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Searching for New Physics at CDF

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Abstract

We present recent results on searches for physics beyond the Standard Model obtained from the analysis of $1 fb^{-1}$ of data collected at the Tevatron Collider by the CDF Collaboration. We report on model-independent studies for anomalous production of $\ell\gamma + X$, $\ell\gamma b \not{E}_T$ and $\gamma\gamma + \not{E}_T$, Standard Model $t\bar{t}\gamma$ production. We also present results for the Randall-Sundrum Gravitons, the same-sign dileptons and the trileptons searches. No significant excess of data over the predicted background is observed.

1 Introduction

Although the Standard Model (SM) of elementary particles and fundamental interactions has withstood all experimental tests to date, many important questions remain open. The SM does not include gravity and is expected to be an effective low-energy field theory. It is believed that there could be some effects beyond the SM on the TeV scale.

The Fermilab Tevatron collides protons and anti-protons at a center-of-mass energy of 1.96 TeV. So far the machine has delivered over 1.5 fb^{-1} of data to the two experiments, CDF and D0. The higher center-of mass energy, improved detector and significant amount of data give a potential to discover a physics beyond the SM, New Physics. In this proceedings we present recent results on searches for New Physics at CDF using $1 fb^{-1}$ of data.

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2 Search for Anomalous Production of $\ell\gamma + X$ Events

In 1995 CDF experiment, measuring $\bar{p}p$ collisions at a center-of-mass energy of 1.8 TeV using 86 pb^{-1} of data, observed an event consistent with the production of two energetic photons, two energetic electrons, and large missing transverse energy, $ee\gamma\gamma\not{E}_{\mathrm{T}}$ [1].

This signature is predicted to be very rare in the Standard Model of the particle physics (10^{-6} events expected in Run I data). The detection of this single event led to the development of 'signature-based' inclusive searches in Run I.

One of the signature-based searches in Run I was a search for anomalous production of the events containing a charged lepton (ℓ, either e or μ) and a photon (γ), both with high transverse momentum, accompanied by additional signatures, X, including missing transverse energy ($\not{E}_{\mathrm{T}}$) and additional leptons and photons. In general Run I data agree with the expectations for the $\ell\gamma + X$ search, with the exception for the $\ell\gamma\not{E}_{\mathrm{T}}$ category. We have observed 16 $\ell\gamma\not{E}_{\mathrm{T}}$ events on a background of 7.6 $\pm$ 0.7 expected.

For Run II we use the same kinematic selection criteria as in a previous CDF Run I search, but with a substantially larger data set, $\approx$1 fb^{-1} and the upgraded CDF II detector. A priori definition of the selection cuts allows to test Run I anomalies with Run II data.

We find 163 $\ell\gamma\not{E}_{\mathrm{T}}$ candidate events versus the SM expectation of 148.1 $\pm$ 13.0 events. The level of excess observed in Run I is not supported by the new data. Details on the search for $\ell\gamma\not{E}_{\mathrm{T}}$ and information about searches for anomalies in other $\ell\gamma + X$ subchannels are presented in [2].

3 Search for Anomalous Production of $l\gamma\not{E}_{\mathrm{T}}b$ Events and SM $t\bar{t}\gamma$ Production

The $\ell\gamma b\not{E}_{\mathrm{T}}$ signature is possible [3] in different models beyond the SM, such as gauge-mediated Supersymmetry (SUSY) models. This search is related to the $\ell\gamma+X$ search, described in the section 2, but with a b-tag requirement in addition to a lower photon $\mathrm{E_T}$ ($\mathrm{E_T} > 10$ GeV), a lepton (either e with $\mathrm{E_T} >$ 15 GeV or μ with $\mathrm{p_T} > 15$ GeV) and $\not{E}_{\mathrm{T}}$ ($\not{E}_{\mathrm{T}} > 15$ GeV) requirements.

The signature has known SM backgrounds, and could be produced in decays of heavy particles. This signature contains production of fundamental particles, such as two third generation quarks,a t-quark and a b-quark, and two gauge bosons, W and γ.

We find 15 $\ell\gamma b\not\!\!E_{\rm T}$ events (7 in the electron channel and 8 in the muon channel) versus the SM expectation of 11.23±1.52 (8.15±1.44 and 3.08±0.59, respectively) events. The dominant background comes from the events with misidentified leptons, b-jets and photons.

