Introduction to Particle Accelerator

JATUPORN PUNTREE, MWIT

โครงการอบรมฟิสิกส์อนุภาคพื้นฐาน 2565

5 – 7 พ.ค. 2565

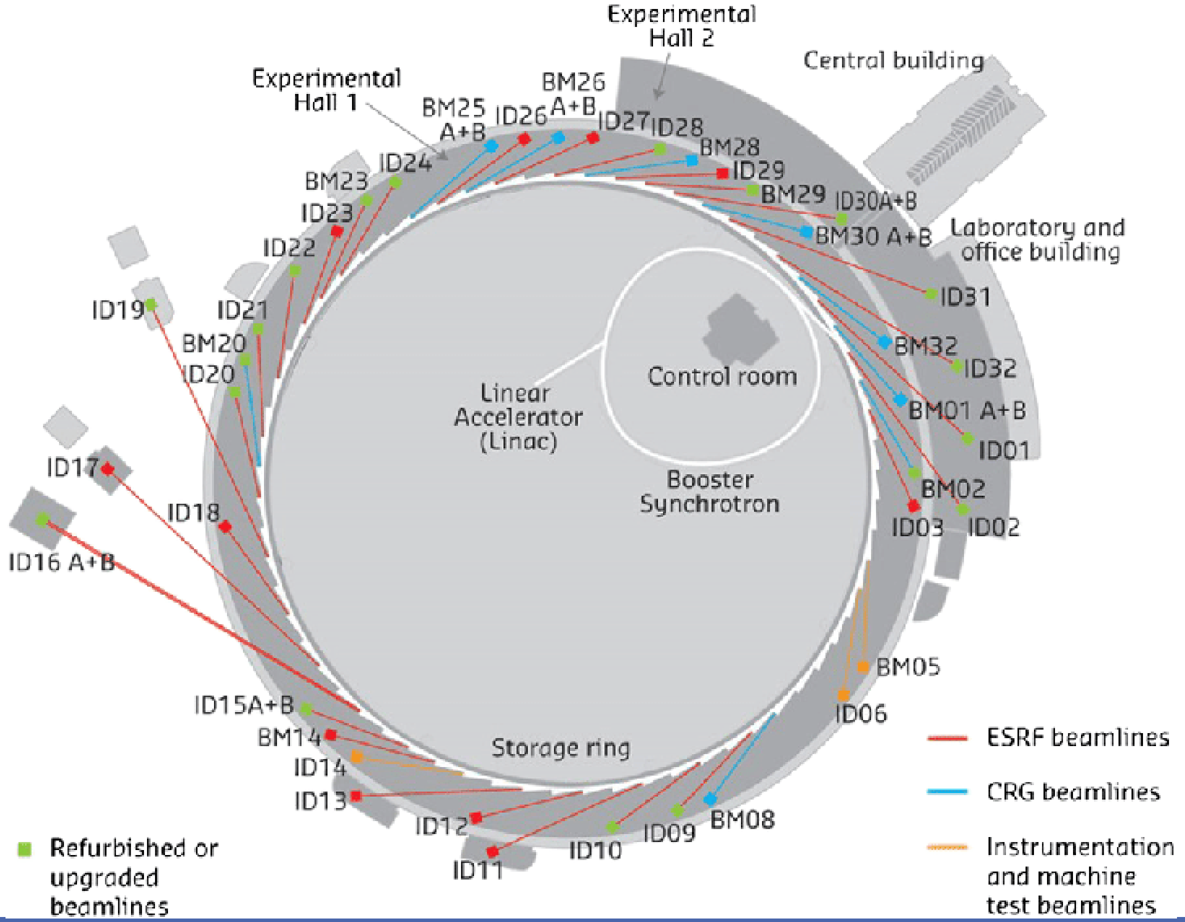
Why we accelerate particles?
เราเร่งอนุภาคทำไม?

- as a tool probe → Synchrotron/Spectroscopy Facilities

- as a time machine → Collider

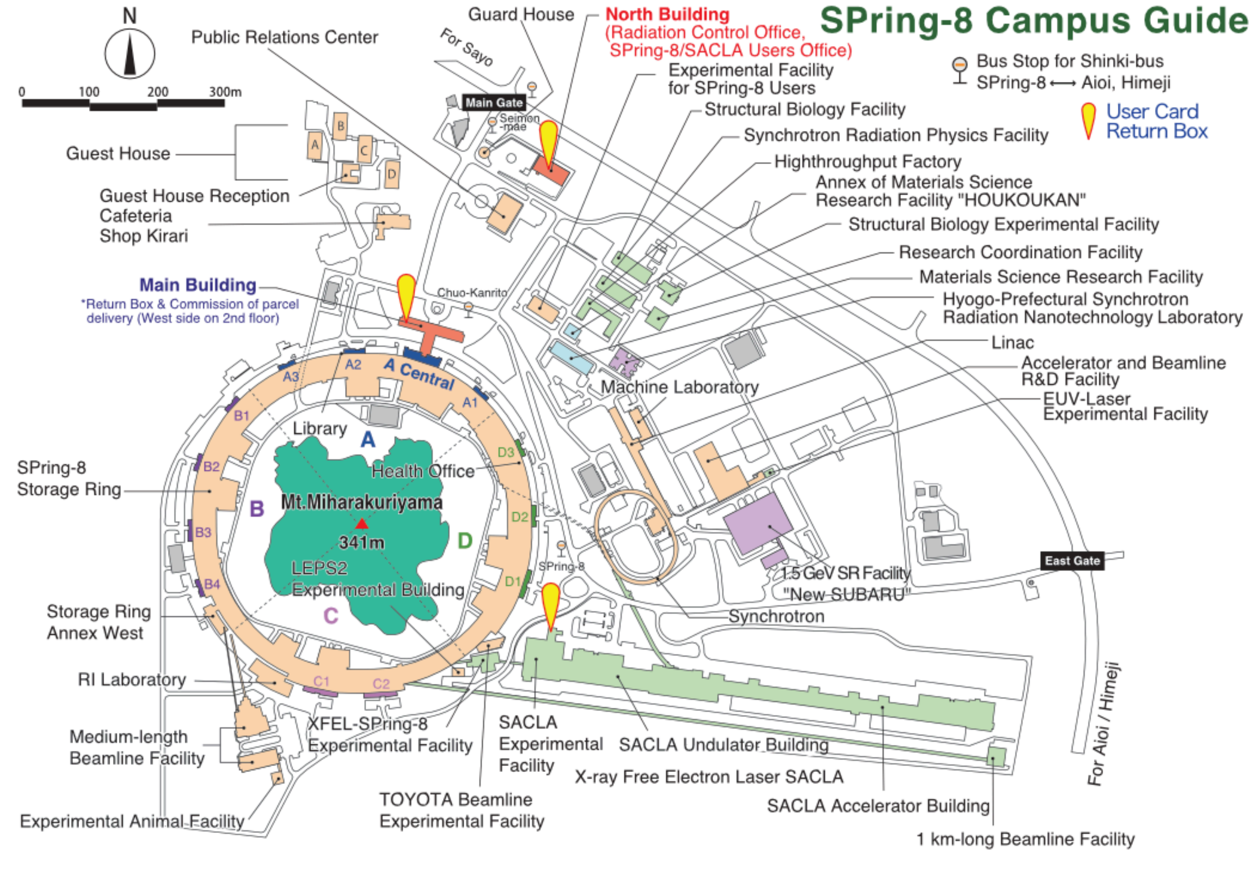
Synchrotron/Spectroscopy Facilities

European Synchrotron Radiation Facility (ESRF)

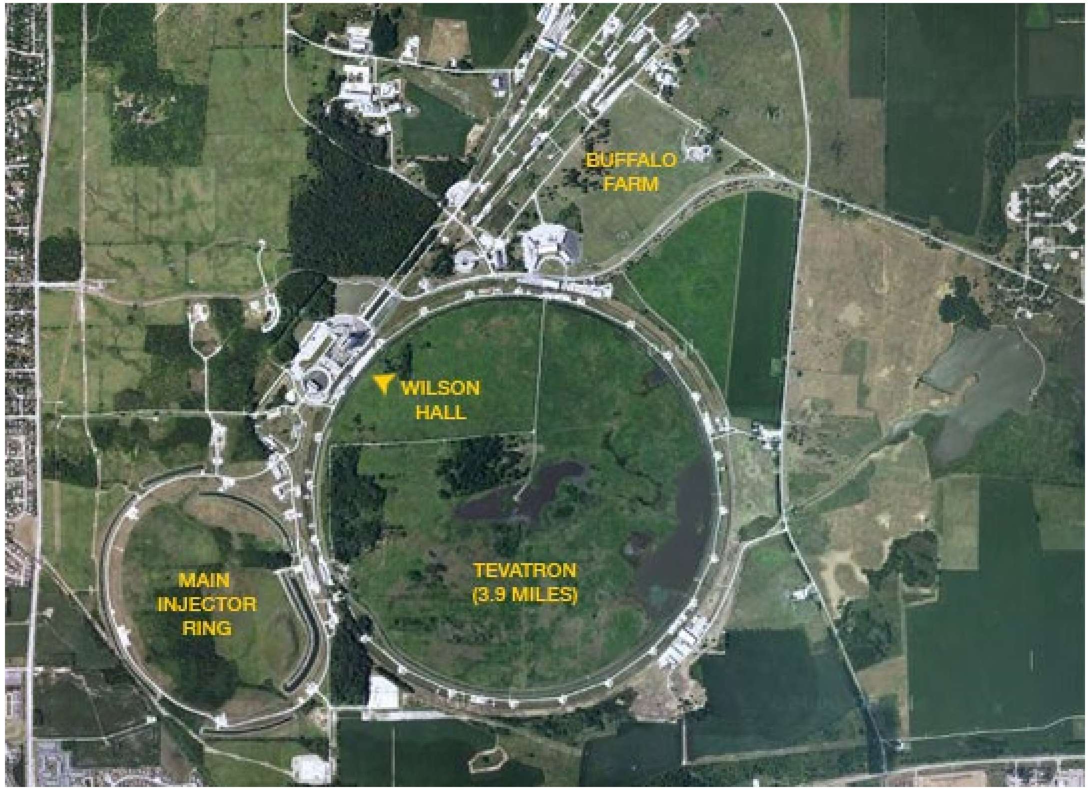


Synchrotron/Spectroscopy Facilities

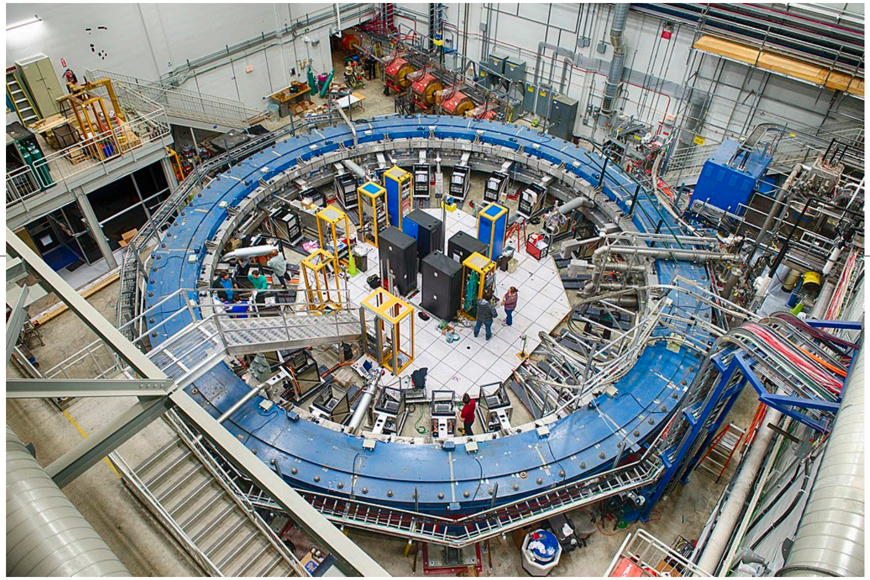
Super Photon ring-8 GeV = “Spring-8”

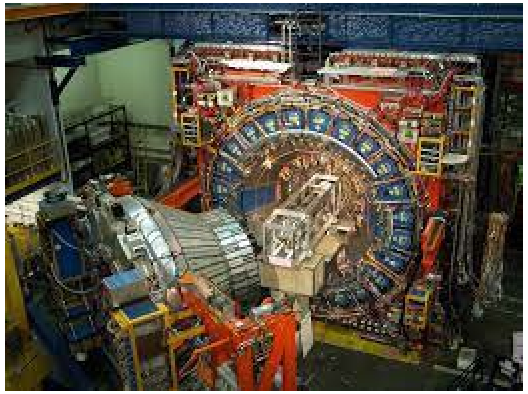


Collider

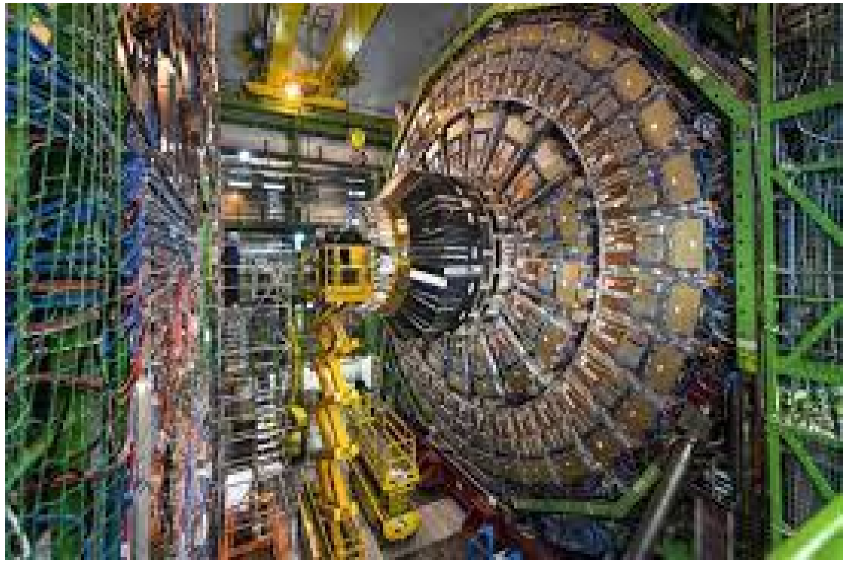


“Tevatron”, FermiLab





Collider



Large Hadron Collider, “LHC”, CERN

Accelerator as a tool probe

- We observe everything around with EM wave [λ]

