Electron-Ion Collider

Technical Note

EIC - EPIC DETECTOR SUPERCONDUCTING MAGNET SPECIFICATIONS

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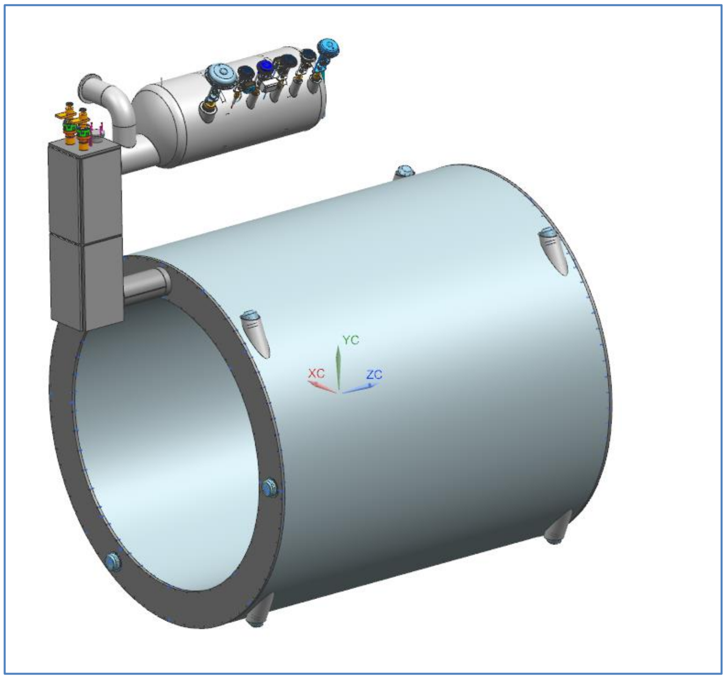

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VERSION HISTORY

Version #	Effective Date	Reviewer(s)	Summary of Change
1.0	04/12/2023	Rolf Ent (JLab), Elke Aschenauer (BNL)	Initial release
2.0	12/05/2024	Rolf Ent (JLab), Elke Aschenauer (BNL)	Updated after final design review New figures and design details added

MARCO Magnet Design Team

- **JLab**
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- **CEA, Saclay**
    - Team Lead: Valerio Calvelli
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- **BNL**
    - Team Members: Rahul Sharma, Roland Wimmer and Roberto Than

Contents

List of Acronyms

BNL	Brookhaven National Laboratory
EIC	Electron-Ion Collider
ESR	Electron Storage Ring
HCal	Hadronic Calorimeter
IP	Interaction Point
IR	Interaction Region
JLAB	Thomas Jefferson National Accelerator Facility
QA	Quality Assurance
RCS	Rapid Cycling Synchrotron
RHIC	Relativistic Heavy Ion Collider
RICH	Ring-Imaging Cherenkov
SOW	Statement of Work
VCL	Vapor Cooled Leads
WCL	Water Cooled Leads

1. Introduction to the EIC project

The Electron Ion Collider (EIC) at Brookhaven National Laboratory (BNL) is being designed and constructed in close partnership between BNL and the Thomas Jefferson National Accelerator Facility (JLab). The physics requirements that drive the EIC design are specified in the 2015 and 2023 Nuclear Science Advisory Committee Long-Range Plan documents and in the 2018 National Academies of Sciences, Engineering and Medicine reports. The high-level parameters of the BNL-sited EIC are given below in table 1:

Table 1: EIC Parameters

Parameter	Value/Range
Center of Mass Energies	29 GeV -140 GeV
High Luminosity	$10^{33} – 10^{34} cm^{-2} sec^{-1}$
Hadron Beam Polarization	70 %
Electron Beam Polarization	70 %
Ion Species Range	Proton to Uranium
Number of Interaction regions	Up to 2

The EIC design is based on the existing Relativistic Heavy Ion Collider (RHIC) at BNL. The EIC will use the existing hadron storage ring at 40 GeV and in the range 100-275 GeV, a new electron ring 5-18 GeV, a new electron rapid cycling synchrotron (RCS) and a new high luminosity interaction region (IR). The basic layout of the EIC rings is shown in Figure 1. The layout indicates the possible locations of the detectors. The magnet described in this design report is for the first detector-1 (ePIC detector). The ePIC detector will be installed at the IR6 location at 6 o'clock. A possible future second detector can be installed at the IR8 location at 8 o'clock.

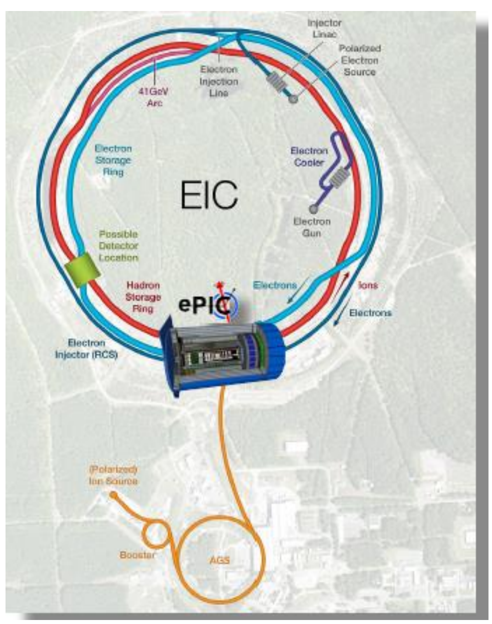

Fig. 1: EIC Layout

2. Interaction region and the detector area

The EIC baseline configuration has one interaction region and therefore one detector. The IR layout is shown in Fig. 2. The overall length of the interaction region is approximately 75 m.

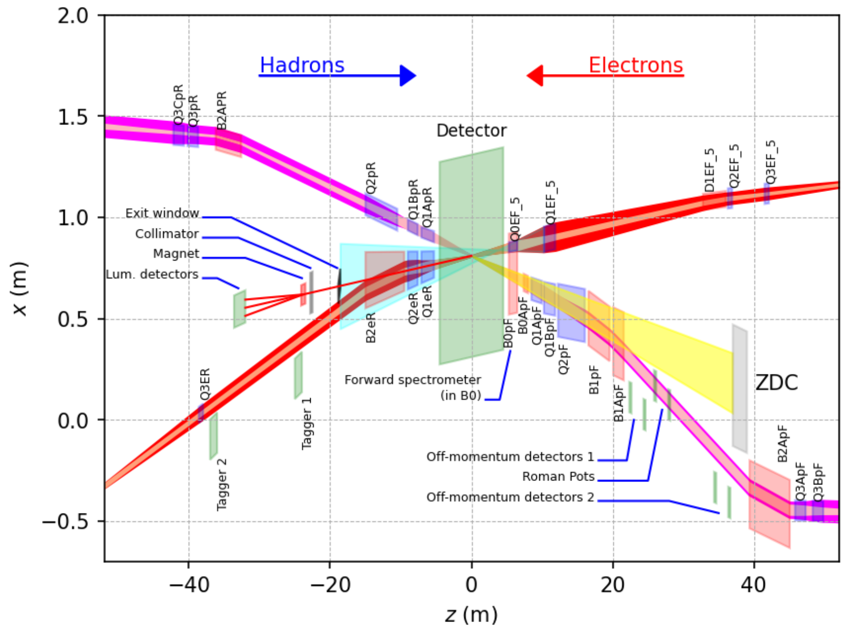

Fig 2: Interaction region layout

The detector solenoid will be centered in this area and located in the experimental wide-angle Hall. The magnet will be aligned to the electron beam axis. Fig 3 shows the layout of the ePIC detector.

