CDF Note 10500

Search for the Standard Model Higgs in $l\nu + \tau\tau$ and $ll + \tau\tau$ channel

The CDF Collaboration
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We search for the standard model Higgs boson associated with vector boson using all lepton decay mode. Signal processes are $WH \to l\nu + \tau\tau$ and $ZH \to ll + \tau\tau$. We select 3 or 4 leptons including hadronic tau to pick candidate events out. To improve search sensitivity, we adopt Support Vector Machine (SVM) to discriminate signals from backgrounds.

Using $6.2fb^{-1}$ data, there was not a clear discrepancy between data and our background estimation. Therefore, we extract cross section limits on the standard model Higgs bosons production at 95% confidence level. The observed upper limits on assumption of $M_H = 115GeV/c^2$ is $18.5 \times (SM)$ at 95% confidence level while the expectation is 17.3, which is within one standard deviation.

I. INTRODUCTION

We can search for the Standard Model Higgs boson in several capable production channels and decay modes. Our target M_H region is $[100, 150] GeV/c^2$ which we call low-mass search region because $M_H = 89^{+35}_{-26} GeV/c^2$ (68% confidence level) as of July 2010 [1], as which top quark mass and W boson mass constrain, indirectly. In the low-mass search region the standard model Higgs boson dominantly decays into b quark pair, but it can also decay into a Tau pair ($\simeq 7\%$ for $M_H = 120 GeV/c^2$).

Here, we show the results of a search for the standard model Higgs boson associated with vector boson using all leptonic decay modes. The final states considered are $l\nu + \tau\tau$ and $ll + \tau\tau$ as in Figure 1.

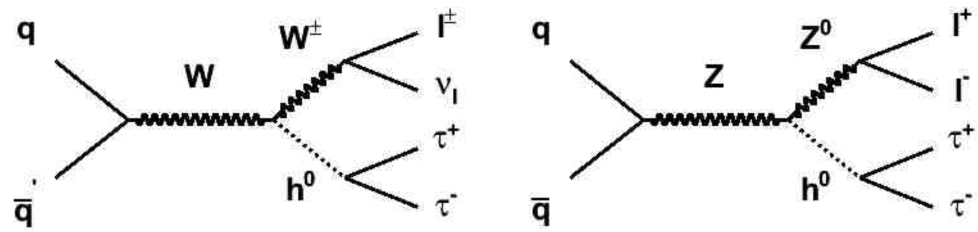

FIG. 1: Feynman diagrams of target process.

II. DETECTOR & DATA DESCRIPTION

The CDF II Detector is cylindrically and symmetrically surrounded around beam pipe by many different layers. Using the azimuthal angle ϕ and the pseudorapidity η, we describe the detector geometry. Whole description of CDF II detector can be found in [2].

Each of these layers work simultaneously with the other components of the detector; Silicon detector, Central Outer Tracker, Solenoid Magnet, Electromagnetic calorimeter, Hadronic calorimeter and Muon detector. The luminosity of $p\bar{p}$ collisions at CDF is measured by Cherenkov luminosity counters.

We conduct the analysis using an integrated luminosity of $6.2 fb^{-1}$ accumulated with CDF II detector from March 2002 through February 2010.

III. EVENT SELECTION

We require event quality, topological and kinematical condition. At first, we require vertex quality. Then, We require the number of leptons in an event, which is 3 or 4 leptons for WH and ZH processes respectively. Each lepton needs to have enough distance between each other in $\eta - \phi$ plane ($\Delta R(lepton, lepton) > 0.2$) and be close to z-vertex ($|\Delta z(vertex, lepton)| < 4.0cm$) and z position of each other ($|\Delta z(lepton, lepton)| < 4.0cm$). We also require the sum charge of leptons must be ± 1 for WH case and be 0 for ZH case. We require transverse missing energy significance just to clean up events, especially Drell-Yan and QCD processes. These are the minimal requirements designed to accept as many signal events as possible. We also use a multivariate technique to further discriminate signals from backgrounds.

After we select candidate events, we categorize these events to five sets; lll, $ll\tau_h$, $e\mu\tau_h$, $l\tau_h\tau_h$ and $LLLL$, which l denotes e or μ, and L denotes e, μ or τ_h.

Monte Carlo samples for our analysis have been generated by PYTHIA (v6.216) [3] with run-dependent CDF II detector simulation and overlayed minimum bias appropriately. Some of background samples (Z+jets and W+jets) are generated by using ALPGEN (v2.10) with PYTHIA parton showering.

Table I shows background estimation and observed events. Table II and III show the number of expected signal events in various mass points.

