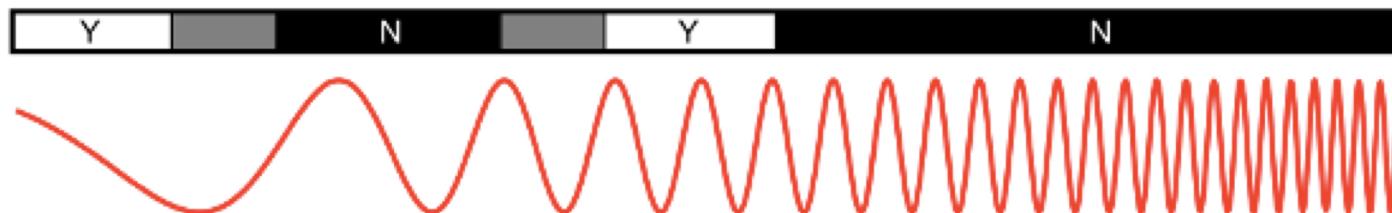


Synchrotron Light Source

Radiation Spectrum

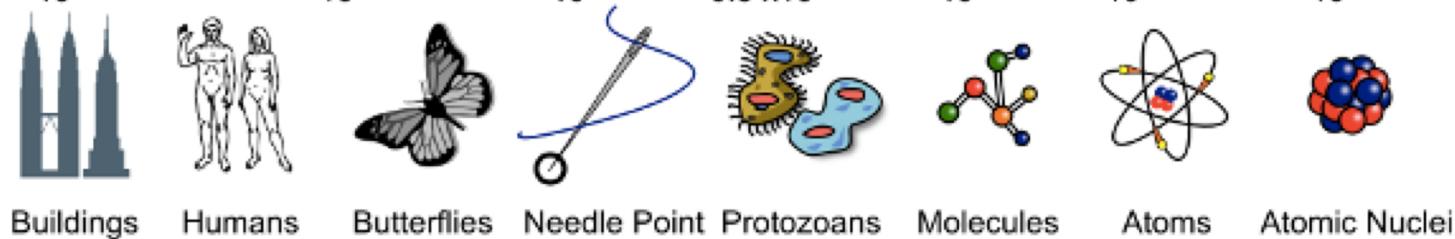
Penetrates Earth's Atmosphere?



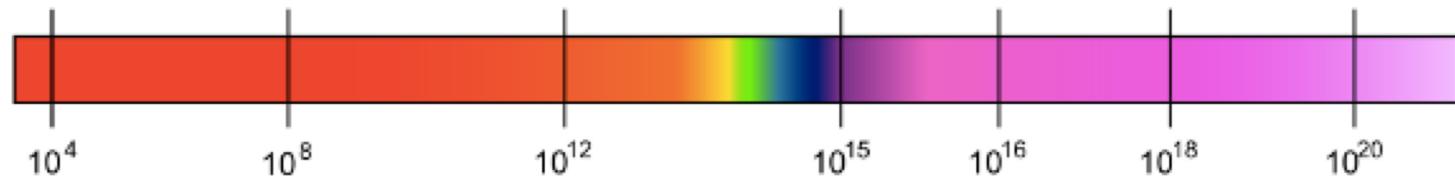
Radiation Type
Wavelength / m

Radio 10^3 Microwave 10^{-2} Infrared 10^{-5} Visible 0.5×10^{-6} Ultraviolet 10^{-8} X-ray 10^{-10} Gamma ray 10^{-12}

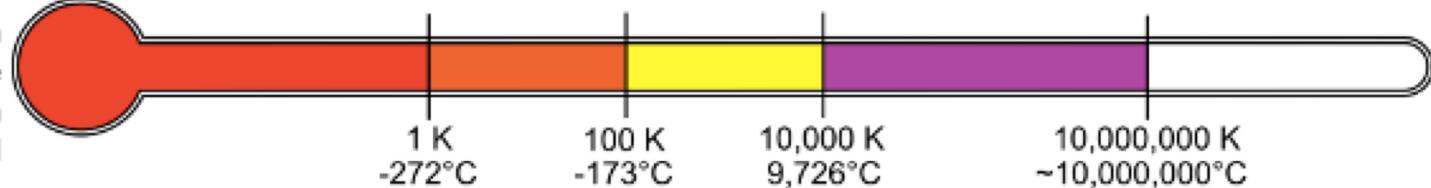
Approximate Scale
of Wavelength



Frequency / Hz



Temperature of
objects at which
this radiation is the
peak wavelength
emitted



Wavelength and Photon Energy

- The following relations are readily used:

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

$$E_p [keV] = \frac{12.4}{\lambda [\text{\AA}]}$$

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

SR Light Source Worldwide

Map Satellite

Google

APS at Argonne National Laboratory

ALBA

ALS Advanced Light Source

Argonne National Laboratory

Australian Synchrotron

HZB Helmholtz Zentrum Berlin

Canadian Light Source Centre canadien de rayonnement synchrotron

CHESS CORNELL HIGH ENERGY SYNCHROTRON SOURCE

diamond

Elettra Sincrotrone Trieste

ESRF The European Synchrotron

LNLS

MAXIV

BROOKHAVEN NATIONAL LABORATORY

NSI S-II at Brookhaven National Laboratory

NSRRC

DESY

Photon Factory Institute of Materials Science High Energy Accelerator Research Organization KEK

SESAME (Honorary Member)

