LCLS Ultrafast Science Instruments

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Data Acquisition Specifications for the CXI Experiment

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Brief Summary:

This document describes the engineering requirements for the CXI experiment data acquisition system.

Change History Log:

Rev Number	Revision Date	Sections Affected	Description of Change
0	07/28/08	All	Initial Version

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Chapter 1: Introduction

Data acquisition for all experiments at the LCLS will be based on the 120Hz (or lower rate) x-ray pulses from the FEL. The design of the data acquisition system for the CXI instrument is based on the assumption that a complete data set must be acquired on each shot or pulse of FEL radiation. The experimental data can later be combined or binned into sets based on similarities in the properties of the LCLS pulse and irradiated sample that they are derived from and thus improve the statistical quality of the data set. Data from each pulse should be preserved for later analysis using different binning criteria. It will also be possible to associate data from diagnostics instruments in the CXI as well as upstream linac and FEL diagnostics, such as the EO instrument, with data from the scientific instruments for each individual pulse, forming the basis of the criteria used to bin and/or reject the data for each shot.

There are several different types of scientific and diagnostic instruments in the CXI experiment that need to be read on a shot-by-shot basis. They include:

- Pixellated detector
- Ion time-of-flight detector
- LUSI in-situ intensity/profile monitor
- LUSI pop-in intensity monitor
- LUSI pop-in profile monitor

Descriptions of the data expected from each instrument along with the instrumentation and software requirements for data acquisition and preliminary data analysis are provided below.

1.1 Software Infrastructure

Software will be required to acquire, process, monitor, and store the data from the digitizers in real time. Additional software will be utilized to analyze the data off-line.

Data processing and analysis needs will evolve with time as the experimenters gain more experience with the LUSI CXI instrumentation. Software needs to be modular to accommodate changes and additions.

As new and faster imaging chips become available, they will be implemented into the data acquisition system. Most of the software infrastructure will be written to be independent of the particular hardware used.

It is difficult to completely pre-determine the algorithms that will be most useful in analyzing and sorting the data. A period of software development will be required following commissioning of the experiment to make most efficient use of the data it produces.

All the CXI specific software will be built on top of the common data acquisition software provided by the Photon Controls and Data Systems (PCDS).

1.1.1 Configuration

The configuration software will allow the operator to create profiles of the detector and upload these profiles to the various instruments and online processing elements before data taking starts.

The configuration data will describe the instrument settings and the output data types. The configuration data will also describe the online process filtering and transformations of the data. The configuration data will be saved together with the science data and it will always be possible to correlate the configuration with the corresponding event data.

The common PCDS data acquisition software will provide the base classes for the CXI configuration objects and the data type classes.

1.1.2 Calibration

A "fast calibration" mode of data taking is an automated sequence of synchronized, configured stimulus and readout elements. No need for such in-situ automation has yet been demonstrated for the CXI instrument, though the core data acquisition system should maintain flexibility to accommodate fast calibrations if the need arises. The set of manual calibrations for each device will be listed in the instrument detail sections that follow.

1.1.3 Acquisition

The data stream from all the instruments will operate at up to 120Hz and the acquisition hardware/software combination will need to be able to acquire and process the data on a real time basis. Preprocessing in the form of zero-suppression and bad pulse rejection is envisioned during the acquisition stage in order to simplify the downstream data processing.

Each event will be labeled with a pulse ID for later reconstruction of the data, allowing association with data collected from other instruments on the same pulse or range of pulses.

1.1.4 Processing

The processing stage will perform feature extraction on the data. These features will include the statistical parameters (area under the curve, average value, RMS, etc.) of the different waveforms (single shot and averaged) and the centroid determination of the image data.

The information collected at this stage will be used for monitoring and may also be stored together with the data to simplify and expedite the off-line analysis stage.

Currently, it's expected that all data sorting and binning will occur during the off-line analysis stage. This assumption may change as more experience is acquired and more processing will be carried through by the on-line processing stage prior to archiving of the data.