For the $t\bar{t}\gamma$ production we apply the same kinematic selection criteria as for the $\ell\gamma b\not\!\!E_{\rm T}$ category with additional cut, $H_T > 200$ GeV which was selected *a priori*. The variable H_T is defined for each event as the sum of the transverse energies of the leptons, photons, jets, and $\not\!\!E_{\rm T}$. H_T distribution for $\ell\gamma b\not\!\!E_{\rm T}$ events is shown on Figure 1.

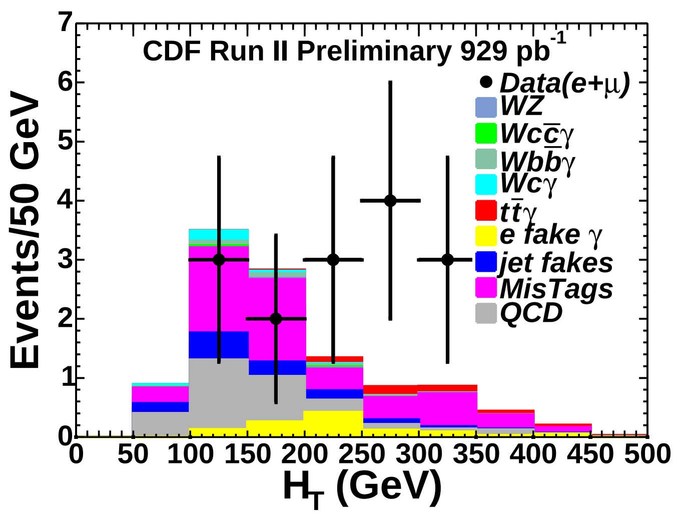


Figure 1: Distribution of $\rm H_T$ in $\ell\gamma b\not\!\!E_{\rm T}$ events. The variable H_T is defined for each event as the sum of the transverse energies of the leptons, photons, jets, and $\not\!\!E_{\rm T}$.

We find 10 $t\bar{t}\gamma$ candidate events (6 in the electron channel and 4 in the muon channel) versus the SM expectation of 4.68±0.99 (3.43±0.83 and 1.24±0.55, respectively) events. Figure 2 shows kinematic distributions for the $t\bar{t}\gamma$ category, namely lepton $\rm E_T$ (upper left), photon $\rm E_T$ (upper right), b-jet $\rm E_T$ (bottom left) and $\not\!\!E_{\rm T}$ (bottom right).

4 Search for Anomalous Production of $\gamma\gamma+$ lepton Events

Another CDF search motivated by the $ee\gamma\gamma\not\!\!E_{\rm T}$ Run I event (see Section 2) is a search for an inclusive production of two photons ($E_T > 13$ GeV, $|\eta_\gamma| < 1.1$) and a lepton (a muon with $P_T > 20$ GeV and $|\eta| < 1.0$ or an electron with $E_T > 20$ GeV and $|\eta| < 2.0$). Analysis is based on approximately 1 fb^{-1} of data.

