Light Fantastic: The Science and Instrumentation of the ALS

Howard Padmore

Outline

Synchrotron radiation

- what is it
- historical development
- how its produced in the ALS
- how we monochromatize and focus x-rays

Three example applications

- protein crystallography
- soft x-ray bio-imaging
- angle resolved photoelectron spectroscopy

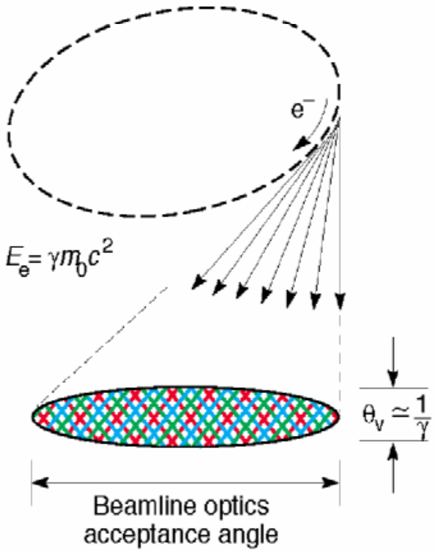
Detectors

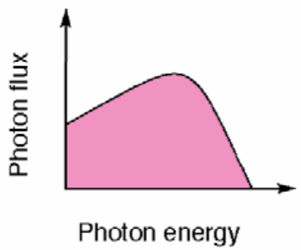
- what is being developed now
- what we are hoping to develop
- what the international competition is doing
- what technologies and skills do we need to be competitive

ALS Radiation is Produced by Bend Magnets and Undulators

ALS

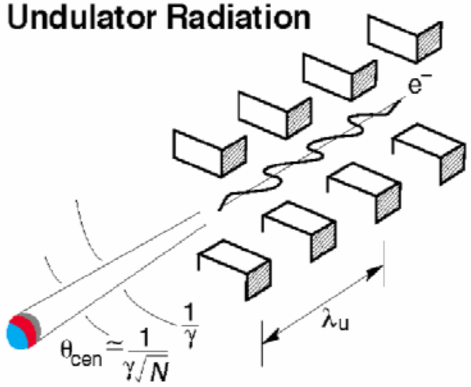
Bend-Magnet Radiation





meV to 50 keV
- high brightness

Undulator Radiation

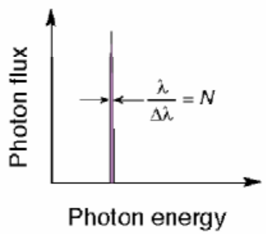


$$\lambda_x = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2} + \gamma^2\theta^2\right)$$

In the central radiation cone:

$$\frac{\Delta\omega}{\omega} \simeq \frac{1}{N}$$

$$\theta_{cen} \simeq \frac{1}{\gamma\sqrt{N}}$$

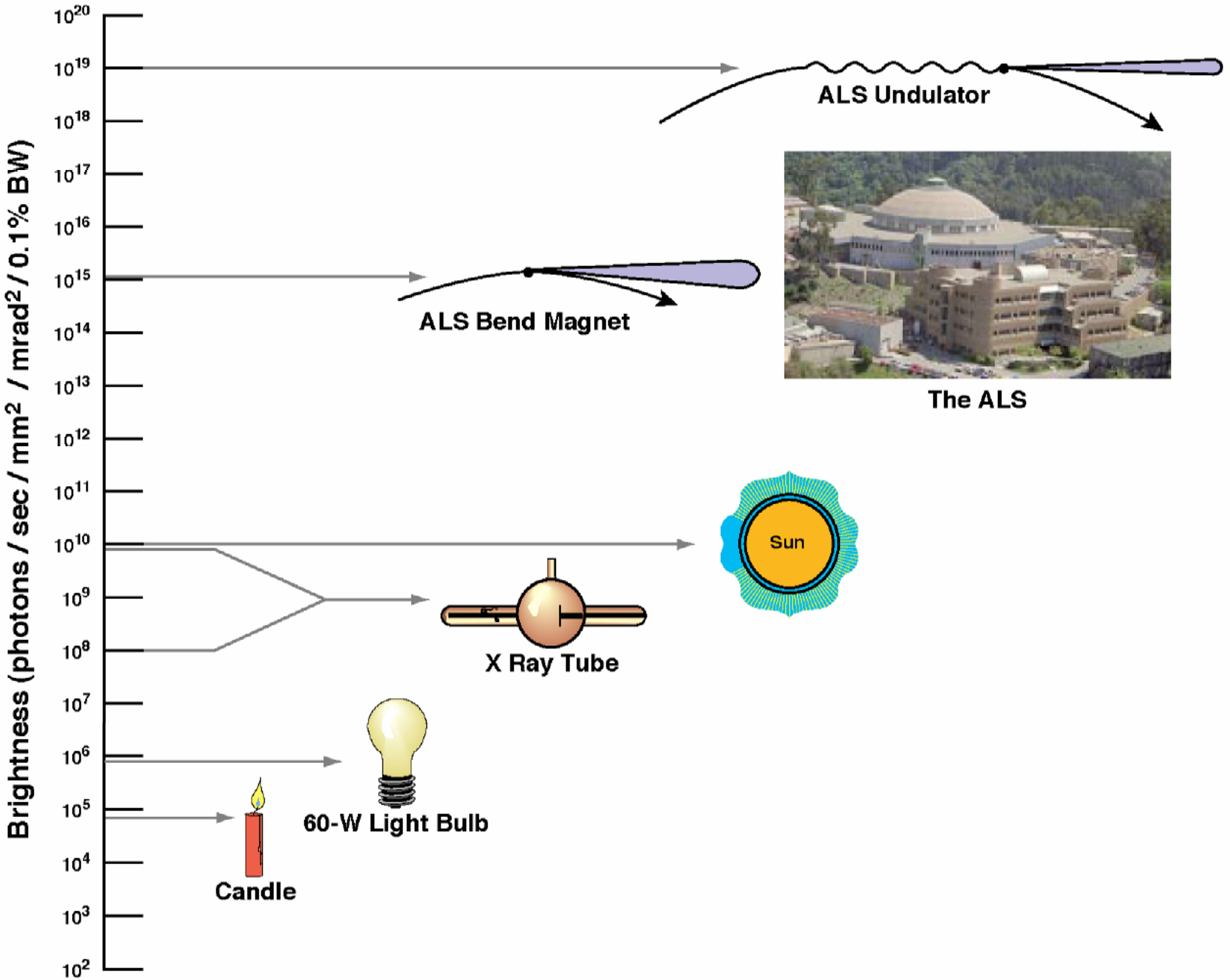


jc.fs/bend&und/12-95

5eV to 2keV
- extreme brightness

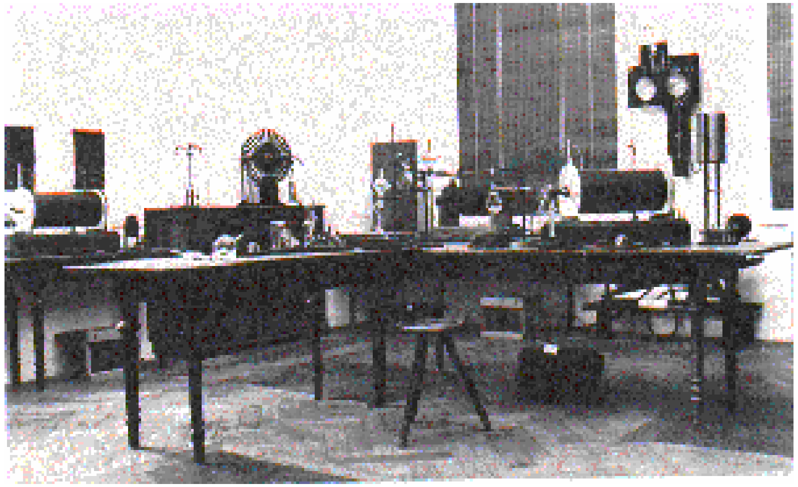
How Bright Is the Advanced Light Source?

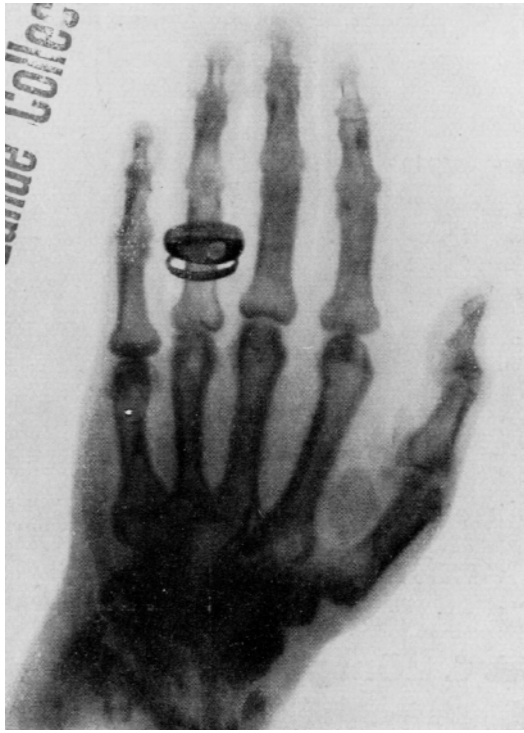
ALS



Wilhelm Conrad Roentgen
1845-1923

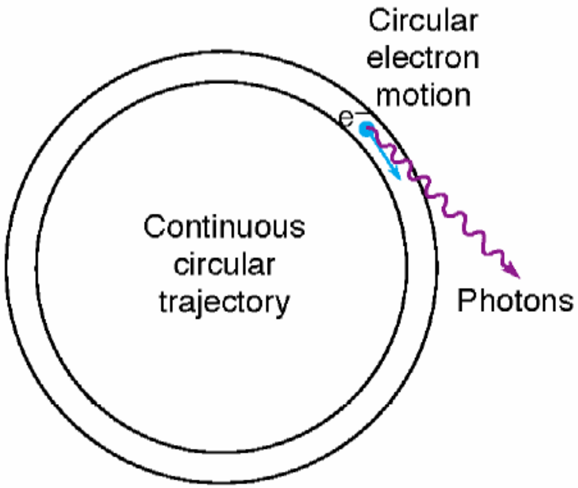
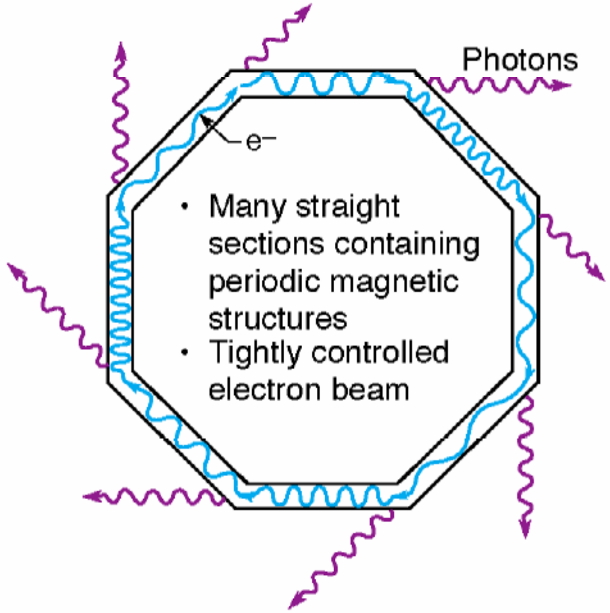
An X-ray lab – circa 1895

