The Standard Model

Particle physics is a branch of physics which studies and describes fundamental elements of matter and interactions between them. So far we know 18 elementary particles, which are described by a theory called the Standard Model. Twelve of those particles, fermions, build up the matter. Among them are quarks (it is impossible to observe these particles directly, they always form some complex particles, like a proton) and leptons (for example electron). Bosons are the particles which are responsible for interactions between fermions. So far we know four fundamental interactions:

- electromagnetic interaction (mediating boson: photon)
- weak interaction (mediating bosons: W^+, W^-, Z)
- strong interaction (mediating bosons: gluons)
- gravitation (hypothetical mediating particle: graviton)

The electromagnetic interaction, apart from its most obvious applications in electronics, electrotechnics, transmission of sounds and moving images, is responsible for many other effects which we observe daily, like a friction or existence of different states of matter. The weak interaction rules processes like a beta decay, for example: $^{11}C \rightarrow {}^{11}B + e^+ + \nu_e$. The strong interaction binds quarks together into hadrons: mesons and barions (for example, proton, neutron) and is also responsible for forming atomic nucleus. The Standard Model unifies all these interactions, but not gravity.

The Standard Model

Fermions		Bosons
Quarks:		photon γ
quark u quark c quark t	quark d quark s quark b	boson W boson Z
		gluons
Leptons:		Higgs boson
electron muon tau	electron neutrino muon neutrino tau neutrino	

Three year ago the LHC experiment confirmed existence of the last unknown so far particle of the Standard Model - the Higgs boson. One year later Peter Higgs, François Engler and Robert Brout won the Nobel Prize for their theoretical prediction of its existence.

The Higgs boson

According to all data available so far, photon and gluon are massless particles. But bosons W and Z are massive (about 80 GeV/c^2 and 91 GeV/c^2, respectively, which are equivalent to about $1{,}5x10^{-34}$ kg and $1{,}7x10^{-34}$ kg). Direct introduction of their masses into theoretical models is forbidden because of the gauge symmetry. In physics we are able to connect conservation laws in nature (e.g. laws of energy, momentum and angular momentum conservation) with some mathematical symmetries (invariance under time and space translation, under space rotation). Moreover electric charge conservation can be connected with another abstract symmetry: gauge symmetry. Requirement of the local gauge symmetry implies masslessness of all mediating bosons. To satisfy both the gauge symmetry and existence of massive gauge bosons, one needs to unify the electromagnetic and weak interactions, and to add new scalar fields to the theory, which is finally the Higgs boson.

Physics beyond the Standard Model?

The Standard Model contains just one such physical scalar particle, which is a neutral Higgs boson. Its discovery confirmed theoretical mechanism of mass generation, which we know from the Standard Model. However, this mechanism does not falsifies existence of extended models, which would contain also additional particles. In this project such additional scalar (spinless) particles will be considered.

During the studies specific type of models which contain additional scalar particles, neutral, singly and doubly charged, will be considered.

The aim of the studies undertaken in the project is an estimation of a possibility to observe such particles experimentally. Particular processes with scalar particles will be analysed. Two ways of searching for new particles will be considered:

1. High energy collisions in particle accelerators.

During collisions, in some processes scalar particles may play a special role. This year the LHC started to work with the energy of 13 TeV, that is significantly more than the energy available so far, which was equal to 8 TeV. According to the mass-energy equivalence, higher energy of collision, heavier particles could be produced. This gives experimental opportunities to observe new heavy particles beyond the Standard Model, among them scalar particles. The LHC is a hadronic accelerator working presently. Future accelerators working at higher energies will be also considered. There are plans that the LHC successor might be the FCC collider (Future Circular Collider), also located in CERN, near to Geneva. Foreseen FCC accelerator collision energy is up to 100 TeV. Several options of future accelerators are considered: hadron-hadron collisions (FCC-hh), hadron-lepton collisions (FCC-he) and lepton-lepton collisions (FCC-ee). There are also independent plans to create new accelerators in China (CEPC - Circular Electron-Positron Collider) and in Japan (ILC - International Linear Collider) and in Switzerland (CLIC - Compact Linear Collider). So the hadron-lepton and lepton-lepton processes will be also taken into account.

2. Lepton flavour number violating processes at low energies.

So far no lepton number violating processes have been observed (lepton number is violated if the total number of leptons in the initial and final states are not the same). An example of a process which can violate lepton number is the double neutrinoless beta decay which is intensively searched for in experiments. However, observation of neutrino oscillations shows that the lepton flavour number is not conserved, so the same still can happen in another processes with charged leptons. There are many ongoing and planned experiments aiming to study and observe such lepton flavour violating (LFV) processes, e.g. muon decay to electron (with simultaneous emission of a photon), muon-electron conversion through interaction with a nucleus. Future experiments like Mu2e in Fermilab, MEG in Switzerland or COMET (COherent Muon to Electron Transition) in Japan will enhance our potential for observing such LFV processes. During the project also potential contributions of scalar particles to such processes will be analysed.