Lecture 25

6. Synchrotron radiation and radiative damping effects

- **6.1 Synchrotron radiation (in bends)**
- **6.2 Wigglers and undulators**
- **6.3 Damping of synchrotron oscillations**
- **6.4 Damping of betatron oscillations**

Synchrotron radiation: Frequency spectrum

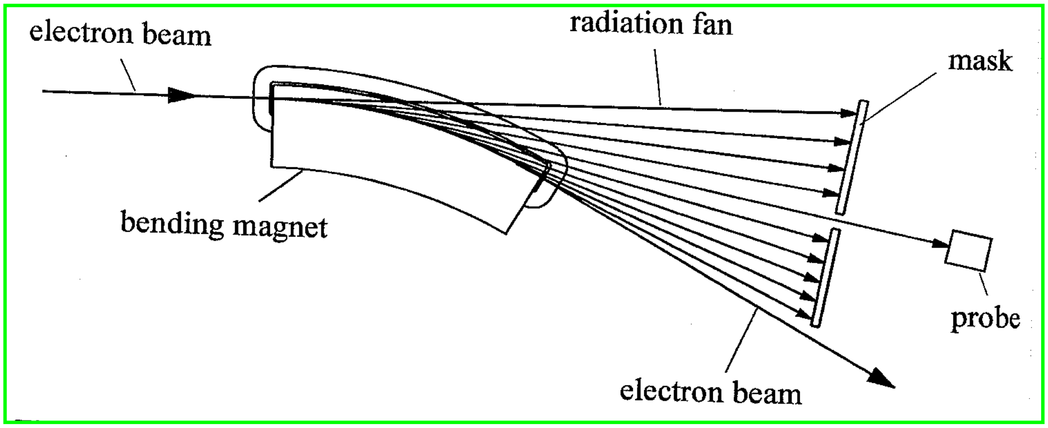
Critical frequency:

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

g) Quantum nature of synchrotron radiation

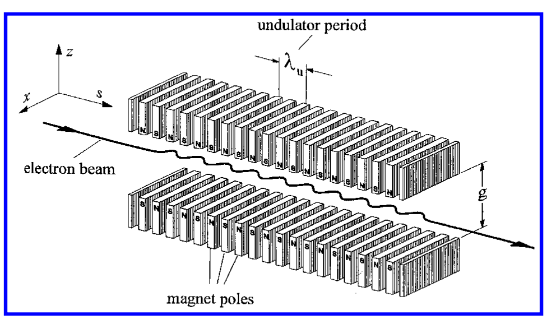
6.2 Wigglers and undulators

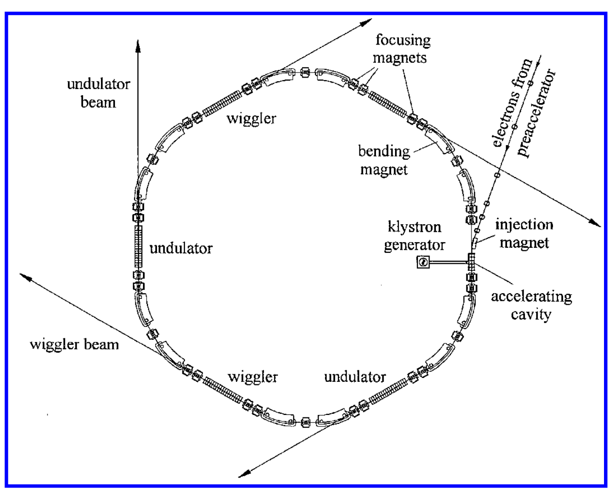
- **1st Generation** (1970s): Many HEP rings are parasitically used for X-ray production
- **2nd Generation** (1980s): Many dedicated X-ray sources (light sources), optimized for small beam size. But: Bending magnets give horizontal fan of radiation!



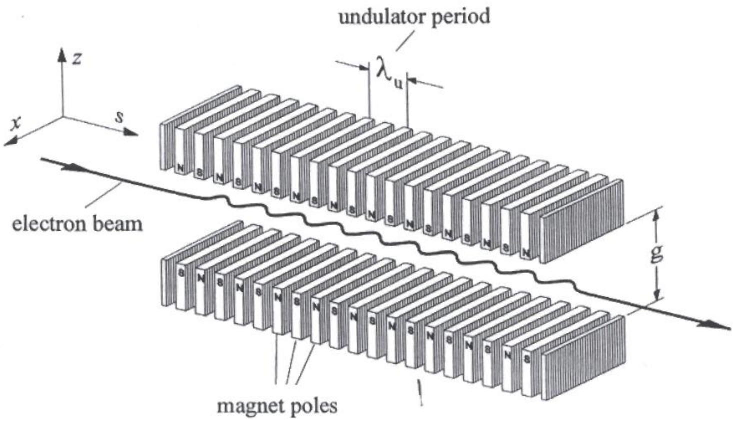
Radiation Sources using wigglers and undulators

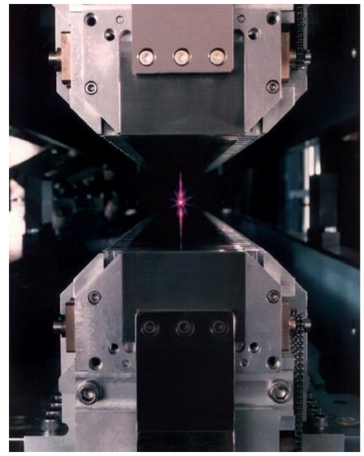
- **3rd Generation** (1990s): Several rings with dedicated radiation devices (wigglers and undulators)
- Today: Construction of Free Electron Lasers (FELs) driven by LINACs (**4th Generation**) and Energy-Recovery-Linacs (ERLs)





Wigglers and undulators





- Periodic structure of dipole magnets enhances photon flux and brightness
- The static magnetic field is alternating along the length of the undulator with a period λ_u.
- The radiation produced in an undulator is very intense and concentrated in narrow energy bands in the spectrum. It is also collimated on the orbit plane of the electrons.

