### DESIGN REVIEW REPORT

The Design Review Report shall include at a minimum:

- The title of the item or system;
- A description of the item;
- Design Review Report Number;
- The type of design review;
- The date of the review;
- The names of the presenters;
- The names, institutions, and department of the reviewers;
- The names of all the attendees (attach sign-in sheet);
- Completed Design Checklist.

- Findings/List of Action Items – these are items that require formal action and closure in writing for the review to be approved. See SLAC Document AP-391-000-59 for LUSI Design Review Guidelines.
- Concerns – these are comments that require action by the design/engineering team, but a response is not required to approve the review.
- Observations – these are general comments and require no response.

### TYPE OF REVIEW: Preliminary Design Review

<table>
<thead>
<tr>
<th>WBS:</th>
<th>1.5 Diagnostics</th>
<th>Common Optics</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th><strong>Title of the Review</strong></th>
<th>Profile Monitor and Wavefront Monitor, Optics Preliminary Design Review</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Presented By:</strong></td>
<td>Yiping Feng,</td>
</tr>
<tr>
<td><strong>Report Prepared By:</strong></td>
<td>Sebastien Boutet, Date: 02-10-09</td>
</tr>
<tr>
<td><strong>Reviewers/Lab:</strong></td>
<td>Bill White – SLAC, Sebastien Boutet – SLAC</td>
</tr>
</tbody>
</table>
LUSI Diagnostics and Common Optics

Pop-in Profile/Wavefront Monitors
Optics Review

Yiping Feng – LUSI Instrument Scientist
February 10, 2009
Outline

- Introduction
  - Performance requirements
- Device concept
  - Optical components
    - X-ray scintillator
    - Optical mirror
    - Vacuum window
    - Optical zoom lens
    - Pixelated optical sensor
- Simulations
  - Expected imaging performance
- Surveying
- Size calibration
- Resolution testing
Introduction

- **Performance Requirements**
  - Capturing 2D beam profile
  - Operating energy 2-25 keV
  - Variable field of views (FOV) & resolution
    - Large FOV of 25x25 mm², 100 μm
    - Small FOV of 2x2 mm², 8 μm
  - Capable of high resolution operation
    - Extra-small FOV of 1x1 mm² FOV, 4 μm
  - Intensity levels, 256 or 8 bits, w/ goal of 1024 or 10 bits
  - Capable of per-pulse operation
    - Optional for only one per instrument
  - Attenuation acceptable in high fluence
    - Using LCLS designed performance parameters
Device Concept

- Device concept
  - Technical choices
    - 2D imaging by X-ray direct detection
      - In charge collection mode
        - Can afford high signal-to-noise ratio, but essential to application
      - Quantum efficiency very high
        - > 90% at 8.265 keV
      - Resolution limited to pixel size ~ 100 μm
        - Medium to high resolution capability not possible
      - Dynamic range limited to $10^4$ photons/pulse
        - Requiring up to $10^7$ in attenuation if $10^{12} \gamma$/pulse in main beam
        - Capable of working w/ spontaneous or monochromatized beam
      - Detector very expensive, cost not viable
      - Detector in-line w/ FEL beam, not compatible w/ instrument’s layout except being placed at the end, which is also NOT allowed by radiation physics considerations
Device Concept

- Technical choices (con’t)
  - Optical imaging by indirect X-ray scintillation
    - Capable of very high spatial resolution
      - 2 μm has been achieved elsewhere
    - Suitable for fully saturated FEL w/ proper attenuation
    - Capable of partial transmission for more elaborate schemes if desired, e.g. AMO implementation
  - Imaging optics not collinear w/ FEL propagation when mirror is used
  - Same concept used
    - By XTOD group for FEE diagnostics – “direct imager”
    - Accelerator group for electron beam diagnostics
  - But inefficient
    - Conversion from X-ray to optical
    - $4\pi$ sterradian distribution in optical fluorescence emission
    - Lens system always has limited numerical aperture
Device Concept

- Conceptual geometry
  - Normal incidence
    - Scintillator surface normal to incident FEL
  - Components
    - X-ray scintillator
    - 45 mirror
    - Quartz window
    - Zoom lens
    - Pixelated sensor

Components:
- X-ray scintillator
- 45 mirror
- Quartz window
- Zoom lens
- Pixelated sensor

