



# Particle Accelerators Explained for Everybody

## “Without Math”

Rende Steerenberg – BE/OP

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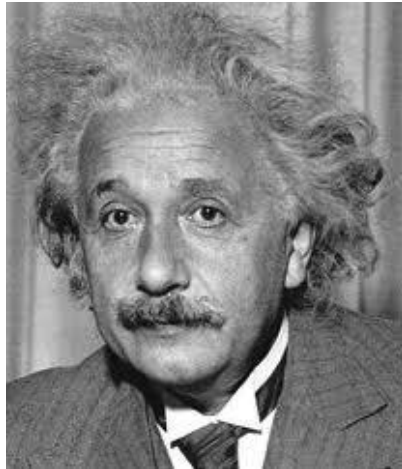
- Why Accelerators and Colliders ?
- The CERN Accelerator Complex
- The Main Ingredients of an Accelerator
- A brief word on the Future

- **Why Accelerators and Colliders ?**
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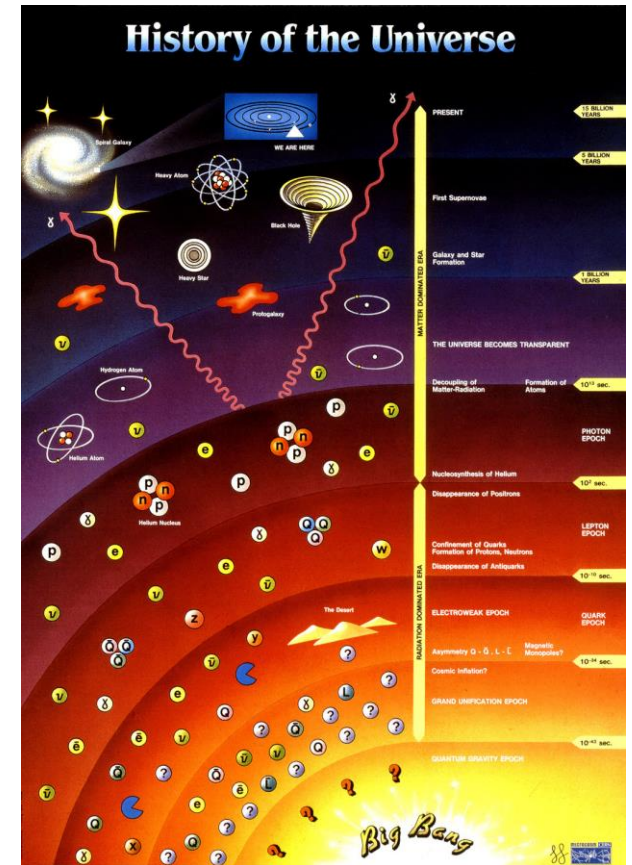
# Creating Matter from Energy

$$E = m c^2$$

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**

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



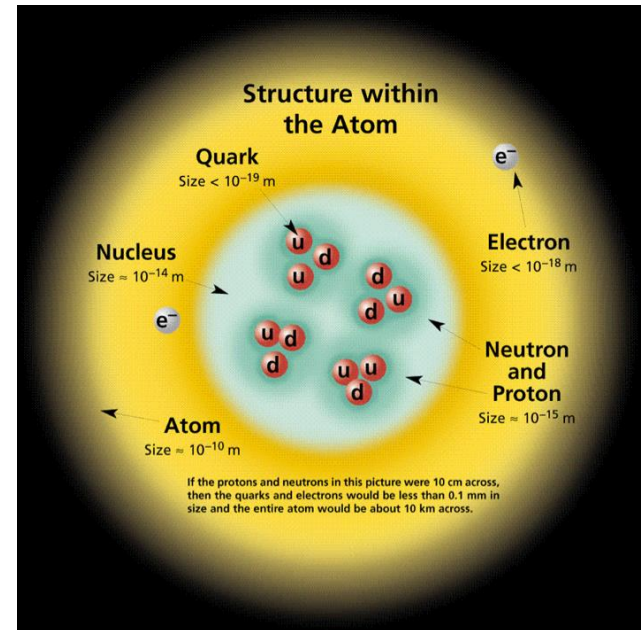
**X-ray**

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



**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



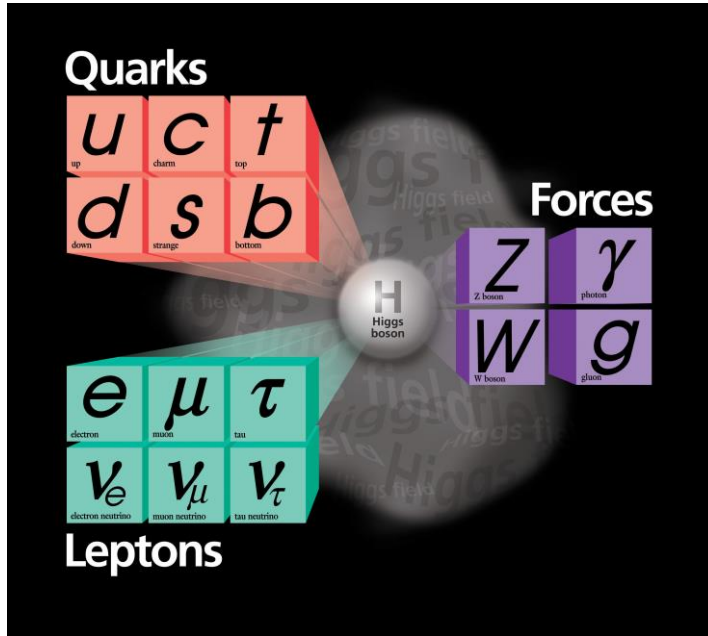
$$E = E_{beam1} + E_{beam2}$$

All energy will be available for particle production

# The Aim:

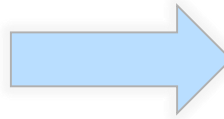
Specific assemblies of quarks form hadrons. Protons, Neutrons, pions,...

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



# Accelerators and Their Use



Today: ~ **30'000 accelerators** operational world-wide\*

The **large majority** is used in **industry** and **medicine**

Industrial applications: ~ 20'000\*

Medical applications: ~ 10'000\*

**Les than a fraction of a percent** is used for **research** and discovery science

Cyclotrons

Synchrotron light sources (e<sup>-</sup>)

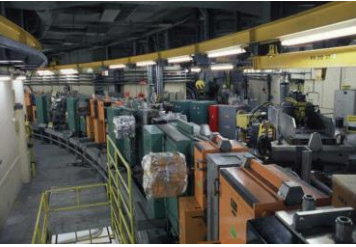
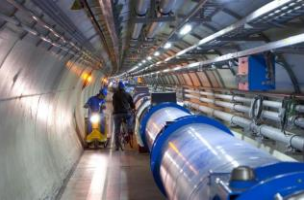
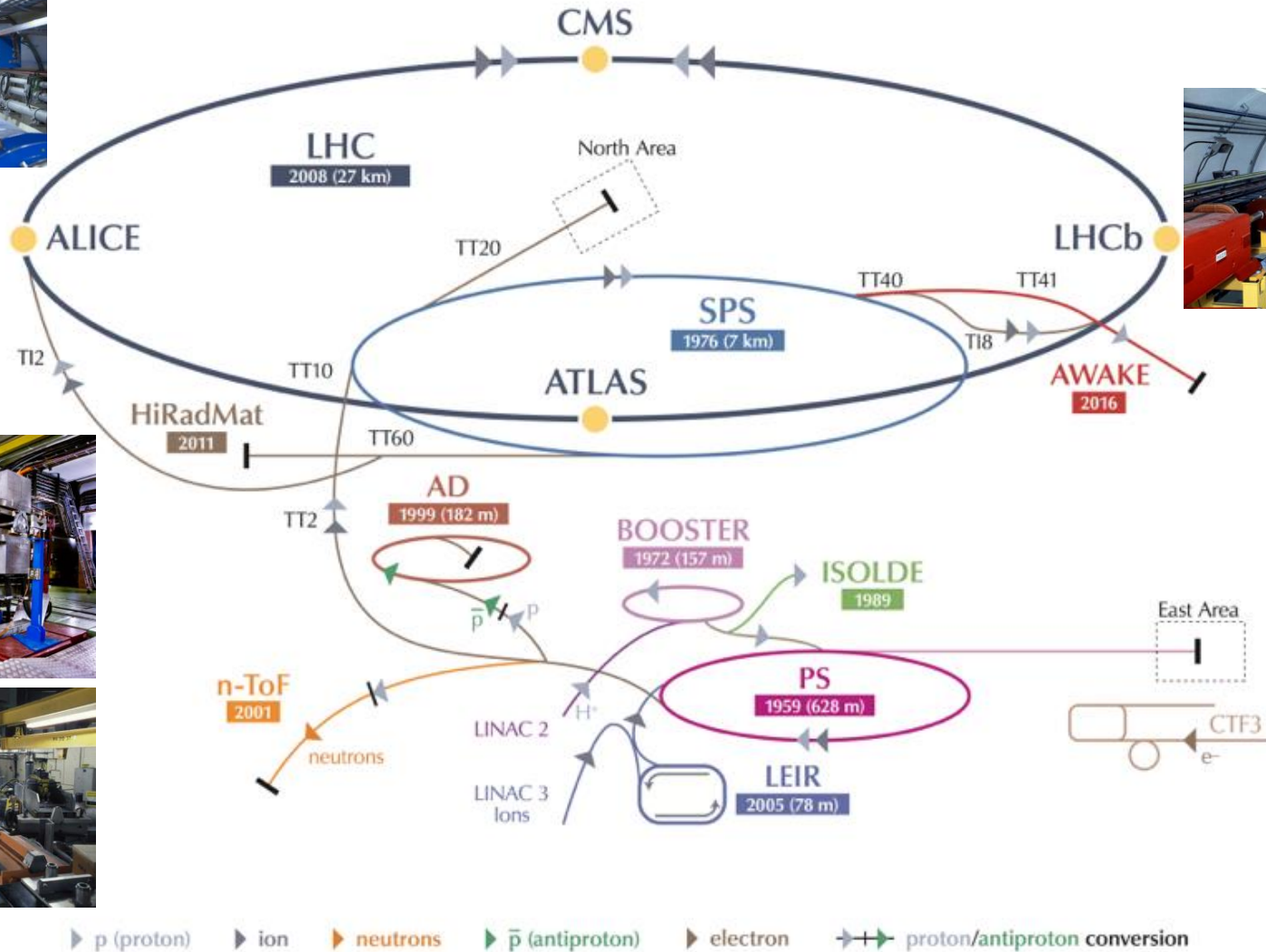
Lin. & Circ. accelerators/Colliders

This lecture will concentrate on the CERN type machines of which the majority are **Synchrotrons**

