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Standard Model and Supersymmetric Higgs Searches at CDF

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Abstract.
We present the results on the searches for the SM and the MSSM Higgs boson production in proton-antiproton collisions at $\sqrt{s}$ = 1.96 GeV with the CDF detector. The Higgs bosons are searched for in various production and decay channels, with data samples corresponding to 400 pb^{-1}. Using these measurements, we set an upper limit on the production cross section times branching fraction for the Standard Model Higgs as a function of the Higgs mass, and we obtain exclusion regions in the tanβ vs mass for the neutral MSSM Higgs, and branching fraction vs mass for the charged Higgs.

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STANDARD MODEL AND MINIMALLY SUPERSYMMETRIC STANDARD MODEL HIGGS

The mass of fundamental particles in the Standard Model (SM) is explained by the Higgs mechanism, which requires the existence of a physical particle called the Higgs boson. Since experiments have not yet discovered this particle, an alternative description of the Higgs mechanism that is part of the Minimally Supersymmetric Standard Model (MSSM) is also a major focus of current research. Figure 1 compares the SM and MSSM theories as they relate to the Higgs particles. The SM has not yet been proven wrong, but the MSSM may explain some of its mysteries, while taking an additional step toward a grand unified theory. The SM Higgs is mainly produced through gluon fusion with $\sigma \sim 1$ pb. This direct production is an order of magnitude larger than associative Higgs production, in which the Higgs is produced with a Z or W. For low $M_H < 135$ GeV, the Higgs decays mainly to bb, and for high mass, W^+W^-. In the MSSM, Higgs production and decay depend strongly on the tan β parameter which describes the ratio of the vacuum expectation values for up- and down-type particles. Direct searches at LEP have excluded $M_H < 114$ GeV @ 95% CL, and precision fits of electroweak data have excluded $M_H > 186$ GeV @ 95% CL [1]. As recent experimental bounds have pushed the SM Higgs mass lower, MSSM Higgs models have become more favorable.

CDF [2] has recently searched for the SM Higgs in both direct and associative production, as well as for both charged and neutral MSSM Higgs, in 1.96 TeV $p\bar{p}$ collisions at Fermilab.

TABLE 1. Comparison of Higgs in SM and MSSM theories.

Property	SM	MSSM
Particles	H	h, A, H, H^+, H^-
Spin	0	0
Electrically	0	-1,0,+1
Interaction	all SM particles	all SM particles
Coupling	stronger to high mass particles	stronger to high mass particles, stronger to down-type particles

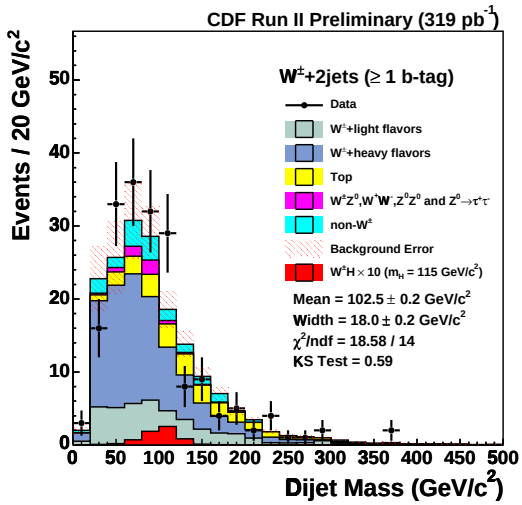

FIGURE 1. Dijet mass distribution used to search for Higgs signal in $WH \to l\nu b\bar{b}$ analysis.

STANDARD MODEL HIGGS SEARCHES AT CDF

Search for $WH \to l\nu b\bar{b}$

Although the cross-section for WH production is only 0.16 pb for $M_H = 120$ GeV, $WH \to l\nu b\bar{b}$ provides a clean channel for measuring the Higgs due to its association with a leptonically decaying W. Candidate events must have an e or μ with $P_T > 20$ GeV/c, missing transverse energy from the neutrino or $\not{E}_T > 20$ GeV, and two 15 GeV jets. The main background is W+jets production, which is greatly reduced by requiring at least one "b tag", a jet which has a displaced secondary vertex consistent with the long lifetime of b hadrons. The remaining background is dominantly W+ real b and c jets, called "W+heavy flavor". A likelihood fit is performed in the dijet mass distribution (Figure 1) to detect the Higgs resonance. No evidence for the Higgs is found, and so exclusions limits are placed as a function of Higgs mass. For $M_H = 115$ GeV, $\sigma_{WH} <$ 8.6 pb.

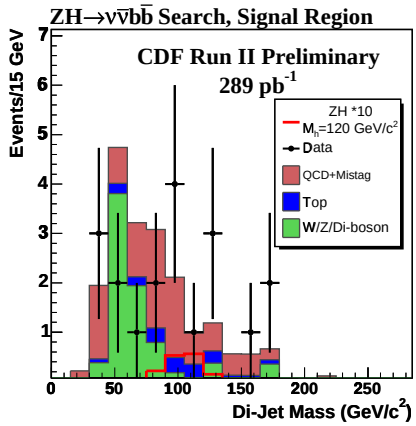

FIGURE 2. Dijet mass distribution used to search for Higgs signal in $ZH \to \nu\bar{\nu}b\bar{b}$ analysis.

