THE FIFTH FORCE

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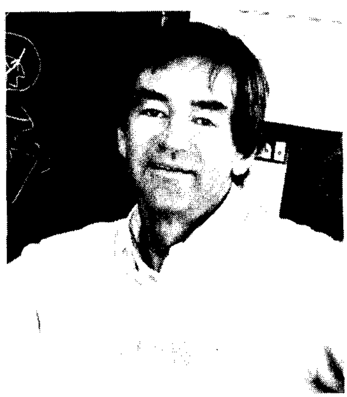

I. Introduction

There has been some talk lately about a possible new force of gravitational strength and macroscopic range, dubbed the "fifth force". This is not what this talk is about. While the reanalysis by Fischbach et al[1] of the Eotvos experiment has served a useful purpose in stimulating a new round of experiments, I personally find much of the remainder in that story objectionable. Amongst the objections is the claim that such a force, were it to exist, would be the fifth known force. To be sure Fischbach et. al. are not alone in this view. Everyone counts to four with ease: strong, electromagnetic and weak (or SU(2) and U(1) electroweak), and gravitational. But the SU(3)xSU(2)xU(1) standard model, which we must acknowledge even in these days of GUTS, SUSY, and superstrings is all we can trust with reasonable assurance from experiment to be true, already contains a fifth force - that associated with the Higgs sector. It surprises me how often distinguished popularizers of the field choose to leave it out. I looked at the expositions found in Scientific American in the last half-decade to see what was said. What I found includes the following:

> "An understanding of how the world is put together requires a theory of how the elementary particles of matter interact with one another. Equivalently, it requires a theory of the basic forces of nature.
>
> Four such forces have been identified, and until recently a different kind of theory was needed for each of them... ; all four forces are now described by means of theories that have the same general form.Thus if physicists have yet to find a single key that fits all the known locks, at least all the needed keys can be cut from the same blank. The theories in this single favored class are formally designated non-Abelian gauge theories with local symmetry..." (G. t'Hooft, April 1980, p.104)

> "Of the four established fundamental forces, gravitation must be put in a category apart. It is too feeble even to be detected in the interactions of individual particles, and it is not understood in terms of microscopic events. For the other three forces successful theories have been developed and are now widely accepted. The three theories are distinct, but they are consistent with one another; taken together they constitute a comprehensive model of elementary particles and their interactions, which I shall refer to as the standard model..." (H. Harari, April 1983, p.56)

> "Each of the four fundamental forces is now thought to arise from the invariance of a law of nature, such as the conservation of charge or energy, under a local symmetry operation, in which a certain parameter is altered independently at every point in space..." (C. Quigg, April 1984, p.84)

> "In the past two decades remarkable progress has been made in identifying the basic constituents of matter and the fundamental forces by which they interact. According to what is now called the standard model of elementary processes, all matter is made up of quarks and leptons, whose interactions with one another are mediated by the exchange of so-called gauge particles. It is also thought there are four basic kinds of interactions: electromagnetic, weak, strong and gravitational..." (D. Jackson, M. Tigner and S. Wojcicki, March 1986, p.66)

Only the last entry begins to meet my standards. The authors are the senior members of the SSC Central Design Group; hence they are used to choosing their words with care.

It is always a dangerous business to make quotations such as these out of context. To be sure, all authors emphasize the problem of the Higgs sector and the deficiencies of the standard model, but without mention - or at least emphasis - that extra forces beyond gauge forces are implied. Deeper in those articles appear the caveats. For example:

> "The strength of the gauge theories is that they require comparatively few parameters: about 18 constants of nature must be supplied to account for all the known forces... . The fundamental questions that remain unanswered by the gauge theories center on these apparent constants of nature. Why do the quarks and the other elementary particles have the masses they do? What determines the mass of the Higgs Particle?... The answers to such questions cannot come from the existing gauge theories but only from a more comprehensive theory..." (t'Hooft, op.cit.)

> "If the standard model has proved so successful, why would anyone consider more elaborate theories? The primary motivation is not a suspicion that the standard model is wrong but rather a feeling that it is less than fully satisfying. Even if the model gives correct answers for all the questions it addresses, many questions are left unanswered and many regularities in nature remain coincidental or arbitrary. In short, the model itself stands in need of explanation... .

