WHERE ARE THE HIGGS?

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ABSTRACT

We briefly review the theoretical motivation for the existence of Higgs particles and theoretical bounds on their mass. We discuss experimental searches for Higgs bosons and limits on the value of the mass. New results from the CUSB–II collaboration are presented.

1. Introduction

1.1 WHY HIGGS'?

In the so called standard model of Glashow, Weinberg and Salam the gauge group of the electroweak interaction is $SU(2)_L \otimes U(1)_Y$, which has 3+1 generators. There are therefore 3+1 vector gauge bosons. The addition to the langrangian of a complex weak-isospin doublet of scalar fields with appropriate couplings breaks both $SU(2)_L$ and $U(1)_Y$ but not $U(1)_{em}$, whose generator is the charge $Q = T_3 + Y/2$, so that two charged and one neutral gauge bosons acquire mass, while the gauge boson of $U(1)_{em}$, the photon, remains massless. Two charged Higgs and a neutral one provide the third polarization degree of freedom for W^+, W^- and Z^0 and one neutral scalar particle is left over as a physical state, of unknown mass. The Higgs field was of course put in 'by hand' in the lagrangian and perhaps we should not expect too much. Higgs bosons do not explain the values of the gauge bosons or fermions masses and mixing angles. The low energy phenomenology of the weak interaction is reflected in the vacuum expectation value (G_F is the Fermi coupling constant):

$$v \equiv \langle \phi_0 \rangle = \sqrt{\frac{1}{\sqrt{2} G_F}} = 246 \text{ GeV}$$

This minimal construct allows also to give masses to the fermions by introducing terms in the lagrangian, with mass $m_f = G_f v/\sqrt{2}$, one arbitrary constant G_f per fermion, at the same time fixing the strength of the Hff Yukawa coupling as m_f/v.

Extensions of the Higgs mechanism involve more Higgs doublets, with a variety of options as to how the different doublets couple to up–like and down–like quarks. In the simplest extension, two Higgs doublets are introduced, one coupling to up–like quarks, the other to down–like quarks. Introduction of two Higgs doublets results in five physical states: two charged bosons, two neutral scalars and a neutral pseudoscalar. At least two Higgs doublets are necessary in supersymmetric models.

1.2 LIMITS ON THE HIGGS MASS

There are very few restrictions on the Higgs mass. Coleman and Weinberg [1] had argued some time ago, for the case of one Higgs doublet, that a massless Higgs would acquire a mass of ~10 GeV from radiative corrections. Cosmological arguments based [2] on the stability of the vacuum give a bound approximately $\sqrt{2}$ time lower. This arguments are not valid if the top quark is very heavy. For one Higgs doublet, [3] and one heavy quarks one obtains:

$$M_H^2 > \frac{3}{16\pi^2 v^2}(2M_W^4 + M_Z^4 - 4M_q^4)$$

where M_q is the mass of the heavy quark. This bound coincides with that of reference 2 for $M_q = 0$ and vanishes for $M_q = 79$ GeV. Upper bounds of about 200 GeV have also been derived by the same authors in grand unified theories, for the unifying groups SU(5) or SO(10), for which however there is at present no compelling evidence. These bounds are in general not valid in models with more then one Higgs doublet. If $M_H > 1000$ GeV, the Born amplitude for gauge boson scattering violates unitarity. This fact *per se* does not of course constrain the Higgs mass but has interesting implication about the existence of new structure at a scale of 10^{-17} cm, if the Higgs still will elude us at one TeV. A serious problems with a Higgs so heavy, is that its width becomes of the order of its mass. The Higgs width is given by

$$\Gamma_H \sim \frac{1}{2} M_H^3, \quad M_H,\ \Gamma_H \text{ in TeV} \ \Rightarrow\ \Gamma_H \sim 1.4 \text{ Tev for } M_H \sim 1.4 \text{ TeV}.$$

In addition to making the search for heavy Higgs very problematic, perhaps impossible, it does not appears very convincing to construct the standard model upon such a vague picture of an elementary particle ...even if such an ill defined object were ever to be hinted at by some experiment, how would one ever prove it's ***the Higgs***?

The only experimental limit which has not been disputed so far is $M_H > 15$ MeV. It is derived from the absence of long range effects in atomic and nuclear physics.[4] Light Higgs are ***"almost"*** predicted in supersymmetric[4] theories, where the mass of two of the neutral Higgs' is pushed below that of the weak gauge bosons. For a two Higgs case, there are two vacuum expectation values: $v_1 = \langle\phi_1\rangle$ and $v_2 = \langle\phi_2\rangle$, which, in the simplest extension satisfy $\sqrt{v_1^2 + v_2^2} = 246$ GeV. Correspondingly the couplings to fermions become $m_f/v_{(1,2)}$, depending on which Higgs they are coupled to and generates their masses.

