Conference Summary

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1. Introduction

The plenary session rapporteurs have given excellent summaries of the main contributions made to the Conference: it would be pointless for me to summarize their reports further, I could only distort the content of their messages. My rôle is rather to select some highlights which can be expected to leave a mark on the evolution of our understanding of particle physics. This unavoidably implies subjectivity and arbitrariness in the choices made, and much unfairness towards those whose contributions I chose to omit. I apologize in advance to them. I have deliberately set aside topics such as 'New Detectors and Experimental Techniques', 'Future Accelerators', and 'Particle Astrophysics and Cosmology', which are self-contained subjects and which have been superbly summarized by their respective rapporteurs. I also left aside Theory, which I am not competent to review, and, but this may be less justifiable, the many contributions which provide deeper and improved confirmation of the Standard Model, in both the electroweak and perturbative QCD sectors.

I chose to select three main topics: 'The third quark family', 'What are nucleons made of?' and 'Questions in neutrino physics', keeping for a last section 'Other selected topics' which did not fit into the three main chapters.

2. The third quark family

Glasgow has already been the host of a Conference in the Rochester series, more precisely in what was to become the Rochester series. It was in 1954, the 'Glasgow Conference on Nuclear and Meson Physics'. The mark it left in the history of our field is due to Gell-Mann and Pais. At that time the hyperons and the θ^0—the K_s of today—had already been observed and were known to decay weakly. The observation at the Brookhaven cosmotron that hyperons were produced copiously in π^-p interactions was a puzzle: if a reaction such as $\pi^- p \rightarrow \Lambda x$ could occur with a large cross-section why should Λ not decay promptly? Gell-Mann and Pais conjectured that while the electric charge and the third component of the isotopic spin ($I_z = Q - (S+1)/2$) were conserved in strong interactions, the latter was not in weak interactions. This, together with the concept of associated production, $\pi^- p \rightarrow \Lambda$ K, was providing an elegant solution to the problem: strangeness and the second quark family were born. It took twenty more years to unearth its other member, charm: the J/Ψ was discovered simultaneously at Brookhaven and SLAC in 1974. Here we are, another twenty years later, and to celebrate this double anniversary the Fermilab top data are offered as a present, a timely conclusion—as we today believe—to the history of the discovery of quarks. In this context it is amusing to remember a highlight of the 1984 Leipzig Conference, where strong presumptions in favour of the existence of a 40 GeV top quark were presented. It was undoubtedly a hiccup of Destiny who was confused between a twenty-year cycle and a ten-year cycle...

2.1. *The b sector: spectroscopy and couplings*

Before addressing the t sector a survey of the situation in the b sector is appropriate as a host of new data have been presented in many sections of this Conference.

The production of $b\bar{b}$ quark pairs is studied at Fermilab (CDF and D0) from a gluon source, at LEP (ALEPH, DELPHI, L3, OPAL) and the SLC (SLD) from a Z source, and at Cornell (CLEO) from an Υ (4S) source. In the latter case, the production of a pair of B mesons at rest is the only process kinematically allowed. In all other cases, B hadrons are produced with high momenta, and progress has been subjected to the availability of sophisticated vertex detectors which measure the impact parameter of a 10 GeV track with typical accuracies of 20 μm in the transverse plane, and 50 μm in the beam direction. It is interesting to remark that such detectors were generally not part of the original experiment design, they have been added at a later stage, and in most cases further upgrades are many decay channels possible, and contain several particles, B's and D's, having a proper lifetime in the picosecond range. In spite of the high quality of the vertex detector performance, it is usually not possible to resolve all vertices from the interaction point. This is a challenge for experimental ingenuity and a broad spectrum of analysis methods is being used. They range from fully reconstructed exclusive final states (at the price of low statistics) to inclusive studies using the large b mass as a tag (presence of a large impact parameter high momentum track, of a hard lepton and/or of a hard strange hadron, broad jet topology, etc.). From a comparison between events with a single jet tagged, and events with both jets tagged, it is possible to deduce both the tagging efficiency and the fraction of real b jets. Excellent control of systematics is mandatory to avoid the potential strong biases which threaten such analyses. As an illustration of current achievements, Fig. 1 shows a decay time distribution measured by OPAL where the contribution of $Z \to b\bar{b}$ decays is clearly demonstrated.

Figure 1. Distribution of $Z \to$ hadrons events in the OPAL detector plotted against the ratio between the decay length L and its error σ_L. The upper curve is for all events, the lower curve for non-tagged jets.

The fragmentation of b-quarks has been studied at LEP. On average, B-mesons identified from a characteristic semi-leptonic decay, carry a fraction $\langle x_B \rangle = 0.702 \pm 0.002 \pm 0.008$ of their parent quark momentum, and the x_B distribution is well reproduced by a Peterson function. However, pseudoscalar B-mesons are often not primordial but of vector parentage. The ratio $\Gamma(b \to B^*)/\Gamma(Z \to b\bar{b})$ is measured around compared to 0.75 naively expected. The radiative decay $B^* \to B\gamma$ has been studied in events where the radiated photon converts inside the detector into a measured e^+e^- pair. The angular distribution of the radiated photon in the B^* rest frame is isotropic, corresponding to a longitudinal fraction of about one third ($\pm \sim 0.1$).

In addition to the Υ and χ states of the $b\bar{b}$ family, the B hadrons currently identified are listed in Table 1 (note the puzzling low value of the Λ_b to B^0 lifetime ratio, ~ 3 standard deviations from expectation).

The universality of quark couplings to the gauge bosons has been verified in the b-sector. At LEP and the SLC the measurements of the forward–backward asymmetry A^b_{FB} and of the ratio

$$R^z_b = \Gamma^z_{b\bar{b}}/\Gamma^z_{hadrons} = 21.92 \pm 0.18\%$$

are in acceptable agreement with Standard Model predictions (R^z_b is 1.8 σ away). The measurement of the strong coupling constant in $Z \to b\bar{b}g$ events is consistent with that obtained with jets of lighter flavours. Moreover, the b production cross-section in $p\bar{p}$ collisions has been measured by CDF a factor of 1.5 to 2 above QCD NLO predictions. The disagreement corresponds to only 2 standard deviations when experimental and theoretical uncertainties are taken into account. Moreover, D0 data indicate a much better agreement with theory.

