Searches for New Physics at CDF

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In this note we present the results of several searches for physics beyond the standard model (SM). All final states use 2 fb^{-1} of data produced at Tevatron in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV and collected by the CDF Run II detector. None of the analysis is heavily optimized for any specific model. All signatures contain missing transverse energy ($\not\!\!E_{\rm T}$) in the final state and all, except for one, have at least one photon (γ) in the final state. Unfortunately, no interesting excesses of events over the SM prediction are observed in any final states, except may be for the last one.

1. Introduction

This note describes the results of CDF exotic searches in six final states: di-jet + $\not\!\!E_{\rm T}$, di-photon + $\not\!\!E_{\rm T}$, photon + jets + $\not\!\!E_{\rm T}$, photon + b-jet + jet + $\not\!\!E_{\rm T}$, and photon + lepton + b-jet + $\not\!\!E_{\rm T}$. All final states, especially the first two, are sensitive to production cross-section enhancements due to gauge-mediated super-symmetry (GMSB) models [1], while the last one, for example, is essentially $t\bar{t}\gamma$ final state that has never been looked into at CDF. All analysis either exploit new data driven techniques to estimate the SM backgrounds or make use of new hardware that became available after Run IIb upgrade.

The di-jet + $\not\!\!E_{\rm T}$ analysis uses data driven background estimates that were perfected in the monojet channel [2]. The di-photon + $\not\!\!E_{\rm T}$ and photon + jets + $\not\!\!E_{\rm T}$ signatures make use of newly developed $\not\!\!E_{\rm T}$ model that allows to separate events with real $\not\!\!E_{\rm T}$ from events with fake $\not\!\!E_{\rm T}$ based on the extensive knowledge of energy fluctuations in the CDF detector. They also use the EMTiming system [3] to cut away or estimate non-collision photon candidates induced by cosmic rays and beam halo. The photon + jets + $\not\!\!E_{\rm T}$ photon + b-jet + jet + $\not\!\!E_{\rm T}$ signatures use newly installed shower pre-radiator system [4] that allows to predict the fraction of pure photons in all photon candidates.

2. Exclusive Di-jet + $\not\!\!E_{\rm T}$

Events with large $\not\!\!E_{\rm T}$ and one or more energetic jets can be produced in many models of new physics as well as in SM electroweak and QCD processes. The magnitude of the $\not\!\!E_{\rm T}$ and the number of jets depend on the specific model of new physics, while the SM backgrounds and instrumental effects can be studied independently. The base event sample is selected using kinematic requirements of event $H_{\rm T} > 125$ GeV [5] and $\not\!\!E_{\rm T} > 80$ GeV. We also perform a separate search in the high kinematic region defined by $H_{\rm T} > 225$ GeV and $\not\!\!E_{\rm T} > 100$ GeV. In both regions, we compare the expected SM backgrounds with observed data.

The SM estimate reveals 2312 ± 140 events from SM on top of 2506 events observed in data. For high kinematic region we find 196 ± 26 events from SM and 186 events in data. The two leading backgrounds are $W +$ jet, $W \to l\nu$ (102 ± 10) and $Z +$jet, $Z \to \nu\bar{\nu}$ (71 ± 12) production. We interpret the result in terms of cross-section limits on generic minimal super-symmetric (MSSM) models. Figure 1 shows $\not\!\!E_{\rm T}$ and $H_{\rm T}$ distributions, aw well as the prediction from MSSM model.

3. Di-photon + $\not\!\!E_{\rm T}$

In this section we present a model-independent search for anomalous production of $\gamma\gamma + \not\!\!E_{\rm T}$ events. New $\not\!\!E_{\rm T}$ model is developed that uses the best of our knowledge about energy fluctuations, or energy mis-measurements, in the CDF detector. The model provides the $\not\!\!E_{\rm T}$ probability distribution function for individual events and allows