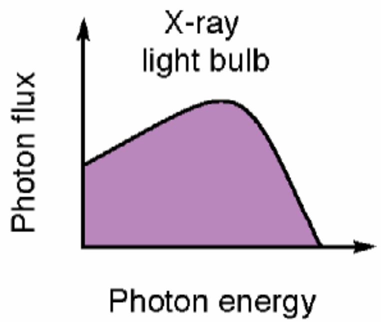
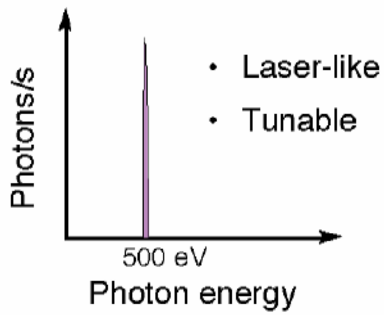




Evolution of Synchrotron Radiation

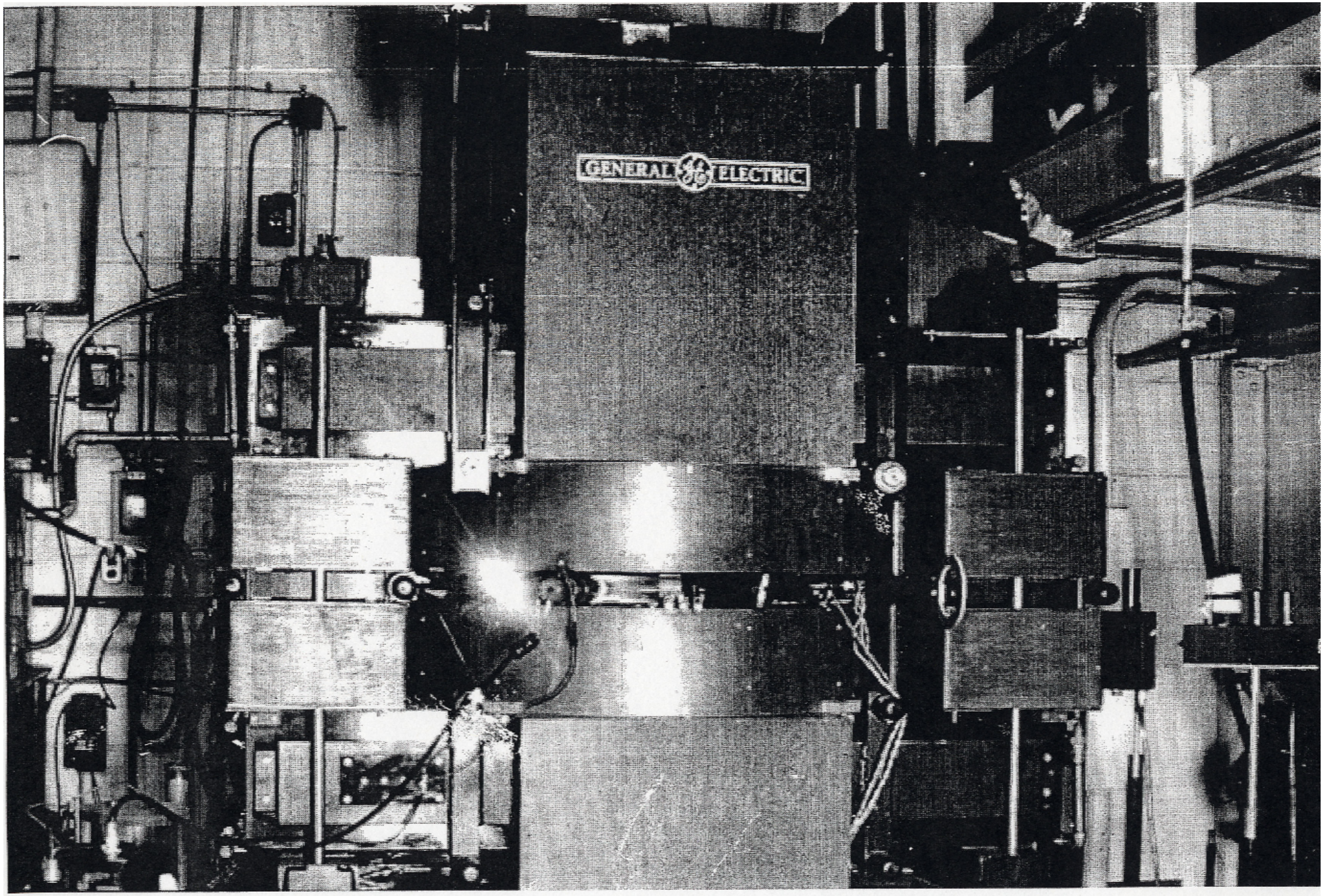
ALS

	Yesterday's Synchrotrons	Third-Generation Synchrotrons
Technology		

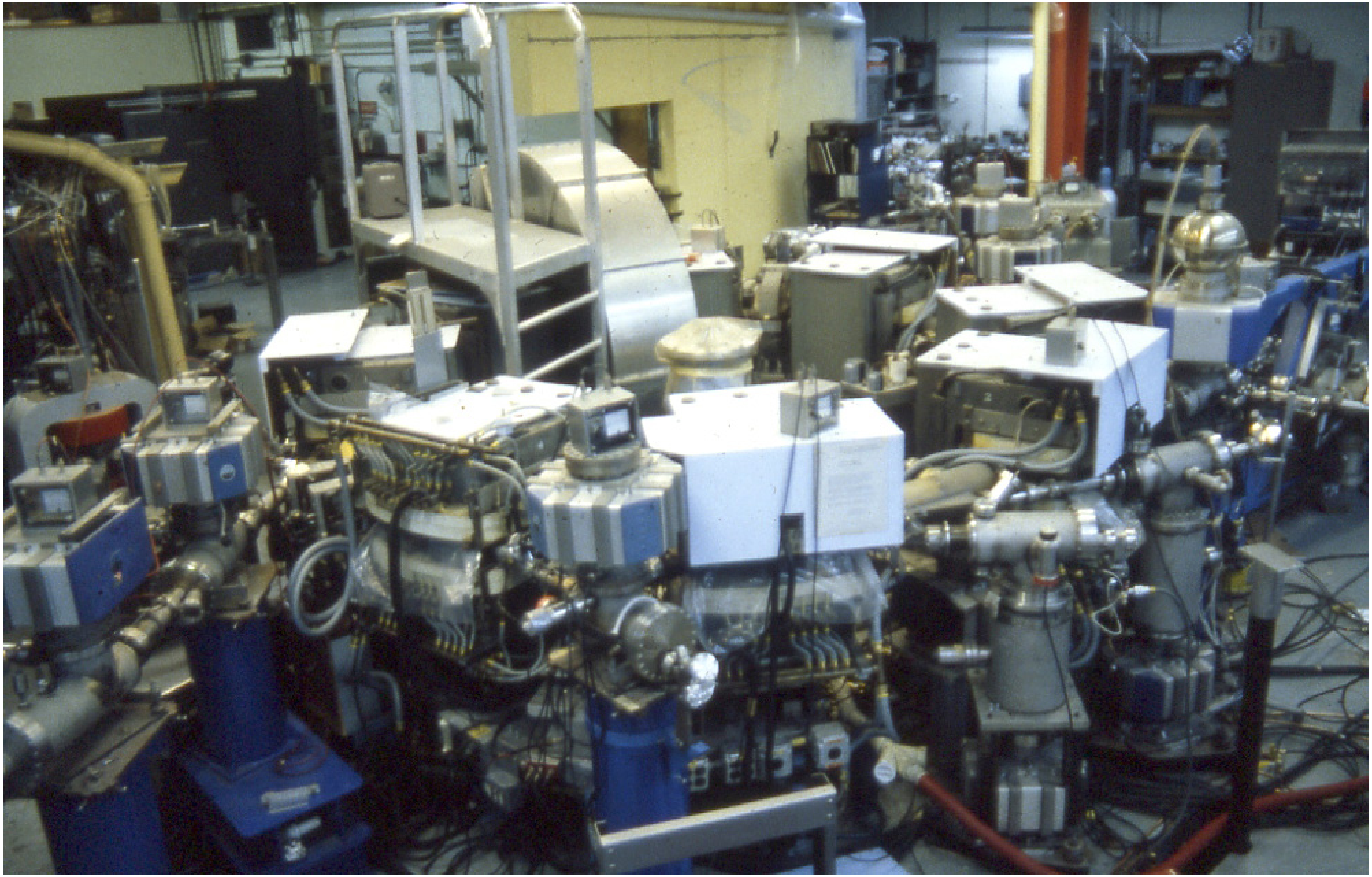
	Bend Magnet Radiation	Undulator Radiation
Spectral Distribution		

jc.fs/evolution/6-95

First visual observation of synchrotron light at the General Electric 70 MeV synchrotron in 1947

