SLAC–PUB–4327
May 1987
T/E

# Generation Mixing and CP-Violation - Standard and Beyond*

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## ABSTRACT

We discuss several issues related to the observed generation pattern of quarks and leptons. Among the main topics: Masses, angles and phases and possible relations among them, a possible fourth generation of quarks and leptons, new bounds on neutrino masses, comments on the recently observed mixing in the $B - \bar{B}$ system, CP- violation, and recent proposals for a b-quark "factory".

*Invited talk presented at*
*Les Rencontres de Physique de la Vallee d'Aosta,*
*La Thuile, Aosta Valley, Italy, March 1-7, 1987*

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⋆ Work supported by the Department of Energy, contract DE–AC03–76SF00515.
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## 1. Introduction

Among all the open problems of the standard model, none is more intriguing and frustrating than the generation puzzle. The puzzle itself has been with us, in one form or another, for the last forty years or so, since it was realized that the "$\mu$-meson" is actually a lepton.

At our present level of understanding, the standard model would have been more satisfactory if the only fermions we had were the $u$ and $d$ quarks, the electron and its neutrino. We would then have only eight arbitrary parameters (rather than 18) and there would be a reasonable "justification" for the existence of each type of particle. Instead, we have additional angle and phase parameters, a complicated mass spectrum which is not understood and a completely mysterious replication of particles which differ from each other by their masses and by no other known property.

This lecture is devoted to a variety of topics related to the generation puzzle. We can offer no solution to the puzzle itself, but we discuss the mass, angle and phase parameters, their experimental values, their regularities, possible relations between masses and angles, etc. We then present a brief discussion of four topics of much recent interest:

(*i*) A possible fourth generation of quarks and leptons?

(*ii*) New bounds on neutrino masses.

(*iii*) $B - \bar{B}$ mixing and CP violation.

(*iv*) Proposals for a $b$-quark "factory".

We conclude with some general remarks.

## 2. Counting the Parameters of the Standard Model

The *minimal* version of the standard model is based on the gauge group $SU(3)_c \times SU(2) \times U(1)$ with three generations of quarks and leptons and *one* physical Higgs particle. If we assume that there are no right-handed neutrinos and that there is no *strong* CP violation, the minimal model contains 18 arbitrary parameters:

(*i*) Three gauge couplings for the three gauge groups.

(*ii*) Two parameters representing the Higgs sector, even in the absence of fermions.

(*iii*) Nine masses for the six quarks and three charged leptons of the three generations.

(*iv*) Three generalized Cabibbo angles for the quark sector.

(*v*) One Kobayashi-Maskawa (KM) phase for the quark sector.

The possible existence of strong CP-violation would add a 19th arbitrary parameter (whose value must be tiny).

Of these parameters, the first five relate to the gauge group and to the Higgs potential. The other 13 parameters are related, in one way or another, to the generation structure. There is no hope to calculate them or to understand their pattern without solving the generation puzzle.

The standard model may have several different extensions which will add no fundamental new physics but will increase the number of arbitrary parameters. The three most direct extensions are the following:

(*i*) *Neutrino masses.* If neutrinos are not exactly massless, we have three additional neutrino mass parameters. The existence of these masses opens the door to generation mixing among the leptons, leading to three leptonic Cabibbo angles and one leptonic KM phase. If the neutrinos have both Dirac and Majorana masses, the number of parameters is even larger, but, in that case, additional Higgs (and possibly Goldstone) particles must also exist. The existence of non-vanishing neutrino masses therefore adds at least seven new parameters, possibly many more.

(*ii*) *Additional generations.* It is entirely possible that additional generations of quarks and leptons, following the pattern of the first three generations, will be discovered. Since we have no reason to expect precisely three generations, we should not consider the possible existence of additional generations as a major extension of the model. However, a fourth generation will add nine additional arbitrary parameters if all neutrinos are massless and at least fourteen parameters if neutrinos have masses.

(*iii*) *Additional Higgs particles.* The standard model may include any number of Higgs doublets without changing its main features. However, the introduction of such additional doublets opens the way to a variety of additional terms in the Higgs potential. The couplings of the new Higgs fields as well as their masses and vacuum expectation values (v.e.v.'s) are additional free parameters. The relative magnitudes of the v.e.v.'s and the Yukawa couplings are directly linked to the fermion mass spectrum.

We therefore conclude that even the least controversial extensions of the standard model are likely to increase its number of arbitrary parameters to anywhere between 25 and 40, most of which are directly related to the generation puzzle.

It would have been bad enough if we had 18 or 25 or 40 arbitrary parameters whose observed experimental values obeyed some simple patterns. For instance, a reasonable unbiased guess in the minimal standard model would suggest that $M_W$, $M_\phi$ and all quark and lepton masses should be roughly of the same order of magnitude. If that were the case, we might still wonder about the origin of so many independent parameters but their general behavior would have posed no striking puzzles. Instead, we have unexplained mass ratios like $\frac{m_e}{M_W} = 6 \times 10^{-6}$, quark masses covering at least four orders of magnitudes, etc. Not only we cannot calculate the various parameters, we have no understanding of their general orders of magnitude and no explanation for the observed hierarchy of masses.

## 3. Masses and Angles: Experimental Values and Numerology

In the minimal standard model we have 13 parameters representing the fermion masses (nine parameters), mixing angles (three) and KM-phase (one). If we *assume* that the top quark will be found somewhere in the 40-60 GeV range and that the observed value of $\epsilon$ in the $K^0 - \bar{K}^0$ system is fully accounted for by the KM-phase, we can quote either precise values or reasonable estimates for all of these parameters. The values are (all masses in $GeV$ units):

First generation masses: $m_u = 0.004$; $m_d = 0.007$; $m_e = 0.0005$ .
Second generation masses: $m_c = 1.3$; $m_s = 0.15$; $m_\mu = 0.1$.
Third generation masses: $m_t \sim 50 \pm 10$; $m_b = 5$; $m_\tau = 1.8$ .
Mixing between adjacent generations: $\theta_{12} = 0.22$; $\theta_{23} = 0.05$ .
Mixing between "distant" generations: $\theta_{13} \sim 0.01$ .
KM-phase: $\delta \sim 90° \pm 30°$ .

A few comments are in order:

(*i*) All masses of the five *known* quarks are approximate, but their order of magnitude is correct and we will not need here more than that.

(*ii*) The top-quark mass may turn out to be above the range listed here. In fact, the only upper limit[1] we have is $m_t \leq 180\ GeV$, obtained from a recent detailed analysis of all determinations of $sin^2\theta_W$, including all one-loop radiative corrections. The main remaining ambiguity in these calculations is introduced by the unknown $t$-quark mass, and the consistency of the different determinations leads to the 180 $GeV$ bound. We return to comment about the $t$-quark mass in section 9, where we discuss the recent observation of $B_d^0 - \bar{B}_d^0$ mixing.

(*iii*) We are using a choice of mixing angles which is the most convenient for most considerations. We will comment on this issue in some detail in the section 4.

