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BEYOND TRUTH AND BEAUTY

H. Fritzsch^{*)}

CERN - Geneva
and
Sektion Physik der Universität München

Summary Talk given at the
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This Meeting started three days after receiving the exciting news that a supernova has exploded in our cosmic neighbourhood. Last Monday the first photons from the new supernova, which exploded about 150 000 years ago in the Great Magellanic cloud, reached the earth and alerted the astronomers. From a particle physics point of view the interesting question arises whether anything else has reached the earth at about the same time or slightly before, for example neutrinos or gravitons. The theoretical models of supernova explosions suggest that a large part of the energy in a supernova explosion is emitted in terms of neutrino radiation. Those neutrinos should be detectable here on earth, and a careful investigation of the neutrino pulse might even reveal details like information about the neutrino mass spectrum. The times of flight of the various neutrinos arriving here on earth depend on the masses. For mass splittings in the eV-range differences in the time of flight of the order of a few seconds are expected, and they may be measurable, since the initial neutrino burst of a supernova explosion is expected to be very sharply peaked. Probably the supernova of February 1987 is still too far away and too weak to allow such an investigation. However the next and probably more powerful supernova, this time not in the backyard of our galaxy, but

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right in its basement, may be just around the corner. Let us hope that all neutrino and gravity wave detectors are ready then to receive the signal.

The title of this summary talk reflects the theme of this conference. Everyone attending this meeting is interested in the possibility that the spectrum of leptons and quarks may extend beyond the heavy b and t quarks and the τ -lepton discovered (or in the case of t anticipated firmly) thus far. And everyone will agree that such an insight into the lepton-quark spectrum would have immediate consequences with respect to our theoretical understanding of the particle physics universe. Thus far all particle physics phenomena have been found to be in accordance with the standard model - the well-known superposition of QCD and the electroweak theory. No doubt, the standard model exhibits signs of eternal truth. Our understanding of, in particular, the basic interaction of photons with electrons and quarks (QED) and of the gluons with themselves or with quarks (QCD), and to a somewhat lesser extent the interaction of the weak bosons with the leptons and quarks show the simplicity and beauty which one expects from a basic and true theory. The old saying of Plato "Beauty is the Splendor of Truth" finds here its well-justified application.

All the complexities of atomic physics can be explained in terms of the fundamental interaction among charged objects (electrons, protons, nuclei) and photons, dictated by the principle of the electromagnetic gauge invariance. The coupling strength, given in terms of the coupling constant α , and the various masses of the particles serve as independent and free parameters.

Likewise the huge body of complex nuclear and hadronic phenomena is uniquely determined by the QCD interaction among quarks and gluons, which is determined by requiring the non-Abelian gauge invariance in the color space. Unlike in atomic physics, in nuclear and hadronic physics there is no strength parameter like α which can be changed arbitrarily, since the QCD strength parameter $\alpha_s(\mu)$, which depends on the associated energy scale μ , determines not only the basic strength of the quark-gluon or gluon-gluon interaction, but at the same time the hadronic mass parameters like the nucleon mass. A change of $\alpha_s(\mu)$ would simply result in a rescaling of all mass parameters, e.g. the QCD scale Λ_c (we disregard all quark masses for a moment). But the absolute scale of the latter is a free parameter; the ratio Λ_c / m_e , for example, is a parameter which cannot be determined by the QCD interaction,

but only within an extended theory of QCD and QED, possibly including the weak interactions. Of course, the various quark masses serve as independent and free parameters in QCD.

It is surprising that on the one hand a dramatic breakthrough has been made in understanding the structure of the basic interactions, but on the other hand little progress has been made in order to understand the rather bizarre looking tower of mass scales in the standard model, especially those of the mass spectrum of the leptons and quarks. The "explanation" of these mass scales given in the standard model by relating them to a set of Yukawa coupling constants describing the strengths of the couplings of the leptons and quarks to the scalar Higgs field is nothing but a convenient parametrization. It offers no insight into the dynamical details of the mass generation. A deeper understanding of the problem can only be reached by going beyond the standard model, which probably means also going beyond some of the apparent beauty and truth of the standard model and replacing some of its features by something else.

If we look with scrutiny at the physics displayed by the standard model including gravity, we observe that three of the basic interactions are mediated by massless gauge quanta and are intimately related to exact conservation laws, namely gravity, the QED and the QCD interaction. On the other hand the fourth interaction, the weak interaction, violates many symmetries. But the mass generation and the breaking of symmetries seem to be related to each other. One may suspect that some, if not all the clues to understand the complex tower of quark and lepton masses are hidden in the weak interaction sector, and a careful study of the dynamics of the weak bosons, e.g. at LEP II, could reveal enough **secrets** to enable us to find these clues.

At present the theorists contemplating how physics might look beyond the standard model can be divided into two groups:

a) The large number of theorists who have adopted the "string dogma". For them the real world is simply a superficial and nearly irrelevant shadow of the complex underlying ten-dimensional world of superstrings. The theory stands out as a consistent theory of gravity and other interactions. But thus far this is the only achievement of the theory. Whether some or all the outstanding

puzzles of the standard model can eventually be explained by the underlying dynamics of the superstring world remains to be seen. Personally I am sceptical that such a step will be made soon. It may well be that the superstring theories remain in the future what they are today - new approaches to generalize the quantum field theory. The direct contact with the standard model might come on a different level as assumed by most researchers today, e.g. one at which a non-trivial substructure of the quarks and leptons plays a significant rôle.

