FERMILAB-CONF-07-077-E



# NEW PHYSICS SEARCHES AT CDF

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We report on recent results of New Physics searches from the CDF experiment, which is accumulating data from proton-antiproton collisions with $\sqrt{s} = 1.96$ TeV at Run II of the Fermilab Tevatron. The new phenomena being explored include MSSM and GMSB models as well as searches for the MSSM and SM Higgs. We also present results on searches for heavy particles, that would indicate physics beyond the Standard Model, and signature-based searches.

## 1. Introduction

We report on recent results of both Higgs and New Physics searches from the CDF experiment, which is accumulating data from proton-antiproton collisions with $\sqrt{s} = 1.96$ TeV at Run II of the Fermilab Tevatron. The data in most searches comprise $\sim$1 fb$^{-1}$ of luminosity.

## 2. Signature-based $\gamma\gamma + (\not{E}_T, \gamma, e$ or $\mu)$

We perform a signature-based search of events with at least two photons of $p_T > 13$ GeV both for the presence of significant $\not{E}_T$, a lepton or a third photon in 1.0-1.2 fb$^{-1}$ of data. New Physics with at least two photons in such final states are expected in many models such as GMSB $\widetilde{\chi}_1^0 \to \gamma\widetilde{G}$. The dominant backgrounds are QCD $\gamma$ as well as $W/Z\gamma$ production. We expect $1.6 \pm 0.3$ $\gamma\gamma$ events with $\not{E}_T > 50$ GeV and observe 4. We expect $6.82 \pm 0.75$ ($0.79 \pm 0.11$) events to have a lepton $p_T > 20$ GeV and observe 3 (0) in the electron (muon) channels. We expect $2.2 \pm 0.6$ events with a third photon with $p_T > 13$ GeV and observe 4. Soon we expect to add the $\gamma\gamma + \tau$ and $\gamma\gamma + b$ search channels.

*On behalf of the CDF Collaboration

## 3. High Mass Decays to $Z+$jets

We search for new particles that decay to $Z$'s in association with jets as can occur in Higgs or sparticle decays, using 1.055 fb$^{-1}$ of data. We study the acceptance to hypothetical particles using the production of 4th generation down-type quark ($b'$) pairs assuming 100% branching ratio for decays to $bZ$. Two leptons with a mass consistent with a $Z$ are required to have an $p_T > 18$ GeV/$c$. To reduce the major SM $Z$+jets background, at least three jets are required to have a $p_T > 30$ GeV. The sensitivity for a $b'$ signal is optimized by requiring the scalar $p_T$ sum of all jets to be greater than the assumed $b'$ mass. The major SM $Z+$jets background is entirely estimated from data by parametrizing the jet $p_T$ distributions of events with one or two jets and extrapolating the resulting fit into the blinded signal region with $\geq 3$ jets. There is no significant excess in the data so we set a 95% C.L. $b'$ mass limit of 270 GeV/$c^2$.

## 4. High Mass $Z' \to ee$

High Mass resonances in the $ee$ channel are expected in SM and $E_6$ $Z'$ models (spin-1) as well as from Randall-Sundrum (RS) spin-2 graviton ($G$) decays (spin-2). A major background is Drell-Yan that is estimated with MC, normalized to the $Z$ boson resonance peak. Using 1.3 fb$^{-1}$ of data we search the blinded mass range of 150-950 GeV/$c^2$ for a narrow $Z'$ mass resonance. We calculate the probability of the background fluctuating up or above the data in 1 GeV/$c^2$ intervals and observe the lowest probability at $m_{ee} \approx 367$ GeV/$c^2$, consistent with a statistical fluctuation. Using a Bayesian binned likelihood method we set the 95% C.L. mass limits on SM-like $Z'$ models at 923 GeV/$c^2$, and on $E_6$ bosons at 729 ($Z'_I$), 822 ($Z'_\psi$), 822 ($Z'_\chi$) and 891 GeV/$c^2$ ($Z'_\eta$). We exclude RS models with $m_G \leq 807$ GeV/$c^2$ for $k/m_{pl} = 0.1$. This result is extended to $m_G \leq 889$ GeV/$c^2$ if combined with the di-photon channel producing the world's most stringent limit on this model.

