CDF/ANAL/EXOTIC/CDFR/9279
April 1, 2008
Version 1.0

Update Combined Upper Limit on Standard Model Higgs Boson Production at CDF for Winter 08

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Abstract

This note describes an updated combination of several searches for Standard Model Higgs boson production at CDF using a data sample of 1 to 2.4 fb^{-1} of integrated luminosity. The channels considered are $WH \to l\nu b\bar{b}$, $VH \to \nu\bar{\nu}b\bar{b}$, $ZH \to l^+l^-b\bar{b}$, $VH(VBF, ggH) \to \tau^+\tau^- + 2jet$, and $gg \to H \to W^+W^-$. We have calculated combined upper limits on the ratio of Higgs boson cross section times the branching ratio to the Standard Model prediction (R_{95}) for Higgs boson masses between 110 and 200 GeV/c^2. The results are in a good agreement with the expectations obtained from pseudo-experiments. As a cross check, we have recomputed upper limits for each individual channel using the same technique and are able to reproduce the blessed results over all the channels. The 95% CL upper limits observed (expected) are a factor of 5.0(4.5) and 1.58(2.55) away from the Standard Model cross section for Higgs boson mass 115 and 160 GeV/c^2, which are significantly improved by 40% (20%) for low (High) Higgs mass over the luminosity gain since last summer (LP07).

1 Introduction

CDF has updated several searches for the Standard Model Higgs boson production using a data sample up to 2.4 fb^{-1} of integrated luminosity [1] [2] [3] [4] [5] [6] [7]. Clearly it is necessary to combine the results of all the channels to maximize the search sensitivity. The most sensitive channels are $WH \to l\nu b\bar{b}$, $VH \to \nu\bar{\nu}b\bar{b}$, and $ZH \to l^+l^-b\bar{b}$ in the low mass range, and $g\bar{g} \to H \to W^+W^- \to l^+l^-\nu\bar{\nu}$ in the high mass range. The $VH \to \nu\bar{\nu}b\bar{b}$ has been reanalyzed using neural network to gain sensitivity. The $H \to W^+W^-$ analysis has been improved using more data and a combined Matrix Element method and neural network approach to separate signal from the background events. We also add for the first time searches for Higgs bosons decaying to $\tau^+\tau^-$ in VH, VBF, and $g\bar{g} \to H + 2jet$ processes.

For the combination, we follow the same procedure that was used in the previous Higgs combination analysis [10], which is a Bayesian framework that would allow us to handle the systematic properly on the large number of background and efficiency parameters involved. This note is organized as follows. In section 2, we will briefly describe the combination results including the method and systematic correlations. In section 3, we will discuss the expected limits. Finally, we will conclude in section 4.

2 Combination Method

In order to combine channels with different decay modes, we are assuming that the relative rates of SM Higgs boson production between WH, ZH and $gg \to H \to W^+W^-$ are the same as SM expectations even though they can all scale up or down together. So, we can combine the limits on the ratio of Higgs boson production cross section times the branching ratio to the SM value. The statistical method employed here is a Bayesian framework, that is the same technique used in the Run1 Higgs combination [11]. For a given Higgs boson mass, the combined likelihood is a product of likelihood in the individual channels, each of which is a product over histogram bins of Poisson densities

$$\mathcal{L}(R, \vec{s}, \vec{b}|\vec{n}) = \prod_{i=1}^{N_C} \prod_{j=1}^{Nbins} \mu_{ij}^{n_{ij}} e^{-\mu_{ij}} / n_{ij}!,$$

where the prior densities for all the parameters in the likelihood are background normalization ($\vec{b}$), expected Standard Model signal ($\vec{s} = \sigma_{SM} \times B \times L \times \vec{\epsilon}$), luminosity (L), acceptance $\vec{\epsilon}$, and the ratio $R = \sigma \times B/(\sigma_{SM} \times B_{SM})$. The first product is over the number of channels (N_C), the second product is over histogram bins with observed data events. The parameters that contribute to the expected bin contents are $\mu_{ij} = R \times s_{ij} + b_{ij}$ for the channel i and the histogram bin j.

The Standard Model Higgs boson production cross sections at the Tevatron and the decay branching ratios are obtained from the Tev4LHC Higgs working group [12] and HDECAY [13], which are summarized in Table 1 as function of Higgs boson masses. The residual theoretical uncertainties for WH and ZH production cross section are rather small, less than 5%, but there is about 10% for gluon fusion $gg \to H$ and vector boson fusion (VBF) processes.

