Today's outline - August 31, 2021

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Reading Assignment: Chapter 2.3–2.4

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Reading Assignment: Chapter 2.3–2.4

Homework Assignment #01:
Chapter 2: 2,3,5,6,8
due Tuesday, September 07, 2021

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Homework Assignment #01:
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due Tuesday, September 07, 2021

Homework Assignment #02:
Problems on Blackboard
due Tuesday, September 21, 2021

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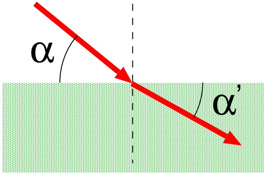

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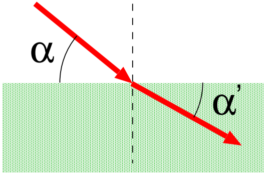

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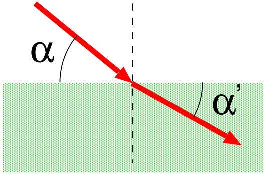

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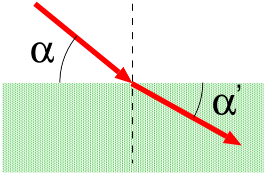

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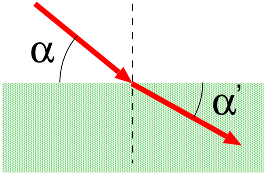

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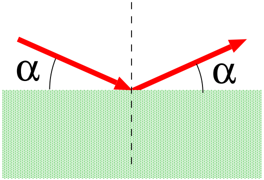

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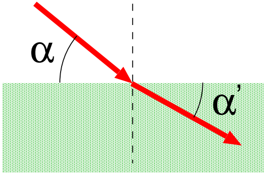

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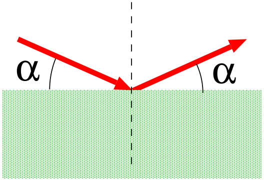

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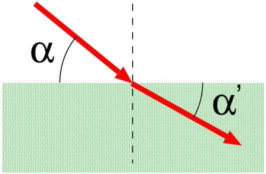

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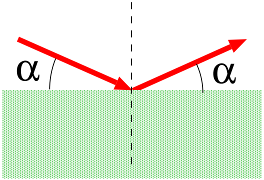

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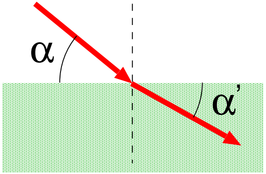

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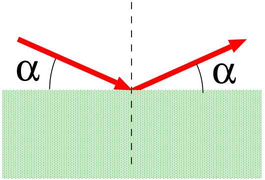

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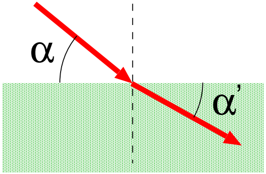

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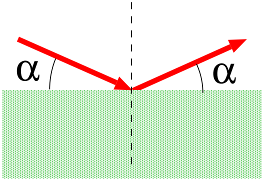

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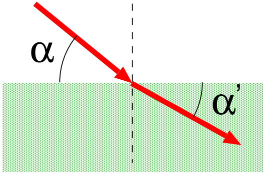

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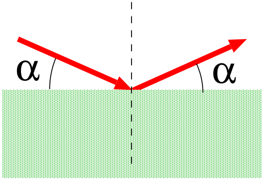

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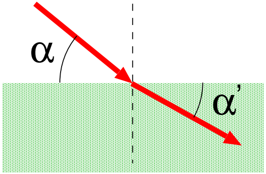

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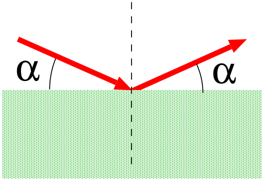

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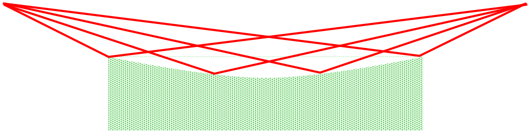

X-ray mirrors

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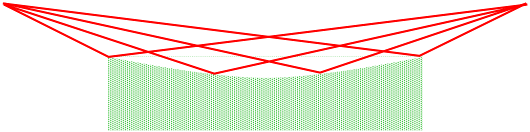

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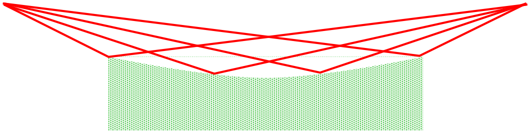

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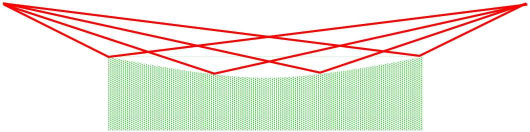

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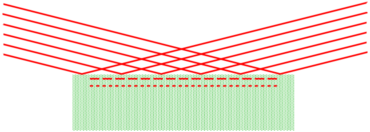

