CERIC

PaGES[4]

Pianificazione, Gestione ed esecuzione di un Esperimento Scientifico in un centro di ricerca internazionale

# Introduction to Particle Accelerators

## *With Focus on Synchrotron Light Sources*


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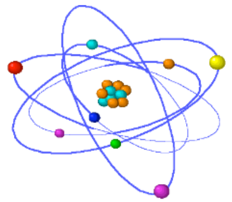
REGIONE AUTONOMA FRIULI VENEZIA GIULIA

*The project is funded by the Italian Region Friuli Venezia Giulia, within the program "Regional plan for the building up of the formative offer for the academic year 2017/2018", in the section "Special projects"*

# Ingredients



- **Charged particles:** electrons, protons, ions, anti-particles

$$E = \gamma(v) m_0 c^2$$

$$F_L = q\left(\vec{E} + \vec{v} \times \vec{B}\right)$$

➡ ***Special Relativity*** *is all we need. Includes kinematics and dynamics of relativistic charged particles.*

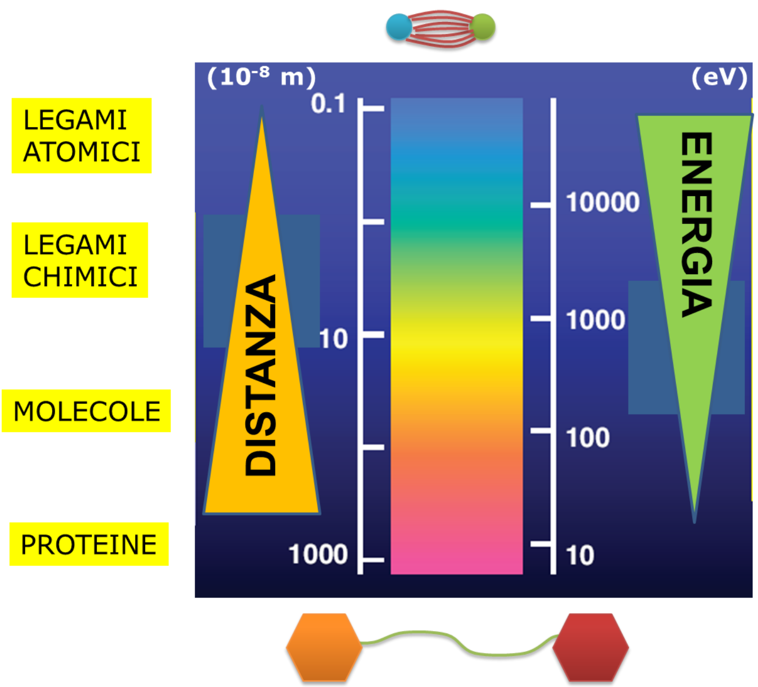
- Static and time-varying ***electric field*** increases the particle kinetic energy.

➡ ***Radiofrequency (RF) accelerating structures***

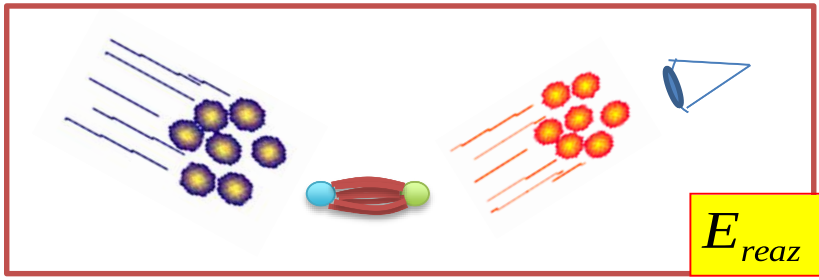
- Static and time-varying ***magnetic field*** bounds the particle inside the vacuum chamber.

➡ ***Magnetic elements*** *for controlling the particles direction (orbit) and beam size (focusing).*

# Why High Energy Particle Beams ?

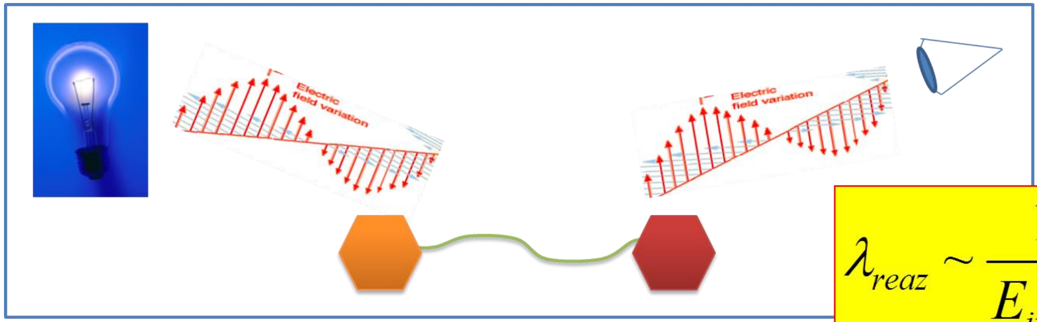



"Colliders" (LHC,…)



$$E_{reaz} \sim E_{incid}$$

"Synchrotron Light Sources" (Elettra,…)




