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Fermilab Engineering Document
LCLS-II 1.3 GHz and 3.9 GHz Cryomodule Stand Design
ED000xxxx, Rev. -

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-	15 Nov 2016	Initial Release	*Michael McGee*		

1. Introduction

The original cryomodule stand design was conceived by INFN (Milan) for DESY regarding use within XFEL. The modified version of the DESY cryomodule stand design was applied at New Muon Lab (NML) at Fermilab regarding support for both Cryomodules; CM1 and CM2[1]. In 2014, this same design was adapted for use at Cryomodule Test Facility (CMTF) within the Cryomodule Test Stand (CMTS-1) cave at Fermilab under a reduced magnetic material construction. Figure 1 shows the LCLS-II Cryomodule stand assembly solid model with two supporting stands.

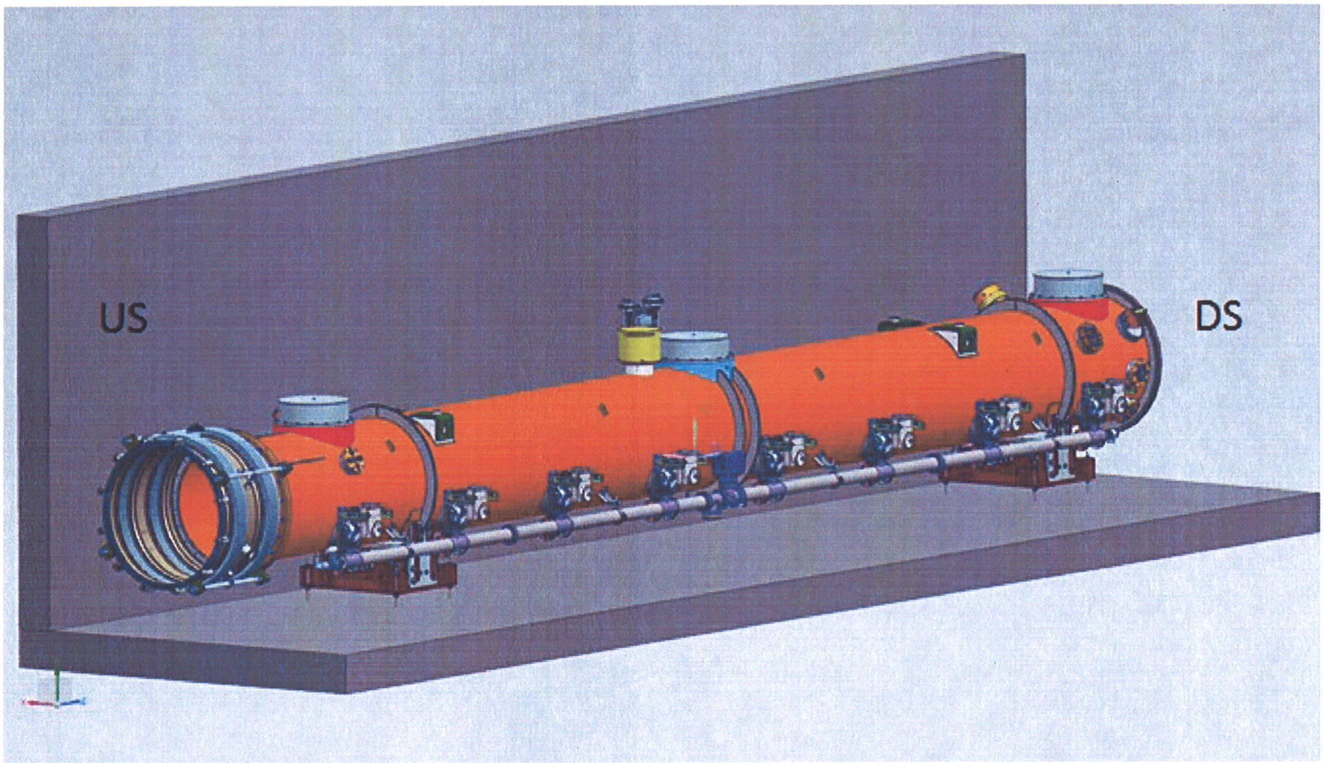

Figure 1: LCLS-II Cryomodule support stand solid model.

