Gamma Flux from SUSY Dark Matter Annihilation

Mario E. Gómez

Universidad de Huelva, Spain

GALEON

Universidad de Huelva

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

The DM gamma signal

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

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
- $\langle \sigma \cdot v \rangle$: 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:

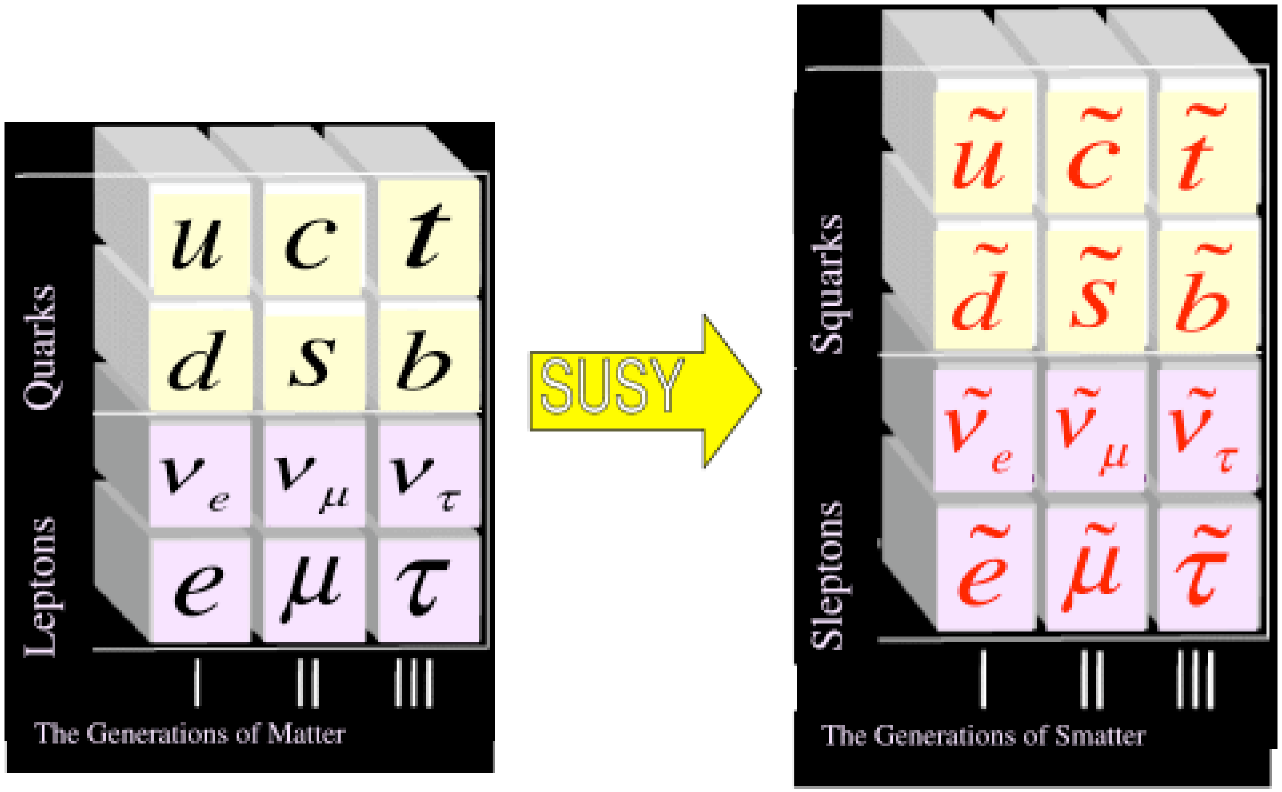
$$B(\Omega) d\Omega = \exp\left(\frac{-\theta^2}{2\sigma_t^2}\right) \sin\theta d\theta d\phi$$

Where to search?

