LUSI

Preliminary Instrument Design Review

X-ray Correlation Spectroscopy

Aymeric Robert – XCS Instrument Scientist

July 25, 2008
Outline

- XCS Science and Scientific Scope
- Experimental Technique
- Instrument Layout
- Component Descriptions and Requirements
  - X-ray Optics & Diagnostics
  - Diffractometer System
  - Detector
- Alternative Designs
- Safety
- Major Interfaces to other LCLS Systems
Contributors

Team Leaders
- Brian Stephenson (ANL)
- Gerhard Grübel (DESY)
- Karl Ludwig (Boston U.)

LUSI Scientists
- J. Hastings (XFD)
- D. Fritz (XPP)
- S. Boutet (CXI)
- Y. Feng (DCO)
- M. Messerschmidt (XPP)

Engineering
- Eric Bong (Lead Eng.)
- Jean-Charles Castagna
- Jim Delor
- Ted Osier
- Don Arnett
Characterizing the time fluctuations of speckle patterns (scattering patterns produced by the coherent illumination of the sample)

Characterizing the underlying dynamics of the system
XCS Science: the mystery of the XPCS area


Frequency [Hz]

10^-2

10^-1

10^0

10^1

10^2

10^3

10^4

10^5

10^6

10^7

10^8

10^9

10^10

10^11

10^12

10^13

10^14

10^15

10^16

10^17

10^18

Q [Å^-1]

2D-XPCS with CCD

1D-XPCS with autocorrelator

XPCS in Grazing Incidence

Visible Raman

Visible Brillouin

Visible PCS

X-ray PCS

Compton

X-ray Raman

RIXS

INS

IXS
XPCS is a "photon hungry" technique!

Limited by:
- coherent flux
- degree of coherence
- detector performances
- beam damage


Visible Raman

Visible Brillouin

GI X-ray PCS

Visible PCS

X-ray PCS
Dynamics of interest

<table>
<thead>
<tr>
<th>Ultra-dilute systems (gazes, aerosols, fogs, fumes)</th>
<th>Biological sample dynamics (folding-unfolding transition)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ionic Liquids, liquids and Transport Theories</td>
<td>Dynamics of condensed matter (Phonons,…)</td>
</tr>
<tr>
<td>Nano-systems (nanoscale=sub-ns dynamics)</td>
<td>Hard Condensed Matter Phase transitions (CDW, …)</td>
</tr>
</tbody>
</table>
XCS Prelim. Instr. Design Review
Jul. 25, 2008

LCLS Parameters

Full Transverse Coherence
8 and 24 keV

High Time–average Brilliance
Rep. Rate 120 Hz

Sequential Mode

Dedicated 2D-Detector
Sequential XCS

Intensity autocorrelation function

\[ g_2(Q, \tau) \]

- **Time-average Brilliance**
  - \( 10 \text{ ms} < \tau_c < \text{hrs} \)
  - Large Q's accessible
XCS Science @ LCLS

LCLS Parameters

- Full Transverse Coherence
- 8 and 24 keV
- High Time–average Brilliance
- Rep. Rate 120 Hz
- High Peak Brilliance
- Short pulse duration 230fs
- Dedicated 2D-Detector
Ultrafast XCS : Split & Delay 2

Detector
Ultrafast XCS: Split & Delay

No Dynamics (zero delay)

Dynamics

\[ \Delta t \]
Ultrafast XCS : Split & Delay

No Dynamics over $\Delta t$
(Zero Delay)

Dynamics over $\Delta t$

Reduction of contrast
Peak Brilliance & Pulse Duration
- pulse duration $< \tau_c <$ several ns
- Large Q’s accessible
X-ray Photon Correlation Spectroscopy

- Small Angle X-ray Scattering geometry
- Diffraction (Wide Angle Diffraction up to $2\theta=55^\circ$)
- Reflectivity
- Grazing Incidence Diffraction
- Grazing Incidence SAXS

Operation both in sequential and split-delay mode
Instrument will operate in the 6-25 keV photon energy range
Versatility of the instrumentation

<table>
<thead>
<tr>
<th>X-ray Wavelength and Bandwidth</th>
<th>Sample Environments</th>
<th>Scattering Technique</th>
</tr>
</thead>
</table>
| - Monochromatic Fundamental   | • Room Press. & Room Temp  
- Monochromatic 3rd Harmonic | • Temperature Controlled Cryostat  
- $10^{-6}<\Delta\lambda/\lambda<10^{-4}$ | • Liquid  
- Vacuum  
- Others … | • Wide Angle Scattering  
- Small Angle Scattering  
- Reflectivity  
- Grazing Incidence Diff.  
- GI-SAXS |

Facility Advisory Committee Report Oct. 2007
“… The committee recommends that the XCS staff retain flexibility in their designs to facilitate change as opportunities and problems are discovered. …”
Source to Sample distance: ~ 420 m
### Source Parameters

- **LCLS energy range (fundamental):** 800 – 8300 eV
- **3rd harmonic up to 24.9 keV (1% of the fundamental)**
- **XCS instrument uses hard X-ray branch:** ~ 6-25 keV
- **Source size and location varies with energy**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Value 2</th>
<th>Value 3</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photon energy</td>
<td>24.813</td>
<td>8.271</td>
<td>6</td>
<td>keV</td>
</tr>
<tr>
<td>Wavelength</td>
<td>0.05</td>
<td>0.15</td>
<td>0.21</td>
<td>nm</td>
</tr>
<tr>
<td>Source size (FWHM)</td>
<td>60</td>
<td>60</td>
<td>67</td>
<td>μm</td>
</tr>
<tr>
<td>XPP Hutch distance from source</td>
<td>420</td>
<td>420</td>
<td>420</td>
<td>meters</td>
</tr>
<tr>
<td>Source divergence (FWHM)</td>
<td>0.73</td>
<td>1.1</td>
<td>1.34</td>
<td>μrad</td>
</tr>
<tr>
<td>Pulse duration</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>fs</td>
</tr>
<tr>
<td>Number of photons</td>
<td>1.7E+10</td>
<td>1.7E+12</td>
<td>2.7E+12</td>
<td>photons</td>
</tr>
</tbody>
</table>
### Expected Fluctuations of LCLS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse intensity fluctuation</td>
<td>~ 30 %</td>
</tr>
</tbody>
</table>
| Position & pointing jitter \((x, y, \alpha, \beta)\) | ~ 25 % of beam diameter  
~ 25 % of beam divergence                         |
| Source point jitter \((z)\)                    | ~ 5 m  
(leads to variations in apparent source size, or focal point location if focused) |
| X-ray pulse timing \((arrival time)\) jitter    | ~ 1 ps FWHM                                                           |
| X-ray pulse width variation                    | ~ 15 %                                                                |
| Center wavelength variation                    | ~ 0.2 %  
(comparable to FEL bandwidth)                     |

