Astrophysical and accelerator constraints on SUSY

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Overview

Master thesis goals

To study the expected detection and exclusion potential of CTA, and to compare this with the current and expected reach of the LHC for specific dark matter models.

This requires experience in using, adapting and writing code packages such as ISAJET, DarkSusy, and others.

An effort of this kind is inherently collaborative; a working relationship with writers of the code packages, and other experts is essential.

ATLAS Astro Forum

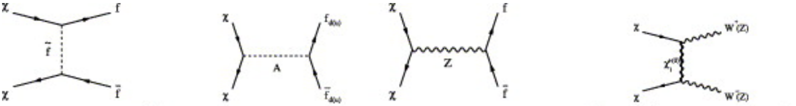
ATLAS Astro Forum ATLAS has recently instituted an astro forum. One of four of the approved first studies will focus on the high tanβ region of SUSY parameter space (see Heidi's talk). Studying this particular region will provide very relevant limits for astrophysics, and demonstrate complementarity between accelerator and astrophysical experiments.

Beyond the standard model

Supersymmetry is a proposed candidate for physics beyond the standard model. It introduces transformations between fermions and bosons; giving each a superpartner.

In supergravity, this is taken as a local symmetry, and a spin-2 graviton appears. In the minimal case- mSUGRA - the number of parameters is reduced to 5; m_0, $m_{1/2}$, A_0, $tan\beta = v_1/v_2$ and sgnμ.

Supersymmetry provides a candidate for dark matter- the lightest supersymmetric particle cannot decay if R-parity is conserved.



$\propto \frac{m_\chi m_f}{m_{\tilde f}^2} Z_{11}^2 \quad \propto \frac{m_\chi^2}{m_A^2}\frac{Z_{11}Z_{13,14}}{m_W} m_{f_d}\tan\beta(\frac{m_{f_u}}{\tan\beta}) \quad \propto \frac{m_f m_\chi}{m_Z^2} Z_{13,14}^2 \quad \propto \frac{[-Z_{14}V_{21}^* + \sqrt{2} Z_{12}V_{11}^*]^2(-Z_{13}N_{31}^*+Z_{14}N_{41}^*)^2}{1+m^2_{\chi_i^{+(0)}}/m_\chi^2 - m_{W(Z)}^2/m_\chi^2}$

Possible annihilation channels from[1]

[1] Y. Mambrini/C. Mu±oz: Gamma-ray detection from neutralino annihilation in non-universal SUGRA scenarios, in: Astroparticle Physics 24.3 (2005), pp. 208 –230, URL: http://www.sciencedirect.com/science/article/pii/S0927650505001003.

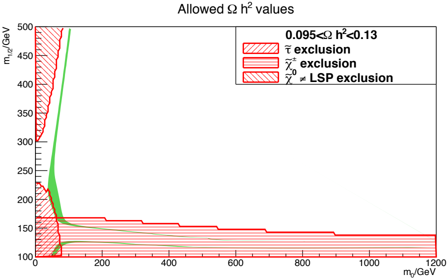
The mSUGRA parameter space

The five mSUGRA parameters are; The common sfermion mass, m_0, the common gaugino mass $m_{1/2}$, the trilinear coupling A_0, the ratio of higgs expectation values $tan\beta = v_1/v_2$ and the higgsino mass parameter, sgnμ.

When setting limits, it is common to use m_0 and $m_{1/2}$ as x and y axes, and keep the other parameters fixed.

Mass isolines will be roughly vertical for sfermions, and horizontal for gauginos. The below plot shows the Darksusy/LEP limits for charginos at the bottom and sleptons in the lower left corner.

