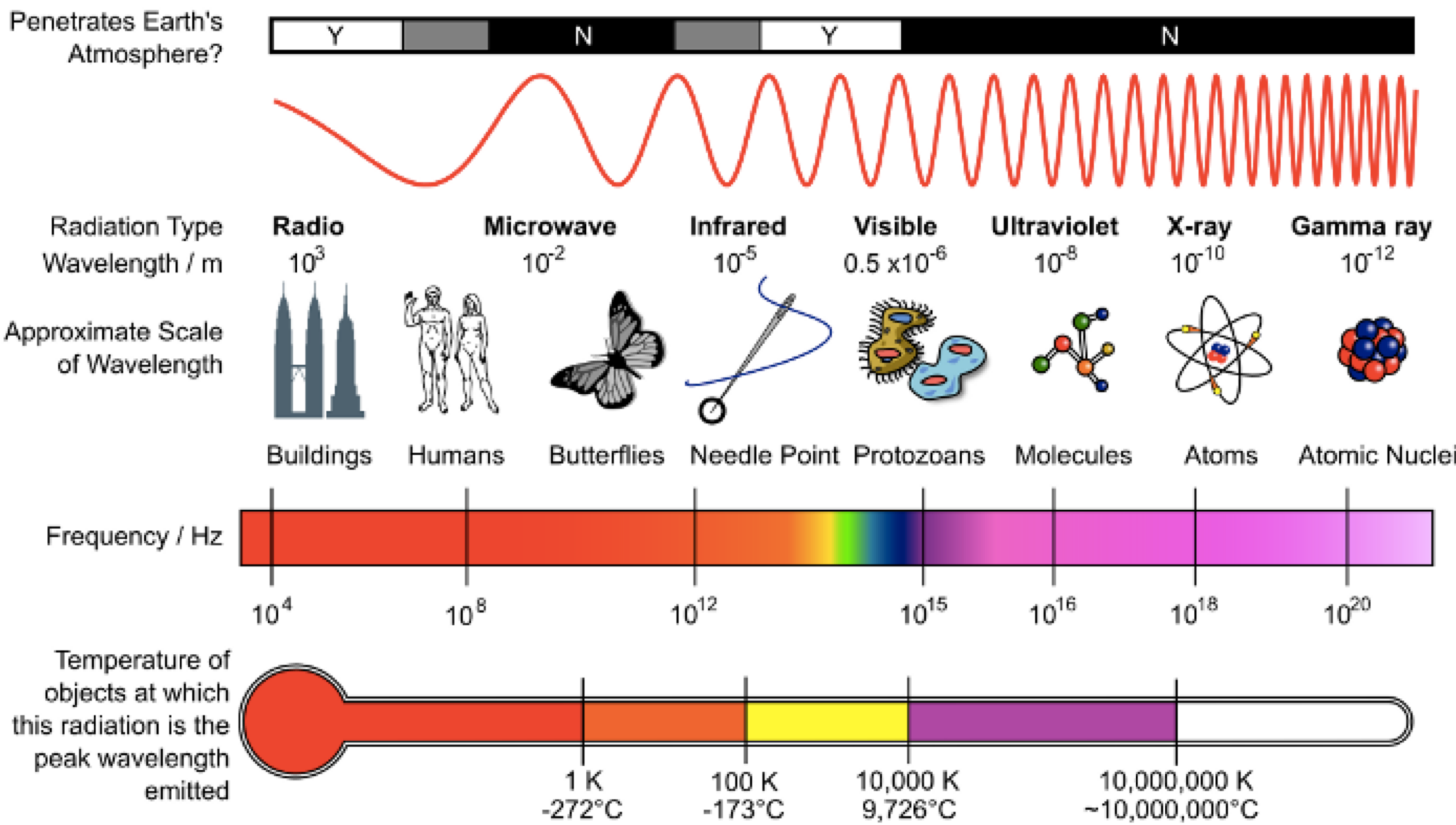
Synchrotron Light Source

Radiation Spectrum



Wavelength and Photon Energy

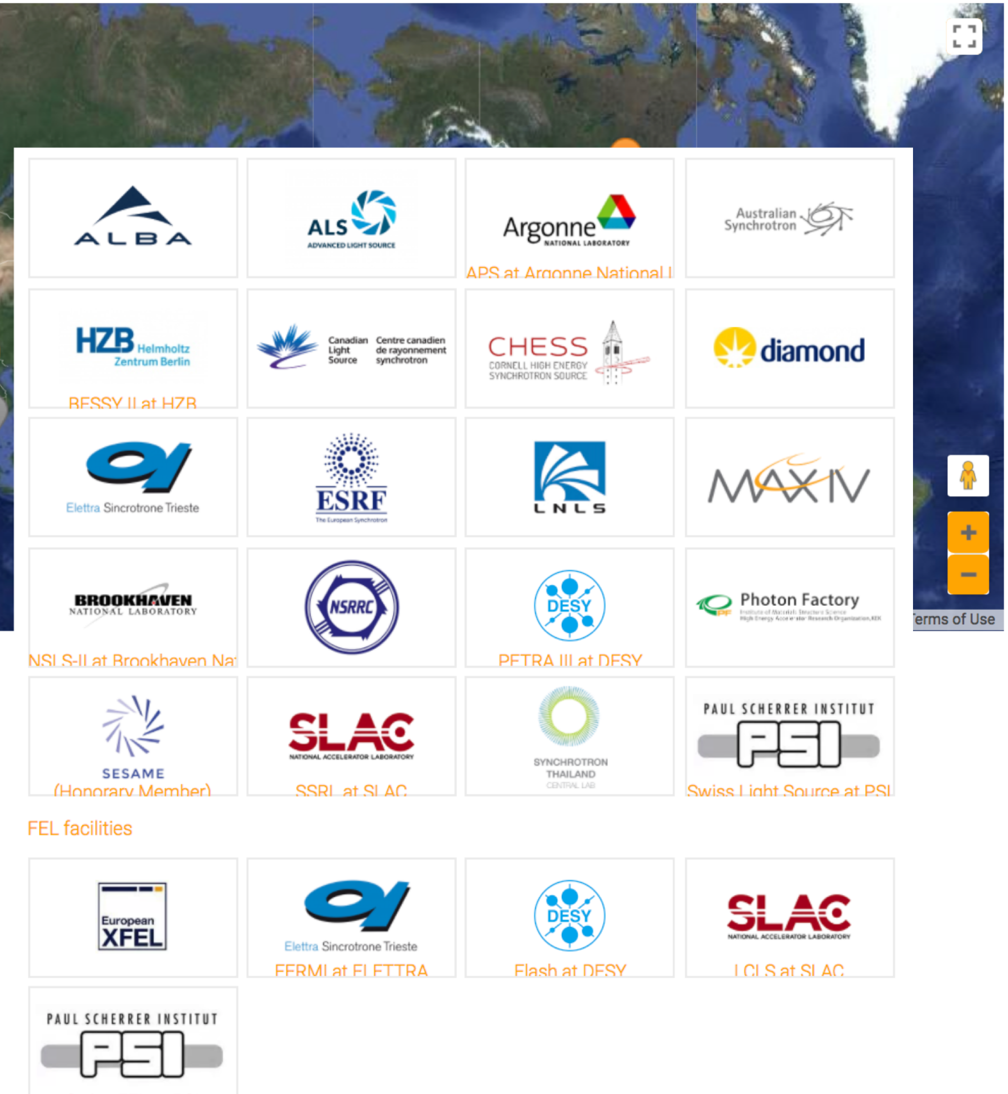
- The following relations are readily used:

$$E_p = \hbar\omega = \hbar c \frac{2\pi}{\lambda}$$

$$E_p[keV] = \frac{12.4}{\lambda[\mathring{A}]}$$

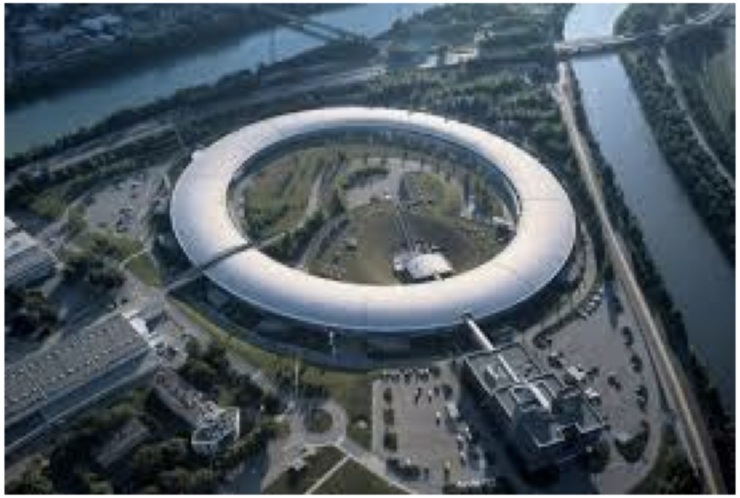
- 1 angstrom hard x-ray, energy is 12.4keV
- Visible light 500nm, energy is 2.4 eV

