LUSI LCLS Ultrafast Science Instruments

PHYSICS REQUIREMENT DOCUMENT (PRD)	Doc. No. SP-391-000-19 R3	LUSI SUB-SYSTEM Coherent X-Ray Imaging

Physics Requirements for the CXI Instrument

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Revision	Date	Description of Changes	Approved
R0	30NOV07	Initial release	
R1	23JUN08	Updated the list of devices in LUSI scope, Updated the instrument layout, Added global requirements section, Added Safety requirements section, Added quality assurance section, Added operations and maintenance requirements section, Added installation requirements section, Added commissioning plans section, Added acceptance testing requirements section, Added codes and standards section	
R2	29JUL08	Updated the document to reflect the addition of a second sample chamber and a second instrument stand	
R3	15DEC08	Defined 2 interaction planes (section 3), Modified the instrument layout to move some equipment from the X-ray Tunnel to hutch 5 due to XCS layout modifications (section 5 and 6), Updated the design of the FEH (Section 7)	

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1. Applicable Documents

PRD# SP-391-000-03	LUSI Controls and Data System
PRD# SP-391-000-04	LUSI Pop-in Profile Monitor
PRD# SP-391-000-06	LUSI Data Management System
PRD# SP-391-000-08	LUSI Intensity-Position Monitor
PRD# SP-391-000-09	LUSI Pop-in Intensity Monitor
PRD# SP-391-000-10	LUSI Attenuator System
PRD# SP-391-000-11	LUSI X-ray Focusing Lens System
PRD# SP-391-000-14	LUSI Slit System
PRD# SP-391-000-15	LUSI Wavefront Monitor
PRD# SP-391-000-20	CXI 0.1 micron Sample Chamber
PRD# SP-391-000-21	CXI Reference Laser System
PRD# SP-391-000-23	LUSI Pulse Picker
PRD# SP-391-000-24	CXI 0.1 micron KB System
PRD# SP-391-000-25	CXI 1 micron KB System
PRD# SP-391-000-26	CXI Particle Injector System
PRD# SP-391-000-28	CXI Detector Stage
PRD# SP-391-000-30	CXI Ion TOF
PRD# SP-391-000-63	CXI 0.1 micron Precision Instrument Stand
PRD# SP-391-001-41	CXI 1 micron Sample Chamber
PRD# SP-391-000-63	CXI 1 micron Precision Instrument Stand
LCLS PRD # 1.6-002	2-D X-Ray Detector

2. Overview

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. 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.

This document contains a general description of the CXI instrument. A separate PRD for each component of the instrument provides more specific details.

The coordinate system is defined in Mechanical Design Standards Supplement DS-391-000-36.

3. Interaction Regions and Coordinate System

The interaction region is the volume of space where the LCLS X-ray beam interacts with the sample. The entire instrument must be designed around that small volume. The plane perpendicular to the beam direction, the z-direction, in which the interaction occurs, is the interaction plane. The CXI instrument will have two interaction regions, one in each of two sample chambers. Each of the two KB focusing mirror systems will have its own associated interaction region. We will use the right hand rule coordinate system with +z along the beam propagation, +y vertical up and +x to the left when looking downstream. For this document, we define z=0 as the interaction plane associated with the 1 micron KB System. The 1 micron interaction point will be in this plane with varying x and y position. The 0.1 micron interaction point will be located in a plane upstream, at a z position smaller than zero but greater than -8 m.

4. Configurations

Several configurations of the instrument are necessary for the various samples that will be studied. These are introduced below. All these experiments require high vacuum to minimize background scatter. Every component of the instrument is therefore required to be in vacuum.

4.1. *Fixed Target Forward Scattering*

The schematic for fixed target experiments in the forward scattering geometry is shown on Figure 4-1. The focused x-ray beam passes through a final aperture before it impinges on the sample. The aperture and the sample can be translated in all directions and independently, while the sample can also rotate about the x and y axes. The aperture stage can also be used to mount optical components such as Fresnel zone plates to produce a very divergent focused beam. This would be used to perform imaging experiments with a curved wavefront. The 2D detector measures the diffracted beam while letting the direct beam passe through a hole in the center. The sample to detector distance can be varied to achieve the desired resolution and oversampling of the diffraction pattern.

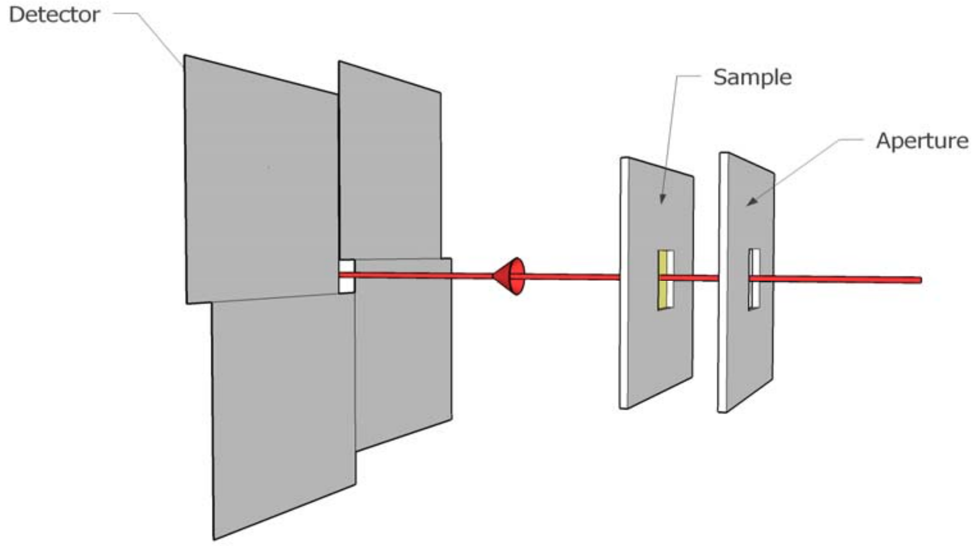

Figure 4-1: Schematic representation of the experimental geometry for forward scattering from fixed targets.

4.2. *Injected Particles Forward Scattering*

The schematic for forward scattering measurements of injected particles is shown in Figure 4-2. A focused beam of particles exits the nozzle of the particle injector. This beam can be steered and is made to intersect with the X-ray beam at the interaction region. The injection is done vertically from the top. An elliptically polarized laser beam may be used to align particles along a preferred and adjustable axis. A clear line-of-sight to the particle beam is necessary for the particle alignment laser. In these experiments, the sample is typically small and therefore does not scatter the X-ray beam strongly. It is of the utmost importance to reduce the background as much as possible in order to accurately measure the small signal from the sample. This is achieved using two or more apertures in close proximity to the interaction region. The downstream aperture is made slightly larger than the upstream one so it does not generate extra scatter and it can be used to remove the slit scatter from the upstream aperture. The fixed target sample-aperture assembly can be used in the particle injector setup. The sample is replaced by an aperture and the entire assembly is translated sufficiently upstream for the particle beam to pass just downstream of the last aperture. The scattered beam is detected by the area detector. The sample stage may be adapted to be used to support an electrostatic focusing device to increase the particle density at the interaction region.

The intense X-ray pulse will completely destroy the particle. Electrons will be freed and ions will be created. Those yield important information about the interaction between the X-ray beam and the sample. An ion time-of-flight mass spectrometer is used to probe the interaction region to detect the explosion fragments.

All the components are in close proximity to the interaction region and must all be kept upstream of the interaction region. The area downstream of the interaction region must be kept clear so that the detector is not screened by any component and has an unimpeded view of the interaction with a large numerical aperture.