$$\lambda < size\ of\ object$$

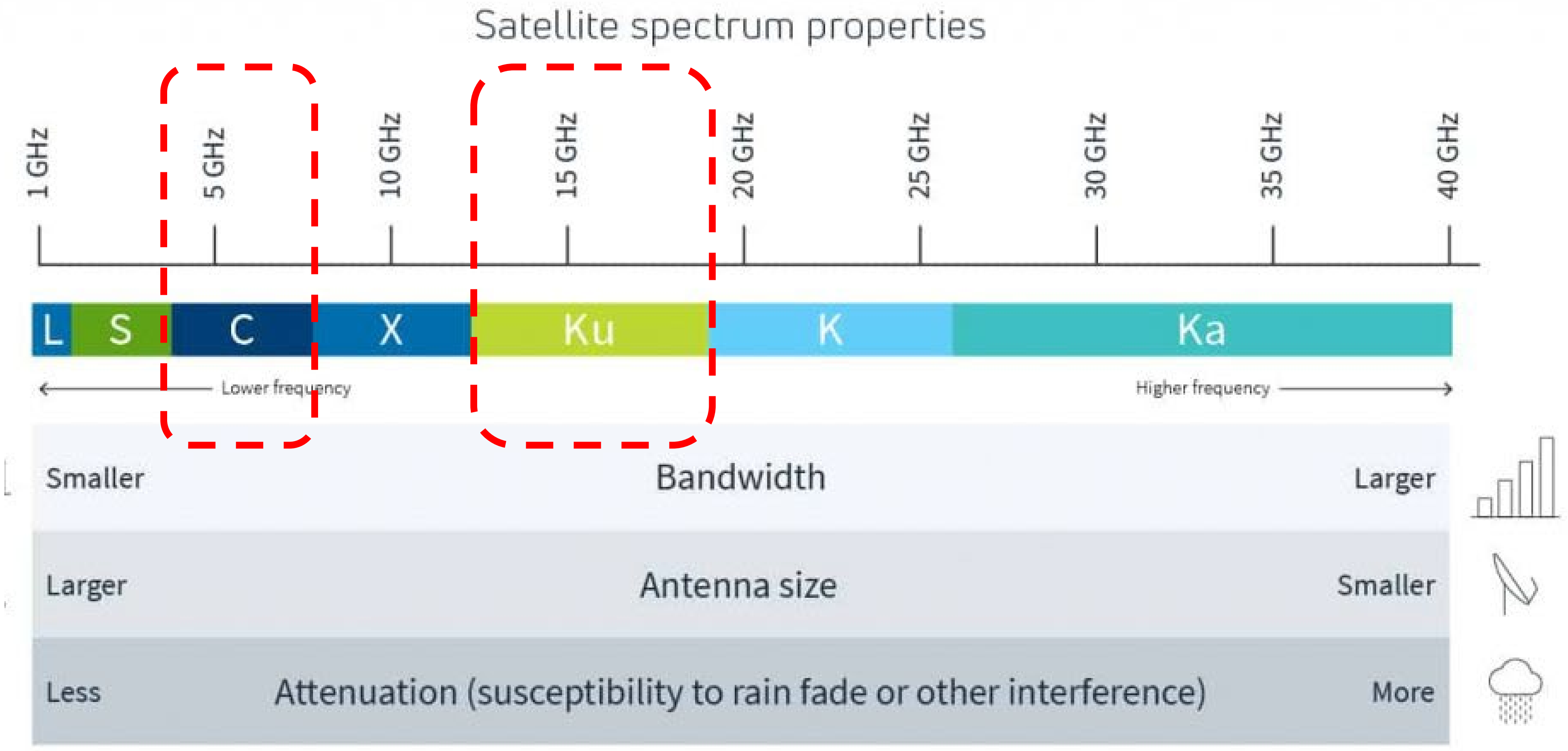
↓

Resolved

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{5 \times 10^9} = 0.06\ m = 6\ cm$$

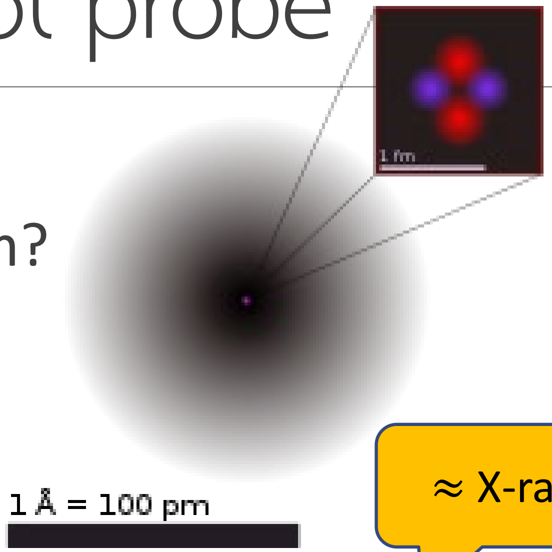
C Band Dish
5.5ft.-12ft.

Ku Band Dish
0.35m.-1.80m.



Accelerator as a tool probe

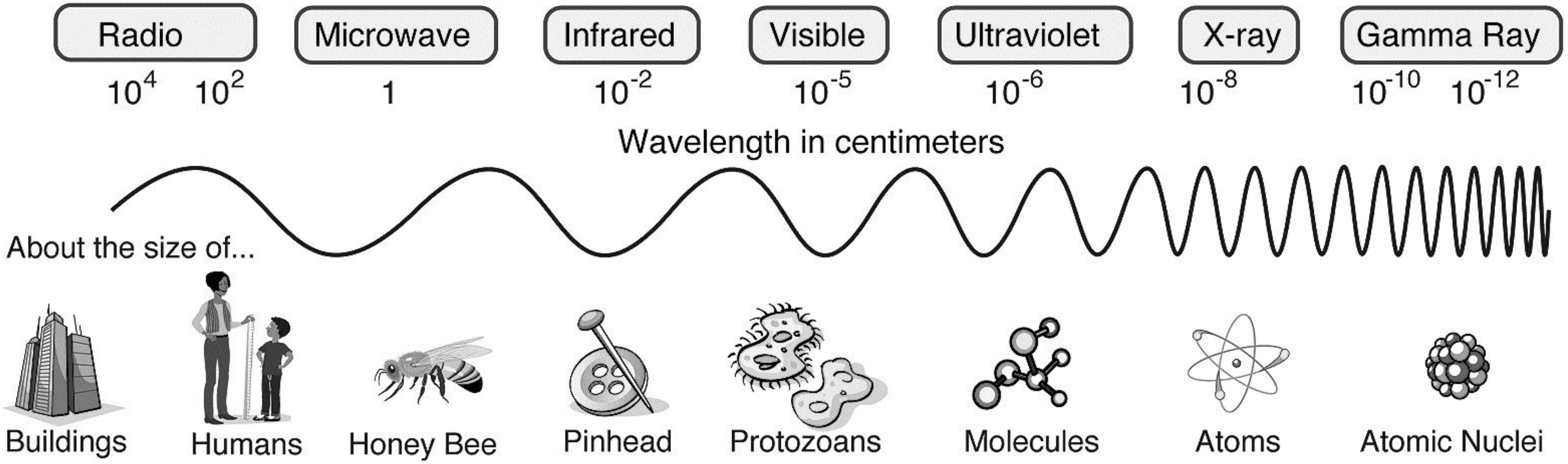
- What if we want to observe atom?



Size $\approx 1\ \text{Å} = 10^{-10}\ m$

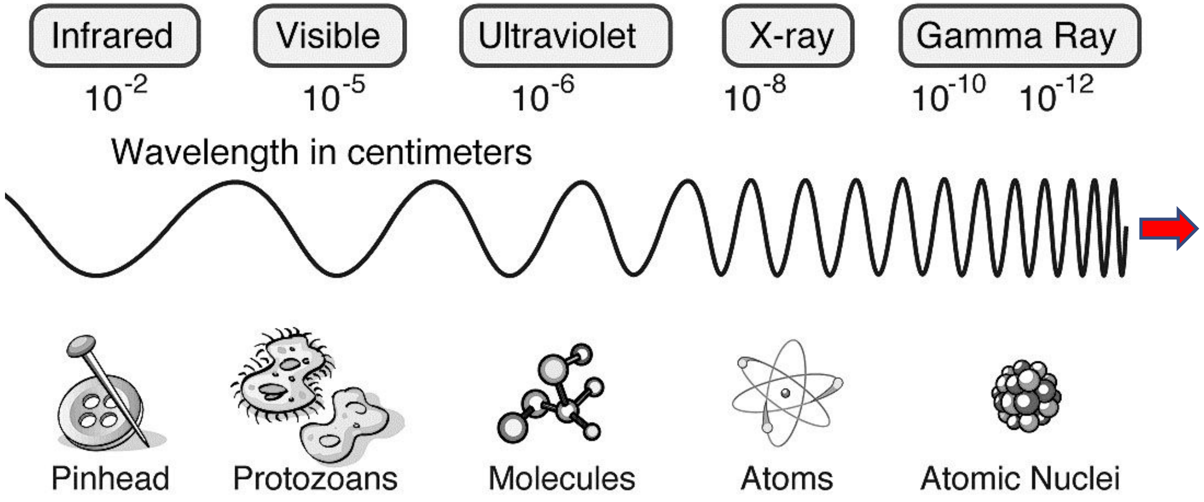
$\approx$ X-ray

EM wave $\lambda \approx 1\ \text{Å} = 10^{-10}\ m$
$= 10^{-8}\ cm$

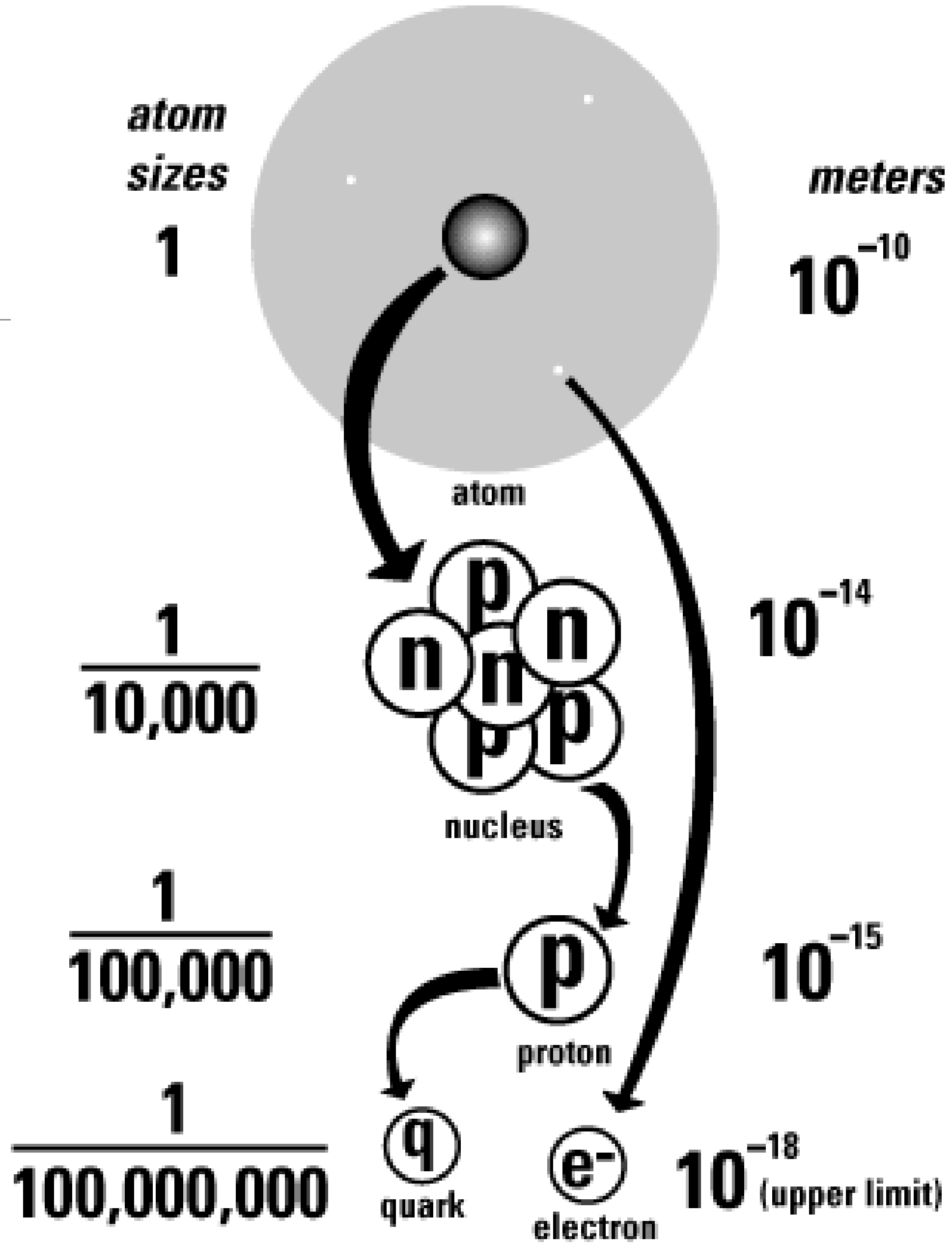


Accelerator as a tool probe

- What if we want to observe deeper?