SR Light Source Worldwide



Source: Lightsources.org

SR Light Source Worldwide



ESRF, 6 GeV

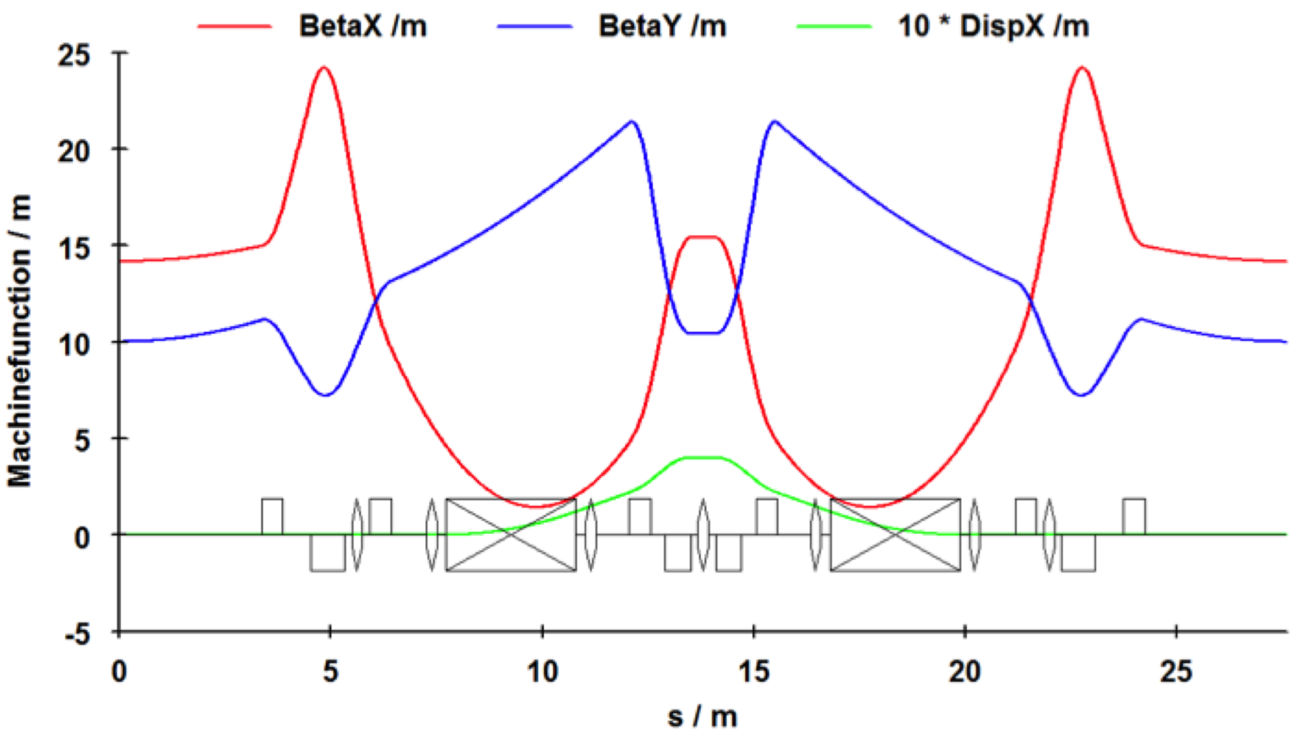
SPring-8, 8 GeV

NSLS II, 3 GeV

SSRF, 3.5 GeV

Example Lattice APS - DBA

Parameters	value
Energy	7 GeV
C	1104 m
Ns	40
eps	8.22 nm rad
Qx	35.22
Qy	14.30
alpha	2.28e-4

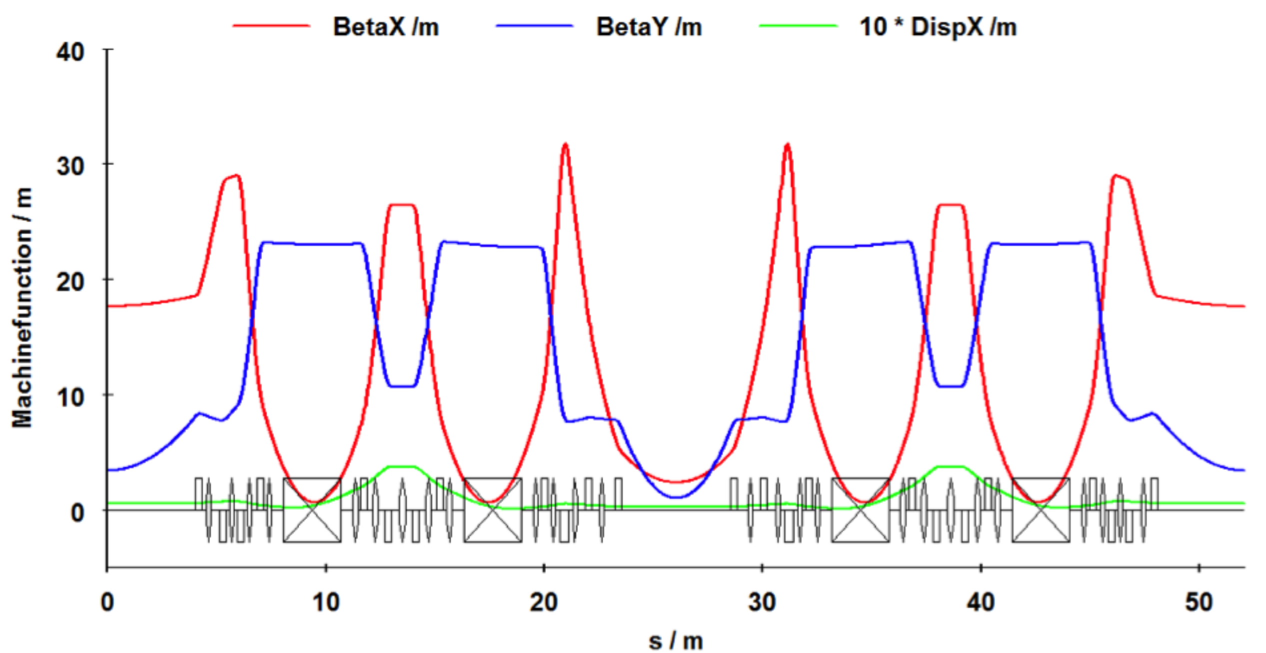


APS @ ANL

APS-U project upgrade the lattice to MBA

Example Lattice NSLS II - DBA

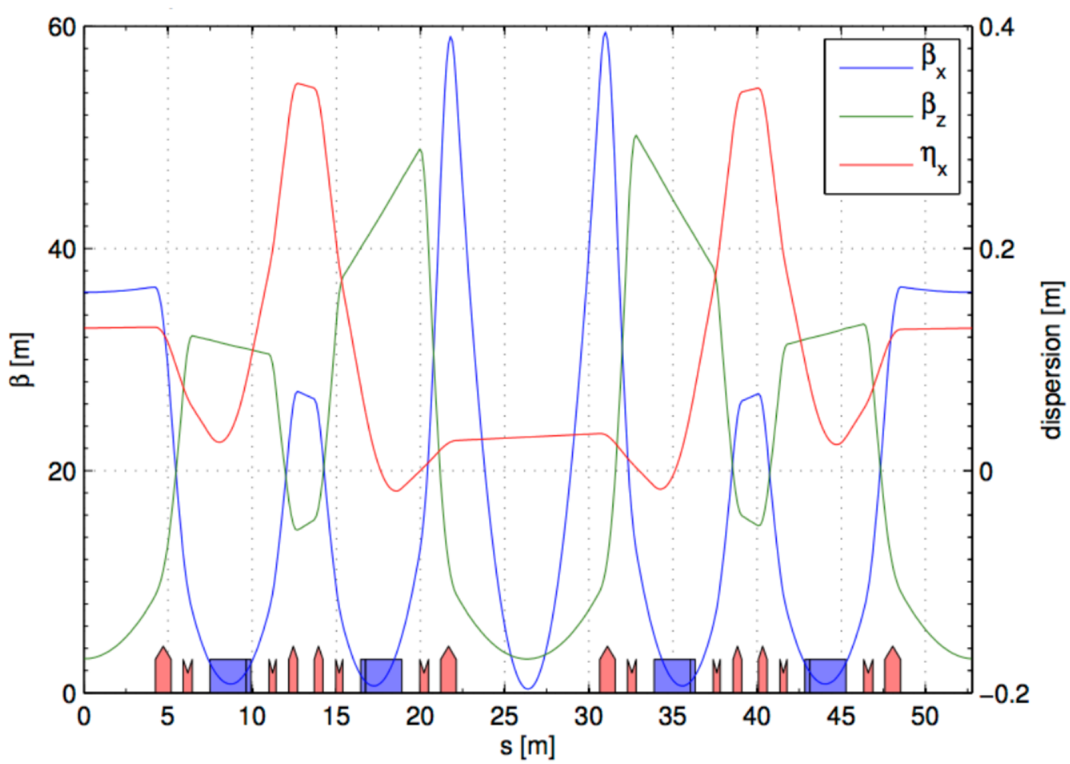
Parameters	value
Energy	3 GeV
C	781.0 m
Ns	15
eps	2.03 nm rad
Qx	32.34
Qy	16.28
alpha	3.67e-4



