PRAMANA
— journal of
physics

© Printed in India

Supplement to Vol. 41
December 1993
pp. 525–540

Summary : Tenth DAE symposium on high energy physics

H S MANI

Mehta Research Institute, 10 Kasturba Gandhi Marg, Allahabad 211002, India

Abstract. An enormous amount of material has been covered in the last five days and my summary talk is clearly biased by my limitations.

1. Precision tests

Several precise experiments carried out in the last few years have led to remarkable confirmations of the Standard Model. These also imply constraints on possible new physics. The experiments are the measurements carried out in LEP at the Z^0–pole [1], along with low energy experiments measuring the ratio

$$R_\nu = \frac{\sigma(\nu_\mu N \to \nu_\mu X)}{\sigma(\nu_\mu N \to \mu^- X)}$$

and the weak charges Q_W from atomic parity violation [2].

First, we write down the tree level answers in the Standard Model with

$$\sin^2\theta_W \equiv S_W^2 = 1 - M_W^2/M_Z^2 = 1 - C_W^2.$$

From μ^- decay, which involves a W-exchange, we get

$$M_Z^2 S_W^2 C_W^2 = \frac{\pi\alpha(0)}{\sqrt{2}G_\mu} \qquad (1)$$

where M_Z = mass of Z^0, $\alpha = e^2/4\pi$ evaluated at $(q^2 = 0)$ and G_μ, the weak interaction constant.

The matrix element $(i \to f)$ involving Z^0 exchange from i to f [$e.g. e^+e^- \to f\bar{f}$, f = fermion] is given by

$$M_{if} = \frac{\sqrt{G}_F M_Z^2}{D(s)}(J_3^i - 2S_W^2 J_{em}^i) \times (J_3^f - 2S_W^2 J_{em}^f), \qquad (2)$$

where D(s) is the Z-propagator and the $Zf\bar{f}$ coupling is

$$\frac{e}{2S_W C_W}[v_f\gamma_\mu - a_f\gamma_\mu\gamma_5] \quad \text{with} \quad v_f = t_{3f} - 2Q_f S_W^2 \quad \text{and} \quad a_f = t_{3f}.$$

One loop corrections

Here we consider only the one loop corrections to the vector boson propagators, that of W, Z and γ through fermion and Higgs loops. These corrections usually dominate and are gauge invariant amongst themselves.

Consider, for example, μ^- decay with the W-propagator being modified by loop corrections. The propagator gets modified from $1/(q^2 - M_W^2)$ to $1/[q^2 - M_W^2 - \Pi_{WW}(q^2)]$, q being the momentum of the W-meson. This modifies (1), with $q^2 \approx 0$, to

$$M_W^2 S_W^2 = \frac{\pi\alpha(0)}{\sqrt{2}G_{\mu\mu}(1-\Delta r)}, \tag{3}$$

where

$$\Delta r = -\Pi_{WW}(0)/M_W^2. \tag{4}$$

Similarly, (2) is modified to

$$M_{if} = \frac{\sqrt{2}G_F M_Z^2}{D(s)}\,\rho\,(J_3^i - 2kS_W^2 J_{em}^i) \times (J_3^f - 2kS_W^2 J_{em}^f). \tag{5}$$

This can be interpreted as a modification of v_f and a_f with

$$v_f = \sqrt{\rho} \quad (t_{3f} - \bar{S}_W^2 J_{emf}), \tag{6(a)}$$

$$a_f = \sqrt{\rho} \quad (t_{3f}), \tag{6(b)}$$

$$\bar{S}_W^2 = kS_W^2. \tag{6(c)}$$

As an example, consider the $\rho-$*parameter* which occurs through the self-energy correction to Z propagator leading to (at $q^2 = 0$)

$$\begin{aligned}\frac{e^2}{4S_W^2 C_W^2}\frac{1}{(-M_Z^2)} &\rightarrow \frac{e^2}{4S_W^2 C_W^2}\frac{1}{(-M_Z^2 - \Pi_{ZZ}(0))}\\ &= \frac{e^2}{4S_W^2 C_W^2}(-\frac{1}{M_Z^2})\frac{1}{1+\Pi_{ZZ}(0)M_Z^{-2}}.\end{aligned} \tag{7}$$

Using (3), we get for the right hand side of (7)

$$-\sqrt{2}G_\mu\left(1 + \frac{\Pi_{WW}(0)}{M_W^2} - \frac{\Pi_{ZZ}(0)}{M_Z^2}\right), \tag{8}$$

leading to

$$\Delta\rho = \frac{\Pi_{WW}(0)}{M_W^2} - \frac{\Pi_{ZZ}(0)}{M_Z^2}. \tag{9}$$

Using

$$\Pi_{WW}(q^2) = \frac{e^2}{S_W^2}\Pi_{11}(q^2), \tag{10(a)}$$

$$\Pi_{ZZ}(q^2) = \frac{e^2}{C_W^2 S_W^2}(\Pi_{33}(q^2) - 2S_W^2\Pi_{3Q}(q^2) + S_W^4\Pi_{QQ}(q^2)), \tag{10(b)}$$

$$\Pi_{\gamma\gamma}(q^2) = e^2 \Pi_{QQ}(q^2), \qquad 10(c)$$

$$\Pi_{\gamma Z}(q^2) = \frac{e^2}{C_W S_W}(\Pi_{3Q}(q^2) - S_W^2 \Pi_{QQ}(q^2)) \qquad 10(d)$$

and $\Pi_{QQ}(0) = \Pi_{3Q}(0) = 0$, we get [4]

$$\Delta\rho \quad \frac{\equiv e^2}{S_W^{-2} M_W^{-2} [\Pi_{11}(0) - \Pi_{33}(0)]} \qquad (11)$$
$$\equiv \alpha T,$$

where

$$T = \frac{4\pi}{S_W^2 M_W^2}[\Pi_{11}(0) - \Pi_{33}(0)]. \qquad (12)$$

The parameter k deviates from 1 because of $Z^0 - \gamma$ mixing and a similar analysis leads to

$$\Delta k = \frac{\alpha}{4(C_W^2 - S_W^2)S_W^2}(S - 4C_W^2 S_W^2 T), \qquad (13)$$

where

$$S = \frac{16\pi}{M_Z^2}\left[\Pi_{33}(M_Z^2) - \Pi_{33}(0) - \Pi_{3Q}(M_Z^2)\right]. \qquad (14)$$