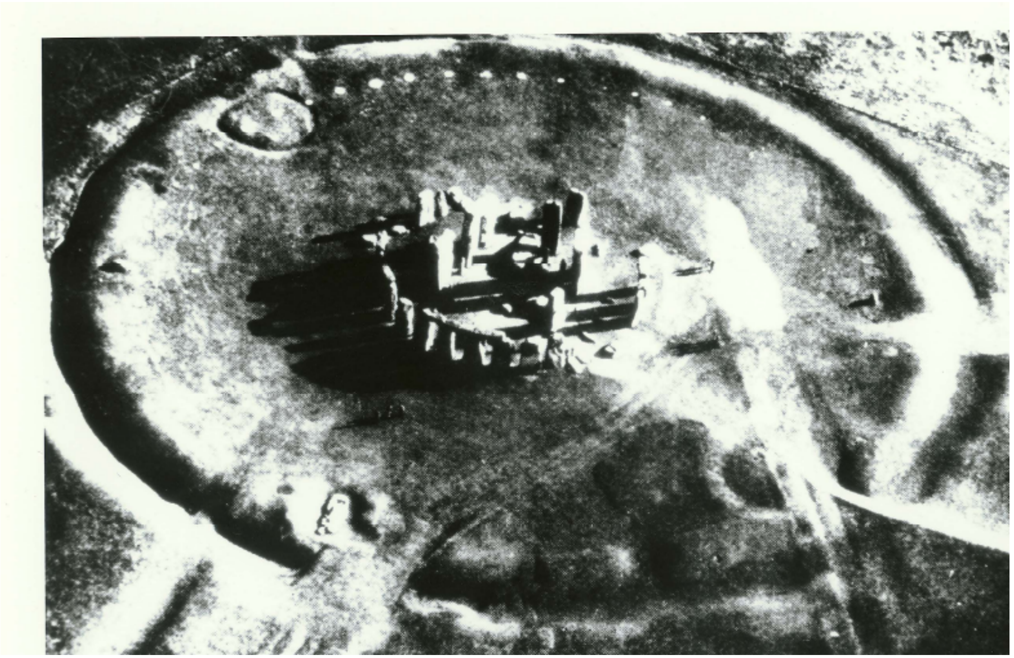


SR in the early days: Tantalus at Univ. Wisconsin

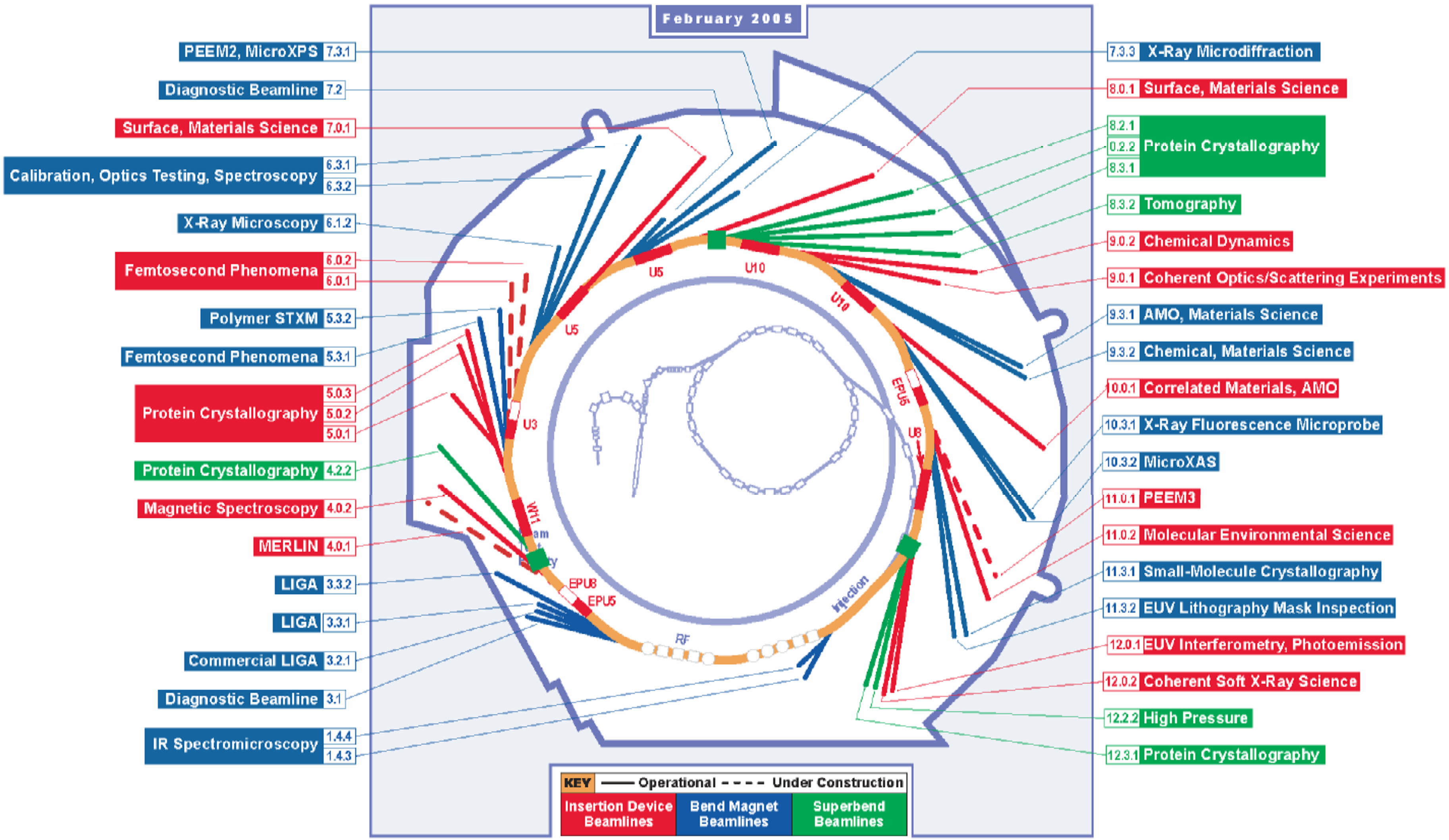


European Synchrotron Radiation Facility

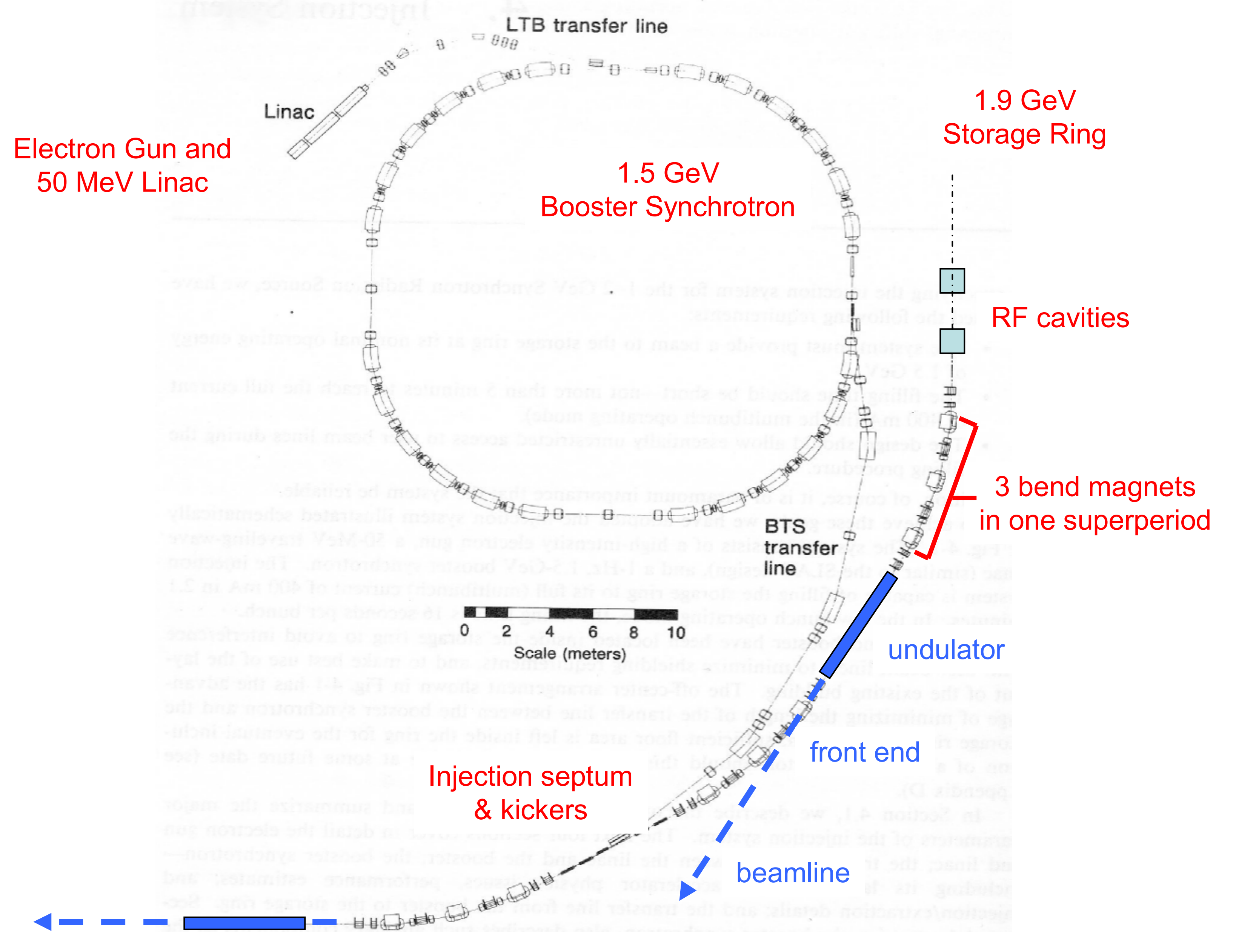
STONEHENGE
Remains of the first synchrotron light source



