Light stops at the ILC in view of the latest Higgs results by LHC

Aleksandrina Nikolova

Supervised by: Prof. Gudrid Moortgat-Pick
Stefano Porto

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Abstract

Although the recent discovery of a Higgs-like particle at the LHC did not hint to any new physics, it was a welcomed constraint on the large parameter space for many theoretical models extending the Standard Model of particle physics. This is the case for the Minimal Supersymmetric Standard Model, which we will consider in this paper.

The following report is intended to aid in the work of P. Bechtle *et. al.* in the pMSSM-7 [4]. We look for the possibility of predicting a mass for the lightest supersymmetric Higgs of ≈ 125.5 GeV but also having $\tilde{t}_1$ with mass below 600 GeV that has not been excluded by the direct SUSY searches done at ATLAS and what the prospects are for measuring the stop mass at a linear collider and thus fixing the SUSY parameters.

This paper does **not** consider the possibility of having any of the other (heavier) Higgs being the one discovered at the LHC in 2012. Also not considered are any kind of constraints on the parameter space by either naturalness arguments or cosmological searches for dark matter.

1 Overview and motivation

The Standard Model (SM) of particle physics has succeeded in explaining three of the four known fundamental interactions in Nature - the electromagnetic, weak and strong. It has been tested numerous times at LEP, HERA, Tevatron and (continues to be tested at) LHC and has not made any predictions that have contradicted observations so far. There are, however, several puzzling aspects of our Universe that simply cannot be accounted for by the current picture (dark matter, gravity, baryon asymmetry, $(g-2)$ anomaly of magnetic moments, etc...). One of the most ambitious candidates for a more general theory of our Nature is a supersymmetric (SUSY) extension to the SM.

The Standard Model has 19[1] free parameters and until recently all but one had been measured. The missing piece was the only fundamental scalar particle predicted by SM, namely the Higgs boson, which came out as a prediction by the Higgs mechanism [6]. As successful as this tool may be in explaining how fundamental particles acquire their mass,[2] it makes no prediction whatsoever for the mass of this boson. SUSY, on the other hand, describes a symmetry at a higher level and thus the mass of the Higgs is fixed by the SUSY free parameters. In the Minimal Supersymmetric Model (MSSM) one needs to introduce two scalar Higgs doublets and their two corresponding fermion superpartners. These give five mass eigenstates: two neutral CP-even (h and H), one neutral CP-odd (A) and two charged ones ($H^{\pm}$). One of the two CP-even neutral ones is expected to behave very much like the Higgs boson predicted by the Standard Model. So the question arises: if a SM-like Higgs is observed, is it the only one or one of several predicted by Beyond the Standard Model (BSM) theories such as SUSY.

The MSSM puts a limit of around 135 GeV to the mass a Higgs with properties resembling the SM one can have [5]. With the announcement of a Higgs-like particle at ≈ 126 GeV by the ATLAS [1] and CMS [2] collaborations on July 4th 2012 the last of the SM parameters was fixed while still allowing the possible existence of SUSY. If one is to look for supersymmetry, however, one needs to take this value as one of the strongest constraints for the SUSY parameters.

2 Where to look for SUSY?

Supersymmetry relates bosons and fermions and expects each particle to have a partner obeying different statistics, but otherwise having the same charges and mass. Since such boson-fermion pairs of particles have not been observed, if SUSY is to explain what the Standard Model cannot, it must be a broken symmetry. One way to break it while still keeping the benefits of SUSY (removes the need for fine tuning, gives a dark matter candidate, etc...) is to introduce (sort of) a mass offset (needs to be on the order of TeV) for the sparticles with respect to the particles. This is done by putting by hand mass terms into the Lagrangian. These terms are controlled by parameters, so called soft breaking parameters, and in the MSSM they number 105. It is not practical to let all of them unconstrained and scan the entire 105 dimensional

[1] Not considering part of the neutrino sector.

[2] Only the small but non-zero mass of the neutrinos remains unexplained by now.

parameter space. Many constrained models have been considered, some having more stringent relations between the parameters than others. After the 2012 discovery these have been under tension as they do not have much freedom if they are to explain the observed Higgs mass and it's branching ratios. This is why in this paper we shall not consider any of them, nor do we need to. Most of the parameters play little to no role in the Higgs sector. We will therefore fix them to some values of order TeV and not mention them again.

Using the soft breaking mechanism shifts the masses of all sparticles but leaves their couplings to Higgs identical to those of their Standard Model partners. The top quark, being the heaviest fundamental particle observed so far, couples to the Higgs most strongly. We, therefore, expect the most relevant parameter to be the coupling of it and of it scalar partners, the $\tilde{t}_{1,2}$ to the Higgs. The top quark, being a Dirac spinor, has a left- and a right-handed components. It is these components that have a corresponding superpartner - $\tilde{t}_L$ and $\tilde{t}_R$.[3] If supersymmetry were exact then these would also be the mass eigenstates of the sparticles. Introducing the soft mass terms in the Lagrangian, however, forces us to go into a different basis where the mass eigenstates are a mixture of $\tilde{t}_L$ and $\tilde{t}_R$ given by [4]:

$$\begin{pmatrix} \tilde{t}_1 \\ \tilde{t}_2 \end{pmatrix} = \begin{pmatrix} {M_{\tilde{t}_L}}^2 + m_t^2 + D_t^1 & m_t(A_t^* - \mu \cot\beta) \\ m_t(A_t - \mu^* \cot\beta) & {M_{\tilde{t}_R}}^2 + m_t^2 + D_t^2 \end{pmatrix} \begin{pmatrix} \tilde{t}_L \\ \tilde{t}_R \end{pmatrix} \tag{1}$$

where

$$\begin{aligned} D_t^1 &= \cos 2\beta \left(\frac{1}{2} - \frac{2}{3} s_W^2 \right) M_Z^2 \\ D_t^2 &= \frac{2}{3} \cos 2\beta \; s_W^2 M_Z^2 \end{aligned}$$

In a most general form this can be written as a rotation in 2D space (with $\tilde{t}_L$ and $\tilde{t}_R$ being the basis):

$$\begin{pmatrix} \tilde{t}_1 \\ \tilde{t}_2 \end{pmatrix} = \begin{pmatrix} \cos\theta_{\tilde{t}} & \sin\theta_{\tilde{t}} \\ -\sin\theta_{\tilde{t}} & \cos\theta_{\tilde{t}} \end{pmatrix} \begin{pmatrix} \tilde{t}_L \\ \tilde{t}_R \end{pmatrix}$$

where θ would be the mixing angle. This mixing angle can be measured at a linear collider, since it affects the cross section for $\tilde{t}_i \tilde{t}_j$ production for a given mass of $\tilde{t}$.

The first two generations having such weak coupling to Higgs do not play a key role, so we can safely fix their soft mass parameters to some values of order TeV. For the leptons we choose a value of 300 GeV and for the quarks - 1000 GeV. The first major simplification we will do is to assume one value of the soft mass parameter of the right and left sparticles of the third generation (but still keeping leptons and quarks separate), i.e. $M_{\tilde{\tau}_R} = M_{\tilde{\tau}_L}$ and $M_{\tilde{b}_R} = M_{\tilde{t}_R} = M_{\tilde{b}_L} = M_{\tilde{t}_L}$. The other assumption would be that the soft parameters for all fermion types take on the same value: $A_e = A_\mu = A_\tau = A_u = A_c = A_t = A_d = A_s = A_b$. This way we only need to vary seven parameters (μ, $\tan\beta$, A_t, $M_{\tilde{\tau}_L}$, $M_{\tilde{t}_L}$, M_2 and M_A) while still having a lot of parameter space to explore and have a large range in the mass spectrum of the sparticles.[4] It is worth

[3] These are two separate scalar particles, therefore having no helicity! The left and right are just labels to indicate which particle they correspond to.

