Searching for the SM Higgs with $\tau$ leptons at the Tevatron

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Higgs searches with $\tau$ leptons

- $\text{BR}(H \rightarrow \tau\tau) \sim 10\%$ for $m_H < 135 \text{ GeV/c}^2$
  - measure branching ratio
  - sensitive to different production mechanisms
  - in MSSM, $gg \rightarrow H$ cross section enhanced for high $\tan\beta$
    increased sensitivity in this channel

Analysis presented today:

$H \rightarrow \tau\tau + \text{jets}$
$ZH \rightarrow ll\tau\tau / WH \rightarrow lv\tau\tau$

- Including channels with $\tau$s into main analyses (e/\mu final states) increases acceptance
  higher backgrounds $\rightarrow$ limited sensitivities

Analysis presented today:

$H \rightarrow WW \rightarrow \tau\nu\nu$
$WH \rightarrow \tau\nu\nu$

$WH \rightarrow \tau\nu\nu$
τ experimental signature

- τ lifetime: 0.29 ps
  → reconstruct in the detector only decay products

- τ decays produce neutrinos
  - only visible energy reconstructed
  - softer energy spectrum of decay products

- BR(τ → lνν): 35% and BR(τ → hadron ν): 65%
  - e/μ decays are indistinguishable from prompt ones
  - hadronically decaying τs
    - narrow, isolated jet in the calorimeter
    - jet → τ fake rate non-negligible, and difficult to model
Tevatron (p\bar{p} collider, \sqrt{s} = 1.96 TeV) is doing great:
- weekly integrated luminosity \sim 50 \text{ pb}^{-1}
- 11.5 \text{ fb}^{-1} delivered ( > 9.5 \text{ fb}^{-1} on tape per experiment)

Analysis presented today: \( 5.5 \text{ fb}^{-1} < \int L < 8.2 \text{ fb}^{-1} \)
$H \rightarrow \tau\tau + \text{jets}$

- Sensitive at low masses - BR($H \rightarrow \tau\tau$) $\sim 10$

- Many decay modes
  - only **hadronic $\tau + \text{lepton}$** final state (BR: 46%) explored

- Sensitive to **many production mechanisms**:
  - **Gluon fusion**:  
    $\sim 77\%$ of total cross section, irreducible main background ($Z \rightarrow \tau\tau$)
  - **Associated Production**:  
    $\sim 18\%$ of total cross section, extra jets in event improve S/B
  - **Vector Boson Fusion (VBF)**:  
    $\sim 5\%$ of total cross section, jet kinematics provide extra discrimination
H → ττ + jets: Event Selection

➢ One identified e/µ + one hadronic τ
  - opposite charge, $E_T > 10-15$ GeV (CDF/D0)

- Multivariate technique to distinguish τ from jets:
  Improve efficiency by ~15%
  CDF: train Boosted Decision Tree separately for 1-3 prongs
  D0: reconstruct different decay modes using NN
    - $\tau \rightarrow \pi^{\pm} \nu$, $\tau \rightarrow \pi^{\pm} \pi^{0} \nu$, $\tau \rightarrow \pi^{\pm} \pi^{\pm} \pi^{\pm} (\pi^{0})$

➢ Reject events with extra e/µ (suppress $Z/\gamma* \rightarrow ee/\mu\mu$)

➢ Jet Selection:
  - DO : 2 jets  \quad (E_T > 20$ GeV, \ |\eta| < 3.4 )
  - CDF: 1 and 2 jets  \quad (E_T > 20$ GeV, \ |\eta| < 2.5 )
H → ττ + jets: Background Estimation

- Irreducible Z/γ* → ττ estimated from Monte Carlo
  - also other small background (Z/γ* → ee/µµ, top, di-boson)

- Fake background: described with data-driven method
  - include γ+jets and multijet production
  - no charge correlation between lepton candidates → use same sign events

- W+jets
  - charge correlation between lepton candidates → described using MC
Distinguishing Signal From Background

➢ Signal peak on top of the Drell-Yan background - neutrinos and detector resolution broaden $Z$ and Higgs mass distribution $\rightarrow Z/H$ peaks not distinguishable

➢ Use multivariate techniques - exploit different kinematics of background and signal processes

D0: BDTs to separate each signal process from each background, in different mass regions
Output of BDTs used as input of final discriminant
CDF: Use BDT to reduce fakes, $W+$jets and $Z \rightarrow ee/\mu\mu$ contributions
Final discriminant trained against $Z \rightarrow \tau\tau$
H $\rightarrow \tau\tau + \text{jets}$: results

Limit at $m_H = 115$ GeV/c$^2$

Obs (Exp) = $32.8$ (12.8) $\sigma_{\text{SM}}$

Sensitivity in a wide mass region
- include also $H \rightarrow WW$ decays

CDF has a dedicated analysis for high mass (later in this talk)
ZH → llττ/WH → lνττ

