





Introduction to Particle Accelerators @ CERN

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Contents

- Why Accelerators and Colliders ?
- The CERN Accelerator Complex
- An Accelerator's Main Ingredients
- A brief word on the Future
- Opportunities for Industry

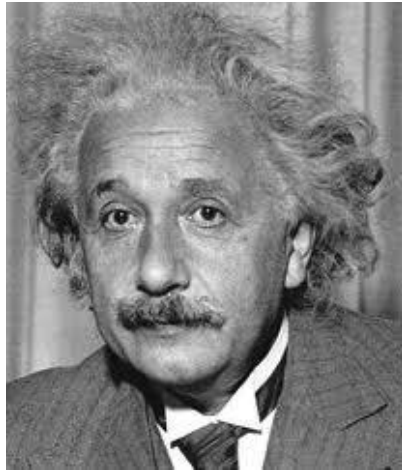


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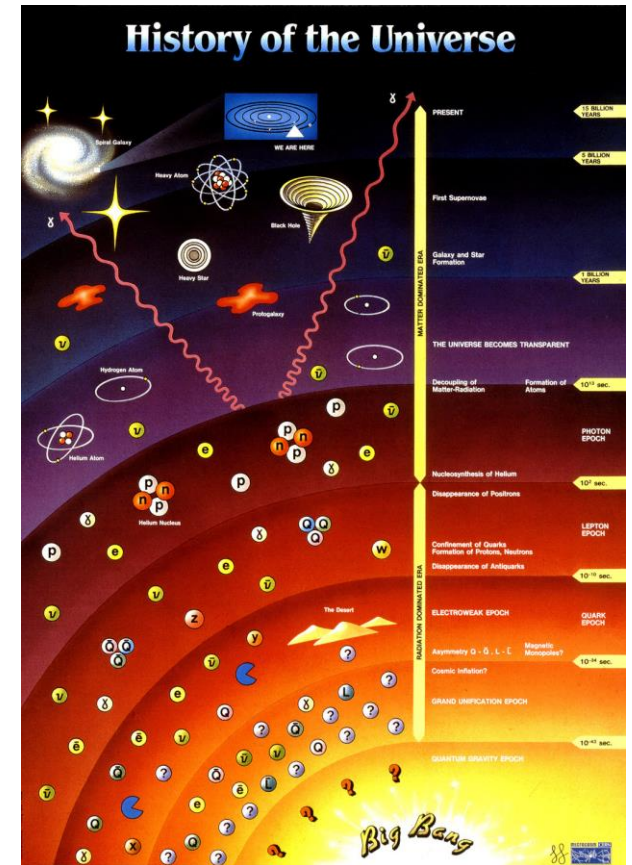
Creating Matter from Energy

$$E = m c^2$$

During the Big Bang Energy was transformed in matter



In our accelerators we provide energy to the particles we accelerate.
In the detectors we observe the matter created



Looking to smaller dimensions

Visible light

$\lambda = 400 \rightarrow 700 \text{ nm}$



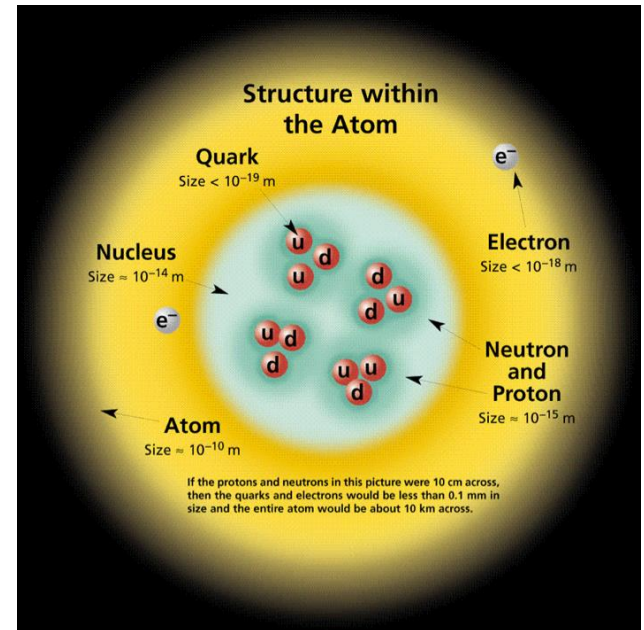
X-ray

$\lambda = 0.01 \rightarrow 10 \text{ nm}$



Particle accelerators

$\lambda < 0.01 \text{ nm}$



$$\lambda = \frac{h c}{E}$$

Increasing the energy will reduce the wavelength

Fixed Target vs. Colliders

Fixed Target



$$E \propto \sqrt{E_{beam}}$$

Much of the energy is lost in the target and only part is used to produce secondary particles

Collider



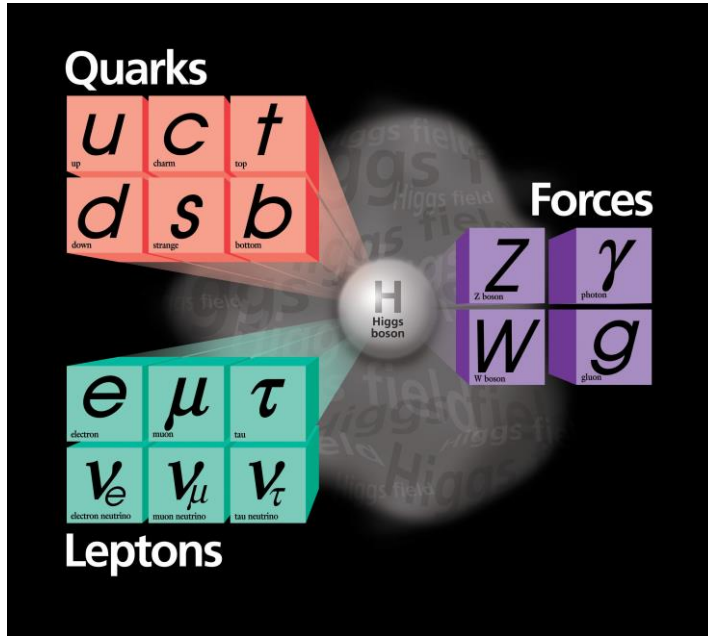
$$E = E_{beam1} + E_{beam2}$$

All energy will be available for particle production

The Aim:

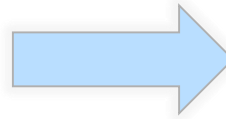
Specific assemblies of quarks form hadrons. Protons, Neutrons, pions,...

For every particle there is a corresponding anti-particle



Gravitational force
Electromagnetic force
Strong interacting force
Weak interacting force

