



NRL

NSLS II Workshop, 18 July 2007

X24C

***Development and Calibration of EUV and Soft X-Ray Optics and Detectors
for NRL/NASA/NOAA Solar, Astrophysical, and Laboratory Instrumentation***

**John Seely, Naval Research Laboratory
Space Science Division, Washington DC
john.seely@nrl.navy.mil, tel. 202-767-3529**

X24C research focus:

Scientific research and development related to the optical properties of materials, multilayer reflective coatings, diffraction gratings and zone plates, transmissive filters, electronic detectors, and material interface science in the extreme ultraviolet and soft x-ray regions.

NRL is interested in transferring these capabilities at NSLS II.



NRL

X24C Key Personnel

X24C

Position	Name	Institution
Spokesperson	Jack Rife	NRL
PRT management, scheduling	John Seely	NRL
Beamline Scientist, Safety, Training, Local Contact	Benjawan Kjornrattanawanich	USRA
Technical Staff, Local Contact	Johnny Kirkland	SFA Inc.
Technical Staff	Glenn Holland	SFA Inc.

Key PRT Members	Institution
Mike Kowalski	NRL
Bill Hunter	NRL
Jim Long	NRL
Charlie Brown	NRL



NRL

NRL Commitment to NSLS

X24C

- **NRL originally designed and built X24C and has operated it continuously since the beginning (> 20 years).**
- **NRL Space Science Division periodically invests capital equipment funds for X24C improvements:**
 - **Recently upgraded the monochromator and reflectometer motors and the computer control system from the original CAMAC to Mac.**
 - **\$188K is budgeted in FY08 for replacement valves, ion pumps, and ion gauges.**