$$\lambda_{reaz} \sim \frac{1}{E_{incid}}$$

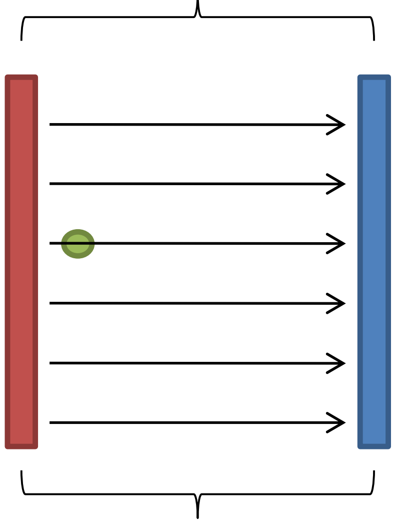
# Acceleration, Particle Energy

$$L = F \cdot \vec{s} = qE \cdot \vec{s} = -q\Delta V$$

Electric field

Energy


$\Delta V$



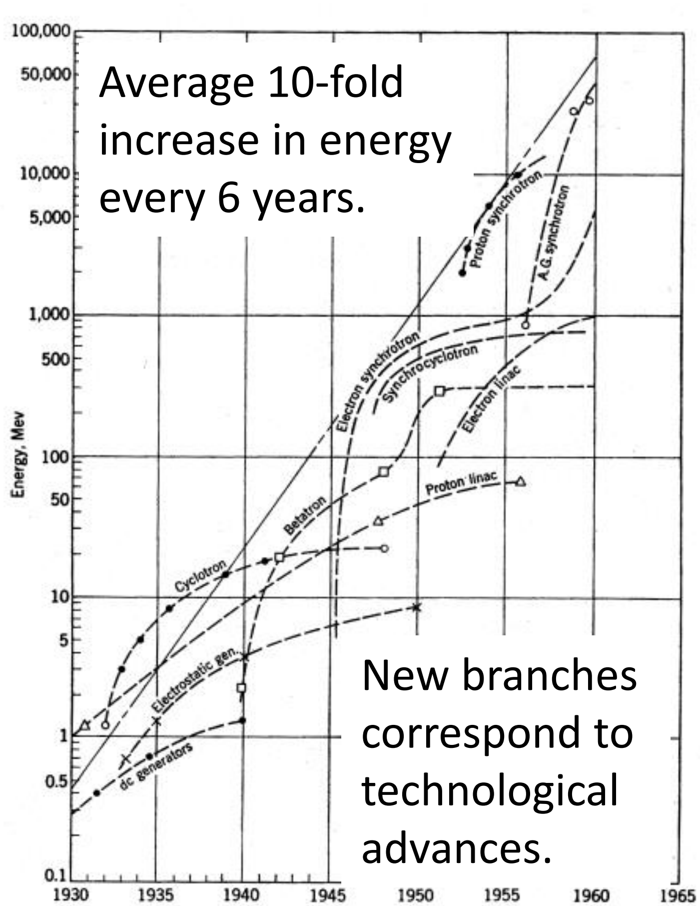
$\Delta E = -q\Delta V$

J = N x m = C x V

1 eV (electronvolt) = 1 e x 1 V

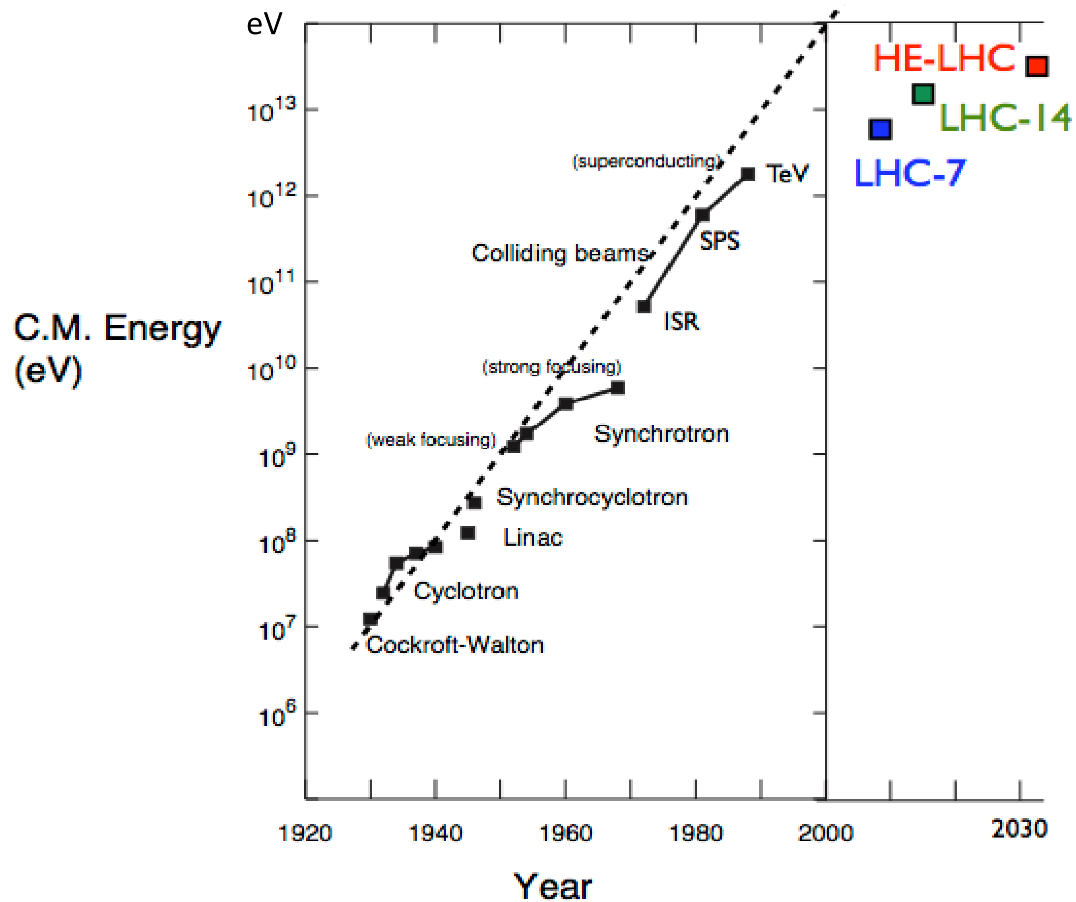
e = -1.6e-19 C

# Livingstone Chart




Average 10-fold increase in energy every 6 years.

New branches correspond to technological advances.

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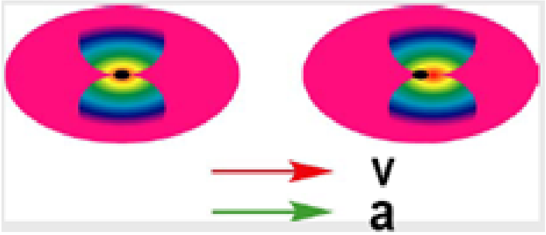
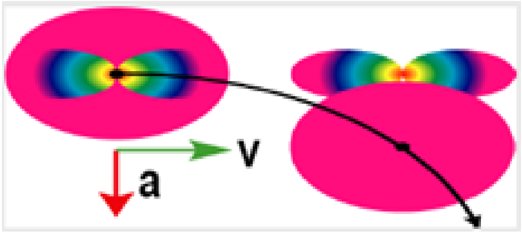
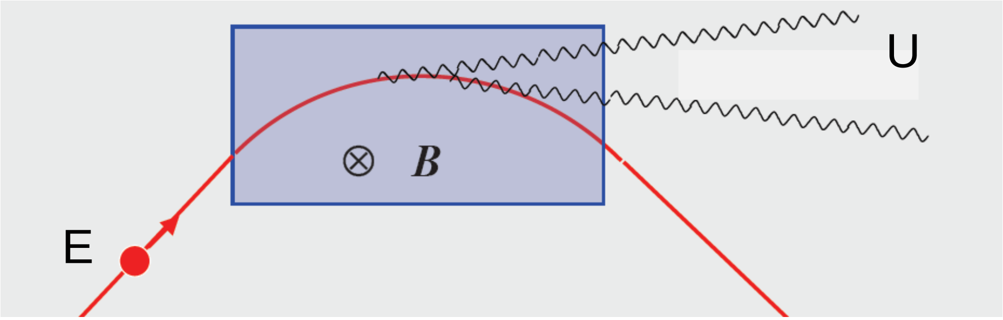
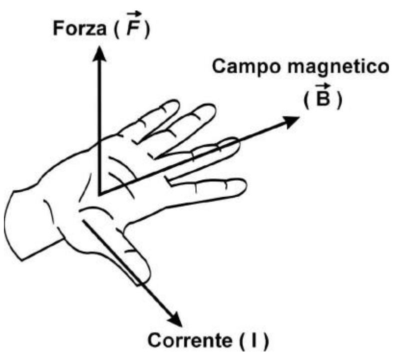
# Synchrotron Radiation

