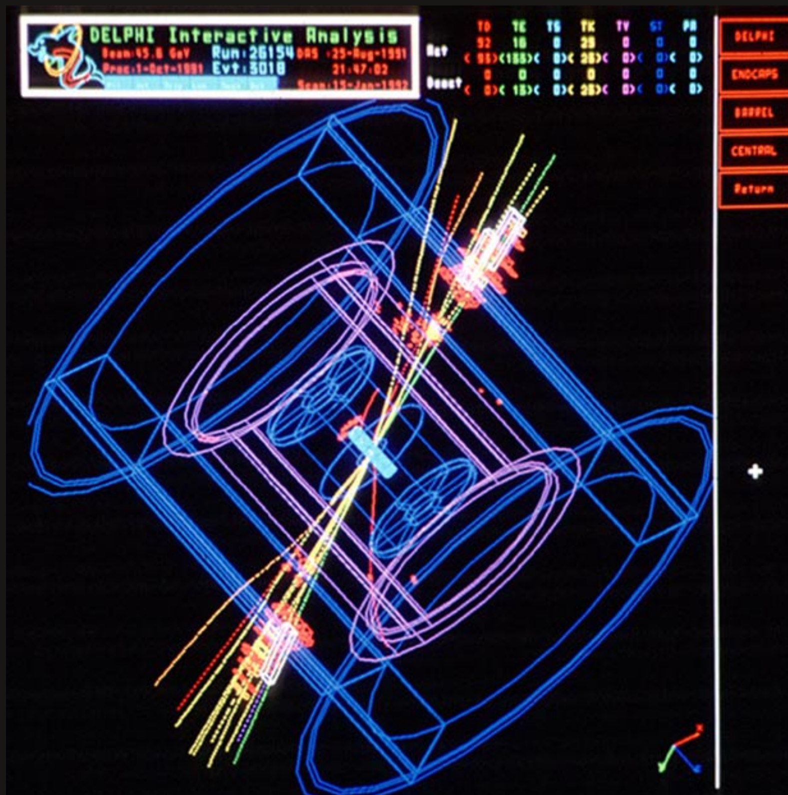


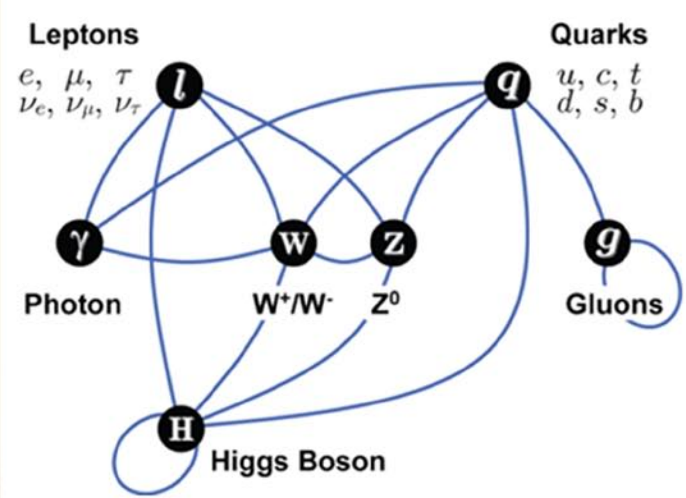
Exploring the microcosmos

How physicists in Lund measured a new scattering effect, helped determine the number of families of leptons and quarks, and took part in the hunt for the Higgs particle.

What we know, and what we want to know

We know, today, that the three main forces of nature, the electromagnetic, the weak and the strong force, can be described with the aid of field theories, but can gravity be described by a field theory, and are the most elementary particles in that case strings?

What is dark matter and what is dark energy?
Why is there only matter and not antimatter?
Do the forces of nature have a common origin?