Systematic uncertainties in the various analyzes come from Monte Carlo modeling of the geometrical and kinematic acceptance, btag efficiency scale factor, lepton identification, the effect due to the jet energy scale, background uncertainties, and the uncertainty on the luminosity. We divide these systematics into several groups.

- Signal acceptance: luminosity, btag efficiency scale factor, lepton identification,

Mass (GeV/c^2)	σ_{WH} (fb)	σ_{ZH} (fb)	σ_{WW} (fb)	$B(H \to b\bar{b})$ (%)	$B(H \to W^+W^-)$ (%)
110	207.70	123.33	1281	77.02	4.41
115	178.08	106.70	1099	73.22	7.97
120	152.89	92.70	1006	67.89	13.20
130	114.51	70.38	801	52.71	28.69
140	86.00	54.20	646	34.36	48.33
150	66.14	41.98	525	17.57	68.17
160	51.03	32.89	431	4.00	90.11
170	38.89	26.12	357	0.846	96.53
180	31.12	20.64	297	0.541	93.45
190	24.27	16.64	249	0.342	77.61
200	19.34	13.46	211	0.260	73.47

Table 1: The (N)NLO production cross sections and the decay branching ratios as function of Higgs boson masses.

the jet energy scale, MC modeling (ISR/FSR+PDF), and the rest of the uncertainties.

- Background normalization: heavy flavor fraction, mistags, top contributions, non-W, diboson and the rest of the backgrounds.
- Background shape uncertainties are estimated using Gaussian sampling of two different input templates that results in changes of expected limit in $\pm\sigma$.
- For $H \to WW$ ME analysis, the signal and background systematic break into various sources of systematic, such as $\not\!\!E_T$, conversion, NNLO, cross section, PDF, lepton identification, and triggers, and are treated fully correlated with the rest of channels.

The breakdown of systematic for each channel are summarized in Table 2 where a positive value indicates 100% correlated systematic among the channels and a negative value indicates the systematic uncorrelated. The priors used are truncated Gaussian densities constraining a given parameter to its expected value with its uncertainty and positive. The S indicates where additional shape systematic uncertainty is evaluated.
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Since there is nothing known about the Higgs boson production cross section, we assign a flat prior to the total number of Higgs boson events $R \times s_{tot}$, instead of the cross section. The posterior density function becomes

$$p(R|\vec{n}) = \int d\vec{s} \int d\vec{b} \mathcal{L}(R, \vec{s}, \vec{b}|\vec{n}) \times s_{tot} / \int dR \int d\vec{s} \int d\vec{b} \mathcal{L}(R, \vec{s}, \vec{b}|\vec{n}) \times s_{tot},$$

where $s_{tot} = \Sigma_{i=0}^{Nc} \Sigma_{j=0}^{Nbins} s_{ij}$.

Channels	$l\nu b\bar{b}$			$\nu\bar{\nu}b\bar{b}$		$l^+l^-b\bar{b}$		W^+W^-		$\tau^+\tau^-$
	DT	STJP	STNN	ST	DT	ST	DT	HS/B	LS/B	
Acceptance										
Lumi (%)	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
btag (%)	8.4	8.9	5.0	4.3	8.7	5.3	16	0.0	0.0	0.
Lepton(%)	2.0	2.0	2.0	2.0	2.0	1.	1.	3.6	3.6	5.0
JES (%)	3	3.0	3.0	S	S	3.0	3.0	1.0	1.0	5.0
MC (%)	5.6	4.9	5.0	3.0	3.0	3.0	3.0	2.2	2.2	4.0
Trigger (%)	0.0	0.0	0.0	S	S	0.0	0.0	1.5	1.5	0.0
NLO (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0	10.0	10.0
Backgrounds										
Mistag (%)	9	8	9	20	29	13	24	0.0	0.0	-6.7
QCD (%)	18	18	18	-50	-50	-50	-50	-29	-23	-15
V+HF (%)	45	45	42	40	40	40+S	40+S	0	0	-20
Top (%)	15	15	15	16	18	20	20	15	15	13
Diboson (%)	10	10	10	20	20	20	20	10	10	10

Table 2: The breakdown of systematic uncertainties for each individual channel where the positive values mean correlated between the channels while the negative ones are uncorrelated with the rest of channels with up to 2.4 fb^{-1}. The S indicates where additional shape systematic uncertainty is evaluated.