In the standard model the masses are determined by approximately 20 "free" parameters that can be assigned any values the theorist chooses; in practice the values are generally based on experimental findings. Is it possible the 20 parameters are all unrelated? Are they fundamental constants of nature with the same status as the velocity of light or the electric charge of the electron? Probably not..." (Harari, op. cit.)

"Although the standard model is remarkably free of inconsistencies, it is incomplete; one is left hungry for further explanation. The model does not account for the pattern of quark and lepton masses or for the fact that although weak transitions usually observe family lines, they occasionally cross them. The family pattern itself remains to be explained. Why should there be three matched sets of quarks and leptons? Might there be more... ?

Twenty or more parameters, constants not accounted for by theory, are required to specify the standard model completely. These include the coupling strengths of the strong, weak and electromagnetic interactions, the masses of the quarks and leptons, and parameters specifying the interactions of the Higgs boson..." (Quigg, op. cit.) (my italics)

"The interaction of a particle with the Higgs field contributes to the energy of the particle with respect to the vacuum. That energy is equivalent to a mass. In the simplest model of the Higgs field the masses of the quarks, the leptons and the weak vector bosons are all explained as a result of the interaction with a single Higgs field..." (Jackson, Tigner, and Wojcicki, op. cit.) (my italics)

I congratulate my colleague Chris Quigg for at least mentioning the self-interactions of the Higgs particle. And again the SSC CDG trio have chosen their words with care.

Why such reticence to overtly acknowledge that the Higgs sector contains a fifth force? The reason for this attitude may be in part psychological. The forces associated with the Higgs sector are not obviously derived from gauge principles, and everyone wants to believe all basic forces are derivable from gauge principles - hence it is convenient to repress the candidate force which doesn't yet fit.

A less psychological reason is the argument that there is not yet anything directly known experimentally about the Higgs sector - hence no experimental evidence for this fifth force. For example, in last year's Moriond meeting, Shelly Glashow expressed this view:[2]

"Fischbach et al. recently published a reanalysis of the Eotvos experiment in which they present three raisons d'etre for the existence of a new long-range force in nature, a force beyond the strong and weak interactions, electromagnetism, and gravity. Its claim to being the fifth force is justifiable since there is not yet seen any direct manifestation of the Higgs-mediated force nor of the GUT force leading to proton decay."

This is the argument which really is to be addressed here, an argument which I find not very acceptable on logical grounds. In particular, if one accepts only the most basic premises of the standard model, I will argue that the indirect evidence for the fifth force is extremely persuasive, and that renunciation of it is tantamount to refusal to use the standard-model formalism in interpretation of existing data, in particular data on W and Z properties.

The elements in this line of argument[3] are as follows:

i) According to the SU(3)xSU(2)xU(1) standard model, the following are independent parameters:

a) The gauge couplings α_s, α, α_W (or $\sin^2\theta_W$)
b) The Fermi constant G_F (or, equivalently, the Higgs-field vacuum expectation value v)
c) Quark and lepton masses
d) The Kobayashi-Maskawa mixing matrix elements

This is not intended to be a complete listing. But note here that we have not yet committed ourselves to a specific formalism for the Higgs sector.

ii) Given that the gauge coupling constants are independent parameters, we can analyze the standard-model predictions as a function of these parameters, in particular as they tend to zero.

iii) In such a limit (which is taken with the other parameters such as G_F, quark and lepton masses, etc. held fixed), we would expect that, if only the known gauge forces mattered, there would be no interactions remaining. Instead we find that the electron is unstable, with a lifetime of 10.3 nsec.

It is surprising to me how many people are startled by this result. Most (I trust this does not include you, dear reader) have to be told what the final state is. But upon the slightest reflection, it should not be startling at all. And in any case it dramatizes the unsolved problem of the Higgs sector and is an initial step in exposing how much we really "know" about the existence and low-energy properties of this "fifth force". It is a lot.

The remainder of this piece is devoted to developing this viewpoint. By setting "irrelevant" gauge couplings to zero (or near-zero) values, we may see the problems of the standard model in a different, much harsher light. We must emphasize that this exercise is pedagogical - there is absolutely no new physics to be seen here. But there may be be some advantage in looking at this old, knotty, and absolutely crucial problem from this viewpoint.

