Properties of Synchrotron Radiation

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Comparison of Synchrotron Radiation from Synchrotrons and Storage Rings

	Synchrotron	*Storage Ring*
Spectrum	Varies as e^- energy changes on each cycle	Constant
Intensity	Varies as e^- energy changes on each cycle, also; cycle to cycle variations	Decays slowly over many hours
Source Position	Varies during the acceleration cycle	Constant within 1-50 microns
High Energy Radiation Background	High – due to loss of all particles on each cycle	Low – particles are stored for many hours

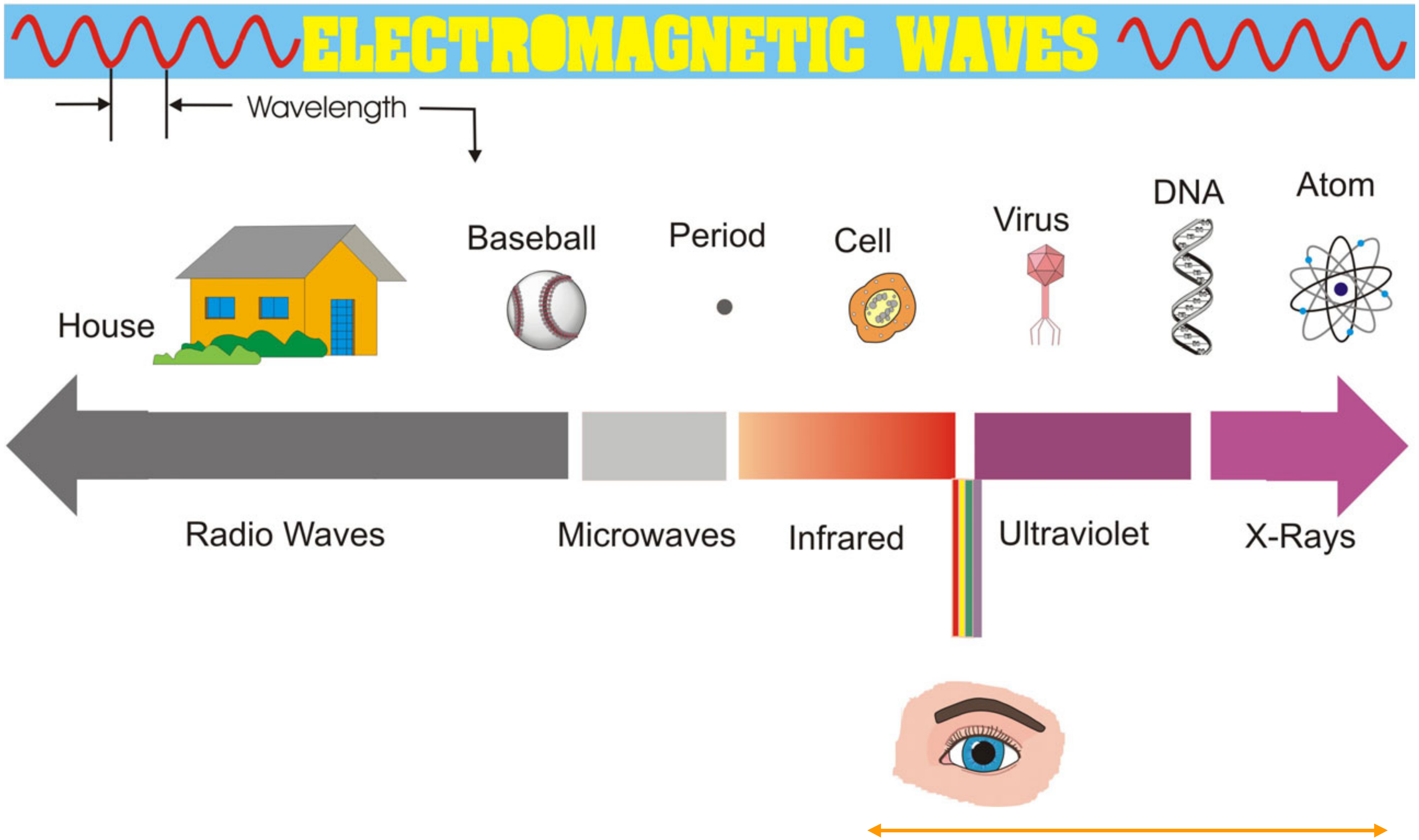
Radiation Fundamentals

- When electrons are accelerated (*e.g*. linear acceleration in a radio transmitter antenna) they emit electromagnetic radiation (*i.e*., radio waves) in a rather non-directional pattern
- Electrons in circular motion are also undergoing acceleration (centripetal)

