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Conceptual Design of DUNE Near Detector Superconducting Magnet System

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Abstract

The Deep Underground Neutrino Experiment (DUNE) has formed a near detector design group (NDDG) tasked with delivering a CDR by the end of the year. The DUNE Near Detectors will be housed in an underground hall on the Fermilab site. The two main detector systems are a liquid argon detector and a high-pressure gas time projection chamber (HPgTPC). The HPgTPC requires a magnet that generates a 0.5 T solenoidal magnetic field in a large volume of 6 m diameter, and 5 m length. In this paper, we present a superconducting magnet system design. We investigated: an open air core magnet with three coils, and a five coils system having two active fringe field shielding coils. Coils positions were optimized to obtain the specified field homogeneity in the magnet good field region, while minimizing the Lorentz forces and the superconductor volume. We discuss the magnetic, mechanical, and thermal conceptual designs.

Introduction

The Deep Underground Neutrino Experiment (DUNE) will have underground the Near Detector (ND) on the Fermilab site. The magnet system of this detector should generate 0.5 T horizontal magnetic field in a large volume of 6 m diameter, and 5 m length. In the paper we present the magnet system conceptual design with corresponding magnetic, mechanical, and thermal designs which are strongly coupled. During this design study we investigated variants: a long solenoid with end shims and with or without an iron core, an open air core magnet with three coils, and a five coils system having three main coils and two active fringe field shielding coils. The five coils magnet system is at that time a baseline version. The general view of superconducting magnet system shown in Fig. 1.

Magnet System Specification

Parameter	Units	Value
Magnetic field configuration		Axial-Symmetric
Center peak field	T	0.5
Good field area diameter/width	m	4/4
Field homogeneity	%	±10
Clear bore diameter	m	7.0
Maximum outer diameter	m	9.0
Maximum length	m	12.0
Superconductor type		NbTi
Material for coils support structure and superconductor stabilizer		Aluminum
Coils operating temperature	K	≤ 5
Maximum coil deformation	mm/m	1.7
Maximum vacuum wall deformation	mm/m	2.0
Coils positional tolerance	mm	±5
Admissible bucking limit	MPa	120
Cooling source		Cryoplant or Cryocoolers

Baseline of ND magnet conceptual design was chosen five round coils configuration. This configuration has following advantages: low weight, suppressed fringe fields, meet shaft dimensions, all coil with same ID and OD, aluminum structures easy for neutrinos penetration, assembled on the surface.