Lastly, we have U given by

$$U = \frac{16\pi}{M_W^2}\left[\pi(M_W^2) - \Pi_{11}(0)\right] - \frac{16\pi}{M_Z^2}\left[\Pi_{33}(M_Z^2) - \Pi_{33}(0)\right]. \qquad (15)$$

One can evaluate the contribution to S,T and U from the Standard Model. However m_t and m_H are unknown and we choose m_t = 140 Gev, m_H = 100 Gev and $\alpha_s = 0.120$ as a reference point. At the one loop level, all the contributions add linearly and we write $\tilde{S} = S - S^{SM}$, $\tilde{T} = T - T^{SM}$ and $\tilde{U} = U - U^{SM}$. Here $T^{SM} \sim 3/(16\pi)\ m_t^2\ M_W^{-2}\ S_W^{-2} \sim 0.78$; $S^{SM} = 1/(6\pi)\ \ln(m_H/m_Z)\ -1/(3\pi)\ \ln(m_t/m_W) \sim -.06$ and $U^{SM} = \pi^{-1}\ \ln(m_t/m_Z) \simeq 0.18$.

The experimental numbers of (a) $\Gamma(Z \to f\bar{f})$ (f = lepton, quark) (b) forward-backward asymmetry and the constraints coming from R_ν and $Q_W({}^{133}_{55}Cs)$ were used to obtain [5]

$$\begin{aligned} \tilde{S} &= -0.76 \pm 0.71, \\ \tilde{T} &= -0.70 \pm 0.49, \\ \tilde{U} &= -0.11 \pm 1.07. \end{aligned} \qquad (16)$$

It is worth noting that Q_W depends mainly on S. In particular,

$$Q_W\ ({}^{133}_{55}Cs) \cong -72.84 \pm 0.13 - 0.8S \qquad (17)$$

Before we discuss the constraints imposed by the experimental determination of $\tilde{S}$,$\tilde{T}$ and $\tilde{U}$ on possible new physics, it will be useful to discuss the role of custodial symmetry $SU_{L+R}(2)$ [6]. The Standard Model has a global symmetry $G = SU_L(2) \times SU_R(2) \times U_A(1)$ in the unbroken phase when one sets g' coupling of $U_Y(1)$ to zero. The subgroup $H = SU_L(2) \times U_Y(1)$ (with $Y = I_{3R} + A$, $A = \frac{B-L}{2}$) of G is gauged. The symmetry is broken down to $U_{em}(1)$ by the Higgs field developing a vacuum expectation value, which leaves $SU_{L+R}(2) \times U_A(1)$ unbroken. In this limit $\rho = 1$. The radiative corrections in general

(a) violate G, preserving $SU_{L+R}(2)$ (example : degenerate fermion doublets)

(b) violate $SU_{L+R}(2)$ (example : gauging of hypercharge).

The currents J_i and J_Q in Π_{ii}, Π_{iQ} and $\Pi_{QQ}(i = 1,2,3)$ transform under $SU_{L+R}(2)$ as

$$J_i \qquad vector$$

$$J_Q = J_{L3} + J_{R3} + J_A \ : \ \text{vector + scalar.}$$

Thus

$$\begin{aligned} T &\propto \Pi_{11} - \Pi_{33} \\ &\propto \langle J_1 J_1 \rangle - \langle J_3 J_3 \rangle \end{aligned}$$

which transforms as a pure '5' of $SU_{L+R}(2)$ and

$$S \qquad \propto \qquad a\langle J_{33}\rangle + b\langle J_{3Q}\rangle, \tag{18}$$

which transforms as '1' + '3' +'5' under $SU_{L+R}(2)$.

Thus S gets a contribution from a singlet but T does not. If these are degenerate fermion doublets which are heavy (Mass $\gg M_W$)m they contribute to S as (number of doublets) / (6π). Using the constraints that $\tilde{T} = 0$, G. Bhattacharyya et al. [5] have obtained a constraint ruling out more than three heavy chiral doublets at the 90% confidence level. If $M_U \neq M_D$ in the doublet $\binom{U}{D}$, we also get nonvanishing $\tilde{T}$ and the contribution to $\tilde{S}$ is also modified.

$$T = \frac{1}{16\pi S_W^2}\left[x_U^2 + x_d^2 - \frac{2x_u^2 x_d^2}{x_u^2 - x_d^2} \quad ln \quad \frac{x_U^2}{x_D^2}\right] \tag{19}$$

when $x_U = m_U/M_W$, $x_D = m_D/M_W$ Note that this is symmetric under $u \leftrightarrow d$ because the contribution comes from a pure '5'.

It is possible to express the effects discussed in terms of an effective chiral-Lagrangian [7], and chiral perturbation theory. One can write $U = \exp i\sigma^a w^a/v$, where w^a's represent the Goldstone bosons which become longitudinal modes of the gauge bosons and v is the vacuum expectation value. The lowest order Lagrangian density, using two derivatives, is given by

$$L = \frac{v^2}{4} tr\left[D_\mu U \, D^\mu \, U^+\right], \tag{20}$$

with

$$D_\mu U = \partial_\mu U + U L_\mu - R_\mu U$$

and

$$L_\mu = ig\sigma^a \frac{W_\mu^a}{2}, \quad R_\mu = ig'\frac{\sigma^3}{2} B_\mu.$$

