Beyond the Standard Model
Higgs Searches at the Tevatron

presented by
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on behalf of the DØ and CDF Collaborations

XLIV$^{th}$ Rencontres de Moriond: EW Interactions and Unified Theories
La Thuile, Val d’Aoste, Italy
March 7-14, 2009
BSM Higgs: Outline

- In addition to SM searches, several extensions to SM predict Higgs
  - behave similar to SM Higgs, but exhibit different couplings
  - branching ratio of various Higgs decays can be enhanced significantly

I. Fermiophobic Higgs Search
- Higgs primarily couples to bosons and branching ratios to fermions substantially suppressed
- depending on mass: decays mostly to γ or W bosons
  + $h_f \rightarrow \gamma\gamma$, $WH \rightarrow WWW^*$

II. MSSM Higgs Search
- 5 physical Higgs bosons
  + $\phi (= h^0, H^0, A^0)$ and $H^\pm$
- main searches
  + $\phi \rightarrow b\bar{b}b$
  + $\phi \rightarrow \tau\tau$ and $\phi \rightarrow \tau\tau\tau$
  + charged Higgs in top decays
    (see talk on Tevatron $t\bar{t}$ Prod. results)

A. Patwa: Moriond 2009
**WH → WWW* → ℓ±ν ℓ±ν + X Search**

- For Fermiophobic Higgs: \( M_h > 110 \text{ GeV} \) \( \Rightarrow \) \( \text{Br}(h \rightarrow \text{WW}^*) \) supersedes \( \text{Br}(h \rightarrow \gamma\gamma) \)
- Signature of associated Higgs production requires like-sign dileptons (e, \( \mu \))
  - sign from one of W’s via Higgs = sign from associated W
- [updated since ICHEP ‘08] 2.7 fb\(^{-1}\) search: use data-driven methods in control regions to estimate fake leptons and residual photon-conversion backgrounds
- Implement Boosted Decision Tree to improve search sensitivity
  - BDT outputs: data agrees with expected background
  - ratio of \( \sigma \times \text{BR} \) limit to theory prediction \( \sim 8.8 \) at \( M_h = 120 \text{ GeV} \) (at 95% CL)

![Graphs](image.png)

A. Patwa: Moriond 2009
\[ \text{WH} \rightarrow \text{WWW}^* \rightarrow l^\pm \nu l^\pm \nu + X \]

- Similarly, DØ considers like-sign isolated dileptons with 1.0 fb\(^{-1}\) dataset
- Likelihood discriminant used to separate signal from physics backgrounds:
  - physics: \( WZ \rightarrow l\nu ll \), with lost lepton from Z
  - QCD: b-jets, punch-throughs, \( \gamma \rightarrow e \)
  - charge flips: mainly from \( Z/\gamma^* \rightarrow ll \)
- For each final state, data agrees with expected backgrounds \( \Rightarrow \) similar sensitivity for \( \sigma \times \text{Br} \)
Fermiophobic $h_f \to \gamma\gamma$ Search

- [updated] 3.0 fb$^{-1}$ result roughly doubles acceptance by including one forward $\gamma$
- $M_{\gamma\gamma}$ fitted with smooth function
  - peak hunt: no evidence of narrow resonance in di-photon data spectrum

Fermiophobic $h \to \gamma\gamma$ (3.0 fb$^{-1}$)

- For Fermiophobic couplings, limit set at 95% CL: $m_{hf} > 106$ GeV
  - for model, strongest limit to date by hadron collider
- $\mathrm{D}\Phi$ (1.1 fb$^{-1}$): $m_{hf} > 100$ GeV
  - new result expected soon
- Tevatron results: extend sensitivity for $\mathrm{Br}(h_f \to \gamma\gamma)$ into $m_{hf} > 130$ GeV region, not accessible by LEP
Higgs bosons in the MSSM

- MSSM Higgs requires 2 doublets
  - yields: $\phi = (h^0, H^0, A^0)$ and $H^\pm$
- At tree-level, MSSM Higgs fully specified by two free parameters
  - $M_A$
  - $\tan\beta = \langle H_u \rangle / \langle H_d \rangle$
    (ratio of v.e.v. of 2 Higgs doublet)
- Radiative corrections introduce dependence on additional SUSY parameters
- $\sigma(p\bar{p} \to h/H/A) \propto \tan^2 \beta$
  - at large $\tan\beta$ (low $M_A$) $\Rightarrow$ enhanced production cross-section
- $h/H/A$ decays, in most parameter space:
  - $\phi \to b\bar{b}$ ($\sim 90\%$)
  - $\phi \to \tau\tau$ ($\sim 10\%$)
    - smaller BR but cleaner signature
      (vs. large QCD background in $b$ mode)
**DØ: φb → bbb Search**

