XXXVIIiéme Rencontres de Moriond: Electroweak 2002 Conference Summary

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A substantial body of data is described by the *Standard Model* of particle physics. However the description is far from perfect and there is a growing number of internal inconsistencies. These fall short of qualifying as discoveries; nevertheless, examination of their merits is both interesting and worthwhile. The existence of three families of quarks and leptons is not understood. There are new data, especially from the B factories; the latter are shining new light on the problem. From several experiments, data show that our thoughts about the existence of transitions between neutrino flavors, oscillations, may be correct but the understanding of the patterns needs work. However, we see the opening of a number of avenues of investigation as new facilities and experiments come online.

1 Introduction

A conference summary, even in this case, in which the summary is limited to the experimental talks and presentations, is problematic. Neither the talk nor the written summary do justice to the total content of the individual contributions. Nevertheless, in this paper, I attempt to give a sense of the physics I have learned from the more than fifty talks about experiments presented at the XXXVIIiéme Rencontres de Moriond (Electroweak).

The paper is organized such that I start with a brief discussion of a number of *Searches for New Phenomena* which, unfortunately, did not find anything which goes beyond our current description of the world. This is followed by a discussion of the advances in *Neutrino Physics*. A sub-field enjoying focussed attention is that of the *Quark Flavor Physics* of quarks. There are beautiful measurements and some surprises as competitive experiments present independent preliminary results and these are discussed in Section 4. In section 5, we embark on a discussion of the *Precision Electroweak Measurements*. It was a surprise to me that it is difficult to make a clear distinction between the precision measurements and what I call *Puzzles*. These measurements, which do not fit well into the standard model, are discussed in Section 6 followed by consideration of the way forward with *New Starts* being discussed in Section 7. Finally, Section 8 contains a very brief *Perspective*.

2 Searches for New Phenomena

Among the searches [1] for weakly interacting massive particles(WIMPs), the results from the DAMA [2] experiment, which initially indicated a possible signal, are now not generally accepted by the community. The CDMS experiment has limits [3], which exclude much of the phase space favored by DAMA, and at the time of writing, there are rumors of new results from the EDELWEISS experiment. The regions of sensitivity are usually displayed in the plane of cross section of the WIMP with matter and of the mass of the WIMP. There are many experiments planned to extend the reach in WIMP-nucleon cross section, from about $10^{-41} cm^{-2}$, by several orders of magnitude. Prerequisites are low backgrounds; the concurrent use of two detection techniques, to combat that background, is generally expected. For example, some experiments use cryogenic germanium detectors and detect both the recoil/phonon and the ionization signals. The greatest sensitivity for all these experiments is in the range of 20-90 GeV.

The couplings between the gauge bosons of the electroweak model are completely prescribed by the theory. There have been studies at the Tevatron Collider, which established [4] the non-Abelian nature of the couplings. At LEP, the couplings are directly measured [5] and the central values correspond well with expectations.

The Tevatron collider experiments have traditionally performed especially sensitive searches for signals of new physics involving strongly interacting partons, quarks and gluons. New results [6,7] continue to consolidate these searches using data from 1992-96, Run I of the Tevatron Collider. The new fashion is to search for extra dimensions through the actual production of Kaluza-Klein gravitons in the final state. These could be in conjunction with either jets or vector bosons. In both cases, missing transverse energy is a key signature. Limits of several hundred GeV are obtained. These are similar to equivalent limits [8] from the LEP experiments. Specifically, from LEP, we see limits of about 800 GeV on the masses in low scale gravity models. In all these searches, it has been demonstrated that the use of angular distributions is a powerful tool with which to discriminate against backgrounds.

There are new results [9] from the HERA experiments, H1 and ZEUS, on the search for leptoquarks. This is the classic opportunity for this machine, which nicely complements the measurements at the Tevatron. There are also some new limits on the masses of excited leptons, both charged and neutral (heavy neutrinos) in the range 200-250 GeV for couplings of order 10^{-2} to 10^{-3} times the electroweak coupling.

The parameter space associated with supersymmetric models is enormous, even when rationalizations and approximations are made. The minimial supersymmetric standard model, in particular, the "supergravity" species, requires the specification of five or so parameters. Generally applicable representations of the results are important and, with the now very mature analyses [10], we see that the kinematic limits are being approached, almost independently of the channel, for most scenarios. The lightest supersymmetric particle is a key state in many models; it is also thought to be a candidate for identification as the embodiment of cold dark matter. At arbitrarily high values of $tan\ \beta$, the ratio of the vacuum expectation values associated with the two Higgs doublets in this model, and thus essentially independent of other model parameter values, the lower mass limit is 56 GeV at 95% confidence level. The experimental mass limit, as a function of $tan\ \beta$, is shown in Fig. 1.

