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Combined Upper Limit on Standard Model Higgs Boson Production at CDF with $2.4\,\mathrm{fb}^{-1}$ Data

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 data samples varying from 1.1 to 2.4 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: $WH \rightarrow l\nu b\bar{b}$, $ZH \rightarrow \nu\bar{\nu}b\bar{b}$, $ZH \rightarrow \ell^+\ell^- b\bar{b}$, $VH(VBF, ggH) \rightarrow \tau^+\tau^- + 2jet$, and $gg \rightarrow H \rightarrow W^+W^-$. 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 5.0 (4.5) and 1.58 (2.55) higher than the Standard Model production cross sections for Higgs boson masses of 115 and 160 GeV/c^2, respectively. The result presents a considerable improvements of 40% (20%) for low (High) Higgs mass over the luminosity gain since last summer (LP07).

Preliminary results for Winter 2008 conferences

I. INTRODUCTION

The CDF collaboration has performed several searches for Higgs boson production in data samples up to 2.4 fb^{-1} of integrated luminosity. Clearly it is necessary to combine the results of all the channels to maximize the search sensitivity. The search for $WH \to l\nu b\bar{b}$ has been updated with 1.9 fb^{-1}, while the $ZH \to \ell^+\ell^- b\bar{b}$ analyses use approximately 1 fb^{-1} [1, 2]. The $VH \to \nu\bar{\nu}b\bar{b}$ has been reanalyzed with 1.7 fb^{-1} using neural network to gain sensitivity [3]. The $g\bar{g} \to H \to W^+W^- \to l^+l^-\nu\bar{\nu}$ result uses approximately 2.4 fb^{-1} and a combined Matrix Element method and neural network approach to separate signal from the background events [4]. 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 with 2.0 fb^{-1} [5].

To combine the search results, we follow the same procedure that was used in the previous Run2 [6] and Run1 Higgs combination analysis [7]. 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 the neural network discriminator. 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]. 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 $gg \to H$ and vector boson fusion (VBF) processes.

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

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.

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 II: 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.

Gaussian densities constraining a given parameter to its expected value within some uncertainty and to be positive. The S indicates where additional shape systematic uncertainty is evaluated.

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.

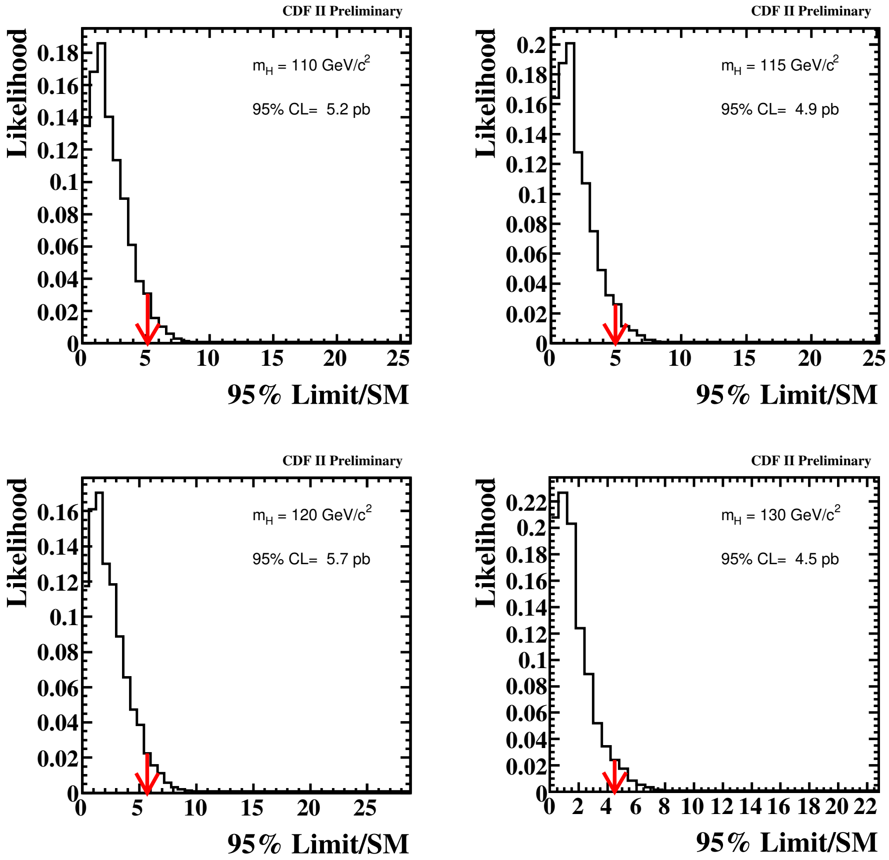

FIG. 1: The posterior densities for all channels combined for Higgs boson mass hypotheses between 110 and 130 GeV/c^2 where the arrows indicate the 95% credibility upper limit R_{95}.

