ENGINEERING SPECIFICATION DOCUMENT (ESD)	Doc. No. SP-391-000-64 R1	LUSI SUB-SYSTEM CXI

Engineering Specifications for the CXI 0.1 micron KB System

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1. Overview

The Coherent X-ray Imaging (CXI) instrument to be built at the Linac Coherent Light Source (LCLS) by the LCLS Ultrafast Science Instruments (LUSI) project on the SLAC National Accelerator Laboratory site requires a mirror system to produce a 100x100 nm^2 FWHM focal spot at the sample. The mirror system shall be made of 2 mirrors each with an elliptical figure and arranged in a Kirkpatrick-Baez (KB) configuration. The system is known as the CXI 0.1 micron KB System or KB1.

The LCLS will produce a laser-like beam of X-rays in the 800 to 8300 eV range for the fundamental energy. Also, the 3rd harmonic will be present at up to 25 keV. The CXI instrument will use the hard X-ray branch which uses 2 offset mirrors that reflect energies between 2 keV and 25 keV. The KB mirrors will be located 420 m away from the source, which ranges in size from 60 μm to 78 μm FWHM, depending on the energy. The X-ray beam at the mirror location will range from 500 μm to 1500 μm depending on the energy.

The KB mirror combination shall reflect more than 75% of the X-rays over the 2-18 keV range. This will be achieved by coating the mirrors with two strips. The first strip will be a Silicon Carbide (SiC) monolayer and the second strip will be a bilayer consisting of a heavy material (either Rhodium (Rh) or Ruthenium (Ru)) deposited underneath a thin layer of Silicon Carbide (SiC).

These mirrors will be located in an Ultra-High Vacuum (UHV) environment (10^{-9} Torr). They require a very precise positioning system with the mirrors located inside a vacuum enclosure which will be mounted on a stable stand.

The LUSI project is building two KB systems, the 0.1 micron KB system outlined in this document and a 1 micron KB system outlined in SLAC document ESD# SP-391-000-65. These two systems shall be mechanically identical in almost every way and therefore, the specifications in document ESD# SP-391-000-65 shall apply and not be repeated here. Only the distinctions between the two KB systems are described in the present document.

2. Scope

This document contains the specifications for the fabrication and delivery of a KB mirror system capable of producing a focal spot of roughly 100 nm x 100 nm (FWHM) for the CXI instrument built by LUSI at LCLS. Here, we say roughly 100 nm x 100 nm (FWHM) because the source size and location varies with the photon energy and therefore the focal spot will vary with energy and it will not be possible to obtain a 100 nm focus at all energies. The focal lengths of the optics described in this document were chosen to allow a minimum focal spot of less than 70 nm in one direction. This minimum focal size was chosen to allow sufficient space between the downstream mirror and the interaction region at the focal plane.. The specifications described in this document were chosen to satisfy this requirement. Multiple activities and components are required to build the complete mirror system. They are as followed.

Mirror Substrates (Described in Section 6)

Mirror Coating (Described in Section 7)

Mirror Metrology (Described in Section 8)

Mirror Mechanical Support System (Described in Section 9)

Vacuum Enclosure (Described in Section 9.2)

Support Stand (Described in Section 9.2.24)

All the requirements are summarized in Section 17 at the end of this document. The details for all these requirements are found in the Sections 3 to 16.

3. Applicable Documents, Specifications and Codes

3.1. SLAC Specifications

- SLAC document No. SP-391-000-24, "Physics Requirements for the CXI 0.1 micron KB System"
- SLAC document No. SP-391-000-19, "Physics Requirements for the CXI Instrument"
- SLAC document No. SP-391-000-20, "Physics Requirements for the CXI 0.1 micron Sample Chamber"
- SLAC document No. SP-391-000-63, "Physics Requirements for the CXI 0.1 micron Precision Instrument Stand"
- SLAC document No. SP-391-000-65, "Engineering Specifications for the CXI 1 micron KB System"
- SLAC document No. SP-391-000-67, "Engineering Specifications for the CXI 0.1 micron Sample Chamber"
- SLAC document No. SP-391-000-69, "Engineering Specifications for the CXI 0.1 micron Precision Instrument Stand"
- SLAC drawing No. DS-391-000-36, "Mechanical Design Standards Supplement"

- SLAC drawing No. SC-700-866-47, "Specification Kly & Vac Machining Fluids"
- Fed-STD-595B, "Colors Used in Government Procurement"

3.2. Other Specifications

- MIL-PRF-13830B: "Optical Components for Fire Control Instruments; General Specification Governing the Manufacture, Assembly, and Inspection of."

4. Definitions

Mirror substrate vendor

The entity entering into a contract with SLAC to provide mirrors meeting all requirements listed in Section 6.

Mirror coating vendor

The entity entering into a contract with SLAC to provide coating for mirrors meeting all requirements listed in Section 7.

Mirror metrology vendor

The entity entering into a contract with SLAC to provide metrology measurements on mirrors as described in Section 8.

Mirror support vendor

The entity entering into a contract with SLAC to provide a mirror mechanical support system meeting all requirements described in Section 9

Vacuum enclosure vendor

The entity entering into a contract with SLAC to provide a vacuum enclosure meeting all requirements described in Section 9.2. This entity shall be the same entity as the mirror support vendor.

Stand vendor

The entity entering into a contract with SLAC to provide a stand meeting all requirements described in Section 9.2.24. This entity shall be the same entity as the mirror support vendor and the vacuum enclosure vendor.

5. General Requirements

See Section 5 of SLAC document SP-391-000-65.

6. Optical Requirements, Mirror Requirements

6.1. Scope

This section describes the requirements for 2 mirrors to be delivered to SLAC. The mirrors shall be polished with an elliptical figure as described below.

6.2. Mirror Definitions

See Section 6.2 of SLAC document SP-391-000-65.

6.3. Performance Requirements

The mirrors will be used in a Kirkpatrick-Baez configuration to produce a 100 nm FWHM focal spot. The mirrors will accept the full beam width (4 standard deviations or more) at all energies above 5 keV and will be > 86% reflective (each mirror for a total reflectivity > 75%) over the 2-18 keV range with the proper coating applied. The mirror parameters listed in Table 1 and Table 2 as well as the coating parameters listed in Table 3 and Table 4 were chosen to meet these requirements. The mirror vendor shall be only responsible for meeting the requirements listed in these two tables and shall not be responsible for demonstrating or meeting the reflectivity requirements, which shall be met with proper coating given that the requirements of Table 3 and Table 4 are met.

6.4. Mirror Dimensions Requirements

See Section 6.4 of SLAC document SP-391-000-65.

6.5. Optical Surface Requirements

6.5.1. Figure Requirements

The requirements are the same as described in SLAC document SP-391-000-65 except that the curvatures of the mirrors are different. The specifications of the mirrors for this system are found in Table 1 and Table 2 below. Highlighted in red are the values which are different from the mirrors of the 1 micron KB System.

