LUSI — LCLS Ultrafast Science Instruments

PHYSICS REQUIREMENT DOCUMENT (PRD)	Doc. No. SP-391-001-35 R0	LUSI SUB-SYSTEM XCS

Physics Requirements Document for the X-ray Correlation Spectroscopy Instrument

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Table of Contents

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
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-391-000-23	LUSI Pulse Picker
PRD# SP-391-001-32	LUSI XCS Diffractometer system
PRD# SP-391-001-33	LUSI XCS Large Angle Detector Stage
PRD# SP-391-000-34	LUSI Harmonic Rejection Mirror System
PRD# SP-391-001-38	FEH Hutch 4
PRD# SP-391-001-39	Hutch 4 Control Room

The coordinate system is defined in Design Standards Supplement DS39100036.

2. Overview

The X-ray Correlation Spectroscopy (XCS) instrument will enable the study of dynamical phenomena in condensed matter system down to nanometric lengthscales by mean of X-ray Photon Correlation Spectroscopy. It takes advantage of the full transverse coherence and both the time average and peak brilliance of the LCLS X-ray beam.

The range of dynamical phenomena to be investigated requires a large versatility of the instrument in order to be used in various scattering geometries (Small Angle X-ray Scattering, Wide Angle X-ray Scattering and Grazing Incidence techniques).

The instrument will operate in two different modes, depending on the timescales of interest :

- **A Sequential Mode :** This mode is dedicated to the investigation of slow dynamics with characteristic relaxation times longer than 10ms (i.e limited by the 120Hz repetition rate of the LCLS) and could reach very long timescales (i.e hours) with a good stability of the LCLS beam. All scattering geometries/techniques are intended to be used in that mode of operation. In sequential mode, the experiment is performed by measuring time-resolved speckle patterns, as is done on third generation storage ring instruments.
- **An Ultrafast Mode :** This mode is dedicated to the investigation of ultrafast dynamical phenomena with characteristic relaxation times ranging typically from 200fs (i.e limited by the ~200fs pulse duration of the LCLS) and several nanoseconds. This mode of operation requires the use of a split and delay technology. There is currently no plan in the XCS instrument scope to build a split and delay unit. However a Split and delay unit will be

provided to the XCS instrument by DESY via a SLAC/DESY MoU. This device will allow probing dynamics up to 3ns. In that mode of operation, one no longer measure time-resolved speckles patterns, but the sum of the two delayed speckles patterns, out of which a contrast analysis is performed on a pulse by pulse basis.

The experiments on the X-ray Correlation Spectroscopy Instrument will require x-ray optical components to tailor the x-ray beam parameters, but also to control the coherence lengths of the incident beam. Special care will be taken in order to minimize coherence loss due to x-ray optics imperfections. It also requires a 2-dimensional detector performing at the repetition rate of the LCLS and in single photon counting mode with sufficient resolution to characterize speckle patterns.

This document contains a general description of the XCS instrument. Specific details of the XCS instrumentation and XCS subsystems are provided in separate PRD's.

3. Instrument Performance goals

3.1. *Experimental Versatility*

The X-ray Photon Correlation Spectroscopy technique can be applied to any x-ray scattering geometry (wide angle diffraction, small angle x-ray scattering, reflectivity, Grazing Incidence SAXS or diffraction). As such, the X-ray Correlation Spectroscopy instrument shall have sufficient flexibility to accommodate as many classes of experiments as reasonably achievable.

3.2. *Observation of Coherent diffraction patterns*

One of the main performance parameters of the XCS instrument is the observation of speckle patterns (i.e coherent diffraction patterns). These patterns differ from "usual" scattering patterns by their grainy appearance (as a result of the complex interference patterns in the coherent scattering process). This is characterized by a parameter known as contrast. LCLS will be the first X-ray laser source and thus is the most coherent hard x-ray source ever built. This opens the possibility to measure speckle patterns with degrees of contrast never achieved until now (up to unity) and with sufficient flux to perform XPCS experiments. The initial design goal of the XCS Instrument is to measure characteristic relaxation time in sequential mode with very large contrast (> 0.5).

