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Combined Upper Limit on Standard Model Higgs Boson Production at CDF for Summer 2006

The CDF Collaboration
http://www-cdf.fnal.gov
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This note describes a combination of several searches for Standard Model Higgs boson production at CDF. The searches were performed in a data sample with up to 1 fb^{-1} of integrated luminosity collected in $p\bar{p}$ collisions at $\sqrt{s} = 1.96\,\mathrm{TeV}$. The channels considered are the dominant ones: $WH \to l\nu b\bar{b}$, $ZH \to \nu\bar{\nu}b\bar{b}$, $ZH \to \ell^+\ell^- b\bar{b}$, 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 its Standard Model prediction (R_{95}) for Higgs boson mass hypotheses between 110 and 200 GeV/c^2. The results are in good agreement with the expectations obtained from background-only pseudo-experiments. The 95% CL upper limits observed (expected) are factors of 12.8(9.1) and 10.2(11.4) higher than the Standard Model production cross sections for Higgs boson masses of 115 and 160 GeV/c^2, respectively.

Preliminary results for Summer 2006 conferences

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

I. INTRODUCTION

The CDF collaboration has performed several searches for Higgs boson production in data samples up to 1 fb^{-1} of integrated luminosity. Clearly it is necessary to combine the results of all the channels to maximize the search sensitivity. The searches for $WH \to l\nu b\bar{b}$, $ZH \to \nu\bar{\nu}b\bar{b}$, and $ZH \to \ell^+\ell^- b\bar{b}$ in the low mass range have been updated with approximately 1 pb^{-1} of data [1–3], while the $g\bar{g} \to H \to W^+W^- \to l^+l^-\nu\bar{\nu}$ result uses approximately 300 pb^{-1} [4].

To combine the search results, we follow the same procedure that was used in the Run1 Higgs combination analysis [5]. A Bayesian framework allows us to handle properly the systematic uncertainties for the large number of background contributions and efficiency parameters in the analyses. Within this framework the relative rates of SM Higgs boson production among the different production modes are assumed to be the same as the SM prediction. We combine the limits on the ratio of Higgs boson production rate (cross section times branching ratio) to the SM value.

II. COMBINATION RESULTS

For a given Higgs boson mass hypothesis, the combined likelihood is a product of the likelihoods in the individual channels, each of which is a product over histogram bins of Poisson probabilities. Specifically,

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

where the prior densities for all the parameters in the likelihood relate to the 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), and the second product is over histogram bins with observed data events (n_{ij}) in either dijet mass for WH and ZH or $\delta\phi$ of two leptons in WW. 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 [6] and HDECAY [7]. They are summarized in Table I as function of Higgs boson masses. The residual theoretical uncertainties for WH and ZH production cross section are rather small, less than 5%. There is also an uncertainty of about 10% for the gluon fusion $gg \to H$ process.

Channels	$l\nu b\bar{b}$		$\nu\bar{\nu}b\bar{b}$		$l^+l^-b\bar{b}$	W^+W^-
	Single	Double	Single	Double		
Acceptance						
Luminosity (%)	6.0	6.0	6.0	6.0	6.0	6.0
btag SF (%)	5.3	16.0	8.0	16.0	8	0.0
Lepton ID (%)	2.0	2.0	2.0	2.0	1.4	3.0
JES (%)	3.0	3.0	6.0	(1-20)	(1.6-20)	1.0
MC modeling (%)	4.0	10.0	4.0	5.0	2.0	5.0
Trigger (%)	0.0	0.0	3.0	3.0	0.0	0.0
Shapes (%)	0.0	0.0	0.0	0.0	-20.0	0.0
Backgrounds						
Mistag (%)	22	15	17	17	17	0.0
QCD (%)	17	20	-10	-44	-50	0
W/Z+HF(I) (%)	33	34	12	12	40	0
W+HF(II) (%)	0	0	-10	-42	0	0
Z+HF(II) (%)	0	0	-6	-19	0	0
Top(I) (%)	13.5	20	12	12	15	0
Top(II) (%)	0.	0.	-2	-3	0	0
Diboson(I) (%)	16	25	12	12	20	11
Diboson(II) (%)	0	0	-5	-10	0	0
Other (%)	0	0	0	0	0	-(12-18)

TABLE II: The breakdown of systematic uncertainties for each individual channel. Correlated uncertainties have positive sign, while uncorrelated uncertainties have negative sign.

