1. Introduction. The physical world from the view point of particle physics.

The basic goal of this lecture is to give a qualitative notion about the surrounding us world from the view point of particle physics. A basic characteristic feature of surrounding us world is existence of discreet structure like is molecule, atom, atomic nucleus etc. On qualitative levels we will show what are the ground building particles of our physical world, what are ground forces acting between these particles, as well as by what means myself we get information about particles and their interactions.

Discreteness of the physical world can be characterized by the scheme shown in Fig. 1. As can be seen from Fig. 1 the most elementary components of matter are electrons and quarks. Electrons are elements of atomic envelope surrounding atomic nucleus and quarks are the basic components of nucleons that create atomic nucleus.

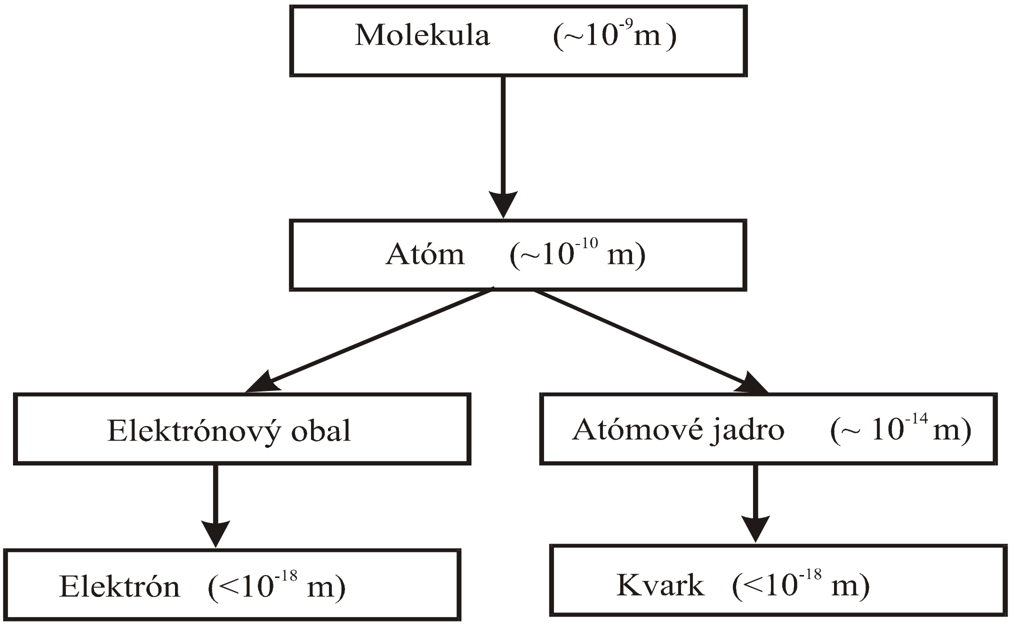

Fig. 1: Scheme of discrete structure of physical world.

In the following part we will briefly outline how is obtained information about the elementary particles as well as how many elementary particles we now at present and what are the forces acting between them.

1.2 Source of information on elementary particles.

The basic source of information on the elementary particles comprises the study of particle interactions in experiments of various types. Essentially the experiments could be divided into three main groups:

- Experiments in accelerators with colliding beams (the so-called collider experiments),

  Used beams**:** ***pp***, $p\bar{p}$, ***ep***, $e^{-}e^{+}$
- Experiments in accelerators with fixed targets (the so called fixed target experiments)

  Used beam - target***:*** ***pA***, ***πA***, ***KA*** (A≡atomic nucleus)
- Non–accelerator experiments, i.e. experiments based on detection of cosmic particles – neutrinos and protons (of high energies). Here can be comprised also the experiments studying rare processes as is the proton decay or double beta-decay.

Table 1: Parameters of Large Hadron Collider (LHC), L is luminosity, τ is interval between collisions.

Incident particles:	energy	*L* (10^{30} cm^{-2} s^{-1}):	τ (μs):
p → ← p	7 TeV ⊗ 7 TeV	10^4	0.025
Pb → ← Pb	574 TeV ⊗ 574 TeV	0.002	0.135
Accelerator circumference:	26.659 km		
Main experiments:	**ATLAS** (p-p)		
	CMS (p-p)		
	ALICE (Pb-Pb)		
	LHCb **(**p-p, B-physics**)**		

At present the main source of information about particles constitute the accelerator with colliding beams though for selected processes acquire a considerable significance the non-accelerator experiments (neutrino processes) and still find their applications also the fixed target experiments. A survey of basic parameters of the present accelerators is shown in Table 1 and 2 where are summon up the parameters of the accelerator LHC (Table 1) and parameters of the present and recently finished accelerators (Table 2).