[4] M_1 is fixed by M_2 and using the GUT relation: $M_1 \approx 0.5 M_2$.

mentioning that here we are not considering any phases the parameters might in general have, i.e. all parameters were set to real values.

We use `FeynHiggs-2.9.5` [9] to calculate the mass of the Higgs with up to two-loop corrections. The procedure is as follows: at first we scan the parameter space by varying only one parameter at a time (for several values of the other parameters) to see which ones are decisive for the masses of h and $\tilde{t}$. Next we choose a broad range of values to loop over and then narrow down this range by observing which values lead to a mass of the (lightest) Higgs of $\approx$ 126 GeV. Finally we select only a few points consistent with the observed Higgs mass while still predicting mass of $\tilde{t}$ within the expected reach of the linear collider that have still not been excluded by ATLAS or CMS.

3 Scanning the parameter space

3.1 2D scans

Unless indicated otherwise, the values at which the parameters were set to while varying only one of them are as follows:

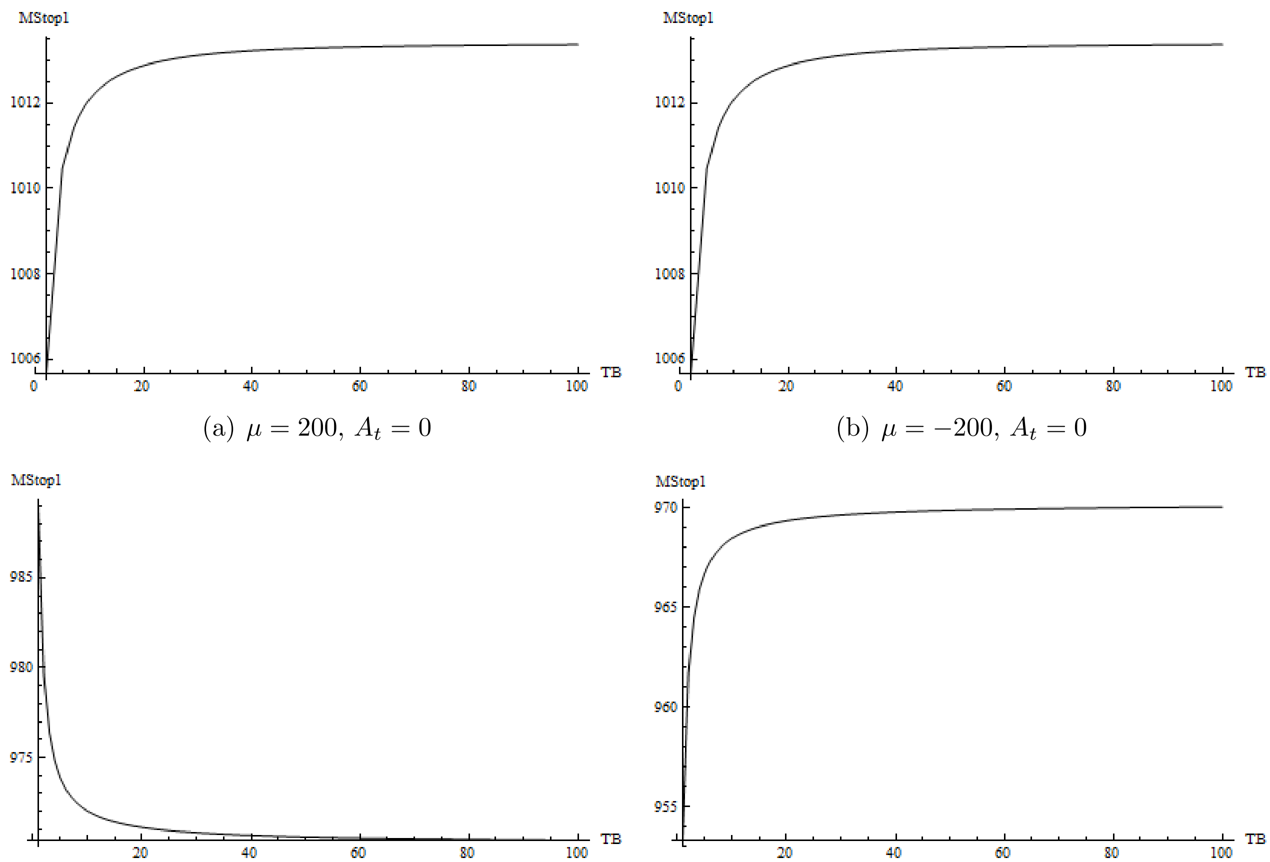
$$\begin{aligned}
\mu &= 200 \text{ GeV} \\
\tan\beta &= 5 \\
A_t &= 2000 \text{ GeV} \\
M_{\tilde{\tau}_L} &= 300 \text{ GeV} \\
M_{\tilde{t}_L} &= 1000 \text{ GeV} \\
M_2 &= 500 \text{ GeV} \\
M_A &= 250 \text{ GeV}
\end{aligned}$$

The result of the scan of the space indeed confirmed that the three most crucial parameters are μ, A_t and $M_{\tilde{t}_L}$. The lattermost parameter is found in the diagonal elements of (1) and accounts for the overall scale at which the masses of the $\tilde{t}$ reside, while the first two parameters can be seen in the off-diagonal elements and thus determine the amount of mixing (the larger the mixing, the further apart are the masses of the two stops).

Further investigation revealed that A_t and μ affect the way the masses of the sparticles depend on the other parameters and in particular on $M_{\tilde{t}_L}$ and $\tan\beta$.

3.1.1 The mass of $\tilde{t}$

- If A_t is 0 all dependencies on μ are symmetric (i.e. it only depends on $|\mu|$), but for any other A_t, flipping the sign of μ, changes the dependency of $M_{\tilde{t}}$ on $\tan\beta$ (Figure 1).