The superstring theory starts with the dynamics at energies of the order of the Planck energy (10^{19} GeV). The physics of the standard model is considered as a low energy phenomenon eventually explained as the low energy tail of the superstring dynamics. Thus one starts from high up on the energy scale and works oneself down, from a speculative 10^{19} - GeV utopia to the 10^2 GeV reality.

b) The second group of theorists tries to go the other way, the inductive way. They start from the observed dynamics of the standard model at energies of about 0.1 TeV and try to extrapolate to the next level up in the energy scale, taking into account both theoretical insights and experimental facts. Physics has always developed that way. But this aspect is largely ignored by the theorists of the first group. Maybe, this time the direction of research is indeed reversed, and those which start from the speculative heights of the superstring mountain gain eventually enough sight to overlook the standard model. But thus far the mountain is surrounded by clouds, which may never disappear. Most theorists in this audience, however, seem like myself to belong to the second group which slowly climbs upward, keeping in constant touch with the standard model physics, i.e. with the real world.

The center of the discussion at this meeting was a possibly existing fourth family of leptons and quarks. This is, of course, a legitimate topic, since thus far no good explanation exists why there should be just the three families observed today. We do not even know whether the number of lepton-quark families is a well-defined number. It might well be that leptons and quarks are composite systems in which case an infinite number of families are expected to exist, just as there exists an infinite number of baryon octet or decuplet states. Thus many opportunities would arise to organize meetings like this one.

But one could also have a situation in which the number of families plays a significant rôle as an important algebraic number of the underlying theory, as in the standard model the number of space dimensions or the number of QCD colors. Since at present a large number of theorists works on superstring theories, I like to remind the audience that the space we live in has three dimensions, not nine or ten. It is rather suspicious that the number three enters three times in the present form of the standard model: there are three space dimensions, three QCD colors, and three families. Could there be a connection between these apparently unrelated different kinds of "threenesses"?

Of course, everyone knows that we should extend the three-dimensional space to the four-dimensional or rather 3+1-dimensional space- time- manifold. Besides the three QCD colors another conserved quantum number is important, the electric charge. The group of exactly conserved gauged charges in the standard model is $SU(3)^C \times U(1)$, i.e. again a 3+1-pattern appears. Following these analogies, one might suspect that another fourth family exists, or that in particular the physics of the family space exhibits an underlying 3+1 pattern as follows:

$$\begin{pmatrix} \nu_e & | & u \\ e^- & | & d \end{pmatrix} \quad \begin{pmatrix} \nu_\mu & | & c \\ \mu^- & | & s \end{pmatrix} \quad \begin{pmatrix} \nu_\tau & | & t \\ \tau^- & | & b \end{pmatrix}$$

$$\left[\begin{pmatrix} \nu_\sigma & | & h \\ \sigma^- & | & l \end{pmatrix} \right]$$

The fourth family consists of a new lepton called σ , its neutral partner ν_σ , a new quark h of charge $2/3$, and a new quark l of charge $-1/3$. In naming these objects, I followed the tradition to denote new charged leptons (all, except the electron) by Greek letters, and the neutral partner by the symbol ν with the corresponding subscript, although the ν_σ -particle might not be a traditional neutrino with a vanishing or very small mass, but rather a very heavy particle. The letters denoting the new quarks h and l are derived from "high" and "low", in analogy to "top" and "bottom". (People who are less pragmatically oriented might prefer "hate" and "love", in analogy to "truth" and "beauty".)

As alluded to above, there might be a 3+1 - structure in the family space, not a simple-minded generalization from three to four, in the sense that the fourth family is perhaps nearly decoupled from the first three families, or that it plays a significant rôle in the generation of the masses for the members of the first three families.

Of course, presently we do not know whether a fourth family exists, not to mention possible values for the masses of its members. Possible guesses can be obtained by looking at the masses of the members of the first three families.

The observed mass spectrum shows an interesting feature, which is not understood: the mass ratios m_i/m_{i+1} (m_i : mass of a quark or a charged lepton belonging to family i ; m_{i+1} : mass of the corresponding quark or lepton of family $i+1$) are all small and, very roughly speaking, of similar order of magnitude such that one is tempted to connect the mass values by straight lines on a logarithmic scale. This works well for the quarks of charge $-1/3$, since $m_d/m_s \approx m_s/m_b \approx 1/20$. If this trend continues, the fourth quark of charge $-1/3$, the l -quark, should have a mass of about $20 \cdot m_b \approx 105$ GeV. But this is the mass value, obtained at an energy scale of 1 GeV, where the other quark mass values are defined. The physical l -mass, relevant for the spectroscopy of $l\bar{l}$ -onia or l -flavored mesons, is reduced by a factor of about 0.6 such that $m_l \approx 60 \dots 65$ GeV.

An important parameter to extrapolate to the fourth family is the t -quark mass. But one might expect that the ratios m_h/m_l , m_t/m_b and m_c/m_s are of similar order of magnitude, in which case we would have $m_h \approx 5 \dots 10 \cdot m_l \approx 250 \dots 600$ GeV.