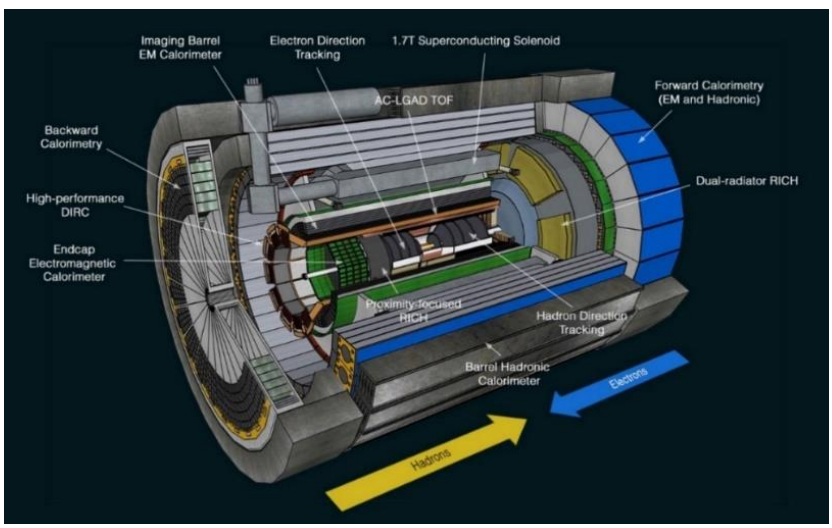

Figure 3: The Detector layout

3. Magnet Specifications

A 2T solenoid (called MARCO) will be used for the ePIC detector. This document outlines the specification of the new solenoid for the EIC. These specifications are with the return flux around the magnet. The details of the return flux is given in the design report. The magnetic return flux is not part of the magnet vendor contract. The magnet specifications are given in Table 2:

Table 2: Magnet Specifications

Parameter	**Detector 1-Solenoid**
Nominal Central Field at IP (T)	2
Operating Field Range (T)	0.5-2.0
Magnetic Field Polarity	Bipolar
Coil length (mm)	3492
Warm bore diameter (m)	2.84
Cryostat length (m)	<3.85
Cryostat outer diameter (m)	<3.54
Flat Field area	± 100 cm around center 80 cm radius
Field uniformity in Flat field Area (%)	12.5
RICH area	From z=+180 cm to 280 cm
Projectivity in RICH Area (mrad@30GeV/c) Projectivity in RICH Area (T/Amm^2)	0.1 10
Stray field requirement	<10 G @ z=-5.3 m, @z=+7.4 m, and @R=3.4 m
Charging voltage (V)	10
Fast discharge voltage maximum (V)	500
Quench hot spot temperature (K)	<150
Temperature margin (K)	>1.5
Current margin (%)	<30
Charging time (hr)	2-3
Cooldown time (weeks)	3-4
Cooling scheme	Thermosiphon
Conductor	Cu Stabilized NbTi Rutherford cable
Operating Temperature	4.5

There are three areas of importance from the magnetic field point of view, these are:

1. Flat Field Area
2. RICH detector Area
3. Stray field limitation at IR magnets

The details of these areas are given below. The steel around the magnet governs the magnetic field quality and stray field. These specifications are for the reference purpose only and will be met as long as coils are built to the design.

3a. Flat Field Area

This is 200 cm long and 80 cm in radius around the IP, the field uniformity required in this area is 12.5%. The field uniformity definition, used in this document, is:

$$Field\ Uniformity\ (\%) = \frac{dB * 100}{B_{Center}}$$

Where,

dB= B_{max}- B_{min} (in the area of interest), and

B_{center}= B at the magnet center

The flat field area with respect to the magnet and cryostat is shown in figure 4.

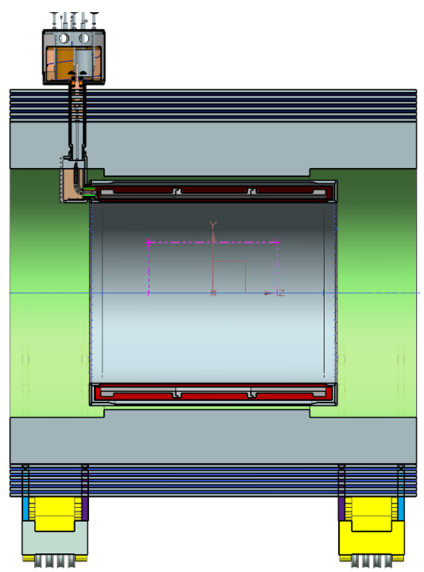

Figure 4: Flat Field Area

3b. RICH detector area

In order to maximize the RICH performance based on the gas radiator it is critical to minimize the bending of the tracks in the volume of the gas radiator, for this one needs to shape the field that it is parallel to the different scattering angles of particles covered by the RICH. The RICH area extends from z=+180 cm to +280 cm. The projectivity in this region should be less than 10 T/Amm^2 or less than 0.1 mrad @30GeV/c. The projectivity can be calculated as below:

$$Proj = \frac{1}{\Omega}\int_{\Omega} \frac{|B_r| - \left|\frac{r}{z}B_z\right|}{J_e} d\Omega \leq 10\frac{T}{Amm^2}$$

Where Ω is the gas volume of the detector, B_r and B_z are respectively the radial and the axial component of the magnetic, J_e the engineering current density of the magnet.

The RICH area with respect to the magnet and cryostat is shown in figure 5.

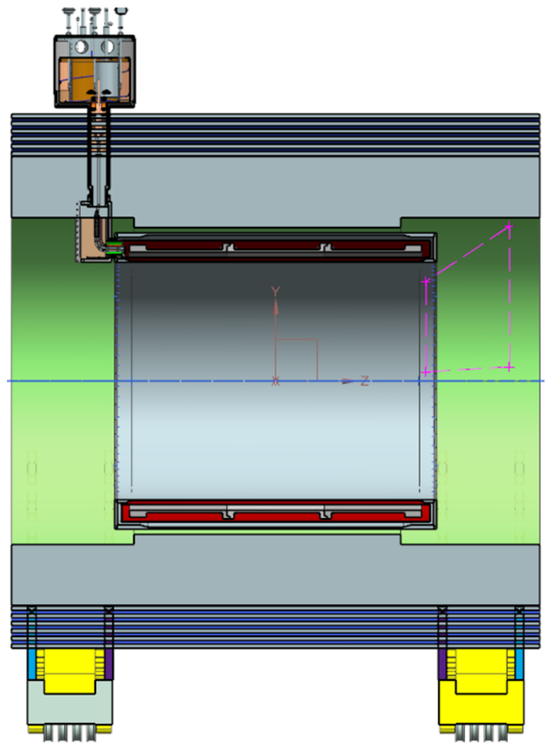

Figure 5: RICH area

3c. Stray field limitations at IR magnets

The detector solenoid has neighboring IR magnets, in order to reduce the effect of solenoid magnet on IR magnets, there is a requirement of stray field less than 10 G at the B0ApF and Q1ApR magnets (see Fig. 2), these magnets extends from z= 7.4 m to 8 m and z=-5.3 m to -7.1 m respectively. As mentioned earlier that the steel around the magnet governs the stray field. These specifications will be met as long as coils are built to the design.

4. Magnet Design

The main parameters of the MARCO magnet which are related to the physics requirements are the following:

- Field at center: 2 Tesla,
- Field homogeneity: 12.5%
- Projectivity: <10 T·mm²/A

- Yoke diameter: 6.5 m on the HCal Barrel Calorimeter,
- Axial yoke length including endcaps: 9.5 m

Only the magnetically active elements are considered for the magnetic design. The magnetic flux generated by the superconducting coils is returned via three distinct sections of yoke as shown in figure 6.

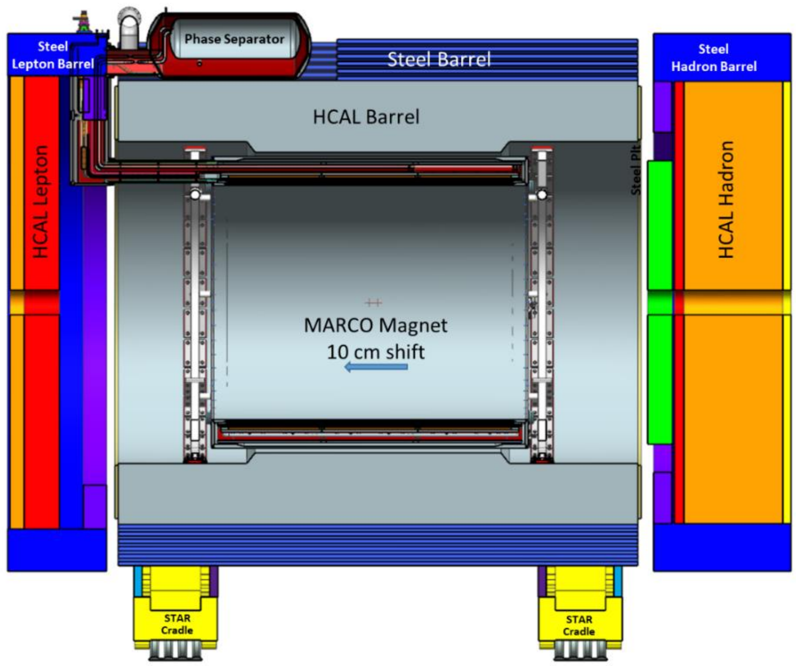

Figure 6: The yoke surrounding the coils

The magnetic field produced by the MARCO solenoid has been calculated using OPERA, 2D and 3D finite elements models. Given the high level of symmetry in the magnet, both models give the same results in terms of magnetic field and magnetic performances. The 2D axisymmetric model has been used to compute the magnetic field turn-by-turn and determine the magnetic field peak on the cable, while the 3D model has been used to take into account the limited effect of the cradles—the only non-symmetric elements present in the yoke.

