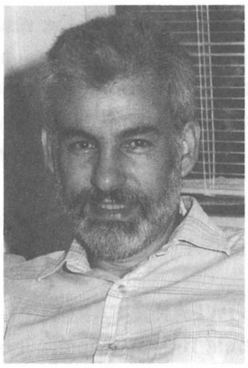
MORIOND '94 ELECTROWEAK SUMMARY TALK

Bruce Winstein
The University of Chicago, The Enrico Fermi Institute,
5640 South Ellis Avenue, Chicago, IL 60637



Abstract
This summarizes the presentations given at the 1994 Rencontre de Moriond on "Electroweak Interactions and Unified Theories." About 70 talks were given in the areas of precision electroweak physics, searches, 3rd generation decay physics, other experimental phenomena, speculative theory, and CP violation.

I. INTRODUCTORY REMARKS

For the purposes of this talk, I have divided the talks given into 5 categories. This classification is of course not unique. The categories are:

- Precision Electroweak, Searches
- 3rd Generation Decay Physics
- Other Experimental Phenomena
- Speculative Theory
- CP Violation

I will discuss the results presented in each category and will follow with some summary remarks.

Care should be taken in citing any of the results presented here: they range over published, submitted for publication, near-final, preliminary, very preliminary, pretty shaky, etc. One should definitely refer to the original material for the appropriate qualifications as well as for the relevant graphs and figures. The presenters for each topic discussed are noted and the reader is urged to check the individual write-ups.

By necessity, a selection of topics needed to be made for this summary. Those whose work is not reviewed should not feel slighted.

II. PRECISION ELECTROWEAK, SEARCHES

In this section, I will treat four subtopics: results from CHARM II, W mass measurements, measurements on the Z^0, and searches for leptoquarks, excited quarks, top quarks and Higgs bosons.

II-1. CHARM-II

The final determinations of g_V and g_A from νe^- cross-section measurements by the CHARM-II collaboration were presented by Coco. The results are g_V = -0.035(12)(12) and g_A = -0.503(6)(16). Using $g_V^l = e(-1/2 + 2\sin^2\Theta_W)$, and g_A^l = -1/2e, we find $\sin^2\Theta_W$ = 0.232(6)(6) and e = 1.006(12)(31). While these results are not competitive with those from the LEP experiments, they are of interest since they are obtained at significantly lower Q^2.

II-2. W Mass measurements

Both CDF and D0 have measurements of the W mass. This measurement tests the consistency of the electroweak relation:

$$\rho = \left(\frac{M_W}{M_Z}\right)^2 \frac{1}{1-\sin^2\Theta_W} = 1.$$

The measurement is made by fitting the "transverse mass" spectrum for carefully selected events with a leptonic W decay:

$$M_T^2 = 2P_T^l P_T^\nu [1 - \cos \Phi_{l\nu}].$$

The D0 result was presented by Choudhary. They use the eν decay and report M_W = 79.86(16)(20)(31) GeV where the last error is due to uncertainties in the calorimeter calibration. Calibration is an issue for D0 (lacking, for now, a magnetic field) and they must scale from the Z^0. They do see the J/ψ and the π^0 which are useful in checking the calibration.

The CDF result was presented by Kim. CDF uses both eν and $\mu\nu$ decays. The error resulting from structure function uncertainties is reduced by their own measurements of the leptonic charge asymmetry. They also show very good understanding of the calorimeter response to electrons, with distributions agreeing over several decades. This kind of understanding is characteristic of mature experiments. CDF reports M_W = 80.38(23) GeV.

These results are within a factor of two of the precision of $\sin^2\Theta_W$ from all of the LEP measurements. They are consistent, i.e., in agreement with the Standard Model. They will be improved with increasing statistics at the Tevatron. However, the measurements are difficult: the transverse mass distribution has a characteristic fall off over a range of about 10 GeV, dominated almost exclusively by detector resolution effects. These must be understood at the level of 1-2% to make further progress. The systematic uncertainty may well be less using LEP-II to make W pairs.

II-3. Precision Measurements on the Z^0

LEP continues to produce ever more precise results and a very high degree of understanding of a variety of effects is displayed. Here I divide this section into two parts: technology, and measurements.

II-3-A. Technology

There are a number of questions regarding the “technology” of understanding the Z^0 production process.

1. “Is theory ready to meet 10^{-3} precision with 5 x 10^{-4} theoretical uncertainties?”

This question was asked by Bardin. He reported on the workings of the LEP-I Precision Calculation Working Group which considers a whole variety of higher order corrections to the Z propagator, etc. Different fitters are used with different schemes for electroweak corrections to estimate the uncertainties. The answer is in the affirmative for now but more precise calculations will be needed to go below the 10^{-3} level.

2. Do we know the beam energy?

Wenninger reported on the technique of resonant depolarization used to determine the LEP beam energy. The current uncertainties in the beam energy give the following uncertainties on the Z parameters: $\delta \Gamma_Z = 3$ MeV; $\delta M_Z = 4$ MeV. These arise primarily from interpolation between calibrations and can be improved in the future. The technique allows the circumference of the LEP ring to be determined to 40 μm!