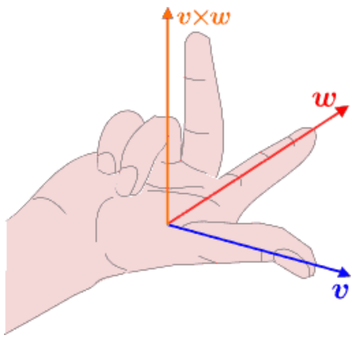


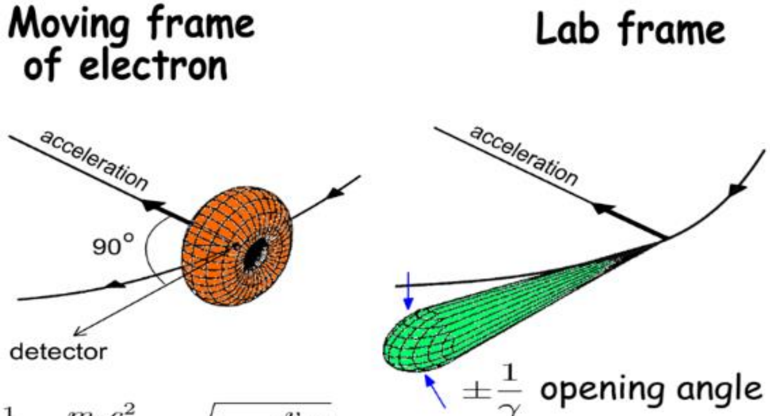




$$U_{turn}[keV] = 88.5\frac{E_b^4\,[GeV]}{R\,[m]}$$

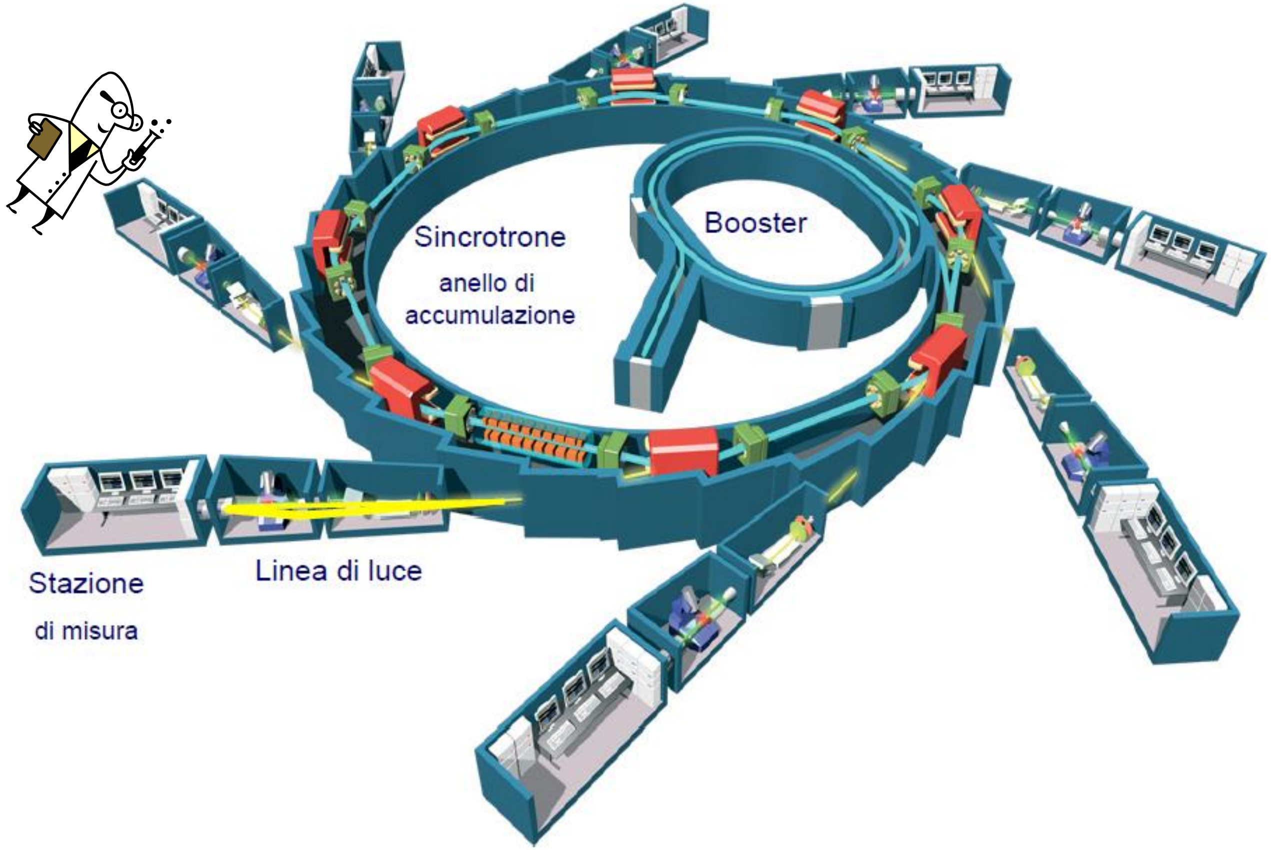


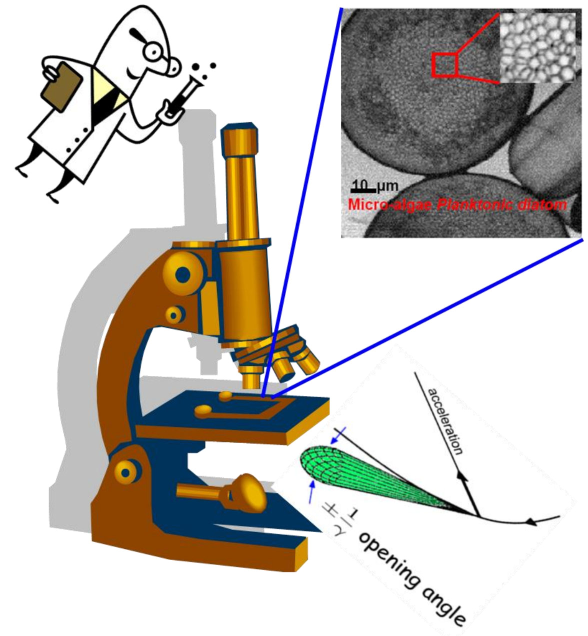




$$\frac{1}{\gamma} = \frac{m_o c^2}{E} = \sqrt{1-(\frac{v}{c})^2}$$

# Synchrotron Light Source



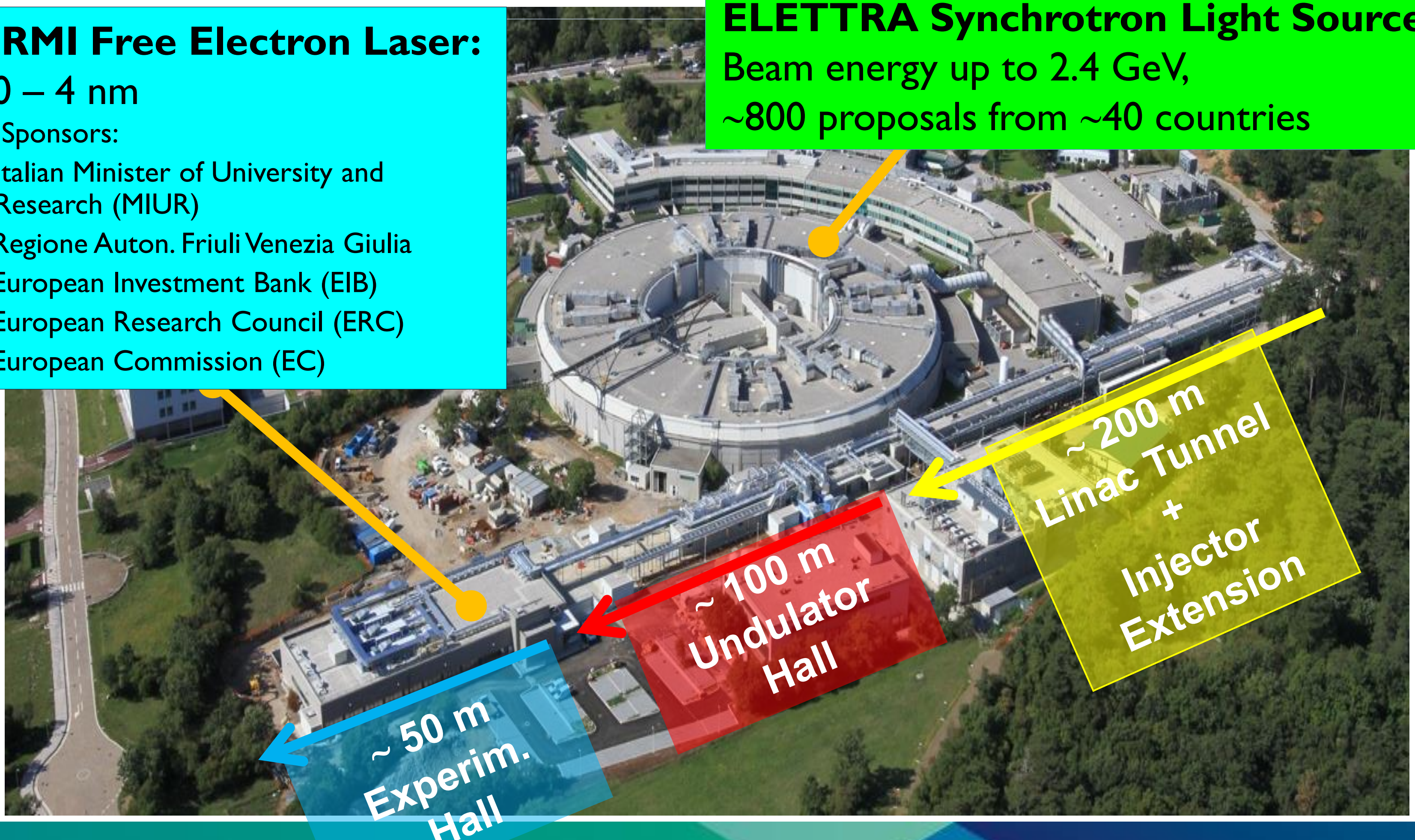
# Elettra Sincrotrone Trieste

Elettra Sincrotrone Trieste is a nonprofit shareholder company of Italian national interest, established in 1987 to construct and manage synchrotron light sources as international facilities.