(a) $\mu = 200,\ A_t = 0$

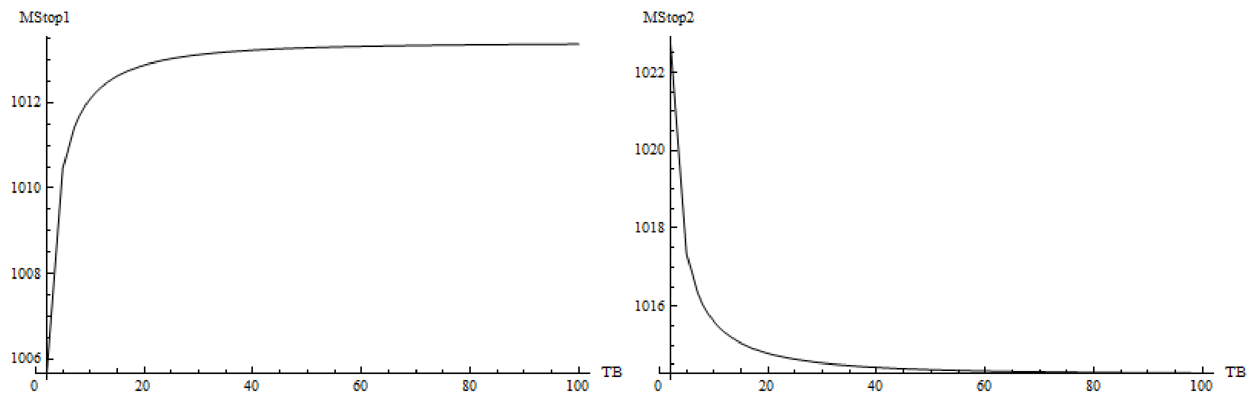
(b) $\mu = -200,\ A_t = 0$

(c) $\mu = 200,\ A_t = 500$

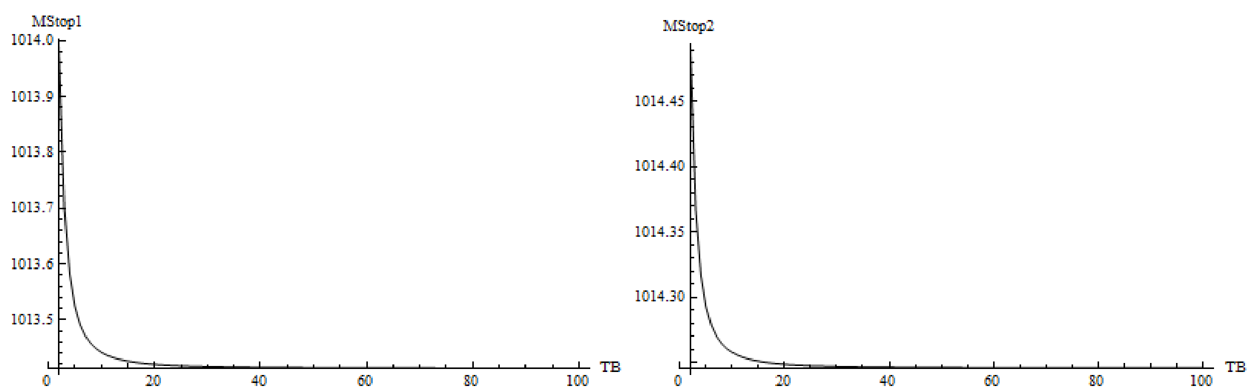
(d) $\mu = -200,\ A_t = 500$

Figure 1: A_t determines whether μ dependency is symmetric or not.

- In the above figure it was not shown that the masses of the two stops go in opposite directions with $\tan\beta$. If $\mu = 0$, however, they follow the same trend regardless of the value of A_t (Figure 2). Note that if $A_t = 0$ and $\mu \neq 0$ both masses **increase** with $\tan\beta$ and if $\mu = 0$ both **decrease** with $\tan\beta$.



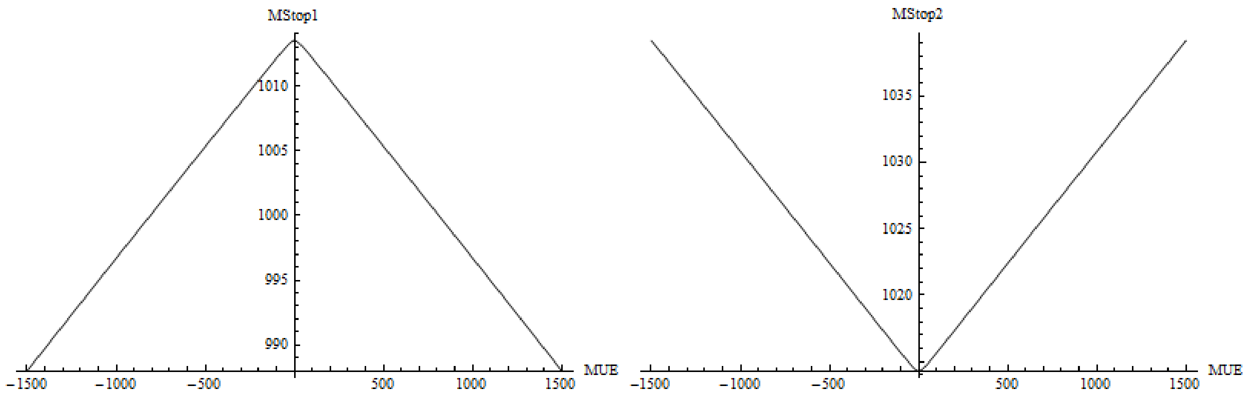
(a) $\mu = 200$



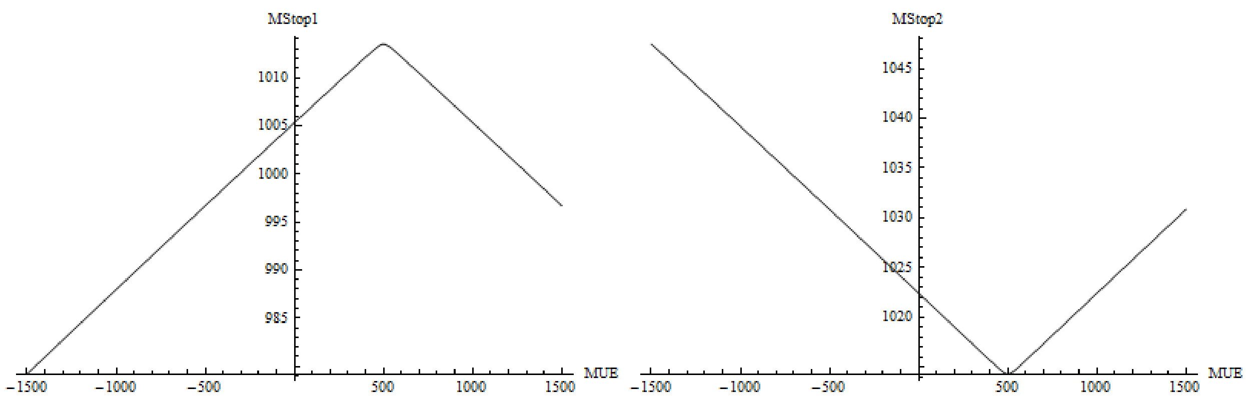
(b) $\mu = 0$

Figure 2: Setting μ to 0 makes both stops decrease with it.

- Going away from $A_t = 0$ also changes the dependency of $M_{\tilde{t}}$ on μ (Figure 3). The shift of the peak in the graphs is because maximum $M_{\tilde{t}_1}$ (and minimum $M_{\tilde{t}_2}$) is expected for no mixing, i.e. $A_t = \mu \cot \beta$.



