Signatures of GMSB with Non-Pointing Photons at the ATLAS Detector

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Abstract. Signatures of gauge-mediated supersymmetry breaking include events in which the NLSP is a neutralino decaying to a photon and a gravitino. In this scenario, the photon can have a distinct signature of apparently late arrival in the calorimeter and a directionality not consistent with having been produced at the primary interaction point. These “non-pointing” photons can be reconstructed and identified. Furthermore, techniques are shown which demonstrate how the lifetime of the neutralino could be measured.

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GAUGE MEDIATED SUPERSYMMETRY BREAKING

Supersymmetry (SUSY) is a good candidate for physics beyond the Standard Model. In Gauge Mediated SuperSymmetry Breaking (GMSB), the symmetry is broken by gauge interactions through messenger gauge fields. The event signature is dependent on the next-to-lightest supersymmetric particle (NLSP). In one region of phase space, the NLSP is the $\tilde{\chi}_1^0$which typically decays to a photon and gravitino[1]. A typical decay chain is shown in figure 1. Due to the presence of two SUSY decay chains in the event, the typical signature for the GMSB events are jets, 2 leptons, missing transverse energy ($E_{\mathrm{T}}^{\mathrm{miss}}$), and 2 photons with a large transverse momentum (p_T).

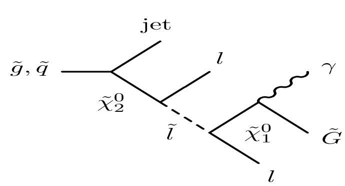

FIGURE 1. Typical SUSY decay chain for a neutralino NLSP decaying to a photon and a gravitino.

If the mean lifetime of the $\tilde{\chi}_1^0$ is long enough such that the decay length is comparable to the size of the ATLAS inner-detector, photons with a high p_T could enter the calorimeter at angles (η_γ) deviating significantly from the nominal angle from the interaction point to the calorimeter cell (η_1). This is shown schematically in figure 2.

PHOTON RECONSTRUCTION AND IDENTIFICATION

Full details of the ATLAS detector can be found in [2]. The granularity of the liquid argon electromagnetic (LAr) calorimeter allows the shower barycenter to be measured

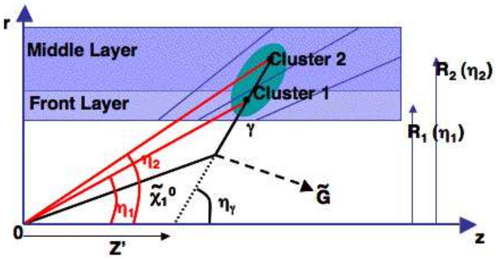

FIGURE 2. Schematic diagram of a non-pointing photon in the LAr calorimeter. The $\tilde{\chi}_1^0$ travels before decaying into a photon and a gravitino. A photon produced in this manner can enter the calorimeter at a significantly different angle (η_γ) than a photon produced at the primary vertex (η_1).

in η at two depths, in the 1st and 2nd sampling layers. By constructing a vector between these two positions, the direction of the electromagnetic shower can be reconstructed with a resolution of less than $80\sigma_\theta \times \sqrt{E}(mrad \times \sqrt{GeV})$[1]. The calorimeter has also been designed to measure the timing of the electromagnetic shower. The timing resolution is better than $1ns$ for electromagnetic showers greater then 1 GeV [3].

A "sliding window" clustering algorithm[4] is used to find electromagnetic showers produced by electrons and photons in the LAr calorimeter. Calorimeter cells are clustered in 3x7 fixed-size rectangles ($\eta \times \phi$), the position of which optimises the transverse energy contained within. The efficiency of this photon reconstruction algorithm has been measured from Monte Carlo simulation, for 14 TeV collision data, for GMSB samples of two different mean $\tilde{\chi}_1^0$ lifetimes(3.17 ns and 10.7 ns) and is shown in figure 3. The photons used in this calculation are required to originate from $\tilde{\chi}_1^0$ decay occurring inside the volume of the inner detector, have a generated p_T greater than 20 GeV and to be located inside $|\eta| < 2.5$. Out of this sample, the reconstruction algorithm is defined to be efficient if a cluster is found within a distance of 0.2 in $\eta - \phi$ of a truth photon. As photons become more "non-pointing", the energy can be deposited in more cells. This reduces the chance that the sliding window algorithm can correctly identify the photon.

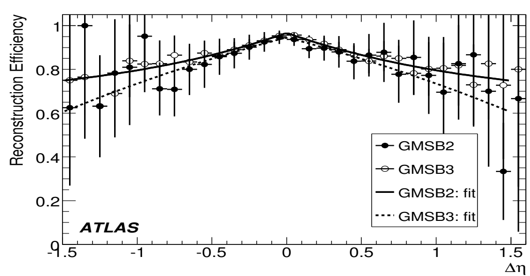

FIGURE 3. Photon reconstruction efficiency as a function of $\Delta\eta = |\eta_\gamma - \eta_1|$ for two GMSB Monte Carlo simulations with mean $\tilde{\chi}_1^0$ lifetimes of 3.17 ns (GMSB2) and 10.7 ns (GMSB3).

Photon identification criteria are used to select photons efficiently, whilst rejecting fake photon signatures. The photon identification criteria is based on variables describing the shape of energy deposit in the calorimeter. Photons not originating from the primary interaction can enter the calorimeter at an angle that differs from that of a photon produced at the primary vertex. They can have a wider shower profile than pointing

TABLE 1. Event selection for signal (GMSB sample with 10.7 ns mean $\tilde{\chi}_1^0$ lifetime) and background Monte Carlo samples for $1fb^{-1}$. The signal significance is defined as $Sig = S/\sqrt{B}$, where at least one background event is assumed.