(*iv*) Direct searches for $b \to u$ transitions give only an upper limit for $\theta_{13}$. The value of that *upper* limit depends on the algorithm used in interpreting the observed momentum spectrum of the leptons in $b$-decay and it ranges between 0.007 and 0.015. Since no $b \to u$ transition has been directly observed, the data by itself would still allow $\theta_{13} = 0$. At the same time, no direct determination of the phase $\delta$ is available. In the *minimal* standard model, the *approximate* expression for the CP-violating parameter $\epsilon$ can be written as:

$$\epsilon = 2.3 \times 10^{-3} \times \left[\frac{\theta_{13}}{0.01}\right] \left[\frac{\sin\delta}{1}\right] \left[\frac{m_t}{50\ GeV}\right] \left[\frac{B}{0.5}\right]$$

where the approximation is valid for $m_t$ values which are not too far from 50 $GeV$ and $B$ is expected to be somewhere between $\frac{1}{3}$ and 1. The full expression for $\epsilon$ is more complicated[2], but the crude approximation presented here is sufficient for our qualitative purposes. It is clear that if we wish to explain the observed value of $\epsilon$ *and* the upper limit on $\frac{\Gamma(b\to u)}{\Gamma(b\to c)}$ in terms of a minimal three-generation standard model without additional Higgs particles or "beyond standard" physics, we must assume that $\theta_{13}$ is not too far below 0.01 and that $\delta$ is not too far from 90°. This conclusion can be somewhat relaxed if $m_t$ is much larger than 50 $GeV$ (in which case the above approximation is not valid and the dependence on $m_t$ is more complicated).

In searching for regularities among the above 13 parameters, it is instructive to consider the dimensionless ratios of fermion masses in different generations. In fact, we may wish to consider the following:

Quantities relating generations 1 and 2:

$$\sqrt{\frac{m_u}{m_c}} = 0.06; \ \sqrt{\frac{m_d}{m_s}} = 0.22; \ \sqrt{\frac{m_e}{m_\mu}} = 0.07; \ \theta_{12} = 0.22 \ .$$

Quantities relating generations 2 and 3:

$$\sqrt{\frac{m_c}{m_t}} \sim 0.16; \ \sqrt{\frac{m_s}{m_b}} = 0.17; \ \sqrt{\frac{m_\mu}{m_\tau}} = 0.24; \ \theta_{23} = 0.05 \ .$$

Quantities relating generations 1 and 3:

$$\sqrt{\frac{m_u}{m_t}} \sim 0.01; \ \sqrt{\frac{m_d}{m_b}} = 0.04; \ \sqrt{\frac{m_e}{m_\tau}} = 0.02; \ \theta_{13} \sim 0.01 \ .$$

Here, again, we arbitrarily assumed $m_t \sim 50\ GeV$.

So far, no one has offered a satisfactory explanation for the observed pattern of masses and angles. Eventually, we might hope that some new physics will enable us to calculate the exact values of some or all of these parameters. But before we attempt to do that, we should have at least some qualitative understanding of the general orders of magnitude and the observed hierarchy of mass values. Here we are essentially reduced to naive "numerological" attempts and to possible relations between mass ratios and mixing angles.

In order to pursue some of these attempts, we should first inspect the observed pattern of the parameter values and try to identify simple regularities.

A brief inspection indicates that all mixing angles and square roots of mass ratios connecting *adjacent* generations are of order $\frac{1}{10}$. In fact, if we arbitrarily define a parameter $\alpha = 0.1$, the correct orders of magnitude of the angles and the mass ratios are approximately given by:

$$\theta_{ij} \sim O(\alpha^{|(j-i)|}); \qquad \sqrt{\frac{m_i}{m_j}} \sim O(\alpha^{i-j}).$$

We will refer to this crude empirical pattern as "Numerology I".

A somewhat more detailed numerical observation is the fact that all the above mass ratios and angles actually cluster around three values: 0.2; 0.05;

0.01. Consequently, one may introduce a parameter $\lambda$ such that $\lambda \sim 0.22$ and:

$$\sqrt{\frac{m_d}{m_s}} \sim \sqrt{\frac{m_c}{m_t}} \sim \sqrt{\frac{m_s}{m_b}} \sim \sqrt{\frac{m_\mu}{m_\tau}} \sim \theta_{12} \sim \lambda;$$

$$\sqrt{\frac{m_u}{m_c}} \sim \sqrt{\frac{m_e}{m_\mu}} \sim \sqrt{\frac{m_d}{m_b}} \sim \theta_{23} \sim \lambda^2;$$

$$\sqrt{\frac{m_u}{m_t}} \sim \sqrt{\frac{m_e}{m_\tau}} \sim \theta_{13} \sim \lambda^3.$$

This empirical pattern is correct within a factor 1.5. We refer to it as "Numerology II".

"Numerology I" is extremely crude but is a simple, easy to remember pattern. "Numerology II" is more accurate, but seems to follow an irregular pattern.

At present, the above numerological observations are useful either as a simple method of remembering the orders of magnitude of the parameters or as an approximation procedure for certain calculations, keeping terms up to a certain order of $\alpha$ or $\lambda$. There is no convincing explanation or theoretical foundation for the observed pattern.

As we will see in the next sections, these naive numerological observations may provide us with some guidance in attempting to obtain relations between mass ratios and mixing angles.

## 4. A Recommended Choice of Mixing Angles and Phases

The mixing among the three generations of quarks is defined by a unitary $3 \times 3$ matrix $V$ whose matrix elements can be parametrized in terms of the three generalized Cabibbo angles and a single KM-phase. In the general case of $N$ generations, we have an $N \times N$ matrix, described in terms of $\frac{1}{2}N(N-1)$ angles and $\frac{1}{2}(N-1)(N-2)$ phases. Clearly, there are many ways of choosing the angles and phases. Among the well-known choices: the original KM-choice[3] (probably the least convenient for any purpose), the Maiani choice[4] (convenient for angles but less so for phases), the Wolfenstein choice[5] (convenient for phases but based on "Numerology II" for angles) and others. We strongly recommend that the standard choice of angles and phases become the choice first introduced by Chau and Keung[6] for three generations (incorporating the main ideas of both Maiani and Wolfenstein) and later generalized[7] to the case of $N$ generations.

In this choice every angle has a clear and direct relation to one matrix element of the matrix $V$. All angles are denoted by $\theta_{ij}$ (for any $j-i>0$), representing the mixing among generations $i$ and $j$. Each phase is denoted by $\delta_{ij}$ (for any $j-i>1$), and the related $e^{i\delta_{ij}}$ factor always multiplies the corresponding $\sin\theta_{ij}$. Assuming that the pattern of "Numerology I" persists in the general case of $N$ generations, the above choice of parameters obeys, for any $N$ and for all $j-i>0$:

$$V_{ij} = s_{ij}(1 + O(\alpha^4))$$

where $s_{ij} = \sin\theta_{ij}$ for $j-i=1$ and $s_{ij} = \sin\theta_{ij} e^{i\delta_{ij}}$ for $j-i>1$. In practice, this means that all $V_{ij}$ values above the main diagonal are given, to an accuracy of three or more significant figures, by the corresponding values of $s_{ij}$.

The explicit form of the matrix $V$ in the case of three generations is:

$$V = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}^* & c_{12}c_{23} - s_{12}s_{23}s_{13}^* & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}^* & -c_{12}s_{23} - s_{12}c_{23}s_{13}^* & c_{23}c_{13} \end{pmatrix}$$

where $c_{ij} = \cos\theta_{ij}$; $s_{ij} = \sin\theta_{ij}$(for $j-i=1$); $s_{13} = \sin\theta_{13}e^{i\delta_{13}}$.

