Conceptual Design of a C-shaped 6.4 T Superconducting Dipole Magnet

Vianna, A.A.; Seraphim, R.M.; Pereira, A.G.C.; Limeira, B.E.; Brunheira, G.O.; Duarte, H.O.C.; Cavassani, I.B.; Citadini, J.F.; Silva, J.H.R.; Galvez, J.G.; Vilela, L.N.P.; Oliveira, L.P.; Martins, P.H.S.; Defavari, R.; Neuenschwander, R.T.; Rocha, T.M.

alan.vianna@cnpem.br

TUE-PO1-LN1-12

CNPEM

MINISTRY OF SCIENCE, TECHNOLOGY AND INNOVATIONS

PÁTRIA AMADA BRASIL
BRAZILIAN GOVERNMENT

Introduction

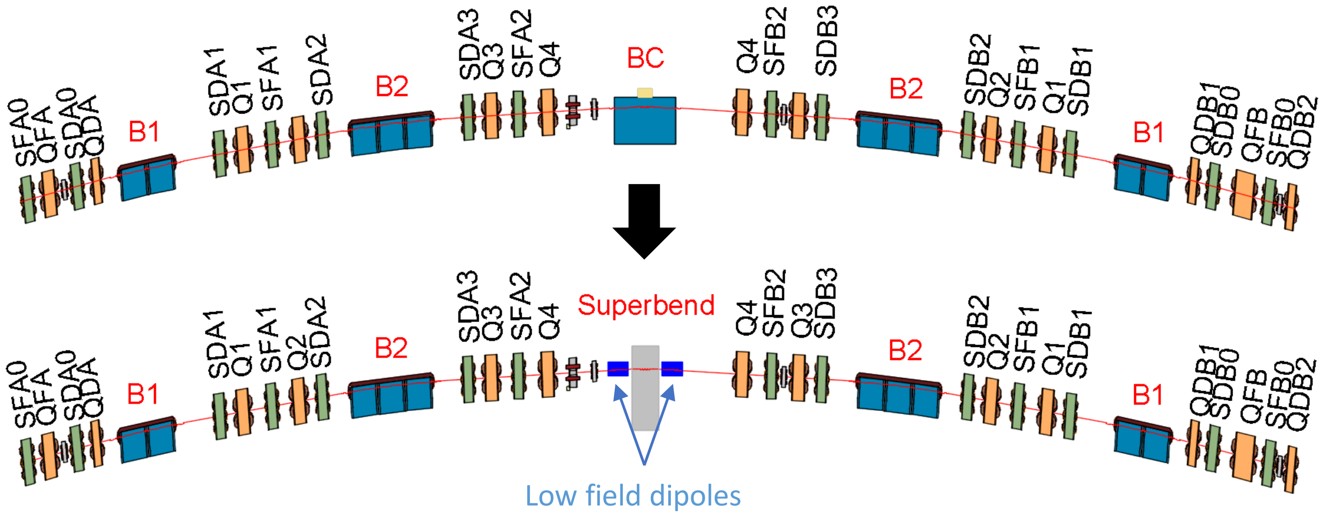
Motivation

- Current non-superconducting magnets produce 3.2 T –> Photons with critical energy 19 keV
- New high-energy x-ray tomography beamline –> Need for critical energy of at least 39 keV
- CNPEM is entering the field of superconducting magnets –> Design of a 6.4 T superconducting dipole (CERN-CNPEM agreement)