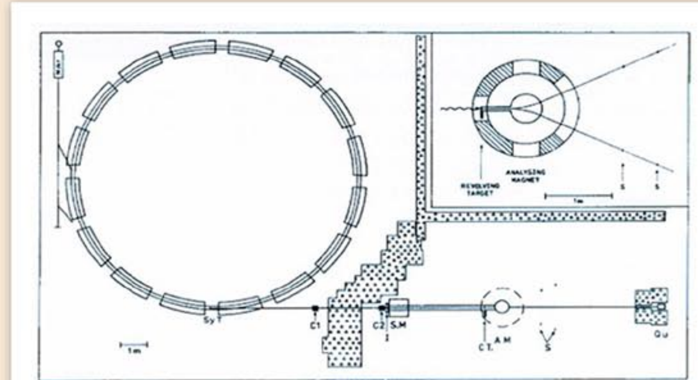
The interactions between particles can be described by the so-called Standard Model, in which quarks and leptons are divided into three families, with four members in each family. Until recently, the only piece of the puzzle missing from the Standard Model was the Higgs particle, which was assumed to give the other particles their mass.

The transformation of particle physics

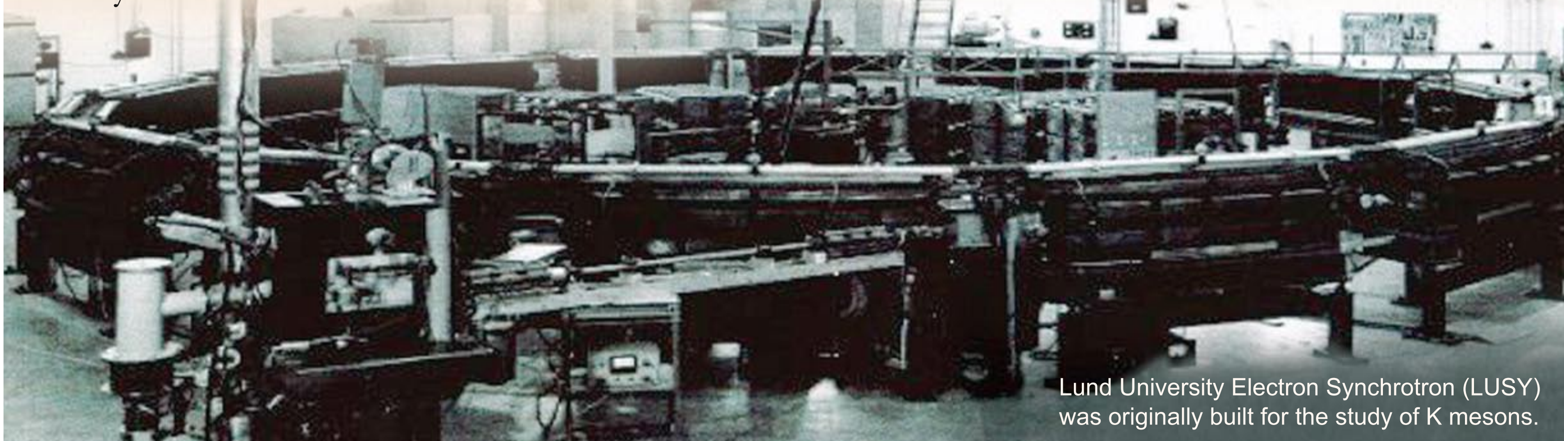
Particle physicists study the smallest building blocks of matter and the interactions between them. Experimental particle physics started in Lund in 1962, when the first parts of an accelerator built at KTH (The Royal Institute of Technology) arrived in Lund.

It was Professor Sten von Friesen who was successful in getting the 1.2 GeV electron accelerator located in Lund, rather than Uppsala.

The Lund University Electron Synchrotron, or LUSY as it was known, paved the way for MAX-lab, and with it a completely new research division at the Department of Physics.



Enlargement of target area.

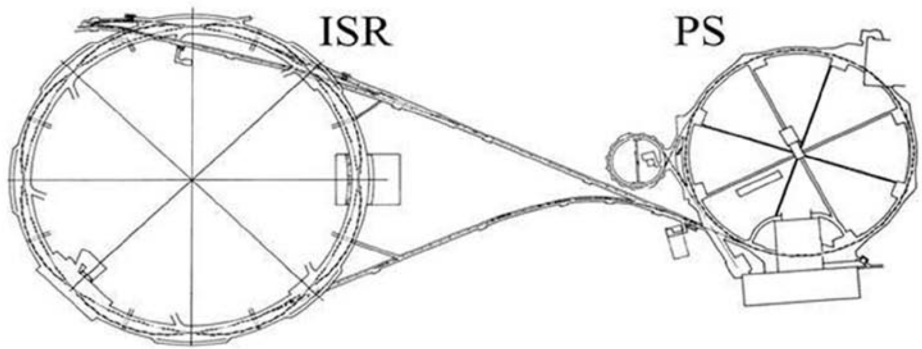


Lund University Electron Synchrotron (LUSY) was originally built for the study of K mesons.