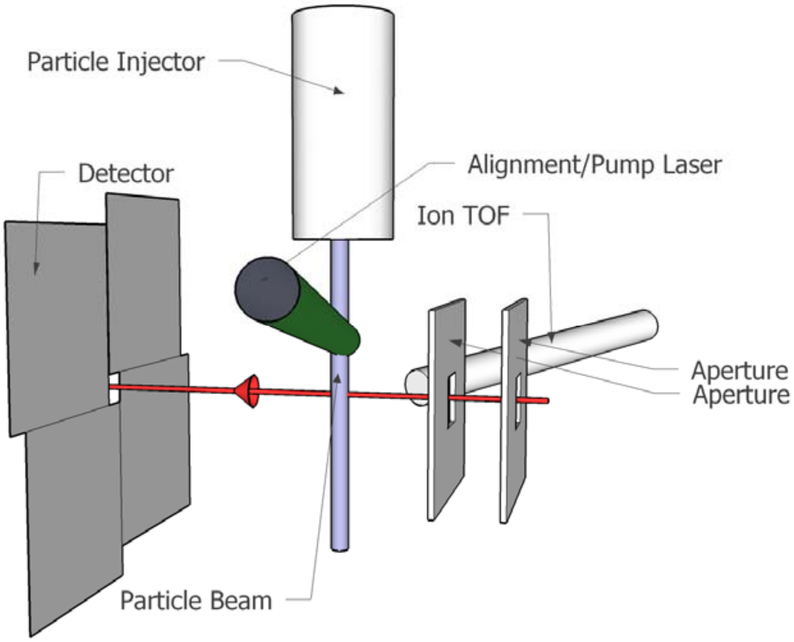

Figure 4-2: Schematic representation of the experimental geometry for forward scattering from injected submicron particles.

4.3. *Pump-Probe Imaging*

Photo-induced changes in samples can be imaged at various times following a laser excitation. In these experiments, a short laser pulse will be synchronized with the X-ray pulse. The laser pulse can be made to impinge on the sample a short controlled time before the arrival of the X-ray pulse. Fixed targets and injection experiments can be performed in a similar way as described above, with the addition of the laser pump.

4.3.1. Fixed Target

The schematic representation of the pump-probe experiments on fixed targets in the forward scattering geometry is shown in Figure 4-3. A port for the laser beam to enter the vacuum chamber must allow a direct line of sight to the interaction region. The laser beam can strike the upstream or downstream face of the sample depending on the sample. The excitation laser beam could be made collinear with the X-ray beam by the use of a mirror with a hole.

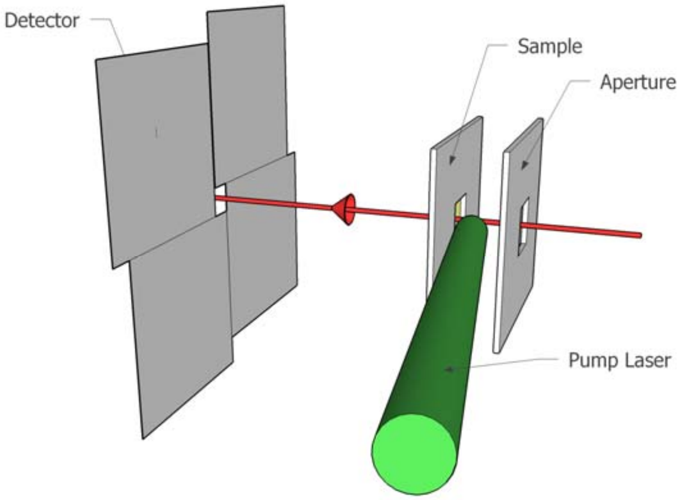

Figure 4-3: Schematic representation of the experimental geometry for forward scattering from samples on a fixed target that is photoexcited a short time before the arrival of the X-ray pulse.

4.3.2. Injected Particles

The schematic representation of the pump-probe experiments on injected particles in the forward scattering geometry is shown in Figure 4-4. The layout is identical to the layout described in Section 4.2 with the addition of the pump laser. The pump laser requires precise synchronization with the LCLS beam. A port for the laser beam to enter the vacuum chamber must allow a direct line of sight to the interaction region. The ion TOF is used to detect fragments of the particle after it undergoes a Coulomb explosion.

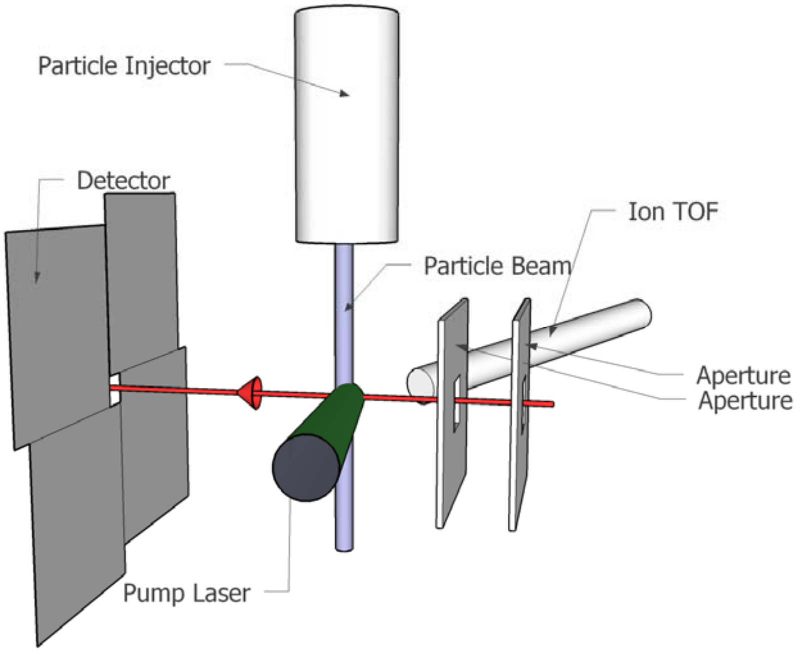

Figure 4-4: Schematic representation of the experimental geometry for forward scattering from injected particles that are photoexcited a short time before the arrival of the X-ray pulse.

4.4. *Time-Delay Holography*

Time-delay holography is a technique which allows X-ray pump-X-ray probe experiments to be performed with time delays ranging from a few hundred femtoseconds to hundreds of picoseconds. The technique will allow a sample exploding due to the LCLS pulse to be characterized at defined times after the initial interaction.

4.4.1. Fixed Target

The explosion of the sample caused by the impinging X-ray beam can be probed by sending the unscattered part of the beam back onto the sample a second time. This is accomplished as shown in Figure 4-5. The incident beam comes in from the right through the hole in the detector. The beam interacts with the sample a first time. A small fraction of the beam is scattered by the sample and most of it propagates through. This unscattered beam is back-reflected by an X-ray mirror and then interacts with the sample a second time. The mirror will likely consist of a silicon crystal with the X-ray energy tuned to a backscattering Bragg reflection. On the second pass, the sample is undergoing a Coulomb explosion and looks different depending on the time delay, which is set by the distance between the sample and the mirror. The reflected beam scatters off the sample a second time and the diffraction pattern of the exploding object is measured by the area detector. The diffracted signal from the first pass through the sample is not reflected at hard X-ray wavelengths since no mirror can be made to reflect over this wide range of angles. Therefore, there is no interference between the two diffracted beams, from the first and second passes through the sample. A large diffuse background from, among other things, the Compton scattering from the mirror is blocked using a small support window for the sample. In order to perform this type of experiment, the detector must be mounted upstream of the sample instead of downstream.