FEL pulses

Conceptual geometry:
- Scintillator surface normal to incident FEL
- Normal incidence

Components:
- X-ray scintillator
- 45 mirror
- Quartz window
- Zoom lens
- Pixelated sensor
Device Concept

- Conceptual geometry (con’t)
  - Oblique incidence
    - Scintillator surface inclined w/ respect to incident FEL, and axis of optical system normal to scintillator surface
  - Components
    - X-ray scintillator
    - Zoom lens
    - Pixelated sensor
  - Image smearing
    \[
    \Delta y = t \frac{\sin \phi}{\cos \theta} \\
    = t \text{ if } \phi = 45^\circ, \theta = 45^\circ
    \]
Device Concept

- Mechanical model

- Quartz window
- YAG:Ce screen
- 45° mirror
- Zoom lens
- Pixelated camera

*Working distance will include distance from YAG screen to 45 mirror*
Optical Components

- YAG:Ce scintillation screen
  - characteristics
    - High radiation hardness
      - High melting temperature
      - High thermal conductivity
    - In NEH & FEH, capable of sustain full unfocused X-ray FEL beam at normal incidence w/ moderate attenuation
    - Fast scintillator
    - Good fluorescence yield
      - Peak response (550 nm) matches CCD QE curve
    - High spatial resolution
      - Capable of normal incidence
      - Clear, not diffuse as phosphor
    - Vacuum compatible

<table>
<thead>
<tr>
<th>YAG:Ce</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical formula</td>
</tr>
<tr>
<td>Ce doping</td>
</tr>
<tr>
<td>Melting point</td>
</tr>
<tr>
<td>Fluorescence spectral peak</td>
</tr>
<tr>
<td>Light yield (Ce doping dependent)</td>
</tr>
<tr>
<td>Decay constant</td>
</tr>
<tr>
<td>After glow (at 6 ms)</td>
</tr>
<tr>
<td>X-ray attenuation length</td>
</tr>
<tr>
<td>Size (diameter/side)</td>
</tr>
<tr>
<td>Thickness</td>
</tr>
</tbody>
</table>
YAG:Ce Scintillator

- **Size**
  - The bigger, the thicker
    - 25x25 mm\(^2\), 75 μm
    - 12x12 mm\(^2\), 50 μm

- **Thickness**
  - Affect resolution achievable
    - < Depth of field
    - Requiring telecentric lens if too thick
  - Limited for free standing crystal (>= 50 μm)
  - Thinner sample could be obtained by using epitaxial YAG:Ce on YAG substrate
    - ~ 5 μm epi layer
    - But YAG glows as well affecting resolution
YAG:Ce Scintillator

- Resolution limits
  - Parallaxial distortion
    - Proportional to thickness

- Diffusive broadening
  - Proportional to thickness

\[ \Delta_{\text{para}} = -\frac{Mtr}{(Z_{WD} - f)} \]

\[ \Delta_{\text{diff}} = \alpha t \]
Resolution Limit from Survey Tolerance w/ Pre-alignment

- Alignment tolerance
  - Assuming camera optical axis is perpendicular to scintillator surface via pre-alignment
  - Assembly is then aligned to FEL beam axis

![Diagram showing resolution limit and alignment tolerances](image)

\[ \Delta y = t \frac{\sin \theta}{\cos \theta} \]

- if \( \theta \) is small

Targeted YAG:Ce Thickness

Targeted Resolution

Resolution Limit from Survey Tolerance in pitch/yaw
YAG:Ce Scintillator

- Quantum efficiency
  - $1 - \text{transmission} > 20\%$
  - Optical output weakly energy dependent $< a$ factor 4
    - Lower QE made up by higher photon energy $\Rightarrow$ more optical phonon
    - 1% flux of fundamental for 3$^{rd}$ harmonic

![Graph showing optical output as a function of energy](image)

"Y3Al5012 Density=4.457 Thickness=75. microns"

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YAG:Ce Scintillator

- Damage consideration
  - Attenuation required at lower energies (< 6 keV) in FEH-3
  - A factor of 10 to 100 will be sufficient

---

![Graph](image-url)

**Peak Fluence at 8.265 keV for YAG:Ce at normal incidence**

- Peak Fluence (eV/atom)
- Beam Waist (m)

