Phenomenology of Supersymmetric Models with Mirage Unification

XERXES TATA
University of Hawaii

Work in collaboration with Howie Baer, Eun-Kyung Park and Ting Wang

JHEP **08**041 (2006); Phys. Lett. **B641**, 447 (2006); JHEP **06**, 033 (2007).

Motivation and Framework

Sparticle phenomenology depends on how SUSY breaking effects are communicated to MSSM fields

- ⋆ Modulus (Gravity)-mediation+ assumptions mSUGRA Model $\Longrightarrow$ Universality (usually bino-like neutralino or gravitino LSP)
- ⋆ Gauge-mediation GMSB Models $\Longrightarrow m_i \propto g_i^2$ (light gravitino LSP)
- ⋆ Anomaly-mediation AMSB Models $\Longrightarrow m_i \propto \beta_i$ wino-like neutralino LSP
- ⋆ Gaugino mediation $m_{1/2} \gg m_0$ mSUGRA with small m_0

Mixture of Modulus+Anomaly mediated SUSY breaking

WHY MM-AMSB?

Usually, AMSB contribution $\ll$ modulus-mediated SUSY breaking contribution.

KEY IDEA

If scale of modulus-mediated contributions to MSSM SSB parameters, $m_{\rm SUSY} \ll m_{3/2}$, then AMSB contributions ($\sim m_{3/2}\times$ loop factor) may be comparable to $m_{\rm SUSY}$

This structure of MSSM soft SUSY breaking terms arises if the moduli of type IIB superstring are stabilized because space curls up with fluxes (non-zero field strengths) along the extra dimensions.

Kachru, Kallosh, Trivedi and Linde toy scenario with a stable ground state in controlled approximation, a de Sitter universe, and small SUSY breaking.

In original KKLT proposal, $m_{3/2} \simeq m_{\rm SUSY} \ln(\frac{M_P}{m_{3/2}})$.

MIXED MODULUS-ANOMALY MEDIATION LEADS TO NOVEL MASS PATTERNS AND PHENOMENOLOGY

Universal SSB parameters at a scale $\mu_{\rm mirage}$ where there is no physical threshold.

MM-AMSB, Mirage-mediation, Mirage unification

No concrete realization of KKLT idea with an explicit C-Y space and choice of fluxes that leads to a ground state with all the required properties (e.g. SM, dS spacetime, broken SUSY)!

PHENOMENOLOGICAL APPROACH.

Choi, Falkowski, Nilles, Olechowski, Pokorski; Choi, Jeong, Okumura; Falkowski, Lebedev, Mambrini; Endo, Yamaguchi, Yoshioka, Also, Kitano, Nomura.

Generalization to allow the ratio between anomaly and modulus mediated SUSY breaking contributions to be arbitrary.

Parametrize this ratio by α. Since it is a ratio of products of VEVs, α can take either sign, BUT CAN BE $\mathcal{O}(1)$.

Warning: There are two conventions for α in the literature!

$$\alpha_{\rm Our} = \alpha_{\rm FLM} = \frac{16\pi^2}{\ln(M_P/m_{3/2})}\frac{1}{\alpha_{\rm Choi}}$$

Parameter Space

MSSM sparticle mass scale $\sim \frac{m_{3/2}}{16\pi^2} \equiv M_s$

Ratio of modulus-mediated and anomaly-mediated contributions set by a phenomenological parameter α

Modulus-mediated contributions depend on so-called "modular weights" of the fields, which (for toroidal compactifications) are determined by where these fields are located in the extra dimensions.

Matter modular weights n_i= 0 (1) [1/2] for matter on D7 (D3) branes [on brane intersections].
Gauge kinetic function indices l_a= 1 (0) on $D7$ ($D3$) branes.

Model completely specified by

$$m_{3/2},\ \alpha,\ \tan\beta,\ sign(\mu),\ n_i,\ l_a$$

Radiative EWSB determines μ^2 as usual.

More on modular weights

The modular weights, 0 (1) for chiral superfields on D7 (D3) branes (1/2 on brane intersections) were obtained in examples with toroidal compactifications. Ibañez and collaborators

These modular weights are generic for adjoint superfields.

