

Searches for New Physics in $\gamma + \cancel{E}_T$ Events at CDF Run II

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The addition of the EMTiming system installed to provide the time measurements of the electromagnetic calorimeter signals has significantly increased the sensitivity of CDF to events with $\gamma + \cancel{E}_T$. Here I review recent searches in this signature performed by CDF using data from $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV. They provide new constraints on models with large extra dimensions and with gauge mediated supersymmetry breaking.

1. INTRODUCTION

Searches for physics beyond the standard model (SM) in hadron collisions cover a variety of final states, in particular in events with a photon and a large missing transverse energy (\cancel{E}_T) [1]. The large \cancel{E}_T is associated with particles that weakly interact with matter and leave the detector undetected. In supersymmetric (SUSY) models they are the lightest supersymmetric particles (LSP), the natural candidates to account for the dark matter [2]. In models with large extra dimensions which provide a solution to the hierarchy problem they are the Kaluza-Klein gravitons [3]. A photon can be produced at the collision point (prompt photon) or away from it, like in a decay of a heavy long-lived particle, in which case it is detected later in time (delayed photon). Other contributions to the $\gamma + \cancel{E}_T$ signature in CDF are from non-collision sources: a high energy muon from beam or from cosmic ray interactions can radiate in the detector and be misidentified as a photon (a beam halo or a cosmic photon respectively). Each type of photons has a unique distribution of the time they reach the electromagnetic calorimeter. This time can be measured by the EMTiming system installed in 2005 [4].

Here I present two analyses which benefit the most from the EMTiming system. The first analysis is a search for delayed photons motivated by the model with gauge mediated supersymmetry breaking (GMSB), performed in the $\gamma + \cancel{E}_T + \text{jet}$ signature using 570 pb^{-1} of data [5]. The second is a search in the exclusive $\gamma + \cancel{E}_T$ signature motivated by the model with large extra dimensions (LED), performed using 2 fb^{-1} of data [6].

2. CDF DETECTOR

A detailed description of the CDF detector can be found in Ref. [7]. The vertexing and the tracking detectors surrounding the interaction region placed in solenoidal magnetic field of 1.4 T are used to reconstruct trajectories of charged particles and measure their momenta and points of origin. Further out are the calorimeters with electromagnetic and hadronic longitudinal segmentation used to identify and measure photons, electrons, and jets. The EMTiming system is used to measure the calorimeter signal time with resolution of 0.5 ns and a threshold of about 3 GeV. Placed outside the calorimeter are the muon detectors used to identify muons from the collisions and cosmic rays.

3. SEARCH FOR HEAVY LONG-LIVED NEUTRALINOS

A search for delayed photons [5] is motivated by the GMSB model in which the lightest neutralino $\tilde{\chi}_1^0$ decays to a photon and a gravitino \tilde{G} . Given the resolution of the EMTiming system and the CDF detector geometry the sensitivity to the delayed photons is the best for a proper lifetime of the $\tilde{\chi}_1^0$ in the nanosecond range. This range is

consistent with the mass of the gravitino to be in the keV/c^2 range which would explain the dark matter abundance. In $p\bar{p}$ collisions the $\tilde{\chi}_1^0$'s are produced in chain decays of heavier particles and the events with $\gamma + \cancel{E}_T$ are expected to have some additional activity in the calorimeter.

The pre-selected events are required to have an isolated photon with $E_T > 30$ GeV and $|\eta| < 1$, the missing energy of $\cancel{E}_T > 30$ GeV, a jet with $E_T^{\text{jet}} > 30$ GeV and $|\eta^{\text{jet}}| < 2$, and a vertex with track- $\sum p_T$ above 15 GeV/c [1]. The backgrounds are from events with prompt, beam halo, and cosmic photons. The photon time t_c^γ , measured relative to the vertex time, is used to discriminate the signal from the backgrounds. The contributions from each background are predicted from the t_c^γ distributions extracted from data outside the region of $1.2 \text{ ns} < t_c^\gamma < 10 \text{ ns}$. The expected contribution from the GMSB is estimated using simulation for points in the $(m_{\tilde{\chi}_1^0}, c\tau_{\tilde{\chi}_1^0})$ space.