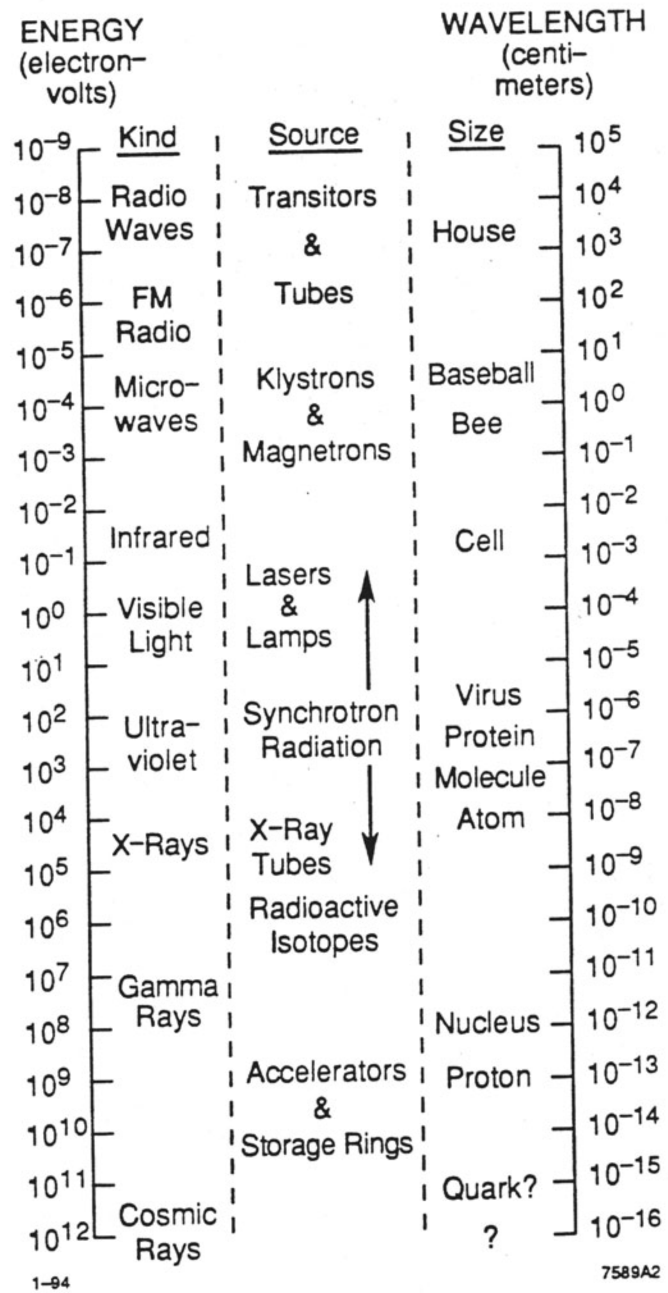
At low electron velocity (non-relativistic case) the radiation is emitted in a non-directional pattern

When the electron velocity approaches the velocity of light, the emission pattern is folded sharply forward. Also the radiated power goes up dramatically

