Introduction to Beam Physics and Accelerator Technology

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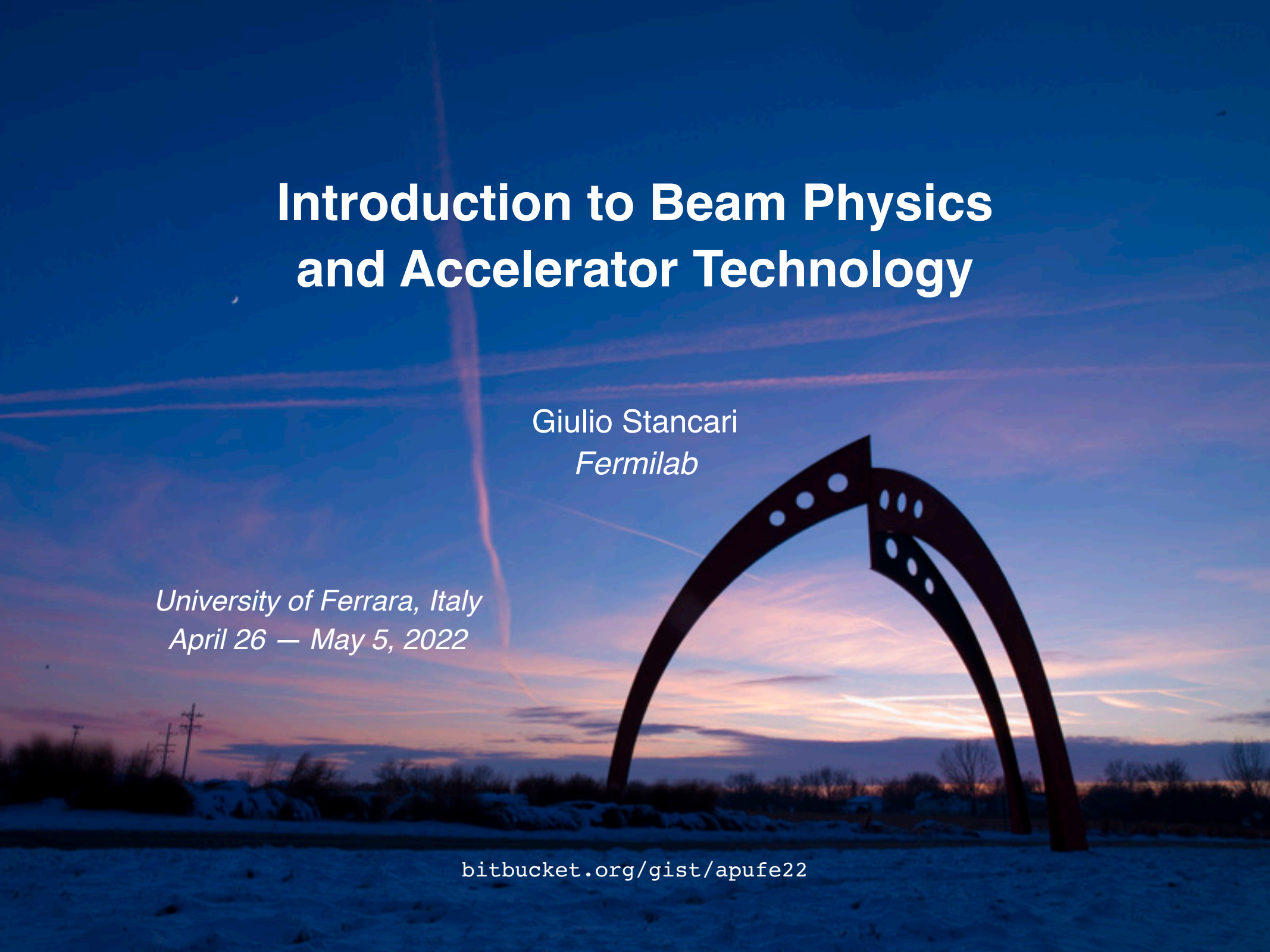


bitbucket.org/gist/apufe22

Applications of accelerators

What are accelerators used for?