Masses are given in GeV in all plots in this talk.



the mSUGRA parameter space at A_0=0,tan$\beta = 3$,$\mu > 0$ with exclusion from DarkSusy 5-0-5

Reasons to exclude a point

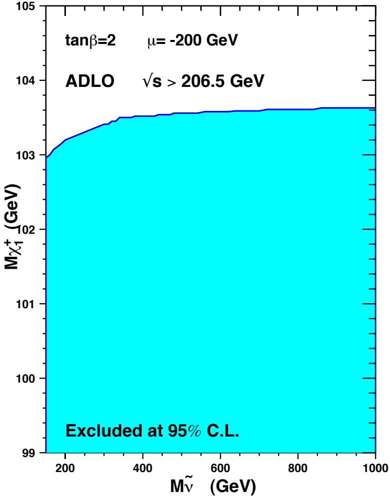
Three areas of research give excluded parameter regions; theory, accelerator experiments and astrophysics observations.

Exclusion	Program	value	Origin
No EW symmetry breaking	IsaJet		theory
$Z^0 \neq$LSP	IsaJet		theory
stop mass	DarkSusy	$m_{stop} < 92.5$	LEP
chargino mass	DarkSusy	$m_{charg} < 103.5$	LEP
higgs	FHHB		LEP+Tevatron+LHC
$b\gamma$	DarkSusy	$2.71d-4 < bsg < 4.39d-4$	
$B_s \rightarrow \mu\mu$	IsaJet	$BR < 4.5E-9$	LHCb
Ωh^2	DarkSusy	< 0.13	WMAP
σ_{LSP-p} spindep	DarkSusy		IceCube
σ_{LSP-p} spinINdep	DarkSusy		Xenon
$< \sigma_{LSP-LSP} v >$	DarkSusy		Fermi, CTA

LEP

LEP searched for sleptons and charginos.
In my code, they are implemented as straight cuts on, for example chargino mass[2].
Except through $B_s \to \mu\mu$ and Higgsbounds, no other LHC exclusions are included; they are contours in parameter space, not bounds on a single observable.

[2]

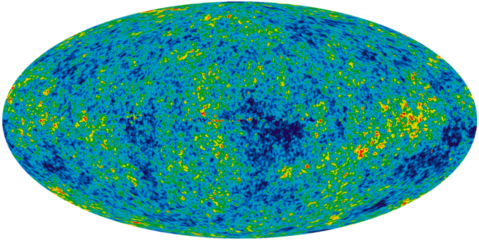


LEP chargino limit

[2] LEPSUSYWG et al.: note LEPSUSYWG/01-03.1, http://lepsusy.web.cern.ch/lepsusy/Welcome.html, p. 2.

WMAP

In addition to measuring the famous 2.7K microwave backgroung, WMAP has put limits on dark matter. A fit to the ΛCDM constrains the dark matter density to $\Omega h^2 = 0.1109 \pm 0.0056$[3]. Most mSUGRA points have much too high relic densities; areas that are not excluded have, for example, close LSP and stau masses to allow coannihilation.



WMAP Seven year sky

[3] N. Jarosik et al.: Seven-Year Wilkinson Microwave Anisotropy Probe (WMAP) Observations: Sky Maps, Systematic Errors, and Basic Results, in: Astrophys.J.Suppl. 192 (2011), p. 14.

Dark Matter Bounds

ICECUBE detects neutrinos with a giant array of Cherenkov detectors suspended in Antartic ice.

Assuming that the amount of dark matter captured by the sun is in equilibrium, ICECUBE looks for an excess of neutrinos from the sun, and sets limits on the rate of capture, and the spin-dependent cross section[4].

The XENON experiments look for the chance neutralino to scatter off a target of xenon, and constrains the spin-independent cross section[5].

Both experiments report experimental bounds as a function of m_{LSP}

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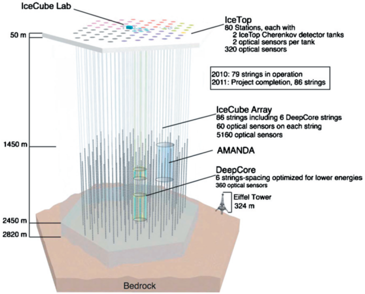


The IceCube experiment (by Nasa-verve@wikipedia)

[4] R. Abbasi et al.: Multi-year search for dark matter annihilations in the Sun with the AMANDA-II and IceCube detectors, in: Phys.Rev. D85 (2012), p. 042002, here p. 4.

