Combined Limit on Standard Model Higgs Production at CDF

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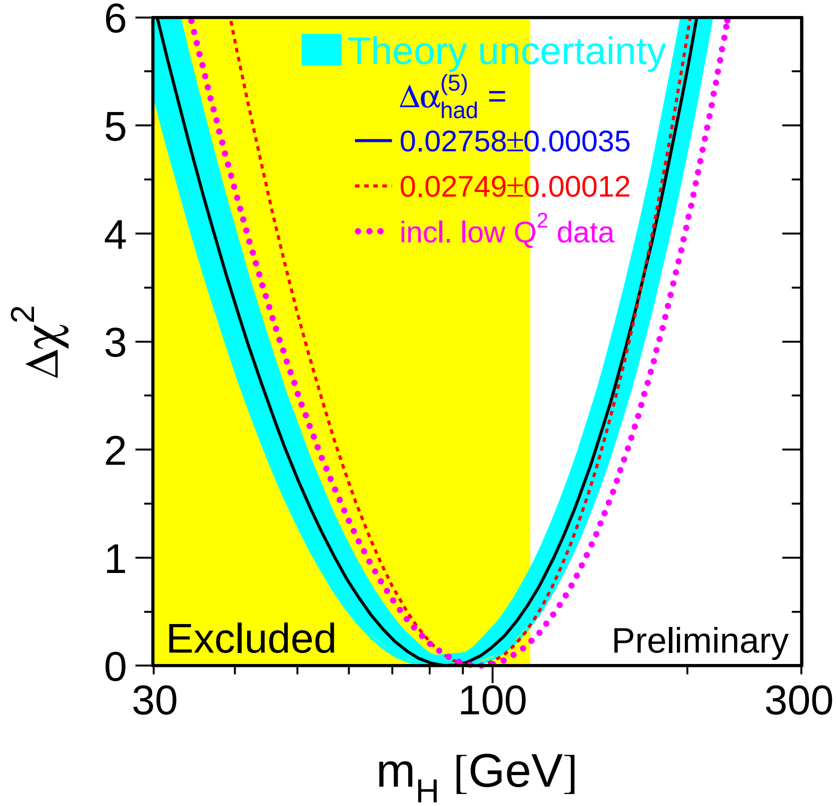
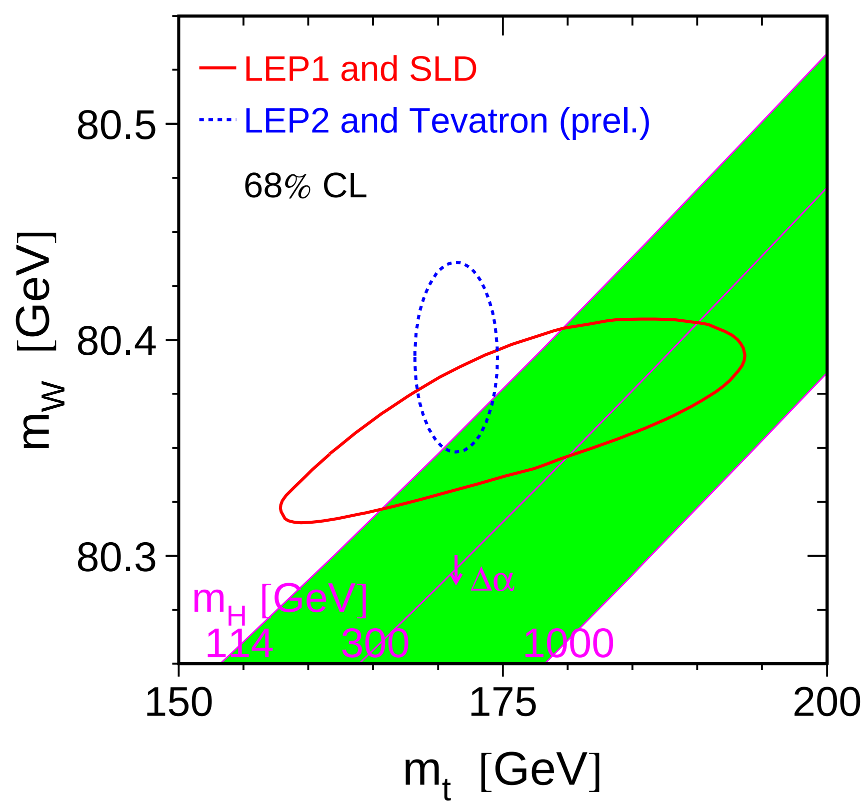
Introduction

- The corner stone of Standard Model is electroweak symmetry breaking (EWSB).
- SM predicts the existence of Higgs boson, but requires "new physics" to stabilize its mass (the hierarchy problem).
- Without it, the W, Z bosons would be massless.
- Precision tests of electroweak theory show no signs of deviation and predict a low mass Higgs boson.
- Possible source of new physics:
  - SUSY and its variants
  - Extra dimensions
  - Little Higgs ($m_h \approx m_t$, t' and other Higgs at TeV scale)
  - Higgsless ...
- Experimental inputs are crucial for determining the future directions (Tevatron, LHC, ILC...)