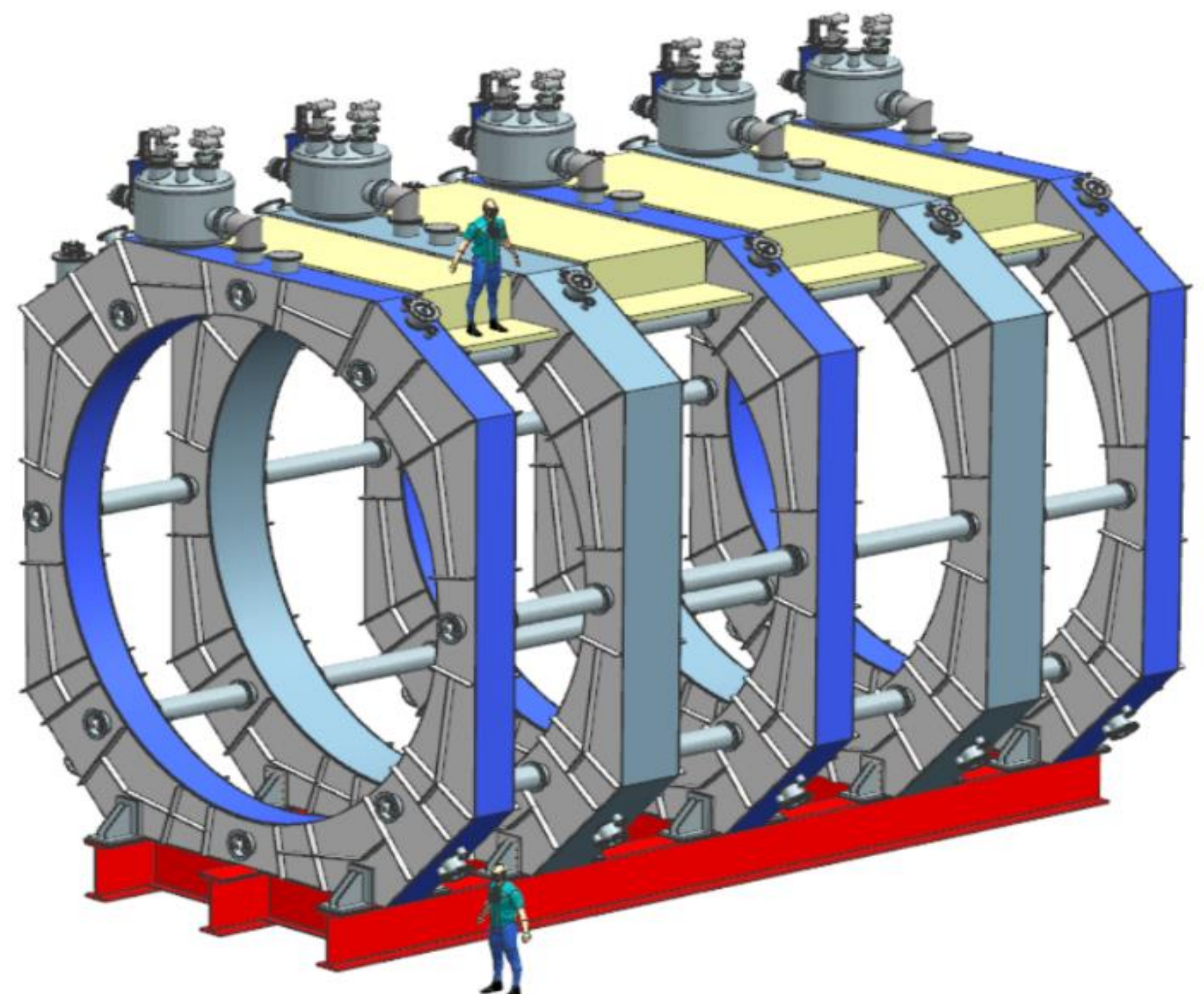


Fig. 1 DUNE Near Detector magnet system view.

