Supersymmetric Interpretation of the EGRET Excess in Diffuse Galactic Gamma Rays

Is Dark Matter of Supersymmetric Origin?

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Spectral Analysis of Excess

- Excess independent of sky direction
- Excess above 1 GeV is compatible with DM annihilation of WIMPs
- **Lower** limit on WIMP mass: $m_{WIMP} > M_Z/2$ from LEP
- **Upper** limit: depending on Galactic bg model: $m_{WIMP} < 70 \ldots 130$ GeV

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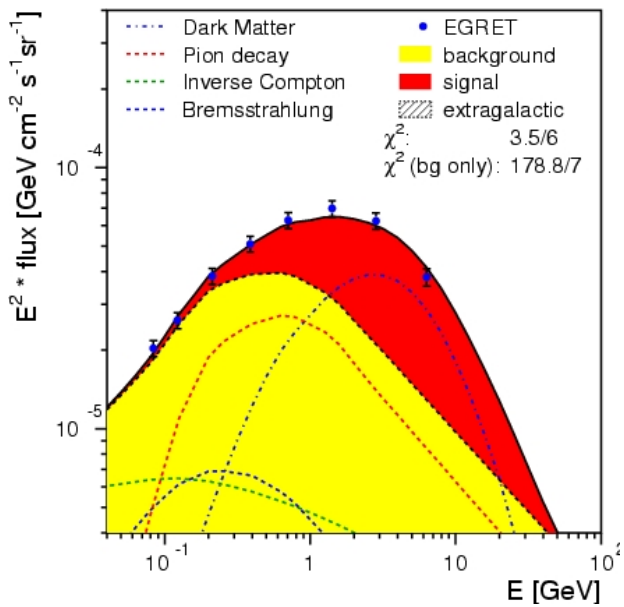
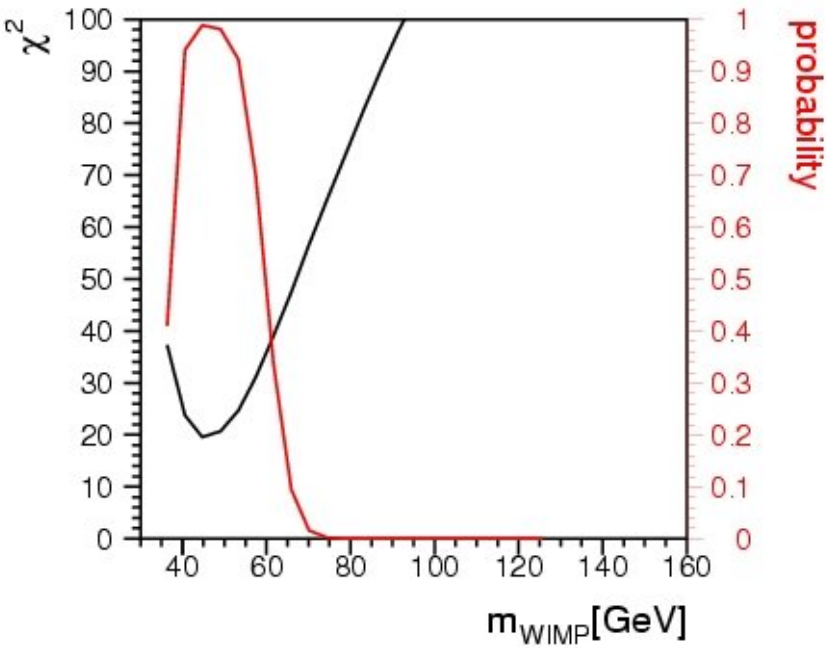
γ rays from the Galactic center:



χ^2 and probability:



Extragalactic Background

- Newly determined including DMA and using only spectral shapes
- Residual isotropic EGB shows bump at a few GeV
- Fit of new EGB with double power law and DMA signal ($\chi^2/d.o.f.$=5.7/4 $\Rightarrow$ 22.4%)
- Fit with single power law ($\chi^2/d.o.f.$=11.7/6 $\Rightarrow$ 6.9%)

