

GMSB SUSY MODELS WITH NON POINTING PHOTONS SIGNATURES IN ATLAS AT THE LHC

D. PRIEUR

*Laboratoire d'Annecy-le-vieux de Physique des Particules,
9 chemin de Bellevue, BP 110, 74941 Annecy-le-vieux, France*

The reconstruction of non pointing photons is a key feature for studying gauge mediated supersymmetry breaking (GMSB) models at the LHC. In this article the angular resolution of the ATLAS electromagnetic calorimeter is characterized from a detailed simulation of the detector. Resulting performances are used to reconstruct GMSB events with a fast simulation program, taking into account reconstruction effects. Finally, the sensitivity to extract the particles masses and the lightest neutralino lifetime is estimated.

1 Gauge mediated supersymmetry breaking models and non pointing photons

The origin of the supersymmetry (SUSY) breaking and its mediation to the MSSM sector are key features of SUSY models. In gauge mediated SUSY breaking (GMSB) models¹, the breaking of SUSY takes place in a hidden sector at a high energy scale $\sqrt{F_0}$. Contrary to SUGRA type models, SUSY breaking is not generated at the Planck scale but at a much lower energy scale. This breaking is then transmitted to the MSSM sector through chiral superfields belonging to an intermediate messenger sector at energy scale M_{mess} . The coupling between the messenger and the MSSM sector is made through classical $SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$ gauge interactions. Gravitational interactions are still present but their contributions are small. Since the gravitino \tilde{G} gets its mass only through gravitational interaction, it is the lightest SUSY particle (LSP). We assume here that the R-parity is conserved so that all heavier SUSY particles will produce decay chains leading to the production of gravitinos. The minimal GMSB model is driven by six arbitrary parameters. Depending on these parameters, the next to lightest SUSY particle (NLSP) can either be the lightest neutralino ($\tilde{\chi}_1^0$) or a right handed slepton (\tilde{l}_R). One of the feature of GMSB models is that the NLSP lifetime $c\tau$ may be macroscopic and can vary from micrometers to kilometers. The value of $c\tau$ is linked to m_{NLSP} and to $\sqrt{F_0}$ through the relation²

$$c\tau = \frac{1}{k_\gamma} \left(\frac{100 \text{ GeV}}{m_{NLSP}} \right)^5 \left(\frac{\sqrt{F_0}}{100 \text{ TeV}} \right)^4 \times 10^{-2} \text{ cm} \quad (1)$$

where $k_\gamma \equiv |N_{11}\cos\theta_W + N_{12}\sin\theta_W|$ with θ_W the Weinberg angle and N_{ij} the mixing angles of the neutralinos.

We consider here that the NLSP is the lightest neutralino, so that the dominant decay mode is $\tilde{\chi}_1^0 \rightarrow \gamma\tilde{G}$. If the NLSP has an intermediate lifetime, its decay products will emerge away from the primary vertex: missing energy and non pointing photons will be the signature for such a decay. Measuring the NLSP lifetime provide a way to access $\sqrt{F_0}$, the fundamental

supersymmetric breaking scale. This can be done by reconstructing the decay vertex of the neutralino from the photon direction and its time of arrival.

In the following, the reconstruction of the photon direction using the electromagnetic calorimeter is explained and the polar angular resolution of non pointing photon is characterized from a detailed simulation of the ATLAS detector. Resulting performances are used to reconstruct the specific decay chain $\tilde{l} \rightarrow \tilde{\chi}_1^0 l \rightarrow \tilde{G} l \gamma$ with a fast simulation program, taking into account reconstruction effects, to determine the mass and the lifetime of $\tilde{\chi}_1^0$ and finally the sensitivity to $\sqrt{F_0}$.

2 ATLAS electromagnetic calorimeter

2.1 Description

The ATLAS electromagnetic calorimeter³ is a projective calorimeter with a fine granularity to perform precision measurements of the shower position. It is longitudinally divided into three layers (figure 1). The first layer is longitudinally segmented along η into very thin cells of $\Delta\eta = 0.003125$, leading to a resolution on η position with pointing photons of 0.30×10^{-3} . The second layer has a wider η granularity of $\Delta\eta = 0.025$ and it is designed to contain most of the shower energy. It has a resolution on η position of 0.83×10^{-3} . By combining the measurement of the η position in the first two layers (η_1 and η_2), it is possible to determine the shower direction along η . Having a parametrization of the shower depth³ for each layers ($R_1(\eta_1)$ and $R_2(\eta_2)$), the shower polar direction $\eta_{pointing}$ is reconstructed using the relation:

$$\sinh(\eta_{pointing}) = \frac{R_2(\eta_2)\sinh(\eta_2) - R_1(\eta_1)\sinh(\eta_1)}{R_2(\eta_2) - R_1(\eta_1)} \quad (2)$$

It is important to notice that the coarse granularity of the layers along the ϕ direction do not permit to reconstruct the ϕ direction of non pointing photons using only the electromagnetic calorimeter.

