


Accelerators for Beginners


Rende Steerenberg BE/OP

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



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Contents



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

Basics of Accelerator Science & Technology at CERN

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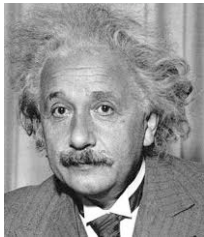
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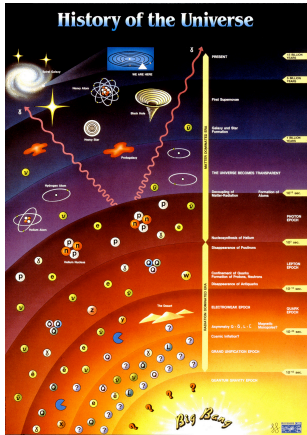
Creating Matter from Energy

$E = m c^2$


During the Big Bang Energy was transformed in matter




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



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Looking to smaller dimensions



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Visible light



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

$$\lambda = \frac{hc}{E}$$

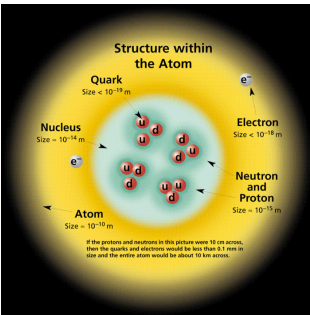
X-ray

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


Particle accelerators

$\lambda < 0.01 \text{ nm}$




Increasing the energy will reduce the wavelength

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Fixed Target vs. Colliders



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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

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The Aim

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Verify the Standard Model

Search for physics beyond the Standard Model

“Standard Model and Beyond” by Paris Sphicas *This afternoon*

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The diagram shows the Standard Model of particle physics. It is divided into three main sections: Quarks (top left, red and orange blocks), Leptons (bottom left, green and blue blocks), and Forces (right, purple and blue blocks). The central part features a circular arrangement of particles, including the Higgs boson (H) and various quarks and leptons.


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The Aim


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

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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**


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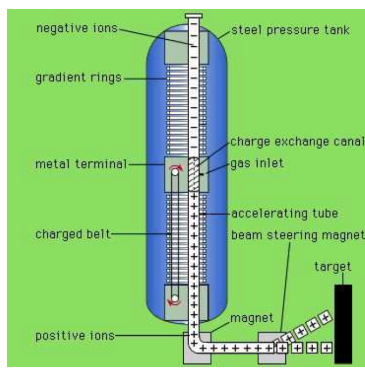
*Source: World Scientific Reviews of Accelerator Science and Technology
A.W. Chao
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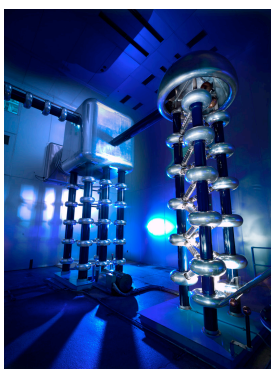


Cockroft, Walton & Van de Graaff



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







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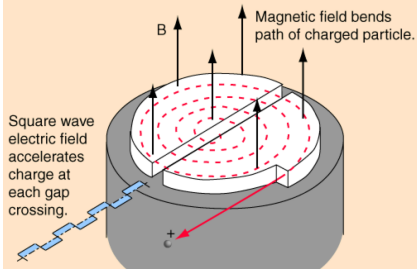
Cyclotron




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- 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.






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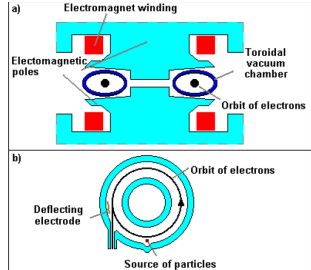



Betatron




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- 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.






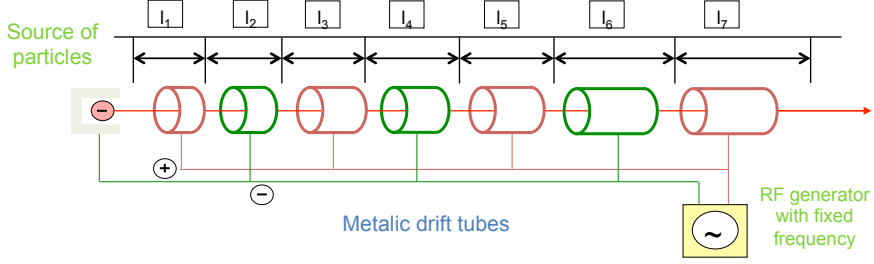
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Linear Accelerator



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- 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.