Space must be available for the detector. This may require the removal of the 0.1 µm focus KB mirror assembly that is located immediately upstream of the sample chamber (see layout in Section 5). The focal point of the X-ray beam can be placed at the plane of the mirror or the plane of the sample by translating the whole sample-aperture assembly along the beam. The mirror is only reflective for a single shot since it also gets damaged by the beam. It is therefore necessary to translate the mirror to a new spot after each shot.

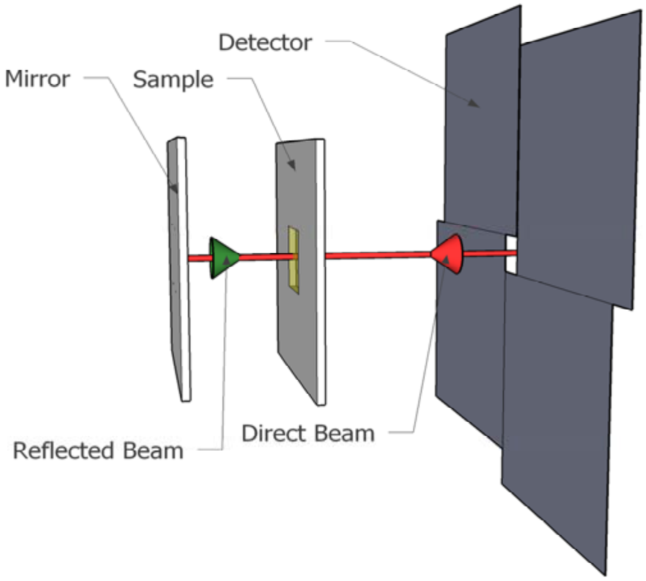

Figure 4-5: Schematic representation of the experimental geometry for time-delay holography using a sample on a fixed target.

4.4.2. Injected Particles

Similar time-delay holography measurements can be performed with injected submicron particles. The area detector is placed upstream of the interaction region. The beam is back-reflected using a mirror placed downstream of the interaction region. An aperture is also necessary to remove the strong diffuse scattering from the mirror. The fragments of the injected particle created by the X-ray pulse are detected by the ion TOF. The particles can be aligned in the particle beam using a particle alignment laser. The mirror is only reflective for a single shot since it also gets damaged by the beam. It is therefore necessary to translate the mirror to a new spot after each shot.

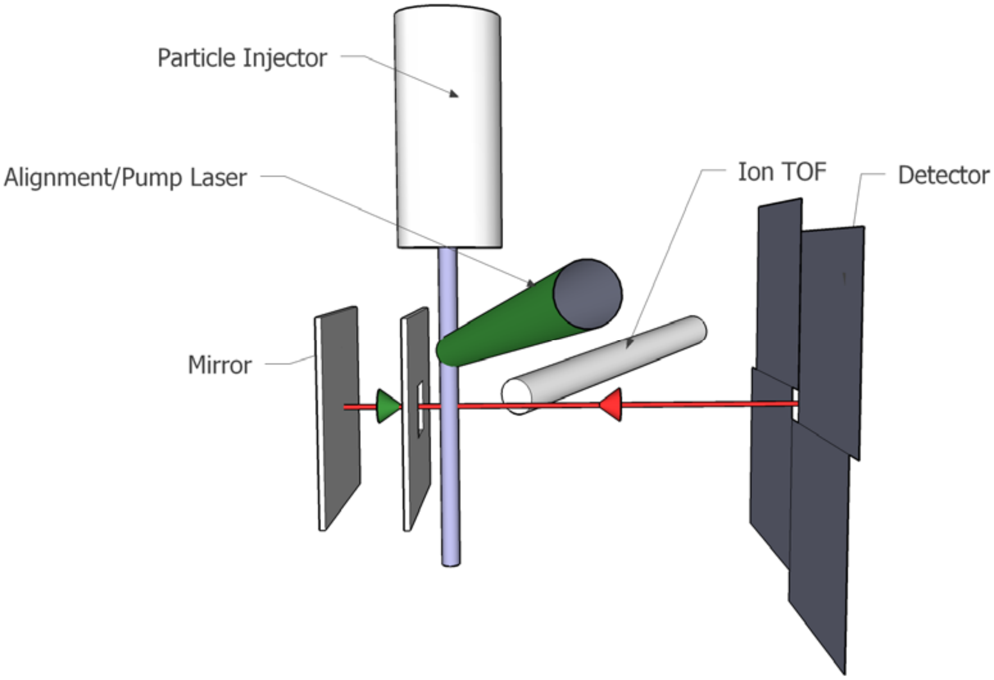

Figure 4-6: Schematic representation of the experimental geometry for time-delay holography with injected particles.

5. Layout

The layout of the components of the CXI instrument is shown in Figure 5-1 and Figure 5-2**Error! Reference source not found.**. All dedicated CXI components are located inside hutch #5 and near the exit of the X-ray Tunnel. Devices highlighted in gray are not built by the LUSI project but would be possible future additions to the instrument. Therefore, space will be reserved for these components to be added at a later time. The focusing lens assembly for example would be a future addition and would be located between the two sample chambers. Space will be reserved for future addition of this device.

A pulse compressor is also planned as a possible addition at a later time. Depending on the details of the future compressor, it may displace the beam by a small amount in the horizontal direction (+x). A maximum displacement of 5 mm is planned, which allows both the compressed and uncompressed beams to travel within the same beam pipe. The components downstream of the pulse compressor must be designed for that possible beam displacement. The pulse compressor would be located in the X-ray transport Tunnel and be a device that can be used by both the CXI and XCS instruments.

The layout of the components in the CXI hutch is shown in Figure 5-2. The very top line represents the direction of the unfocused beam. The CXI instrument shall also be capable of using the unfocused beam along this top line and all components downstream of the first KB mirror system shall be capable of moving to all three beamline directions. The middle line represents the use of the 0.1 micron KB and the bottom line represents the use of the 1 micron KB. The KB mirrors change the direction of the beam so that each component must be displaced a different amount, as shown in the layout.

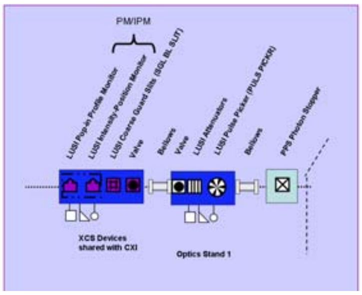

Figure 5-1: Layout of CXI specific and components shared between CXI and XCS in the X-ray Transport Tunnel. Purple devices are shared.

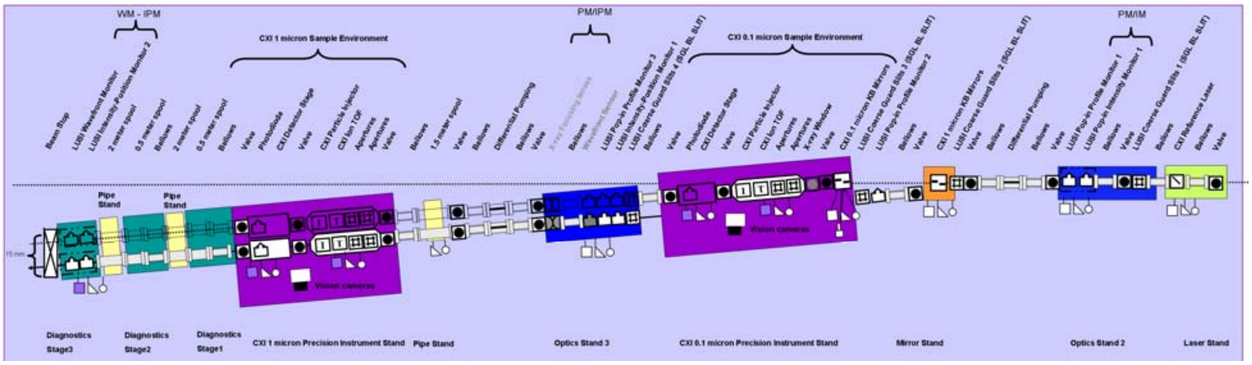

Figure 5-2: Layout of the components in the CXI hutch (Hutch #5 in the FEH). Transparent components indicate that these components need to move with the beam. Components on the 2 branches to the left need to move with the beam when different focusing optics are used, including the unfocused beam direction indicated by the top line.