1.1.5 Monitoring

One important function of the software infrastructure will be to provide user displays of the data as the experiment progresses. The user will need to determine whether the experimental conditions are appropriate from the quality of the signal. Individual or summed images will be displayed graphically with a user selectable refresh rate of up to 10 Hz. Users will be able to select the number of shots to display the data over, or whether a running total is displayed.

The time-frame of the display will be selectable (i.e. last *n* shots, cumulative data set, etc.). It will be possible to zoom on the display, with options for linear or log scales and auto-scaling or user defined ranges. Storage and printing capabilities will also be included for the displayed data. All data will be converted from hardware format to physical units before being displayed on the operator console.

1.1.6 Storage

Data from each individual shot will be uniquely identified, retrievable, and all software controlled and measured parameters will be readily determined and correlated with the data.

It will likely be more economical to store the data in the hardware word format, potentially with data reduction through zero suppression, along with sufficient information to decode it later.

1.1.7 Analysis (off-line)

The data acquisition will need to provide access to recent data, not yet available in the offline archive, in a well-defined format, so users can make use of a common framework to reformat the data for either in-depth monitoring or scientific analysis of the data. Long term storage will be provided by SCCS in a standardized format.

Chapter 2: Instruments

2.1 Pixellated Detector

The primary detector for the CXI apparatus will be the pixellated x-ray camera developed by Cornell. This CMOS camera contains an array of 736 x 736 pixels each measuring 110 µm x 110 µm in size. The components of the detector are arranged so that a square hole is vacated in the center of the detector to allow the beam to pass. The hole can be varied in size from 1 to 10 mm. The camera is especially designed for readout at the maximum beam rate of 120 Hz.

2.1.1 Signal Description

The pixel array is readout by an ASIC containing a charge-sensitive amplifier, and these analog signals are digitized in a 10 bit ADC. The digitized information is then serialized onto a 3.125 GHz fiber optic link where it is transmitted to the data acquisition system using PGP ("pretty good protocol").

2.1.2 Data Acquisition Hardware

In summary the following requirements emerge for the data acquisition hardware for the pixellated detector:

- Supply a trigger signal and uniquely identifying timestamp for capture of the data.
- Readout the full detector at up to 120 Hz over the fiber optic link using PGP.

2.1.3 Data Acquisition Software

Software will be required to acquire, validate, and process the data from the 2D camera, storing it to be readily accessible during analysis of the science data.

- *Configuration:* Operation of the camera will require selection of bias voltages and currents, comparator reference voltages, integration time, and amplifier gain settings. Online processing will also require configuration, namely "region of interest" and pixel binning definitions.
- *Calibration:* Two calibrations must be acquired and their corrections applied. The dark image calibration is acquired in-situ in the absence of beam over the same duration and conditions as science data. The result will be stored and its correction subtracted from the readout data. The flat-field calibration is acquired under the exposure of an external source with known uniform illumination. The resulting non-uniformity of response is stored and the correction applied within a processor in the readout stream. The preference is to perform the calibration in-situ, but the mechanical details of the source may require the calibration to be performed off the beamline.
- *Processing:* Early stages of processing will validate the integrity of the readout data and extract features useful for filtering or binning decisions. The region of interest and pixel binning definitions can be used to reduce the size of the data. In the later stages, where processed data from other sensors are combined, more selective filtering and binning can be done. For example, binning information from the EO can be applied to accumulate averaged images as a first pass at pump-probe analyses, or algorithms for classifying the sample orientation can be applied.
- *Monitoring:* Both raw images and highly processed results can be accumulated in the later stages of online processing for viewing by the operating scientists. Operator viewing of raw and processed data will be possible at rates of at least 5 Hz.

- *Storage:* The images will be stored with identifying information to be able to identify the data for each LCLS pulse. The image may be compressed to reduce the data set size based on the ratio of signal to zeros.

2.2 Ion Time of Flight Detector

An ion time-of-flight (TOF) mass spectrometer will be used to detect the ions produced by the exploding particles from exposure of the sample to the x-ray beam. 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 diagnostic on whether or not a particle was hit for a given pulse.