## 5. Searches for Massive, Long-Lived Particles

We search for heavy, neutral, long-lived particles that decay to photons using a new timing technique at CDF. While many models predict such particles, we use a GMSB $\widetilde{\chi}_1^0 \to \gamma \widetilde{G}$ model to set our event selection criteria. We retain, however, some model-independence by requiring a high-$p_T$ photon, significant $\not\!\!p_T$ and at least one jet. Using a recently installed system

to measure the arrival time of photons at the EM calorimeter ("EMTiming") we discriminate against prompt SM photons, non-collision photon candidates from cosmic ray muon bremsstrahlung and beam related backgrounds. In the signal time window between 2 and 10 ns after the collision, we expect $1.3 \pm 0.7$ events and observe 2. We can exclude a signal that would produce more than 5.5 events in this window and set the world-best 95% C.L. limits on the GMSB cross section as a function $\widetilde{\chi}_1^0$ mass and lifetime as shown in Fig. 1a.

Long-lived or stable, charged, heavy particles can occur in models such as GMSB where the next-to-lightest SUSY partner can be the $\widetilde{\tau}$ or $\widetilde{t}$. In this search candidates are selected as tracks that have a time of flight consistent with a very massive particle. We measure the mass spectrum of muons with $p_T > 40$ GeV/$c$ and extrapolate into the blinded signal region of $m > 100$ GeV/$c^2$. Using 1.0 fb$^{-1}$ of data, we predict $1.5 \pm 0.2$ events in the signal region and observe 1. We set model-independent 95% C.L. cross section limits of 48 fb (10 fb) for strongly (weakly) interacting charged, heavy particles, respectively, that fall within our geometric and kinematic acceptance. We exclude SUSY $\widetilde{t}$ production with $m < 255$ GeV/$c^2$.

## 6. Combined SUSY Searches in the Multilepton "Golden Modes"

We have searched for a tri-lepton signal in $p\bar{p} \to \widetilde{\chi}_1^{\pm}\widetilde{\chi}_2^0$ processes followed by the decays $\widetilde{\chi}_1^{\pm} \to l^{\pm}\nu\widetilde{\chi}_1^0$ and $\widetilde{\chi}_2^0 \to l^{\mp}l^{\pm}\widetilde{\chi}_1^0$ ("golden mode") with 14 different strategies. Each search is performed with a blind signal region and requires significant $\not\!\!E_T$. The data correspond to a luminosity between 0.7 and 1 fb$^{-1}$. In 6 searches we only require the two highest-$p_T$ leptons to be of the same charge ("like-sign" analyses), for the other "tri-lepton" searches we require three leptons, where the third (low-$p_T$) lepton is only required to pass tracking cuts to gain acceptance and be sensitive to hadronic $\tau$ decays. While the SUSY production cross section at the Tevatron is small ($\sim$0.1-0.4 pb), the backgrounds are also very small. The dominant backgrounds are di-boson production and Drell-Yan with an additional lepton candidate from a conversion or a mis-identified bremsstrahlung photon. The largest excess is observed in the $ee$+track search where $0.97 \pm 0.3$ events are predicted and 3 are observed. As no evidence of SUSY has been found we combine the analyses using a frequentist approach that takes the systematic uncertainties and their correlations into account to set 95% C.L. cross section limits, as shown in Fig. 1b. We improve the Run I limits and exclude

$m_{\widetilde{\chi}_1^\pm} < 130$ GeV/$c^2$ in mSUGRA-like MSSM models.

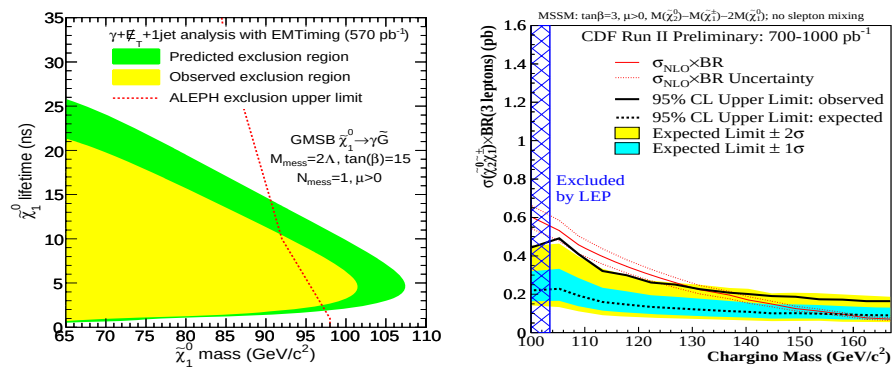


Figure 1. Left: The GMSB 95% C.L. exclusion region on heavy, neutral, long-lived particles that decay to photons. Right: The combined multi-lepton SUSY mass exclusion for an MSSM scenario.