- φ→b̅b search difficult due to large multi-jet background
  - consider φ produced in association with at least one b-jet
- 2.6 fb⁻¹ data requires 3 b-tagged jets via NN b-tagger
  - likelihood discriminates b-jets via Higgs signal from multi-jet backgrounds
- Improve sensitivity by separating into 3, 4, and 5-jet channels
- No excess in di-jet invariant mass: 95% C.L. exclusion limits in MSSM benchmark parameter space

**Higgs mass term, \( \mu < 0 \):** enhanced production for 3b mode gives strongest limits

A. Patwa: Moriond 2009
CDF: $\phi b \rightarrow b\bar{b}b$ Search

- Require 3 b-tagged jets with 1.9 fb$^{-1}$ data
- Search for enhancements in mass of 2 lead jets, $m_{12}$
- Fit 2- and 3-tag distributions to estimate quark content from heavy-flavor multi-jet backgrounds
  - vertex mass fits $\Rightarrow$ set mass-dependent cross section limits
  - translate limits in $(M_A, \tan\beta)$ plane

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A. Patwa: Moriond 2009
CDF: $\phi \rightarrow \tau \tau$ Search

- CDF considers $\tau_\mu \tau_{\text{had}}$, $\tau_\mu \tau_{\text{had}}$, and $\tau_e \tau_\mu$ channels with 1.8 fb$^{-1}$ data, selected by:
  - isolated $e$ or $\mu$: opposite sign (OS) from hadronic $\tau$
  - $\tau$’s selected using variable-size cone algorithm
  - $W$+jets background removed by requirement on relative direction of visible $\tau$ decay products and $E_T$

<table>
<thead>
<tr>
<th>Final State: $\tau_\mu \tau_{\text{had}}$</th>
<th>Sum Background</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau_\mu \tau_{\text{had}}$</td>
<td>1750.8 ± 41.8</td>
<td>1666 ± 41</td>
</tr>
<tr>
<td>$\tau_e \tau_{\text{had}}$</td>
<td>1921.1 ± 43.8</td>
<td>1979 ± 45</td>
</tr>
<tr>
<td>$\tau_e \tau_\mu$</td>
<td>701.9 ± 26.5</td>
<td>726 ± 27</td>
</tr>
</tbody>
</table>

- Data agrees with backgrounds for visible mass
  - set $\sigma \times \text{BR}$ limits for $90 \text{ GeV} < M_A < 250 \text{ GeV}$
DØ: Inclusive $\tau\tau$ Search

- Result using 1.0 fb$^{-1}$ dataset for $\tau_\mu \tau_{\text{had}}$, $\tau_e \tau_{\text{had}}$, and $\tau_e \tau_\mu$: PRL 101, 071804 (2008)

- 2.2 fb$^{-1}$ of Run II data considers $\tau_\mu \tau_{\text{had}}$
  - isolated $\mu$ separated from $\tau$: opposite sign
  - hadronic $\tau$ categorized by decay types
    - discriminated from jets using $\tau$-ID NN
  - $M_T < 40$ GeV $\Rightarrow$ reject W+jets

- No excess in data across visible mass spectrum
  - extract upper limits on $\sigma \times \text{BR}$ as function of $\phi$ mass
    - 2.2 fb$^{-1}$ result:
      - $\sim 10$ - 20% improvement
    - dominant systematic:
      - $\tau$-ID (4 - 8%)
**ττ Search: MSSM Interpretation**

- Interpret limits into MSSM $m_h^{\text{max}}$ and no-mixing benchmark scenarios
- Exclusion results similar for each experiment
  - reached sensitivity $\tan \beta \sim 40 - 50$ for $M_A < 180$ GeV

**MSSM Higgs $\rightarrow \tau \tau$ Search, 95% CL Exclusion**

- $m_h^{\text{max}}$, $\mu = +200$ GeV
- No-mixing, $\mu = +200$ GeV

**CDF Run II Preliminary, 1.8 fb$^{-1}$**

- CDF Run II Preliminary, 1.8 fb$^{-1}$
- No mixing
- $\mu > 0$
- $\mu < 0$
**φb → ττb Search: σ × BR and MSSM Limits**