	3L				4L
	lll	$ll\tau$	$e\mu\tau$	$l\tau\tau$	$LLLL$
ZZ	6.55 ± 0.89	2.36 ± 0.41	0.22 ± 0.05	0.24 ± 0.05	0.92 ± 0.13
WZ	23.45 ± 3.10	3.78 ± 0.60	0.67 ± 0.11	0.53 ± 0.09	0.07 ± 0.02
WW	1.62 ± 0.35	1.77 ± 0.54	0.27 ± 0.10	0.50 ± 0.22	0.01 ± 0.01
$DY(ee)$	133.80 ± 20.26	84.50 ± 23.61	0.01 ± 0.01	0.96 ± 0.46	0.52 ± 0.12
$DY(\mu\mu)$	59.22 ± 9.24	55.58 ± 15.99	0.77 ± 0.33	1.09 ± 0.29	0.29 ± 0.07
$DY(\tau\tau)$	12.38 ± 1.49	22.95 ± 6.63	2.58 ± 1.06	7.69 ± 2.66	0.05 ± 0.02
$Z\gamma$	12.22 ± 1.98	4.95 ± 1.55	1.46 ± 0.63	0.60 ± 0.23	0.06 ± 0.02
$t\bar{t}$	19.01 ± 3.91	6.30 ± 1.73	0.55 ± 0.19	0.38 ± 0.15	0.24 ± 0.06
$W\gamma$	0.21 ± 0.06	0.27 ± 0.09	0.11 ± 0.05	0.03 ± 0.02	0.00 ± 0.00
$W + Jets$	11.22 ± 2.38	15.32 ± 4.65	0.38 ± 0.19	5.44 ± 2.03	0.00 ± 0.00
QCD	12.23 ± 9.19	27.43 ± 11.52	$0.00 + 1.32$	$4.83^{+5.35}_{-4.83}$	1.63 ± 1.04
total	291.91 ± 24.86	225.20 ± 31.90	$7.03^{+1.80}_{-1.32}$	$22.28^{+6.74}_{-5.91}$	3.80 ± 1.06
Data	284	203	8	16	6

TABLE I: The expected number of events for each lepton category. The notation of "l" in the above table means electrons and muons. The notation of "L", any charged leptons including hadronic tau (τ_h). Errors in table include all systematic uncertainties.

	3L				4L
	lll	$ll\tau$	$e\mu\tau$	$l\tau\tau$	$LLLL$
100	0.23 ± 0.03	0.34 ± 0.05	0.18 ± 0.02	0.20 ± 0.03	0.0028 ± 0.0007
105	0.21 ± 0.03	0.30 ± 0.04	0.16 ± 0.02	0.18 ± 0.02	0.0025 ± 0.0006
110	0.18 ± 0.02	0.27 ± 0.04	0.14 ± 0.02	0.16 ± 0.02	0.0018 ± 0.0005
115	0.16 ± 0.02	0.23 ± 0.03	0.12 ± 0.02	0.13 ± 0.02	0.0017 ± 0.0004
120	0.14 ± 0.02	0.19 ± 0.03	0.10 ± 0.01	0.11 ± 0.02	0.0015 ± 0.0004
125	0.11 ± 0.01	0.16 ± 0.02	0.08 ± 0.01	0.09 ± 0.01	0.0014 ± 0.0004
130	0.09 ± 0.01	0.12 ± 0.02	0.063 ± 0.008	0.07 ± 0.01	0.0010 ± 0.0002
135	0.066 ± 0.009	0.09 ± 0.01	0.048 ± 0.006	0.051 ± 0.007	0.0007 ± 0.0002
140	0.047 ± 0.006	0.066 ± 0.009	0.035 ± 0.005	0.037 ± 0.005	0.0005 ± 0.0001
145	0.032 ± 0.004	0.045 ± 0.006	0.024 ± 0.003	0.025 ± 0.003	0.00029 ± 0.00007
150	0.020 ± 0.003	0.028 ± 0.004	0.014 ± 0.002	0.016 ± 0.002	0.00019 ± 0.00005

TABLE II: Expected number of events for $WH \rightarrow all + \tau\tau$

IV. DISCRIMINATION

To discriminate signals from backgrounds in candidate events, we adopt Support Vector Machine as a multivariate technique.

a. Support Vector Machine[4] Machine learning can distinguish 2 categories. One is supervised learning, the other is unsupervised learning. Support Vector Machine (SVM) is a kind of supervised learning method. Basic concept of simple SVM is classifying given data into 2 categories in a hyperspace having dimension with the order of the number of input variables.