2.2. The b-sector: decays

Standard b-decays proceed via a $b \to cW$ transition and are governed by the CKM matrix element V_{cb}. The W may decay on its own, as in B$\to D\ell\nu$, or recombine with the quarks in the original hadron, either internally or externally. Several new results have been presented in this sector: an update by CLEO of their measurement of

$$\Gamma(\bar{B}_0 \to D^{*+}\pi^-)/\frac{d\Gamma}{dq^2}\,(\bar{B}_0 \to D^{*+}\ell^-\nu)$$

at $q^2 = m^2_\pi$, equal to $6\pi^2\ |V_{ud}|^2\ f^2_\pi$, which provides an elegant test of the factorization of the weak $b \to cW$ vertex from the strong processes at work; a measurement of the average number of c quarks per b decay, 1.072 ± 0.076 as compared with 1.15 expected from $c\bar{u}d$ and $c\bar{c}s$ together; a measurement of $b \to c\bar{c}s/b \to c\bar{u}d = 20 \pm 13 \pm 4\%$; the observation of 15 ± 5 reconstructed $B \to \Lambda_c^+\ \bar{p}\ \pi^+\pi^-$ decays corresponding to a branching ratio of the order of 2‰, etc. They refine our knowledge and understanding of the relevant processes. An important puzzle concerning semi-leptonic decays may be on its way to being solved. The new measured value of the semi-leptonic branching

$B_d^0,\ \bar{B}_d^0$	0^-	$d\bar{b},\ \bar{d}b$	$5279 \pm\ 2$	1614 ± 78
$B^\pm$	0^-	$u\bar{b}, \bar{u}b$	$5279 \pm\ 2$	1652 ± 65 $(1.003 \pm 0.069)\tau^0$
$B_s^0,\ \bar{B}_s^0$	0^-	$s\bar{b}, \bar{s}b$	5368.1 ± 3.8	1560 ± 40
$B_c^\pm$	0^-	$c\bar{b}, \bar{c}b$	not identified - limits available in the $\mathrm{J}/\Psi x$ and $\mathrm{J}/\Psi \ell \nu x$ modes	
B*	1^-	like B's	$\Delta m(B^* - B) = 45 \pm 1$	Prompt $B^* \rightarrow B\gamma$
Λ_b	$1/2^+$	udb	no exclusively reconstructed events	1170 ± 110 $\tau_\Lambda/\tau_{B^0} = 0.72 \pm 0.08$
Ξ_b	$1/2^+$	usb		$\simeq 1140^{+55}_{-38}$

Table 1.

ratio, 11.2 ± 0.3%, is not much higher than last year's value, 10.7 ± 0.3%, and remains well below the theoretical lower limit of $\simeq 12.5\%$. QCD corrections to this limit are now available, but lower it only slightly. It has been argued that the discrepancy can be removed by using a low c mass in the calculation but this would have the effect of unduly increasing the $b \rightarrow c\bar{c}s / b \rightarrow c\bar{u}d$ ratio as the available phase space would increase. The problem is therefore still with us but somewhat toned down. Finally, semi-leptonic decays with a D or D* in the final state are known to account for only 70% of all semi-leptonic decays. Decays with a D** in the final state have now been observed in agreement with expectations.

In principle rare B-decays are a powerful laboratory to set limits on non-standard processes which could be competitive mediators. In practice, the limits obtained are not yet very constraining but their potential interest calls for a brief review of the main results. Limits on the branching ratio of $\mathrm{B}^\pm \rightarrow \tau^\pm \nu$ are available from CLEO and ALEPH, 2.2‰ and 1.5‰, respectively, as compared to about 10^{-4} expected from the $b\bar{u} \rightarrow W^- \rightarrow \tau^- \nu$ Standard Model process. In addition to the information they contribute to V_{ub}, they set a limit on to the mass of the charged SUSY Higgs which could mediate the decay in the place of W, $m\ (H^\pm) > 1.5 \tan\beta$ GeV ($\tan\beta$ is the usual vacuum expectation value ratio).

From a very beautiful analysis of a sample of 2 million $\mathrm{B}\bar{B}$ decays accumulated by CLEO (2 fb^{-1}) the $b \rightarrow s\gamma$ branching ratio is measured to be $(2.3 \pm 0.7)\,10^{-4}$, at the level expected from the Standard Model where the decay is dominated by a Wt penguin loop from which the photon is radiated. The decay $b \rightarrow s\ell^+\ell^-$ may proceed via the same diagram with $\gamma, Z \rightarrow \ell^+\ell^-$ but may also be mediated by a Wt box diagram with a lepton emitted from each of the two remaining vertices. A limit on

$$BR\ (B^\pm \rightarrow \mu^+\mu^- K^\pm) < 3.2\ \times\ 10^{-5}$$

has been presented by CDF, still two orders of magnitude above the Standard Model expectation.

Hadronic charmless decays may result from a $b \rightarrow s$ or $b \rightarrow d$ transition mediated by a Wt penguin loop as for $b \rightarrow s\gamma$, the photon being replaced by a gluon, but may also proceed via a Cabibbo suppressed $b \rightarrow Wu$ transition. New results include limits on

$$BR\ (B \rightarrow \pi^+\pi^-) < 2.2\ \times\ 10^{-5}\ ,$$

on the ratio

$$BR\ (B \rightarrow \rho/\omega\gamma)/BR(B \rightarrow K^*\gamma) < 0.34$$

(which constrains the ratio $|Vtd|/|Vts|$) and, from LEP, on numerous processes such as $\mathrm{B}_s \rightarrow \phi\gamma$, $\Lambda_b \rightarrow \Lambda\gamma$, $B \rightarrow \eta\eta$, $\eta\pi^0$, B → pions and/or kaons, $\mathrm{B} \rightarrow h^+h^-$, etc. In addition to the constraints they place on the CKM matrix they provide precious material

B-decays are an important ingredient in the determination of the CKM matrix elements, in particular as a much more accurate evaluation of V_{cb} has now become available. Together with data obtained in other quark sectors (including the Fermilab top data) they allow for an updated fit to be obtained, using the standard Wolfenstein form

$$1+\lambda \left|\begin{array}{ccc} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 0 \end{array}\right| + \frac{\lambda^2}{2} \left|\begin{array}{ccc} -1 & 0 & 0 \\ 0 & -1 & 2A \\ 0 & -2A & 0 \end{array}\right| + A\lambda^3 \left|\begin{array}{ccc} 0 & 0 & \rho^* \\ 0 & 0 & 0 \\ 1-\rho & 0 & 0 \end{array}\right|$$

The result (A. Ali) is

$$\begin{aligned} \lambda &= 0.2205 \pm 0.0018 \\ A &= 0.80 \pm 0.12 \\ |\rho| &= 0.36 \pm 0.14 \\ & \sin 2\beta \geq 0.2 \end{aligned}$$

as illustrated in Fig. 2.

Figure 2. The allowed domain in the complex ρ plane of a fit (Ali) of the CKM matrix using $f(B_d) = 180 \pm 50$ MeV and box parameters $B(B_d) = 1.0 \pm 0.2$ and $B(K) = 0.8 \pm 0.2$.

An unfortunate consequence of the large top mass is the very low rate expected for direct CP violation in neutral kaon decays, $|\epsilon'/\epsilon| \lesssim 10^{-3}$.