What distinguishes one supersymmetric model from another for the theorist is the mechanism by which the symmetry is broken. A popular class of models falls under the designation "gauge mediated supersymmetry breaking". These models tend to lead to a preponderance of photons in the final state, but they can also lead to relatively long lifetimes for some of the sparticles. The extra parameter means that the experimental groups present the results [11] of their searches in terms of cross section limits as a function of both mass and lifetime. Typical lower limits for the mass of the sleptons in the range of 60-90 GeV have been obtained.

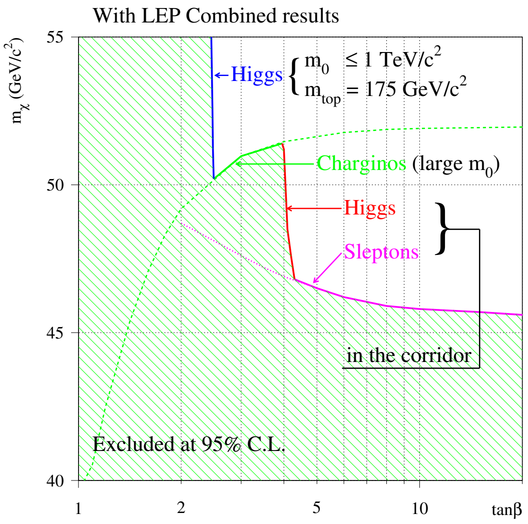

Figure 1: Lightest Supersymmetric Particle(LSP) Combined Limit from LEP experiments.

Initially the searches for supersymmetric particles concentrated on the pair production of supersymmetric partners of which the decays were constrained to conserve R-parity(R_p), the quantum number, which distinguishes a particle from a super-partner. The corollary is that the cascade decays should terminate with a neutral lightest-supersymmetric particle(LSP), of relatively low mass, which escapes detection and thus leaves missing transverse energy as its signature. Admitting the non-conservation of R-parity deprives the experimentalist of this rather distinctive signature. Nevertheless, the increasing sophistication of searches for supersymmetric particles is demonstrated by the fact that the current LEP limits [12] on the masses of sparticles in R_p violating models approach very closely the equivalent limits for the R_p conserving cases.

The adjective "exotic" is often applied to those searches for which no clear, currently fashionable, theoretical justification can be found. However, that does not invalidate them; indeed for many people such possibilities are the most exciting. The searches at LEP yield 80-100 GeV lower limits [13] on the masses of excited leptons, leptoquarks (cf. the searches from HERA and the Tevatron discussed above), heavy leptons, and technicolor. It is interesting to look for shorthand representations of negative results and in this spirit we can surmise that, lower mass limits ranging from 80 GeV to 200 GeV have been set with the respective couplings varying from 10^{-3} to 1.

The multiplicity of models for the physics beyond the standard model have, as a corollary, just as many different scenarios for the structure in the Higgs sector. In the realm of SUSY, the parameters such as *tan* β can lead to different branching ratios. The Higgs particles may decay dominantly to bosons, or to leptons, to the first, second, or third generations. The presentation [14] of the results can be correspondingly complicated. However, it is reassuring to see that the generic models with one and two Higgs doublets, and searches with decay-mode-independent techniques, as well as flavor-independent techniques complement the specialised, Minimal Supersymmetric Standard Model and other, model dependent searches. The lower mass limits range from about 80 GeV up to the limit on the mass of the standard model Higgs at slightly greater than 114 GeV.