4. Components

4.1. *FEH Hutch 4 (SP-391-001-38) / Hutch 4 Control Room (SP-391-001-39)*

These two documents describe the requirements of the hutches and collocated rooms (i.e control room) related to the X-ray Correlation Spectroscopy Instrument. The XCS instrument will be installed in the hutch 4 in the Far Experimental Hall. Figure 1 presents a 3D-layout of the XCS experimental hutch (i.e. FEH hutch4) and the adjacent control room.

4.2. *LUSI Attenuator System (SP-391-000-10)*

Attenuators will be used to reduce the X-ray flux during alignment procedures, as well as during some experiments where the sample must be protected from damage by the beam. They will also be used in order to reduce the measured scattered intensity, when this one is larger than the acceptable dynamic range of the detector. Attenuators will consist of highly polished foils of damage resistant material, in order to preserve the degree of coherence of the beam to the extent possible. The combination of multiple foils of multiple thicknesses will be used to vary the attenuation.

4.3. *LUSI Slit System (SP-391-000-14)*

Slits will be used in order to define the beam size all along the path of the beamline. They will in particular be used to define the incident beam size at the sample. The slit blades will be engineered to tolerate the full LCLS peak flux and special care will be taken in the design of the blades in order to reduce their parasitic scattering. Slit systems will be positioned on the beamline as shown on the layout displayed in Figure 1.

4.4. *LUSI X-ray Focusing Lens System (SP-391-000-11)*

Compound refractive lenses will be used to decrease the X-ray spot size at the sample when required. Three lens assemblies will be accommodated, thus providing the possibility to switch between three different focusing lengths. The X-ray focusing lens system will be place at a given distance from the sample area. Variable amount of focusing will be obtained by tuning the number of lenses in each lens assembly.

4.5. *LUSI Harmonic Rejection Mirror System (SP-391-000-34)*

A double mirror system will be used to reject high energy X-rays from the fundamental X-ray wavelength (i.e 3rd harmonic). This device will be used when experiments are operating with the fundamental radiation and removed when experiments require the 3$_{rd}$ harmonic. This device also offers the capability to perform grazing incidence scattering experiment on liquid surfaces.

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

The LUSI pulse picker is used to select a single LCLS pulse or pulses at a desired frequency below the 120 Hz repetition rate of the LCLS.

4.7. *LUSI Pop-in Profile Monitor (SP-391-000-04)*

The Pop-in Profile monitor will be used to characterize the spatial profile of the X-ray beam. This diagnostic will be used to align X-ray optics, diagnostics and samples. The monitor consists of a scintillation screen placed into the beam followed by a mirror (operating in the visible range). A CCD camera will capture the scintillation signal from the screen, reflected by the mirror. The monitor is not a transmissive diagnostic. Therefore, the screen will be retracted out of the beam when not in use.

4.8. *LUSI Pop-in Intensity Monitor (SP-391-000-08)*

The LUSI Pop-In Intensity monitor is an X-ray photodiode placed directly into the beam. The integrated signal is measured in a destructive fashion and is proportional to the incident beam intensity. These monitors will be used for alignment of X-ray optics and samples. It will be retracted out of the beam once alignment is complete.

4.9. *LUSI Intensity-Position Monitor (SP-391-000-09)*

The LUSI Intensity-Position monitor is a device that will measure the incident X-ray intensity and position in a non-destructive manner. The information obtained from this device will be used to normalize experimental data as well as for alignment of X-ray optics. The device is designed to measure the Compton backscattering from a foil. Upstream of the foil is a tiled photodiode arrangement with a central hole to let the beam pass. The integrated signal is proportional to the incident beam intensity while the relative signal from each tile gives an estimate of the beam position. The measurement is not destructive provided the foil is thin, uniform and constructed from a light element.