Systematic uncertainties in the various analyses 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 the following groups:

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

For each group, we assign each measurement to be 100% correlated or uncorrelated with other measurements. The breakdown of the systematic uncertainty for each channel is summarized in Table II where a positive value indicates 100% correlated systematic uncertainty among the channels and a negative value indicates an uncorrelated systematic uncertainty. The priors used are truncated Gaussian densities constraining a given parameter to its expected value within some uncertainty.

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

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

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

The posterior densities for all channels combined are shown in Figure 1 and Figure 2 for Higgs boson mass hypotheses between 110 and 200 GeV/c^2 where the arrows indicate the 95% credibility upper limit R_{95}. Figure 3 re-summarizes the limits from each individual channel and all the channels combined as function of Higgs boson masses.

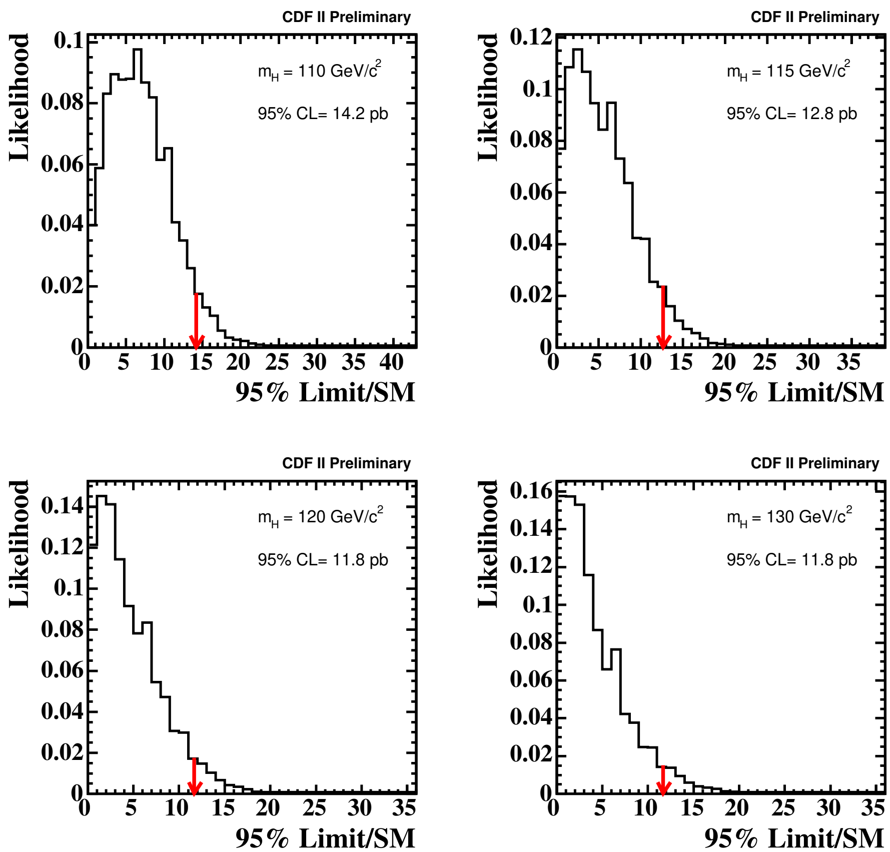

FIG. 1: The posterior densities for all channels combined for Higgs boson mass hypotheses between 110 and 140 GeV/c^2 where the arrows indicate the 95% credibility upper limit R_{95}.

III. EXPECTED UPPER LIMIT

To check the sensitivity of different channels, we calculate the mean 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 within their uncertainties. Figure 4 and Figure 5 show the distributions of upper limits from the pseudo-experiments for various Higgs boson mass hypotheses. The observed upper limits from data are also shown by the red arrows, which are consistent with the expectation of pseudo-experiments. The final CDF combined limits and corresponding expectations are listed in Table III.