Professor Guy von Dardel

Guy von Dardel became Professor of Elementary Particle Physics in Lund in 1965. He was born in Stockholm and, after obtaining his doctorate at KTH in 1954, took part in the construction of the world's largest particle research facility, CERN in Switzerland. He coordinated the development of the instrumentation for several experiments and, amongst other things, performed renowned measurements of the lifetime of the neutral pi-meson (π^0), which were of great importance for the understanding of the nature of the strong force.

Guy von Dardel 1919 - 2009



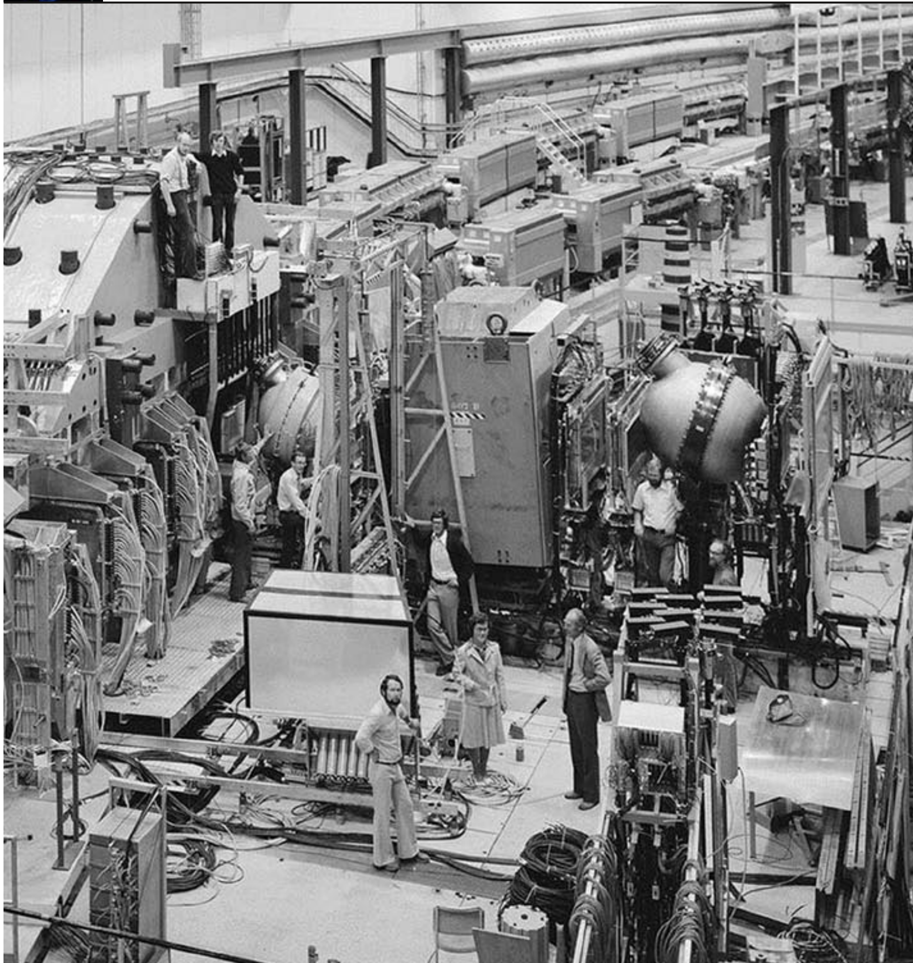
Protons from the PS are led into the ISR where they circle in two rings which cross each other at eight points.

CERN was founded in 1954 by 12 European countries, among them Sweden, and its development is directly related to the history of its accelerators and storage rings.

The first accelerator, a proton synchrotron (PS) with a circumference of over 600 metres, came into operation in 1959.

