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

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Abstract

This note describes a combination of several searches for Standard Model Higgs boson production at CDF using a data sample up to 1 fb^{-1} of integrated luminosity. The channels considered are $WH \to l\nu b\bar{b}$, $ZH \to \nu\bar{\nu}b\bar{b}$, $ZH \to l^+l^-b\bar{b}$, and $gg \to H \to W^+W^-$. The first two results have been recently updated and the $ZH \to l^+l^-b\bar{b}$ is newly available for the first time using a neural network technique in order to take advantage of clean final states. 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 masses between 110 and 200 GeV/c^2. The results are in a good agreement with the expectations obtained from pseudo-experiments. We have also recomputed upper limits for each individual channel using the same technique as a consistent check and are able to reproduce the blessed results over all the channels. The 95% CL upper limits observed (expected) are a factor of 12.8 (9.1) and 10.2 (11.4) away from the Standard Model cross section for Higgs boson mass 115 and 160 GeV/c^2.

1 Changes from V3.0

We have updated the combined limit with the bin size of 20GeV in dijet mass in $WH \to l\nu b\bar{b}$ and $ZH \to \nu\bar{\nu}b\bar{b}$ in order to be consistent with each individual analysis. This results in some minor changes in the final limit, but does not seem unreasonable due to low statistics in $ZH \to \nu\bar{\nu}b\bar{b}$ double tags.

2 Changes from V2.0

We have updated the combination on Standard Model Higgs boson production at CDF using a data sample up to 1 fb^{-1} of integrated luminosity. The method is remain Bayesian as before, but the combination includes new preliminary results from $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ and $ZH \rightarrow l^+l^-b\bar{b}$, which are preblessed on July 7th, 2006, as well as the blessed $WH \rightarrow l\nu b\bar{b}$ result with 1 fb^{-1} data.

3 Changes from V1.0

We have made few changes since the previous version 1.0, which are summarized in following:

- Use more iterations for integration and finer steps in sampling.
- Fix to include the mass window cut efficiency in $ZH \rightarrow \nu\nu b\bar{b}$ channel, which was ignored previously.
- Some minor bug fixes in the code.

4 Introduction

CDF has made several searches for the Standard Model Higgs boson production using a data sample up to 1 fb^{-1} of integrated luminosity [1] [2] [3] [4] [5] [6]. Clearly it is necessary to combine the results of all the channels to maximize the search sensitivity. The most sensitive channels are $WH \rightarrow l\nu b\bar{b}$, $ZH \rightarrow \nu\bar{\nu}b\bar{b}$, and $ZH \rightarrow l^+l^-b\bar{b}$ in the low mass range, and $g\bar{g} \rightarrow H \rightarrow W^+W^- \rightarrow l^+l^-\nu\bar{\nu}$ in the high mass range. Recently, the WH and ZH results have been updated to 1 fb^{-1}. The $g\bar{g} \rightarrow H \rightarrow W^+W^-$ result is still based on a much smaller data sample of about 300 pb^{-1}. For the combination, we follow the same procedure that was used in the Run1 Higgs combination analysis [7], 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.

5 Combination Results

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 $gg \rightarrow H \rightarrow W^+W^-$ 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

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.

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 [7]. 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 (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 [8] and HDECAY [9], 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%. Also there is about 10% for gluon fusion $gg \to H$ process.

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, 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. In order to treat the backgrounds in ZH channel properly, we have divided most backgrounds into two parts: one is correlated among the channels due to common systematic(luminosity, btagging, the jet energy scale and Monte Carlo modeling), the second is uncorrelated due to limited Monte Carlo statistics.

- Background shape uncertainties are estimated using pseudo-experiment with different input shapes that results in changes of expected limit. We treat it as part of systematic uncertainties on the signal, which effectively smears the final likelihood.

For each group, we assign each measurement to be 100% correlated or uncorrelated with other measurements. 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.

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

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}. Figure 3 summarizes the limits from each individual channel and all the channels combined as function of Higgs boson masses.

