The Coherent X-ray Imaging (CXI) Instrument at LCLS

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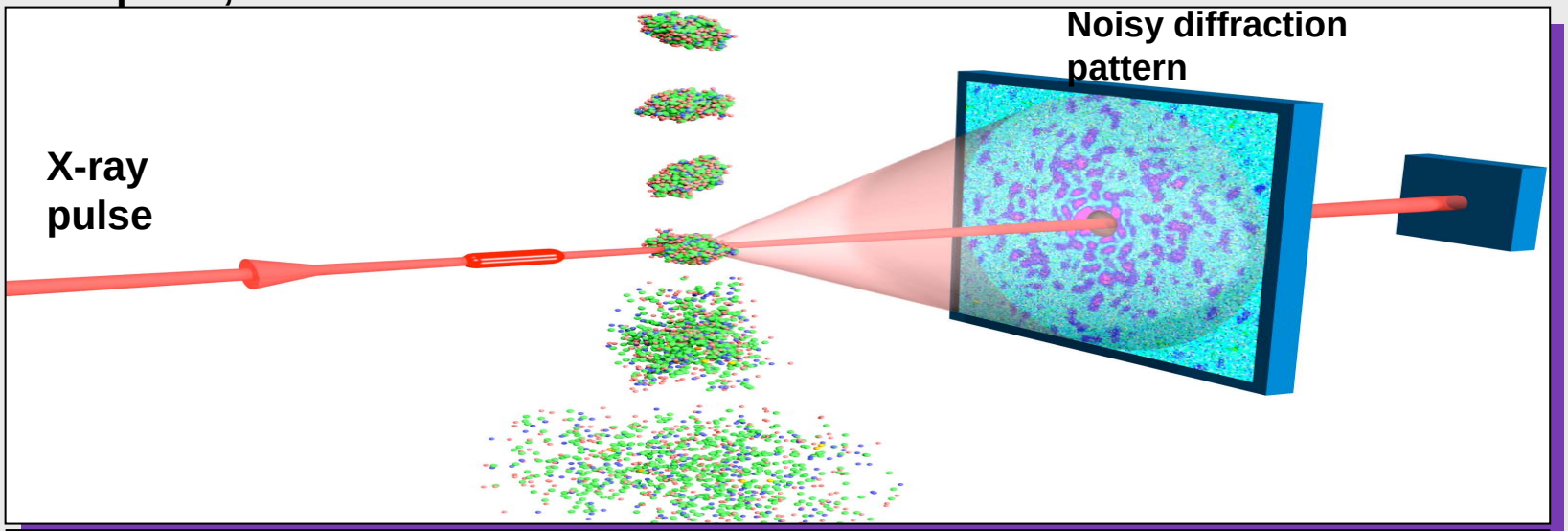
Outline

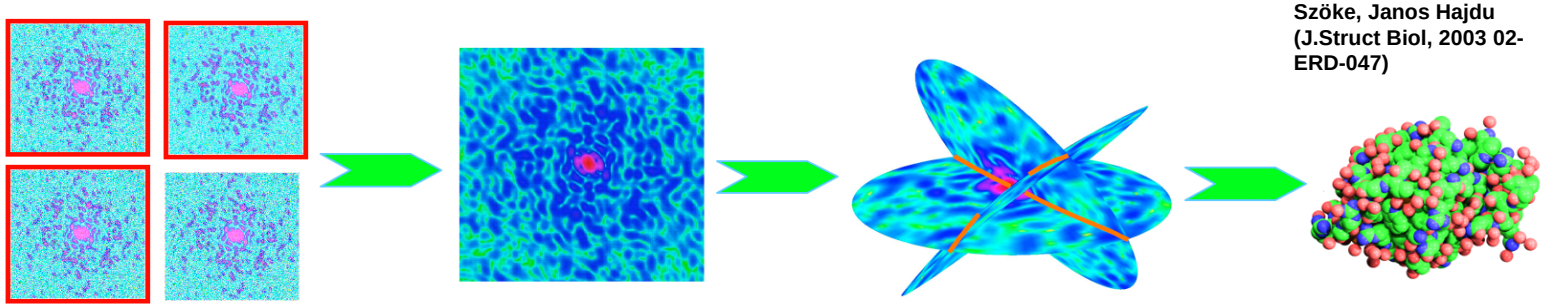
- LCLS
- Front-end optics
- Coherent X-ray Imaging (CXI) Instrument
  - Hutch
  - Diagnostics
  - Optical System
  - Sample Environment
  - Detector
- Summary

One pulse, one measurement



Combine 10^5-10^7 measurements into 3D dataset

Gösta Huldt, Abraham Szöke, Janos Hajdu (J.Struct Biol, 2003 02-ERD-047)



CXI Capabilities

- CXI instrument not only designed for biological imaging
  - Suitable for imaging any object in forward scattering
    - Not suitable for Bragg geometry
      - XPP, XCS instruments at LCLS can be used for that
- Other techniques compatible with CXI
  - SAXS / WAXS
  - Protein crystallography
  - Nanocrystal studies
  - Solution scattering

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- LCLS energy range (fundamental) : 800 – 8265 eV
  - 3rd harmonic up to 24.9 keV (1% of the fundamental)
- Repetition rate: 120 Hz

Parameter	*Value*	*Value*	*Value*	*Value*	*Value*	*Units*
Photon energy	*24795*	*8265*	*6000*	*4000*	*2000*	*eV*
Wavelength	*0.05*	*0.15*	*0.21*	*0.31*	*0.62*	*nm*
Source size (FWHM)	*60*	*60*	*67*	*73*	*78*	*µm*
CXI Hutch distance from undulator exit	*385.5*	*385.5*	*385.5*	*385.5*	*385.5*	*meters*
Source divergence (FWHM)	*0.73*	*1.1*	*1.34*	*1.89*	*3.47*	*µrad*
Pulse duration	*~70*	*~70*	*~70*	*~70*	*~70*	*fsec*
Number of photons	*1.7E+10*	*1.7E+12*	*2.7E+12*	*4E+12*	*8E+12*	*photons*

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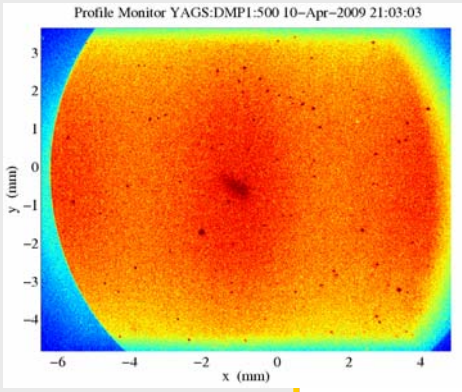
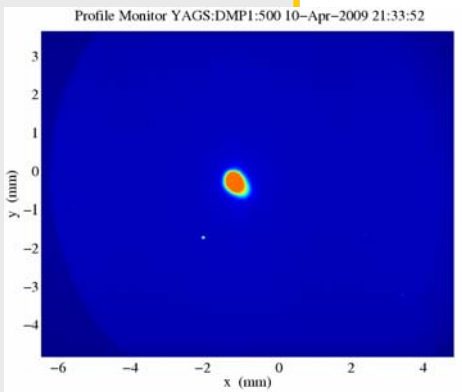
X-ray Transport Optics & Diagnostics

- Soft X-ray Offset Mirror System (SOMS) selects 800-2000 eV range for soft X-ray line
- Hard X-ray Offset Mirror System (HOMS) reflects up to 25 keV.
- 385 mm clear aperture mirrors → <70% transmission at 2 keV and >98% at 8.3 keV
- Offset mirror systems separate FEL beam from spontaneous background and removes high harmonics
- **CXI instrument uses the hard x-ray branch**
  - **~3-25 keV**

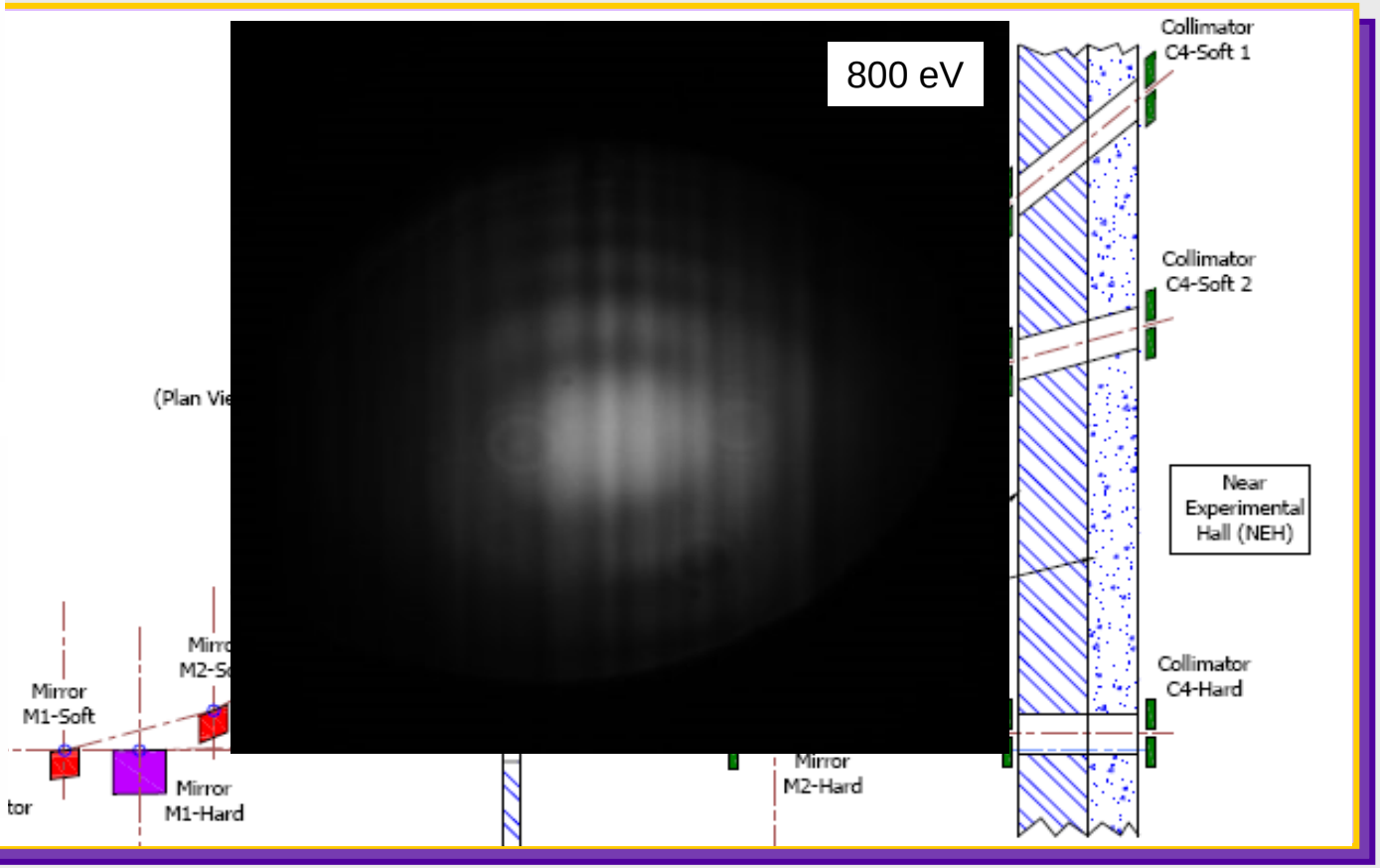


Spontaneous Beam



FEL beam

Measured unfocused AMO beam



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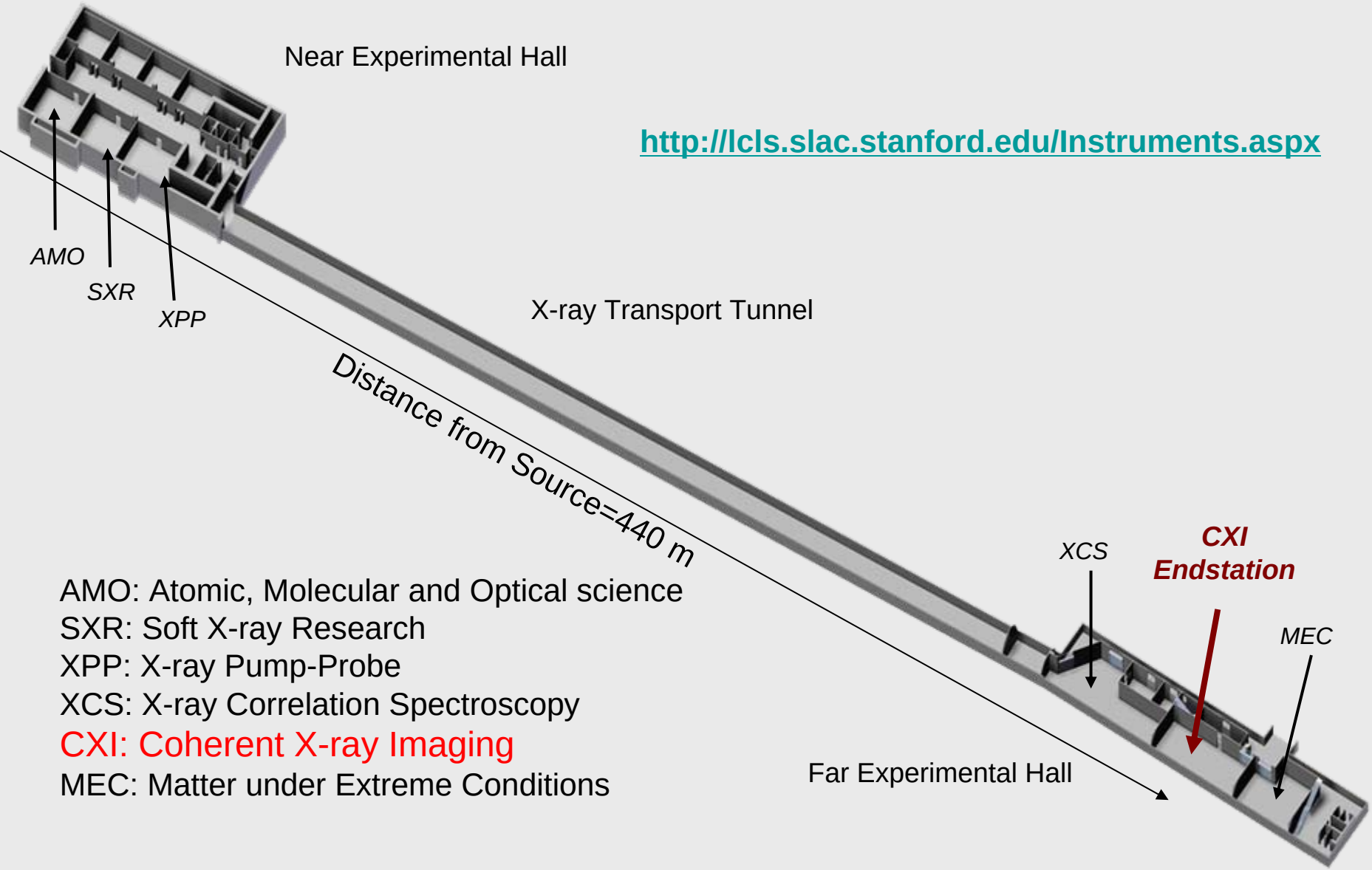
LCLS Instruments



http://lcls.slac.stanford.edu/Instruments.aspx

AMO: Atomic, Molecular and Optical science
SXR: Soft X-ray Research
XPP: X-ray Pump-Probe
XCS: X-ray Correlation Spectroscopy
CXI: Coherent X-ray Imaging
MEC: Matter under Extreme Conditions

