

Comparing electroweak data with a decoupling model

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Abstract. Present data, both from direct Higgs search and from analysis of electroweak data, are starting to become rather restrictive on the possible values for the mass of the standard model Higgs. We discuss a new physics scenario based on a model with decoupling (both in a linear and in a non linear version) showing how it allows for an excellent fit to the present values of the ϵ parameters and how it widens the allowed ranges for the Higgs mass (thought as elementary in the linear version, or as composite in the non linear one).

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INTRODUCTION

The new LEP data presented at the recent Winter Conferences in Moriond and La Thuile give strong restrictions on the Higgs mass. Direct Higgs search gives $m_H \geq 89.3 \text{ GeV}$ at 95% CL [1]. From the global fit to all electroweak data one obtains $m_H \leq 215 \text{ GeV}$ at 95% CL [2]. The corresponding bounds from the Jerusalem Conference of 1997 [3] were $77 \leq m_H(\text{GeV}) \leq 420$ at 95% CL. One reason for the difference in the upper limit is the inclusion of the most important part of the two-loop radiative corrections [4].

The upper bound on the Higgs mass comes mainly from the experimental determination of $\sin^2 \bar{\theta}$ (where $\bar{\theta}$ is the effective Weinberg angle). However there is still a 2.3σ deviation between LEP and SLD averages. The LEP average is by far dominated by the determination of A_{FB}^b which has the smallest experimental error. An upward change of $\sin^2 \bar{\theta}$ would increase the upper bound on m_H , whereas a downward shift would lower it.

The SLD average, $\sin^2 \bar{\theta}_{SLD} = 0.23084 \pm 0.00035$, lies on the lower side of the central value, $\sin^2 \bar{\theta}_{world \text{ average}} = 0.23149 \pm 0.00021$, whereas the LEP average, $\sin^2 \bar{\theta}_{LEP} = 0.23185 \pm 0.00026$, lies on the higher side [2]. Possible future experimental results in the direction of lowering $\sin^2 \bar{\theta}$ could thus eventually lead to a conflict between the upper bound for m_H and the lower bound obtained from the direct search of the Higgs. In such a situation hints for physics beyond the standard model would be obtained by looking at the ϵ parameters [5]. The ellipses in Figs. 1 and 2 are derived at $1 - \sigma$ from all the latest electroweak data [6].

One notices that in these graphs the standard model points lie in general at higher values than the central experimental points, indicating a constraint on the ϵ parameters to be smaller than the standard model values.

Not all models invoking new physics would satisfy such a constraint. For instance, elementary technicolor gives a contribution only to ϵ_3 , but of the wrong sign. The situation would be better for supersymmetric models with appropriate choices of the parameters [7].

In this note we shall discuss the implications of a decoupling model [8,9] for new physics which presents the general feature of leading to contributions to all the ϵ parameters, contributions all of negative sign.

By the requisite of decoupling, in a model for new physics, we mean that the model is such that when the mass scale for the new physics is made infinitely large the model goes back to the standard model. The new mass scale controls the contributions to the ϵ parameters. The non linear effective Lagrangian model of ref. [8] goes back for infinite mass scale to the standard model without elementary Higgs. The renormalizable linear decoupling model of ref. [9] coincides for infinite mass scale with the standard model, including its elementary Higgs, at all perturbative orders.

THE MODEL

We will discuss the decoupling models described in refs. [8,9]. The relation between the model introduced in ref. [8] and the one of [9] is analogous to the one between the non linear and the linear σ -model. Both models are based on the gauge group $SU(2)_L \otimes U(1) \otimes SU(2)'_L \otimes SU(2)'_R$ with gauge fields corresponding to the ordinary gauge bosons W^\pm , Z and γ and new heavy gauge fields \mathbf{L} and \mathbf{R} . A discrete symmetry $L \leftrightarrow R$ is also required such that the new gauge fields have equal gauge couplings $g_L = g_R \equiv g_2$. The symmetry also implies that at the lowest order in weak interactions the masses of the new vector bosons are equal, $M_L = M_R \equiv M$.

The gauge boson masses are generated through the breaking of the gauge group down to $U(1)_{\text{em}}$, implying 9 Goldstone bosons.

In the non linear model [8] these are all the scalar fields. They all disappear from the physical spectrum through Higgs phenomenon.

