13 October 2001

Quarks, Leptons and Galaxies for students

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Presented at the International Europhysics Conference
on High Energy Physics, Budapest 12-18 July 2001,
Journal of High Energy Physics, PRHEP-hep2001/282

Abstract

The aim of this education project is to use the forefront of physics – the exploration of the most fundamental level in the interior of matter and the exploration of the Universe – to inspire students and teachers and to increase the understanding of and interest in natural science. Research councils, foundations and other financing bodies regard this type of outreach activity as more and more important for the future of basic science.

Introduction

Teachers and students are thrilled to interact with modern physics experiments at the forefront of scientific research. With the Hands on CERN education project [1,2] it is possible to "take part" in a modern particle physics experiment at the forefront of scientific research using scientific data transmitted via Internet. The primary aim is to show particle collisions from the physics frontline and to stimulate interest in science and technology. Hands on CERN complements the traditional physics education and confronts the students with contemporary physics and technology – both detector technology and data transmission technology via Internet - at its most fundamental level.

During a 10 day course in astronomy and particle physics, groups of 17 – 18 year old secondary school students studied the differential rotation of the Milky Way, the intricacies of high energy particle collisions and learned about the origin of the Universe. The combination of making their own measurements of the Milky Way with a small radio telescope, using scientific data from high energy particle collisions and having the Big Bang explained by scientists created an attractive and fascinating course in contemporary science. In the astronomy course the differential rotation of the Milky Way was measured with a small radio telescope. In the particle physics course the students got acquainted with the quarks and leptons, the fundamental building blocks of Nature. Plenary talks by scientists in astronomy, cosmology and particle physics were given to both classes to make all the students familiar with the different subjects and the fascinating connection between cosmology and particle physics.

Experiment and particle collisions

With high energy particle collisions it is possible to study the smallest building blocks in Nature - the quarks and the leptons. Some of these build up the world we see around us, some existed naturally only at the beginning of time, the Big Bang, but are now produced in high energy collisions at a few large physics laboratories in the world.

The scientific data come from the DELPHI experiment [3] at the Large Electron Positron Collider (LEP) at CERN [4]. LEP is providing high energy collisions between

electrons and positrons. During the first phase of LEP the collision energy was 91 GeV and a single Z^0 particle was produced in the collisions. During the second phase the collision energy was increased to around 210 GeV sufficient to produce WW and ZZ pairs.
The following subjects can be explored:

- the observation of quarks
- the observation of the gluon
- the decay of the Z^0 to quarks and leptons
- the study of electroweak and strong interaction.

With these particle collisions on the web (Fig. 1 and 2) the fundamental level of matter and the Standard Model of microcosm can be introduced in an interesting and dynamic way.

The Radio Telescope

A small radio telescope is used to map the Milky Way. The telescope is equipped with a 2.3 m diameter parabolic antenna and detects radiation in the frequency interval 1419 to 1421 MHz. It is set to detect the 21.1 cm radio wavelength or 1420 MHz frequency, which emanates from a hyperfine transition in atomic hydrogen. By measuring the Doppler effect [5] in the received radiation one can measure the radial movements of the spiral arms relative to us and also calculate the distance from the observed cloud of hydrogen to the Galactic Centre.

Investigating the structure of our Galaxy

It is not possible to see very far in the Galactic plane in the optical wavelength region. This is due to the large extinction caused by clouds of dust that are distributed among the stars in the galaxy. This interstellar medium is however quite transparent to radiation from the well known 21.1 cm line in atomic hydrogen. This radiation enables us to study the distribution of hydrogen in our Galaxy and thereby study the spiral structure – presupposing that the gaseous clouds are concentrated to the areas where we find the bright, massive stars, i. e. in the spiral arms.

Assuming a simple dynamic model of the galaxy (including that an individual star or gas cloud will move in a circular orbit around the Galactic Centre and that the tangential velocities in these orbits are roughly independent of the radius of the orbits) the distance of the cloud to the galactic centre can be calculated from the radial velocities [6]. Knowing the direction in which the measurement was made and the distance to the Galactic Centre a map of the hydrogen gas distribution can be plotted. This education project is described in more detail in [7].

The assumption of the tangential velocities being practically constant outside the central part of the galaxy has been experimentally verified for several galaxies, but is nevertheless quite surprising. The measured rotational velocities indicate the presence of matter in addition to the matter of the luminous stars. This unknown type of matter, the dark matter, seems to be a very important component of our Universe. We now approach the dynamic field of research concerning the evolution of the Universe and the Standard Model of Macrocosm, the Big Bang model.

The Science Laboratory

This project was conducted at the Science Laboratory [8] at Stockholm University, a laboratory devoted to teachers and students at school. It has become a platform for many projects in modern science [2, 7, 9, 10].