Verify the Standard Model

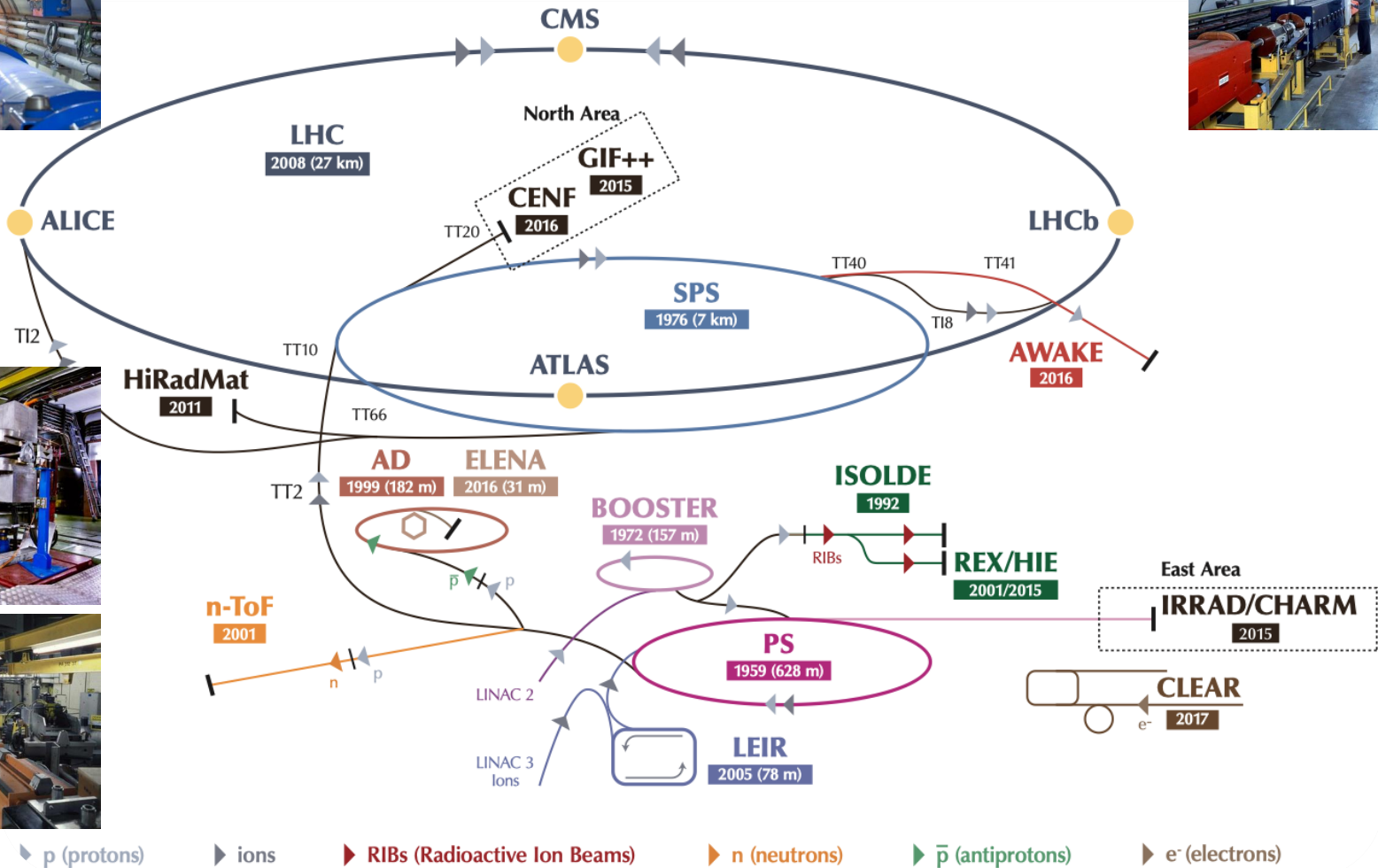


Search for physics beyond the Standard Model

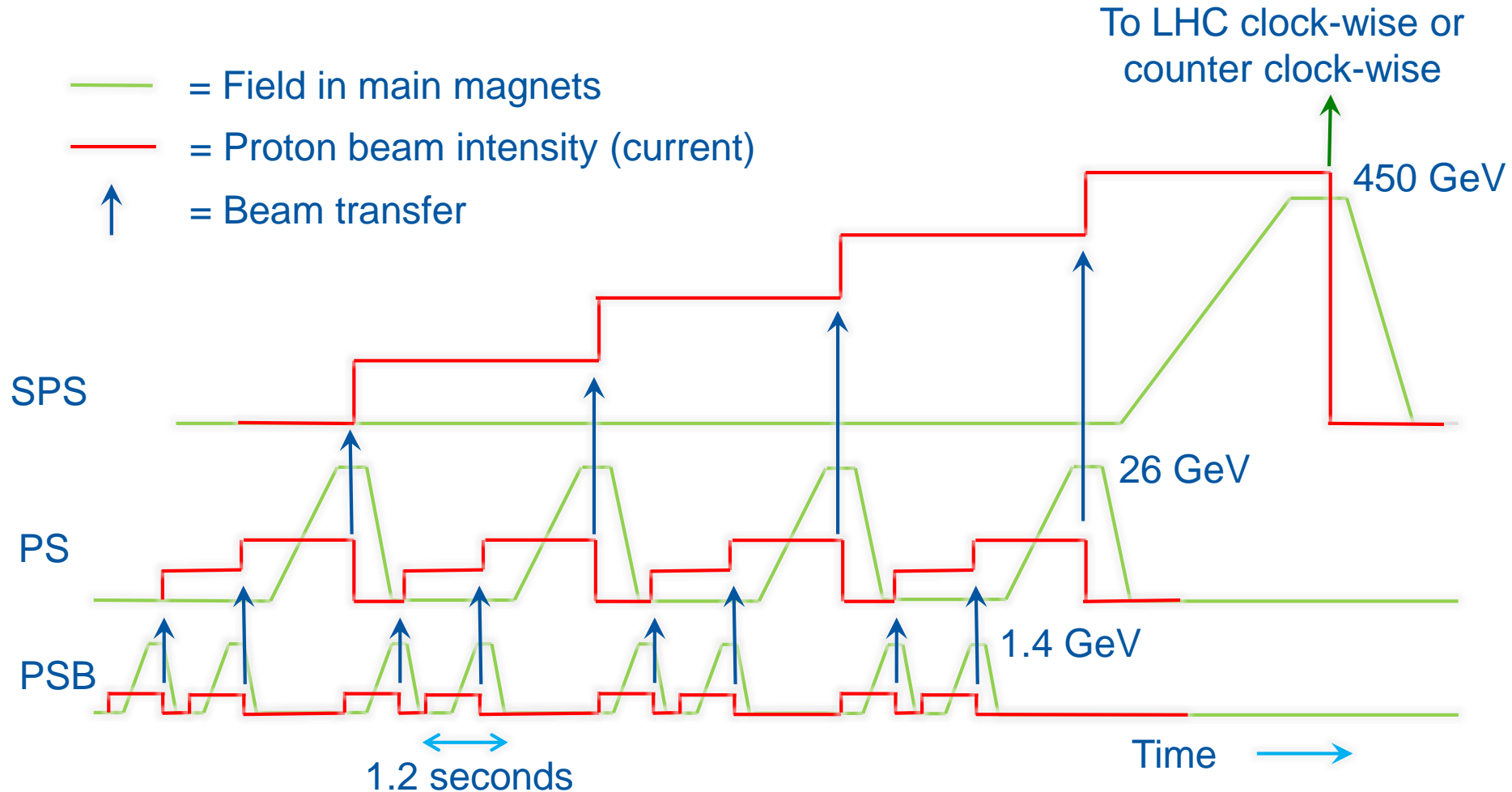


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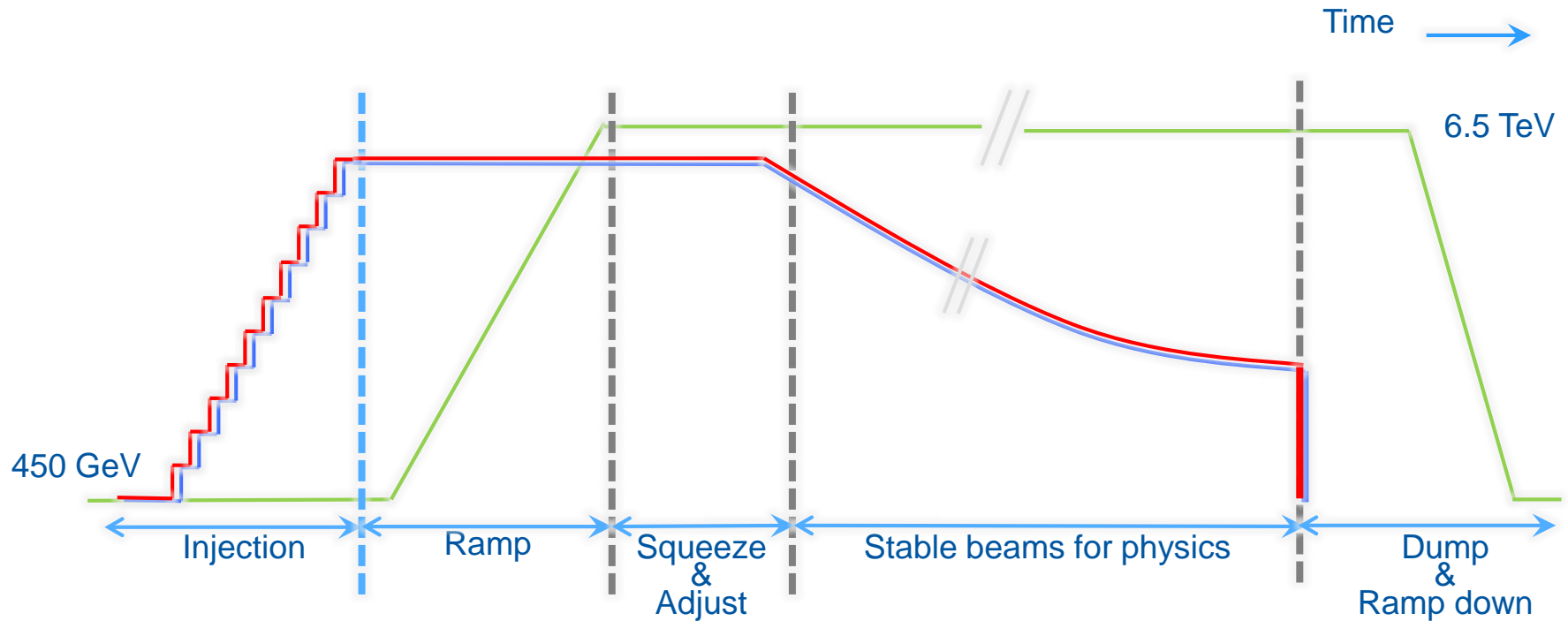
The CERN Accelerator Complex



Filling the LHC and Satisfying Fixed Target users



How does the LHC fit in this ?



- = Field in main magnets
- = Beam 1 intensity (current)
- = Beam 2 intensity (current)

The LHC is built to collide protons at 7 TeV per beam, which is **14 TeV centre of Mass**

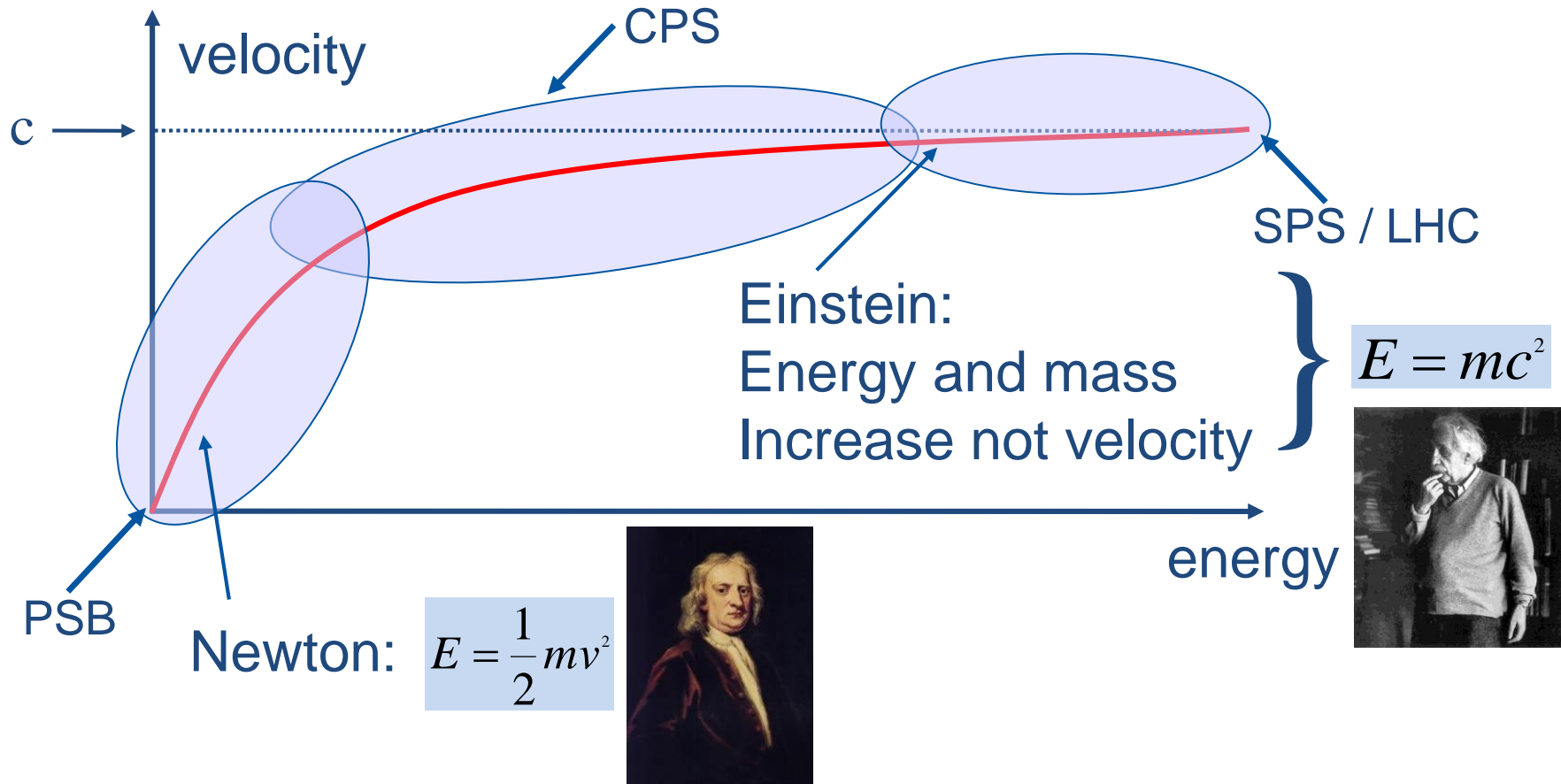
In 2012 it ran at 4 TeV per beam, 8 TeV c.o.m.

In 2015 it ran at 6.5 TeV per beam, 13 TeV c.o.m



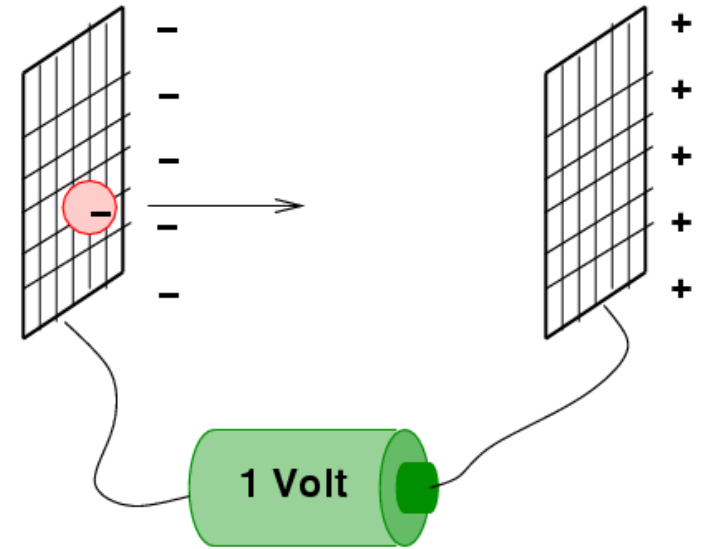
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Towards Relativity



The Units we use for Energy

- The energy acquired by an electron in a potential of 1 Volts is defined as being 1 eV
- Thus $1 \text{ eV} = 1.6 \times 10^{-19} \text{ Joules}$



- The unit eV is too small to be used today, we use:

$$1 \text{ KeV} = 10^3, \text{ MeV} = 10^6, \text{ GeV} = 10^9, \text{ TeV} = 10^{12}$$

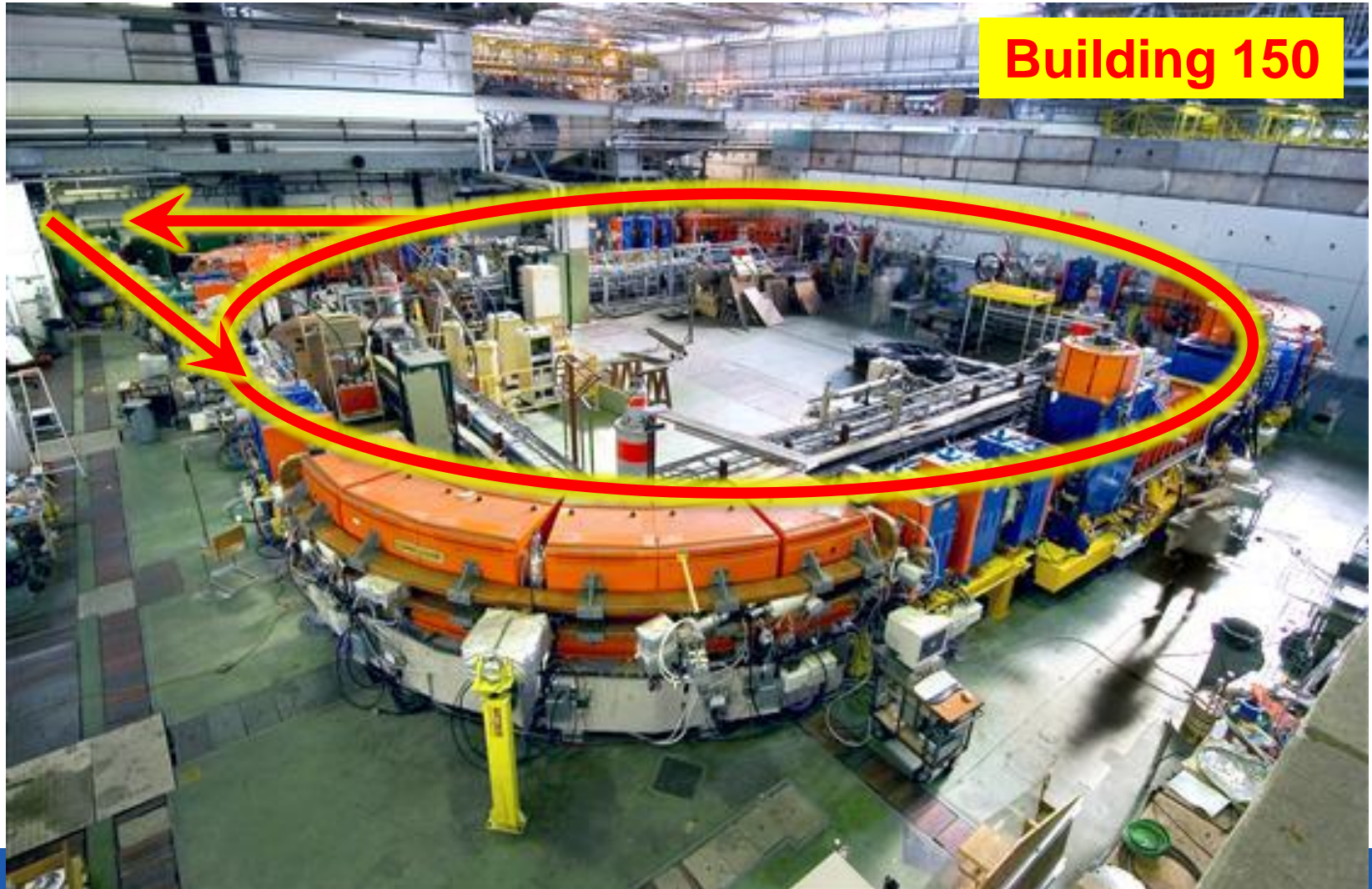
The Energy in the LHC beam

- The energy in one LHC beam at high energy is about 320 Million Joules
- This corresponds to the energy of a TGV engine going at 150 km/h