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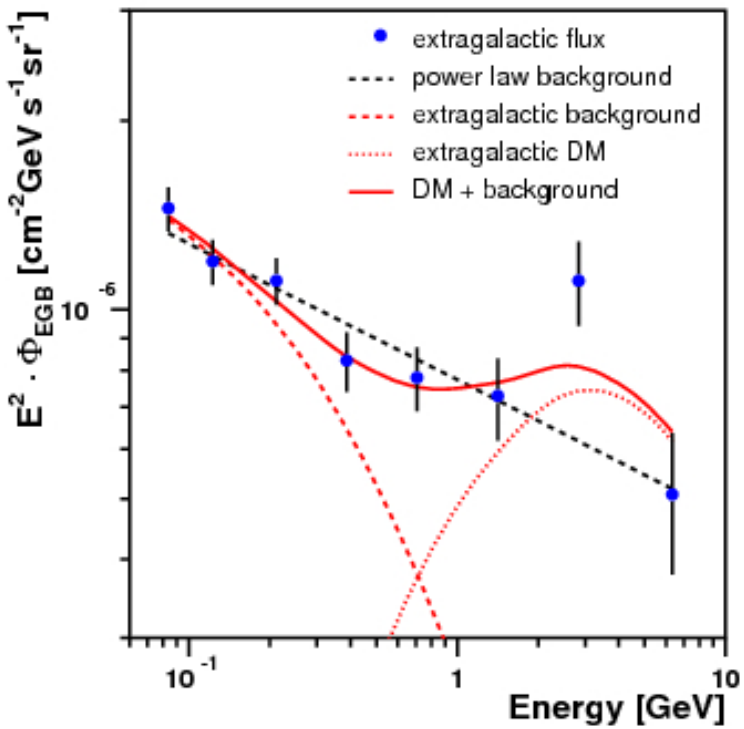
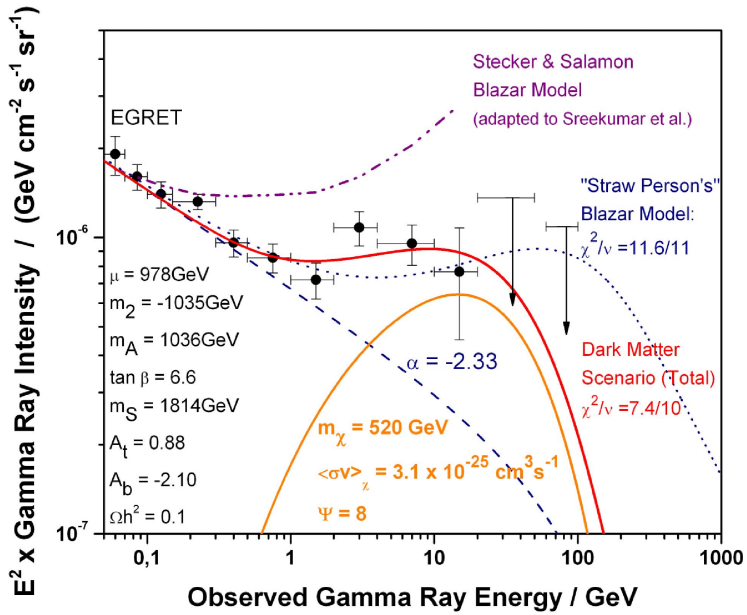


Elsaesser *et al.*, astro-ph/0405235



Supersymmetry

mSUGRA Parameter Space

SUSY is broken, e.g. mSUGRA $\rightarrow$ 5 new Parameters

- m_0: unified mass of the fermion partners
- $m_{1/2}$: unified mass of the gauge boson partners
- $\tan\beta$: ratio of the VEVs of the 2 Higgs doublets
- unified trilinear coupling A_0, sign(μ)

