Light Higgs boson searches at the Tevatron

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Tevatron, **DØ** and CDF

Higgs production

Search channels for a light Higgs

- **WH** → ℓνbb
- **ZH** → ννbb
- **ZH** → ℓℓbb

Outlook

Conclusion
Run II Integrated Luminosity

<table>
<thead>
<tr>
<th>Run IIa</th>
<th>Delivered</th>
<th>Recorded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run IIb (so far)</td>
<td>1.9 fb⁻¹</td>
<td>1.7 fb⁻¹</td>
</tr>
<tr>
<td>Total</td>
<td>3.5 fb⁻¹</td>
<td>3.0 fb⁻¹</td>
</tr>
</tbody>
</table>

2006 shutdown:
- new Layer 0 silicon installed
- trigger upgrades installed

Passed 3fb⁻¹ milestone in recorded luminosity on 16 January 2008
Two General Purpose Detectors: CDF, DØ

- Electron acceptance: $|\eta| < 2.0$, $|\eta| < 3.0$
- Muon acceptance: $|\eta| < 1.5$, $|\eta| < 2.0$
- Silicon Precision tracking: $|\eta| < 2.0$, $|\eta| < 3.0$
- Hermetic Calorimeter: $|\eta| < 3.6$, $|\eta| < 4.2$

Powerful trigger systems (2.5MHz → 50Hz)
Dilepton triggers with $p_T > 4\text{GeV}$
Total inelastic cross section.

Cross section (barns) vs. Higgs mass (GeV/c^2) graph showing:
- m_b
- b\bar{b}
- \mu_b
- W
- n_b
- Z
- t\bar{t}
- p_b
- single top
- Higgs (ZH + WH)

Values:
- 2 \cdot 10^{10}
- 1 \cdot 10^{7}
- 6,000
- 600
- \geq 1
Tevatron Cross Sections

Light quarks are ubiquitous.

Total inelastic cross section.
Tevatron Cross Sections

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Plenty of W and Z bosons → calibration.

Total inelastic cross section.

Higgs (ZH + WH)
Tevatron Cross Sections

Evidence of single top production is an important milestone towards the Higgs boson.

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The Higgs cross section is 10-11 orders of magnitudes lower than the total inelastic cross section.

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Higgs Production and Decay
Higgs Production and Decay

Cross section (pb)

BR for SM Higgs

Higgs Mass (GeV)

$M_H$ (GeV/c²)

140 GeV

$gg \rightarrow H$

$Hq\bar{q}$

$Hb\bar{b}$

$Hz$

$H\tau^+\tau^-$

$\gamma\gamma Z\gamma$

$cc$

$\tau^+\tau^-$

$WW$

$ZZ$

$tt$
Tools: b–tagging

- lepton
- jet
- B hadron
- K

Tagger
- NN
- JLIP

CDF Run II Preliminary L=584 pb⁻¹

Events per 2 GeV/c²

$M_\ell$ (GeV/c²)

$E_{\ell\ell}$ (GeV)

$p_T > 15$ and All
Low Mass Higgs Channels

\[ ZH \rightarrow l^+l^- bb \]

2 b jets \( \sim \frac{1}{2} M_H \) each  
2 leptons \( \sim 45 \) GeV each  
Z mass constraint  

Cleanest signal

\[ WH \rightarrow l\nu bb \]

2 b jets \( \sim \frac{1}{2} M_H \) each  
0 leptons  
Missing \( E_T \) \( \sim 100 \) GeV  

Largest expected signal
WH → lνbb

\[ q \rightarrow W^* H \rightarrow W^{\pm} l \bar{b} \]

Events

L = 1.7 fb^{-1}

W + 2 jets

Data

W + jets

QCD

SM bkgd

\[ P_T \text{ of Lepton (GeV)} \]
WH → ℓνbb

4 different analyses:
- Double b-tag (S/B ~ 2.3/204)
- Single b-tag (S/B ~ 4/1400)
- W → ev
- W → µν

W + 2 jets

Data

W + jets

QCD

SM bkgd

L = 1.7 fb⁻¹

DØ Preliminary
WH → lνb¯b: Neural Net

- **P_{T} leading jet**
- **Dijet Mass (GeV)**
- **ΔR jets**
- **m(jet1,jet2)**
- **p_{T} 2nd jet**
- **Δφ jets**
- **p_{T} di-jet**
- **p_{T} (l,E_T^{miss})**

**L = 1.7 fb^{-1}**

**DØ Preliminary**

- Data
- W + jets
- QCD
- t¯t
- Wbb
- other
- WH
  115 GeV (x10)
Combining WH Results

single b-tag

double b-tag
Combining WH Results

single b-tag

double b-tag

Limits relative to SM expectation
Combining WH Results

- single b-tag
- double b-tag

CDF Run II Preliminary (1.7 fb⁻¹)

**Limit relative to SM expectation**
ZH → ννb¯b

E_{T}^{\text{miss}} + 2\text{ jets}

**Invariant Mass (GeV)**

- Events/10 GeV
- 200, 300, 400, 500, 600, 700, 800
- Simulated Physics Bkg
- Data
- W+jets MC
- Z+jets MC
- H MC
- TOP MC
- MISC MC
- QCD

**Basic selection:**
- two ... 1 tagged b-jets (CDF)
- two ... 2 tagged b-jets (DØ)
- ET_{miss} > 70 GeV (CDF)
- 50 GeV (DØ)

