Search For The Higgs Boson At The Tevatron

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Abstract. The Higgs boson remains one of the last unverified predictions of the Standard Model, and is of interest in various SUSY models. Searches have been underway at the Tevatron, with recent findings giving good boundaries. This article discusses the origin and theoretical reason the Higg's boson poses an important challenge to modern physics, finishing by summarizing results from the latest Tevatron Run II Standard Model and SUSY Higgs searches.

Keywords: higgs boson, standard model, Tevatron
PACS: 14.80.Bn

INTRODUCTION

We have strong evidence that the electromagnetic and weak nuclear forces can be described by a gauge theory as the so-called "electroweak" force. In particular, weak currents are often electrically charged and have a mathematical form equivalent to a non-Abelian symmetry based on a particular semisimple group. Thus, a gauge theory should describe electroweak interactions.

Recall that a gauge theory has particular implications based upon particular symmetries.

For example, a quantum field theory that holds the Lagrangian invariant under coordinate transformations exhibits general covariance which implies general relativity. In general, we expect that a gauge field should be quantized by gauge bosons. But there's a problem.

We know from various experiments (to an accuracy of better than one part in 10^{11} that the electromagnetic force interaction distance is infinite.

But from Yukawa, if two particles interact by exchanging a virtual particle of mas m, the maximum propagation distance is then $\hbar/mc$. This follows because emission of a particle violates energy conservation by $\Delta E = mc^2$, which is allowed by the Heisenberg uncertainty principle provided that $\Delta t\ \Delta E < \hbar$. Thus, via simple algebraic substitution we see maximum propagation distance for a particle traveling at c is $c\ \Delta t = c\hbar/ mc^2$.

Experimentally, the weak force interaction range is finite, on the order of 10^{16} centimeters. This interaction distance in turn puts a mass estimate on the vector bosons $W^{\pm}/Z$ in the 80-90 GeV/c^2 range.

So, the question is, how do we end up with massless and massive gauge fields while preserving gauge invariance?

We need a quantum field theory (array of quanta at all spacetime lattice points):

- with a non-zero Vacuum Expectation Value (VEV)
- with zero spin (otherwise its angular momentum would break rotational invariance)
- with the VEV independent of space-time coordinate (otherwise it would break translation invariance)
- that couple to each other to form a vacuum condensate (requiring strong enough attraction to each other at low density, but strong enough repulsion at high density to prevent a runaway situation)
- Where the vacuum condensate in turn couples with particles to give them mass

This is called the Higgs field, Higgs condensate, and Higgs mechanism respectively.

Then the Higg's boson is:

- Scalar massive particle composing the Higg's field
- With a non-zero VEV
- Gauge invariant under the Standard Model SU(2)xU(1)
- Forming a Higgs condensate

The discovery of the Higg's boson is the last test for the Standard Model. If we find it, then everything works the way we think it does. If we don't, we've got a lot of things to think about and reconsider.

THEORETICAL MOTIVATION

Let us choose a complex scalar Lagrangian (density) given by:

$$\mathrm{L} = \partial_\mu.\varphi\partial^\mu\varphi^* - V(\varphi,\varphi^*)$$

$$V(\varphi,\varphi^*) = \mu^2\varphi\varphi^* + \frac{1}{4}\lambda(\varphi\varphi^*)^2$$

This is invariant under $\varphi \to e^{-i\alpha}\varphi$ and $\varphi^* \to e^{i\alpha}\varphi^*$.

Assume α is arbitrary real constant and $\lambda > 0$. Then for $\mu^2 < 0$, $|\varphi|^2 = -2\mu^2/\lambda$ so we have infinite number of degenerate minima in a circle (see Figure 1).

FIGURE 1. The Mexican Hat potential, demonstrating spontaneous symmetry breaking

Pick a value to break the symmetry, $<\varphi>=v/\sqrt{2}$ for $v=\sqrt{(-4\mu^2/\lambda)}$.