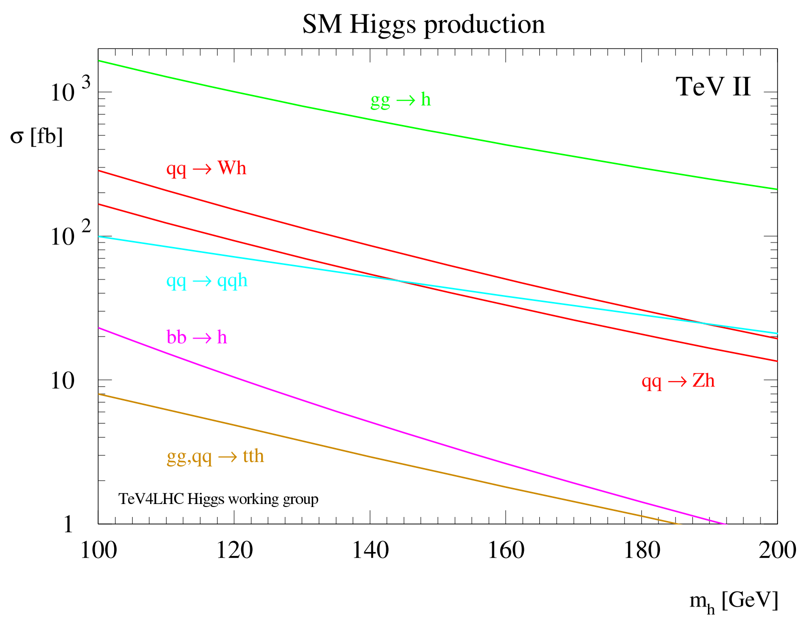
Higgs Mass Limit

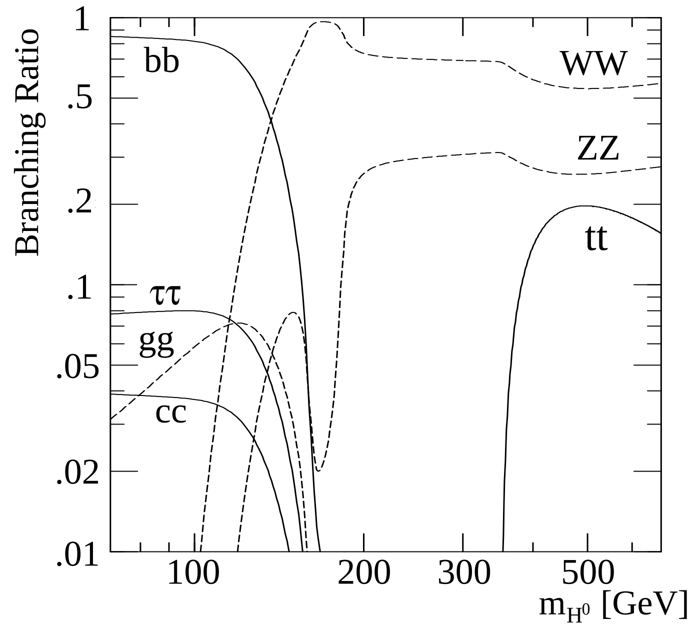




- Global fit to electroweak data with latest $M_{top} = 171.4 \pm 2.1$ GeV/c^2
- Best fit of $M_h = 85^{+39}_{-28}$, or $M_h < 166$ GeV/c^2 at 95% C.L.
- LEP excludes $M_h \leq 114.4$ GeV at 95% C.L.
- The Higgs boson remains elusive, but the data prefers a low mass Higgs that the discovery may be just in the corner.

Higgs Production and Search Strategies



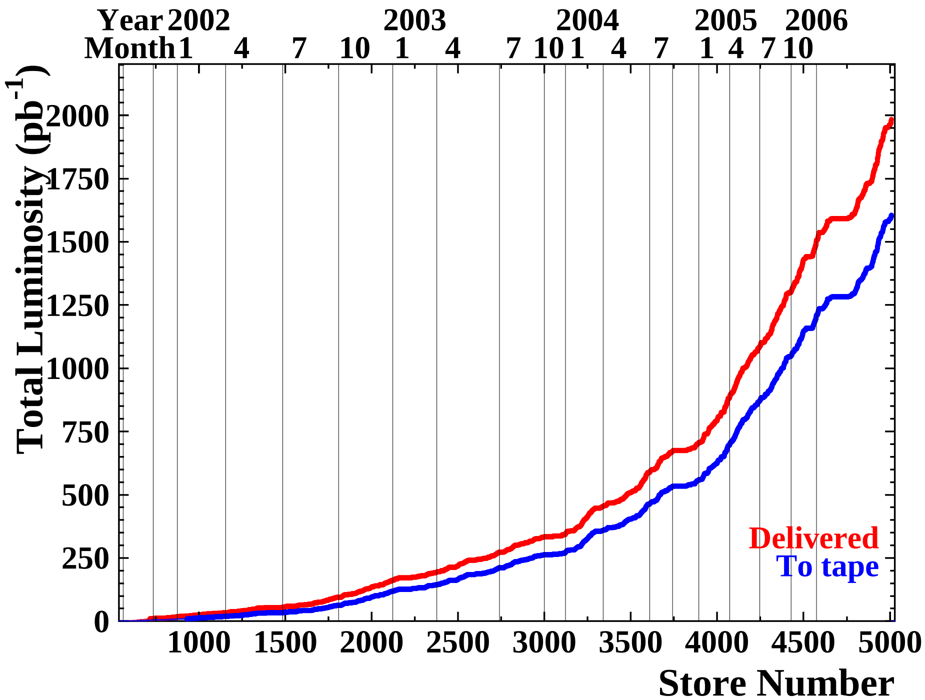


- $M_h < 130$ GeV: $h \to b\bar{b}$
  - Wh, Zh are most accessible, easy to trigger
  - Excellent b-tag efficiency and dijet mass resolution

- $M_h > 130$ GeV: $h \to WW^*$
  - Exploit the large $\sigma(gg \to h)$
  - Identify clean final states with leptons

- Very Challenging...

