Gamma Flux from SUSY Dark Matter Annihilation

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GALEON

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Sanchez-Conde, Prada, Lokas , Wojtak, Cannoni, MEG, PRD77(2007)+work in progress

The DM gamma signal

$$F_\gamma\left(E > E_{th}\right) = \frac{1}{4\pi} f_{susy} \cdot U(\Psi_o)$$

photons cm^{-2} s^{-1}

Particle physics

Astrophysics

SUSY Model:

$$f_{susy} = \frac{n_\gamma \langle \sigma \cdot v \rangle}{2 m_\chi{}^2}$$

- n_γ: Number of photons
- $<\sigma \cdot v>$: cross section
- m_χ: neutralino mass

'ery large uncertainties!

(No evidence as yet)

$$U(\Psi_o) = \int J(\Psi) B(\Omega) d\Omega$$

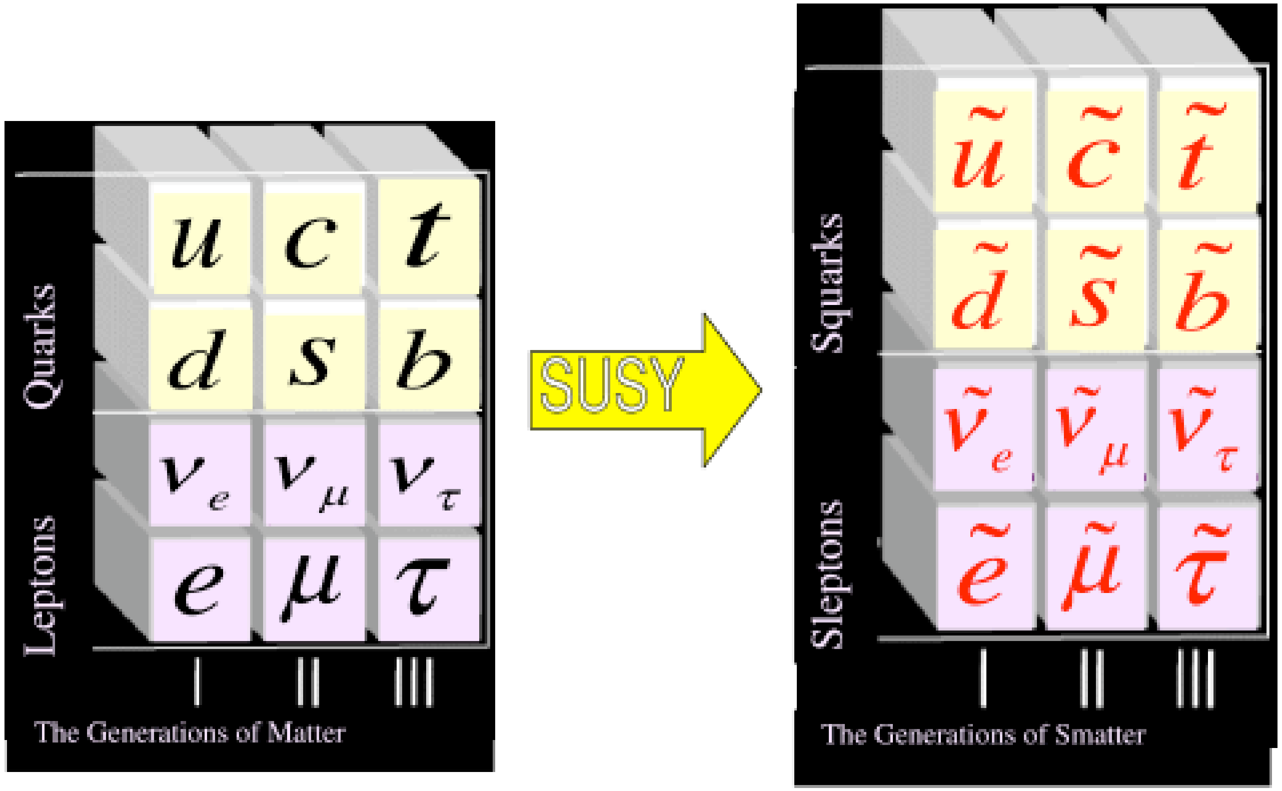
Integral along the l.o.s.: $J(\Psi) = \int_{l.o.s} \rho_{dm}^2(r) dl$

Telescope PSF: $B(\Omega) d\Omega = \exp\left(\frac{-\theta^2}{2\sigma_t{}^2}\right) \sin\theta d\theta d\phi$

Where to search?

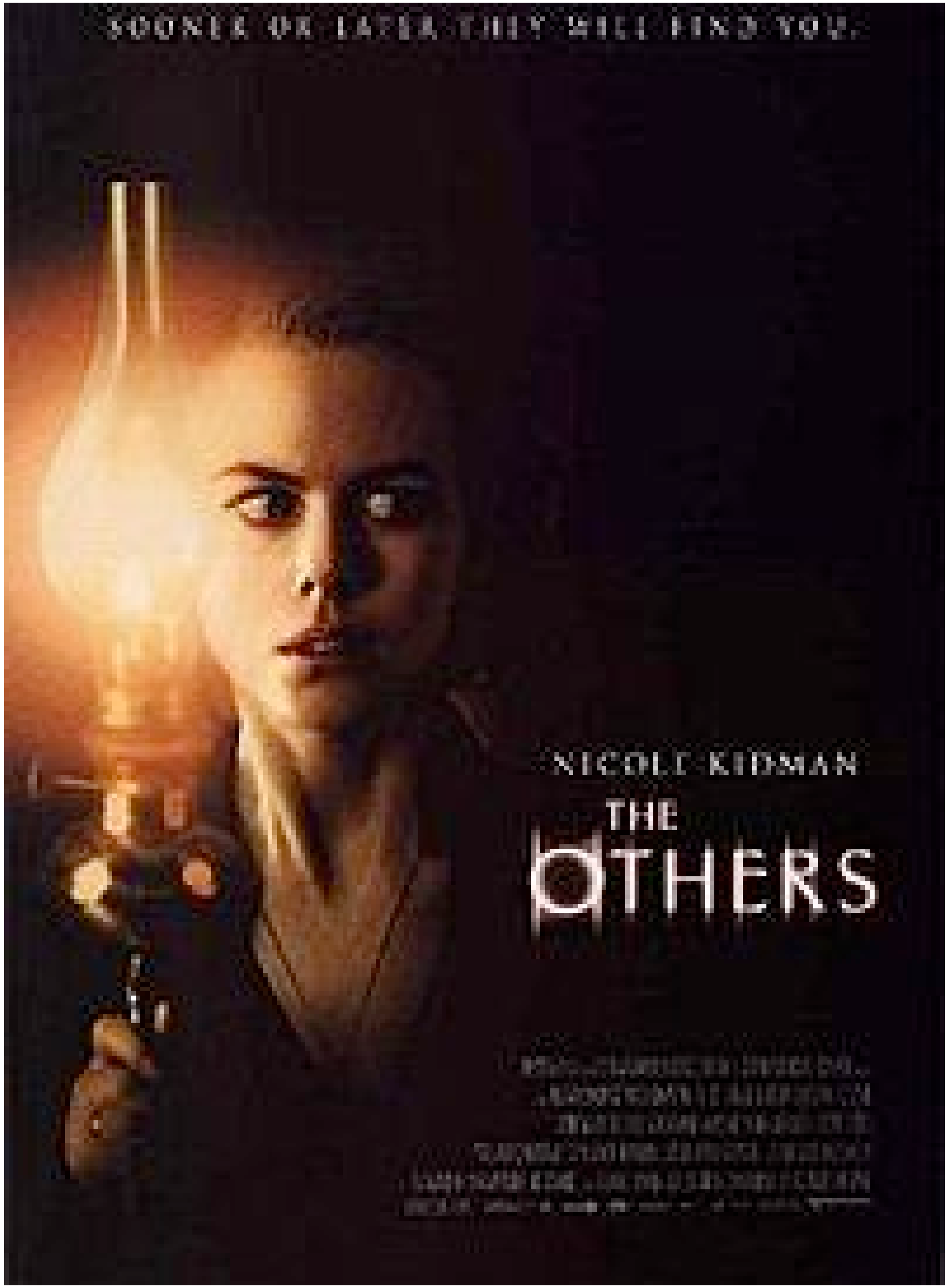
- Our galaxy (Galactic Center, substructure…)
- Dwarf spheroidal galaxies (e.g. Draco, Willman-1…)
- Andromeda
- Galaxy clusters (e.g. Virgo, Coma)

