Accelerators for Beginners

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CERN Accelerator School
Basic Accelerator Science & Technology at CERN
3 – 7 February 2014 – Chavannes de Bogis

The CERN Accelerator School

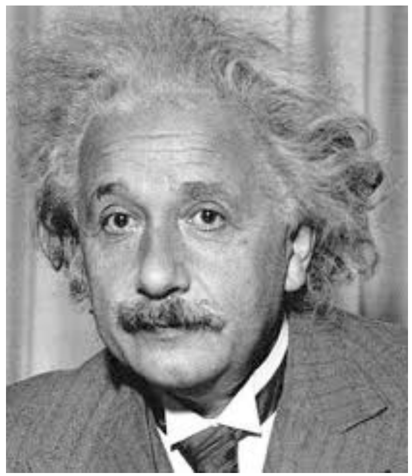
Contents

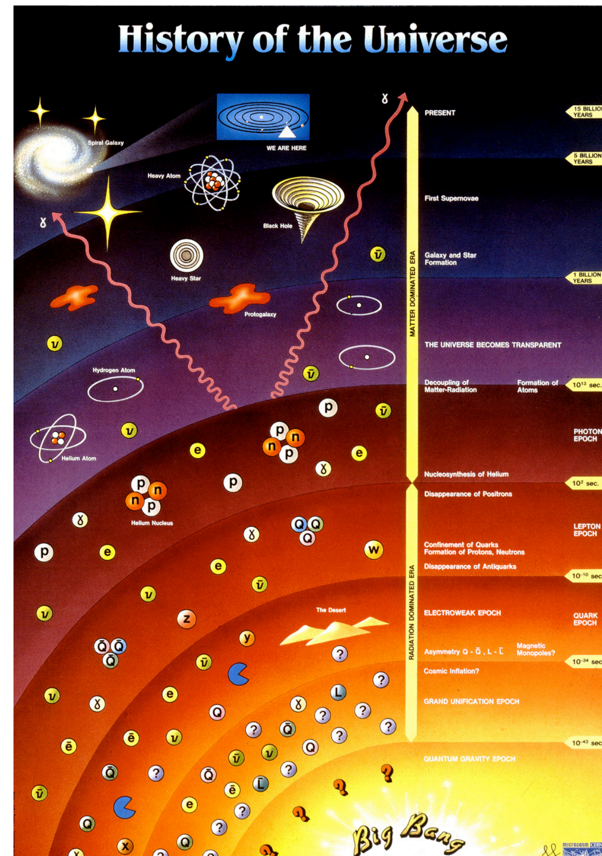
- **Why Accelerators and Colliders ?**
- A very Brief Historic Overview
- The Main Ingredients of an Accelerator

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 particle we accelerate.

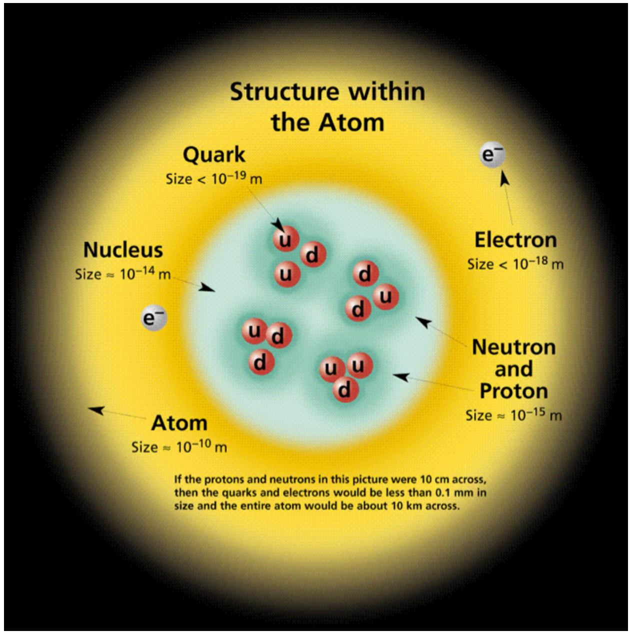
In the detectors we observe the matter created

Looking to smaller dimensions

Visible light
λ = 400 → 700 nm

X-ray
λ = 0.01 → 10 nm

Particle accelerators
λ < 0.01 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

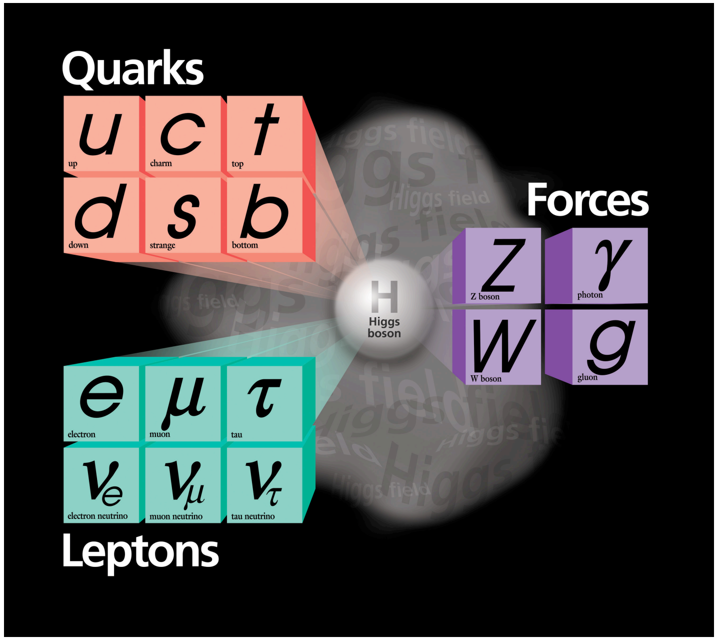
Collider

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

All energy will be available for particle production

The Aim

Verify the Standard Model



Search for physics beyond the Standard Model

"Standard Model and Beyond" by Paris Sphicas

This afternoon

- Why Accelerators and Colliders ?
- **A very Brief Historic Overview**
- The Main Ingredients of an Accelerator

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^-)
- Lin. & Circ. accelerators/Colliders

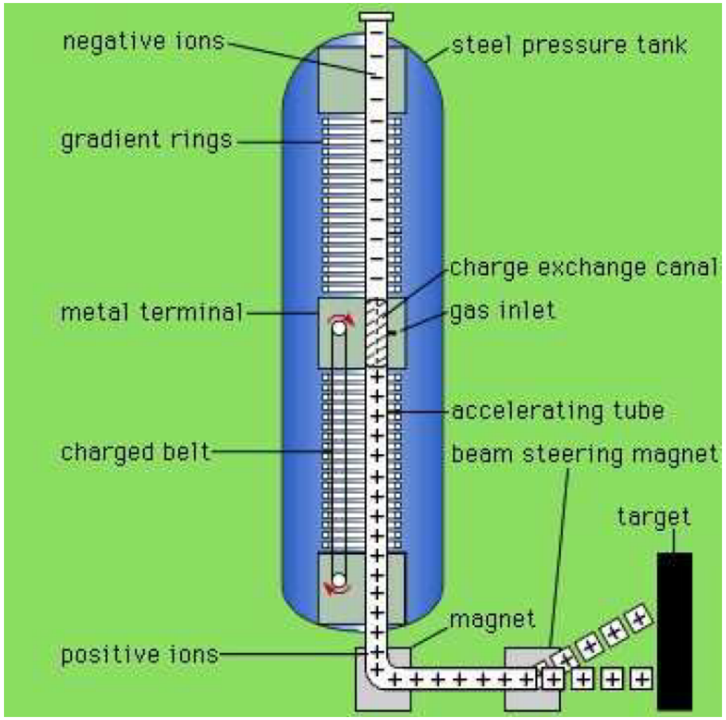
This lecture will concentrate on the CERN type machines of which the majority are

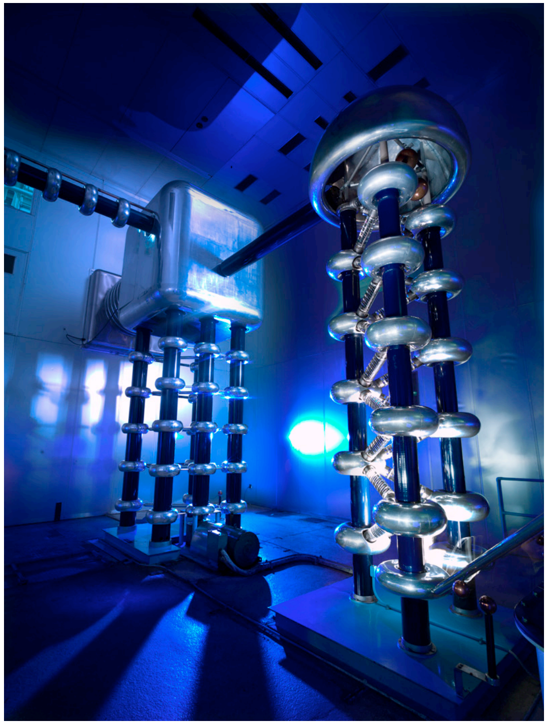
Synchrotrons

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

Cockroft, Walton & Van de Graaff

- 1932: First accelerator – single passage 160 keV
- Static voltage accelerator
- Limited by the high voltage needed.