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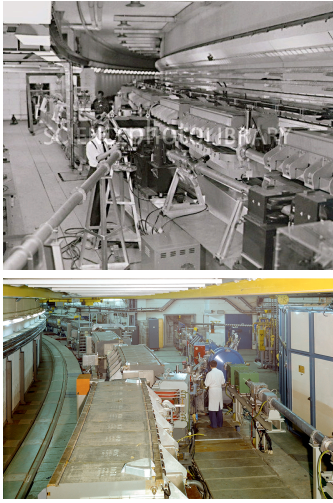
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Synchrotrons



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- 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

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Towards Relativity

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velocity

c

PSB

CPS

SPS / LHC

energy

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

Einstein: energy increases not velocity } $E = mc^2$

“Relativity” by Werner Herr This afternoon

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The CERN Accelerator Complex

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Mostly Circular Machines.

In less than 1 hour

“Overview of the CERN Complex” by Reyes Alemany Fernandez
“Sources” by Richard Scrivens
“LINACS” by Maurizio Vretenar

Wednesday morning
Thursday afternoon

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LEIR as an Example


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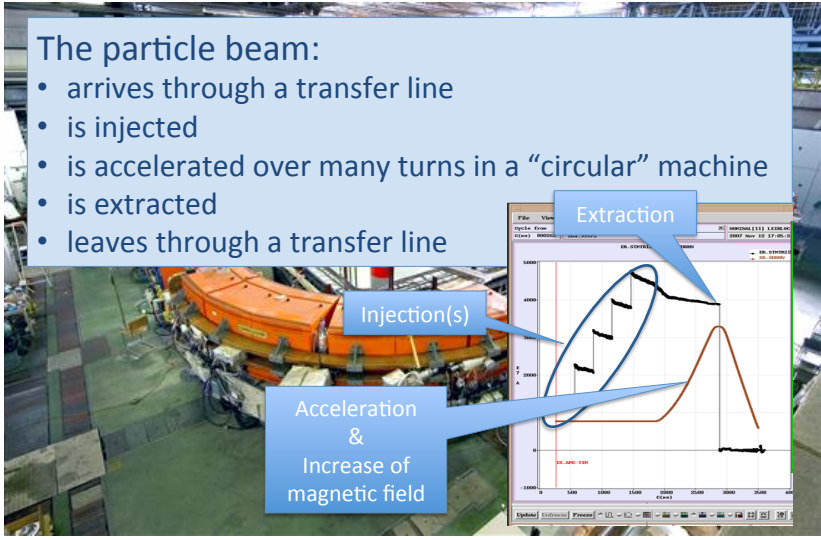
LEIR as an Example



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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




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Travelling Through nothingness



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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**

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Thursday afternoon



 **Injecting & Extracting Particles** 

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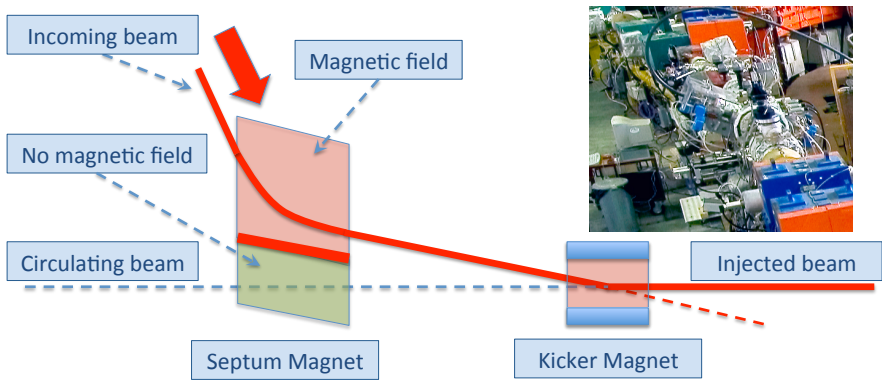


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 **Injecting & Extracting Particles** 

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Incoming beam

Magnetic field

No magnetic field

Circulating beam

Septum Magnet

Kicker Magnet

Injected beam

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Injecting & Extracting Particles

The diagram illustrates the process of injecting and extracting particles from a circulating beam. A red line represents the beam path. It starts as a 'Circulating beam' moving horizontally. A 'Septum Magnet' is positioned to deflect the beam upwards. A 'Magnetic field' is applied to the beam, causing it to curve upwards and outwards, labeled as 'Extracted beam'. A 'Kicker Magnet' is positioned to deflect the beam downwards, labeled as 'Beam to be extracted'. An inset photograph shows the physical equipment in a laboratory setting.