- Include all tau decay modes
  - 5 channels:
    - lll, llτ_h, eμτ_h, lτ_h, 4 leptons (any type)
  - |Σ Q| = 1 (NL=3), |Σ Q| = 0 (NL=4)

Most sensitive channel: llτ_h

- Dominant backgrounds: DY and Multijet
  - model Multijet from same sign data (ΣQ = 3)
  - model all other backgrounds with Monte Carlo
    - jet → τ fake rate systematic is dominant one (30%)

- Control region:
  - di-lepton samples
  - tri-lepton, MET/ΣE_T < 1.
ZH → lℓττ/WH → lνττ

- MET/\sqrt{\sum E_T} > 1.
  reduce DY and Multijet background contributions

- Use **Support Vector Machine** to discriminate
  - effective when training on low statistic samples
  - separate events in two regions with an hyperplane

Limit at @ m_H = 115 GeV/c²

Obs (Exp) = 46 (38.2) \sigma_{S.M.}

- eμτ_h, lτ_h h channels comparable sensitivity
ZH $\rightarrow l\ell\tau\tau$ / WH $\rightarrow l\nu\tau\tau$

- MET/$\sqrt{\sum E_T} > 1$.
  reduce DY and Multijet background contributions

- Use **Support Vector Machine** to discriminate
  - effective when training on low statistic samples
  - separate events in two regions with an hyperplane

**COMBINED Limit at** $m_H = 115 \text{ GeV/c}^2$

**Obs (Exp) = 18.5 (17.3) \(\sigma_{S.M.}\)**
$H \rightarrow WW \rightarrow 1\nu\tau\nu$

➢ e/µ ($E_T > 20$ GeV), hadronic tau candidate ($E_T > 15$ GeV)

➢ Backgrounds: $Z/\gamma^* \rightarrow \tau\tau$, $W$+jets and Multijet
  - fake rate of $e \rightarrow \tau$, $\mu \rightarrow \tau$, jet $\rightarrow \tau$ from MC
  - same sign data events to model events with double fakes $\gamma +$ jets, multijets production

➢ Topological cut to reduce backgrounds
  → Invert them to define control regions
H \rightarrow WW \rightarrow l\nu\tau\nu

- After selection, W+jets is dominant background
  - no Higgs mass reconstruction

- Use Boosted Decision Tree to discriminate
  - exploit kinematical differences
  - add tau specific variables: help separate real/fake taus
$H \rightarrow WW \rightarrow l\nu\tau\nu$

Limit at $m_H = 160$ GeV/c$^2$

Obs (Exp) = 23.3 (15.6) $\sigma_{S.M.}$
WH → τνbb

- WH → lvbb: one of the most sensitive channels at the Tevatron target e/μ final state, not optimized for hadronic tau

**Challenges:**
- trigger
- identification (τ ID efficiency ~ 40-60%)
- jet → τ fake rate non-negligible, and difficult to model
=> add ~ 10% to main channels acceptance, but S/B limits sensitivity

**Basic selection:**
Identified τ, $E_T > 12$ GeV (D0)/ 25 GeV (CDF), $|\eta| < 2$. (D0)/ 1. (CDF)
2 high $P_T$ jets, b-tagged, large MET

Sample dominated by Multijet production
- use data-driven model
  - D0: invert NN cut on identified tau candidate
  - CDF: identified tau candidate, 2 tracks
All other backgrounds: modeled by MC

CDF Preliminary \( \int L = 5.7 \text{ fb}^{-1} \)
Multijet fraction: 97.8%
Reduce Multijet contribution:

**CDF:**
- optimize cut on MET Perpendicular for each sub-samples classified by number of b-tagged jets
- fit di-jet mass

**D0:**
- MET Significance > 4.5
- Delta Phi(Missing $P_T$, MET) < 2.
- Use BDT to separate signal and background

Limit at @ $m_H = 115$ GeV/c$^2$

Obs (Exp) = 22.4 (14.1) $\sigma_{S.M.}$
Summary

➢ Presented most recent Higgs searches at the Tevatron with $\tau$ leptons
  - many different analysis, one of which has never been performed before

➢ Analyses with $\tau$ leptons are challenging:
  lower selection efficiency
  Multijet background has significant contribution
  $\rightarrow$ limited sensitivity, but every channel counts in combination

➢ Not all data available analyzed yet $=>$ Stay tuned for more results
BACK UP
H → WW → ℓντν : Control regions

QCD region:
\[ M_{τl} > 20 \text{ GeV/c}^2, \text{ MET} > 20 \text{ GeV} \]

Z/γ* → ττ region:
\[ M_{τl} > 20 \text{ GeV/c}^2, \text{ MET} < 20 \text{ GeV}, \Deltaφ_{l-MET} < 0.5 \]

W+jets region:
\[ M_{τl} > 20 \text{ GeV/c}^2, \text{ MET} > 20 \text{ GeV}, \Deltaφ_{τl} < 0.5 \]