III. EXPECTED UPPER LIMIT

To check the sensitivity of different channels, we calculate the median upper limits one would obtain from a large ensemble of experiments. In vthe 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.

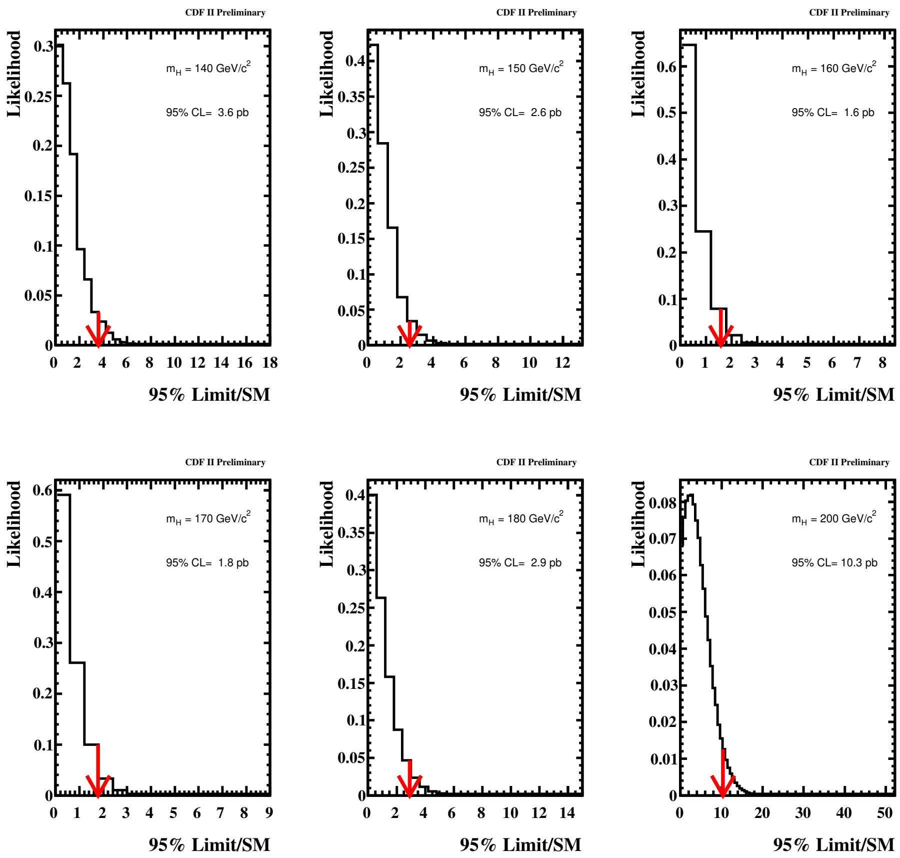

FIG. 2: The posterior densities for all channels combined for Higgs boson mass hypotheses between 140 and 200 GeV/c^2 where the arrows indicate the 95% credibility upper limit R_{95}.