NSLS-II @ BNL

Example Lattice: ESRF - DBA

Parameters	value
Energy	6 GeV
C	844 m
Ns	32
eps	4.0 nm rad
Qx	36.44
Qy	13.39
alpha	1.78e-4

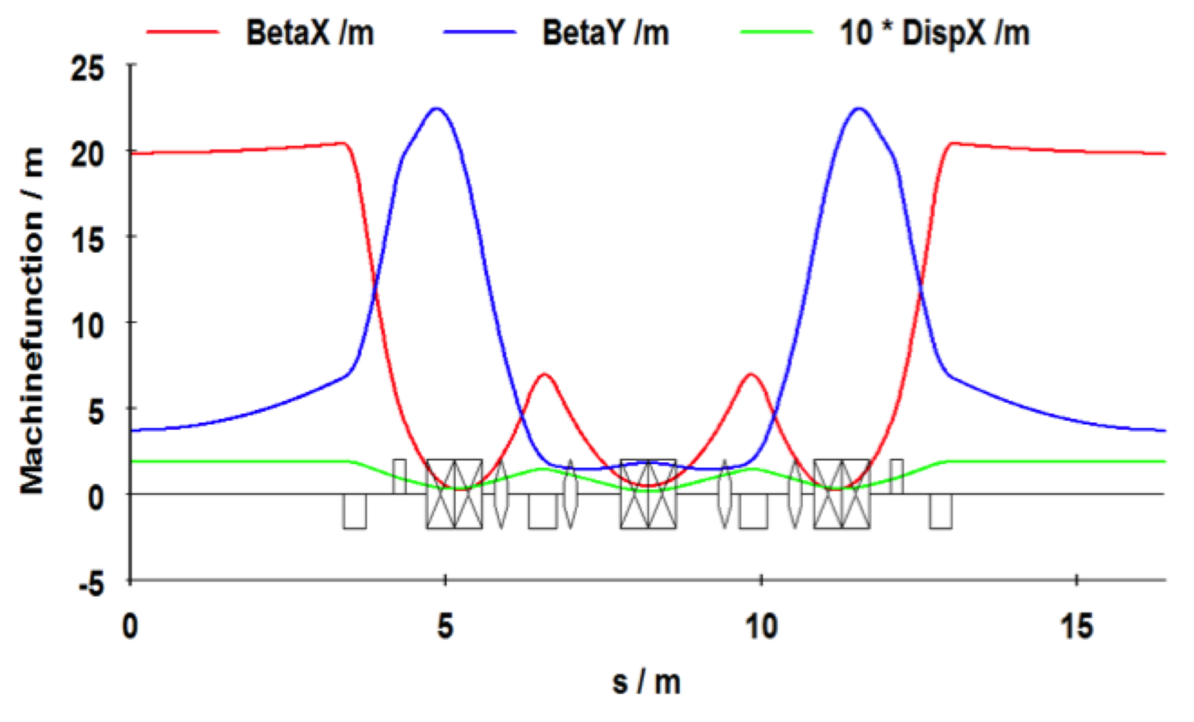


ESRF @ France

Old DBA lattice

Example Lattice: ALS - TBA

Parameters	value
Energy	6 GeV
C	844 m
Ns	32
eps	0.134 nm rad
Qx	76.21
Qy	27.34
alpha	8.4e-5

