SUSY WITH TAUS IN ATLAS
WORK IN PROGRESS

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INTRODUCTION

One of the favoured models for Physics Beyond the Standard Model is Supersymmetry (SUSY). If the Minimal Supersymmetric Extension of the Standard Model (MSSM) is realised in nature, and if the masses of the SUSY particles lie below the TeV scale, sparticles are foreseen to be copiously produced at the LHC, and SUSY signatures should hence be detectable in ATLAS. In some SUSY models, the lightest $\widetilde{\tau}$ is the next-to-lightest SUSY particle, thus taus may provide an important signature [1]. The aim of this project is to exploit these taus in hope of extracting important SUSY model parameters. We study the decay chain

$$\widetilde{q}_L \to q\widetilde{\chi}_2^0 \to q\tau\widetilde{\tau} \to q\tau^{\pm}\tau^{\mp}\widetilde{\chi}_1^0 \quad , \tag{1}$$

and construct invariant mass distributions from the resulting Standard Model (SM) particles. The endpoints of these distributions contain information about the masses of the unknown SUSY particles involved in the decay chain, thus precise measurements of these endpoint could reveal important SUSY model parameters.

THE MSUGRA $\widetilde{\tau}$-COANNIHILATION REGION

The minimal Super Gravity model (mSUGRA) is a constrained version of the MSSM, where assumptions based on a Grand Unified Theory (GUT) significantly decrease the number of SUSY parameters. By assuming a common scalar mass and a common gaugino mass at the GUT-scale, together with a fixed Higgs Vacuum Expectation Value ratio, a common trilinear coupling constant and the sign of the Higgs mass parameter, the parameter space of mSUGRA is defined by 5 parameters (m_0, $m_{1/2}$, $\tan(\beta)$, A_0, $sign\,\mu$).

The starting point of this analysis has been to consider the ATLAS selected SU1 benchmark point, which lies within the so-called $\widetilde{\tau}$-Coannihilation region. This region is characterised by a small mass difference between the two lightest SUSY particles, $\Delta m = m_{\widetilde{\tau}} - m_{\widetilde{\chi}_1^0} = 5 - 15\,\text{GeV}$, to allow a coannihilation process to have taken place between the two sparticles in the early Universe.

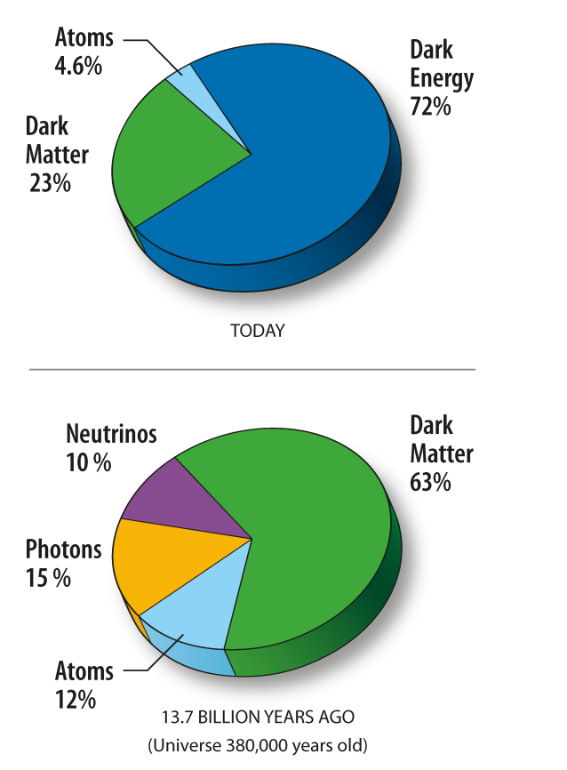
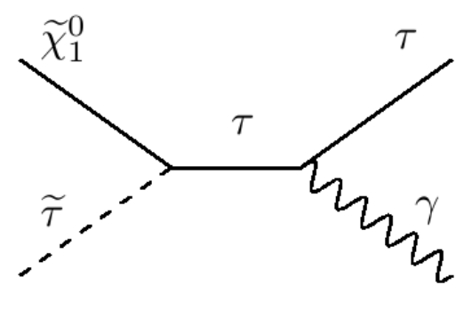


Figure 1: A pie chart of the content of the Universe, both today and 13.7 billion years ago, using five years of WMAP data [2].