As a check of the robustness of our calculation, we repeated the calculation by treating most systematics uncorrelated, except the luminosity and btag efficiency scale factor. This results in almost identical combined upper limits, shown in Table 3 as "uncorrelated", which indicates that the impact of correlations are small at the present time.

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 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.

6 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 with their uncertainties. Figure 4 and Figure 5 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.

The final combined limit and its expectation are listed in Table 3.

7 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 are $WH \to l\nu b\bar{b}$, $ZH \to \nu\bar{\nu}b\bar{b}$, and $gg \to H \to W^+W^-$. We have

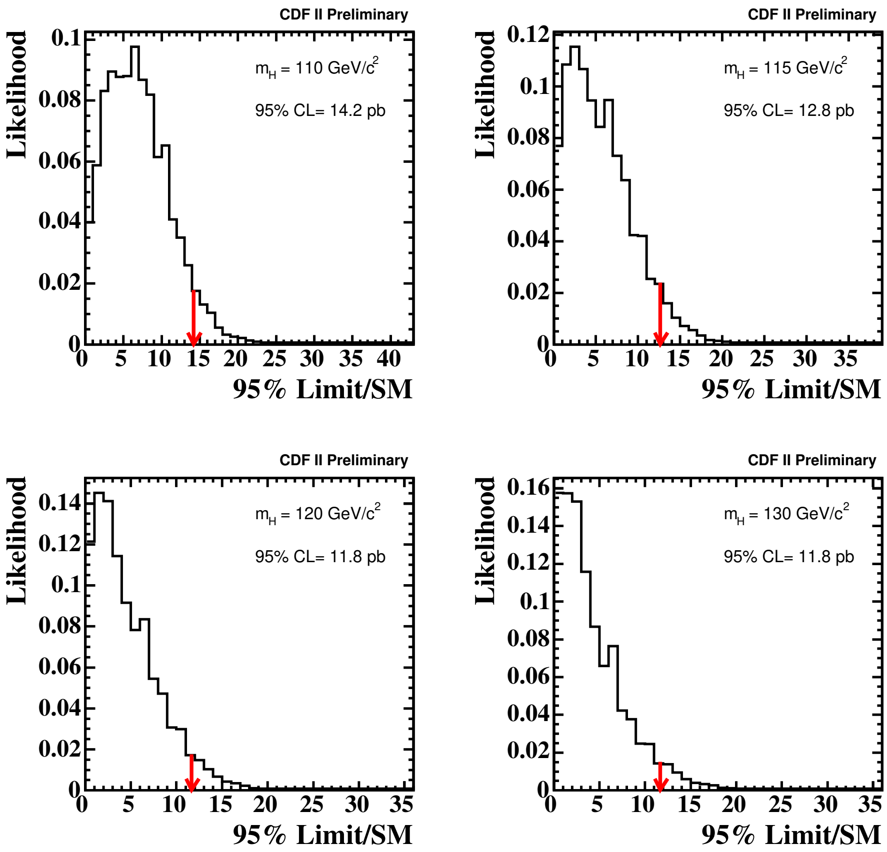

Figure 1: The posterior densities for all channels combined for Higgs boson mass between 110 and 130 GeV/c^2 where the arrows indicate the 95% credibility upper limit R_{95}.

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 masses between 110 and 200 GeV/c^2. The results are in a good agreement with the expectations obtained from pseudo-experiments. We have also recomputed upper limits for each individual channel using the same technique as a consistent check and are able to reproduce the blessed results over all the channels. The 95% CL upper limits observed (expected) are a factor of 12.8 (9.1) and 10.2 (11.4) away from the Standard Model cross section for Higgs boson mass 115 and 160 GeV/c^2.