	Parameter	Value	Units	Comment
1	Mirror Shape	Tangential ellipse		Pre-figured mirrors
2	Clear aperture length	350	mm	Length over which the coating will be applied and the surface specifications must be met
3	Clear aperture width	30 ≥ width ≥ 12	mm	Width over which the 2 coating strips will be applied and the surface specifications must be met
4	Mirror Length	375 ≥ length ≥ 360	mm	Extra length is to allow mounting during the coating process and mirror use
5	Mirror Width	60 ≥ width ≥ 45	mm	
6	Mirror Thickness	>50	mm	
7	Substrate material	Si <100>		Single crystal
8	Figure height error	<1.00	nm rms	Over dimensions from 1mm to the clear aperture size from best-fit ellipse
9	Mid-spatial roughness	<0.25	nm rms	Over the 10^{-3} to 0.5 μm^{-1} frequency range
10	High-spatial roughness	<0.25	nm rms	Over the 0.5 to 50 μm^{-1} frequency range
11	Tangential Slope error	<0.25	µrad rms	Over dimensions from 1mm to the clear aperture size from best-fit ellipse
12	Sagittal Slope error	<2	µrad rms	Over dimensions from 1mm to the clear aperture width from best-fit sagittal radius
13	Mean Tangential Radius of curvature tolerance	0.1	%	
14	Sagittal radius of curvature	>400	m	
15	Distance from source	420	m	
16	Focal length	0.9	m	
17	Maximum incidence angle	3.4	mrad	Angle of incidence at downstream end of the mirror
18	Vacuum pressure	$<10^{-9}$	Torr	
19	Temperature	22	^{o}C	
Calculated parameters from the specifications				
A	Maximum height of surface	28.9	µm	Surface profile is shown on Figure 1 below. For pre-figured mirrors only.
B	Tangential Radius of curvature	425.8-767.8	m	Elliptical profile (see Figure 2 below). For pre-figure mirrors only
C	Average incidence angle	3.067	mrad	Angle of incidence at the mid-point of the mirror
D	Ellipse parameter (a)	219.45	m	
E	Ellipse parameter (b)	60.6	mm	

Table 1: Parameters for first mirror of the CXI 0.1 micon KB system.

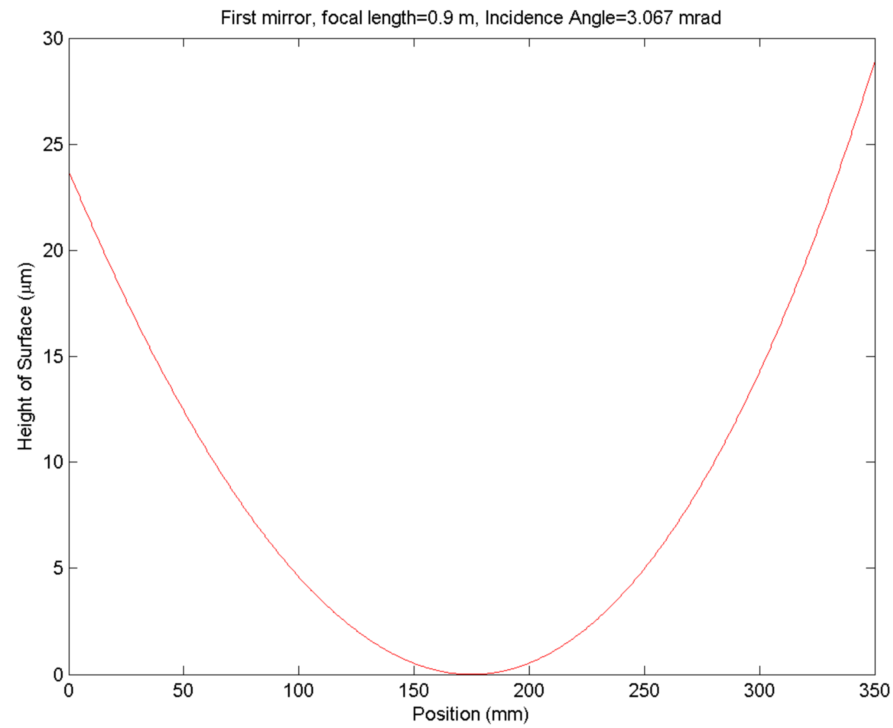

Figure 1: Surface profile of the first mirror.

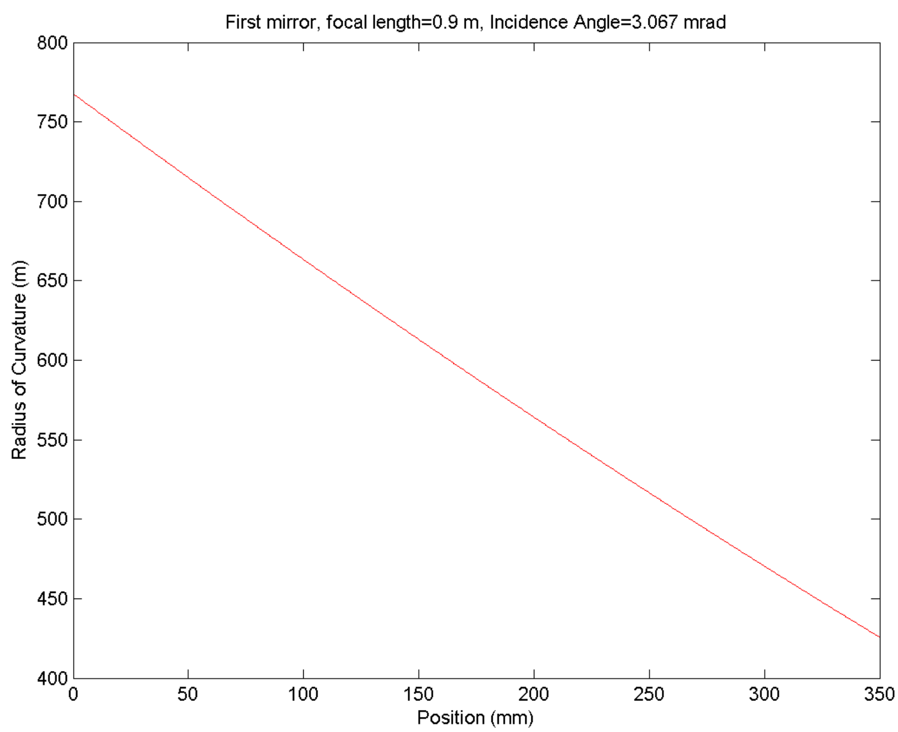

Figure 2: Radius of curvature of the first mirror surface as a function of position along the mirror.