SLAC NATIONAL ACCELERATOR LABORATORY

SRI at SLAC

SYNCHROTRON THAILAND CENTRAL LAB

PSI

European XFEL

Elettra Sincrotrone Trieste

FLASH at DESY

SLAC NATIONAL ACCELERATOR LABORATORY

CLS at SLAC

Swiss FEL at PSI

FEL facilities

Source: Lightsources.org

SR Light Source Worldwide



ESRF, 6 GeV



SPring-8, 8 GeV



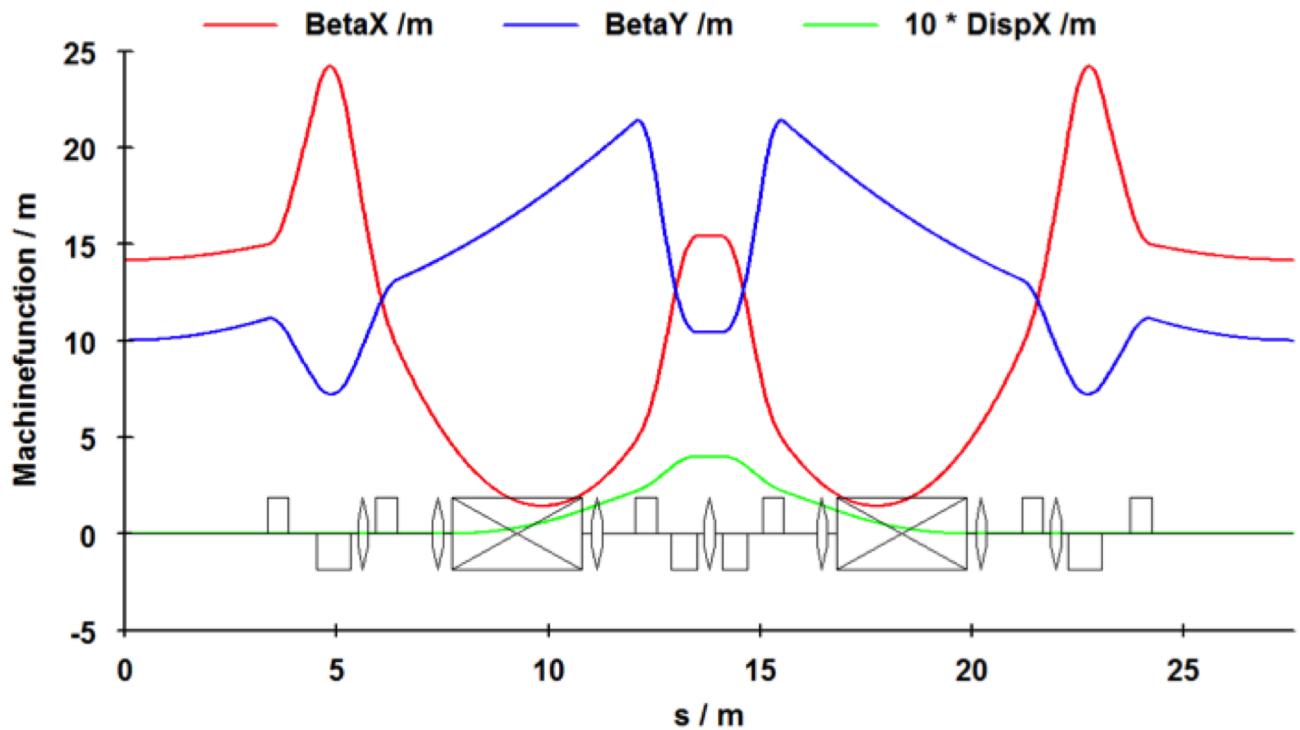
NSLS II, 3 GeV



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

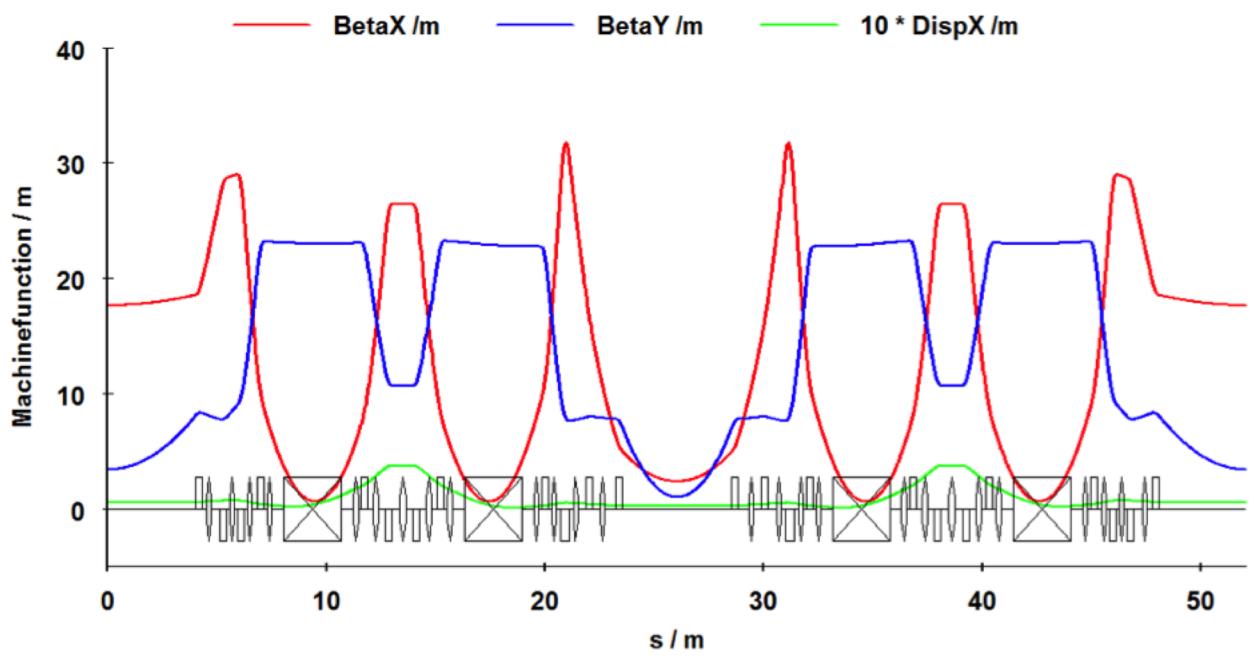


APS @ ANL

APS-U project upgrade the lattice to MBA

Example Lattice NSLS II - DBA

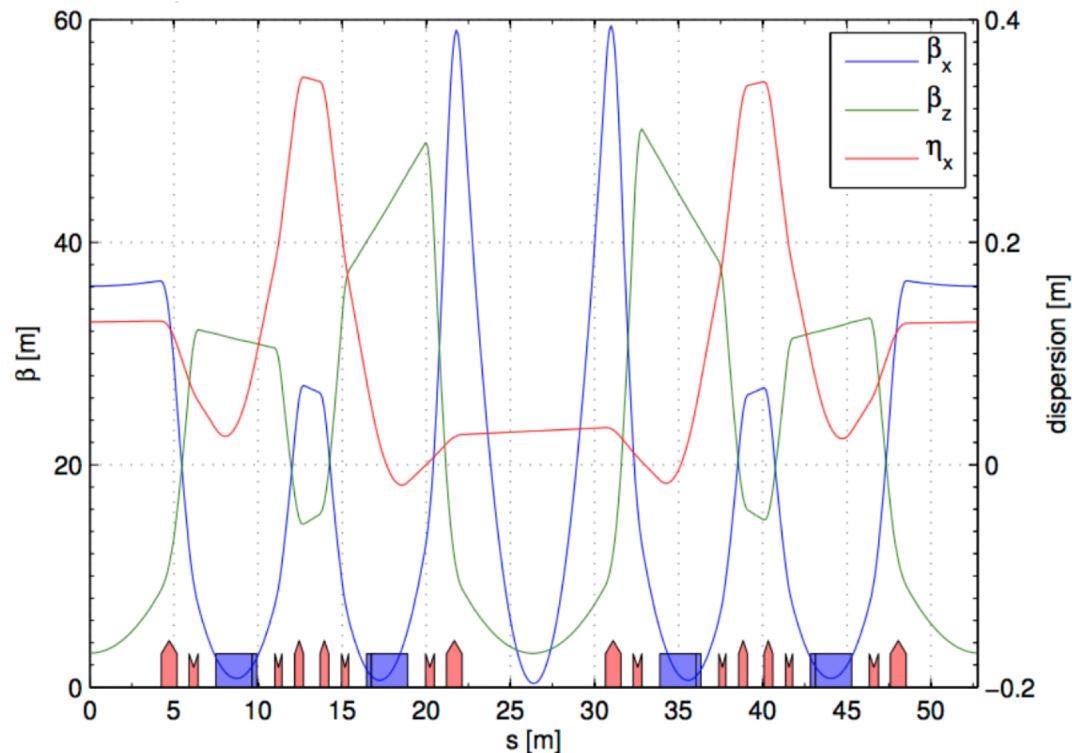
Parameters	value
Energy	3 GeV
C	781.0 m
Ns	15
eps	2.03 nm rad
Qx	32.34
Qy	16.28
alpha	3.67e-4



