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Status of CDF II Higgs Searches

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Abstract. The status of recent CDF Higgs searches is reviewed. Recently revised sensitivity estimates show that the chances for a Higgs discovery remain promising for run II of the Tevatron.

INTRODUCTION

The question of the origin of EW symmetry breaking is arguably the most important question in particle physics. Upon arriving at Fermilab and viewing the "broken symmetry" sculpture, one is prompted to wonder if the answer to this question can be discovered at Fermilab. Indeed, the search for the Higgs is one of the major goals of the Tevatron Run II program. In this talk I present the status of this search with CDF II.

The limits from CDF in run I searches for Standard Model (SM) Higgs, expressed as limits on the combined WH+ZH cross section, are shown in Figure 1. Note that the ratio of WH/ZH is $\approx 2/3$. With the recently revised D0 top-mass, the best fit SM Higgs mass is now 117 GeV– just slightly above the LEP II limit.[1] The associated production cross section of $\sim$ 0.2pb is about a factor of 5 below the direct production cross section via gluon fusion.

The various on-going CDF Higgs searches are listed in Table 1. These searches include the most promising modes for discovery of a light-Higgs via associated production, as well as the H to W-pair mode for masses approaching and above the W-pair threshold. Other searches include signatures for H and H^+ Higgs in models with two Higgs SU(2) doublets such as the MSSM, as well as the more exotic doubly-charged Higgs of models with Higgs triplets, or exotic decays such as lepton-flavor violating (LFV) decays.

SEARCH FOR DOUBLY-CHARGED HIGGS

I will first discuss the recently completed doubly-charged Higgs search. Such a particle is predicted in models with Higgs triplets, such as the Left-Right SUSY model, where it could be as light as 100 GeV. A doubly-charged Higgs would decay to lepton pairs

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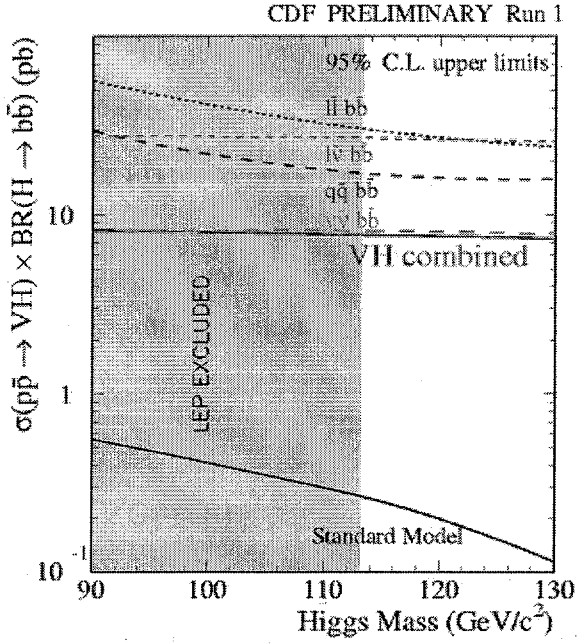

FIGURE 1. CDF run 1 limits on the SM Higgs

TABLE 1. On-going CDF Higgs searches. The checked searches are discussed in this talk. Many models beyond the SM predict enhanced or novel decay modes, or additional Higgs scalars.

$WH \to \ell\nu bb$	√
$ZH \to \ell\ell bb$	
$ZH \to \nu\nu bb$	
$H \to WW^* \to \ell\nu\ell'\nu'$	√
Hbb→ bbbb (large $\tan\beta$)	
$H \to \tau\tau$ (large $\tan\beta$)	
$H^+ \to \tau\nu$	
$t \to H^+ b$ (direct, $B(t \to \ell\nu b)$)	
$H^{\pm\pm}$ (Higgs triplet)	√
$H \to \tau\mu$ (LFV)	

with couplings that are free parameters of the theory. These couplings are constrained by direct searches at Lep II ($h_{ee} < 0.07$) as well as by g-2 ($h_{\mu\mu} < 0.25$) and rare muon decay searches ($h_{e\mu}h_{ee} < 3 \times 10^{-7}\ \mu \not\to 3e$, $h_{e\mu}h_{\mu\mu} < 2 \times 10^{-6}\ \mu \not\to e\gamma$).[2] These limits are weak enough to allow prompt decays. At the Tevatron the $H^{\pm\pm}$ are pair produced, and we search for same-sign dileptons that reconstruct to the $H^{\pm\pm}$ mass.