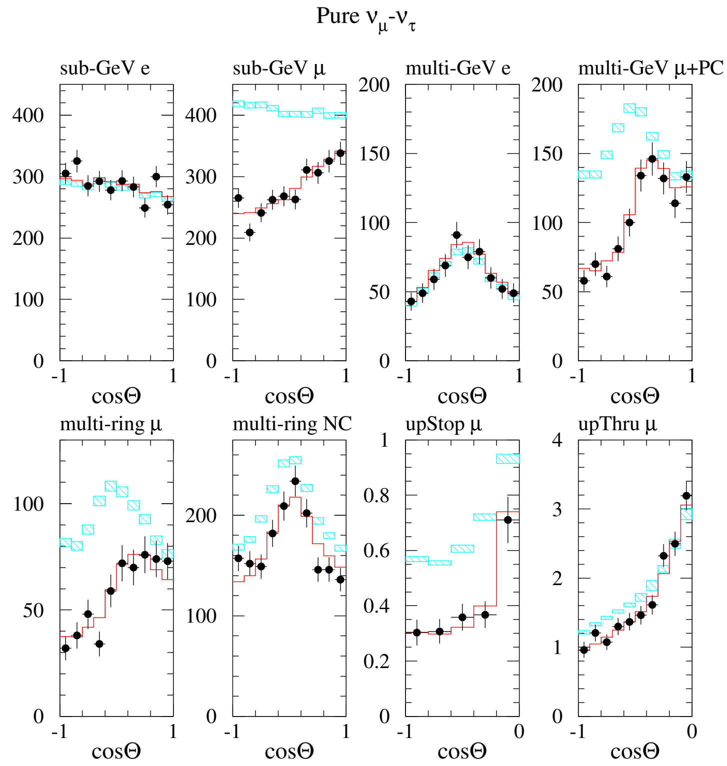

Figure 2: Data from the SuperKamiokande Experiment showing the agreement between several atmospheric data sets as a function of angle and a model of oscillations of ν_μ into ν_τ.

3 Neutrino Physics

In preparing for this conference I looked back at a transparency that I had used in 1999. At that time the neutrino oscillation scene included three regions with possible positive signals. The "LSND anomaly", is a putative signal, with Δm^2 greater than $0.1(eV)^2$. There were first indications of oscillations with Δm^2 of a few $\times 10^{-3}$ $(eV)^2$ and a large mixing angle, primarily from SuperKamiokande but with supporting results from other experiments. Finally, the long standing solar neutrino deficit suggested neutrino mixing at with a very small mass difference squared: less than $10^{-4}(eV)^2$.

At this conference the conclusions of the Chorus and Nomad experiments at CERN were described [15]. These experiments were designed with tau neutrino appearance in mind and they have provided limits on the oscillations of both muon neutrinos, which was the primary aim, and electron neutrinos, to tau neutrinos. For mass difference squared above 40 eV^2, they exclude, with 90% confidence level, $\sin^2(2\theta) > 5\times 10^{-4}$. For electron neutrinos to oscillate to tau neutrinos the NOMAD limits, which are the better of the two, are nearly an order of magnitude less restrictive in each of the mass difference squared and the square of twice the mixing angle. Finally the NOMAD limits for muon neutrinos to oscillate to electron neutrinos exclude a substantial fraction of the space occupied by the LSND results.

In the atmospheric neutrino arena, the array of SuperKamiokande work [16,17] was rapidly advancing until the recent problems with the detector brought progress to a halt. These results include not only the rates, but several measurements of the dependence of the fluxes on angle or time. The results in parameter space are now really beginning to look like a rather clear indication that $\Delta m^2 \simeq 2 - 3 \times 10^{-3}$ $(eV)^2$ and that $\sin^2(2\theta)$ is close to unity. Several of their data sets are displayed in Fig. 2. There is good agreement between the data and the description provided by a model in which the muon neutrino is transformed into the tau neutrino.

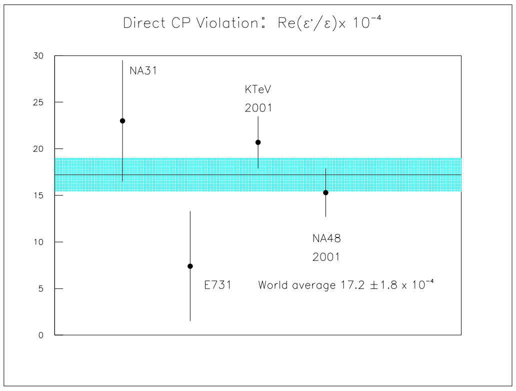

Figure 3: Recent Results on $\mathcal{R}(\epsilon'/\epsilon)$.

K2K is the first accelerator-based neutrino oscillation experiment with a moderately long baseline. The experiment [18] operates with approximately one GeV neutrinos. Fifty-six events are observed in the far detector when eighty-one are expected. The probability for a null oscillation hypothesis is 3%; the result would be well described with $\Delta m^2 \simeq 3 \times 10^{-3}$ $(eV)^2$. It seems that there is a good plan to resume operation of SuperKamiokande in a year or so with a reduced complement of photomultiplier tubes. Since the present results seem to show the biggest effect at an energy of 0.6 GeV, K2K also will rebuild their near detector to better match this energy.

The SuperKamiokande experiment has also produced prominent results relevant to the understanding of the solar neutrino deficit. They have measured angular distributions as well as making rate comparisons. The SNO experiment [19] produced its first results a year ago based on their measurement of charged current interactions, which are sensitive only to electron neutrinos, and elastic scattering. The latter is sensitive primarily to electron neutrinos but also, with a relative sensitivity of about 15%, to muon and tau neutrinos. In SNO the statistics for the elastic scattering are rather limited. However, SuperKamiokande has made a precise measurement of that quantity. Together the charged current and elastic scattering measurements permit a solution for both electron and non-electron neutrino fluxes. The results beautifully demonstrate that the non-electron neutrino flux is indeed non-zero. Further, when added to the electron neutrino flux, the sum matches well to the standard solar model. In this way, a convincing case is constructed, that neutrino flavor transitions have been observed. Since the time of the conference, SNO has presented [20] results on the measurement of the neutral current neutrino interactions. These confirm and take a step further than the earlier measurements.

