CDF/ANAL/EXOTIC/PUBLIC/8326

Combined Upper Limit on Standard Model Higgs Boson Production at CDF

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 695 pb^{-1} of integrated luminosity collected in $p\bar{p}$ collisions at $\sqrt{s} = 1.96\,\text{TeV}$. The channels considered are the dominant ones: $WH \rightarrow l\nu b\bar{b}$, $ZH \rightarrow \nu\bar{\nu}b\bar{b}$, and $gg \rightarrow H \rightarrow W^+W^-$. We have calculated combined upper limits on the ratio of Higgs cross section times the branching ratio to its Standard Model prediction (R_{95}) for Higgs 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 combined production limit is still an order of magnitude higher than the Standard Model prediction, but it will be greatly improved once the results are updated with $1\,\text{fb}^{-1}$ of data in late summer 2006.

Preliminary results for early Summer 2006 conferences

I. INTRODUCTION

The CDF collaboration has performed several searches for Higgs production in data samples up to 695 pb^{-1} of integrated luminosity [1] [2] [3] [4]. The individual results are summarized in Figure 1, which shows the ratio of the observed 95% CL upper limit on the production cross section times the branching ratio to the Standard Model prediction as a function of the Higgs masses. Clearly it is necessary to combine the results of all the channels to maximize the search sensitivity. The most sensitive channels are $WH \to l\nu b\bar{b}$ and $ZH \to \nu\bar{\nu}b\bar{b}$ in the low mass range [1] [2], and $g\bar{g} \to H \to W^+W^- \to l^+l^-\nu\bar{\nu}$ in the high mass range [3]. Recently, the $WH \to l\nu b\bar{b}$ result was updated with 695 pb^{-1}, but the other two analyses are 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 [5]. This Bayesian framework allows us to handle properly the systematic uncertainties for the large number of background contributions and efficiency parameters in the analyses.

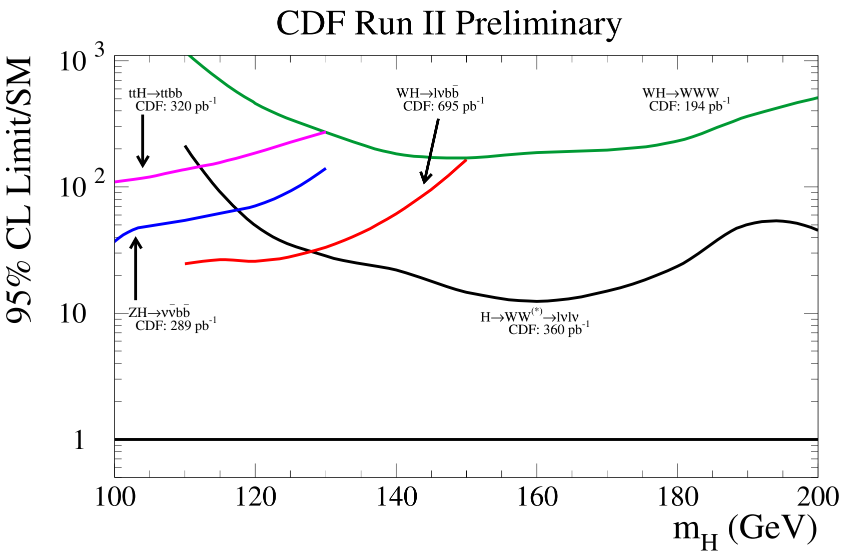

FIG. 1: Summary of Higgs 95% CL upper limits on the ratio of the production cross section times the branching ratio to the Standard Model expectations as function of Higgs masses. Each line represents a separate search.

II. COMBINATION RESULTS

For a given Higgs 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,

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

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 masses.

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 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 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.

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.

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 production cross section, we assign a flat prior to the total number of Higgs 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

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

Channels	$l\nu b\bar{b}$ Single	$l\nu b\bar{b}$ Double	$\nu\bar{\nu}b\bar{b}$	W^+W^-
Acceptance				
Luminosity (%)	6.0	6.0	6.0	6.0
btag SF (%)	5.3	16.0	6.3	0.0
Lepton ID (%)	2.0	2.0	2.0	3.0
JES (%)	3.0	3.0	8.0	1.0
MC modeling (%)	4.0	10.0	2.0	5.0
Trigger (%)	0.0	0.0	2.0	0.0
Backgrounds				
Heavy Flavor (%)	33	34	0	0
Mistag (%)	22	15	16	0
Top (%)	13.5	20	18	0
QCD (%)	17	20	-34	0
Diboson (%)	16	25	18	11
Other (%)	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.

