Electroweak Interactions

SEARCHING FOR THE HIGGS AT TEVATRON II

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Introduction

We have recently arrived at a successful theory of the weak and electromagnetic interactions, the Weinberg-Salam model. However, there are two ingredients of this theory which remain to be uncovered, i.e., the gauge bosons ($W^{\pm}$, Z^0) and the Higgs particle.[1,2] The latter is a necessary ingredient in the theory; it is not optional. Many experiments, and even accelerators, are being designed to find the $W^{\pm}$ and Z^0. No experiment has yet proposed a dedicated search for a Higgs. This is unfortunate since, while the uncovering of the $W^{\pm}$, Z^0 will lead to much satisfaction in the high-energy community, the discovery of the Higgs would be a much more exciting and informative event. In this report we will describe various ways to find a light Higgs boson in the fixed-target Tevatron program.

The physics of the Higgs boson in the minimal Weinberg-Salam theory is dominated by the fact that its coupling to fermions is proportional to the mass of the fermion.

$$L = \frac{m_f}{\sqrt{2}} \sqrt{\frac{G_f}{2}} \; \bar{\psi}_f \psi_f \phi \qquad (1)$$

Thus processes with light quarks do not produce a Higgs readily, and a Higgs is often accompanied by heavier quarks. In theories with a more complex Higgs structure than the minimal model stronger couplings are often found.

For the phenomenology we will assume the minimal coupling; however, it should be kept in mind that much stronger effects could be envisioned. It is of interest to restrict these couplings, and many experiments can be analyzed to do so. It is hard to understand why experimenters would accept the minimal theory couplings as correct and not push experimentally to restrict the Higgs couplings; often couplings two orders of magnitude greater than the usual theorist's ones are not excluded.[3] In the more complex theories charged Higgs also occur and we consider some of their effects, although e^+e^- machines are superior for charged Higgs. In Table I we list some expected branching ratios for a neutral Higgs with minimal coupling.

Table I. Estimated Branching Ratios of Higgs.

Mode	200 MeV$<M_H<$3.4 GeV	3.4 GeV$<M_H<$10 GeV	10 GeV$<M_H$
e^+e^-	10^{-5}	10^{-8}	10^{-9}
$u\bar{u}$ or $d\bar{d}$	10^{-2}	10^{-5}	10^{-1}
$\mu^+\mu^-$[a]	3 → 14%	10^{-3}	10^{-4}
$s\bar{s}$	86 → 97%	1 → 3%	10^{-3}
$c\bar{c}$	-	70%	9%
$\tau^+\tau^-$	-	30%	4%
$b\bar{b}$	-	-	87%

[a] In technicolor models this mode could be a factor of three larger because of the absence of a color suppression factor when the decay mechanism is t-channel.

There are a class of theories (technicolor or hypercolor) which have composite Higgs. These will display many characteristics of ordinary Higgs in low energy processes and our work applies to them also. (One difference is that the neutral technicolor bosons are pseudoscalars while ordinary Higgs are scalars.) A recent calculation gives light technicolor bosons,[4] with charged Higgs at 8 GeV and an upper bound on neutral Higgs at 2.5 GeV. This provides strong motivation to search the low mass spectrum as well as possible.

In the following we discuss several mechanisms of interest for the Tevatron. Some signals do exist but they are small if the coupling is no larger than Eq. (1). Nevertheless **any** search provides more information than is available at present. We have tried to point out the directions in which improvements in experimental techniques would make the search more powerful. Almost all discussion applies equally to fundamental Higgs or pseudo Nambu-Goldstone bosons for technicolor theories.

Properties of Higgs Bosons

The purpose of this section is to provide enough background to enable one to understand the experimental requirements for Higgs production and detection. Higgs bosons (either fundamental or composite) are the essential ingredient that enable gauge theory to be applied to the weak interactions. The symmetry of the gauge theory is not manifest in low-energy phenomena because the lowest energy configuration of the Higgs system is not the symmetry case $\phi = 0$, but a configuration $\phi = v$ (where v is the "vacuum expectation value" of the field). This situation breaks the symmetry and gives the $W^{\pm}$, Z^0 masses. In the process we end up with one or more physical scalar or pseudoscalar particles -- the Higgs bosons.