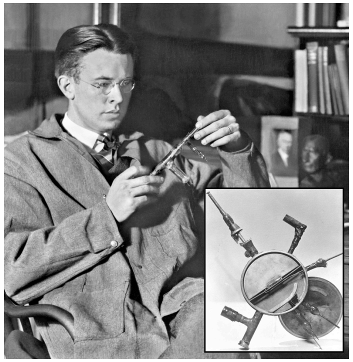


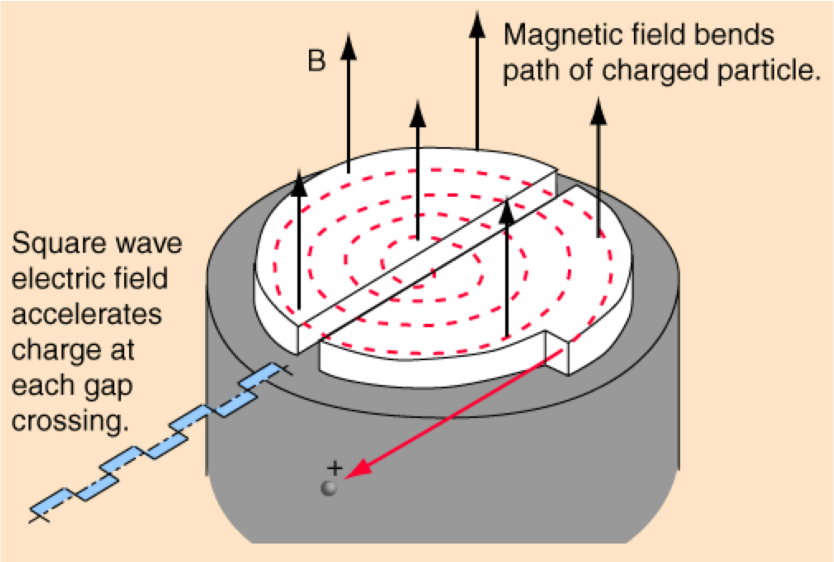


Cyclotron

- 1932: 1.2 MeV – 1940: 20 MeV (E.O. Lawrence, M.S. Livingston)
- Constant magnetic field
- Alternating voltage between
- Increasing particle trajectory radius
- Development lead to the synchro-cyclotron to cope with the relativistic effects.

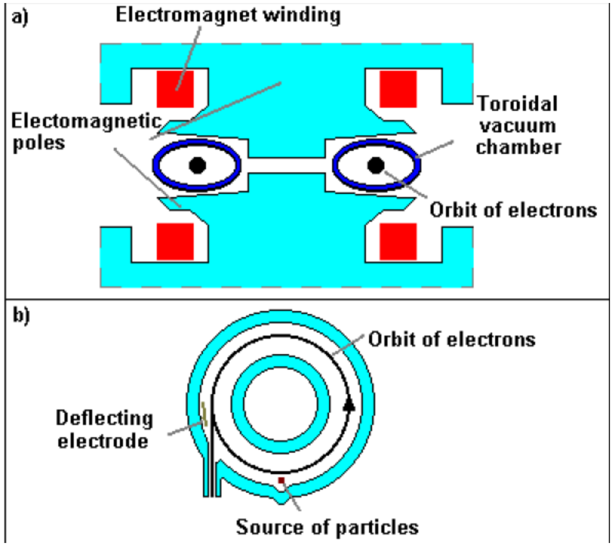
In 1939 Lawrence received the Noble prize for his work.



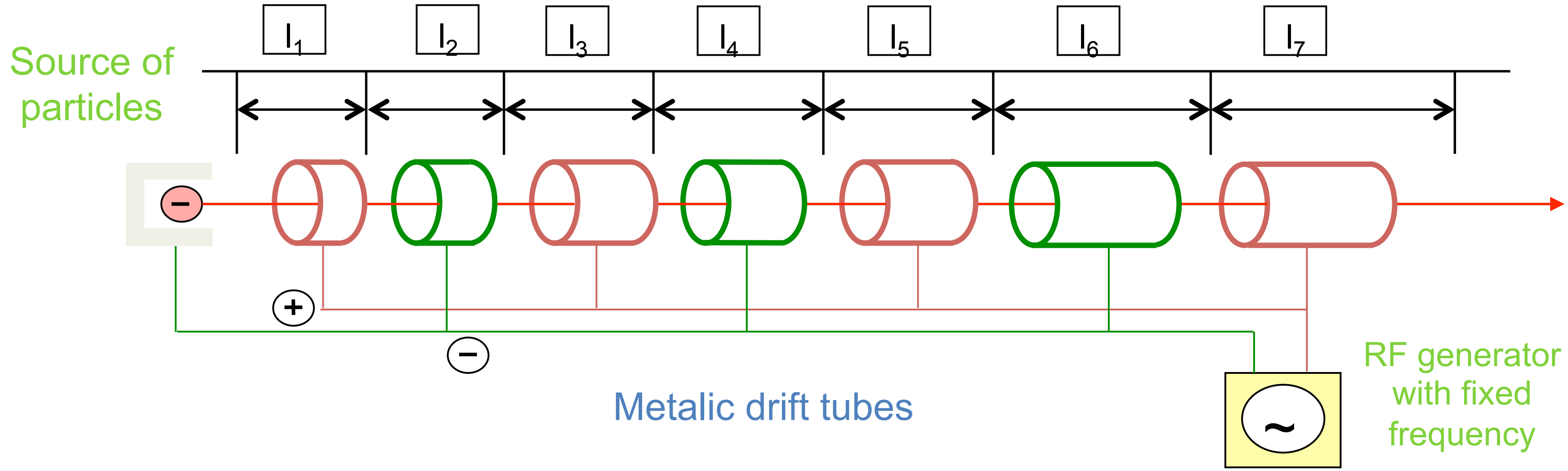


Betatron

- 1940: Kerst 2.3 MeV and very quickly 300 MeV
- It is actually a transformer with a beam of electrons as secondary winding.
- The magnetic field is used to bend the electrons in a circle, but also to accelerate them.
- A deflecting electrode is use to deflect the particle for extraction.



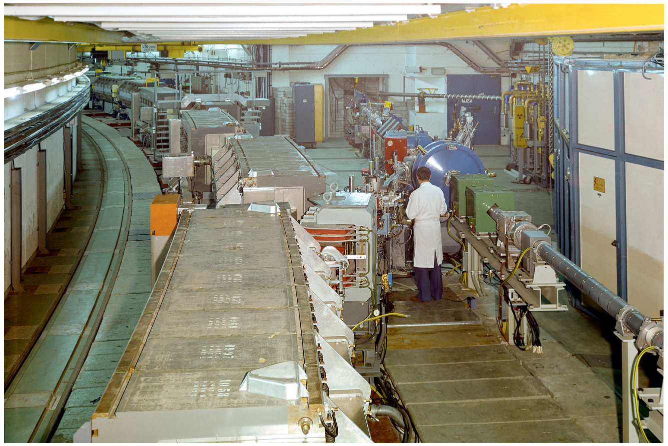
Linear Accelerator



- Many people involved: Wideroe, Sloan, Lawrence, Alvarez,….
- Main development took place between 1931 and 1946.
- Development was also helped by the progress made on high power high frequency power supplies for radar technology.
- Today still the first stage in many accelerator complexes.
- Limited by energy due to length and single pass.