2. Stand Design and Functionality

The basic dimensions and functionality of the original INFN/DESY Stand design were conserved. The overall stand height was increased in order to accommodate vertical differences between the designs. The pseudo W-beam web material thickness was also increased to compensate for any reduction in strength as a result. The LCLS-II Stand Design utilizes a pseudo W-beam construction. A description of the stand is provided in Figure 2 with the main components listed.

1. Aisle Seismic Restraint
2. Wall Seismic Restraint
3. Threaded Rod (x4)
4. Leveling Nut With Washer (x4)
5. Securing Nut With Washer (x4)
6. Embedded Base Plate

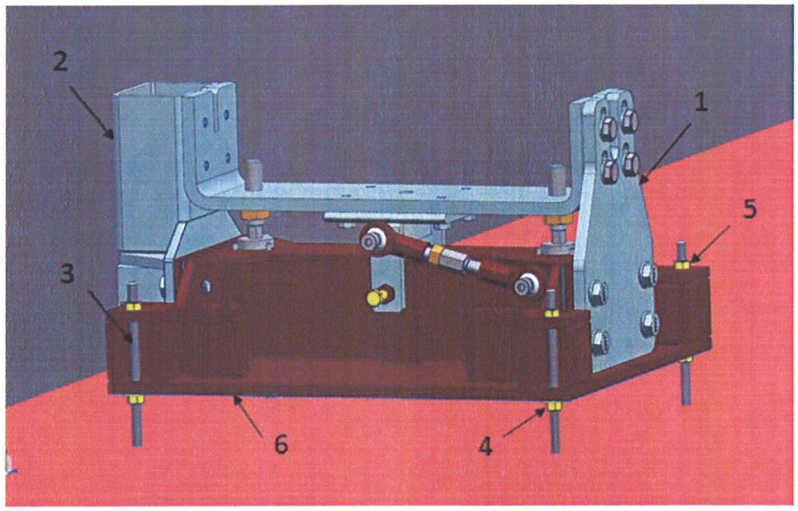

Figure 2: LCLS-II Cryomodule support stand solid model.

Each stand allows nominally for greater than +/- ½ in. [+/- 12.7 mm] adjustment in the vertical, transverse and longitudinal axis. The vertical adjustability also considers this spread with an additional 0.787 in. [20 mm] upward movement to compensate for any settling during the life of LCLS-II Project. The actual adjustability is vertical +2.23 in. [+56.642 mm], -0.534 in. [-13.564 mm], transverse +/- 0.534 in. [+/- 13.564 mm] and longitudinal +/- 0.875 in. [+/- 22.225 mm]. Figure 3 shows each adjustment system and their respective locking feature (typically a jam nut). These features are implemented (locked) following final alignment. Besides these locking mechanisms, a more robust seismic restraint system is attached at each stand at the aisle and wall sides. These seismic restraint designs are not symmetric due to the existence of the input coupler vacuum manifold found on the aisle.

The sources and values for error (rms) are given in Table 1. Positional requirement of roll is 300 mrad. Adjustment resolution of this system is vertical 56 μ, transverse 59 μ, longitudinal 71 μ, roll 6.78 μrad, pitch 87.6 μrad and yaw 7.1 μrad.

Table 1: Summary of LCLS-II Cryomodule errors[2].

Error Source	RMS error	unit
Cryomodule X,Y misalignments	0.3	mm
Cryomodule Z misalignments	2	mm
Cryomodule tilt misalignments	0.05	mrad
Cryomodule roll	2	mrad

1. Vertical Adjustment and Locking System
2. Transverse Adjustment and Locking System
3. Longitudinal Adjustment and Locking System
4. Hardened Disc (x2)
5. Hardened Spherical End Rod (x2)
6. U-Bracket (Cryomodule Attachment)
7. Grout
8. Floor Elevation