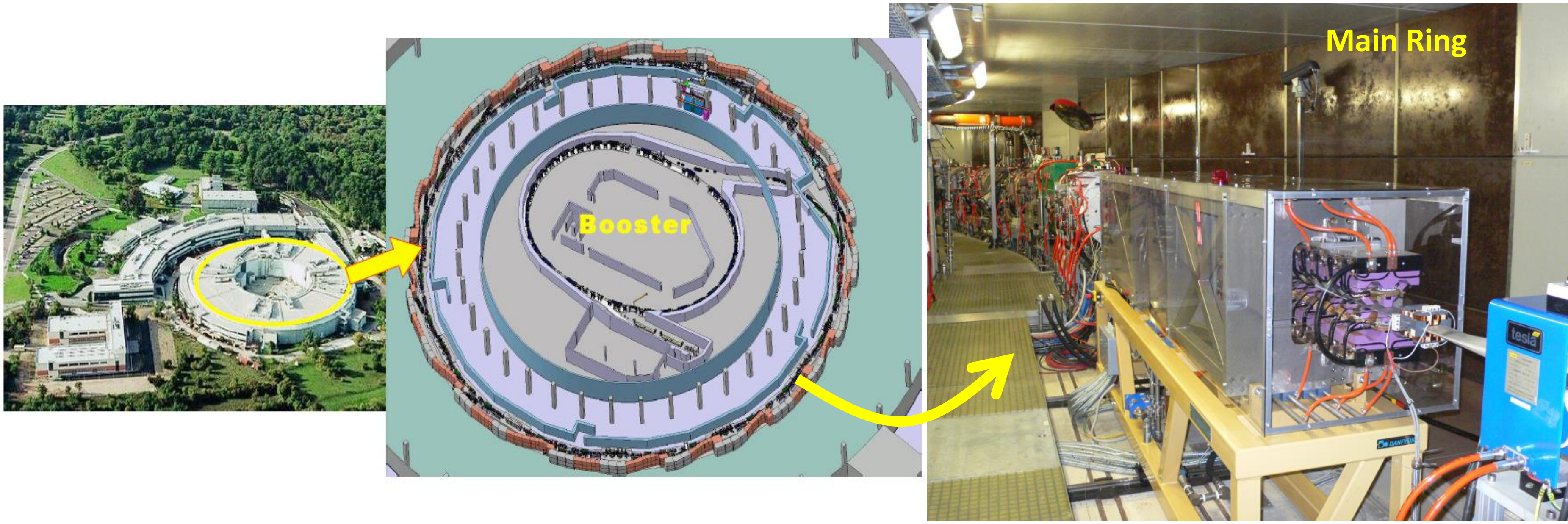
**FERMI Free Electron Laser:**
100 – 4 nm

- Sponsors:
  - Italian Minister of University and Research (MIUR)
  - Regione Auton. Friuli Venezia Giulia
  - European Investment Bank (EIB)
  - European Research Council (ERC)
  - European Commission (EC)

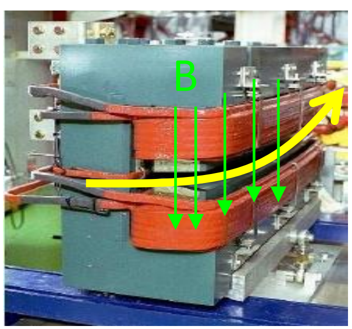
**ELETTRA Synchrotron Light Source:**
Beam energy up to 2.4 GeV,
~800 proposals from ~40 countries