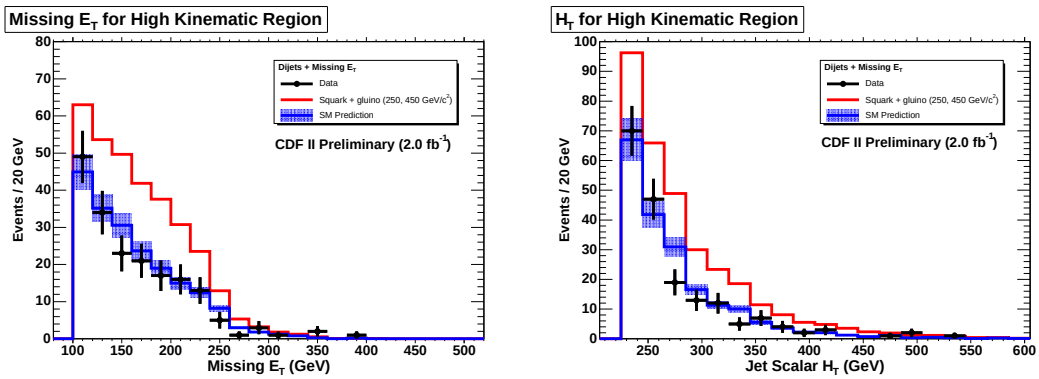

Figure 1: Comparison of Standard Model Background Estimate with events observed in data in the high kinematic region as a function of event missing E_{T} and jet scalar H_{T} (linear scale). The additional potential signal contribution from MSSM spectrum S2 – one of the points ruled out at leading order – is also shown. Note that the high kinematic region is the more sensitive of the two for this mass spectrum.

efficient separation of events with $\not\!\!E_{\mathrm{T}}$ due to undetectable particles, like ν or $\tilde{G}$, from events where $\not\!\!E_{\mathrm{T}}$ is caused by mis-measured jet energies.

Two top plots in Figure 2 show the model performance for $Z \to e^+e^-$ events. After applying $\not\!\!E_{\mathrm{T}}$ significance cut only SM processes with real $\not\!\!E_{\mathrm{T}}$ are left in the sample. The bottom two plots in Figure 2 show the technique applied to the sample of di-photon events. The observed number of events (34) is consistent with the sum of a predicted number of SM events (48.6 ± 7.5). Two largest background contributions are electroweak events with real $\not\!\!E_{\mathrm{T}}$ (41.6 ± 7) and events with fake $\not\!\!E_{\mathrm{T}}$ (6.2 ± 2.7).