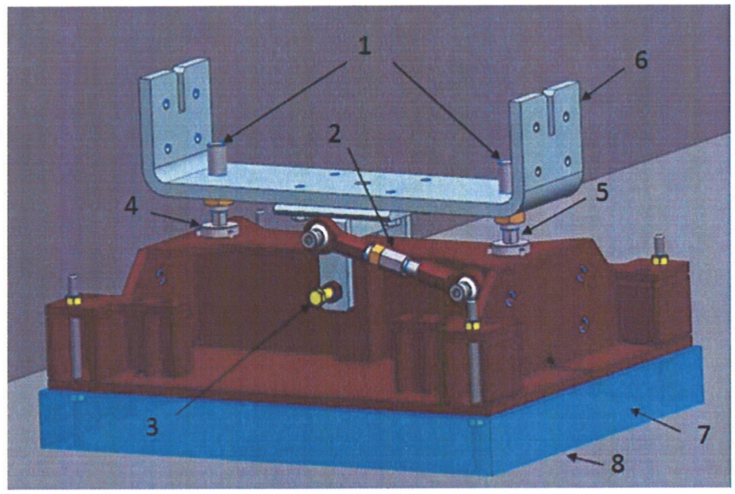

Figure 3: LCLS-II Cryomodule support stand (only) solid model.

The identical stand design is used at the upstream (US) and downstream (DS) support of both the 1.3 GHz and 3.9 GHz cryomodules. However, each stand location (US/DS) will function differently in the longitudinal direction, one fixed and one free to move (sliding). This longitudinal freedom allows for bending in the vessel and thermal expansion/contraction. The placement of the fixed stand, for example, either US or DS is to be determined. The expected temperature swing within the SLAC tunnel is estimated to be 40 to 100 degrees F [33.3 degrees C]. Given a 326.77 in. [8,300 mm] support-to-support initial longitudinal span, the cryomodule may expansion/contraction 0.12 in. [2.93 mm] absolute. From the nominal position, the design allows longitudinal movement of +/- 0.41 in. [+/- 10.29 mm].

The ability for longitudinal movement was built into the original DESY/INFN stand design as the (4) hardened supporting rods bear on (4) hardened discs (items 4 and 5 in Figure 3). The LCLS-II Cryomodule stand design allows for the set of seismic restraints to either constrain the cryomodule longitudinally or slide as necessary. In the case of the longitudinally sliding configuration, a flanged sleeve design prevents the clamping force given the torqueing of (4) bolts from locking the stand. These sleeves are coupled with a slot and a (DL-5) Dichronite dry film lubricant coating which exists on the surfaces of the relative sliding plates.

Figures 4(a) and 4(b) provide the details regarding this flanged sleeve design and application. The only difference between the fixed and sliding stand configuration involves the use of the sleeve or its removal. An ASTM A-325 [SAE J429] Grade 5, 1 in. - 8 hex head bolt was specified for this connection with a (lubed) torque value of 480 ft-lbs is applied to tighten each bolt in either case, fixed or sliding[3]. The upper connection of (4) SHCS M24-3 x 60 mm long, Class 8.8 (~Grade 5) is made using a (lubed) torque value of 407 ft-lbs[4]. Chesterton 622 white grease, H1 food-grade lubricant[5] shall provide lubrication for all threaded connection and resists breakdown due to high radiation. The components shall receive a 0.0003 – 0.0005 in. layer of electroless Nickel plating. Threaded holes shall not be plated. The hardware shall be either plated or made of stainless steel.

