CDF & D0 Higgs Search

Results from the Full Tevatron Data Set

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On Behalf of the CDF and DØ Collaborations

Tevatron Higgs Seminar
2 July 2012, Fermilab
The 2nd Half of Today's Presentation

DØ Higgs boson searches in a nutshell
- Discussion of updates since winter 2012
- Short review on what's to come
- DØ Higgs search results

New Tevatron Higgs search results
- Details of combination procedures
- Updated CDF + DØ Higgs combination
- Discussion of results
The DØ Higgs Search

- A broad search program
  - Search for Higgs decays in $H \rightarrow b\bar{b}/WW/\gamma\gamma/\tau\tau$
  - Allow acceptance from $H \rightarrow ZZ/cc/Z\gamma$
  - Production is dominated by gluon fusion and associated production

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The DØ H→diphoton Analysis

- Update recovers improvements unrealized for winter 2012 conferences
  - Improvement in MC/data statistics for background modeling
  - To combat systematic uncertainties, analysis is now split into jet-dominated vs photon-dominated fake rate regions
  - Bottom line: 20-30% improvement in expected limits
The DØ H→WW→l⁺l⁻νν Analysis

- More data & refined analysis technique
  - Di-electron channel adds 12% more data & improves electron identification efficiency
  - Di-muon and di-electron channels now split search sample into regions dominated by Diboson and W/Z+jet backgrounds
  - Technique improves expected limits by 5-10%

![Comparison of Expected limits: H→WW→e⁺e⁻νν](image)

**W/Z+jet Dominated**

- Events vs Final Discriminant

**Diboson-Dominated**

- Events vs Final Discriminant
The DØ WH→lνbb Analysis

- Updates to the WH→lνbb Higgs search
  - Additional muon triggers
  - Improved multijet modeling & rejection
  - Improved signal isolation via separation into 3 double b-tagged final states (vs 2 previously)
  - Bottom line: 10-17% improvements in expected limits

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2 Loose b-tags

DØ Preliminary, 9.7 fb⁻¹

Events/Bin

Total Signal ×100

<table>
<thead>
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<tr>
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2 Medium b-tags

DØ Preliminary, 9.7 fb⁻¹

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2 Tight b-tags

DØ Preliminary, 9.7 fb⁻¹

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Updates to the ZH→llbb Higgs search
- Selection requirements relaxed
- Isolation of top quark backgrounds represents largest change

Bottom line: 10-15% improvement in expected limits
Updates to other DØ Analyses

Added new e/μ+MET+4Jets analysis
- Primarily sensitive to VH→VWW processes
- Contributes mostly for m_H ~165 GeV

Update to VH→VVV→trileptons+X (μeμe) search
- Additional data (~12%), improved Zγ background model, further reject backgrounds

ZH→ννbb search significantly refines MVA training
- Boost training performance via large increase in MC statistics (true for other analyses too)
Planned analysis updates

- Winter→Summer time window was short: some updates didn't make it
  - $H\rightarrow WW\rightarrow \ell \nu jj$: will add 80% in data with significant search improvements
  - $VH\rightarrow VVV\rightarrow ee\mu, \mu\tau\tau$: add ~12% in data, MVA analysis improvements
  - $VH\rightarrow SS \mu\mu$: many new studies in multijet modeling & MVA treatment
  - $H\rightarrow WW\rightarrow e\nu\mu\nu$: adopt splitting in WW vs W+jets enriched regions (5-10% gain)
  - $ZH\rightarrow \nu\nu bb$ (3jets): challenging final state for trigger modeling
  - $VH\rightarrow e/\mu\tau+jj$: Will update to full luminosity, with modeling improvements

**Bottom line:** 5-10% overall improvement still possible for DØ

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The Updated DØ Higgs Search

- 95% C.L. upper limits on SM Higgs boson production at the Tevatron
  - Expected exclusion: $156 < M_H < 173$ GeV
  - Observed exclusion: $159 < M_H < 170$ GeV
The Look Elsewhere Effect

– Could a significant result happen “by chance”? Two main considerations: p-values & the look elsewhere effect (LEE)

p-value:
– The probability of obtaining a result as extreme as the one observed, assuming the NULL hypothesis is true. (NULL hypothesis = “there is no Higgs boson”)
– In other words, “The probability that the background fluctuated up by chance.”
– p-values of 0.15866 / 0.02275 / 0.00135 correspond to 1/2/3 standard deviations

The Look Elsewhere Effect (LEE)
– The probability of obtaining a result as extreme as the one observed in all of the places that you looked.
– We test Higgs masses from 100-200 GeV (100-150 GeV for H→bb), so we must account for the number of independent search regions in that range.