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

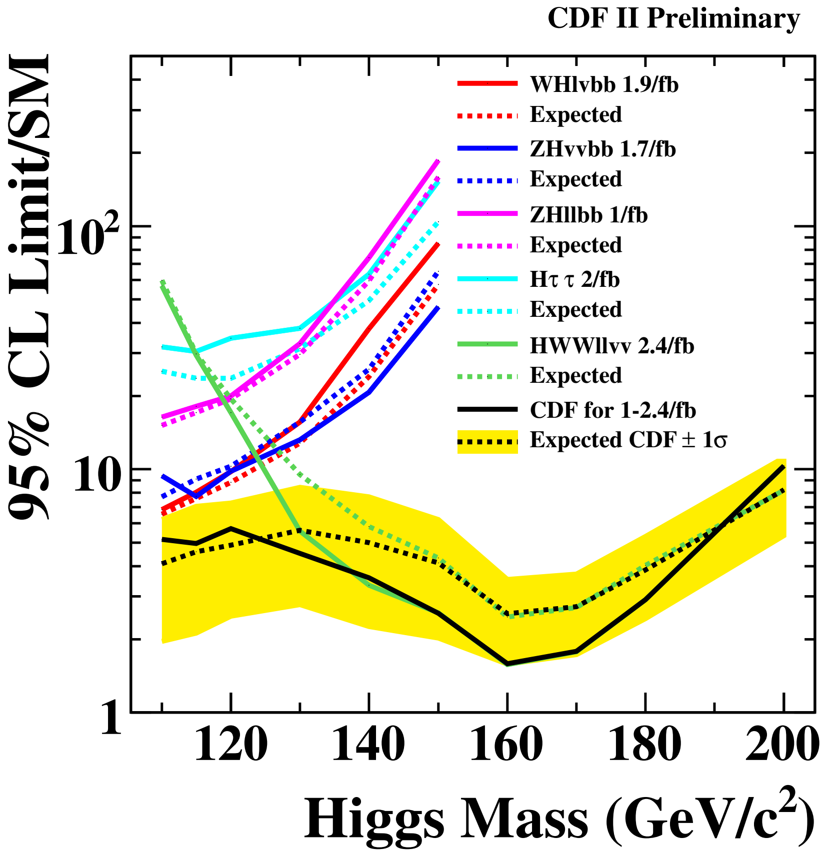

FIG. 3: The combined upper limit as function of Higgs boson mass hypotheses between 110 and 200 GeV/c^2 as well as the individual limits from individual channels.

IV. CONCLUSIONS

We have described a combination of several searches for Standard Model Higgs boson production at CDF using a data sample up to 2.4 pb^{-1} of integrated luminosity. The channels considered are the dominant ones: $WH \to l\nu b\bar{b}$, $ZH \to \nu\bar{\nu}b\bar{b}$, $ZH \to \ell^+\ell^- b\bar{b}$, $VH(VBF, ggH) \to \tau^+\tau^- + 2jet$, 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 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 5.0 (4.5) and 1.58 (2.55) higher than the Standard Model production cross sections for Higgs boson masses of 115 and 160 GeV/c^2, respectively. The results present a considerable improvement of 40% (20%) for low (High) Higgs mass over the luminosity gain since last summer (LP07) **??**.

V. ACKNOWLEDGEMENTS

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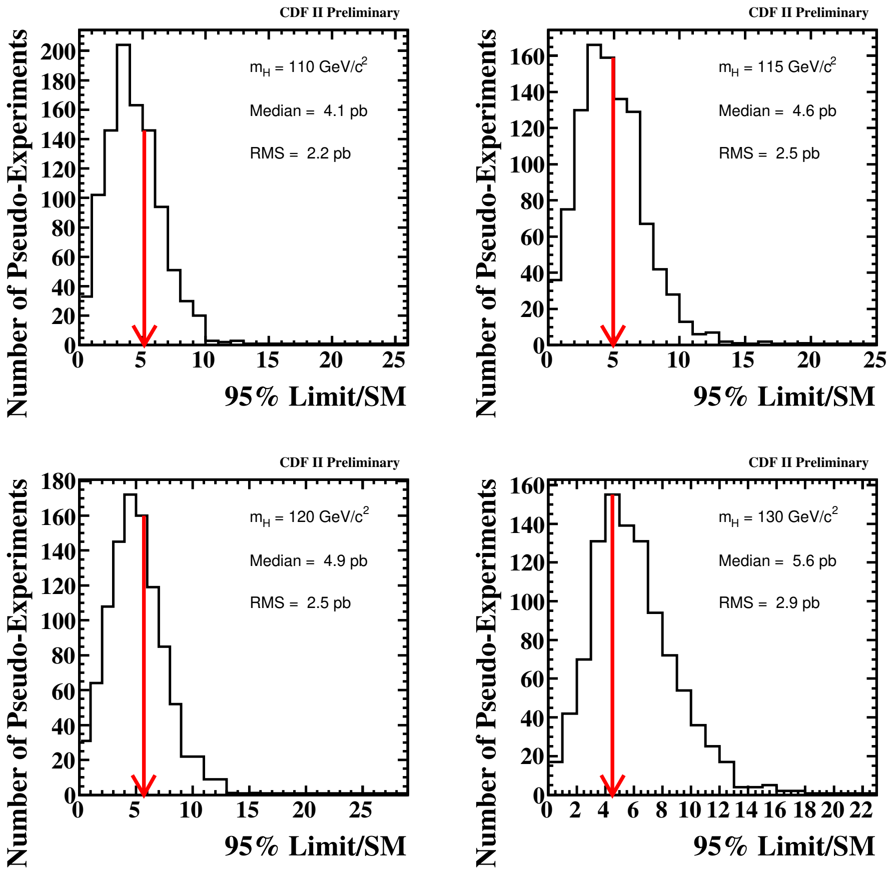

FIG. 4: The distributions of upper ratio limits from the pseudo-experiments for Higgs boson mass hypotheses between 110 and 130 GeV/c^2 where the arrows indicate the observed 95% upper limit from data.

