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| * The title of the item or system
* A description of the item
* WBS Number
* Type of design review
* Date of the review
* Names of the presenters
* Names, institutions and department of the reviewers
* Names of all the attendees (attach sign-in sheet)
* Completed Design Checklist (if utilized)
 | * Findings/List of Action Items – these are items that require formal action and closure in writing for the review to be approved. See Document LCLSII-1.1-QA-0009 for Design Review Requirements and Guidelines
* Concerns – these are comments that require action by the design/engineering team, but a response is not required to approve the review
* Observations – these are general comments and require no response
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| Type of Review: | Final Design Review (FDR) |
| Title of the Review: | LCLS-II 3.9 GHz Cryomodule Final Design Review |
| WBS: | 1.04.05.05.03 - 3.9 GHz Engineering & Design1.04.05.12 - 3.9 GHz Cryomodule Procurement and Fabrication |
| Presented By: | FNAL Design Team (agenda includes presenters)  |
| Report Prepared By: | Joel Fuerst / ANL for Reviewers |
| Reviewers / Lab : | Ian Evans / SLAC, Joel Fuerst / ANL (chair), John Hogan / JLab, Paolo Pierini / INFN-DESY, Jacek Sekutowicz / DESY-SLAC | Date: | Review Date: 31 JAN 2017Report Date: 22 FEB 2017 |
| Distribution: | C. Ginsburg, G. Wu, E. Harms and Design Team / FNAL, M. Ross / SLAC |

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| Attachments: | [ ]  Review Slides [ ]  Design Checklist [ ]  Calculations [ ]  Other |

| Purpose and Goal of the Review |
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| The review committee was charged to evaluate the system design readiness to approve implementation, procurement, and fabrication activities. This focus of the review was on the cryomechanical aspects of the design, since the RF component design verification tests (for dressed cavity, magnetic shielding, tuner and coupler) are ongoing. The committee was requested to consider only the functional design and integration of these RF components into the cryomodule, and a subsequent follow-on review for these three elements will be held after design verification is completed.The review committee was requested to evaluate the cryomodule design readiness by responding to the following questions:**1 Technical Scope**1. Are the designs mature and technically sound to satisfy design specifications?

**Yes**; specifications and drawings are complete, approved and distributed.* Is the design likely to meet performance expectations?

**Yes**; however the results of the verification tests are critical to identifying any potential design issues and ensuring performance meets the design requirements.1. Does the cryomodule cryogenic design meet the heat load requirements?

**Yes**; The designed capacity of the cryogenic system for the 3.9GHz cryomodule is 36W/cavity. The expected heat load is ~24W/cavity equating to ~50% margin in the worst case scenario. 1. Would potential modifications to RF component designs after design verification tests significantly impact the cryomodule cryomechanical design?

**Unlikely.** The potential impact of design changes due to degraded performance results are expected to be limited to documentation, procedures and software development, with a minimal impact to hardware. 1. Have cryomodule assembly procedures and tooling been adequately developed?

**Yes**; Assembly procedures and tooling have been successfully exercised in the production of two previous 3.9GHz CM’s. The identified changes in the procedures and tooling to accommodate the CW requirement of the LCLS-II 3.9GHz CM’s are expected to be minimal. The travelers need to be completed in advance of production activities. * Have shipping, rigging, and handling procedures been adequately developed?

**Mostly Yes**; A thorough analysis is in progress for the 3.9 GHz that mimics the transportation analysis currently being done in conjunction with Jefferson Lab for the 1.3GHz CM transport from VA & IL to CA respectively. The transportation carriage will be optimized for the 3.9GHz transport following the last shipment of the 1.3GHz CM to SLAC. 1. Have all the major interfaces been identified and incorporated into the design?

**Yes**; The major interfaces (as defined 3.9GHz CM Tech Spec) of vacuum vessel, CM beamline, RF waveguides, instrumentation, alignment fiducials, CV’s and cryo circuits have been identified and incorporated into the design. * Are all design specifications, requirements, performance, and interface documents reviewed, approved and released?

