THE PRESENT POSITION AND FUTURE PROSPECTS FOR THE DISCOVERY OF NEW PARTICLES

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Introduction

We seem to live in a period when it appears that physics would, somehow, be simplified or at least enriched, if certain particles, now living only spiritually, in our vocabularies or imaginations, were to reveal a corporal existence. Man, in the role of physicist, seems to be sufficiently ingenious (or ingenuous) to construct a rather full pantheon of these half-mystic particles. In general, it is as impractical to attempt to discuss all experiments which bear on all possible particles of this kind as it is to conduct the experiments which would reveal all possible particles. I shall then concentrate on discussions of the more important of these conjectural particles, quarks, magnetic monopoles, the intermediate vector boson or W, and those heavy leptons which are supposed to be brothers to the electron and muon. Aside from any intrinsic virtues, these listed particles, real or imaginary, are important at this time from their popularity as subjects of inquiry alone: there are 23 proposals to the American National Accelerator facility for searches for these particles.

Aside from the fact that we have not demonstrated that any of these particles really exist, there is little that they are supposed to have in common and then little cement to bind together discussions of the searches for the various particles. In my discussions, however, I will attempt to emphasize the particular importance of those experimental results which have a broad negative value inasmuch as they establish regions of particle parameters (typically mass) which are excluded by the experimental results. It is in this sense, that the searches for the W-bosons using neutrino beams have an important negative value inasmuch as the results of the measurements tell us that no W with a mass less than 2 GeV/c^2 exists. On the other hand, because of the complexities involved in understanding the strong interactions of quarks and monopoles, and in spite of elegant and ingenious searches, it is difficult to make a statement concerning the existence of these particles which is stronger than the simple conclusion that quarks and monopoles have not been found.

Quarks

It is only proper to introduce a discussion of the quark, the most literary and humanistic of these particles, with a section from a learned discourse[1] by Professor Denys Wilkinson of Oxford, the well known ornithologist, student of Middle English and sometime physicist, concerning his inquiry into the historic origins of the concepts of quark and parton. Professor Wilkinson finds in the 14th century writings of John Wyclif (also an Oxford man) the statement which I submit below in the Middle English together with a translation for which I must take some responsibility:

> "For soth it is: that alle þese partyes ben contenyd in thre. And eche on of
> þese thre partyes contenys many partyclys. But we schul wele wyte: that
> þese thre thyngys ben wel sotel and diuers."
>
> J. Wyclif, The Lay Folks' Catechism

"Indeed, it is such that all of these parts are made out of three, and each of these three parts contains many particles. But we should certainly note that the three things be subtle (minute) and diverse."

Professor Wilkinson points out that Wyclif indicates clearly that he is writing an expository document considering matters which are well known and that the true origins of these ideas must lie further in the past and not necessarily in England. In view of the importance of this vein of inquiry I hope that those of our Russian colleagues who read Old Church Slavonic manuscripts for recreation, will note if there are similar references in those old writings and then if these concepts of quarks and partons, so wide-spread in the 20th century, were equally universal before the 14th century.

Even if we are to accept the view that the concept of a quark has always been with us, however obscured, I suppose that we can presume safely that the relevant experimental limits placed on the production of these particles is relatively modern. These limits are derived from accelerator experiments and from cosmic ray experiments. The accelerator experiments, typically, actually measure, or better put limits on, values of $d\sigma/dp\ d\Omega$ and then estimate the relevant value of σ, the quark total production cross section, from rather arbitrary models of quark production. While there is, necessarily, some uncertainty in the values of σ so calculated, it seems safe to summarize the results as indicating that quarks with charges of e/3 or 2e/3 are not produced by nucleon-nucleon interactions at laboratory energies[2] below 70 GeV with a cross section greater than $10^{-36}\,cm^2$. This cross section limit is relevant to the production of quarks with masses less than 5 GeV which is near the kinematic limit for pair production by nucleon-nucleon interactions at 70 GeV.

