Synchrotron Radiation

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Useful books and references

H. Wiedemann, *Synchrotron Radiation*
Springer-Verlag Berlin Heidelberg 2003

H. Wiedemann, *Particle Accelerator Physics I and II*
Springer Study Edition, 2003

A.Hofmann, *The Physics of Synchrotron Radiation*
Cambridge University Press 2004

A. W. Chao, M. Tigner, *Handbook of Accelerator Physics and Engineering*, World Scientific 1999

CERN Accelerator School Proceedings

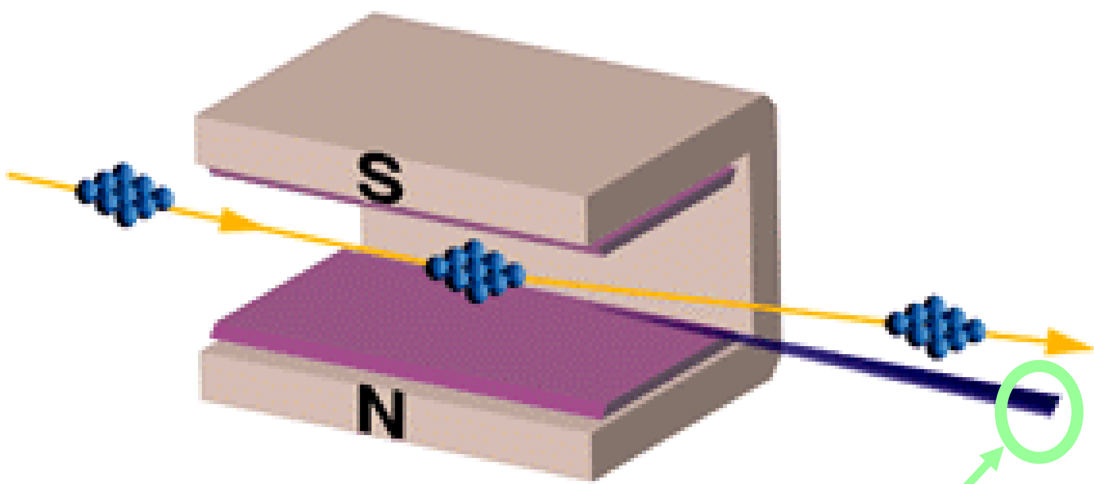
Synchrotron Radiation and Free Electron Lasers

Grenoble, France, 22 - 27 April 1996
(A. Hofmann's lectures on synchrotron radiation)
CERN Yellow Report 98-04

Brunnen, Switzerland, 2 – 9 July 2003
CERN Yellow Report 2005-012

Previous CAS Schools Proceedings

Curved orbit of electrons in magnet field



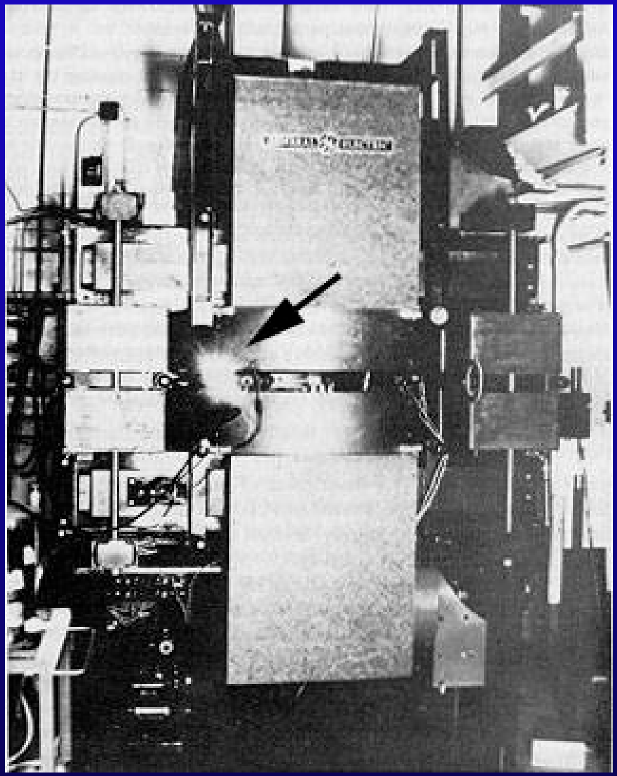
Accelerated charge → Electromagnetic radiation

Electromagnetic waves

Crab Nebula
6000 light years away

First light observed
1054 AD

GE Synchrotron
New York State



First light observed
1947

Synchrotron radiation: some dates

- 1873 Maxwell's equations
- 1887 Hertz: electromagnetic waves
- 1898 Liénard: retarded potentials
- 1900 Wiechert: retarded potentials
- 1908 Schott: Adams Prize Essay

... waiting for accelerators …
1940: 2.3 MeV betatron,Kerst, Serber

Maxwell equations (poetry)

War es ein Gott, der diese Zeichen schrieb
Die mit geheimnisvoll verborg'nem Trieb
Die Kräfte der Natur um mich enthüllen
Und mir das Herz mit stiller Freude füllen.

Ludwig Boltzman

Was it a God whose inspiration
Led him to write these fine equations
Nature's fields to me he shows
And so my heart with pleasure glows.

translated by John P. Blewett

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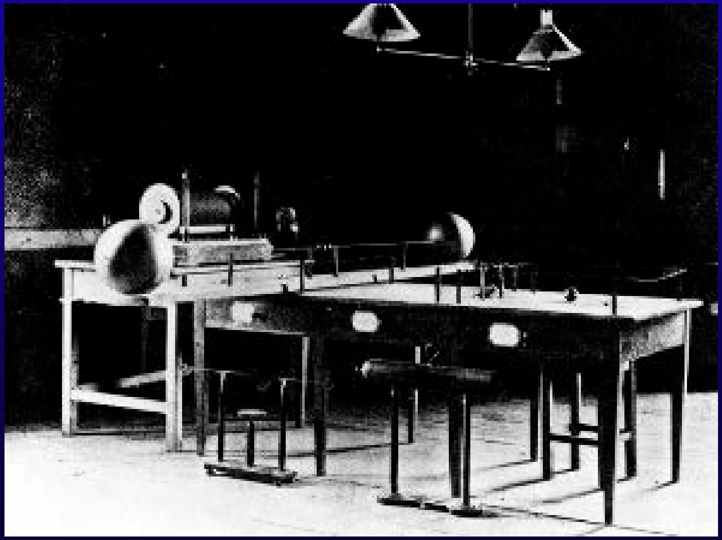
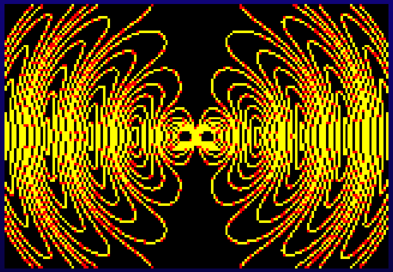
THEORETICAL UNDERSTANDING →

1873 Maxwell's equations

→ made evident that changing charge densities would result in electric fields that would radiate outward

1887 Heinrich Hertz demonstrated such waves:





It's of no use whatsoever[...] *this is just an experiment that proves Maestro Maxwell was right—we just have these mysterious electromagnetic waves that we cannot see with the naked eye. But they are there.*


Radiowaves für www.senderfotos.de

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1898 Liénard:

ELECTRIC AND MAGNETIC FIELDS PRODUCED BY A POINT CHARGE MOVING ON AN ARBITRARY PATH

(by means of retarded potentials …
proposed first by Ludwig Lorenz in 1867)

L'Éclairage Électrique

REVUE HEBDOMADAIRE D'ÉLECTRICITÉ

CHAMP ÉLECTRIQUE ET MAGNÉTIQUE

PRODUIT PAR UNE CHARGE ÉLECTRIQUE CONCENTRÉE EN UN POINT ET ANIMÉE D'UN MOUVEMENT QUELCONQUE

Admettons qu'une masse électrique en mouvement de densité ρ et de vitesse u en chaque point produit le même champ qu'un courant de conduction d'intensité $u\rho$. En conservant les notations d'un précédent article (1) nous obtiendrons pour déterminer le champ, les équations

$$\frac{1}{4\pi}\left(\frac{d\gamma}{dy} - \frac{d\beta}{dz}\right) = \rho u_x + \frac{df}{dt} \qquad (1)$$

$$V^2\left(\frac{dh}{dy} - \frac{dg}{dz}\right) = -\frac{1}{4\pi}\frac{d\alpha}{dt} \qquad (2)$$

avec les analogues déduites par permutation tournante et en outre les suivantes

$$\rho = \left(\frac{df}{dx} + \frac{dg}{dy} + \frac{dh}{dz}\right. \qquad (3)$$

$$\frac{d\alpha}{dx} + \frac{d\beta}{dy} + \frac{d\gamma}{dz} = 0. \qquad (4)$$

De ce système d'équations on déduit facilement les relations

$$\left(V^2\Delta - \frac{d^2}{dt^2}\right)f = V^2\frac{d\rho}{dx} + \frac{d}{dt}(\rho u_x) \qquad (5)$$

$$\left(V^2\Delta - \frac{d^2}{dt^2}\right)\alpha = 4\pi V^2\left[\frac{d}{dz}(\rho u_y) - \frac{d}{dy}(\rho u_z)\right] \qquad (6)$$

Soient maintenant quatre fonctions ψ, F, G, H définies par les conditions

$$\left(V^2\Delta - \frac{d^2}{dt^2}\right)\psi = -4\pi V^2\rho. \qquad (7)$$

$$\left.\begin{aligned}\left(V^2\Delta - \frac{d^2}{dt^2}\right)F &= -4\pi V^2\rho u_x\\ \left(V^2\Delta - \frac{d^2}{dt^2}\right)G &= -4\pi\rho u_y\\ \left(V^2\Delta - \frac{d^2}{dt^2}\right)H &= -4\pi V^2\rho u_z\end{aligned}\right\} \qquad (8)$$

On satisfera aux conditions (5) et (6) en prenant

$$4\pi f = -\frac{d\psi}{dx} - \frac{1}{V^2}\frac{dF}{dt} \qquad (9)$$

$$\alpha = \frac{dH}{dy} - \frac{dG}{dz}. \qquad (10)$$

Quant aux équations (1) à (4), pour qu'elles soient satisfaites, il faudra que, en plus de (7) et (8), on ait la condition

$$\frac{d\psi}{dt} + \frac{dF}{dx} + \frac{dG}{dy} + \frac{dH}{dz} = 0. \qquad (11)$$

Occupons-nous d'abord de l'équation (7). On sait que la solution la plus générale est la suivante :

$$\psi = \int \frac{\rho\left[x', y', z', t - \frac{r}{V}\right]}{r}\, d\omega' \qquad (12)$$

(1) La théorie de Lorentz, *L'Éclairage Électrique*, t. XIV, p. 417. α, β, γ, sont les composantes de la force magnétique et f, g, h, celles du déplacement dans l'éther.

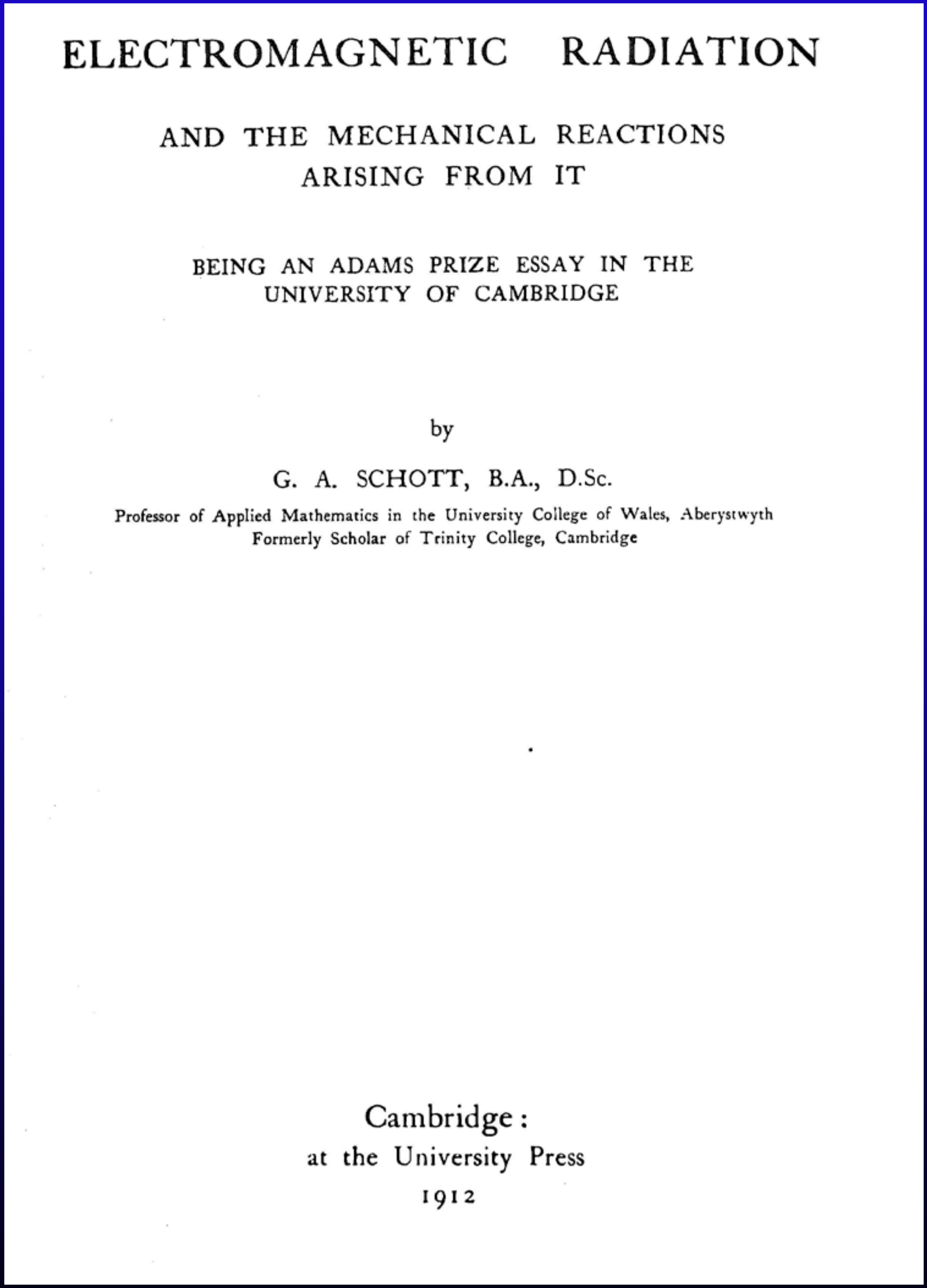
Fig. 1. First page of Liénard's 1898 paper.

1912 Schott:

COMPLETE THEORY OF SYNCHROTRON RADIATION IN ALL THE GORY DETAILS (327 pages long)

… to be forgotten for 30 years

(on the usefulness of prizes)



ELECTROMAGNETIC RADIATION

AND THE MECHANICAL REACTIONS ARISING FROM IT

BEING AN ADAMS PRIZE ESSAY IN THE UNIVERSITY OF CAMBRIDGE

by

G. A. SCHOTT, B.A., D.Sc.

Professor of Applied Mathematics in the University College of Wales, Aberystwyth
Formerly Scholar of Trinity College, Cambridge

Cambridge:
at the University Press
1912

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Donald Kerst: first betatron (1940)

"Ausserordentlichhochgeschwindigkeitelektronenent wickelndenschwerarbeitsbeigollitron"

Synchrotron radiation: some dates

- 1946 Blewett observes energy loss due to synchrotron radiation
  100 MeV betatron
- 1947 First visual observation of SR
  70 MeV **synchrotron**, GE Lab

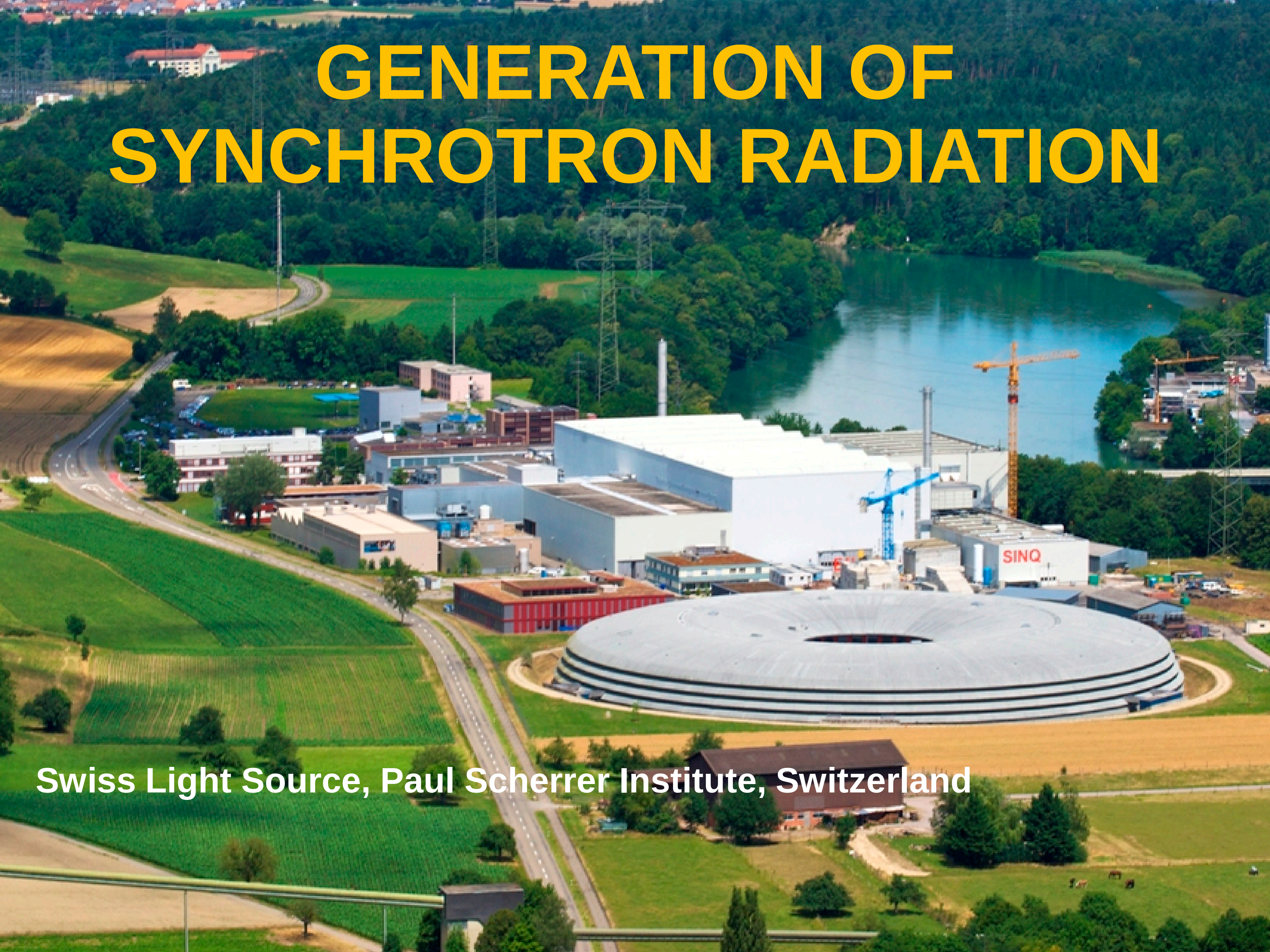
NAME!