The same-sign di-electron invariant mass is shown in Figure 2. Note the large Drell-Yan background (BG) coming from electron Bremstrahlung followed by photon conver-

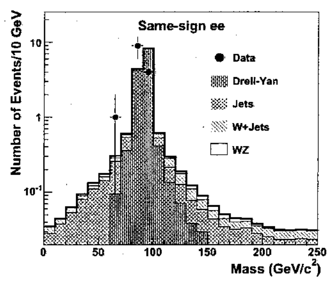

FIGURE 2. Same-sign di-electron invariant mass in the $H^{\pm\pm}$ search.

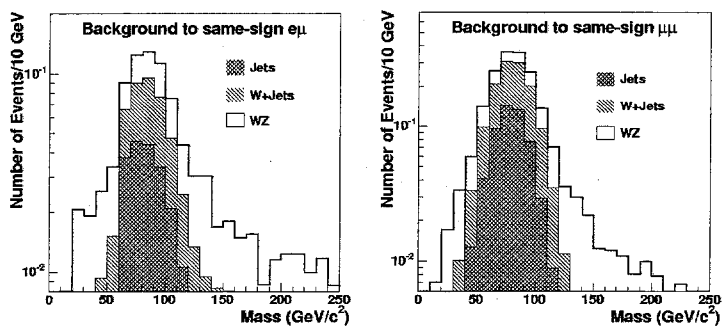

FIGURE 3. Same-sign di-muon (left) and electron-muon (right) invariant mass in the $H^{\pm\pm}$ search.

sion. We normalize this BG in the Z-peak region. BGs from QCD and W+jets are included with rates derived from data, and the WZ BG is added normalized to the NNLO cross section. The sum of these BGs predict 1.1 ± 0.3 events below the Z-peak, consistent with one observed event.

The BGs for $\mu^\pm\mu^\pm$ and $\mu^\pm e^\pm$, lacking the conversions, are considerably smaller (see Figure 3). We expect 0.3 ± 0.1 $M < 80$ $\mu^\pm\mu^\pm$ and expect 0.9 ± 0.4 $\mu^\pm e^\pm$ events with $M < 80$. No events are observed in either of these channels.

The signal acceptances for di-muons are about 33% at 90 GeV $H^{\pm\pm}$ mass, slowly rising to 38% at 150 GeV. Similarly for the di-electron acceptance, except it is cut off at 110 GeV by the conversion BG. The $e\mu$ acceptance is about half the di-muon; the di-muon acceptance is high because we require only a min-ionizing track for the second (non-triggering) muon in the event.

The cross section times branching ratio limits are shown in Figure 4, corresponding to 100% branching ratio in each channel separately. Corresponding mass limits are given in Table 2. We are able to exclude masses at the lower end of the interesting region for the LR SUSY model. Figure 4 also shows our results compared to other current direct search limits. Here again all limits are for exclusive decays. For very small couplings, the $H^{\pm\pm}$ would be long-lived. A search for such a heavy, stable, doubly charged massive particle is in progress.