Electromagnetic Radiation - How It Relates to the World We Know



Synchrotron radiation is used for experiments typically over this region



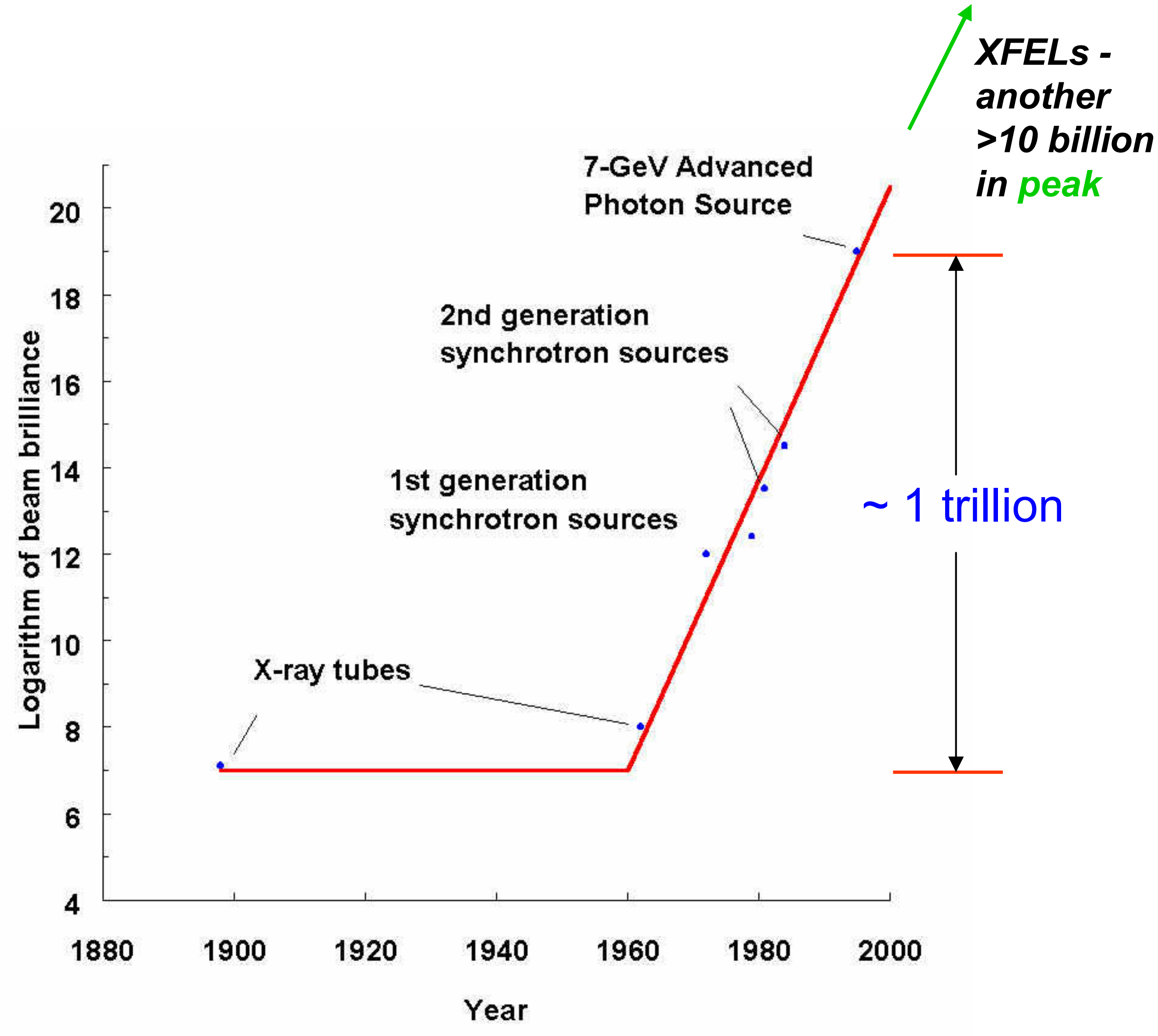
The Electromagnetic spectrum showing the region occupied by synchrotron radiation

What Properties Make Synchrotron Radiation (SR) so Useful?

High brightness:
SR is extremely intense (hundreds of thousands of times higher than conventional X-ray tubes)

Wide energy spectrum:
SR is emitted with a wide range of energies

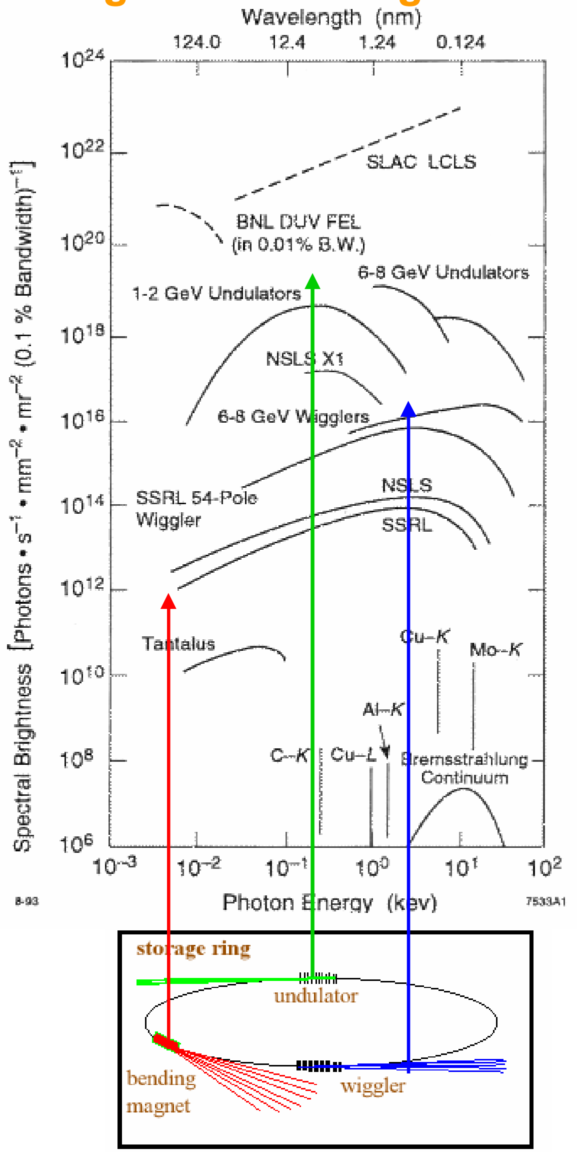
Highly polarized and short pulses:
SR is emitted in very short pulses, typically less that a nano-second (a billionth of a second)