As high energies are needed to study the interaction of elementary particles, this field of physics is often called high-energy physics. A significant step forward in terms of energy was taken in 1971 when the world's first storage ring for protons, the Intersecting Storage Ring (ISR), was completed. This made it possible to test the quark model.

Lund makes its mark on CERN



Guy von Dardel established a Scandinavian research group at the new proton-proton collider (the ISR) at CERN. During a period of over ten years, they studied the properties of the strong force, or quantum chromodynamics (QCD).

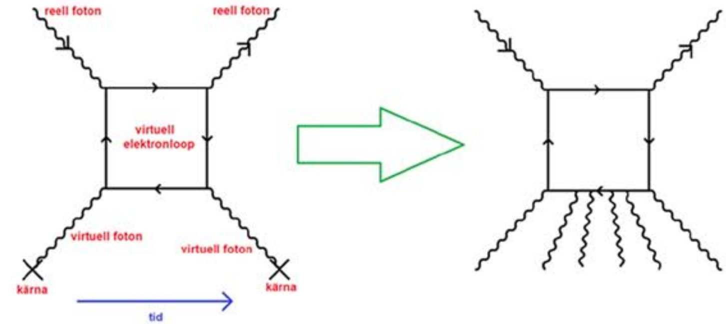
They were especially interested in how quarks manifest themselves as showers of correlated particles, so-called jets, the subject of Torsten Åkesson's PhD thesis.

In another experiment carried out by Lund physicists, observations that were made showed that the number of quarks and gluons increased as their momentum decreased.

Intersecting Storage Ring (ISR) at CERN, where the highest collision energy of the day was achieved (63 GeV). The technical resources in Lund were good, and the group, which can be seen in the photograph, contributed to the construction of the instrumentation for the ISR experiments.

The Delbrück experiment

In 1969, the accelerator in Lund, LUSY, paved the way for an interesting experiment. Two young physicists, Göran Jarlskog and Leif Jönsson, happened to see a theoretical paper by H Cheng and TT Wu on Delbrück scattering. Jarlskog applied to DESY in Hamburg, Germany to carry out an experiment. His application was accepted and the results showed that Cheng and Wu had to extend their calculations to include multiphoton exchange to obtain agreement with the experimental data.



First-order diagram with an incoming real photon, which is split into a virtual electron-positron pair, which in turn couples to the core via virtual photons at the points marked X. In the final state a real photon is recreated.

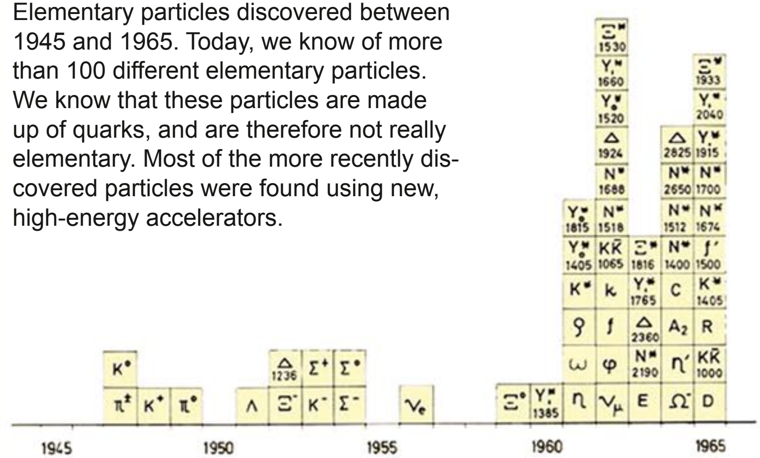
Diagram illustrating multiphoton exchange.

The final piece of the puzzle?

