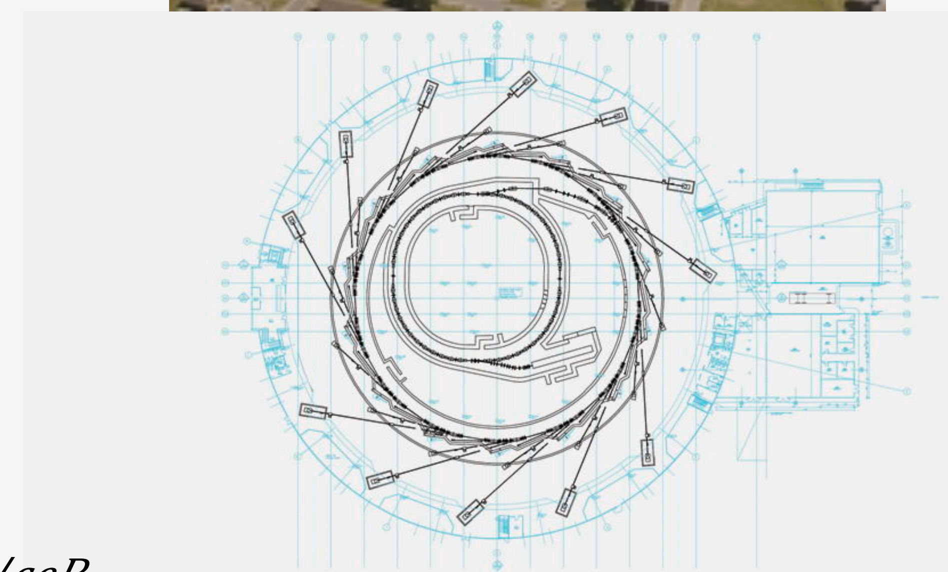
SYNCHROTRONS

WHAT IS A SYNCHROTRON?

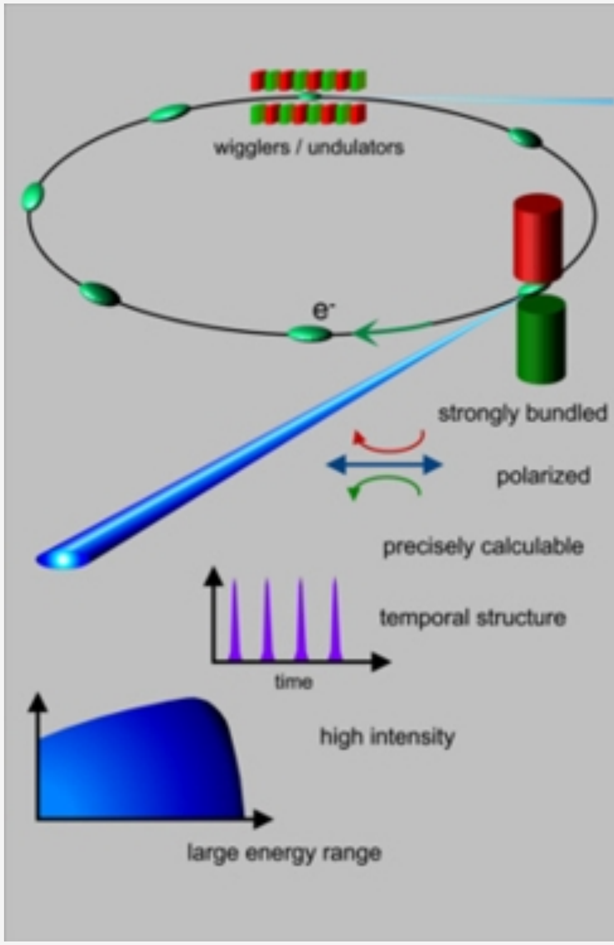
- It's a particle accelerator, fixed R
- Can be used as a collider or a experiment light source
  - Largest synchrotron is the LHC in Swizerland / France (27km)
  - This presentation focuses on light source
- Particles are accelerated to relativistic speed
  - By E field in microwave
- Magnetic field changes according to particle energy / speed to keep particles in the same circuit radius
  - Thus SYNchrotron
- About 40 Synchrotrons in operation

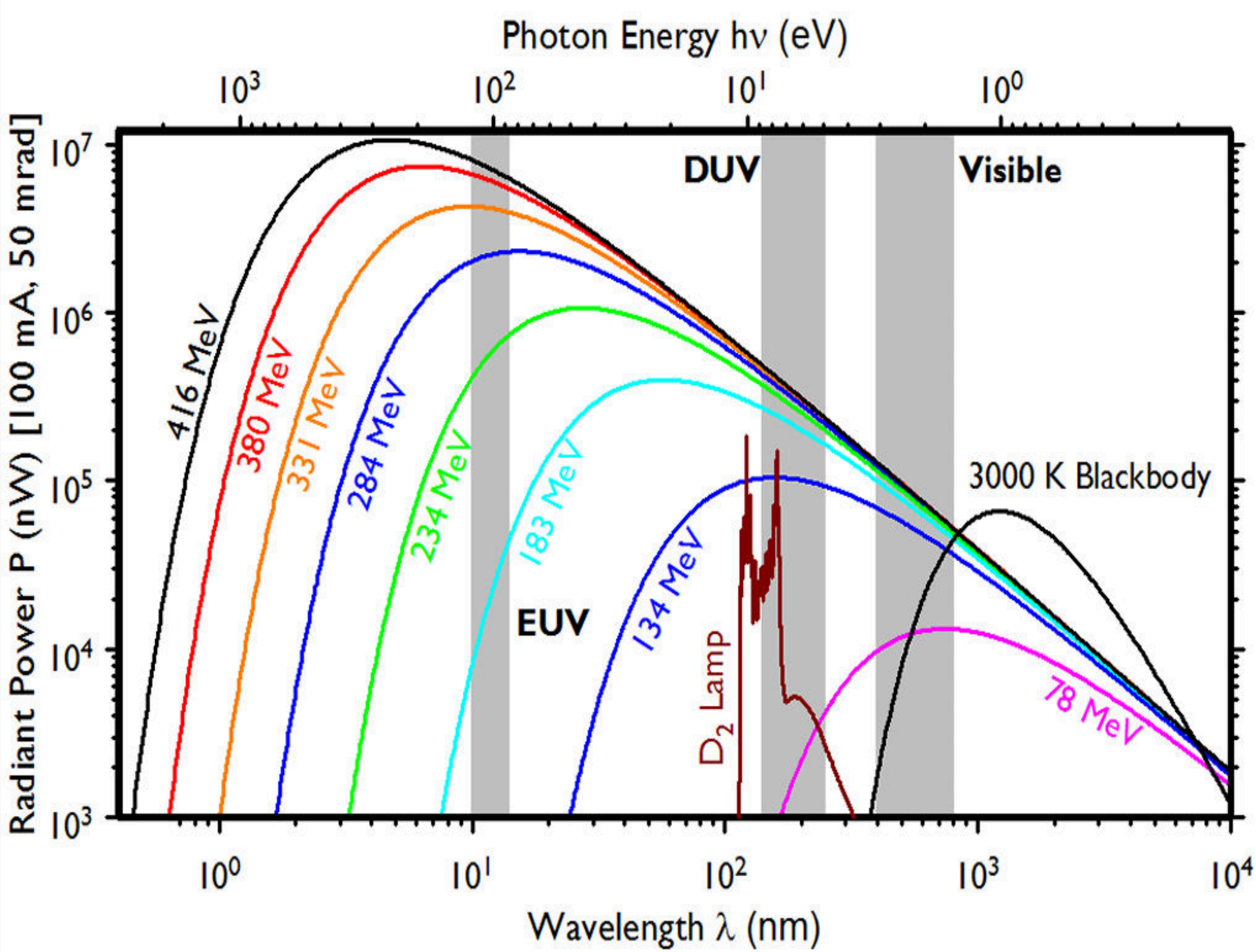


$$E_c = \frac{3}{2}\frac{\hbar c}{R}\gamma^3 = 0.655 E_e[GeV]^2 B[T] \quad R = E/ceB$$