3. Do we know the beam polarization?

This question is relevant for the SLC. Here there have been advances in the understanding of Moller scattering due to the work of Levchuk, resolving a discrepancy in redundant polarization measurements as described by Woods. The polarization is determined most directly with a Compton polarimeter in the e^- beam immediately downstream of the interaction point. By this technique, the polarization is determined to roughly 1% every 3 minutes. This yields the result $P_e = (62.6 \pm 1.2)\%$, including a small chromatic correction and associated systematic errors. It thus seems that the beam polarization is well determined.

4. Do we know the luminosity?

Uncertainties in the luminosity measurements at the Z^0 effect the extracted physics. Relative errors during a scan across the peak will affect the determinations of M_Z and of Γ_Z while absolute errors will affect the extractions of the hadronic cross-section at the peak, $\sigma_h{}^0$, and the invisible width, R_{inv}.

The luminosity is monitored using Bhabha events; the distribution is very steep, $\approx \frac{1}{\theta^2}$, requiring high resolution, far forward detectors. The theoretical uncertainty (where the integral over the detector acceptance is done) is now at the 0.25% level with higher order calculations underway which should allow 0.1% uncertainty. These calculations were described by Trentadue and Jadach.

Three groups now have high precision Si detectors in place with geometry known to about 50 μm. The L3 monitor, described by Merk, has achieved 0.12% uncertainty. Comparable precision has been obtained by ALEPH and OPAL will soon be reporting on its precision.

II-3-B. The Electroweak Measurements

Now we are prepared to describe and discuss the measurements made on, or near to, the Z^0 resonance. These are divided into line shape measurements, b width measurements, and asymmetry measurements.

1. Line shape Measurements

Increased precision over earlier data sets was obtained primarily as a result of about a 4 times greater sample of off-peak data collected in 1993. The results, from simultaneous fits to the data from all four detectors, were presented by Clark. They are:

$M_Z = 91.1899(17)(40)_{LEP}$ GeV;
$\Gamma_Z = 2.4971(27)(27)_{LEP}(10)_{BKG}$ GeV;
$\sigma_h{}^0 = 41.51(3)_{stat.}(5)_{syst.}(6)_{exp.\ lum}(10)_{th.\ lum}$ nb; and,
$R_{had} = 20.789(40)$.

Then the following derived quantities result:

$\alpha_s = 0.1270(53)$;
$N_\nu = 2.980(24)$; and,
$M_t = 172(17)(19)_{Higgs}$ GeV.

These measurements are quite consistent among the different collaborations. There are roughly 1% shifts in the residuals across the Z^0 peak comparing data sets from year to year but, even so, these measurements are very impressive. They come entirely from the data from the Z^0 line shape.

2. $R_b = \Gamma_{b\bar{b}}/\Gamma_{had}$ Measurements

The status of these measurements was reviewed by Siegrist. R_b is sensitive to vertex effects including the top quark and a possible charged Higgs boson. For example, a 200 GeV top quark will alter this width by 2.2%. The extracted R_b is nearly independent of the Higgs mass and is obviously independent of the luminosity.

The measurement is difficult, depending on clean tagging of $b\bar{b}$ events. Different techniques are employed (lepton tagging, tagging by event shapes, tagging with recognized vertices). The experiments are internally consistent, using the different tagging techniques, and consistent with each other with the combined value being

$R_b = 0.2210(5)(18)$.

The result is about 2.9σ higher than expected using the central value of M_t obtained from the line shape measurements. It would be important to significantly improve this measurement; however it may be difficult to reduce the relatively large systematic error.

3. Asymmetry Measurements

The forward-backward asymmetry, extrapolated to the Z^0 pole, in the process ee $\rightarrow$ ff is given by $A^0 = \frac{3}{4}A_eA_f$ where

$$A_f = \frac{2g_Vg_A}{g_V^2 + g_A^2} = 2\frac{1-4Q\sin^2\Theta_W}{1 + (1-4Q\sin^2\Theta_W)^2}.$$

Also, we have:

$$A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = P_eA_e,$$

where P_e is the polarization of the electron beam.

The four kinds of asymmetry measurements that are distinguished are: forward backward (A_{LR}); lepton asymmetries (e, μ, τ); τ polarization asymmetries; and quark asymmetries (primarily b).

A. A_{LR} at SLD

This measurement was described by Woods; it is relatively straightforward, at least once you have polarized electrons! Event selection is not critical and is done using the calorimeter. The corrections are relatively small at this point; however, statistics are limited with only about 50,000 events collected. The result is

$$A_{LR} = 0.1656(73)_{stat}(32)_{syst}.$$

This leads to the value for $\sin^2\Theta_W$ of:

$$\sin^2\Theta_W = 0.2288(9)(4) \quad \text{SLD '93;}$$

including earlier data, the result is

$$\sin^2\Theta_W = 0.2290(10) \qquad \text{SLD '92-3.}$$

This result is about 2.5σ away from that derived from the LEP line shape data alone and by itself would imply a top mass above 200 GeV. This discrepancy should get resolved one way or the other soon as significantly more statistics will be collected by SLD.

It is interesting that the SLD result implies

$$\boxed{\Theta_W = \frac{1}{2}}$$

within the errors! (At least it's an easy expression to remember.)

B. Lepton Asymmetry Measurements

All the asymmetry measurements were reviewed by Pietrzyk; there was also a contribution from Vitale on the DELPHI results on asymmetries with s quarks.