The ratio $m_b(1 \text{ GeV}) / m_\tau$ is about three, in accordance with the expectation within the minimal SU(5) theory, and a reasonable guess would be to take a similar value for the ratio $m_l(1 \text{ GeV}) / m_\sigma$, in which case we have $m_\sigma \approx m_b(1 \text{ GeV}) / 3 \approx 35$ GeV.

These values are, of course, nothing but rough guesses, with little theoretical foundations, but they might provide some preliminary guidance for the experimentalists searching for phenomena due to the presence of a fourth family.

The observed lepton-quark spectrum is of an exponential type, i.e. the mass values increase roughly like $\exp(\text{const.} \cdot i)$ [i : family quantum number]. Thus this spectrum is unlike any other spectrum of states observed in physics before, e.g. the spectrum of atoms, nuclei or hadrons. Atomic levels are most suitably displayed on a linear energy scale, likewise nuclear levels. The spectrum of the light hadrons, on the other hand, should be displayed on a scale quadratic in the energy; this reflects the relativistic dynamics of the light quarks.

It looks like as if the masses of the lighter families are generated by a perturbative mechanism involving the masses of the members of the heavier families, a mechanism, which at the same time could lead to the phenomenon of weak interaction mixing.

Suppose there exists a fourth generation, and suppose that the masses of the h and l quarks serve as driving terms for the generation of the lighter quark masses by a mixing phenomenon which at the same time leads to the observed flavor mixing. In this case the mass matrix for the up and down type quarks could be:

$$M = m_{h,l} \cdot \begin{pmatrix} 0 & a & 0 & 0 \\ a & 0 & b & 0 \\ 0 & b & 0 & c \\ 0 & 0 & c & 1 \end{pmatrix} \quad (1)$$

It is well-known that such an ansatz, in the case of three generations, describes well the observed flavor mixing angles in terms of quark mass ratios. In the case of four generations the masses m_h and m_l would be the dominating and most important mass terms. The ratio m_h/m_l might be of special relevance, since this ratio would presumably not be influenced by the flavor mixing phenomenon, due to the large mass values. It could be close to four, i.e. given by the ratio of the squares of the quark charges, as suggested by simple composite models in which the lepton and quark masses are of electromagnetic origin. (If the ratio were four, the h -mass would be $m_h = 4 m_l \approx 250$ GeV, using $m_l \approx 60 \dots 65$ GeV, as mentioned above).

Independent of any particular model for the mass matrices, the idea of connecting the mass eigenvalues and the mixing angles leads one to the possibility of estimating the order of magnitude of the t-quark mass. Since the u and d masses are very small compared to m_t or m_b , we can neglect the first family and look solely at the interplay between the second and the third one. The flavor mixing between these two families is observed to be rather small, the relevant mixing angle being of the order of 0.04. Thus it would be a good approximation to start from the limit in which there is no flavor mixing. In this case one might expect that the various masses are proportional: $m_t/m_b = m_c/m_s$, i.e. $m_t(1 \text{ GeV}) \approx m_b \cdot (1 \text{ GeV}) \cdot (m_c/m_s)$. The ratio m_c/m_s is not well determined, due to the rather uncertain value of m_s , which may vary between about 120 MeV and 220 MeV. The ratio m_c/m_s correspondingly varies between 5 and 10, thus $m_t(1 \text{ GeV}) \approx 26 \text{ GeV} \dots 55 \text{ GeV}$. Taking into account the QCD rescaling factor (about 0.6) to obtain the physical t-mass, one obtains $m_t \approx 15 \text{ GeV} \dots 34 \text{ GeV}$. The lower part of this spectrum is already ruled out by the e^+e^- -annihilation experiments, while the upper part may still be consistent with the present experimental constraints.

Taking into account the flavor mixing between the second and third family, a larger range of t-quark values is obtained. The exact range depends on the specific ansatz, which determines the interplay between the masses and the mixing angles. In general we expect:

$$\frac{m_c}{m_t} \approx \frac{m_s}{m_b} - c_1 \cdot \theta - c_2 \cdot \theta^2 \dots \quad (2)$$

Such an expansion makes sense since $\theta = \theta_{cb}$ is observed to be rather small: $\theta \approx 0.045$, and the second order term $c_2 \theta^2$ can already be neglected. If we start from a mass matrix of the type (1) (with a specific choice of the phase parameters), one finds, for example,

$$\frac{m_c}{m_t} \approx \frac{m_s}{m_b} - 2 \theta \sqrt{\frac{m_s}{m_b}} \quad (3)$$

Given the uncertainty of the various quark mass values (especially the uncertainty of m_s), one obtains in this case a rather broad range for the

physical t-quark mass: $30 \text{ GeV} < m_t < 80 \text{ GeV}$. The uncertainty of the strange quark mass comes essentially from our inability to extract the expectation value of the s-quark bilinear $s^\dagger \gamma_0 s$ in a hyperon state. The naive quark model suggests that this expectation value is close to the expectation value of $s^\dagger s$, which counts the number of strange quarks in the wave function. Personally I believe that in reality one is close to that situation, in which case the strange quark mass is most likely in the range between 150 and 180 MeV. In this case the physical t quark mass is restricted to the range $40 \text{ GeV} < m_t < 60 \text{ GeV}$. Notice that rather little room is left for the possibility to produce $\bar{t}t$ -pairs at the SLC (this would require $m_t \lesssim 47 \text{ GeV}$).