The posterior densities for all channels combined are shown in Figure 2 and Figure 3 for Higgs mass hypotheses between 110 and 200 GeV/c^2 where the arrows indicate the 95% credibility upper limit R_{95}. Figure 4 re-summarizes the limits from each individual channel and all the channels combined as function of Higgs masses.

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

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 signal, the pseudo-experiment is generated by fluctuating the expected backgrounds within their uncertainties. Figure 5 and Figure 6 show the distributions of upper limits from the pseudo-experiments for various Higgs 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.

IV. CONCLUSIONS

We have described a combination of several searches for Standard Model Higgs production at CDF using a data sample up to 695 pb^{-1} of integrated luminosity. The channels considered in this combinations are $WH \to l\nu b\bar{b}$, $ZH \to \nu\bar{\nu}b\bar{b}$, and $gg \to H \to W^+W^-$. We have calculated combined upper limits on the ratio of Higgs cross section times the branching ratio to its Standard Model prediction (R_{95}) for Higgs mass hypothese between 110 and 200 GeV/c^2. The results are in a good agreement with the expectations obtained from background-only pseudo-experiments. The combined limit is still an order of magnitude higher than the Standard Model prediction, but it will be improved once all results are updated with 1 fb^{-1} of data for late Summer 2006.

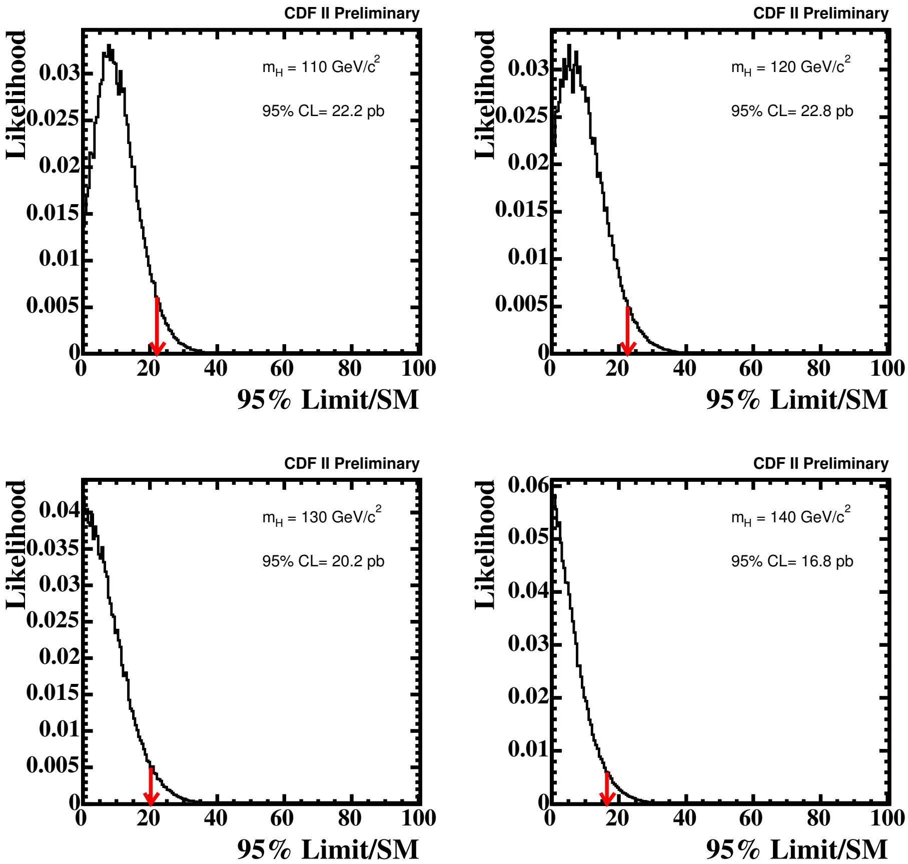

FIG. 2: The posterior densities for all channels combined for Higgs mass hypothese between 110 and 140 GeV/c^2 where the arrows indicate the 95% credibility upper limit R_{95}.