[5] E. Aprile et al.: Dark Matter Results from 100 Live Days of XENON100 Data, in: Phys.Rev.Lett. 107 (2011), p. 131302, here p. 5.

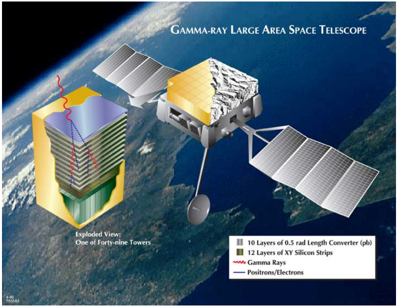
Gamma telescopes

Another signature of dark matter would be photons from the annihilation of two neutralinos.

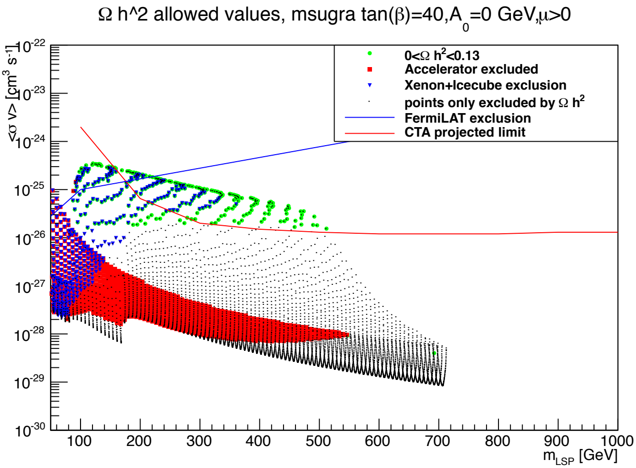
This may be detected by gamma telescopes as a line spectrum that is strongest near massive objects.

The FERMI satellite has set new limits on the neutralino-neutralino cross section.

The Cherenkov Telescope Array is a proposed air Cherenkov telescope that would be sensitive to higher energies.



The Fermi space telescope (image courtesy: NASA)



Exclusion graphs for FERMI[6] and a projection for CTA[7]

[6] M. Ackermann et al.: Constraining Dark Matter Models from a Combined Analysis of Milky Way Satellites with the Fermi Large Area Telescope, in: Phys.Rev.Lett. 107 (2011), p. 241302.

[7] Pierre Brun et al.: Searches for dark matter subhaloes with wide-field Cherenkov telescope surveys, in: Phys.Rev. D83 (2011), p. 015003.

Grids in mSUGRA

The observable predictions of mSUGRA change with the parameters.

Many parameter sets are already excluded by current experiments, and some are theoretically forbidden.

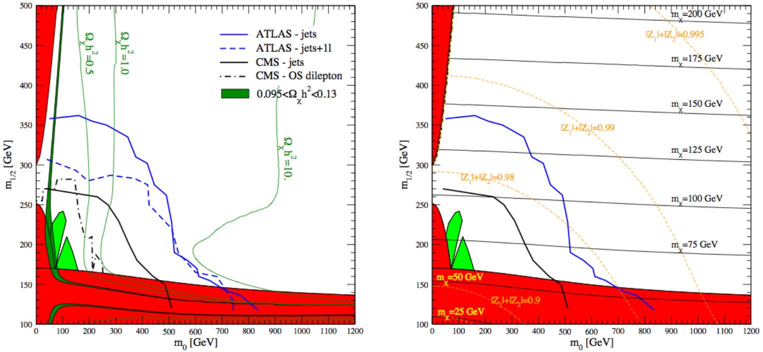
ATLAS searches are model dependent; it is not possible to directly compare ATLAS limits with astrophysics.

Therefore, to find forbidden parameter regions, one has to produce models with some parameters and check.

The simplest solution is to sample a regularly sized grid of points, and intrapolate between them.