2.2 Polar angular resolution

The angular performances of the electromagnetic calorimeter were studied with a detailed simulation⁴ of the ATLAS detector. Several sets of 60 GeV singles photons were generated at different positions along the beam axis with $|\eta| < 2.5$. The reconstruction of all events was done using ATLAS standard reconstruction software. No electronic noise or pile-up effects were added during the reconstruction. If the contributions of the electronic noise should be small, influence of pile-up on the angular resolution will have to be studied.

The angular resolution achieved using the standard reconstruction with pointing photons is $\sigma_\theta = 60 \text{ mrad}/\sqrt{E(\text{GeV})}$. The results concerning the non pointing photons are shown in figure 2. The performances are worsened as the position of the photon generation vertex increase along the z axis. The deterioration comes from several systematic biases at different levels of the reconstruction algorithms. The S-shape effect is a distortion of the reconstructed η position due to the finite cluster size. The S-shape corrections, that were tuned for pointing photons are no more valid. The 3×3 cells cluster size used is not sufficient to contain all the electromagnetic

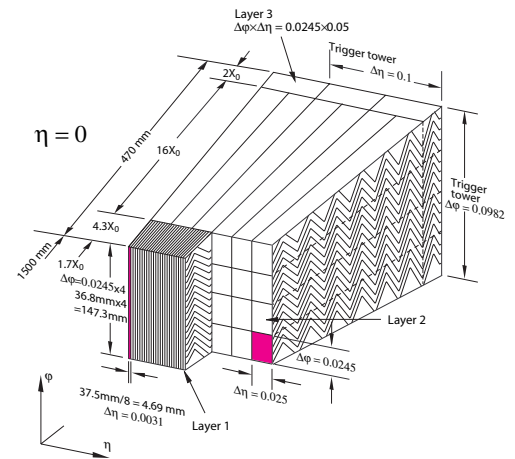


Figure 1: Readout cells granularity of the ATLAS electromagnetic calorimeter.

shower and some energy leakage outside the cluster is possible. Finally, for large deviation from pointing, the shower depth parametrization is no longer valid.

To improve the resolution several changes have been made. The cluster size has been extended to 5×3 cells and S-shape corrections are not applied. An iterative algorithm has been developed to correct for the systematic biases of the reconstructed position in each layer. Results of this correction on the angular resolution is presented on figure 2. The resolution can be improved by 30 to 40% for photons coming from an effective vertex up to 100 cm along the beam axis. This polar angular resolution has been parametrized and is used in the following analysis.

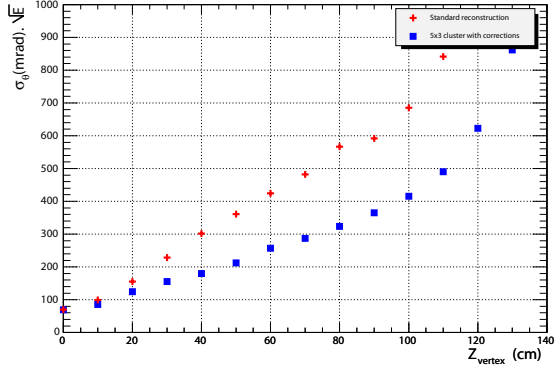


Figure 2: Polar angular resolution σ_θ for $|\eta| < 1.4$ before (red crosses) et after (blue squares) corrections, for non pointing photons generated with different Z_{vertex} position along the beam axis.

3 Study of $\tilde{l} \rightarrow \tilde{\chi}_1^0 l \rightarrow \tilde{G} l \gamma$ decay channel

From this point we consider the specific decay chain $\tilde{l} \rightarrow \tilde{\chi}_1^0 l \rightarrow \tilde{G} l \gamma$ leading to the production of non pointing photons. It is possible to solve the gravitino momentum and the $\tilde{\chi}_1^0$ decay position for this cascade decay⁵ by knowing the energy of the lepton, the energy and the time of arrival of the photon, and by reconstructing the three angles between the lepton, the photon and the gravitino. The analysis takes place at the GMSB point G1 (table 1), with $m_{\tilde{\chi}_1^0} = 117$ GeV, $m_{\tilde{l}_R} = 162$ GeV and we consider a neutralino lifetime $c\tau$ between 10 cm and 2 m. Two sets of 10^5 and 10^6 SUSY events were generated, corresponding to one year of LHC at respectively low and nominal luminosity. Final state particles were passed through the fast simulation of the ATLAS detector and observables were smeared according to realistic resolutions from test-beam data or detailed simulation (table 2).

Point	Λ (TeV)	M_{mess} (TeV)	N_5	$\tan\beta$	$sgn(\mu)$	C_{grav}
G1	90	500	1	5.0	+	-

Table 1: GMSB model parameters at point G1.