- 1949 Schwinger PhysRev paper

…

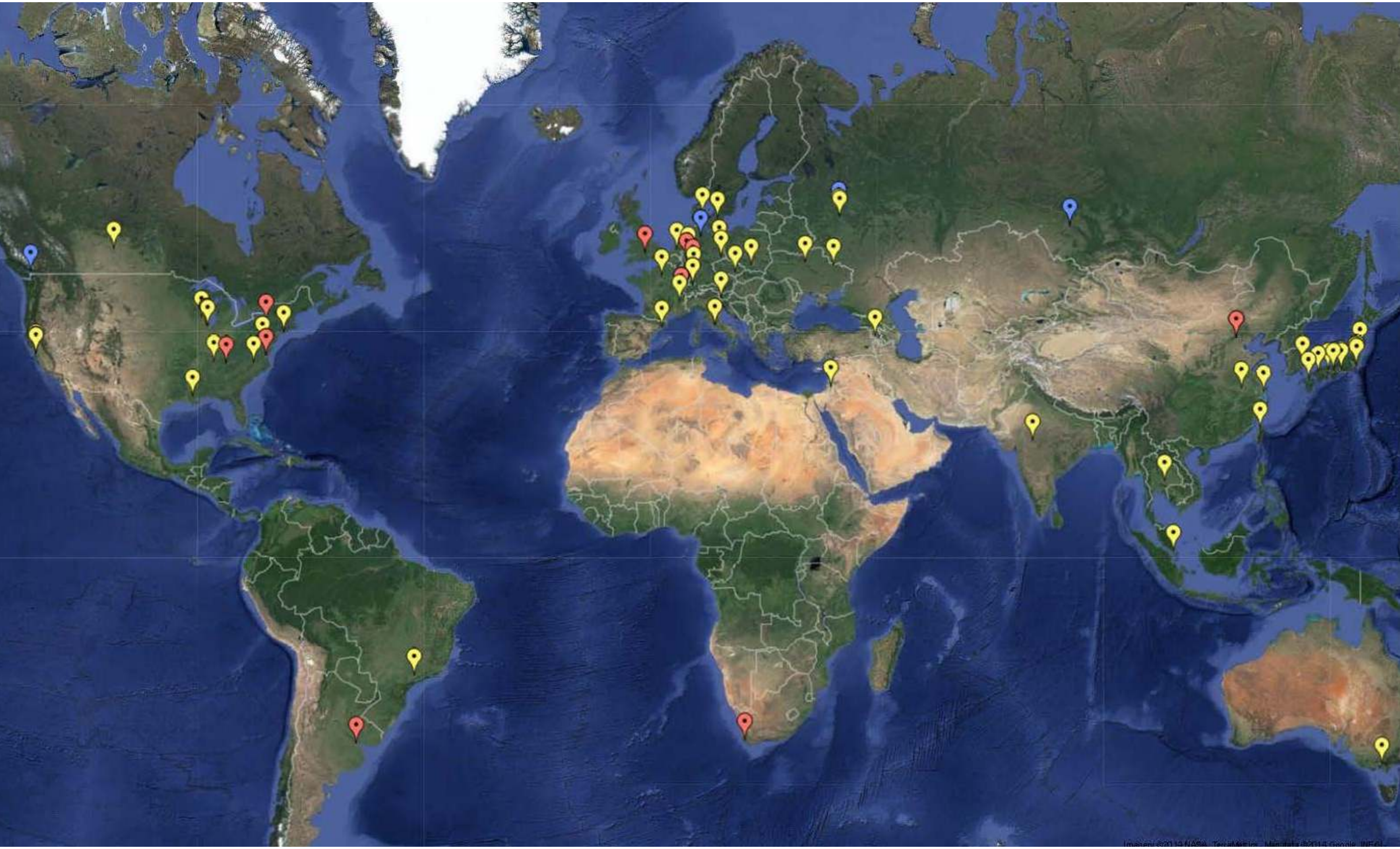
- 1976 Madey: first demonstration of Free Electron laser

GENERATION OF SYNCHROTRON RADIATION



Swiss Light Source, Paul Scherrer Institute, Switzerland

60‘000 SR users world-wide

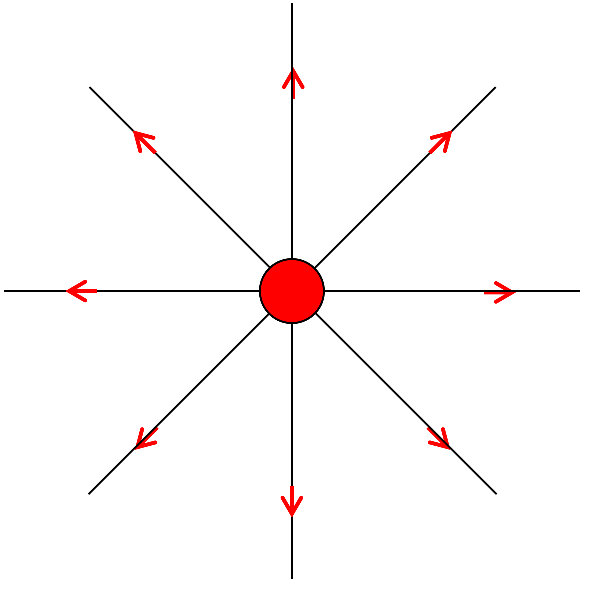


Why do they radiate?

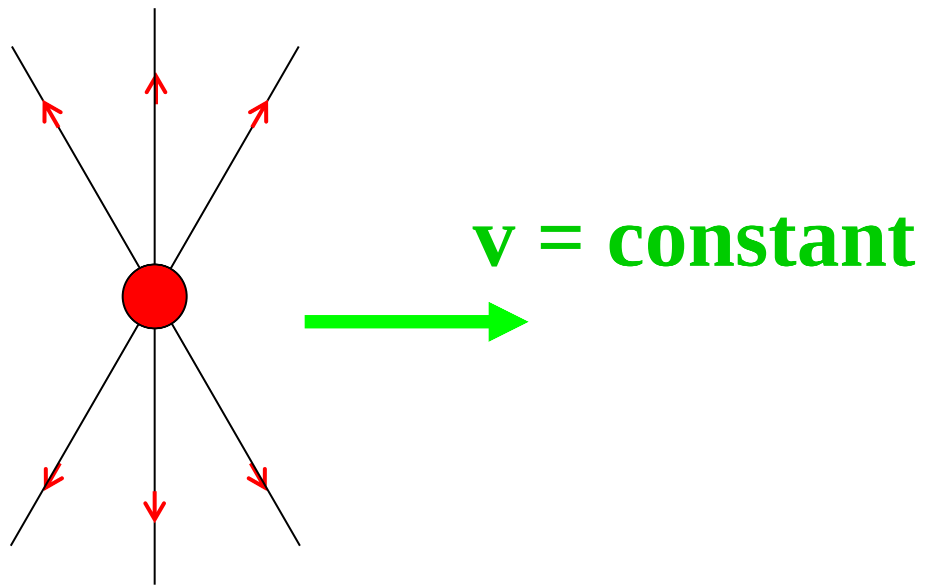
Synchrotron Radiation is not as simple as it seems

… I will try to show that it is much simpler

Charge at rest
Coulomb field, no radiation



Uniformly moving charge does not radiate



But! Cerenkov!

Free isolated electron cannot emit a photon

Easy proof using 4-vectors and relativity

- momentum conservation if a photon is emitted

$$\boldsymbol{P}_i = \boldsymbol{P}_f + \boldsymbol{P}_\gamma$$

- square both sides

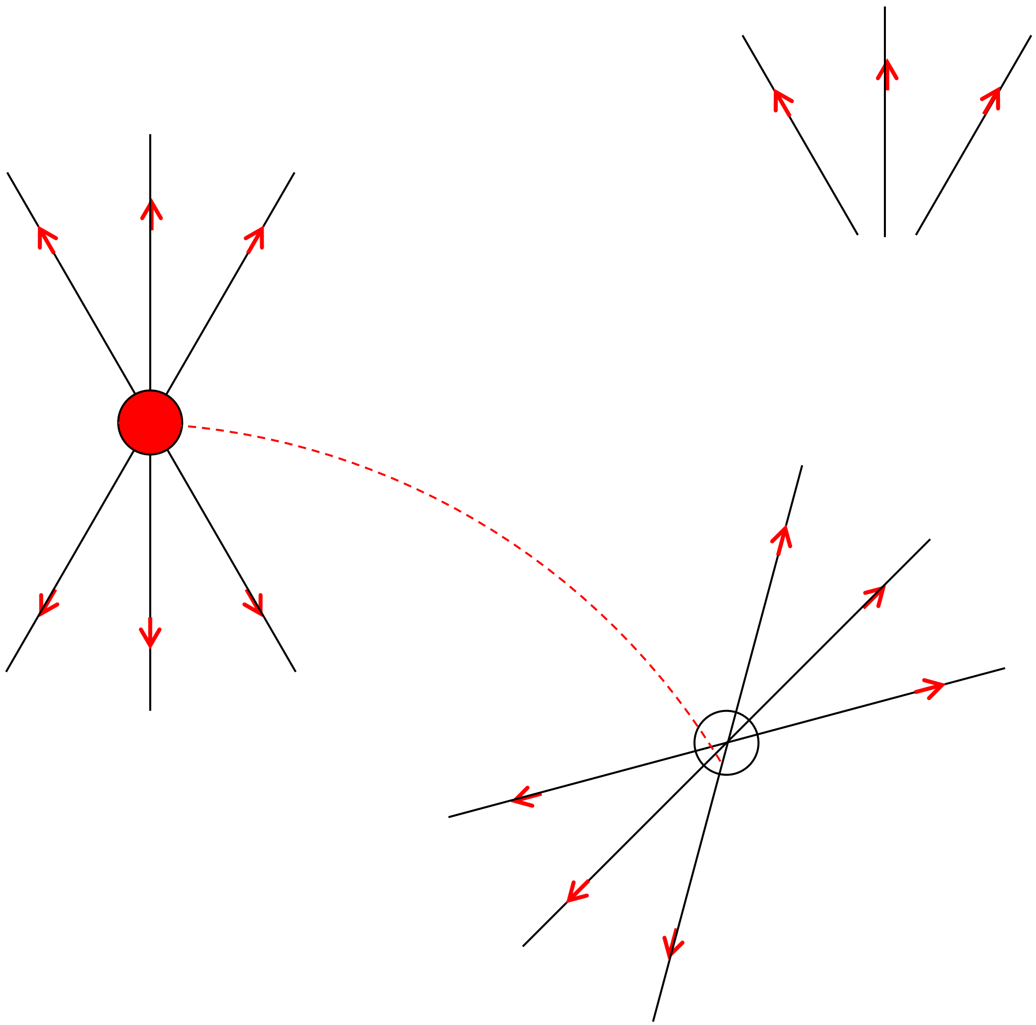
$$m^2 = m^2 + 2\boldsymbol{P}_f \cdot \boldsymbol{P}_\gamma + 0 \;\Rightarrow\; \boldsymbol{P}_f \cdot \boldsymbol{P}_\gamma = 0$$

- in the rest frame of the electron

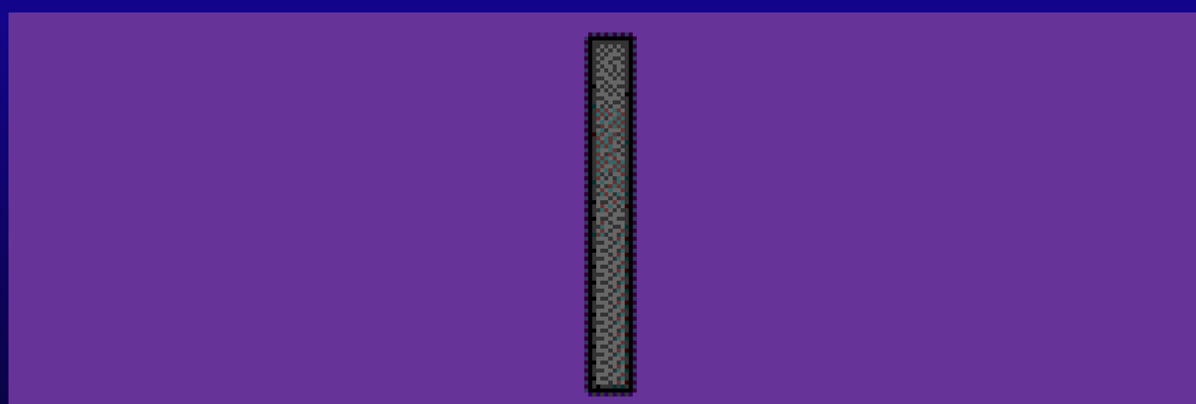
$$\boldsymbol{P}_f = (m, 0) \qquad \boldsymbol{P}_\gamma = (E_\gamma, p_\gamma)$$

this means that the photon energy must be zero.

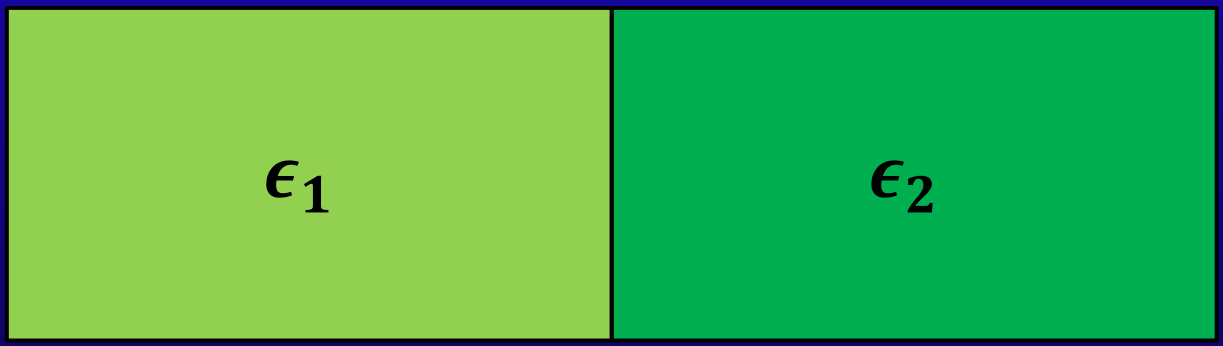
We need to separate the field from charge



Bremsstrahlung
or
“braking” radiation



Transition Radiation



$$c_1 = \frac{1}{\sqrt{\epsilon_1 \mu_1}} \qquad c_2 = \frac{1}{\sqrt{\epsilon_2 \mu_2}}$$

Liénard–Wiechert potentials

$$\varphi(t) = \frac{1}{4\pi\varepsilon_0}\frac{q}{\left[r\left(1-\vec{\mathbf{n}}\cdot\vec{\boldsymbol{\beta}}\right)\right]_{ret}}$$

$$\vec{\mathbf{A}}(t) = \frac{q}{4\pi\varepsilon_0 c^2}\left[\frac{\vec{\mathbf{v}}}{r\left(1-\vec{\mathbf{n}}\cdot\vec{\boldsymbol{\beta}}\right)}\right]_{ret}$$

and the electromagnetic fields:

$$\nabla\cdot\vec{\mathbf{A}} + \frac{1}{c^2}\frac{\partial\varphi}{\partial t} = 0$$

(Lorentz gauge)

$$\vec{\mathbf{B}} = \nabla\times\vec{\mathbf{A}}$$

$$\vec{\mathbf{E}} = -\nabla\varphi - \frac{\partial\vec{\mathbf{A}}}{\partial t}$$

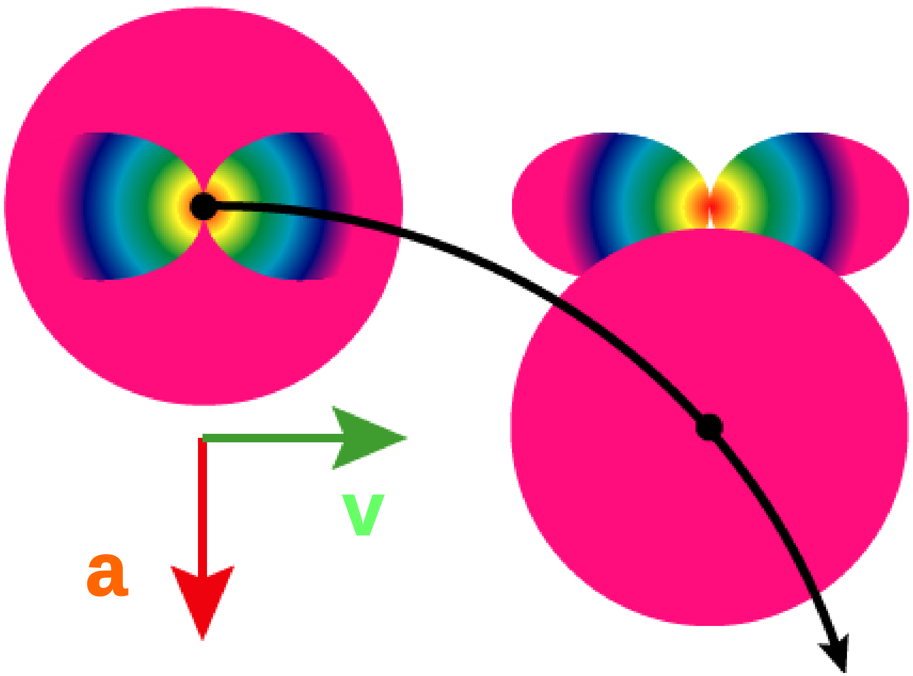
Fields of a moving charge

$$\vec{\mathbf{E}}(t) = \frac{q}{4\pi\varepsilon_0}\left[\frac{\vec{\mathbf{n}} - \vec{\boldsymbol{\beta}}}{\left(1 - \vec{\mathbf{n}} \cdot \vec{\boldsymbol{\beta}}\right)^3 \gamma^2} \cdot \frac{\mathbf{1}}{\mathbf{r}^2}\right]_{ret} +$$

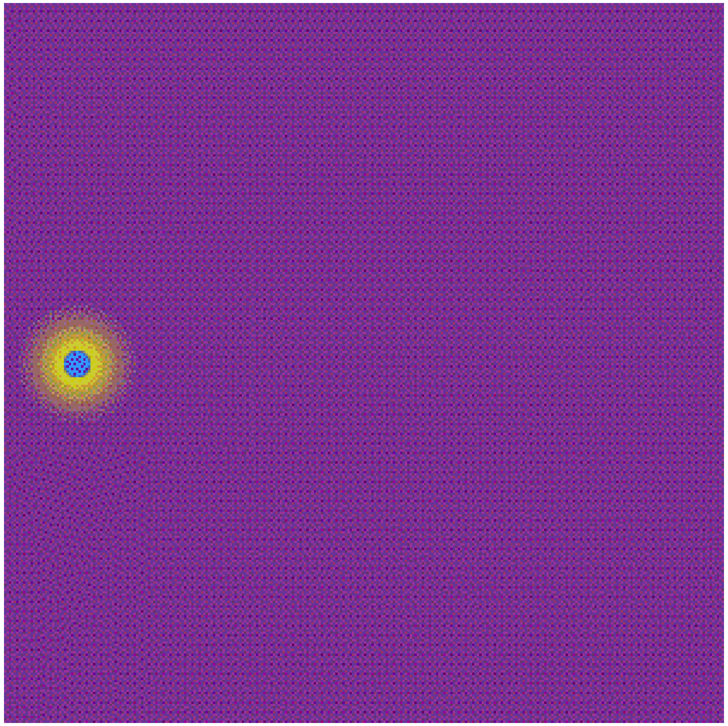
$$\frac{q}{4\pi\varepsilon_0 c}\left[\frac{\vec{\mathbf{n}} \times \left[\left(\vec{\mathbf{n}} - \vec{\boldsymbol{\beta}}\right) \times \dot{\vec{\boldsymbol{\beta}}}\right]}{\left(1 - \vec{\mathbf{n}} \cdot \vec{\boldsymbol{\beta}}\right)^3 \gamma^2} \cdot \frac{\mathbf{1}}{\mathbf{r}}\right]_{ret}$$

$$\vec{\mathbf{B}}(\mathrm{t}) = \frac{1}{\mathrm{c}}\left[\vec{\mathbf{n}} \times \vec{\mathbf{E}}\right]$$