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“Injection and Extraction” by Wolfgang Bartmann
“Beam Transfer” by Verena Kain
“Kickers and Septa” by Mike Barnes

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Make Particles Circulate


A photograph of a large industrial facility, likely an accelerator tunnel, showing a large circular structure labeled 'Main Dipoles'. The structure is composed of several large, orange-colored cylindrical components arranged in a ring. The surrounding area is filled with various pieces of equipment, cables, and structural elements.

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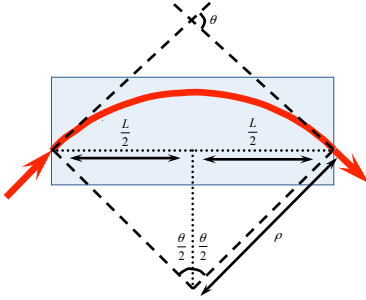
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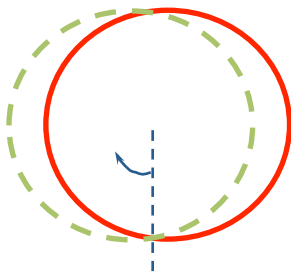
Charged Particles Deviated



Charged Particles are deviated in magnetic fields



Two charged Particles in a homogeneous magnetic field




Lorentz force:

$$F = e v \times B$$


— Particle A

- - - Particle B

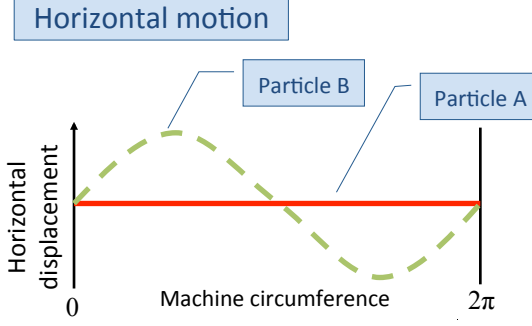
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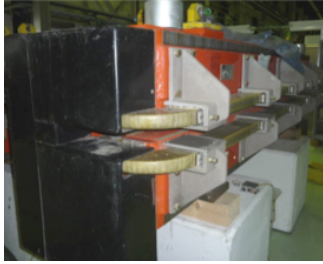


Oscillatory Motion of Particles




Horizontal motion






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

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Oscillatory Motion of Particles



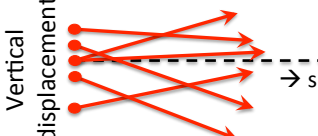
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The horizontal motion seems to be “stable” What about the vertical plane ?

Many particles many initial conditions

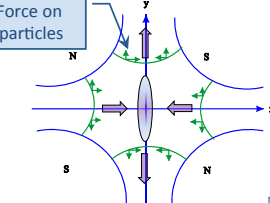
Focusing particles, a bit like light


Vertical displacement



Many different angles

Force on particles





“Transverse Beam Dynamics” by Bernhard Holzer

“Magnets” by Paolo Fessia


“Power Converters” by Jean-Paul Burnet

3 lectures on Tuesday & Wednesday


Tuesday morning

Tuesday afternoon

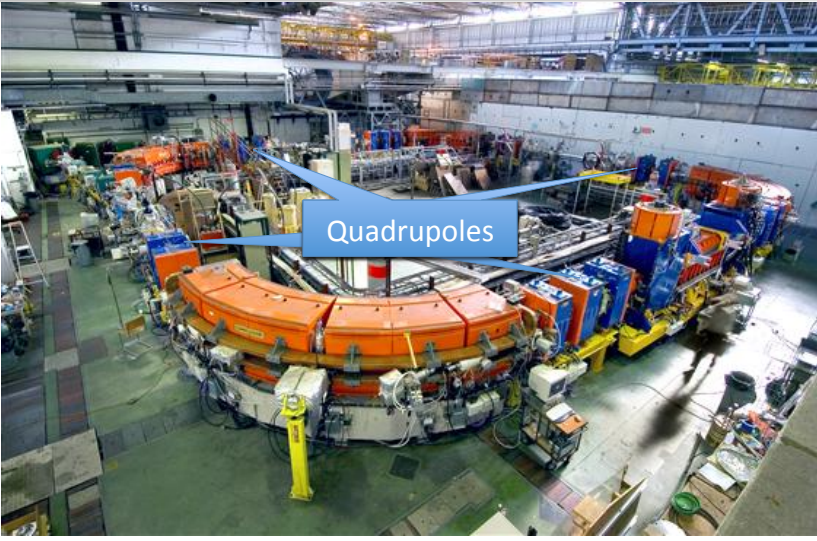
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Focusing the Particles