If a coannihilation process such as the one sketched above have taken place in the early universe, measurements of the Dark Matter density observed today would agree with a $\widetilde{\chi}_1^0$ SUSY DM candidate.

Table 1. lists the mSUGRA parameters defining the SU1 benchmark point together with the theoretical masses of the SUSY particles important for this study. These masses are obtained with the `IsaJet` [3] SUSY mass generator using Renormalisation Group Equations to obtain the masses at the Electroweak scale.

Parameters	Values	Particle	Mass [GeV]
m_0	70 GeV	$\widetilde{\chi}_2^0$	262.0
$m_{1/2}$	350 GeV	$\widetilde{\chi}_1^0$	136.7
A_0	0 GeV	$\widetilde{\tau}_1$	147.7
$\tan(\beta)$	10	$\widetilde{\tau}_2$	253.2
sgn μ	+	$\widetilde{u}_L, \widetilde{d}_L$	$\sim$ 765.0

Table 1. mSUGRA parameters of SU1 together with some sparticle masses at the EW scale

HOW TO EXTRACT SUSY MASS PARAMETERS

The theoretical relations between the unknown SUSY mass parameters $m_{\widetilde{q}_L}$, $m_{\widetilde{\chi}_2^0}$, $m_{\widetilde{\tau}}$ and $m_{\widetilde{\chi}_1^0}$, and the endpoints of the invariant mass distributions are given in Eq. 2 [4]; .

$$\begin{aligned}
(m_{\tau\tau}^{max})^2 &= \frac{(m^2_{\widetilde{\chi}_2^0} - m^2_{\widetilde{\tau}}) \cdot (m^2_{\widetilde{\tau}} - m^2_{\widetilde{\chi}_1^0})}{m^2_{\widetilde{\tau}}} \\
(m_{q\tau\tau}^{max})^2 &= \frac{(m^2_{\widetilde{q}_L} - m^2_{\widetilde{\chi}_2^0}) \cdot (m^2_{\widetilde{\chi}_2^0} - m^2_{\widetilde{\chi}_1^0})}{m^2_{\widetilde{\chi}_2^0}} \\
(m_{q\tau_{near}}^{max})^2 &= \frac{(m^2_{\widetilde{q}_L} - m^2_{\widetilde{\chi}_2^0}) \cdot (m^2_{\widetilde{\chi}_2^0} - m^2_{\widetilde{\tau}_1})}{m^2_{\widetilde{\chi}_2^0}} \\
(m_{q\tau_{far}}^{max})^2 &= \frac{(m^2_{\widetilde{q}_L} - m^2_{\widetilde{\chi}_2^0}) \cdot (m^2_{\widetilde{\tau}_1} - m^2_{\widetilde{\chi}_1^0})}{m^2_{\widetilde{\chi}_1^0}}
\end{aligned} \tag{2}$$

This means that in principle a precise measurement of all these endpoints would allow the four sparticle masses to be determined. The decay chain Eq.(1) upon which this studied is based, is initialised by a left-handed squark, and in 82 % of the cases this squark is of type $\widetilde{u}_L$, $\widetilde{d}_L$, $\widetilde{s}_L$ or $\widetilde{c}_L$, and these four squarks are almost degenerate in mass. The maximum values of the invariant mass distributions given by the expressions above are listed in the table below:

distribution:	$m_{\tau\tau}^{max}$	$m_{q\tau\tau}^{max}$	$m_{q\tau_N}^{max}$	$m_{q\tau_F}^{max}$
end-points:	78 GeV	612 GeV	280 GeV	590 GeV

INVARIANT MASS DISTRIBUTIONS

This analysis has been performed on fully simulated ATLAS data, where the signal statistics correspond to 18 fb^{-1} of collected data with a collision energy of 14 TeV. We construct the four invariant mass distributions and compare them with the "true" information obtained from the Monte Carlo (MC) data at generator level (GLVL). In Figures 2. and 5.-7. the l.h.s show the distributions using the true tau information, whereas the centered plots show the distributions obtained using only the hadronic tau energy, i.e without the neutrino energy as it will escape detection. The plots on the r.h.s show the information obtained from fully reconstructed data after background selection cuts (discussed in a following section).