Design goals

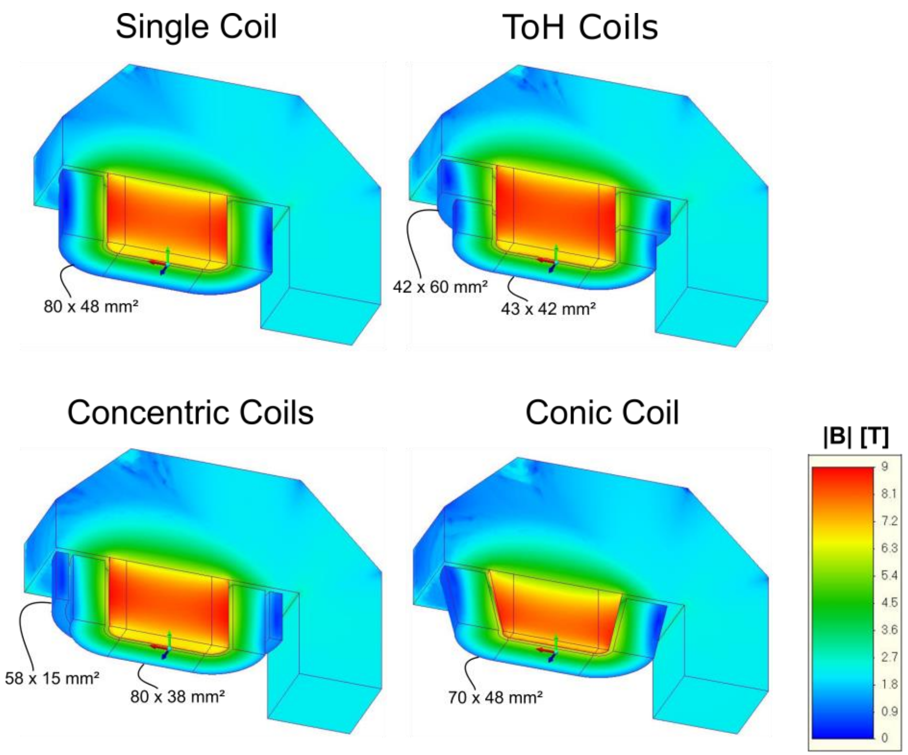
- Match the integrated field and integrated gradient of the BC dipoles
- Use of warm bore vacuum chamber for NEG-coating –> C-shaped magnet
- Use of NbTi wires –> well-known and documented; widely employed; commercially available

