LCLS Ultrafast Science Instruments

ENGINEERING SPECIFICATION DOCUMENT (ESD)	Doc. No. SP-391-000-85	LUSI SUB-SYSTEM Coherent X-Ray Imaging

LUSI Coherent X-ray Imaging (CXI) Instrument Engineering Specification

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1. Scope

This document is intended to consolidate all engineering requirements and specifications related to the LCLS-LUSI Coherent X-ray Imaging (CXI) instrument.

The CXI instrument project is managed under LUSI Work Breakdown Structure (WBS) section 1.3. Only items specifically described in WBS 1.3 will be dealt with in detail.

Elements managed outside of WBS 1.3 will be addressed only insofar as their inclusion provides a more complete understanding of CXI WBS 1.3 requirements.

Numerous documents providing guidance and definition for the design and engineering exist. This ESD is to serve as a "roadmap" to all documents related to the execution of the CXI engineering and design effort. Those supporting documents are referenced in the appropriate section of this document.

2. CXI Instrument Summary

The primary purpose of the Coherent X-ray Imaging (CXI) instrument is to measure the coherent diffraction pattern of any submicron sample of interest. The characteristics of the sample as well as the information one wishes to obtain about it dictate in which environment the sample needs to be delivered to the LCLS beam. There will be two distinct sample environments. The first one will be fixed targets with a sample mounted on a holder, either a thin membrane or a grid. The second will be injected samples with individual micron and submicron particles in the gas phase or droplets flying through the interaction region. The interaction region is defined as the volume of space where the LCLS X-ray beam interacts with the sample. The entire instrument must be designed around that small volume.

Most experiments using the CXI instrument will follow a similar procedure:

1. Focus the LCLS beam into the interaction region or move the interaction region to the focus.
2. Use apertures to reduce background coming from outside the central LCLS beam.
3. Illuminate a submicron object located at the interaction region with the coherent X-ray beam.
4. Measure the diffraction pattern with a 2D detector with a central hole that lets the direct beam pass.
5. Use various diagnostics tools to characterize the incident beam as well as the explosion of the sample caused by the X-ray beam.

The CXI instrument hardware shall conform to the capability of being configured in one of six experimental configurations, namely:

1. Fixed Target Forward Scattering
2. Injected Particles Forward Scattering
3. Pump Probe Imaging
    a. Fixed Target
    b. Injected Particles
4. Time-Delay Holography
    a. Fixed Target
    b. Injected Particles

More detail regarding each configuration may be found in Physics Requirements Documents SP-391-000-19-1, *Physics Requirements for the CXI instrument*.

The CXI instrument shall have portions of its hardware located in both the X-ray Transport Tunnel (XRT) and Hutch 5 (H5) of the LCLS Far Experimental Hall (FEH).

Future enhancement possibilities include the addition of an X-ray Pulse Compressor and X-ray Focusing Lenses in the upstream vacuum drift section of the XRT and an Electron Time-of-Flight mass spectrometer as well as Alignment/Pump Laser and Desorption-Ionization Laser systems in FEH H5. These additions will allow to: minimize sample damage, image larger samples, better understand sample explosion dynamics and excite changes in sample before imaging it.

3. CXI Major Subsystems

The CXI instrument is comprised of five major subsystems:

1. The reference laser system provides a visible, low power laser beam collinear with the LCLS X-ray beam to align the components of the CXI instrument without use of the X-ray beam.

2. The focusing optics systems, i.e. the 0.1μm and 1.0μm Kirkpatrick-Baez (KB) Systems. Each KB system will consist of two orthogonal reflective mirrors at grazing incidence and will be capable of producing focal spots on the order of 100 nm x 100 nm and 1 μm x 1 μm for the CXI instrument.

3. The Room Temperature Sample Environment will consist of a sample chamber, ion time-of-flight mass spectrometer, particle injector, detector stage and precision instrument stand.

    a. The CXI sample chamber will include an interface to the coherent imaging injector, aperture raster stages and a sample raster stage with 2-axis rotation, as well as vacuum equipment to maintain and monitor the high vacuum environment of the chamber. The ion TOF will sample ions created at the interaction region and be mounted on the sample chamber. A high-resolution sample viewing system is also included as part if this hardware.

b. The coherent imaging injector system will be used to deliver support-free particles into high vacuum to be intercepted by the LCLC X-ray beam.

c. The detector stage will support, position and orient the detector inside a vacuum vessel. The 2D detector that is included in the design of the detector stage will be provided by Cornell University through LCLS.

d. The precision instrument stand will support, position and orient the sample chamber, coherent imaging injector and the detector stage consistent with the selected focusing optic. The precision instrument stand will also support the 0.1 μm KB System.