Jan is working with the same models; and is of great help both in software questions as well as in comparing results.

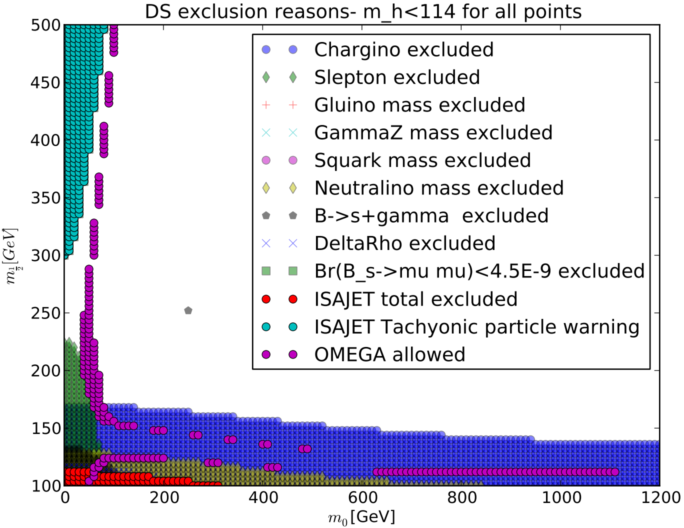
To begin with, I replicated the plots found in a paper by Profumo[8]:



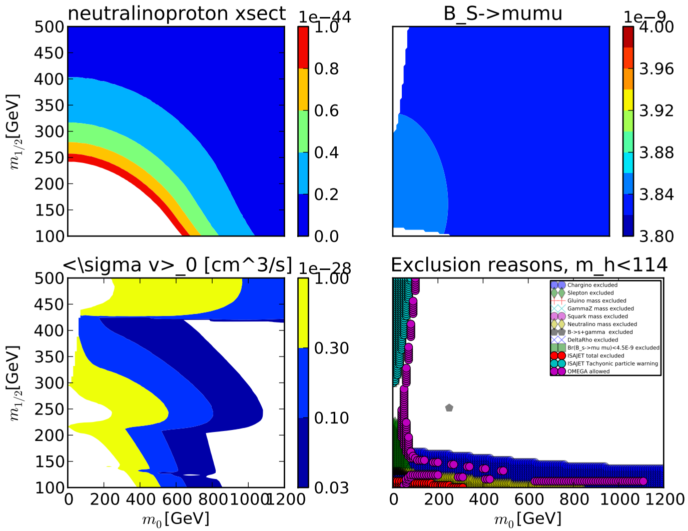
the mSUGRA parameter space as plotted in Profumos paper; A_0=0, tanβ=3, sgn$\mu > 0$

[8] Stefano Profumo: The Quest for Supersymmetry: Early LHC Results versus Direct and Indirect Neutralino Dark Matter Searches, in: Phys.Rev. D84 (2011), p. 015008.

And made my own plots:



the mSUGRA parameter space at $\tan\beta = 3$, $A_0 = 0$, $\text{sgn}\mu > 0$

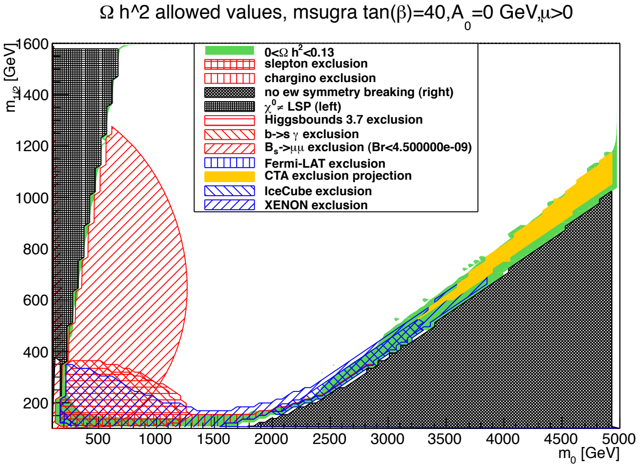


the mSUGRA parameter space at $\tan\beta = 3$, $A_0 = 0$

To check my results with Profumo, I explored the observables he plotted isolines for.

