Higgs Boson at the Fermilab Tevatron in Extended Supersymmetric Models

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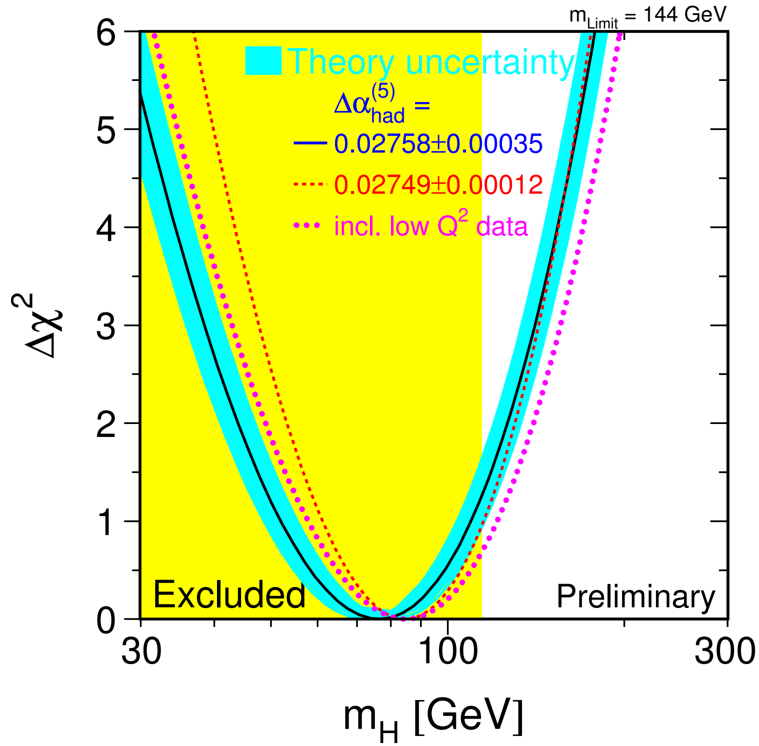
Motivation

The Higgs boson has successfully resisted discovery as yet.

Precision electroweak data, in combination with the direct top-quark mass measurement at the Tevatron, hint at the existence of a light scalar particle—



but LEP has put a lower bound on the Higgs mass within the standard model (SM),

$$M_h > 114.4 \text{ GeV} .$$

This bound has left some doubt as to whether the minimal supersymmetric standard model (MSSM) is viable.

Higgs mass in the MSSM

In the MSSM, $M_h \sim M_Z$ (at tree level: $M_h < M_Z\,|\cos\beta|$);
if the sparticle masses do not exceed 1 TeV, there is an upper bound, $M_h \lesssim 135$ GeV.

In addition, there is a relation between the Z mass, the supersymmetry breaking soft masses m_u and m_d, and μ,

$$\frac{1}{2}\,M_Z^2 = \frac{m_u^2\tan^2\beta - m_d^2}{1-\tan^2\beta} - |\mu|^2 \quad .$$

- μ is the only dimensionful MSSM parameter and completely unrelated to the electroweak and supersymmetry breaking scales;
  in fact, the most natural value would be the Planck scale! (‘μ-problem’)
- The MSSM has a fine-tuning problem unless the Higgs boson is somewhat lighter than the current bound. (‘little hierarchy problem’)

$\rightarrow$ Interest in extensions of the MSSM, where the μ-term arises after an additional singlet field, which does not interact with the MSSM matter and gauge fields, acquires a vev. [NMSSM, MNSSM, mNSSM, UMSSM, . . .]

Extended Supersymmetric Models

Replace $\mu\, H_u\, H_d$ with $h_S\, S\, H_u\, H_d$.

The vevs of the Higgs doublets and the singlet are generically of the same order.

The singlet field provides an additional scalar, a pseudoscalar, and an accompanying Higgsino. These mix with the neutral fields from the two doublets, yielding five neutral Higgs bosons: three scalars and two pseudoscalars.

In general, their masses are expected to be comparable; on the other hand, these extended models possess approximate U(1) symmetries, protecting the mass of one pseudoscalar, a.

A light pseudoscalar is natural, allowing the decay $h \to aa$ (where h is approximately SM-like) with a branching ratio of nearly unity.

[Gunion, Haber, Moroi 1996; Dobrescu, Landsberg, Matchev 2001; Ellwanger, Gunion, Hugonie 2001, . . . ; Dermisek, Gunion 2005, . . . Chang, Fox, Weiner 2006; Graham, Pierce, Wacker 2006; . . .]