2.3. The b-sector: oscillations and mixing

$B^0\bar{B}^0$ mixing proceeds via box diagrams dominated by the Wt loop and is therefore proportional to $|V_{td}^*\ V_{tb}|^2$ and $|V_{ts}^*\ V_{tb}|^2$ for B_d^0 and B_s^0, respectively. Using standard notations,

$$\sqrt{2}\ B_1 = B^0 + \bar{B}^0 \qquad \sqrt{2}\ B_2 = B^0 - \bar{B}^0$$

$$m(B_2) - m(B_1) = \Delta m \qquad \Gamma(B_2) \simeq \Gamma(B_1) = \Gamma$$

$$x = \Delta m/\Gamma\ ,$$

the time dependence of the flip probability is given by

$$P(t) = \frac{1}{2}\ e^{-\Gamma t}\ (1 - \cos\ \Delta m t)\ ,$$

$$\chi = x\ /2(1 + x\ )\ .$$

While B mixing is by now well established, the observation of time-dependent oscillations is recent and several new results were presented for the first time at the Conference.

If $Z \rightarrow b\bar{b}$ events could be unambiguously and fully reconstructed the resolution of the B decay vertices from the e^+e^- interaction vertex (from which the other quark fragments originate) would be a trivial matter. Moreover, as double flips occur rarely and can easily be corrected for, one could tell whether one of the B-mesons had flipped before decaying whenever the B-decay modes sign their B^0 or $\bar{B}^0$ nature (as is the case for semi-leptonic decays). However, the number of unambiguously and fully reconstructed events is small, and such analyses suffer from low statistics. It is therefore important to seek more inclusive signatures in order to deal with larger event samples, and various methods have been used which differ by their degree of inclusiveness and which provide evidence for time-dependent oscillations. On average the LEP experiments measure

$$\Delta m_d = 0.52 \pm 0.05\ (for\ \tau_B = 1.5\ ps)\ .$$

In such analyses an important asset is the ability to tell a $b\bar{b}$ from a $\bar{b}b$ configuration of the two-jet final state without requiring the identification of the B decay products. In the case of light quark jets the charge flow, $\sum q_i\ p_{i\|}$, is known to be a good indicator. In the present case, however, the sum includes the $B^0\bar{B}^0$ decay products which, in principle, should not contribute. As they carry a large fraction of the jet momenta and as the charge flow is not conserved in the decay process, they spoil the value of the information contained in the charge flow significantly. Another possible indicator is simply $\sum q_i$ (jet 1) $-\sum q_i$ (jet 2) which is of course conserved in the decay process but which is too sensitive to possible misassignments of the low momentum tracks. An intermediate indicator, $\sum q_i y_i$, where y_i stands for the rapidity measured along the axis of the jets, has been used by ALEPH with success. Their result (Fig. 3) sets a limit on the B_s contribution,

$$x_s > 9.0,\ \Delta m_s > 6.0\ ps^{-1}$$

(for $f_{Bs} = 12 \pm 4\%$). As can be seen in Fig. 3, such a limit is entirely defined from the very first lifetimes where early flips would be mostly due to $B_s^0 - \bar{B}_s^0$ transitions (and not on the non-observation of micro-oscillations superimposed on the global curve!)

A better limit on x_s would very valuably constrain V_{ts}: one may expect that an improved control and understanding of these analysis methods will soon make it possible to reach this goal.

Figure 3. Mixed fraction as a function of proper time. Left: the ALEPH fit with $x_s = 9$. Right: the B_s and B_d individual components. Also shown is the exponential decay rate.

2.4. The t-sector: constraints from Z data

The orthodox behaviour of the b-quark within the Standard Model framework imposes that the left-handed and right-handed third components of its weak isospin take the values $-1/2$ and 0, respectively. If the t-quark, its partner in the left-handed doublet, were absent, our understanding of particle physics would need a drastic revision—and we have no idea which kind. The quest for the top quark is therefore an essential objective of current experiments. Before addressing the evidence presented by Fermilab for top quark production in $\mathrm{p}\bar{p}$ collisions, let me briefly recall the constraint imposed on its mass by the Standard Model analysis of the very accurate Z data which are currently available.

The 1993 LEP run was dedicated to a refined measurement of the Z line shape. Significant progress with respect to earlier data resulted from major improvements in the measurements of the energies and luminosity of the colliding beams.

The LEP beam energy is obtained from a measurement of the electron spin precession by resonant depolarization. A spectacular demonstration of the precision achieved is illustrated in Fig. 4 which shows the effect of terrestrial tides on the beam energy. Terrestrial tides have a vertical amplitude reaching 25 cm (4×10^{-8} earth radius) corresponding to periodic variations of the circumference of the LEP ring reaching $\simeq 1\ mm$. Such changes induce in turn variations of the mean beam energy amplified by a factor of $\simeq$ 5000 by the strongly focusing quadrupoles and reaching ± 4 MeV. The agreement with a model calculation taking into account the relative positions of the sun and the moon with respect to the earth is impressive.

Less spectacular, but equally essential, have been the improvements achieved by the LEP experiments in measuring the collider luminosity. New silicon luminosity monitors have been installed to measure the Bhabha scattering cross-section in the angular range 25 to 60 mrad with an accuracy of the order of 1‰, typically five times better than previously.

Figure 4. LEP measurement of the Z line shape. Left: terrestrial tides, the relative energy variation $\Delta E/E$ in parts per million as a function of time (28 hours full scale). Right: the Z line shape in $Z \rightarrow$ hadrons.

As a result of these improvements (Fig. 4) the Standard Model parameters are now measured at LEP with unprecedented accuracies. In particular

$$\begin{aligned} m(Z) &= 91188.7\,(4.4)\ MeV \\ \alpha_s &= 0.126 \pm 0.005 \pm 0.002 \\ m(t) &= 173^{+12+18}_{-13-20}\ GeV\ . \end{aligned}$$

In the expressions for α_s, the strong coupling constant, and $m(t)$, the top quark mass, the second error accounts for our ignorance of the mass of the Higgs boson. The value of the top mass, which is obtained from higher-order terms dominated by the t loop correction to the W and Z propagators and to the $Z \rightarrow b\bar{b}$ vertex, is now much more strongly constrained than it was previously.

2.5. The t-sector: the Fermilab data

The evidence obtained at Fermilab for top quark production in $\mathrm{p}\bar{p}$ collisions has been presented in detail in both parallel and plenary sessions, and it would be pointless for me to repeat it here. It is conveniently summarized in Fig. 5 where the CDF and D0 results are compared with a QCD calculation to the second next leading order which is expected to be reliable to better than ±30% because of the very large q^2 scale. Let me simply recall that $t\bar{t}$ production in this mass range is dominated by $q\bar{q} \rightarrow g \rightarrow t\bar{t}$ diagrams, and that the t quark is expected to decay promptly as $t \rightarrow Wb$ before having a chance to fragment. Each W may decay into hadrons (BR $\simeq$ 68%) or into a lepton-neutrino pair (BR $\simeq$ 11% for each family), implying three possible kinds of events: $(W \rightarrow q\bar{q})^2 b\bar{b}$, $(W \rightarrow q\bar{q})(W \rightarrow \ell\nu)b\bar{b}$, and $(W \rightarrow \ell\nu)^2 b\bar{b}$. Events of the first kind are unsuitable been studied in great detail and much of the evidence presented rests on their analysis. A powerful signature is obtained by tagging one (or both) of the b jets by the presence of an extra lepton or, in the case of CDF, by the presence of a displaced vertex. The ten tagged events presented by CDF stand above background, by less than three standard deviations, however . Their distribution in phase space favours $t\bar{t}$ kinematics over background. The top mass inferred from the CDF data is

$$m(t) = 174 \pm 10^{+13}_{-12}\ GeV\ .$$

Figure 5. The CDF and D0 measurements of the $p\bar{p} \rightarrow t\bar{t}$ cross-section are compared with a QCD calculation to second next leading order.

