SURF III

Calibration capabilities

Synchrotron radiation research since 1963.

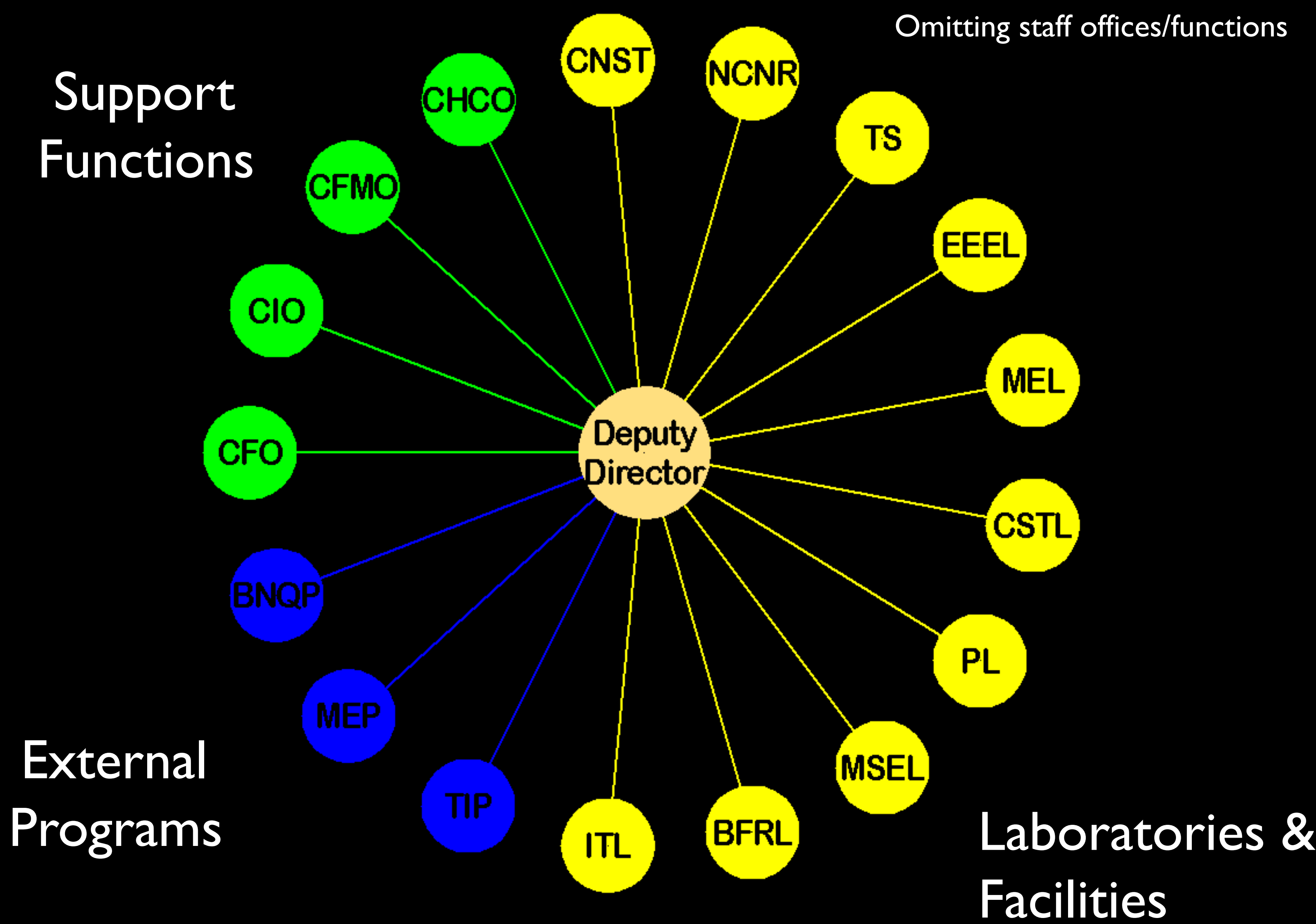
Outline

- NIST Reorganization

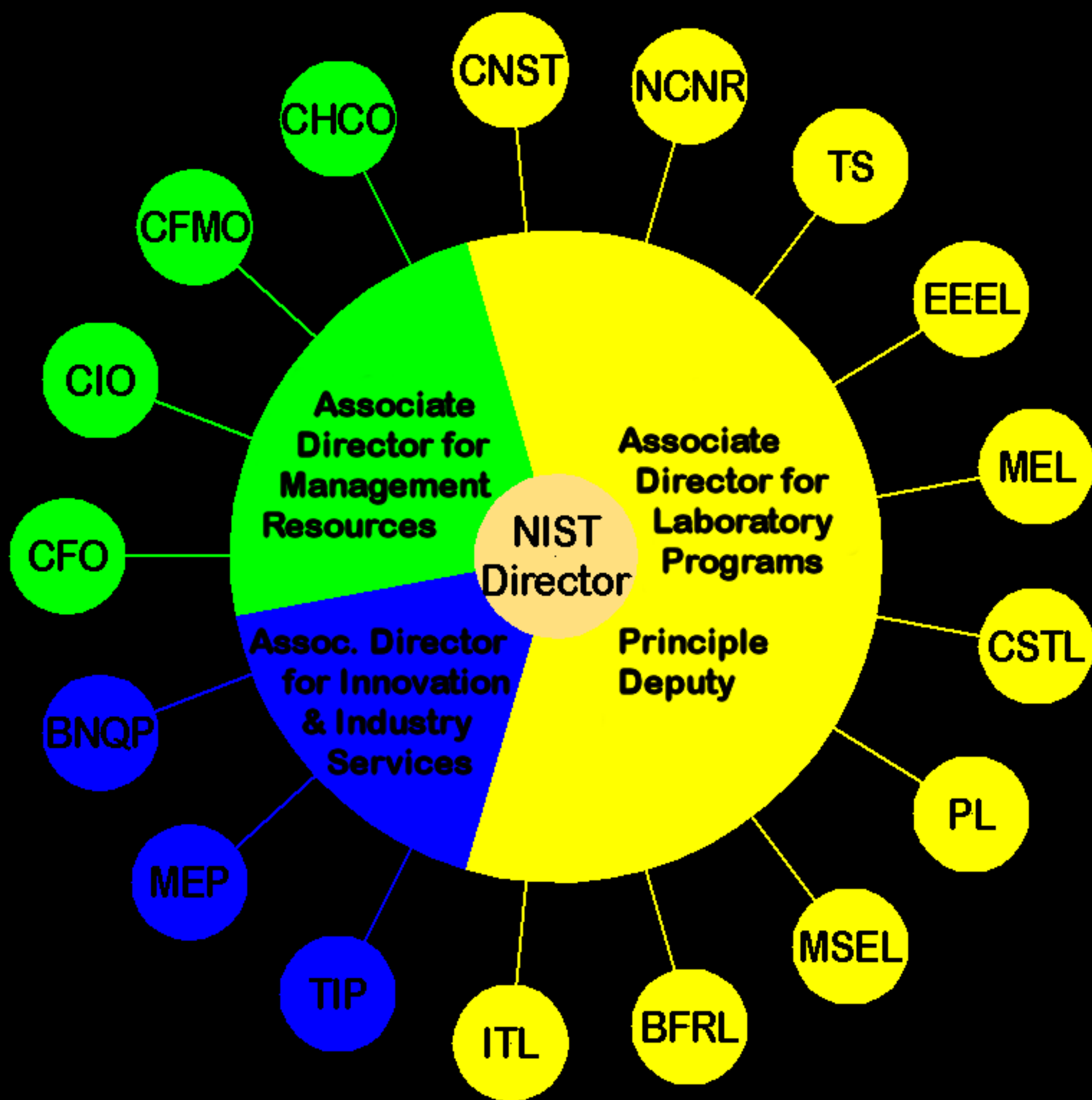
- Physical Measurement Laboratory

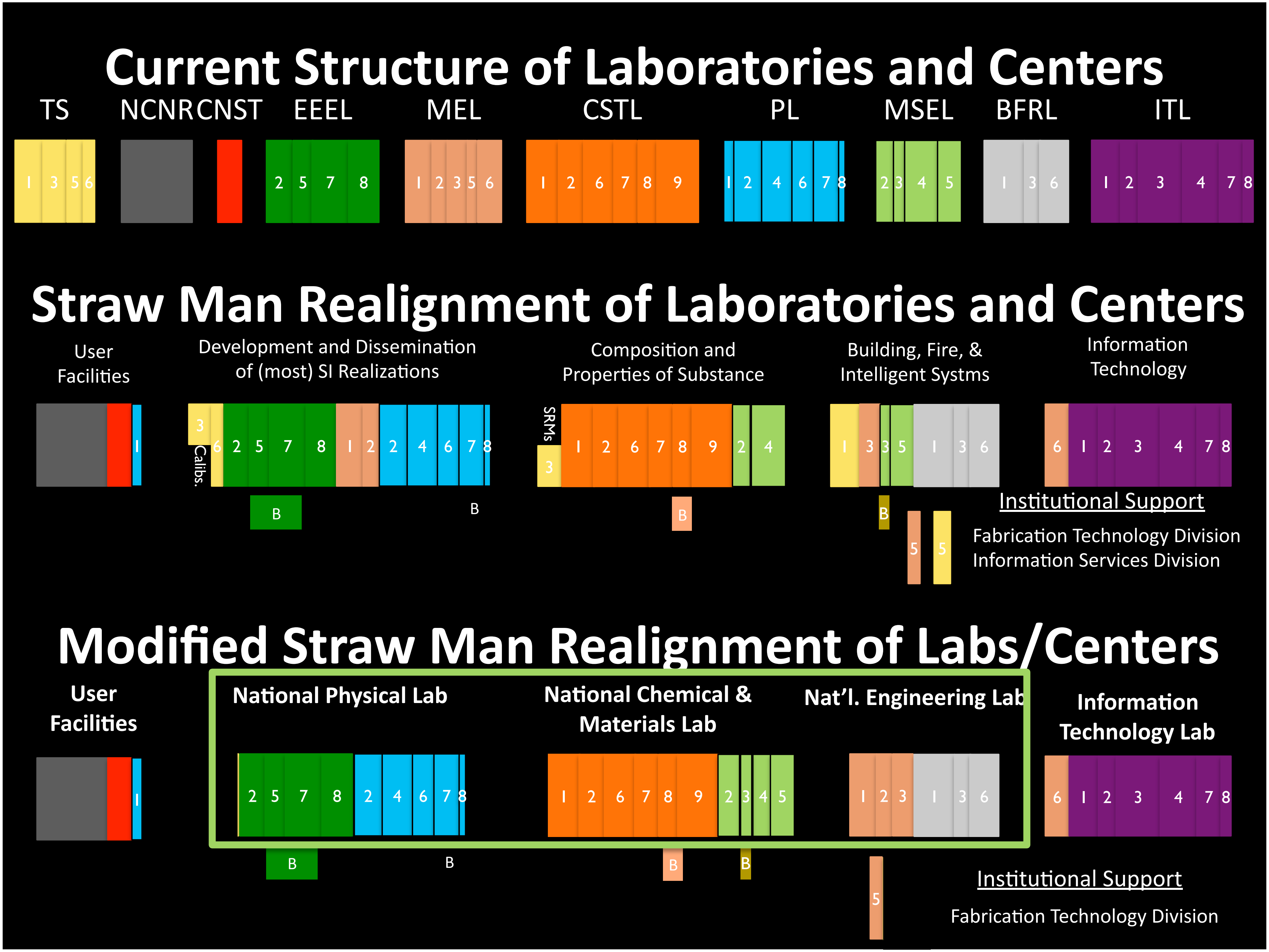
- Synchrotron light: What is and why is it useful?
- Basic properties of synchrotron light at SURF
- Absolute source- and detector-based radiometry
- SURF
- Calibrations on Beamline 2
- Transfer of X24C from NSLS to SURF