5.1. *Forward Scattering versus Time-Delay Holography*

The CXI instrument will have 2 distinct interaction planes, one for each sample chamber. The forward scattering geometry will be available in both sample chambers while the time-delay holography geometry, which requires the detector to be mounted upstream of the sample, will only be available in the 1 micron Sample Chamber. The CXI Detector Stage will be mounted directly upstream of the 1 micron Sample Chamber for time-delay holography experiments.

6. Components

A short description of each component of the CXI instrument is found below. More detailed specifications are found in individual Physics Requirements Documents for each component.

6.1. *CXI Reference Laser (PRD SP-391-000-21)*

A reference laser (class IIIa or less such as a He-Ne laser) collinear with the LCLS beam will be used to verify the alignment of the apparatus. The reference laser beam will be introduced in the vacuum spool at the very entrance of the CXI hutch and will be aligned to the direct LCLS beam. When the photon stopper is blocking the X-ray beam, a mirror inside vacuum will be translated into the X-ray beam path. The photon stopper must be closed so that the X-ray beam does not hit the back of the mirror and damage it. The mirror will reflect the reference laser beam that will be introduced through a window-flange. Rotation of the mirror (pitch and yaw) will allow the reference laser to be properly aligned. Beam viewers located downstream will be used to verify that the X-ray and reference laser beams overlap to ensure proper pointing.

6.2. *LUSI Pulse Picker (PRD SP-391-000-23)*

The pulse picker will be used to select a single LCLS pulse or pulses at a desired frequency below the 120 Hz repetition rate of the LCLS source. The pulse picker will be located in the X-ray transport tunnel. The pulse picker must be synchronized with the LCLS. It must withstand the full LCLS beam and have a short enough response time to allow a single pulse to come through.

6.3. *X-ray Pulse Compressor (Not in current LUSI scope)*

The proposed pulse compressor would consist of at least two dispersive gratings a certain distance apart that depends on the characteristics of the gratings. X-rays of longer wavelength are deflected more when passing through the grating. They are made to travel a longer path than the shorter wavelength X-rays. The pulse can be compressed if the incident pulse has the proper positive chirp. For the pulse compressor to work, the LCLS source must first develop the capacity to produce a chirped X-ray beam. The pulse compressor would be located in the X-ray transport tunnel. The beam exits the compressor in the same direction as the incident beam but offset by as much as 5 mm, depending on the design. The offset direction will be chosen to be in the +x-direction to move away from the beamline going to hutch #6, as described in Section 7. The gratings of the compressor can be moved out of the beam when compression is not required. A combination of 3 or four gratings could allow for zero displacement pulse compression. The pulse compressor will not be built by the LUSI project but it will be taken into account in the design so that it can later be implemented.

6.4. *LUSI X-ray Focusing Lenses (PRD SP-391-000-11) (Not in current LUSI scope)*

Plans will be made to include X-ray focusing lenses that would be used to produce a focal spot of ~10 μm, or a collimated beam with a size similar to the unfocused beam at the interaction plane in the 1 micron Sample Chamber. The x-ray focusing lenses would be a stack of in-line refractive Beryllium lenses that are removable from the beam. To produce the desired spot size, the lenses assembly would have a variable focal length and it would therefore consist of multiple lens stacks and would need to have a variable position along the beam. The lenses will only be used to refocus the beam after it has been focused by the 0.1 micron KB System. The LUSI project will not build X-ray Focusing Lenses for the CXI instrument but the design will allow for their addition in the future.

6.5. *LUSI Guard Slits (PRD SP-391-000-14)*

The LUSI Guard Slits will be used to absorb the halo surrounding the central X-ray beam. They will not be used to define the beam and will not be cutting into the central peak. They must however be made of a material that can tolerate the full beam since they may be hit by the full beam during alignment procedures. Multiple sets of slits will be used along the beamline at various locations as shown on the layout of Figure 5-1 and Figure 5-2**Error! Reference source not found.**. They will be used after optical elements to assure only the central peak of the beam propagates further. The slit assembly must be able to account for the beam shift produced by the pulse compressor so it can be used with the compressed and uncompressed beam.

6.6. *LUSI Attenuators (PRD SP-391-000-10)*

Attenuators will be used to reduce the X-ray flux on the sample during alignment procedures as well as during some experiments where the sample must be protected from damage by the beam. Attenuators will be located in the X-ray transport tunnel, where the beam size is large to minimize radiation damage. They will consist of thin highly polished foils of damage resistant material. Multiple foils will be used to vary the attenuation up to a factor of 10^8 at 8.3 keV.

6.7. *CXI 1 Micron KB Mirror System (PRD SP-391-000-24)*

KB mirrors are a pair of elliptical mirrors perpendicular to each other. Each mirror focuses in a single direction and the combination of both produces the point focus. A KB pair taking the full direct beam will be used to produce a 1 micron focus at the interaction plane in the 1 micron Sample Chamber. This will be achieved using a KB pair with an 8 m average focal length, with the center point between the 2 mirrors located at z=-8 m, inside the CXI hutch. The KB mirrors will produce a focused beam that is not in-line with the incident beam. Therefore, the focal spot will not be at the same location as the unfocused beam. Each mirror deflects the beam by 3.4 mrad along their respective axis. The sample chamber will require translation with a large enough stroke to account for this shift. The KB mirrors will be rotated by 45 degrees from the conventional arrangement. That is the mirrors will not be vertical and horizontal but rotated by 45 degrees. This will allow for a single horizontal translation in the +x-direction to move the chamber to the correct position. The 1 micron beam will pass through the 0.1 micron Sample Chamber and be focused inside the 1 micron Sample Chamber. The 1 micron KB assembly must be able to account for the beam shift produced by the pulse compressor so it can be used with the compressed and uncompressed beam. The KB system will be held under ultrahigh vacuum ($<10^{-9}$ Torr).

6.8. *CXI 0.1 Micron KB Mirror System (PRD SP-391-000-25)*

A focal spot of less than 0.1 μm will be achieved with a second KB mirror pair, used separately from the 1 micron KB system and also taking the full direct beam. The focal length of this KB assembly will be roughly 0.9 m for the first mirror and roughly 0.5 m for the second mirror to produce the proper demagnification of the source. The exact focal length will be determined during the design phase by the interface requirements with the sample chamber as well as the mechanical design and length of the mirrors. The setup for this KB will be the same as for the larger focus KB. The only difference will be in the profile of the mirrors to yield the proper focal length. The angular deflection of the X-ray beam will also be 3.4 mrad for each mirror. The beam direction of the 0.1 micron KB system will be the same as the 1 micron beam but shifted in the –X direction by roughly 20 mm from the 1 micron KB beam. The 0.1 micron focus will be located inside the 0.1 micron Sample Chamber. The 0.1 micron KB assembly must be able to account for the beam shift produced by the pulse compressor so it can be used with the compressed and uncompressed beam. The KB system will be held under ultrahigh vacuum ($<10^{-9}$ Torr).