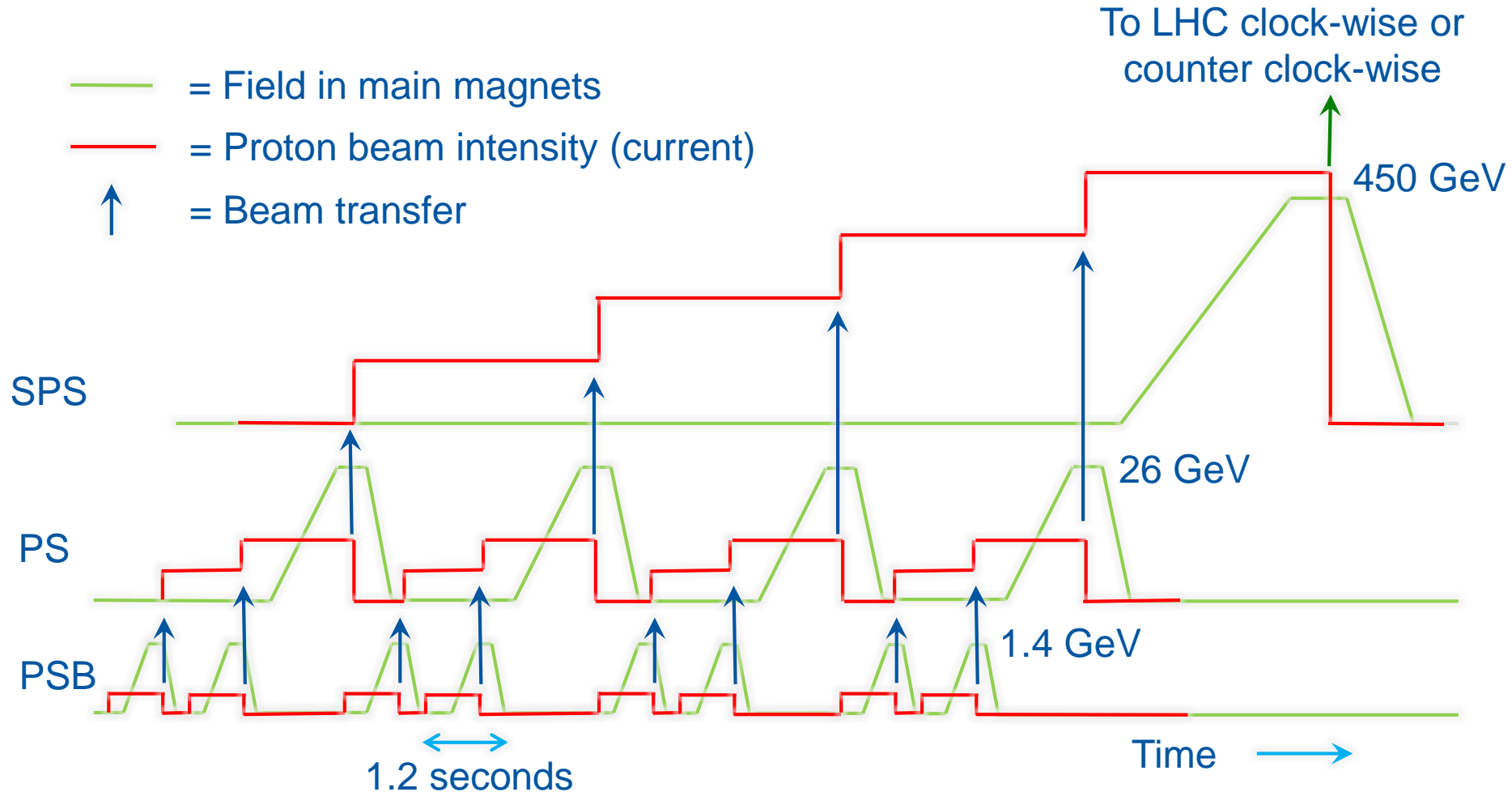
*\*Source: World Scientific Reviews of Accelerator Science and Technology  
A.W. Chao*

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- **The CERN Accelerator Complex**
- The Main Ingredients of an Accelerator
- A brief word on the Future

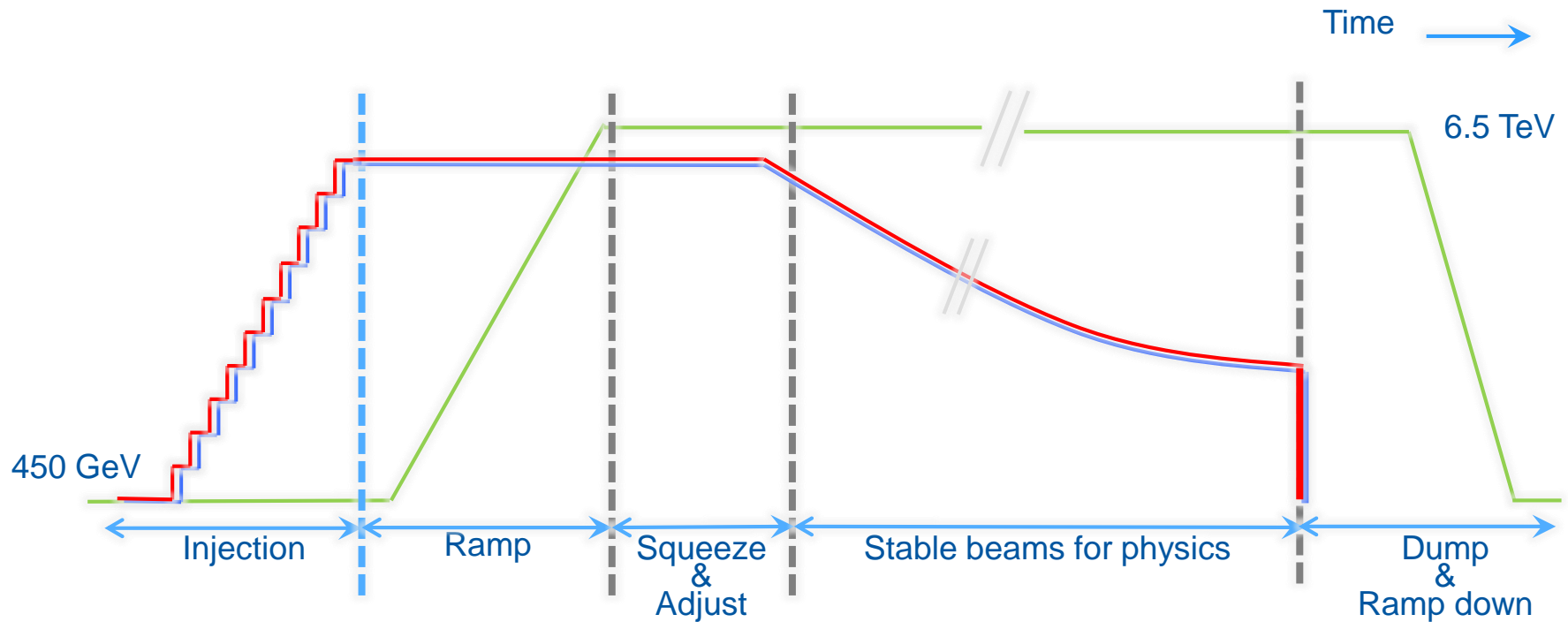
# The CERN Accelerator Complex



# 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

16-Oct-2016 07:48:46

Fill #: 5418

Energy: 6499 GeV

I(B1): 1.87e+14

I(B2): 1.83e+14

	ATLAS	ALICE	CMS	LHCb
Experiment Status	PHYSICS	PHYSICS	PHYSICS	PHYSICS
Instantaneous Lumi [(ub.s) <sup>-1</sup> ]	7346.231	1.672	7730.174	355.048
BRAN Luminosity [(ub.s) <sup>-1</sup> ]	7462.0	1.8	6917.8	181.2
Fill Luminosity (nb) <sup>-1</sup>	265785.063	49.302	293245.594	10312.992
Beam 1 BKGD	0.927	1.401	1.645	0.000
Beam 2 BKGD	4.488	0.042	1.143	0.001

LHCb VELO Position

IN

Gap: -0.0 mm

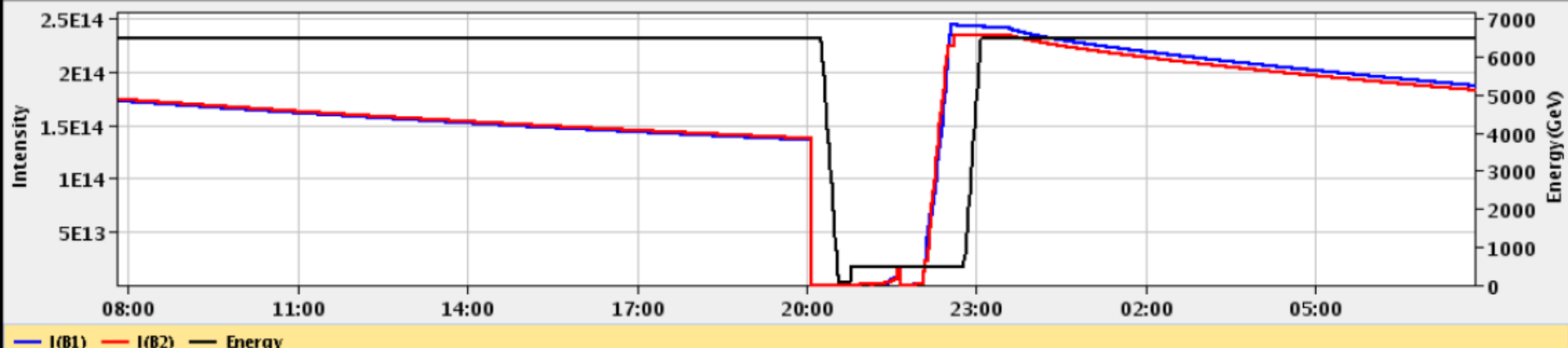
STABLE BEAMS

TOTEM:

PHYSICS

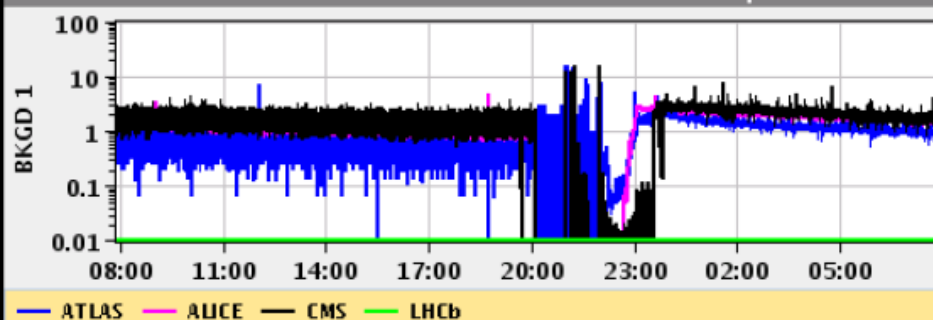
Performance over the last 24 Hrs

Updated: 07:48:42



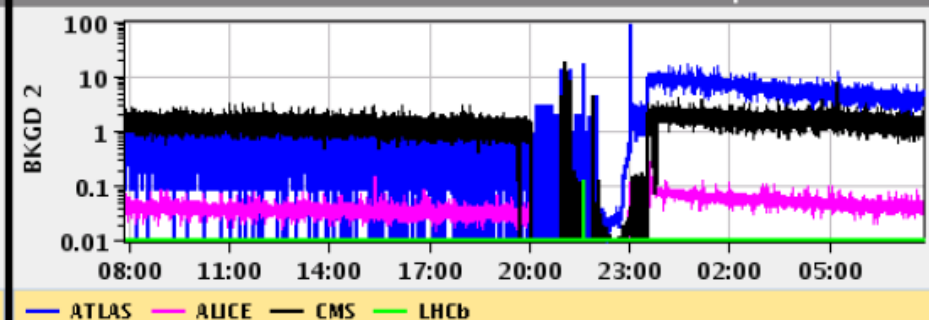
Beam 1 BKGD

Updated: 07:48:41



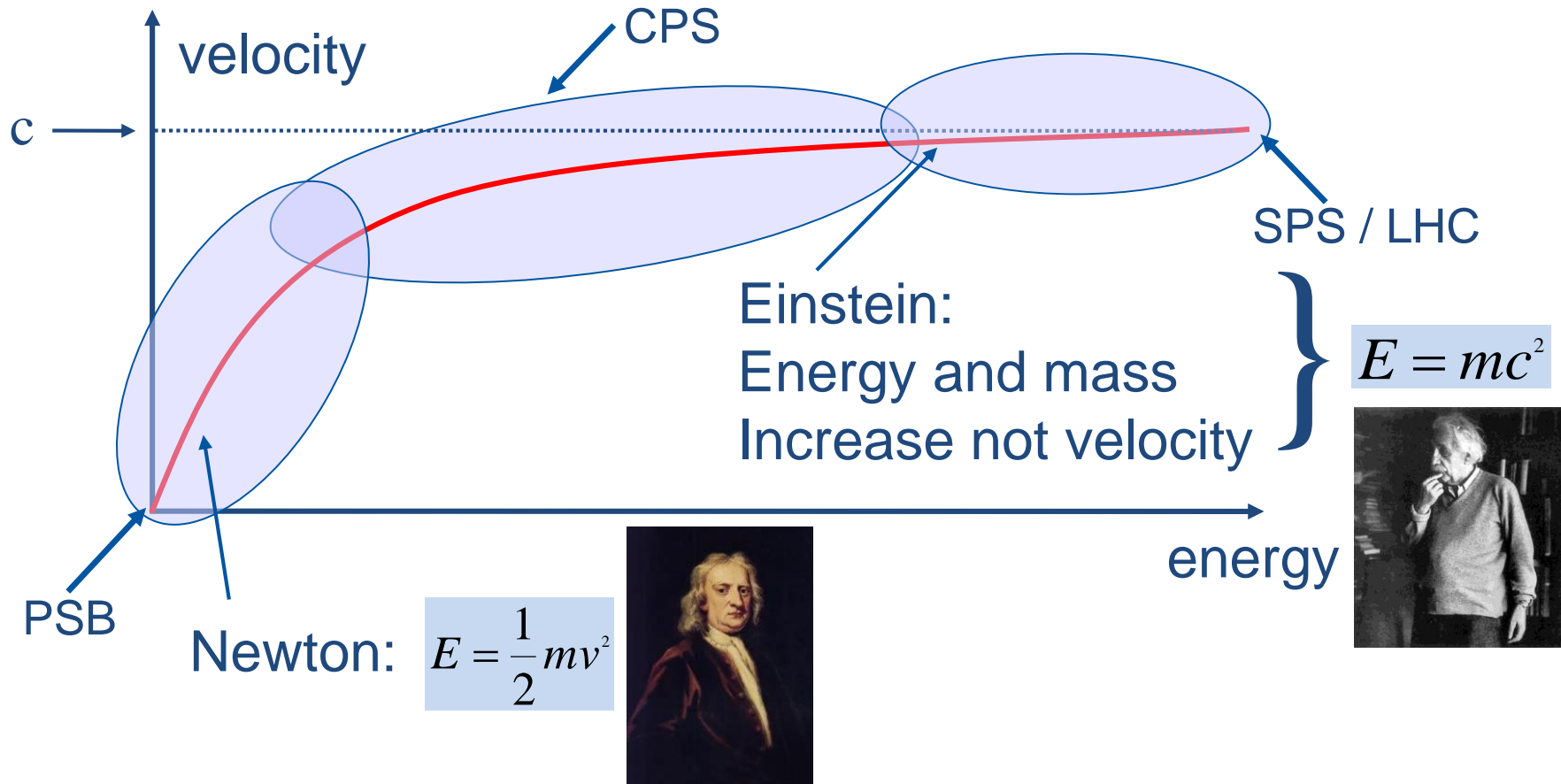
Beam 2 BKGD

Updated: 07:48:41



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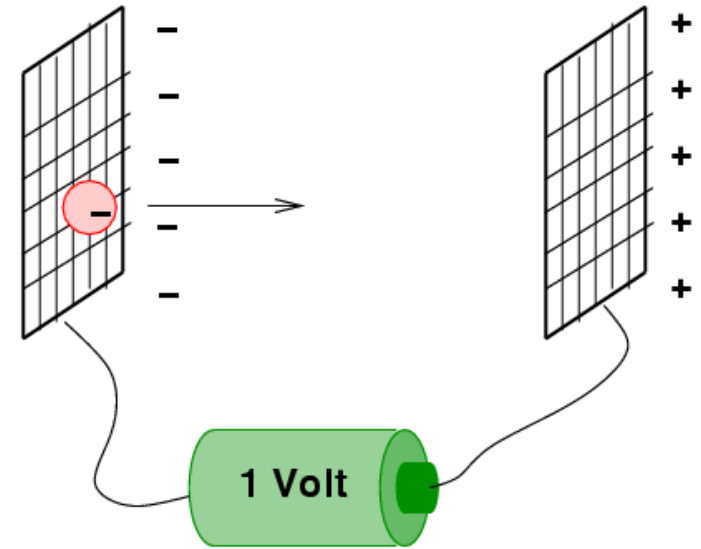
# Towards Relativity