The asymmetries when extrapolated to the pole are small; the result of the grand average over all three leptons and four experiments is:

$$A_{FB}{}^{0}\text{ (lepton)} = 0.0170(16).$$

However, the two most precise experiments (ALEPH and OPAL) differ by 0.0089(35) or 2.5σ. Also, the two most precise asymmetries (τ and μ) differ by 2.4σ: $A_{FB}{}^{0}(\tau) - A_{FB}{}^{0}(\mu) = 0.0078(32)$. Thus it may be premature to average all of these results, at least not without inflating the error as is standard practice by the Particle Data Group.

C. τ Polarization Asymmetries

The angular distribution of the τ polarization is given by:

$$P_\tau = -\frac{A_\tau(1-\cos^2\theta) + 2A_e\cos\theta}{(1+\cos^2\theta) + 2A_eA_\tau\cos\theta}).$$

The measurements of the polarization are fit for the quantities

$$A_\tau{}^0 = -\langle P_\tau \rangle \text{ and } A_e{}^0 = -\frac{3}{4}P_\tau{}^{FB}.$$

The results are shown below, again in comparison with the corresponding measurement from SLD:

$A_e{}^0 = 0.120(12)$ LEP;
$A_\tau{}^0 = 0.150(10)$ LEP;
$A_{LR}{}^0 = 0.166(8)$ SLD.

These measurements are not in the best agreement, especially considering that it is very difficult to blame the 3.2σ discrepancy between the first and third of the measurements on any “new physics.” There is also an anomaly in the polarization observed across the ρ peak by the L3 collaboration so that it may again be premature to average these results to draw conclusions about $\sin^2\Theta_W$, the top mass, or the absence of “new physics.”

D. Forward-backward asymmetry in $b\bar{b}$ events.

Here the agreement among the four experiments is very good as is the consistency with different methods of tagging the b quarks. The result is $A_{bb}{}^{FB} = 0.095(4)(2)$. This leads to $A_b = 0.84(6)$ from LEP which can be compared to the value obtained from SLD: $A_b = 0.99(14)$ as presented by Junk.

Grand Fit To All LEP Results

The result of the grand fit to all of the new LEP results, including asymmetries, was presented by Pietrzyk. The fit gives $M_t = 165(13.5)(18.5)$ and $\alpha_s = 0.125(5)$ although I have some reservations, as described above, about taking these determinations too seriously at the present time.

In general, the LEP results are precise and impressive. What do they tell us? This was discussed by Caravoglias and Schildknecht. In general, we are beginning to see pure electroweak radiative corrections, i.e., the data demand that these be included; M_t in the 150-200 GeV range is favored; and we can't as yet either confirm or rule out supersymmetry.

II-4. Searches

Here we discuss searches for new signatures being carried out in ep collisions (HERA) and in $\bar{p}p$ collisions (TEVATRON). We also mention the latest Higgs search results from LEP.

HERA SEARCHES

The center-of-mass energy is about 300 GeV and the accumulated luminosity to date is about 0.5 pb^{-1} per experiment. When design luminosity is reached (100 pb^{-1}), the sensitivities will be greatly extended.

Hapke presented the results of the H1 experiment. The charged current cross-section has been measured and found to be:

$$\sigma^{cc}(P_T^{\nu} > 25 \text{ GeV}) = 55(15)(6) \text{ pb}$$

a value that is now 5σ away from the value neglecting the W propagator.

HERA is a good place to look for leptoquarks which can be formed in the s-channel. Limits are now in the 150-200 GeV range from both H1 and ZEUS. These ZEUS results and those on searches for excited quarks were presented by Murray.

TEVATRON SEARCHES

CDF and D0 are looking for new particles produced at the highest available center of mass energies. D0 limits on leptoquarks were presented by Merritt. The limits are 133 GeV for first generation scalars and range from 193 to 244 GeV for first generation vector leptoquarks. D0 has a limit of 600 GeV for a high mass W particle and 440 GeV for a high mass Z particle; for the latter, CDF has a limit of 495 GeV (Hauser). Both groups have limits on SUSY particle production and their limits on $W\gamma$ structure are shown in the following Table.

Collider Limits on Wγ Structure

	Δk	λ
CDF	-2.3 – 2.3	-0.7 – 0.7
D0	-2.5 – 2.7	-1.2 – 1.1

Both groups are also seeking the top quark. The reaction is $\bar{p}p \rightarrow \bar{t}\,t + X$ where both t quarks can decay semileptonically and/or one can use a b tag, either with a lepton or a secondary vertex. Cochran presented the D0 result, a 95% confidence level limit of 131 GeV. CDF has candidates but is not yet reporting a result[1] from their latest run. It would be good to determine the mass of this quark: in the Standard Model, it can begin to put constraints on the Higgs mass. However, Orr presented a phenomenological analysis indicating that it would be hard to measure the top mass to better than about 10 GeV at a hadron collider.

HIGGS LIMITS FROM LEP

Wyatt presented the most up-to-date analysis of the Higgs sensitivities of the four LEP experiments. These results are shown in the following Table.

Higgs Limits from the four LEP Experiments

Experiment	OPAL	ALEPH	L3	DELPHI
Data	93	93	92	93
95% Limit [GeV]	56.9	60.3	57.5	55.5

Only very small advances from here on will be possible before the beginning of LEP-II.