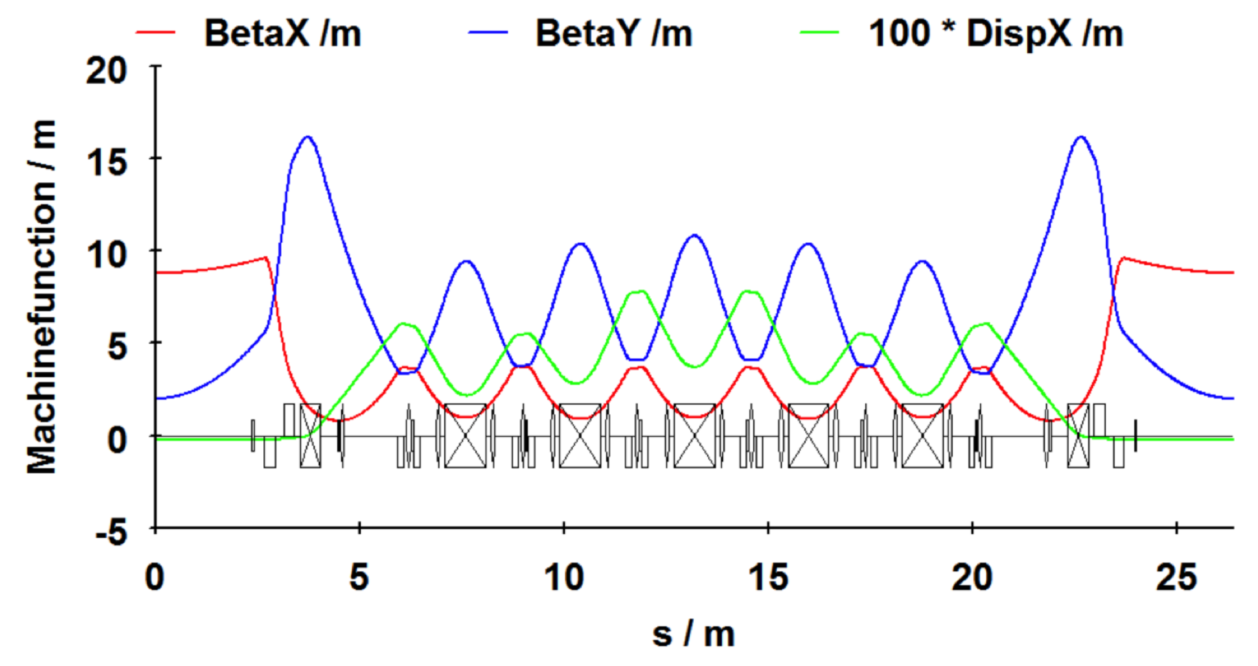


ALS @ LBNL

ALS-U project upgrade the lattice to MBA

Example Lattice: MAX-IV - 7BA

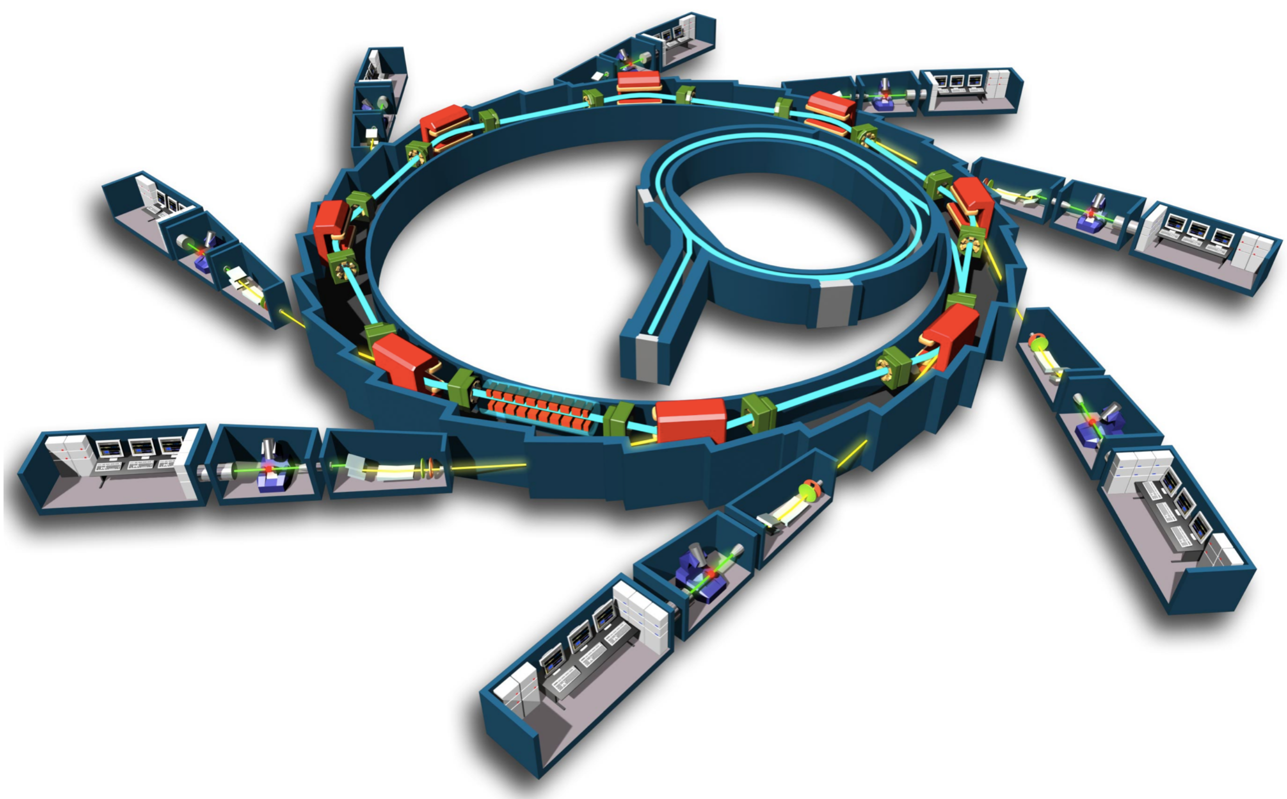
Parameters	value
Energy	3 GeV
C	528 m
Ns	20
eps	0.33 nm rad
Qx	42.24
Qy	16.28
alpha	3.07e-4



MAX-IV @ Sweden

SR Light Source

- To produce UV, (soft/hard) X-ray source
  - Dipole, undulator/wiggler



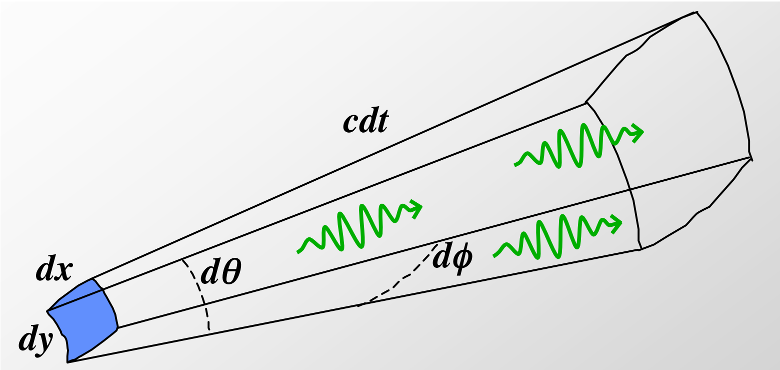
EXCITING SCIENTIFIC TOOL.

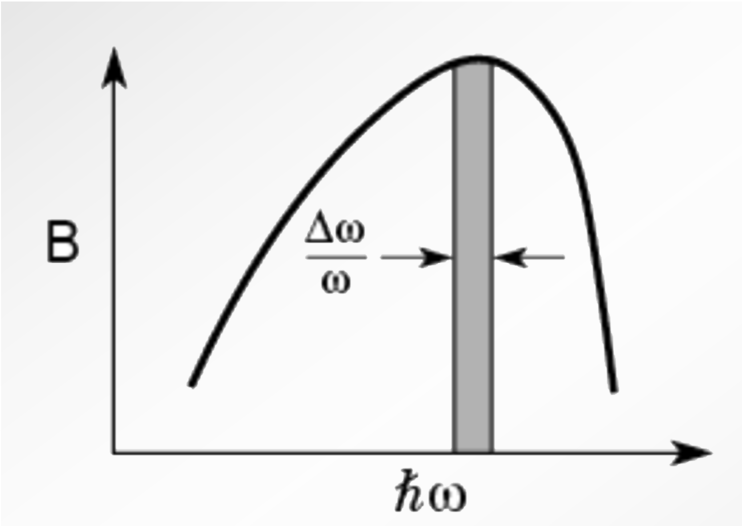
LET LIGHT MEET MATTERS

Performance of light source

- Brightness of photon

$$B = \frac{d^4 N}{dt d\Omega dS (d\lambda/\lambda)}$$





- Flux $= \frac{d^2 N}{dt (d\lambda/\lambda)} = \int B dS d\Omega$

Higher Brightness Enable Us…

- Process with less cross section
- Trim the light for better
  - Coherence, monochromatic radiation