SuperSymmetric Extension of the SM

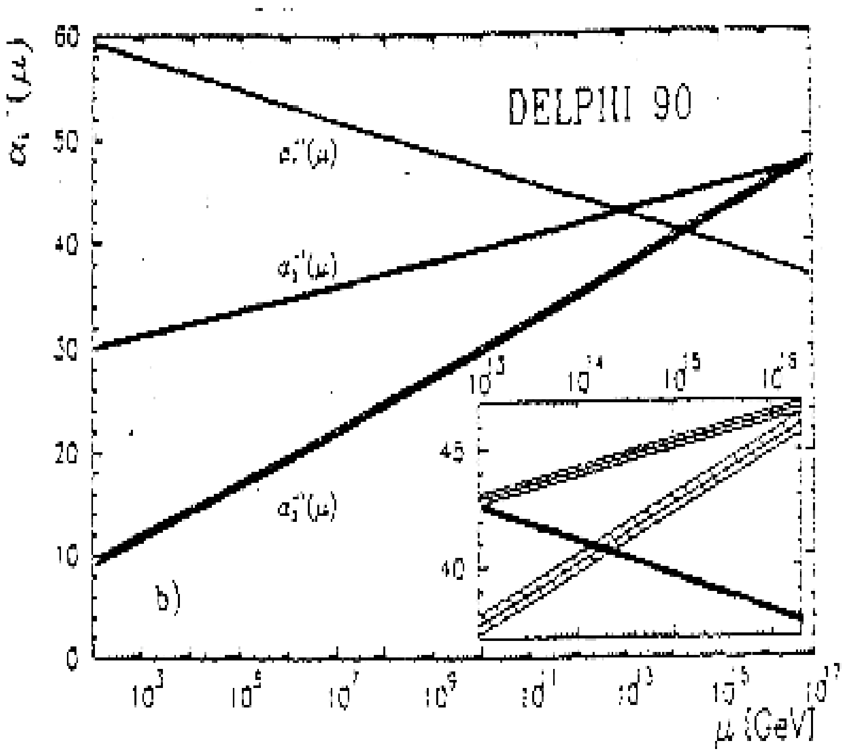


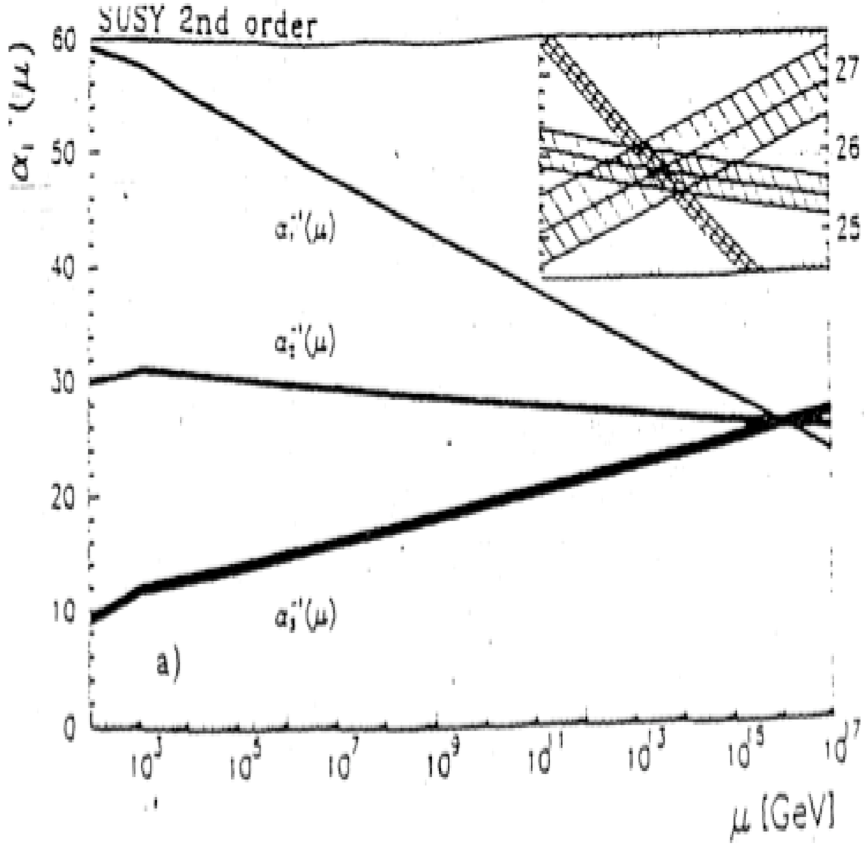
SUSY->fermion-boson Symmetry:

$$Q|Boson\rangle = |Fermion\rangle; \qquad Q|Fermion\rangle = |Boson\rangle$$


SOONER OR LATER THEY WILL FIND YOU.
NICOLE KIDMAN
THE OTHERS

Unification of the Interactions





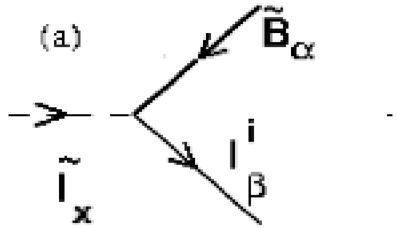
$$\mu \frac{d\alpha_i(\mu)}{d\mu} = -\frac{1}{2\pi}\,[b_i + \frac{1}{4\pi}\sum_j b_{ij}\alpha_j(\mu)]\;\alpha_i^2(\mu)$$

$$b_i = (0,-6,-9) + N_F(2,2,2) + N_H(3/10,1/2,0)$$

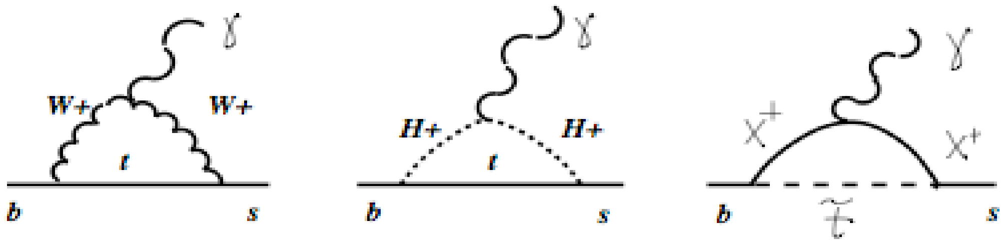
$$b_i = (0,-22/3,-11) + N_F(4/3,4/3,4/3) + N_H(1/10,1/6,0)$$

Hierarchy Problem:

R-parity warranties that SUSY particles only appear in pairs:



therefore SM model phenomenology is only modified at *loops level*:



The present average given by the

$$\mathrm{BR}(b \to s\gamma) = (3{,}55 \pm 0{,}24^{+0{,}09}_{-0{,}10} \pm 0{,}03) \times 10^{-4}$$

The SM prediction:

$$BR(b \to s\gamma) = (3.15 \pm 0.30) \times 10^{-4}$$

Soft SUSY Breaking Terms

The soft SUSY breaking masses

$$
\begin{aligned}
-\mathcal{L}_{\text{soft}} = & -\frac{1}{2}\left(M_3 \lambda_{\tilde{g}}^a \lambda_{\tilde{g}}^a + M_2 \lambda_{\widetilde{W}}^i \lambda_{\widetilde{W}}^i + M_1 \lambda_{\widetilde{B}} \lambda_{\widetilde{B}} + \text{h.c.}\right) \\
& + M_L^2 \widetilde{L}^\dagger \widetilde{L} + M_Q^2 \widetilde{Q}^\dagger \widetilde{Q} + M_U^2 \widetilde{U}^* \widetilde{U} + M_D^2 \widetilde{D}^* \widetilde{D} + M_E^2 \widetilde{E}^* \widetilde{E} + \\
& m_{H_d}^2 \widetilde{H}_d^\dagger \widetilde{H}_d + m_{H_u}^2 H_u^\dagger H_u - \left(B\mu \widetilde{H}_d^T H_u + \text{h.c.}\right) \\
& + \left(y_\ell A_\ell H_d^\dagger \widetilde{L}\widetilde{E} + y_d A_d H_d^\dagger \widetilde{Q}\widetilde{D} - y_u A_u H_u^T \widetilde{Q}\widetilde{U} + \text{h.c.}\right),
\end{aligned}
$$

Inspired from supergravity assume universal soft breaking, $\mathcal{L}_{\text{soft}}$:

$$
\sum_{f,H} m_0^2 \tilde{f}\tilde{f} + \sum_{\lambda} m_{\frac{1}{2}} \lambda\lambda + \sum_{f} A_0 Y_f \tilde{f}\tilde{F} H_f + B\mu H_u H_d
$$

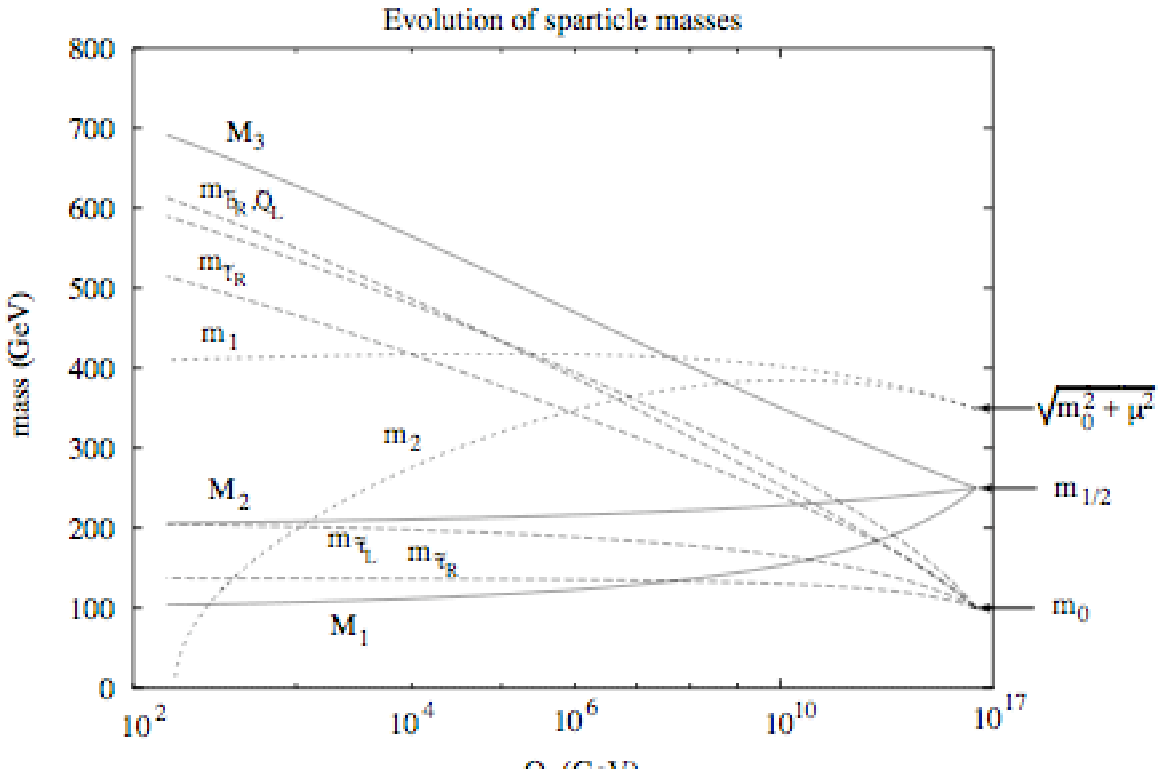
$m_0,\ m_{\frac{1}{2}},\ A_0,\ \tan\beta,\ \text{sign}(\mu)$

μ and A_0 can be complex, however their phases contraint to be $< 0{,}2$ rad by the bounds on the fermion EDM.