Searching for the fourth family of leptons and quarks means for the experimentalists: searching for the effects of the production of the new heavy lepton or of the new quarks. Useful information in this respect was given in the talks of Cline and Branson. The UAI-group has searched for a standard new charged lepton, produced in the W-decay and decaying into a massless or light neutrino under the emission of a virtual W disintegrating into a $\bar{q}q$ -pair. The signal would be quite clear: a large amount of missing energy, accompanied by two quark jets. Masses up to 41 GeV for the new lepton are excluded. This limit is very useful. It implies, that the new lepton, if it exists, cannot be lighter than about twenty times the τ -mass. This poses already or slight problem for our guess of the masses described in the introduction above. In any case it is demonstrated that a hadron-collider is able to yield useful information even about purely leptonic phenomena - a field which used to be thus far the topic of e^+e^- -colliders. It is not excluded that the new lepton is eventually found that way - it may be just around the corner. If our guess made above contains some truth, the mass of the fourth charged lepton should not be much heavier than 50 GeV.

The mass constraint is not valid, if the new charged lepton is accompanied by a heavy, perhaps even stable neutrino such that the mass difference is relatively small (of the order of a few GeV or less). Such a possibility, employing a stable heavy neutrino, can be utilized, as described by G. West, to solve the solar neutrino problem and the missing matter problem of cosmology at the same time. In order to take part actively in the solar dynamics, the new heavy neutrino must have a rather large magnetic moment - an aspect

which I find less attractive, since special new Higgs fields have to be designed in order to generate it. In composite models, however, the situation may be less serious, since here a magnetic moment may appear due to the internal structure, like the neutron magnetic moment in hadron physics.

How the UAI bound on the heavy lepton mass can be evaded, has been discussed in detail by Barger. Especially the case $m_{\nu_L} > M_W - m_L$ is worth being considered. In this case no bound exists. In the case $m_L < m_{\nu_L} < M_W - m_L$ the bound is reduced to about 22 GeV (i.e. the limit set by PETRA).

Thus far the search for the t-quark at the CERN collider has not led to a positive result, as described by Eggert. However the prospects are still there to find the t-quark at a hadron collider, either at CERN or at FNAL (as emphasized by Yoh), and a hopeful method employing a sophisticated jet analysis for the UA2-detector at CERN was described by Minkowski.

The new quarks have been searched for in the e^+e^- -annihilation at DESY, as reported by Branson. The appearance of the t-quark throughout the energy region searched at DESY (up to about 47 GeV) can be ruled out safely, posing a limit on the t-mass of the order of 24 GeV. As noted especially by the Mark J and Jade groups, one seems to find a signal in low thrust hadronic events with isolated muons for $\sqrt{s} > 46.3$ GeV. It is completely unclear how this signal should be interpreted. It may come from the production of a new quark of charge $-1/3$, the b' or l quark, but due to the planarity of the events and the lack of the corresponding inclusive electron signal this interpretation begins to look unlikely. Perhaps new, exotic objects, e.g. leptoquark bosons, are produced. In any case, one may have a repetition of the ADONE-DORIS syndrome. The ADONE storage ring was operating for a long time just below the $\bar{c}c$ -systems, and DORIS likewise just below the $\bar{b}b$ -systems. Thus PETRA and PEP are perhaps unlucky by not quite reaching the energy for the abundant production of the new objects, and what Branson has reported was just a short look through the peep-hole before the slide came down and PETRA was closed. In any case, the matter will be settled soon, since TRISTAN just started to operate.

Atwood presented the news from the construction site of the SLC, which soon will be ready as the first Z^0 factory of the century, followed more than one year later by LEP. If new quarks and / or leptons exist with a mass less

than $M_{Z^0}/2$, they will be discovered first at the SLC, and presumably investigated in detail at LEP. The event topology of the new quarks and leptons is such that 10 000 Z^0 events would be enough to obtain a clear signal. However the prospects of the SLC to find the t , $b'(l)$ or $t'(h)$ quark or the $L^-(\sigma^-)$ lepton are somewhat reduced by the UAI limit on the heavy lepton mass and by the naive guesses for the mass scales made above (of course, these guesses could be entirely wrong, and the UAI limit would not be applicable if the new lepton is accompanied by a sufficiently heavy neutrino).

Let me try to assess the probabilities to find new quarks or leptons at the SLC, taking it for granted (100 % chance) that a fourth family exists. On the basis of the mass ranges discussed above the guess is:

t -quark:	20 %
l -quark:	5 %
h -quark:	1 %
σ -lepton:	30 %
ν_σ -neutrino:	95 %.

The SLC will also offer for the first time the possibility to count the number of neutrinos at $E > M_Z$, by looking for the reaction $e^+e^- \rightarrow \gamma Z^0 \rightarrow \gamma(\bar{\nu}\nu)$. All neutrinos with masses $m_\nu < M_{Z^0}/2$ will be counted that way. That way one will find out whether the neutrino counting of high energy physics and the neutrino counting of the astrophysicists or cosmologists converge to the same number. The latter way was described in the talk by D. Schramm, who during his talk was in a more excited state than usual, as a result of the supernova explosion 150 000 years ago.