Summary

During the research project the students doing particle physics realised that they could determine some of the most fundamental quantities in the Standard Model of microcosm. The study of the Z^0 particle, both its production and decay, was a good way to introduce quarks and leptons as well as processes like the weak interaction. The determination of the strong coupling constant and the study of the produced quarks and gluons gave a good insight also in the strong interaction. The other group could draw conclusions about the structure and dynamics of our own galaxy, the Milky Way, by analysing radiation from a hyperfine transition in interstellar hydrogen clouds. With scientific data, the right tools and instructors the students could explore fundamental processes in Nature normally only accessible to scientists. We should profit from and promote this interest by making scientific outreach activities a natural component in our future scientific projects.

Acknowledgements

Many people from the astronomy department, the particle and astroparticle physics group and the Science Laboratory at Stockholm University have been involved in this project. We are also very grateful to the Swedish Foundation for Knowledge and Competence Development for their support of the Hands on CERN project and to the Knut and Alice Wallenberg Foundation for their support of the Science Laboratory, which has become an important platform for school projects and outreach activities in science.

References

1. Hands on CERN home page: http://hands-on-cern.physto.se
2. Hands on CERN - a Particle Physics Education Project utilising the Internet, K.E. Johansson and T.M. Malmgren, Physics Education 34/5(1999)286-293
3. DELPHI home page: http://www.cern.ch/Delphi/Welcome.html
4. CERN home page: http://www.cern.ch
5. See for example D. Morrison, S.Wolff and A.Fraknoi, Abell's Exploration of the Universe, 7th ed (Saunders College, Philadelphia, 1995) p. 120-122.
6. P. O Lindblad: Some Complements to Binney and Tremaine *Galactic Dynamics*, (Compendium, Stockholm Observatory, Saltsjöbaden, 1993) p.4.
7. Astronomy and particle physics research classes for secondary school students, K.E. Johansson, Ch. Nilsson, J. Engstedt and Aa. Sandqvist, American Journal of Physics. Vol. 69, No. 5, May 2001, p. 577
8. Stockholm Science Laboratory for Schools, K.E. Johansson and Ch. Nilsson, Physics Education 34/6(1999)345
9. Experiments in Modern Physics for the General Public, K.E.Johansson and Ch. Nilsson, Physics Education 35/4(2000)256

10. The physics of ‘Copenhagen’ for students and the General Public, L. Bergström, K.E. Johansson and Ch. Nilsson, Physics Education. Physics Education 36/5 (2001)388

Figures

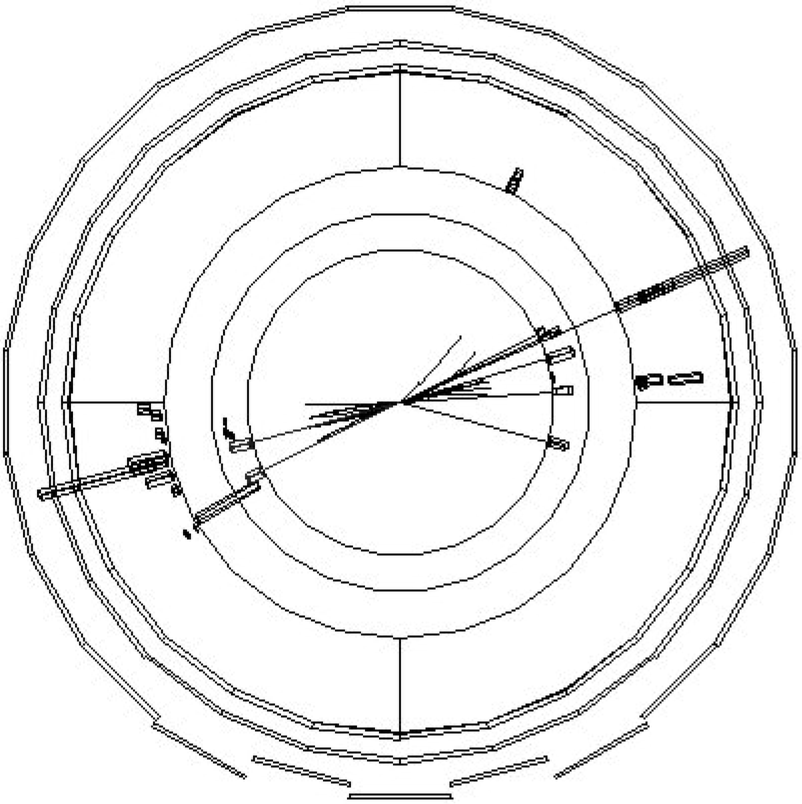

Fig. 1 The production of a Z^0 particle that decays into a pair of quarks (a quark and an antiquark).