II. The Instability of the Electron

The standard-model formula for the mass of the W is

$$m_W^2 = \frac{\pi \alpha_W}{G_F \sqrt{2}} \tag{2.1}$$

where

$$\alpha_W = \frac{\alpha}{\sin^2\theta_W} \tag{2.2}$$

The partial width for $W \to e\nu$ is

$$\Gamma\ (W \to e\nu) \cong \frac{\alpha_W m_W}{12} \tag{2.3}$$

provided $m_W \gg m_e$. We note that both these formulae are those used by experimentalists to interpret existing data.

However as $\alpha_W \to 0$, we see that $m_W \to 0$. Hence at a critical value ($\alpha_W \sim G_F m_e^2$), the electron becomes heavier than the W, and the process becomes,

$$e \to W + \nu \tag{2.4}$$

When $m_e >> m_W$, the decay process is dominated by emission of the longitudinal W, and the width is readily calculated to be

$$\Gamma_e = \frac{\alpha_W m_e^3}{16 m_W^2} = \frac{\sqrt{2}\, G_F m_e^3}{16\pi} \tag{2.5}$$

where we use the standard-model formula for m_W. The naive expectation that $\Gamma_e \to 0$ as $\alpha_W \to 0$ is vitiated by the presence of the longitudinal degree of freedom of the W, which remains coupled in the limit.

What is happening is the essence of the Higgs mechanism. As $\alpha_W \to 0$, the gauge-quanta which are transverse do decouple and no longer contribute significantly to the decay process. The longitudinal quantum is to be interpreted in the limit as the spinless Nambu-Goldstone boson associated with the spontaneous symmetry breaking of the Higgs sector. We note that even at this simplest level of calculation a viable alternative to the Higgs mechanism is already difficult to find.

In Section III we will review in more detail the nature of the coupling of these Nambu-Goldstone bosons, which we denote by $w^{\pm}$ and w^{o}, to matter and to each other. Here, we only note that

i) The Yukawa coupling strength to fermions is proportional to $\sqrt{G_F}$ and to fermion mass.

ii) The coupling of $w^{\pm}$ violates C and P maximally.

iii) The strength of the coupling of $w^{\pm}$ to quarks Q and q is proportional to the appropriate element V_{Qq} of the Kobayashi-Maskawa mixing matrix.

iv) The couplings of the neutral member w^0 are flavor diagonal and pure pseudoscalar. They do not depend upon the nature of the limit α, $\alpha_w \to 0$, i.e. on what choice of $\sin^2\theta_W \sim \alpha/\alpha_W$ is made for the limiting case.

We may readily complete the decay phenomenology of quarks and leptons. The decay table is as follows:

Primary Processes	Lifetime
$e^- \to \nu_e + w^-$	1.03×10^{-8} sec.
$\mu^- \to \nu_\mu + w^-$	1.17×10^{-15} sec.
$\tau^- \to \nu_\tau + w^-$	2.35×10^{-19} sec.
$d \to u + w^-$	4×10^{-11} sec.
$s \to u + w^-$	4×10^{-16} sec.
$c \to s + w^+$	4×10^{-19} sec.
$b \to c + w^-$	1×10^{-20} sec.
$t \to b + w^+$	$\tau < 8 \times 10^{-23}$ sec.

Some Rare Decays	Branching Ratio	
$c \to d + w^+$	$\lvert V_{cd}/V_{cs}\rvert^2 \simeq$	5.2 %
$b \to u + w^-$	$\lvert V_{ub}/V_{cb}\rvert^2 \lesssim$	4 %
$t \to s + w^+$	$\lvert V_{ts}/V_{tb}\rvert^2 \sim$	3±2 %
$t \to d + w^+$	$\lvert V_{td}/V_{tb}\rvert^2 \lesssim$	.04 %?

If neutrinos possess masses and mixings, they will decay, with very long lifetime, into the lightest member via w^+w^- or w^0 emission. Ignoring here this phenomenology, we see that big-bang cosmology would lead, in an SU(3)xSU(2)xU(1) world with zero gauge couplings, to a collection of neutrinos, u quarks and w^- bosons (assuming that the baryon asymmetry still survives this modification) as the stable constituents of matter.