Y. Feng
XPCS Experiments

- Observing speckle patterns
- Fluctuations from the source cannot alter the X-ray scattering pattern for XPCS experiments
- A scheme to minimize the impact of source fluctuation must be realized
- LCLS is a transversely coherent beam
- The LCLS is a serial experiment operation – instrument downtime is not acceptable!
- Experimental efficiency is a top priority - time is extremely precious
Slits and imager’s not designed for FEL radiation
No diagnostics after the offset mirror system
Hard X-ray Offset Mirror System (HOMS)
XCS Instrument Location

Near Experimental Hall

X-ray Transport Tunnel
(200m long)

Source to Sample distance: ~ 420 m

Far Experimental Hall

XPP

AMO (LCLS)

XCS

CXI Endstation

LUSI LCLS Ultrafast Science Instruments
LUSI Slit System

Slit systems requirements

- Primary and mono types
- Precision (0.5 \( \mu \text{m} \)) & coarse (5 \( \mu \text{m} \))
- 0 – 10 mm gap setting
- \( 10^{-9} \) in transmission from 2-8.3keV
- \( 10^{-8} \) in transmission at 25 keV
- Control parasitic scattering from blades

D. Le Bolloc’h et al., *J. Synchrotron Rad.*, 9, 258-265 (2002).
LUSI Slit System

- **[PS]** Primary Slits
  - Clean up beam halo
  - Define beam for alignment of 1st Xtal
  - Mitigate spatial fluctuations of the beam

- **[SS0]** Secondary Slits
  - Define beam for Split and Delay
  - Mitigate spatial fluctuations of the beam

- **[SS1]** Secondary Slits
  - Clean beam halo and define beam for transport
  - Mitigate spatial fluctuations of the beam

- **[SS2]** Secondary Slits
  - Clean beam halo and define beam (for XFL)
  - Mitigate spatial fluctuations of the beam

- **[DS]** Defining Slits
  - Define incident beam size
  - Mitigate spatial beam fluctuations

- **[GS]** Guard Slits
  - Clean beam halo and diffraction from DS
Each section is equipped with the same diagnostics suite:

- Pairs of Slits
- Intensity Position Monitor [IPM]
- Pop-in Position Monitor [PPM]
- Pop-in Intensity Monitor [PIM]
### Requirements

- Characterization of the spatial/angular jitter (25%)
- Preserve transverse coherence
- In-situ, retractable if necessary
- Highly transmissive (< 5% loss);
- Relative accuracy < 0.1%;
- Dynamic range 1000;
- Per-pulse op. at 120 Hz;

**LUSI Intensity-Position Monitor**

**FEL**

- Be thin foil
- Array Si diodes
LUSI Intensity-Position Monitor

- **IPM1 Purpose**
  - Characterize incident LCLS intensity (1st diagnostic after XPP)
  - Locate initial beam position in the XRT
  - Normalization for alignment monochromator crystal1

- **IPM2 Purpose**
  - Provide normalization signal for alignment of monochromator
  - Normalization for characterizing Split and Delay, [SS0]

- **IPM3 Purpose**
  - Provide normalization signal for alignment of Split and Delay
  - Normalization for characterizing X-ray Transport[SS1]

- **IPM4 Purpose**
  - Provide normalization signal for X-ray Transport
  - Normalization for characterizing downstream optics (focusing lenses, attenuators, harmonic rejection mirrors, SS2)

- **IPM5 Purpose**
  - Experimental normalization signal
LUSI Pop-in Profile Monitor

- **Requirements**
  - Destructive; Retractable
  - Variable FOV and resolution
    - At 100μm resolution, 24x24 mm² field of view;
    - At 8μm resolution, 2x2 mm² field of view;
  - Capable of per-pulse op. @ 120 Hz
LUSI Pop-in Profile Monitor

**PPM1 Purpose**
- Characterize spatial mode of incident beam

**PPM2 Purpose**
- Positioning of monochromator crystal 2
- Steering of monochromator crystal 1
- Characterize spatial profile of beam after mono

**PPM3 Purpose**
- Alignment of IPM2, Split and Delay.
- Characterize spatial profile of beam after Split and Delay
- Steering of monochromator crystal 2 and Split and Delay

**PPM4 Purpose**
- Alignment of IPM3
- Steering of monochromator crystal 2, Split and Delay
- Characterize the spatial profile after 150 meter propagation

**PPM5 Purpose**
- Alignment of IPM4
- Steering of focusing lenses, attenuators, harmonic rejection mirror
- Steering of Guard Slits [GS]
- Characterize the spatial profile of the incident x-ray
**Requirements**

- Destructive; Retractable;
- Relative accuracy < 1%;
- Dynamic range 100;
- Large working range 20x20 mm²
- Capable of per-pulse op. @ 120 Hz
LUSI Pop-in Intensity Monitor

- **PIM1 Purpose**
  - Calibration of PS
  - Calibration of IPM1

- **PIM2 Purpose**
  - Calibration of Monochromator
  - Calibration of SS0, IPM2

- **PIM3 Purpose**
  - Calibration of Split and Delay
  - Calibration of SS1, IPM3