III. THIRD GENERATION DECAY PHYSICS

There were many new results presented in τ decays and in B decays; these will be summarized here, along with a few of the results in charm decays.

III-1. Tau Decays

Here there were results presented from LEP, from Argus, and from CLEO.

A. LEP

The LEP efforts were reviewed and presented by Kounine and Beck. Each experiment now has about 55,000 events with which to work. Results from an average of all four experiments on the lifetime, semileptonic branching ratio, and universality are given below:

$$\tau_\tau = 292.2 \pm 2.4 \text{ fs};$$

$$BR\,(\tau \to l\nu\bar{\nu}) = 17.85(14)\%;$$
$$G_\mu/G_e = 0.999(16);$$
$$G_\tau/G_e = 0.997(11).$$

From the measurement of the hadronic branching fraction,

$$R_\tau = \frac{\Gamma(\tau \to \text{hadrons})}{\Gamma(\tau \to \text{lepton})} = 3.62(3),$$

one can determine α_s; the result is:

$$\alpha_s = 0.1220(15)(40),$$

where the second error is from uncertainties in the theory.

Better measurements of multibody decays led to the killing of the "one-prong problem" in τ decays by L3, again by OPAL, and yet again by ALEPH.

B. ARGUS

The ARGUS collaboration is working with 354,000 τ pairs. Results from ARGUS, including branching ratio measurements of four modes with K and K* final states and modes with multiple π^0s, were presented by Hast. A V–A test was done: $\gamma_{AV} = 0.977(40)28$), showing that g_A and g_V are equal to within 4%. The Michel parameters in τ decay were measured; the results, presented by Goultvin, were:

$$\rho = 0.735(36)(20), \text{ and,}$$
$$\eta = 0.03(15).$$

This is the most precise measurement of ρ and the first measurement of η.

C. CLEO

The CLEO collaboration has a sample of 3,600,000 τ pairs. They have searched for neutrinoless decays in a variety of modes, setting limits in the 10^{-5} to 10^{-6} range. For modes with π^0s, they have determined:

$$BR(\tau \to h^\pm \pi^0) = 25.87(12)(42)\%,$$

once again killing the "one-prong problem." This work is described by Urheim.

CLEO has also determined the branching fraction

$$BR(\tau \to K\nu) = 0.66(7)(9),$$

consistent with the value from ALEPH of 0.63(7) reported by Ganis.

III-2. B Decays

HQET was reviewed by Mannel. From the $D^*e\nu$ decay of the B^0, the CKM parameter V_{cb} can be derived. Using CLEO data, the result is:

$$V_{cb} = 38(5)(4) \times 10^{-3}.$$

From this, we can calculate the Wolfenstein parameter A, finding 0.78.

Semileptonic decays are fairly well understood in this framework. Paschos presented ideas on hadronic energy distributions which may prove useful in the extraction of V_{ub} when more statistics are available. Nonleptonic decays still represent a theoretical problem.

Results on the $b \to s\gamma$ transition were presented by Martinelli and this mode was also discussed by Nath. This mode is sensitive to new physics, receiving contributions from charged Higgs', charginos, etc. It is penguin dominated. The inclusive branching ratio calculation is in progress, perhaps already limiting two-Higgs models.

CLEO has determined the K* branching ratio: $BR(B \to K^*\gamma) = (4.5 \pm 1.5 \pm 0.9) \times 10^{-5}$; a preliminary next-to-leading order calculation, using lattice QCD, of this exclusive mode was presented by Martinelli, giving $BR(B \to K^*\gamma) = (2.9 \pm 0.6) \times 10^{-5}$, at $M_t = 160$ GeV and increasing with M_t.

Experiments at the 4S, at the Z^0, and from the $\bar{p}p$ collider are all contributing new measurements in B physics and all are improving for the future.

A. LEP Results at the Z^0

The $b \to \tau\nu X$ branching ratio, which is sensitive to the contributions from a charged Higgs, has been measured by both ALEPH and L3 as presented by Diemoz. The Standard Model predicts 2.36(58)%; ALEPH finds 2.76(43)%, and L3 finds 2.4(7)(8)%. These results limit the charged Higgs coupling: $\tan\beta < 0.47\ M_H$[GeV].

Many results on masses and lifetimes were presented by Hessing. The major results are:

$$\tau_{B^\pm}/\tau_{B^0} = 1.14(15);$$
$$\tau_{B_s^0}/\tau_{B^0} = 1.11(18);$$
$$\tau_{\Lambda_b}/\tau_{B^0} = 0.75(12);$$
$$M_{B_s} = 5368 \pm 5.2 \text{ MeV};$$
$$M_{\Lambda_b} = 5627 \pm 22 \text{ MeV}.$$

For these results, ALEPH, OPAL, and DELPHI are in good agreement with each other and with theory; L3 will be getting into the game soon with its new vertex detector.

Abbaneo discussed the latest measurements of flavor oscillations in the B sector. Combining all experiments, the mass difference in the B_d system is determined to be $\Delta m_d = 0.519(61)\ ps^{-1}$; ALEPH is able to exclude low values for Δm_s, finding $\Delta m_s > 1.8\ ps^{-1}$.

