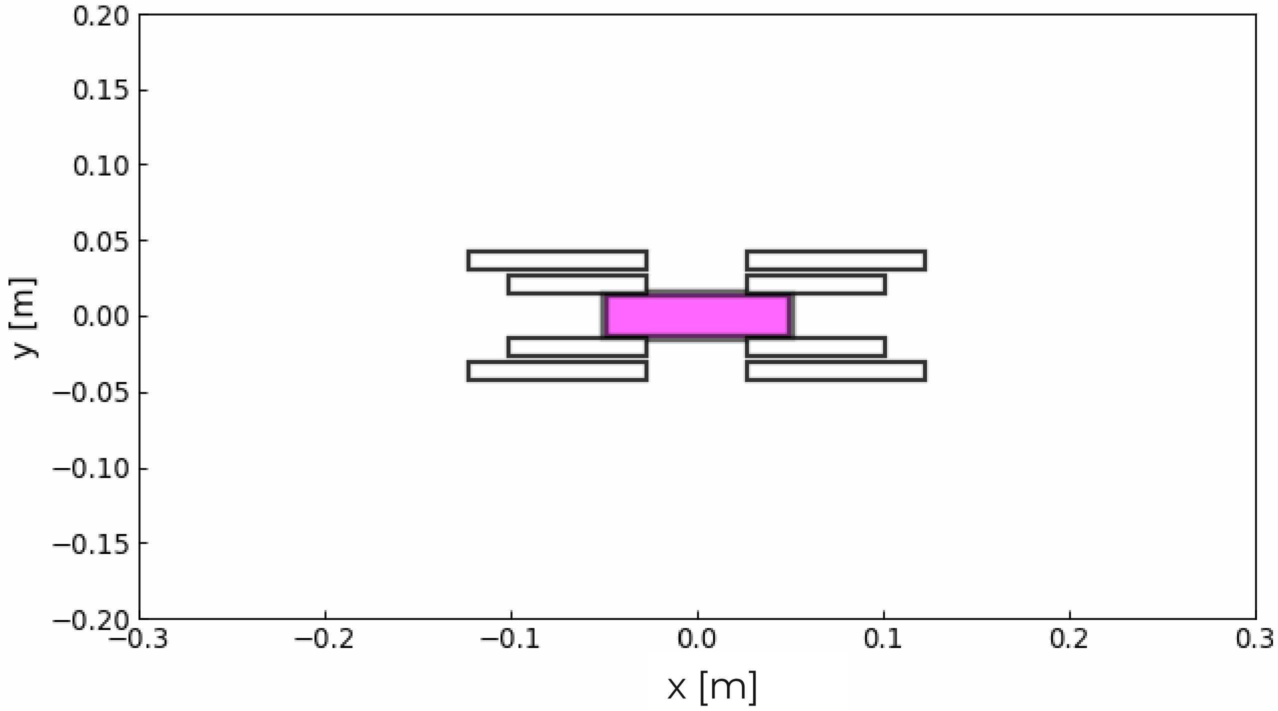
- A look at the contributions to higher order terms in this space





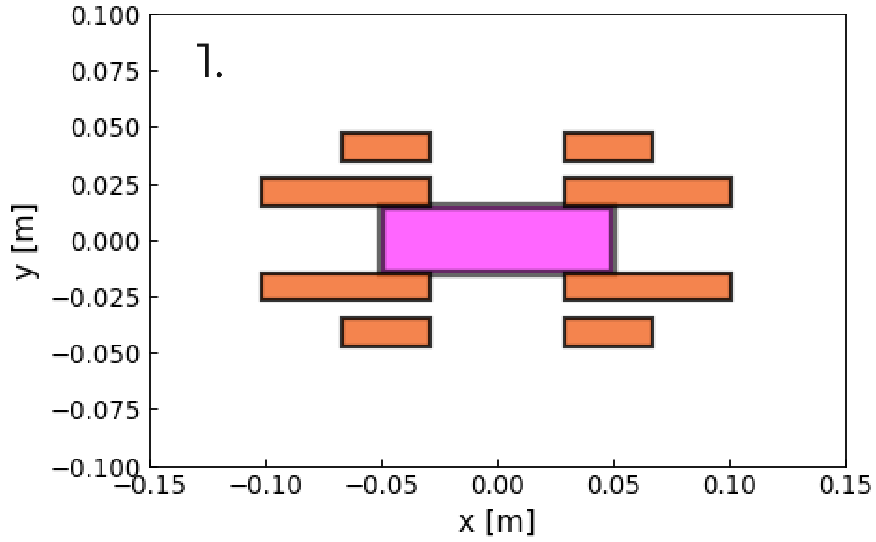
Numerical Optimization Routine – **Example: 2 racetracks**

