Report of the

Incremental Design and Safety Review of the Electron-Ion Collider Tracking Detectors

Performed Remotely at Jefferson Lab
Newport News, Virginia

March 20-21, 2024

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1. Executive Summary

The review committee was chaired by Andy White from University of Texas at Austin. The reviewers included Michael Begel from Brookhaven National Laboratory, Maxim Titov from CEA Saclay, David Lynn from Brookhaven National Laboratory, and Piotr Gasik GSI Helmholtz Centre for Heavy Ion Research.

The review included all aspects of tracking detectors in the central EIC detector, which includes the barrel, the forward endcap, and the backward endcap regions. This includes three types of detector systems. In particular, a Si/MAPS-based vertex detection and central tracking system including forward and backward disks, a MicroMegas detector system in the barrel region to aid in track reconstruction, an outer GEM-uRWELL detector to aid in particle identification of the high-performance DIRC system, and GEM-uRWELL based disks in the backward and forward regions.

In general, although good progress has been made with the tracking systems, the committee points out that the planned date of April 2025 for CD2/3 might not be achieved. To satisfy CD2 requirements the date might need to be moved to the end of 2025, followed by CD3 up to a year later. The committee found that generally the system requirements were well defined for the MPGD elements but that more work is required to specify the requirements for the silicon elements. At the time of this review the tracking system was viewed as in a conceptual stage and as such was not at the point where plans for construction could be assessed in terms of schedule and associated risks.

In view of potential delays to ITS3 or the Large Area Sensors (LAS), an alternate tracking system based on ITS2 and replacement of some silicon layers by MPDs was proposed and considered. However, it has been determined that ITS2 does not meet system requirements and the path forward therefore lies with ITS3 and LAS with schedule adjustments as needed.

For the MPGD tracking elements plans were shown for fabrication and assembly including a list of sites and resources. Similar plans are needed for the silicon system with specification of institutional commitments.

For the integration of the tracking system into the overall ePIC detector, there is a general understanding of the sequence of steps needed. However, as support structures and services are being defined, close attention needs to be paid to the associated material profile and budget so as not to degrade detector performance.

Overall, the committee felt that significant progress had been made on the tracking system in the year since its original definition and congratulates the tracking team on this achievement. However we feel the silicon tracker schedule is unrealistically optimistic. A significant effort needs to be invested to develop a bottom-up schedule, including detailed institutional commitments and external constraints, that will be needed for CD2/3.

2. Reponses to Charge Questions

<u>Responses to Questions</u>

Charge Question 1:

Are the technical performance requirements appropriately defined and complete for this stage of the project?

Partially. Performance requirements are well defined for each component of the tracking system. Technical requirements are well defined for the MPGD but not for the silicon detector.

Comments

- ePIC features an impressive and ambitious 25 subsystems with 5 being a world's first implementation. Construction, installation, and integration will be a significant challenge. The Project should carefully consider the impact on physics performance in the case that one or more of these technologies will need to be replaced with fallback solutions.
- CD-2/3 is planned for April 2025. It is noted that this date might slip with CD-2 by end of 2025 and CD-3 up to a year later.
- It is noted that the work of detector modelling and development of requirements and interfaces is ongoing, but that the status of detector design and specification is appropriate for this stage of the project.
- The design and philosophy behind managing the performance requirements is well defined and has a clean implementation.
- The review committee is pleased to note that the detector technical requirements are being integrated into the Vizure system that allows the management and coordination of general, functional, and performance requirements. This, in turn, allows the definition of interfaces and dependencies.
- The Project should document how performance requirements flow down to the technical requirements on detector components and incorporate them into the Vizure system.

MPGDs

- Momentum resolution requirements are defined for the range $-3.5 < \eta < 3.5$, and the spatial requirements and constraints for the tracking system and associated cooling, power and other services are defined in the WBS interface documentation.

Silicon

- Special requirements are noted for the beampipe bakeout with the associated temperature limitations for the close-in silicon layers.
- With regards to the silicon system, the only performance requirements that were given were on the momentum and spatial resolutions. There are many more requirements that need to be specified, e.g. thermal performance of stave elements, stability of staves, positioning, etc.