III. Properties of the Decay Products

Thus far we have not used much which is specific to the gauge theories - only that α_w, G_F and fermion masses are independent parameters of an underlying theory. However, an underlying Higgs sector which has undergone spontaneous symmetry breaking is strongly implied. Let us examine the fermion Yukawa couplings in a little more detail. Looking at charged current couplings, we started with the Fermi theory and made the transition to intermediate boson exchange

$$\frac{G_F}{\sqrt{2}} J_\mu{}^\dagger J^\mu \rightarrow \frac{g^2}{8(m_W^2-q^2)} J_\mu{}^\dagger J_\nu \left(g^{\mu\nu} - \frac{q^\mu q^\nu}{m_W^2}\right) \qquad (3.1)$$

where the familiar tensor ensures that only the three physical polarization states of W are exchanged. As $m_W \rightarrow 0$, we obtained the effective interaction

$$\frac{G_F}{\sqrt{2}} J_\mu{}^\dagger J^\mu \rightarrow \frac{-g^2}{8m_W^2(m_W^2-q^2)} (q_\mu J^\mu)^\dagger (q_\nu J^\nu) \rightarrow \frac{G_F}{\sqrt{2}} (q^\mu J_\mu)^\dagger \frac{1}{q^2} (q_\nu J^\nu)$$

(3.2)

The coupling of the spinless degree of freedom is to the divergence of the current, and the coupling strength is $\sim G_F^{1/2}$.

There is no freedom of choice in this coupling, and it corresponds to the coupling of the Nambu-Goldstone bosons $w^\pm$ of the spontaneously broken gauge theory. Because the diagonal vector current (in tree approximation) is conserved, the neutral boson couples only to the divergence of the axial neutral current; the coupling is therefore proportional to fermion mass, is pure pseudoscalar, and is independent of $\sin^2\theta_w$.

The couplings of the $\vec{w}$'s to each other at low energy are specified as well, provided they are identified as Nambu-Goldstone bosons. This identification, in addition to being already strongly implied by the structure of the Yukawa couplings, is also strongly suggested by the (necessary) masslessness of the $\vec{w}$'s. (What other principle keeps them massless?) It can also be found by assuming the standard-model structure of the W-W scattering amplitude and again taking the $m_W \to 0$ limit.[4]

A simple, perhaps familiar way to obtain the couplings is via an effective low-energy Lagrangian obtained from the standard-model formalism. Defining the 2x2 matrix for the Higgs-field

$$\Phi = \sigma \exp i \frac{\vec{\tau}\cdot\vec{w}}{\sigma} \qquad (3.3)$$

the effective Lagrangian (as gauge couplings vanish) is simply that of the nonlinear σ-model[5]

$$\mathscr{L} = \frac{1}{4} \operatorname{Tr} \partial_\mu \Phi^\dagger \partial^\mu \Phi + V(\Phi) \qquad (3.4)$$

In the low energy limit, the σ degree of freedom (the Higgs field in the standard formalism) is frozen out, i.e. can be regarded as a c - number constant. An expansion to leading nonvanishing order in the $\vec{w}$'s leads to only a quartic effective interaction[6]

$$\mathscr{L} = - \frac{1}{2} (\partial_\mu \vec{w})^2 - \frac{1}{2\sigma^2} (\vec{w}\cdot\partial_\mu \vec{w})^2 \qquad (3.5)$$

The structure is determined only by the magnitude of σ, which is

$$\frac{1}{\sigma^2} = 2\sqrt{2}\, G_F = (173 \text{ GeV})^{-2} \qquad (3.6)$$

Scattering amplitudes of w's are therefore of weak strength, inversely proportional to σ^2 and thus proportional to G_F. Because of the derivative coupling, they have a growth with energy similar to neutrino cross-sections. Simply to underline the fact that, within the standard model, these cross-sections are known in the low-energy limit, we tabulate them below and plot them in Fig. 1.