This gives the kinetic energy and masses for the gauge bosons. If we write L_{eff} upto four derivatives we can have terms like

$$L_1 \; tr\; (D_\mu U \;\; D^\mu U^+) \; tr \; (D_\nu U \; D^\nu \, U^+)$$

and

$$L_2 \; tr\; (D_\mu U \, D_\nu U^+) \; tr \; (D^\mu U \, D^\nu U^+)$$

The corrections to the self energies of gauge bosons (oblique corrections) coming from the heavy particle sector are of the form

$$L_9 \left[tr\,(F_R^{\mu\nu} D_\mu U D_\nu U^+) + tr\,(F_L^{\mu\nu} D_\mu U D_\nu U^+) \right], \; L_{10}\, tr\,(U^+ F_R^{\mu\nu} U F_{L\mu\nu})$$

with

$$\begin{aligned} iF^L_{\mu\nu} &= \partial_\mu L_\nu - \partial_\nu L_\mu - [L_\mu, L_\nu], \\ iF^R_{\mu\nu} &= \partial_\mu R_\nu - \partial_\nu R_\mu. \end{aligned}$$

L_9 and L_{10} are constants upto 1-loop, in the minimal Standard Model :

$$L_1^{MSM} = \frac{v^2}{8M_H^2} + \frac{1}{16\pi^2}\left(\frac{9\pi}{16\sqrt{3}} - \frac{47}{48}\right), \tag{21}$$

$$L_2^{MSM} = L_9^{MSM} = L_{10}^{MSM} = 0.$$

For a QCD-like $SU(N)_{TC}$ symmetry breaking,

$$L_1 = \frac{N_{TC}}{384\pi^2}, \qquad L_2 = \frac{N_{TC}}{192\pi^2},$$

$$L_9 = \frac{N_{TC}}{48\pi^2}, \qquad L_{10} = -\frac{N_{TC}}{96\pi^2}. \tag{22}$$

L_9 and L_{10} are related to S, T and U.

In the near future we expect the analysis of 92 data and also the measurement of polarised $e^- e^+$ scattering

$$A_{LR} = \frac{\sigma(e_L^- e^+) - \sigma(e_R^- e^+)}{\sigma(e_L^- e^+) + \sigma(e_R^- e^+)}$$

These will confine $\tilde{S}$ and $\tilde{T}$ even further and if top and Higgs are discovered, we can decide if there is any need to modify the Standard Model.

Grand unified theories

The minimal $SU(5)$ model does not lead to a universal coupling when the renormalisation group equations are extended to 10^{15} Gev. This is shown in Figure 1. [Here the breaking is $SU(5) \xrightarrow[M_U]{24plet} SU_L(2) \times U(1) \times SU_C(3) \xrightarrow[M_W]{5plet} U_{em}(1) \times SU_C(3)$]

For grand unification to occur, one more scale is needed between the M_W and M_U and such a scale is provided by supersymmetry or $S0(10)$. A particular supersymmetric model where the breaking is induced through radiative corrections was discussed [8] and has quite a few light particles in the range of 50 to 100 Gev. Signals of such particle may occur in the Tevatron. This model is constrained by proton decay, which can occur through a dimension 5 operator.

At present, no clearcut evidence for supersymmetry exists and it is only one of the possible solutions.

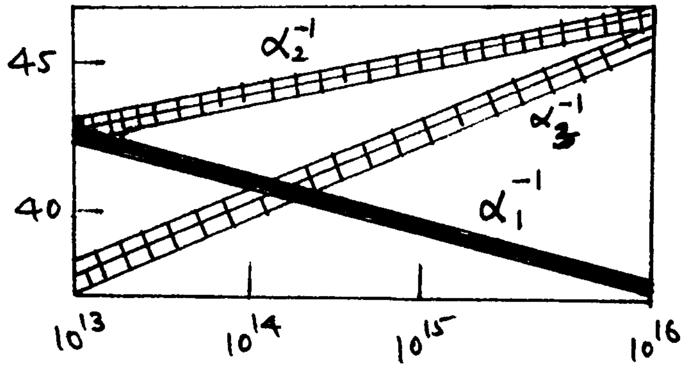

Figure 1. Variation of coupling constant in SU(5).

2. Neutrino physics

Neutrinos from the sun

Two new experiments, one from SAGE [9] and GALLEX [10], have reported in 1992 their observations of solar neutriones. Both have ^{71}Ga as detectors (threshold .233 Mev). The numbers quoted are the ratio of the observed number of neutrinos to the calculated number of neutrinos. The calculation is based on the Standard Solar Model. The new data are consistent with the earlier data of ^{37}Cl and the Kamioka data. The numbers are

Old

Experiment	Process	Threshold	Ratio	# events
Homestake	$^{37}Cl \rightarrow ^{37}Ar$	0.8 Mev	0.28 ± 0.04	750
Kamioka	νe scatt	7.5 Mev	0.49 ± 0.11	400

New

Experiment	Process	Threshold	Ratio	# events
SAGE (I + II)	^{71}Ga $\rightarrow^{71}$ Ge	.233 Mev	$0.44^{+0.17}_{-0.21}$	35
GALLEX (I + II)	^{71}Ga $\rightarrow^{71}$ Ge	.233 Mev	0.63 ± 0.17	

There is no significant day-night effect, and there is no evidence of correlation with sunspots.

Possible solutions

1. The Standard Solar Model (SSM) requires a modification. This is not very easy if we take all the data. Kamiokande sees the neutrio flux from ^8B decay and it sees at least 30% of the flux predicted by the SSM. The prediction for the contribution of ^8B flux to the ^{37}Cl experiment by SSM is about 6 SNU (1 SNU $= 10^{-31}$ capture per second per atom) and so 30% would account for 1.8 SNU of the observed 2.1 SNU's. This implies that the neutrinos produced by other reactions do not contribute at all, in particular the ^{7}Be neutrino flux should not contribute. Small changes in temperature cannot accommodate such a large reduction of the neutrino flux from ^{7}Be.