Run2 Performance



- Tevatron are doing well. The record peak luminosity exceeded $2.3 \times 10^{32} cm^{-2} s^{-1}$
- CDF recorded > 1.5 fb^{-1} on tape, but results shown here mostly based on $\approx 1 fb^{-1}$, up to Feb. 2006.
- Total expected int luminosity 4 - 8 fb-1 in 2009

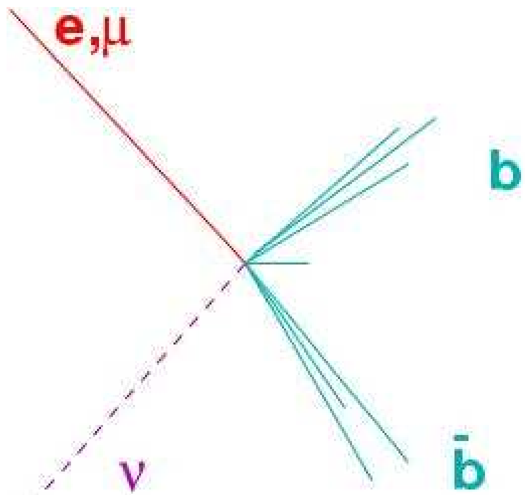
Recent CDF Run2 Higgs Results

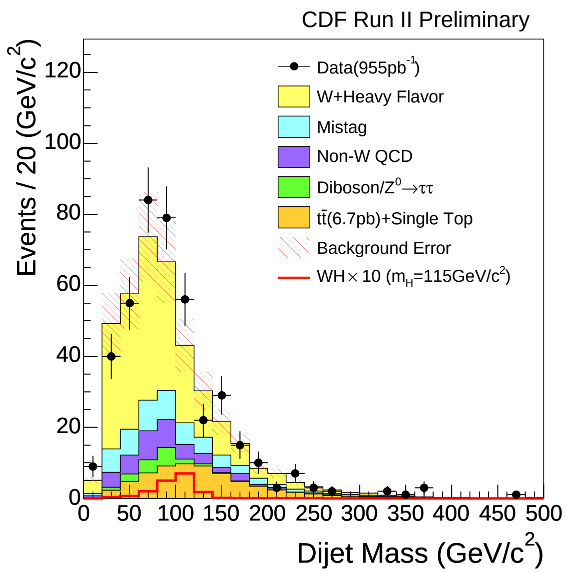
- CDF have reported direct searches for SM Higgs production in many different final states with sufficient integrated luminosity ($\approx 1 fb^{-1}$)
  - Search for SM Higgs Boson in WH at CDF [360] (Yoshiaki Kusakabe)
  - Higgs Search in the ZH$\rightarrow l^+l^-b\bar{b}$ at CDF [462] (Jonathan Efron)
  - Search for SM Higgs in $ZH \rightarrow b\bar{b} + \not{E}_T$ at CDF [365] (Viktor Veszpremi)
  - $gg \rightarrow H \rightarrow W^+W^- \rightarrow l^+l^-\nu\nu$: 360 pb^{-1}

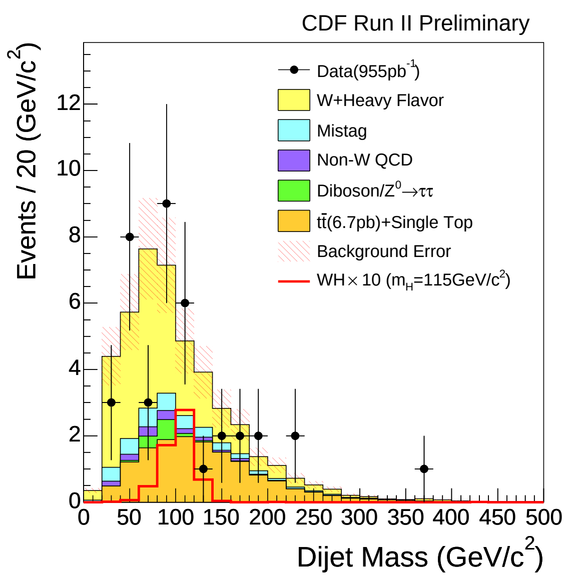
- A combination limit would significantly improve the individual limits for CDF

- Apologized for not including $ttH \rightarrow ttb\bar{b}$, $WH \rightarrow WWW$, $H \rightarrow \tau^+\tau^-$ this time. Will do next around for sure.