	3L				4L
	lll	$ll\tau$	$e\mu\tau$	$l\tau\tau$	$LLLL$
100	0.22 ± 0.03	0.25 ± 0.03	0.031 ± 0.004	0.04 ± 0.01	0.09 ± 0.01
105	0.20 ± 0.03	0.22 ± 0.03	0.027 ± 0.004	0.04 ± 0.01	0.08 ± 0.01
110	0.18 ± 0.02	0.19 ± 0.03	0.027 ± 0.004	0.033 ± 0.005	0.07 ± 0.01
115	0.15 ± 0.02	0.16 ± 0.02	0.021 ± 0.003	0.028 ± 0.004	0.06 ± 0.01
120	0.13 ± 0.02	0.14 ± 0.02	0.019 ± 0.003	0.025 ± 0.004	0.06 ± 0.01
125	0.10 ± 0.01	0.11 ± 0.01	0.016 ± 0.002	0.020 ± 0.003	0.05 ± 0.01
130	0.08 ± 0.01	0.09 ± 0.01	0.014 ± 0.002	0.016 ± 0.002	0.036 ± 0.005
135	0.059 ± 0.008	0.066 ± 0.009	0.010 ± 0.001	0.012 ± 0.002	0.026 ± 0.003
140	0.043 ± 0.006	0.046 ± 0.006	0.007 ± 0.001	0.009 ± 0.001	0.020 ± 0.003
145	0.028 ± 0.004	0.030 ± 0.004	0.0045 ± 0.0006	0.0061 ± 0.0009	0.013 ± 0.002
150	0.018 ± 0.002	0.019 ± 0.003	0.0027 ± 0.0004	0.0035 ± 0.0005	0.008 ± 0.001

TABLE III: Expected number of events for $ZH \rightarrow all + \tau\tau$

We use support vector machine in the TMVA tool kit (TMVA v4.0.7 & ROOT v5.27/04) for our analysis.

b. Training & Testing classifiers We prepare for eight trained classifiers to discriminate signal from backgrounds. Our training strategy is to discriminate signals from dominant background (Drell-Yan plus fake lepton), backgrounds (top pair production) have different kinematics and backgrounds (WZ/ZZ) have similar kinematics backgrounds.

In lll and $ll\tau$ cases, we have large contribution from Drell-Yan process (ee,$\mu\mu$) as shown in Table I. These cases include Drell-Yan plus one fake lepton, which is mostly making a fake of electron or hadronic tau. In $e\mu\tau$ and $l\tau\tau$ cases, there are smaller statistics than lll and $ll\tau$ cases, and we also have smaller MC statistics. These cases indicate such events that Z boson decays to $\tau\tau$ and jet makes a fake of hadronic tau. In 4 lepton case, WH signal process does not fall into much.

For lll and $ll\tau$ cases, we train 3 classifiers for each case, that is "VH vs WZ/ZZ", "VH vs Drell-Yan(ee,$\mu\mu$)" and "VH vs $t\bar{t}$". For $e\mu\tau$ and $l\tau\tau$ cases, we train 1 classifier. For 4 lepton case, we also train 1 classifier, which is trained using ZH Monte Carlo sample and all background Monte Carlo samples. About signal process WH/ZH, $WH \rightarrow L\nu + \tau\tau$ ($M_H = 120GeV/c^2$) and $ZH \rightarrow LL + \tau\tau$ ($M_H = 120GeV/c^2$) Monte Carlo samples are used to train. In whole, we train eight classifiers for analysis as in Table IV.

3L			4L
lll	$ll\tau$	$e\mu\tau$, $l\tau\tau$	$LLLL$
VH vs DY($ee,\mu\mu$) (f^{DY0}) 12 inputs	VH vs DY($ee,\mu\mu$) (f^{DY1}) 16 inputs	VH vs All Bkg (f^{AL0}) 12 inputs	ZH vs All Bkg (f^{AL1}) 20 inputs
VH vs $t\bar{t}$ (f^{TT0}) 9 inputs	VH vs $t\bar{t}$ (f^{TT1}) 16 inputs		
VH vs WZ/ZZ (f^{DB0}) 16 inputs	VH vs WZ/ZZ (f^{DB1}) 16 inputs		

TABLE IV: Training Categories. "V" stands for vector boson, "W/Z". DY stands for Drell-Yan. "All Bkg" means that all kind of background Monte Carlo samples are used for training. The number of input variables is also shown for each classifiers training. Each classifier has different set of input variables.