![Graph](image-url)

**Peak Fluence at 2.000 keV for YAG:Ce at normal incidence**

- Peak Fluence (eV/atom)
- Beam Waist (m)
45º Mirror

- Optical Mirror
  - Optical specifications
    - Quality: optical
    - Material: UV grade
    - Transmitted wavefront: $\lambda/4$ @ 632 nm
    - Flatness: $\lambda/4$
    - Scratch-Dig: 20-10
    - Mil-C-675-A adhesion & durability specs
    - Reflectivity: > 95% @ 45º incidence, 475-650 nm
      - Broadband so permitting visual inspection using white light
        - May require metallic coating
        - Or metal mirror
  - Viewing aperture
    - Consistent w/ size of YAG:Ce screen
  - Thickness
    - Not critical
45º Mirror

- **Radiation consideration**
  - If Al is used, no damage issues
    - Transmission < 0.5% for energy < 6 keV
    - Al is safe in NEH for energy > 6 keV

![Graph showing transmission vs photon energy for Y3Al5O12 with 75 μm YAG:Ce](image)
Vacuum Window

- Optical specifications
  - Material: UV grade
  - Transmitted wavefront: $\lambda/4$ @ 632 nm
  - Flatness: $\lambda/4$
  - Parallelism: 10 arc seconds
  - Scratch-Dig: 20-10
  - Mil-C-675-A adhesion & durability specs
  - AR coating: $R_{ave} < 0.5\%$, 0° incidence, 475-650 nm

- Viewing aperture
  - Consistent w/ zoom lens

- Thickness
  - Consistent w/ vacuum requirement and size of the view aperture

- Radiation consideration
  - Not in direct line-of-sight other than stray radiation
2D Pixelated Camera

- Fast 2D pixelated camera
  - 1/3 inch optical CCD - Pulnix TM-6740CL (CameraLink)
    - Sensor size - 4.74x3.55 mm²
    - Optimal response
      - @ 550 nm, QE = 45%
    - 648x484 pixels
    - Progressive scan up to 200 Hz
    - 7.4x7.4 μm² square pixels
  - Dynamic range
    - > 10 bit
    - 20 ke- full well @ 40 MHz
    - 16 e- noise @ 40 MHz
- Use Cameralink™ protocol
- Frame grabber on Linux OS
2D Pixelated Camera

- **CCD data sheet (Kodak KAI-0340)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architecture</td>
<td>Interline CCD; Progressive Scan</td>
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<tr>
<td>Total Number of Pixels</td>
<td>696 [H] x 492 [V]</td>
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<tr>
<td>Number of Effective Pixels</td>
<td>648 [H] x 484 [V]</td>
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<tr>
<td>Number of Active Pixels</td>
<td>640 [H] x 480 [V]</td>
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<tr>
<td>Pixel Size</td>
<td>7.4 μm (H) x 7.4 μm (V)</td>
</tr>
<tr>
<td>Active Image Size</td>
<td>4.736mm [H] x 3.552mm [V]</td>
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<tr>
<td></td>
<td>5.920mm (diagonal) 1/3° optical format</td>
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<tr>
<td>Aspect Ratio</td>
<td>4:3</td>
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<tr>
<td>Number of Outputs</td>
<td>1 or 2</td>
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<tr>
<td>Charge Capacity</td>
<td>40 MHz – 20,000 electrons</td>
</tr>
<tr>
<td></td>
<td>20 MHz – 40,000 electrons</td>
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<tr>
<td>Output Sensitivity</td>
<td>30 μV/e</td>
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<tr>
<td>Photometric Sensitivity KAI-0340-ABB</td>
<td>3.61 V/lux-sec</td>
</tr>
<tr>
<td>Photometric Sensitivity KAI-0340-CBA</td>
<td>1.17[(B), 1.54(G), 0.65(R)] V/lux-sec</td>
</tr>
<tr>
<td>Readout Noise</td>
<td>40 MHz – 16 electrons</td>
</tr>
<tr>
<td></td>
<td>20 MHz – 14 electrons</td>
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<tr>
<td>Dynamic Range</td>
<td>40 MHz – 62 dB</td>
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<tr>
<td></td>
<td>20 MHz – 69 dB</td>
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<tr>
<td>Dark Current</td>
<td>Photodiode &lt; 200 eps</td>
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<td></td>
<td>VCCD &lt; 1000 eps</td>
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<tr>
<td>Maximum Pixel Clock Speed</td>
<td>40MHz</td>
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<tr>
<td>Maximum Frame Rate</td>
<td>KAI-0340-Dual – 210 fps</td>
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<td>KAI-0340-Single – 110 fps</td>
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<tr>
<td>Package Type</td>
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<td>Package Size</td>
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<tr>
<td></td>
<td>0.625” [15.87mm] length</td>
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<tr>
<td>Package Pins</td>
<td>22</td>
</tr>
<tr>
<td>Package Pin Spacing</td>
<td>0.050”</td>
</tr>
</tbody>
</table>