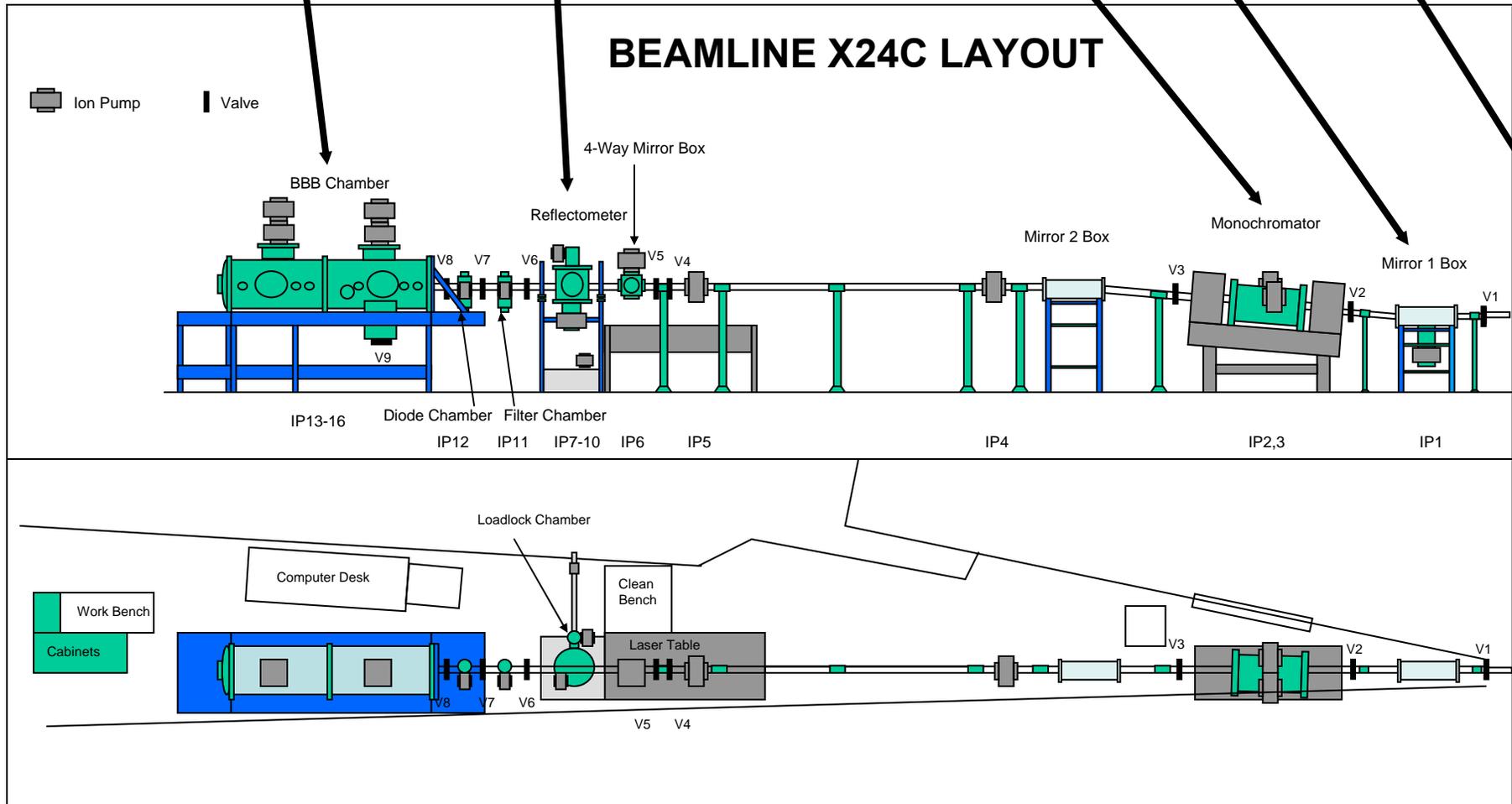


NRL

X24C Layout

X24C

Calibration Chamber Reflectometer Monochromator M1(2°) Bending Magnet



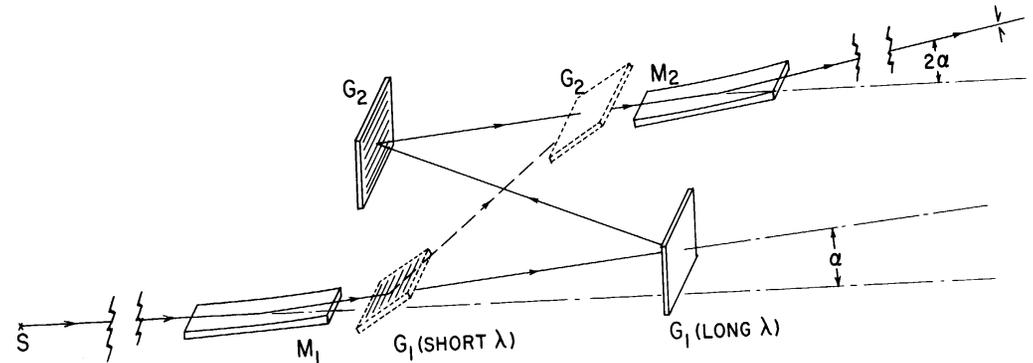


NRL

X24C Monochromator

X24C

- Two elements (e.g. grating and mirror) are precisely translated and rotated by computer control while maintaining fixed entrance and exit slits.
- Gratings are selected without breaking vacuum and cover from 1 keV through the visible.
- 2° grazing mirrors M1 and M2 were upgraded in 1999 with NRL capital equipment funds.
- 10^8 to 10^{12} photons/sec/0.1% bandpass peaking at ~ 100 eV, resolution up to 1000.



The radiation is 90% polarized with the electric field vector in the plane of the storage ring. This permits the study of the polarization properties of EUV/x-ray optics. The polarization properties impact the science that can be accomplished with solar and astrophysical spaceflight instruments. X24C is the world's leading beamline for these studies.

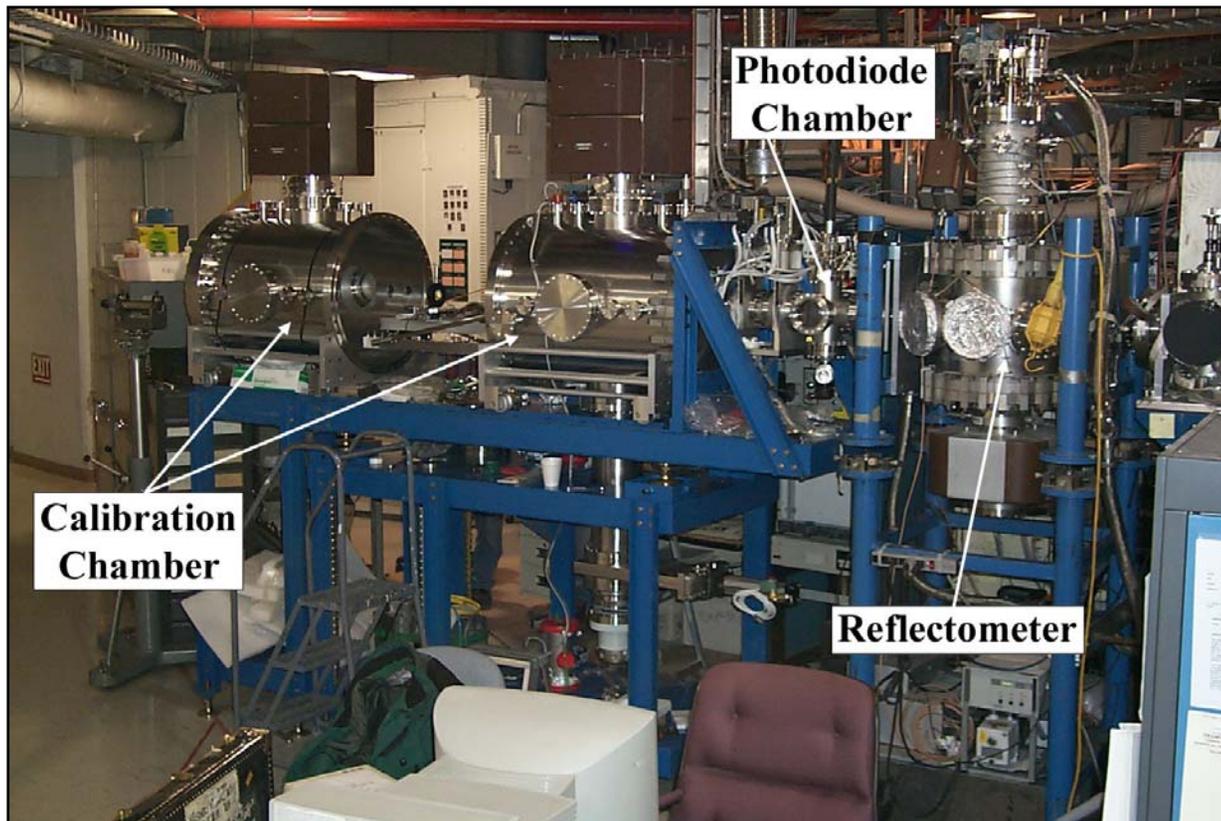


X24C Sample Chambers

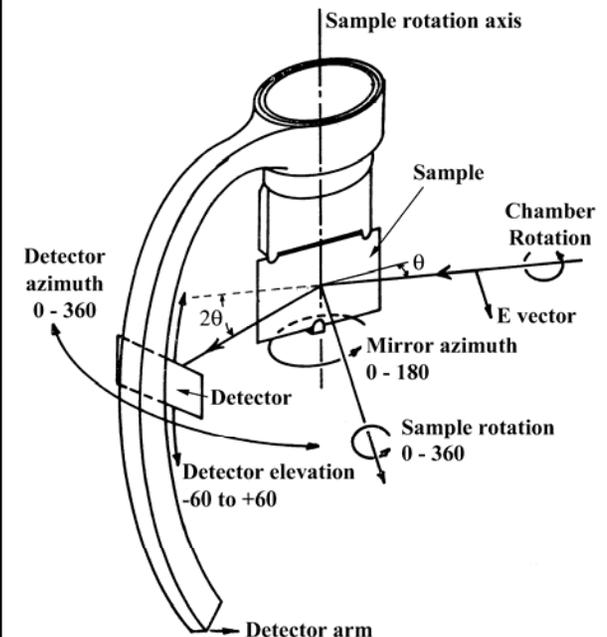
X24C

NRL

- UHV reflectometer is used for small sample measurements:
 - Can be rotated about the incident beam for S and P polarization studies.
 - High reflectance multilayer interference coatings on mirror/grating substrates.
 - High efficiency diffraction gratings (reflection and transmission gratings).
- Photodiode chamber for detector sensitivity and radiation damage studies.
- Large calibration chamber for large optics and spaceflight instrument components.



