NUCLEI AND PARTICLES
PHYS3002
2014/2015

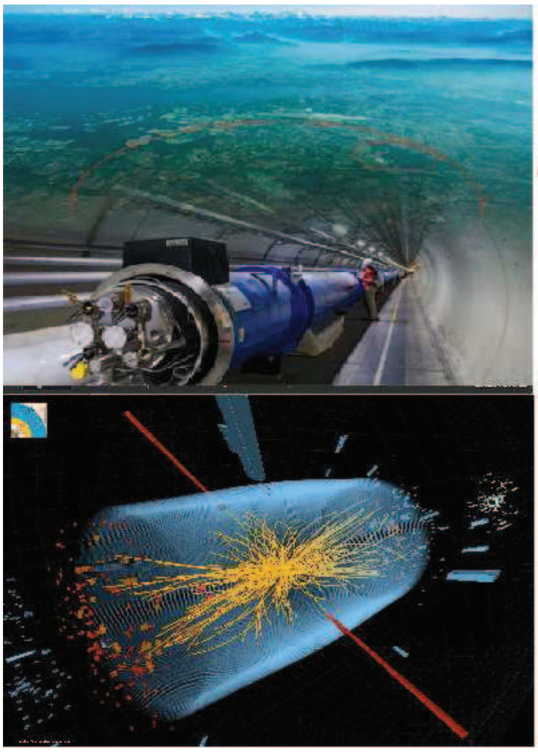
Prof. Alexander Belyaev

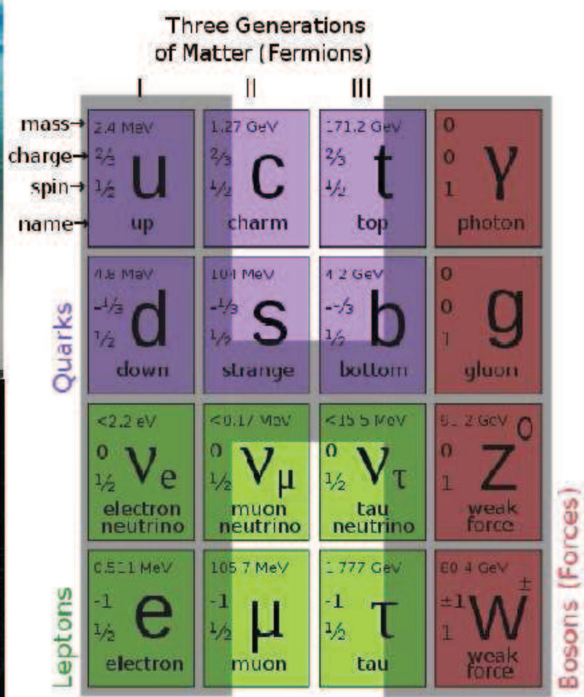
a.belyaev@soton.ac.uk

http://www.personal.soton.ac.uk/ab1u06/webpage/phys3002.html

Monday: 11:00 -13:00 02a/2065(L/T)

Friday: 09:00 -10:00 58/1067 (L/T)





Contents

Chapter 1

Introduction

1.1 Module Profile

1.1.1 Teaching and learning Methods

This course provides an introduction to nuclear and particle physics. There are approximately 16 lectures for each section supplemented by directed reading. Lectures delivered using mainly white board/blackboard and with a slight admixture of computer presentation for selected topics. There will be five problem sheets with respective five sessions devoted to the respective problem solutions. Model solutions will be provided after the problem sheets are due to be handed in. The problem sheets also contain non-assessed supplementary questions usually of a descriptive nature designed for deepper understanding of the material.

1.1.2 Learning Outcomes

This course provides a working knowledge of nuclear structure, nuclear decay and certain models for estimating nuclear masses and other properties of nuclei. Alo students will become familiar with the basics of elementary particle physics and particle accelerators. They will have an understanding of building blocks of matter and their interactions via different forces of Nature.

Students will learn about Nuclear Scattering, various properties of Nuclei, the Liquid Drop Model and the Shell Model, radioactive decay, fission and fusion. By the end of the course, the students should be able to classify elementary particles into hadrons and leptons, and understand how hadrons are constructed from quarks. They will also learn about flavour quantum numbers such as isospin, stangeness, etc. and understand which interactions conserve which quantum numbers. They will study the carriers of the fundamental interactions and have a qualitative understanding of QCD as well as the mechanisms of weak and electromagnetic interactions.

1.1.3 Syllabuses

Nuclei
1.Rutherford scattering (classical treatment)
2.and nuclear diffraction.
3.Nuclear properties.
4.Binding energies and Liquid Drop Model.
5.Magic Numbers and the Shell Model.
6.Radioactive decay
7.Fission and fusion
8.Isospin

Particles
1.Accelerators
2.Forces of Nature (strong, weak and electromagnetic interactions and their force carriers)
3.Particle classification
4.The constituent quark model
5.Weak Interactions (W and Z bosons)
6.Electromagnetic interactions
7.Quantum Chromodynamics (interactions of quarks and gluons)
8.Charge conjugation and parity

1.1.4 Non-contact Hours

Students are expected to devote a minimum of 6 hours per week of private study to background reading and problem solving.

