SOVIET PHYSICS USPEKHI VOLUME 8, NUMBER 4 JANUARY-FEBRUARY, 1966

539.12

ON DIRECTIONS OF THE DEVELOPMENT OF HIGH ENERGY PARTICLE PHYSICS

N. A. DOBROTIN

Usp. Fiz. Nauk 86, 725-728 (August, 1965)

MODERN science is characterized by a great reduction in the time that elapses between the discovery of a new phenomenon and its practical utilization. The nineteenth century distinction between pure and applied science is becoming increasingly arbitrary and illusory. At the same time, and in some contrast with this tendency, the physics of high-energy particles has developed very rapidly, accompanied by the construction of increasingly powerful and correspondingly more expensive accelerators. We have learned that the United States government intends to allot 400 million dollars annually to high-energy physics during the next few years. The program of work in this field has been discussed in the parliaments of different countries and by large classes of society as well as by scientists.

What has brought about this situation? At one time the experiments performed with accelerators were closely associated with nuclear physics and with atomic power. This is now past history. When high-energy particles are discussed it is sometimes stated that the discovery of antiparticles enables us in principle to utilize all the energy contained in matter. However, for the foreseeable future such utilization is possible only as a "scientific basis" of science fiction. At the present time there is not even the remotest prospect of such a development. Of course, many examples can be found in the history of science when what seemed to be the most abstract knowledge began to be of practical value within a short time. We cannot exclude the possibility that some entirely new discoveries in high-energy physics will change the entire situation radically. But we are not here concerned with such expectations. It is very clear that this field has become very important mainly because it is the experimental basis of the science of "elementary particles" and serves as the foundation for the entire colossal structure of natural science that is being built so very rapidly. The study of the fundamental laws of nature is very closely related to the study of "elementary particles" and to the problem of their structure.

When we survey the past development of high-energy physics we can easily distinguish two tendencies. On the one hand, whenever the investigations entered a still relatively unexplored region of higher energies, new facts of primary importance were discovered. In this way most of the elementary particles were discovered, many of their properties were determined (including the fundamentally new phenomenon of particle decay), multiple particle production in a single event was discovered etc. This line of development is mainly associated with cosmic rays.

On the other hand, equally important discoveries were often made at energies far below the maximum energies attainable for the purposes of detailed investigations in a given period. This resulted from new ideas and the of course very important utilization of new, improved, and precise methods and means of investigation. Examples are the discoveries of parity nonconservation, resonances etc. This line of development characterizes principally the investigations performed with accelerators.

In work with accelerators success depends to a considerable degree on the intensity and purity of separated particle beams, the utilization of large detectors (such as large liquid-hydrogen bubble chambers), and suitable electronics, in conjunction with automatic equipment and computers for treating the experimental data.

In our country the world's largest accelerator is now being constructed at Serpukhov, for the purpose of supplying 70-GeV protons. However, this is only twice the proton energy attained by the Brookhaven and CERN accelerators, while in the center-of-mass system the energy is increased only 50%. It is unlikely that this narrow energy interval will contain the threshold of some important new process that has not been observed in cosmic rays, such as the creation of W bosons or the so-called quarks.

From experiments using accelerators and especially from investigations of cosmic rays it is also clear that all characteristics of the interactions of nuclear-active particles (cross sections, the composition of secondary particles and their energy spectra, angular distributions, transverse momenta, inelasticity factors etc.) vary very slowly as the energy of the primary particle is changed. The situation with regard to the asymptotic values of the cross sections will not be essentially changed for the Serpukhov accelerator as compared with the accelerators already in existence. Therefore work with the Serpukhov accelerator will not automatically bring advances.

The possibility of discovering new important facts will depend considerably on the extent to which the intensity and purity of the different particle beams and the speed and precision of the apparatus exceed the capabilities of other contemporary accelerators, and on the new ideas underlying experimental work.

At the present time, both in the Soviet Union and abroad, a spirited discussion is in progress concerning the construction of a "new generation" of accelerators in the 200—300 GeV range and even up to 1000 GeV. This is a very complicated problem. On the one hand, the cost of such accelerators will certainly be extremely high. American scientists have estimated that the construction of a 400-GeV circular accelerator would cost about 300 million dollars. The apparatus required for the operation and utilization of accelerators is also very costly. On the other hand, advances in the development of new methods for investigating cosmic rays (the ionization calorimeter, large cloud chambers, large emulsion stacks, different kinds of spark chambers, experiments on artificial satellites) enable us, in the range of hundreds of GeV, to measure inelastic interaction cross sections to within a few percent and to determine reliably many of the most important characteristics of the interactions.