2.2.1 Signal Description

The ion TOF consists of a few electrodes used to accelerate the ions and a drift tube to separate mass-charge ratios. A multi-channel plate detector at the exit of the flight tube detects the arrival time of the ions. The waveform of the signal will be digitized for the period following each LCLS pulse.

2.2.2 Data Acquisition Hardware

In summary the following requirements emerge for the data acquisition hardware for the CXI ion TOF detector:

- Digitize and the signal waveform at a sampling frequency of 1GHz and depth of 8 bits for a period of 200 microseconds following each LCLS pulse.
- The sample window timing must be stable to a fraction of a sample (1 ns).

2.2.3 Data Acquisition Software

Software will be required to acquire, validate, and process the data from the CXI ion TOF detector, storing it to be readily accessible during analysis of the science data.

- *Configuration:* Waveform acquisition from the TOF detector will require configuration of the sampling ADC input gain and window time offset.
- *Calibration:* The sampling window time offset must be calibrated to the location of a well-known peak in the spectroscopy.
- *Processing:* Early stages of processing will attach the timestamp identifying the LCLS pulse and possibly filter the event based upon a threshold for a certain peak in the spectrum.
- *Monitoring:* Spectra can be accumulated in the later stages of online processing for viewing by the operating scientists either for individual pulses or sums of many pulses. Operator viewing of spectra will be possible at rates of at least 5 Hz.
- *Storage:* The spectra will be stored with the timestamp identifying the associated LCLS pulse.

2.3 LUSI In-situ Intensity-Position Monitor

The LUSI in-situ intensity-position monitor is composed of four silicon diodes arranged around the cross-section of the x-ray beam to detect back-scattered Compton photons off a thin low-Z material window just downstream. The response from each diode is separately digitized and made available for calculation of the x-ray beam position and intensity at the location of the window. The CXI setup will have 3 in-situ intensity-position monitors.

2.3.1 Signal Description

The charge collected on the four diodes will each go through an amplification and shaping stage, and the result will be digitized by a peak-sensing ADC for each beam pulse.

2.3.2 Data Acquisition Hardware

The requirements for the data acquisition hardware are:

- Supply a gate for the ADC digitization.
- Readout the four ADC results at a rate up to 120 Hz.

2.3.3 Data Acquisition software

Software will be required to acquire and process the data from the intensity-position monitor, storing it to be readily accessible during analysis of the science data.

- *Configuration:* Operation of the intensity-position monitor will require selection of the integration window and, possibly, amplifier gain settings.
- *Calibration:* The relative response of the four quadrants' amplification stages must be calibrated.
- *Processing:* Algorithms or lookup tables for extracting the beam intensity and position from the responses of the four quadrants must run in the online processing at full beam rate.
- *Monitoring:* The raw and extracted values will be available for viewing in the form of numeric displays for the average and most recent pulse and strip charts and histograms for the history of several pulses.
- *Storage:* The raw and extracted values will be stored with timestamp information to be able to identify the data with each LCLS pulse.

2.4 LUSI Pop-in Intensity Monitor

The pop-in intensity monitor is a single channel radiation sensing diode that can be lowered directly into the path of the x-ray beam. The charge collected on that diode will be proportional to the intensity of the x-ray beam pulse. The CXI setup will have 2 pop-in intensity monitors.

2.4.1 Signal Description

The readout electronics will amplify, shape, and digitize the amount of charge collected for each LCLS pulse. The result will be a single ADC word per pulse.

2.4.2 Data Acquisition Hardware

The requirements for the data acquisition hardware are:

- Supply a gate for the ADC digitization.
- Readout the ADC result at a rate up to 120 Hz.