The corresponding 95% credibility upper limit R_{95} is

$$\int_0^{R_{95}} p(R|\vec{n})dR = 0.95.$$

The posterior densities for all channels combined are shown in Figure 1 and Figure 2 for Higgs boson mass between 110 and 200 GeV/c^2 where the arrows indicate the 95% credibility upper limit R_{95}. Table 3 summarizes the limits recomputed for each individual channel as function of Higgs boson masses, which are in good agreement with the blessed results.

3 Expected Upper Limit

To check the sensitivity of different channels, we calculate the median upper limits one would obtain from a large ensemble of experiments. In the absence of Higgs boson signal, the pseudo-experiment is generated by fluctuating the expected backgrounds with their uncertainties. Figure 3 and Figure 4 show the distributions of upper limits from the pseudo-experiments for various Higgs boson masses. The observed upper limits from data are also shown by the red arrows, which are consistent with the expectation of pseudo-experiments.

mh	110	115	120	130	140	150	160	170	180	200
$Hl\nu b\bar{b}$(1.9 fb^{-1})	6.8	8.0	9.8	15.6	37.9	85.1				
Expected	6.5	7.6	8.8	12.8	24.0	57.5				
$H\nu\bar{\nu}bb$ (1.7 fb^{-1})	9.4	7.7	9.8	13.2	20.7	46.6				
Expected	7.7	9.1	10.3	15.6	25.8	65.2				
Hl^+l^-bb (1 fb^{-1})	16.2	17.8	19.8	32.8	73.8	185.2				
Expected	16.4	18.2	20.7	31.0	62.6	164.0				
HWW (2.4 fb^{-1})	56.9		17.1	5.57	3.34	2.56	1.57	1.78	2.90	10.35
Expected	59.8		19.5	9.5	5.82	4.32	2.46	2.70	4.03	8.21
$\tau^+\tau^-$ (2.0 fb^{-1})	31.8	30.5	34.6	38.0	63.5	152.8				
Expected	25.3	23.7	23.7	31.4	49.3	104.2				

Table 3: The summary of observed, expected limits recomputed for each individual channel as function of Higgs boson masses.

Mass (GeV/c^2)	Combined Limit(1-2.4 fb^{-1})	Expected	RMS
110	5.15	4.09	2.1
115	4.95	4.58	2.5
120	5.70	4.88	2.4
130	4.50	5.61	2.8
140	3.58	4.99	2.7
150	2.56	4.13	2.1
160	1.58	2.55	1.0
170	1.79	2.72	1.0
180	2.91	3.86	1.4
200	10.34	8.24	2.9

Table 4: The summary of observed, expected limits for various Higgs boson masses.

The final combined limit and its expectation are listed in Table 4. Figure 5 shows the combined upper limit as function of Higgs boson masses between 110 and 200 GeV/c^2 as well as the individual limits from individual channel.

4 Conclusions

We have described an updated combination of several searches for Standard Model Higgs boson production at CDF using a data sample of 1 to 2.4 fb^{-1} of integrated luminosity. The channels considered are $WH \to l\nu b\bar{b}$, $VH \to \nu\bar{\nu}b\bar{b}$, $ZH \to l^+l^-b\bar{b}$, $VH(VBF, ggH) \to \tau^+\tau^- + 2jet$, and $gg \to H \to W^+W^-$. We have calculated combined upper limits on the ratio of Higgs boson cross section times the branching ratio to the Standard Model prediction (R_{95}) for Higgs boson masses between 110 and 200