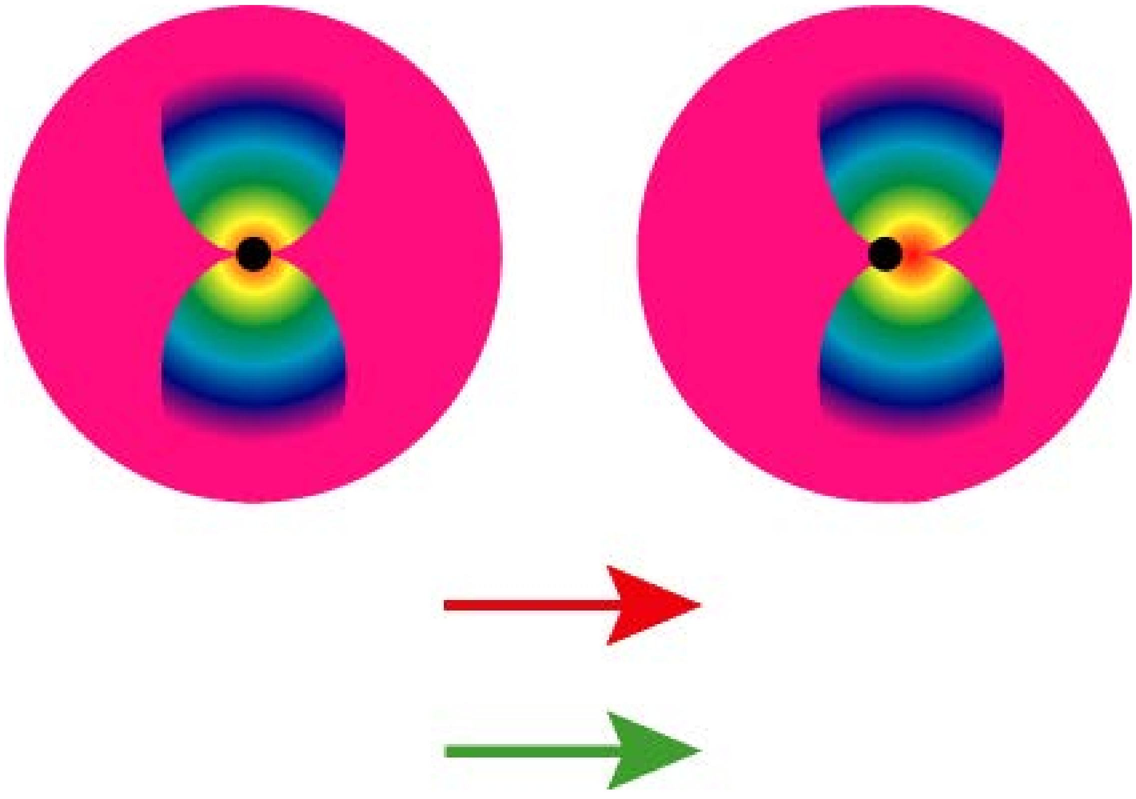
Transverse acceleration



Radiation field quickly separates itself from the Coulomb field



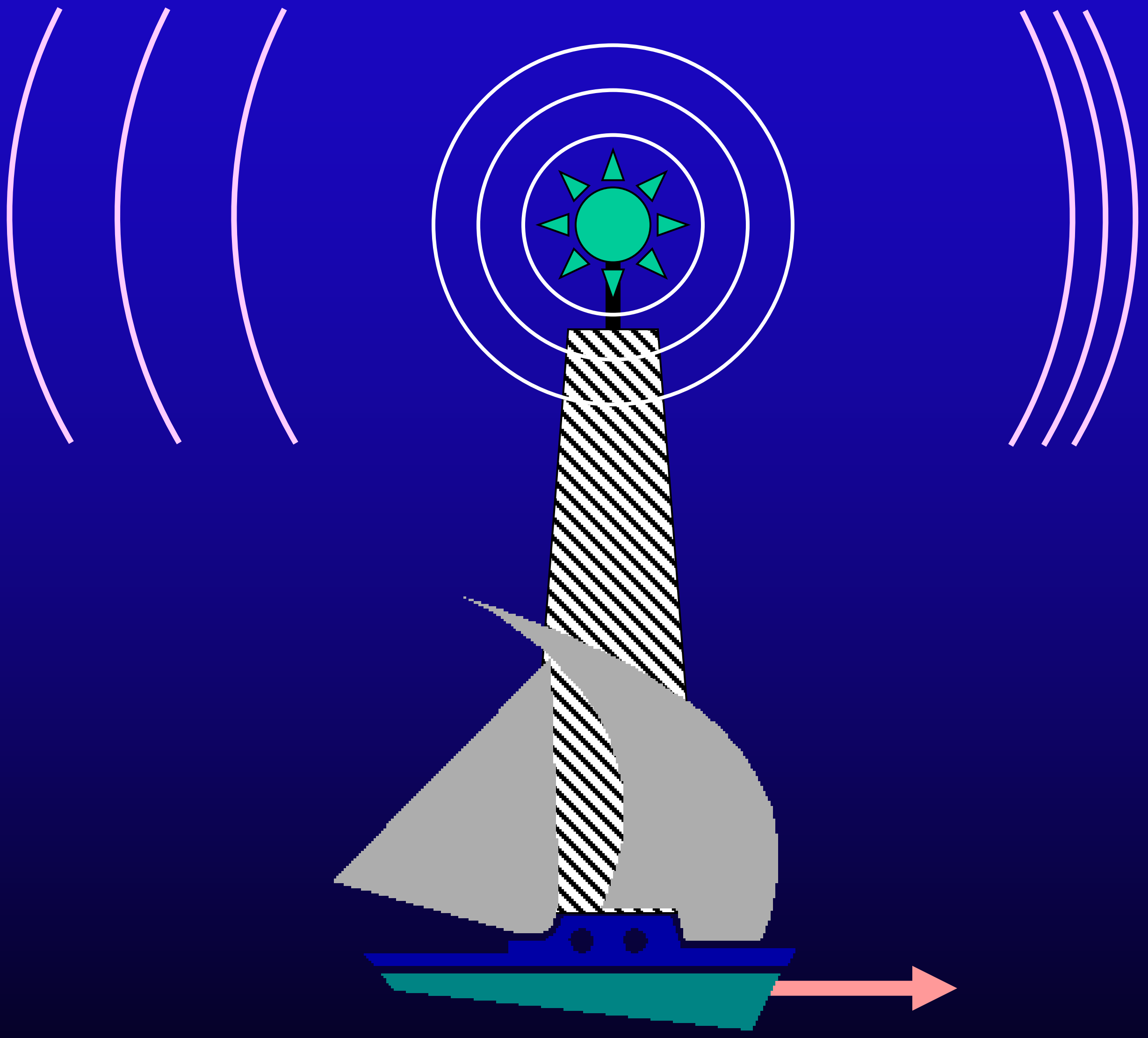
Longitudinal acceleration



Radiation field cannot separate itself from the Coulomb field

Synchrotron Radiation Basic Properties

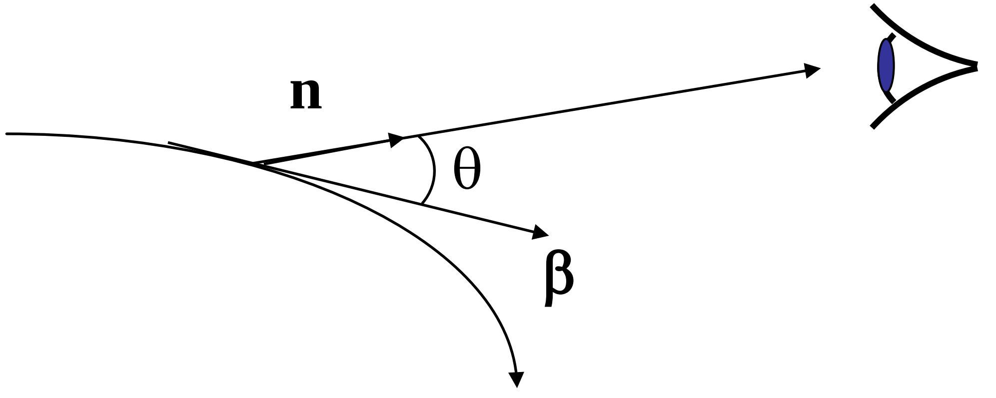
Moving Source of Waves



Cape Hatteras, 1999

Time compression

Electron with velocity β emits a wave with period T_{emit} while the observer sees a different period T_{obs} because the electron was moving towards the observer



$$T_{obs} = (1 - \mathbf{n} \cdot \boldsymbol{\beta})\, T_{emit}$$

The wavelength is shortened by the same factor

$$\lambda_{obs} = (1 - \beta \cos\theta)\, \lambda_{emit}$$

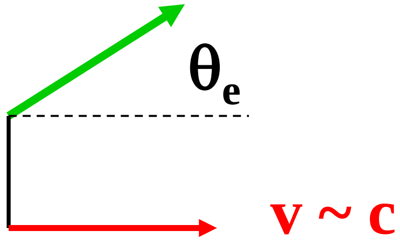
in ultra-relativistic case, looking along a tangent to the trajectory

$$\lambda_{obs} = \frac{1}{2\gamma^2} \lambda_{emit}$$

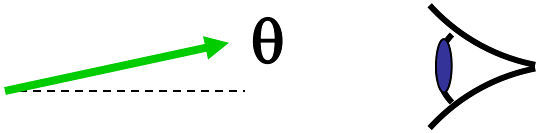
since

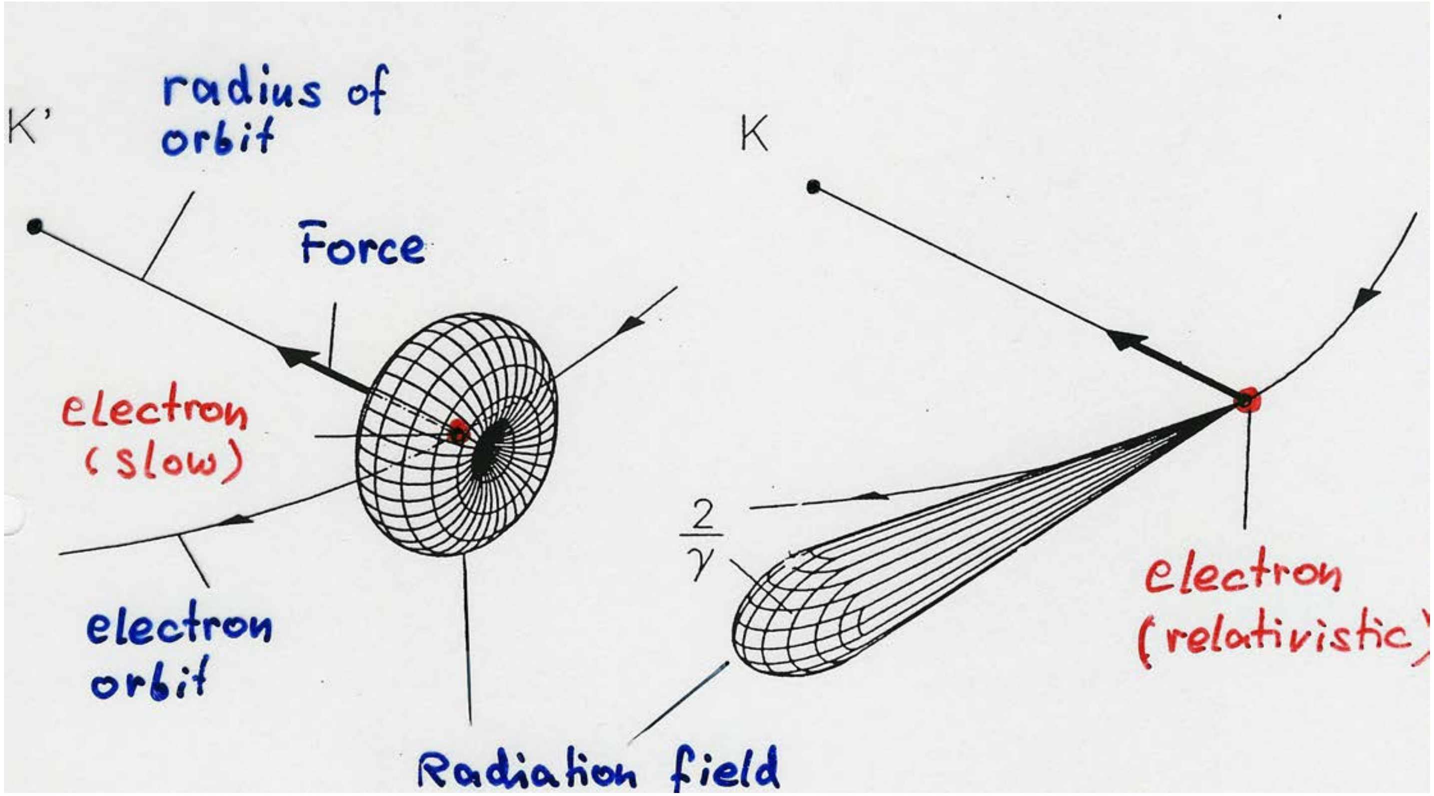
$$1 - \beta = \frac{1-\beta^2}{1+\beta} \cong \frac{1}{2\gamma^2}$$

Radiation is emitted into a narrow cone



$$\theta = \frac{1}{\gamma} \cdot \theta_e$$



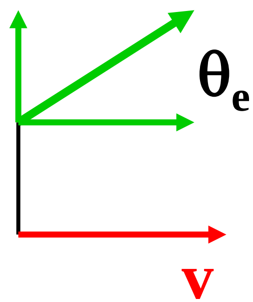


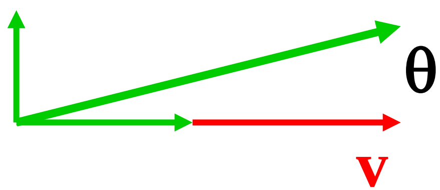
v << c

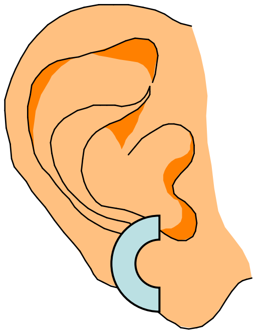
v ≈ c

Sound waves (non-relativistic)

Angular collimation







$$\theta = \frac{v_{s\perp}}{v_{s\parallel} + \mathbf{v}} = \frac{v_{s\perp}}{v_{s\parallel}} \cdot \frac{1}{1 + \frac{\mathbf{v}}{v_s}} \approx \theta_e \cdot \frac{1}{1 + \frac{\mathbf{v}}{v_s}}$$

Doppler effect (moving source of sound)

$$\lambda_{heard} = \lambda_{emitted}\left(1 - \frac{\mathbf{v}}{v_s}\right)$$

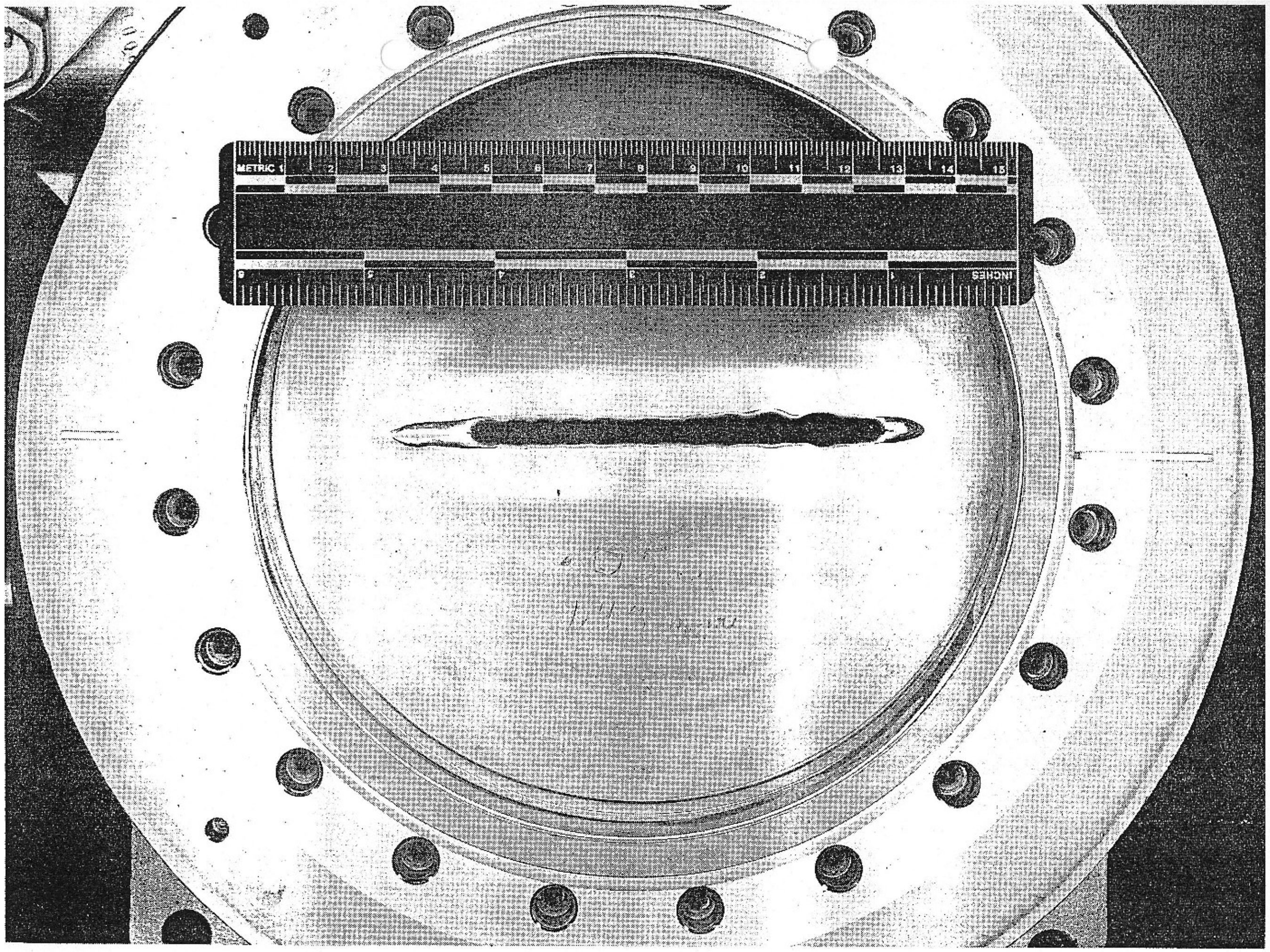
Synchrotron radiation power

Power emitted is proportional to: $P \propto E^2 B^2$

$$P_\gamma = \frac{cC_\gamma}{2\pi} \cdot \frac{E^4}{\rho^2}$$

$$C_\gamma = \frac{4\pi}{3} \frac{r_e}{\left(m_e c^2\right)^3} = 8.858 \cdot 10^{-5} \left[\frac{\mathrm{m}}{\mathrm{GeV}^3}\right]$$

The power is all too real!



'ig. 12. Damaged X-ray ring front end gate valve. The power incident on the valve was approximately 1 kW for a duration estimated to 2–10 min and drilled a hole through the valve plate.