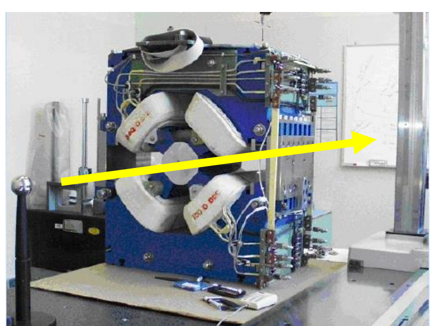
# Elettra Synchrotron Light Source



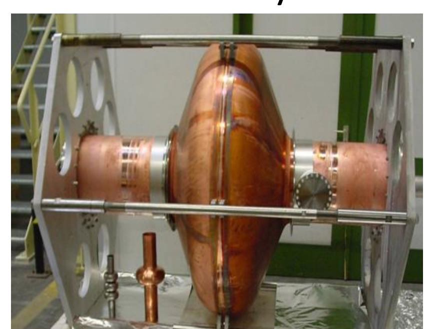

Dipole Magnet

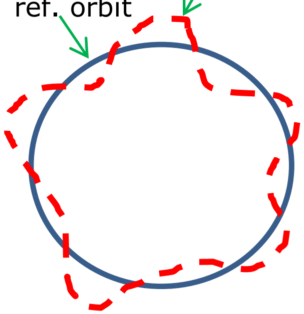



Quadrupole Magnet

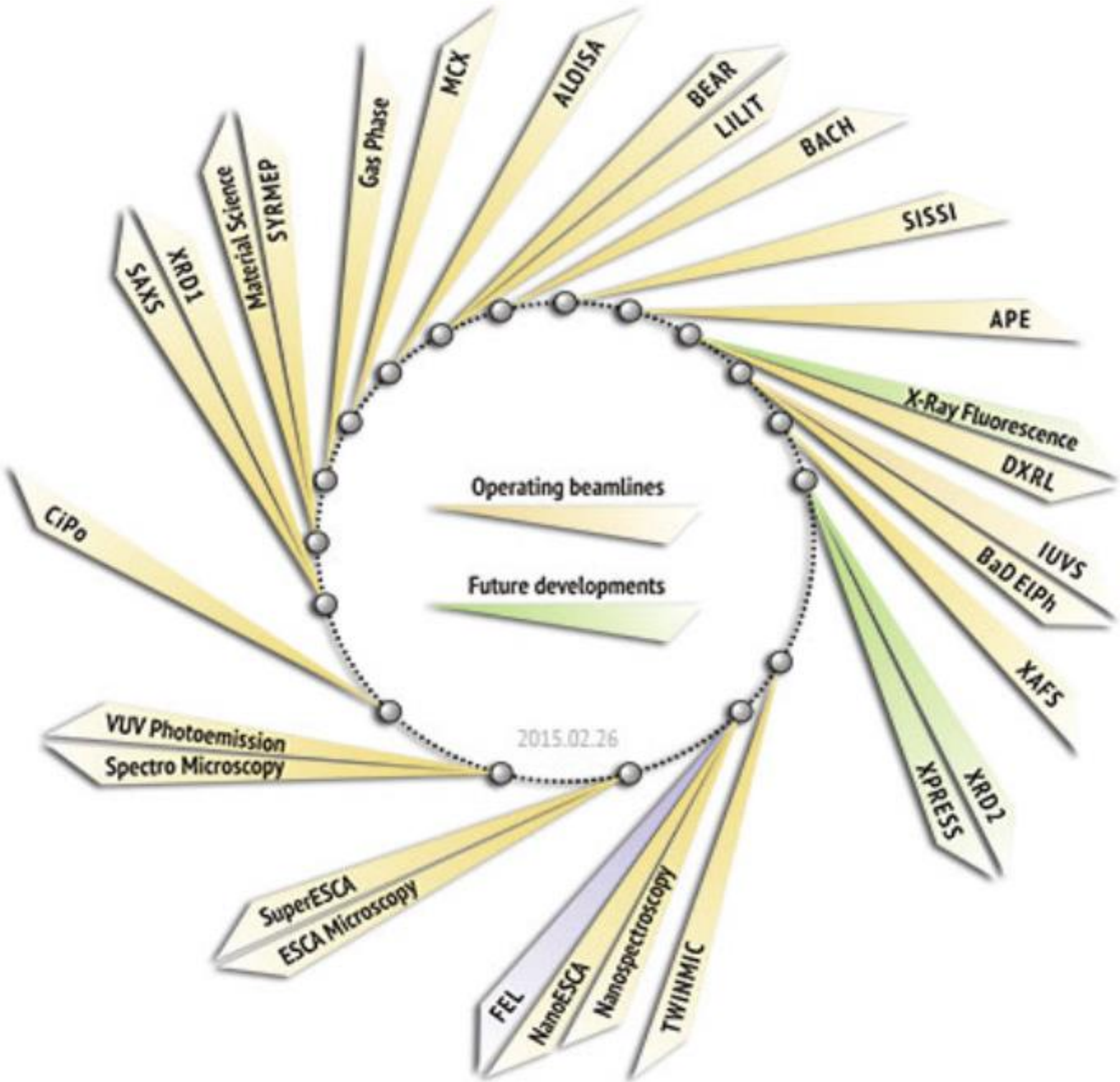


RF cavity



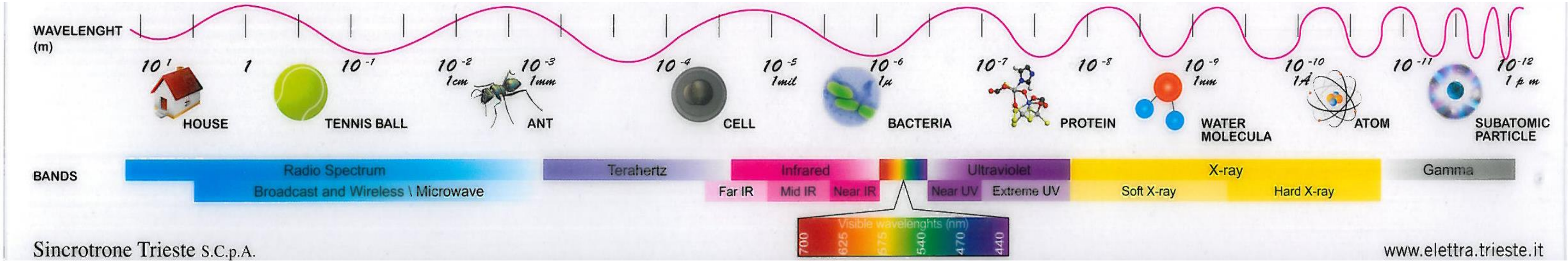


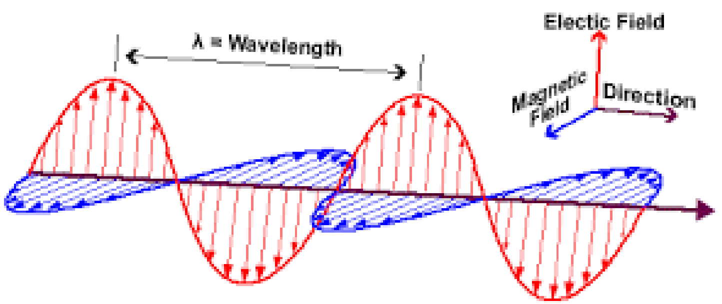
# Elettra Photon Beamlines




- 28 beamlines open to Users
- Physics of Matter, Biology, Chemistry, Medical Science, Technology Materials, Environment, etc…

# Wavelength, Photon Energy




$$c\ [m/s] = \lambda \cdot \nu$$

$$f\ [Hz] = 2\pi\nu$$

$$E\ [J] = h \cdot \nu$$

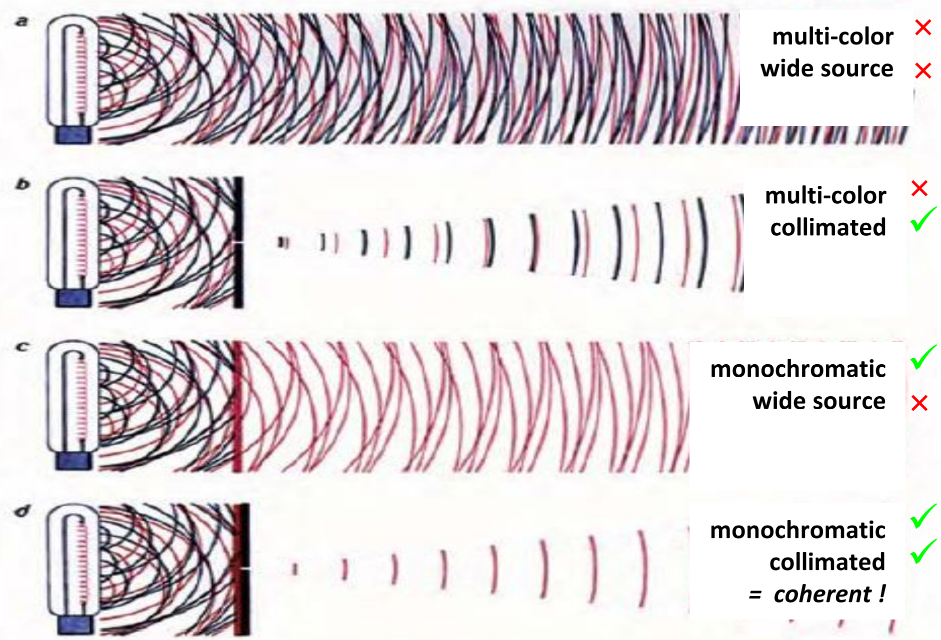
$c$ = 2.998e8 m/s *Light speed in vacuum*

$h$ = 6.626e-34 J s *Planck constant*

- An e.m. wave can be described also as a bunch of massless particles, named “photons”.
- Photons travel at speed *c* in vacuum.
- The energy of an e.m. wave (monochromatic) is the photon energy times the number of photons.

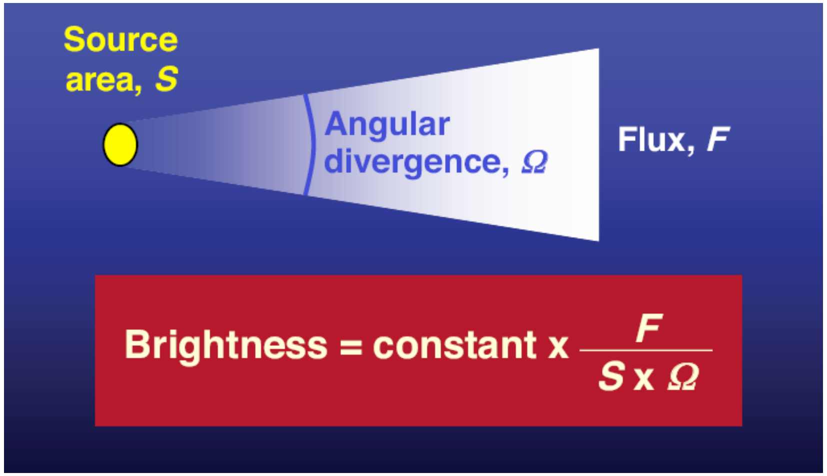
# Radiation Properties

***Transverse & Longitudinal Coherence***

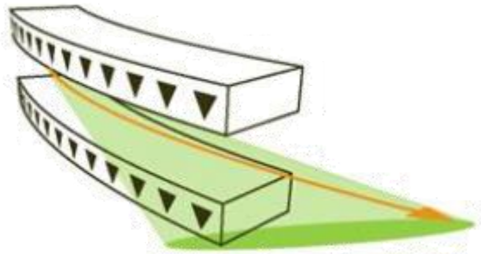



Courtesy of A. Schawlow, Stanford.