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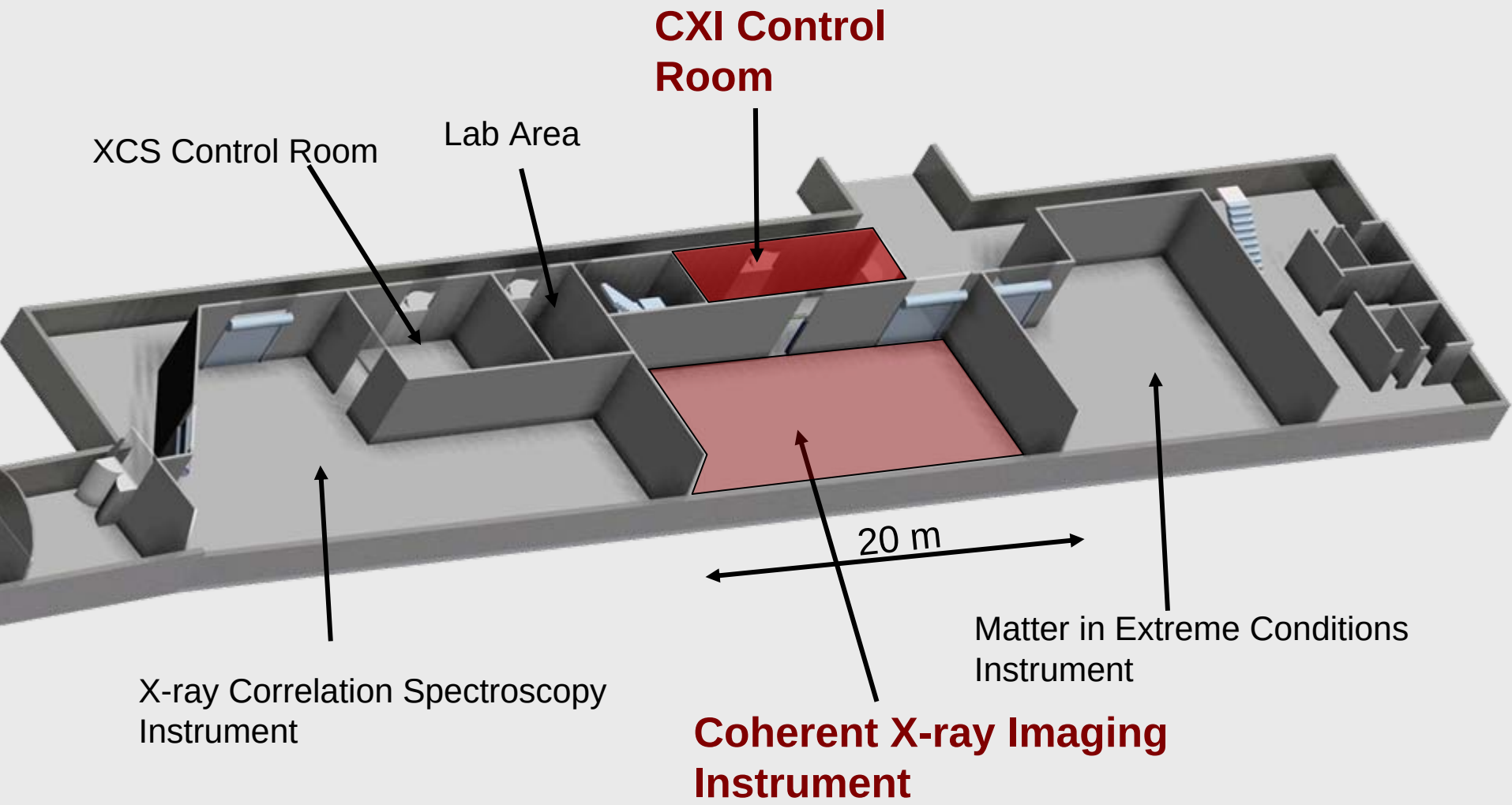
Far Experimental Hall



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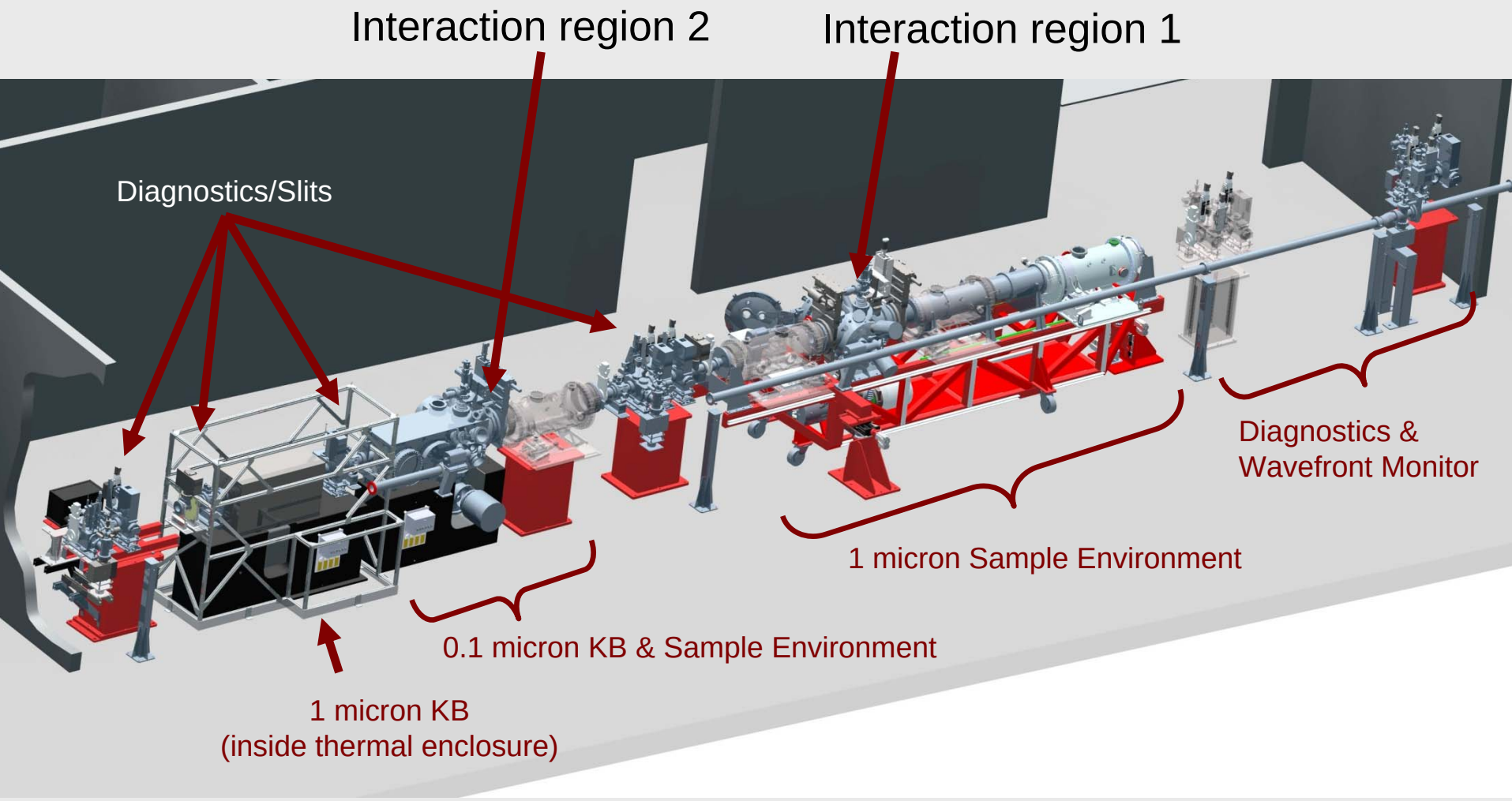
Coherent X-ray Imaging (CXI) Instrument

Insert compact 0.1 micron system in empty drift space between 1 micron KB mirrors and focal plane



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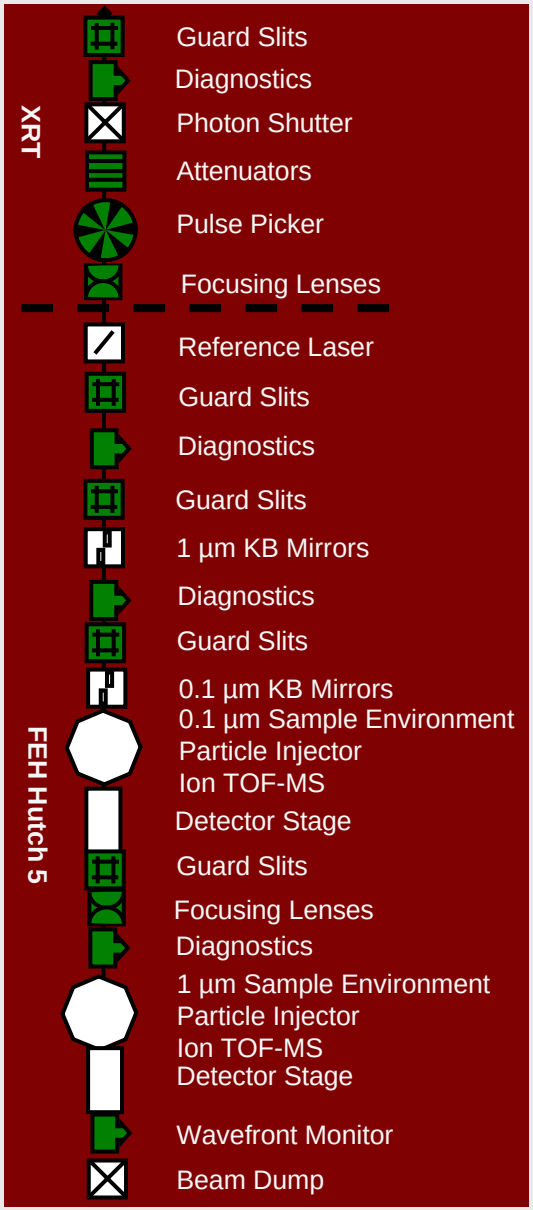
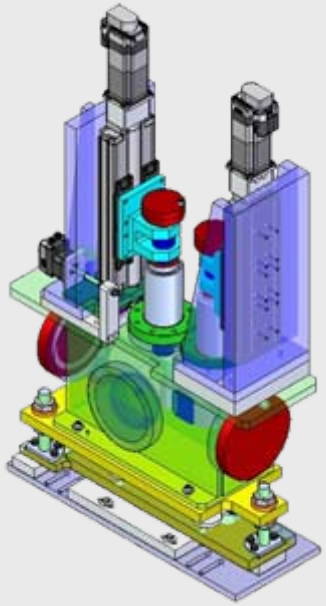
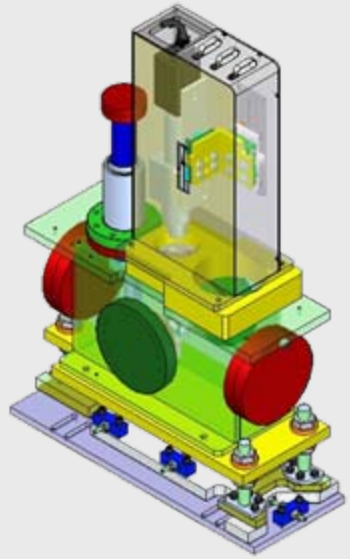
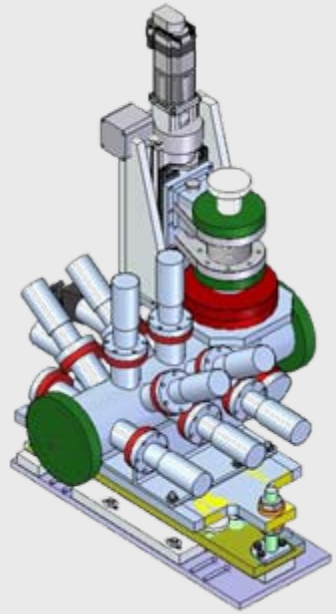
Diagnostics and Common Optics









Requirement	Device
Remove X-ray beam halo	X-ray Guard Slits
Tailor X-ray intensity	Attenuators
Tailor X-ray repetition rate	Pulse Picker
Characterize X-ray pulse intensity	Intensity Monitor
Characterize X-ray spatial profile	Profile Monitor
Characterize X-ray focus	Wavefront Monitor
Tailor focal spot size to the sample	X-ray Focusing Lenses