Each classifier f returns a response for i th input variables $\mathbf{x}_i$. For example, a classifier f^{DY0} which was trained by "VH vs Drell-Yan (ee,$\mu\mu$)" in lll case returns a response r^{DY0} as below.

$$r_i^{DY0} = f^{DY0}(\mathbf{x}_i)$$

We prepare for three classifiers for lll and $ll\tau$ categories, resulting in three responses for each event. So, we convolute three responses into one response using a simple function below.

$$g(x_1, x_2, x_3) = (x_1 \cdot x_2 + x_2 \cdot x_3 + x_3 \cdot x_1)/3.$$

Then, we get a response for i th event as below.

$$r_i = g(r_i^{DY0}, r_i^{TT0}, r_i^{DB0})$$

We finally have 5 responses for 5 lepton combination categories.

c. Responses in Control Region We choose a control region $\not{E}_T/\sum E_T \leq 1.0$ to confirm our background modeling and methodology. This control region has Drell-Yan process that is dominant background of this analysis and also almost negligible signal events is expected in this region. These are a good agreement for each lepton category.

From response distributions shown in Figure 2, we conclude that our modeling is reasonably well even though statistics is not enough for lll and $ll\tau$ cases. Therefore at this time we do not assign systematic uncertainty on methodology itself.

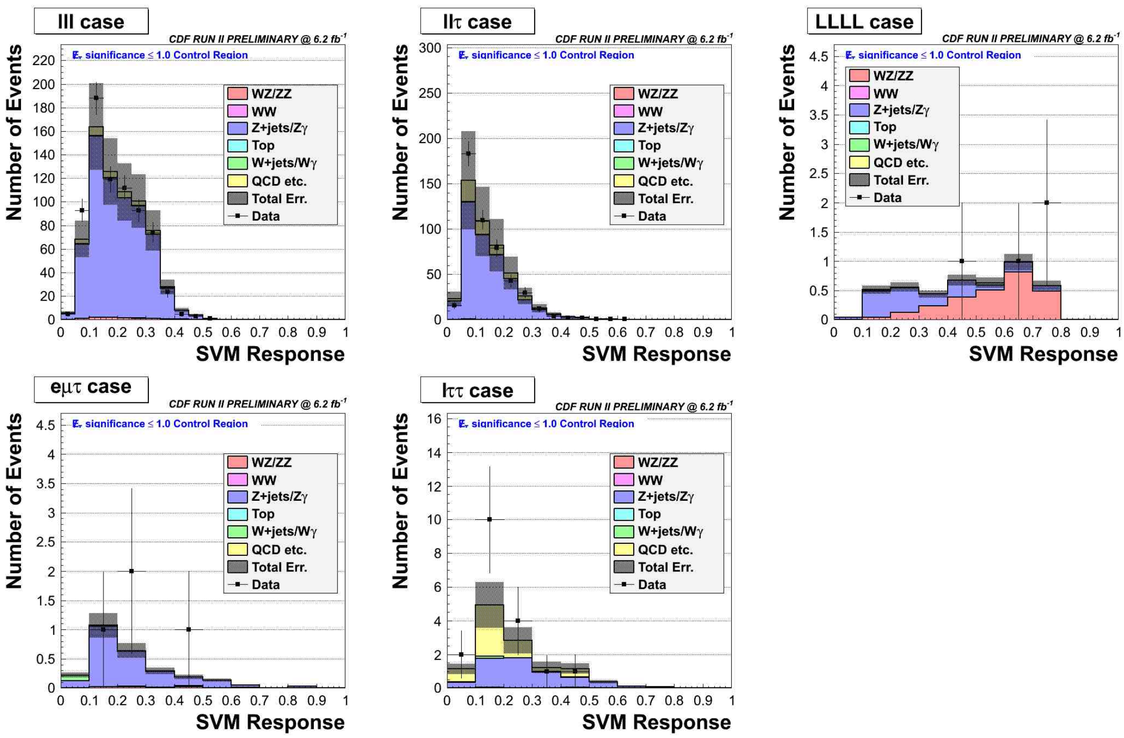

FIG. 2: Discrimination Plots for each category in control region.

d. Responses in Signal Region We show the response distribution of each category. In figures we show here, black line shows signals (VH) and colored histograms shows backgrounds. Signal histogram area is scaled by $200 \times \sigma(VH)$. Figure 3 shows the response distribution of lll case, $ll\tau$ case, $e\mu\tau$ case, $l\tau\tau$ case and $LLLL$ case in signal region. The lll case has more events than any other categories. As mentioned before, we unify 3 responses to 1 response in these case (lll and $ll\tau$) by using function $g(x_1, x_2, x_3) = x_1 \cdot x_2 + x_2 \cdot x_3 + x_3 \cdot x_1$. These distributions are discriminant templates.