- $B_0 = 10$ T, Field quality < 10 units, 10 mm radius
- Fixed to have same inner radius, but not length, and max distance apart of 16 mm
- 9k solutions (for previous grid shown, J < 700 A/mm2)

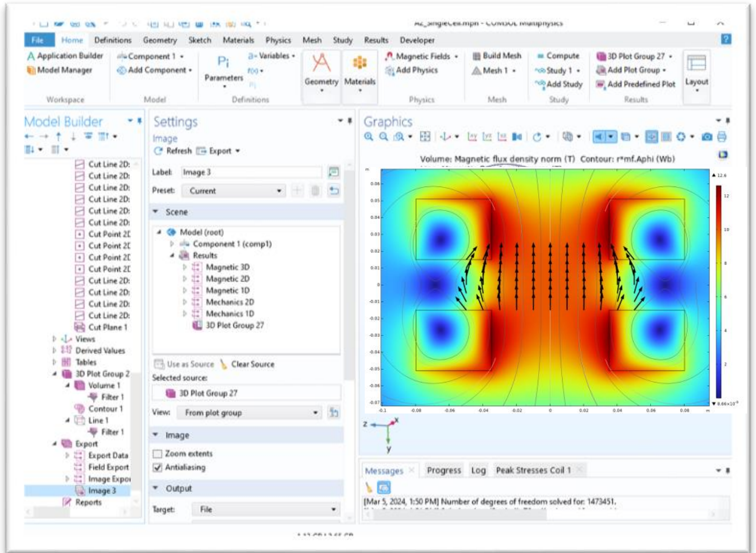


Numerical Optimization Routine – **Example: 2 racetracks**

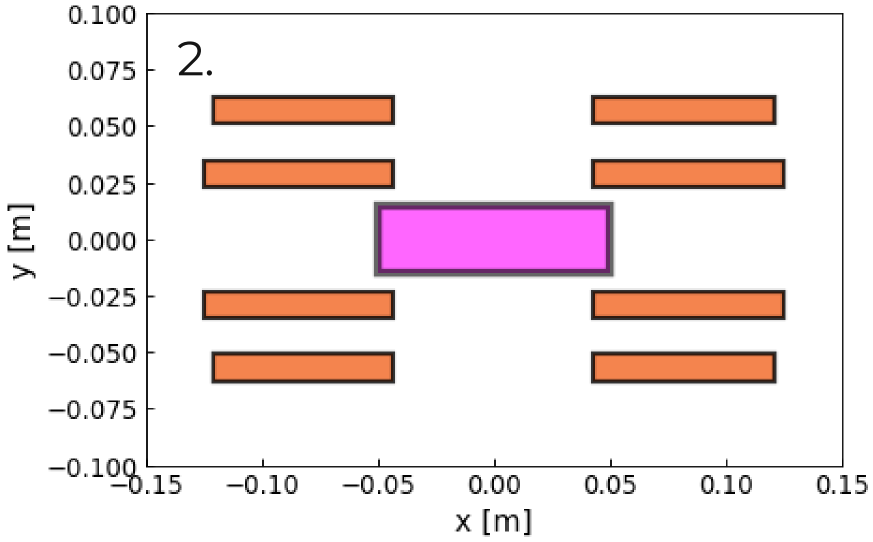
	J [A/mm²]	Total Length (2 tracks) [mm]	Tot Cross Sec [mm²]	No. of tapes [15 tapes in 1.85 mm]	b3	b5
1. Minimum Volume	691.8	110.0	5280.0	891.9	-9.1	-9.3
2. Best Field Quality	679.2	160.0	7680.0	1297.3	0.0	-2.1