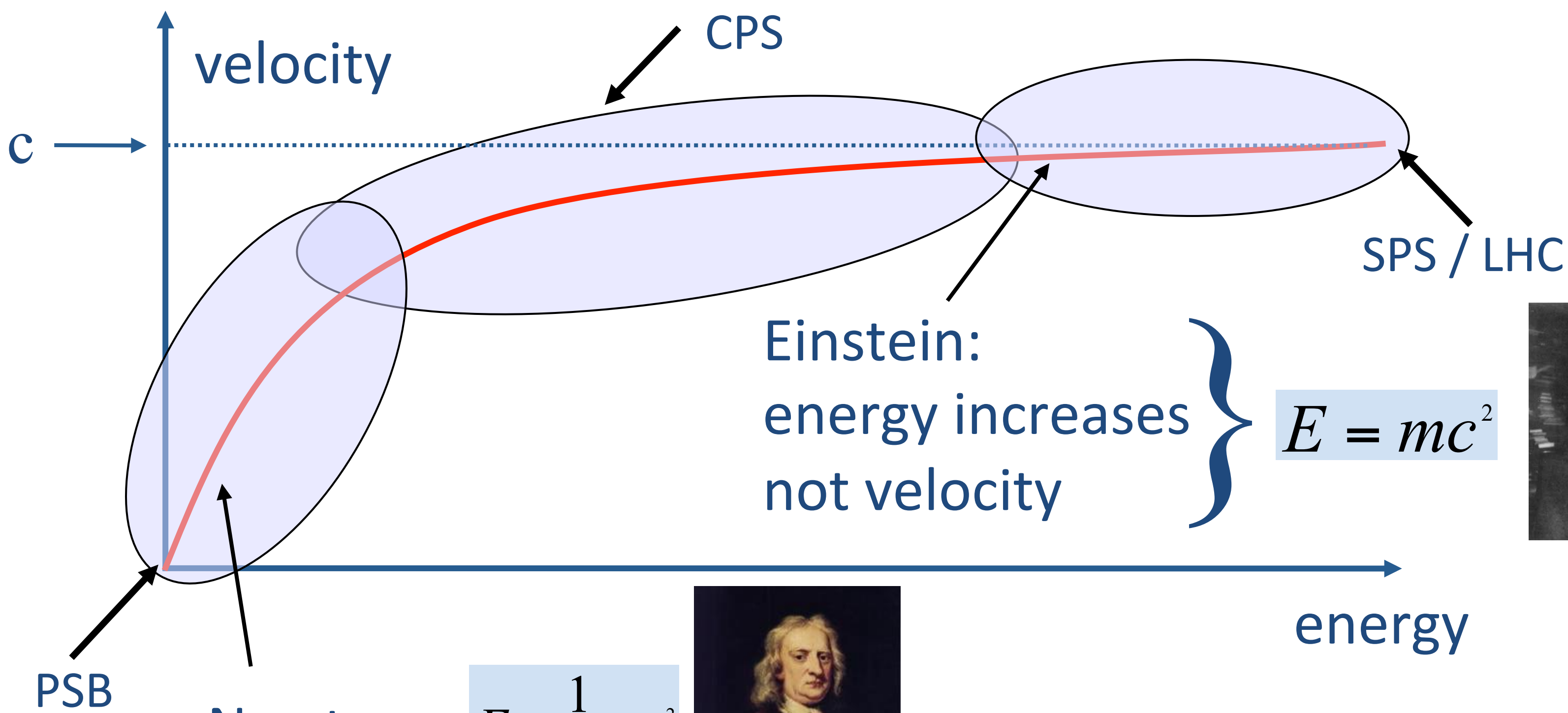
Synchrotrons

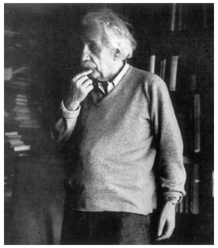
- 1959: CERN-PS and BNL-AGS
- Fixed radius for particle orbit
- Varying magnetic field and radio frequency
- Important focusing of particle beams
- Providing beam for fixed target physics
- Paved the way to colliders



- Why Accelerators and Colliders ?
- A very Brief Historic Overview
- **The Main Ingredients of an Accelerator**

Towards Relativity



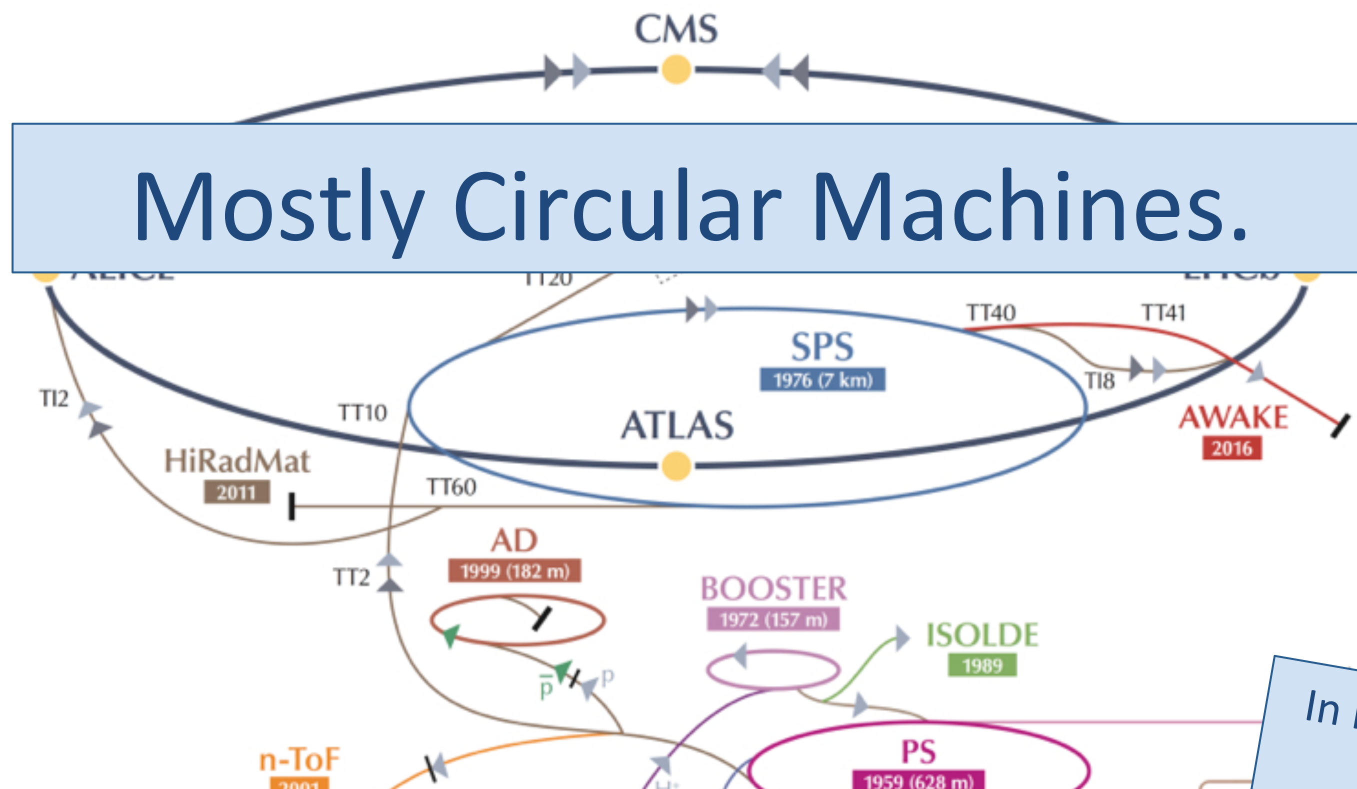


Newton: $E = \frac{1}{2}mv^2$

"**Relativity**" by Werner Herr

This afternoon

The CERN Accelerator Complex



Mostly Circular Machines.