NSLS-II @ BNL

Example Lattice: ESRF - DBA

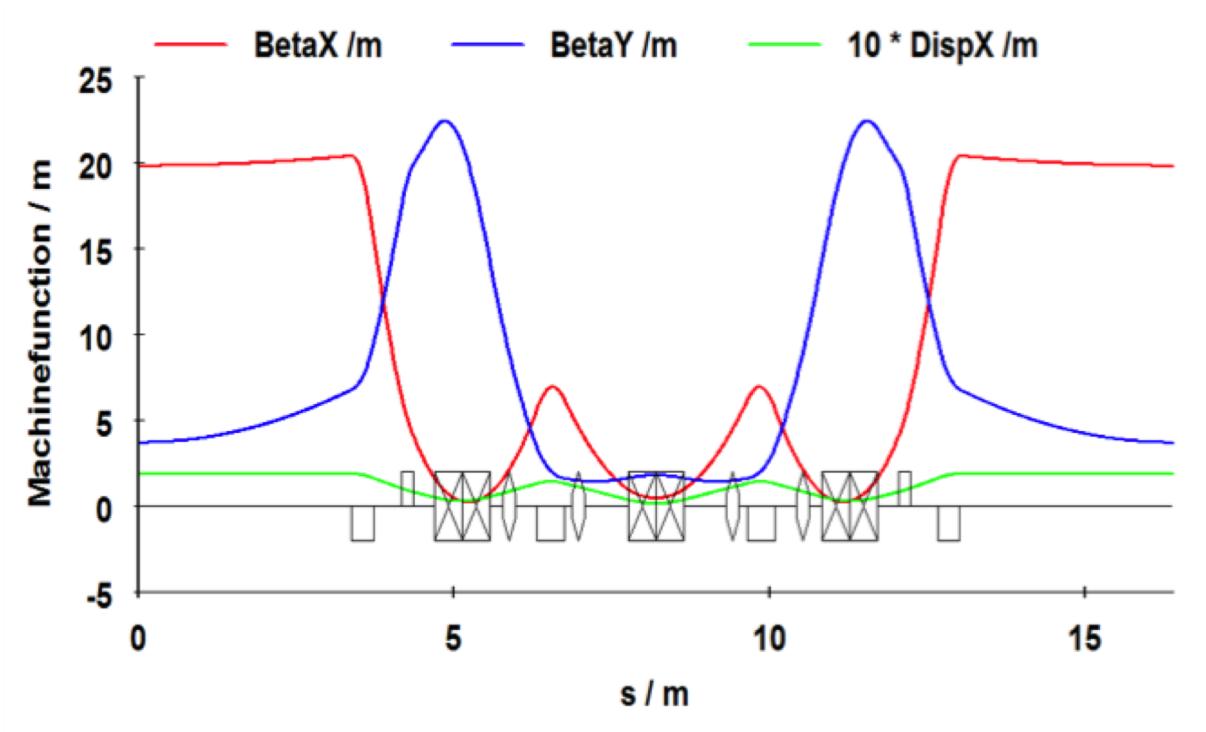
Parameters	value
Energy	6 GeV
C	844 m
Ns	32
eps	4.0 nm rad
Qx	36.44
Qy	13.39
alpha	1.78e-4