Most of these experiments, as well as most cosmic ray experiments have been designed to identify quarks through their anomalous ionization or energy loss which will be proportional to the square of their charge. Some measurements at accelerators have been designed so as to identify the particles through their possible large mass and, then, low velocity.[3] Cosmic ray experiments have also been conducted which measured the mass of the particles directly by measuring velocity and momentum.[4, 5] An interesting class of measurements of fluxes of particles which lag behind shower fronts[6] have also placed limits upon the production of quarks or triplets with normal charge assignments which might have large masses and then subrelativistic velocities upon production by the interactions of very high energy components of the primary cosmic ray flux with atmospheric nucleons.

None of these experiments, analyzing fluxes from either accelerators or cosmic rays, has led to any reliable positive evidence for the existence of quarks. The few premature indications of a positive nature were quickly disposed of. Of course, the cosmic ray results do extend the searches to larger values of mass, even as the cosmic ray flux extends, albeit with small fluxes, to extremely high energies. Curiously enough, the interpretation of the cosmic ray results in terms of a total cross section for the production of quarks is, in some sense, more straight forward than the similar analysis required in accelerator experiments. In the absence of an anomalously large quark-nucleon interaction cross section, it appears, that for heavy quarks with masses greater than that accessible to the accelerators, essentially all quarks produced in high energy interactions will reach sea level traveling at relativistic velocities. Then a detector, sensitive to relativistic quarks, with an acceptance of S cm^2 sr, will detect all quarks produced by a flux of primary nucleons incident upon such an area-angular acceptance region at the top of the atmosphere. With a well defined correction, of the order of 2, for the probability that a high energy nucleon will make more than one effective collision, the cross section is simply the total absorption cross section taken usually as $30 \cdot 10^{-27}$ cm^2 divided by the number of primary nucleons passing through the effective acceptance area and time interval covered by the measurement. A summary of all measurements to date, suggests that no quarks have been produced in about $2 \cdot 10^6$ nucleon-nucleon interactions where the incident nucleon had an energy greater than 1200 GeV, the energy which corresponds to the energy easily available for quark experiments at the CERN ISR. The relevant cross section limit is then about $1.5 \cdot 10^{-32}$ cm^2.

At the present time, the measurements at the ISR[7], made with a number of telescopes at different angles designed to detect particles with an ionization loss in matter (usually scintillator) which was 1/9 or 4/9 that of a singly charged particle moving with relativistic velocities, have detected no such anomalously charged particles in a total flux of $6 \cdot 10^8$ normal particles. Given a mean multiplicity of the order of 10 charged particles per interaction and a total inelastic cross section of about 30 mb, we can immediately estimate a limit on the cross section for the production of quarks as about $(30 \cdot 10^{-27}) \cdot 10/(6 \cdot 10^8) = 5 \cdot 10^{-34}$ cm^2: This experiment is about 30 times as sensitive as the cosmic ray measurements.

A more careful analysis of their measurements, considering the precise position of their telescopes, allows the CERN group to derive two different cross sections for two different, perhaps extreme, assumptions concerning the angular distributions. They assume on one hand that the transverse momentum distribution of the quarks is very much the same as measured for less exotic particles, the mean transverse momentum is about 400 MeV/c, and the quarks are concentrated then in the forward direction. With this assumption, they find values of cross section vs mass as shown by the lower curves on Fig. 1. Then they make a similar calculation assuming that the quarks are produced isotropically and using this model they deduce the cross section limits shown on the upper curves of Fig. 1.

It seems likely that massive quarks will be produced (either in pairs or triplets) with rather larger mean momenta than lighter particles but not in so singular a production so that isotropy results. We might estimate the mean momentum by considering that large momenta for strongly interacting particles can be considered to be precluded inasmuch as production is damped by the production of field particles. Assuming that the pion is the lightest field particle coupled to the quark, we cannot expect much damping until quarks are produced with a kinetic energy equal to the pion mass and then a momenta of about $p = \sqrt{2 M_q m_\pi}$, which will be of the order of 1.7 GeV/c for a quark with a mass $M_q = 10$ GeV/c^2. Using such a guess, we might presume that a most reasonable value for the cross section limit will be about half way between the extreme limits of Fig. 1 and about an order of magnitude less than their estimate of the limits from the cosmic ray experiments.

These ISR results follow from preliminary measurements and the experimenters believe that they can extend the limits about one more order of magnitude.