In less than 1 hour

"**Overview of the CERN Complex**" by Reyes Alemany Fernandez

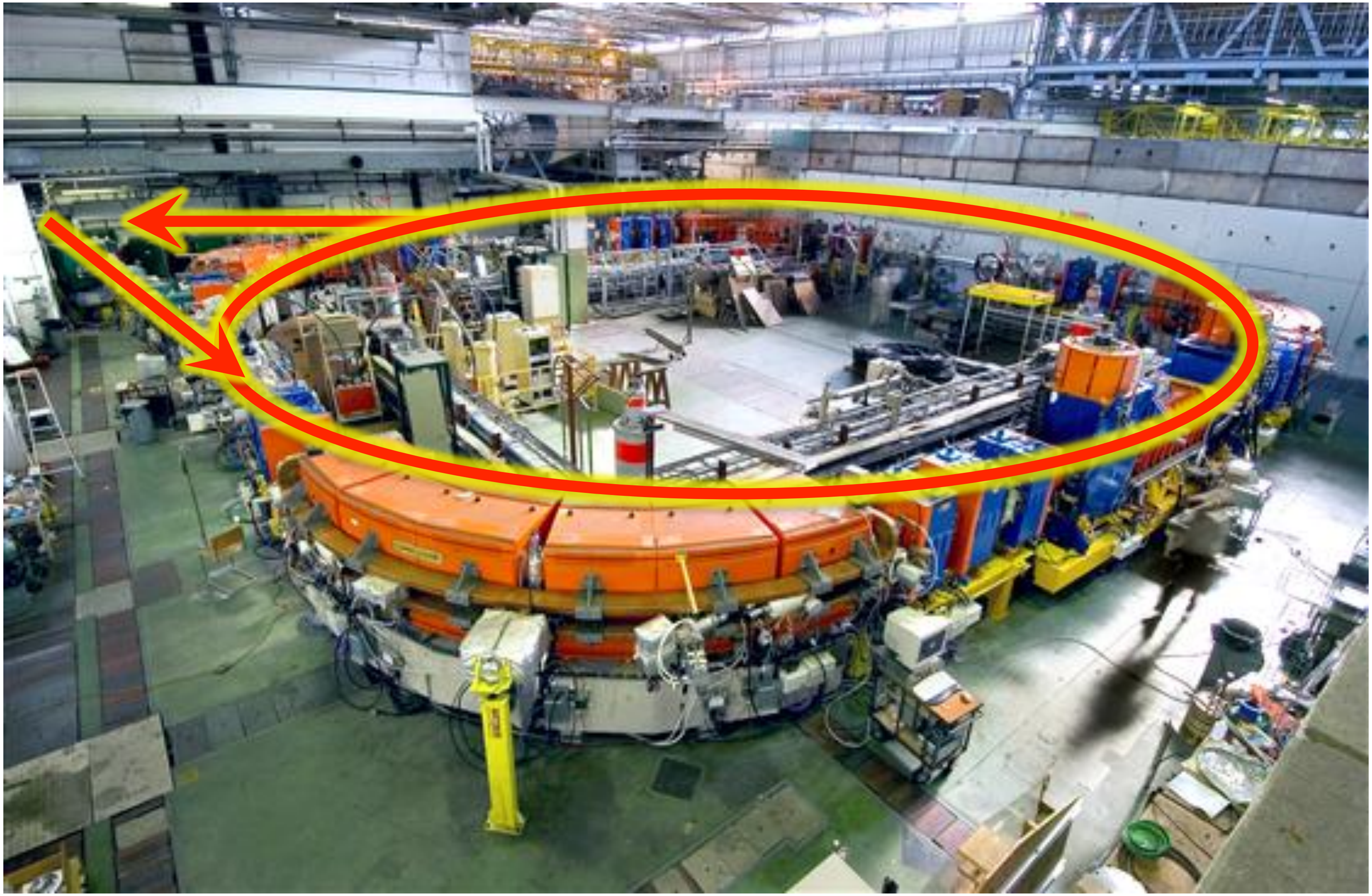
"**Sources**" by Richard Scrivens

Wednesday morning

"**LINACS**" by Maurizio Vretenar

Thursday afternoon

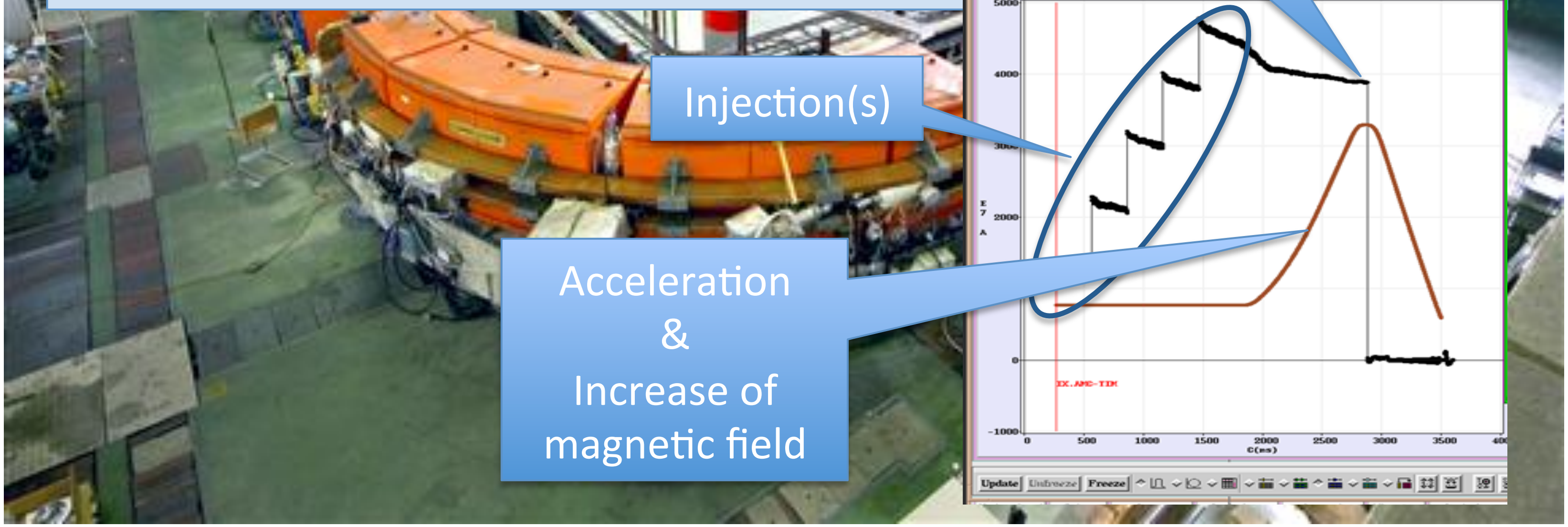
LEIR as an Example



LEIR as an Example

The particle beam:

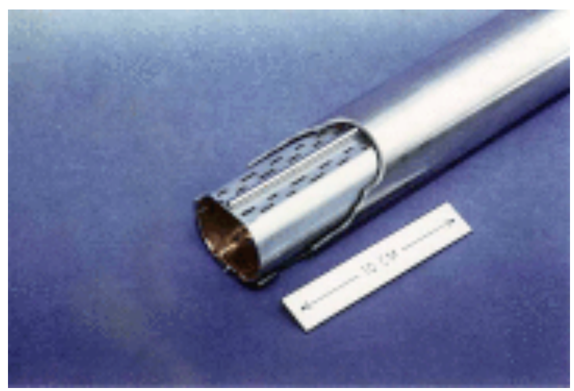
- arrives through a transfer line
- is injected
- is accelerated over many turns in a "circular" machine
- is extracted
- leaves through a transfer line



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



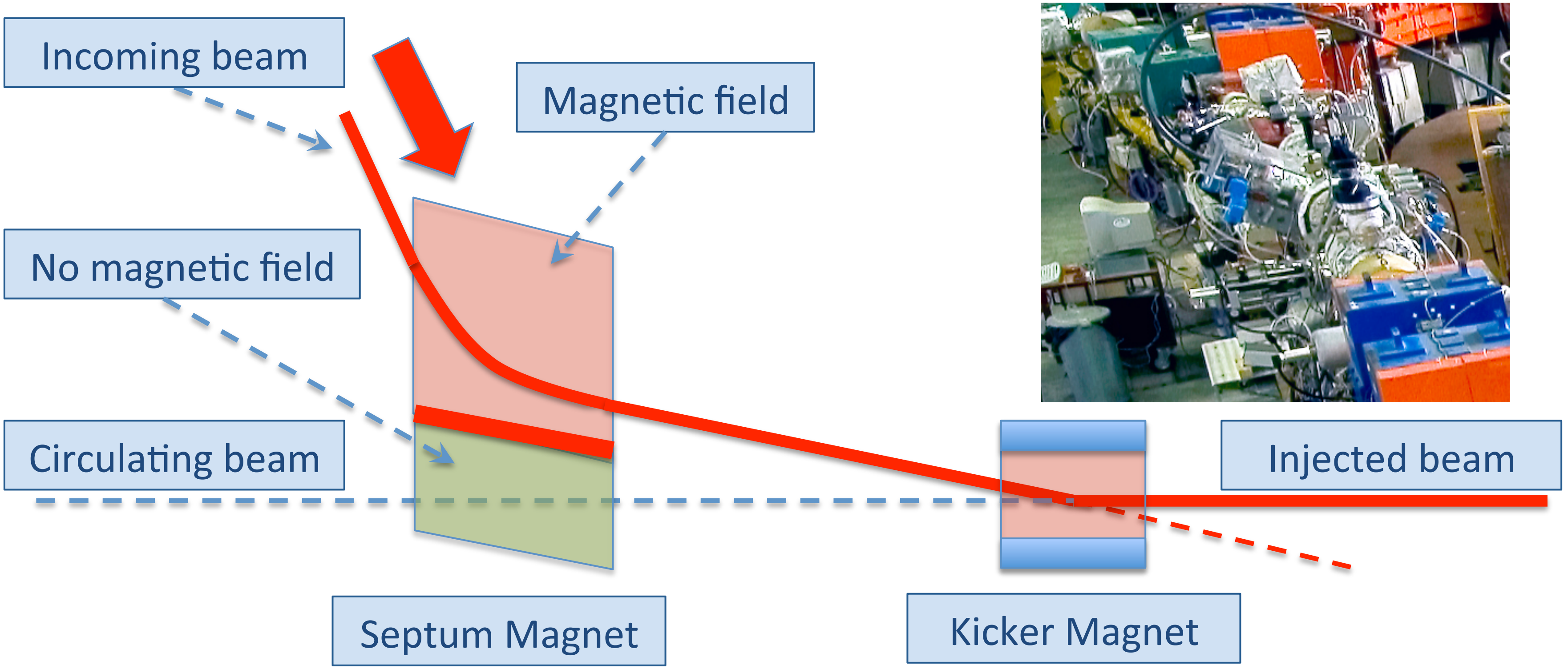
In the LHC **vacuum** is also used as **insulator**