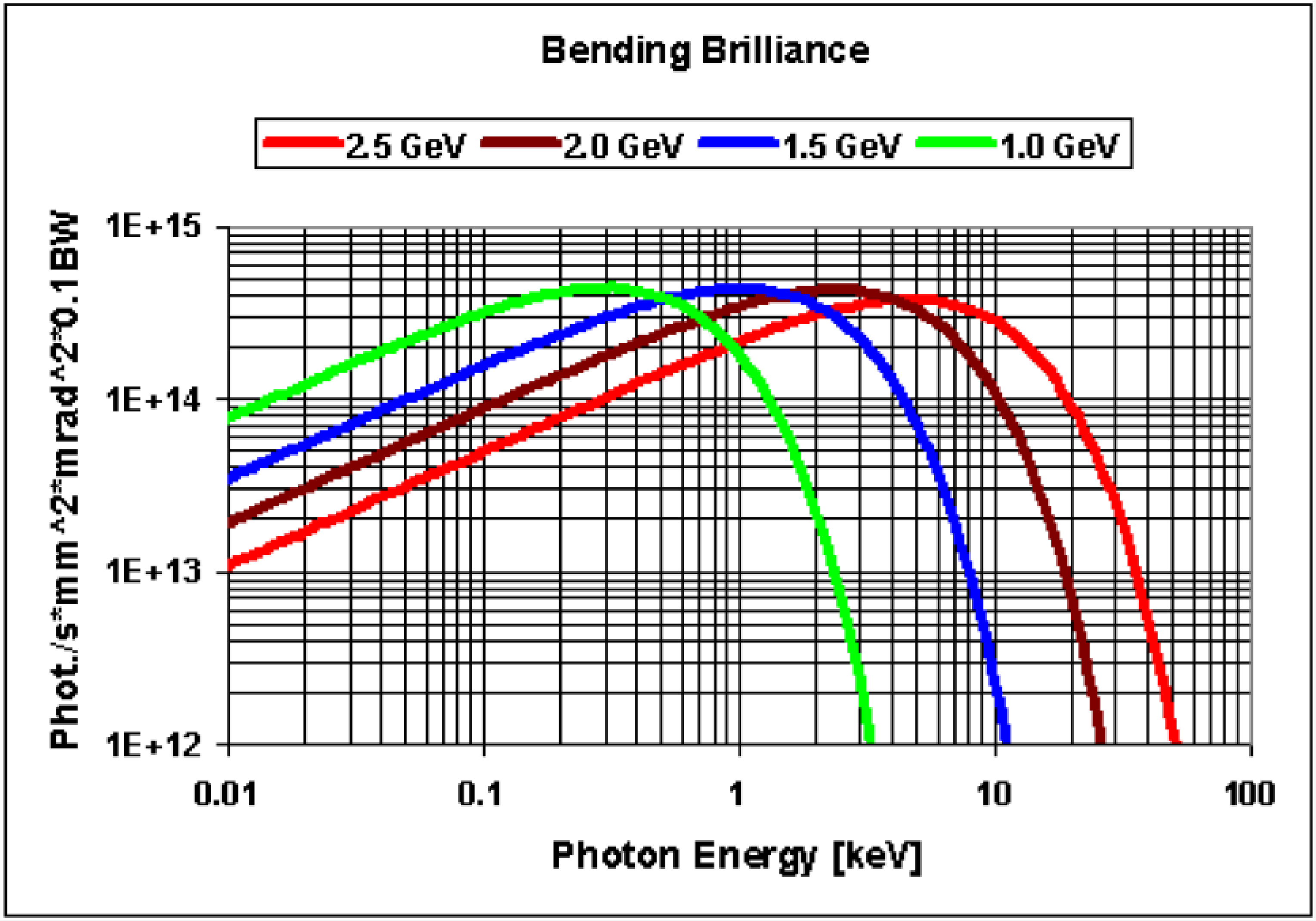
SYNCHROTRON RADIATION

- History
  - First observed in 1947 by GE as a waste product of high energy experiments
  - In 1960s, scientists started using the radiation in condensed matter research
- Characteristics
  - When a charged particle is directed in a curved trajectory, EM radiations are generated in a narrow cone in the direction of motion of the charged particle
  - Brightest / most powerful source of light on earth
    - 8k MW/m^2 vs. 63 MW/m^2 of the sun
  - Broad, continuous spectrum of energy
  - Angular Collimation
  - Come in a series of flashes
  - Polarized
    - Due to Sokolov-Ternov effect



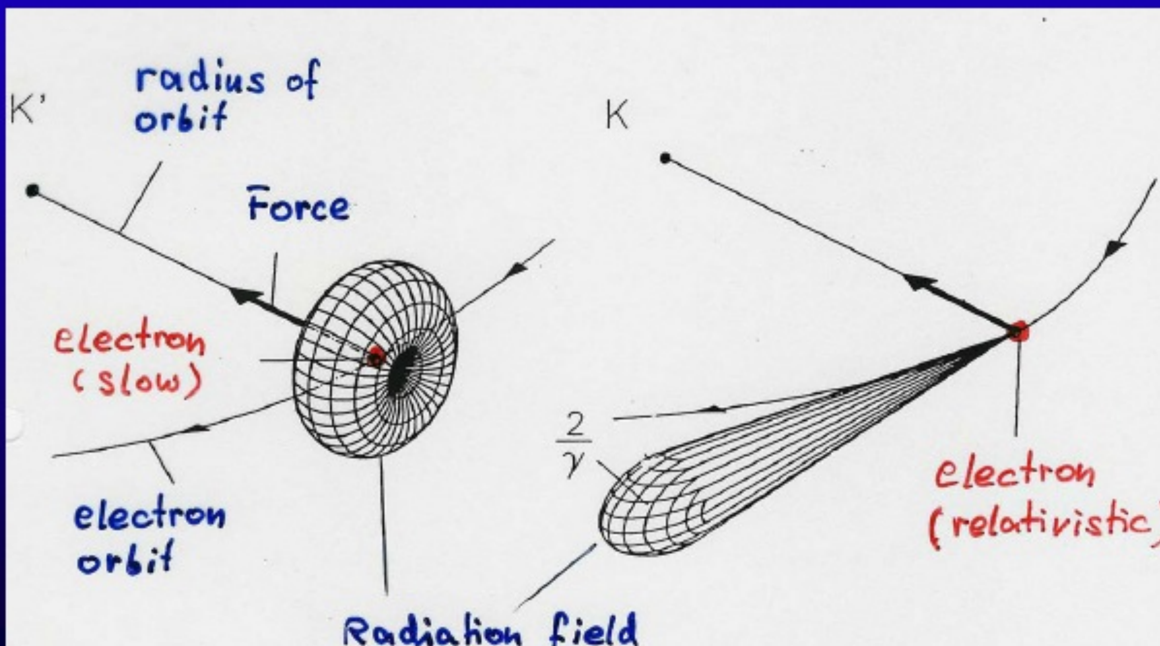


Photon Energy hν (eV)
10^3
10^2
10^1
10^0
Radiant Power P (nW) [100 mA, 50 mrad]
10^7
10^6
10^5
10^4
10^3
DUV
Visible
EUV
416 MeV
380 MeV
331 MeV
284 MeV
234 MeV
183 MeV
134 MeV
D2 Lamp
78 MeV
3000 K Blackbody
10^0
10^1
10^2
10^3
10^4
Wavelength λ (nm)

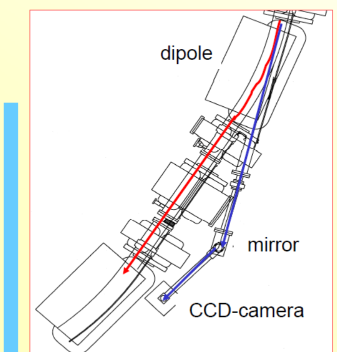


Bending Brilliance
2.5 GeV
2.0 GeV
1.5 GeV
1.0 GeV
Phot./s*mm^2*mrad^2*0.1BW
1E+15
1E+14
1E+13
1E+12
0.01
0.1
1
10
100
Photon Energy [keV]

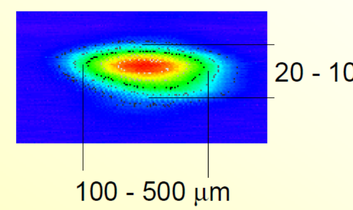
Radiation is emitted into a narrow cone



a very tiny, extremely well characterised and intense

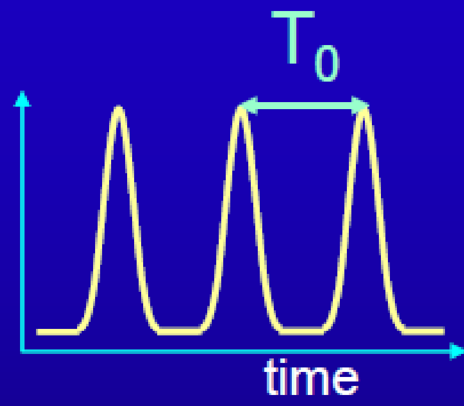


beam current I = 130 mA
E = 1,5 GeV
radiated power = 20 kW



Spectrum of synchrotron radiation

- Synchrotron light comes in a series of flashes every T_0 (revolution period)



