Un-Ki Yang
The University of Manchester

for the CDF and D collaborations

BSM Higgs at Tevatron

Higgs Hunting Workshop, July 29-31 2010, Orsay, France
Incredible efforts by thousands of physicists: the SM Higgs.
Incredible efforts by thousands of physicists: the SM Higgs

- The searches for the SM Higgs are extremely challenging
- But very crucial to discover it !!!
But the Real World is …

- The BSM Higgs(?) World

- The SM is not complete;
  - Hierarchy problem (fine tuning)
  - Effective theory at low energy?

- Dark Matter
- Neutrino Oscillation
The Strategy: SM Higgs

- Maximize acceptance while reducing bkgds: better triggers, lepton IDs, b-tagging, mass resolution etc
- Use advanced analysis algorithms (NN, BDT, MET etc)
- Analyse all possible channels separately, then combine them

See talks by R. Hughes & M. Kirby
- Enhance production: MSSM, 4th gen. model

- Different Higgs couplings to fermions & bosons: fermiophobic,

- New allowed final states:
  NMSSM (2 extra Higgs, $h \rightarrow aa \rightarrow 4\tau$), charged Higgs ($t \rightarrow H^\pm b$)
BSM Higgs Searches

- Tevatron Status
- MSSM Higgs
  - Neutral Higgs ($\phi \rightarrow \tau\tau$, $b\phi \rightarrow bbb$, $b\phi \rightarrow b\tau\tau$)
- Charged Higgs

- NMSSM Higgs
- Fermiophobic Higgs
- 4th generation of fermions
- Higgsless model (NO Higgs, not supposed to talk about)
The Tevatron has been running beautifully
- Delivered lum. $9.0 \text{ fb}^{-1}$ per experiment (acquired lum. $7.5-8 \text{ fb}^{-1}$)
- The highest inst. lum. $4.08 \times 10^{32} \text{ cm}^{-2} \text{s}^{-1}$
- Production is enhanced by $\tan\beta^2$
- Another factor of 2 due to degeneracy of two Higgs bosons
- Coupling to $b$ quark is increased by $\tan\beta$: greatly enhanced $\sigma(b\bar{b}\rightarrow H)$
Search Modes

- At high $\tan\beta$, for all $m_A$:
  - $Br(\tau\tau) \approx 90\%$ (but large bkgds)
  - $Br(\tau\tau) \approx 10\%$ (but distinct signature)

Three searches:
- $\phi \rightarrow \tau\tau$
- $b\phi \rightarrow bbb$
- $b\phi \rightarrow b\tau\tau$

Good $b$-jet and $\tau$ identification are essential!
- Searches in three different channels: $\tau_e\tau_{\text{had}}, \tau_\mu\tau_{\text{had}}, \tau_e\tau_\mu$
- At least one lepton ($e/\mu$), but only $e\mu$ dileptons (no $ee, \mu\mu$)

eff:~50%
Dominant backgrounds:
• Irreducible $Z \rightarrow \tau\tau$ (MC)
• $W^{+}$jet fake (data)

$D\emptyset$: $M_T < 40$ GeV

CDF: use relative directions of visible $\tau$ and MET

$\tau^-_{id}$ is a main systematic

No excess over the prediction $m_{\phi}(\text{vis+MET})$
3 b-tag events to reduce bkgds selected with SVT trigger

Fully data-driven bkgds: use 2 b-tagged events to model bb+(b,c,mistag) with flavor separation using tag properties
MSSM Higgs: $\phi \rightarrow b\bar{b}$

- **Set $\sigma_x BR$ @95% C.L.**

- **MSSM exclusion in $m_A$ vs $\tan \beta$**

Interesting deviation at ~140 GeV with p-value=0.9%
3 b-tagged events using NN tagger (implemented in trigger)
- Search in $b\tau_\mu\tau_{\text{had}}$ channel with 4.3 fb$^{-1}$ data
MSSM Higgs:

\[ \phi \rightarrow b \tau^+ \tau^- \]

- Set \( \sigma \times BR @ 95\% C.L. \)
- MSSM exclusion in \( m_A \) vs. \( \tan \beta \)
- Comparable to D∅ combination limit from \( \tau \tau \), \( b \bar{b}, b \tau \tau \) (1-2.6 fb\(^{-1}\))

\[ \sigma_{\text{MSSM}} \times BR = 2 \sigma_{\text{SM}} \times \frac{\tan^2 \beta}{(1 + \Delta_s)^2} \]
(no loop effects, \( \Delta_s^{\text{tree}} = 0 \))

DO preliminary, \( L = 4.3 \) fb\(^{-1}\)
Charged Higgs: $H^+$

- Only exists in the BSM: direct evidence of new physics
- If $m_{H^+} < m_t$: search in top events for $t \to H^+ + b$ decay
  - Two main decays; $H^+ \to \tau \nu$ (high $\tan\beta$), $cs$ (low $\tan\beta$)
    - $H^+(cs)$ dijet shape and counting experiments
- If $m_{H^+} > m_t$: search in top events for $H^+ \to t\bar{b}$ decay

Left panel: Diagram of decay pathways and particles:
- $W^+$, $t$, $\bar{t}$, $H^-$, $\ell$, $b$-jet, $s(\nu)$, $c(\tau)$, $b$-jet
- $\nu W^-$

Right panel: Branching ratio vs. $\tan\beta$:
- $H^\pm$ decay
  - $H^\pm \to \text{cs}$
  - $H^\pm \to \tau \nu$
  - $H^\pm \to t\bar{b}$
  - $H^\pm \to W^+ A^0$
  - $H^\pm \to W^+ h^0$
- $B(t \to H \bar{b})$
\[ \text{Light H} + \text{Search: } \text{H} \rightarrow \text{cs} \]

Search for a second bump in the di-jet mass (W/H) from top decays.

