Accelerators for Beginners

Rende Steerenberg BE/OP

CERN Accelerator School
Basic Accelerator Science & Technology at CERN
4 – 8 November 2013 – Chavannes de Bogis
Contents

• Why Accelerators and Colliders?

• A very Brief Historic Overview

• The Main Ingredients of an Accelerator
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• The Main Ingredients of an Accelerator
Creating Matter from Energy

During the Big Bang Energy was transformed in matter

\[ E = m c^2 \]

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
\[ \lambda = 400 \rightarrow 700 \text{ nm} \]

X-ray
\[ \lambda = 0.01 \rightarrow 10 \text{ nm} \]

Particle accelerators
\[ \lambda < 0.01 \text{ nm} \]

Increasing the energy will reduce the wavelength

\[ \lambda = \frac{h c}{E} \]
Fixed Target vs. Colliders

**Fixed Target**

\[ E \propto \sqrt{E_{\text{beam}}} \]

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

**Collider**

\[ E = E_{\text{beam1}} + E_{\text{beam2}} \]

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?

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- The Main Ingredients of an Accelerator
Today: ~ 30’000 accelerators operational world-wide*

The large majority is used in industry and medicine
- Industrial applications: ~ 20’000*
- Medical applications: ~ 10’000*

Less 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
• 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?

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Towards Relativity

Einstein: energy increases not velocity

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

CPS

SPS / LHC

velocity

energy

“Relativity” by Werner Herr

This afternoon
Mostly Circular Machines.

“Overview of the CERN Complex” by Paul Collier
“Sources” by Richard Scrivens
“LINACs” by Maurizio Vretenar

In less than 1 hour

Wednesday morning
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
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.

“Vacuum Systems” by Vincent Baglin

Thursday afternoon
Injecting & Extracting Particles
Injecting & Extracting Particles

- Incoming beam
- Magnetic field
- No magnetic field
- Circulating beam
- Injected beam
- Septum Magnet
- Kicker Magnet
Injecting & Extracting Particles

**Extracted beam**

**Magnetic field**

**No magnetic field**

**Circulating beam**

**Septum Magnet**

**Kicker Magnet**

**Beam to be extracted**

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

Wednesday afternoon
Make Particles Circulate
Charged Particles Deviated

Charged Particles are deviated in magnetic fields

Two charged Particles in a homogeneous magnetic field

Lorentz force:

\[ F = e \, v \times B \]
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

Vertical displacement

Many different angles

Focusing particles, a bit like light

“Transverse Beam Dynamics” by Bernhard Holzer
“Magnets” by Paolo Fessia
“Power Converters” by Jean-Paul Burnet

3 lectures on Tuesday
Thursday morning
Thursday afternoon
Focusing the Particles

Quadrupoles
Accelerating Particles
Accelerating Beams

Net result:
No Acceleration
Accelerating Beams

First attracted
Acceleration
Then repelled
Acceleration

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

3 lectures on Tuesday
Thursday morning

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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

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

Tuesday morning

Friday morning

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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

“Magnets” by Paolo Fessia
“Cryogenics” by Serge Claudet
“Machine Protection” by Jorg Wenninger
Everything must be made as simple as possible. But not simpler....