Computer controlled θ - 2θ reflectometer:





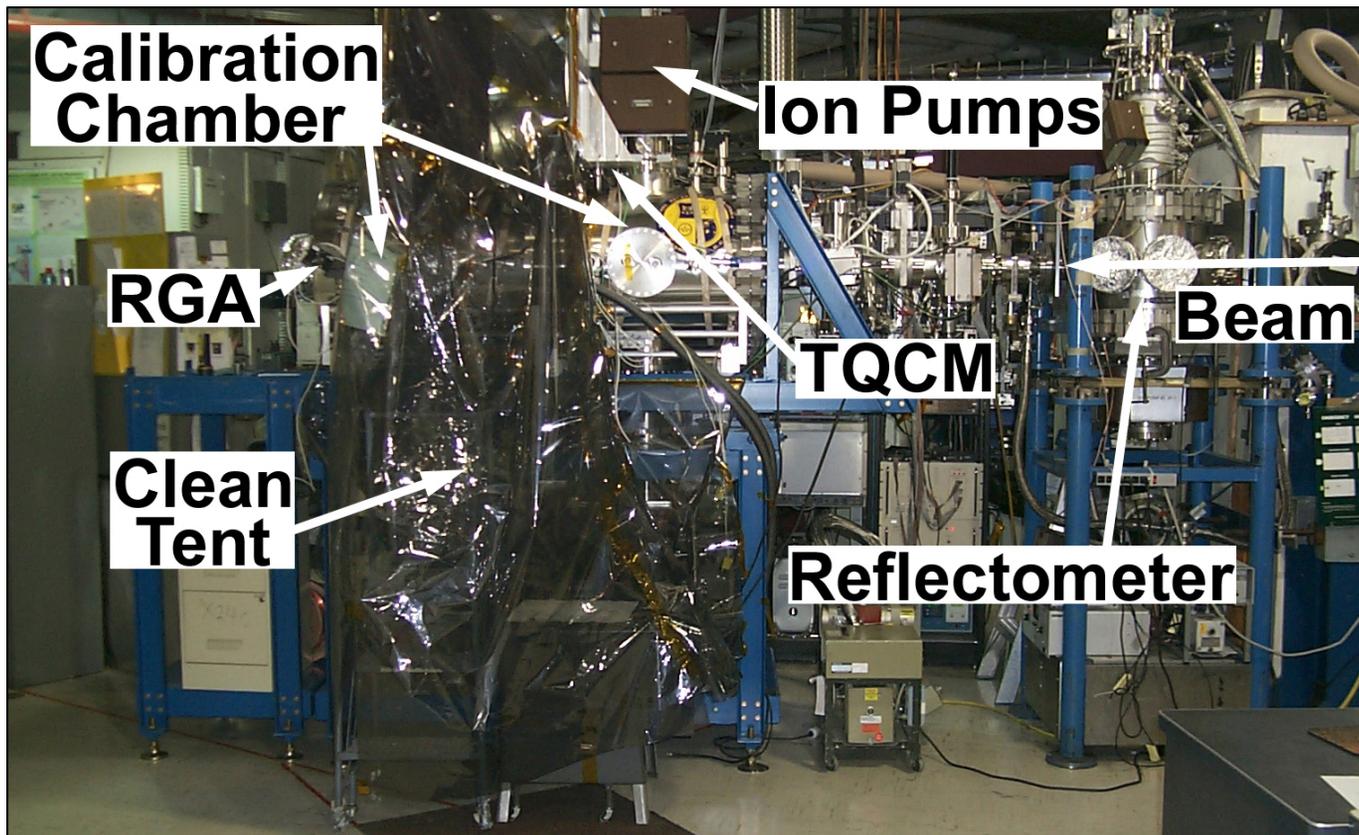
NRL

Large Calibration Chamber

X24C

Research, development, and calibration of spaceflight optics and detectors:

- Large (up to 1 m long) optics, detectors, instrument components can be calibrated.
- Clean vacuum conditions (RGA and TQCM monitors).
- Isolated from the UHV reflectometer and beamline by differentially pumped filters.
- Sample and detector mounts/goniometers with computer-controlled, precision translational and angular motions.



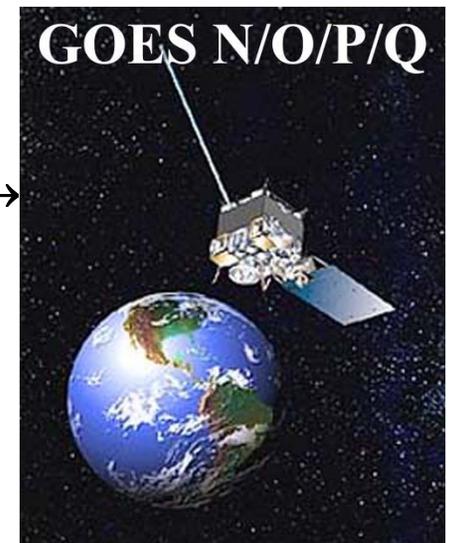


Projects and Collaborations

X24C

NRL

- NRL/ONR: High efficiency multilayer-coated EUV gratings
- NASA: High-resolution EUV spectrometer for the Solar-B mission →
Normal-incidence multilayer grating covering 17-30 nm wavelengths.
ISAS/Japan, Mullard Space Lab/England; Reflective X-Ray Optics
- NASA: $\lambda < 3$ nm multilayers and interface engineering < 0.1 nm
Reflective X-Ray Optics (David Windt)
- NASA: Optical properties of materials in the extreme ultraviolet
Reflective X-Ray Optics, Lebedev Institute/Russia
- NASA/Goddard: Multilayer telescope/grating absolute calibrations
Goddard Space Flight Center
- NOAA: Solar spectrometer calibrations for the GOES N/O/P/Q satellites →
Boeing Aerospace/Seattle, Assurance Technology Corp/Boston,
International Radiation Detectors Inc/Los Angeles
- CCD Absolute Calibrations in the extreme ultraviolet region
MIT Lincoln Lab, Mullard Space Lab/England, NASA
- DOE: Time-resolved soft x-ray flux from laser-produced plasmas
Silicon photodiode sensors, absolute calibrations, subnanosec time response.
NRL Plasma Physics Division, NIKE laser