- the spectrum consists of harmonics of

$$\omega_0 = \frac{1}{T_0}$$

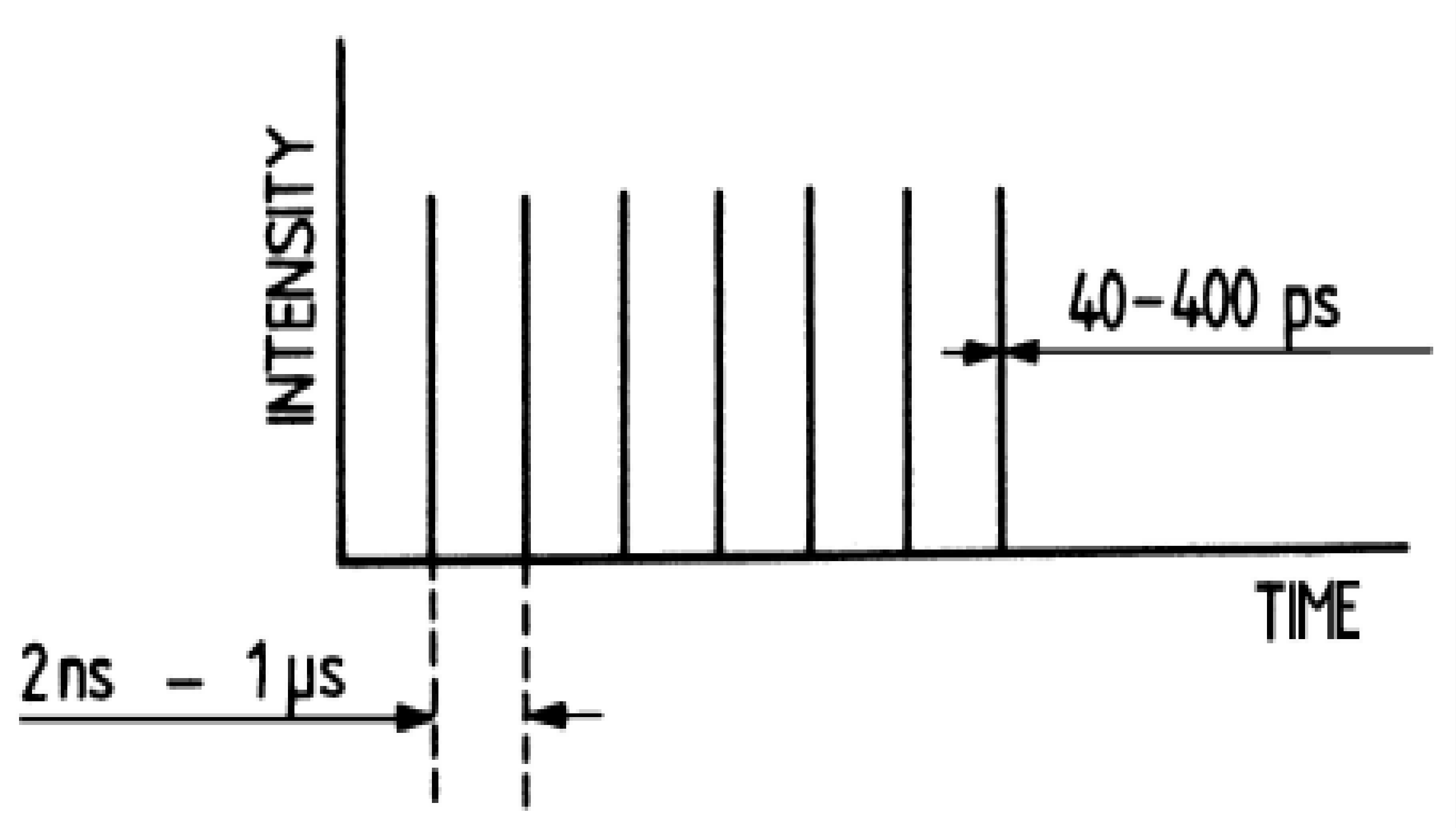
- flashes are extremely short: harmonics reach up to very high frequencies

$$\omega_{typ} \cong \gamma^3 \omega_0$$

$$\omega_0 \sim 1 \text{ MHz}$$
$$\gamma \sim 4000$$
$$\omega_{\text{typ}} \sim 10^{16} \text{ Hz !}$$

- At high frequencies the individual harmonics overlap

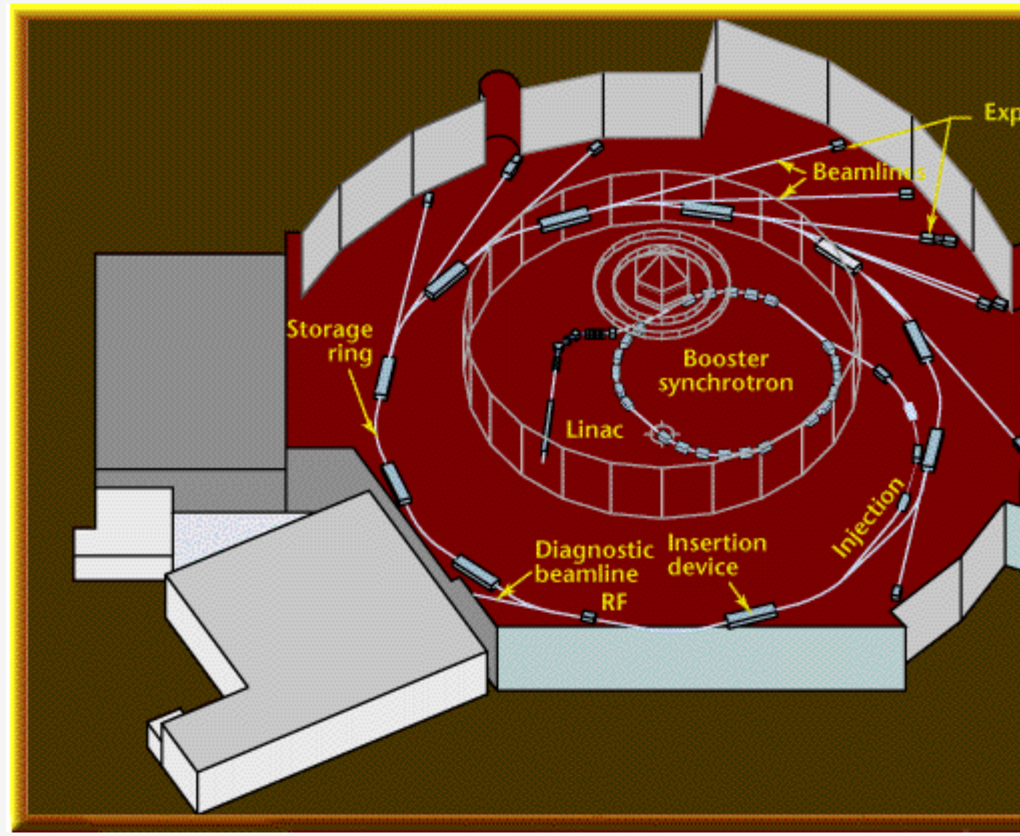
continuous spectrum !



