Search for the Standard Model Higgs in $\gamma\gamma$ and $\tau+$lepton final states

Tevatron, $pp \sqrt{s} = 1.96$ TeV

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for the DØ Collaboration
At the Tevatron, SM Higgs is produced by gluon gluon fusion (GGF), associated VH (V=W/Z) production and vector boson fusion (VBF).

For $M_H < 135$ GeV, the dominant decay is $H \rightarrow bb$, for which the GGF process is swamped by multijet QCD background.

For $M_H > 135$ GeV, $H \rightarrow WW/ZZ$ dominates, but gives diminishing sensitivity at lower $M_H$.

No single channel is capable of Higgs discovery, so subdominant channels are useful for improving the search.

We report here on the $H \rightarrow \gamma\gamma$ channel for which the good mass resolution partly overcomes the small BR (0.23% at $M_H = 125$ GeV) and the $\tau$ lepton+($e/\mu$) channel which is moderately low background and sensitive to a variety of production and decay processes, giving a relatively flat sensitivity for $100 < M_H < 200$ GeV.
H → γγ

9.7 fb⁻¹ of data

D0 Notes xxxx-CONF 6297-CONF
GGF, VBF, VH production
Updated from Moriond 2012

Select events: 2 EM clusters in φ,η cone<0.2
- E_T>25 GeV and |η|<1.1
- Isolation from other calorimeter energy
- Shower shape consistent with e/γ
- No associated track or hits in road

Jet/photon discrimination using neural network (O_{NN}) based on Σp_T^{trk}, calorimeter early shower deposits, preshower energy pattern before calorimeter. Train on MC and verify with Z→llγ events

Backgrounds: 

a) Drell Yan: Z/γ*→ee/ττ from MC using NNLO cross section

b) γ+jet and dijet: flag leading and second γ as Photon or Fake by NN < or >0.75

\[
\begin{pmatrix}
N_{FF} \\
N_{FP} \\
N_{PF} \\
N_{PP}
\end{pmatrix}
= \begin{pmatrix}
N_{JJ} \\
N_{Jγ} \\
N_{γJ} \\
N_{γγ}
\end{pmatrix}
\]

\[M\]_ij taken from efficiencies for jet/γ to pass NN cut, corrected using Z→llγ data. Use \[M^{-1}\] to obtain JJ, Jγ, γJ, γγ contributions.

γγ background shape from SHERPA.

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<tr>
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<tr>
<td>DY</td>
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<tr>
<td>Jet Jet</td>
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<td>Jet γ+γ jet</td>
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**H → γγ Multivariate analysis**

Train boosted decision trees to discriminate signal and background

**Inputs:** $p_T$ and NN output for both $γ$s; $M_{γγ}$, $p_{Tγ}$, $Δφγ$, $cosθ^*$, $φ^*$ (Collins Soper), $E_T$

At each $M_H$ hypothesis, train BDTs for both $γ$s good ($O_{NN} > 0.75$) as well as one $γ$ good and one bad to obtain information on backgrounds.

**Systematic uncertainties:** Lumi, photon ID, signal acceptance (PDFs), GGF $p_T$, track veto, NN efficiencies, higher order K factors
Modified frequentist (CLS) using ensembles of simulated experiments to obtain –LLR distributions for S+B and B only. Best fits of systematic uncertainties with Gaussian priors, maintaining correlations.

Ratio of 95% C.L. exclusion XS to SM Higgs XS. Observed (expected) ratio is 12.9 (8.2) at $M_H=125$ GeV.

Best fit background subtracted data, showing background uncertainty and 125 GeV signal at the observed limit.

The analysis can be recast as a search for Fermiophobic Higgs, for which the $\gamma\gamma$ BR is enhanced by $\sim x10$. There is now no GGF production, which is dominantly through top loops. The observed (expected) 95% C.L. limits are 111.4 (114) GeV, above the LEP limits.

(not updated from MoriondEW 2012)
τ leptons decay hadronically, principally by $\tau \rightarrow \pi \nu$, $\tau \rightarrow \rho \nu$, and $\tau \rightarrow a_1 \nu$.

Hadronic taus ($\tau_H$) can be distinguished from jets by the track multiplicity, the presence of EM activity in close proximity to tracks, and isolation from other energy deposits. However, the multijet (MJ) background for Higgs decay to 2 hadronic taus is large, so we restrict ourselves to final states with one $\tau_H$ and a lepton (e or $\mu$).

