Searching for Resonant Higgs Production at CDF

AKA: $H \rightarrow WW$ at CDF

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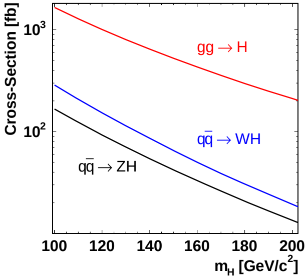
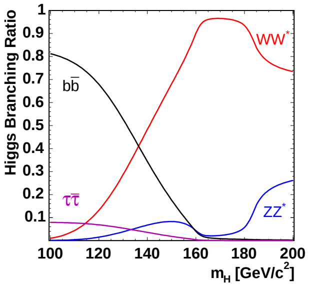
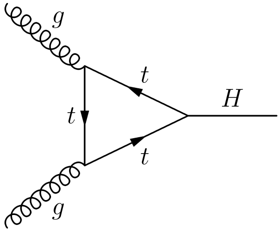
Why $H \to WW$?



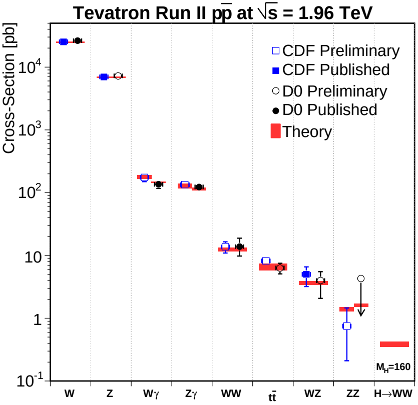
Cross-Section



Branching Fraction



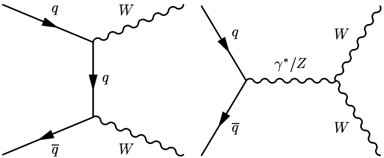
- $H \to WW$ dominates the branching fraction down to $\approx$ 135 GeV
- $gg \to H$ with both Ws decaying leptonically is sufficiently clean
- Loop process is sensitive to new physics (enhancements up to $\approx$ 9)

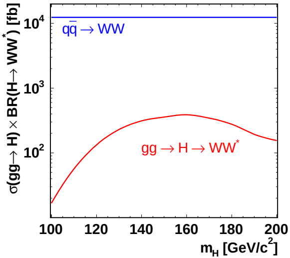


The Backgrounds

The Higgs is underneath
the needle in the haystack

Dominant Background:
$q\bar{q} \to WW^*$



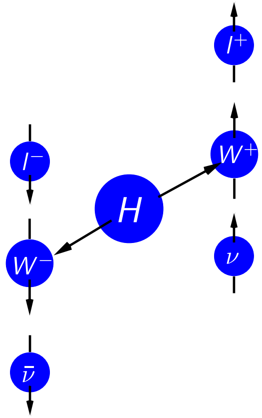


BR×Cross-Section

Telling $H \to WW^*$ from the $q\bar{q} \to WW$ Continuum

The Handles

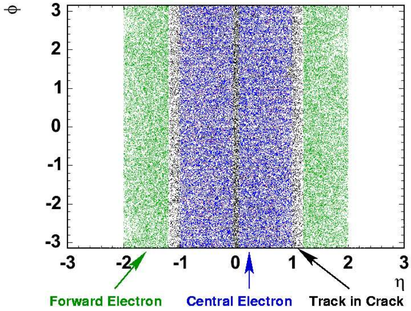
- Parity violation makes W an excellent spin analyzer
  - Higgs is scalar $\Rightarrow$ charged leptons go $\approx$ same direction
  - t-channel WW: Ws $\approx$ polarized along the beam direction
- At low masses one W is off-shell
  - One lepton is lower energy
- gg vs $q\bar{q}$: less understood
  - Fragmentation
  - WW system z-momentum



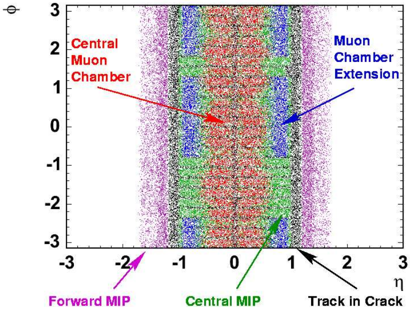
Two Analyses:

- Matrix Element: Probability of the full lepton and $\not\!\!E_T$ kinematics
- Neural Network: Detector and physics model from simulated data

Dilepton Selection



e Acceptance



μ Acceptance

- We only use the fully leptonic channel because backgrounds are too big with jets
- Optimized lepton acceptance
- Two *e* or μ leptons, one with $p_T > 20$ GeV, one $p_T > 10$

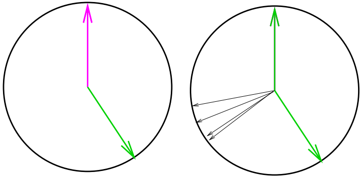
Backgrounds

- $Z/\gamma^* \rightarrow ll$ $WW \rightarrow ll\nu\nu$
- $W\gamma$ and W+jets with γ or jet misidentified as lepton
- $WZ \rightarrow lll\nu$,$ZZ \rightarrow ll\nu\nu$, and $t\bar{t} \rightarrow ll\nu\nu jj$

$(H \to)WW \to ll\nu\nu$ Selection

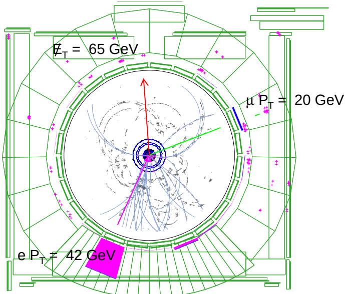
- Neutrinos show up as missing transverse energy $\not\!\!E_T$
- Large Z/γ^* background has two lepton, but no νs
- WW will produce $e\mu$ events, while Drell-Yan is only ee and $\mu\mu$
- $\not\!\!E_T$ cannot point along a jet or lepton

Event Topology Cartoons



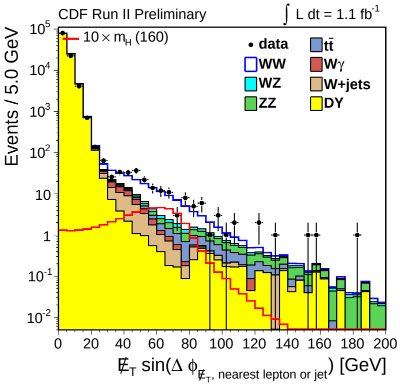
$(H \to)WW$ Drell-Yan

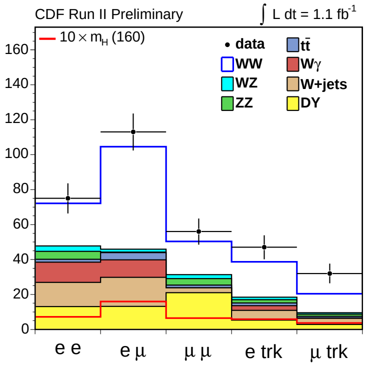
Source	Expected $\pm$ Systematic
WW	132.9 ± 15.0
WZ	9.5 ± 1.4
ZZ	11.7 ± 1.7
$t\bar{t}$	9.6 ± 1.8
DY	55.4 ± 12.0
$W\gamma$	24.7 ± 6.1
W+jets	42.4 ± 11.4
Total	286.1 ± 23.3
Observed	323



Beam's Eye View of CDF

$WW \rightarrow ll\nu\nu$ and $H \rightarrow WW \rightarrow ll\nu\nu$

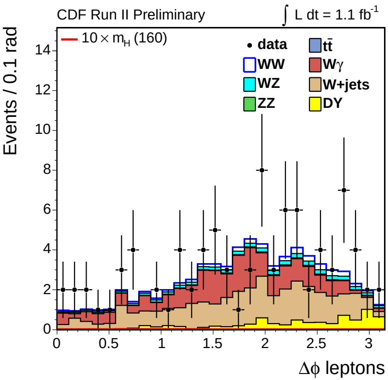


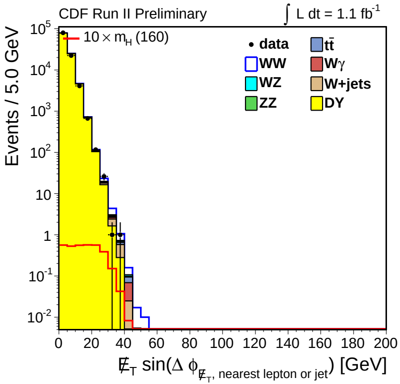


Predicted Higgs Yields

Higgs Mass (GeV)									
110	120	130	140	150	160	170	180	190	200
0.2	0.6	1.4	2.4	3.2	3.9	3.9	3.3	2. 4	2.0