The optimal event selection in $\cancel{E}_T, E_T^{\text{jet}}, t_c^\gamma$, and the angular separation between the \cancel{E}_T and the jet vectors $\Delta\phi(\cancel{E}_T, \text{jet})$ is chosen to provide the minimal expected upper limit on the $\tilde{\chi}_1^0$ production cross section at the 95% confidence level (CL) for the highest $m_{\tilde{\chi}_1^0}$ expected to be excluded. It is found to be $\cancel{E}_T > 40$ GeV, $E_T^{\text{jet}} > 35$ GeV, $\Delta\phi(\cancel{E}_T, \text{jet}) > 1$ rad, and $2 \text{ ns} < t_c^\gamma < 10 \text{ ns}$. Two events pass this selection compared to 1.3 ± 0.7 events expected from 0.7 ± 0.6 , 0.5 ± 0.1 , and 0.1 ± 0.1 events of the prompt, cosmic, and beam halo photon backgrounds respectively. The expected and observed exclusion regions are shown in Fig. 1, together with the exclusion region expected from a future analysis which would probe the region where the gravitino can be the dark matter particle.

4. SEARCH FOR LARGE EXTRA DIMENSIONS

A search in events with \cancel{E}_T and a prompt photon [6] is motivated by the LED model [3]. In this case a graviton produced in a $p\bar{p}$ collision recoils against a photon and leaves the detector undetected. Since the graviton momentum can have a component in extra spacial dimensions, it is visible in our space-time as a massive particle. In the LED model the graviton mass spectrum is essentially continuous and a large number of modes contribute to high energy interactions with a production rate potentially observable at the Tevatron depending on the number of extra dimensions n and the fundamental mass parameter M_D .