Table 2: Parameter of the present and recently finished accelerators.

accelerator	*beam*	energy	*L (10^{30} cm^{-2} s^{-1})*
Tevatron (Fermilab)	p $\rightarrow$ $\leftarrow$ p	0.9-1 TeV $\otimes$ 0.9-1 TeV	10
LEP I (CERN) **LEP II**	$e^+ \rightarrow \leftarrow e^-$	55 GeV $\otimes$ 55 GeV 100 GeV $\otimes$ 100 GeV	11
SLC (SLAC)	$e^+ \rightarrow \leftarrow e^-$	50 GeV $\otimes$ 50 GeV	0.35
HERA (DESY)	e $\rightarrow$ $\leftarrow$ p	30 GeV $\otimes$ 820 GeV	16
KEKB (KEK)	$e^- \rightarrow \leftarrow e^+$	8 GeV $\otimes$ 3.5 GeV	10 000
PEP-II (SLAC)	$e^- \rightarrow \leftarrow e^+$	9 GeV $\otimes$ 3.1 GeV	3 000
DAΦNE (Frascati)	$e^- \rightarrow \leftarrow e^+$	0.51 GeV $\otimes$ 0.51 GeV	5($\rightarrow$50)

1.3 The Standard Model (SM)

The present particle physics is grounded on the conception called Standard model (SM) which consists of the following parts:

- ***Theory of electro-weak interactions***

This theory is based on Lagrangian with the calibration symmetry $SU(2)_L \otimes U(1)_Y$ and explain the electromagnetic phenomena and the weak ones (beta decays). Under this theory the electromagnetic and weak interactions are only two different manifestations of one more universal electroweak interaction which is mediated by 4 vector bosons: photon, $W^{\pm}$ bosons a Z-boson. These bosons are the quanta of the force fields of the electro-weak interaction.

- ***Theory of strong interactions - quantum chromodynamics (QCD)***

This theory is based on Lagrangian with the $SU(3)_C$ calibration symmetry and explains the forces acting between quarks (components of nucleon). Strong interaction is mediated by 8 gluons which are vector bosons with zero masses.

It should be noted that the SM dose not include gravitation, as the gravitation interaction cannot be „squeezed “ in quantum pictures that is valid for the electromagnetic and strong interaction. Practically it means that there does not exist the quantum theory of gravitation.

During the second half of the 20th century have been discovered hundreds of new „elementary“ particles and resonances. In frame of the SM all these particles or resonances have been successfully classified as the systems composed of a few number of so called „fundamental“ particles, i.e. the “truly “ elementary particles.

The fundamental particles of the SM could be divided into 3 basic sectors of fundamental particles:

- ***Fundamental fermions* –** these are the basic building blocks of the physical world which create structures as is nucleon, atomic nucleus, atom, etc. They are fermions, i.e. they obey the Pauli exclusive principle .
- ***Quanta of force fields (intermediate particles)*** – in this case are meant the particles that intermediate interactions between particles. These intermediate particles are vector bosons – it means they did not obey the Pauli principle.
- ***Higgs particles***. In the minimal SM this sector consists of 1 neutral Higgs boson. These particles are distinguished by creating the so called Higgs condensate i.e. the Higgs field has non-zero mean vacuum value. This circumstance leads to the fact that interaction of particles with Higgs field (more correct with Higgs condensate) gives mass to particles.

There exists 3 families of fundamental fermions, at the same time each family consists of

Table 3: fundamentálne fermióny: 3 pokolenia kvarkov a leptónov

ELECTRIC CHARGE	QUARKS			LEPTONS			ELECTRIC CHARGE
+ 2/3	u UP	c CHARM	t TOP	e^- ELECTRON	μ^- MUON	τ^- TAU	−1
−1/3	d DOWN	s STRANGE	b BEAUTY	ν_e ELECTRON NEUTRINO	ν_μ MUON NEUTRINO	ν_τ ? TAU NEUTRINO	0

3 colours

pair of leptons (they interact only through the electroweak interaction) and pair of quarks (they can interact through all interactions). Fundamental fermions are summarized in Table 3. It should be noted that to each particle corresponds its antiparticle that has the same mass but its charge has opposite sign and the opposite sign have also other quantum number as is the strangeness, charm etc.