Values of $d\sigma/d\Omega$ for Scattering of Nambu-Goldstone Bosons

$$\frac{d\sigma}{d\Omega} = \frac{G_F^2 \, s \, f(\theta)}{8 \pi^2}$$

$$w^+ w^+ \to w^+ w^+ \qquad f(\theta) = 1$$

$$w^+ w^- \to w^+ w^- \qquad f(\theta) = \frac{1}{4} (1 + \cos\theta)^2$$

$$w^+ w^- \to w^o w^o \qquad f(\theta) = 1$$

$$w^+ w^o \to w^+ w^o \qquad f(\theta) = \frac{1}{4} (1 - \cos\theta)^2$$

$$w^o w^o \to w^o w^o \qquad f(\theta) = 0$$

It is curious that the angular distribution also looks like neutrino processes. (SUSY, where are you?) We note that, within this limited sector of the theory, there exists an SU(2) global "isotopic-spin" (custodial) symmetry which governs these processes. This is the same symmetry that leads to a $W^{\pm}$ - Z^o degeneracy in the limit of $\sin^2\theta_W \to 0$ (or equivalently to a ρ-value of unity). This symmetry is broken when coupling to fermions is included. For example, the processes of fermion pair production

$$w + w \to f + \bar{f} \qquad (3.7)$$

are comparable to the elastic and charge-exchange cross-sections near threshold. However, they have a gentler energy-dependence. The cross-sections for light external fermions of mass m and heavier, exchanged internal fermions of mass M are the most important They are given by the following formulae:

$$\sigma = \begin{cases} \dfrac{G_F^2 s}{12\pi}\left(1 + \dfrac{2m^2}{s}\right)\sqrt{1 - \dfrac{4m^2}{s}} & s \ll 4M^2 \\ \dfrac{G_F^2 M^4}{2\pi s}\,\ell n \dfrac{s}{4M^2} & s \gg 4M^2 \end{cases} \tag{3.8}$$

For quarks, these cross sections must be multiplied by 3, the final state color factor. The results are plotted in Fig. 1. Plotted in Fig. 2 is the ratio

$$R = \sigma_{tot} \Big/ \left(\frac{G_F^2 s}{12\pi} \right) \tag{3.9}$$

Contributions from individual fermions come and go, but up to present energies $\langle R \rangle \cong 3$.

As usual, the dynamics at the TeV mass scale, $\sqrt{s} \gtrsim G_F^{-1/2}$, is indicated as what is most relevant to resolving the question of the ultimate importance of the empirical low-energy "isospin" symmetry possessed by the Nambu-Goldstone boson interactions.

Evidently the low energy limits we have calculated would not apply at all energies. The natural scale at which the low-energy limit breaks down is, in the Lagrangian version of the standard model, that of the Higgs-particle mass. Unitarity requires in any case the effective Lagrangian of Eqn. 3.5 to be modified at or below the TeV mass scale characterized by $G_F^{-1/2}$. However, there is no compelling reason that the remaining high-energy dynamics of this system be concentrated in that of a single elementary scalar particle.

IV. CP Violation

In the standard-model, CP violation is supposed to originate in the quark mass-matrix and manifest itself in the complex phases of the Kobayashi-Maskawa mixing matrix. These parameters remain in the theory as the gauge couplings are removed. It is therefore of some interest to see what physical processes actually exhibit the CP violating phases. One does not have to go too far to find an example. The process, say

$$w^+ + w^- \to b + \bar{s} \qquad (4.1)$$

suffices, provided the polarization of at least one of the produced quarks is measured. But this is no problem; the weak decays of b and s themselves provide 100% polarization asymmetry; the phenomenology is similar to that of hyperon nonleptonic decays. The relevant asymmetry in the above process occurs in the quantities $\vec{\sigma}_b \times \vec{\sigma}_s \cdot \vec{k}$ and $\vec{\sigma}_q \cdot \vec{k} \times \vec{q}$ where $\vec{k}$ is the cms momentum vector of the $\vec{w}$ and $\vec{q}$ the cms momentum vector of the quark. The formula is lengthy and not given here. We only note that the coefficient of the relevant kinematic invariant is the quantity J = Im $V_{i\alpha} V_{j\beta} V^*_{i\beta} V^*_{j\alpha}$, proportional to all CP violating phenomena in the 3-generation standard model.

We conclude that the standard-model CP-violating phenomena are in principle accessible in the gaugeless limit. However we do not trouble ourselves here to assess the actual practicability.