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

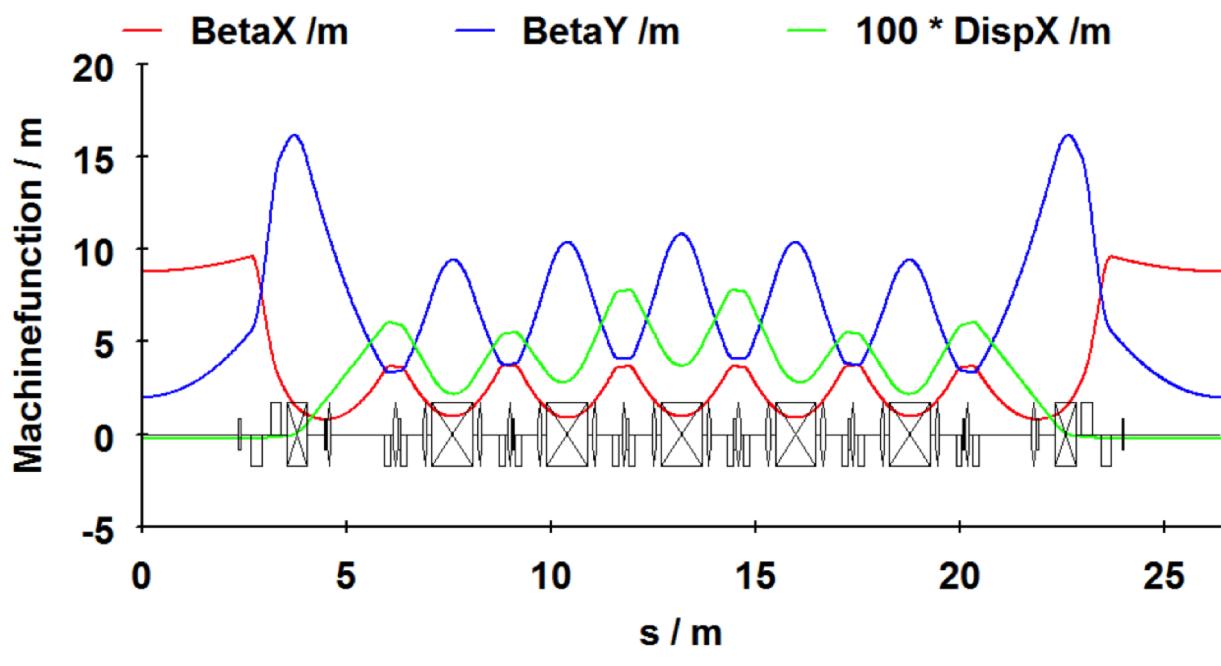


ALS @ LBNL

ALS-U project upgrade the lattice to MBA

Example Lattice: MAX-IV - 7BA

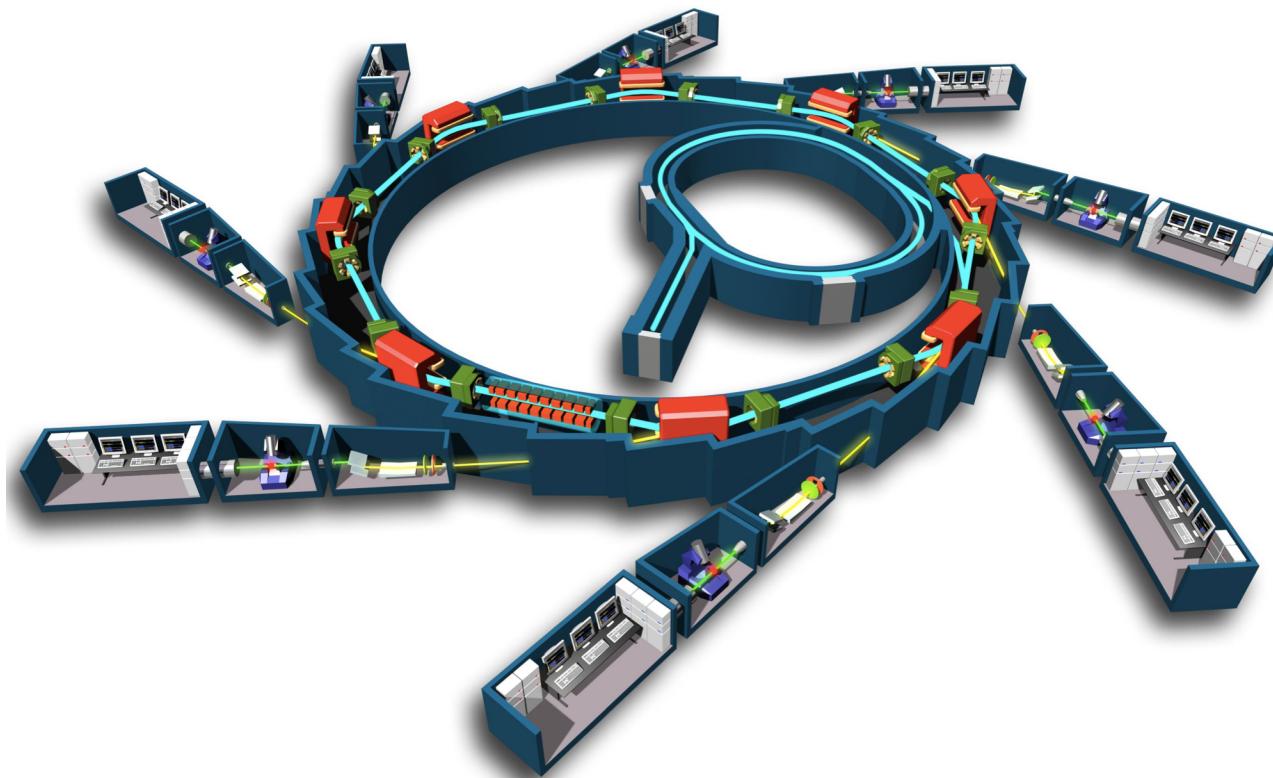
Parameters	value
Energy	3 GeV
C	528 m
Ns	20
eps	0.33 nm rad
Qx	42.24
Qy	16.28
alpha	3.07e-4



MAX-IV @ Sweden

SR Light Source

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



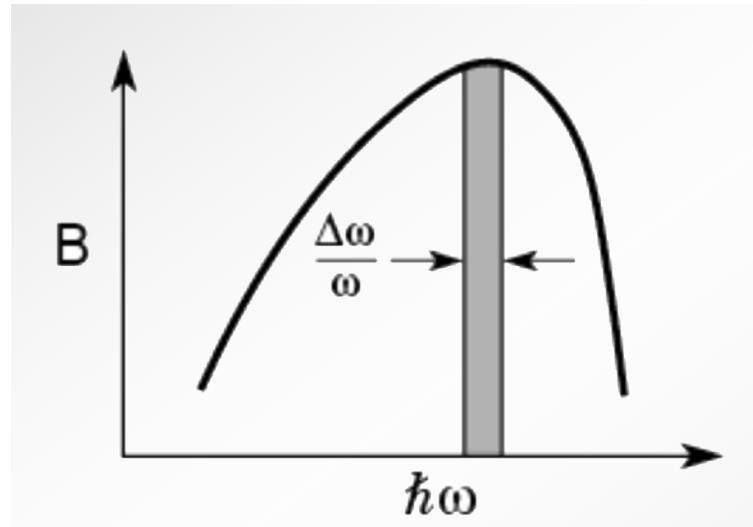
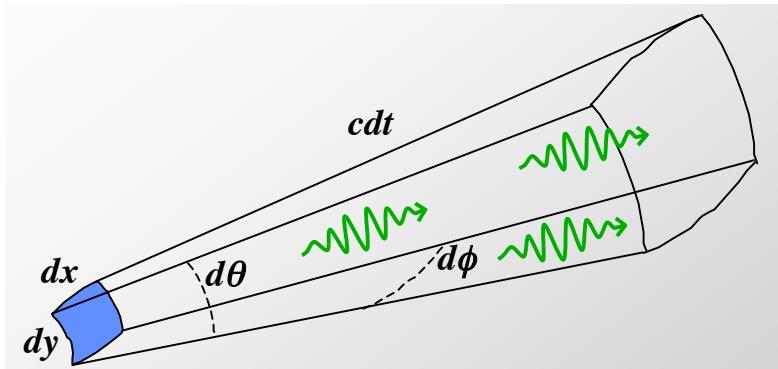
EXCITING
SCIENTIFIC
TOOL.

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

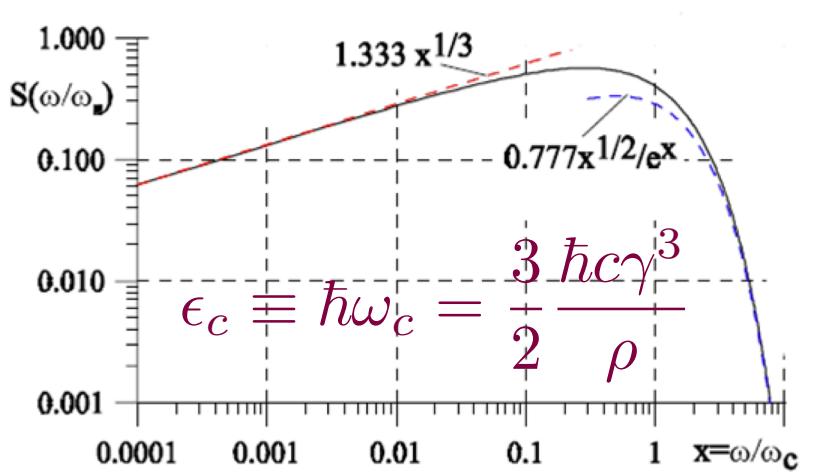
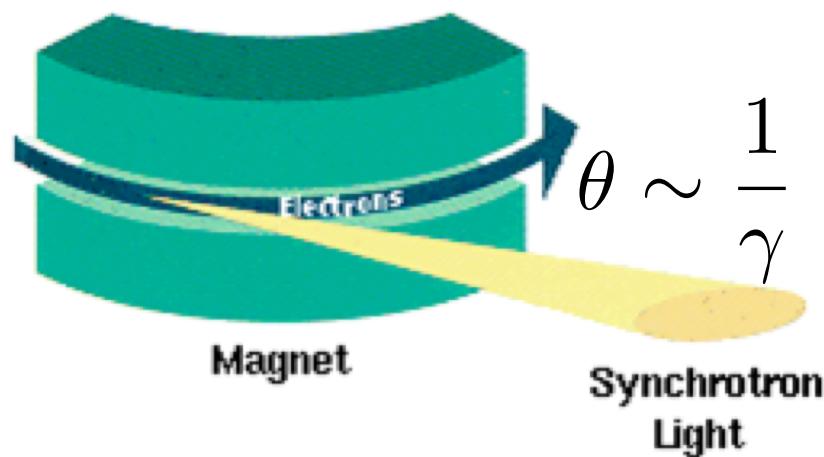
Crystal Diffraction

Many More...