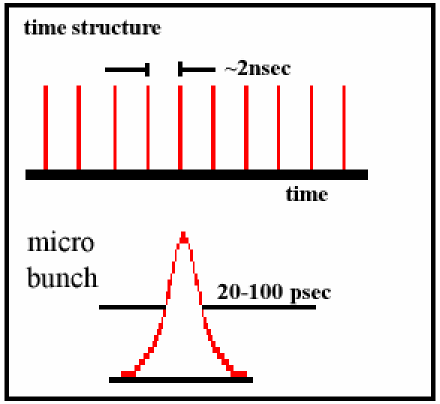
SR offers many characteristics of visible lasers but into the x-ray regime!

Synchrotron Radiation - Basic Properties

High flux and brightness



Pulsed time structure



Broad spectral range

Polarized (linear, elliptical, circular)

Small source size

Partial coherence

High stability

$$\textbf{Flux} = \frac{\text{\# of photons in given } \Delta\lambda/\lambda}{\text{sec, mrad } \theta}$$

$$\textbf{Brightness} = \frac{\text{\# of photons in given } \Delta\lambda/\lambda}{\text{sec, mrad } \theta\text{, mrad } \varphi\text{, mm}^2}$$

(a measure of concentration of the radiation)

SYNCHROTRON RADIATION

BASIC PROPERTIES

1. **HIGH FLUX, BRIGHTNESS, STABILITY**
2. **BROAD SPECTRAL RANGE - Tunability**
3. **POLARIZATION (linear, elliptical, circular)**
4. **PULSED TIME STRUCTURE (0.01 - 1 nsec)**
5. **SMALL SOURCE SIZE ($\leq$ mm)**
6. **PARTIAL COHERENCE**
7. **HIGH VACUUM ENVIRONMENT**

Flux = $\dfrac{\text{No. of Photons at given } \lambda \text{ within a given } \Delta\lambda/\lambda}{\text{s, mrad } \Theta}$

Brightness = $\dfrac{\text{No. of Photons at given } \lambda \text{ within a given } \Delta\lambda/\lambda}{\text{s, mrad } \Theta\text{, mrad } \varphi\text{, mm}^2}$

(a measure of the concentration of the radiation)