A detailed discussion of our recommended choice of parameters can be found in Reference 7.

## 5. Why Do We Expect Relations Between Masses and Angles?

Within the standard model, all masses and angles are free parameters. There are no relations among them.

Within some new "beyond standard" theory which describes physics at a high energy scale $\Lambda$, we may be able to calculate *all* the masses, angles and phases, starting from some new set of (hopefully few) fundamental parameters.

Until such a time comes, it may be interesting to try to find some relations among the observed mixing angles and the pattern of masses. We may not be able to derive the masses and the angles from first principles, but we may be able to relate quantities which we do not yet know to compute.

Why do we believe that such relations must exist? Within the standard model, there are several "low-energy" quantities which we can calculate both in the tree approximation and in higher orders. We often discover that some low-energy quantity depends on the masses of intermediate particles which can be exchanged in a one-loop diagram. That, by itself, is no surprise. However, our physics intuition tells us that it is unlikely that a low-energy quantity will become indefinitely *larger* if the mass of such an intermediate particle *increases.* Such is the case at least in three simple examples which we now list:

(*i*) $\Delta M(K_S^0 - K_L^0)$. In this case the contribution of the top quark is such (because of the GIM mechanism) that for $m_t \to \infty$ we find $\Delta M \to \infty$.

(*ii*) $\mu \to e+\gamma$. Here, again, a GIM mechanism operates. The rate of the process depends on the masses of intermediate neutrinos in a way which does not disappear for $m_\nu \to \infty$.

(*iii*) The $\rho$-parameter of the standard model gets a contribution[8] from any pair of quarks with charges $\frac{2}{3}, -\frac{1}{3}$ which have a non-vanishing coupling to $W^+$ (in other words: when the relevant mixing angle does not vanish). Here, again, we may consider *e.g.* the contribution of a loop with a t-quark and a d-quark. If we hold everything else fixed and send the t-quark mass to infinity, we obtain a divergent contribution to $M_W$ (and to $\rho$).

In all of these cases, there is a very simple way out of the paradox. The contribution of the intermediate quark or lepton is always multiplied by a mixing angle. If we assume that the mixing angle *must* decrease when the fermion mass increases to infinity, we will encounter no difficulty whatsoever. Thus, for instance, if the angle $\theta_{23}$ is proportional to $\sqrt{\frac{m_c}{m_t}}$, the contribution of the t-quark to $\Delta M(K_S^0 - K_L^0)$ will not "explode" when $m_t \to \infty$. Similarly, if $\theta_{13}, \theta_{23} \to 0$ fast enough for $m_t \to \infty$, the t-quark contribution to the $\rho$-parameter will not "explode".

We have therefore reached a remarkable conclusion: We have supplemented the standard model by a simple physical assumption stating that low-energy quantities must remain stable when masses of intermediate particles in higher order corrections increase indefinitely. We then find that this simple assumption forces us to have relations between masses and angles. More specifically: It tells us that mixing angles between a given pair of generations must decrease when the mass ratios of the fermions in the same generations decrease. We cannot derive a precise relation but the necessity of having some such relation is a significant result.

Since both the masses and the angles are obtained in the standard model from the mass matrices (which, in turn, are based on the Yukawa couplings of the Higgs fields), we must therefore conclude that *within the mass matrices*, some new symmetries or relations must exist. It is possible that some elements of the mass matrices vanish because of some new symmetry or that some otherwise unrelated matrix elements become related as a result of some new principle. Only such relations can yield the necessary connections between masses and angles.

We can now formulate two approaches to the problem of understanding the observed values of the masses, angles and phases:

(*i*) *The theoretical approach.* We search for the new theory, discover the new Lagrangian $\mathcal{L}_{NEW}$, derive the new symmetries which appear in the mass matrices and find the resulting relations among masses, angles and phases.

(*ii*) *The phenomenological approach.* We start from the observed pattern of masses and angles. Assuming what we earlier called "Numerology I" or "Numerology II" *and imposing mass-angle relations of the type suggested* *above* (i.e. $\theta_{ij} \sim \sqrt{\frac{m_i}{m_j}}$) we search for simple patterns in the mass matrices. On the basis of these, we guess the new symmetry or principle and then, hopefully, try to start building a convincing new model for the new physics at the high-energy scale.

Clearly, the first method is superior, if we can pursue it. No one has succeeded in doing so. The second method is less ambitious and much less profound. Several interesting attempts have been made along its lines but no great success can be reported. In the following section we briefly review some such attempts, mainly in order to show the type of work that can be done, at present.

## 6. Trying to Derive Relations Between Masses and Angles

Consider the quark mass matrix for the case of three generation. For simplicity, we assume that all mass matrices are Hermitian (in general they are not, but we are only illustrating the methods here). The simplest game one can play is to assume that certain matrix elements vanish (presumably as a result of a new symmetry of the Higgs Yukawa couplings). With a sufficient number of vanishing matrix elements , one can derive new relations between masses and angles.

The best known ansatz is the one proposed by Fritzsch[9] several years ago. According to his hypothesis, the $3 \times 3$ mass matrices for the up and down sectors have the form:

$$M_u = \begin{pmatrix} 0 & X_u & 0 \\ X_u^\star & 0 & Y_u \\ 0 & Y_u^\star & Z_u \end{pmatrix} \; ; \; M_d = \begin{pmatrix} 0 & X_d & 0 \\ X_d^\star & 0 & Y_d \\ 0 & Y_d^\star & Z_d \end{pmatrix} .$$

In this case we can express all masses, angles and phases in terms of eight real parameters. Since we have ten measurable quantities (six masses, three angles and one phase) we may obtain two relations. These relations are, at present, consistent[10] with the available experimental information.

Another ansatz, based on a different theoretical motivation has been proposed by Stech.[11] He postulates different forms for the mass matrices in the up and down sectors. According to Stech:

$$M_u = S; \; M_d = \beta S + A$$

where S and A are, respectively, a symmetric and an antisymmetric $3 \times 3$ matrix. Here, again, we are able to describe the ten measurable quantities in terms of a smaller number of parameters, obtaining relations which are, consistent with all data prior to the recent observation[12] of $B_d^0 - \bar{B}_d^0$ mixing.

Using the empirical fact that:

$$\frac{m_u}{m_c} \ll \frac{m_d}{m_s}$$

we obtain from both the Fritzsch ansatz and the Stech ansatz:

$$\theta_{12} \sim \sqrt{\frac{m_d}{m_s}}.$$

We also obtain, for the Fritzsch case:

$$\theta_{23} \sim \sqrt{\frac{m_s}{m_b}} - \sqrt{\frac{m_c}{m_t}}$$

and for the Stech case:

$$\theta_{23} \sim \sqrt{\frac{m_s}{m_b} - \frac{m_c}{m_t}}.$$

All of these results are consistent with all data prior to the recent observation[12] of $B_d^0 - \bar{B}_d^0$ mixing. Moreover, both schemes provide us with a qualitative explanation for one interesting feature of the pattern of masses and angles. We have noticed in section 3 that $\theta_{23}$ was significantly smaller than $\theta_{12}$. In fact, in what we called "Numerology II" we quoted $\theta_{23} \sim \lambda^2$, $\theta_{12} \sim \lambda$. In the same numerological exercise we noted that $\sqrt{\frac{s}{b}} \sim \sqrt{\frac{c}{t}} \sim \lambda$ while $\lambda^2 \sim \sqrt{\frac{u}{c}} < \sqrt{\frac{d}{s}} \sim \lambda$. Now we learn that the smallness of $\theta_{23}$ is related to the similar values of $\frac{m_s}{m_b}$ and $\frac{m_c}{m_t}$ while the difference between $\frac{m_u}{m_c}$ and $\frac{m_d}{m_s}$ is related to the fact that $\theta_{12}$ is larger. Thus, both the Fritzsch[9] and the Stech[11] guesses account for an important regularity in "Numerology II".