- **PIM4 Purpose**
  - Calibration of upstream optics after transport
  - Calibration of SS2, IPM4

- **PIM5 Purpose**
  - Calibration of upstream optics
  - Calibration of DF, GS, IPM5
LUSI Offset Monochromator System

LUSI Offset Monochromator Purpose
- Narrow X-ray spectrum
  - Mitigates spectral fluctuations of the LCLS
  - Increase/Control long. coherence length

Specifications
- 6-25keV
- $10^{-6}<\Delta\lambda/\lambda<10^{-4}$
- Large-offset (600mm)
Split and Delay

Split and Delay unit in kind contribution
DESY, via SLAC/DESY MoU

- Provided by DESY/SLAC MoU
  - Prototype existing
  - 1st Commissioning May 07 (ESRF, Troika beamline)
  - Pulse duration < delay < 3 ns
  - Based on Si (511)
  - $E=8.389$ keV
  - Last commissioning May 08

G. Grübel
W. Roseker

Image of Split and Delay setup with labeled components:
- Splitter
- Delay Tuning
- Adder
- Delay ($\Delta t$)
LUSI X-ray Focusing Lens System

LUSI X-ray Focusing Lens Purpose
- Reduce the spot size at the sample while maximizing flux

LUSI X-ray Focusing Lens Requirements
- Produce a smaller spot size between 1-50μm
- Preserve coherence
- Withstand full flux

LUSI Attenuator System

LUSI Attenuator Purpose
- Reduce incident X-ray flux
  - Sample damage
  - Detector saturation
  - Diagnostic saturation
  - Alignment of optics and diagnostics

LUSI Attenuator Requirements
- Preserve coherence
- Withstand unfocused flux
- $10^8$ attenuation at 8.3 keV
- $10^4$ attenuation at 24.9 keV
- 3 steps per decade
LUSI Pulse Picker

**Pulse Picker Purpose**
- Reduce LCLS repetition rate or pick pulse pattern
  - Important if longer sample recover time is needed
  - Damage experiments - sample needs to be translated

**Pulse Picker Requirements**
- < 3 ms switching time
- < 8 ms in close/open cycle time
- <= 10 Hz operation
- Withstand full LCLS flux - unfocused
- Requires 1 mm B4C to protect the steel blade

http://www.azsol.ch/
LUSI Harmonic Rejection Mirror System

LUSI Harmonic Rejection Mirror Purpose
- Isolate fundamental radiation from 3rd harmonic
- Tilt incident beam downward (GI experiments)

LUSI Harmonic Rejection Mirror Requirements
- Energy range - 6-8.265 keV
- $10^4$ contrast ratio between fundamental and the 3rd harmonic
- 80% overall throughput for the fundamental
- Coherence preservation of the mirrors
XCS Diffractometer Purpose
- Orient and position samples
- Position local detector for sample alignment

XCS Diffractometer Requirements
- Horizontal scattering 4-circle diffractometer
- No interference with CXI beamline (600mm)
- No interference with Large Angle Detector Stage
- Identical platform-to-COR distance as XPP diffractometer
- Removable from beam path to accommodate large sample env.
- Accommodate large sample environments (up to 50 kg)
XCS Large Angle Detector Mover Purpose
- position XCS detector in the region of interest

XCS Large Angle Detector Mover Requirements
- Horizontal scattering 4-circle diffractometer
- No interference with CXI beamline (600mm)
- Sample/detector distance > 7-8m
- Decoupled from diffractometer
- SAXS, WAXS, GI
- $2 \theta$ up to 55°
- -0.5 < GI-angle < 2
Integration as a 4-circle horizontal scattering diffractometer
XCS Large Angle Detector Mover

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Jul. 25, 2008

LUSI LCLS Ultrafast Science Instruments

Aymeric Robert
aymeric@slac.stanford.edu
Global X-ray Beamline Requirements

- **Layout Requirements**
  - Large offset to reduce setup time of experiments
  - Components placed in the order displayed in block diagram
  - Maximize sample detector distance by placing diffractometer as close to the alcove corner as possible while allowing convenient access

- **Mechanical Requirements**
  - Stability of X-ray components
    - 5-10 microns for PIM, Slits, Lenses, Mirrors, sample position
    - Monochromator will have special needs
    - 25 microns for everything else for long-term drifts

- **Vacuum Requirements**
  - Pressure at the location of any component that intercepts the beam shall be less than $10^{-6}$
  - 10 year ion pump lifetime
  - Vacuum better than $10^{-4.5}$ for the flight path on large detector mover.

- **Access Requirement**
  - Instrument design shall permit access in FEH Hutch 4 while beam delivered into the CXI/HED.
2D Detectors

- **2D detector (BNL)**
  - Developed at BNL (MoU)
  - 1024 x 1024 pixels
  - 35 x 35 μm² pixel size
  - High DQE
  - $10^2$ dynamic range
  - Noise << 1 photon
  - 120 Hz Readout Rate

![Diagram of 2D detector layout]

- Pixel separator $p^+$
- Pump electrodes $p^+$
- Charge extraction $n^+$

**Parameters**

- $\Delta \lambda / \lambda = 1.4 \times 10^{-4}$
  - 20 μm, Flat
  - 20 μm, Focussed

- $\Delta \lambda / \lambda = 1.5\%$
  - 12 μm, Focussed

![Image of beam size and optical change]
Monochromator Design Choices

Trade off between:
- Offset distance
- Low angle that can be reached (3rd harmonic flux)
- Monochromator length (space for other optics)

Decision was made to only reach Si 111 at 24.9 keV and to offset by 600mm
Large Angle Detector Mover Design Choices

Spring-8/ESRF/APS Existing Designs

- BL35XU: High Resolution Inelastic X-Ray Scattering
- HERIX, sector 30
- ID28, IXS

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LUSI
LCLS Ultrafast Science Instruments
2θ=55°

