Electron-Ion Collider

Technical Design Review of the EIC 60% Solenoid Magnet Subsystem

Performed In-Person and Remotely at Jefferson Lab

Newport News, Virginia

October 18-19, 2022

Table of Contents

1. Executive Summary

Significant progress has been made since the 30% design review point in Feb 2022. However, a change to the magnet field requirements and the conductor design approach (i.e., utilizing Cu-clad instead of Al-clad) has meant that some work has had to be repeated, and as a result other work required for the 60% design point has perhaps lagged somewhat.

The formalization of the requirements and interface documents is still a work in progress and further changes at this stage in the design process could pose a risk to schedule and cost.

The collaboration between Jlab, CEA-Saclay and BNL is working very well.

The current JLab/CEA-Saclay team will be on track to be ready for the 90% design review in 2023 as long as the recommendations are addressed adequately.

2. Responses to Charge Questions

Charge Question 1:

Have the technical performance requirements for the EIC detector magnet been appropriately and sufficiently defined?
MOSTLY – the requirements document seems to be a work in progress.

Charge Question 2:

Is the design at this stage well developed, and likely to meet the technical performance requirements?
MOSTLY – the core of the magnet design seems to be fairly mature. However, there are some aspects of the design, notably iron optimization, suspension links, multi-physics quench analysis which appears to be at a maturity level lower than the 60% design level.

Charge Question 3:

Are the recommendations from the previous review appropriately addressed?
MOSTLY – the team has done a great job in starting to address some of the recommendations, but some will still need to stay open.

Charge Question 4:

Is the procurement strategy and the planning for vendor interactions sound and sufficiently well-developed for this stage of the project?
YES – however development of the conductor development program remains a key priority.

Charge Question 5:

Is the design sufficiently mature for this stage of the project to support the anticipated SC magnet procurement award date?
YES – we believe that the core magnet design is sufficiently mature for this stage of the project as it is based on an existing design and utilizes fairly conservative assumptions. However, as there are several design aspects which appear to be low maturity (i.e. lower than the 60% design point), it is essential to ensure that there are no show- stoppers between this deign point and the 90% design point in 2023.

Charge Question 6:

Have interfaces with other systems such as cryogenics been appropriately defined and appraised?
PARTIALLY – The interface document is in development and some progress has been made with cryogenic interfaces, but it is not clear how much work has been completed for system integration and interfaces with accelerator and detector systems.

Charge Question 7:

Have ESH&Q considerations been adequately incorporated into the design at its present stage?

The design criteria being applied is sound. The design is still being optimized and as such there are no ESH&Q considerations to be presented at this stage of the design.

3. Comments

Collaboration/Management

- The excellent collaboration between CEA-Saclay, JLab and BNL has continued to make progress. The committee strongly supports extending this design collaboration to the 90% design point as currently planned.

Magnet Requirements and Detector/Accelerator Interfaces

- Obtain a formal specification of the operating field by using a single value that the design needs to satisfy. Magnet designers should establish the required margins to meet the operational requirement based on magnetic, mechanical, protection and powering considerations. For example, in the physical requirements document (PRD), fix the maximum operational field 2 T. It is always easier to proceed to lower field.
- Add to the PRD the expected heat load from external sources.
- Obtain a formal confirmation that the proposed use of Cu-cladded conductor and brass support structure provide adequate transparency to meet detector requirements.

Magnet Design

- Because of significant changes in operating field (DPAP decision) and conductor design (Cu-cladding) the 60% review includes some conceptual design elements that would normally be part of a 30% review. Some of these aspects are still in progress, such as iron yoke geometry optimization, which has implications on magnetic forces and mechanical supports; and quench protection analysis, needed to confirm the conductor design.
- The iron yoke geometry optimization is still in progress. Balancing EM forces on the coil should be given higher priority, to reduce mechanical support requirements and heat loads. Stray field optimization should focus on the needed locations (IR magnets, RCS) with appropriate shielding as needed.
- Consider the possibility of fringe field suppression by active coils at ends.
- Consider in the field analysis influence of external ferromagnetic objects.
- Consider substantial cryogenic cooling margin to operate at elevated heat loads (vacuum issues, thermal insulation, fabrication errors).
- Consider splitting solenoid on sections in an axial direction. For example, 4 sections substantially improve the magnet reliability and fabrication process.

- Consider protecting the solenoid with combination of external diodes combined with dump resistors.
- Consider the possibility of using belt type suspension instead of Inconel links.
- The team is taking the correct approach by considering various failure analyses including coil short, broken links, switch failure, etc.