INTENSITY
40-400 ps
TIME
2 ns – 1 μs

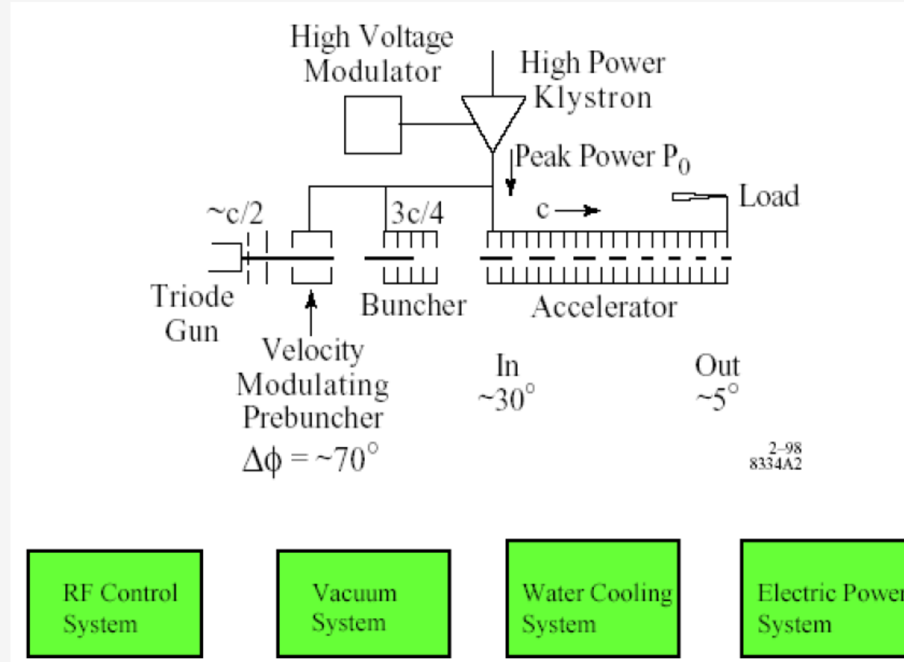
MAJOR PARTS OF A SYNCHROTRON

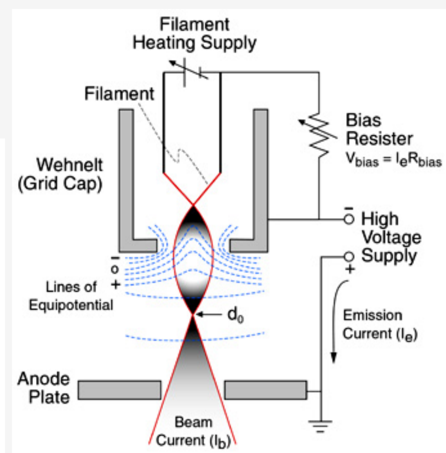
- Electron Gun
- LINAC
- Booster Ring
- Storage Ring
- Undulators / Wigglers
- Beamline
- Experimental Station

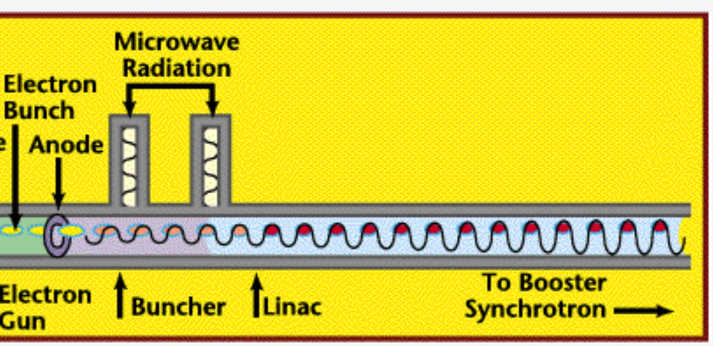


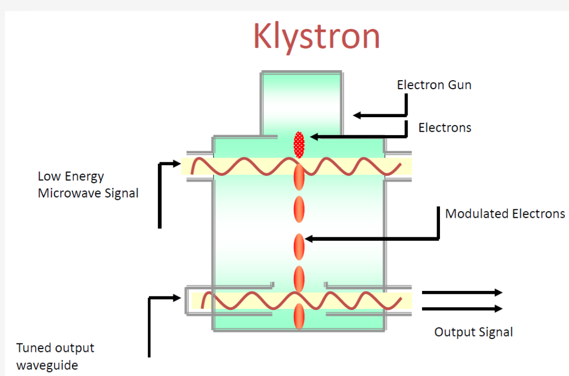
ELECTRON GUN, LINAC AND BOOSTER

- Accelerate particles from 0 to 0.99c
- Energy of particle exits LINAC ~250MeV
- Vacuum at ~100 Pa (less air pressure than ISS)
- Klystron generate microwave
  - To group and accelerate particles
- Accelerator is a tuned waveguide
- Booster Ring boosts energy to 3 – 6 GeV within 1 second.



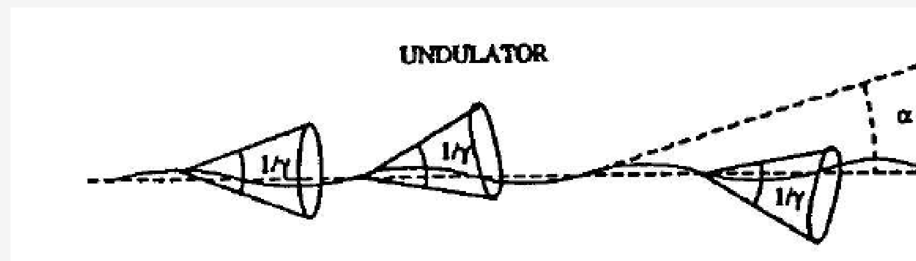




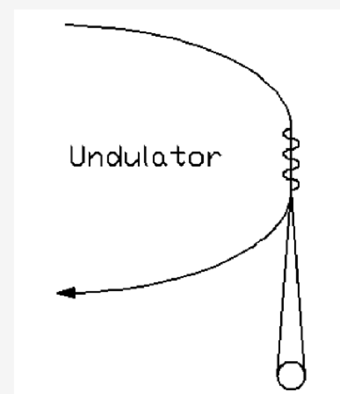


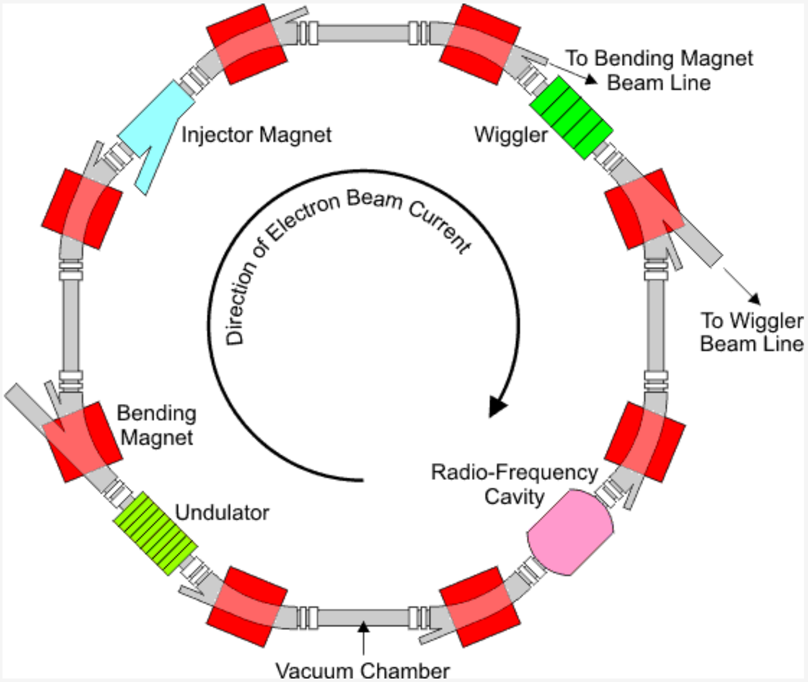
STORAGE RING AND UNDULATORS

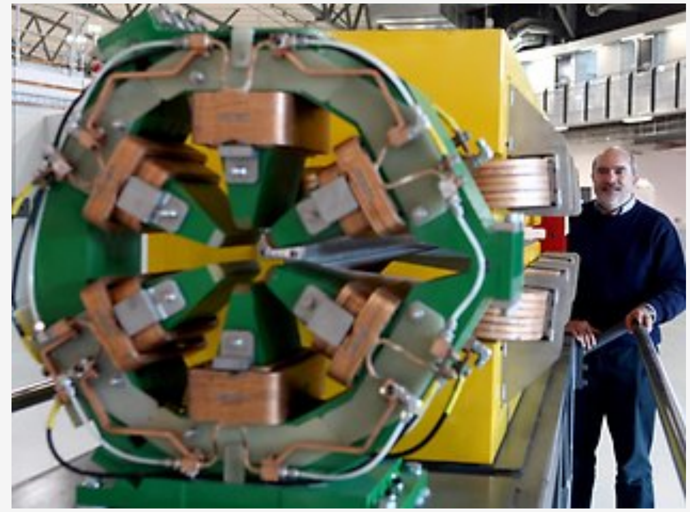
- Electrons injected into storage ring from booster ring
  - 1 injection / second for 10 mins
- Electrons stay in the storage ring for 4 – 12 hours
- Particle energy range from 0.1 – 6 GeV
  - Typical is at 3GeV as light source
- Undulators are highly precise magnets that periodically displace the electrons
  - Produce more photons and higher brilliance
  - About 5m long on the straight section