To check whether points in the mSUGRA parameter space are excluded; I run four code packages in addition to a python script.
Information is passed as text files in the Susy Les Houches Accord format.
I have adapted the programs to make three small tools that may be called with one line of commands, making it easier to manage from the python steering procedure.
In the end, the output is collated into a ROOT file, which is read by the plot scripts, and to which I can easily add more parameters without hassle.

Program	input	output
ISASUGRA	coordinates	mass spectrum, Br($B_s \to \mu\mu$)
DarkSUSY	mass spectrum in SLHA	Ωh^2 and χ^0_{LSP} cross-sections
FeynHiggs and HiggsBounds	mass spectrum in SLHA	Higgs masses and higgs exclusion



The $m_0 m_{1/2}$ plane of mSUGRA

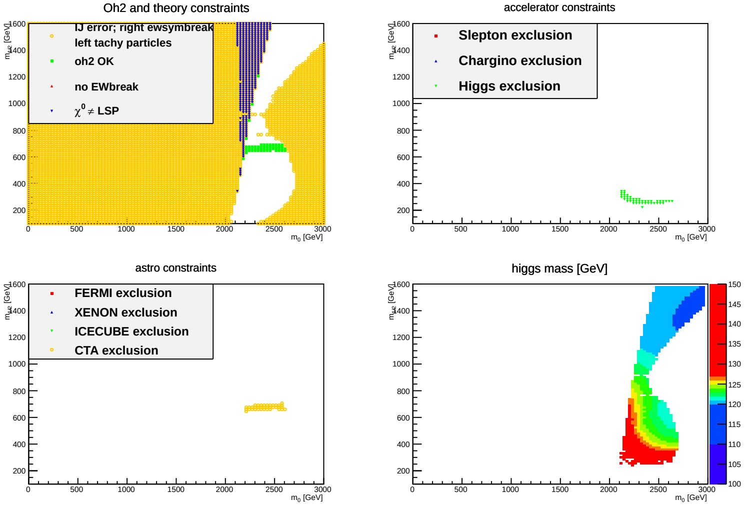
At high tanβ, we see that astrophysical searches(blue and orange) and accelerators(red) together exclude big parts of the mSUGRA parameter space.

Higgs Demands

The discovery of a higgs-like particle at 125GeV places a new, stringent constraint on mSUGRA.

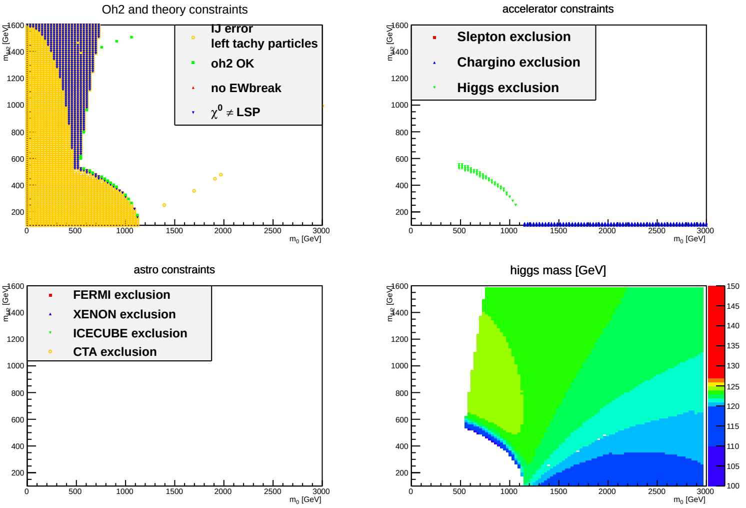
Jan and Thomas have explored a larger section of the parameter space, and looking closer at some of their favored points, there are still some allowed models.

