Search For the Standard Model Higgs at the Fermilab Tevatron

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on behalf of the CDF and D0 collaborations
EWSB Workshop May 7, 2011
**Outline**

- Talk will cover recent CDF & D0 SM Higgs results
- High Mass searches
- Low Mass searches
- Prospects for the remainder of Run II and beyond

For Additional Details and Latest Results see:

http://tevnphwg.fnal.gov/results/SM_Higgs_Winter_11/
http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.htm
http://www-cdf.fnal.gov/physics/new/hdg/Results.html
SM Higgs

- Higgs mechanism is simplest way to achieve EWSB, get W/Z masses and allows for massed fermions

- Predicts Higgs Boson of ‘unspecified’ mass $M_H$, existence not confirmed by experiment

- Direct searches at the LEP experiments exclude values of $M_H$ below $114.4 \text{ GeV}/c^2$ @ 95% CL

- Combined with indirect constrains from measurements of SM parameters ($M_w, M_{top}$, ..) get $114 < M_H < 185 \text{ GeV}/c^2$ @ 95% CL

- This mass range is accessible at the Tevatron and in recent years, Tevatron experiments have excluded values of $M_H \sim 165 \text{ GeV}/c^2$
The Tevatron

- pp collider $\sqrt{s} = 1.96$ TeV
- ~11/fb delivered to each experiment so far
- Expect ~12/fb total before the end of operations in September 2011
- By the end of Run II should have around 10/fb recorded and analyzable

Luminosity (pb$^{-1}$)

- Delivered
- Acquired

up to 8.2/fb for results in this talk
The Detectors

- D0 and CDF are general purpose detectors
- Silicon Vertex Detectors (critical for b-jet ID)
- Tracking Chambers (CDF Drift Chamber, D0 Fiber Tracker)
- Calorimeter + Muon Systems (jet, electron, tau, muon ID)
- Combined with multi-level ‘trigger systems’ to select events with topologies of interest (missing transverse energy, energetic jets/leptons)
Main production modes are:

I. Gluon-gluon fusion ($gg\rightarrow H$)
II. Associated Production ($ZH/WH$)
III. Vector Boson Fusion ($qq\rightarrow qqH$)

Dominant decay mode defines 2 search regimes:

I. $H\rightarrow WW$ “high mass $M_H > 135$ GeV”
II. $H\rightarrow bb$ “low mass $M_H < 135$ GeV”
The Search Environment

- Background rates many orders of magnitude higher than predicted SM Higgs rates

- Searches target Higgs production/decay modes with ‘distinguishing’ final states:
  \[ q, q', W^*, W^\pm, l^\pm, b \]

- Analysis methods proven successful in picking out signals as small as single top production (~pb)
The Search Blueprint

• Typical Higgs Search can be summarized in a few steps:

I. Identify final state of interest & choose corresponding ‘trigger signature’

II. Model expected backgrounds & signal

III. Select events with series of kin. cuts or more advanced algorithms

IV. Separate signal from background using Multivariate Technique (MVT)

V. Compare binned MVT output for model, signal and data to extract upper limits on the signal contribution in the data
High Mass Search

- Primary mode:
  - Additional sensitivity gained by including contributions from:

- Select events with high $P_T$ leptons and significant missing $E_T$

- Optimize selection and signal discriminants separately for the various (46 D0+CDF) final states:
  - number of leptons
  - lepton sign (OS vs SS)
  - lepton quality
  - lepton flavor
  - number of jets

- Sensitivity from individual sub-channels ranges from 1.5 to ~20 times SM Higgs rate
ee/μμ/eμ + 0,1,2 jets

- Selection and final classifier optimized for different background & signal composition for each jet bin:

Background Composition

0 jet  
1 jet  
≥2 jets  

Signal Composition

0 jet  
1 jet  
≥2 jets  

CDF Run II Preliminary

OS 0 Jets, High S/B

M_H = 165 GeV/c^2

in 7.1/fb 95%CL Upper Limits for M_H = 165 GeV/c^2
~1.5 X SM Prediction
**ee/μμ/μμ + 0,1,2 jets**

CDF Run II Preliminary

**OS 1 Jet, High S/B**

- Wj
- Wγ
- tt
- WZ
- ZZ
- DY
- WW
- HWW × 10
- Data

![Graph showing events distribution for 1 jet](image)

**1 jet**

*in 7.1/fb 95%CL Upper Limits for M_H = 165 GeV/c^2 ~2.3 X SM Prediction*

CDF Run II Preliminary

**OS 2+ Jets**

- Wj
- Wγ
- tt
- WZ
- ZZ
- DY
- WW
- HWW × 10
- Data

![Graph showing events distribution for ≥ 2 jets](image)

**≥ 2 jets**

*in 7.1/fb 95%CL Upper Limits for M_H = 165 GeV/c^2 ~2.7 X SM Prediction*
• Each experiment performs careful evaluation of systematic uncertainties

• Some (ex. Tevatron luminosity) are correlated across experiments, others (ex. Jet Energy Scale) are correlated across sub-channels within an experiment

• The effect of a given systematic is estimated through all levels of the analysis from event reconstruction/selection through to the final MVT output shape and/or normalization
Values for $\sigma_{gg\rightarrow H}$ obtained from


Uncertainty from higher order processes estimated (7-33%) by factor of 2 variation on factorization & renormalization scales ($\mu_R/\mu_F$)