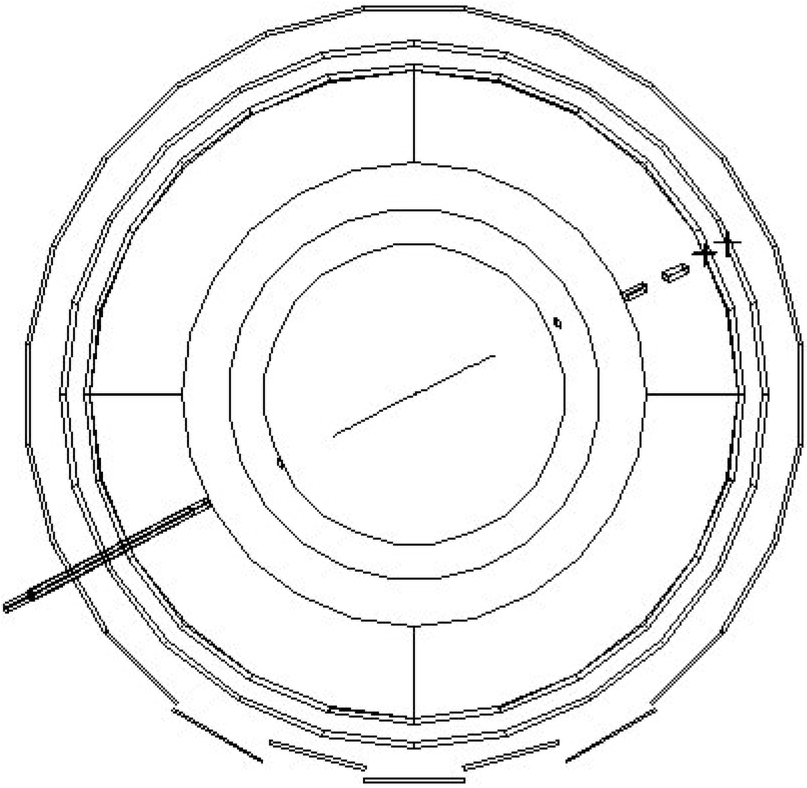

Fig. 2 The production of a Z^0 particle that decays into a pair of tau leptons, decaying into an electron and a muon (plus unseen neutrinos) respectively.

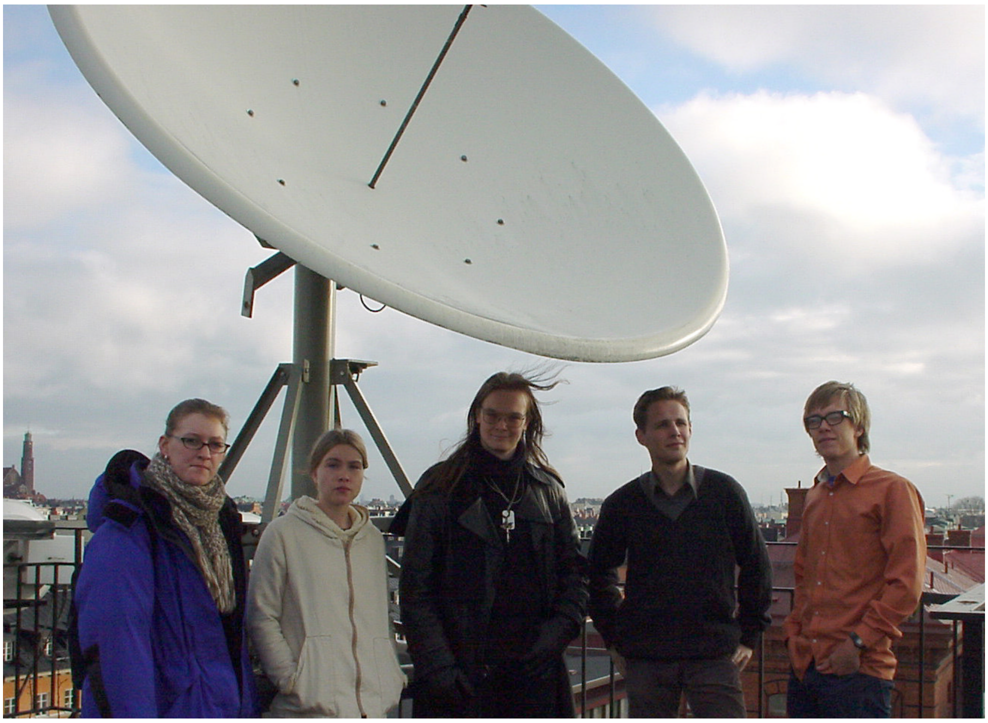

Fig. 3. Students in front of the parabola antenna on the roof of Fysikum at Stockholm University.