Constraints on the Parameter Space

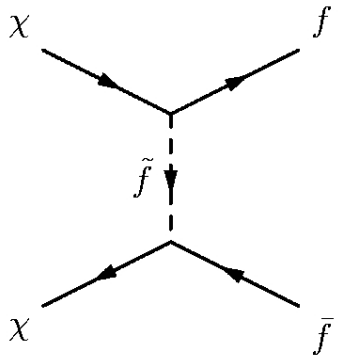
- Higgs mass $m_h > 114.4$ GeV (`SuSpect`, `hep-ph/0211331`)
- $Br(b \rightarrow X_s\gamma) = (3.43 \pm 0.36) \times 10^{-4}$ (`micrOMEGAs`, `hep-ph/0112278`)
- $\Delta a_\mu = (27 \pm 10) \times 10^{-10}$ (`micrOMEGAs`)
- $\Omega_{\text{DM}} = 0.113 \pm 0.008$ (`micrOMEGAs` or `DarkSusy`, `astro-ph/0406204`)
- SUSY mass limit, EWSB, LSP neutral ... (`SuSpect`)
- $m_{WIMP} < 70 \ldots 130$ GeV

Neutralino Annihilation

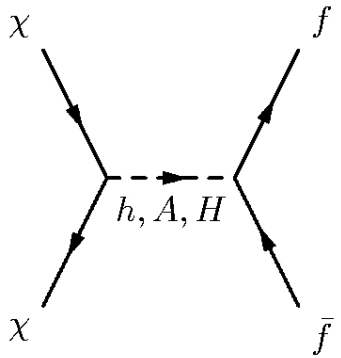
Dependence on Model Parameters

- Neutralino is mixture: $|\chi_0\rangle = N_1|B_0\rangle + N_2|W_0^3\rangle + N_3|H_1\rangle + N_4|H_2\rangle$
- Annihilation cross section depends on SUSY **and** SM parameters
- For Relic Density calculations also coannihilation, e.g. $\chi_0\tilde{\tau} \to Z\tau$, may contribute

Many Feynman graphs, e.g.:

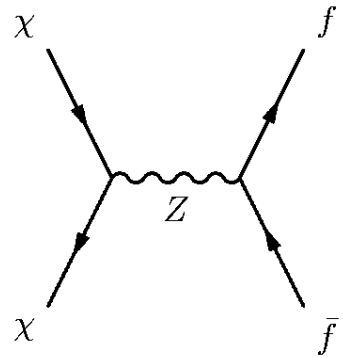


$\propto \frac{\mathbf{m_\chi \cdot m_f}}{\mathbf{m_{\tilde{f}}^2}}$



$\propto \frac{\tan\beta \cdot \mathbf{m_{f_d}}}{\mathbf{m_W}} \mathbf{N_1 N_{3(4)}}$

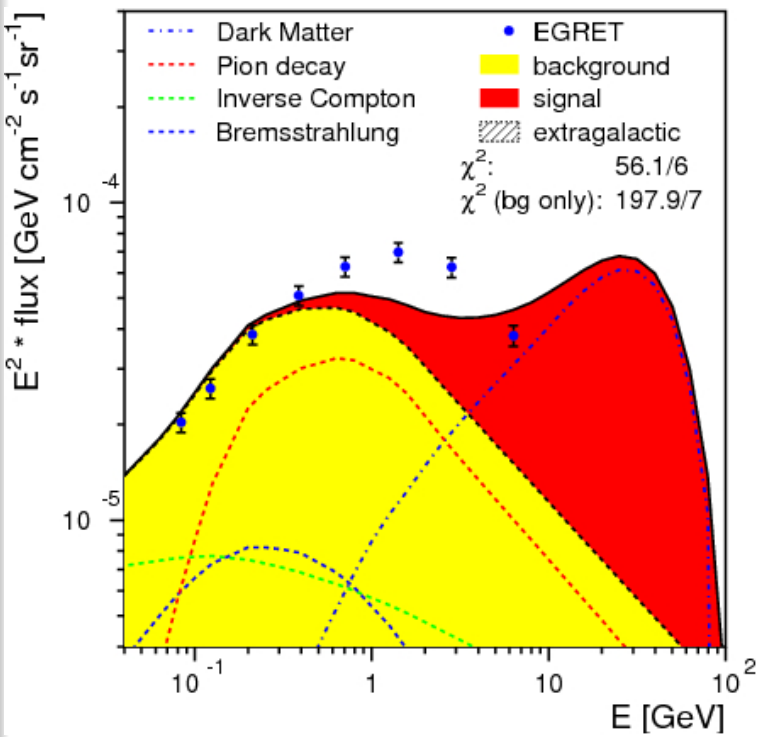
$\tan\beta \cdot \mathbf{m_{f_d}} \leftrightarrow \frac{\mathbf{m_{f_u}}}{\tan\beta}$