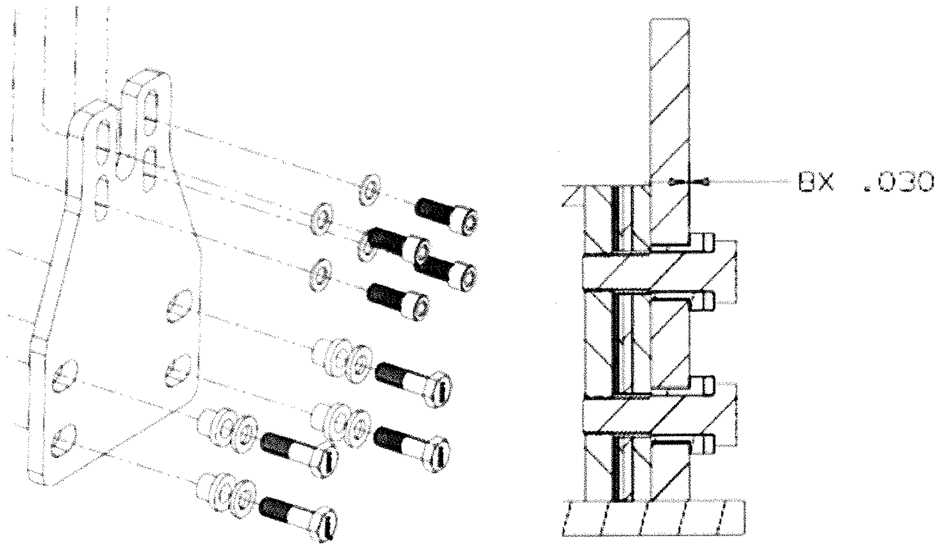

Figure 4(a): Iso-view of sleeve attachment. **4(b):** Section-view of sleeve implemented for sliding configuration.

3. Stand Design Seismic Analysis

A seismic and structural analysis of the LCLS-II Stand design was completed[6]. The seismic loading on each stand was considered under LCLSII-4.5-EN-0226 (Cryomodule Seismic Design Criteria) and document, SLAC-I-720-0A24E-001-R004 (Seismic Design Specification for Buildings, Structures, and Systems: 2014). Structurally, the ASIC Manual of Steel Construction was applied[7]. In general, allowable stress in each case is found using values from structural steel.

4. Prototype Stand at CMTS-1

A set of prototype LCLS-II cryomodule stands were fabricated for the Cryomodule Test Stand 1 (CMTS-1) at CMTF, Fermilab.

4.1 Reduced Magnetic Design Option

Initially, the stands for CMTS-1 considered the reduced magnetic design (material) consisting mainly of 316 L stainless steel. Recent findings show that the cavity quality factor, Q_0 is enhanced by expelling the magnetic flux during rapid cooldown. Meeting the LCLS-II Q_0 specification of 2.7×10^{10} requires an ambient magnetic field of 5 mGauss or less, averaged over the RF surface of the cavities[8,9]. Stray magnetic fields external to the cryomodule may be more than the assumed average and must be minimized.

There are two ways to approach the stray field issue (or minimize the effect); provide magnetic shielding or eliminate the source(s). Each girder consists of common structural steel found either in Europe (used by DESY) or within the USA (applied here at Fermilab). The chosen approach involved changing the original girder material specification from A36 structural steel to 316L stainless steel. This change also applies to any hardware used within the design, especially near the cryomodule. Structural steel hardware (such as critical girder and Hilti ™ bolt connections) used with the original design have been retained in the CMTS-1 girder design. These components are far enough from the cavity string to prevent stray field exposure. We learned through this process that permabilities below 1.05 and stray magnetic fields of 500 mGauss above background at contact were achievable[10].

However, even if the cryomodule stands were constructed from a non-permeable material, other permeable (or potentially magnetic) sources within the SLAC tunnel still exist. Stay magnetic issues shall be addressed during fabrication and at the QC stage of procurement through measurement and possible degaussing of affected components.

4.2 Prototype Stand

In March of 2016, the two prototype cryomodule stands were loaded using the pCM vacuum vessel and the yellow strongback cryomodule lifting fixture (see Figure 5). Then, each stand was adjusted in the vertical, transverse and longitudinal direction to check functionality. It was determined that less than 50 ft-lbs of torque was needed to drive the cryomodule in any direction. Note that small incremental changes are necessary to efficiently move the cryomodule as binding may occur when an un-coordinated adjustment (US and DS) is attempted. Also, the horizontal tie-rods need to be loosened while driving longitudinally.