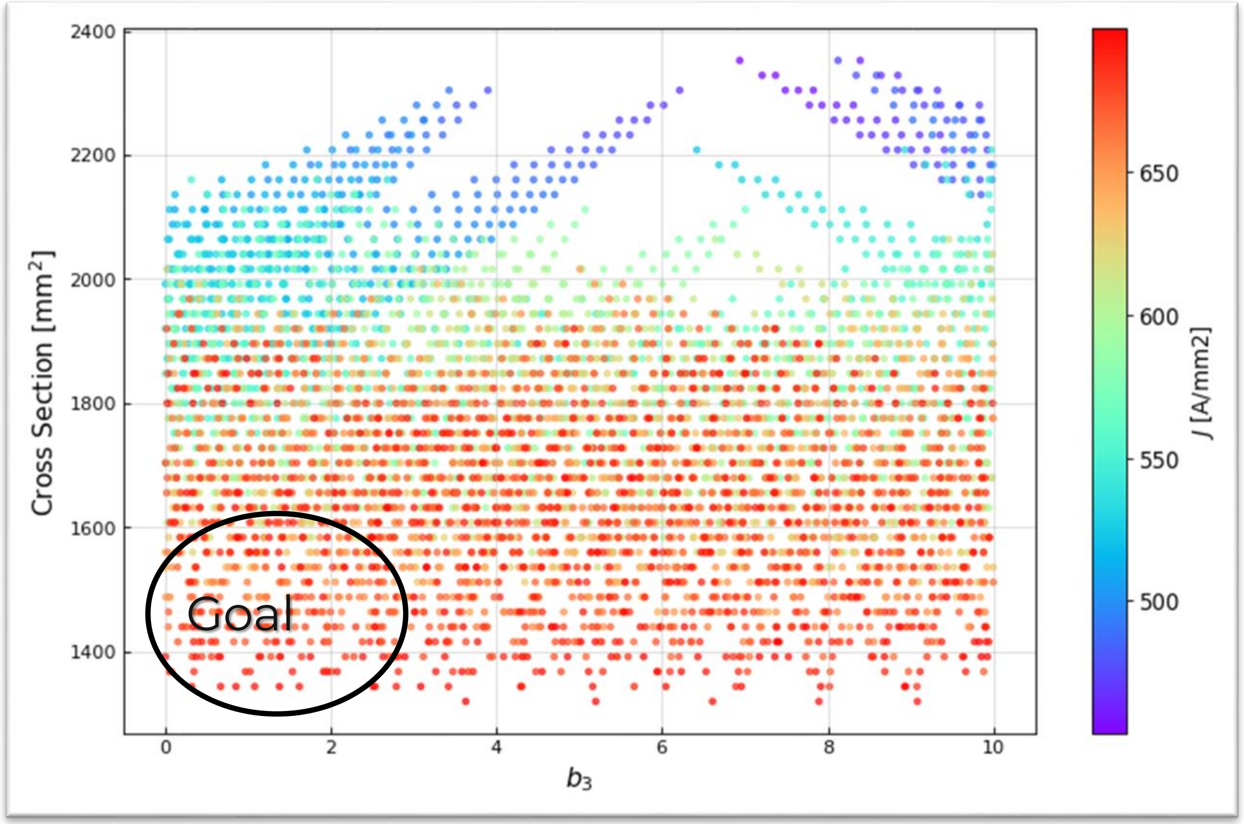
COMSOL or ROXIE

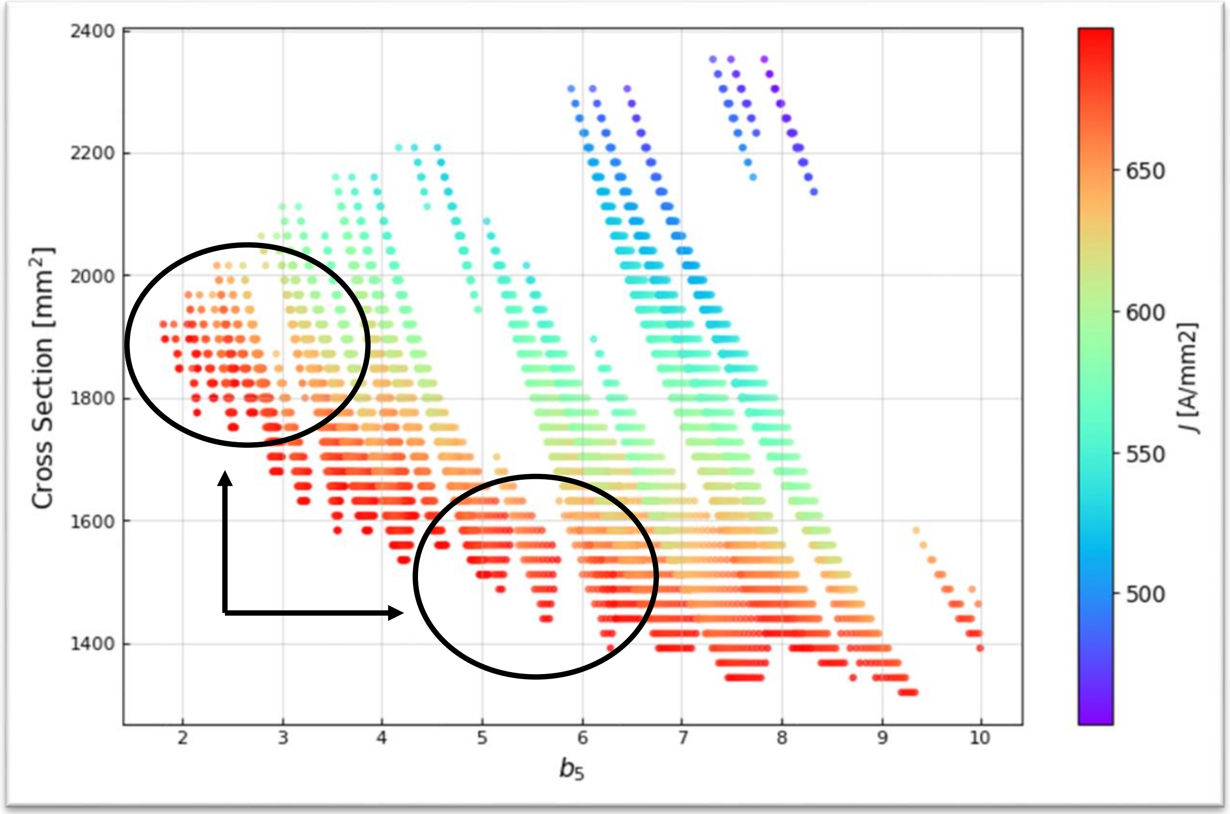


Full stress, critical current