The Future with Particle Accelerators: New Concepts and New Applications

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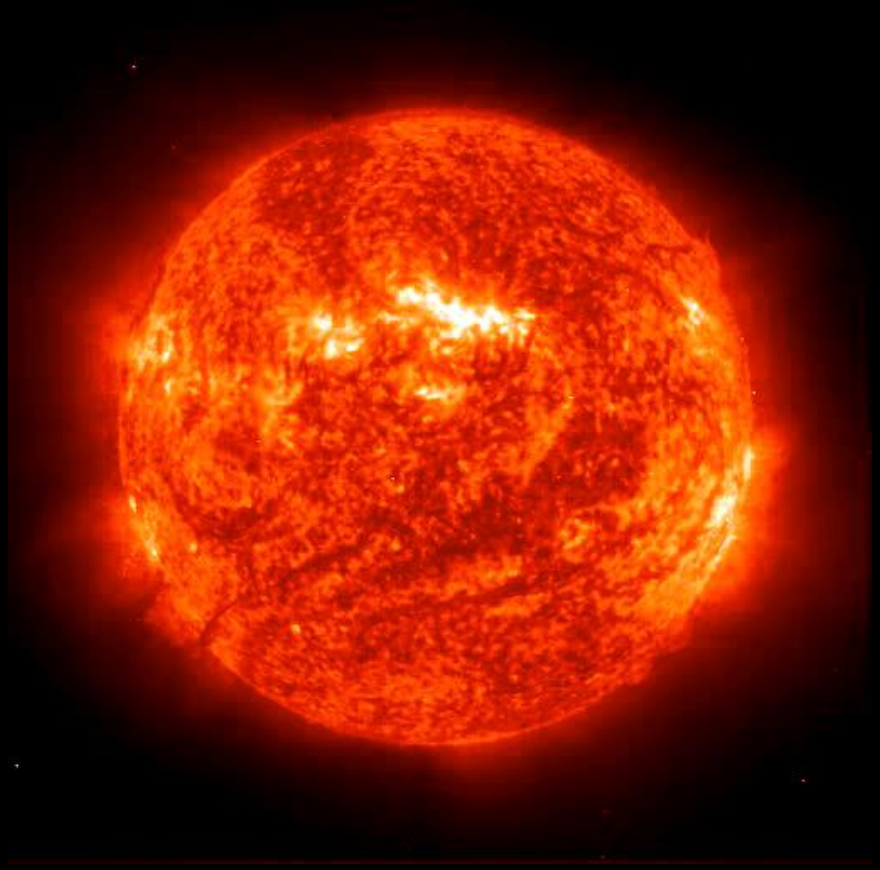
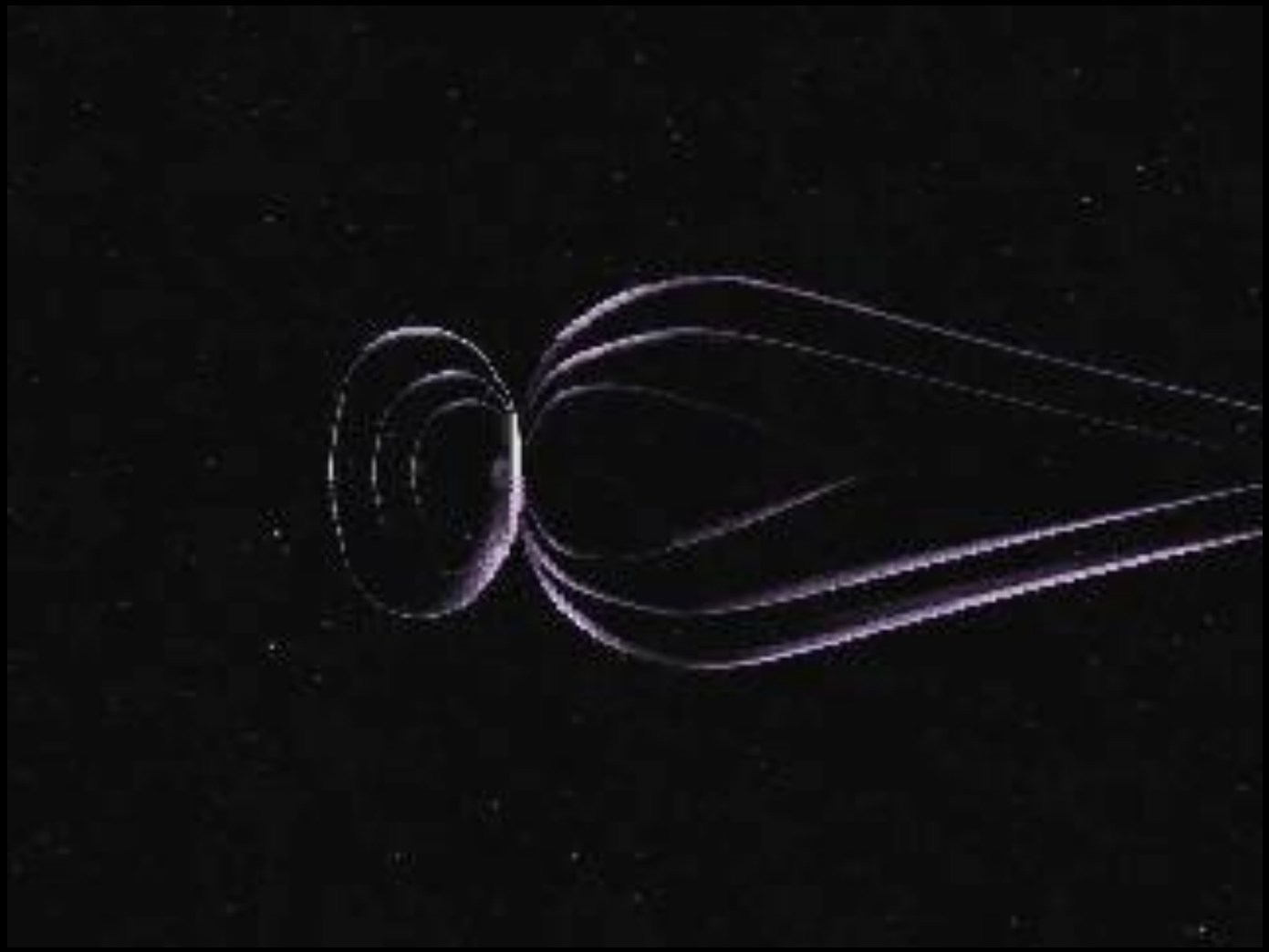


Solar wind

protons + electrons , 800 kg/s , 500 km/s , 4 days

Magnetic field Sun/Earth: 1 kG/0.5 G




IMAGE–FUV–2000/07/15–14:00:39.UT


Ne

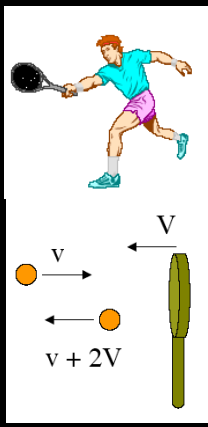

Ar


He

Aurora Borealis

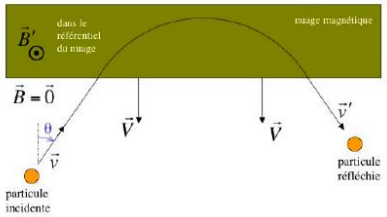
Cosmic ray acceleration according to E. Fermi

Galactic source



Primary cosmic ray
(proton, nucleous)

Earth
atmosphere



$$\begin{cases} E'_{in} = \gamma(E_{in} - p_{in\parallel}V) \\ p'_{in\parallel} = \gamma(p_{in\parallel} - \frac{V}{c^2}E_{in}) \end{cases}$$

$$\begin{cases} E_{out} = \gamma(E'_{out} + p'_{out\parallel}V) \\ p_{out\parallel} = \gamma(p'_{out\parallel} + \frac{V}{c^2}E'_{out}) \end{cases}$$

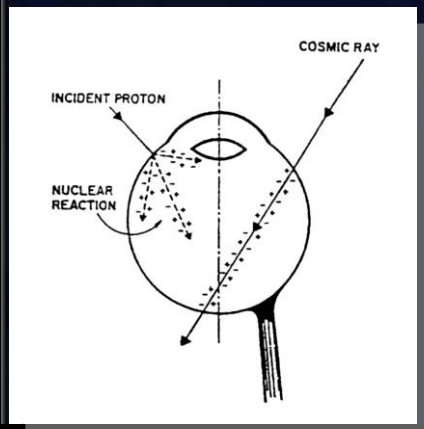
$$\left.\begin{array}{l} p'_{out\parallel} = -p'_{in\parallel} \\ p'_{out\perp} = p'_{in\perp} \\ E'_{out} = E'_{in} \end{array}\right\} \Rightarrow E_{out} = \gamma^2[E_{in}(1+\tfrac{V^2}{c^2}) - 2p_{in\parallel}V]$$

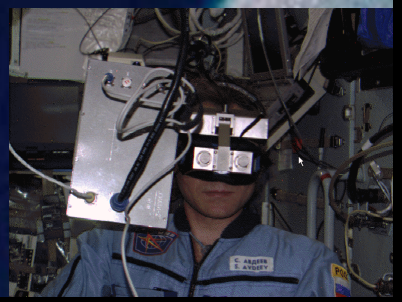
$$\left.\begin{array}{l} p_{\parallel} = -Ev\cos\theta/c^2 \\ \theta = -(\widehat{\mathbf{v},\mathbf{V}}) \end{array}\right\} \Rightarrow E_{out} = E_{in}(1+\frac{2vV\cos\theta}{c^2}) \Rightarrow \boxed{\frac{\Delta E}{E} = -2\frac{\mathbf{v}\cdot\mathbf{V}}{c^2}}$$

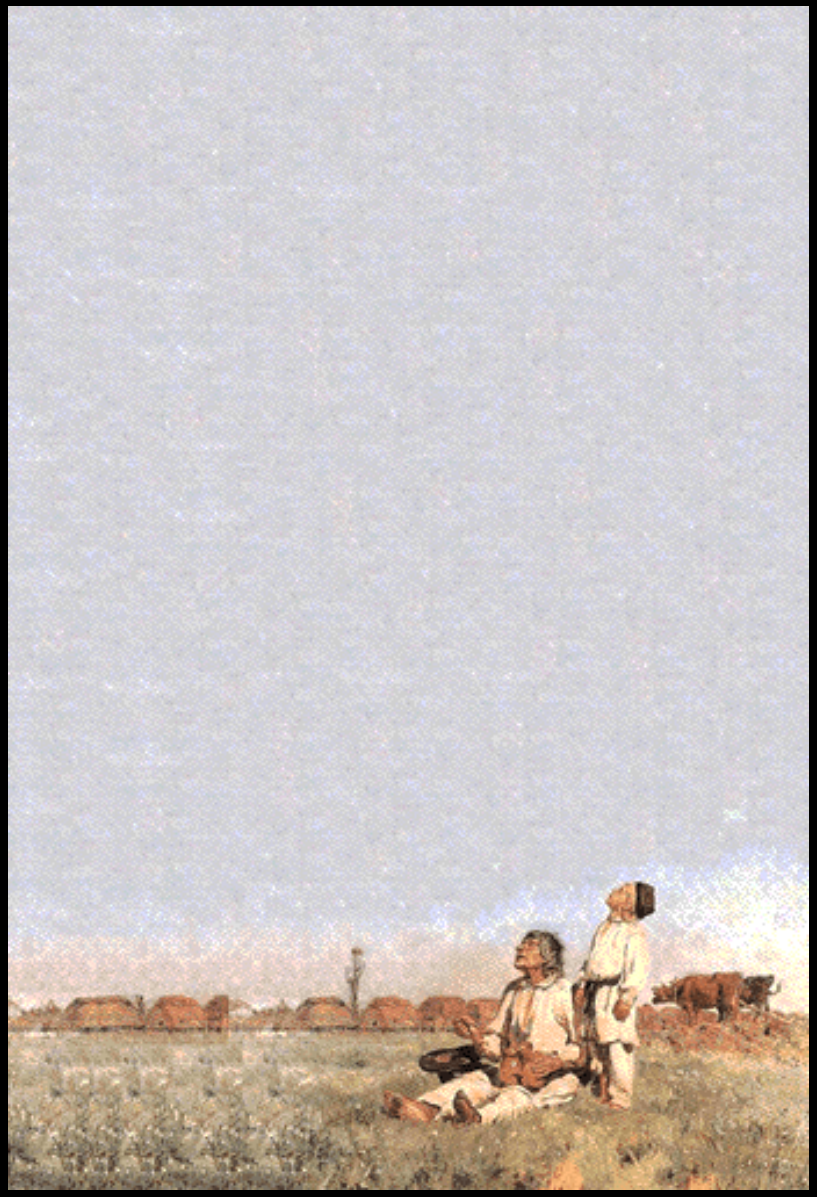
Lights in the sky

Obseved during the Apollo missions

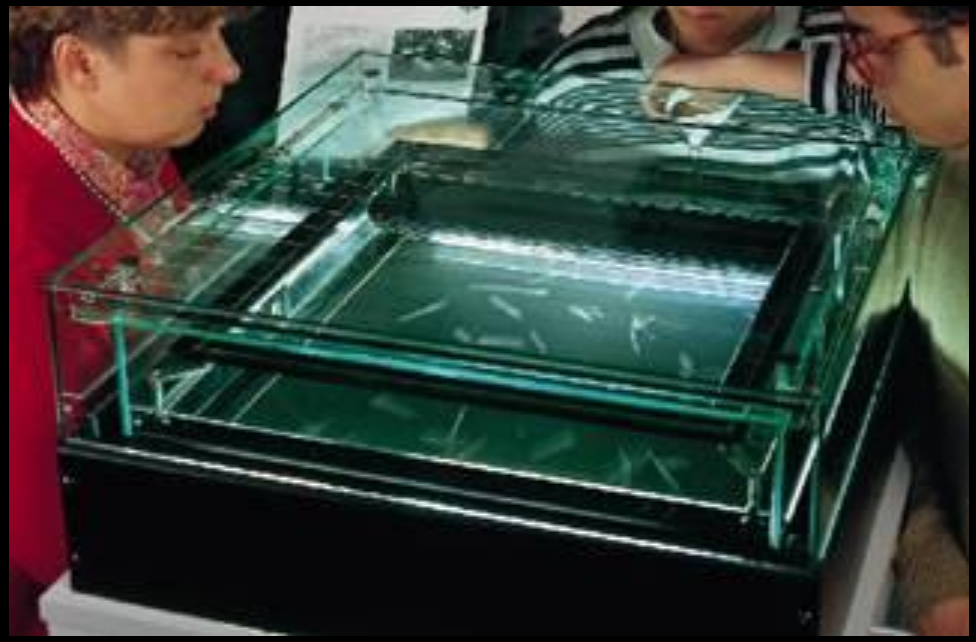
P.Maponi, M.Ricci, F.Zirilli,_B.Spataro_IL NUOVO CIMENTO vol. *116 *B, N.*10*,(2001)

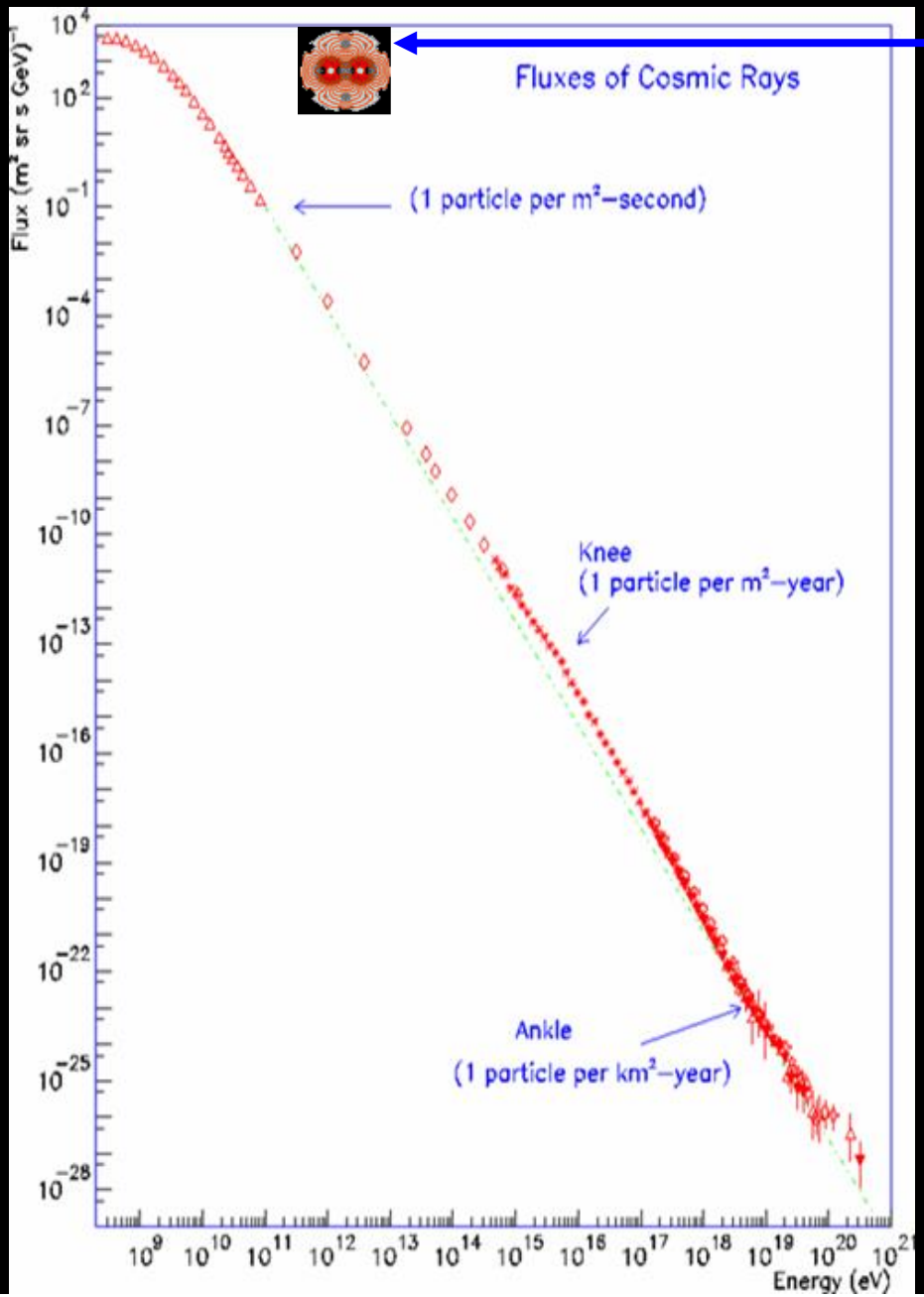






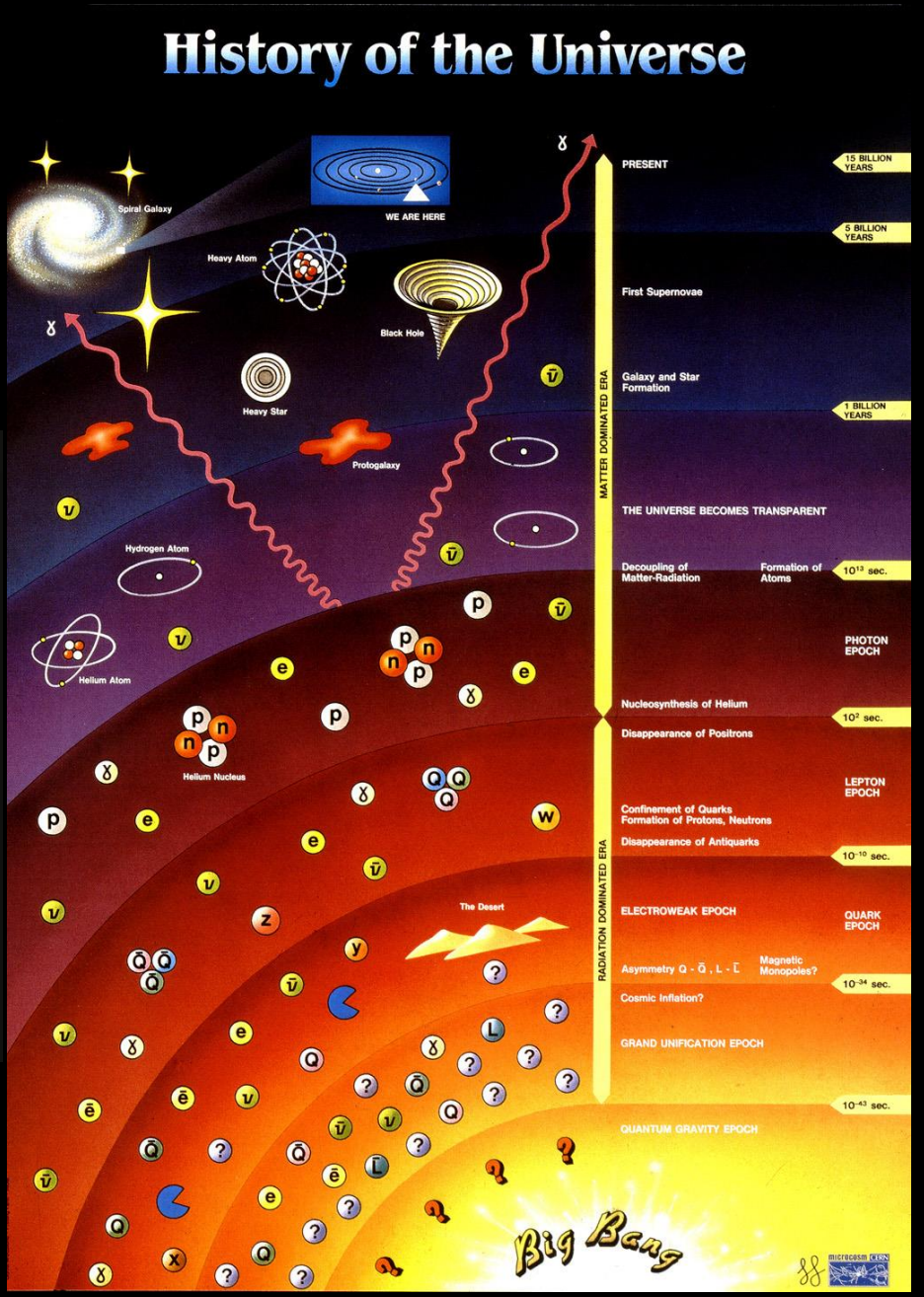
Cloud chamber





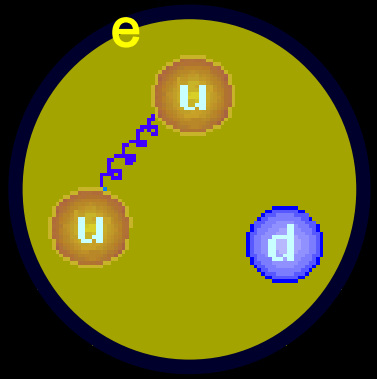
LHC
14 TeV
$>10^{30}$ / $cm^2 s$

Particle accelerators are born from the need for systematic and repeatable experiments to study the ultimate constituents of matter, the laws that govern them and understand the origin and evolution of the Universe