**Variables:**
- q
- Z
- q
- Z
- q
- Z
- H
- b
- b
- QCD
- MET

**MET scale:** 19 GeV

**Diagrams:**
- ZH decay to ννb¯b
- E_{T}^{\text{miss}}
- 2 jets
ZH → ννb¯b

**ET\text{miss} + 2 jets**

1 tight b–tag + 1 loose b–tag

S/B ~ 1.4/134
ZH → ννb¯b

\[ E_T^{\text{miss}} + 2 \text{ jets} \]

1 tight b-tag + 1 loose b-tag

S/B ~ 1.4/134

Neural Net
ZH → \nu\nu\bar{b}\bar{b}

Upcoming improvements:
- Analyse complete dataset
- QCD–multijet understanding.
- Run Iib Level 1 CAL trigger upgrade.
- Include single–tag.
ZH → ννb¯b

Upcoming improvements:
• Analyse complete dataset
• QCD–multijet understanding.
• Run IIb Level 1 CAL trigger upgrade.
• Include single–tag.
ZH → llbb: DØ
ZH → llbb: DØ

S/B ~ 0.53/74 before NN
ZH → llbb: DØ

S/B ~ 0.53/74 before NN

ZH → ll bb

Neural Net

DØ Preliminary (920 pb⁻¹)

Events / 2 GeV

DØ Preliminary, L=1.1 fb⁻¹

Limit / σ(pF → ZH→llbb)

obs: 18

exp: 20
Two independent neural nets are trained to separate ZH from:

- $t\bar{t}$ background
- $Z+\text{jet}$ background

**Search for $ZH \rightarrow llb\bar{b}$**

- **Exp:** 16
- **Obs:** 16

**CDF II Preliminary $\int Ldt = 1 \text{ fb}^{-1}$**

- **NN Output - Data (Single Tag)**

**$M_H$ (GeV/c$^2$)**

- **Observed Limit (Combined)**
- **Expected Limit (Combined) $\pm 1\sigma$**
- **Observed Limit (1 tag)**
- **Expected Limit (1 tag)**
- **Observed Limit (2 tag)**
- **Expected Limit (2 tag)**
Tevatron Combination

Tevatron Run II Preliminary, L=0.9-1.9 fb\(^{-1}\)

- LEP Limit
- CDF Expected
- DØ Expected
- Tevatron Expected
- Tevatron Observed

obs: 6.2
exp: 4.3

95% CL Limit/SM

m\(_H\) (GeV/c\(^2\))

Projecting Higgs Reach to 2010

Improvements assumed in projections

✦ b-tagging
  • b-tagging with Layer 0 (~8% per tag efficiency increase, DØ)
  • add semileptonic b-tags (~5% per tag efficiency increase, DØ)
  • improved usage of existing taggers (~25%, CDF)
  • add single-b-tag channel to ZH→vwb (DØ)

✦ Acceptance
  • include forward electrons in WH (DØ)
  • include 3-jet sample in WH (DØ)
  • 25% trigger acceptance (CDF)

✦ Analysis techniques
  • improved multivariate analyses (~20% in sensitivity)
  • better usage of $E_{T}^{\text{miss}}$
  • di-jet mass resolution (from 18% to 15% in $\sigma(m)/m$, DØ)

✦ scaling of systematic uncertainties as a function of luminosity

Additional improvements not yet included in projection

inclusion of tau channels
charm rejection in single b-tag analyses
optimizing H→WW at low mass

...
Higgs Status and Projections

- **Expected Limit/SM**
  - Summer 2005 Channels
  - Summer 2006 Channels
  - With CDF Update Winter 2008
  - With Improvements

- **Integrated luminosity/Experiment (fb⁻¹)**

- **m_H = 160 GeV**
- **115 GeV CDF & DØ combined**

- **Sensitivity Improvements**

Rob Roser, P5 Meeting, 01/02/08
Conclusion

With data accumulated by the end of 2010, we expect
- 95% exclusion possible over almost entire allowed mass range
- 3σ evidence possible at low and high ends of range
Backup Slides
Limit Setting

- In the absence of signal, we set limits on Standard Model Higgs boson production.

  - We calculate limits via the CLs prescription:
    \[
    CL_s = \frac{CL_{s+b}}{CL_b}
    \]

  - Using a Log-Likelihood Ratio test statistic:
    \[
    Q(\vec{s}, \vec{b}, \vec{d}) = \prod_{i=0}^{N_{Chan}} \prod_{j=0}^{N_{bins}} \frac{(s+b)^{d_{ij}} e^{(s+b)_{ij}}}{d_{ij}!} \frac{b^{d_{ij}} e^{b_{ij}}}{d_{ij}!}
    \]
    \[
    LLR = -2 \times \log Q
    \]

  \[d_{ij}\] refers to “data” for model being tested

- Distributions of simulated outcomes are populated via Poisson trial with mean values given by B-only or S+B hypotheses.

  - Systematics are folded in via Gaussian marginalization.
  
  - Correlations held amongst signals and backgrounds.
Limit Setting: LLR

Sample LLR Distributions

"Data excess" scenario
Tevatron Combination

CDF + DØ SM Higgs Combination
L=0.9-1.9 fb⁻¹

m_H (GeV/c²)
$\int L \, dt = 30 \, fb^{-1}$
(no K-factors)

ATLAS