$\propto \frac{\mathbf{m_f \cdot m_\chi}}{\mathbf{m_Z^2}} \mathbf{N_{3(4)}^2}$

Dominant Annihilation Channel

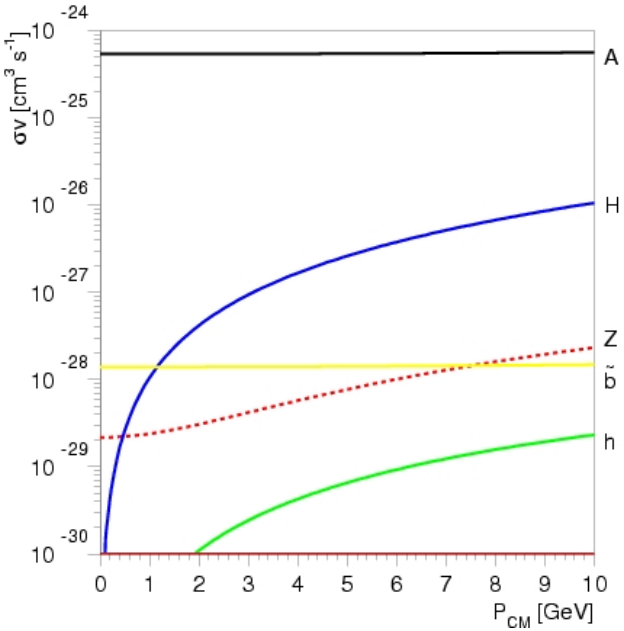
- Annihilation to 3rd generation fermions is dominant (Yukawa coupling (h,H,A) or spin flip (weak processes)
- Annihilation to $\tau^+\tau^- \rightarrow$ too hard signal
- t-channel requires light sfermions $\tan\beta$ large $\rightarrow \tilde{\tau}$ is lightest fermion $\rightarrow$ too hard signal
- For large $\tan\beta$ annihilation via Higgs into up-type quarks suppressed $\rightarrow b\bar{b}$ is dominant ($m_b > m_\tau$)



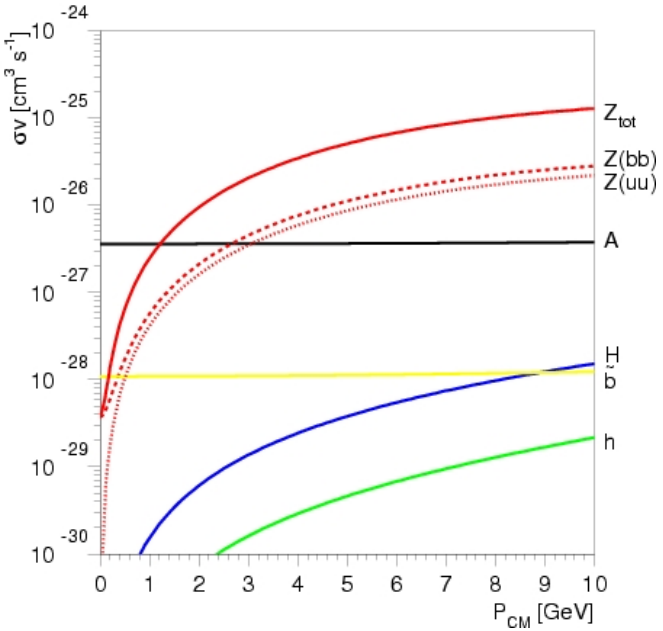
Energy Dependence of Annihilation

- *s*-wave (z.B. *s*-channel via *A*): $\langle \sigma v \rangle = \text{const}$
  with $\Omega_{DM} = 0.113 \pm 0.008$ yields $\langle \sigma v \rangle \approx 2 \times 10^{-26}$ cm^3/s
- *p*-wave (z.B. *s*-channel via *Z*): $\langle \sigma v \rangle \propto v$
  todays DMA cross section is very small $\rightarrow$ large boostfactors

σ via A is dominant:



σ via Z is dominant:

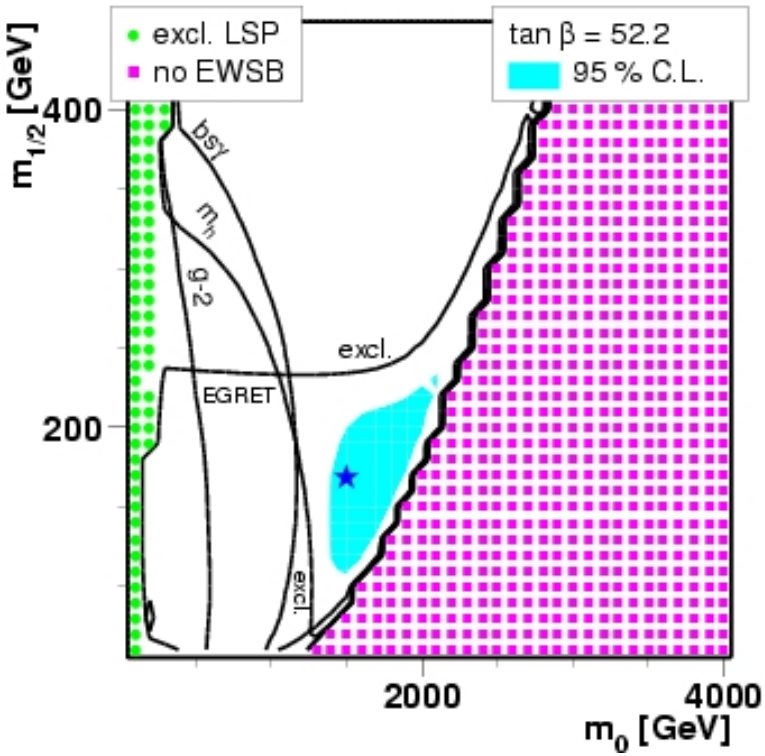


Cross sections calculated with `CalcHEP, hep-ph/0412191`

Allowed Parameter Space

Not Including Ωh^2

- Scan over m_0-$m_{1/2}$-plane for fixed values of $\tan\beta = 52.2$ and $A_0 = 0$ GeV
- 2σ-contours for allowed region + consistency of the models (LSP neutral, EWSB ok)
- with EGRET-excess only a small region is left over:
  m_0: $\sim$1500 GeV ... $\sim$2000 GeV
  $m_{1/2}$: $\sim$100 GeV ... $\sim$250 GeV
- For fixed parameters $\tan\beta$, A_0, m_t etc. allowed Ωh^2 regions are thin stripes