Recommendations

- Document the flow down of performance requirements to technical requirements on detector components and incorporate them into the Vizure system.

Charge Question 2:

Are the plans for achieving detector performance and construction sufficiently developed and documented for the present phase of the project?

Partially. The specification and plans for the proposed MPGD components of the tracking system are defined and documented while project R&D and engineering tasks are ongoing as are the designs of services to maintain detector performance.
For the silicon systems plans exist for achieving detector performance, but little was stated regarding construction.

Comments

- The tracker is at the conceptual stage and does not yet have detailed plans for detector construction that can be assessed for schedule and risk. Thermomechanical models are planned to be built for the silicon tracker. It is not clear that fully functional prototypes will be ready by CD-2. It should be noted that some other large projects (e.g., ATLAS, CMS, DUNE, sPHENIX) all had full size and/or full chain prototypes for these critical detectors prior to CD-2 (PD-2).
- The layout of the tracking system was finalized in Spring 2023, but it is noted that the specification of services is still being developed and the associated material profile may affect detector performance.
- Tracking performance simulation results for the extreme negative eta region still show (as in earlier results) under performance with respect to requirements – the simulation needs to have the EMCal data included. Inclusion of calorimeter data is also expected to fix a dip in NHits at +/- 1 in eta.
- It is highly appreciated that simulation tools are in place for performing tracking in background environment. It is very important to implement the timing information and disabled modules as soon as possible, to study an impact of background on tracking performance, and physics performance eventually, with the free-streaming readout.

MPGDs

- Simulation results show the planned and expected increase in Nhits versus eta with the additional MPGD tracking layers.

Alternatives

- In the event of delays to LAS and/or ITS3 an alternate tracker layout was proposed. The Inner barrel was proposed to be replaced by two or three layers of ITS2; the outer barrel is proposed to be replaced with two Micromegas layers. The electron and hadron endcap disks are proposed to be replaced by micro-RWELL disks. ePIC has concluded that detector performance with ITS2 does not meet requirements. Performance with micromegas & micro-RWELL disks replacing silicon detectors was not shown.

Recommendations

- Include the calorimeters in the simulation to verify full detector performance meets

requirements.

- Alternate tracker solutions, including potentially time-phasing installation of the silicon tracker, should be developed to maintain physics performance within schedule constraints.
- Build thermomechanical models and mockups for each silicon detector subsystem that can be utilized to understand construction and installation constraints as well as the thermal and mechanical performance.

Charge Question 3:

Are the current designs and plans for detector, electronics readout, and services sufficiently developed to achieve the performance requirements?

Yes.

Comments

- It is noted that there is a sizeable team of mechanical and electrical engineers, and other detector experts on the project with plans to add more personnel. No FTE profiles were presented.
- Design envelopes exist for the components of the tracking system, services, and electronics. Presentations were inconsistent in their description of the envelopes. This should be corrected for future reviews.
- The plan for readout of the detector is well defined and sound. There is sufficient flexibility in the back-end to ensure streaming readout will succeed.
- Evolution of the services and associated material profile may significantly affect detector performance. Design of services should be completed and prototyped prior to start of tracker construction.
- The SALSA development schedule remains tight, despite the great experience of designing teams. The impact of Salsa 2 (32-ch version) on the MPGD detector readout layout should be investigated and scrutinized.

Recommendations

- None

Charge Question 4:

Are plans in place to mitigate risk of cost increases, schedule delays, and technical problems?

Yes, but see comments.

Comments

- A plan was presented if the development of ITS3 (and associated modifications for LAS) does not succeed. This could potentially introduce a significant schedule delay.
- Access to the inner detector will only be possible in the assembly hall. This places a high premium on reliability. There is an associated risk – failure of the inner detector after installation would incur a significant schedule delay.

- Backgrounds in the detector rely strongly on a good vacuum making a good bakeout critical.
- It is noted that all simulations use the more favorable curve for residual pressure, raising the question of the effect on simulations/physics performance if this curve is not achieved.
- Liquid cooling is a possibility for parts of the inner detector system if air cooling is insufficient. Are there plans for mitigation and isolation if leaks occur? What is the expected impact on physics performance if liquid cooling is required?