SR is polarized light

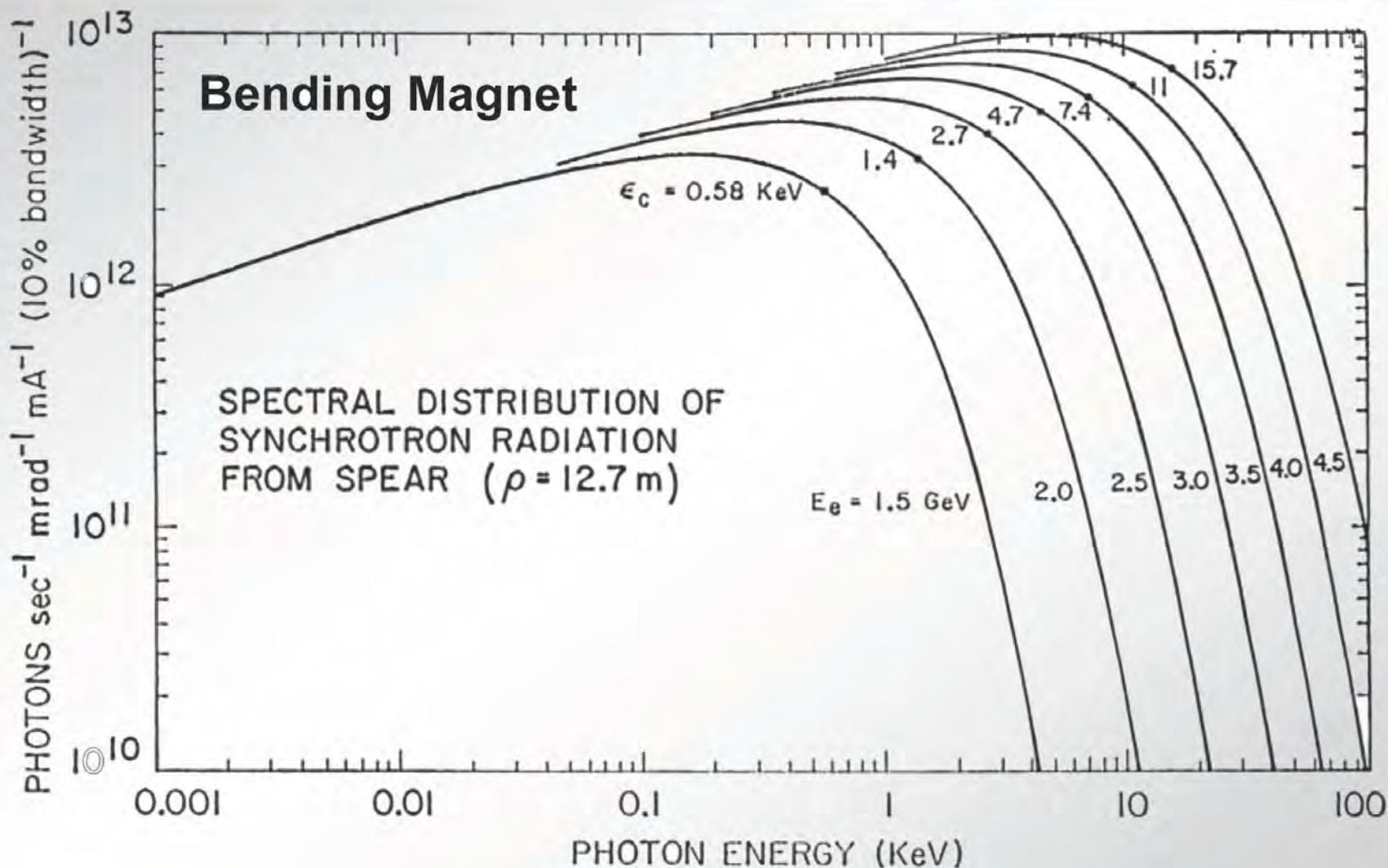


SR from Bending Magnet



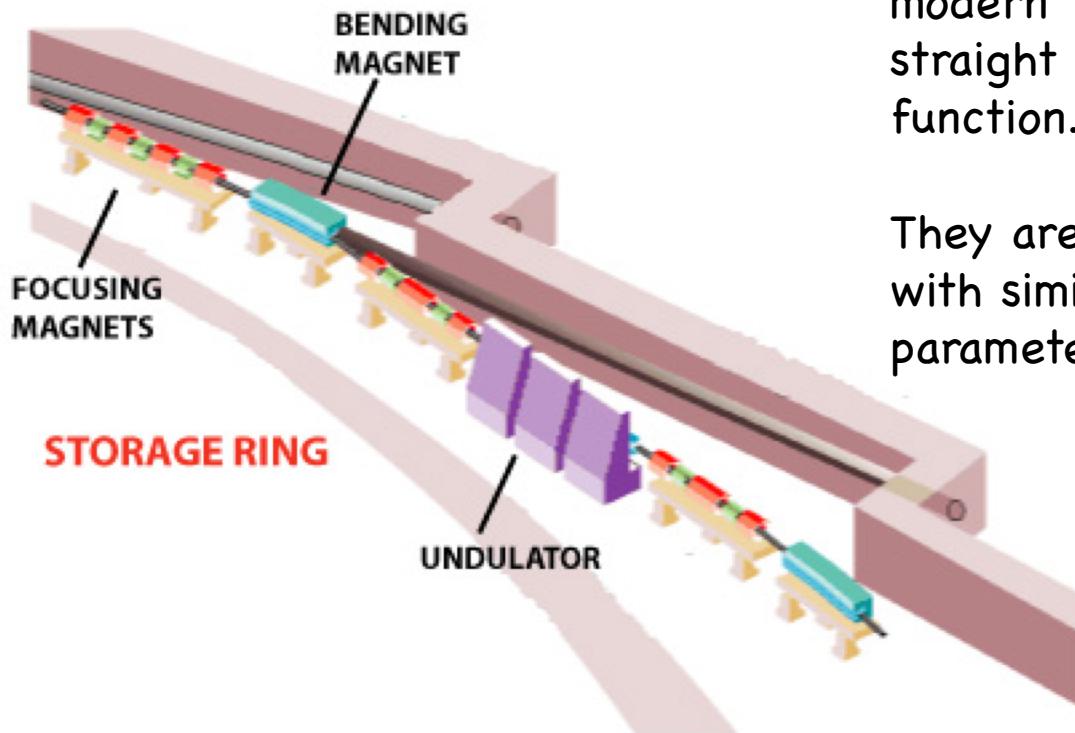
- $$P = \frac{e^2 c}{6\pi\epsilon_0} \frac{\gamma^4}{\rho^2}$$
- Goods
 - Simple, inexpensive
 - Broad spectral range
 - Many beamlines
 - Bads
 - Limited hard x-ray components
 - Not very bright