	Parameter	Value	Units	Comment
1	Mirror Shape	Tangential ellipse		Pre-figured mirrors
2	Clear aperture length	350	mm	Length over which the coating will be applied and the surface specifications must be met
3	Clear aperture width	30 ≥ width ≥ 12	mm	Width over which the 2 coating strips will be applied and the surface specifications must be met
4	Mirror Length	375 ≥ length ≥ 360	mm	Extra length is to allow mounting during the coating process and mirror use
5	Mirror Width	60 ≥ width ≥ 45	mm	
6	Mirror Thickness	>50	mm	
7	Substrate material	Si <100>		Single crystal
8	Figure height error	<1.00	nm rms	Over dimensions from 1mm to the clear aperture size from best-fit ellipse
9	Mid-spatial roughness	<0.25	nm rms	Over the 10^{-3} to 0.5 μm^{-1} frequency range
10	High-spatial roughness	<0.25	nm rms	Over the 0.5 to 50 μm^{-1} frequency range
11	Tangential Slope error	<0.25	µrad rms	Over dimensions from 1mm to the clear aperture size from best-fit ellipse
12	Sagittal Slope error	<2	µrad rms	Over dimensions from 1mm to the clear aperture width from best fit sagittal radius
14	Mean Tangential Radius of curvature tolerance	0.1	%	
15	Sagittal radius of curvature	>400	m	
16	Distance from source	420	m	
17	Focal length	0.5	m	
18	Maximum incidence angle	3.4	mrad	Angle of incidence at downstream end of the mirror
19	Vacuum pressure	$<10^{-9}$	Torr	
20	Temperature	22	^{o}C	
	Calculated parameters from the specifications			
A	Maximum height of surface	51.52	µm	Surface profile is shown on Figure 1 below. For pre-figured mirrors only.
B	Tangential Radius of curvature	191-571.1	m	Elliptical profile (see Figure 2 below). For pre-figure mirrors only
C	Average incidence angle	2.786	mrad	Angle of incidence at the mid-point of the mirror
D	Ellipse parameter (a)	219.25	m	
E	Ellipse parameter (b)	40.6	mm	

Table 2: Parameters for second mirror of the CXI 0.1 micron KB system.

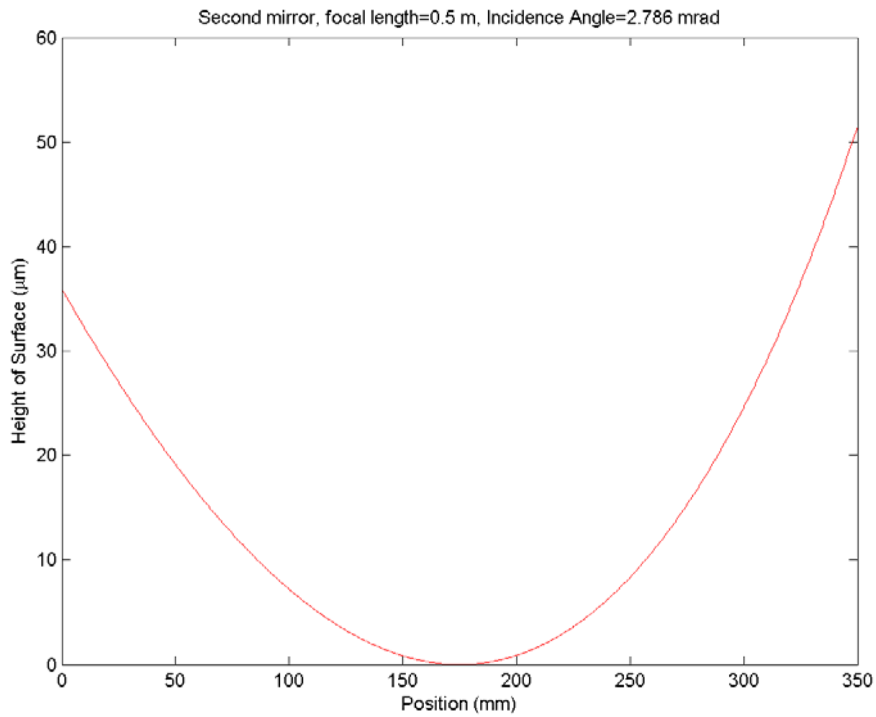

Figure 3: Surface profile of the second mirror.

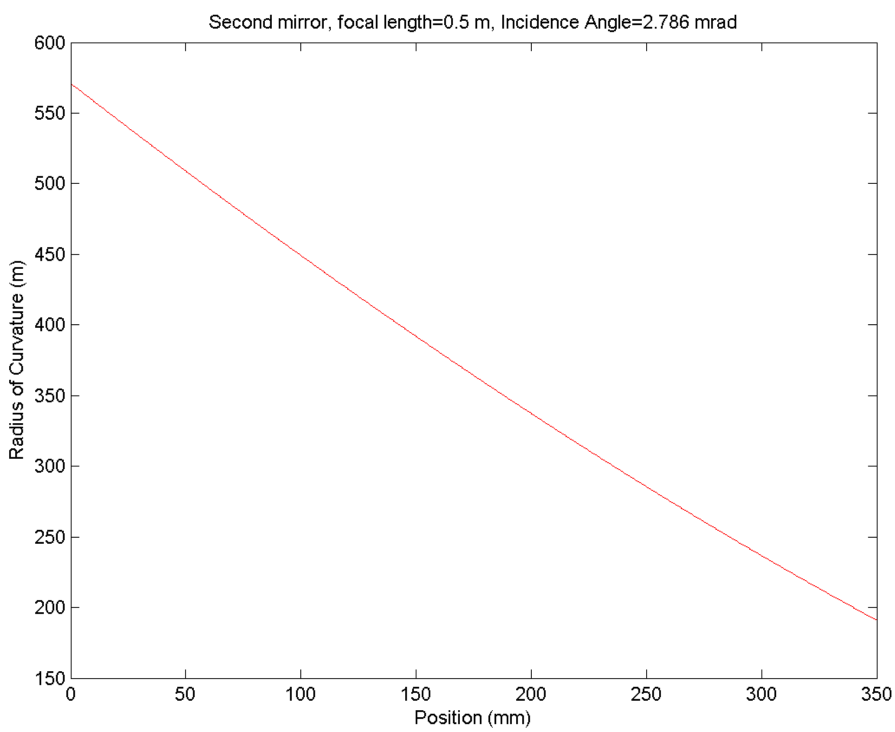

Figure 4: Radius of curvature of the second mirror surface as a function of position along the mirror.

6.5.2. Roughness Requirements

The roughness requirements are listed in Table 1 and Table 2 and the requirements are the same as those in Section 6.5.2 of SLAC document SP-391-000-65.

6.6. Design and Construction

See Section 6.6 of SLAC document SP-391-000-65 except that the vendor is not required to provide a test substrate and test coupons.

6.7. Quality Assurance Provisions

See Section 6.7 of SLAC document SP-391-000-65.

7. Coating Requirements

7.1. Coating Materials

Each mirror shall be coated with 2 reflective strips, each 5 mm wide. The first strip shall consist of a single layer of SiC.

The second strip shall consist of a single layer of a high atomic number material to be specified later by the SLAC group. The two likeliest candidate materials are Rhodium (Rh) and Ruthenium (Ru).

The materials for each strip are listed in Table 3 and Table 4.

7.2. Coating Figure

The coating process of the mirrors shall preserve the figure of the polished Silicon substrates as described in Section 6. The figure error requirements listed in Table 3 and Table 4 shall not be exceeded after the coating is performed unless the mirror substrate that was delivered did not meet these specifications and a relaxed tolerance was agreed upon by the SLAC group.