2. The MSW solution, which involves neutrinos having mass, oscillations, and resonance in matter, is a more interesting possibility. There are 3-regions allowed in $\Delta m^2 - \sin^2\theta$ plane

   (1) $\Delta m^2 \sim 10^{-5}\, eV^2 \quad \sin^2 2\theta \sim 10^{-3}$
   (2) $\Delta m^2 \sim 10^{-5}\, eV^2 \quad \sin^2 2\theta \sim 0.8$
   (3) $\Delta m^2 \sim 10^{-7}\, eV^2 \quad \sin^2 \theta \sim 0.8$

   The third solution involves a large day and night shift for $\nu_e +^{71}\text{Ga} \to^{71}\text{Ge} + e^-$. The present data is insufficient to see the effect.

3. Vacuum oscillations or 'Just so' solutions. These need $\Delta m^2 \sim 10^{-10} eV^2$ with $\sin^2 2\theta \sim 0.8$.

4. Neutrino decays with mixing : One can also have a solution which combines the ν being unstable and also having vacuum oscillations. Such a model has been constructed by Pakvasa [11] with parameters $\Delta m^2 \sim 10^{-2}$ to $10^{-3} eV^2, \theta \sim 45^0$ and $\tau \sim 600s$.

   The future looks promising with Sudbury Neutrino Observatory, Borexino, Icarus etc. being planned. These experiments are aimimg to detect the neutral current reactions ($\nu_x + d \to \nu_x + p + n$, $\nu_e + d \to e^- + p + p$) leading to the ratio of the ν_e flux to the $\sum_i \nu_i$ flux at the detector. The statistics are to be an order of magnitude more and one is looking forward to finding out which of the solutions survive.

Atmospheric neutrinos

Primary cosmic rays striking the atmosphere produce pions and kaons which subsequently decay. Thus we expect

$$[\pi^\pm \to \mu^\pm + \overset{(-)}{\nu}_\mu],$$

$$\hookrightarrow e^\pm + \overset{(-)}{\nu}_e + \overset{(-)}{\nu}_\mu,$$

$$\frac{\#(\nu_\mu + \bar{\nu}_\mu)}{\#(\nu_e + \bar{\nu}_e)} \simeq 2 \tag{23}$$

This naive expectation is also borne out in all the detailed calculations [12]. The neutrinos and antineutrinos enter from all directions. Experiments have been done to study the electron and muon spectrum by Kamiokande in 88 and 92, IMB in 91 and Frejus in 89-90 (produced by ν_e, ν_μ). Both Kamiokande and IMB find the ratio to 1.2, instead of 2 The energy distribution of the lepton observed is in the momentum range 0.1 GeV/c to 1.3 GeV/c. If this is attributed to oscillations, $\nu_\mu \leftrightarrow \nu_e$ is ruled out , $\nu_\mu \leftrightarrow \nu_\tau$ is allowed with $\Delta m^2 \sim 10^{-2} eV^2$ and $\sin^2\theta \sim 0.9$.

There is another interesting explanation suggested by W.A. Mann et al. [13]. The observation is interpreted as an excess of events of e^+ which could come from a proton decay of the type $p \to e^+ + \nu_e + \bar{\nu}_e$. The momentum range in which such an excess of data exists is suggestive of the above decay mode. The excess number of e^+ is estimated to be about 40 in a detector with 5 kiloton-yr which leads to proton lifetime of 10^{32} yr for this mode. The question then arises as to what happend to the mode $p \to \mu^+ + \nu_\mu + \bar{\nu}_\mu$, which would need more new physics.

Double - β decay

The first double β-decay was observed by Elliot et al in 1987 [14] :

$$^{82}Se \rightarrow ^{82}Kr + 2e^- + 2\bar{\nu}_e \tag{24}$$

with $\tau_{1/2} = 1.1 \times 10^{20} yrs$. If we have a Majorana neutrino, we also have the possibility of neutrinoless double β decay $(\beta\beta)_{o\nu}$:

$$(A, Z) \rightarrow (A, Z + 2) + 2e^-. \tag{25}$$

One serious model leading to neutrinos having Majorana masses comes through the breaking of lepton number spontaneously leading to a massless particle – the Majoron. Some of the models leading to the presence of the Majoron have already been ruled out from the Z^0 - width. However it is of interest to find out whether the decays of the type (J=Majoron)

$$(A, Z) \rightarrow (A,\ Z + 2) + 2e^- + J \tag{26}$$

exist. Such an emission can take place from the diagram The absence of $(\beta\beta)_{o\nu}$ decay implies

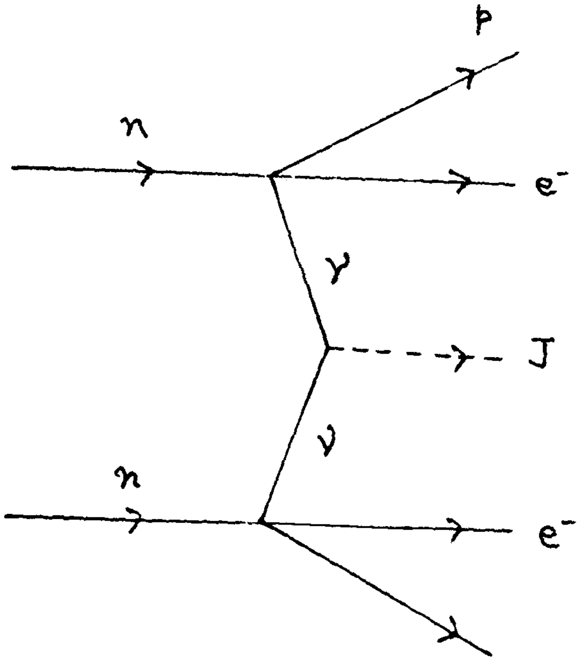

Figure 2. Majoron emission

$$m_{eff} < 1\text{eV}$$

where

$$m_{eff} = \sum_{i\, =\, \text{all } \nu\text{'s}} m_i \theta_i^2,$$

θ_i being a set of mixing angles.