Evanscent wave experiments

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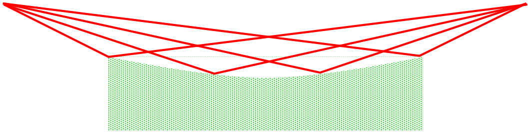

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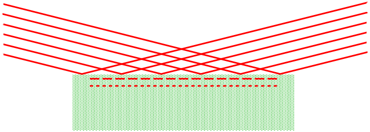

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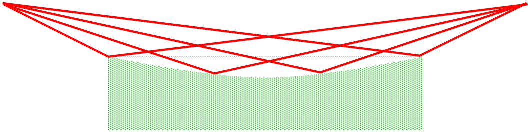

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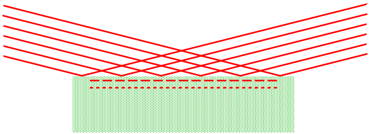

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Because of these imperfections the "coherence length" of an x-ray beam is finite and we can calculate it.

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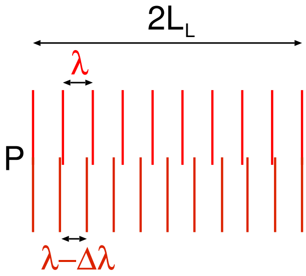

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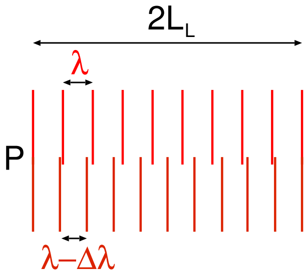

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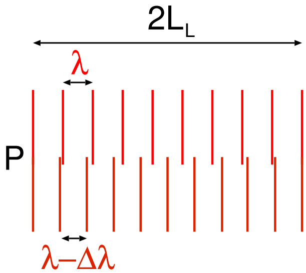

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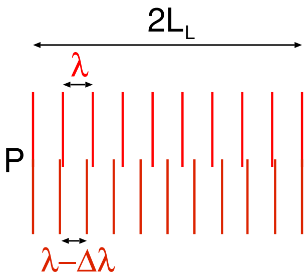

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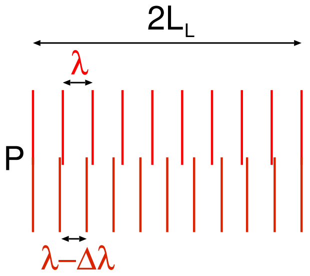

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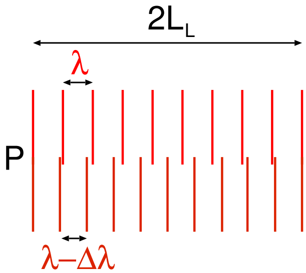

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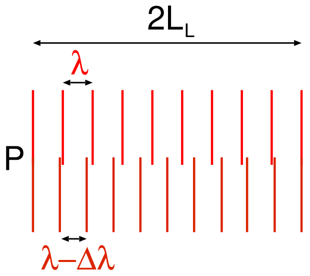

Two waves of slightly different wavelengths λ and $\lambda - \Delta\lambda$ are emitted from the same point in space simultaneously.

After a distance L_L, the two waves will be exactly out of phase and after $2L_L$ they will once again be in phase.

$$2L_L = N\lambda$$
$$2L_L = (N+1)(\lambda - \Delta\lambda)$$

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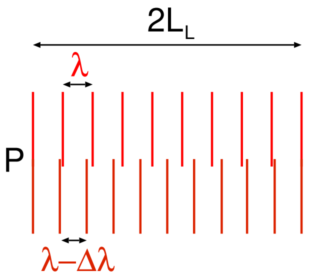

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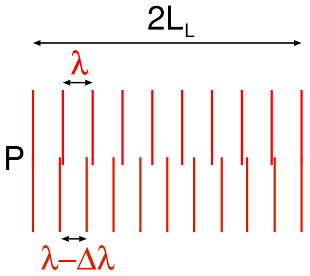

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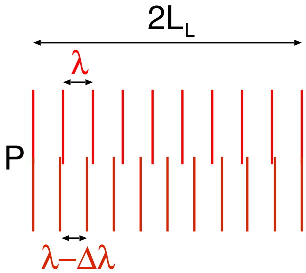

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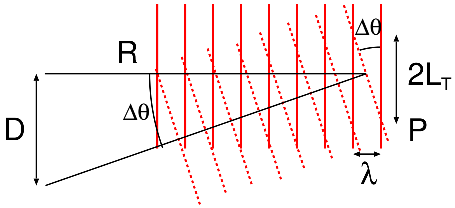

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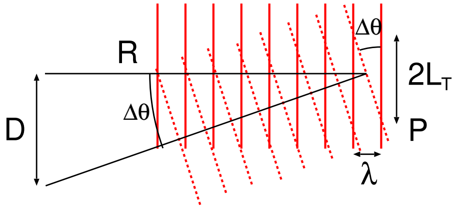