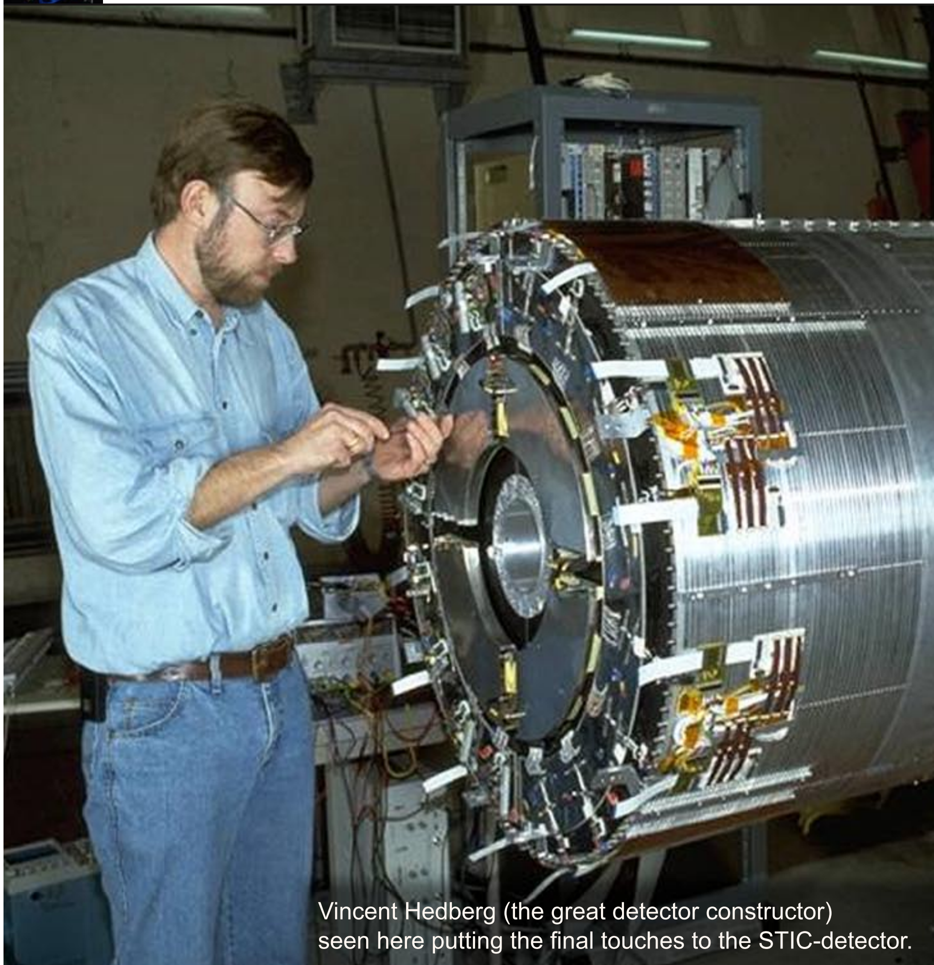
The quark model was formulated in 1964 by systematizing the current knowledge on the building blocks of matter (the hadrons) and arranging them into systems.

Following this, the so-called Standard Model was developed, which has been shown to describe the interaction between various particles very well.

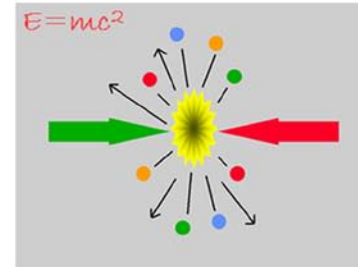
Elementary particles discovered between 1945 and 1965. Today, we know of more than 100 different elementary particles. We know that these particles are made up of quarks, and are therefore not really elementary. Most of the more recently discovered particles were found using new, high-energy accelerators.



From ISR to LEP



Vincent Hedberg (the great detector constructor) seen here putting the final touches to the STIC-detector.



The conversion of energy to mass, according to Einsten's famous equation.

CERN changed direction, and in 1988 experiments started using the large electron-positron collider (LEP), in which the collision energy is known when an electron and a positron annihilate.

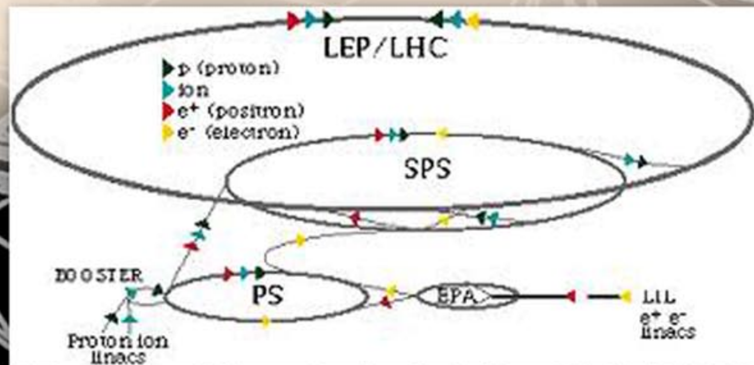
This accelerator was built to study the electroweak force in detail, and the properties of the W and Z particles in particular. When electrons and positrons collide, they annihilate, releasing energy. Some of this energy is converted into new particles, which can be studied in a detector.