10m long

Fixed Point of rotation

Real rotation

Airpad motion with granite support

Large Angle Detector Mover Design Choices

ID28, IXS

- $2\theta \approx 50^\circ$
- 7-12m long
- Point of rotation
- Lateral motion of the point of rotation with diffractometer
- Real rotation
- Translation stages
20°≈30°
9m long
NO Point of rotation
Lateral motion of the point of rotation
Translation stages
Software control of COR centering
Large Angle Detector Mover Design Choices

- APS-HERIX-Design based
- $2\theta$ up to 55°
- Up to $\approx$ 8m long
- NO “real” Point of rotation
- Lateral motion of the pseudo point of rotation by software
- Translation stages
- No contact with the diffractometer
- SAXS, WAXS, Refl., GID, GISAXS

Flexible instrument with capability of accommodating any sample environment
Technical Issues

1. Flexible Diffractometer/LADM Design
   - 4 circle horizontal scattering
   - Diffractometer out of the way if required
   - No interference with other equipment
   - Adjustment of the CoR of the assembly

2. Monochromator Precision Motion
   - 200 nRad motion & stability
   - Long translation of 2\textsuperscript{nd} Xtal
   - Or ½ long translation of each Xtal
Controls Group – Actively working with LUSI controls group
- Responsible G. Haller
- Working on PRD’s for XCS controls
- XCS has provided controls with a detailed list of planned hardware
- Weekly Controls meeting with the LUSI group
  - Discuss hardware, standardization, data acquisition, machine protection system, instrumentation, etc.

BNL Detector
- Responsible LUSI Physicist – Niels Van Bakel
- MoU in place
- PRD is being drafted
Major System Interfaces (2)

- Conventional Facilities (Hutches and utilities). A. Robert
  - Conventional facilities work is coordinated with XCS team
  - Most design requests from the XCS team are implemented.
  - Remaining responsibilities have been defined
  - Designing overhead crane
  - Responsible engineer – A. Busse
LCLS -LUSI Integration

- Weekly meetings to discuss LUSI and LCLS integration issues
- Meeting led by Jerry Hastings and John Arthur
- Attendees – LUSI & LCLS Management, Physicists and System Engineers
ES&H

- General environmental, health and safety issues
- Safety Overview Committee Review completed December 2006 and identified the following committee reviews:
  - Earthquake Reviews
  - Radiation Safety Reviews
  - Laser Safety Reviews
  - Electrical Safety Reviews
  - Hoisting and Rigging Safety Committee
  - Fire Marshall
  - Hazardous Experimental Equipment Committee
Earthquake Committee

- Open dialog with the head of the earthquake (S. Debarger) committee to identify components requiring review
- General standard is all devices weighing over 400 lbs requires a peer review followed by an approval by the Earthquake Committee
- Responsible Engineer – E. Bong, XCS Lead Engineer

Radiation Physics

- All LUSI radiation physics issues are being coordinated by Hal Tomkins. It is the responsibility of the System Manager to monitor the approval process and to provide information as needed
- Approval required for Personal Protection System (PPS) scenarios and shielding for PPS
- Radiation Physics Committee led by Sayed Rokni
  - Experimental Systems Radiation Physicist is J. Vollaire
Electrical Safety

- Current < 5 ma AC /DC or < 10A, < 50V does not require special approval
- NRTL approved equipment required or SLAC in house program required for approval on non-listed equipment
- Electrical Safety Committee led by Fred Jones (acting)
- Responsibility – G. Haller & E. Bong, System Managers

Hazardous Experimental Equipment Committee (K. Jobe – Chair)

- Pressure/Cryogenic/Vacuum Systems
  - All vacuum equipment shall be compliant with new DOE Worker Safety and Health Program 10CFR851
  - This will require the use of burst disk and documented procedural practice for using pressure relief valves
  - Engineering analysis, review and committee approval to show that equipment is safe beyond the pressure vessel code
  - Responsibility – E. Bong
**Safety Issues and Interfaces (4)**

- Hazardous substances – discussions on approved practices standards with K. Jobe
  - Waste disposal (User samples)
  - Cryogenics
  - Biohazards
  - Compressed gas cylinders
  - Lead
  - Responsibility – A. Robert & E. Bong

- Fabrication, Installation, Hoisting & Rigging
  - Plan the work – develop, review and approve work plans
  - Write up and obtain approvals for standard and special rigging operations.
  - Responsibility – E. Bong
Summary

- Instrument design emphasizes flexibility
- X-ray scattering techniques
  - WAXS
  - SAXS
  - Reflectivity, Grazing Incidence
- X-ray optics can tailor FEL parameters
- Many sample environments can be accommodated
  - Vacuum
  - Low temperature (cryostat, cryostream)
  - Samples in solution
- Major system interfaces are well defined
- Safety issues are identified
XCS Preliminary Instrument Design Review
Engineering
Eric L. Bong
XCS PIDR
July 25, 2008

X-Ray Transport Hall (XRT)
Outline

- **Instrument Configuration**
- **Component Sources**
- **Integration**
- **XCS Scope of Design**
  - **XRT (Stands & Vacuum)**
  - **Hutch (Stands, Vacuum & Utilities)**
  - **Diffractometer**
  - **Large Angle Mover**
- **Detector (BNL WBS 1.4.3)**
- **Diagnostics & Optics (WBS 1.5)**
- **Controls (WBS 1.6)**
- **Cost & Schedule**
**XCS Staff**

*Instrument Scientist*
- Aymeric Robert

*Engineering Staff*
- Eric Bong - Lead Engineer
- Don Arnett – Mechanical Design Engineer, XRT & Documentation
- Jim Delor – Mechanical Design Engineer, Diffractometer
- Ted Osier – Mechanical Design Engineer, Hutch 4
Two major regions; XRT and H4

X-Ray Transport Tunnel
- Monochromator – WBS 1.5 LUSI Diagnostics & Common Optics
- Split & Delay – Loan From Foreign Laboratory (Not XCS Scope)
- Diagnostics – WBS 1.5 LUSI Diagnostics & Common Optics
- Long Drift – WBS 1.4.6.1 XCS Vacuum
- Vacuum System, Supports & Tables - WBS 1.4.2.1 XCS Supports & 1.4.6.1 XCS Vacuum