6.9. *Room Temperature Sample Environments*

Two sample chambers with their associated stands will be built by the LUSI project for the CXI instrument. The chamber to be built first will be compatible only with the 1 micron KB System and its design will be independent of the exact design of the 0.1 micron KB System. This sample chamber is called the CXI 1 micron Sample Chamber.

The second sample chamber will be known as the CXI 0.1 micron Sample Chamber and will be identical in functionality to the 1 micron Sample Chamber except that it will be compatible with the 0.1 micron KB System.

6.9.1. CXI 0.1 micron Sample Chamber (PRD SP-391-000-20)

The sample chamber will be able to accommodate multiple types of samples and experimental geometries as described in Section 4. The chamber position will be varied to account for the beam movements due to the optics and will be compatible with the beam focused by the 0.1 micron KB System. The 1 micron focused beam will only pass through the 0.1 micron Sample Chamber without interacting with any device inside it. The chamber will contain the following:

- 2-axis first aperture stage
- 2-axis second aperture stage
- 3-axis third aperture stage
- 3-axis sample stage with pitch/yaw
- 1-axis coarse positioning platform on which the second aperture and sample stages are mounted
- 2-axis sample viewer with pitch/yaw
- 2-axis particle injector aperture stage
- port on top for the particle injector
- port for the ion TOF
- port for the electron TOF
- port for particle alignment laser
- port for pump laser
- port for a desorbtion-ionization laser
- port for optical inspection of the sample
- particle beam diagnostics
- valves isolating the chamber from the 0.1 micron KB and the detector vacuum spools
- hatch for rapid access to the inside of the chamber
- Feedthrough flanges
- vision cameras

Most ports are facing a common point, the interaction region. The 0.1 micron Sample Chamber will be moved to place the focal spot at this position in the chamber. The pressure in the chamber will be lower than 10^{-7} Torr.

6.9.2. CXI 0.1 micron Precision Instrument Stand (PRD SP-391-000-63)

The 0.1 micron Precision Instrument Stand will be used to support the 0.1 micron Sample Chamber, the Detector Stage and the 0.1 micron KB System. It will also be used to accurately position the 0.1 micron Sample Chamber and the Detector stage with respect to the LCLS beam.

6.9.3. CXI 1 micron Sample Chamber (PRD SP-391-001-41)

The sample chamber will be able to accommodate multiple types of samples and experimental geometries as described in Section 4. The chamber position will be varied to account for the beam movements due to the optics and will be compatible with the beam focused by the 1 micron KB System and refocused by the X-ray Focusing Lenses. It will not be compatible with the 0.1 micron KB System. The chamber will contain the following:

- 2-axis first aperture stage
- 2-axis second aperture stage
- 3-axis third aperture stage
- 3-axis sample stage with pitch/yaw
- 1-axis coarse positioning platform on which the second aperture and sample stages are mounted
- 2-axis sample viewer with pitch/yaw
- 2-axis particle injector aperture stage
- port on top for the particle injector
- port for the ion TOF
- port for the electron TOF
- port for particle alignment laser
- port for pump laser
- port for a desorbtion-ionization laser
- port for optical inspection of the sample
- particle beam diagnostics
- valves isolating the chamber from the 0.1 micron KB and the detector vacuum spools
- hatch for rapid access to the inside of the chamber
- Feedthrough flanges
- vision cameras

Most ports are facing a common point, the interaction region. The 1 micron Sample Chamber will be moved to place the focal spot at this position in the chamber. The pressure in the chamber will be lower than 10^{-7} Torr.

6.9.4. CXI 1 micron Precision Instrument Stand (PRD SP-391-001-42)

The 1 micron Precision Instrument Stand will be used to support the 1 micron Sample Chamber and the Detector Stage. It will also be used to accurately position the 1 micron Sample Chamber and the Detector stage with respect to the LCLS beam.

6.10. *CXI Particle Injector (PRD SP-391-000-26)*

The particle injector is a differentially pumped nozzle that produces a focused beam of submicron particles delivered from an aerosol at atmospheric pressure to the high vacuum of the chambers. The injector nozzle protrudes into the chamber with its tip roughly 2 inches away from the interaction region. The injector is oriented vertically with the particles traveling down. Steering of the injector will allow the beam to be directed into the path of the X-ray beam.

6.11. *CXI Ion Time-of-Flight (PRD SP-391-000-30)*

An ion time-of-flight mass spectrometer will be used to detect the ions produced by the exploding particles. The ion TOF will not only provide information about the fragmentation pattern of the particles but it will also be used as a trigger signal during injection experiments. The ion TOF will provide a rapid diagnostics on whether or not a particle was hit for a given pulse. The ion TOF consists of a few electrodes used to accelerate the ions and a drift tube to separate mass-charge ratios. A detector at the exit of the flight tube detects the arrival time of the ions.

6.12. *Electron Time-of-Flight (Not in current LUSI scope)*

An electron time-of-flight mass spectrometer can be used to detect the electrons liberated by the exploding particles. It consists of a drift tube in which the electrons fly toward a detector. Electrostatic lenses are used to direct the electrons toward the detector which measures the arrival time of the electrons. The electron TOF will not be built by the LUSI project but it will be taken into account in the design so that it can later be implemented.

6.13. *Alignment/Pump Laser (Not in current LUSI scope)*

Lasers can potentially be used for aligning the particles along a preferred axis or to excite a transformation in the sample. The lasers would be located in a separate laser room, not in the experimental hutch and a laser penetration through the hutch wall or ceiling would be used to transport the laser beam into the hutch. Two ports with direct line-of-sight to the interaction region for the alignment laser and the pump laser will be included in the sample chamber design. These lasers will not be provided by the LUSI project but they will be taken into account in the design so that they can later be implemented.

6.14. *Desorption-Ionization Laser (Not in current LUSI scope)*

A laser capable of causing ionization of a nanoparticle can be used to simulate the LCLS beam during off-line testing and alignment of the particle injector. It creates ions that can be detected with the CXI Ion TOF. This laser beam would be aimed at the interaction region and hit rates will be quantified using the ion TOF to detect the produced ions. This laser will not be provided by the LUSI project but it will be taken into account in the design so that they can later be implemented.

6.15. *2-D X-Ray Detector (LCLS PRD # 1.6-002)*

The X-ray detector to measure the diffraction pattern from the sample will have a central hole to let the direct beam pass. This will be accomplished using a tiled design. The tiles will be positioned in such a way as to leave a hole in the middle as shown on Figure 4-1. The detector will be read out after every LCLS pulse, at 120 Hz. The size of the hole will be variable from 1 to 10 mm.

6.16. *CXI Detector Stage (PRD SP-391-000-28)*

The sample to detector distance needs to be varied depending on the sample used, with larger objects requiring a larger distance to allow for the diffraction pattern to be properly sampled. The detector will be located in its own vacuum spool and it will be mounted on a coarse slide in the z-direction. The detector will be positioned between 50 mm and 2600 mm from the 1 micron interaction region and 50 to 650 mm from the 0.1 micron interaction region. A translation in the x-direction of 30 mm will be necessary to center the detector on the incident beam, which moves around depending on which focusing optic is used. This will be accomplished by mounting the detector stage on the same stand as the sample chamber so that they move together.