In fact if $^{76}Ge \rightarrow ^{76} Se + 2e^-$ is seen with a lifetime $\tau(Ge)$ (in years), then the mass of the heaviest ν for a large class of gauge theories is given by

$$M_{heaviest} \sim \sqrt{\frac{10^{24} yr.}{\tau(Ge)}} \; (eV) \tag{27}$$

There is a slight indication [15], from the study of the spectra of double beta decay in ^{82}Se, ^{100}Mo, $50Na$, and ^{76}Ge of an excess number of high energy electrons. If this is interpreted as due to Majoron emission, the coupling constant to the Majoron is $\sim 10^{-4}$. Clearly more data are needed.

COBE results (see below) can also be understood with neutrinos with mass around 7 eV being part of dark matter. Thus one possible solution could be the masses of neutrinos are of the order of 7 eV, 10^{-1} eV and 10^{-5} eV, which would explain the present data.

3. Results from COBE

Fluctuations in the temperature of the cosmic microwave background ($2.735 \pm 0.06^0 K$) have been observed and reported in April 92 [16]. This has been done with the help of the Cosmic Background Explorer, which has looked for anisotropy in the microwave radiation. After subtracting the dipole effects, one looks for the quadrupole term. The effect was studied by looking at two points in the sky separated by an angle of 10^0. Writing $\Delta T/T = \sum_{\ell,m} a_{\ell m} \; Y_{\ell m}(\theta, \phi)$ where T is the temperature and ΔT the fluctuation, the observation indicates $Q = \left(a_2^2/4\pi\right)^{1/2} = 13 \pm 4\mu K$ $(a_\ell^2 = \sum_m |a_{\ell m}|^2)$

Such anisotropies cannot be due to processes initiated after the era of recombination, as they would be widely separated (causal processes after era of recombination subtend an angle much less than 1^0). Thus the effect is primordial in nature and it can arise from density fluctuations of dark matter. Such a fluctuation is also needed for structure and the eventual galaxy formulation.

Observationally, the galaxy angular correlation functions

$$W(\theta) = \langle n\,(\hat{\Omega} + \theta) \;\; n(\hat{\Omega})\rangle_{\hat{\Omega}} \;\; - \;\; \langle n(\hat{\Omega})^2\rangle_{\hat{\Omega}}, \tag{28}$$

where $\hat{\Omega}$ is some direction and $n(\hat{\Omega})$ = number density of galaxies along $\hat{\Omega}$, has been painstakingly studied. Primack [17] presented a theoretical model with hot dark matter and cold dark matter with Ω (hot dark matter) $\sim 30\%$. Such hot dark matter can be due to a neutrino background with $m_\nu \sim 7$ eV.

4. Results from HERA

The γp total cross sections (almost real photons) have been measured recently at HERA [18] at $\sqrt{s} \sim 200 GeV$ and we know that $\sigma_{\gamma p}$(total) $\sim 150\mu$ barns. The value shows an increase from the value of $\sigma_{\gamma p}(\sqrt{s} = 20$ GeV) $\sim 120\mu b$. This has been analysed in terms of the direct contribution and the resolved contribution when the photon has quarks in it as "structure function". The photon structure function was originally introduced in the discussion of $\gamma+\gamma \to$ hadrons and a recent analysis of this process, using the Tristan and LEP data, has been done. The analysis shows very good agreement with the experimental data.

There are several ways in which one can develop the theory of photon structure functions :

(1) operator product expansion and renormalisation group equation,

(2) Dokshitzer-Gribov-Lipatov-Altarelli-Parisi equations,

(3) perturbative QCD as a sum of ladder diagrams.

The present HERA experiment, because of the small value of Q^2, get a dominant contribution from the resolved part (derived by F_2^γ). The resolved contribution is, in fact, more important for smaller p_T. The energy dependence of the two contributions are also different - the resolved contribution increasing faster with the increase of energy.

There are other phenomenological models which gives $\sigma(\gamma p) \sim 150\mu b$ at $\sqrt{s} \sim 200GeV$ and it would be interesting to see whether these models can be distinguished in the near future. The structure functions for very low x, which will be studied at HERA, require more than the standard evolution functions [19]. One has to study the semi-inclusive processes and the concept of a structure function at such low x may be insufficient.

5. Flavour physics

The Cabbibo-Kobayashi-Maskawa matrix

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix},$$

described by three angles and one complex phase, provides a basis to discuss flavour physics. If there are no more flavours this is a unitary matrix giving three conditions :

$$\begin{aligned} V_{ud}V_{us}^* + V_{cd}V_{cs}^* + V_{td}V_{ts}^* &= 0, \\ V_{us}V_{ub}^* + V_{cs}V_{cb}^* + V_{ts}V_{tb}^* &= 0, \\ V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* &= 0. \end{aligned} \tag{29}$$

We already know [20] that

$|V_{ud}| = 0.9744 \pm 0.0010$ (from nuclear β decay) ;

$|V_{us}| = 0.2205 \pm 0.0018$ (from $K \to \pi \ell \nu$) ;

$|V_{cd}| = 0.204 \pm 0.017$ (from $D \to \pi e \nu$ and charmed production);

$$|V_{cs}| = 1.06 \pm 0.18 \text{ (from } D \rightarrow Ke\nu \quad \text{and charmed production);}$$

$$|V_{cb}| = 0.042 \pm 0.007 \text{ (from } B \rightarrow D^{*}e\nu\text{);} \; |\frac{V_{ub}}{V_{cb}}| = 0.05 - 0.20$$
$$0.050 \pm 0.08$$

In the first two equations of (29), two terms are much larger than the third and thus in a complex plane they almost collapse to a line. In the third equations all three terms are small and the triangular nature can be tested. The area of all the triangle is the same and has the value J/2 where [21]

$$J \sum_{m,n=1}^{3} \varepsilon_{ilm}\varepsilon_{jkn} = Im \; [V_{ij} V_{ik}^{*} V_{lk} V_{lj}^{*}] \qquad \text{(no sum over } i, j, k, l\text{).}$$

If we choose V_{cd} V_{cb}^{*} as real and divide the third equation by it we get the triangle of Fig. 3 in the (ρ, η) plane.