and field calculations



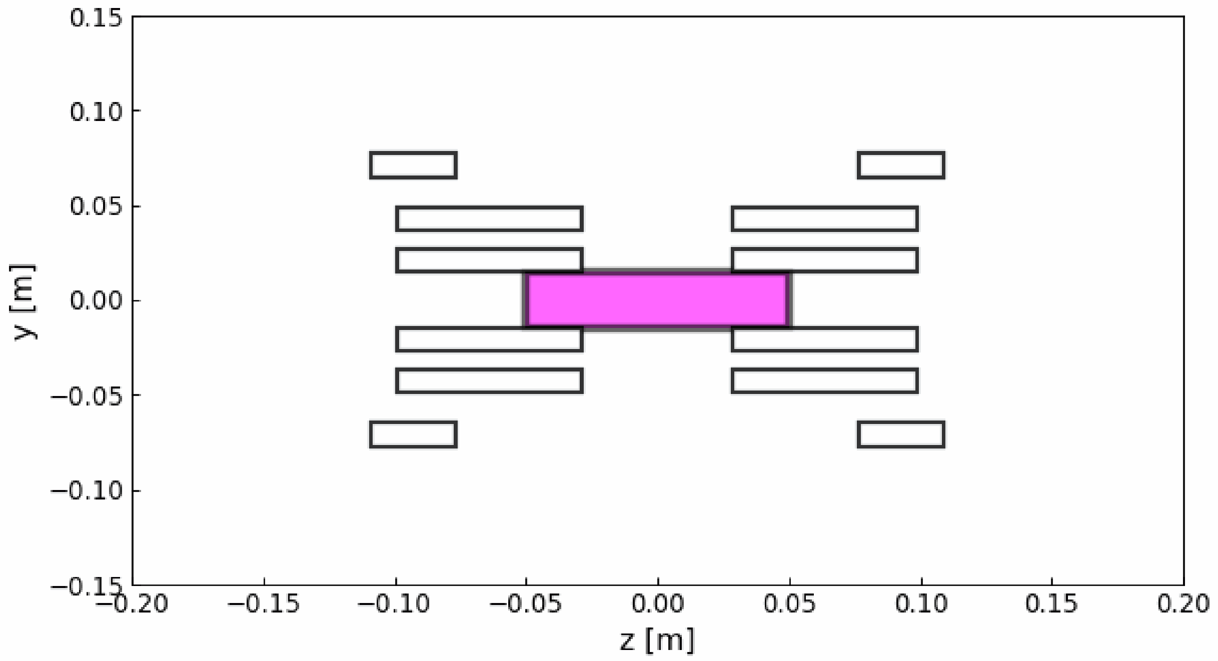
Numerical Optimization Routine – **Example: 2 racetracks**