Mass (GeV/c^2)	Combined Limits (pb)		Expected Limits (pb)	
	Correlated	Uncorrelated	Mean	RMS
110	22.2	21.8	14.0	5.0
120	22.8	22.8	18.0	6.3
130	20.2	20.8	20.3	6.9
140	16.8	17.2	18.6	6.4
150	12.8	12.8	15.0	5.2
160	11.8	11.8	10.9	3.8
170	12.8	12.8	11.6	4.0
180	20.2	20.2	15.6	5.4
190	43.8	43.8	27.6	9.7
200	35.2	35.2	30.3	10.8

TABLE III: The summary of observed and expected upper limits for various Higgs masses.

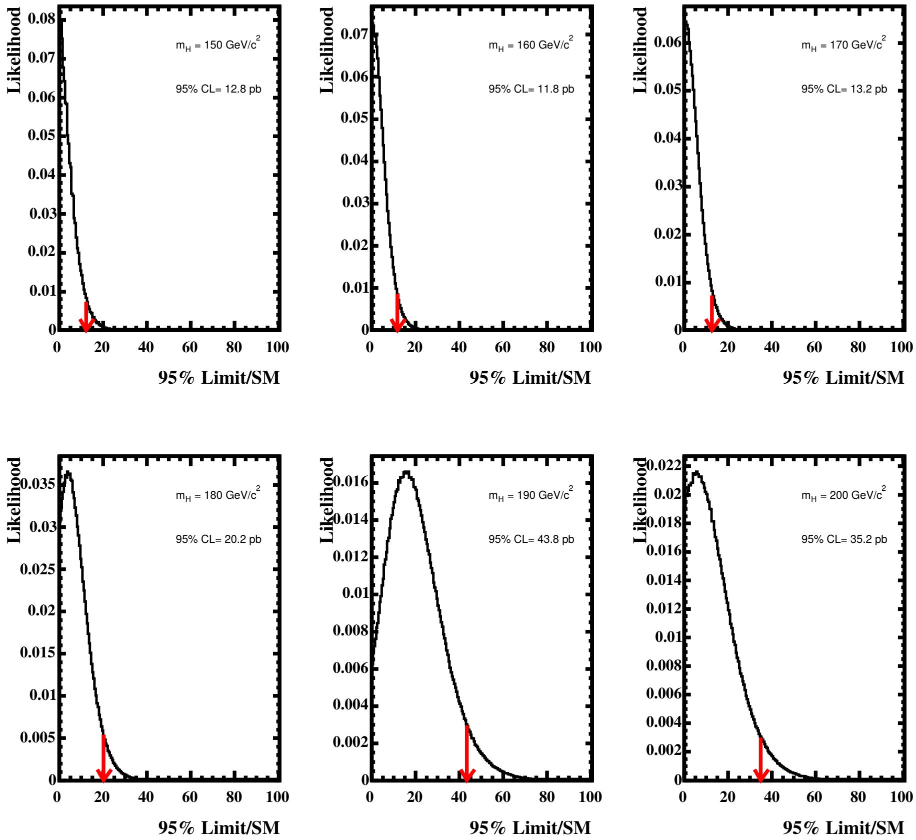

FIG. 3: The posterior densities for all channels combined for Higgs mass hypotheses between 150 and 200 GeV/c^2 where the arrows indicate the 95% credibility upper limit R_{95}.

V. ACKNOWLEDGEMENTS

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[1] CDF Collaboration, "Search for Standard Model Higgs Boson Production in Association with $W^{\pm}$ Boson at CDF with 695 pb^{-1}," CDF/ANAL/EXOTIC/PUBLIC/8194. 2

