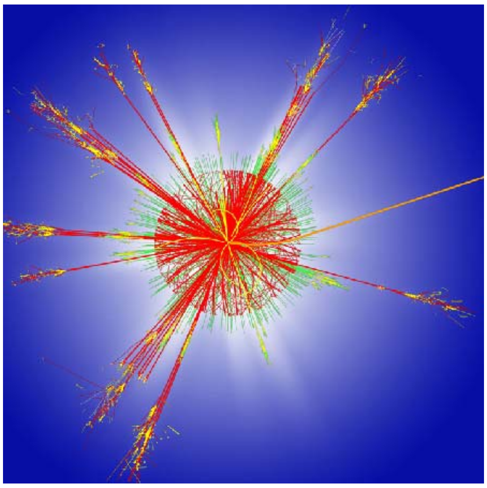
13. Particle physics



Particle studied within the ATLAS-project CERN

In the beginning of 1930, it seemed that all the physics fundaments was placed within the new areas of elementary particle physics. The world around us could be described with well-known build up stones, the electron, the proton and the newly discovered neutron. The neutrino was postulated but not yet detected. This idyllic state drastically changed and in the 1970-ies there were more than 200 ”elementary particles”, with names as muon (μ), pion (π) , kaon (K) and sigma (Σ). All these particles are instable and have lifetimes between 10^{-6} s and 10^{-23} s. The newest particles are produced in collisions at accelerators. The most well known accelerators are

Fermilab (Chicago)
DESY (Hamburg)
SLAC (Stanford)
CERN (Genève)

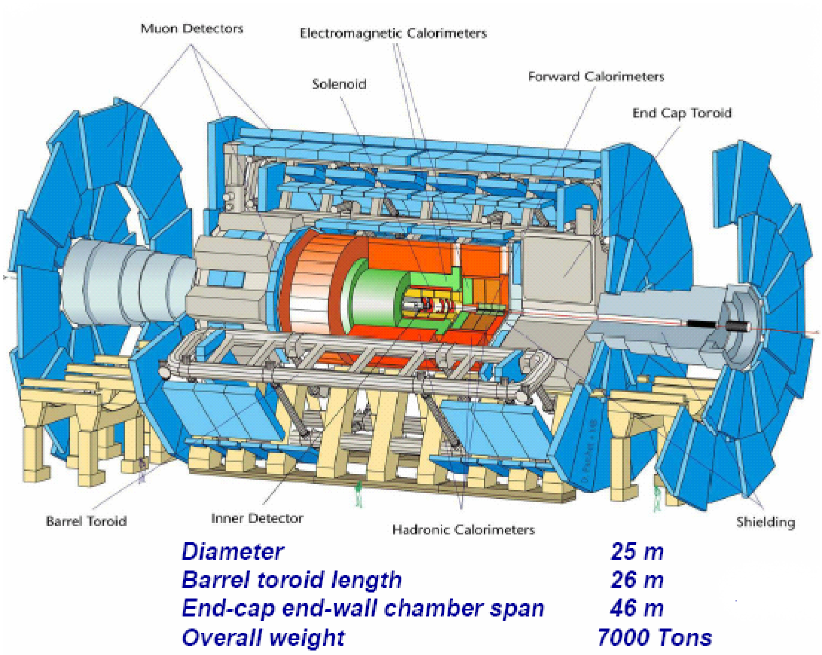
Conseil Européen pour la Recherche Nucléaire, situated on the border between France and Switzerland, can be seen on the picture below.

CERN-laboratories in Genève

The largest circle in the picture indicates the circumference of the new accelerator LHC (Large Hadron Collider) that will be in action at the end of 2007. The start and landing lanes of the Geneva airport (in the right part) shows the dimensions of the CERN laboratories. The reason for the laboratories being so large depends on the fact that large energies of the accelerated particles are needed (that is short deBroglie wavelength) in order to study small objects. The same holds for the detectors that will "see" the decays. Below is shown the ATLAS detector at CERN, which will be in operation during 2007.