In the linear version [9] one introduces 3 complex doublets belonging to the following representations of the global group $SU(2)_L \otimes SU(2)_R \otimes SU(2)'_L \otimes SU(2)'_R$

$$\tilde{L} \in (2, 0, 2, 0), \quad \tilde{U} \in (2, 2, 0, 0), \quad \tilde{R} \in (0, 2, 0, 2) \quad (1)$$

These 3 doublets describe 9 Goldstone bosons and 3 physical neutral scalar fields, one of which is the ordinary Higgs field in the decoupling limit.

In the linear model the breaking of the symmetry is supposed to come in two steps characterized by the expectation values $\langle \tilde{L} \rangle = \langle \tilde{R} \rangle = u$ and $\langle \tilde{U} \rangle = v$ respectively. The first two expectation values induce the breaking $SU(2)_L \otimes SU(2)'_L \rightarrow SU(2)_{\text{weak}}$ and $U(1) \otimes SU(2)'_R \rightarrow U(1)_Y$, whereas the third one induces in the standard way $SU(2)_{\text{weak}} \otimes U(1)_Y \rightarrow U(1)_{\text{em}}$. We assume that the first breaking corresponds to a scale $u \gg v$. In the limit $u \rightarrow \infty$ the model decouples and one is left with the standard model with the usual Higgs [8].

One can think of the non linear version as the one to be used in a scenario where the Higgs is thought as composite with a mass at the TeV scale. In ref. [8] we have shown that also the non linear model decouples.

A feature of both models, the linear and the non linear one, is that they have an additional accidental global symmetry $SU(2) \times SU(2)$, which acts together with the usual $SU(2)$ to form a custodial symmetry. As a consequence the new physics contribution to the ϵ parameters, at the lowest order in the weak interactions, vanishes. In fact, the usual $SU(2)$ custodial requires the vanishing of the contributions to ϵ_1 and ϵ_2 , whereas the new larger custodial symmetry implies also the vanishing of the contribution to ϵ_3 .

Physically this is due to the mass and coupling degeneracy between the new \mathbf{L} and \mathbf{R} resonances at the lowest order. For this reason contributions to the

ϵ parameters appear only to the next-to-leading order in the expansion in the heavy masses. The tree-level contribution to the ϵ parameters at the first non trivial order in $1/M$ is given for both linear and non linear version by [8,9]

$$\Delta\epsilon_1 = -\frac{c_\theta^4 + s_\theta^4}{c_\theta^2}X, \quad \Delta\epsilon_2 = -c_\theta^2X, \quad \Delta\epsilon_3 = -X \quad (2)$$

with θ the Weinberg angle. All the contributions are negative and are all parametrized by the single parameter

$$X = \left(\frac{g}{g_2}\right)^2 \frac{M_Z^2}{M^2} \quad (3)$$

with g the standard gauge coupling and M_Z the Z mass.

The linear model is renormalizable and the corresponding radiative corrections can be evaluated by following the lines of ref. [9]. The one-loop contribution to ϵ parameters is given by the usual radiative corrections of the standard model plus the radiative corrections coming from new physics. As far as these last corrections are concerned, one can show (see [9]) that, due to the decoupling property, they are typically smaller than 10% of the tree-level contributions. Therefore we will neglect them in our following considerations since they are well below the experimental error on the ϵ parameters which is of the order of 20 ÷ 30%.

The non linear model can be regularized assuming the linear model as the regularizing theory and taking the Higgs mass as a cutoff at the TeV scale.

Therefore in both cases we get the same expressions for the radiative corrections, except that in linear case the parameter m_H is the physical Higgs mass, whereas in the non linear case (where no elementary Higgs is present) one takes m_H as describing a cutoff, to be chosen at around 1 TeV .

COMPARISON TO ELECTROWEAK DATA

As explained in the previous Section the contributions of new physics to the ϵ parameters in the models considered here are all negative and parameterized in terms of the single variable X , which depends on a combination of the new mass scale M and of the gauge coupling of the new vector bosons g_2 . In Figs. 1,2 we have drawn the $1 - \sigma$ experimental ellipses [6] for the pairs (ϵ_1, ϵ_3) and (ϵ_3, ϵ_2) . The thick bars correspond to the ϵ values of the standard model at given Higgs mass ($m_H = 70, 300, 1000 GeV$) and with the top mass varying in each case between 170.1 and 181.1 GeV (from left to right in Fig. 1 and from up to down in Fig. 2).