Now define a shifted complex field χ such that:

$$\varphi = <\varphi> + \frac{1}{\sqrt{2}}\chi = \frac{1}{\sqrt{2}}(v + \chi_1 + i\chi_2)$$

Both χ_1 and χ_2 have zero VEV. Then:

$$V = -\mu^2\chi_1^2 + \frac{\lambda}{16}(\chi_1^2 + \chi_2^2)(4v\chi_1 + \chi_1^2 + \chi_2^2) + \frac{\mu^2 v^2}{4}$$

And the Lagrangian becomes:

$$L = \frac{1}{2}[\partial_\mu.\chi_1\partial^\mu\chi_1 - (2\mu^2)\chi_1^2] + \frac{1}{2}\partial_\mu.\chi_2\partial^\mu\chi_2 - \frac{\lambda}{16}(\chi_1^2 + \chi_2^2)(4v\chi_1 + \chi_1^2 + \chi_2^2) - \frac{\mu^2 v^2}{4}$$

By inspection, we can see that the χ_1 term acquires a mass of $\sqrt{(-2\mu^2)}$ while the χ_2 remains massless. We have thus exhibited a model with spontaneous symmetry breaking that generates massive and massless complex fields. This is the famous Higgs mechanism.

THE SEARCH FOR THE HIGGS AT THE TEVATRON

The Tevatron is a $p\bar{p}$ collider with the following production mechanisms expected to be dominant for a low-mass Higgs given in Table 1.

TABLE (1). Summary of Analyses for low-mass (m_H=115GeV/c^2) Higgs searches as of 9/29/08.

Channel	**CDF** 95% C.L. Limits σ·BR/SM obs (exp)	**D0** 95% C.L. Limits σ·BR/SM obs (exp)
WH→lνbb (NN)	5.0 (5.8) 2.7fb^{-1}	9.3 (8.5) 1.7fb^{-1}
WH→lνbb (ME+BDT)	5.7 (5.6) 2.7fb^{-1}	-
WH→τνbb (NN)	-	35.4 (42.1) 0.9fb^{-1}
VH→qqbb (ME)	37.0 (36.6) 2.0fb^{-1}	-
ZH→llbb (NN)	11.6 (11.8) 2.4fb^{-1}	11.0 (12.3) 2.3fb^{-1}
ZH→llbb (ME) (m_H=120GeV)	14.2 (15.0) 2.0fb^{-1}	-
ZH→νν/WH→ (l) νbb (NN)	7.9 (6.3) 2.1fb^{-1}	7.5 (8.4) 2.1fb^{-1}
ttH→lνbbbbqq	-	63.9 (45.3) 2.1fb^{-1}
H→γγ	-	30.8 (23.2) 2.7fb^{-1}
H→ττ	30.5 (24.8) 2.2fb^{-1}	-
Combined	4.2 (3.6)	5.3 (4.6)

There are two types of Higgs searches underway at the Tevatron: Standard Model searches and beyond Standard Model searches, typically the Minimally Supersymmetric Standard Model (which is close to being disproven, leading to the NMSSM or Next to MSSM). Due to recent results, both SM and MSSM Higg's are now expected to be low mass.

Figure 2 gives the Higgs production cross section and the Higgs branching ratios for the Standard Model Higgs searches..