Parameter	Value	Units	Comment
Coating material	SiC		
Coating thickness	50	nm	
Figure height error	<1.00	nm rms	Over dimensions from 1mm to the clear aperture size
Mid-spatial roughness	<0.25	nm rms	Over the 10^{-3} to 0.5 μm^{-1} frequency range
High-spatial roughness	<0.25	nm rms	Over the 0.5 to 50 μm^{-1} frequency range
Coating Strip width	5	mm	

Table 3: Mirror coating requirements for the first strip

Parameter	Value	Units	Comment
Coating layer material	Rh or Ru		
Coating layer thickness	30	nm	
Figure height error	<1.00	nm rms	Over dimensions from 1mm to the clear aperture size
Mid-spatial roughness	<0.25	nm rms	Over the 10^{-3} to 0.5 μm^{-1} frequency range
High-spatial roughness	<0.25	nm rms	Over the 0.5 to 50 μm^{-1} frequency range
Coating Strip width	5	mm	

Table 4: Mirror coating requirements for the second strip

7.3. Coating Roughness

See Section 7.3 of SLAC document SP-391-000-65.

7.4. Workmanship

See Section 7.4 of SLAC document SP-391-000-65.

7.5. Process Development

See Section 7.5 of SLAC document SP-391-000-65.

7.6. Handling and Cleaning

See Section 7.6 of SLAC document SP-391-000-65.

7.7. Packaging and Shipping

See Section 7.7 of SLAC document SP-391-000-65.

7.8. Test Coupon Packaging and Shipping

See Section 7.8 of SLAC document SP-391-000-65.

7.9. Handling and Coating Process Plan

See Section 7.9 of SLAC document SP-391-000-65..

7.10. Quality Assurance Provisions

See Section 7.10 of SLAC document SP-391-000-65.

7.11. Test Coupons

No test coupons will be provided, contrary to the specifications in SLAC document SP-391-000-65.

8. Metrology Requirements

See Section 8 of SLAC document SP-391-000-65.

9. Mechanical Requirements

A single vendor will be responsible for all 3 components in this section (Mirror Support, Vacuum Enclosure and Support Stand). While the document refers to 3 distinct vendors: the mirror support vendor, the vacuum enclosure vendor and the support stand vendor, these three vendors shall be one and the same company that is responsible for the delivery of the full system.

9.1. Mechanical Requirements

All the specifications described in Section 9.1 of SLAC document SP-391-000-65 shall apply and the mechanical systems for both CXI KB systems shall be identical except for the different nominal positions of some of the angles due to the different incidence angles for the two mirror systems. The new nominal values are highlighted in red in Table 5 and Table 6 below.

Motion	Motorization Required	Nominal Position	Range	Resolution	Repeatability	Stability
x1	Yes	0	-7 mm < x < 7 mm	4 µm	4 µm	1 (10) µm
y1	Yes	0	-10 mm < y < 4 mm	4 µm	4 µm	0.1 (1) µm
z1	Yes	-0.9 m (from focus)	± 20 mm	8 µm	8 µm	1 (1) µm
Grazing angle (θ1)	Yes	3.067 mrad	2.5 mrad < θ < 3.5 mrad	0.5 µrad	0.5 µrad	0.01 (0.1) µrad
In-plane rotation (ψ1)	No	0	-10 mrad < ψ < 10 mrad	1 mrad	1 mrad	0.1 (0.1) mrad
Perpendicularity (φ1)	Yes	0	-100 µrad < φ < 100 µrad	5 µrad	5 µrad	1 (1) µrad

Table 5: Motion requirements for the upstream mirror. The stability number corresponds to short term (~1 minute) stability while the number in parentheses correspond to long term stability (over 1 day).

Motion	Motorization Required	Nominal Position	Range	Resolution	Repeatability	Stability
x2	Yes	0	-7 mm < x < 7 mm	4 μm	4 μm	1 (10) μm
y2	Yes	0	-10 mm < y < 2 mm	4 μm	4 μm	0.1 (1) μm
z2	No	-0.5 m (from focus)	Fixed	Fixed	Fixed	1 (1) μm
Grazing angle (θ2)	Yes	2.786 mrad	2.5 mrad < θ < 3.5 mrad	0.5 μrad	0.5 μrad	0.01 (0.1) μrad
In-plane rotation (ψ2)	No	3.1 mrad	-10 mrad < ψ < 10 mrad	1 mrad	1 mrad	0.1 (0.1) mrad
Perpendicularity (φ2)	No	0	-100 μrad < φ < 100 μrad	5 μrad	5 μrad	1 (1) μrad

Table 6: Motion requirements for the downstream mirror. The stability number corresponds to short term (~1 minute) stability while the number in parentheses correspond to long term stability (over 1 day).

9.2. Vacuum Enclosure Requirements

The mirrors fabricated by the mirror substrate vendor are described in Section 6. They will then be coated by the mirror coating vendor as described in Section 7. After characterization by the metrology vendor, described in Section 8, they will be mounted on the mirror support system described in Section 9.1.

The fully assembled system will then be placed in the mirror vacuum enclosure designed and built by the vacuum enclosure vendor.

The same vendor shall be responsible for the mirror support system (Section 9.1), the vacuum enclosure (Section 9.2) and the support stand (Section 9.2.24) Therefore all three systems (support, enclosure and stand) may be designed as a single entity.

Due to the very short focal length of the mirrors in the CXI 0.1 micron KB System, there is very little useable space between the KB system and the focal plane. It is therefore necessary that the vacuum enclosure of the CXI 0.1 micron KB System also serves as the CXI 0.1 micron Sample Chamber described in SLAC document ESD# SP-391-000-67.

The vacuum enclosure vendor shall be responsible only for the vacuum enclosure and the vacuum ports that are necessary for the CXI 0.1 micron Sample Chamber. These ports shall be defined iteratively between SLAC and the vacuum enclosure vendor during the design phase. SLAC shall be fully responsible for any attachments to the chamber downstream of the mirrors and for any internal components required by SLAC document SP-391-000-67.

The responsibility of the vacuum enclosure vendor shall be to make the vacuum enclosure long enough for it to hold the sample manipulation components and include the ports required. The dimensions will be fully defined in the design phase by SLAC but will likely require the vacuum enclosure to be roughly 600 mm longer on the downstream end as compared to the 1 micron KB System described in SLAC document SP-391-000-65.

9.2.1. Performance Requirements

The vacuum enclosure shall be compatible with 10^{-9} Torr or better vacuum pressure.

9.2.2. Dimensions

Same as for the 1 micron KB System described in Section 9.2.2 of SLAC document SP-391-000-65 except for an extra 600 mm on the downstream end. It is also possible that the extra downstream end of the chamber may need to be made slightly wider to accommodate the sample environment. The requirements for the Sample Chamber part of the vacuum enclosure are found in SLAC document ESD# SP-391-000-67.

9.2.3. Kinematics/Supports

See Section 9.2.3 of SLAC document SP-391-000-65.

9.2.4. Mechanical Interfaces

The vacuum enclosure will be linked to its environment as follows:

Entrance port: A 6" non-rotatable flange upstream centered on a beam height of 1400mm

Exit port: A 19.5625" non-rotatable wire-seal flange downstream centered on the exit beam. This large exit port is required to allow large scattering angles to be measured.

The vacuum enclosure entrance and exit ports must accommodate the 180° included angle between the incident and reflected x-ray beam. The mirror's reflecting surface should line up with the centers of the entrance and exit ports

The downstream and upstream flanges will be able to support a gate valve that will isolate the chamber from its external environment.

Both downstream and upstream components of the KB mirror vacuum enclosure will be linked to it by a welded bellows assembly.