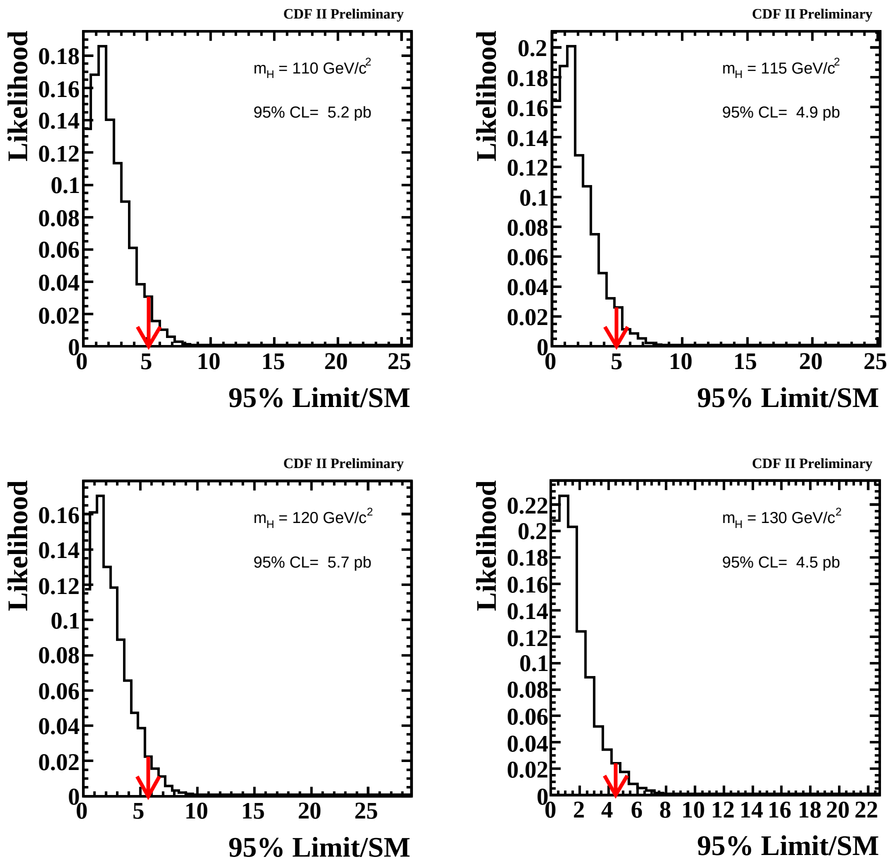

Figure 1: The posterior densities for all channels combined for Higgs boson mass between 110 and 130 GeV/c^2 where the arrows indicate the 95% credibility upper limit R_{95}.

GeV/c^2. The results are in a good agreement with the expectations obtained from pseudo-experiments. As a cross check, we have recomputed upper limits for each individual channel using the same technique and are able to reproduce the blessed results over all the channels. The 95% CL upper limits observed (expected) are a factor of 5.0(4.5) and 1.58(2.55) away from the Standard Model cross section for Higgs boson mass 115 and 160 GeV/c^2, which are significantly improved by 40% (20%) for low (High) Higgs mass over the luminosity gain since last summer (LP07).

5 Acknowledgments

We thank D. Hidas, S.-C. Hsu, B. Kilminster, T. Masubuchi, Y. Nagai, B. Parks, V. Veszpremi, and K. Yorita for providing the results of their analysis, which makes this combination possible.