$WH \rightarrow l\nu b\bar{b}$

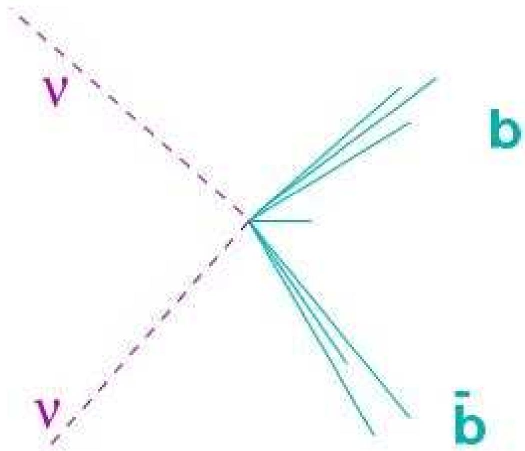


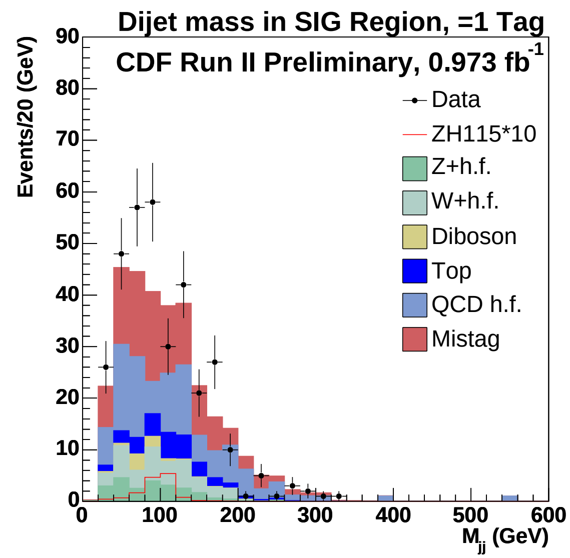


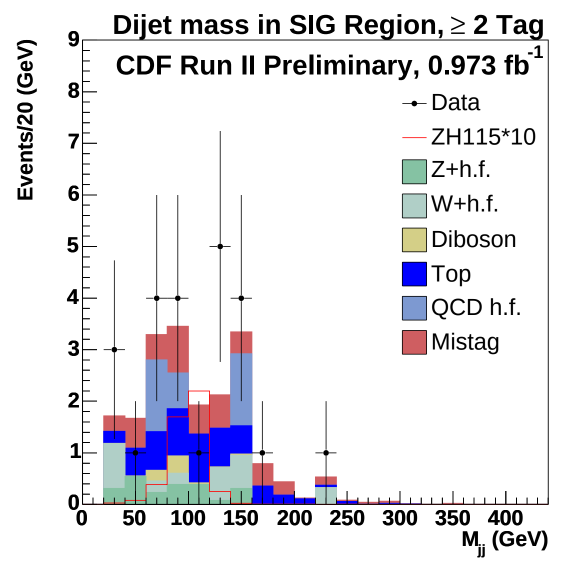


- Selecting $P_T(lepton) > 20$, $\not{E}_T > 20$ GeV, 2jet
- Divide one NN b-tagged jets and doule secvtx tagged jets
- Events agree with the expectation.

$ZH \rightarrow \nu\bar{\nu}b\bar{b}$

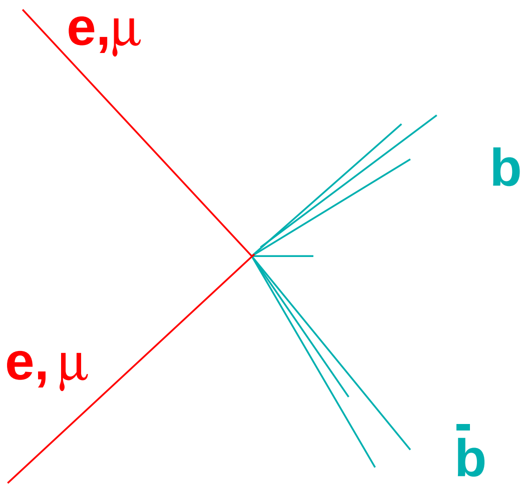


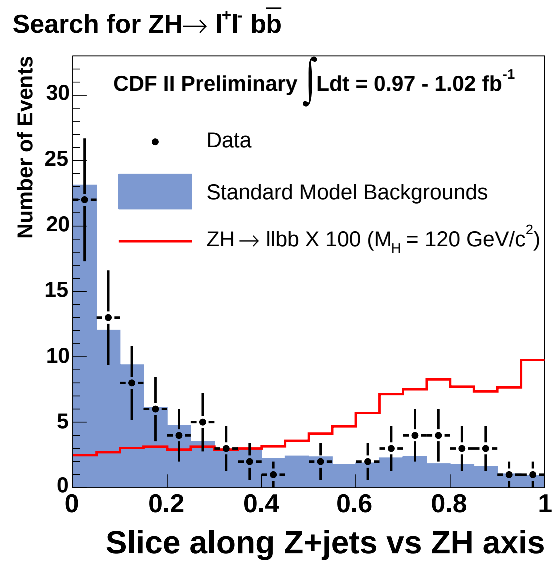


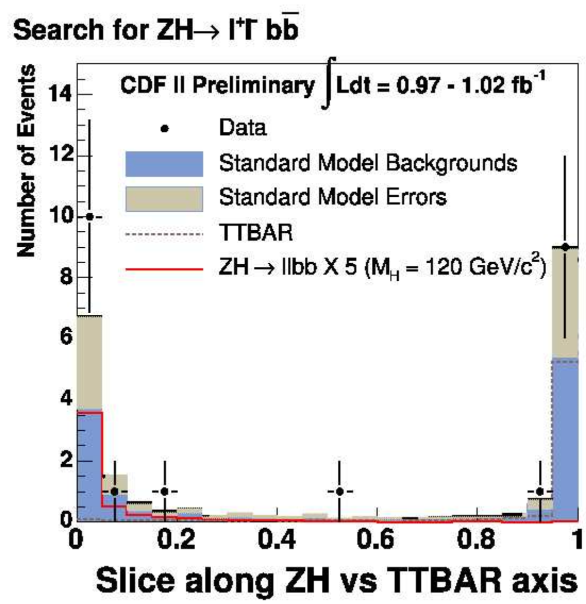


- Veto leptons, $\not{E}_T > 55$ GeV, $E_{j1(j2)} > 35(20)$ GeV, b-tagging.
- Significant contributions from $WH \rightarrow l\nu b\bar{b}$ where lepton is missing
- Events agree with the expectation.

