Standard Model Higgs searches at the Fermilab Tevatron

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For the CDF and DØ Collaborations

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Outline

• Search overview
• Tevatron performance and extrapolations
• Search methods
• Low mass limits: associated production (WH and ZH)
• High mass limits: \( H \rightarrow WW^*(\rightarrow l^+l^-) \) searches
• Summary and outlook

Thanks to the Fermilab accelerator team for providing collisions at increasing luminosities and to CDF and DØ physicists for their tireless efforts in collecting the collisions and understanding them.
114 GeV < $M_H$ < 251 GeV (95% CL)
(LEP Direct and $M_W$ / $M_{top}$ global fit)

$L = 4$ fb$^{-1}$ buys 50% chance of a $3\sigma$
SM Higgs signal for $M_H = 120$GeV
(Both experiments, combined channels, smart analyses, no systematics…)

For $M_H = 200$GeV, relevant production cross sections down by a factor of 8.
Tevatron Integrated Luminosity (fb⁻¹)

12 pb⁻¹/week currently: above “design”

Aug 04: ~0.7fb⁻¹ delivered: above design

4 fb⁻¹ line: 2009? 2010? Earlier?
Tevatron Delivered Luminosity (pb⁻¹)

Collider Run II Integrated Luminosity

Weekly Integrated Luminosity (pb⁻¹)

Run Integrated Luminosity (pb⁻¹)

Week #

(WEEK 1 STARTS 03/05/01)

Integrated

Last 30 weeks
CDF Integrated Luminosity (pb$^{-1}$) vs Store No.
The SM Higgs production cross sections

- Low $M_H$: Standalone Higgs ($gg\rightarrow H$) swamped: WH, ZH (associated production) better (with $H\rightarrow bb$)
- High $M_H$: $H\rightarrow WW, WW^*$

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**Diagrams:**
- **Branching Ratios:**
  - $bb$
  - $WW$
  - $\tau\tau$
  - $gg$
  - $ZZ$
  - $c\bar{c}$

- **Cross Sections:**
  - $gg\rightarrow H$
  - WH
  - ZH

**Equations:**

$$pp, \sqrt{s}=1.96 \text{ TeV}$$
The upgraded CDF and DØ Run II detectors

• New
  ➢ silicon detector
  ➢ drift chamber
  ➢ TOF PID system

• Upgraded
  ➢ calorimeter, muon system
  ➢ DAQ/trigger
  ➢ displaced-vtx trigger

• New (tracking in B-field)
  ➢ silicon detector
  ➢ fiber tracker

• Upgraded
  ➢ muon system, calorimeter
  ➢ DAQ/trigger
  ➢ (displaced-vtx trigger soon)
b-jet tagging

- CDF:
  - 50% b-tag efficiency (top) for
  - ~0.6% light quark mis-tag rate in $|\eta| < 2$

- D0:
  - 40% efficiency for < 1% mis-tag rate in $|\eta| < 2.5$
Low Mass Higgs Search

For $m_H<135$ GeV, $b\bar{b}$ decays dominate:

- Need good $b$ tagging, $b\bar{b}$ mass resolution
- Understand background (amount & shapes)
Synopsis: $W(\rightarrow e\nu/\mu\nu)H(\rightarrow bb)$; Low $M_H$ Assoc Prod

- $\sigma.$ BR ($WH \rightarrow l\nu bb$) $\sim 150$ fb ($M_H=120$GeV, $l=e,\mu$)
- Acceptance $\sim 2\%$ (CDF)
- Background $\sim 400$ events per fb$^{-1}$ (CDF)
- $S/N(120$GeV,$1$fb$^{-1}) = (150 \times 2\%)/\sqrt{400} = 3/20$
- Need: Higher luminosity
- Need: improved b-tag, bb mass resolution etc
- Need: to combine channels and experiments
$W(\rightarrow e\nu/\mu\nu)H(\rightarrow bb)$; Low $M_H$ Assoc Prod: CDF (1)

- Look for $e$ or $\mu$ with two jets and $E_T^\gamma$:
  - Central isolated $e/\mu$, $p_T > 20$ GeV
  - Missing $E_T > 20$ GeV
  - Two jets: $E_T > 15$ GeV, $|\eta| < 2$
  - Veto Di-lepton, extra jet, etc.