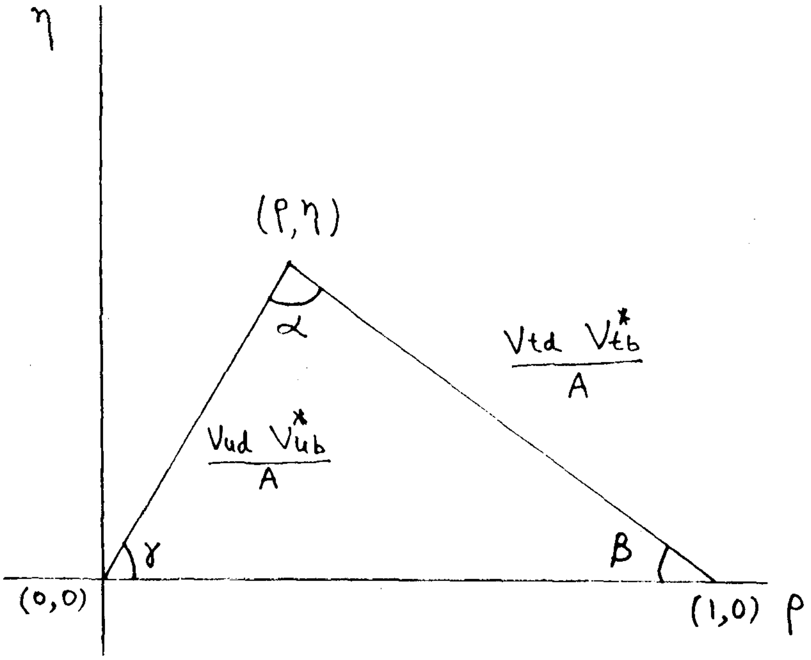

Figure 3. The unitarity triangle. The CP violating phases α, β, γ can be measured in the B-system. $A = V_{cd}V_{cb}^{*}$.

The measurement of CP violating phases α, β, γ is difficult but, in principle, possible from the study of the mixing of B and $\overline{B}$, along with its decay into a definite CP eigenstate. Consider $B_d \rightarrow$ definite eigenstate of CP say $\psi + K_s, \rho K_s$ or $\pi\pi$ [22]. Now

$$| B_d(t) > \; = [\, |B_d > \cos\frac{\Delta mt}{2} - i\lambda \mid \bar{B}_d > \sin\frac{\Delta mt}{2}]\, e^{-\Gamma t/2}. \tag{30}$$

Neglecting $\Delta\Gamma/\Gamma$,

$$\lambda = e^{i\theta};\;\; \theta = \text{phase of } \langle \bar{B}_d \mid \frac{\Delta M}{2} \mid B_d \rangle.$$

The matrix element for $B_d \rightarrow \psi K_s$ is

$$M(B_d \rightarrow \psi K_s) \propto (V_{cb} \cos\frac{\Delta mt}{2} \pm i\lambda V_{cb}^{*} \sin\frac{\Delta mt}{2})\, e^{-pt/2}. \tag{31}$$

The decay rate is given by

$$\frac{dN}{dt} = N_0[1 \pm \sin\phi \;\; \sin\Delta mt]\, e^{-\Gamma t}, \tag{32}$$

$$\phi = 2\text{Arg}\;\; V_{td} = 2\beta.$$

Thus a study of dN/dt, as a function of time, can lead to the determination of β. A similar study of $B_d \rightarrow \pi\pi$ gives α and of $B_s \rightarrow \rho K_s$ gives γ.

If we use some theory (box diagram) and the experimental information regarding $x_d = \Delta m_B/\Gamma_B = 0.67 \pm 0.10$ in $B^0 - \bar{B}^0$ mixing and the CP-violating parameter ε in the $K^0 - \bar{K}^0$ system ($|\varepsilon| = 2.26 \pm 0.02 \times 10^{-3}$) the phase of V_{ub} can be fixed. However, the uncertainty in the top quark mass and the bag constant, dilutes the result to a mild constraint :

$$20^0 \leq \text{phase} \leq 170^0$$

This brings us to B-physics and Vivek Sharma [23] gave a wonderful review in which he announced that

$$\tau\;(B^-) \;=\; 1.33 \pm 0.19\;\; ps.$$

It gives credance to the theoretical analysis that all b-quark systems should have the same lifetime.

The analyses of B-meson decays have led to some very interesting theoretical developments, which were summarised by M.P. Khanna [24]. We review here some of the essential points.

Consider a hadron with one heavy quark and several light quarks. In the rest frame of the hadron, the heavy quark is almost at rest and is a source (static) of gluons, whose momenta are of the order of $\Lambda, \Lambda \sim 300$ MeV. For the momentum p_μ of the heavy quark, one writes

$$p_\mu \;=\; m_Q\, v_\mu + k_\mu \quad (v_\mu v^\mu = 1), \tag{33}$$

$$k_\mu \;=\; 0(\Lambda).$$

The tree level propagator then simplifies to

$$\frac{i}{\not{p} - m_Q} \rightarrow i\; \frac{(1+ \not{v})}{2v.k} \tag{34}$$

and the vertex becomes

$$\frac{i}{\not p - m_Q}\,(-ig_s T^a \gamma^\lambda)\,\frac{i}{\not p + \not q - m_Q}\;\Delta_{\lambda\rho}\ \text{(gluon propagator)}$$

$$\rightarrow \frac{1+\not v}{2}\;\frac{i}{v.k}\;(-ig_s T^a v^\lambda)\;\frac{i}{v.(k+q)}\,\Delta_{\lambda\rho}(q) \qquad (35)$$

Both these (simplified versions of the propagator and the vertex) can be obtained from an effective Lagrangian density .

$$\mathcal{L}_{eff} = \bar{Q}_v (i.\vec{v}.\vec{D}) Q_v, \qquad (36)$$

$$D_\mu = \partial_\mu + ig_s A^a_\mu T^a,$$

where $\vec{v}$ is the velocity vector of the heavy quark. This procedure can be extended to higher orders with some important modifications, with the help of renormalisation group equations.