4. The diagnostics and common optics suite is used to analyze and optimize the X-ray beam properties. These components are located in both the XRT and FEH H5 and consist of a suite of X-ray optic and diagnostic components that are common with the other instruments developed by LUSI as well as CXI specific hardware, i.e. wavefront monitor.

5. The vacuum system will create and support a high vacuum environment along the entire CXI beamline. Included in this subsystem are equipment, hardware, bellows, spools and vacuum supports

4. CXI Beamline Schematic

Figure 1 shows in schematic form, the CXI components that are CD-4c deliverables.

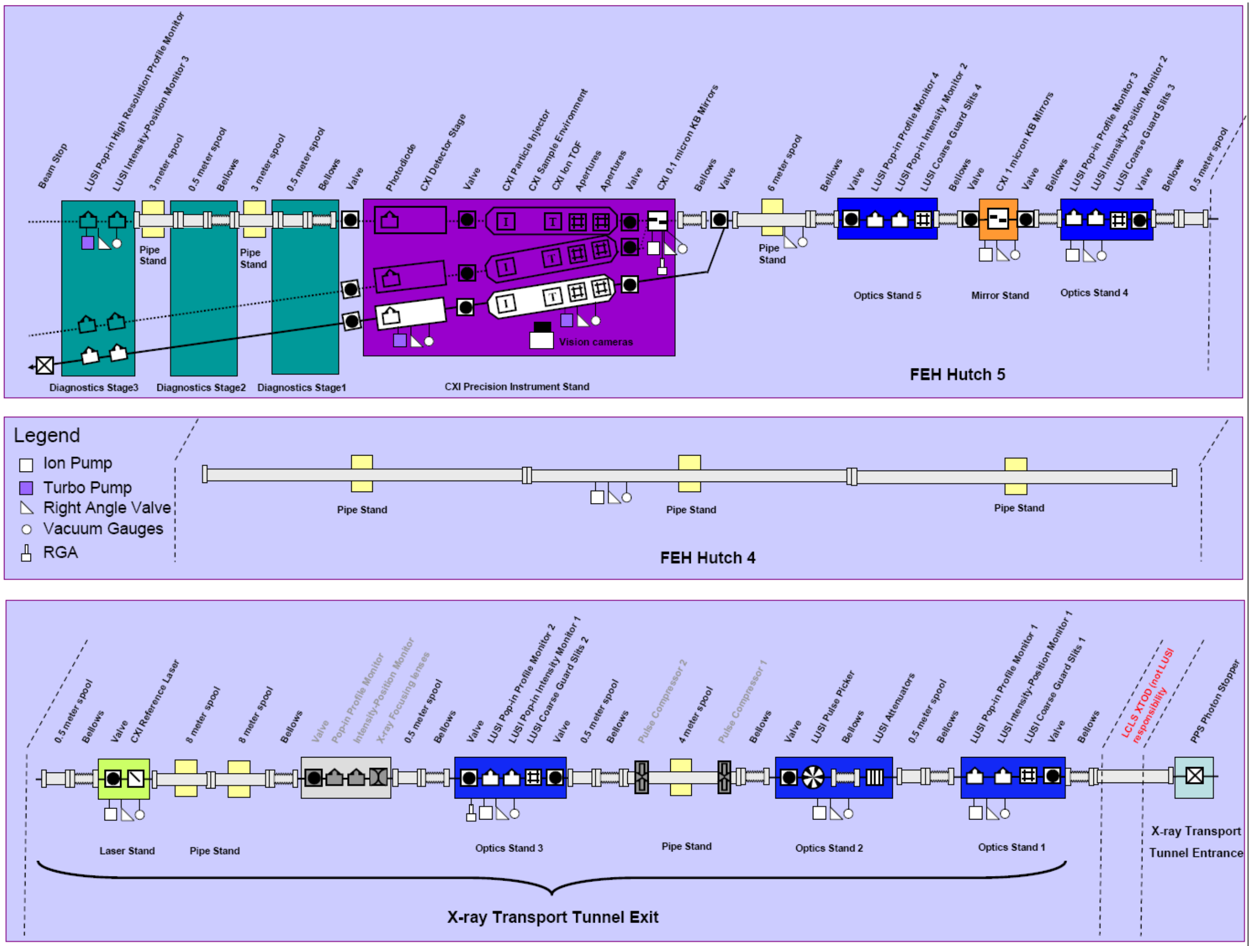

Figure 1:CXI CD-4c deliverables

5. MIE Interface Control Documents

The documents identified in Table 1 define the interface responsibilities between groups working in support of CXI instrument major item of equipment (MIE).