***Brilliance***



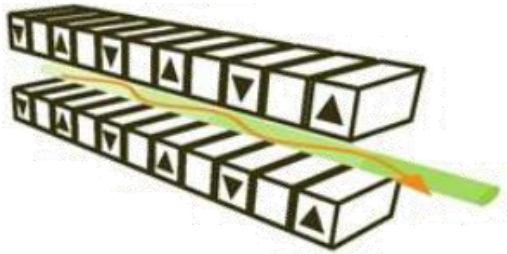
# Radiation Sources

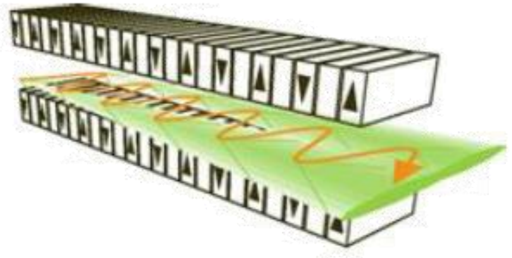


**Magneti Curvanti**

I magneti Curvanti mettono in connessione due sezioni diritte del sincrotrone: la luce è prodotta mediante la "bremesstralung radiations".

I Magneti di Inserzione (straight sections) sono nelle sezioni diritte e producono radiazione più intensa: gli elettroni fanno un moto a zig-zag, emettendo luce.





**Ondulatore**

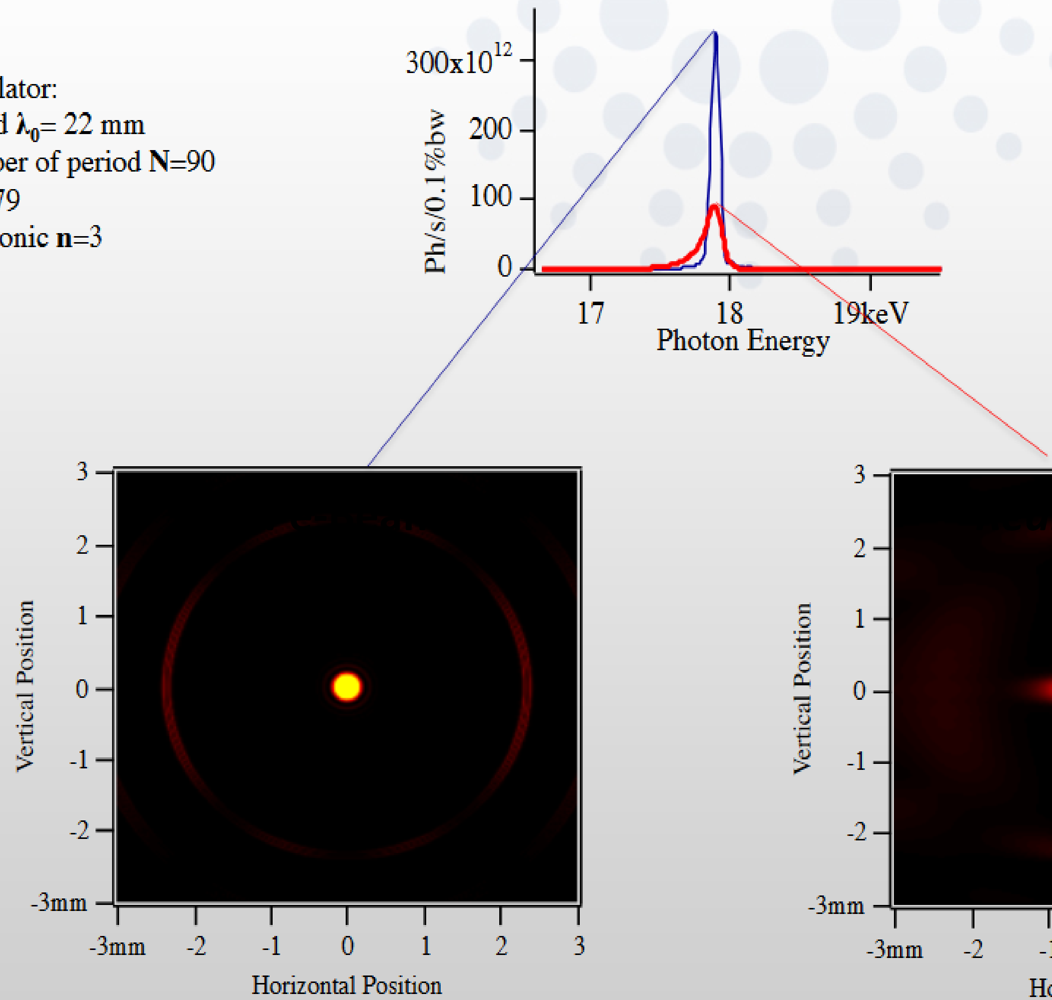
La luce del raggio è coerente e collimata

**Wiggler**

La luce del raggio è incorente e non collimata

# Spectral Flux

Undulator:
Period $\lambda_0$= 22 mm
Number of period **N**=90
K=1.79
Harmonic **n**=3




***Undulator resonance wavelength:***

*undulator period*

*magnetic field*

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

*e-beam energy*

*e-beam divergence*

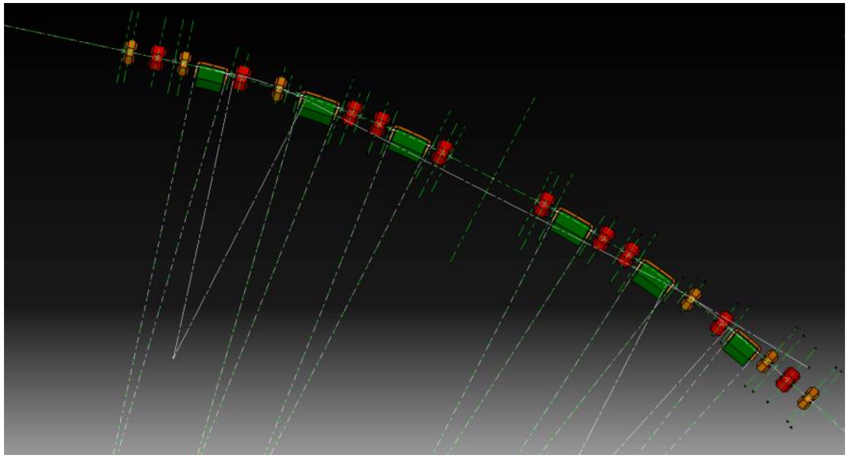
**"undulator parameter", it is proportional to the undulator magnetic field:**
**K ∝ B**