8 Acknowledgments

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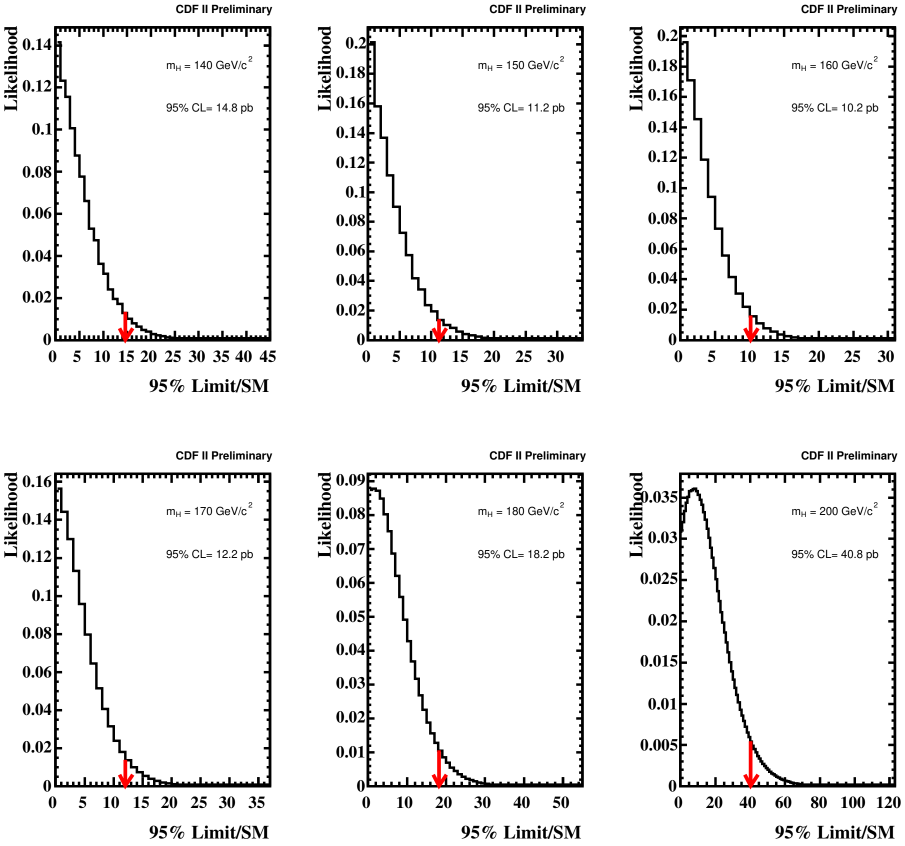

Figure 2: The posterior densities for all channels combined for Higgs boson mass between 140 and 200 GeV/c^2 where the arrows indicate the 95% credibility upper limit R_{95}.

contributions that give us an independent cross checks on the previous results.

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[1] Y. Kusakabe et al, Search for Standard Model Higgs Boson Production in Association with W Boson at CDF with 1 fb^{-1}, CDF Note 8355;
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[2] V. Veszpremi et al, Search for the Standard Model Higgs Boson in the Missing Et and b-jet Signature, CDF Note 8362;
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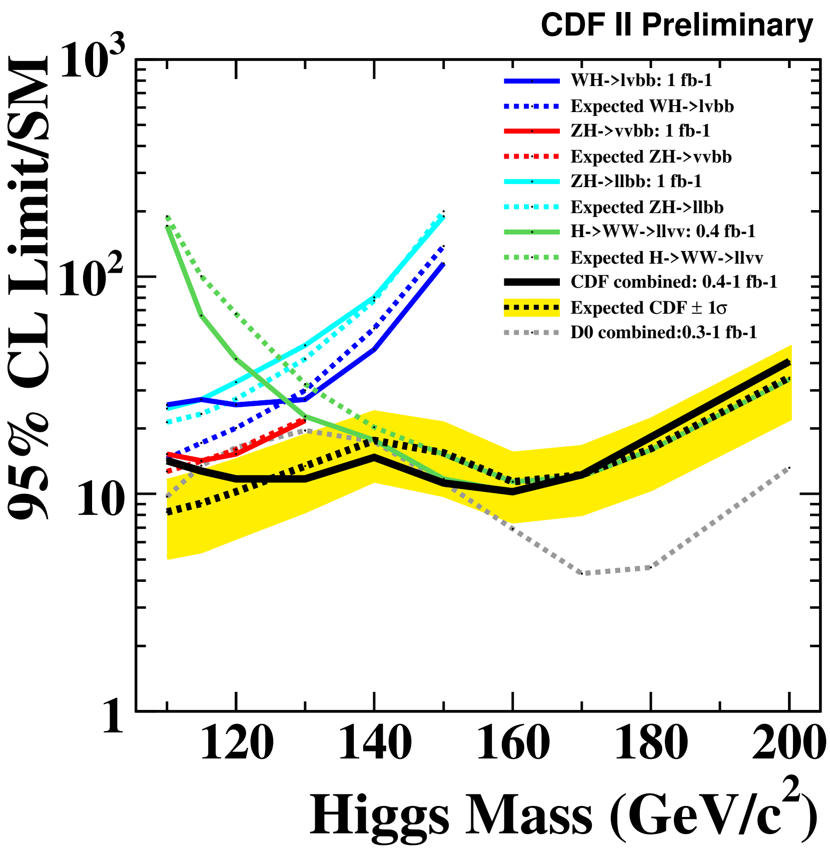