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

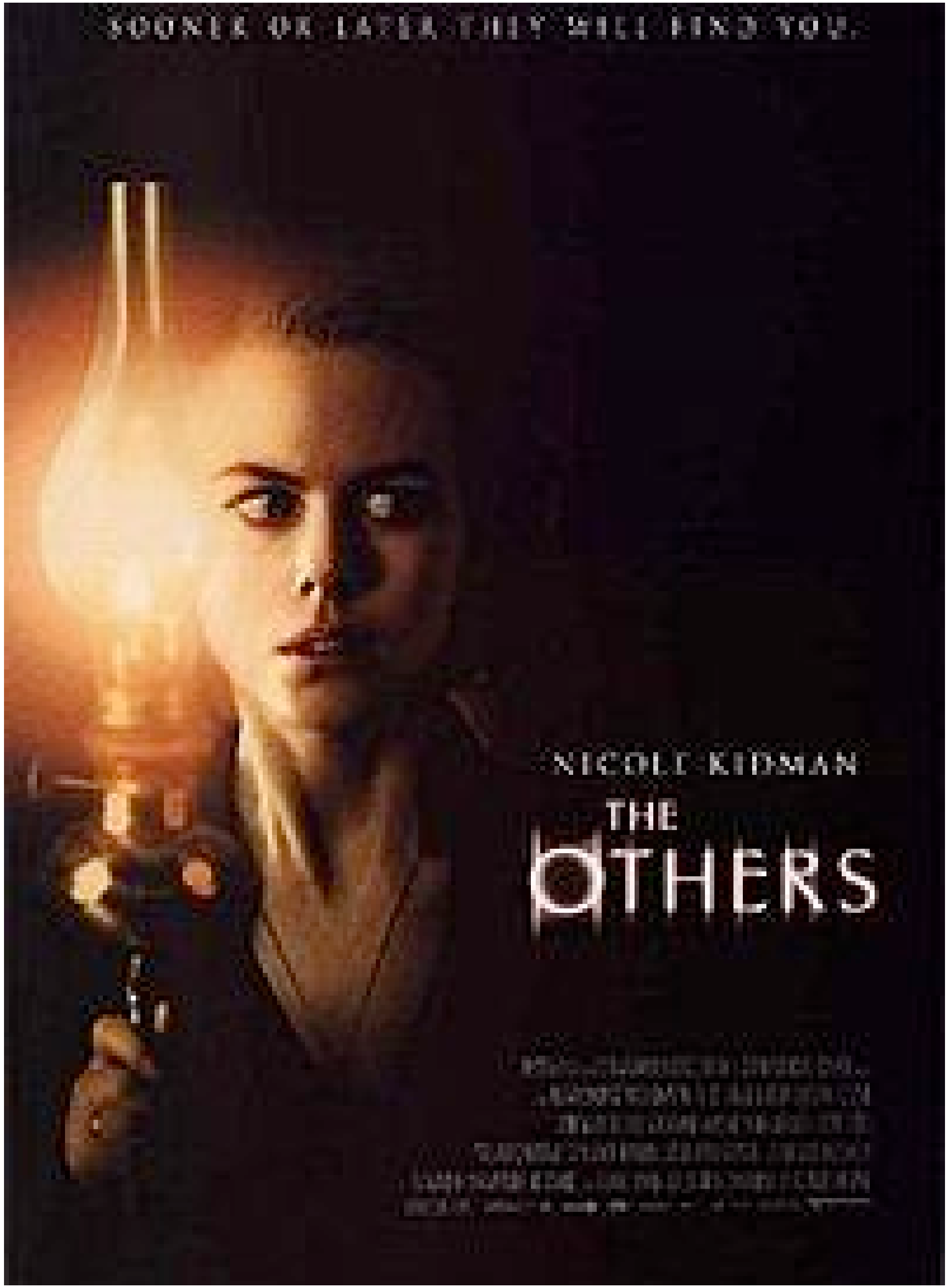
(Sánchez-Conde, Prada, Lokas, Gómez et al. 2007)