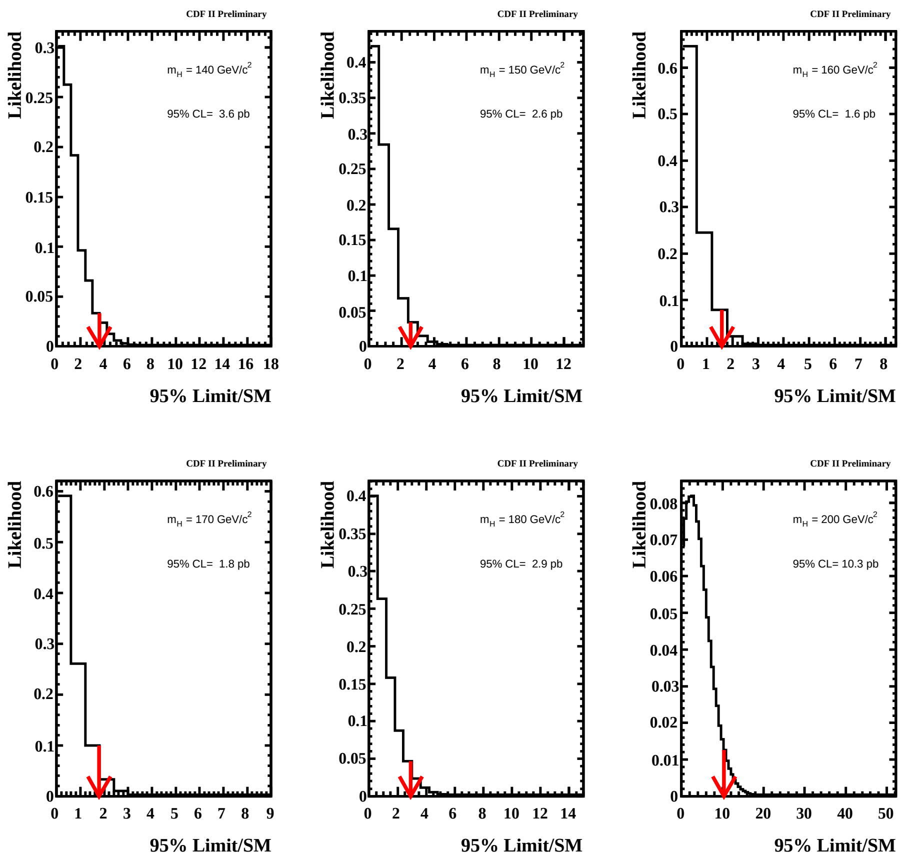

Figure 2: The posterior densities for all channels combined for Higgs boson mass between 140 and 200 GeV/c^2 where the arrows indicate the 95% credibility upper limit R_{95}.

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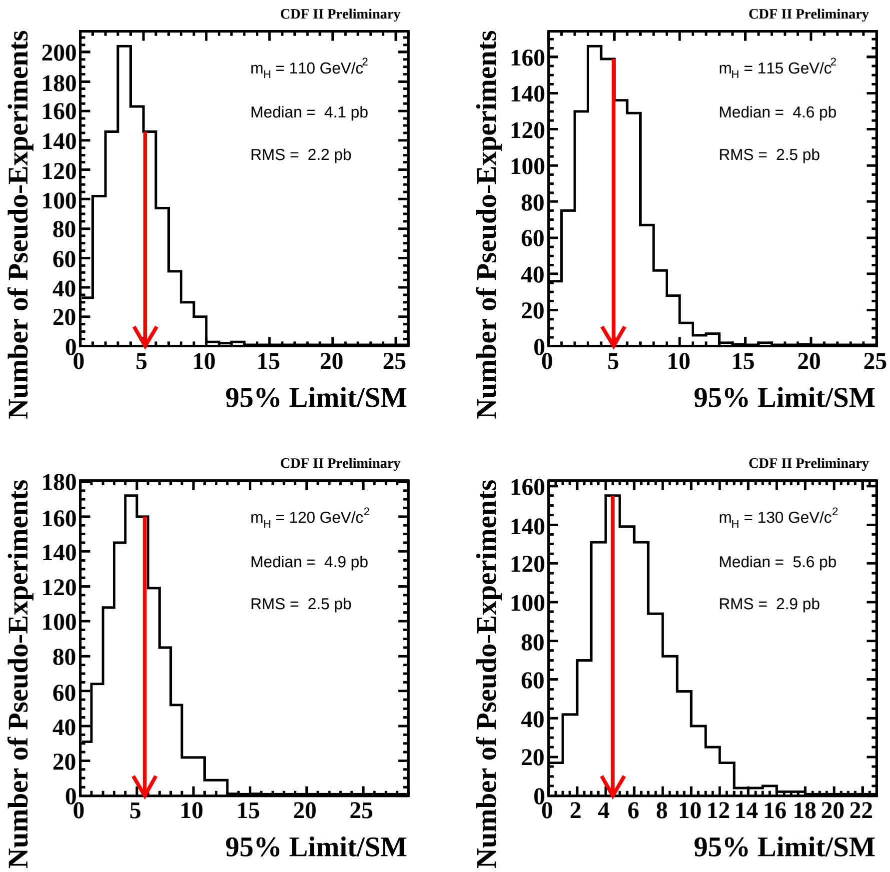

Figure 3: The distributions of upper limits from the pseudo-experiments for Higgs boson mass between 110 and 130 GeV/c^2 where the arrows indicate the observed 95% upper limit from data.