(a) $A_t = 0$

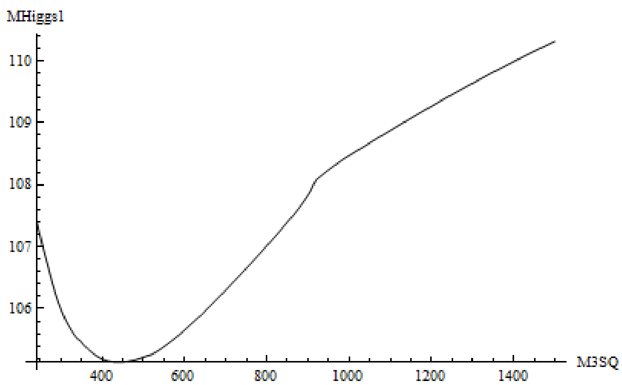


(b) $A_t = 100$

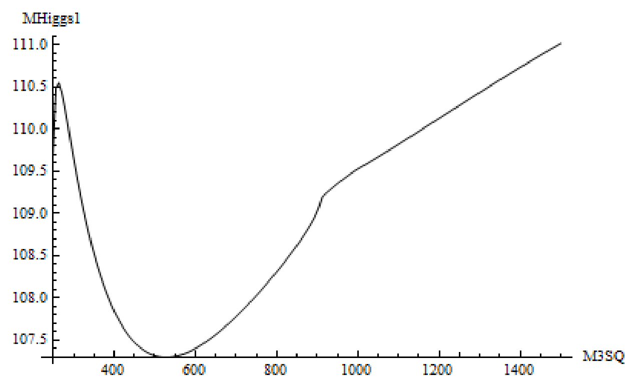
Figure 3: Only if $A_t \neq 0$ the dependencies on μ are skewed.

3.1.2 The mass of h

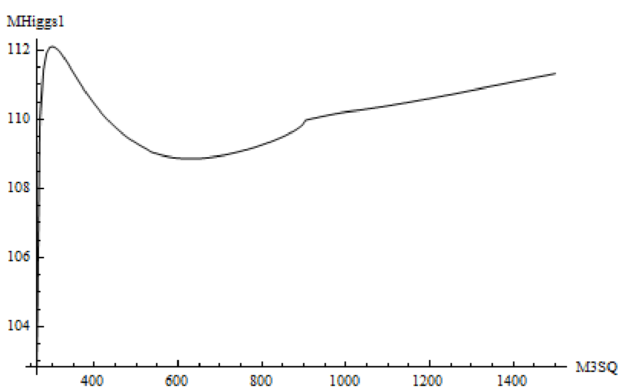
- If A_t is well away from 0, decreasing μ makes M_h rise for the same value of $M_{\tilde{t}_L}$ (Figure 4(a) to 4(c)).
- However, if μ is small enough (large negative value) to keep M_h high, decreasing A_t makes the Higgs mass drop (Figure 4(c) and 4(d)).
- If $A_t = 0$ M_h starts off at a small value and rises steadily (no minimum) with $M_{\tilde{t}_L}$ regardless of μ (Figure 5(a)).



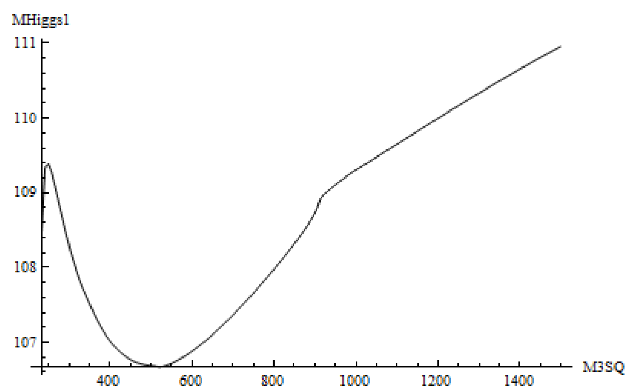
(a) $\mu = 300, A_t = 500$



(b) $\mu = 0, A_t = 500$



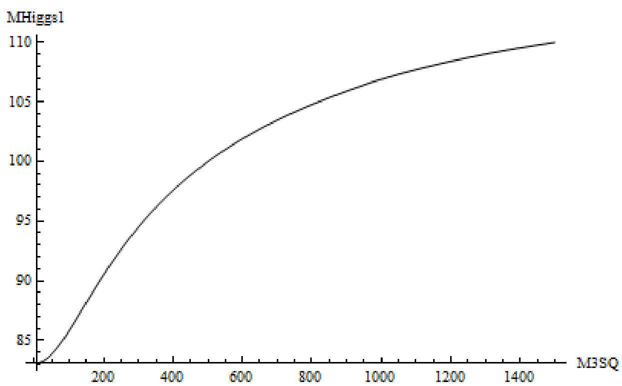
(c) $\mu = -300, A_t = 500$



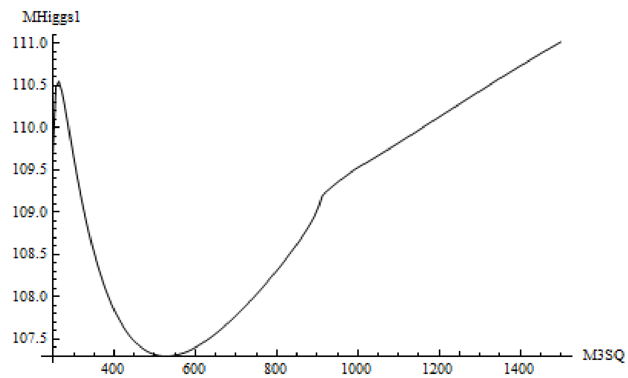
(d) $\mu = -300, A_t = 400$

Figure 4: The amount of mixing determines how M_h depends on $M_{\tilde{t}_L}$.

- But going to very high A_t does not allow one to go to low $M_{\tilde{t}_L}$ without facing the problem of negative Higgs mass, because M_h would fall very rapidly as $M_{\tilde{t}_L}$ decreases (Figure 5, **note the horizontal scale!**). This can be explained by noting that small $M_{\tilde{t}_L}$ leads to light $\tilde{t}_{1,2}$ and large A_t (mixing) leads to $\tilde{t}_1$ very much lighter than $\tilde{t}_2$ and at some point both $M_{\tilde{t}_1}$ and M_h would go negative.

