European Summer University

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Strasbourg

Scientific Programme

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Université Européenne d'Eté 2006

Particles and the Universe

Strasbourg 3-12 July 2006
Lectures

Physics brings Nations together, CERN and SESAME as examples
H.Schopper, CERN
Laws of physics are universally valid and provide an excellent basis for international cooperation between scientists from different mentalities, traditions, religions and political systems. Basic science cannot succeed without open communication without secrets and elementary particle physics needs large installations which require also cooperation with administrations and connections with even highest political levels. Particle physics has pioneered several steps in international collaboration.
CERN, the oldest European organisation, was founded after World War II not only to promote science in Europe but also to bring European nations together. In the past CERN has put at the disposal of physicists several unique facilities (continuing with LHC in the future) and consequently CERN has become in practice a world laboratory. The large scientific collaborations, called 'experiments', presently involving up to 2000 scientists and engineers, radiated into the political domain and contributed to establish mutual understanding and trust. They promoted cultural exchanges and sometimes even providing help to individuals.
The latest offspring of CERN is the SESAME Laboratory in Jordan with a synchrotron radiation source as the main facility. It was founded according to the CERN model under the auspices of UNESCO. Like CERN with two objectives - promote science in the Middle East and the Mediterranean Region but also serve the slogan "science for peace" in this conflict - torn part of the world.

The Standard Model of Fundamental Interactions, Achievements and Prospects
(Introduction, 2-3 lectures)
Gilles Cohen-Tannoudji, CEA Paris
The standard model of fundamental interactions is based on the quantum theory of fields in particle physics and on general relativity in cosmology. It consists on a set of effective theories (the Electroweak theory, Quantum Chromodynamics and the Big Bang cosmological model) that give, with the help of a finite and fixed number of adjustable parameters, an acceptable agreement with all experimental and observational data on the microscopic structure of matter and on the evolution of the universe. These introduction lectures are devoted to a historical and epistemological overview of the main achievements and prospects of this standard model. The dynamical tension between its robustness and its upgradeability appears to be a characteristic of the methodology of modern scientific research.

Gigantic Experiments at ever Larger Accelerators
(1 lecture)
Ulrich Goerlach, University Louis Pasteur, Strasbourg
This Lecture will introduce the main concepts and features of the very large detectors which have been designed for High Energy Physics experiments and explain the enormous technological challenges which had to be met for the LHC and which have to be faced for the future projects.

Neutrino mysteries (Part I, Oscillations)
(1 lecture)
Marcos Dracos, IPHC, Strasbourg
After the latest experimental results, neutrino physics became a very exciting subject and took a very rapid expansion. Neutrino, the most elusive elementary particle has always reserved surprises to theorists and experimentalists. Its existence has been predicted by W. Pauli in 1930, at a moment where only the electron and proton were known, in order to save the energy conservation low. Due to the very weak interaction with matter, only 26 years later the first neutrino has been detected.
In the first part of this lecture, a neutrino historical review will be given. In the second part, the relation between the Standard Model (particle theory) and the oscillation formalism will be introduced. The third part will be devoted to the experimental results extracted from the most representative experiments. In the last part, new projects proposed for a better understanding of neutrino properties will be presented.

Classic Big Bang Cosmology, Dark matter and Galaxy formation:

(1 lecture at observatory)
Bernd VOLLMER, Observatoire Strasbourg
This conference will describe the main modern observations and ideas relevant to the expanding universe and to the development of inhomogeneities, eventually leading to galaxy formation. The evidence for the existence of so-called dark matter in different cosmic structures will be presented and the importance of dark matter in the process of galaxy formation will be emphasized.

Cosmic High Energy Phenomena
(1 lecture at observatory)
Jean HEYVAERTS, ULP and Observatoire Strasbourg
High Energy activity from compact stars and collapsed objects: The high energy activity near compact objects, isolated or in binary systems, will be presented. The high voltage environment of these objects and associated high energy photon or particle emission will be discussed. The mechanisms that may accelerate in the bulk matter to relativistic speeds and focus it into narrow jets near compact stars and black holes will be described.

Primordial Cosmology
(1 lecture at observatory)
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The hot big-bang model has changed a lot since its formulation due to both a better theoretical understanding and an increasing quantity of observational data. In this lecture, the hot big-bang model will be described. Its successes will be detailed as well as its problems. One of the most important evolutions lies in the understanding of the structure formation. In particular, the origin of the density perturbation during inflation and their imprint of the cosmic microwave background will be explained. Among the recent developments, the acceleration of the universe is one of the puzzles to be resolved. The origin of these problems and various models to solve it will be presented. We will finish by some highlights on various links between cosmology and high energy physics (such as topological defects, dark matter and others).