The MARCO solenoid is made of three modules with three identical superconducting coils wound internally on a mandrel made of brass 70-30. The coils are indirectly cooled using a thermosiphon. As the Interaction Point (IP) is the center of the detector, the cold mass center is shifted along the axis at Z = +100 mm. The three modules are named, from Z- to Z+, MOD1, MOD2, and MOD3. For each module, 6 single layers of superconductor are wound internally to a mandrel, for a total number of turns per layer varying between 92 and 93, according to the conductor exits. The total number of turns per module is 556. Each layer is separated by an inter-layer fiber glass insulation of 2 layers of 0.2 mm to achieve a good electrical insulation after winding and to prevent the conductor damages. The coil pack is separated from the mandrel by 1 mm of ground insulation, the same value as CMS solenoid, to prevent electrical short-circuits, to protect the conductor insulation during winding, and to facilitate the impregnation keeping a good thermal coupling for cool-down and quench-back. A schematic drawing of the coil pack and the mandrel is shown in figure 7 and conductor dimensions shown in figure 8. The geometric specifications of the solenoid are given in table 3. The nominal magnetic performance of the magnet is given in table 4.

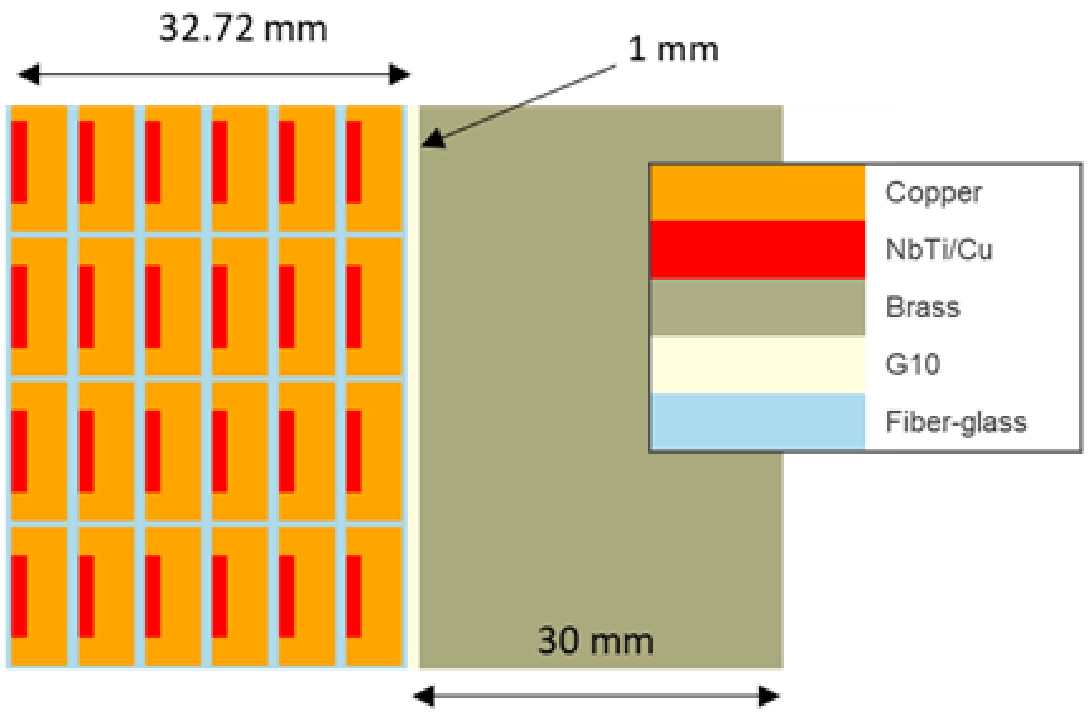

Figure 7: Schematic cross-section of the coil and the mandrel

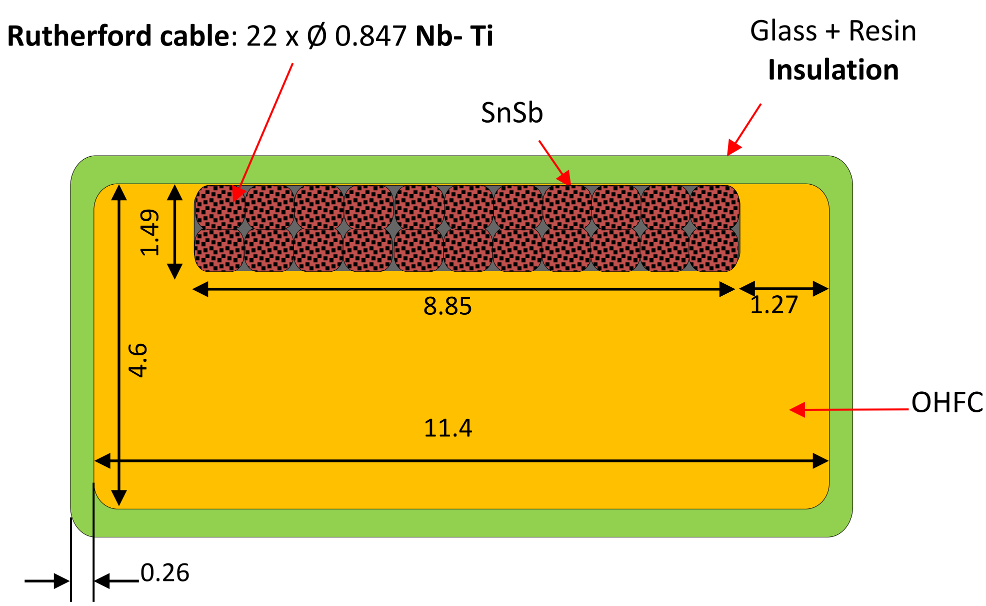

Figure 8: Detailed Dimensions on the conductor (dimensions are in mm)

Table 3: Geometric specifications of MARCO solenoid

Parameter	Value	Dimension
Bore radius	1420	mm
Mandrel Length (300K)	3620	mm
Mandrel Length (4K)	3608	mm
Number of Modules	3	
Z- (MOD1) / Z+ (MOD3) Modules Length (300K)	1228	mm
Central Module (MOD 2) Length (300K)	1164	mm
Coils Inner Radius (300K)	1509.5	mm
Coil Inner Radius (4K)	1502.5	mm
Coils Thickness	32.7	mm
Coils Outer Radius (300K)	1542.2	mm
Ground Insulation Thickness	1	mm
Mandrel Inner Radius	1543.2	mm
Mandrel Thickness	30	mm
Mandrel Outer Radius (300K) without Flanges	1573.2	mm
Mandrel Outer Radius (4K) without Flanges	1566.2	mm
Mandrel Outer Radius (300K) including Flanges	1646.1	mm
Mandrel Outer Radius (4K) including Flanges	1639.1	mm
Number of Layers per Module	6	
Number of Turns per Module	556	

Table 4: Nominal magnetic performance of the magnet

Parameter	2.0 T	Unit
Current	3924	A
B_0	2.000	T
B_{peak} MOD 1	2.672	T
B_{peak} MOD 2	2.478	T
B_{peak} MOD 3	2.660	T
Energy	45.008	MJ
Inductance	5.846	H
F_z MOD 1	11.88	MN
F_z MOD 2	31.9	kN
F_z MOD 3	-12.00	MN
F_z tot	-32.2	kN

At the ultimate working field (B_0) of 2.0 T, the magnet has a stored magnetic energy of 45 MJ and an inductance of 5.847 H. The inductance is constant at every current value up to the nominal current of 3924 A. At nominal position, the magnet is well balanced within the yoke. The maximum axial force (Fz) along the axis of the magnet is 32.2 kN pointing towards the lepton calorimeter.

The magnet satisfies the requirements for magnetic field at center, the projectivity and the field uniformity. Local solutions for the stray field are summarized in the design report. The field uniformity and projectivity is governed by the coil placement, but the stray field is controlled by the return flux. The performance of the magnet versus the requirement for the physics is given in table 5.