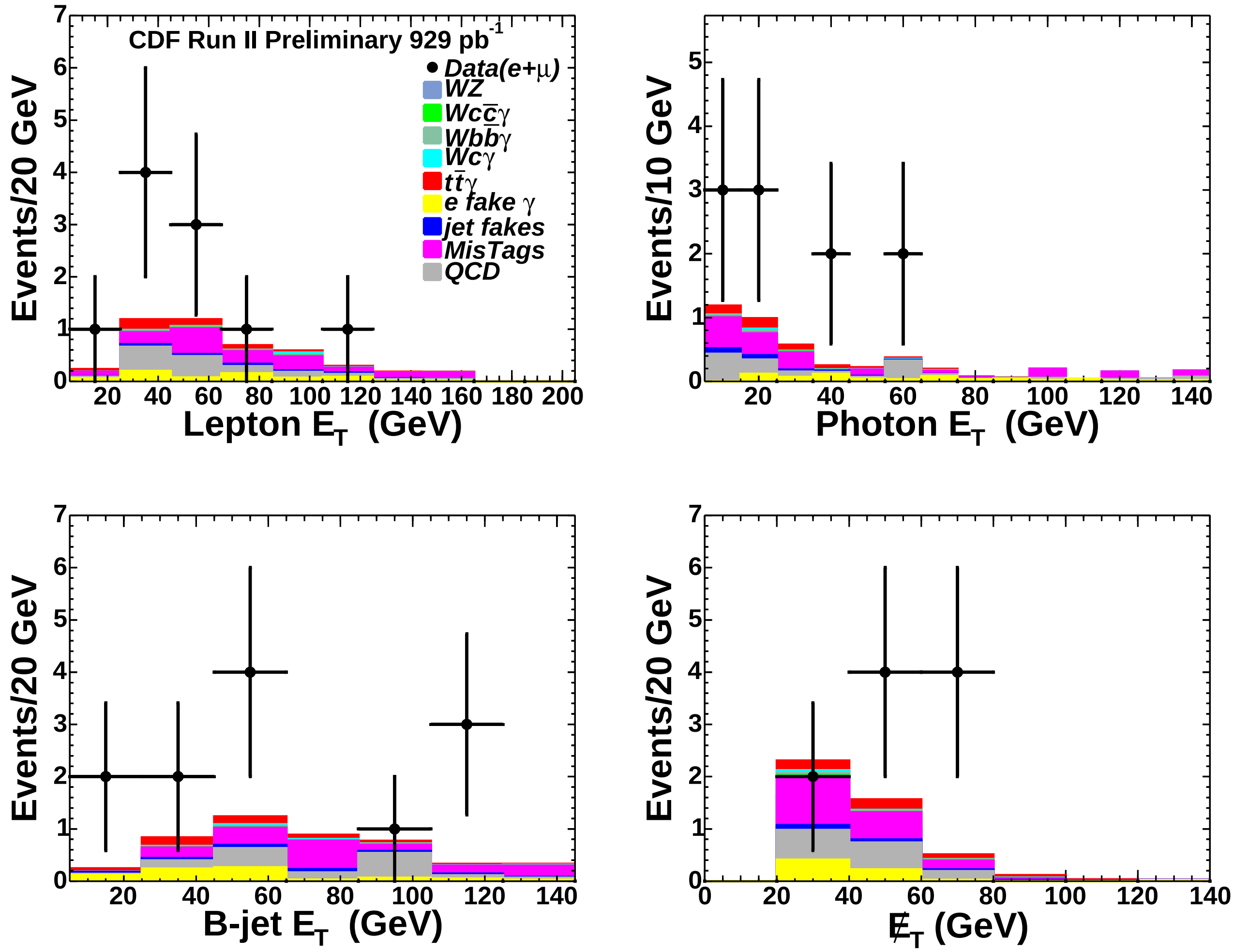


Figure 2: Distribution of lepton $\mathrm{E_T}$ (upper left), photon $\mathrm{E_T}$ (upper right), b-jet$\mathrm{E_T}$ (bottom left) and $\not{E}_{\mathrm{T}}$ (bottom right) in $t\bar{t}\gamma$ events.

We expect 6.82 ± 0.75 events in the electron channel. The leading background in the electron channel is fake photons from electron bremsstrahlung. From the muon channel we expect 0.79 ± 0.11 events, and it is dominated by the electroweak tri-boson production of $Z^0/\gamma^* + \gamma\gamma$.

After the event selection we observe 3 $\gamma\gamma e$ events and 0 $\gamma\gamma\mu$ events. We cross-checked our background estimate and we attribute the deficit in the electron channel to a downward statistical fluctuation.

Figure 3 shows electron E_T (left) and H_T (right) distributions for $\gamma\gamma + e$ channel.