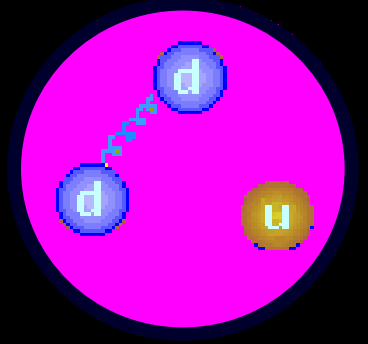


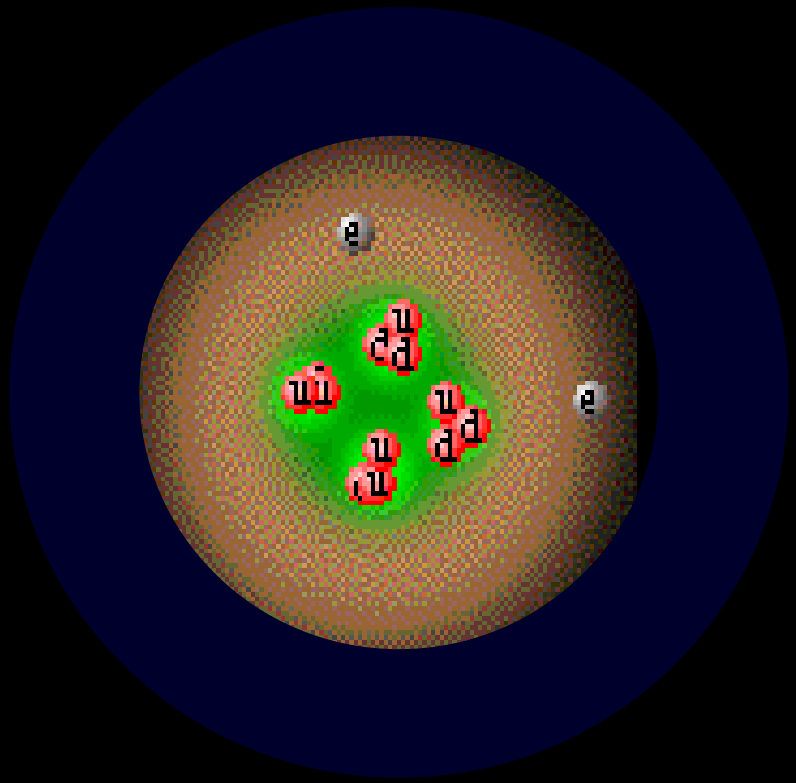
proton

e

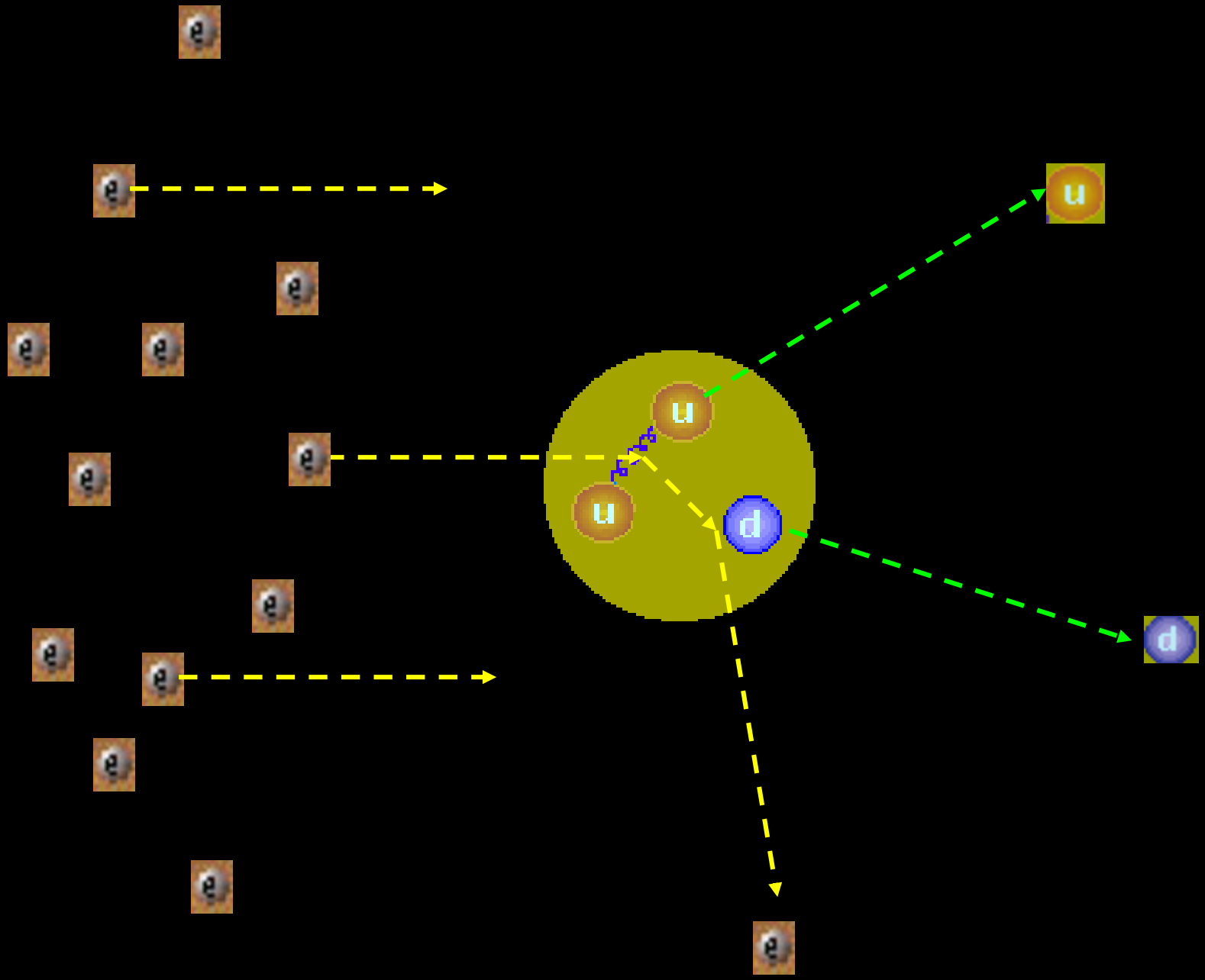


neutron





Helium Atom: 2 p +2n + 2 e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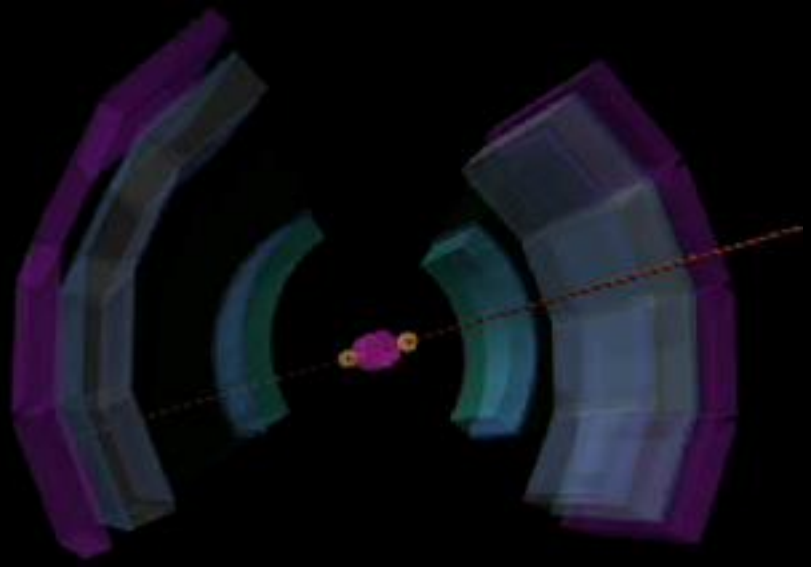
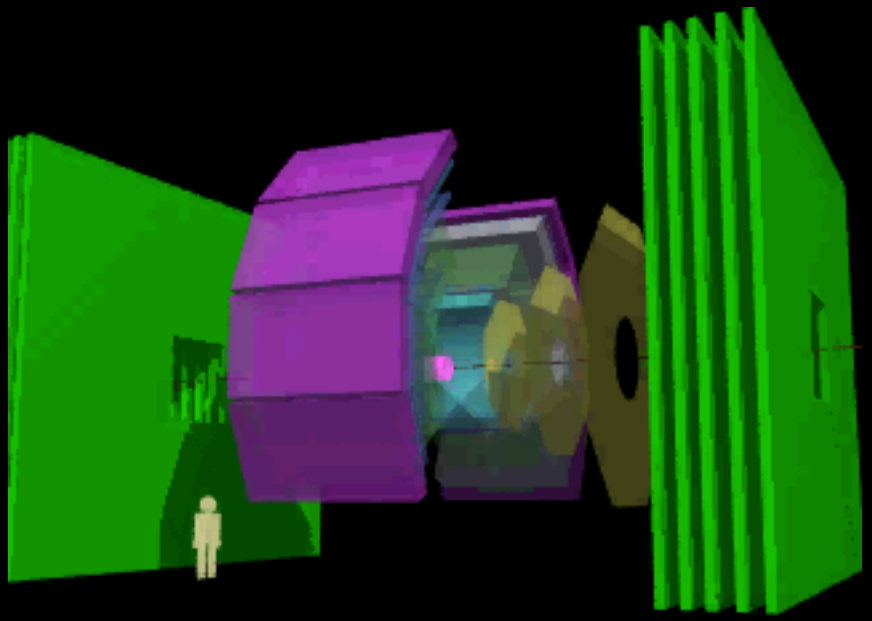
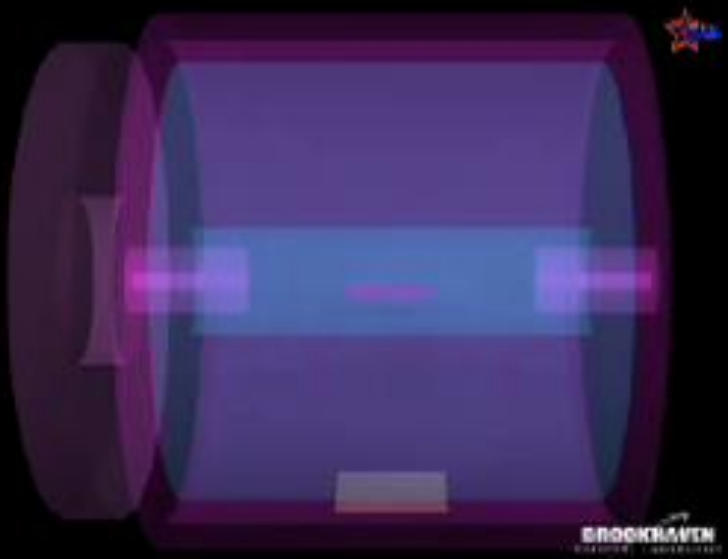
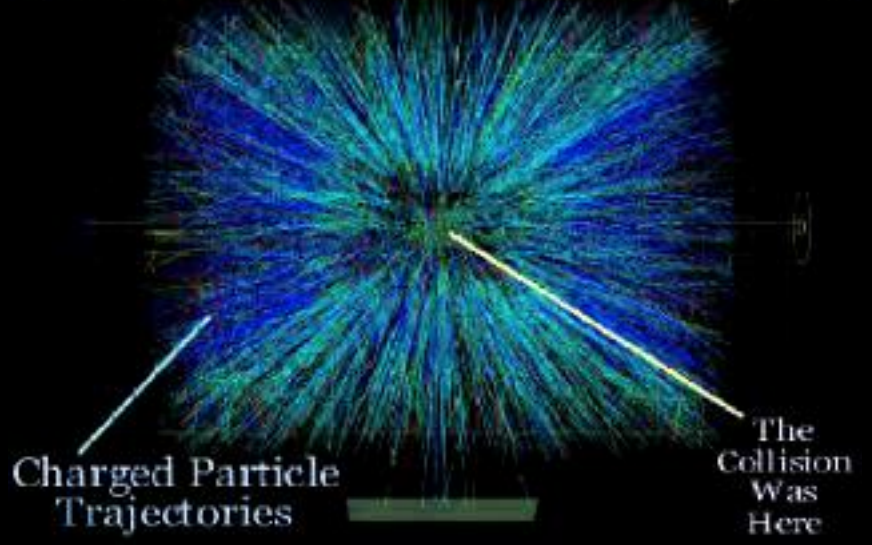
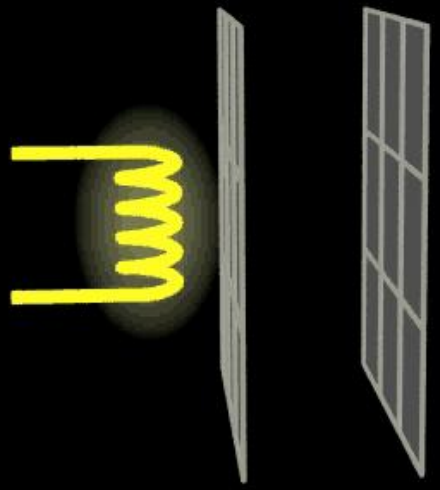






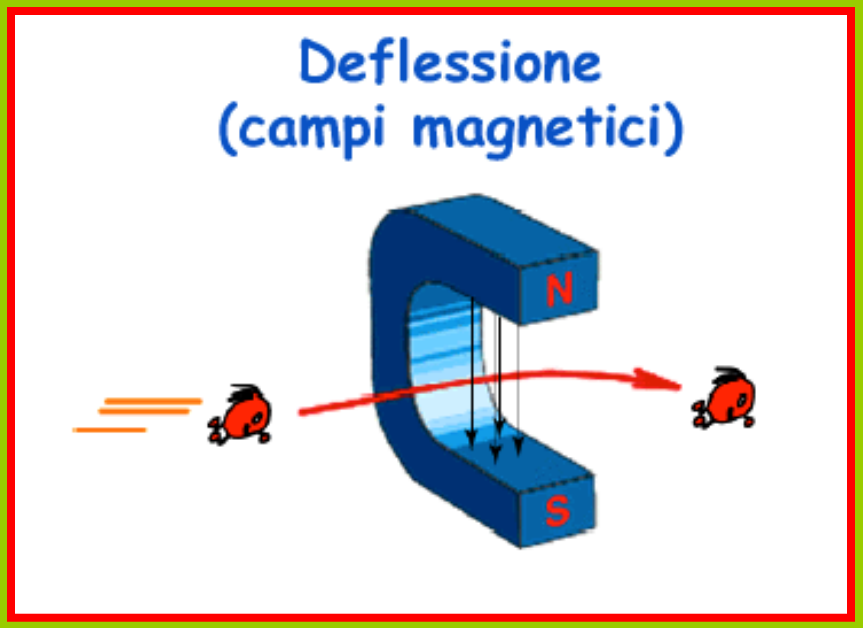
A Head-On Gold-Gold Collision as seen by STAR

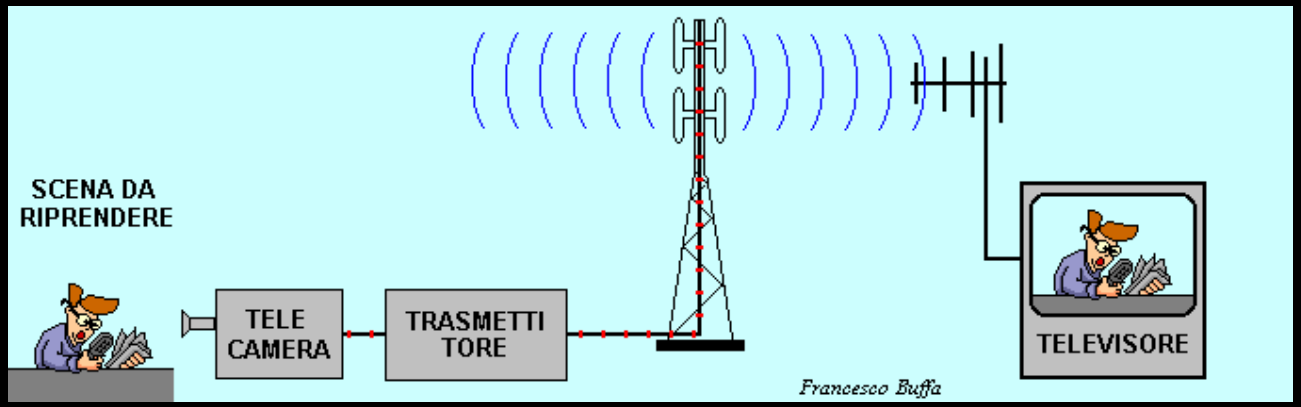




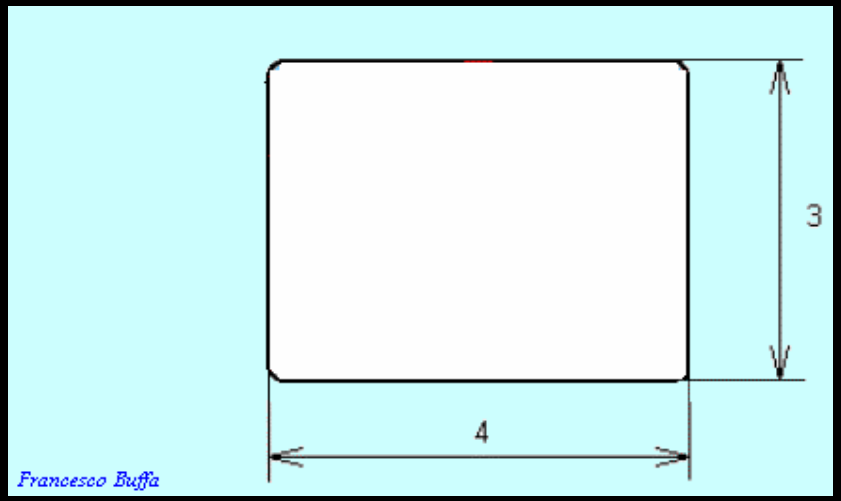
A unit of energy commonly used in particle physics is the **electron volt** (**eV**), which is defined as the energy an electron gains when is moved through a potential difference of 1 V.

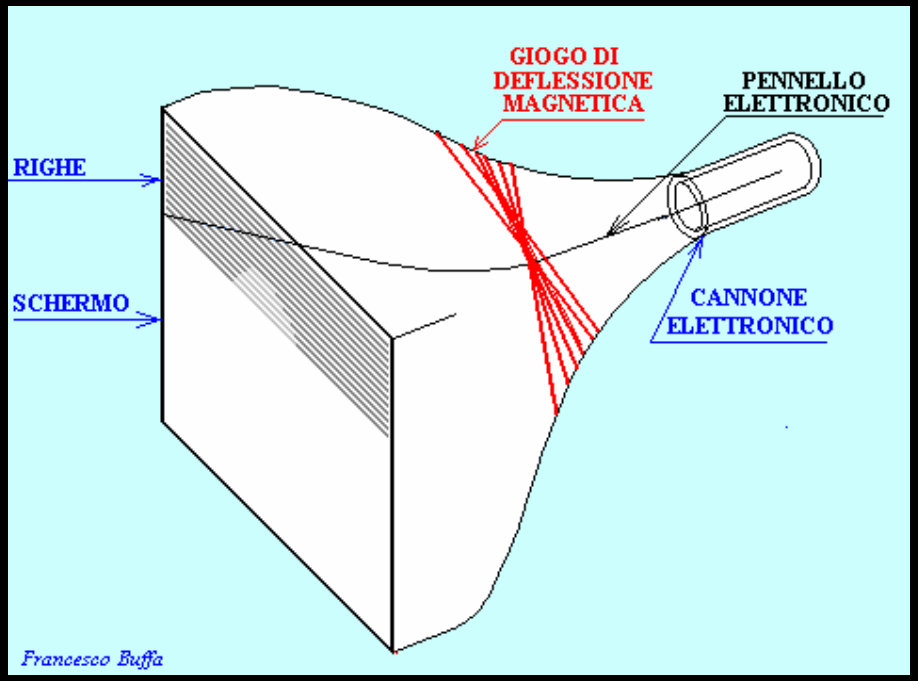
Magnetic Force



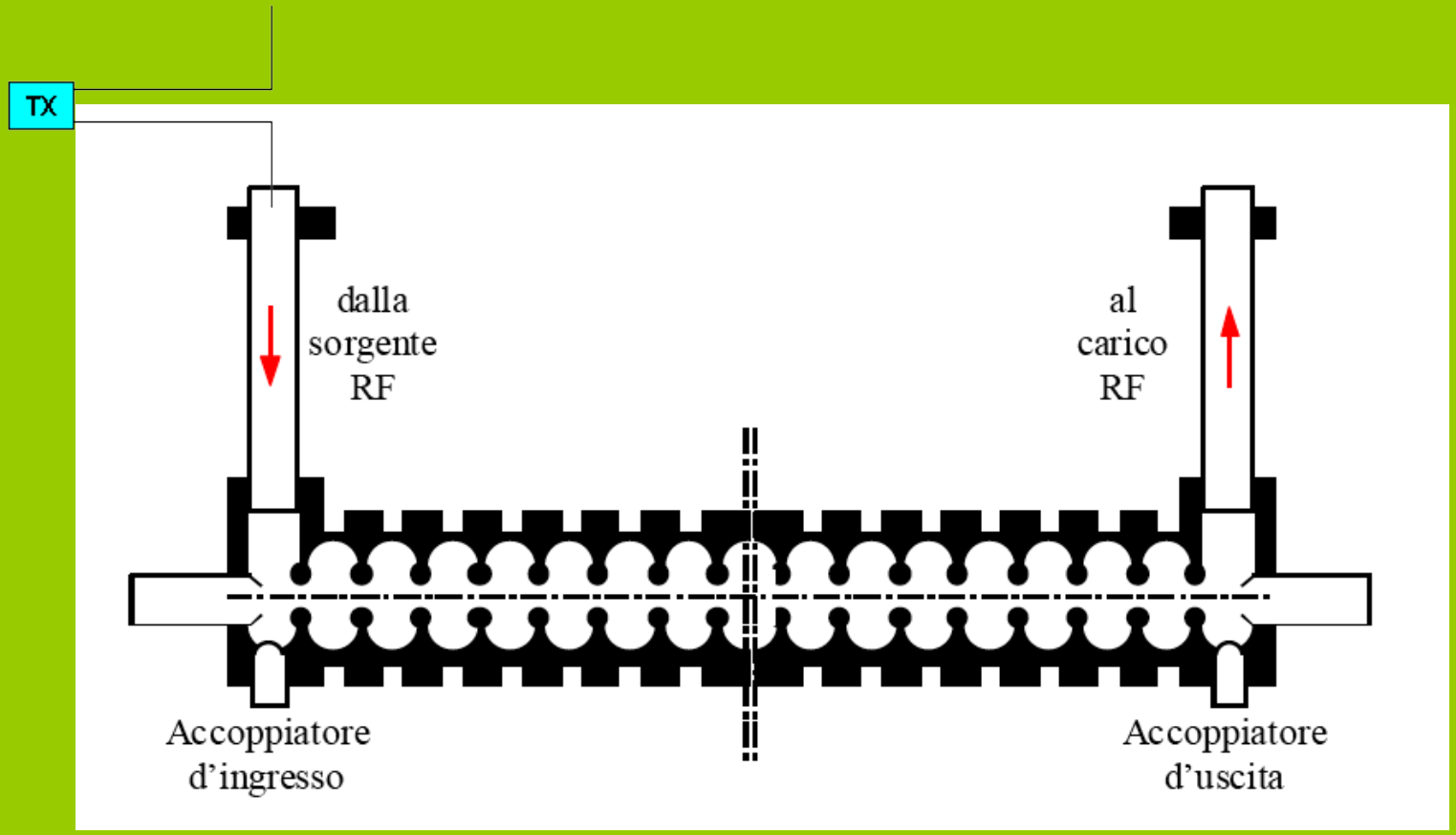

SCENA DA
RIPRENDERE
TELE
CAMERA
TRASMETTI
TORE
TELEVISORE
Francesco Buffa

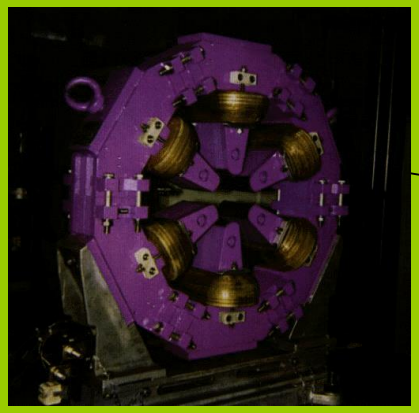
E = 10 keV


3
4
Francesco Buffa


GIOGO DI
DEFLESSIONE
MAGNETICA
PENNELLO
ELETTRONICO
RIGHE
SCHERMO
CANNONE
ELETTRONICO
Francesco Buffa

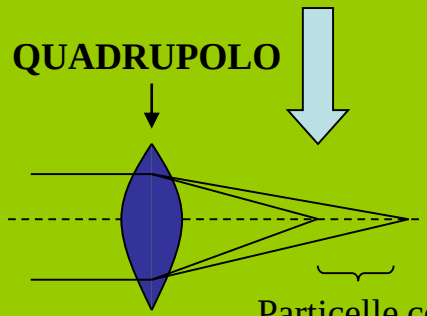
Electromagnetic Waveguide



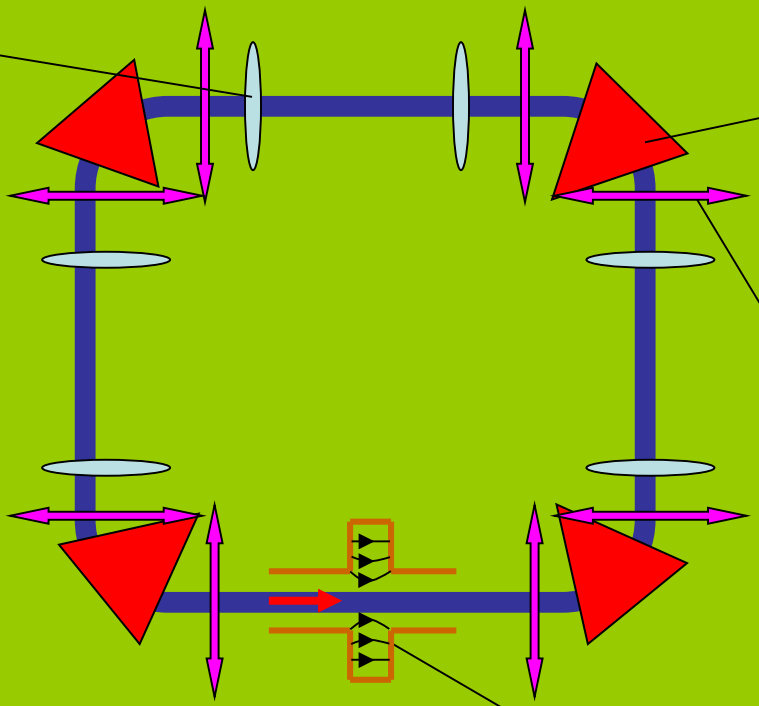


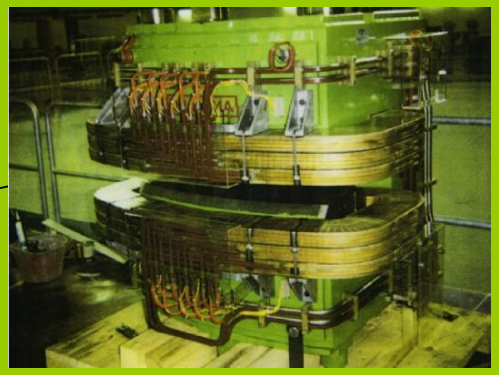
I sestupoli correggono l'effetto cromatico dei quadrupoli