$ll\not{E}_T$ Selection Controls Regions





- Same event selection but with same-sign leptons
- Tests model of jet or γ misidentified as leptons

- Events with lots of hadronic activity
- Worse $\not{E}_T$ resolution $\Rightarrow$ mostly Drell-Yan
- Tests $\not{E}_T$ modeling

Event-by-event probability density using the **full kinematic information**

$$P(\vec{x}_{obs}) = \frac{1}{<\sigma>} \int \frac{d\sigma_{th}(\vec{y})}{d\vec{y}} \epsilon(\vec{y}) G(\vec{x}_{obs}, \vec{y}) d\vec{y}$$

What we measure

$\vec{x}_{obs}$	observed "leptons" and $\vec{\not{E}}_T$

Theory at leading order

$\sigma_{th}(\vec{y})$	leading order calculation of the cross-section
$\vec{y}$	true lepton four-vector (include neutrinos)

Detector Effects

$\epsilon(\vec{y})$	total event efficiency $\times$ acceptance
$G(\vec{x}_{obs}, \vec{y})$	resolution effects

- Integration over missing neutrino information
- Photons and jets additional factor = fraction detected as leptons
- Modeled modes: WW, ZZ, $Wp \rightarrow W +$ fake, $W\gamma \rightarrow We_{conv}$

Likelihood Ratio Discriminant

Using the Calculated Probabilities

$$LR = \frac{P_{Higgs}(M_H)}{P_{Higgs}(M_H) + \sum_i f_{\mathrm{bkg,i}} P_{\mathrm{bkg,i}}}$$

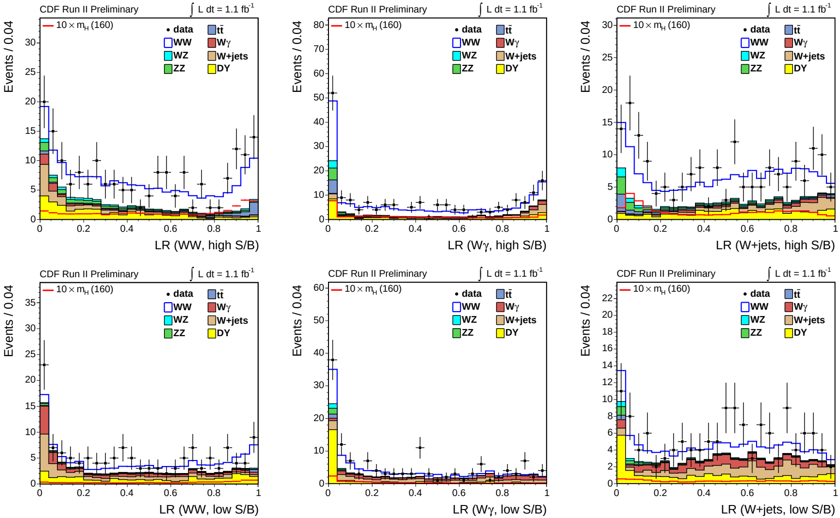
- Models don't have to be perfect
  - Monte Carlo and Data-based estimates of a 1-d distribution
- Don't have to model everything
  - Small diffi cult to model backgrounds: Drell-Yan
  - Next-to-leading order effects...

First a cross-check ...