With the larger effective fluxes which should be available at N.A.L. in the near future, it should be possible to make measurements about two orders of magnitude more sensitive than at the ISR but the mass limit will be appreciably more restricted. At 200 GeV beam energy, quark masses of up to 10 GeV/c^2 should be accessible, at beam energies of 400 GeV, searches can be extended to values of M_q near 15 GeV/c^2.

Because of the strong interactions of quarks and, then, their unknown form factors, no one has any great confidence in his ability to predict the cross sections for the production of quarks of a given mass and none of these experiments has any very substantial negative value. On one extreme, calculations made on the basis of the postulated existence of a thermodynamic equilibrium among created particles at high energies find factors in their calculation of cross sections of the form exp $(-2M_q/kT)$, where kT is of the order of 160 MeV. Then for large masses, the cross section for quark production is far below that which could be reached by any possible cosmic ray or accelerator measurement. On the other hand, if we expect that quarks should actually be produced by mechanisms which can be described by a kind of impulse approximation, we might well expect that the production cross section is rather large, perhaps something like the square of the compton wave length of the particle, and then we would have to conclude that we do not see quarks because of their very large mass. All of this leaves us with the rather empty conclusion that, if physical quarks exist at all, they are either very massive (e.g. $M_q \gg 20$ GeV/c^2) or they are produced with very small cross sections.

If the production cross sections are indeed extremely small, we might still hope to see quarks as they might be found in macroscopic matter. It is well known by gold miners, that geological (and biological) processes have existed which have enormously concentrated intrinsically rare minerals or elements. Surely quark atom chemistry must be special and we can hope that some processes may have acted to concentrate quarks somehow and then that this concentration together with the sensitive techniques which are being developed may allow us to find quarks even though they are exceedingly rare.

Heavy Leptons

The term "heavy lepton" has been used to cover a variety of conceptions but we will consider here a specific conjecture, the hypothesis that two (the electron and the muon) is most unlikely to be God's choice of the number of leptons. This number was used in biology, of course, with no end of trouble. We then consider the possibility that the electron and muon -- and their accompanying neutrinos -- have some, or a host, of siblings. These new particles are then identical to the electron and muon except for their mass as far as measurements at moderate energies are concerned. Any new lepton, by this definition, will couple to electrons and to hadrons in precisely the same manner as the muon, and will couple to muons as to electrons.

Since the coupling of the heavy lepton with nature takes place largely through its electric charge, we can calculate the electromagnetic production of heavy leptons with the same kind of precision that obtains for other electromagnetic processes. For large invariant masses, the production of heavy lepton pairs will be the same as the production of muon pairs or electron-positron pairs.

If the heavy lepton mass is not too large, the character of the decays of the particles is almost as well defined. Since the weak coupling is known precisely, we can calculate the transition rate for the decay of a heavy lepton to an electron and two neutrinos or to a muon and two neutrinos very easily. The calculation of the transition rate for the decay to a pion and neutrino (corresponding to the decay of a pion to a neutrino and lepton) is, again, trivial and the transition rate for the decay to two pions and a neutrino can be deduced reliably since the uncertain effects of the strong interactions between the two pions will not be important in the long wavelength (or low lepton mass) limit, a conclusion[8] which follows from the conservation of the hadron vector current (CVC) and the knowledge of the form factors from measurements of the production of two pions by colliding electron-positron beams. Of course, for very high masses, the transition rate to states with many hadrons is uncertain but it seems possible that the increase in phase space which follows from the opening of so many hadron channels is largely compensated by small form factors and that the total transition rate to hadrons may not increase with lepton mass any faster than the transition rate to the lepton modes. To the extent that this is true, and the approximations are almost certainly nearly valid for heavy lepton masses not greatly in excess of one GeV/c^2, the lifetime and the branching ratios to the various final states can be considered to be known for our hypothetical heavy leptons. With both the production and decay mechanisms well known, it then becomes possible to design experiments which will certainly result in the detection of heavy leptons if they exist with masses in the range accessible to the experiment. In the course of such experiments at the intersecting electron-positron ring at Frascatti, a group working there has shown[9] that leptons, defined according to our prescriptions, do not exist with a mass less than 700 MeV/c^2. Now this group has extended their searches, again with negative results, and now they can establish a mass limit of 900 MeV/c^2. Eventually they hope to increase their sensitivity so that they might be sensitive to the decays of such leptons with masses as great as 1100 MeV/c^2.