Beamlines at the ALS 2005



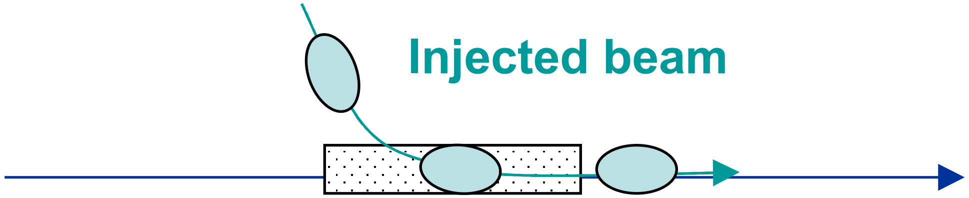
ALS: From the Booster to the Beamlines



Bunchers and Acceleration Section

Linac to Booster

Transfer line

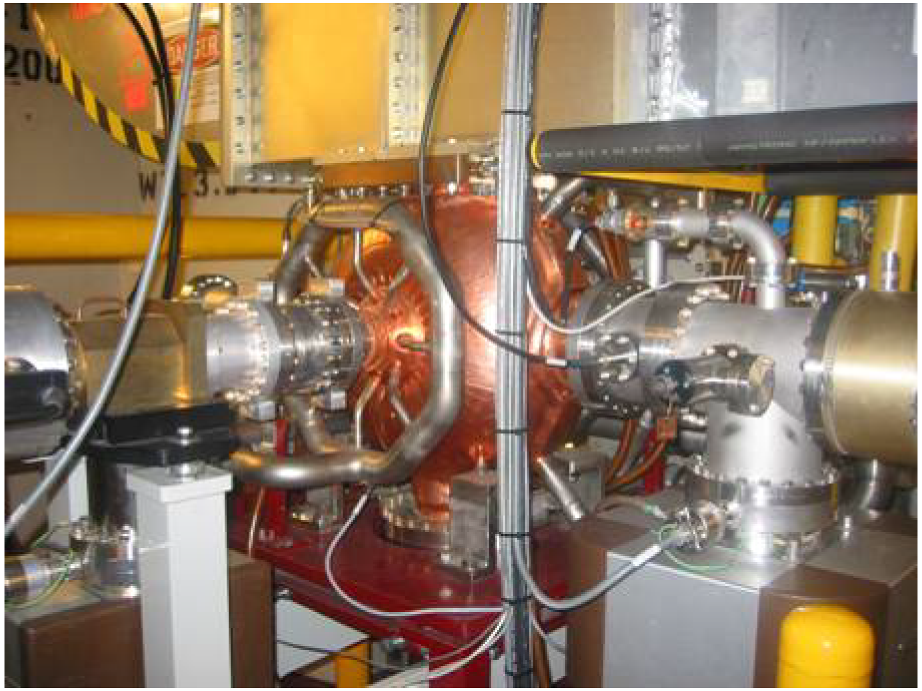


Booster Injection

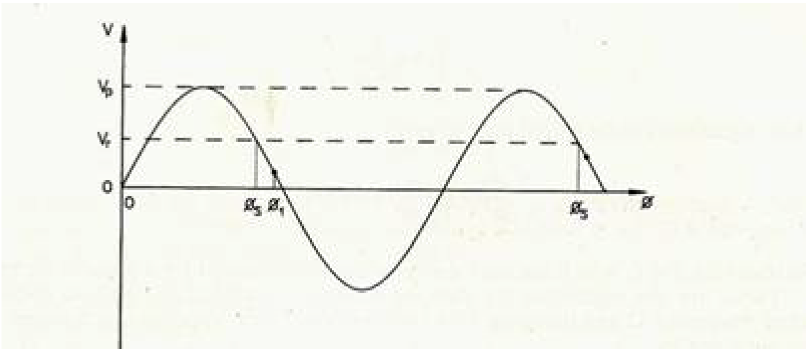
Booster Synchrotron

Storage Ring

RF Cavities



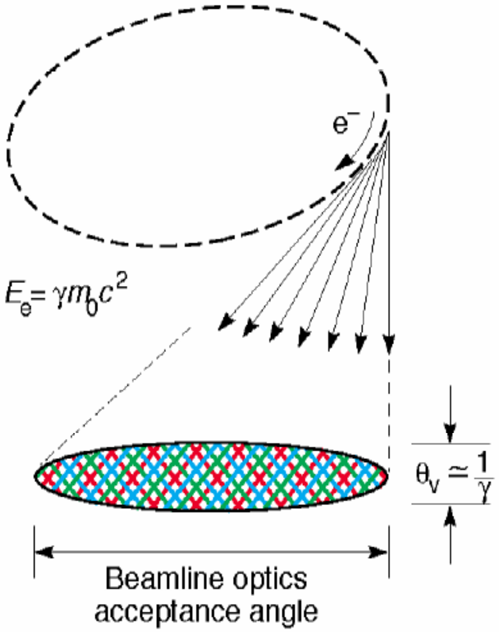
- **Restores synchrotron radiation losses**
- **Provides longitudinal bunching**

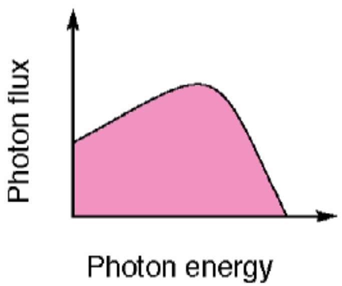


ALS Radiation is Produced by Bend Magnets and Undulators

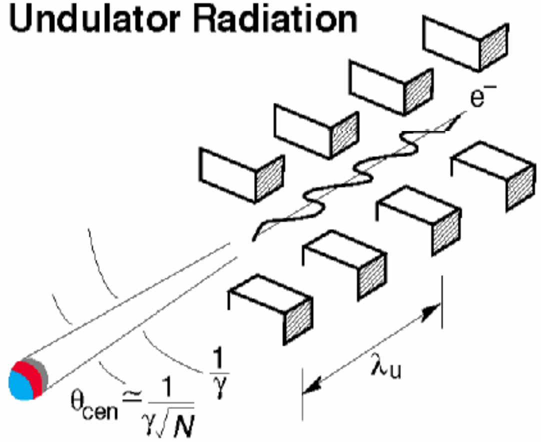
ALS

Bend-Magnet Radiation





Undulator Radiation



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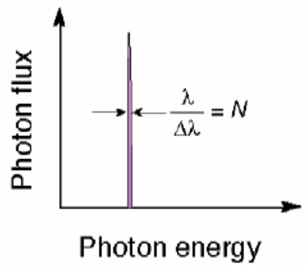
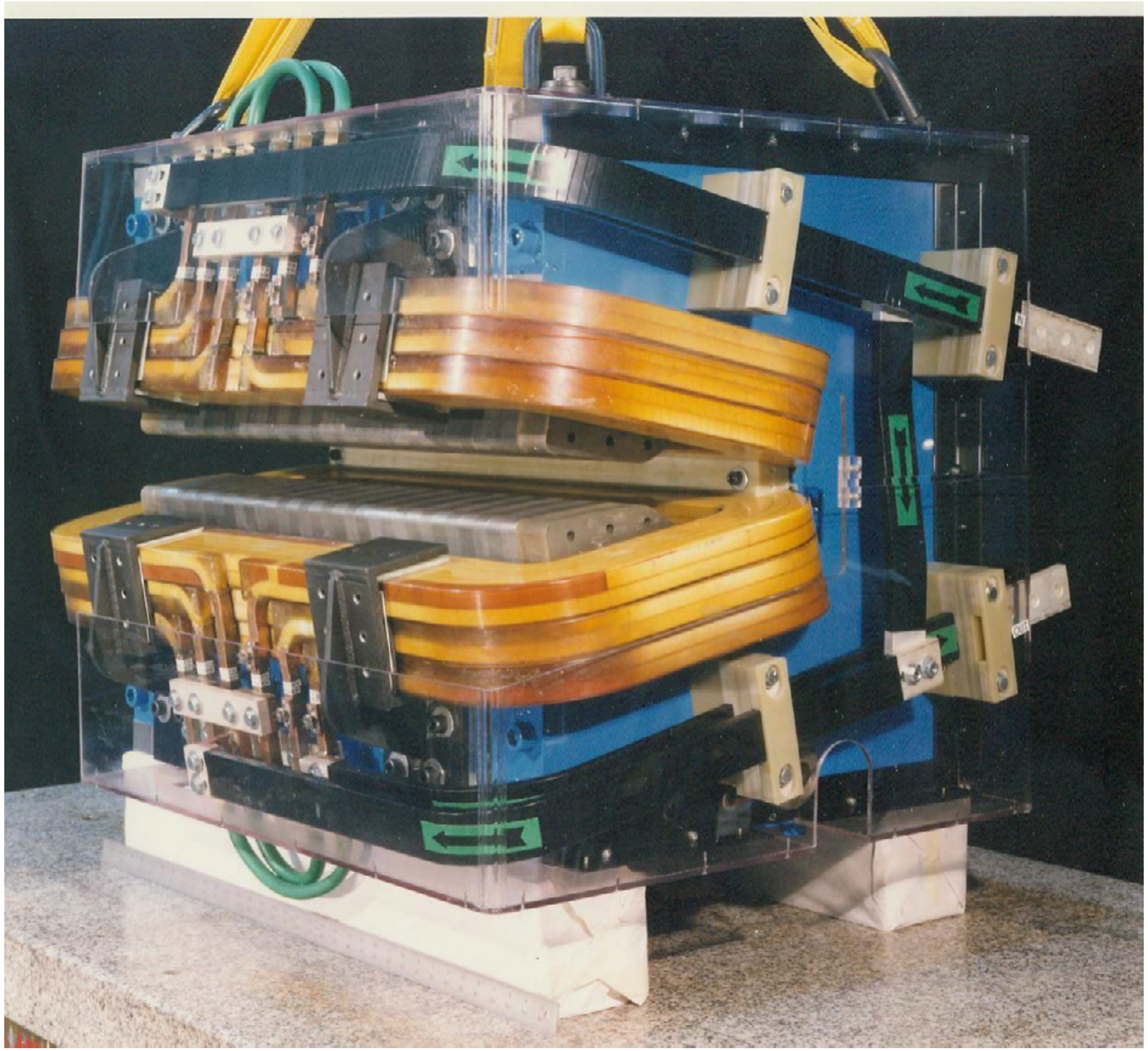


Normal conducting bending magnet: E < 16 keV

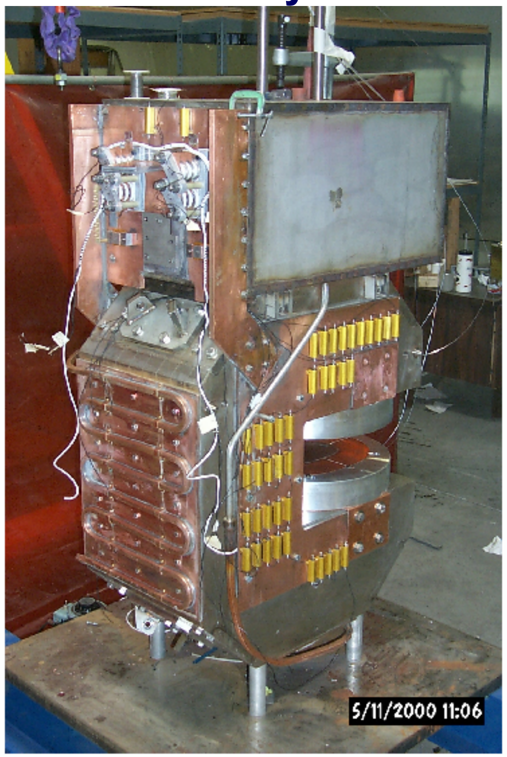


Superconducting bending magnets: E < 60 keV

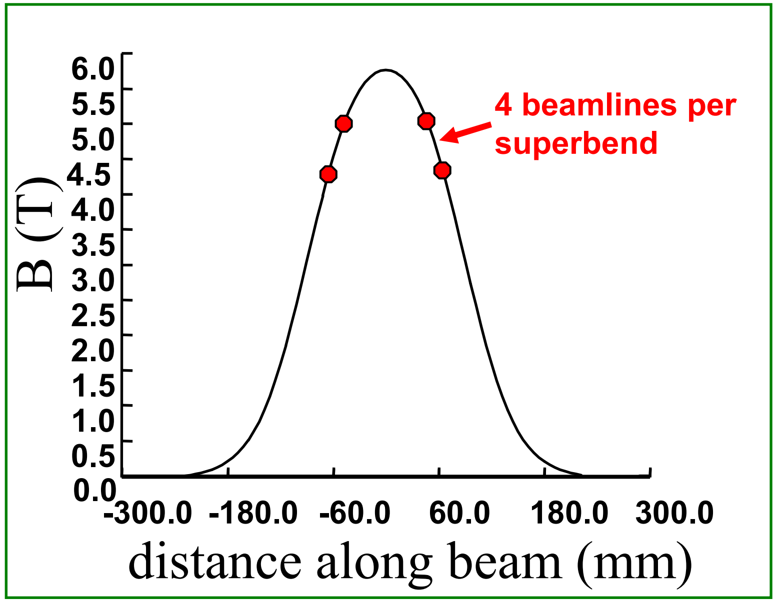
Three of the existing thirty six 1.3 Telsa dipoles have been replaced with three 5 Tesla superconducting dipoles