..... but then concentrated in the size of a needle

Low Energy Ion Ring as an Example

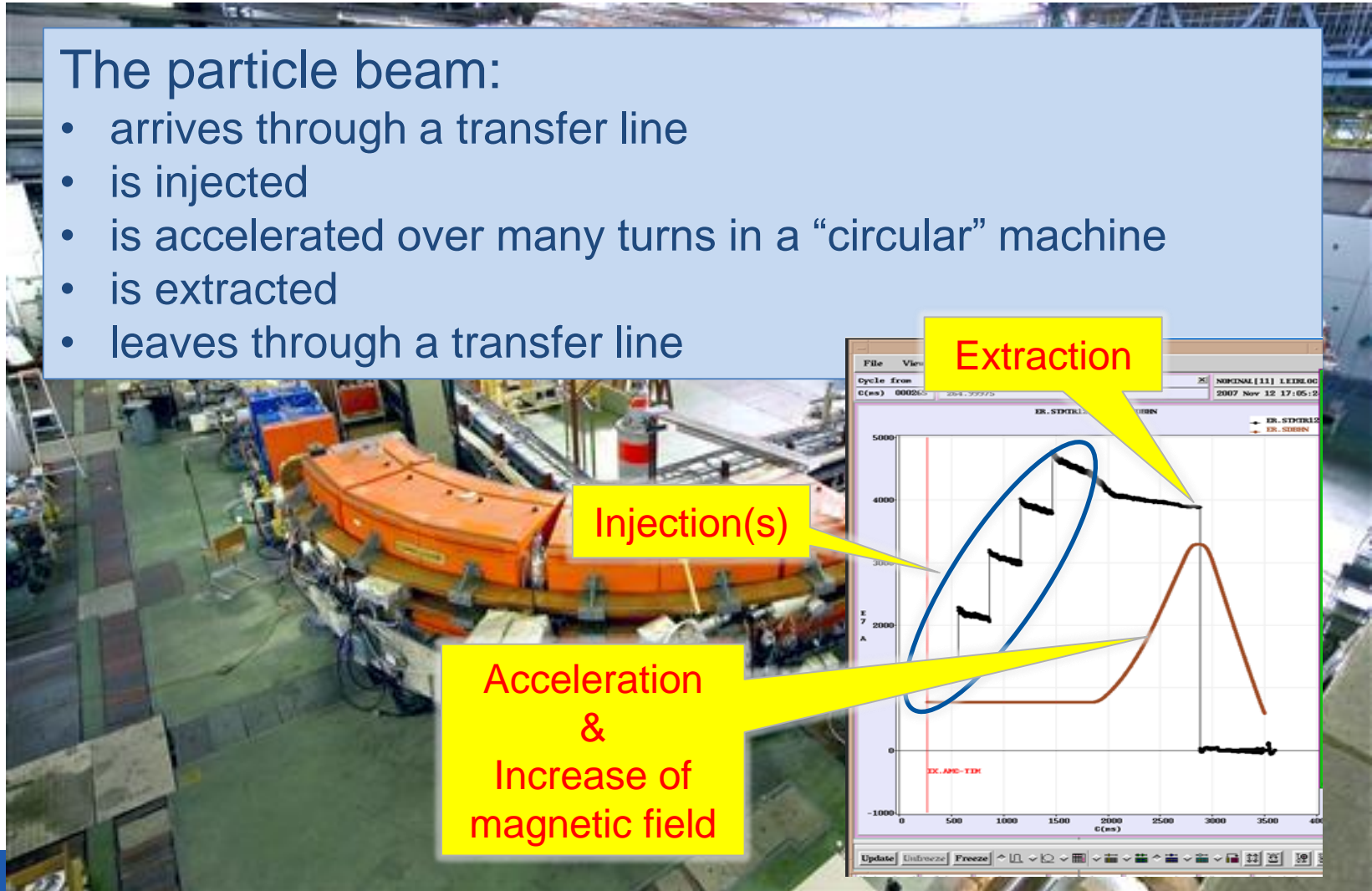


Building 150

LEIR as an Example

The particle beam:

- arrives through a transfer line
- is injected
- is accelerated over many turns in a “circular” machine
- is extracted
- leaves through a transfer line



Extraction

Injection(s)

Acceleration
&
Increase of
magnetic field

Travelling Through nothingness



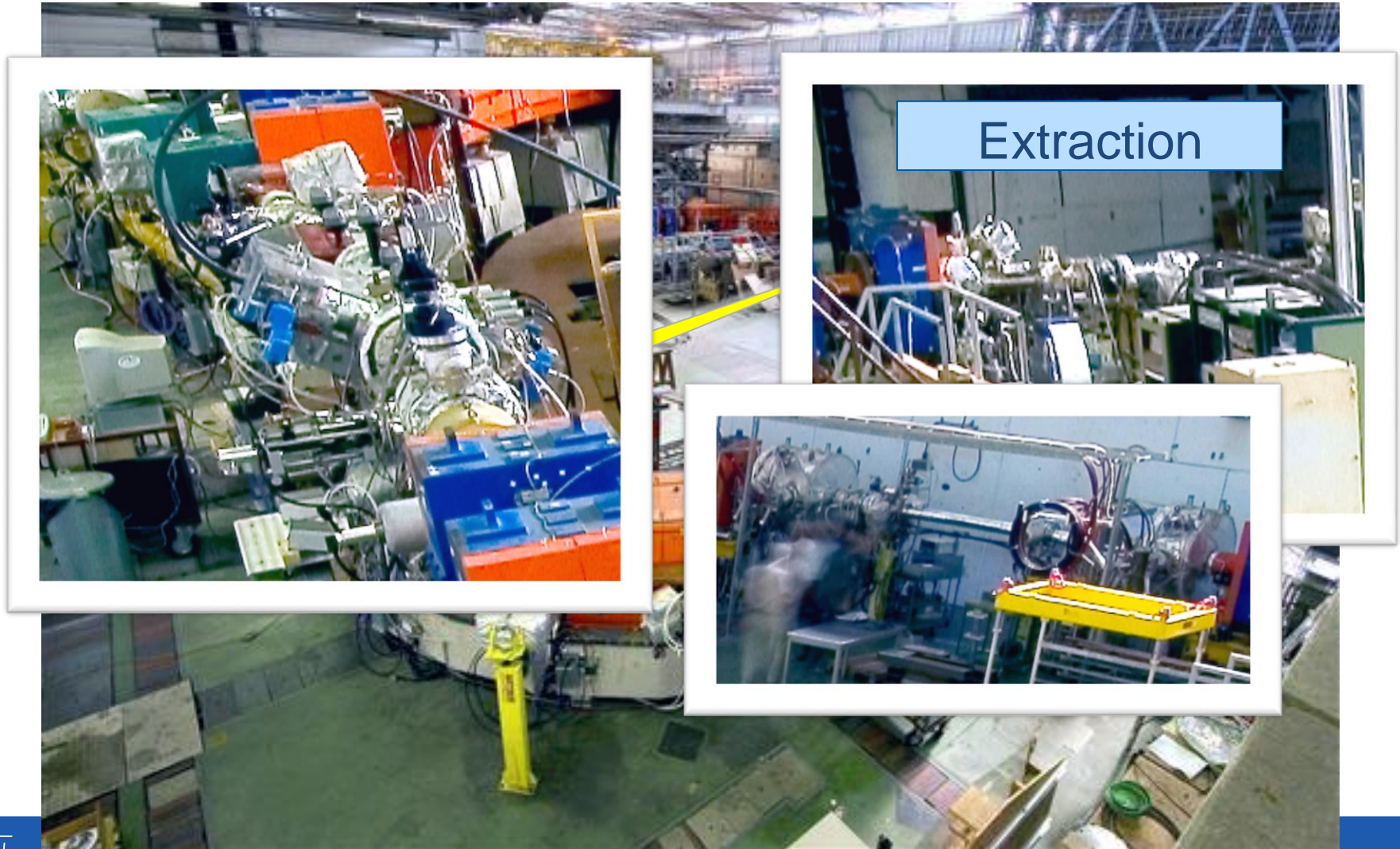
Vacuum in a mostly **stainless steel vacuum chamber** is required to **avoid** the particles to **interact** with the **gas molecules**

Especially important for low energy particles and anti-matter particles, but also for colliders Why actually ???



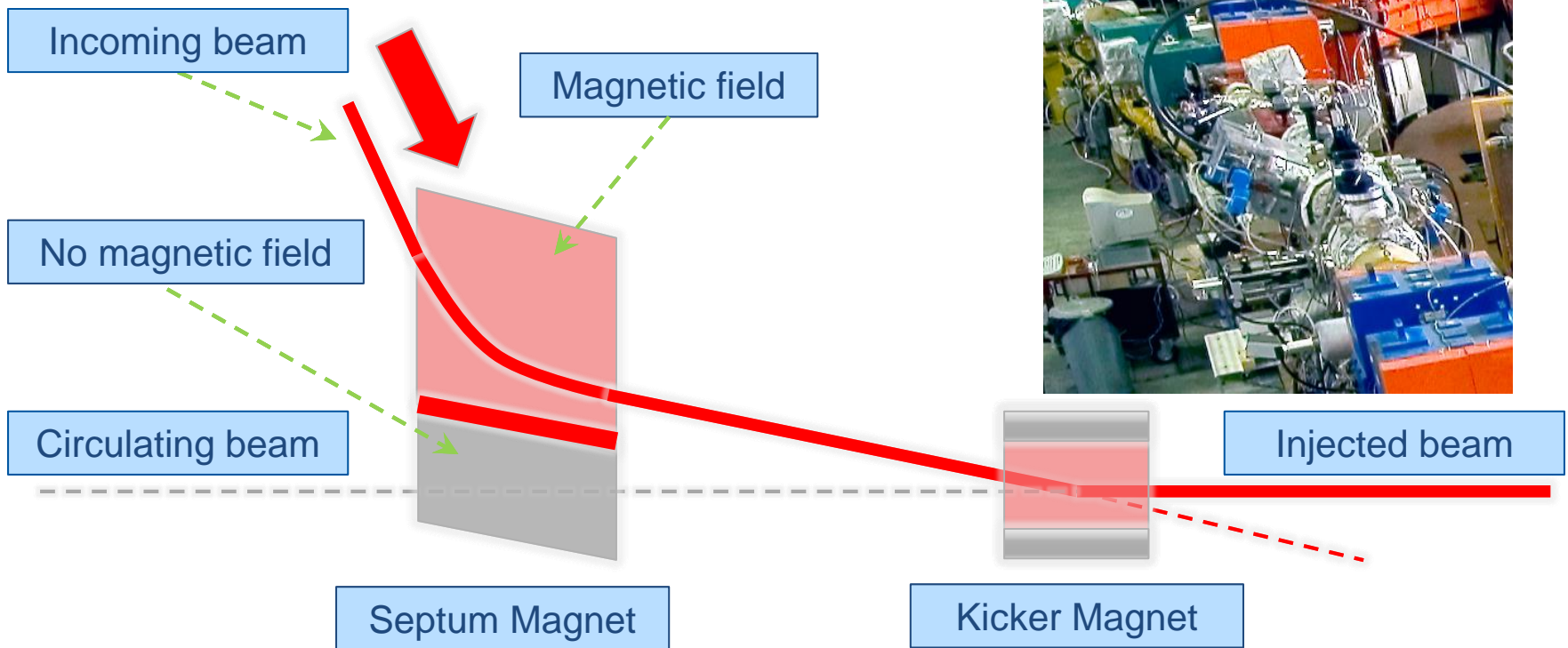
In the LHC **vacuum** is also used as **insulator**