Table 5: Performance of the MARCO magnet vs requirements

Parameter	2.0 T	Requirement	Unit	Validation
B_0	2.000	2.0	T	OK
Field uniformity	12.5	12.5	%	OK
Projectivity	3.28	< 10	$T/(A\cdot mm^2)$	OK
Transparency	0.468	< 0.5	-	OK
B5300	< 10	< 10	G	OK
B7200	< 10	< 10	G	OK

The coils will be wound using Cu-cladded Rutherford cable. The Rutherford cable will be made using 22 strands of NbTi conductor of 0.847 mm. The Rutherford cable will then be soldered in the copper channel. JLab will be responsible for providing the soldered conductor to the vendor. The conductor quality assurance is in progress and all the testing data will be shared with the vendor. The detailed conductor parameters will be defined and shared with the vendor at the time of contract award. The conductor details are given in table 6.

Table 6: Conductor specifications

	Parameter	Value	Unit
Strand	Strand diameter	0.847	mm
	Cu/NbTi	1.31	
	I_c @ 3T & 4.7K	> 735	A
	Filament diameter	< 30	µm
	Filament twist pitch	30	mm
Cable	NbTi strands	22	
	Transposition pitch	50	mm
	Width	8.85	mm
	Thickness	1.49	mm
Conductor	Copper channel section	43.7	mm^2
	Nominal current @2 T	3924	A
	RRR conductor	>= 80	
	Yield strength $\sigma_{0.2\%}$ @ 293 K	>= 165	MPa
	Unit length	1.05	km
	Total length	18.9	km

The magnet will be protected using a dump resistor across the magnet. The preliminary quench protection circuit is shown in figure 9. There will be voltage taps across each joint, the layout of this is given in the design report. There will be other diagnostic instrumentation such as temperature sensors, load sensors etc. in the magnet.

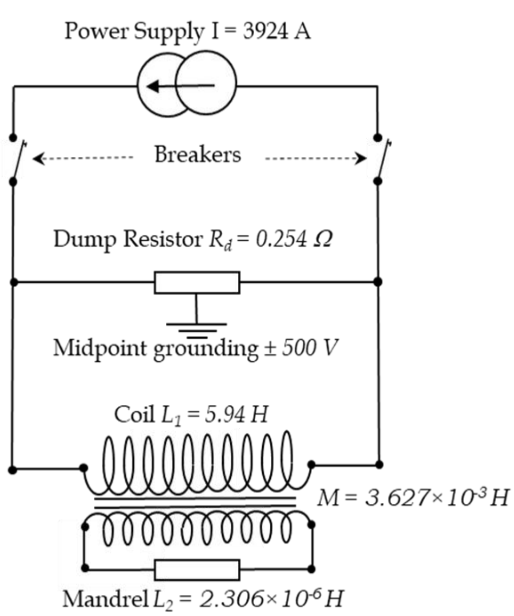

Figure 9: Quench protection circuit

5. Mechanical Design

Contrary to the usual detector magnets made with an aluminum stabilizer conductor, MARCO is made with a copper stabilized NbTi Rutherford in channel, making it one of its kind. The design draws significant design inspiration from the CMS magnet. The three modules are impregnated independently, joined altogether with the brass rods and nuts, and aligned with the centering geometry in the mandrel. The mandrel is made of brass 70/30 due to its slightly higher coefficient of expansion than that of the coil. The resulting slight constraint created on the coil during cool-down maintains continuous contact between the two components over the magnet's lifetime. To compensate the fabrication imperfections, customized G10 shims are placed between two adjacent mandrels. At the extremities of each coil module, a G10 wedge allows the conductor terminals to exit and serves as a shear stop. The flanges are designed to be discontinuous to provide space for the thermosiphon pipes (essentially the distributor and collector manifolds) and also for the exiting conductor. The inter-module M30 rods are made with the same brass of the mandrel to avoid any shrinkage difference during cool-down. The use of Belleville washers for stress relieving are avoided this way. The M30 rods are positioned at every 10° except in the cuts; there are a total of 25 rods per flange. Figure 10 shows the cold mass of the magnet showing 3 modules and figure 11 shows the details of inter-module fixation.

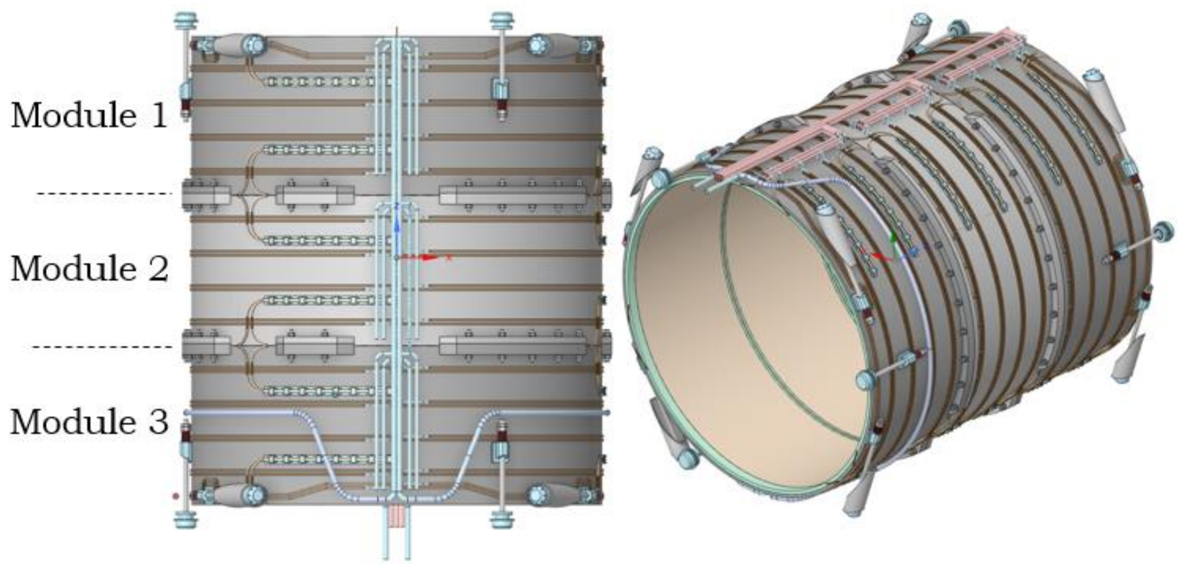

Figure 10: Cold Mass of the magnet

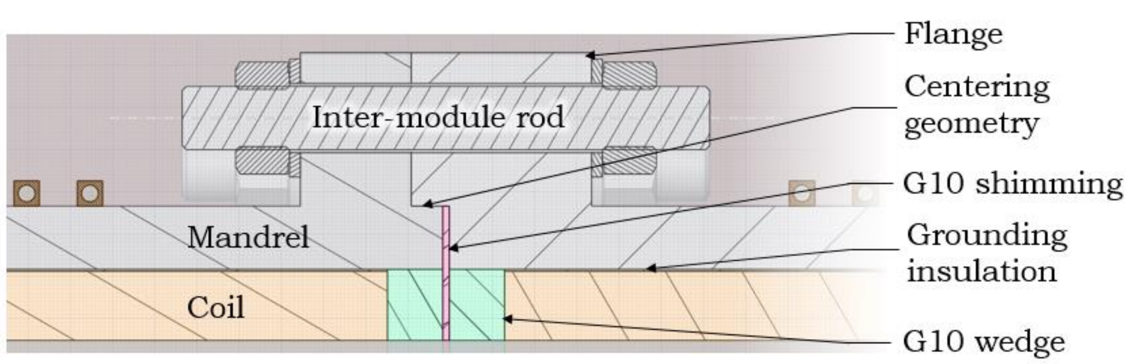

Figure 11: Inter-module fixation

The cold mass assembly is suspended and adjusted with respect to the vacuum vessel with 8 radial and 6 axial tie rods figure 12. The cold interfaces are made by brass brackets attached to the mandrel. The tie rods are captured by the brackets and have Belleville washers and nuts to reduce thermal stress due to differential contraction. The warm sides of the tie rods are fixed on the vacuum vessel with nuts. A O-ring-sealed cap is bolted around the warm interface to maintain the vacuum inside. At both interfaces, female/male ball joints are installed to allow movements during the calibration phase and the cool down phase. These two-ball joint assemblies are designed in a manner to have the largest center-to-center distance. The length of the tie rods has been chosen by considering the available footprint, the heat load conducted to the magnet and the initial length versus shrinkage displacements.