The Minimal Model

The simplest Weinberg-Salam model contains one neutral physical Higgs boson. The mass is a free parameter in the theory, although some bounds are possible. The requirement that radiative corrections do not restore the SU(2)×U(1) symmetry leads to a bound $M_H > 7$ GeV. An upper bound, depending on somewhat weaker theoretical considerations, suggests that the Higgs should be lighter than 1 TeV. In this range there is little to pin down any particular mass. One theoretical argument of considerable interest suggests that the mass should be $M_H = 10.5$ GeV.

To understand the couplings of quarks to the Higgs bosons one should understand the way that quarks get a mass. There are no quark mass terms in the original Lagrangian; however, there is a coupling to the Higgs bosons of the form.

$$g_y \bar{\psi}\phi\psi.$$

When we expand the Higgs field about its vacumm expectation value

$$\phi = v + \tilde{\phi}$$

with $\tilde{\phi}$ being the observed quantum Higgs field, one obtains

$$g_y v \ (\bar{\psi}\psi + \bar{\psi}\psi\tilde{\phi}/v).$$

The product $g_y v$ is then a quark mass and the coupling of the Higgs to quarks is proportional to the quark mass. In particular it makes the coupling

$$L_H = \frac{1}{\sqrt{2}} \sqrt{\frac{G_f}{2}} \ m_q \ \bar{q}q\tilde{\phi}.$$

This is the most important influence on Higgs phenomenology. Since their couplings to light quarks is tiny, Higgs particles will not be readily produced with standard probes. Most of the phenomenology which we discuss tries to rely on couplings to heavier quarks.

In a like fashion, the decay of the Higgs bosons will be preferentially to the heaviest particles available to it, with branching fractions proportional to the $(\text{mass})^2$ of the final-state particles. Table I displays the branching fractions for various modes, for Higgses in various mass ranges.

The Higgs coupling to quarks is semi-weak, intermediate between electromagnetic couplings and weak effects. The lifetime of a few GeV Higgs would be $< 10^{-17}$ sec, so that it will always be narrower than any experimental resolution.

More Complex Higgs Sectors

There are many strong theoretical motivations for expanding the Higgs boson sector of the Weinberg-Salam model. These include the study of CP violation and the attempts at grand unification. In fact aside from simplicity there is little justification to restrict the Higgs sector. In most cases the standard weak phenomenology is not affected by an enlargement. However the physical Higgs spectrum becomes richer.

Beyond the minimal model there will in general be charged and extra neutral bosons. For example, a model with two Higgs doublets contains 4 additional physical Higgs $H^{\pm}$, H^0, and $H^{0\prime}$. The lower bound on the mass now becomes only a lower bound on the **heaviest** mass. In other words any light mass is possible. In fact light masses are often theoretically desirable, and masses of order 2 GeV arise naturally in the composite models.

A second feature of a richer Higgs structure is that the couplings can be stronger from than in the minimal model. Many models would retain the same relative strengths of couplings as the minimal model, but the overall strength would be greater or lesser than that theory by a ratio of vacuum expectation values. Other models end up with large Higgs couplings to all fermions, often governed by the largest fermion mass (τ or t) in the spectrum. These possibilities lead to a much greater Higgs production rate, and would be very advantageous for detecting a Higgs boson.

Most of our discussions in following sections concentrate on Higgs couplings which are similar to that of the minimal model. However it should always be kept in mind that rates may be much larger than such estimates, and **all** experiments of even marginal sensitivity can be used to look for and set limits on Higgs physics. Even these limits, if analyzed thoroughly and published, can be of use.

The phenomenology of charged Higgs is somewhat different from that of neutral Higgs.(5,3) Most importantly they can be produced electromagnetically. Their decays follow the same pattern as would a $W^{\pm}$ at the same mass, except for an extra weighting by the mass of the quarks involved in the transition. For example, a 5 GeV charged Higgs would decay to $\bar{c}s$ and $\tau\nu_{\tau}$ predominantly.

One additional word of caution should be mentioned in these richer schemes. If a neutral Higgs is heavier than twice the charged Higgs mass, the neutral will decay 100% of the time into H^+H^- with a width comparable to its mass. It will, therefore, become essentially impossible to find the neutral Higgs.