In cosmology one finds constraints on neutrinos (and possibly other particles) provided they have a mass of less than 10 MeV. Originally the constraints on the number of (lefthanded) neutrinos came from the observed abundance of ^4He . As emphasized by Schramm, other constraints can be found by considering the D and ^3He abundances, as well as the ^7Li abundance. All constraints converge to the same number, allowing 3, at most 4 neutrinos. As he said, the possibility to have four neutrinos begins to look unlikely but, in view of the systematic errors affecting most astrophysical observations, cannot be ruled out. Thus cosmology and the 4th family are not yet married, but

they are only dating each other occasionally. It is safe to predict that the marriage will happen quickly, once the first member of the 4th family is discovered.

Whether a fourth family exists at relatively low energies will depend on the details of the mass generation mechanism, which in the standard model is provided by the Higgs mechanism. If the Higgs particle(s) exist(s), it can be found at LEP, as described by S. Wu. LEPI and SLC could find the H^0 particle, if it has a mass of less than about 40 GeV. If it is heavier, we have to wait a few years for the completion of the LEP 200 stage. As Wu explained in detail, LEP 200 has good prospects to find the H^0 , if its mass is in the range 40 GeV ... ~80 GeV. The range could perhaps be slightly extended, up to ~ 110 GeV. This shows that it may take many years until the details of the "Higgs sector" are understood. If the H^0 is heavier than 100 GeV, only the experimentalists in the next millenium, who are still in high-school at present, may be able to discover it. But in those days the theorists may have come up with another idea!

D. Nanopoulos, the conductor of the Madison superstring orchestra, has discussed the problems in the superstring theory which suddenly arise if a 4th family is admitted. The problem is not one connected with the basic foundations of the superstring theories, but is rather related to the extrapolations of the various mass scales entering in the theory. But even for three families related problems exist, although less serious. In any case, we predict that the problems will evaporate once the 4th family is discovered.

The spectrum of views regarding the 4th family displayed at this meeting can be appreciated by quoting the following three statements from three different talks:

West: The 4th family is the most important one, providing more than 90 % of all matter, in the universe.

Schramm: The 4th family is almost ruled out.

Nanopoulos: The 4th family and superstrings do not mix.

I should like to mention an interesting aspect of the superstring theory as far as the lepton-quark mass spectrum is concerned. Since the details of

the mass generation are linked to specific algebraic properties of the underlying Calabi - Yau or orbifold compactification, one has a realistic chance to obtain specific algebraic patterns for the mass matrices, such as described in eq. (1). More work needs to be done in this direction. The observed pattern of the flavor mixing matrix and the possible underlying pattern of the quark and lepton mass matrix, discussed also in the introduction, was described by Gronau, supplemented by a specific analysis of the 4th family by Shin. Mohapatra analyzed these patterns with respect to their stability under radiative corrections.

The mass matrices were studied from a different approach based on invariant functions by C. Jarlskog. To underline the beauty of her approach, she started with a beautiful transparency with Gothic letters painted by her daughter. She emphasizes correctly that the mass matrices are not directly observable, but rather theoretical constructions, which are by no means unique. Especially noteworthy is her approach to the flavor mixing problem based on invariants. For a dynamical theory of the flavor mixing to be developed in the future this may be very important, if it turns out that these invariants enter in the theory in a crucial manner. A good example in this respect is General Relativity. Not the metric tensor of the space-time, which can be considered as the analog of the mass matrix, is the relevant dynamical quantity of General Relativity, but invariant functions like the space-time curvature R , which enters directly in the Einstein field equations.

Arguments speaking for the existence of a 4th family were presented by C. Hill, who noted that the masses of the members of a fourth family are expected to be such that their couplings to the Higgs field are about the same as the $SU(2)$ gauge coupling.

Repond described the new experimental τ -decay result from PEP (HRS detector). The observation of the decay $\tau^- \rightarrow \nu_\tau \eta \pi^-$ (BR $5.1 \pm 1.0 \pm 1.2 \%$) by the HRS group would constitute a major blow for the standard electroweak model, if it would be confirmed by other experiments. This decay is forbidden in the standard model, since the W^- couples to the quark current $\bar{u}_L \gamma_\mu d_L$ (L : left-handed), which acts like a superposition of ρ^- and A_1^- . G -parity forbids the transition $\rho^- \rightarrow \eta \pi^-$, while parity conservation of the strong interaction does not allow the transition $A_1^- \rightarrow \eta \pi^-$. Typical estimates of the violation of

G-parity via isospin violations due to electromagnetism or the u-d mass difference give a branching ratio of at most 10^{-3} for the decay $\tau \rightarrow \nu_{\tau} \eta \pi$. If the effect is indeed confirmed, new weak currents (e.g. second class currents, scalar contributions to the weak current) would have to be introduced. I am sceptical as far as such modifications are concerned, since new weak currents imply new contributions to the total decay rate, and it would be a miracle why the τ -lifetime is consistent with estimates based on the standard electro-weak model. I am reminded of the quotation of Sir Arthur Eddington: "It is also a good rule not to put too much confidence in experimental results, until they have been confirmed by theory".