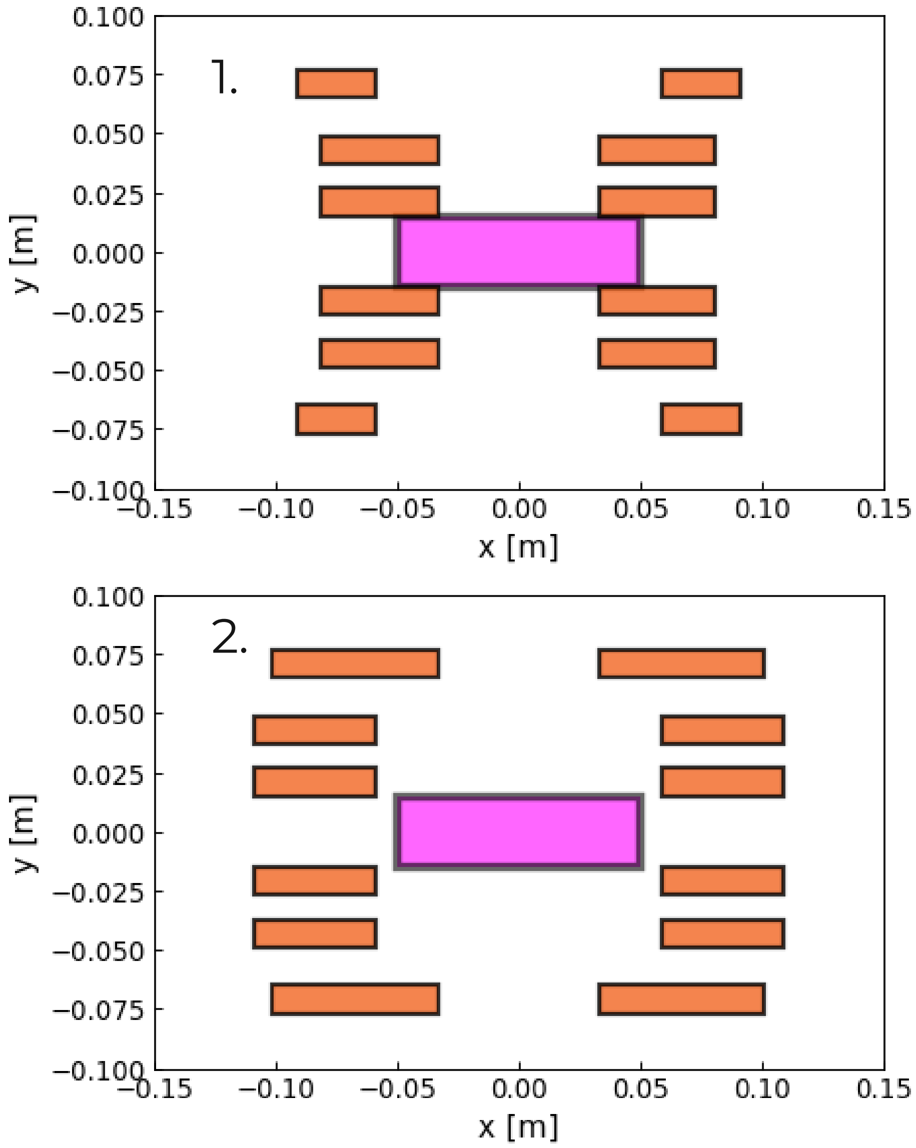
Numerical Optimization Routine – **Example: 3 racetracks**

- $B_0 = 10$ T, field quality < 10 units, 10 mm radius
- First 2 racetracks fixed to be the same, with a 10 mm gap. 3rd racetrack explored at a + 16 mm and +32 mm gap. Min length of 30 mm.
- 52k solutions (for previous grid shown, J < 700 A/mm2)



Numerical Optimization Routine – **Example: 3 racetracks**

	J [A/mm²]	Total Length (2 tracks) [mm]	Tot Cross Sec [mm²]	No. of tapes [15 tapes in 1.85 mm]	b3	b5
1. Minimum Volume	689.9	128.0	6144.0	1037.8	-9.5	-5.9
2. Best Field Quality	694.0	168.0	8064.0	1362.2	-0.0	-0.3



- To investigate further to understand advantages/disadvantages compared to 2 racetracks, etc.

➢ **Goals going forward:** finish study considering up to 6 racetracks, considering cost, field quality (*Updated), and engineering complexity → Integrate with ROXIE simulations.