Composite Higgs Bosons - Technicolor

For several aesthetic reasons, there is considerable dissatisfaction with the usual fundamental Higgs scalars. An alternative possibility, which is being explored vigorously at present, is that Higgs bosons are composite particles made of fermion-antifermion pairs. The most common scheme of this type goes by the name technicolor or hypercolor. In such theories the bound states play the same role that elementary Higgs do, and there also will be physical particles whose properties are similar to the standard models. It is worth belaboring the point that technicolor theories do not mean that the Higgs disappears. There will be a physical boson state.

There is, however, a distinction between technicolor and conventional theories. In the latter the neutral boson is a scalar, while in the technicolor it is pseudoscalar. When a boson is found, there are standard parity tests to distinguish these two cases. In what follows technicolor bosons will be included under the general name of Higgs boson.

One of the hopes of technicolor is that one can make predictions which were not possible in the standard theory. This has recently been realized in the Higgs sector by a calculation of the Higgs masses.[4] This is performed in the framework of an extended technicolor model which seems most favorable for the generation of fermion masses. In this model there are 4 physical Higgs bosons, $H^{\pm}$, H^0, $H^{0\prime}$. The charged Higgs mass is calculated to be about

$$M_{H+} = 8 \text{ GeV},$$

while the two neutral Higgs are bounded by

$$m_{H^0} \lesssim 2.5 \text{ GeV}$$

with the expectation being that in fact they would be not far below this bound. These results provide the exciting possibility that experiments, if pursued vigorously, will either find these particles or disprove the general idea. (It should be remarked that while the specific calculation above was done in a framework which may not be as popular by the time the Tevatron turns on, the lightness of the physical Higgs is a feature of essentially all technicolor schemes which are even moderately realistic.)

Conclusion

We see that the Higgs bosons are an essential ingredient in weak gauge theory. There are few constraints on their masses, but light masses are certainly plausible. As of now the experimental bounds on the Higgs mass and couplings are very poor. Hopefully this will be improved by experimenters soon.

General Remarks on a Fixed-Target Tevatron Program

We are charged with describing ways to search for a Higgs boson at the fixed-target Tevatron. This leads us to concentrate on certain avenues of exploration to the exclusion of others more suitable for other machines. The Tevatron will produce an available energy $s^{1/2} \approx 40$ Gev. This will be suitable for the production of light Higgs, but makes a search of a large mass range impossible. We will primarily discuss the range $M_H = 1 \to 10$ GeV. However, a fixed-target program has advantages in the variety of beams, sophistication of detectors, and number of events. Since Higgs physics requires searching for elusive modes, these are helpful. One feature that will surface throughout is the need for a good mass resolution. The Higgs particle is narrower than any experimental resolution. Therefore, when bump hunting one can always double the signal-to-noise ratio by increasing the resolution by a factor of two. On the other hand, poor resolution wipes out any chance of observing a Higgs. Throughout, when needed, we assume a mass resolution such as is expected in the forthcoming dimuon experiment, E-605, $\sigma_m \sim 50$ MeV. This is the point to push to increase sensitivity.

The other general feature which we have found in our study is that the main hope in locating a Higgs in the general spray of hadrons, is to design fairly restrictive triggers. This is in fact especially useful for Higgs particles because they are most often produced in association with heavy flavors. Such a procedure cuts down background significantly without reducing too drastically the Higgs signal. However, high intensities are needed.

Working at the right energies in the right process can lead to the production of a sizeable number of Higgs particles. However, the detection is difficult. Looking through Table I in the previous section, the most promising final state for looking for a bump is $\mu^+\mu^-$. For a Higgs lighter than 3.4 GeV this branching ratio is of order (10% and is a very favorable mode. For heavier Higgs the $\tau^+\tau^-$ and $c\bar{c}$ modes dominate and the branching ratio into muon pairs plummets to about 10^{-3}. Nevertheless, it remains a useful handle. For these heavier Higgs the $\tau^+\tau^-$ mode does offer a distinctive signal with its decay into (μ^+e^- or $e^-\mu^+$) plus missing neutrinos. These may be used to flag Higgs events. A mass determination from the μe spectrum would be crude but useful. Calorimeter experiments can trigger on μe + missing energy. Most experiments can use $\mu^+\mu^-$ and $\tau^+\tau^- \to \mu e$ information in conjunction (although clearly not on an event-by-event basis). It is reasonable to expect that some Higgs physics in this mass range will have been completed before the turn-on of the 1-TeV beam. Charged Higgs of $m < 10$ GeV are accessible to