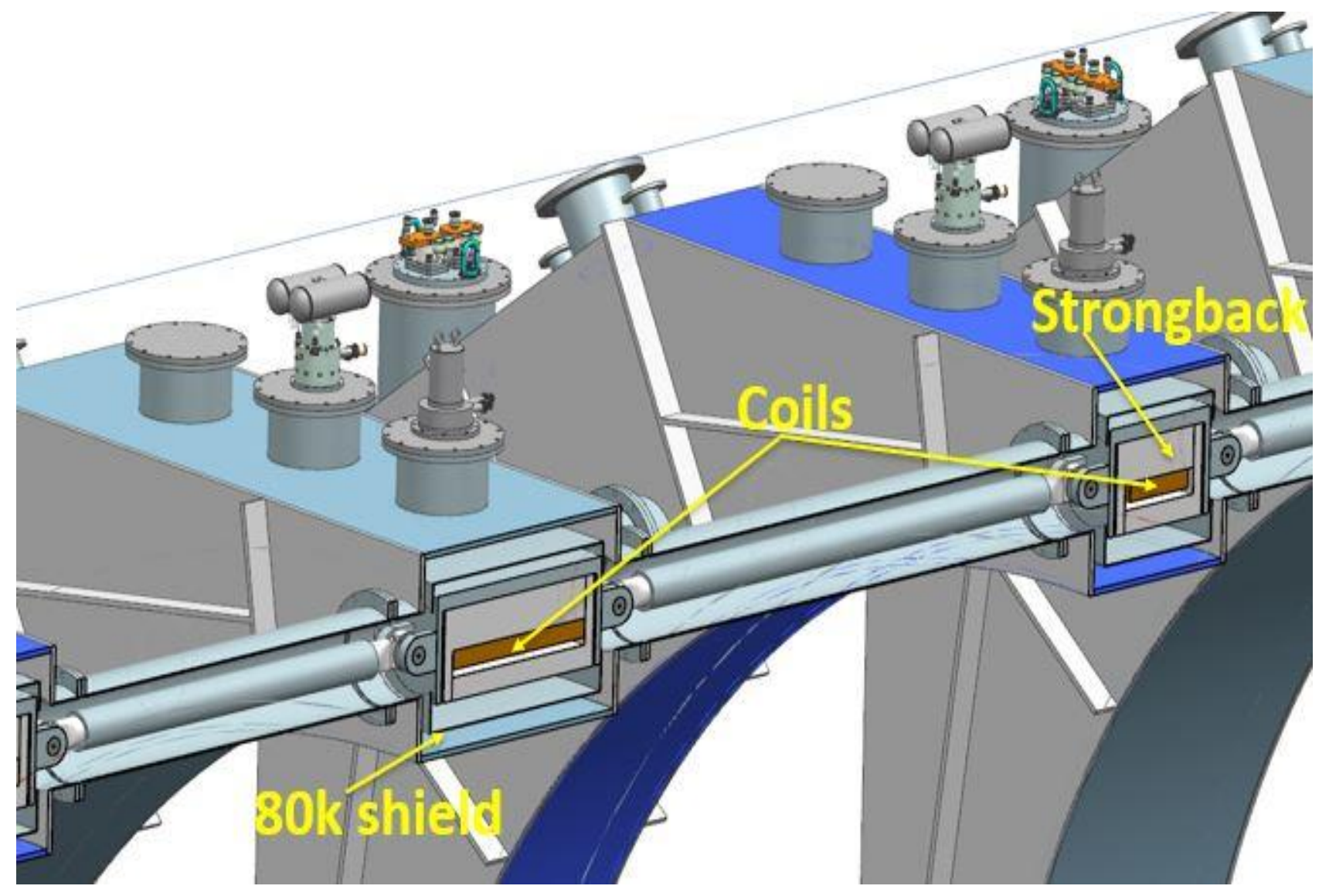
Coil Parameters

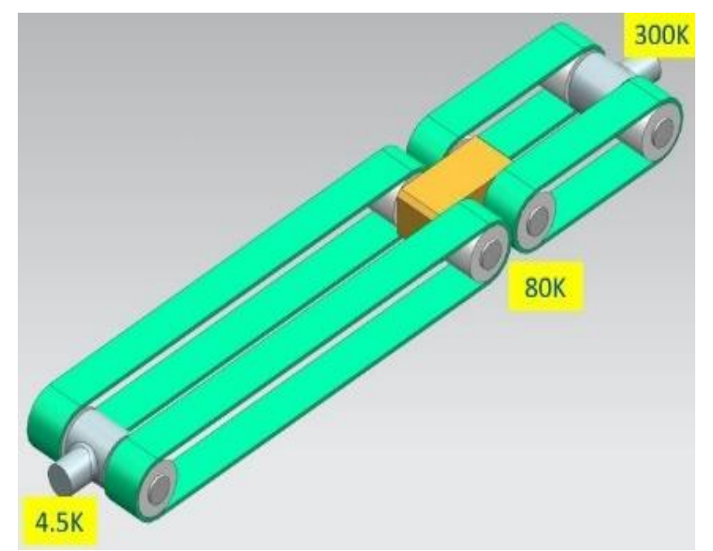
Parameter	Units	Center coil	Side coil	Shield coil
Number of coils		1	2	2
Coil ampere-turns	MA	1.08	2.46	1.08
Coil peak field	T	2.53	3.32	2.72
Coil inner radius	m	3.8	3.8	3.8
Coil outer radius	m	3.862	3.862	3.862
Coil width along	m	0.27	0.616	0.27
Coil position in Z	m	0	3.0	5.5
Lorentz force in Z	MN	0	8.17	4.49