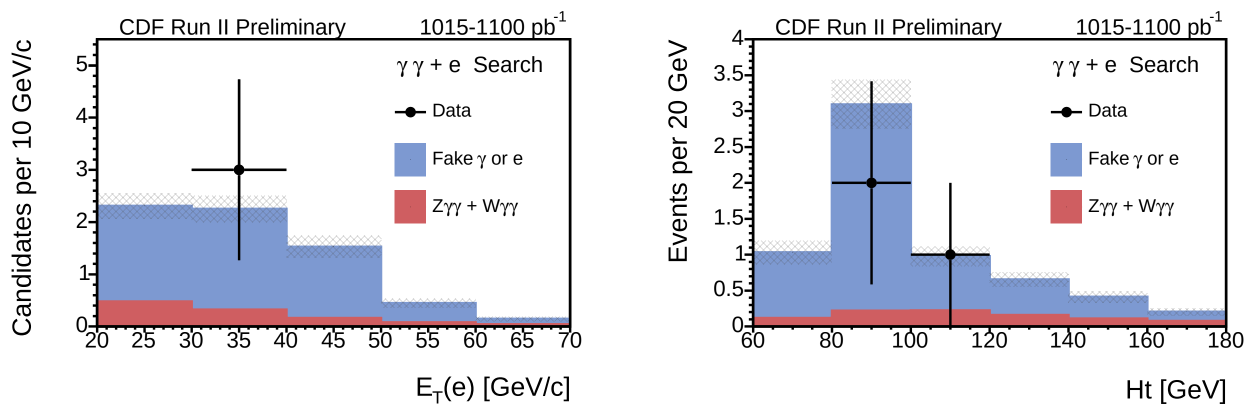


Figure 3: Distribution of Electron E_T (left) and H_T (right) in $\gamma\gamma + e$ events.

5 High Mass Diphoton and Dielectron Searches

5.1 High Mass Diphoton Searches

Searches for new particles decaying in two identical particles are broad, inclusive and sensitive. The discovery of a sharp mass peak over background would be compelling evidence for a New Physics.

One of the models producing a diphoton sharp mass peak is Randal-Sundrum (RS) gravitons [4]. The RS model has two free parameters, the mass of graviton and k/M_{pl} which determines the width of the resonance.

CDF has searched for diphoton mass resonance with a data sample of

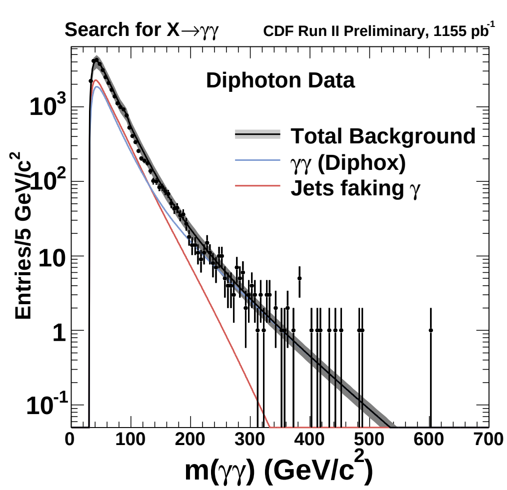


Figure 4: Observed diphoton mass distribution compared to SM prediction.

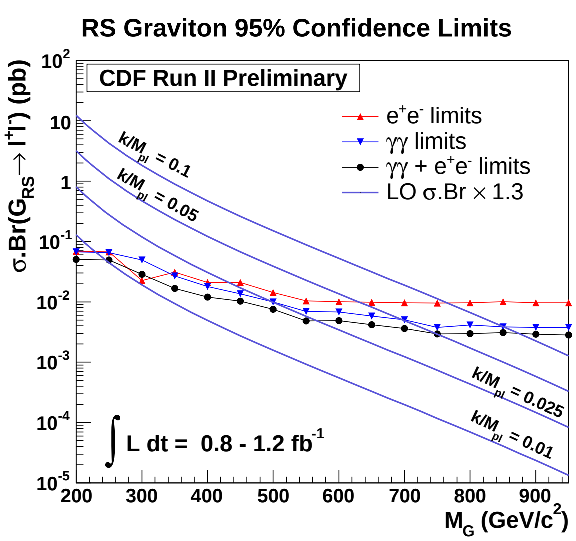
1 fb^{-1}. The measured diphoton mass spectrum, shown in Figure 4, is in a good agreement with the SM prediction.

Since the data are consistent with the SM prediction, we place the upper limit on the cross section times branching ratio on RS graviton production (see Section 5.2).

5.2 Combination of Diphoton and Dielectron Limits

As the RS graviton couples to all SM particles, it can be searched for in various channels. The result of these channels can be combined to further improve the limit on RS Graviton production. At CDF we combine $\gamma\gamma$ and ee channels to give the current world best limit on RS Graviton production. The luminosities are 820 pb^{-1} for dielectron and 1070-1155 pb^{-1} for the diphotons. The branching ratio to the photons is twice that of the electrons.