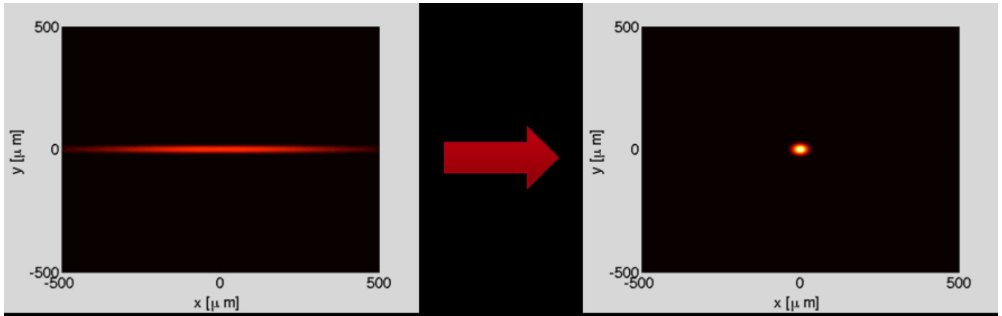
# New Generation is Coming

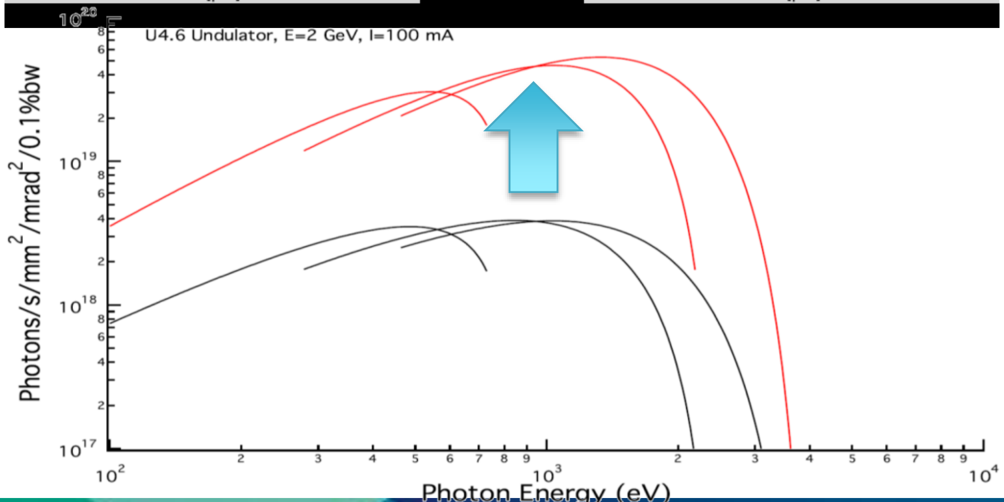
Upgrade of synchrotron light sources is planned worldwide, in order to reach a higher photon brilliance.

More dipoles, smaller bending angle, smaller e-beam sizes, higher charge density.

*From Elettra to Elettra 2.0:*



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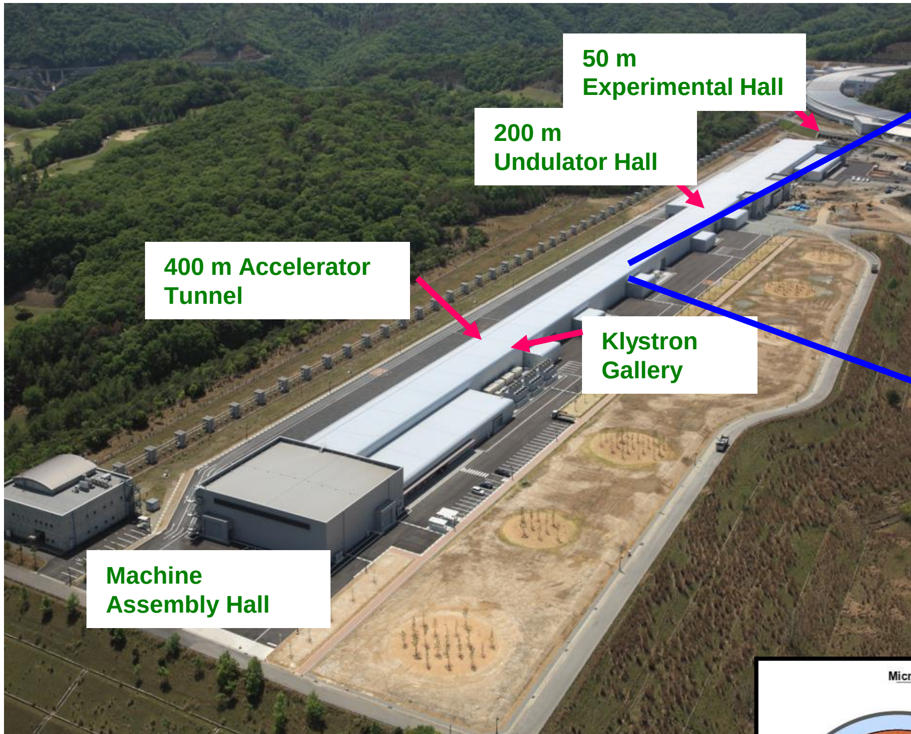
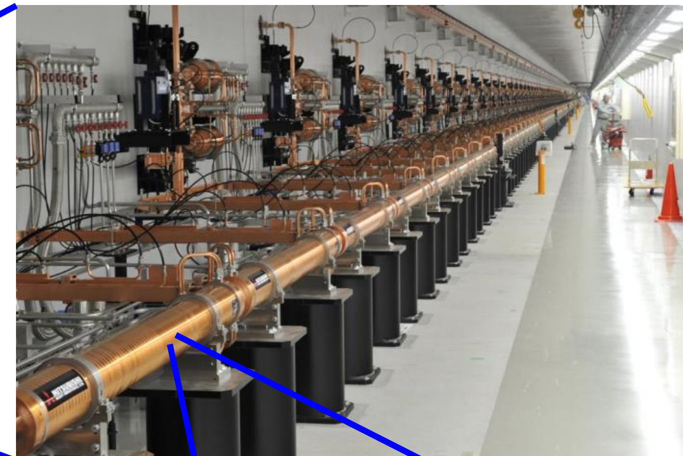
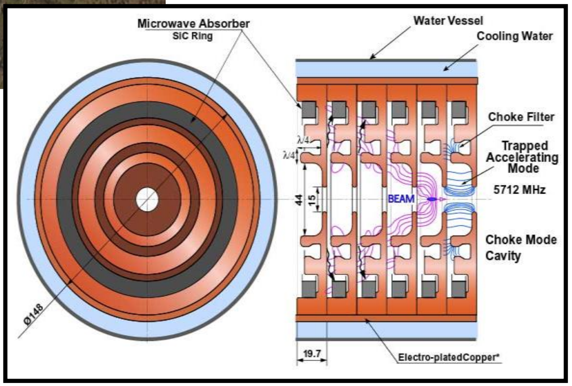
# Back Slides Follow