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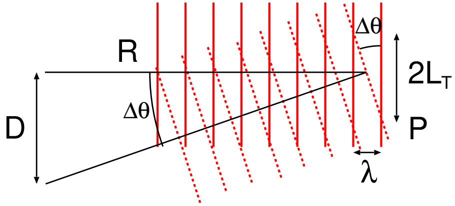

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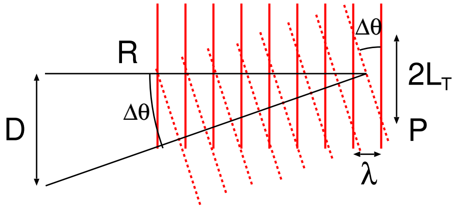

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Coherence lengths at the APS

For a typical 3^{rd} generation undulator source, such as at the Advanced Photon Source the vertical source size is $D_v = 10\mu\text{m}$ and we are typically $R = 50\text{m}$ away with our experiment. If we assume a typical wavelength of $\lambda = 1\text{Å}$, and a monochromator resolution of $\Delta\lambda/\lambda = 10^{-5}$ we have for the vertical direction:

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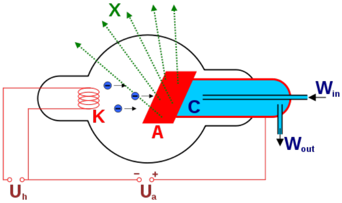
$$L_T = \frac{\lambda R}{2D} = \frac{(1 \times 10^{-10}) \cdot 50}{2 \cdot (10 \times 10^{-6})} = 250\mu\text{m}$$

Lab x-ray source schematics

Fixed anode tube



- low power
- low maintenance

Lab x-ray source schematics

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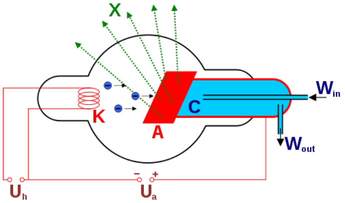
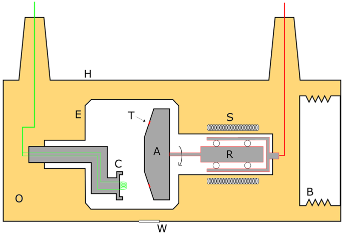


Rotating anode tube



- low power
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- high power
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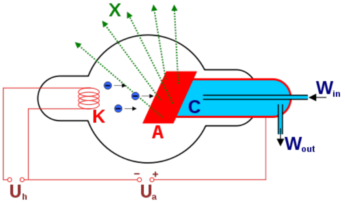

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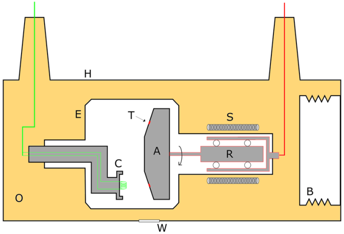

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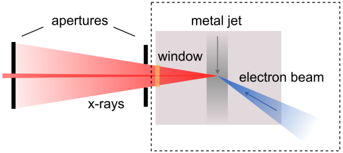
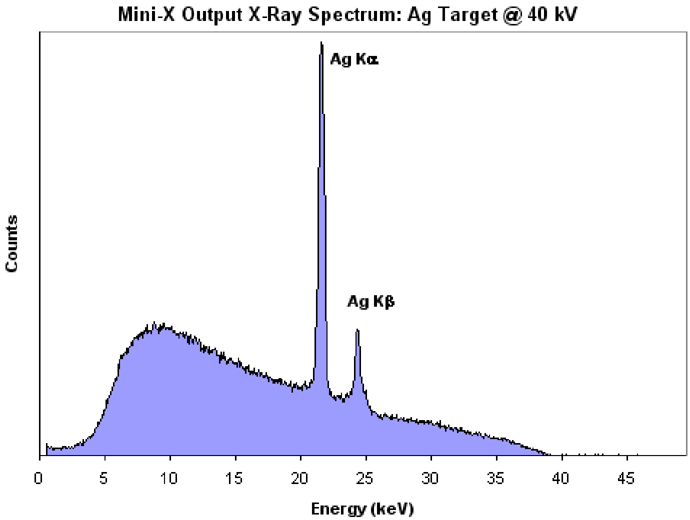
- high maintenance

Liquid metal jet



- high brightness
- small spot size

X-ray tube spectrum



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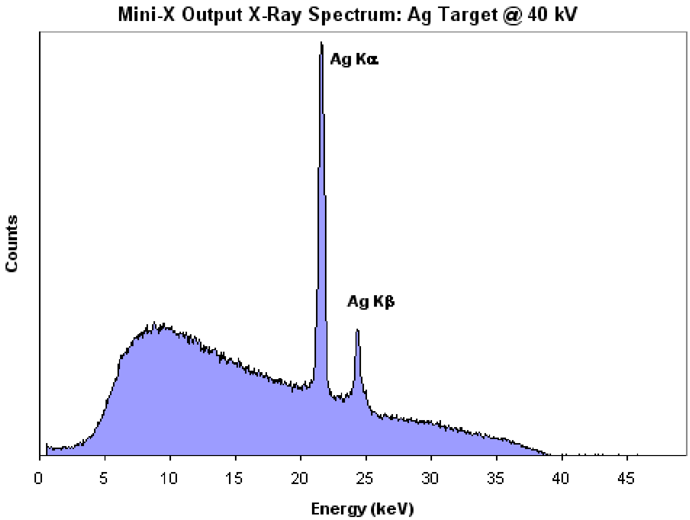