NIST at the beginning of 2010

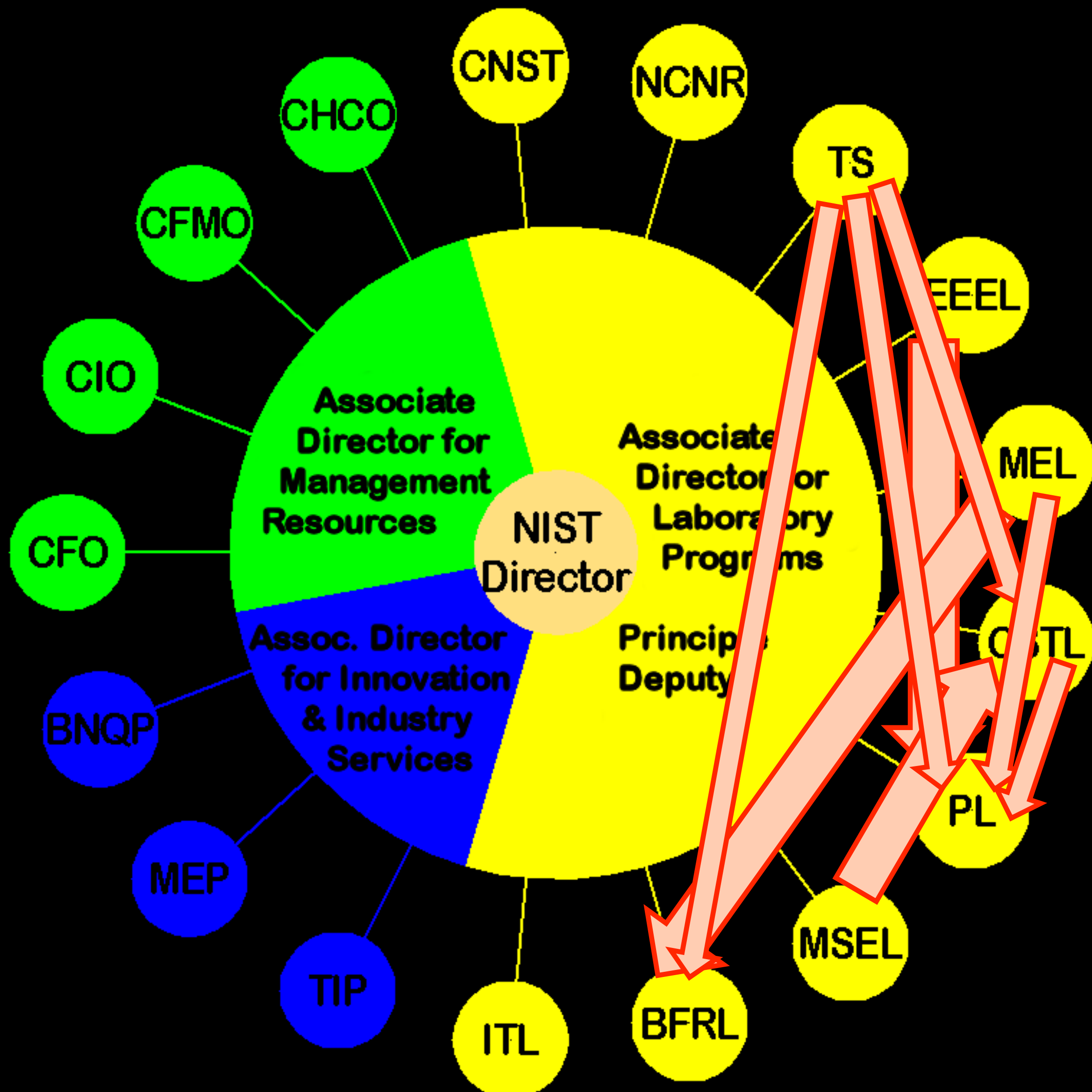


NIST Summer 2010

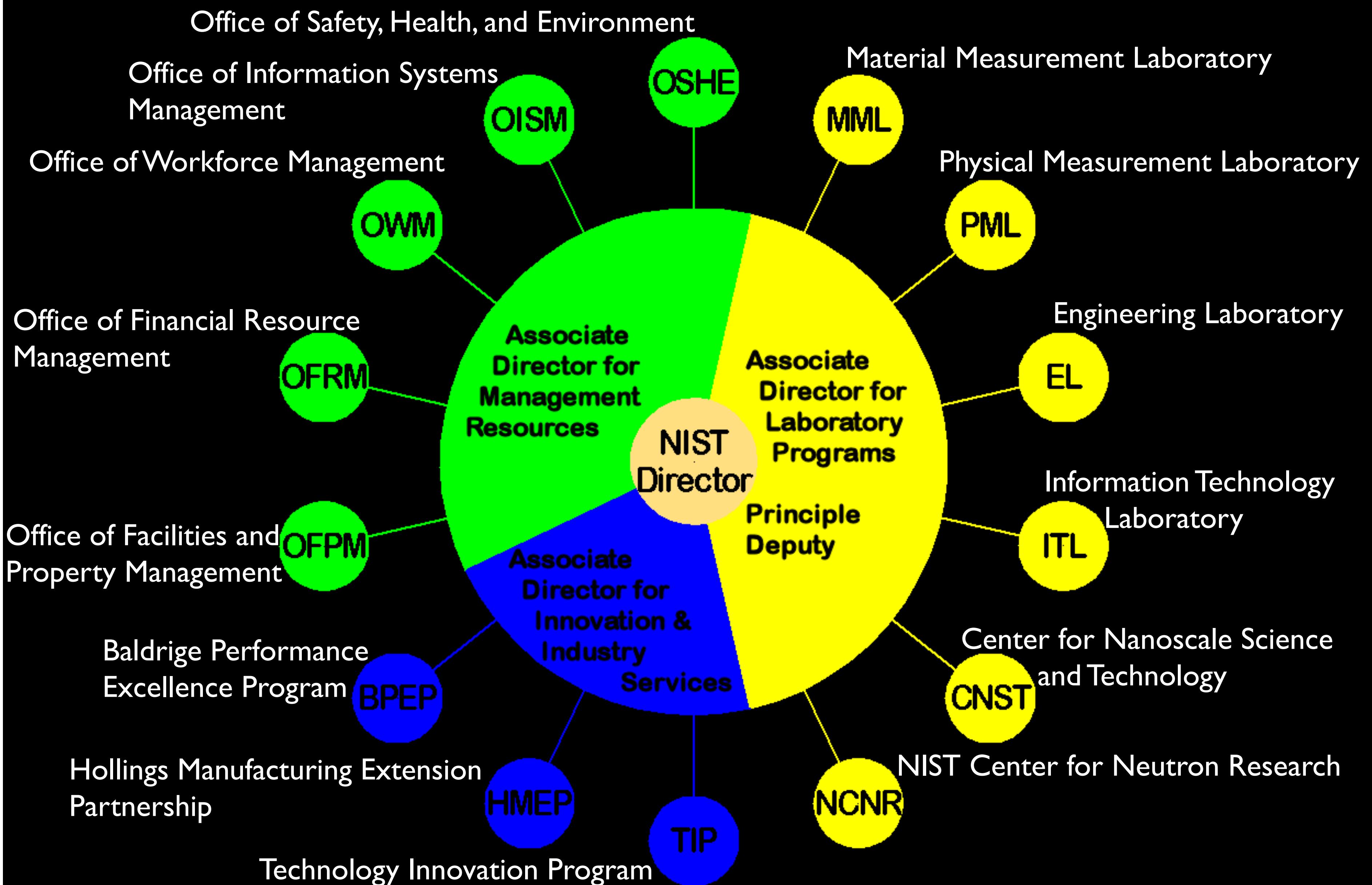



Current Structure of Laboratories and Centers
TS
NCNR
CNST
EEEL
MEL
CSTL
PL
MSEL
BFRL
ITL
1 3 5 6
2 5 7 8
1 2 3 5 6
1 2 6 7 8 9
1 2 4 6 7 8
2 3 4 5
1 3 6
1 2 3 4 7 8
Straw Man Realignment of Laboratories and Centers
User Facilities
Development and Dissemination of (most) SI Realizations
Composition and Properties of Substance
Building, Fire, & Intelligent Systms
Information Technology
1
3
Calibs.
6 2 5 7 8 1 2 2 4 6 7 8
B
B
SRMs
3
1 2 6 7 8 9 2 4
B
1 3 3 5 1 3 6
B
5
5
6 1 2 3 4 7 8
Institutional Support
Fabrication Technology Division
Information Services Division
Modified Straw Man Realignment of Labs/Centers
User Facilities
National Physical Lab
National Chemical & Materials Lab
Nat'l. Engineering Lab
Information Technology Lab
1
2 5 7 8 2 4 6 7 8
B
B
1 2 6 7 8 9 2 3 4 5
B
B
1 2 3 1 3 6
5
6 1 2 3 4 7 8
Institutional Support
Fabrication Technology Division

NIST Summer 2010



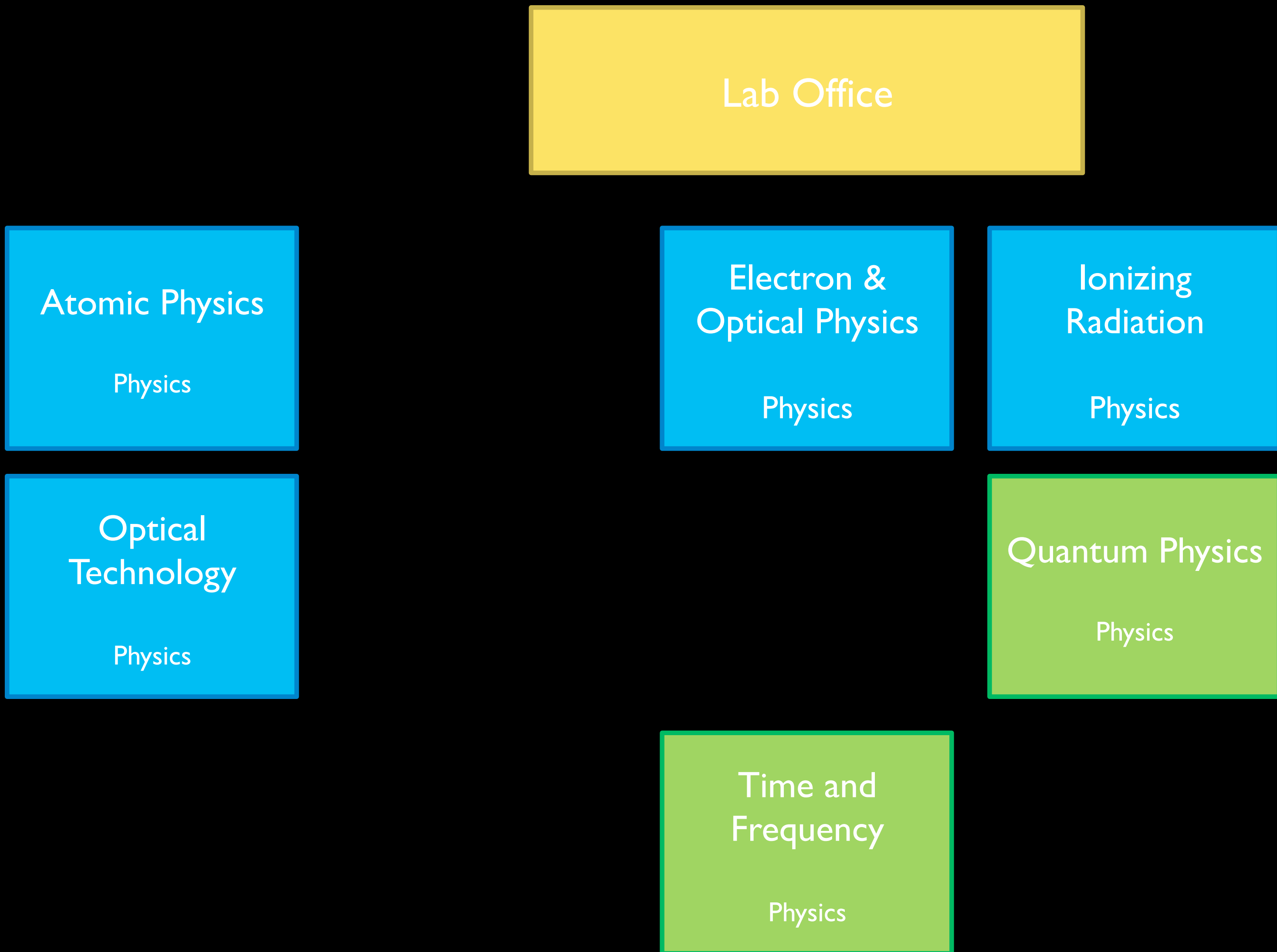
NIST Fall 2010



Outline

- NIST Reorganization
- Physical Measurement Laboratory
- Synchrotron light: What is and why is it useful?
- Basic properties of synchrotron light at SURF
- Absolute source- and detector-based radiometry
- SURF
- Calibrations on Beamline 2
- Transfer of X24C from NSLS to SURF

Physics Lab, September 30th, 2010

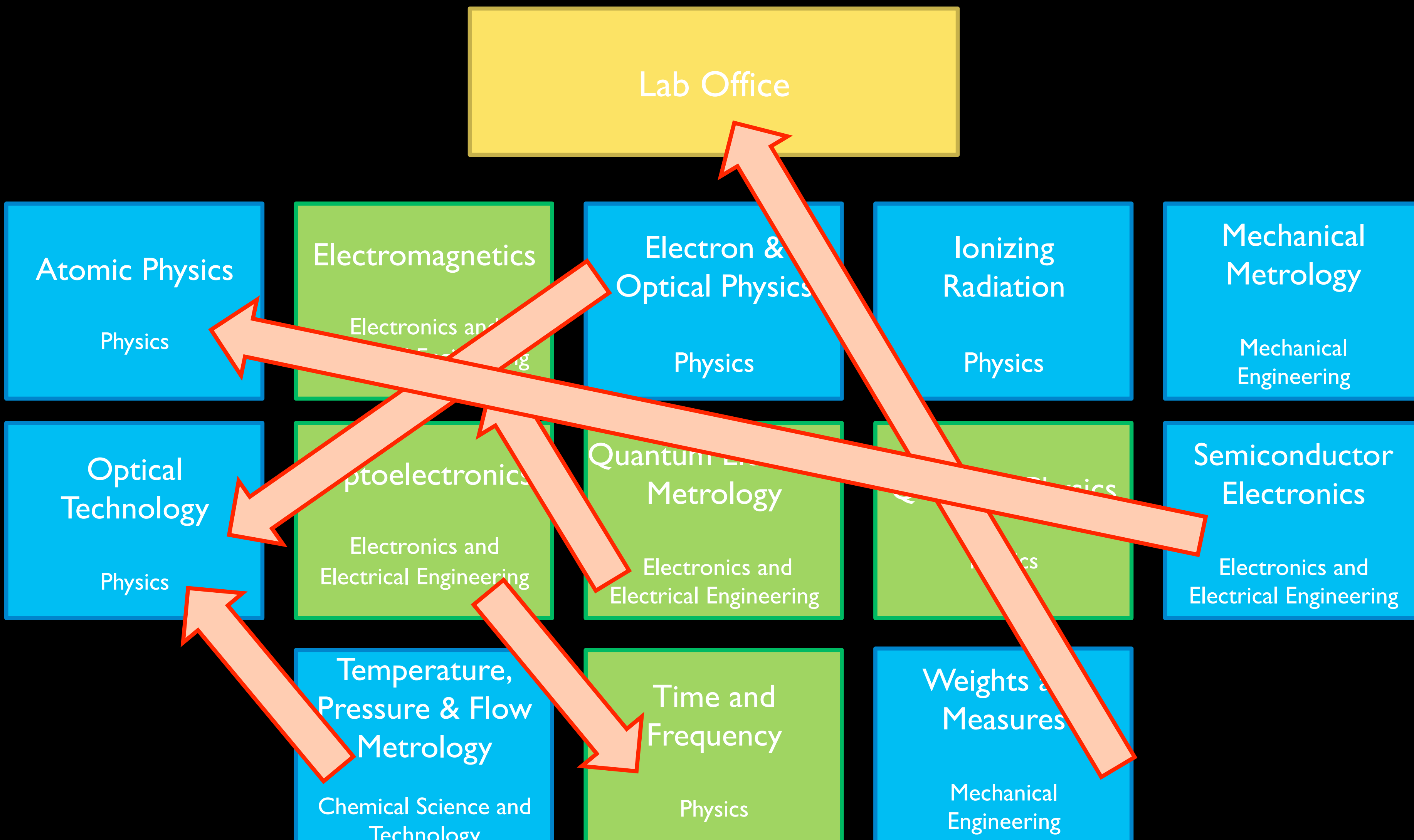


Physical Measurement Lab, October 1, 2010

Lab Office

Atomic Physics Physics	**Electromagnetics** Electronics and Electrical Engineering	**Electron & Optical Physics** Physics	**Ionizing Radiation** Physics	**Mechanical Metrology** Mechanical Engineering
Optical Technology Physics	**Optoelectronics** Electronics and Electrical Engineering	**Quantum Electrical Metrology** Electronics and Electrical Engineering	**Quantum Physics** Physics	**Semiconductor Electronics** Electronics and Electrical Engineering
	Temperature, Pressure & Flow Metrology Chemical Science and Technology	**Time and Frequency** Physics	**Weights and Measures** Mechanical Engineering	