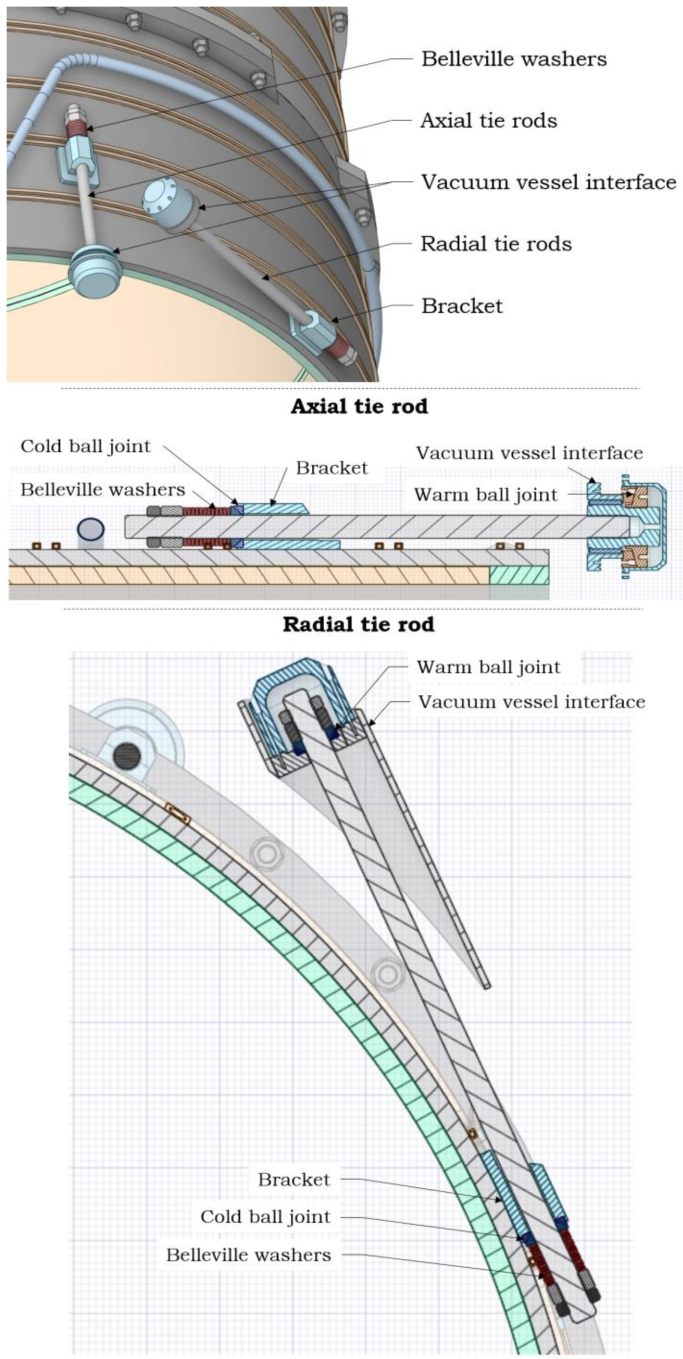

Figure 12: Axial and radial tie rods on the cold mass

The specifications of the tie rods are given in table 7.

Table 7: Specifications of the Tie Rods

Specification	Radial tie rod	Axial tie rod	Total
Number	8	6	14
Calculated diameter (mm) (Transportation load = 3g + Safety factor = 3)	36	37	NA
Chosen diameter			NA
Length - center distance between cold and warm ball joints (mm)	657	880	NA
Heat load to the cold mass at 4.5 K (W)	0.24 per rod	0.34 per rod	3.95
Heat load to the thermal shield at 60 K (W)	4.67 per rod	7.44 per rod	82
Shrinkage between 293 K and 4 K (mm)	1.29	0.85	NA

The detail simulations and material properties used in the simulations are given in the design report.

6. Materials Used in the Magnet

The materials in the EIC detector, including those in the solenoid, must be consistent with the overall material budget that allows detection of relevant particles for EIC science, with their specific energies. At the EIC, the barrel Hadron Calorimeter (bHCal) needs to act as tail catcher following the barrel Electromagnetic Calorimeter (bECal) that is approximately 1.0 λI (nuclear interaction length). This implies that the solenoid material needs to be "light" (approximately 1.3 λI) to contain 95% of the hadrons with energy of science interest in the EIC. This leads to the need for all the material thickness to be less than "one" interaction length—the lower, the better. The current material budget for current design is well within this limit. Table 8 lists the materials in the magnet and table 9 summarizes the thickness of all these materials, their nuclear interaction length and the total interaction length.

Table 8: Materials in the Magnet

	Component	Length along z (m)	Number of component	i.d. (m)	o.d. (m)	Thickness in radial direction (mm)	Volume (m^3)	Material	Starting position from magnet center (mm)	End position from magnet center (mm)	Starting position from magnet center (mm)	End position from magnet center (mm)	Inner radius (mm)	Outer radius (mm)
Radial	Inner vacuum vessel	3.79	1	2.8400	2.8600	10	0.339	Al	-1895	1895			1420	1430
	MLI	3.7	1	2.8600	2.9000	20	0.670	MLI	-1850	1850			1430	1450
	Inner thermal shield	3.7	1	2.9450	2.9550	5	0.171	Al	-1850	1850			1472.5	1477.5
	MLI	3.7	1	2.9550	3.0190	32	1.111	MLI	-1850	1850			1477.5	1509.5
	Inner G10	3.492	1	3.0130	3.0190	3	0.099	G10	-1746	1746			1506.5	1509.5
	Coil	3.492	1	3.0190	3.0862	33.6	1.125	Coil	-1746	1746			1509.5	1543.1
	Outer G10	3.492	1	3.0862	3.0922	3	0.102	G10	-1746	1746			1543.1	1546.1
	Coil Former	3.492	1	3.0922	3.1522	30	1.028	Brass	-1746	1746			1546.1	1576.1
	MLI	3.7	1	3.1522	3.1522	0	0.000	MLI	-1850	1850			1576.1	1576.1
	Outer Thermal shield	3.7	1	3.3550	3.3650	5	0.195	Al	-1850	1850			1677.5	1682.5
	MLI	3.7	1	3.3650	3.4900	62.5	2.490	MLI	-1850	1850			1682.5	1745
	Outer Vacuum vessel	3.79	1	3.4900	3.5400	25	1.046	Al	-1895	1895			1745	1770
Axial	Coil end support	0.0452	2	3.0190	3.0862	33.6	0.015	Brass	-1746	-1791.2	1746	1791.2	1509.5	1543.1
	G10 ends	0.003	2	3.0130	3.0922	39.6	0.001	G10	-1746	-1749	1746	1749	1506.5	1546.1
	MLI	0.015	2	2.9450	3.3650	210	0.031	MLI	-1746	-1761	1746	1761	1472.5	1682.5
	Thermal shied end 1	0.003	1	2.9450	3.3650	210	0.006	Al	-1850	-1853	1850	1853	1472.5	1682.5
	Thermal sheild 2	0.005	1	2.9450	3.3650	210	0.010	Al	-1850	-1855	1850	1855	1472.5	1682.5
	MLI	0.02	2	2.8400	3.5400	350	0.070	MLI	-1850	-1870	1850	1870	1420	1770
	Vacuum vessel end	0.04	2	2.8400	3.5400	350	0.140	Al	-1895	-1935	1895	1935	1420	1770
Miscellaneous	Axil and radial coil support	size and locations of these will be decided after full mechanical analysis						Tungsten / carbon fiber						
	Instrumentation (sensors etc.)	number and locations of these will be decided later						Cu/magainin/constantan						

Table 9: Material Thickness and Interaction Length

Material	Material Thickness (mm)	Nuclear interaction length (mm)	Thickness/Nuclear interaction length
Total Al	45.00	397.04	0.113
Total Cu	25.39	153.24	0.166
Total SS/Brass	30.00	165.50	0.181
Total NbTi	1.76	232.07	0.008
Total G10	12.00	435.56	0.028
		Total Interaction Length	0.495

7. Cryostat

The cryostat length is 3.85 m, to accommodate 3.512 m coil length. The room temperature bore of this magnet is 2.84 m and outer diameter of the cryostat is 3.54 m. The detailed dimensions of the magnet are shown in figure 13. The section showing cooling lines and conductor exiting the magnet through the thermal shield to the chimney connection box in shown in figure 14. The overall size of the magnet along with the phase separator is shown in fig 15 and figure 16 shows the cross-sectional view of the magnet system.

