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Prospects of a Search for Neutral, Long-Lived Particles using Photon Timing at CDF

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We present the prospects of searches for neutral, long-lived particles which decay to photons using their time of arrival measured with a newly installed EMTiming system at CDF. Using GMSB $\tilde{\chi}_1^0 \to \gamma\tilde{G}$ models we estimate the expected 95% confidence level exclusion regions as a function of the neutralino mass and lifetime. We find that a combination of single photon and diphoton analyses should allow the Tevatron in run II to easily extend the exclusion regions from ALEPH at LEP II, and cover parts of the theoretically favored $m_{\tilde{G}} <$ few keV/c^2 GMSB parameter space.

Keywords: GMSB; EMTiming; CDF; long-lived; neutralino; time of arrival; photons.

The electromagnetic (EM) calorimeter at CDF has recently been equipped with a new timing system, EMTiming[1], to measure the arrival time of energy deposited (e.g. from photons). While it was initially designed to reject cosmics and accelerator backgrounds[2], we summarize the prospects of using it to search for neutral particles with a lifetime of the order of a nanosecond which decay in flight to photons[3]. An example of a theory which would produce these particles is gauge mediated supersymmetry breaking (GMSB)[4] with a neutralino, $\tilde{\chi}_1^0$, as the next-to-lightest supersymmetric particle (NLSP) and a light gravitino, $\tilde{G}$, as the LSP. In this scenario the neutralino decays preferably (~100%) as $\tilde{\chi}_1^0 \to \gamma\tilde{G}$ with a macroscopic lifetime for much of the GMSB parameter space.

Since decay photons from long-lived particles will have a later arrival time than prompt photons produced from standard model (SM) sources, a suitable separation variable is[5]:

$$\Delta s \equiv (t_f - t_i) - \frac{|\vec{x}_f - \vec{x}_i|}{c} \tag{1}$$

Prompt (SM) photons will produce $\Delta s \equiv 0$ and photons from long-lived particles $\Delta s > 0$, for perfect measurements. In general, only neutralinos with both a long

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lifetime and a low momentum produce large Δs photons. Therefore, the efficiency of a Δs cut depends slightly on its momentum distribution, i.e. the production mechanism of the event. As an example, if a neutralino has an event lifetime of 10 ns, then it has roughly 1% probability to decay in the detector. However if it does decay, the decay photon would pass a cut of $\Delta s > 3$ ns in 100% of the cases. For the CDF detector the system resolution is $\sigma_{\Delta s} \sim 1.0$ ns[6].

We investigate separately a $\gamma\gamma + \not\!\!E_T$ and a $\gamma + \not\!\!E_T$ + jets analysis for the following reasons: 1) with neutralino lifetimes longer than a nanosecond, one or both of the neutralinos can leave the detector before they decay, 2) gravitinos or the neutralino leaving the detector provide missing transverse energy, $\not\!\!E_T$, and 3) in GMSB models the neutralinos are part of cascades from gauginos which produce additional particles which, in general, could be identified as jets. We use PGS[7] as a simple detector simulation and ISAJET[8] to generate the SUSY masses. The sensitivity is estimated using the expected 95% C.L. cross section upper limits for 2 fb^{-1}, as that is a conservative estimate for the integrated luminosity at the end of run II.

A $\gamma\gamma + \not\!\!E_T$ analysis has the best sensitivity for low neutralino lifetimes. The background for this analysis consists of QCD events with fake $\not\!\!E_T$[2]. We find that adding the Δs values, $\Delta s_{12} = \Delta s^{\gamma_1} + \Delta s^{\gamma_2}$, and selecting signal events with *either* large $\not\!\!E_T$ *or* large Δs_{12}, either of which is not SM-like, maximizes the separation of signal and background. We find that both the Δs_{12} and $\not\!\!E_T$ cuts are stable at around 7 ns and 50 GeV for non-zero lifetimes.

Analogously we proceed with the $\gamma + \not\!\!E_T +$ jets analysis which is most sensitive to neutralinos with long lifetime. The backgrounds are dominated by QCD and W+jets[9]. We find that the optimal final selection requirements accept events with either large $\not\!\!E_T$ *or* large Δs. We find a Δs cut around 4 ns which is stable for all masses and lifetimes and $\not\!\!E_T > 25$ GeV.