Physics at Future High Energy Colliders
(2 lectures)
Albert DeRoeck, CERN
This course will discuss the physics program and goals for the next projects at the high energy

frontier. The Standard Model for Particle Physics has been tested to great detail over the last 20 years, and measurements are in excellent agreement with the data. But this model has its shortcomings and does not explain why the world is as it is. It is furthermore expected that at higher energies new physics effects will manifest itself, which are needed to allow the Standard Model to be stable at our present energies. The next high energy machines will seek answers to these questions.
In less than two years from now the Large Hadron Collider (LHC) at CERN will become operational, and will collide protons at a centre of mass energy of 14 TeV. This high collision energy will allow to study physics at the TeV energy scale. These lectures will introduce the LHC machine and make a tour of the experiments, presently under construction, that will measure these collisions. The physics program and measurments at the LHC, and at its potential luminosity upgrade (SLHC), will be discussed. Special attention will be given to the long awaited start-up schedule of the collider and the first results that can be expected from the LHC experiments.
One of the most important questions which the LHC will settle is that of electroweak symmetry breaking -- or the mechanisme that gives mass to the fundamental particles-- which is currently still mysterious. The presently most popular solution to this problem is the anticipation of the existence of a scalar "Higgs" field, with associated Higgs particle. If such particle exists with Standard Model properties, LHC will find it.
Another major question is what lays beyond the Standard Model. The high energy limit shortcoming of the Standard Model suggests that in the region around a TeV or higher, signals from new physics will set it, through the production of new particles or the onset of new processes. In these lectures we will discuss the potential for discovering Supersymmetry, large extra space dimensions, and a few other new scenarios.
At a later time, perhaps 10 years from now, an e+e- linear collider can be the next collider which will be largely complementary to the LHC, allowing for precision measurements to be made, in order to understand the exact nature of the underlying theory for the new physics, when discovered at the LHC.
These lectures will give a short introduction to the present linear collider projects and studies, ILC and CLIC, and will discuss the synergy with the LHC physics program.

Introduction to High-Energy Cosmic Ray Physics
(in Karlsruhe,1 lecture)
Haungs, Andreas, Forschungszentrum Karlsruhe
Energetic particles, traditionally called Cosmic Rays, were discovered nearly a hundred years ago, and their origin is still uncertain. Their main constituents are normal nuclei as in the standard cosmic abundances of matter; there are also electrons, positrons and anti-protons, but no anti-nuclei. Today we also have information on isotopic abundances, which show some anomalies, as compared with the interstellar medium. The cosmic ray all-particle spectrum extends over energies from a few hundred MeV to 3x1020 eV and shows few clear spectral signatures: There is a small spectral break near 5x1015 eV, the "knee", where the spectrum turns down; there is another spectral break near 3x1018 eV, the "ankle", where the spectrum turns up again. Up to the ankle the cosmic rays are usually interpreted as originating from Galactic sources; however, we do not know what the origin of the knee is. The particles beyond the ankle have to be extragalactic, but due to interaction with the cosmic microwave background there is a strong cut-off expected near 5x1019 eV, which is, however, not seen; The measured high energy cosmic rays beyond this "GZK-cutoff" (after its discoverers Greisen, Zatsepin and Kuzmin) are the challenge to interpret.
High-energy primary cosmic rays above energies of about 1x1014 eV are investigated by observations of extensive air showers (EAS) using large area ground based detector installations for registering various components of the EAS cascade development. In the present lecture different experimental approaches deducing mass and energy sensitive information from the most sophisticated EAS experiments and their results are presented. In particular the KASCADE-Grande experiment for measurements around the knee and the Pierre Auger Observatory for detecting highest energy cosmic rays will be discussed in detail. These experiments involve measurements of secondary particle distributions, as well as measurements of air Fluorescence light and radio waves emitted during the EAS development.
The physical and astrophysical implications of the current findings in various energy regions are

briefly discussed and prospects of the KASCADE-Grande and Pierre-Auger experiments are presented.

Laboratory Search for Cosmological Dark Matter
(in Karlsruhe,1 lecture)
Klaus Eitel

In recent years, measurements of the red shift of light from distant Supernova explosions, new observations of the cosmic microwave background with unprecedented precision as well as galaxy redshift surveys of hundreds of thousand of galaxies have revealed an expanding Universe almost completely filled with Dark Energy and Dark Matter. Although there are good motivations from theoretical and experimental particle physics for the existence of Dark Matter in form of non-baryonic elementary particles, we have only restricted or very little information from direct investigations on these particles.