→ Observe 2072 events in data
  (jets are not b's yet)

- Simulations with Alpgen plus Herwig with detailed detector response

$W^\pm b\bar{b}$ Search Dijet Mass Distribution (no b-tag)

CDF Run II Preliminary 162 pb$^{-1}$

$W^\pm + 2$jets (no b-tag)

- Data
- $W^\pm$ + light flavors
- $W^\pm$ + heavy flavors
- Top
- $W^\pm Z^0$, $W^0 W^\pm$, $Z^0 Z^0$ and $Z^0 \rightarrow \tau^+\tau^-$
- non-$W^\pm$

$\chi^2/ndf = 40.6/22$
W(→eν/μν)H(→bb); Low M_H Assoc Prod: CDF  

- Enrich b-content by requiring at least one b-tagged jet

→ Observe 62 events in data
→ Expect 61 ± 5 events

- Main contributions to the bkgd.

<table>
<thead>
<tr>
<th>Mistags</th>
<th>Wc(c)</th>
<th>Wbb</th>
<th>QCD</th>
<th>top</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>13</td>
<td>12</td>
<td>10</td>
<td>9</td>
</tr>
</tbody>
</table>

- Expect 0.3 evts from Higgs
  - Signal acceptance of ∼ 1.8% for M_H = 110 – 130 GeV
**W(\rightarrow e\nu/\mu\nu)H(\rightarrow bb); Low M_H Assoc Prod: CDF** (3)

- Limit Higgs prod cross section times branching fr. $\sigma \times B < 5$ pb
- Improve CDF’s Run I limit $\sigma \times B < 14–19$ pb for $M_H = 70–120$ GeV

<table>
<thead>
<tr>
<th>Source</th>
<th>Uncertainty (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISR / FSR</td>
<td>19</td>
</tr>
<tr>
<td>Secondary vertex</td>
<td>8.6</td>
</tr>
<tr>
<td>Lepton ID</td>
<td>5</td>
</tr>
<tr>
<td>Jet energy scale</td>
<td>3</td>
</tr>
<tr>
<td>PDF</td>
<td>1</td>
</tr>
<tr>
<td>Trigger</td>
<td>0.7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>22</strong></td>
</tr>
</tbody>
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*Expected Limit ± 1σ*

**W^+b\bar{b}** Search 95% C.L. Upper Limit

- CDF Run II Preliminary 162 pb$^{-1}$
- Data
- LO Technicolor ($p\bar{p} \rightarrow W^{\pm}\pi^0 \rightarrow W^\pm b\bar{b}$)
- NLO Standard Model Higgs ($p\bar{p} \rightarrow W^\pm H \rightarrow W^\pm b\bar{b}$)

- Expect improvements due to better di-jet mass resolution
• Central isolated e, $p_T > 20$ GeV
• Missing $E_T > 25$ GeV
• ≥2 jets: $E_T > 20$ GeV, $|h| < 2.5$
• $L_{int} = 174$ pb$^{-1}$ of data
• B-tag jets
• Suppress top: exactly two jets
• Sample composition:

<table>
<thead>
<tr>
<th>Wbb</th>
<th>Wc(c)</th>
<th>Wjj</th>
<th>tt'+t</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4±0.4</td>
<td>0.3±0.1</td>
<td>0.1±0.03</td>
<td>0.6±0.2</td>
<td>0.1±0.03</td>
</tr>
</tbody>
</table>

• Observe 2 evts., expect 2.5±0.5
• Set 95% CL limits
  - $\sigma(Wbb) < 20.3$ pb
  - $\sigma(WH)B(H\rightarrow bb) < 12.4$ pb
    for $M_H = 115$ GeV
$H \rightarrow WW(*) \rightarrow (e/\mu)(e/\mu)\nu\nu$; High $M_H$

$gg \rightarrow H \rightarrow WW \rightarrow ll\nu\nu$  
$ZH/WH \rightarrow WWW/ZWW$