Search for $ZH \to l^+l^-b\bar{b}$

The $ZH \to l^+l^-b\bar{b}$ analysis requires two high P_T e's or μ's, low $\not{E}_T$, and two or more jets with at least one b tag. The production cross-section and Z finding efficiency is smaller than that of the W, but the signature is clean with 90% of the background originating from events with Z+jets. To improve sensitivity, an artificial neural network (NN) has been developed using multiple variables to distinguish between signal and background. By fitting the neural network discriminant rather than the dijet mass, the expected sensitivity improves as if there were 60% more statistics. Results are expected in this channel with 1 fb^{-1}.

Search for $ZH \to \nu\bar{\nu}b\bar{b}$

In this channel, $Z \to \nu\bar{\nu}$ leaving a large energy imbalance opposite the two jets. In addition to two jets, with 1 or more b tags, $\not{E}_T$ is required to be at least 70 GeV. The main background is QCD heavy flavor, where at least one jet is mismeasured, causing $\not{E}_T$ to be reconstructed poorly. This background is reduced by removing events where the $\not{E}_T$ direction is aligned too closely with a jet. After carefully comparing data to Monte Carlo in control regions rich in QCD and electroweak background events, the signal region of the dijet mass distribution is examined (Figure 2). With no evidence of a Higgs signal, a limit is set such that for $M_H = 115$ GeV, $\sigma_{ZH} < 5.0$ pb.

Search for $H \to W^+W^- \to l^+l^-\nu\bar{\nu}$

The $W^+W^- \to l^+l^-\nu\bar{\nu}$ analysis is most sensitive to higher Higgs masses where $H \to W^+W^-$ is close to being on-shell. Two opposite sign 20 GeV leptons are required,

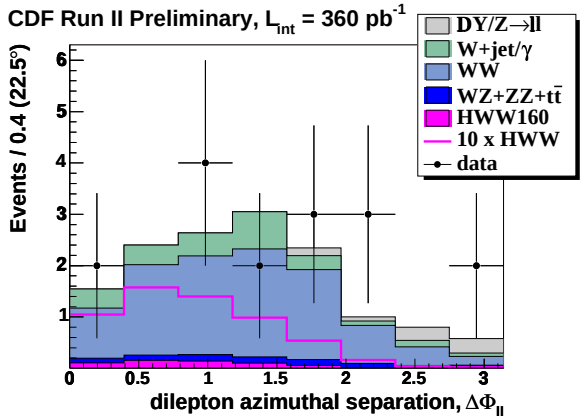

FIGURE 3. dϕ distribution used to search for Higgs signal in $WW \to l^+l^-\nu\bar{\nu}$ analysis.

and the $\not{E}_T$ requirement is derived from MC studies to be $\not{E}_T > M_H/4$. The angular distribution between the leptons is used to distinguish signal from W^+W^- background since H decays as a scalar, whereas W^+W^- is produced from vector Z/γ^* production (Figure 3). No evidence is found for Higgs, and a limit is set such that for $M_H = 160$ GeV, $\sigma_H < 3.2$ pb.

Summary of SM Higgs Searches

CDF limits for Higgs production as a function of Higgs mass are shown in Figure 4. While there is no Higgs signal, we expect to gain a factor of 20 in luminosity by 2009, and are improving the sensitivity of these analyses by using better jet resolution algorithms, improved lepton acceptance, and multivariate approaches.

MSSM HIGGS SEARCHES AT CDF

Search for $t \to H^+b$

Top quark production has been well studied at the Tevatron. If the charged MSSM Higgs has a mass such that $M_H^+ < M_t$, then the top quark can decay into the charged Higgs, affecting the expected yields from SM $t \to W^+\nu$. In the SM, BR($W \to l^+\nu$) = 1/3, and BR($W \to q\bar{q}'$) = 2/3. In the MSSM, for low tan β, $H^+ \to c\bar{s}$, and for high tan β, $H^+ \to \tau\nu$, leading to excesses and deficits with respect to SM $t\bar{t}$. Careful accounting of event yields in various $t\bar{t}$ channels provides limits both on low tan β and high tan β regions. Strong model-independent limits are also placed on the Tauonic Higgs Model where the charged Higgs (Figure 5).