Events of the third kind are particularly interesting and deserve further comments. The table below shows the number of dilepton events surviving successive cuts in the CDF analysis:

Cut	eμ	ee	$\mu\mu$
$P_T > 20$ GeV	8	702	588
Opposite charge	6	695	583
Isolation	5	685	571
Invariant mass	5	58	62
$\not{E}_T$ magnitude	2	0	1
$\not{E}_T$ direction	2	0	0
Two jets	2	0	0

The ee and $\mu\mu$ events show a low contamination of same-sign pairs, $\simeq$ 1%, indicating a small background contribution from 'fake' leptons, i.e. hadrons misidentified as leptons. Most of them ($\simeq$ 98%) survive the isolation cut and are well balanced in transverse energy They illustrate the quality of the lepton identification achieved by CDF.

The simple requirement that a $p\bar{p}$ interaction should produce an eμ pair with both lepton transverse momenta in excess of 20 GeV retains only 8 events, namely less than one event in one hundred billion interactions. This amazing rejection power illustrates the scarcity of possible sources of eμ pairs, essentially $b\bar{b}$, $Z \rightarrow \tau^+\tau^-$, W^+W^-, and of course $t\bar{t}$. At variance with the $t\bar{t}$ case, the first three categories do not need to be associated with additional jets which cost extra energy (their total transverse energy, $\sum E_T$, is accordingly expected to have a steeply falling distribution); while in the $t\bar{t}$ case, once you have paid the (high!) price for producing a top pair, you get the additional jets as a free gift: their $\sum E_T$ distribution is expected to be broad. Moreover, the first two categories, $b\bar{b}$ and $Z \rightarrow \tau^+\tau^-$, generate a much softer missing transverse energy ($\not{E}_T$) distribution than the last two: the two eμ events surviving the $\not{E}_T$ cut have indeed a much higher $\not{E}_T$ than the three rejected events. These remarks suggest that the probability for the two surviving events to result from known, non-top, sources must be very low. The existence of two additional eμ pairs, one in the D0 data and one in more recent CDF data (as announced at the Conference) reinforces this impression. The eμ backgrounds confessed by CDF and D0, 0.24 ± 0.06 and 0.27 ± 0.09 events, respectively, are somewhat arbitrary as they depend upon selection criteria which have been chosen to maintain a good detection efficiency for $t\bar{t}$ pairs down to m(t) $\simeq$ 100 GeV. But someone who knows nothing about top, not even that it may exist, would choose stricter cuts, in particular in $\not{E}_T$ and $\sum E_T$, in order to lower the expected background down to 0.01 events or so, and would most likely retain the 4 eμ events ... and claim compelling evidence for new physics. This argument is too naive and too superficial, and it should not be taken more seriously than it deserves to be. My point is simply to remark that the results quoted by CDF and D0 (3 eμ events above a background of 0.5 ± 0.1) do not tell us what the probability is for these 3 eμ events to have a standard, non-top origin. As far as we can judge from the information available to us, this probability must be very low.

Before concluding, we cannot ignore a number of oddities, which however can all be blamed on statistics: the CDF detector seems to attract $t\bar{t}$ pairs more than the D0 detector does (although both should have similar sensitivities to a top signature), all three dileptons (two from CDF and one from D0) are eμ pairs, two of the $Z+ \geq 3$ jets events in the CDF data are tagged (instead is saturated by $t\bar{t}$ pairs).

Quoting from CDF: 'the data give evidence for, but do not firmly establish the existence of, $t\bar{t}$ production in p$\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV'. I am not sure what this means exactly except that Fermilab must now give top priority to collider operation as the world is eagerly awaiting more data. Both D0 and CDF detectors are under excellent control, they explore a territory to which they have exclusive access, they address a physics issue of the utmost importance, they seem to have a spectacular eμ signal (if it is not top, what else could it be?), their lepton + jets data need significantly improved statistics, and the Fermilab Collider is now reaching luminosities in excess of 10^{31} cm^{-2} s^{-1}. An integrated luminosity of $\simeq 200$ pb^{-1} should be sufficient and is a goal which seems to be attainable: we all hope that it will be reached soon.

2.6. The t-sector: is m(t) trying to tell us something?

Before leaving the subject let us accept the CDF result and have a (coarse) look at the mass spectrum of all known elementary particles (Fig. 6). The very high value of the top mass is really intriguing. The fermion mass spectrum, excluding neutrinos, spans nearly six orders of magnitude and the coupling constant of the top quark to the standard Higgs boson is of order unity, $(\sqrt{2}\ G_F)^{1/2}\ m(t) \simeq 0.7$. Is this trying to tell us something? This question has triggered a revived interest in theories which, in the wake of Nambu's original ideas, assign a dynamical rôle to the Yukawa couplings. It was also found that in the minimal SUSY model it is possible to generate the correct quark mass spectrum from the fixed point solution of the renormalization group equation by relating the ratio tanβ of the two vacuum expectation values to the top mass via $m(t) \simeq$ (190 GeV) sinβ. Such ideas, and many others, illustrate the recrudescence of theoretical activity triggered by the large top mass in this domain.

Finally we note that using the CDF value of $m(t)$ when setting to zero the quadratic divergences in SU(2)$_L\times$ U(1) implies $m(H) = 316 \pm 35$ GeV for the standard Higgs boson.

3. What are nucleons made of?

3.1. Up and down quarks

Several new results have been presented which improve significantly our knowledge of the distributions of u, $\bar{u}$, d, and $\bar{d}$ quarks inside the nucleon.

Figure 6. The mass spectrum of the known elementary bosons and fermions.

In p$\bar{p}$ collisions the charge asymmetry of the rapidity distribution of leptons from W decays reveals the asymmetry of the parent W's and is a sensitive measure of the u/d ratio [a W$^+$ is produced at tree level from the fusion of u(p) and $\bar{d}(\bar{p})$, a W$^-$ from d(p) and $\bar{u}(\bar{p})$] down to low x values ($\simeq 0.01$) and in a region where perturbative QCD is reliable. High statistics data are now available from Fermilab which constrain efficiently the relative distributions of u and d quarks inside the proton.