SR spectrum of Dipole, Energy Dependence



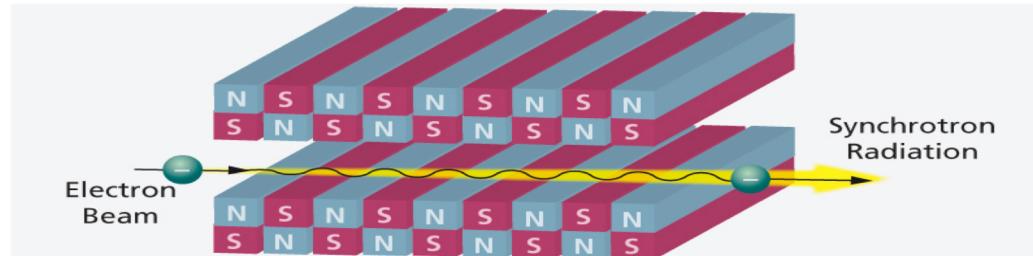
Undulator/Wiggler

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

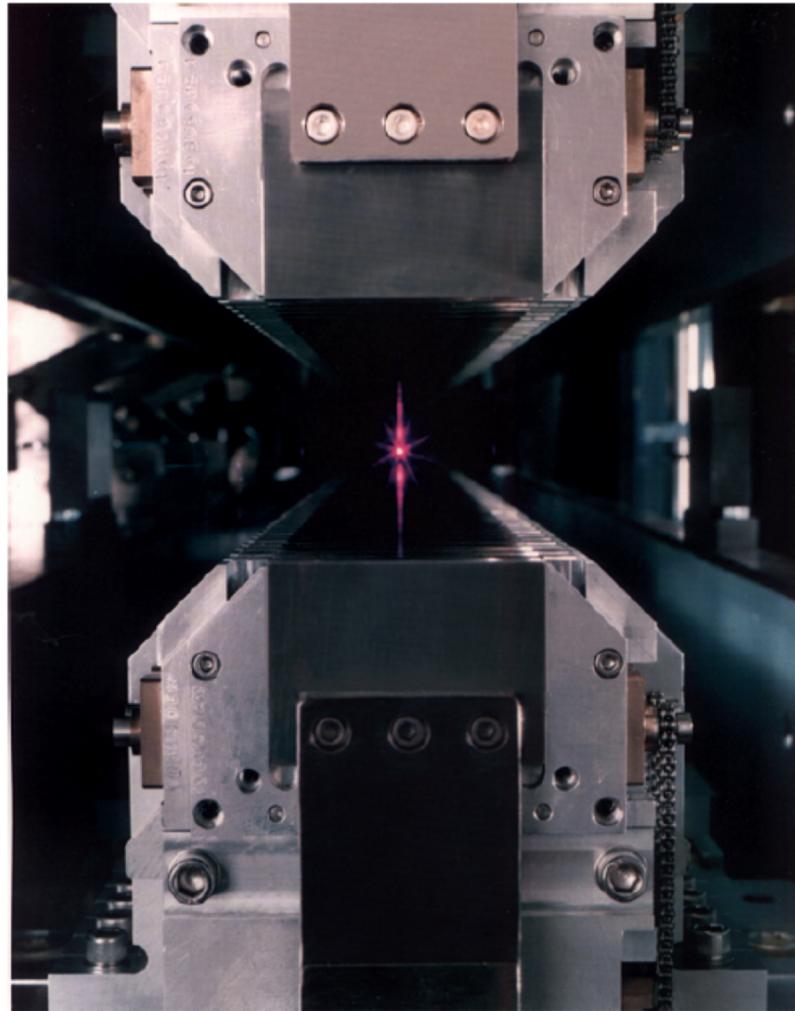


They are undulators and wigglers with similar shape but different parameter.