But for chiral superfields, this is not so. Recent analysis with Calabi-Yau compactfication shows that modular weight 2/3 is possible. Conlon, Quevedo and collaborators

We will take $n_i = 0, 1/2, 1$ as choices that guide our phenomenological analyses.The choice 2/3 will give a phenomenology somewhere "in between".

Soft SUSY Breaking Terms

The soft terms renormalized at $Q \sim M_{\rm GUT}$ are given by,

$$
\begin{aligned}
M_a &= M_s \left(\ell_a \alpha + b_a g_a^2\right), \\
A_{ijk} &= M_s \left(-a_{ijk}\alpha + \gamma_i + \gamma_j + \gamma_k\right), \\
m_i^2 &= M_s^2 \left(c_i \alpha^2 + 4\alpha\xi_i - \dot{\gamma}_i\right),
\end{aligned}
$$

with

$$c_i = 1 - n_i,$$

$$a_{ijk} = 3 - n_i - n_j - n_k,$$

$$\xi_i = \sum_{j,k} a_{ijk} \frac{y_{ijk}^2}{4} - \sum_a l_a g_a^2 C_2^a(f_i), \text{and } \dot{\gamma}_i = 8\pi^2 \frac{\partial \gamma_i}{\partial \log \mu}$$

Note that if $n_i = 0$, $A_{ijk}^2 \sim 9m_i^2$ for the modulus-mediated contribution.

Large A-parameters $\Longrightarrow$ Light $\tilde{t}_1$ possible.

$\alpha = 0$ gives us the AMSB Model with wino-like neutralino LSP.

For large $|\alpha|$, AMSB terms subdominant. With universal l_a (n_i) we will have common gaugino (scalar) masses.

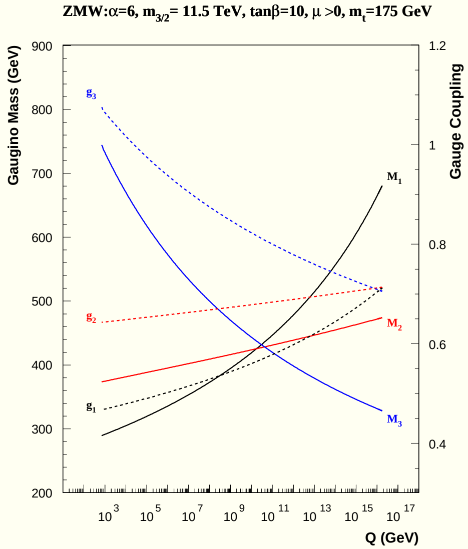
Generation-independent modular weights for MSSM multiplets ensures FCNC OK. SUSY CP problem also ameliorated.

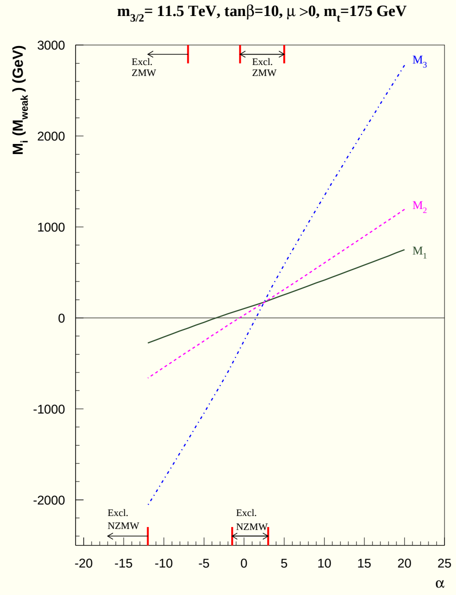
(n_m, n_H) each $=$ 0, 1/2, 1 $\Longrightarrow$ 9 cases