4.10. *LUSI XCS Diffractometer system (SP-391-001-32)*

The XCS diffractometer will be used in order to orient and position samples in the X-ray beam. It is equipped with a local detector (consisting of a diode and pairs of slits) for alignment purpose. The diffractometer is a 4-circle diffractometer operating in the horizontal scattering geometry (with a limited range in the vertical plane in the vicinity of the horizontal plane). The XCS diffractometer also offer the capability to be totally removed from the XCS beamline path in order to accommodate any large sample environment with its own support table/mount.

4.11. *LUSI XCS Large Angle Detector Stage (SP-391-001-33)*

The XCS Large detector stage holds the XCS pixelated detector, used to perform X-ray Photon Correlation Spectroscopy experiments. It offers a large sample detector distance in order to spatially resolve coherent diffraction patterns. It enables to position the XCS detector to scattering angles ranging from 0 to 55 degrees. It also enable to perform Grazing Incidence experiment in the vertical plane.

5. Global requirements

5.1. *Crane*

5.1.1. A crane is required for introducing/removing and setting up heavy equipment (i.e beamline equipment but also equipment required to perform user experiments) on the beamline. This device is in particular needed in order to safely exchange sample environment on the XCS diffractometer system, but also in order to place custom sample environment in place of the XCS diffractometer when needed.

5.2. *Layout Requirements*

5.2.1. The X-ray Photon Correlation Spectroscopy component will be positioned as displayed in the block diagram presented in Figure 2.

5.2.2. The XCS diffractometer system will be place as upstream as possible on the beamline path, thus accommodating sufficient space for upstream optics but also maximizing the sample/detector distance

5.3. *Mechanical requirements*

5.4. *Vacuum requirements*

5.4.1. The vacuum pressure at the location of any optical component along the XCS beamline shall not exceed 1.10^{-7} Torr to avoid x-ray optics degradation.

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

5.5. *Access requirements*

5.5.1. The design of the XCS instrument and its location (experimental Hutch 4 in the Far Experimental Hall) shall permit entrance in the FEH Hutch 4 while beam is being delivered to the CXI or HED instruments.