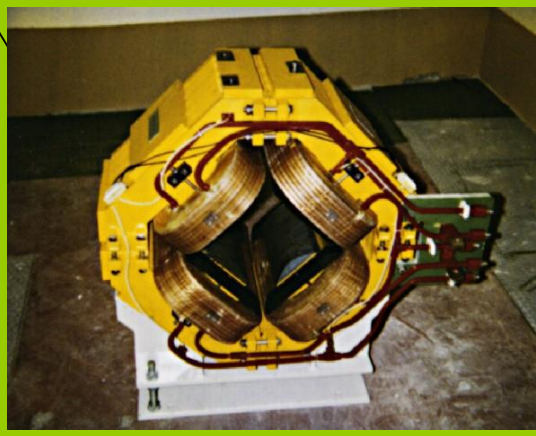
QUADRUPOLO

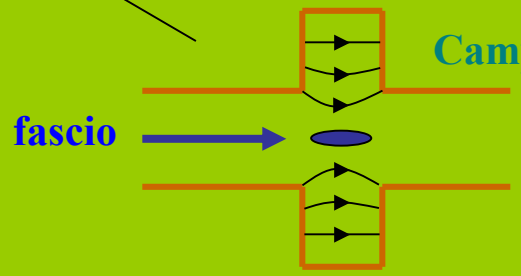


Particelle con diversa energia vengono focalizzate in modo diverso: aberrazione cromatica

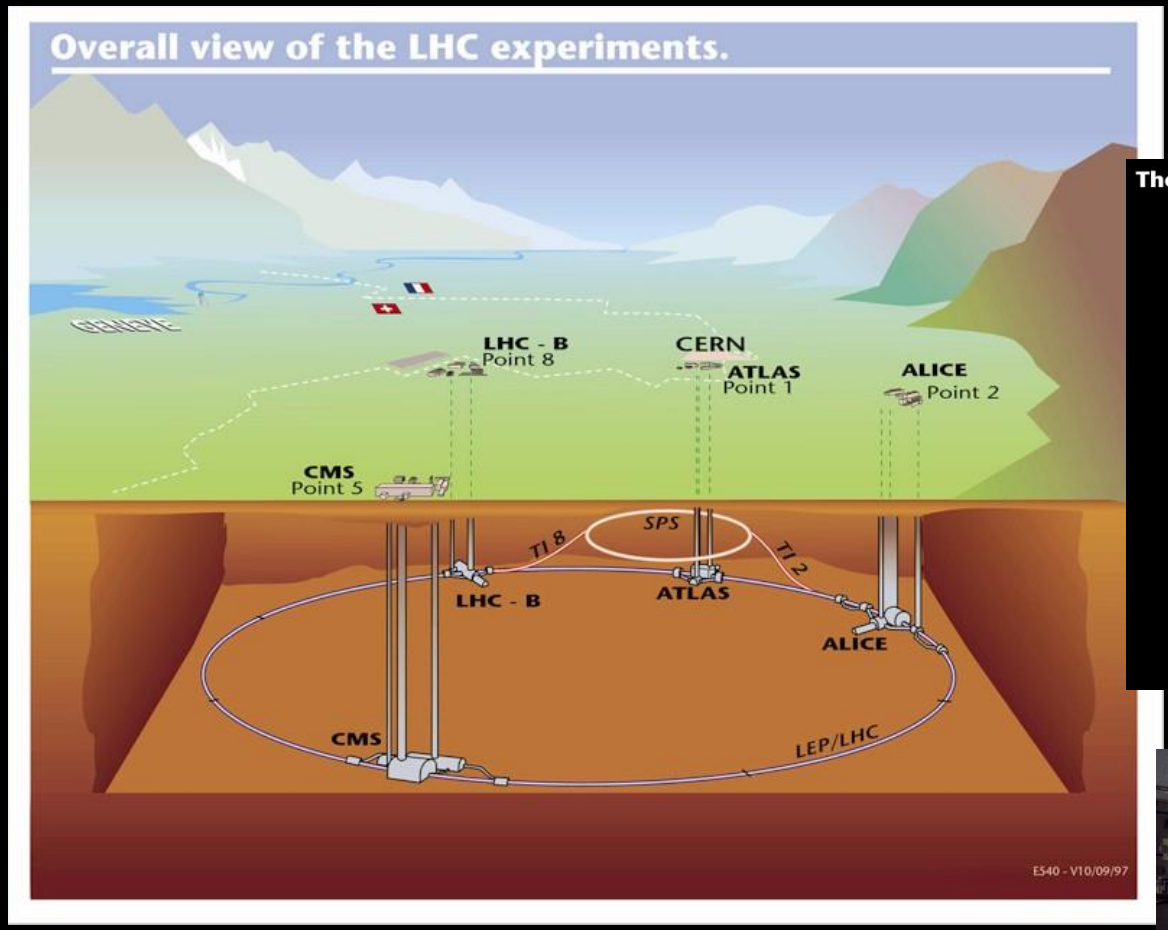


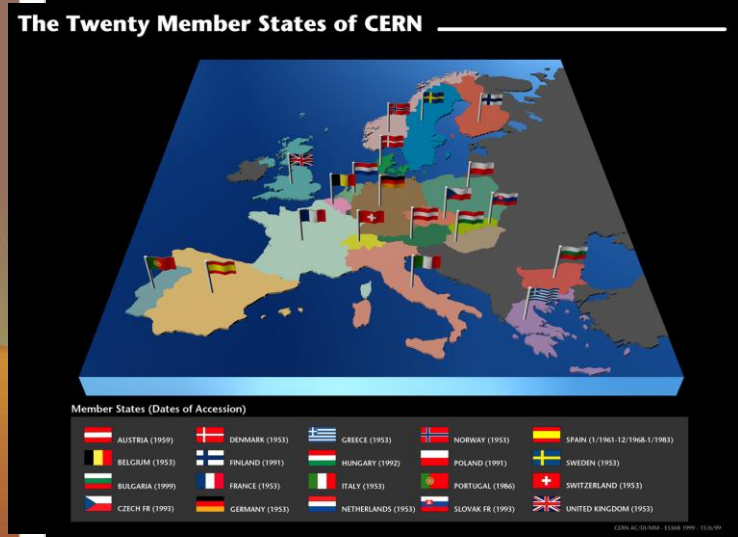


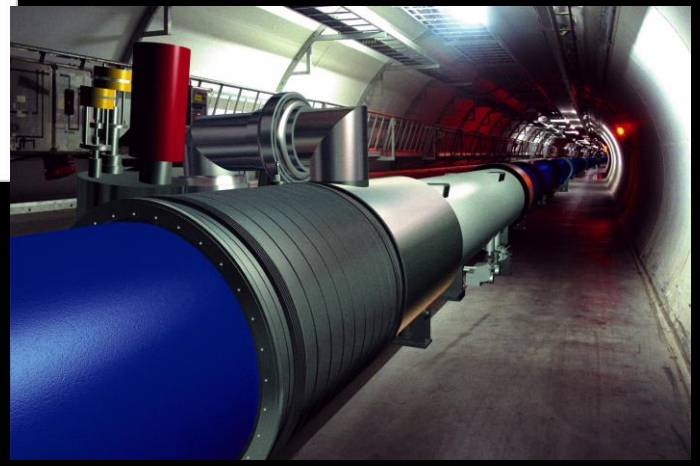




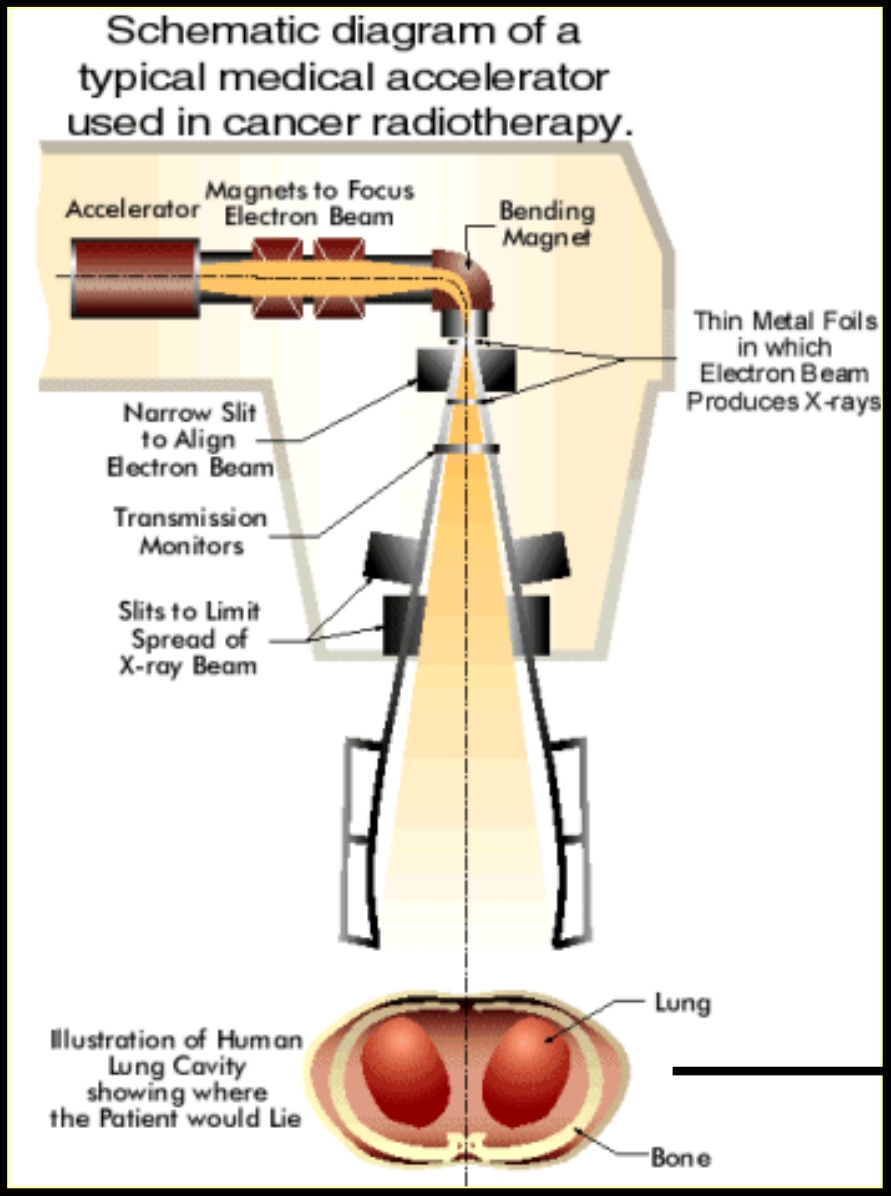
DIPOLI – determinano la traiettoria di riferimento
QUADRUPOLI – mantengono le oscillazioni di tutte le particelle intorno alla traiettoria di riferimento
SESTUPOLI – correggono l'effetto cromatico dei quadrupoli

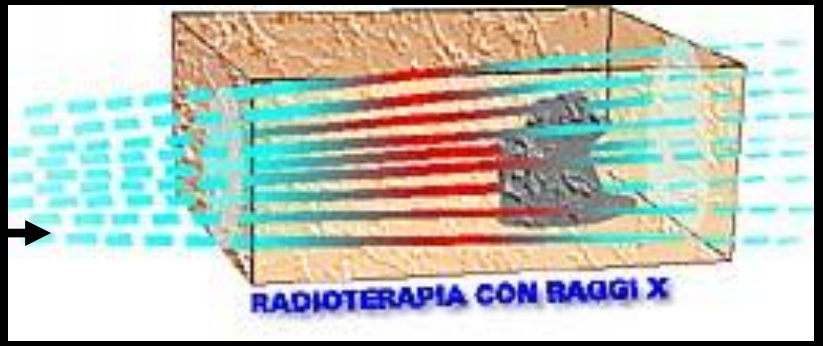

Overall view of the LHC experiments.
GENEVE
LHC - B
Point 8
CERN
ATLAS
Point 1
ALICE
Point 2
CMS
Point 5
TI 8
SPS
TI 2
LHC - B
ATLAS
ALICE
CMS
LEP/LHC
E540 - V10/09/97


The Twenty Member States of CERN
Member States (Dates of Accession)
AUSTRIA (1959)
BELGIUM (1953)
BULGARIA (1999)
CZECH FR (1993)
DENMARK (1953)
FINLAND (1991)
FRANCE (1953)
GERMANY (1953)
GREECE (1953)
HUNGARY (1992)
ITALY (1953)
NETHERLANDS (1953)
NORWAY (1953)
POLAND (1991)
PORTUGAL (1986)
SLOVAK FR (1993)
SPAIN (1/1961-12/1968-1/1983)
SWEDEN (1953)
SWITZERLAND (1953)
UNITED KINGDOM (1953)



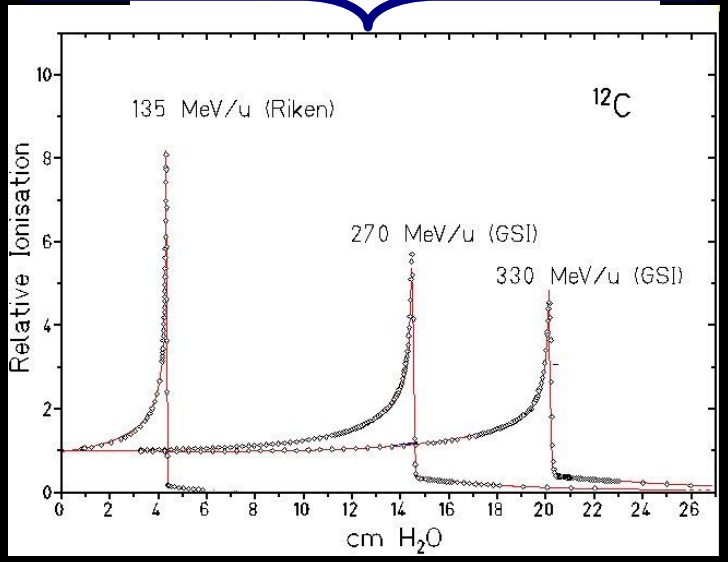
Medicine: Radiotherapy

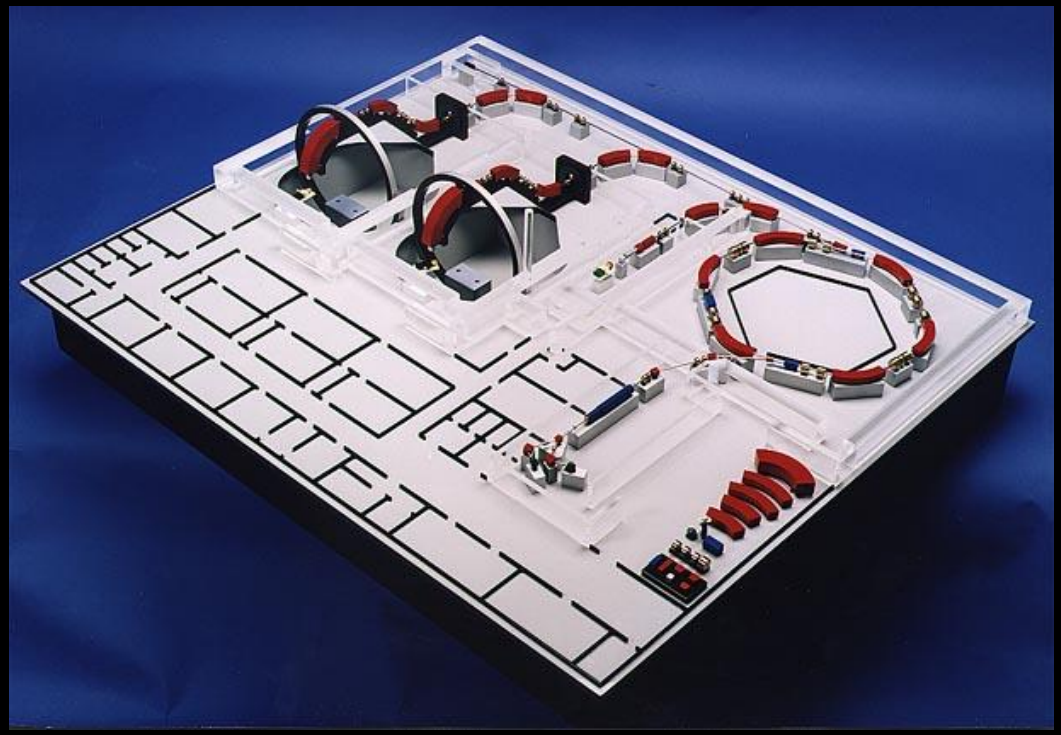




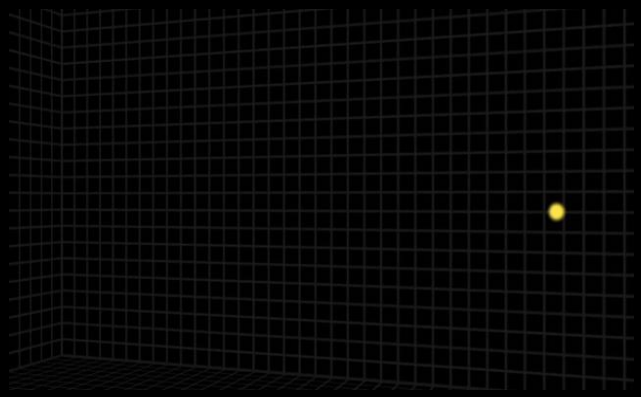
Medicine: Adrontherapy

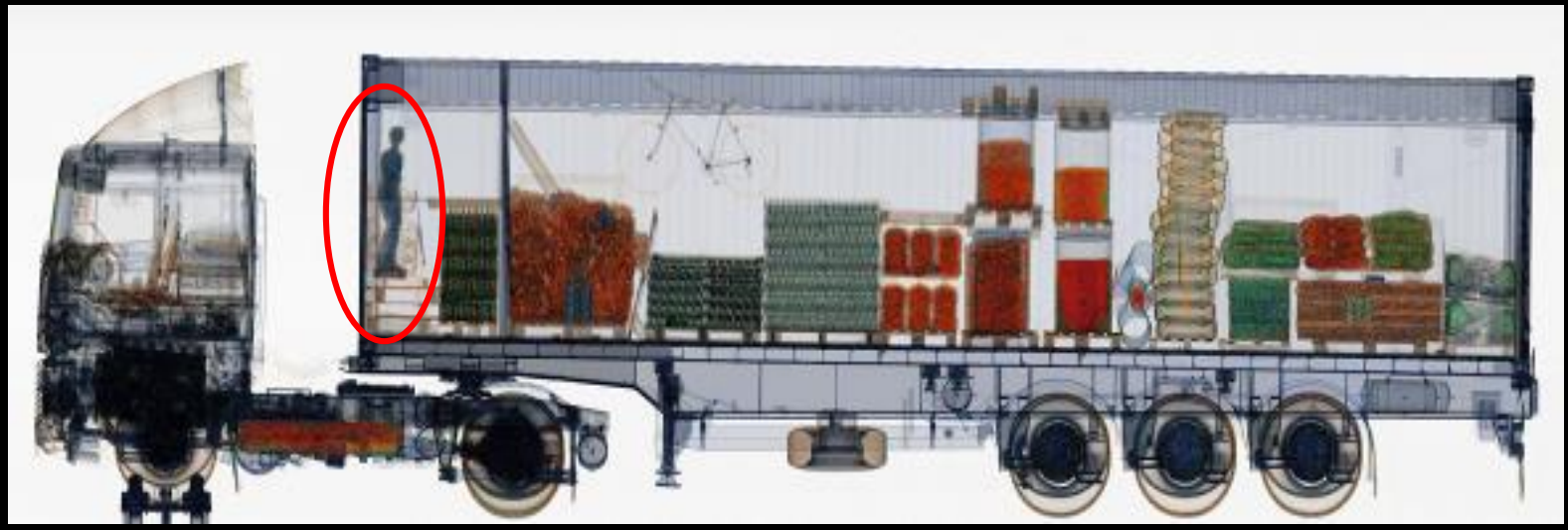
Terapia con protoni e ioni pesanti più efficace e più localizzata (risonanza di Bragg)