1.1.5 Assessment Methods

Assessment is done by written examination at the end of the course. The exam will have a compulsory section A covering the whole course, with 4 - 6 questions and a section B on Nuclei where answers to 1 question out of 2 will be required, and a section C on Particles where answers also to 1 question out of 2 will be required. Each section carries 1/3 of the total marks for the exam paper and you should aim to spend about 40 mins on each.

The problem sheets will contribute 10% to the final mark and only 3 out 5 problems (1^{st},3^{rd} and the 5^{th}) will be marked. It is important to stress that the history of this course clearly shows that only those students who have been attempting to solve *all* problems from the very beginning were the most successful. The completed solutions should be handed in before the deadline indicated on the problem sheet. The problem sheets also contain non-assessed questions which are of a qualitative nature or pure bookwork. The student should work through all of these and ensure that he/she would be able to answer them under examination conditions.

1.1.6 Recommended Books

1. R.A.Dunlap - An Introduction to the Physics of Nuclei and Particles, Thomson, 2004 (- main text)
2.W S C Williams - Nuclear and Particle Physics, Oxford University Press, 1991.
3.D Perkins - Introduction to High Energy Physics, Addison-Wesley, 4th edition.
4.Francis Halzen, Alan D. Martin - Quarks and Leptons: An Introductory Course in Modern Particle Physics, John Wiley, 1984

1.1.7 Other Course Information

The course website
`http://www.hep.phys.soton.ac.uk/~belyaev/webpage/physics_phys3002.html` contains course notes and problem sheets (solutions will be uploaded after their due date) and the selected past exam papers. It also contains revision notes on topics from previous courses, familiarity with which will be assumed during the lectures.

Please note, that all course notes are acessible at the website and not ment to be printed for you.

1.2 History of Particle Physics

Since long ago people were trying to understand the Nature and its fundamental building blocks. We know several 'theories' which came from the ancient philosophers. More than two thousand years ago Empedocles (490-430 B.C.) suggested that all matter is made up of four elements: water, earth, air and fire. On the other hand, Democritus developed a theory that the universe consists of empty space and an (almost) infinite number of invisible particles which differ from each other in form, position and arrangement. He called them *atoms*(indivisible in Greek).

Since that time our understanding of fundamental building blocks of Nature has evolved into powerful science called Particle Physics. The main difference between Particle Physics and ancient philosophy is that Particle Physics, as a science, verifies its theoretical predictions by experiment. Theory and Experiment are vital interacting components of Particle Physics and because of these components Particle Physics can be called science. That is exactly the way how Standard Model (SM), which describes our present understanding of fundamental particles and their interactions, has been established. In this course we will briefly discuss the SM elementary particles and their interactions summarized in Fig. 1.1. The last particle

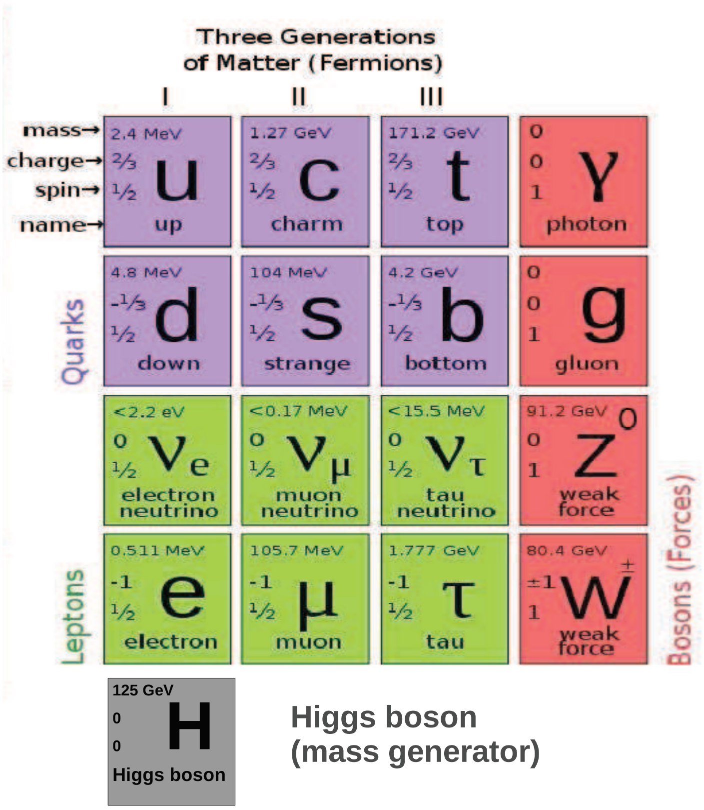


Figure 1.1: A summary of elementary particles of the Standard Model and their interactions.

in the SM, Higgs boson, responsible for the mass generation of other partcles, was discovered on the 4th of July 2012 which was announced by both, ATLAS and CMS collaborations at the Large Hadrom COllider (LHC). This was truly historical event. There could be more particles and theories beyond the SM: presently there are many new promising models beyond the SM which will be tested experimentally in the nearest future.

