Some Interesting Aspects of Particle Physics at Super High Energies

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(Z. Naturforschg. **21 a**, 1744—1747 [1966]; received 21 March 1966)

Dedicated to Professor Dr. W. GENTNER *on the occasion of his 60th birthday*

A brief account is given on some specific aspects of particle physics at super high energies which are of major importance to the understanding of nature of matter with the expectation that the related experiments can be carried out when these high energies become available. The discussions include 1) Asymptotic Behavior, 2) Dispersion Relations, 3) Broken Symmetry, 4) Heavy Triplets, and 5) Intermediate Bosons.

In the last few years, interest in particle physics at very high energies of the order of a few hundred BeV has become increasingly intensive. It is strongly believed by a vast majority of physicists concerned that by extending the frontier of high energy physics we will enter into a new realm of enlightenment. It is also believed that any progress in the techniques of super high energy research will be of the most profound value to science in general.

Since 1961, extensive studies [1] on the feasibility of a super high energy accelerator in the range of 300 – 1000 BeV as well as the desired physics programs have been carried out at many institutions in the world, notably Brookhaven National Laboratory, CERN, Lawrence Radiation Laboratory, etc. The general conclusions reached in these studies are that not only is it feasible to build a super high energy accelerator in the energy region up to 1000 BeV by using the present available techniques, but it is also possible to perform many basic and important experiments envisaged in these studies.

It would be of interest to present here some specific aspects of particle physics at super high energies which are of major importance to the understanding of the nature of matter with the expectation that the related experiments can be carried out when these high energies become available.

1. Asymptotic Behavior

Our present theoretical ideas concerning the dynamics of strong interactions indicate that the complicated behavior of elementary particles would become much simpler in the very high energy region which is called the asymptotic region. For example, the theorem of POMERANCHUK states that the total cross section of a particle becomes constant and equal to that of the corresponding antiparticle in the asymptotic region. As we can see from Fig. 1

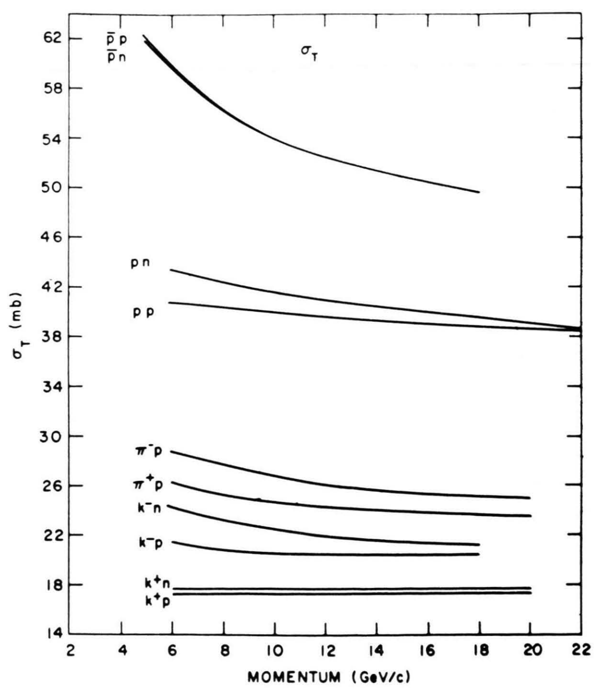

Fig. 1. Total cross section.

where the total cross section is plotted as a function of energy, while these cross sections do seem to become less irregular, they certainly do not yet satisfy the asymptotic or very high energy conditions of the POMERANCHUK theorem in the present energy

[1] Nature of Matter-Purposes of High Energy Physics, Edited by LUKE C. L. YUAN, 1965 (Clearing House for Federal Scientific and Technical Information, National Bureau of Standards. U.S. Department of Commerce, Springfield, Virginia, U.S.A.).

range. To establish firmly the existence of such an asymptotic region, much higher energies of the order of several hundred BeV would be needed.

2. Dispersion Relations

The existence of an asymptotic region as described above is also one of the bases of almost all the theoretical considerations of the so-called dispersion relations. The dispersion relations form one of the main theoretical approaches to the understanding of elementary particle physics; they are founded on some very general and deep principles. It is of major importance that the experimental test of the dispersion relations be extended to the very highest attainable energies since it involves the knowledge of the total cross sections at all energies.