**Yes**; All design specifications, requirements, performance, and interface documents have been reviewed, approved and released. **2 Design Management**1. Is the design team organized and staffed to successfully complete the project?

**Yes**; The design team is experienced, knowledgeable, well prepared and organized to successfully complete the 3.9GHz CM portion of the LCLS-II project. * Have all of the major risks been identified and managed?

**Yes**; But the technical risks identified with regard to the design verification test associated with the coupler, tuner and helium vessel need to be vetted via the verification tests. These technical risks will need to be managed efficiently in order to address the schedule risk associated with a delayed cavity delivery. (see concerns)1. Are procurements appropriately planned?

**Yes**; The procurements are well defined and planned. The Fermilab team has extensive experience with these procurements. * Is the development of associated drawing packages sufficiently mature?

**Yes**; The 3D model and 2D engineering drawings were presented as 100% complete. **3 Cost and Schedule**1. Is the cost and schedule reasonable to achieve the planned scope?

**Yes**; the cost and schedule appear reasonable as presented. However, the execution of the verification tests and follow-on implementation of lessons learned must be closely monitored and managed to minimize impact on schedule. **4 ES&H**1. Are all related ES&H aspects being properly addressed?

**Yes**; the ES&H aspects were presented and addressed. Notable:* + Administration of compliance to ASME B&PV code and 10CFR851 is thorough and comprehensive.
	+ Integrated Safety Management (ISM) and the flow down of ESH requirements is incorporated via Institutional Programs as evidenced by review of supporting documents and FNAL staff interviews.
	+ Dedicated ESH Support Staff help ensure Project compliance to program ESH/WPC requirements.
	+ The Production Facility (MP9) and Assembly Area were clean and orderly. We were able to see work being performed on LCLSII cryomodules at both facilities and interview staff. All recognize ESH as a core value of working at FNAL.
	+ Presentations discussed ESH risks as it affects discreet tasks or activities. In particular, there was discussion on both pressure and seismic safety, and integration of both into design, manufacturing and installation requirements. (851 umbrella rules for DOE facilities and ASME B&PV codes).
* Has the appropriate failure modes and effects analysis (FMEA) been performed on the components and system?

**Yes**; the FMEA & What-if analysis is complete, reviewed and documented. FMEA and “What-if” scenarios have been explored for cryogenic safety and folded in to the SLAC preliminary ODH analysis. These have been documented and accepted at SLAC. **5 Miscellaneous**1. Have all the previous design review action items/comments been addressed?

**Yes**; recommendations from the PDR (Nov2015) were presented in detail. Some items remain open and need to be diligently driven to closure. 1. Are there any other issues that have been identified that need to be addressed?
* The handling of the coupler offset during the final stages of the module assembly operations may be problematic as the bellows has been redesigned with fewer convolutions and thicker plating – consider building the offset into the verification test when mounting the coupler
* Fixed couplers may not achieve desired coupling criteria and may require implementation of a tuning mechanism, e.g. with stub tuners, which the couplers may not be able to handle due to possible heating effects in CW mode
* Piezo tuner operation (along with coarse blade tuner operation) must be verified, including exploration of hysteresis for both the coarse tuner and piezo.
* Microphonics stabilization at the location of the Horizontal Test Cryostat, because it may be different from that in the SLAC tunnel, will not be sorted-out in the verification tests, but functionality of the tuner system and RF-feedback can be tested, and heating of the FPC can be monitored.
* Questions were raised about the stiffness of the helium tank-to-GRP mount, which would be worth simulation, especially in light of the ongoing 1.3GHz cryomodule microphonics issues.

**6 Overall Readiness**1. Is the design sufficiently mature so as to allow Final Design Review approval?

**Yes**; Overall they have earned final design approval subject to the verification test completion for sensitive subcomponents.  |
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| Introduction and Outcome Summary of the Review |
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| For LCLS-II, final designs are defined as having 90 – 100% design maturity. Subject to the charge’s instruction to focus on the cryomechanical aspects of the design, the presentation materials for the 3.9 GHz cryomodule described the design in sufficient detail to provide approval, comments and recommendations.  |

| Findings and Action Items |
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| The charge, agenda, presentations and supporting materials can be found at FNAL’s Indico site - <https://indico.fnal.gov/conferenceDisplay.py?confId=13697>.