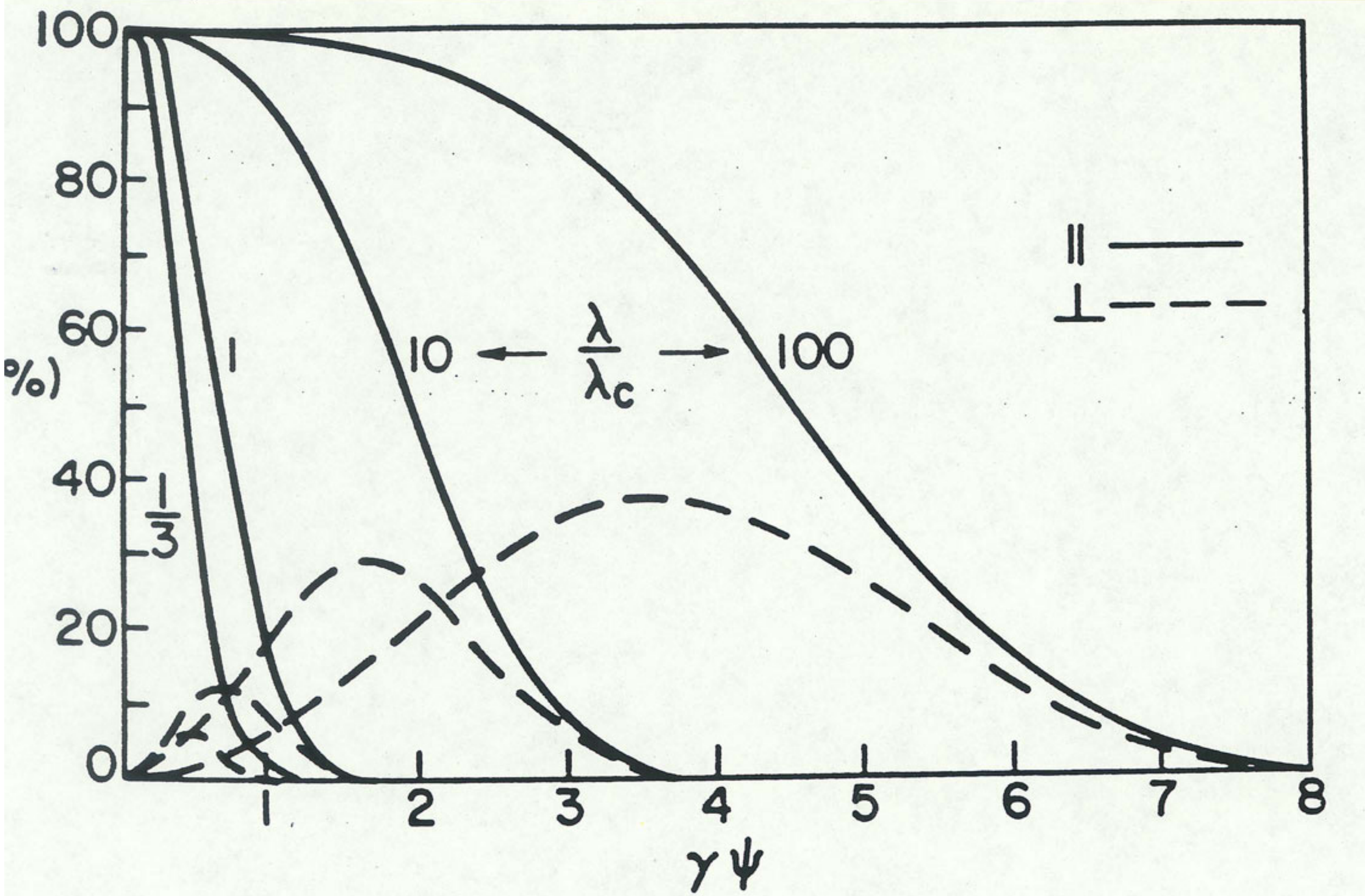
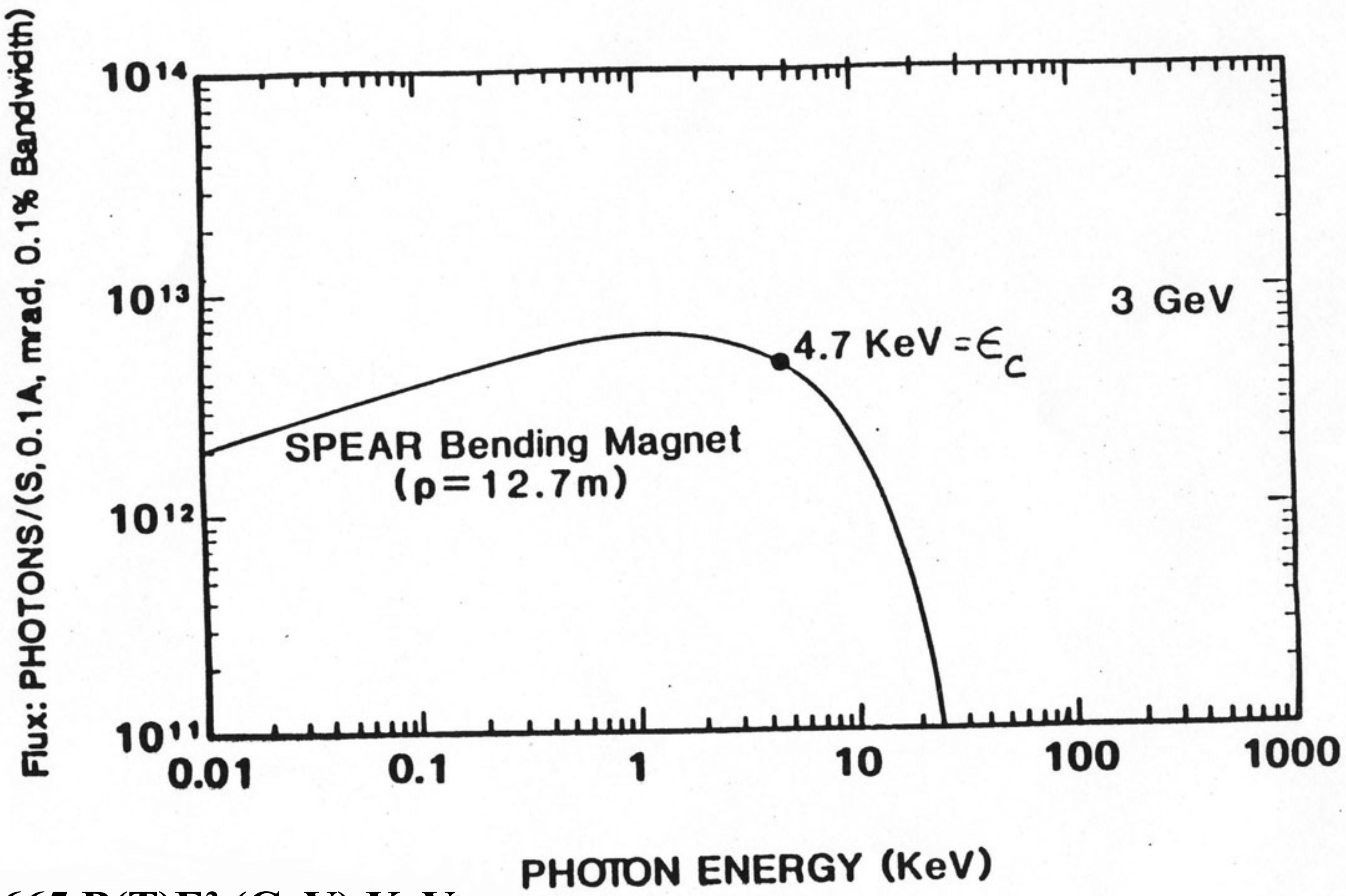