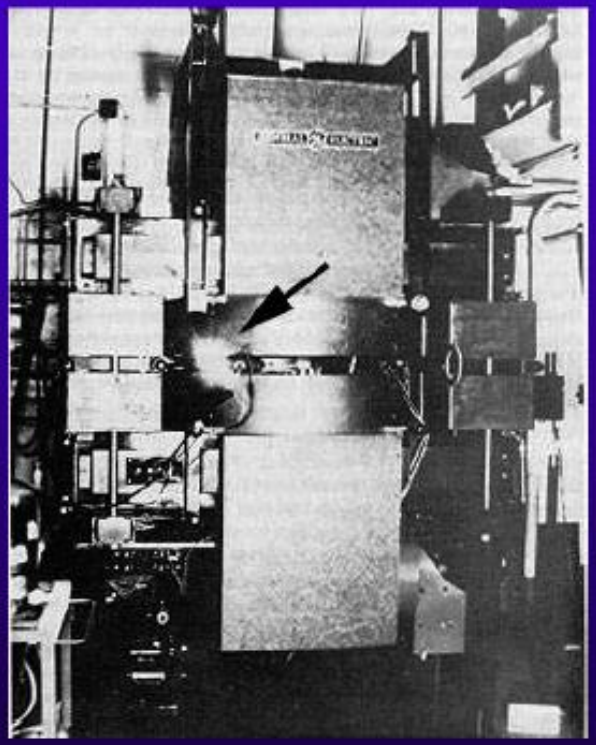
National Security





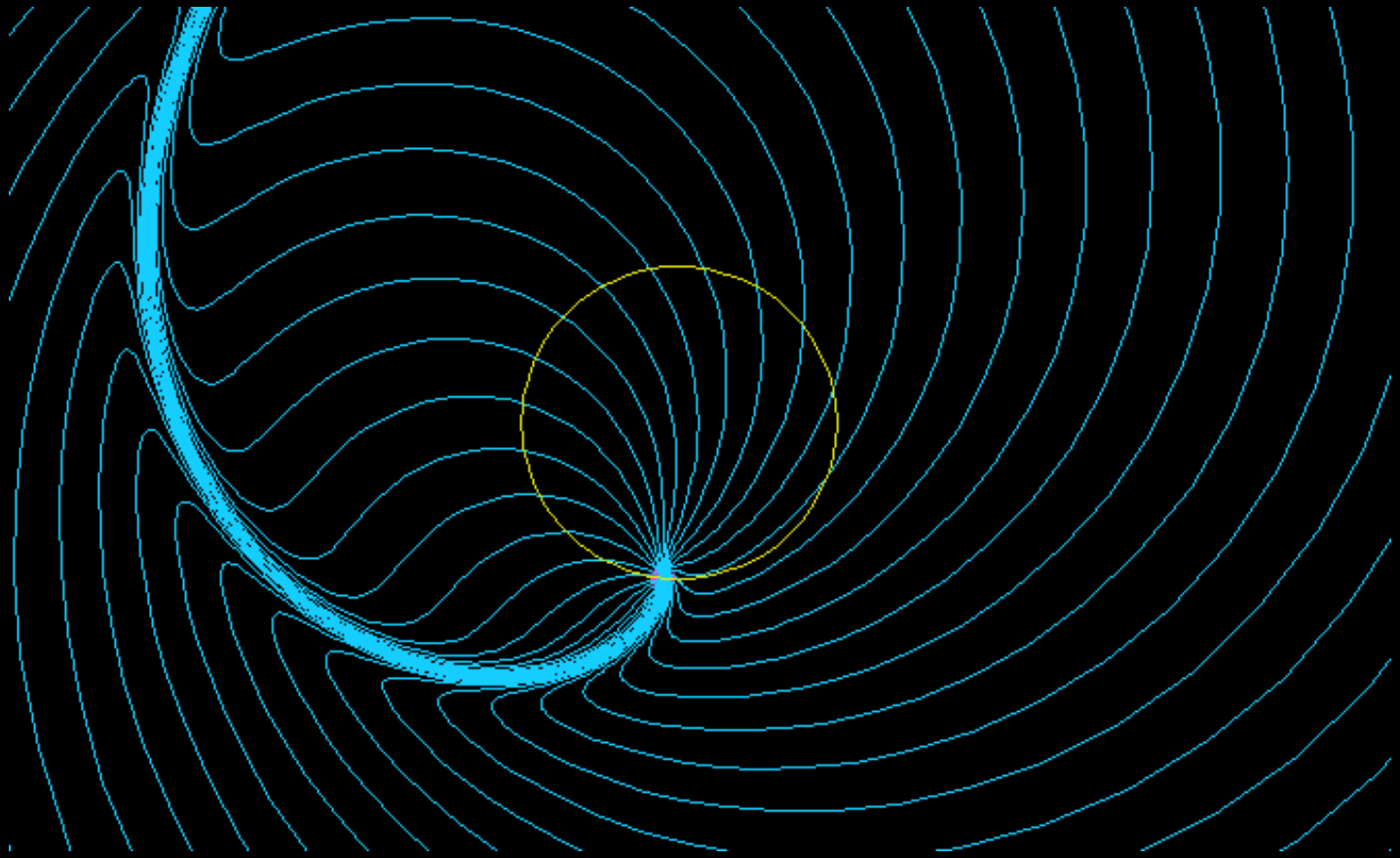
Synchrotron Light

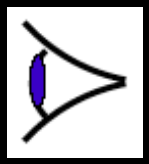
GE Synchrotron
New York State



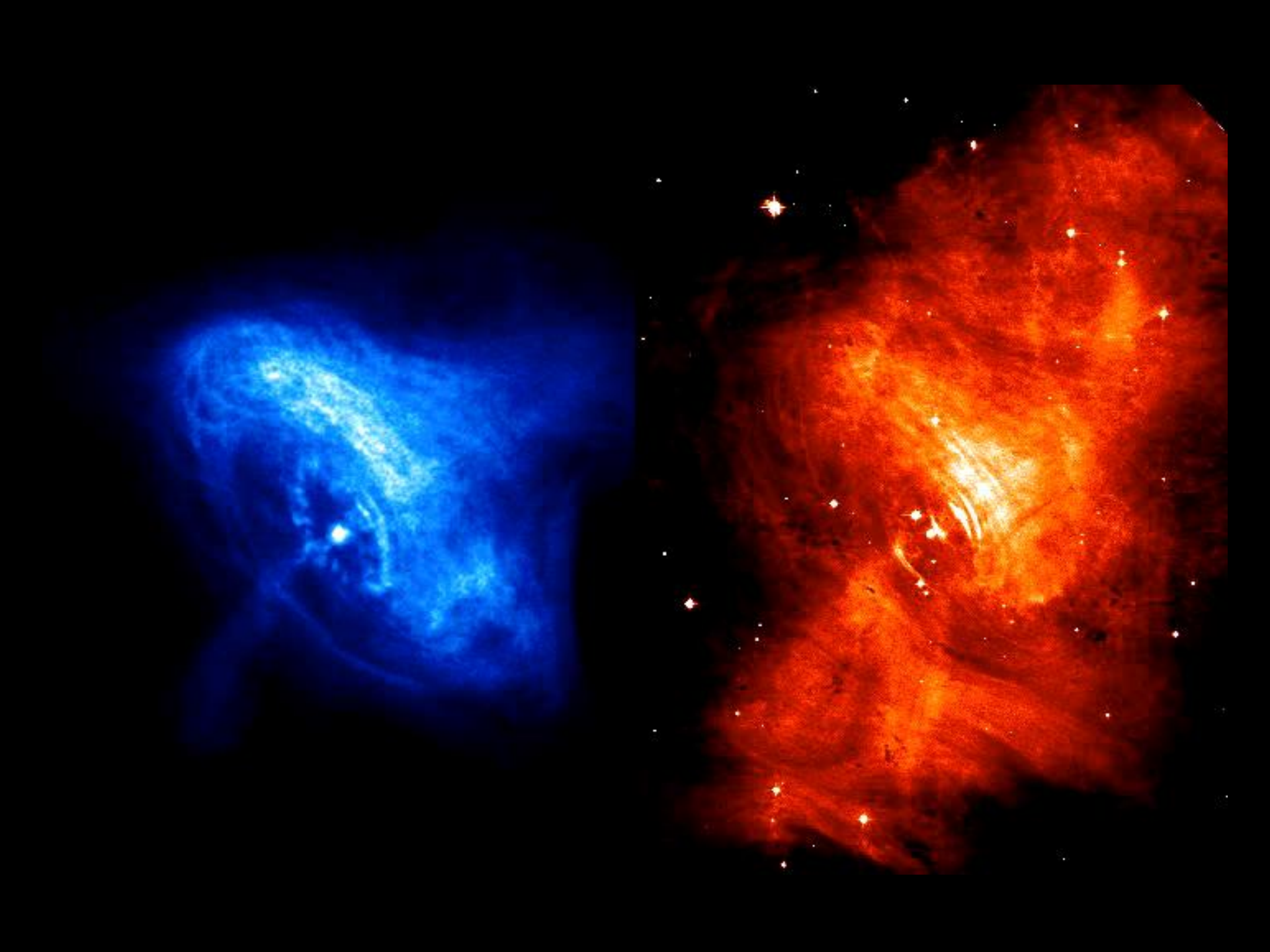
First light observed
1947

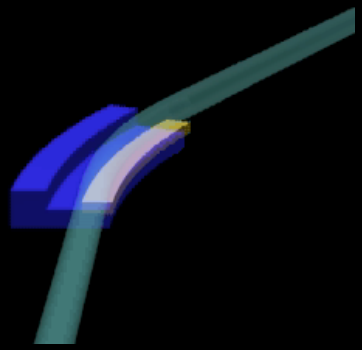
Charged particle in circular motion

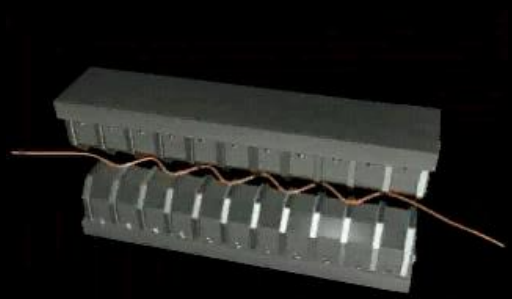


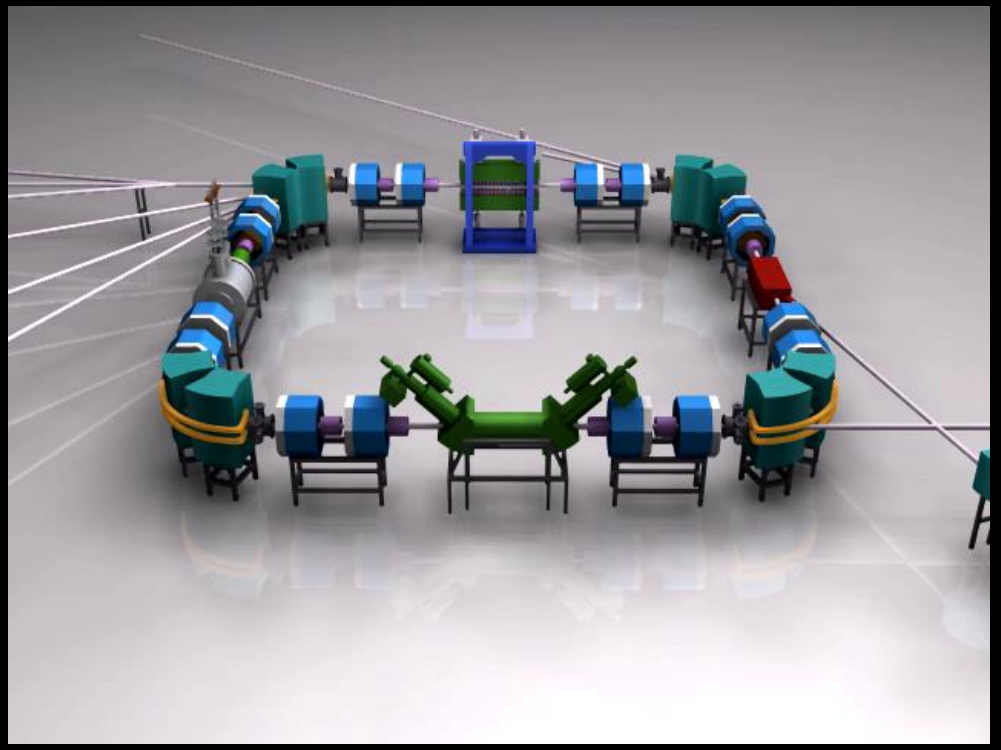


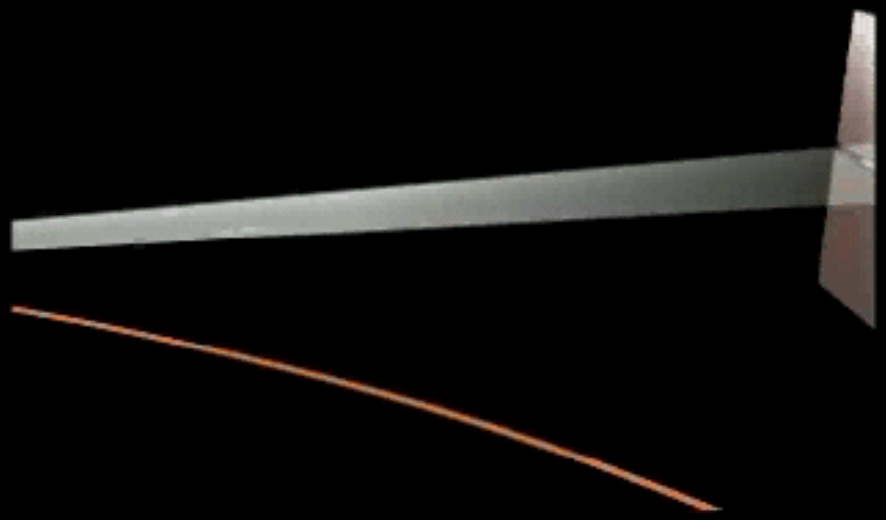
Radiation Simulator – T. Shintake, @ http://www-xfel.spring8.or.jp/Index.htm