The NMC Collaboration has presented a new measurement of the Gottfried sum

$$S_G = \int_0^1 (F_2^p - F_2^n)\ \frac{dx}{x} = \frac{1}{3} + \frac{2}{3}\int_0^1 (\bar{u} - \bar{d})dx\ ,$$

in deep inelastic muon scattering. The difference, $F_2^p - F_2^n$, is obtained from a measurement of F_2^n/F_2^p deduced from the deuterium to hydrogen ratio (and free of normalization errors) and from an improved evaluation of F_2^d extending to lower x values than previously. The result, $\int_0^1 (\bar{d} - \bar{u})dx = 0.147 \pm 0.039$, is about 4 standard deviations away from zero and confirms the evidence for an excess of $\bar{d}$ over $\bar{u}$ quarks in the proton sea. An independent and direct confirmation is given by experiment NA51 which compares the Drell–Yan production of a muon pair in pp and pn collisions at $x \simeq 0.18$. The cross-section difference $\sigma_{pp} - \sigma_{pn}$ is proportional to $u(\bar{u} - \bar{d})$ to within a correction term, $(u - d)\ (5\bar{u} - 2\bar{d})/3$ accounting for the different u and d distributions. It is measured negative, three standard deviations away from zero. The flavour asymmetry of the nucleon sea is therefore now firmly established as shown in Fig. 7 which shows the result of a global fit to all available data. It is usually explained as being a consisting of a π^+ cloud around an n core, with the effect of pulling the $\bar{d}$ sea towards the periphery.

Figure 7. The difference between the $\bar{d}$ and $\bar{u}$ distributions as a function of x from a global fit to available data (Martin et al.).

3.2. The spin structure of nucleons

In electron and muon deep inelastic scattering on nucleons the structure function $g_1(x)$ describes the dependence upon the spin configuration in the initial state. Experiments using longitudinally polarized projectiles and targets measure the asymmetry between the parallel (+) and antiparallel (−) configurations. In the naive parton model $g_1(x) = 1/2 \sum e^2 \, (q^+ - q^-)$, where q^+ (q^-) describes the distributions of quarks and antiquarks having their spin parallel (antiparallel) to the nucleon spin. A few years ago the surprising EMC measurement of a low value of $\Delta q = q^+ - q^-$ suggested that quarks carry only a small fraction of the nucleon spin and prompted new measurements of g_1^p and g_1^d which have been presented at the Conference. They include electroproduction data from SLAC using NH_3 and ND_3 targets (E143), and muo-production data from CERN using hydrogenated and deuterated butanol targets (SMC). The CERN and SLAC data complement each other as SMC is at higher energy, and therefore reaches higher values of q^2 and $1/x$, while E143 have much higher statistics. The results are summarized in terms of sums, $\Gamma_1 = \int_0^1 g_1(x)dx$, implying extrapolations of the measured distributions to the full x-range:

$E143,\ q^2 = 3\ GeV^2 \qquad \Gamma_1^p = 0.129 \pm 0.004 \pm 0.010$
$E143,\ q^2 = 3\ GeV^2 \qquad \Gamma_1^d = 0.044 \pm 0.003 \pm 0.004$
SMC, $q^2 = 10\ GeV^2 \qquad \Gamma_1^p = 0.136 \pm 0.011 \pm 0.011$
SMC, q$^2 = 5\ GeV^2 \qquad \Gamma_1^d = 0.023 \pm 0.025$.

The neutron sum Γ_1^n is obtained from $\Gamma_1^n = 2\Gamma_1^d - \Gamma_1^p$ corrected for the D-state admixture in the deuteron

$$\Gamma_1^n = -0.033 \ \pm \ 0.008 \ \pm \ 0.013 \ ,$$

is in good agreement with the earlier E142 result obtained on a polarized ^{3}He target. The comparison of data from different experiments requires their evolution to a common value of q^2 as done by SMC in Fig. 8. It shows a compilation at $q^2 = 5\ GeV^2$ of all data excluding the new E143 results which are in good agreement with the overall picture.

Figure 8. The spin structure of the nucleon. Top: a compilation of available data (excluding E143) in the $\Gamma_1^p - \Gamma_1^n$ plane and the Bjorken sum rule. Bottom: The ratio $\Delta g/g$ for three different parametrizations from a global fit to available data (Gehrmann and Stirling).

$$S_{B_j} \equiv \Gamma_1^p \ - \ \Gamma_1^n = \frac{1}{6}\left|\frac{g_A}{g_V}\right| (1 - \frac{\alpha_s}{\pi} ...)$$

where the QCD corrections are now available to order α_s^3. The data of Fig. 8 ($q^2 = 5$ GeV^2) give

$$S_{B_j} = 0.163 \ \pm \ 0.017 \ ,$$

only 1.2 standard deviation below the theoretical value 0.185 ± 0.004, and the preliminary E143 data ($q^2 = 3$ GeV^2) give

$$S_{B_j} = 0.162 \pm 0.024 \ ,$$

in agreement with the theoretical value 0.171 ± 0.005. The Bjorken sum rule is therefore obeyed at the current level of experimental accuracy. However Δq remains low, although less than measured by the earlier EMC experiment, and quarks now appear to carry only one third of the proton spin. While some contribution of the strange quark sea cannot be ruled out, Gehrmann and Stirling have performed a global fit to all available data by assuming that it is unpolarized, and by putting the blame on a polarized gluon distribution, $\Delta g = g^+ - g^-$, which contributes a term $-\frac{1}{3} \ \frac{\alpha_s}{2\pi} \ \Delta g$ to g_1. Their result, shown in Fig. 8, indicates that the data are consistent with such a hypothesis and with a reasonable Δg distribution (which however remains unconstrained at large values of x). More data are required to understand better the gluon contribution to g_1. Processes in which the gluon polarization is probed directly, such as inelastic J/Ψ photoproduction, are particularly valuable. In electro- and muo-production experiments the measurement of semi-inclusive asymmetries should help disentangle sea from valence contributions. Preliminary results from SMC indicate $\Delta u > 0$ and $\Delta d < 0$ for valence quarks, while $\Delta\bar{q}$ is consistent with zero for sea quarks, $\int_0^1 \ \Delta\bar{q}dx = 0.07 \pm 0.07$.

3.3. HERA measurements of the proton structure

A highlight of the Conference has been the multitude of HERA contributions presented by the ZEUS and H1 Collaborations. They cover the totality of their 1993 data on ep collisions at $\sqrt{s} \simeq 300$ GeV (27 *GeV e* × 820 *GeV p*) for integrated luminosities or the order of 500 nb^{-1} per experiment. They give access to a completely new domain of x and q^2 (Fig. 9) where the proton structure can now be explored with good sensitivity. In particular the measurement of the scattering angle and energy of the electron makes it possible to calculate the structure function $F_2(x, q^2)$ down to x values two orders of magnitude Fig. 10. When analysed in terms of perturbative QCD, using the standard Altarelli–Parisi evolution equations, they imply a steep gluon distribution of the form $x \ g(x) \propto x^{-\omega}$ with $\omega \simeq 0.3$ to 0.5.