Thursday afternoon

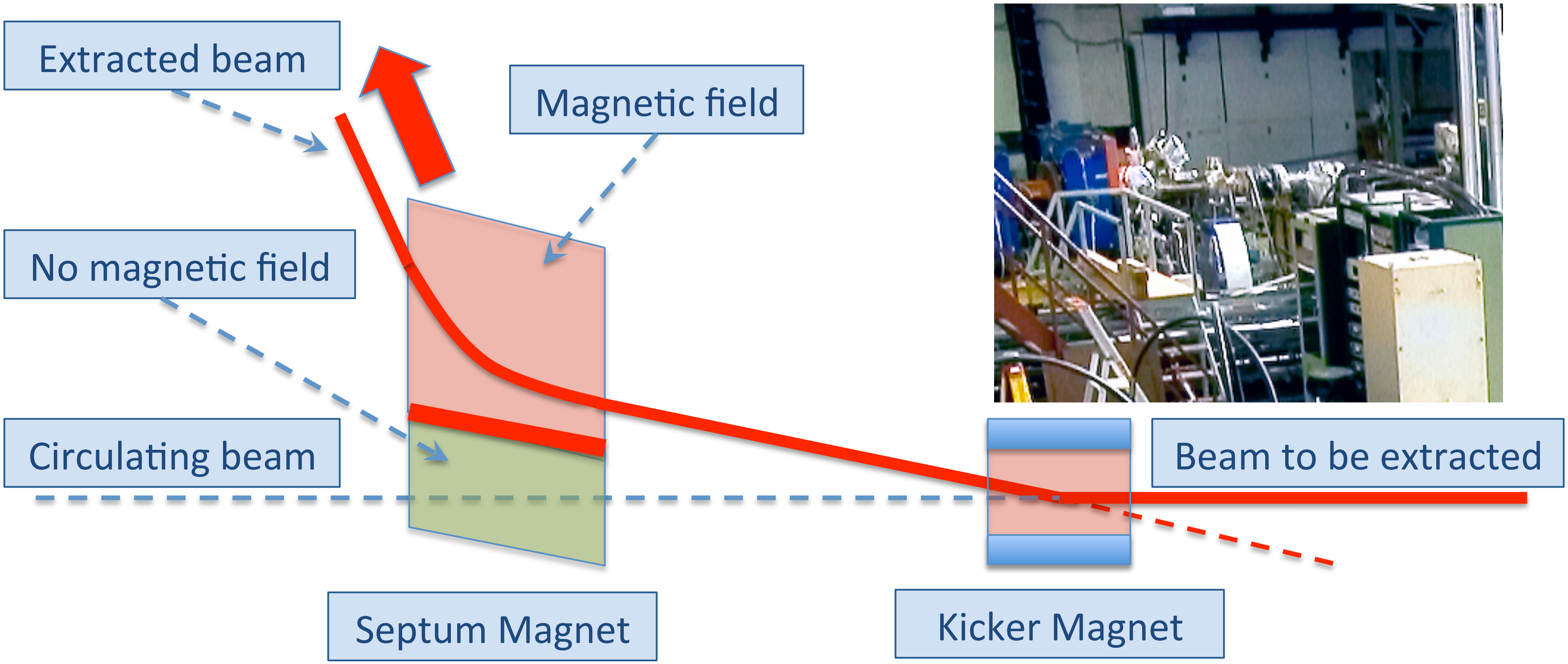
"**Vacuum Systems**" by Vincent Baglin

Injecting & Extracting Particles

Injecting & Extracting Particles



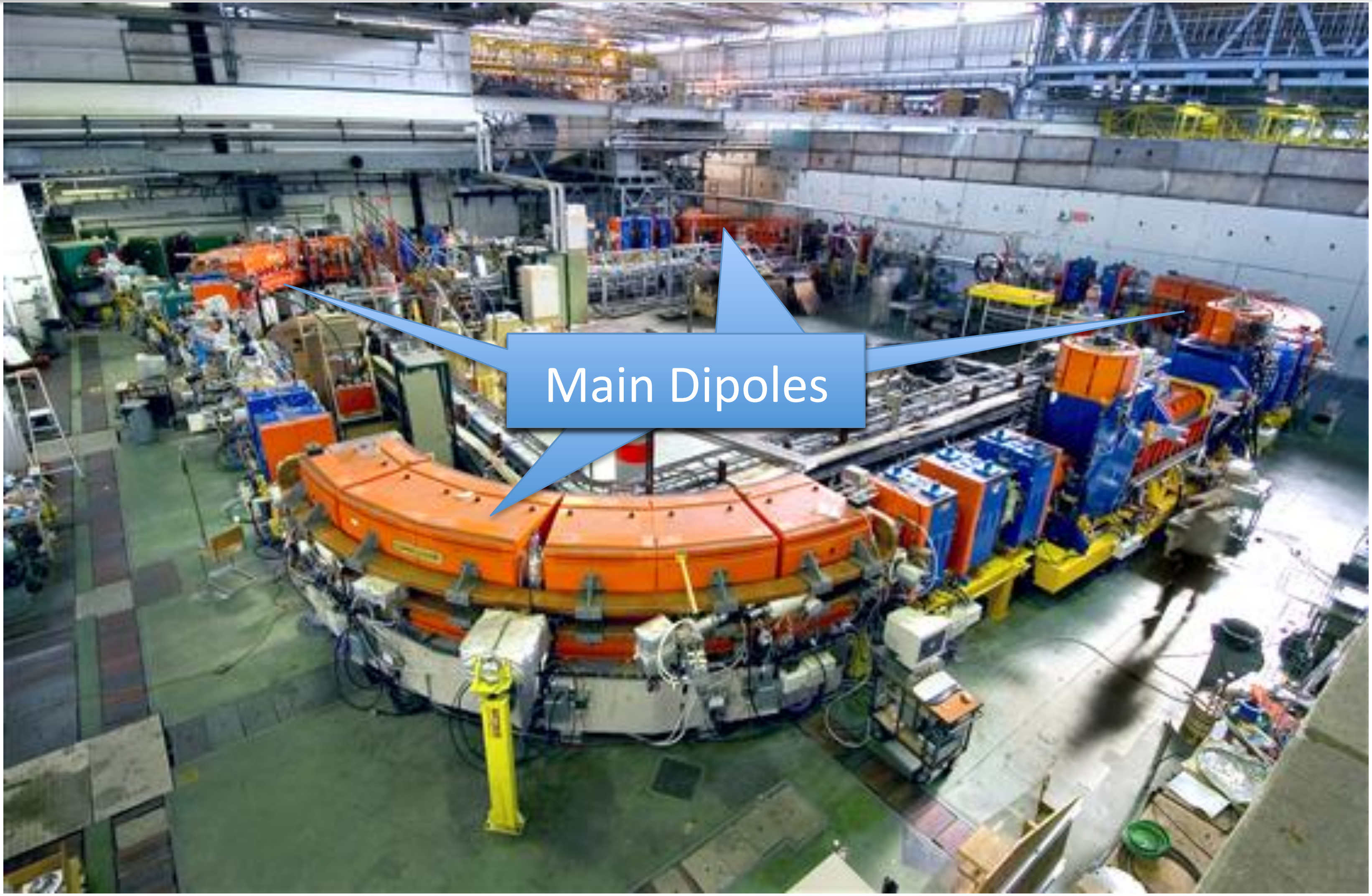
Injecting & **Extracting** Particles



"**Injection and Extraction**" by Wolfgang Bartmann
"**Beam Transfer**" by Verena Kain
"**Kickers and Septa**" by Mike Barnes

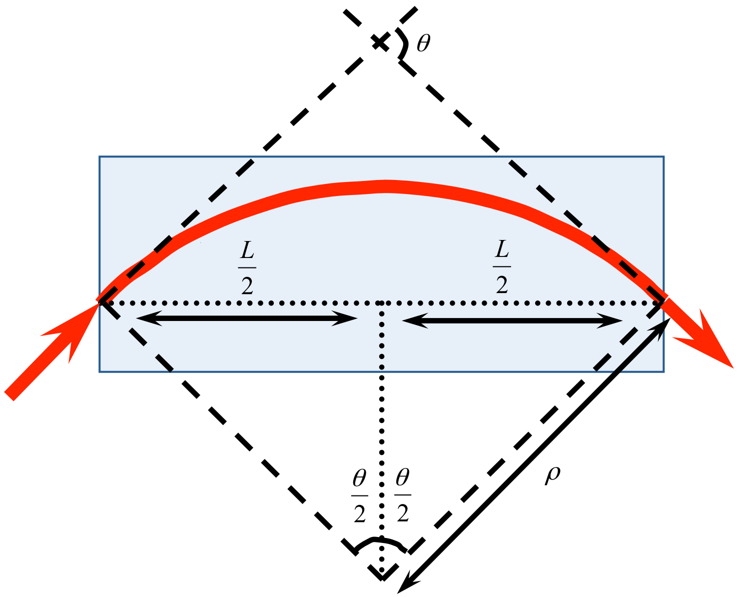
Thursday morning

Make Particles Circulate



Charged Particles Deviated

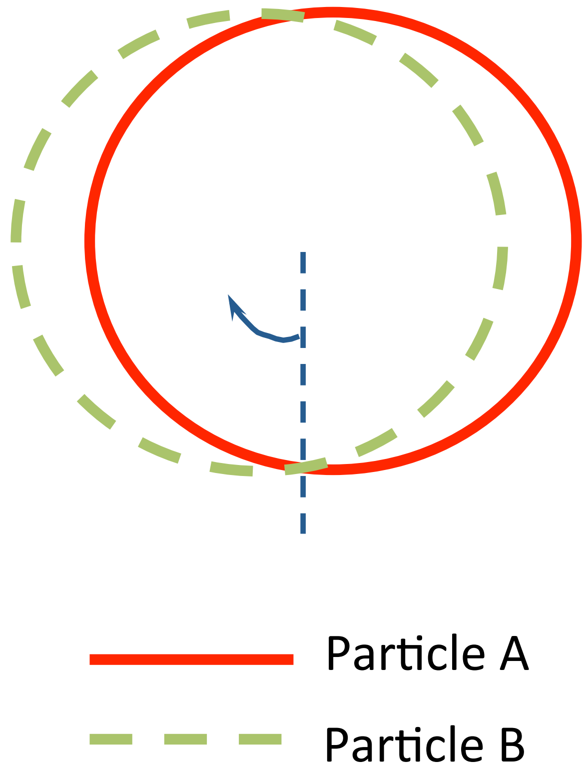
Charged Particles are deviated in magnetic fields