The cross section for the production of heavy lepton pairs from the annihilation of electrons and positrons does not decrease dramatically with increasing energy of the intersecting beams and it seems likely that measurements at the higher energy positron-electron storage rings can extend the searches for heavy leptons to masses of several GeV/c^2 in the near future. At such high masses, the theoretical calculations of branching ratios will not be so reliable, but good experiments should still result in a credible negative results if, indeed, such particles do not exist in this mass range.

Of course, there is the possibility that heavy particles exist which may hold an electromagnetic charge but will not decay very quickly to lighter particles. Perhaps there exists a class of particles which couple to a weak interaction field (and might, therefore, be called leptons) but have a symmetry of some kind which precludes or strongly inhibits their decays to lighter leptons and hadrons. These particles might then have a lifetime which is long compared to travel-times to typical detectors and can be considered then very much as stable particles. Since the electromagnetic coupling is known, and since only the weak coupling to other states is also important, we know that the particle can be considered as a point particle as far as the electromagnetic form factor is concerned: the production of these particles by electromagnetic interactions is then well defined. In such cases, if appropriate detection schemes can be constructed, unsuccessful searches can, again, have a negative value: again, it is possible to construct experiments such that a negative result proves the absence of a class of particle.

A particularly well defined inquiry into the possibility of the existence of such charged, weakly interacting, long lived particles was made by a group[10] working at Serpukhov. They looked at long lived charged particles produced by interactions of the 70 GeV proton beam with an aluminum target. The particles were determined to be weakly interacting by requiring that they pass through a 400 gm/cm^2 absorber without interacting strongly and they were required to have a mass much greater than a muon mass by measurements of their velocity with a Cerenkov counter.

The production cross section was derived, implicitly, from an estimate of the production cross section for muon pairs of large invariant mass. Aside from some well defined correction terms, which are functions of the particle mass, for invariant masses which are large compared to the rest masses of a pair of particles, the production of pairs of heavy leptons should be the same as the production of muon pairs. Although the production of such muon pairs has not yet been measured at 70 GeV, this group felt that they could adequately estimate this production by making an extrapolation of appropriate Brookhaven measurements of muon pair production at 30 GeV using plausible scaling arguments. Since their limits on the cross sections for heavy lepton production fell below these estimates of the production of large invariant mass muon pairs, they concluded that particles of the character they were able to detect did not exist. Specifically, they concluded that their negative results indicated that no such heavy, charged, weakly interacting particles exist with masses between 1 GeV/c^2 and 5 GeV/c^2 with a lifetime greater than 10^{-8} seconds.

W - Production

Like the quark, the intermediate vector boson, which is supposed to mediate the weak interactions, has assumed a reality of a kind solely by weight of conjecture. Since this particle, labeled the W, has no strong interactions, it is possible to calculate the production cross section by the interaction of neutrinos with nucleons with a considerable degree of reliability. From the negative results of the production of the W by high energy neutrinos, we can state that the W does not exist with a mass less than 2 GeV/c^2. In general, the production of the W by neutrino beams is so well defined and so well encompassed by experimental and theoretical studies of neutrino interactions, that it seems best to leave the detailed discussions of the status and prospects for this kind of search to those who are to consider the weak interactions at this conference. We will then discuss only the more exotic measurements of W production in hadron-hadron interactions.

Like such weakly interacting particles as the heavy leptons, the cross sections for the electromagnetic production of W pairs can be derived uniquely. It is then possible to construct experiments, using real or virtual photons, where the production of the W can be predicted for any given W mass. For hadron-hadron interactions, it is generally impossible to calculate the flux of virtual photons with large invariant mass from first principles, but such fluxes can be measured by determining the production cross section for muon pairs with large invariant masses.