- **1.2 fb⁻¹ search considers φb → τμτₜₕₜd b**
  - use developed techniques from both φ → ττ and φb → bbb searches
  [published 330 pb⁻¹ result: PRL 102, 051804 (2009)]
- **Pre b-tag:** dominated by QCD multi-jet and Z → ττ, μμ backgrounds
- **Post b-tag:** dominated by QCD multi-jet and top events
- **Limits calculated for σ × BR and translated into MSSM exclusions**
  - complementary to φ → ττ channel as it does not suffer from Z → ττ background

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**Contribute to overall Tevatron Sensitivity:** μ > 0, τ mode competitive to b mode despite 1:9 BR
**DØ: NMSSM h → aa Search (I)**

  - $h \rightarrow b\bar{b}$ branching ratio greatly reduced
  - $h$ dominantly decays to pair of pseudo-scalar Higgs “a”: $h \rightarrow aa$

**For Masses: $2M_\mu < M_a < \sim 2M_\tau$ (∼3.6 GeV)**

- $\text{BR}(a \rightarrow \mu^+\mu^-) \sim 100\%$: 4$\mu$ final state
  - signature: two pairs of extremely collinear muons due to low $M_a$
- Require “companion-track” for each of two $\mu$’s
  $\Rightarrow$ redefine object ID: $\mu$ isolation for “pair”

**Background Events**

<table>
<thead>
<tr>
<th>Background Events</th>
<th>4$\mu$ Final State</th>
</tr>
</thead>
<tbody>
<tr>
<td>QCD background</td>
<td>1.2 ± 0.4</td>
</tr>
<tr>
<td>[$\mu$’s from $\pi/K$ in-flight decays or $\mu$’s from heavy-flavor decays]</td>
<td></td>
</tr>
<tr>
<td>$Z/\gamma^* \rightarrow \mu\mu + \text{jets}$</td>
<td>0.25 ± 0.03</td>
</tr>
<tr>
<td>Data</td>
<td>3</td>
</tr>
</tbody>
</table>

Assume Higgs cross-section of $\sim 1000$ fb at $M_h = 120$ GeV and $\text{BR}(h \rightarrow aa) \sim 1$  $\Rightarrow$

95% CL exclude: $\text{BR}(a \rightarrow \mu\mu) \gtrsim 10\%$
**DØ: NMSSM h → aa Search (II)**

For Masses: $2M_\tau < M_a < 2M_b$ ($\sim 9.0$ GeV)

- $\text{BR}(a \rightarrow \mu^+\mu^-)$ suppressed and “a” dominantly decays to tau pairs
  - $2\mu2\tau$ final state: one pair of collinear muons and large $E_T$ from $a \rightarrow \tau^+\tau^-$ decay
- Select back-to-back $\mu\mu$- and $\tau\tau$-paired topologies: $\Delta\phi(E_T, 2\mu) > 2.5$
- Fit signal di-muon mass: data consistent with expected backgrounds within ±2σ window

Current Tevatron limit: $\times \sim 4$ larger than expected Higgs production

Tevatron: requires $\mathcal{O}(\sim 40$ fb$^{-1}$) data to reach sensitivity at expected signal level

LHC: need $\mathcal{O}(\sim 1$ fb$^{-1}$) due to $\times \sim 50$ larger Higgs cross section
Closing Summary

- CDF and DØ actively searching for Higgs boson in models beyond SM
  - results with up to 3.7 fb⁻¹ reported with no excess observed in data

- Fermiophobic Higgs
  - strong mass-dependent limits established for \( h \rightarrow \gamma \gamma, WH \rightarrow WW \ast \) searches
    + Higgs decays also contribute to SM Higgs searches

- MSSM Higgs
  - 95% CL exclusions in MSSM parameter space calculated for neutral Higgs search
    + reached sensitivity \( \tan \beta \sim 40 \rightarrow 50 \) for \( M_A < 180 \) GeV
    + combination of different channels and with experiments is in progress

- NMSSM Higgs
  - new search at Tevatron, offers promising prospects for Higgs physics at LHC

- Tevatron delivered > 6.0 fb⁻¹ of Run II data ...and more coming
  - updated results from searches expected soon
  - expect sensitivity to continually improve
    + if a key value of \( (M_A, \tan \beta) \) achieved, aim for observation

DØ: [http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.htm](http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.htm)
Reference Slides
Ref: SM Higgs Production at Tevatron