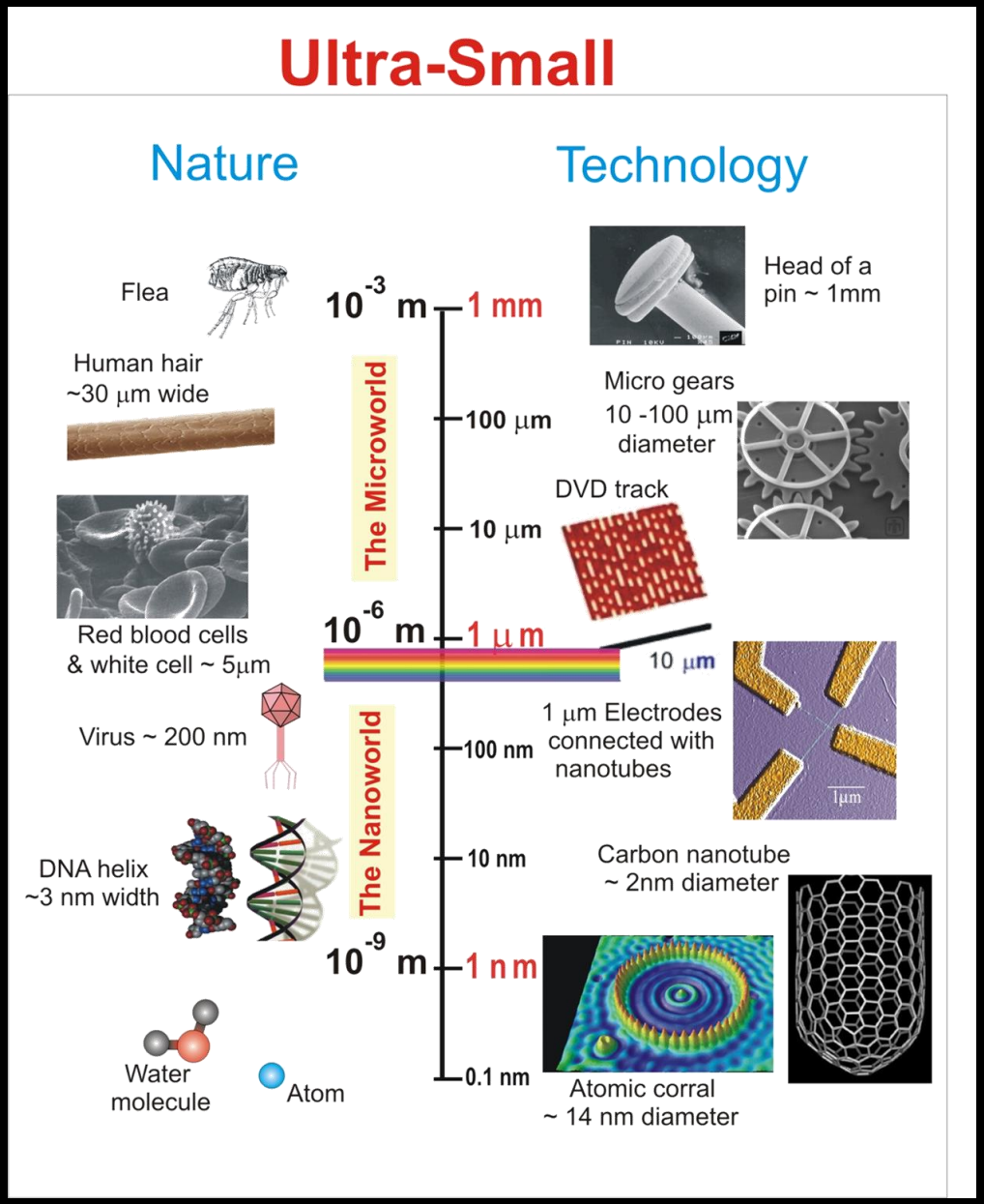


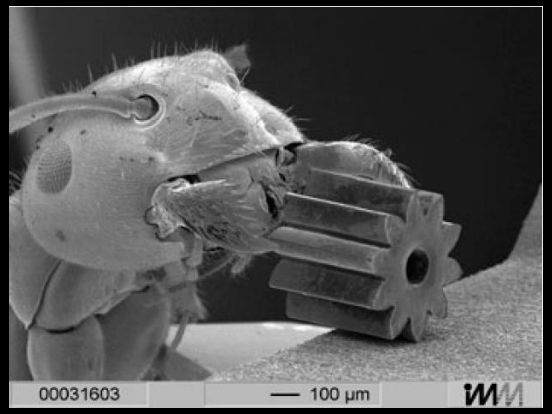


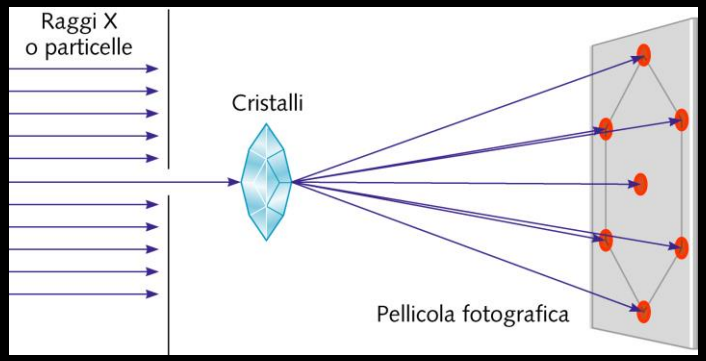


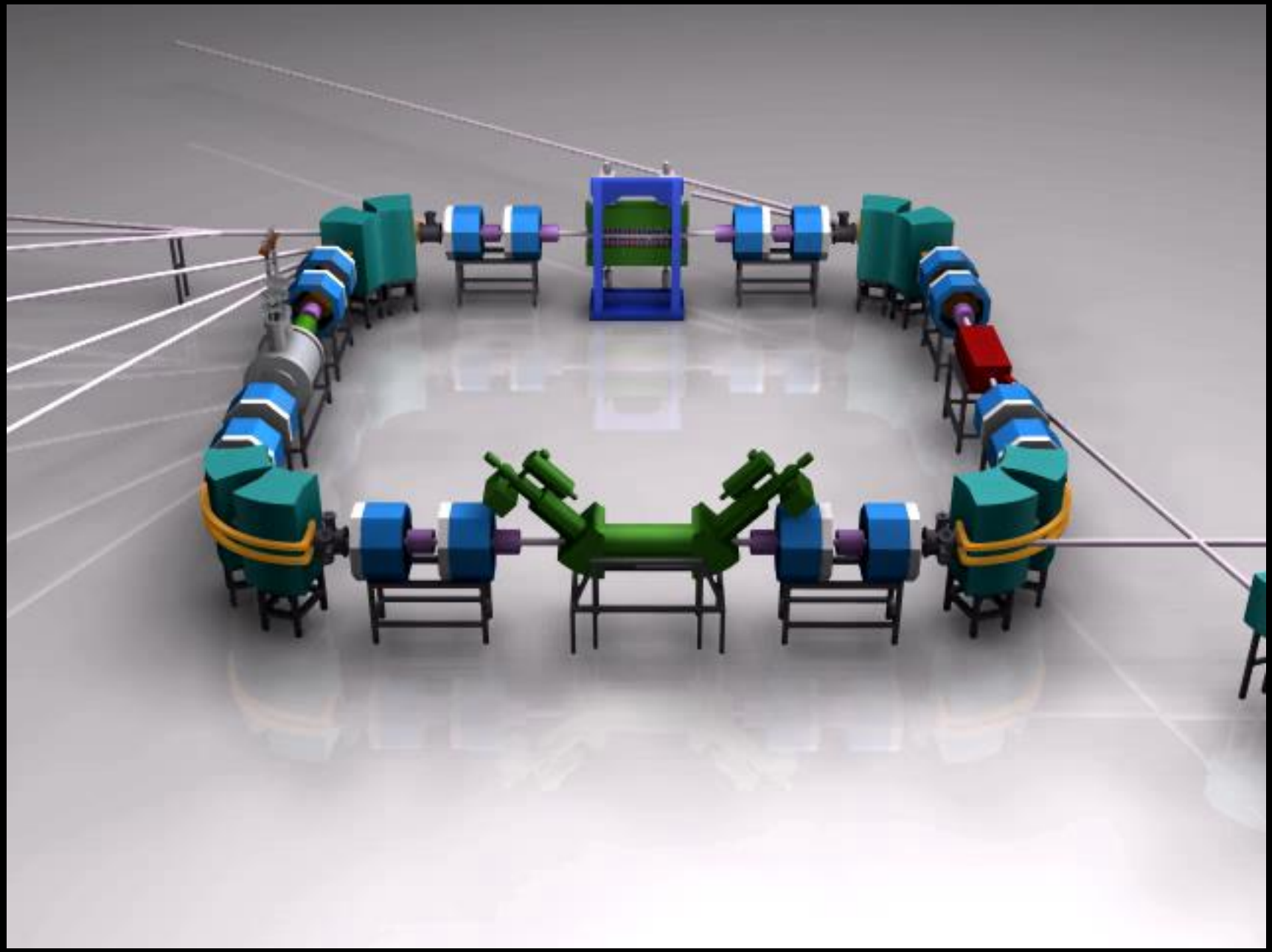


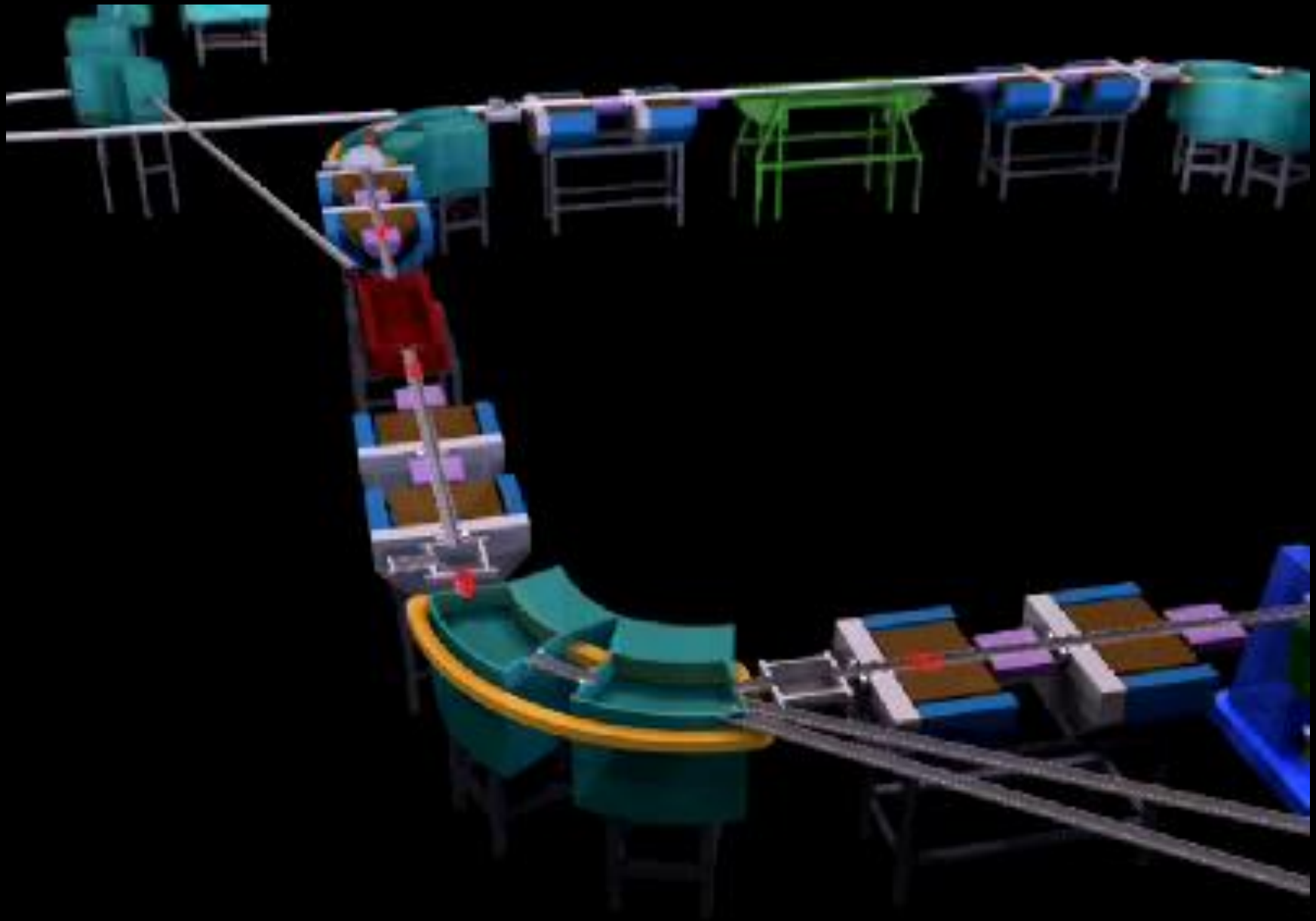
Ultra-Small


Nature
Technology
Flea
Human hair
~30 μm wide
Red blood cells
& white cell ~ 5μm
Virus ~ 200 nm
DNA helix
~3 nm width
Water
molecule
Atom
10-3 m
1 mm
100 μm
10 μm
10-6 m
1 μm
100 nm
10 nm
10-9 m
1 nm
0.1 nm
The Microworld
The Nanoworld
Head of a
pin ~ 1mm
Micro gears
10 -100 μm
diameter
DVD track
10 μm
1 μm Electrodes
connected with
nanotubes
1μm
Carbon nanotube
~ 2nm diameter
Atomic corral
~ 14 nm diameter


00031603
100 μm


Raggi X
o particelle
Cristalli
Pellicola fotografica

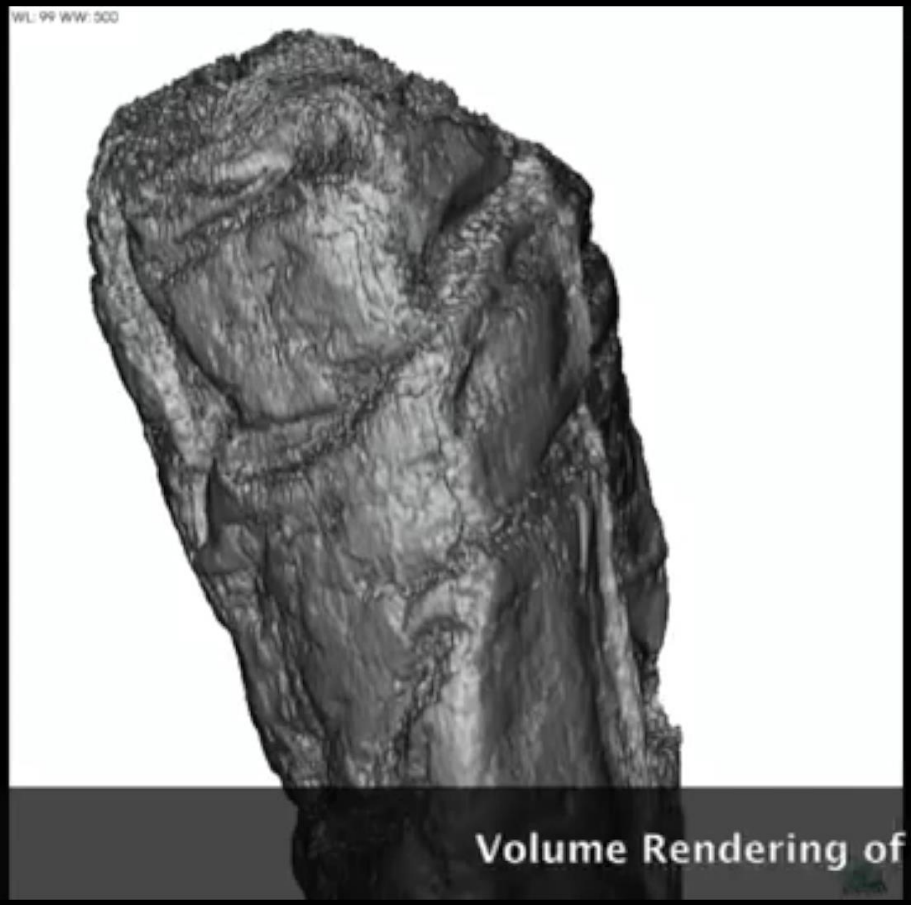




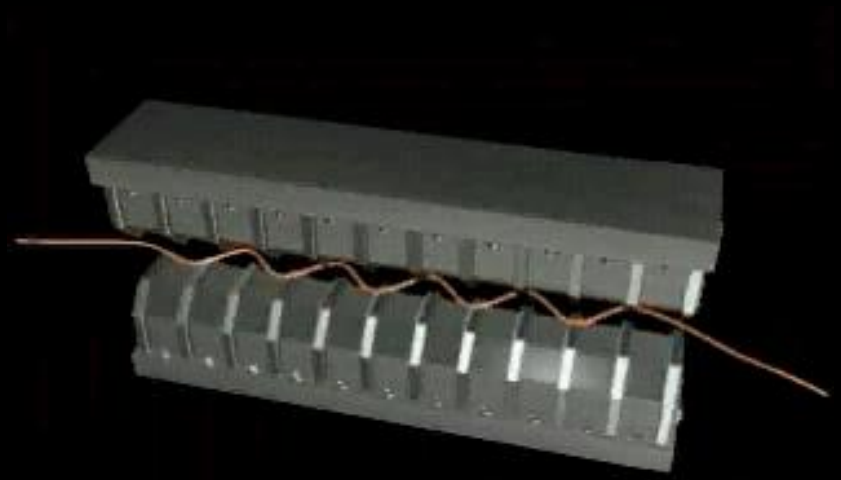
Scrolls Villa– Ercolano – 79 d. C.

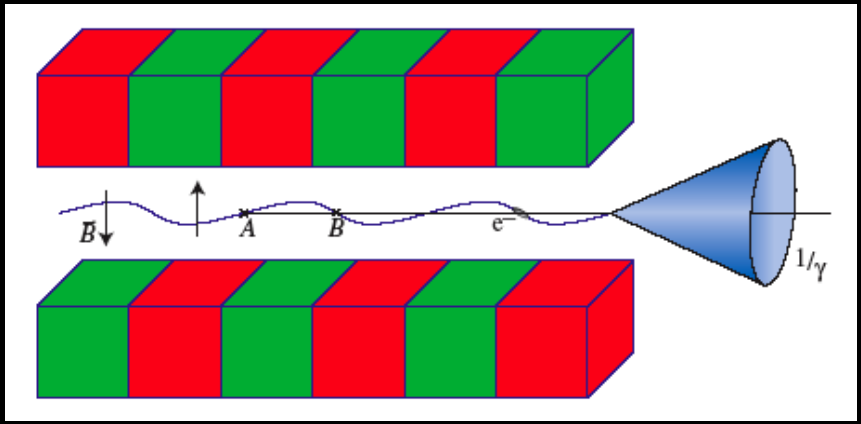
Tomografia a raggi X in contrasto di fase

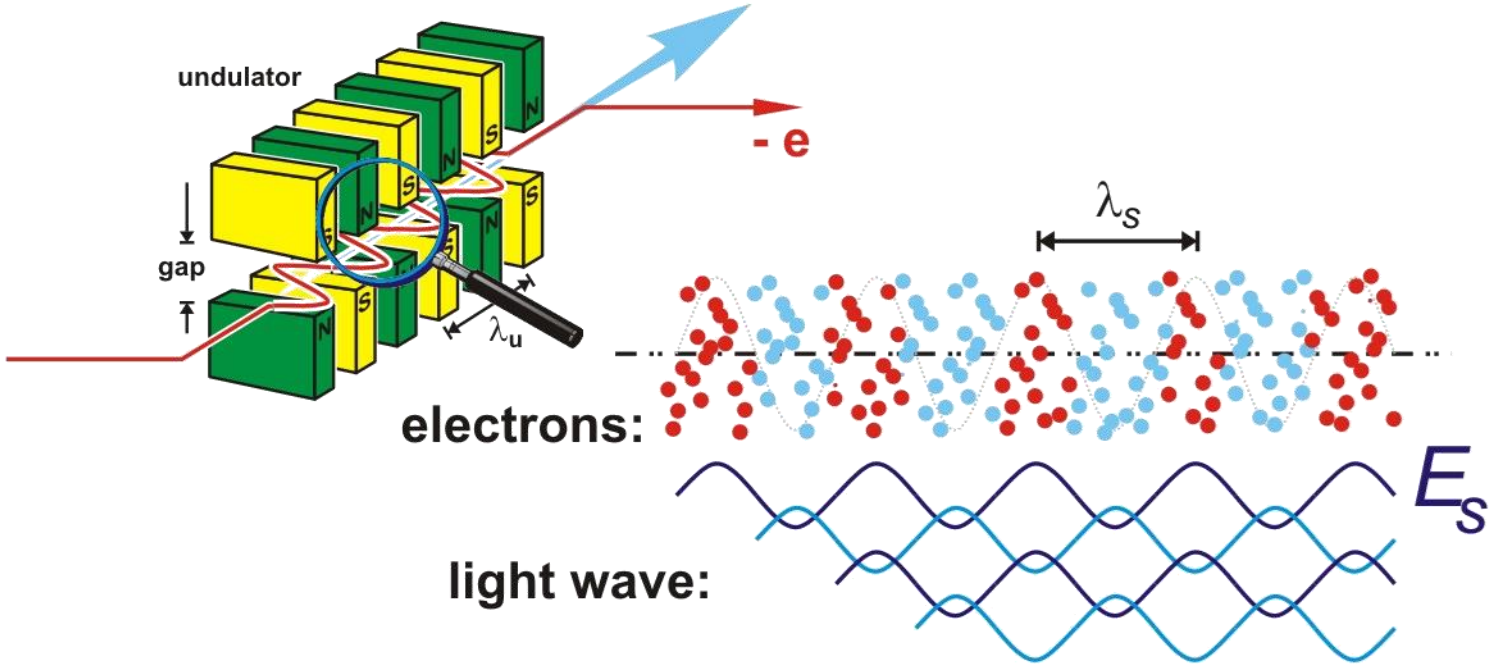
Vito Mocella del CNR-IMM di Napoli in collaborazione con E.Brun e C. Ferrero dell'ESRF



Free Electron Laser





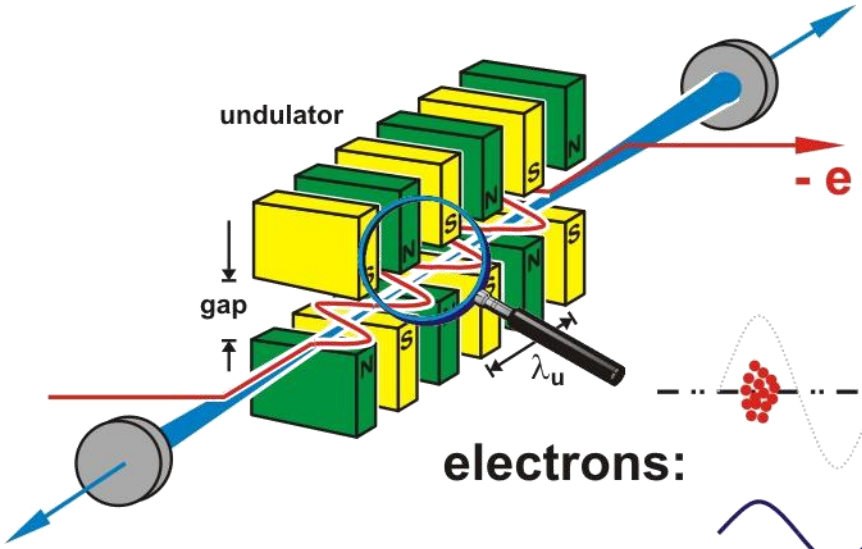


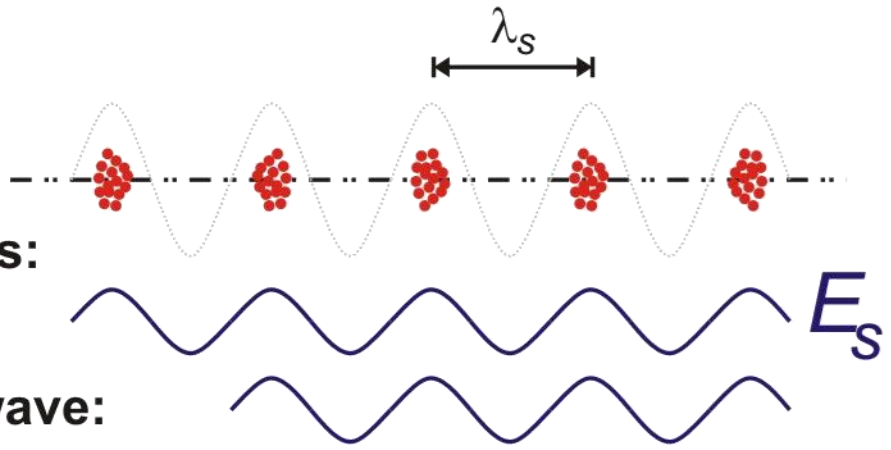
Radiated Power :

$P \propto n_e$ (number of electrons)

destructive interference

⟶ **shotnoise radiation**



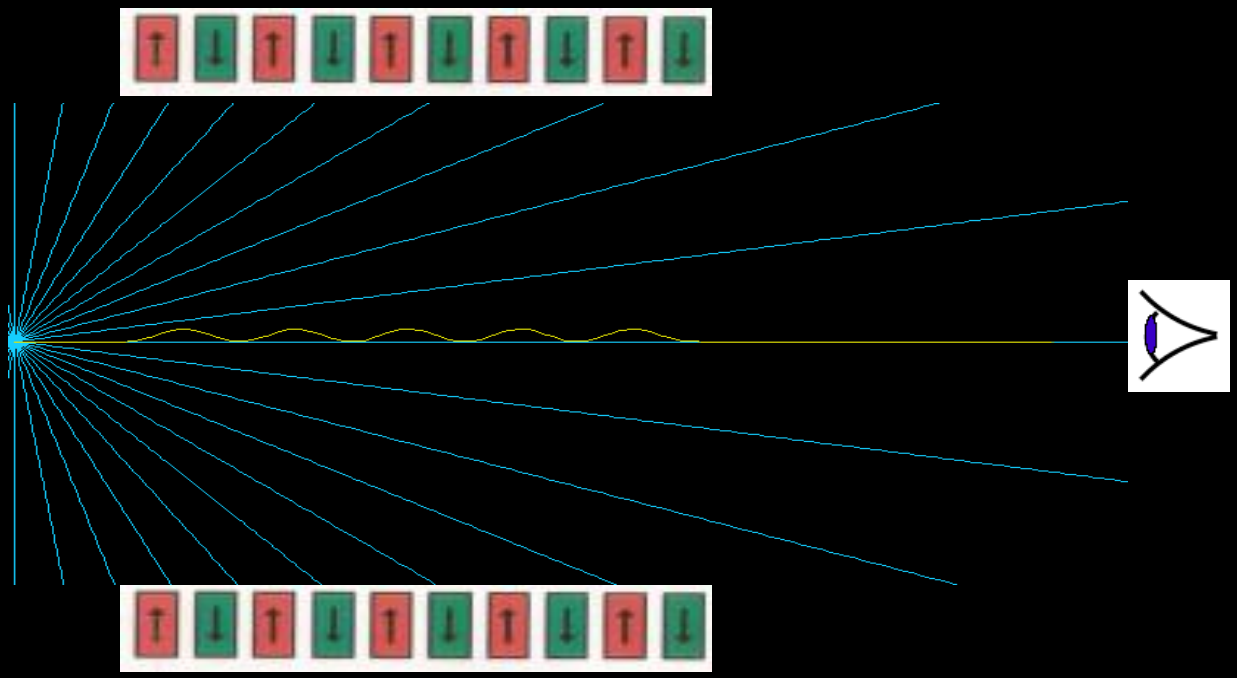


Radiated Power :

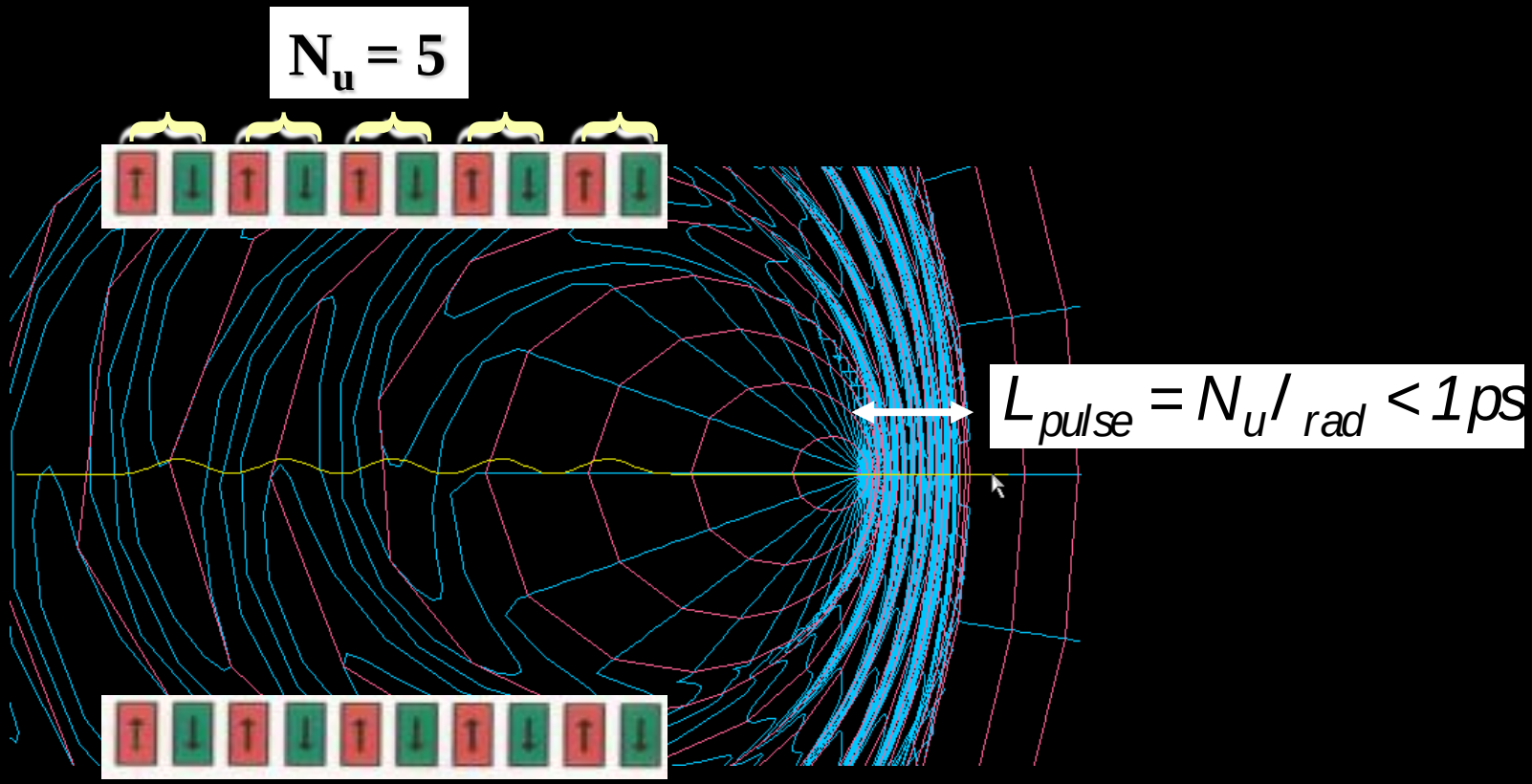
$$P \propto n_e^2 \begin{pmatrix} \text{number of electrons} \\ n_e \sim 10^6 - 10^9 \end{pmatrix}$$