TABLE 2. $H^{\pm\pm}$ Limits for 100% branching fraction

133 GeV	$ee\ H_L^{\pm\pm}$
136 GeV	$\mu\mu\ H_L^{\pm\pm}$
115 GeV	$e\mu\ H_L^{\pm\pm}$
113 GeV	$\mu\mu\ H_R^{\pm\pm}$

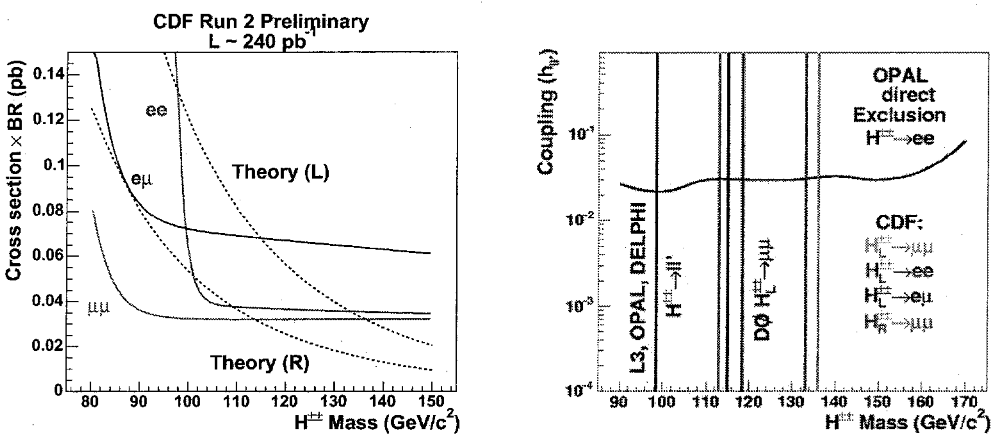

FIGURE 4. CDF limits on limits on σB as a function of $H^{\pm\pm}$ mass (left). Summary of $H^{\pm\pm}$ mass limits in direct searches (right). All limits are for exclusive decays.

SEARCH FOR SM HIGGS DECAYING TO WW

Turning now to the SM searches, the primary question here is one of our expected sensativity for high luminosity. The best way to answer this question is by doing searches and setting limits. I'll first discuss the W-pair channel which dominates for $M_H \gtrsim 135$ GeV.

We search for 2 and only 2 oppositely charged, high-pt, isolated leptons (e or mu). To further supress the di-Boson BG, we require no reconstructed jets above 8 GeV. We require significant missing transverse energy ($\not{E}_T > 25$ GeV) and in a direction not along a lepton, in order to ensure that the $\not{E}_T$ is well measured. Events consistent with the Z mass are removed.

The BG s are estimated from Monte Carlo using theoretical cross sections. The most significant BG is from SM produced W-pairs (13 pb). [2] Other backgrounds include WZ (4pb), ZZ (1.4pb), $t\bar{t}$ (7pb) and Drell-Yan (1.4 pb, LO$\times$ k-factor). Additionally, the BG from W+jets with a fake lepton is estimated from the inclusive lepton data.

To further reduce the SM W-pair BG, we exploit the kinematics of the decay of a spin-zero resonance to W-pairs, which tends to produce the leptons close together in angle. We therefore make a M_H dependent cut on the lepton pair mass (Figure 5).

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[2] The theoretical cross section is in good agreement with our recent measurement.

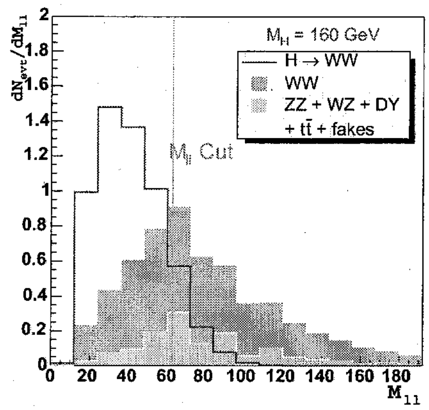

FIGURE 5. The dilepton pair mass for the signal and BG. The cut for $M_H = 160$ GeV is shown.

TABLE 3. Heavy Higgs search results. The differences in the columns correspond to different di-lepton mass cuts. Cross section limits based on counting (σ_N) are given. The SM expectation in this mass range is about 0.2 events.

M_H	150	160	170
WW	3.8 ± 0.5	4.5 ± 0.5	5.4 ± 0.6
other	0.9 ± 0.2	1.3 ± 0.4	1.9 ± 0.5
data	2	3	7
σ_N 95%	< 9.8 pb	< 6.2 pb	< 8.2 pb

The search results are summarized in Table 3. The number of expected events and observed events are in good agreement, and we derive cross section limits based on counting (σ_N).

As shown in 6, we can further exploit the kinematics of the H decay to W-pairs. First, we do a partial mass reconstruction. The signal would appear at larger mass than the SM BG. Second, we use the difference in azimuth of the leptons which tend to be small for the H decay. A fit to this distribution gives a significantly improved sensitivity over counting alone: $\sigma_{fit} = 5.6$ pb at 95% CL for $160 < M_H < 170$ GeV.