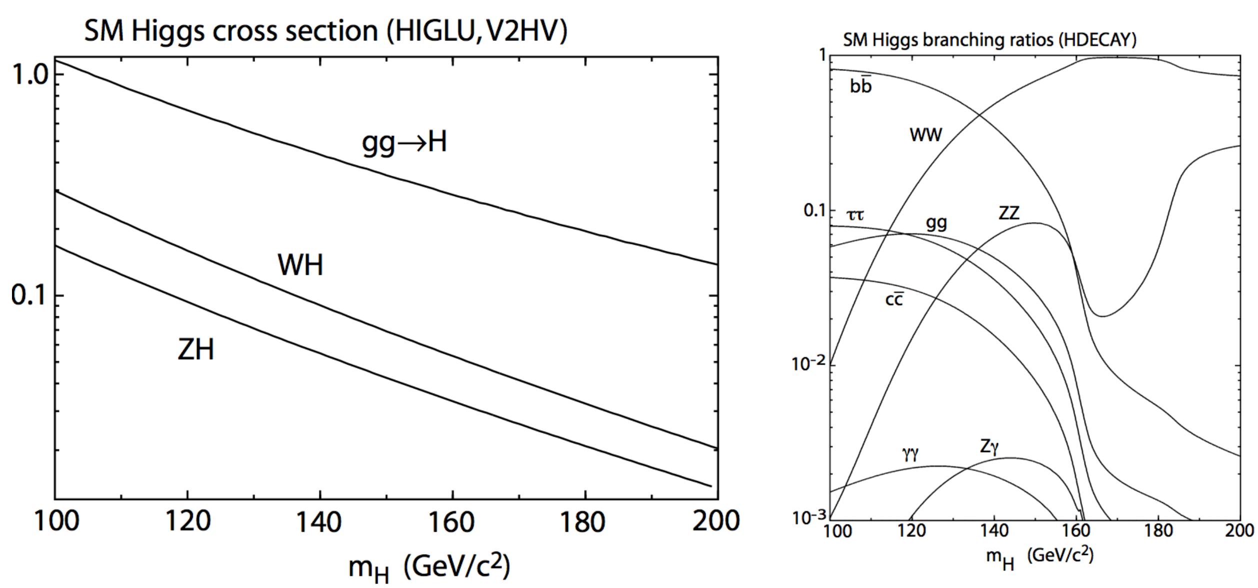

FIGURE 2. Standard Model Higgs production and decay at the Tevatron for m_H < 130 GeV/c^2

Figure 3 gives the Higgs branching ratios for the MSSM.

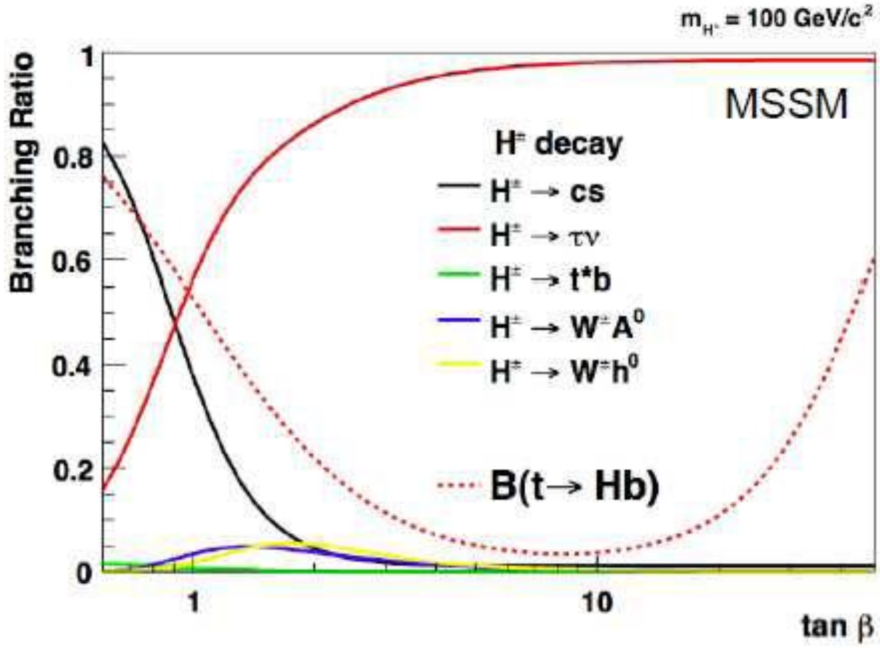

FIGURE 3. MSSM Higgs branching ratios at the Tevatron for m_H = 100 GeV/ c^2

RESULTS

Figure 4 gives preliminary MSSM search results.