Document Name	Document Number
X-ray End Stations to Conventional Facilities	LCLS Doc No. 1.1-509
Vacuum controls to Vacuum Mechanical	LCLS Doc No. 1.1-510
XES to LUSI ICD	LCLS Doc No. 1.1-523-r0
CXI Controls & DAQ	SP-391-001-14
Diagnostics to CXI	TBD

Table 1: CXI Interface Documents

6. MIE Physics Requirements Documents

The documents identified in Table 2 define the physics requirements for CXI instrument major item of equipment (MIE).

Document Name	Document Number
Physics Requirements for the CXI Instrument	SP-391-000-19
CXI Sample Chamber	SP-391-000-20
CXI Reference Laser System	SP-391-000-21
CXI 0.1 micron KB System	SP-391-000-24
CXI 1 micron KB System	SP-391-000-25
CXI Particle Injector System	SP-391-000-26
CXI Detector Stage	SP-391-000-28
CXI Ion ToF	SP-391-000-30
CXI Precision Instrument Stand	SP-391-000-63
CXI Instrument Start-up Plan	SP-391-001-16

Table 2: CXI Physics Requirements Documents

7. MIE Engineering Specification Documents

The documents identified in Table 3 define the engineering specifications for CXI instrument major item of equipment (MIE).

Document Name	Document Number
CXI 0.1 micron KB System	SP-391-000-64
CXI 1 micron KB System	SP-391-000-65
CXI Sample Chamber	SP-391-000-67
CXI Ion ToF	SP-391-000-68
CXI Precision Instrument Stand	SP-391-000-69
CXI Detector Stage	SP-391-000-70
CXI Reference Laser System	SP-391-000-73
CXI Particle Injector System	SP-391-000-75
CXI Instrument Engineering Specification	SP-391-001-73

Table 3: CXI Engineering Specifications Documents

8. Supplemental Specifications and Requirements Documents

The documents identified in Table 4 define the supplemental specifications and requirements for CXI instrument major item of equipment (MIE).

Document Name	Document Number
2-D X-Ray Detector	LCLS PRD # 1.6-002
LUSI Controls and Data System	PRD# SP-391-000-03
LUSI Data Management System	PRD# SP-391-000-06
Engineering Specifications for Common Room of the FEH	SP-391-001-40
Engineering Specifications for the CXI Room of the FEH	SP-391-001-37
Engineering Specifications for Hutch 5 of the FEH	SP-391-001-36

Table 4: CXI Supplemental Specifications and Requirements

9. Basic Instrument Design Criteria

9.1. *Hutch PPS Access State Criteria*

No access to the FEH H5 hutch shall be permitted unless the PPS photon stopper is in the closed position.

9.2. *Basic Hardware Design Criteria*

The design service life of the CXI hardware is 10 years.

Three interaction regions shall be used for all experimental configurations. One point will be designed for the unfocused beam, the second for the beam focused by the 1 micron KB and the third for beam focused by the 0.1 micron KB beam. These points will be located at a common Z position.

All components downstream of the 0.1 micron KB system shall be capable of translating and rotating to follow the deflection of the focused beam which depends on the which optic is used.

There shall be a heating system and an air conditioning system capable of maintaining the operational hutch temperature at 72 ±1 °Fahrenheit. Time stability at any given point is required while spatial fluctuations greater than 1 °F are allowable.

The CXI hardware will support data acquisition at operational temperature/tolerance.

The CXI hardware will accommodate extreme temperature/tolerance without permanent damage.

All hardware will return to nominal position when hutch temperature returns to operational specifications.

No extraordinary hutch humidity is anticipated.

The nominal experiment duration is on the order of several days. An experiment is defined as use of the FEH H5 hardware during which the hardware configuration is not substantially modified or reconfigured.