LEP & DELPHI

The large electron-positron collider (LEP) in CERN was the world's most advanced in the 1990s. In the 27 km long underground ring, electrons and positrons could be accelerated to energies above 200 GeV, providing extremely good conditions for new discoveries.

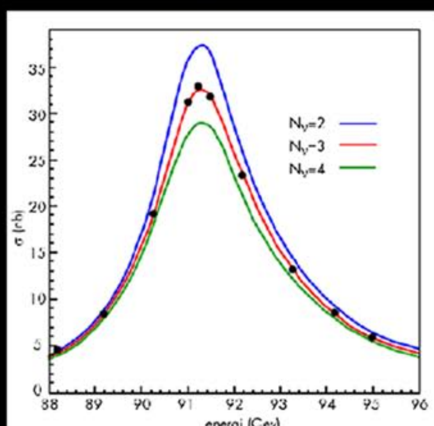
The group from Lund contributed to the construction of the successful DELPHI experiment, where they were involved from the beginning thanks to Göran Jarlskog who succeeded Guy von Dardel as professor in Lund in 1987.

Göran Jarlskog



Detector construction in Lund

An event showing Z→qq(–). The quarks are converted into showers of hadrons (jets).



Measurements of the resonance width of the Z particle compared with predictions for 2, 3 and 4 families. The experimental data are consistent with 3 families, each including a neutrino.

The Lund group was active in this fundamental discovery.

DELPHI was the name given to an experiment carried out during the 1990s at the LEP, in which Lund took part in the design of the central track detector.

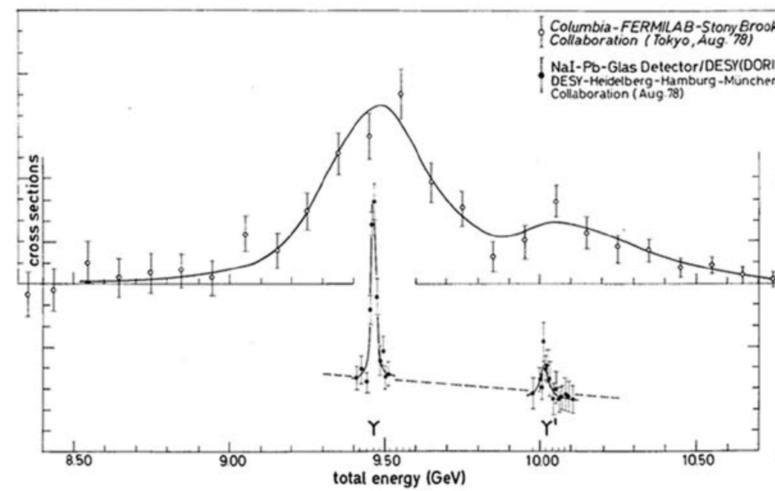
Some of the most important events were the measurement of the width of Z bosons (which gives the number of families of quarks and leptons), tests of the predictions of the Standard Model regarding the electroweak and strong interactions (where all the present results support the model), and the unexpectedly high lower limit for the mass of the Higgs particle (114 GeV).

Lund’s involvement at DESY

Evidence of the existence of a new particle, the ypsilon particle (Y), were obtained with the proton accelerator at Fermi Labs in Chicago, USA.

The DORIS collider at DESY in Hamburg was used to study the charge on the particle, as this was the only accelerator with sufficiently high energy to study this newly discovered quark-antiquark state.

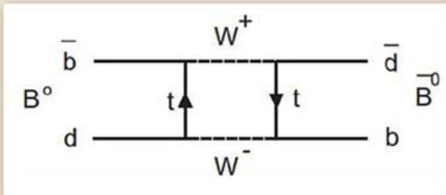
Physicists from Lund were invited to take part in the over 15-strong research group formed in 1977. Only one year later, 1978, it was confirmed that the Y particle was indeed a bound quark-antiquark pair with a charge of -1/3.