Physical Measurement Lab, October 1, 2011



PML Organized into Eight Divisions

PML Office
Boulder Labs Director Office
Office of Weights & Measures
National Voluntary Laboratory Accreditation Program (NVLAP)

Semiconductor & Dimensional Measurement
Dimensional and surface metrology (e.g., length, roughness)
Microscopy (e.g., optical, electron, atomic force)
Semiconductor manufacturing applications, and reliability

Quantum Electronics and Photonics Division
Quantum devices
Radiometry and detectors
Nanophotonic metrology

Quantum Measurement Division
Atomic physics, spectroscopy, and quantum information
Electrical measurements based on quantum standards
Mass and force measurements

Electromagnetics Division
Radio-frequency electronics
Radio-frequency fields
Magnetics

Sensor Science Division
Temperature, humidity, pressure, vacuum, flow
Photometry and radiometry (from far infrared to soft x-ray)
Optical radiation standards and measurement methods

Time and Frequency Division
Standards for civil timekeeping
Frequency standards
Quantum Information with ion qubits

Radiation and Biological Physics Division
Biophysics and molecular imaging
Medical imaging and radiation dosimetry
Standards for radioactivity and neutron dosimetry

Quantum Physics Division
NIST at JILA
Advances the frontiers of measurement science
in partnership with the University of Colorado

Synchrotron Ultraviolet Radiation Facility

- What does this mean for SURF?
  - Electron & Optical Physics Division has been disbanded
  - Far UV Physics and Photon Physics Groups are combined
  - The new Ultraviolet Radiation Group is part of the Sensor Science Division (former Optical Technology Division, Chief Gerald Fraser)
- Charles Clark is not Division Chief anymore, he is now a NIST fellow
- Tom Lucatorto is Group Leader

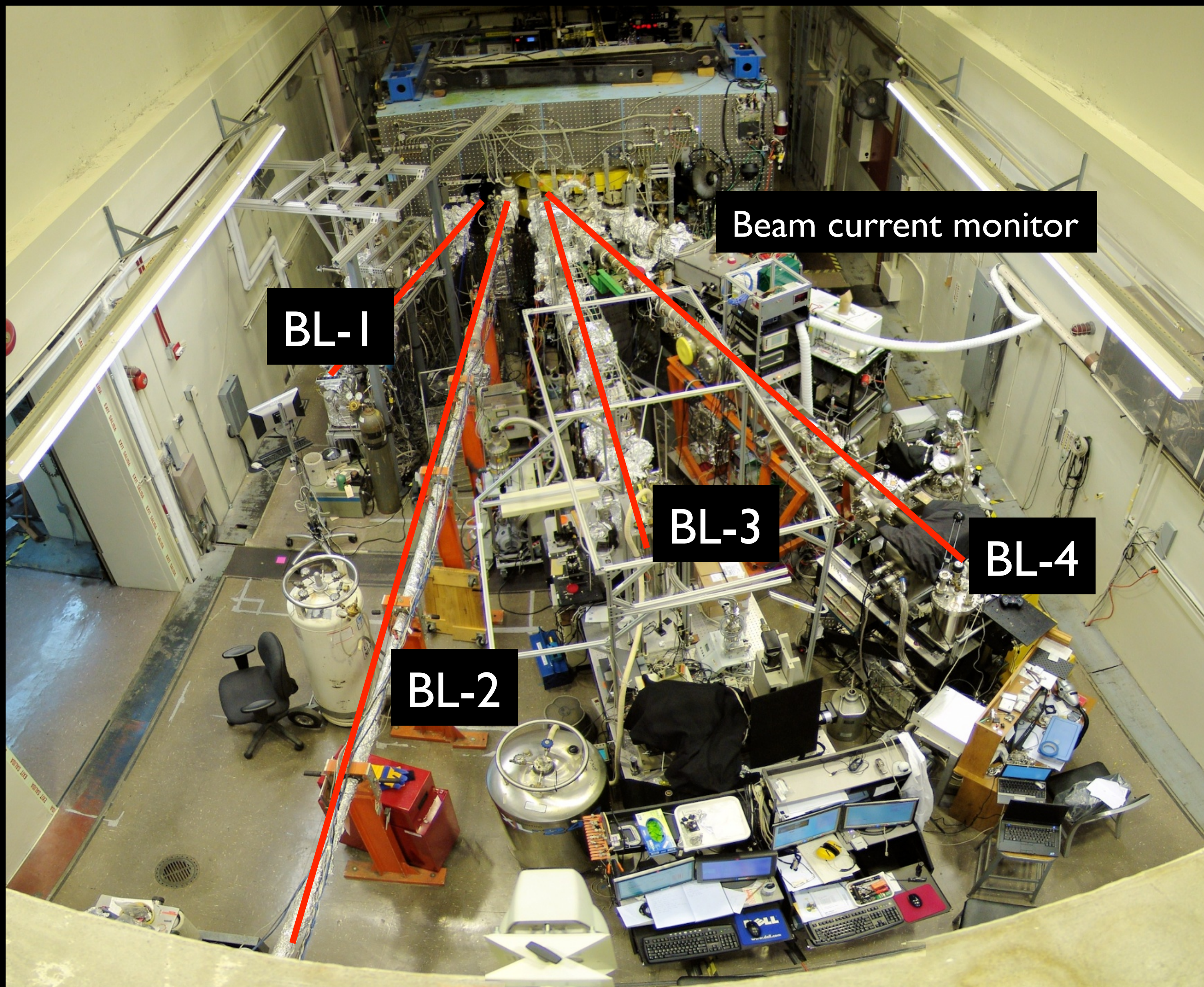
Outline

- NIST Reorganization

- Physical Measurement Laboratory

- Synchrotron light: What is and why is it useful?
- Basic properties of synchrotron light at SURF
- Absolute source- and detector-based radiometry
- SURF
- Calibrations on Beamline 2
- Transfer of X24C from NSLS to SURF

Synchrotron Ultraviolet Radiation Facility

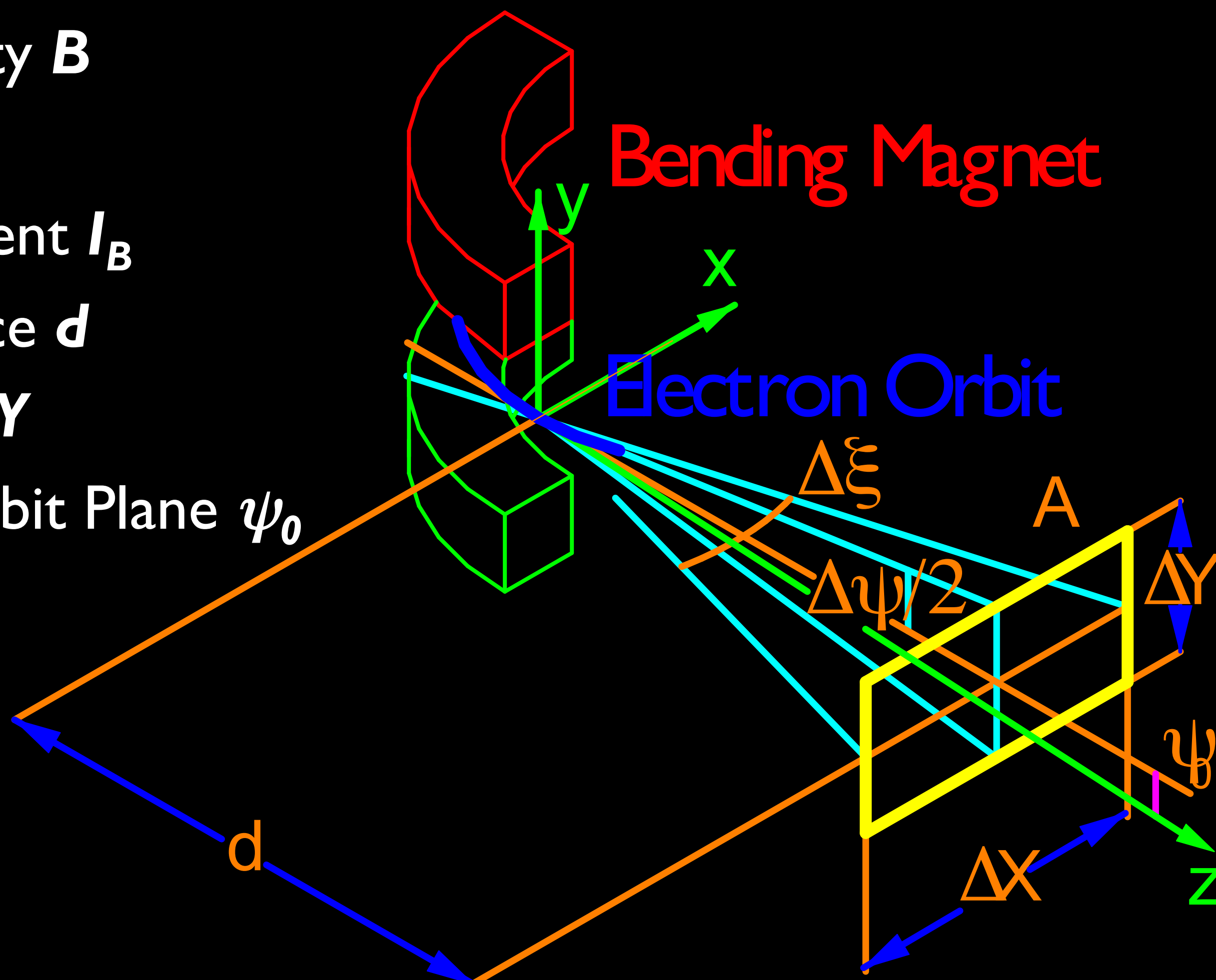


Why is Synchrotron Radiation useful?

- Electromagnetic radiation emitted by highly relativistic electrons or positrons bend onto an orbit by magnets (Magneto-Bremsstrahlung).
- Emitted spectrum: broadband from microwave (harmonics of driving RF field) to x-rays, highly collimated, polarized, calculable.
- Output scales with electron beam current.
- Extremely clean lightsource operated in oil-free vacuum, which avoids photo-activated polymerization of hydrocarbons.
- Synchrotron radiation provides an absolute source!

SURF as an Absolute Source

- Magnetic Flux Density ***B***
- Radio-frequency ν_{rf}
- Electron Beam Current I_B
- Source Point Distance ***d***
- Aperture Size ΔX, ΔY
- Angle Relative to Orbit Plane ψ_0



$$\rho = \frac{E\,\beta}{e_0\,B\,c} = \sqrt{\left(\frac{c}{\pi \cdot \nu_{rf}}\right)^2 - \left(\frac{m_e \cdot c}{B \cdot e_0}\right)^2}$$

$$\gamma = \frac{E}{m_e\,c^2} = \frac{B \cdot e}{\pi \cdot \nu_{rf} \cdot m_e} \approx 744 \text{ @ } 380 \text{ MeV}$$