Lorentz force:

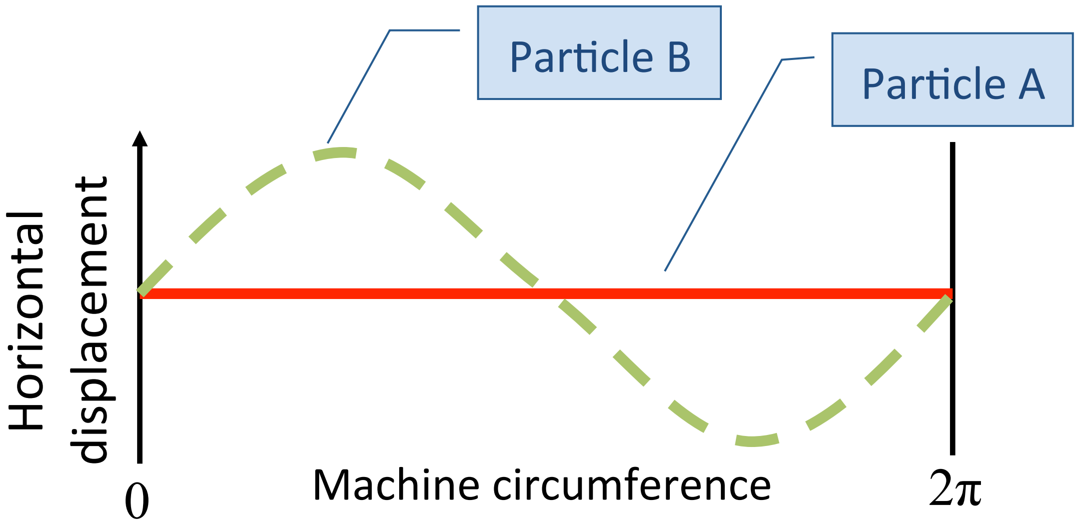
$$F = e\, v \times B$$

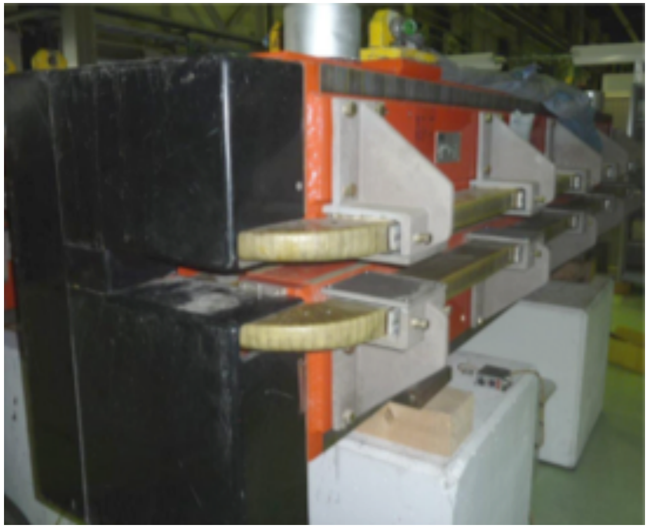
Two charged Particles in a homogeneous magnetic field



Oscillatory Motion of Particles

Horizontal motion





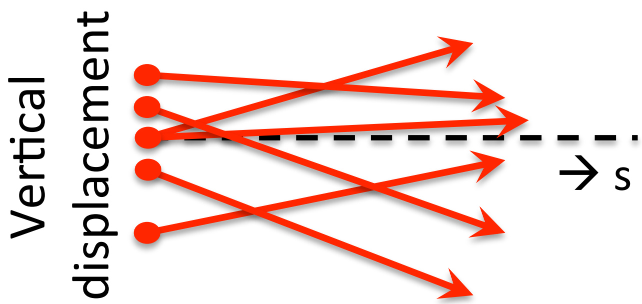
Different particles with different initial conditions in a homogeneous magnetic field will cause oscillatory motion in the horizontal plane

Oscillatory Motion of Particles

The horizontal motion seems to be "stable"…. What about the vertical plane ?