Lepton (e/\mu)+4jets with loose 2b-tag jets, MET.

Understanding of the tail in the di-jet mass: essential.

\[ B(t \rightarrow H^+b) = 0.1 \]

\[ W^+ \text{ in } t\bar{t} \]

\[ \text{non-t\bar{t} bkg} \]

\[ \text{Data} \]

\[ \text{Observed at } 95\% \text{ C.L.} \]

\[ \text{Expected at } 95\% \text{ C.L.} \]

\[ 68\% \text{ of SM at } 95\% \text{ C.L.} \]

\[ 95\% \text{ of SM at } 95\% \text{ C.L.} \]

PRL 103, 101803 (2009)

\[ \triangleright \text{ 10\% better limit for } H^+ \rightarrow \text{ud} \]
Higgs Searches: H → τν, cs

- Counting exp.: dilepton, lep+jets, lep+τ
- Assuming leptophobic (100% cs) and tauonic (100%) scenarios
- Fit to BR(t → H^+b) with the NLO \( \sigma(tt) \), 7.3 ± 0.7pb

PRL 103, 101803 (2009)
Counting exp.: dilepton, lep+jets, lep+$\tau$:

- Data vs. expected assuming leptophobic (100% cs) and tauonic (100%) scenarios

- Fit to $\text{BR}(t \rightarrow H^+ b)$ with the NLO $\sigma_{(tt)}$, $7.3 \pm 0.7 \text{pb}$
2-D fits to BR & $\sigma(\ttbar)$ together: 30% improvement

MSSM exclusion limit in $m_A$ vs $\tan\beta$ plane for leptophobic (100% $c\bar{s}$) and tauonic (100% $\tau\nu$)
The Next-to-MSSM adds singlet superfield to the MSSM

- Two additional Higgs: CP-even and CP-odd ($a$)

- The CP-odd ($a$) (pseudo-scalar) can be the lightest Higgs

- The SM-like Higgs: $h \rightarrow aa$ (dominant decay), $h \rightarrow bb$ (suppressed)

- It can avoid the LEP direct limit, $M_h > 114$ GeV, the most general LEP limit, $M_h > 82$ GeV

- $2m_\mu < M_a < 2m_\tau$: $a \rightarrow \mu\mu$ (dominant decay)

- $h \rightarrow aa \rightarrow 4\mu$, search for two pairs of the very collinear muons

- $2m_\tau < M_a < 2m_b$: $a \rightarrow \tau\tau$ (primary decay)

- $4\tau$ final states challenging, search for $h \rightarrow aa \rightarrow \mu\mu\tau\tau$

- $H^+ \rightarrow aW \rightarrow \tau\tauW$, search for $H^+$ from top decays in top pair events
Search for $h \rightarrow a a \rightarrow 4 \mu$

- Two muons
  - $\Delta R(\mu, \mu) > 1$, different isolation cut
- Two companion tracks
  - $\Delta R(\mu, \text{track}) > 1$
- Counts events in 2D Higgs ($a$) mass windows
- 2 exp. evts against 2.2 $\pm$ 0.5 bkgds

Search for $h \rightarrow aa \rightarrow \mu\mu\tau\tau$

- $\Delta R(\mu, \mu) < 0.5$ & MET > 25 GeV
- $\Delta R(\text{MET}, \mu\mu) > 2.5$
- Looking in dimuon mass windows
- Lepton+3 jets with one b-jet, one isolated track
In the 2-D Higgs Doublet Model, Higgs couples only to bosons when the mixing angle $\alpha = \frac{\pi}{2}$: different origin of mass for fermions and bosons.

Two promising channels:

- $H \gamma \gamma$ at low mass: large BR due to no $bb$ decay.
- $WHW$, $WZW$ at high mass

See M. Kirby's talk.
Search for a diphoton mass resonance

- Much better energy resolution than jets (<3%)
- Large recoil against H

CDF:
- \( P_T(\gamma\gamma) > 75 \text{ GeV} \)
- Background shape from sideband
- Excluded \( M_h < 106 \text{ GeV} @95\% \text{ CL} \)

DØ:
- \( P_T(\gamma\gamma) > 35 \text{ GeV} \)
- Background shape from data and MC
- Excluded \( M_h < 102.5 \text{ GeV} @95\% \text{ CL} \)
• Precision EWK fit results are consistent with a heavy Higgs boson up to $m_H = 300$ GeV at 68% CL, $m(4\text{th} \nu) > 45$ GeV

• $ggH$ coupling by a factor of 3 larger, but no change for $WWH$, $ZZH$

• Focus on $ggH \rightarrow WW$: 2 OS leptons with MET

• Combined analysis of the WW CDF (4.8 fb$^{-1}$) and D (5.4 fb$^{-1}$) results

➤ Exclude a SM-like Higgs boson for $131 < m_H < 204$ GeV @ 95% CL
Summary

- BSM Higgs boson hunting effort at the Tevatron are diverse and vigorous, looking for every corners even not allowed by the SM.
- No evidence of BSM Higgs in up to 5.4 fb$^{-1}$ of data.
- The Tevatron is running extremely well.
- With >10 fb$^{-1}$ data, we hope to make significant statements about BSM Higgs.