The Search For The Brout-Englert-Higgs Boson

With Up To 10/fb

With CDF

Homer Wolfe
The Ohio State University
On Behalf of the CDF Collaboration

Rencontres de Moriond
7 March 2012, La Thuile, Italy
● Goal: Direct evidence for or exclusion of the SM Higgs boson

● Overview of new results

● The CDF experiment

● Overview of searches

● Recent advancements in search Techniques

● Full dataset results

● Conclusions/prospects
CDF: A General Purpose Experiment

- ~5K tons (~2.5K central only)
- ~10 m each direction
- ~100 Hz readout
- ~720 K silicon tracker readout channels
- Muon chambers: $|\eta| < 1.5$
- Silicon tracking $|\eta| < 2.2.5$
- Drift cell tracker 1.4 Tesla B field, $|\eta| < 1.1$
- Pb/Cu/scint calor. $|\eta| < 3.2$
  - JES uncertainty 2-3%
Candidate VH Events at CDF

CDF
Candidate
ZH→ννbb
Data Event

CDF
Candidate
ZH→eebb
Data Event

CDF
Candidate
WH→eυbb
Data Event
The CDF Higgs Search

- For the 2012 CDF Winter results:
  - SM predicts ~167 Higgs (125 GeV) events *reconstructed and selected*
  - SM background of ~200K
- Small signal on diverse background
  - Maximize signal acceptance
  - Maximize signal significance
- Partitioned over many final states
  - Low (<150 GeV) mass
    - WH, ZH, METbb, tth, γγ, VBF→bbjj
  - High (>150 GeV) mass
    - WWW, WWZ, WW, ZZ, τ-decays, full/semi-leptonic...
- 16 CDF analyses:
  - 93 orthogonal sub-channels.
- In non-excluded region, associated production and WW contribute ~90% of total weight.
Comparing Search Channels

- **Expected Sensitivities** (January 2012, 125 GeV):
  - VH, H→bb:
    - ATLAS,CMS: ~4.3xSM
    - CDF, D0: ~2xSM
  - H→γγ:
    - ATLAS,CMS: ~1.5-2xSM
    - CDF, D0: ~10-13xSM
  - H→WW:
    - ATLAS,CMS: ~1-2xSM
    - CDF, D0: ~3.5xSM

- **Tevatron’s strength in the light-SM-Higgs scenario is the branching fraction of H to bb!**
Massive Search Strategy Improvements

- The combined CDF Higgs search:
  - Sensitivity improvements:
    ~2X beyond dataset increases since 2007
  - 2012: ~30% more sensitive at low-mass than summer 2011
  - 1.46*SM or better from 115 to 180
  - This talk outlines how
Online Event Selection

- Tevatron bunch crossing rate: \(~MHz\)
  - CDF data taking rate: \(~100\ Hz\)
  - Triggers select most interesting events

- To maximize the number of recorded candidates
  - Optimized generic single-object triggers
  - Triggers designed specifically for SM Higgs searches

- 2010-2012: Inclusive Triggering:
  - Resulting gain was \(>20\%\) more signal acceptance in \(ZH\rightarrow\mu\mu bb\)
    - Trigger on “MET” at trigger level caused by muons
    - Utilize MET+jets triggers originally intended for \(Z\rightarrow\nu\nu bb\)
    - Accept events with muons non-fiducial to muon chambers used for triggering

- \(~30\%\) signal gain seen in METbb, 5\% in WH Analyses.
Reconstruct Events

- Original CDF definitions of leptons were designed for purity and efficient triggering, not acceptance
  - $WW \rightarrow l\nu l\nu$ analysis: uses small opening angle of two leptons to identify signal
    - Spin of $W$s correlated in Higgs decays
    - Two nearby leptons spoil each other’s track isolation, flagged as background
    - 2011: WW-specific event selection retains these events
- 2010-2012: WW, WH, ZH Analysis:
  - Employ multivariate lepton identification
Select Events Offline, Reject Background

- To maintain high efficiency, with good simulation, multivariate rejection of difficult backgrounds is performed
  - 2011-2012: WH Analysis:
    - Reject instrumental background via a Support Vector Machine:
      - Retains 95% EWK, 24% Instrumental
      - Compare to previous cut-based instrumental rejection: 84% EWK, 29% Instr.
New b-Jet Identification

- **2011:** CDF WH, ZH, VH used 2 or 3 different b-taggers in orthogonal series

- **2012:** New CDF Neural Network b-tagger
  - More jets are taggable
  - For identical false-positive rates of previous taggers, b-jet efficiency:
    - **Tight:** $38.6 \rightarrow 53.6\%$
      - False Positive: 1.4\%
    - **Loose:** $47.1 \rightarrow 59.3\%$
      - False Positive: 2.8\%

- Calibrated on multiple sideband samples of varying flavor composition
  - Adjustments to simulation in each sample are comparable
  - Differences taken as systematic
  - Adjustments for true bs: 5\%±4\%

Neural Network Output
Major Improvements: 2012

- **WW:**
  - Major backgrounds: SM WW, Drell-Yan
  - Acceptance from many production modes, both WW and ZZ decay modes.
  - Biggest improvement: Data increase
    - ~10% improvement in expected sensitivity
  - Added acceptance from new low-dilepton-mass channel
  - Best s/b: ~1:1
  - Exclude MH=(147,175) GeV
Major Improvements: 2012

- **METbb:**
  - Major backgrounds:
    - WW+bb,
      Multijets+Instrumental MET
  - Biggest improvement: Data increase
  - New MET correction offers better BG rejection
  - Best s/b: ~1:5
  - ~Summer 2012 improvement: new tagging
    - ~10-12% additional sensitivity improvement
Major Improvements: 2012

