Search for a low mass SM Higgs Boson at the Tevatron

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What do we know?

- Something is accountable for EWSB
- SM allows for Higgs mechanism
- Manifests a heavy spin-0 boson
- SM predicts most properties and decay channels of Higgs
  - but not its mass
- Experimental evidence so far:
  - Direct searches at LEP exclude \( m_H < 114 \text{ GeV}/c^2 \)
  - Direct searches at Tevatron beginning to exclude around \( m_H = 160 \text{ GeV}/c^2 \)
  - Indirect constraints from precision measurements (\( m_W \) and \( m_t \)) prefer low mass Higgs: \( m_H < 157 \text{ GeV}/c^2 \) (186 GeV when including LEP limit)
What do we look for?

Separate according to decays:

- **Low mass** \(m_H < 135\text{ GeV}\):
  - Decays dominated by \(H \rightarrow b\bar{b}\)
  - \(gg \rightarrow H \rightarrow b\bar{b}\) difficult to see experimentally
  - Rely on primarily on associated production with \(W\) or \(Z\)
  - **This talk**

- **High mass** \(m_H > 135\text{ GeV}\):
  - Decays dominated by \(H \rightarrow W^+W^-\)
  - Easiest to look for leptonic decays of \(W\)s
  - Considerable contribution from VBF and associated production
  - **Marc’s talk** (next)
Experimental setup: Tevatron

- 1.96 TeV ppbar collider
  - Highest energy collider in the world
- Excellent accelerator performance
  - Quick startup after summer shutdown
  - Inst. lum. exceeding $3 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$
  - Over 7 fb$^{-1}$ delivered to each experiment
  - Results shown today use $\lesssim 5.4$ fb$^{-1}$
- Every bit of data helps
- Many thanks to the Fermilab accelerator division!
Experimental setup: CDF and DØ

Wall Calorimeter (Had)
Plug Calorimeter (EM+Had)
Forward Muon Detectors
Forward Calorimeter (EM)
Silicon Vertex Detector (L00+SVX+ISL)
Drift Chamber (COT)
Central Muon Detectors
Central Calorimeter (EM+Had)

Muon Scintillators
Muon Chambers
Toroid
Calorimeter

–5
0
5

η = 0
η = 1
η = 2
η = 3

Shielding

–5
0
5
10

1.4 T Solenoid

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Low mass Higgs search strategy

- Identified leptons
  - \( WH \rightarrow lvb\bar{b}, ZH \rightarrow llb\bar{b} \)
- Invisible leptons
  - \( WH \rightarrow (l)vb\bar{b}, ZH \rightarrow vvb\bar{b} \)

1. Identify \( W/Z \): leptons (e,\( \mu \))
- Maximize lepton coverage
  - e.g. leptons not in fiducial region of calorimeter

2. Identify Higgs decay: jets
- Develop NN and other advanced tagging algorithms
- Develop multivariate jet corrections

3. Reduce backgrounds
- Multijet backgrounds particularly difficult
  - Model using data
  - Use NN to separate
Signal extraction

- Expected signals too small for counting experiments
- Don’t want to rely on single kinematic distribution
- Exploit all possible information in an event: multivariate discriminants
  - Output single variable that looks at all event kinematics
  - Artificial Neural Networks (NN)
  - Boosted Decision Trees (BDT)
  - Matrix Element (ME) probabilities

- Can we discover rare processes using these techniques? Yes
  - Single top
  - Hadronic decays of dibosons: very similar final states to low mass Higgs
ZH → llbb

- Fully reconstructible final state
- Backgrounds primarily Z+jets, diboson and ttbar (little QCD)
- Very small signal rate

Expand lepton selection to maximize acceptance
Select events with 2 leptons, 2 jets, at least one of which is b-tagged
Can use NN to improve dijet mass resolution
ZH→llb¯b results

• CDF: 2D NN (ZH vs ttbar, ZH vs Z+jets), include leading order ME as input
  • 4.1 fb⁻¹ Observe (expect) $5.9 \times 6.8 \times \sigma_{SM}$ @95% CL for $m_H=115$ GeV
• DØ: boosted decision tree
  • 4.2 fb⁻¹ Observe (expect) $9.1 \times 8.0 \times \sigma_{SM}$ @95% CL for $m_H=115$ GeV
• Largest cross section of $VH$ states with identified lepton
• Select events with high-$p_T$ electron or muon, 2 or 3 jets at least one with a $b$-tag, and large missing $E_T$
• As with $ZH$, can use NN to improve dijet mass resolution
• Dominant backgrounds are $W+$jets, QCD multijet and top
• Split sample up according to number of jets and tags
**WH→νb¯b results**