As far as quarks are concerned, that exclusively interact by means of strong interactions, they can be in 3 different charge states usually denoted as R,G a B (red, green a blue). A very important characteristics of the strong interactions is comprising in the fact that in the nature are observable only so called white states, i.e. quarks as colored objects does not occur in the nature. In the nature could exist as free only certain quark combinations, namely **mesons** (structures $q\bar{q}$) and **baryons** (structures ***qqq***). Among baryons are also protons (***uud***) and neutrons (***udd***), which are the basic components of atomic nucleus.

Te second sector of the fundamental particles is formed by so called intermediate particles which are the quanta of the exchange forces. As is shown in Fig. 2 the

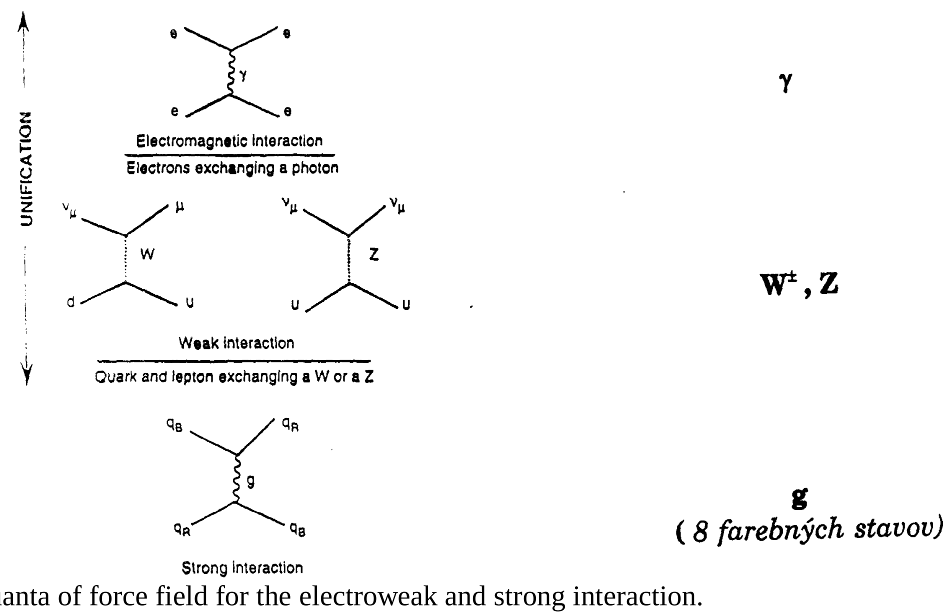

Fig. 2 Quanta of force field for the electroweak and strong interaction.

fundamental fermions at interactions among them they mutually exchange virtual intermediate bosons and as a consequence they change their states.

It should be noted that the all up to now mentioned SM particles are experimentally confirmed including the quarks and gluons which could not be observed directly but we positively know about their existence by observing jets i.e. showers of particles that are results of quarks and gluons‘ hadronization.

The third sector of the SM particles should be occupied by Higgs bosons. If in the nature actualize the so called minimal SM then there should be one neutral Higgs boson which has not been discovered yet. The search of Higgs boson is a basic task of the present particle physics – it is the most important task of the final phase of the Tevatron experiment and will be one of the main tasks in the experiments at LHC. From existing direct measurements (LEP II) it follows that the mass of Higgs boson, M_H, should by higher than 114.1 GeV/c. (95% CL). On the other hand from the precise electroweak measurements (LEP + Tevatron) it follows also the upper limit on the M_H which is ≈ 160 GeV/c^2 (95% CL). In spite of the fact that the SM predictions are in an excellent agreement with experiment, finding of Higgs boson presents a critical moment for the SM as Higgs boson plays a key role in the SM spontaneous symmetry breaking ($SU(2)_L \otimes U(1)_Y \otimes SU(3)_c \rightarrow U(1)_Q \otimes SU(3)_c$) that finally leads to non-zero masses of W and Z bosons, quarks and leptons.

1.4 Standard model its pros and cones

In spite of the SM excellent agreement with experiment there is a displeasure with it. The basic objections against the SM can be summarized as follows**:**

- The SM does not include one of the fundamental interactions – gravitation
- It does not explain the hierarchy of the masses of particles – the particles of a given generation have lower masses than the particles of the next generation.
- It does not explain the number of generations – the fact that in the SM there are 3 generations is a result of experimental measurements and not a result of theory.