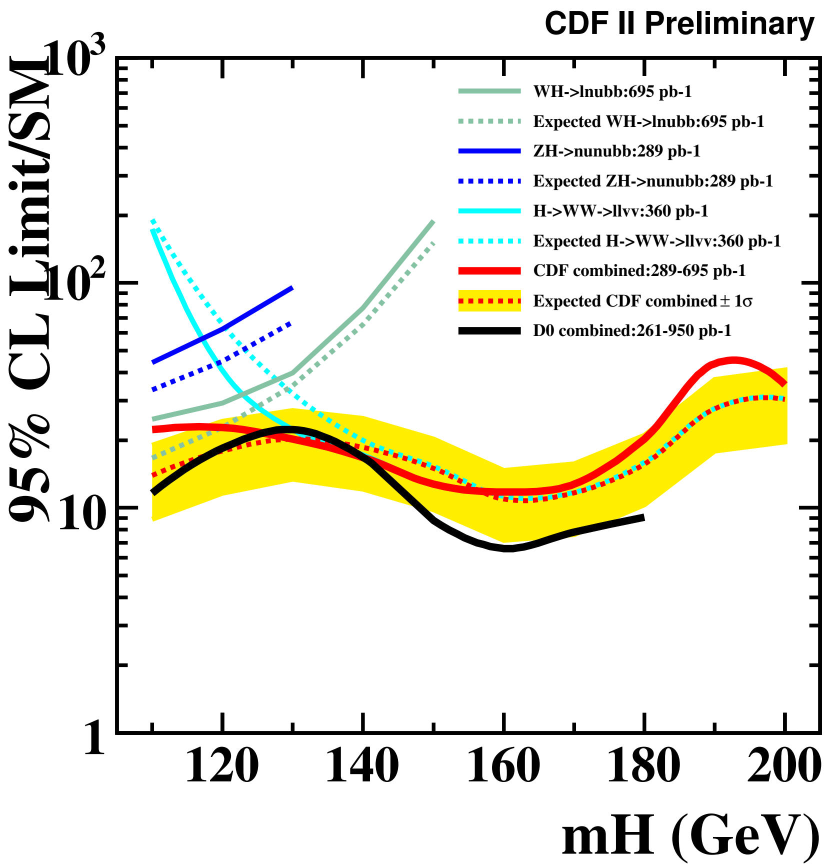

FIG. 4: The combined upper limit as function of Higgs mass hypotheses between 110 and 200 GeV/c^2 as well as the individual limits from individual channels.

[2] CDF Collaboration, "Search for the Standard Model Higgs Boson in the ZH→ $\nu\bar{\nu}b\bar{b}$ channel," CDF/ANAL/EXOTIC/PUBLIC/7983. 2
[3] CDF Collaboration, "Search for a SM Higgs Boson in the $gg \to H \to WW^*$ Dilepton Channel with 360 pb^{-1} Run II Data," CDF/DOC/EXOTIC/PUBLIC/7893. 2
[4] CDF Collaboration, "Search for the WH Production Using High-P_T Isolated Like-Sign Dilepton Events in Run II," CDF/PUB/EXOTIC/PUBLIC/7307. 2
[5] D. Acosta *et al.* (CDF Collaboration), PRL **95** 051801 (2005) 2
[6] Tev4LHC Higgs working group at http://maltoni.home.cern.ch/maltoni/TeV4LHC/SM.html. 3
[7] A. Djouadi, J. Kalinowski, and M. Spira, Comp. Phys. Commun. **108 C** (1998) 56. 3