All parameters above are specified at T = 40°C.
2D Pixelated Camera

- Frame rate
  - @ 30 Hz for all cameras except one per instrument @ 120 Hz
  - With CameraLink™ protocol, 120 Hz frame rate could be readily achieved w/ ¼ Mpixel cameras, thus not driving the design other than a cost increase < $500
  - In almost all case, the resolution of the current system will be lens-limited
    - Working distance is limiting the available NA
    - More pixels would not improve resolution for high magnification settings
Zoom Lens

- Zoom lens (Navitar)
  - Modular/flexible design
    - Attachment+zoom+adapter
  - Large range of FOV ~ 12x
    - Maintaining focus while zooming
  - Good working distance
    - 165, 108, 86 mm
    - Trade-off btw FOV and resolution
  - Sufficient depth of field
    - ~ Min. 200, 89, 50 μm
  - Sufficient NA
    - Max. NA ~ 0.05, 0.075, 0.1
  - Readily Motorizable
    - Focus or zoom or focus&zoom

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## Zoom Lens

### Zoom selection

**FOV** = \( \frac{D}{\text{Sys. Mag.}} \)

- \( D_{\text{camera}} = 3.6 \text{ mm} \)
- 1/3 Mpixel CCD 7.4 μm

**Optical resolution**

**Matching pixel size** = \( \Delta_{\text{optical}} \cdot \frac{\text{Sys. Mag}}{2} \)

<table>
<thead>
<tr>
<th>12X Zoom Combinations</th>
<th>W.D.</th>
<th>System Mag.</th>
<th>N.A. -obj-</th>
<th>Feature Size micron</th>
<th>Pixel Size microns</th>
<th>Depth of Field</th>
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<tbody>
<tr>
<td><strong>Config.- A (WFOV)</strong></td>
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<td></td>
<td></td>
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<td></td>
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<tr>
<td>25 mm</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>0.5x + 12X Zoom + 0.5x</td>
<td>165</td>
<td>0.14</td>
<td>1.75</td>
<td>0.009</td>
<td>0.051</td>
<td>6.60</td>
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<tr>
<td>0.5x + 12X Zoom + 0.67x</td>
<td>165</td>
<td>0.19</td>
<td>2.35</td>
<td>0.009</td>
<td>0.051</td>
<td>3.60</td>
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<td>0.29</td>
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<td>0.58</td>
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<td>0.22</td>
<td>2.62</td>
<td>0.014</td>
<td>0.076</td>
<td>18.89</td>
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<td>0.29</td>
<td>3.52</td>
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<td>0.87</td>
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<td>18.40</td>
<td>0.014</td>
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<td>10.35</td>
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<tr>
<td>None + 12X Zoom + 0.5x</td>
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<td>0.29</td>
<td>3.49</td>
<td>0.019</td>
<td>0.101</td>
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<td>None + 12X Zoom + 0.67x</td>
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<td>0.39</td>
<td>4.69</td>
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<td>0.101</td>
<td>3.42</td>
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<td>0.58</td>
<td>7.00</td>
<td>0.019</td>
<td>0.101</td>
<td>5.09</td>
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<td>1.16</td>
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<td>2.03</td>
<td>24.50</td>
<td>0.019</td>
<td>0.101</td>
<td>18.79</td>
</tr>
</tbody>
</table>

**Config.- B (NFOV) 12 mm**

<table>
<thead>
<tr>
<th>12X Zoom Combinations</th>
<th>W.D.</th>
<th>System Mag.</th>
<th>N.A. -obj-</th>
<th>Feature Size micron</th>
<th>Pixel Size microns</th>
<th>Depth of Field</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Optional Config.- C</strong> (MACRO) 6.2 mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2x of listed values based on Rayleigh Criteria

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Zoom Lens

- **Working distance (W.D.) & Depth of field**
  - Resolution generally would increase when going to smaller focal length (thus shorter working distance) for a given optics diameter
  - It is thus desirable to use a lens system that has shorter W.D. if the requirements for the field of view (FOV) could be met.
  - In addition, light collection efficiency is higher at short W.D.