Injecting & Extracting Particles

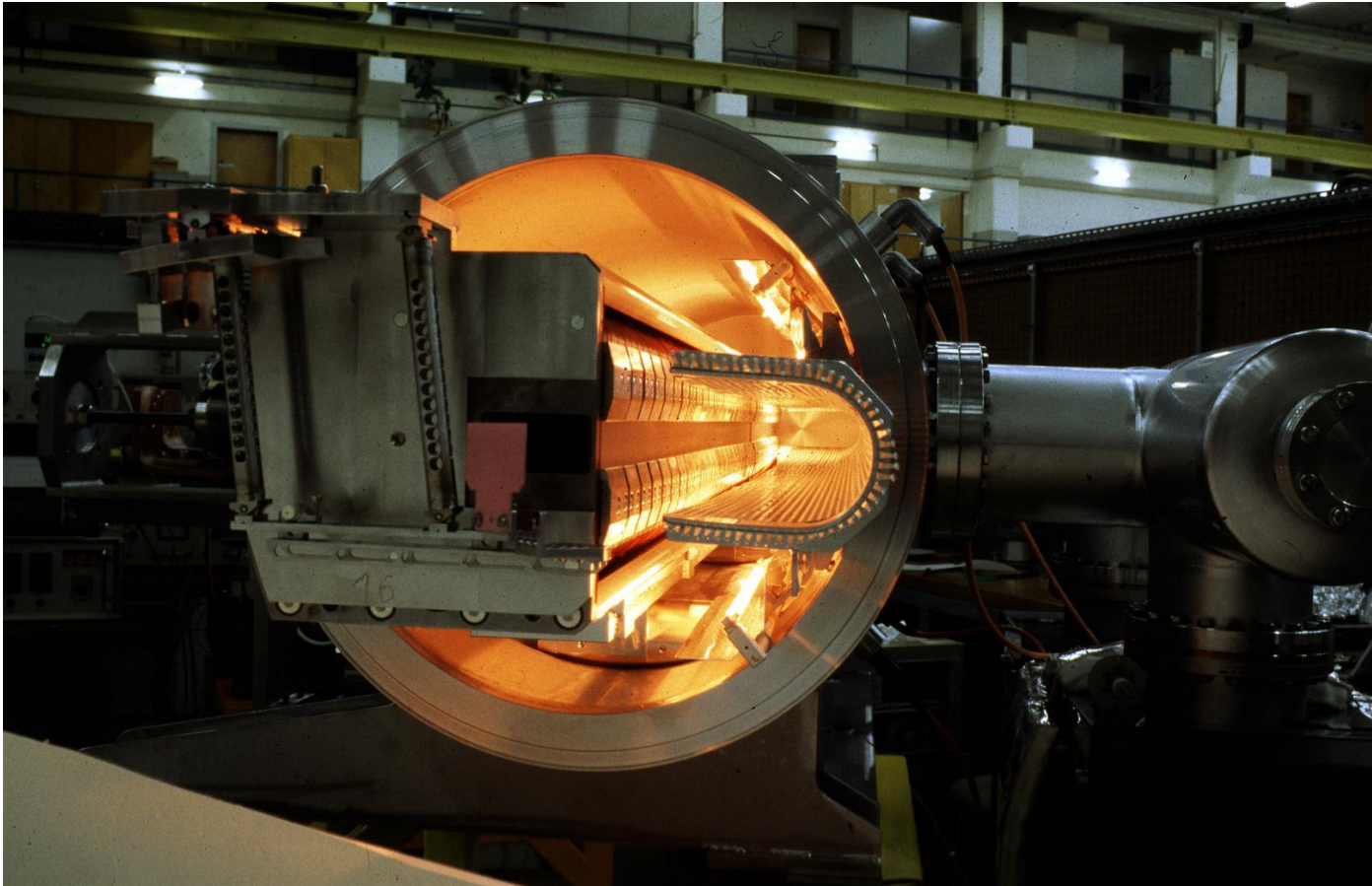


Extraction

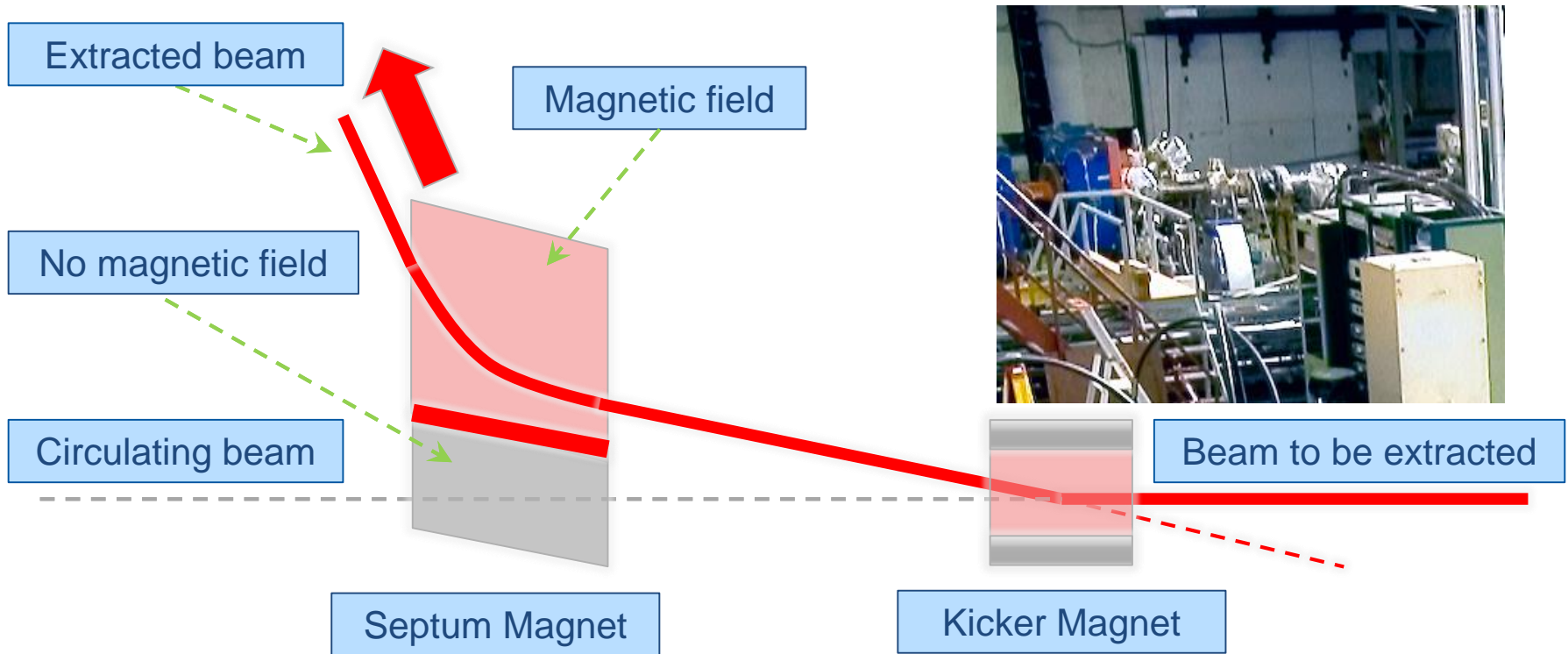
Injecting & Extracting Particles



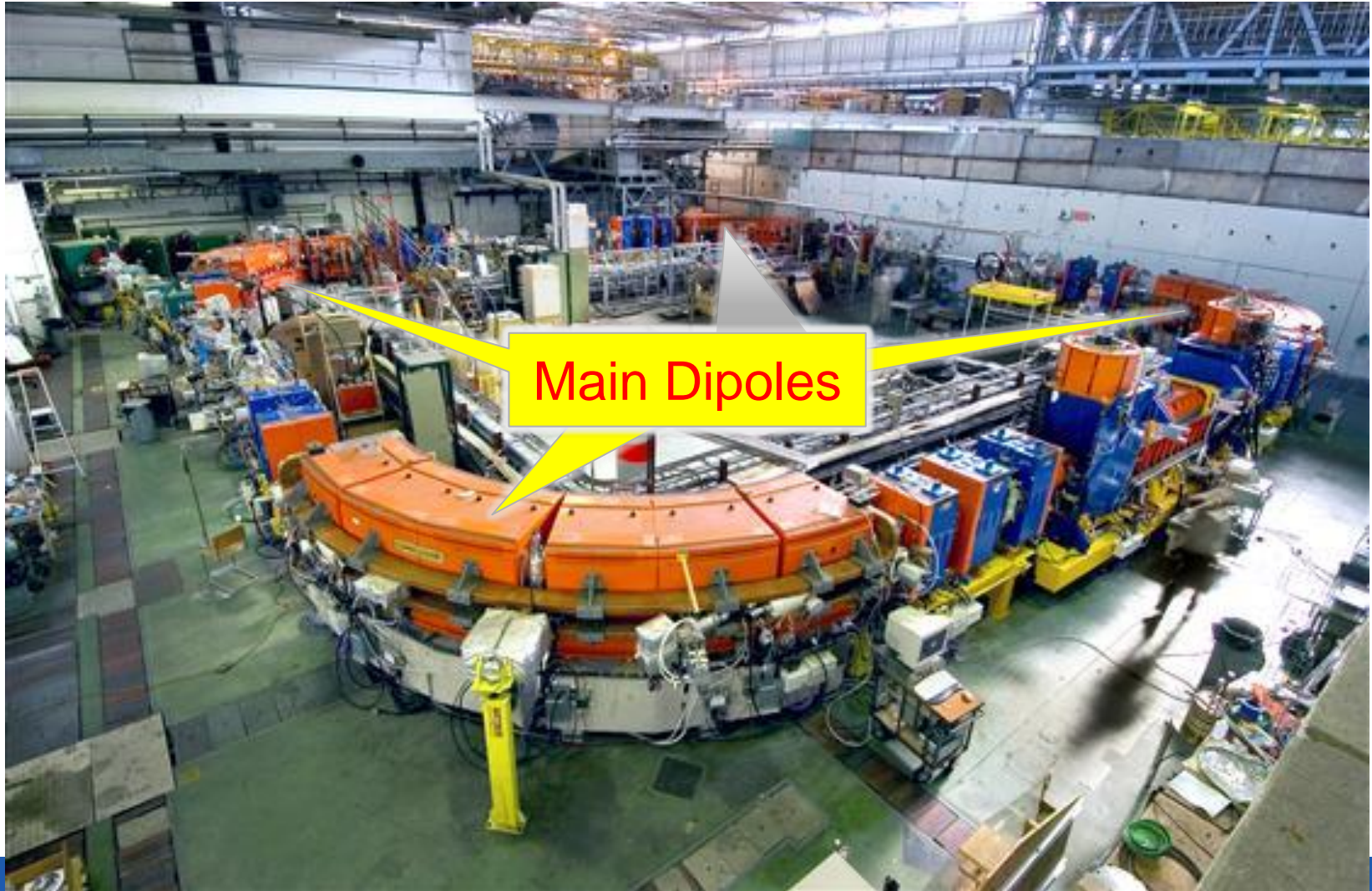
Septum Magnet



Injecting & Extracting Particles

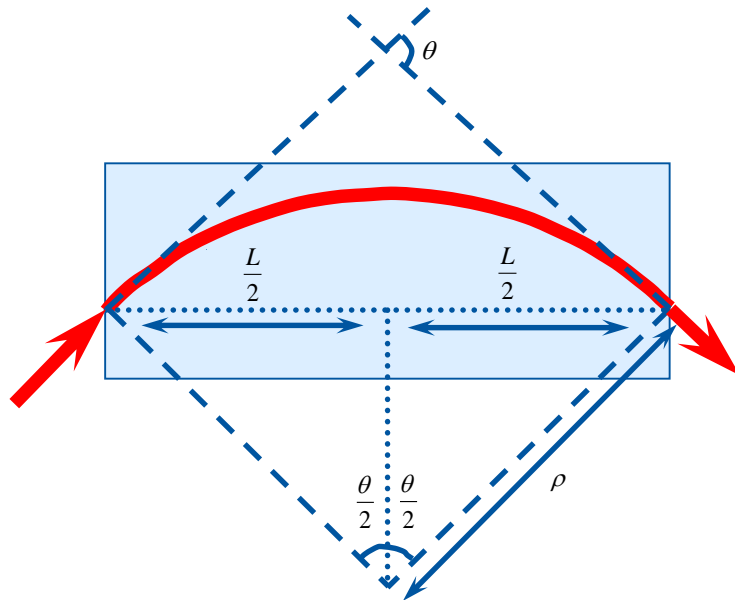


Make Particles Circulate



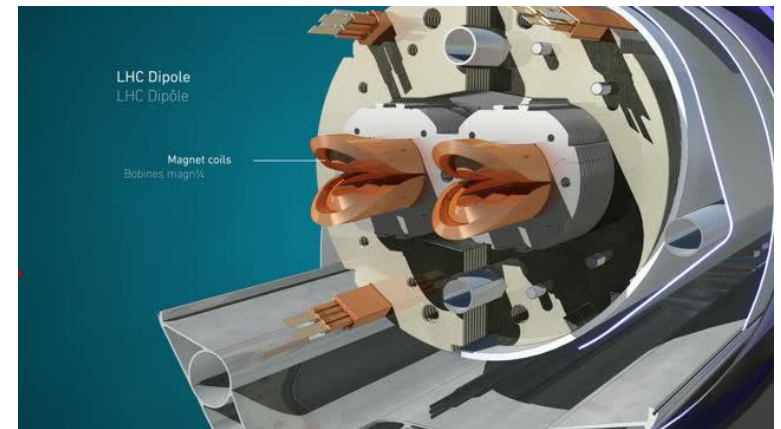
Deviating Charged Particles

Charged Particles are deviated in magnetic fields



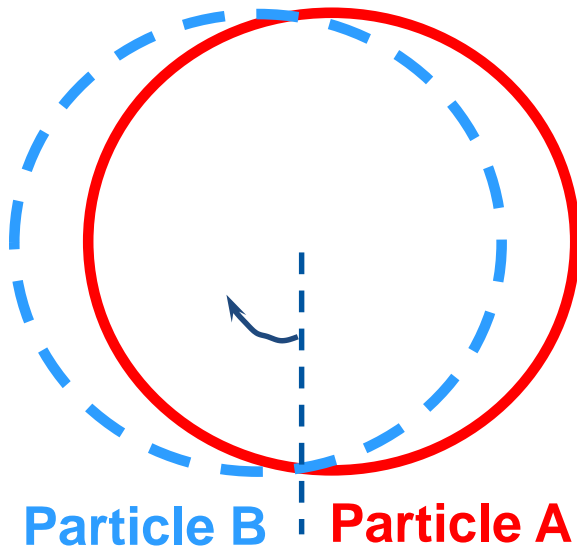
Lorentz force:

