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CONFERENCE SUMMARY

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1. INTRODUCTION

In the opening talk of this meeting[1], G. Kane defined "the minimal standard model" to be:

a) Three generations of quarks and leptons;
b) Massless neutrinos;
c) $SU(3)_{colour} \times SU(2)_L$ gauge theory;
d) One neutral Higgs boson; and
e) CP violation solely in the mass matrix.

Reaching this point has been the tremendous achievement of the past decade. We have witnessed the discoveries of charm and the third generation, the discovery of neutral currents and the detailed confirmation of $SU(2)_L \times U(1)$, and the discovery of asymptotic freedom and the development of QCD and its experimental tests. In spite of these achievements, the resulting standard model is not entirely esthetically pleasing. It lacks a coherence which would explain its varied form and parameters; as a result, I would wager that none of us here believes that it represents the end of physics.

Our experimental activities fall into three general categories. The first is searching for evidence of physics beyond the minimal standard model. At the moment, we have no solid evidence, in the sense of a confirmed experiment, of any such physics. The first such evidence, whenever we obtain it, will undoubtedly be an important clue to what lies ahead. Thus, it is appropriate that we spend an appreciable part of our time and resources searching for it, even though the chance of success for any single experiment may be small.

Our searches are often motivated by the theoretical ideas we have heard discussed at this meeting -- grand unified theories, supersymmetry, composite models, among others. Often, however, we are motivated only by a sense of "pourquoi pas?" -- it could exist; let us look for it. In this spirit, we search for extended gauge group structures, extended Higgs sectors, and extra quarks and leptons.

The second category of experimental activity is testing the standard model. In this regard, it is important to remember that there are four particles which are required by the standard model but which have not yet been fully confirmed. The W and the Z have masses which are specified by the model, and we now have some evidence for both. As we will discuss in a few minutes, the evidence is rather direct for the W, but considerably less direct for the Z. The masses of the other two particles, the t quark and the Higgs boson, are not specified by the model, and for these two particles we have no evidence whatsoever. The existence of a single neutral Higgs boson is the weakest point of the standard model; thus its discovery would be of tremendous importance because it would put important constraints on the physics beyond the standard model.

Finally, the third category of experimental activity is making detailed measurements within this standard model. For want of a better name we can call this "spectroscopy". Some of these measurements are clearly fundamental, such as the measurement of the Kobayashi-Maskawa mixing angles. Others are apparently less so, involving detailed structure controlled by non-perturbative QCD. But taken in total these measurements provide the building blocks of our knowledge.

These three categories do not always have clear boundaries. It is clear that if one performs a test of the standard model and the test fails, one has found evidence for physics beyond the standard model. And many times in the history of physics a routine measurement has uncovered a surprise which has led to a new level of understanding. Nevertheless, I will use these three categories to organize the contributions to this meeting.

2. SEARCHES FOR PHYSICS BEYOND THE STANDARD MODEL

2.1 Monopole catalysis of proton decay

These are only two major windows to the energy scale of physics required by the theories of grand unification -- magnetic monopoles and proton decay. We have heard discussed at this meeting the marvelous suggestion[2)] that perhaps both could be seen in the same experiment, and, furthermore, that perhaps this would be the best way to see both phenomena.

Perhaps the suggestion is too good to be true, for we have also seen the impressive result from the Irvine-Michigan-Brookhaven (IMB) proton decay experiment that, in 80 days of running with a detector of effective area 340 m^2 (about a tenth of a football field), no candidates for successive proton decays were seen[3)]. With the most optimistic cross section assumptions, this result sets an upper limit on the magnetic monopole flux of 6×10^{-15} cm^{-2} str^{-1} s^{-1}, a limit which approaches the

Parker bound of about 10^{-15} cm^{-2} str^{-1} s^{-1}, an upper limit to magnetic monopole fluxes obtained from astrophysical considerations[4].

2.2 Other searches for monopoles

This subject has been beautifully reviewed by B. Barrish at this meeting[5], and there is nothing useful that I can add to his talk. Let me only underline his statement that there are no experiments which are sensitive at the level of the Parker bound. If we are going to search seriously for magnetic monopoles, then we may have to consider detectors the size of football fields.