6.17. *Wavefront Sensor (Not in current LUSI scope)*

A second detector can be used to measure the missing part of the diffraction pattern passing through the hole in the first detector and also to characterize the wavefront of the X-ray beam. The wavefront sensor would consist of a detector with 120 Hz readout, sometimes used alone and sometimes used with a sampling plate upstream of it. The sampling plate produces a diffraction pattern which can be interpreted to retrieve the wavefront at the sample location by back-propagating the wavefield to the sample plane. The wavefront sensor will only be used to characterize the beam focused by the 0.1 micron KB System in the location shown on the layout. This wavefront sensor will not be provided by the LUSI project but it will be taken into account in the design so that it can later be implemented.

6.18. *CXI Diagnostics Stages*

The position of the wavefront sensor and other diagnostics along the z axis will vary depending on the focusing optic in use and the size of the sample. Three locations will be used, at z=3 m, z=7 m and z=10 m, downstream of the interaction plane. The diagnostics stages will consist of a 7.5 m long vacuum spool directly downstream of the detector spool. A mount for the diagnostics will be located at the three locations specified. The mount will provide a 2-axis translation (x and y) to center the sensor on the direct beam which moves with different optics.

6.19. *Diagnostics*

A suite of diagnostics that are common with the other instruments developed by LUSI will be used. Multiple copies of identical diagnostic tools will be required at multiple points along the beamline.

6.19.1. LUSI Pop-in Profile Monitor (PRD SP-391-000-04)

The pop-in profile monitor will consist of a scintillation screen placed directly into the beam. A CCD camera will capture the scintillation signal bouncing off a mirror. The measurement is destructive of the X-ray beam. The screen can be retracted out of the beam when not in use.

6.19.2. LUSI Wavefront Monitor (PRD SP-391-000-15)

The Pop-in High Resolution Profile Monitor will be a modified Pop-in Profile Monitor that will have a camera capable of 120 Hz operation and that will allow the camera to be placed closer to the scintillator screen. If possible, this device shall also have a larger dynamic range. An attenuator foil will also be present in front of the screen to allow imaging of the beam downstream of the interaction region.

6.19.3. LUSI Pop-in Intensity Monitor (PRD SP-391-000-09)

The pop-in intensity monitor will be a photodiode placed directly into the beam. The integrated signal will be measured in a destructive fashion and will be proportional to the incident beam intensity. The monitor can be retracted out of the beam when not in use.

6.19.4. LUSI Intensity-Position Monitor (PRD SP-391-000-08)

The intensity-position monitor will be a thin Beryllium screen placed directly into the beam. Upstream of the screen will be a tiled photodiode arrangement with a central hole to let the beam pass. The Compton backscattering will measured with the tiled photodiodes. The integrated signal will be proportional to the incident beam intensity while the relative signal from each tile will give a rough estimate of the beam position. The measurement will not be destructive provided the Beryllium screen is thin and uniform. This monitor will also be retractable out of the beam when not in use.

6.20. *Crane*

An overhead crane with a 1-ton capacity will be required for introducing or removing heavy devices into the beamline. The hook of the crane will be at a maximum height of 10 ft. The crane will be capable of traveling from at least 4 meters upstream of the interaction plane to the back of the hutch in the z-direction. It will also move in the x and y directions to drop or pick up loads off the floor next to the instrument.

6.21. *Window Valves*

All the valves 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.

7. Stay Clear Areas

A beam transport line will be present in the CXI hutch to carry the LCLS beam to Hutch #6 in the FEH, as shown in Figure 7-1. The direction of this beam line will be deflected by 2.8 mrad toward the south using a mirror at a point roughly 20 m into the X-ray Transport Tunnel. The exact location of the mirror is still undetermined. However, the current estimate provides a minimum distance between the 2 beamlines at the entrance of the CXI hutch of 550 mm. A 4” beam pipe will be used for the transport of the beam to Hutch #6 leaving 500 mm of space from the CXI beam axis to the beam pipe. This puts restrictions on the size of all CXI devices located to the south side (-x-direction) of the main CXI beam line.

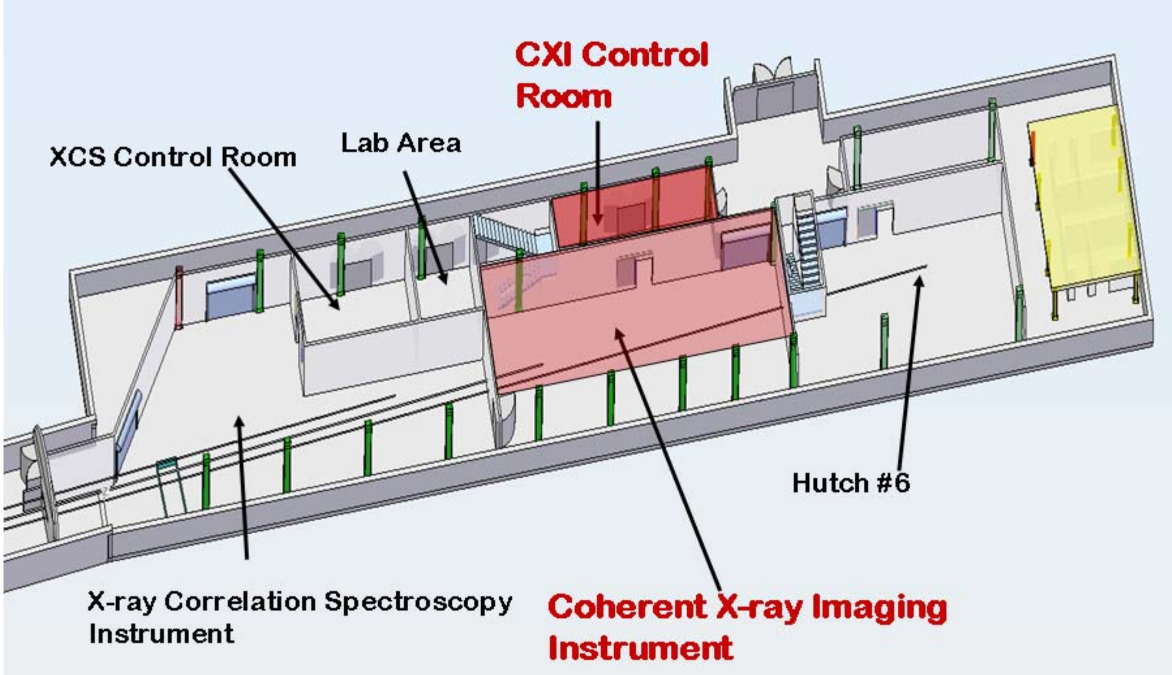

Figure 7-1: Schematic of the hutches in the FEH. The beamlines for each hutch are indicated. The south wall is at the bottom of the drawing.

8. Global Requirements

8.1. *Layout Requirements*

8.1.1 Three interaction points 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 not be located at a common Z position.

8.1.2 CXI components shall be positioned in the order displayed in Figure 5-1 and Figure 5-2**Error! Reference source not found.**.

8.1.3 The CXI 0.1 micron Sample Chamber shall be placed in a location that is as close to the west wall of the CXI hutch, while allowing sufficient space for the devices located upstream and inside the hutch as displayed in Figure 5-2**Error! Reference source not found.** .

8.2. *Mechanical Requirements*

8.2.1 All components downstream of the 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. The requirements for the Precision Instrument Stands are described in PRD SP-391-000-63 and PRD SP-391-001-42.

8.2.2 Stringent thermal and vibration requirements apply to the LUSI Intensity-Position monitors. Once these devices are aligned in the beam, their location shall not deviate from the aligned location by more than 5 microns in position and 10 μrad in angle over the course of an experiment (~ days).