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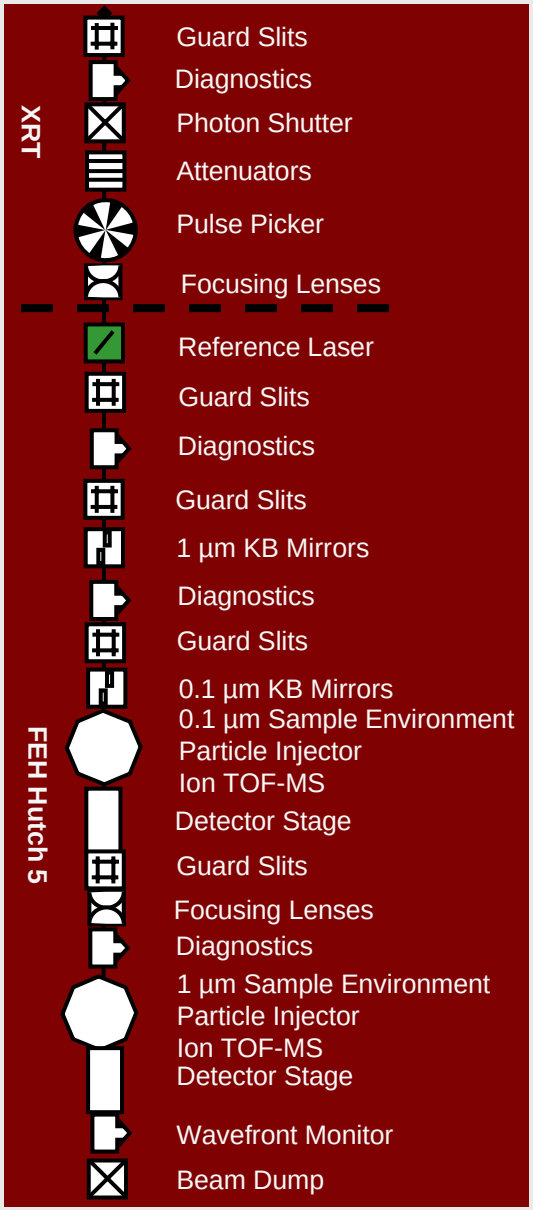
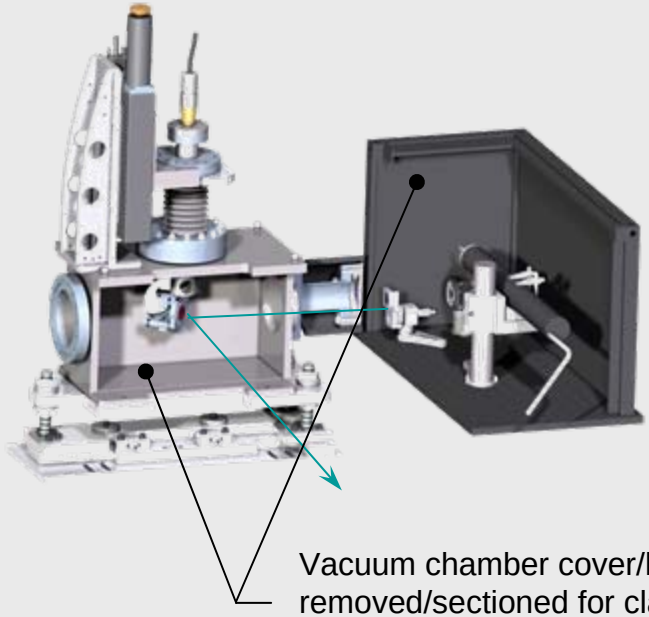
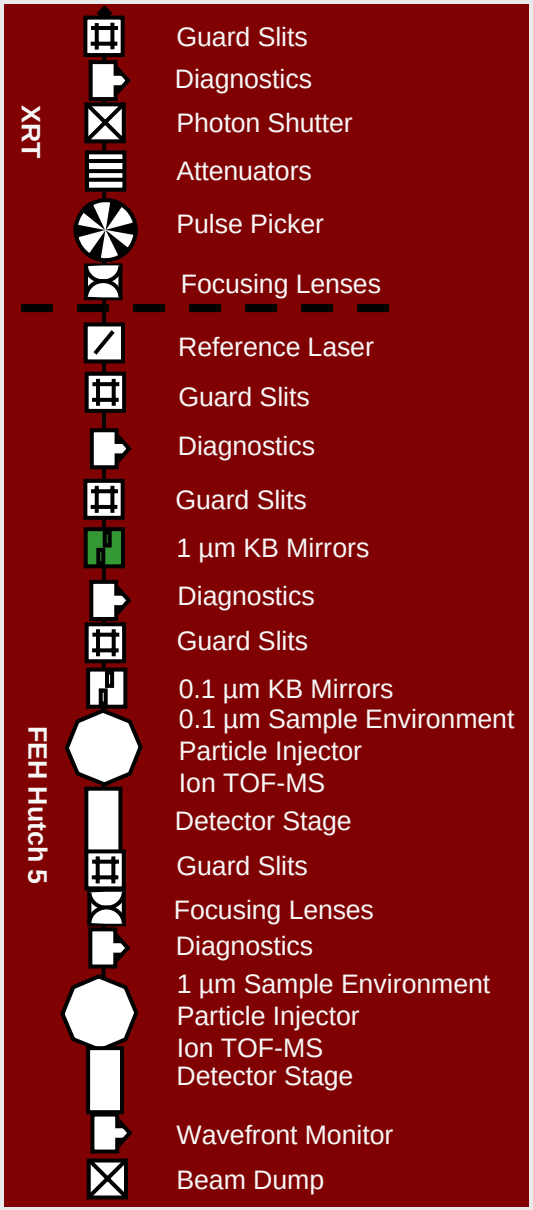
CXI Reference Laser

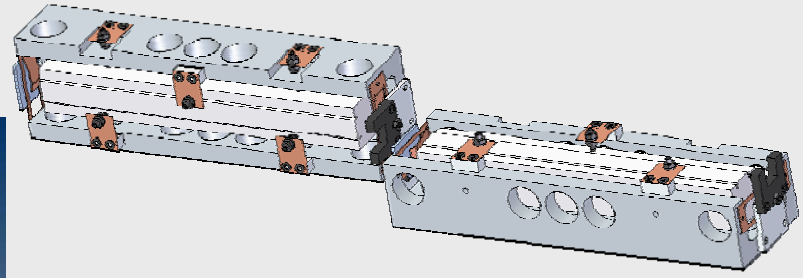




- Purpose
  - Rough alignment of the experiment without the X-ray beam
  - Provides a visible line to align components
- Requirements
  - Useable with any part of the instrument vented to air
    - Window valves
  - Aligned to the unfocused FEL beam to within 100 microns

CXI 1 µm KB Mirrors





- Purpose
  - Produce a 1 µm focus
    - Focal lengths
      - 8.7 m for M1
      - 8.3 m for M2
- Requirements
  - 350 mm clear aperture
  - 3.4 mrad maximum incidence angle
  - SiC coating
  - <1 nm rms height error over entire mirror
  - 2-11 keV energy range

KB focusing also provides harmonic rejection

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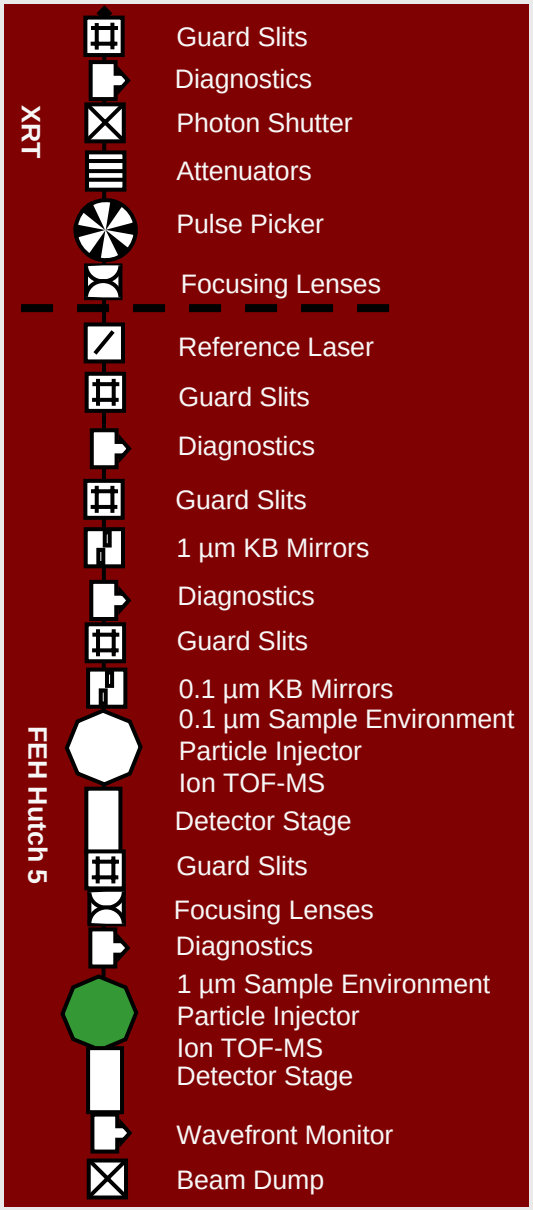
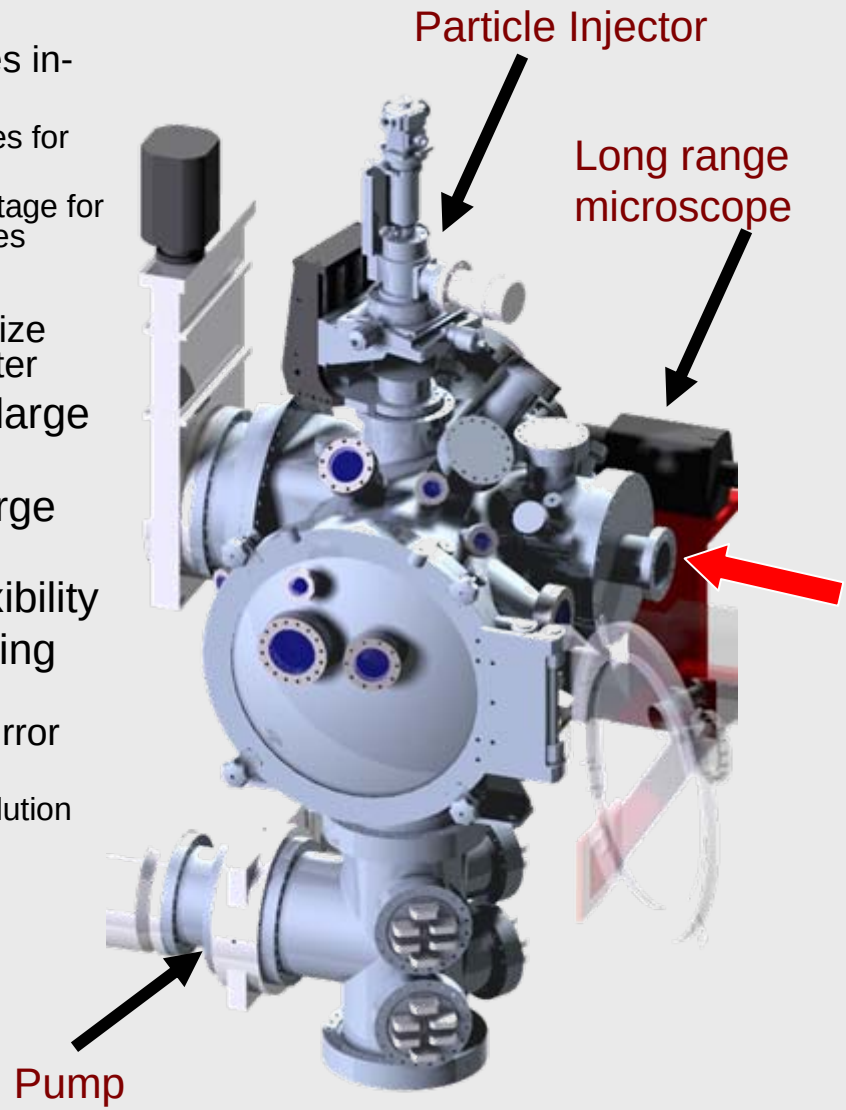
CXI Sample Chamber

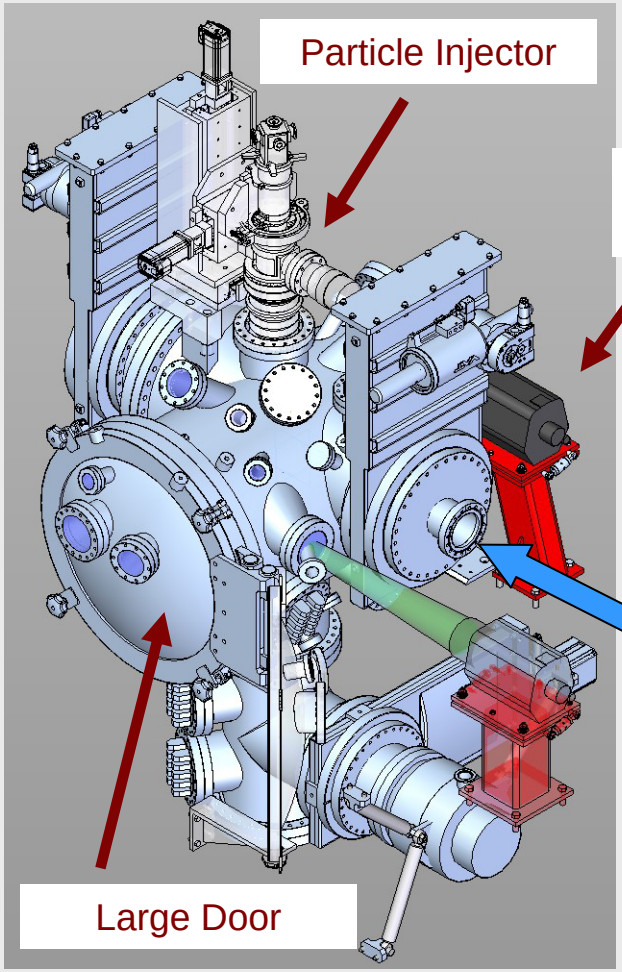


- Position apertures and samples on grids
  - Piezoelectric stages in-vacuum
    - 3 aperture stages for noise reduction
    - 5-axis sample stage for mounted samples
- High Vacuum
  - 10^{-7} mbar to minimize noise from air scatter
- Large exit flange for large detector
- Rapid access with large door
- Large volume for flexibility
- On-axis sample viewing
  - Using long-range microscope and mirror with hole
    - 2-3 micron resolution
- Multiple laser ports