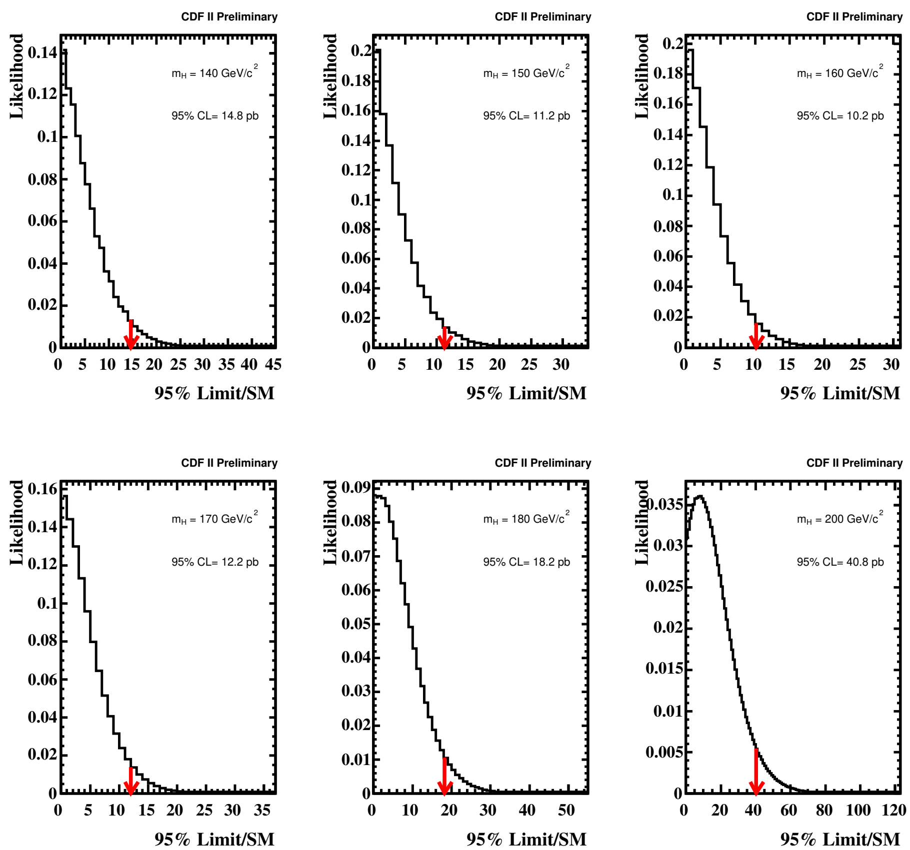

FIG. 2: The posterior densities for all channels combined for Higgs boson mass hypotheses between 150 and 200 GeV/c^2 where the arrows indicate the 95% credibility upper limit R_{95}.

Mass (GeV/c^2)	Combined Ratio Limits	Expected Ratio Limits	
	Correlated	Mean	RMS
110	14.2	8.3	3.2
115	12.8	9.1	3.6
120	11.8	10.3	3.9
130	11.8	13.4	5.0
140	14.8	17.6	6.1
150	11.2	15.4	5.5
160	10.2	11.4	3.9
170	12.2	12.3	4.1
180	18.2	16.2	5.6
200	40.8	34.4	12.2

TABLE III: The summary of observed and expected limit ratios (with respect to the SM Higgs boson production rate) for various Higgs boson masses.