- **Particle and nuclear physics**

  creation of new forms of matter, study of the fundamental interactions, measurement of particle properties and cross sections
- **Biology, chemistry and material science**

  FEL ("free-electron lasers") to measure the structure and dynamics of microscopic systems with synchrotron light, neutron sources to investigate the structure of solids, …
- **Medicine**

  radiotherapy, hadron therapy, isotope production for diagnostics, sterilization,…
- **Archeology and art**

  ^{14}C dating, sensitive chemical analyses of small samples, …

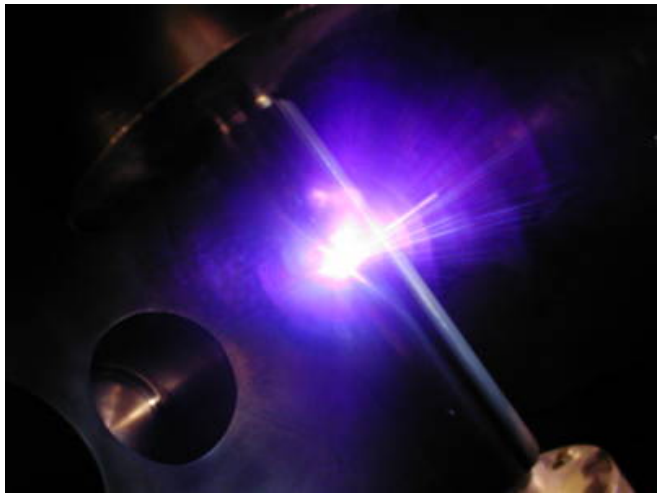
What are accelerators used for?

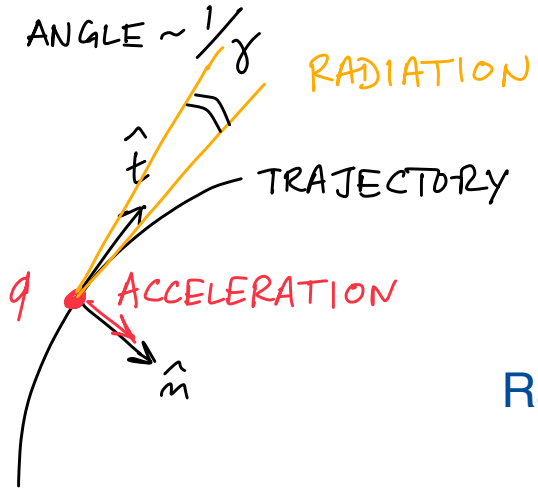
- **Industrial processes**
  ion implants in semiconductors, micro-lithography, food sterilization, polymerization, treatment of materials
- **Defense**
  detection of illicit cargo, neutralization of suspicious packages, …
- **Energy and environment**
  activation of nuclear fission reactors (Accelerator-Driven Systems), nuclear fusion, treatment of radioactive waste, …

There are **tens of thousands of accelerators in the world**. Most of them are used in **industry** and **medicine**.