- WH:
  - Major background:
    - W+bb, di-top, instrumental non-W.
  - Added data + improved b-tagging + new triggers + update of 3-jet bin
  - Best s/b: ~1:5
  - 2012: 22.7 → 40.2
  - Expected Signal Events!!!
  - 1-2012/2011=~30%
    stronger expected limits than summer 2011
**Major Improvements: 2012**

- **ZH**
  - **Major backgrounds:** Z+bb, di-top
  - Added data + improved b-tagging + better background rejection + improved lepton acceptance + sifted background discrimination
  - **2011/2012 Doubled integrated s/√b!**
  - Best s/b: ~1:1
  - 1-2012/2011 = ~34% stronger expected limits than ZH summer 2011
Overview of 4 Strongest Channels

- **VH → METbb**
- **ZH → llbb**
- **W → lvbb**
- **H → WW**
Process Specific Combined Results

- Broad excess observed in $H \to b\bar{b}$
- Largest Excess: 135 GeV
- Global p-value (LLE=2) = 2.7 sigma
The CDF Combined Higgs Search

- Exclude 147-175 GeV
- Broad excess observed. Largest excess: 120 GeV
- Global p-value (LLE=4) = 2.1 sigma
CDF has made major improvements to its SM Higgs searches
- A factor of 2 lower expected limits compared to 2007
- 1-2012/2011= ~20% beyond new data at low mass since summer 2011

The CDF Combination:
- Expected sensitivity: 1.46xSM or better < 185 GeV
- Exclude 147-175 GeV

Associated production H→bb channels
- Broad excess observed.
  - Largest Excess: 135 GeV: Global p-value (LLE=2) = 2.7 sigma

CDF Combination:
- Broad excess observed at masses below 150
  - Largest Excess: 120 GeV: Global p-value (LEE=4) = 2.1 sigma

Timescale of Summer 2012:
- Update METbb channel for better sensitivity to H→bb.

Next Talk by W.Fisher will cover Tevatron Combination.
Conclusions

● For additional details see
  - Tevatron: http://tevnphwg.fnal.gov/results/SM_Higgs_Winter_12/
  - CDF: http://www-cdf.fnal.gov/physics/new/hdg/Results.html
  - D0: http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.html

● Thanks to everyone at CDF who contributed to this update!

● Bigger thanks to everyone who designed, built, or operated CDF!

● FNAL Computing Division: Thanks for all the computing power and software!

● FNAL Beams Division: Thanks for all the collisions!
Thank you for your attention

Questions?
New b-Jet Identification

- 2011: CDF WH,ZH,VH used 2 or 3 different b-taggers in orthogonal series
- 2012: New CDF Neural Network b-tagger
  - Uses most sensitive variables from previous CDF taggers
    - Uses semileptonic b-decay muons, Jet tower mass, secondary vertex mass...
    - Can tag jets with only one charged particle track
  - Continuous variable output allows for analysis group to choose cuts:
    - optimize expected sensitivity
  - For identical false-positive rates of previous taggers, b-jet efficiency:
    - Tight: 38.6→53.6%
      - False Positive: 1.4%
    - Loose: 47.1→59.3%
      - False Positive: 2.8%
New b-Jet Identification

- Calibration samples
  - Kinematic selection of \(W+4,5\) jets events (di-top)
  - QCD dijets with low relative-pt electrons
    - Not an input to tagger
    - Semileptonic decay electrons
      - Enriched in \(b,c\)
    - Photon conversion electrons (New method)
      - Primarily \(u,d,s,c,g\)
  - Examine both e-jet and opposing side jets

- These samples produce correction factors and uncertainty estimates for simulated events

- Resulting b-jet tag-rate corrections: \(~5\%\pm4\%\)
New Additional Jet Systematics

While performing tagged WW/WZ search

- Gluon-Quark separator
- Z+1Jet balancing studies performed
- Poor description of Z-jet balance seen in gluon-like jets.
  - MC gluon jets harder in ET than data by ~5% of ET
  - MC quark jets well described
- Origin of mismodeling still under investigation

- Affects jet energies, dijet mass spectrum of untagged jets
  - Negligible effect on tagged jets
  - For 2012 results, MC simulation has been corrected for this effect
  - Change to expected or observed limits far below other systematics

For more information:
Comparison of Summer 2011 to Winter 2012

- Tevatron 2011 vs CDF 2012
- The observed limit went UP?
- Are these consistent?
  - If we had only added data, the observed limit should not have gone up.
    - Down or no change
  - These plots are not directly comparable:
    - the included analyses have changed: data reinterpreted
    - This plot is for exclusion, not cross section measurement.

![Graph](image-url)
Comparison of Summer 2011 to Winter 2012

- Diboson measurement if Heavy Flavor Jets
- See presentations at Moriond by J. Vizan Garcia (QCD) and J. Sekaric (EWK)
Comparison of Summer 2011 to Winter 2012

- Diboson measurement if Heavy Flavor Jets
Comparison of Summer 2011 to Winter 2012

- ZH: s:b of new events in 2012

ZH → e⁺e⁻b̅b̅ best S/B events

- New Candidates For Winter 2012 Analysis
- Previously Observed Candidates
Comparison of Summer 2011 to Winter 2012

- ZH: s:b of new events in 2012

CDF Run II Preliminary (9.45 fb⁻¹)

- Expected
- Observed
- ±1 σ
- ±2 σ
- red: best new candidate
- blue: 2nd best new candidate

ZH → e⁺e⁻b¯b

95% CL Upper Limit/SM

Mₜ (GeV/c²)
Comparison of Summer 2011 to Winter 2012

- ZH: s:b of new events in 2012