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| **ID** | **Committee Action Items/Recommendations** |
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| **1** | Perform a full scenario operational analysis for available RF-power to address:1. High QL spread due to:
	1. Deviation in field flatness during cavity preparation and ancillary assembly;
	2. Machining & assembly tolerance over/under build
2. Microphonic due to:
	1. Unknown instability within the support system and/or cryogenic system

Should include the impact of coupler overheating deriving from the increased RF-power needed to compensate the worst case deriving from the above non-idealities.  |
| **2** | Provide complete listing of all technical specifications and their status (draft, reviewed, approved, etc.)  |
| **3** | Add the following activities to verification testing:1. Incorporate measured performance of coarse & fine tuning into the LLRF control system (most notably damping microphonics), taking into account possible hysteresis effects in the tuner actions
2. Incorporate mockup of max-offset of power coupler (mimic compensation for differential thermal contraction)
3. Investigate long term stability; establish the steady-state operational condition at high power performance.
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| **4** | The stress analysis document for the 3.9 GHz Cryomodule under Seismic Loads should be finalized by SLAC no later than 01-March-2017.  |

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| Concerns |
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| In this section, concerns identified by the review team are given. In some cases, the concerns are formulated as questions provided by review team members. In all cases the comments and questions here are intended to provide background in order to clarify recommendations.1. There is a risk associated with testing only one dressed cavity, especially concerning the assessment of the impact of the non-idealities mentioned in items e and f.
2. Gradient & Q are likely to be OK and not require redesign.
3. Input coupler performance at the design power level is still being addressed in the Design Verification phase, but it is not likely to require a major redesign of the cryomodule.
4. The proposed modifications of the warm coupler part (bellows convolution reduced from 20 to 15 and increased Cu deposition) may have consequences during the last stages of the module assembly, when these part need to be assembled with an offset (max 1.7 mm horizontal and approximately 2 mm vertical) of the vessel flange with respect to the coupler position. The ACC39 module had a much reduced length and the operation was possible, but tricky, for the eight cavity string of the XFEL module. Consider building the ability to cope with this offset into the verification test when mounting the coupler.
5. Experience at the XFEL with the achieved coupling factor shows that the combination of geometrical tolerances (flange position, antenna length) and cavity field flatness (>95% up to the last check in the fabrication stages) resulted in a spread of more than a factor 2 from the minimal to the maximum measured values and an average offset of the mean distribution from the nominal value of about 30%. While this was well within the range of the 3-stub tuners foreseen in the XFEL RF distribution, this is much larger than the envisaged 10% spread reported by the project team. The possible use of stub tuners could allow the QL adjustment, but may result in higher dissipations.
6. A full scenario of the effect of combined non-ideal effects (microphonic levels, detuning levels coming from tuner hysteresis effects, large spread of main coupler QL) on the required RF power level would be needed (welcome, beneficial, useful?).
7. Piezo tuner operation (along with coarse blade tuner operation) must be verified including exploration of hysteresis. Microphonics will not be sorted out in verification tests due to the different environment of the horizontal test station, but the activity would be beneficial for the development of the proper control algorithms.
8. HOM and magnetic shield verification is low risk
9. Questions about the stiffness of the helium tank-to-GRP mount which would be worth simulation, especially in light of the ongoing 1.3GHz cryomodule microphonics issues.
10. Positive comment – design team is experienced and well-equipped to complete the project. They are building on experience of two earlier 3.9GHz versions.
11. Cost #’s look reasonable relative to the experience in the development of the two XFEL third harmonic modules, the schedule show that the activity is in the critical path for the project, may be OK (need to dig deeper – need more specifics) but the verification tests are critical and success oriented – failure would cause delay to the project. **Homework – give us detailed schedule to get from now to OCT2018 final shipment to SLAC**
12. Positive comment – ES&H is well controlled as is QA.
13. Overall they have earned final design approval subject to the verification test completion for sensitive subcomponents.
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| Observations |
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