Synchrotron radiation power

Power emitted is proportional to:

$$\boldsymbol{P \propto E^2 B^2}$$

$$P_\gamma = \frac{cC_\gamma}{2\pi} \cdot \frac{E^4}{\rho^2}$$

$$P_\gamma = \frac{2}{3}\alpha\hbar c^2 \cdot \frac{\gamma^4}{\rho^2}$$

$$C_\gamma = \frac{4\pi}{3}\frac{r_e}{(m_e c^2)^3} = 8.858 \cdot 10^{-5}\left[\frac{\text{m}}{\text{GeV}^3}\right]$$

$$\alpha = \frac{1}{137}$$

$$\hbar c = 197 \text{ Mev} \cdot \text{fm}$$

Energy loss per turn:

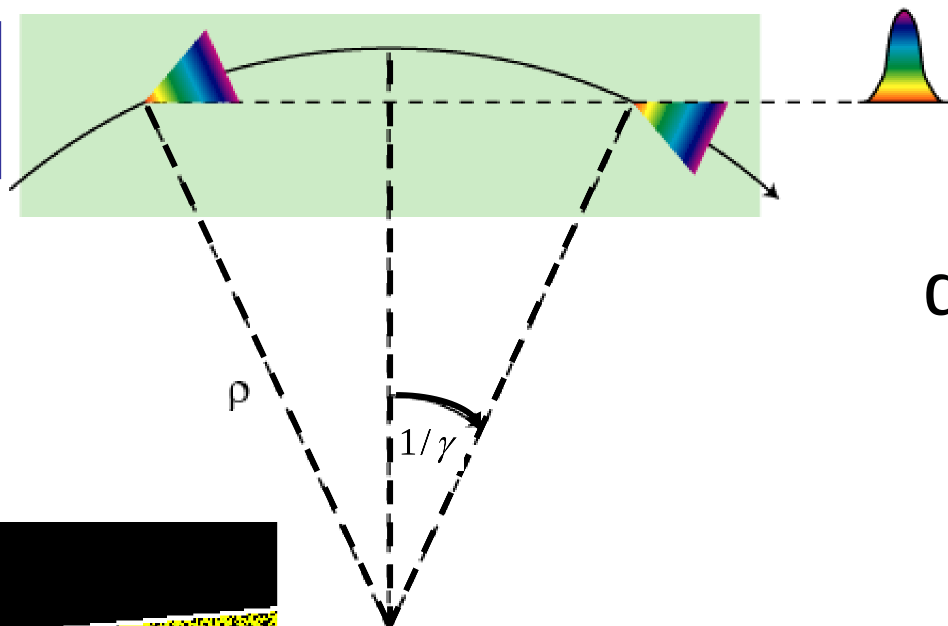
$$U_0 = C_\gamma \cdot \frac{E^4}{\rho}$$

$$U_0 = \frac{4\pi}{3}\alpha\hbar c\frac{\gamma^4}{\rho}$$

Typical frequency of synchrotron light

Due to extreme collimation of light observer sees only a small portion of electron trajectory **(a few mm)**

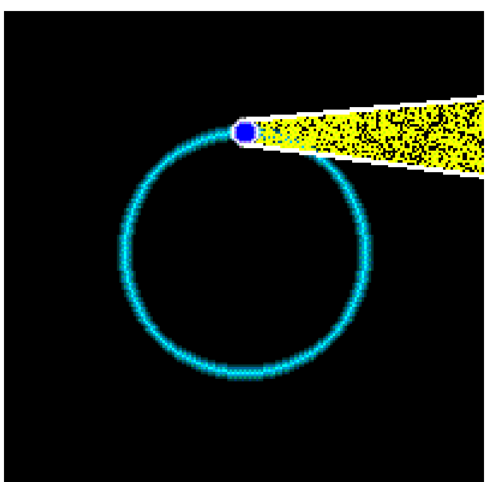
$$l \sim \frac{2\rho}{\gamma}$$



Pulse length: difference in times it takes an electron and a photon to cover this distance

$$\Delta t \sim \frac{l}{\beta c} - \frac{l}{c} = \frac{l}{\beta c}(1-\beta)$$

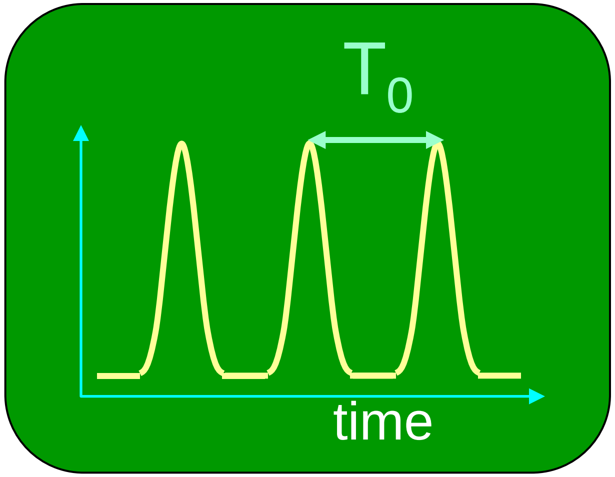
$$\Delta t \sim \frac{2\rho}{\gamma c} \cdot \frac{1}{2\gamma^2}$$



$$\omega \sim \frac{1}{\Delta t} \sim \gamma^3 \omega_0$$

Spectrum of synchrotron radiation

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



- the spectrum consists of harmonics of

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

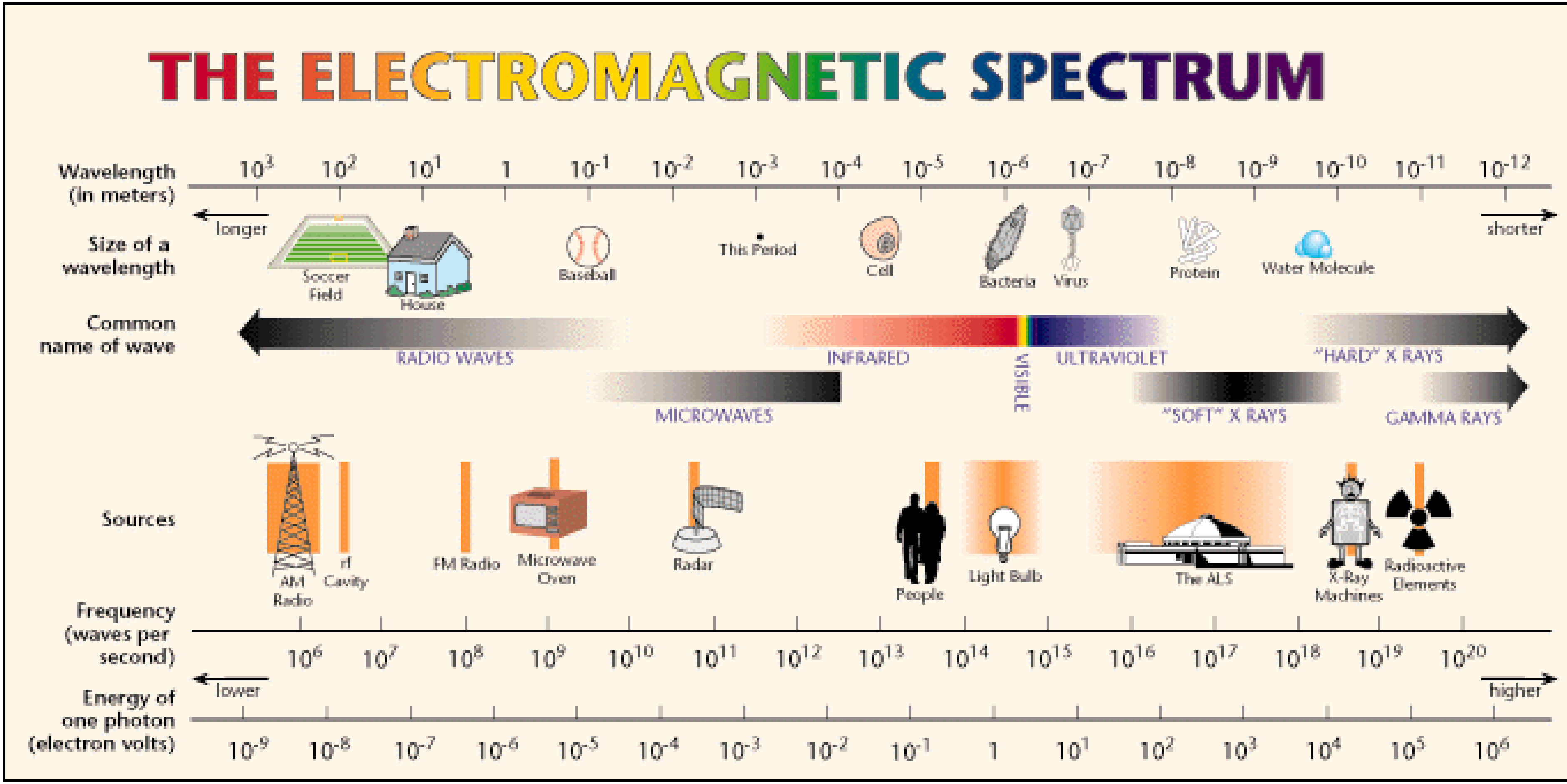
- flashes are extremely short: harmonics reach up to very high frequencies

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

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

- At high frequencies the individual harmonics overlap

continuous spectrum !



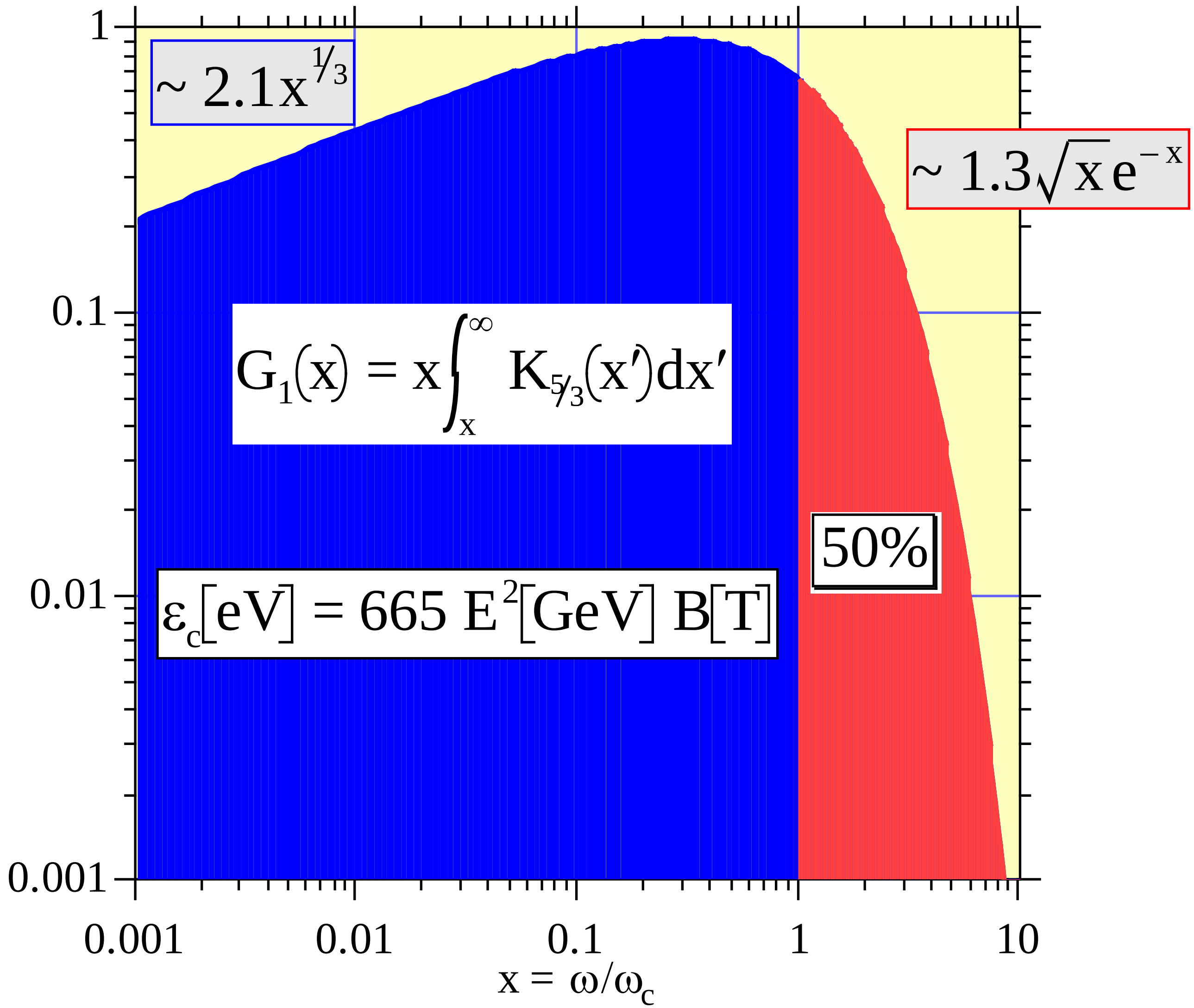
Wavelength continuously tunable !

$$\frac{dP}{d\omega} = \frac{P_{tot}}{\omega_c} S\left(\frac{\omega}{\omega_c}\right)$$

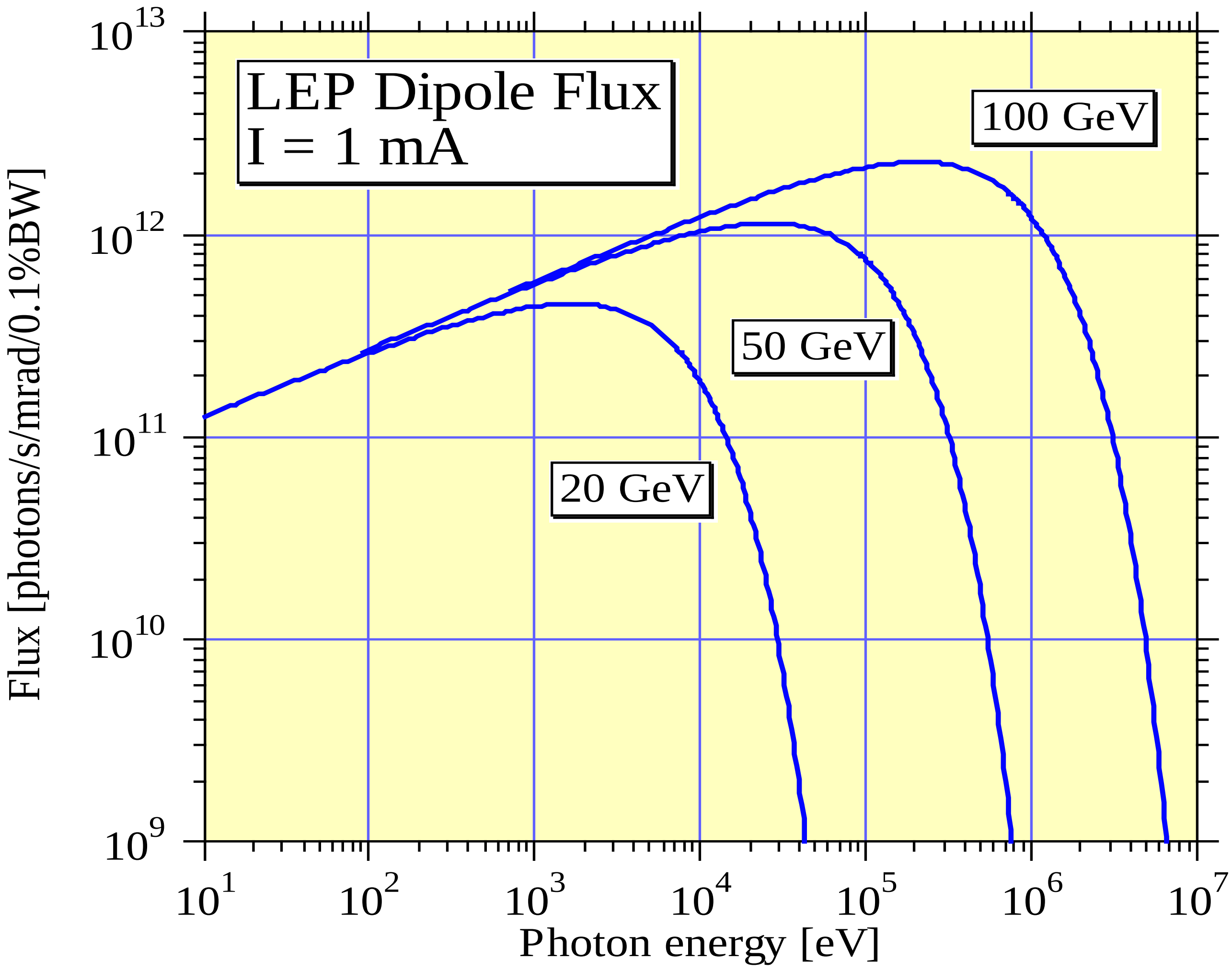
$$S(x) = \frac{9\sqrt{3}}{8\pi} x \int_x^\infty K_{5/3}(x')dx' \qquad \int_0^\infty S(x')dx' = 1$$

$$P_{tot} = \frac{2}{3} \hbar c^2 \alpha \frac{\gamma^4}{\rho^2}$$

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



Synchrotron radiation flux for different electron energies



Angular divergence of radiation

The rms opening angle R'

- **at the critical frequency:**

$$\omega = \omega_c \qquad R' \approx \frac{0.54}{\gamma}$$

- **well below**

$$\omega \ll \omega_c \qquad R' \approx \frac{1}{\gamma}\left(\frac{\omega_c}{\omega}\right)^{1/3} \approx 0.4\left(\frac{\lambda}{\rho}\right)^{1/3}$$

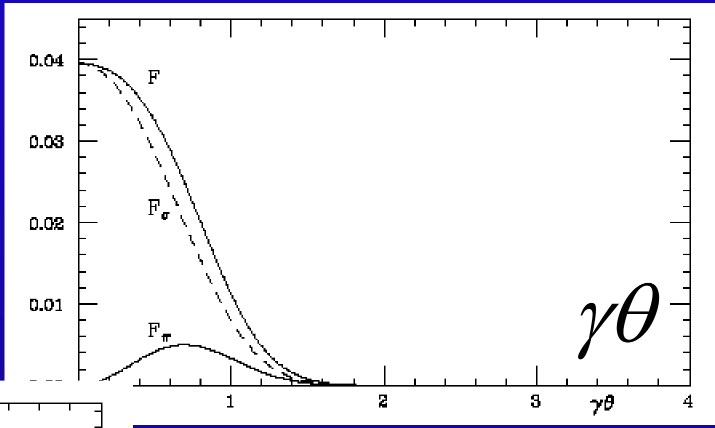
independent of γ !