V. The Fifth Force and The Strong Force

The analogy between how we here see the fifth force and how the strong force was seen in the 1950's and early 1960's is striking. The Nambu-Goldstone bosons $\vec{w}$ are analogous to the pions. The same low energy theorems which control pion-pion scattering apply to low energy scattering of the $\vec{w}$'s. Their Yukawa couplings to quarks are controlled by the analogues of the Goldberger-Treiman relation for couplings of the π's to nucleons. Low energy scattering of $\vec{w}$'s by quarks are controlled by Adler-Weisberger theorems analogous to those for pion-nucleon scattering.

This analogy is well-recognized, and forms the basis for technicolor models of the fifth force: if the fifth force is indeed so similar to strong interactions in the low-energy limit, perhaps it is likewise so in the ultraviolet limit, with a new (technicolor) gauge force binding techniquarks into the $\vec{w}$ bosons and into other excitations analogous to the ρ, ω, η, etc. of the strong interactions.[7] Irrespective of the ultimate fate of technicolor, there may be an important lesson here: the true nature of the Higgs sector and the true manifestations of the "fifth force" may be complex - perhaps even more complex than in the technicolor model. For example this model does not possess the extra flavor degrees of freedom such as strangeness and charm which are found in the phenomenology of the strong force.

It is fun to build an analogy between the present-day search for the Higgs particle and what might have been the same program in the late 1950's for the strong force had there been a full understanding then of chiral symmetry and spontaneous symmetry-breaking. The low-energy pion interactions would have been successfully modeled by the linear σ-model, which would be the "standard-model" of the strong force. Perhaps the nucleon would have been generally understood to be a "Skyrmion" soliton state. The clear challenge to experiment would be to find the σ - particle. What has happened? The σ is presumably related to the π-π I=0 s-wave phase-shift which smoothly moves through 90° between 500 MeV and 1 GeV. This phenomenon is so diffuse that the σ is not tabulated in the Particle Data Group meson tables. A tabulated resonance, the $f_0(975)$, has a large $s\bar{s}$ quark component and does not qualify as a σ. And to this day the $\pi\pi$ I=0 s-wave is a topic of active research and controversy: the latest round is whether there exists a third I=0, J=0 state (gluonium?) at $\sim$ 1 GeV. Au, Morgan, and Pennington claim evidence for this via double-pomeron production of pion pairs at the ISR.[8] Of these three phenomena, we leave to the reader which is intrinsically the most interesting.

But no matter what one thinks of s-wave π-π scattering, I think it can be agreed that this never was, is not, and never will be the crucial experiment for unraveling the nature of the strong interaction. I think the odds are in favor of this being the case for the fate of the Higgs particle and the comprehension of the fifth force as well.

VI. Concluding Remarks

I find the gaugeless limit as one which helps to clarify and expose the heart of the problems confronting the standard-model. The existence of a residual force not proportional to gauge couplings manifests itself very clearly, and it is difficult to avoid facing its reality. Whether this is a fifth force is an arguable matter of semantics. If (as the SSC CDG define it) the weak force is what is mediated by W and Z, then the 5th force may be as yet undiscovered. However, we must still conclude that the W-exchange force is not "pure gauge"; it is nonvanishing in the gaugeless limit.

But semantics is not the point. What is important is whether the gaugeless limit, as we have described it, makes sense. In particular what is to be done if the phenomenological formulae for the $W^{\pm}$ masses and for the partial width into electron and its neutrino are renounced? That is all that is needed to infer electron instability in the gaugeless limit. This is not to say that there are no alternatives possible, only that alternatives require a serious change or extension of the conventional point of view.

What might such alternatives be? Perhaps in some extended theory (e.g. GUT) the gauge couplings are themselves functions of some parameter, call it λ, which has the property that $\alpha \to 0$ as $\lambda \to 0$. It may be that some of the remaining standard-model parameters (e.g. quark and lepton masses) also vanish as $\lambda \to 0$; this would then protect electron stability. This state of affairs might occur because the Yukawa couplings of fermions to the Nambu-Goldstone bosons $\vec{w}$ vanish as $\lambda \to 0$ or even that $G_F \to \infty$ as $\lambda \to 0$. And if superstring theory fulfills the promises of its prophets, then it may be arguable that the α's are not parameters at all and cannot be varied, since the theory contains no free dimensionless parameters.