Figure 3: The combined upper limit as function of Higgs boson masses between 110 and 200 GeV/c^2 as well as the individual limits from individual channels.

[3] J. Efron et al, Search for $ZH \to l^+l^-b\bar{b}$ in 1 fb^{-1} of CDF Run 2 Data, CDF Note 8363. 2

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[6] H. Kobayashi, K. Yamamoto, and Y. Seiya, Search for the WH Production Using High-Pt Isolated Like-Sign Dilepton Events in Run II, CDF Note 7262. 2

[7] L. Demortier, M. Kruse, J. Valls, and W. Yao, Combined Upper Limits on Run I Higgs Production, CDF Note 4985. 2, 3

[8] Tev4LHC Higgs working group at http://maltoni.home.cern.ch/maltoni/TeV4LHC/SM.html. 3

Mass (GeV/c^2)	Combined Limits (pb)		Expected Limits (pb)	
	Correlated	Uncorrelated	Mean	RMS
110	14.2	13.8	8.3	3.2
115	12.8	12.8	9.1	3.6
120	11.8	11.8	10.3	3.9
130	11.8	11.2	13.4	5.0
140	14.8	14.8	17.6	6.1
150	11.2	11.8	15.4	5.5
160	10.2	10.2	11.4	3.9
170	12.2	12.2	12.3	4.1
180	18.2	18.2	16.2	5.6
200	40.8	40.8	34.4	12.2

Table 3: The summary of observed, expected limits for various Higgs boson masses.

[9] A. Djouadi, J. Kalinowski, and M. Spira, Comp. Phys. Commun. 108 C (1998) 56. 3