B. Results at the 4S

The recent analysis efforts from ARGUS were given by Golutvin while those from CLEO were presented by Fujino.

Both ARGUS and CLEO have reported new measurements of the absolute branching ratio for $D^0 \to K^-\pi^+$; these are 3.41(12)(58)% and 3.95(8)(17)%, respectively.

Argus claims the observation of the $b \to sg$ transition at the level of 2%. This interesting measurement is in agreement with the expected rate; however, it is based on only two fully reconstructed non-charm B decay events: $K^+\pi^-$ and $K^-2\pi^- 2\pi^+$.

CLEO, based upon about 1200 fully reconstructed events, was able to:

1. Find (suppressed) internal and external spectator diagrams which interfere constructively in B decays, in contrast to destructively in charm decays;
2. Test factorization to about the 20% level;
3. Test the spin symmetry of HQET to about 30%.

All of these studies at the 4S will improve as the statistics is expected to improve markedly in the future.

C. CDF Results

Studies of B physics with the CDF detector at the Fermilab Tevatron were presented by Lockyer. Their silicon vertex detector (SVX) permits the reconstruction of displaced vertices in a high luminosity environment. They find τ_{B_s} = 1.41(25)(10) ps, in agreement with the LEP average value of 1.66(22) ps. CDF already has the largest samples of $B \to \psi K_S$ and $B_s \to \psi\Phi$ decays. It is now clear that CDF will be able to do a significant amount of B physics in the future, with more luminosity and better coverage with their Si detector.

IV. OTHER EXPERIMENTAL PHENOMENA

In this section, I briefly mention three topics: solar neutrinos, double β decay, and dark matter.

IV-1. Solar Neutrinos

The most recent results and status of Gallex were presented by Anselmann. Gallex is a 30.3 tonne detector of $GaCl_3$; the experiment and detector look to be very well understood. The reaction studied is:

$$^{71}Ga + \nu_e \to {}^{71}Ge + e^-.$$

For the grand average of the neutrino flux, taken over all Gallex running, a result which has been submitted for publication, they find 79(10)(6) SNUs. This appears to be in conflict with what is called the standard solar model which would predict about 135 SNUs.

This result is in good agreement with the less precise one from SAGE: 70(22) SNUs. If taken literally, this could be interpreted as strong evidence for neutrino oscillations with the favored MSW values of $\Delta m^2 \approx 5 \times 10^{-6}$ ev^2, $\sin^2(2\theta) \approx 5 \times 10^{-3}$. However, this interpretation is not unique.

Gallex will soon be checking its calibration, using a very hot ^{51}Cr ν source; this will provide an important confirmation of their understanding of the detector.

IV-2. $\beta\beta$ decay

Progress on double β decay experiments with Baksan was presented by Kirichenko. Pure $\beta\beta$ decay would signal lepton number violation and the ultimate goal is to reach $\approx 10^{24}$ year sensitivities with ^{136}Xe.

The $\beta\beta\nu\nu$ final state (in ^{150}Nd decay) is of interest in its own right and this has been studied using a prototype of the TPC which will ultimately be used for the ^{136}Xe experiment. The result is:

$$T_{1/2}\,(^{150}\mathrm{Nd}\ \beta\beta\nu\nu) = (1.7^{+0.62}_{-0.35} \pm 0.35) \times 10^{19}\ \mathrm{yrs},$$

in agreement with an earlier positive result from a UCSB group and a limit from Baksan.

IV-3. Dark Matter

We heard talks by de Rujula, Combes, Spiro, and Frank on the subject of dark matter. Do we really need it?; What's it composed of?; A cocktail, or a Norwegian Omelet?; What is the value of Ω? These were some of the issues addressed.

The MACHO and EROS collaborations (Laurent) have interesting evidence for "machos", compact dark objects, through micro-lensing of starlight. The duration of these "events" should be on the order of $\tau \approx 70\,(\frac{M}{M_0})^{1/2}$ days and it may not be an accident that the results are compatible with the galactic halo consisting entirely of machos with a mass of about 0.1 solar masses!

We are in a state of rapid development on this important problem, primarily brought about by new technologies (*e.g.* CCDs). There are many new galactic "rotation curves" available and it seems as if each galaxy has its own personality, many showing flat curves, consistent with a uniform distribution of dark matter, some showing falling curves consistent with no dark matter, and even some showing rising curves. Macho and Eros are both upgrading and running, and we are going to be learning a great deal more in the immediate future. Cold gas appears to be a new, viable possibility as well (Coombes) which can be experimentally probed. This is clearly an exciting time and we eagerly await further results.

V. Speculative Theory

There were many speculative theoretical talks presented at this conference. I originally wanted to rank these theories according to how easily they could be ruled out. But that tack did not work very well.

Various versions of and problems in string theory were presented by Kounnas, Brustein, West, and Veneziano. The avoidance of singularities and the inclusion of gravity are very appealing, even to experimentalists. Evidently, with "hyperunification", we'd be able to "unify all of the forces" and calculate everything were it not for some "technical difficulties." By the way, do we have "all of the forces?" If we found another one, would that rule out string theory? I doubt it.