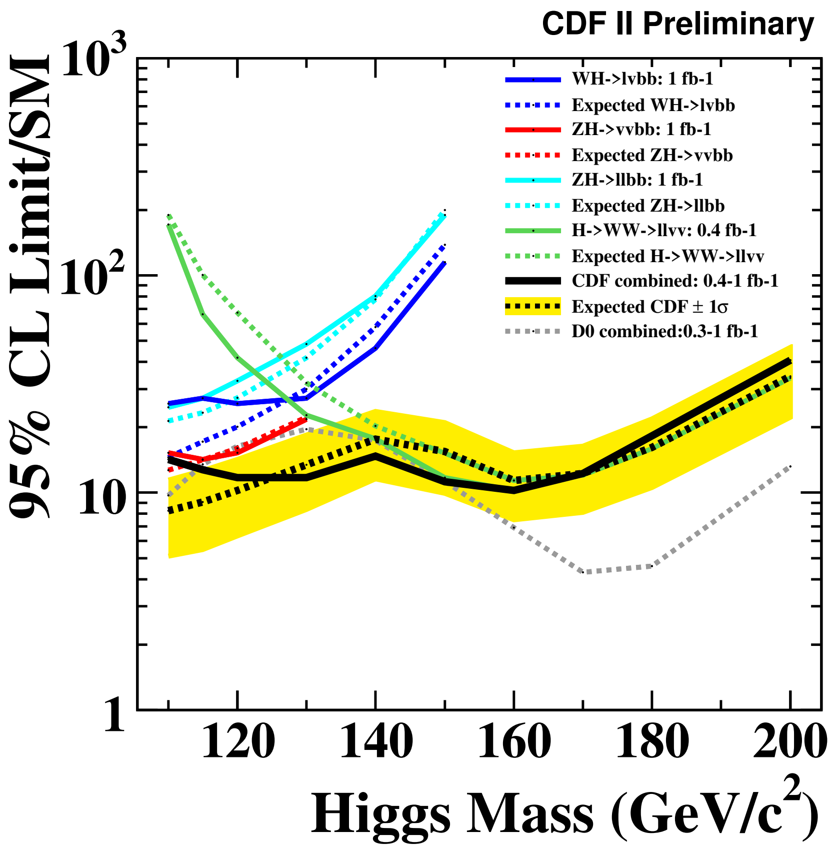

FIG. 3: The combined upper limit as function of Higgs boson mass hypotheses between 110 and 200 GeV/c^2 as well as the individual limits from individual channels.

IV. CONCLUSIONS

We have described a combination of several searches for Standard Model Higgs boson production at CDF using a data sample up to 695 pb^{-1} of integrated luminosity. The channels considered in this combinations are $WH \to l\nu b\bar{b}$, $ZH \to \nu\bar{\nu}b\bar{b}$, $ZH \to \ell^+\ell^- b\bar{b}$, 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 its Standard Model prediction (R_{95}) for Higgs boson mass hypotheses between 110 and 200 GeV/c^2. The 95% CL upper limits observed (expected) are a factor of 12.8 (9.1) and 10.2 (11.4) higher than the Standard Model production rates for Higgs boson masses of 115 and 160 GeV/c^2, respectively.

V. ACKNOWLEDGEMENTS

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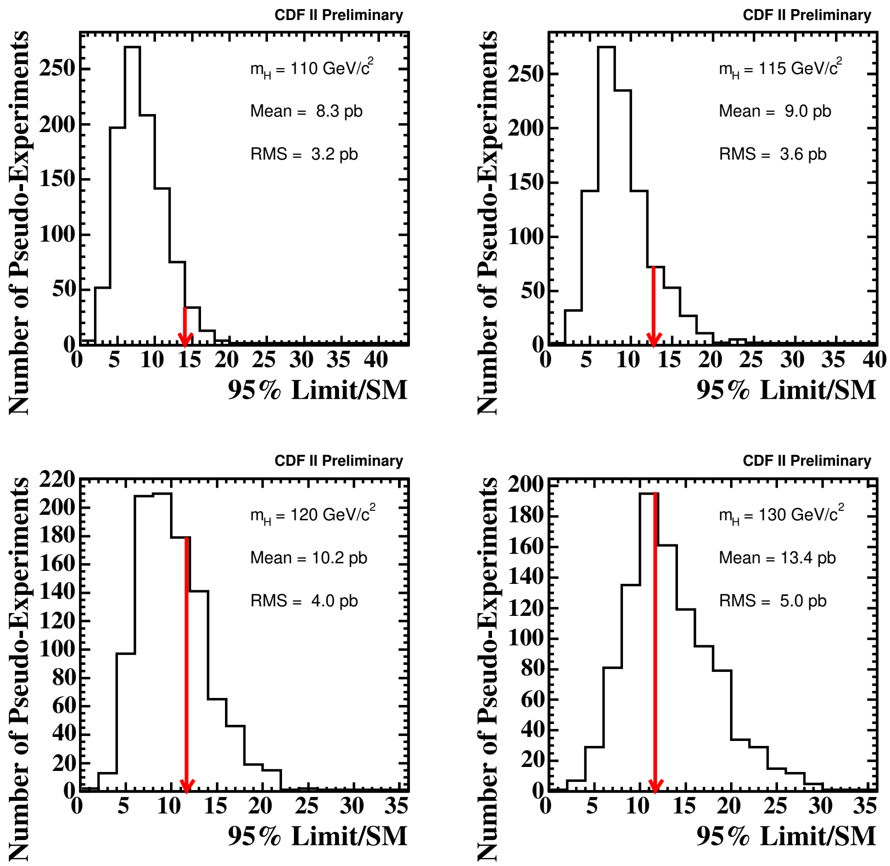