Impossible to produce EM wave at these wavelength



Accelerator as a tool probe

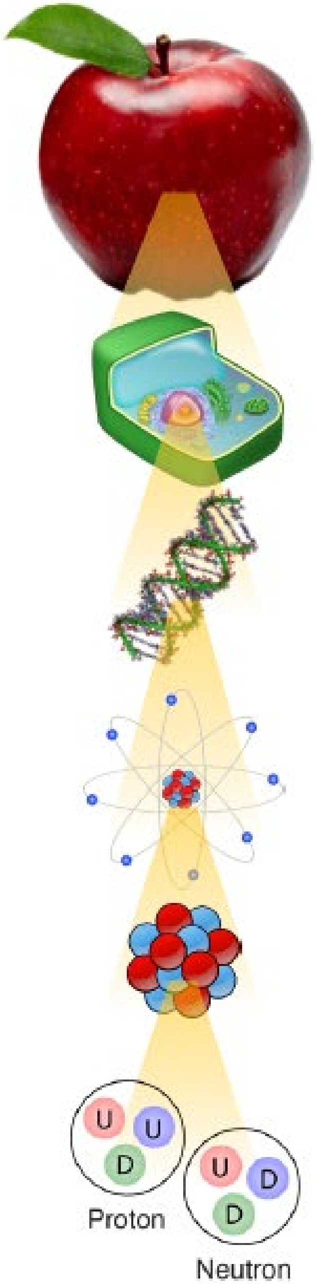
- What about using 'matter wave'?

$$\lambda = \frac{h}{p} = \frac{hc}{pc}$$

- According to De Broglie wavelength, we can decrease wavelength of matter wave by increasing Kinetic energy in term of momentum.

Exp.

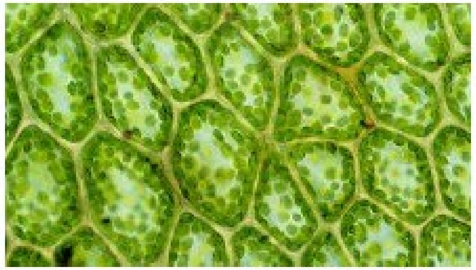
- Wavelength of electron with 50 eV kinetic energy $K = \frac{p^2}{2m_e} = \frac{h^2}{2m_e\lambda^2} \rightarrow \lambda = \frac{h}{\sqrt{2m_eK}} = 1.7 \times 10^{-10} \ m$



Size	Energy
Everyday object > 1 cm	(Quite easy to see)
Cell 10-100 μm	0.01-0.1 eV
DNA ~2 nm Molecule <1 nm	~1 keV
Atom 10^{-10} m	~10 keV
Nucleus 10^{-14} m	>100 MeV
Hadron 10^{-15} m	>1 GeV
Quark and lepton 10^{-18} m	>1 TeV

Bare eye

Light microscope



Credit: BBC Bitesize

Electron microscope

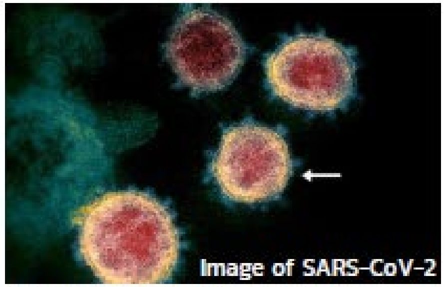


Image of SARS-CoV-2

Credit: National Institute of Allergy and Infectious Diseases (NIAID)

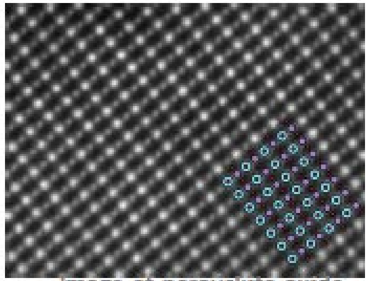
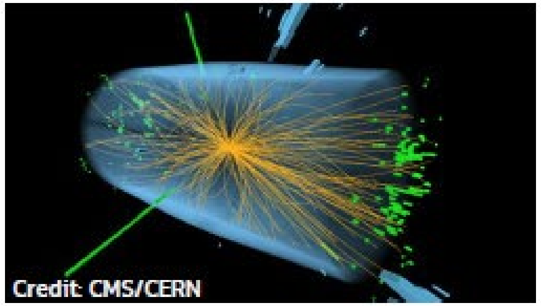


Image of perovskite oxide

Credit: Magnunor, Wikimedia Commons

Credit: CERN

Particle accelerator



Credit: CMS/CERN

Courtesy: T. Chanwattana, SLRI

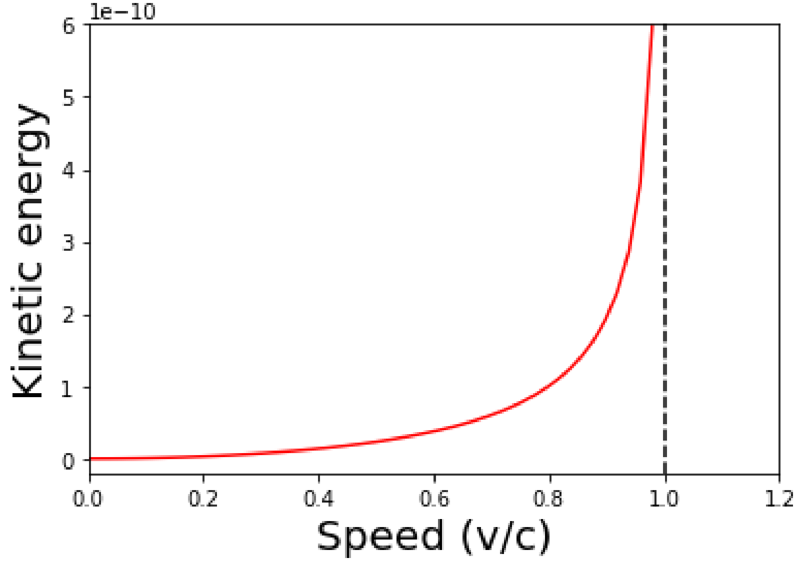
Accelerator as a tool probe

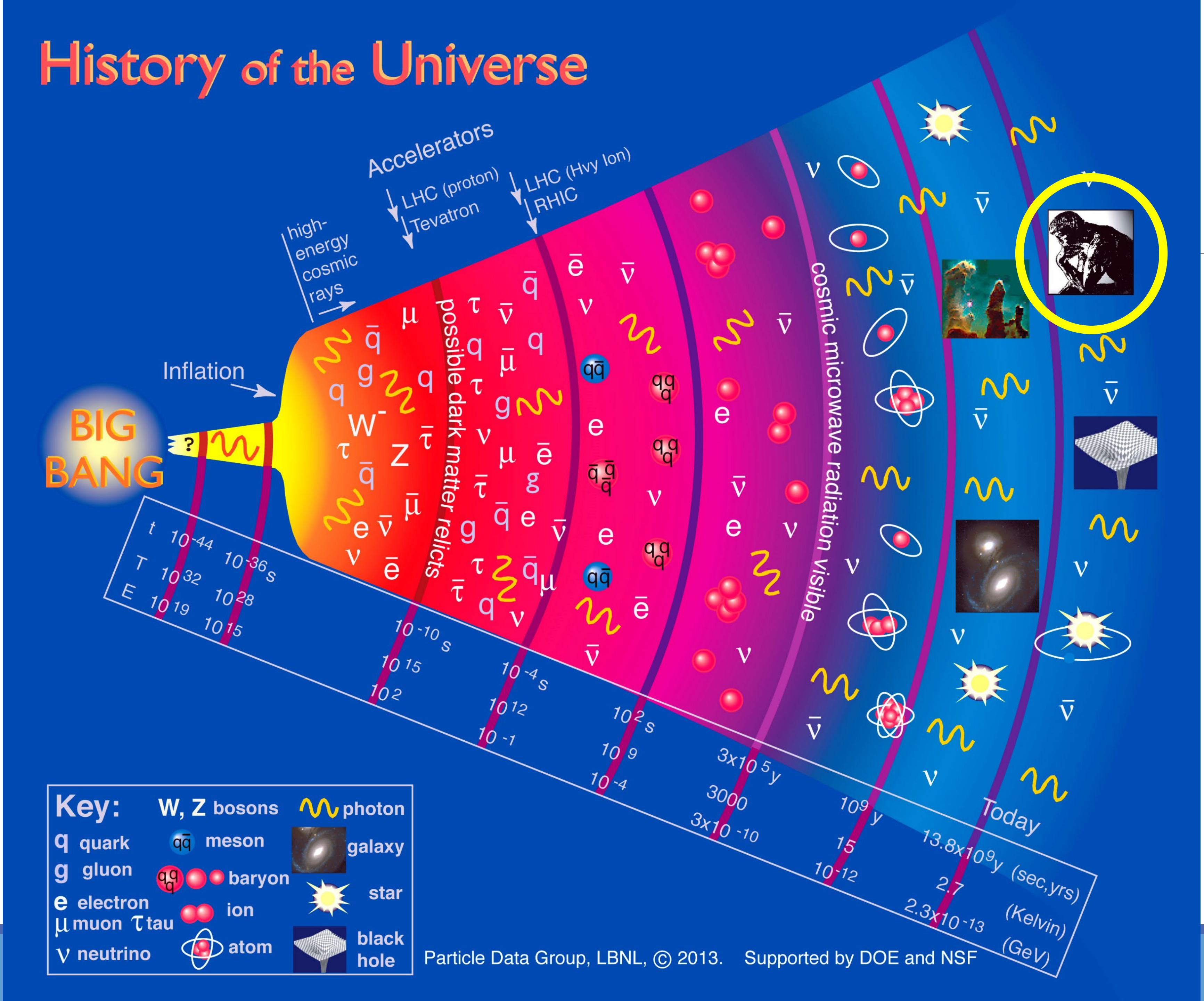
$\downarrow \lambda \longrightarrow \uparrow p \longrightarrow \uparrow kinetic\ energy$

What we want.

What we want to do.

What we have to do.





Accelerator as a time machine

- Simulate the early universe state
- Observe matter

Particle energy

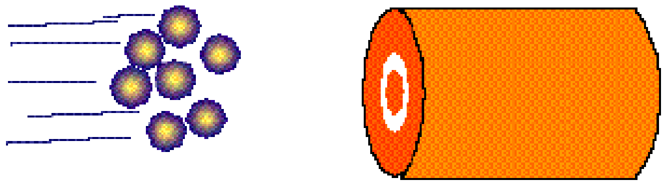
- New physics can be found at larger energy

- Energy for particle creation: centre-of-mass energy, E_{CM}

W = Energy available in center-of-mass for making new particles

For fixed target :

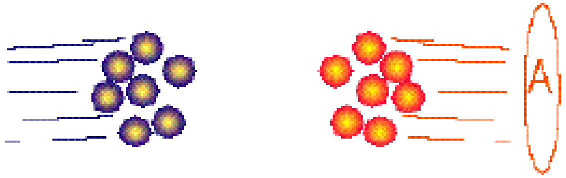
$$E_{c.m.} \cong \sqrt{2m_T E_B}$$



... and we rapidly run out of money trying to gain a factor 10 in c.m. energy

But a storage ring , colliding two beams, gives:

$$E_{c.m.} \cong 2\ E_B$$

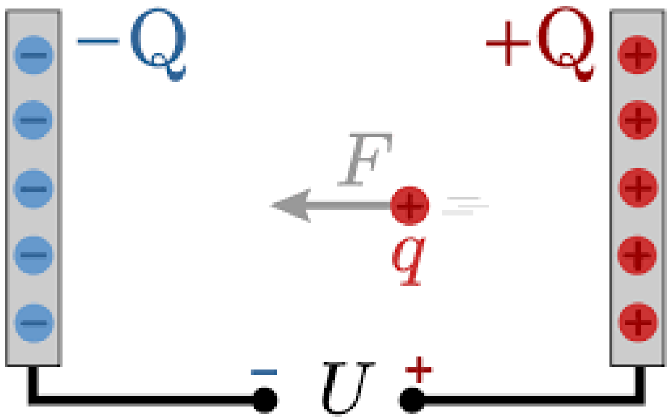


- Fixed target gives a lot of collision
- Collider gives a lot of energy

Forces

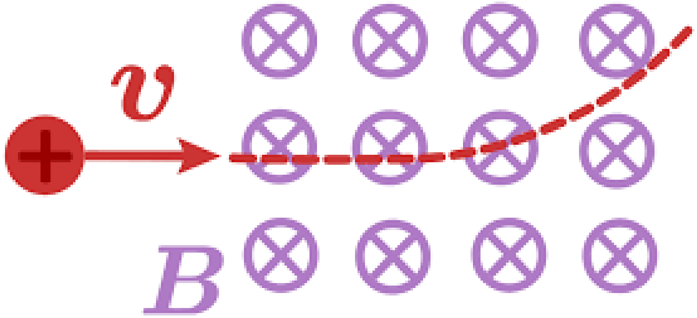
$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$$