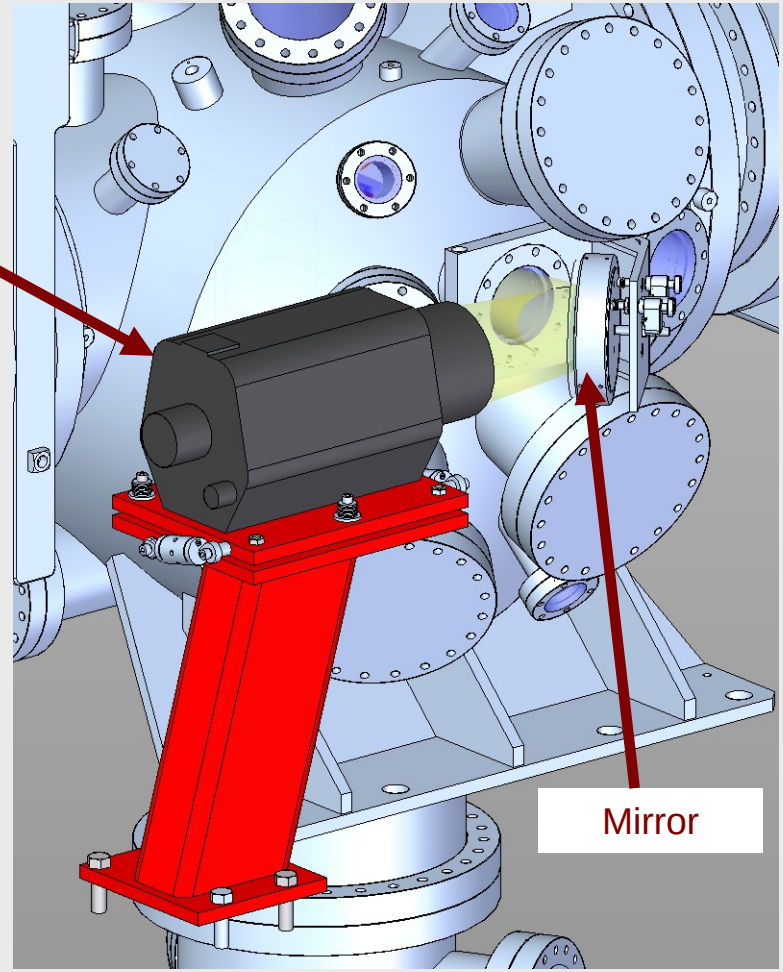


CXI Sample Chamber

Front view



Back view



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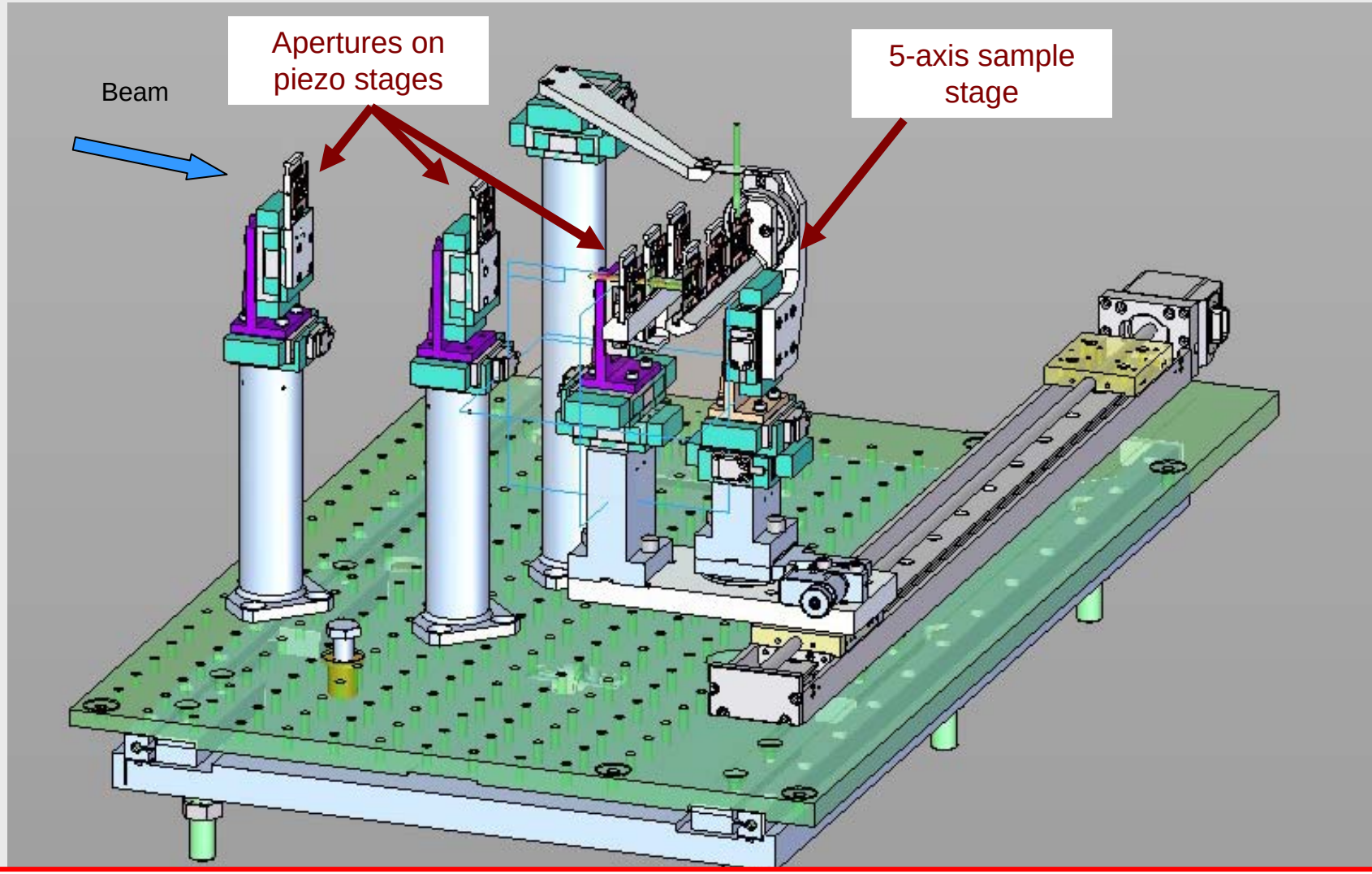
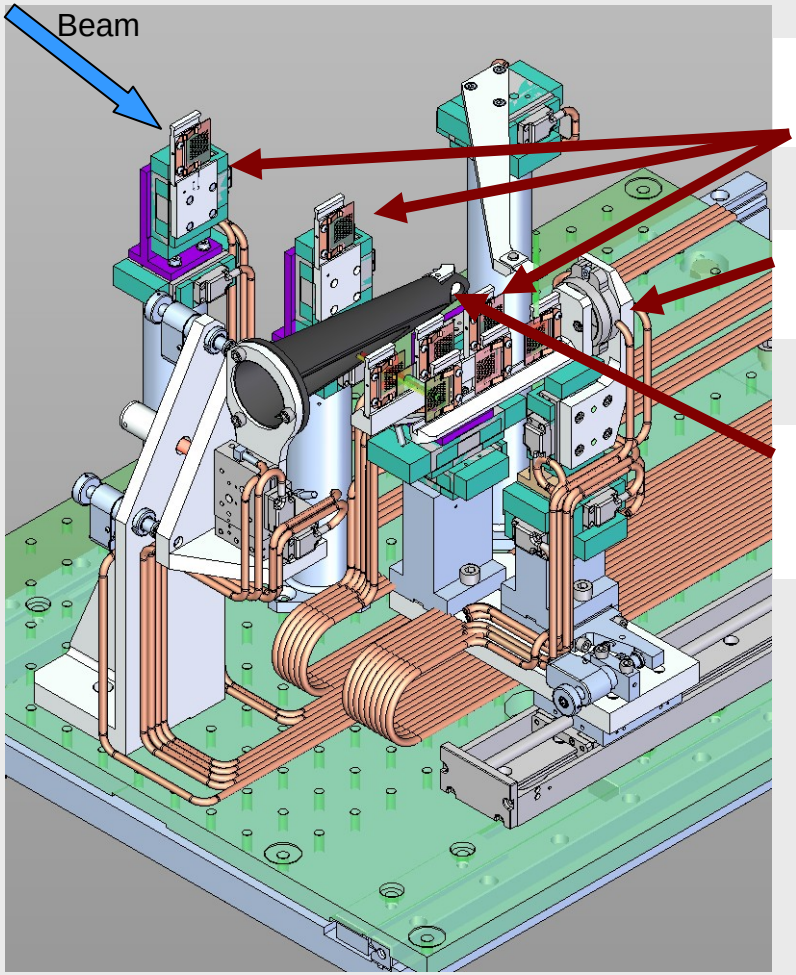
Sample Chamber Interior



Many apertures are needed to measure signal at small angles

CXI Sample Chamber (Internal Views)