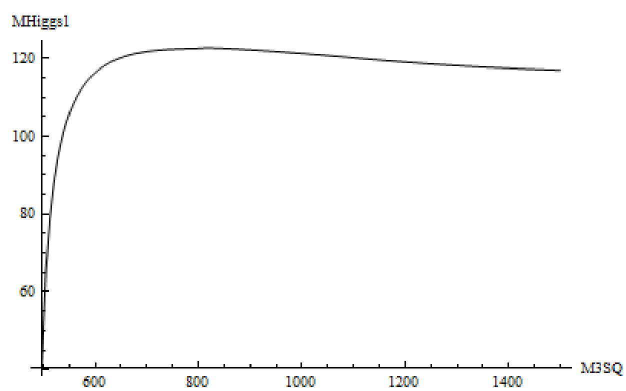


(a) $\mu = 0, A_t = 0$



(b) $\mu = 0, A_t = 500$

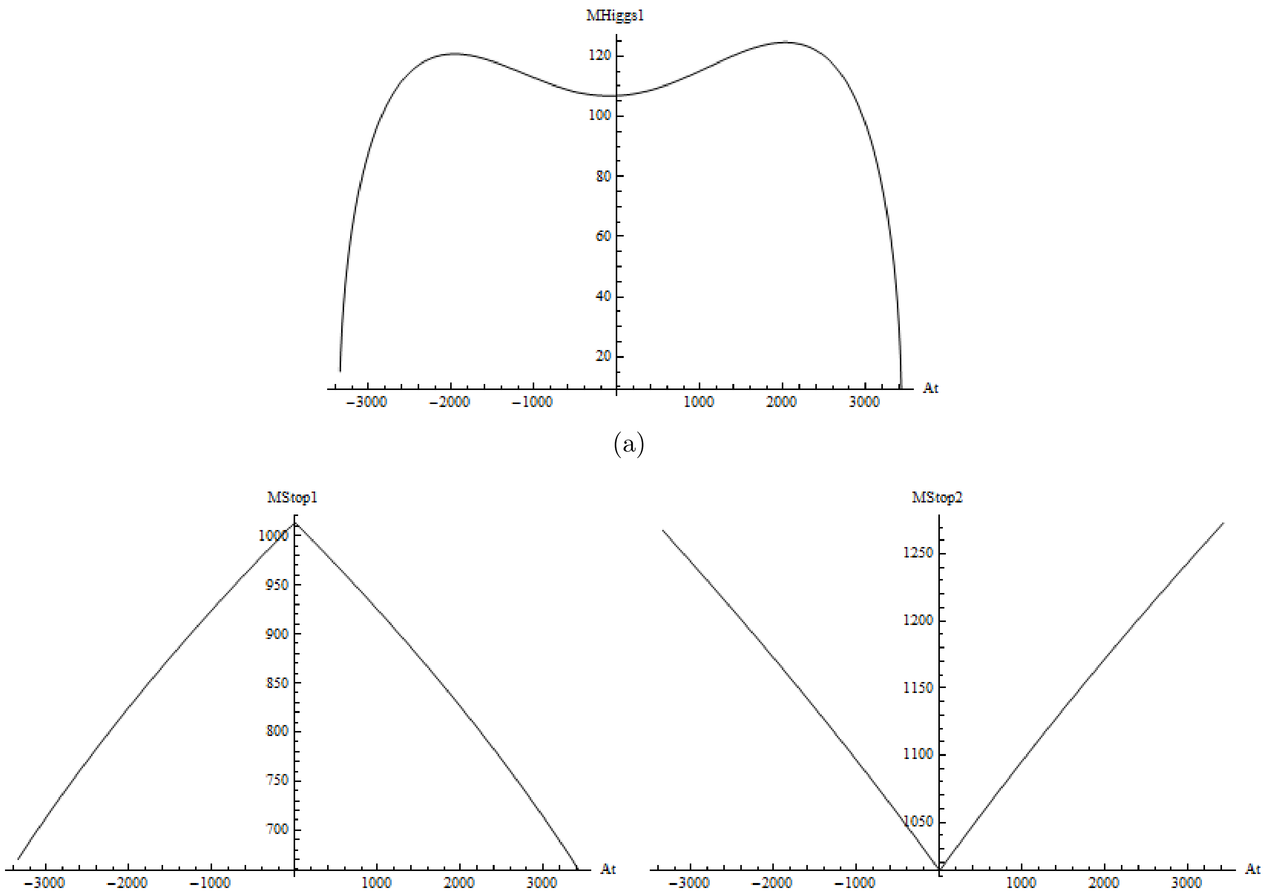
(c) $\mu = 0, A_t = 1000$



(d) $\mu = 0, A_t = 1500$

Figure 5: Very high A_t does not allow for very small $M_{\tilde{t}_L}$.

- Another reason why $|A_t|$ should not be too large is because it would make the mass of the Higgs fall well below its tree level value (which is already lower than the observed value at the LHC!) (Figure 6). Keep in mind the dependency on A_t is not affected by μ at all.



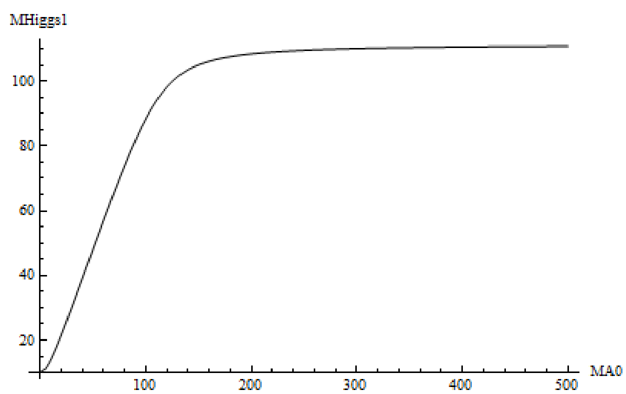
(a)

(b)

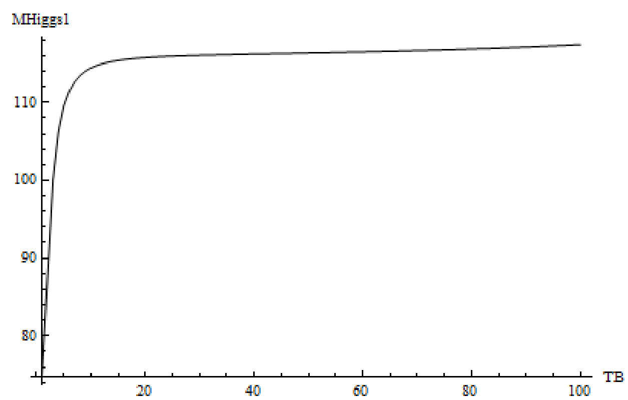
(c)

Figure 6: A_t should not be much above 2000 GeV.

- As a final remark we show how the mass of the lightest Higgs depends on $\tan\beta$ and M_A (the mass of the CP-odd Higgs, which needs to be put in by hand) (Figure 7).[5] These dependencies are not affected by the other parameters.



(a)



(b)

Figure 7: Sharp rise for small values of M_A and $\tan\beta$.

3.1.3 Summary

Out goal is to maximize M_h for minimal $M_{\tilde{t}_1}$. Therefore:

- We want $M_{\tilde{t}_1}$ to decrease with $\tan\beta$, because M_h increases with it $\Rightarrow$ either $A_t \neq 0$ and $\mu > 0$ OR $\mu = 0$.
- We want to be far away from the maximum of $M_{\tilde{t}_1}$ vs $\mu \Rightarrow$ either A_t is large and $\mu \leq 0$ OR $A_t = 0$ and $|\mu|$ is large.
- We want large M_h and small $M_{\tilde{t}_L} \Rightarrow 1000 > A_t > 500$ and $\mu < 0$.
- M_A and $\tan\beta$ should be large, but there is no need to go above $M_A = 250$ GeV and $\tan\beta = 10$.

We therefore expect our favoured region to be:

$$0 \leq |\mu| \leq 500, \quad \tan\beta \approx 10, \quad 0 < |A_t| \leq 500, \quad 100 < M_{\tilde{t}_L} < 800, \quad M_A \approx 250$$

[5]The dependency on $M_{\tilde{\tau}_L}$ and M_2 was negligible.

3.2 Multi-D scans

3.2.1 Determining bounds on the parameters

Taking into account the cut-off values above which M_h and $M_{\tilde{t}}$ hardly depend on the input, the first loop over all seven parameters was performed in the following range:

Parameter	Range			Number of points
μ	-3000	;	3000	3
$\tan\beta$	1	;	60	2
A_t	$-3 \times M_{\tilde{t}_L}$	;	$3 \times M_{\tilde{t}_L}$	7
$M_{\tilde{\tau}_L}$	200	;	1500	2
$M_{\tilde{t}_L}$	200	;	1500	50
M_2	200	;	500	2
M_A	90	;	1000	10
Total number of points:				84000
Number of points with no error:				38524
Number of points with $M_h \in [123.5; 127.5]$ GeV:				1617

If we also impose the condition that $M_{\tilde{t}_1} < 600$ GeV we only get 573 points located the following range:

$$\mu = 0, \quad \tan\beta = 60, \quad -1520 < A_t < 1250, \quad 380 < M_{\tilde{t}_L} < 800$$

If we want an even lighter $\tilde{t}_1$ (< 300 GeV) we have 103 points in:

$$\mu = 0, \quad \tan\beta = 60, \quad 770 < A_t < 930, \quad 380 < M_{\tilde{t}_L} < 480$$

From this we can deduce that we don't need to go to such high $|\mu|$. To increase the resolution in each parameter we are going to decrease the range as well as we are going to keep $M_{\tilde{\tau}_L}$ fixed at 300 GeV and M_A fixed at 250 GeV, since these play very little role in what we are interested here.[6]

[6] We will, however, let M_2 vary as it affects the masses of χ^0 and $\chi^\pm$.