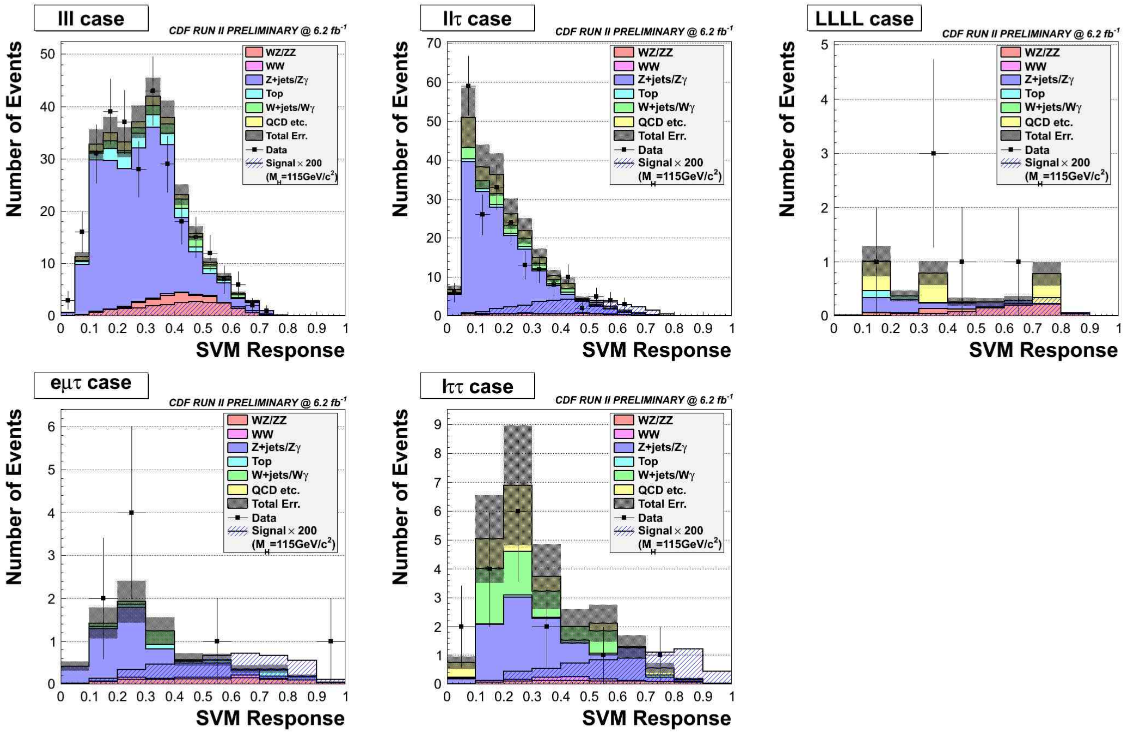

FIG. 3: Discrimination Plots for each category in signal region.

V. SYSTEMATIC UNCERTAINTIES

We distinguish 5 categories of candidate events, which are lll, $ll\tau$, $e\mu\tau$, $l\tau\tau$ and $LLLL$. The notation of "l" represent electron and muon, and the notation of "L" represent electron, muon and hadronic tau.

Some sources of systematic uncertainties are take into account in this analysis. About the integrated luminosity calculation, we assign 5.9% uncertainty. About the z-vertex cut efficiency, we assign 0.5% uncertainty. Uncertainties on trigger and lepton identification efficiency depend on lepton type and lepton combination. Our background estimation depends on fake lepton estimation based on MC samples. We assign the discrepancy between data and MC fake rates as the systematic uncertainty of jet fake rate. Uncertainty from parton distribution function (PDF) is taken into account for the Standard Model Higgs signal. Uncertainties on initial and final state radiation (ISR/FSR) for signal process are very small.

The systematic uncertainties for each category are summarized in Table V, VI,VII,VIII and IX.

VI. RESULTS

We do not clearly see any significant discrepancy between data and our background estimation. Therefore, we extract the expected and observed limit at 95% confidence level.

At first, we define the likelihood function from the response distributions, here.