# 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:

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

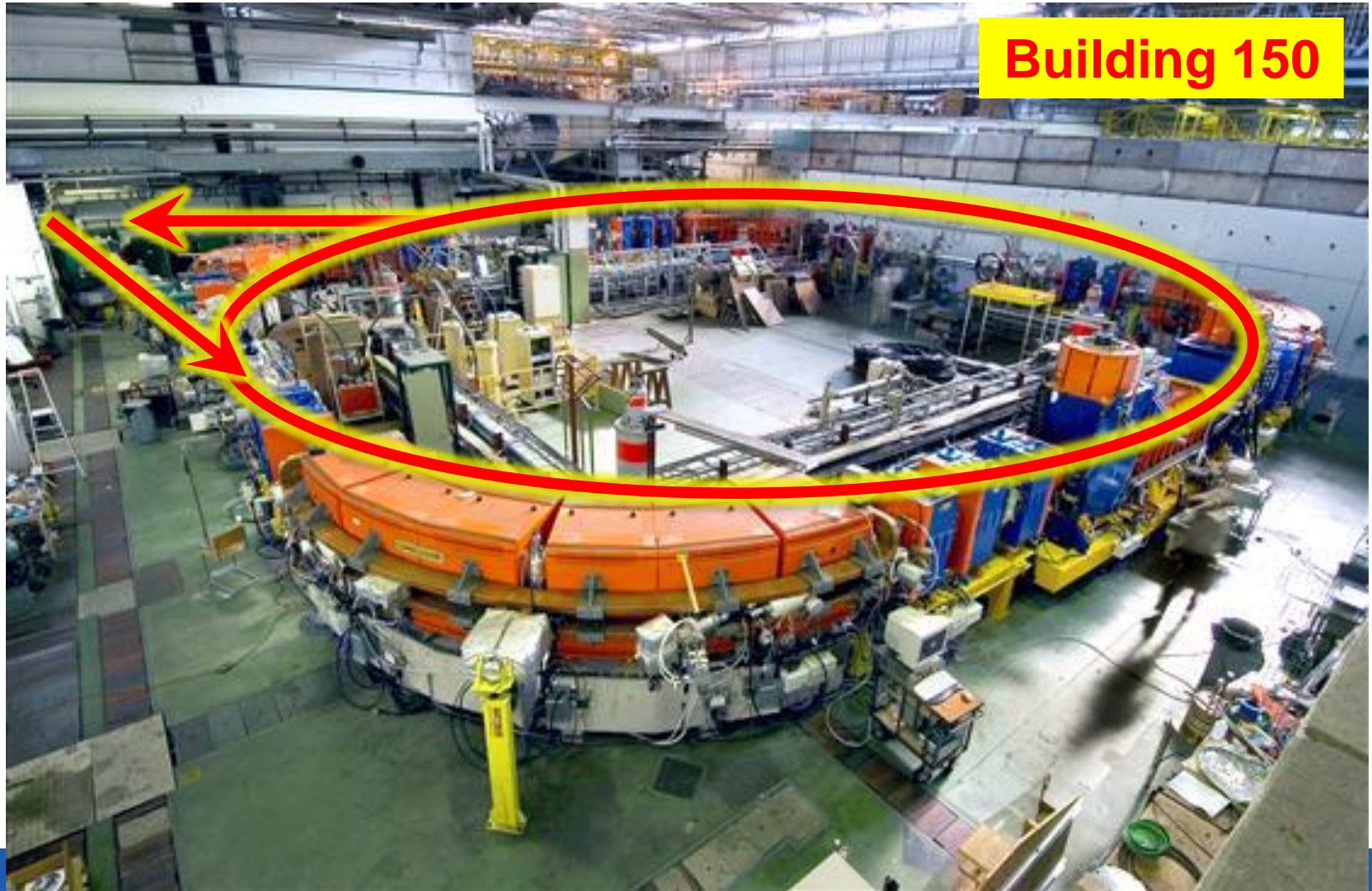
# The Energy in the LHC beam

- 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

# LEIR as an Example

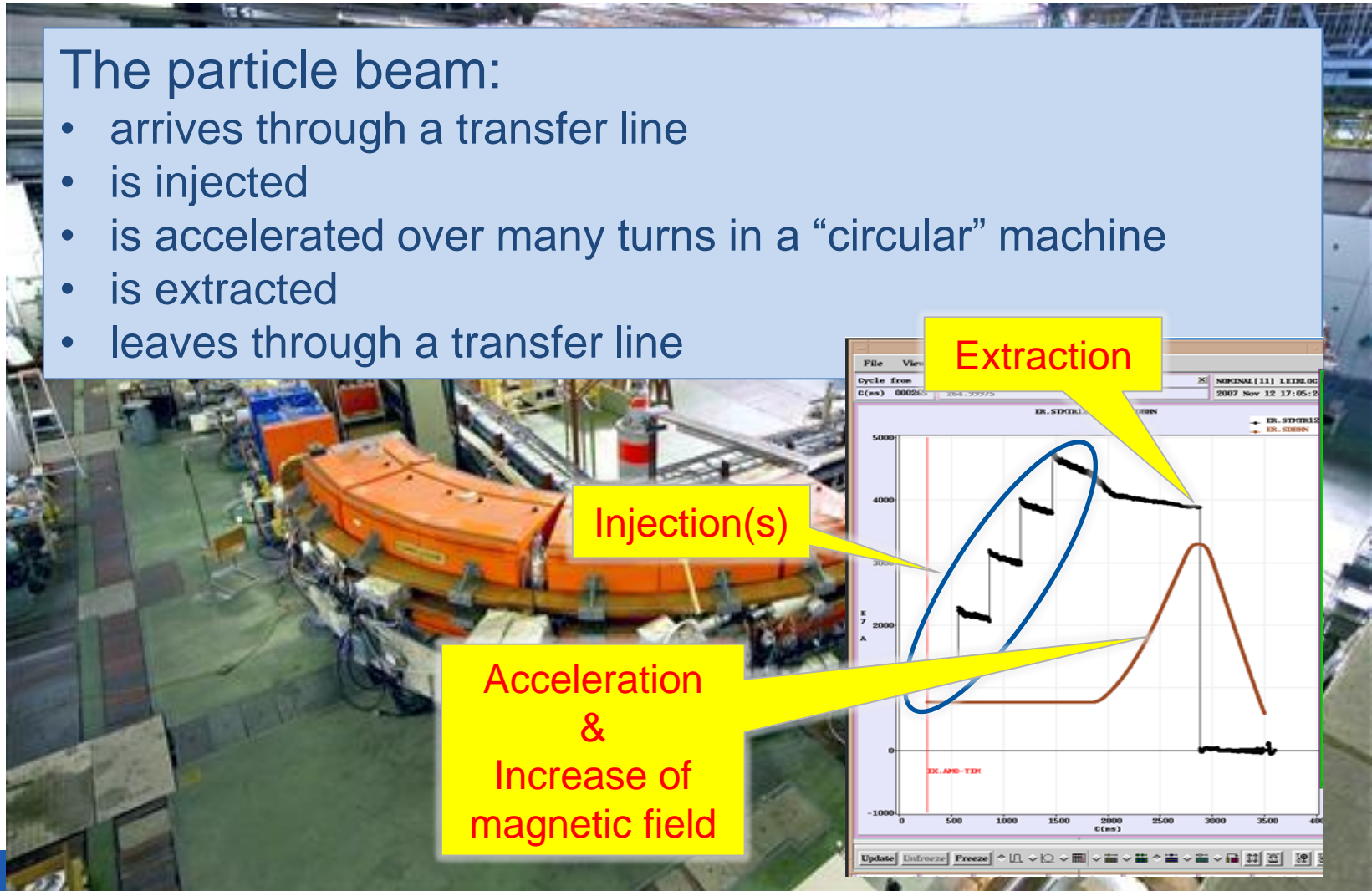


**Building 150**

# 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



# Travelling Through nothingness



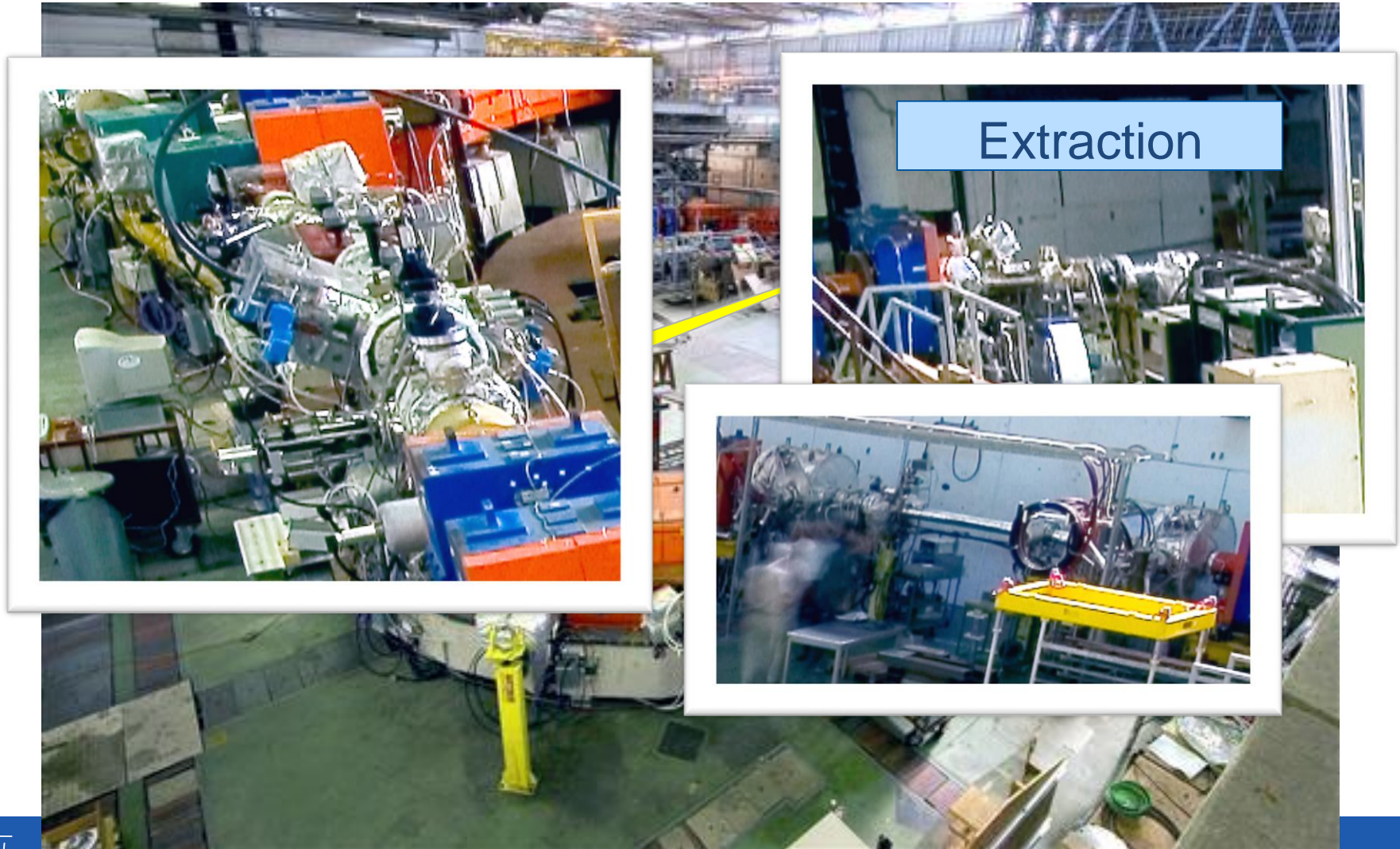
Vacuum in a mostly **stainless steel vacuum chamber** is required to **avoid** the particles to **interact** with the **gas molecules**

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



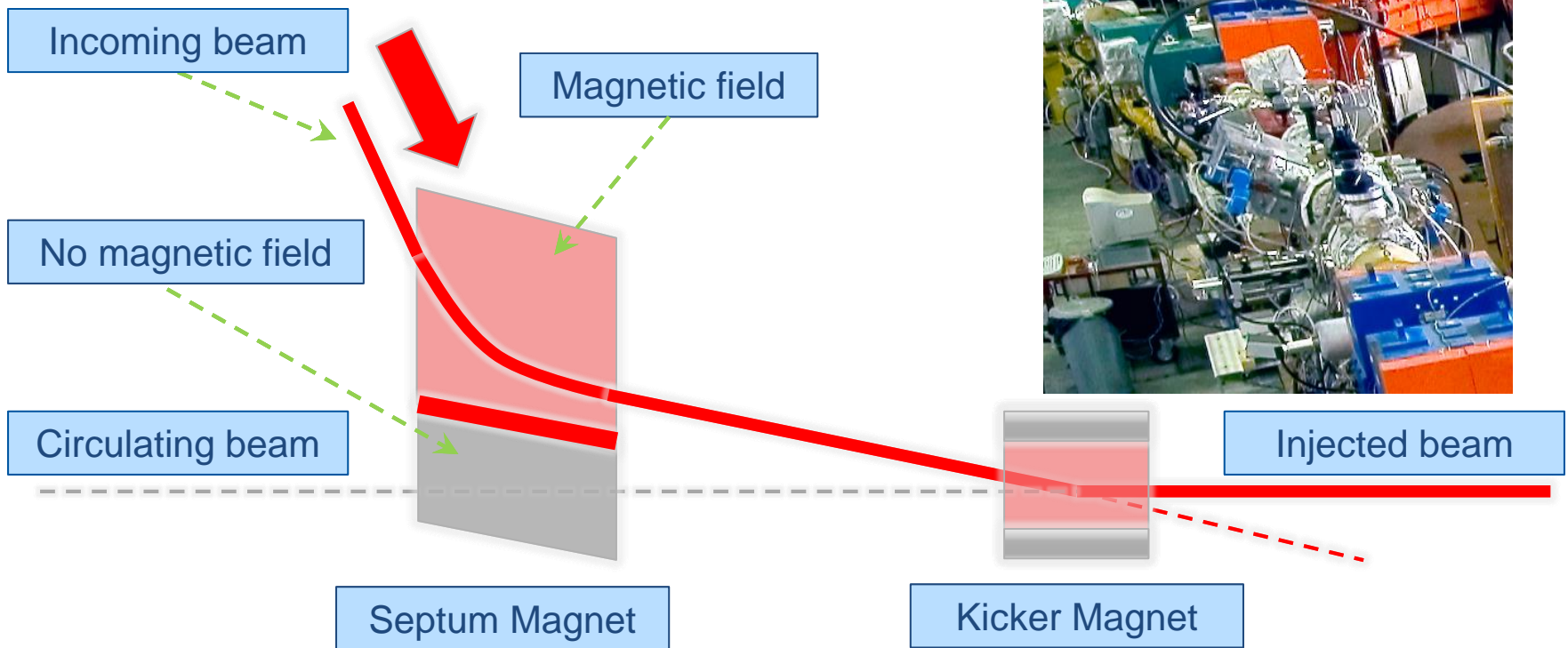
In the LHC **vacuum** is also used as **insulator**