Electric force



Acceleration
--> Energy gain

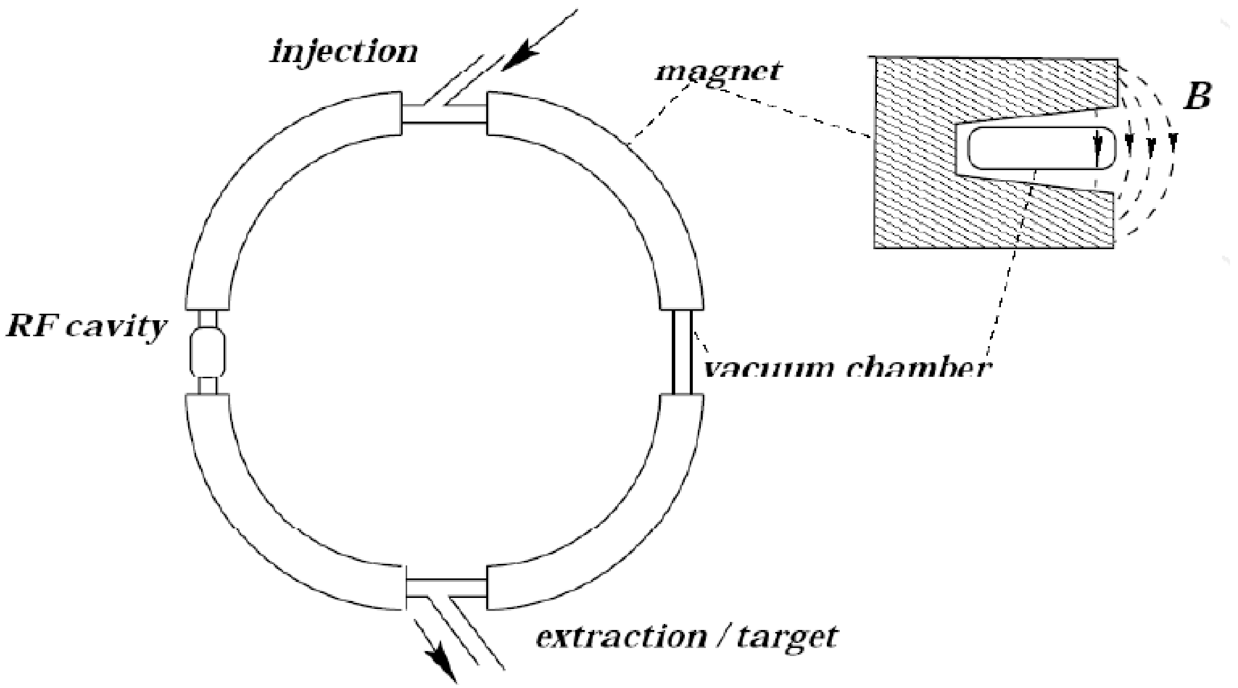
Magnetic force



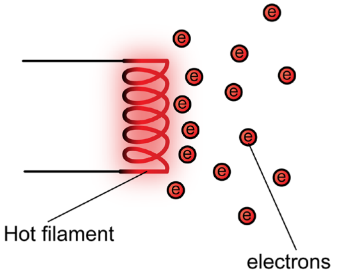
Change direction
--> Control & Focus

Basic components of accelerator

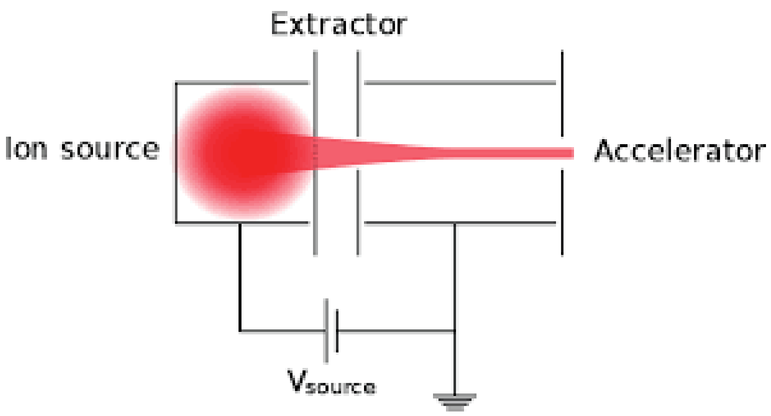
- Particle source
- Accelerating system
- Guiding system
- Focusing system



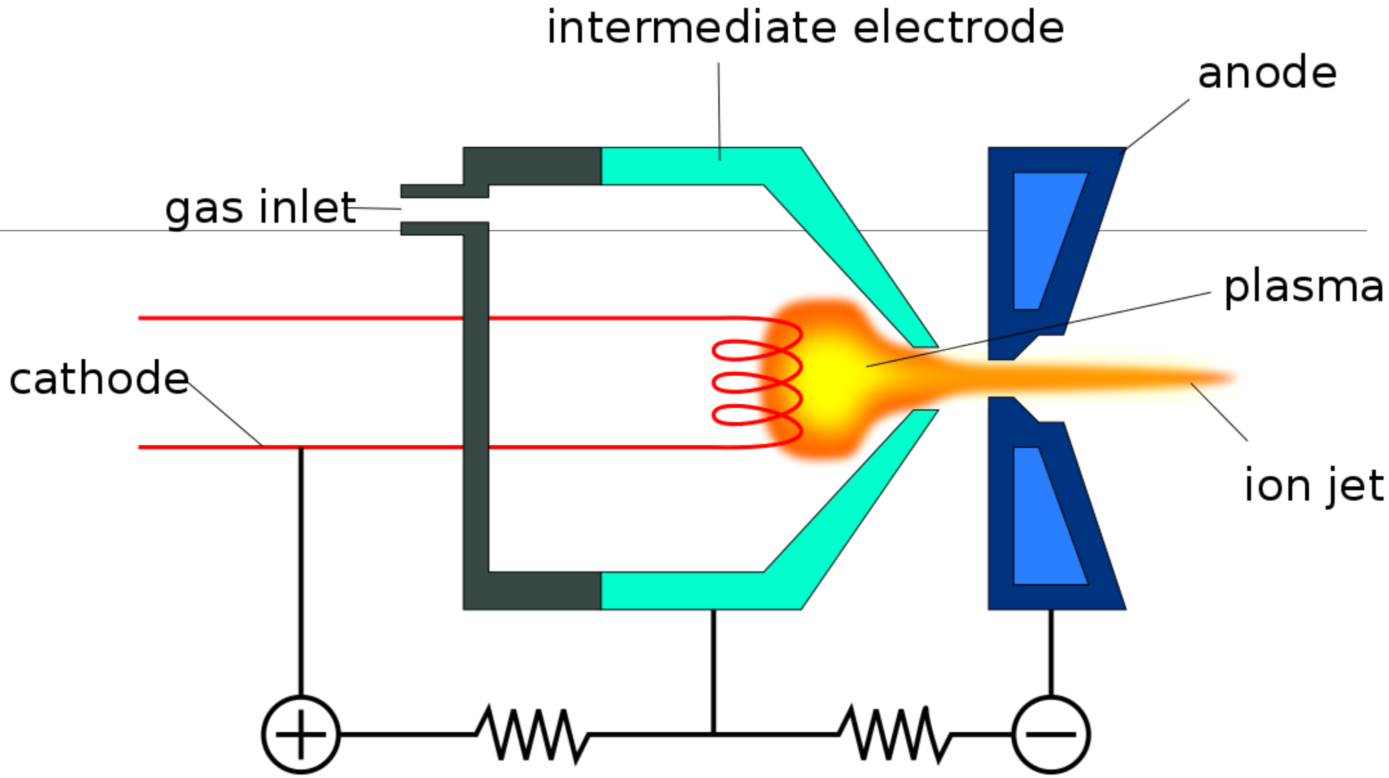
Particle sources



particle emitter

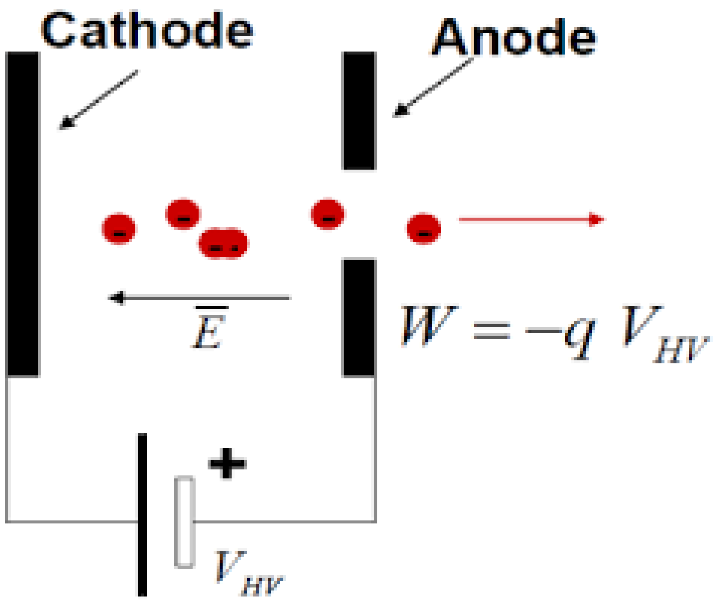


layout

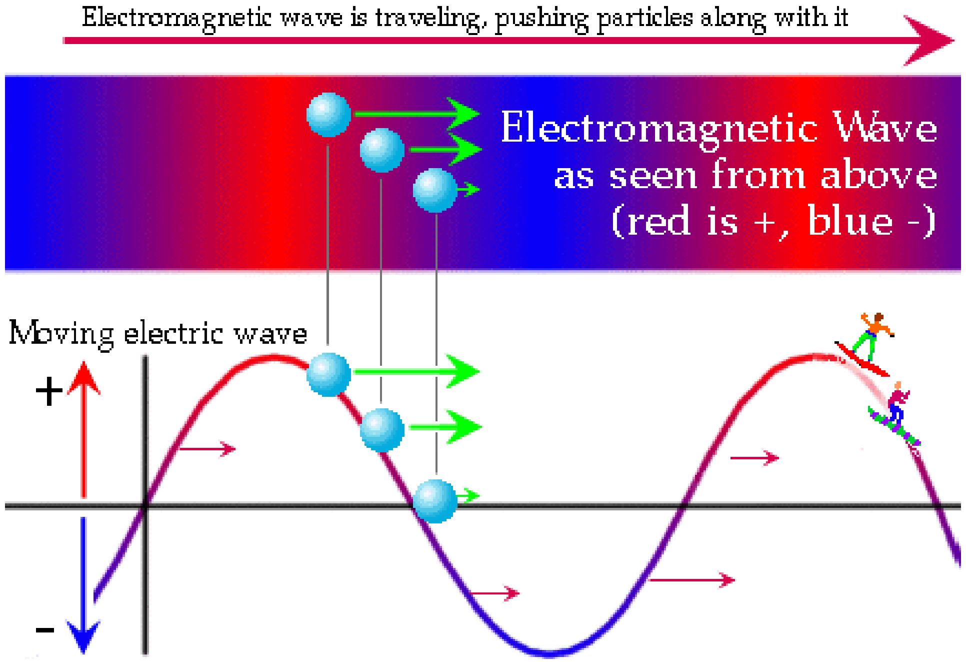


- Charged particle emitter
- Extraction system

Accelerating system - Electric field is a key !



Static field (DC) acceleration



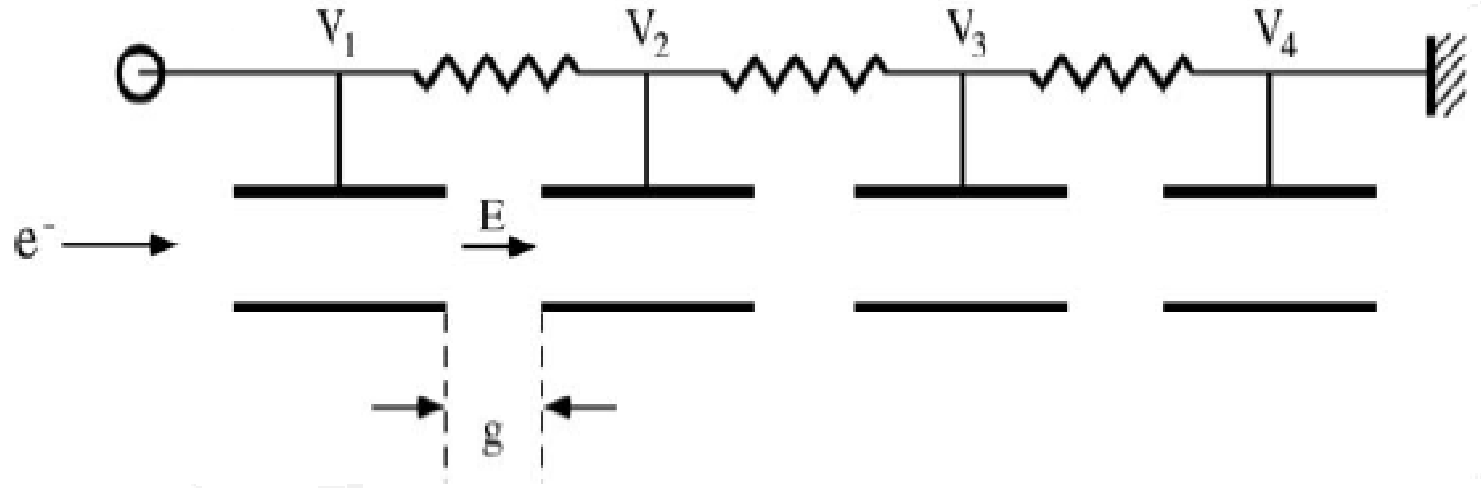
Time varying field (RF) acceleration

Accelerating system – DC Field

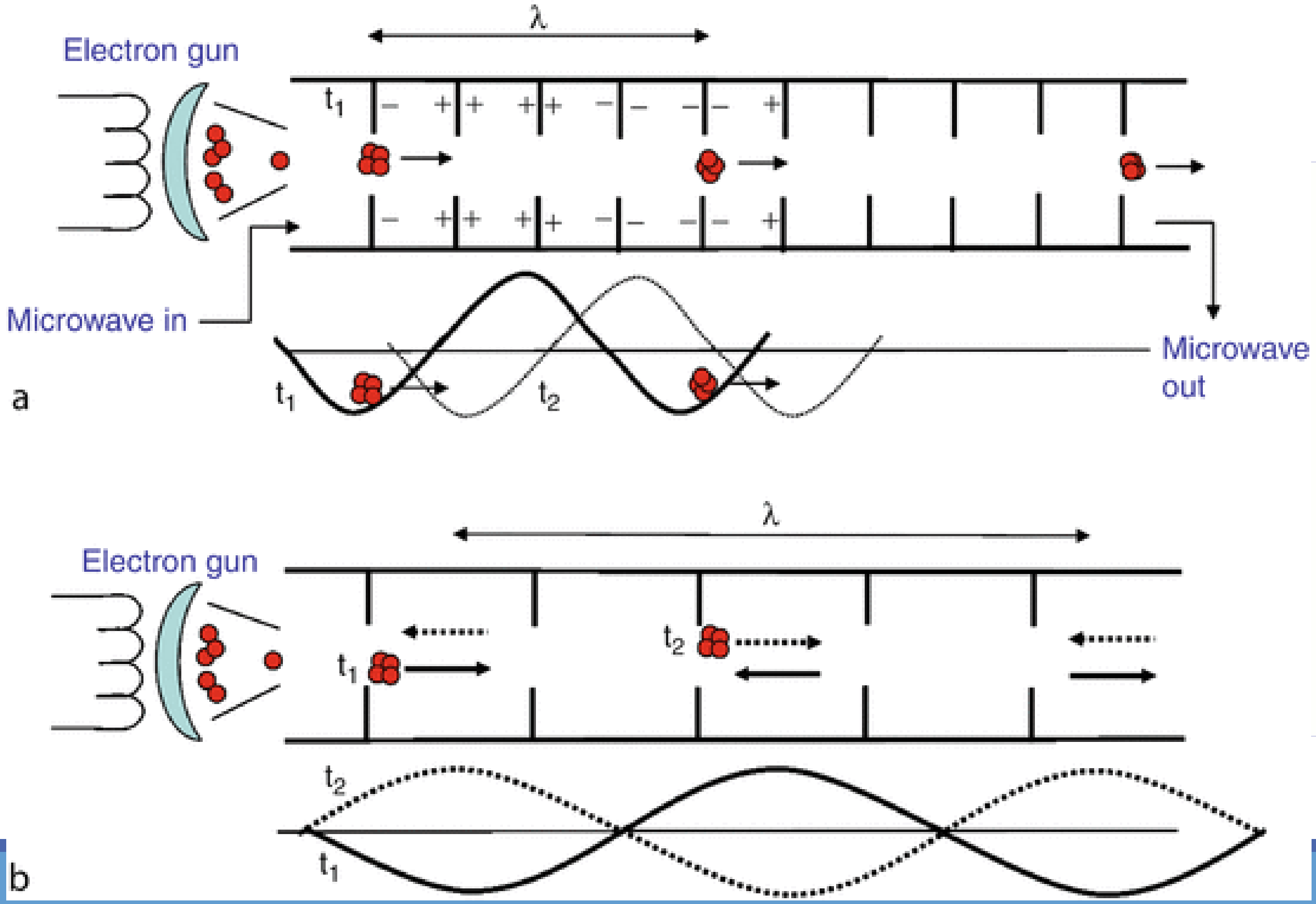
- The simplest acceleration method: DC Voltage