PEP and PETRA, and some effort is being made to search for them at present. Most likely they will either be found or excluded by 1983. Therefore, we will not describe much for charged Higgs, with the exception of a rather spectacular signal in neutrino scattering. There is also the chance that something will be known about light neutral Higgs from ψ and γ spectroscopy by that time. However, this is far from certain and a Higgs search at the Tevatron is called for.

In Table II, on the next page, we list most of the more promising suggestions for producing a Higgs which we have found in the literature. The first four of these are ones which are of interest for the Tevatron and which we discuss in the following section in more detail. The rest we have eliminated for the reasons given. The processes involving charmed and b particles are discussed somewhat in the next section because it is possible that the Tevatron may prove advantageous for some aspects of heavy flavor physics.

Specific Modes

In this section we discuss various mechanisms appropriate to the Tevatron. Most of them are useful for putting limits on Higgs couplings but end up being marginal for the detection of Higgs with standard couplings. Further improvement in experimental techniques would make them feasible, and so they are of interest. We have not had access to Monte-Carlo programs for the production and detection and have relied primarily on published results. Hopefully these discussions will prompt more detailed considerations by people who are closer to the measurements. We will refer to either fundamental or composite bosons as Higgs bosons.

Low $p_\perp$ Drell-Yan Production

There have been two mechanisms in particular which have been suggested for the low $p_\perp$ production of Higgs bosons. One takes advantage of the Higgs coupling to gluons through a heavy quark loop.

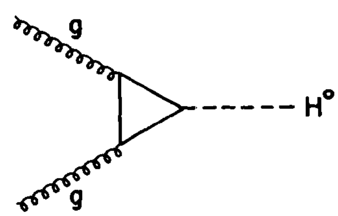


Fig. 1

Another uses the s quark in a K^+ beam to couple more strongly than light quarks can via the direct annihilation

Table II. Ways to Produce Higgs.

1) Drell-Yan in
   a) $p\bar{p}$
   b) K^+p

2) High $p_\perp$ physics
   - see text

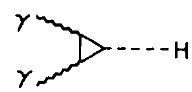
3) Photoproduction
   - see text

4) $\nu_\mu + T \rightarrow H^+ + T + \mu$
   - see text

5) Other neutrino scattering
   - rates too small

6) Produce $t\bar{t}$ which decays into H^+ semi-weakly
   - not enough energy at Tevatron

7) Two photon production
   - not for Tevatron



8) Decay of heavy vector state $V \rightarrow H^0\gamma$
   - better at e^+e^- machines

9) Mixing[3] through scalar states of heavy quarkonium spectroscopy
   - e^+e^- machines

10) Direct resonance in e^+e^-

11) W or Z decays
   - most favorable mode at LEP

12) Decays of heavier Higgs
   $H^0 \rightarrow H^+H^-$, $H^0 \rightarrow H^+ \bar{c}s$, $H^+ \rightarrow H^0 \bar{s}c$
   - may occur but one would expect to produce the lightest state first.

13) $e^+e^- \rightarrow H^+H^-$
   - good for PEP and PETRA

14) $e^+e^- \rightarrow \gamma H^0$
   $\rightarrow VH^0$

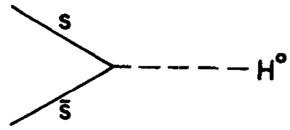


Fig. 2

For Higgs bosons with mass of a few GeV these couplings are comparable, within the uncertainties of masses and coupling constants. For pp collisions it is clear that Fig. 1 will dominate, as the $s\bar{s}$ content of the proton is small compared to the gluon conponent; however, one can utilize Fig. 2 in K^+p experiments. K^+p is superior to K^-p in that the u in K^+p does not have strong Drell-Yan annihilation with any of the valence quarks in the proton, whiles the $\bar{u}$ in K^- does. This considerably reduces the background in K^+p experiments.