- Minimum wavelength (maximum energy) set by accelerating potential

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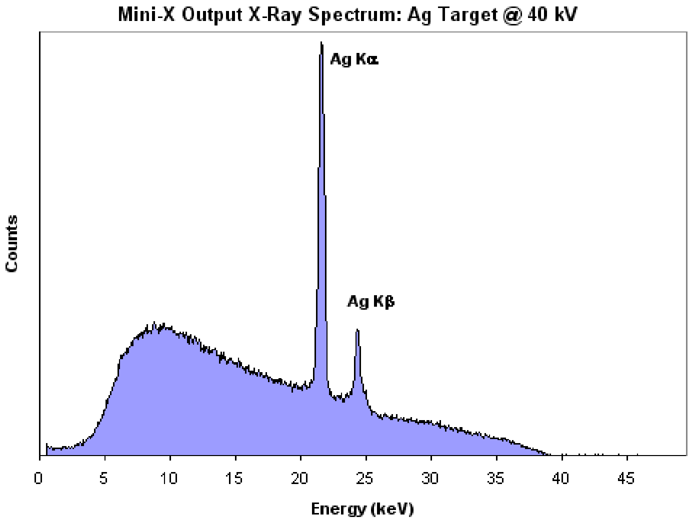

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- Bremßtrahlung radiation provides smooth background (charged particle deceleration)

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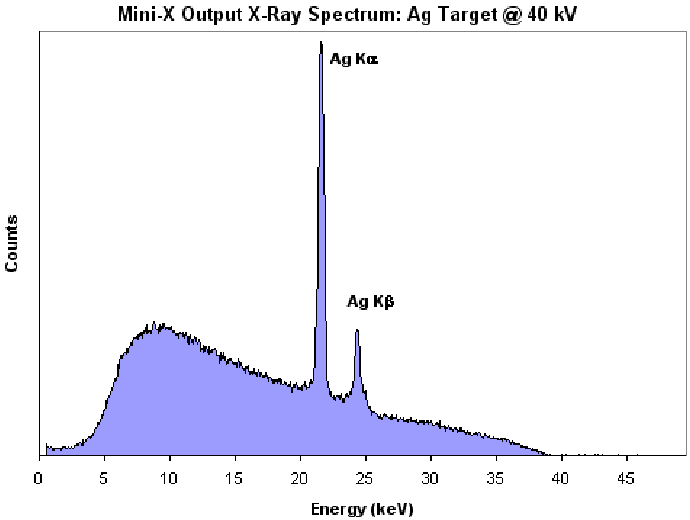

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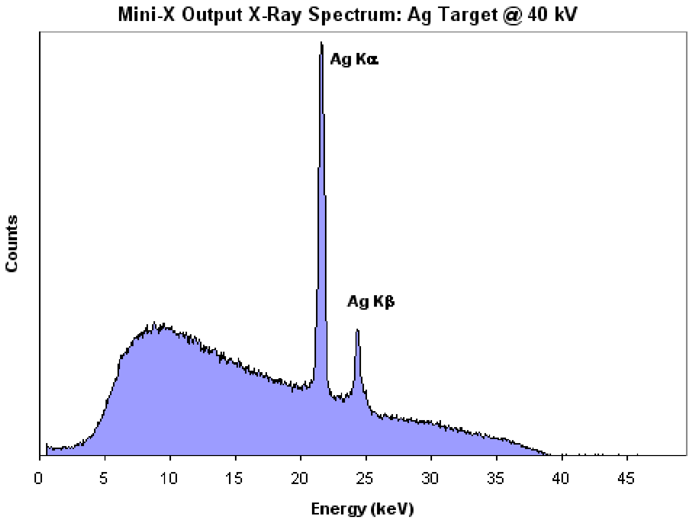
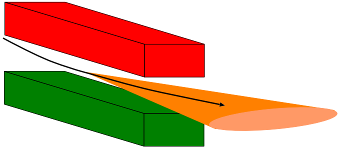


- Minimum wavelength (maximum energy) set by accelerating potential
- Bremßtrahlung radiation provides smooth background (charged particle deceleration)
- Highest intensity at the characteristic fluorescence emission energy of the anode material
- Unpolarized, incoherent x-rays emitted in all directions from anode surface, must be collimated with slits