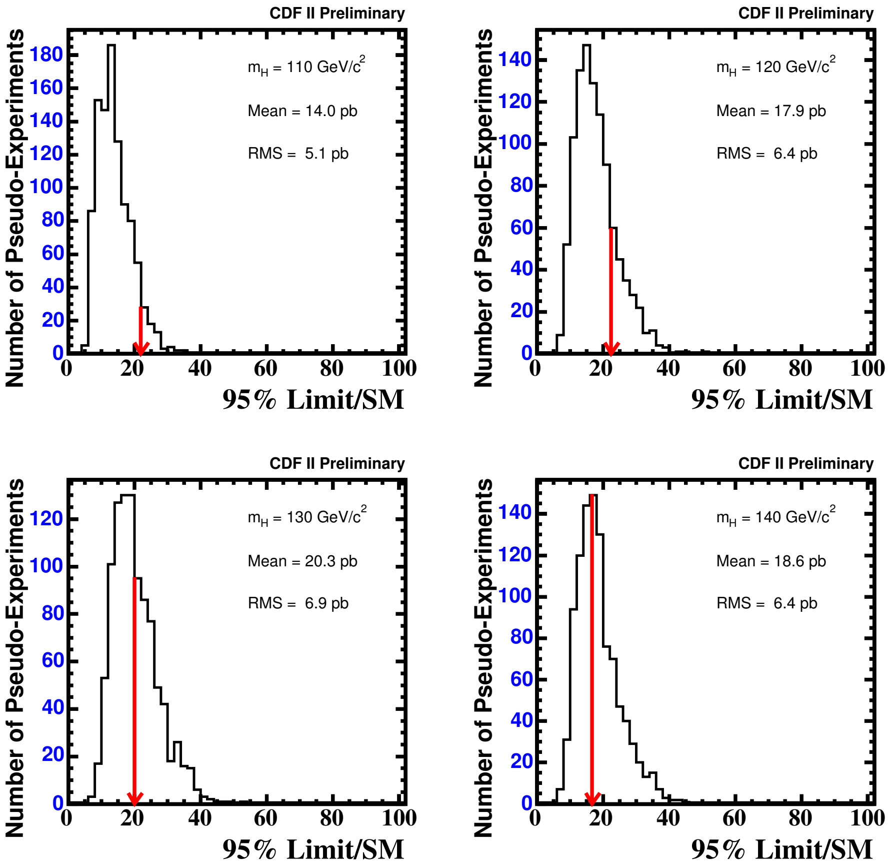

FIG. 5: The distributions of upper limits from the pseudo-experiments for Higgs mass hypotheses between 110 and 140 GeV/c^2 where the arrows indicate the observed 95% upper limit from data.

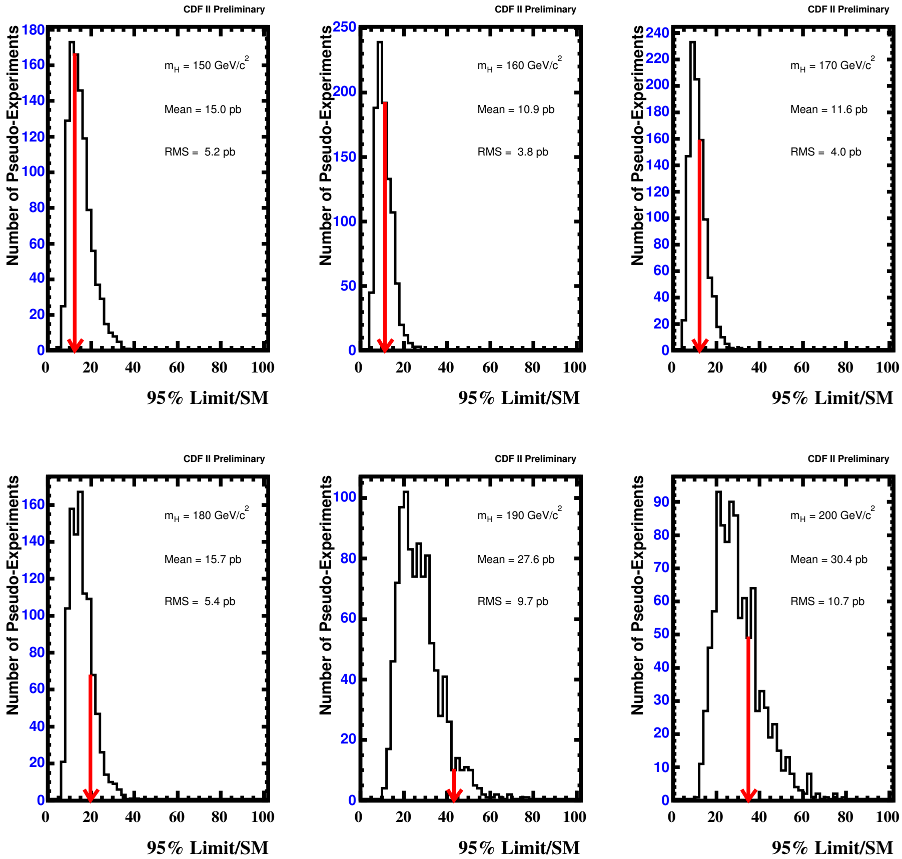

FIG. 6: The distributions of upper limits from the pseudo-experiments for Higgs mass hypotheses between 150 and 200 GeV/c^2 where the arrows indicate the observed 95% upper limit from data.