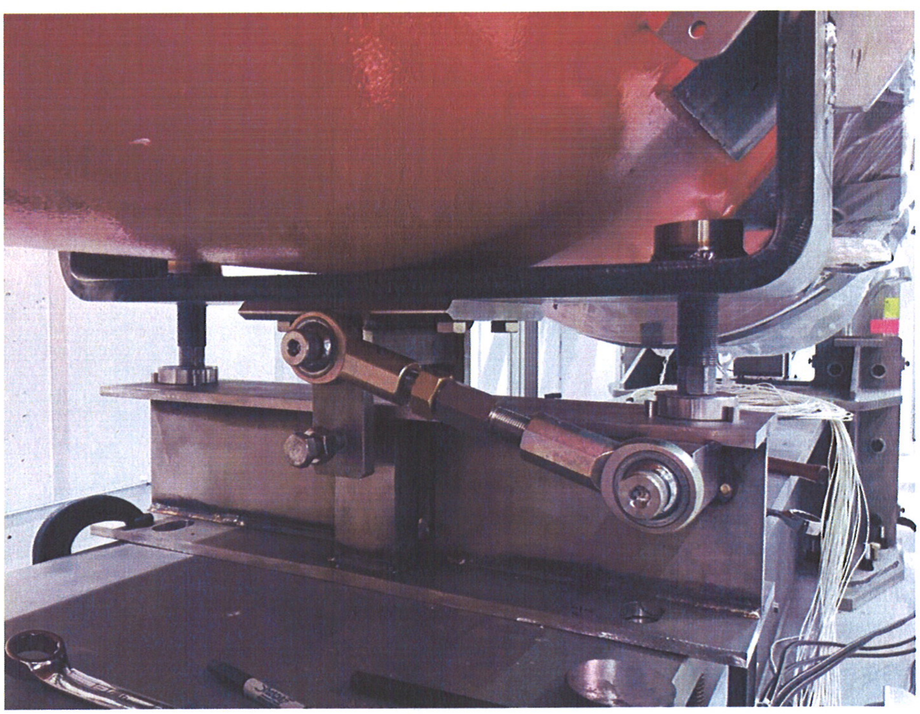

Figure 5: CMTS-1 DS reduced magnetic stand (prototype).

5. Procurement & Fabrication

Under Fermilab drawing F10063423 SLAC/LCLS-II CROMODULE – ADJUSTABLE SUPPORT ASSEMBLY, a fabrication specification, "LCLS-II 1.3 GHz and 3.9 GHz Cryomodule Stand Specification" as created.

6. Tunnel Installation

The proposed LCLS-II 1.3 GHz and 3.9 GHz Cryomodule stand installation at SLAC involves three basic steps; preparation, stand placement and installation. Preparation work to remove the existing SLAC components shall first proceed. Following this removal effort, all existing grout from the old supports shall also be removed. The floor shall then be cleaned and prepared for the LCLS-II components.

A drilling template with fiducials and an alignment crew using either optics or a laser tracker system shall locate the (4) holes needed for the 5/8 in.- 11 threaded rods. The drilling fixture required to locate the holes shall have a set of three fiducial 0.25 in. holes. The position of the drilled holes and fiducials are defined within +/- 0.005 in. Leveling screws shall be used to bring the drilling fixture to a level plane. A Hilti DD 150U Coring Motor with stand shall ensure a straight core of drilled holes. This drilling template shall accommodate (4) sets of (3) corner ϕ13/16 in. holes and (2) additional holes at the transverse center for shear-only anchors. A contractor crew shall then drill the holes at a maximum depth of 12-1/2 in. at each stand location along the LCLS-II beamline.

The drilling operation shall meet the treatment requirement per ICC-ES ESR-3814, for use in cracked concrete, where holes shall be drilled using a hammer drill or using a coring drill and a roughening tool. The diamond tip drill may only be used to cut through existing rebar. However, the final coring shall be completed using a roughening tool for proper epoxy preparation.

Finally, the rods (anchors) shall be installed at each location after cleaning out the holes. The 5/8 in. – 11 ASTM A193 B8 Class 1 steel threaded rods cut to length (assuming a maximum embedment of 12-1/2 in.) and HIT-RE 500 V3 adhesive system by Hilti applied[11]. This adhesive system is then allowed to cure.

Each of the (4) 5/8 in. – 11 threaded rods shall be lubricated with Chesterton 622 white grease and a nut with oversized washer shall be positioned ~ 4 inches above the floor. The cryomodule preassembled stand (without seismic restraints) shall be lowered onto the (4) nuts using a ½ Ton folding floor crane, eyelets and (2) lifting straps. Then, the stand load is completely lowered onto the threaded supports and crane is removed. A second nut and washer set is attached at each support point.