At present there is a pp Drell-Yan experiment being set up at Fermilab, the Columbia-Stony Brook-Saclay-Washington-Japan-Fermilab collaboration E-605. This has a good mass resolution, making it a favorable detector for Higgs. The Higgs production rate, coupled with decay to $\mu^+\mu^-$ has been calculated[6] for the present energies available at Fermilab. With 50-MeV mass resolution the Higgs boson would produce a 1% bump in the mass spectrum of μ pairs for Higgs of mass 5 → 10 GeV. This is clearly a difficult signal to see, although some feel not impossible.

There are some ways to enhance the signal. The strongest way to do so would be to improve the mass resolution. If a factor of 10 would be possible by the time of the Tevatron (it probably isn't, but...) this would become a 10% peak. Some slight improvement can be gained by noting that the Drell-Yan background has the usual $1 + \cos^2\theta$ distribution, while the Higgs, being spinless, leads to a flat angular distribution. Cuts can somewhat enhance the signal. Likewise, the other properties of Higgs can be utilized. No Higgs signal should be seen in e^+e^- at the same mass.

Going to higher energy at the Tevatron will improve slightly the situation. At higher energies one can probe the gluon distributions at low x [the average x is $M_H/(s)^{1/2}$], increasing the rate. The background rate, however, also goes up. The conventional Drell-Yan mechanism is a product of sea and valence distributions and with the conventional assignments for x distributions [$(1-x)^n$ with n = 3 for valence, 5 for gluons and 7 for sea] the signal/background will rise together. The main help with the Tevatron will be a factor of 4 better rate.

If the Higgs coupling is stronger than in the minimal model, this process becomes a very good way to see the Higgs. By looking for a small bump one can at least provide a bound on the Higgs couplings in this mass range. (Remember there are some

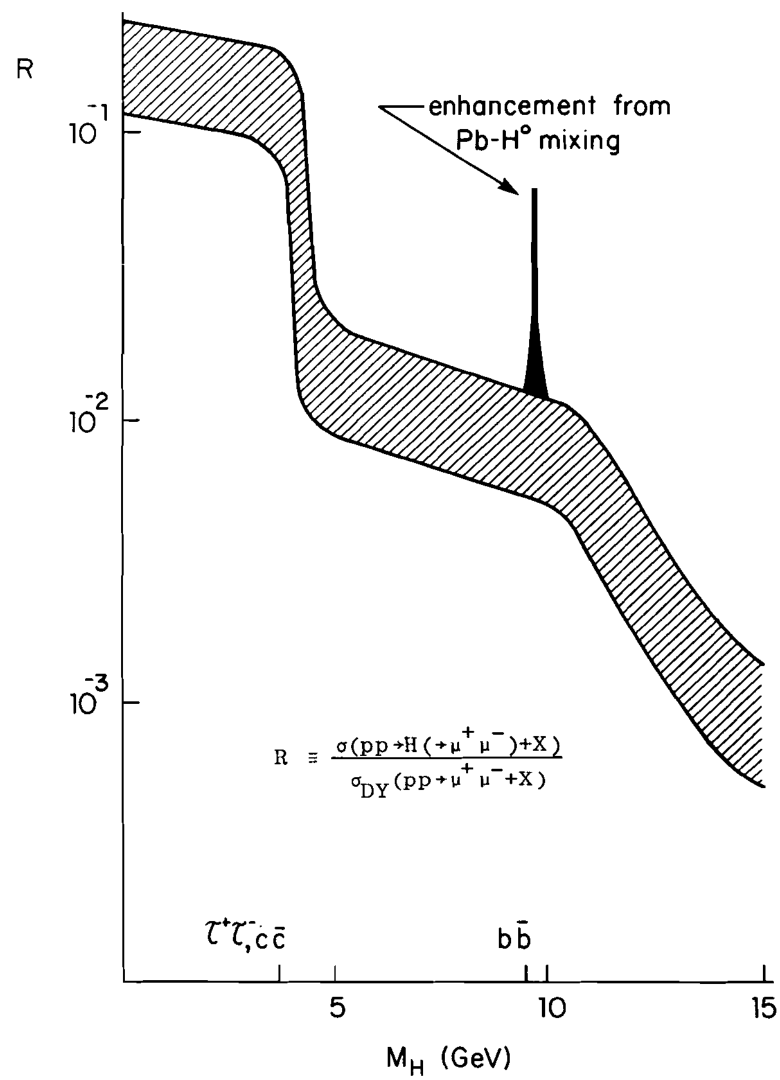


Fig. 3. Ratio of dimuons from Higgs decay to continuum.