# Radiofrequency Electron Linac




Source: T. Inagaki, T. Shintake

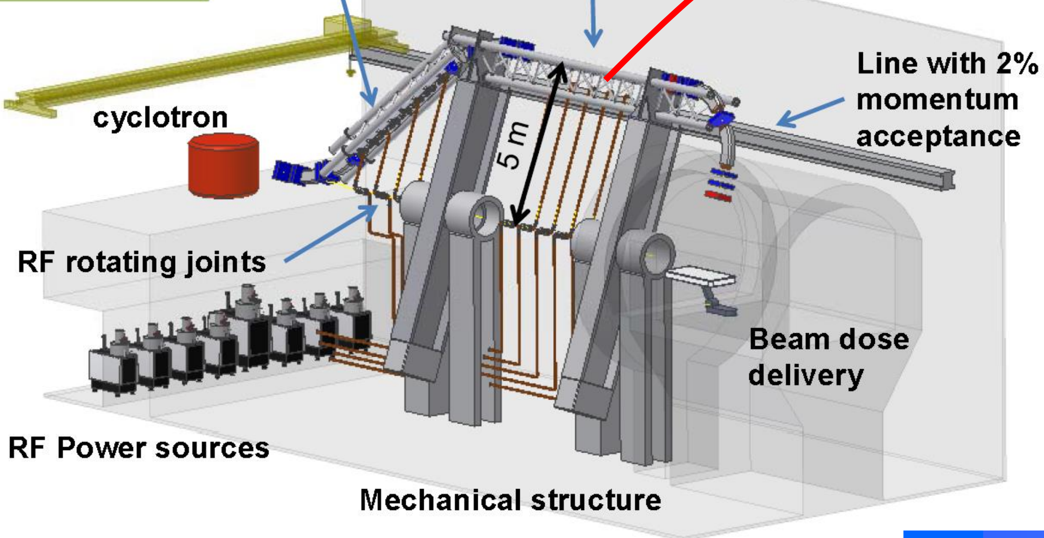




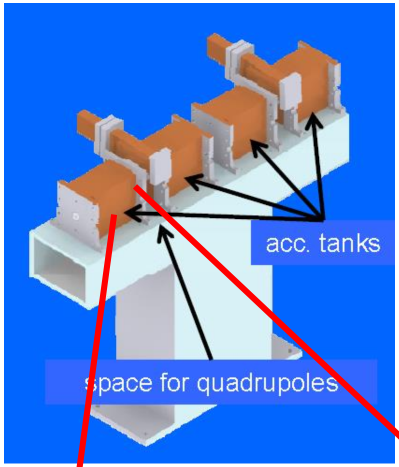

8 GeV e-linac
C-band (5.7 GHz)
35 MV/m acc. gradient
13000 cells mass production

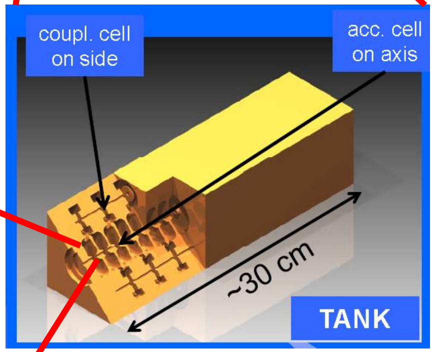
# Radiofrequency Proton Linac

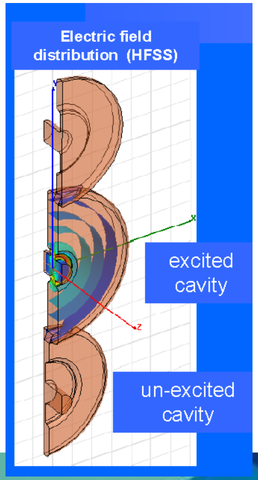
***TULIP* =**
**TUrning LInac for Protontherapy**




Source: A. Degiovanni, U. Amaldi

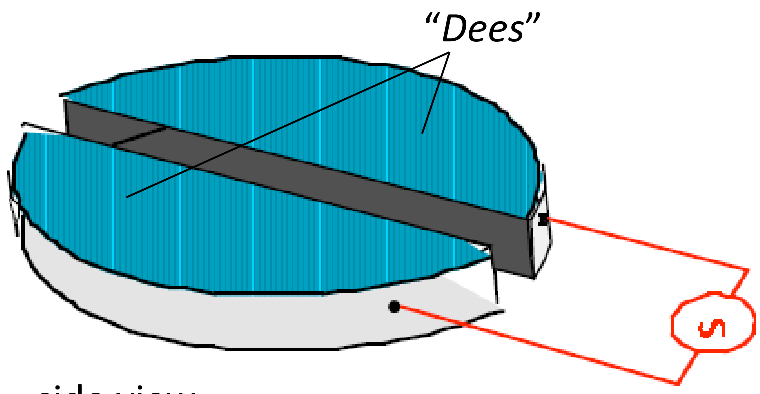


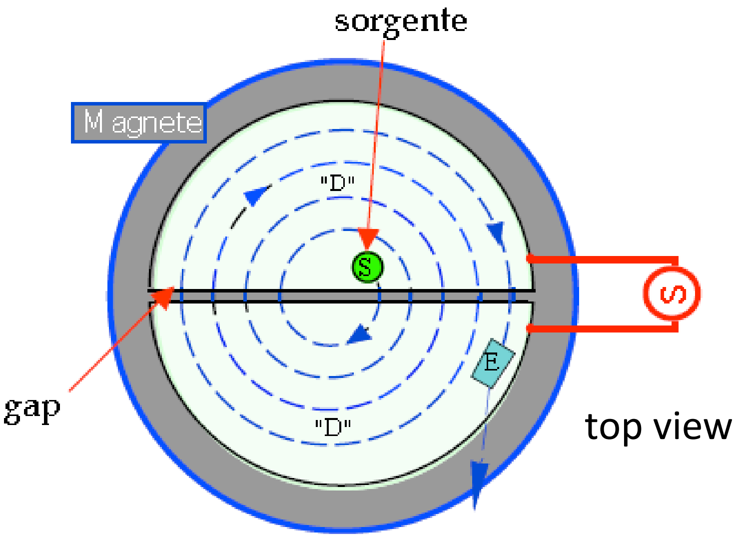




80–210 MeV p-linac
C-band (5.7 GHz)
<38 MV/m acc. gradient
Rep.rate, 200 Hz

# Cyclotron (E.O.Lawrence & M.S.Livingstone, Berkeley 1931)




$$f_{RF} = (2n+1) f_C$$ Synchronism

$$\Delta T(t) = qV_o \sin(\omega_{RF} t + \varphi)$$ Energy gain / turn

$$\rho = \frac{P}{|q| B_o}$$ Lorentz force

$$P = \sqrt{2 m_o T}$$ Classical approximation (e.g., massive particles)

- Spiraling motion:

$$\Delta\rho = \rho \frac{1}{2} \frac{\Delta T}{T} = \frac{\Delta T}{|q| c B} \sqrt{\frac{m_0 c^2}{2T}}$$

- Maximum kinetic energy:

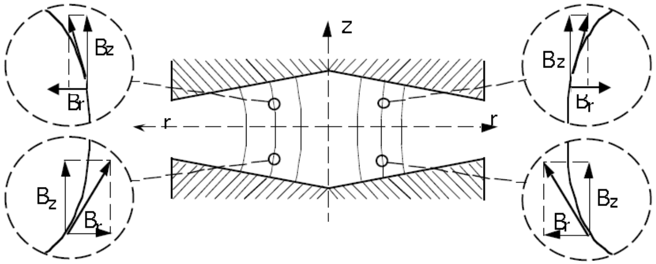
$$\frac{\sqrt{2 m_o T_{max}}}{|q| B} = R$$

# Sinchro- and Sector- Cyclotron

$$\omega_c = \frac{B}{|q|m} = \frac{1}{\gamma}\frac{B}{|q|m_0} \equiv C\omega_{RF}$$

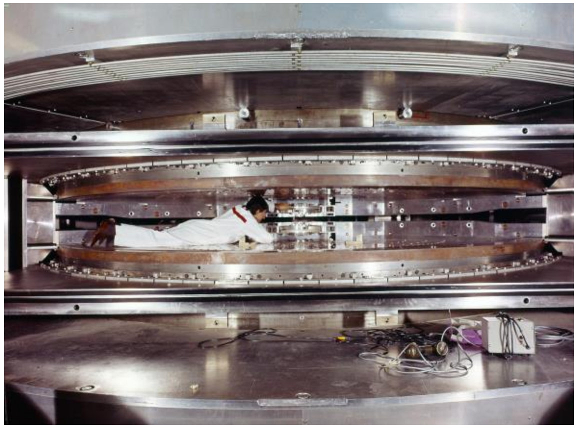
To maintain the synchronism, which ensures the multi/turn acceleration, one has two ways:

1. Increase B(t) synchronous to $\gamma$(t), $\propto \rho$(t) → *"sector cyclotron"*




TRIUMPH, Canada

CERN SC



2. Increase $\omega_{RF}$ (t) synchronous to $\gamma$(t)

→ *"sincro-cyclotron"*

N.B.: here the beam is ***bunched***, over one period of modulation of $\omega_{RF}$ !!