Gluon densities inside the nucleon depend upon log (1/x) and log (q^2) as very schematically indicated in Fig. 9. At fixed x, as q^2 increases, each gluon becomes better localized ($r \ \propto \ 1/q$) and occupies less of the nucleon cross-section. They increase in number and their evolution is well described by the Altarelli–Parisi equations. In the low x region the evolution is best described by the BFKL equation which, at fixed α_s, implies $x \ g(x) \propto \ x^{-\omega}$ with

$$\omega = 12 \ \log \ 2 \ \alpha_s/\pi \simeq 0.4$$

for $\alpha_s = 0.15$. At fixed q^2, when $1/x$ increases, more and more gluons appear in the nucleon up to a point where they saturate the nucleon cross-section and where shadowing must be taken into account to describe their recombination. The shadowing threshold in $1/x$ increases with q^2. The HERA data are consistent with a precocious onset of the BFKL regime, but provide no compelling evidence for shadowing. More detailed comments are premature at this stage. What matters is that a new domain is now open to exploration where our understanding of the transition between the perturbative and non-perturbative regimes of QCD can be expected to progress significantly.

3.4. The Pomeron

Another feature of the HERA data triggered intense interest: the occasional, but not rare, occurence of events with a large rapidity gap in the hadron distribution. This feature, which came as a surprise to the HERA community, is illustrated in Fig. 11 on H1 deep inelastic data. Rapidity gaps are also observed in p$\bar{p}$ collisions by CDF and D0 (Fig. 11) who report the existence of a significant fraction of two-jet events having very little hadronic ‘activity’ in the rapidity interval between the two jets. Such events find a simple explanation in terms of Pomeron exchange.

The exchange of a Pomeron having the quantum numbers of vacuum was first introduced in a Reggeon framework to describe diffractive and elastic scattering—and therefore the total cross-section—in hadron interactions. Donnachie and Landshoff have shown that an excellent description of the data is obtained with a Pomeron flux factor in the proton having the form $F(t, x) = (9\beta^2/4\pi^2) \ x^{1-2\alpha(t)} \ F_1^2(t)$, where $F_1(t)$ is the elastic form factor of the proton, $\beta^2 \simeq 3.5$ GeV^{-2} and where $\alpha(t) \simeq 1.08 \ + \ 0.25 \ t$ is the Pomeron trajectory. The first experimental evi-

Figure 9. HERA kinematics in the log $(q^2) - \log(1/x)$ plane. Upper part: the region accessible to ZEUS and H1. The straight lines are for constant y (1, 0.1, and 0.01, from top to bottom) and the curved lines for constant scattering angle of the electron (173°, 160°, and 150° from left to right). Earlier experiments were limited to the region in the lower left corner. Lower part: artist's view of the relevant dynamics. Saturation (shadowing) is expected to occur in the upper left corner.

dence for Pomeron exchange in hard $p\bar{p}$ interactions was found by UA8 several years ago in an experiment suggested by Ingelman and Schlein: they observed events in which the diffractive dissociation of one (or both) of the incident nucleons was associated with large transverse momentum jets produced centrally, implying that the Pomeron couples to pointlike partons. Indeed it was suggested long ago by Low and Nussinov that the Pomeron could consist of a pair of gluons in a colour singlet state. Chehime and Zeppenfeld have given support to this interpretation in a contribution to the Conference where they calculate the t-channel exchange of a colour singlet gluon pair between two quarks and find evidence for a rapidity gap within which gluon radiation is suppressed.

This picture is very successful in giving a qualitative description of the data. Naively it suggests that whenever a gluon can be replaced by a Pomeron in a leading order perturbative QCD process, implying that colour recombination can take place elsewhere, the resulting process will occur at a non-negligible relative rate, and be characterized by a rapidity gap between the two groups of hadrons coupled to the Pomeron. This is illustrated in the lower part of Fig. 11 where standard one-gluon-exchange PQCD diagrams are shown. Colour recombines in subsystems 1 as well as in subsystem 2. When the gluon is replaced by the Pomerons colour recombines only in subsystems 1 leaving a rapidity gap in subsystem 2. The mass scales of subsystems 1 may then become small and the Pomeron become soft as for VDM in the photon case and for diffractive dissociation in the proton case.

Figure 10. The proton structure function $F_2(x)$ measured at HERA for two values of q^2. Full dots are from H1 and open dots from ZEUS. Error bars have been omitted from the latter for clarity.

How does the soft Pomeron relate to the hard Pomeron, which is active in the BFKL regime (in both cases gluon ladders play an important rôle) and, more trivially, which is the practical recipe to calculate perturbative QCD diagrams involving hard Pomerons? Such questions are of obvious importance. Here again HERA is a powerful laboratory for their study which will undoubtedly provoke a resurgence of theoretical activity.

3.5. Glueballs

The gluon pair structure of the Pomeron may be used as a plea to say a few words about glueballs. Another excellent candidate was presented at the Conference by the Crystal Barrel Collaboration. They observe

Figure 11. Left: rapidity gap distribution in deep inelastic events measured at HERA by H1. The histogram is the prediction of a QCD calculation excluding diffraction. Right: fraction of two-jet events having no activity in the rapidity interval $\Delta\eta$ as a function of $\Delta\eta$ as measured by CDF (crosses) and D0 (dots) in $p\bar{p} \rightarrow 2$ jets $+\ x$. The two experiments use slightly different definitions of the hadron activity. In the lower part related diagrams involving the exchange of a gluon or of a Pomeron have been drawn (R stands for proton remnants, see text).

a narrow 0^{++} resonance, f_0 (1500) ($m \simeq 1520$ MeV and $\Gamma \simeq 100$ MeV) in the $\eta\eta$ channel of $\eta\eta\pi^0$ final states produced at LEAR from $p\bar{p}$ collisions. It couples strongly to $\eta\eta$ and $\eta\eta'$ (together more than half than to $\pi\pi$, and more than to $K\bar{K}$) and has no place to fit in conventional $q\bar{q}$ nonets. While it seems to have a lower mass than the $f_0(1590)$ discovered by the GAMS Collaboration, one cannot exclude that they are one and the same particle as the limited phase space available at LEAR may pull the mass down.

We are now in a situation where the standard $q\bar{q}$ nonets are overcrowded, in particular in the 0^+ sector. While some may be molecular states, several are naturally described as gluon rich states, hybrids or glueballs. It seems that the naïve idea of a 'golden' glueball has now become obsolete but that progress will result from an improved understanding of the spectroscopy of these gluon rich states. We may hope that after so many years during which several new resonances have been found—unfortunately their spacings are often not much smaller than their widths—we will soon understand how they are organized, another possible clue towards decrypting QCD in the non-perturbative sector.