N_γ	N_{OSSF}	**Signal**	**Σ Background**	**Sig**	N_W	N_Z	$N_{t\bar{t}}$
0	0	825.2	929.6	27.1	274.4	21.0	632.8
0	1	265.2	73.0	33.2	8.7	1.4	63.0
1	0	255.8	51.7	35.7	19.5	2.0	30.1
1	1	68.6	1.4	58.6	0.2	0.0	1.2
2	0	12.5	0.1	12.5	0.0	0.0	0.1
2	1	4.7	0.0	4.7	0.0	0.0	0.0

photons and identification variables based on shower width can be biased with respect to photons produced from long-lived $\tilde{\chi}_1^0$. It has been shown that by using only the photon identification variables that are unbiased with respect to the direction of the photon, the selection cuts can be loosened, at the cost of increasing the fraction of jets identified as photons from 0.19±0.03 % to 0.70±-0.07 %. Full details can be found in [1].

EVENT TRIGGERING AND SELECTION

Two philosophies are considered for triggering the GMSB events. The first is to trigger on the photon objects, the second is to trigger on the other characteristics of the events such as the jets and $E_{\mathrm{T}}^{\mathrm{miss}}$. The Monte Carlo samples investigated are for $\sqrt{(s)} = 14$ TeV collisions. The trigger efficiency for all GMSB events with a mean neutralino life time of 10.7 ns and $L = 10^{33} cm^{-2} s^{-1}$ was measured as 36.9±1.8%[1] for a single photon trigger ($E_T > 55GeV$) and 12.9±1.2% for a double photon ($E_T > 17GeV$) trigger. This is due to the probability of the $\tilde{\chi}_1^0$ decaying outside the volume of the inner detector increasing with the mean neutralino lifetime. The standard ATLAS SUSY triggers which are based on looking for events with jets and $E_{\mathrm{T}}^{\mathrm{miss}}$ have efficiencies of 71.2±0.6% for the one jet trigger ($E_T > 65GeV$) plus $E_{\mathrm{T}}^{\mathrm{miss}}$ ($E_T > 70GeV$) and 79.6±0.6% for the three jet ($E_T > 65GeV$) trigger after all events. The SUSY trigger efficiencies are high after offline event selection cuts.

In order to select GMSB candidate events at least 4 jets with $p_T > 50GeV$ and a leading jet of $p_T > 100GeV$ are required. The $E_{\mathrm{T}}^{\mathrm{miss}}$ is required to be greater than 100 GeV and 0.2 times the effective mass (the scalar sum of the $E_{\mathrm{T}}^{\mathrm{miss}}$ and pt of the 4 leading jets) of the event. Table 1 shows the effect of different requirements on the number of photons and opposite-sign, same-flavour (OSSF) lepton pairs on the signal and background event rates after this preselection. It is shown that $t\bar{t}$ is the major source of background and that the event selection can be optimised by requiring 1 photon and 1 opposite-sign-same-flavour pair of leptons.

EXTRACTION OF NEUTRALINO LIFETIME

The directional and timing capabilities of the LAr Calorimeter can be utilised to determine the mean lifetime of the $\tilde{\chi}_1^0$. The distribution of the projected longitudinal impact parameter (Z' in Figure 2) of the photon candidates is an exponential distribution, modified by vertex and acceptance effects. To remove these effects, the distribution is fitted from 50-500mm, by an exponential function. Due to correlation between the slope parameter of the exponential and the mean $\tilde{\chi}_1^0$ lifetime, a suitable calibration curve produced from MC samples produced with different mean lifetimes can be used to extract the lifetime of the $\tilde{\chi}_1^0$, if GMSB SUSY events are observed. The preliminary results [1] show how the slope of the Z' distribution can be determined to an accuracy of 10%.

A comparison has been made of the timing of the electromagnetic shower in the calorimeter, to the lifetime of the generated $\tilde{\chi}_1^0$ (in its rest frame). A Gaussian is fitted to this distribution for different bins of true lifetime, and the resultant mean cluster-time per generated $\tilde{\chi}_1^0$ mean lifetime is extracted[1]. The fit to this plot is used to calibrate the calorimeter time. Using this calibrated calorimeter time, the $\tilde{\chi}_1^0$ lifetime is plotted for each photon. This distribution has the expected exponential shape modified by acceptance and resolution effects. In order to remove these effects, an exponential is fitted between 0.2 and 1 ns. The mean lifetime of the sample was calculated from the slope of the fitted exponential distribution.

Two GMSB samples were simulated with neutralino lifetimes of 3.17ns (GMSB2) and 10.7ns (GMSB3). The measured lifetimes for these samples were 2.9 $\pm$ 0.2ns and 9 $\pm$ 4 ns. Both samples assumed an integrated luminosity of $1fb^{-1}$. The systematic error on the lifetime determination due to uncertainties in the reconstruction efficiency was determined to be 2%. A systematic error of 1(10) ns was obtained for the GMSB2(3) samples due to the choice of fitting region or a global shift in the timing calibration.

SUMMARY

GMSB SUSY is distinguished by the presence of high pt photons in the decay cascade. The ATLAS calorimeters have been designed with good timing and directional resolution suitable for the reconstruction and identification of the unique signature from photons that do not point back to the primary interaction vertex. Techniques are being developed at ATLAS to optimize the detection of non-pointing photons and the extraction of the lifetime of $\tilde{\chi}_1^0$ using timing and directional information from the LAr Calorimeter.

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