Back view

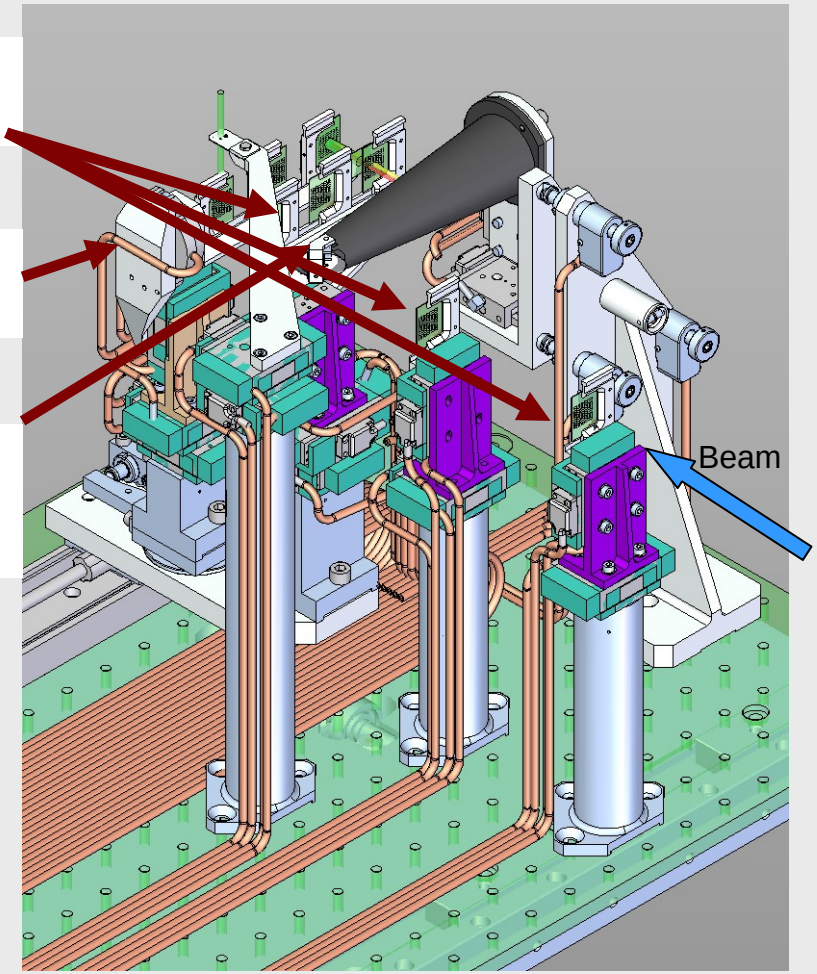


Apertures on piezo stages

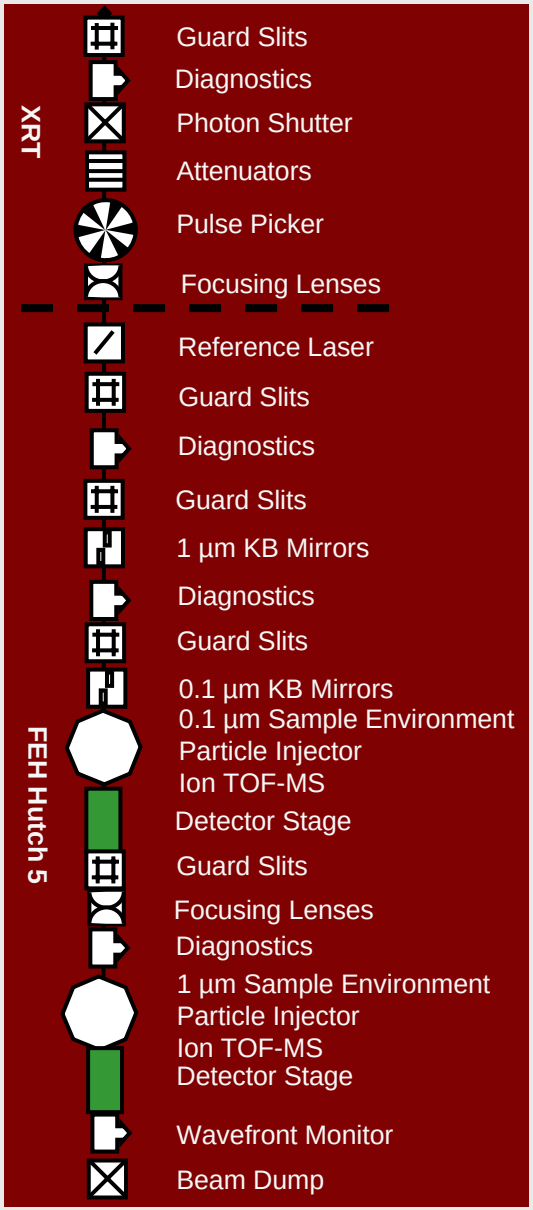
5-axis sample stage

Mirror with hole for sample viewing

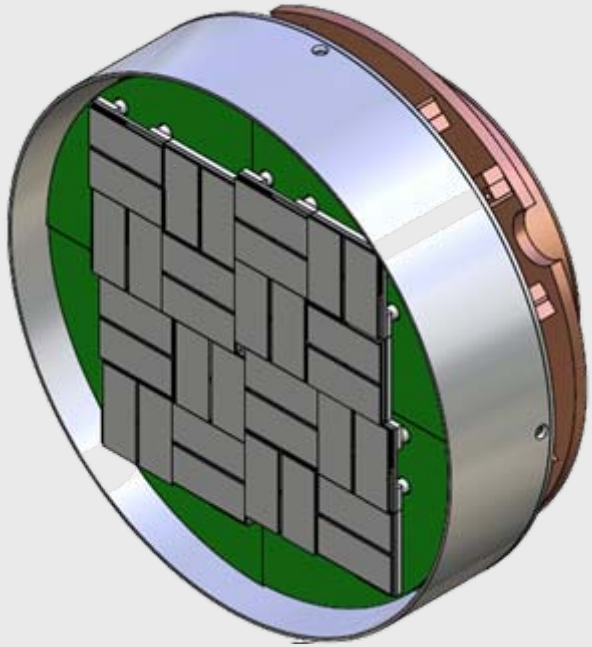
Front view



CXI Detector



Collaboration with the Gruner Group at Cornell University



- 2D Pixel Array Detector
  - High resistivity Silicon (500 µm) for direct x-ray conversion.
  - Reverse biased for full depletion.
  - Bump-bonding connection to CMOS ASIC.
- <1 photon readout noise
- 110x110 μm^2 pixels
- 1520x1520 pixels
- 10^3 dynamic range
- 120 Hz readout

- **Tiled detector, permits variable 'hole' size**

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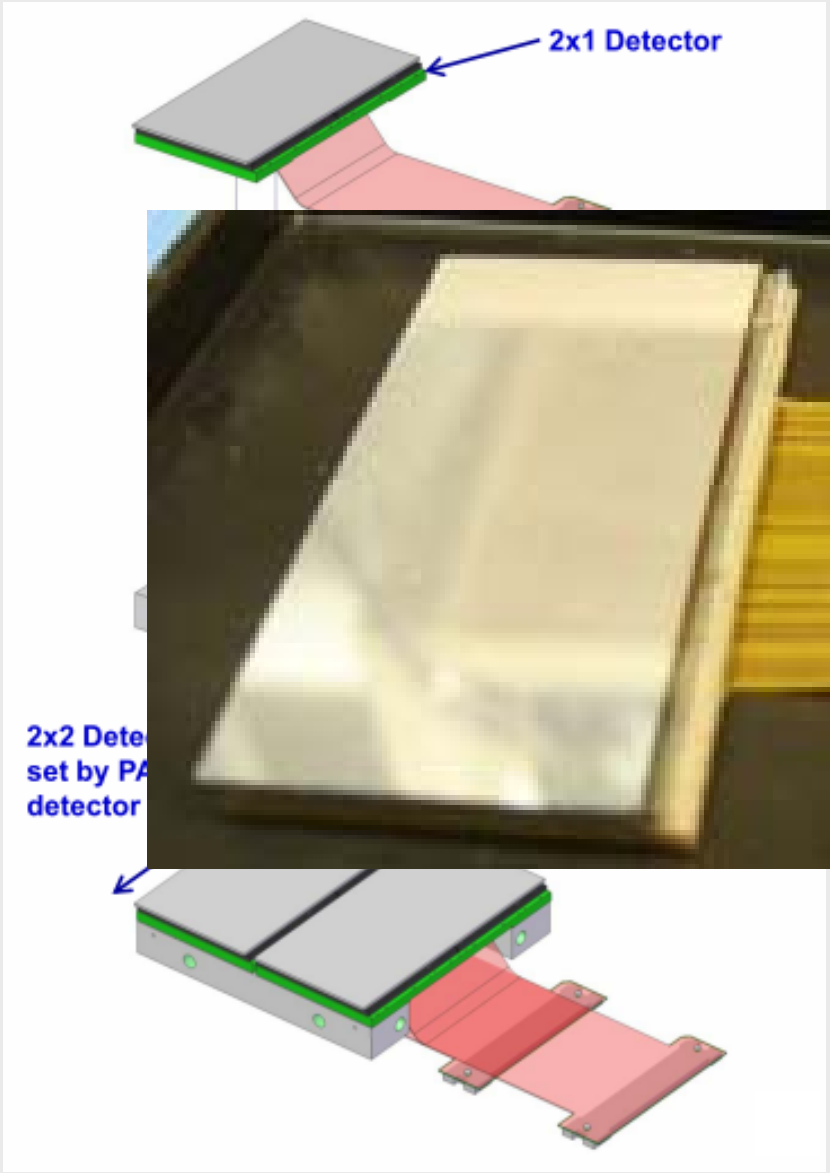
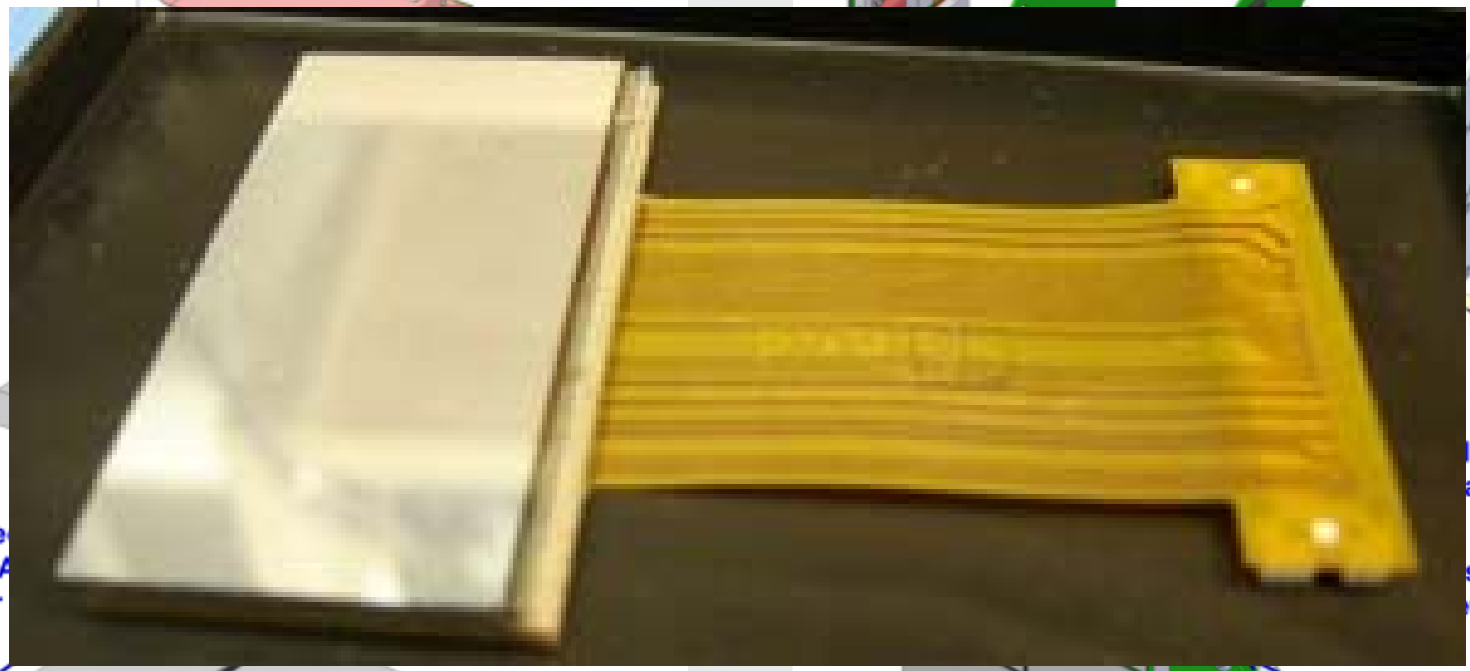
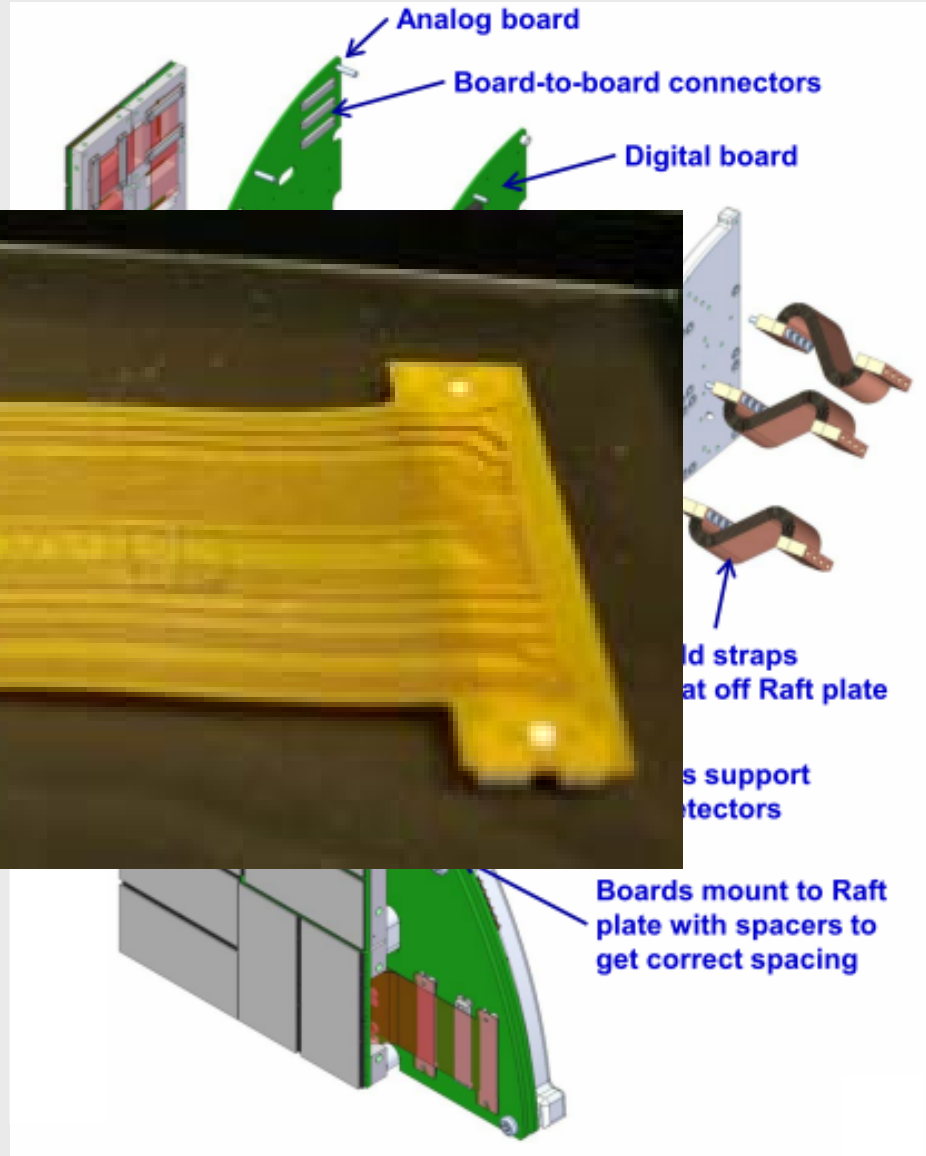
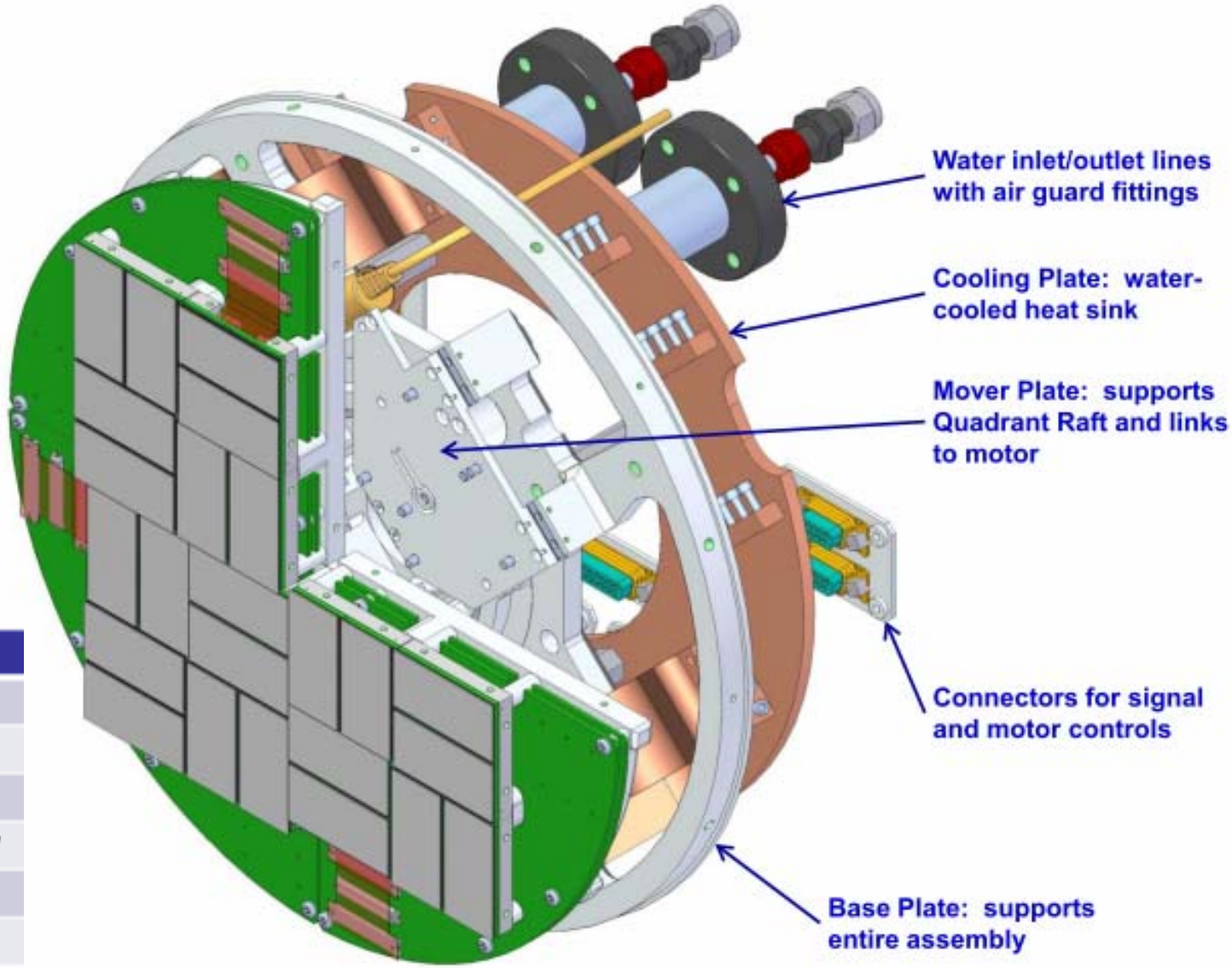
Detector Modules and Quadrant Rafts