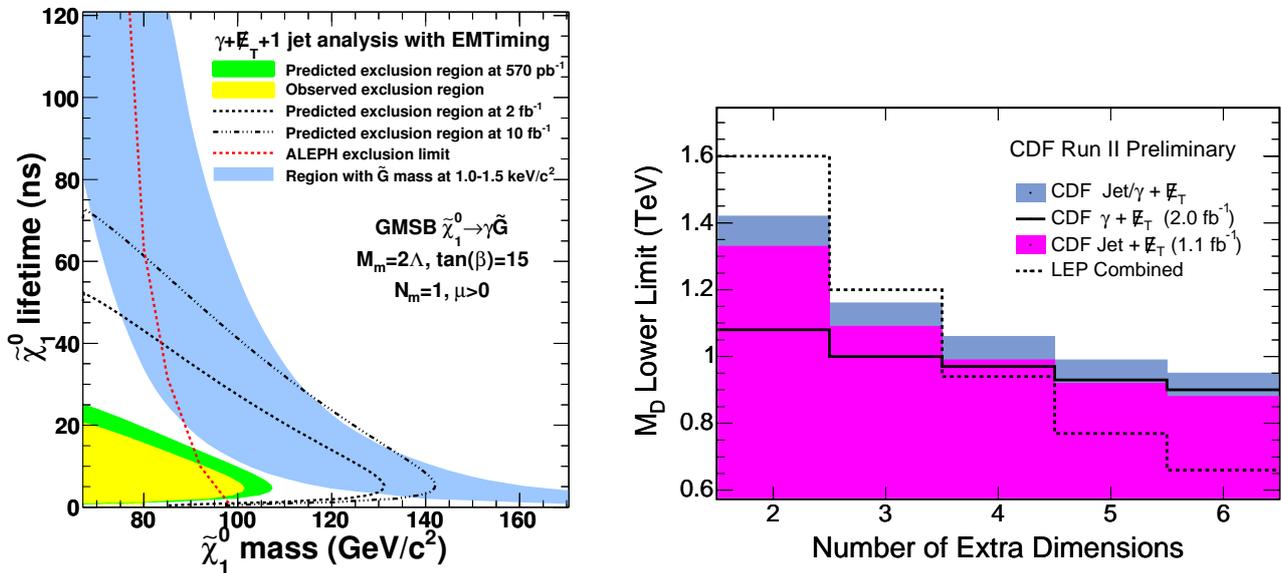


Figure 1: Predicted and observed region in $(m_{\tilde{\chi}_1^0}, c\tau_{\tilde{\chi}_1^0})$ excluded at 95% CL in the delayed photon analysis together with the expected sensitivity for a future analysis compared to results from LEP and the region favored by cosmological observations (left). Observed 95% CL upper limit on M_D for different numbers of extra dimensions using $\gamma + \cancel{E}_T$ events together with the limit obtained from the combination with a similar analysis of jet + \cancel{E}_T events compared to the limit from LEP (right).

Pre-selected $\gamma + \cancel{E}_T$ events are required to have one photon with $E_T > 40$ GeV and $|\eta| < 1$ and $\cancel{E}_T > 50$ GeV. Events from non-collision sources are suppressed by requiring a collision vertex with at least 3 tracks, and the photon time to be within 3 ns from the expected collision time. Contributions from cosmic rays are additionally suppressed using hits in the muon systems and measurements in the calorimeter. Contributions from the beam halo are suppressed by topological event selections to a negligible level. The remaining backgrounds are coming from $p\bar{p}$ collisions. The only irreducible background coming from $Z\gamma$ production, where $Z \rightarrow \nu\bar{\nu}$, is estimated from simulation. Other prompt photon backgrounds are either from events with particles misidentified as a photon or from events with a mismeasured \cancel{E}_T from an object (a lepton, photon, or a jet) lost in an uninstrumented region. These backgrounds are suppressed by requiring no jets with $E_T > 15$ GeV and no tracks with $p_T > 10$ GeV/ c . The contribution from $W \rightarrow e\nu$, where the electron is identified as the photon, is estimated from the electron sample scaled by the misidentification rate. The contribution from cosmics is estimated using events with the photon time away from the collision time. Except for $W \rightarrow \tau\nu$, which is estimated from simulation, the number of events with a lost object is derived from events in data with this object identified, scaled by the simulated rate for it to be lost.

After a selection optimized for the best 95% upper limit, corresponding to the photon $E_T > 90$ GeV, 40 events are observed compared to 46.3 ± 3.0 expected from the background contributions. The expected number of background events are 24.8 ± 2.8 , 9.8 ± 1.3 , 7.3 ± 1.5 , and 3.6 ± 0.4 coming from $Z\gamma \rightarrow \nu\bar{\nu}\gamma$, cosmics, a lost object, and a lepton from a W decay misidentified as a photon respectively. The constraints on the LED shown in Fig. 1 are comparable to those provided by a similar analysis of jet + \cancel{E}_T events and can be combined for a better limit.

5. SUMMARY

Among the recent searches for physics beyond the SM in events with $\gamma + \cancel{E}_T$, the search for delayed photons motivated by the GMSB and the search for prompt photons motivated by the LED benefit the most from the measurements provided by the EMTiming system installed at CDF in 2005. The search for delayed photons employs purely data-driven background estimation methods and provides the best reach in $\tilde{\chi}_1^0$ mass with a proper lifetime of about 5 ns. Similar analysis performed with more data is expected to probe extensively the region consistent with the gravitino being the dark matter particle. The search in the exclusive $\gamma + \cancel{E}_T$ signature provides constraints on the LED model comparable to those from a similar analysis in the jet + \cancel{E}_T signature.

Acknowledgments

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References

- [1] The polar coordinate system is used with the z -axis along the proton beam. The pseudorapidity is defined as $\eta = -\ln[\tan(\theta/2)]$. The transverse momentum is defined as $p_T = p \cdot \sin \theta$, where p is the momentum. The transverse energy is defined as $E_T = E \cdot \sin \theta$, where E is the energy measured by the calorimeter. The missing E_T is defined as $\cancel{E}_T = -\sum_i E_T^i \hat{n}_i$, where the sum is taken over calorimeter cells, and \hat{n}_i is a unit vector in xy -plane pointing to the cell from the origin.
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