For each given pair of values of m_t and m_H , one considers a corresponding line, parameterized by X (see eq. (2)), whose points give for each X the values of the ϵ after inclusion of the new physics discussed here. All these lines lie, in

the figures, within the strips attached to each of the thick bars. For each line originating from the standard model points one can evaluate the best value for X to fit the experimental values of the ϵ parameters. The corresponding best fit points lie on the dashed bars of Figs. 1,2.

m_H (GeV)	$\bar{\epsilon}_1 \times 10^3$ m_t (GeV) =			$\bar{\epsilon}_2 \times 10^3$ m_t (GeV) =			$\bar{\epsilon}_3 \times 10^3$ m_t (GeV) =		
	170.1	175.6	181.1	170.1	175.6	181.1	170.1	175.6	181.1
70	4.17	4.52	4.88	-8.44	-8.77	-9.11	3.62	3.42	3.22
100	3.94	4.29	4.65	-8.47	-8.79	-9.13	3.83	3.63	3.43
200	3.44	3.79	4.15	-8.41	-8.73	-9.06	4.23	4.03	3.83
300	3.13	3.47	3.83	-8.30	-8.61	-8.94	4.47	4.27	4.07
400	2.89	3.23	3.59	-8.19	-8.50	-8.83	4.64	4.44	4.24
500	2.67	3.04	3.39	-8.09	-8.39	-8.71	4.77	4.57	4.37
600	2.53	2.88	3.23	-7.99	-8.29	-8.61	4.87	4.68	4.47
700	2.39	2.74	3.09	-7.90	-8.20	-8.51	4.96	4.77	4.57
800	2.27	2.61	2.96	-7.81	-8.11	-8.43	5.04	4.85	4.64
900	2.16	2.50	2.85	-7.73	-8.03	-8.34	5.11	4.92	4.71
1000	2.06	2.40	2.75	-7.66	-7.95	-8.26	5.18	4.98	4.78

Table 1 - ϵ parameters in the decoupling model derived from the best fit value for X for any pair (m_t, m_H) . The experimental values for the $(\epsilon_i) \times 10^3$ are: $\epsilon_1 = 3.85 \pm 1.20$, $\epsilon_2 = -8.3 \pm 1.9$, $\epsilon_3 = 3.85 \pm 1.21$ [6].

The quality of the fit can be appreciated from Table 1 where we give the values of the ϵ parameters derived in each case from the best value for X . The best fit values for X lie within $1.3 \times 10^{-3} \div 2 \times 10^{-3}$ for $170.1 \leq m_t(\text{GeV}) \leq 181.1$ and $70 \leq m_H(\text{GeV}) \leq 1000$.

It is already clear from Figs. 1,2 that, for any pair (m_t, m_H) , there is a value of X which gives a fit to the experimental data better than the one of the standard model. This is emphasized in Fig. 3 where, for three values of the top mass $m_t = 170.1, 175.6, 181.1 \text{ GeV}$, we plot, as a function of the Higgs mass, the χ^2 for the standard model, and the χ^2 for the decoupling model, where for each pair (m_t, m_H) the value of X has been fixed at its best value.

This figure makes clear what we said before and shows also that one gets an almost perfect agreement with the data in a region of m_H of order $100 \div 300 \text{ GeV}$. This should be compared with the result for the standard model which gives a best value for m_H of $66_{-39}^{+74} \text{ GeV}$ [2]. Correspondingly the 95% CL bound on the Higgs mass goes from the limit of 215 GeV , within the standard model, to values above 1 TeV for the models presented here.

CONCLUSION

The standard model fit to the electroweak data based on the latest experiments has considerably narrowed the allowed interval for the standard Higgs particle mass. From the present situation one might be afraid that the future increased experimental accuracy could evidence a conflict between the lower bound on the Higgs mass coming from the direct search of the particle and the upper bound from the precision experiments. For this reason we have discussed here the fit to the ϵ parameters in a decoupling model (in two versions, a linear and a non linear one) showing that within such a scenario such a possible conflict would be avoided. At the same time, an excellent fit is obtained to the present determinations of ϵ parameters.