2.3 Searches for proton decay

The major new development in these searches was the report to this meeting of the first results from the IMB experiment[6]. The experimenters have analysed 80 days of running with a 3300 ton fiducial volume for the $e^+\pi^o$ and μ^+K^o modes. They find no candidates for the $e^+\pi^o$ mode, yielding a lifetime divided by branching ratio of $\tau/B > 6.5 \times \times 10^{31}$ yr. There is one candidate for the μ^+K^o mode. The significance of this is not that there is one candidate (for, indeed, no evidence was presented to indicate that this event was not due to backgrounds), but that there is only one candidate.

I have three comments to make at this stage:

1) The IMB experiment seems to work well.
2) From the first results, it is clear that protons do not decay as readily as some had hoped. It would seem imprudent to build any future detectors with fiducial masses less than 1000 tons, because no matter how powerful they might be, they simply would not have the rate to be effective.
3) It is too early to say anything more. Regardless of the results of the IMB experiment, we will need fine-grained detectors such as the one being planned for the Fréjus tunnel[7].

2.4 Searches for supersymmetric particles

Supersymmetry is an elegant theoretical idea[8], but one which is somewhat frustrating for experimenters for two reasons:

1) There are no solid predictions. The theory has a large number of branch points which allow the creation of an endless number of models. No experimental results can eliminate the theory; the most they can do (other than discover supersymmetric particles) is to limit the possible models.

2) The presently accessible energies are probably too low to detect these particles.

Nonetheless, there has been a large effort to search for these particles. Above threshold, scalar leptons would be copiously produced in e^+e^- annihilation and be easily recognized. Searches for these particles give lower limits for their masses just slightly lower than the available beam energies, around 16 to 17 GeV [9]. We have also heard negative results on searches for massive, unstable photinos in e^+e^- annihilations[9], and for gluinos in neutrino beam dump experiments[10,11].

2.5 Searches for fundamental scalars

Charged fundamental scalars, either charged Higgs bosons or technicoloured pseudo-Goldstone bosons, would be produced in a predictable way in e^+e^- annihilations. Despite the criticism we have heard at this meeting[12], there have been reasonable searches for these particles[9] which set lower limits on the mass at about 13 GeV.

2.6 Search for right-handed currents in muon decay

Many people commented to me that they felt the highlight of the meeting was the report of the beautiful experiment of the Berkeley-Northwestern-TRIUMF Collaboration[13]. I have no argument with this assessment. By measuring the polarization of muon decay, this experiment has set an upper limit on $(1 - \xi P_\mu \delta/\rho)$, which is zero in the absence of right-handed currents, of 0.0041. This increases the previous lower bound on the mass of a right-handed W from 220 GeV to 380 GeV.

2.7 Searches for neutrino oscillations

Progress reports were given on searches for neutrino oscillations which have been done or are underway at Fermilab[14] and CERN[15]. These searches are looking primarily for "ν_μ disappearance", that is, an oscillation of ν_μ into any other form. There are presently no limits on ν_μ disappearance. These experiments together will be sensitive to mass squared differences in the entire range between 0.3 eV^2 and 1000 eV^2.

2.8 Neutrino beam dump experiments

The outstanding anomaly in the beam dump experiments is the ratio of prompt ν_e to prompt ν_μ. All known sources of prompt neutrinos would give a value of this ratio close to unity. The results of three CERN experiments (all in the same beam line) gave values of ν_e/ν_μ ranging from 0.49 to 0.64 with typical errors of 0.2 [16]. The latest results from the Fermilab beam dump experiment which were reported to this meeting give a ratio of 1.29 ± 0.21 [11]. Thus, there is a discrepancy of three standard deviations in the combined errors between CERN and Fermilab. The only thing we can do is wait for the results of latest round of beam dump experiments from CERN, which should be ready this summer, to see if we still have an anomaly.

2.9 Other searches

There were a fair number of other searches for physics beyond the standard model which I do not have time to review here. The total extent of our efforts on all these searches is impressive, and, as I said at the outset, quite appropriate.

3. TESTS OF THE STANDARD MODEL

3.1 The W discovery

It appears unavoidable to me that there is some particle being produced in the CERN $p\bar{p}$ collision which has a mass of around 80 GeV or more and whose decay produces an electron and missing energy. I have taken the liberty of combining the UA1 [17] and UA2 [18] data for events with an isolated electron and missing transverse momentum as a function of the electron's transverse momentum. The data are shown in Fig. 1.