- **CDF**: ME (2 and 3-jet events)
  - 4.3 fb⁻¹ Observe (expect) \(6.6 (4.1)\times\sigma_{SM}\) @95% CL for \(m_H=115\) GeV
- **CDF**: NN (2-jet events)
  - 4.3 fb⁻¹ Observe (expect) \(5.3 (4.0)\times\sigma_{SM}\) @95% CL for \(m_H=115\) GeV
- **DØ**: NN (2 and 3-jet events)
  - 5.0 fb⁻¹ Observe (expect) \(6.9 (5.1)\times\sigma_{SM}\) @95% CL for \(m_H=115\) GeV
$VH \rightarrow b \bar{b} + E_T$

- Includes contributions from
  - WH→(l)vb\bar{b}
  - ZH→v\bar{v}b\bar{b}
- Select events with large missing $E_T$ and jets with at least 1 $b$-tag
- Exclude identified leptons
  - Ensures independent channel from other $VH$ searches
- Backgrounds by source of missing $E_T$
  - Instrumental: QCD multijet
  - Real: W/Z+jets, top, diboson
- Large QCD background drives analysis design
  - Model using data
  - Use NN (CDF), BDT(DØ) to separate QCD background
• CDF: neural net
  • 3.6 fb\(^{-1}\) Observe (expect) \(6.1 \times \sigma_{\text{SM}}\) @95\% CL for \(m_H=115\) GeV
• DØ: boosted decision tree
  • 5.2 fb\(^{-1}\) Observe (expect) \(3.7 \times \sigma_{\text{SM}}\) @95\% CL for \(m_H=115\) GeV
qqbb final state

- Search for $VH\rightarrow qqbb$ as well as Vector Boson Fusion (VBF)
- Good
  - Has the largest signal yield of low mass searches
  - Fully reconstructable final state
- Ugly
  - Massive QCD multijet background
- Select events with $\geq 4$ jets and 2 $b$-tags
- Use NN to separate QCD from Higgs
- 4 fb$^{-1}$ Observe (expect) $10.4 \ (19.9) \times \sigma_{SM}$ @95% CL for $m_H=120$ GeV
**WH → τνbb and ττqq final state**

- WH → τνbb complements WH → lνb̄b̄
  - Select events with 2 b-jets, missing $E_T$ and hadronic τ
  - Use BDT as discriminant
  - 4.0 fb$^{-1}$ Observe (expect) $14.1 (22.4) \times \sigma_{SM}$ @95% CL for $m_H=115$ GeV

- Look for ττqq to catch remaining tau final states
  - Includes events from ZH → ττb̄b̄, HZ → ττqq, HW → ττqq, VBF, and $gg \rightarrow H \rightarrow ττ+\text{jets}$
  - Require one hadronic τ and one decaying to $μν_μν_τ$
  - Use BDT as discriminant
  - 4.9 fb$^{-1}$ Observe (expect) $27.0 (15.9) \times \sigma_{SM}$ @95% CL for $m_H=115$ GeV
Conclusion

- Comprehensive search for low mass SM Higgs at CDF and DØ
  - Cover all associated production channels
  - High mass $H \to W^+W^-$ search also contributes at low mass
- Combined CDF+DØ sensitivity at $m_H=115$ GeV is now $1.78 \times \sigma_{SM}$
  - Observed limit of $2.70 \times \sigma_{SM}$ at $m_H=115$ GeV
  - See Marc’s talk (next) for latest combination and future projections for Tevatron Higgs searches

![Tevatron Run II Preliminary, L=2.0-5.4 fb$^{-1}$](chart.png)

95% CL Limit/SM

- LEP Exclusion
- Expected
- Observed
- $\pm 1 \sigma$ Expected
- $\pm 2 \sigma$ Expected

$m_H$(GeV/c$^2$)

LEP Exclusion

SM=1

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