Nevertheless, I think that, in order to be of use, an alternative attitude to the gaugeless limit should be as concrete as what has been presented here. I would be not at all disappointed to be convinced that this gaugeless limit does not make sense. I only want to know why.

VII. Acknowledgments

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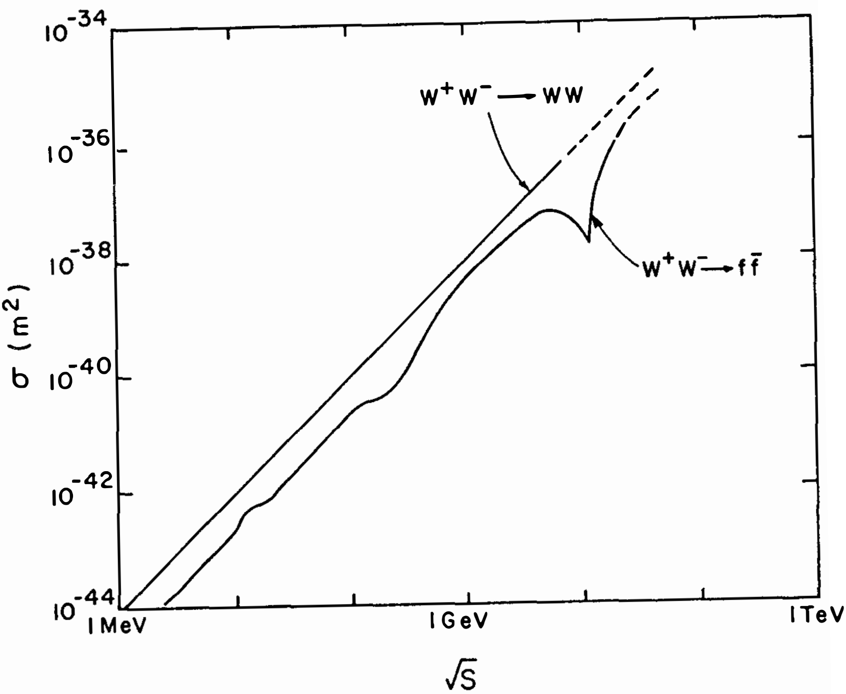
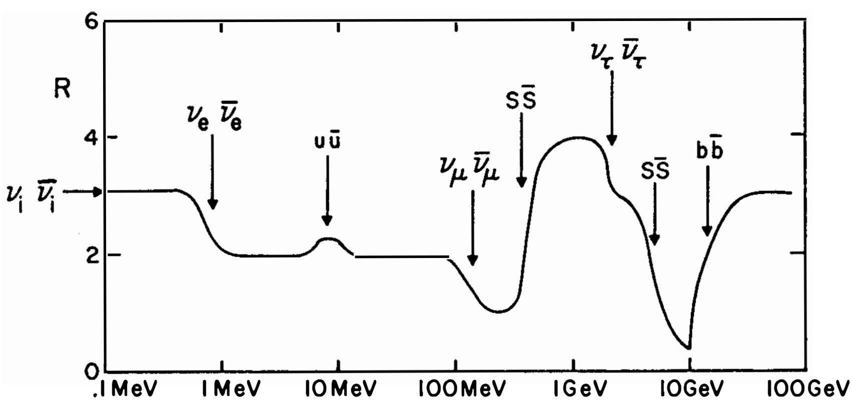


Fig. 1 : *Plot of w^+-w^- scattering cross sections versus energy. The elastic (plus charge exchange) cross-section must be modified in some way (Higgs-exchange?) for $\sqrt{s} \lesssim$ 1-2 TeV; the plotted curve is valid only in the low energy limit.*



<u>*Fig. 2*</u> : *Plot of the quantity* $\sigma\ (w^+w^- \to \text{all } f\bar{f})/G_F^2\ (12\pi)^{-1}$.

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4 The uniqueness of the low energy gaugeless limit is well known; exploitation of this is especially prominent in recent work by the LBL group; cf. e.g. M. Chanowitz, preprint LBL-22841 and references therein.

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