MPGDs

- The production of the moderately high number of MPGD structures should not pose a major risk for the project. Still, the full-size structures (1800 mm long) should be produced as soon as possible and the prototypes should be constructed to ensure timely realization of the prototyping and production plans.

Silicon

- No assembly and construction plan for silicon tracker was presented but a timeline was shown. It is difficult to understand whether construction will fit within the allotted schedule.

Recommendations

- None.

Charge Question 5:

Are the fabrication and assembly plans for the various tracking detector systems consistent with the overall project and detector schedule?

Yes, for the proposed design and technologies of the MPGD tracking system.
For the silicon tracking, fabrication and assembly need to be defined.
A switch to an alternate tracking system design would result in a delay in completing overall detector integration.

Comments

- There is a significant planned period of ongoing R&D/engineering for the tracking systems in 2024-2028, which extends well beyond CD-2/3, for the silicon system.

MPGDs

- The timeline towards production assumes one iteration of full-size prototyping before CD-2. Given the large dimensions of the MPGD structures (up to 180 cm length for the OB modules) further iterations may be required to achieve expected performance figures, uniformity, mechanical stability, etc. Till now, proof of concept exists based on small area prototype measurements.

Silicon

- The silicon systems need a fabrication and assembly plan including institutional commitments.
- In the event of unavailability of ITS3 there is a plan for using MPGDs for the OB and disks. The construction period for the IB could remain the same, but a significant delay could occur for the LAS replacements with MPGDs.

Recommendations

- Develop a fabrication and assembly plan for the silicon tracker with emphasis on institutional commitments.

Charge Question 6:

Are the plans for detector integration in the EIC detector appropriately developed for the present phase of the project?

Yes, to the extent that all components have been shown to fit together.

Comments

- Plans have been developed for integration sequence of the tracking system in two sub-assemblies – TOF-LGAD + MPGDs and Beampipe+SVT, followed by the forward/backward Discs.
- The plans for the integration of the tracking system in the overall detector are at an appropriate level for the current stage. However, close monitoring for potential performance degradation is needed as the designs evolve.
- Closely monitor the development of the material budget as support structures become better defined.
- First results from an FEA of the inner detector support tube have been obtained and stiffness/deflection studies versus mass optimization are ongoing.
- Producing FEA mechanical simulation and/or mockup for full silicon tracker, with emphasis on stress and vibrations due to the anticipated 8 m/s airflow, should be a priority.

Recommendations

- None.

Charge Question 7:

Have ES&H and QA considerations been adequately incorporated into the designs at their present stage?

Partially. ES&H considerations were well incorporated, but QA was only addressed for MPGD.

Comments

- For the current design stage there are no safety issues for the tracking system.
- The possible future use of flammable gas mixture(s) raises potential safety issues.
- Detector development and testing using test stands adhere to relevant institutional

safety procedures.

- BNL ES&H requirements, particularly NEC/NFPA 70E 2021 and DOE-HDBK-1092-2013, should be incorporated into the design review process for all components. The EEI should take part in all design reviews.
- Detector safety systems, particularly hardware interlocks, were, in general, not described.

Recommendations

- Document quality assurance procedures for each component.
- Document requirements for qualifying each production site for deliverables distributed across multiple sites. Each site should produce at least one pre-production module.

3. Conclusion

The review committee congratulates the ePIC tracking system team on its significant progress since the definition of the system in 2023. The technologies for each component of the tracker have been settled and development paths are being defined from final prototypes to pre-production and final production. The schedule is aggressive and critically dependent on the success of the ITS3 project.