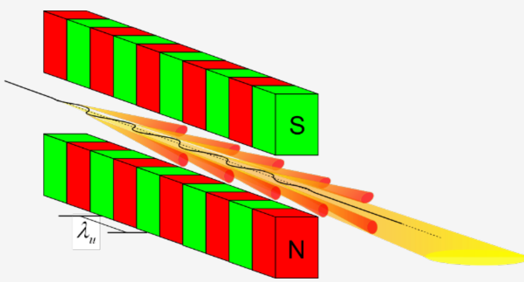


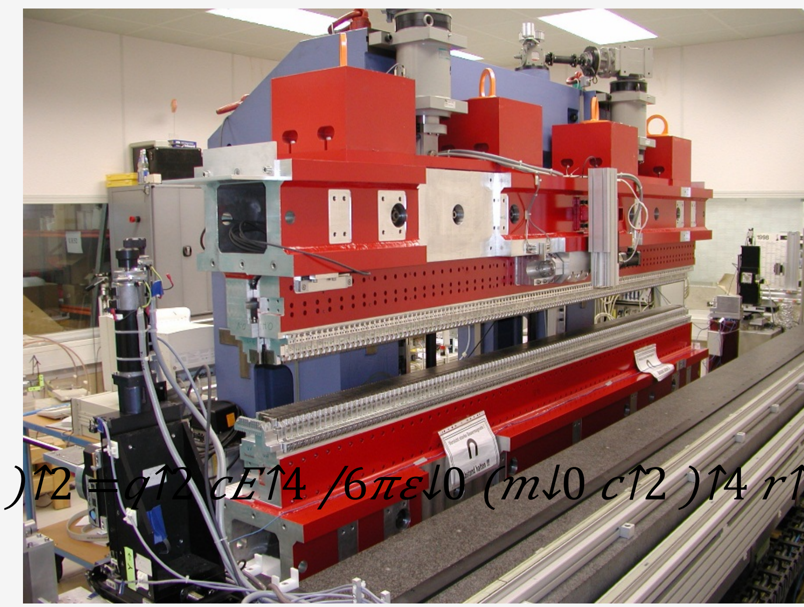
$\theta \sim 1/\gamma\sqrt{nN}$,







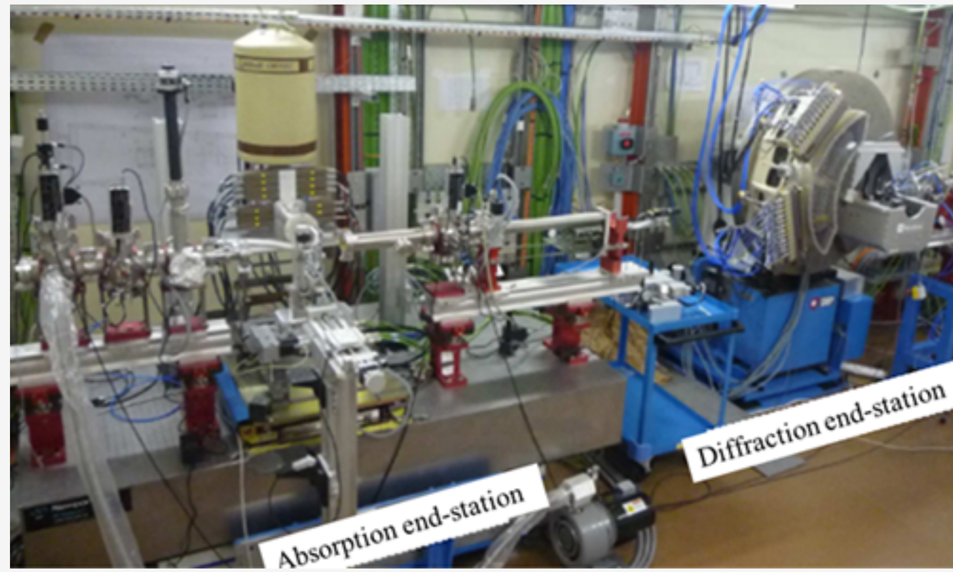


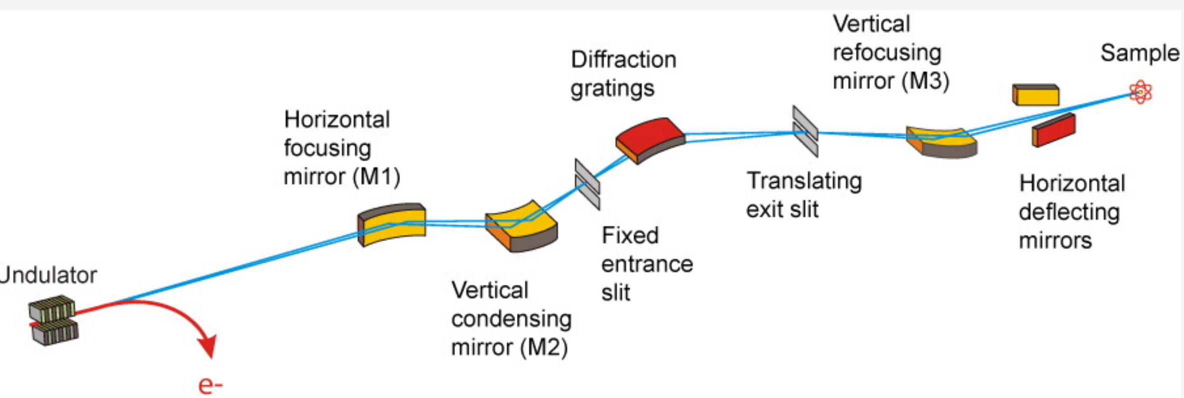


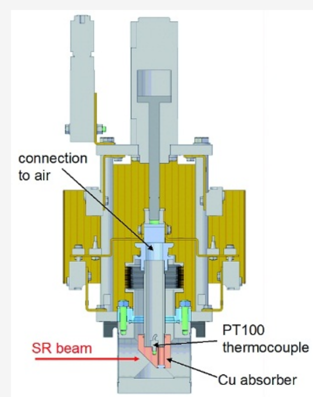
$$P_s = \frac{q^2 c \cdot \gamma^2}{6\pi\varepsilon_0 (m_0 c^2)^2} \left(\frac{dp}{dt}\right)^2 = \frac{q^2 c E^4}{6\pi\varepsilon_0 (m_0 c^2)^4 r^2}$$

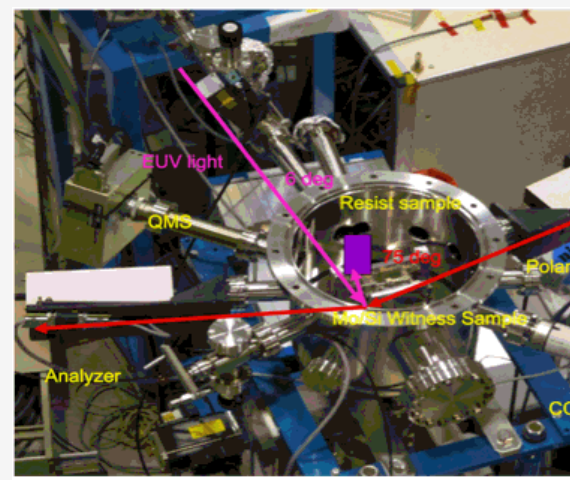
BEAMLINE & EXPERIMENTAL STATION

- Beamline transports and "customizes" synchrotron radiation to the experiment target
  - Major component includes shutter, slits, aperture, mirrors, monochromator…
  - Complex design to get desired radiation
- Experiments to study materials: (X-ray) Spectroscopy, (X-ray) Crystallography…