Observable	Sub-detector	Resolution
Energy	EM CAL.	$\frac{\delta E}{E} = \frac{10\%}{\sqrt{E}} \oplus \frac{245 \text{ MeV}}{E} \oplus 0.7\%$
Time	EM CAL.	$\sigma_t = 100 \text{ ps}$
Position	EM CAL.	$\sigma_\eta = \frac{0.004}{\sqrt{E(\text{GeV})}}, \sigma_\phi = \frac{5 \text{ mrad}}{\sqrt{E(\text{GeV})}}$
Direction	EM CAL.	σ_θ
	TRT	$\sigma_{\Delta\phi} = 1 \text{ mrad}$

Table 2: Resolution applied to the reconstructed non pointing photons observables.

3.1 Reconstruction of particle masses

In this part we consider a typical lifetime for the NLSP of 100 cm. To reconstruct $m_{\tilde{\chi}_1^0}$ and $m_{\tilde{l}_R}$ we have to fully determine the direction of the photon. Since the electromagnetic calorimeter

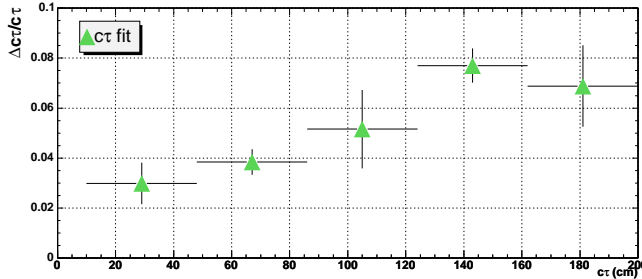


Figure 3: Sensitivity on the measure of the $\tilde{\chi}_1^0$ lifetime $c\tau$.

can only reconstruct the polar direction we require the photon to convert inside the fiducial volume of the inner detector, in order to measure ϕ with the TRT detector.

Standard pre-selection cuts⁶ to limit background contribution from standard model are applied. An effective mass M_{eff} is defined as the sum of the missing transverse energy E_T^{miss} and the transverse momentum of the four hardest jets. Requiring $M_{eff} > 400$ GeV, $E_T^{miss} > 0.1M_{eff}$ and at least two leptons and two photons for each events has an efficiency of 55%. Converted non pointing photons candidates are then selected by imposing $E_\gamma > 30$ GeV, a non pointing angle $\alpha > 0.2$ rad and an arrival time $\Delta t_\gamma > 1$ ns. Finally each selected non pointing photon is paired, if possible, with an isolated lepton with $p_T > 20$ GeV. Lepton/photon pairs are used to solve the decay chain kinematic relations and to determine sparticles masses. At GMSB point G1, for $c\tau_{\tilde{\chi}_1^0} = 100$ cm, the mass resolution is $\sigma_{\tilde{\chi}_1^0} = 1.7$ GeV and $\sigma_{l_R} = 2.1$ GeV for 10^5 generated SUSY events.

3.2 Reconstruction of NLSP lifetime

Once the sparticle masses are known, the entire decay chain can be reconstructed. At this stage we no longer need to know the photon ϕ direction and so can remove the requirement on conversion. The photon ϕ direction and the position of the $\tilde{\chi}_1^0$ decay vertex are extracted by using a minimization procedure. The same cuts as in the previous part are applied, except the cut on the non pointing angle α which becomes a cut on the polar direction θ of the photon.

To study the sensitivity of the reconstructed NLSP lifetime, we make $c\tau_{\tilde{\chi}_1^0}$ vary from 10 cm up to 200 cm. The $\tilde{\chi}_1^0$ lifetime is extracted by fitting an exponential function to the proper time distribution of the $\tilde{\chi}_1^0$ in the laboratory frame. For the studied $c\tau_{\tilde{\chi}_1^0}$ range, the sensitivity $\Delta c\tau/c\tau$ is found to vary from 3 to 8% (figure 3). For $c\tau_{\tilde{\chi}_1^0} = 100$ cm, one can expect to reconstruct the $\tilde{\chi}_1^0$ mass with a 2% precision and a 5% precision on $c\tau_{\tilde{\chi}_1^0}$. The sensitivity on the fundamental SUSY breaking scale $\sqrt{F_0}$ and on the gravitino mass $m_{\tilde{G}}$ are respectively 4% and 8%. Statistical methods to extend the accessible $c\tau$ range are under consideration: they require that systematics errors and detector acceptance are carefully studied with a detailed simulation.

References

1. G.F. Giudice and R. Rattazzi, Phys. Rept. **322**, 419 (1999)
2. S. Ambrosanio *et al*, Phys. Rev. D **54**, 5395 (1996).
3. A. Airapetian *et al*, CERN-LHCC-96-40.
4. A. Artamonov *et al*, ATLAS-SOFT/95-14c.
5. K. Kawagoe *et al*, Phys. Rev. D **69**, 035003 (2004).
6. I. Hinchliffe and F.E. Paige, Phys. Rev. D **60**, 095002 (1999).