- **well above**

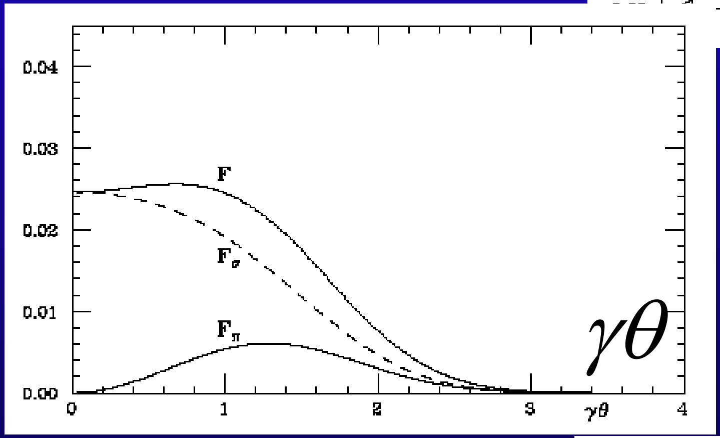
$$\omega \gg \omega_c \qquad R' \approx \frac{0.6}{\gamma}\left(\frac{\omega_c}{\omega}\right)^{1/2}$$

Angular divergence of radiation

- **at the critical frequency**



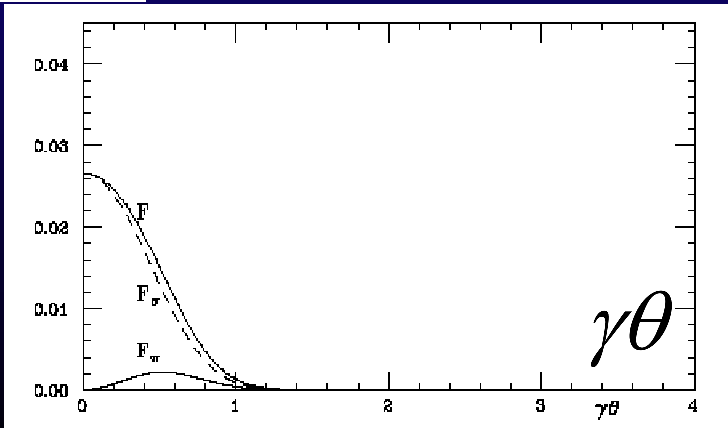
- **well below**



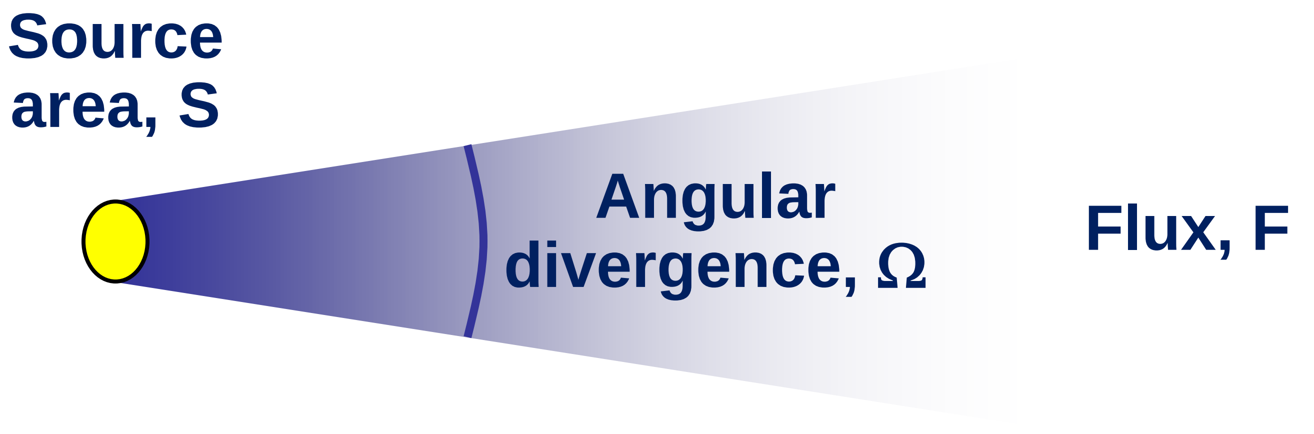
$$\omega = 0.2\,\omega_c$$

- **well above**

$$\omega = 2\,\omega_c$$



The "brightness" of a light source:

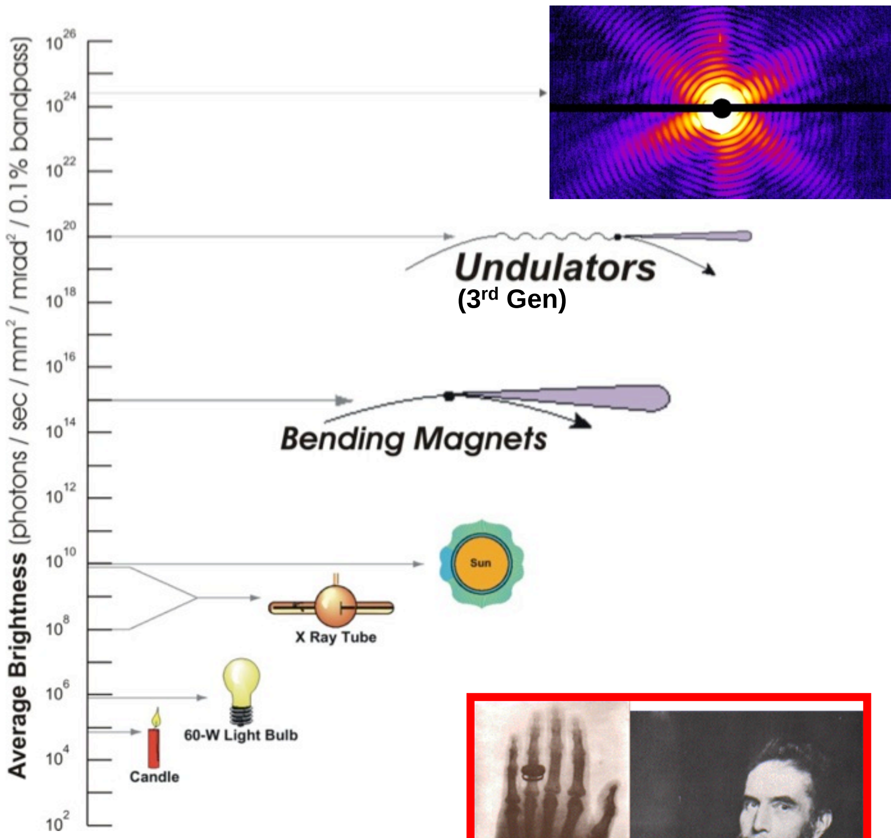


$$\text{Brightness} = \text{constant} \times \frac{F}{S \times \Omega}$$

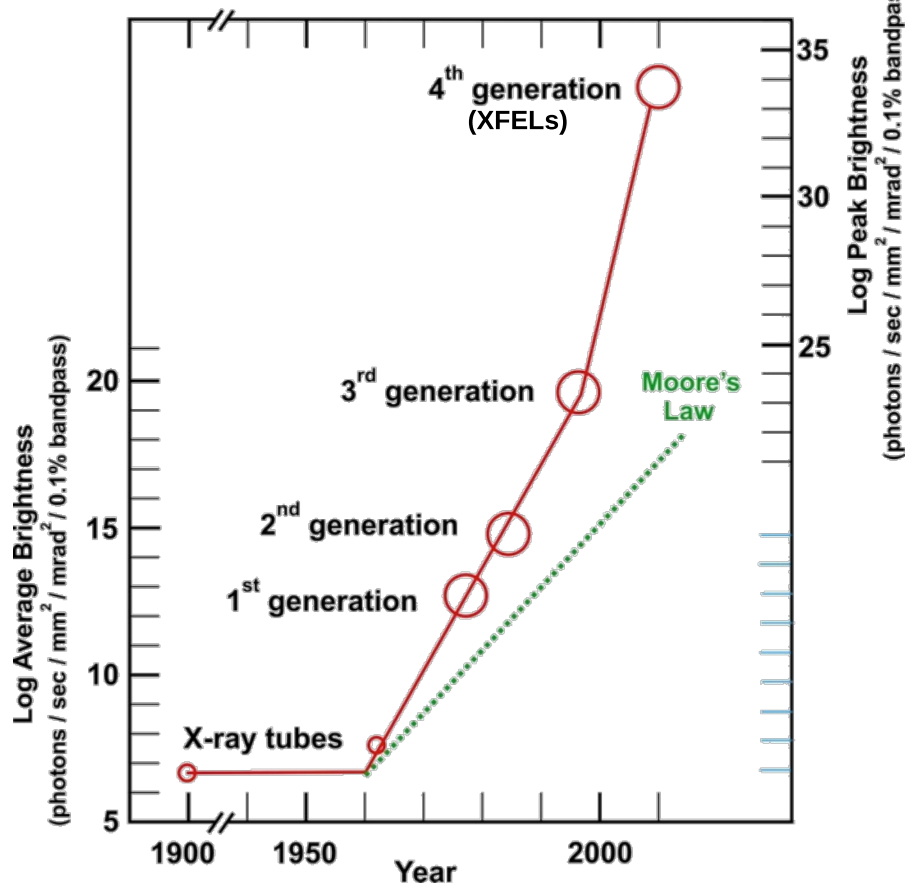
X-rays Brightness

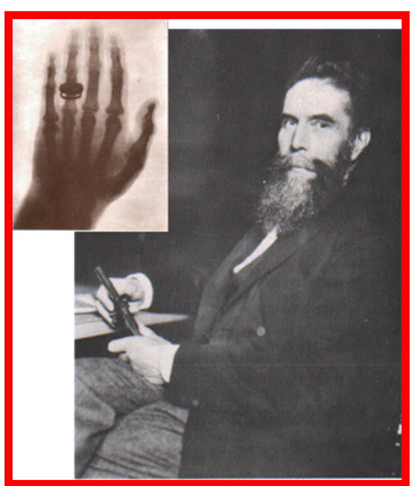
Average Brightness

XFELs



Peak Brightness



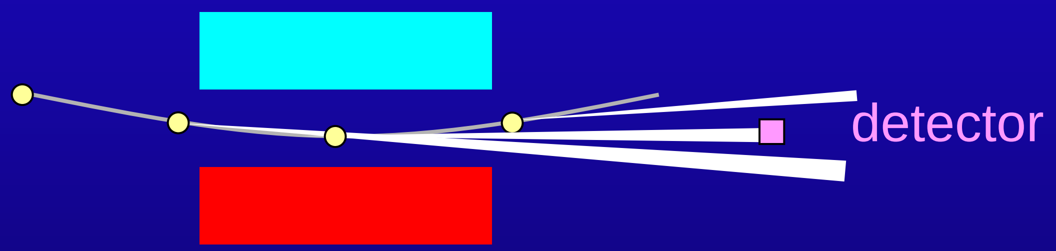


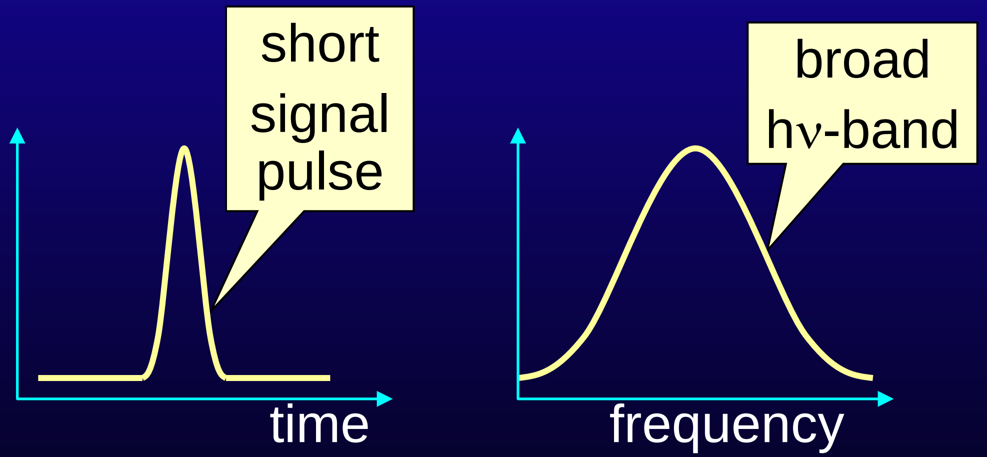
Bertha Roentgen's hand
(exposure: 20 min)

Sources of Synchrotron Radiation

3 types of storage ring sources:

1. Bending magnets: B ~ N_e

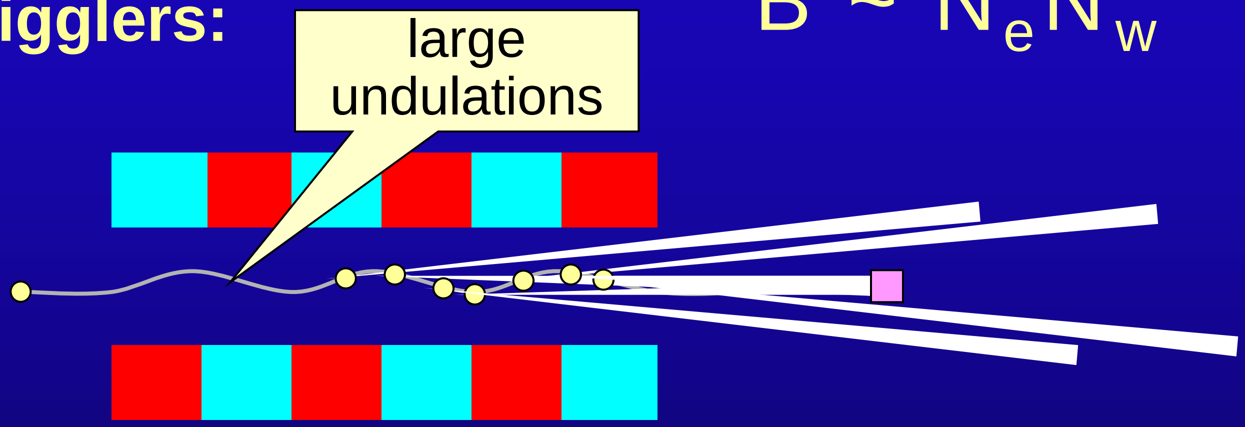


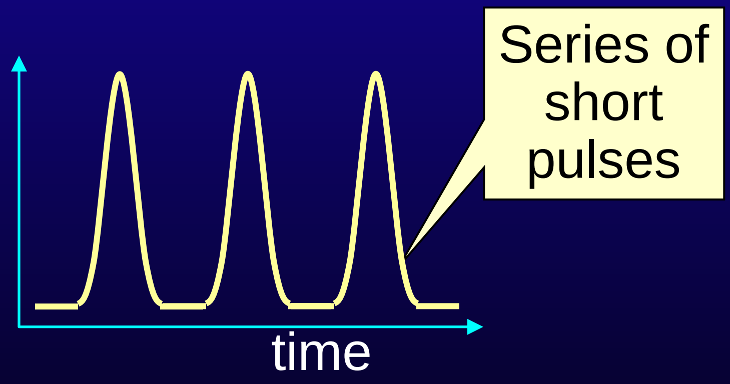


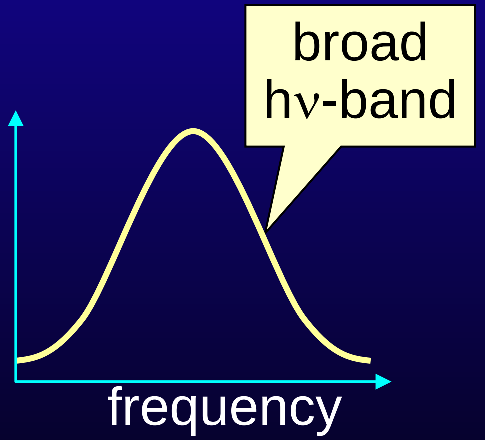
3 types of storage ring sources:

2. Wigglers:

$B \sim N_e N_w$ x10

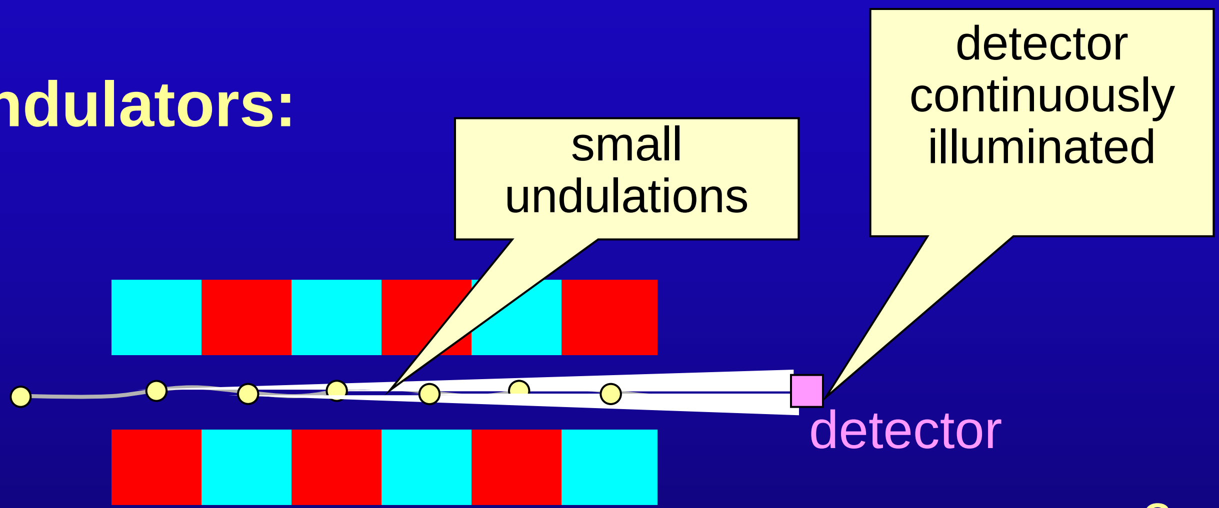




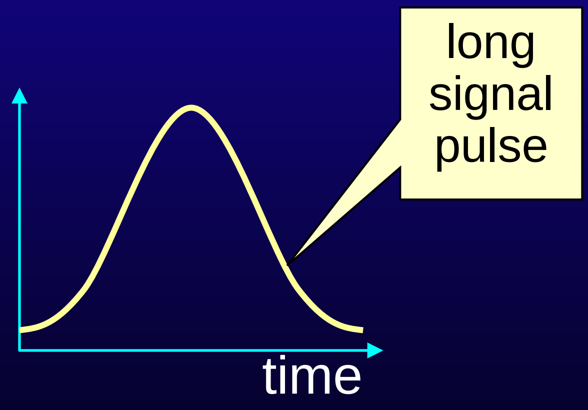


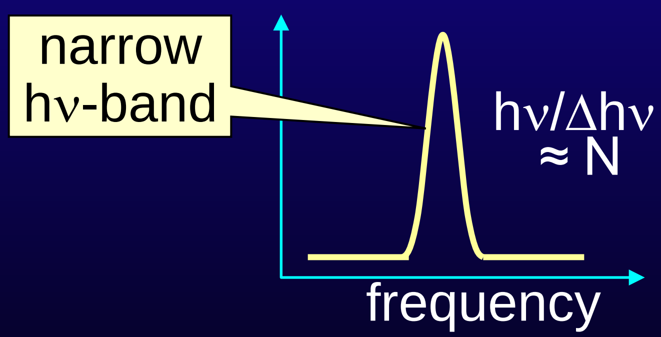
3 types of storage ring sources:

3. Undulators:



$$B \sim N_e N_u^2 \quad \times 10^3$$



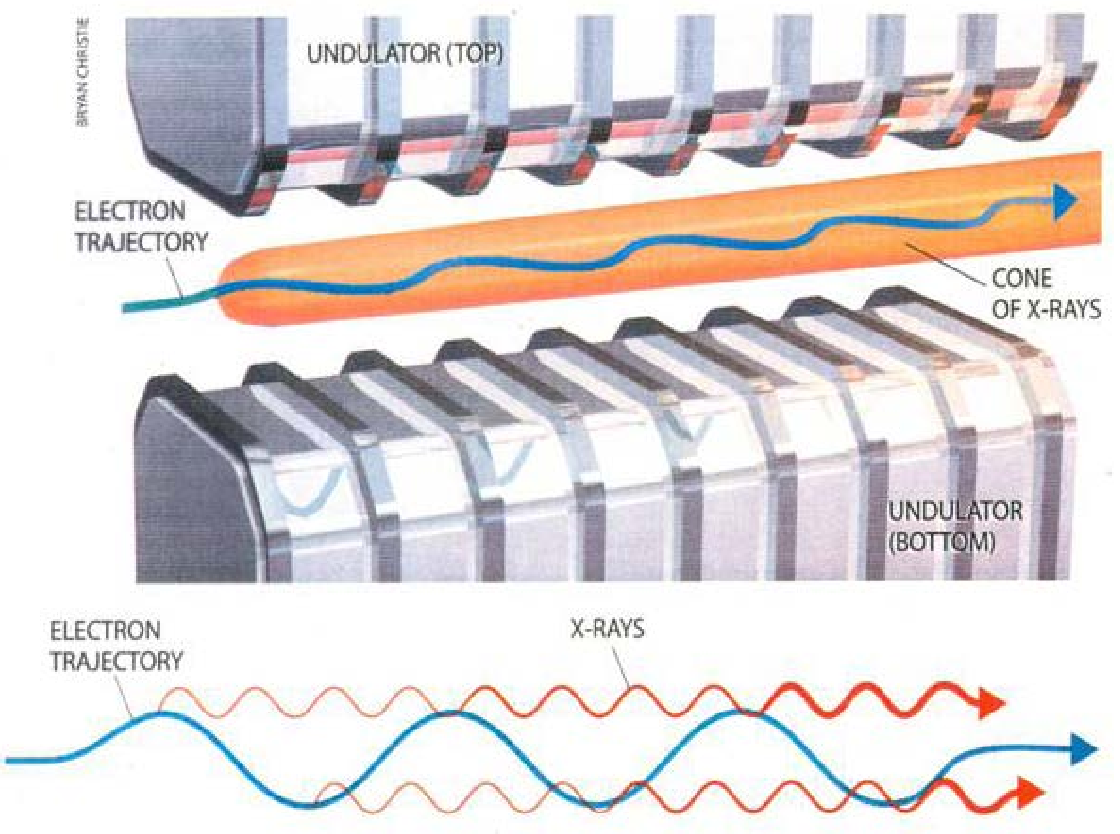


Bright beams of particles: phase space density

Incoherent, spontaneous emission of light:

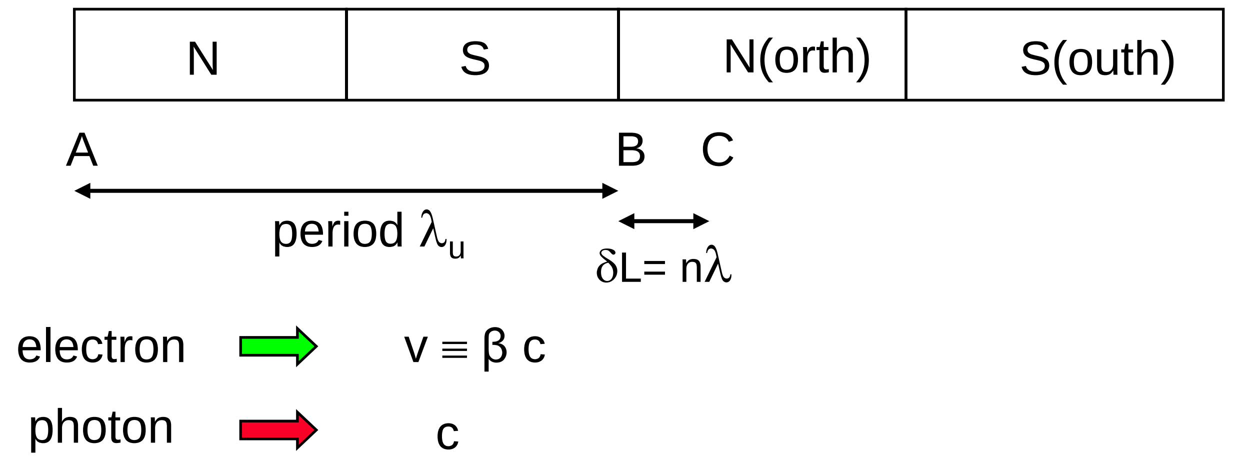
Large phase space

Coherent, stimulated emission of light



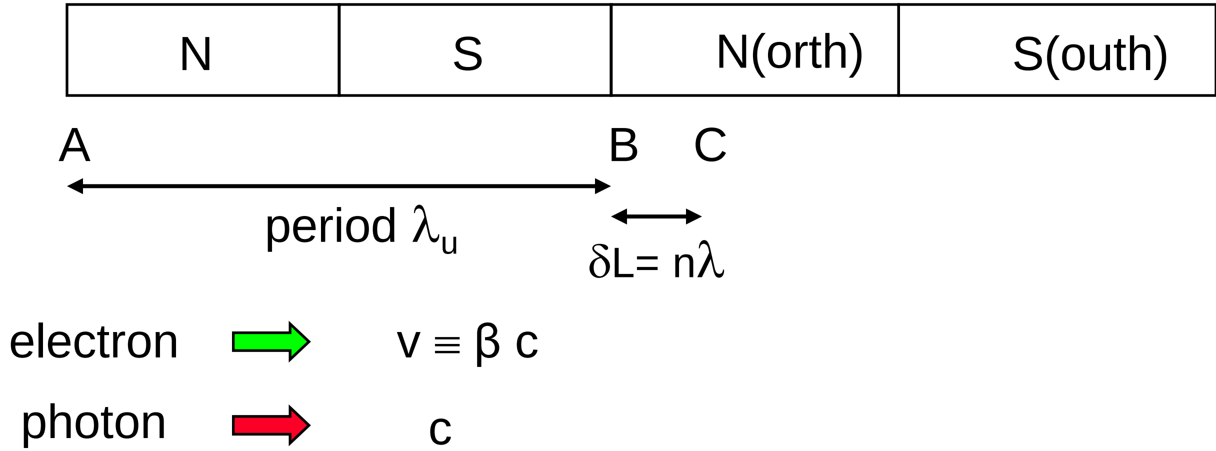
Selection of wavelength in an undulator

In an undulator
an electron
(on a slalom)
races an emitted
photon



at A an electron emits a photon with wavelength λ and flies one period λ_u ahead to B with velocity $v = \beta c$. There it emits another photon with the same wavelength λ. At this moment the first photon is already at C. If the path difference δL corresponds to n wavelengths, then we have a positive interference between the two photons. This enhances the intensity at this wavelength.

Selection of wavelength in an undulator II



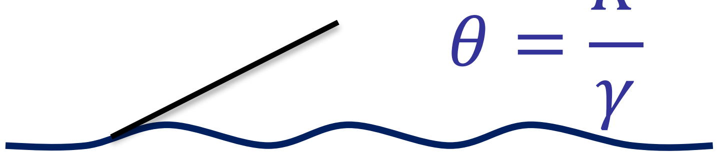
The path difference $$\delta L \equiv n\lambda \approx (1-\beta)\lambda_u \,, \quad 1-\beta \approx \frac{1}{2\gamma^2}$$

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

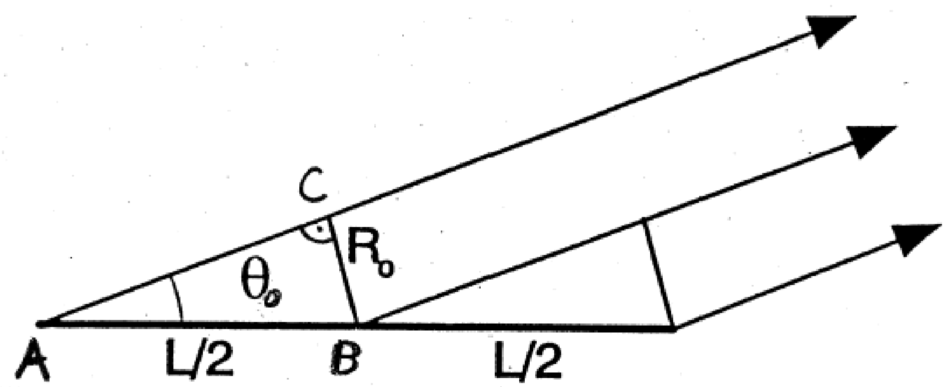
detour through slalom

$$K = 0.0934 \cdot \lambda_u[mm] \cdot B[T]$$

$$\theta = \frac{K}{\gamma}$$



Radiation cone of an undulator



Undulator radiates from the whole length L into a narrow cone.

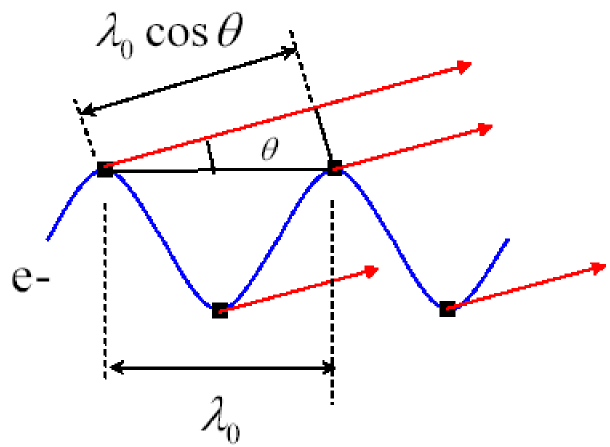
Propagation of the wave front BC is suppressed under an angle θ_0, if the path length AC is just shorter by a half wavelength compared to AB (negative interference). This defines the central cone.

$$\Delta L = AB - AC = \frac{1}{2} L (1 - \cos\theta_0) \approx \frac{1}{4} L \theta_0^2$$

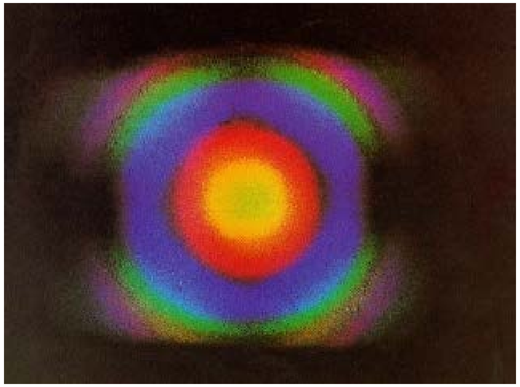
Negative interference for $\Delta L = \dfrac{\lambda}{2}$

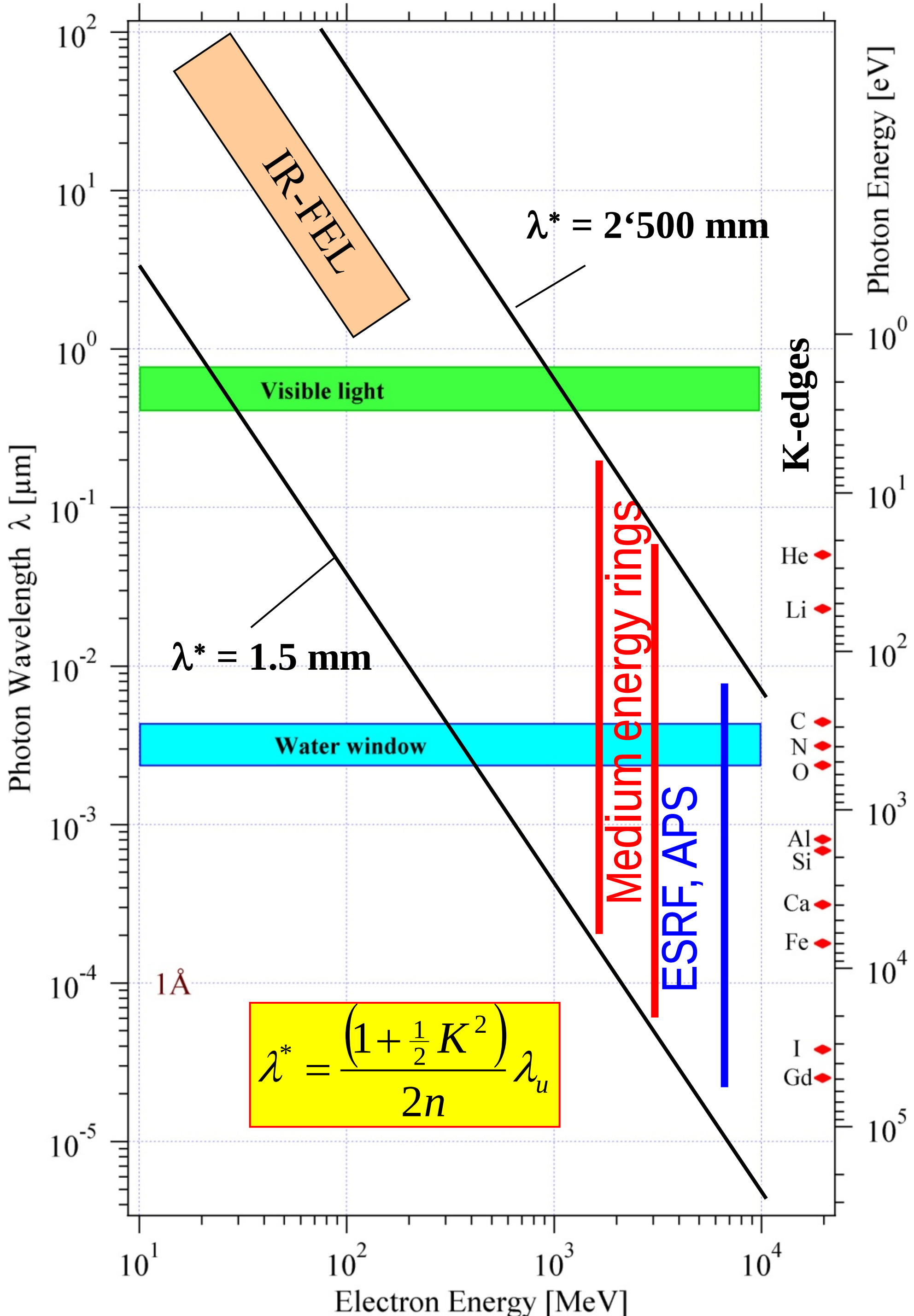
$$\theta_0 = \sqrt{\frac{2\lambda}{L}} \qquad R_0 = \sqrt{\frac{\lambda \cdot L}{2}} \qquad \varepsilon_0 = \theta_0 R_0 = \lambda$$

Undulator radiation



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





Microwave, laser undulators

Development of Microwave Undulator

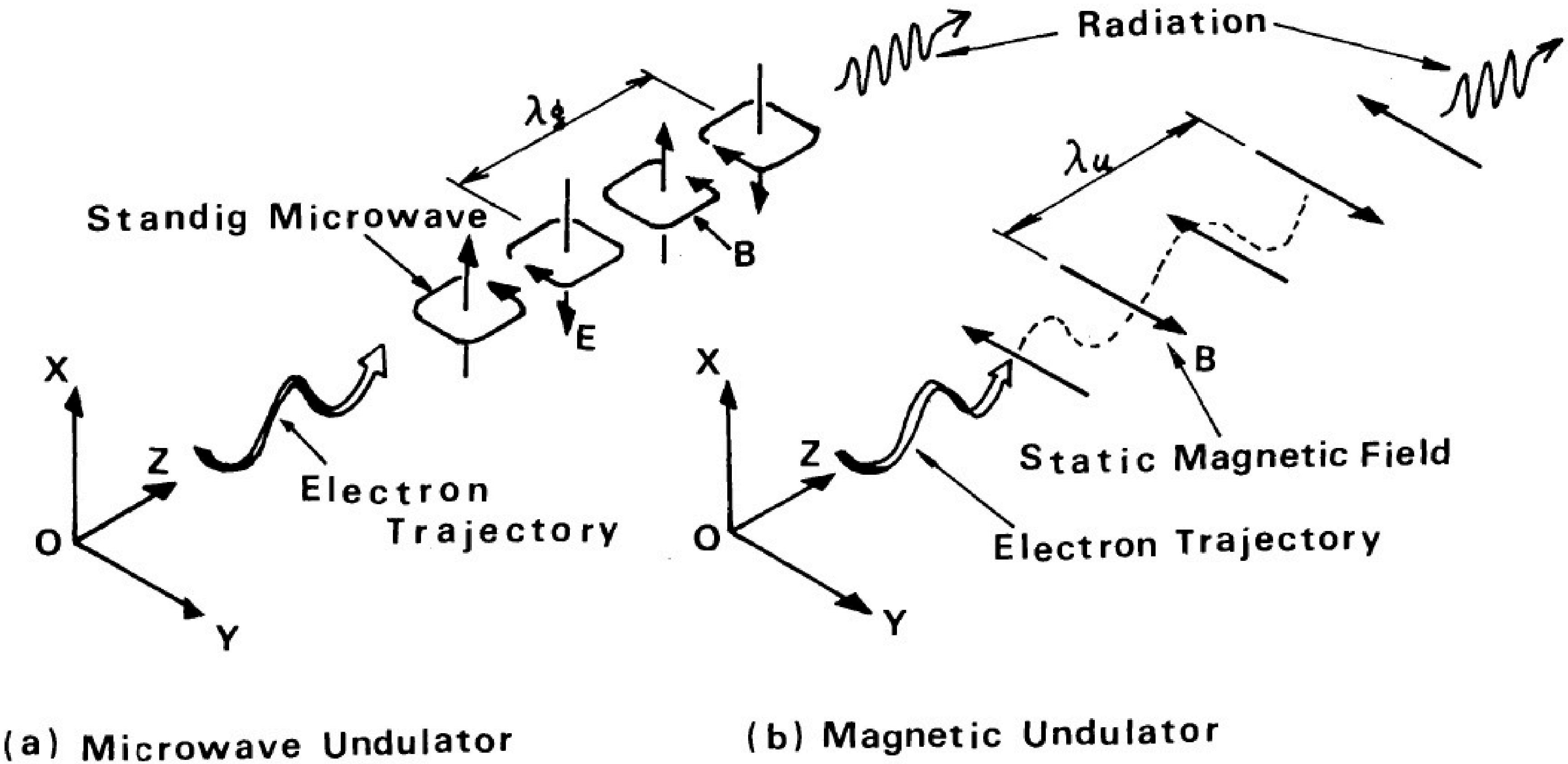
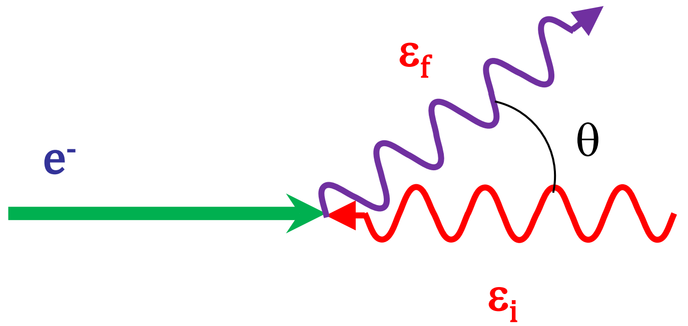


Fig. 1. Coordinates of microwave undulator and magnetic undulator. Electrons undulate in xz-plane.