Symmetries.

Consider

$$\mathcal{L}^{(v)}_{eff} = \sum_{j=1}^{n} \bar{Q}^{(j)}_v (i\vec{v}.\vec{D}) Q^{(j)}_v \qquad (37)$$

which has n heavy quarks. This Lagrangian density has a $U(N)$ symmetry (and not just $U(1) \times U(1) \cdots \times U(1)$). This extra symmetry can be exploited to obtain relations like [25]

$$\frac{M_{B^*} - M_B}{M_{D^*} - M_D} = \frac{m_c}{m_b} \qquad (38)$$

(in reasonable agreement with experiment).

Heavy quark effective theory has been used to extract the matrix element $\bar{B} \rightarrow De\bar{\nu}$ & $D^* e\bar{\nu}$ and one obtains [25]

$$\langle D^*(v', e)\, |J_\mu|\, \bar{B}(v)\rangle = \xi\,(\vec{v}.\vec{v}')\,[\varepsilon^*_\mu(1 + v.v') - v'_\mu(\varepsilon^*.v)], \qquad (39)$$

where ξ is a universal function of one variable with $\xi(1) = 1$. There is a very simple physical picture which enables us to understand the above normalisation. When b decays to c and both are at rest, the wave function of $\bar{u}$ (in $\bar{B}$ and D respectively) does not change, in the $m_{heavy} \gg \Lambda$ limit. Thus we just have the normalisation of the $\bar{u}$ wave function. However we need $\xi(\vec{v}.\vec{v}')$ for values $\vec{v}.\vec{v}'$ different from 1 and there the theory is not that predictive. The idea has also been useful in extracting non leptonic decays where one assumes the factorisation of the matrix elements. I refer to Khanna's article for details.

One can also formulate Heavy Quark effective theory as chiral perturbation theory [26]. We have $SU_v(2)$ invariance for Heavy quarks and $SU_L(3) \times SU_R(3)$ for light quarks and one can use the machinery of chiral perturbation theory. This has been used to study several decay processes recently.

Finally, the study of $b \rightarrow s\gamma$ [27], se^+e^- and the experimental limit on $BR(b \rightarrow s\gamma) < 8.4 \times 10^{-4}$ has been used to put an upper limit $>$ 155 GeV on the mass of the charged Higgs in the two-doublet Higgs model.

6. Quark-gluon plasma

We recollect that a quark-gluon plasma should form when $T_c \sim m_\pi$ and the energy density $\varepsilon \sim 2$ GeV/fm^3. Such a phase transition has been confirmed by Lattice calculations. They also show the naive model in which the quark and gluons are treated as ideal gas is not correct till $T_c \sim 2m_\pi$. These calculations have all been done with the chemical potential $\mu = 0$ (no. of baryons = no. of anti baryons). The production of plasma occurs in a nucleus-nucleus collision with $\sqrt{s}/A > 5$ GeV. The central region where the plasma is formed can be treated to be baryonless. The signals of the formation of plasma can be [28] the following.

(1) J/ψ suppression: This occurs because the colour charges are Debye screened and J/ψ cannot be formed inside the plasma. Such a suppression has been seen in ^{16}O impinging on Uranium (CERN). Further, one expects the suppression to be less for large p_T. This is also reported. However the data can also be explained on the basis of hadronisation and is not considered as a clear signal for the occurance of quark-gluon plasma [29].

(2) Strangeness enhancement: (Here one needs to produce only $\bar{s}s$ which has a lower threshold than $\bar{K}K$). Such an enhancement has been observed.

(3) Photons and dileptons: These emanating from the plasma have the temperature dependance associated with the plasma $(e^{-E/T})$. The background problems are still unresolved. A clear signal indicating quark-gluon plasma is still to be indentified.

7. Lattice gauge theory

The basic idea is to calculate

$$\langle\ 0\ \rangle = \int [d\Phi]\, e^{-Z[\Phi]}\ O, \tag{40}$$

where O could be $\bar{q}q$, $\bar{q}\lambda_8\, q$ etc. Some examples of physical quantities determined are the mass spectrum, f_π, f_K. The fermionic determinant occuring in the functional integral is dropped (quenched approximation). Recently better extrapolation procedures to the lattice length $a \to 0$ limit have been used. Bigger lattice sites are also available.

A. Patel [30] presented several results on the $q-\bar{q}$ potential. Further, the $I = 2$ π-π scattering length agrees with the Weinberg formula. f_P $[\langle 0|A_\mu|P\rangle = f_P p_\mu]$ for B and D ($f_B \sim 200$ MeV, $f_D \sim 200$ MeV) have been determined. These can give rise to large CP violating effects in $B \to K_s\psi$.

8. Top quark and Higgs boson

The mass of the top quark has been constrained to be in the range 150 ± 30 GeV/c^2 if we use LEP data and assume the Standard Model. However the Higg's boson mass is not that well constrained. Accelerator experiments give a lower bound of 60 GeV/c^2. Theoretical arguments based on the stability of the vacuum have been made. They lead to $\gtrsim$ 10 GeV/c^2, if $m_t \sim$ 100 GeV/c^2 and $\geq$ 100 GeV/c^2 if $m_t \sim$ 200 GeV/c^2. If the mass of Higgs boson is more than 500 GeV/c^2, one expects the electroweak sector to become strong in the TEV region. If $m_H < m_Z$, $H \rightarrow b\bar{b}$ would be the dominant channel. If $m_Z < m_H < 2m_Z$, $H \rightarrow \gamma\gamma$, ZZ^*, WW^* are important and for $m_H > 2m_W$, $H \rightarrow WW$, ZZ will be the channels to look for. In LEP II one can see the Higgs upto $m_H \sim m_Z$. If the Higgs has a mass in the range m_Z to $2m_Z$, it will be difficult to identify it because of the background in hadron colliders. The best channel in SSC would be $PP \rightarrow HX$ with $H \rightarrow Z^*Z^*X$ and each $Z^* \rightarrow \ell^+\ell^-$, for $m_H \gtrsim$ 130 GeV.