Sirius arc layouts

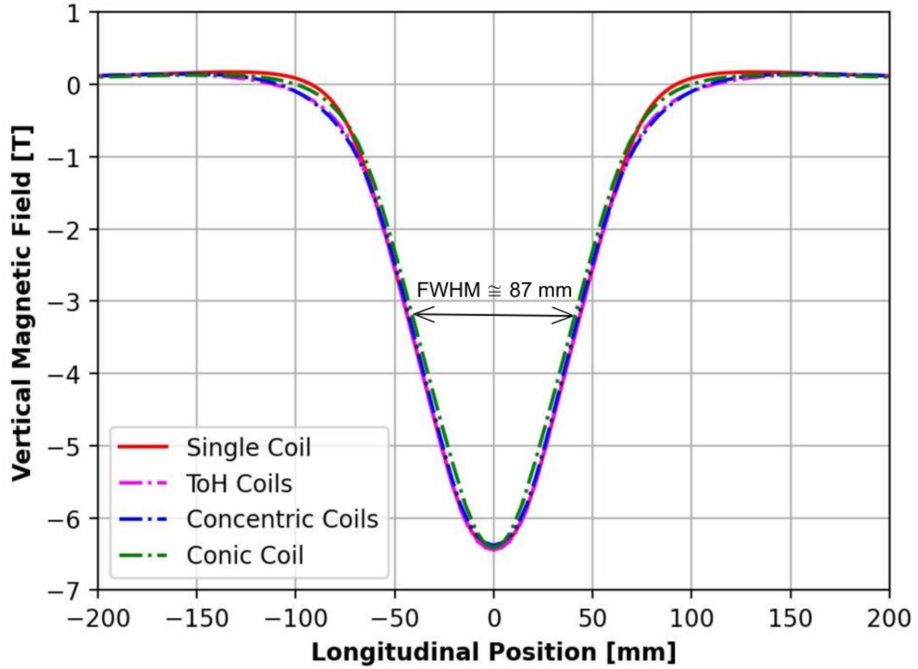


Electromagnetic Design

Studied coil designs



Studied coils magnetic field profile

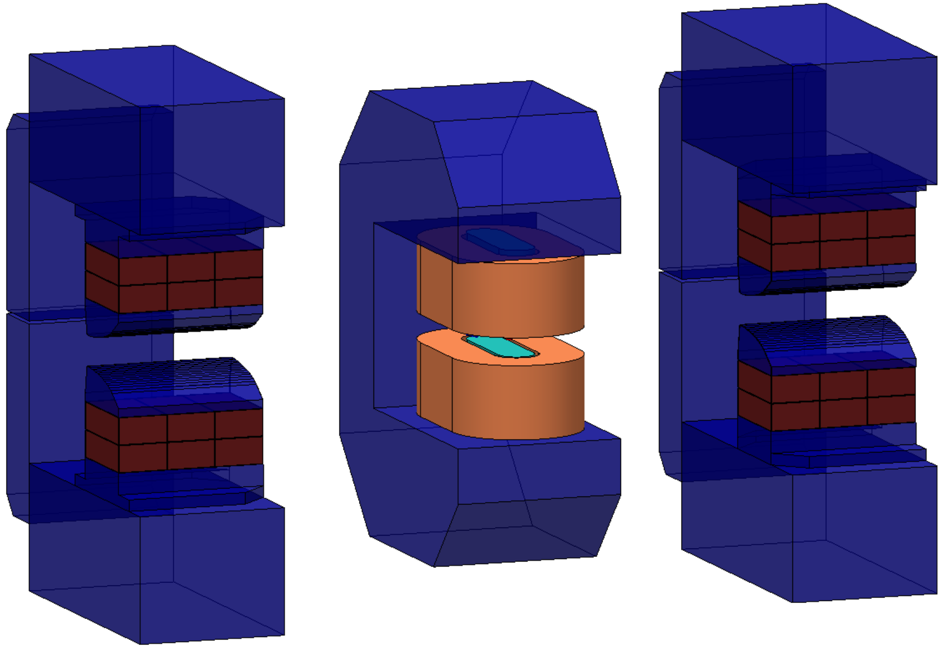


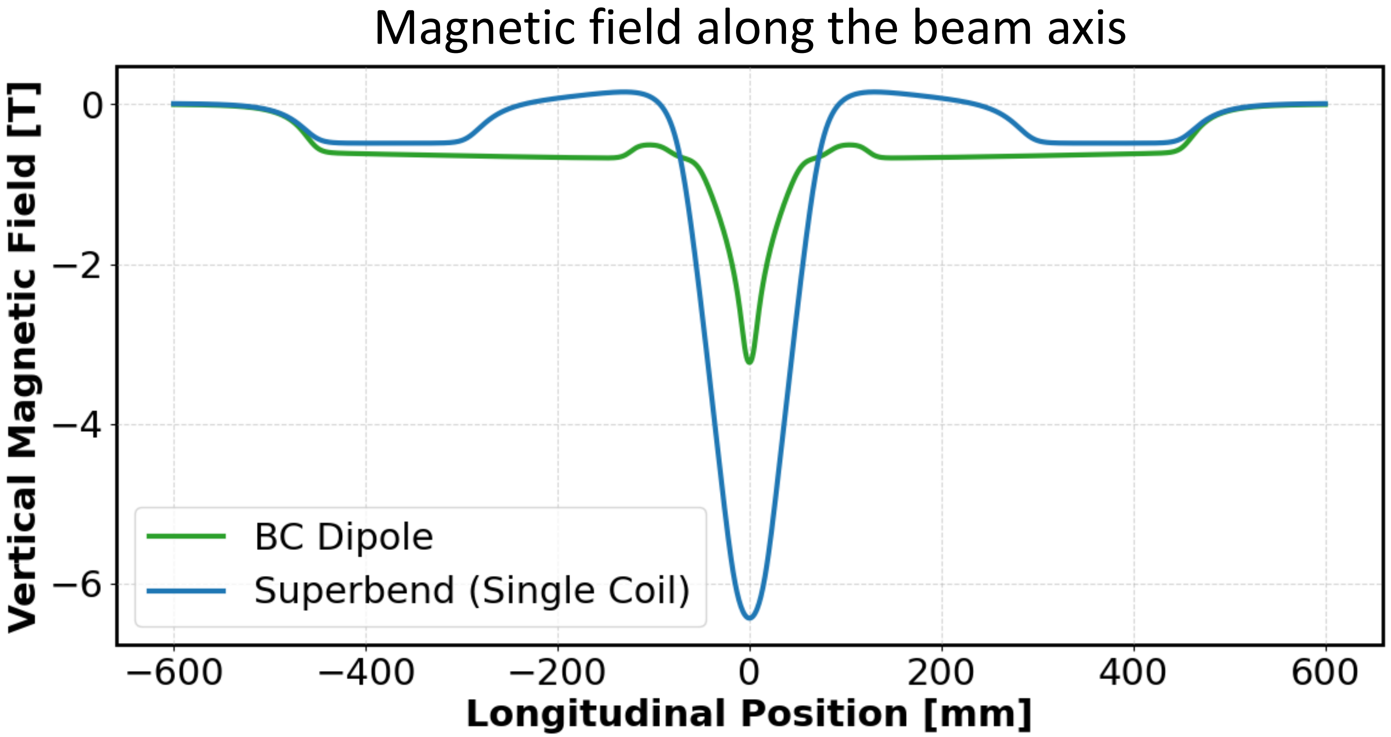
Electromagnetic Design Parameters	
Magnetic gap	30 mm
Bare wire dimensions	0.80 mm
Cu/NbTi ratio	1.4
Engineering current density	254 A/mm²
Operating current	128 A
Critical current (J_c) @ 5 K, 7.6 T	772 A/mm²
Load-line margin	79% of J_c @ 5 K

- Different coil designs were studied: Single Coil, ToH Coils, Concentric Coils and Conic Coil -> Similar results between designs -> Single Coil chosen due to its simpler design
- Single Coil -> dimensions and materials optimized. Best design chosen based on field's intensity, peak's FWHM and integrated field

Electromagnetic Design

- Permanent magnet low field dipoles added on each side of the superbend to match the integrated field of the BC dipoles
- More studies are needed to match the integrated gradient of the BC dipoles and suppress the positive portion of the field
- The stronger peak field and different longitudinal gradient would require a machine optics redesign