No such problems exist with the theory as far as neutrinos from supernovas are concerned. Nussinov discussed in his talk the neutrino flux emitted by a supernova. He estimated that the Kamioka detector should observe about a dozen neutrino events in a short time interval (~ 10 s). (His prediction came quite close to the observation of the Kamioka group reported one week after this meeting.) :

A number of talks were concerned with possible signatures of a fourth family in the physics observed today, i.e. below the energy for exciting the new flavors directly. Gilman discussed the constraints on the weak interaction parameters imposed by the low and high energy experiments. By now the various weak interaction mixing parameters are determined quite well such that due to the observed smallness of the transition $b \rightarrow u$ a possible problem exists as far as the measured value of the CP parameter ϵ is concerned. Since the contribution from the short distance physics to ϵ is proportional to m_t^2 , it might be that one needs a fairly large value of m_t ($m_t > 60$ GeV) in order to get agreement with the experiments. However the uncertainty in the relevant hadronic matrix elements is still large (a factor which could be as large as 5).

Still a lot of fog is surrounding the ratio ϵ'/ϵ . Assuming that the $|\Delta I| = \frac{1}{2}$ weak transitions are dominated by the penguin contributions, one may connect the latter and the ratio ϵ'/ϵ predicting $\epsilon'/\epsilon \sim 10^{-2}$. Such a relatively large value seems unlikely now, in view of the new experimental results, reported here by Bock ($\epsilon'/\epsilon \cong 0.0035 \pm 0.030 \pm 0.02$, E 731 experiment at FNAL). As discussed by Holder, the new experiments, e.g. the one

under way at CERN, will either establish a nonzero value of ϵ'/ϵ , or set a new limit at the 1 % level.

Gilman discussed possible ways to accommodate such a small value of ϵ'/ϵ , especially by raising the value of m_t , or the B-parameter. In this context I should like to emphasize that there exists not yet a well-established direct link between the $|\Delta I| = 1/2$ enhancement of the nonleptonic K decays, the ϵ -parameters and the penguin - terms. Furthermore, as mentioned by Gronau and Paschos, the ϵ -parameters are rather sensitive to possibly existing contributions of further families.

Very interesting new results were presented in the talk of Albrecht, (ARGUS group, DESY) which established the existence of $B_d^0 - \bar{B}_d^0$ mixing. In the standard 3 generation model taking into account the observed flavor mixing pattern such a mixing must exist, since it can always proceed via the box diagram which likewise in the two - generation model causes the $K^0 - \bar{K}^0$ mixing. The short distance contribution to the $B_d^0 - \bar{B}_d^0$ transition mass $|M_{12}| = (\Delta M/2)$ is proportional to $\eta f_B^2 B_B |V_{td}|^2 m_t^2$, where η is a QCD parameter estimated to be of order 1, f_B the B-meson decay constant, and B_B the parameter relating the relevant four-quark matrix element to the one derived from the vacuum insertion approximation. The mixing is only observable if the $B^0 - \bar{B}^0$ transition takes place fast enough, i.e. before the decay takes place. The relevant experimental quantity is $r = (\Delta M/\Gamma)^2 / [2 + (\Delta M/\Gamma)^2]$.

The Argus result implies $r_d \sim 20\%$, which gives $(\Delta M/\Gamma) \sim 0.7$. It is very surprising that this value of $\Delta M/\Gamma$ is of the same order of magnitude as $\Delta M_K/\Gamma_{K_S}$. In view of the vastly different decay mechanisms for B and K mesons - the B mesons decay dominantly by the well-understood β -decay of the b-quark, while the large value of Γ_{K_S} is still not understood - the coincidence of $\Delta M_K \sim \Gamma_{K_S}$ and $\Delta M_B \sim \Gamma_B$ looks like a miraculous coincidence, and that's what it probably is. It seems a useless undertaking to find a dynamical explanation for this coincidence.

As emphasized by Paschos (see also the talk of Gilman), the large value of the B_d^0 mixing observed at DESY did not come as a complete surprise for all theorists. In fact, using $f_B = f_K$, $B_B = 1$ and $V_{td} \approx 0.02$, one finds agreement with the observation for $m_t \approx 60$ GeV, as mentioned by Gilman. In view

of the uncertainties involved, it is remarkable that one obtains at least the correct order of magnitude. I should like to mention that the B decay constant f_B might be slightly larger than f_K (note, that $f_K/f_\pi \sim 1.25$, thus one might have $f_B/f_K > 1$). Nevertheless it seems, as emphasized by Bigi, that in view of the observation of the B_d^0 - mixing at the level seen at DESY one should be prepared for a rather large value of m_t (probably larger than 50 GeV), and the prospects to see the $t\bar{t}$ -production at the SLC or LEP I dwindle down. Furthermore it is remarkable that a large value of m_t , say $m_t > 60$ GeV, would solve three potential problems at the same time:

- a) The observed magnitude of the B_d^0 - mixing does not cause problems.
- b) The observed value of the ϵ -parameter of CP violation is easily reproduced.
- c) The smallness of the ratio ϵ'/ϵ is understood.