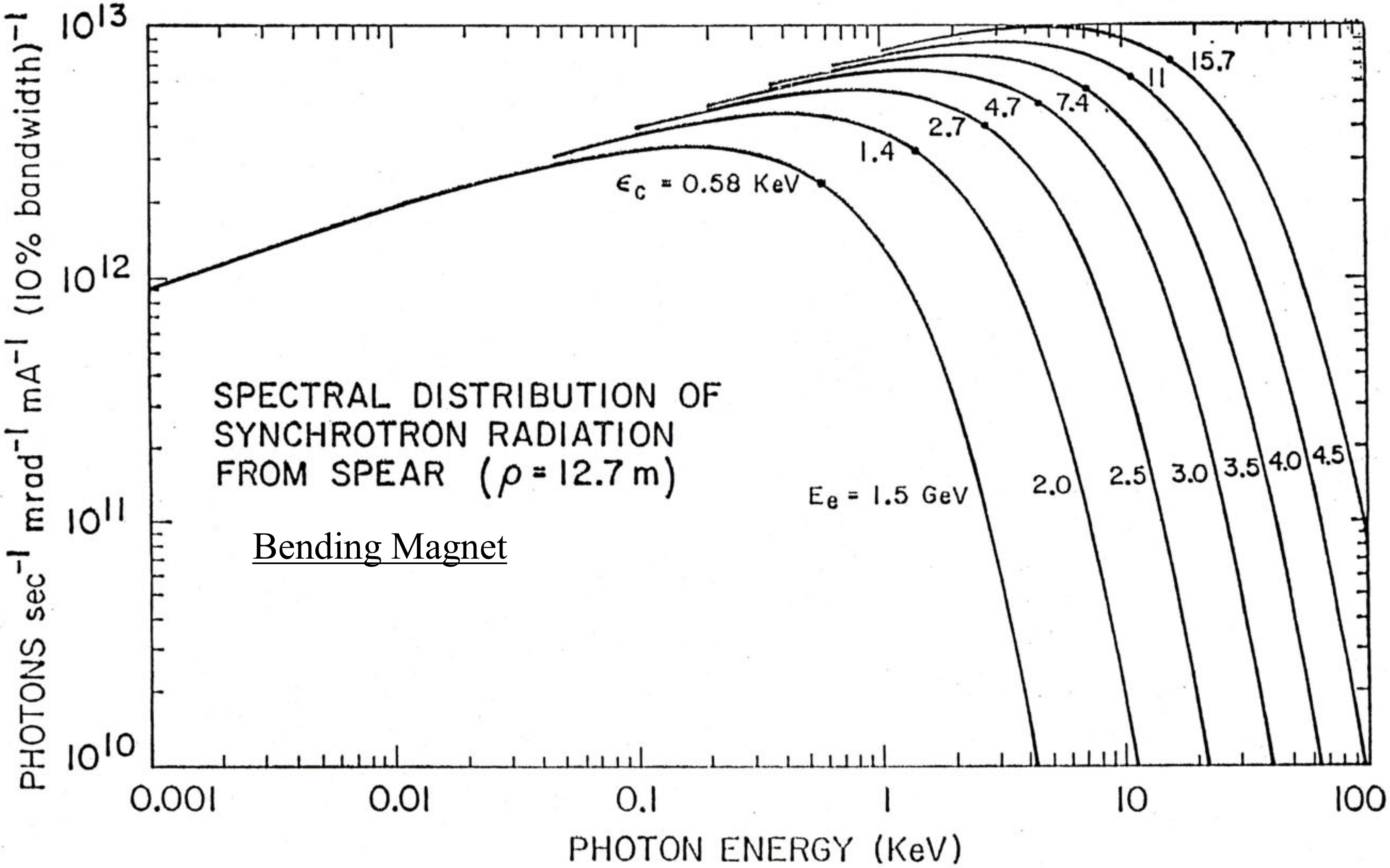