The second run was done with the following bounds:

Parameter	Range			Number of points
μ	-1500	;	1500	15
$\tan\beta$	1	;	20	3
A_t	$-3 \times M_{\tilde{t}_L}$	;	$3 \times M_{\tilde{t}_L}$	15
$M_{\tilde{\tau}_L}$	100	;	1500	3
$M_{\tilde{t}_L}$	0	;	1500	20
M_2	0	;	500	3
M_A	0	;	500	3

Total number of points:	364500
Number of points with no error:	184198
Number of points with $M_h \in [123.5; 127.5]$ GeV:	16541

There are 2380 points where $M_{\tilde{t}_1} < 600$ GeV (consistent with the desired Higgs mass) in the range:

$$-1500 \leq \mu \leq 1500, \quad 1 \leq \tan\beta \leq 20, \quad -1700 < A_t < 2030, \quad 230 < M_{\tilde{t}_L} < 790$$

and 149 points with $M_{\tilde{t}_1} < 300$ GeV:

$$-650 \leq \mu \leq 1500, \quad 1 \leq \tan\beta \leq 20, \quad 0 < A_t < 1020, \quad 230 < M_{\tilde{t}_L} < 480$$

thus confirming our conclusions from Section 3.1.3 that for light $\tilde{t}_1$ we need relatively small A_t and $M_{\tilde{t}_L}$. Also we expect that $\mu < 0$ would result in lighter $\tilde{t}_1$ for the same Higgs mass.

Therefore, the final run scanned the part of the parameter space defined by:

Parameter	Range	Number of points
μ	-650 ; 650	27
$\tan\beta$	5 ; 35	4
A_t	-1200 ; 1200	25
$M_{\tilde{t}_L}$	100 ; 1200	23
M_2	0 ; 500	3
Total number of points:		186300
Number of points with no error:		148585
Number of points with $M_h \in [123.5; 127.5]$ GeV:		6956

From the 6956 points consistent with h at ≈ 125.5 GeV 4041 of them have $M_{\tilde{t}_1} < 600$ GeV:

$$-650 \leq \mu \leq 650, \quad 15 \leq \tan\beta \leq 35, \quad -1200 \leq A_t \leq 1200, \quad 400 \leq M_{\tilde{t}_L} \leq 700$$

and 419 of them with $M_{\tilde{t}_1} < 300$ GeV:

$$-600 \leq \mu \leq 650, \quad 15 \leq \tan\beta \leq 35, \quad 800 \leq A_t \leq 1200, \quad 400 \leq M_{\tilde{t}_L} \leq 500$$

Like the previous run, this one shows the slight assymetry in A_t seen in Figure 6 - light stops favour $A_t > 0$

3.2.2 Large or small mixing?

To characterize the strength of the mixing between $\tilde{t}_L$ and $\tilde{t}_R$ we can use the mixing angle (or the cosine of it), but we can also look at $^{X_t}/_{M_{\tilde{t}_L}}$, where $X_t = A_t - \mu \cot \beta$ is the off-diagonal element in the $\tilde{t}$ mixing matrix. The relation between X_t and $\cos \theta_{\tilde{t}}$ is given by [7]:

$$\cos \theta_{\tilde{t}} = \frac{-m_t X_t}{\sqrt{(M_{\tilde{t}_L}^2 - m_{\tilde{t}_1}^2)^2 + m_t^2 X_t^2}}$$