Superbend with cryostat

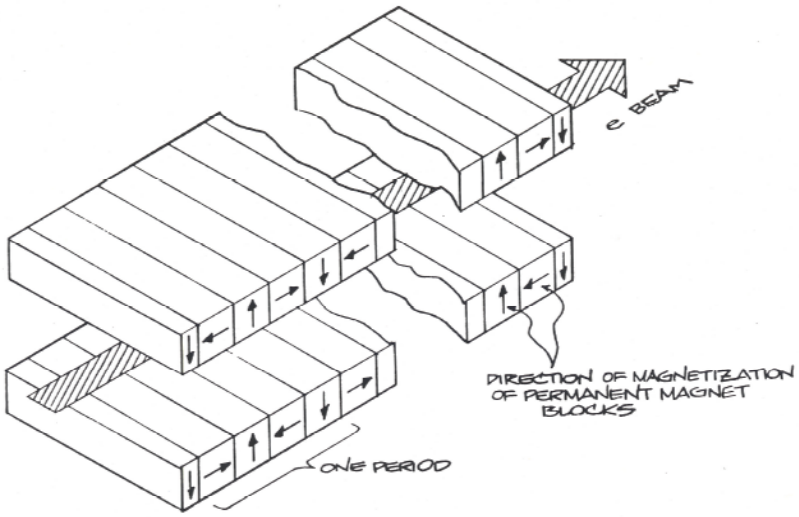
Superbend without cryostat



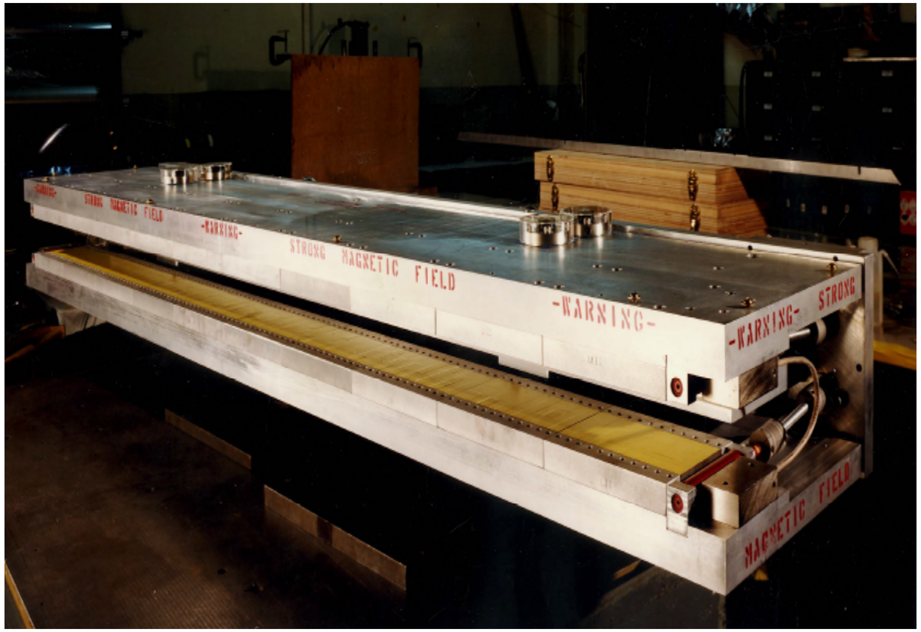
Superbend magnetic field



The First Permanent Magnet Undulator

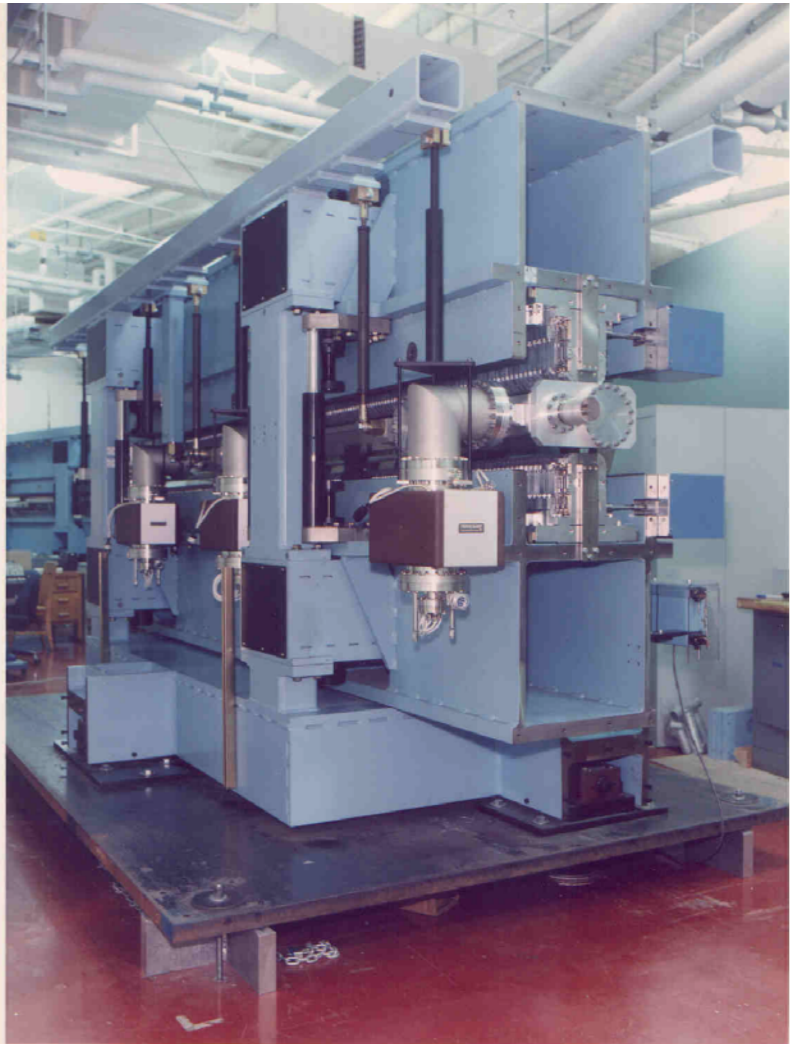


PERMANENT MAGNET UNDULATOR CONCEPTUAL DRAWING

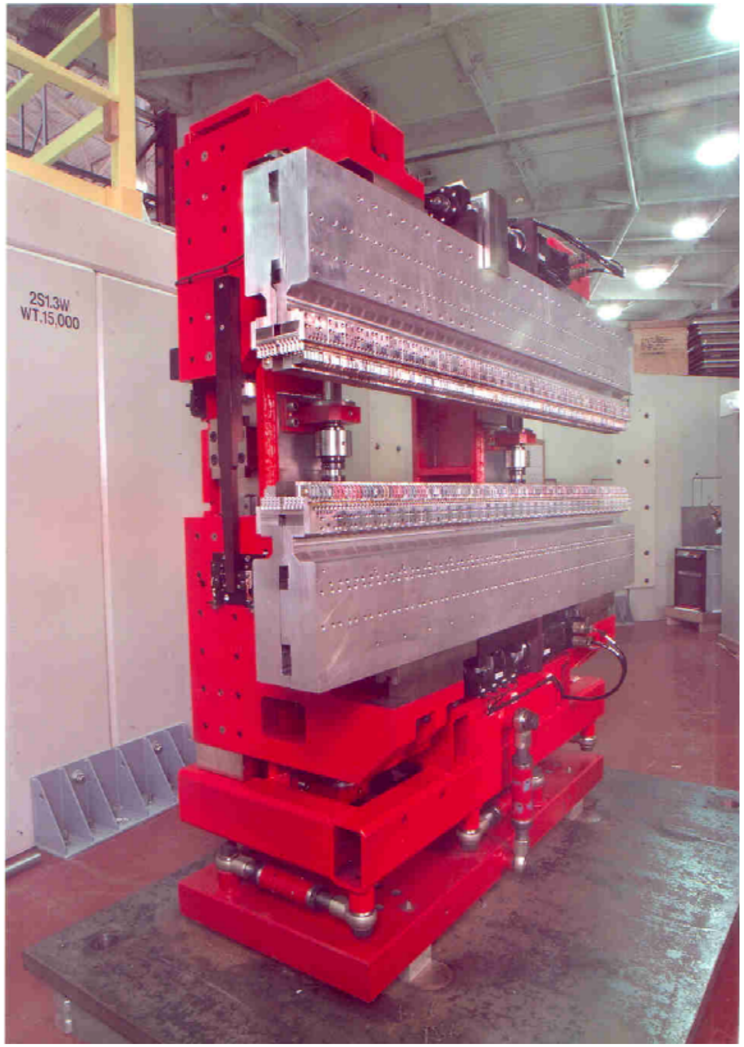


- invented by Klaus Halbach
- built at LBL
- installed at SSRL in 1980

Undulators at the ALS

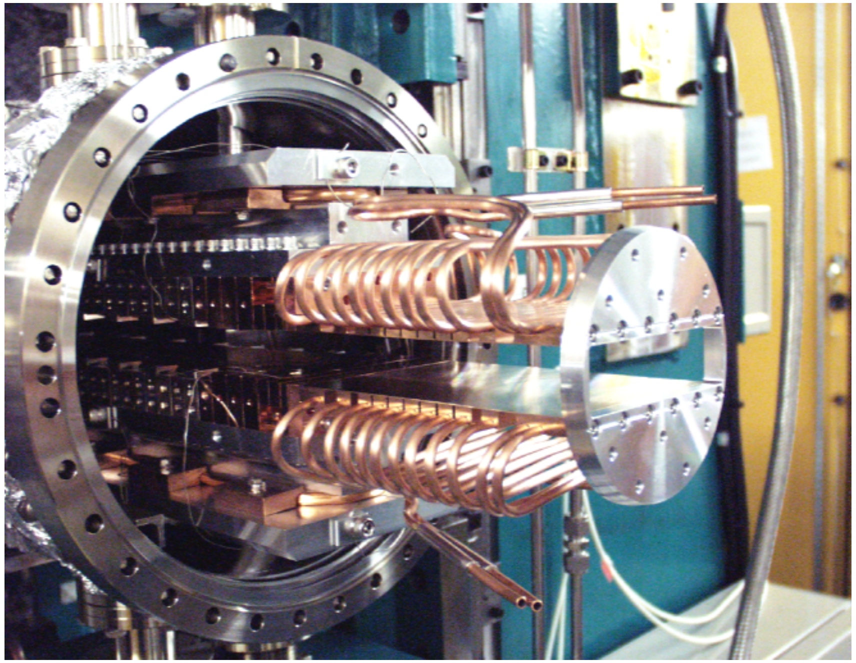


ALS U50 (1993)