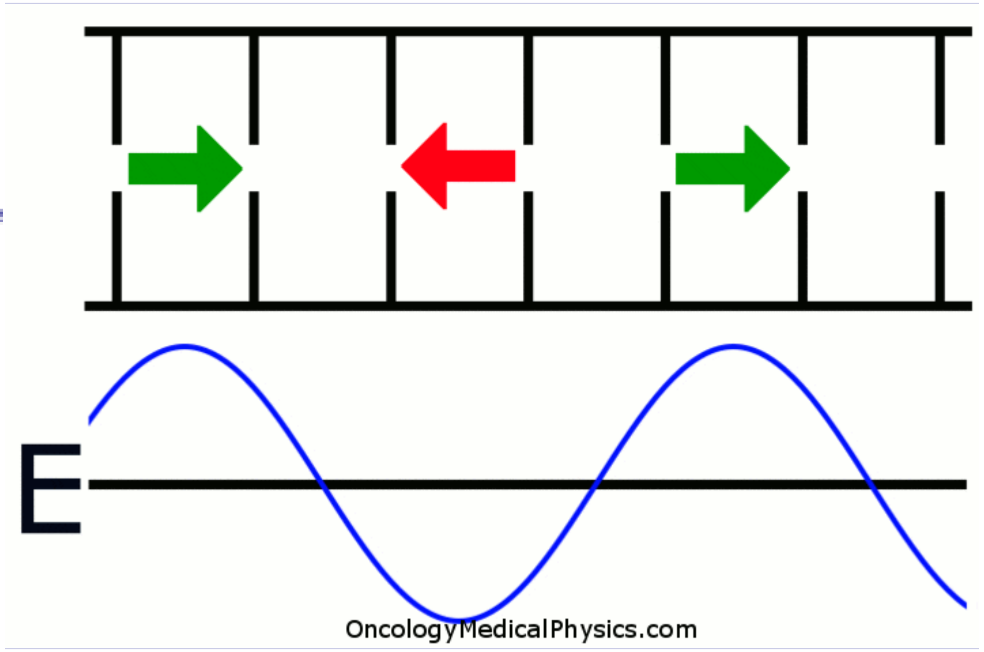
- Energy kick $\Delta E = qV$

- Breakdown at $\approx$10 MV

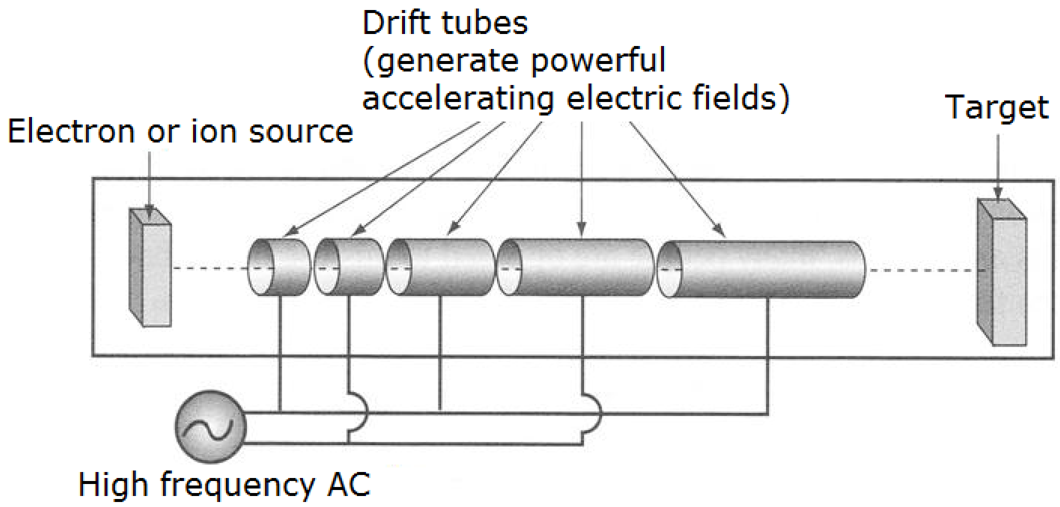


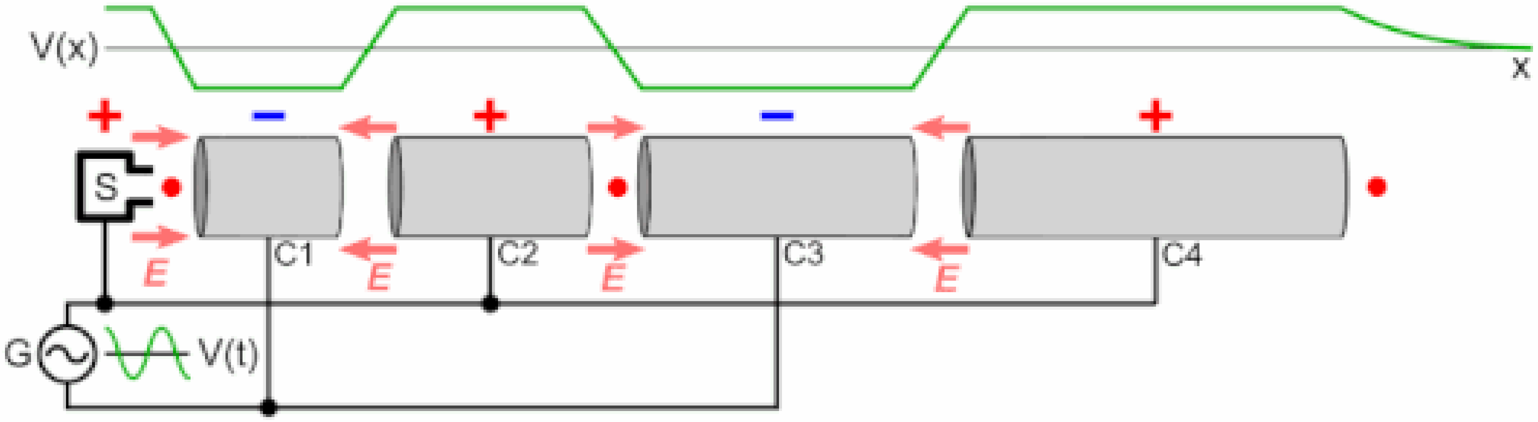
Accelerating system – RF Field : Disc-loaded



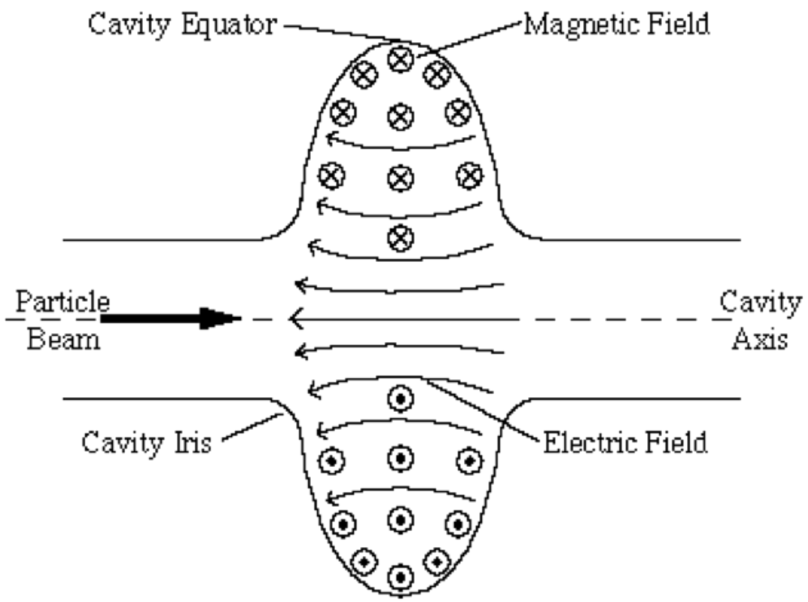


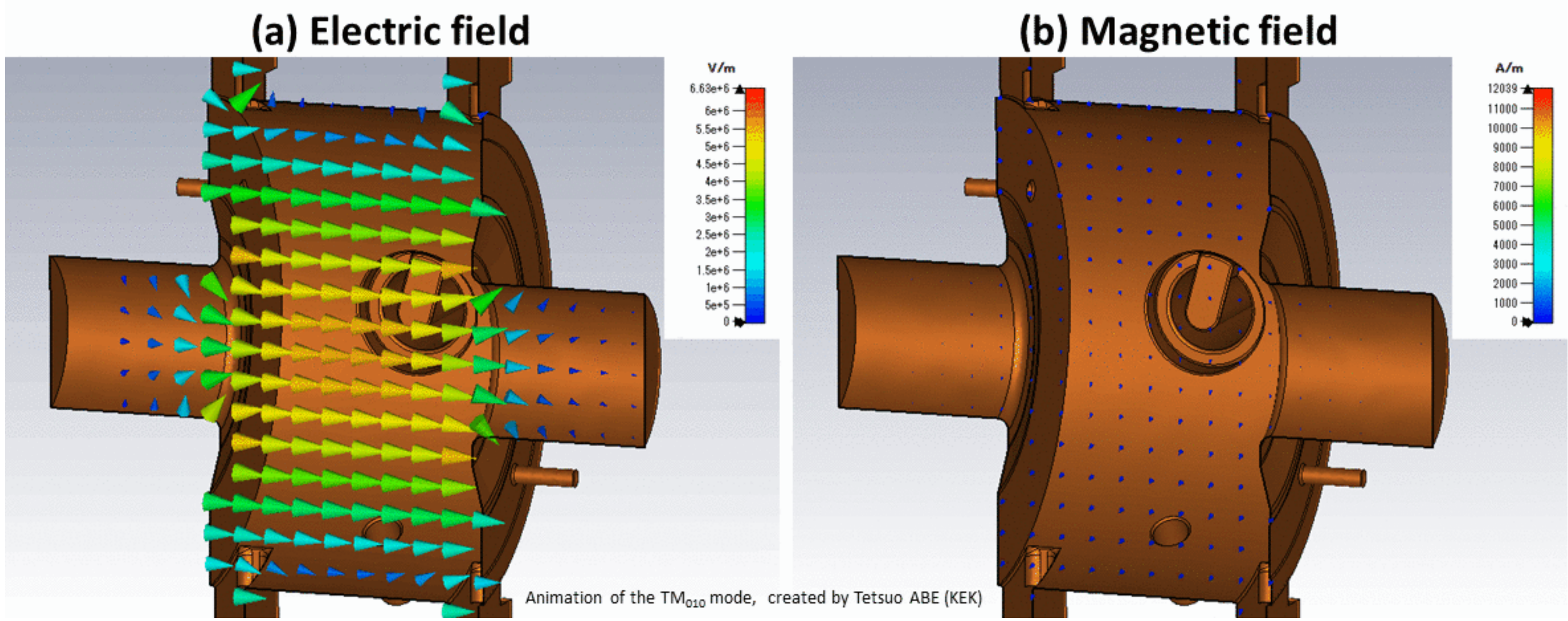
Accelerating system – RF Field : Drift Tube