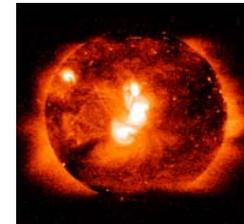
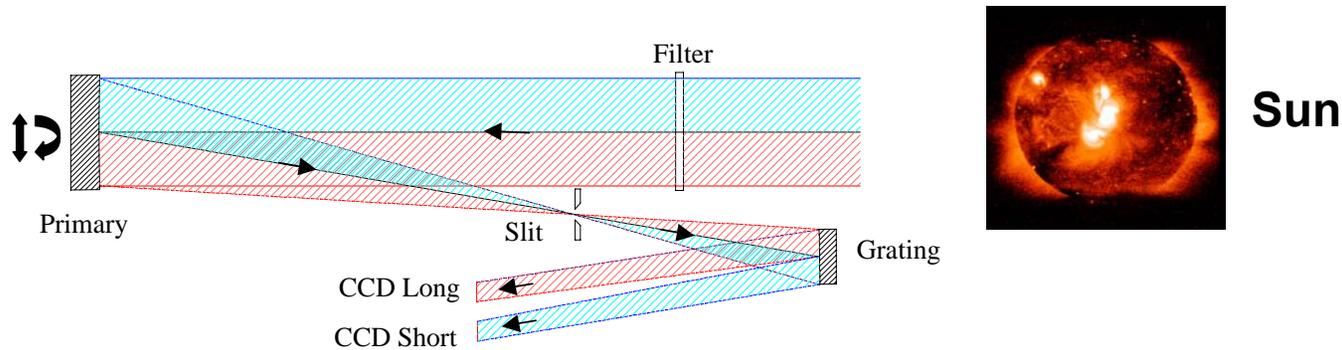
Extreme Ultraviolet Imaging Spectrometer (EIS)

X24C

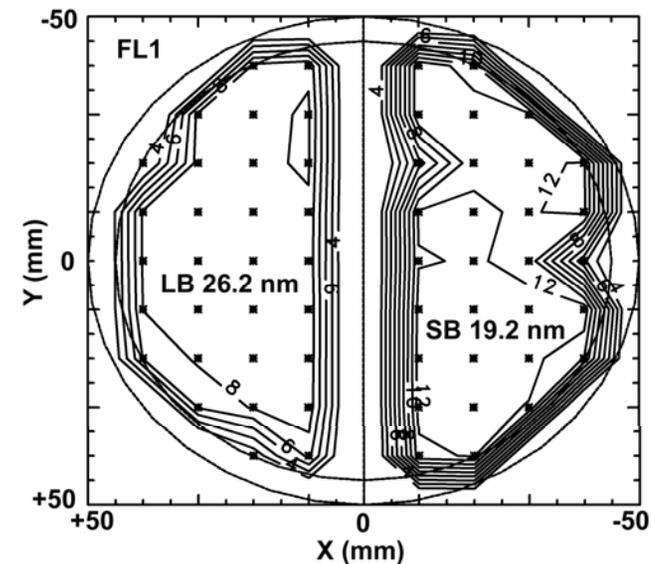
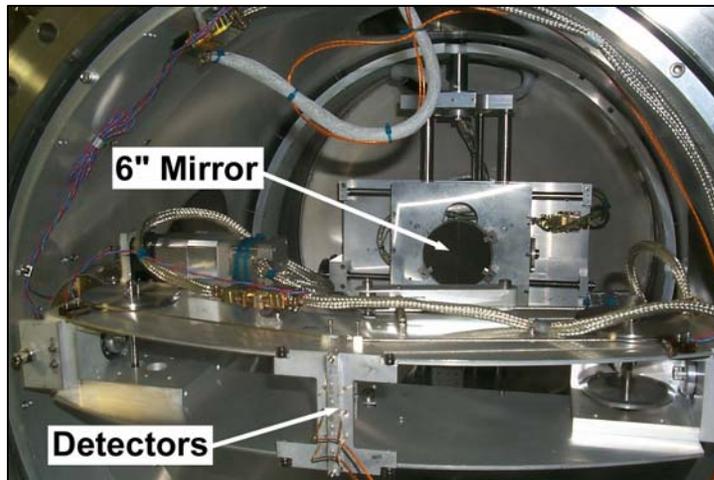
NRL

First satellite spectrometer with a multilayer grating:

- Built by NRL, Mullard Space Lab/England, GSFC, ISAS/Japan, launched in 2006.
- Multilayer coatings cover 17-21 nm and 23-29 nm.
- Designed for the study of solar regions: corona, active regions, flares.
- Measurement of temperatures, densities, emission measure, Doppler shifts.