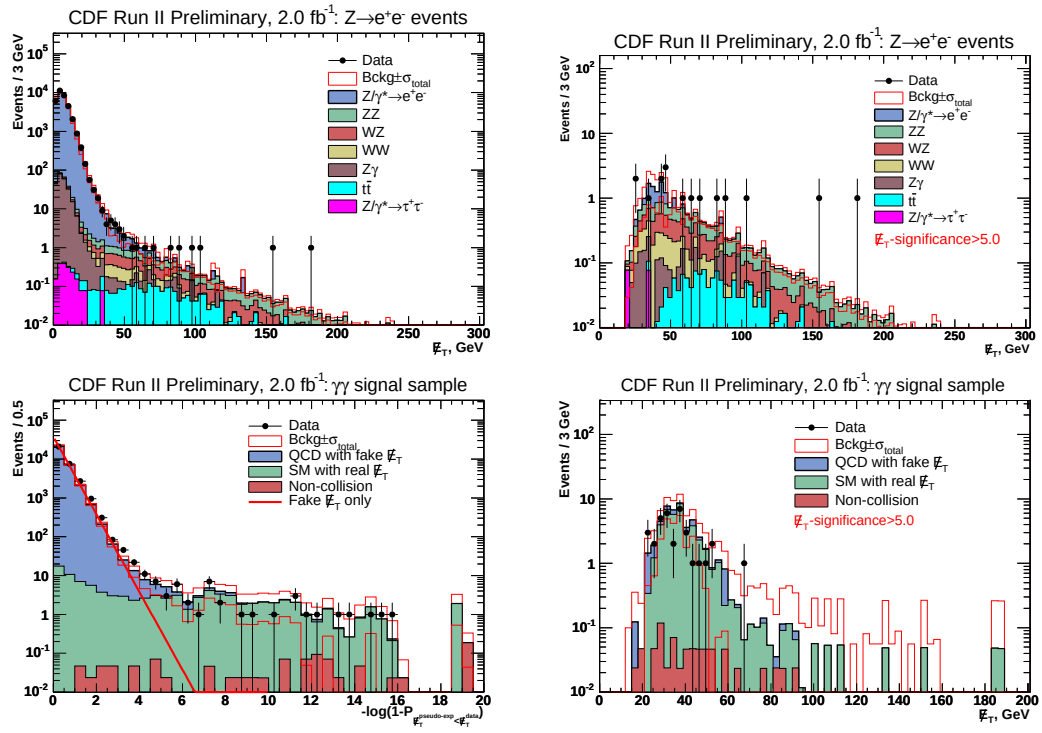

Figure 2: Top: observed $\not\!\!E_{\mathrm{T}}$ distribution in $Z \to e^+e^-$ control sample and $\not\!\!E_{\mathrm{T}}$ distribution after $\not\!\!E_{\mathrm{T}}$ significance > 5 cut. Bottom: $\not\!\!E_{\mathrm{T}}$ significance distribution in di-photon signal sample and observed $\not\!\!E_{\mathrm{T}}$ distribution after $\not\!\!E_{\mathrm{T}}$ significance > 5 cut.

4. Photon + jets + $\not\!\!E_{\rm T}$

Many new physics models predict mechanisms that could produce a Photon + jets + $\not\!\!E_{\rm T}$ signature. This section presents the generic search in the γ + jets. A variety of techniques are applied to estimate the SM expectation and non-collision backgrounds. We examine several kinematic distributions like the ones shown in Figure 3. At the moment the background estimation describes data well in the wide kinematic regions that spans five orders of magnitude in production cross-section. The next step will be applying the $\not\!\!E_{\rm T}$ model described in the previous section in order to select interesting events with large real $\not\!\!E_{\rm T}$.

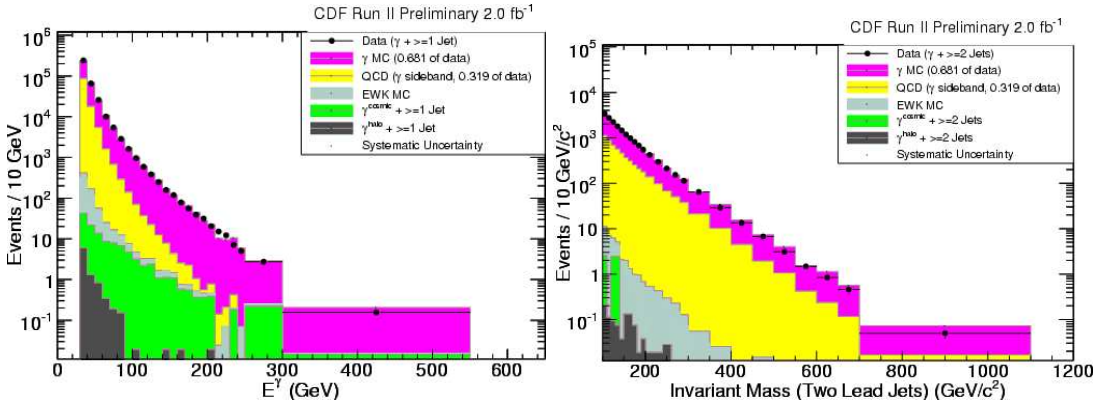

Figure 3: Two kinematic distributions that compare data with the expected backgrounds from SM. They show excellent agreement over several magnitudes of production cross-section

5. Photon + b-jet + jet + $\not\!\!E_{\rm T}$

This section describes the results of a search for new physics in events containing a photon, $\not\!\!E_{\rm T}$, a b-tagged jet, and a second jet. This final state has low background from SM and is a promising place to look for new phenomena. Various extensions of the SM, such as GMSB, predict enhanced decay rates into this final state.

We find 617 events with $\not\!\!E_{\rm T} > 25$ GeV and two jets with $E_{\rm T} > 15$ GeV, at least one identified as originating from a b quark, versus an expectation of 637 ± 139 events. Figure 4 shows the quark mass template fit used to estimate the backgrounds from light quarks and the predicted $H_{\rm T}$ distribution.