This figure shows the two lowest mass states of the Υ particle, and illustrates the difference in resolution between a proton accelerator (above) and an electron-positron collider (below).

Leif Jönsson was responsible for the Lund group’s participation in the research at DESY.

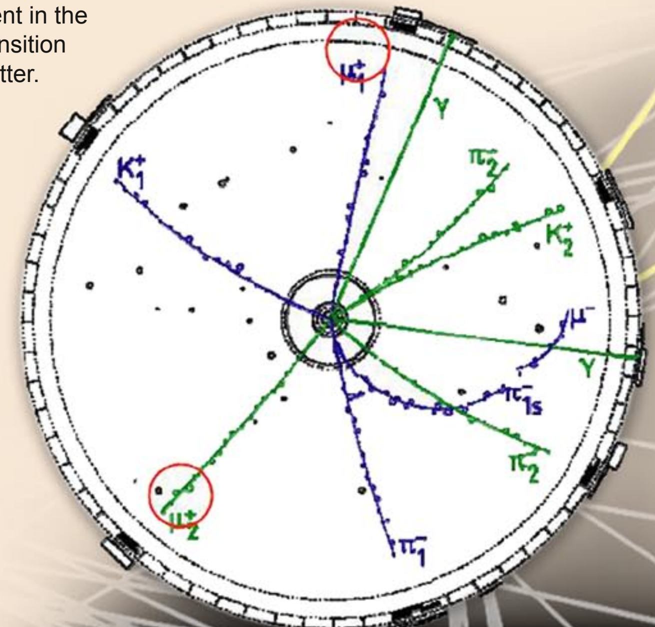
Matter and antimatter



A Feynman diagram of the transition between matter and antimatter.

$$e^+e^- \rightarrow \bar{B}^0 \rightarrow \text{oscillation} \rightarrow B_1^0 B_2^0 \rightarrow \pi_1^- K_1^+ \pi_1^- \mu_1^- \nu_1 \quad K_2^+ \pi_2^- \pi_2^- \pi^0 \mu_2^+ \nu_2$$

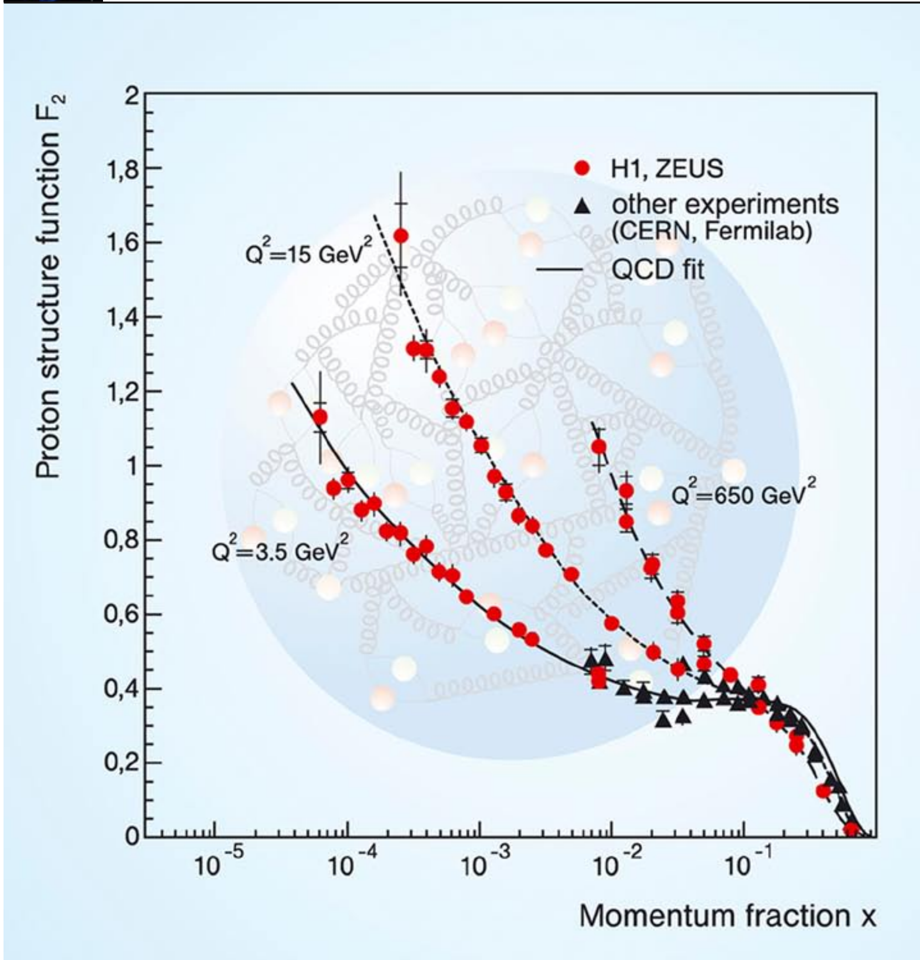
The first detected event in the observation of the transition from matter to antimatter.