All Hardware for CXI will be specified, designed, fabricated and installed in such a way as to provide for function at all hardware positions.

All tasks to reconfigure the CXI hardware will be within the competency of a typical SLAC mechanical technician. A design goal shall be that no specialized technical capabilities, such as alignment engineers/riggers/etc., will be required to reconfigure CXI.

9.3. *Basic X-ray beam parameters for mechanical design baseline*

The nominal height of the X-ray beam is 1.4 meter above the hutch floor.

The distance from the 1μm KB system to the interaction region is 8m and the corresponding distance for the KB0.1 system is 0.7m. The distance from the upstream hutch wall in FEH H5 to the 1.0um KB is ~2m.

The actual, nominal, global position of the X-ray beam will be known before CXI hardware is installed in the hutch. Any difference between design beam location and actual beam location will be addressed prior to installation.

The nominal X-ray beam position will drift to such an extent that repositioning-alignment of CXI hardware will be required at every experiment reconfiguration. This includes X-ray optics, sample chamber and detector. Any repositioning will be accomplished using typical SLAC mechanical technicians' competency.

The X-ray beam will maintain precise position throughout the course of each experiment (on the order of several days) to the extent that realignment during the experiment will not be necessary.

9.4. *Baseline Instrument Reconfiguration Procedure*

Hardware will be design to accommodate the following work flow between equipment configuration changes and alignment procedures.

1. Alignment of FEH H5 beamline components with reference laser:

   a. Close PPS photon stopper: FEH H5 Access permitted
   b. Enable reference laser
   c. Serially view reference laser/direct beam to ensure spatial overlap
   d. Align components
   e. Disable reference laser
   f. Enable attenuator
   g. Alignment complete
   h. Open PPS photon stopper

2. Experiments with 0.1μm (or 1μm) KB system

   a. Close PPS photon stopper: FEH H5 Access permitted
   b. Ensure 2-D detector retracted
   c. Close valves on sample chamber
   d. Vent sample chamber
   e. Access to sample chamber available
   f. Reconfigure sample chamber hardware appropriate to experiment

g. Coarse alignment with reference laser (see Section A)
h. Close/pump sample chamber
i. Open valves
j. Enable attenuator
k. Open PPS photon stopper
l. Verify alignment
m. Optimize aperture location
n. Experiment configuration change completed

3. Procedure for changing location of detector stage

    a. Close PPS photon stopper: FEH H5 Access permitted
    b. Ensure detector retracted
    c. Close upstream/downstream valves on detector stage
    d. Vent detector stage and spools
    e. Disassemble/reconfigure detector
    f. Coarse alignment with reference laser (see Section A)
    g. Pump detector stage
    h. Open sample chamber valves
    i. Enable attenuator
    j. Open PPS photon stopper
    k. Verify alignment
    l. Optimize detector position
    m. Detector stage location change completed

4. Changing focusing optics (1 μm KB to 0.1 μm KB)

    a. Close PPS photon stopper
    b. Vent diagnostics stage
    c. Disconnect diagnostics stage from detector
    d. Activate reference laser
    e. Insert detector stage photodiode
    f. Retract 1.0 μm KB system
    g. Translate sample chamber/detector stage to offset location
    h. Translate 0.1 μm KB system into reference laser path
    i. Coarse alignment of mirrors
    j. Reconnect diagnostic stage to detector
    k. Pump diagnostic stage
    l. Enable attenuator
    m. Open PPS photon stopper
    n. Verify alignment

o. Optimize mirror/detector position
p. Focusing optic change completed

10. Optical-Diagnostic Suites Support System Design Criteria

Prioritized design criteria are:

1. All translating beamline elements must be under positive control at all times.

    a. All elements will have fixed (immovable) hard stops defining motion extents
    b. Human intervention will not be required to confine elements within their intended range of motion.