Hutch 4
- Optics & Diagnostics - WBS 1.5 (Not XCS Scope)
- Diffractometer – WBS 1.4.4.1
- Detector – WBS 1.4.3 (BNL Scope)
- Large Angle Detector Mover – WBS 1.4.3.3
- Vacuum System, Supports & Tables - WBS 1.4.2.2 XCS Supports & 1.4.6.2 XCS Vacuum
**XRT Configuration (1)**

**XCS X-Ray Transport Tunnel Region**

- **Divided into Vacuum Sections**
  - Sections Bounded by Valves
  - Two Pump Minimum per Section
- **Offset Monochromator Section**
  - Monochromator and Diagnostics are provided to XCS from WBS 1.5
- **Split & Delay Section**
  - Split & Delay On Loan From Foreign Laboratory
  - Diagnostics are provided to XCS from WBS 1.5
- **Long Drift Section**
  - Long Drift Divided in Two by Valve
  - Drift-End Diagnostics Section
  - Diagnostics are provided to XCS from WBS 1.5
- **XCS Responsible for Vacuum Equipment, Drifts and Floor Stands, Girders and Stoppers.**
**XRT Configuration (2)**

- **Instrument Floor Support Stands**
  - Modification of SSRL support “rafts”

- **Vacuum Component Support Stands**
  - LLNL Designs approved for SLAC use including earthquake safety approval.

- **Vacuum Components**
  - Consistent with LCLS vacuum system design

- **Drift Chamber Support Stands**
  - LLNL Designs approved for SLAC use including earthquake safety approval.

- **Stoppers**
  - Beginning and end PPS stoppers provided by LCLS
  - Between diagnostics stoppers modification of LCLS PPS design
XRT Configuration (3)

- **Long Drift Section – 150 m**
- **One Valve Breaks the Drift Section Into Two Pumping Regions; Three Pumps Per Region**
- **LLNL Vacuum Design Approved for 200m**
- **Use LLNL Designed Components**
  - **LLNL Pump Supports**
    - Design Complete, Reviewed
  - **LLNL Drift Tube Supports**
    - Design Complete, Reviewed
  - **LLNL Valve Supports**
    - Design Complete, Reviewed
- **LLNL Supports Earthquake Approved**
Hutch 4 Configuration (1)

- **Local Optics Table** - Provides Location for Experiment Specific Conditioning Optics – uses modification of XPP design
- **Diagnostics Table** – Provides Mounting Location for Final Diagnostics – uses modification of XPP design
- **Diffractometer** – Positions Sample
- **Large Angle Mover** – Positions Detector
- **Detector** - 1024 x 1024 Charge Pump Structure, BNL
- **LLNL Pump Supports**
Hutch Configuration (2)

XCS Diffractometer System

- **Diffractometer**
  - Components sourced from reputable outside vendor with exemplary reputation
  - Components assembled at SLAC
  - Diffractometer base required to move off beam-line on air-pads, requires marble floor insert

- **Large Angle Detector Mover**
  - Includes vacuum system
  - Provides mount for BNL detector
  - Provides 0 to 55 degrees of rotation of 8 meter detector arm
Component Sources Outside XCS

Multiple sources of instrument components come from outside the XCS budgetary and management scope

Within LUSI – Diagnostics & Common Optics, Controls
ICDs, PRDs ESDs Reviews

Outside LUSI – Split & Delay
MOU
XCS Scope

**Scope of Work**
- **Integration**
- **Tables & stands**
- **Detector System (BNL)**
  - Sub-contracted to BNL through MOU
- **Diffractometer System**
  - Diffractometer
  - Large Angle Detector Mover
- **Hutch Facilities**
- **Vacuum System**
- **Installation**

**Work managed through Instrument Scientist and Lead Engineer partnership**

**Design & fabrication & installation split between SLAC in-house, outside contract and MOU**

<table>
<thead>
<tr>
<th>WBS</th>
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<tr>
<td>1.4</td>
<td>X-RAY CORRELATION SPECTROSCOPY (XCS)</td>
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<tr>
<td>1.4.01</td>
<td>XCS System Integration &amp; Design</td>
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<td>1.4.02</td>
<td>XCS X-ray Optics and Support Table</td>
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<td>1.4.02.02</td>
<td>XCS Hutch Supports, Tables and Shielding</td>
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<td>XCS Stoppers</td>
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<td>1.4.04.03</td>
<td>XCS Large Angle Mover &amp; Chamber</td>
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<td>1.4.05</td>
<td>XCS Hutch Facilities</td>
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<td>XRT Installation</td>
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<tr>
<td>1.4.07.02</td>
<td>Hutch Installation</td>
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</table>
A variety of sources are used to design – build - install XCS components based on experience and cost (coded in P3).

Previous designs and Off-The-Shelf components are used whenever available.
Integration

- Reliance on component design for other instruments
  - Diagnostics & Common Optics
  - Controls
  - Rafts from SSRL
  - Hutch Tables from XPP
  - Vacuum Supports from LCLS
- Monitor engineering on other LUSI instruments & groups
  - Participate in generating specifications
  - Participation in design reviews
- Outside Design within XCS scope
  - Diffractometer – Require design reviews to authorize next phase of work
  - Large Angle Mover - Require design reviews to authorize next phase of work
  - Detector – Empower review committee to validate design
- Equipment provided by external laboratory
  - Split & Delay – Manage participation through MOU
Supports & Stoppers WBS 1.4.2

- XRT Supports & Stoppers – preliminary layout complete, ready for design
  - Utilize modification of existing SSRL “raft” design to support diagnostics components
  - PPS Stoppers provided by LCLS
  - Diagnostics stoppers modification of LCLS design

XRT Vacuum System

- WBS Subsections include vacuum equipment, drift tubes, bellows and supports
- Cost of vacuum system components from established vendors and from actual costs of previous designs
- Long drift vacuum system costs same as LCLS XRT system