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



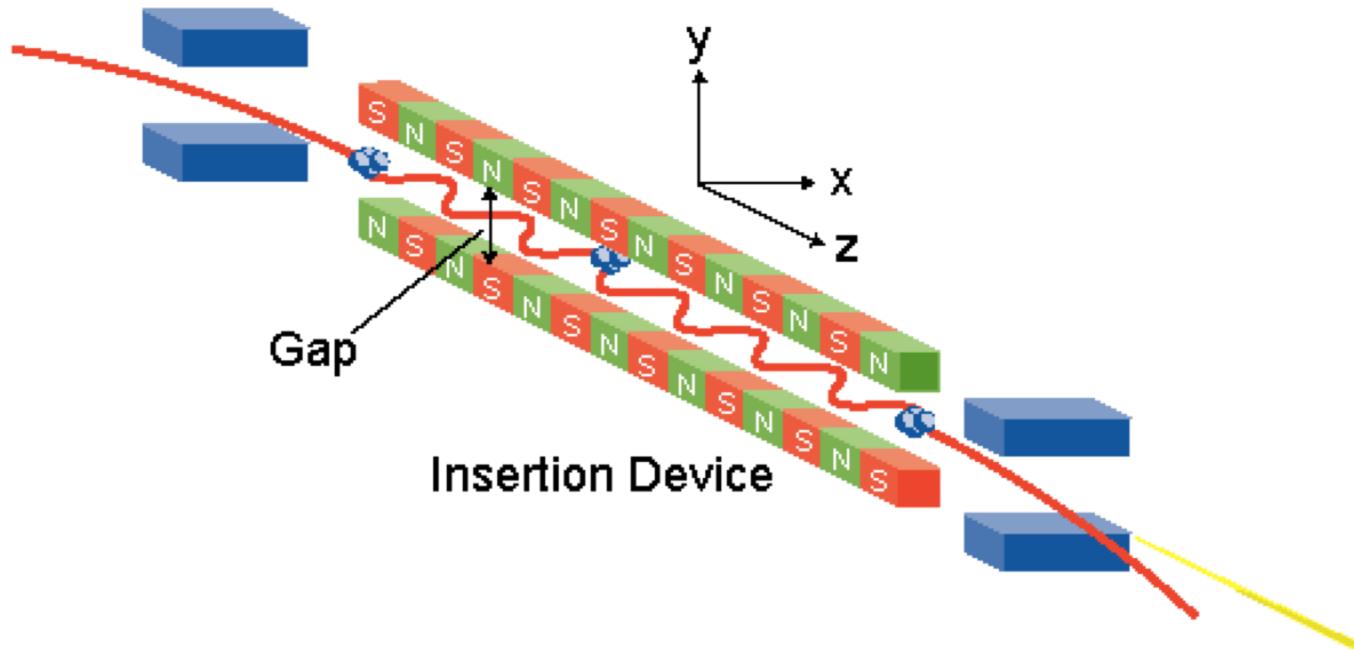
Real Example



ALS U5 undulator, beamlne 7.0, $N = 89$, $\lambda_u = 50$ mm

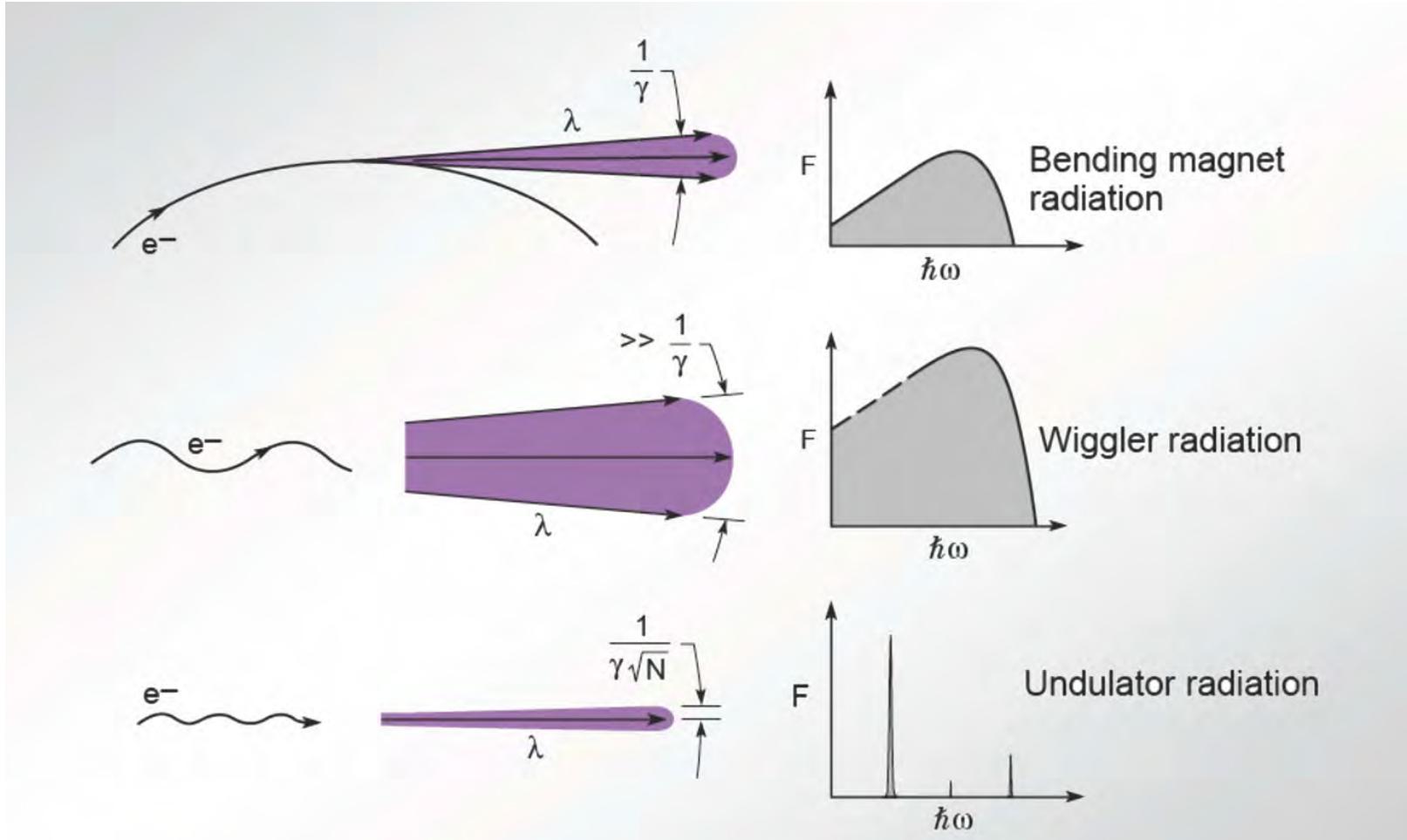
SR from Undulator/Wiggler

Bending Magnet



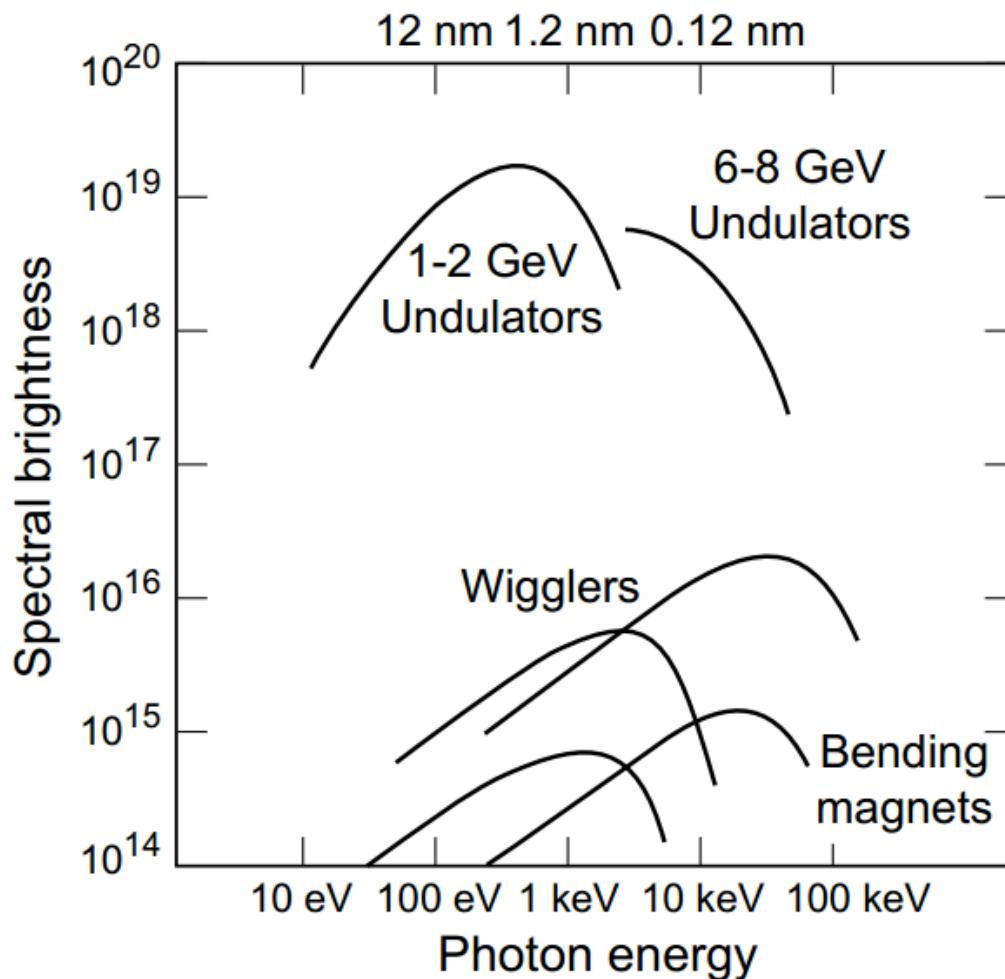
They are 'insertion devices' in straight sections. Modern accelerators provide many long straight sections.

Difference between bending magnet and Undulator/Wiggler



Courtesy of W. Barletta

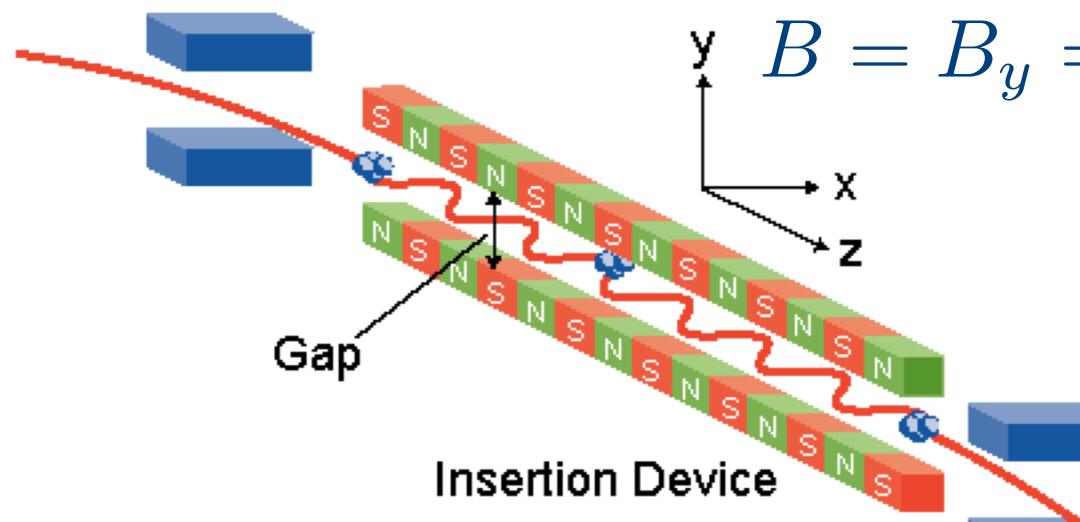
Brightness Comparison



Courtesy of W. Barletta

Electron Motion inside Undulator

Bending Magnet



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

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

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

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

Undulator 'Slows down' the electron

$$v_z = \sqrt{v^2 - v_x^2} = c \sqrt{1 - \frac{1}{\gamma^2} - \frac{K^2}{\gamma^2} \sin^2 \frac{2\pi z}{\lambda_u}}$$
$$= c \left(1 - \frac{1 + K^2/2}{2\gamma^2} + \frac{K^2}{4\gamma^2} \cos \frac{4\pi z}{\lambda_u} \right)$$

$$\bar{v}_z = c \left(1 - \frac{1 + K^2/2}{2\gamma^2} \right)$$

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:

$$\bar{v}_z = c\left(1 - \frac{1 + K^2/2}{2\gamma^2}\right)$$

- 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

Bending Magnet

Radiation Bandwidth:

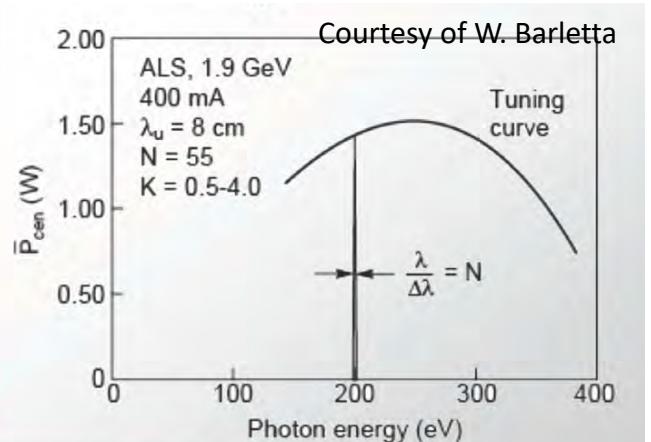
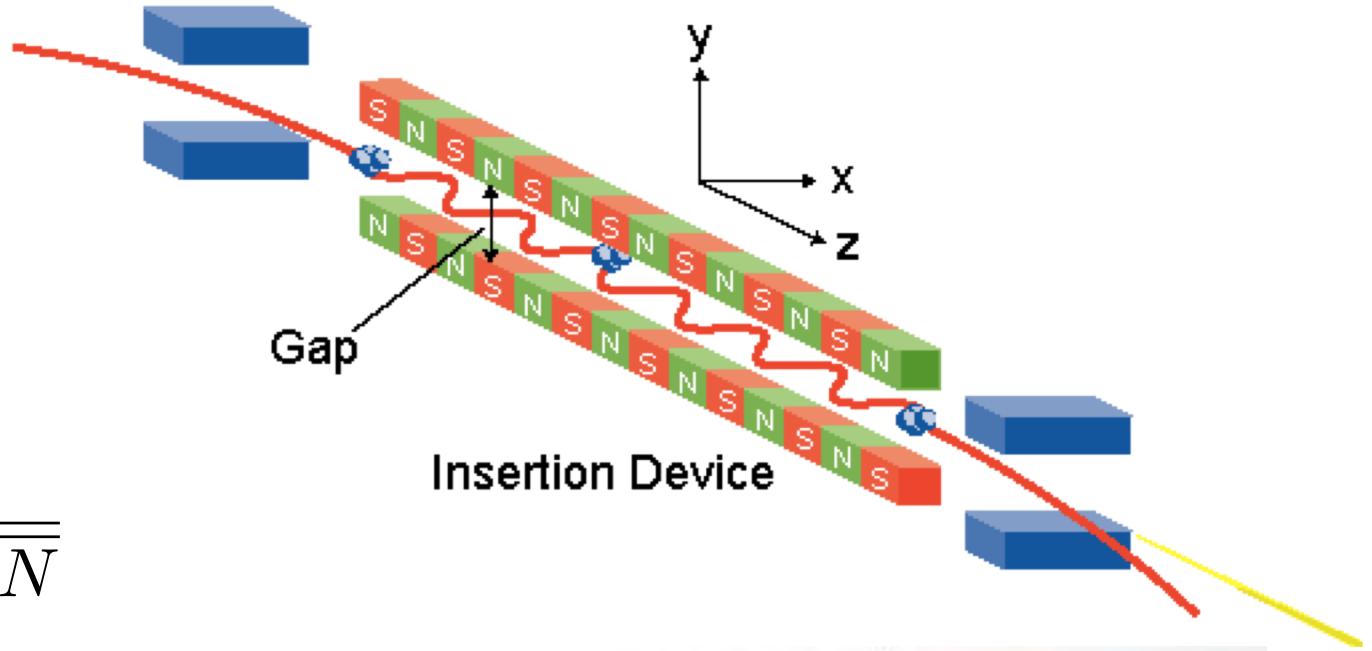
$$\frac{\Delta\lambda}{\lambda} = \frac{1}{N}$$

Angle for central cone

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

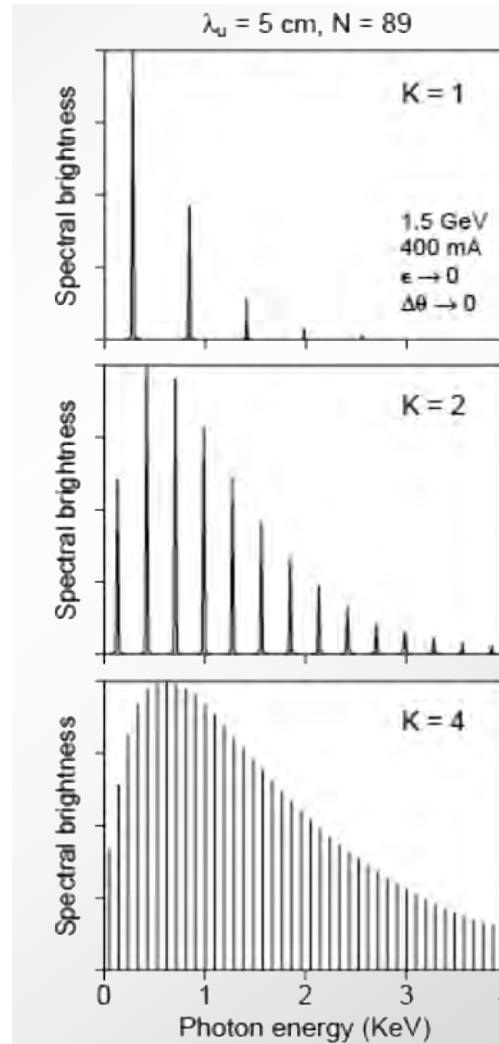
Power:

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



Wiggler Radiation

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



Undulator radiation ($K \leq 1$)

- Narrow spectral lines
- High spectral brightness
- Partial coherence

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

$$K = \frac{eB_0\lambda_u}{2\pi mc}$$

Wiggler radiation ($K \gg 1$)

- Higher photon energies
- Spectral continuum
- Higher photon flux ($2N$)

$$\hbar\omega_c = \frac{3}{2} \frac{\hbar\gamma^2 e B_0}{m}$$

$$n_c = \frac{3K}{4} \left(1 + \frac{K^2}{2} \right)$$

(Courtesy of K.-J. Kim)

Beamline 101