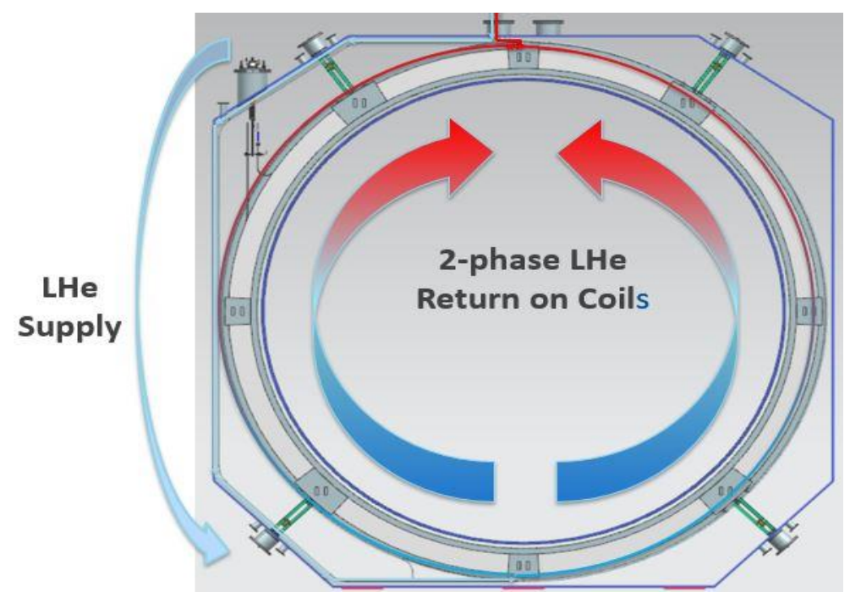
Superconductor Parameters

Parameter	Units	PS	DS
Bare cable width	mm	30	20.1
Bare cable height	mm	5.5	7.0
Number of NbTi strands		30	12
Strand diameter	mm	1.44	1.3
Strand Cu/Sc		0.95	1.0
Critical current density at 4.2 K, 5 T	A/mm²	2750	2750
Aluminum RRR		600	1000
Copper RRR		80	80