Protein Crystallography

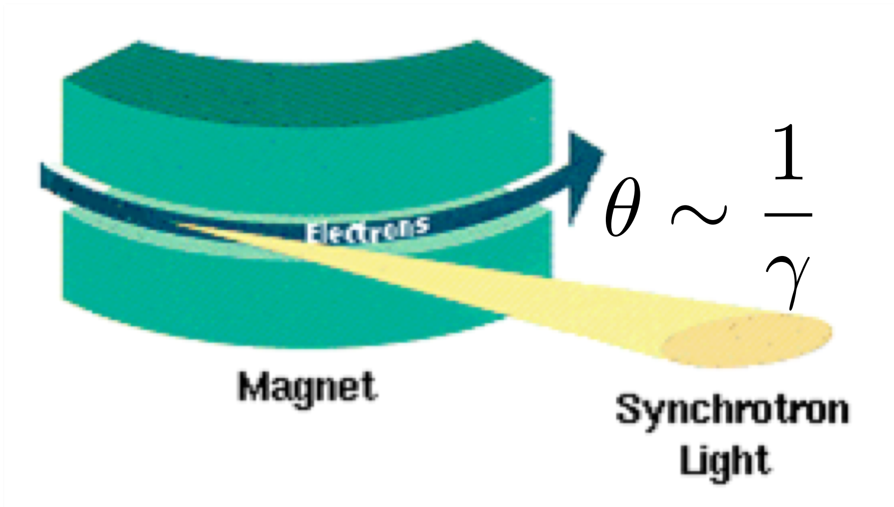
Spectroscopy with high resolution

Crystal Diffraction

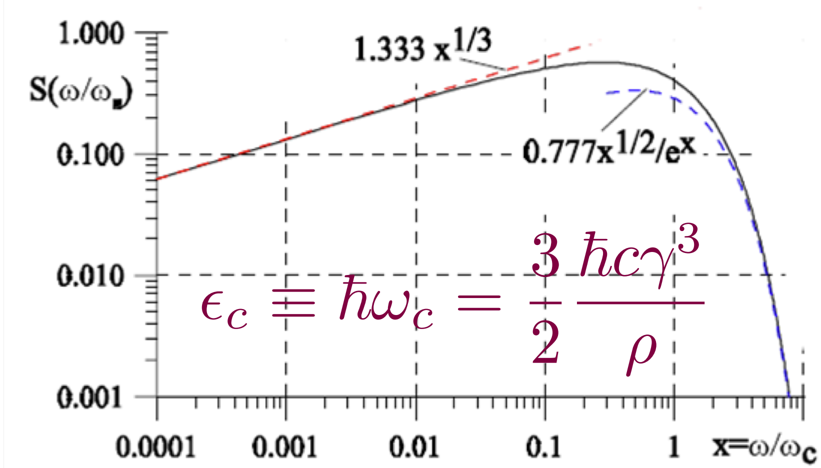
Many More…

SR is polarized light

SR from Bending Magnet



$$\theta \sim \frac{1}{\gamma}$$

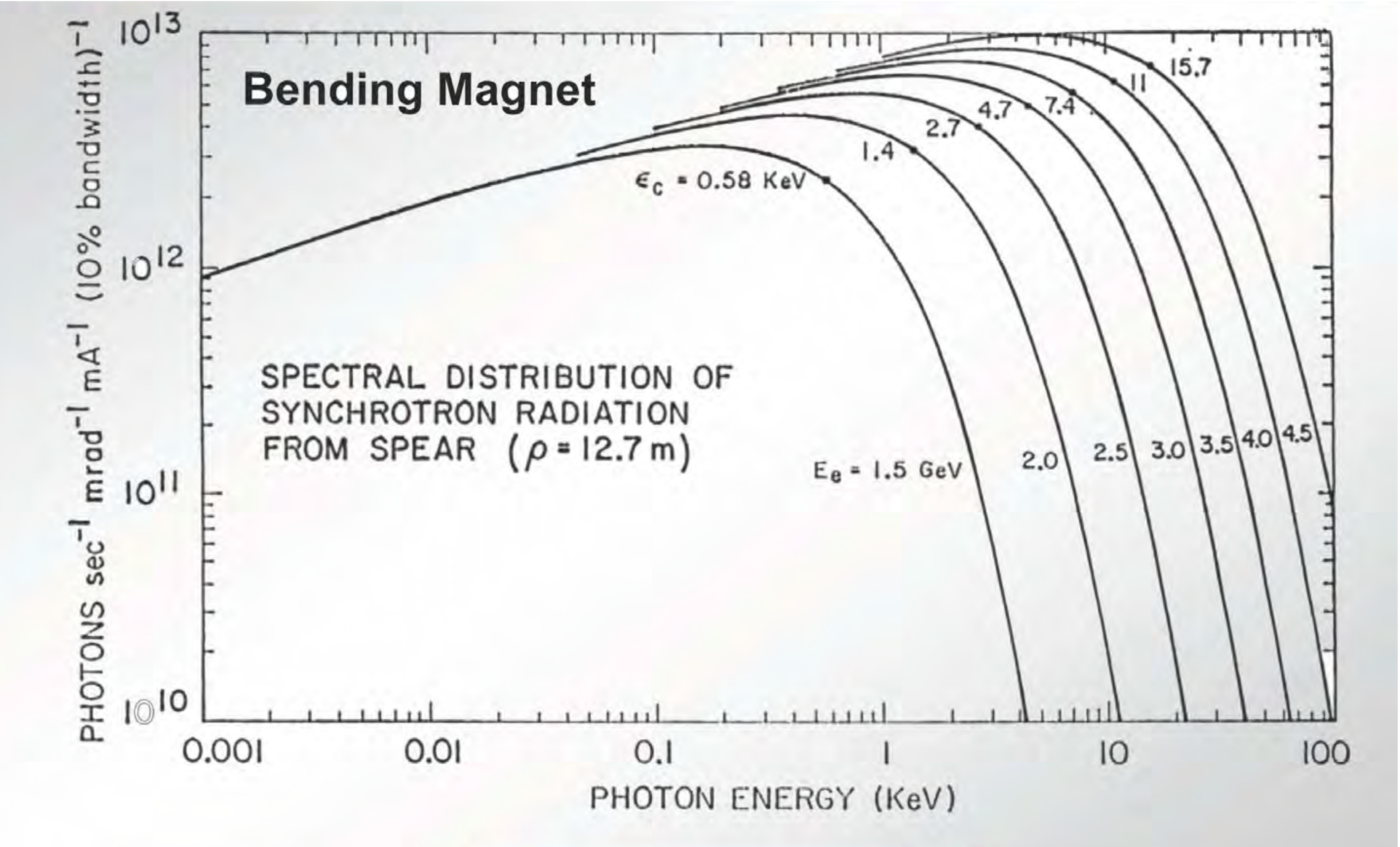


$$\epsilon_c \equiv \hbar\omega_c = \frac{3}{2}\frac{\hbar c\gamma^3}{\rho}$$

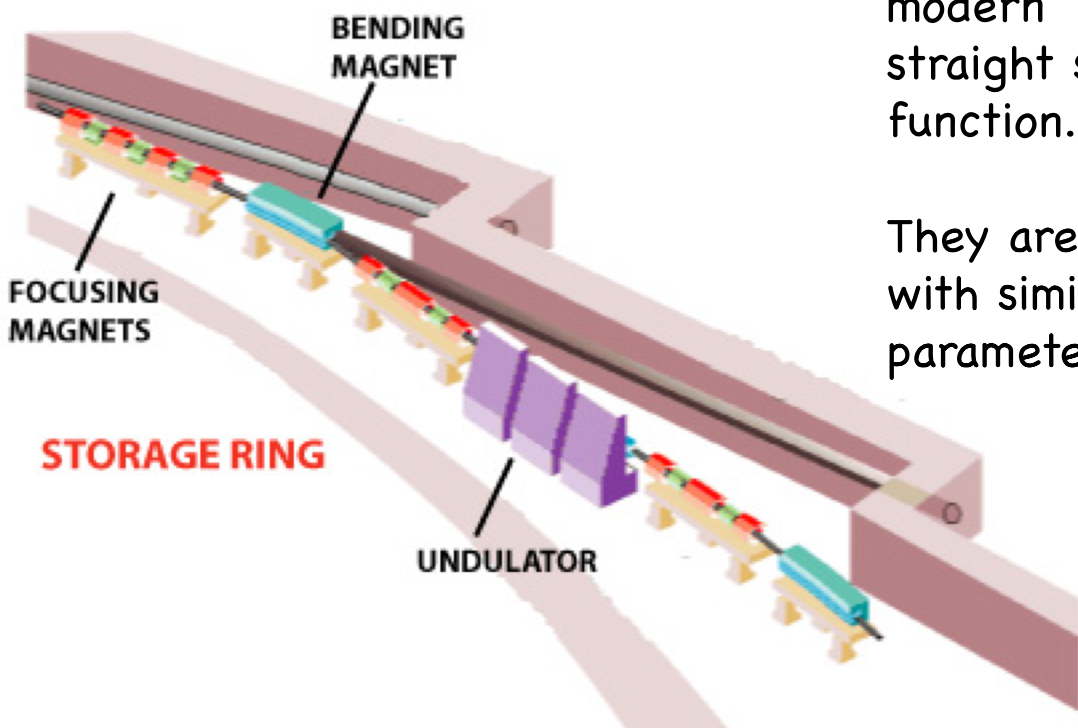
$$P = \frac{e^2 c}{6\pi\varepsilon_0}\frac{\gamma^4}{\rho^2}$$

- Goods
  - Simple, inexpensive
  - Broad spectral range
  - Many beamlines
- Bads
  - Limited hard x-ray components
  - Not very bright