models with couplings to muons a factor of 100 greater than the minimal model.) A lack of a bump x% above background corresponds to a statement that no Higgs exist in this range with couplings larger than $x^{1/2}$ times the minimal model.

High $p_\perp$ Drell-Yan

We have thought about ways to increase the signal to noise above 1% of the Drell-Yan at low $p_\perp$. Going to high $p_\perp$ does not by itself lead to any improvement over regular Drell Yan, as the latter also has mechanisms to generate high $p_\perp$ events. There is the possiblity of requiring a more restrictive trigger which can enhance the signal.

A good example is in $K^+ p \rightarrow h + X$. At low $p_\perp$ we expect this to occur through the strange quark annihilations graph (Fig. 2), at a rate comparable to the Drell-Yan rate in pp via Fig. 1 (i.e., ~ 1% signal). We can produce a Higgs and strange quark, both at higher $p_\perp$, by the following graph.

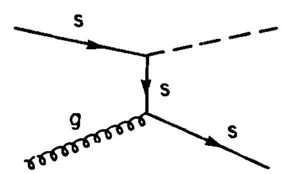


Fig. 4

This involves the valence quark in the K^+ and a gluon in the proton, and this is fairly well favored. The trigger is a high $p_\perp$ strange particle and high $p_\perp$ muon pair at the H mass. It removes all sources of background not involving stange quarks, and we estimate reduces the background by greater than a factor of 5.

Another possibility that has been suggested is to use the diagram

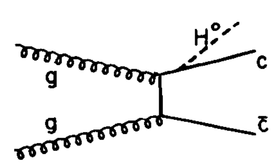


Fig. 5

to produce Higgs in association with charmed non-zero $p_\perp$. This would allow a trigger to be improved through use of the c and/or $\bar{c}$. An example of an experiment of this type would be a beam-dump experiment where muons from the H^0 and c or $\bar{c}$ can be detected. The trigger would be a high $p_\perp$ muon pair reconstructing to a Higgs in coincidence with a high $p_\perp$ muon from charm decay. Because of all the massive particles in the final state the cross section is a sharply falling function of Higgs mass. It has been calculated by Raitio and Wada, and for light masses can be in the 10^{-3}nb range. A high-intensity experiment is clearly needed.

Other Triggers

Because of the smallness of the $H^0 \rightarrow \mu^+\mu^-$ rate it might be advisable to look for other signals. We have not found any. One suggestion was to use the decay $H^0 \rightarrow \tau^+\tau^-$ and look for (μe + missing mass) in a calorimeter experiment. This gives up reconstructing the Higgs, but the hope was that a signal for its existence might remain. It has to compete, however, with associated production of charm which gives a μe signal ~ 5% of the time. The charm cross section is many orders of magnitude larger than that of Higgs. By not reconstructing the full events one gets lost in a deep sea of background.

Photoproduction of Higgs

Consider the diagram shown below.

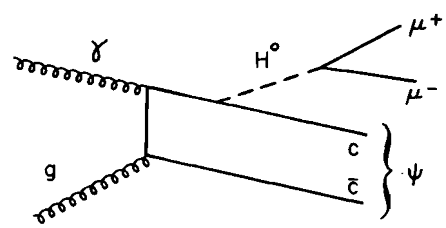


Fig. 6

It involves the production of a charmed Higgs meson in association with a ψ. Both the Higgs meson and ψ are expectd to be produced with fairly high p_T and could subsequently give a clean trigger. The H is expected to decay into $\mu^+\mu^-$ pairs and so does the ψ. Mass reconstruction of the two $\mu^+\mu^-$ pairs will give the necessary trigger.