Mechanical and Thermal Designs





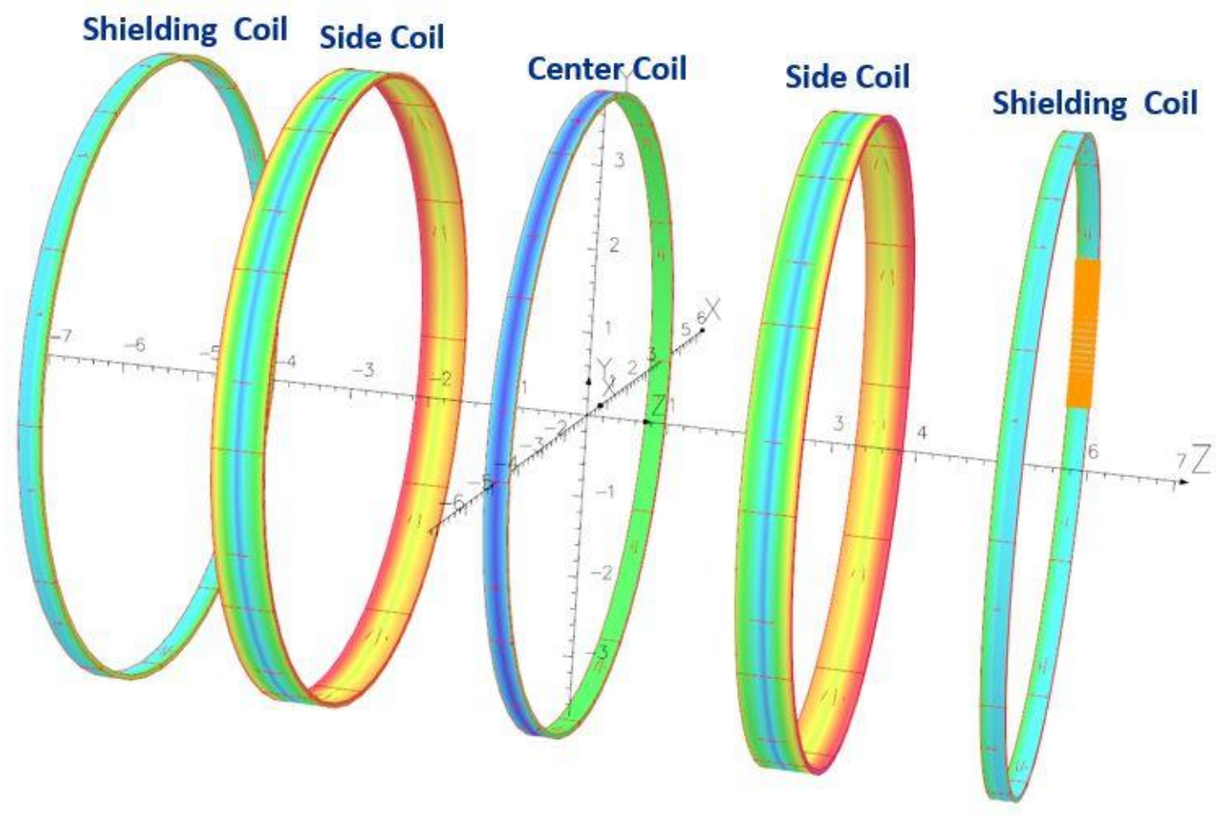


The magnet coil will be housed within a strongback designed to absorb the forces of the magnet and minimize flexure in the structure during operation. Each strongback will be held within a cryostat.

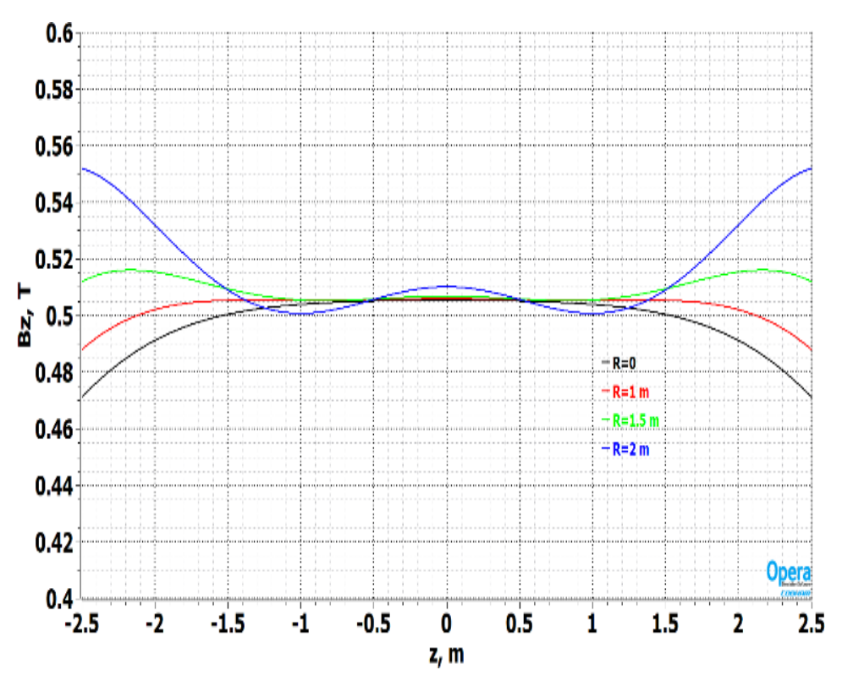
The total heat load from straps for the cooling will be 1 W at 4.5K and 15W at 80K.

Thermosyphon cooling with cryoplant or cryocoolers will be used.