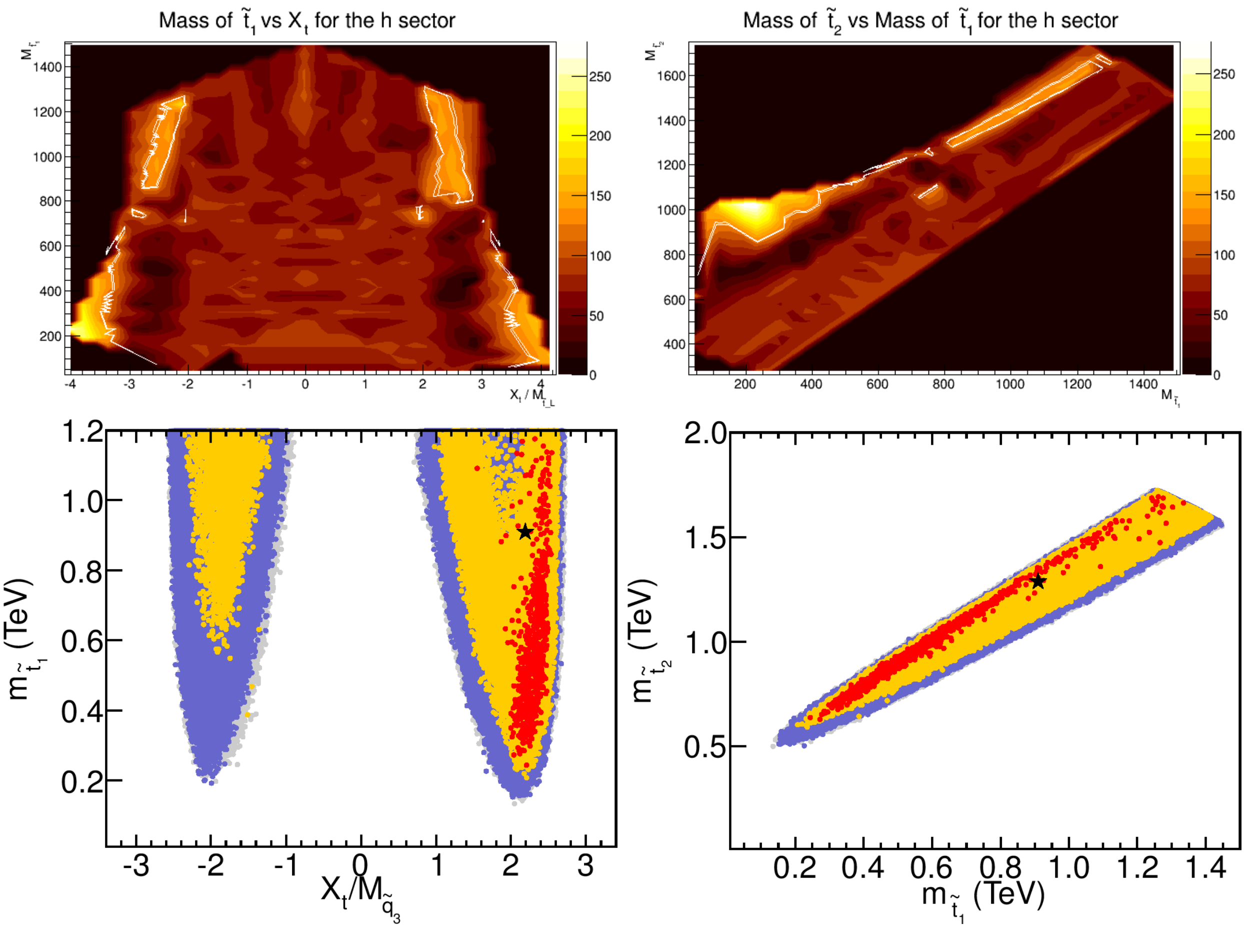


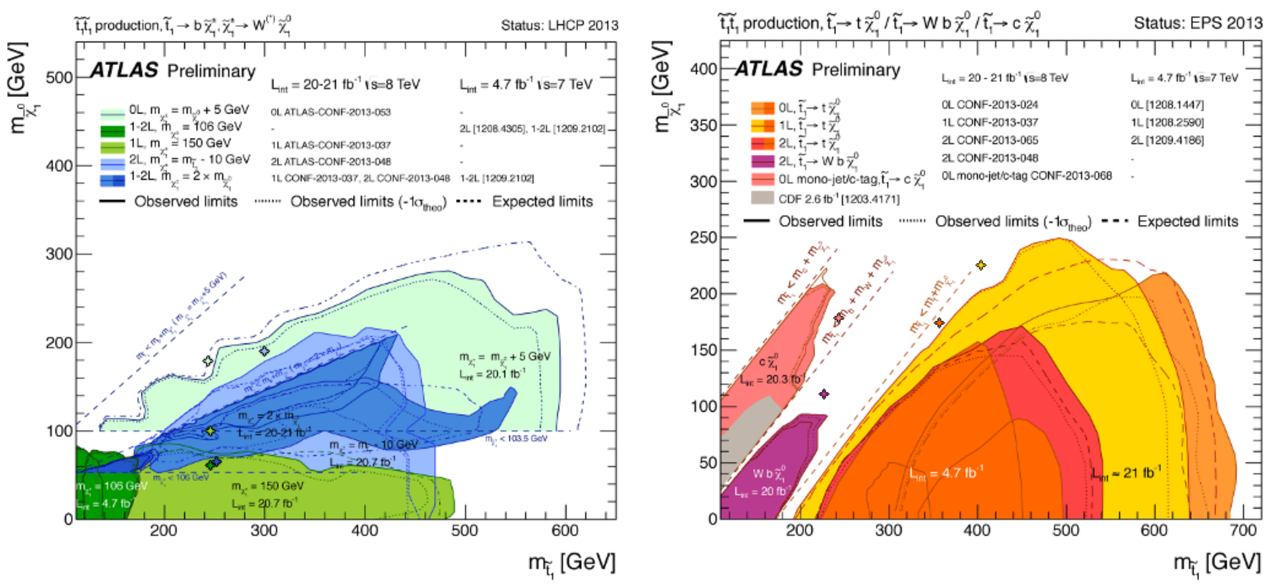
Figure 8: The data from the first scan plotted as a density plot in the mass of the h (top) vs same quantities but as a density plot in probability coming from a χ^2 fit [4] (bottom).

Figure 10 confirms our expectations as well as the results in [4][7] that large mixing is needed for $M_h \approx 125.5$ GeV. The colour-coding indicated on the legend corresponds to the mass of the lightest Higgs, h. The white contour lines show where $M_h = 123.5$ and 127.5 GeV. The favoured regions are small and are all located at large mixing angles. This means that we can get a light $M_{\tilde{t}_1}$ at the expense of having a much heavier $M_{\tilde{t}_2}$ (Figure **??**).

[7]Note that the plots there show a probability density coming from a χ^2 fit that includes not only the calculated vs measured mass of Higgs, but many other observables such as cross sections and branching ratios.

4 Comparison with ATLAS data

Figure 9 shows the latest exclusion plots from ATLAS [3] in the search for direct $\tilde{t}_i\tilde{t}_j$ production in several channels. The assumptions made for each channel are indicated. Furthermore it should be noted that each channel has been considered separately with 100% branching ratio. For each channel we selected a few data points that pass the criteria (assumptions) for the masses of $\tilde{t}$, χ^0 and $\chi^{\pm}$ and are outside the excluded regions while still having accessible $\tilde{t}_1$ masses. These points are shown superimposed on the ATLAS plots in the corresponding colour.



(a) $\tilde{t} \to b\chi^{\pm}$

(b) $\tilde{t} \to t\chi^0$, $\tilde{t} \to Wb\chi^0$, $\tilde{t} \to c\chi^0$

Figure 9: ATLAS exclustion plots for direct $\tilde{t}_i\tilde{t}_j$ production [3] and our selected regions superimposed in the corresponding colours.

Parameter values for each nine points are shown below:

μ	$\tan\beta$	A_t	$M_{\tilde{t}_L}$	M_2	$M_{\tilde{t}_1}$	M_{χ^0}	$M_{\chi^\pm}$	M_h
$\tilde{t} \to b\chi^\pm$:								
-200	35	1000	450	500	237.4	177.8	195	123.6
200	20	915	431.6	136.4	239.9	60.1	109	123.8
200	20	915	431.6	227.3	239.9	99.4	159.2	123.5
-300	20	962.5	478.9	409.1	296.9	189.4	282.8	124.3
-350	20	867.5	431.6	136.4	247	64.7	130.7	123.8
$\tilde{t} \to t\chi^0$:								
200	15	1200	550	500	353.7	174	192.2	124.9
300	15	1000	550	500	401	224.2	286.6	123.6
$\tilde{t} \to Wb\chi^0$:								
-200	35	800	400	250	220.1	111.4	171.9	123.7
$\tilde{t} \to c\chi^0$:								
-200	35	1000	450	500	237.4	177.8	195	123.6

Note:

- For all points: decay to $c\chi^0$ and $b\chi^\pm$ channel is also open.
- For all but point 1 in the $b\chi^\pm$ channel: decay to $Wb\chi^0$ channel is also open.

5 Prospects and to do

The International Linear Collider (ILC) is expected to run at $\sqrt{s} = 350 - 1000$ GeV, which means that if any of the above scenarios are correct, the lighter stop can be discovered at the linear collider. Whether and how quickly this happens depends on the cross section for $e^+e^- \to \tilde{t}_1\tilde{t}_1$ for a particular mass of the stop, center of mass energy and **polarization of the beams**. Below we list the expected cross sections for the nine points (removing two of them, since for these $M_{\tilde{t}_1}$ and hence all other quantities below are duplicates). The cross sections are listed for polarizations of $P_{e^-} = \pm 90\%$ and $P_{e^-} = \pm 60\%$. σ_{+-} stands for left e^- and right e^+ beam polarizations. Values for the cross sections do **not** include radiative correction or errors.[8] We've also listed the predicted left-right asymmetry A_{LR} (note that it is quite large):

$M_{\tilde{t}_1}$ / GeV	$\sqrt{s}$ / GeV	$\cos\theta_{\tilde{t}}$	σ_{+-} / fb	σ_{-+} / fb	A_{LR}
237	500	-0.766	9.08	3.30	-0.467
237	600	-0.766	44.9	16.5	-0.463
240	600	-0.772	41.3	16.0	-0.442
296	1000	-0.767	36.7	13.5	-0.462
246	600	-0.774	36.6	13.4	-0.464
354	1000	-0.757	24.3	9.39	-0.443
401	1000	-0.767	15.0	5.48	-0.465
220	500	-0.781	29.4	11.6	-0.434
220	600	-0.781	59.7	23.7	-0.432