# Injecting & Extracting Particles

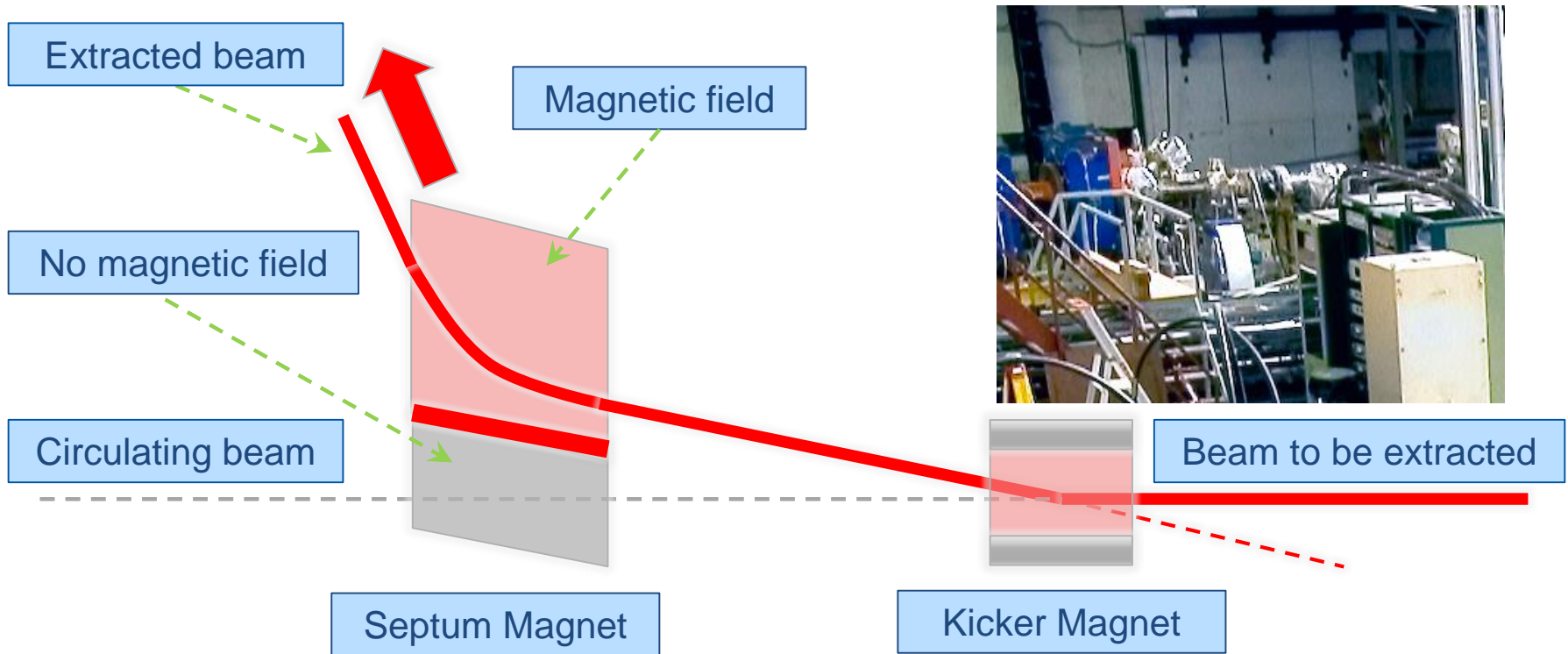


Extraction

# Injecting & Extracting Particles

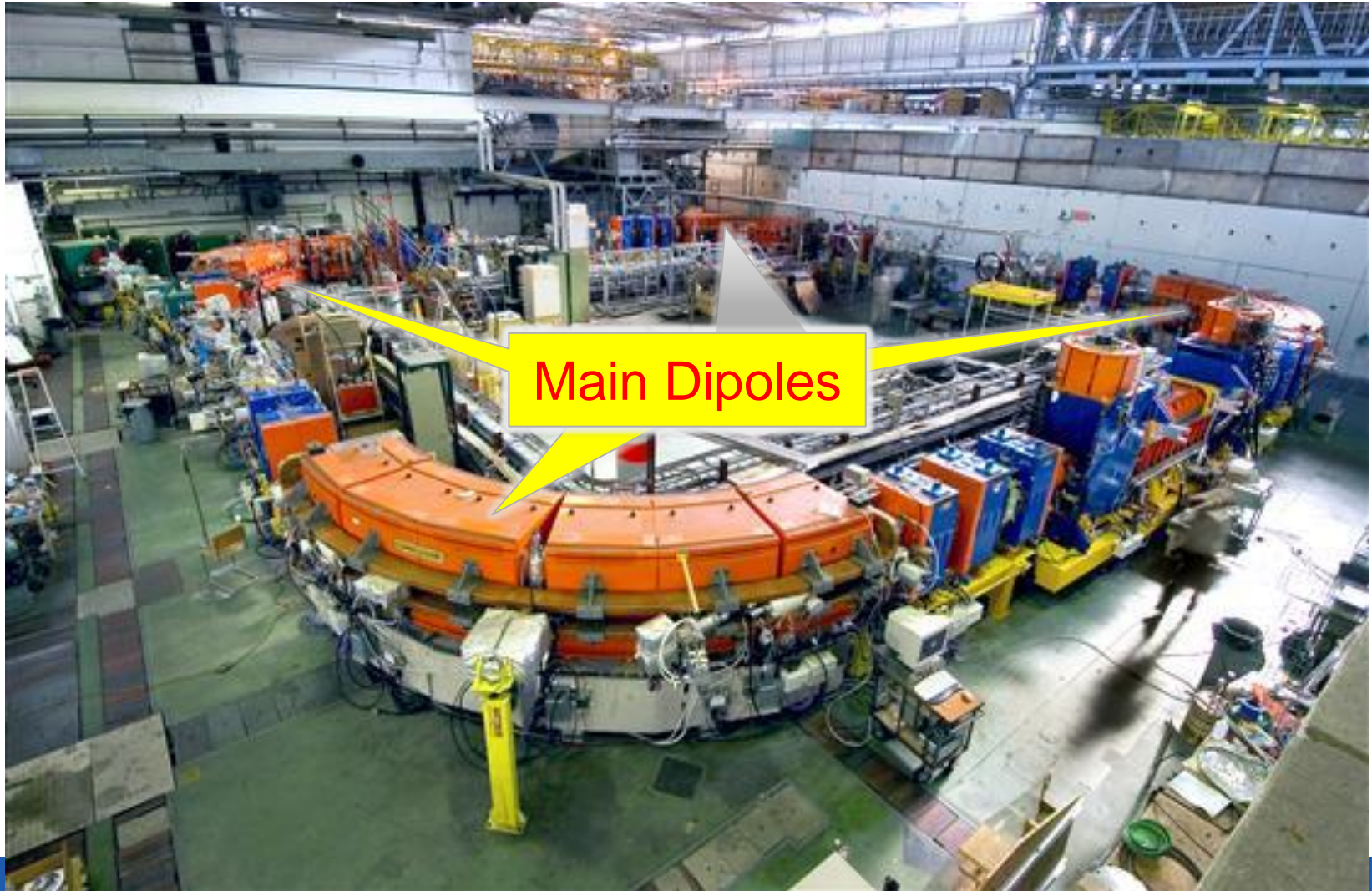


# Injecting & Extracting Particles



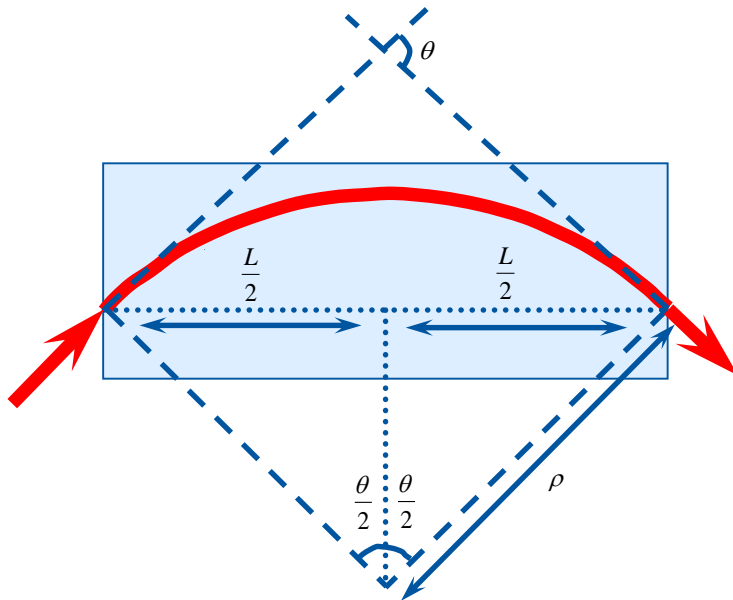


# Make Particles Circulate



# Deviating Charged Particles

Charged Particles are deviated in magnetic fields

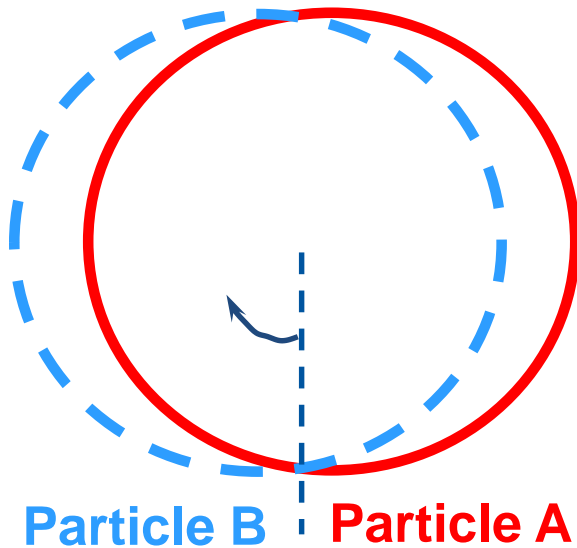


Lorentz force:

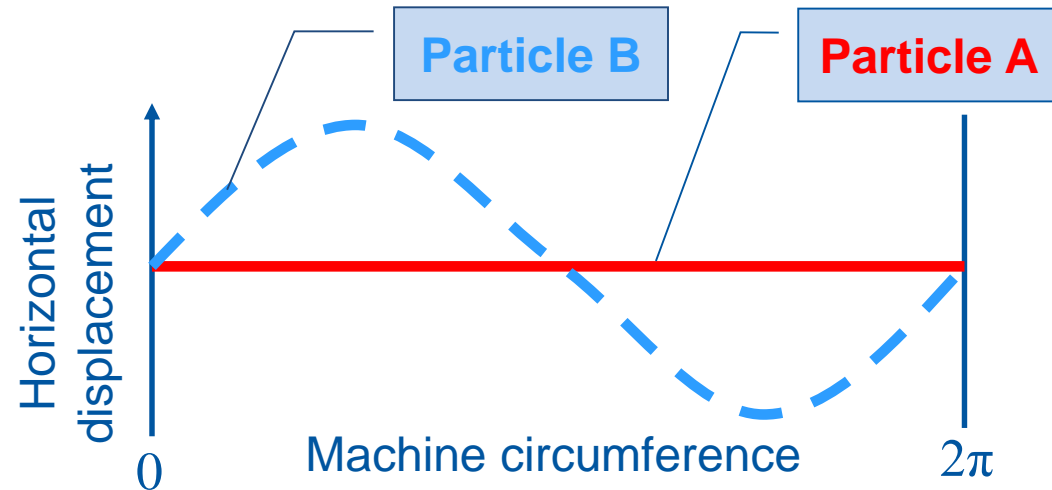
$$F = e v \times B$$

# Oscillatory Motion of Particles

Two charged Particles in a homogeneous magnetic field



Horizontal motion

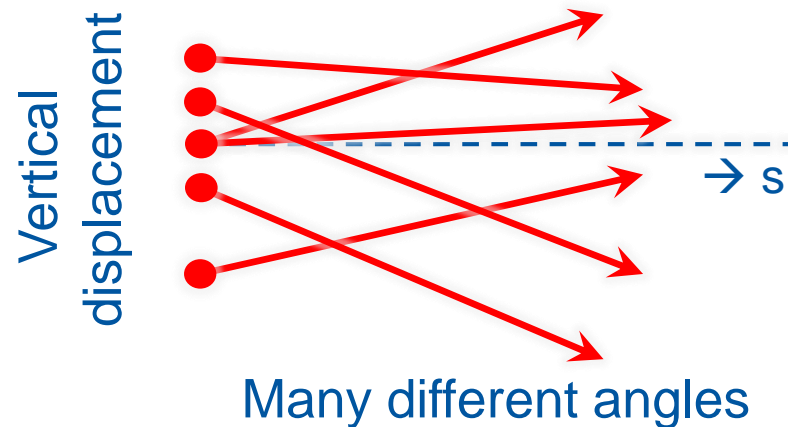


Different particles with different initial conditions in a homogeneous magnetic field will cause oscillatory motion in the horizontal plane → **Betatron Oscillations**