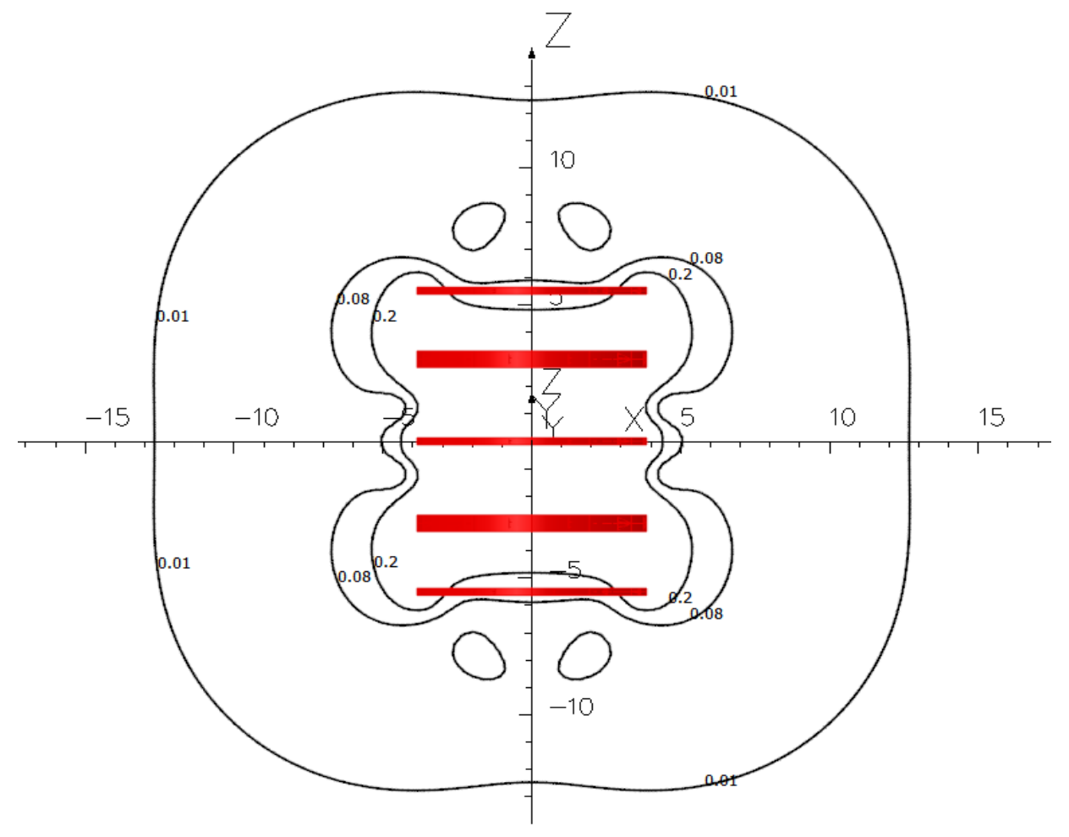
Magnetic Design



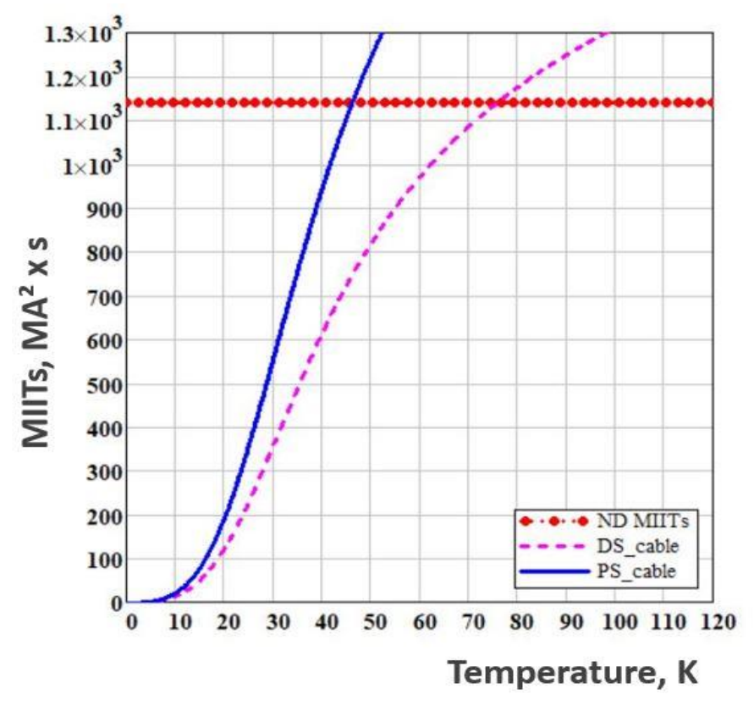
5 – Superconducting coils.



