Search for a Standard Model Higgs in H \rightarrow ZZ \rightarrow 4 ℓ and H \rightarrow WW \rightarrow $\ell\nu$ jj decays at the Tevatron

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On behalf of the CDF and DØ collaborations



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Overview

- Introduction/Motivation
 - The Higgs
 - The Tevatron
- $H \rightarrow WW \rightarrow \ell \nu jj$
 - Selection
 - Analysis
 - Results
- $H \rightarrow ZZ \rightarrow 4\ell$
 - Selection
 - Analysis
 - Results
- Summary



The Higgs

- The Higgs is an important part of the standard model that has yet to be seen.
 - Mechanism for Electroweak Symmetry Breaking
 - Gives mass to Vector Bosons and Fermions.



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- For $M_H > 140$ GeV, the Higgs decays dominantly via H \rightarrow WW and H \rightarrow ZZ.
- Most sensitive search is $H \rightarrow WW \rightarrow \ell \nu \ell \nu$.
- Can gain sensitivity by considering other channels such as:
- $H \rightarrow WW \rightarrow \ell \nu jj$ and $H \rightarrow ZZ \rightarrow 4\ell$.

The Tevatron

The Tevatron is a $p\bar{p}$ collider operating at \sqrt{s} =1.96 TeV.



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- Silicon Vertex Detector
- Scintillating Fibre Tracker
- Liquid Argon Uranium Calorimeter
- Muon Detection



- Silicon Vertex Detector
- Wire Drift Chamber Tracker

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- Lead-Iron Scintillator Calorimeter
- Muon Detection

Performance

- Thanks to the accelerator division, the Tevatron is performing fantastically.
 - Expect 12 fb⁻¹ delivered.
 - Data recording is $\sim 90\%$ efficient.



$H \rightarrow WW \rightarrow \ell \nu j j$

- Analyzed using 5.4 fb^{-1} of data collected using the DØ detector.
- Branching fraction for WW $\rightarrow \ell \nu j j$ much larger than for WW $\rightarrow \ell \nu \ell \nu$
- Much more background.



Signal

- $H \rightarrow WW \rightarrow \ell \nu q q'$
- $H \rightarrow ZZ \rightarrow \ell \ell \ell q q$
- $H \rightarrow WW \rightarrow \tau \nu q q'$
 - where $\tau \rightarrow \ell \nu \nu$
- WH $\rightarrow \ell \nu bb$ (adds sensitivity for $M_H < 140$ GeV).



- One charged lepton.
- lepton $p_T > 15~{\rm GeV},~|\eta_{\mu}| < 1.6,~|\eta_{e}| < 1.1$
- $\not\!\!E_T > 15~{\rm GeV}$
- At least two jets, with $p_T>20~{\rm GeV},~|\eta|<2.5$
- $\Delta R(\ell, j) > 0.5$
- $M_T^W < 40 0.5 \not E_T$

Backgrounds

- W/Z+jets
- Diboson production
- $t\bar{t}$, single-top
- multijet events





 $H \rightarrow WW \rightarrow \ell \nu jj, H \rightarrow ZZ \rightarrow 4\ell$

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Reconstructing the Higgs

- Can use W mass as constraint to obtain $p_Z^{
 u}$ up to two-fold ambiguity
 - If both solutions are real, choose the smallest absolute value solution.
 - If the solution is complex use $Re(p_z^{\nu})$
- For $M_H < 160$ GeV, this constraint yields poorer resolution.
- The hadronic W is reconstructed from the two leading jets.



Kinematic Information



Decision Tree



- Find best variable, and best cut on that variable to maximally separate signal from background.
- Stop either when leaf is pure signal or background, or when a minimum number of leaf events is reached.

Random Forest

- 50 Decision trees combined into Random Forest
 - A forest is trained for each $115 \le M_H \le 200$ in 5 GeV steps.
- Each tree is trained with a random subsample of events.
- At each tree node, a random subset of variables is sampled.



At $M_H = 160$ GeV, the expected/observed limits are 5.0/3.9 times the standard model cross-section.



 $H \rightarrow WW \rightarrow \ell \nu jj, H \rightarrow ZZ \rightarrow 4\ell$

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$\mathsf{H}{\rightarrow}\mathsf{Z}\mathsf{Z}{\rightarrow}\,4\ell$

- Analyzed using 8.2 fb^{-1} of data collected with the CDF detector.
- Small branching fraction for ${\rm ZZ}{\rightarrow}~4\ell$
- Incredibly clean signal.



Signal

This search uses the following as signal events:

- gg \rightarrow H \rightarrow ZZ
- VBF \rightarrow H \rightarrow ZZ
- W/Z H \rightarrow W/Z ZZ
 - Where the associated W/Z decays hadronically, or invisibly.
- $ZH \rightarrow ZWW$
 - where the Z decays to charged leptons, and the Ws decay to a pair of electrons or muons.



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Signal

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- gg \rightarrow H \rightarrow ZZ
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- W/Z H \rightarrow W/Z ZZ
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- ZH→ZWW
 - where the Z decays to charged leptons, and the Ws decay to a pair of electrons or muons.



Selection Requirements

- Require either 4 electrons, or four muons, or 2 electrons + 2 muons.
- Leading lepton $p_T > 20$ GeV, other leptons $p_T > 10$ GeV.
- Separation between leptons: $\Delta R > 0.1$.
- Invariant mass of di-lepton systems: $20 < M_{\ell\ell} < 140$ GeV.



- Dominant background is non-resonant ZZ production.
- Also have events from Z/ γ production in association with jets, where the jets are misidentified as leptons.
 - The rate of these events is determined from data, and the shapes of kinematic distributions from MC.



Dilepton Invariant Mass



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Reconstructing the Higgs

CDF Run II Preliminary	∫Ĺ	$\int \mathcal{L} = 8.2 \text{ fb}^{-1}$		
$M_H = 190 \text{ GeV}/c^2$				
ZZ	8.83	±	1.12	
$Z(\gamma)$ +jets	0.30	±	0.10	
Total Background	9.13	±	1.12	
$gg \rightarrow H \rightarrow ZZ$	0.329	±	0.042	
$VH \rightarrow V + ZZ$	0.053	\pm	0.007	
$ZH \rightarrow Z + WW$	0.054	\pm	0.007	
$VBF \rightarrow H \rightarrow ZZ$	0.038	\pm	0.005	
Total Signal	0.474	±	0.043	
Data		8		

 $H \to 4\ell$



Results

At $M_H = 190$ GeV, the expected/observed limits are 11.1/11.6 times the standard model cross-section.



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- A search for the Higgs was performed in H \rightarrow WW $\rightarrow \ell \nu jj$ at DØ (5.4 fb⁻¹), and H \rightarrow ZZ $\rightarrow 4\ell$ at CDF (8.2 fb⁻¹).
- At $M_H = 160$ GeV, the H \rightarrow WW $\rightarrow \ell \nu$ jj search has an expected/observed limit of 5.0/3.9 times the standard model cross-section.
- At $M_H = 190$ GeV, the H \rightarrow ZZ $\rightarrow 4\ell$ search has an expected/observed limit of 11.1/11.6 times the standard model cross-section.
- These results are two from a very broad Higgs program at the Tevatron.