For i th bin of responses, the expected number of events (μ_i) including signals is evaluated as below.

$$\mu_i = \sum_{k}^{N_B} f_i^k N^k + \sum_{l}^{N_S} f_i^l \cdot (\epsilon^l \cdot \sigma^l \cdot \int L dt),$$

lll case	Systematic Uncertainties (%)													
	ZZ	WZ	WW	$DY(ee)$	$DY(\mu\mu)$	$DY(\tau\tau)$	$Z\gamma$	tt	$W\gamma$	W	WH	ZH	VBF	H
Luminosity	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9
σ	6.0	6.0	6.0	5.0	5.0	5.0	5.0	10.0	5.0	5.0	5.0	5.0	10.0	10.0
σ(NLO)	10.0	10.0	10.0	-	-	-	11.0	10.0	11.0	-	-	-	-	-
$\|Z_{vertex}\|$	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
$\epsilon^{trigger}$	1.5	1.4	1.5	1.3	1.5	1.4	1.4	1.4	1.4	1.5	1.4	1.5	1.4	1.4
$s^{leptonID}$	0.7	0.7	0.7	0.6	0.7	0.7	0.7	0.7	0.6	0.7	0.7	0.7	0.7	0.7
$s^{Fakelepton}$	2.1	0.6	15.5	11.9	12.2	12.6	6.9	13.5	12.7	18.7	2.1	1.3	14.0	11.2
JES	1.7	0.0	0.3	0.7	2.2	0.3	5.1	0.2	1.9	0.2	0.1	0.02	1.4	0.9
MC stat	2.2	1.2	7.4	0.8	1.1	2.9	2.4	1.7	19.6	3.4	1.7	1.4	5.7	13.1
PDF	-	-	-	-	-	-	-	-	-	-	1.2	0.9	2.2	4.9
ISR/FSR	-	-	-	-	-	-	-	-	-	-	0.1	0.3	0.3	0.02

TABLE V: Systematic Uncertainties on acceptance for lll case of MC process

$ll\tau$ case	Systematic Uncertainties (%)													
	ZZ	WZ	WW	$DY(ee)$	$DY(\mu\mu)$	$DY(\tau\tau)$	$Z\gamma$	tt	$W\gamma$	W	WH	ZH	VBF	H
Luminosity	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9
σ	6.0	6.0	6.0	5.0	5.0	5.0	5.0	10.0	5.0	5.0	5.0	5.0	10.0	10.0
σ(NLO)	10.0	10.0	10.0	-	-	-	11.0	10.0	11.0	-	-	-	-	-
$\|Z_{vertex}\|$	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
$\epsilon^{trigger}$	1.1	1.1	1.0	1.0	1.0	1.1	1.1	1.0	0.8	1.0	1.2	1.2	1.2	1.1
$s^{leptonID}$	2.4	2.3	2.4	2.4	2.4	2.4	2.4	2.4	2.3	2.4	2.4	2.4	2.4	2.4
$s^{Fakelepton}$	10.7	8.0	26.7	26.0	26.6	15.1	27.1	22.4	22.8	28.7	2.9	2.3	15.1	13.6
JES	1.3	1.1	0.0	3.2	5.1	0.6	6.6	0.1	2.0	0.2	0.1	0.03	0.6	0.4
MC stat	3.7	2.9	7.6	1.5	1.7	2.2	4.1	3.1	20.0	3.1	1.5	1.4	3.8	9.4
PDF	-	-	-	-	-	-	-	-	-	-	1.2	0.9	2.2	4.9
ISR/FSR	-	-	-	-	-	-	-	-	-	-	1.3	2.1	0.6	0.2

TABLE VI: Systematic Uncertainties on acceptance for $ll\tau$ case of MC process

$e\mu\tau$ case	Systematic Uncertainties (%)													
	ZZ	WZ	WW	$DY(ee)$	$DY(\mu\mu)$	$DY(\tau\tau)$	$Z\gamma$	$t\bar{t}$	$W\gamma$	W	WH	ZH	VBF	H
Luminosity	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9
σ	6.0	6.0	6.0	5.0	5.0	5.0	5.0	10.0	5.0	5.0	5.0	5.0	10.0	10.0
σ(NLO)	10.0	10.0	10.0	-	-	-	11.0	10.0	11.0	-	-	-	-	-
$\|Z_{vertex}\|$	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
$\epsilon^{trigger}$	1.4	1.4	1.1	1.1	1.3	1.1	1.4	1.1	1.0	0.7	1.3	1.3	1.2	1.2
$s^{leptonID}$	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
$s^{Fakelepton}$	9.0	6.5	26.6	20.8	31.4	25.2	39.4	27.8	19.3	41.9	1.6	2.5	28.5	29.2
JES	0.0	0.3	2.2	0.0	0.8	1.5	0.5	0.8	0.0	0.0	0.2	0.1	1.7	0.0
MC stat	12.9	7.2	20.9	57.7	12.6	7.7	10.2	12.4	35.4	25.8	2.1	3.9	13.0	44.7
PDF	-	-	-	-	-	-	-	-	-	-	1.2	0.9	2.2	4.9
ISR/FSR	-	-	-	-	-	-	-	-	-	-	0.6	0.2	0.1	0.0