SUSY spectrum

CMSSM, mSUGRA. Parametros de masa universales:

$$m_0,\ M_{1/2},\ A_0,\ \mu_0,\ \alpha_G,\ M_{GUT},\ \tan\beta\ .$$

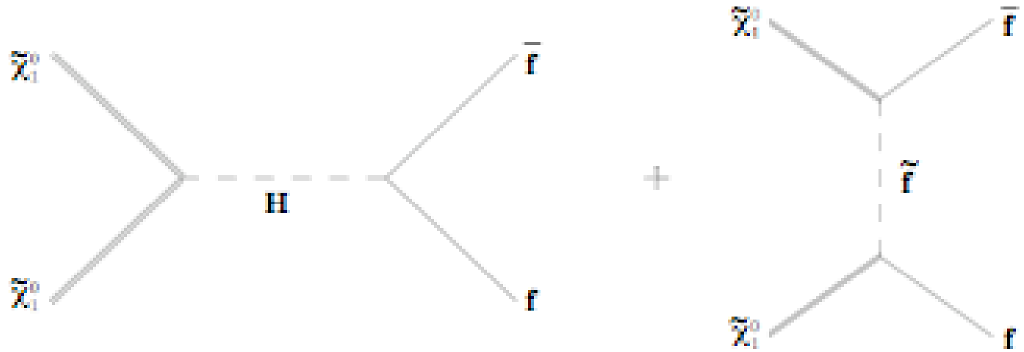


LSP, WIMP candidate

The lightest SUSY particle (LSP or χ) is in general the lightest neutralino:

$$\begin{pmatrix} M_1 & 0 & -m_Z s_{\theta_W} c_\beta & m_Z s_{\theta_W} s_\beta \\ 0 & M_2 & m_Z c_{\theta_W} c_\beta & -m_Z c_{\theta_W} s_\beta \\ -m_Z s_{\theta_W} c_\beta & m_Z c_{\theta_W} c_\beta & 0 & -\mu \\ m_Z s_{\theta_W} s_\beta & -m_Z c_{\theta_W} s_\beta & -\mu & 0 \end{pmatrix}$$

in the basis $\tilde{B}, \tilde{W}_3, \tilde{H}_u, \tilde{H}_d$. They can only coanihilate when they find each other:



its relic density is of the order of magnitude needed to fit WMAP data

$$\Omega h^2 \sim \frac{3 \times 10^{-27} \mathrm{cm}^3 s^{-1}}{\langle \sigma_{\mathrm{ann}} v_{Mol} \rangle}$$

Goldberg 83, Ellis et al 84

The LSP on the CMSSM

In the CMSSM the LSP is almost a pure Bino, since σ_{ann} is small Ω_χ is, in general, *very big*. The regions on the parameter space predicting $\Omega_\chi h^2$ in the WMAP bounds,

$$0{,}94 < \Omega_\chi h^2 < 0{,}129$$

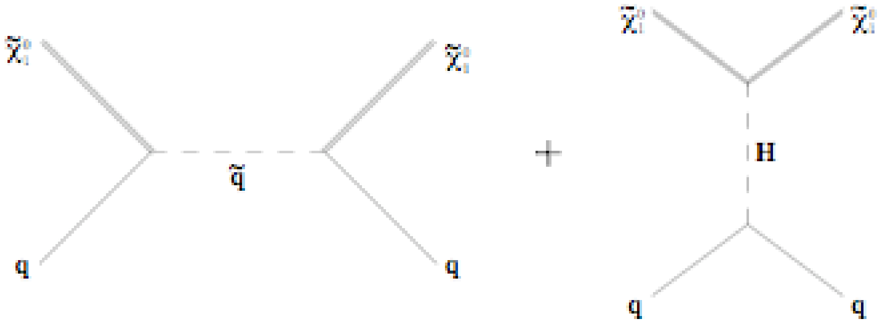
Are "fine tuned" in the sense:

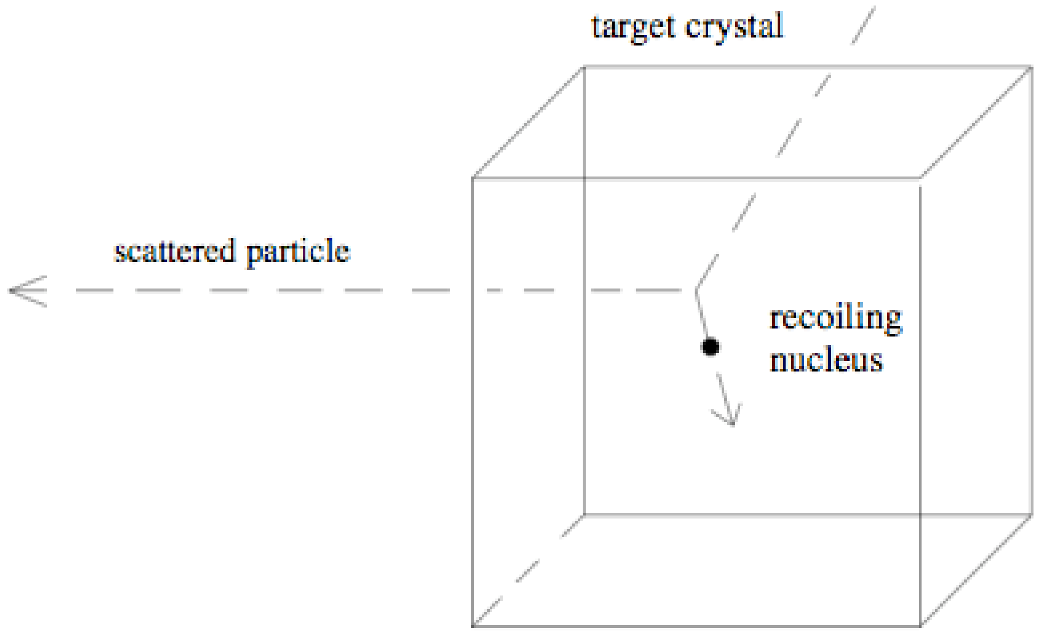
- Coanihilation area, where $m_{\tilde{\tau}} \simeq m_\chi$. χ_0 is bino like.
- Focus-point/ Hyperbolic Branch, here μ is small. Low values of $m_{\frac{1}{2}}$ and big m_0. χ_0 can have sizeable higgsino components. New channels $(WW, ZH$, etc) and coanihilations $\chi - \chi^+$
- Resonnances in the Higgs mediated channels, here $m_A \simeq 2m_\chi$. The dominant channels are the pseudoscalar higgs mediated to give $f\bar{f}$ in the final states. This region requires large $\tan\beta$. χ_0.

INITIAL STATE	FINAL STATE	INTERACTION CHANNELS
$\tilde{\chi}\tilde{\chi}$	$f\bar{f}$	$s(h), s(H), s(A), s(Z)$
	(f: Fermions)	$t(\tilde{f}_{1,2}), u(\tilde{f}_{1,2})$
	$H^{\pm}W^{\mp}$	$s(h), s(H), s(A), t(\tilde{\chi}_i^{\pm}), u(\tilde{\chi}_i^{\pm})$
	hA, ZH	$s(A), s(Z), t(\tilde{\chi}_i^0), u(\tilde{\chi}_i^0)$
$\tilde{\chi}\tilde{\tau}_2$	$\tau h, \tau H, \tau Z$	$s(\tau), t(\tilde{\tau}_{1,2}), u(\tilde{\chi}_i^0)$
	τA	$s(\tau), t(\tilde{\tau}_1), u(\tilde{\chi}_i^0)$
	$\tau\gamma$	$s(\tau), t(\tilde{\tau}_2)$
	$\nu_\tau H^-, \nu_\tau W^-$	$s(\tau), t(\tilde{\chi}_i^{\pm}), u(\tilde{\nu}_\tau)$
$\tilde{\tau}_2\tilde{\tau}_2$	$\tau\tau$	$t(\tilde{\chi}_i^0), u(\tilde{\chi}_i^0)$
$\tilde{\tau}_2\tilde{\tau}_2^*$	hh, hH, HH, ZZ	$s(h), s(H), t(\tilde{\tau}_{1,2}), u(\tilde{\tau}_{1,2})$, PI
	AA	$s(h), s(H), t(\tilde{\tau}_1), u(\tilde{\tau}_1)$, PI
	H^+H^-, W^+W^-	$s(h), s(H), s(\gamma), s(Z), t(\tilde{\nu}_\tau)$, PI
	$H^{\pm}W^{\mp}$	$s(h), s(H), t(\tilde{\nu}_\tau)$
	AZ	$s(h), s(H), t(\tilde{\tau}_1), u(\tilde{\tau}_1)$
	$\gamma\gamma, \gamma Z$	$t(\tilde{\tau}_2), u(\tilde{\tau}_2)$, PI
	$t\bar{t}, b\bar{b}$	$s(h), s(H), s(\gamma), s(Z)$
	$\tau\bar{\tau}$	$s(h), s(H), s(\gamma), s(Z), t(\tilde{\chi})$

Neutralino Direct Detection

Neutralino-Matter interaction is very weak





Experimental Prospects

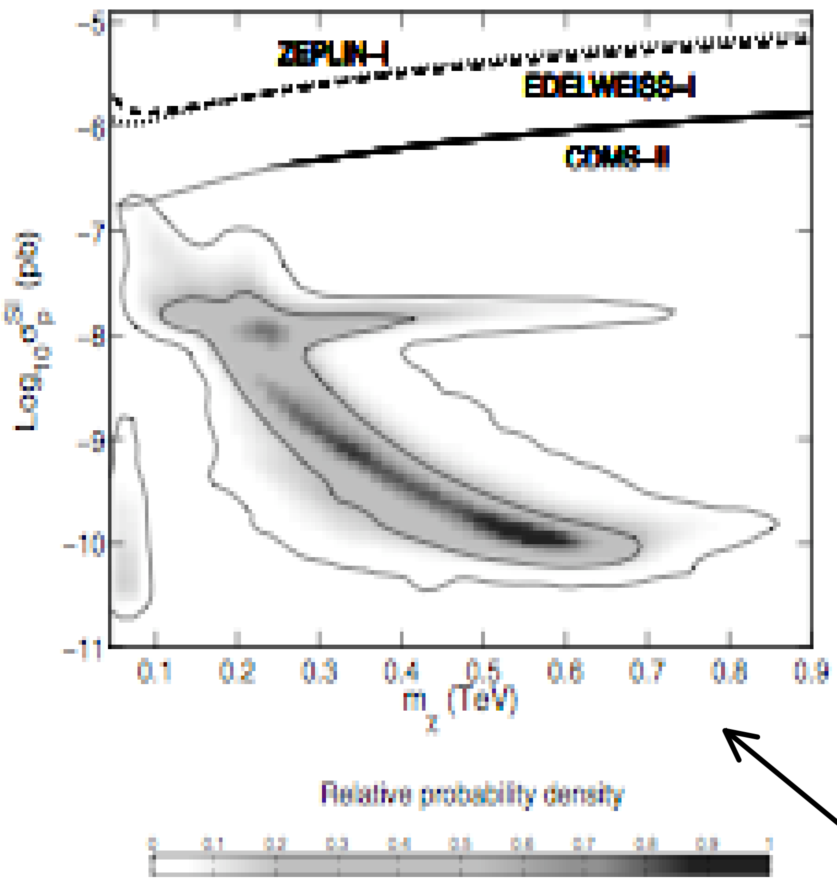
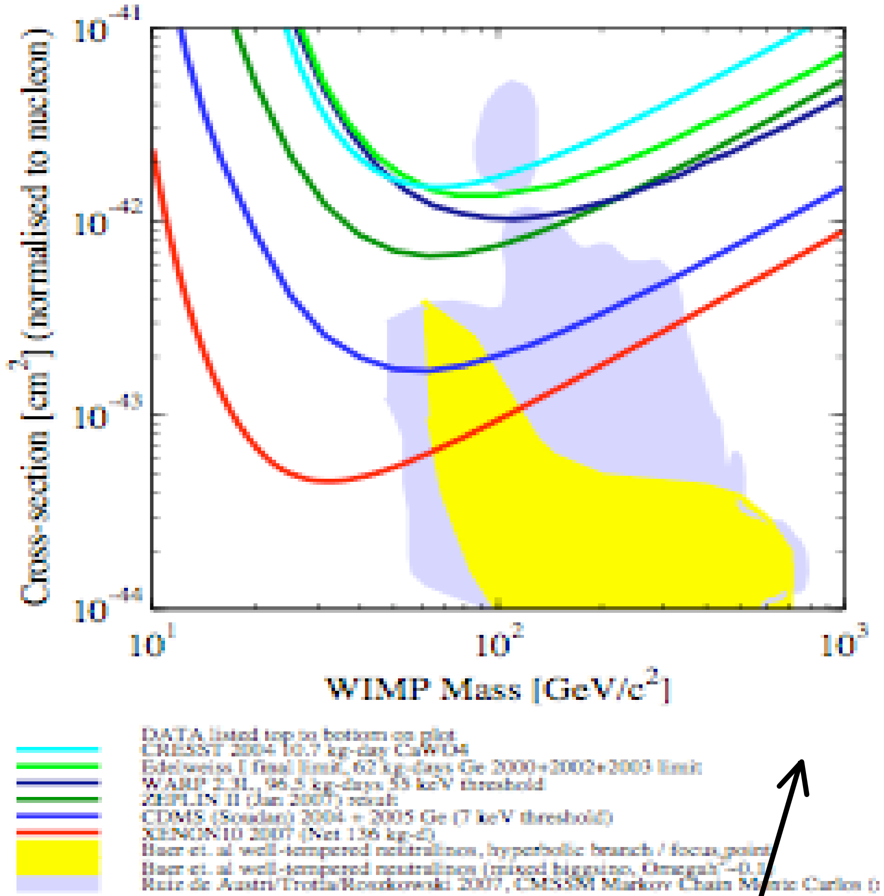