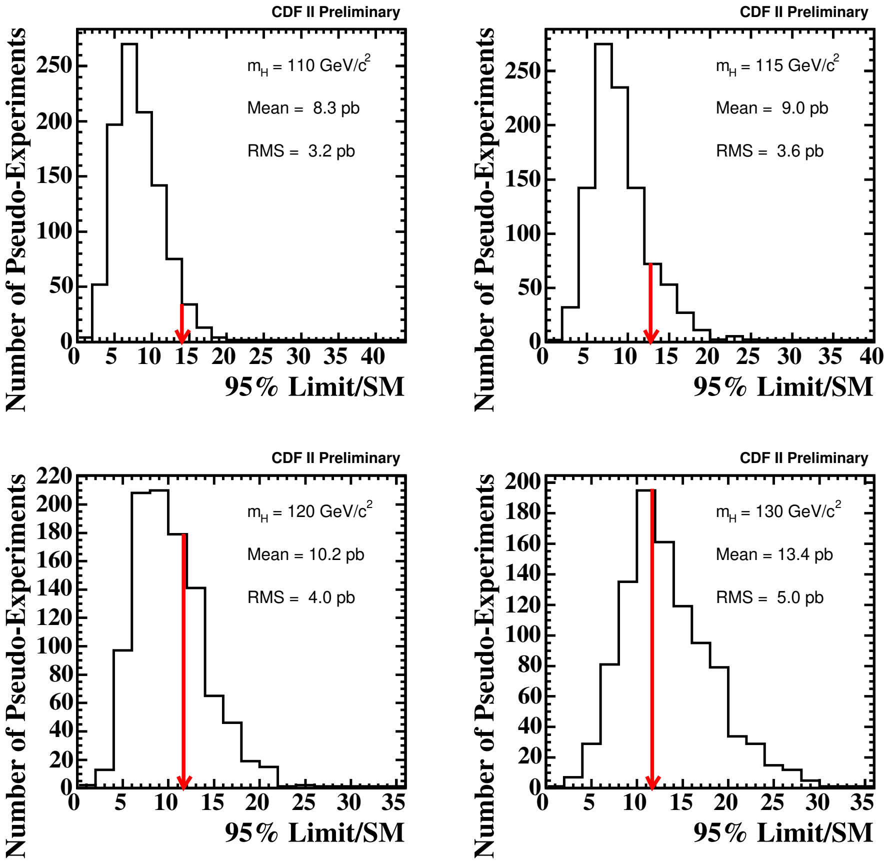

Figure 4: The distributions of upper limits from the pseudo-experiments for Higgs boson mass between 110 and 130 GeV/c^2 where the arrows indicate the observed 95% upper limit from data.

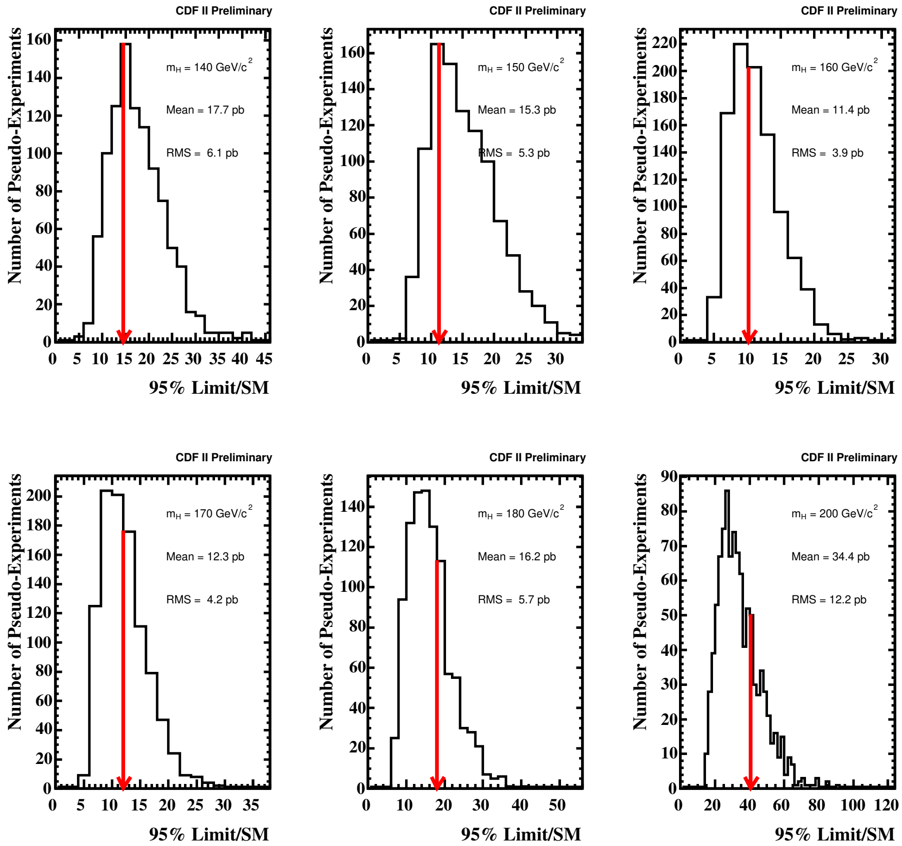

Figure 5: The distributions of upper limits from the pseudo-experiments for Higgs boson mass between 140 and 200 GeV/c^2 where the arrows indicate the observed 95% upper limit from data.