4 Quark Flavor Physics

K mesons were discovered some fifty years ago. Their importance was enhanced by the discovery of CP violation in the neutral kaon system in 1964. With the discovery of the Upsilon, the b quark joined the game, and the physics of flavor started to be described by the, now very famous, Cabibbo-Kobayashi-Maskawa matrix, which relates the strong interaction, mass, eigenstates to the weak interaction states of the three families.

The recent observation [21] by BNL-E787 of a second example of the decay $K^+ \to \pi^+ \nu \bar{\nu}$ has been interpreted by many as a demonstration that a substantive measurement of that decay rate is just around the corner; a bright future is presaged for this avenue of investigation, perhaps with a next-generation experiment, dubbed CKM, at Fermilab. Such an experiment [22] is thought to provide a theoretically clean measurement of one of the sides of "the" unitarity triangle representing the CKM matrix.

There have been theoretical predictions suggesting that an accessible degree of CP violation

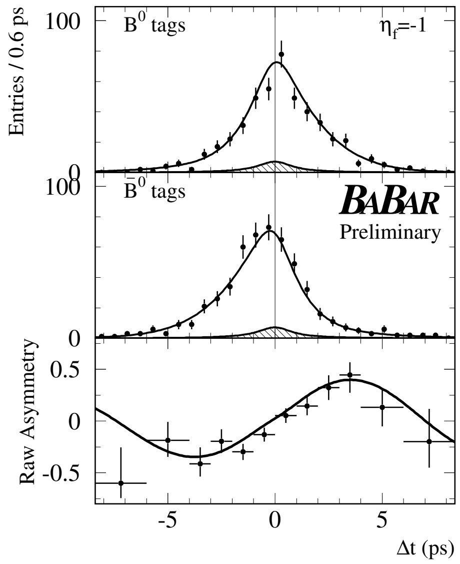

Figure 4: The CP asymmetry for $B \to (J/\psi, \psi(2S), \chi_{c1})K^0_S$ decays, as observed by the BaBar experiment.

might occur in hyperon decays. An experiment called Hyper-CP has been performed at Fermilab, which has measured [22] the branching fraction for the flavor changing neutral current decay $K^+ \to \pi^+\mu^+\mu^-$. The result, $(9.8 \pm 1.0(stat) \pm 0.5(syst)) \times 10^{-8}$ appears to distinguish between two previous measurements, which were at variance.

Another initiative in search of CP violation is the KLOE experiment at the DAΦNE accelerator. While accumulating the requisite luminosity for the CP violation measurement, this experiment, which will exploit the mutual tagging of neutral kaons from the decay of the ϕ particle, has measured [23] a number of radiative ϕ decays as well as the rare kaon branching fraction, $\mathrm{BR}(K_s \to \pi e\nu) = (6.79 \pm 0.33(stat) \pm 0.16(syst)) \times 10^{-4}$.

There are two recent experiments, which have measured CP violation in the neutral K_L system. The NA48 at CERN has results [24], which cover their data through 1999 but which do not incorporate any information from their running in 2001 with a reconstituted spectrometer, after their accident of 2000. The KTeV experiment at Fermilab has results [25], which are limited to their data through 1997; there are more data taken through 1999. These are the latest, and perhaps last, in a series of experiments at the two laboratories, which have continued over 20 years. Agreement between the two has not always been evident, but the current results, illustrated in Fig. 3, are in accord at a confidence level of 13%, and yield a world average of $\mathcal{R}(\epsilon'/\epsilon) = (17.2 \pm 1.8) \times 10^{-4}$.

The two experiments also contribute numerous other measurements of the neutral kaon system. For example, they have measured a large number of branching fractions of rare decays. The decay $K_L \to \mu\mu$ depends on different components, one of which, in turn, depends on the $K\gamma^*\gamma^*$ vertex. This vertex is determined by a measurement of the branching fraction, $BF(K^0_L \to ee\mu\mu) = (2.62 \pm 0.23(stat) \pm 0.18(syst)) \times 10^{-9}$. In addition, there are vital parameters, such as the mass differences and lifetimes associated with the different states K_L and K_S, which are now known with exquisite precision.