If the W is quite massive, it is attractive, however, to look for the production of single muons through the weak interactions. For massive Ws, the threshold will be lower for this mode of production and for a given hadron beam energy, heavier Ws can then be produced through the weak interaction coupling of a single W to the hadron current than through the coupling of W pairs to the hadron current through electromagnetic couplings. As with the electromagnetic couplings, it is possible to make quite reasonable estimates of the production of single Ws through the weak interaction by using other experimental information. While direct calculations of W production have been attempted, there are too many different results to encourage one to have confidence in any. However, the very close relation between the coupling of the W to the hadron current and the coupling of the photon to the same current, suggests that there will be a similarly close relation between the production of muon pairs of a given invariant mass (and then the flux of virtual photons of that mass) and the production of Ws with the same mass. This is indeed the case[11] and, for the rather poor effective W mass resolution which one might expect from most experiments, the flux of muons from W-decays will be of the same magnitude as the flux from the production of muon pairs of similar invariant mass. Conversely, if no muons derived from pair production are detected, it is unlikely that the experiment could be sensitive to muons from W-decays. There are some uncertainties in these calculations. In particular, as with the consideration of the decays of heavy leptons, it is quite easy to calculate the transition rates for W decay to lepton states but the transition rates to hadron states are uncertain and then the branching ratio for decays to the rather distinctive lepton states must be equally uncertain. Again, there is a body of opinion to the effect that the small form factors for decay to hadron states will approximately compensate for the large phase space which follows from the large number of open channels and then the branching ratio for W decays to leptons will not vary strongly with the W mass and will always be substantial.

The procedures used to detect the production of Ws in hadron interactions varies but usually depends upon one or more of three factors; a) the decay of a massive W will result in leptons -- and perhaps hadrons--

with large transverse momenta, b) the muons which result from such a decay will have the longitudinal polarization to be expected from allowed leptonic decays in contradistinction to muons from meson decays, which will have the opposite polarization, and to muons produced in pairs through electromagnetic processes, which will have no longitudinal polarization, and c) the muons from W-decay, unlike the muons from meson decay, are produced promptly at the point of the hadron interaction and the production is then independent of the density of the target while the muon flux from meson decays will vary inversely with the target density even as the competing absorption of the mesons through interaction is proportional to the target density. These three conditions also follow from the production and decay of heavy leptons.

The diagram of Fig. 2a suggests the character of the variation of such flux with target density. The intercept at the extrapolated position of infinite target density, corresponds to the intensity of prompt muon production -- that is the intensity of muons from the production of pairs through electromagnetic processes, from the production of muons through the decays of heavy leptons and from the decays of Ws. The character of these prompt muons can be determined by a measurement of their longitudinal polarization (again by extrapolation): if any longitudinal polarization is detected in the opposite direction to that expected from meson decays, one could presume some contribution from W-decay, or perhaps from the decay of heavy leptons.

The experiments of this character which have been conducted at the lower energy accelerators have neither indicated the presence of a W nor have they been sufficiently sensitive to place any very stringent limits on the mass of the W. Perhaps, new measurements planned at N.A.L. and underway at the ISR at CERN may produce more definitive results. We might expect reasonable sensitivity to the existence of Ws with masses as great as 10 GeV for the NAL experiments. The ISR experiments may extend to higher masses but the smaller effective luminosity at the ISR may make it impossible to reach the requisite sensitivity.

At any rate no experiments contemplated at present accelerators will be sensitive to Ws which are coupled to lepton currents with the same strength as the photon is coupled to charge, a conjecture which is very popular today. The mass of such Ws must be of the order of 50 GeV (where the particular mass depends upon the exact formulation of the theory). However, cosmic ray measurements on muon flux extend, albeit with low counting rates, to muons produced by hadron interactions at very high energies, energies sufficient to produce W particles of very high mass.

The detection of a component of this flux which might derive from the decay of Ws follows from a method similar to that used for the machine experiments. The intensity of muons of very high energy is measured as a function of sec θ, where θ is the angle of incidence of the muon with respect to the vertical. It is possible to show that the effective density of the atmosphere is inversely proportional to sec θ (i.e. the atmospheric density decreases exponentially with distance from the earth's surface where the scale factor is inversely proportional to sec θ). At very high energies, where the decay probability of a meson is small compared with the interaction probability, the probability of decay is inversely proportional to the density of the atmosphere and then proportional to sec θ. When the intensity, plotted as a function of sec θ, is extrapolated to sec $\theta = 0$, which corresponds to an infinitely dense atmosphere, we should expect that intercept to correspond to the intensity of promptly produced muons, muons produced through electromagnetic processes and the decays of Ws and heavy leptons. The diagram of Fig. 2b suggests something of the character expected of such measurements if there were a substantial production of prompt muons.