The MARCO magnet is a conduction-cooled magnet and is indirectly cooled using the cooling tubes on the outside of the brass mandrel. Detail simulations were done to calculate the size of the tube, number of tubes, spacing of tubes. Figure 17 shows the cryogenic flowchart of the magnet. The internal cryogenic system of the Marco solenoid for EIC experiment involves a cold mass, which consists of a mandrel and coils with two 28-tube exchangers of the thermosiphon soldered on the mandrel, a phase separator on top used also as a storage tank of liquid helium at 4.55 K, and one cryogenic chimney that holds the helium vapor cooled current leads and connect the phase separator to the cold mass. The Marco solenoid is equipped with 5 cold valves with warm actuators and 3 warm valves. It also has a thermal shield to insulate the parts at 4.5 K; the thermal shield is cooled by helium gas between 45 K and 65 K. The internal cryogenic system is connected to the BNL refrigeration supply through flexible lines. The details of all the valves and cryogenic processes is given in the detail design report.

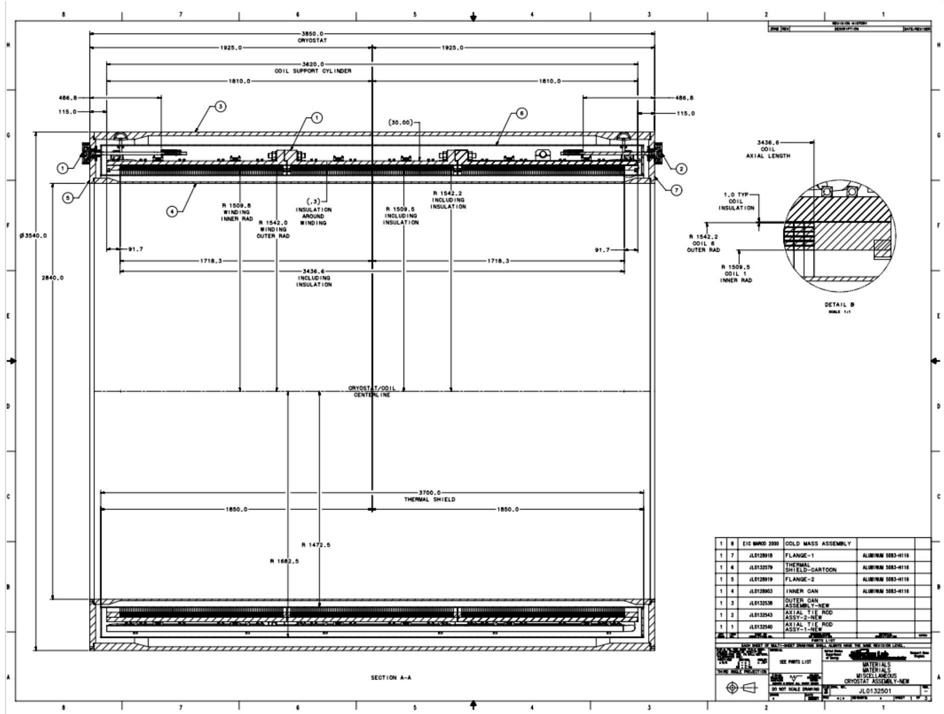

Figure 13: Dimensions of the Cryostat

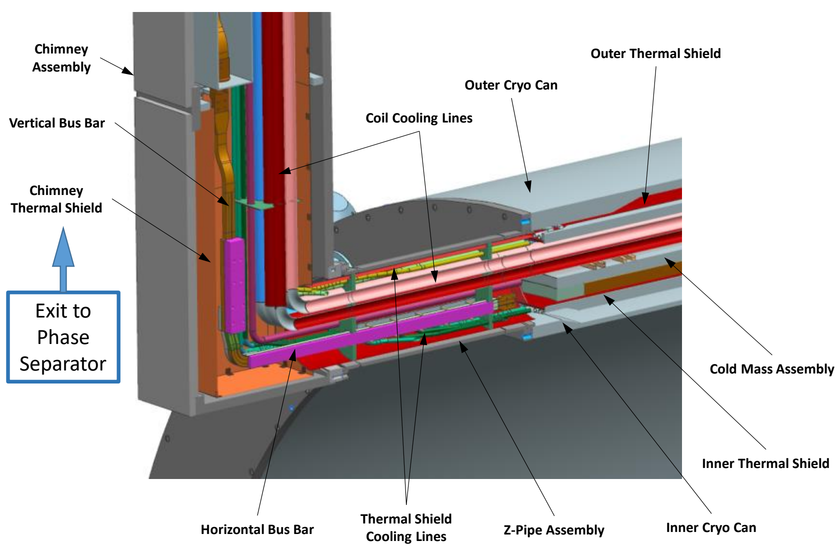

Figure 14: Cross-section showing the cooling lines and conductor exit

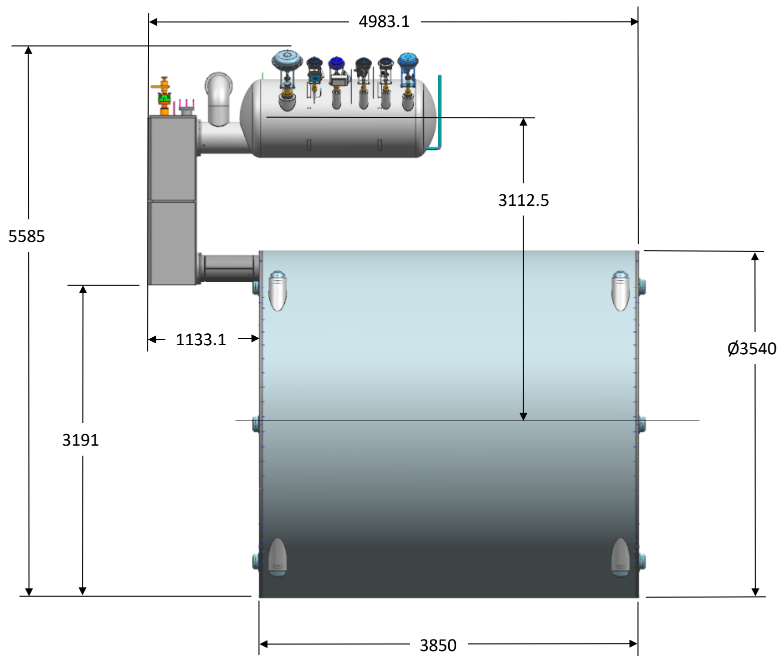

Figure 15: Overall Dimensions of the Cryostat and Phase Separator

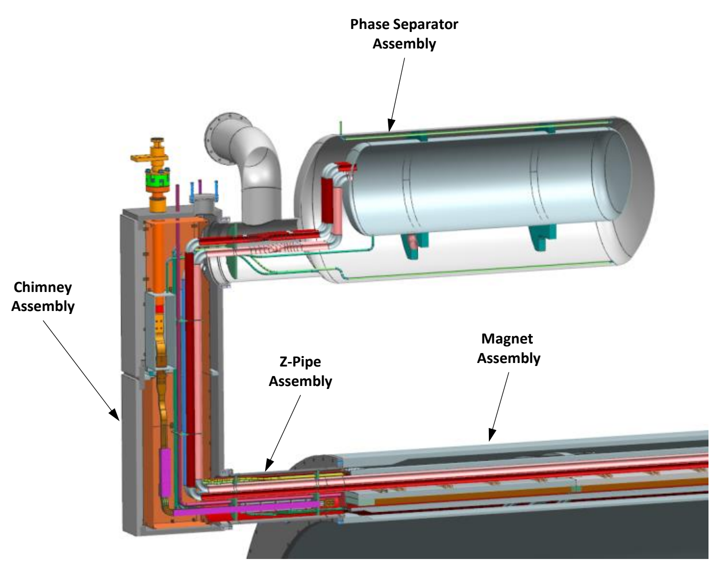

Figure 16: Cross-sectional View of the Magnet System

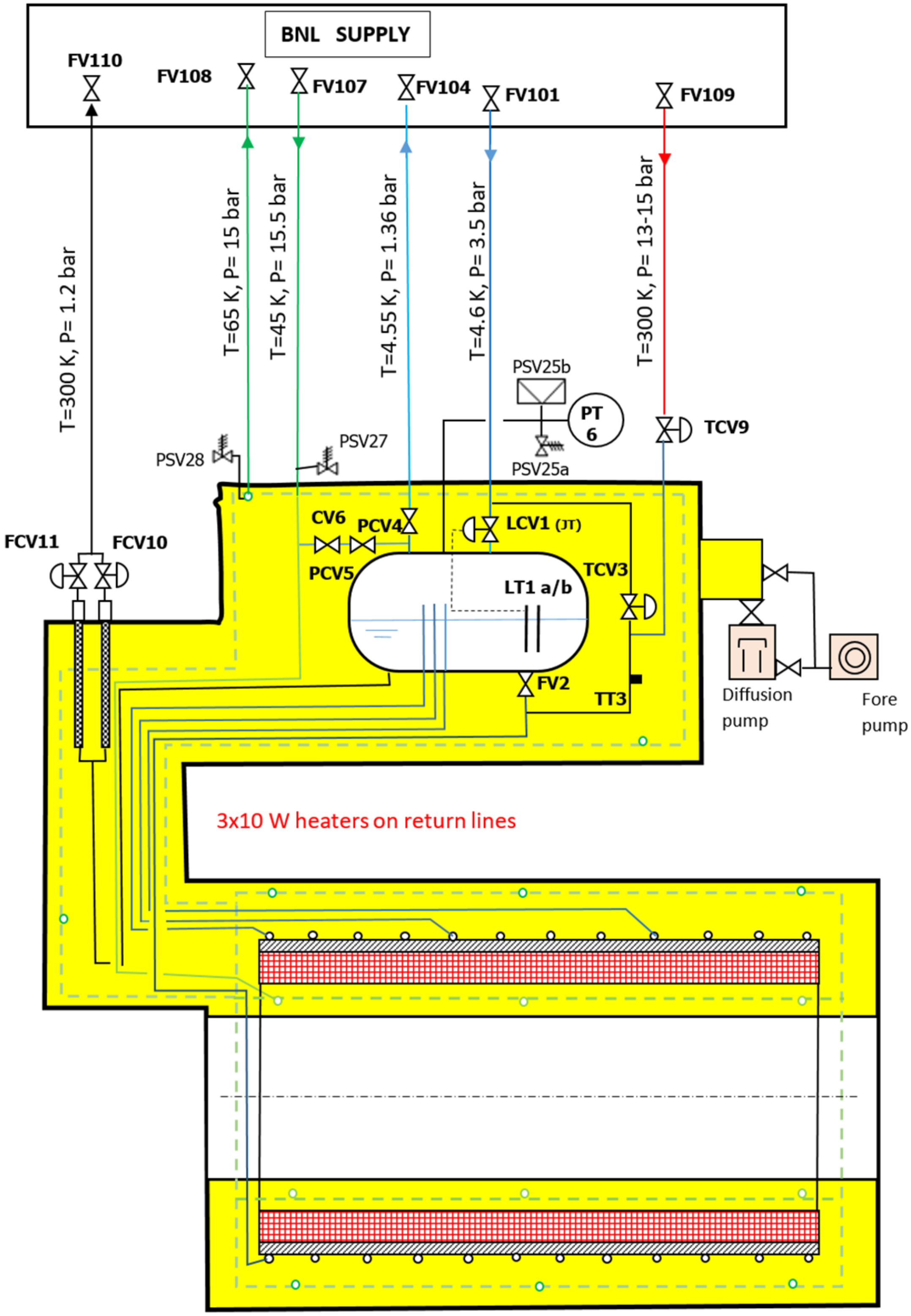

Figure 17: Cryogenic FLowchart

Magnet structure, especially all the vessels and piping, is designed in accordance with the ASME codes. EIC detector magnet shall meet the requirements of Jefferson Lab's ES&H manual, which dictates that pressure system design and construction shall comply with the ASME BPV Code and/or B31 Code for Pressure Piping as applicable. The vacuum system of the EIC detector magnet is a Category 2 system per Jefferson Lab's ES&H Manual, not a pressure vessel system; however, ASME BPV Code shall be used to design and construct the vessels to guarantee safety. The inner vessel of phase separator shall be designed per ASME BPV Code as well. The piping system shall be governed by ASME B31.3.

The governing codes of the magnet are ASME VIII Division 1 and B31.3; the record year of the code is 2023 for Division 1 and 2022 for B31.3. It should be noted that Division 1 uses formulas and material property graphs while Division 2 is formula-based or finite element analysis based. Since Division 2 can be used to design Division 1 vessels, to avoid manually reading the graphs of material properties, Division 2 was chosen to design the helium inner vessel, vacuum vessels, but the with the design factors of Division 1.