Same context as WW analysis
H → WW(*) → (e/μ)(e/μ)νν; High M_H: D0  (1)

- Two isolated leptons with p_T > 12/8 GeV (20/10 GeV for μμ)
- Missing E_T > 20 GeV (30GeV for μμ)
- Veto Z resonance, Energetic jets

- Simulation: Pythia + detector
- Data Integrated luminosity ~ 180 (ee), 160 (eμ) and 150 (μμ) pb⁻¹
Two neutrinos: No reconstructed Higgs mass

Employ spin correlations (lepton-lepton angle) to suppress the background

Leptons from Higgs tend to be collinear

\[ \text{H} \rightarrow \text{WW}^{(*)} \rightarrow (e/\mu)(e/\mu)\nu\nu; \text{ High } M_H: \text{ D}0 \quad (2) \]
**H \rightarrow WW(\star) \rightarrow (e/\mu)(e/\mu)\nu\nu; \text{ High } M_H: D0 \ (3)**

- Number of events after all cuts

<table>
<thead>
<tr>
<th></th>
<th>ee</th>
<th>e(\mu)</th>
<th>(\mu\mu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed</td>
<td>2</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Expected</td>
<td>2.7±0.4</td>
<td>3.1±0.3</td>
<td>5.3±0.6</td>
</tr>
</tbody>
</table>

- Dominant background in e\(\mu\) sample

<table>
<thead>
<tr>
<th>Process</th>
<th>Expected</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>WW</td>
<td>2.51±0.05</td>
<td>0.34±0.02</td>
</tr>
<tr>
<td>W+jets</td>
<td>0.34±0.02</td>
<td>0.11±0.01</td>
</tr>
<tr>
<td>WZ</td>
<td>0.11±0.01</td>
<td>0.13±0.01</td>
</tr>
<tr>
<td>tt</td>
<td>0.13±0.01</td>
<td>0.13±0.01</td>
</tr>
</tbody>
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- Signal acceptance is \(\sim 0.02 - 0.2\) depending on the Higgs mass/final state

Excluded cross section times Branching Ratio at 95% C.L.

### Graphs

1. **Higgs of 160 GeV**
2. **Excluded at LEP**
3. **4th Generation Model**
4. **Topcolor**
5. **Standard Model**

**Vietnam'04**

Sunil Somalwar, CDF/Rutgers
$H \rightarrow WW(\ast) \rightarrow (e/\mu)(e/\mu)\nu\nu$; High $M_H$: CDF

- Use dilepton invariant mass as discriminating variable ($> 60$ GeV)
- 8 events seen (8.9 expected, mostly WW)

Perform likelihood fit using angular distribution

Vietnam'04
Summary & Outlook

• Low and high mass Higgs (associated production) limits from both CDF and D0 with about 0.2 fb\(^{-1}\) data.

• Tevatron needs to beat the “street estimate”. Recent record-setting performance is encouraging.

• Detector/analysis efficiency improvement is a must. Good news: as shown, B-tagging, background understanding and other tools are in place.

• Things sometimes go bump in the run!

• Maybe \(M_H\) is on the low side or we will get lucky with Susy (and Susy likes high tan(\(\beta\))).
MSSM Higgs to $\tau\tau$ Search (CDF)

CDF Run2 Preliminary (195 pb$^{-1}$)

MSSM Higgs $\rightarrow \tau\tau$ Search

95% CL Upper Limit

$\sigma(p\bar{p} \rightarrow A) \times BR(A \rightarrow \tau\tau)$ (pb)

$M_A$ (GeV)

- Expected Limit
- Observed Limit
MSSM Higgs to $\tau\tau$ Search (CDF)

CDF Run2 Preliminary (195 pb$^{-1}$)

MSSM Higgs $\rightarrow \tau\tau$ Search

95% CL Upper Limit

$\sigma(pp \rightarrow A) \times BR(A \rightarrow \tau\tau)$ (pb)

- Expected Limit
- Observed Limit

My $\tan\beta$ curves not to be taken seriously!

$\tan\beta = 30, 60$