Field in the magnet bore.



Fringe field.



Coil adiabatic heating.

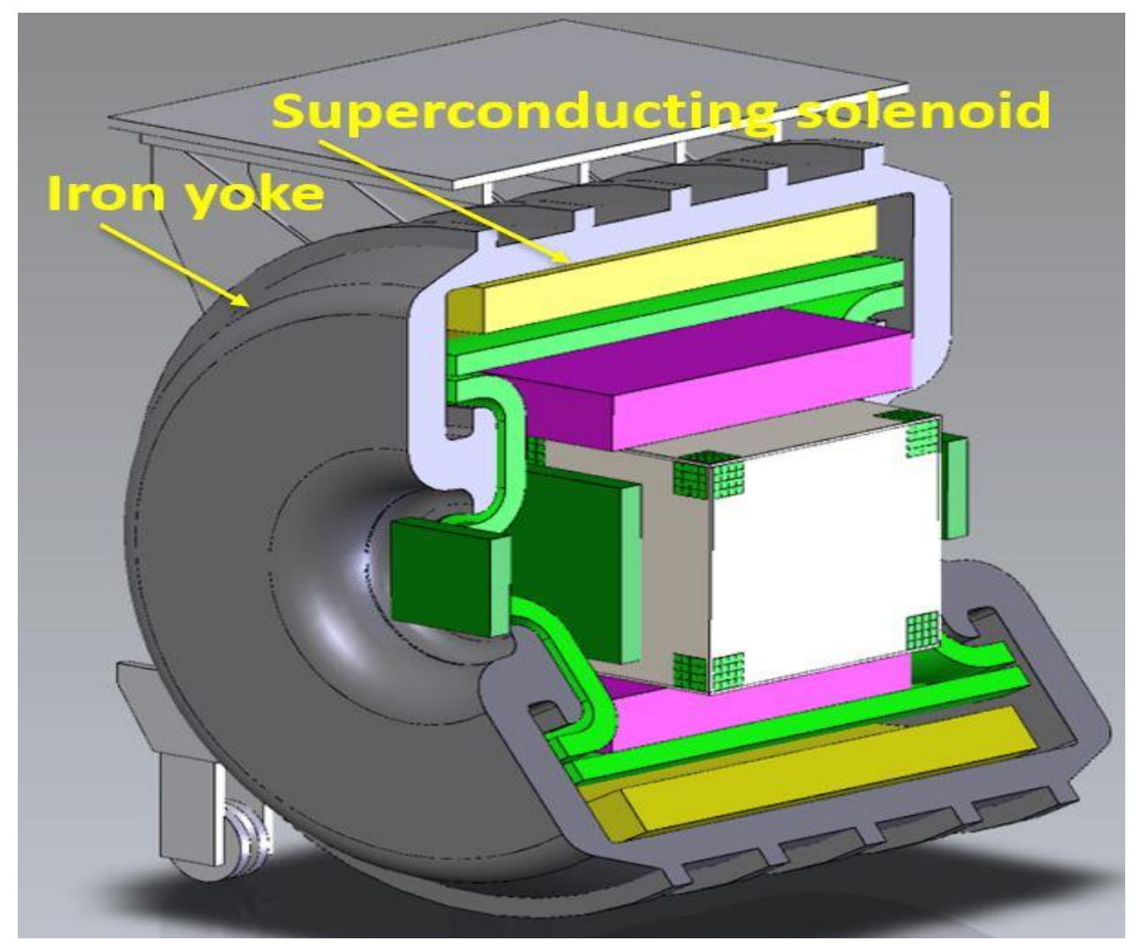
Coil	Iw MA	Fz MN	Iw* MA	Fz* MN	Iw** MA	Fz** MN
Shield	1.08	-4.49	0	0	1.08	-0.65
Side	-2.46	8.17	-2.46	4.33	0	0
Center	-1.08	0	-1.08	-0.4	-1.08	2.91
Side	-2.46	-8.17	-2.46	-8.48	-2.46	-6.45
Shield	1.08	4.49	1.08	4.55	1.08	4.19