- **Gluon fusion:** \( gg \rightarrow H \)

  \[ \sigma = 0.70 \text{ pb} \]
  for \( M(H) = 120 \text{ Gev/c}^2 \)
  with QCD NLO correction

- **Higgsstrahlung:** \( q\bar{q} \rightarrow VH \)  
  \((V=\text{W, Z})\)

  \[ \text{WH: } \sigma = 0.16 \text{ pb} \]
  \[ \text{ZH: } \sigma = 0.10 \text{ pb} \]

- **Vector Boson Fusion:** \( q\bar{q} \rightarrow q\bar{q}H \)

  \[ \sigma = 0.10 \text{ pb} \]

- **Radiation off heavy quark:** \( q\bar{q} \rightarrow t\bar{t}H, b\bar{b}H \)

  \[ \sigma = 0.004 \text{ pb} \]

A. Patwa: Moriond 2009
**τ properties**

- **Mass** = 1.78 GeV; Short lifetime, $c\tau = 87.11 \, \mu m$
  - $\mathcal{O}(10^{-13} \, s)$
  - taus decay prior to reaching any detector active element

- **Main decay channels:**

<table>
<thead>
<tr>
<th>τ Decay Final State</th>
<th>BR (%)</th>
<th>Decay Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e + \nu_e + \nu_\tau$</td>
<td>17.8</td>
<td>Leptonic</td>
</tr>
<tr>
<td>$\mu + \nu_\mu + \nu_\tau$</td>
<td>17.4</td>
<td></td>
</tr>
<tr>
<td>$\pi(K) + \nu_\tau$</td>
<td>11.8</td>
<td>1-prong</td>
</tr>
<tr>
<td>$\pi(K) + \nu_\tau + \geq 1\pi^0$</td>
<td>36.9</td>
<td>(48.7%)</td>
</tr>
<tr>
<td>$\pi\pi\pi + \geq 0\pi^0 + \nu_\tau$</td>
<td>13.9</td>
<td>3-prong</td>
</tr>
</tbody>
</table>

- Detect using standard electron / muon ID algorithms
- Need dedicated tau ID to measure “narrow”, low multiplicity jet objects

- **Taus decay** ~17% to $e$, $\mu$; ~65% to hadrons
- **For Higgs to di-tau final state, three channels studied**
  - $\tau \rightarrow \mu \, \nu\nu$ + $\tau \rightarrow$ hadrons $\nu$ : $\tau_\mu \tau_h$
  - $\tau \rightarrow e \, \nu\nu$ + $\tau \rightarrow$ hadrons $\nu$ : $\tau_e \tau_h$
  - $\tau \rightarrow e \, \nu\nu$ + $\tau \rightarrow \mu \, \nu\nu$ : $\tau_e \tau_\mu$

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Detectors

- silicon detector and scintillating fiber tracker in 2.0 T solenoidal field
- liquid argon/uranium calorimeters: central (CC) and two forward, end (EC) calorimeters
- muons: scintillators and mini-drift tubes, coverage up to $\eta = 2.0$

- silicon and central outer tracker system in 1.4 T magnetic field
- lead (iron) scintillating calorimeter for EM (hadronic) showering
- forward end-plug cal, $\eta \rightarrow 3.0$
- muon coverage to $\eta = 1.0$

A. Patwa: Moriond 2009
b-jet identification & tagging

- B-hadrons are long lived
  - search for displaced vertices & tracks with large impact parameters
- Tag via neural network (NN) tagger
  - combines several dca & vertex based tagging algorithms

Neural Network Input Variables

- vertex mass
- number of tracks for vertex
- vertex decay length significance
- \( \chi^2/\text{d.o.f.} \) of vertex
- number of vertices
- combined impact parameter significances from two methods

Loose tag: \(~70\%\) eff; \(~4.5\%\) mis-tag
Tight tag: \(~48\%\) eff; \(~0.3\%\) mis-tag
**τ Identification**

— narrow calorimeter clusters matched to low multiplicity tracks
  + define [shrinking] signal and isolation cones around seed track’s axis (= highest \( p_\tau \) track; > 6 GeV)
  + # of tracks inside signal cone = \( \tau \) decay mode
  + add \( \pi^0 \) info to track-cal cluster ⇒ consistent with \( \tau \) mass
  + EM-fraction < 0.8 ⇒ remove electrons
  + \( \tau \)-id based on “cuts” to key variables (e.g., sum of isolation \( E_T \), \( p_\tau \) tracks inside cone)