# Oscillatory Motion of Particles

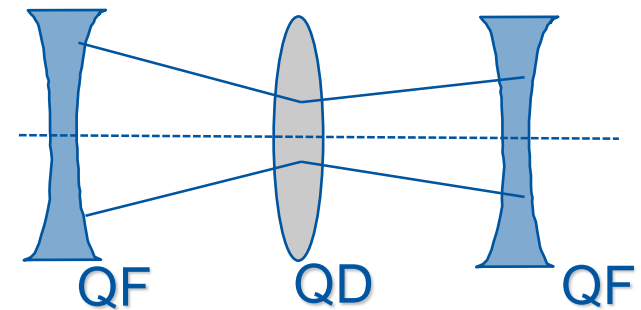
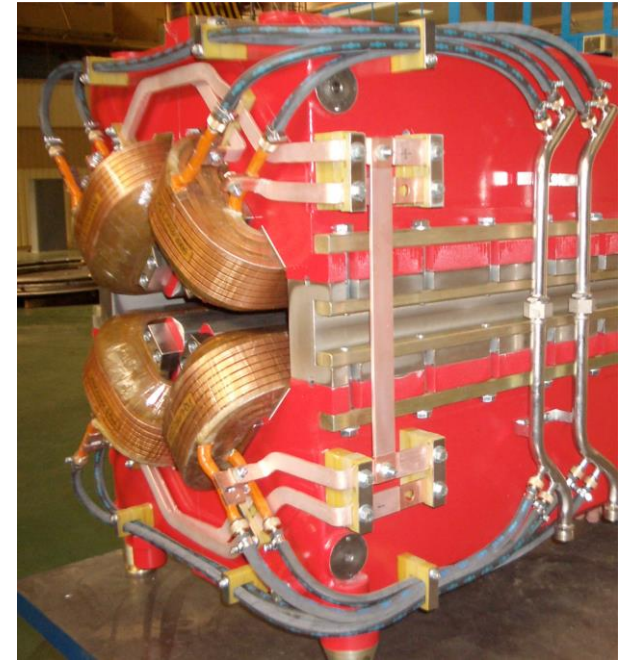
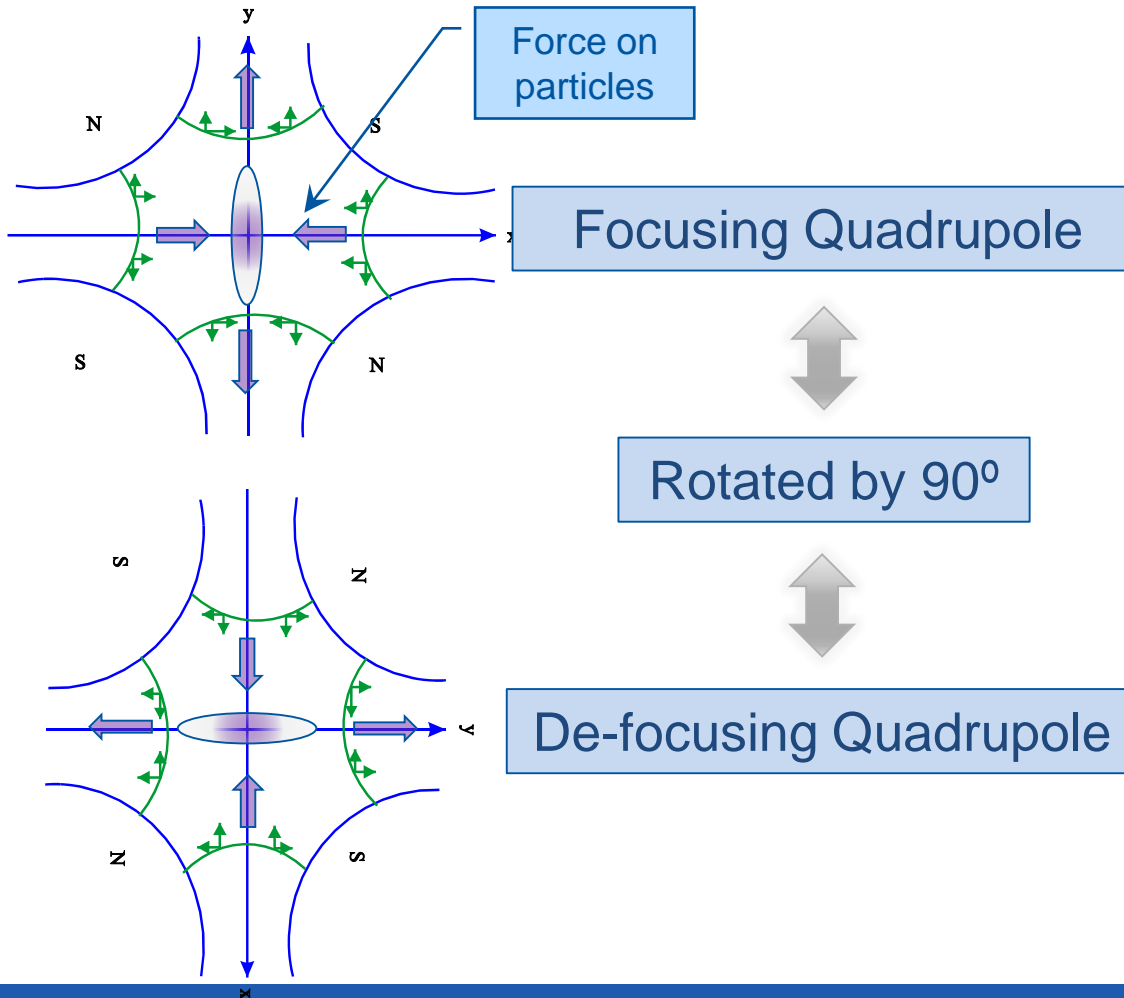
The horizontal motion seems to be “stable”.... What about the vertical plane ?

Many particles many initial conditions

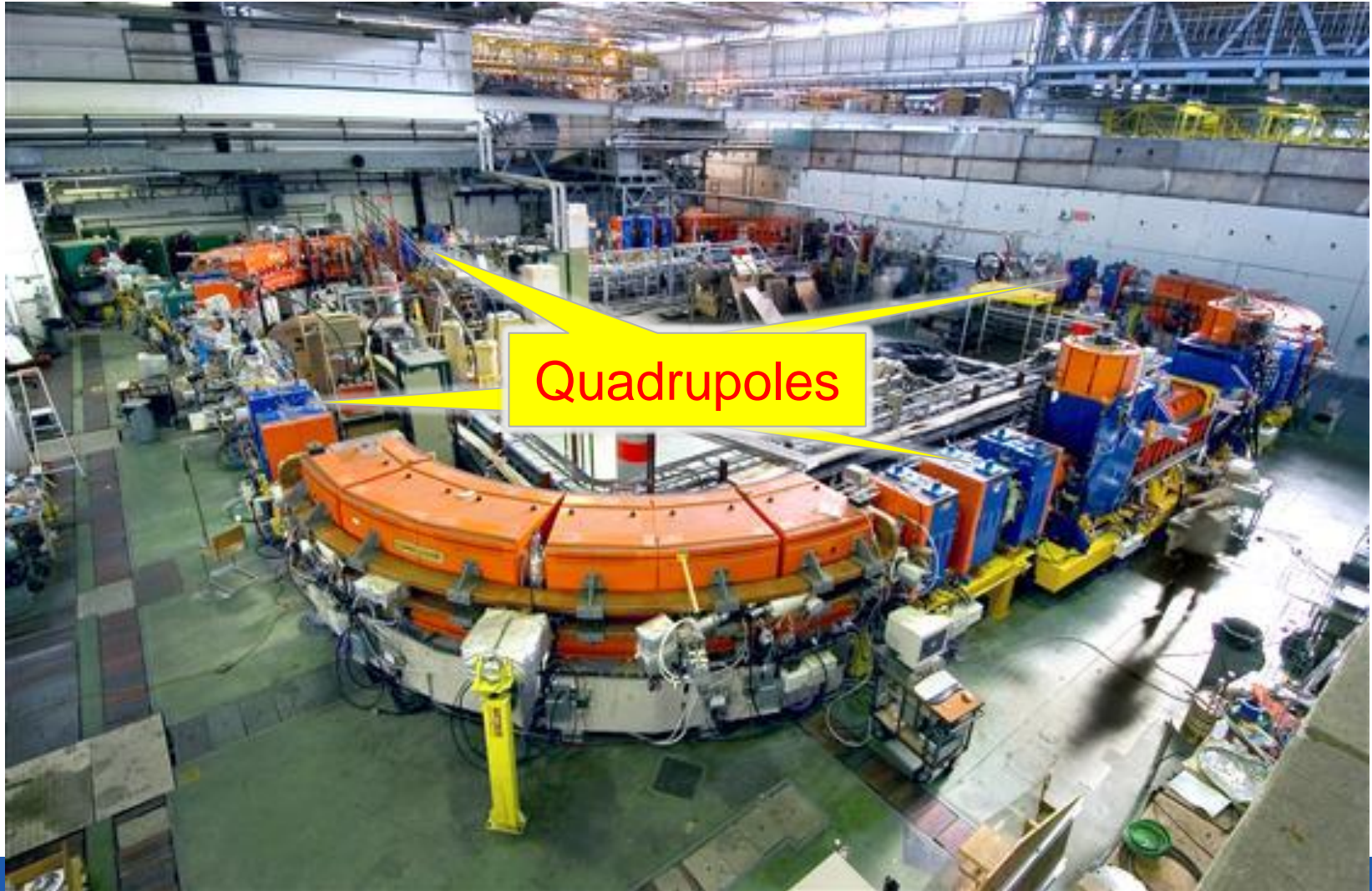


# Focusing Particle Beams

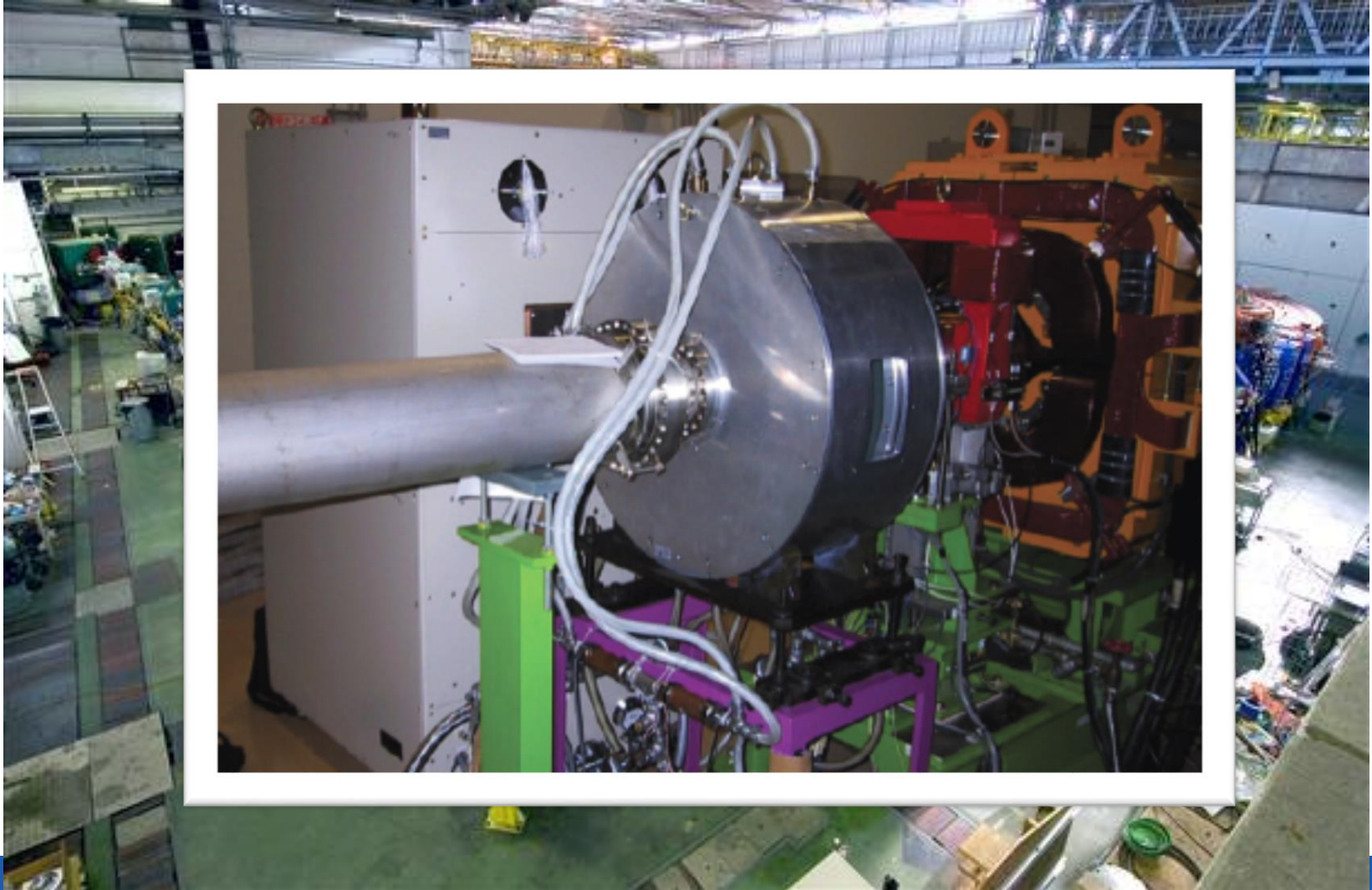
Focusing particles, a bit like light in a lens



