

## LCLS-II CM Transportation Review June 12, 2018

### Responses to recommendations

1. Complete the redesign and manufacture of end restraints capable of securely restraining the GHRP ends in all three directions.  
The XFEL end caps with the conically shaped end restraints have been adapted for use with the LCLS-II cryomodule, through small modifications to the structural fins to accommodate the different end configurations of LCLS-II cryomodules. We have added flattened Belleville washers to maintain compression in case of relative thermal contraction/expansion between the end cap spindles and the GHRP, while not unnecessarily introducing another spring into the system. The modified end caps are available at both Fermilab and JLab
2. Restrain the warm end of all three support posts to prevent rocking and reduce lateral motion.  
The support posts are clamped down using a scheme very similar to that used for shipping the 3.9 GHz cryomodule to FLASH. The center post is completely constrained with bolted down brackets. The end posts are bolted down similarly, but with a sheet of mylar between the bracket and the support post to allow some relative longitudinal motion due to thermal contraction/expansion, while avoiding putting undue stress on the support post.
3. Add temporary damping material at the ends of the thermal shield and, if possible, at the center of the 50 K shield (through one or more tuner access ports).  
Foam is installed between vacuum vessel and MLI of the 50 heat shields. A map was created to show where the foam is installed to ensure it is all removed prior to cryomodule installation in the SLAC tunnel.
4. Remove or back out the earthquake bolts on the 50 K shield.  
We decided that with the foam inserted between the 50K lower thermal shield and the vacuum vessel, as described for recommendation 3, it was unnecessary to back out the earthquake bolts during transportation. This way, we minimize the work needed at SLAC to prepare the cryomodule for installation.
5. Continue instrumenting cryomodules throughout all shipments.  
The final shipment instrumentation shall be decided when the shipping tests are complete. We shall continue instrumenting cryomodules for all shipments, but it's possible that the exact configuration will change through optimization determined from our shipping experience.
6. Continue bore-scoping end-most components, e.g. G-10 blocks.  
Determining the distance between coupler and G10 blocks has been done for cavities 1 and 8 prior to and after shipping tests, and shall be done on subsequent cryomodules. To access other couplers, the tuner port has to be opened and MLI cut. We shall not do the latter unless we have a strong reason, because of the risk of damaging instrumentation cables etc.
7. Short shipping test should be out I-90/US-20 to Galena and back on I-80/I-88. Utilize a pilot car to assess the usefulness.  
Unfortunately, I-88 is under construction and is single lane all the way to I-39. Therefore, an alternate route was chosen for shipping tests which has some hills and some rougher pavement: east on I-88 to I-355, south to I-80 and west to Morris, IL and back. A pilot car accompanied the cryomodule trailer on the second transportation test. The roughness of the route was not well determined by the pilot car, because of the substantially different suspension of a car vs. truck, but the other values of having the pilot car, listed under recommendation 8, are evident.

8. Pilot car is a good idea for a couple reasons, some feedback on road conditions, control of speed.

A pilot car, procured through a third party (not the cryomodule transportation company) will be engaged at least for the first cryomodule shipment. A report shall be requested from the pilot car driver including any abnormalities (detours from planned route, problems encountered, need to tighten straps, observed movement of load, etc.), the route (any stops, weigh stations, or getting off the highway when and where), road conditions (any excessively bumpy roads or times of reduced speed), and confirmation that the cryomodule transport truck did not exceed the maximum speed limit of 55 mph.

9. Advise on the route, with some flexibility, and limit the speed to no more than 55 mph.

The exact route and the 55 mph speed limit are written explicitly in our next shipping contract. Deviations shall be logged and reported to Fermilab. A GPS device that transmits location is part of the instrumentation package.

10. Removing the warm coupler should be a last resort.

Transporting the cryomodule with warm couplers removed would require substantial study and verification, as well as the procurement of infrastructure for re-installation at SLAC. Therefore, we agree that this would be a last resort if all other methods of ensuring safe couplers transportation are exhausted.

11. Continue bellows testing to better quantify the fatigue life.

Bellows movement data from three shipping tests (J1.3-07, and two from F1.3-05) are being studied. We received the bellows data from the manufacturer for maximum compression, extension (longitudinally and laterally), operating pressure, and cycle lifetime and spring rate. We also performed two independent EJMA bellows fatigue analyses, which were consistent once the input parameters were aligned. The key question is how much lateral motion occurs during shipment. SLAC is initiating a study at BNL to help quantify the allowable movement of the bellows before failure.

12. Develop a scheme of securing the shipping frame to the trailer and use it consistently.

An improved method of securing the shipping frame to the trailer was developed through consultation with truck shipping experts and road tests. Three configurations were tested: 1) As-is for CM06 return, with 12 total straps looped around the longitudinal frame member and no shims; 2) With shims installed at the ends of the transport frame and 12 total straps looped around the longitudinal frame ; and 3) With shims and 4" wide ratchet straps with a 2' section of chain on the end, with each end of the strap attached to one end of the trailer and passed under the lowest longitudinal members of the frame. No significant performance difference was observed between configurations 2 and 3. Configuration 2 was selected based on shipment data analysis and the expectation that this was superior to configuration 3 for redundancy in case any single strap failed.

13. Ensure all requirements are in the contract with the shipping company including logging route deviations.

All requirements noted in recommendations 8 and 9 have been added to the shipping contract. In addition, we added that the trailer must not be disconnected from the cab at any time during the trip.

14. Study the viability of controlling the shipping environment, especially the temperature.

We are investigating the use of a temperature-controlled truck for the next cryomodule shipment to SLAC. For shipping tests, it was not possible to get the temperature-controlled truck in time. The improved GHRP restraints described under recommendation 1 reduce, but do not eliminate, the concern about large temperature excursions during transportation.

15. Ensure that all the work that has been identified is completed prior to shipping the next cryomodule.

All work described above has been completed prior to the next cryomodule shipment.