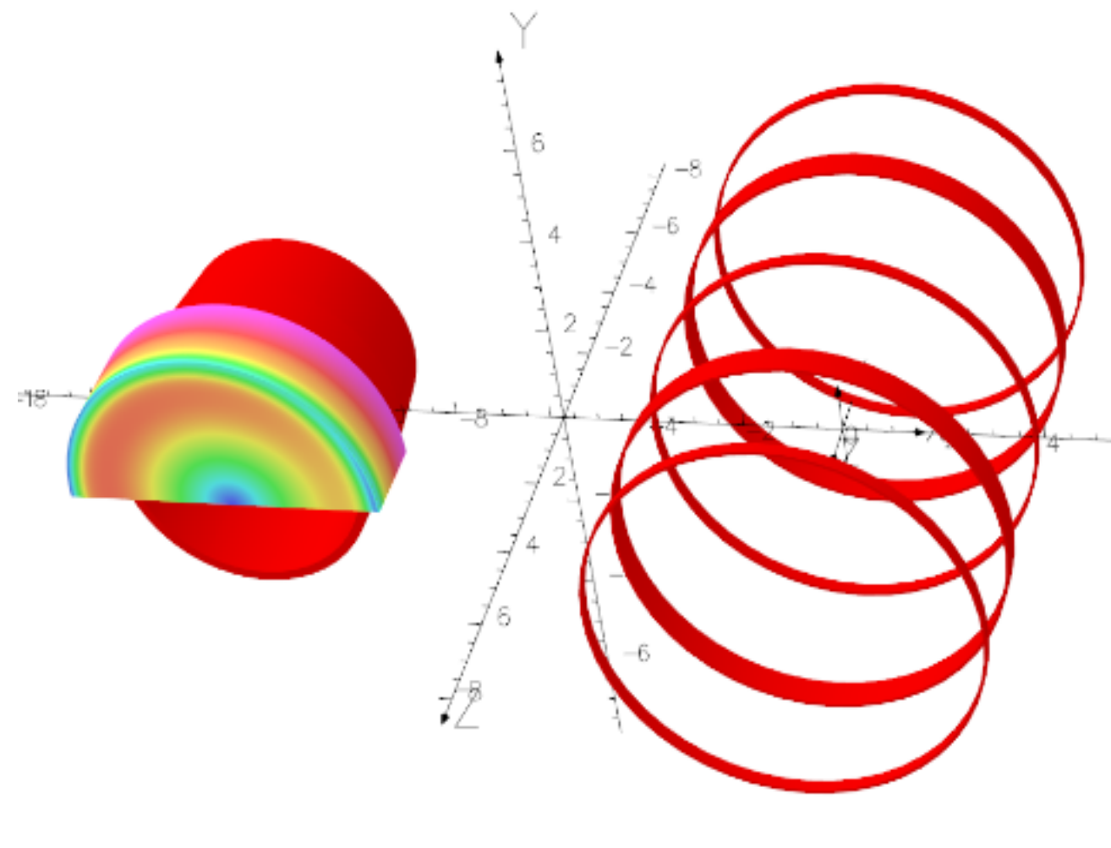
Lorentz forces at failure scenarios.

The maximum allowable 0.2 T fringe field for cryocoolers is inside the magnet system mechanical structures. The 0.08 T field line showed the boundary where the ferromagnetic objects levitates into the solenoid under magnetic forces ("bullet" effect).

Another critical issue is the quench protection of this 109 MJ stored energy system. It is supposed to use an active quench protection system where coil heaters energized when the voltage rise detected on monitored voltage taps.

Interaction KLOE and ND magnets.





The field analysis showed the substantial coupling between two magnets. There is rather large 0.18 MN residual force along x-axis applied to the ND magnet and KLOE iron yoke, and much lower only 7.1 kN to the KLOE solenoid.

Summary

The DUNE Near Detector magnet system conceptual design confirmed the visibility of proposed magnet configuration. The preliminary magnetic, mechanical, and thermal analyses did not show up any critical issues. The next step will be to perform more deep analyses for the Technical Design Report related to the quench protection and possible field and forces coupling with surrounding objects.