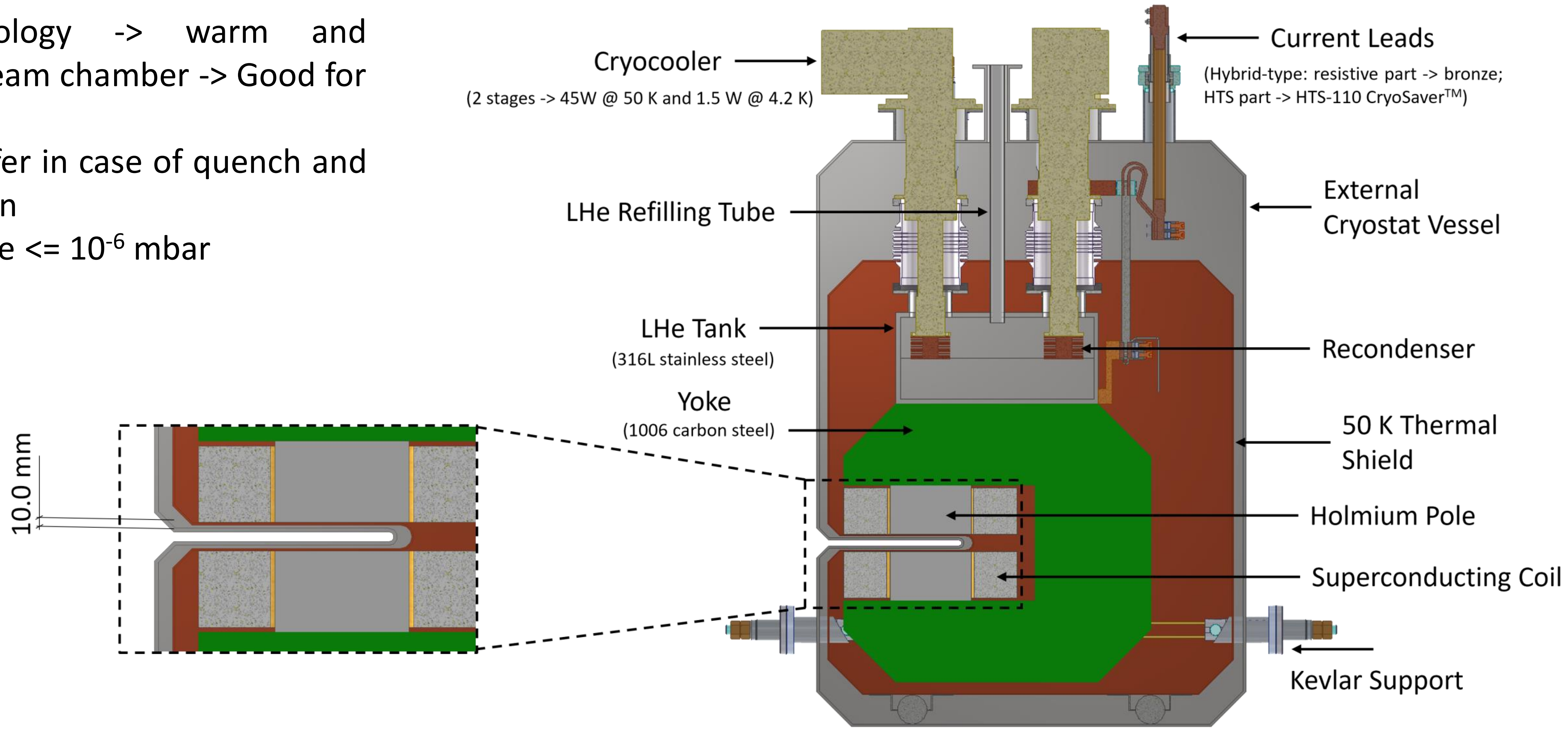


	BC Dipole	Superbend (Single Coil)
Integrated Field [T.m]	-0.7507	-0.7507
Integrated Gradient [T]	6.2508	1.8915

Mechanical and Cryogenic Designs

- Replace one BC dipole -> smaller than 900 mm
- C-shaped topology -> warm and disconnected beam chamber -> Good for NEG-coating
- LHe tank -> buffer in case of quench and speeds cooldown
- Vacuum pressure <= 10^{-6} mbar