The vacuum system and inner vessel of the helium phase separator shall be constructed in accordance with ASME VIII Division 1. The piping shall be constructed in conformance with B31.3. A stamp is not required for the any pressure or vacuum component of the EIC detector magnet.

ASME-qualified Welding Procedure Specification (WPS) and Procedure Qualification Record (PQR) for 314L are required; the base metal, heat-affected zone and weld metal shall be impact-tested at 77 K per ASME VIII Division 1. Type 316L weld filler metal, or Type 308L filler metal shall be used; weld metal deposited from each heat of Type 316L filler metal shall have a Ferrite Number (FN) not greater than 10, and a weld metal deposited from each heat of Type 308L filler metal shall have a FN in the range of 4 to 14. ASME-qualified WPS and PQR shall be used to fabricate the 316L inner vessel and the stainless steel piping.

The base metal of the inner vessel of the helium phase separator shall be impact-tested at 77 K per ASME VIII Division 1. ASME-qualified WPS and PQR for aluminum shall be used to fabricate the outer vacuum vessel and the cryogenic chimney.

8. Power supply requirement

The solenoid power supply will be a standard superconducting magnet power supply. A polarity reversal switch should also be included in the power supply. The power supply will be located about 300 feet far from the magnet. The power supply will be a 5000A, 20V superconducting magnet power supply. The power supply procurement will be done by JLab and this procurement is in progress. The power supply specification are given in the detailed design report.

9. Current Leads

The solenoid will be connected to vapor cooled superconducting leads (VCL) from the ends of the magnet to the top of the chimney (chimney location shown in Fig.10). The water-cooled leads (WCL) will be connected from the top of the chimney to the power supply. The VCL will be the vendor's responsibility. The WCL will be the responsibility of JLab.

10. Detectors around the Magnet

There are a number of detectors shown in the layout (Figure 3), but for magnetic analysis, only the HCals will be considered, these are the only detectors made of magnetic material. There are three HCals,

(i) Electron HCal Endcap,
(ii) Hadron HCal endcap, and
(iii) Barrel HCal.

Figure 18 shows the coil in the HCals and Figure 19 shows the various components of HCal.

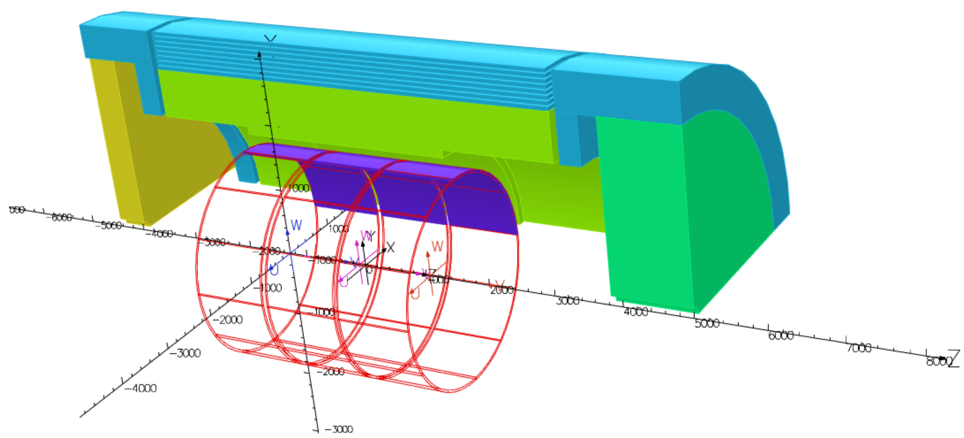

Figure 18: Coil and HCal

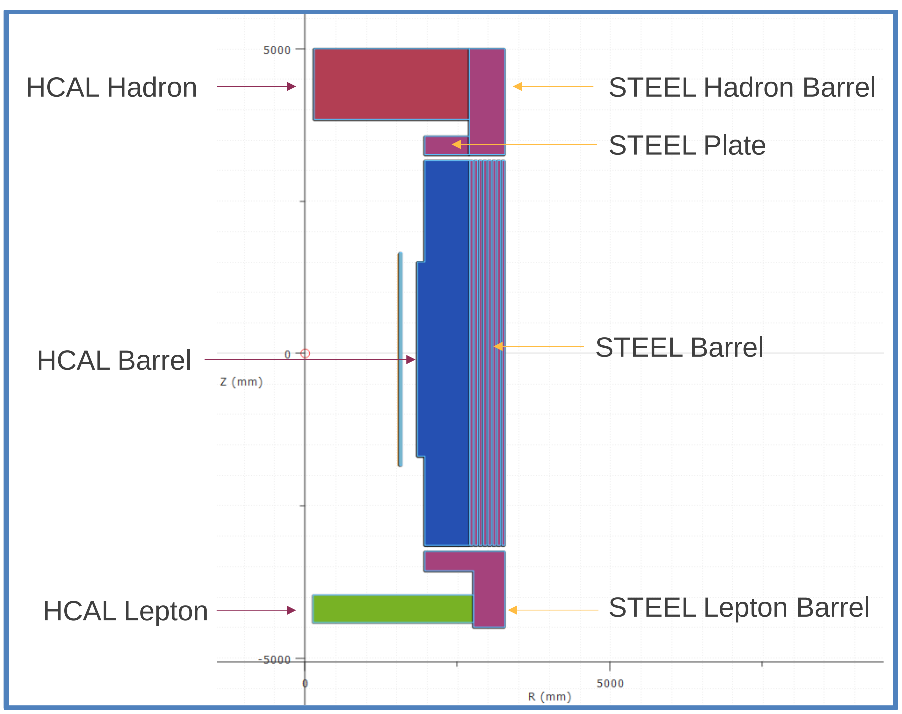

Figure 19: Various part of HCal

The detailed composition of HCals is given in the design report.