Figure 1. The 2-dimensional probability density in the neutralino mass and spin-independent cross section plane in the CMSSM (all other parameters marginalized) with the contours containing 68% and 95% probability also marked. Current 90% experimental upper limits are also shown. A large fraction of the high-probability region lies just below current constraints and it will be probed by the next generation of dark matter searches, starting from the focus point region (horizontal region at $\sigma_p^{SI} \sim 10^{-8}$).



Ruiz de Austri, Roszkowski, Trotta

Baudis 0902.4253

Indirect Dark Matter Searches

* Detectability of gamma rays coming from the annihilation of SUSY DM particles.
* IACTs and satellites: MAGIC, HESS, VERITAS, CANGAROO, Fermi, AGILE…

IACT example: MAGIC

E. range: 100 GeV - 30 TeV

E. resolution: >20%

FOV: ≈ 4 deg.

Angular resolution: ≈ 0.1º

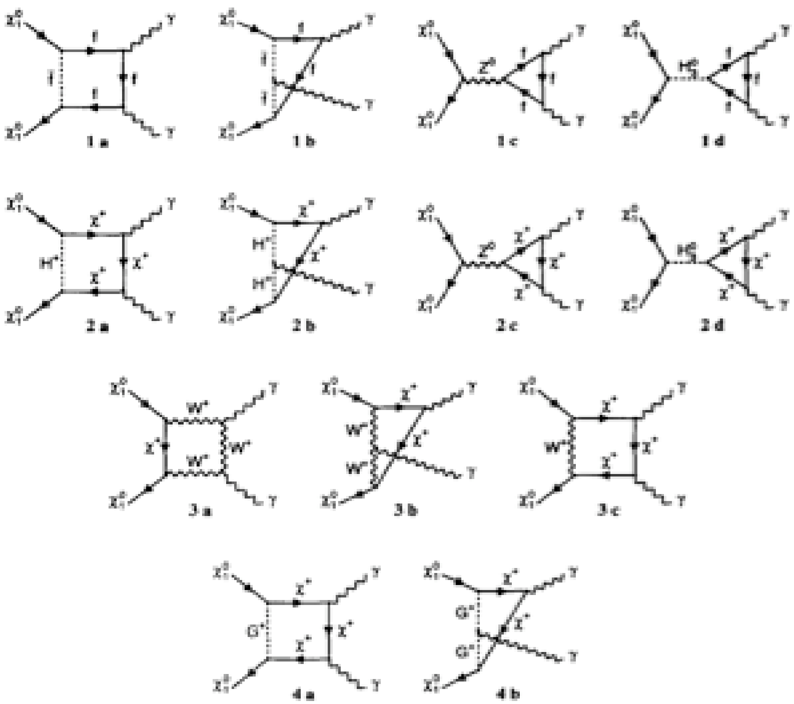
LSP Anihilation into Gammas

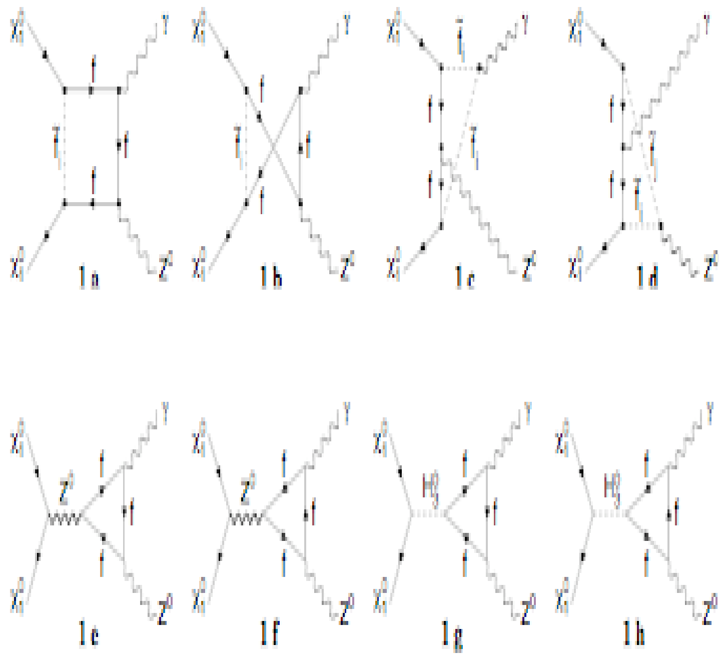
Subdominant channels because:

❖**Loop Supressed Monoenergetic Channels:**

$$\chi + \chi \rightarrow \gamma\gamma \qquad\qquad \chi + \chi \rightarrow Z\gamma$$

L. Bergström, P. Ullio / Nuclear Physics B 504 (1997) 27–44





$$E_\gamma \sim m_\chi \qquad\qquad E_\gamma \sim m_\chi - \frac{m_Z^2}{4m_\chi}$$

Continuum Spectrum

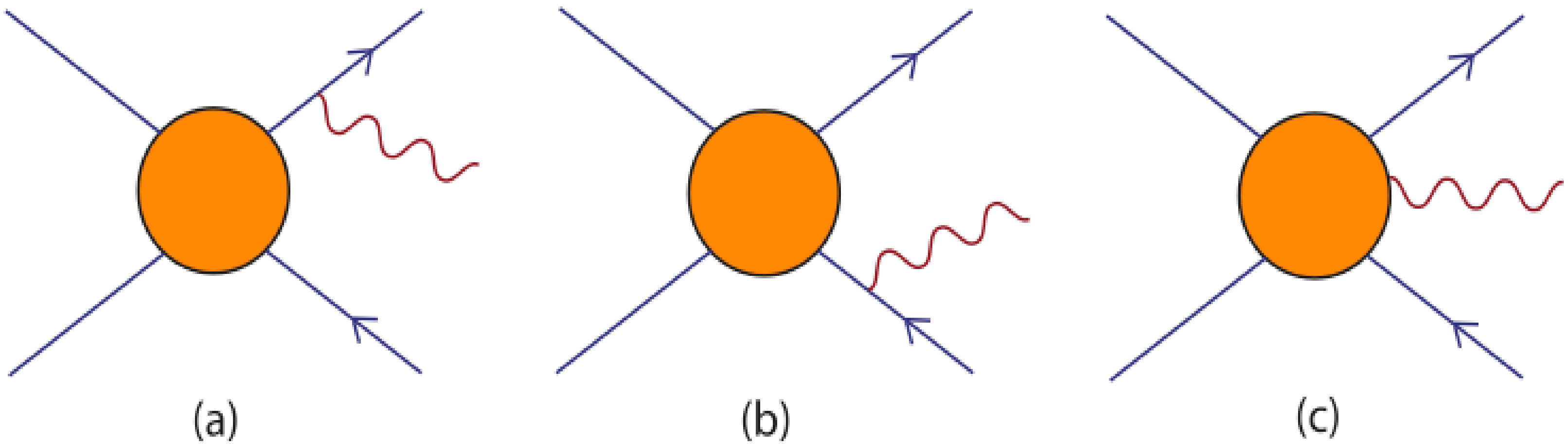
❖ Secondary Gamma's from annihilation's:

$$\chi\chi \to \cdots \to \pi^0 \to \gamma\gamma$$

Computation of the number of Gammas/Annihilation requires one event simulator (DarkSusy uses PHYTIA).