This is precisely the type of qualitative features which we may be able to understand by "playing" with mass matrices.

Another interesting exercise was recently proposed by Gronau et al.[13] They subscribe to *both* the Fritzsch and the Stech hypotheses and combine them to suggest the following mass matrices:

$$M_u = \begin{pmatrix} 0 & A & 0 \\ A & 0 & B \\ 0 & B & C \end{pmatrix} ; \; M_d = \beta \begin{pmatrix} 0 & A & 0 \\ A & 0 & B \\ 0 & B & C \end{pmatrix} + \begin{pmatrix} 0 & ia & 0 \\ -ia & 0 & ib \\ 0 & -ib & 0 \end{pmatrix} .$$

Here all masses, angles and phases are expressed in terms of only six real parameters $(A, B, C, \beta, a, b)$ and the predicted relations are still in reasonable agreement with the existing data, except for the recently observed[12] $B_d^0 - \bar{B}_d^0$ mixing.

The above "games" can teach us something about the physics beyond the standard model only if they can be based on some reasonable theoretical foundations. Typically, one would have to introduce some kind of a "horizontal symmetry" according to which different generations are labeled by different values of a new (spontaneously broken) quantum number. By applying such a symmetry to the fermion sector *and* to the Higgs sector, one immediately obtains selection rules preventing certain Higgs particles from coupling to certain fermions, depending on their generation. In this way we obtain vanishing matrix elements in the mass matrices, leading to one pattern or another.

Unfortunately, all the "horizontal symmetries" which were suggested so far, appear to be fairly artificial in the sense that they are designed to produce a specific ansatz for the mass matrices without explaining or solving other important issues of the standard model. Nevertheless, we believe that the problem of masses and angles is so important that we should continue to pursue it even at the simple-minded level described here with the hope of obtaining some clues to the real mystery behind the experimentally observed pattern.

## 7. A Fourth Generation of Quarks and Leptons?

There is no known fundamental reason for the existence of three generations of quarks and leptons. There is no good argument for or against the existence of additional generations. Accepting the pattern of "Numerology I", we would guess that the mixing angles of a possible fourth generation with the first two are probably very small: $\theta_{14} \sim 10^{-3}$, $\theta_{13} \sim 10^{-2}$. It is unlikely that the fourth generation will have a substantial influence on low energy quantities involving the *first two generations*, with the possible exception of CP-violating amplitudes in the $K^0 - \bar{K}^0$ system. Even in this latter case, we do not expect fourth generation effects to dominate, but they may lead to terms which are comparable to those induced by the third generation particles. On the other hand, fourth generation quarks *may* influence measurable quantities involving third generation quarks (such as $B^0 - \bar{B}^0$ mixing and other amplitudes involving $b$-quarks).

There are several interesting experimental and theoretical constraints concerning a possible fourth generation:

(*i*) The UA1 collaboration[14] obtained a lower limit of 41 GeV for the mass of a possible fourth generation charged lepton $\sigma$. This result assumes that the corresponding neutrino $\nu_\sigma$ is much lighter than the hypothetical $\sigma$-lepton. Note that this limit already indicates that

$$\frac{m(\sigma)}{m(\tau)} > \frac{m(\tau)}{m(\mu)}$$

while the $\frac{\tau}{\mu}$ mass ratio ($\sim$ 17) is much smaller than the $\frac{\mu}{e}$ mass ratio ($\sim$ 210).

(*ii*) Cosmological and astrophysical considerations seem to limit the number of light neutrino generations to at most four, possibly three.

($iii$) Measurements of the $Z$ width should soon provide us with strong limits on the number of light neutrinos.

($iv$) The present value of the $\rho$-parameter in the standard model leads to an upper limit[8] on the *mass difference* between the two quarks of a hypothetical fourth generation. We obtain[1]

$$m(t') - m(b') < 180\ GeV.$$

If we assume (for no good reason) that the approximate relation $\frac{m(s)}{m(c)} \sim \frac{m(b)}{m(t)} \sim \frac{1}{10}$ carries over to a fourth generation, we conclude that $m(t')$ must be below 200 $GeV$. However, we cannot exclude heavier $t' - b'$ pairs which are almost degenerate.

($v$) If the mass difference within a hypothetical fourth generation of quarks allows the decays $t' \rightarrow b' + W^+, t' \rightarrow b' + \phi^+$ where $\phi^+$ is a charged Higgs particle, such decays should dominate over the usual weak decays $t' \rightarrow b' + e^+ + \nu_e,\ t' \rightarrow b' + u + \bar{d}$.

($vi$) If quark masses in the fourth generation exceed a few hundred GeV's, the Yukawa couplings of these quarks may become strong, leading to a variety of unpleasant effects of the so-called "strong weak interactions". However, such a situation cannot be excluded and it may very well happen.

Our overall conclusion from the above assortment of comments is the following: There is no urgent need for additional generations. If they exist, they are not likely to solve or to illuminate any *presently* existing problem in the standard model. Extrapolating present mass patterns and using various bounds it is reasonable to guess that *at most* one additional generation exists. If it does, a reasonable guess for the masses (within, say, a factor of two) would be:

$$m(t') \sim\ 200\ GeV;\ m(b') \sim\ 100\ GeV;\ m(\sigma) \sim\ 50\ GeV.$$

Other mass values cannot be excluded, but would have to follow patterns which are quite different from the ones observed so far.

## 8. New Bounds on Neutrino Masses.

Neutrinos are either exactly massless or extremely light. All three known neutrinos are much lighter than the corresponding charged leptons. The mass ratios between each neutrino and its corresponding charged lepton is much smaller than the mass ratio between the two quarks in the same generation or even than the mass ratio between charged leptons and quarks in the same generation.

The present direct experimental bounds on the masses of $\nu_e, \nu_\mu$ and $\nu_\tau$ are, respectively, 18 $eV$, 250 $keV$ and 70 $MeV$[15]. All neutrino masses are still consistenet with zero.

If neutrinos are exactly massless, there must be an exact symmetry which keeps them massless to all orders in the standard model and to all orders in any "beyond standard" theory which may emerge as the correct theory. No one has proposed such a symmetry principle. We will therefore assume that neutrinos are *not* exactly massless.

We also assume that the neutrino masses are not pure Dirac masses. If they were, there would be no known reasonable explanation for their small values. For the same reason, we believe that the masses of the left-handed neutrinos are not pure Majorana masses.