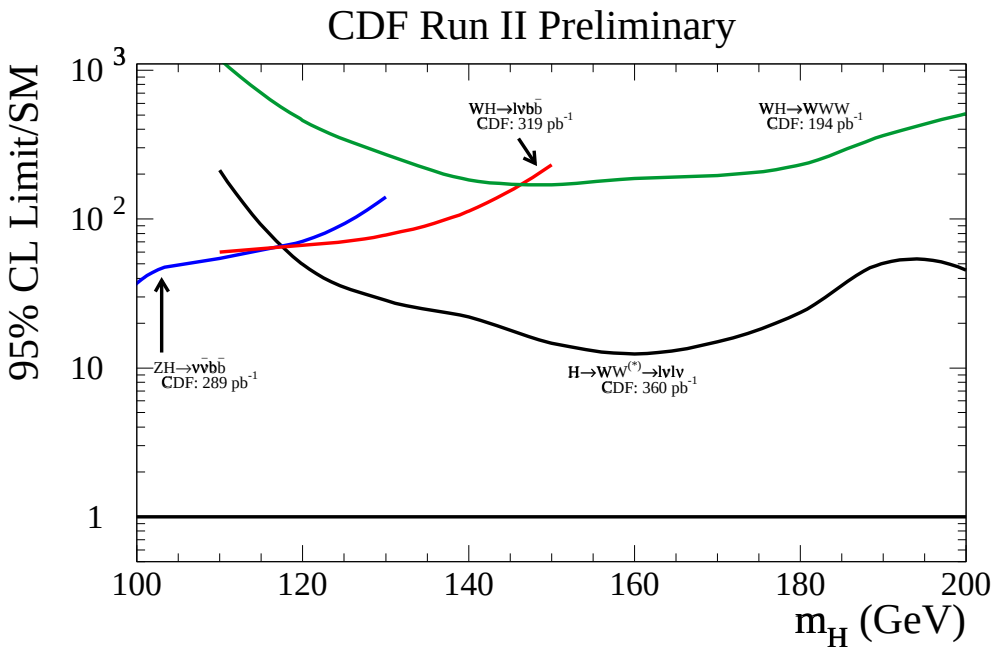

FIGURE 4. Summary of Standard Model Higgs searches showing 95% exclusion limit divided by Standard Model expectation, indicating factors of improvement necessary before Higgs is discovered.

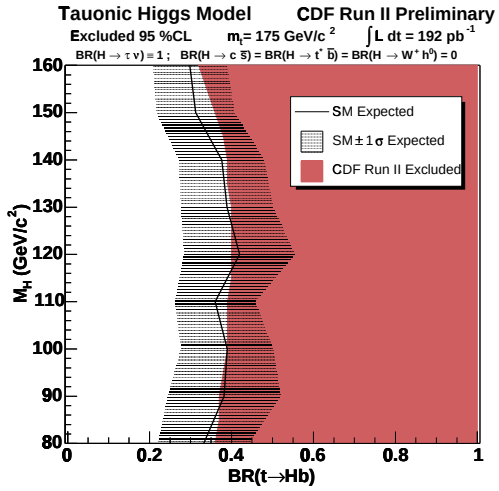

FIGURE 5. Excluded branching ratios of $t \to H^+ b$ assuming Tauonic Higgs Model where charged Higgs only decays to $\tau + \nu_\tau$.

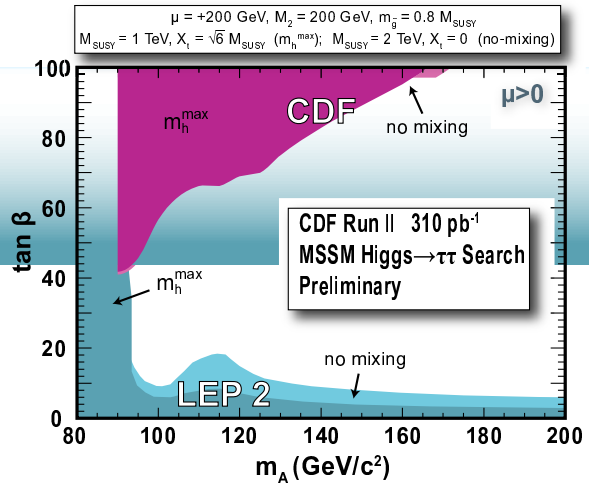

FIGURE 6. Exclusion limits on production cross-section times branching fraction to tau pairs for Higgs masses in the range from 90 to 250 GeV/c^2 for $\mu > 0$.

Search for $A/h \rightarrow \tau^+\tau^-$

The SM Higgs decays to $\tau^+\tau^-$ 8% of the time, compared to 80% to $b\bar{b}$. While in these channels it is nearly impossible to measure the SM Higgs due to the high background levels, the production of the MSSM Higgs is enhanced by $tan\beta^2$, leading to much higher expected signals. We search in $A/h \rightarrow \tau^+\tau^-$, where one τ decays leptonically and one hadronically, which has the benefit of cleaner event reconstruction and smaller backgrounds as compared to the $b\bar{b}$. The transverse sum of visible and missing energy is used to discriminate signal from the dominant $Z \rightarrow \tau^+\tau^-$ background. While no evidence is found for A/h, limits are are set, as in Figure 6.

CONCLUSIONS

CDF has searched for both SM and MSSM Higgs. No evidence for Higgs production in the SM or MSSM scenarios is found, and limits have been placed on five different Higgs channels. As more data is collected and more advanced analysis techniques are used, CDF and D0 combined analyses have the potential to discover low mass or high mass SM Higgs, as well as low mass charged MSSM Higgs, and high tan β neutral MSSM Higgs.

REFERENCES

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2. D. Acosta, et al., Phys. Rev. D71, 032001 (2005).