Both the KEK-B and PEP-II asymmetric electron-positron colliders are working extremely well. Almost step for step, the luminosity of each, and the integrated luminosity analysed by the two experiments, BELLE and BaBar respectively, has increased. It is an impressive performance by all.

As anticipated the first results in CP violation appeared in the classic $B \to J/\psi\ K_S$ channel, which determines the parameter $sin\ 2\beta$ (When in Rome ....; I will follow the European/North

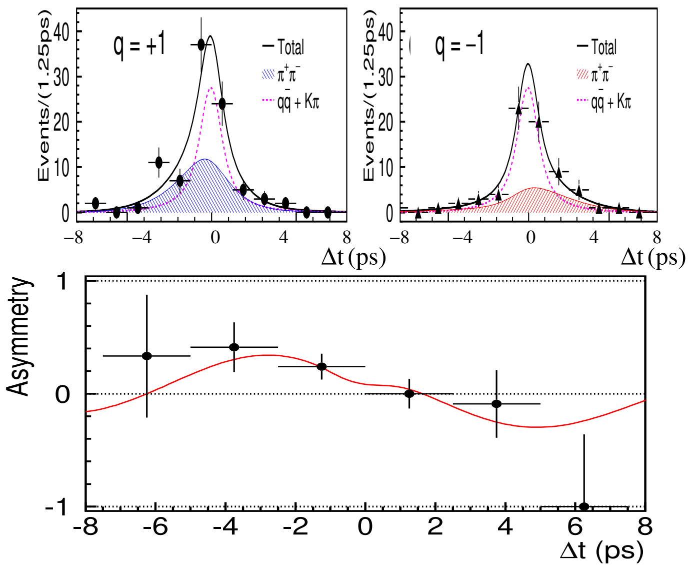

Figure 5: Measured CP Asymmetry in the Decay $B \to \pi^+\pi^-$ as a function of the time difference as measured by the BELLE experiment.

American convention). While a year ago, there were differences between the two experiments, at this conference BELLE reported [26] $sin\ 2\beta = 0.82 \pm 0.12(stat) \pm 0.05(syst)$ while BaBar reported [27] $sin\ 2\beta = 0.75 \pm 0.09(stat) \pm 0.04(syst)$. The quality of the BaBar results is illustrated in Fig. 4. The agreement is now satisfactory. The changes to the results from each experiment, came not only from the increased statistics accrued during the past year but also from refinements to the analyses.

The decay $B \to \pi\pi$ is related to the CKM parameter $sin\ 2\alpha$; unfortunately this relationship is not as clean as that for $sin\ 2\beta$. There are several different phases at work since the loop (penguin) diagrams are expected to play a large rôle. The data are fit for both sine and cosine variation; the latter indicates the possible direct CP violation component. BaBar sees [28] essentially no CP violation with the results $S = -0.01 \pm 0.37(stat) \pm 0.07(syst)$ and $C = -0.02 \pm 0.29(stat) \pm 0.07(syst)$. In contrast BELLE sees substantial CP violation, indeed, their fit results [29] violate a constraint that the quadratic sum of C and S not exceed unity. They find $S = -1.21 + 0.38 - 0.27(stat) + 0.16 - 0.13(syst)$ and $C = -0.94 \pm +0.25 - 0.31(stat) \pm 0.09(syst)$ (Again we use the sign convention used by BaBar, which changes the sign of the cosine coefficient presented by Belle). The results from BELLE are shown in Fig. 5.

The B factory experiments and their predecessor CLEO have a broad physics program. The yield of final states with charm is impressive [34] and the resulting physics is very interesting [35]. In this context the recent B-factory measurements of $D^0 - \bar{D}^0$ mixing now have uncertainties of about $\pm$ 1%, slightly less than the previous Fermilab experiments, FOCUS and E791(FNAL), and of CLEO. Thus far their results [34] are consistent with zero at this level.

Beyond the reach of the B factories are the B_s states and the mixing between the neutral B_s mesons, which is controlled by the length of one side of the unitarity triangle. Results come from LEP [36], and from the SLD [37] experiment at SLAC. The results from the SLD experiment are not quite final; the present limit, based on the world data, gives a limit of $\Delta m_s > 14.9\ ps^{-1}$ at 95% confidence level, on the mixing parameter.

The study of the CKM matrix, will eventually depend on the interweaving of many different measurements. In addition to the much touted measurements of $B \to J/\psi K_S$ or $B \to \pi\pi$, many of the rare decays can shed light on different aspects of the problem. By using more than one measurement, the relevant CP violating parameters are indirectly accessible. This has led to a recognition that a systematic approach, the *CKM Fitter*[30] is needed. In particular this initiative leads immediately to the incorporation of many of the rare B decay measurements[31,32,33] from BaBar, BELLE, and CLEO as well as rare K decays.