The most attractive possibility is to suggest that neutrinos have ordinary Dirac masses (more or less comparable to those of the corresponding charged leptons) *and* that they also have Majorana masses. Majorana masses for left handed neutrinos can only be due to Higgs triplets whose vacuum expectation values must be small (or else the Weinberg mass relation is destroyed). Majorana masses of right handed neutrinos must be due to Higgs singlets whose vacuum expectation values can be arbitrarily large, without affecting the masses of $W$ and $Z$ or breaking $SU(2)$. The Higgs singlet(s) may represent some new physics "beyond the standard model" and its v.e.v. represents the energy scale $\Lambda$ of that new physics.

We are therefore led in a very natural way to a neutrino which has both a Dirac and a Majorana mass, yielding a $2 \times 2$ mass matrix for *one generation*:

$$\begin{pmatrix} 0 & m \\ m & M \end{pmatrix}$$

where m is a "normal" Dirac mass ($m \sim m(\ell)$ where $\ell$ is a charged lepton) and $M$ is a Majorana mass ($M \sim O(\Lambda)$ where $\Lambda$ is the scale of some new physics).

This is the famous "see-saw" matrix[16] whose eigenvalues are:

$$m_1 \sim \frac{m^2}{M} \; ; \; m_2 \sim M.$$

For each generation we then obtain a light neutrino which is almost purely left-handed and is much lighter than the corresponding charged lepton, and a very heavy neutrino who is almost purely right-handed.

It is not possible to calculate the neutrino masses without knowing the values of the Majorana masses. However, it is reasonable to assume that the Majorana masses of the different generations of neutrinos follow a simple pattern and are either of the same order of magnitude or related to each other by ratios similar to the corresponding ratios of the Dirac masses. These possibilities lead to rough estimates on the mass *ratios* of the light neutrinos of different generations. In particular we get:

$$\frac{m(\nu_\tau)}{m(\nu_\mu)} \sim \left[\frac{m(\tau)}{m(\mu)}\right]^p$$

Where $p = 2$ if the Majorana masses of $\nu_\tau$ and $\nu_\mu$ are the same, $p = 1$ if they are proportional to the corresponding Dirac masses and $1 \leq p \leq 2$ if the truth is somewhere in between. We refer to the relation $1 \leq p \leq 2$ as the "reasonable see-saw" assumption[17]. It provides us with a sensible guess for neutrino mass *ratios*, although it gives us no information on the absolute values of the masses.

Simple cosmological arguments[18] lead to relations between neutrino masses and lifetimes. Stable neutrinos must be lighter than 65 $eV$ or heavier than 4 $GeV$. Unstable neutrinos can have any mass in the range between 65 $eV$ and 4 $GeV$, provided that they decay sufficiently fast. For a given lifetime we can restrict the allowed mass range for the relevant neutrino.

For any specific decay mode for neutrinos *within the standard model* it is well known that there is a simple relation between the mass of a decaying neutrino and its lifetime. By combining this relation and the cosmological relation, we can then eliminate certain mass ranges and derive new bounds on the neutrino masses.

The problem is that the most likely neutrino decays are probably induced by "beyond standard" physics and, in such models, the resulting relations between mass and lifetime are not so easy to calculate. A recent analysis of all possible neutrino decays in models such as GUTS, SUSY, Left-Right Symmetry, Horizontal Symmetry, Substructure and Majoron schemes has led us[17] to the following results:

(*i*) The mass of $\nu_\mu$ must be below 65 $eV$[17]. This result is obtained by considering all possible $\nu_\mu$ decays and deriving a relation between $m(\nu_\mu)$ and $\tau(\nu_\mu)$ for each decay mode and decay mechanism. In all cases the resulting relation, together with the cosmological constraint, lead to the conclusion that $m(\nu_\mu)$ must be below the cosmological limit for stable neutrinos, *i.e.* 65 $eV$. There is a tiny "window"[19] (or perhaps "peephole") for the decay $\nu_\mu \rightarrow \nu_e$+majoron if *all* the following unlikely conditions are simultaneously obeyed: $m(\nu_\mu) \sim$ 200 $keV$ *and* the age of the universe is *less* than $12 \times 10^9$ years *and* the new scale of the Majorana masses is smaller than $M(W)$ (around 50 $GeV$). With such parameters, the mass and lifetime of $\nu_\mu$ just barely survive the various bounds, at the price of making the universe uncomfortably young. Any improvement in the present experimental bound on $m(\nu_\mu)$ and/or a definite knowledge that the age of the universe must be larger than 12 $Gy$ will eliminate this "Glashow peephole"[19].

($ii$) The mass of $\nu_\tau$ is[17] either below 65 $eV$ or between 900 $keV$ and the present experimental bound of 70 $MeV$. This result is, again, based on a detailed study of all possible decay modes and decay mechanisms of $\nu_\tau$, without appealing to the see-saw mechanism. However, if $m(\nu_\mu) < 65\ eV$ (as stated above in (i)) and $m(\nu_\tau) > 900\ keV$, we find $\frac{m(\nu_\tau)}{m(\nu_\mu)} > 14,000$. This would strongly contradict the "reasonable see-saw" assumption, according to which $p \leq 2$ and $\frac{m(\nu_\tau)}{m(\nu_\mu)} < 300$. Even allowing $p \leq 3$ (rather than $p \leq 2$) will not enable us to have $m(\nu_\tau) > 900\ keV$. We therefore conclude[17] that a combination of cosmological considerations, calculations of $\nu_\tau$ decay rates and the "reasonable see-saw" give us an extremely strong bound: $m(\nu_\tau) < 65\ eV$.

($iii$) Having established that $m(\nu_\tau)$ is below 65 $eV$, we may now return to the "reasonable see-saw" assumption and now use the inequality $p \geq 1$. We immediately obtain[17] : $m(\nu_\mu) < 4\ eV$, $m(\nu_e) < 0.02\ eV$. Our new bounds for the three neutrinos are, respectively, six, five and three orders of magnitudes below the present experimental upper bounds on $m(\nu_\tau)$, $m(\nu_\mu)$, $m(\nu_e)$.

($iv$) Using the bound $m(\nu_\tau) < 65\ eV$ we may also derive a *lower* bound on the Majorana mass of $\nu_\tau$, leading to a bound on the energy scale of the new physics which is responsible for this Majorana mass term. We obtain[17]: $M >\ 50\ PeV$. In the case of Grand Unified Theories, this is a useless bound. However, if the Majorana mass reflects a left-right symmetry, a horizontal symmetry or a substructure of leptons, we deduce that the relevant energy scale must be above 50 $PeV$. This result is particularly crucial for the minimal version of the Left-Right Symmetric theory, in which a neutrino Majorana mass is a necessary consequence. We learn that, in this case[17], $M(W_R) >\ 50\ PeV$, three or four orders of magnitudes above the previous lower bounds for $M(W_R)$.

All of these bounds are perfectly compatible with the neutrino mass scale which is required for solving the solar neutrino puzzle in terms of resonant neutrino oscillations[20]. They are also compatible with the limit obtainable on the neutrino mass from the recent observation of neutrinos from the Supernova SN1987A.

## 9. $B^0 - \bar{B}^0$ Mixing and CP-Violation in the $B$-System

It has been known for quite some time that the neutral $B$-meson system offers the best chance (outside of the neutral $K$ system) to study the effects of CP-violation and of mixing and flavor changing transitions. The crucial parameter is the ratio $\frac{\Delta M}{\Gamma}$ which is relatively large for the $B^0 - \bar{B}^0$ system as a result of the long lifetime of the $b$-quark.