## 7. MSSM and SM Higgs Searches

We search for the neutral MSSM Higgs bosons $h$, $H$ and $A$ that decay to $\tau^+\tau^-$ with a branching ratio of ∼10% in a mass range of 90-250 GeV/$c^2$. We consider leptonically ($\tau_{e/\mu}$) and hadronically ($\tau_{\rm had}$) decaying $\tau$: $\tau_e\tau_{\rm had}$, $\tau_\mu\tau_{\rm had}$ and $\tau_e\tau_\mu$. We allow low-$p_T$ $\tau$ candidates and do not reject the major irreducible $Z/\gamma^* \to \tau\tau$ background to also be sensitive to low Higgs masses. To reduce multi-jet background we require $|p_T^{e/\mu}| + |p_T^{\rm had}| + \not{E}_T \gtrsim 50$ GeV in the $\tau_{e/\mu}\tau_{\rm had}$ channel and $|p_T^e| + |p_T^\mu| \gtrsim 30$ GeV in the $\tau_e\tau_\mu$ channel. We remove $W$+jets events by requiring the direction of the $\not{E}_T$ to be consistent with the assumed direction of the $\tau$ decay products. We perform binned likelihood fits to the visible di-$\tau$ mass distribution $m(\tau_1, \tau_2, \not{E}_T)$ ($m_{vis}$) with a varying Higgs mass, as shown in Fig. 2a. In 992 pb$^{-1}$ of data we observe a slight excess in the $\tau_{e/\mu}\tau_{\rm had}$ channel for a Higgs mass of 160 GeV/$c^2$ corresponding to a $<2\sigma$ fluctuation if the full mass parameter range is considered. While the observed 95% C.L. $\sigma \cdot BR$ limits are weaker due to the slight, but not statistically significant excess in the data, the expected reach extends down to $\tan\beta \sim 45$ for $m_A = 120$-140 GeV/$c^2$,

We search for the SM Higgs in the $WW^*$ decay channel in a Higgs mass range of 110-200 GeV/$c^2$, using 1 fb$^{-1}$ of data. At the Tevatron the dominant production process of the SM Higgs is $gg \to h$ with a mass-

dependent cross section of 0.2-1 pb. We require two leptons ($e$ or $\mu$) with $p_T > 20$ GeV and $p_T > 10$ GeV, respectively, from the leptonically decaying $W$'s. To eliminate $b\bar{b}$ and Drell-Yan production from this sample we require the leptons to have opposite sign, an invariant mass $m > 16$ GeV/$c^2$, and significant $\not\!\!E_T > \frac{m_h}{4}$. The $t\bar{t}$ contribution in the remaining sample is reduced by requiring little jet activity. After additional requirements to reduce the major SM $WW$ contribution, we fit the angular correlation in azimuth of the two leptons to separate the spin-0 Higgs boson signal. No statistically significant excess is found. As shown in Figure 2b, the highest sensitivity is in the region $m_h \approx 160$ GeV/$c^2$ where the ratio of expected (observed) cross section limit to the expected SM cross section is 6.0 (9.2).

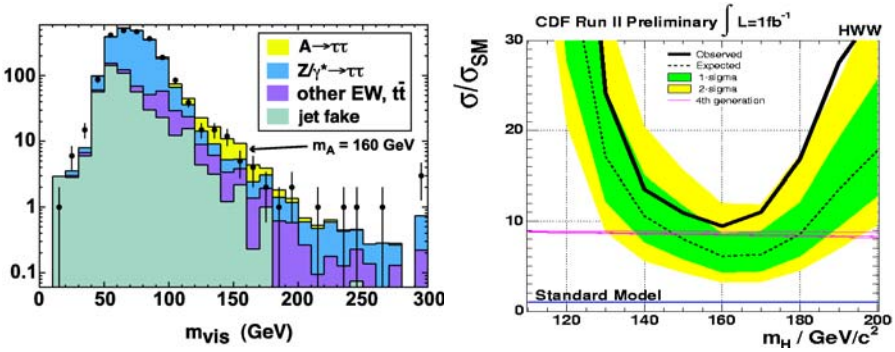


Figure 2. Left: The $m_{vis}$-distribution along with the prediction of all di-$\tau$ channels combined, for an example MSSM Higgs mass of 160 GeV/$c^2$. Right: The ratio of the 95% C.L. cross section limits on the SM $h$ in the $h \to WW^*$ channel to its production cross section. The highest sensitivity is at $m_h \approx 160$ GeV/$c^2$.

## 8. Conclusion

We have presented a portion of the new physics search results at the CDF detector for $\sim$1 fb$^{-1}$ of luminosity. We have since doubled the data and continue to make progress in probing important theoretical models. As the presented Higgs results show, an exciting time is ahead of us.

## Acknowledgments

We thank our colleagues at the CDF Collaboration, the Lake Louise conference organizers and participants, and the funding agencies for making this work possible.