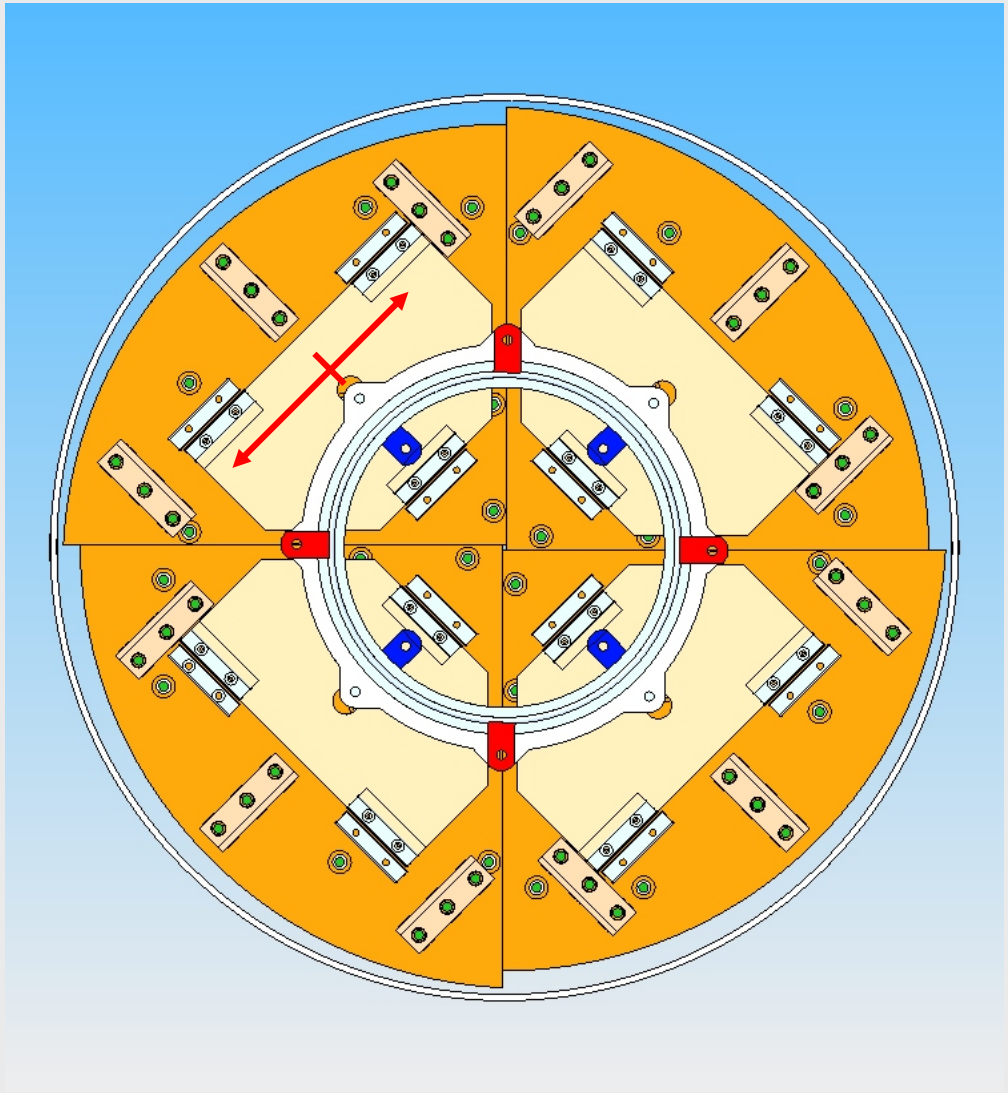


Detector Partially Disassembled



Mechanical Parameters
Diameter: 11.25”
Length: 6”
Max weight: 25 lbs
Total heat dissipated: 44 W
Cooling: 0.3 gpm water
Actuation: stepper motor

Back View with Base Plate Removed—1 mm Aperture



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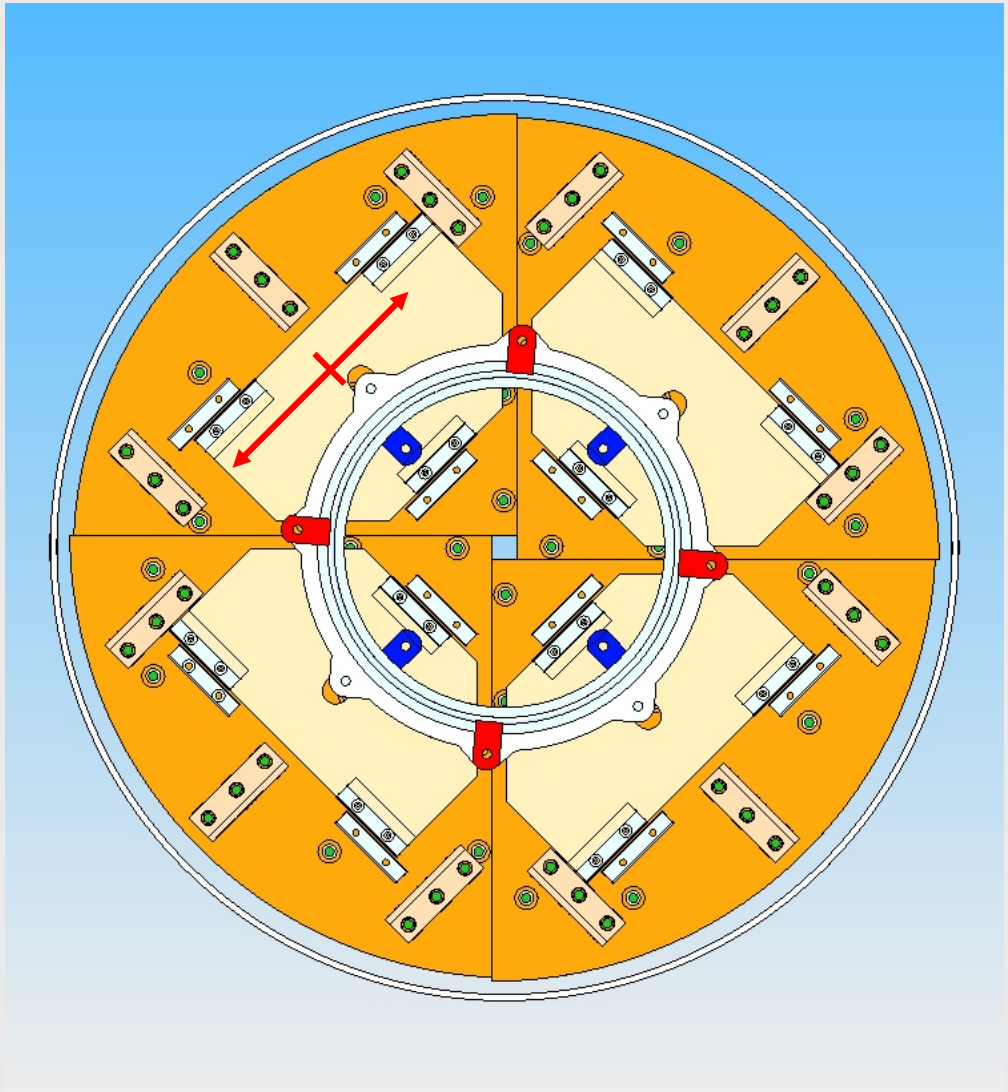
Back View with Base Plate Removed—6 mm Aperture



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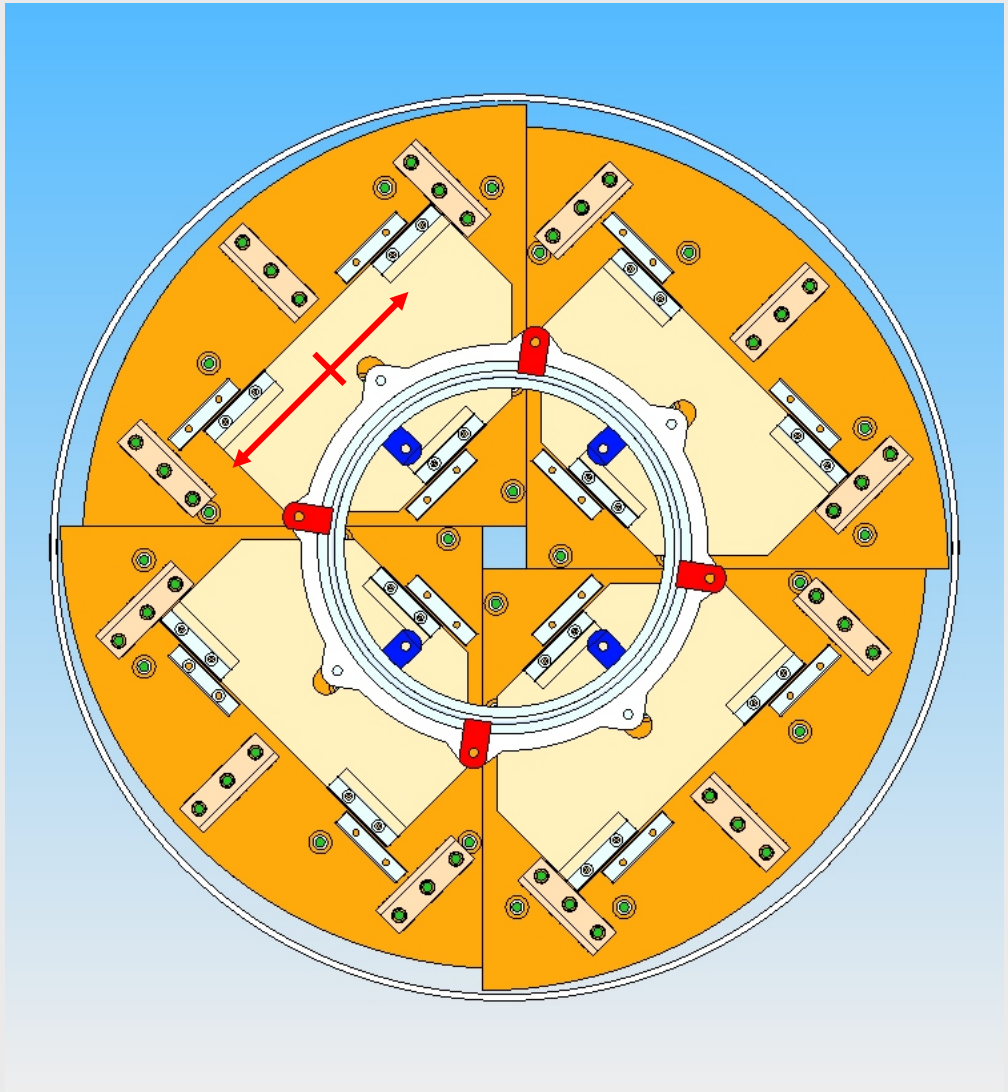
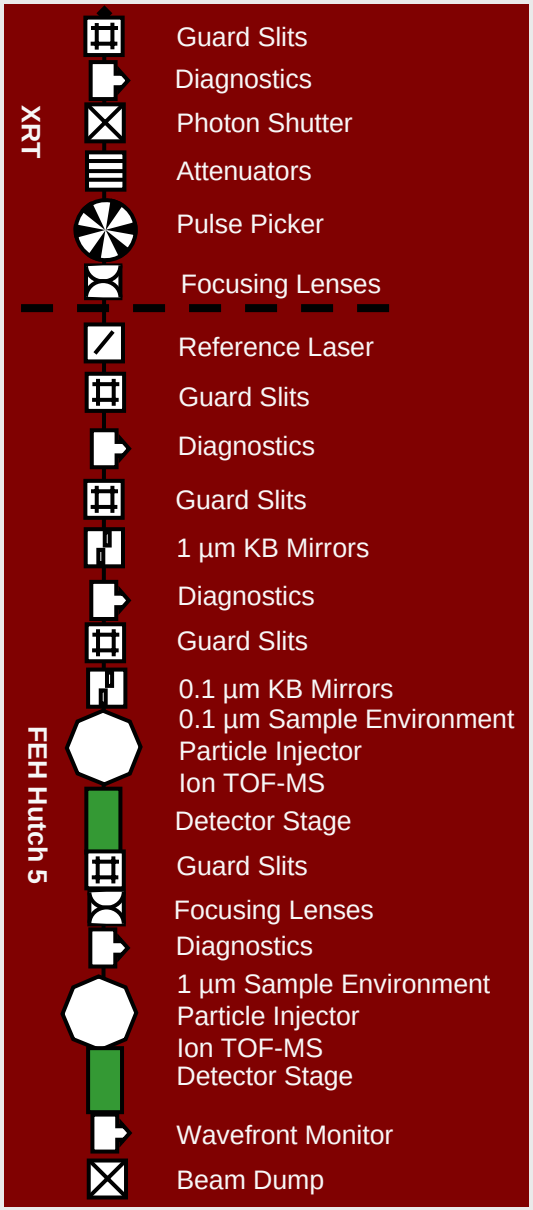
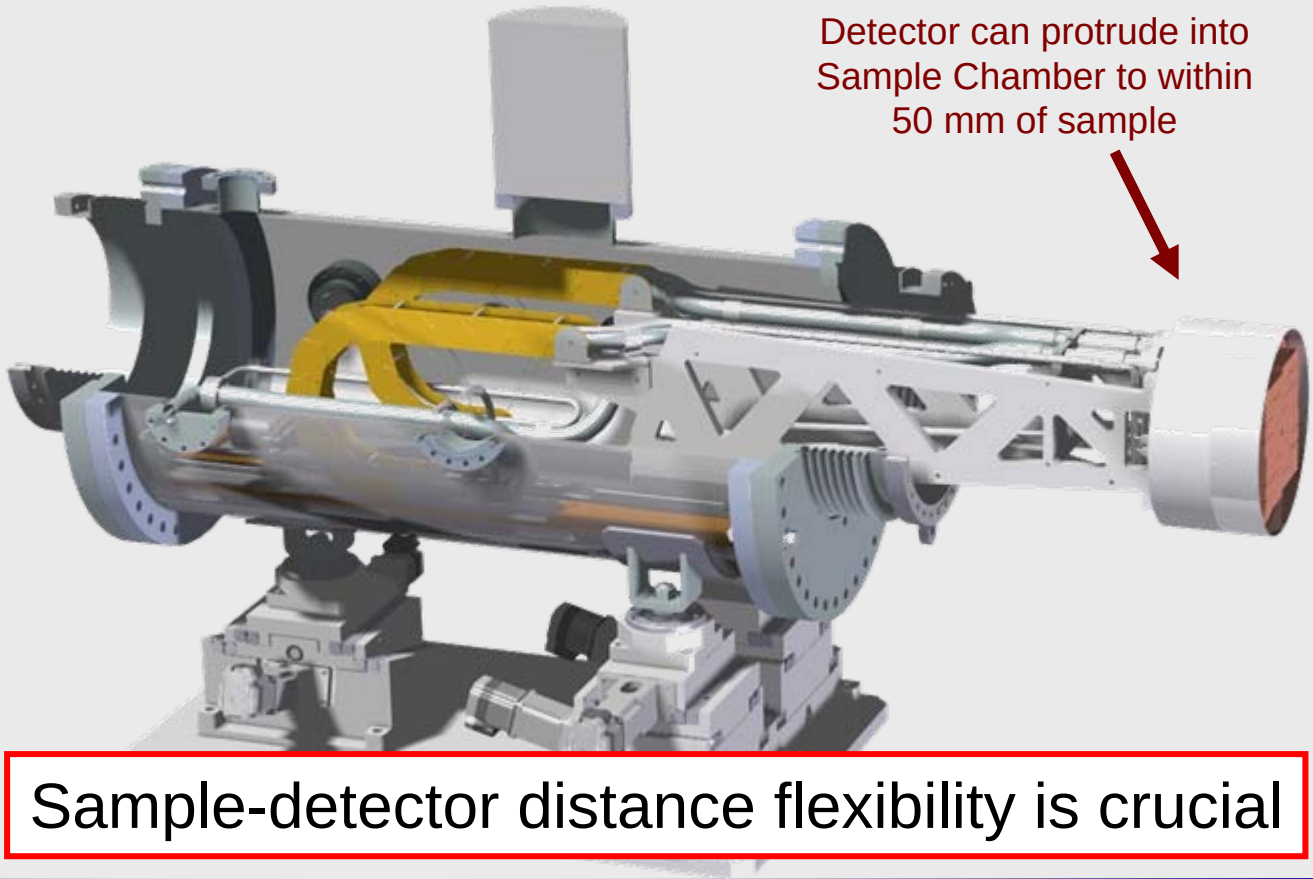
Back View with Base Plate Removed—10 mm Aperture