Sun



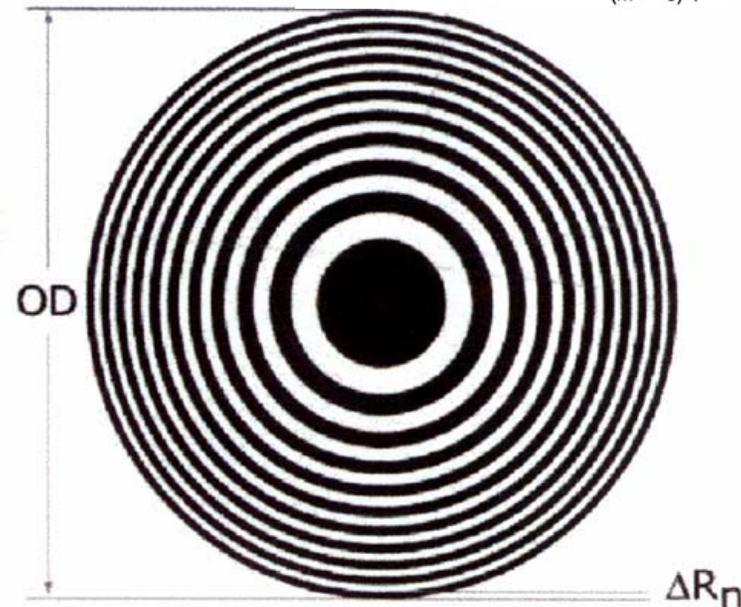
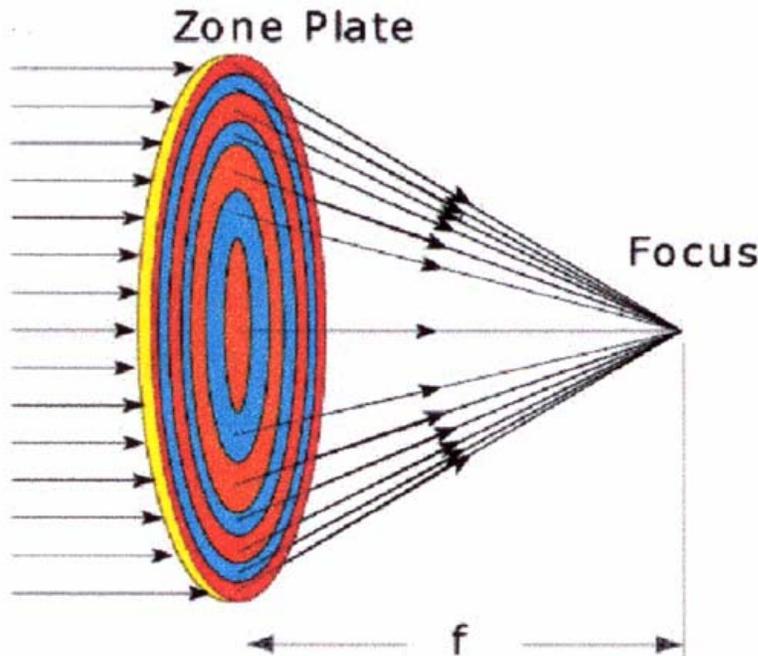
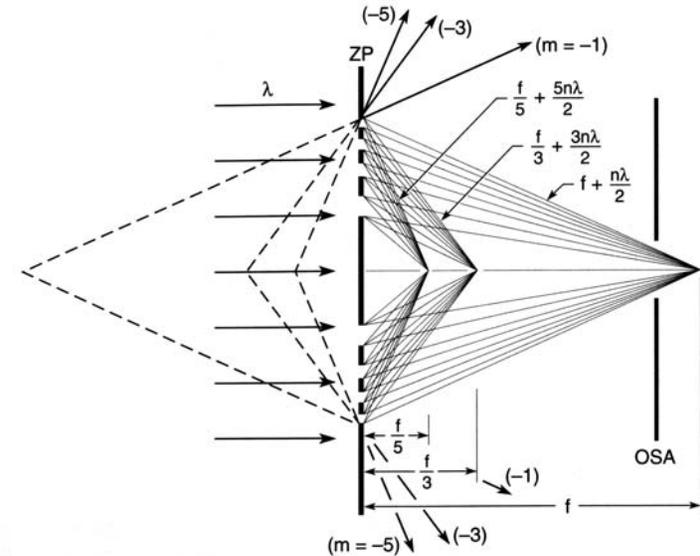


Characterization of Xradia Zone Plate (1)

X24C

NRL

- Fresnel zone plate is composed of open and opaque circular zones designed to focus the +1 diffraction order on the axis with focal length $f \sim 1/\lambda$.
- The $-N$ orders are diverging, and the N =even orders ideally have zero efficiency.





Characterization of Xradia Zone Plate (2)

X24C

NRL

Important experimental parameters:

- 2 mm OD, 180 nm thick gold.
- 1 mm central stop, 0.5 mm thick ss.
- Si₃N₄ support membrane, 2.5x2.5 mm² area, 100 nm thick.
- $f = OD \Delta R_n / N\lambda = 300 \text{ mm} / N\lambda[\text{nm}]$ where N=order number.

Zone Plate Parameters:

Outer Diameter	μm	2000
Inner Diameter (no zones)	μm	1000
Outermost Zone Width	nm	150
Zone Material		Electroplated Gold
Zone Height	nm	180 +/- 10%
Number Of Zones ²		3330
Suggested Energy Range ³	keV	0.13-1.4
Theoretical Max. Diffraction Efficiency ¹	%	15 (@ 1.1 keV)
Support Membrane Material		Si ₃ N ₄
Support Membrane Thickness	μm	0.1
Support Membrane Size	mm	2.5 x 2.5
Support Silicon Frame Size	mm	6 x 6
Central Stop Diameter ⁴	μm	1000
Central Stop Height / Material	μm	500/stainless steel

¹ The guaranteed focusing efficiency for condenser zone plates is 50% of the theoretically calculated value.

² Number of fabricated rings calculated for a full zone plate (no missing inner zones).

³ Energy range for which the theoretical efficiency is greater 10%.

⁴ The stop for the condenser is a EDM-cut stainless steel plate.

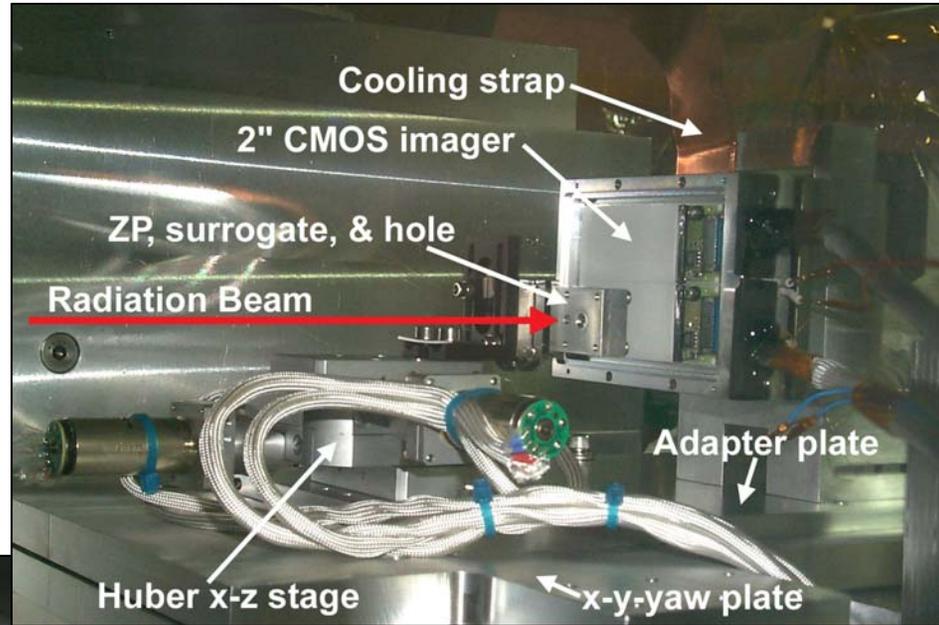


Characterization of Xradia Zone Plate (3)