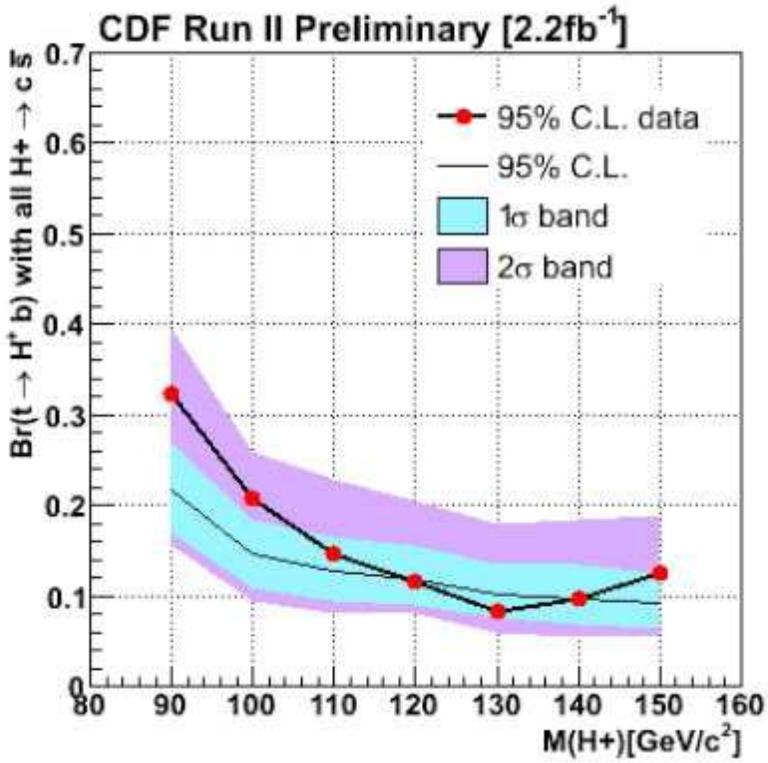

FIGURE 4. MSSM Higgs search results as of 9/18/2008

Figure 5 gives preliminary Standard Model Higgs search results from Tevatron Run II.