Are neutrinos massless? This question plays such an important rôle in today's particle and astroparticle physics that I find it inconceivable to omit it from this summary, even if it was not really a major highlight of this Conference. It is central to many theoretical ideas and motivates an intense experimental activity in accelerator, reactor, and underground laboratories. I have selected three topics which have been addressed at the Conference and which deserve a few words.

4.1. Tritium beta decay

Preliminary results of a new measurement of the tritium beta decay end-point have been presented by Lobashev. It uses a cryogenic cylindrical electrostatic spectrometer, $\simeq 6$ m in length and $\simeq 1.2$ m in diameter, evacuated down to 10^{-9} Torr. A lithium drifted silicon counter, 2 cm in diameter, detects electrons at one end of the cylinder axis while gazeous tritium is injected and differentially pumped at the other end. Superconducting solenoids create a smoothly varying magnetic field within the spectrometer volume, such that electrons reaching the detector must originate from the tritium source. The electric field is varied in steps, with a full width resolution of 3.7 eV, to scan the β spectrum near its 18.6 keV end-point. Background, calibration, dead time, detection efficiency, and various potential sources of systematic uncertainties are under excellent control. The measured spectrum is fitted to a form $\mathrm{I} = \mathrm{I}_0\ F(E - E_0, m_\nu^2) + \mathrm{B}$ by varying the four parameters B (background), I_0 (normalization), E_0 (end-point energy) and m_ν (electron antineutrino mass) with the result $m_\nu^2 = -18 \pm 6$ eV^2.

Negative m_ν^2 values have also been measured by earlier experiments which, together, give only a 3.5% probability of m_ν^2 being positive (if m_ν^2 is set to zero the upper limit on m_ν obtained by these earlier experiments increases from 5.1 to 7.0 eV). The high statistics and low background of the new experiment make it possible to notice the presence of small spikes in the spectrum which are unlikely to be statistical fluctuations, starting approximately 7 eV below the end-point. For the time being it has not been possible to understand the origin of such spikes, but if one assumes that they are due to an effect not accounted for in $F(E - E_0,\ m_\nu^2)$ one finds that the fit improves significantly and gives $m_\nu^2 = 0$ with an upper limit $m_\nu < 4.5$ eV at 95% CL. Further data will hopefully clarify the issue and significantly improve our detailed understanding of experiments measuring the tritium β-decay end-point.

Finally it should be noted here that new limits have been presented on the rate of neutrinoless double β decay, probing the mass of a Majorana neutrino below

4.2. Solar neutrinos

The GALLEX, SAGE and Kamiokande experiments have presented updates of their results which they compare with standard solar model predictions by Bahcall and Pinsonneault (BP) and by Turck-Chieze, and Lopes (TCL).

Experiment	Data/SSM (BP) %	Data/SSM (TCL) %
GALLEX	$60 \pm 8 \pm 5$	$64 \pm 8 \pm 5$
SAGE	$52 \pm 8 \pm 5$	$56 \pm 9 \pm 5$
Kamiokande	$51 \pm 4 \pm 6$	$66 \pm 5 \pm 8$
Homestake	(Pro memoria) $29 \pm 3 \pm 9$	

All three experiments confirm an observed deficit of one third to one half with respect to the expected rate (remember that the Homestake experiment sees only one third of it). To explain these results one may invoke experimental errors, misconceptions of our understanding of how the sun burns, or neutrino oscillations.

There is no obvious experimental flaw one may point to. Kamiokande, the only experiment having been able to measure the direction of the detected neutrinos and to check their solar origin, have verified that the observed deficit has no significant time or energy dependence, but is consistent with a single scale factor. However, it is not clear to which extent the uncertainties in the solar model calculation are properly taken into account in the quoted result. GALLEX are in the process of testing the reliability of their chemical method using a 1.7 MCi ^{51}Cr neutrino source. A new run should start in October 1994 and stop at the end of 1996.

The standard solar model calculations are now very sophisticated and their validity has been checked in several respects. Taking them at face value, Kamiokande measures exclusively ^{8}B neutrinos and its result saturates the rate observed in the Homestake experiment which measures both ^{8}B and ^{7}Be neutrinos, implying a very severe deficit of the latter. The GALLEX and SAGE experiments measure the dominant pp neutrinos which contribute more than half of the expected rate and nearly saturate the observed rate. It seems difficult to escape the conclusion that the ^{7}Be neutrino rate is strongly suppressed, a conclusion which no viable solar model can accommodate. There are therefore internal inconsistencies between the data and the current version of the standard solar model, but some of the uncertainties in its predictions may still be underestimated.

If the deficit were due to oscillations a solution having Δm^2 in the range $6 \pm 4 \times 10^{-6}$ eV^2 and $\sin^2 2\theta$ in the range $5 \pm 3 \times 10^{-3}$ would be favoured (taking the MSW regeneration mechanism into proper account). It is of course premature, in the current state of our understanding, to support such an explanation. We

Kamiokande, which will become operational in 1995 and 1996, respectively, and possibly Borexino and ICARUS.

4.3. Atmospheric neutrinos

When the primary cosmic radiation enters the atmosphere it initiates hadron showers dominated by pions which decay as $\pi \rightarrow \mu\nu_\mu$, $\mu \rightarrow e\nu_\mu\nu_e$ with neutrino chiralities depending upon the pion charge. Atmospheric neutrinos are therefore expected to be in the ratio $\nu_\mu/\nu_e \simeq 2$, a prediction which needs to be refined with a model calculation describing production and absorbtion in the atmosphere and in the earth, and taking into proper account the energy spectrum and the particle composition of the shower. The Kamiokande detector, an underground (-1 km) water Cherenkov counter with a fiducial volume of 680 t, can detect selectively ν_μ's and ν_e's from the shape of their Cherenkov rings. They have checked the validity of their $\nu_\mu - \nu_e$ discrimination method in a test experiment at KEK. Two years ago they reported the observation of a ν_μ deficit relative to ν_e from the analysis of fully contained events having a visible energy smaller than 1.33 GeV and a mean energy of 0.7 GeV. They have now extended their analysis to all events. The sample of new events, either fully contained (FC) with an energy in excess of 1.33 GeV (8.2 k ton year) or partially contained (PC, 6.0 kton year) have a mean energy of the order of 6 GeV and consist of 98 FC ν_e, 31 FC ν_μ, and 104 PC ν_μ.