9.2.5. Ports

See Section 9.2.5 of SLAC document SP-391-000-65. Also required will be extra ports for the 0.1 micron Sample Chamber described in SLAC document SP-391-000-67. The exact number and location of the ports will have to be defined during the design phase.

9.2.6. Vacuum Requirements

See Section 9.2.6 of SLAC document SP-391-000-65.

9.2.7. Seals

Only metal seals shall be used on the vacuum enclosure.

9.2.8. Materials

See Section 9.2.8 of SLAC document SP-391-000-65.

9.2.9. Mirror Support Mount

See Section 9.2.9 of SLAC document SP-391-000-65.

9.2.10. Thermal Issues

See Section 9.2.10 of SLAC document SP-391-000-65.

9.2.11. Alignment/Fiducialization

See Section 9.2.11 of SLAC document SP-391-000-65.

9.2.12. Stability

See Section 9.2.12 of SLAC document SP-391-000-65.

9.2.13. Workmanship

See Section 9.2.13 of SLAC document SP-391-000-65.

9.2.14. Handling and Cleaning

See Section 9.2.14 of SLAC document SP-391-000-65.

9.2.15. Packaging and Shipping

See Section 9.2.15 of SLAC document SP-391-000-65.

9.2.16. Electrical Requirements

See Section 9.2.16 of SLAC document SP-391-000-65.

9.2.17. Quality Assurance Provisions

See Section 9.2.17 of SLAC document SP-391-000-65.

9.2.18. Quality Assurance Requirements

See Section 9.2.18 of SLAC document SP-391-000-65.

9.2.19. Manufacturing and Assembly

See Section 9.2.19 of SLAC document SP-391-000-65.

9.2.20. Installation

See Section 9.2.20 of SLAC document SP-391-000-65.

9.2.21. Maintenance and Accessibility

See Section 9.2.21 of SLAC document SP-391-000-65.

9.2.22. Documentation

See Section 9.2.22 of SLAC document SP-391-000-65.

9.2.23. Part Marking

See Section 9.2.23 of SLAC document SP-391-000-65.

9.2.24. Separation of the Mirror Vacuum from the Sample Area

The mirrors require an ultra-high vacuum. For some samples, it may not be practical to have such high vacuum. A physical separation is therefore required between the two parts of the vacuum enclosure. There shall be a solid wall with a small aperture (~15 mm diameter) separating the mirrors from the downstream part of the vacuum enclosure (the Sample Chamber area). This aperture shall be large enough to allow both the mirror deflected beam and the direct unfocused beam to pass. This small aperture will allow differential pumping to maintain the ultra-high vacuum around the mirrors. Also, a thin window may be placed at the aperture to separate the two vacuum areas. Concept drawings are shown below.

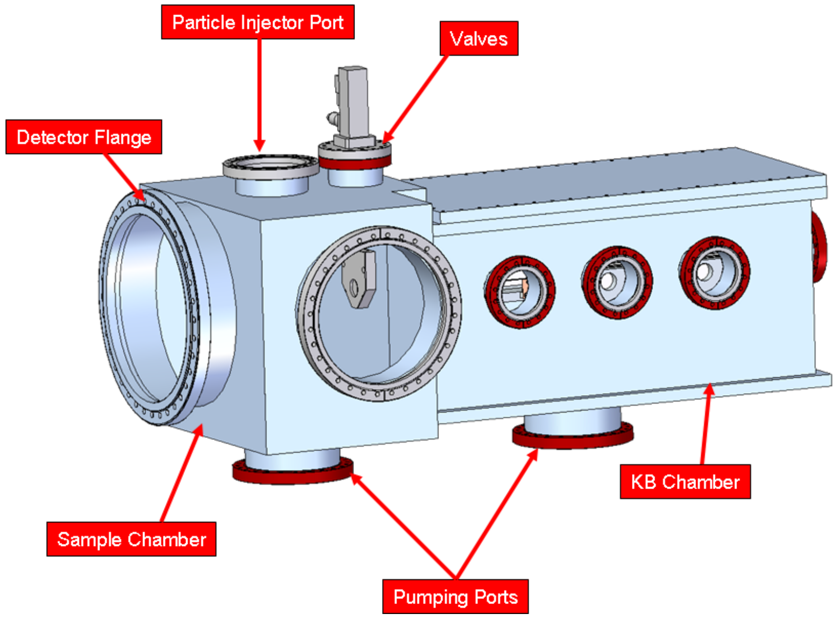

Figure 5: Conceptual design of the 0.1 micron KB vacuum enclosure with the 0.1 micron Sample Chamber as a single assembly. The KB chamber and the Sample Chamber are separated by a wall with a small aperture and two custom valves allowing the Sample Chamber to be vented while maintaining the vacuum in the KB chamber.

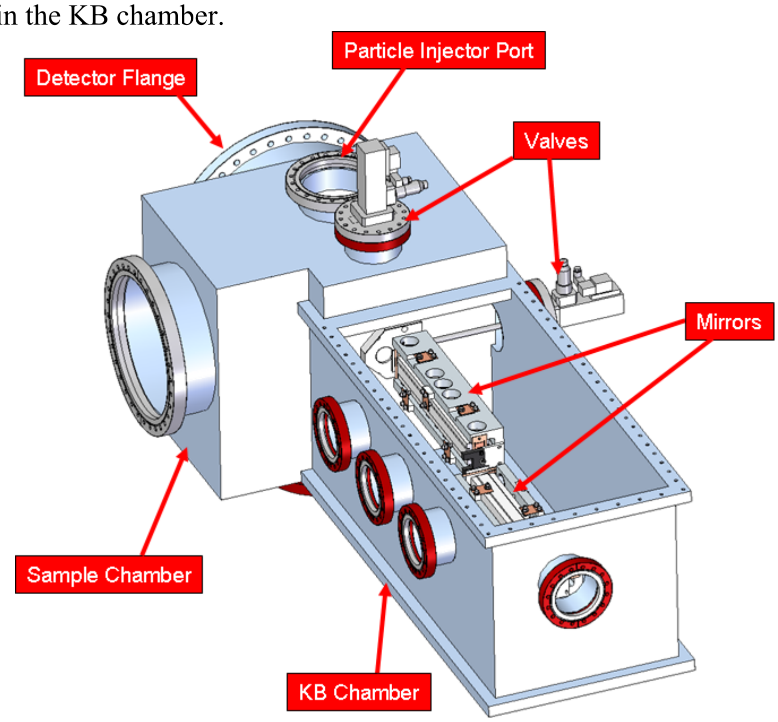

Figure 6: Conceptual design of the 0.1 micron KB vacuum enclosure with the 0.1 micron Sample Chamber as a single assembly. The KB chamber and the Sample Chamber are separated by a wall with a small aperture and two custom valves allowing the Sample Chamber to be vented while maintaining the vacuum in the KB chamber. The mirrors are shown with the KB lid removed.