SR spectrum of Dipole, Energy Dependence



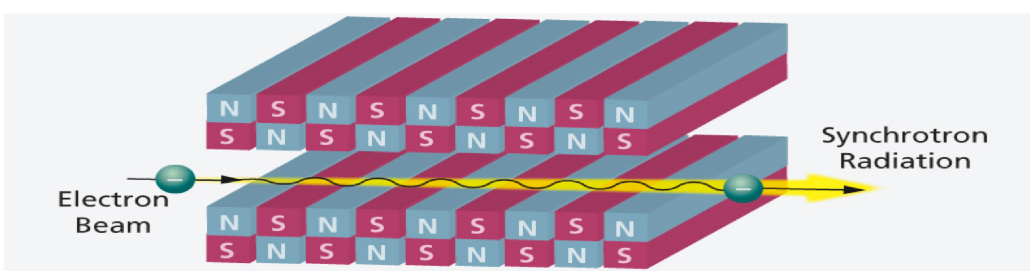
Undulator/Wiggler



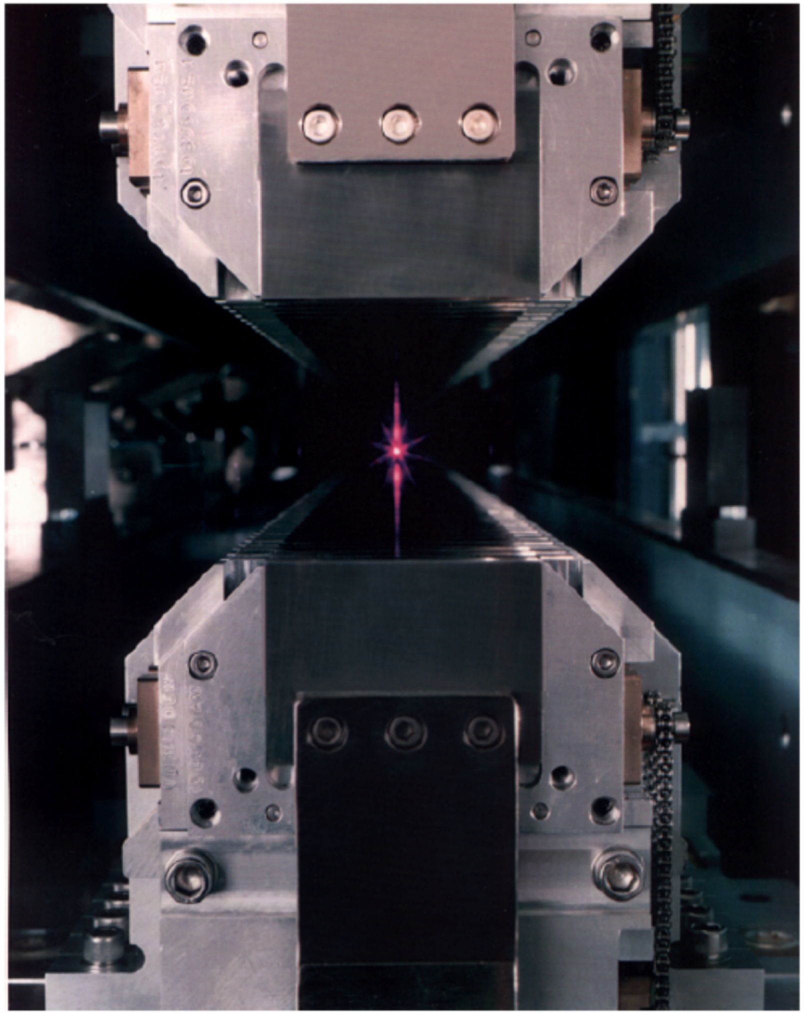
In addition to the SR from dipoles, modern light sources has many long straight section with zero dispersion function.

They are undulators and wigglers with similar shape but different parameter.

Example: NSLS II
# of DBA cells: 30
# of 5m straights: 15
# of 8m straights: 15

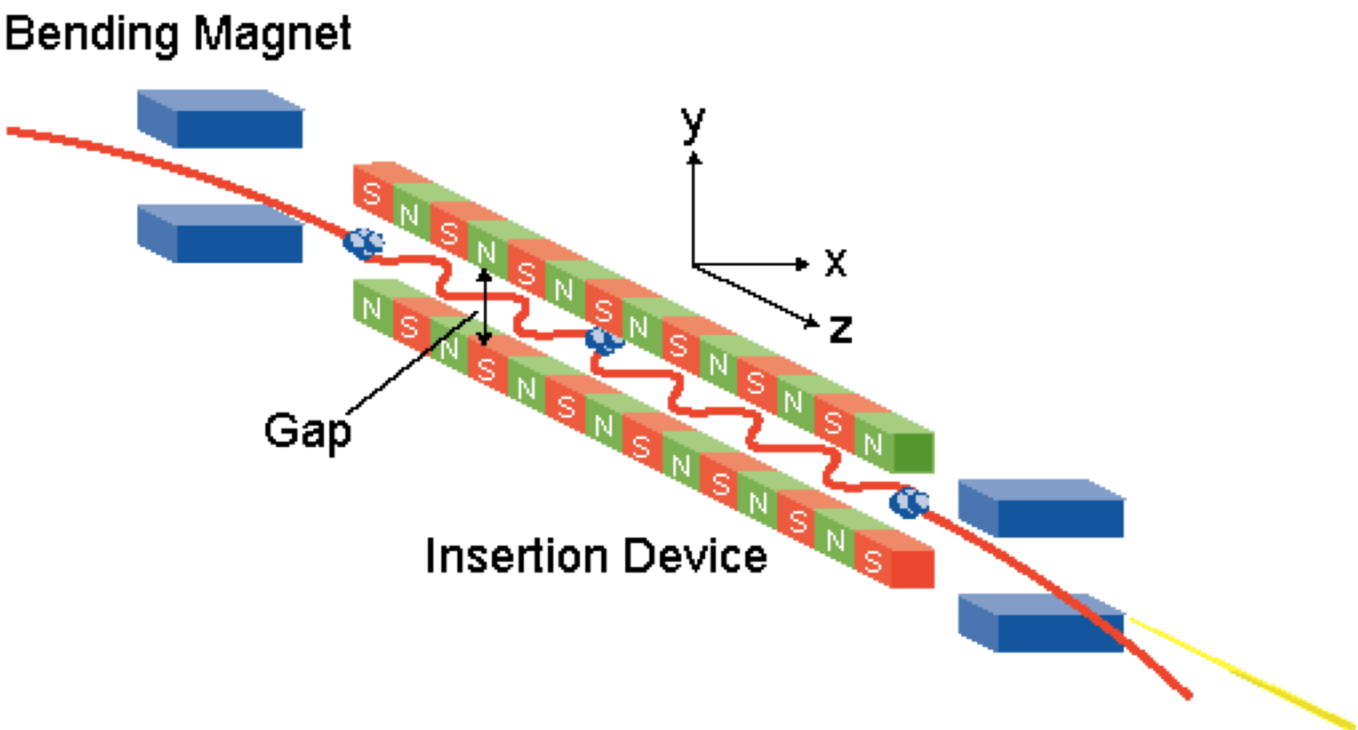


Real Example



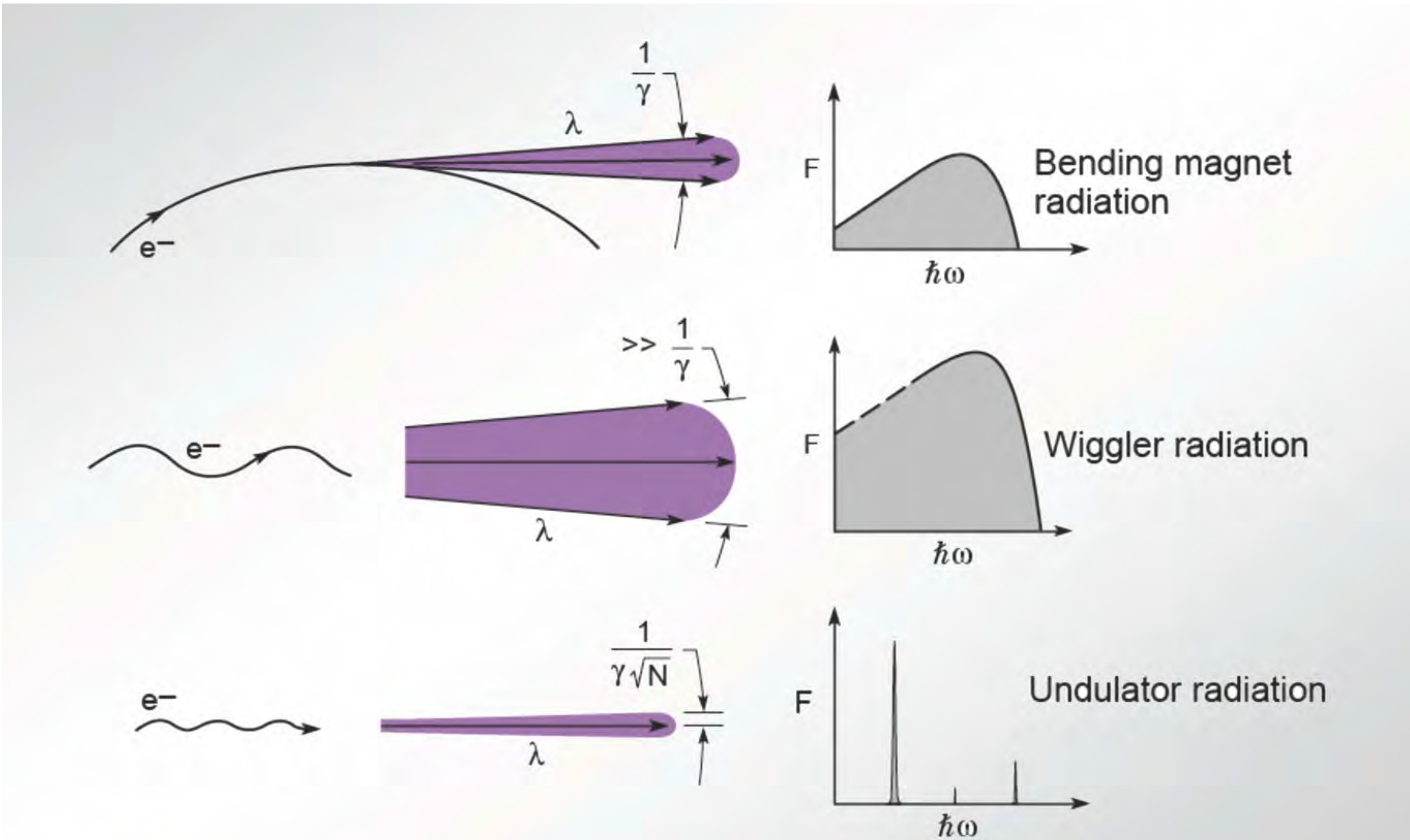
ALS U5 undulator, beamline 7.0, N = 89, λ_u = 50 mm

