FASCINATION OF THE MUON

The Muon is the Cinderella of the world of particles. It is a most natural and attractive thing which promises to be the most mysterious of them all. We do not know whence it came but we do know that it is there and that we shall not be satisfied until we know the Muon intimately.

In many ways the muon is just a heavy electron. It has the same charge as the electron, it has the same spin as the electron; and, as far as we know, it has the same electromagnetic, weak and strong interactions as the electron. It is true that in the study of the weak interactions of the muon we did get surprised by the discovery of the second neutrino; but, then, it has been the study of the muon's weak interactions that led to the discovery of the theory of the Universal Law of Chiral V-A Weak Interactions.

As far as we know the muon is a heavy lepton with properties which are equivalent if not identical with the electron. It seems to have no strong interactions at all. Its electromagnetic interaction is that of a simple Dirac particle with unit charge. It has a lepton number very analogous to the lepton number of the electron. Its intrinsic parity is as ambigous as that of the electron since its single creation or

destruction is via the chiral V-A interaction only. Yet the muon is heavy, with a mass more appropriate to a hadron than a lepton. What is the source of its mass? If the muon's mass is purely mechanical and arbitrary, what of our numerous hopeful theories of the "elementary" particle spectrum?

But then we ask ourselves: Why should the muon not have a large mass? Is there anything in the theory of weak and electromagnetic interactions that says that the muon should not develop a large mass by virtue of interactions?

Pressed for an answer, we must admit we do not yet have a consistent quantum field theory which could adequately deal with this question. Quantum field theory as formulated for quantum electrodynamics of spin ½ particles cannot be handled in a manner which is neither inconsistent (in the sense that physical quantities are predicted to take on divergent meaningless values), nor so obscurely formulated that these questions cannot be asked. We note that this difficulty is not typically a quantum field theory malady: the Lorentz electron could not be prevented from exploding if no non-electromagnetic forces were holding the electron together. We simply have not bothered to solve this problem and the problem does not seem to go away by simply being ignored. It has stayed with us all along. The puzzle of the muon mass

calls our attention to this question again.

Leptons do provide a peephole into the world of elementary particles. We must therefore take the theory of leptons and their interactions seriously. If we believe that quantum theory of fields is the proper language for our description of particles and their interactions we must formulate and proceed to solve the quantum field theory of leptons and their interactions.

For the past decade I have been pursuing such a program (Theory of Leptons, I; Nuovo Cimento 21, pp. 7-28, (1961); Finite Quantum Electrodynamics: A Field Theory Using an Indefinite Metric; Phys. Rev. 137, 1085-1104, (1965); Indefinite Metric and Nonlocal Field Theories, "Proceedings of the Fourteenth Solvay Converence", Brussels, Belgium, 1967, page 97, (1967); Physics of Complex Mass Particles, "Proceedings of the Coral Gables Conference on Fundamental Interactions at High Energy II", Gordon and Breach Publishers, New York, 1970. Action-at-a-Distance, Fields and Quanta, Vol.2, Number 3 (Feb. 1972); Leptonic Resonances, These proceedings.) The general idea is to observe that as long as only local interactions of quantized fields is considered, the conventionally formulated theory gives unsatisfactory divergences. Hence we should proceed to generalize the notion of quantum field theory to a theory

of linear operators in a vector space with indefinite metric. The probability interpretation of quantum mechanics now demands that these should be a subset of the vectors of this vector space which is the physical sector. We must then assure ourselves that the theory contains an automatic assurance that the transition amplitudes restricted to the physical sector satisfies the requirements of unitarity i.e., probability is conserved. It has been a satisfying feature of this line of theoretical development that the formalism of shadow states provides precisely such a framework (see also, C. A. Nelson and E. C. G. Sudarshan: Quantum Field Theory with Shadow States I & II; submitted to Phys. Rev.). This program has now been taken up many other authors including, in particular, T. D. Lee who has rigorously pursued some of the relevant subsidiary questions.

One of the immediate predictions of this new theory of leptons is that there should be leptonic resonances (see the short article "Leptonic Resonances" in these Proceedings). These may be very narrow or may have a sizable width. Some of them at least should have the phase shift rotating the "wrong way" since they correspond to poles on the physical sheet of the scattering amplitude. If this resonant behavior is not found then we will be forced to reexamine our notions

of relativistic field theory and the assumptions that particle interactions are really field interactions.

Muons are a fascinating topic. They appear to be sluggish electrons but they hold the key to our understanding of the world of particle interactions. He who understands the nature and the role of the muon would take us a long way in our understanding of particle physics.