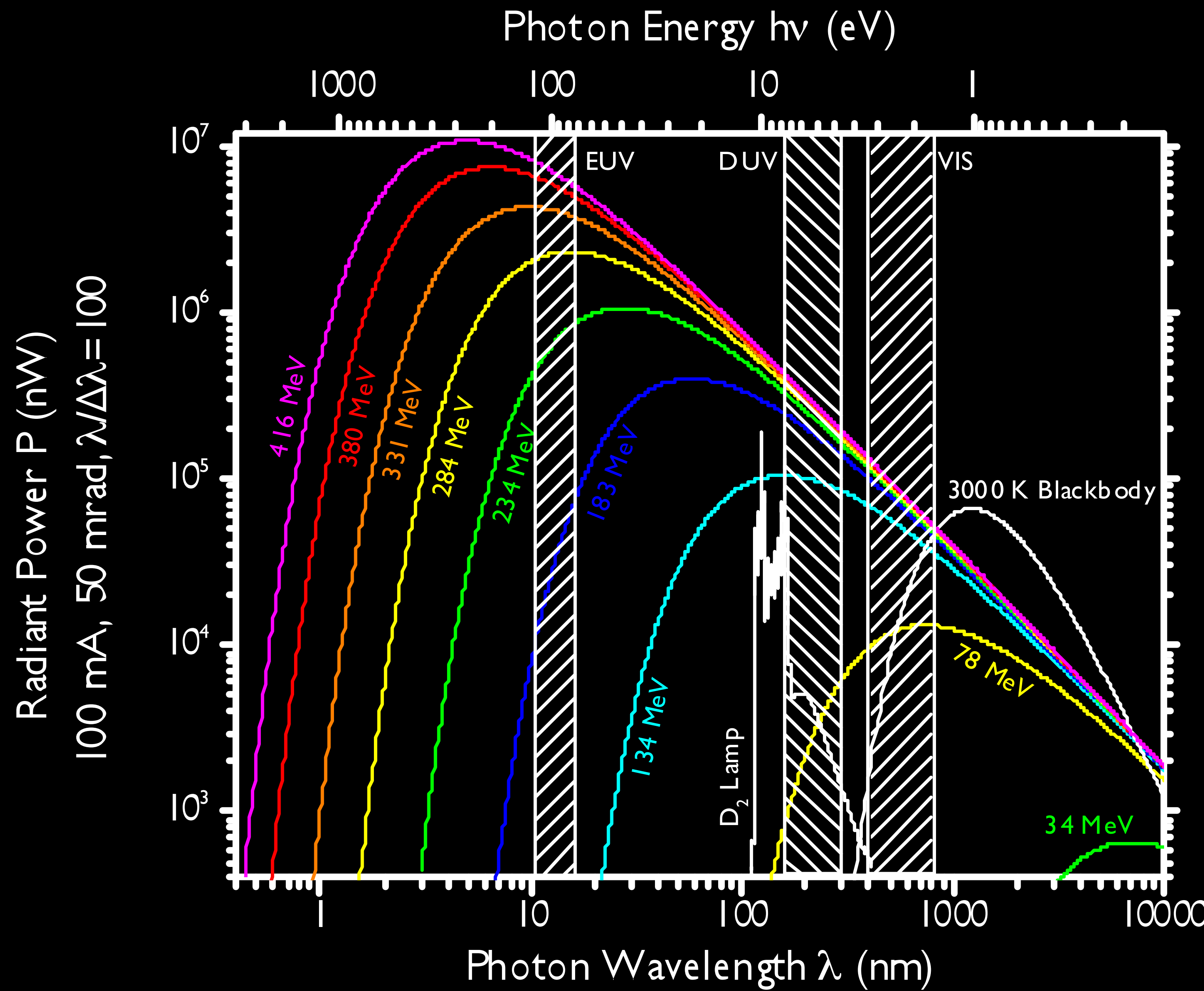
Outline

- NIST Reorganization

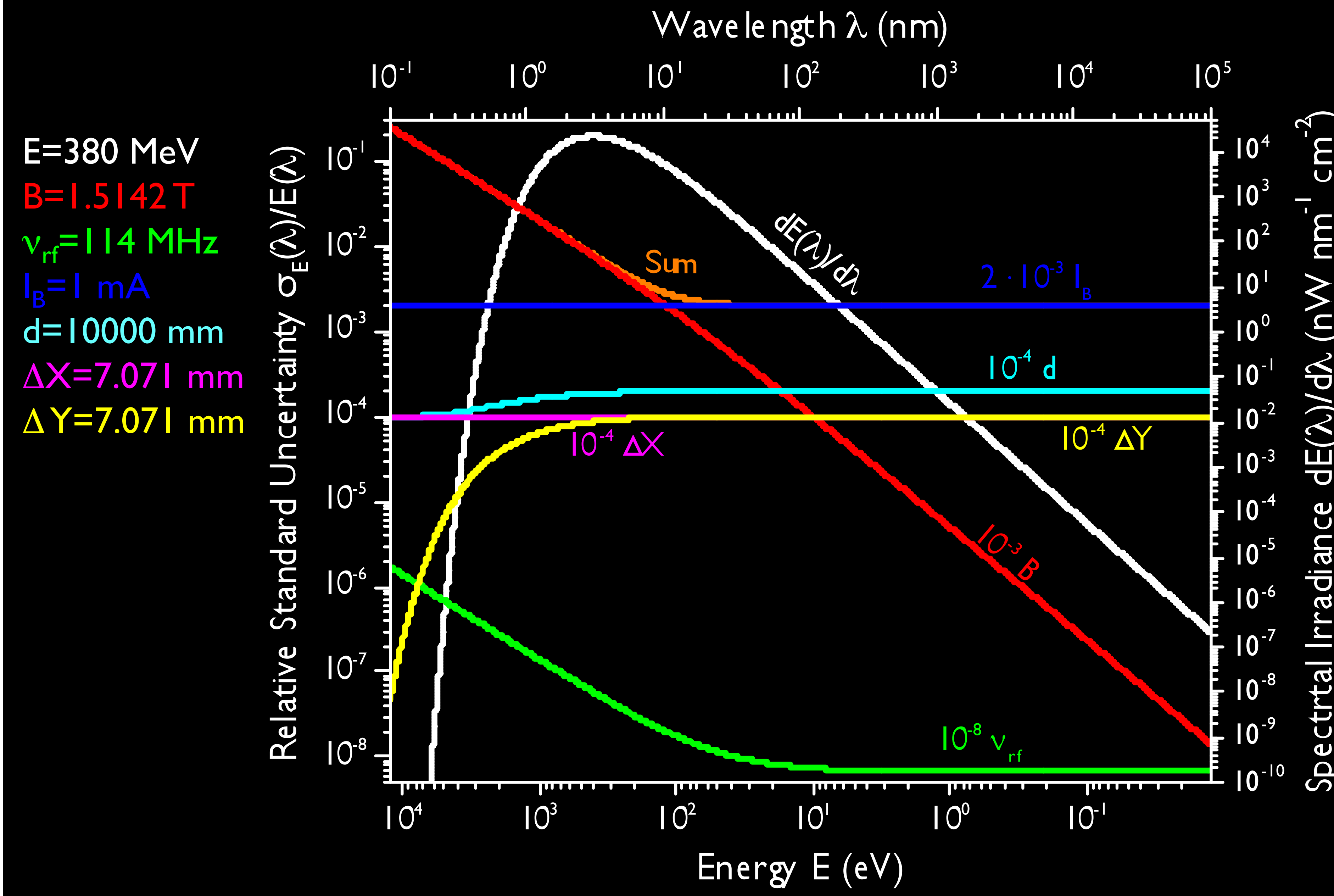
- Physical Measurement Laboratory

- Synchrotron light: What is and why is it useful?
- Basic properties of synchrotron light at SURF
- Absolute source- and detector-based radiometry
- SURF
- Calibrations on Beamline 2
- Transfer of X24C from NSLS to SURF

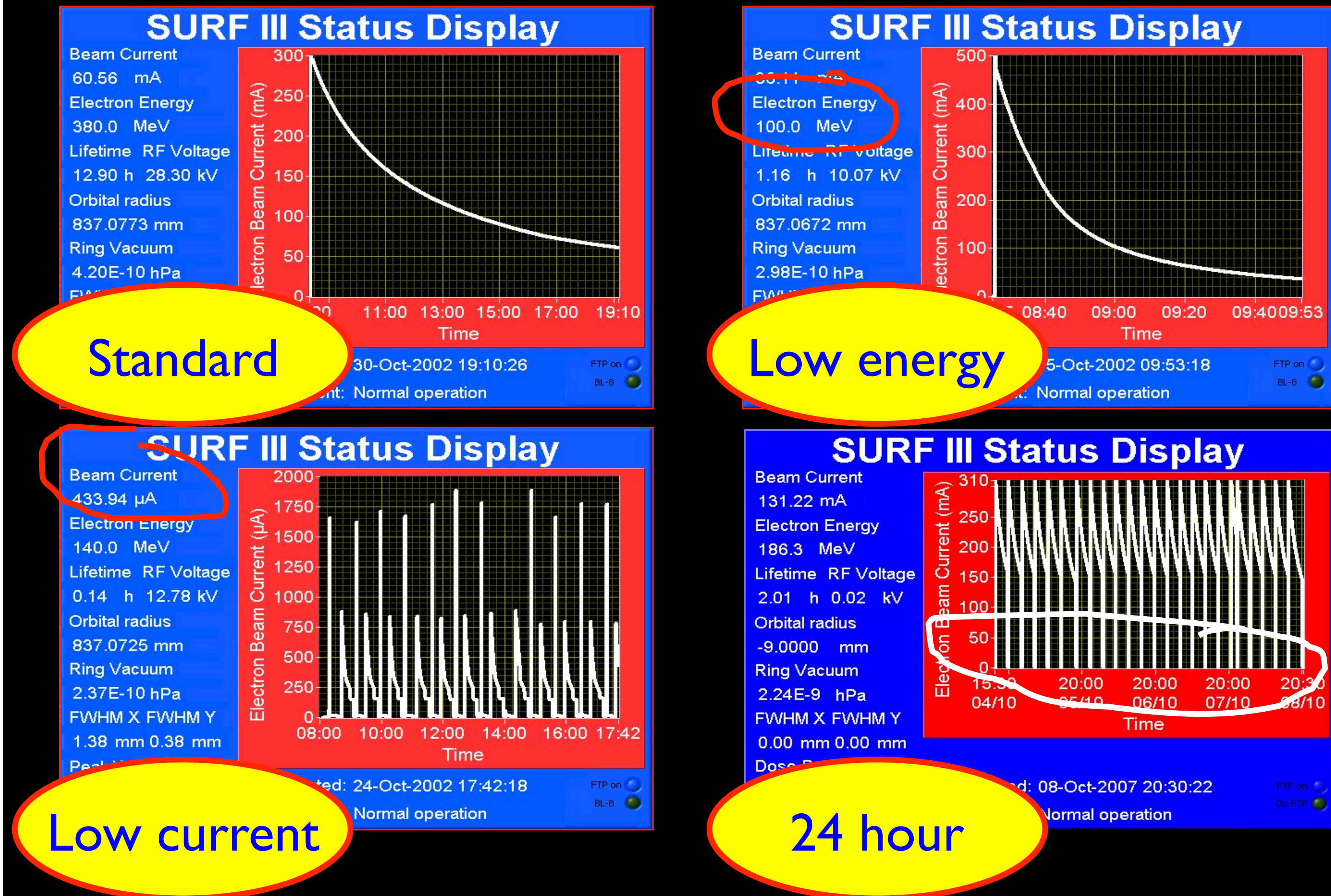
Custom-Tailored Output Spectrum



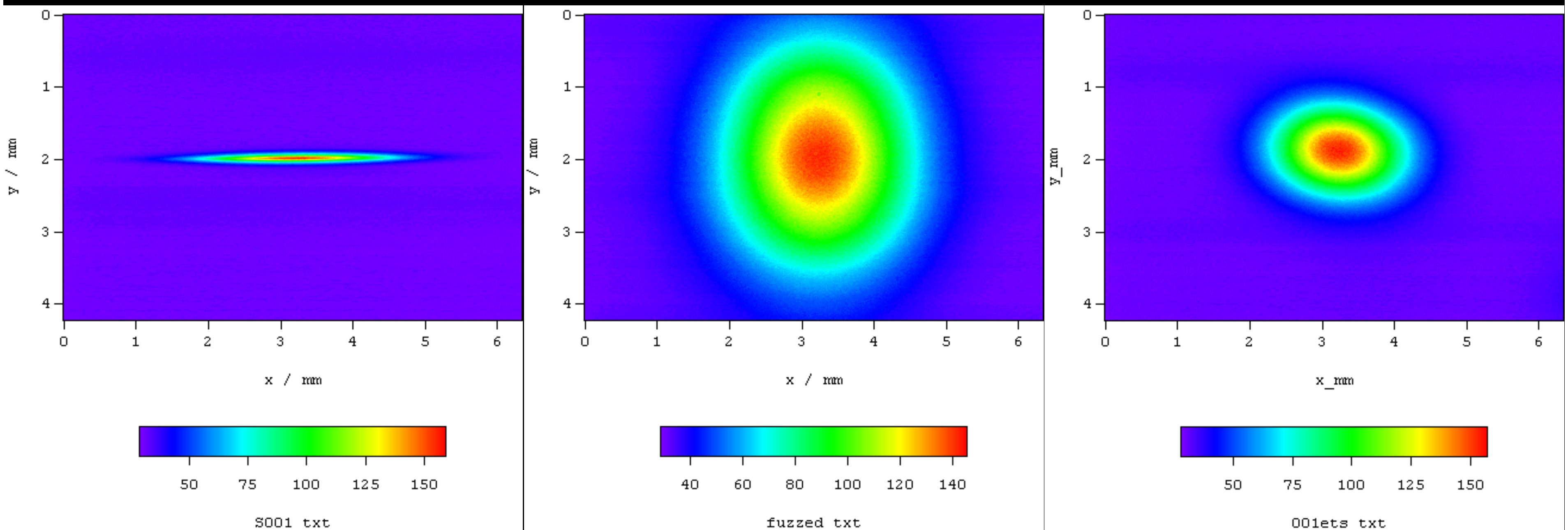
Absolute Source Uncertainty



Flexibility in Operation



Flexibility in Beam Size



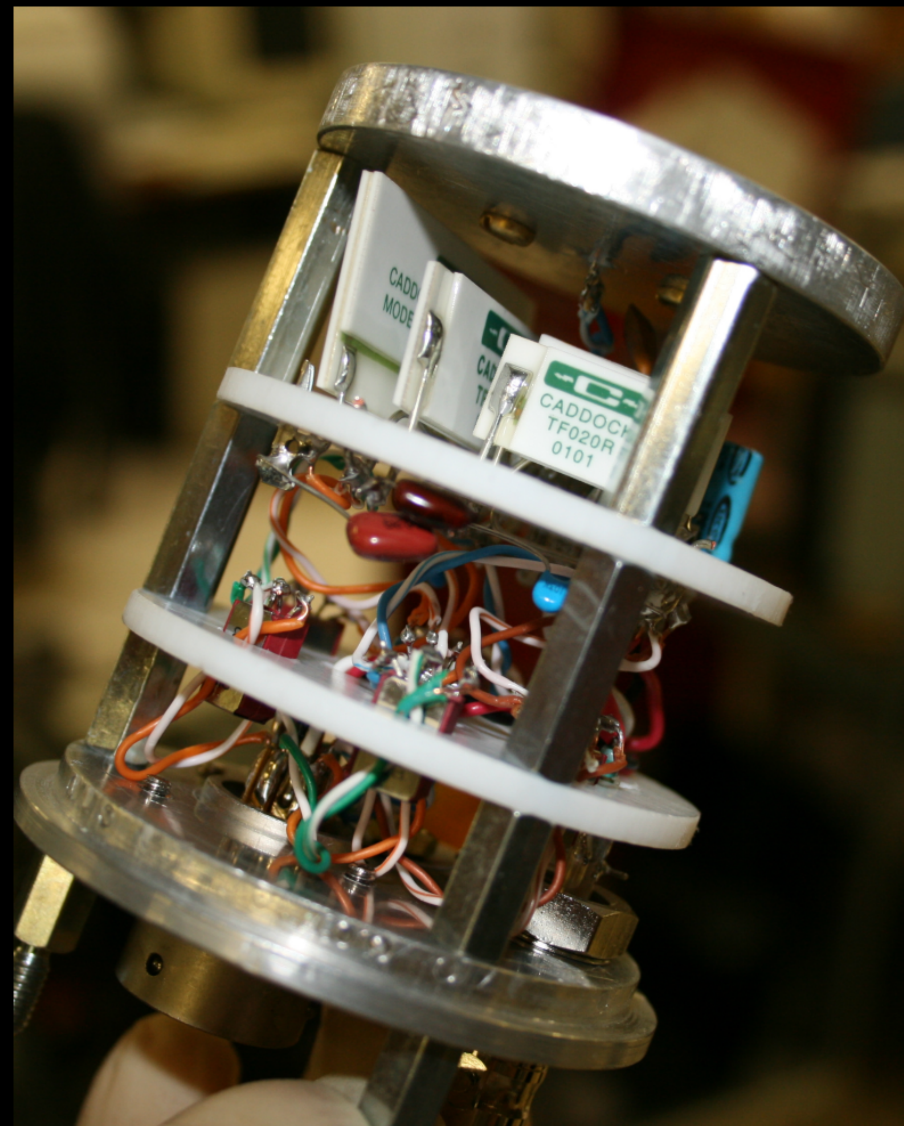
No fuzz **12 W fuzz** **Full coupling**

	σ_y (mm)	σ_x (mm)
No fuzz	0.042	0.889
Full fuzz	1.202	0.914
Full coupling	0.440	0.636