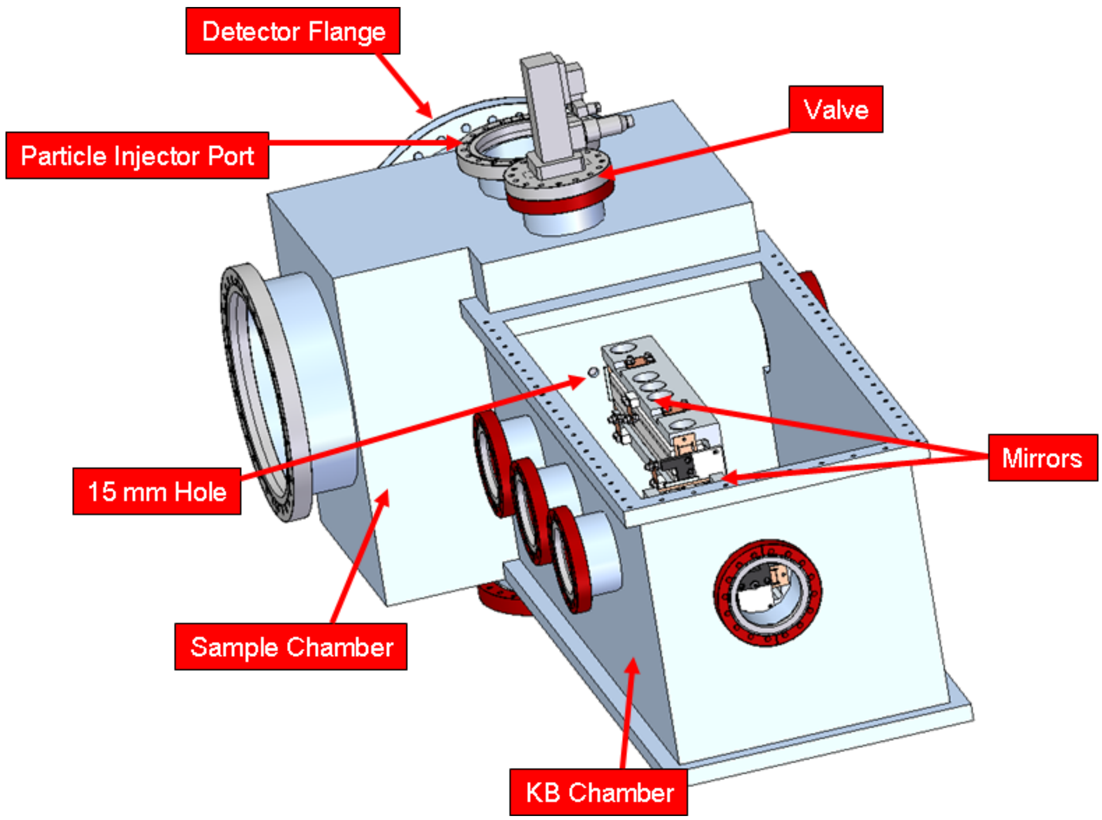

Figure 7: Conceptual design of the 0.1 micron KB vacuum enclosure with the 0.1 micron Sample Chamber as a single assembly. The KB chamber and the Sample Chamber are separated by a wall with a small aperture and two custom valves allowing the Smaple Chamber to be vented while maintaining the vacuum in the KB chamber. The small aperture between the 2 sections of the vacuum enclosure is highlighted. The valve on the KB Chamber side is hidden in this view.

9.3. Stand Requirements

This section describes the requirements for the stand which supports the vacuum enclosure of the 0.1 micron KB system. The requirements for the support stand of the 0.1 micron KB System are identical to the requirements of the 1 micron KB System described in Section 9.2.24 of SLAC document SP-391-000-65 except that the length of the stand is increased due to the longer vacuum enclosure required for the 0.1 micron system. The expected increase in length is roughly 600 mm. This stand serves as the 0.1 micron Precision Instrument Stand and renders SLAC document SP-391-000-69 obsolete. Except for the length, all the specifications of this stand are identical to those in Section 9.2.24 of SLAC document SP-391-000-65.

10. Major Interfaces

10.1. Detector Stage

The CXI Detector Stage, described in SLAC Document ESD # SP-391-000-70 shall interface with the downstream port of the vacuum enclosure through a 19.5625" non-rotatable wire-seal flange downstream centered on the exit beam. This large exit port is required to allow large scattering angles to be measured.

11. Installation

The LUSI project is responsible for the installation of all components in the CXI instrument. The mirror substrate vendor and the mirror support system vendor shall provide on-site assistance during installation as required by the LUSI project.

12. Nonconformance and Corrective Action

Any departure from the requirements of this specification that the vendor proposes to make shall be documented and submitted to SLAC for approval.

13. Proprietary Information

Any information of a proprietary nature shall be noted in the bid response and final vendor documentation.

14. Controls

The KB mirror system will be remotely operated and controlled for all motions. If the design allows it, it is preferable but not required that the actuators used are compatible with the Experimental Physics and Industrial Control System (EPICS) software tools and have existing EPICS drivers.

Developing the controls will be the responsibility of the LUSI project. The motors and stages used by the vendors shall first and foremost meet the positioning requirements. However, if multiple options exist, the LUSI project requests that the vendors select devices for which EPICS software already exists. The list of EPICS supported hardware is available here http://www.epics.org/.

All functions of the KB system shall be controlled remotely.

An interlock shall be provided by LUSI for the vacuum system. A vacuum gauge will control the vacuum level in the KB vacuum enclosure. An interlock will trigger the closing of the upstream and downstream gate valve in the case of an abnormal pressure rise.

Software limits shall be provided by LUSI to restrict the range of motion of the mirrors once they are aligned.

An interlock shall be provided by LUSI between the PPS photon stopper and the mirror positioning stages in order to ensure that the X-ray beam is turned off during large motions of the system.

15.Environmental Safety and Health Requirements

15.1. Seismic

SLAC National Accelerator Laboratory (SLAC) is situated in an active seismic zone. All hardware exceeding a weight of 400 Lbs. and / or mounted greater than 4 feet above the floor will be reviewed by a SLAC "citizen safety committee" for seismic loading resistance. Applicable loads and structural behavior will be evaluated for compliance to the 2007 version of the California Building Code (CBC) and SLAC ES&H Division document SLAC-I-720-0A24E-001-R002: "Seismic Design Specification for Buildings, Structures, Equipment, and Systems".

Submission of the seismic calculations shall be provided for SLAC approval prior to the start of manufacturing. (Allow for at least one month of time for seismic approval.)

15.2. Radiation Physics

The KB system will be installed inside hutch 5 which is not accessible while the X-ray beam is allowed to enter the hutch. Therefore no radiation shielding for personnel protection is required.

15.3. Pressure Vessel/Vacuum Vessel

The 0.1 micron KB vacuum vessel shall be designed for use in a Ultra-High Vacuum environment with the appropriate safety factors.

Pressure relief safe guards will be provided, where appropriate, to ensure compliance with all applicable guidelines/regulations, i.e. 10CFR851.

16. Acronyms

CXI: Coherent X-ray Imaging

EPICS: Experimental Physics and Industrial Control System

FEH: Far Experimental Hall

FEL: Free Electron Laser

FWHM: Full-Width Half-Maximum

KB: Kirkpatrick-Baez

LCLS: Linac Coherent Light Source

LUSI: LCLS Ultrafast Science Instruments

NRTL: Nationally Recognized Testing Laboratory

QA: Quality Assurance

rms: Root Mean Square

UHV: Ultra-High Vacuum

17.Summary of the Specifications

17.1. Mirror Substrates

The mirror substrate vendor shall provide 2 mirror substrates meeting the requirements summarized below. Highlighted in red are the differences between the 1 micron KB System and the 0.1 micron KB System.