Synchrotron radiation

When **accelerated**, charged particles **emit electromagnetic radiation**





Radiated power

$$P = \left(\frac{1}{4\pi\epsilon_0}\right)\frac{2}{3}\frac{q^2a^2}{c^3}$$

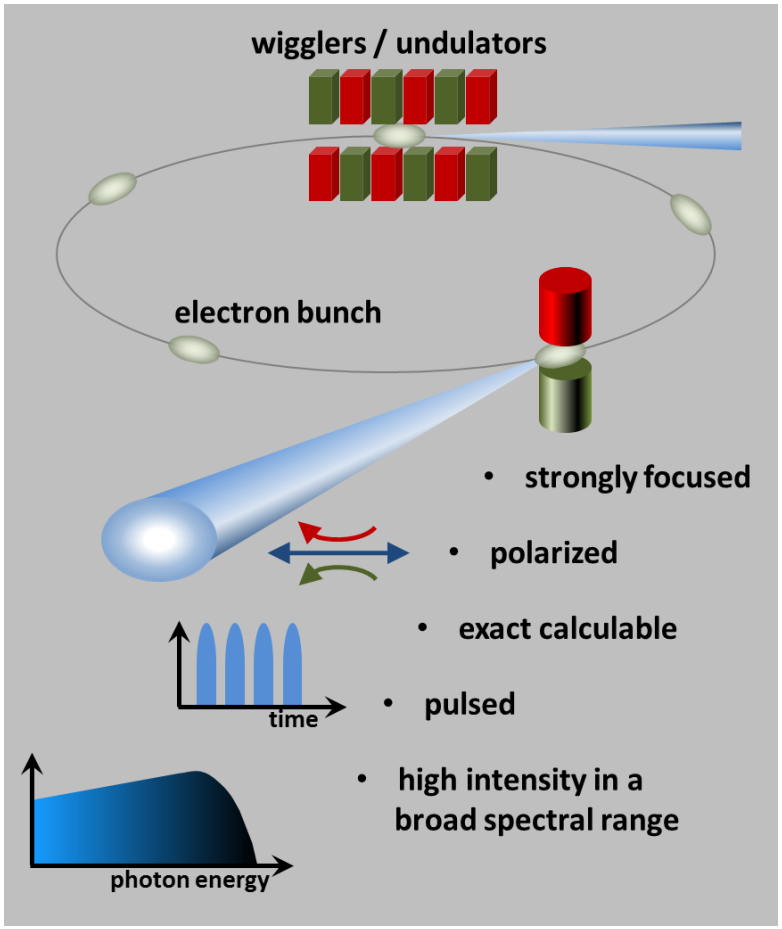
Called **"synchrotron radiation"** or "synchrotron light" after the first observations in electron synchrotrons

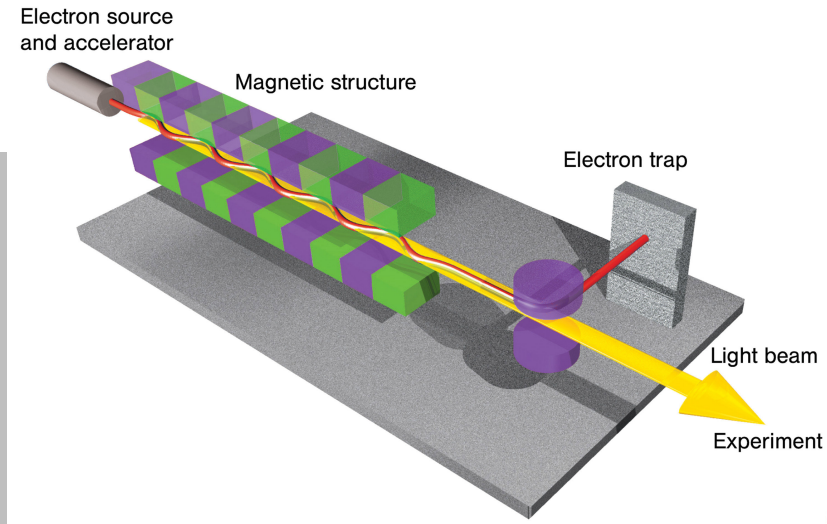
In accelerators:

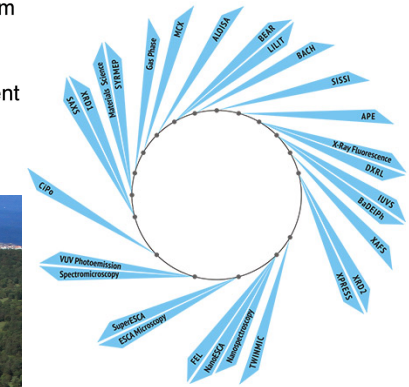
- the **energy loss must be compensated** by the accelerating cavities
- the combined effect of radiation emission and acceleration generates **synchrotron damping**, a form of **cooling**