Foundation; the Italian Istituto Nazionale di Fisica Nucleare; the Ministry of Education, Culture, Sports, Science and Technology of Japan; the Natural Sciences and Engineering Research Council of Canada; the National Science Council of the Republic of China; the Swiss National Science Foundation; the A.P. Sloan Foundation; the Bundesministerium für Bildung und Forschung, Germany; the Korean Science and Engineering Foundation and the Korean Research Foundation; the Particle Physics and Astronomy Research Council and the Royal Society, UK; the Russian Foundation for Basic Research; the Comision Interministerial de Ciencia y Tecnologia, Spain; and in part by the European Community's Human Potential Programme under contract HPRN-CT-20002, Probe for New Physics.

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[2] CDF Collaboration, "Search for ZH→ $\ell^+\ell^- b\bar{b}$ channel in 1 fb^{-1} of CDF Run 2 Data," CDF/ANAL/EXOTIC/PUBLIC/8422.

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[4] CDF Collaboration, "Search for H to WW Production Using 2.4 fb^{-1},"

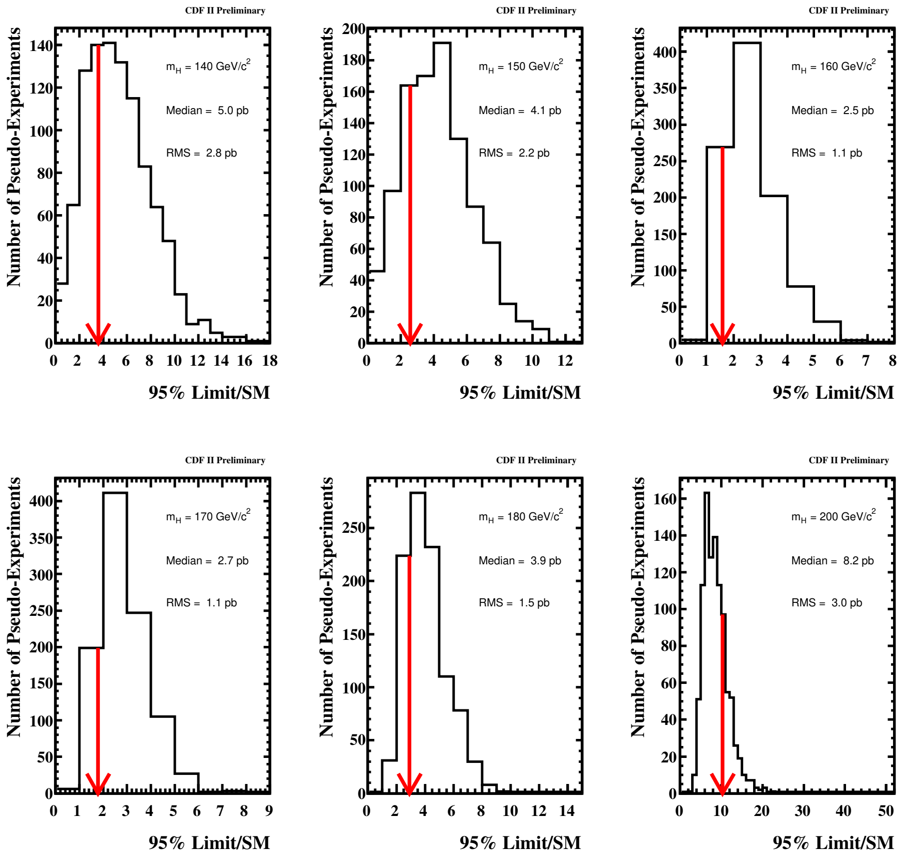

FIG. 5: The distributions of upper ratio limits from the pseudo-experiments for Higgs boson mass hypotheses between 140 and 200 GeV/c^2 where the arrows indicate the observed 95% upper limit from data.

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