Meanwhile the measurements involving electroweak penguins, for example those of $b \to s\gamma$ transitions, immediately provide search windows beyond the standard model. We would expect the particles associated with the new physics to participate in the loops. Thus far nothing unexpected has been been seen[31,32].

5 Precision Electroweak Measurements

An important barometer of our understanding and comfort with the standard model is provided by the fit of a broad spectrum of electroweak data by the LEP Electro-Weak Working Group(EWWG).

The recently updated fit[38] contains several new components; however, let us begin with a well established parameter, the electromagnetic coupling constant $\alpha_{em}(m_Z)$ evaluated at the mass of the Z. α_{em} is well measured at low momentum transfers, however the extrapolation to m_Z involves a dispersion integral, which is usually evaluated using input from the experimental measurement of the ratio R of hadron production and muon pair production in electron-positron collisions. A similar, but not identical, integral also enters the hadronic component of the anomalous magnetic moment of the muon, $(g-2)_\mu$. The precision of the extrapolation has been improved[39] by the recent high precision data from the BES experiment on the BEPC collider in Beijing. These data are in the centre of mass energy range from 2 to 5 GeV. With uncertainties of about 6% on each measurement point, the contribution to the integral from this energy range has been reduced from more than 50% to less than 30% of the total error. This has prompted some imaginative attempts to obtain good measurements in other energy ranges. There are attempts to use initial state radiation in both the KLOE experiment[40] and the BaBar experiment[41]. The studies are in the preliminary stages, indeed at this conference there was considerable discussion as to how well the initial state radiation can be understood. Is the uncertainty near 2-3 % or much smaller? The energy ranges targeted are from threshold for $\pi\pi$ production to 1 GeV at KLOE, and in the ranges 1-2 GeV and 2-6 GeV at BaBar.

New this year are the direct measurements[43] of the W boson width from LEP and we can expect that the equivalent measurements from the Tevatron will also be incorporated soon. The W masses themselves are not yet final[43]. There remain some final evaluations of systematic uncertainties by the experiments, which are expected soon. Of some concern are the possible effects of Bose-Einstein correlations and color recombination. In the former case, the effects are observed[42] when the two particles originate from a single W decay, but not when the the two pions originate from different W bosons. Since I had understood Bose-Einstein correlations to be simply related to the source size, this appears bizarre to me. As for the attempts to determine the color-recombination effects, the experiments appear to have a broad range of results. Fortunately, even if it is decided that a strategic retreat is necessary, relinquishing the all-hadronic decays would only lead to an increase of a few MeV in the final LEP W mass uncertainty.

Also fresh are the determinations of the forward-backward asymmetries $A^{0,b}_{fb}$ and $A^{0,c}_{fb}$, as a result of a new analysis[44,45] from ALEPH. In truth, the numbers have changed very little as a result of this reanalysis. Nevertheless, it is clear that a vital piece of the story is the judgement as to which errors are common to the several experiments and which are not. Those in the former category do not decrease with multiple measurements. As presented, the data sets seem to be remarkably consistent across the LEP experiments; there is nothing remarkable about the ALEPH result.

In the past year the neutrino scattering experiment, NuTeV at the Fermilab Tevatron has presented new results[46] on the determination of $sin^2\theta_W^{on-shell} = 0.2277 \pm 0.0013(stat) \pm 0.0009(syst)$,

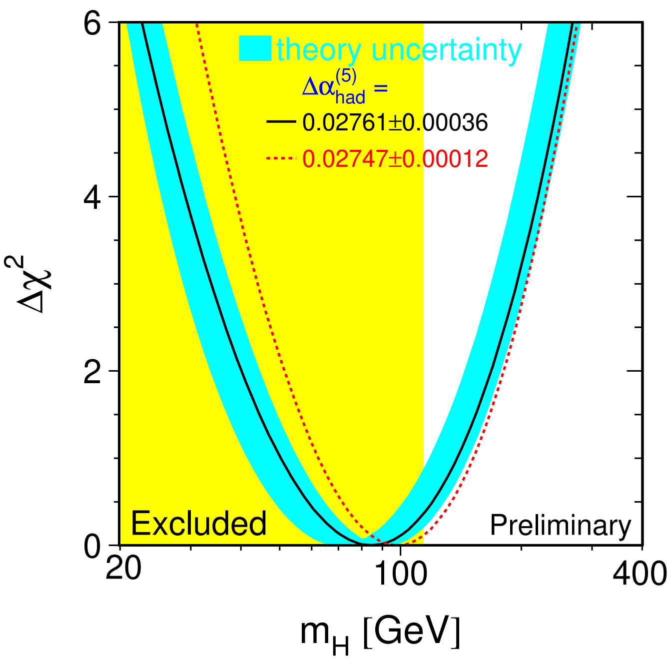

Figure 6: The Winter 2002, ElectroWeak Working Group fit showing the $\Delta\chi^2$ as a function of Higgs mass, and the region of Higgs mass excluded by the direct searches.

the electro-weak mixing angle. The basic measurement is that of the ratio between the neutral and charged current interactions using beams of both neutrinos and antineutrinos. If expressed in terms of the W mass, to which it is closely related, the precision is of order 100 MeV, comparable to that from any individual measurement from either LEP or the Tevatron collider.