2. Stable relative optical–diagnostic element position (i.e., elements with respect to other).

    a. Goal: < 5 micron (±2.5) relative position stability.
    b. Assumed sources of deviation:
        i. Thermal gradients within supports
        ii. Loads across bellows due to remote commanded component motions
        iii. Dynamic response to cyclic input loads

3. Stable absolute optic-diagnostic suite position (i.e., elements as a unit in global space)

    a. Goal: < 15 micron (±7.5) with 2 (±1) °F variation
    b. Assumed sources of deviation:
        i. Gross bulk thermal variation
        ii. Dynamic response to cyclic input loads
        iii. Unintended redundant loads
    c. Slits to serve as position datum for optic-diagnostic suite
    d. Assumes use of invar component fine align supports

4. High repeatability of translation hardware (i.e., moving between positions 1 and 2)

    a. Goal: <25 micron horizontal
        i. Assumed sources of deviation:
        ii. Unintended redundant loads
        iii. Improper restraint load input
        iv. Hard strike while contacting stop
    b. Goal: < 15 micron vertical
        i. Same as 3 above

5. Minimize adjacent component motion due to alignment/bellows /external loads

    a. Goal: <2 micron
    b. Assumed sources of deviation:
        i. Force couples through support structure from remote command motions

6. Intuitive and clearly marked methods of traversing beamline components.

7. Absolute alignment of support structure

    a. Goal: < 200 micron

10.1. *Materials*

Use of materials with low coefficients of thermal expansion is highly desirable to reduce thermal motion

Use of materials with low thermal diffusivity to limit the displacement effects of short-term temperature excursions is highly desirable

10.2. *Thermal Issues*

All supports for CXI will have deterministic constraints fully compliant to thermal variations or gradients. Thermal variations or gradients will not create redundant loads on the support system.

10.3. *Structural Issues*

All support system hardware will be engineered to equal or exceed the seismic accelerations or loads prescribed by SLAC directive at the time of design.

10.4. *Precision motion*

Motion control elements will be specified such that the requirements of section 10 are achieved.

When consistent with physics and engineering requirements manual control of translation hardware is acceptable, i.e., no need for remotely operated motor control.

A high level of repeatability when reconfiguring between KB focusing systems is far more important than the absolute position of the support structures. All components to be mounted on the support structures will have their own fine alignment supports.

10.5. *Alignment/Fiducialization*

The X-ray optic-diagnostic support system hardware will not be fiducialized for precision alignment.

Support system hardware will be located in the hutch via measurements taken from nominal features/surfaces/edges.

Individual optic-diagnostic components will be fiducialized and precisely aligned after mounted on the support structures.

11. Vacuum System Design Criteria

In both the XRT and FEH H5, the average beamline pressure shall be 10^{-7} Torr or better with the exception of the 1.0µm and 0.1µm KB mirror systems. To prevent contaminants from condensing on mirror surfaces, due to the higher average beamline pressure, differential pumping of the mirror systems will be employed to achieve an average pressure of 10^{-9} Torr or better for these systems.

Base pressure at vacuum pumps will be consistent with manufactures recommendations for 10-year life expectancy.

For high vacuum (up to 10^{-7} Torr) applications, monitoring of background gases in the range of 1-50 AMU shall be required. For UHV applications, RGA scans shall be performed to monitor background gases in the range of 1-200 AMU. RGA scans must indicate the predominant gas component to be hydrogen and it must be a minimum of 60% of the total pressure. High masses, greater than 28, shall be less than 10% of total pressure.

There shall be no evidence of leaks (external, virtual, etc.) in the system, air or other.

All sections between valves will have a minimum of one gauge set providing pressure sensitivity from atmosphere to 10^{-9} Torr.

All seals nominally to atmosphere will be all metal construction. Non-metallic seals in normally open valves are acceptable. Normally closed (vent/purge) valves will be all metal seal types.

All valves in the path of the X-ray beam located downstream of the CXI reference laser must be window valves, transparent to visible light and of optical quality to allow for the use of the reference laser with parts of the beamline vented to atmosphere while the upstream components are under vacuum.

All sections between valves will have a minimum of one vent/purge valve.

Dry pumping systems shall be used to minimize contamination.

All lubricants, cutting fluids, etc., used in manufacturing shall be "sulfur-free". Reference SLAC document No. SC-700-866-47 for a complete list of approved machining lubricants. The use of sanding discs, abrasive paper or grinding wheels is typically prohibited. In special circumstances good vacuum practices should be followed when grinding and polishing is required. This process shall be reviewed and approved by the engineer for its vacuum compatibility.

All parts and subassemblies shall be cleaned for UHV. Once parts are cleaned for vacuum they are to be handled only with clean latex or nitrile gloves. All components that cannot be made vacuum tight and purged with dry nitrogen shall be wrapped in SLAC approved lint free paper and Aluminum foil or sealed in a purpose approved vacuum container. Components should only be vented, unwrapped or otherwise exposed in a clean room environment. This includes all piece parts, subassemblies and completed instruments. For storage or transportation, place in clean sealed vacuum grade plastic bag that has been back-filled with nitrogen.