Synchrotron sources

Bending magnet



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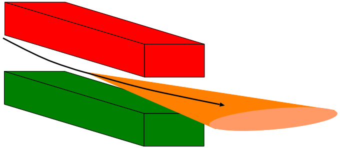

- Wide horizontal beam

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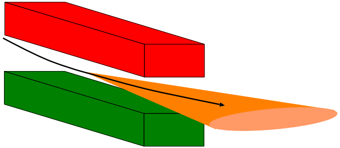

- Wide horizontal beam
- Broad spectrum

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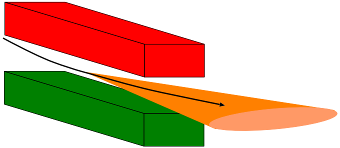

- Wide horizontal beam
- Broad spectrum
- Low brilliance

Synchrotron sources

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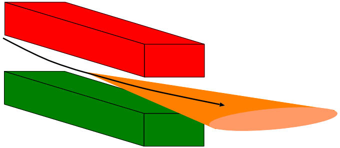
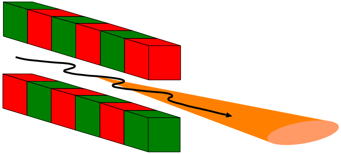


Wiggler



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Synchrotron sources

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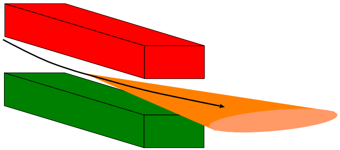

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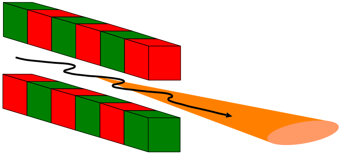

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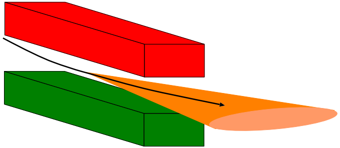

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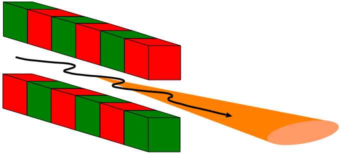

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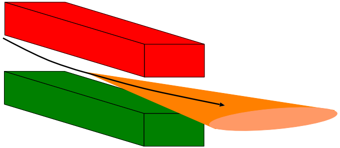

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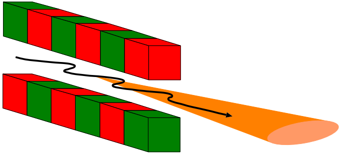
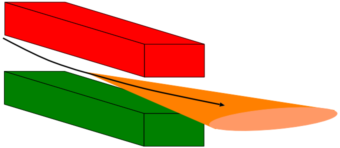


- Wide horizontal beam
- Broad spectrum
- Higher critical energy

Synchrotron sources

Bending magnet



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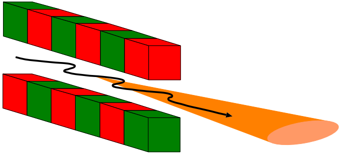

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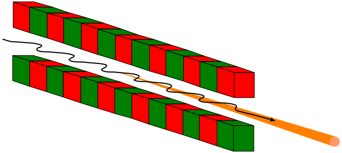
Undulator



Synchrotron sources

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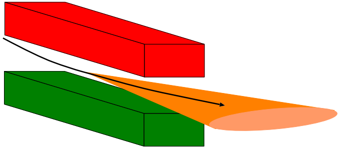

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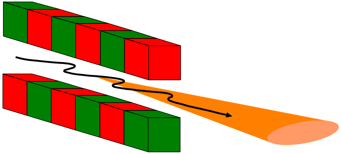

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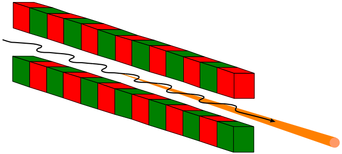
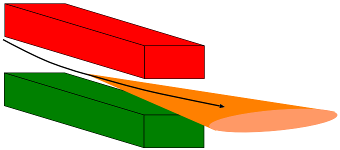


- Highly collimated beam

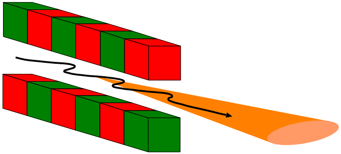
Synchrotron sources

Bending magnet



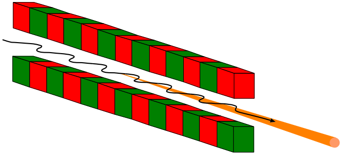
- Wide horizontal beam
- Broad spectrum
- Low brilliance

Wiggler



- Wide horizontal beam
- Broad spectrum
- Higher critical energy

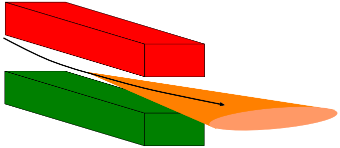
Undulator



- Highly collimated beam
- Highly peaked spectrum

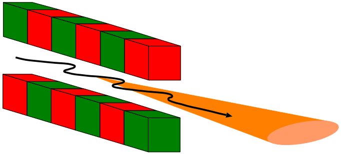
Synchrotron sources

Bending magnet



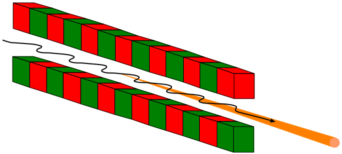
- Wide horizontal beam
- Broad spectrum
- Low brilliance