For low mass Higgs, we consider five channels: (1) $WH$, (2) $ZH$, (3) $GGF$, and (4) $VBF$ where $H \rightarrow \tau_H \tau_\ell$ as well as (5) $HZ$ with $H \rightarrow q\bar{q}$ and $Z \rightarrow \tau_H \tau_\ell$.

For higher mass Higgs, the $H \rightarrow VV$ becomes dominant, and the $\ell\tau_X$ final state in reactions (1 – 4) can occur through a mixture of $W/Z$ decays directly to $\tau$ or $\ell$, or through $V \rightarrow \tau \rightarrow \ell$.

We analyze:

- $\mu\tau_H + 0$ or 1 jet (7.3 fb$^{-1}$) – $\mu\tau_0$
- $\mu\tau_H + 2$ jets (6.2 fb$^{-1}$) – $\mu\tau_2$
- $e\tau_H + 2$ jets (4.3 fb$^{-1}$) – $e\tau_2$

The resulting yields for each of the production/decay/$N_{\text{jet}}$ channels vary with $M_H$ but the sum of yields is relatively constant as $M_H$ varies.
- $p_T^{\tau} > (12.5, 12.5, 15)$ GeV for $\tau_H$ types (1,2,3); $|\eta_{\tau}| < 2$
- $p_T$ of e or $\mu > 15$ GeV; $|\eta_{\mu}| < 1.6$; $|\eta_e| < 1.1$ or $1.5 < |\eta_e| < 2.5$
- Neural net $\tau$ vs. jet discriminant based on calorimeter and tracking variables required to be $>(0.9, 0.9, 0.95)$ for $\tau_H$ types (1,2,3)
- For $\ell\tau_2$, $p_T^j > 20$ (15) GeV for jet 1(2) and $|\eta_{\text{jet}}| < 3.4$. These cuts reversed for $\mu\tau_0$
- For $e\tau_2$, additional $\tau_H$ cuts to reduce $Z \rightarrow ee$ and MET significantly non-zero
- $\mu\tau_0$ requires $M_T > 25$ GeV
- Require opposite sign $\tau_H$ and $\ell$. Require $\tau$, $\ell$, jets well separated in $\phi$ and $\eta$

**Backgrounds**

*Simulated by MC:*
- $t\bar{t}$ and single top
- W+jets (for $\ell\tau_2$)
- Z+jets
- WW/WZ/ZZ

*Measured in data:*
- MJ (use orthogonal MJ enriched samples to get shapes and normalize to signal sample)
- W+jets (for $\mu\tau_0$)

**Event yields**

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<th>Z_\tau_jet</th>
<th>Z_\mu_jet</th>
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<th>MJ</th>
<th>$\Sigma$Bkd</th>
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<td>$e\tau_2$</td>
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**τ ℓ +X Multivariate analysis**

Each analysis uses 17 well modeled variables (object $p_T$, $E_T^{\text{miss}}$, mass combinations, separations in $\eta, \phi$, NN$_\tau$ etc.) as inputs to Multivariate classifier. Variable examples:

- $\mu\tau_0$: Inv. mass($\mu\tau$MET)
- $\mu\tau_2$: Dijet Inv. mass
- $\tau\tau_2$: Di-tau Inv.mass

**Multivariate output**

- **NN output for $\mu\tau_0$, $M_{H}=165$ GeV**

- **BDT output for $\mu\tau_2$, $M_{H}=150$ GeV**

- **BDT output for $\tau\tau_2$, $M_{H}=150$ GeV**
Systematic uncertainties determined for luminosity; background and signal cross sections; MJ background determination; lepton and tau energy and ID; jet energy/resolution/ID.

Modified frequentist (\(CL_s\)) using ensembles of simulated experiments to obtain –LLR distributions for S+B and B only. Best fits of systematic uncertainties with Gaussian priors, maintaining correlations.

Combine limits for \(\mu\tau0\), \(\mu\tau2\) and \(e\tau2\), together with previous independent 1 fb\(^{-1}\) \(\mu\tau2\) analysis. Systematic uncertainties are correlated across channels as appropriate.

Combined 95% C.L. limit ratio to SM XS observed (expected):
- 125 GeV: 15.7 (12.8)
- 150 GeV: 9.5 (10.8)
- 175 GeV: 8.0 (9.6)
Summary

Higgs searches in both the \(\gamma\gamma\) and \(\ell\tau+X\) channels have reached sensitivity levels of about 10 times the SM cross section in the most interesting region between 115 and 140 GeV.

Both analyses continue with more data, improved triggering and particle ID, and improved multivariate analyses.

The addition of subdominant channels aids the overall Tevatron Higgs search sensitivity.