17.1.1. Substrate Specifications

	Parameter	Value	Value	Units	Comment
		Mirror 1	Mirror 2		
1	Mirror Shape	Tangential ellipse			
2	Clear aperture length	350		mm	
3	Clear aperture width	30 ≥ width ≥ 12		mm	
4	Mirror Length	375 ≥ length ≥ 360		mm	
5	Mirror Width	60 ≥ width ≥ 45		mm	
6	Mirror Thickness	>50		mm	
7	Substrate material	Si <100>			
8	Figure height error	<1.00		nm rms	Over dimensions from 1mm to the clear aperture size from best-fit ellipse
9	Mid-spatial roughness	<0.25		nm rms	Over the 10^{-3} to 0.5 μm^{-1} frequency range
10	High-spatial roughness	<0.25		nm rms	Over the 0.5 to 50 μm^{-1} frequency range
11	Tangential Slope error	<0.25		µrad rms	Over dimensions from 1mm to the clear aperture size from best-fit ellipse
12	Sagittal Slope error	<2		µrad rms	Over dimensions from 1mm to the clear aperture width from best-fit sagittal radius
13	Sagittal radius of curvature	>400		m	
14	Focal length	0.9	0.5	m	
15	Maximum incidence angle	3.4		mrad	
16	Average incidence angle	3.067	2.786	mrad	
17	Distance from source	420		m	
18	Vacuum pressure	$<10^{-9}$		Torr	

Table 7: Summary of the mirror substrate specifications

17.1.2. Other Requirements

Item	Comments
Surface finish on non-optical surfaces	Ground and wet-chemical etched
Operating environment and service temperature range	Normal operation in ultrahigh vacuum (UHV) at ~20°C. UHV bake out at 125°C.
Mirror Coating	Provided by Others
Test Coupons	No test coupons required
Inspection	After initial shaping of the mirrors
Metrology	Provide metrology plan to SLAC. Perform metrology after final polishing is complete
Handling and Cleaning	Full, Ultrahigh Vacuum (UHV) practice required. Provide a summary of proposed handling and cleaning procedures in the "Handling and Process Plan".
Packaging and Shipping	Vendor shall be responsible for design and fabrication of the mirror shipping container(s). Best protection against contamination and shock/vibration is essential. All-metal, dust-free interior-most enclosure desirable. Include a description of proposed packaging and shipping arrangements in the "Handling and Process Plan"
Documentation	Include a description of proposed characterization metrology in the "Inspection Test Procedure".
	Supply machine-readable raw data sets for all metrology performed of mutual agreement. as part of the "Inspection Test Report".
	Describe file format and supply necessary constants and parameters to permit independent data analysis of the raw data.
Quality Assurance	Provide detailed project schedule
	Identify project manager as single point of contact
	Monthly teleconferences with SLAC

Table 8: Summary of all requirements to be satisfied by the mirror substrate vendor.

17.2. Mirror Mechanics

A single vendor shall be responsible for all the mirror mechanical system specifications and requirements summarized below. Three distinct components are identified

- The in-vacuum mirror support system (Mirror Support System)
- The Vacuum Enclosure in which the Mirror Support System is located
- The Support Stand on which the Vacuum Enclosure in mounted

All reporting, documentation and quality assurance requirements apply to each component.

17.2.1. Mirror Support System

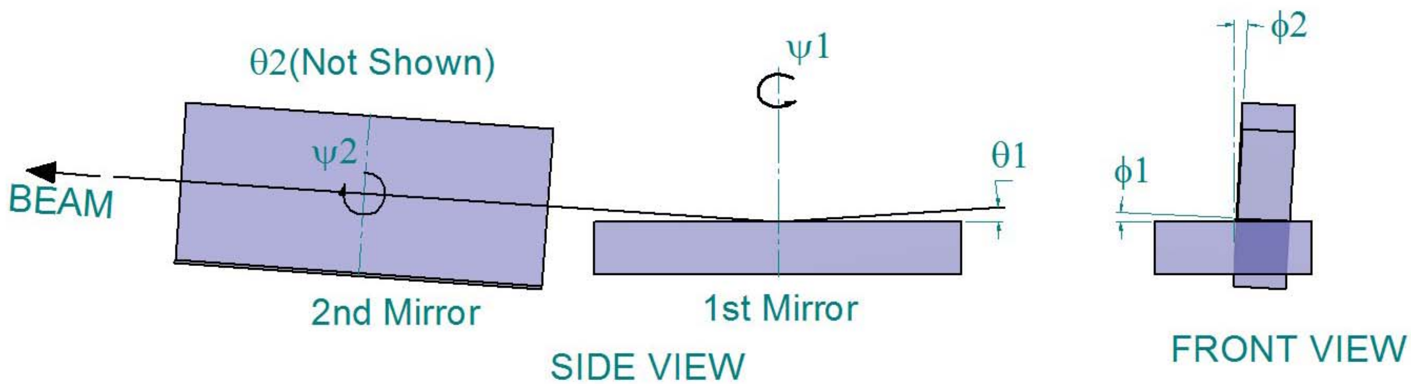

Figure 8: Definition of the KB mirror system axes of rotation

Mirror	Motion	Nominal Position	Range	Resolution	Repeatability	Motorized	Manually Adjusted	Vibrational Stability	Thermal Stability
1	x1	0	-7 mm < x < 7 mm	4 µm	4 µm	Yes	No	1 µm	10 µm
1	y1	0	-10 mm < y < 4 mm	4 µm	4 µm	Yes	No	0.1 µm	1 µm
1	z1	-0.9 m (from focus)	± 20 mm	8 µm	8 µm	Yes	No	1 µm	1 µm
1	Grazing angle (θ1)	3.067 mrad	2.5 mrad < θ < 3.5 mrad	0.5 µrad	0.5 µrad	Yes	No	0.01 µrad	0.1 µrad
1	In-plane rotation (ψ1)	0	-10 mrad < ψ < 10 mrad	1 mrad	1 mrad	No	Yes	0.1 mrad	0.1 mrad
1	Perpendicularity (φ1)	0	-100 µrad < φ < 100 µrad	5 µrad	5 µrad	Yes	No	1 µrad	1 µrad
2	x2	0	-7 mm < x < 7 mm	4 µm	4 µm	Yes	No	1 µm	10 µm
2	y2	0	-10 mm < y < 2 mm	4 µm	4 µm	Yes	No	0.1µm	1 µm
2	Grazing angle (θ2)	2.786 mrad	2.5 mrad < θ < 3.5 mrad	0.5 µrad	0.5 µrad	Yes	No	0.01 µrad	0.1 µrad
2	In-plane rotation (ψ2)	3.1 mrad	-10 mrad < ψ < 10 mrad	1 mrad	1 mrad	No	No	0.1 mrad	0.1 mrad
2	Perpendicularity (φ2)	0	-100 µrad < φ < 100 µrad	5 µrad	5 µrad	No	No	1 µrad	1 µrad
2	z2	-0.5 m (from focus)	Fixed	Fixed	Fixed	Fixed	Fixed	1 µm	1 µm