Finally there is a new value [38] for the atomic parity violating parameter Q_W measured with Cesium, which is also incorporated in the fit.

The result of the global fit of all the 20 parameters (at the highest level, many more when individual measurements are counted) gives a χ^2 of 29 for 15 degrees of freedom. This is a poor fit! Although one can read off the curve of $\Delta\chi^2$ that the mass of the Higgs should be less than 196 GeV with 95% confidence level, it is my opinion that it would be inappropriate to use such a fit to deduce such a limit. In olden times, we used to scale the individual uncertainties by a factor $\sqrt{\chi^2/n_{dof}}$ before making predictions!

Further, in an earlier section, the limit on the mass of a standard model Higgs from a direct searches was given [14] as about 114 GeV. As shown in Fig. 6 this limit is higher than the Higgs mass which gives the best fit of the standard model to the data.

6 Puzzles

Clearly the description of the previous section yields a puzzle. Why is the electroweak fit so bad? In straightforward terms the fit is bad because, as shown in Fig. 7, the NuTeV measurement, the forward-backward assymmetry for b quarks, and the W mass differ from the central value by +3.0, -2.64, and +1.73 σ, respectively. Chanowitz [47] has argued that the distinct differences, the inconsistency, between the leptonic and heavy quark determinations of the weak mixing, makes a physics statement. He also points out that, were the heavy quark measurements to be rejected for some reason, the central value of the Higgs mass would be much lower. I am hesitant

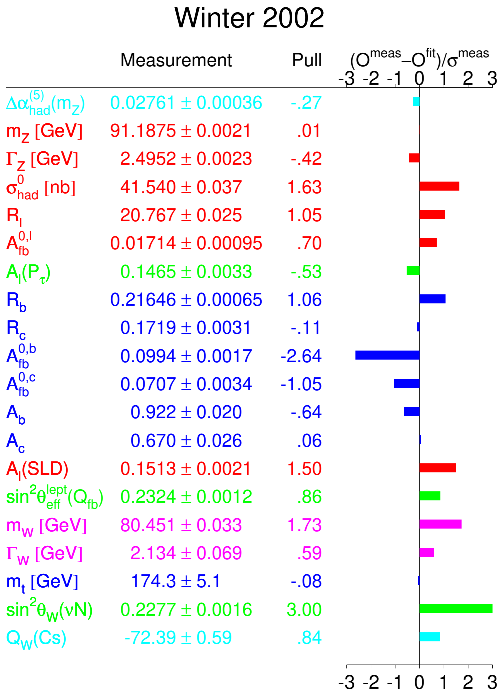

Figure 7: The Winter 2002, ElectroWeak Working Group fit showing the pulls of the twenty experimentally determined parameters.

to follow this path because there are many potential fault lines along which we might split the measurements; and, however well motivated, this is only one of the possibilities. Nevertheless, I would like to repeat my earlier conclusion that the fit is currently so bad that I would not use the implicit Higgs-mass limits for anything serious.

It is interesting that we are able to improve on classic experiments. In the late 1950s, the observation of parity violation in nuclear β decay changed the thinking about physics. A modern version of that same experiment, in which beams of neutrons are allowed to decay in a magnetic field, reports [48] that its results are at variance with what one deduces based on measurements with the 2nd and 3rd generations of quarks. The experiment, in combination with the neutron lifetime determines $V_{ud} = 0.9713 \pm 0.0013$. The expectation that $V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 1$, if the CKM matrix is unitary, appears to be violated at the level of more than 2σ.

In the high energy regime, the Tevatron Collider experiments continue to analyse their 1992-96 data and CDF has found [7] a couple of issues in their data. One is that in the events with a W boson and several jets, it is very difficult to explain the yield of jets in which there are two B-tags of the jet. The two tags are provided by the presence of a soft lepton and by a large impact parameter. The probability of a standard explanation is about 0.4%. Similarly they have an abnormal yield of events with both leptons, a photon, and missing transverse energy. The anomaly has a probability of 0.7% to be explained by standard sources.