Detector Stage



- Center the detector hole on the direct beam
  - X, Y, Pitch and Yaw control
    - In-air motion of entire chamber
- Position the detector at the appropriate distance from the interaction region
  - Range along the beam : 50-2400 mm
    - Non-continuous
  - 500 mm travel range along the beam inside vacuum



Sample-detector distance flexibility is crucial

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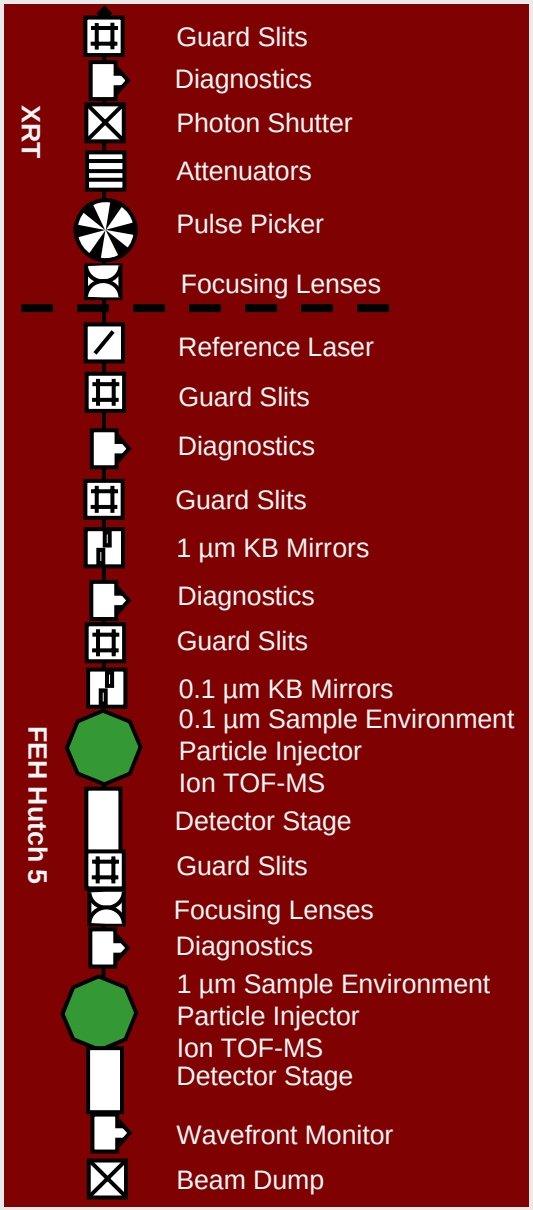
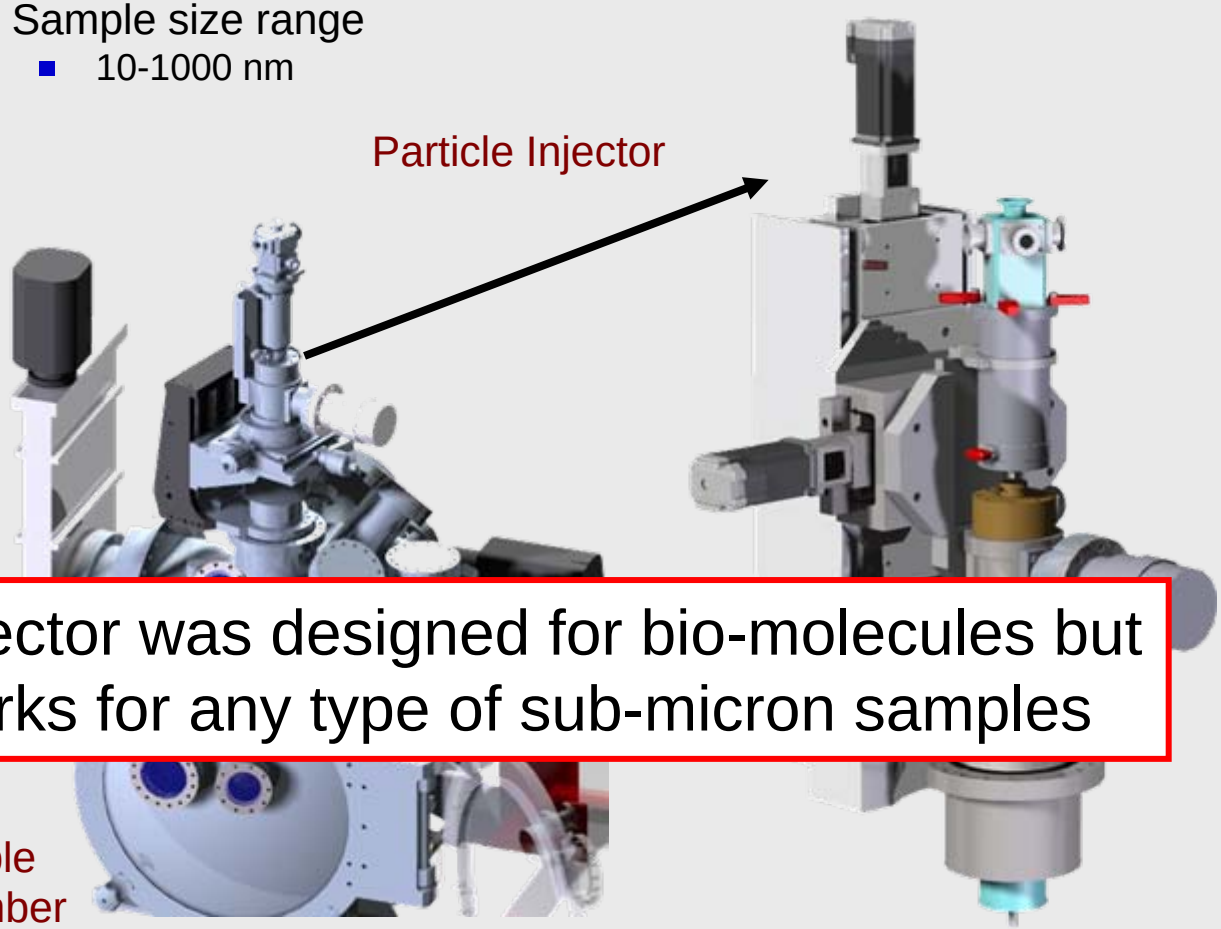
CXI Particle Injector



- Deliver support-free single particles to the LCLS beam
  - Aerodynamic lens technology to transfer aerosols to vacuum in a particle beam
- Non-synchronous particle arrival with the LCLS beam
  - Requires highly concentrated aerosol samples for high hit rate
- Sample size range
  - 10-1000 nm



Injector was designed for bio-molecules but works for any type of sub-micron samples