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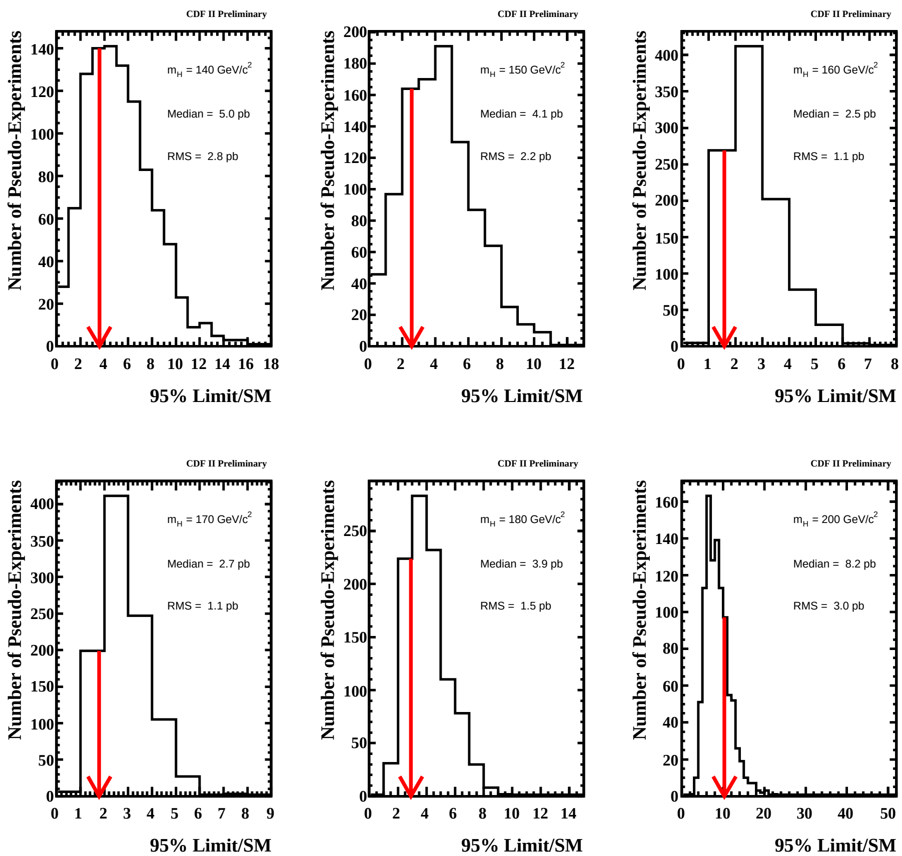

Figure 4: The distributions of upper limits from the pseudo-experiments for Higgs boson mass between 140 and 200 GeV/c^2 where the arrows indicate the observed 95% upper limit from data.

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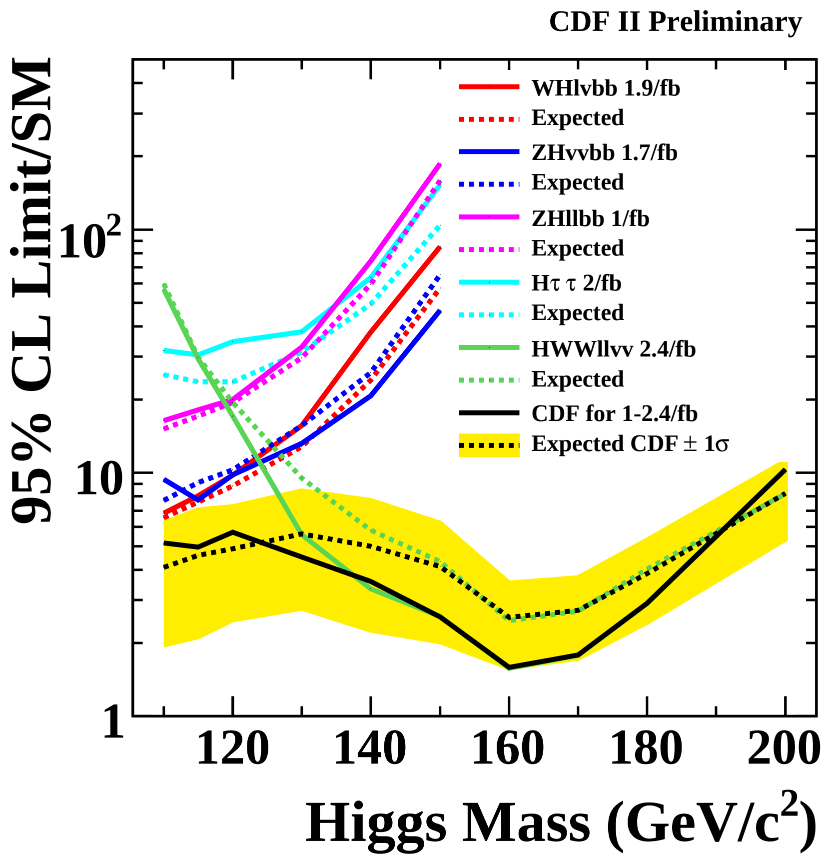

Figure 5: The combined upper limit as function of Higgs boson masses between 110 and 200 GeV/c^2 as well as the individual limits from individual channel.

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