The analysis assumes that the PC events are ν_μ induced, an assumption which cannot bias the ν_μ/ν_e ratio towards low values. Nevertheless, the new result, $(\nu_\mu/\nu_e)_{obs}/(\nu_\mu/\nu_e)_{expected} = 0.57^{+0.08}_{-0.07} \pm 0.07$, confirms the earlier evidence for a significant ν_μ to ν_e deficit. An intriguing feature of this result is its dependence upon the zenith angle which is illustrated in Fig. 12: the ν_μ to ν_e deficit is stronger for upward moving neutrinos, suggesting an interpretation in terms of oscillations having an oscillation length commensurate with the earth's radius. Indeed the zenith angle distribution is well reproduced by $\nu_\mu \leftrightarrow \nu_\tau$ or $\nu_\mu \leftrightarrow \nu_e$ oscillations having $\sin^2 2\theta \gtrsim 0.7$ and Δm^2 in the 5×10^{-3} to 5×10^{-2} range. While the latter are largely excluded by existing reactor experiments (in particular by the latest Bugey data reported at the Conference) the $\nu_\mu \leftrightarrow \nu_\tau$ sector remains open. Future long base line experiments such as E889 and ICARUS should be able to cover it. It should also be noted that the limits set by MACRO and Frejus are not strongly inconsistent with the Kamiokande and IMB results.

In future years several other new experiments will probe unexplored regions of the $\sin^2 2\theta - \Delta m^2$ plane: CHORUS, NOMAD and E803 for short base

Figure 12. Zenith angle dependence of the ratio between (ν_μ/ν_e) observed and (ν_μ/ν_e) expected in the Kamiokande detector, cos $\theta = -1$ corresponds to upward moving muons. The histograms are for $\nu_\mu \leftrightarrow \nu_\tau$ oscillations (dotted line, $\Delta m^2 = 1.6 \times 10^{-2}$ eV^2) and $\nu_\mu \leftrightarrow \nu_e$ oscillations (dashed line, $\Delta m^2 = 1.8 \times 10^{-2}$ eV^2) and $\sin^2 2\theta = 1$ in both cases.

line $\nu_\mu \leftrightarrow \nu_\tau$ oscillations, CHOOZ, San Onofre, and LSND in the $\nu_\mu \leftrightarrow \nu_e$ sector, Super Kamiokande, SNO, and ICARUS in several domains. They should all be given strong support as the issues at stake are of such importance.

5. Other selected topics

Several other important results were reported at the Conference which I cannot afford to cover here, such as new limits on particle searches, more accurate measurements of the Standard Model parameters in both electroweak and perturbative QCD sectors, and many others. However, I still wish to mention two topics: the improvement of our knowledge of the τ sector, and the measurements of $\sin^2 \theta_W$ at LEP and at the SLC.

The τ data have been superbly summarized by R. Patterson: I do not wish to add a single word to what she said but simply to recall the most important results which greatly clarify our understanding of this topic (Fig. 13):

- the one-prong inclusive branching ratio, 84.74 ± 0.30% is now in good agreement with the sum of the exclusive branching ratios, 84.65 ± 0.70%;
- the relation between the electronic branching ratio and the lifetime, BR $(\tau \rightarrow e\nu\nu) \propto \tau(\tau)\ m^5(\tau)$, is obeyed to within $\simeq$ 1 standard deviation;
- lepton universality is verified with excellent accuracy, in particular $g_\tau/g_\mu = 0.995 \pm 0.004$.

Figure 13. Upper part: consistency check between the τ lifetime and its leptonic branching fraction BR $(\tau \rightarrow e\nu\nu)$. Lower part: the BES measurement of the τ-pair cross-section near threshold.

The LEP and SLC measurements of

$$\sin^2\ \theta_W = 1/4(1 - v_e/a_e)$$

are 2.5 standard deviations apart, 0.2322(4) and 0.2294(10), respectively. What would in other circles be considered an acceptable agreement is embarassing in a domain where the keyword is precision. Moreover, the SLC measurement has the attractive feature of measuring $\sin^2\ \theta_W$ directly: to a good approximation the quantity

$$A_{LR} \simeq 2v_e/a_e = 2(1 - 4\ \sin^2\theta_W)$$

A/P.

Figure 14 was shown at the Conference to illustrate the fact that the W mass is now measured with an accuracy commensurate with the difference between the LEP and SLC predictions. This is better seen in the plane $\sin^2\,\theta_W$ *vs* $s^2 = 1 - m^2(W)/m^2(Z)$ where the Standard Model ascribes a point to each pair of values $\{m(t),\ m(H)\}$ of the top and Higgs masses. It is illustrated in Fig. 14 where the measurements of $m(t) = 176 \pm 14$ GeV (CDF), of $s^2 = 0.2259(35)$ obtained from the world average $m(W) = 80.23(18)$ GeV, and of $\sin^2\,\theta_W$ (LEP and SLC) are also shown. The LEP measurement overlaps fully with $m(W)$ and $m(t)$ in the upper diamond, while the SLC measurement misses $m(W)$ and $m(t)$ by just a little bit (lower triangle). Moreover, the LEP + $m(t) + m(W)$ overlap diamond is well within the Standard Model region defined by $50 < m(H) < 1000$ GeV.

It would be tempting to blame the difference between LEP and the SLC on the P measurement but $\delta\sin^2\theta_W$ is only 2% of δP/P: reconciling LEP and the SLC to within one standard deviation takes a δP/P of $\simeq$ 8.5%, five times larger than allowed by the P measurement accuracy, δP/P = 1.1/63 = 1.7%.

6. Conclusion

It is superfluous to summarize a Conference summary. Let me simply remark that we still have a lot to do while the new accelerators (LEP 2, the Fermilab upgrade, the B factories, and the LHC) are being constructed. We will be eagerly awaiting more data from CDF and D0 which should keep running until they reach $\simeq$ 200 pb^{-1}. This should be sufficient to clarify the $e\mu$ signal and to settle the situation in the top sector. New results are expected in the B sector, with upgraded vertex detectors and improved mastering of the analysis techniques. They will further constrain our knowledge of the CKM matrix and pave the way towards the observation of CP violation at the B factories.

HERA has opened a promising window on the transition between the perturbative and non-perturbative QCD regimes. They will produce many more data and trigger a welcome resurgence of theoretical activity. The intricacies of gluon rich meson spectroscopy should start being unravelled.

In the neutrino sector new experiments aiming at a broader coverage of the $\Delta m^2 - \sin^2\ 2\theta$ plane, in particular in the region left open by the atmospheric neutrinos Kamiokande experiment, and at elucidating the solar neutrino problem should receive strong support.

Figure 14. The p$\bar{p}$ collider measurements of $m(W)$ are compared with the LEP and SLC predictions (upper part). In the lower part the overall situation in the $\sin^2\,\theta_W - s^2$ plane is shown.

The pursuit of high precision electroweak measurements at LEP and the SLC should hopefully resolve the 2.5 standard deviation effect currently observed. Moreover, new particle searches will keep pushing further the limits currently obtained, and hopefully find a positive signal.

It is a pleasure to express my deep gratitude to the Conference Organizers, and to all those who helped me with the preparation of my talk during the Conference. I am grateful to A. Ali, G. Altarelli, P. Landshoff, and D. Schlatter for their careful reading and useful comments on the manuscript.

As all the material used in this summary can be found in the present Proceedings it is unnecessary to append a list of references.