Some early measurements by the Utah group[12] suggested that there was indeed a substantial flux of such prompt muons at energies consistent with a mass of the W of near 50 GeV. The production cross sections derived from this intensity were very large (the order of 0.1 millibarn), however, and inconsistent with any conventional model of W production. However, the Utah group[13] has now largely withdrawn their results noting that certain instrumental problems complicated their own measurements and other difficulties attended those measurements (of the depth intensity curve for muons underground) of others which were used with the Utah measurements to give precise measures of the anomalous intensity.

Magnetic Monopoles

The concept of magnetic monopole was probably first attractive to physicists inasmuch as the existence of such a charge would symmetrize the form of Maxwell's equations. Dirac then showed that the magnetic monopole must have a charge g such that $eg = n/2$, $n = 1, 2, \ldots$, where e is the electric charge in natural units, or measurements could be made which would violate the uncertainty principle. Schwinger later refined the argument to show that $n = 2, 4, \ldots$. This quantization condition of Dirac, made monopoles more attractive aesthetically inasmuch as their existence would now demand the quantization of electric charge, a property not otherwise understood in any way. However, the universe was then clearly not symmetric with respect to electric and magnetic charge as the smallest possible magnetic charge must be 137 times the electric charge. Furthermore, it was easy to see that any universe which contained both electric charges and magnetic poles could not be invariant with respect to CP. The discovery that the universe was, indeed, not invariant with respect to CP then added to the attractiveness of the concept of magnetic charge.

Even as particles with an electric charge have, invariably, other couplings, weak or strong, we can presume that particles carrying a magnetic charge may well carry electric charge or strong or weak couplings. However, the magnetic charge will be so great that the production of pairs of these particles and their subsequent interaction with each other and with other matter, is likely to be dominated by the interaction with their magnetic charge.

Unlike particles coupled primarily through electric charge, we cannot very well calculate production cross sections for monopoles. The magnetic charge is so strong that the perturbation techniques used so successfully to calculate the effects of charges in quantum electrodynamics are completely inadequate to consider effects of poles. Therefore, it does not seem to be possible to construct experiments designed to detect magnetic monopoles where the results can have any very strong negative meaning: We do not now know how to prove that magnetic monopoles of a given mass do not exist. We can only establish limits for the production cross section for various monopole masses.

It seems likely that the mass of a particle carrying a magnetic charge will be quite large even as the energy stored in the magnetic field derived from the charge will be large even at considerable distances from the charge. The energy stored outside of a sphere about the charge, where the radius is the classical radius of the electron, will be about equal to $(137)^2 m_e$ or about 10 GeV if the charge is the smallest allowed by the Dirac-Schwinger condition. Pairs of particles with so large a mass cannot be made by the accelerators in existence a few years ago so the more important searches for monopoles were made by considering the production by the primary cosmic radiation. The most sensitive of these measurements were made by examining the induced voltage in a superconducting loop when material which had been subjected to a long bombardment by cosmic rays was passed through the hoop.[14] Such measurements, usin; material from meteorites and the moon, placed limits of about $10^{-41}E_t^2$ cm^2 on the production cross section where E_t is an effective energy threshold which must vary with the mass of the monopole and depends somewhat on the production characteristics. The energetic threshold for the production of pairs of monopoles of mass M by nucleon-nucleon interaction is: $E_t = 2M^2/M_p$, where M_p is the proton mass. Measurements which are only a little less sensitive have been made by searching for tracks left in naturally occurring solid state detectors[15] such as mica or obsidian.

If the mass of the monopole is as small as 5 GeV/c^2, the present accelerators may be sources of monopoles. An experiment at Serpukhov using a ferromagnetic trap for monopoles which are later extracted by a pulsed 300 k gauss magnet place a limit of $1.4\cdot 10^{-43}$cm^2 on monopole production while an experiment designed to detect the monopoles by detecting their Cerenkov radiation in flight was somewhat less sensitive.

A number of experiments to detect monopoles at NAL have been proposed. In particular, conventional experiments (a conventional experiment is a very ingenious, very unusual experiment where the design is two years old) constructed to detect the existence of free monopoles using the methods introduced in the cosmic ray studies are expected to detect monopoles made with a cross section of the order of 10^{-42}cm^2.