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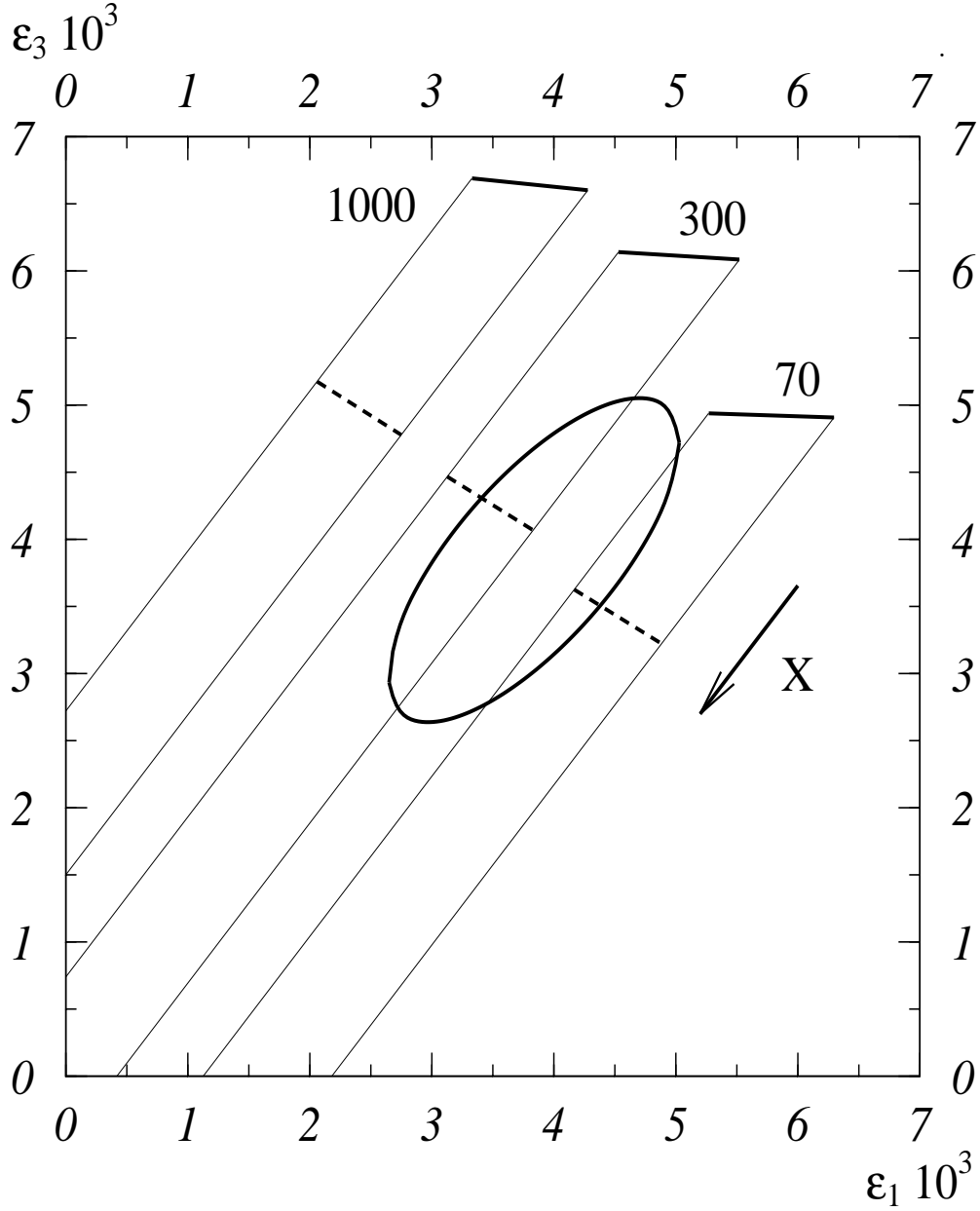


Fig. 1 - Decoupling model predictions in the plane (ϵ_1, ϵ_3) . The ellipse corresponds to the $1 - \sigma$ (38% probability contour) experimental data. The thick continuous bars correspond to the standard model predictions for $m_H = 70, 300, 1000$ GeV, and, for each case, $170.1 \leq m_t(\text{GeV}) \leq 181.1$. For each choice of the Higgs mass, the oblique strips correspond to the predictions of the model discussed here as parameterized by X , see eq. (3). The dashed bars describe, for each choice of the Higgs mass, the best fits.