Figure 5, left, shows the k/M_{pl} model lines overlayed over the limits with the systematic errors included. The k/M_{pl} vs mass exclusion limit is shown in Figure 5, right.



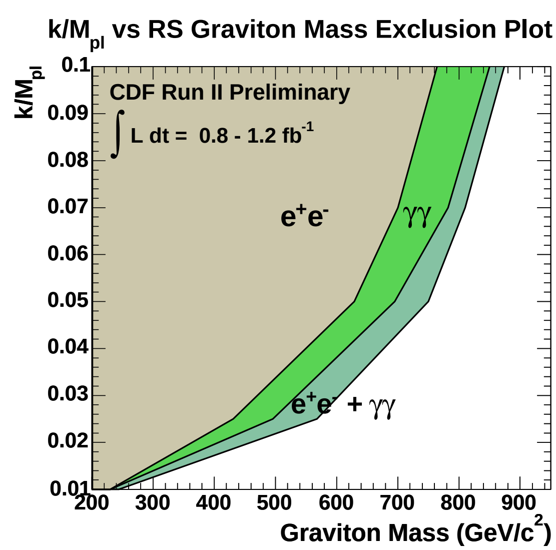


Figure 5: Left: combined 95% confidence level RS graviton mass limits of the di-photon and di-lepton searches vs graviton mass. Right: combined 95% confidence level RS graviton mass limits of the di-photon and di-lepton searches in the graviton mass versus coupling, k/M_{pl}, plane.

6 Search for Trileptons

SUSY [5] is one of the most appealing theories for physics beyond the SM. SUSY predicts the existence of a super-partner for each SM particle with the same quantum number but spin. Since SUSY particles have not been observed yet, the SUSY must be a broken symmetry.

One of the most popular SUSY models is the minimal gravity mediated supersymmetry breaking (mSUGRA) with R-parity conservation. In mSUGRA the lightest neutralino ($\tilde{\chi}_1^0$) is identified as an excellent candidate for the Dark Matter [6]. At the CDF we perform searches for the associated production of chargino and neutralino when they decay leptonically into three charged leptons and two neutralinos.

In this section we present the results for the final states with one electron and two additional leptons (electrons or muons) using 1 fb^{-1} of data. The selection of the events requires one electron in a central region ($\eta \lesssim 1$) with $\mathrm{E_T}$ greater than 20 GeV and a second lepton with $\mathrm{E_T}$ greater than 8 GeV and a third lepton which can be an electron or a muon with $\mathrm{E_T} > 4$ GeV. After requiring 3 candidate leptons, the background is dominated by $WZ/W\gamma^*$ production, fake leptons and conversion electrons. The analysis is carried out as three separate analyses, depending if two additional leptons are two cental electrons (CC), one central and one electron in the forward region (CP), or an electron and a muon (EM).

We observe zero events with 3 leptons, with an expected background of 0.73±0.09 events. Figure 6 shows ($\not{E}_\mathrm{T}$) distribution for the events with two electrons (CC + CP).

The CDF will combine these results with the other trilepton and same-sign dileptons (see Section 6.1) CDF analyses to obtain a limit on the cross section times branching ratio and the mass of the chargino.

6.1 Search for New Physics in Like-Sign Dileptons

We present a search for a New Physics in Like-sign dileptons using the inclusive high $\mathrm{p_T}$ lepton sample. The expectation from the SM is very low, which makes this search sensitive to, for example, Supersymmetry [5] (SUSY) trilepton signatures. Analysis is based on 1 fb^{-1} of data.