Both experiments have a similar analysis chain with a cut at 15 GeV/c, but no bias beyond that point. The data do not pile up against the cut, as would be expected for any reasonable background, but rather peak between 35 and 40 GeV/c.

Since these data show the expected signature of the W, it is logical to make this assignment. However, on the basis of the present meager data other explanations are probably not excluded.

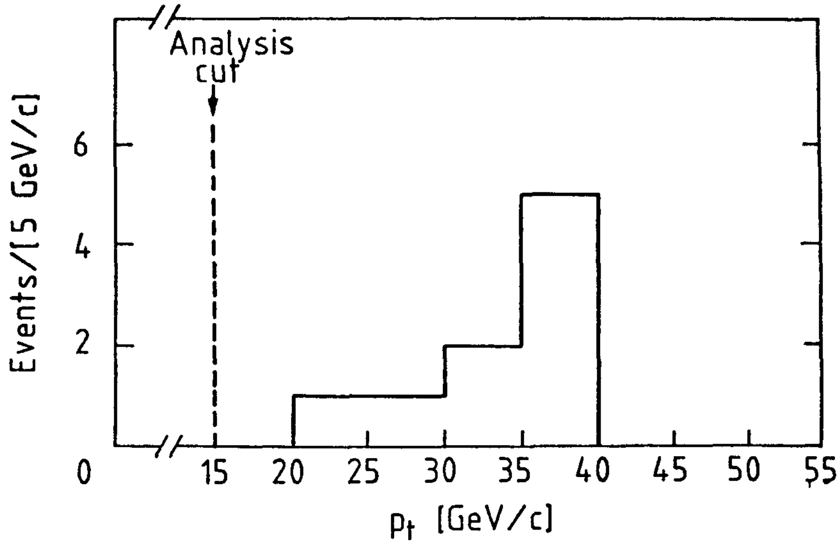

Fig. 1 Electron transverse momentum for events with an isolated electron and missing energy in the combined UA1 and UA2 data.

In particular there is one UA1 event which has the wrong asymmetry for a W decay. There are three possibilities:

1) It is a background event (10% confidence level, i.e. the number of background events in the sample is expected to be of the order of 0.1).

2) It is an unusual W decay (10% confidence level, i.e. it is ten times more likely to have the opposite asymmetry).

3) It is something interesting (there is no way to estimate a confidence level on the unknown).

In any case we look forward to the large increase in data expected by this summer.

If there has been a surprise in the $p\bar{p}$ running so far, it is that the data are very clean at high transverse momentum. Jets are unambiguous and one does not need complicated algorithms to count them. This bodes well for the future of high-energy $p\bar{p}$ physics.

3.2 Neutral currents in e^+e^- annihilation

The best way to see the effect of weak neutral currents in present energy e^+e^- annihilation data is in the backward-forward asymmetry in μ pair production. This asymmetry is proportional to $s/(1 - s/m_z^2)$.

Thus, at sufficiently high s and sufficiently high precision one is sensitive to the Z mass. The combined results of five PETRA experiments measure this asymmetry to be (-11.3 ± 1.3)% and set limits on the Z mass: $55 < m_Z < 110$ GeV [9]. Thus, in some sense, one can claim to have seen evidence for the Z, albeit with rather poor mass resolution.

At this meeting we have heard reported the first measurement of the neutral current coupling to the c quark by a measurement of the asymmetry in the angular distribution of D* production[9]. The TASSO result gives $g_A^c = 0.89 \pm 0.44$.

3.3 Neutral currents in ν scattering

The only comment I have here is to underline arguments that were put forth at the recent CERN Workshop on SPS Fixed-Target Physics[19]. At present the most precise measurements of $\sin^2 \theta_W$ come from neutral current ν interactions. In the future one will be able to measure the Z mass to about 100 MeV which will give $\sin^2 \theta_W$ to a precision of better than 0.001, subject, however, to weak radiative corrections of about 0.02. These weak radiative corrections will be our first look at weak interactions beyond the Born approximation. To measure the radiative correction we need an independent determination of $\sin^2 \theta_W$ to a precision of at least 0.005, a value which is factors of 8 and 3 below that now obtainable from $\nu_\mu e$ scattering and from $\nu_\mu N$ scattering, respectively. In the former case there are no theoretical uncertainties and the present experiments are limited by statistics; in the latter case hadronic corrections have to be understood. The question is whether either or both measurements can be improved to the required accuracy.