Wiggler



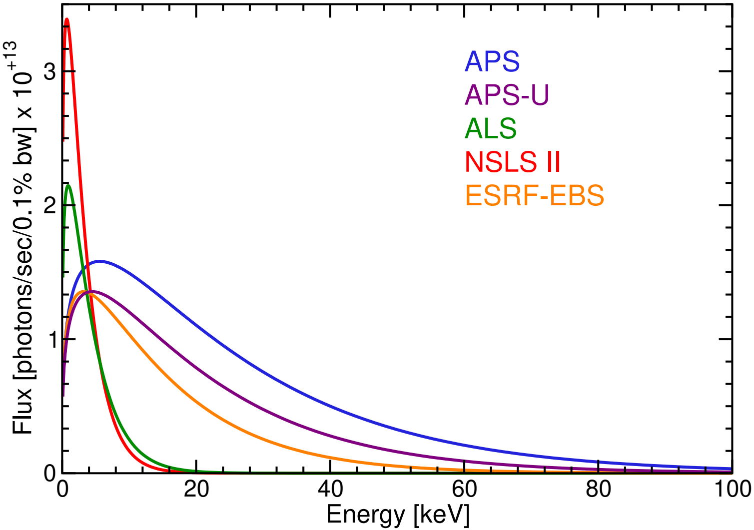
- Wide horizontal beam
- Broad spectrum
- Higher critical energy

Undulator

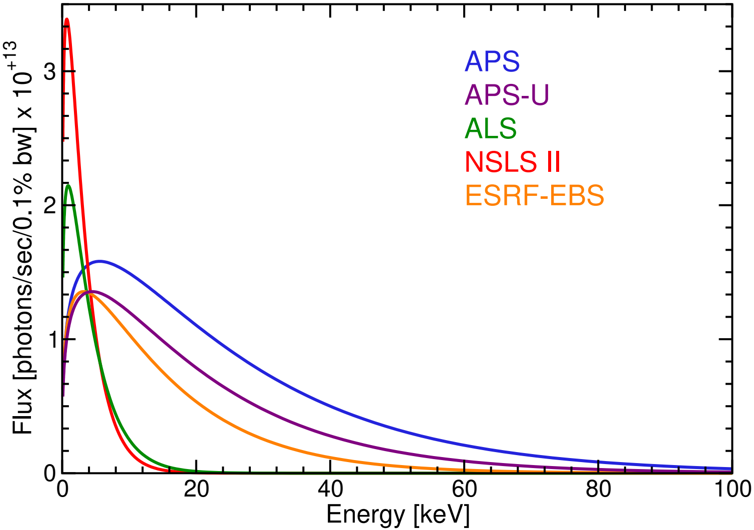


- Highly collimated beam
- Highly peaked spectrum
- High brightness

Bending magnet spectra



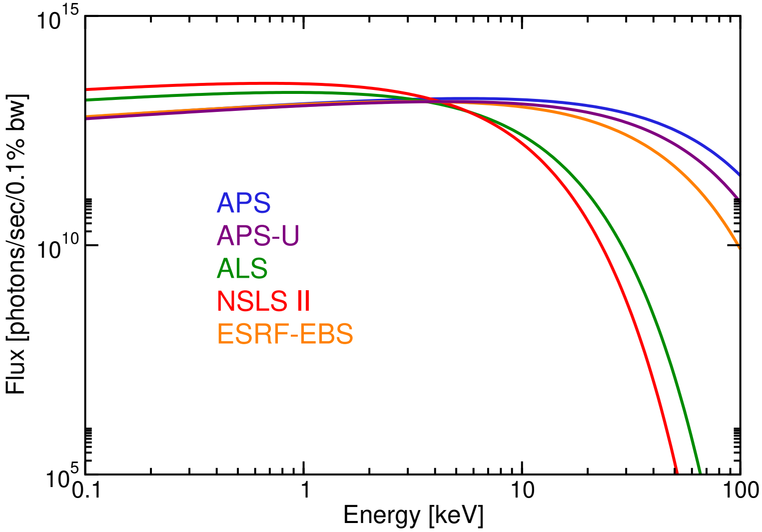
Bending magnet spectra



Lower energy sources, such as NSLS have lower peak energy and higher intensity at the peak.

Logarithmic scale shows clearly how much more energetic and intense the bending magnet sources at the 6 GeV and 7 GeV sources are.

Bending magnet spectra

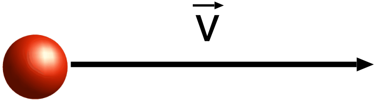


Lower energy sources, such as NSLS have lower peak energy and higher intensity at the peak.