SEARCH FOR LIGHT SM HIGGS

Let us turn now to the associated production mode WH. The signature is one central, isolated, high-pt lepton, missing transverse energy, and 2 jets. An optimization of the jet Et selection for signal over the square-root of BG shows that the second jet E_T should be at least as low as 15 Gev (see Figure 7, left). Also shown (Figure 7, right) is the dijet

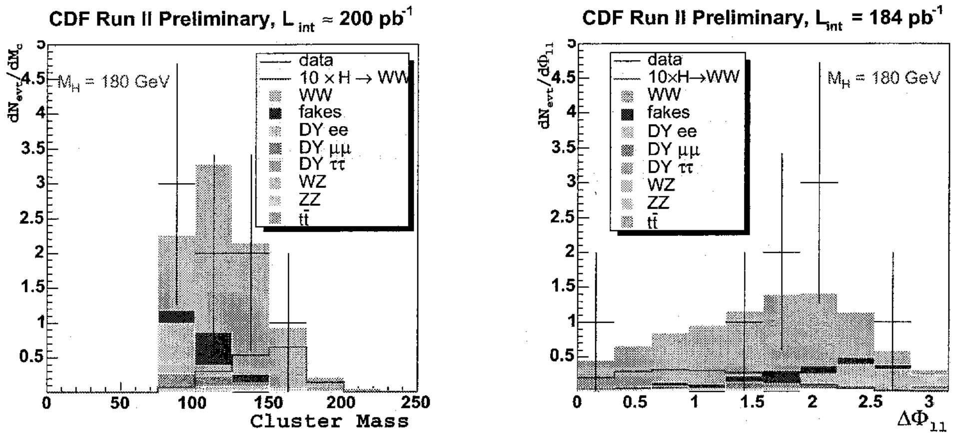

FIGURE 6. Exploiting the kinematics of the $H \rightarrow WW^*$ decay: partial mass reconstruction (left), and difference in azimuthal angle of the leptons (right). An improved cross section limit (σ_{fit}) is obtained based on a fit to the difference in azimuth.

mass distribution. The BGis overwhelming without requiring a heavy flavor-tagged jet.

We look for heavy flavor jets by reconstructing a displaced secondary vertex. Remaining BGs due to mis-tags and QCD are derived from the data. The mis-tag rate is normalized to the rate in the data of secondary verticies that reconstruct on the wrong side of the primary vertex relative to the jet direction, multiplied by a MC derived correction factor. The mis-tag rate is estimated to be a few percent per jet. Additional BGs from $t\bar{t}$, di-Bosons and $Z \rightarrow \tau\tau$ are included from MC.

The heavy flavor tagging efficiency is dervied from a sample of inclusive electrons. This sample is further enriched in heavy flavor by tagging the jet opposite to the electron-associated jet, and then measuring the tagging rate in the electron-jet. Up to an over-all scale factor, there is good agreement between data and MC for the efficiency versus jet E_T. The scale factor is measured to be 82% to better than 10%.

The distribution of jet multiplicity after requiring at least one b-tagged jet is shown in Figure 8. The agreement between the data and the total BG is excellent. Note that the counting differs from that in the CDF top cross section analysis by the removal of events with additional low-E_T jets or leptons.

The higgs signal is searched for in the two jet events by looking for a peak in the dijet invariant mass. Figure 9 shows that the di-jet invariant mass distribution is in good agreement with the SM BG. The shape of the expected signal given by the di-jet mass resolution is shown (scaled by a factor of 100).

Our current limit on σB, shown in Figure 10, is consistent with our expectation for 0.16 fb^{-1}. The total acceptance times efficiency in this search (central leptons only) is $(1.7 \sim 1.9) \pm 0.4\%$ over this M_H range. Figure (right) summarizes our current SM Higgs sensitivity both WW and WH channels. After accounting for the difference in luminosity, we see a significant improvement in sensitivity compared to run I. (Note that $\sigma_{VH} = 1.6\sigma_{WH}$ in comparing to Figure 1.) This is in part due to the increased acceptance