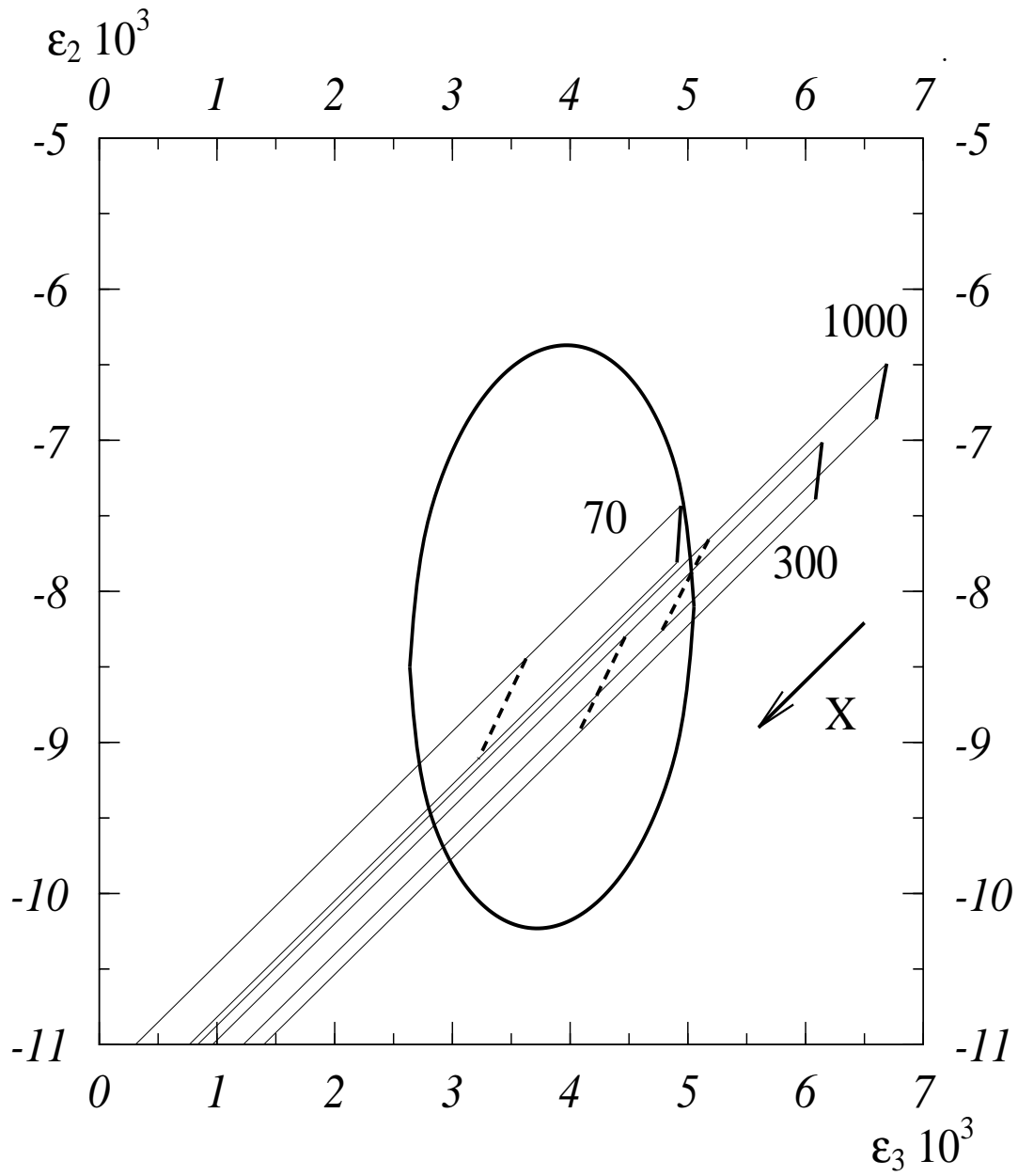


Fig. 2 - Decoupling model predictions in the plane (ϵ_3, ϵ_2) . The graphical representation is the same as for Fig. 1.