Higher energy sources, such as APS have higher energy spectrum and are only off by a factor of 2 intensity at low energy.

Logarithmic scale shows clearly how much more energetic and intense the bending magnet sources at the 6 GeV and 7 GeV sources are.

Review of special relativity



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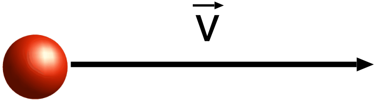

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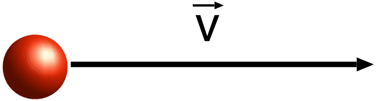

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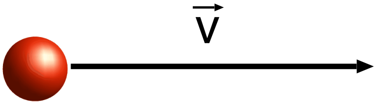

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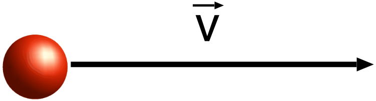

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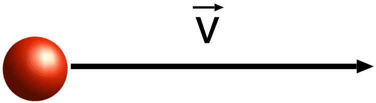

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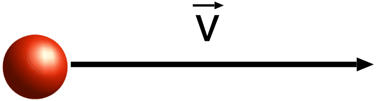

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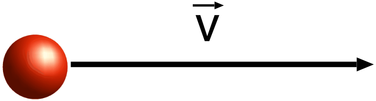

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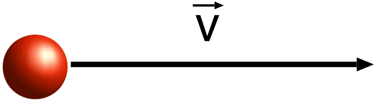

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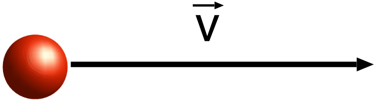

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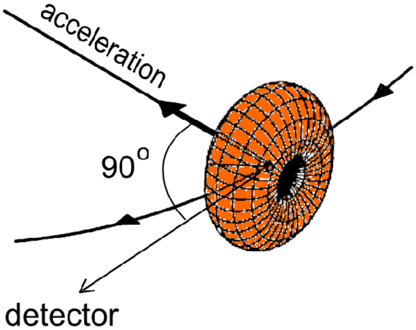
"Headlight" effect

In electron rest frame:



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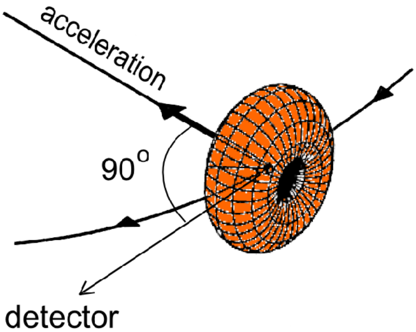

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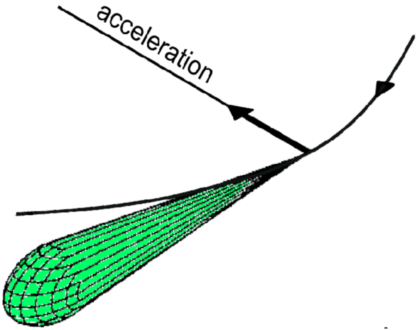
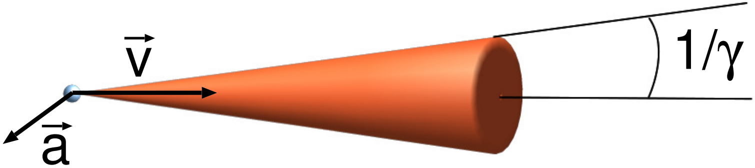
In lab frame:



emission is pushed into the direction of motion of the electron

Relativistic emission



the electron is in constant transverse acceleration due to the Lorentz force from the magnetic field of the bending magnet

$$\vec{F} = e\vec{v} \times \vec{B} = m_e\vec{a}$$

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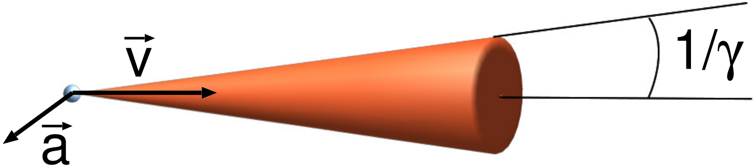

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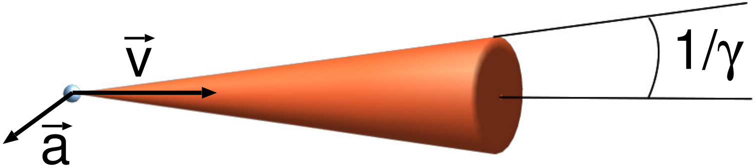

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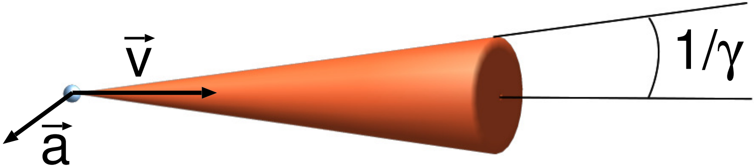