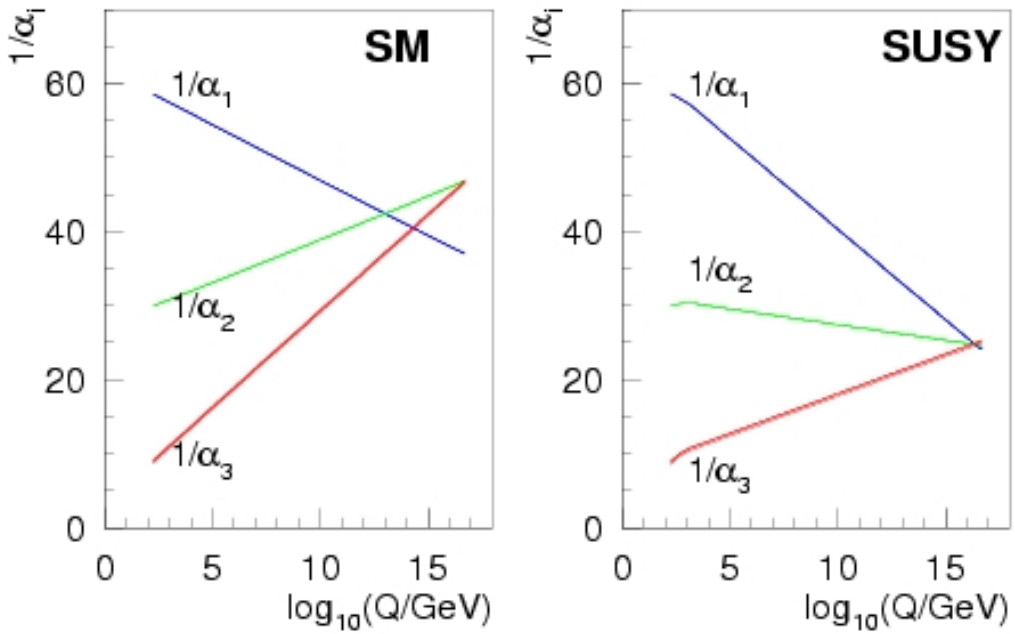


SUSY Mass Spectrum

Typical Parameter Set

Parameter	value
m_0	1500 GeV
$m_{1/2}$	170 GeV
A_0	$0 \cdot m_0$
$\tan\beta$	52.2
$\alpha_s(M_Z)$	0.122
$m_t(pole)$	175 GeV
$m_b(m_b)$	4.214 GeV
Particle	mass [GeV]
$\tilde{\chi}^0_{1,2,3,4}$	64, 113, 194, 229
$\tilde{\chi}^\pm_{1,2}, \tilde{g}$	110, 230, 516
$\tilde{t}_{1,2}$	906, 1046
$\tilde{b}_{1,2}$	1039, 1152
$\tilde{\tau}_{1,2}$	1035, 1288
$\tilde{\nu}_e, \tilde{\nu}_\mu, \tilde{\nu}_\tau$	1495, 1495, 1286
$h, H, A, H^\pm$	115, 372, 372, 383

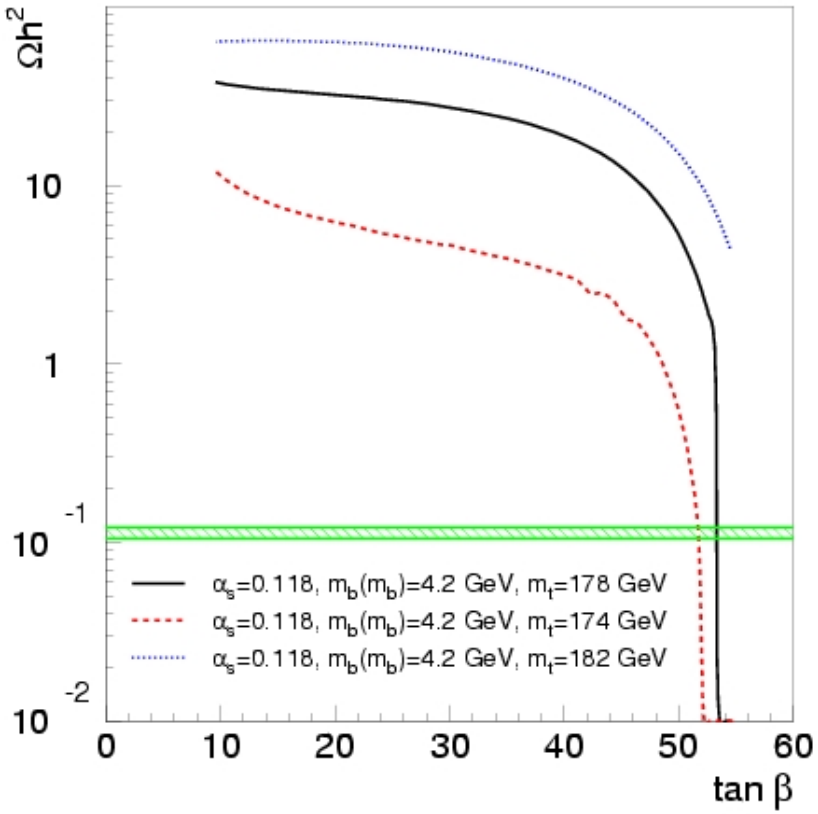
Unification of gauge couplings:



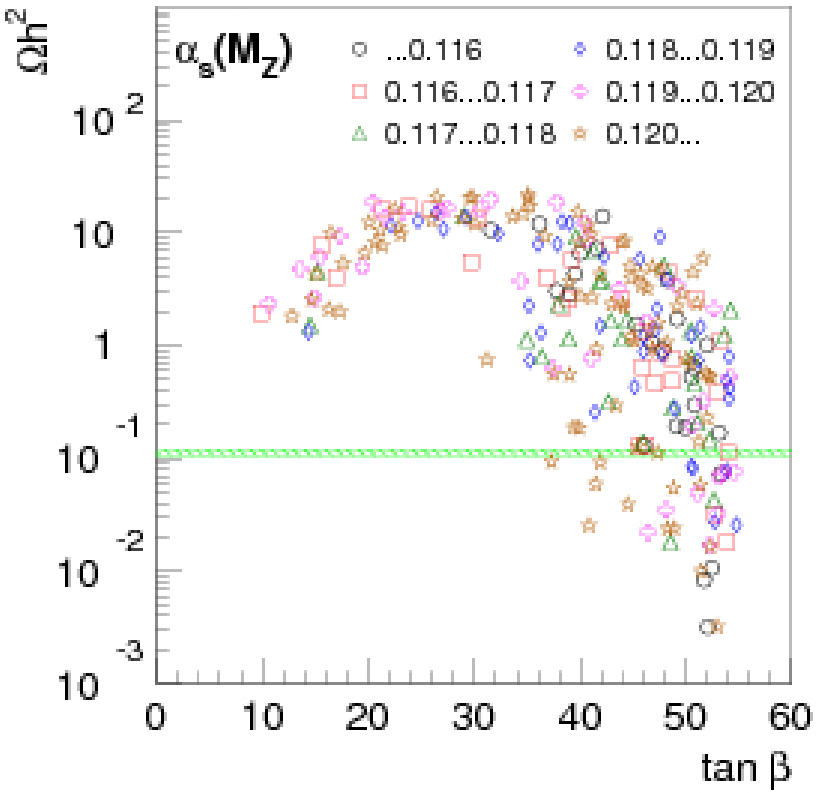
Observable	value
$Br(b \to X_s\gamma)$	$3.02 \cdot 10^{-4}$
Δa_μ	$1.07 \cdot 10^{-9}$
Ωh^2	0.117

RD Dependence on SM and mSUGRA Parameters

Top mass m_t dependence, other parameters fixed:



with m_b, α_s and mSUGRA parameters m_0, $m_{1/2}$, A_0:

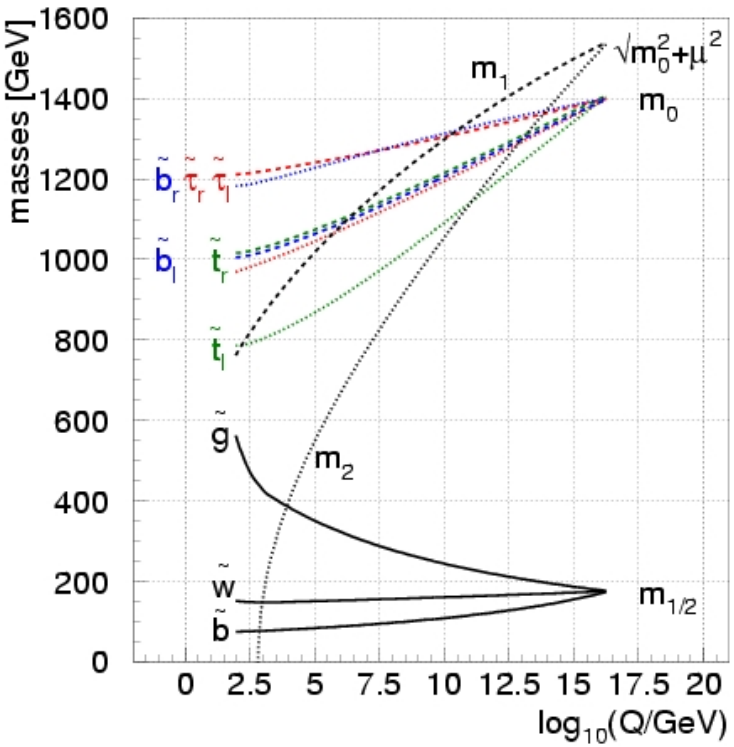


Large uncertainty, in particular for large $\tan\beta$; **Reason:** RGE of breaking parameters and EWSB