Nominally, the upper surface of each embedded base plate is found 4.135 in. above the LCLS-II tunnel floor (see Figure 6). This floor is pitched in two directions; 0.286 degrees north-to-south based on the Earth's curvature and 0.62 degrees east-to-west for drainage purposes. Also, the floor's elevation varies +/- 1 in. along the LCLS-II tunnel length. The double (above and below plate) nut and washer design found at each 5/8 in. – 11 supporting rod allows a leveling feature for each base plate as well as a torqueing feature. Each embedded base plate is roughly leveled using the lower 5/8 in. – 11 nuts.

Again, a set of three fiducial holes have been provided at the seismic restraint attachment surface at the stand. These fiducials also allow alignment between stands within +/- 0.005 in. during the installation in order to limit the relative yaw from stand to stand. These fiducial holes (found on both the drilling fixture and stand) shall accommodate the use of either an optical or laser tracker alignment system after inserting the proper tooling ball or nest, respectively. The possibility of yaw offset is minimized through the positioning (and drilling) and securing process of each stand (US and DS). Each stand has a positional tolerance of +/- 0.005 in. regarding the attachment areas for the seismic restraints.

The relative roll of a cryomodule with respect to the stand is consider through the use of wedged shims applied between the seismic restraint and attaching surface at the stand. The LCLS-II alignment requirement for cryomodule roll is 2 mrad. Given a shim height of 8.25 in., a 0.017 in. thickness difference would exist between the upper and lower ends of the shim. Therefore, only a minute wedge is required to properly compensate for the expected roll.

Once each embedded base plate has been located and a torque of 110 ft-lbs is evenly applied to secure each base plate. Alignment spot-checks are used to track any movement of the embedded base plates while torqueing. This procedure is repeated for the other stand base plates while moving DS.

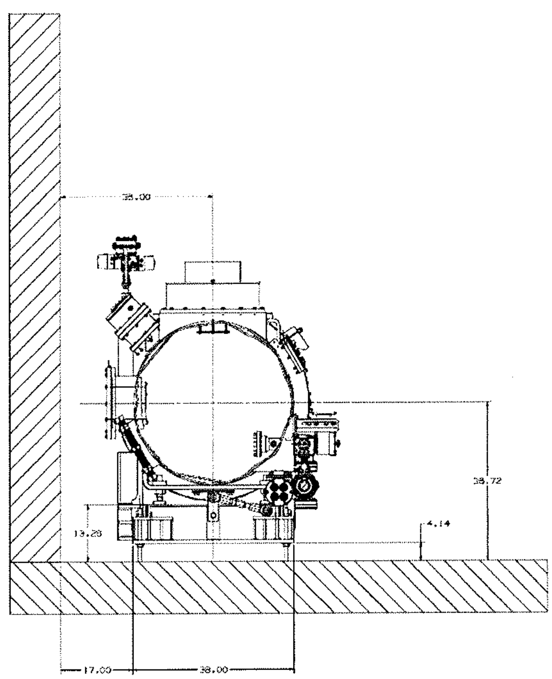

Figure 6: LCLS-II Cryomodule installation at SLAC.

Following the preassembled stand installation phase, each cryomodule shall be transported to its location via tunnel transport device, moved into the beamline and lowered onto the stands.

Alignment shall follow as stand adjustments are made to position each cryomodule. Finally, the wall and aisle seismic restraints are attached to each stand. The attachment of the seismic restraints is the most challenging phase of the installation. Access to the wall-side seismic restraints is made from the tunnel floor beneath each cryomodule using a mechanics creeper. A pneumatic impact tool with hex head wrench is used on the (4) upper connections, SHCS M24-3 fasteners (shown in Figure 4(a)) to reach the recommended torque values.