$$F = e v \times B$$

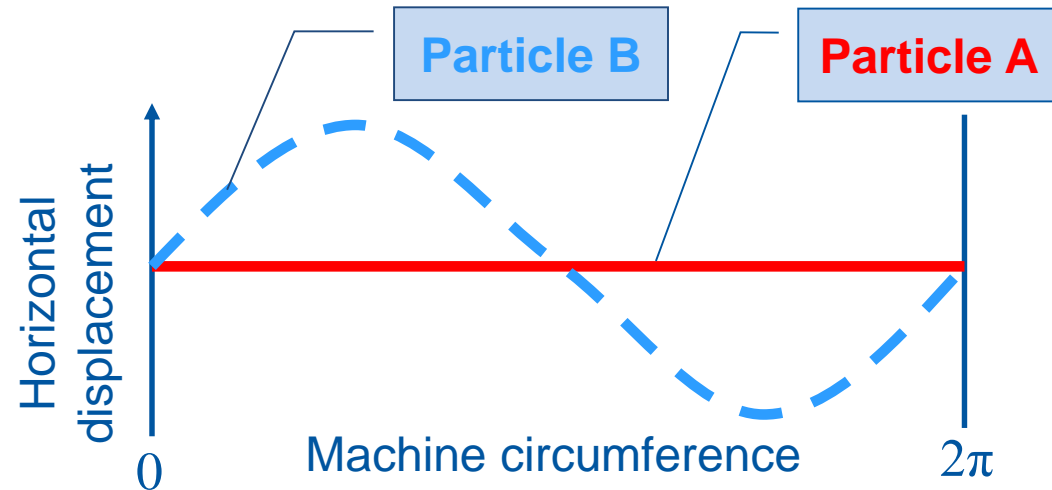


Oscillatory Motion of Particles

Two charged Particles in a homogeneous magnetic field



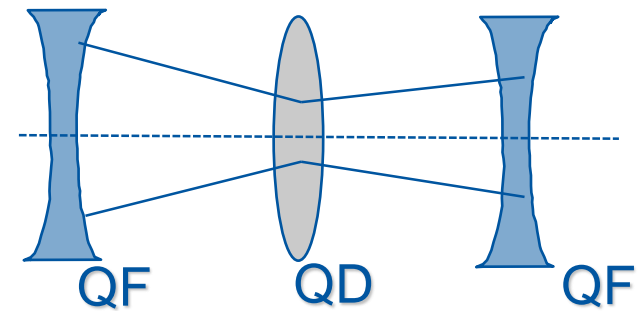
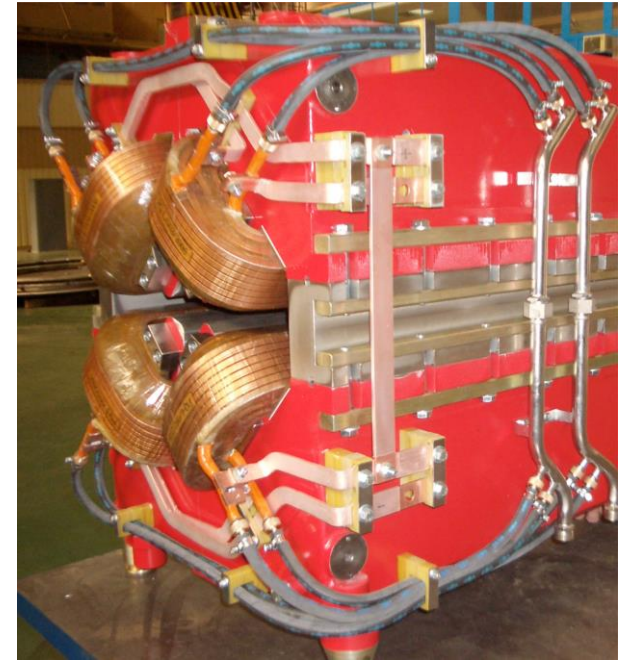
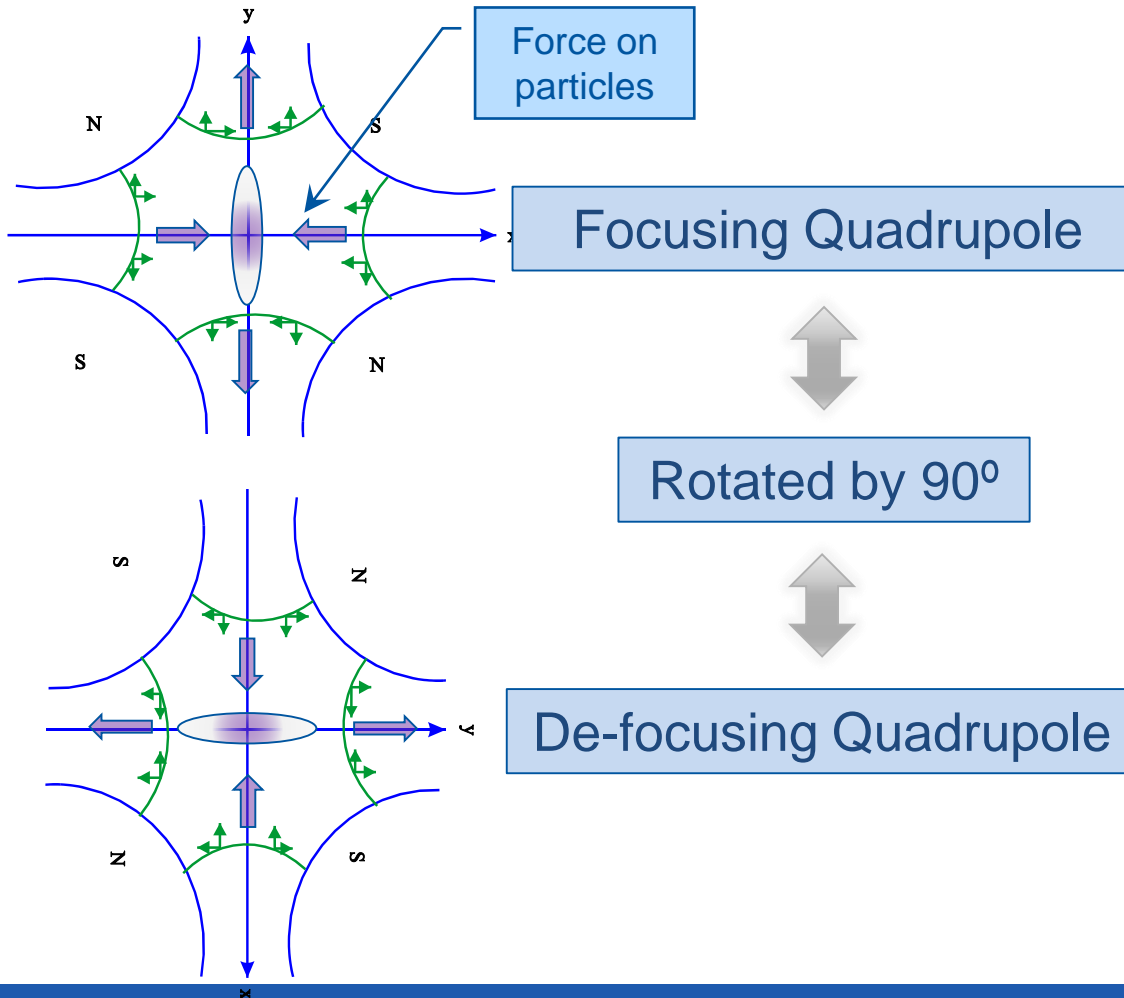
Horizontal motion



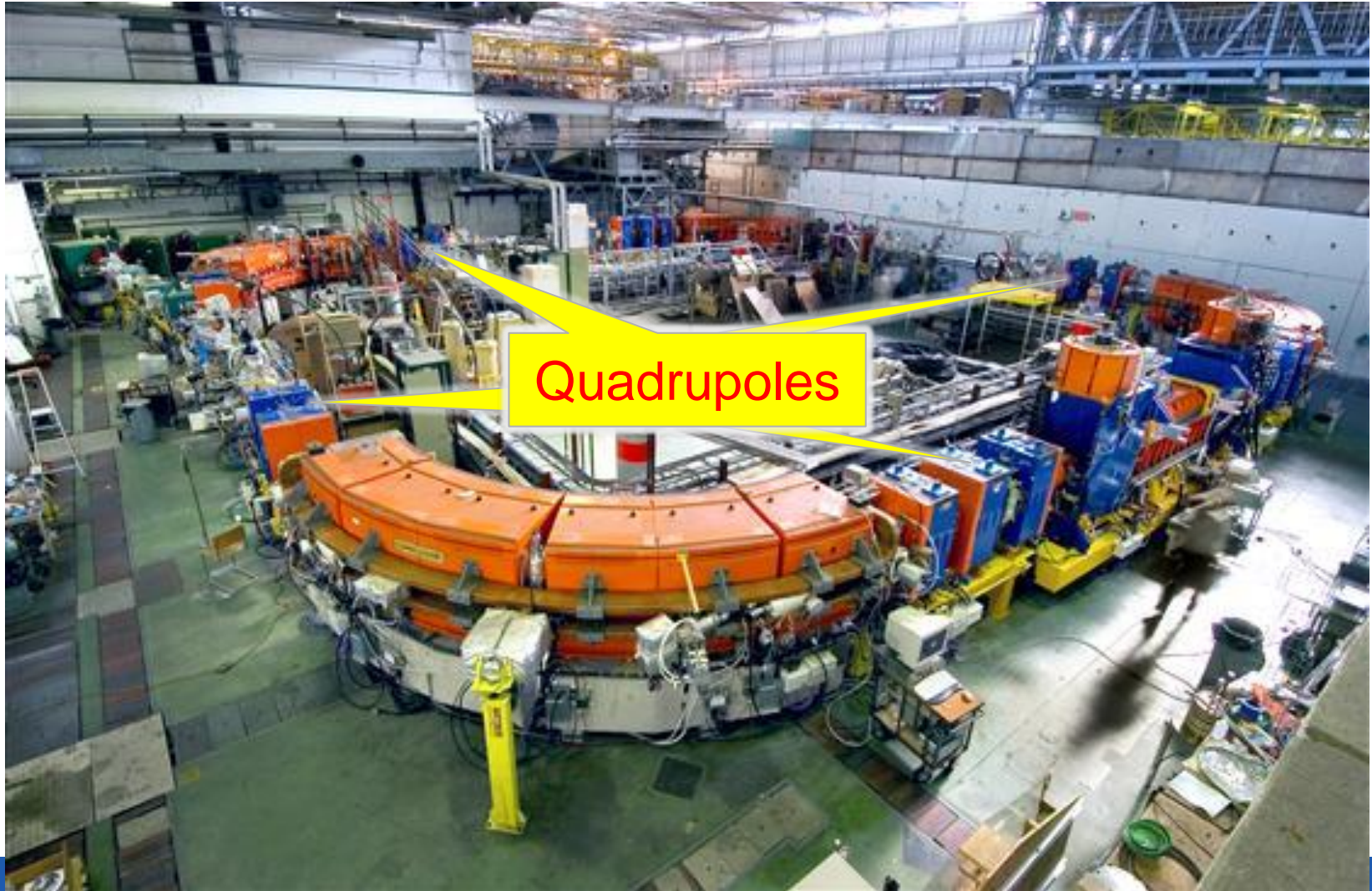
Different particles with different initial conditions in a homogeneous magnetic field will cause oscillatory motion in the horizontal plane → **Betatron Oscillations**