— narrow calorimeter energy clusters matched to tracks, with or without EM subclusters
  — separate \( \tau \)'s into 3 categories, defined by their decay mode
    + \( \pi\nu \)-like (type 1), \( \rho\nu \)-like (type 2), and 3-prongs (type 3)
    + implement neural nets (NN) for each \( \tau \)-type to discriminate \( \tau \) signal from QCD jets

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**Type 1**

\[ \tau^\pm \rightarrow \pi^\pm, \nu_\tau \]

**Type 2**

\[ \tau^\pm \rightarrow \rho^\pm, \pi^0, \nu_\tau \]

**Type 3**

\[ \tau^\pm \rightarrow \pi^\pm, \pi^\pm, \nu_\tau \]

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MSSM Benchmark Scenarios

- For neutral Higgs searches: $\sigma \times \text{BR}$ limits $\Rightarrow$ interpreted in MSSM

- Tree-level: Higgs sector of MSSM described by $M_A$ & $\tan\beta$
  - radiative corrections introduce dependence on additional SUSY parameters

- Five additional, relevant parameters
  - $M_{\text{SUSY}}$ Common Scalar mass: parameterizes squark, gaugino masses
  - $X_t$ Mixing Parameter: related to the trilinear coupling $A_t \rightarrow$ stop mixing
  - $M_2$ SU(2) gaugino mass term
  - $\mu$ Higgs mass parameter
  - $m_{\tilde{g}}$ gluino mass: comes in via loops

- Two common benchmarks
  - $m_h^{\text{max}}$ (max-mixing): Higgs boson mass, $m_h$, close to maximum possible value for a given $\tan\beta$
  - no-mixing: vanishing mixing in stop sector $\Rightarrow$ small Higgs boson mass, $m_h$

<table>
<thead>
<tr>
<th>Contrained Model: Unification of SU(2) and U(1) gaugino masses</th>
<th>$m_h^{\text{max}}$</th>
<th>no-mixing</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_{\text{SUSY}}$</td>
<td>1 TeV</td>
<td>2 TeV</td>
</tr>
<tr>
<td>$X_t$</td>
<td>2 TeV</td>
<td>0</td>
</tr>
<tr>
<td>$M_2$</td>
<td>200 GeV</td>
<td>200 GeV</td>
</tr>
<tr>
<td>$\mu$</td>
<td>$\pm 200$ GeV</td>
<td>$\pm 200$ GeV</td>
</tr>
<tr>
<td>$m_{\tilde{g}}$</td>
<td>800 GeV</td>
<td>1600 GeV</td>
</tr>
</tbody>
</table>
Fermiophobic $h_f \rightarrow \gamma \gamma$ Search

- 1.1 fb$^{-1}$ result: PRL 101, 051801 (2008)
- Distinguish photons with misidentified jet backgrounds by using NN
  - implement energy-weighted width of DØ central preshower clusters
  - exploit fact that preshower width narrower for photons than for jets

Fermiophobic $h \rightarrow \gamma \gamma$ (1.1 fb$^{-1}$)

- Search for excess of events in $\gamma \gamma$ mass spectrum
- Exclude Fermiophobic Higgs of mass up to 100 GeV at 95% C.L.
- Extends sensitivity for $\text{Br}(h_f \rightarrow \gamma \gamma)$ into $m_{hf} > 130$ GeV region, not accessible by LEP
# Multivariate Methods: Variables

## WH → WWW⁺ Search

### 8-variable Boosted Decision Tree (BDT)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st lepton πₜ (pₜ₁)</td>
<td></td>
</tr>
<tr>
<td>2nd lepton πₜ (pₜ₂)</td>
<td></td>
</tr>
<tr>
<td>Dilepton System πₜ (pₜ₁₂)</td>
<td></td>
</tr>
<tr>
<td>Missing Eₜ (MET)</td>
<td></td>
</tr>
<tr>
<td>Dilepton Mass</td>
<td></td>
</tr>
</tbody>
</table>

**MetSpec:** MET if \( \Delta \phi (\text{MET}, \ell \text{ or jet}) > \pi/2 \)

\[
\text{MET} \times \sin(\Delta \phi (\text{MET}, \ell \text{ or jet})); \text{ otherwise}
\]

- \( Hₜ \) (sum of \( pₜ₁ \), \( pₜ₂ \), jets \( Eₜ \), MET)
- \( N_{jets} \) for jet’s \( Eₜ \) > 15 GeV