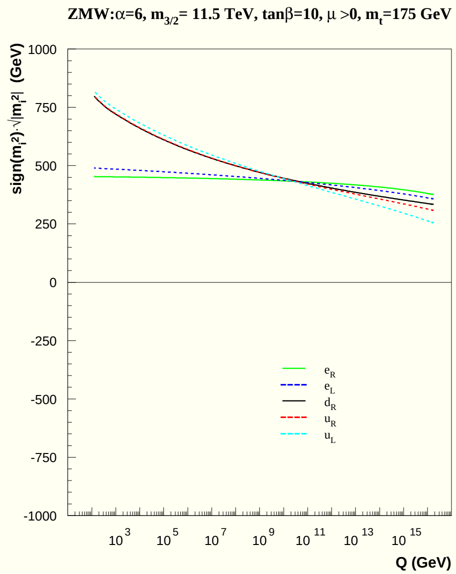
Models potentially have smaller fine tuning: even for heavy stop, $m_{H_u}^2$ can be modest at weak scale. (Lebedev,Nilles, Ratz; Choi et al; Kitano and Nomura).

Possibility of a compressed sparticle spectrum.

True Unification and Mirage Unification



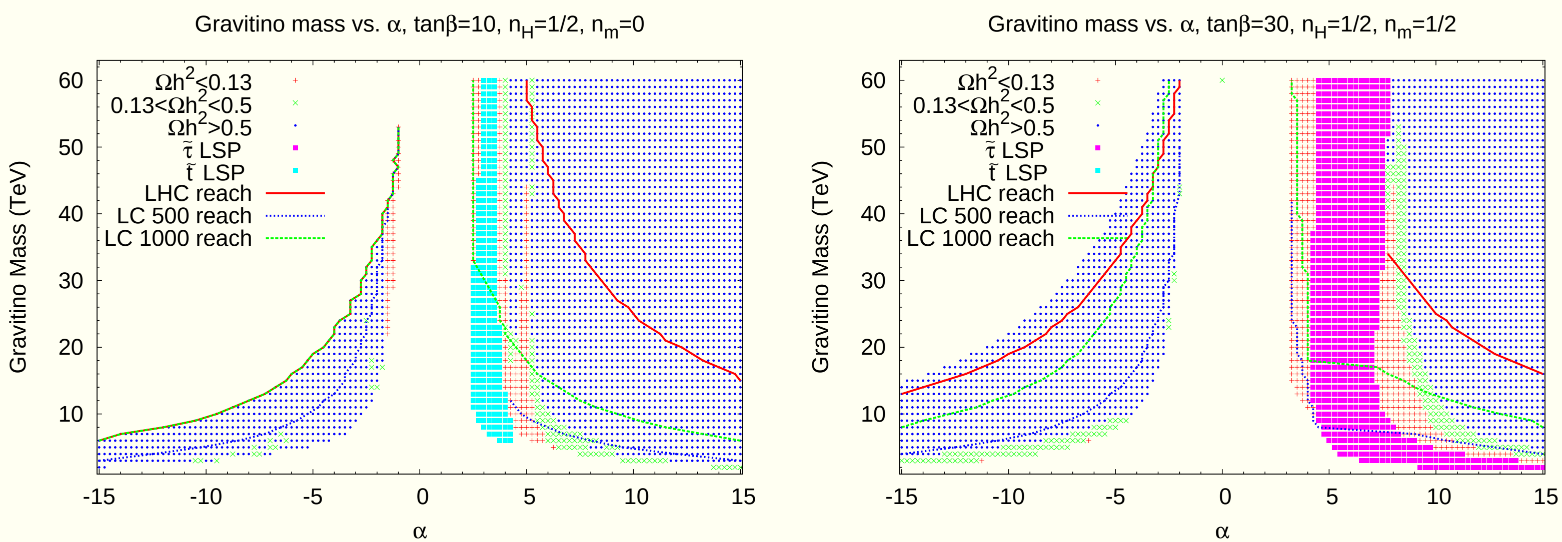




Mirage unification   Low mirage unification scale   Scalar mass unification

NOTE: $M_1(\text{weak}) = \pm M_2(\text{weak})$ is possible, depending on α. This has implications for dark matter.