SR from Undulator/Wiggler



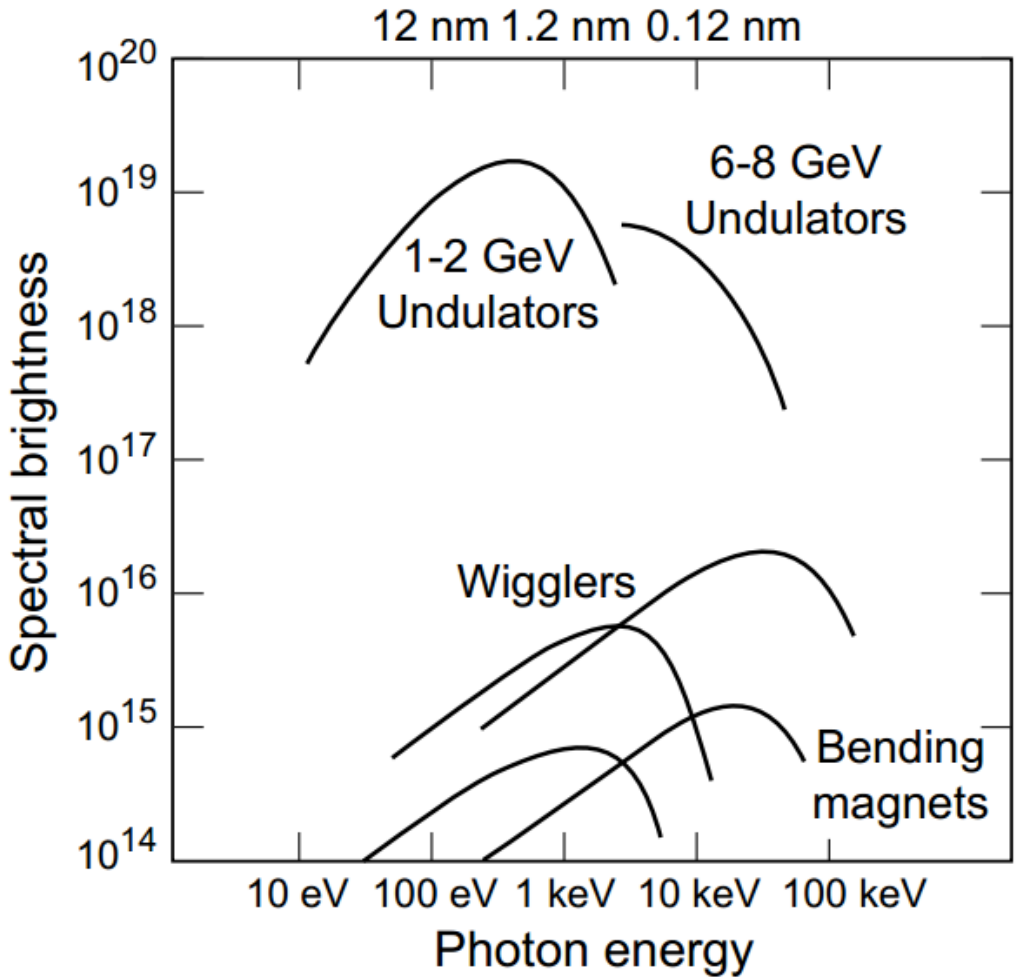
They are 'insertion devices' in straight sections. Modern accelerators provides many long straight sections.

Difference between bending magnet and Undulator/Wiggler



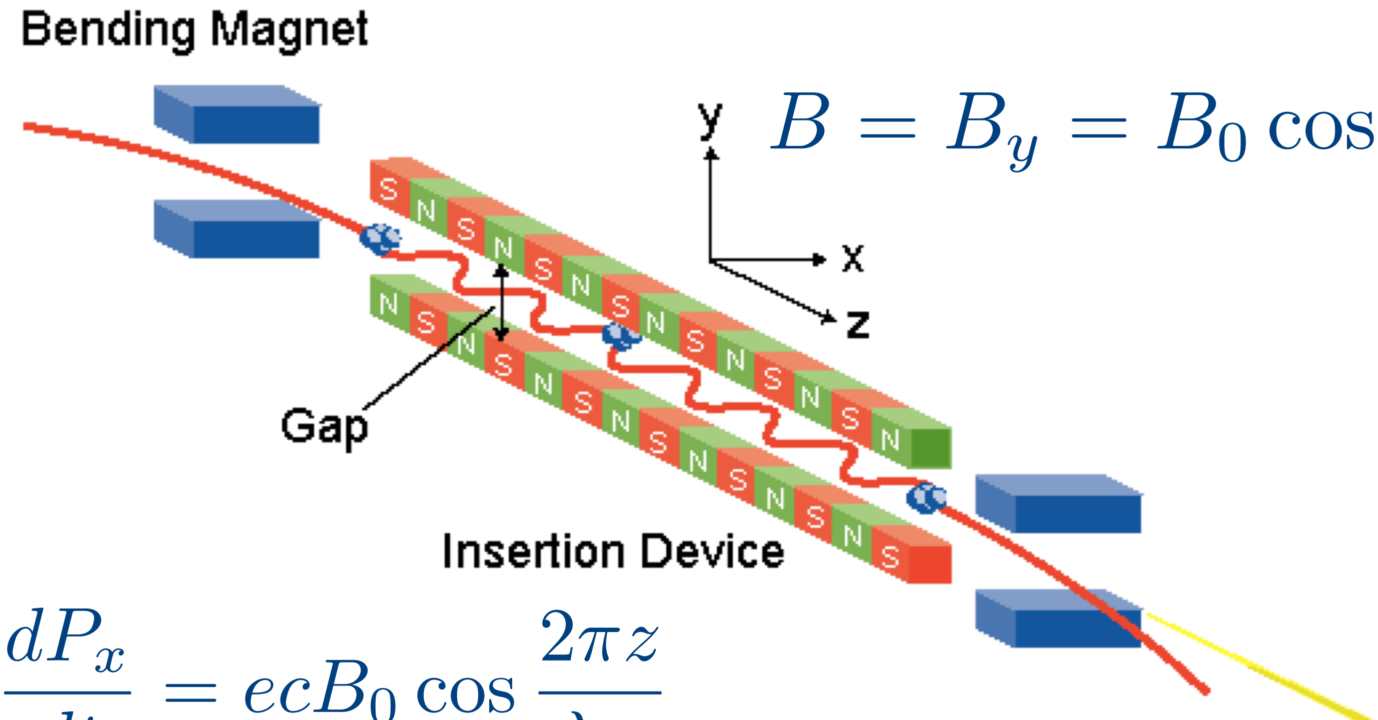
Courtesy of W. Barletta

Brightness Comparison



Courtesy of W. Barletta

Electron Motion inside Undulator



$$B = B_y = B_0 \cos \frac{2\pi z}{\lambda_u}$$

$$\frac{dP_x}{dt} = ecB_0 \cos \frac{2\pi z}{\lambda_u}$$

$$v_x = \frac{eB_0\lambda_u}{2\pi m\gamma} \sin \frac{2\pi z}{\lambda_u} \equiv \frac{Kc}{\gamma} \sin \frac{2\pi z}{\lambda_u}$$

$$K = \frac{eB_0\lambda_u}{2\pi mc} = 0.934 B_0[T]\lambda_u[cm]$$

Undulator 'Slows down' the electron

$$v_z = \sqrt{v^2 - v_x^2} = c\sqrt{1 - \frac{1}{\gamma^2} - \frac{K^2}{\gamma^2}\sin^2\frac{2\pi z}{\lambda_u}}$$

$$= c(1 - \frac{1 + K^2/2}{2\gamma^2} + \frac{K^2}{4\gamma^2}\cos\frac{4\pi z}{\lambda_u})$$

$$\bar{v_z} = c(1 - \frac{1 + K^2/2}{2\gamma^2})$$

oscillating part is averaging to zero

As if the energy of beam changes:

$$\gamma^* = \gamma/\sqrt{1 + K^2/2}$$

In electron 's rest frame

- The electron sees contracted undulator

$$\lambda_u' = \lambda_u/\gamma^*$$

- The frequency of the radiation is

$$f' = \frac{c}{\lambda_u'} = \frac{c\gamma^*}{\lambda_u}$$

- In lab frame, the frequency of the radiation is different(relativistic Doppler Effect)

$$f = \frac{f'}{\gamma^*(1-\bar{\beta}_z\cos\theta)} = \frac{c}{\lambda_u(1-\bar{\beta}_z\cos\theta)}$$