Hybrid permanent magnet technology



ALS EPU50 (1998)
Pure permanent magnet technology, elliptically polarizing capability

Undulators at the ALS

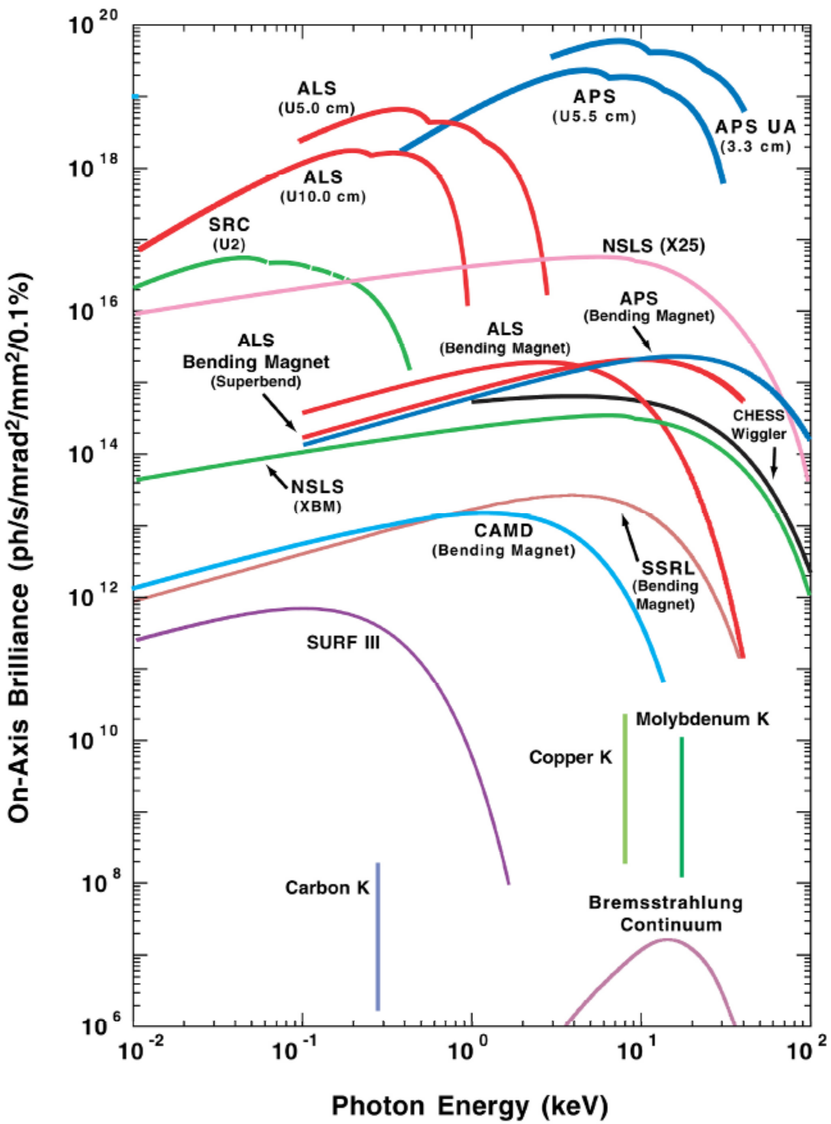


30 mm period, 1.5T wiggler / undulator (2005)

- in-vacuum magnets

- commercial device

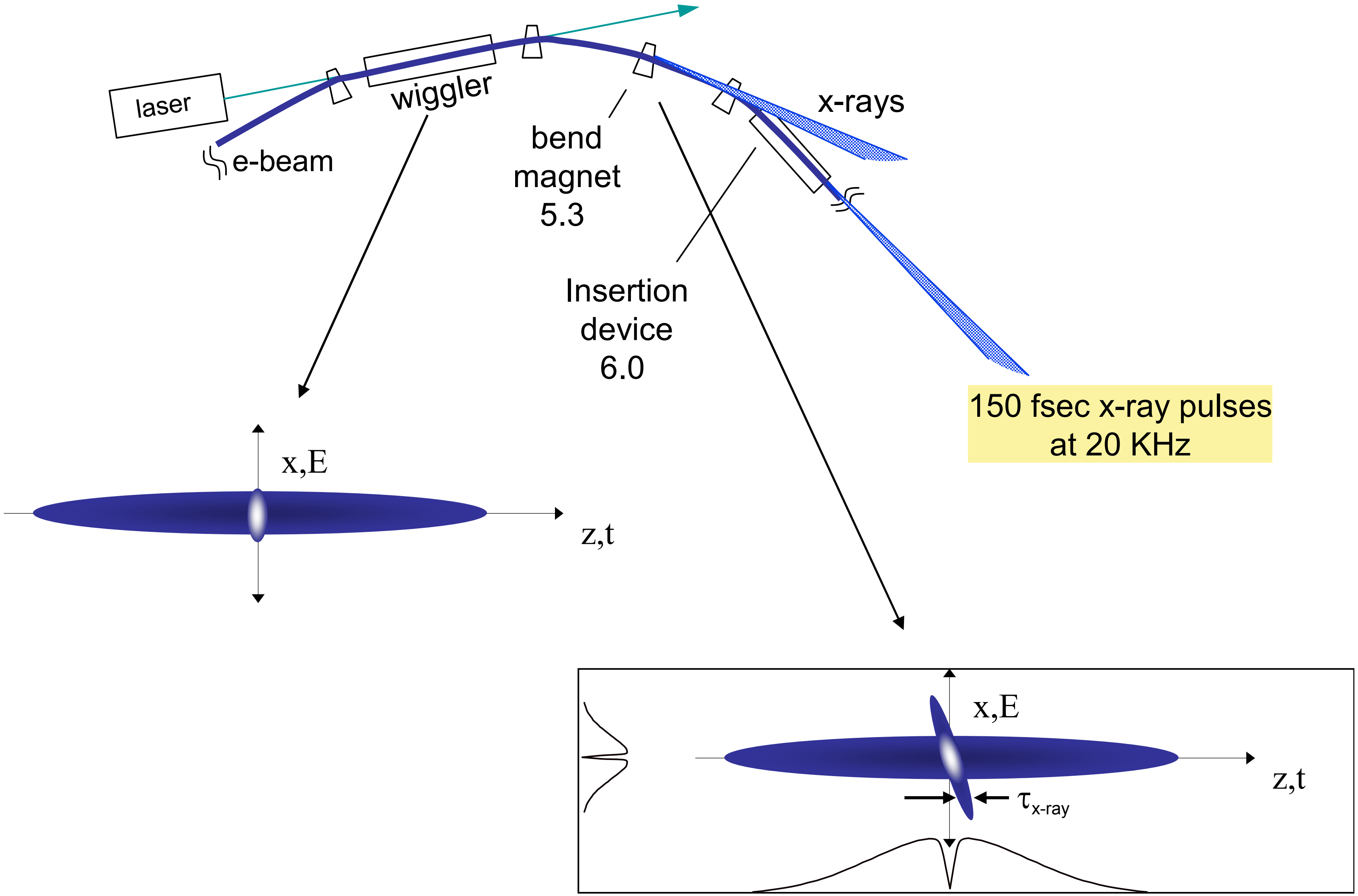
On-Axis Brightness of SR Sources



New devices:

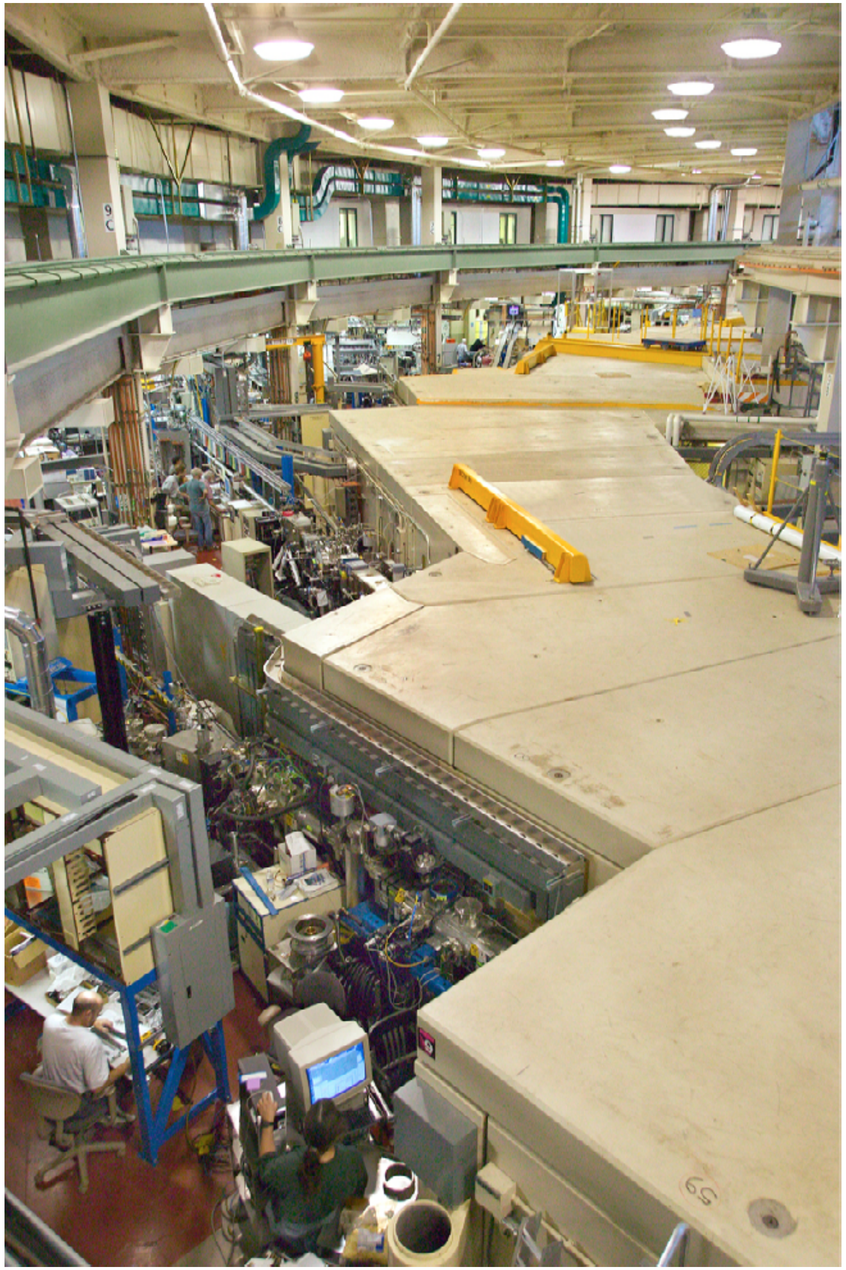
- in-vacuum permanent magnet
- in-vacuum cryo permanent magnet
- superconducting