Super symmetric theories were discussed by Ellwanger, Nath, Zwirner, and Altarelli. The fermion↔boson symmetry is again very appealing, even to experimentalists. Supersymmetry was depicted by Altarelli as "the standard way beyond the standard model." Fits for the parameters of supersymmetry are not conclusive and it seems that either one must observe directly the super symmetric partners or see proton decay in the channel $p \to \bar{\nu}K^+$. Again, supersymmetry appears to be hard to rule out.

Callan discussed the possible evolution of pure quantum mechanical states to mixed ones in the presence of black holes. It is interesting to ask if there could be a laboratory manifestation of this apparent violation of the superposition principle.

Yamawaki discussed the interesting speculation that the Higgs is really a $\bar{t}t$ condensate. Aside from the mass relation, it may be hard to distinguish this scenario from many other possibilities.

There were talks concentrating on the spectrum of fermion masses by Ramond, Hung, Fritzsch, and G. Cvetic.

Hung, with a 4 generation theory, related the flavor violating decay $K_L \to \mu e$ to the rate for $K_L \to \mu\mu$, limiting the masses of horizontal bosons.

Fritzsch, in his scenario, has $m_s \approx 200$ MeV: if true, this rather high value would further push down the expected value of ε'/ε in the standard model.

Ramond emphasized his "looking for zeros" in the mass matrix, to be able to predict the observed pattern of masses. It's like the game of "What's the next number in the series: 102, 119, 138, 151, 162, ___ ?"

The difference is that we've had the first five numbers now for more than 18 years. And we know that the series very likely terminates at 6 entries. And we pretty much know the range for the last number. It certainly didn't take Balmer that long, but of course he wasn't a theoretical physicist.[2]

VI. CP VIOLATION

After some introductory comments on CP non-conservation, I will discuss the status of current studies and prospects for further studies in K experiments, and the prospects for its study in B decays.

VI-1. Introduction

CP Violation is (evidently) important in the evolution of our world. To date, we have only one confirmed (laboratory) manifestation of the phenomenon, that being the impurity in the long-lived neutral kaon:

$$K_L \approx K_2 + \varepsilon K_1,$$

where $K_{1(2)}$ are the even(odd) CP eigenstates of the neutral kaon.

The origin of this impurity is a phase between kaon transition amplitudes to real and virtual states in the $K^0 \leftrightarrow \bar{K}^0$ transition.

There are many possible mechanisms that can account for this phase. Three are listed in the Table below.

Model	Mechanism	ε' ?	B asymmetries	electric dipole moments?	baryo-genesis?
Super-weak	$\Delta S = 2$	0	possible: $\sin(2\alpha)=-\sin(2\beta)$	0	No
Standard Model	$Im(V_{td}) = \eta\lambda^3$	10^{-4} - 10^{-3}	large	negligible	No (Gavela)
L–R	W_L, W_R box	$\neq 0$	generally small	within range	Yes (Tytgat)

Superweak type models effectively involve a direct transition changing strangeness by two units. In such models, the direct effect, parameterized by ε'/ε in the 2π decays of the neutral kaon, will vanish. Such models can have general $\Delta F = 2$ transitions so mixing can show up in the B (and even D) system. But such an effect will be characterized by precisely equal and opposite effects in the ΨK_S and $\pi\pi$ final states. Superweak models give no electric dipole moments and cannot themselves account for baryogenesis.

On the other hand, the standard model can accommodate CP violation quite naturally in the CKM matrix. The phase is most conveniently located with the elements V_{ub} and V_{td}, the latter appearing both in the $K^0 \leftrightarrow \bar{K}^0$ box and the $K \rightarrow 2\pi$ penguin decay diagrams. ε'/ε is in the range 10^{-4} to 10^{-3} in the Standard Model (more on this later), the B asymmetries are expected to be large, and electric dipole moments are expected to be negligible. There has been quite a bit of speculation recently about whether Standard Model physics alone can give baryogenesis; Gavela answered in the negative at this conference.

Finally, left/right symmetric models can also have CP violation; more phases are possible and ε is generated by means of the W_L, W_R box diagram. In these models, ε' is generally non-zero but B asymmetries are also generally small. Electric dipole moments are within the range of the next generation experiments. At this conference, Tytgat presented arguments in favor of the speculation that such models **can** account for baryogenesis.

One unique measurement in this area reported at the conference was a determination of the weak electric moment of the τ lepton by the ALEPH collaboration. In this first measurement, they find

$$|d_\tau^W| < 1.4 \times 10^{-17}\ e{*}cm\ (95\%).$$

VI-2. K Decay Experiments

There are six on-going experiments around the world whose primary interest is the study of CP violation in Kaon decays. These are KEK 246, KEK 162, CPLEAR, CERN NA48, FNAL KTeV, and DAPHNE. At this conference, we heard about all of these excepting KEK 162 which is a dedicated search for the mode $K_L \rightarrow \pi^0 e^+ e^-$, a channel which, in the Standard Model, will have a relatively large direct component. All in all, this effort is being carried out by about 400 physicists.

KEK 246 was described by Kedenko. Here one searches for T-odd correlations in the $K^+ \rightarrow \mu^+ \pi^0 \nu$ decay; a sensitivity of 6×10^{-4} in the polarization asymmetry error is expected which is nearly an order of magnitude improvement over existing measurements. Such an effect would signal physics beyond the Standard Model.