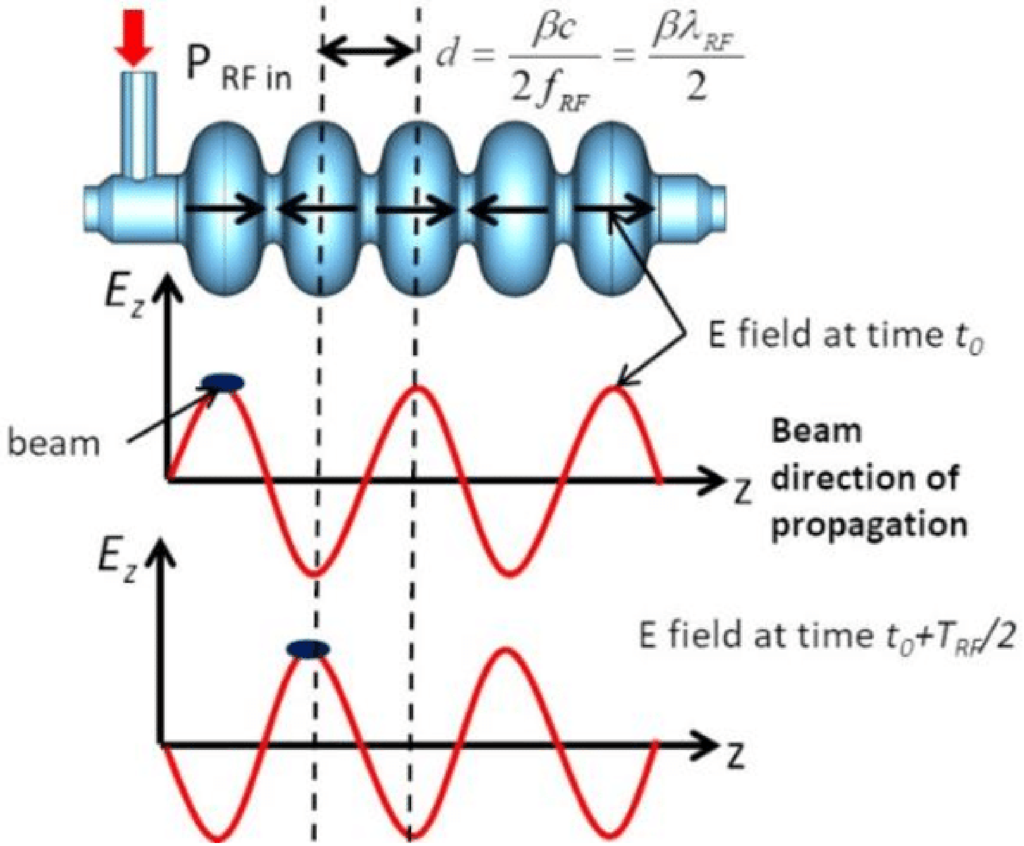


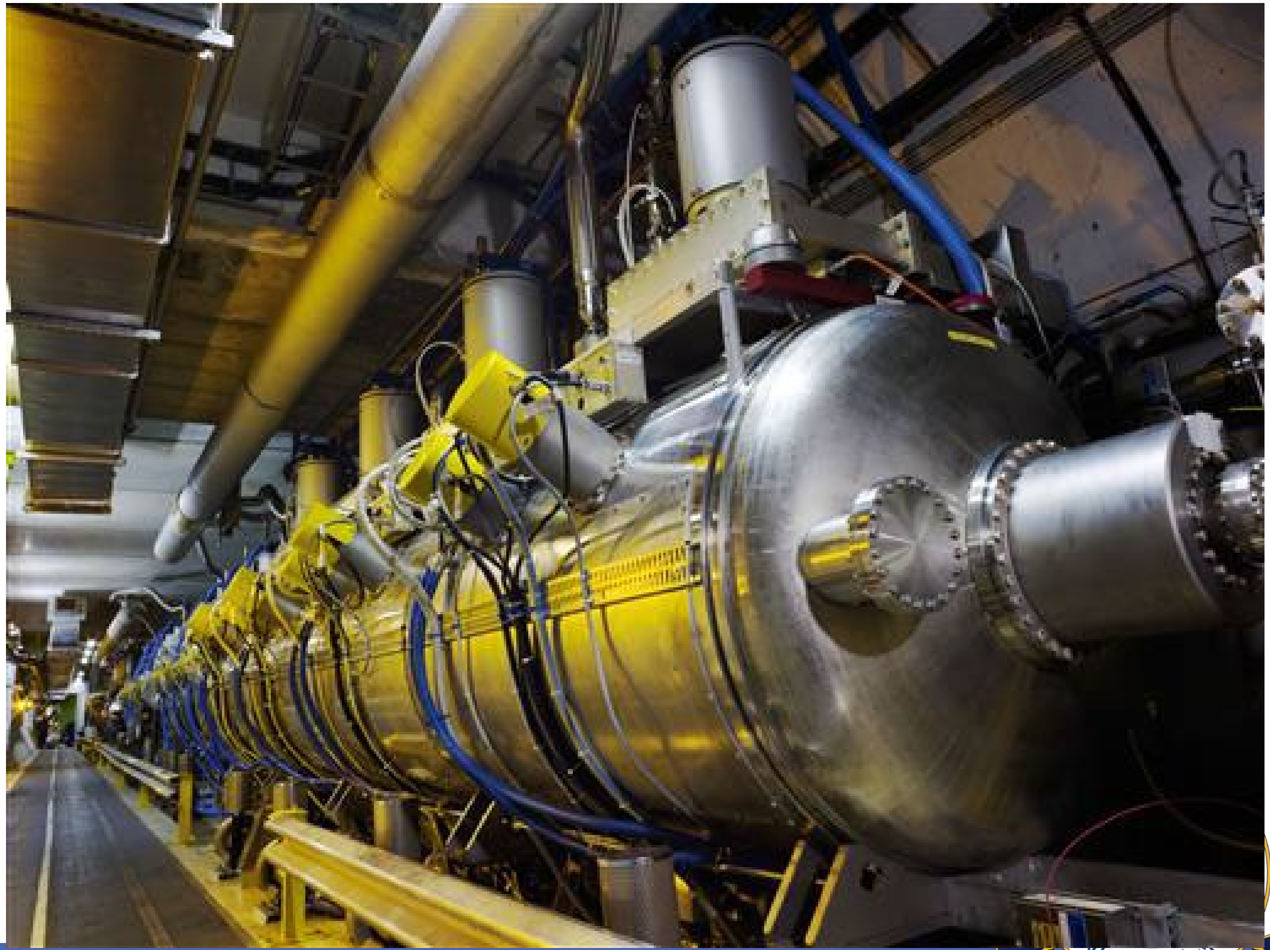
Accelerating system – RF Cavity



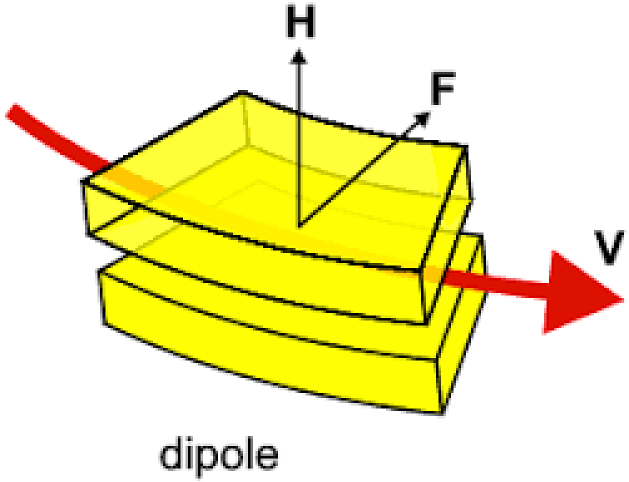


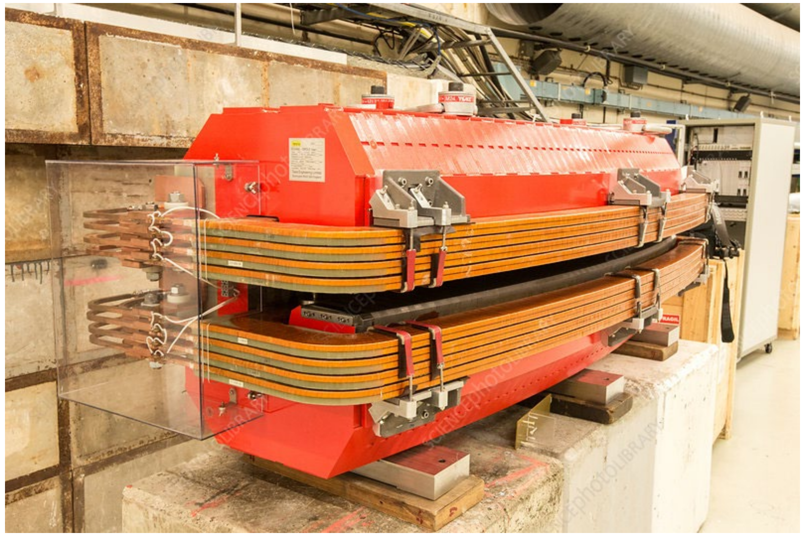
Accelerating system – RF Cavity

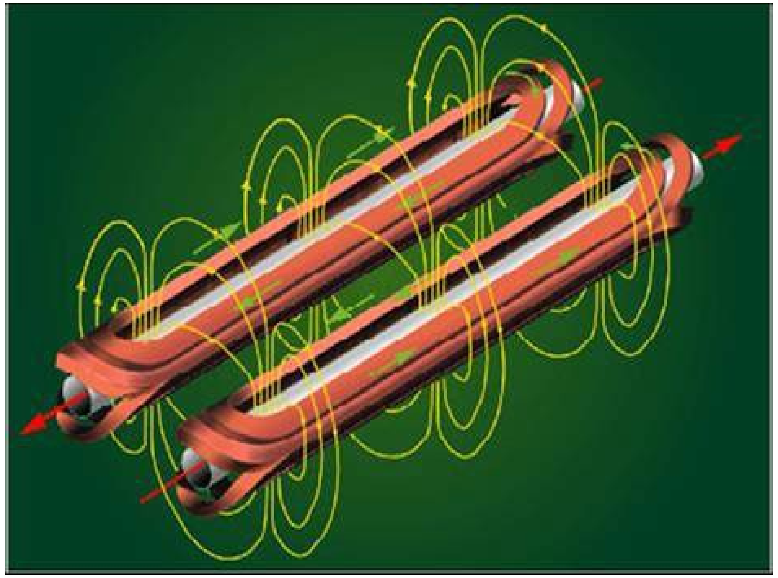




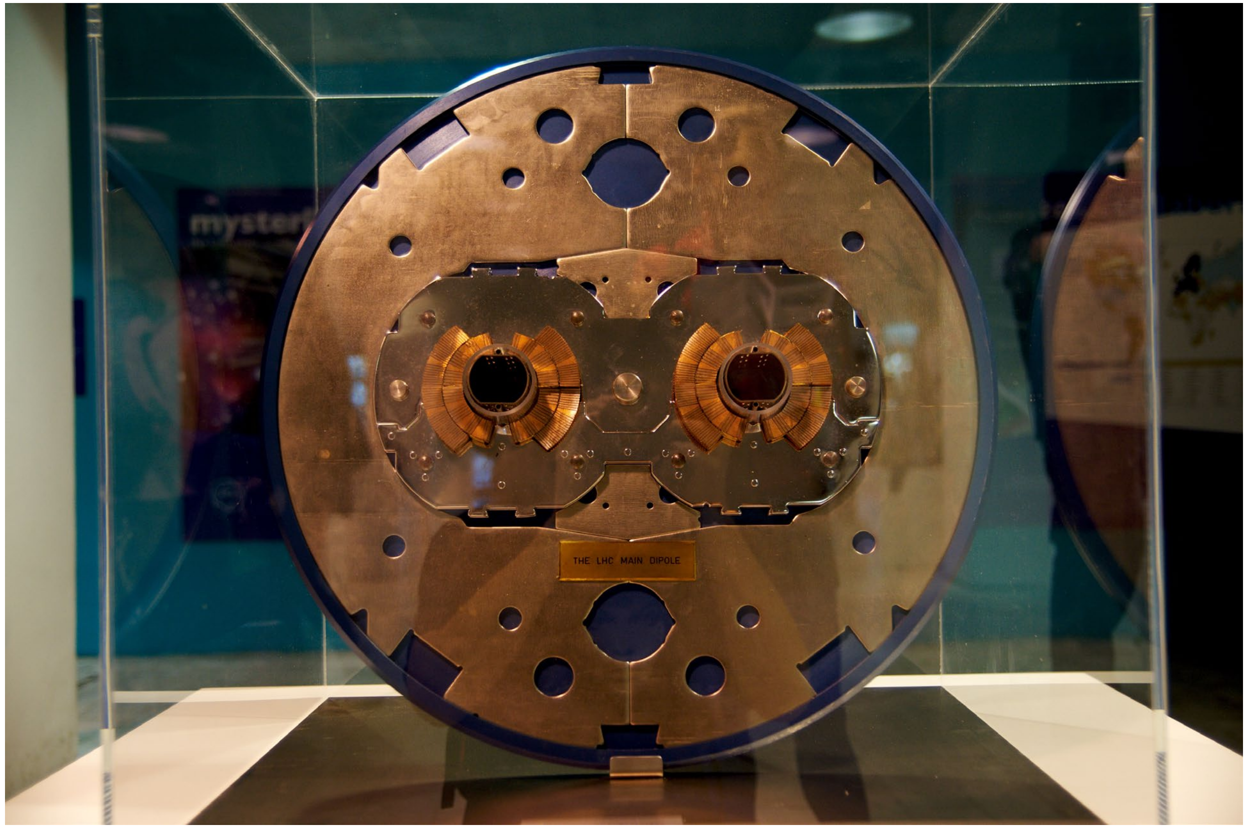
Guiding system (Dipole) – Magnetic field is a key !