Vacuum System WBS 1.4.6

- XRT Vacuum System
  - WBS Subsections include vacuum equipment, drift tubes, bellows and supports
  - Cost of vacuum system components from established vendors and from actual costs of previous designs
  - Long drift vacuum system costs same as LCLS XRT system

- Hutch Vacuum System
  - WBS Subsections include vacuum equipment, drift tubes, bellows and supports
  - Cost of vacuum system components from established vendors and from actual costs of previous designs
  - LCLS XRT pump support designs used in Hutch
Hutch, XCS Scope (1)

- **Hutch 4 definitive layout complete, ready for preliminary design**
- **Supports**
  - Utilize modification of XPP support table for fine positioning of diagnostics components
- **Vacuum**
  - Conservative vacuum design redundant pumping
  - Use LLNL Pump Supports
- **Diffractometer**
  - Definitive layout complete
  - ESD draft complete
  - Meeting with potential vendor conducted June 16th
    - Vendor preliminarily agreed to design-build of integrated assembly.
- **Large Angle Detector Mover**
  - Similar to ANL HERIX detector mover, without complex chamber
  - Received quotes to reproduce HERIX (original vendor)
  - Received requests from two additional vendors to be included on bid
  - Search performed to establish availability of rails and lead screw
Hutch Utilities, WBS 1.4.5

- Provides infrastructure for XCS instrument not provided for in other LUSI WBS section nor from LCLS
- Ongoing meetings established to define infrastructure requirements
- Positions of walls, raised floor, crane, marble floor insert established and incorporated into hutch model
- Instrument stay-clears defined modeled and incorporated in hutch utility model
- Detailed cost estimate established for hutch utilities and incorporated into resource loaded schedule
Diffractometer WBS 1.4.4.1

- Provides sufficient degrees of freedom to position sample relative to beam
- Definitive layout complete
- ESD draft complete
- SOW in process
- Components sourced from reputable outside vendor with exemplary reputation
- Components assembled at SLAC
- Diffractometer base required to move off beam-line on air-pads, requires marble floor insert
Large Angle Detector Mover Motion
Large Angle Detector Mover

Large Angle Detector Mover WBS 1.4.4.3
- Detector Arm: 8 meters
- Angular Range: 0 to 55 degrees
- Vertical Tilt: -0.5 to +2.0 degrees
- Vertical Offset: +/- 20 mm
- Horizontal Offset: Capable of intercepting the CXI beam-line

Subsystems
- Vacuum: Initial design for UHV
- Position Diode: Finds maximum signal center
- Stopper: Blocks maximum power at pattern center to detector
- Slits: Defines signal delivered to detector
- Detector Positioner: Translates detector relative to signal pattern
**XCS Detector**
- Within XCS, WBS 1.4.3
- MOU with BNL
- Work managed by BNL
- LUSI Oversight by (Niels van Bakel)
- Detector Advisory Committee (LDAQ)
  - Periodic reviews
Detector Specification

- Image the temporal changes in a speckle patterns that are related to the sample’s dynamics. The method takes advantage of the coherence properties of the beam.
  - Energy range 4 - 25 keV
  - Need a high QE (> 90%) to measure the spiky nature of the speckle pattern
  - Total angular range is $2\theta = 55^\circ$
  - The detector size is determined by the maximum Q value achievable in the small angle regime
  - Angular resolution or pixel size: the pixel size should be $\leq$ speckle size
  - For $L = 7 - 8$ m, $Db = 10 - 100\ \mu$m the speckle size $Ds = 11 - 120\ \mu$m (@ 8 keV)
  - Number of pixels calculated by the total angular coverage and angular resolution needed for SAXS @ 8m. The basic detector module has 1024 x 1024 pixels
  - Read-out noise $<< 1$ equivalent 8.2 keV photon to allow single photon sensitivity

Niels Van Bakel
1.5.2 Diagnostics
- 1.5.2.1 Pop-in profile/wave-front monitor
- 1.5.2.2 Pop-in intensity monitor
- 1.5.2.3 Intensity-position monitor

1.5.3 Common Optics
- 1.5.3.1 Monochromator
- 1.5.3.2 X-ray focusing lenses
- 1.5.3.3 Slit system
- 1.5.3.4 Attenuators/Filter
- 1.5.3.5 Pulse picker
- 1.5.3.6 Harmonic rejection mirrors

Managed as a project similar to LUSI instruments (Lead Engineer, Eliazar Ortiz; Lead Scientist, Yiping Feng)

Requirements specified by the LUSI XPP, CXI and XCS instrument scientists

Periodic reviews with instrument engineer and scientist participation to assure component design meets instrument requirements
Controls, LUSI WBS 1.6 Scope

**Controls (WBS 1.6)**

*Interface Control document – defines division of responsibility between mechanical device and controls*

- Meetings are required to agree and document controls interface to each device

**Device control requirements**

- Defined per-device through Physics and Engineering requirements documents

**System control**

- Responsibility of Controls – Vacuum, Personnel Protection

**Control integration of vendor provided systems**

- Requires participation of the controls group during the component design phase and design reviews.
XCS uses outside expert vendors for critical procurements – Diffractometer, Large Angel Mover

XCS also utilizes expertise in outside labs for specialized equipment – Split & Delay, Detectors

XCS also intends to use components designed for other LUSI instruments – XPP Tables

XCS also intends to use components designed for other SLAC departments – SSRL Rafts in XRT

LUSI schedule places XCS last in schedule allows XCS to choose the best of recent designs in XCS construction.
## Requirement Documents

### All XCS PRD’s, ESD’s in Draft or Identified

### APP, Risk Reg, all BOE’s up to date and complete

<table>
<thead>
<tr>
<th>LUSI-XCS (WBS 1.4) REQUIREMENTS STATUS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TOPIC AREA</strong></td>
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<tr>
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<tr>
<td>WBS STRUCTURE &amp; DICTIONARY</td>
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<td>MILESTONE DICTIONARY</td>
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<td>INSTRUMENT PRD</td>
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<td>INSTRUMENT ESD</td>
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<tr>
<td>PRELIMINARY INSTRUMENT DESIGN REVIEW</td>
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<td>PRD LIST AND COMPLETION STATUS</td>
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<td>ESD LIST AND COMPLETION STATUS</td>
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<td>INSTRUMENT EQUIPMENT LIST &amp; STATUS</td>
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<td>DESIGN REVIEW LIST &amp; STATUS</td>
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<td>START-UP TEST PLAN</td>
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</table>
Basis of Estimates