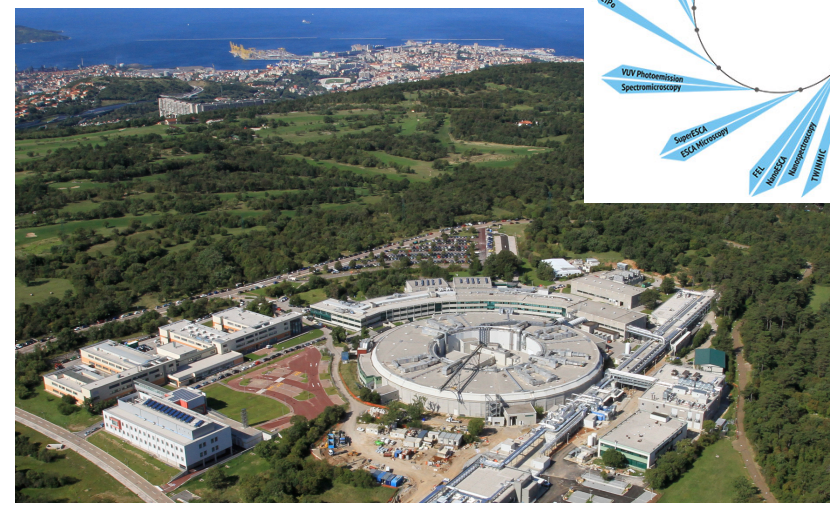
Synchrotron radiation sources

Electron synchrotrons and **free-electron lasers** (FELs) generate **radiation with unique properties**









Elettra (synchrotron) and FERMI (FEL) near Trieste, Italy

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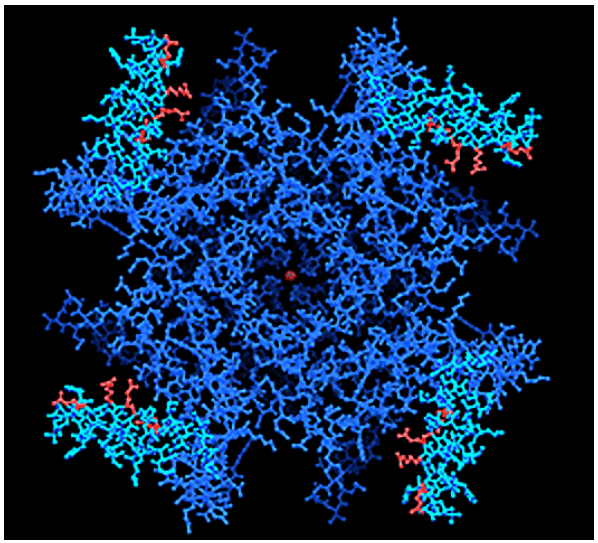
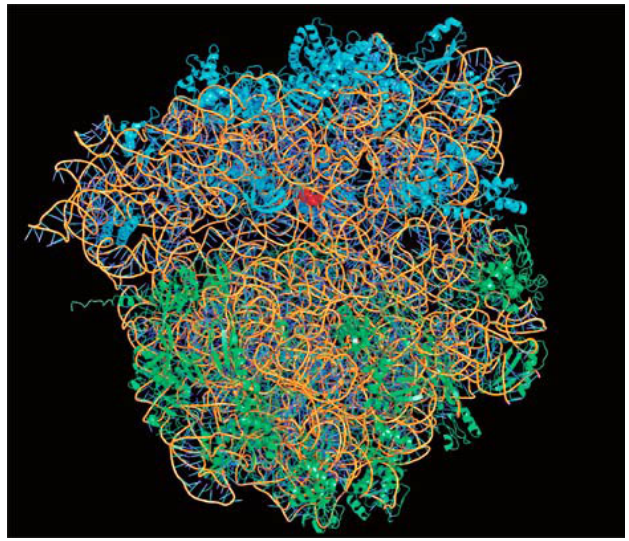
Numerous applications of synchrotron radiation

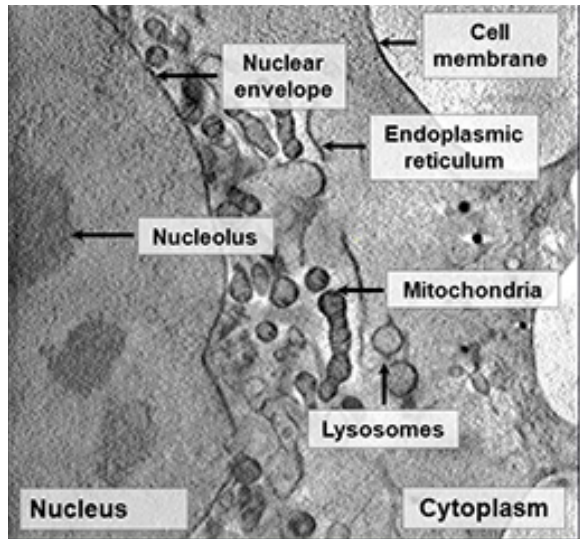
Tens of laboratories around the world are dedicated to synchrotron radiation applied to **biology**, **medicine**, **chemistry**, **physics** and **material science**

structure of macromolecules (several Nobel Prizes)