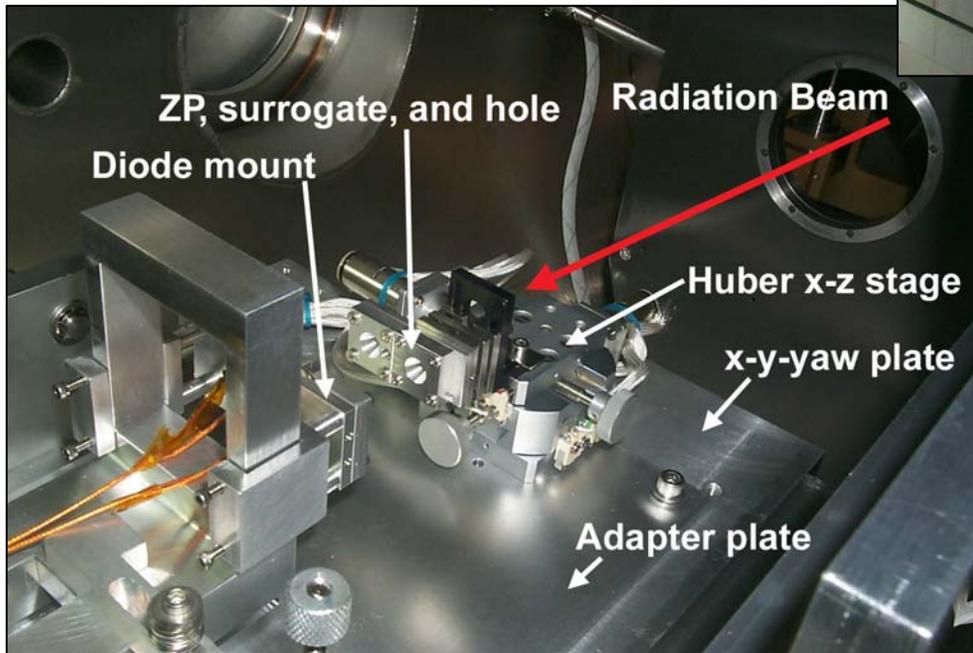
X24C

NRL

Front view of the CMOS imager:



Back view of the diode mount:



Motions controlled from outside

- Calibration chamber x-y-yaw plate:
 - Center ZP or surrogate in beam.
 - Rotate ZP off-axis.
- Huber x-z relative to x-y-yaw plate:
 - Change ZP-detector distance.
 - Move ZP or surrogate into beam.
- Detector x-y relative to ZP:
 - Center detector behind ZP.

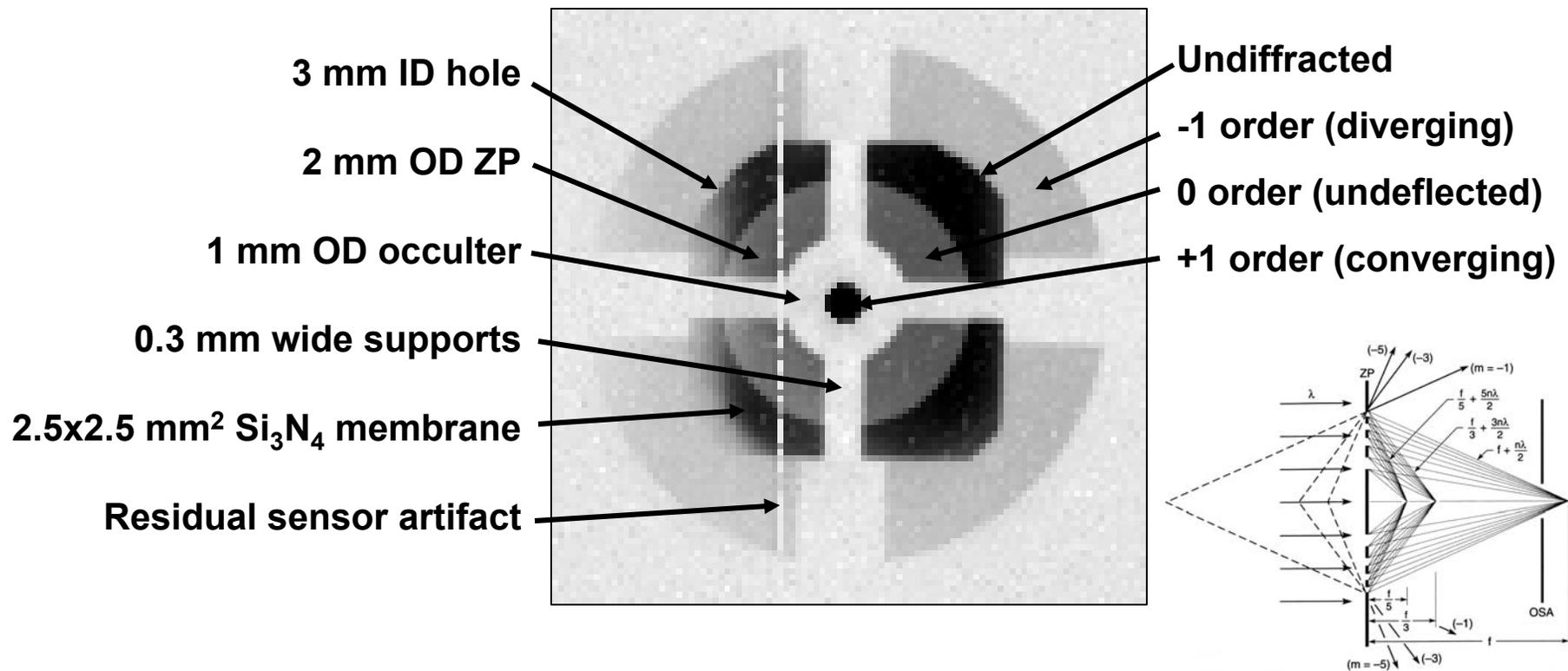


Characterization of Xradia Zone Plate (4)

X24C

NRL

- Apertures upstream of the ZP define the radiation beam diameter/divergence.
- The beam divergence was ± 5 mrad (small, resulting in sharp shadows).
- The beam through the 2 mm aperture overfilled the ZP and revealed features.
- Image has 100x100 pixels ($48 \mu\text{m}$), $4.8 \times 4.8 \text{ mm}^2$ size (13.5 nm wavelength):