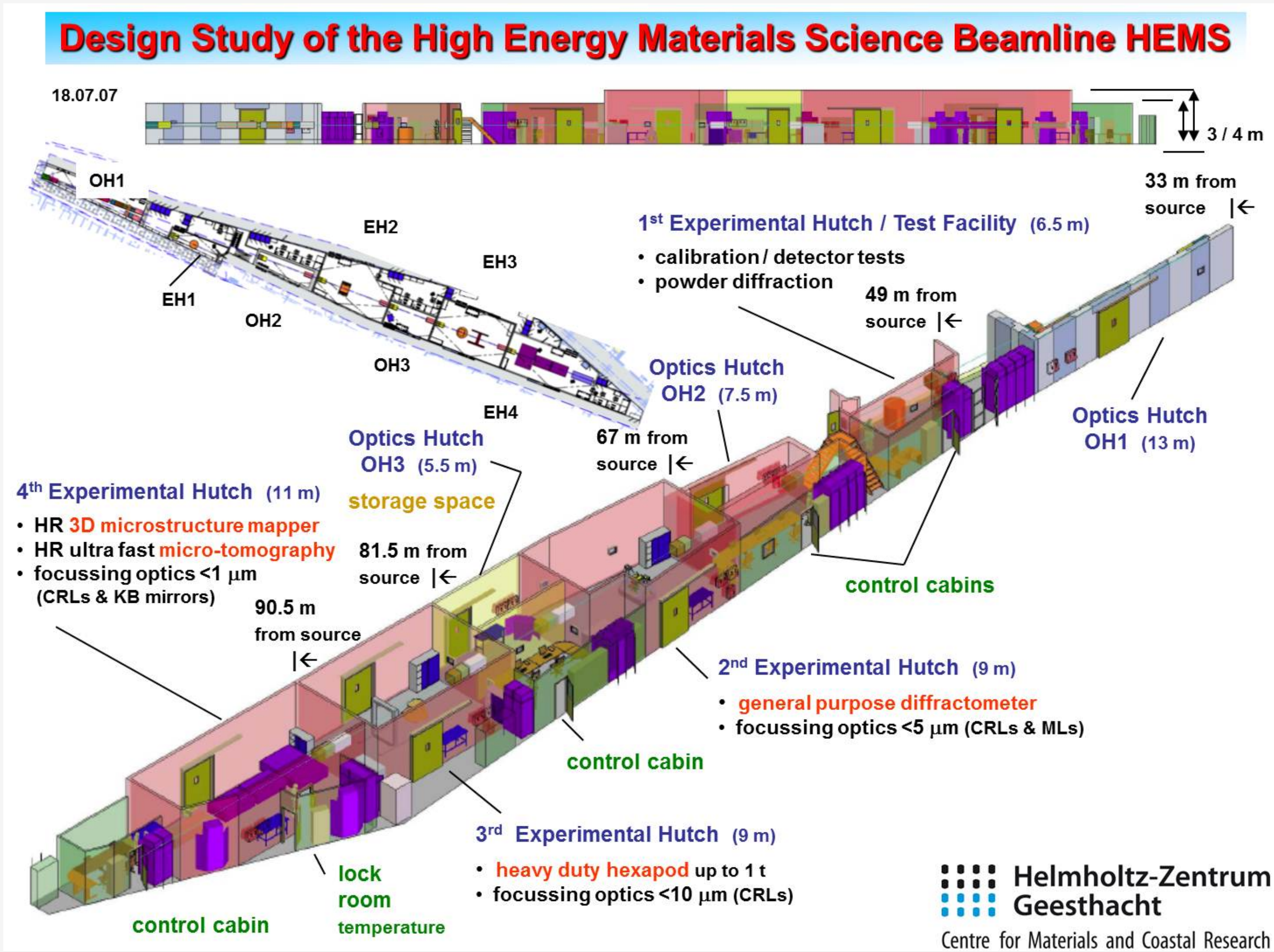






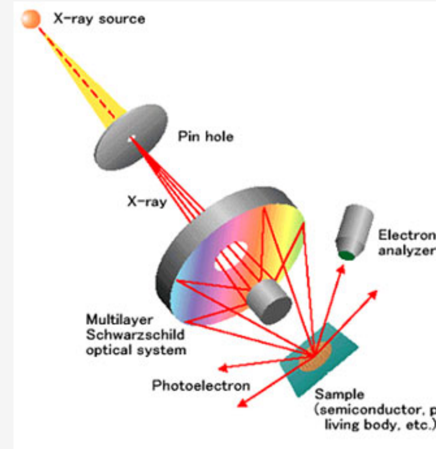


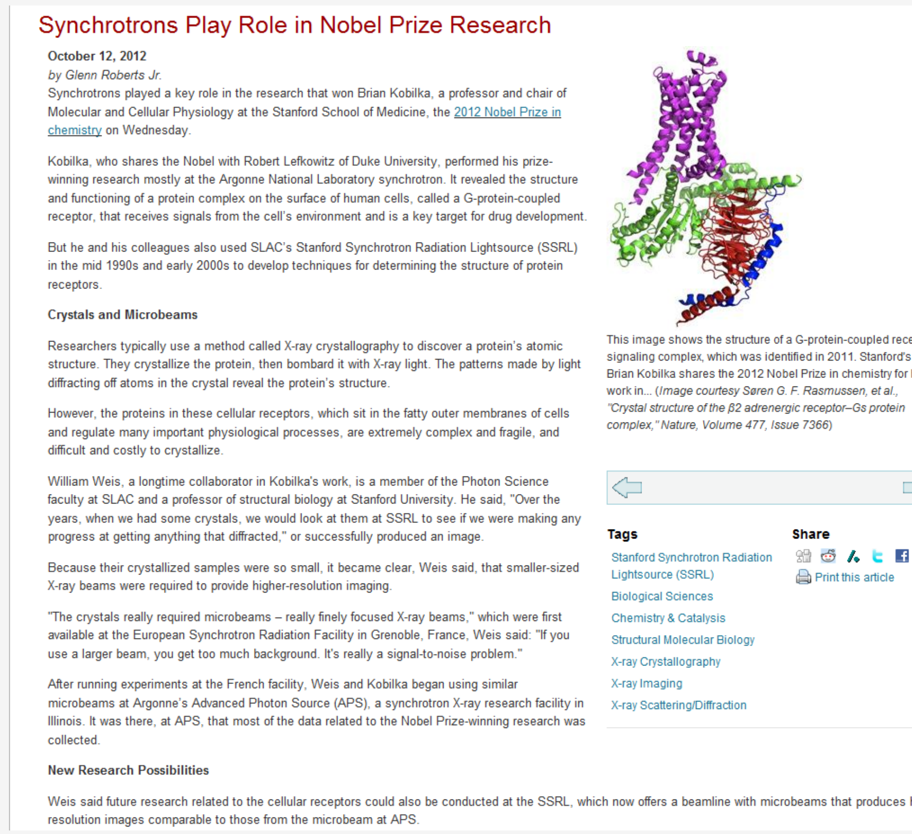
SPECTROSCOPY	SCATTERING	IMAGING
01 Low-Energy Spectroscopy	05 Hard X-Ray Diffraction	09 Hard X-Ray Imaging
02 Soft X-Ray Spectroscopy	06 Macromolecular Crystallography	10 Soft X-Ray Imaging
03 Hard X-Ray Spectroscopy	07 Hard X-Ray Scattering	11 Infrared Imaging
04 Optics/Calibration/Metrology	08 Soft X-Ray Scattering	12 Lithography



WHO USE SYNCHROTRON?

- Life Science
  - Pharmaceuticals
  - Protein, biomaterial
  - Ultra dilute pollutants
- High Energy Physics / Astrophysics
  - Simulate high energy radiation
- Engineering
  - Material stress (polarization)
- Even humanities… (Non-Destructive)
  - Art history
  - Archaeology





Synchrotrons Play Role in Nobel Prize Research

October 12, 2012

by Glenn Roberts Jr.

Synchrotrons played a key role in the research that won Brian Kobilka, a professor and chair of Molecular and Cellular Physiology at the Stanford School of Medicine, the 2012 Nobel Prize in chemistry on Wednesday.

Kobilka, who shares the Nobel with Robert Lefkowitz of Duke University, performed his prize-winning research mostly at the Argonne National Laboratory synchrotron. It revealed the structure and functioning of a protein complex on the surface of human cells, called a G-protein-coupled receptor, that receives signals from the cell's environment and is a key target for drug development.

But he and his colleagues also used SLAC's Stanford Synchrotron Radiation Lightsource (SSRL) in the mid 1990s and early 2000s to develop techniques for determining the structure of protein receptors.

Crystals and Microbeams

Researchers typically use a method called X-ray crystallography to discover a protein's atomic structure. They crystallize the protein, then bombard it with X-ray light. The patterns made by light diffracting off atoms in the crystal reveal the protein's structure.