7 New Starts

If we had no experiments in view, the puzzles described in the previous section would truly represent a conundrum. Fortunately we are in a position to discuss a number of initiatives which can hope to illuminate our issues and to extend our horizons.

Over the past few years, the HERA machine has been upgraded and the experiments are poised[49] for a run which, through 2006, would take them into the realm of large statistics charged current measurements, and, using polarization, the decomposition of the observed cross sections into the multiple structure functions. The B factories have demonstrated superiority in e^+e^- collisions at the energy of the $\Upsilon(4S)$ so the CESR accelerator and the CLEO experiment have refocussed themselves[50] on the charm system and on a concerted attack on numerous outstanding issues concerning the QCD description of the bound states of quarks and gluons.

The neutrino field is rich in new experiments. The SNO experiment is ongoing[19], and, as we remarked earlier, is in a very productive phase. The KamLAND experiment[53] starts to use the neutrino fluxes from multiple reactors, and a new detector at the Kamioke mine to examine, in the laboratory, the low mass solar neutrino range of oscillations. Its sensitivity covers that of the popular Large Mixing Angle(LMA) solution, in which Δm^2 is a few 10^{-6} $(eV)^2$. The MiniBooNE detector[52] is taking its first beam this spring as it gears up to resolve the LSND mystery. The minimalists will hope for a negative result while others will hope that the results demand a fourth neutrino-like state. The definitive measurements concerning the intermediate mass mixing solutions, used to describe the atmospheric neutrino phenomena may well come from the new long-baseline accelerator-based experiments[17] NUMI/MINOS(Fermilab to Soudan) and CNGS(CERN to Gran Sasso) with the Icarus[54] and Opera experiments; the former will be operating in about 3 years. However, we should note with pleasure that the Super-Kamiokande and K2K experiments will also be operational by then. Last-but-very-importantly, we are seeing serious initiatives, the HARP experiment[55] at CERN and the MIPP-E907 experiment at Fermilab, to measure the relevant hadron production cross sections and characteristics needed to determine the all-important source terms for many of the neutrino oscillation experiments.

The program of neutrino measurements, described above, can lead to an understanding of the systematics of the neutrino sector. Oscillations imply mass and the determining parameter is a mass difference squared. In order to obtain information on the masses themselves, we must look elsewhere. The NEMO 3 experiment[51] in the Frejus Laboratory, not to be confused with the putative underwater experiment in the Mediterranean Sea, is just starting to look for neutrino-less double-β decay. It incorporates important ancillary measurements designed to ensure that all the unknowns are systematically explored.

The energy frontier continues to attract a large fraction of our field; for the present and for several years to come, that frontier is at the Tevatron Collider. After an extensive upgrade to the accelerator complex at Fermilab, Tevatron operations have been reestablished during the past year. Although, as yet, the luminosity is modest, the experiments, also extensively upgraded, are operational. CDF shows off[57], among a number of interesting distributions, clear charm signals produced online on the basis of its new displaced vertex trigger. DØ touts[56] mass distributions obtained using its new tracking systems, silicon and scintillating fiber and, of course, its new solenoid. Both experiments have the traditional high energy signals of W and Z production and, with the jet signals at high E_T, it seems that the benefit to high mass production, of the modest(9%) increase in the Tevatron energy is visible.

All these new experimental efforts generate a clear and justified sense of expectancy in the field.

8 Perspective

When I accepted the task of giving the summary talk for this conference, I anticipated that the challenge would be to find any data, which could be taken as disagreeing slightly with our standard model. What I found was different.

The neutrino field is clearly pushing to extend and enrich the lepton sector. Incorporation of a neutrino mixing matrix into our accepted paradigm, seems only to be a matter of time.

The advance of the B factory measurements is truly impressive; as is often the case in our field, hero status goes to the accelerators as much as to the experiments. Of course the youth of the experiments, and of the analyses, ensures that agreement between the two experiments does not always come with the first presentations; this is healthy.

However, in the sectors already incorporated in a non-trivial manner in the model, the description of the data, as it presently stands, is distinctly ragged. The electroweak fit has a very low probability, P(χ^2). In the section entitled *Puzzles*, we enumerated the problems and also pointed out some others which, for me, are new, such as the neutron β decay asymmetry result.

Fortunately, at the same time, we can see that we have a number of experimental initiatives. In neutrino physics we have the opportunity to immediately push further. In high energy hadron collisions we are remounting an attack at the energy frontier which has been dormant for five years. In the lower energy arena, we are again demonstrating the ability of the field to maximize the exploitation of its investments, no matter how venerable.

In all, I learned a lot and I also learned that the field is healthy, where healthy means that it is not so easy to describe all the data to hand, and we will soon have more such data.

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