Table 9: Summary of the mirror mechanical motion specifications

17.2.2. Other Specifications

Item	Comments
45 degree geometry	Provide an option for mounting the mirrors at 45 degrees from the standard KB configuration to deflect the beam in the horizontal direction only. SLAC will decide to exercise the option or not after the receipt of the proposal
Mirror mounting	Preserve the figure of the mirrors without the specifications of the substrates Clear aperture of at least 2 mm x 12 mm
Motion limits	Two sets of limit switches, for small and large motions Motions limits to be implemented for beam confinement by SLAC Hard stops for full range of motion
Expected lifetime of device	10 years
Dimensions inside vacuum	Length: < 0.8 m Width : < 350 mm from center in the –x direction No restriction in the +x direction Height: No restriction other than the beam height of 1.4 m and ceiling of 3 m
Vacuum	Normal operation in ultrahigh vacuum (UHV) at ~20°C. UHV bake out at 125°C.
Thermal issues	<34 mW of heat will be absorbed by the mirror substrates during operations. Vendor to perform analysis to demonstrate the performance of the system given this heat load
Radiation protection	The LCLS beam will damage most materials except for light materials. Only the optical surface shall be exposed to the beam. Any other surface exposed to the beam shall be protected with a B4C shield B4C shield to protect the leading edge of the mirrors
Operating conditions	SLAC to provide a thermal enclosure stable to within 0.01 degree Celcius
Design and Analysis	Vendor design to include : Interface definition Component design Stress and thermal analysis Reliability analysis System performance analysis Verification and test plans Integration of the mirror substrates into the mechanical system

Materials	Provide list of materials to be used
Electrical	Provide all vacuum feedthroughs and UHV connectors
Controls and motors	Use device with existing EPICS drivers to the extent possible
Handling and Cleaning	Full, Ultrahigh Vacuum (UHV) practice required. Provide a summary of proposed handling and cleaning procedures in the "Handling and Process Plan".
Packaging and Shipping	Vendor shall be responsible for design and fabrication of the system shipping container(s). Best protection against contamination and shock/vibration is essential. All-metal, dust-free interior-most enclosure desirable. Include a description of proposed packaging and shipping arrangements in the "Handling and Process Plan"
Documentation	Include a description of proposed characterization fabrication, assembly and inspection in the "Inspection Test Procedure".
	Supply machine-readable raw data sets for all measurements performed of mutual agreement.as part of the "Inspection Test Report".
	Describe file format and supply necessary constants and parameters to permit independent data analysis of the raw data.
	Provide all as-built drawings to SLAC in PDF format and all 3D models in agreed upon formats
	Provide a qualification and verification matrix with pass/fail grades after final testing
	Report all non-conformance with the specifications to SLAC
Part marking	Vendor to inscribe all parts, assemblies and sub-assemblies with a unique serial number, whenever possible
Quality Assurance	Provide detailed project schedule
	Identify project manager as single point of contact
	Monthly teleconferences with SLAC
	Configuration control to be implemented by vendor with a formal change process to drawings
Reviews	Conceptual Design Review : 2 months after award
	Preliminary Design Review : 4 months after award
	Final Design Review: 10 months after award
	Manufacturung Readiness Review: Prior to start of fabrication
	Pre-Ship Review: Acceptance testing prior to shipping
Installation at SLAC	Vendor responsible for assembly and installation at SLAC SLAC will provide all necessary assistance

Table 10: Summary of all the mirror mechanical specifications and requirements

17.2.3. Vacuum Enclosure

Item	Comments
Vacuum	Normal operation in ultrahigh vacuum (UHV) at ~20°C. UHV bake out at 125°C.
Dimensions	0.8 m < Length < 1.75 m Width : < 450 mm from center in the –x direction No restriction in the +x direction Height: No restriction other than the beam height of 1.4 m and ceiling of 3 m
Vacuum Separation	A solid wall with a 15 mm hole shall separate two sections of the chamber Two valves shall be used to isolate the vacuum of each section. A thin window shall be included in the second valve for X-ray transmission
Mounting	Reproducible to within 0.1 mm
Environment	Vacuum enclosure to be located inside a thermal enclosure controlled to 0.01 degree Celcius Stability requirements to be met under these conditions
Fiducialization	Provide external references outside the vacuum enclosure for surveying External references to be at known positions relative to the mirrors inside vacuum
Maintenance and Accessibility	Design to allow removal of the in-vacuum components without removing the vacuum chamber from the beamline Multiple access ports to be provided for small maintenances Removal top of the chamber with fixtures for lifting with a crane No trip hazards, pinch points, loose cables

Table 11: Summary of all specifications and requirements for the Vacuum Enclosure.

17.2.3.1. Vacuum Ports

	Port type or use	Orientation	Location	Purpose
1	Entrance Port (6" non-rotatable)	Along the beam	Upstream of chamber, centered on the beam	Let the beam in
2	Exit Port (6" rotatable)	Along the beam	Dowstream of chamber, centered on the beam	Let the beam out
3	Viewport (4.5")	Along $\psi 1$ axis	Midpoint along z of mirror 1	Future addition of interferometer
4	Viewport (4.5")	Along $\theta 1$ axis	Midpoint along z of mirror 1	Future addition of interferometer
5	Viewport (4.5")	Along $\psi 2$ axis	Midpoint along z of mirror 2	Future addition of interferometer
6	Viewport (4.5")	Along $\theta 2$ axis	Midpoint along z of mirror 2	Future addition of interferometer
7	Vacuum gauge (2.75")	Any	Anywhere	Measure the pressure
8	Vacuum gauge (2.75")	Any	Anywhere	Measure the pressure

9	Rough pumping (2.75”)	Any	Anywhere	Pump down the enclosure from atmosphere
10	Ion Pump (6”)	Any	Bottom of enclosure	Create Ultra-high vacuum
11	Feedthrough (6”)	Any	Near the back side of mirror 1	Connect cables for motorized motions
12	Feedthrough (6”)	Any	Near the back side of mirror 2	Connect cables for motorized motions
13	Miscellaneous (6”)	Any	Anywhere	Future expansion
14	Miscellaneous (6”)	Any	Anywhere	Future expansion
15	Miscellaneous (2.75”)	Any	Anywhere	Future expansion
16	Miscellaneous (2.75”)	Any	Anywhere	Future expansion

Table 12: List of required vacuum ports for the Vacuum Enclosure

17.2.4. Support Stand

Item	Comments
Stability	Shall meet the vibrational and thermal requirements of the mirror support system described above
Dimensions	0.8 m < Length < 1.75 m Width : < 450 mm from center in the –x direction No restriction in the +x direction Height: Must position the mirrors at a beam heigh of 1.4 m
Structural issues	Design to be certified by the SLAC Earthquake Safety Committee is the total weight of the system exceeds 400 pounds Vendor to allow 6 weeks for SLAC approval
	Design shall satisfy the 10CFR851 requirements for pressure vessels
Positioning	Allow the vacuum enclosure and mirror support system to be positioned over a ± 12.5 mm range for coarse positioning in case of beam drifts over long periods
Color	Painted with red color matching the US Federal Standard FS11140

Table 13: Summary of all specifications and requirements for the Support Stand.