Cable Development:

- Demonstrating the capability to procure Cu-cladded conductor with required unit length and performance should be a high priority. If needed, proceed with alternative approaches in parallel until a solution is in hand. This also requires procuring a first batch of strand and Rutherford cable and organizing the characterization effort at each stage (strand, Rutherford cable, final cable). Produce a plan which clearly lays out all the key tasks together with milestones.
- Based on cable manufacturing experience and full quench protection analysis (including fault scenarios) a final optimization of the cable dimensions vs. number of layers may be performed.

NbTi strand parameters:

- Strand specification has filament size <70 μm and Cu RRR > 80. Reduced filament size and higher RRR may have benefits for stability and cabling degradation. The team should compare with parameters used by other detector magnets and evaluate if the anticipated cost savings are sufficient to justify this potentially higher risk.

Copper Stabilized Conductor

- Consider the possibility of using larger copper stabilized conductor. For example, 2.5 mm x 20 mm, Bmax 3.58 T, I=3770 A which was used for JLAB CLAS12 Torus magnet system and carefully investigated. Successful operation has been confirmed for this magnet now.

General

- It might be advisable to start investigating the availability of vendors for the brass outer mandrel with the required properties, and at the same time consider alternative materials as a backup – for example aluminum or stainless steel shells.
- It might be advisable to start investigating the availability of conductor testing facilities. A test requirements document will be required first.
- Resources appear to be in place for FY23 leading up to the 90% design review. However, resources for the out-years appear to be rather light – resource requirements should be reassessed.

4. New Recommendations

1. By end Dec 2022, reassess the use of the BABAR magnet as an opportunity, now that the team has a better understanding of the requirements and any shortcomings of the BABAR magnet in achieving those requirements. Given the field requirement of 1.7 T to 2.0 T, we recommend dropping the BABAR magnet option.

2. By end Feb 2023, approve the magnet requirements document formally, and utilize a change control process for any further changes to requirements.

3. By Mar 2023, fast-track the design aspects of the magnet that presently appear to be at a lower maturity level than the 60% design point.

4. By Sep 2023, complete and approve the interface document. Utilize a change control process for any further changes to interfaces.

5. By Sep 2023, include ESH&Q considerations in the magnet and system design.

6. By the CD2/3A review date, demonstrate significant progress in prototyping and characterization of sample conductor and plans for full conductor production.

5. Previous Recommendations

1. **5 Gauss stray field requirements –** Review the requirements and continue to evaluate the possibility and trade-offs of using local shielding around affected IR magnets and sub-systems → OPEN

2. **Calculated peak Von Mises stress** at energization is 63 MPa in coils vs. 70 MPa design limit. We recommend to increase margin, which appears to be feasible without significant design complications or cost increase. → CLOSED

3. **Conductor development** – It should be a high priority to start the development work as soon as possible. Produce a plan which clearly lays out all the key tasks together with milestones → OPEN

4. **Fault Conditions** – Carry out a FMEA to investigate and mitigate potential fault conditions for all the magnet sub-systems for the 60% design review → CLOSED

5. **Integration** – Address interface and integration requirements between solenoid magnet and all other detector components as part of the 60% design review → OPEN

6. **sPHENIX (BABAR) 1.5 T magnet –** Re-evaluate the remaining risk of re-using this magnet under the assumption that only minimal (non-invasive) refurbishment is carried out → OPEN

7. **New 1.5 T magnet design –** Produce a resource-loaded plan for the design of this magnet → CLOSED

6. Appendices

6.1 Appendix A: Charge to the Review Committee

Jefferson Lab
Thomas Jefferson National Accelerator Facility

MEMO

Date:	October 11, 2022
To:	Ruben Fair (PPPL), Vladimir Kashikhin (FNAL) , and Gianluca Sabbi (LBL)
From:	Elke Aschenauer and Rolf Ent
Subject:	Charge for the Design and Safety Review of the EIC Detector Magnet –60% Design, October 18–19, 2022

The scope of this review includes the 60% design of a new EIC detector solenoid magnet and the planning for the design continuation and procurement strategy.

For the 60% Design and Safety Review, you are asked to address the following questions:

1. Have the technical performance requirements for the EIC detector magnet been appropriately and sufficiently defined?
2. Is the design at this stage well developed, and likely to meet the technical performance requirements?
3. Are the recommendations from the previous review appropriately addressed?
4. Is the procurement strategy and the planning for vendor interactions sound and sufficiently well-developed for this stage of the project?
5. Is the design sufficiently mature for this stage of the project to support the anticipated SC magnet procurement award date?
6. Have interfaces with other systems such as cryogenics been appropriately defined and appraised?
7. Have ESH&Q considerations been adequately incorporated into the design at its present stage?