The status of CPLEAR was presented by Yeche. They are performing precision measurements of many of the parameters of neutral kaon decay, including η_{+-} and ϕ_{+-}. These allow sensitive CPT tests. Also, very sensitive measurements of the 3π decay asymmetries are being made.

NA48, KTeV, and DAPHNE are all focusing on measuring ε'/ε. There still remains a discrepancy in this quantity: NA31 (see the presentation of Buchholz) found $(23 \pm 6.5) \times 10^{-4}$ whereas E731 (see the presentation of Hsiung) found $(7.4 \pm 5.9) \times 10^{-4}$. While only about 2σ, the issue is whether the quantity is zero or non-zero. Both groups are constructing new experiments and beams to reach the 10^{-4} level of sensitivity. The new experiments should be taking first data in early 1996.

Both NA48 and KTeV will have new beam lines, calorimeters, triggers, and DAQ systems. NA48 will use liquid Krypton while KTeV will use pure CsI crystals for the calorimeter material. KTeV will use the same technique as employed in E731 while NA48 will now use two simultaneous beams.[3]

There is a difference in the way in which the two groups generate the K_S component. KTeV uses regeneration, employing a long active regenerator made of scintillation counters; in this way, inelastic events occurring in the regenerator are self-vetoing but nevertheless they do contribute to the ambient rate in the detector. NA48 uses a new technique which completely avoids the problems of a regenerator. A small part of the primary proton beam is channeled onto a close-by target and both this and the far upstream target are struck simultaneously, creating the two beams. Any detected event is associated with the proper target by means of a very finely constructed set of tagging counters in the K_S beam line.

Both of these are fixed target experiments. DAPHNE (also described by Buchholz) will use Φ decays to make correlated K_L-K_S pairs; this allows unique CPT symmetry tests as pointed out by Shabalin. Also, by tagging with the K_L, one can look for rare K_S decays particularly cleanly.

Other rare decay physics can be done with these kaon detectors. KTeV has emphasized many decays that can be probed at the 10^{-11} level. The same detector, upgraded, using the much higher intensity Fermilab Main Injector can increase the sensitivity to the 10^{-13} level.

At such levels of sensitivity, it is possible to cleanly determine important parts of the "unitarity triangle." The mode $K_L \to \pi^0\nu\nu$ remains a long term goal in the kaon decay community; its determination will directly measure the height of the triangle or the parameter η in the Wolfenstein notation. The "long-leg" of the triangle (V_{td}) can be measured using the decay $K^+ \to \pi^+\nu\nu$, as described by Witzig. And from B decays, the included angle β can be determined with good accuracy, allowing a precise, correction free check of the consistency of the picture. Here one does not need to accurately measure V_{ub} or the angles α and γ, each of which may be very difficult.

To summarize the Kaon sector, there could be results on ε'/ε by as early as 1997. Direct CP violation should be established by this coming generation of experiments, if it is bigger than about 3×10^{-4}. If so, we will have gone from one manifestation of the phenomena to two, a 100% increase in information. For the future, the rarer decays are promising avenues.

What is the theoretical situation? Martinelli presented the latest results of the lattice calculations from the Rome group in the context of the Standard Model. These results (which are in general agreement with those of Buras and collaborators from Munich) indicate $\varepsilon'/\varepsilon = (5.6 \pm 2.7) \times 10^{-4}$ and the distribution of the results, where the phase space over all variations of the relevant parameters is populated uniformly, indicates that $\varepsilon'/\varepsilon > 3 \times 10^{-4}$ more than 90% of the time.

VI-3. B Experiments

The "lamp post" that our community is preparing to look under now appears to be in the sector of B decays. It is well known that, in principle, there is a clean association between measured asymmetries in the decays of the B^0 and its anti particle to CP eigenstates and the interior angles of the unitarity triangle. (In fact, the entire triangle can be determined, in principle, from only CP violating asymmetry measurements, as discussed by Kayser.) It is this association coupled with the expected large asymmetries in the standard model that is attracting a very large segment of our community.

We list in the following Table B experiments on CP violation together with some characteristics of each.

Thirteen Ways of Looking at Beauty Asymmetries				
Experiment/ Facility	Category	Status	Environment	Discussed by:
SLAC B	Dedicated e^+e^-	Approved	e^+e^-	Marsike
TRISTAN (BELLE)	"	Approved	e^+e^-	Prebys
HERA B	Dedicated hadron	Proposed	fixed target 800 GeV	Spengler
FNAL B	Dedicated hadron (Tevatron)	To be proposed	$\bar{p}p$ 2 TeV	Lockyer
COBEX	Dedicated hadron (LHC)	Proposed	$\bar{p}p$, 14 TeV	Carboni
GAJET	Dedicated hadron (LHC)	"	fixed target 7 TeV	"
LHB	Dedicated hadron (LHC)	"	fixed target 7 TeV	"
RHIC	Dedicated hadron	To be proposed	$\bar{p}p$	
CLEO	Ongoing		e^+e^-	
CDF	"		$\bar{p}p$, 2 TeV	Lockyer
D0	"		$\bar{p}p$, 2 TeV	
Atlas	"Ongoing"		$\bar{p}p$, 14 TeV	Carboni
CMS	"Ongoing"		$\bar{p}p$, 14 TeV	"

The approved new facilities are the two dedicated asymmetric e^+e^- factories, at SLAC and at KEK. CLEO operates in the symmetric mode but with their increasing luminosity, there is a small chance that they could detect a CP violating asymmetry in various self-tagging modes. The five possibilities at LHC were discussed in detail by Carboni; even the large collider experiments will have sensitivity to the angle β but it will take one of the smaller, dedicated experiments,[4] with particle identification, to have good sensitivity to α.