Treat Backgrounds as Signal in Likelihood Ratio

High $\frac{Signal}{Background}$

Low $\frac{Signal}{Background}$

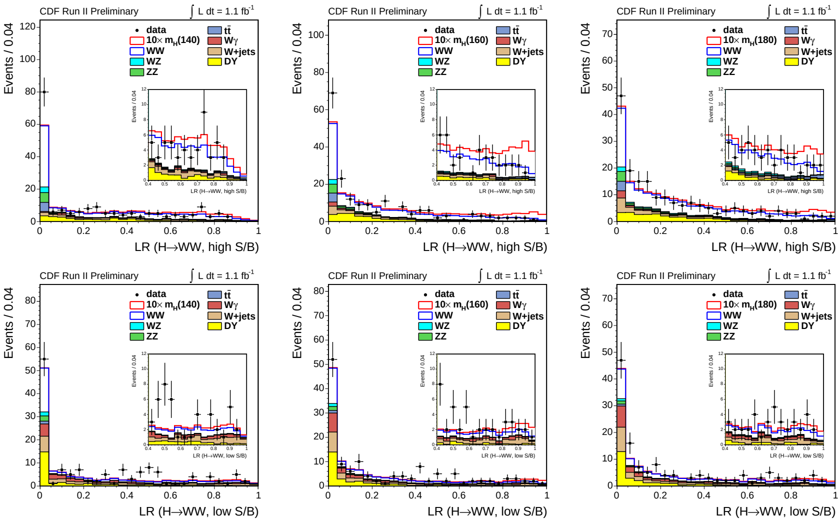


$$\frac{P_{WW}}{P_{WW}+\sum_i f_{\mathrm{bkg,i}} P_{\mathrm{bkg,i}}} \qquad \frac{P_{W\gamma}}{P_{W\gamma}+\sum_i f_{\mathrm{bkg,i}} P_{\mathrm{bkg,i}}} \qquad \frac{P_{W+\mathrm{jets}}}{P_{W+\mathrm{jets}}+\sum_i f_{\mathrm{bkg,i}} P_{\mathrm{bkg,i}}}$$

Likelihood Ratio Discriminant

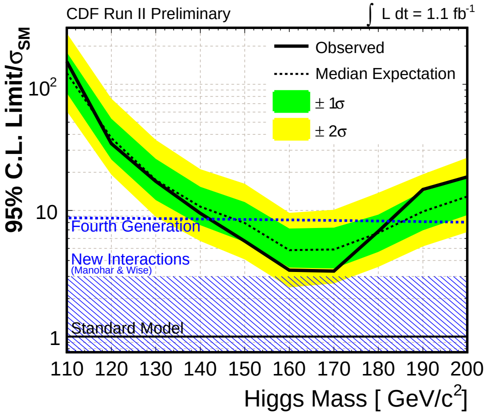
High $\frac{Signal}{Background}$

Low $\frac{Signal}{Background}$



$m_H = 140$ GeV $m_H = 160$ GeV $m_H = 180$ GeV

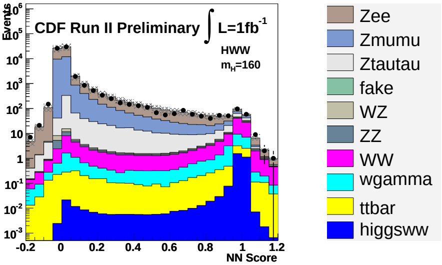
The Matrix Element Analysis Limits



$M_H(GeV/c^2)$	110	120	130	140	150	160	170	180	190	200
Median(pb)	7.1	4.9	3.8	3.4	2.9	1.8	1.7	1.8	1.9	2.0
Observed(pb)	8.9	4.7	4.0	3.0	2.1	1.3	1.2	1.9	2.8	2.8
Expected/σ_{NNLL}	122.6	37.4	17.4	10.7	8.0	4.8	4.9	6.6	9.8	12.9
Observed/σ_{NNLL}	151.2	33.9	17.0	9.5	5.7	3.4	3.3	6.8	14.6	18.4

The Neural Network Analysis I

- Two neural networks:
  - One to differentiate $H \to WW$ from Drell-Yan
  - One for $H \to WW$ vs WW



Neural Network to Differentiate $H \to WW$ from Drell-Yan

Variables used in the NNs

Lepton Kinematics:

- Dilepton mass
- Leading and subleading lepton p_T
- Lepton angular separation
- Lepton azimuthal separation