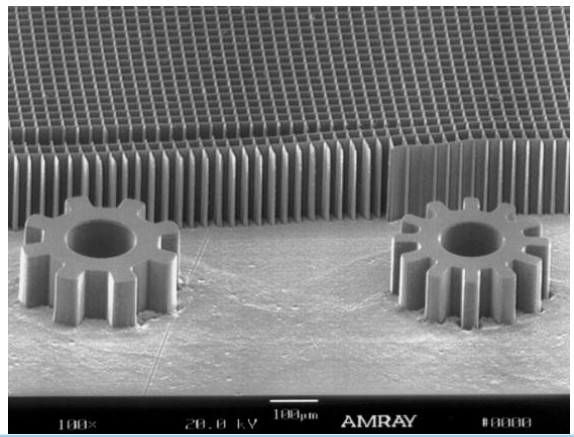




tomography



lightsources.org



micro-lithography

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Accelerators for cancer treatment

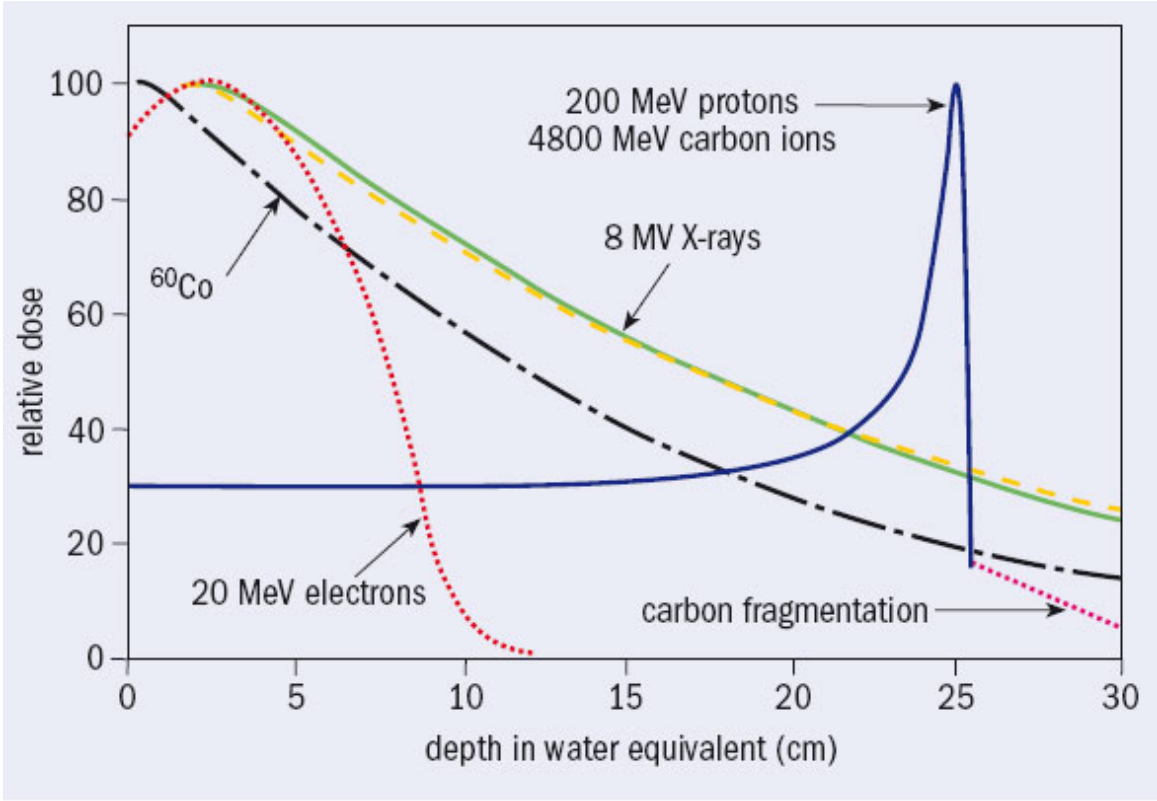
- **Ionizing radiation** consists of photons, electrons, protons, ions, neutrons, etc. that have enough energy to free electrons from molecules
- The **dose** is the total amount of energy deposited in tissue
- **Cancer therapy** is based on the **effect of ionizing radiation on DNA**
- Often cancer cells are more vulnerable than healthy cells: there is a **therapeutic window**