Slicing the electron beam for ultrashort pulses

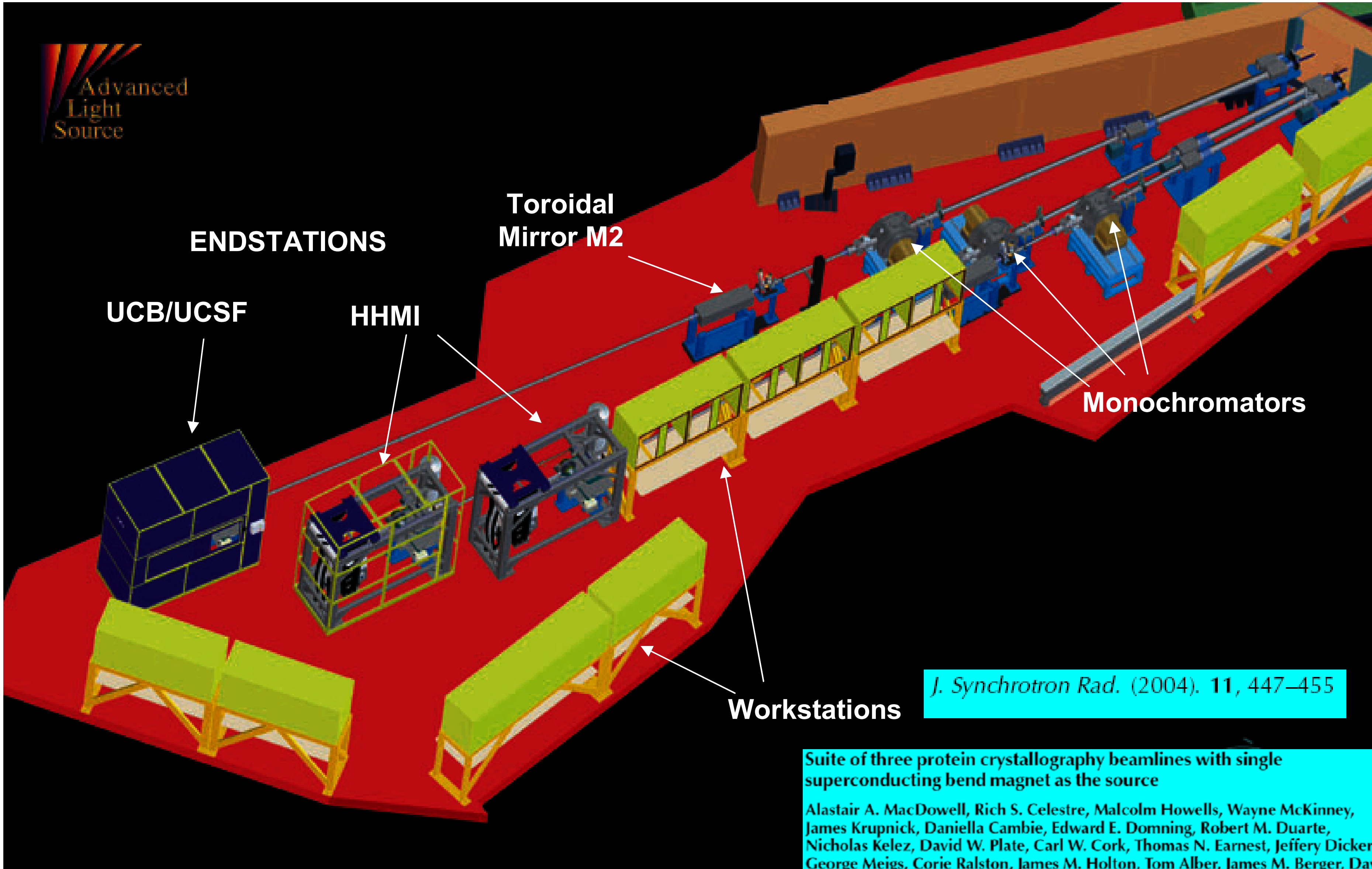


150 fsec x-ray pulses
at 20 KHz

ALS Beamlines



Protein Crystallography Beamline Layout

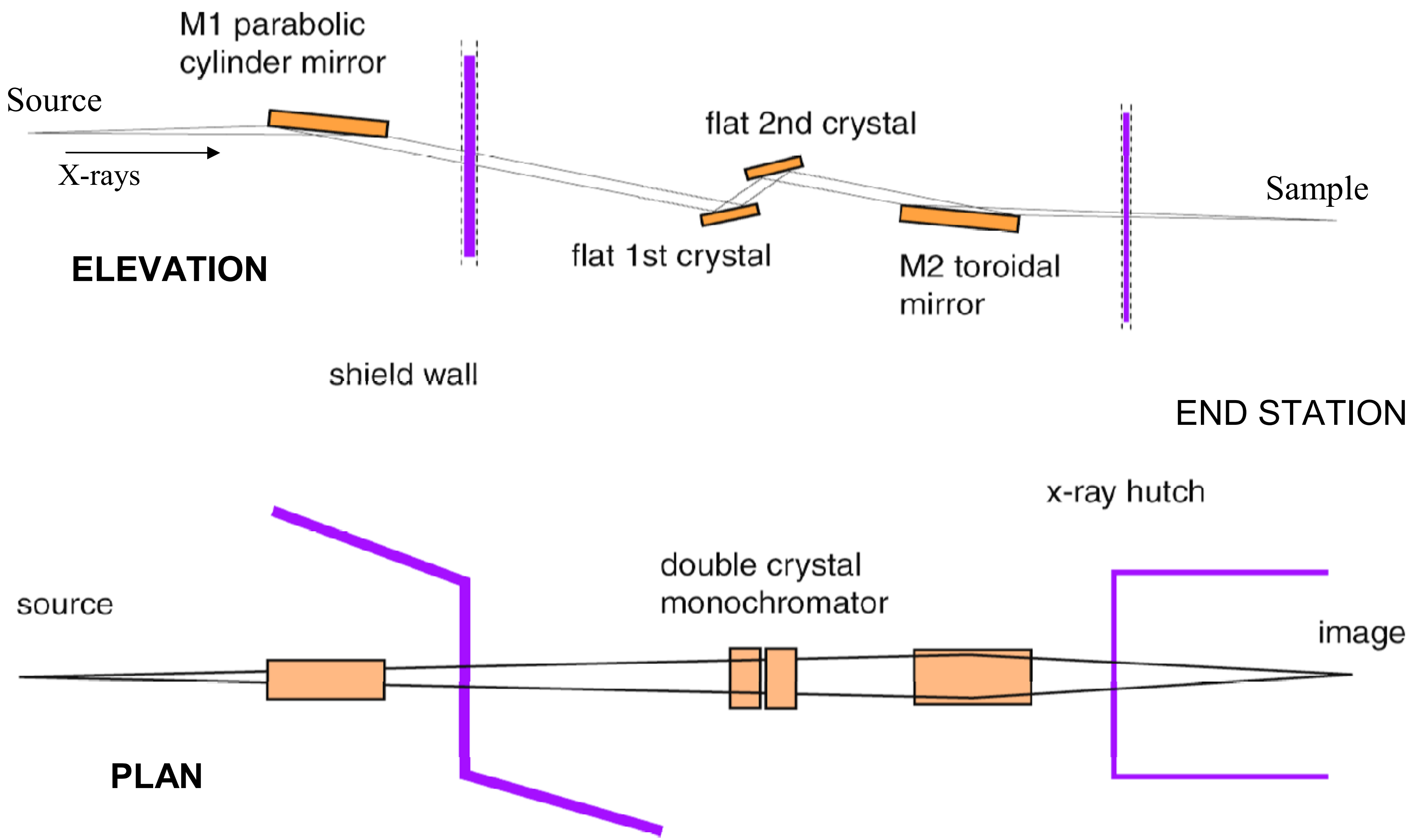


J. Synchrotron Rad. (2004). **11**, 447–455

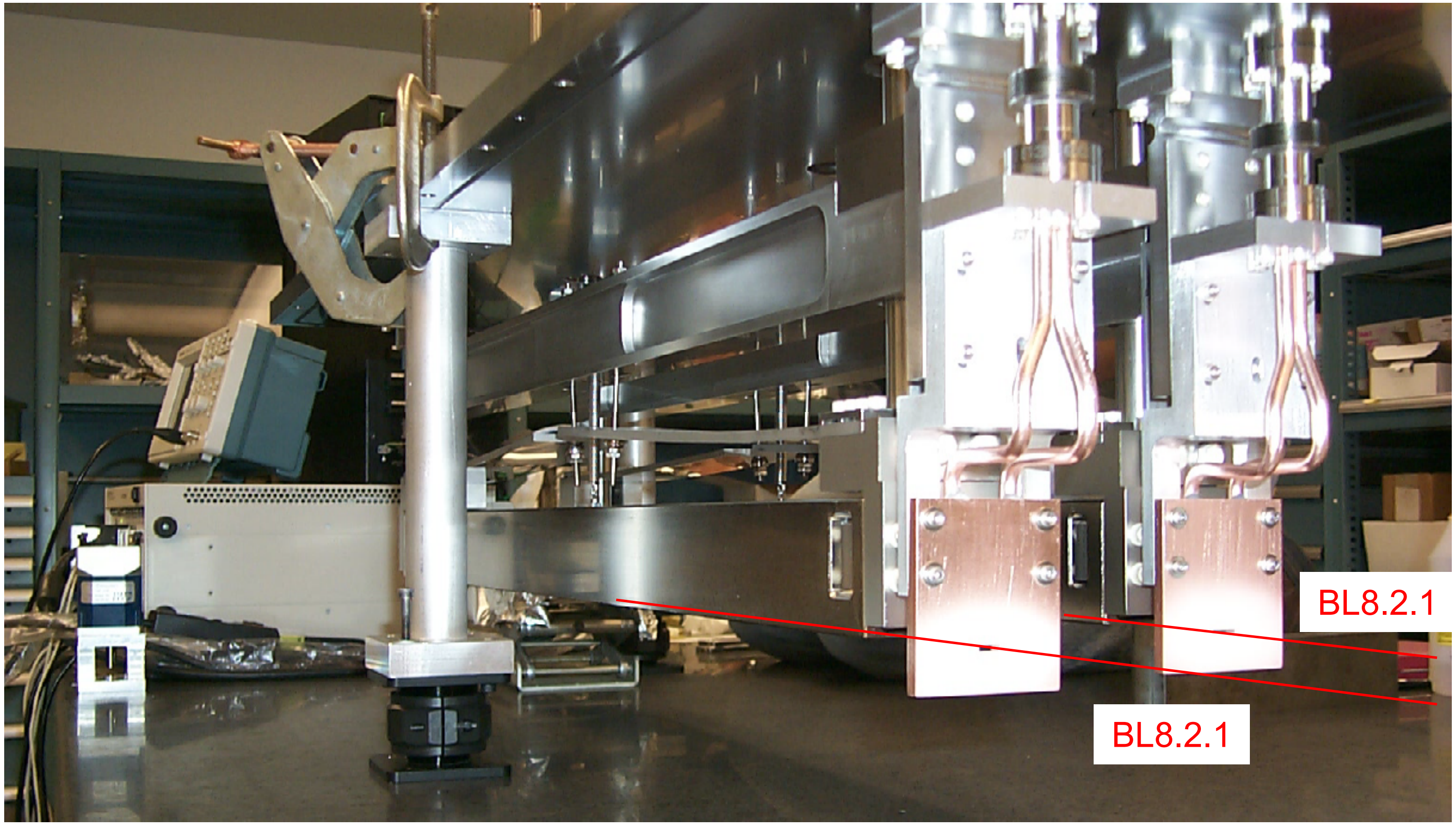
Suite of three protein crystallography beamlines with single superconducting bend magnet as the source

Alastair A. MacDowell, Rich S. Celestre, Malcolm Howells, Wayne McKinney, James Krupnick, Daniella Cambie, Edward E. Domning, Robert M. Duarte, Nicholas Kelez, David W. Plate, Carl W. Cork, Thomas N. Earnest, Jeffery Dickert, George Meigs, Corie Ralston, James M. Holton, Tom Alber, James M. Berger, David A. Agard and Howard A. Padmore