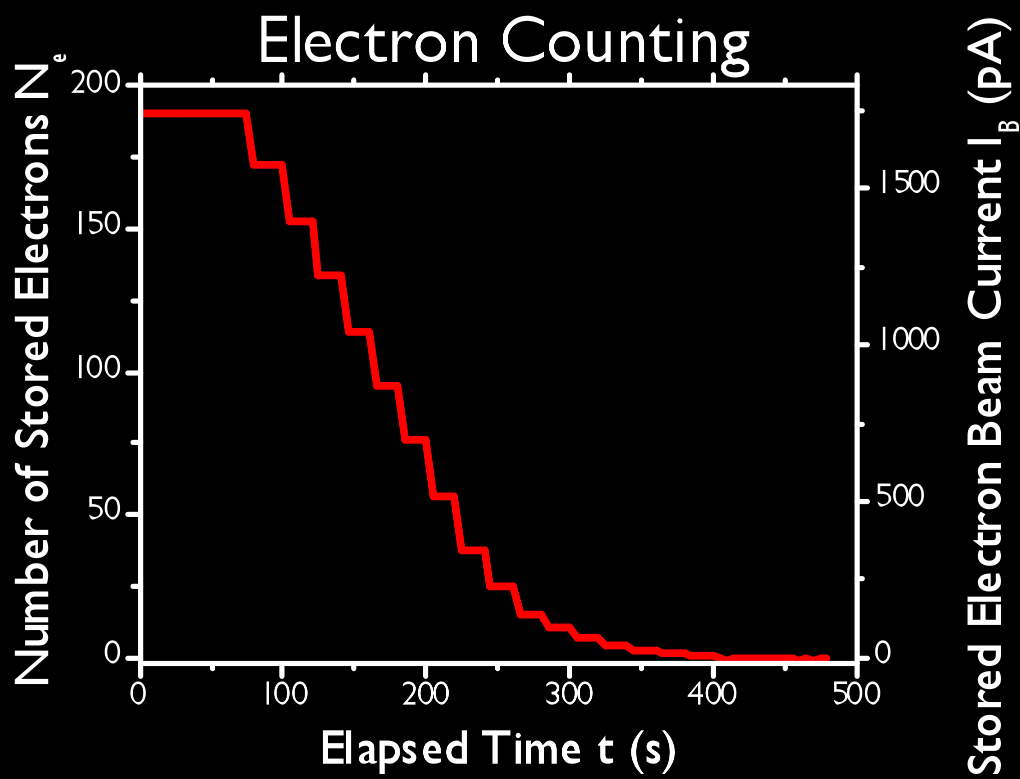
SURF Electron Beam Current Monitor

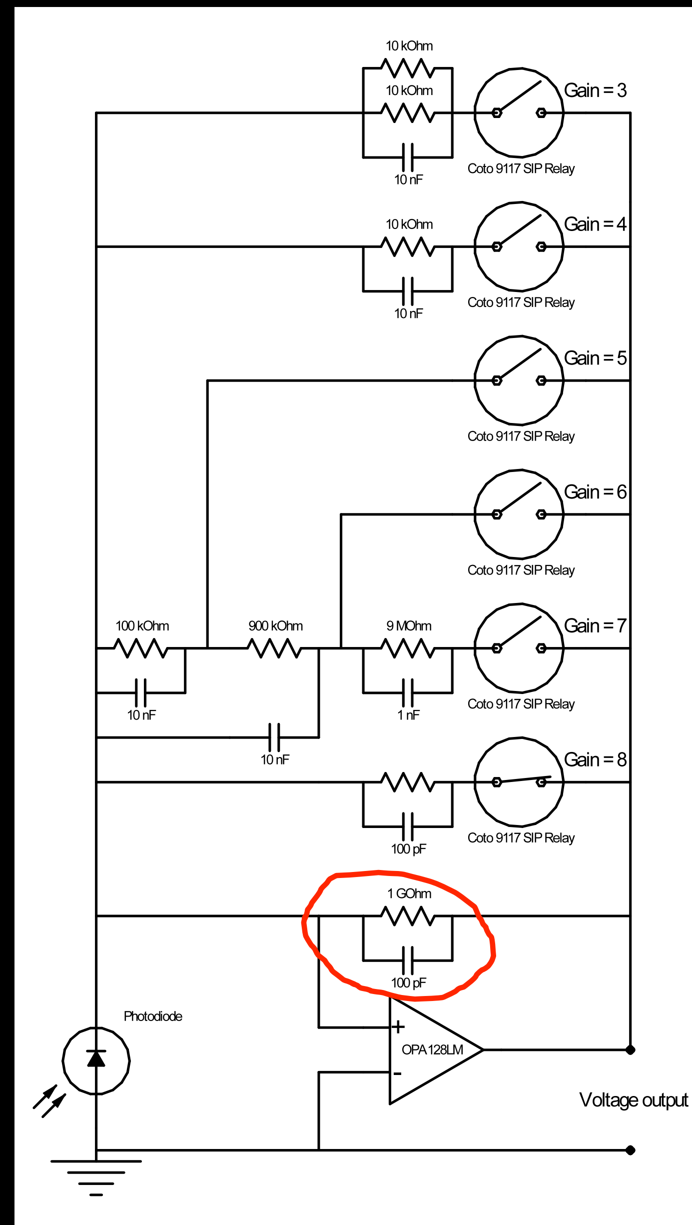
- Beam current is measured optically using ND filter + Si diode + operational amplifier (Eppeldauer and Hardis, *Appl. Opt.* **30** (22), 3091-9 (1991)). Relative standard uncertainty 0.2 %.

- System is linear over 11 orders of magnitude. Extrapolate from the light from a single electron to that of 10^{11} electrons.



Electron Counting





Hughey and Schaefers

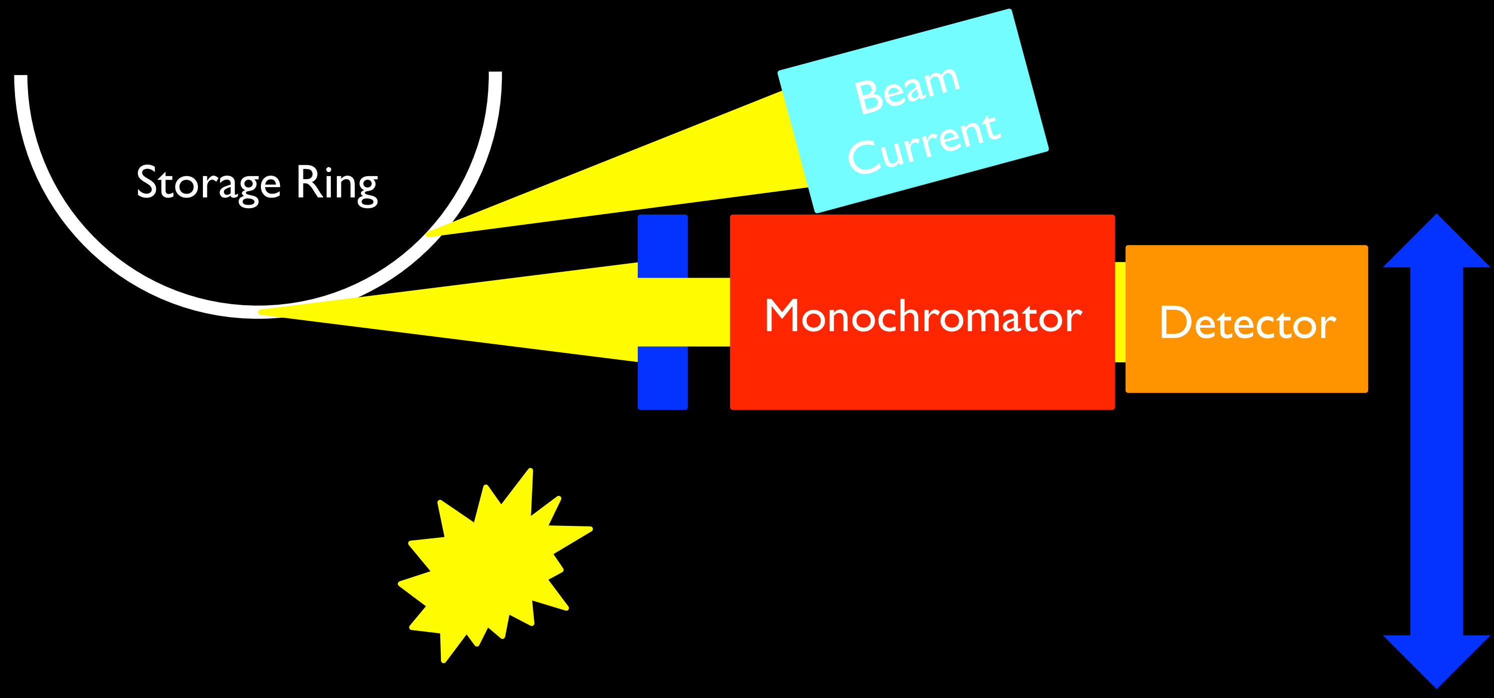
Nucl. Instrum. & Meth. 195, 367 (1982)

Outline

- NIST Reorganization
- Physical Measurement Laboratory
- Synchrotron light: What is and why is it useful?
- Basic properties of synchrotron light at SURF
- Absolute source- and detector-based radiometry
- SURF
- Calibrations on Beamline 2
- Transfer of X24C from NSLS to SURF

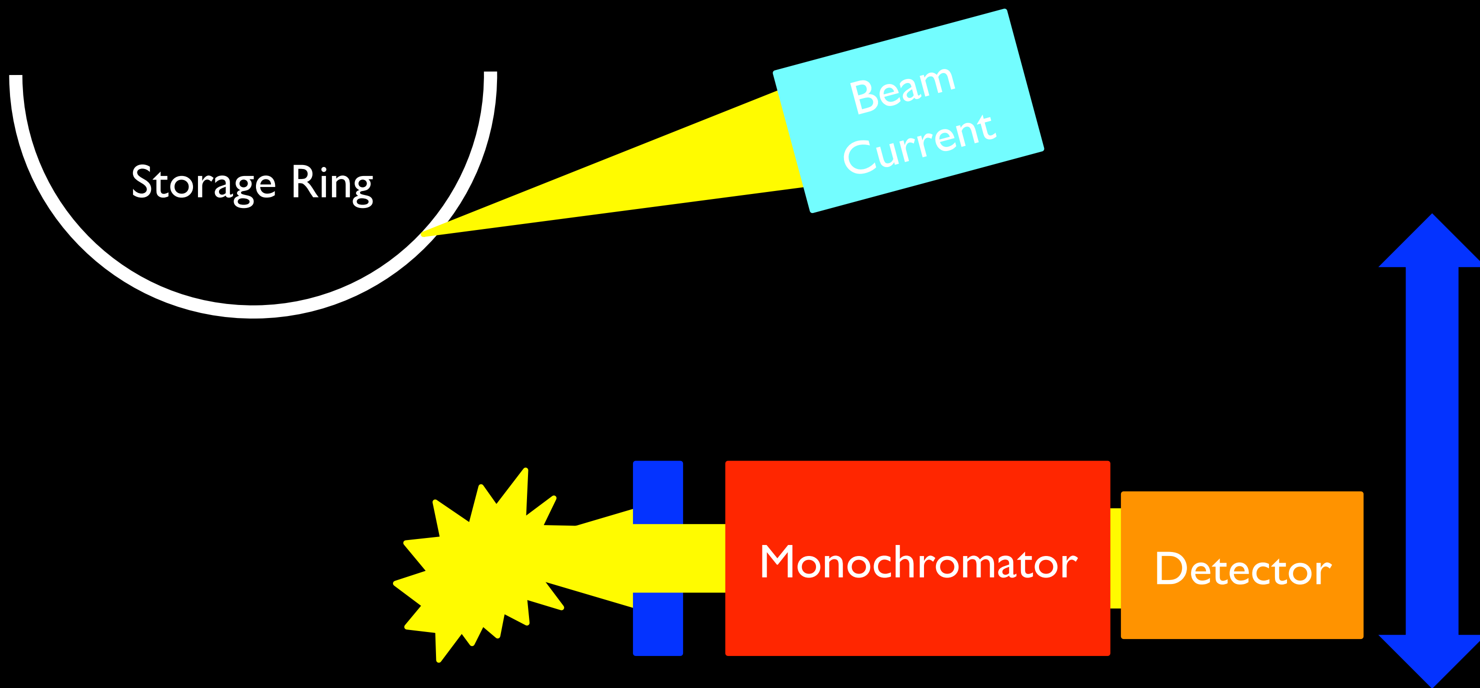
Absolute Radiometry: Source Based

Absolute source based Radiometry: Calibrate different standard sources, spectrometers