FIG. 4: The distributions of upper ratio limits from the pseudo-experiments for Higgs boson mass hypotheses between 110 and 140 GeV/c^2 where the arrows indicate the observed 95% upper limit from data.

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[3] CDF Collaboration, "Search for the Standard Model Higgs Boson in the ZH→ $\ell^+\ell^-b\bar{b}$ channel," CDF/ANAL/EXOTIC/PUBLIC/7983.
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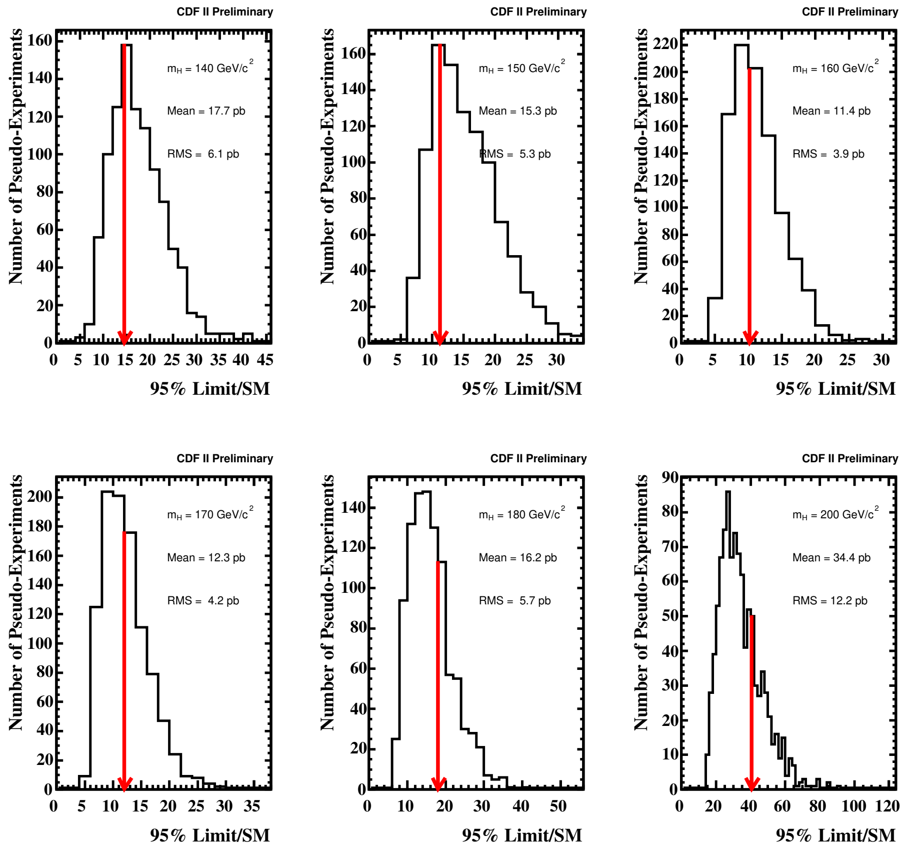

FIG. 5: The distributions of upper ratio limits from the pseudo-experiments for Higgs boson mass hypotheses between 150 and 200 GeV/c^2 where the arrows indicate the observed 95% upper limit from data.