The two major candidates for Dark Matter particles are the well-known neutrinos and the yet unknown so-called WIMPs, weakly interacting massive particles. Whereas the first are very light and thus considered as “Hot Dark Matter”, WIMPs are expected to be very massive and would thus be “Cold Dark Matter”.

The observation of neutrino oscillations is an unambiguous proof of a non-zero neutrino mass. However, the absolute mass scale cannot be extracted from such experiments. The most sensitive laboratory search on the neutrino mass is the investigation of the kinematics of the ß decay, especially the decay 3H □□3He + e- +anti(□e). At the Forschungszentrum Karlsruhe, the KArlsruhe TRItium Neutrino experiment KATRIN is under construction to improve the existing sensitivity on the neutrino mass by more than one order of magnitude down to 200meV. Thus, KATRIN will be able to decide whether neutrinos play a significant role in the structure formation of the early Universe.

About 23% of the Universe´s mass content should be in form of Cold Dark Matter. WIMPs as particle candidates for this contribution would have formed the seeds of galaxy formation in the early Universe and would hence also form the Dark Halo surrounding our galaxy, the Milky Way. One attempt to detect them is the measurement of the energy released in elastic scattering of these halo WIMPs off nuclei of the detector material. The Forschungszentrum Karlsruhe is involved in the EDELWEISS direct Dark Matter search experiment installed in the Laboratoire Souterrain de Modane in the French-Italian Fréjus tunnel. The detectors used in EDELWEISS are Ge crystals of 320g mass operated at a temperature of 17mK.

In this lecture, we shortly review the cosmological motivation for particle Dark Matter and describe in detail the physics scheme, the experimental set-ups and technical challenges for laboratory Dark Matter search with KATRIN and EDELWEISS.

Neutrino mysteries (part II, Cosmological Neutrinos)
(1 lecture)
Julien Lesgourgues, LAPP Annecy

After a brief summary of the evolution of cosmological perturbation in the Friedmann universe, I will show why neutrinos are expected to leave a signature in the spectrum of CMB anisotropies and in the distribution of large scale structures. I will present current cosmological bounds on neutrino physics, based on various types of cosmological observations. Finally, I will intruduce the techniques with which cosmologists expect to probe neutrino masses in the next decades.

WWW, Grid, Neural Computing, Spin-Offs from High Energy Physics
(1 lecture)
Michael Feindt, Technische Universität Karlsruhe

The quest for the very fundamental mysteries of nature by exploring the smallest scales and highest energies at particle colliders requires a huge technological and intellectual effort.

While many people think this is a purely intellectual exercise for some crazy super-brains without any impact on society, the spin-offs from High Energy Physics research actually has and will have a number of consequences also for non-scientists.

The most famous example is the World Wide Web which has its roots at CERN. It clearly has revolutionized nearly everybody's life. The huge amount of data collected at the next generation of accelerator experiments led to the development of grid technology, i.e. computing power and storage "out of the plug" in a world wide grid of computer centres.

Accelerator and detector development has led to progress in medical imaging and radiation therapy.

Very powerful regularised neural network algorithms developed for reconstruction and statistical analysis of high energy physics experiments have been proven to be extremely good prediction and risk assessment methods. These now have first applications in banks, insurances, car and steel industry as well as trading companies.

The lecture describes the major ideas of some important spin-offs and their consequences for society. Finally career possibilities for physicists outside public research are described.

Supersymmetry and String Theories
(1 lecture)
Marios Petropoulos, CPHT Ecole Polytechnique, Palaiseau
In the first lecture, I will motivate the search for extra space-time symmetries and the emergence of supersymmetry. I will present some technical developments around extensions of Poincaré algebra and discuss their applications. In the second lecture, I will focus on what could stand beyond ordinary relativistic quantum field theory of point-like particles. The technical part of the lecture will be the description of relativistic-string classical dynamics. A discussion on the various facets of string theory and its relevance for high-energy physics and cosmology will follow.

Silicon Detectors in Particle Physics – from Strip Detectors to Medipix
(1 lecture)
Ulrich Parzefall, University of Freiburg
Semiconductor detectors for particle tracking and vertex finding have started to play an important role in High Energy Physics roughly since the LEP era. Present experiments at the Large Hadron Collider (LHC) or Tevatron would be impossible with Silicon detectors around the interaction point.
This lecture gives an introduction to the topic, starting from the fundamental operating principles of semiconductor detectors, and leading up to the detectors used in the tracking systems of the LHC experiments. Applications of detectors from particle physics in other fields are shown, using the Medipix chip as an example.

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