At the same time as the DESY group was formed, plans were also started for a new detector, ARGUS. It was ready to provide its first data in 1982, and allowed studies of phenomena in the energy range 3-10 GeV.

The detector was in use for more than ten years, and provided data for many important discoveries, the most important being the discovery of the oscillations between B mesons and anti-B mesons, i.e. transitions between matter and antimatter.

Looking into the proton



In 1992, the HERA collider at DESY was ready to produce their first collisions to study the inner structure of the proton.

The Lund group was, together with others, the first to make direct measurements of the momentum spectrum for the gluons in a proton.

Together with the theoretical group from Lund, a model was constructed describing quark dynamics, making Lund world leaders in the field.

A unique discovery was made in 1993, which confirmed the measurements previously made at ISR, in which clear indications were seen that the number of partons (quarks and gluons) in the proton increased as their momentum decreased.

The hunt for the Higgs particle

In the Large Hadron Collider (LHC), which came into operation in 2009, protons can be collided with each other, producing a maximal collision energy of 14000 GeV, which should be more than sufficient to see beyond the Standard Model.

LHC started in September 2008, but collapsed after a week. At the relaunch November 29, 2009, one was very excited.

The LHC at CERN seen from above.

Finally!

The reaction of particle physicists when the Large Hadron Collider was started up on 29 November 2009.

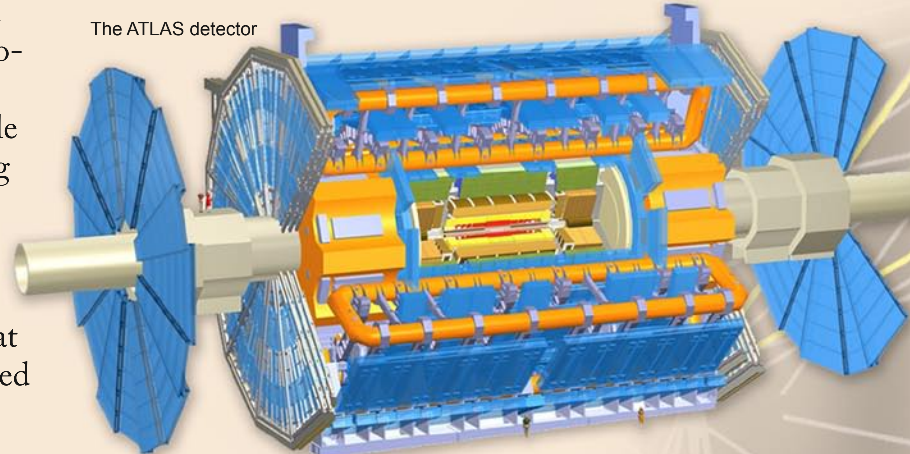
ATLAS

The largest detector system at CERN is called ATLAS, and is the result of worldwide collaboration between 38 countries. It was built with the aim of finding the final piece of the particle puzzle. The Lund group's participation is being led by Torsten Åkesson, who was also the mainstay of the group that first proposed the building of the LHC.

In June 2012 a great breakthrough was made at the ATLAS detector, when experiments showed that the famous boson, Higgs particle, almost certainly exists.

The search for the Higgs particle gave results and on the 4th of July 2012, there were clear evidence of the particle's existence.

The ATLAS detector



Torsten Åkesson is the director of the Division of Particle Physics at the Departmen of Physics, Lund.