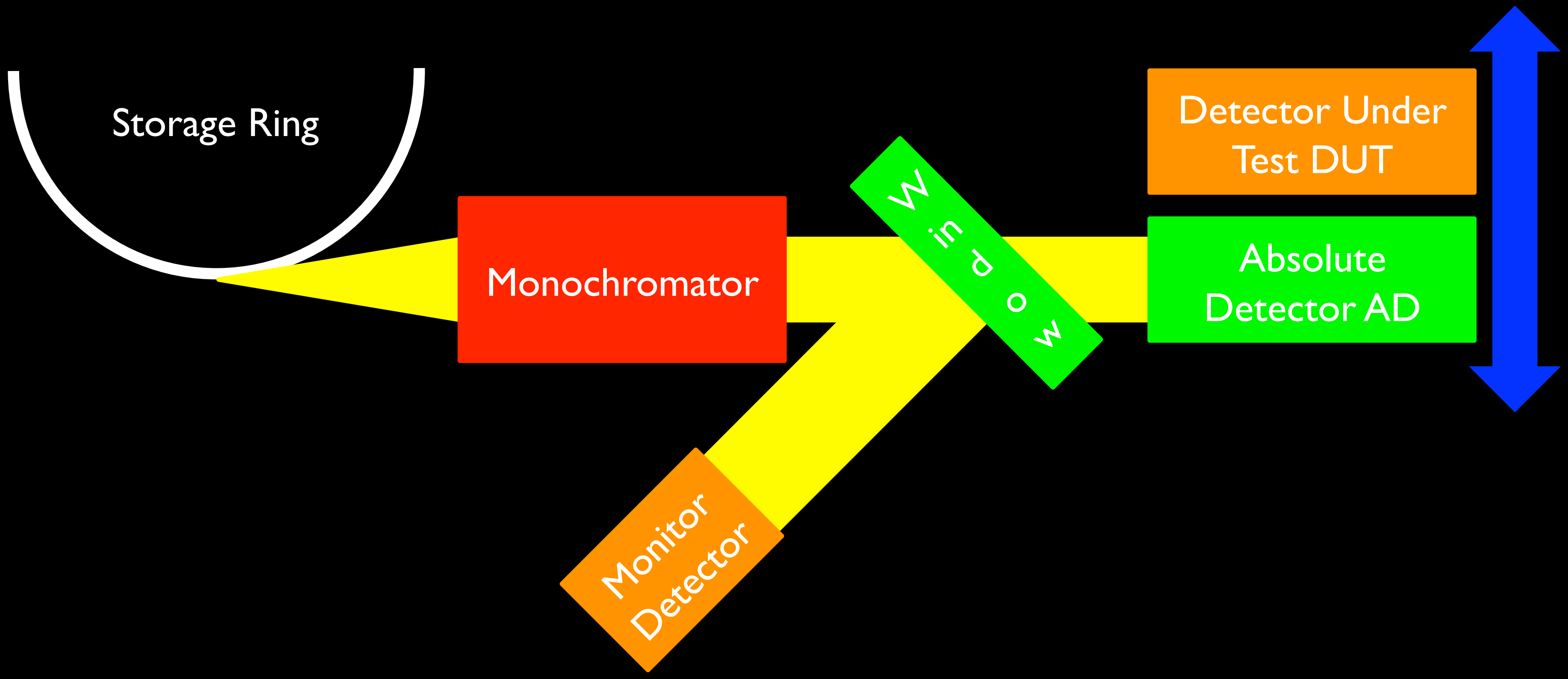
Absolute Radiometry: Source Based

Absolute source based Radiometry: Calibrate different standard sources, spectrometers



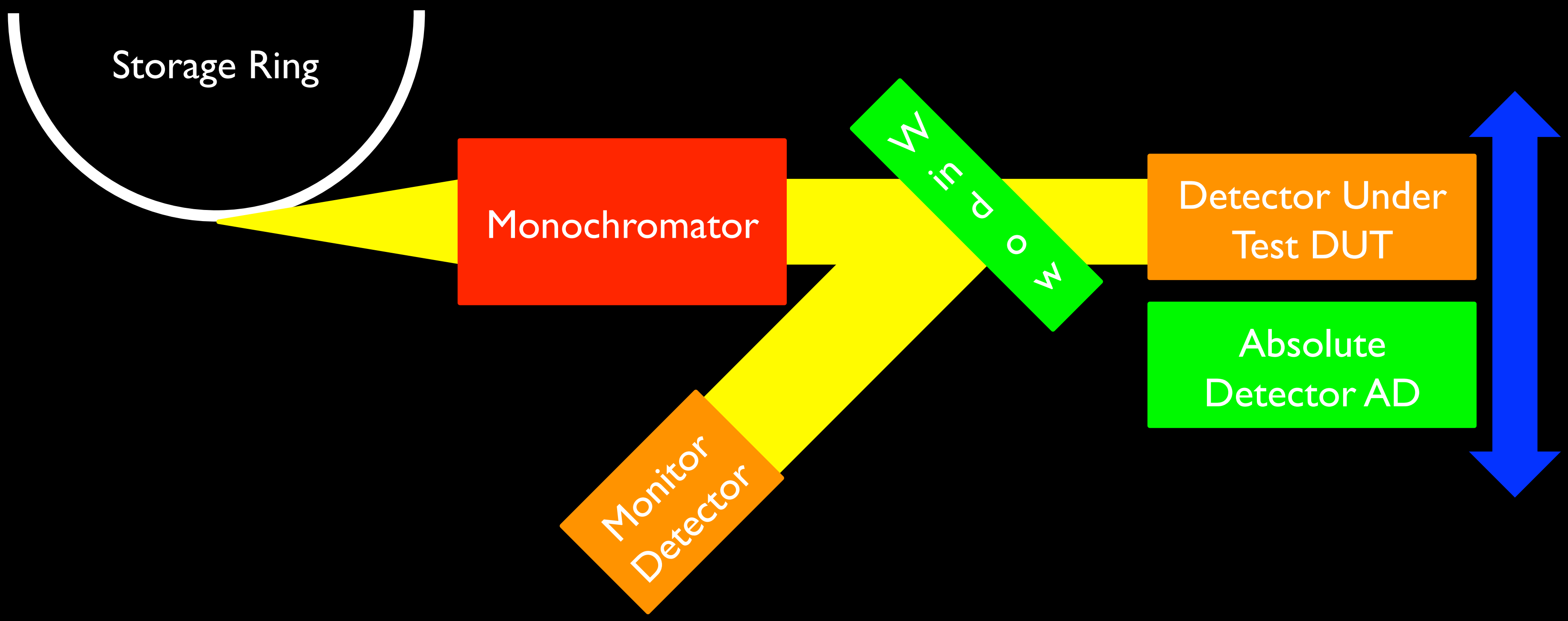
Absolute Radiometry: Detector Based

Absolute Detector based Radiometry: Calibration of detectors, filter detector packages

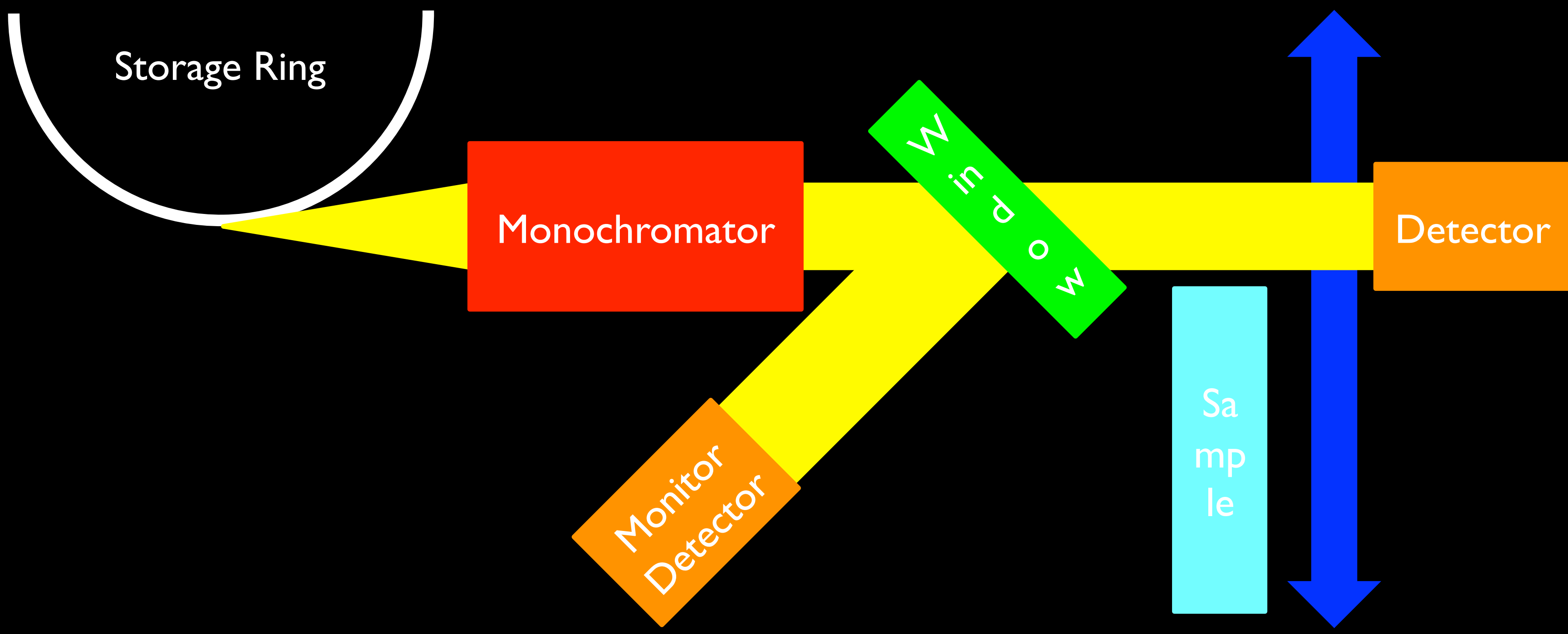


Absolute Radiometry: Detector Based

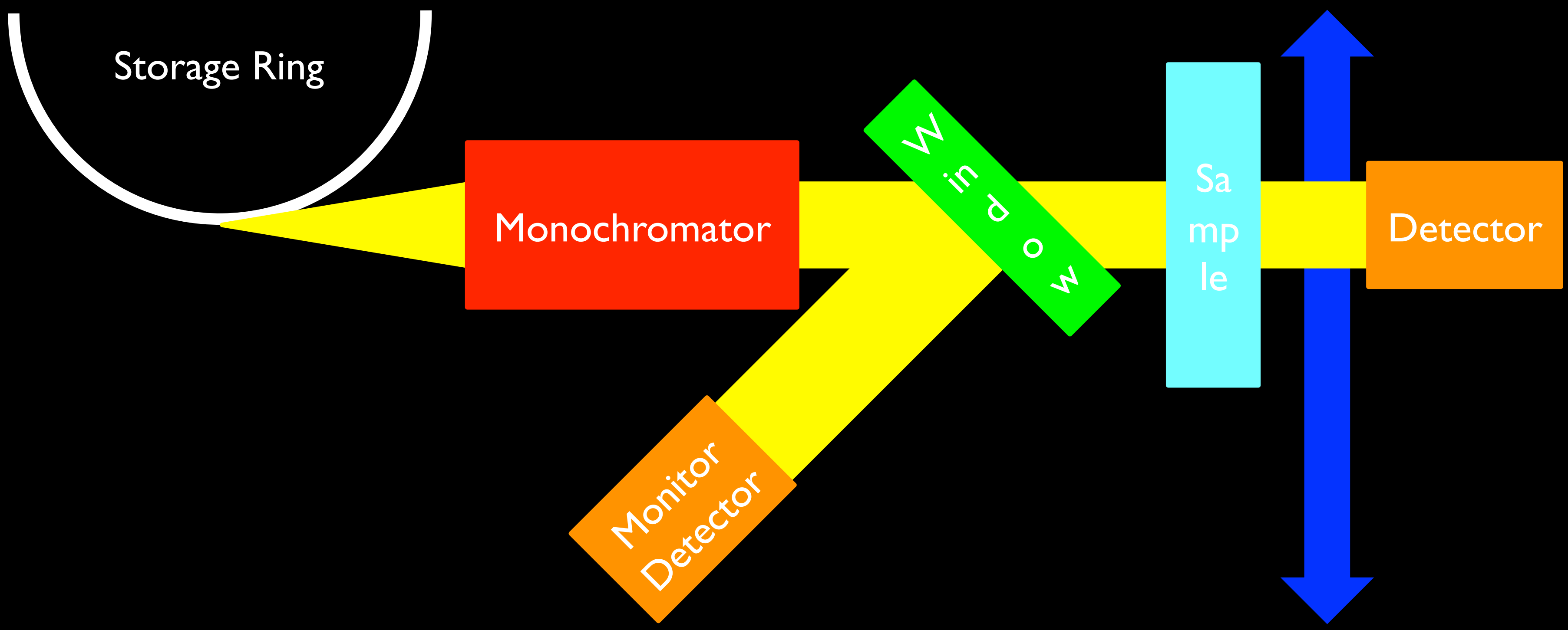
Absolute Detector based Radiometry: Calibration of detectors, filter detector packages



Transmission Measurement



Transmission Measurement



Outline

- NIST Reorganization

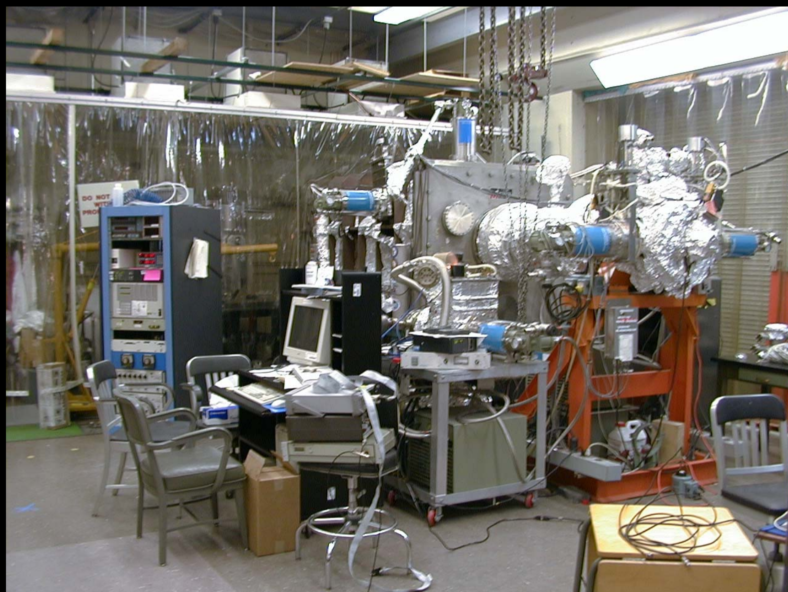
- Physical Measurement Laboratory

- Synchrotron light: What is and why is it useful?
- Basic properties of synchrotron light at SURF
- Absolute source- and detector-based radiometry
- SURF
- Calibrations on Beamline 2
- Transfer of X24C from NSLS to SURF

Beamlines at SURF III/NIST

#	Wavelength range	Calibration	Accuracy
1a	13 nm	Resist sensitivity (EUV)	
1b	5 nm – 20 nm	Photoresist prequalification testing (EUV) Optics lifetime (EUV)	
2	0.3 nm - 400 nm	EUV/UV spectrometer calibrations	<1.0 %
3	200 nm – 400 nm 200 nm – 2000 nm	Light sources (D_2 and other UV) Filtered radiometers (UV,VIS, NIR)	<1.0 % <0.5 %
4	140 nm - 320 nm (110 nm – 320 nm)	Detector calibrations (DUV, UV) Detector radiation damage (DUV, UV) Optical properties (DUV, UV)	< 0.5 % (AXUV) < 1.0 % < 1.0 %
5	100 nm - 400 nm	Index measurements (DUV)	< 0.0001 %
6		Beam Current Monitor	0.2 %
7	7 nm - 35 nm	Reflectometry (EUV) Optical properties (EUV) Detector calibrations (EUV)	< 1 % < 1 % < 2 %
8	13 nm	Optics lifetime(EUV) EUV-induced surface chemistry	
9	5 nm - 50 nm	Detector calibrations (EUV)	< 5 %
10	550 nm	Beam imaging	< 5 %