An estimate of the cross section for this process can be made by comparing it with estimates of Higgs production cross section in pp $\rightarrow$ H+ anything via gluon component of the proton, in Fig. 5. In making the comparison we should be careful about the kinematics involved in replacing the gluon by a photon. The effective s for the 2-gluon process is

$$s = x_{1},x_{2}s \simeq x_{1},m(s)^{1/2},$$

where x_1 and x_2 are the fractional component of s carried by the gluons. The approximation $x_2 \approx m/(s)^{1/2}$ is a standard "rule of thumb" of Drell-Yan phenomenology where m is the mass of the state produced. For the process under consideration $x_2 \sim 1/10$, so that a 1-TeV photon is equivalent to a 10-TeV proton which gives a $(s)^{1/2} \approx 150$ GeV. Using Fig. 3 of Ref. 5 and a Higgs meson of mass 2.5 GeV, we got a cross section of $(10^{-3}$ nb$)$ $\alpha/\alpha_s = 4 \times 10^{-5}$ nb for photoproducing the Higgs meson, using a 1-TeV photon beam. This cross section has to be multiplied by the branching ratio of the Higgs particle into $\mu^+\mu^-$ which is $\sim 1/10$. This gives a cross section of 4×10^{-6}nb. this value can now be compared to the cross section for photoproducing the $\psi(c\bar{c})$ which is 2×10^{-5}mb,[7] giving a ratio of about 2×10^{-7}.

In order to get a rough estimate on the expected number of events within a reasonable period of time we compare with ψ photoproduction estimates of Fermilab proposal #627. (The down-stream chain of detectors of this proposal is capable of hadron, lepton, and photon detection and seems to be fairly good for the type of trigger that we require because it is designed for high mass vector mesons.)

Proposal #627 estimates about 100K ψ's with an average photon flux of 2×10^5, 100 GeV $< E_\gamma <$ 200 GeV.[8] This gives the ratio of fluxes $= R_f = 7.5 \times 10^6 / 2 \times 10^5 \approx 40$. So a rough estimate of the yield (for 500 hours running time) is

$$\frac{\sigma(\gamma N \to HX)}{\sigma(\gamma N \to \Psi X)} \times R_f \times (10^5 \text{ events})$$
$$= 2 \times 10^7 \times 40 \times 10^5 \simeq 1 \text{ event.}$$

Background

The most important background contribution for the trigger event would come from the diagram with a γ instead of a H^0, where the $\mu^+\mu^-$ comes off an off-mass shell photon. We expect this background to be small if we require that the $\mu^+\mu^-$ pairs carry a large invariant mass.

Conclusion

We expect 1 event per 500 hours of running time. So a sufficient high statistics experiment would be able to pick up a Higgs meson signal especially if it has a very good resolution.

Neutrino Production of a Charged Higgs

While the neutrino cross section of a neutral Higgs is too small to be worthwhile, there is a favorable mode for the production of a charged Higgs.[5] This occurs through the coherent scattering off of nuclei, with the diagrams given below.

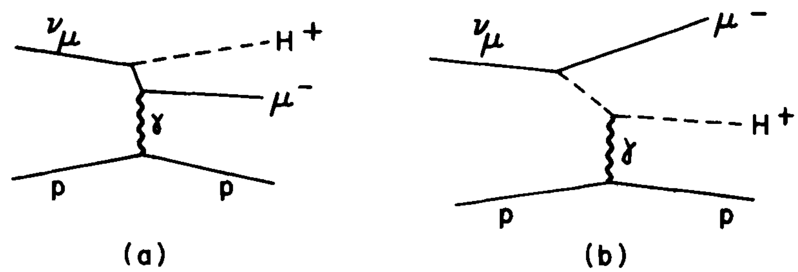


Fig. 8

Figure 8(a) gives the dominant contributions. The cross sections on Ne is given by Fig. 9 where the standard cross section is given for comparison. We see that for light Higgs the relative size of the signal is $O(10^{-3})$. (Remember, however, in theories with charged Higgs the couplings can easily be stronger by a ratio of vacuum expectation values, thus enhancing the signal.)