- However, there are other resolution effects that must be considered, such as the parallaxial distortion.
  - When the object is extended in the direction of the optical axis, parallaxial effects can smear the resolution by appearing in the image space being tilted away from the axis.
  - Only telecentric lens system could correct for this kind of distortion
    - But, telecentric lens is expensive
    - Light collection efficiency lower
  - Or thinner YAG:Ce screen

- **Depth of field**
  - DOF generally decreases with W.D.
  - At 86 mm or shorter, the DOF would be smaller than the thickness (75 μm) of the YAG:Ce screen
Zoom Lens

- Working distance & Depth of field (con’t)
  - W.D. of 165 & 108 mm was a good comprise
    - Resolution limited to 6.6 μm & 4.4 μm
    - Parallaxial distortion limited to < 3 μm
    - Light collection seems adequate
    - Good depth of field @ 200 & 89 μm, making focusing requirement somewhat relaxed
  - Shorter W.D. would be required if higher resolution (< 3 μm) is required, or light collection is an issue with 165 & 108 mm system
    - Change W.D. to 86 mm
    - Would work w/ 50 μm YAG:Ce to reduce parallaxial distortion

- Focus test
  - DOF > 89 μm, > YAG:Ce thickness of 75 μm
    - Thus focusing requirement could be easily met
  - See surveying and calibration
    - Use scratches on YAG:Ce screen
    - Or use test patterns
## Zoom Lens/Camera Configuration

### Configurations

<table>
<thead>
<tr>
<th>Config. (att.+zoom+ adapter)</th>
<th>Zoom lens FOV (mm²)</th>
<th>Working Distance (mm)</th>
<th># of pixels</th>
<th>Expected resolution (μm)</th>
<th>Digital output</th>
<th>Frame rate</th>
<th>Frame grabber OS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5x+12x+0.5x</td>
<td>25.7x25.7 – 2.06x2.06</td>
<td>165</td>
<td>648x484</td>
<td>106 – 8.5</td>
<td>Cameralink</td>
<td>Up to 120</td>
<td>Linux/RTEMS</td>
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<tr>
<td>0.75x+12x+0.67x</td>
<td>12.4x12.4 – 1.03x1.03</td>
<td>108</td>
<td>648x484</td>
<td>51 – 4.4</td>
<td>Cameralink</td>
<td>Up to 120</td>
<td>Linux/RTEMS</td>
</tr>
<tr>
<td>High resolution configuration (optional)</td>
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<td>6.2x6.2 – 0.51x0.51</td>
<td>86</td>
<td>648x484</td>
<td>26 – 3.3</td>
<td>Cameralink</td>
<td>Up to 120</td>
</tr>
</tbody>
</table>
Lens Characteristics

- Lens/camera config. A
  - CCD chip 3.6 mm in height
  - FOV 25.71 mm (3.6 mm/Magnification)

\[ y = 0.1101x^4 - 0.3335x^3 + 0.3921x^2 - 0.2255x + 0.0667 \]
\[ R^2 = 1 \]
Signal Calculations

- Image Brightness

Pixel Brightness and Scene Brightness

\[
\frac{da \cos \alpha}{(f / \cos \alpha)^2} = \frac{dA \cos \theta}{(Z / \cos \alpha)^2} \quad \Rightarrow \quad \frac{dA}{da} = \frac{\cos \alpha \left( \frac{Z}{f} \right)^2}{\cos \theta} \\
dP = LdA \Omega \cos \theta \quad \Rightarrow \quad dP = LdA \frac{\pi}{4} \left( \frac{D}{Z} \right) \cos^3 \alpha \cos \theta \\
E = \frac{dP}{da} = L \frac{dA}{da} \frac{\pi}{4} \left( \frac{D}{Z} \right)^2 \cos^3 \alpha \cos \theta \quad \Rightarrow \quad E = \frac{\pi}{4} \left( \frac{D}{f} \right)^2 \cos^4 \alpha \cdot L
\]
Factors Considered