Include ~2% uncertainty from NNLO QCD corrections applied to light loop contributions based on top loop computation

Cross sections calculated with MSTW 2008 NNLO PDF set; uncertainty estimated (17-30%) using PDF4LHC recommendation (http://www.hep.ucl.ac.uk/pdf4lhc/)

Full discussion of signal cross sections and uncertainty treatment available in arXiv:1103.3233v2 [hep-ex]
Single Experiment Results

**CDF Run II Preliminary H→WW Search, L = 7.1 fb⁻¹**

- 95% CL Limit / SM
- CDF Exclusion
- Expected
- Observed
- ±1σ Expected
- ±2σ Expected

- SM = 1

**CDF Preliminary, L = 4.3 - 8.2 fb⁻¹**

- SM Higgs Combination
- Observed
- Expected
- ±1σ Expected
- ±2σ Expected

- Standard Model = 1

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**in up to 7.1/fb 95%CL Upper Limit:**

- Expected Exclusion [159,168] GeV/c²
- Observed Exclusion [158,168] GeV/c²

**in up to 8.2/fb 95%CL Upper Limit:**

- Expected Exclusion [160,168] GeV/c²
- Observed Exclusion [163,168] GeV/c²
in up to 8.2/ fb 95%CL Upper Limit:

Low Mass Searches

- For $M_H < 135$ GeV/c$^2$ searches focus on $H \rightarrow bb$
- $gg \rightarrow H \rightarrow bb$ overwhelmed by multi-jet production
- Instead search for associated $Z/W +$ Higgs production

![Higgs Events Produced / fb$^{-1}$](image)

- Signal rates are low (~100 events/10$^{14}$ collisions)
- Aim for maximum signal/background (b-tagging is key)
b-jet Tagging

- Distinguish b-jets from c/light jets
- Various algorithms available @ CDF & D0 which exploit long lifetime of b to ‘tag’ jets
- Typically tag ~60% of b-jets with 1%≤ “mis-”tag rate
• b-tagging in WH:

CDF Data
WH (115 GeV)
Single Top
tt
W+HF
W+LF
Other

PreTag

W + 2 Jets, 0 b Tags  CDF Preliminary, L = 5.6 fb⁻¹

Candidate Events

Normalized to Data

Dijet Invariant Mass [GeV/c²]

0
10
20
30
0
10
20
30

CDF Preliminary, L = 5.6 fb⁻¹

W + 2 Jets, SVnoJP

Candidate Events

Normalized to Data

Dijet Invariant Mass [GeV/c²]

0
10
20
30
0
10
20
30

CDF Preliminary, L = 5.6 fb⁻¹

W + 2 Jets, SVSV

Candidate Events

Normalized to Data

Dijet Invariant Mass [GeV/c²]

0
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20
30
0
10
20
30
• Limits in WH:

<table>
<thead>
<tr>
<th>Channel</th>
<th>Obs. (Exp) 95% CL upper limits / SM @ $M_H = 115$ GeV/$c^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$WH \rightarrow l^\pm \nu bb$</td>
<td>4.5 (3.5) in 5.7 fb$^{-1}$</td>
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</table>
• Signal from $Z \rightarrow \nu \nu$ and $W$ with a missed lepton

• lack of a charged lepton requires additional tool to reduce multijet background:

- Decision Tree cut rejects 90% of multijet background
- Retains $\sim 84\%$ of Higgs Signal
• Limits in $\nu\nu bb$:

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<td>$VH\rightarrow\nu\nu bb$</td>
<td>2.3 (4) in 5.7 fb$^{-1}$</td>
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</table>
• Low signal rate, but Z and H decay products are observable

• Allows the jet system (where energies are more likely to be mis-measured) to be balanced against the dilepton system to improve resolution on the dijet Mass
• Limits in $ZH \rightarrow \ell^+ \ell^- bb$:

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<td>$ZH \rightarrow \ell\ell bb$</td>
<td>6 (5.5) in 5.7 fb$^{-1}$</td>
<td>8 (5.7) in 6.2 fb$^{-1}$</td>
</tr>
</tbody>
</table>
• Tevatron “re-”excludes 100-109 GeV Higgs @ 95% CL

• @ $M_H = 115$ GeV :

  95%CL Upper Limit :
  
  Expected Limit $1.45 \times$ SM Prediction
  Observed Limit $1.56 \times$ SM Prediction
Moving Forward

- Tevatron operations will continue through Sept 2011
- Final datasets should be 2-4/fb larger than those currently utilized by the main search channels
- Working on technical improvements for summer results, and winter result with the full Tevatron dataset
• Tevatron operations will continue through Sept 2011
• Final datasets should be 2-4/fb larger than those currently utilized by the main search channels
• Working on technical improvements for summer results, and winter result with the full Tevatron dataset
• Stay tuned for new Tevatron results this summer ..

Thanks!
Selection in PhysRevLett.106.171801

WH Search Selection
2xCDF Preliminary Projection, $m_H=115$ GeV

Expected Limit/SM

Projected Improvements

SM=1
single e/µ + 2 jets

- Signal is mainly gg→H with one hadronically decaying W
- Dominant background is V+jets

in 5.4/fb 95%CL Upper Limits for M_H = 165 GeV/c^2
~5 X SM Prediction