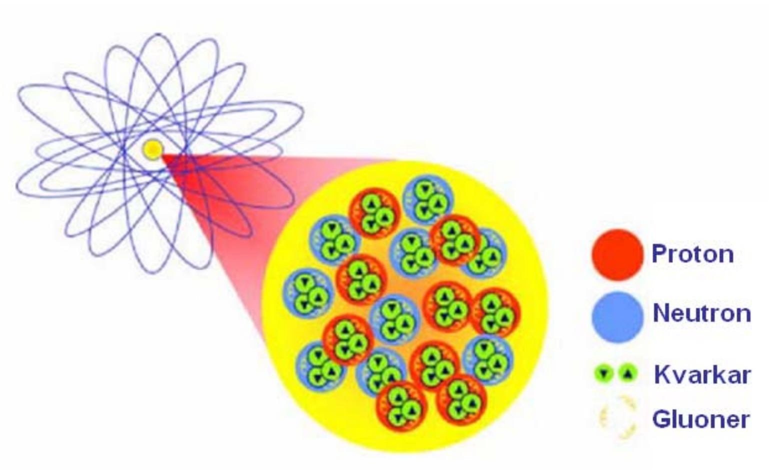
In the large circular ring below the surface there are super conducting magnets and accelerating sections in order to achieve the great velocities of the particles.

Vacuum pumps see to that the pressure in the tubes is being kept at a very low level. When the accelerated particles reach the reaction area the particle collisions are studied in detail by the large ATLAS-detector:

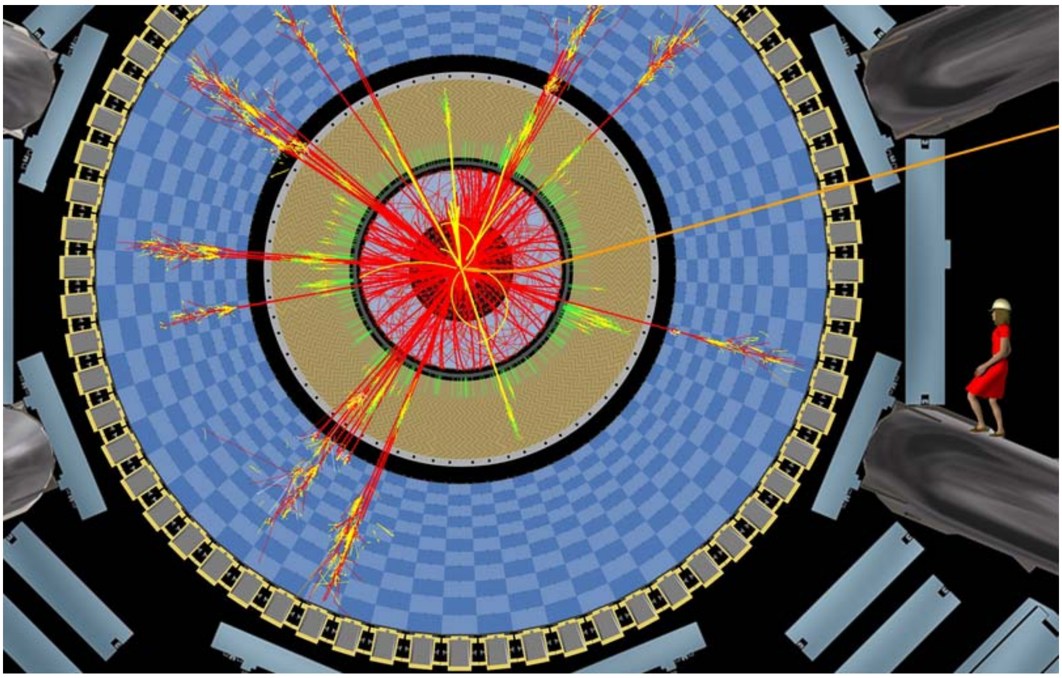


ATLAS-detector at CERN in Genève

One denoted the particles elementary since one believed that they were elementary, i.e. not possible to divide into smaller parts. However, the theoretician Murray Gell-Mann showed that the complex situation with many particles drastically would change if one supposed they were built by smaller parts, called Quarks, that were kept (interacted) together by an attractive force represented by *gluons*. A normal nucleus of an atom could then be illustrated in the following way:

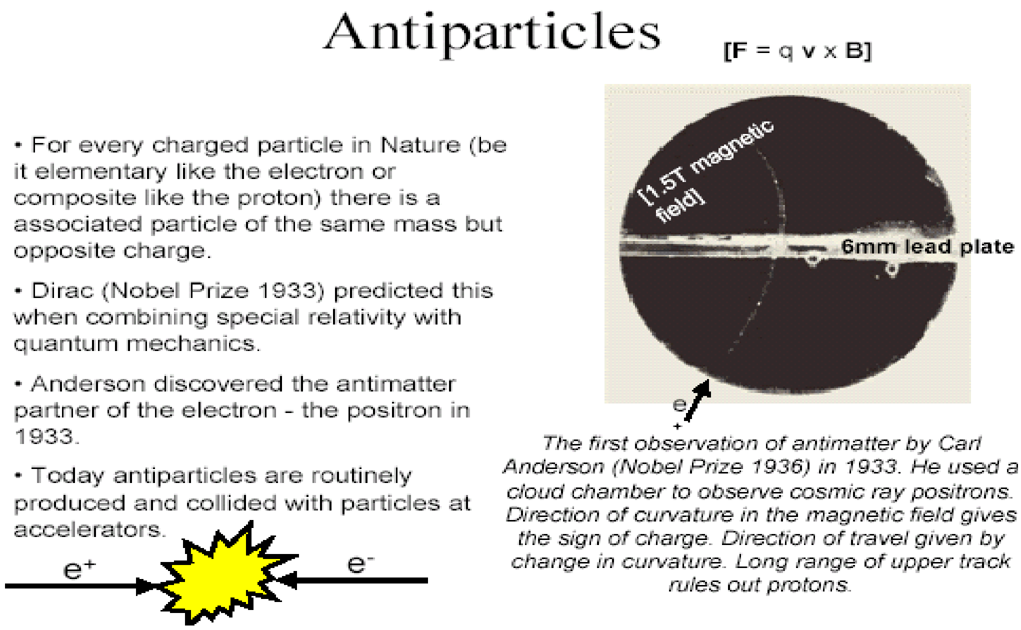


The electron is, as far as we know, elementary down to a characteristic length of 10^{-18} m. It belongs to a certain class of particles called *leptons*. To this class, also the (electron)-neutrino (ν_e), from the β-decay, also the myon (μ) and tau particle (τ) and their respective companions, the myon-neutrinon (ν_μ) and the tau-neutrino (ν_τ) belongs. These particles can be collected into three families, where the electron and its neutrino belongs to the first family.



The picture model shows how the Atlas detector will work at a particle collision

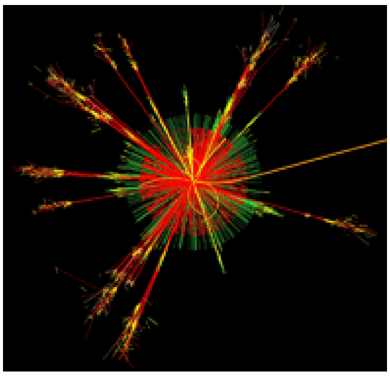
Paul Dirac already in the 1920-ies proposed that every charged particle should have a partner with the same mass, but with opposite charge. This was verified for the *electron* in the beginning of the 1930-ies when Carl Anderson discovered the *positron* in the cosmic radiation. These two particles were also the main actors of the CERN first accelerator LEP, Large Electron Positron collider. LEP was very successful during the whole of the 1990-ies. The new LHC accelerator is placed in the same tunnel as the old one.



A research team at CERN succeeded in December 2002 to produce nine anti-hydrogen atoms, consisting of one anti-proton surrounded by a bounded positron. Thus the first atoms of *anti-matter* had been created.

To bring order among all particles one can divide them into groups in various ways. We can classify particles by looking at their *anti-particle.* Since the positron is the anti-particle of the electron, they annihilate and at least two photons are created (since the momentum has to be conserved) with a very precise energy, each (The photon is its own anti-particle).

$e^+ + e^- \rightarrow \gamma + \gamma$



Particles momentum, energy etc can be determined from experiments

Another way of classifying the particles is by measuring their internal angular momentum, which we call the particles *spin*.

Classification of some particles regarding their spin (in the unit $h/2\pi$)

Spin	0	½	1	3/2
	π^+	e	W^+	Ω^-
	μ	p	W^-	
	ν	n	Z^0	
	K^-	Λ	ρ+	

Particles with spin ½ are called *fermions,* after Fermi who has described the statistics governing their behaviour, while particles with integer spin are called *bosons* after Bose who described their statistics. Fermions obey the *Pauli principle* that says that only one particle can have a given quantum state described by a set of quantum numbers, while bosons do not follow this principle.
We can classify particles by studying the forces affecting them:
Hadrons are affected by the *strong* force and hadrons can be *mesons* (that are bosons) or *baryons* (proton), which are fermions.
Leptons are affected by the *weak* force

Look for instance at the annihilation process proton/anti-proton.
$p + anti\text{-}p \rightarrow 4\pi- + 4\pi +$

This is a strong decay (produced by the strong force), since all particles involved are hadrons.