– Ultimately it’s driven by mass resolution. Eg, dijet invariant mass for H→bb.
– We use a LEE factor of 4 (2) for our global (H→bb) search.
Two different test of the data

- **Left:** Local p-value distribution for background-only expectation.
  - Minimum local p-value: 2.0 standard deviations
  - Global p-value with LEE factor of 4: **1.3 standard deviations**
- **Right:** Maximum likelihood fit to data with Higgs boson production rate as free parameter.
CDF & DØ Individual Results

- Results from Tevatron experiments
  - Similar search sensitivity over entire probed mass region
    - DØ: Exclude $159 < M_H < 170$ GeV
    - CDF: Exclude $90 < M_H < 97$ & $147 < M_H < 175$ GeV
Right-to-left integral yields a means to compare data with signal and background predictions.
CDF & DØ Combined Distributions

Fit to data, with background subtraction can reveal potential excesses

$M_H = 115$ GeV

$M_H = 165$ GeV
95% C.L. upper limits on SM Higgs boson production at the Tevatron

- Expected exclusion: $100 < M_H < 120$ GeV  $139 < M_H < 184$ GeV
Upper Limits on Higgs Boson Production

95% C.L. upper limits on SM Higgs boson production at the Tevatron

- Expected exclusion: $100 < M_H < 120 \text{ GeV}$ $139 < M_H < 184 \text{ GeV}$
- Observed exclusion: $100 < M_H < 103 \text{ GeV}$ $147 < M_H < 180 \text{ GeV}$
Two different tests of the data, comparing to S+B and B-only predictions

- **Left**: Local p-value distribution for background-only expectation.
  - Minimum local p-value: 3.0 standard deviations
  - Global p-value with LEE factor of 4: **2.5 standard deviations**

- **Right**: Maximum likelihood fit to data with Higgs rate as free parameter.
Quantifying the Excess

- Considering separately the $H \rightarrow bb$ and $H \rightarrow WW$ channels
  - Local p-value distribution for background-only expectation.
    - Minimum $H \rightarrow bb$ local p-value: 3.2 standard deviations
    - Global $H \rightarrow bb$ p-value with LEE factor of 2: 2.9 standard deviations
Quantifying the Excess

- Considering separately the H→bb and H→WW channels
  - Local p-value distribution for background-only expectation.
    - Minimum H→bb local p-value: 3.2 standard deviations
    - Global H→bb p-value with LEE factor of 2: 2.9 standard deviations
Quantifying the Excess

Tevatron Run II Preliminary
$L \leq 10.0 \text{ fb}^{-1}$

$m_H = 125 \text{ GeV/c}^2$

Combined (68%)

Single Channel

$H \rightarrow W^+W^-$

$H \rightarrow \gamma\gamma$

$H \rightarrow b\bar{b}$

Best Fit $\sigma/\sigma_{SM}$

June 2012

$L \leq 10.0 \text{ fb}^{-1}$

$m_H = 125 \text{ GeV/c}^2$

Posterior Density

Maximum

68th Percentile

95th Percentile

Full Distribution

June 2012
Revisit s/b rebinned distribution plot for $M_H = 125$ GeV

- Cumulative distribution seems to prefer S+B model
- Background-subtracted plot illustrates several interesting candidate events

Quantifying the Excess
Overlaying a Higgs Signal

- Diboson measurement in dijet final states
  - Data and diboson prediction come from Tevatron low mass WZ/ZZ measurement
Overlaying a Higgs Signal

- Diboson measurement in dijet final states
  - Data and diboson prediction come from Tevatron low mass WZ/ZZ measurement
  - Simple overlay of $H \rightarrow bb$ signal prediction for the dijet invariant mass ($M_H = 120$ GeV)
  - Additional signal is not incompatible with data
Log-Likelihood Distributions

- The log-likelihood ratio helps to gauge the relative agreement of the data with the background or signal+background models.

- Distributions are populated with pseudo-experiments to get an estimate of significance.

Background-Only Pseudo-Experiments

Signal+Bkgd Pseudo-Experiments

Observed LLR
Quantifying the Excess

**Tevatron Data**

Tevatron RunII Preliminary

SM Higgs, $L_{\text{int}} \leq 10.0$ fb$^{-1}$

**Signal Injection Study**

Tevatron RunII Preliminary

$m_H=125$ Signal Injection

June 2012
Quantifying the Excess

**Tevatron Data**

Tevatron RunII Preliminary

SM Higgs, \( L_{\text{int}} \leq 10.0 \text{ fb}^{-1} \)

**Signal Injection Study**

Tevatron RunII Preliminary

\( m_{\nu} = 125 \) Signal Injection

Rate = 1.5×SM

June 2012
Conclusions

- Tevatron program analyzing full data set
- The data appear to be incompatible with the background, with a global p-value of:
  
  2.5 s.d. (3.0 local)

  H→bb only: 2.9 s.d. (3.2 local)

- Tevatron data are compatible with SM Higgs boson production for $115 < M_H < 140$

- Tevatron data will play a large role in any potential measurements of $\sigma(WH+ZH) \times BR(H\rightarrow bb)$ for years to come

For additional details see

- Tevatron: http://tevnphwg.fnal.gov/results/SM_Higgs_Summer_12/index.html
- CDF: http://www-cdf.fnal.gov/physics/new/hdg/Results.html
- DØ: http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.html
Thank you, Fermilab

Special thanks to every single person & group at Fermilab who made this possible

It really is a huge team effort!!