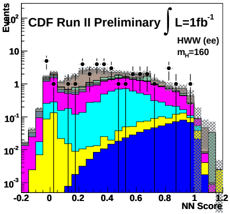
Global Event:

- $\not\!\!E_T$
- Total transverse energy
- Azimuthal between $\vec{\not\!\!E}_T$ and nearest lepton or jet
- $\not\!\!E_T / \sqrt{\sum E_T}$

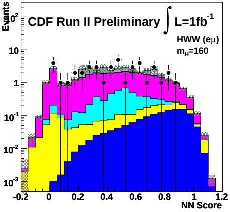
Jet structure:

- Number of jets
- Leading and subleading jet E_T

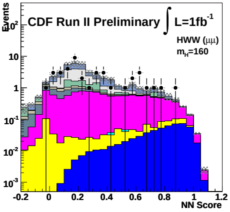
The Neural Network Analysis II



ee

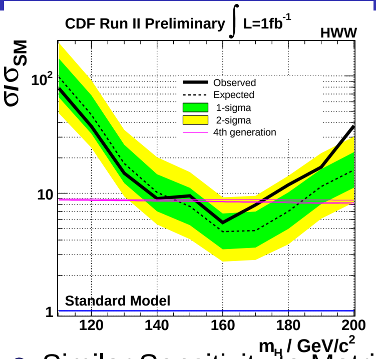


$e\mu$



$\mu\mu$

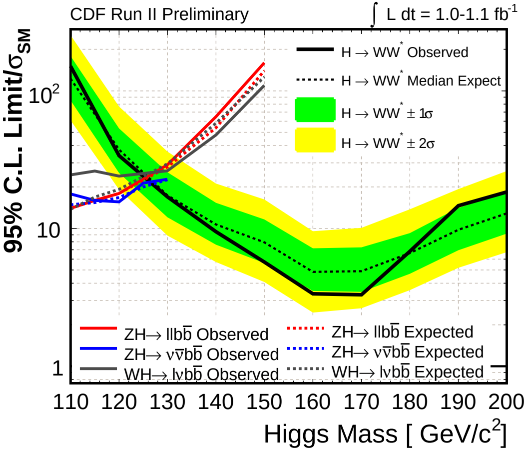
Neural Network for $H \to WW$ vs WW



- Similar Sensitivity to Matrix Element Analysis
- Different selections
  - Matrix Element: larger lepton acceptance
  - NN: $16 < m_{ll} < 25$ GeV
- Combination with new data is in the works

Summary

- $H \rightarrow WW$ is the most sensitive channel above $\approx 135 >$ GeV
- New physics at the TeV scale can have a large effect on the $gg \rightarrow H$ coupling



- Closing in on the Standard Model

... and limiting new physics on the way

Backup: Systematic Uncertainties

Source	WW	WZ	ZZ	$t\bar{t}$	DY	$W\gamma$	W+jets	Higgs
$\not\!\!E_T$ Modeling	1.0	1.0	1.0	1.0	20.0	1.0	-	1.0
Conversions	-	-	-	-	-	20.0	-	-
NLO Acceptance	4.2	5.0	5.0	5.0	5.0	5.0	-	5.0
Cross-section	10.0	10.0	10.0	15.0	5.0	10.0	-	-
PDF Uncertainty	1.9	2.7	2.7	2.1	4.1	2.2	-	2.2
LepId $\pm 1\sigma$	1.4	1.5	1.4	1.3	1.7	1.3	-	1.2
Trigger Eff	0.3	0.3	0.3	0.4	0.4	0.5	-	0.6
Fake Rate	-	-	-	-	-	-	32.8(23.3)	-
Total	11.1	11.6	11.6	16.0	21.7	23.1	32.8(23.3)	5.7

Estimation Methods

- $\not\!\!E_T$: Comparison of data and simulation in large hadronic activity events
- Conversions veto efficiency: study of independanty derived sample of conversions
- Fake rates: variation in sample used to derive the fakes rates
- Fake rates+Conversions cross-checked in trilepton low-$\not\!\!E_T$ sample which 50/50 Fake and Conversions