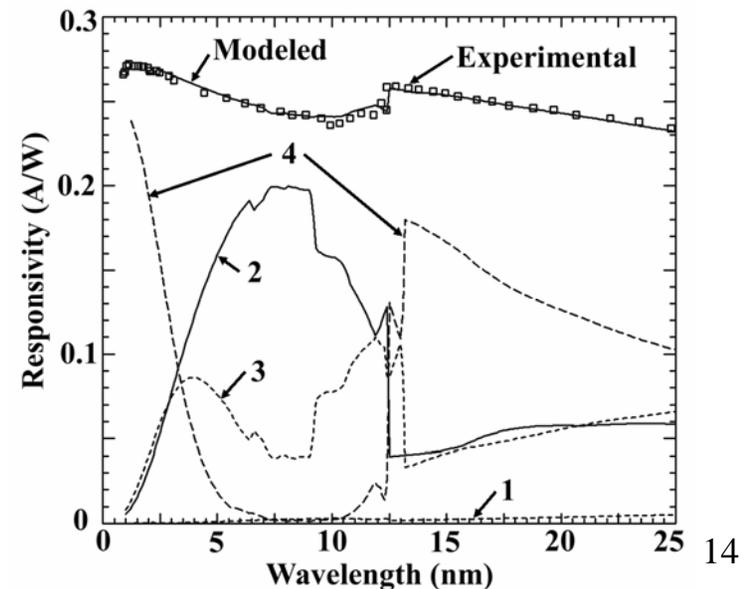
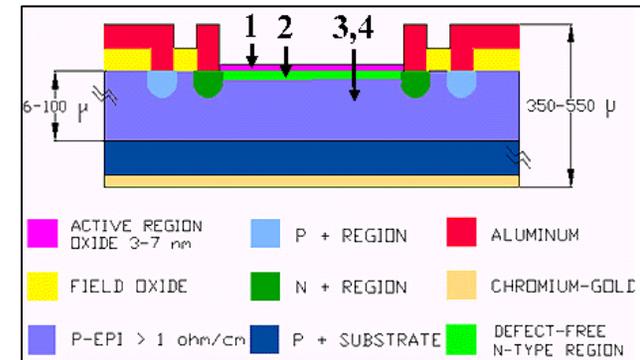
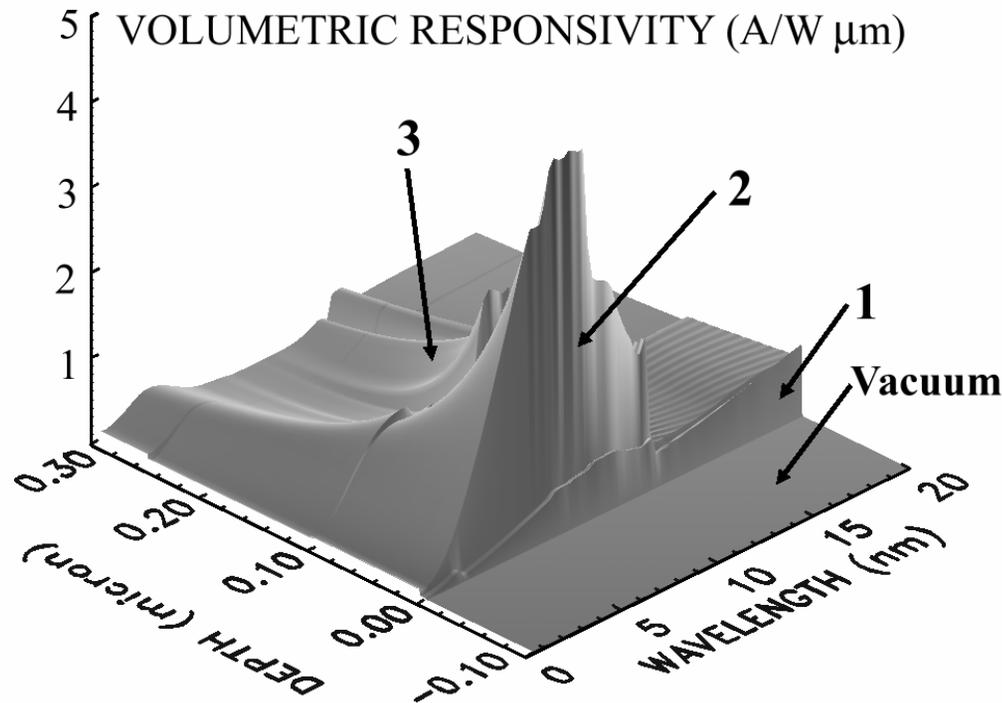


NRL

Photodiode Responsivity

X24C

- Optical models for the responsivities of EUV/x-ray photodiodes (Si, SiC).
- Multiple-layer coatings provide EUV bandpasses, polarization sensitivity, and visible light blocking.
- Adopted for GOES EUV spectrometers and for NRL laboratory x-ray measurements.
- Calibration model for an uncoated Si photodiode:



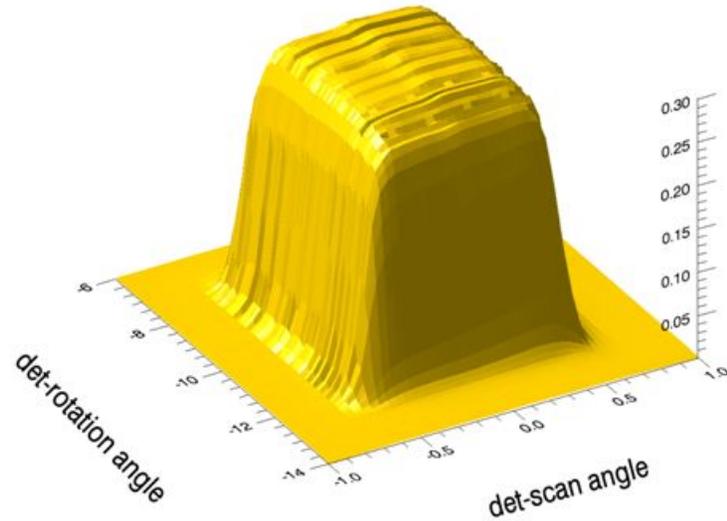


NRL

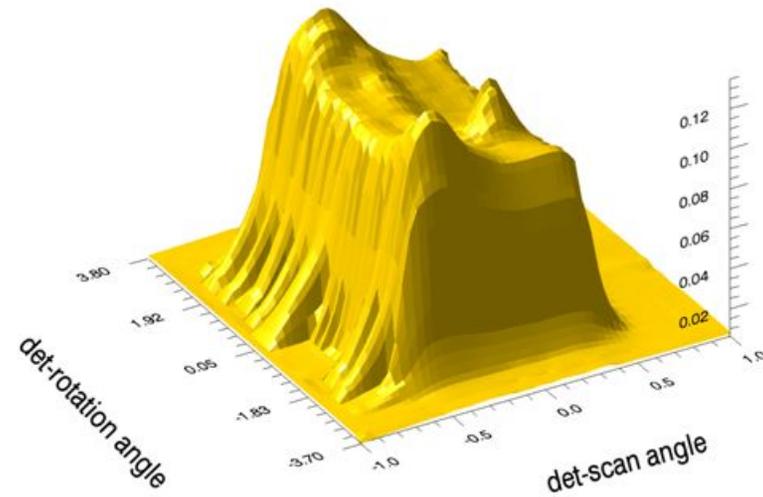
Radiation Damaged Photodiodes

X24C

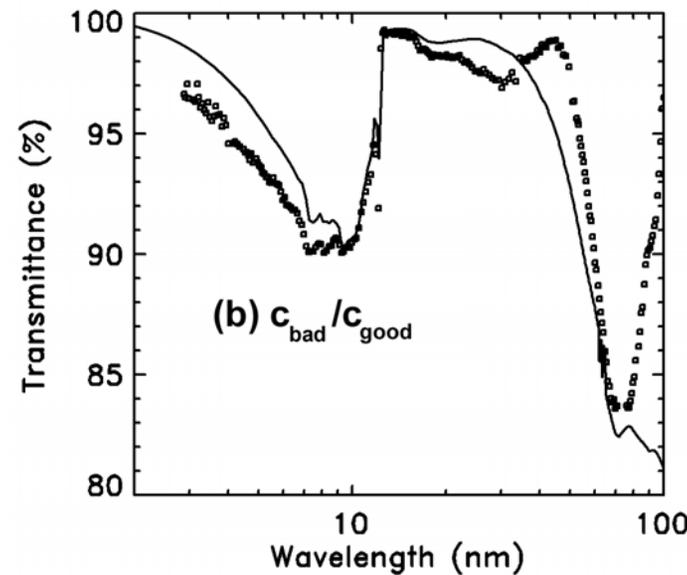
Pristine AXUV100G (1 cm square)



Radiation Damaged AXUV100G



Radiation damaged is modeled by reduced charge collection efficiency in the topmost Si layer.



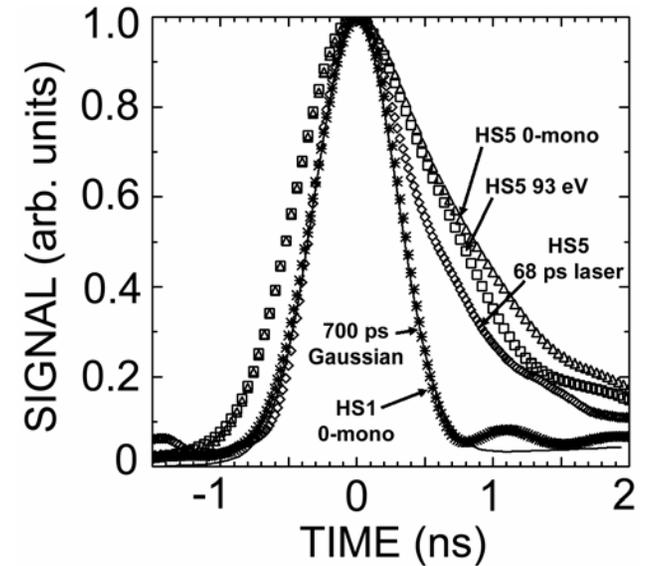


NRL

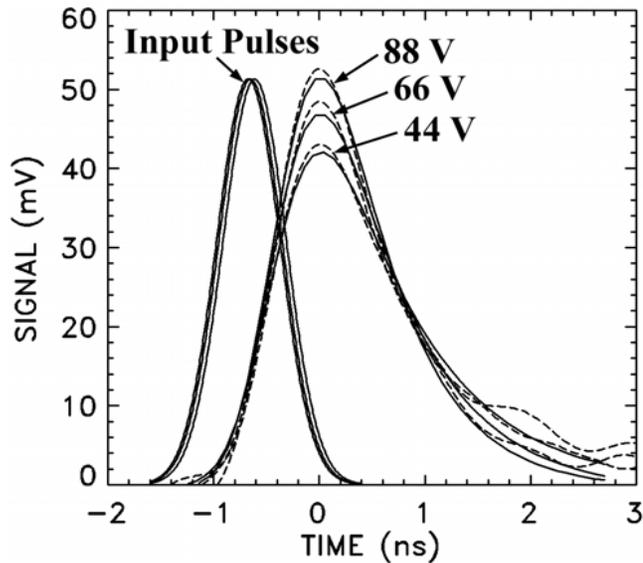
Pulsed Photodiode Responsivity

X24C

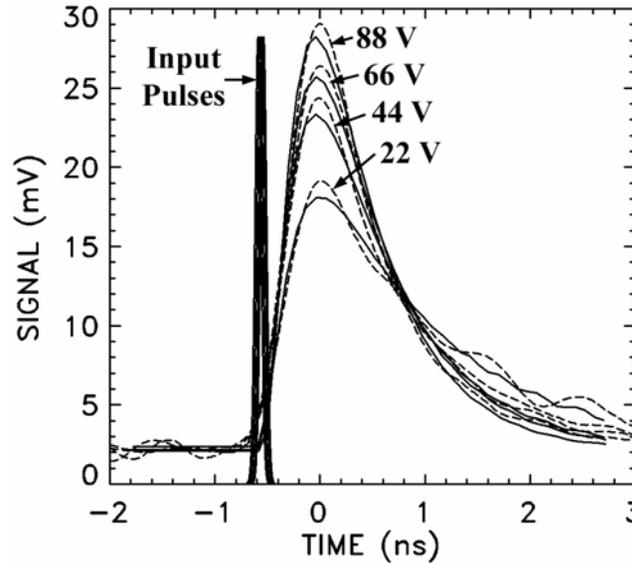
Number	Type	Area (mm ²)	Aperture Diameter (mm)
1	AXUV-HS5	1 x 1	0.8
2	AXUV-HS5	1 x 1	0.4
3	AXUV-HS1	0.22 x 0.22	0.15
4	AXUV-100G	10 x 10	0.8



HS5: 700 ps NSLS single bunch



68 ps laser



Inferred Capacitance