BL-2: UV/EUV Spectrometer Calibrations

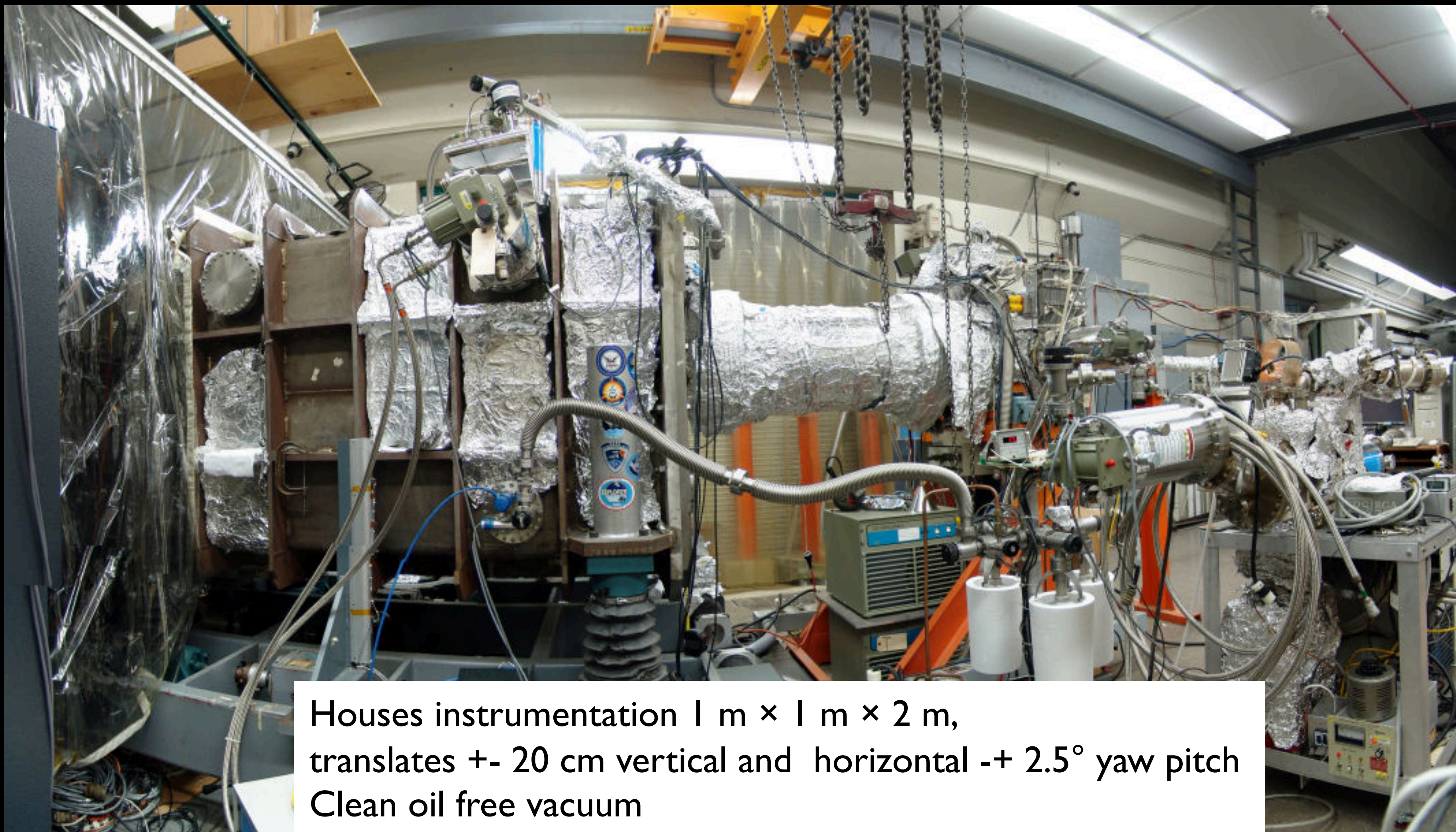


- Undispersed synchrotron radiation and instrument aperture are used as a standard of irradiance.
- Class 10,000 clean room access to large chamber.
- Calibrations provided from 2 nm to 400 nm with uncertainty from 0.6% to < 0.1%

EVE (Extreme Ultraviolet Variability Experiment) of NASA's Solar Dynamics Observatory (SDO) Mission prepared for calibration

Continuous calibration of twin-instruments using rocket underflights

BL-2: Large chamber and clean room



Houses instrumentation 1 m × 1 m × 2 m,
translates +- 20 cm vertical and horizontal -+ 2.5° yaw pitch
Clean oil free vacuum

BL-2: NASA Missions

- Since 1971 most of our spectrometer calibrations have been for NASA missions.
- These include sounding rocket, Space Shuttle cargo bay, and satellite experiments.
- Most experiments measure full-disk solar radiation.
- Several stellar missions have been calibrated.

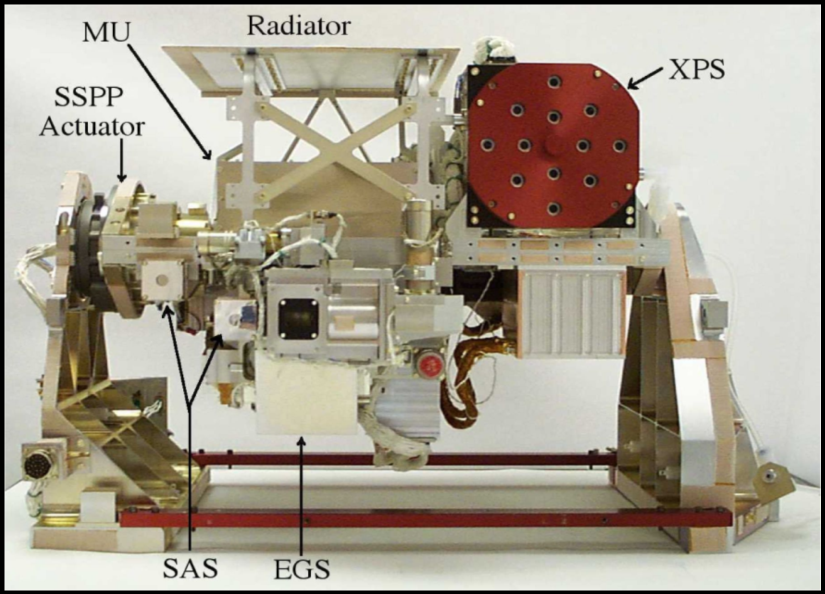
BL-2: LASP SOLSTICE and NRL SUSIM

LASP SOLSTICE and NRL SUSIM were aboard the UARS satellite deployed from shuttle in 1991

NRL SUSIM

LASP SOLSTICE

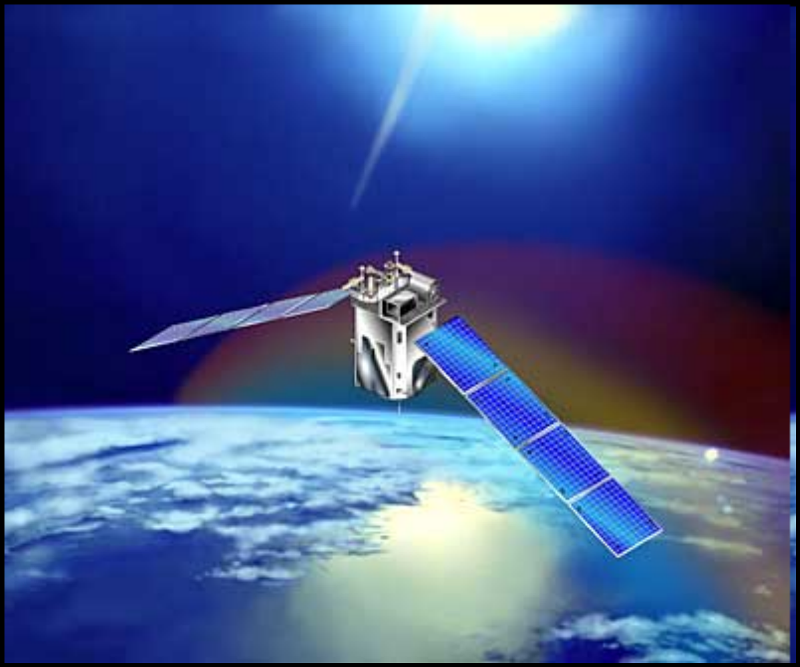
BL-2: TIMED satellite



LASP Solar Extreme Ultraviolet Experiment EUV Grating Spectrometer aboard the TIMED satellite

launched in 2001

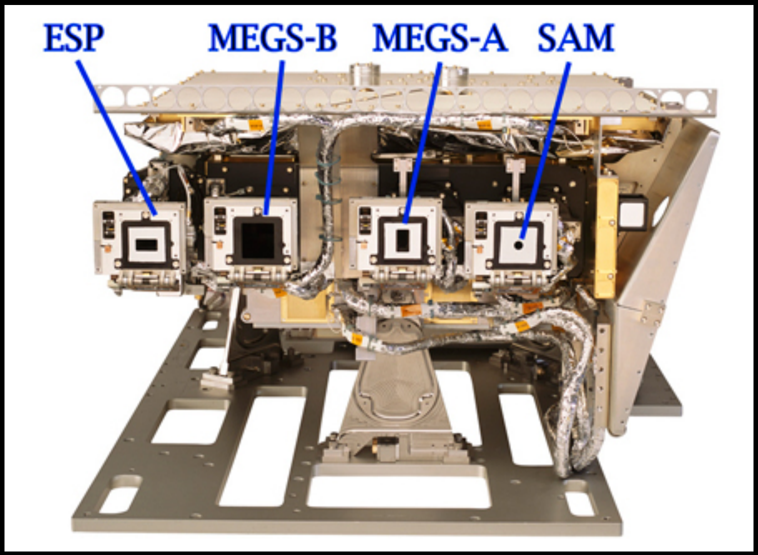
Measuring the solar EUV incident on the earth's mesosphere and lower thermosphere and ionosphere where all vacuum UV is absorbed



BL-2: LASP SOLSTICE A and SOLSTICE B

LASP SOLSTICE A and SOLSTICE B are monitoring solar UV radiation aboard the SORCE (SOlar Radiation and Climate Experiment) satellite launched in 2003.

BL-2: LASP/USC Extreme UV Variability Experiment on SDO

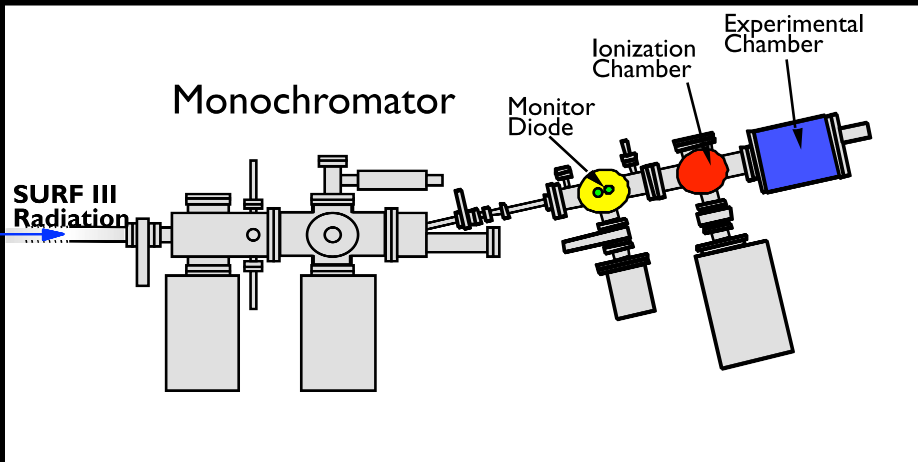


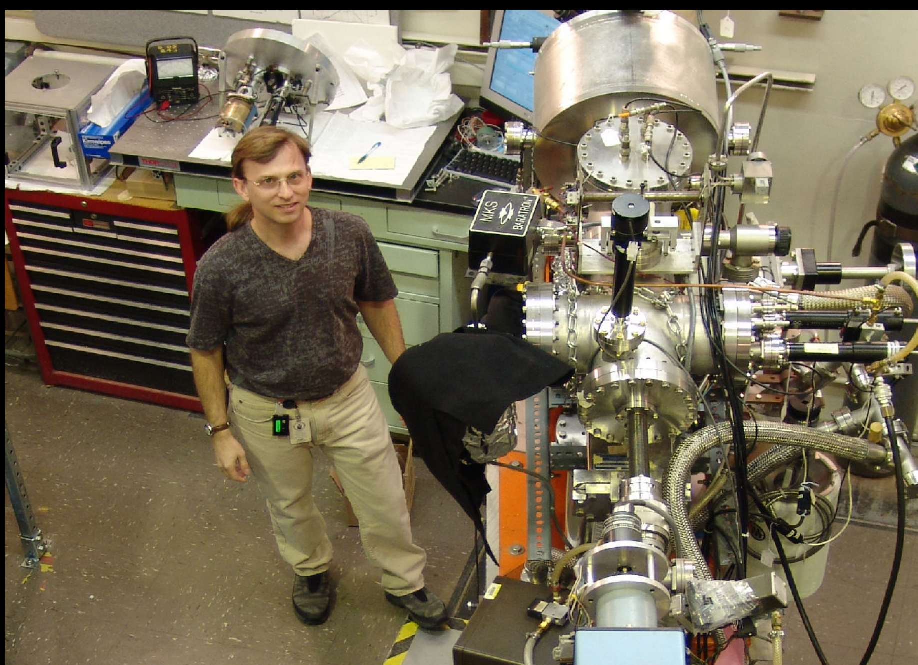
Studying EUV over various time scales relevant to space weather and its effect on communications and navigation

BL-2: Maintaining Satellite Calibrations

- SUSIM: multiple onboard D_2 lamps intercompared with SURF
- SOLSTICE: use stellar slits and measure ensemble of low variability stars
- Periodic sounding rocket underflights with similar instruments