The $\tau\tau$ invariant mass distribution has a theoretical endpoint at 80 GeV, which can clearly be seen from the l.h.s plot. This information does not agree very well with what is obtained using the reconstructed data (r.h.s), where the endpoint is located $\sim$ 100 GeV.

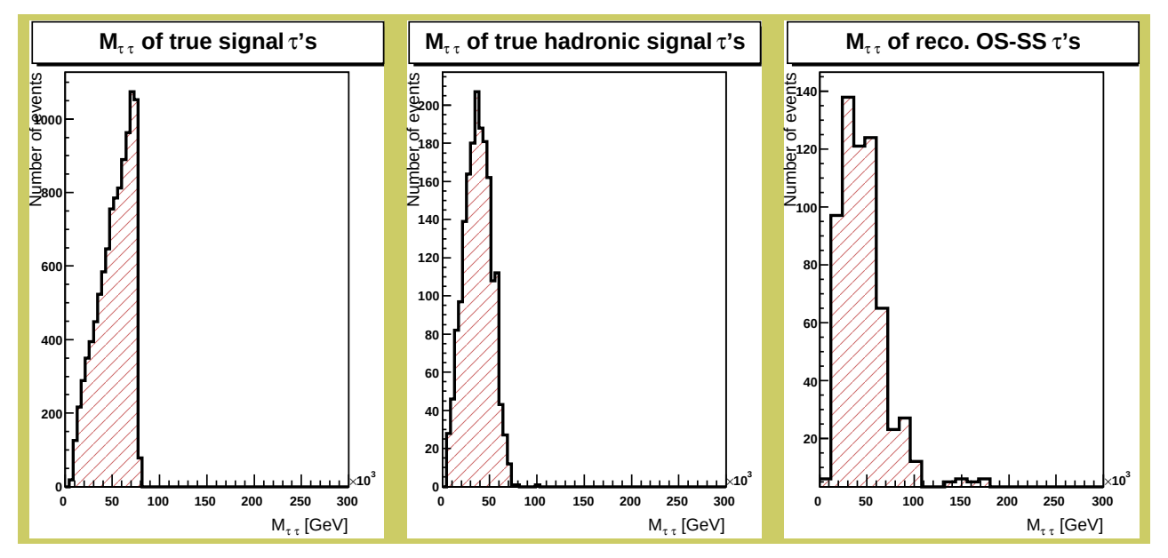


Figure 2. Invariant mass distribution of two taus.

However, the distribution has a very clear maximum value, although shifted to the right by $\sim$ 20 GeV with respect to what is obtained using only the MC data. Thus we investigate if there might be a plausible way to convert the measured value of the endpoint obtained from the reconstructed data to the one we observe from the MC truth information. This is briefly discussed in the next section. Figure 3. indicates the three further invariant mass distributions that can be constructed from the decay chain shown in Eq. (1);

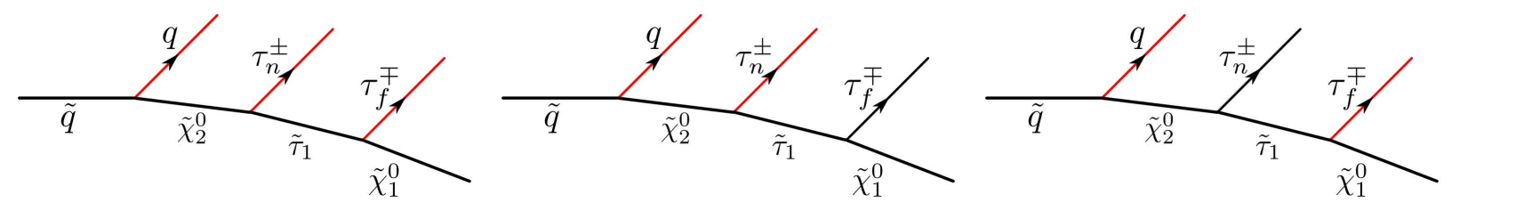


Figure 3. The signal decay chain indicating from which SM particles invariant mass distributions are constructed.