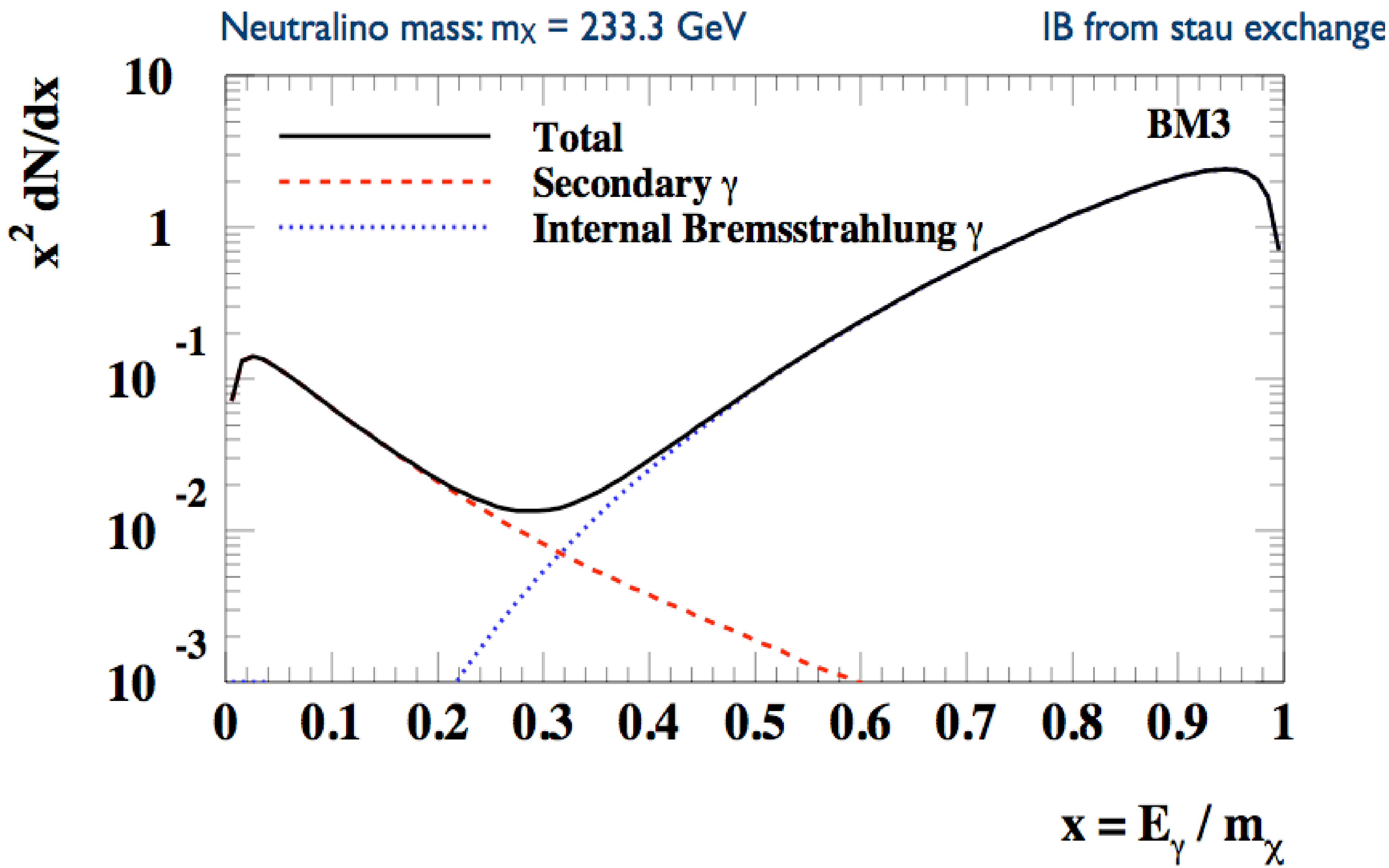
Internal Bremsstrahlung

From annihilation channels with charged particles on the final state:



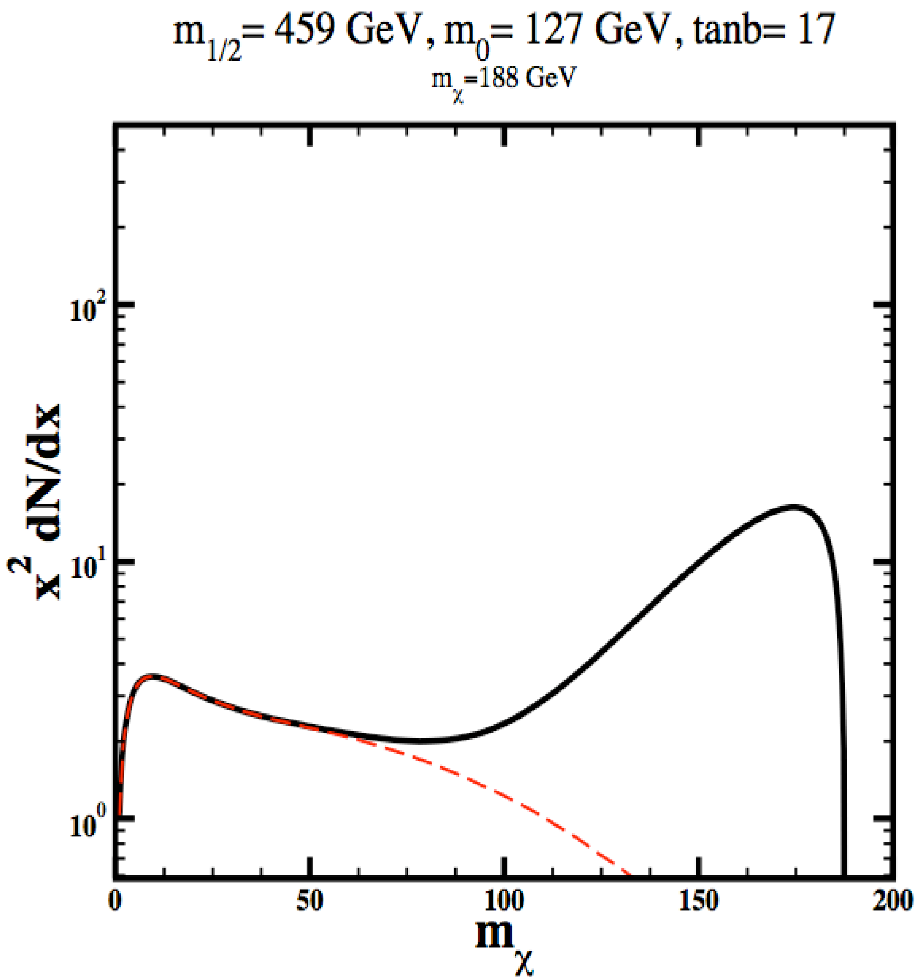
Bringmann, Bergstrom, Edsjo 2008
and references there in.

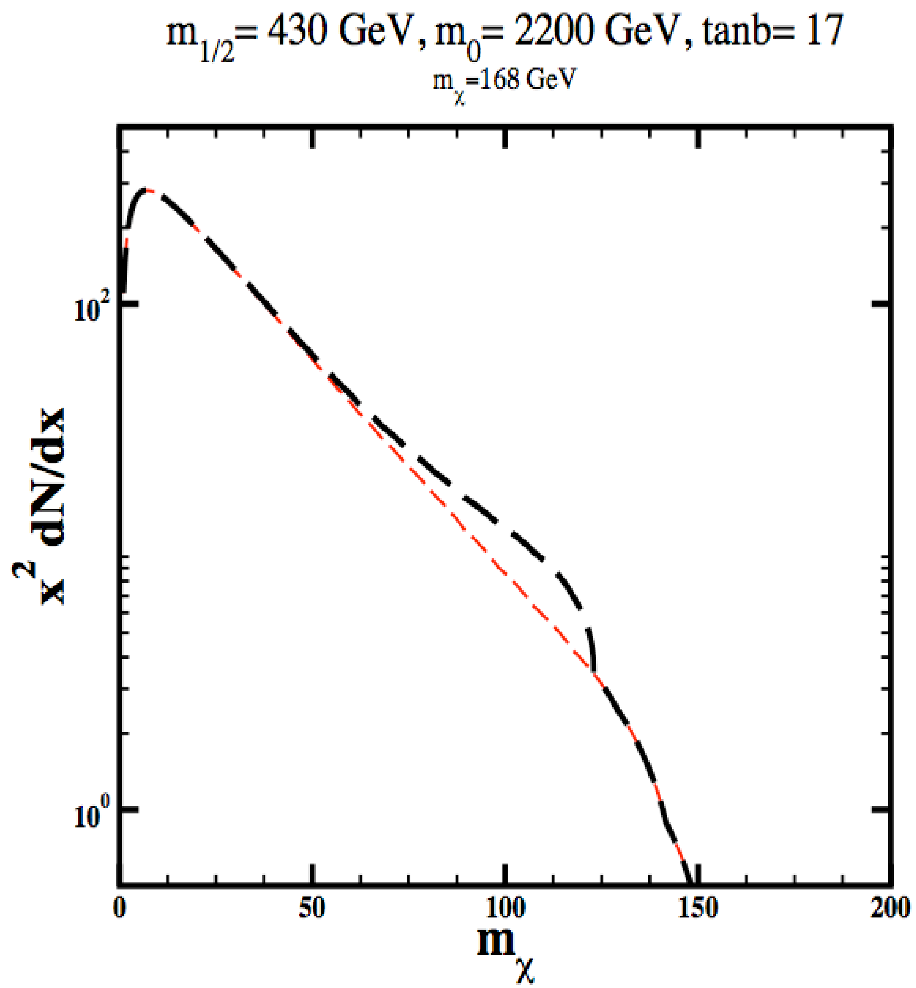
Example



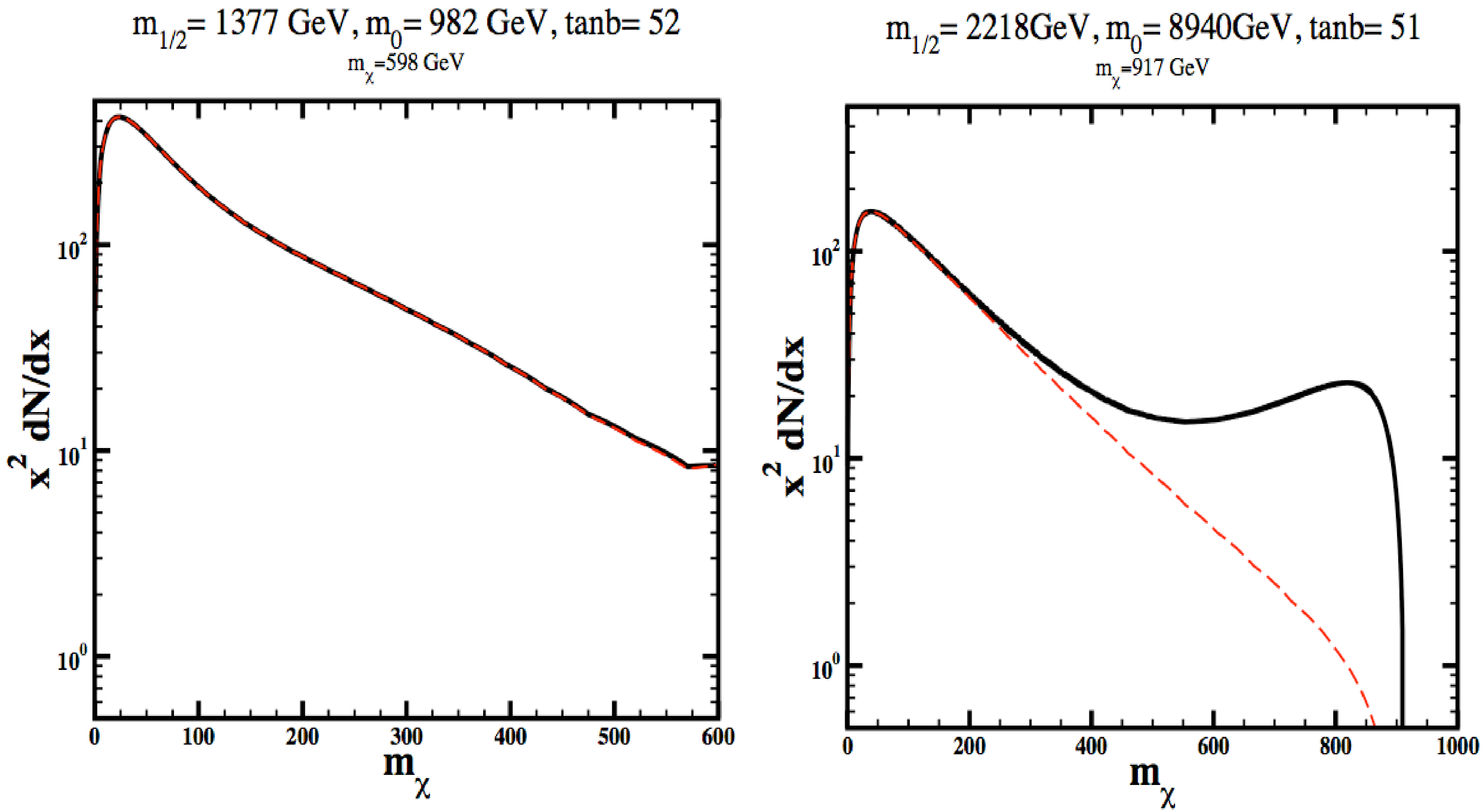
T. Bringmann, L. Bergstrom and J. Edsjo, JHEP 01 (2008) 049