Protein Crystallography Beamline Layout



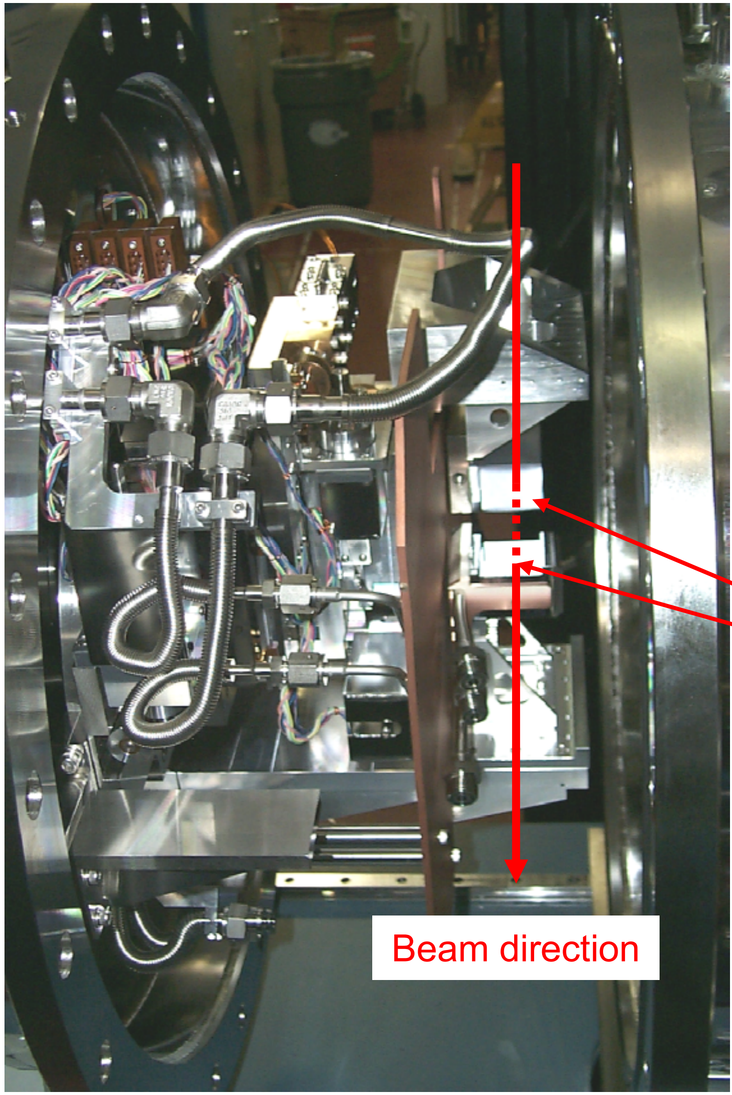
Protein Crystallography Parabolic Pre-mirrors



- parabolic collimating mirrors bent from flats

- cooled
- figure perfection ~ 1 microradian
- surface roughness ~ 0.5 nm rms

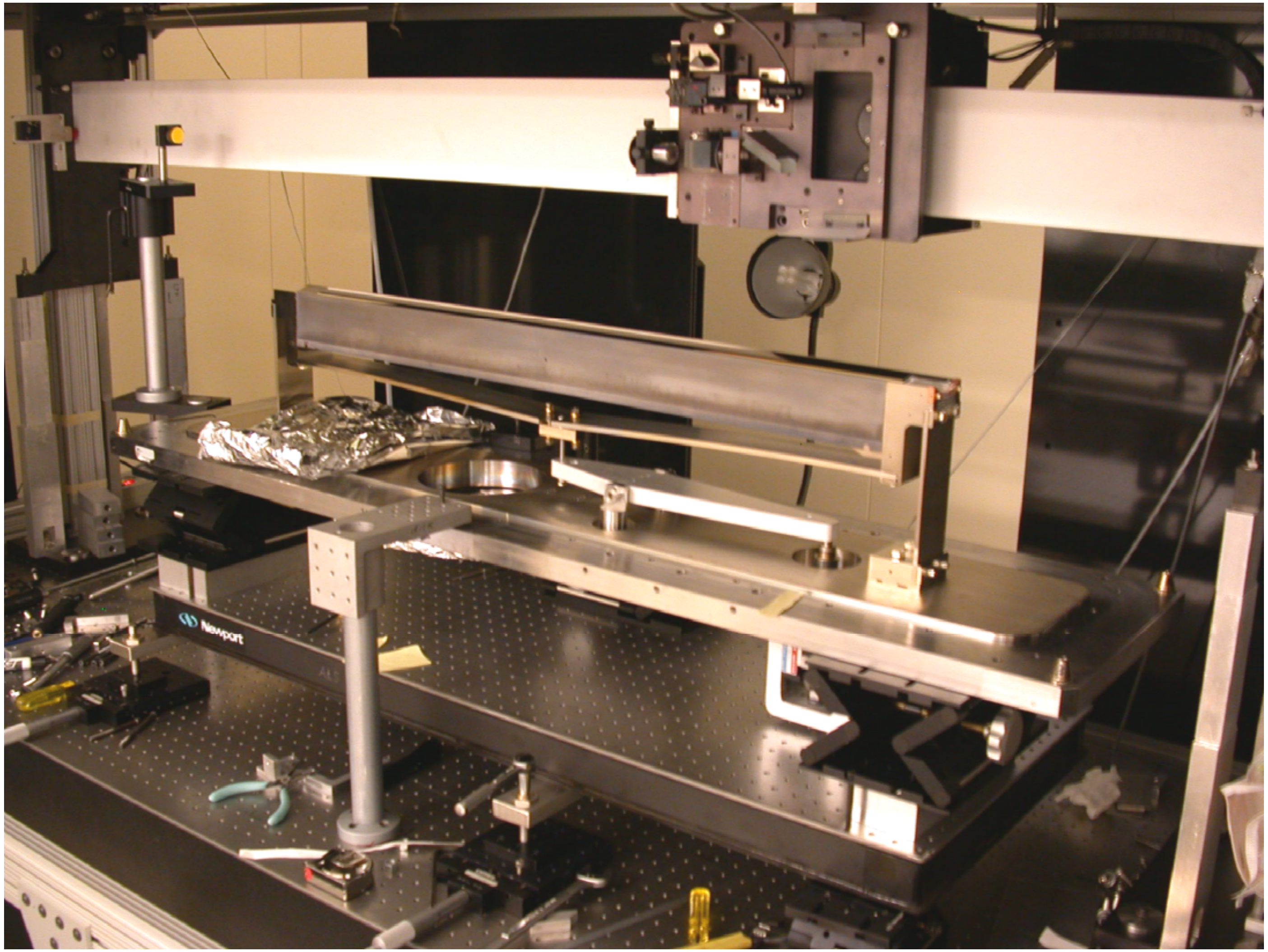
Protein Crystallography Crystal Monochromator



- energy changes by rotation of parallel crystals
- constant exit height by translation of 2nd crystal
- water-cooled crystals
- sub-microradian angular tolerances

S[111] crystals

Protein Crystallography M2 Toroidal Mirror



- sagittal cylinder bend into a toroidal shape (R ~ 2 km, rho ~ 10 cm)

- figure testing in progress on LTP

Protein Crystallography HHMI end station