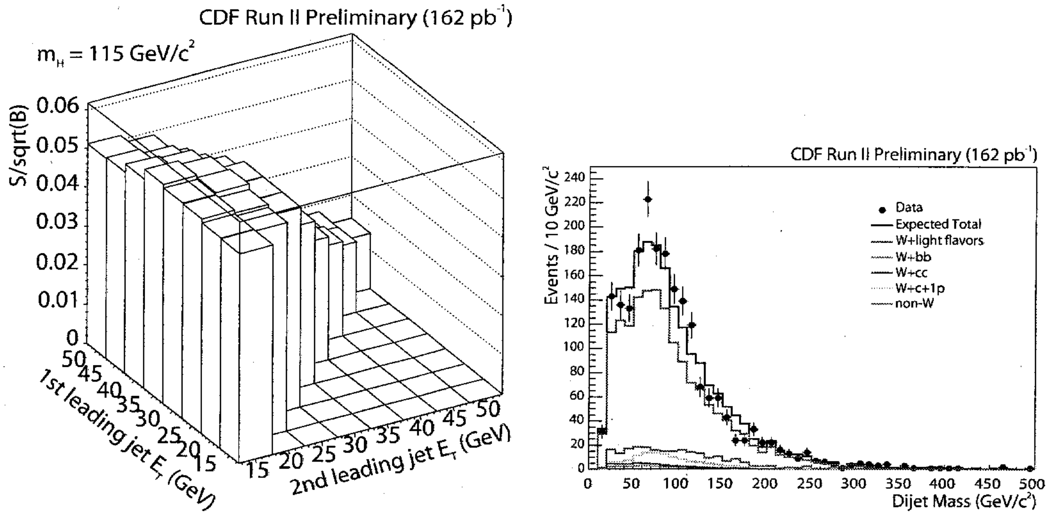

FIGURE 7. Jet cut optimization (left). The di-jet mass in the pre-tag sample compared to BG(right).

of the upgraded silicon vertex detector.

PROSPECTS

I'll conclude this talk with some comments on our ultimate senstivity. The original Higgs sensitivity study has been updated to include realistic simulation and the revised Tevatron environment. The beam crossing time of 132 $\rightarrow$ 396 ns increases the mean number of minimum bias over-lapping events from 5 to about 8. This degrades our tagging efficiency by 10-15%. On the other hand, we can improve our tagging efficiency by using a somewhat complementary impact parameter-based tag in addition to the secondary vertex reconstruction technique (Figure 11). We also expect 30% more acceptance using the full power of our lepton detection. Furthermore, studies show we can significantly improve the di-jet mass resolution (See Figure 12). Most importantly, we can correct for calorimeter non-linearity by using track information. Of course, this works best for central jets where the improvement is almost 1/2. We can also gain from correcting from leptons identified inside jets and from using global event information such as missing transverse energy. Ultimately we will be able to measure our resolution in the data (Figure 12). Finally, much work has been done in reconstructing hadronic taus. (A $H \rightarrow \tau\tau$ result will be released shortly.)

Our updated sensitivity is summarized in Figure 13. We look forward to the continued improved performance of the Tevatron!

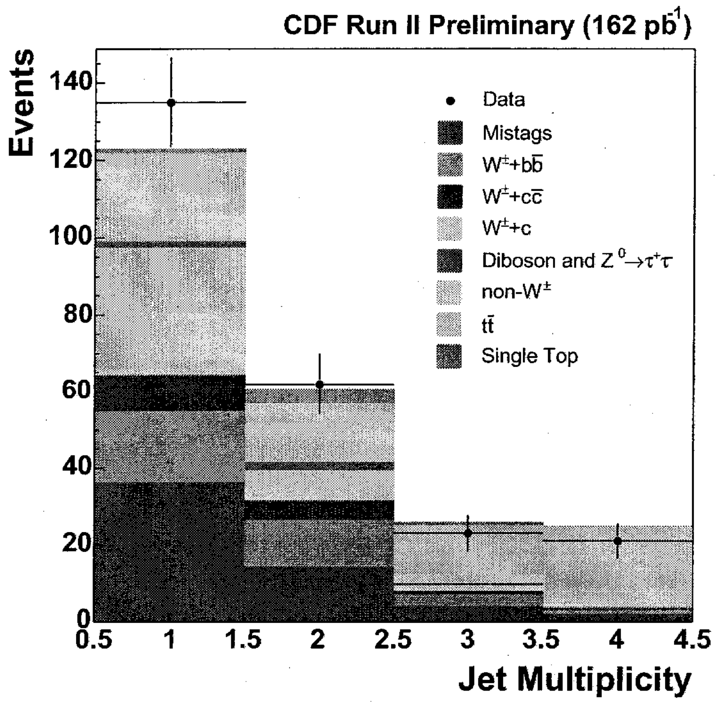

FIGURE 8. Jet multiplicity in W+jets events with at least one b-tagged jet. The counting here differs from the CDF top analysis by the removal of events with extra low-E_T jets or leptons.