The process of transferring the cryomodule load first assumes that the cryomodule is completely supported by a hydraulic system which is used to lower the cryomodule onto the US and DS stands. As the cryomodule is lowered, (4) M36 rods are mostly extended down and are allowed to bear slightly on the hardened discs as shown in Figure 7(a). This step stabilizes the cryomodule, while the hydraulic system still carries the load. The plate (with pin) welded assembly is lifted by hand to meet the bottom of the cryomodule u-bracket, the pin is inserted into the bottom of u-bracket and (4) M20 bolts secure the plate to the cryomodule (shown in Figure 7(b)). This operation is completed on the aisle side of the cryomodule. The M36 rods are carefully retracted and then the hydraulic system is used to lower the cryomodule into a position where the tie rod may be connected. The tie rod is attached at a nominal position (design elevation), the load is slowly transferred onto the stands by lowering the hydraulic system. The longitudinal adjusting screws are driven in from end side to secure the cryomodule longitudinally as shown in Figure 8.

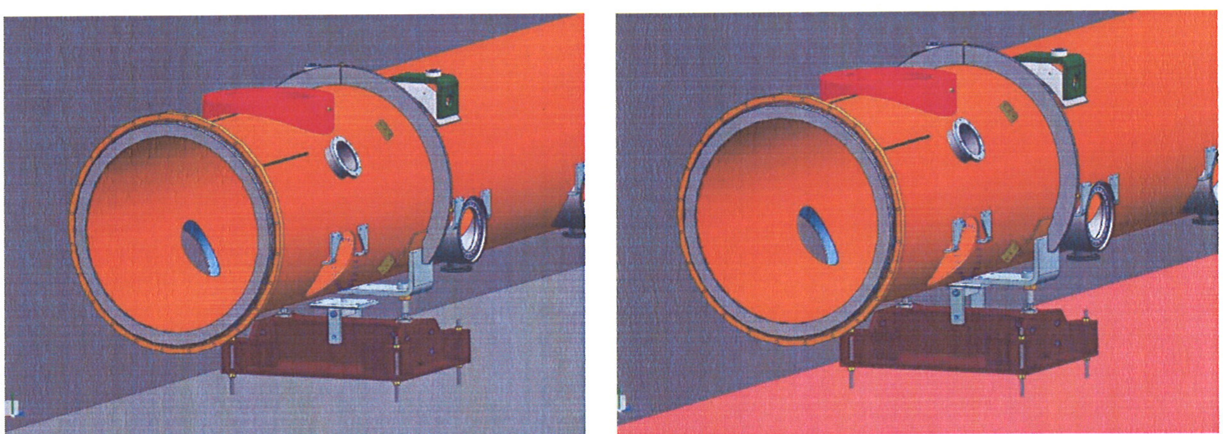

Figure 7(a): LCLS-II Cryomodule installation at SLAC. **7(b):**

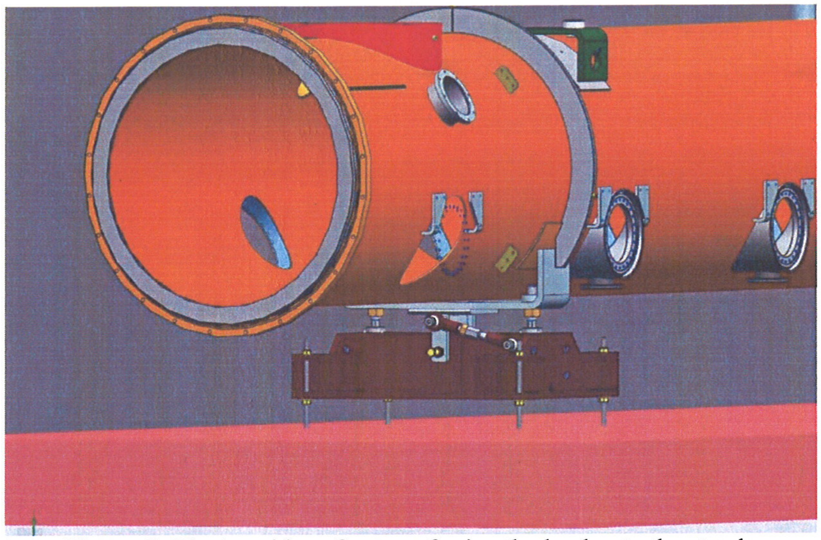

Figure 8: Final position after transferring the load onto the stands.

7. References

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