Energy deposition in tissue: radiotherapy and hadron therapy

Each type of radiation has a characteristic effect on tissue

Electrons and X rays *(radiotherapy) deposit energy on a large volume*

Protons and ions *(hadron therapy) release most of the energy at the end of their path (Bragg peak)*



*The **energy of the beam** determines the **penetration depth**. For instance, 200-MeV protons are necessary to reach a depth of 25 cm.*

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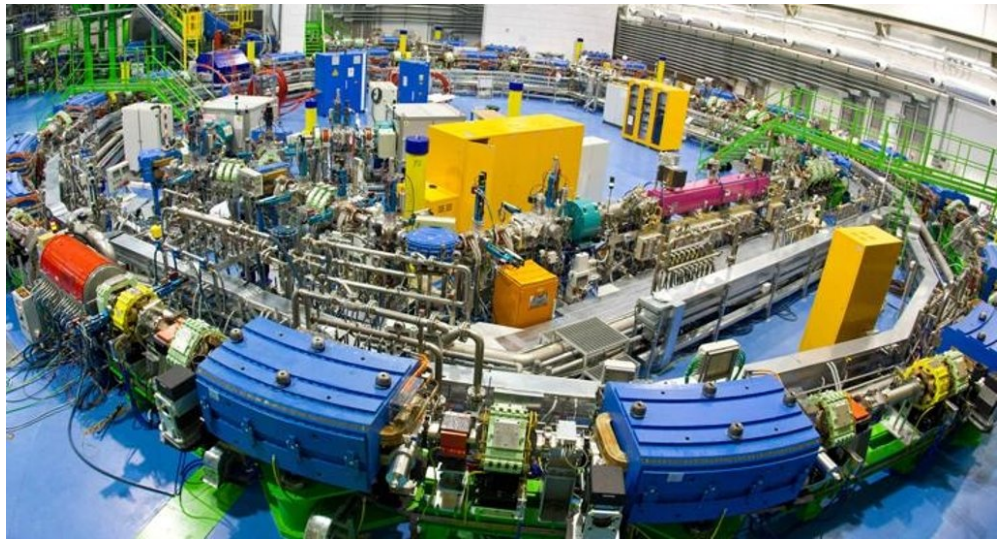
Accelerators for radiotherapy and hadron therapy

Radiotherapy system (Varian)

Electrons and **X rays** are produced using **compact linacs**

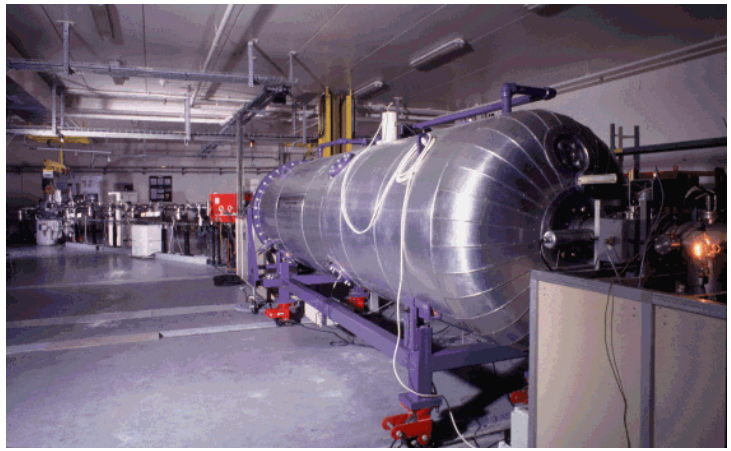
Synchrotrons are necessary to generate **proton** and **ion beams** with the required characteristics and performance