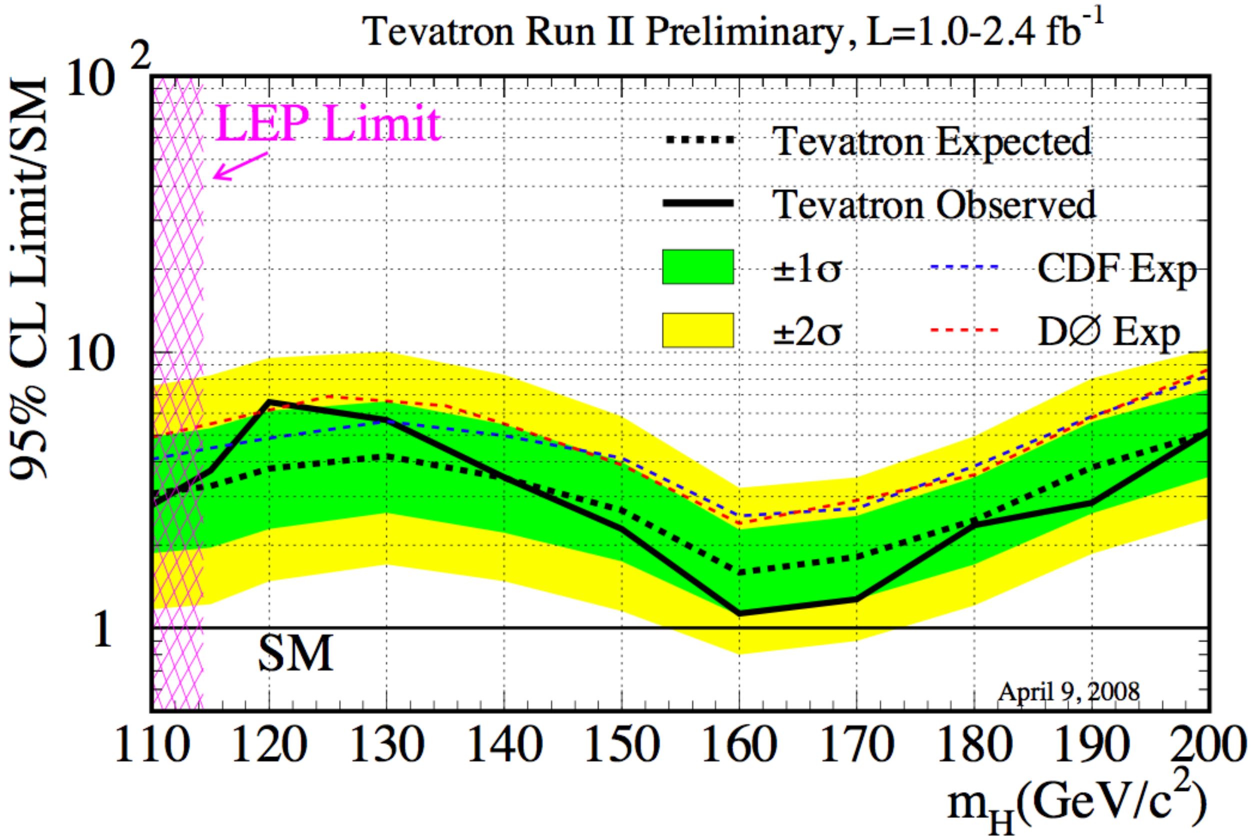

FIGURE 5. Tevatron Run II Preliminary, L=1.0-2.4 fb^{-1} as of 4/9/2008

A very important result is that the Tevatron has now excluded high mass Higgs (m_H=170 GeV/c^2)!

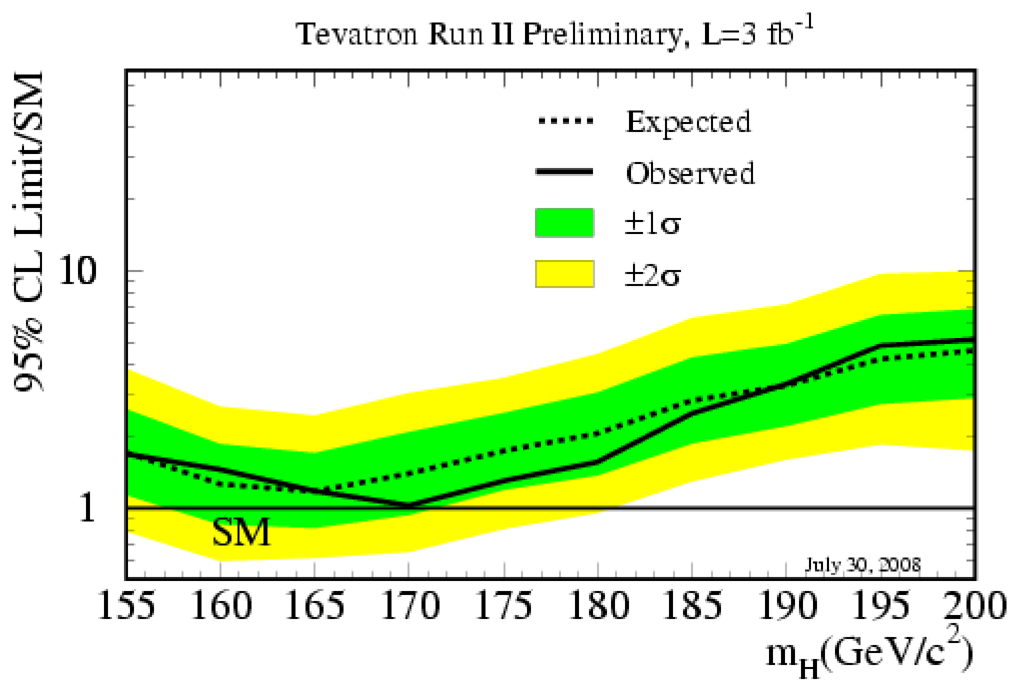

FIGURE 6. Exclusion of M_H=170 GeV/c^2 at 95% CL

ACKNOWLEDGMENTS

I wish to acknowledge excellent references on the status of the Higg's search relayed to me by Prof. Robin Erbacher.

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