3.4 τ lifetime

The Mark II measurement[20] which sets bounds on the τ coupling to the charged weak current, $g_\tau/g_e = 0.92 \pm 0.12$, is the last of a long series of measurements on the τ lepton which appear to rule out the possibility that the τ is anything other than a sequential lepton with its associated neutrino coupling in a universal way to the weak current[21].

4. SPECTROSCOPY

4.1 The EMC effect

The biggest physics surprise in the past year has been the discovery by the European Muon Collaboration at CERN that structure functions measured in iron differ significantly from those measured in deuterium[22]. At this meeting we have heard a delightful report from Bodek[14] which showed that decade-old SLAC empty-target data confirm this effect and even might clear up an old mystery as to why shadowing disappears so quickly with q^2 in electroproduction[23].

The data from these two experiments seem clear and convincing. What are the consequences? There are two basic reasons for studying deep inelastic scattering. One is to study the q^2 development of QCD. This can be done just as well in iron as on free nucleons, so for this purpose the EMC effect is unimportant. The second reason, however, is to measure the parton distributions in protons and neutrons. It is now clear that for this purpose measurements in iron distort these distributions at the 15% level.

There has been a great deal of enthusiasm voiced at this meeting for systematic programs to measure parton distributions in nuclei. This should be recognized, however, as the study of a (probably quite interesting) nuclear physics question, rather than anything fundamental in elementary particle physics. If one is going to be serious about studying this effect, then it would be useful to have a detailed measurement of νd interactions, since it is only through neutrino interactions that one can separate valence and sea quark contributions.

4.2 Search for gluonium states

The radiative decays of heavy charmonium states such as the ψ or the Υ are presumably among the best places to search for gluonium states because the decay results in two gluons in a colour-singlet state of variable mass. Searches were made for ψ decays into a photon and a resonance. In addition to the expected resonances such as the η, η', and f, two surprises were found, the $\iota(1440)$ [24] decaying into $K\bar{K}\pi$ and the $\theta(1670)$ [25] decaying into $\eta\eta$. Since then there have been attempts to measure or set upper limits on other decay modes of these resonances[26,27]. At this meeting we have had a report from DCI setting an upper limit of $B(\psi \rightarrow \gamma\theta) \cdot B(\theta \rightarrow \rho\gamma) < 8 \times 10^{-5}$ at the 99% confidence level[28].

A clear picture of the identity of these particles has not yet emerged. Part of the problem is that there is no quantum number which defines a gluonium state; in general it will mix with $q\bar{q}$ and $qq\bar{q}\bar{q}$

states. Furthermore, hadronic states in this mass region are wide, and in any given final state at any given mass it is likely that there will be several overlapping states.

What is needed is a more systematic and detailed study with considerably more data than we have now. With detectors such as the Mark III at SPEAR this can be done. The question is will it?

4.3 Heavy quark fragmentation

Progress has been made recently on measuring heavy quark fragmentation functions, that is, answering the question "How much of the energy of a heavy quark does the weakly decaying heavy meson carry?" The charmed quark fragmentation function has been measured directly by reconstructing exclusive D^{*+} decays[9,20,29]. The data from the three high-energy experiments are plotted in Fig. 2.

The fractional cross section, $(1/\sigma)\ d\sigma/dz$, is used to eliminate differences in normalizations and branching fraction assumptions among the three experiments. The results show that the charm fragmentation function is fairly hard, with an average z of about 0.6.

The Mark II experiment has measured the bottom quark fragmentation by statistically separating electrons from b decay from those from c decay and backgrounds[20]. The result is an even harder fragmentation function for b quarks with an average z of about 0.75.