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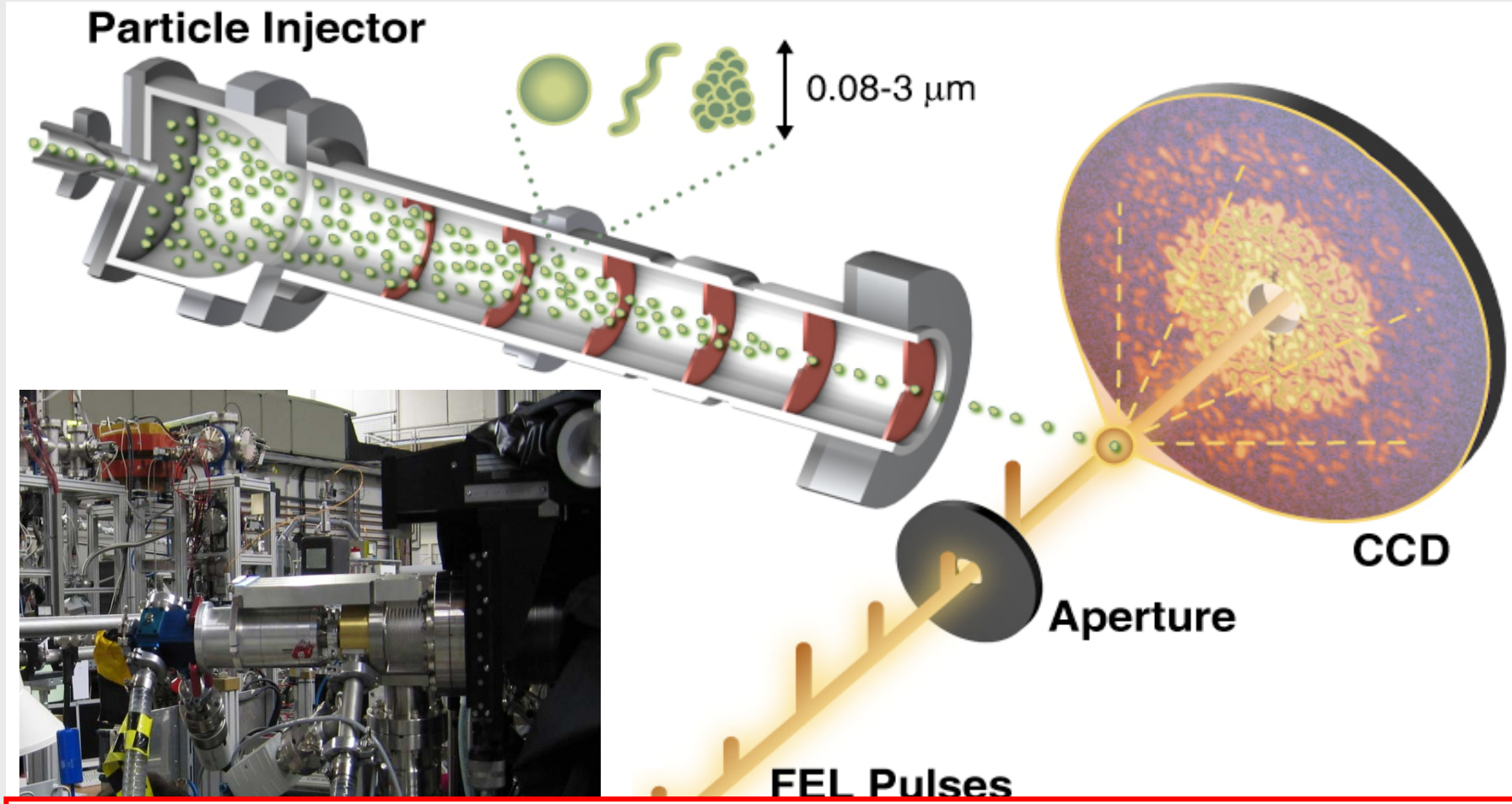
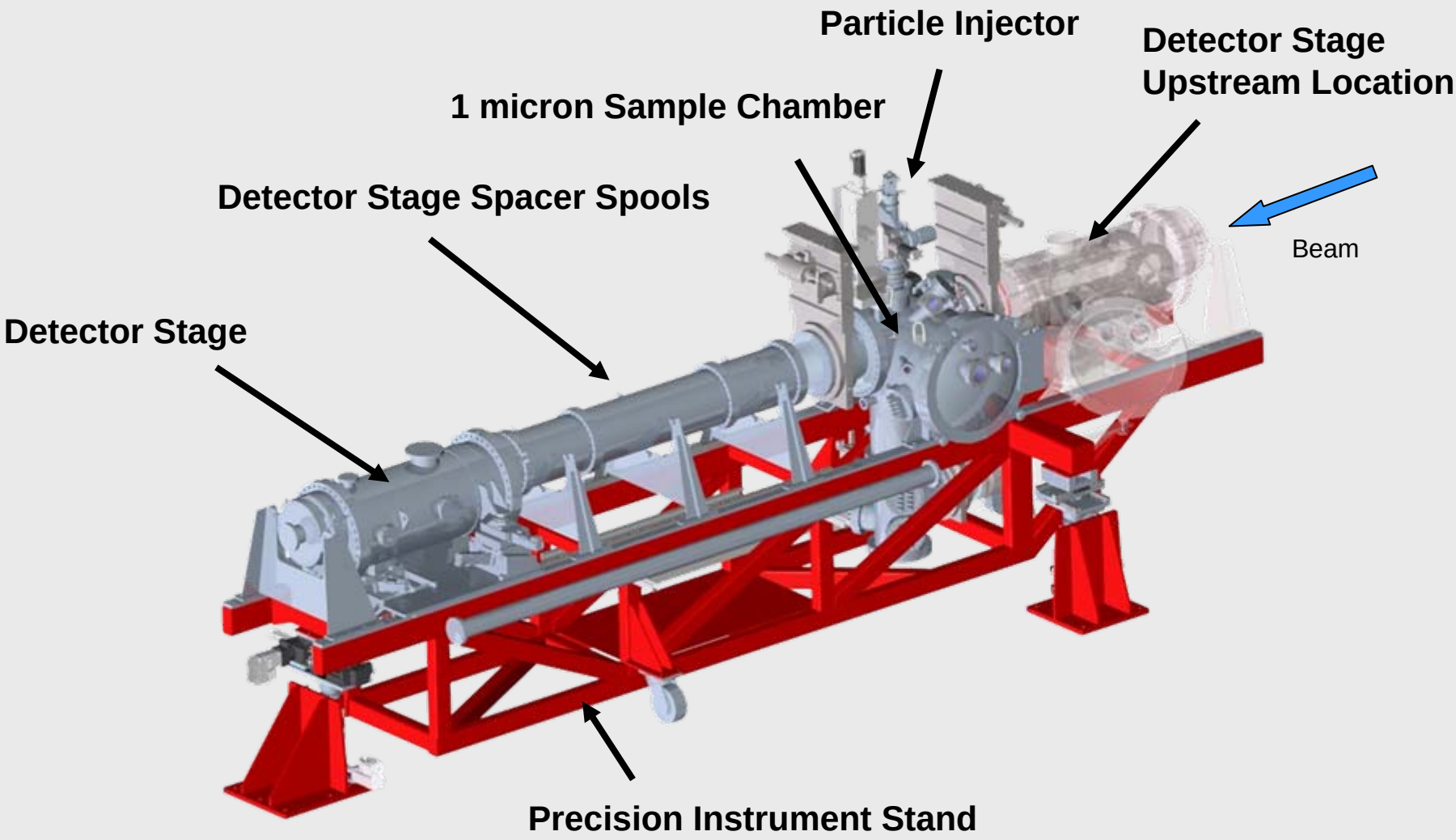
Aerodynamic Focusing

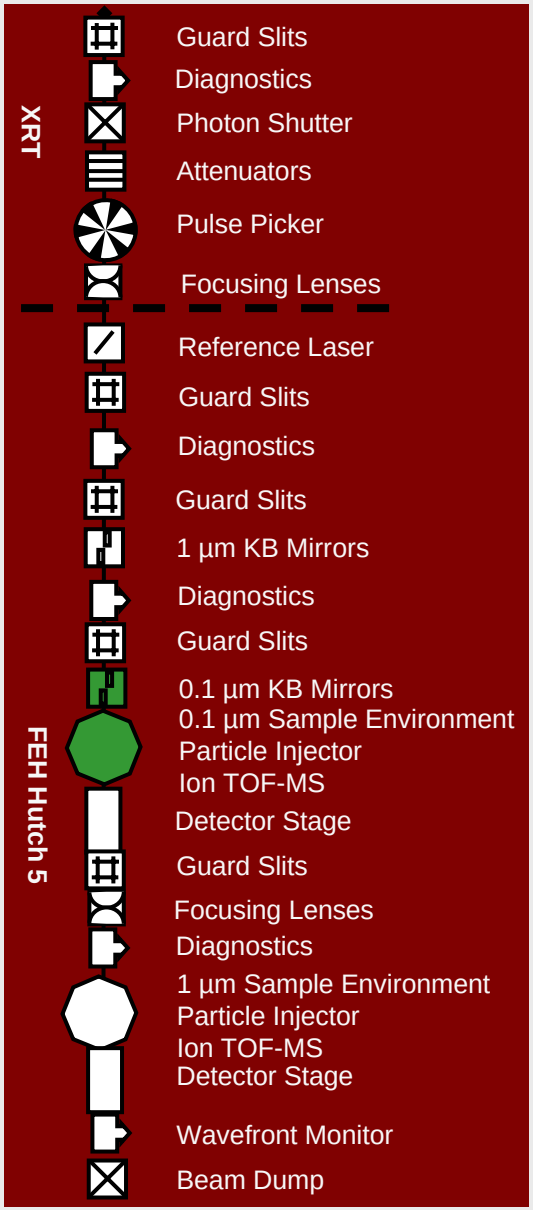


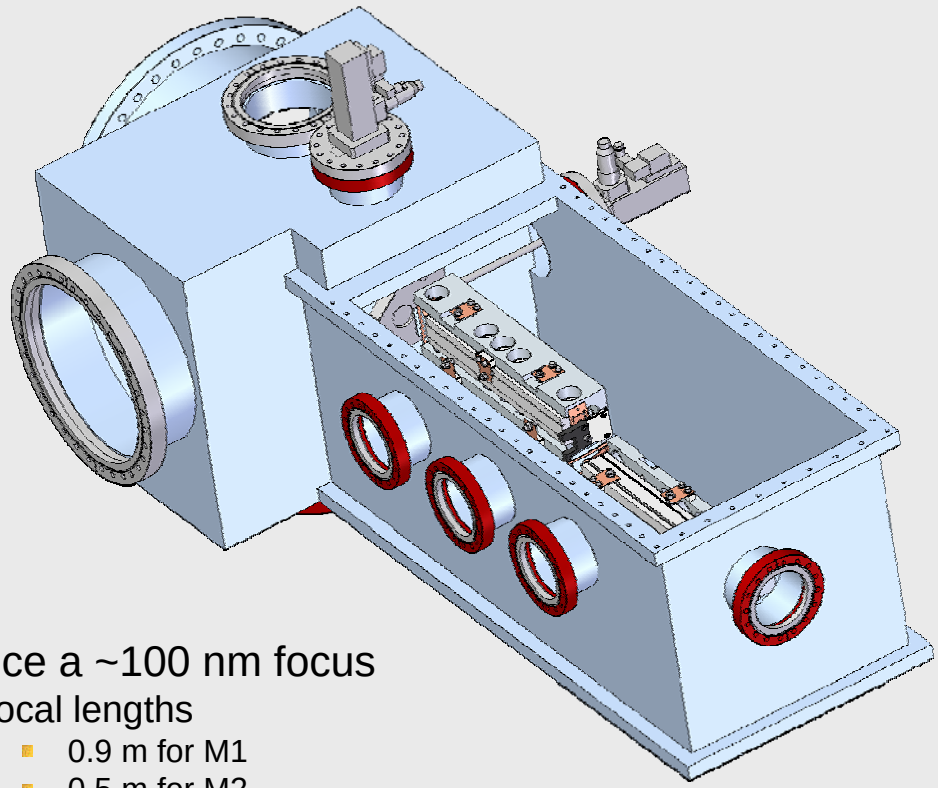
Design is compatible with other technologies (droplet sources, aerojets)

CXI 1 micron Sample Environment



CXI 0.1 µm KB Mirrors/Sample Environment





- Purpose
  - Produce a ~100 nm focus
    - Focal lengths
      - 0.9 m for M1
      - 0.5 m for M2
- Requirements
  - Identical to 1 micron KB System in every way except for the mirror curvature
- Integrated system with 0.1 micron Sample Chamber due to close proximity
- Separating sample from mirror environment is challenging with short working distances

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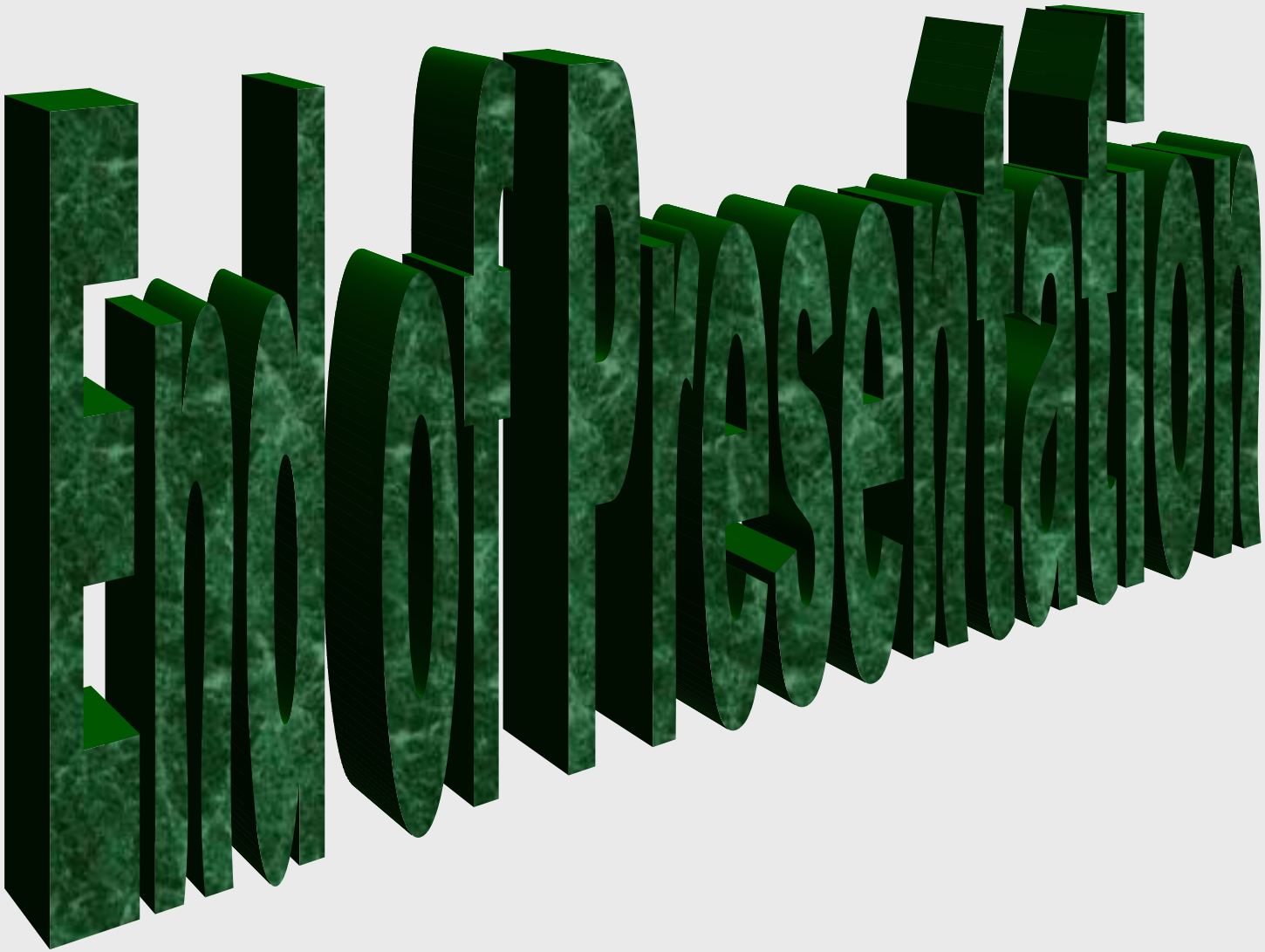
Summary

- CXI instrument is designed for imaging of any submicron particles at near atomic resolution
- Sample environments are provided
  - Fixed targets
  - Injected samples
  - Plans to add cryo-cooled stage
- X-ray optics can tailor FEL parameters for users
  - 3 focal spot size : 0.1, 1 and 10 microns
    - Unfocused beam is possible
    - Possibility to refocus the beam for serial operation
  - Variable attenuation
  - Single pulse selection with pulse picker
  - Diagnostics on every pulse
- User operations start planned for early 2011
  - Website: http://lcls.slac.stanford.edu/Instruments.aspx


End of Presentation