2. Searching for light Higgs'

2.1 INTRODUCTION

Higgs bosons have been searched in the flavor changing decays, $K \to H + \pi$, $B \to H + K$ and the decays of vector mesons, J/ψ, $\Upsilon \to H + \gamma$. From the study of K and B decays, lower bounds for the Higgs mass have been claimed, although uncertainties in the calculation of the form factors which appear in the decay rates, have cast doubts on the validity of the bounds obtained. Both the J/ψ and the Υ have the dubious distinction of having been claimed to actually decay into Higgs bosons. The $\xi(2.2)$,[5] found in J/ψ decays (the existence of the $\xi(2.2)$ is still[6] somewhat questionable) is not a Higgs. The $\varsigma(8.3)$ reported at the Leipzig conference,[7] was not observed by CUSB.[8] Other null searches were also reported soon thereafter.[9] It should be noted that the $\xi(2.2)$ would require $1/x = 100$ and the $\varsigma(8.3)$, x=10.

2.2 $K \to H + \pi$

No signal attributable to the existence of a Higgs with mass smaller then about 350 MeV, (*i.e.* smaller than $\sim m_K - m_\pi$ has so far been observed. This has been interpreted as yielding:

1. M_H >350 MeV.[10] (1980).
2. No bound on the Higgs mass.[11] (1982,1985).
3. 50 MeV< M_H < 140 MeV.[12] (1986).

These changes are mostly due to uncertainties in computing the appropriate form factors in the matrix elements between a K and a π, as discussed below for B decays. We can however look forward to great increases in the sensitivity of K decay experiments, especially from Brookhaven National Laboratory, which will overcome the uncertainty in the calculation and obtain firm limits for the mass of (or prove the existence of) the Higgs boson. This is particularly important for excluding Higgs masses below $\sim 2m_\mu \sim 0.21$ GeV, a mass region, as discussed later, not accessible to other experiments.

2.3 $B \to H + K$; $H \to \mu\mu$, $\pi\pi, \ldots$

The flavor changing vertex, $b \to s + H$, is shown in figure 1.

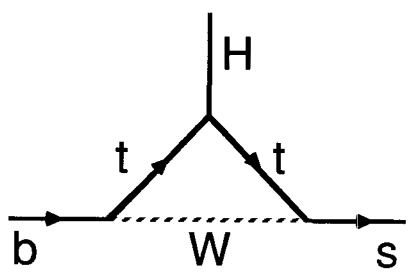

Figure 1. Flavor changing vertex $b \to s + H$

This amplitudes gives a quartic dependence on the top mass, therefore, given the present lack of knowledge about the top mass, predictions about $B \to H + K$ are rather meaningless at this moment. In addition, while at the parton level the amplitude of fig. 1 is perfectly defined, the problem is complicated by the inability to calculate the wave functions of the B and K mesons. We hide as usual our ignorance in the form factor $F(q^2)$, defined by $\langle K|\cdots|B\rangle = \cdots \times F(q^2)$, where $\cdots$ stands for operators and results which are trivial at the parton level. Searches for this mode have been carried out in semi–exclusive modes $B \to K +\ \mu\mu,\ \pi\pi$. Another problem here is that of knowing the relative decay rates for the Higgs. Combining all this uncertainties, it seems possible that CLEO results[13] exclude Higgs' in the mass range 210 to 700 MeV. There are also uncertainties about the branching ratio for Higgs decays into $\mu\mu$ and $\pi\pi$. Chosing reasonable values for the form factor and branching ratios, results in no limits, except for a very large top mass.

2.4 Higgs from Upsilon Decays

The decay $\Upsilon \to H+\gamma$ is due to the annihilation of the annihilation of the $b\bar{b}$ pair bound in the Υ into a photon and a Higgs. From the strength of the bbH vertex, $M_b/v = M_b\sqrt{\sqrt{2}G_F}$, we can compute the annihilation rate. The form factor problem, the value of $|\Psi(0)|^2$ in this case, is very easily avoided here by comparing to the decay $\Upsilon \to \mu\mu$, obtaining the well known Wilczek–Weinberg[14] result:

$$\frac{\Gamma(\Upsilon \to H+\gamma)}{\Gamma(\Upsilon \to \mu\mu)} = \frac{G_F M_b^2}{\sqrt{2}\pi\alpha}\left(1-\frac{M_H^2}{M_\Upsilon^2}\right)x^2$$

where x=1 for a single Higgs doublet and $x = v_1/v_2$ for two Higgs doublets. Here v_1 is the vacuum expectation value of the (neutral component of the) Higgs field coupled to the b quark. For decays to a very light Higgs (and x=1) one finds $BR(\Upsilon \to H+\gamma) \sim 2.5 \times 10^{-4}$.