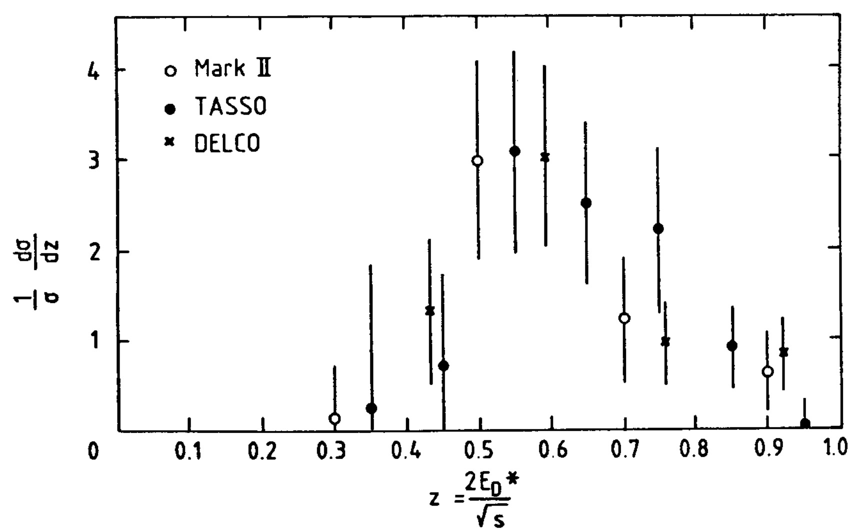

Fig. 2 The fractional cross section for D^{*+} production as a function of $z \equiv 2E_D{}^*/\sqrt{s}$.

4.4 Lifetime

The Mark II has measured the D^{o} lifetime to be $(3.7^{+2.5}_{-1.5} \pm 1.0) \times 10^{-13}$ s, based on a sample of seven high-z reconstructed D^{*+} decays. The importance of this result is that it demonstrates that it is possible for $e^{+}e^{-}$ storage rings to compete in this field. With the additional data which will be available soon we can expect higher statistics on the D^{o} lifetime as well as measurements of the D^{+} and B lifetimes.

4.5 $b\bar{b}$ spectroscopy

At this meeting we have seen very beautiful single photon spectra from $\Upsilon(2s)$ and $\Upsilon(3s)$ decays from the CUSB experiment[30]. Although the individual transitions have not been separated, the centre-of-gravity of the χ_b masses has been determined. We look forward to upcoming Crystal Ball results from DORIS, which may have higher resolution.

4.6 Studies of B decay

In recent years we have accumulated an impressive amount of information on the decays of the B mesons. I will just briefly list here some of the measurements which have been reported to this meeting.

1) $b \rightarrow u / b \rightarrow c$

Both CUSB and CLEO have tried to determine the fundamental mixing angle of b decay by measuring the electron spectrum[29,30]. The shape of this spectrum is affected by the mass of the hadronic state produced in the semi-leptonic decay. The result is somewhat model-dependent, but assuming that the hadronic state produced from a u quark has a mass of not more than 1 GeV, the fraction of $b \rightarrow u$ decays is limited to 5% or less.

2) B semi-leptonic decay fractions

Four experiments have reported results with an average value of $B(B \rightarrow \ell \nu X) = (12.6 \pm 1.2)\%$ [20,29,30]. This agrees well with the value expected from a simple spectator model, 1/9.

3) Observation of B exclusive states

The branching ratio for the B meson to go into any given exclusive state is quite small. Thus, CLEO has accomplished a formidable task in reconstructing enough B exclusive states to measure the B masses and mass difference[29]. This was only possible because of the mass constraint provided by the $\Upsilon(4s)$ state.

4) ψ production in B decays

CLEO has measured the branching fraction for $B \rightarrow \psi X$ to be $(6.4 \pm 2.3) \times 10^{-3}$, a value smaller than had been expected by some predictions[29]. This has obvious practical consequences for anyone hoping to use the ψ to tag B's.

5. CONCLUSION

The conclusion to this talk was really given in the introduction: our field is quite healthy. We have made tremendous gains in the past decade and we are consolidating these gains while, at the same time, earnestly searching for the clues which will tell us what lies beyond the standard model.

Acknowledgements

I thank all of the speakers at this meeting for their cooperation which made the preparation of this talk sufficiently simple that I was able to ski at least a little each afternoon. I am particularly indebted to F. Dydak for several discussions which helped to clarify some of the points covered in this talk.

Enfin, comme j'étais le dernier à parler à cette semaine de la Rencontre de Moriond, j'ai l'honneur, de la part de tous les participants, de remercier Tran, le Secrétariat, et tous les organisateurs d'avoir fait une conference très agréable, qui était pleine de physique et pleine de soleil.

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