Electroweak Symmetry Breaking

- Pseudoscalar Higgs mass:
  $m_A^2 = m_1^2 + m_2^2 = m_{H_1}^2 + m_{H_2}^2 + 2\mu^2$
- Condition: $\frac{M_Z^2}{2} = \frac{m_1^2 - m_2^2 \tan^2\beta}{\tan^2\beta - 1}$
- Dependence on SM parameters by RGE
- For large $\tan\beta \rightarrow$ running of m_1 and m_2 is steep
  $\rightarrow$ large uncertainty in m_A ...
  $\rightarrow$ ... in $\langle\sigma v\rangle$ ...
  $\rightarrow$ ... and in RD

Running of breaking parameters:

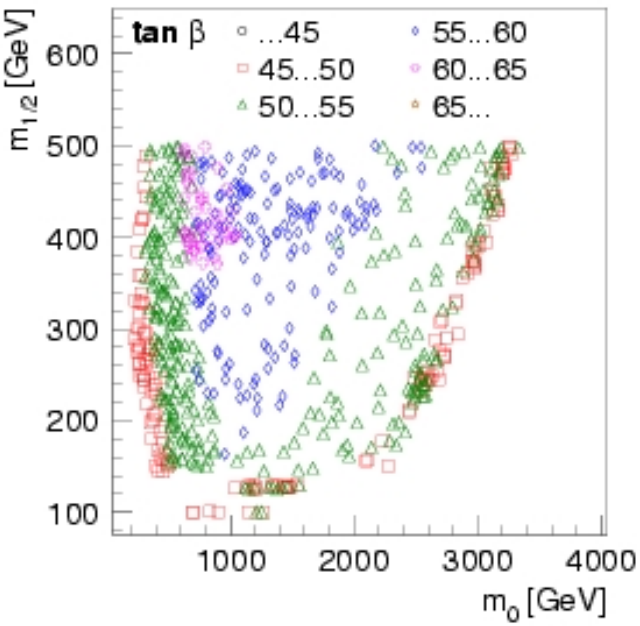


Allowed Parameter Space

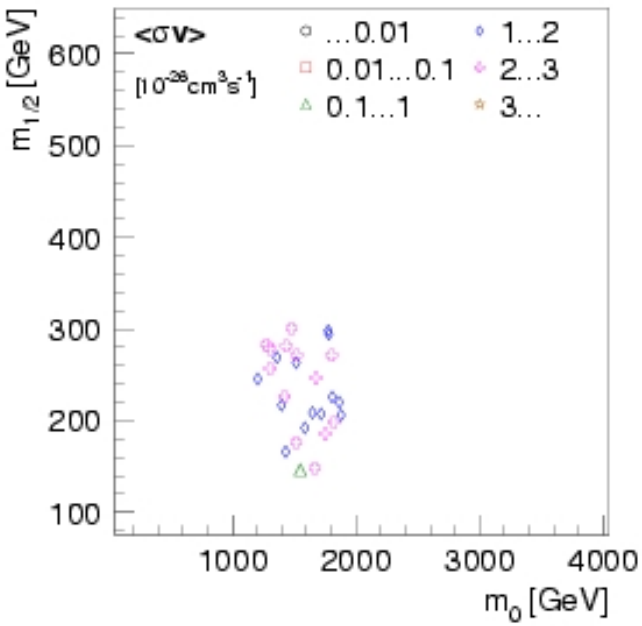
Including Constraint from Ωh^2

- Scatterplot of m_0, $m_{1/2}$ and $\tan\beta$; only parameter sets with correct RD are plotted
- Solutions at smallest $m_{1/2}$ yield at low T too small c.s. (p-wave) $\rightarrow$ large unphysical boost factors

wo. exp. constraints:



w. exp. constraints:



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Summary

- EGRET excess in the conventional Galactic model can be explained as Dark Matter annihilation of WIMPs in a mass range between 50 and 130 GeV
- Consistently determined Extragalactic background also shows a bump at interesting energies
- EGRET data are compatible with DM consisting of supersymmetric neutralinos $\Rightarrow$ together with constraints from EWSB, Higgs mass, $Br(b \rightarrow X_s\gamma)$, a_μ only a small region of mSUGRA parameter space is left over
- At large $\tan\beta$ and large m_0: Relic Density does not constrain parameter space
- Particle masses are in the discovery range of the LHC