## h_f → γγ Search

### 5-variable Artificial NN

- \( \Sigma \piₜ(\text{trks}) \)
- \( N_{\text{cells}} \) in CAL Layer 1 within \( \Delta R < 0.2 \)
- \( N_{\text{cells}} \) in CAL Layer 1 within \( 0.2 < \Delta R < 0.4 \)
- Number of associated CPS clusters with EM
- Energy-weighted width of CPS clusters

## φb → b¯b Search

### 6-variable Likelihood Discriminant

- \( \Delta \eta \) of 2-jets in the pair
- \( \Delta \phi \) of 2-jets in the pair
- angle: \( \phi (\text{lead jet, total } \piₜ \text{ of jet}) \)
- Momentum balance: \( |p_{b₁} - p_{b₂}| / |p_{b₁} + p_{b₂}| \)
- combined rapidity of jet pair
- event sphericity

## φb → ττb Search

### kNN (anti-top) vs Log-Likelihood (anti-QCD)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N_{jets} )</td>
<td>Muon ( \piₜ )</td>
</tr>
<tr>
<td>( Hₜ )</td>
<td>Tau ( \piₜ )</td>
</tr>
<tr>
<td>( E(\tau + \mu + j) )</td>
<td>( \Delta R(\mu, \tau) )</td>
</tr>
<tr>
<td>( \Delta \phi(\mu, \tau) )</td>
<td>( M_{\mu\tau}: \mu-\tau \text{ Mass} )</td>
</tr>
<tr>
<td>Visible Mass, ( M_{\text{vis}} )</td>
<td></td>
</tr>
</tbody>
</table>
Visible Mass

- After final event selections for $\phi \rightarrow \tau\tau$, irreducible background from $Z \rightarrow \tau\tau$
  - small contribution from EW and QCD multi-jet
- Distinguish Higgs boson by its mass
  - presence of neutrinos in final states $\Rightarrow$ not possible to reconstruct $\tau\tau$ mass
  - use visible mass: the invariant mass of the sum of the $\tau$ decay plus missing transverse energies
  * exploit fact that signal appears as an enhancement above $Z \rightarrow \tau\tau$

$$M_{VIS} = \sqrt{(P^{\tau_1} + P^{\tau_2} + P_T')^2}$$

- Use 4-vectors of:
  - $P^{\tau_1}, P^{\tau_2}$ of visible tau decay products
  - $P_T = (E_T, E_x, E_y, 0)$, where $E_x$ and $E_y$ indicate components of $E_T$
Study $M_{\text{vis}}$ for Higgs boson masses from 90 to 300 GeV
- no significant evidence for Higgs production observed
  + modified frequentist ($C_{s}$) method used to extract upper limits on $\sigma \times \text{BR}$
  + $M_{\text{vis}}$ used as input to limit calculation

2.2 fb$^{-1}$ DØ Combination in Run II:
10 – 20% improvement in $\sigma \times \text{BR}$ from PRL result
**DØ: φb → ττb Channel**

- 1.2 fb⁻¹ search considers φb → τμτhadb
  - isolated muon, p_T > 12 GeV; hadronic τ selected via τ-ID NN
  - one b-tagged jet using NN b-tagger: p_T > 15 GeV, ΔR(ℓ_{μ,τ}, j) > 0.5

- Pre b-tag: dominated by QCD multi-jet and Z→ττ, μμ backgrounds
- Post b-tag: dominated by QCD multi-jet and top events

<table>
<thead>
<tr>
<th>All τ_h-decay types</th>
<th>Z→(ττ; μμ)</th>
<th>Top</th>
<th>Multi-jet</th>
<th>Other EW</th>
<th>Total Pred.</th>
<th>DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRE b-tag</td>
<td>532.3 ± 5.6</td>
<td>26.5 ± 1.0</td>
<td>252.7 ± 17.0</td>
<td>56.0 ± 2.1</td>
<td>867.4 ± 24.8</td>
<td>906 ± 30</td>
</tr>
<tr>
<td>POST b-tag</td>
<td>7.8 ± 0.1</td>
<td>16.0 ± 0.6</td>
<td>16.8 ± 1.4</td>
<td>1.0 ± 0.1</td>
<td>41.7 ± 1.5</td>
<td>54 ± 7.4</td>
</tr>
</tbody>
</table>

*(★ = largest contribution)*

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A. Patwa: Moriond 2009