8.2.3 The thermal and vibration stability of the KB mirrors, the detector stage, the precision instrument stands and the sample chambers are described in PRDs SP-391-000-24, SP-391-000-25, SP-391-000-28, SP-391-000-63, SP-391-001-41, SP-391-001-42 and SP-391-000-20.

8.2.4 All other components require a stability of 25 microns in position and 50 μrad in angle over the course of an experiment (~ days).

8.3. *Vacuum Requirements*

8.3.1 The vacuum pressure at any point along the CXI beamline shall not exceed 10^{-7} Torr to avoid contamination.

8.3.2 Special vacuum requirements exist for the KB mirror systems where the vacuum pressure shall not exceed 10^{-9} Torr. Differential pumping may be required.

8.3.3 A level of vacuum should be maintained in the system to permit a 10 year ion pump lifetime.

8.3.4 Dry pumping systems shall be used to minimize contamination.

8.4. *Access Requirement*

8.4.1 The particle injector will be located on top of the sample chamber and the intake will be be over 7 feet high. It will be required that the particle transport line from the electrospray source to the intake of the injector be kept as short as possible. Therefore, a platform shall be present around the sample chamber that allows equipment to be placed at a height near that of the injector intake. This platform shall also allow an experimenter to stand near the equipment for tuning of the injector.

8.4.2 The platform shall be moveable to allow for use of the crane to move components when needed.

9. Assembly

The majority of the components of the CXI instrument are not expected to be removed once installed. The components will be designed to be moved out of the beam when not in use. Only the components downstream of the 1 micron KB will be removed occasionally and modified on a weekly basis. These components shall be designed for rapid exchange and easy access for modifications. The components that are too heavy to be mounted by hand should have mounts for handling with the crane.

10. Controls and Data Acquisition

10.1. *Equipment Racks*

Water-cooled enclosed 19” equipment racks will be located in the hutch, on both sides of the beamline to house electronic components necessary for the control of the equipment. The racks shall be located near the data ports. Between 3 and 6 racks will be required. The racks will be 7’6” in height and space must be clear along the walls up to this height.

10.2. *Gas Bottles*

Gases are required for the particle injector and also possibly for cooling the detector. Dry N_2 and $C0_2$ are needed with other gases possibly to be determined. Gas bottles will be secured to the wall at a given location in the hutch and a gas distribution system shall be present to allow use of the gas with the desired component of the instrument.

10.3. *Motion Control*

All motions for the CXI instrument are required to be controlled from a single workstation. Each move shall be recorded and the user shall have the ability to record all motor positions whenever desired. Also, each motor position shall be recorded whenever data is recorded from either the detector, the ion TOF or any of the diagnostic components. The stroke and resolution requirements for each motion will be outlined in individual documents for each component.

10.4. *Timing & Triggering*

Precise (<100 fs) timing and triggering will be required for experiments using either a pump laser or a particle alignment laser. The lasers will be located in the laser bay, either adjacent to the CXI hutch in the common laboratory area or on a second floor to the FEH. The requirements for timing will be identical to those for the lasers located in the NEH.

Other components of the CXI instrument will need to be synchronized with the LCLS pulse but with much looser timing requirements (500 ps). For example, the detector and diagnostics will need to be read after every pulse and before the next pulse and require adequate timing. The ion TOF will also require triggering synchronized with the LCLS beam.

10.5. *Environmental Controls*

A resistive temperature device (RTD) will be placed near the sample chamber to monitor the ambient temperature. Controls are required to interface to and record this device. The RTD could provide feedback to a PID controller that drives the air conditioning unit depending on the feedback-free stability of the air conditioning unit.

10.6. *High Level Applications*

As described above, the CXI instrument will function in two main modes: fixed target experiments and injected particles experiments. The controls and data collection will be different between both cases due to the fact that during injection experiments, not every LCLS pulse will result in a particle hit while a fixed target is always hit by the beam. Below is a description of the software applications required for each mode of operation.

10.6.1. Fixed Target Single Shot Mode

Alignment Mode

For alignment purposes, the ability to view the data on the screen at the highest possible rate is required. The sequence of events will be as follows:

- Choose attenuator
- Open pulse picker
- Readout detector, wavefront monitor and all diagnostics at 120 Hz
- Display detector, wavefront monitor and all diagnostics at 10 Hz or more
- Move motors
- Inspect alignment with vision cameras
- Maximize a diagnostic signal
- Close shutter
- Stop reading detectors
- Stop display

Single Shot Mode

The full LCLS beam will destroy the sample with a single shot. It is therefore required to select a single pulse and measure the diffraction pattern and all other parameters for that single pulse. The sequence will be (see Figure 10-1):

- Send acquire trigger from computer
- Wait for next LCLS trigger
- Open pulse picker
- Pulse the excitation laser synchronized with LCLS
- Readout detector, wavefront monitor and all diagnostics
- Display detector, wavefront monitor and all diagnostics
- Scale and correct the data using diagnostics measurements
- Save scaled detector, scaled wavefront monitor, all diagnostics and motor positions
- Close shutter before the next shot

Multiple Shots Mode

Measurements with the attenuated beam will be required in some situations. The attenuated beam may be weak enough to allow the sample to survive. In this case, a better signal-to-noise ratio will be obtained by collecting multiple images and averaging them. The sequence is shown in Figure 10-1.

- Send acquire trigger from computer
- Wait for next LCLS trigger
- Open pulse picker
- Pulse the excitation laser synchronized with LCLS at 120 Hz
- Readout detector, wavefront monitor and all diagnostics at 120 Hz

- Display detector, wavefront monitor and all diagnostics at 10 Hz or more
- Scale and correct the data using diagnostics measurements
- Save detector, wavefront monitor, all diagnostics and motor positions at 120 Hz
- Close fast shutter after N pulses
- Stop data recording

10.6.2. Particle Injection Mode

Alignment mode

The alignment procedure for injected samples will be the same as for fixed target with the exception that a few new diagnostics for the particle beam will be present, along with time-of-flight (TOF) mass spectrometers. The motors that will be moved during alignment will also include the particle injector steering mechanism.

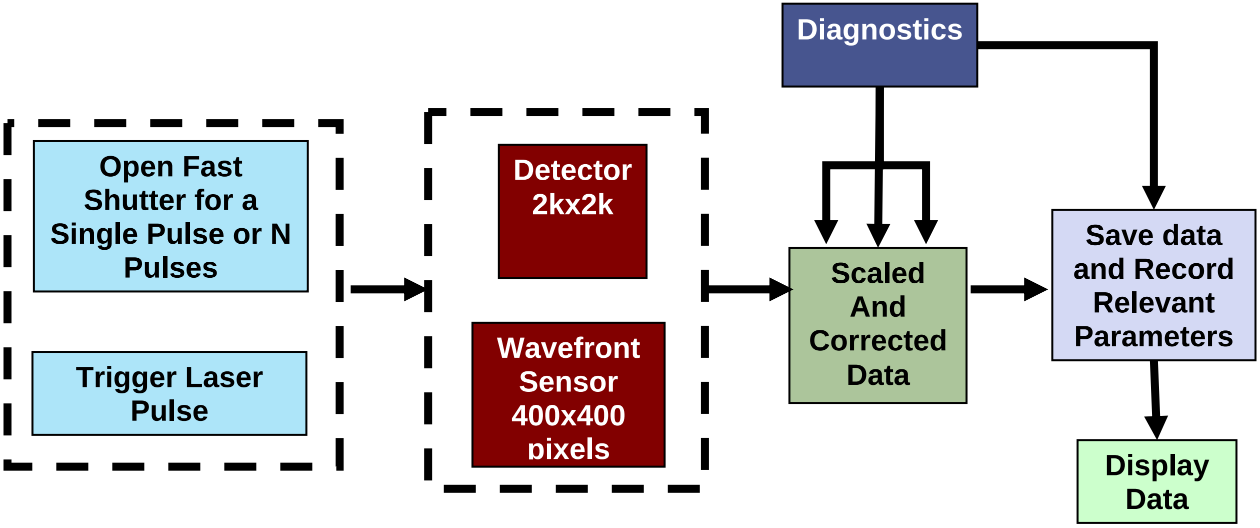

Figure 10-1: Data collection sequence for fixed target experiments.