More examples

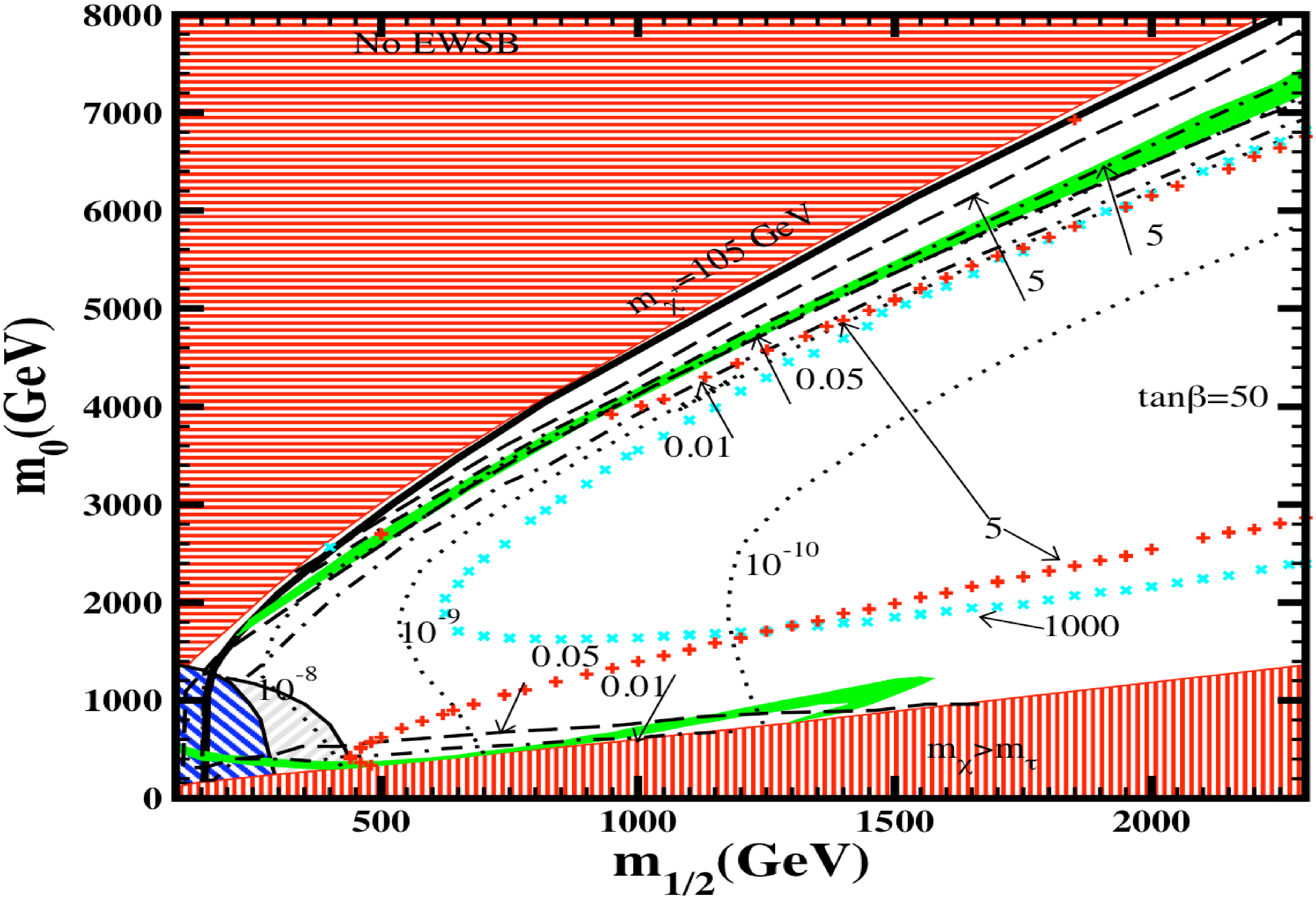




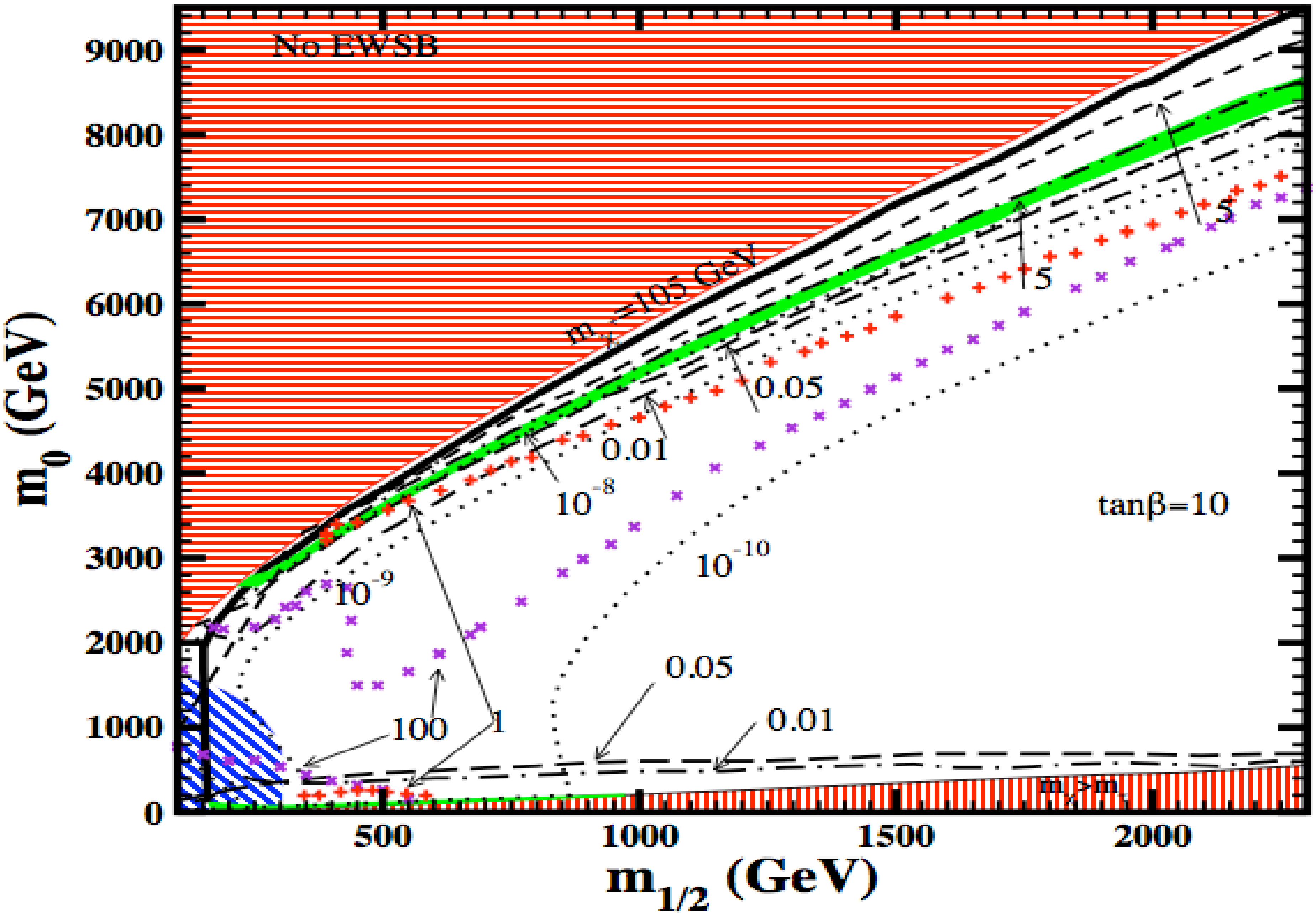
More examples, large tanb



mSUGRA Parameter Space, Large tanβ



Parameter Space Low tanβ



THE GAMMA-RAY FLUX IN IACT'S

Flux above a certain Eth:

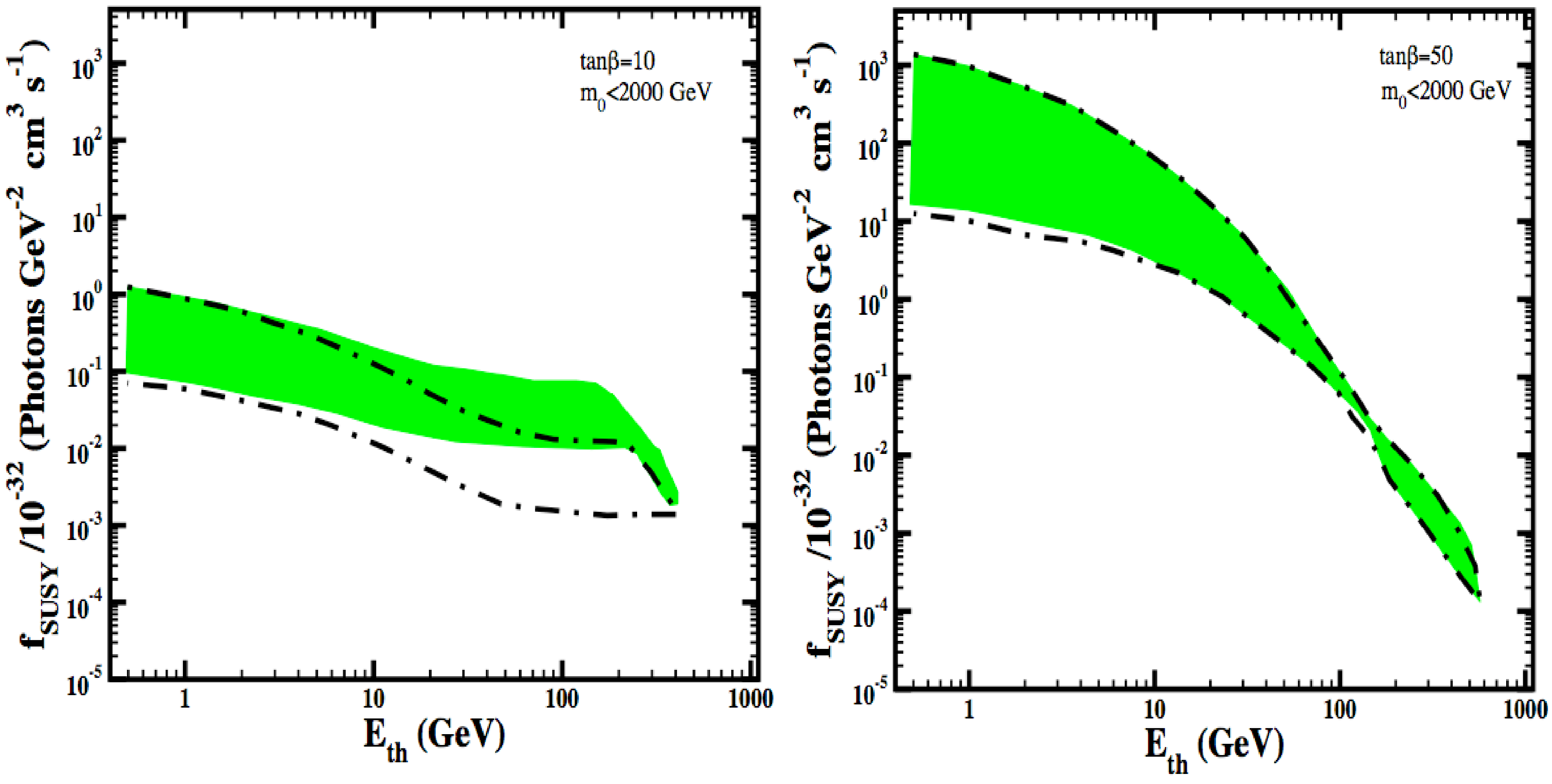
$$F(E > E_{\text{th}}) = \frac{1}{4\pi} f_{\text{SUSY}} \cdot U(\Psi_0)$$

Particle Physics

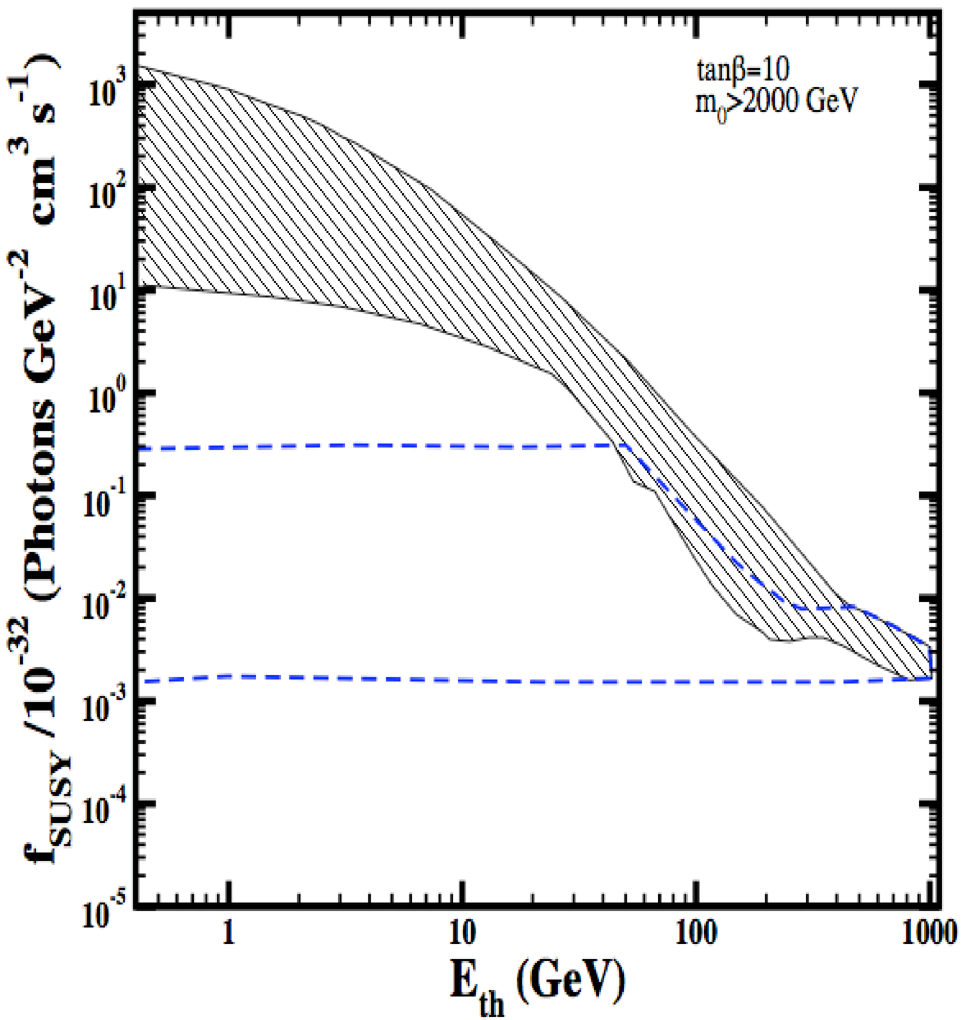
Astrophysical

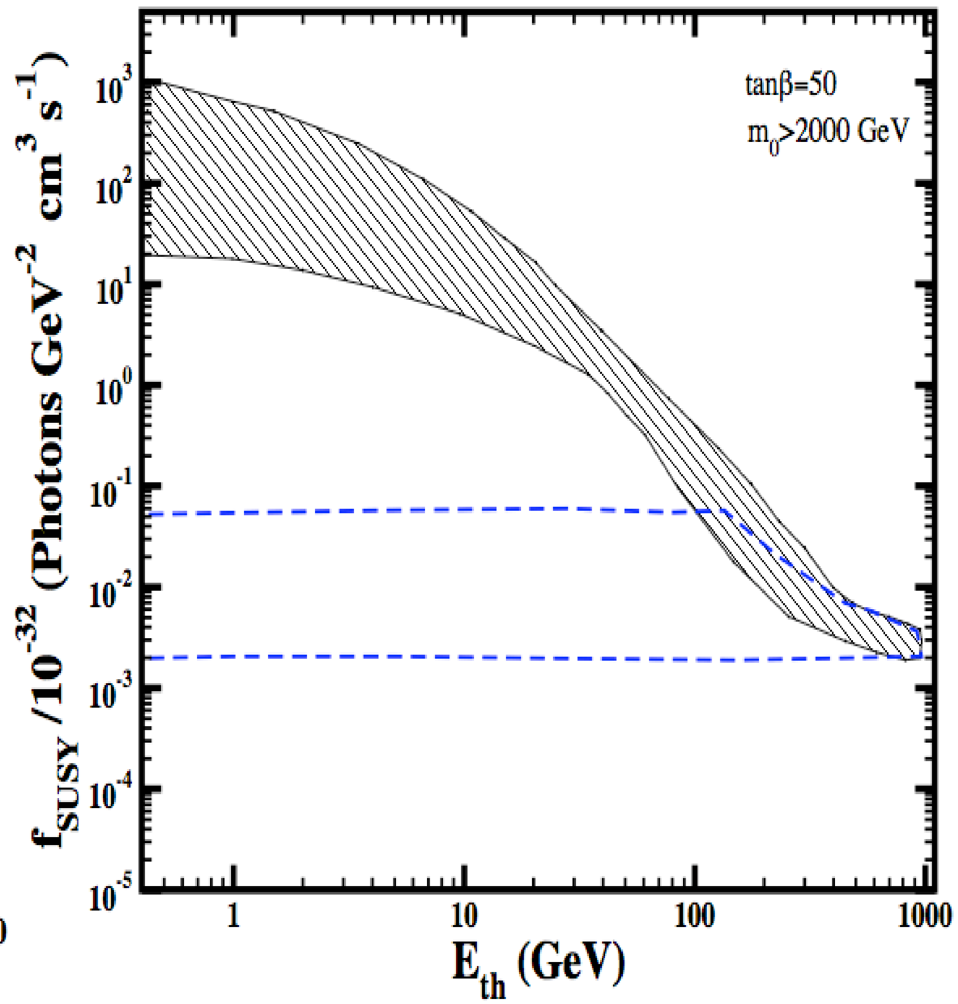
$$f_{\text{SUSY}} = \frac{\theta(E_{\text{th}} > m_\chi) \cdot 2\langle v\sigma_{\gamma\gamma}\rangle}{2m_\chi^2} + \frac{\theta(E_{\text{th}} > m_\chi - \frac{m_Z^2}{4m_\chi}) \cdot \langle v\sigma_{\gamma Z}\rangle + k\langle v\sigma_{\text{cont.}}\rangle}{2m_\chi^2}$$