**BOE packages contain**
- **Description of the Component**
- **3D model if applicable and available**
- **Detailed cost estimate**
  - Part number, drawing number, vendor, notes, weight, qty, cost, risk and contingency analysis, etc.
- **Supporting quotations, drawings, catalogs, etc.**
- **Configuration Controlled with the CD2 baseline**

---

### BOE packages

<table>
<thead>
<tr>
<th>Description</th>
<th>Part Number</th>
<th>Material</th>
<th>Resource</th>
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<th>Direct Unit Cost</th>
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**Total:**
- **$45,555**

**Fabrication**:
- **$10,715**

**Total:**
- **$50,270**

---

**Configuration Controlled with the CD2 baseline**
Cost & Schedule (May Data)

**XCS budget stats**
- Excludes BNL detector
- Peak spending = CY11
- Labor = ~63%
- M&S = ~35%

### CAM - Bong

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### XCS Manpower

- 1.4.1 System Integration
- 1.4.2 Optics, Supports Tables
- 1.4.4 Diffractometer System
- 1.4.5 Hutch Utilities
- 1.4.6 Vacuum System
- 1.4.7 Installation

### XCS budget stats

#### Excludes BNL detector

#### Peak spending = CY11

#### Labor = ~63%

#### M&S = ~35%
Critical Path

- Path - Delayed design start, diffractometer acquisition, installation
- The Project has establish built in schedule contingency at L2 milestones
- “Project Ready” + 40 days is CD-3A Review, Cd-3A + 40 days is approval
- “Project Ready” + 60 days is CD-4A review
- Besides the project-held schedule float, the XCS Schedule has a minimum of 2 days of float in the installation activities; however, engineering and fabrication in XCS is constrained at the start by funding allocation to fit the LUSI budget profile
- Substantial float could be recovered by allocating funds to XCS earlier
- TOTAL SCHEDULE ”FLOAT” for XCS is 2 + 60 = 62 days.
Summary

- XCS preliminary instrument design is mature to the point where it has been able to:
  - Quantify types of components
  - Estimate component costs
  - Specify acquisition methods
  - Establish baseline schedule

- Selection of components supports the instrument intended function

- Cooperation with other LUSI groups and participation in design reviews is required to meet instrument performance goals

- Many of the materials estimates came from vendor quotations, catalogs, previous orders or work performed by other LUSI instrument teams

- The XCS Critical Path is dominated by late start of engineering work, constrained by funding

The committee consisted of E. Alp (APS), B. Brajuskovic (APS) and T. Rabedeau (SSRL).

The committee was charged to review the project from four perspectives as follows:

1 Scientific Goal
2 Technical Design
3 Value Engineering
4 Opportunities

This document is the answer from the X-ray Correlation Spectroscopy Instrument Integrated Team (XCS-IIT) to the report of the XCS PIDR (included as attachment at the end of the present document).

1 Scientific Goal

i No Comment

ii The Small and Wide Angle X-ray Scattering sections were always in the scope of the XCS instrument over the full range of the hard X-ray beam produced by LCLS (i.e 8-25keV). For now the SAXS section is however no longer in the scope of the XCS Instrument. The scientific capabilities of the XCS Instrument were refined with the XCS Team Leaders. The high energy range is of importance for the science to be produced for the XCS instrument, as it would allow widening the type of sample that could be experimentally investigated on the XCS instrument, as a result of smaller issues regarding beam damage for higher energies. This will be re-emphasize during the next XCS Team Leader meeting to be held on Oct 19th.

iii The XCS-IIT agrees with the review committee and expressed the request to LUSI management.

iv These issues are understood and were investigated by the XCS-IIT. This justifies the presence of the whole suite of diagnostics and apertures along the beam path, in order to transform any LCLS beam fluctuation into intensity fluctuations. By measuring these fluctuations, with the appropriate diagnostics, one can then normalize the experimentally measured data.

2 Technical Design

i This issues will be discussed with the XCS Team Leaders on Oct 19th. A new approach taking in consideration this recommendation will be presented by the XCS-IIT.

ii The scheme to be presented to the XCS Team Leaders at the next XCS Team Leaders Meeting includes a change in the monochromatization process.

iii The XCS-IIT agrees. The recommended changes will be applied as soon as possible in the design of the XCS instrument.

iv The XCS-IIT appreciates the recommendation. To the extent possible both monochromator systems will be identical for the XCS and XPP instrument. In case the requirements differ, the XCS-IIT is ready to design its own monochromator system.

A. Robert

September 15, 2008
This recommendation will be communicated to the Diagnostics and Common Optics Integrated Team in charge of the design of the diagnostics. The XCS-IIT supports strongly this recommendation.

The total number of optical elements which may interact with the beam is effectively large, but is required for alignment and commissioning purpose. In running mode of the XCS instrument (i.e. while measuring experimental data) the number of such elements is much less (2 bounces monochromator, 2 mirrors and 2 transmission diagnostics only). These are in any case required to conduct the experiment. The optical quality, especially its coherent preservation character is considered in the design of each of these elements, as required to conduct experiment with coherent x-ray beams.

3 Value Engineering

The XCS-IIT agrees. Even if the Large Angle Detector Mover is based on the design of the HERIX spectrometer of the Inelastic Scattering beamline of the Advanced Photon Source, its specifications are relaxed as compared to it.

The XCS-IIT will consider this recommendation in the design to the extent possible. For a certain degree of modularity of the sample-detector distance, it might be convenient and cost-effective to combine both approaches. More engineering design is required to evaluate that concept.