Recent experiments on high energy elastic scattering at small angles performed at the Brookhaven AGS [2] provide results with high precision to allow a first check on some of the theoertical predictions of the dispersion relations at high energies. These experiments made successful use of new techniques developed at Brookhaven which consist of a system of arrays of several hundred scintillation counter elements (Fig. 2). The information from these counters is computed simultaneously by means of so-called on-line computer. The analyzed results are also displayed simultaneously for the immediate

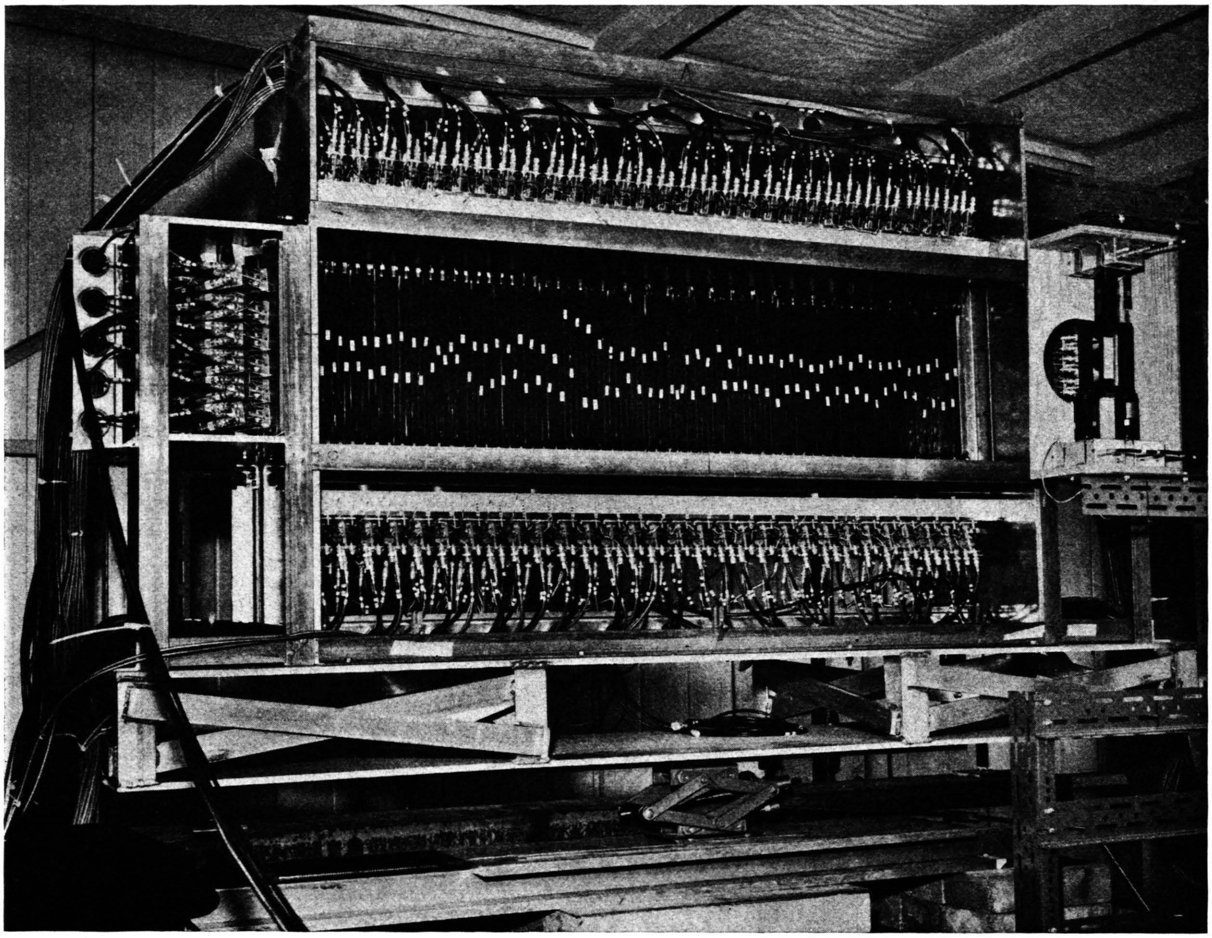

Fig. 2. Photograph of hodoscope.

[2] K. J. Foley, S. J. Lindenbaum, W. A. Love, S. Ozaki, J. J. Russell, and L. C. L. Yuan, Phys. Rev. Letters **10**, 376 [1963]; Nucl. Inst. Methods **27**, 82 [1964].

attention of the experimenters. Thanks to these new techniques, up to two orders of magnitude increase in data accumulation rate as well as high precision in measurement have been made possible. For example, a few days after using this system, one is already able to reach the important conclusion that while the radius of p-p interaction expands with increasing energy, the radius of π-p interaction is independent of energy. This contradicted the then-popular REGGE pole theory, which predicted an expansion of radius with increasing energy in all interactions. It is apparent that such techniques would provide an extremely powerful tool for extending the measurements to very high energies.