Mirage Unification Models



WMAP consistency via stop and stau co-annihilation, via mixed bino-wino-higgsino SM, Higgs funnel or BWCA

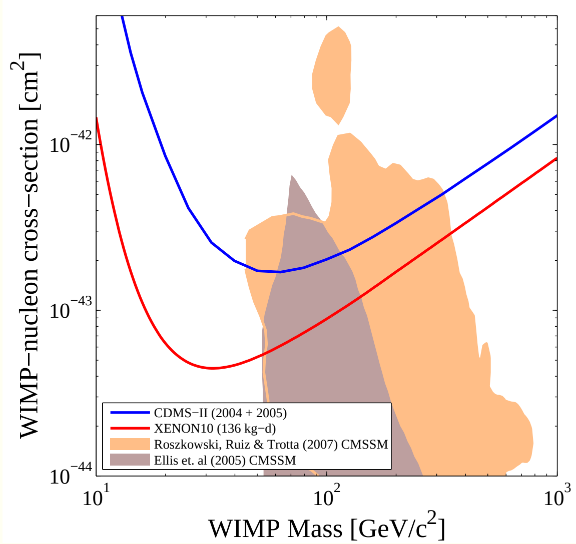
LHC probes *almost* all the WMAP allowed regions. LC probe all BWCA regions.

LC1000 covers all the BWCA region

Direct Detection of dark matter

Detect recoils of nuclei from their collisions with DM in our galactic halo we move through it.

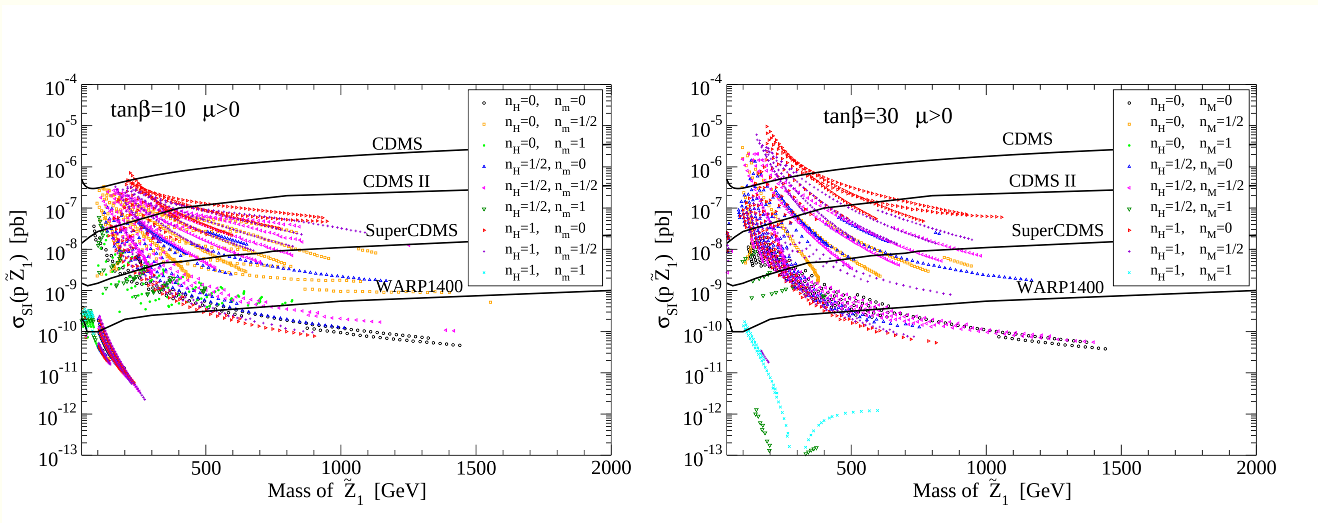
DAMA experiment has claimed a signal which is not seen by other experiments with greater sensitivity $\Longrightarrow$ Upper limits.



New result from Xenon 10 collaboration (red) just beat CDMS bound (blue).

Direct Detection of neutralino dark matter

Direct Detection also leads to observable signals over much of the parameter space of mirage unification models.