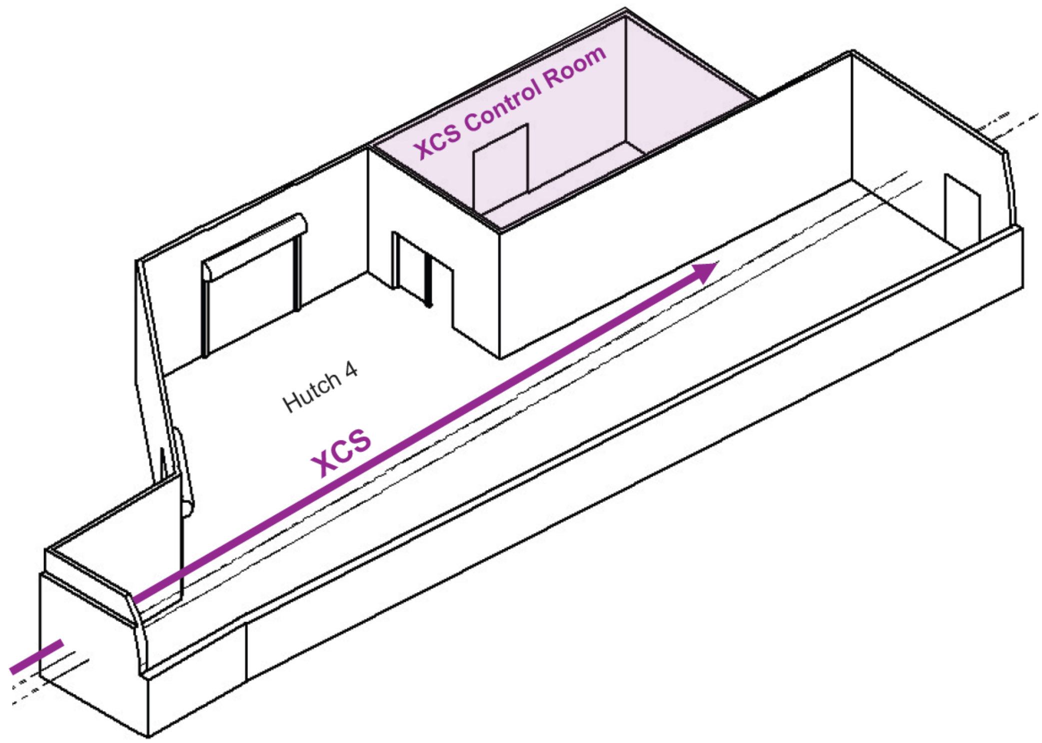

Figure 1 Far Experimental Hall, Hutch 4 and XCS control room. The X-ray beam propagates from left to right

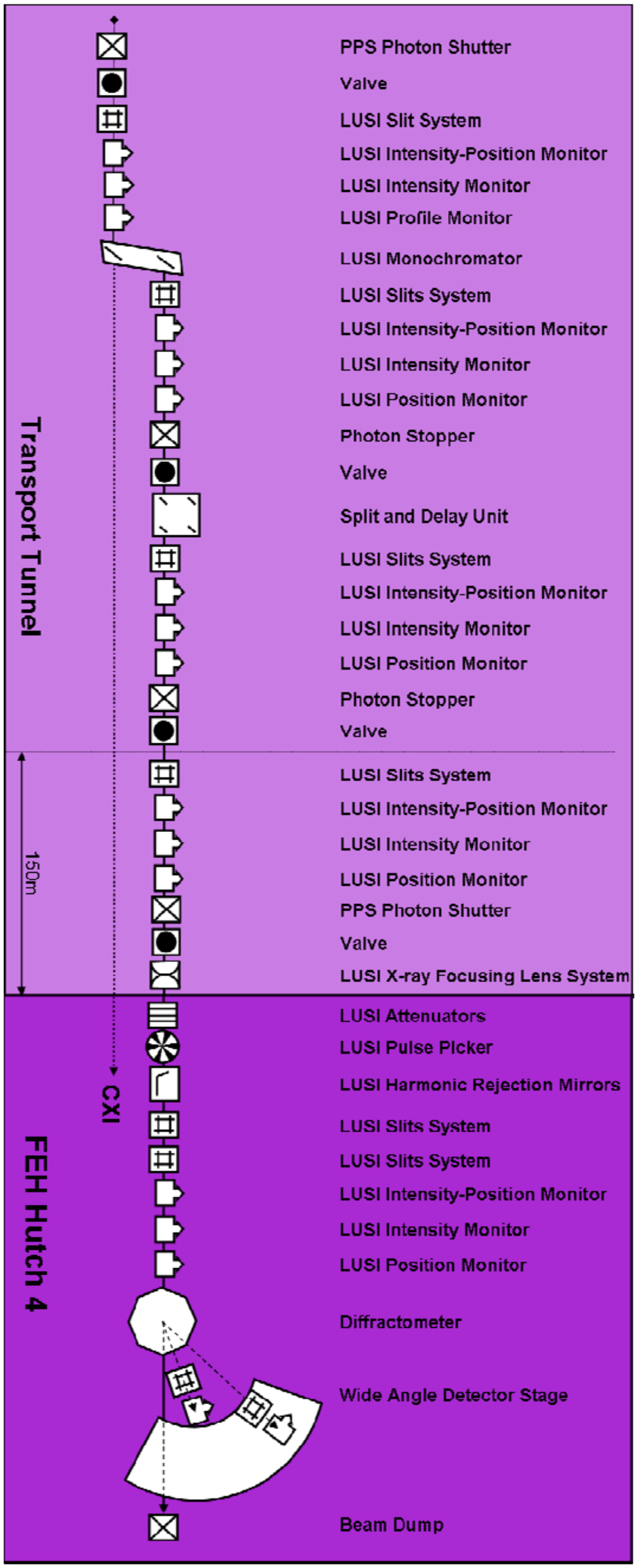

Figure 2 Block diagram describing the various components of the XCS instrument