The XCS-IIT will also investigate different options and proceed to a detailed value engineering investigation of each option.

The XCS-IIT agrees and will discuss this issue with LUSI management.

No comment.

4 Opportunities

No Comment

The current plan for the XCS instrument is to get a first prototype of Split and Delay Unit which perform at fixed energy. This prototype is provided by DESY via a SLAC/DESY MoU. The MoU also states that SLAC and DESY should collaborate regarding the development of the next generation of Split and Delay unit (i.e tunable wavelength). The details of this collaborations are not know yet in terms of its SLAC, LCLS, LUSI contribution. the XCS-IIT will make every effort possible to develop this technology at the laboratory.
Preliminary Instrument Design Review

X-ray
Correlation
Spectroscopy

07/25/2008
Our committee was presented with the technical and scientific aspects of the X-Ray Correlation Spectroscopy Instrument (XCS) as well as budget and WBS.

We were very positively impressed with the technical, budgetary, and scheduling details given at the meeting. It is clear that what was presented is commensurate with the time frame and financial aspects of such a large project. We commend the technical staff and LUSI management for the work they have done so far.

Our committee was charged to review the project from four perspectives as follows:

1. Scientific Goals
2. Technical Design
3. Value Engineering
4. Opportunities

1. Scientific Goals

i) A. Roberts has completed a comprehensive survey of the current worldwide literature to determine the exact energy and momentum transfer map to identify the target domain for the XCS instrument. This survey is the basis of some of the critical scientific decisions with respect to energy and momentum transfer range.

ii) In addition to XCS, the scientific scope has been widened to include small-angle x-ray scattering, SAXS, and wide-angle x-ray scattering, WAXS, over 8-24 keV. This expansion may be difficult to realize with tight budget allocation. It may be advisable to split the low energy part and simplify the high-energy effort. Particularly, the large energy range between 8-24 keV is a major cost-determining factor. The science team is advised to re-visit this issue.
iii) One of the innovative aspects of the scientific program is to extend the time-resolved studies to nanosecond regime by implementing a “split-and-delay” instrument. While this is an exciting prospect, and some early work in Europe proves the feasibility for a fixed-wavelength, it remains to be seen if such an instrument can be developed fully tunable over a large energy range. The committee feels that, if this is part of the scientific program, the “split-and-delay” instrument itself should be included in scope, cost and schedule.

iv) There is a concern that the LCLS electron-beam based source fluctuations may limit the scientific program for XCS.

2. **Technical Design**

i) The committee was surprised to see the length and the number of optical components needed to bring the beam into the experimental area. Because of the complexity of the LCSL machine, and the need for diagnostics over 450 m length of the beamline, the choice of 60 cm horizontal off-set between XCS and CXI beamlines might drive the cost up. This should be re-visited after the exact locations of the XCS upstream components are determined. In particular, the location of the monochromator at 200 m upstream of the sample position may prove to be too long of a level arm, in addition to creating a need for a separate beam pipe and additional diagnostics.

ii) The need for the horizontal deflecting monochromator to operate between 8-24 continuously should be revisited. A tunable monochromator operating in the larger energy half of this energy range significantly complicates the design of the large offset monochromator, raises the cost of the monochromator, and potentially compromises its stability yet it is not well justified. Instead a fixed energy monochromator operating at some appropriate energy inside this upper energy range should be considered in addition to a tunable large offset monochromator operating in the smaller energy half of the energy range. This approach is more consistent with likely beam split and delay systems that will eventually replace the 8.3keV fixed energy system.

iii) Photon shutters after each diagnostic element is not necessary, and should be replaced with simple commercial actuators with a steel block at the end.

iv) The monochromator is supposed to be a common element, and to be duplicated for the XPS beamline, following a contingency plan. Thus any change in scope or implementation is to be coordinated. It may be better to decouple the two instruments, and if in the end, they turn out to be the same, two instruments can be ordered at once.

v) Position sensitive detectors with 4-PIN diodes may not have the sensitivity at low photon flux. So the diagnostics detectors should be re-considered. APD based system may prove to be a better alternative.
vi) There seems to be too many “coherence-reducing” optical elements in the way before the x-ray beam hits the sample. We have counted some 20-bounces or filter transmissions. While the reduction in coherence at each element may be tolerable, when there are so many, the net coherence degradation should be a concern. The team is advised to look at this issue, and reduce the number of elements in the beam to a minimum.

3. **Value Engineering**

i) The long-arm detector mount, LADM, based on the APS-HERIX design, may be overkill in terms of stability and resolution requirements, and therefore a design simplification is recommended for potential cost savings. Specifically, for the XCS application only the detector position need be carefully controlled while the upstream end of the flight arm can be designed with much coarser position control hence cost. The APS HERIX instrument had to line up five elements (sample, slits, detector array, collimator and the analyzer array), thus the requirements were much more stringent. LUSI_XCS team can relax the resolution and the repeatability requirements for the upstream set of stages, and potentially save money.

ii) For the LADM, pipe dimension should grow as the x-ray beam progresses towards the detector to minimize the total weight.

iii) The granite block to move the diffractometer should be either eliminated or replaced with a cheaper design

iv) It was difficult to get a clean break down between instrument and effort costs, since some of the XCS instruments are common with the other two LUSI beamlines. We advise to remove this uncertainty soon to keep the schedule and cost tractable.

v) 35% financial contingency is considered appropriate and adequate. Enough floats in the schedule is provided to allow LCLS management to adjust the work load during the simultaneous construction of 3 beamlines assuming the orally presented figure of 100 working days

4. **Opportunities**

i) The main XCS detector is to be built by BNL. Our review team considers this a wise decision and considers it the right way to go.

ii) The scientific opportunity to implement “split-and-delay” instrument is considered to be very important by our committee, and therefore, every effort should be made to include the construction of this critical component in the main program. However, it is also possible to consider a fixed-wavelength version of the instrument as Phase I, and delay the tunable “split-and-delay” instrument to a later period, after the beamline is completed, and early science experiments are done.