Half Section view of the magnet

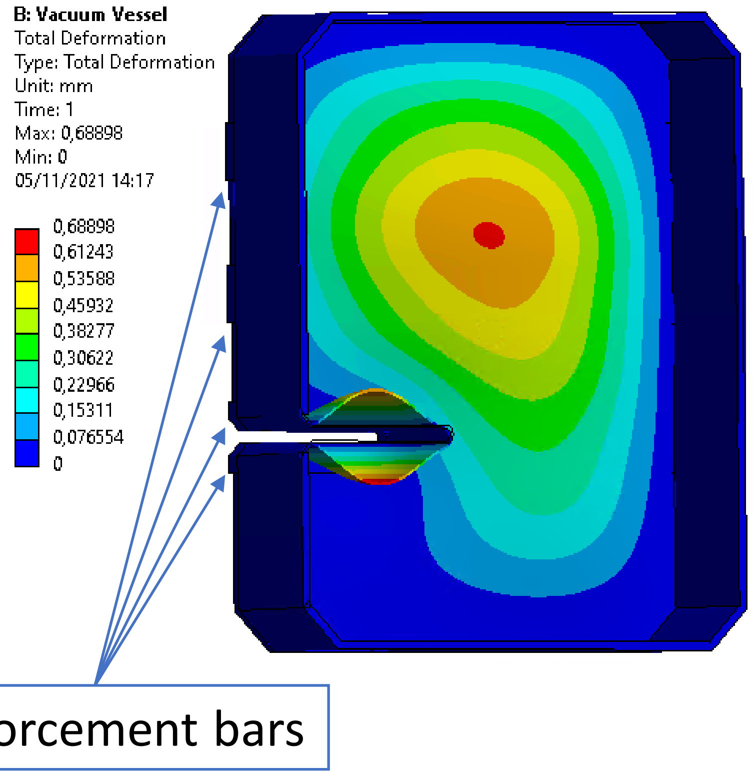


Dimensions: 400 mm length, 740 mm width, 1012 mm height

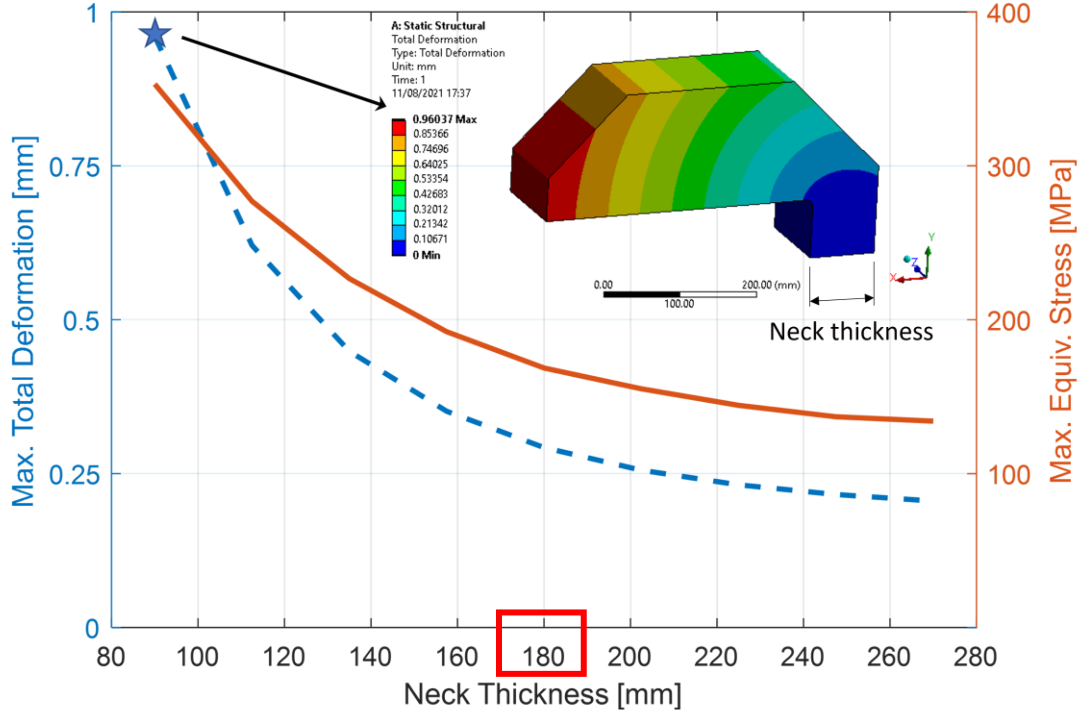
Mechanical and Cryogenic Designs: Structural Analysis

- External vessel -> 12 mm thickness with reinforcement bars 20 mm thick -> max. deformation of 0.7 mm (lateral covers) and stress below material's yield
  - Bars also reinforce C-shaped region -> 4 mm thick (space constraints) -> max. deformation of 0.7 mm
- Yoke's thickness chosen to be 180 mm -> max. deformation of 0.3 mm towards closing the gap