$ZH \to l^+l^-b\bar{b}$

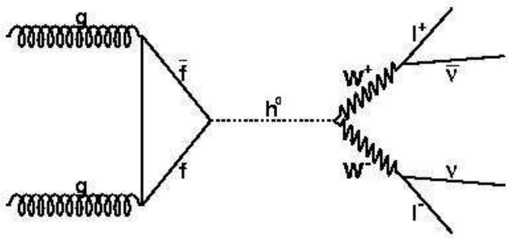


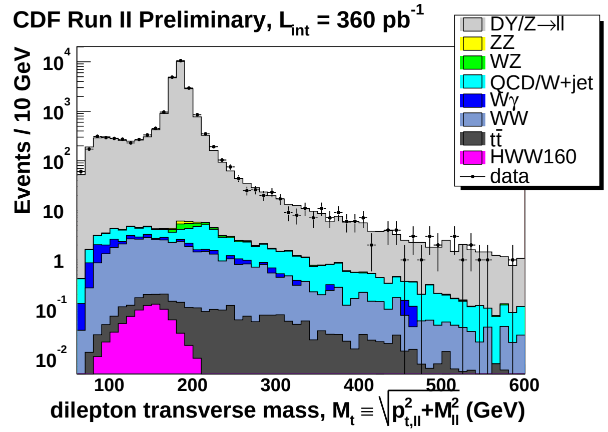


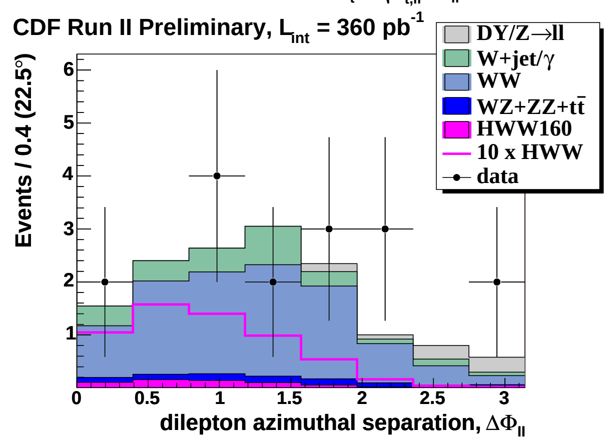


- Selecting $Z \to l^+l^-$ and $H \to b\bar{b}$
- Fully reconstructed events and neural network in 2-d to reject Z+jets and $t\bar{t}$ backgrounds.
- Events agree with the expectation.

$WW \rightarrow l^+l^-\nu\bar{\nu}$

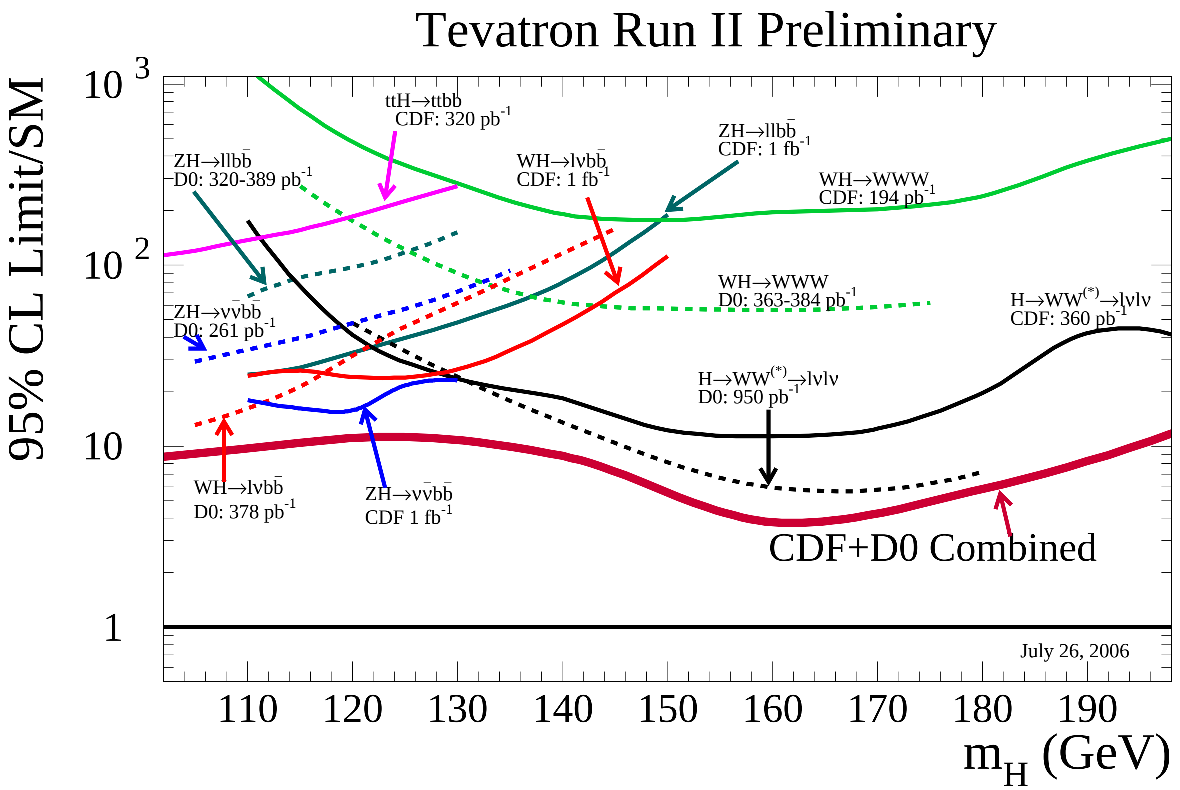






- Take full advantage of large $\sigma(gg \rightarrow h)$
- Two high pt isolated lepton (e or μ) + large $\not{E}_T$
- Major background: W^+W^- production
- Exploit spin correlations of $h \rightarrow W^+W^-$

Summary of Tevatron Higgs Results



- What we measure: the ratio of 95% upper limit on Xsec times branching ratio to SM.
- Assume the ratio the same for different channels, so we can combine them statistically.
- 10% is assigned to $g \rightarrow H \rightarrow W^+W^-$ cross section (NNLO).

Systematic Uncertainties for Combination

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	(1-20)	(1.6-20)	6.0	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	20	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)

- The positive value means correlated, the negative value means uncorrelated
- The results seems insensitive to these correlations changing from 100% to 0%

Special Treatment Shape Uncertainties

- For $ZH \rightarrow l^+l^-b\bar{b}$ with neural network analysis, there is additional systematic uncertainties due to the background shape.
- Estimated the limit change using pseudo-experiment with one shape against another.
- Either implemented as additional systematic on the signal or random sampling two shapes (alpgen*random +(1-random)*pytha).
- Both give almost identical upper limit.