In supersymmetric theories the constraint $m_{n^0} < m_Z$ obtained at the tree level is relaxed by radiative corrections [31].

9. Field theory

A very good pedagogical review was presented by D. Sen [32] discussing fractional statistics ocuuring in 2+1 dimensions. A new and interesting suggestion has been made by A.K. Mishra and G. Rajasekaran [33], with the following commutation relation, for creation and destruction operators.

$$C_{k\alpha}\, C^{+}_{m\beta} \;-\; (q_1 - q_2)\, C^{+}_{m\beta}\, C_{k\alpha} \;-\; q_2\, \delta_{\alpha\beta} \sum C^{+}_{m\gamma} C_{k\gamma} = \delta_{km}\, \delta_{\alpha\beta}. \qquad (41)$$

If we choose $q_1 = +1\ (-1), q_2 = 0$ we get Bose (Fermi) statistics. On the other hand, the choice $q_1 = q_2 = +1\ (-1)$ leads to "ortho Bose (Fermi) statistics". The positive definiteness of the space has been studied by these authors.

There have been substandial work in string theory and other branches of formal field theory. Unfortunately I am not capable of providing an overview on these subjects.

Acknowledgements

I have greatly benefitted from the discussions with M. Drees, R. Gavai, R. Godbole, S. Pakvasa, J.C. Pati, A. Patel, G. Rajasekaran, and K.V.L. Sarma during the conference. I wish to thank the organisers of the conference for excellent hospitality.

References

[1] A. Gurtu : Z^0 parameters from LEP, DAE symposium, Bombay (1992);
ALEPH Collab, D. Decamp et al., Z. Phys. **C53** (1992) 1;
DELPHI Collab, P. Abreu et al., Nucl. Phys. **B367** (1991) 511;
L3 Collab, B. Adeva et al., Z. Phys. **C51** (1991) 172;
OPAL Collab, G. Alexander et al., Z. Phys. **C52** (1991) 175.

[2] A. Blondel et al., Z Phys. **C45** (1990) 361 ;
M.C. Noccker et al., Phys. Rev. Lett. **61** (1988) 310 ;
S.A. Blundell et al., ibid. **65** (1990) 1411;
V. Dzuba et al., Phys. Lett. **A4** (1989) 147; Phys. Lett. **B259** (1991) 377.

[3] See for instance G. Altarelli CERN-TH-6206/91 Aug. 91 and the references contained therein.

[4] Probir Roy : Radiative Electroweak Parameters, DAE symposium, Bombay (1992).

[5] G. Bhattacharyya et al., Phys. Rev. **D45** (1992) R729;
P. Renton, Z. Phys. **C56** (1992) 355.

[6] D. C. Kennedy, Phys. Lett. **B268** (1992) 86.

[7] R. Casalbuoni et al., CERN-TH 4876/87.

[8] P. Nath : Supergravity Phenomenology, DAE symposium, Bombay (1992).

[9] K.S. Hirata et al., Phys. Rev. Lett. **66** (1991) 9;
P. Anselmann et al., Phys. Lett **B285** (1992) 376;
S. Pakvasa, Solar and Atmospheric Neutrino - these proceedings.

[10] K.S. Hirata et al., Phys. Lett **B280** (1992) 146;
R. Becker - S. Zendy et al., Phys. Rev. **D46** (1992) 3720;
D. W. Casper et al., Phys. Rev. Lett. **66** (1991) 2561.

[11] A. Acker et al., Phys. Lett. **B285** (1992) 371.

[12] T.K. Gaisser et al., Phys. Rev. **D38** (1988) 85.

[13] W.A. Mann et al., Phys. Lett. **B291** (1992) 200.

[14] Massive neutrinos in Physics and Astrophysics by R.N. Mohapatra and P.B. Lal, World Scientific (1991).

[15] C.P. Burgess and James M. Cline McGill/92-27 August 1992.

[16] G.F. Smoot et al., Astrophysics J. Lett. **396** (1992) L1.

[17] J. Primack, DAE symposium, Bombay (1992).

[18] K. Charcula et al., Phys. Lett. **B293** (1992) 469.

[19] D.K. Chowdhury : Low x structure functions- HERA physics, DAE symposium, Bombay (1992).

[20] See for instance "B-decays an overview" by A. Ali, DESY.92-090.

[21] CP-violation – Y. Nir, SLAC-PUB-5874 (1992).

[22] K.V.L. Sarma : B-decays and CP violation, DAE symposium, Bombay (1992).

[23] V. Sharma : Heavy Flavour Physics, DAE symposium, Bombay (1992).

[24] M.P. Khanna : Flavour Symmetry and weak decays of Heavy Quarks, DAE symposium (1992).

[25] N. Isgur : Hadron spectrescopy and structure, XXVI int. conference in high energy physics (1992).

[26] H.Y. Cheng et al., preprint no CLNS 92/1158 (1992).

[27] N. G. Deshpande : Penguins in B-decays, DAE symposium (1992).

[28] R.V. Gavai : Status of Quark Gluon-Plasma, DAE symposium, Bombay (1992).

[29] C.P. Singh : Signals of Quark Gluon-Plasma Physics Reports (to appear) and reference therein.

[30] A. Patel : Lattice QCD, DAE symposium, Bombay (1992).

[31] R.M. Godbole : Search for Standard Model Higgs, DAE symposium, Bombay (1992);
P.N. Pandita : Radiative corrections to SUSY Higgs masses, DAE symposium Bombay (1992).

[32] D. Sen : Anyons, DAE symposium, Bombay (1992).

[33] A.K. Mishra and G. Rajasekaran : Pamana J-Phys. **36** (1991) 537, **38** (1992) L411.