However, the proteins in these cellular receptors, which sit in the fatty outer membranes of cells and regulate many important physiological processes, are extremely complex and fragile, and difficult and costly to crystallize.

William Weis, a longtime collaborator in Kobilka's work, is a member of the Photon Science faculty at SLAC and a professor of structural biology at Stanford University. He said, "Over the years, when we had some crystals, we would look at them at SSRL to see if we were making any progress at getting anything that diffracted," or successfully produced an image.

Because their crystallized samples were so small, it became clear, Weis said, that smaller-sized X-ray beams were required to provide higher-resolution imaging.

"The crystals really required microbeams – really finely focused X-ray beams," which were first available at the European Synchrotron Radiation Facility in Grenoble, France, Weis said: "If you use a larger beam, you get too much background. It's really a signal-to-noise problem."

After running experiments at the French facility, Weis and Kobilka began using similar microbeams at Argonne's Advanced Photon Source (APS), a synchrotron X-ray research facility in Illinois. It was there, at APS, that most of the data related to the Nobel Prize-winning research was collected.

New Research Possibilities

Weis said future research related to the cellular receptors could also be conducted at the SSRL, which now offers a beamline with microbeams that produces resolution images comparable to those from the microbeam at APS.

This image shows the structure of a G-protein-coupled rece signaling complex, which was identified in 2011. Stanford's Brian Kobilka shares the 2012 Nobel Prize in chemistry for work in... (*Image courtesy Søren G. F. Rasmussen, et al., "Crystal structure of the β2 adrenergic receptor–Gs protein complex," Nature, Volume 477, Issue 7366*)

Tags

Stanford Synchrotron Radiation Lightsource (SSRL)
Biological Sciences
Chemistry & Catalysis
Structural Molecular Biology
X-ray Crystallography
X-ray Imaging
X-ray Scattering/Diffraction

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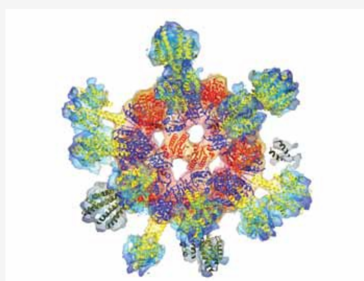
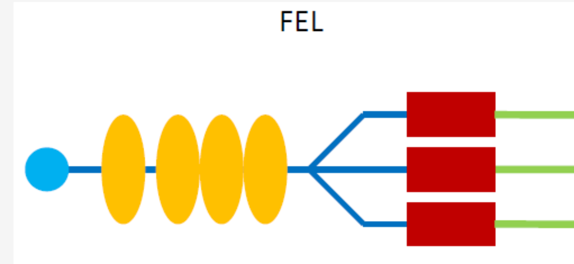
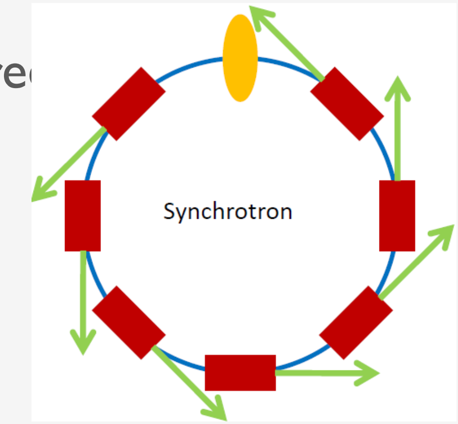
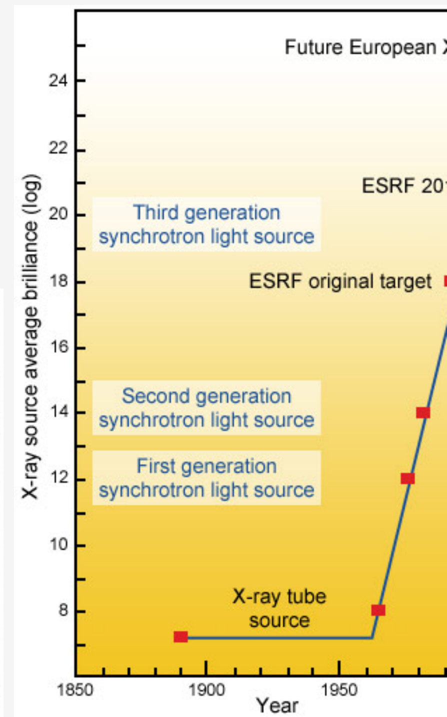


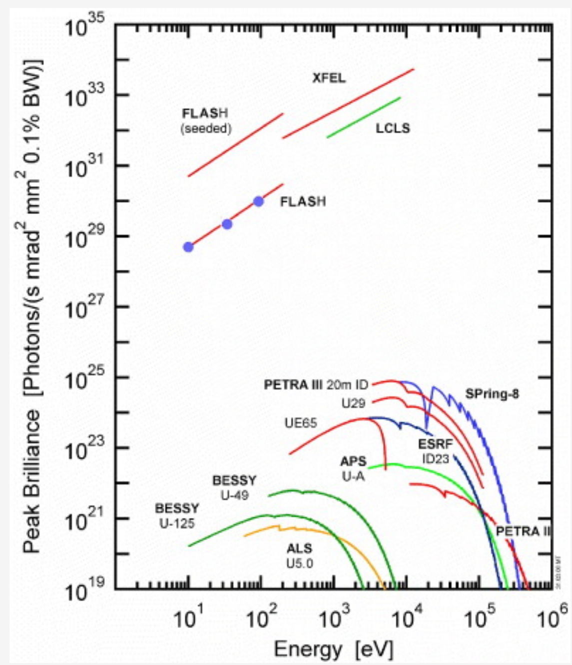
FUTURE DEVELOPMENT

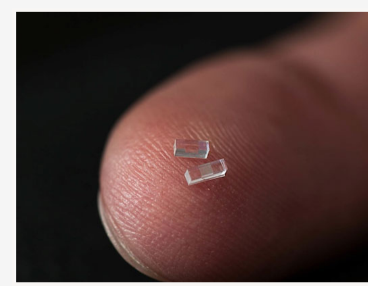
- Most future X-ray sources will come from Fre Electron Lasers (FEL) but not Synchrotrons
  - Higher peak power / brighter
  - Shorter pulse durations
  - Coherent light
  - Simultaneous users, reduce cost
- Laser-Plasma Accelerators
  - Emax ~ 100 GV/m
  - Very compact design
- Accelerator on a chip?
  - Dielectric Laser Accelerators (DLA)