Relic-density-consistent mirage unification models

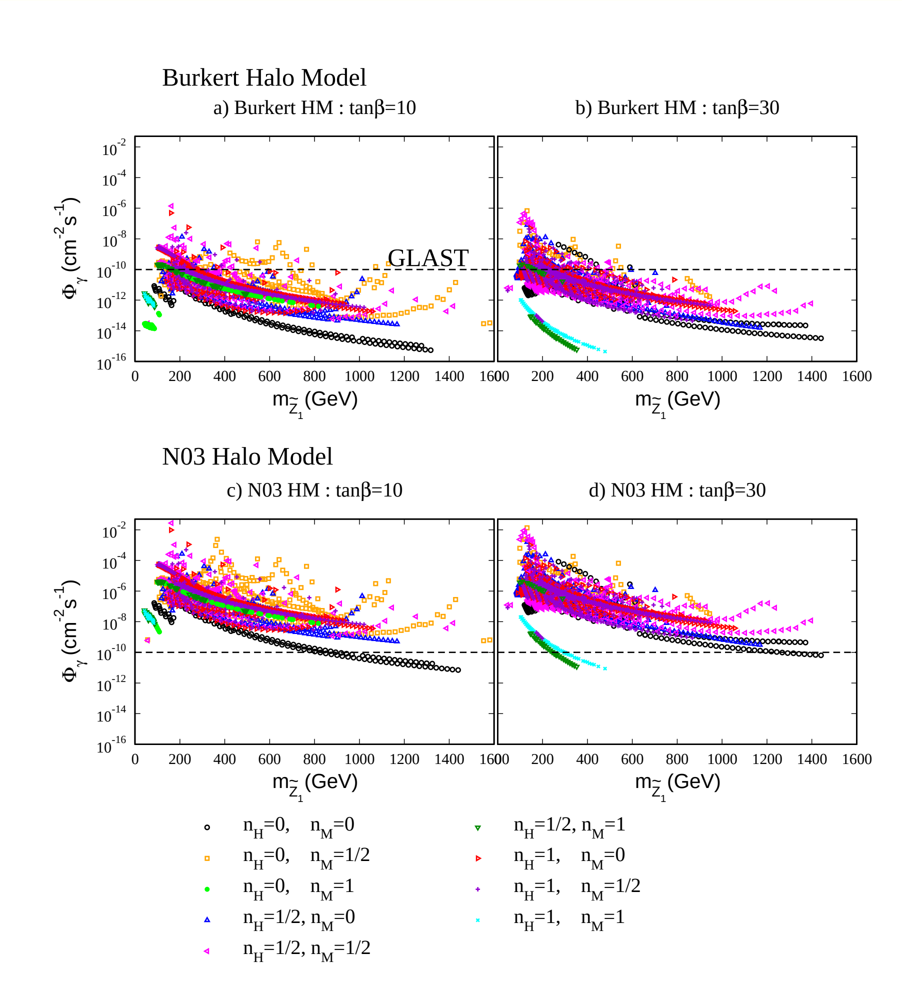
Indirect detection of dark matter

- ⋆ Annihilation of neutralinos accumulating in the sun give high energy neutrinos that can be detected in IceCube. Models with mixed higgsino DM most detectable
- ⋆ Annihilation of neutralinos in our galactic halo can give positrons and $\bar{p}$ [PAMELA], anti-deuterons [GAPS] or high energy gamma rays [GLAST] at observable rates, depending on the composition of the LSP.

  Only a small fraction of models gives observable signals.

WARNING: THE SIGNAL IS SENSITIVE TO THE UNKNOWN DISTRIBUTION OF THE NEUTRALINOS IN OUR GALACTIC HALO. STILL MAY BE ABLE TO INFER INFORMATION ABOUT THE WIMP BY CORRELATING THESE SIGNALS.

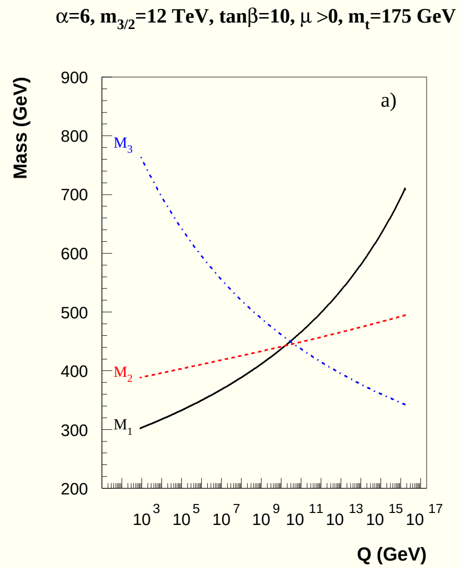
Annihilation of neutralinos clumped at the centre of our Galaxy yields high energy gamma rays. (EGRET, GLAST)



Reach of GLAST satellite experiment shows extreme sensitivity to halo profile.