- Radiance
  - FEL energy and flux
  - YAG photoelectric effect %
  - YAG Fluorescence yield and distribution
    - Assuming uniform over 4\(\pi\)
- Irradiance
  - Numerical aperture
  - YAG refractive index
- Losses
  - Quartz window transmission
  - CCD surface reflection
- CCD quantum efficiency
## Simulations

- **Expected performance**

<table>
<thead>
<tr>
<th>Beam size in vertical (FWHM/waist in μm)</th>
<th>Field of View (mmxmm)/ [Resolution (μm)]</th>
<th>Image size on ½ CCD sensor (# of pixels)</th>
<th># of e⁻ per pixel @ 1.5x10^{12} photons @ 8 keV &amp; 75 μm YAG</th>
<th>Attenuation needed to match full well (20k e⁻)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>221/188</td>
<td>24x24 [99]</td>
<td>4x4</td>
<td>1.08x10^{7}</td>
<td>542</td>
<td>Reduces damages</td>
</tr>
<tr>
<td></td>
<td>2x2 [8.3]</td>
<td>46x46</td>
<td>1.91x10^{6}</td>
<td>96</td>
<td>Reduces damages</td>
</tr>
<tr>
<td>489/416</td>
<td>24x24 [99]</td>
<td>8x8</td>
<td>2.22x10^{6}</td>
<td>111</td>
<td>Reduces damages</td>
</tr>
<tr>
<td></td>
<td>2x2 [8.3]</td>
<td>101x101</td>
<td>3.92x10^{5}</td>
<td>20</td>
<td>FEL only</td>
</tr>
<tr>
<td>221/188 (high resolution configuration)</td>
<td>4.7x4.7 [19]</td>
<td>19x19</td>
<td>2.66x10^{6}</td>
<td>133</td>
<td>Reduces damages</td>
</tr>
<tr>
<td></td>
<td>0.8x0.8 [3.3]</td>
<td>114x114</td>
<td>8.23x10^{5}</td>
<td>41</td>
<td>FEL only</td>
</tr>
</tbody>
</table>

Notes:
- Reduces damages
- FEL only
Operation for XPP in NEH-3
- Aligning optical components
  - Beam-finding in large FOV
  - Fine-tuning in small FOV

24 mm FOV, waist = 3.8 pixels (188 μm @ NEH-3)

2 mm FOV, waist = 46 pixels (188 μm @ NEH-3)
Alignment Operation

- Operation for XCS/CXI in FEH-4/5
  - Aligning optical components
    - 2x bigger beam size

24 mm FOV, waist = 8.4 pixels
(416 μm @ FEH-5)

2 mm FOV, waist = 101 pixels
(416 μm @ FEH-5)
FEL 2D Imaging

- Imaging for XPP in NEH-3
  - Use optional config.
  - Higher resolution (~3.3 μm)
- FEH operation very similar

4.7 mm FOV, waist = 19.4 pixels
(188 μm @ NEH-3)

800 μm FOV, waist = 114 pixels
(188 μm @ NEH-3)
Diffraction Effects

- Imaging for XPP in NEH-3
  - Coherence leads to diffraction effects
    - Slits
    - Surface roughness
Wavefront Monitor

- Performance Requirements
  - Capturing 2D beam profile
  - Operating energy 2-25 keV
  - Variable field of views (FOV) & resolution
    - Large FOV of 24x24 mm², 100 μm
    - Medium FOV of 12x12 mm², 50 μm
    - Small FOV of 1.2x1.2 mm², 5 μm
  - Intensity levels, 256 or 8 bits, w/ goal of 1024 or 10 bits
  - Capable of per-pulse operation
  - Attenuation acceptable in high fluence
    - Using LCLS designed performance parameters
Diffractive Wavefront Reconstruction

- The oversampled diffraction pattern of focus (sample) is measured.
- The focal spot is iteratively reconstructed using standard phase retrieval methods
  - propagating wave from optic to focus and then to detector plane.
  - The constraints are applied at optic and detector planes.