- The SM has too „big“ number of free parameters – in its minimal version, with massless neutrinos, the SM has 18 parameters. In general case when neutrinos are not massless it has 25 parameters.
- The SM does not explain exhaustingly the phenomenon of CP symmetry breaking i.e. the fact that a process and its CP conjugated process goes in some cases with different rates.

In connection with the number of generations it is interesting to notice that the surrounding us material world consists almost exclusively of the particles of the first generation (u, d, e, ν_e). The only particle of the second generation that can be directly observed is muon producing at interactions of cosmic rays with atomic nuclei of the earth atmosphere. However one can say that the world is „conceivable“ also without muon.

In the SM there is no answer why do exist the particles of higher generations. On the other hand the SM in a cardinal way changed our view not only on the surrounding us material world but also on the universe as a whole. In the main it enabled us a new look on the universe early phase and it is just understanding of this phase that point out on the role of the higher generation.

1.4 Cosmology and elementary particles

Under the contemporary conceptions at the beginning of our universe were a singularity, i.e. infinitely hot and infinitely dense universe. This event occurred approximately 13.5 million years ago. This picture was obtain in such a way that the present state of expanding universe was taken into account and using the known physical laws a projection of the universe evolution was done in the reverse time. The scheme of this evolution is shown in Table 4. We will be interested first of all in the following three moments:

1. **t =10^{-11} s**, when the temperature of the universe was ***~10^{15}*** **K** (energy of particles ~ 100 GeV). The reason is that the present experiment enables us to study the processes that were being occurred in the mentioned moment of evolution when the universe consisted of leptons, quarks, photons, $W^{\pm}$ and Z–bosons.
2. A very interesting moment of the evolution occurred at **t =10^{-12} sec**, when the universe temperature was ***~310^{15}*** **K** and this phase it will be possible to study in the LHC experiments ATLAS and CMS. At this evolution moment occurred two, from the universe point of view, extraordinary events:
   a. the so-called Higgs condensate was created and most of particles acquired their masses.
   b. A tiny excess of matter over anti-matter was created in the ratio ~1:10^{10} , thanks to that excess our material world got arise. It is assumed that at the creation of the excess played a basic role the breaking of CP symmetry. From the SM view point the CP symmetry breaking can occur provided that there exist at least 3 generations of particles.
3. **t =10^{-5} s**, when the universe temperature fall down to ***~10^{12}*** **K** (energy of particles ~ 200 MeV), at that moment confinement of quarks occurred, i.e. hadrons were build up from quarks. From this moment in the material world exist only „white“ objects – this phase will be studied by the experiment ALICE (accelerator LHC).

Table 4: Scheme of evolution of the early phase of universe.

time (sec)

0 ⇒ ***Big Bang*** **–** *infinitely hot and dense universe (?)* (T ~ −13.5 $*10^9$)

│

│ ⇒ ***Era of quantum gravitation (?)***

↓

10^{-43}

│ ⇒ ***Era of GUT***

↓

10^{-34}

│ ⇒ ***Cosmic inflation (?)*** *(every 10^{-34} sec the universe doubled in its dimensional)*

↓

10^{-32}

│ ⇒ ***Quark era*** *(colored world)*

│

│ ⇒ ***Temperature ~3*10^{15} K*** *(energy ~200 GeV):*

│ • Phase transition → the Higgs condensate arises → leptons, quarks, $W^{\pm}$, Z–bosons acquire non-zero masses

│ • An excess of matter over antimatter arises (~1:10^{10})

↓

10^{-11} ⇒ ***Temperature ~10^{15} K*** *(energy ~100 GeV):* ← *the present experiment*

│ *content of universe:* leptons, quarks, gluons, $W^{\pm}$,Z–bosons

↓

10^{-5} ⇒ ***Temperature ~10^{12} K*** *(energy ~200 MeV):*

│ "*Confinement" of quark* → formation of hadrons → exist only

│ "white" objects .

↓

1 ⇒ ***Temperature ~10^{10} K :***

│ Exist only protons, neutrons, electrons, photons and neutrinos

│ Nucleo-synthesis of light nuclei (D, He, Be, Li...)