The next slide shows two recent parameter grids using their regions as a starting point.



$$A0 = 4000\text{GeV}, \tan\beta = 59$$

I produce plots that are consistent with Jans result; and may still identify a small region that is not excluded. CTA has some exclusion powers, but the region is at the extreme edge of the parameter space.



$$A0 = -2300\text{GeV}, \tan\beta = 25$$

Comparing Dark matter searches with Fermi and CTA

FERMI has attracted great interest recently, with a papers reporting a $\approx 3 - 4\sigma$ line signal at 130 GeV [9] [10].

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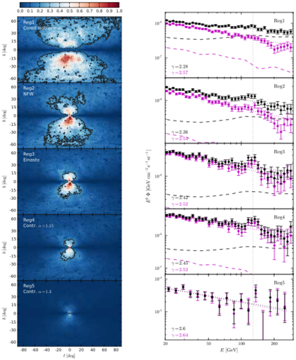


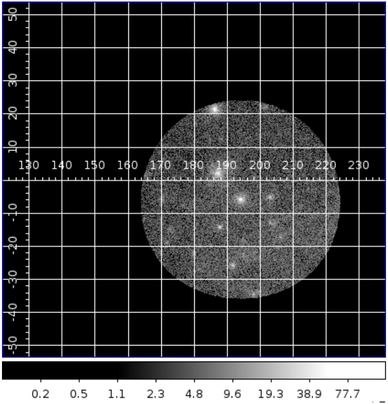
Signal-to noise and gamma ray spectra for different regions from Wenigers paper

[9] Christoph Weniger: A Tentative Gamma-Ray Line from Dark Matter Annihilation at the Fermi Large Area Telescope, in: JCAP 1208 (2012), p. 007, here p. 9.

[10] Torsten Bringmann et al.: Fermi LAT Search for Internal Bremsstrahlung Signatures from Dark Matter Annihilation, in: JCAP 1207 (2012), p. 054, here p. 10.

FERMI releases all data to the public.

Since both FERMI and CTA observe the gamma-ray sky, it would be interesting to compare the two. Trygve is working on CTA, and I would like to modify his code to also take FERMI input.



The gamma ray source 3C279 seen by Fermi

ATLAS bounds

ATLAS is steadily expanding exclusion limits on mSUGRA. However, many of these are given for a specific set of A_0 and tanβ.

The ATLAS EtMiss group is supporting this effort, and have datasets I can use.

The effort on SUSY with taus, as presented by Ørjan will be a starting point in this work.

Summary

- I have explored grids in MSUGRA
- Multiple limits from accelerators and astrophysical dark matter searches have been implemented.
- FERMI show exiting hints on dark matter.
- The ATLAS high tanβ- effort will help set new ATLAS limits in regions of the parameter space that is of great interest to dark matter searches.

Sources

Abbasi, R. et al.: Multi-year search for dark matter annihilations in the Sun with the AMANDA-II and IceCube detectors, in: Phys.Rev. D85 (2012), p. 042002.

Ackermann, M. et al.: Constraining Dark Matter Models from a Combined Analysis of Milky Way Satellites with the Fermi Large Area Telescope, in: Phys.Rev.Lett. 107 (2011), p. 241302.

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LEPSUSYWG et al.: note LEPSUSYWG/01-03.1, `http://lepsusy.web.cern.ch/lepsusy/Welcome.html`.

Mambrini, Y. and C. Mu±oz: Gamma-ray detection from neutralino annihilation in non-universal SUGRA scenarios, in: Astroparticle Physics 24.3 (2005), pp. 208 –230, URL: `http://www.sciencedirect.com/science/article/pii/S0927650505001003`.

Profumo, Stefano: The Quest for Supersymmetry: Early LHC Results versus Direct and Indirect Neutralino Dark Matter Searches, in: Phys.Rev. D84 (2011), p. 015008.

Weniger, Christoph: A Tentative Gamma-Ray Line from Dark Matter Annihilation at the Fermi Large Area Telescope, in: JCAP 1208 (2012), p. 007.

Questions

Are welcome!