Technique for Limit Combination

- Bayesian framework
  - Use Bayesian posterior probability
  - Assume flat prior density for the number of Higgs events
- Combined Binned Poisson Likelihood:

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

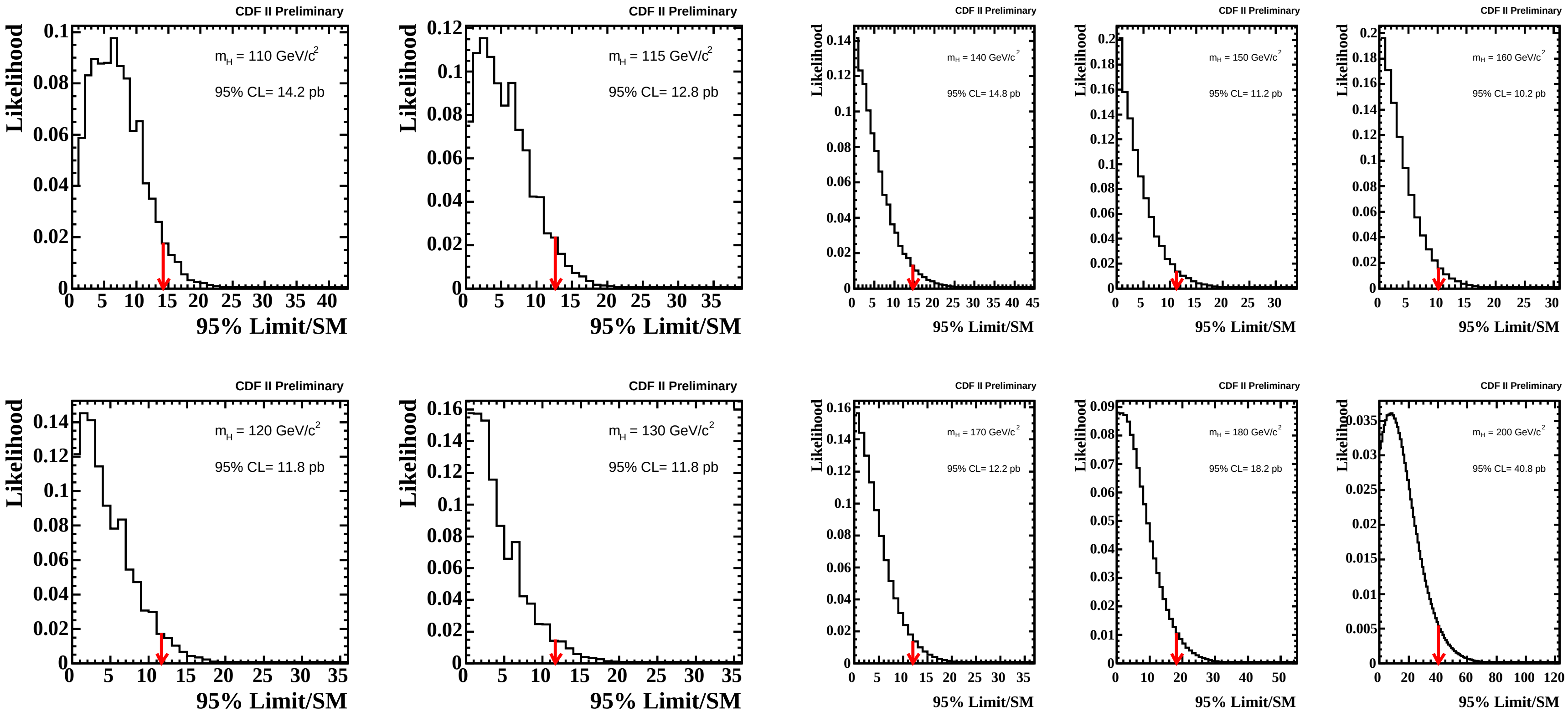
- Combined Posterior Density Function:

$$p(R|\vec{n}) = \int d\vec{s} \int d\vec{b} \mathcal{L}(R,\vec{s},\vec{b}|\vec{n}) \times s_{tot} / \int dR \int d\vec{s} \int d\vec{b} \mathcal{L}(R,\vec{s},\vec{b}|\vec{n}) \times s_{tot}$$

- 95% Credibility Upper Limit R_{95}:

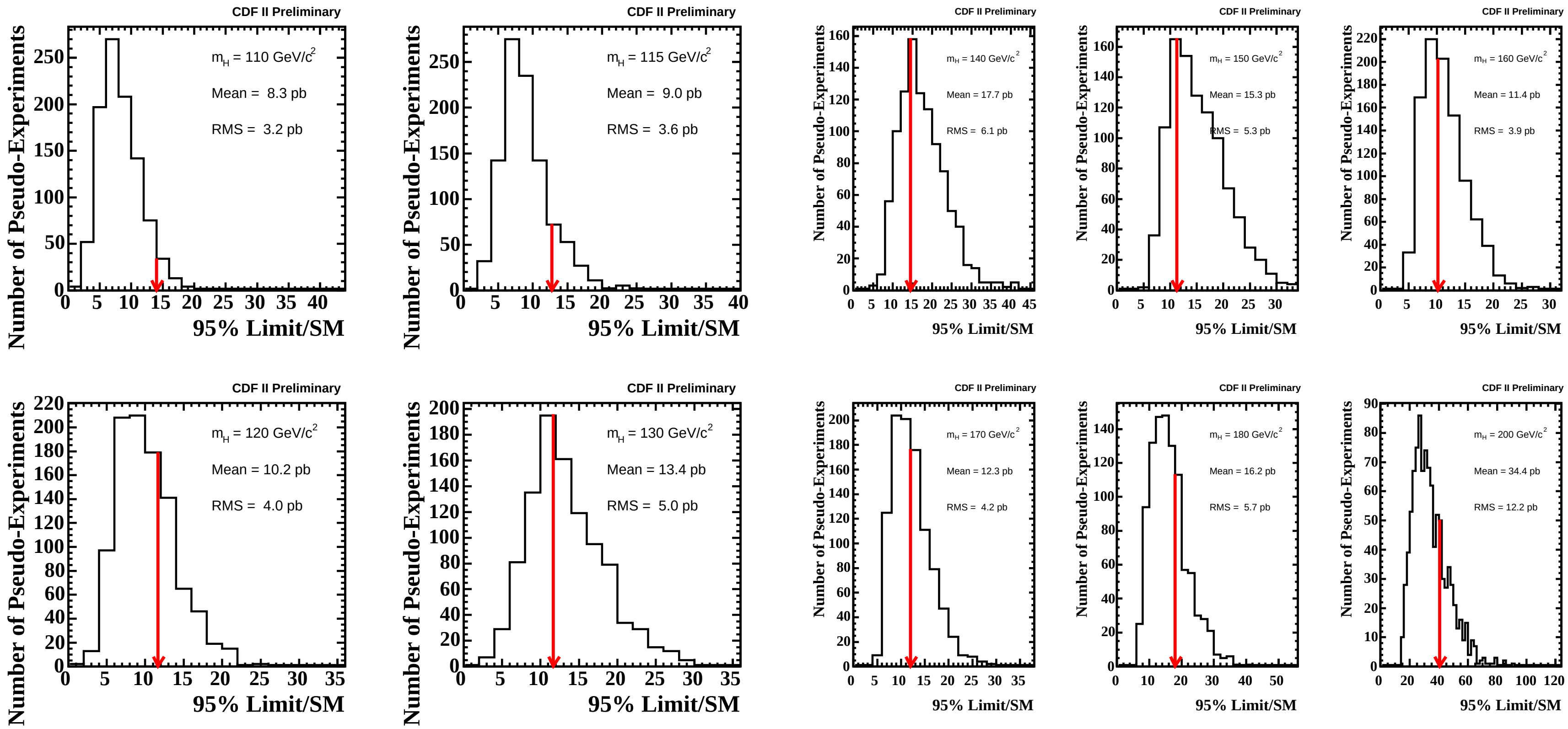
$$\int_0^{R_{95}} p(R|\vec{n}) dR = 0.95.$$

Likelihood of Combined Fit



- Likelihood vs R as M_H (red line: 95% upper limit).

Pseudo-experiments



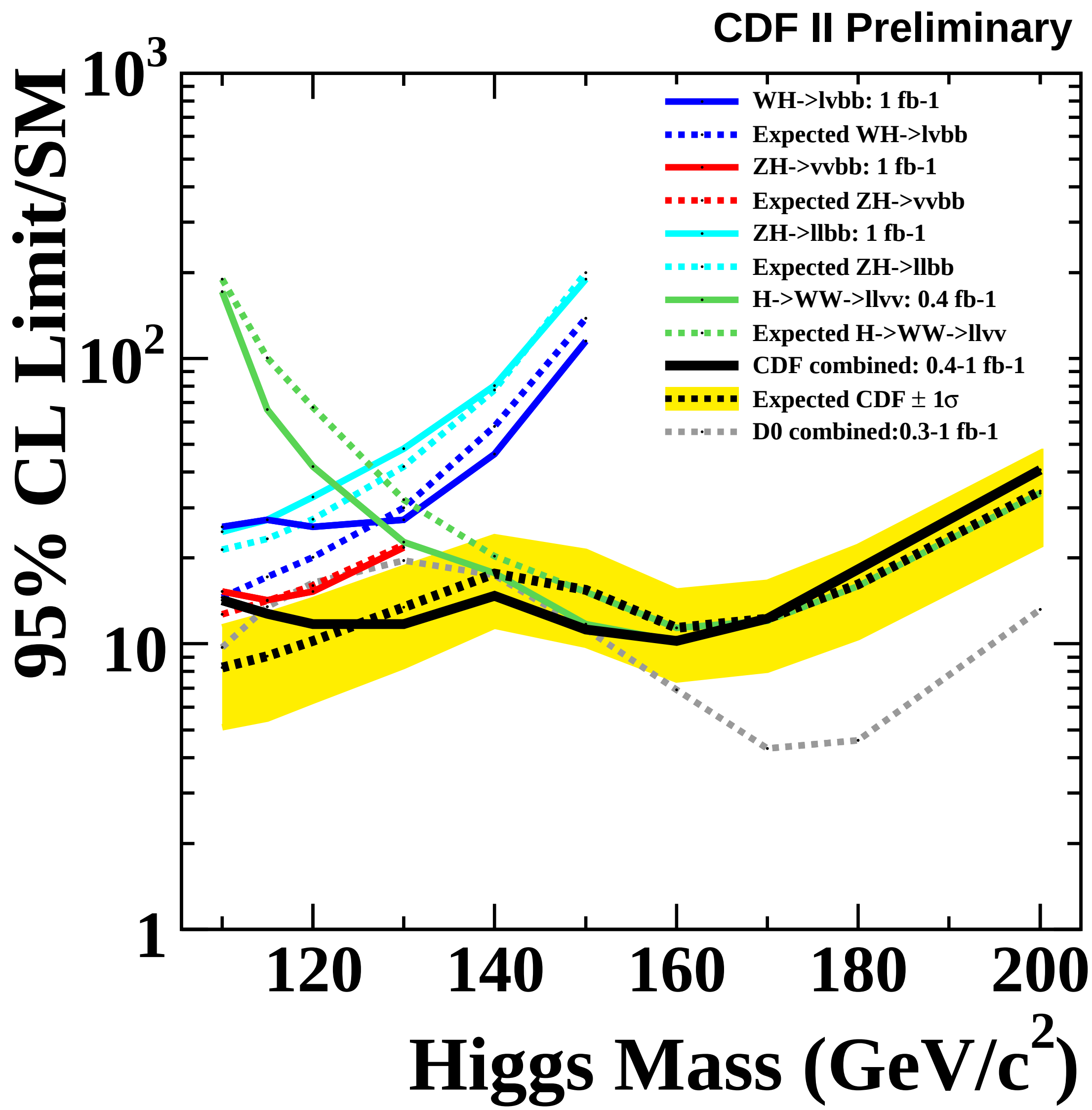
- The observed upper limit shown as in arrow in red, consistent with expectation.
- There are some excesses in both $WH \to l\nu b\bar{b}$ and $ZH \to \nu\bar{\nu}b\bar{b}$ single tags near 100 GeV, but not statistical significant yet.