constructive interference

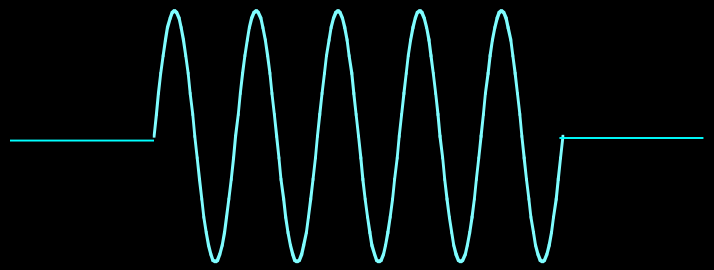
⟶ **enhanced emission**

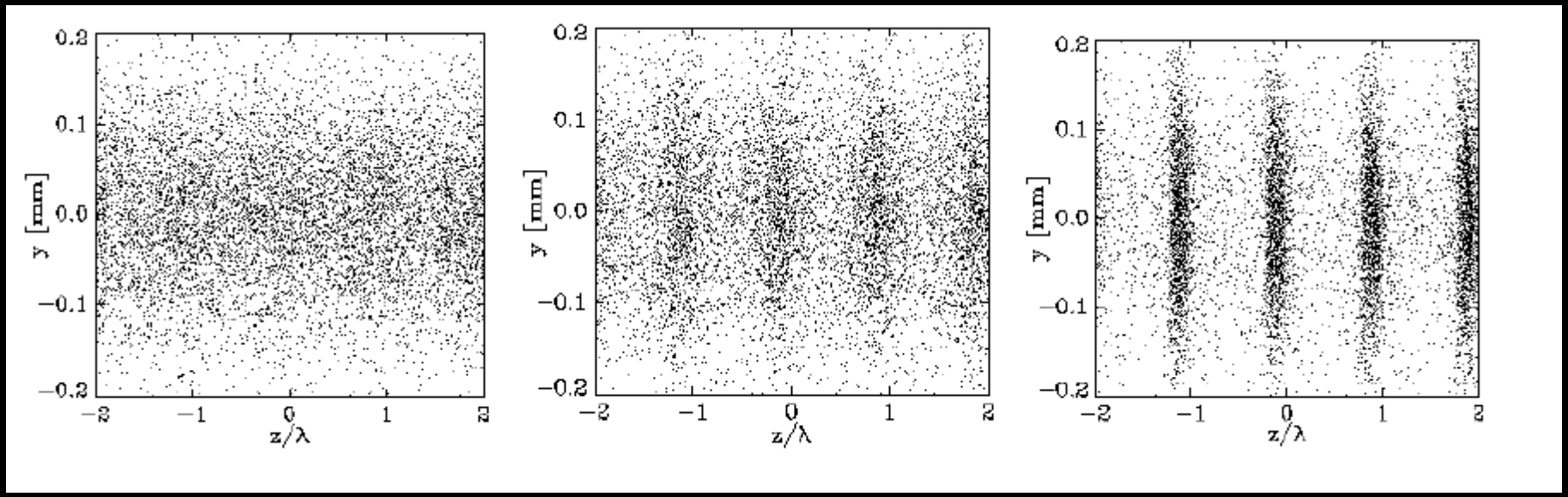


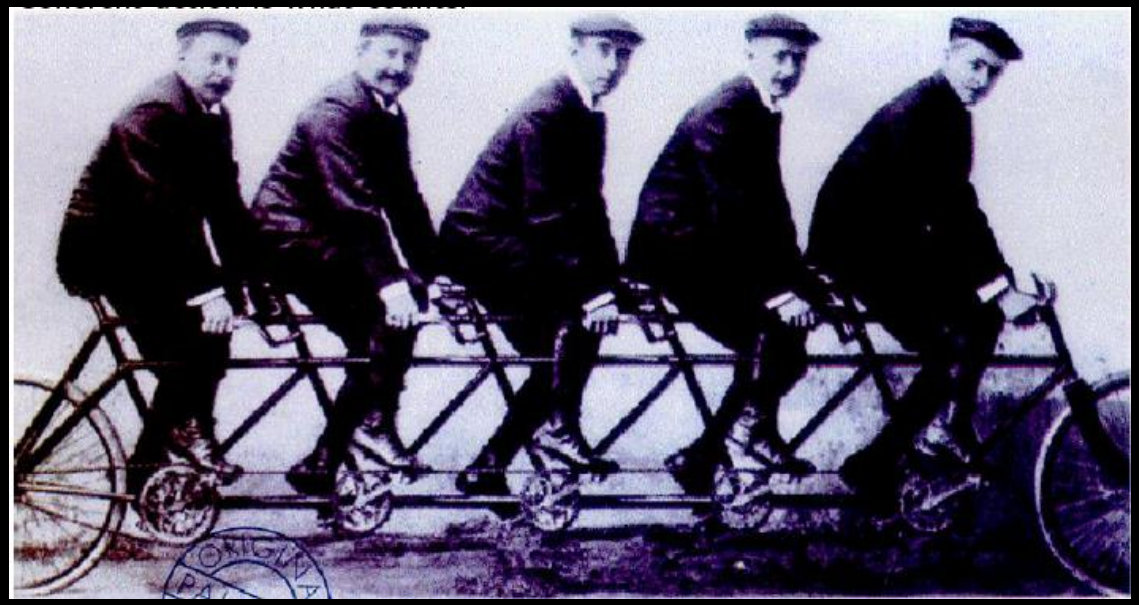
Radiation Simulator – T. Shintake, @ http://www-xfel.spring8.or.jp/Index.htm



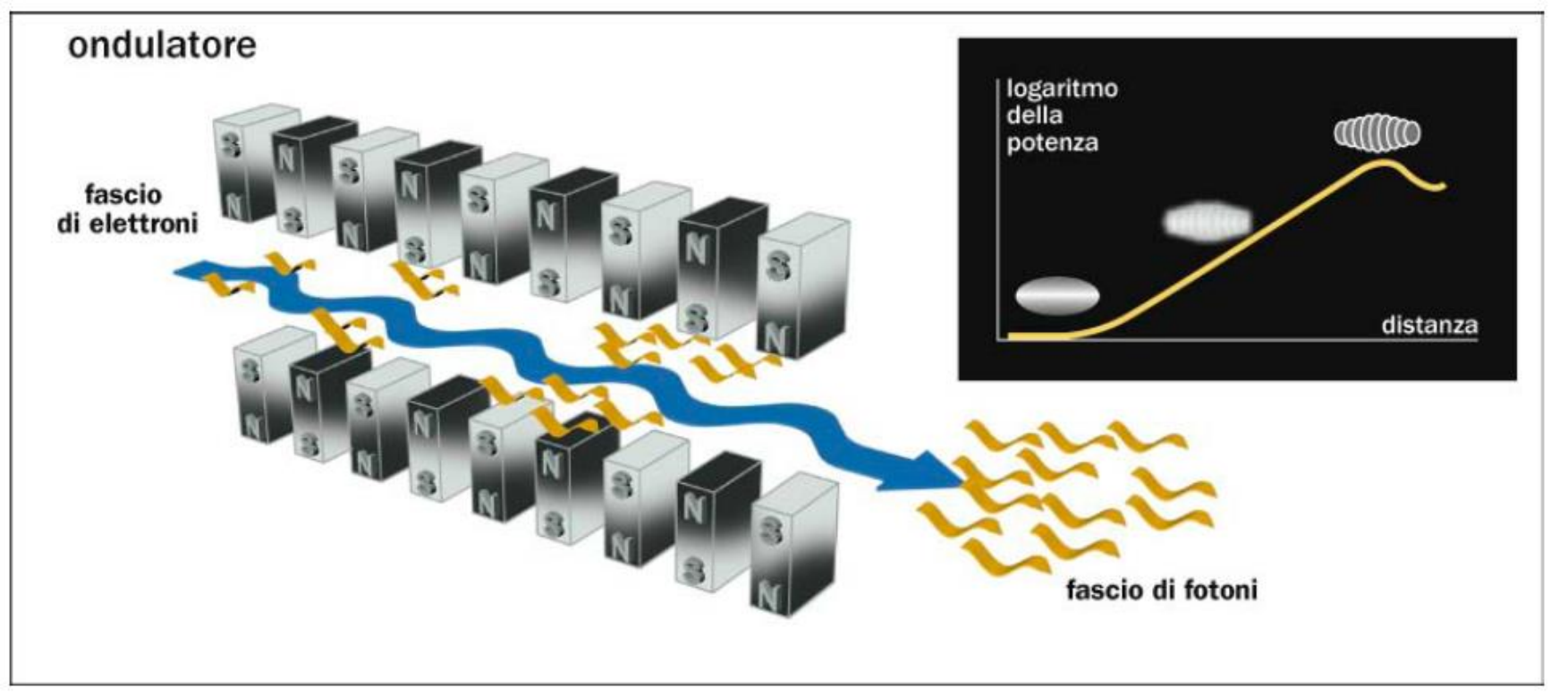
$$\lambda_{rad} \mu \frac{\lambda_u}{2\gamma^2}$$




0.2
0.1
0.0
−0.1
−0.2
y [mm]
−2
−1
0
1
2
z/λ



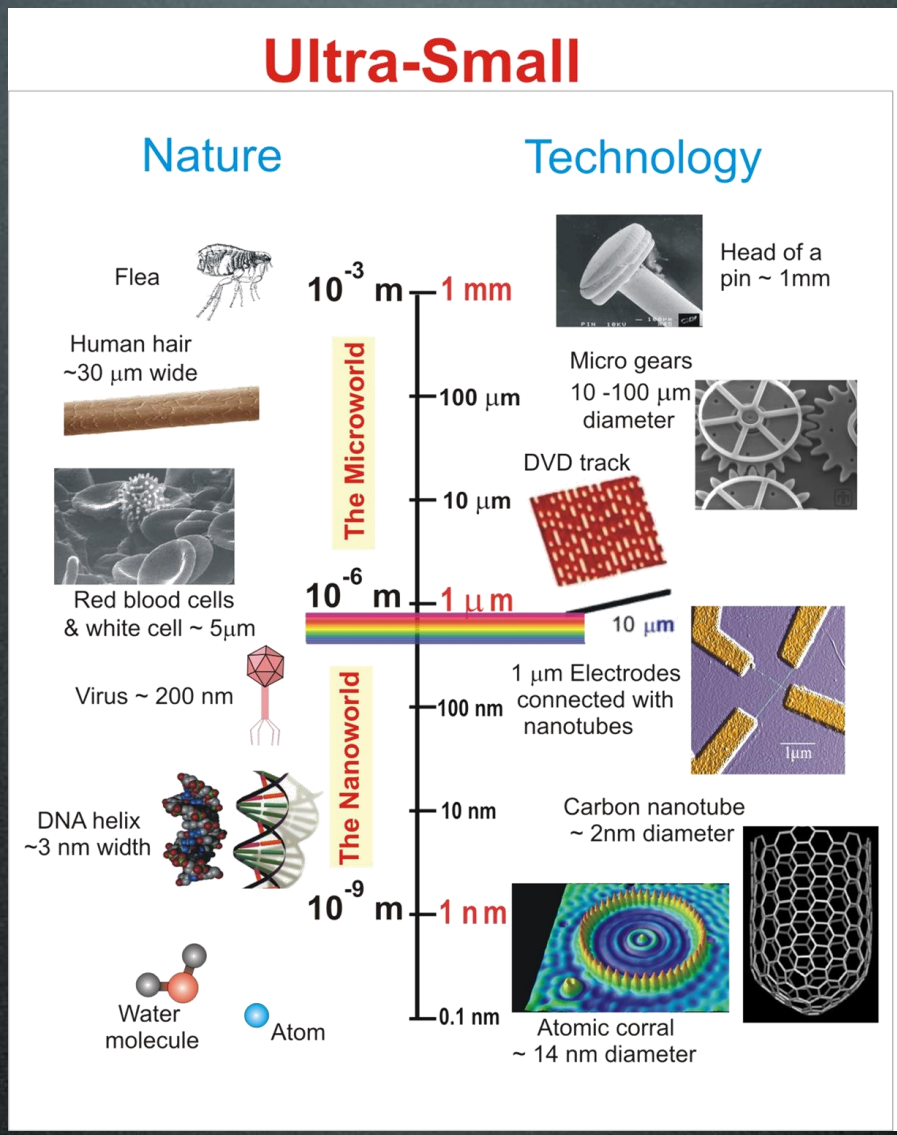
Free Electron Laser
Self-Amplified-Spontaneous-Emission
(Tunable- up to X-ray)



$$\lambda_r = \frac{\lambda_u}{2\gamma^2}(1 + a_u{}^2 + \gamma^2\theta^2)$$

FEL Applications

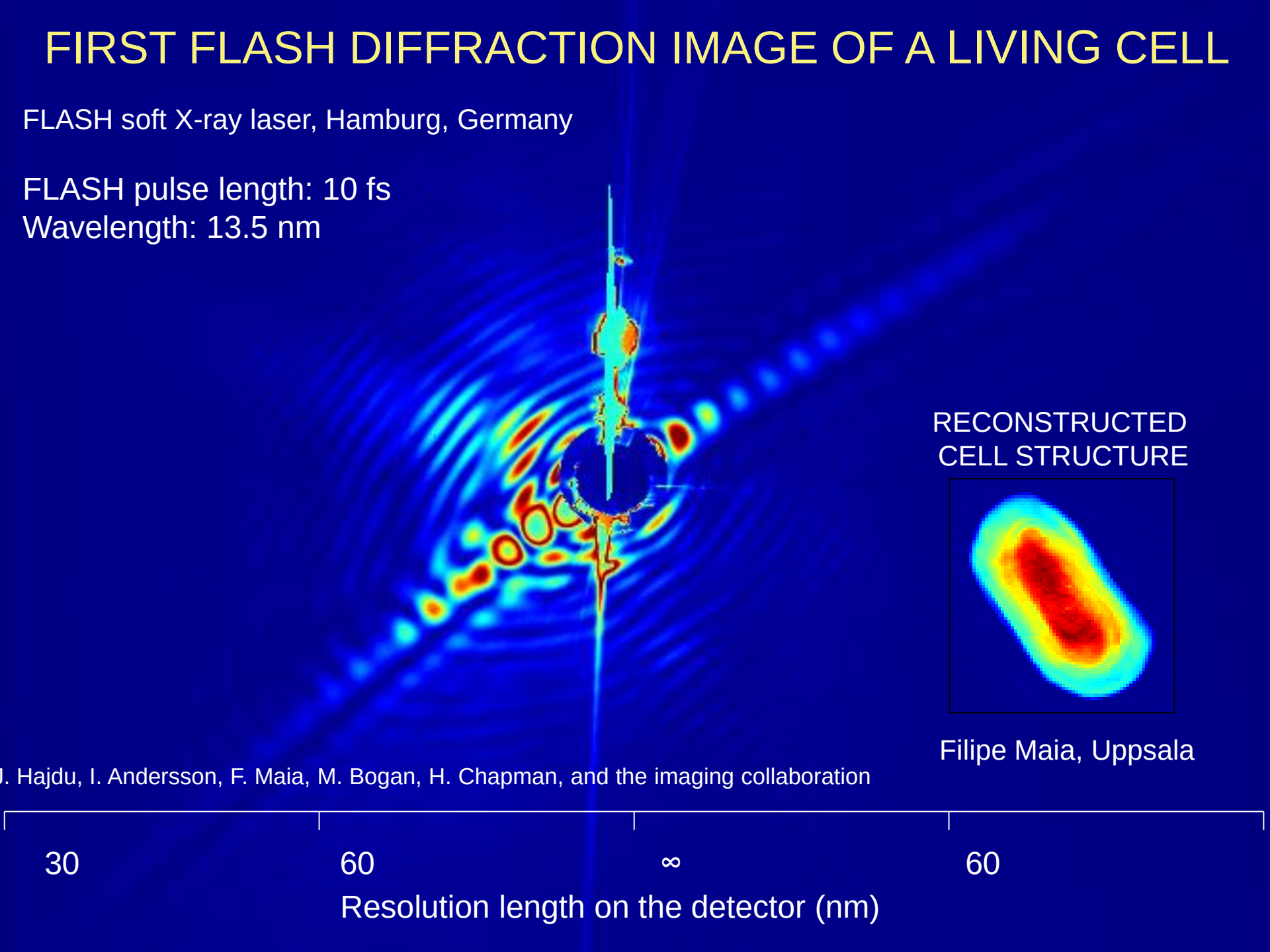
Ultra-Small


Nature
Technology
Flea
Human hair
~30 μm wide
Red blood cells
& white cell ~ 5μm
Virus ~ 200 nm
DNA helix
~3 nm width
Water
molecule
Atom
10-3 m
1 mm
100 μm
10 μm
10-6 m
1 μm
100 nm
10 nm
10-9 m
1 nm
0.1 nm
The Microworld
The Nanoworld
Head of a
pin ~ 1mm
Micro gears
10 -100 μm
diameter
DVD track
10 μm
1 μm Electrodes
connected with
nanotubes
1μm
Carbon nanotube
~ 2nm diameter
Atomic corral
~ 14 nm diameter

FIRST FLASH DIFFRACTION IMAGE OF A LIVING CELL

FLASH soft X-ray laser, Hamburg, Germany

FLASH pulse length: 10 fs
Wavelength: 13.5 nm



RECONSTRUCTED
CELL STRUCTURE

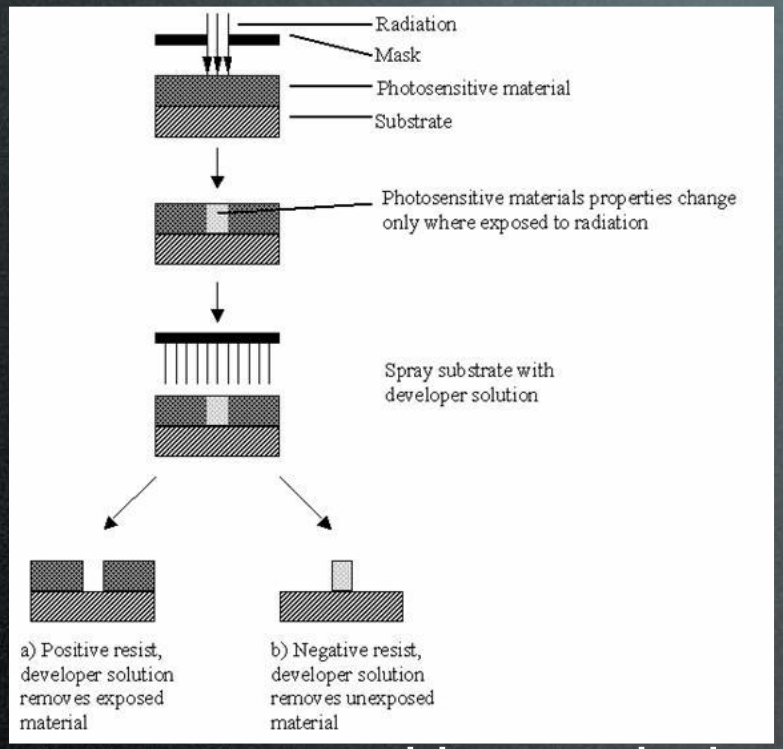
Filipe Maia, Uppsala

J. Hajdu, I. Andersson, F. Maia, M. Bogan, H. Chapman, and the imaging collaboration

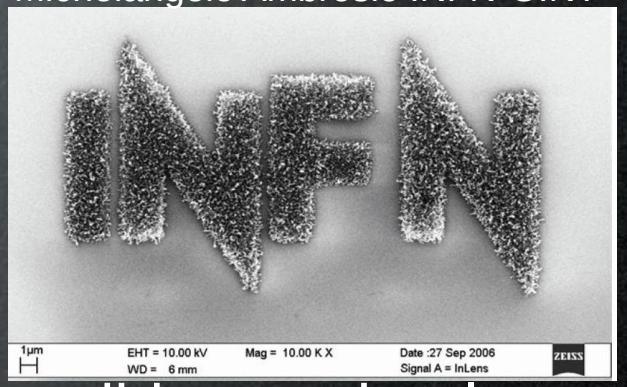
30 60 ∞ 60

Resolution length on the detector (nm)