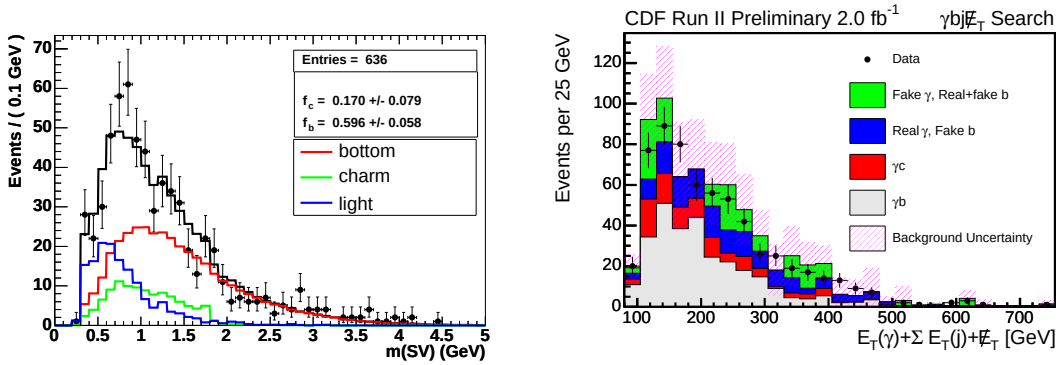

Figure 4: The left plot shows the fit of Secondary vertex mass in the photon + b-jet + jet signal sample. The right plot shows the scalar $P_{\rm T}$ sum of photon, all jets with $E_{\rm T} > 15$ GeV, $|\eta| < 2.0$, and $\not\!\!E_{\rm T}$.

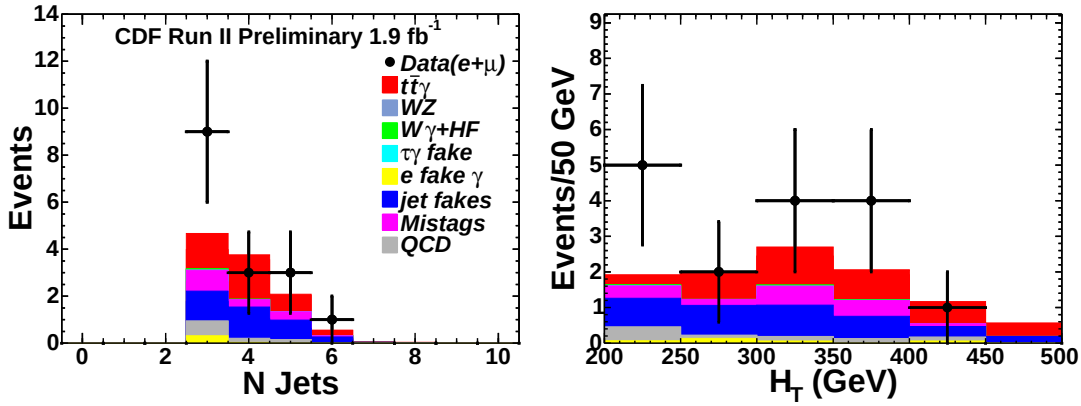

Figure 5: The distributions in H_{T} and Number of Jets, observed in the $t\bar{t}+\gamma$ search. The histograms show the expected SM contributions and observed data.

6. Photon + b-jet + lepton + $\not\!\!E_{\mathrm{T}}$

This section presents a search for anomalous production of γ + b-jet + lepton + $\not\!\!E_{\mathrm{T}}$ events. This signature occurs in GMSB models and other extensions of the SM. Such models would produce this signature with large total energy H_{T}. The SM backgrounds are dominated by production of two gauge bosons, $W\gamma$, and two third-generation quarks (t and b). We find 28 events versus a SM expectation of 27.9 ± 3.6 events.

A search for the production of top pairs with an additional photon, $t\bar{t}+\gamma$, is a natural extension of the signature-based search because $t\bar{t}+\gamma$ is characterized by a high P_{T} lepton, photon, b-tagged jet, and $\not\!\!E_{\mathrm{T}}$. In addition we require large total transverse energy H_{T} and 3 or more jets so that radiative top-pair events dominate the SM predictions. We observe 16 $t\bar{t}+\gamma$ candidate events versus an expectation of 11.1 ± 2.3 events. Assuming the difference between the observed number and the predicted non-top SM total is due to top production, we measure $t\bar{t}+\gamma$ cross-section to be 0.15 ± 0.08 pb. The probability, assuming no true $t\bar{t}+\gamma$ SM signal, for the background alone to produce at least as many events (16) as observed in data, is 1% (2.3 σ). Assuming SM $t\bar{t}$ production, we estimate the $t\bar{t}+\gamma$ cross-section to be 0.15 ± 0.08 pb. Theoretical cross-section 0.08 ± 0.011 pb is obtained from LO MadGraph cross-section (0.076 pb) multiplied by $\mathrm{k_{factor}} = 1.10 \pm 0.15$. We compare the measured $t\bar{t}+\gamma$ cross-section with other SM cross-sections.

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[5] H_{T} is the scalar sum of the transverse energies of the reconstructed jets.