Diffractive Wavefront Reconstruction

- Wavefront monitor
  - Iterative phase retrieval
# Simulations

- **Expected performance**

<table>
<thead>
<tr>
<th>Beam size in vertical (FWHM/ waist in μm)</th>
<th>Field of View (mmxmm)/ [Resolution (μm)]</th>
<th>Image size on ½ CCD sensor (# of pixels)</th>
<th># of e- per pixel @ 1.5x10^{12} photons @ 8.3 keV &amp; 75 μm YAG</th>
<th>Attenuation needed to match full well (20k e⁻)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1567/1331 (0.1 μm focus)</td>
<td>24x24 [99]</td>
<td>27x48</td>
<td>2.17x10^5</td>
<td>11</td>
<td>FEL only</td>
</tr>
<tr>
<td></td>
<td>8x8 [33]</td>
<td>81x143</td>
<td>1.50x10^5</td>
<td>8</td>
<td>FEL only</td>
</tr>
<tr>
<td>714/606 (1.0 μm focus)</td>
<td>12x12 [50]</td>
<td>24x26</td>
<td>8.30x10^5</td>
<td>42</td>
<td>Reduces damages</td>
</tr>
<tr>
<td></td>
<td>2x2 [8.3]</td>
<td>147x156</td>
<td>1.84x10^5</td>
<td>9</td>
<td>FEL only</td>
</tr>
<tr>
<td>75/63 (10 μm focus &amp; high resolution configuration)</td>
<td>1.2x1.2 [5]</td>
<td>26x26</td>
<td>1.08x10^7</td>
<td>538</td>
<td>Reduces damages</td>
</tr>
<tr>
<td></td>
<td>0.80x0.80 [3.3]</td>
<td>38x38</td>
<td>7.26x10^6</td>
<td>363</td>
<td>Reduces damages</td>
</tr>
</tbody>
</table>
Wavefront Characterization

- Wavefront measurement in FEH-5
  - 0.1 \( \mu \)m KB (*in Q space*)

- 24 mm FOV, waist = 27x48 pixels
  (0.1 \( \mu \)m focusing @ FEH-5 @ 3 m from focus)

- 8 mm FOV, waist = 81x143 pixels
  (0.1 \( \mu \)m focusing @ FEH-5 @ 3 m from focus)

- 60 Å resolution, 1.44 \( \mu \)m FOV, 242 resolving power
- Revealing features outside of focal region
Wavefront Characterization

- Wavefront measurement in FEH-5
  - 1.0 \( \mu \text{m} \) KB (*in Q space*)

  - 12 mm FOV, waist = 24x26 pixels (1.0 \( \mu \text{m} \) focusing @ FEH-5 @ 11 m from focus)

  - 2 mm FOV, waist = 147x156 pixels (1.0 \( \mu \text{m} \) focusing @ FEH-5 @ 11 m from focus)

- 438 Å resolution, 10.6 \( \mu \text{m} \) FOV, 242 resolving power

- Revealing features outside of focal region
Wavefront Characterization

- Wavefront measurement in FEH-5
  - 10 \( \mu \text{m} \) Be Lens (in Q space)

  1.2 mm FOV, waist = 26x26 pixels
  (10 \( \mu \text{m} \) focusing @ FEH-5 @ 11 m from focus)
  Using high-res config 4.7 mm FOV

  800 \( \mu \text{m} \) FOV, waist = 38x38 pixels
  (10 \( \mu \text{m} \) focusing @ FEH-5 @ 11 m from focus)

- 0.44 \( \mu \text{m} \) resolution, 106 \( \mu \text{m} \) FOV, 242 resolving power
- Revealing features outside of focal region

- Needs a new picture
Surveying & Calibration

- **Surveying**
  - **Bench top alignment**
    - Use survey laser to establish alignment of laser to fiducials on vacuum housing
      - To ±1°
    - Establish the imaging axis relative to fiducials on the vacuum housing
      - To ±1°
    - Set YAG:Ce screen surface to be perpendicular to laser
      - To ±1°
      - Reflection due to high index
        - $n_{YAG} = 1.9$
Surveying & Calibration

- **Calibration**
  - **Size**
    - Use USAF-1951 standard resolution test pattern
    - Put fiducials on YAG:Ce back side, i.e., Al patterns of known dimensions
  - **Resolution**
    - Use USAF-1951 standard
Summary