The above experiments are essentially of five types. What follows are some personal comments on the various approaches, with the assumption that the Standard Model correctly gives the magnitudes of the expected asymmetries.

Asymmetric e^+e^- Machines (4S)

Here the machine is most critical, in supplying the necessary luminosity and a clean environment for vertex detection. On the other hand, the detector is relatively easy. Sin(2β) should be done; sin(2α) will depend upon the branching ratio to $\pi\pi$, backgrounds, particle ID, penguins, and luminosity. First results could be in about 2000.

800 GeV Fixed Target

This approach seems very difficult with effective operation at 30 MHz necessary. There was, however, not a full discussion of backgrounds, etc.. Sin(2β) may be the only possible measurement. HERA B could provide the first observation of CP violation outside the kaon system.

2 TeV Collider

With upgraded Tevatron collider experiments,[5] sin(2β) looks doable. The luminosity is relatively easy to achieve (Main Injector). Results could be in 2000.

15 TeV Collider

Here a precision sin(2β) measurement looks feasible. There is more uncertainty about sin(2α). Results possible in about 2005.

7 TeV Fixed Target (including COBEX)

These experiments should be able to measure sin(2β) and sin(2α) accurately. They will have particle ID and plenty of rate. Again results in about 2005.

I believe that to do precision studies of the closure of the triangle and to make high statistics comparisons in a variety of modes, it will eventually be necessary to use the higher production rates at the $\bar{p}p$ machines.

VII. Concluding Remarks

This has been a good and stimulating conference! Let me list some of those things that should be put on a "watch list", i.e. some things to pay attention to in the near future.

A_{LR}
M_t
$\Gamma_{b\bar{b}}$
$b \to s\gamma$
Gallex, Sage
ε'/ε
$p \to \bar{\nu}K^+$
Dark Matter
Condensation to B Physics
LEP χ^2
•
•
•

A_{LR} is now about 3σ "off" but what is nice about this discrepancy is that it should be resolved in the very near future: SLAC should be collecting about 3 times the statistics that they now have in their current run.

The top mass has been on the list a very long time; hopefully it will be settled in the near future -- early indications from CDF place it right in the neighborhood predicted from other electroweak measurements. D0 should see it soon.

$\Gamma_{b\bar{b}}$ is a very interesting quantity and is currently high with respect to the standard model expectations. Hopefully ways will be discovered to reduce its (dominant) systematic error.

The interesting penguin process $b \to s\gamma$ should get pinned down further with more data (CLEO).

We are still in the dark about solar neutrinos.

The next generation ε'/ε experiments should find compelling evidence, if the standard model is correct, and this will constitute the first really new CP violating observable since the original discovery.

Proton decay is again something to watch with Super Kamiokanda and the predictions of supersymmetry.

Judging from our recent past, we will no doubt continue to learn rapidly about dark matter.

It will be interesting to watch the development of the many possible B physics initiatives around the globe.

The LEP χ^2 values, after being somewhat low for many years, have climbed up to close to 1 per degree of freedom; will this rising trend continue into 1994, or will they stay level?

It is true that we have nothing definite that points to phenomena "beyond" the Standard Model. But I want to emphasize that this is not our fault! All we can do is continue to perform good, sensitive experiments which this conference clearly shows we are doing.

Although I was forced to leave out some topics for lack of time (*e.g.* a discussion of the merits of a $\gamma\gamma$ collider for the formation of Higgs bosons by Veltman, or a comparison of pp vs. $\bar{p}p$ for SUSY studies by M. Cvetic), I nevertheless learned a great deal from all of the presentations. I wish to thank Tran and the scientific staff for a very well-run conference, and particularly the secretarial staff for their assistance in putting this talk together in real time.

---

[1]A short time after this meeting, the CDF collaboration announced evidence for the top quark. Their signal would imply a mass of 174(17) GeV.

[2]The next number in the series was Pierre Ramond's room number at the conference, a number without zeros!

[3]The most important upgrade for NA48, revealed for the first time at this conference, is that they now write the "double ratio" as $R = \frac{\Gamma(K_L \to 2\pi^0)/\Gamma(K_S \to 2\pi^0)}{\Gamma(K_L \to \pi^+\pi^-)/\Gamma(K_S \to \pi^+\pi^-)}$, rather than as $R = \frac{\Gamma(K_L \to 2\pi^0)/\Gamma(K_L \to \pi^+\pi^-)}{\Gamma(K_S \to 2\pi^0)/\Gamma(K_S \to \pi^+\pi^-)}$.

[4]Since the time of this meeting, the LHC committee has decided to approve one dedicated B experiment, operating in the collider mode, and has called for a letter of intent from the proponents of COBEX, LHB, and GAJET.

[5]Since the time of this meeting, the FNAL PAC has given high priority to a dedicated B experiment, operating in the era of the Main Injector.