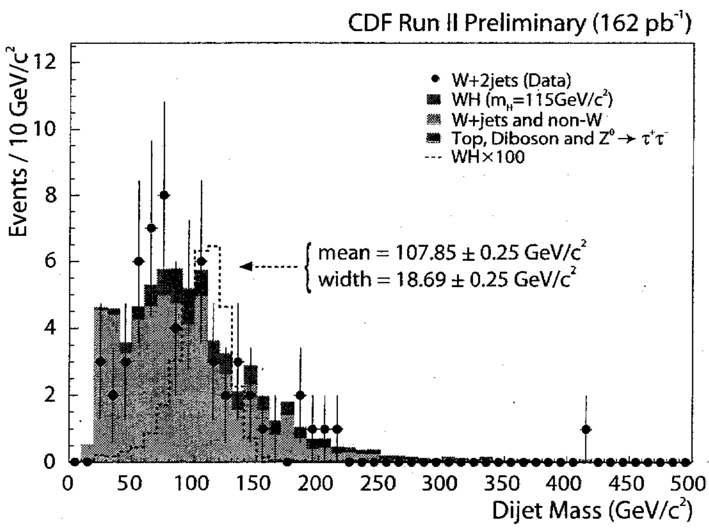

FIGURE 9. Di-jet invariant mass of W+2 jet events. The dotted line shows the shape of our Higgs di-jet resolution used in setting the limit (SM cross section scaled by 100).

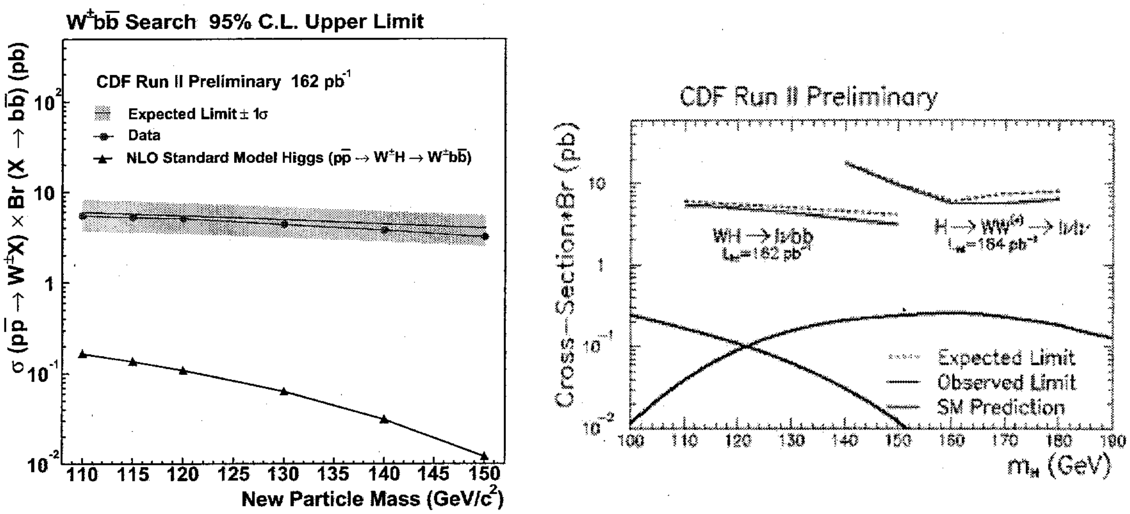

FIGURE 10. Current sensitivity in WH channel (left). Summary of WH and WW limits (right).

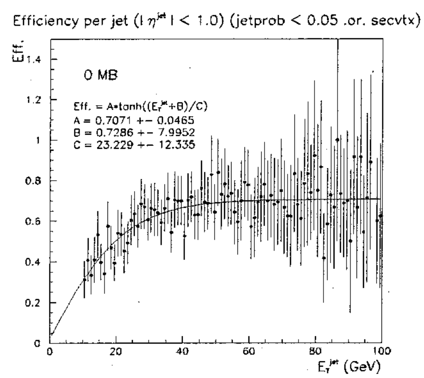

FIGURE 11. Improvements to by combining secondary vertex and impact parameter tagging. Note that this calculation with 0 MB should be multiplied by a factor of 0.8 to account for the multiple interactions.

