The DELPHI experiment at the LEP accelerator at the CERN laboratory

Part 1. The LEP accelerator
Part 2. The DELPHI experiment
Part 3. Particle physics research at LEP
The LEP accelerator

The study of collisions between electrons and positrons.

LEP 1: The collision energy = 91 GeV = Z
LEP 2: The collision energy = 209 GeV > 2W
The largest accelerators in the world

**LEP**
- **(CERN)**
- Length: 27 km (4184 magnets)
- Experiments: DELPHI, OPAL, ALEPH, L3

**HERA**
- **(DESY)**
- Length: 6 km (1650 magnets)
- Experiments: H1, ZEUS

**TEVATRON**
- **(FERMILAB)**
- Length: 6 km (990 magnets)
- Experiments: CDF, D0
In order to increase the collision energy one had to build 240 superconducting radio-frequency cavities.

Accelerating gradient = 6 MV / m
Frequency = 352 MHz

The energy lost due to synchrotron radiation is 2.3 GeV / turn

Radio-frequency accelerating voltage has to be 2.3 GV / turn

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<tbody>
<tr>
<td>Collision energy</td>
<td>91</td>
<td>136</td>
<td>174</td>
<td>184</td>
<td>189</td>
<td>204</td>
<td>209</td>
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The collision energy

At LEP the collision energy could be determined with a very high accuracy:

91.187 GeV with an error of 0.002 GeV

Things which affected the energy of LEP:

1. The level of the water in the lake!
2. The moon!
3. The trains to Paris!
During 1993 the LEP energy was observed to change with time.

Part of the change was due to the water level in lake Geneva which caused small geological shifts of the accelerator.

Rainfalls and the water table in the Jura mountains also affected the LEP energy.
Earth tides caused by the moon will produce small distortions of the earth’s crust.

This can affect the accelerator so that the electrons orbit change.

An orbit change of 1 mm will change the energy with about 10 MeV.
Beampipe current

The trains from Geneva to France caused parasitic currents on the LEP beampipe.

These currents (1 A) affected the magnetic field in the LEP magnets and this changed the energy.
The DELPHI experiment

DELPHI

STIC

Muon detector

Tracking detector

Hadronic calorimeter

Electromagnetic calorimeter
Cross-section

Collision energy
What does a particle physicist do?

• The building of detectors
  Examples:
  - The TPC (Time Projection Chamber)
  - The STIC (Electromagnetic calorimeter)

• Analysis of the data from the experiment
  Examples at LEP 1:
  - Luminosity
  - Studies of the Z-boson

Examples at LEP 2:
  - Studies of the W-boson
  - Search for new particles
The Time Projection Chamber

A charged particle ionize the gas in the cylinder and the electrons drift in an electrical field to the detectors at the ends of the cylinder.

Three-dimensional tracks can be reconstructed from the signals from the detectors.
The calorimetric processes

An electromagnetic shower

A hadronic shower

Hadron-Nucleon Interactions
STIC was two electromagnetic calorimeters built by Lund in collaboration with physicists from 12 other institutes in 6 countries.
What is luminosity?
The number of events per s = cross section x Luminosity

How is the luminosity measured?
By counting the number of events from a process for which the cross section can be calculated.

Which process was used at LEP?

Bhabha Scattering
The hadronic lineshape of the Z-boson

The width of the Z-boson peak depends on the number of light neutrino species (N).

$$\sigma_Z = \frac{\text{Luminosity}}{N}$$
WW-events

\[ e^+ \rightarrow W^+ \gamma/Z^0 \rightarrow q\bar{q} q\bar{q}\]

\[ e^- \rightarrow W^- \rightarrow q\bar{q} l\bar{\nu} \]

\[ e^+ \rightarrow W^+ \rightarrow l\bar{\nu} l\bar{\nu} \]

46%  44%  11%
The mass of the W-boson

\[ M_W^2 = (\vec{P}_q + \vec{P}_{\bar{q}})^2 \]  \hspace{1cm} (4-vectors)

\[ M_W^2 = 2 E_q E_{\bar{q}} (1 - \cos \phi) \]

if \( m_q = 0 \)

\[ \phi \]

\[ q\bar{q} q\bar{q} \]

46%

\[ \begin{align*}
W \text{ mass} \quad \left[ \text{GeV/c}^2 \right] \\
\text{DATA} \\
\text{WW} \quad \text{(M}_W = 80.35) \\
\text{ZZ} \\
\text{QCD}
\end{align*} \]
The W-cross section

\[ \sigma_W = \frac{\text{WW Cross Section (pb)}}{\text{Luminosity}} \]

The W-cross section

\[ \sigma_W = \frac{\text{σ}_W}{\text{Luminosity}} \]

DELPHI

(preliminary)

GENTLE 2.0 (±2%)

RacoonWW, YFSWW
The search for new particles

Extra dimensions

Basic idea: Unification of gravity with other interactions by introducing new compact dimensions of space in which only gravity propagates.

Cross sec.: \( \sigma (e^+e^- \rightarrow \text{Grav.} + \gamma) \) depends on:
- \( n \) - the number of extra dimensions
- \( M_D \) - the fundamental mass scale in the theory

Standard Model:

\[ e^+ e^- \rightarrow \gamma G \]

\( n = 2 \)
\( M_D = 0.75 \text{ TeV} \)

\( \sqrt{s} = 200-210 \text{ GeV} \)
563 events obs.
568 events exp.
The search for Higgs events

$e^+ e^-$

$H^0 \rightarrow b \bar{b}$ (74%)

$Z^0 \rightarrow q \bar{q}$ (70%)

Categorization:
- $b \bar{b}$: 74%
- $\tau \bar{\tau}$: 8%
- $WW$: 8%
- $gg$: 6%
- $c \bar{c}$: 4%
- $q \bar{q}$: 70%
- $\nu \bar{\nu}$: 20%
- $ee$: 3%
- $\mu \mu$: 3%
- $\tau \bar{\tau}$: 3%
The mass spectrum of Higgs candidates

ZZ and WW events that have been wrongly identified as Higgs events

Expected signal from Higgs decays

DELPHI

\[ E_{cm} = 200-209 \text{ GeV} \]
\[ L = 224 \text{ pb}^{-1} \]

- **Data**: 16
- **MC**: 23.5
- **signal**: 3.25

\[ m_H = 114 \text{ GeV/c}^2 \]

![Graph showing mass spectrum with data points and expected signal](image_url)
Summary

The LEP accelerator was the largest accelerator the world has ever seen.

DELPHI was one of the huge experiments that studied the collisions between electrons and positrons.

DELPHI has contributed much to our present understanding of the standard model.

The accelerator and the experiments have been dismantled but the physicists continue to analyze the data that was collected.