Extracting endpoint information from invariant mass distributions involving a jet is more complicated, since it is not straightforward to select which jet to combine with the taus. Further, this jet is combined with the two taus, τ_N and τ_F, separately. Here τ_N and τ_F denotes which of the taus is *near* and *far* from $\widetilde{\chi}_2^0$ in the decay chain (1) respectively. τ_N is expected to be highly energetic whereas τ_F is expected to be very low energetic, the latter due to the small mass difference between $\widetilde{\tau}$ and $\widetilde{\chi}_1^0$, and they are therefore referred to as τ_H and τ_L at reconstructed level.

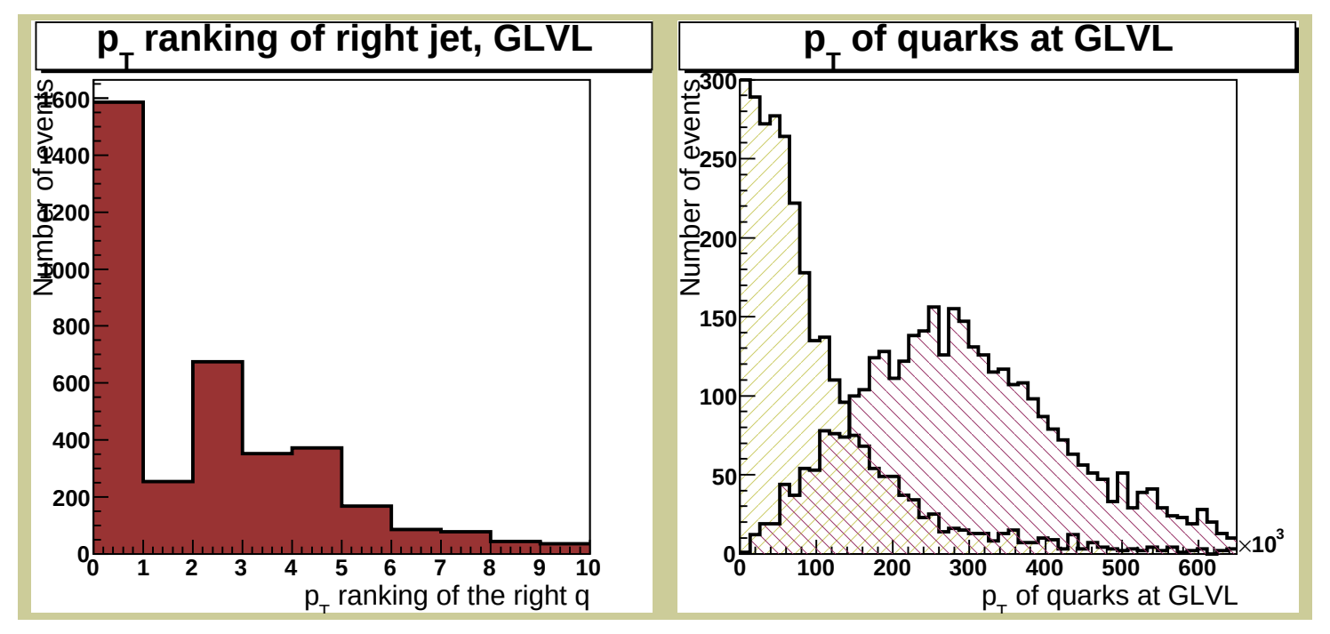


Figure 4. Information from GLVL on how to select the right jet. Right side: The right jet is in pink.