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2. R.N. Mohapatra, Phys. Rev. D46, 2990 (1992).

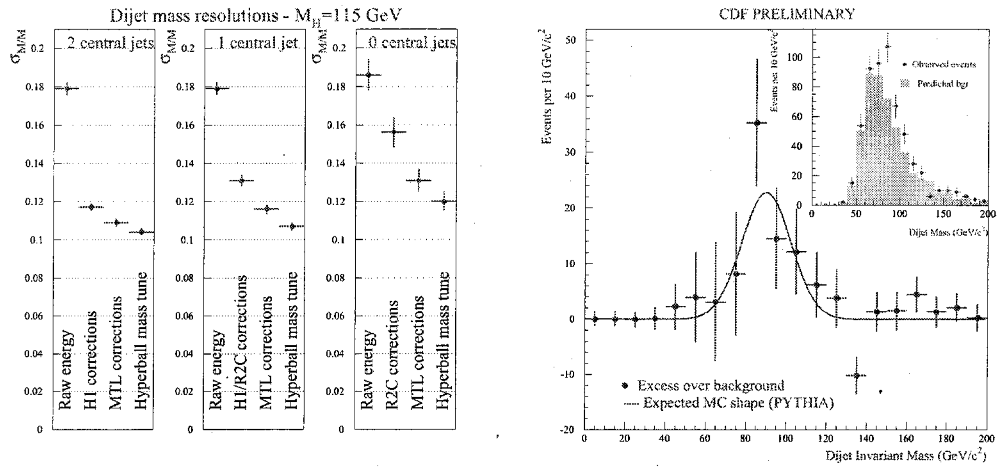

FIGURE 12. Expected improvemants in mass resolution δM_{jj} versus # central jets (left): (1) tracking, (2) soft leptons, (3) global event variables (e.g. $\not{E}_T$); Run 1 reconstructed $Z \rightarrow bb$ mass (right). Observation of the Z above QCD BG in b-enriched di-jets from an inclusive muon trigger, run I data.

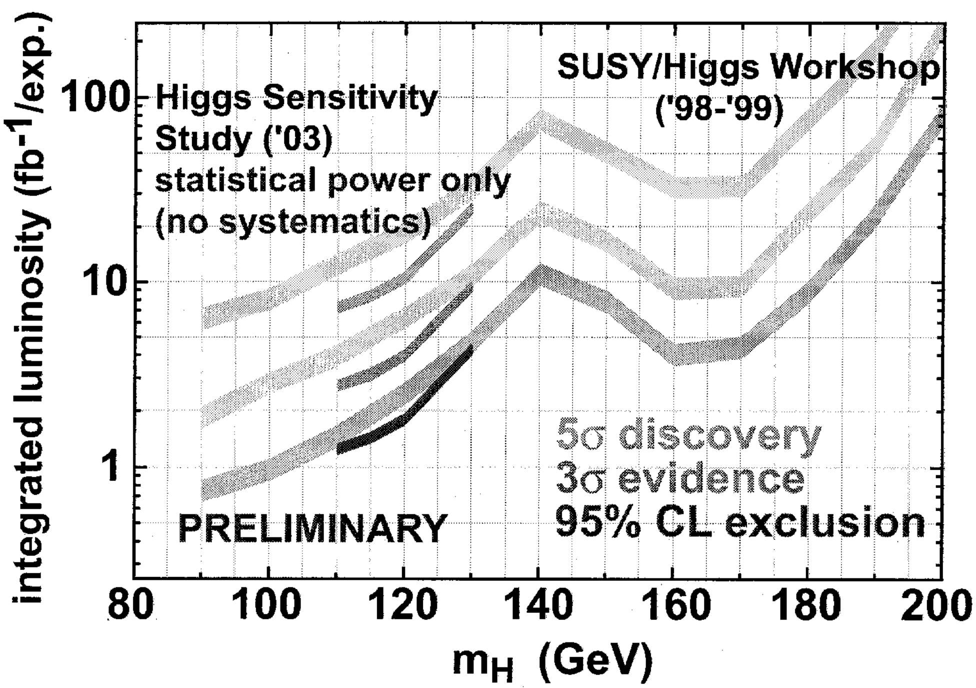

FIGURE 13. Updated Higgs sensitivity