↓

10^2 ⇒ ***End of nucleo-synthesis***

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1.5 Basic tasks of high energy physics on LHC

As it has already mentioned the LHC experiments will investigate the state of matter that occurred in the early phases of universe. Among the main goals of the LHC experiments is to test the SM physics and look for possible signs of physics behind the SM. From view point of the SM physics it will be first of all:

- ***Origin of mechanism of spontaneously broken symmetry in electroweak sector.***

Practically it means the search of Higgs boson and a study of physics connected with production of Higgs boson.

- ***Physics of top quark***

At LHC it will be produced ~ 10^7 tt-pairs/ year, it will enable to study in detail top quark processes: the cross sections are significant means for testing QCD and the top quark decays enables to test V-A structure of weak processes, as top quark decays before it manage to hadronize (in such a way its spin characteristics is not influenced by hadronisation).

- ***B-physics***

Here it goes mainly about the study of violation of the CP symmetry (decays $B^0 \rightarrow J/\psi + K^0_S$, $B^0 \rightarrow \pi^+ + \pi^-$, etc.), the precise measurement of B^0_S – oscillations – it enables to measure directly the element V_{ts} of CKM matrix with a high precision. As very important appears also the spectrometry of b-hadrons.

From view point of physics behind the SM it will go mainly about the search of traces of new theories behind the SM, the first of all about:

- ***Technicolour (QTD),*** this theory enables to explain the symmetry breaking without the Higgs boson.
- ***GUT-theories,*** the theories based on SU(5) symmetry or higher symmetries which enable to unify electroweak and strong interactions.
- ***SuperSymetry (SuSy)***, presents the main candidate for a new theory after the SM. The strong point of the SuSy is that it includes also gravitation. A significant feature of SuSy is the fact that each particle has its super-symmetric partner – the search for super-symmetric partners is one of the most important tasks of LHC.

- ***Theory of superstrings (***its latest offspring is ***M-theory),*** it is known as a candidate for theory of everything. The fundamental object of this theory is superstring existing in D-dimensional space-time (D=10 resp 11, 26), where the redundant dimensions are compactified, the compactification leads to discrete masses of particles.

What are we going to look for?

Among the basic tasks there will be:

- ***Search for the „right“ W- and Z- bosons***

As it is well-known the SM includes the $SU(2)_L$ symmetry which means that in weak processes induced by $W^{\pm}$ bosons take part only the left components of particle fields (particles with left polarization). However there exist conceptions in frame of which the clearly left symmetry is replaced by the „left-right“ one, i.e. the replacement $SU(2)_L \rightarrow SU(2)_L \otimes SU(2)_R$ is carried out. Practically it means that exist also the "right" intermediate bosons W_R a Z_{LR}, for which the experiment gives the following limitations: $m(W_R) > 786$ GeV @95% CL , $m(Z_{LR}) > 650$ GeV @95% CL.

- ***Compositeness of fundamental fermions***

Under the SM the fundamental fermions (quarks and leptons) are point-like particles. The present experiment confirms their point-like structure at the level < ~ 10^{-18} m. The investigation whether the so called fundamental particles have a structure is very important as an eventual structure would mean a new physics – the physics behind SM.

- ***SuSy particles***

Theory of Super Symmetry is the most important candidate for new theory that should substitute the SM. Among its main virtues belongs the fact that it includes the gravitation. This theory assumes that to any fundamental exists its super-symmetrical partner:

quark ⇔ squark , lepton ⇔ slepton. In addition to that the SuSy theory assumes the existence of a more comprehensive Higgs sector that should contain 5 particles: $H^{\pm}$, H, h and A.

The search of Higgs boson.

It is probably the most important task of the LHC experiments. In frame of SM the H boson will be looked for by means of its decays (see Table 5).

M_H int. (GeV)	$90 < m_H < 100$	$90 < m_H < 150$	$130 < m_H < 2m_Z$	$m_H > 2m_Z$	$m_H \leq 2m_Z$
decay	$H \to b\bar{b}$	$H \to \gamma\gamma$	$H \to ZZ^* \to 4l^\pm$	$H \to ZZ \to 4l^\pm,\ 2l^\pm 2\nu$	$H \to WW, ZZ \to l^\pm \nu$ 2 jets, $2l^\pm$ 2 jets

Some examples of the decays that will be used for searching Higgs boson behind the SM are as follows (case of H bosons in frame MSSM):

$$A \to \tau^+\tau^- \to e\mu + 2\nu + 2\,\text{jets}$$

$$H^\pm \to \tau^\pm\nu \to 2\,\text{jets} + \text{l-tag} + \text{b-tag}\,.$$