Figure 4. shows GLVL information about the "right" jet versus the most energetic of the remaining jets in the event. The l.h.s shows that choosing the most energetic jet is the likeliest to be the desired jet, whereas the r.h.s indicates that a p_T-cut at 150 GeV should further optimise this choice. Various angular distributions between the three particles have been investigated for improving the selection criteria, but without useful results. The jet has thus been selected strictly from these two cuts. The resulting invariant mass distributions are shown below.

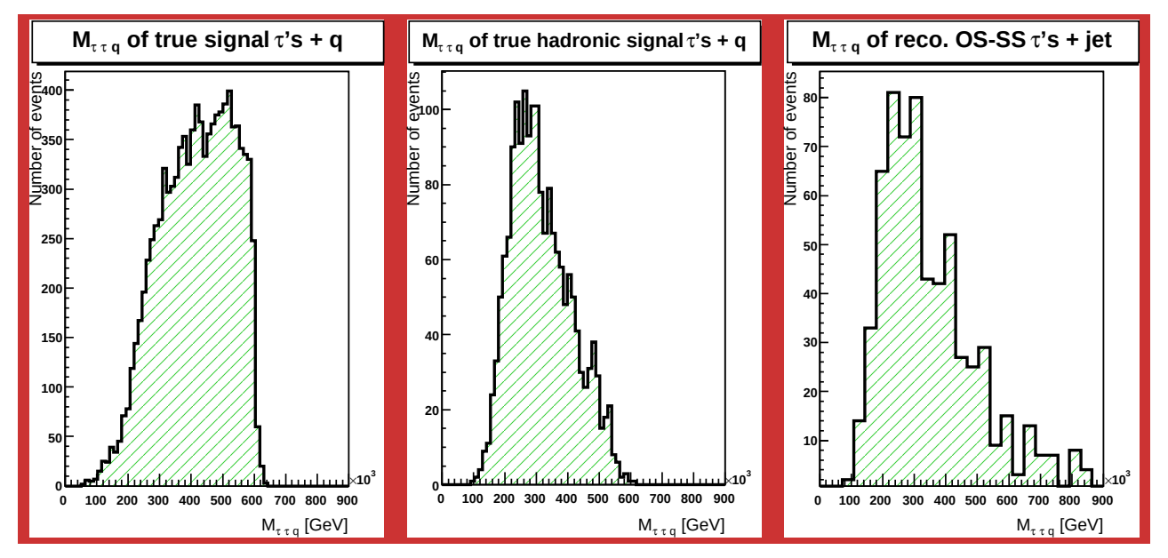


Figure 5. Invariant mass distributions of $\tau\tau q$

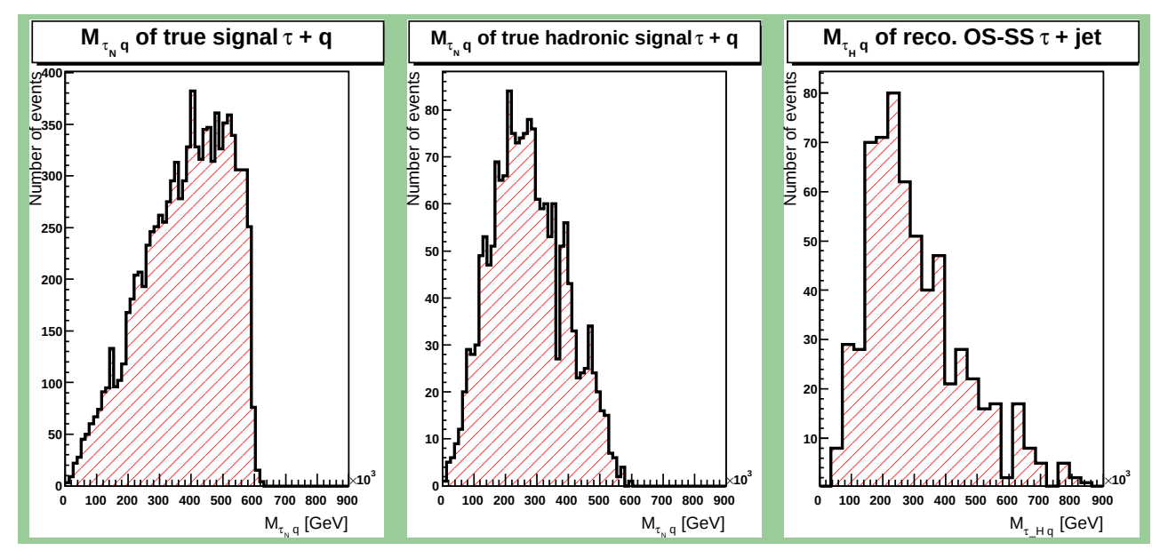


Figure 6. Invariant mass distribution of τ_N (τ_H) and q (jet).