2.5 Experimental results on $\Upsilon \to H+\gamma$.

Given the branching ratio above, a good photon detector and a few hundred thousand Υ's it should not be too difficult to find –or exclude the existence of– light Higgs. Some time ago, at the 1985 Moriond Workshop,[15] we presented results from which we obtained a limit on BR($\Upsilon \to H+\gamma$) which was below the Wilczek–Weinberg value for a mass of the Higgs less than about 4 GeV, at the 90% confidence level. It was promptly pointed out[16] that QCD radiative corrections, to lowest order,[17] reduce the branching ratio for $\Upsilon \to H+\gamma$ by about a factor two.

We have recently improved our sensitivity to the decay of upsilons into Higgs, by both improving our resolution[18] and vastly increasing the statistics of our sample, adding to our previous sample of $\sim$ 400,000 Υ events, $\sim$ 400,000 Υ and 600,000 Υ'' new events. The sensitivity of our search, is therefore improved by $\sqrt{N}$ and $1/\sqrt{\sigma}$, where N, σ are the number of decays collected and the photon energy resolution. (Since $BR(\Upsilon'' \to \mu\mu) \sim 0.6 \times BR(\Upsilon \to \mu\mu)$, we don't get quite the same sensitivity from Υ'' decays.) Figure 2 shows an example of the photon spectra we have studied in our search. We have five different sets of data, corresponding to different detector configurations and/or machine energies and tune, three for Υ and two for Υ'' decays. No significant signal is observed in any of the spectra thus obtained.

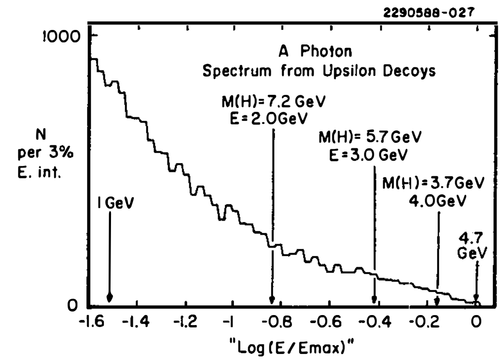

Figure 2. A photon spectrum from Υ decays, events per 3% energy bins.

In order to combine all our data to obtain a bound on the Higgs mass, we compute, by maximum likelihood methods, the upper limit for x vs Higgs mass. The result is shown in figures 3a and 3b for 90% and 95% confidence level.

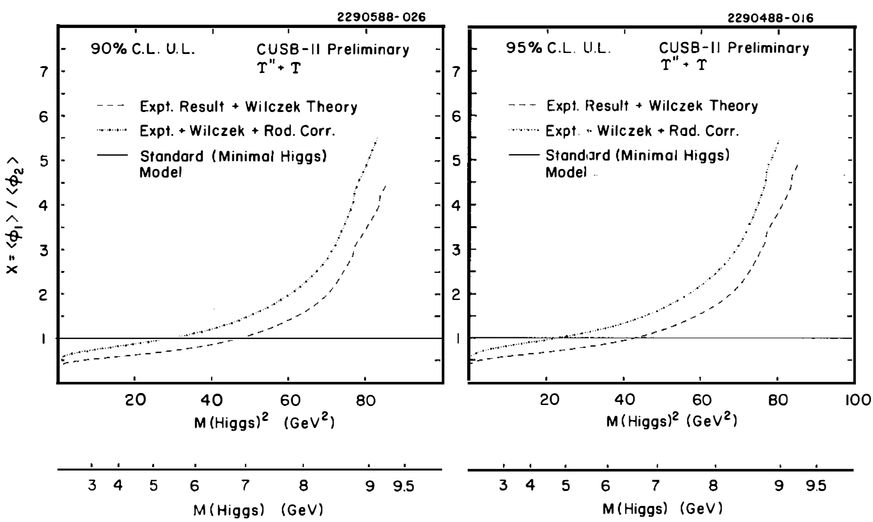

Figure 3. a) 90% and b) 95% confidence level upper limit for x vs Higgs mass.

Since the minimal standard model is equivalent to x=1, the place where the curves for the upper limit on x cross the x=1 line gives the corresponding limit for the Higgs mass. We conclude therefore that, for the case of one Higgs doublet, the mass of the Higgs must be greater than 5.5 (4.8) GeV, at the 90% (95%) confidence level. Since in our search for

$\Upsilon \to H + \gamma$, we require that some decay product, other then a photon or an electron, of the Higgs be observable in the detector, we are not sensitive to Higgs lighter then twice the muon mass or approximately 0.21 GeV. We also show our limit for the case of no radiative corrections, in the hope that somebody, someday, might compute the next order correction.

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