The searches for monopoles which have been made and which we have considered here all concern free monopoles. However, the coupling of monopoles with the magnetic field is so great that doubts have been raised as to whether free magnetic poles can ever be produced.[16] The radiation produced by the acceleration of the poles, which follows from the very strong forces between them, may well reduce the total energy of the pair below the rest mass of a pair of free poles. These bound poles will then continue to radiate until they annihilate in some manner. Since the binding energies of pairs of monopoles is so great, it is also possible that the monopole pairs will often be produced in a positronium-like bound state. In either case, one might expect a shower of gamma rays which do not have very high energies in the monopole rest frame. One consequence of these interesting ideas is a number of proposals to search for gamma ray showers derived from high energy interactions at NAL and at the CERN ISR.

Conclusions and Prophecies

At this time we can consider the meaning of our negative searches. We have not found quarks. Perhaps they do not exist. However, the successful application of scaling to parton (quark?) scattering suggests to the believer that quarks must have very large masses and we have not yet mounted very sensitive searches for quarks with masses greater than 20 GeV/c^2. We have not found Ws. But the interesting new models of the weak interactions predict W masses of the order of 50 GeV/c^2 and we have not penetrated that area. We have not found heavy leptons. But the very great ratio between the electron and muon mass does not make us confident that the ratio of the mass of next lepton to the mass of muon is small and we have only looked carefully at such small masses. We have not found the monopole. But the monopole may be very difficult to separate from its conjugate twin and we may have to search for radiative transitions of the pair states.

We can then anticipate that our ever optimistic faith that the universe is simple and that these simplicities are to be revealed to us will continue to drive us to further searches. This drive is part of our character as the young lady knew who ordered 17 yards of material in a dry goods store to make a nightgown. When the clerk questioned the need for quite so much material, the girl explained that she was getting married, her fiance was a scientist, and that she knew that for a scientist the search was more important than the discovery.

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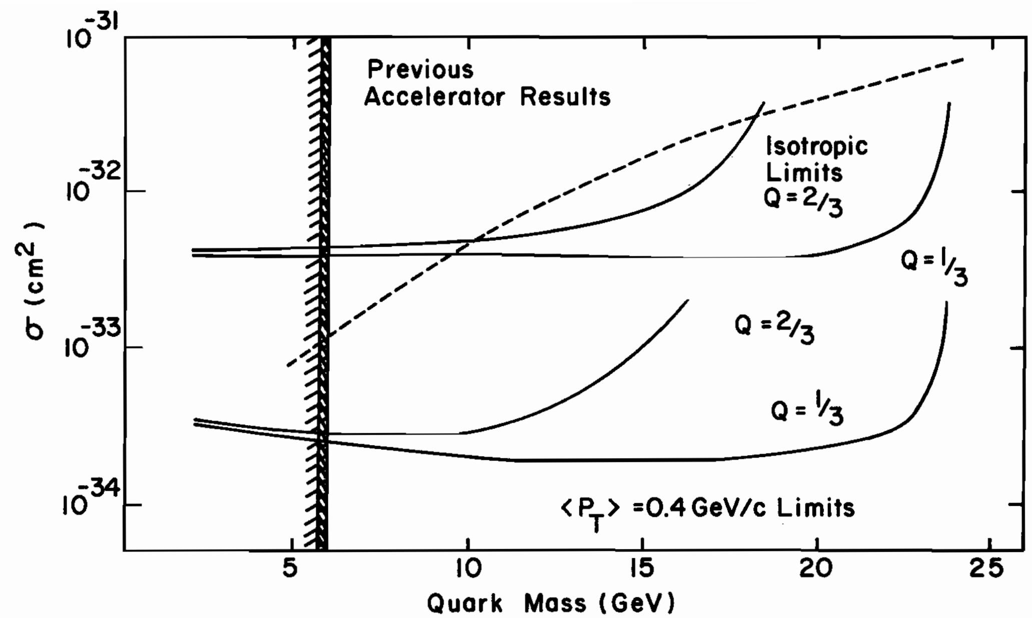

Figure 1. Cross section limits for the production of quarks. The single solid lines represent the limits derived from the CERN ISR experiments, the dashed line represents an estimate of the limits from cosmic ray experiments and the double line shows limits from other accelerator experiments.