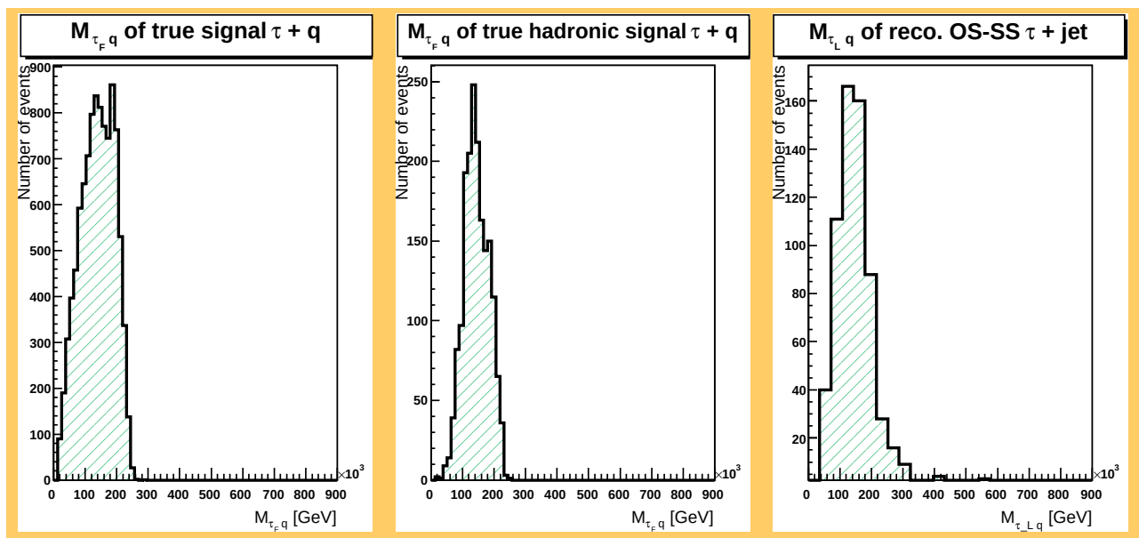


Figure 7. Invariant mass distribution of τ_F (τ_L) and q (jet).

In all cases the endpoints obtained from the reconstructed data are located above one observed at GLVL. A possible method to reveal useful information from these distributions is discussed below.

ENDPOINT MEASUREMENTS

A method developed in [5] has been to use a function that fits the distributions and returns an inflection point (IP) instead of an endpoint. The IP is then converted to a value corresponding to the endpoint obtained from the MC truth data using a calibration curve. The calibration curve is obtained by repeating the procedure for various mSUGRA points. Figure 8 shows such a function together with the calibration curve.