A preliminary indication for $B^0 - \bar{B}^0$ mixing was reported several months ago by the UA1 collaboration[21]. They could not determine experimentally whether their effect is due to mixing of $B_d^0$ or $B_s^0$ mesons. Theoretical arguments indicated that $B_s^0 - \bar{B}_s^0$ mixing is likely to be larger than $B_d^0 - \bar{B}_d^0$ mixing. Very recently, the ARGUS collaboration working at DORIS found[12] three independent pieces of evidence for $B_d^0 - \bar{B}_d^0$ mixing, analysing data obtained at the $\Upsilon(4S)$ energy, below the threshold for producing a $B_s^0 - \bar{B}_s^0$ pair.

The ARGUS result quotes a ratio of approximately $20\% \pm 10\%$ between the number of like sign and opposite sign dileptons at the $\Upsilon(4S)$. That ratio $r_d$ is related to the parameter $x_d$ by the relation:

$$r_d = \frac{x_d^2}{2 + x_d^2}$$

where $x_d = \frac{\Delta M}{\Gamma}$. Solving for $x_d$ we find:

$$x_d \sim 0.7 \pm 0.25$$

A more precise determination of $x_d$ will have to await the official publication of the ARGUS data, including a detailed error estimate etc.

What are the theoretical implications of this new result?

The expression for the quantity $x$ is given by:

$$x_i = \frac{\Delta M}{\Gamma} = \tau_B \frac{G_F^2}{6\pi^2} \eta_{QCD} m_B B_B f_B^2 m_t^2 |V_{ti}^{*2} V_{tb}^2|$$

where $i = d, s$; $\Delta M$ is the $B_i^0 - \bar{B}_i^0$ mass difference; $\Gamma$, $\tau_B$, $m_B$ and $f_B$ are, respectively, the width, lifetime, mass and decay constant of $B_i^0$; $\eta_{QCD}$ is a QCD correction; $V_{ti}$ is the relevant matrix element of the quark mixing matrix; $B_B$ is the usual factor describing the deviation of the $\Delta B = 2$ matrix element from its vacuum insertion approximation.

Substituting the known values of $\tau_b, G_F, \eta_{QCD}, m_B$ and $V_{tb}$ and normalizing the other parameters to their most "reasonable" values we obtain the following prediction for $x_d$:

$$x_d = 0.08 \left(\frac{B_B}{1}\right) \left(\frac{f_B}{0.15\ GeV}\right)^2 \left(\frac{m_t}{50\ GeV}\right)^2 \left(\frac{V_{td}}{0.01}\right)^2$$

The new experimental result for $x_d$ tells us that somewhere in the above equation, among the four unknown parameters, we should be able to "collect" a multiplicative factor of $9 \pm 3$. Let us consider the possibilities:

(*i*) The parameters $B_B$ and $f_B$ are not known. The value of $B_B$ is probably somewhere between, say, 0.4 and 1.5. Estimates of $f_B$ may vary between 0.1 and 0.2 $GeV$. Between these two parameters we can probably safely assume:

$$\left(\frac{B_B}{1}\right) \left(\frac{f_B}{0.15\ GeV}\right)^2 \leq 2.5.$$

If we arbitrarily assume that $B_B f_B^2$ actually obtains this maximal value, we find that the remaining missing multiplicative factor is anywhere between 2.5 and 5.

(*ii*) The value of $\left(\frac{m_t}{50\ GeV}\right)^2$ can easily be 2.5 or 5 (for $m_t \sim$ 80 $GeV$ and $m_t \sim$ 110 $GeV$, respectively) or even 13 (for the upper limit of $m_t \sim$ 180 $GeV$). However, it is interesting to see whether we can account for the observed $B_d^0 - \bar{B}_d^0$ mixing *without* demanding a large value of $m_t$. This can be done *only* if $|V_{td}|$ is relatively large.

(*iii*) The expression for $V_{td}$ in terms of the choice of angles outlined in section 4 is:

$$V_{td} = s_{12}s_{23} - c_{12}c_{23}s_{13}^{\star}$$

Substituting the known values of $\theta_{12}, \theta_{23}$ we obtain:

$$V_{td} = 0.011 - |s_{13}|e^{-i\delta}.$$

We have seen in section 3 that for $m_t$ values around 50 $GeV$, $s_{13}$ cannot be too far below 0.01 (or else we will not be able to recover the correct value of the $\epsilon$ parameter in the $K^0 - \bar{K}^0$ system). The maximal value of $|V_{td}|$ is obtained for $\delta$ values which are close to 180° and we are then allowed to have at most $|V_{td}| \sim$ 0.02. However, if $\delta$ is too close to 180°, we lose CP-violation. In fact, we have stated in section 3 that, for $m_t \sim$ 50 $GeV$, $\delta$ is most likely to be not too far from 90° in order to allow for the observed value of $\epsilon$. In that case $|V_{td}|$ cannot be as large as 0.02. For $\delta = 90°$ we probably have $|V_{td}| \sim 0.015$. We conclude that, depending on the value of $m_t$ and on the value of the $B$ parameter in the $K^0 - \bar{K}^0$ system, we may get values of $|V_{td}|$ which can be as high as 0.02, but are most likely to be somewhat smaller. There is a correlation between the value of $m_t$ and the maximal allowed value of $|V_{td}|$.

Our overall summary of this point is the following[22]: By pushing $V_{td}$, $B_B$ and $f_B$ to their highest reasonable values and by considering the lowest end of the experimentally allowed range of values for $x_d$, we can accommodate the ARGUS results even with $m_t \sim$ 50 $GeV$. However, if we take the central experimental value of $x_d$ and what appear to be the most sensible guesses for the other parameters, we are led to the conclusion that $m_t$ should be larger or else some new physics ingredients are required. We clearly need improved measurements of $x_d, x_s, V_{bu}, \frac{\epsilon'}{\epsilon}$ and several other quantities which may give us additional constraints on the various parameters of the three-generation standard model.

One prediction which seems to be relatively free of ambiguities is the following:

$$\frac{x_s}{x_d} = \left(\frac{|V_{ts}|}{|V_{td}|}\right)^2$$

Here we assume that the parameters $\tau_b, m_B, B_B$ and $f_B$ are identical (to a good approximation) for the $B_d^0$ and the $B_s^0$ mesons and they cancel in the ratio $\frac{x_s}{x_d}$. Assuming $|V_{ts}| = 0.05$ and $|V_{td}| \sim 0.01 \pm 0.005$ we obtain:

$$\frac{x_s}{x_d} = 25^{+40}_{-18}.$$

With the preliminary experimental value of $x_d = 0.7 \pm 0.25$ we therefore conclude:

$$3 < x_s < 60$$

with the most reasonable value of $x_s$ being around 18. This leads in all cases to substantial $B_s^0 - \bar{B}_s^0$ mixing. The ratio between the number of like-sign dileptons and the number of opposite sign dileptons coming from the primary decay of pairs of $B_s^0$ mesons is therefore *at least* 0.8 (for $x_s = 3$) and probably very near 1. If the observed effect is consistent with maximal $B_s^0 - \bar{B}_s^0$ mixing, it will not teach us too much about the actual values of the different parameters. However, if the ratio is only 0.8 or so, it will provide us with a very strong constraint on $V_{td}$, pushing it towards its maximal allowed value.