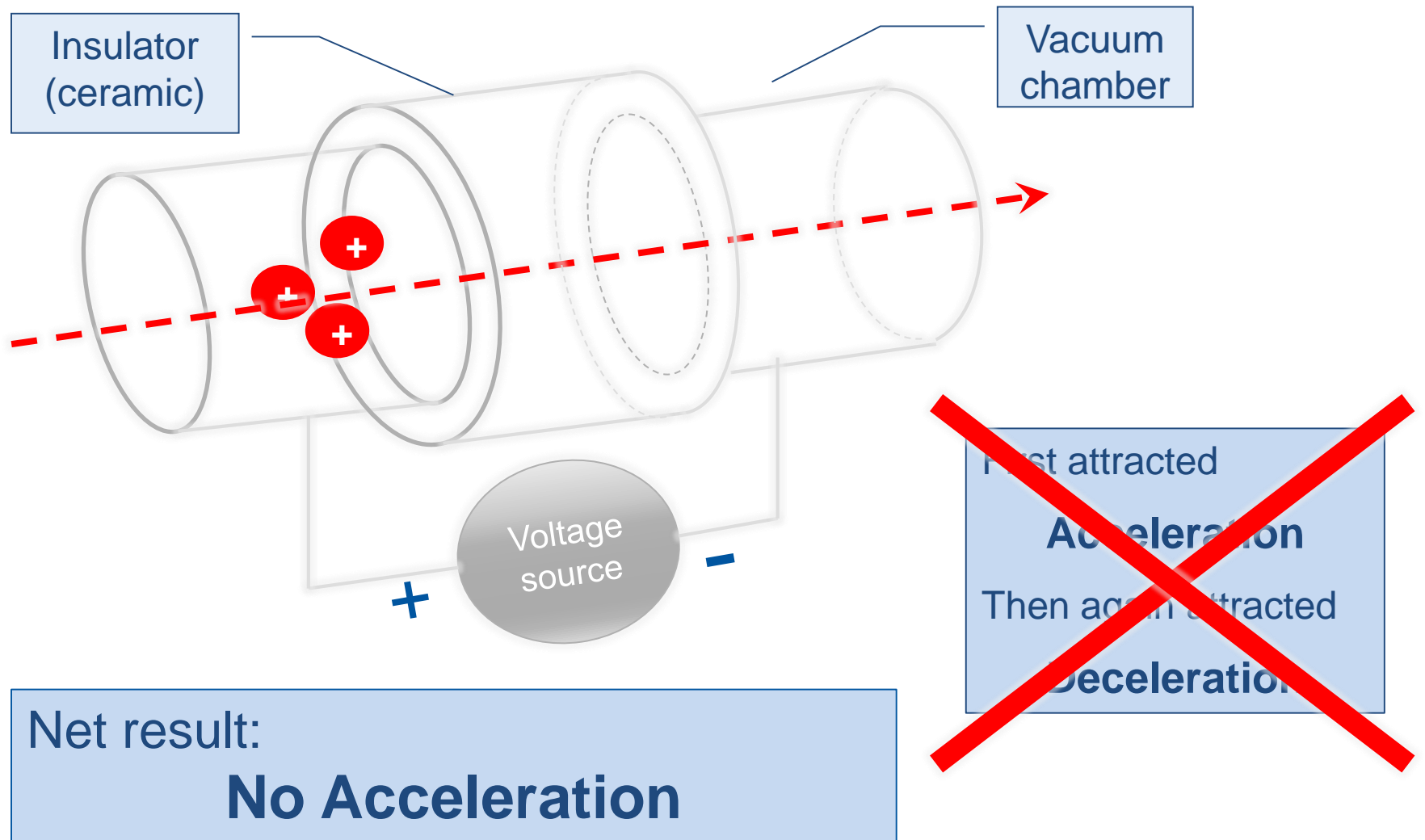
# Focusing the Particle Beam



# Accelerating Particles

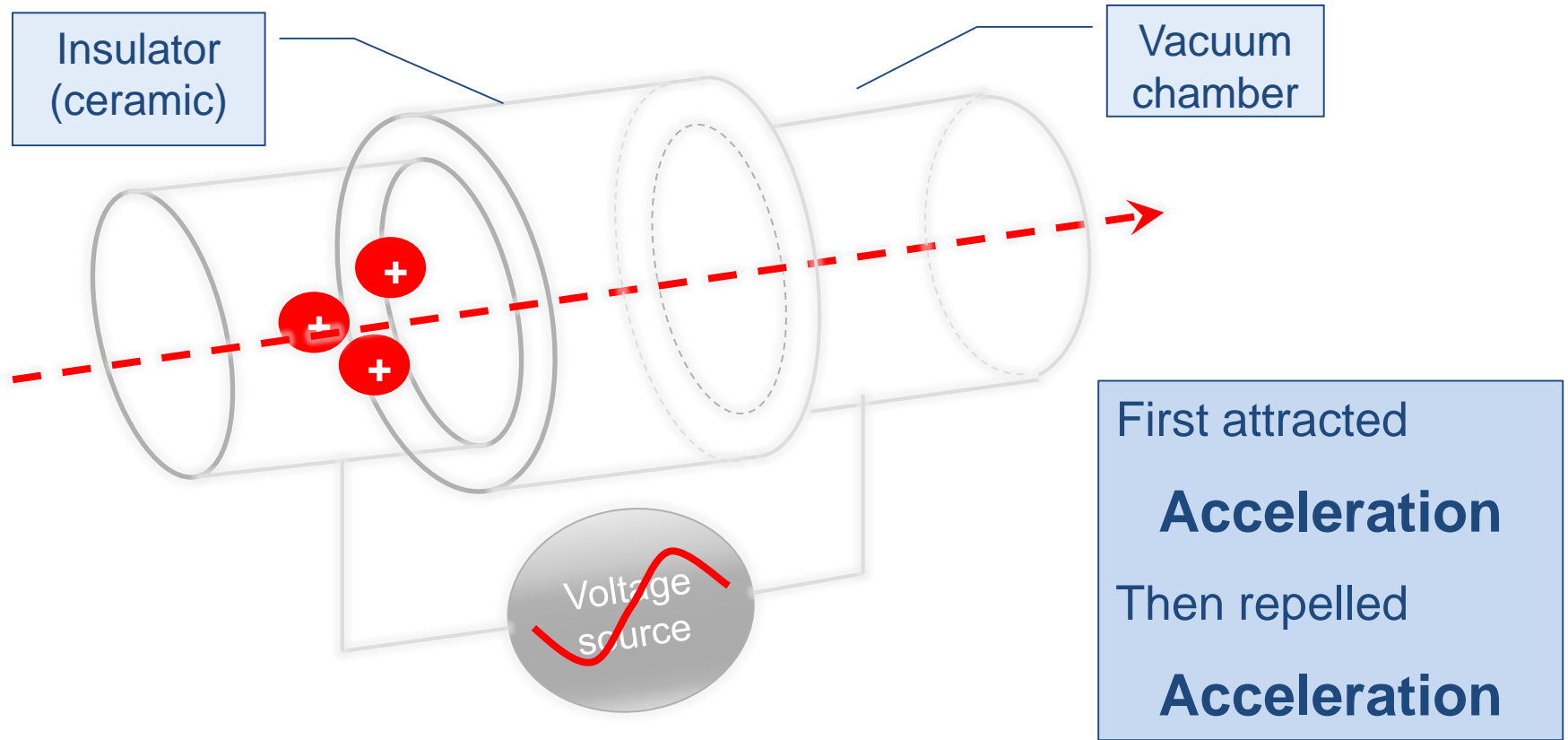


# Accelerating Beams



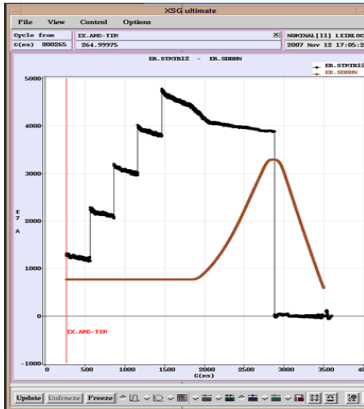


# Accelerating Beams

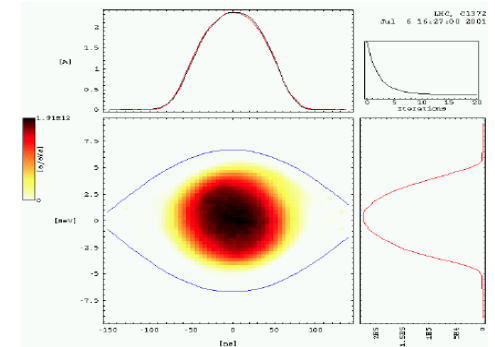
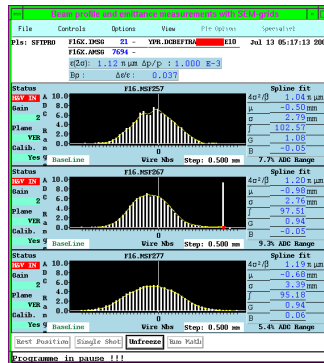


# The Eyes of Operations

Beam intensity or current measurement



Transverse beam profile/size measurement



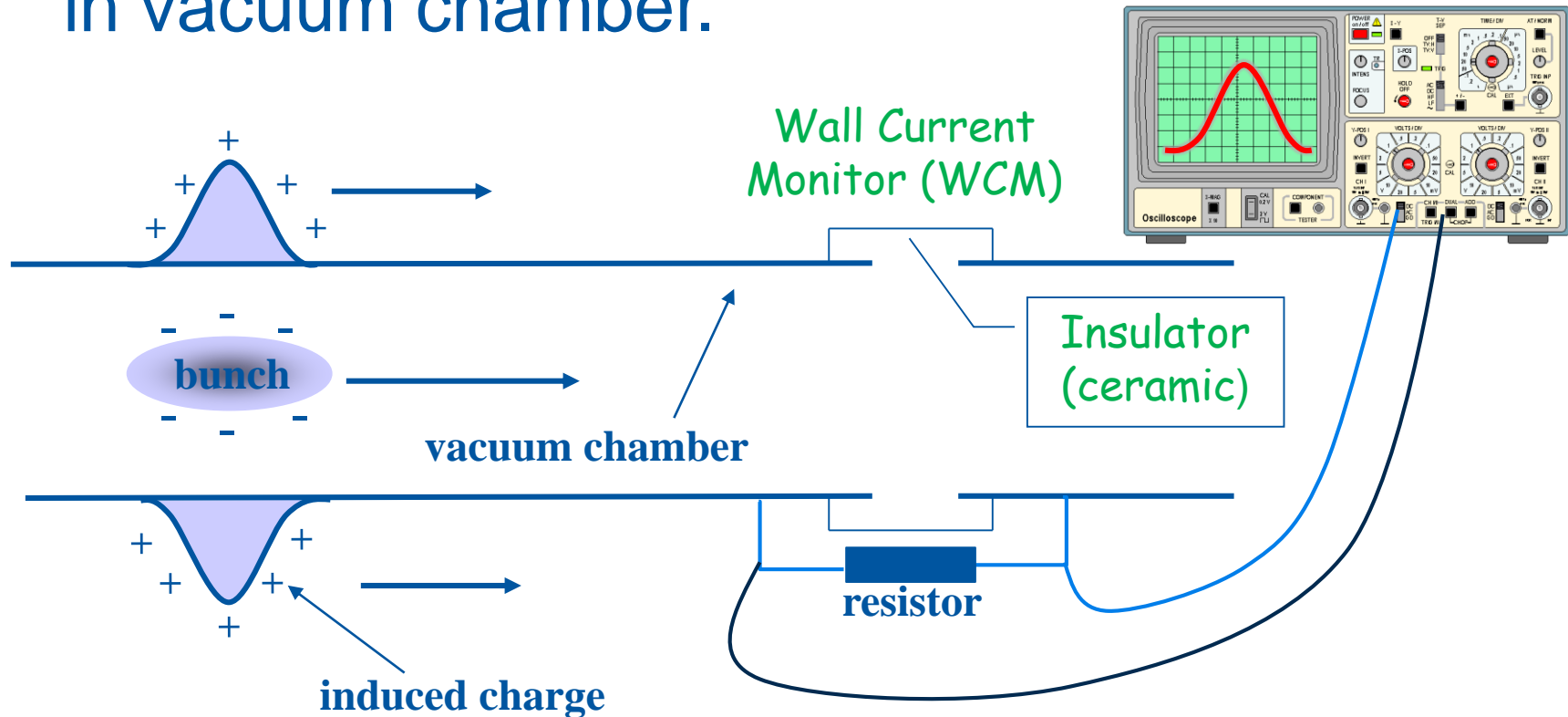
Longitudinal beam profile measurements

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

Any many more beam properties.....