DETERMINATION OF MODULAR WEIGHTS AT COLLIDERS

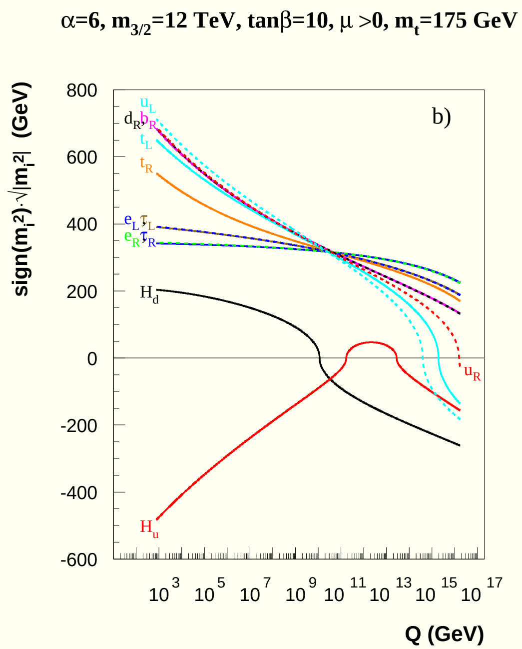
Expect mirage unification of gaugino mass parameters if $l_a \equiv l$ are universal.



If we can determine the gaugino mass parameters at the weak scale, and extrapolate these to high scale using 1-loop RGEs, these should unify at $\mu_{\rm mirage} = M_{\rm GUT} e^{-\frac{8\pi^2}{(l\alpha)}} \Rightarrow (l\alpha)$ determined.

The unified value of the gaugino mass, $M_a(\mu_{\rm mirage}) = M_s \times (l\alpha)$, then gives us M_s.

If the extrapolated values of $m_{\tilde{e}_L}$, $m_{\tilde{e}_R}$, $m_{\tilde{\nu}}$, or first generation squark parameters converge at $\mu_{\rm mirage}$, then we would have a striking confirmation of this picture!



$$\left.\frac{m_i}{M_a}\right|_{\mu_{\rm mirage}} = \frac{\sqrt{c_i}}{l} \Rightarrow$$

Information about matter modular weights (assumed universal for FCNC/GUTS).

CAN WE SEPARATE c_i AND l VALUES?

As long as the Yukawa couplings are negligible, the answer is NO! Boundary conditions depend only on, $M_s,\ (l\alpha)$ and c_i/l^2.

We would this need determination of third generation parameters, as well as ability to extrapolate these to high scales.

I think that this is much more difficult. But we have not made a detailed study.

Summary

★ Mirage unification is a consistent, theoretically-motivated and phenomenologically viable framework. Fewer parameters than mSUGRA if the (discrete) modular weights are fixed.

★ Novel mass patterns possible; Unconventional $M_1 : M_2 : M_3$; $\tilde{t}_1$ may be NLSP and very light for $n_m = 0$, $n_H = 0, 1/2$. (possibly even accessible at the Tevatron).

★ Top-down framework that can give $M_1(\text{weak}) \sim -M_2(\text{weak})$ that was phenomenologically identified as a possibility for obtaining the right CDM relic density; also potentially gives reduced $|\mu|$ via relative reduction of M_3. Correct relic density possible via a variety of mechanisms including, bulk annihilation, Higgs funnel, stop or stau coannihilation, low $|\mu|$ via reduced M_3 and BWCA. MWDM and low $|\mu|$ via non-universal Higgs mass parameters was not possible. Collider and DM searches will serve to discriminate between these various possibilities.

★ SUSY flavour and CP problems ameliorated.

★ Problem with heavy Moduli decay to gravitinos (Thermal inflation era??) Endo, Hamaguchi, Takahashi; Nakamura, Yamaguchi; Dine, Kitano, Morisse, Shirman.