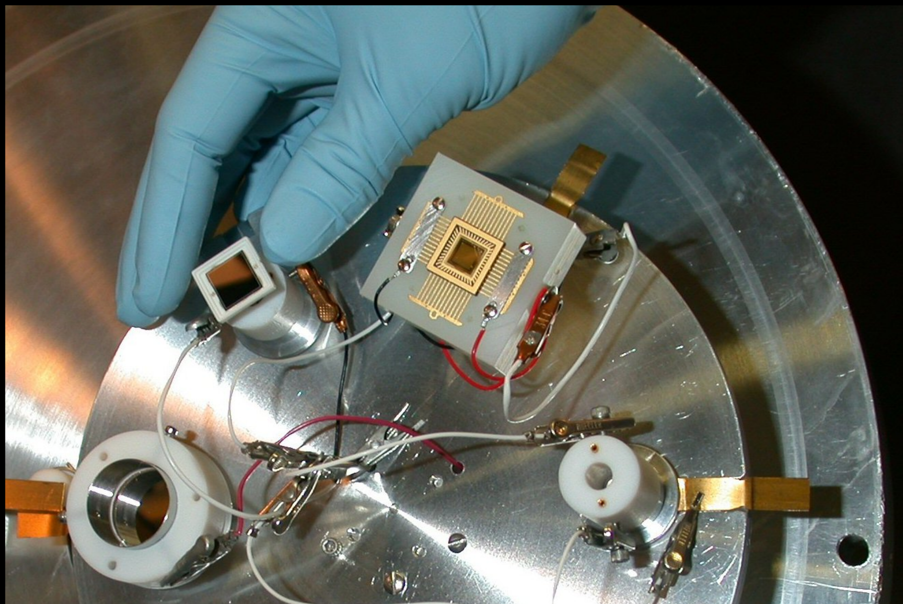
BL-9: EUV Detector Calibrations

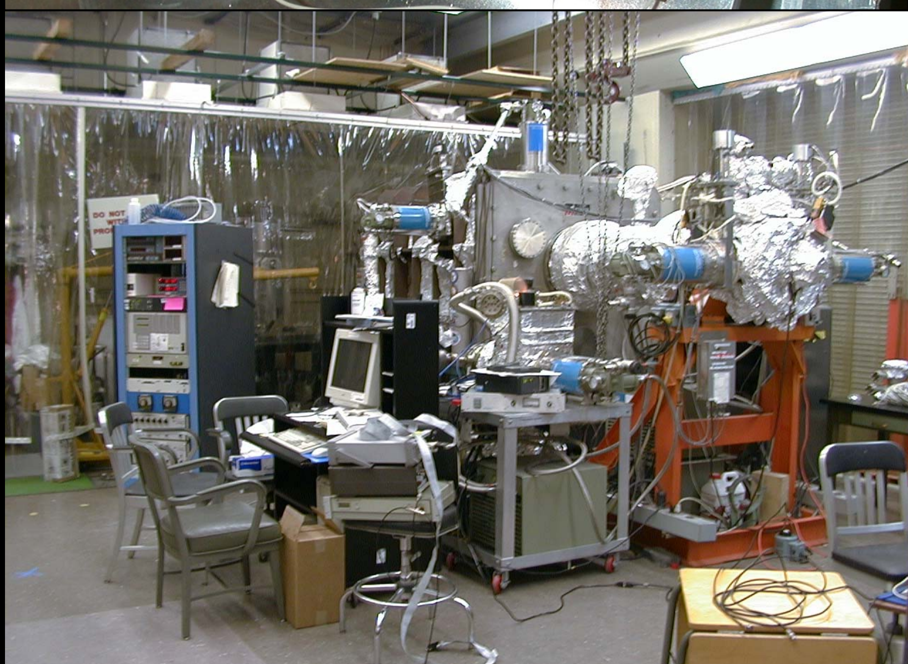




- Grazing incidence monochromator
- SURF used as continuum source from 5 nm to 50 nm
- Accuracy
  - Working standard
    Photodiodes are calibrated by comparing them to a rare-gas ionization chamber: $2\sigma \approx 5$ %. (Not true if ACR is used on BL-7)
  - Transfer standards
    Calibrated against a working standard of the same type: $2\sigma \approx 8$ %.
- Capabilities:
  - Photodetector Efficiency
  - Filter Transmission
  - End-to-End Calibration of Small Instruments
  - Low-Dose-Rate Radiation Hardness

SURF III/NIST Measurement Competences





- Detector efficiency
  - BL-4 ultraviolet, BL-7/BL-9 extreme-ultraviolet
- Filter transmission
  - BL-4 ultraviolet, BL-7/BL-9 extreme-ultraviolet
- Mirror reflectivity
  - BL-4 ultraviolet, BL-7 extreme-ultraviolet
- Whole-instrument efficiency (detector-based or source-based)
  - BL-2 extreme-ultraviolet to visible, BL-3 ultraviolet

Outline

- NIST Reorganization

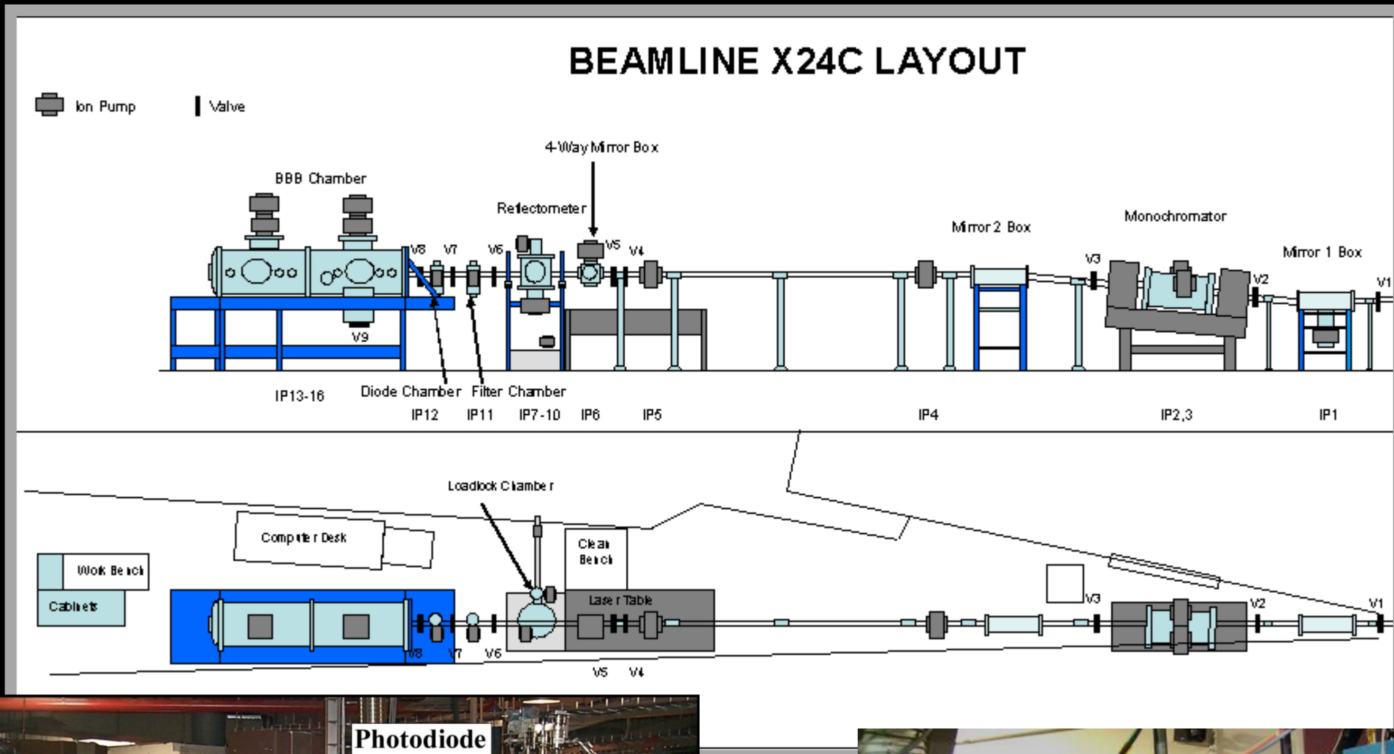
- Physical Measurement Laboratory

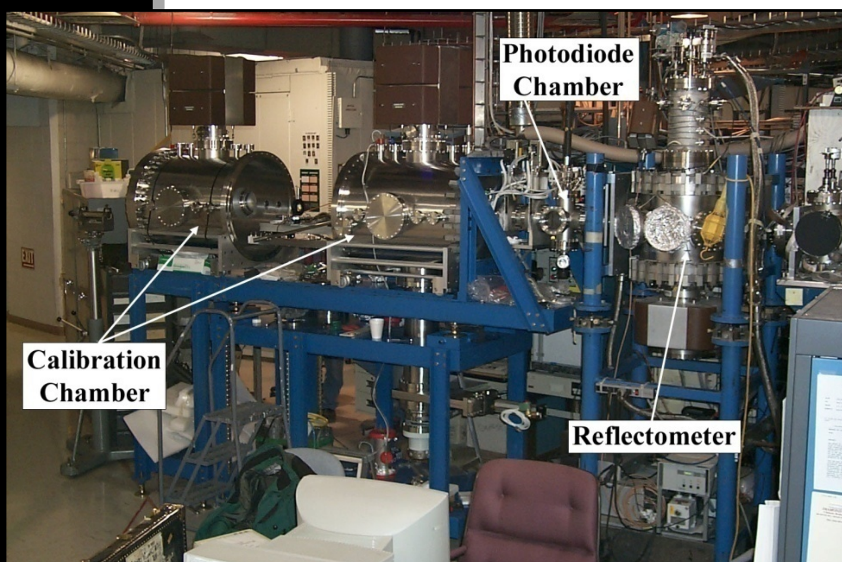
- Synchrotron light: What is and why is it useful?
- Basic properties of synchrotron light at SURF
- Absolute source- and detector-based radiometry
- SURF
- Calibrations on Beamline 2
- Transfer of X24C from NSLS to SURF

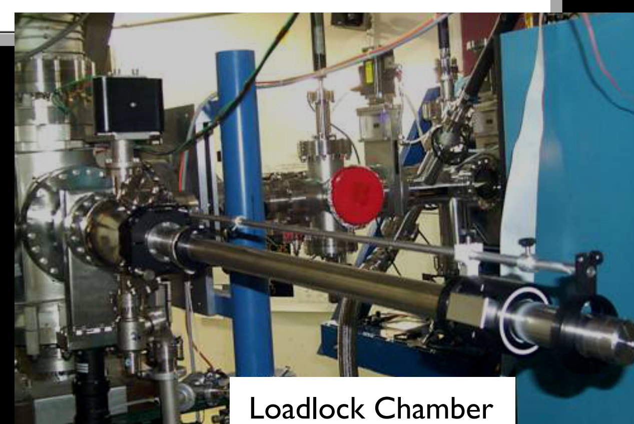
Transfer of NRL's x24c to NIST

- NRL maintains beamline X24C
- Monochromator-based beamline with an absolute-cryogenic radiometer
  - Beamline covers 1 nm to 400 nm with a combination of grazing and normal incidence gratings (can use multilayers)
  - Several large chambers are available
- When NSLS II comes online in 2015 X24C will not be transferred

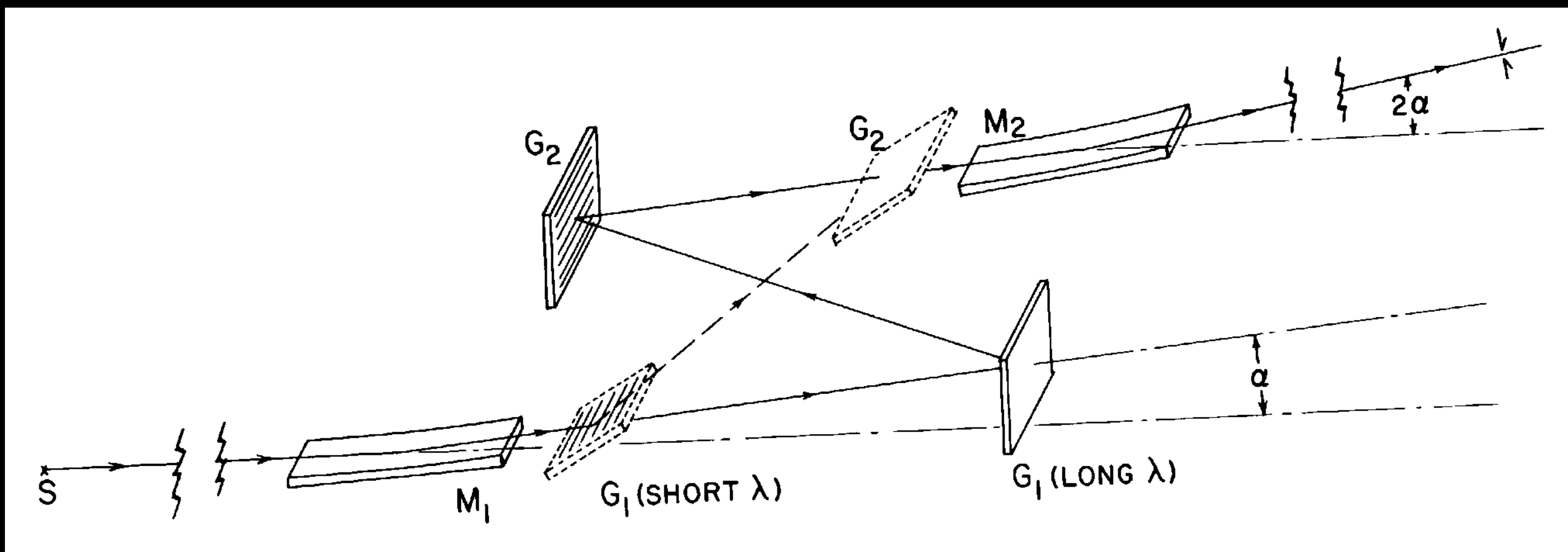
NSLS Beamline Layout and Chambers







Monochromator Optics



Capabilities of X24C Located at SURF III

- Enable cryogenic radiometry with 1% uncertainty by delivering at least 0.5 μW / 100 mA and resolving power of at least 100 from 3.5 nm (354 eV) to 300 nm (4.1 eV).
  - Covers entire calibration range with state-of-the-art cryogenic radiometry.
  - Extends wavelength range: current limits are 5 nm (250 eV) and 254 nm (4.9 eV).
  - Usable over broader wavelength range at somewhat larger uncertainty, including the entire water window between 2.3 nm (O-K; 540 eV) and 4.4 nm (C-K; 280 eV).
  - Fills gap between 92 nm and 116 nm where there is no current detector standard.
- Establish EUV calibration center for detectors and space research instrumentation in a single synchrotron beamline facility at NIST.
- Complements existing source-based radiometric capability at SURF III BL-2