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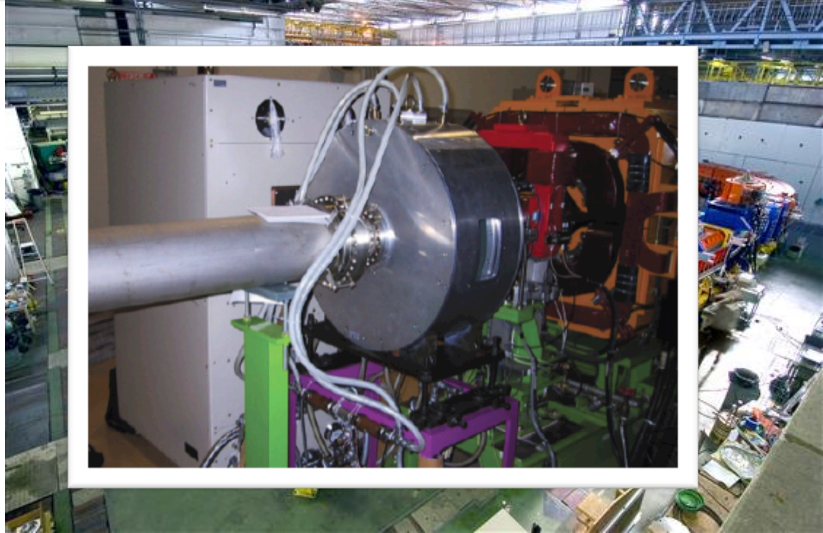

Quadrupoles

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Accelerating Particles

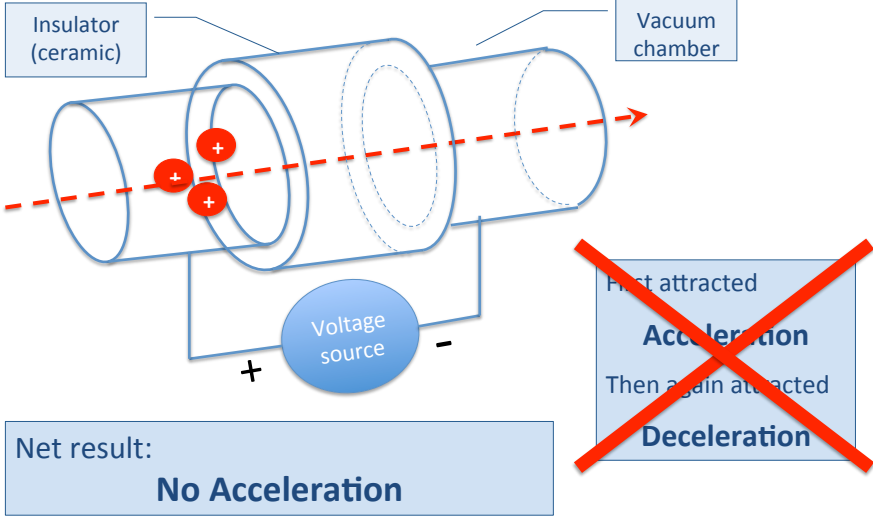



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Accelerating Beams



Insulator (ceramic) Vacuum chamber

Voltage source

Net result: **No Acceleration**

~~First attracted
Acceleration
Then again attracted
Deceleration~~

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Accelerating Beams

Insulator (ceramic) Vacuum chamber

Voltage source

First attracted
Acceleration
Then repelled
Acceleration

3 lectures on Tuesday & Wednesday

“Longitudinal Beam Dynamics” by Frank Tecker
“RF Systems” by Erk Jensen

Wednesday afternoon

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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,


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Possible Limitations




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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

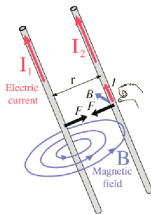
Wednesday afternoon

“Linear Imperfection” by Rogelio

“Collective effects” Giovanni Rumolo

“Colliders and Beam-Beam” by Tatiana Pieloni

Friday morning



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Special Systems



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Ever increasing energies and beam intensities, require special 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

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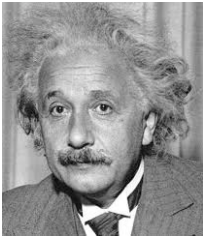
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Everything must be made as simple as possible. But not simpler....



Albert Einstein

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