In all these scenarios the predicted cross sections are high enough to reveal any peak at the mass of $\tilde{t}_1$. The left-right asymmetry is a function of the mixing angle and thus using polarised beams one can also measure $\cos\theta_{\tilde{t}}$. Then with the corrected cross section one can construct a contour plot from its error bands in the $\cos\theta_{\tilde{t}} - A_{LR}$ plane as has been done in the past (Figure **??**). From there, the uncertainty on $M_{\tilde{t}_1}$ can be determined and this will propagate into an uncertainty on the SUSY parameter regions consistent with the observed mass of the stop and mixing angle. Note that other uncertainties also affect the accuracy of the measured mass such as the actual uncertainty on the $\tilde{t}$'s decay products, the theoretical uncertainty due to only correcting for a finite number of loops, uncertainty on the beams polarizations and the statistical uncertainty. The lattermost is given by:

$$\sigma^2_{stat} = \sigma \times L$$

where σ is the cross section (in fb) for the polarizations in question and L is the integrated luminosity (in fb^{-1}).

[8]These are expected to be raise the cross section.

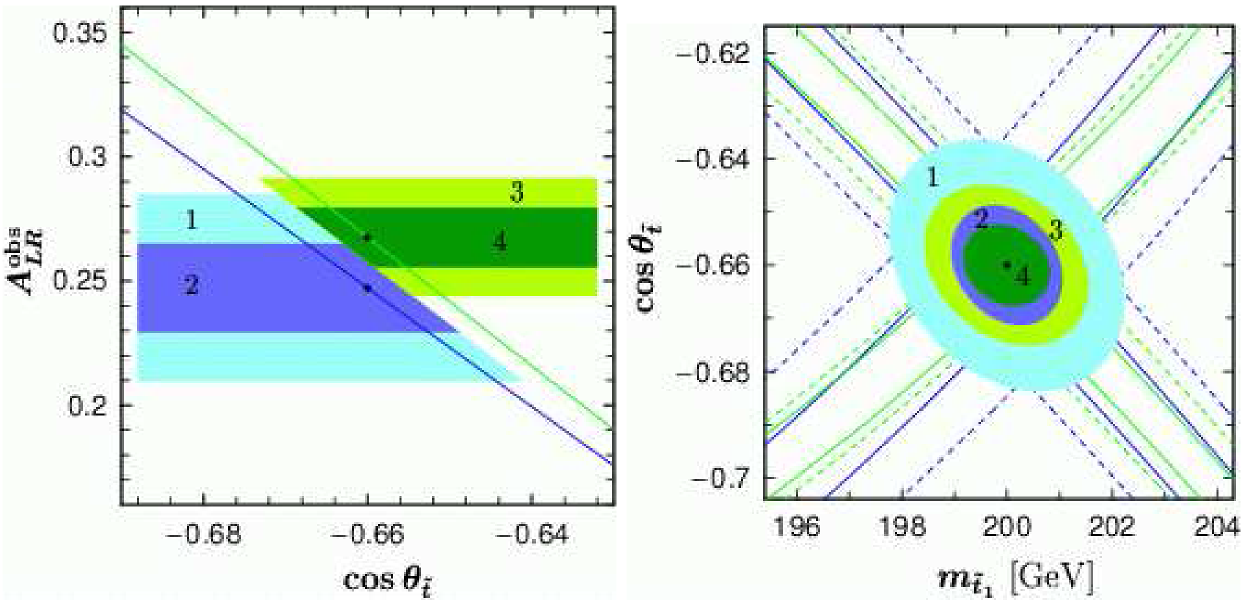


Figure 10: Contour plots for the cross section error bands determine the accuracy with which the mass and the mixing angle can be measured [8].

This error is listed below for 100 and 500 fb^{-1}:

L / fb^{-1}	σ_{+-} / fb	σ_{-+} / fb	$\sigma_{+,stat}$	$\sigma_{-+,stat}$
100	9.08	3.30	30.1	18.2
500	9.08	3.30	67.4	40.6
100	44.9	16.5	67.0	40.6
500	44.9	16.5	150	90.8
100	41.3	16.0	64.3	40.0
500	41.3	16.0	144	89.4
100	36.7	13.5	60.6	36.7
500	36.7	13.5	135	82.2
100	36.6	13.4	60.5	36.6
500	36.6	13.4	135	81.9
100	24.3	9.39	49.3	30.6
500	24.3	9.39	110	68.5
100	15.0	5.48	38.7	23.4
500	15.0	5.48	86.6	52.3
100	29.4	11.6	54.2	34.1
500	29.4	11.6	121	76.2
100	59.7	23.7	77.3	48.7
500	59.7	23.7	173	109

6 Summary

We used `FeynHiggs-2.9.5` to calculate the mass of the lightest MSSM Higgs up to two-loop corrections and the mass of the lighter $\tilde{t}$ at tree level. We varied 7 parameters separately to set loose bounds on them and used these to scan a 7-dimensional region in the SUSY parameter space. From this data we selected nine "candidates" with $M_{\tilde{t}_1} \in [237; 401]$ GeV all having $M_h = (125.5 \pm 2)$ GeV and all being outside of any excluded by up to this date regions (using the ATLAS data for direct stop pair production [3]).

All of the favoured scenarios predicted good cross sections for $e^+e^- \to \tilde{t}_1\tilde{t}_1$ at the ILC with $\sqrt{s} = 500 - 1000$ GeV and the left-right asymmetry from using different beam polarisations can be used to determine the mixing angle between $\tilde{t}_L$ and $\tilde{t}_R$ and thus determine to relatively good precision the mass parameters for the stop quark.

For all nine selected points one needs to check whether the LSP predicted has the properties required by dark matter searches or it can be discarded as a dark matter candidate.

We have also not considered the possibility of having a weakly interacting MSSM Higgs lighter than 125.5 GeV with the second lightest being the one observed at the LHC.

References

[1] ATLAS Collaboration: *Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC* [arXiv:1207.7214]

[2] CMS Collaboration: *Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC* [arXiv:1207.7235]

[3] ATLAS Public: *Combined Summary Plots: Direct $\tilde{t}$ pair production*

[4] P. Bechtle, S. Heinemeyer, O. Stål, T. Stefaniak, G. Weiglein, L. Zeune: *MSSM Interpretations of the LHC Discovery: Light or Heavy Higgs?* [arXiv:1211.1955]

[5] G. Degrassi, S. Heinemeyer, W. Hollik, P. Slavich, G. Weiglein: *Towards High-Precision Predictions for the MSSM Higgs Sector* [arXiv:hep-ph/0212020]

[6] F. Englert and R. Brout: *Broken Symmetry and the Mass of Gauge Vector Mesons* [Phys. Rev. Lett. **13** (1964) 321]

[7] A. Bartl, H. Eberl, S. Kraml, W. Majerotto, W. Porod: *Phenomenology of stops, sbottoms, tau-sneutrinos, and staus at an e^+e^- Linear Collider* [arXiv:hep-ph/0002115]

[8] G. Moortgat-Pick, T. Abe, G. Alexander, *et. al.: The role of polarized positrons and electrons in revealing fundamental interactions at the Linear Collider* [arXiv:hep-ph/0507011]

[9] FeynHiggs: [arXiv:hep-ph/9812320]