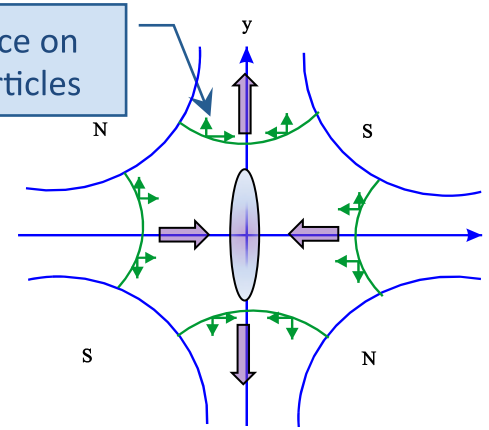
Many particles many initial conditions

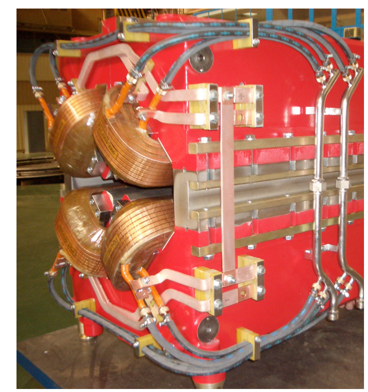
Focusing particles, a bit like light



Many different angles

Force on particles





"**Transverse Beam Dynamics**" by Bernhard Holzer

3 lectures on Tuesday & Wednesday

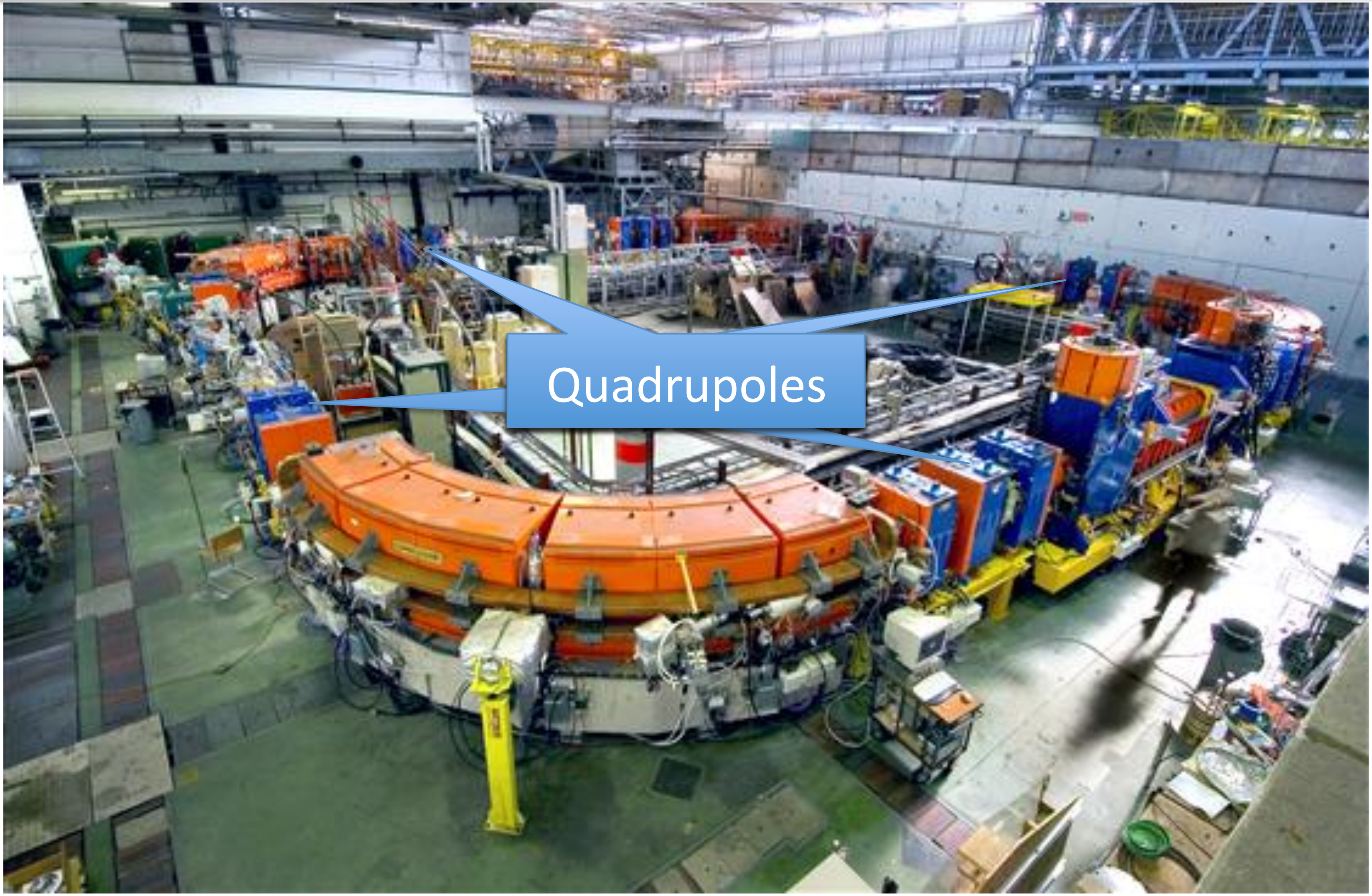
"**Magnets**" by Paolo Fessia

Tuesday morning

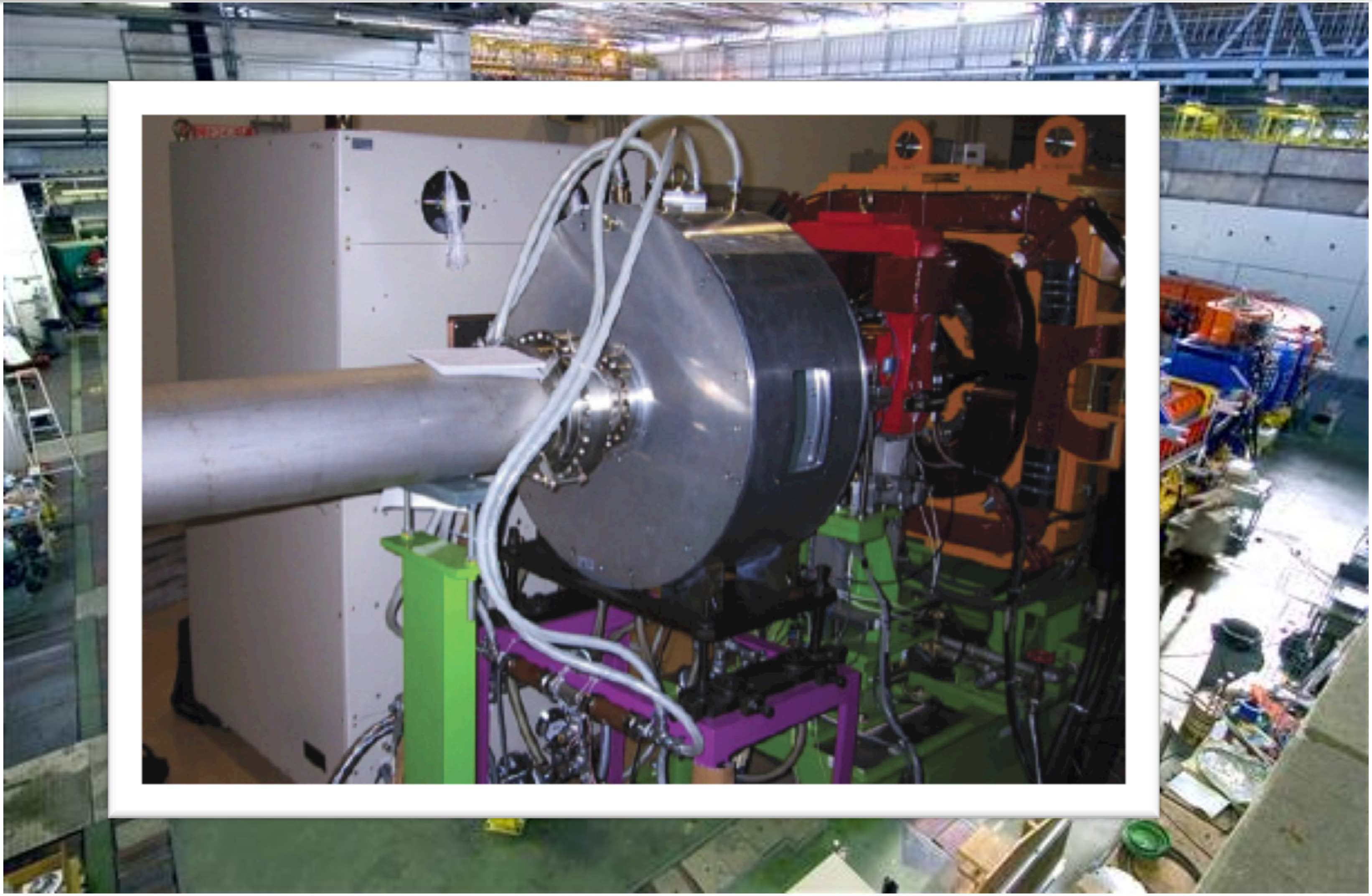
"**Power Converters**" by Jean-Paul Burnet