★ Very large part of parameter space consistent with measured CDM relic density will be probed at LHC; over part of this space, precision measurements will be possible at a 1 TeV e^+e^- LC. Importantly, LC experiments will explore charginos and neutralinos in the BWCA region, difficult to explore at the LHC on account of the small mass gap.

★ Hallmark mirage unification of soft SUSY breaking parameters is testable for gaugino masses and first generation scalars if sparticles are accessible.

★ Possibility of direct determination of modular weights at the LHC and ILC, assuming sleptons and charginos are accessible at ILC. Technical (but not conceptual) difficulties when $\mu_{\rm mir}$ is very large.

IN MY OPINION, MIXED MODULUS-ANOMALY MEDIATION IS A COMPELLING NEW FRAMEWORK FOR SUSY PHENOMENOLOGY.

SCALAR UNIFICATION FOR $\alpha < 0$

We know,

$$\frac{M_i(Q)}{g_i^2(Q)} = K_i, \quad \text{or equivalently, } \frac{1}{M_i(Q)} = K_i^{-1} \times \frac{1}{g_i^2(Q)}$$

and

$$\frac{1}{g_i^2(Q)} - \frac{1}{g_i^2(Q_0)} = -\frac{b_i}{8\pi^2} \ln\left(\frac{Q}{Q_0}\right)$$

For scalars, we have

$$m_i^2(\mu) = Z_i - 2\sum_a \frac{C_2^a(f_i)}{b_a} M_a^2(\mu)$$

where Z_i is μ independent, so that

$$m_i^2(\mu_{\rm mir}) = m_i^2(\mu_{\rm weak}) + 2\sum_a \frac{C_2^a(f_i)}{b_a}\left[M_a^2(\mu_{\rm weak}) - M_a^2(\mu_{\rm mir})\right]$$

.

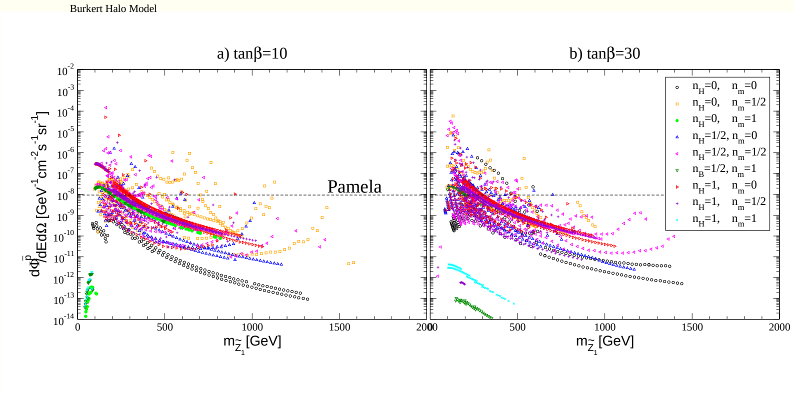
	$n_m = 0$	$n_m = \frac{1}{2}$	$n_m = 1$
$\tilde{Q}$	465^{+203}_{-576}	429^{+211}_{-631}	388^{+222}_{-654}
$n_{\tilde{Q}}^{\rm exp}$	[−7.5, 1.2]	[−6.9, 1.7]	[−6.2, 2.4]
$\tilde{e}_L$	$280.1^{+8.6}_{-8.9}$	$212.8^{+9.6}_{-10.0}$	$110.4^{+14.6}_{-17.1}$
$n_{\tilde{e}_L}^{\rm exp}$	[−0.58, −0.29]	[0.05, 0.27]	[0.70, 0.84]
$\tilde{e}_R$	$257.6^{+3.4}_{-3.5}$	$181.5^{+3.0}_{-3.1}$	$-32.3^{+7.6}_{-6.1}$
$n_{\tilde{e}_R}^{\rm exp}$	[−0.26, −0.13]	[0.34, 0.43]	[1.01, 1.03]