Effect of the Correlation

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	11.2	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

- There are small effects on the limit due to the correlations.

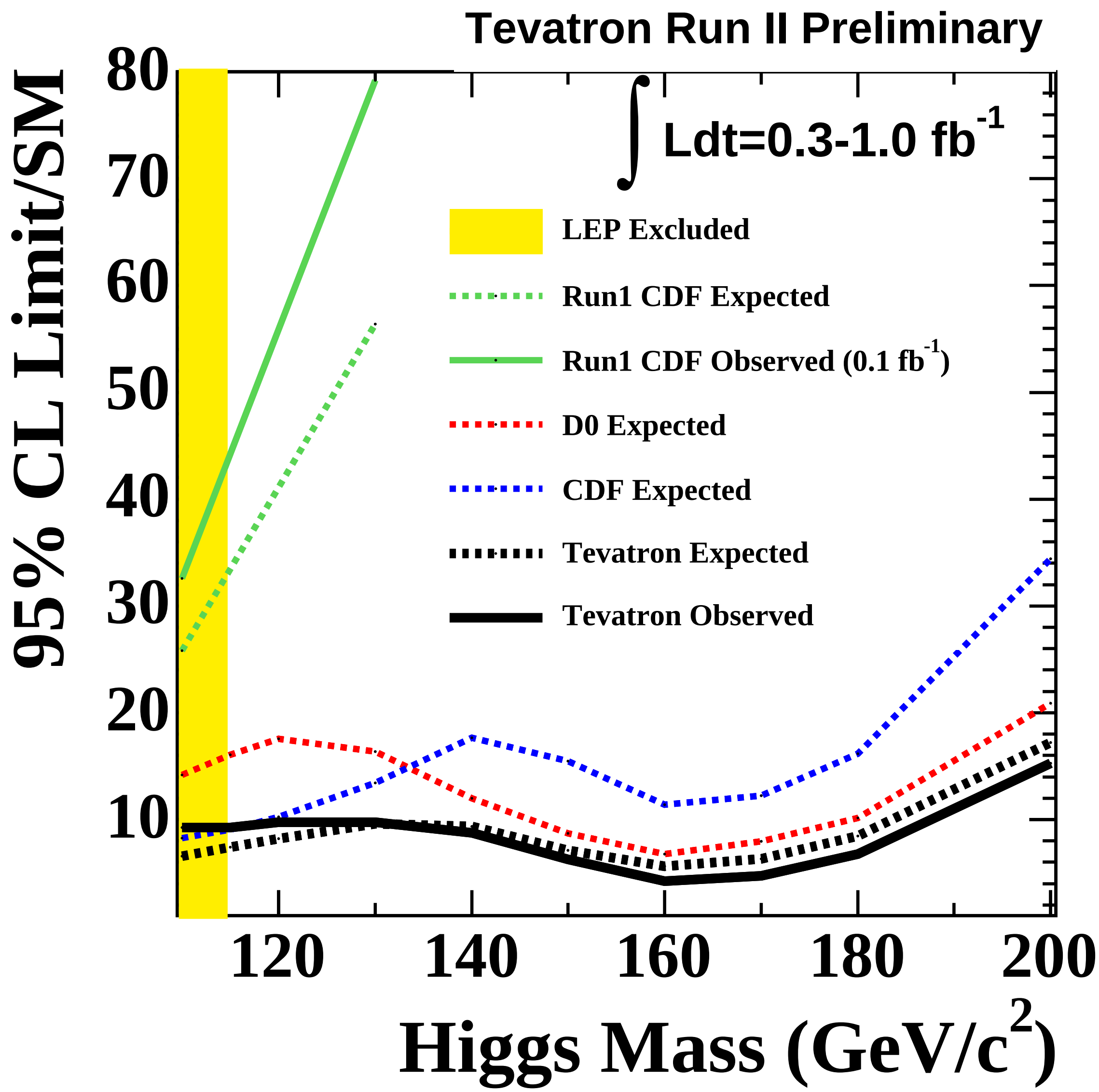
CDF Combined Limit



Future Prospects

- The combined limit is very close to what we expected from the Higgs sensitivity report
- Future improvements
  - Including lepton acceptance with forward electron and muons
  - Including τ-leptons with isolated track
  - Improved tracking and b-tagging in the large η region
  - Improving jet resolution with tracking
  - Improving analysis techniques
    - Neural Network, Matrix-elements ...
    - better Monte Carlo modeling and better optimization
  - Of course, there will be lots of data on the way
- Recent top mass measurements and observation of B_s mixing are few success stories of CDF
- With some luck, the Higgs discovery may be the next...

We are One Step Closer... !



Conclusion

- We obtain a combined Higgs limit from cdf with a data sample of 1 fb^{-1} using Bayesian method.
  - $WH \to l\nu b\bar{b}$
  - $ZH \to \nu\bar{\nu}b\bar{b}$
  - $ZH \to l^+l^-b\bar{b}$
  - $gg \to H \to WW \to l^+l^-\nu\bar{\nu}$
- Observed limits are mostly consistent with the expectation of Pseudo-experiments, except at mh=110, which seems there are some excess of events in both $WH \to l\nu b\bar{b}$ and $ZH \to \nu\bar{\nu}b\bar{b}$ single tag channel.
- The 95% CL upper observed (expected) limits are a factor of 12.8(9.1) and 10.2(11.4) away from the Standard Model cross section for Higgs mass at 115 and 160 GeV/c^2
- The future looks very promising and it's up to us how far we want to push before LHC.