2.4.3 Data Acquisition software

Software will be required to acquire and process the data from the pop-in intensity monitor, storing it for later analysis and correlation with other diagnostics:

- *Configuration:* The location of the monitor (in/out), reference voltage, and amplifier gain setting will be configured prior to acquisition from the pop-in intensity monitor.
- *Calibration:* The absolute response of the monitor and its amplifier gains will be calibrated off the beam line with a controlled intensity laser, and on the beam line against the XTOD total energy monitor.

- *Processing:* The beam intensity will be calculated per pulse while the monitor is in the beam line.
- *Monitoring:* The raw and extracted values will be available for viewing in the form of numeric displays for the average and most recent pulse and strip charts and histograms for the history of several pulses.
- *Storage:* The raw and extracted values will be stored with timestamp information to be able to identify the data with each LCLS pulse for later diagnostics.

2.5 LUSI Pop-in Profile Monitors

The profile of the x-ray beam will provide a diagnostic of the beam size, position, and mode quality. YAG crystals will be used in the vacuum path of the FEL to convert the x-rays into visible light. Video cameras with zoom lenses will be used to image the beam profile screens for subsequent processing. The CXI setup will have 5 pop-in profile monitors.

2.5.1 Signal Description

The primary signal is a digital video image of the intensity profile of the FEL radiation on the YAG crystal. Since the FEL pulses will be chaotic, they must be measured on a shot by shot basis. Positions, sizes, and horizontal and vertical profiles need to be extracted from the measured images and stored with the data stream. Lenses on the cameras should have zoom, focus and aperture control to maximize the signal content of the image.

2.5.2 Data Acquisition Hardware

The data acquisition hardware is the video camera operating at a rate of at least 30Hz, where shuttering must allow the capture of images from individual FEL pulses. A camera resolution of at least 640x480 pixels, readout noise of less than 20 photo-electrons, and at least 10-bit digitization range are required.

In addition, a few locations will make use of a higher resolution camera with 1024 x 1024 pixels and 12-bit digitization with up to 120 Hz readout. The camera readout interface will be the CameraLink protocol which is supported commercially and is extendable in readout bandwidth well beyond the current requirements.

The data acquisition hardware must meet the following requirements:

- Transmit the camera configuration commands on the CameraLink interface,;
- Provide a trigger signal on the CameraLink interface to initiate the frame exposure;
- Receive the full digital video frame on the CameraLink interface at a frame rate of up to 120 Hz.

2.5.3 Data Acquisition Software

Software will be required to acquire and process the data from the cameras, storing it to be readily accessible during analysis of the science data.

- *Configuration:* The focus, zoom and aperture of the lens will be set during a configuration process where the average position and peak brightness of many shots are used to set the lens parameters. After that initial configuration, the lens settings will remain fixed until another configuration is performed. A circular region of interest where the pulse is likely to illuminate could also be defined in the configuration to minimize data processing times.
- *Calibration:* Some cameras with multi-tap (digitization) channel readout may require correction for differing gains on each tap. Similarly, some cameras may require a dark image correction applied to the data.

- *Processing:* Algorithms will be developed to determine the size and position of the beam focus and the beam modal quality. This processing may be done in firmware inline with the image readout.
- *Monitoring:* Centroid and profile width values will be available for viewing in the form of numeric displays for the average and most recent pulse and strip charts and histograms for the history of several pulses. Camera images, single or the sum of several, will also be available for quick rendering.
- *Storage:* Either the compressed images or centroid and profile data will be stored with timestamp information to be able to identify the data for each LCLS pulse where the monitors are in the beamline. In the case where images are required for storage, the image should be compressed to reduce the data set size based on the ratio of signal to zeros.

Chapter 3: Common diagnostics

In addition to the local instrumentation, the data acquisition/control software should provide a means to monitor shared diagnostics instruments in the FEE (i.e. the gas (and possibly solid) attenuators) and machine (i.e. rate) as well as monitor key parameters from various upstream diagnostics to correlate signals with machine behavior. It would be useful, for example, to display the electron beam energy and current measured in the beam dump on a screen on the user console to correlate with the performance of the instrumentation. Further discussions will be needed to define exactly which parameters will be helpful to display.