Wigglers and undulators

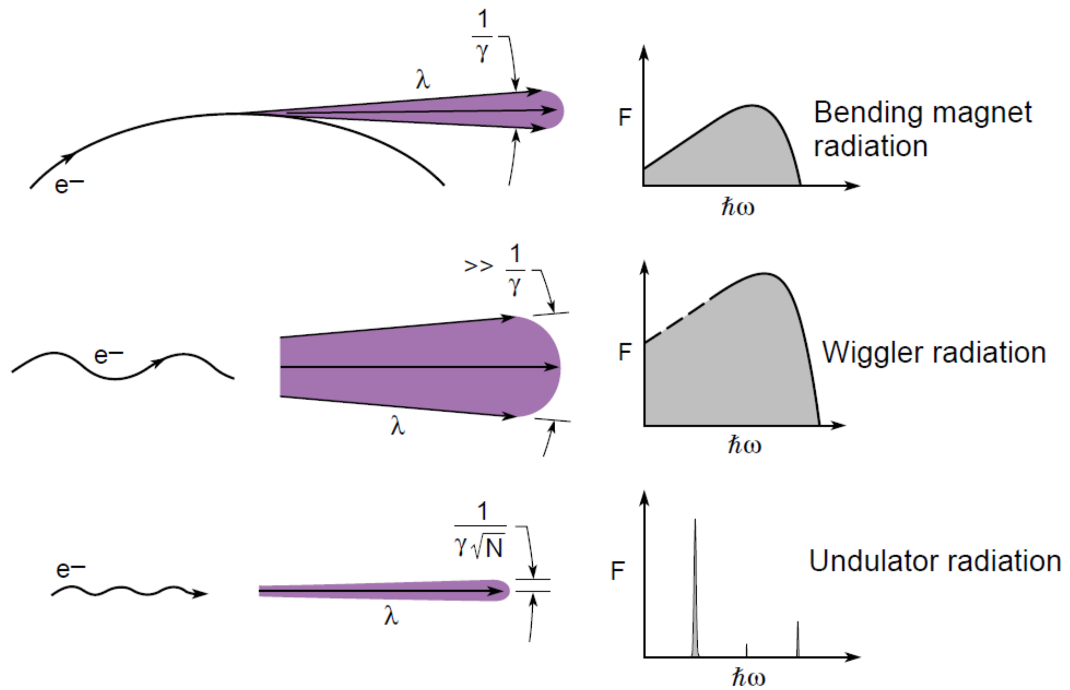
- Important dimensionless parameter:

$$K \equiv \frac{eB_0\lambda_u}{2\pi mc} = 0.9337 B_0(\mathrm{T})\lambda_u(\mathrm{cm})$$

where e is the particle charge, B the magnetic field, m_e the electron rest mass and c the speed of light, characterizes the nature of the electron motion.

- For K<<1 the oscillation amplitude of the motion is small and the radiation displays interference patterns which lead to narrow energy bands.
- If K>>1 the oscillation amplitude is bigger and the radiation contributions from each field period sum up independently, leading to a broad energy spectrum. In this regime of fields the device is no longer called an *undulator*; it is called a **wiggler**.

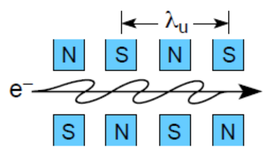
Bending magnet, wiggler and undulator radiation



Courtesy David Attwood, Univ. California, Berkeley

Undulator Radiation

Laboratory Frame of Reference

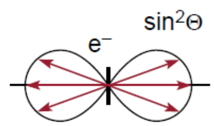


$E = \gamma mc^2$

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

N = # periods

Frame of Moving e⁻



e⁻ radiates at the Lorentz contracted wavelength:

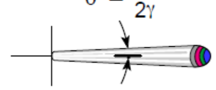
$$\lambda' = \frac{\lambda_u}{\gamma}$$

Bandwidth:

$$\frac{\lambda'}{\Delta\lambda'} \simeq N$$

Frame of Observer

$\theta \simeq \frac{1}{2\gamma}$



Doppler shortened wavelength on axis:

$$\lambda = \lambda'\gamma(1 - \beta\cos\theta)$$

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

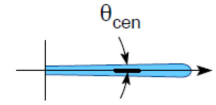
Accounting for transverse motion due to the periodic magnetic field:

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

where $K = eB_0\lambda_u/2\pi mc$

Following Monochromator

θ_{cen}



For $\frac{\Delta\lambda}{\lambda} \simeq \frac{1}{N}$

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

typically

$\theta_{cen} \simeq 40$ μrad

Courtesy David Attwood,

6.3 Damping of synchrotron oscillations

6.4 Damping of betatron oscillations