Please address the above questions.

You will be supplied with the design report, planning documents for the design continuation including schedule and manpower assumptions, and the project milestones extracted from the most current EIC resource loaded P6 schedule as part of the pre-brief material.

cc:
A. Lung
W. Wittmer

12000 Jefferson Avenue, Newport News, VA 23606 • phone 757.269.7100 • fax 757.269.7363 • www.jlab.org
Jefferson Lab is managed by the Jefferson Science Associates, LLC for the U.S. Department of Energy Office of Science

6.2 Appendix B: Review Committee

Ruben Fair	rfair@pppl.gov	PPPL
Gianluca Sabbi	glsabbi@lbl.gov	LBL
Vladimir Kashikhin	kash@fnal.gov	FNAL

6.3 Appendix E: Agenda

Electron-Ion Collider

60% Design Review of the EIC Detector Magnet

Tuesday, October 18, 2022 – Wednesday, October 19, 2022

Tuesday, October 18, 2022 (Day 1)

Click here for Plenary (OPEN) Zoom

CEST	PST	CST	EST	Topic	Presenter	Duration (Min)
3:00 PM	6:00 AM	8:00 AM	9:00 AM	Executive Session (Closed)	Review Committee	15
3:15 PM	6:15 AM	8:15 AM	9:15 AM	Welcome and Project Status	R. Ent (JLab) / E. Aschenauer (BNL)	30
3:45 PM	6:45 AM	8:45 AM	9:45 AM	Solenoid Design Overview & Recommendations	R. Rajput-Ghoshal (JLab)	30
4:15 PM	7:15 AM	9:15 AM	10:15 AM	New Magnet EM Analysis & Transient Analysis	V. Calvelli (CEA Saclay)	30
4:45 PM	7:45 AM	9:45 AM	10:45 AM	Tea Break	All	30
5:15 PM	8:15 AM	10:15 AM	11:15 AM	Conductor Design Study	F. Stacchi (CEA Saclay)	30
5:45 PM	8:45 AM	10:45 AM	11:45 AM	Cryogenic Design Study	J. Lottin (CEA Saclay) S. Gopinath (JLab)	30
6:15 PM	9:15 AM	11:15 AM	12:15 PM	Discussion	All	30
6:45 PM	9:45 AM	11:45 AM	12:45 PM	Lunch (on your own)	All	60
7:45 PM	10:45 AM	12:45 PM	1:45 PM	Mechanical Analysis - Part 1	H. Reymond (CEA Saclay)	45
8:30 PM	11:30 AM	1:30 PM	2:30 PM	Mechanical Analysis - Part 2	E. Sun (JLab)	30
9:00 PM	12:00 PM	2:00 PM	3:00 PM	Tea Break	All	30
9:30 PM	12:30 PM	2:30 PM	3:30 PM	Quench Protection Study	F. Juster (CEA Saclay)	30
10:00 PM	1:00 PM	3:00 PM	4:00 PM	Drawing Status	D. Young / S. Gopinath (JLab)	15
10:15 PM	1:15 PM	3:15 PM	4:15 PM	sPHENIX Risk Analysis Update & FMEA for New Magnet	P. Ghoshal (JLab)	20
10:35 PM	1:35 PM	3:35 PM	4:35 PM	Plan for the 90% Review & Procurement Strategy	R. Rajput-Ghoshal (JLab)	30
11:05 PM	2:05 PM	4:05 PM	5:05 PM	Discussion	All	30
				Dinner (TBD)		

Click here for Plenary (CLOSED) Zoom

3:00 PM	6:00 AM	8:00 AM	9:00 AM	Executive Session (Closed)	Review committee	15

Wednesday, October 19, 2022 (Day2)

Click here for Plenary (OPEN) Zoom

CEST	PST	CST	EST	Topic	Presenter	Duration (Min)
3:00 PM	6:00 AM	8:00 AM	9:00 AM	Homework & Discussion	All	30
3:30 PM	6:30 AM	8:30 AM	9:30 AM	Executive Session (Closed)	Review committee	60
4:30 PM	7:30 AM	9:30 AM	10:30 AM	Closeout	All	30
5:00 PM	8:00 AM	10:00 AM	11:00 AM	Lionel's Seminar on 11.7 T MRI Magnet	Optional	60

Click here for Plenary (CLOSED) Zoom

3:30 PM	6:30 AM	8:30 AM	9:30 AM	Executive Session (Closed)	Review committee	15