- Optics design
  - Commercial systems w/ proven performance
  - Flexible to meet changing requirements in future
  - Performance well understood
    - Resolution
    - Signal level
    - Attenuation requirement

- Will meet physics specifications for LUSI instruments
  - FOV, resolution, and readout speed
DESIGN REVIEW REPORT

The Design Review Report Shall include at a minimum:
- The title of the item or system;
- A description of the item;
- Design Review Report Number;
- The type of design review;
- The date of the review;
- The names of the presenters
- The names, institutions and department of the reviewers
- The names of all the attendees (attach sign-in sheet)
- Completed Design Checklist.

- Findings/List of Action Items – these are items that require formal action and closure in writing for the review to be approved. See SLAC Document AP-391-000-59 for LUSI Design Review Guidelines.
- Concerns – these are comments that require action by the design/engineering team, but a response is not required to approve the review
- Observations – these are general comments and require no response

TYPE OF REVIEW: Preliminary Design Review

WBS: 1.5 Diagnostics  Common Optics

Title of the Review | Profile Monitor and Wavefront Monitor, Optics Preliminary Design Review

Presented By: | Yiping Feng,
Report Prepared By: | Sebastien Boutet
Date: | 02-10-09

Reviewers/Lab: | Bill White – SLAC
Sebastien Boutet – SLAC

Distribution:

Attachments: | Review Slides  Design Checklist
| Calculations  Other

Purpose/Goal of the Review:
Assess the validity of the optical components to be used in the LUSI diagnostics devices

Form AP-391-000-59-0 Design Review Report
**Introduction and outcome summary of the review:**
The optical components of the LUSI diagnostics were presented with calculations validating the technical choices. All the options chosen by the LUSI group seemed valid and the committee recommends continuing to the final design.

**Findings/Action Items:**
The LUSI group should communicate with the in-vacuum mirror vendor to determine if the proposed mirror is vacuum compatible and can be delivered clean and ready for vacuum.

The LUSI group should determine whether a high quality vacuum window is truly necessary. It is unclear if one truly needs such a window for which design work and fabrication would be required to mount the window in a flange. The LUSI group should investigate the use of standard pre-mounted window flanges available commercially.

The LUSI group should communicate with the vacuum window vendor to determine if they can be provided with coating.

**Concerns:**
The vacuum window will bow under vacuum forces. It should be determined whether such bowing will cause image distortions that will prevent the specifications from being met.

**Observations:**
Except for the profile monitor, the 120 Hz readout rate of the CCD camera is not necessary. However, using a common camera for every device is a valid option to simplify the controls requirements.

The cable length on Cameralink devices is limited. It should be verified that is can be long enough for the LUSI needs without the need to use a fiber.

Placing a resolution test pattern on the YAG screen is a good idea and can be achieved using a FIB. Alternatively, one could mount a standard military test pattern next to the YAG. However,
this brings some depth of field issues and the YAG screen and test patterns would have to be well-aligned.

The concept presented, a YAG screen at normal incidence with a 45 degree mirror is valid and the committee recommends using this design. However, it may be possible to improve the resolution with a thinner scintillator, possibly coating a surface placed at 45 degrees in the beam. The committee recommends pursuing this option in parallel for possible future improvements of the system.

**Response to Findings/Action Items:**

The LUSI group should communicate with the in-vacuum mirror vendor to determine if the proposed mirror is vacuum compatible and can be delivered clean and ready for vacuum. 
*Response: DCO will confirm with the mirror vendor for vacuum compatibility issues.*

The LUSI group should determine whether a high quality vacuum window is truly necessary. It is unclear if one truly needs such a window for which design work and fabrication would be required to mount the window in a flange. The LUSI group should investigate the use of standard pre-mounted window flanges available commercially.  
*Response: DCO will confirm the requirements by simulation. XTOD group responsible for the LCLS FEE also specified similar windows for their direct imager based on their simulations. We’ll compare our findings with them.*

The LUSI group should communicate with the vacuum window vendor to determine if they can be provided with coating.  
*Response: DCO will communicate with the window vendor to address any coating issues. Antireflective coatings are available in the ADC and VG Scienta viewport product line.*