T. Shintake, OIST

When an electron collides with a photon…

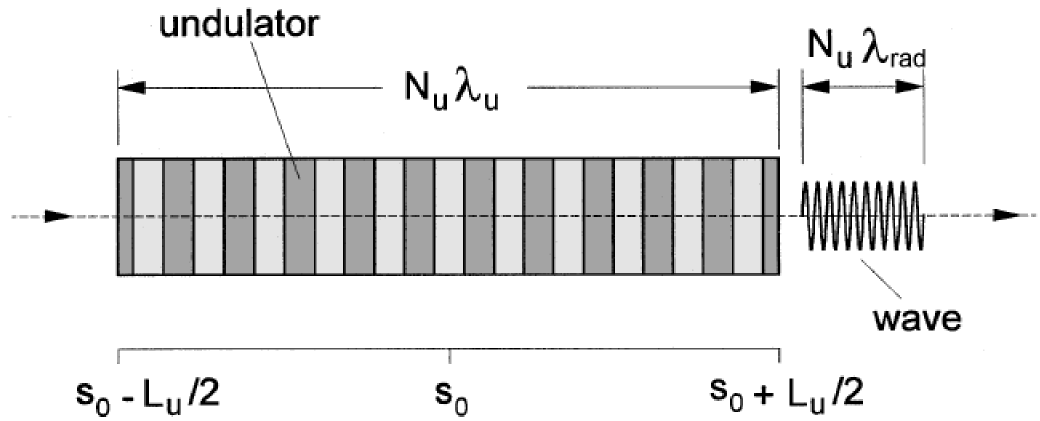
Also known as **Compton** or Thomson scattering



$$\varepsilon_f = \frac{4\gamma^2 \varepsilon_i}{1 + \gamma^2 \theta^2}$$

- backscattered photon has the maximum energy
- at an angle of $1/\gamma$ the energy drops by a factor of 2
- undulator's periodic magnetic field could be viewed as a «photon», with useful parallels between the two cases

Undulator line width



Undulator of infinite length

$$N_u = \infty \quad \Rightarrow \quad \frac{\Delta\lambda}{\lambda} = 0$$

Finite length undulator

- radiation pulse has as many periods as the undulator
- the line width is

$$\frac{\Delta\lambda}{\lambda} \sim \frac{1}{N_u}$$

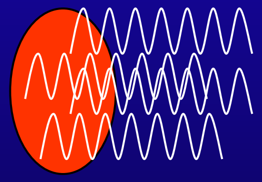
Due to the electron energy spread

$$\frac{\Delta\lambda}{\lambda} = 2\frac{\sigma_E}{E}$$

Free Electron Lasers

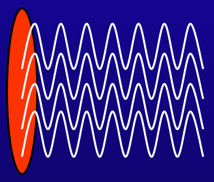
COHERENT EMISSION BY THE ELECTRONS

Intensity $\propto$ N



INCOHERENT EMISSION

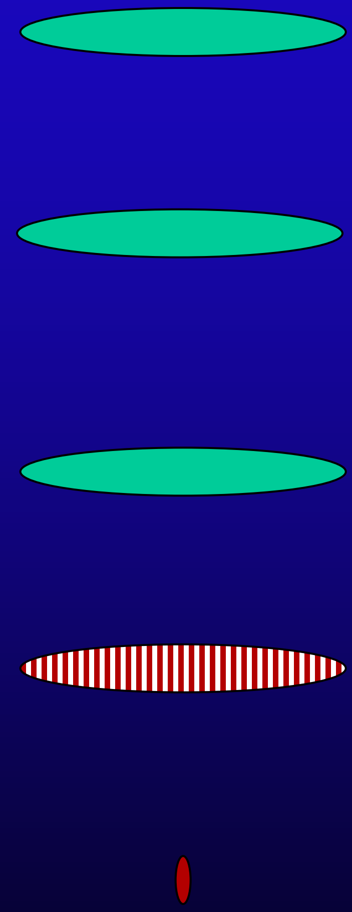
Intensity $\propto N^2$



COHERENT EMISSION

BRIGHTNESS OF SYNCHROTRON RADIATION

	electrons	*periods*	
Bending magnet	$\sim N_e$		
Wiggler	$\sim N_e$	$\sim N$	10
Undulator	$\sim N_e$	$\sim N^2$	10^4
FEL	$\sim N^2_{\mu\text{-}b}$	$\sim N^2$	10^{10}
Superradiance	$\sim N_e^2$	$\sim N^2$	10^{12}



FIRST DEMONSTRATIONS OF COHERENT EMISSION (1989-1990)

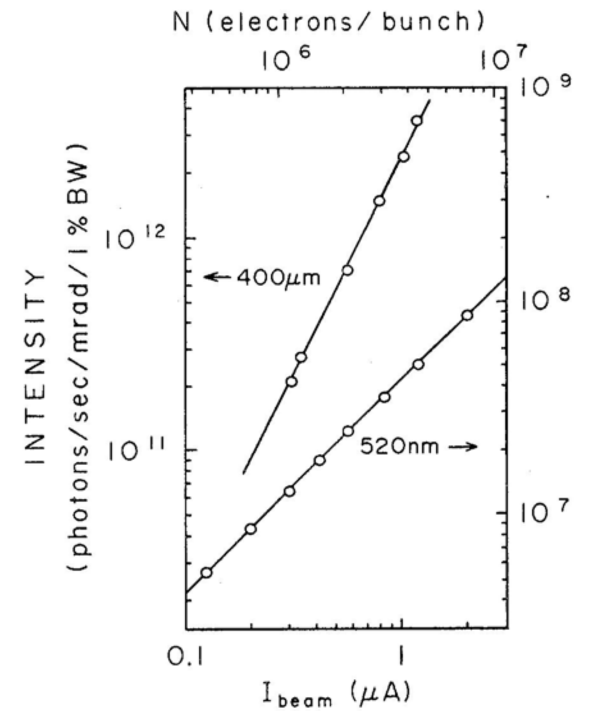


Fig. 4. Dependence of SR intensity on the beam current at λ = 400 μm and λ = 520 nm for the long pulse/short bunch beam. The ordinate is given on the left-hand side for λ = 400 μm and on the right for λ = 520 nm. The two lines show the linear and quadratic relations to the beam current. The beam current is converted to the average number of electrons in a bunch on the upper side.

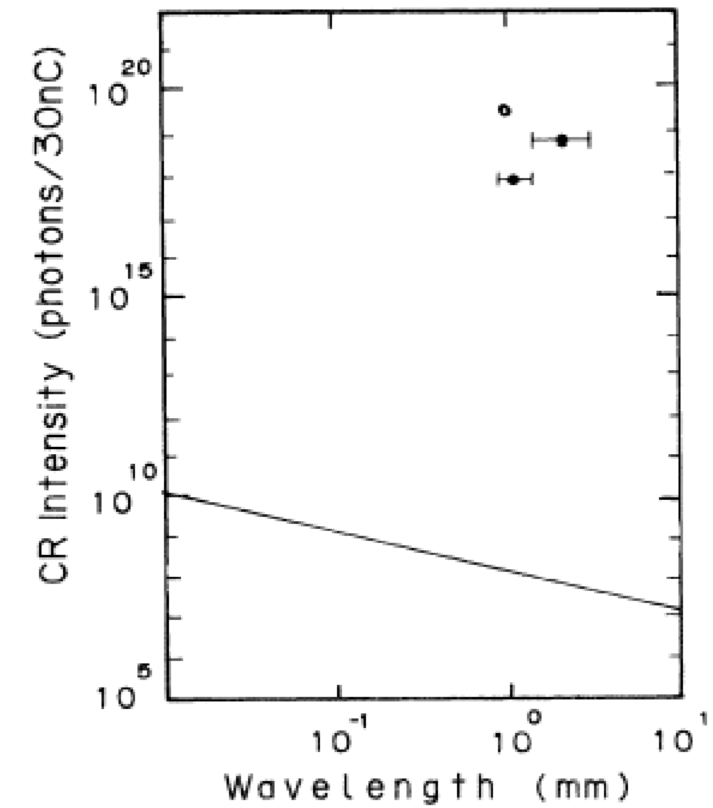


FIG. 3. The intensity of the CR measured for the bandwidths indicated with horizontal bars, the spectrum calculated according to Eq. (1) for 10% bandwidth (solid line), and the intensity expected for the complete coherence over the bunch for 10% bandwidth (open circle).

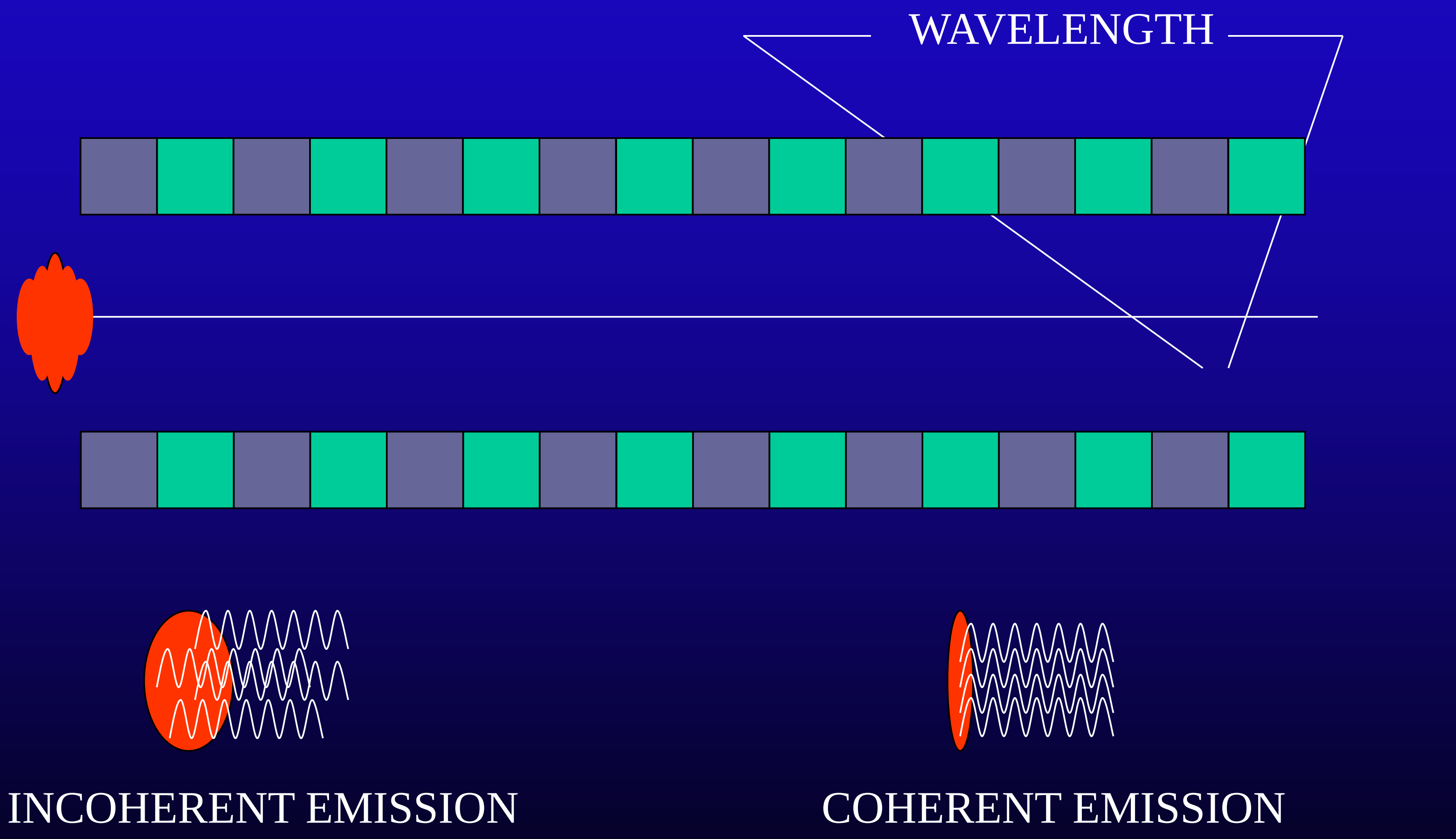
180 MeV electrons

T. Nakazato et al., Tohoku University, Japan

30 MeV electrons

J. Ohkuma et al., Osaka University, Japan

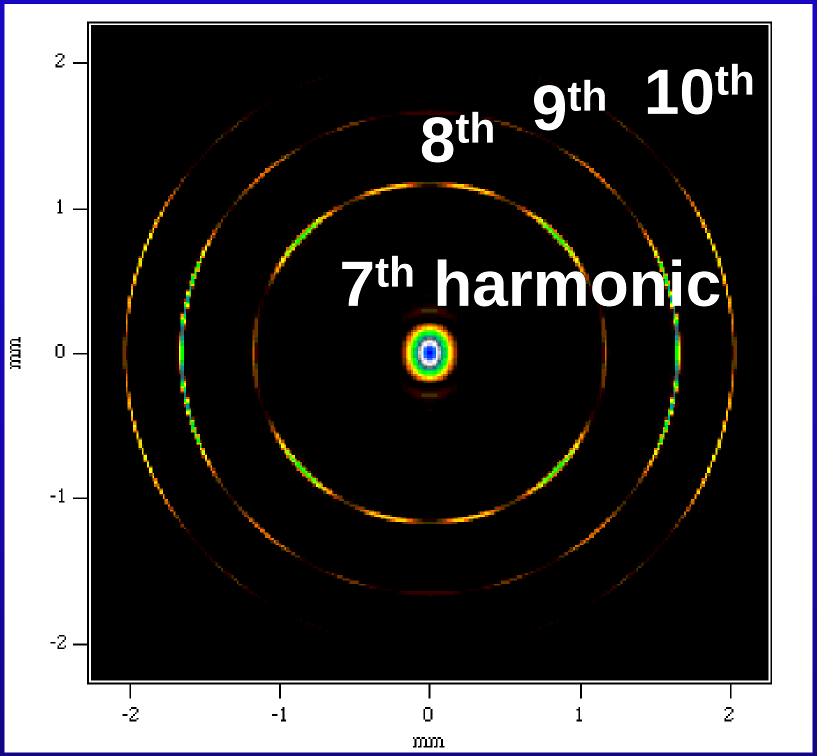
MUCH HIGHER BRIGHTNESS CAN BE REACHED WHEN THE ELECTRONS COOPERATE

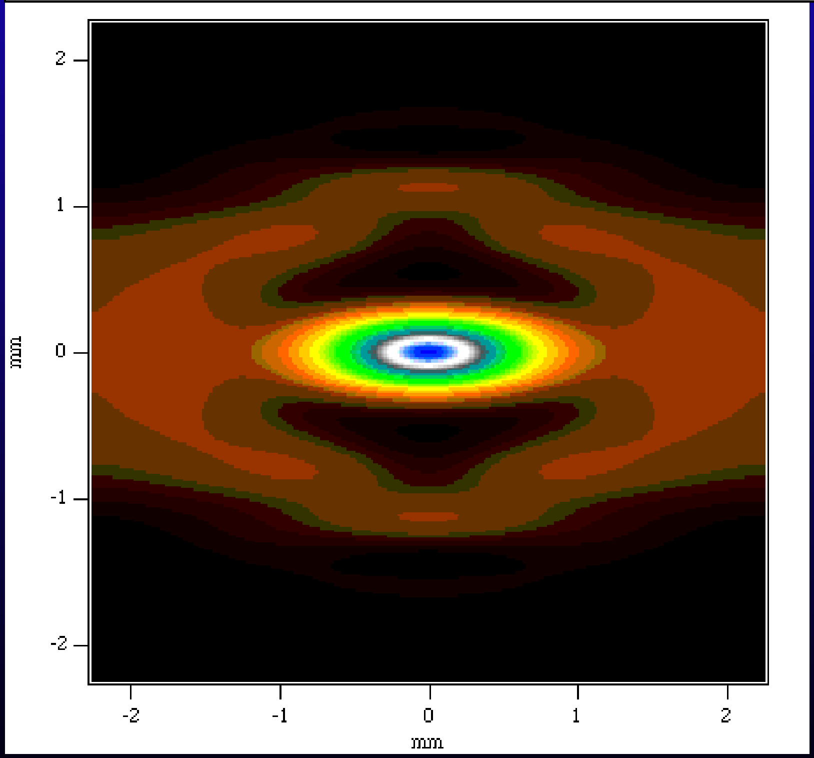


Particle beam emittance:

Emittance = S x Ω

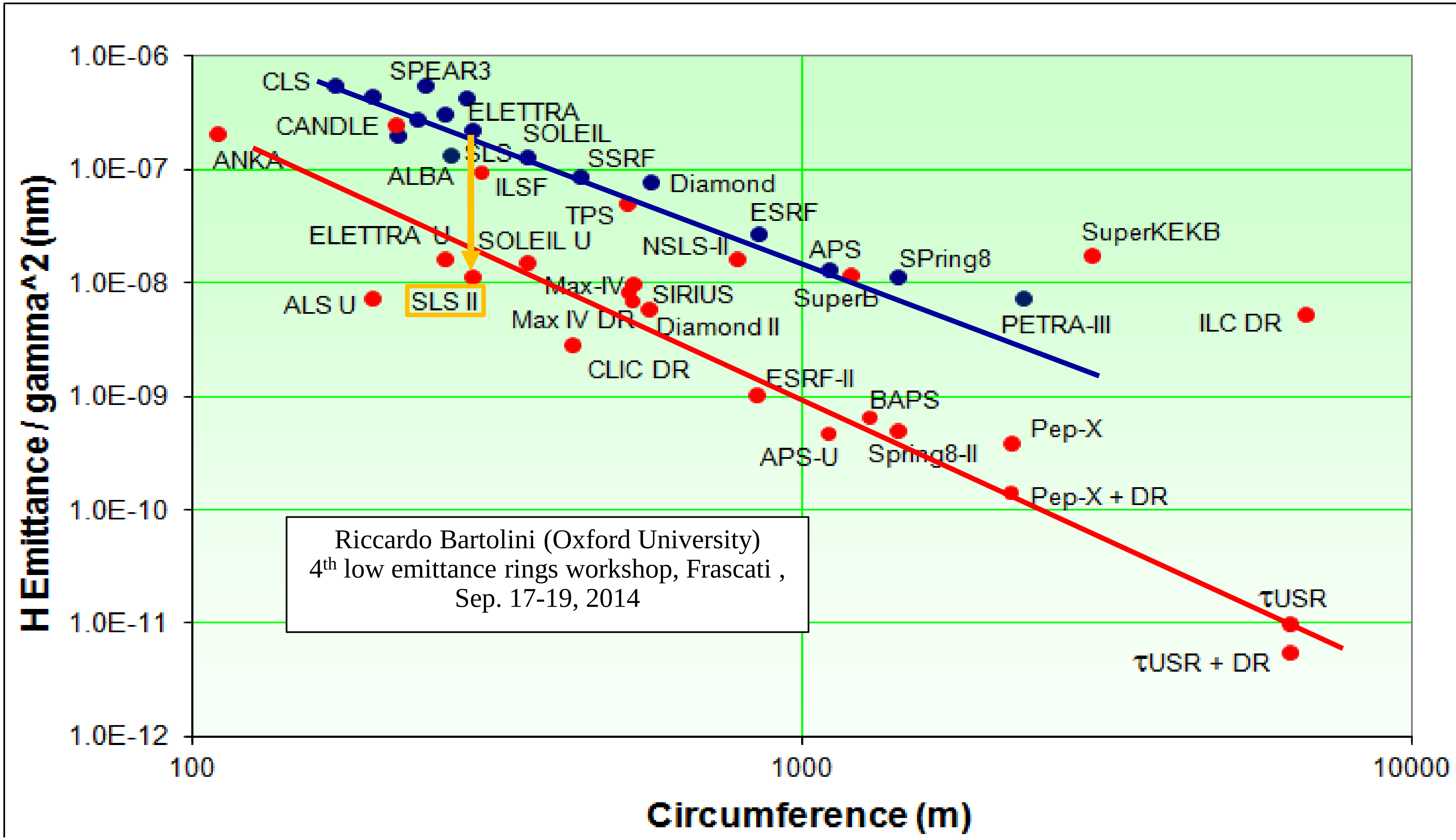
Undulator radiation from 6 GeV beam with zero emittance, energy spread (example ESRF)





Emittance 4 nm·rad, 1% coupling, finite energy spread

The storage ring generational change

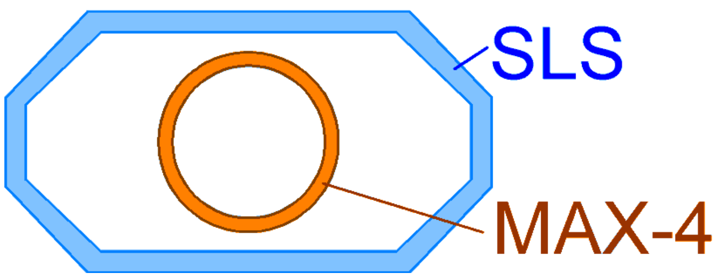


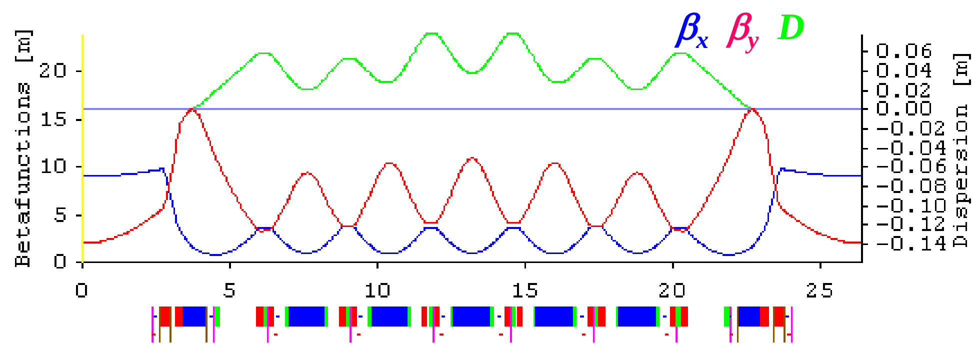
Storage rings in operation (•) and planned (•).
The old (—) and the new (—) generation.