Figure 7. Vertical angular distribution of parallel and perpendicular polarization components.



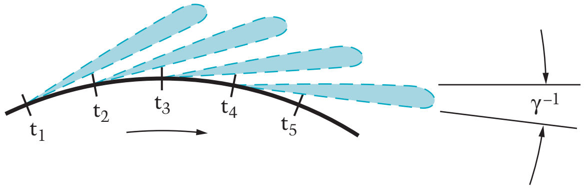
$\epsilon = 0.665\ B(T) E^2\ (GeV)\ KeV$

$= 2.2\ E^3\ (GeV)/\rho(m)$

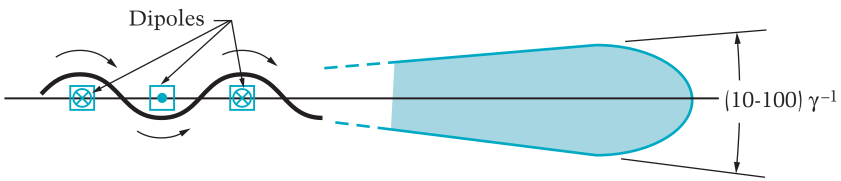


Bending Magnet

Bending Magnets and Insertion Devices on Storage Rings



bending magnet - a "sweeping searchlight"

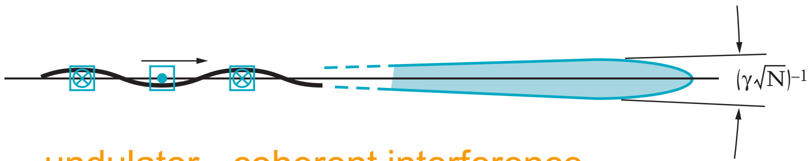


wiggler - incoherent superposition

Continuous spectrum characterized by ε_c = critical energy

ε_c(keV) = 0.665 B(T)E^2(GeV)