Focusing Particle Beams

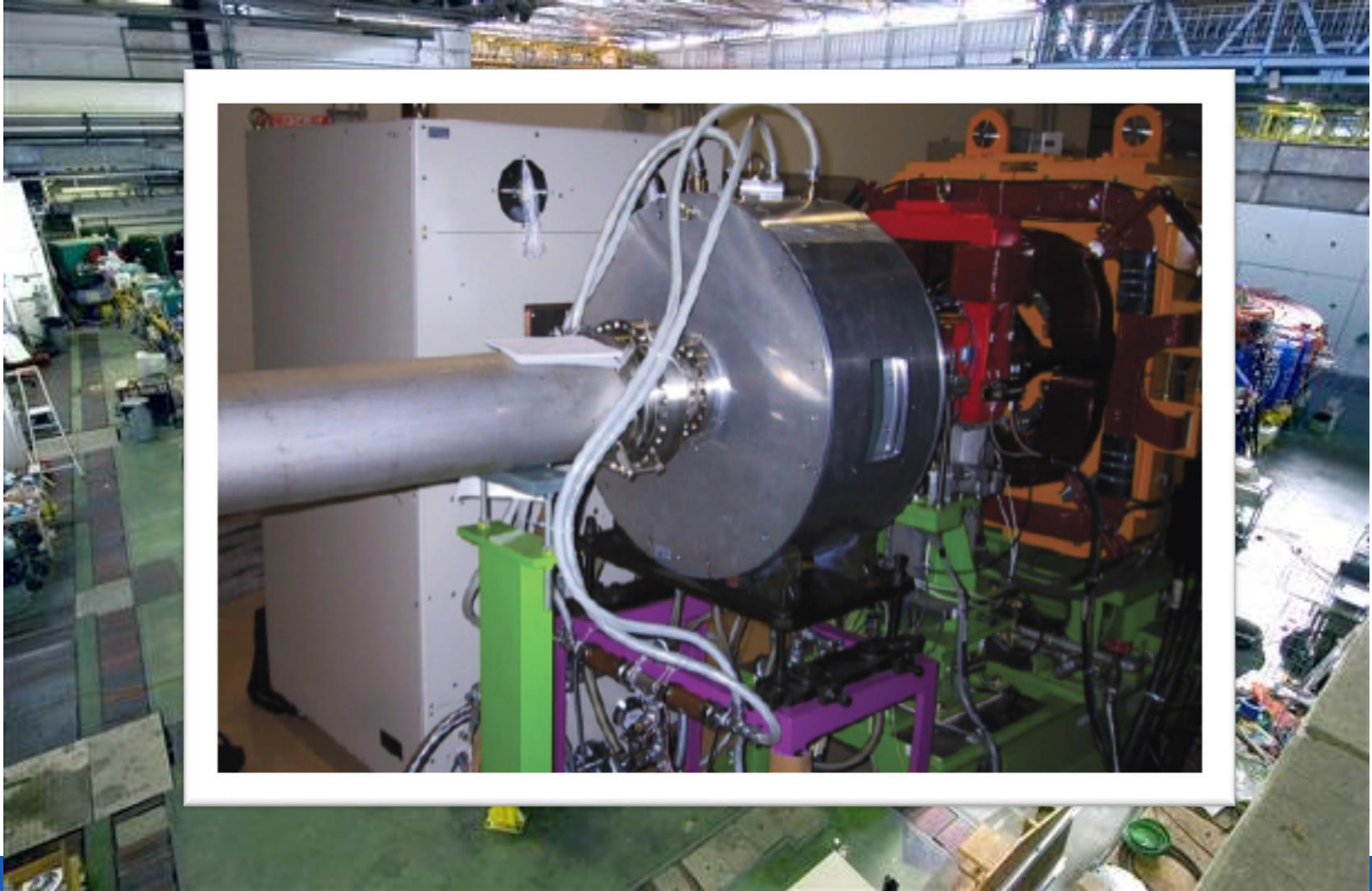
Focusing particles, a bit like light in a lens



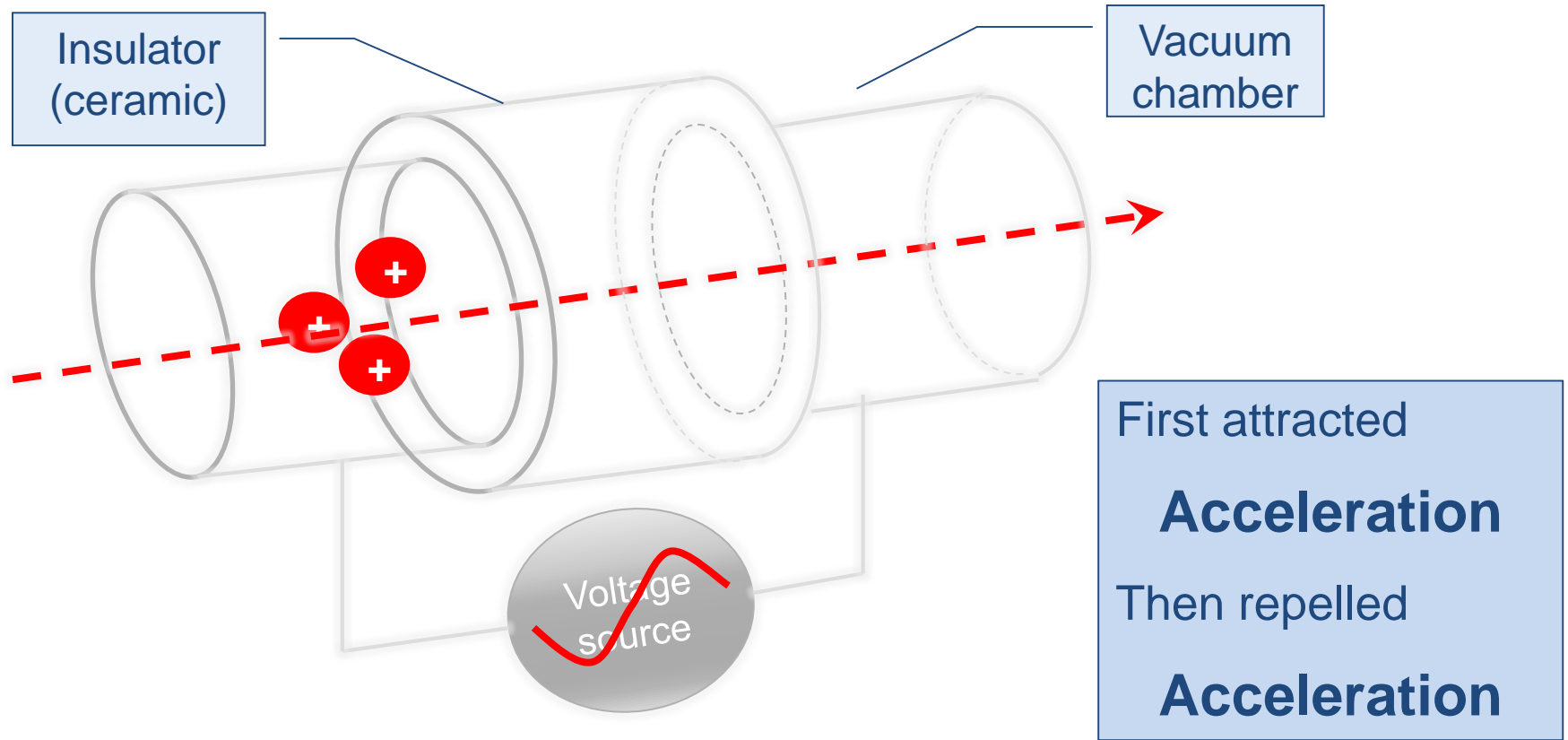
Focusing the Particle Beam



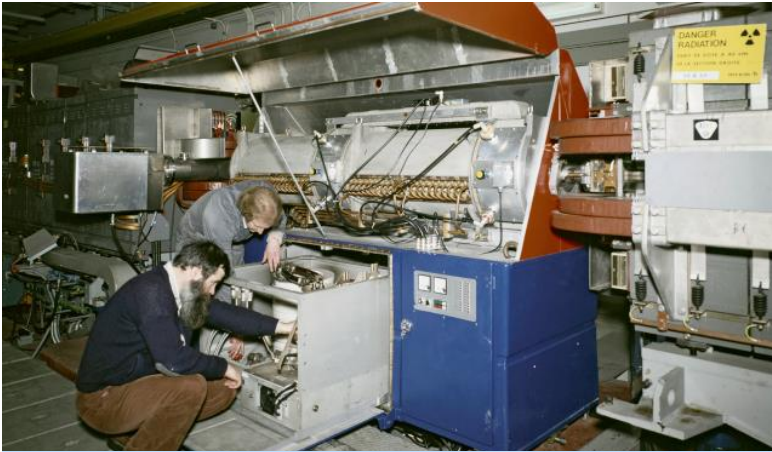
Accelerating Particles



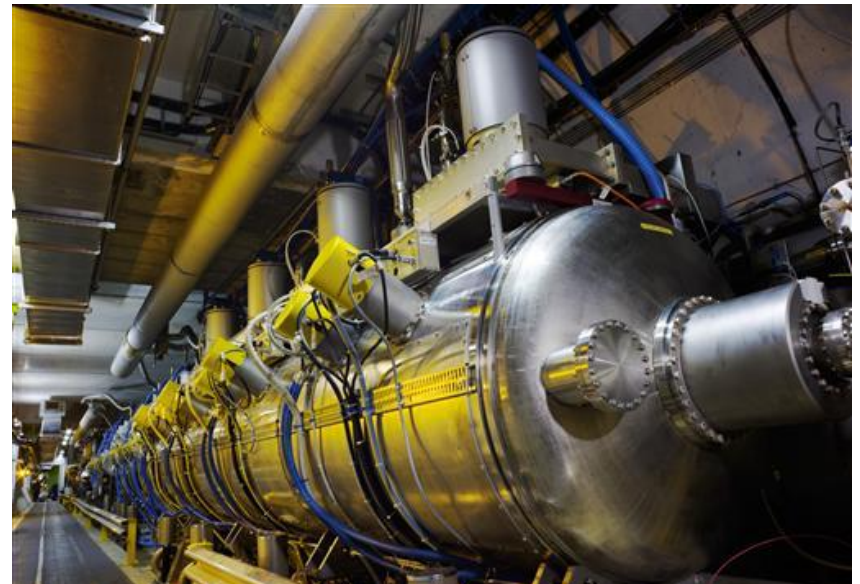
Accelerating Beams



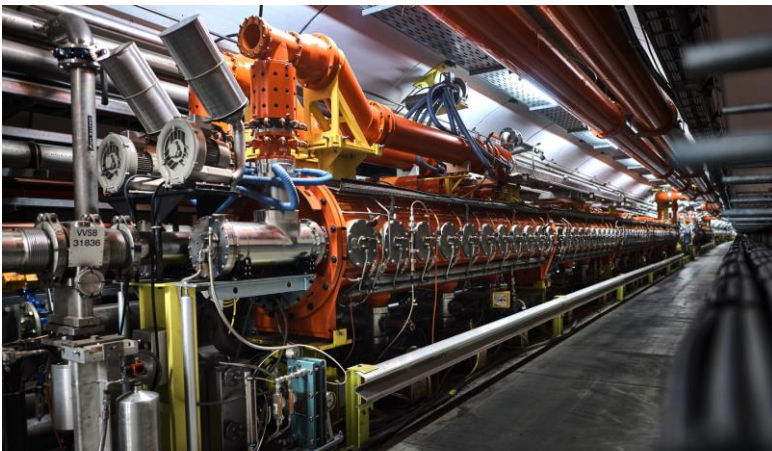
RF Cavities



Variable frequency cavity (PS)



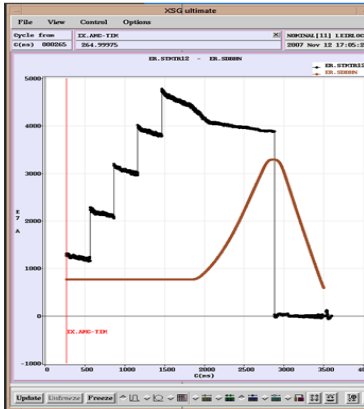
Super conducting fixed frequency cavities (LHC)



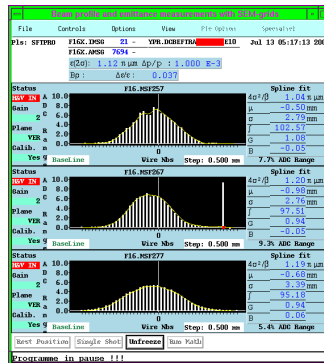
Fixed frequency cavities (SPS)



The Eyes of Operations



Beam intensity or current measurement

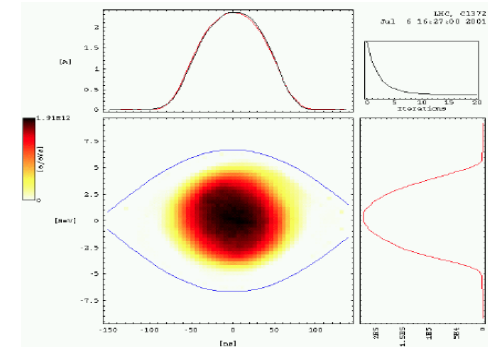


Transverse beam profile/size measurement

Longitudinal beam profile measurements

Measure the LHC luminosity, number of events per surface and time unit.