12. Installation Criteria

Installation requirements will be addressed in the design phase. Access to the 1-ton crane will be factored into the design of components. Building size and access requirements will be considered for large components. Further installation requirements for the CXI instrument will be established during detail design.

13. Operations and Maintenance Criteria

The CXI instrument shall be designed so that equipment failure or the need for maintenance does not impact the operations of the other instruments of LCLS.

The reliability and maintenance requirements for each component are described in the individual Physics Requirement Documents and Engineering Specifications Documents associated with each component.

The CXI instrument shall be designed for maintenance operations within a reasonable amount of shutdown time. Component access and handling will be provided in the design

14. Schedule

The CXI instrument schedule will be created and maintained, throughout the complete project life cycle, under the guidelines established in "LCLS Earned Value Management System Project Schedule Procedure", LCLS Doc No. PMD 1.1-020.

15. Cost Basis-Of-Estimate

The CXI instrument cost basis-of-estimate will be created under the guidelines established in "LCLS Earned Value Management System Cost Estimating Procedure", LCLS Doc No. PMD 1.1-021 and "LCLS Basis of Estimate Methodology" LCLS doc No. ESD 1.1-100.

16. Environmental Safety and Health Design Criteria

All hardware designs will be approved via the LCLS Design Review Guidelines (ref: LCLS Doc No. ESD 1.1-324)

The implementation of the LCLS Project Environment, Safety and Health Plan (LCLS doc No. PMD 1.1-011) will be a key component of the review process. Special attention will be focused on the core functions of the Integrated Safety and Management System (ISMS) in said design reviews.

Vacuum vessels: 10CFR851 Worker Safety and Health Program

17. Radiation Shielding Design Criteria

Radiation physics simulations of sources in FEH H5 will be completed. Local or area shielding will be implemented as required to achieve hutch accessibility to support the requirements of section 9 of this document.

18. Inspection, Testing and Commissioning

Full inspection of piece parts, for geometric and material property acceptance will be required. Written reports of said inspections will become an element of the component pedigree.

Sub-assembly and component level testing will be conducted to establish compliance with engineering specifications and physics requirements. Testing will include, but not be restricted to, any required motion accuracy and precision, controls hardware (limit switch, position encoders, etc) performance, vacuum performance, support stability and any safety system performance (interlock, safety covers, etc). System wide integration testing, without beam, will be conducted to validate component level tests and insure seamless operation at the hutch sight.

Commissioning of the CXI instrument with beam is not a part of the LUSI MIE Project. The LUSI project provides design, procurement, construction, installation, testing without beam, a start-up test plan, operating procedures and training needed for commissioning (not user operation) of the CXI instrument. Construction completion shall be confirmed by an Instrument Readiness Review and resolution of all pre-startup (required before receiving beam) issues generated by the review. All testing shall be appropriately documented.

19. Quality Assurance Criteria

All activities associated with the CXI instrument will be conducted in accordance with accepted engineering standards and practices. Good engineering practices imbedded within the established design process will ensure safe and reliable operation of the instrument and will mitigate conditions that pose a threat to success. In all cases, consensus standards will be used to accomplish design activities. Where standards do not exist to adequately control an activity, appropriate administrative controls will be considered and created if required.

Thoughtfully derived and properly "graded" controls for design, manufacturing, installation, testing, and operation of the CXI instrument will be established before execution of each of these activities.

Additional controls will only be proposed in cases where they enhance the probability of success. Successful quality assurance (QA) program performance will be verified through validation activities such as design reviews, surveillance activities, inspections, tests, and readiness reviews.

A list of drawings will be developed during detailed design.

20. Acronyms

CXI: Coherent X-ray Imaging
ESD: Engineering Specifications Document
FEH: Far Experimental Hall
H5: Hutch 5
KB: Kirkpatrick-Baez
LCLS: Linear Coherent Light Source
LUSI: LCLS Ultra-fast Science Instrumentation
MIE: Major Item of Equipment
PRD: Physics Requirements Document
QA: Quality Assurance
UHV: Ultra High Vacuum
XRT: X-ray Transport Tunnel