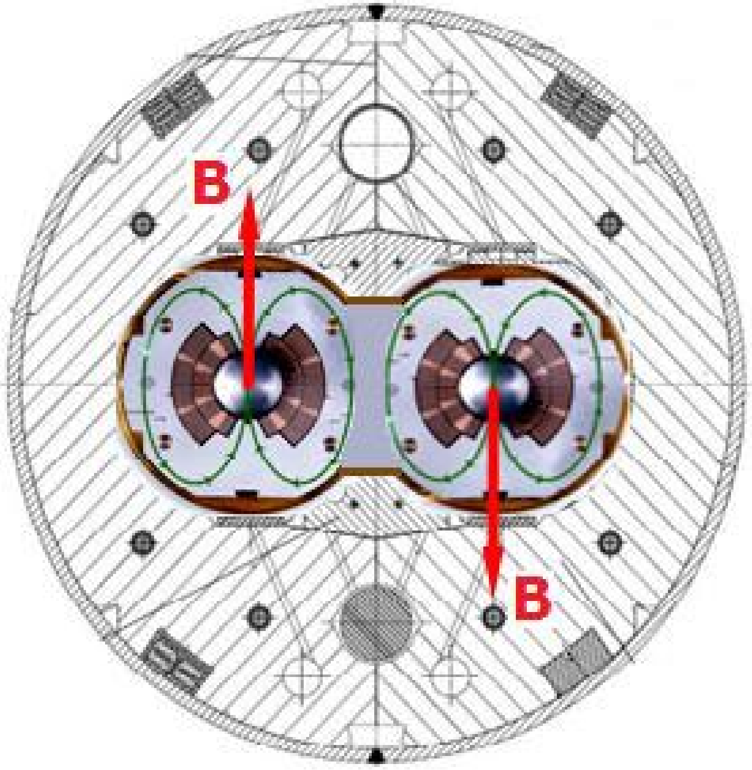




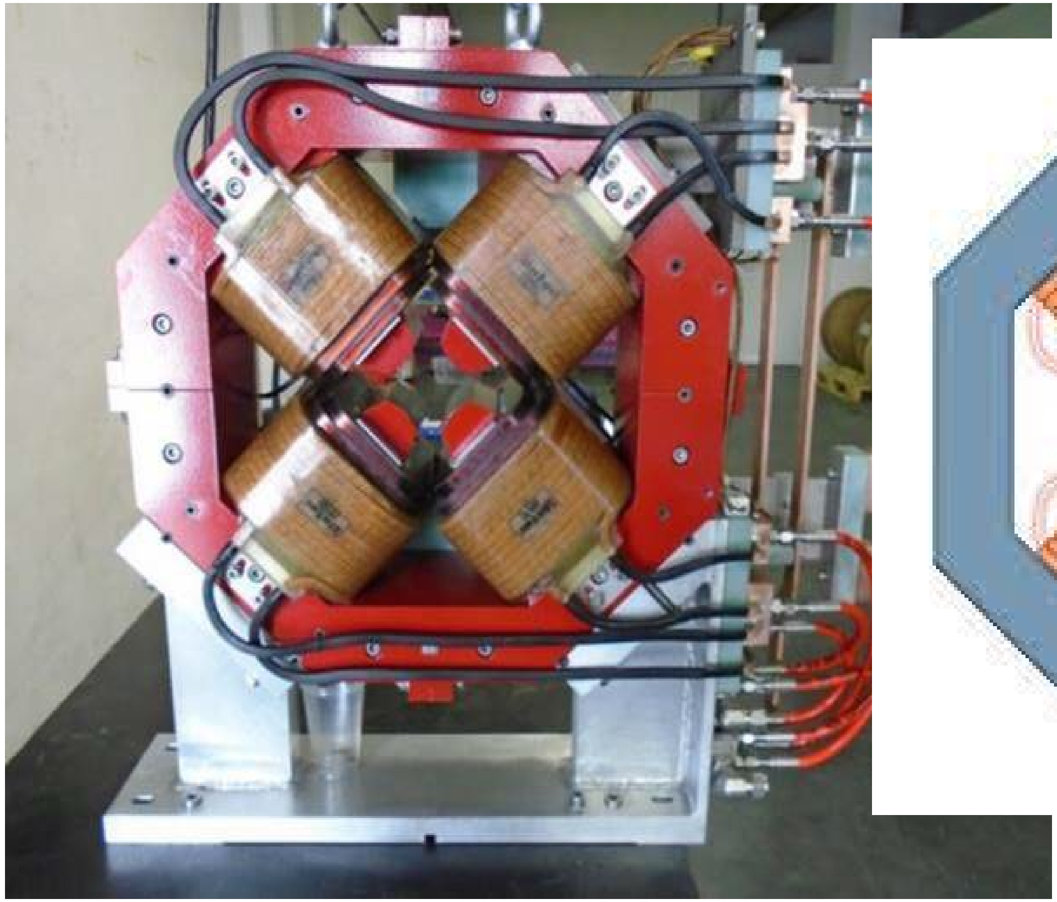


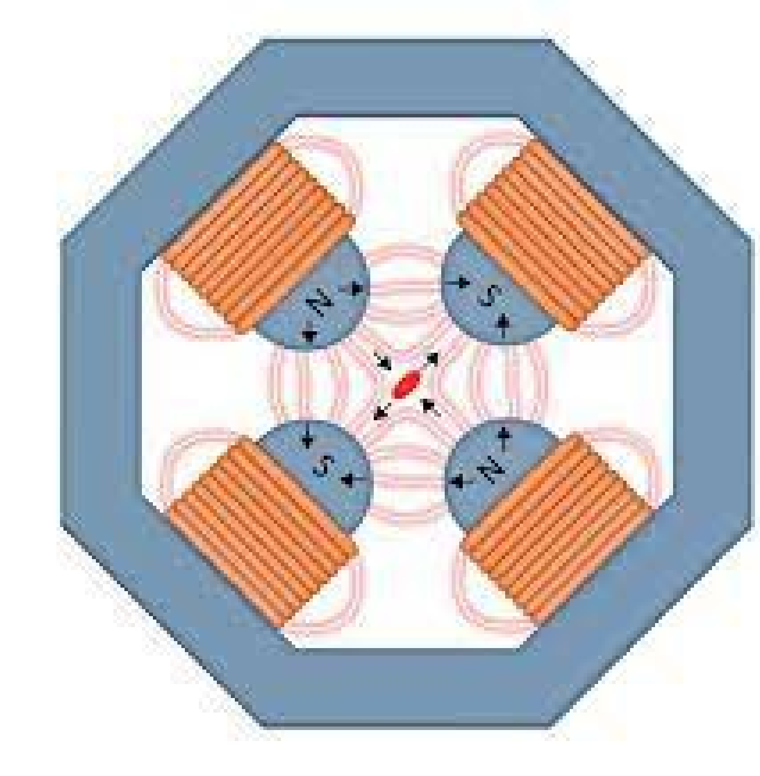
Guiding system (Dipole)

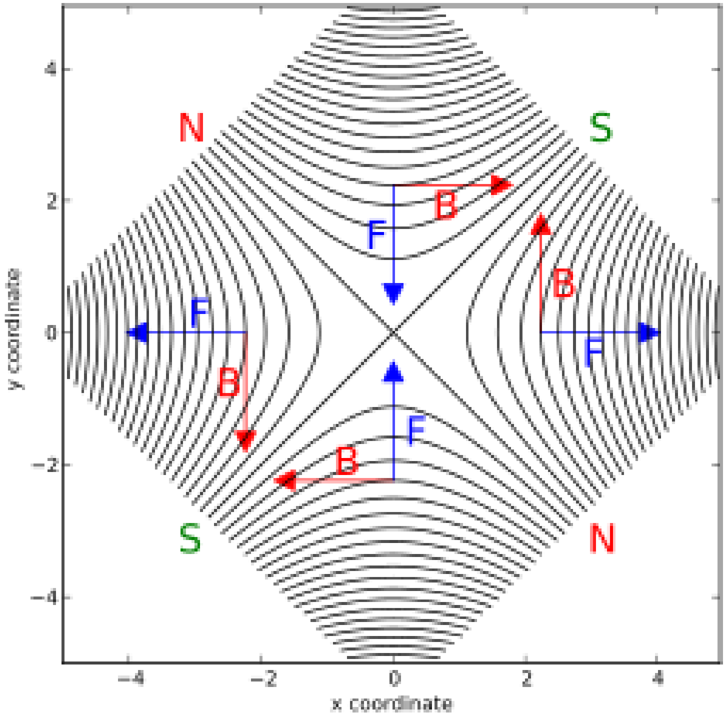




Focusing system (Quadrupole)







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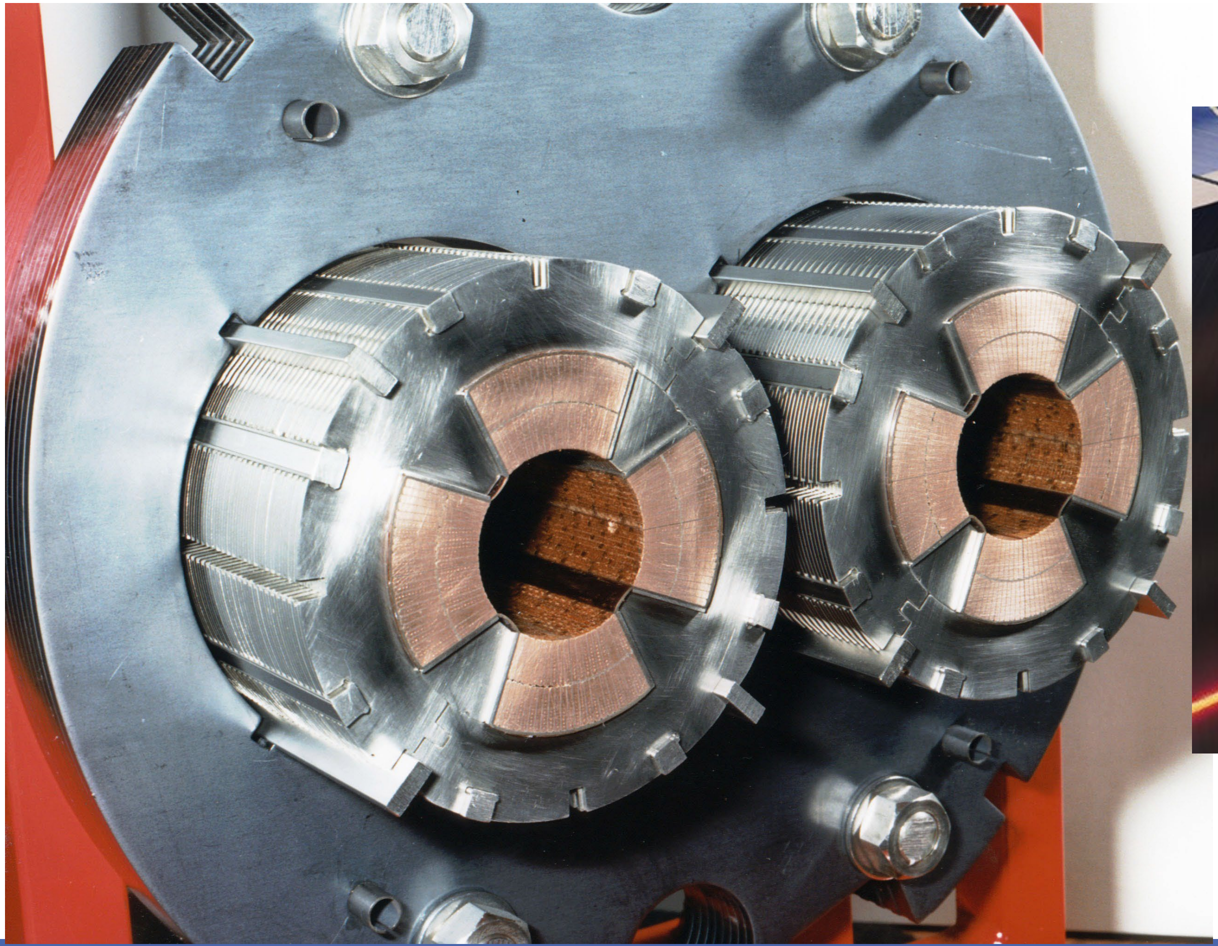
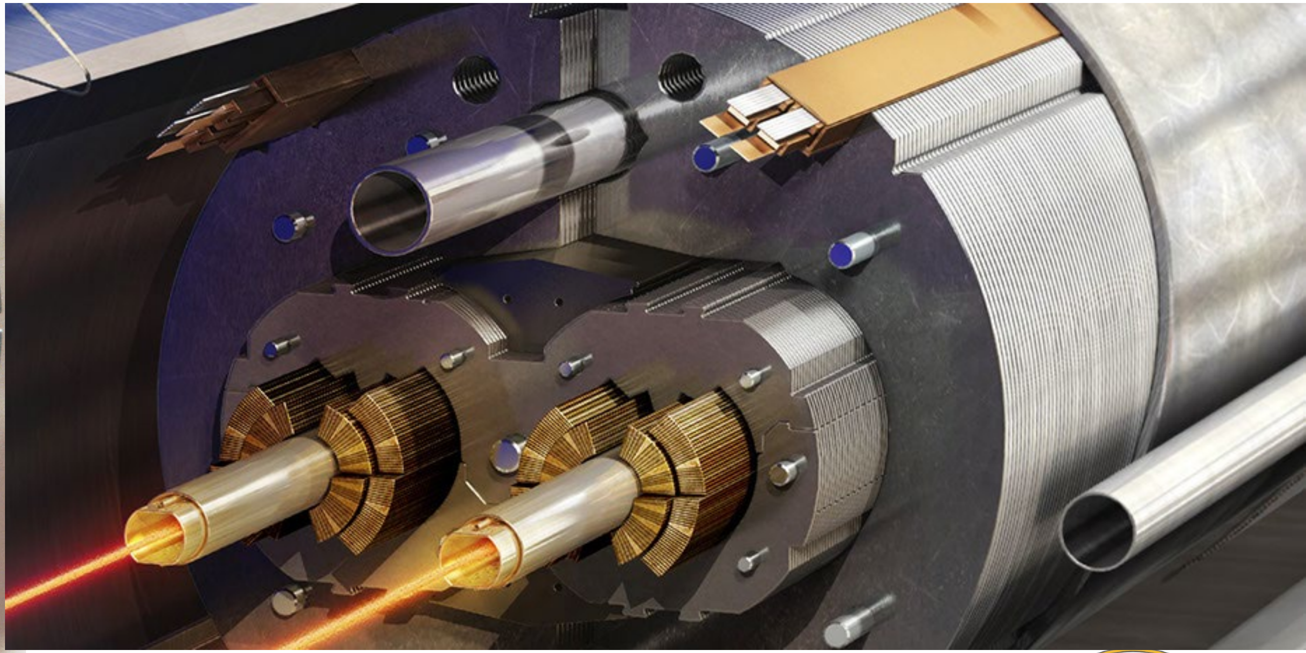
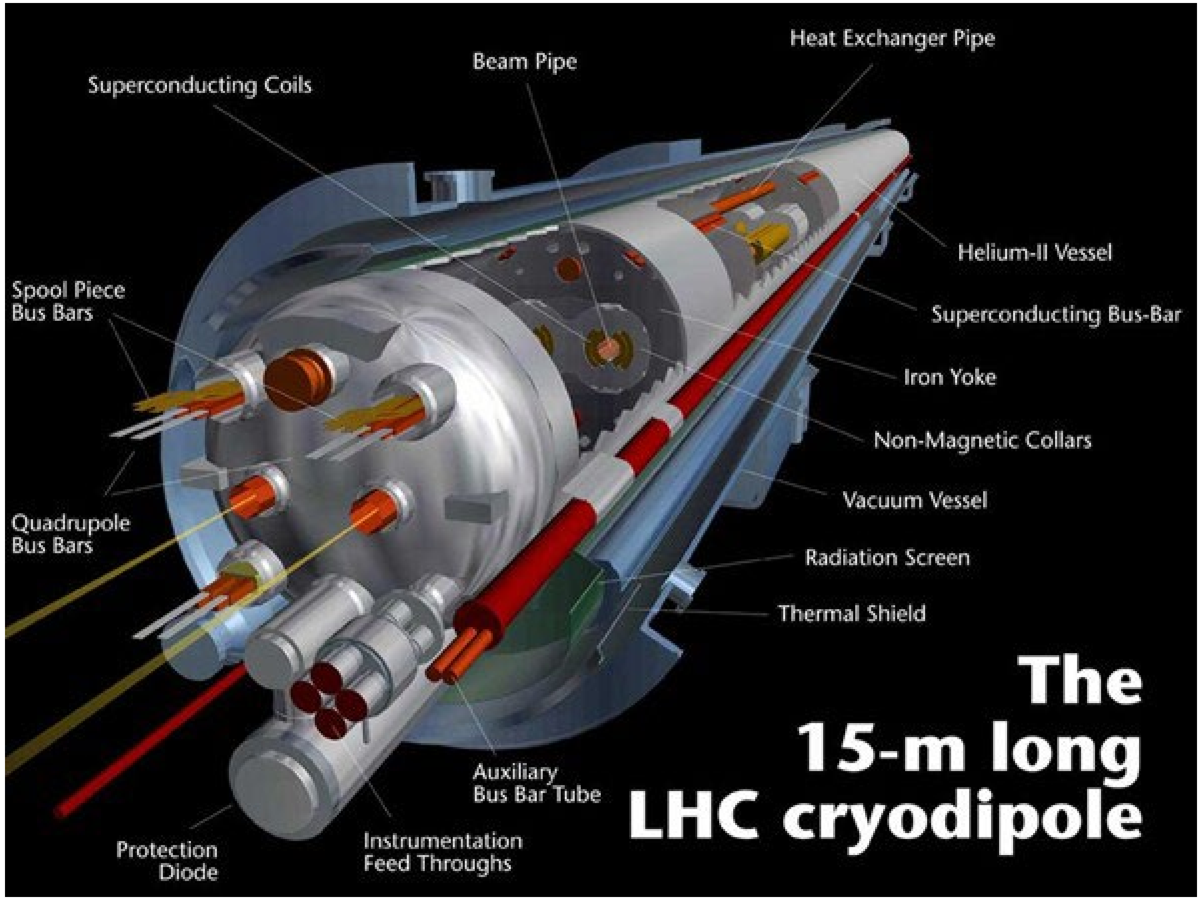
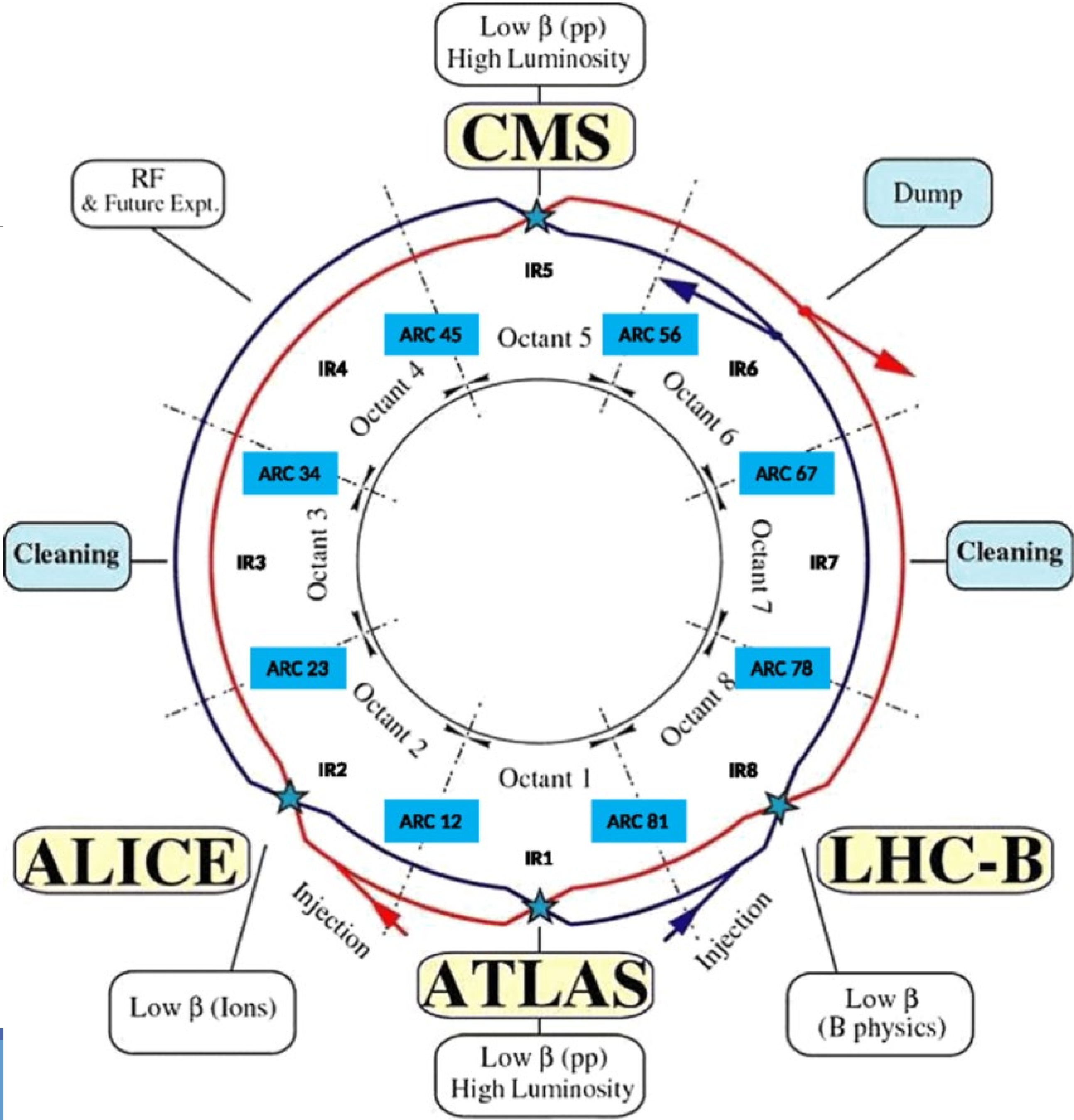