A comparison of the expected cross section limits with the production cross sections in the GMSB model gives the neutralino mass vs. lifetime exclusion regions shown in Fig. 1 at a luminosity of 2 fb^{-1}. Timing has the biggest effect at low masses and high lifetimes. We have also indicated the exclusion regions from ALEPH at LEP II from both direct and indirect searches[10]. For 2 fb^{-1} the Tevatron should significantly extend the sensitivity towards large mass and lifetimes. The mass exclusion limit at 168 GeV for $\tau_{\tilde{\chi}} = 0$ ns is comparable to the limit presented in the DØ study of displaced photons[11]. Since in most cosmological scenarios the relic density of the gravitino will overclose the universe if it has a mass of $\geq$ few keV/c^2 [12], we show the 1 keV/c^2 line as an indicator for this theoretically preferred region. While variations from the chosen GMSB model line have not been further examined, the highest gravitino mass we can exclude is $\sim$1.7 keV/c^2 at $m_{\tilde{\chi}} \approx 130$ GeV/c^2 and $\tau_{\tilde{\chi}} \approx 60$ ns.

We have studied the prospects of using timing information to directly search for neutral, long-lived particles which decay to photons, as one can find in SUSY models. We find that a combination of timing and kinematic requirements provide

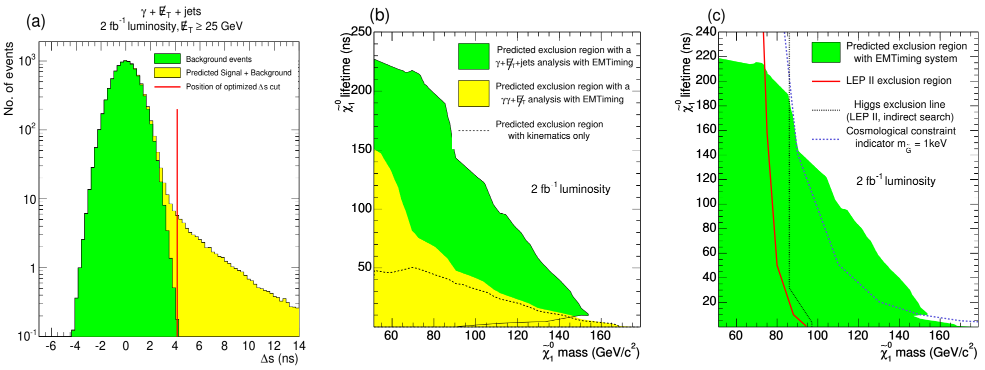

Fig. 1. Plot (a) shows an example of the distribution of signal (bright) and background (dark) vs. Δs in the $\gamma + \not{E}_T +$ jets analysis after a baseline $\not{E}_T$ cut of 25 GeV. The line of the optimized Δs cut shows that there is good separation between signal and background. Figures (b) and (c) show the expected 95% C.L. exclusion regions as a function of neutralino lifetime and mass for full GMSB production at 2 fb^{-1} luminosity. Plot (b) shows separately the exclusion regions for the $\gamma\gamma + \not{E}_T$ (bright) and the $\gamma + \not{E}_T +$ jets analysis (dark). Plot (c) shows the final expected exclusion region from the overlap of the two analyses and compares the results to the direct and indirect search limits from ALEPH at LEP II. The $m_{\tilde{G}} = 1$ keV$/c^2$ line is shown as an indicator for the theoretically favored region from cosmological considerations.

excellent rejection against SM backgrounds in complementary fashion. While the region where timing produces the most additional rejection is already excluded by ALEPH at LEP II, the additional handle it provides should allow the Tevatron in run II to produce the world's most stringent limits at masses above 80 GeV$/c^2$ at high lifetimes. These exclusions have the potential to come close to cosmological constraints for GMSB models. The presented prospective results will be tested with the EMTiming system at CDF whose installation is currently being finished during the CDF shutdown in Fall 2004.

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