In order not to limit this search to a particular New Physics scenario, we do not apply any requirements on the event topology. For this search we require two same-sign lepton candidates with $\mathrm{E_T} > 20$ GeV (e) or $\mathrm{p_T} > 20$ GeV (μ) for leading lepton and $\mathrm{E_T} > 10$ GeV (e) or $\mathrm{p_T} > 10$ GeV (μ) for

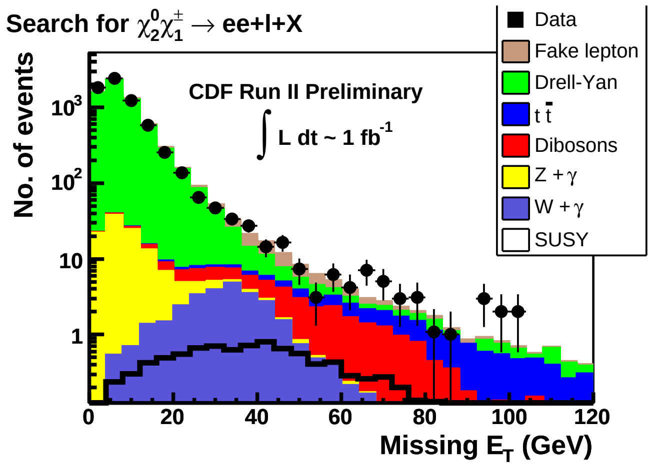


Figure 6: Missing transverse energy($\not{E}_{\mathrm{T}}$) distribution for the events with two electrons (CC+CP).

sub-leading lepton. Both leptons should satisfy strict lepton identification requirements and have an isolated energy in the calorimeter.

The dominant background is from events with a primary lepton and secondary like-sign lepton from an untagged conversion ($Z\gamma$, $W\gamma$). Other backgrounds include WW, ZZ and $t\bar{t}$ events.

We predict 7.9±1.0 events combined from ee, $\mu\mu$ and $e\mu$ channels and observe 13 events. We observe more events that we expect but everything still holds statistically.

Figure 7 shows several kinematics distribution for the events found in the signal region.

7 Conclusions

We have presented new results [7] for searching a New Physics at CDF. While the results do not support evidence of the physics beyond the SM, a very exciting period is ahead of us. We expect to collect 4 to 8 fb^{-1} of data by 2009. The new data that will be collected will provide an opportunity for discovery of the physics beyond the Standard Model before the LHC starts.

8 Acknowledgments

I would like to thank my CDF collaborators and the Crimea conference organizers for making this work possible.

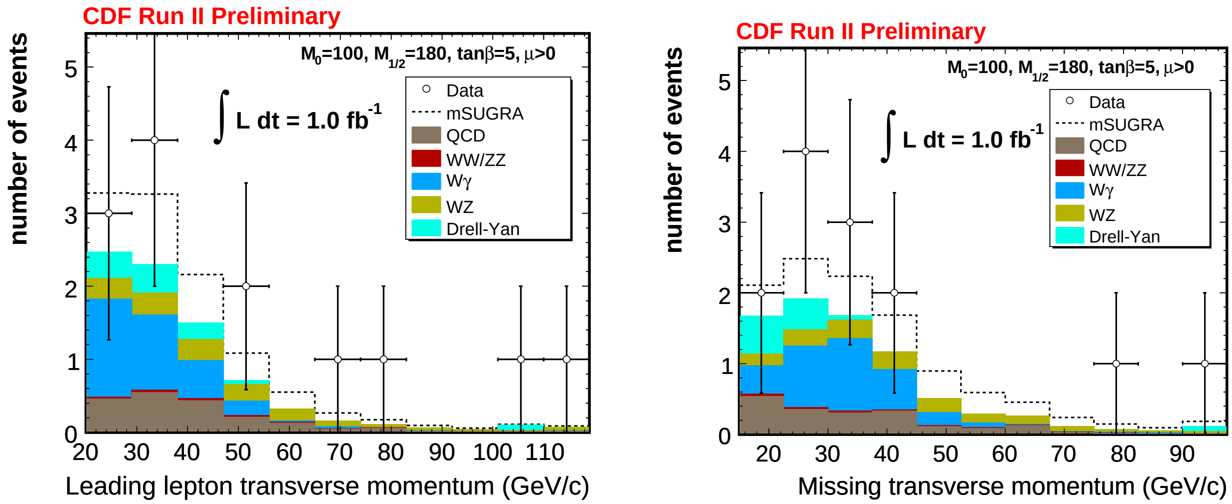


Figure 7: The kinematic distributions of the same-sign lepton events found in the signal region: leading lepton transverse momentum(left) and missing transverse momentum (right).

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http://www-cdf.fnal.gov/physics/exotic/exotic.html.