4. Appendices

4.1 Appendix A: Charge to the Review Committee

Jefferson Lab
Thomas Jefferson National Accelerator Facility

MEMO

Date: March 6, 2024

To: Andy White (UTA) Chair, Michael Begel (BNL), Maxim Titov (CEA), David Lynn (BNL), and Piotr Gasik (GSI)

From: Elke Aschenauer (BNL) and Rolf Ent (JLab)

Subject: Incremental Design and Safety Review of the EIC Tracking Detectors

The scope of this review includes all aspects of tracking detectors in the central EIC detector, which includes the barrel, the forward endcap, and the backward endcap regions. This includes three types of detector systems. In particular, a Si/MAPS-based vertex detection and central tracking system including forward and backward disks, a MicroMegas detector system in the barrel region to aid in track reconstruction, an outer GEM-uRWELL detector to aid in particle identification of the high-performance DIRC system, and GEM-uRWELL based disks in the backward and forward regions. The review may include design and fabrication choices and their cost-effectiveness, the construction schedule, considerations for safety and quality assurance, levels of redundancy, front-end electronics and interface to the data acquisition system, commissioning and calibration procedures, considerations for materials and labor, operational reliability and longevity, and any other considerations that may influence the construction, maintenance and operation of these particle identification detectors.

You are asked to address the following questions:

1. Are the technical performance requirements appropriately defined and complete for this stage of the project?
2. Are the plans for achieving detector performance and construction sufficiently developed and documented for the present phase of the project?
3. Are the current designs and plans for detector, electronics readout, and services sufficiently developed to achieve the performance requirements?
4. Are plans in place to mitigate risk of cost increases, schedule delays, and technical problems?
5. Are the fabrication and assembly plans for the various tracking detector systems consistent with the overall project and detector schedule?
6. Are the plans for detector integration in the EIC detector appropriately developed for the present phase of the project?
7. Have ES&H and QA considerations been adequately incorporated into the designs at their present stage?

Please address these questions point-by-point.

You will be supplied with the project milestones extracted from the most current EIC resource loaded P6 schedule, further P6 schedule and labor assumptions, copies of presentations relevant to this subject material, and the draft CERN ITS3 agreement as part of the pre-brief material.

Several aspects of the EIC detector including its electronics, and data acquisition systems have been reviewed previously. As part of your briefing materials, you will also be supplied with the reports from earlier reviews (e.g., on the magnet design, electronics and data acquisition, calorimetry, and particle identification).

cc: J. Fast

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4.2 Appendix B: Review Committee

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Andy White	University of Texas at Arlington	awhite@uta.edu
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4.3 Appendix E: Agenda

Incremental Design and Safety Review of the EIC Tracking Detectors

March 20-21, 2024

March 20, 2024 (Day 1)

Time	Topic	Speaker
08:00 am	Executive Session	Closed Session
08:30 am	Welcome and Introduction	Elke Aschenauer (BNL) / Rolf Ent (JLab)
09:00 am	Tracking Systems Overview and Requirements	Brian Eng (JLab)
09:30 am	Detector Integration Status and CAD Design	Roland Wimmer (BNL)
10:00 am	Flow of Requirements, Interfaces and System Engineering	Walt Akers (JLab)
10:20 am	**Break**	
10:40 am	Outer MPGD: uRWELL	Kondo Gnanvo (JLab)
11:30 am	Disk MPGD: uRWELL	Annalisa D'Angelo (University of Rome Tor Vergata & INFN Roma Tor Vergata)
12:00 pm	Inner MPGD: CyMBaL Micromegas	Francesco Bossu (CEA-Saclay)
12:50 pm	MPGD Readout Electronics	Damien Neyret / Irakli Mandjavidze (CEA Saclay IRFU/DPhN)
1:20 pm	**Break**	
1:40 pm	Executive Session	Closed Session

March 21, 2024 (Day 2)

Time	Topic	Speaker
08:00 am	Silicon: Overview	Ernst Sichtermann (Lawrence Berkeley National Laboratory)
08:50 am	Silicon: Sensors (Vertex, Outer/Disks)	Laura Gonella (University of Birmingham)
09:25 am	Silicon: Readout	Joachim Schambach (Oak Ridge National Laboratory)
09:55 am	Silicon: Services and Cooling	Nicole Apadula (Lawrence Berkeley National Laboratory)
10:25 am	**Break**	
10:45 am	Support Structure and Installation	Andreas Jung (Purdue Univ)
11:10 am	Tracking Simulation / Reconstruction	Matt Posik (Temple University)
11:35 am	Discussion	**All**
12:35 pm	**Break**	
12:55 pm	Executive Session	Closed
2:40 pm	**Closeout**	