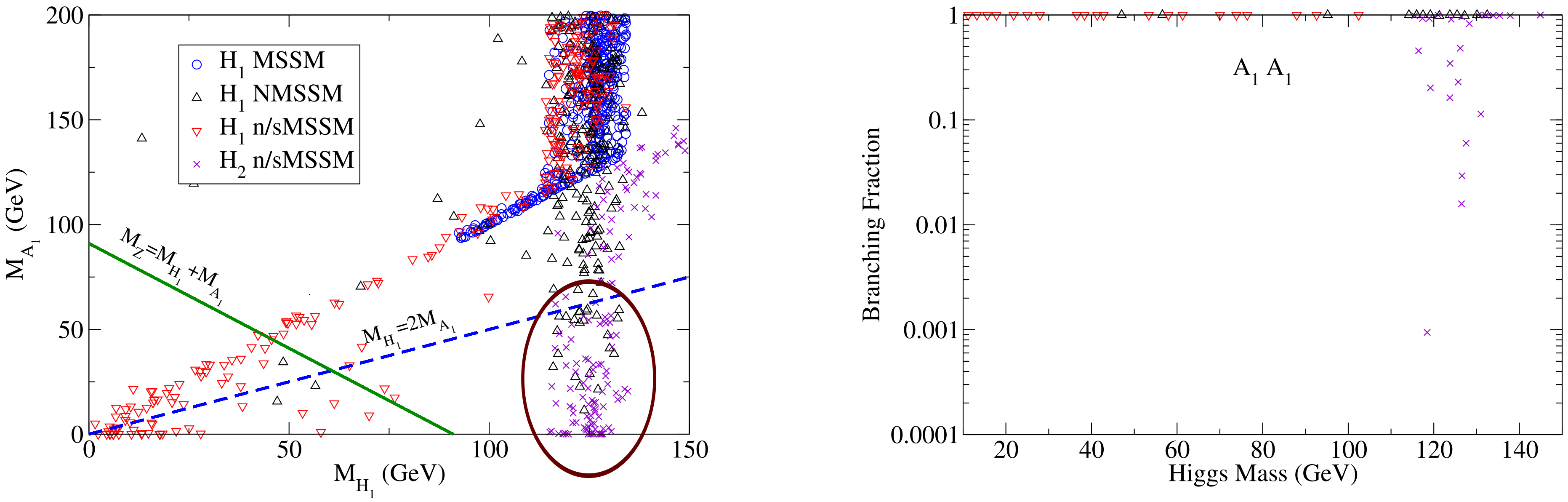
The pseudoscalars then decay to fermion pairs, resulting in a four-fermion final state, to which the LEP searches are less sensitive.

Hence, these models can evade the lower bound on the Higgs mass.

Detection of h at the Tevatron

If the mass of a is above the $b\bar{b}$ threshold, the dominant final state is $b\bar{b}b\bar{b}$.

Rather than to restrict ourselves to one particular model beyond the MSSM, consider the general case, where M_h varies between 110 and 150 GeV.