Tuesday afternoon

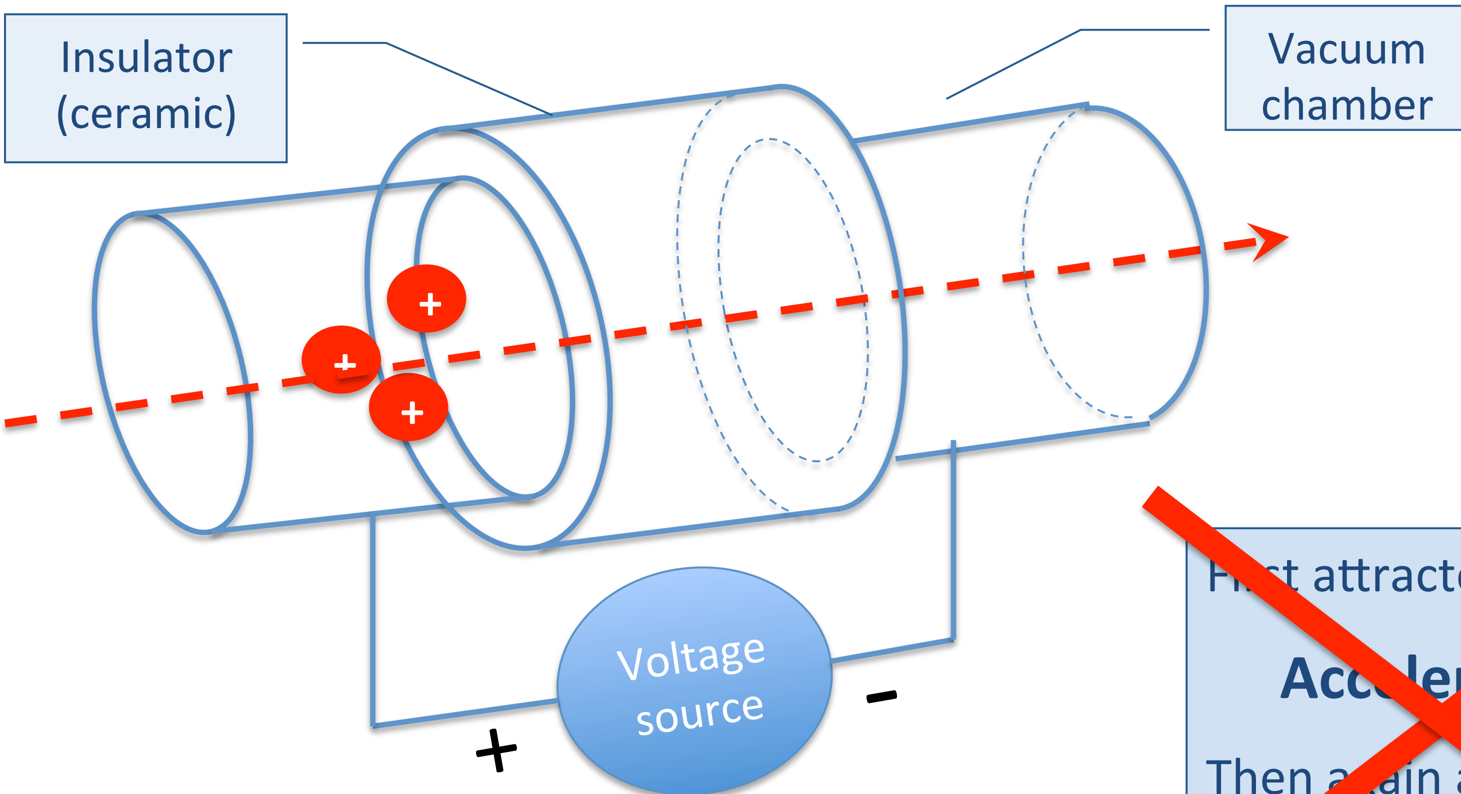
Focusing the Particles



Accelerating Particles



Accelerating Beams



~~First attracted~~

~~**Acceleration**~~

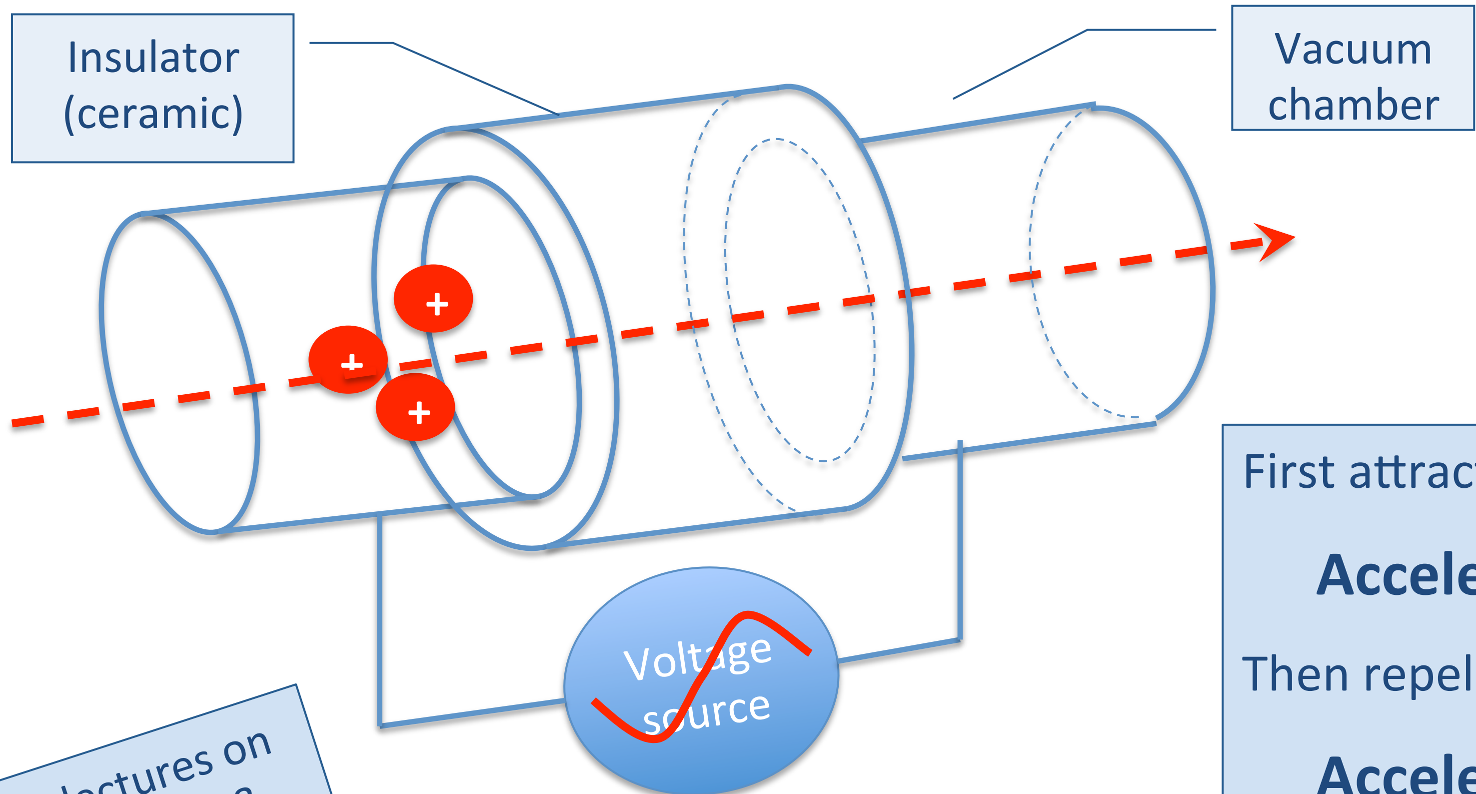
~~Then again attracted~~

~~**Deceleration**~~

Net result:

No Acceleration

Accelerating Beams



First attracted

Acceleration

Then repelled

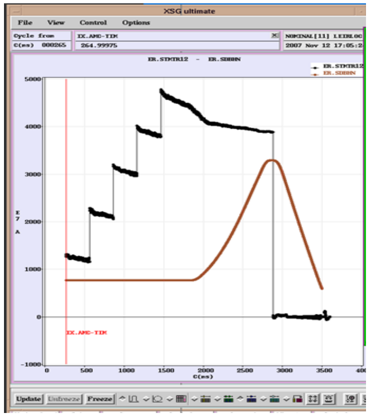
Acceleration

3 lectures on Tuesday & Wednesday

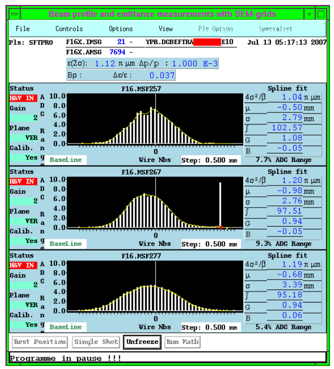
"**Longitudinal Beam Dynamics**" by Frank Tecker
"**RF Systems**" by Erk Jensen

Wednesday afternoon

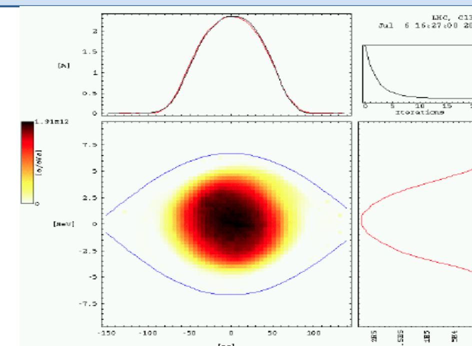
The Eyes of Operations



Beam intensity or current measurement



Transverse beam profile/size measurement



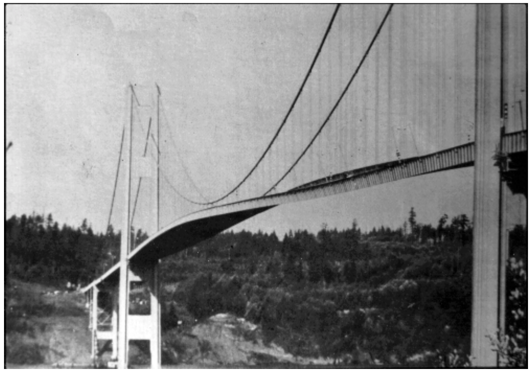
Longitudinal beam profile measurements

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

Any many more beam properties…..

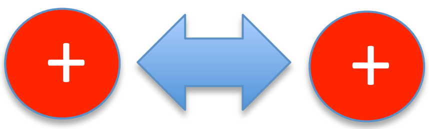
“**Beam Instrumentation**” by Uli Raich, Thursday afternoon

Possible Limitations

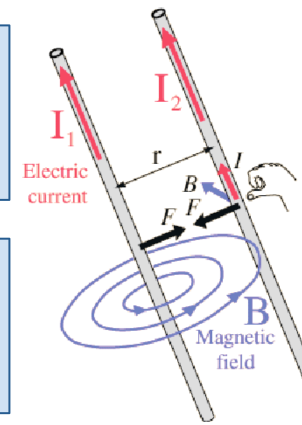


Machines and elements cannot be built with infinite perfection

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



Neighbouring charges with the same polarity experience repelling forces



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

Wednesday afternoon

“**Linear Imperfection**” by Rogelio
“**Collective effects**” Giovanni Rumolo
“**Colliders and Beam-Beam**” by Tatiana Pieloni

Friday morning

Special Systems

Ever increasing energies and beam intensities, require specials techniques

Super conducting magnets, with 8 T or even 11 T instead of 2 T for normal conducting magnets, require cryogenics

High stored beam energies require sophisticated machine protection systems

Tuesday morning

"**Magnets**" by Paolo Fessia

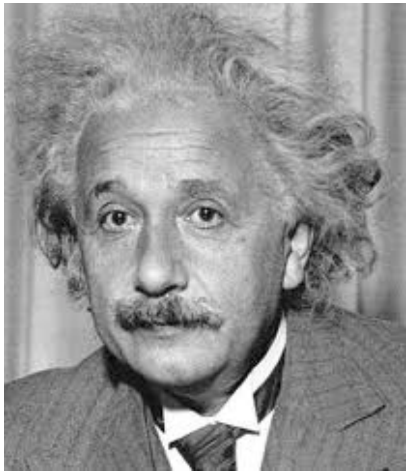
"**Cryogenics**" by Serge Claudet

"**Machine Protection**" by Jorg Wenninger

Tuesday afternoon

Friday afternoon

Everything must be made as simple as possible. But not simpler….



Albert Einstein