Resonance Condition

- The wavelength of the radiation in the lab frame:

$$\lambda = \lambda_u(1 - \bar{\beta_z}\cos\theta)$$

- Recall that:

$$\bar{v_z} = c(1 - \frac{1 + K^2/2}{2\gamma^2})$$

- And we only care of small forwarding angle:

$$\cos\theta \sim 1 - \theta^2/2$$

- Finally the wavelength reads:

$$\lambda = \frac{\lambda_u}{2\gamma^2}(1 + K^2/2 + \gamma^2\theta^2)$$

Radiation for K<1

Radiation Bandwidth:

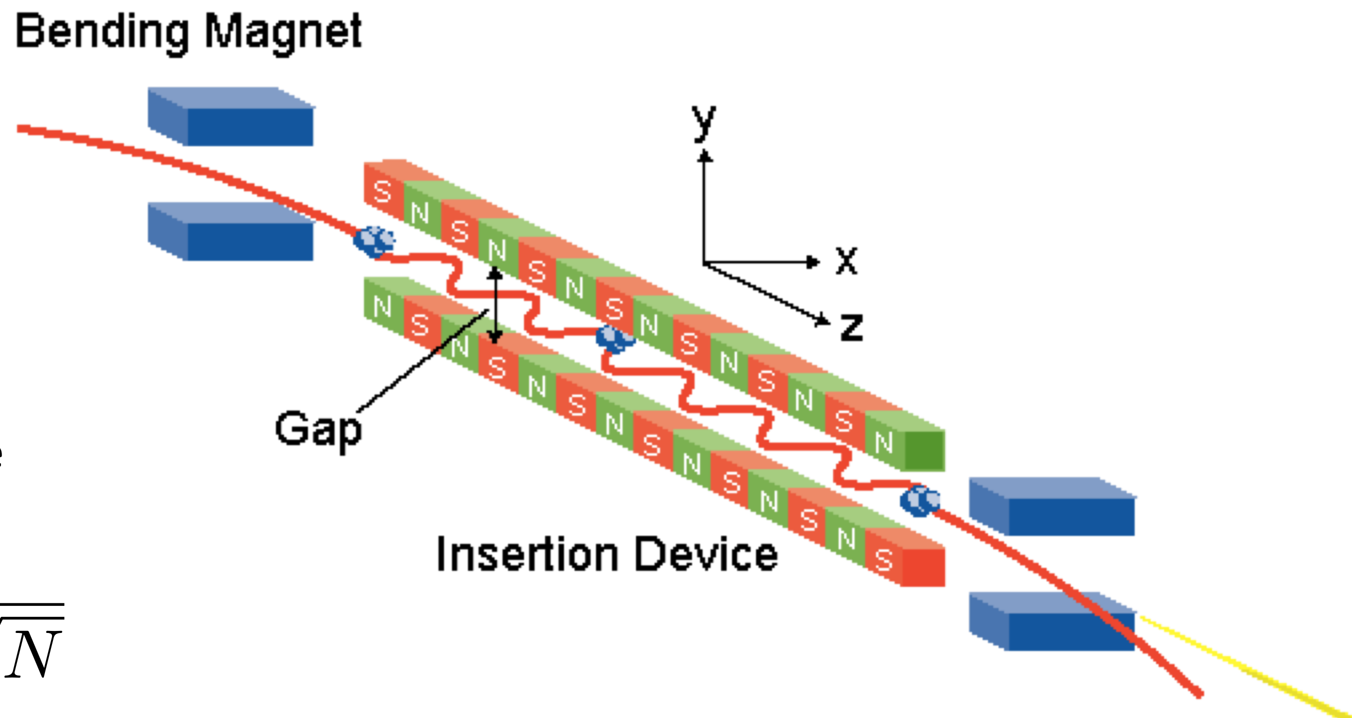
$$\frac{\Delta\lambda}{\lambda} = \frac{1}{N}$$

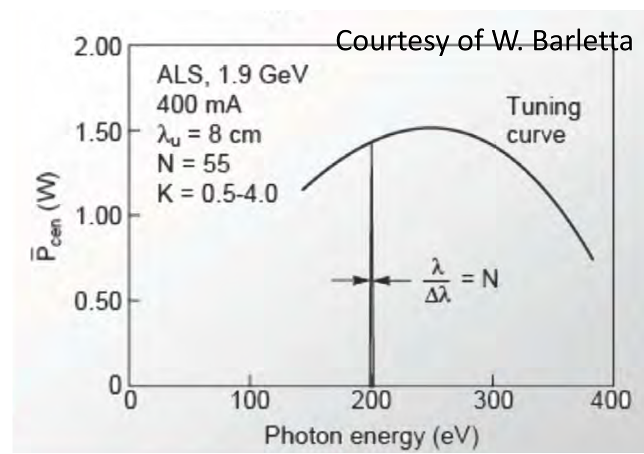
Angle for central cone

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

Power:

$$P_{cen} = \frac{\pi e \gamma^2 I}{\epsilon_0 \lambda_u}\left(\frac{K}{1+K^2/2}\right)^2 f(K)$$

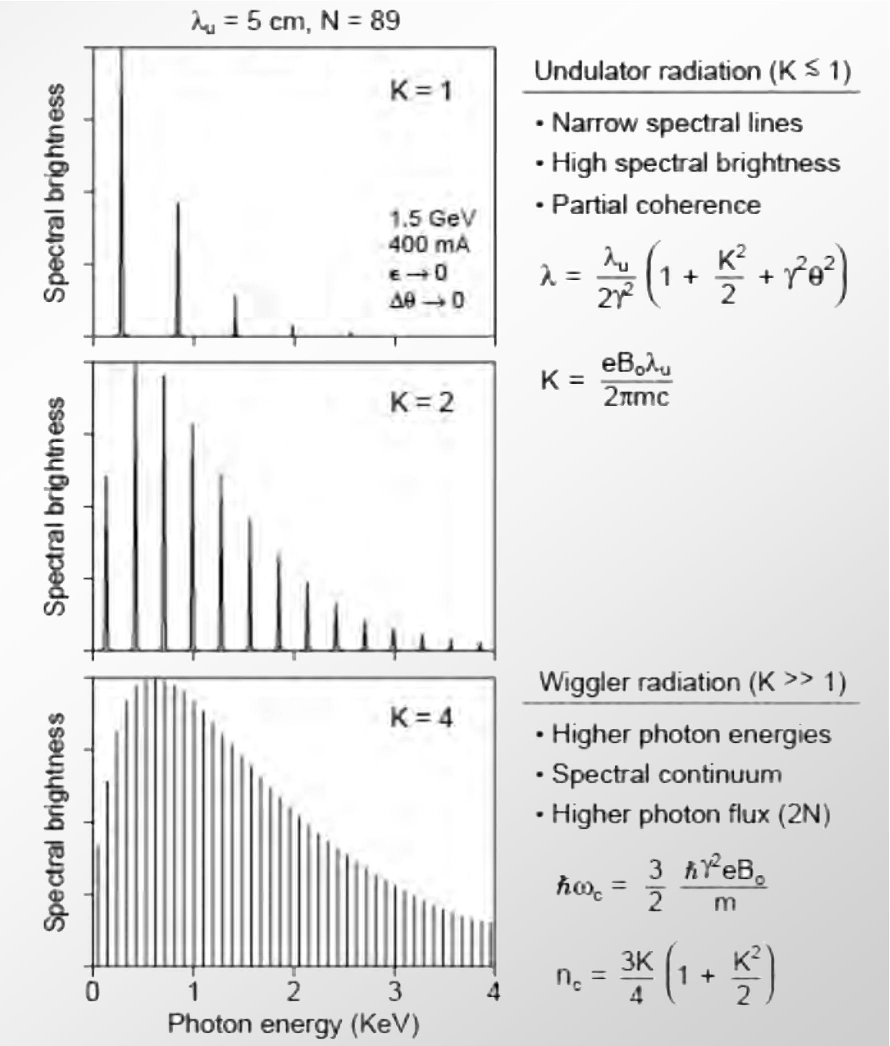




Courtesy of W. Barletta

Wiggler Radiation

- When K>>1, the high harmonics become important and very dense.
- The envelope is similar to the SR from dipoles. The brightness is increased by 2N



(Courtesy of K.-J. Kim)

Beamline 101