At the present time, at a high-altitude cosmic ray station in Tian-Shan new apparatus is being used for the first time to study nucleon-nucleon interactions at 300—500 GeV. This apparatus consists of a cloud chamber in a magnetic field in conjunction with a large ionization calorimeter. The investigated interactions occur in a lithium hydride target located above the cloud chamber. The cloud chamber photographs enable us to determine the number, emission angles, and momenta of secondary charged particles from interactions in the target. The ionization calorimeter is used to determine the total primary particle energy (with 10—20%) and the fraction of the energy that is transferred to neutral pions. Two large cloud chambers will later be added to the apparatus for the purpose of determining the nature of the secondary particles, and the number and emission angles of the neutral pions. More or less similar apparatus of even larger dimensions is now being used in Georgia. This kind of apparatus will enable us to determine reliably the distribution of interactions with respect to inelasticity factors, will elucidate the roles of central and peripheral interactions and the roles of fireballs, resonances, and isobars in creating secondary particles, will study the mechanism of fireball formation etc.

Cosmic ray experiments are also very promising in connection with the search for new particles having larger masses ($M > 3—4\ M_{\text{nucl}}$) than can be obtained with contemporary accelerators. Advances in elementary particle theory indicate that the existence of new classes of particles, such as quarks and W bosons, and including particles having large masses is a distinct possibility. The search for such particles among cosmic rays is becoming especially timely, and has already been begun in several laboratories.

At the present time the accuracy and reliability of data that can be obtained through cosmic ray investigations at hundreds of GeV depend essentially on the financing of the investigations, which are much less costly than the construction and utilization of corresponding accelerators. Professor L. Jones of the University of Michigan has designed apparatus costing ~ 20 million dollars for a high altitude station. He estimates that this apparatus will register about 2000 interactions per month in hydrogen at ~ 300 GeV. The primary particle momentum will be measured to within 1.5—2%; protons in the primary radiation will be practically entirely separated from pions. This apparatus (if it is actually constructed) will apparently give results approaching in accuracy those obtained with an accelerator operated in the same energy range.

Entirely new possibilities for the investigation of nuclear interactions in cosmic rays are opening up through the launching of space ships that are able to carry heavy complicated apparatus. We must remember that outside of the atmosphere cosmic rays are hundreds of times more intense than at sea level. Also, cosmic particles in space impinge singly on the apparatus, thus greatly facilitating their study.

Cosmic ray experiments no longer amount only to reconnaissance in a new, uninvestigated, region, and are beginning to give reliable quantitative information at hundreds of GeV. Much of this kind of information has already been obtained We therefore believe that the construction of proton accelerators in the range of hundreds of GeV is justified only if important experiments are proposed for which 70 GeV would be insufficient and which cannot be performed with cosmic rays.

A distinct property of cosmic rays is the rapid falling off of their energy spectrum. Therefore the transition from energies of about 300 GeV to 1000 GeV would be accompanied by a reduction of an entire order of magnitude in the experimental statistics. Consequently the experimental data that are being obtained and that can be obtained in the near future from cosmic ray studies above 1000 GeV are much more qualitative in character than at energies only a few times lower. We therefore consider the construction of accelerators reaching the very highest energies to be especially important and promising. It must be remembered that the cost of constructing very large accelerators increases more slowly than linearly with the energy of the accelerated particles.

When discussing the directions of investigations in high-energy physics the problem of muons cannot be neglected. As we know, only electromagnetic interactions of muons have thus far been observed. In the contemporary list of elementary particles the muon occupies essentially the same position as the electron, although the two particles differ in mass by a factor of more than two hundred. It is therefore of great importance to study very high-energy muons. In experiments on extensive air showers induced by primary particles having energies of 10^{14} eV and higher groups of muons have been discovered. Their origin has not been determined conclusively, but it is possible that several high-energy muons are produced directly in a single event or through the decay of some still unknown short-lived particles. Unfortunately, it is extremely difficult to study high-energy muons by means of accelerators, because even at 100 GeV the mean path before decay of a muon is ~5 km. Therefore muons having such energies can be studied practically only in cosmic rays.

Neutrino physics is an extremely promising and entirely new branch of high-energy physics. The very first stage of the investigations has led to the discovery that two types of neutrinos exist, which is a fact of the highest importance.

Experiments with neutrinos are, of course, extremely difficult and expensive. They are now being conducted on a large scale with the aid of the CERN and Brookhaven accelerators, which enable the study of interactions between neutrinos and matter at energies up to 10 GeV. Considering that the interaction cross section increases with the energy, experiments with cosmic ray neutrinos (produced in the atmosphere through π-μ decay) at still higher energies will be very important. In order to eliminate the background, cosmic ray neutrino experiments must be conducted at great depths in the earth with detectors having an area of hundreds of square meters. Such experiments have already been begun by several groups of physicists in the United States. It cannot be doubted that work in neutrino physics will develop rapidly on a continually increasing scale and that they will play a major part in solving the problem of weak interactions.

It can be seen from the foregoing that for the further successful development of high-energy physics we must not only use the already available methods of investigation, instruments, and apparatus, but we must also develop new ideas and directions of investigation, especially at the highest energies. Cosmic rays occupy an extremely important place among these new directions. Along with work using very high-energy accelerators, cosmic ray experimentation should be broadened much more than in the past.

Translated by I. Emin