External vessel – total deformation



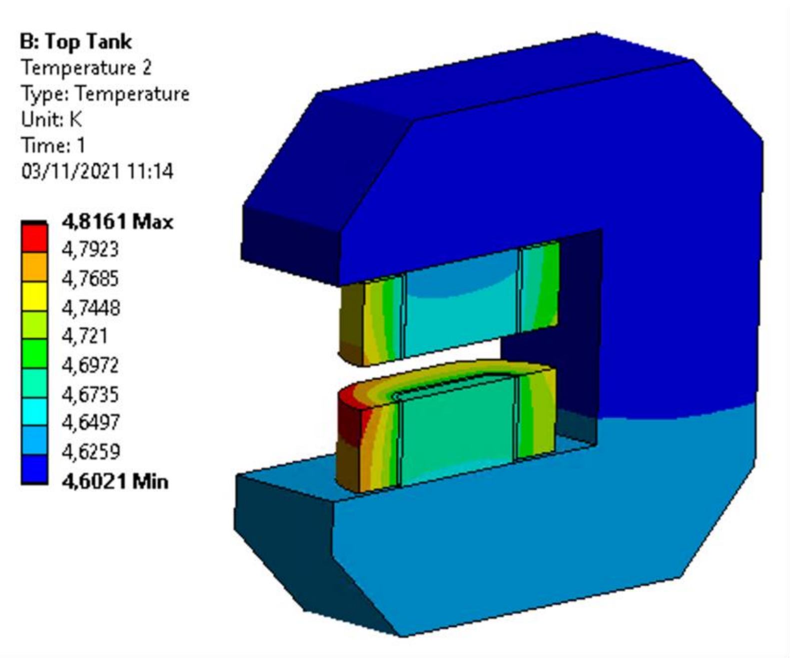
Yoke neck – thickness opmization



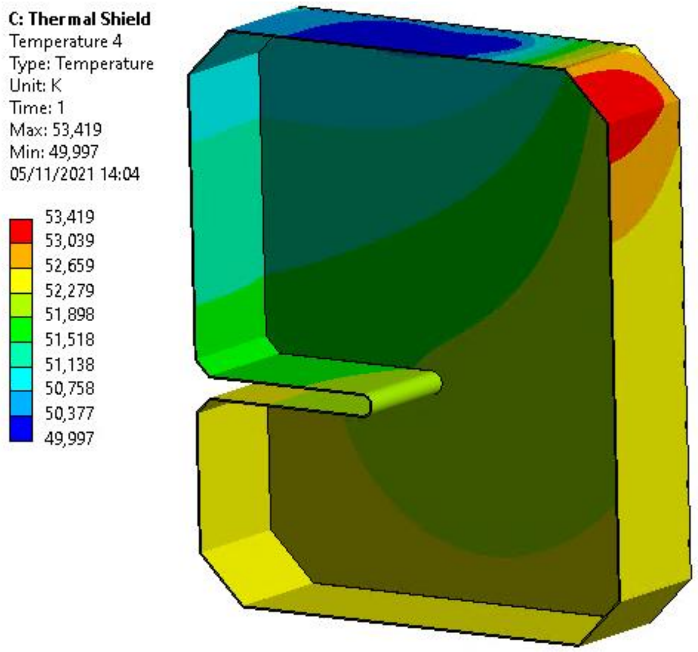
Mechanical and Cryogenic Designs: Thermal Analysis

- Steady state analyzes to determine the heat flux through components:
  - Thermal shield @ 50 K -> max. temperature of 53.4 K
  - LHe tank positioned on the top presented better results -> max. temperature of 4.9 K (bottom coil)