Any many more beam properties.....



Possible Limitations

Machines and elements cannot be built with infinite perfection

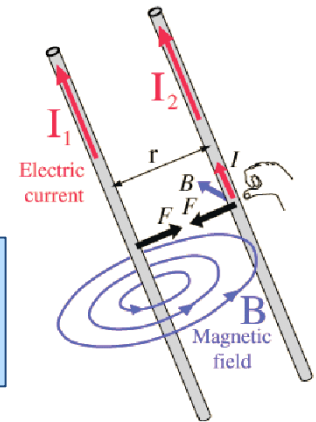


Same phase and frequency for driving force and the system can cause resonances and be destructive



Neighbouring charges with the same polarity experience repelling forces

Moving particles create currents, These currents result in attracting or repelling magnetic fields





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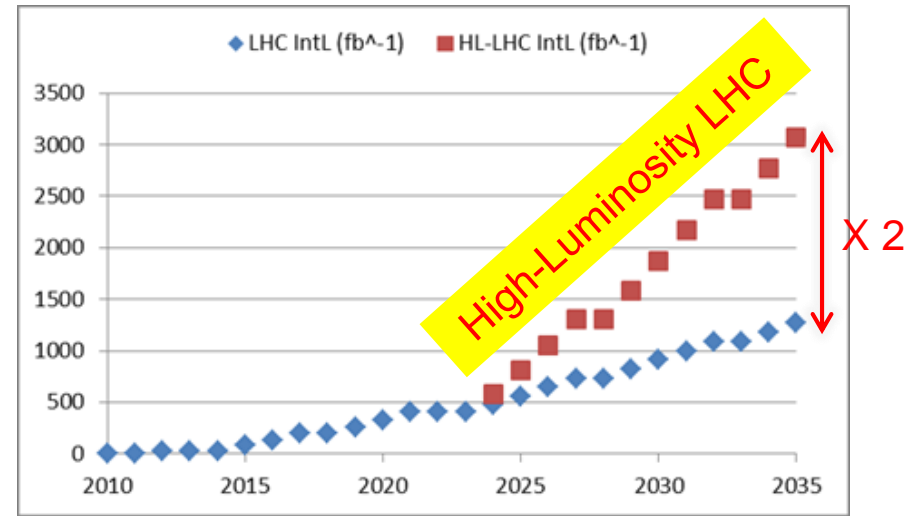
Luminosity, the Figure of Merit

$$LUMINOSITY = \frac{N_{event}/sec}{S_r} = \frac{N_1 N_2 f_{rev} n_b F}{4\rho S_x S_y}$$

Intensity per bunch (points to N_1, N_2)
Number of bunches (points to n_b)
Geometrical Correction factors (points to F)
Beam dimensions (points to S_x, S_y)

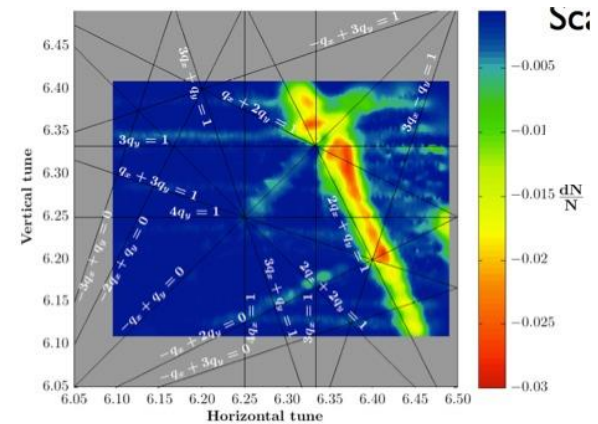
- More or less fixed:
 - Revolution period
 - Number of bunches

- Parameters to optimise:
 - Number of particles per bunch
 - Beam dimensions
 - Geometrical correction factors



The LHC Injector Upgrade Project

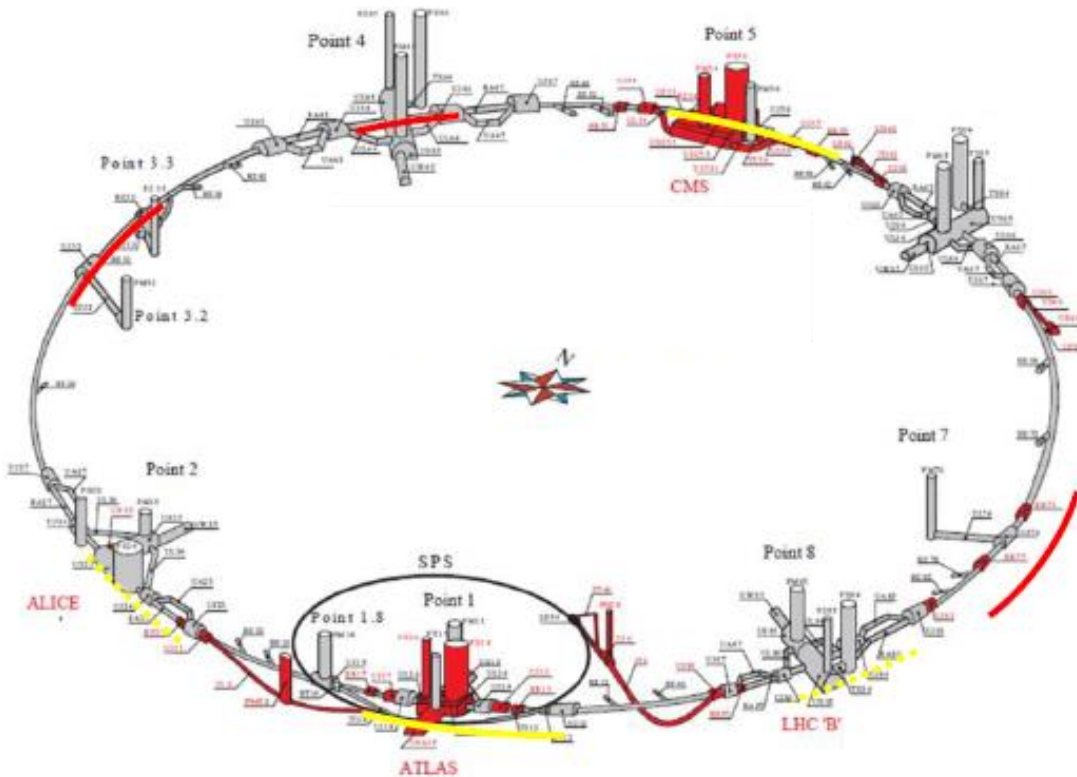
- LINAC4 – PS Booster:
 - New LINAC 4 with H^- injection
 - Higher injection energy
 - New Finemet® RF cavity system
 - Increase of extraction energy
- PS:
 - Injection energy increase from 1.4 GeV to 2 GeV
 - New Finemet® RF Longitudinal feedback system
 - New RF beam manipulation scheme to increase beam brightness
- SPS
 - Machine Impedance reduction (instabilities)
 - New 200 MHz RF system
 - Vacuum chamber coating against e-cloud



Courtesy of A. Huschauer

These are only the main modifications and this list is not exhaustive

The High Luminosity LHC Project



- New IR-quads (inner triplets)
- New 11T short dipoles
- Collimation upgrade
- Cryogenics upgrade
- Crab Cavities
- Cold powering
- Machine protection
- ...

Major intervention on more than 1.2 km of the LHC
These are only the main modifications and this list is not exhaustive

Possible Future Accelerators

Compact Linear Collider (CLIC)

- Linear e^+e^- collider up to 3 TeV

Future Circular Collider (FCC)

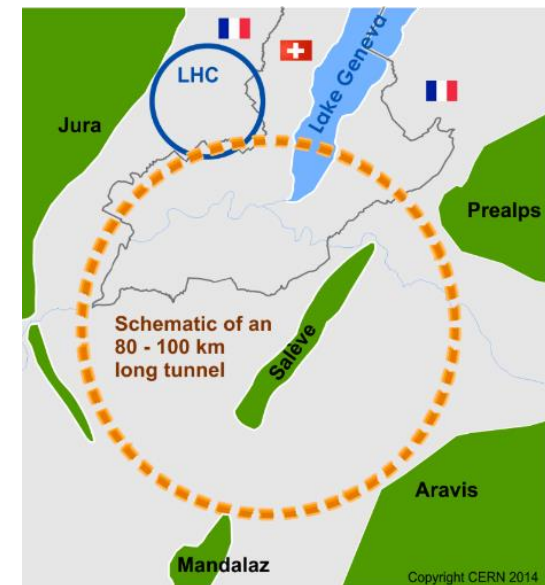
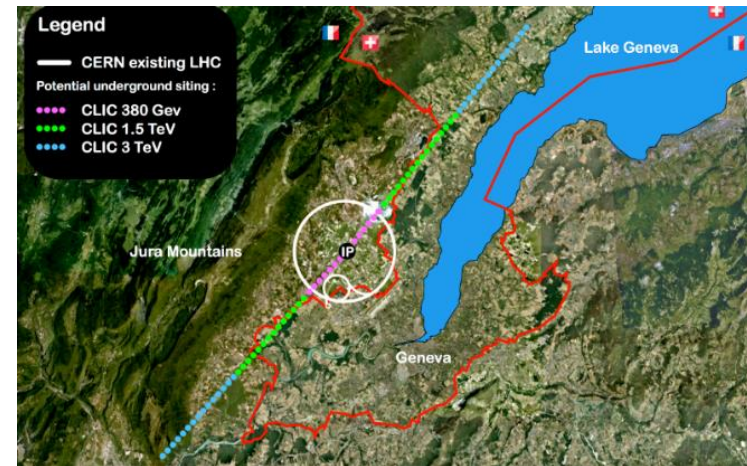
- 100 TeV pp collisions in 100km rin
- Requires new magnet technology
- Possibly e^+e^- collider (FCC-ee) as 1st step

High Energy LHC in the present LHC tunnel

- ~ 30 TeV with FCC magnet technology

European Strategy for Particle Physics

- Preparing next update for 2020

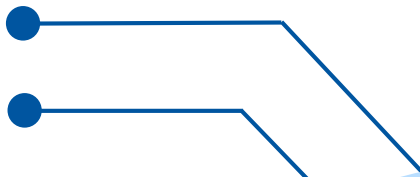




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CERN Technology, Opportunities for Industry