eg: for B = 1.35T E = 2GeV
ε_c = 3.6keV



undulator - coherent interference

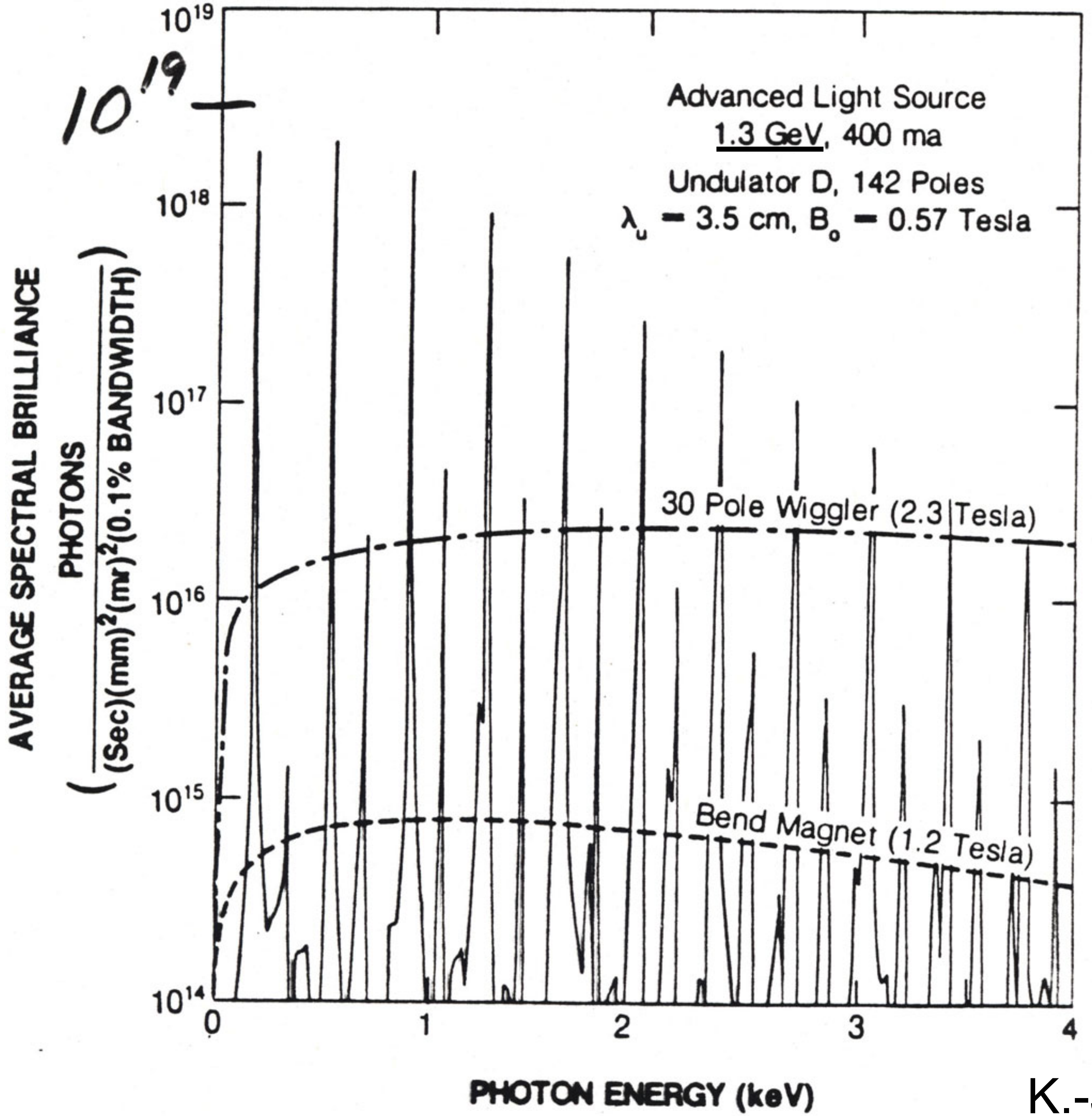
Quasi-monochromatic spectrum with peaks at lower energy than a wiggler

$$\lambda_1 = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2}\right) \sim \frac{\lambda_U}{\gamma_2} \text{ (fundamental)}$$

+ harmonics at higher energy

$$\varepsilon_1 \text{ (keV)} = \frac{0.95\, E^2 \text{ (GeV)}}{\lambda_u^{\text{(cm)}} \left(1 + \frac{K^2}{2}\right)}$$

K = $\gamma\theta$ where θ is the angle in each pole


Advanced Light Source
1.3 GeV, 400 ma
Undulator D, 142 Poles
λ_u = 3.5 cm, B_o = 0.57 Tesla
30 Pole Wiggler (2.3 Tesla)
Bend Magnet (1.2 Tesla)
AVERAGE SPECTRAL BRILLIANCE
PHOTONS / (Sec)(mm)²(mr)²(0.1% BANDWIDTH)
PHOTON ENERGY (keV)
10^19
10^18
10^17
10^16
10^15
10^14
0
1
2
3
4

K.-J. Kim - LEL

End of this part of presentation