Brad Plummer/SLAC

The Man Who Stuck His Head Inside a Particle Accelerator

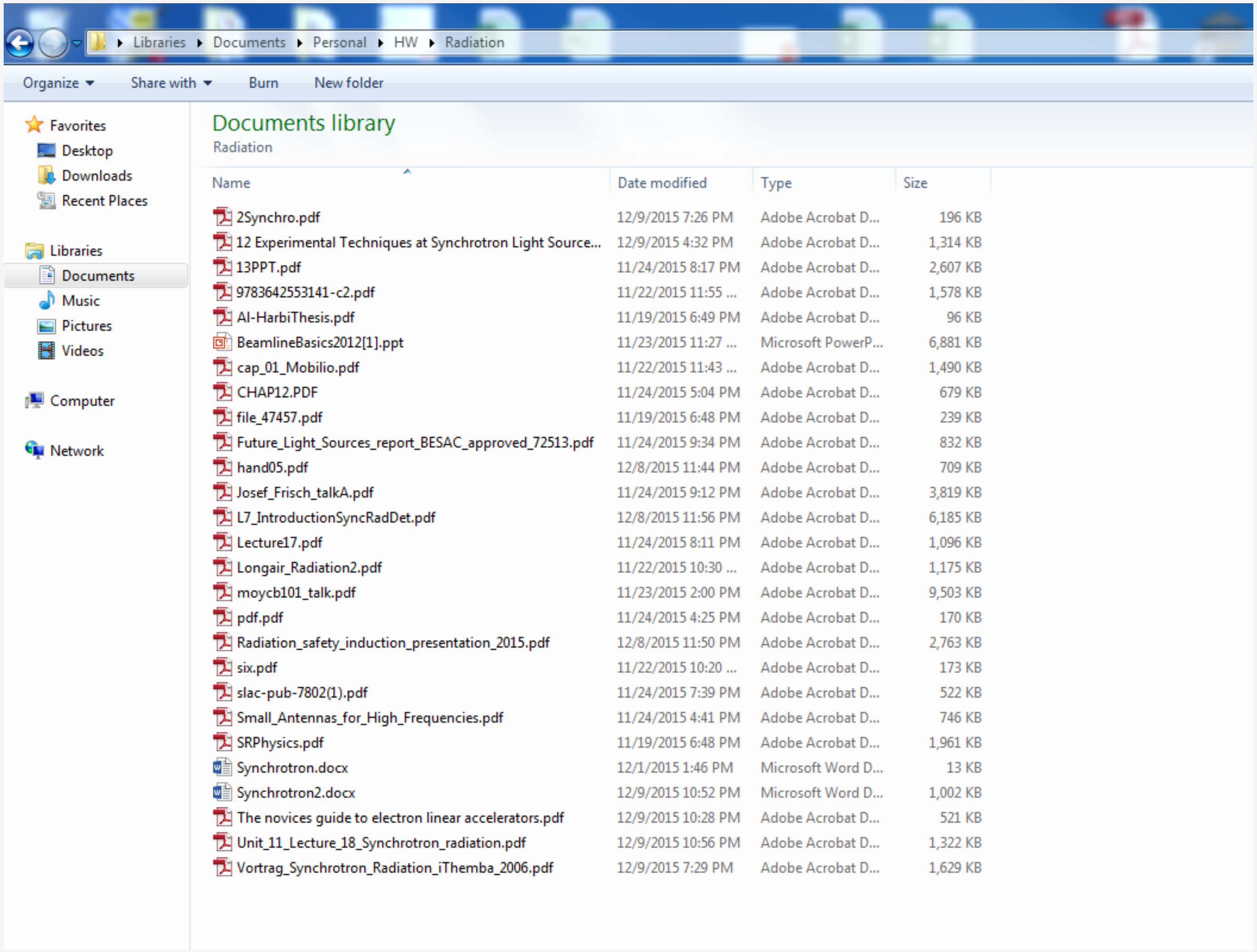
Alex Santoso • Sunday, October 5, 2008 at 1:08 PM • 3

So with all the recent news about the Large Hadron Collider, many of you may have this nagging question: what, exactly, would happen if you stick your head in the particle accelerator?

Well, actually, we know the answer to that because someone *did* stick his head into a particle accelerator. Here's the story of Anatoli Bugorski:

> *Bugorski, a 36-year-old researcher at the Institute for High Energy Physics in Protvino, was checking a piece of accelerator equipment that had malfunctioned - as had, apparently, the several safety mechanisms. Leaning over the piece of equipment, Bugorski stuck his head in the space through which the beam passes on its way from one part of the accelerator tube to the next and saw a flash brighter than a thousand suns. He felt no pain.*
>
> *From what we know about radiation, about 500 to 600 rads is enough to kill a person (though we don't know of anyone else who has been exposed to radiation in the form of a proton beam moving at about the speed of sound). The left side of his face swollen beyond recognition, Bugorski was taken to a clinic in Moscow so that doctors could observe his death over the following two to three weeks.*
>
> *Over the next few days, skin on the back of his head and on his face just next to his left nostril peeled away to reveal the path the beam had burned through the skin, the skull, and the brain tissue. The inside of his head continued to burn away: all the nerves on the left were gone in two years, paralyzing that side of his face. Still, not only did Bugorski not die, but he remained a normally functioning human being, capable even of continuing in science. For the first dozen years, the only real evidence that something had gone neurologically awry were occasional petit mal seizures; over the last few years Bugorski has also had six grand mals. The dividing line of his life goes down the middle of his face: the right side has aged, while the left froze 19 years ago. When he concentrates, he wrinkles only half his forehead.*

REFERENCE



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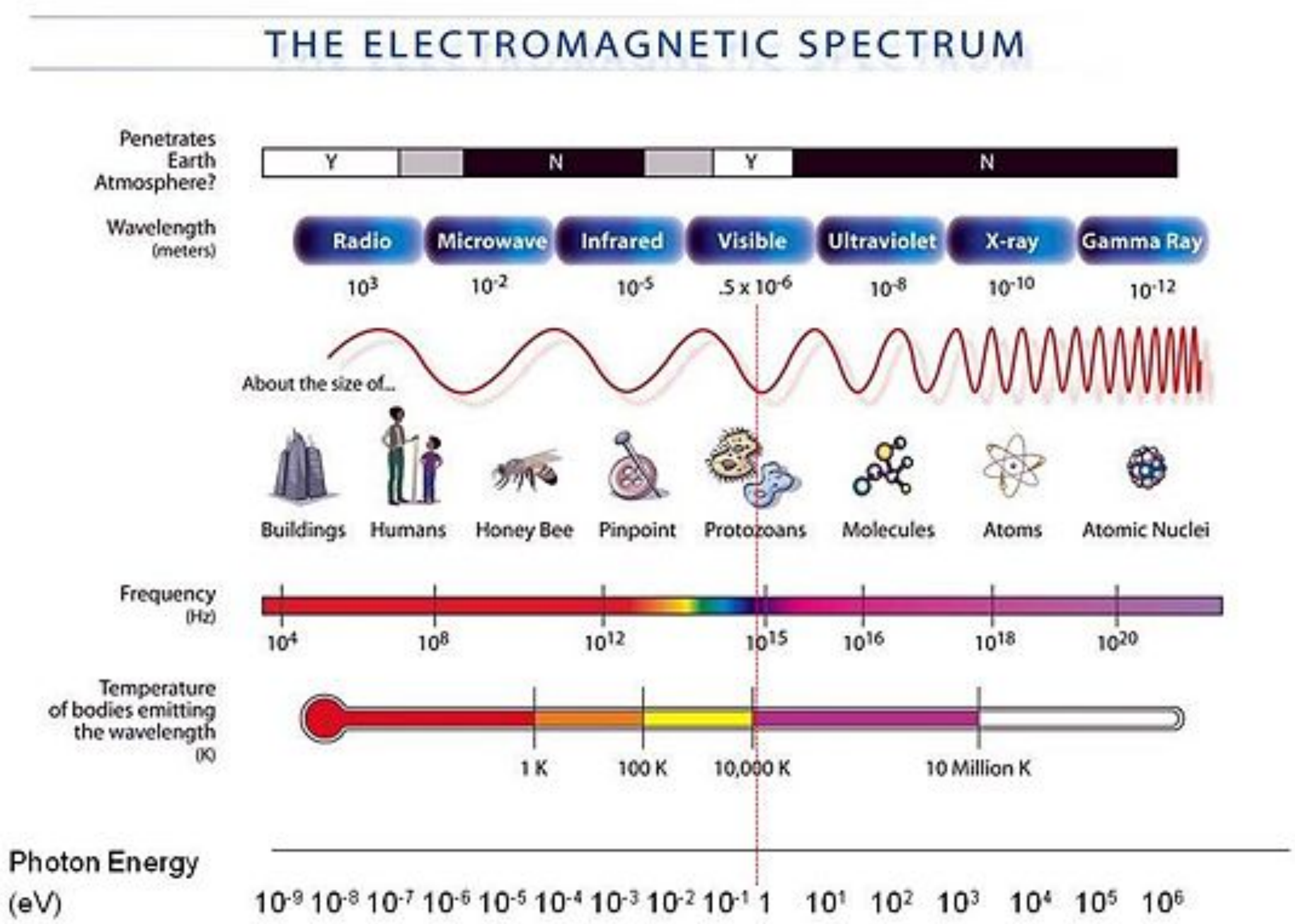
THE ELECTROMAGNETIC SPECTRUM
Penetrates Earth Atmosphere?
Y
N
Y
N
Wavelength (meters)
Radio
Microwave
Infrared
Visible
Ultraviolet
X-ray
Gamma Ray
10^3
10^-2
10^-5
.5 x 10^-6
10^-8
10^-10
10^-12
About the size of...
Buildings
Humans
Honey Bee
Pinpoint
Protozoans
Molecules
Atoms
Atomic Nuclei
Frequency (Hz)
10^4
10^8
10^12
10^15
10^16
10^18
10^20
Temperature of bodies emitting the wavelength (K)
1 K
100 K
10,000 K
10 Million K
Photon Energy (eV)
10^-9 10^-8 10^-7 10^-6 10^-5 10^-4 10^-3 10^-2 10^-1 1 10^1 10^2 10^3 10^4 10^5 10^6