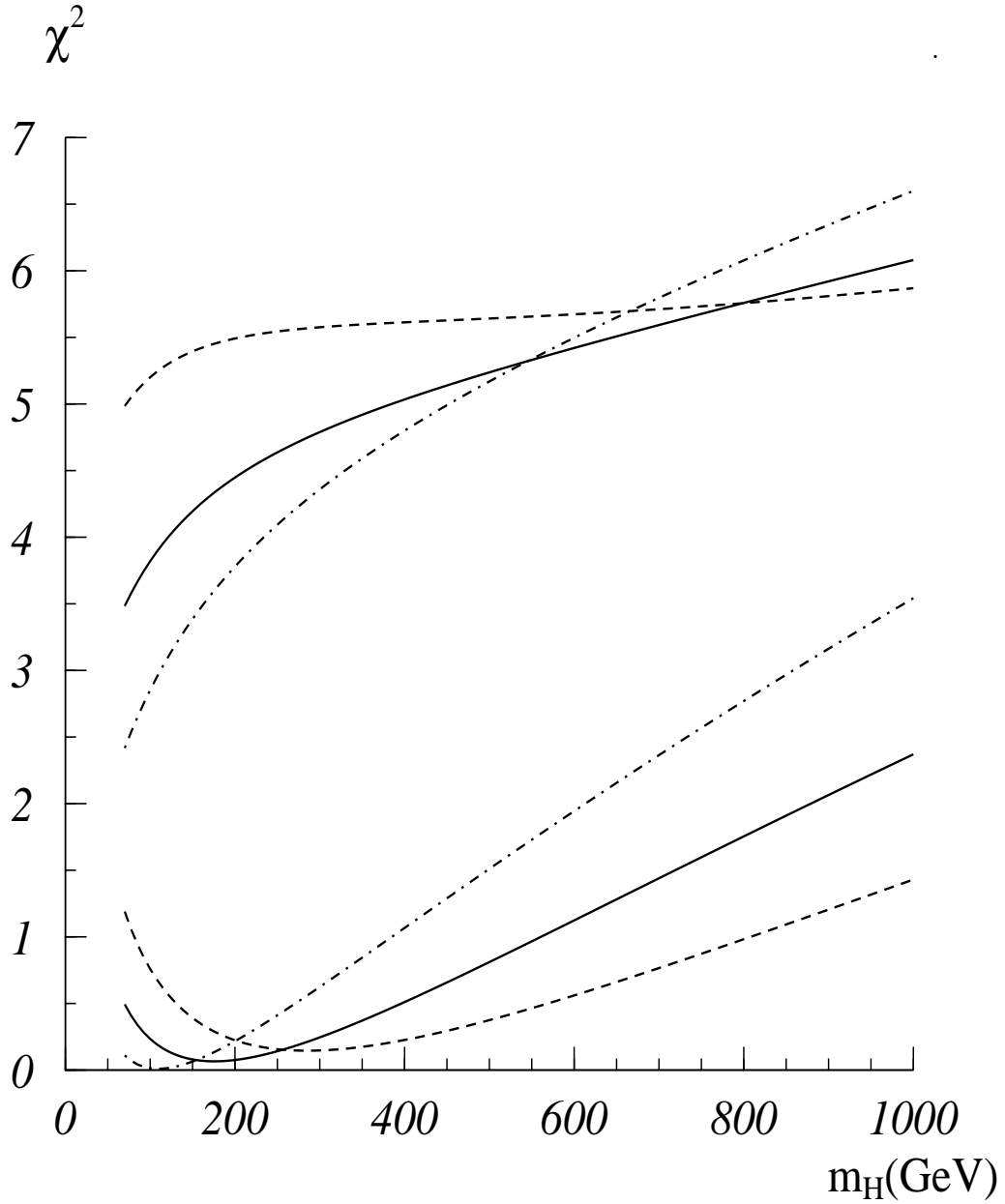


Fig. 3 - χ^2 vs. m_H . The curves in the upper part of the figure correspond to the standard model. Those in the lower part correspond to the decoupling model where at each point the value of the parameter X (see eq. (3)) is that of the best fit. The continuous lines are for $m_t = 175.6$ GeV, the dash-dotted lines are for $m_t = 170.1$ GeV, and the dashed ones are for $m_t = 181.1$ GeV.