When a pion ($\pi\pi$) decays, with a mean life of 2.6 10^{-8} s, it does it via a weak decay (the weak force is responsible) to a myon ($\mu\mu$) and a myon-neutrino ($\nu\nu_\mu$)

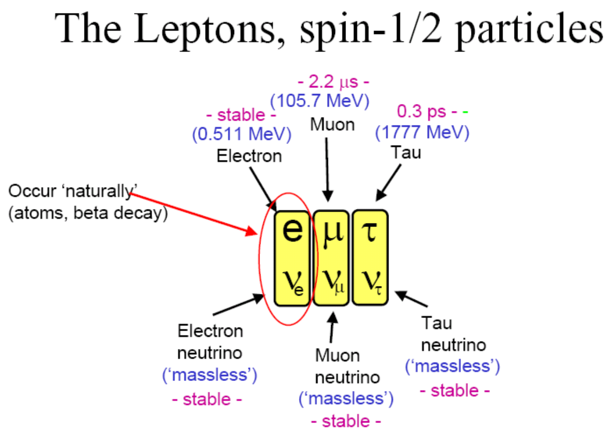
$\pi \rightarrow \mu + \nu_\mu$

The created myon decays with a mean life of 2.2 10^{-6} s, via another weak decay to an electron and two neutrinos.

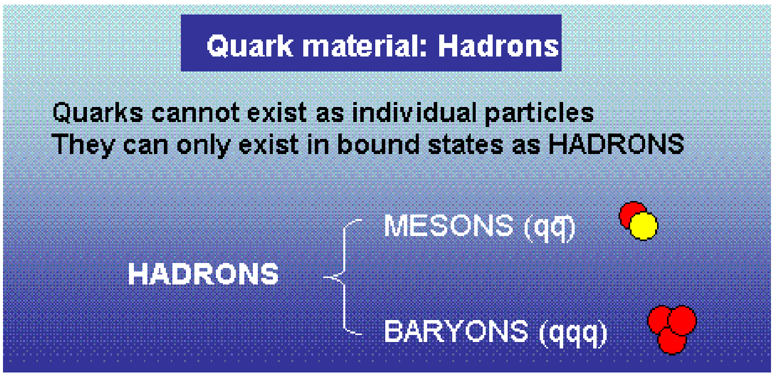
$\mu \rightarrow e + \nu_e + \nu_\mu$

These two neutrinos are different and still one more neutrino, the tauneutrino (ν_τ) was discovered at SLAC in 1975 when one identified the lepton tau (τ) belonging to the third family, and like the electron and myon it has an own associated neutrino.

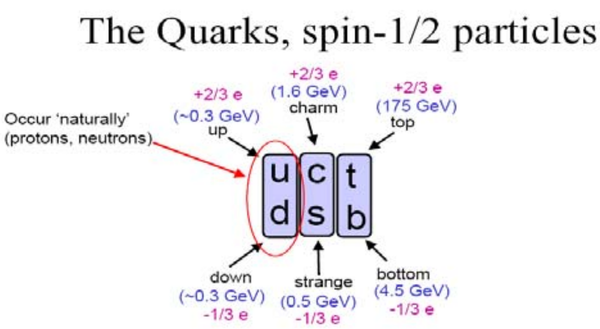
Leptons
One can wonder why there are two neutrinos in this decay, and we have touched the explanation; they belong to two different "families"! Interactions where leptons are involved obey a special law for the Lepton number *L*. Each "particle" gets a quantum number +1 and each antiparticle gets the quantum number –1. Particles not being Leptons, get the quantum number $L = 0$. In all reactions the Lepton number is conserved, why the three Lepton numbers L_e, L and L_τ must be conserved one by one.



Hadrons
They are different from Leptons. The Quarks cannot exist as free particles, but only in bound states. There they can exist as *qq*-states as mesons and in *qqq*-states as *Hadrons*.