nano lithography



Michelangelo Ambrosio INFN-GINT



- Extreme UV Lithographt is the candidate technology with <50-35 nm

- Cost effective solutions based on FEL sources can be foreseen

Ultra-Small

Nature

Flea

Human hair
~30 μm wide

Red blood cells
& white cell ~ 5μm

Virus ~ 200 nm

DNA helix
~3 nm width

Water molecule

Atom

Technology

Head of a pin ~ 1mm

Micro gears
10 -100 μm diameter

DVD track

1 μm Electrodes connected with nanotubes

Carbon nanotube
~ 2nm diameter

Atomic corral
~ 14 nm diameter

The Microworld

The Nanoworld

10^{-3} m — 1 mm

100 μm

10 μm

10^{-6} m — 1 μm

10 μm

100 nm

10 nm

10^{-9} m — 1 nm

0.1 nm

Ultra-Fast

Nature

Hydrogen transfer time in molecules is ~ 1ns

Spin precesses in 1 Tesla field is 10 ps

Shock wave propagates by 1 atom in ~ 100 fs

Water dissociates in ~10 fs

Light travels 1 μm in 3 fs

Bohr period of valence electron is ~ 1 fs

Technology

Computing time per bit is ~ 1 ns

Magnetic recording time per bit is ~ 2 ns

Optical network switching time per bit is ~ 100 ps

Laser pulsed current switch ~ 1ps

Shortest laser pulse is ~ 1 fs

Oscillation period of visible light is ~ 1 fs

10^{-9} s — 1 ns

100 ps

10 ps

10^{-12} s — 1 ps

100 fs

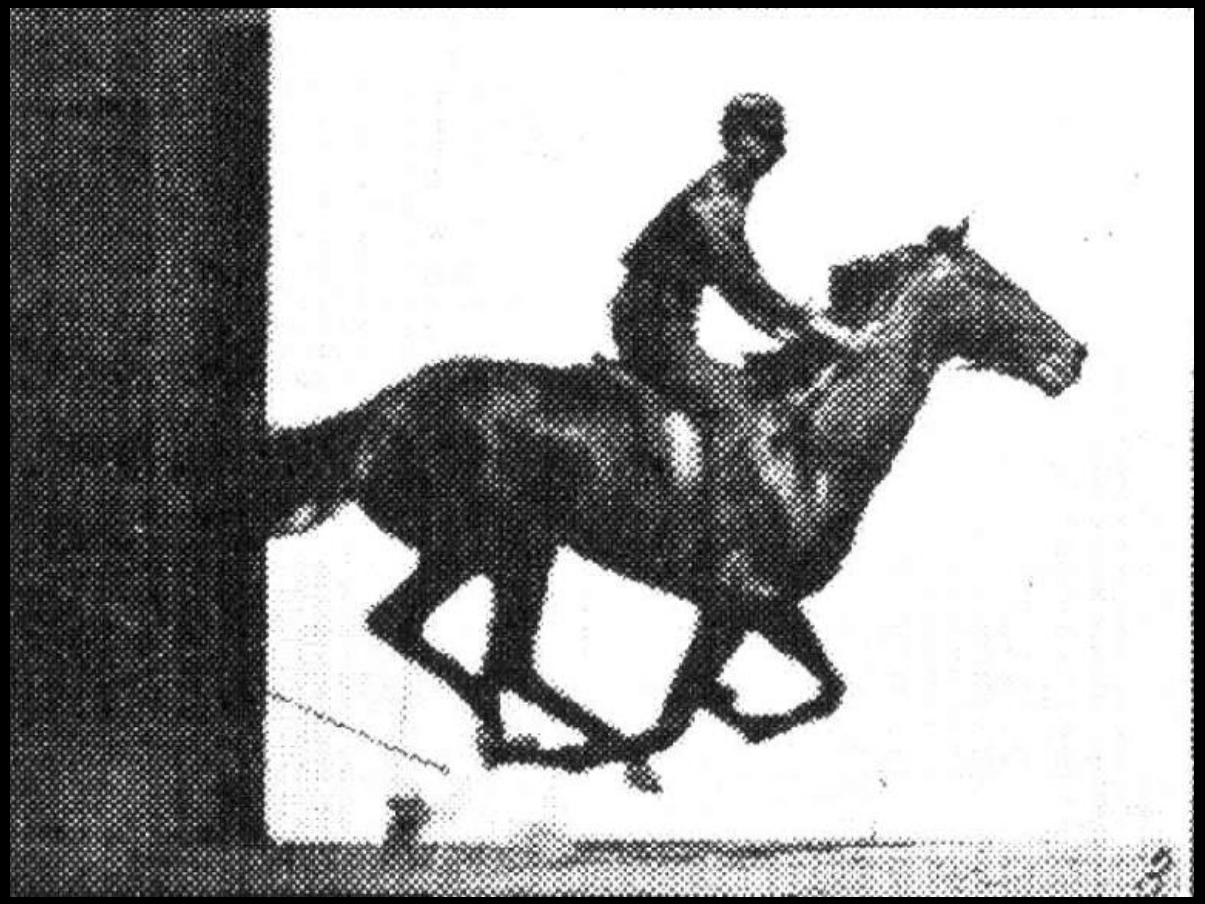
10 fs

10^{-15} s — 1 fs

E. Muybridge

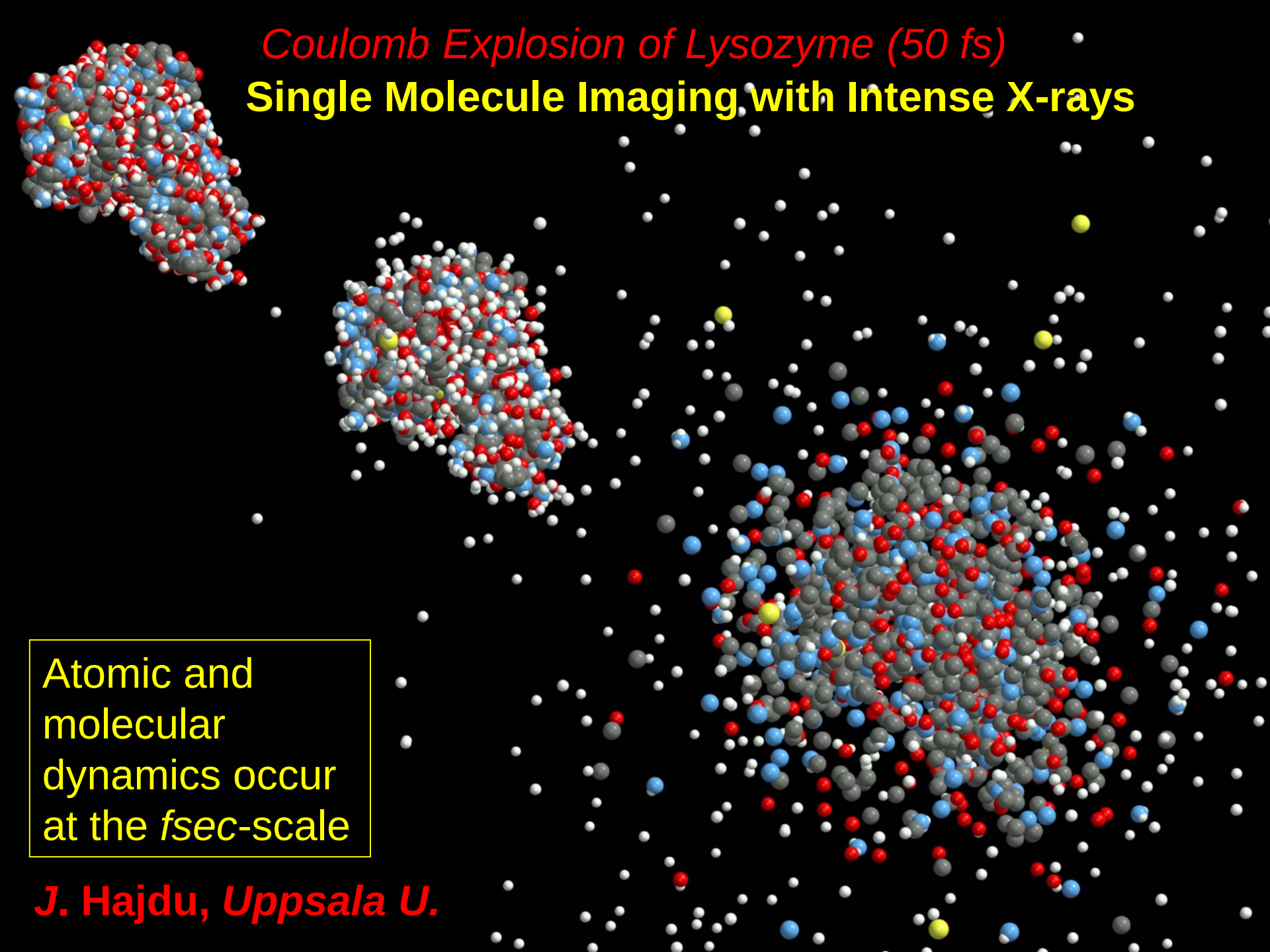
E. Muybridge at L. Stanford in **1878**

disagree whether all feet leave the ground during gallop…

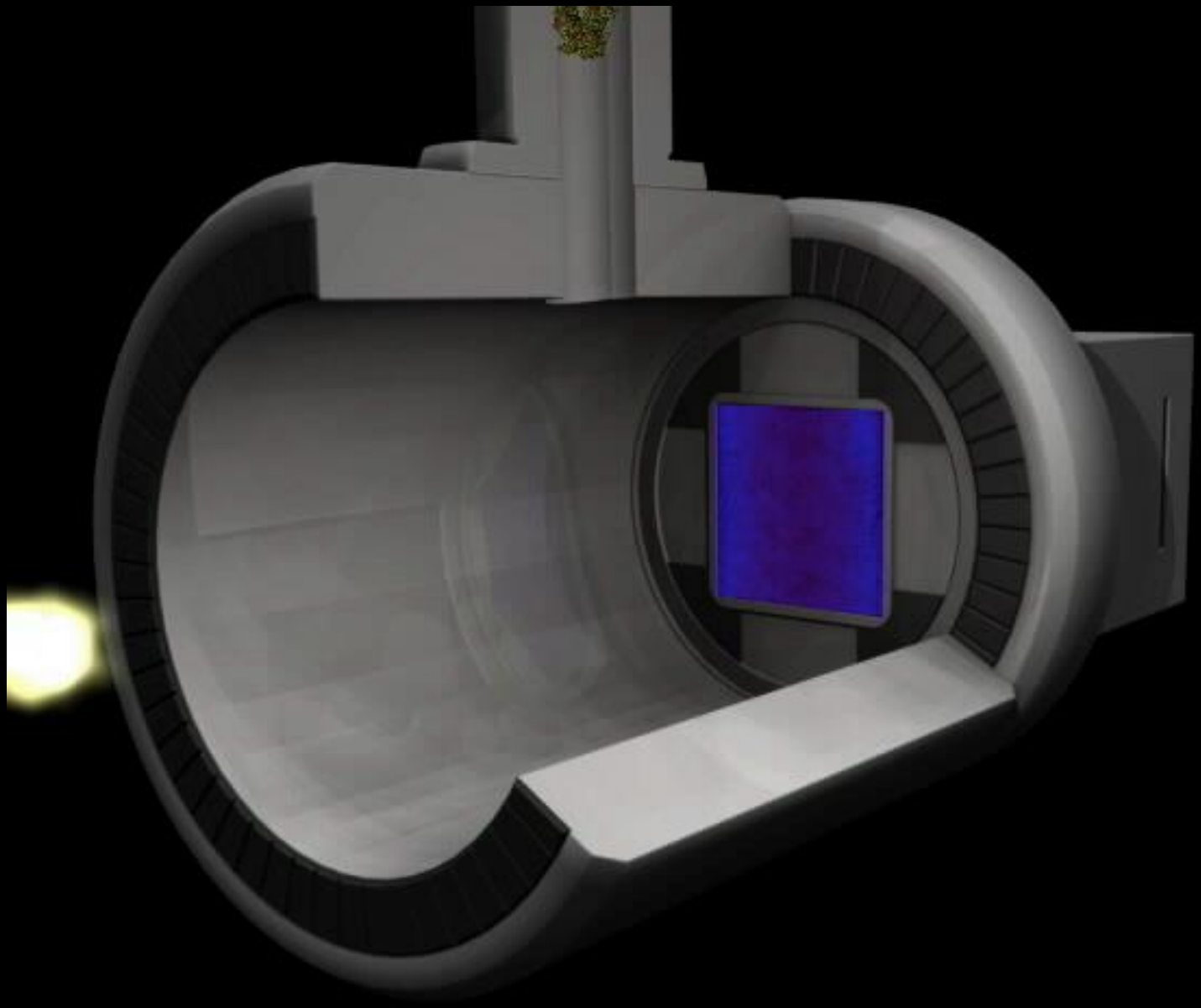


used spark photography to freeze this ‘ultra-fast’ process

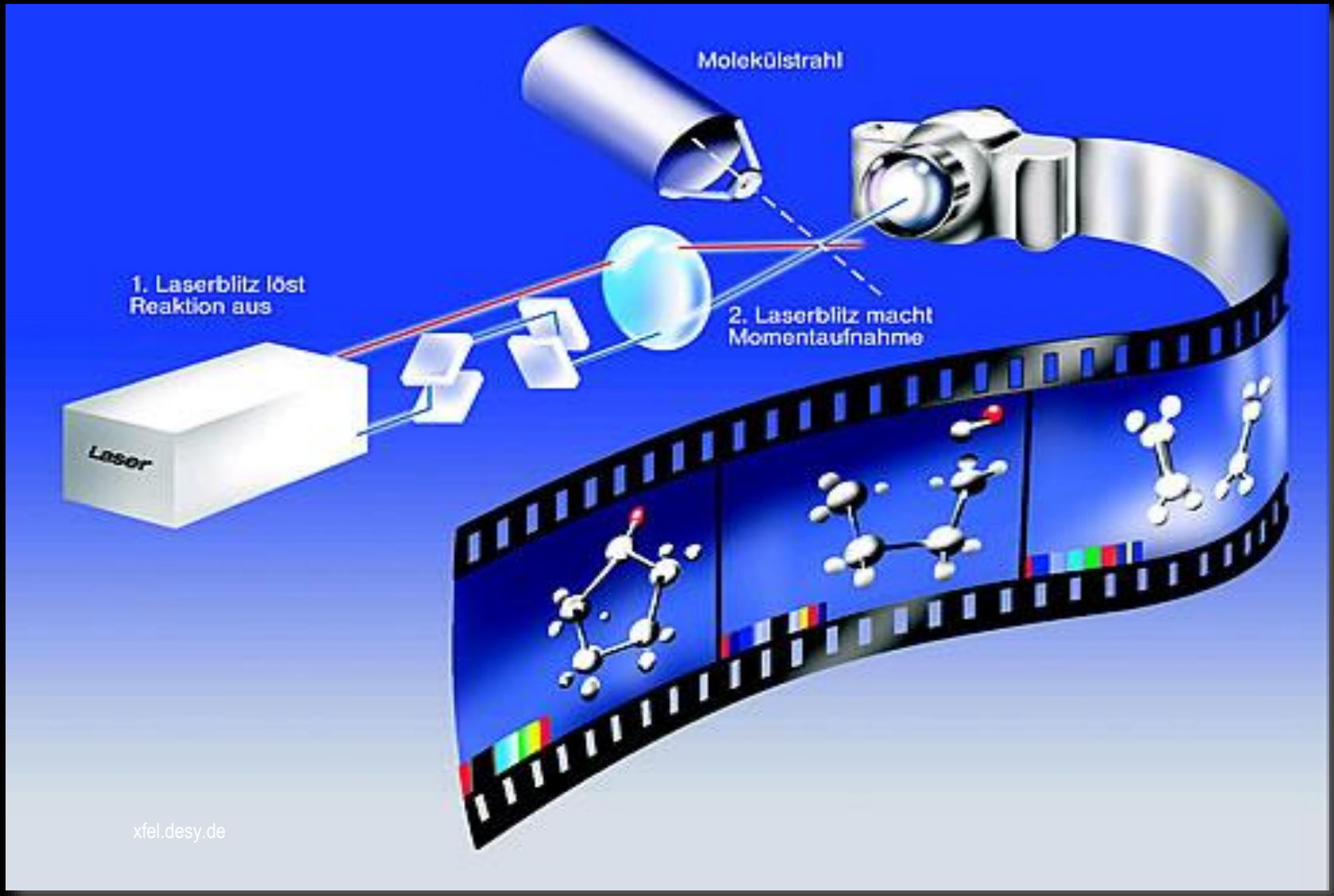
E. Muybridge, *Animals in Motion*, ed. L. S. Brown (Dover Pub. Co., New York 1957)
Courtesy Paul Emma (SLAC).


Coulomb Explosion of Lysozyme (50 fs)
Single Molecule Imaging with Intense X-rays
Atomic and molecular dynamics occur at the *fsec*-scale
J*. Hajdu, *Uppsala U.

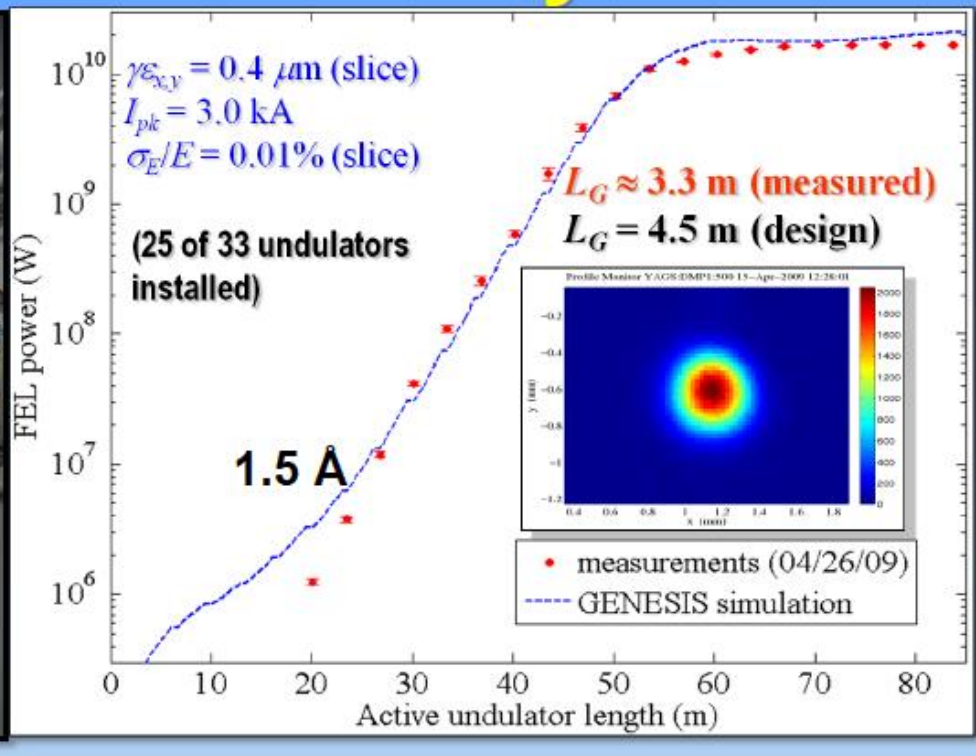
Experimental hall (Single Protein Imaging)



http://lcls.slac.stanford.edu/AnimationViewLCLS.aspx

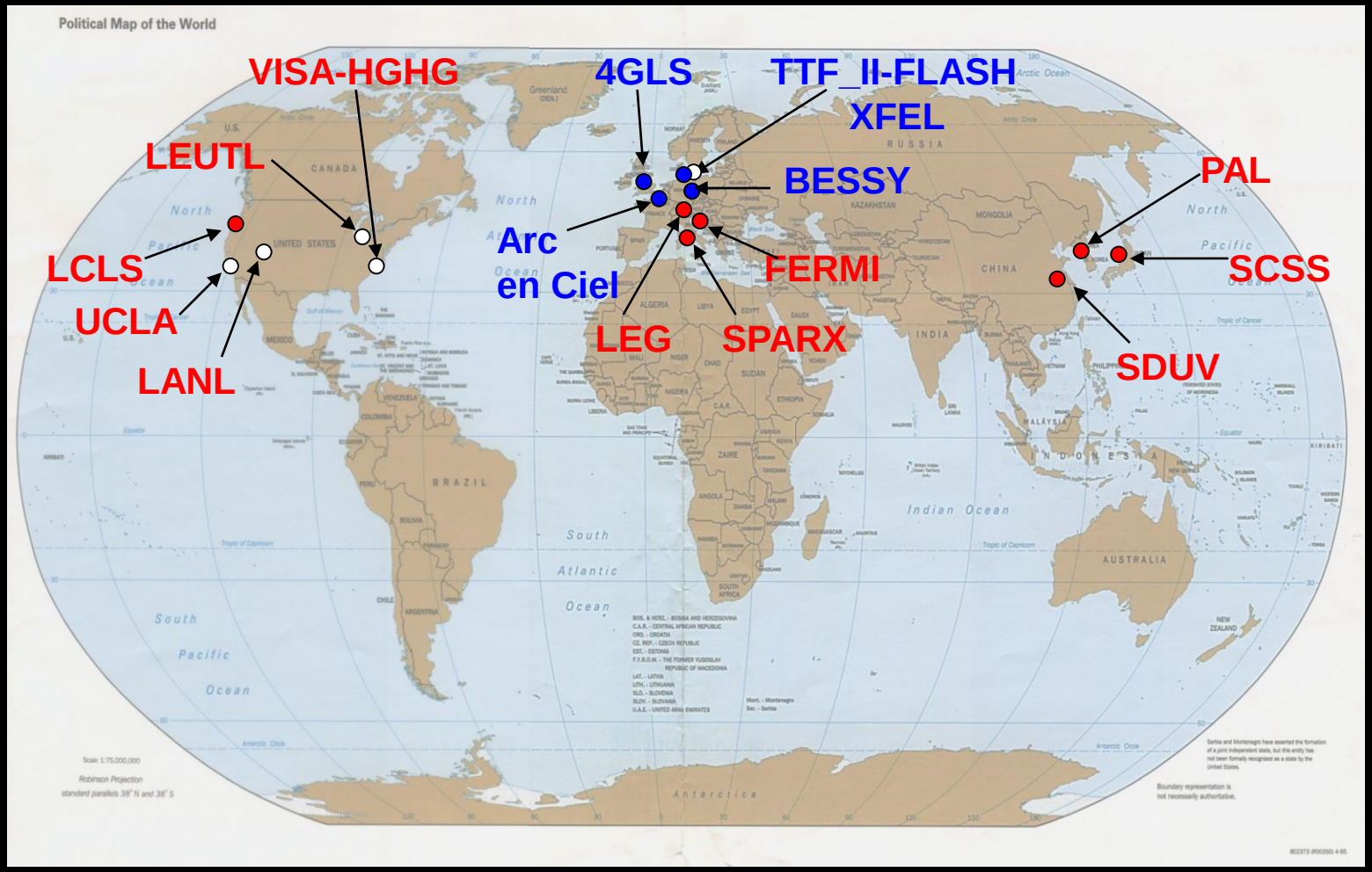

Molekülstrahl
1. Laserblitz löst Reaktion aus
2. Laserblitz macht Momentaufnahme
Laser
xfel.desy.de

LCLS: world's first hard x-ray FEL



- SASE wavelength range: **25 – 1.2** Å
- Photon energy range: **0.5 - 10** keV
- Pulse length FWHM **5 - 500** fs (SXR only)
- Pulse energy up to **4** mJ