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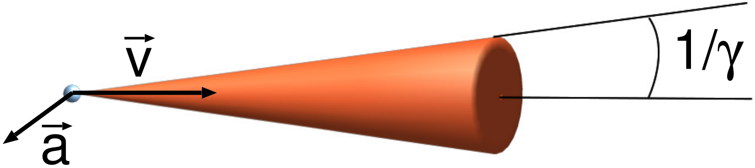

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for the APS, with $\gamma \approx 10^4$ we have

$$E_{max} \approx (10^4)^3 \cdot 10^6 = 10^{18}$$

Flux and brightness

There are a number of important quantities which are relevant to the quality of an x-ray source:

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photon flux | source type | optics

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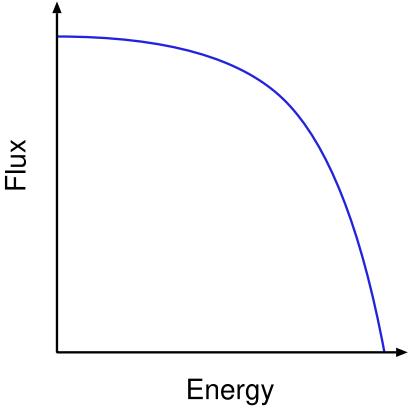

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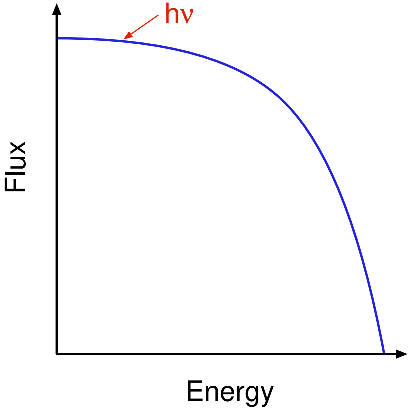

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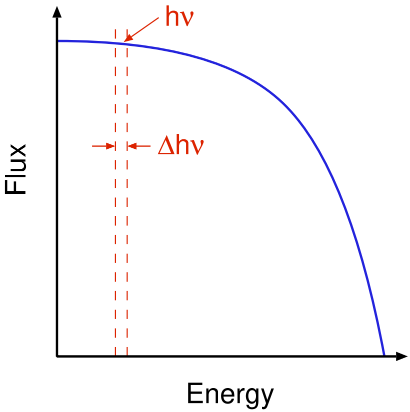

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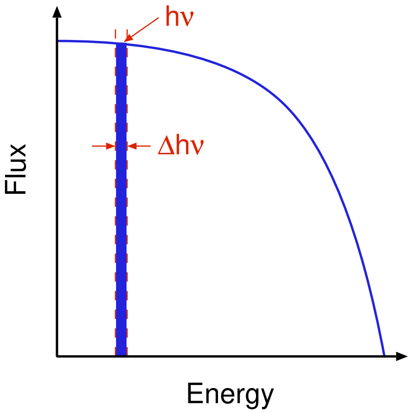

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Compute the integrated photon flux in that bandwidth.

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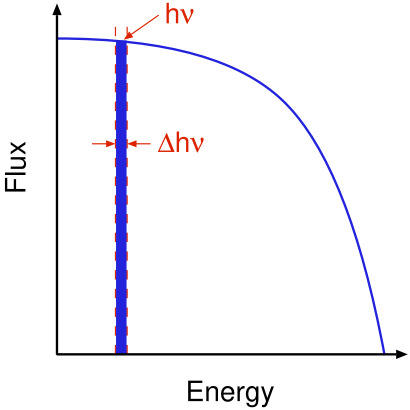

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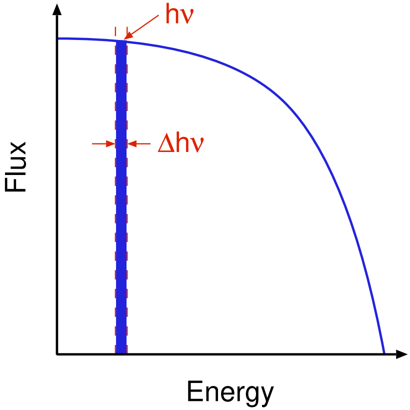

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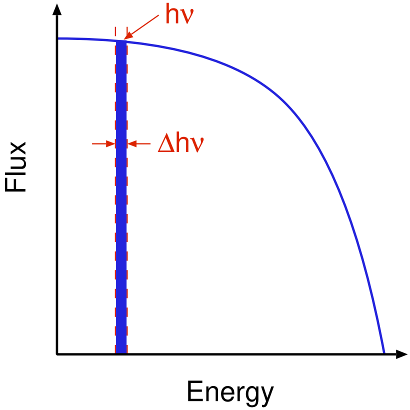

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$$\alpha \approx x/z \qquad \beta \approx y/z,$$

where z is the distance from the source over which there is a lateral spread x and y in each direction