So far, there is no evidence for CP-violation in B-meson decays. The observed $B^0 - \bar{B}^0$ mixing is, of course, unrelated to CP-violation (in the same way that the existence of a $K_S^0 - K_L^0$ mass difference does not imply CP-violation in the $K^0$ system).

A lot of theoretical work has been done on CP violating processes involving $b$-quarks[22]. We will not review here all the results. We only comment that the ***absolute size*** of the CP-violating amplitudes is more or less the same in all cases. In the notation of section 4, any such amplitude must be proportional to $s_{12}s_{23}s_{13}\sin\delta_{13}$. The measured CP-violating *signal* (typically an asymmetry between two CP-related decay modes of a $B$ and a $\bar{B}$ meson) is, in general, given by the ratio of a CP-odd amplitude and a CP-even amplitude. Since all CP-odd amplitudes are comparable, the most significant signals are likely to be observed in those cases in which the CP-even amplitudes are relatively small. Two typical examples are the exclusive decay modes of $B_d^0$ into $\psi K_s^0$ and $D^+\pi^-$. In the first case, the expected branching ratio is somewhere between $10^{-3}$ and $10^{-4}$ and in the second case we probably have a much larger branching ratio of order 1%. If the CP- violating amplitudes in both cases are comparable, the predicted asymmetries are probably of order 10% for $\psi K_s^0$ but only 1% or less for $D^+\pi^-$. In both cases, the required total sample of $b$-quarks is quite large. We need at least $10^6$, probably $10^7$ $b$-quarks in order to perform either measurement in a conclusive way.

A universally accepted yardstick for the possibility of detecting CP-violation in the $B$-system (*e.g.* in the above two cases) is the accumulation of a sample of the order of $10^7$ B-mesons. This exceeds anything available today by two orders of magnitude and anything definitely planned for the next five years by one order of magnitude. We return to this issue in the next section.

## 10. A $b$-Quark "Factory" – Why, How and When?

We have seen that the physics of hadrons containing $b$ quarks offers us substantial information on the parameters of the standard model and on the possibility of new physics beyond it. We list below some of the most important types of measurements:

(*i*) We already have approximate measurements of the $b$-quark lifetime, leading to a value for $\theta_{23}$. However, before we can accept this as a definite determination, we must verify that the lifetimes of $B_u^-$, $B_d^0$, $B_s^0$, $B_c^-$ and of baryons containing $b$ quarks are all approximately equal. This can be verified only by a direct measurement of specific final states.

(*ii*) A direct observation of $b$ decays into non-strange, non-charmed, final states will enable us to directly determine the last missing mixing angle $\theta_{13}$. Here we need to detect both semileptonic and nonleptonic decys. Eventually, we would also like to measure the "cleanest" (and most difficult) purely leptonic decay $B^- \to \tau^- + \bar{\nu}_\tau$.

(*iii*) Measurements of $B_d^0 - \bar{B}_d^0$ and $B_s^0 - \bar{B}_s^0$ mixing are clearly important and should be improved.

(*iv*) A variety of CP-violating transitions can be looked for both in exclusive channels and, given enough statistics, even as an asymmetry between positive and negative like-sign dileptons in semi-inclusive, semi-leptonic $B^0$ decays. Eventually one would like to attempt even a measurement of the time evolution of a $B^0$ state (in analogy with the "standard" $K^0$ measurements).

(*v*) Rare flavor changing decays such as $b \to s + \gamma$ and $b \to s + \nu + \bar{\nu}$ can be searched for.

These and similar measurements represent an extremely important area of experimentation. It may lead to important tests of the standard model, to a precise determination of each parameter and to a possible indirect observation of effects due to a fourth generation of fermions, additional Higgs particles or some other new physics.

However, most of the above experiments require a sample of at least $10^7$ $b$-quarks. We therefore need an accelerator capable of producing, say, $10^7$ $b's$ per year. Such machines (especially if they are primarily dedicated to the production of large numbers of $b$ quarks) have become known as "$b$-factories". Perhaps a more appropriate name might be "heavy flavor factories", since in most cases, they would also provide us with very large samples of charmed particles and $\tau$ leptons.

We believe that it will be extremely helpful to acquire a sample of $10^7$ $b$-quarks within the next few years. We present below a few comments on six possible ways of achieving this, concluding that some of them are totally impractical while others deserve a very careful consideration.

(i) *An $e^+e^-$ collider at $E_{c.m.} = M[\Upsilon(4S)]$.* The cross section for producing $B$-mesons at the $\Upsilon(4S)$ resonance is approximately 1 $nb$. Assuming an "effective year" of $10^7$ $sec$, we can obtain $10^7$ $b's$ per year (one every second!) only if we have a luminosity of $10^{33}$ $cm^{-2}sec^{-1}$. Such a collider is not available, at present. The best existing luminosity in this energy range belongs to CESR which will hopefully run steadily at $10^{32}$ in the foreseeable future. There seems to be no major conceptual or technical difficulty in designing and building a fairly conventional circular machine which can reach (and run regularly at) a luminosity of $10^{33}$. Such a machine has been proposed for SIN[23]. It can presumably be also considered at Cornell or even (with less likelihood) be based on the existing DORIS or PEP machines, with major modifications. If such a machine is built, it will certainly accumulate a sufficient number of $B$-mesons. However, at the $\Upsilon(4S)$ we cannot produce $B_s^0$ mesons which are necessary for some of the more interesting processes.The identification of $b$-quark events at the $\Upsilon(4S)$ will not be based on vertex detection because of the low momentum of the produced $B$. Nevertheless, this option seems to be the only feasible way of obtaining a relatively clean sample of $10^7$ $b's$ within the next five or six years, and with a reasonable cost. As we discuss below all other options are either impossible or too expensive or cannot be ready in less than a decade.

(*ii*) *An* $e^+e^-$ *collider at* $E_{c.m.} \sim 15 - 20$ *GeV*. Here the idea is to work at the lowest possible energies which allow a clean vertex identification, with the possibility of producing all types of $B$ mesons (and $B$-baryons). This overcomes the two drawbacks of the $\Upsilon(4S)$ option, but the price is a $b$ production cross section which is approximately 0.1 $nb$ at $E_{c.m.} \sim 20$ $GeV$. In order to collect $10^7$ events per year we then need a luminosity of $10^{34}$. This can presumably be achieved, if at all, only by building a linear collider (which will also have the advantage of "thin" beams, useful for working with vertex detectors). Several authors[24] have been considering such schemes, among them groups at Frascati and UCLA. Unfortunately, it appears that a significant amount of research has to be done before such a machine can be seriously proposed and the relevant time scale appears to be of the order of ten years. It is extremely unlikely that such a machine can become a reality before 1995.

(*iii*) *An* $e^+e^-$ *collider at the* $Z^0$. The $Z^0$ offers the advantage of a large cross section for $b$ production (approximately 5 $nb$). In that case, a machine which can run steadily at a luminosity of $2 \times 10^{32}$ will produce $10^7$ $b's$ per year. The background problems at the $Z^0$ will be more severe than at low energy machines. However, vertex detectors will be available. Unfortunately, it does not appear that LEP will be able to perform steadily at the above luminosity. It is even less likely that SLC can do it. It is also unlikely that anyone will propose the construction of yet another "$Z$ factory" for the sole purpose of doing $b$ physics. Such a machine would be far too expensive. It is therefore reasonable to assume that, within the next decade, we will not be able to obtain $10^7$ $b's$ per year at the mass of the $Z$.