TABLE VII: Systematic Uncertainties on acceptance for $e\mu\tau$ case of MC process

where the notation of k and l represents kinds of backgrounds (WZ, ZZ, Z+fake and so on) and signals, and N_B and N_S shows the number of kinds of backgrounds and signals, and f represent the expected fraction in bin, and ϵ^l is the detection efficiency including acceptance, trigger efficiency and

$l\tau\tau$ case	Systematic Uncertainties (%)													
	ZZ	WZ	WW	$DY(ee)$	$DY(\mu\mu)$	$DY(\tau\tau)$	$Z\gamma$	tt	$W\gamma$	W	WH	ZH	VBF	H
Luminosity	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9
σ	6.0	6.0	6.0	5.0	5.0	5.0	5.0	10.0	5.0	5.0	5.0	5.0	10.0	10.0
σ(NLO)	10.0	10.0	10.0	-	-	-	11.0	10.0	11.0	-	-	-	-	-
$\lvert Z_{vertex} \rvert$	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
$\epsilon^{trigger}$	1.0	1.1	0.9	1.0	1.1	1.1	1.1	1.0	0.7	0.9	1.1	1.1	1.1	1.1
$s^{leptonID}$	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3
$s^{Fakelepton}$	10.4	6.8	38.1	43.3	39.9	24.8	32.8	34.2	28.8	34.8	3.1	5.9	28.1	26.3
JES	5.5	0.0	0.0	3.3	1.6	1.2	1.6	0.0	0.0	1.1	0.1	0.6	1.8	1.7
MC stat	12.5	8.1	16.9	18.3	12.5	4.9	12.6	14.7	70.7	8.7	2.0	3.3	9.4	18.3
PDF	-	-	-	-	-	-	-	-	-	-	1.2	0.9	2.2	4.9
ISR/FSR	-	-	-	-	-	-	-	-	-	-	1.2	0.5	0.4	0.04

TABLE VIII: Systematic Uncertainties on acceptance for $l\tau\tau$ case of MC process

$LLLL$ case	Systematic Uncertainties (%)													
	ZZ	WZ	WW	$DY(ee)$	$DY(\mu\mu)$	$DY(\tau\tau)$	$Z\gamma$	tt	$W\gamma$	W	WH	ZH	VBF	H
Luminosity	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	-	-	5.9	5.9	5.9	-
σ	6.0	6.0	6.0	5.0	5.0	5.0	5.0	10.0	-	-	5.0	5.0	10.0	-
σ(NLO)	10.0	10.0	10.0	-	-	-	11.0	10.0	-	-	-	-	-	-
$\lvert Z_{vertex} \rvert$	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	-	-	0.5	0.5	0.5	-
$\epsilon^{trigger}$	1.5	1.4	0.7	1.3	1.4	1.2	1.5	1.4	-	-	1.3	1.4	1.0	-
$s^{leptonID}$	1.4	1.2	2.4	1.2	1.4	1.8	1.9	1.0	-	-	2.0	2.2	1.9	-
$s^{Fakelepton}$	2.0	13.8	26.7	20.8	21.8	23.2	17.5	18.1	-	-	15.8	1.2	18.9	-
JES	0.3	0.0	0.0	1.9	0.7	0.0	4.6	0.0	-	-	0.0	0.0	0.0	-
MC stat	5.8	17.1	100	6.9	8.3	23.6	30.2	12.5	-	-	15.0	2.1	40.8	-
PDF	-	-	-	-	-	-	-	-	-	-	1.2	0.9	2.2	-
ISR/FSR	-	-	-	-	-	-	-	-	-	-	0.01	0.4	0.02	-

TABLE IX: Systematic Uncertainties on acceptance for $LLLL$ case of MC process

so on, and $\int Ldt$) is the integrated luminosity, and σ^l is the cross section of signals, which are WH, ZH, VBF and ggH.