A revolution in storage ring technology

Pioneer work: MAX IV (Lund, Sweden)

Aperture reduction ⟷ **Multi–Bend Achromat (MBA)**





Technological achievement:
NEG* coating of small vacuum chambers

⇨ Small magnet bore
⇨ High magnet gradient

⇨ short lattice cells
⇨ many lattice cells
⇨ low angle per bend

emittance $\varepsilon \propto (\text{energy})^2 \times (\text{bend angle})^3$

*Non Evaporable Getter

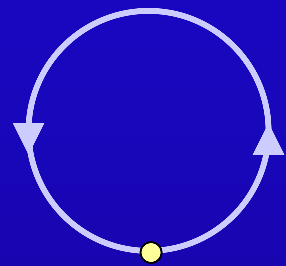
⇨ Emittance reduction from nm to 10...100 pm range

The MAX IV Laboratory in Lund, Sweden

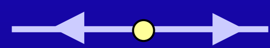
Synchrotron light polarization

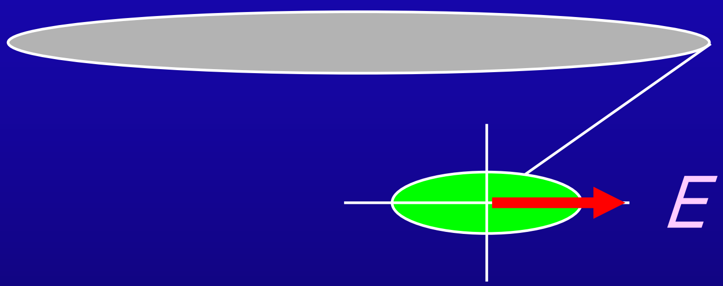
An electron in a storage ring

TOP VIEW



SIDE VIEW



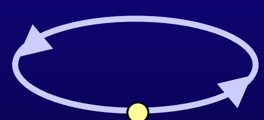


<u>Polarization:</u>

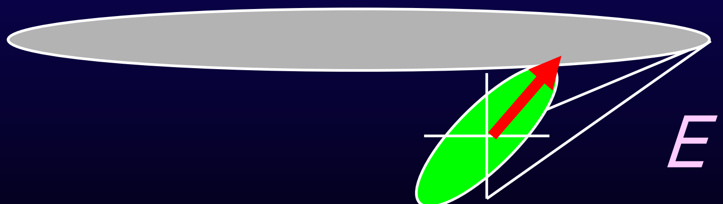
Linear in the plane of the ring

the electric field vector

TILTED VIEW



elliptical out of the plane

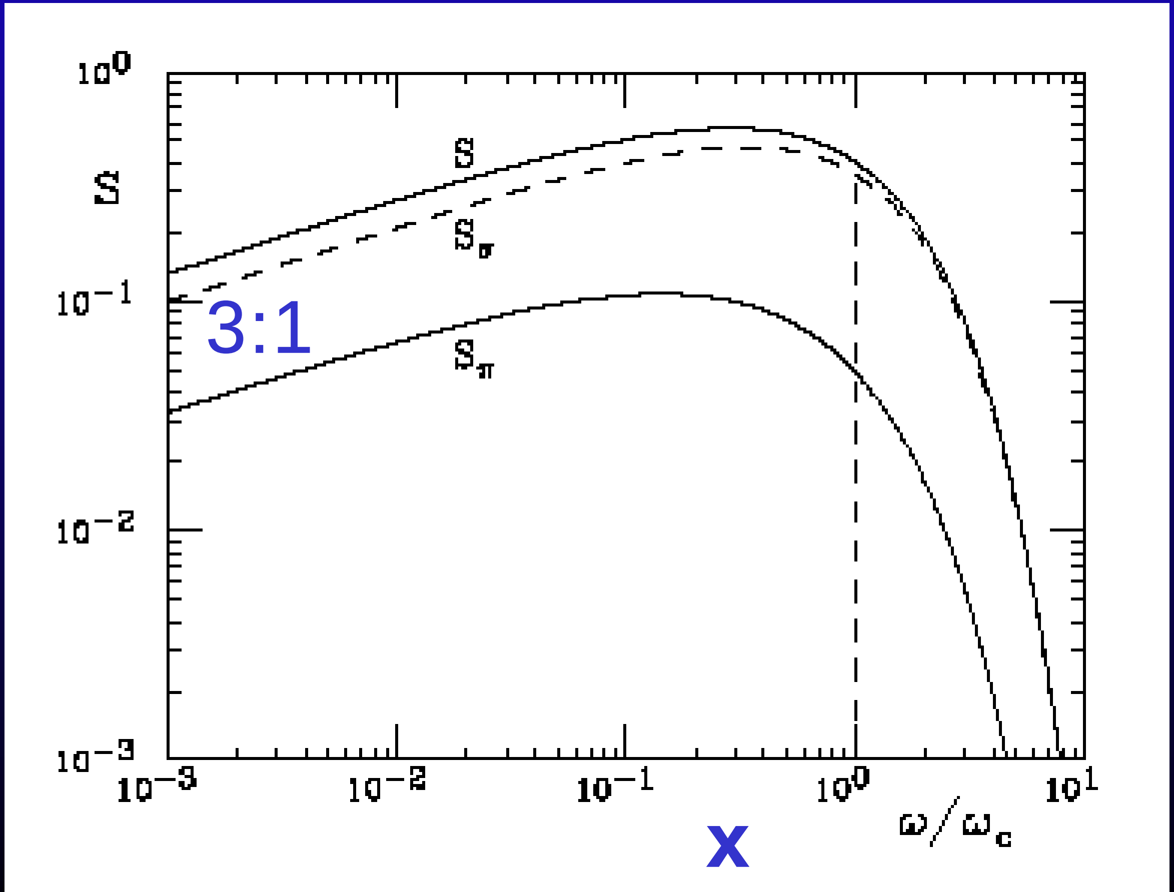


Polarisation: spectral distribution

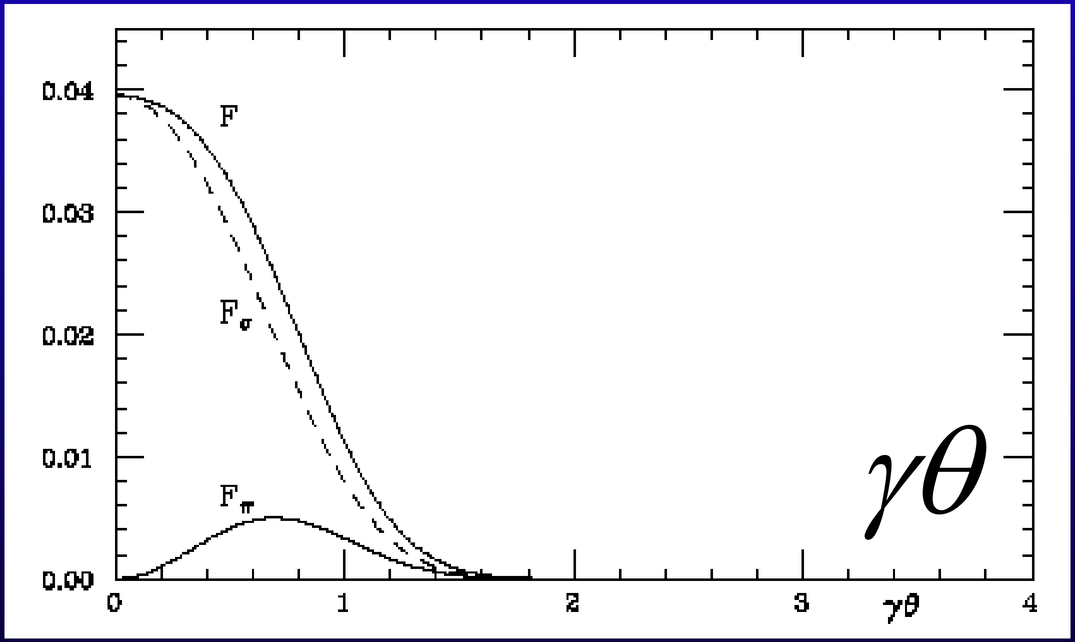
$$\frac{dP}{d\omega} = \frac{P_{tot}}{\omega_c} S(x) = \frac{P_{tot}}{\omega_c}\left[S_\sigma(x) + S_\pi(x)\right]$$

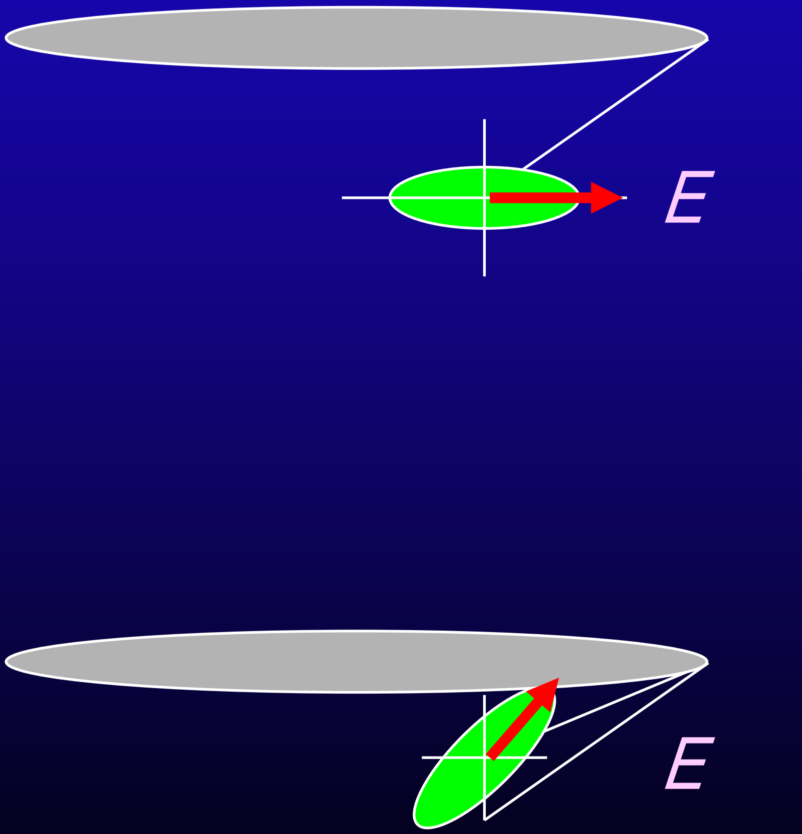
$$S_\sigma = \frac{7}{8} S$$

$$S_\pi = \frac{1}{8} S$$



Angular distribution of SR

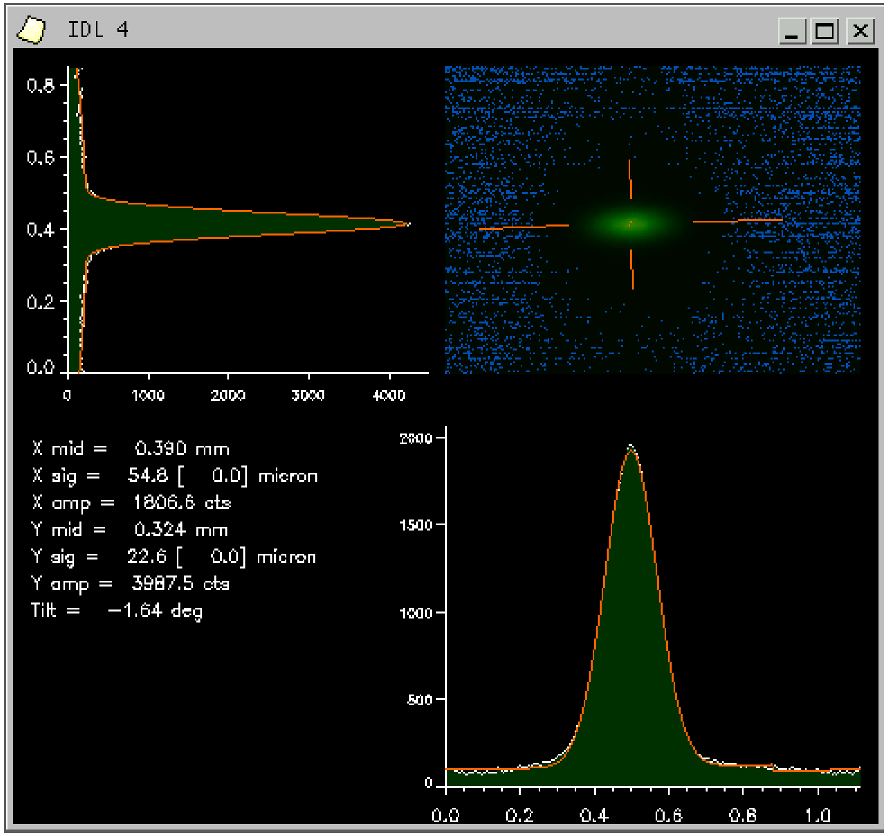




Synchrotron light based electron beam diagnostics

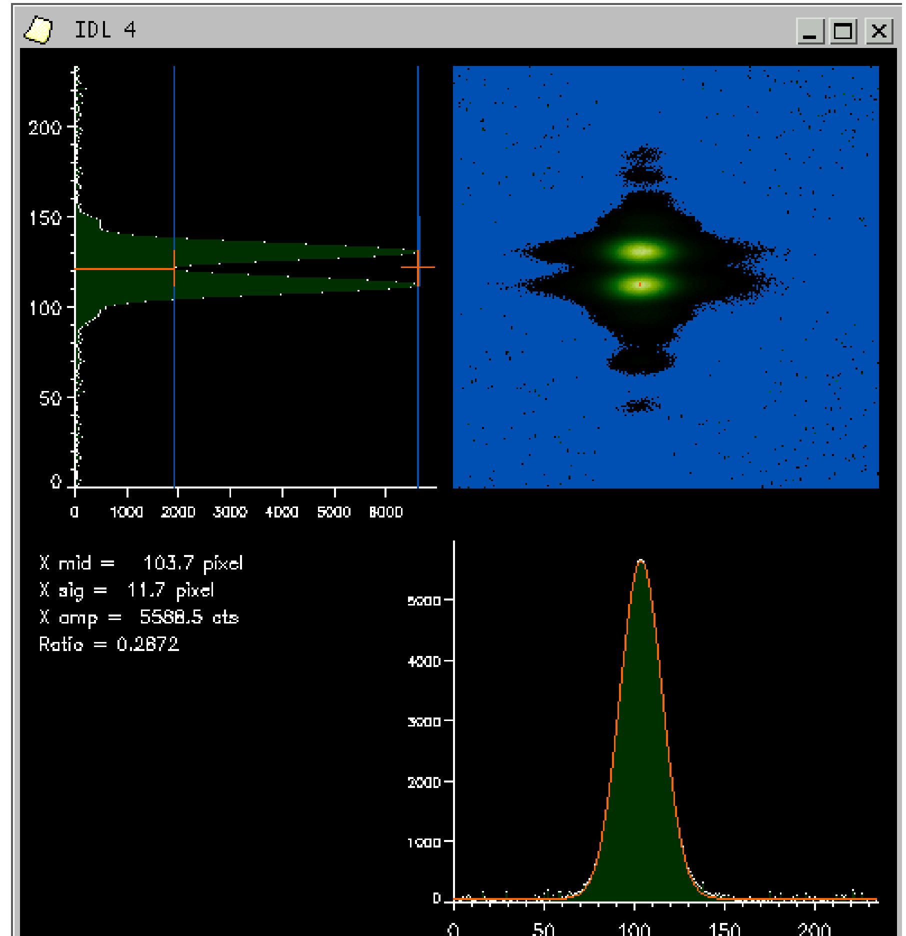
Seeing the electron beam (SLS)

X rays



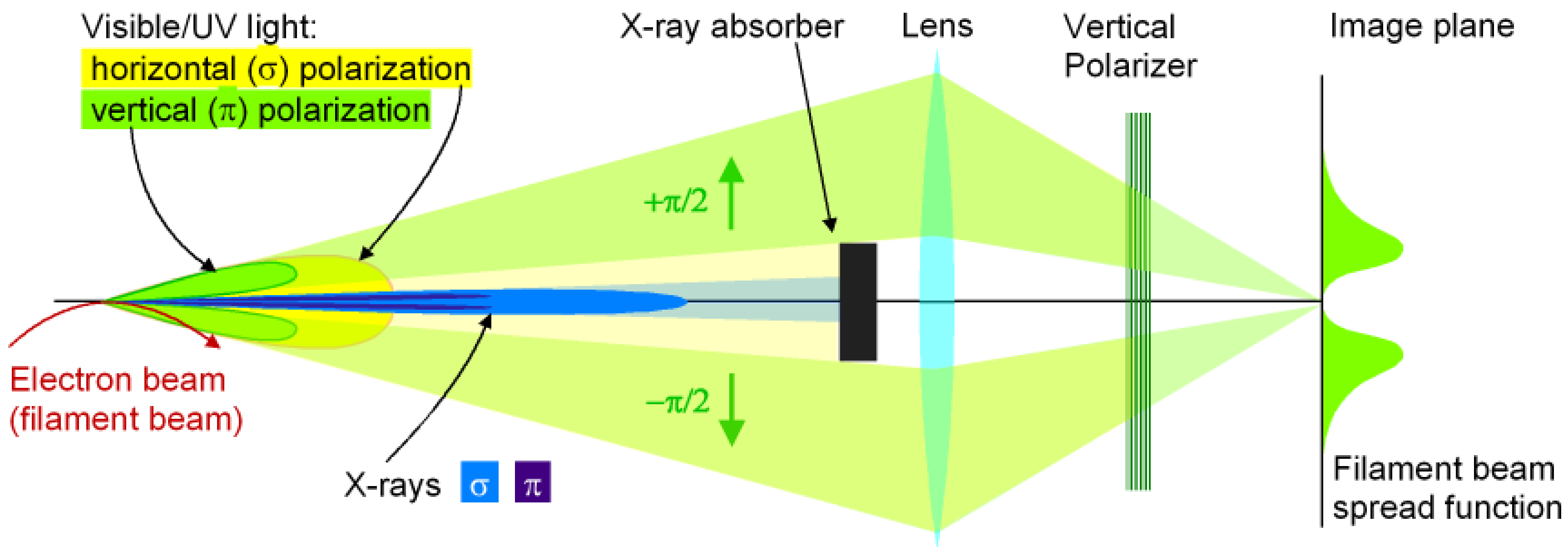
$$\sigma_x \sim 55\mu m$$

visible light, vertically polarised



Seeing the electron beam (SLS)

Making an image of the electron beam using the vertically polarised synchrotron light



High resolution measurement

Wavelength used: 364 nm

For point-like source the intensity on axis is zero

Peak-to-valley intensity ratio is determined by the beam height

Present resolution: **3.5 μm**