# Example: Wall Current Monitor

- A circulating bunch creates an image current in vacuum chamber.



- The induced image current is the same size but has the opposite sign to the bunch current.

# Possible Limitations

Machines and elements cannot be built with infinite perfection

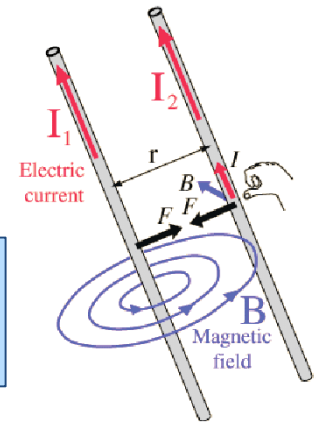


Same phase and frequency for driving force and the system can cause resonances and be destructive



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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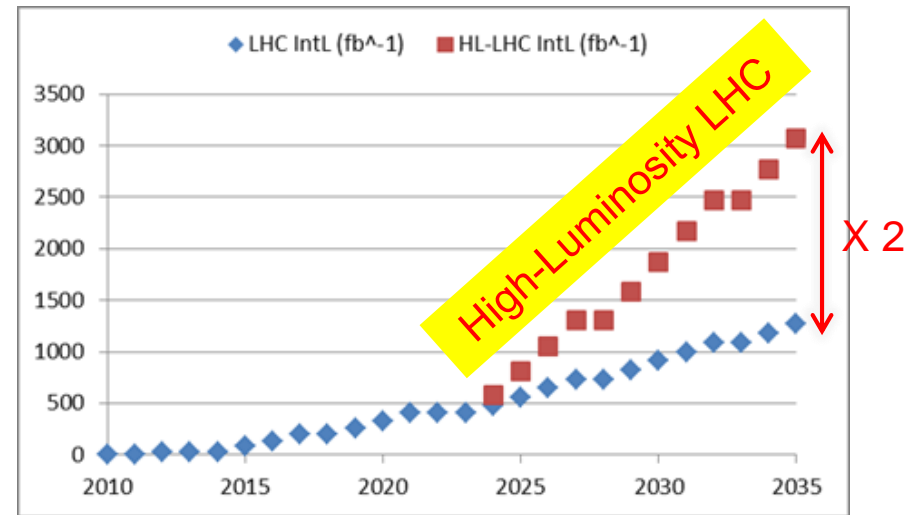
# Luminosity, the Figure of Merit

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

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  $S_x, S_y$ )

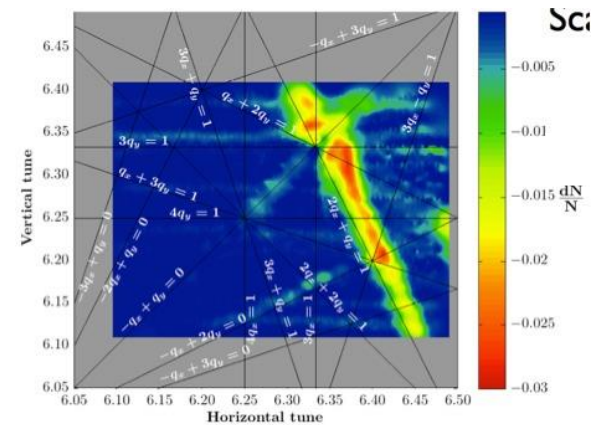
- More or less fixed:
  - Revolution period
  - Number of bunches

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



# LIU: What is being changed ?

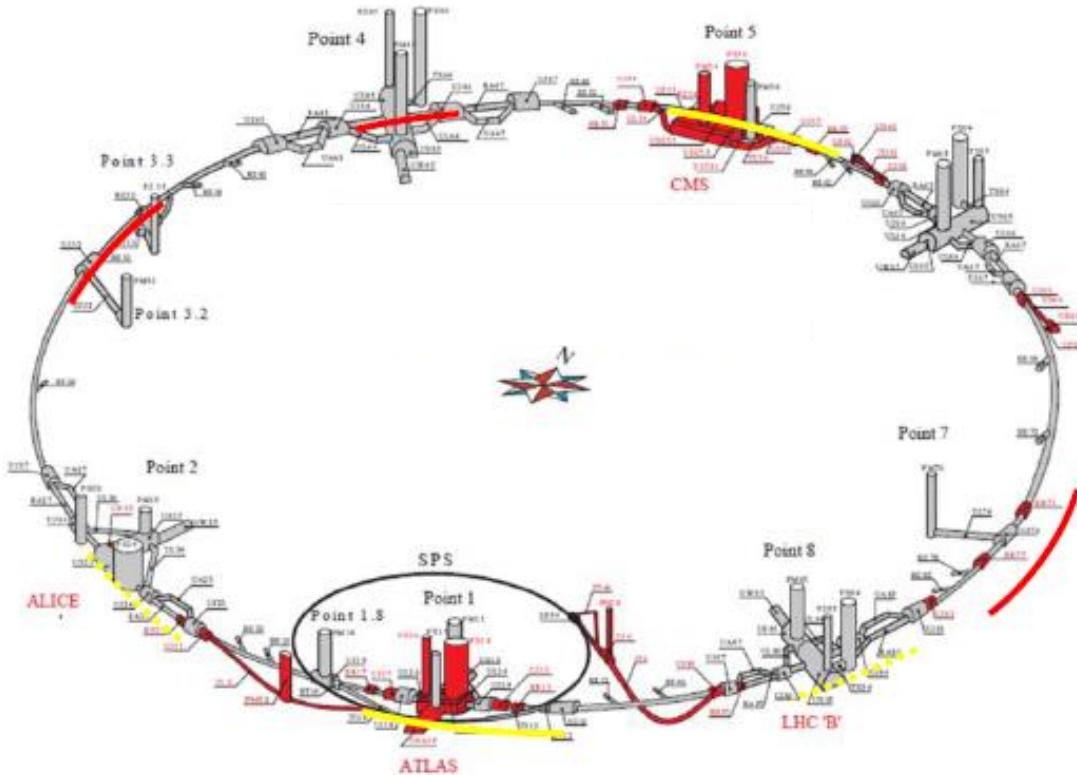
- LINAC4 – PS Booster:
  - New LINAC 4 with  $H^-$  injection
  - Higher injection energy
  - New Finemet® RF cavity system
  - Increase of extraction energy
- PS:
  - Injection energy increase from 1.4 GeV to 2 GeV
  - New Finemet® RF Longitudinal feedback system
  - New RF beam manipulation scheme 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

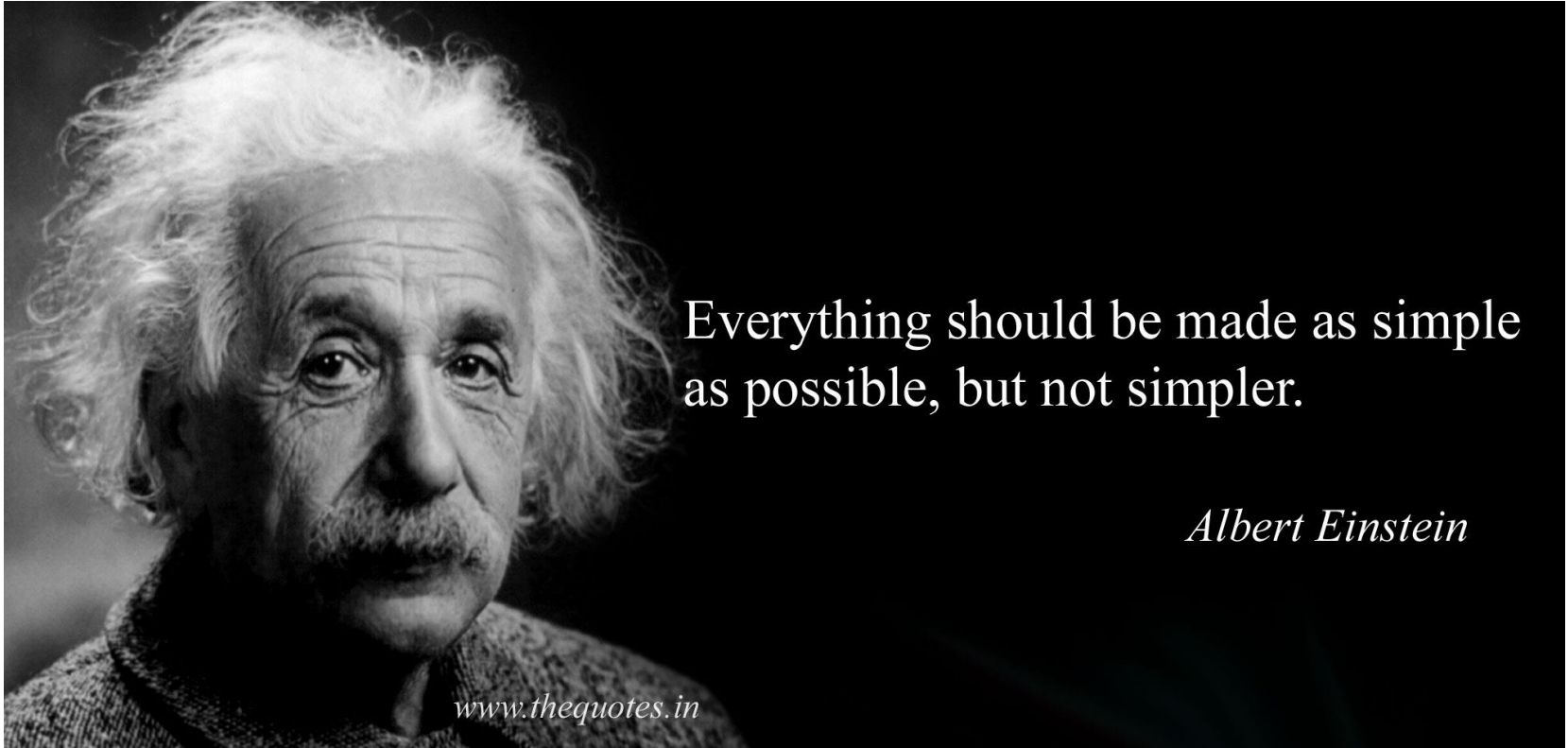
# HL-LHC: What will be changed ?



- 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





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

*Albert Einstein*

*www.thequotes.in*