11. Cryogenics facility and options available

Standard cryogenic facilities are available at the BNL cryogenic facility. Following cryogenic interface is available at BNL:

- Intake: supercritical helium *4.5 K / 3.5 bars (g)* (*100 W* cooling power)
- Return: 4.5K/1.3bar (g)
  (*400 W* cooling power)
- Heat shields cooling: 45K/15bars (g) helium loop (or possibly LN_2)

12. Magnetic Material in the Vicinity of the Magnet

There is no other magnetic material in the vicinity of the magnet. The magnet and the HCals will be installed on the cradle, details of the cradle size will be updated later on. The magnet and HCals in the cradle are shown in Fig. 20. The steel barrel is made up of 6 layers of 50 mm thick with a gap of 40 mm.

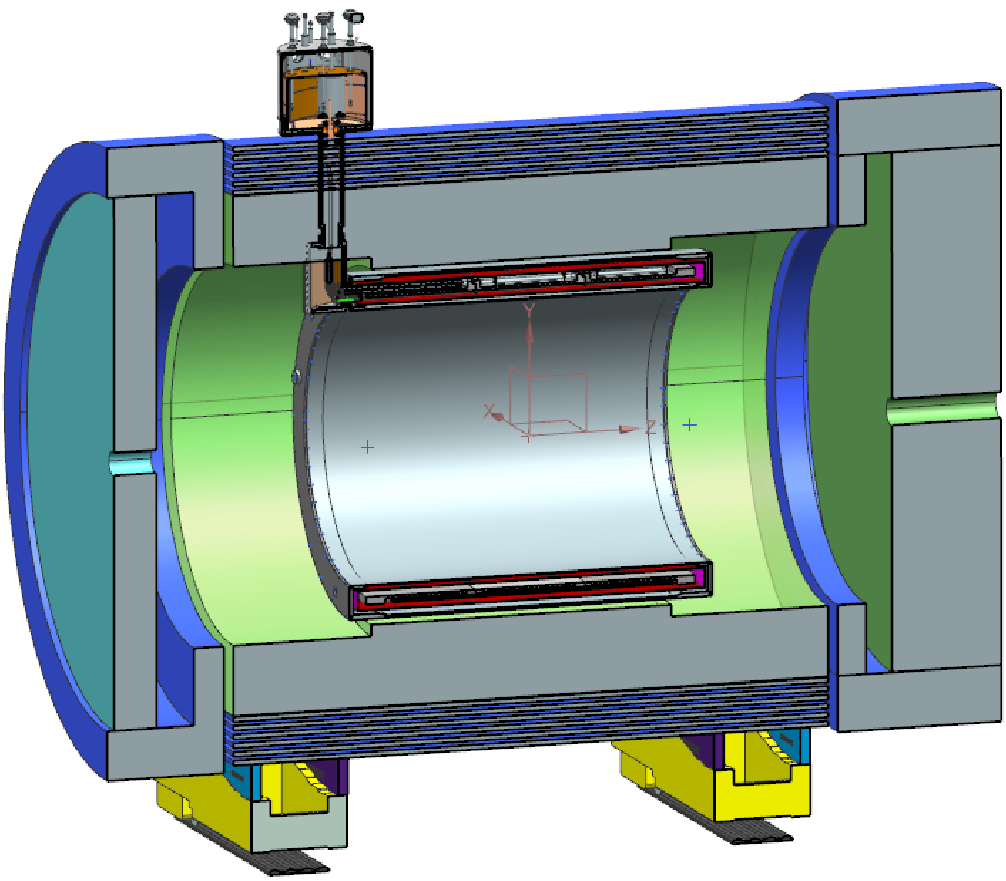

Fig. 20: Magnet and HCal on the Cradle (HCal Cradle is not shown in this picture)

13. Instrumentations

In order to operate and monitor the MARCO solenoid an extensive instrumentation plan has been defined. The instrumentation covers the electrical measurements, the cryogenics data measurements as well as the mechanical ones. The electrical measurements gather the voltage measurements and the current measurements. The cryogenics ones collect the temperature data, the pressure, the liquid helium level, the he mass flows and the vacuum level. Finally, the mechanical measurements concern especially the tie-rods whose stress is monitored during all the magnet life. The detailed instrumentation is given in the design report. The instrumentation racks should be used for all the equipment used for data acquisition. The control system should be compatible to the BNL control system.

14. Vendor/Partner In-Process Monitoring and Measurement Activities

JLab Technical Representative (TR) conducts periodic design and manufacturing status meetings with the International Partner to review:

1. Requirements lists
2. Designs
3. JLAB Inspection and Test Plans status and activities
4. Deliverables Register, Change Logs, Nonconformance
5. Manufacturing schedules and Vendor's Manufacturing Inspection Plan
6. Operational, Functional, Performance and Commissioning Test plans vs. actual

After review of the Partner's manufacturing plans (MIP) JLAB updates the inspection and test plan, and may expand the witness and hold points, or required additional submittals for review or approval.

15. Incoming Inspection and Acceptance Tests

Installation and commissioning of the detector magnet will be performed at BNL; however, the JLab TR and other subject matter experts (SMEs) will oversee the vendor's installation and commissioning activities, including verification of all final acceptance tests.

The vendor must specify in the Quality plan all tests to be carried out during the installation and commissioning of the magnet to comply with the specification of the magnet operation: All acceptance tests must be successfully performed, in particular the final acceptance test of the magnet at low temperature and nominal current; and records are to be provided for JLAB review.

16. Travelers, Procedures, and Checklists

The Vendor (Partner and their manufacturers) will provide the complete list of travelers and procedures which are to be submitted to JLAB.

JLAB TRs review submittal registers and the register/lists of all travelers, procedures and checklists created by the Vendor and identify and track gaps, or changes, to closure.

17. Deliverable Documentation and Records

JLAB defines in a Documents/Records Register(s) the minimum documents and records which the vendor (partner and their manufacturers) shall deliver during the project.

- Content of the Register must be sufficiently
    a. facilitate quality and conformance reviews of designs, manufacturing, shipping preparation, long term storage, etc. to requirements.
    b. include any applicable documented information JLAB is required to submit to BNL.
    c. reference ITP and MIPs and their requirements
    d. reference registers for submittal, traveler, procedure, tools, checklists
    e. design, manufacturing code and standard, and technician qualification records (example, ASME certificate, WPS/WPQ/PQRs, ISO 9001 certificate, ASME certificate, etc).

18. Planned Partner and Vendor Communication & Visits

- JLAB will hold regular, periodic meetings with the vendor during design phase.
- JLAB will hold regular, periodic meetings with the vendor during manufacturing phase.
- Vendor will provide a manufacturing, inspection and test schedule.
- JLAB plans to witness much of the manufacturing process and most or all of the testing.
- Witness/hold point visits will typically be attended by JLAB TR and QA and may include additional subject matter experts and EIC Project representatives. Schedule or nonconformance issues may result in JLAB increasing surveillance.

19. Shipping

The magnet will be shipped to BNL, the shipping crate should be designed considering the loads on the tie rods. The design is based on 3g shipping load in all direction.

20. Installation and Commissioning

Installation and commissioning of the detector magnet will be performed at BNL; however, the JLab TR and other SMEs will oversee the vendor’s installation and commissioning activities, including verification of all final acceptance tests. The vendor must specify in the Quality plan all tests to be carried out during the installation and commissioning of the magnet to comply with the specification of the SM operation: All acceptance tests must be successfully performed, in particular the final acceptance test of the magnet at low temperature and nominal current; and records are to be provided for JLAB review.