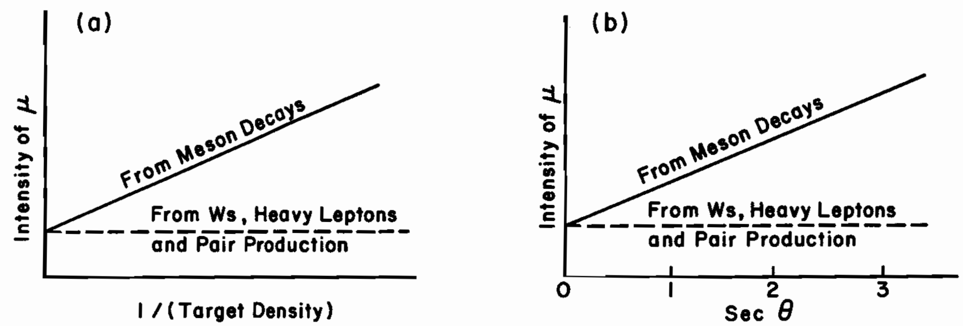

Figure 2 a) The diagram shows the character of the variation of intensity with respect to target density of muons produced in high energy interactions by various processes.

b) The diagram shows the character of the variation of intensity with respect to sec θ, where θ is the angle of incidence measured from the vertical, of cosmic ray muons produced in very high energy interactions by various processes.

DISCUSSION

R. H. Hildebrand (Chicago): Singh and Wolfenstein [Nucl. Phys. B24, 77 (1970)] have considered the possible existence of a heavy lepton with a mass between the muon mass and the K-meson mass. If such a meson existed, the K meson would decay into the heavy lepton and a muon even as the K decays into a muon and neutrino. No such decays have been found. One can place a limit on K decay into such leptons--a limit of $2 \cdot 10^{-7}$ on the branching ratio--which can be translated into a statement about the mass of the hypothetical heavy lepton: if such a lepton exists, its mass differs from that of the K by less than 30 keV.

H. J. Lipkin (Weizmann Institute): I would like to point out the existence of objects referred to as heavy leptons that do not have the properties that you have assumed, and this would affect their searches considerably. These arise particularly in these new attempts to unify electromagnetic and weak interactions. There are also objects like quarks in many models which have integral electric charge, there are neutral heavy leptons, and there are some heavy leptons that do not appear together with their own neutrinos in a doublet but would decay in more complicated ways. Have you considered the implications of these new objects for searches?

R. K. Adair: Professor Lipkin has pointed out that there are all kinds of things predicted one way or another. There are a large variety of searches for integrally charged particles of various types. My colleagues and I have conducted such searches ourselves. Unless one names very specific characteristics of a particle it is very difficult to make a general statement about the relevance of experiments to its existence. I'm sure there are all kinds of experimental holes into which we can fit new particles. On the other hand, many experiments do relate directly or indirectly to limitations on the existence of other kinds of particles.

H. J. Lipkin: Is there any evidence of heavy leptons from analyses of decays into charged particles?

R. K. Adair: I don't know, but I suspect that Professor Zichichi, for example, in his experiment, can eliminate many varities of odd things.

Question from the Floor: In the earlier report of the Utah experiment, it was necessary to use anomalous range-energy curves for the muon, and this was used in general as an argument in favor of a process in which the muons would have the wrong helicity. What is the current status of this?

R. K. Adair: The question is essentially this: If you have certain tupes of X processes which produce muons with a cross section of the order of a tenth of a millibarn, you must introduce some kind of semi-strong interaction to account for such large production. If there is a semi-strong interaction for muon production, the muons are likely to have a semi-strong interaction in passing through matter. This is quite possibly related to the helicity, that is, the muon with the helicity derived from meson decay will not interact but a muon with the opposite helicity, from heavy lepton or W decay, will interact. Such an effect would solve some of the problems of bumps in range-energy curves. I think that this hypothesis was first suggested by Bjorken and his collaborators in a footnote that said that they didn't take it very seriously. If I remember correctly, this is one of the very wide variety of possibilities that exist which would explain the experimental anomalies, and there is no direct information at this time on an anomalous muon interaction.