Particle Physics as a science has started in the very end of the 19th century. In Table 1.1 a timeline of Particle Physics is presented in a very brief way. More detailed history can be found, for example, at `http://en.wikipedia.org/wiki/Timeline_of_particle_physics` or at `http://web.ihep.su/dbserv/compas/contents.html` in much more detail.

1885	Eugene Goldstein discovered a positively charged sub-atomic particle
1897	J. J. Thomson discovered the electron
1909	Robert Millikan measured the charge and mass of the electron
1911	Ernest Rutherford discovered the nucleus of an atom
1913	Neils Bohr introduced his atomic theory
1919	Ernest Rutherford discovered the proton
1920s	Modern atomic theory developed by Heisenberg, de Broglie and Shroedinger
1932	James Chadwick discovered the Neutron
1964	Up, Down and Strange quarks were discovered
1974	Burton Richter and Samuel Ting discovered the J/ψ particle, demonstrating the existence of Charm quark
1977	Upsilon particle discovered at Fermilab, demonstrating the existence of the bottom quark
1995	Top quark discovered at Fermilab
2000	Tau neutrino proved distinct from other neutrinos at Fermilab
2012	Discovery of the Higgs Boson at the LHC

Table 1.1: A very brief timeline of particle physics

One of the most important milestones in the early history of Particle Physics is the experiment of Ernest Rutherford in 1911 which has proved an existence of the atomic structure with an atomic nucleus. We start this course describing this experiment and physics behind it in Chapter 2. Since that time many exciting discoveries has been made. However, one should stress that the principle behind the Rutherford experiment is one of the main ones being used in the modern collider physics. Rutherford has used the short length of the de Broglie wave of the electrons to probe the internal atomic structure. From well-known formula

$$\lambda = \frac{hc}{E}, \tag{1.1}$$

where λ stands for the wave-length, h is the Plank constant and E is the energy, one can see that the de Broglie wave length of the particle is inversely proportional to its energy. One can use this fact and resolve the structure of the tested object if the wave length if the tester particle is comparable or smaller than the size of the object. So, when the energy of the tester particle is large enough, it will interact with the the object at the respective scale. On the contrary, if the energy of the tester particle is too low, then, due to its large

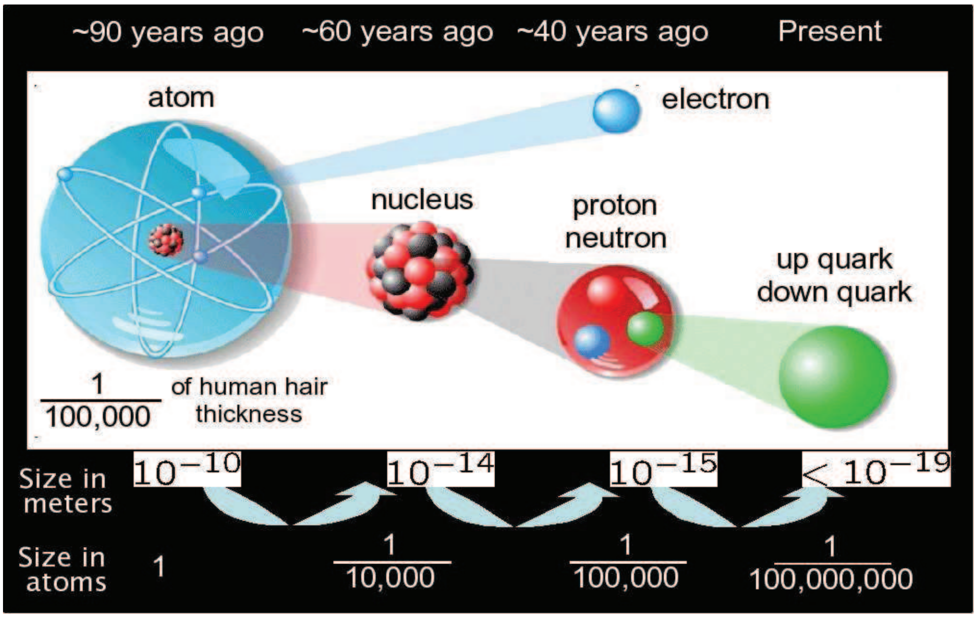


Figure 1.2: Timeline of the scale accessible in Particle Physics

de Broglie wave-length it will just bend around the object under study and no its internal structure will be resolved. The principle behind the Eq.(1.1) which in general relates the scale and the energy, is one of the main foundations of particle physics. Present collider experiments which reached now TeV energy scale (10^{12} electron volt) probe the scale as low as 10^{-19} meters! The timeline of the scale evolution of the distance scale accessible in Particle Physics is presented in Fig. 1.2.

On the other hand, another well known formula

$$E = mc^2 \tag{1.2}$$

relating the energy and the mass tells us that High Energy gives us possibility to produce new heavy particles. This opens another way to explore new theories beyond the SM. The Large Hadron Collider (LHC) is now colliding protons with the highest energy in the world and one can expect that time lime of Particle Physics discoveries will be continued soon.