Radiofrequency



Computing / IT



Magnets



Vacuum &
Cryogenics



Material
Science



Mechanics



Cooling &
Ventilation



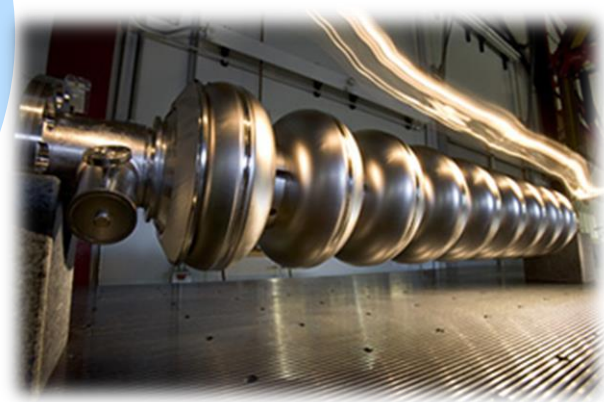
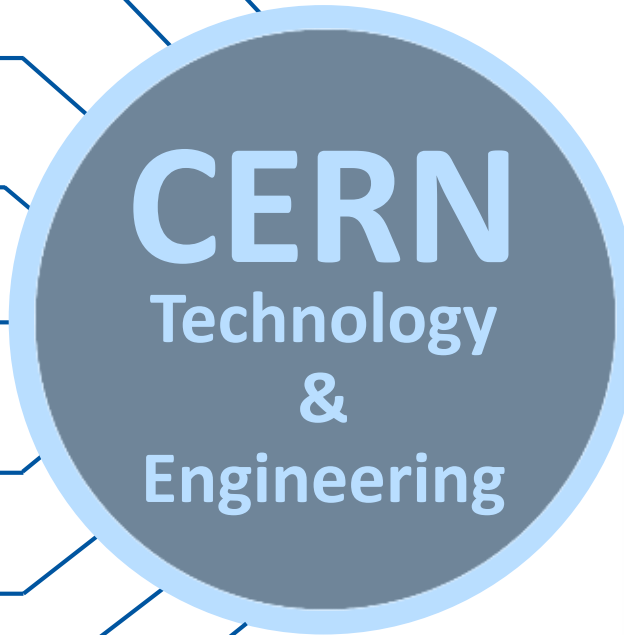
Electronics



Civil Engineering



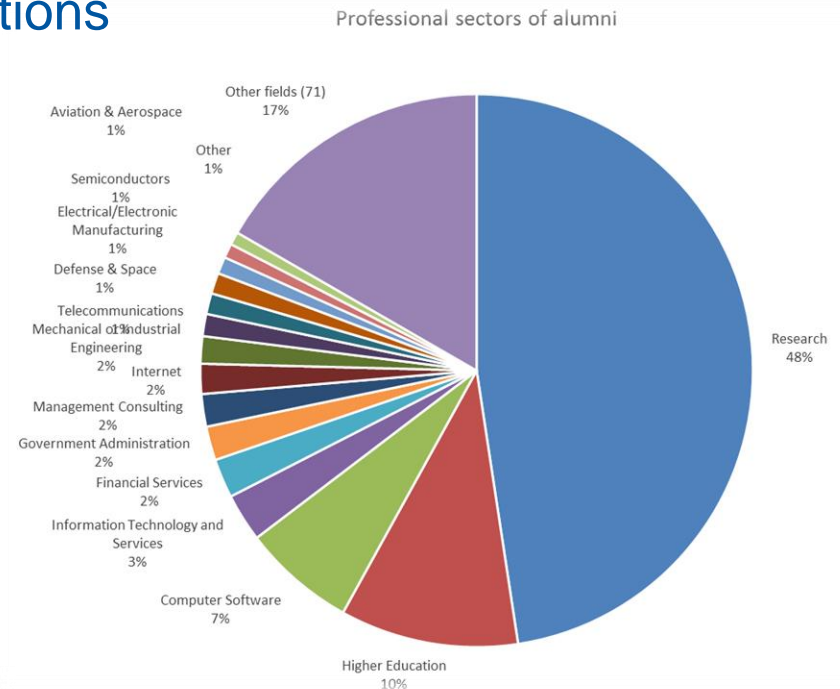
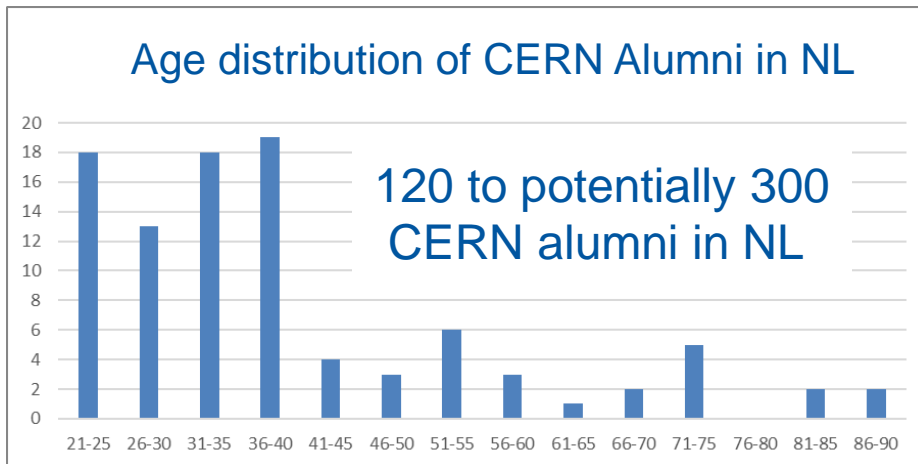
And more....



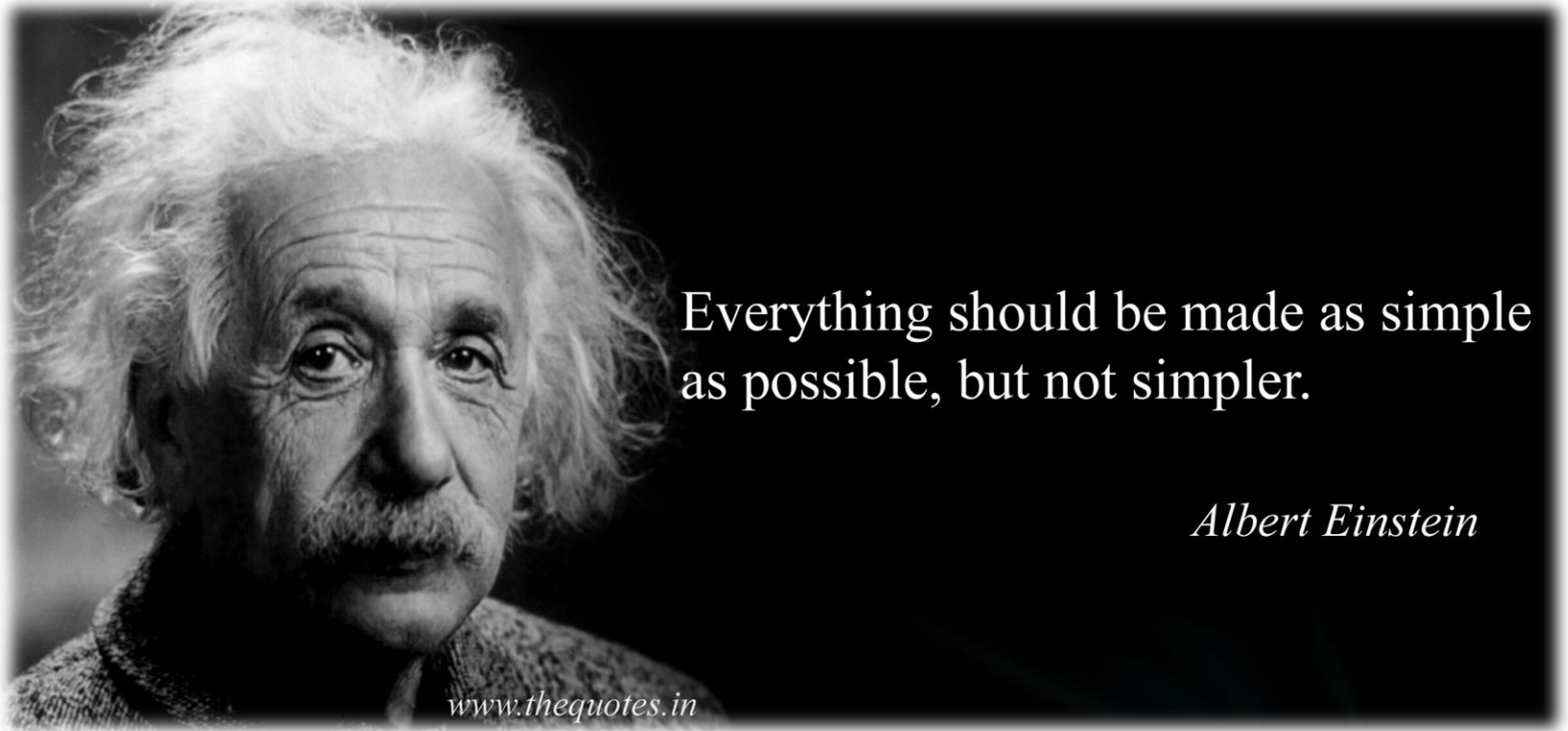
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CERN Alumni, Another Opportunity...

- An important pool of talents and profiles developed at CERN may be available to you...
- A dedicated Office for Alumni Relations
- 6 regional groups, among which a CERN Eindhoven group



- Post your projects and vacancies on <https://alumni.cern>



Everything should be made as simple as possible, but not simpler.

Albert Einstein

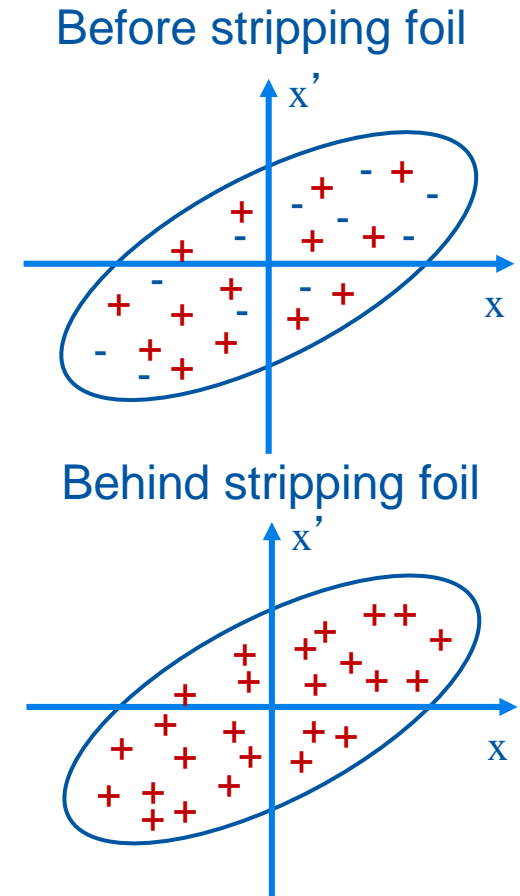
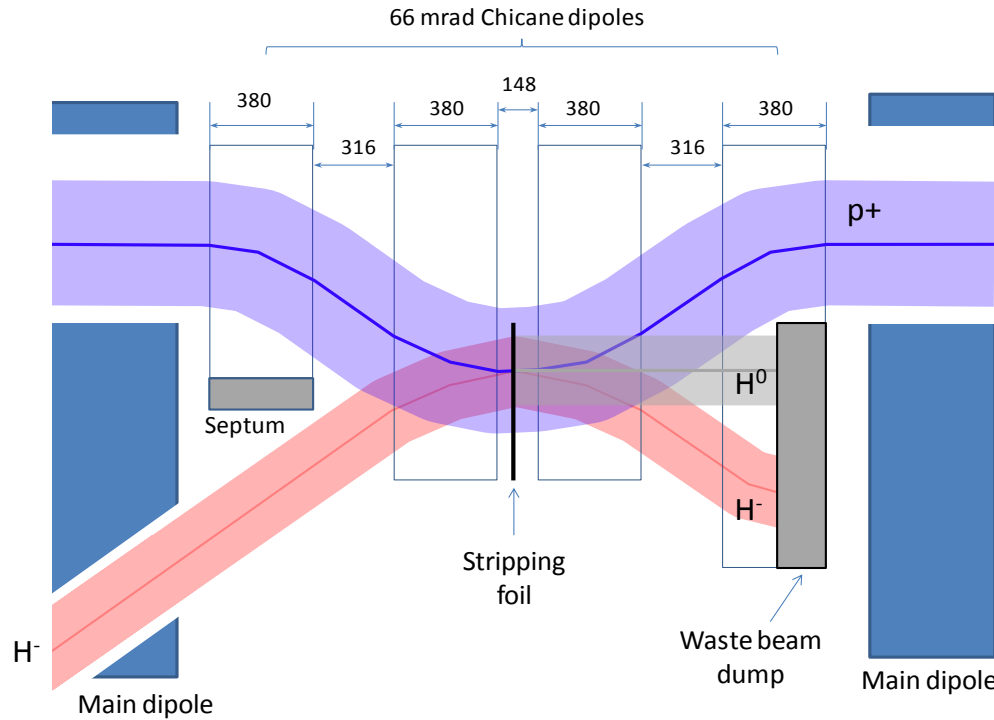
www.thequotes.in



www.cern.ch

PS Booster Injection with LINAC4

- Charge exchange injection with H^-



Phase Space Painting is possible (various particle distributions)
High-brightness beams possible

Oscillatory Motion of Particles

The horizontal motion seems to be “stable” What about the vertical plane ?

Many particles many initial conditions