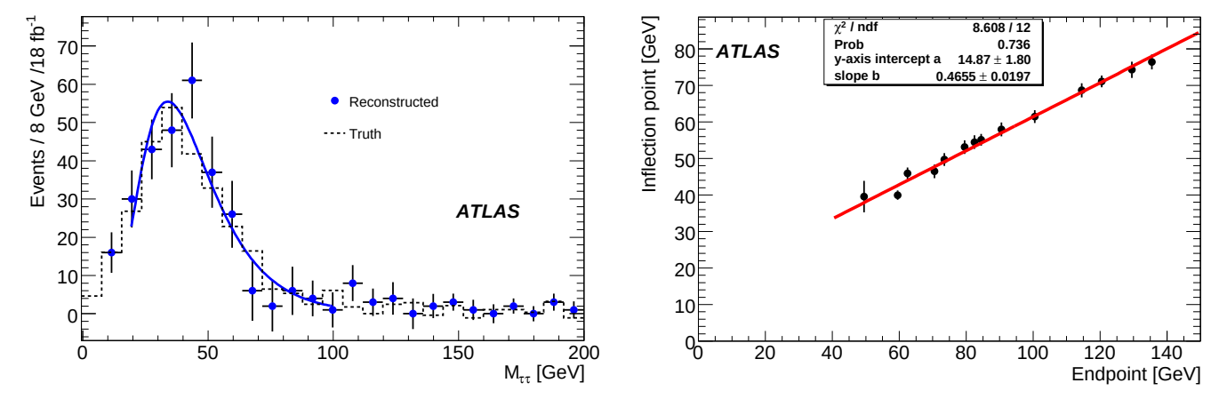


Figure 8. L.h.s. shows a plot with a fit-function returning an inflection point (IP) [1], and the r.h.s shows a calibration curve used to convert the IP to an endpoint [5].

CAN WE SEE THIS SIGNAL?

The remaining question is whether it is possible to observe this signal over the Standard Model background or not. The dominant background for the SUSY signal are events with $t\bar{t}$ production.

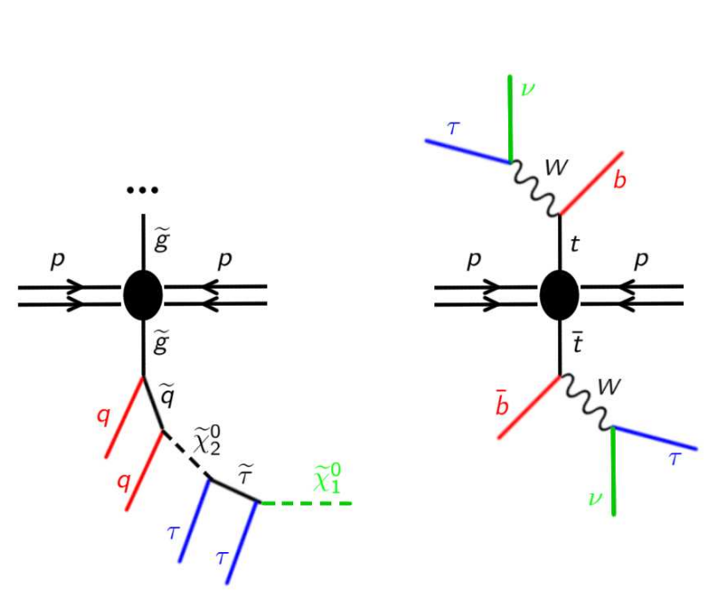


Figure 9. The susy decay chain to the left and and a $t\bar{t}$ process to the right. Similarities are indicated with different colours.

Figure 9. shows the dominant SM background process together with the signal decay chain and illustrates the similarities with different colours. In the $t\bar{t}$ process, each top decay as $t \to W\,b \to \tau\nu b$. Hence both processes give rise to two oppositely charged tau leptons (in blue), at least two high energetic jets (in red), and missing energy (in green).

A very effective method to separate the SUSY signal from SM background processes is to perform an elliptic cut in the plane spanned by E_T^{miss} and the sum of the energy of the two most energetic jets in the event. An example of such a cut is shown in Figure 10. The cut can be optimised by varying the semi minor and semi major axis of the ellipse.