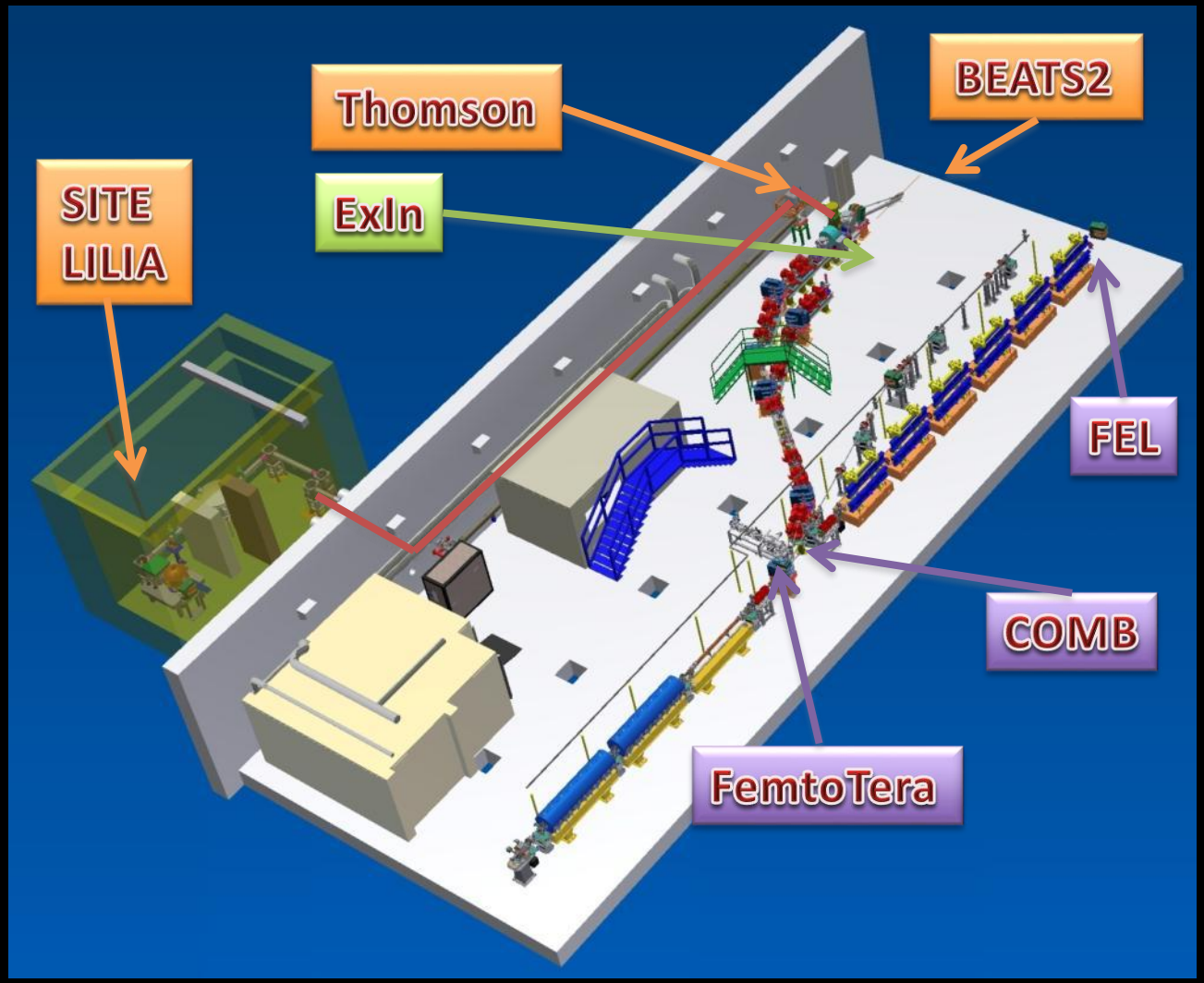
Short Wavelength SASE FEL



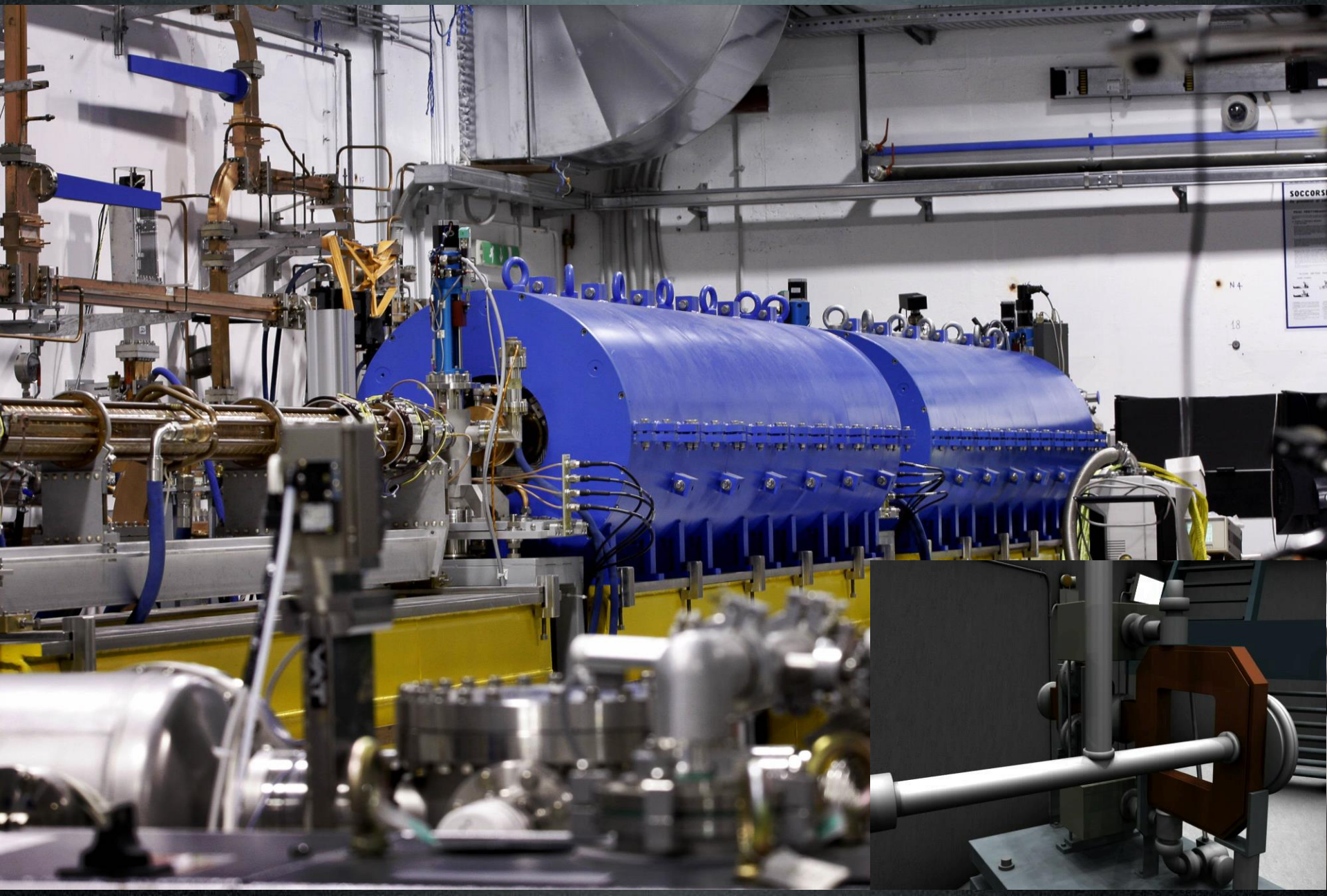
FELs Initiatives in Italy

SPARC_LAB

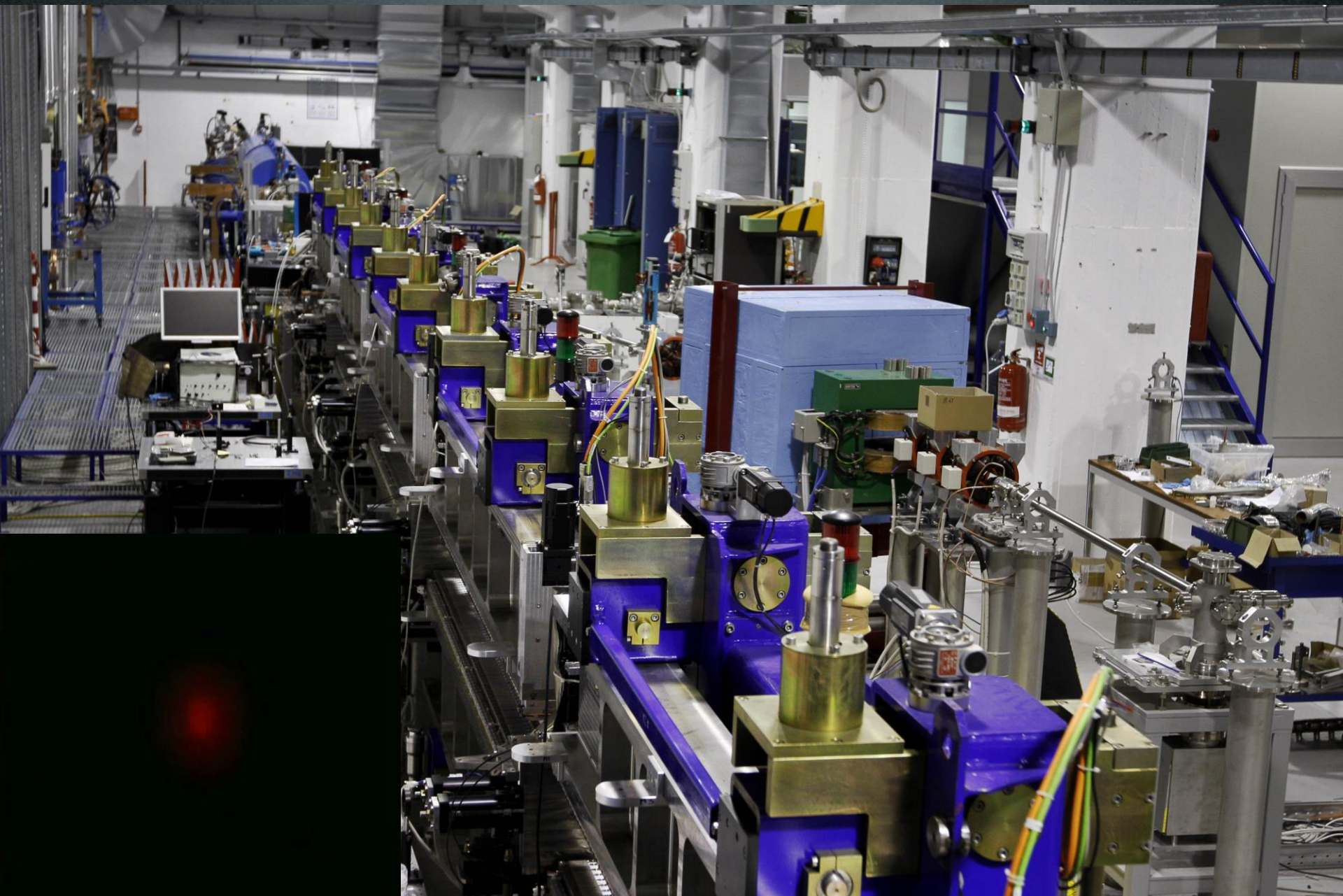
Sources for Plasma Accelerators and Radiation Compton with Lasers And Beams



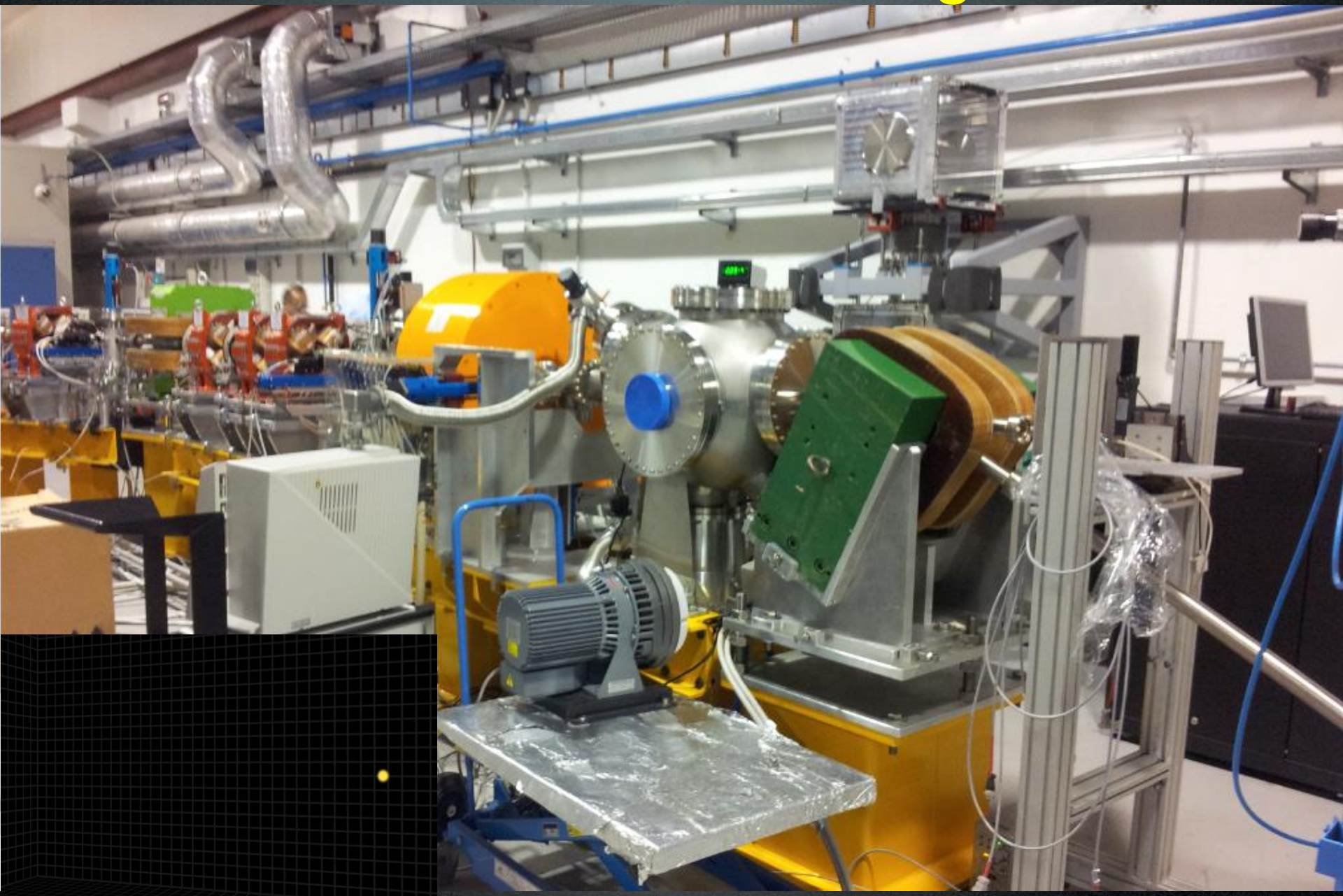
HB photo- injector with Velocity Bunching



Free Electron Laser

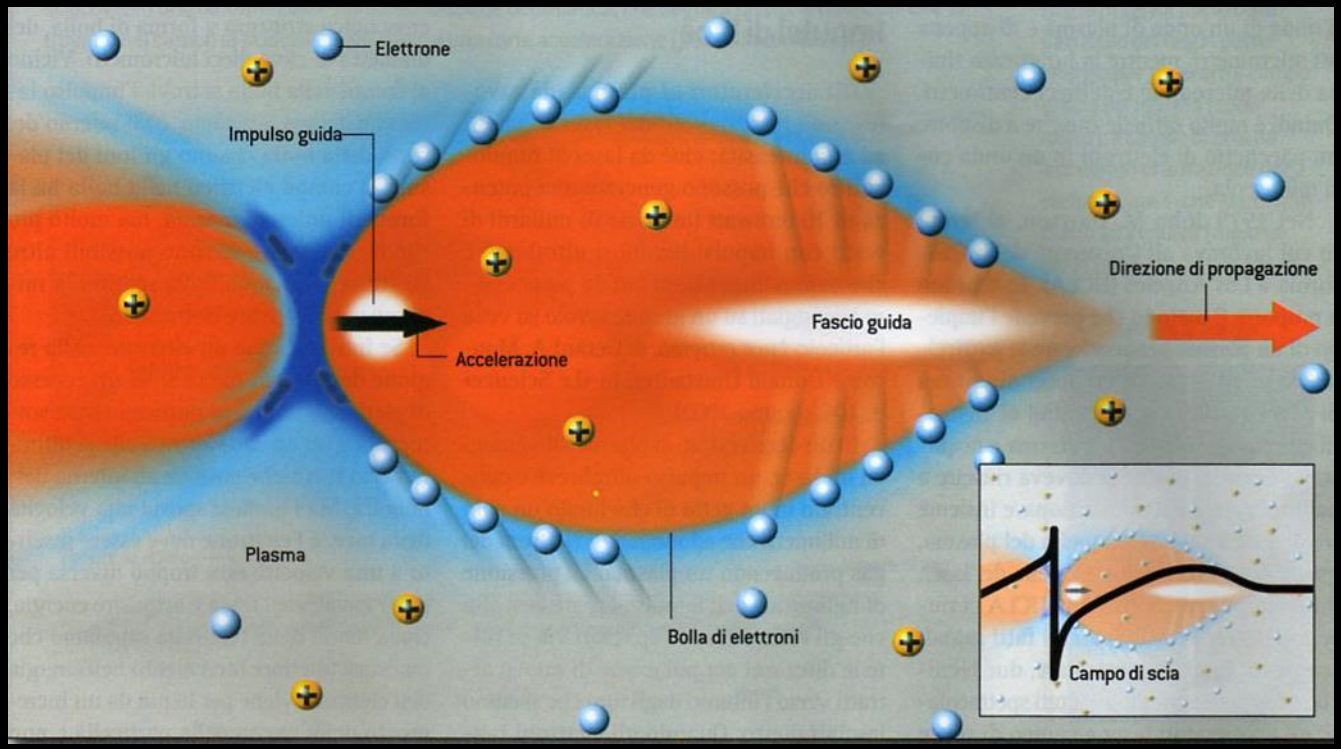


Thomson back-scattering source

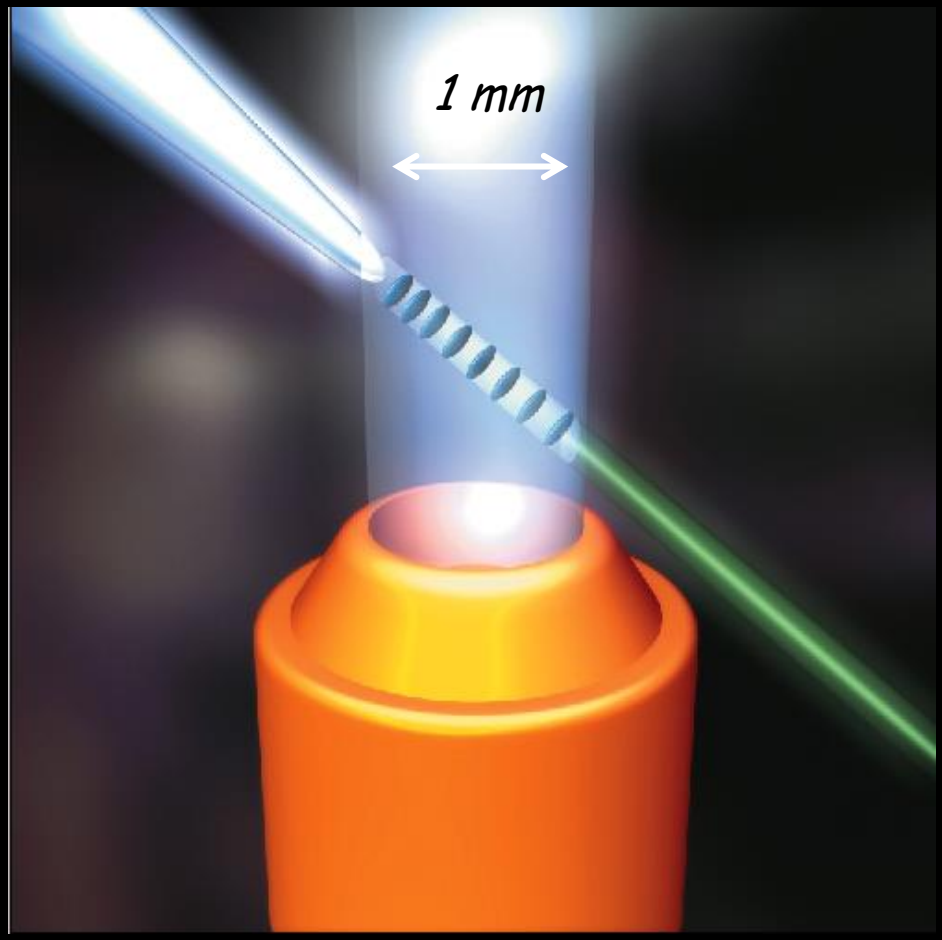


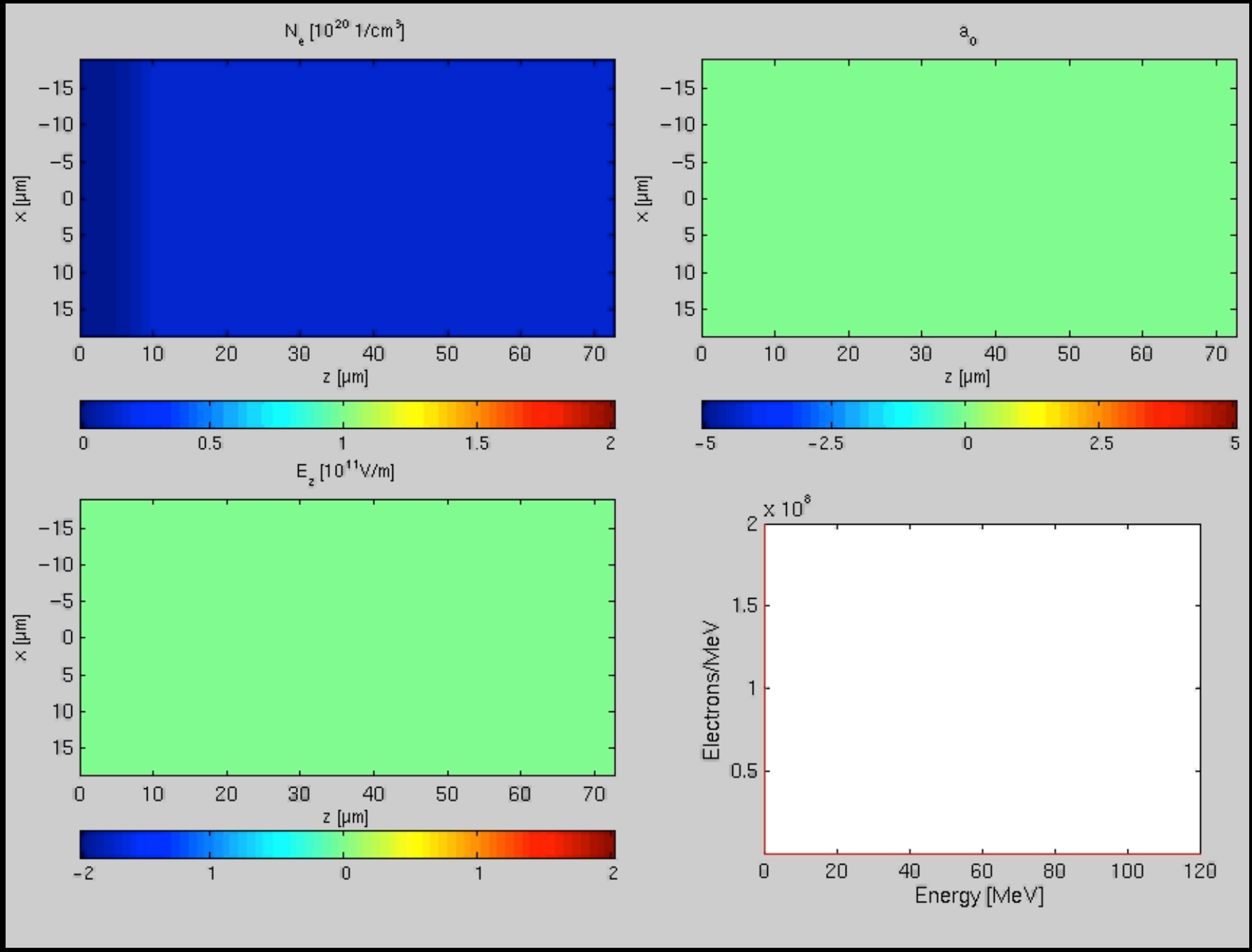
High gradient acceleration

High quality beam Plasma Accelerattion

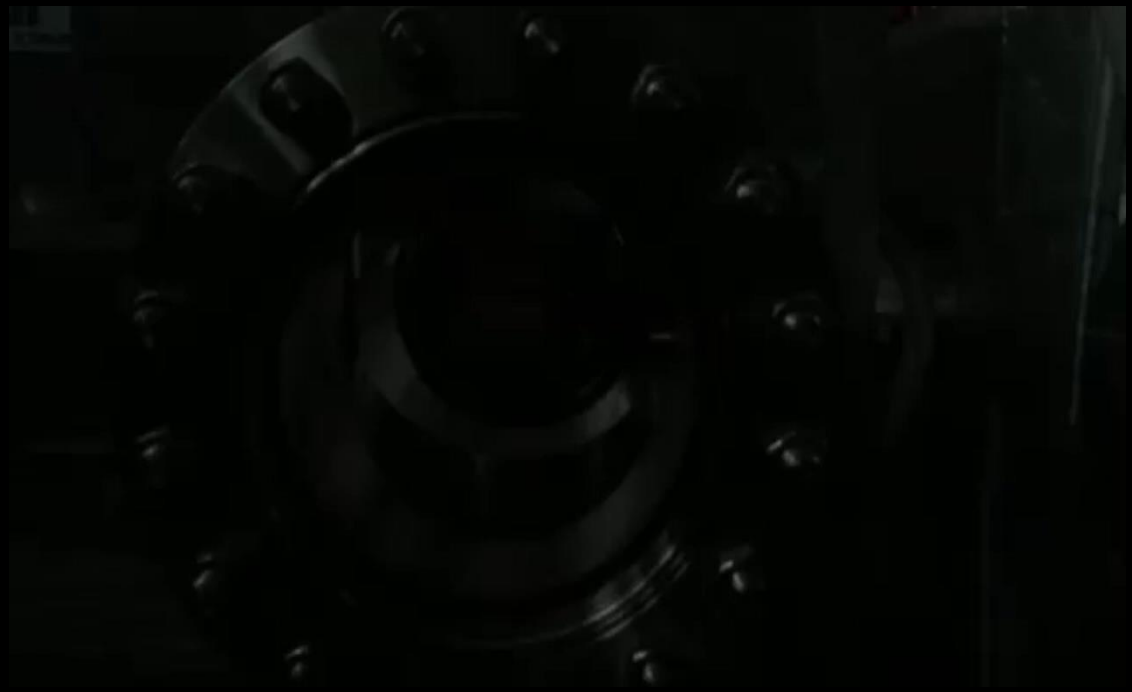


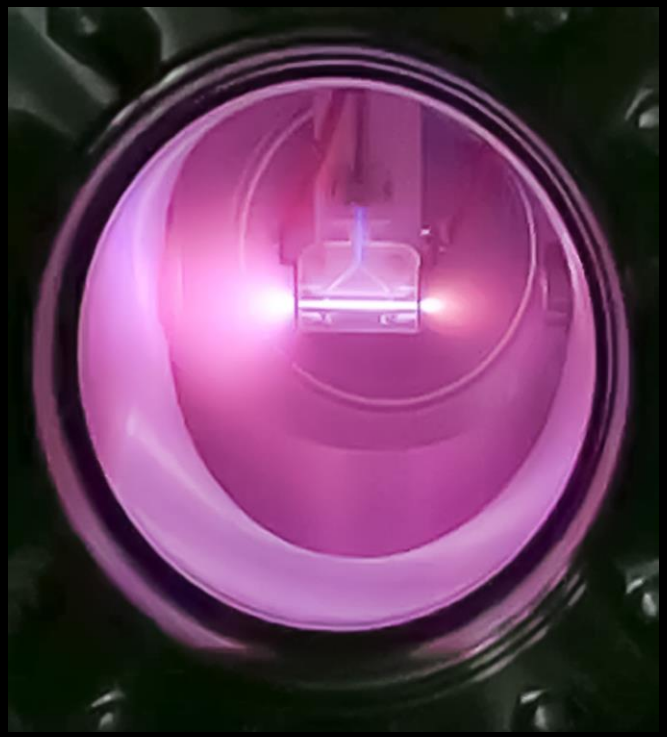
Direct production of e-beam




N_e [10^{20} 1/cm^3]
x [µm]
z [µm]
a_0
E_z [10^{11}V/m]
x 10^8
Electrons/MeV
Energy [MeV]

First Capillary Discharge (Oct. 23)





Thank you

The end