The signal for this process is spectacular. Because of the propagators in Fig. 8(a) the muon comes out fairly slow, with an average of 10% of the neutrino energy. The nucleon picks up almost no energy. Therefore the Higgs particle carries away almost all ($\approx$ 90% on the average) of the neutrino's energy and is peaked very far forward (88% have $\theta < 0.8°$ for $E_\nu = 200$ GeV and $M_H = 8$ GeV). If the Higgs decays leptonically one ends up with a very fast **positive** lepton, a slow μ^- and essentially no hadronic energy. This makes neutrino scattering quite favorable for the detection of a light charged Higgs.

Another possibility is if the t quark can be produced by neutrinos. If there exists a charged Higgs lighter than the t quark, the t will decay 100% of the time to the Higgs. Estimates of t quark production, however, are discouragingly small.

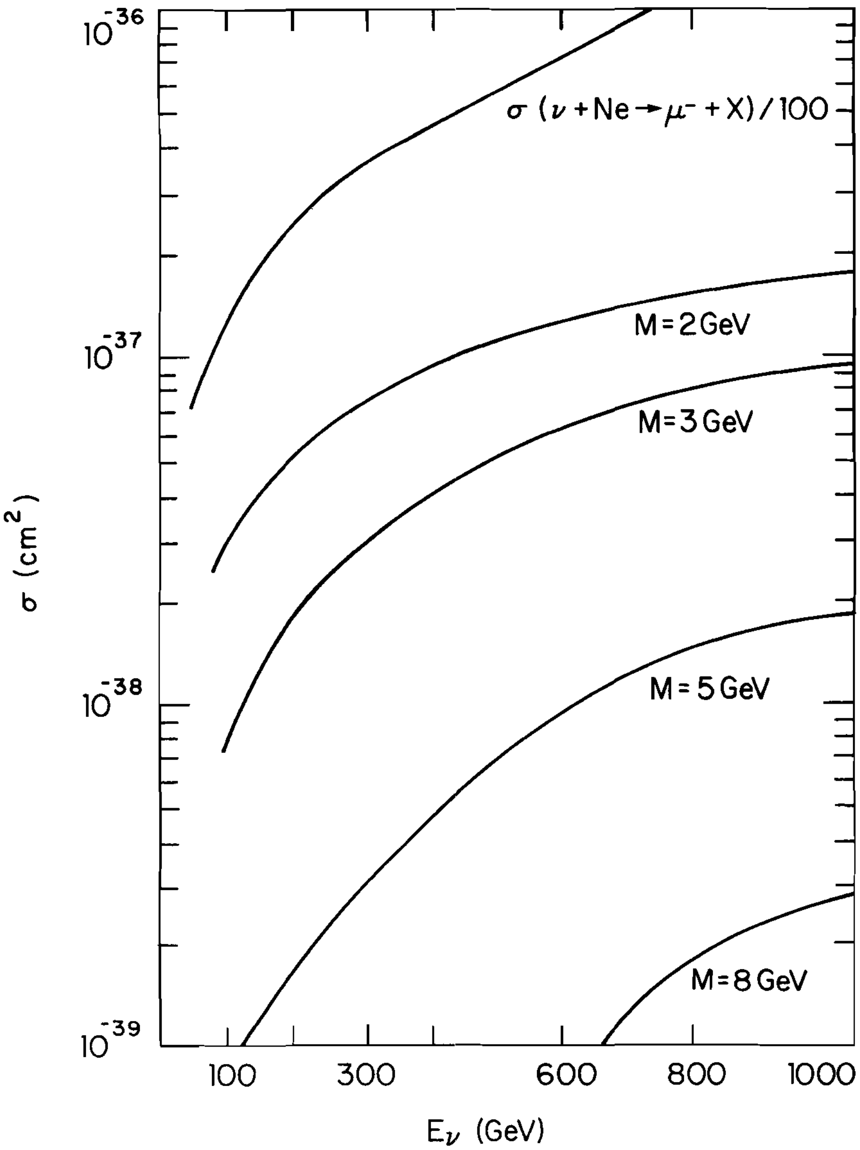


Fig. 9. Cross section for ν + Ne → μ + H^+ + X with the coupling given by Eq. (33) and K_μ = 1 [from Phys. Rev. **D19**, 945 (1979)].

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