(*iv*) *Multi-TeV proton colliders (SSC and LHC).* Here the production cross section for $b$-quarks is estimated to be around 100 $\mu b$. With a luminosity of $10^{33}$ we should get approximately $10^{12}$ $b's$ per year. However, in such a machine, producing a $b$ quark is much easier than detecting it. With hundreds of other hadrons produced in the same event, we need an elaborate tagging procedure. The best suggestion[25], so far, seems to be to identify $b$ quarks by the combination of a finite lifetime observed in a vertex detector and a $\psi$ particle observed among the decay products coming from that same vertex. The $b$ quark is the only object which has a lifetime above $10^{-13}$ *sec* and decays into $\psi + anything$. The detection of the $\psi$ should rely on observing its decay to $e^+e^-$ or $\mu^+\mu^-$. The entire tagging procedure is likely to "cost" at least four orders of magnitudes in the observed rate (two orders of magnitude for the inclusive $\psi$ branching ratio in $b$ decay, one for the dilepton branching ratio in $\psi$ decay and a probable one for the combined efficiency of the vertex detector, the identification of $e$ and $\mu$, etc.). Even if we lose four orders of magnitude to the tagging process and even if the collider will run at a reduced luminosity of $10^{32}$ in order to avoid overloading the data handling system and to avoid rediation damage to the detector, we still remain with $10^7$ tagged $b$ events per year. However, every such event will be accompanied by a large number of additional hadrons and it is not entirely clear whether it will be possible to study the detailed features of the two particles containing $b$ quarks in the event. A lot of preliminary work has yet to be done before we can conclude that $b$ physics at such data rates will be possible at the SSC. Even if it is, it will undoubtedly require an especially designed detector and it will not be available in less than a decade from now.

($v$) *Hadron colliders at the TeV range.* A $pp$ collider with a luminosity of the order of $10^{33}$ at $E_{c.m.} = 1\ TeV$ could produce enough $b$ quarks. However, no such collider now exists or is being planned. The two existing $\bar{p}p$ colliders have enough luminosity for producing more than $10^7$ $b's$ per year, but will remain with very few $b$ quarks after the kind of tagging procedure described above. Without such a procedure, it is not at all clear how large numbers of events containing $b$ quarks can be isolated at the $S\bar{p}pS$ collider or at the Tevatron collider. It therefore seems that there is no hope from this direction.

(*vi*) *Fixed target experiments at proton beams with $E_{beam} \sim 1\ TeV$.* Here the energy and the production cross section are substantially lower than at the hadron colliders, but the background problems are also smaller and the full energy of the beam is available to the $b$ quark, so that vertex detectors can become very efficient. It is clear that some interesting $b$ physics can be done in this way, but it is very unlikely that it can compete with a relatively clean sample of $10^7$ $b's$ from, say, an electron collider at the $\Upsilon(4S)$. A proposal[26] for such an experiment has been submitted in FERMILAB, aiming at producing between $10^6$ and $10^7$ $b's$ per run. However, after the $\psi$-tagging procedure discussed above, at most several thousand events will remain.

Our overall conclusion is the following: Among all projects *which are currently under construction* and will become available within less than five years, the two leading options are LEP and CESR. Neither of these machines can reach our goal of $10^7$ $b's$ per year, but both may produce $10^6$ per year and collect a very healthy sample after a few years of running. The only way of producing and detecting $10^7$ $b's$ per year before 1995 seems to be a new dedicated $e^+e^-$ circular machine with a luminosity of $10^{33}$ at the $\Upsilon(4S)$. Such a machine could also contribute significantly to physics at the lower $\Upsilon$ states, to the physics of $\tau$ leptons and to the physics of charmed particles. It would be very nice if one of the smaller accelerator centers such as Cornell, SIN or Frascati would seriously consider the construction of such a machine. In the second part of the 1990's we may have some good $b$ physics done at the SSC (and/or LHC) and we may also have a high luminosity linear electron collider producing large number of $b's$. It is not clear to us how well the fixed target FERMILAB experiment can compete with these options.

It is important to realize that $b$ physics is probably one of the richest sources of new measurements of the parameters of the standard model and of indirect detection of "beyond standard" physics. We therefore hope that at least some of the above plans will materialize within the next few years.

## 11. Concluding Remarks

We conclude with some trivial (but thought-provoking) observations concerning several aspects of the generation puzzle.

First, we must stress again and again that, although it has been given much less "publicity" than the hierarchy problem, the generation puzzle is one of the most fundamental problems of the standard model. It is also the only important problem for which we do not even have a hint of a solution. It is a problem in which no real theoretical progress has been made over almost forty years. It is also a problem which is responsible, single-handedly, for most of the arbitrary parameters of the standard model (including an important arbitrary parameter which is normally not even counted – the number of generations).

Second, it is often stated that the main difficulty in constructing a convincing theory of the physics "beyond the standard model" is the total lack of "beyond standard" experimental data. However, it is reasonable to demand that any "beyond standard" theory should be able to account for the fermion masses, their mixing angles and the CP-violating phases. If this is the case, the actual numerical values of these parameters *are* experimental clues for the "beyond standard" physics. It is this fact which gives such a crucial importance to precise experimental determinations (and over-determinations) of these parameters.

Third, the problem of CP-violation is not only a matter of discovering a curious phase which cannot be rotated away when we have three or more generations. The net baryon number of the universe and, consequently, our very existence are direct results of the violation of CP. In the standard KM picture, the only source of CP-volatioon is the existence of the $t$ and $b$ quarks. Do we owe our very existence to these quarks? Is it true that in a universe with only two generations, no net baryon number can exist? Is there another source of CP-violation, such that we could exist even if there were only two generations (or only one)? Somehow it would be more gratifying if we did not owe our existence to a third generation which looks like an "afterthought".

Fourth, we are told by cosmologists and astrophysicists that the observed matter in the universe accounts only for a small part of the total matter density and that the majority of matter is "dark". Our theoretical prejudices lean toward the possibility of a "flat" universe, in which case most of the "dark matter" forms an invisible homogeneous background, similar to the famous 3° radiation. One of the candidtes for this "dark matter" is the heaviest neutrino (whichever it is). The most likely neutrino to be heaviest is $\nu_\tau$ (if there are only three generations) or a hypothetical fourth generation neutrino $\nu_\sigma$ (if there is a fourth generation). In both cases we are, again, delegating an enormous significance to the third or fourth generation, which from the point of view of ordinary baryonic matter appear as an "afterthought" of secondary importance. Do we really live in a universe in which the visible matter is due to the first generation fermions $u, d$ and $e$ but most of the dark matter is accounted for by third (or a fourth) generation neutrinos?

It would be very nice to know the answers to these questions before we move into the next millenium. That does not leave us with too much time.

### Acknowledgements

I would like to thank Giorgio Bellettini and Mario Greco for their gracious hospitality and for the excellent organization of the first meeting in this new tradition at the Aosta valley. I thank Ikaros Bigi, Fred Gilman and Yossi Nir for many helpful discussions.

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