The evidence for B meson mixing found some time ago by the UAI group, reported here by Eggert, fits nicely together with the new DESY result, as in particular emphasized by Ali. One observes about twice as many like-sign dimuon events as expected in the case of no mixing. A sizeable mixing of the B^0 mesons is the only explanation of the observed effect within the standard model. However the like - sign dimuons will in general originate both from an original $B_d^0 - \bar{B}_d^0$ or $B_s^0 - \bar{B}_s^0$ production. Theoretically one expects $\Gamma_{B_S^0} / \Gamma_{B_d^0} \approx 1$, $|\Delta M_{B_S} / \Delta M_{B_d}| \approx (f_{B_S} / f_{B_d})^2 (V_{ts} / V_{td})^2$. The latter ratio is expected to be much larger than one; typical estimates range between 5 and 50. Therefore it is likely that $\Delta M_{B_S} \gg \Gamma_{B_S}$, i.e. the B_S - mesons are fully mixed.

The UAI - results are consistent with a 100 % mixing of the B_S - mesons. In this case essentially all the excess of the like - sign dimuons observed in the experiment would be due to $B_S - \bar{B}_S$ - production.

It is quite possible that CP violation is larger for the B mesons than for the K mesons. Presumably such effects are largest for the B_S mesons. If the $B_S - \bar{B}_S$ transitions are indeed as rapid as discussed above, in accordance with the UAI-results, it will be extremely difficult, if not impossible, to measure the CP violating decays directly by sophisticated heavy flavor detectors of the type described by Bjorken.

As mentioned by Eggert, a large part of the J/ψ particles observed in the collider experiments are due to $b\bar{b}$ -production, where one of the b -quarks decays by emitting a J/ψ . This decay may play an important rôle in the future, since at collider energies above $\sqrt{s} \sim 1$ TeV (Tevatron, SSC, LHC) essentially all J/ψ particles produced in the collisions are expected to be due to the b -decay. Thus the J/ψ 's which can easily be identified by their leptonic decay modes could be used as a b -flavor tagging device. Since b -quarks are always produced in pairs, a hadronic collider could be converted into a relatively cheap B -factory identifying one of the b -quark jets via its J/ψ decay mode and studying the decay of the other b -quark, emitted into the opposite direction.

The experimental status of the B decays was reviewed by Horwitz. He concentrated on rare decays, especially on those which can be caused by penguin diagrams, e.g. $B \rightarrow K\pi$, $B \rightarrow K l^+ l^-$ ($l: e, \mu$) or $B \rightarrow K \bar{\nu}\nu$. These decays proceed via a loop involving the t -quark (and possibly heavier quarks of charge $2/3$).

The theoretical aspects of such decays were discussed by Soni. In the absence of any contributions due to the 4^{th} or higher families one expects the leptonic decays like $B \rightarrow K e^+ e^-$ to have a rather small branching ratio of the order of 10^{-6} . However these decays are very sensitive to the presence of higher families. If a fourth family is present, one may have branching ratios of the order of 1 0/00.

No rare decays of this type were found. The BR-limit from CLEO for the decay $B \rightarrow K e^+ e^-$ is $2 \cdot 10^{-4}$, ruling out the upper part of the theoretical estimates for this decay. Likewise no signal has been found in the channels $B \rightarrow K^+ \pi^-$ or $B \rightarrow \phi K^+$.

Of particular interest is the decay $b \rightarrow s + \gamma$. In the standard model with three generations this is a flavor changing radiative decay which is expected to have a sufficiently large branching ratio in order to be seen in the forthcoming experiments, as mentioned by Soni and in the contributed paper of Trampetic. QCD radiative corrections cause the amplitude for this decay not to be multiplied by the suppression factor $(m_t^2 - m_c^2) / M_W^2$, but by $\alpha_s \cdot \ln(m_t^2 / m_c^2)$, which is much larger than the previous factor such that BR ($b \rightarrow s \gamma$) for $m_t \sim 50$ GeV is of the order of 1 0/00. As mentioned by Trampetic, about 10 ... 20 % of all decays $b \rightarrow s + \gamma$ are expected to lead to the

final state K^*_γ , i.e. a monoenergetic γ -ray.

The decay rate for $b \rightarrow s\gamma$ is, of course, dependent on possibly existing further generations. Thus it provides another window to look out for effects of the fourth family.

Horwitz presented the status of the so-called "charm deficit", observed in B decays. In the standard model one expects to see in the average 1.15 charm particles per B-decay (one from the $b \rightarrow c$ transition, 0.15 from the transition $W \rightarrow \bar{c}s$). However the measurements (from CLEO and ARGUS) give 0.86 ± 0.09 , i.e. the B decays seem to be less charming than expected by theorists. As Horwitz stated, the effect may not be as serious as indicated by the number above, since there may be errors in the measurements of the various branching ratios involved, in particular also those for the decays of the charmed particles into the channels detected in the B decays. Nevertheless it seems to me that the issue is important and needs to be clarified. If it turns out that a large fraction (say 15 ... 30 %) of the B decays lead to final states without charmed particles, a serious trouble for the standard model arises. As mentioned by Soni, the decay $b \rightarrow s + \text{gluon}$ would lead to a final state with nonzero strangeness, but no charm. In the standard model this decay contributes at most to a 1 % level of all B-decays. However we must keep in mind that the weak interaction coupling properties of the t-b system are not yet fully known experimentally. It could be that the W boson coupling to the t-b-system has a nonvanishing, but small righthanded component with strength ϵ in which case the gluonic b-decay would proceed via a chromomagnetic transition and one finds:

$$\frac{b \rightarrow s + \text{gluon}}{b \rightarrow s + \chi} \sim \epsilon^2 \alpha_s \cdot \left(\frac{m_t}{m_b} \right)^2$$

i.e. the branching ratio for the $b \rightarrow s + \text{gluon}$ decay could easily be of the order of 10 ... 20 %. A small righthanded current would also enhance the $B-\bar{B}$ transitions and might be the reason for the large effect observed at ARGUS.