Thus, if energy of the order of several hundred BeV became available, the new experimental developments would enable us to perform accurate tests of the existence of an asymptotic region on the one hand, and the detailed predictions of the dispersion relations on the other hand.

3. Broken Symmetry

Another important recent discovery is the property of "broken symmetry", which means that particles of very different masses can have similar behavior. Since the mass differences which broke the symmetry are already of the order of several hundred MeV to 1 BeV, it would be most desirable to test further such symmetry properties with experiments in an energy region high enough so that such mass differences can be neglected. This means a laboratory total energy of a few hundred BeV.

4. Heavy Triplets

Another consequence of the broken symmetry theoretical considerations is the existence of many remarkably accurate mass formulae which are derived in the same spirit as the derivation of, say, the ZEEMAN splitting in atomic spectra. In these derivations, the mass differences between different particles which are of the order of several hundred MeV are regarded as small. When we look at the remarkable regularity of the mass spectrum of the strongly interacting particles, we are deeply impressed by its analogy with the atomic spectra. It would seem logical to think that perhaps all of these particles are not elementary but rather are composite states of some fundamental triplet (α) of much heavier mass. These are the recent speculations of GELL-MANN, and LEE [3] and others. The mass of these triplets was estimated to be of the order of 10 BeV.

According to the present theory, such triplets cannot be produced singly by the very strong symmetry conserving interaction, i. e.

$$\mathrm{p}+\mathrm{p} \not\leftrightarrow \begin{cases} \mathrm{p}+\mathrm{p}+\alpha+\text{pions (or kaons)} \\ \mathrm{p}+\mathrm{p}+\bar{\alpha}+\text{pions (or kaons)} \end{cases} \tag{1}$$

but they are produced in particle-antiparticle pairs such as in the reaction

$$\mathrm{p}+\mathrm{p} \rightleftharpoons \mathrm{p}+\mathrm{p}+\alpha+\bar{\alpha}+\text{pions (or kaons)}. \tag{2}$$

An important question is whether these heavy triplets are stable or meta-stable, i. e., whether the selection rule (1) holds not only for the symmetry conserving interactions but also for all interactions. If they have fractional charges then they must be stable. As analyzed by LEE, they may also be stable even if they have integer charges.

If they are stable, this would lead to some very interesting consequences; for instance: in such a case charged α can easily be stored in ordinary matter, and unlike p, the corresponding charged $\bar{\alpha}$ can also be easily stored separately.

Thus, if the α and $\bar{\alpha}$ are brought together they would annihilate in a reaction such as:

$$\alpha+\bar{\alpha} \rightleftarrows \mathrm{p}+\mathrm{p}+\text{very high energy release}.$$

The energy thus relased would be of the order of 20 BeV, which is about 1000 times more energy release than the corresponding H $\rightarrow$ He reactions which are taking place continuously in the sun, providing its enormous energy.

Assuming the mass of the triplets to be 10 BeV, the energy required to produce such a pair would correspond to a laboratory energy of approximately 210 BeV.

Searches have already begun for the triplets at Brookhaven in case their masses are much lower than expected theoretically. Although there is no positive result as yet, probably because of the low available energy, the techniques developed for searching for these heavy particles proved to be very sensitive and it would be simple to detect them if they are present.

[3] M. GELL-MANN, Phys. Letters **8**, 214 [1964]. — F. GÜRSEY, T. D. LEE, and M. NAUENBERG, Phys. Rev. **135**, B 467 [1964].

5. Intermediate Boson

It has also been speculated that all weak interactions are transmitted by a carrier called the intermediate boson which is similar to the role played by photon for the electromagnetic interaction. From the experimental conclusions obtained in recent experiments both at Brookhaven and at CERN, the mass of this intermediate boson is probably much higher than can be investigated with presently available machine energies. Thus a much higher energy proton machine in the several hundred BeV range appears to be necessary in order to make any extensive investigation of weak interactions.

Conclusions

The topics mentioned above are only some of the interesting aspects of particle physics at super high energies, and the experiments cited are also a few typical examples of those that become possible at these energies. A more detailed discussion of this question can be found in the papers mentioned in Ref. 1.

In conlcusion, the author wishes to emphasize that the experiments stated above are not only important in testing current theoretical ideas concerning particle physics, but are also crucial in uncovering the underlying mechanism of our physical world.