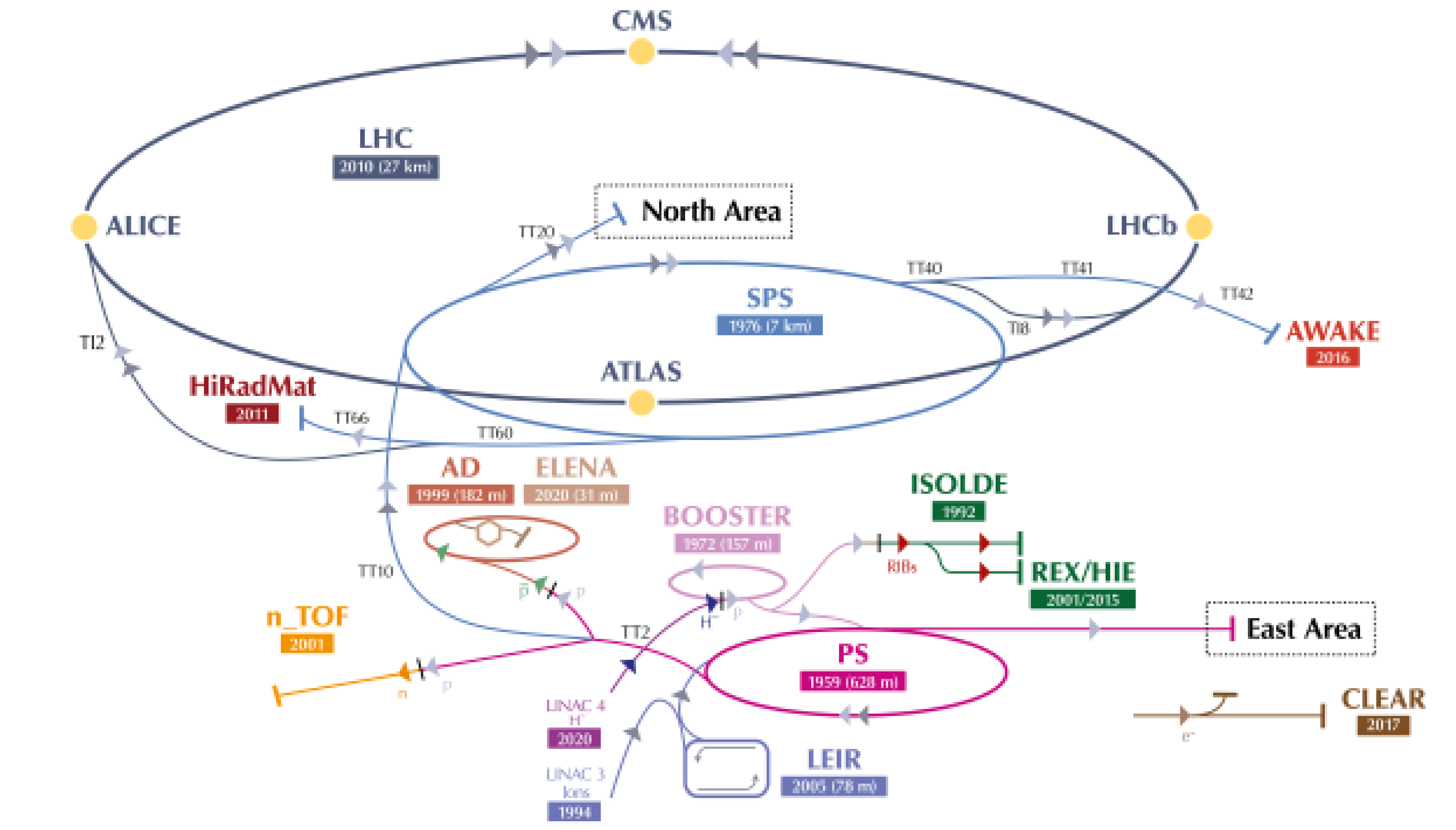


Large Hadron Collider - LHC





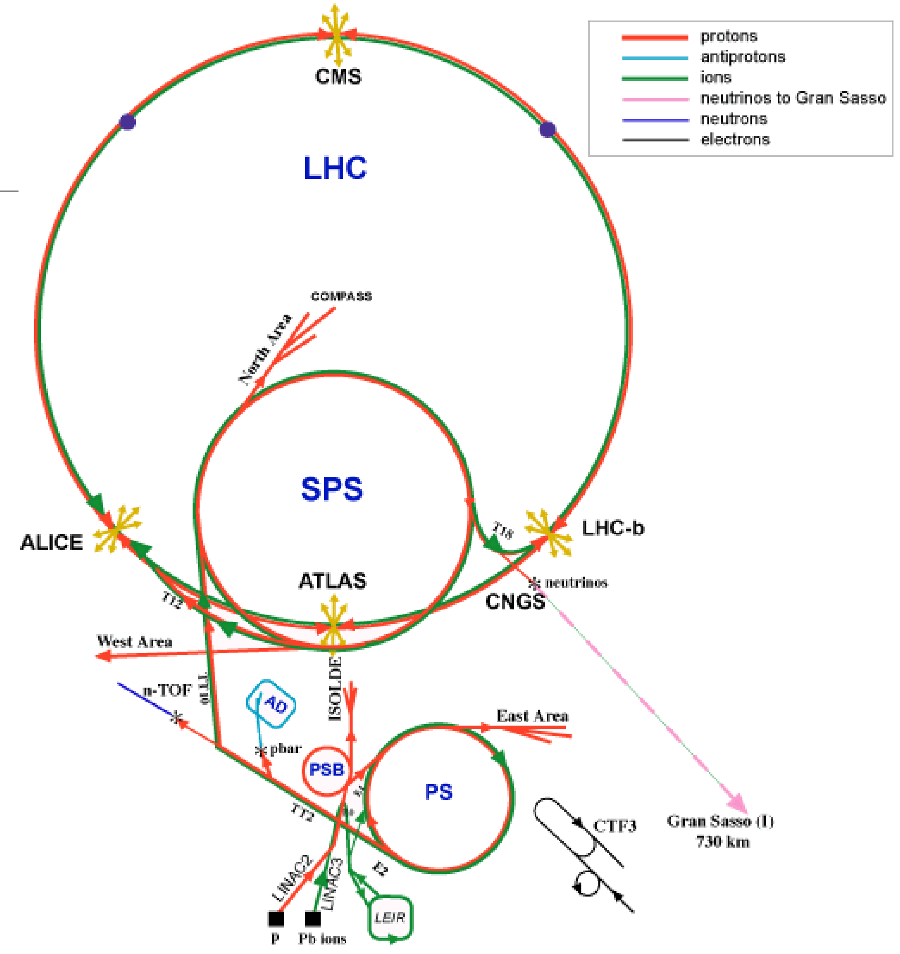
The CERN accelerator complex
Complexe des accélérateurs du CERN



H⁻ (hydrogen anions) p (protons) ions RIBs (Radioactive Ion Beams) n (neutrons) p̄ (antiprotons) e⁻ (electrons)

LHC - Large Hadron Collider // SPS - Super Proton Synchrotron // PS - Proton Synchrotron // AD - Antiproton Decelerator // CLEAR - CERN Linear Electron Accelerator for Research // AWAKE - Advanced WAKefield Experiment // ISOLDE - Isotope Separator OnLine // REX/HIE - Radioactive EXperiment/High Intensity and Energy ISOLDE // LEIR - Low Energy Ion Ring // LINAC - LINear ACcelerator // n_TOF - Neutrons Time Of Flight // HiRadMat - High-Radiation to Materials

CERN Accelerators
(not to scale)



LHC: Large Hadron Collider
SPS: Super Proton Synchrotron
AD: Antiproton Decelerator
ISOLDE: Isotope Seperator OnLine DEvice
PSB: Proton Synchrotron Booster
PS: Proton Synchrotron
LINAC: LINear ACcelerator
LEIR: Low Energy Ion Ring
CNGS: Cern Neutrinos to Gran Sasso