Of course, in view of the great success of the standard model new right-handed currents are not exactly what everybody would like to see. The present status of the electroweak sector of the standard model was reviewed by Marciano. It is impressive to see that the measurements of $\sin^2 \theta_w$ are slowly

reaching a precision at the 1 % level. Furthermore the neutral current strength parameter ρ is settling down on a value very close to one ($\rho = 1.001 \pm 0.004$), not allowing mass splittings among members of weak isospin doublets of more than about 200 GeV. In view of this constraint it is expected that the masses of the members of a fourth family (if it exists) are not larger than a few hundred GeV.

The status of theory of the weak decays of heavy mesons and baryons has been the subject of the talk of L. Chau. Of course, the problems associated with these decays represent a challenge since one is studying here a rather subtle interplay not only between the weak and the strong interactions, but also between the short distance QCD dynamics, which is accessible by perturbative methods and the long distance dynamics plagued by confinement effects. L. Chau's quark diagram scheme is a method to take both into account. During her talk and Hitlins' talk on the Mark III results it became clear that the decays of charm and b particles will remain a rich field of study for many years to come.

Bjorken's talk was setting the scene for the future. As he emphasized, a truly rich data sample for b decay physics can be obtained in hadron-hadron machines (fixed target machines or colliders). In order to be able to investigate CP violation in b-decays, one needs about 10^9 fb / experiment, a number which cannot be reached in e^+e^- collisions. Of course, a very sophisticated and expensive detector would be needed to select and investigate the B particles produced in hadronic collisions, such as Bjorken's $6\pi \times 2$ heavy flavor "taster".

The rôle of high energy e^+e^- - colliders in the search for new quarks and leptons was the topic of the talk of Dorfman. Such machines will be available in the future. LEP II will reach an energy E_{cm} of about 200 GeV. New linear collider projects under study especially at SLAC should be able to reach energies above 1 TeV. Since the annihilation cross section behaves at high energies like $1/s$, a high luminosity ($\mathcal{L} \sim 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$) is a must for these machines.

As Dorfman pointed out, it is not possible to find new quarks and leptons by looking for heavy quarkonia production or by measuring the increase of R. Instead it looks promising to search for distinctive topologies of the final

states, especially for those involving leptons, e.g. by observing a hadronic decay of the b-quark on the one side and a semileptonic decay of the $\bar{b}$ -quark on the other side, leading to a quark jet, an electron or a muon, and a neutrino ("missing energy"). It is curious to note that at energies above the LEP II range the W^+W^- production, i.e. the process which will be the major topic of investigation at LEP II, is the most serious background for finding and investigating new flavors. In general one can say that linear e^+e^- - colliders in the TeV range with a luminosity at about $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ seem to be the best machines, albeit not the ones which can be built today, to study new phenomena, especially new lepton and quark flavors, at energies above the weak interaction energy scale.

The search for new leptons and quarks at the SSC was discussed by Wojcicki, who also described the status of the project today shortly after the decision of the president to approve the project. Of course, the final decision to build the SSC has to be made by Congress. I am impressed by the general enthusiasm towards the SSC prevailing in the physics community of this country - an important factor, which Congress must take into account in its final decision and which will set constraints for the future projects of high energy physics in Europe. But I should like to stress that in view of the unprecedented scale and costs of the SSC project the particle physics community should aim at developing a coherent world-wide programme of research in the future. Such a programme should include the study of hadronic collisions using the SSC and / or the LHC-project (a hadron ring in the LEP tunnel at CERN), of e^+e^- collisions using a linear collider in the TeV energy range, and of electron-proton collisions in the TeV energy range. To carry out such a programme will require a world-wide collaboration, implying e.g. a participation of Europe in US projects and vice versa. High energy physics as a fundamental experimental field of research will only survive in the future, if the available resources provided by the taxpayers are shared wisely and used in the most efficient way.

Acknowledgement:

It is a pleasure to thank the organizers of this meeting, especially the scientific organizers N. Byers, D. Cline, J. Cornwall and A. Soni, for all the efforts made such that this meeting on a very speculative subject turned out to be so lively and stimulating as if one were dealing with observed facts. I am sure that as a result nature cannot resist but to provide us soon with the first hints that the spectrum of leptons and quarks does not end abruptly at the t quark mass.

Note added in proof: A neutrino signal which is most likely related to the supernova in the Great Magellanic cloud has been observed by several groups (Kamioka, IMB - detector, Mont - Blanc detector), as reported two weeks after this meeting at the Moriond conference in Les Arcs (March 87).