Then, we define the likelihood function for each lepton category as below.

$$L(\frac{\sigma}{\sigma_{SM}}) = \int \cdots \int \prod_{i=1}^{N_{bin}} \frac{\mu_i^{N_i}}{N_i!} e^{-\mu_i} \prod_{k=1}^{N_B} G(N^k, \Delta^k) dN_k \prod_{l=1}^{N_S} G(\frac{\sigma^l}{\sigma_{SM}} N^l, \Delta^l) dN_l$$

Δ^k and Δ^l show the uncertainties of each source correlation under consideration. The function G shows Gaussian function; we fluctuate by the expected uncertainties (Δ^k for each background and Δ^l for each signal). N_i shows the number of observed events for i th bin. About signal cross section (σ^l), we assume these are 100% correlated. So, we use the same ratio ($\frac{\sigma}{\sigma_{SM}}$) for signal processes, which means $\frac{\sigma^l}{\sigma_{SM}} = \frac{\sigma}{\sigma_{SM}}$ in above equation.

As above, we define 5 likelihoods (L_0,L_1,L_2,L_3 and L_4) from each response distribution. Then, we simultaneously fit for likelihoods of 5 categories into global likelihood (L_g).

$$L_g = L_0 \times L_1 \times L_2 \times L_3 \times L_4$$

We extract the expected 95% confidence level limit from binned likelihood (L_g) by pseudo experiments. In pseudo experiment, we evaluate the expected number of events by adding the expected number of events for each background source, which is fluctuated with Gaussian function by uncertainties, then the total number of events (N_i) in each bin for one pseudo experiment is determined within Poisson fluctuations.

We summarized the expected and observed upper limit from L_g in Table X and Figure 4.

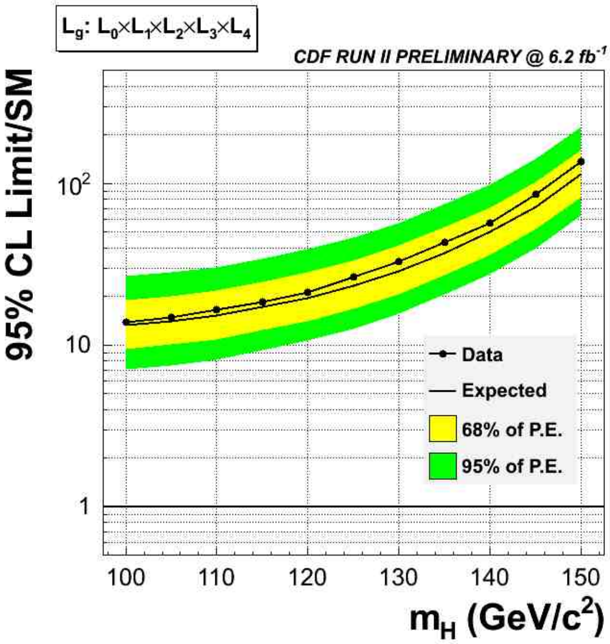

FIG. 4: Cross Section Limit by Global Likelihood (L_g).

L_g	Expected limit/σ(SM)					Observed limit/σ(SM)
M_H (GeV/c^2)	-2σ	-1σ	median	$+1\sigma$	$+2\sigma$	
100	7.1	9.5	13.3	19.1	26.7	13.9
105	7.5	10.1	14.1	20.1	28.4	14.9
110	8.2	10.9	15.3	21.8	30.4	16.6
115	9.4	12.4	17.3	24.7	34.5	18.5
120	10.7	14.2	19.7	28.4	39.4	21.2
125	12.7	16.8	23.3	33.6	46.5	26.5
130	15.7	20.8	28.7	41.4	57.0	33.0
135	20.6	27.1	37.5	54.1	74.6	43.2
140	27.6	36.2	50.3	70.8	98.6	57.3
145	40.1	52.1	72.1	102	141.6	85.4
150	63.1	82.5	113.8	160.7	222.9	136.6

TABLE X: Expected and Observed limit @ 95% C.L.

VII. CONCLUSIONS

We have shown a search for the Standard Model Higgs boson associated with vector boson in all leptonic decay mode; $l\nu + \tau\tau$ and $ll + \tau\tau$ final state using $6.2 fb^{-1}$ data accumulated by CDF Run II detector. Our candidate events are 3 or 4 leptons including hadoronically decaying tau leptons.

The number of expected background events was totally 550 ± 41 events. On the other hand, we observed total 517 events in CDF Run II data. As we also mentioned previous section, the number of observed events were within one standard deviation of our estimation. There is no significant excess that would provide a standard model Higgs boson. Therefore, we extracted the cross section limit at 95% confidence level ($\sigma(95\%C.L.)/\sigma(SM) \times B(H \to \tau\tau)$).

The observed cross section upper limit on assumption of $M_H = 115GeV/c^2$ is $18.5 \times \sigma(SM)$ at 95% confidence level while the expectation is $17.3^{+7.3}_{-4.9}$.

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