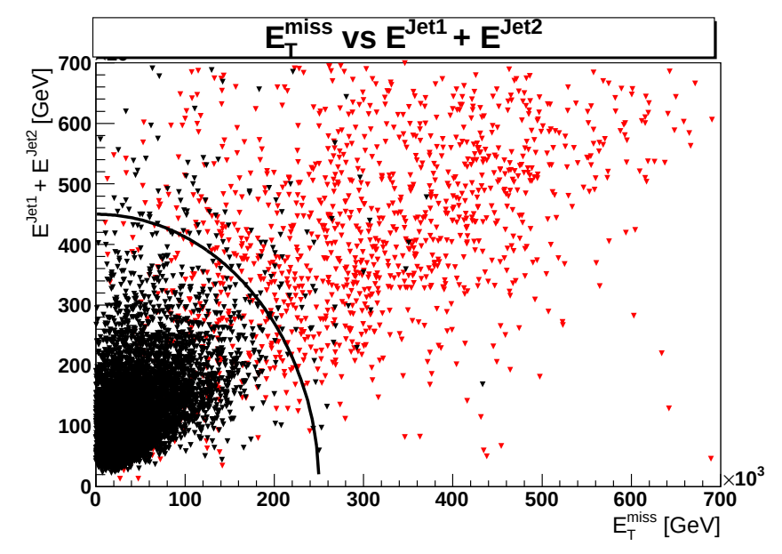


Figure 10: An elliptic cut in the plane spanned by E_T^{miss} and $p_T\,(jet^1 + jet^2)$ has been applied to separate signal (red) from SM background (black)

PLANS

We have studied the ATLAS preselected SU1 point in the $\widetilde{\tau}$-Coannihilation region. The plan is to perform a similar analysis on other point in this region where the branching fraction of $\widetilde{\chi}_2^0 \to \widetilde{\tau}_1\tau$ is significantly enhanced with respect to decay into other slepton-lepton pairs. We have generated `IsaSugra` input files where the parameters m_0, $m_{1/2}$, $\tan(\beta)$ have been varied, and are now simulating `ATLFAST2` samples for 10-15 different points. The collision energy for this study will be 10 TeV.

The fact that tau has hadronic decay products potentially allows measurements of its polarization. Since τ leptons emitted in supersymmetric cascade decades are polarized [6] we plan to study tau polarization effects in ATLAS and, if possible, exploit this information to distinguish the physics process from which tau originate. In this way tau polarization information may serve as a good discrimination factor between SUSY and Standard Model processes.

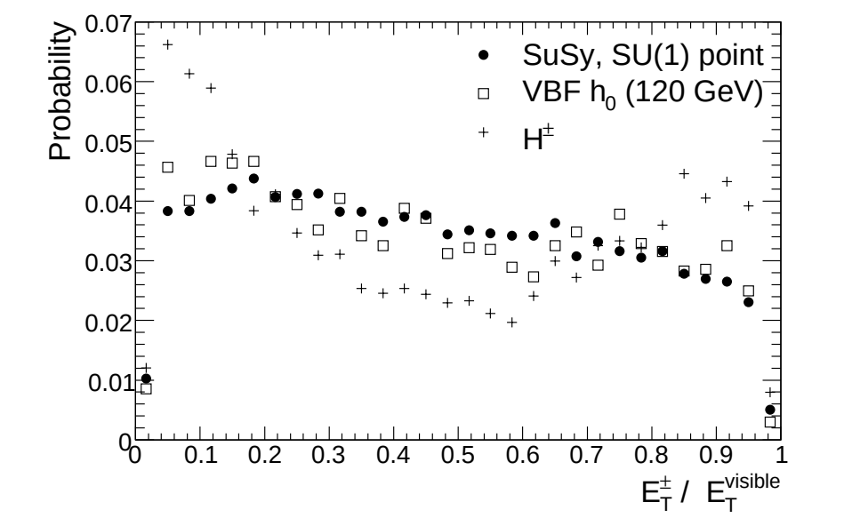


Figure 10. Shows GLVL information on tau polarisation arising form taus from different processes.

References

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[3] F. E. Paige, S. D. Protopopescu, H. Baer, and X. Tata, "ISAJET 7.69: A Monte Carlo event generator for p p, anti-p p, and e+ e- reactions", `hep-ph/0312045`.

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