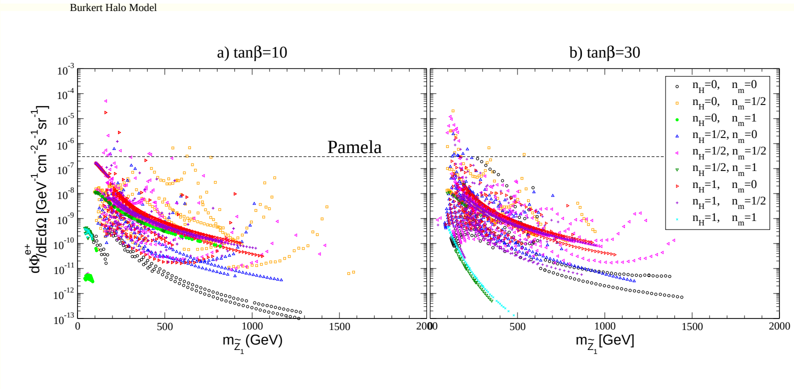
Table 1: Values of sfermion mass parameters at $Q = \mu_{\rm mir}$.

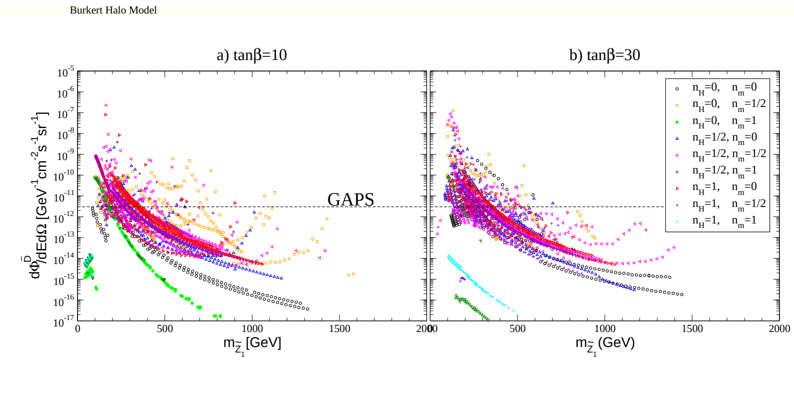
Enormous cancellations for squarks $\Longrightarrow$ large errors in extracting $m_{\tilde{Q}}(\mu_{\rm mir})$.

The offset of selectron mass parameters at $\mu_{\rm mir}$ is due to the error in extraction of the unified gaugino mass.

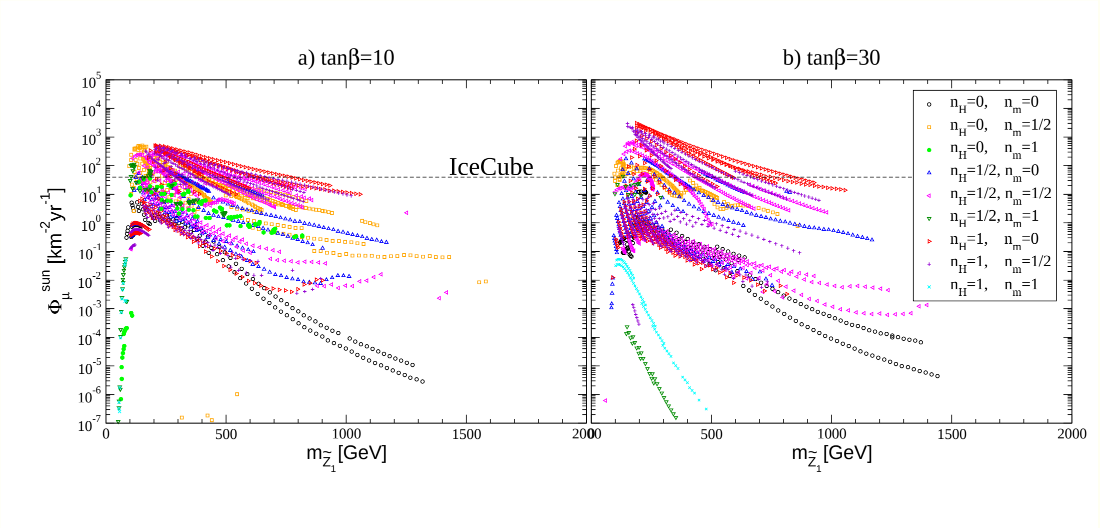
INDIRECT DETECTION OF ANTI-MATTER







INDIRECT DETECTION BY ICECUBE



INDIRECT DETECTION BY GLAST