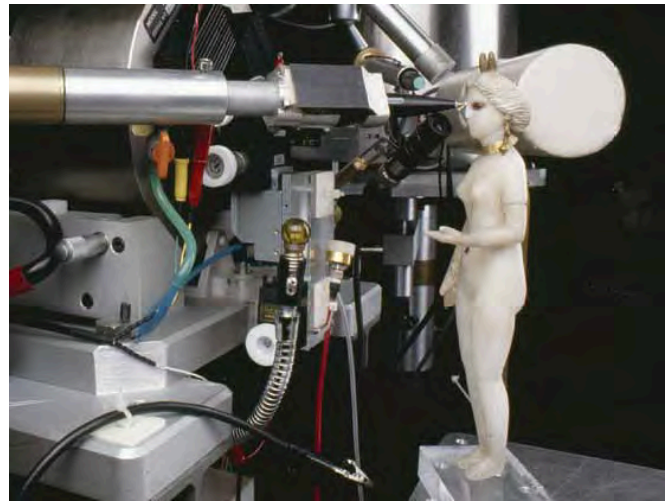


Synchrotron at CNAO, Pavia, Italy

An accelerator at the Louvre museum dedicated to fine arts

AGLAE (Accélérateur Grand Louvre d'Analyse Élémentaire)



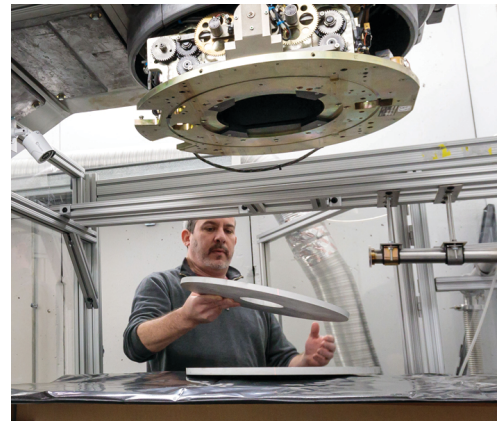


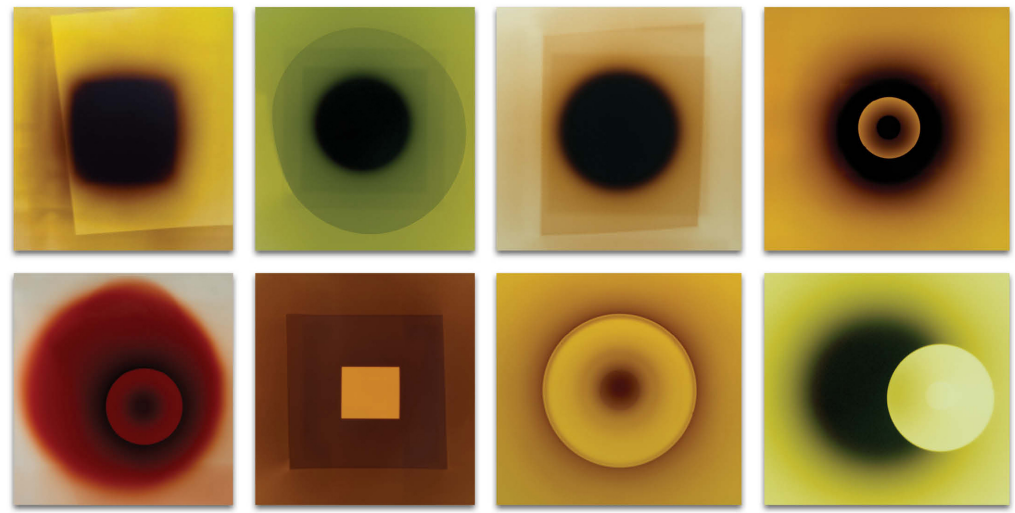
Material analyses using an ion beam, measuring induced X-ray spectra and backscattered protons. Determination of the **age**, **manufacturing process** and **geographical origin of samples and works of art** from various institutions.

Accelerators can also create sculptures and photographs

"Shockfossils" (Lichtenberg figures) by Todd Johnson (Fermilab), are like "frozen lightning": acrylic slabs are charged by exposing them to the electron beam of an industrial accelerator. They are then quickly discharged with a pointed rod.

The photographer Adam Nadel uses electrons from the A2D2 machine at Fermilab (instead of light) to create abstract images on photographic film.





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Questions?