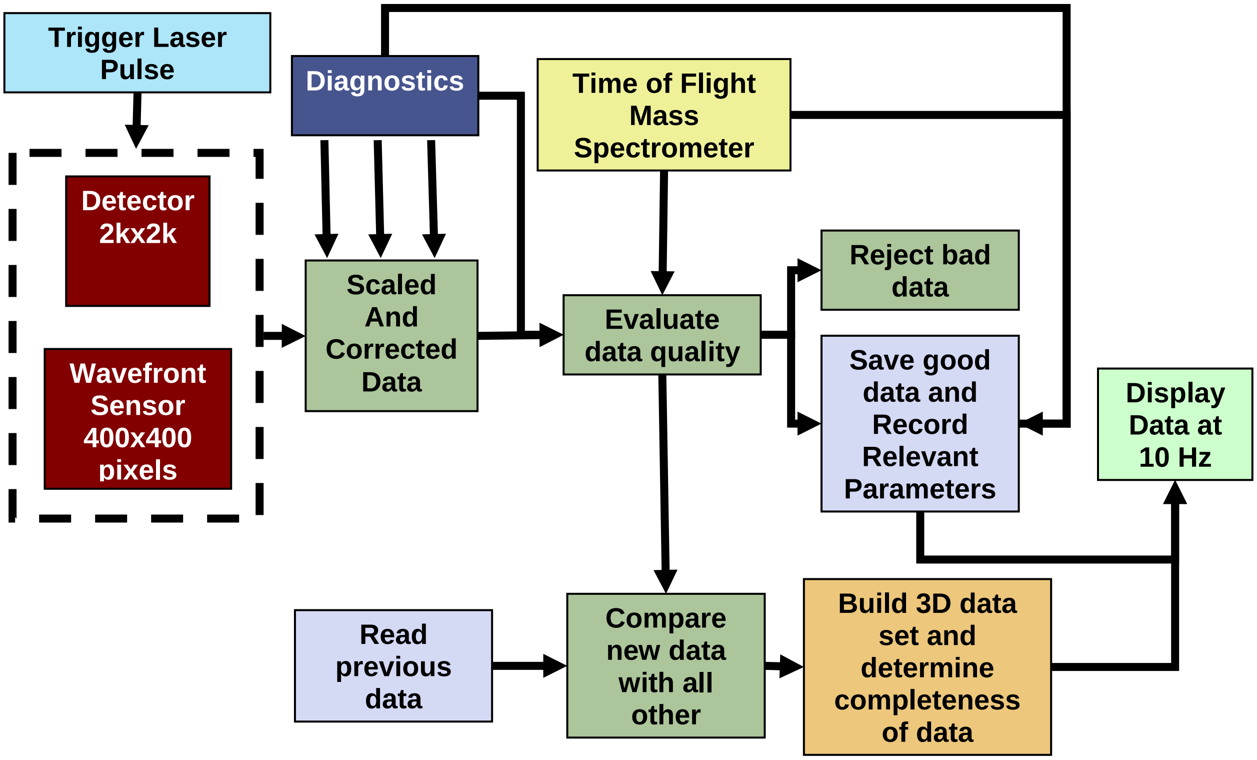

Figure 10-2: Data collection sequence for experiments with injected particles.

Data Collection Mode

The data collection sequence is shown in Figure 10-2. All measurements will be performed at 120 Hz since chance determines whether a particular LCLS pulse consists of a good measurement.

- Send start acquisition trigger from computer
- Wait for next LCLS trigger
- Open pulse picker
- Pulse the excitation laser synchronized with LCLS at 120 Hz
- Readout detector, wavefront monitor and all diagnostics at 120 Hz
- Readout particle beam diagnostics and TOF at 120 Hz
- Scale and correct the data using diagnostics measurements
- Determine if the last data represents a valid hit
    - Reject bad data
    - Save good detector data, wavefront monitor, all diagnostics and motor positions
- Display good detector data, wavefront monitor and all diagnostics at 10 Hz or more
- Compare new data with all previously obtained data
    - Group similar images together and average them
- Determine relative orientation of the averaged data sets
- Build the 3D data set from the many 2D images
- Determine the completeness of the 3D data set
- Collect data until operator stop
- Close fast shutter after operator stop trigger

- Stop data recording

10.7. *Computer Workstation*

At least one computer workstation for control of the entire CXI instrument will be located in the CXI control cabin. The workstation will be required to perform the following tasks:

- Move any desired motor and positioner by interfacing with the EPICS server
- Control the detector and diagnostics readout to save the desired data
- Display video camera images
- Display detector and wavefront monitor images
- Display diagnostics data
- Display status of all components on request
- Perform scans of any axis of motion of the entire instrument
- Select and monitor the signal from any detector or diagnostic during scans

11. Safety Requirements

11.1. *Personnel Protection System*

The personnel working with the CXI instrument will be protected using the LCLS Personnel Protection System. This system, including the interlocks of the photon stopper and the shielding of the hutch is entirely a responsibility of LCLS and LUSI shall provide the required information about the instrument to LCLS.

The instrument layout and its PPS implications shall be reviewed and approved by the Radiation Physics Group.

No modification to the PPS system shall be allowed without approval of the Radiation Physics Group.

11.2. *Seismic Safety*

All equipment heavier than the prescribed limit of 400 pounds shall go through a seismic safety review process. All equipment will possess adequate seismic restraints.

11.3. *Component Specific Safety Issues*

Special safety requirements for each individual component of the CXI instrument are described in the corresponding Physics Requirements Documents and Engineering Specification Documents

11.4. *Occupational Safety and Environmental Requirements*

All designs shall conform to the requirements described in 29 CFR Part 1910 Occupational Safety and Health Standards Dept of Labor. The CXI instrument shall be designed, constructed and operated in a manner to protect the safety of workers, the public and the environment and shall be fully compliant with the Stanford Linear Accelerator Center ES&H policies.

12. Quality Assurance Requirements

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.

13. Operations and Maintenance Requirements

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. Installation Requirements

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.

15. Commissioning Plans

Commissioning the CXI instrument with beam is not a part of the LUSI MIE Project. Only testing without beam shall be performed.

16. Acceptance Testing Requirements

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.

17. Codes and Standards

Design will be performed in accordance with SLAC ISMS. In addition, nationally recognized codes will be employed wherever possible. Pressure-containing components shall be designed and fabricated per the intent of the American Society of Mechanical Engineers (ASME) Boiler & Pressure Vessel Code, Section VIII (Ref. 10) or the ASME Code For Pressure Piping (ASME B31.1), (Ref. 11) applicable and electrical work will comply with the National Electric Code (NEC). Vacuum vessels will be designed per applicable vacuum vessel standards.

Where appropriate procedures do not exist, they will be formulated by the safety review committee. Vacuum vessels will be designed per applicable vacuum vessel standards. The applicable codes for other aspects of the design will be determined during detail design, will be specific to the component to which they are applied, and included in the specifications and drawings used for procurement, fabrication, test, and installation of system components.