M_0 <2000 GeV

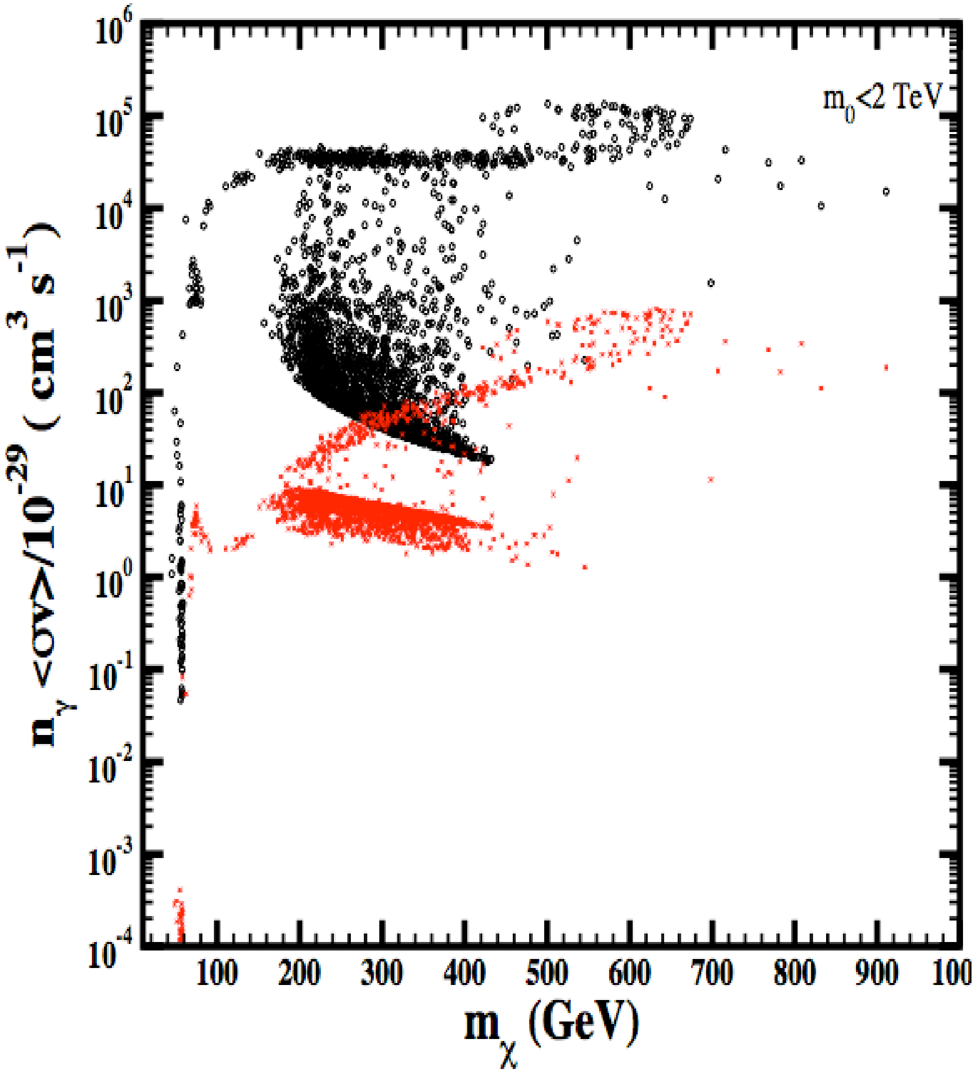

tanβ=10
m0<2000 GeV
tanβ=50
m0<2000 GeV
f_{SUSY} /10^{-32} (Photons GeV^{-2} cm^3 s^{-1})
E_{th} (GeV)
1
10
100
1000

M0 >2000 GeV

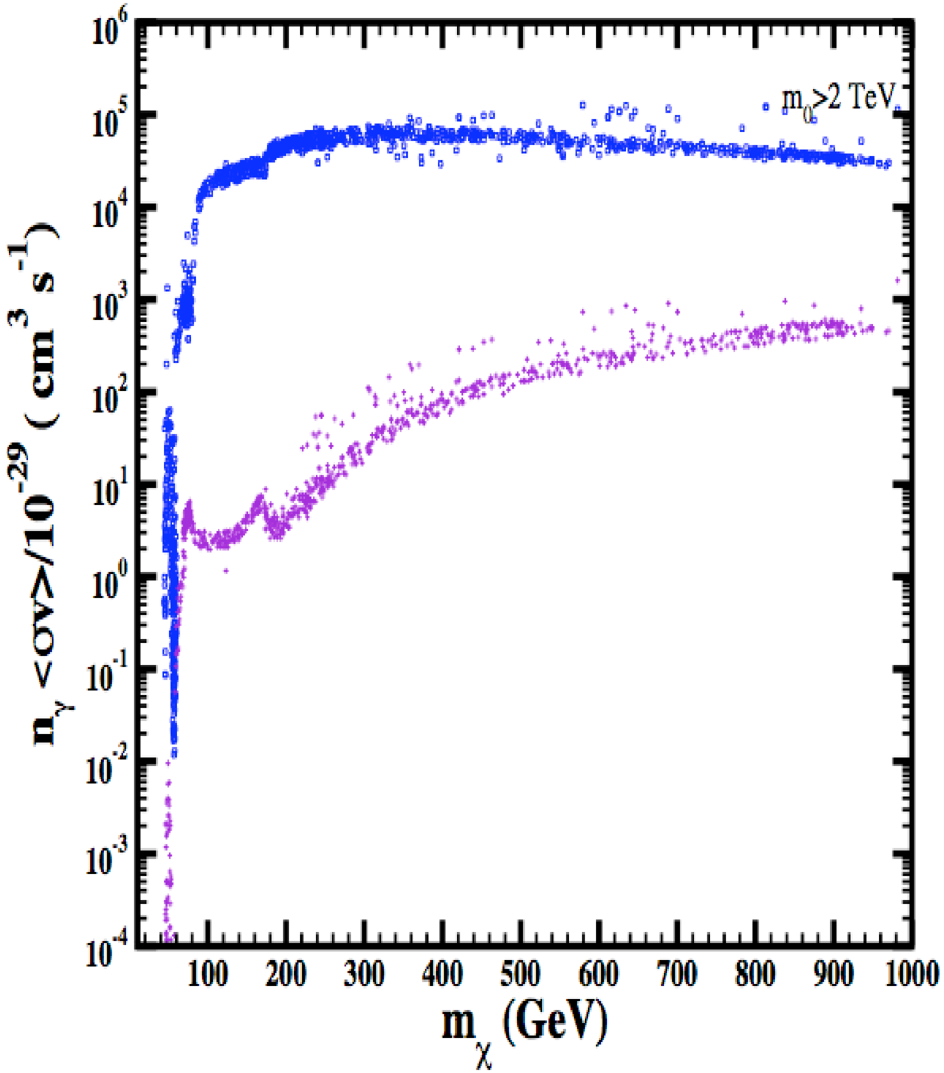

tanβ=10
m0>2000 GeV
f_SUSY /10^-32 (Photons GeV^-2 cm^3 s^-1)
E_th (GeV)
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
1
10
100
1000


tanβ=50
m0>2000 GeV
f_SUSY /10^-32 (Photons GeV^-2 cm^3 s^-1)
E_th (GeV)
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
1
10
100
1000

mSUGRA



m_0<2 TeV
$n_\gamma <\sigma v>/10^{-29}$ (cm^3 s^{-1})
m_χ (GeV)



m_0>2 TeV
$n_\gamma <\sigma v>/10^{-29}$ (cm^3 s^{-1})
m_χ (GeV)

Gammas from dSph galaxies

- DSphs are the most DM dominated systems known in the Universe: very high M/L ratios.
- Many of them nearer than 100 kpc from the GC (e.g. Draco, UMi and new SDSS dwarfs).
- Most of them are expected to be free from any bright astrophysical gamma source.
  - Low content in gas and dust.
  - In contrast with that expected in the GC, nearby galaxies and galaxy clusters.

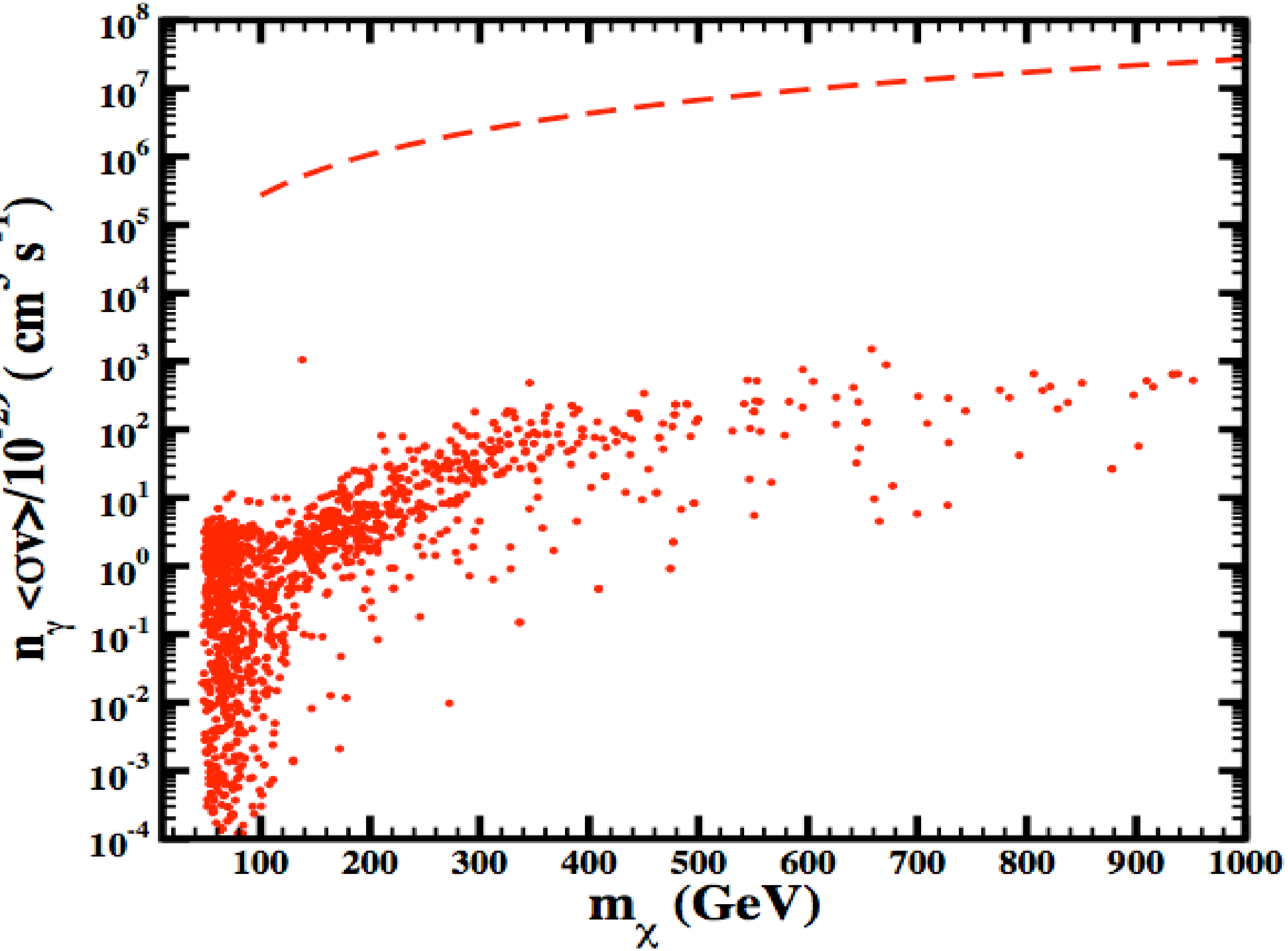
Observations of Draco with MAGIC

- ***Draco is probably the dSph with more observational constraints.***
- ***Near (80 kpc from the GC).***
- ***M/L ~ 300***
- ***High in the Northern Sky --> suitable for MAGIC***

MAGIC observations and analysis

- Total Observation Time of 7.8 HOURS (may 2007)
- Zenith Angle ranges between 29º and 42º
- Calibration of the data and Hillas parameterization of the shower images
- Hadronic background supression and energy estimation by Random Forest method

Results from MAGIC I



Conclusion

- **Neutralinos are the most "admired/studied" candidates to explain the DM problem.**

- **Their annihilation rates are small enough to account for WMAP data. However, the annihilation channels with Gammas in the final states are subdominant: Ether loop supressed or produce a continuum of secondary gammas.**

- dSph galaxies can be studied as good sources of Gamma rays. For the analysed case of Draco (and also Willman) the predicted upper bounds are a few orders of magnitude above the detection limits.