Yoke and Coils – temperature distribution



Thermal Shield – temperature distribution



Summary of calculated heat loads

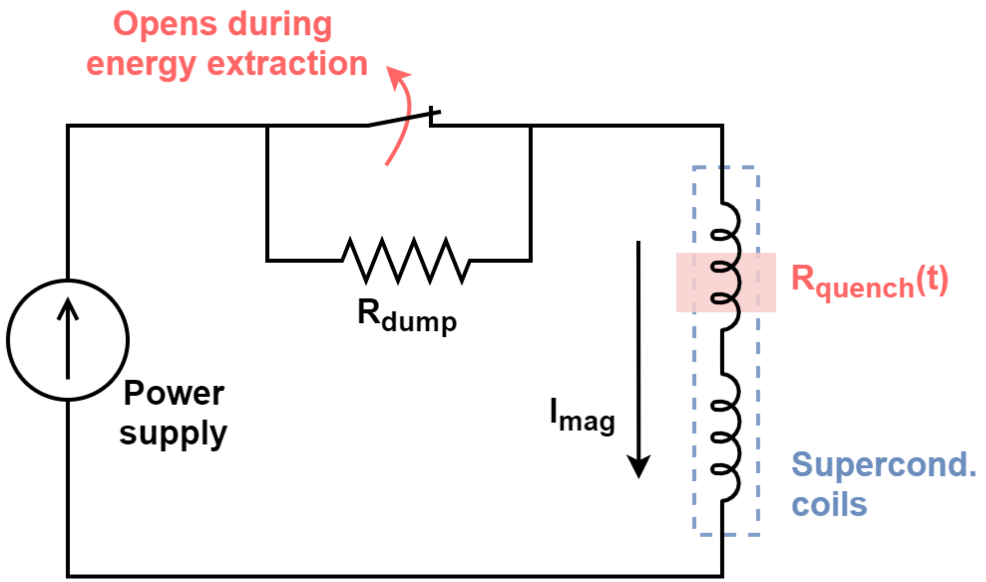
	Inleak @ 50 K (W)	Inleak @ 4.2 K (mW)
Supports	1.60	200
Current leads	16.22	35
Radiation	4.12	51
Total	21.94	286
Cryocooler capacity (x2)	90.00	3000

CNPEM MINISTRY OF SCIENCE, TECHNOLOGY AND INNOVATIONS PÁTRIA AMADA BRASIL BRAZILIAN GOVERNMENT

Quench Protection Design

- Use of an external dump resistor to promote an active energy extraction in case of a quench event
- Monitor voltage across the coil and compare with pre-determined values -> imbalance bridge and over-voltage circuits -> further study for a final specification
- Hot-spot temperature during quench estimated by the MIITS calculation -> two scenarios studied -> temperatures below 40 K

Active energy extraction concept



Two scenarios studied

	I_{nom}: 90 A L = 14 H	I_{nom}: 90 A L = 7.7 H
Stored Energy (kJ)	56.7	40.1
Dump Resistor (Ω)	6.67	5.9
Time constant (s)	2.1	1.3
MIITS/cm^4 (t_{det} = 0.1 s)	149.3	125.8
Max. Temperature (°C)	<40	<40

Summary

- Different coil designs were studied -> Minor differences were found in the peak's FWHM and integrated field -> Single Coil was chosen due to its simpler design
- Permanent magnet low field dipoles added on each side of the superbend to match the integrated field of the BC dipoles and suppress the positive portion of the field
- More studies are needed to match the integrated gradient of the BC dipoles
- The stronger peak field and different longitudinal gradient would require a machine optics redesign
- Mechanical and cryogenic designs are successful in maintaining structural integrity while keeping the temperature of the superconducting coils below 5 K. The estimated heat loads are within the capacity of the cryocoolers, but further studies with more components will be done. Based on the current results, the cryocoolers will have enough cooling power for the system, and maybe one of them can be used as a safeguard
- A first approach that uses an external dump resistor was proposed for the quench protection, but a deeper study needs to be done for the final solution