This means that there is no meson or baryon, which properties cannot be explained by a suitable combination of quarks. In the same way there does not exist any quark combination that does not correspond to an observed meson or baryon. Until the mid-70-ies there were only three quarks known. Up today the opinion is that they are six, where the latest *t*-quark was verified in the middle of the 1990-ties at Fermilab, even though most physicists were convinced of its existence. All quarks can in a convincing way be divided into three families.



Baryons are a combination of three quarks and below is a table of baryons.

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$

Baryons are fermionic hadrons.
There are about 120 types of baryons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c²	Spin
p	proton	uud	1	0.938	1/2
$\bar{p}$	anti-proton	$\bar{u}\bar{u}\bar{d}$	–1	0.938	1/2
n	neutron	udd	0	0.940	1/2
Λ	lambda	uds	0	1.116	1/2
Ω^-	omega	sss	–1	1.672	3/2

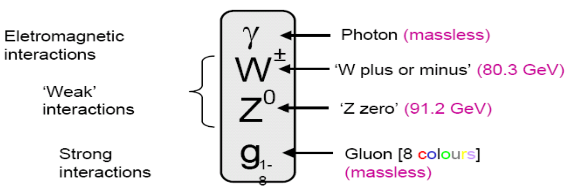
Meson are a combination of a quark-antiquark and below is a table of mesons.
At CERN, The so called Grand Unification Theory will be tested, the proton decay and the neutrino mass. In the so called Standard Model, matter particles (proton, neutron etc), gauge particles (photon etc) and scalar particles will be examined. The scalar particle, the *Higgs* particle will be searched for.

Mesons $q\bar{q}$

Mesons are bosonic hadrons.
There are about 140 types of mesons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c²	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	–1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.770	1
B^0	B-zero	$d\bar{b}$	0	5.279	0
η_c	eta-c	$c\bar{c}$	0	2 .980	0

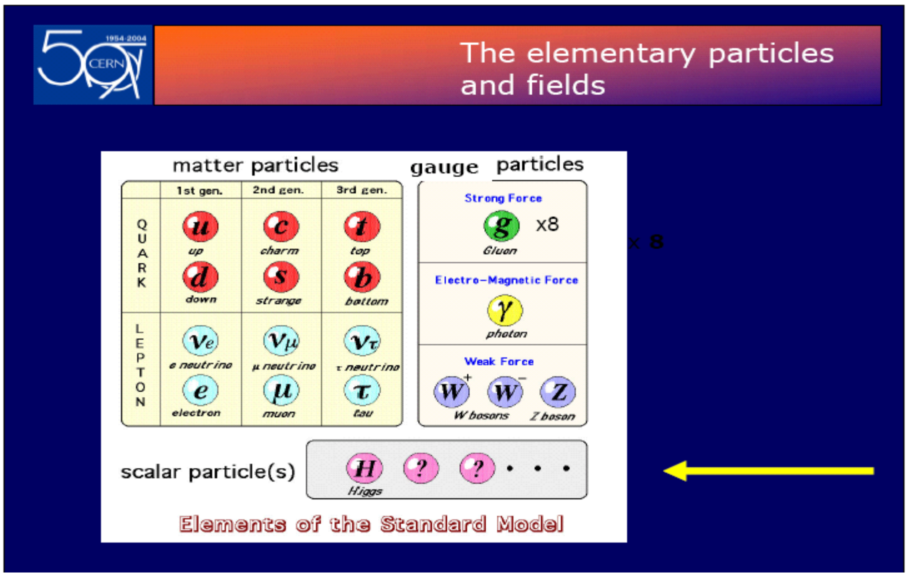
The Force Carriers



Interaction Strengths

Interaction	Strength	Range
Gravitational	*10^{-43}*	*∞ (1/r)*
Electromagnetism	1/137	∞ (1/r)
Weak	10^{-5}	$\sim 10^{-17}$m
Strong	15	$\sim 10^{-15}$m

- Want a Nobel Prize? Work out how to unify these forces into a single description!
- Superstring theorists think they are on the way…


The elementary particles and fields
matter particles
gauge particles
1st gen.
2nd gen.
3rd gen.
QUARK
LEPTON
up
charm
top
down
strange
bottom
e neutrino
μ neutrino
τ neutrino
electron
muon
tau
Strong Force
x8
Gluon
Electro-Magnetic Force
photon
Weak Force
W bosons
Z boson
scalar particle(s)
Higgs
Elements of the Standard Model