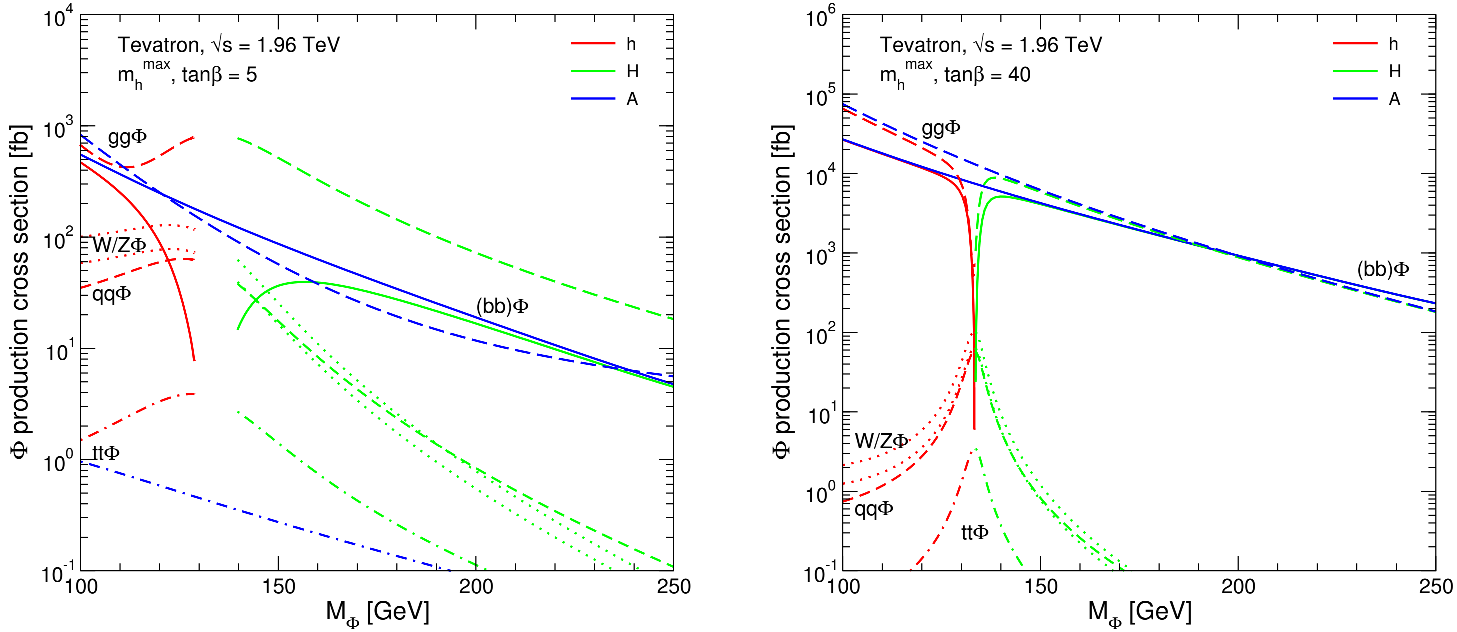


$A_1 \equiv a$: lightest CP odd state

[Barger, Langacker, Lee, Shaughnessy 2006]

Higgs production at the Tevatron

In this mass region, the SM Higgs production cross section at the Tevatron is less than 1 pb, via $gg \to h$. In the MSSM the cross section is much larger for large $\tan\beta$, with both $gg \to h$ and $b\bar{b} \to h$ contributing.



[Hahn, Heinemeyer, Maltoni, Weiglein, Willenbrock 2006]

In the MSSM, however, there do not exist regions of parameter space with both enhanced Higgs production and significant branching ratio for $h \to aa \to b\bar{b}b\bar{b}$.

Background

Use MadEvent to calculate the background [Maltoni and Stelzer 2003].
The dominant background is due to QCD multijet production, with varying combinations of true b tags and mistagged jets.

Cuts	
rapidity	$\lvert\eta\rvert < 2.0$
separation	$\Delta R > 0.4$
jet 1	$p_T > 20$ GeV
jets 2–4	$p_T > 15$ GeV
invariant mass of two jets	$m_{jj} > 10$ GeV
Tagging efficiencies	
b tag	50%
mistag of c	10%
mistag of light quark or gluon	1%

in analogy to CDF and D0 searches for neutral Higgs bosons produced in association with bottom quarks, followed by $h \to b\bar{b}$.

The different processes sum to an enormous background of 380 nb prior to b tagging.

$\longrightarrow$ Require at least three b tags!

Background drops dramatically to 63 pb .

	total	$n_c = 0$	$n_c = 1$	$n_c = 2$	$n_c = 3$	$n_c = 4$
total	63	54	4	5	0.2	0.1
$n_b = 0$	3	0.8	0.2	1	0.2	0.1
$n_b = 1$	1	0.5	0.05	0.5	0	
$n_b = 2$	40	33	4	3		
$n_b = 3$	10	10	0.1			
$n_b = 4$	9	9				

Consider windows in the (M_h, M_a)-plane with size 30×30 GeV for the invariant $b\bar{b}$ and $b\bar{b}b\bar{b}$ masses:

	$M_a = 20$ GeV	$M_a = 40$ GeV	$M_a = 60$ GeV
$M_h = 110$ GeV	15 pb	14 pb	12 pb
$M_h = 130$ GeV	15 pb	15 pb	13 pb
$M_h = 150$ GeV	11 pb	11 pb	11 pb

Signal

Derive the minimum signal cross section for a discovery of h with 2 fb^{-1} of integrated luminosity.
Assume that all signal events pass the mass reconstruction constraints; use an ideal branching ratio for $h \to aa \to b\bar{b}b\bar{b}$ of 100%.

	$M_a = 20$ GeV	$M_a = 40$ GeV	$M_a = 60$ GeV
$M_h = 110$ GeV	12 pb	11 pb	—
$M_h = 130$ GeV	7 pb	9 pb	3 pb
$M_h = 150$ GeV	4 pb	5 pb	3 pb

The minimum cross section required for discovery is an order of magnitude greater than the SM Higgs production cross section, confirming the belief that the *backgrounds overwhelm the signal in this case*.

$\rightarrow$ Do models with both enhanced Higgs production and a significant branching ratio for the above decay mode exist?

Even if the coupling $hb\bar{b} \propto m_b$ is enhanced (yielding enhanced cross sections for $gg \to h$ and $b\bar{b} \to h$), the coupling haa could be competitive.