SuperSymmetric Extension of the SM

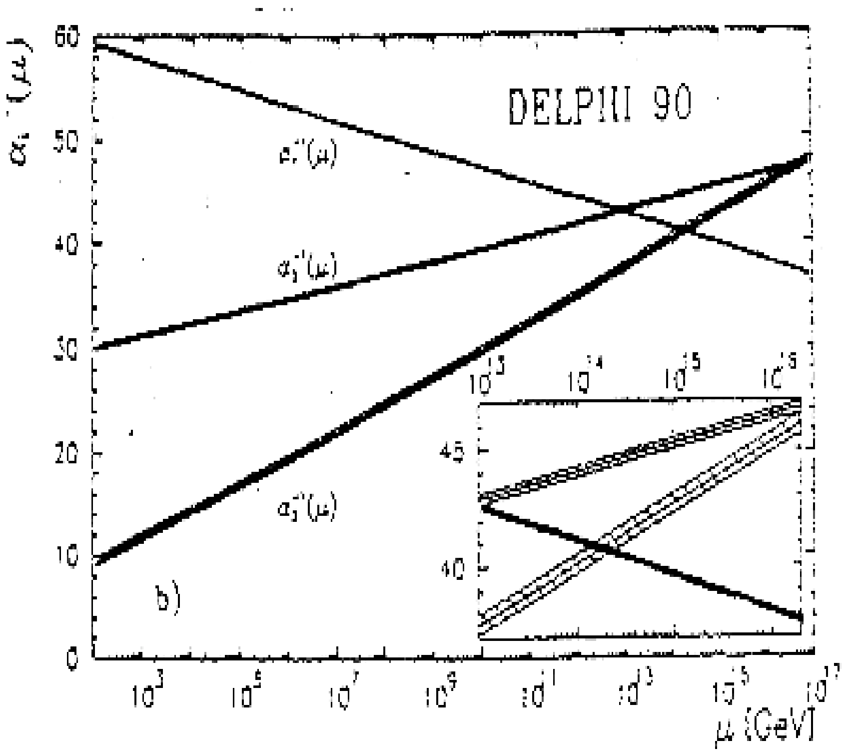


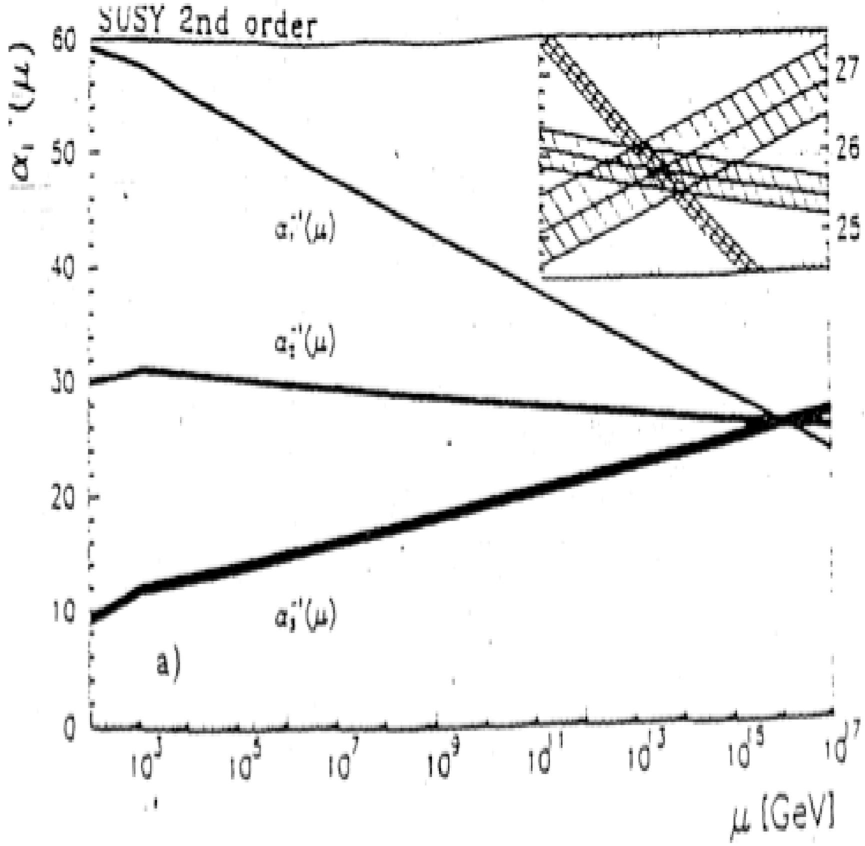
SUSY->fermion-boson Symmetry:

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


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

Unification of the Interactions



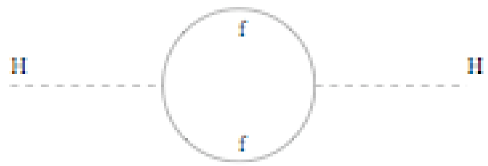


$$\mu \frac{d\alpha_i(\mu)}{d\mu} = -\frac{1}{2\pi}\left[b_i + \frac{1}{4\pi}\sum_j b_{ij}\alpha_j(\mu)\right]\alpha_i^2(\mu)$$

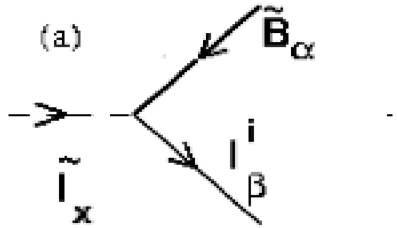
$$b_i = (0,-6,-9) + N_F(2,2,2) + N_H(3/10,1/2,0)$$

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

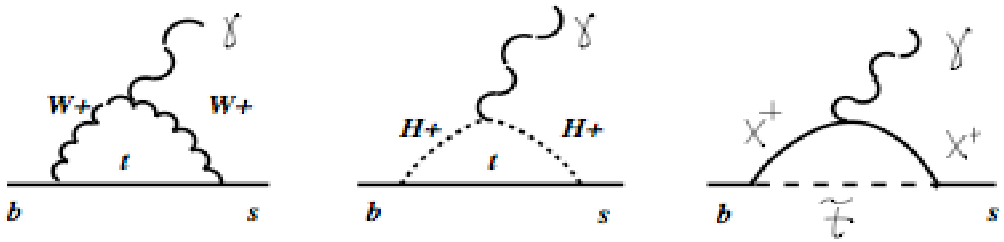
Hierarchy Problem:



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

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

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

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

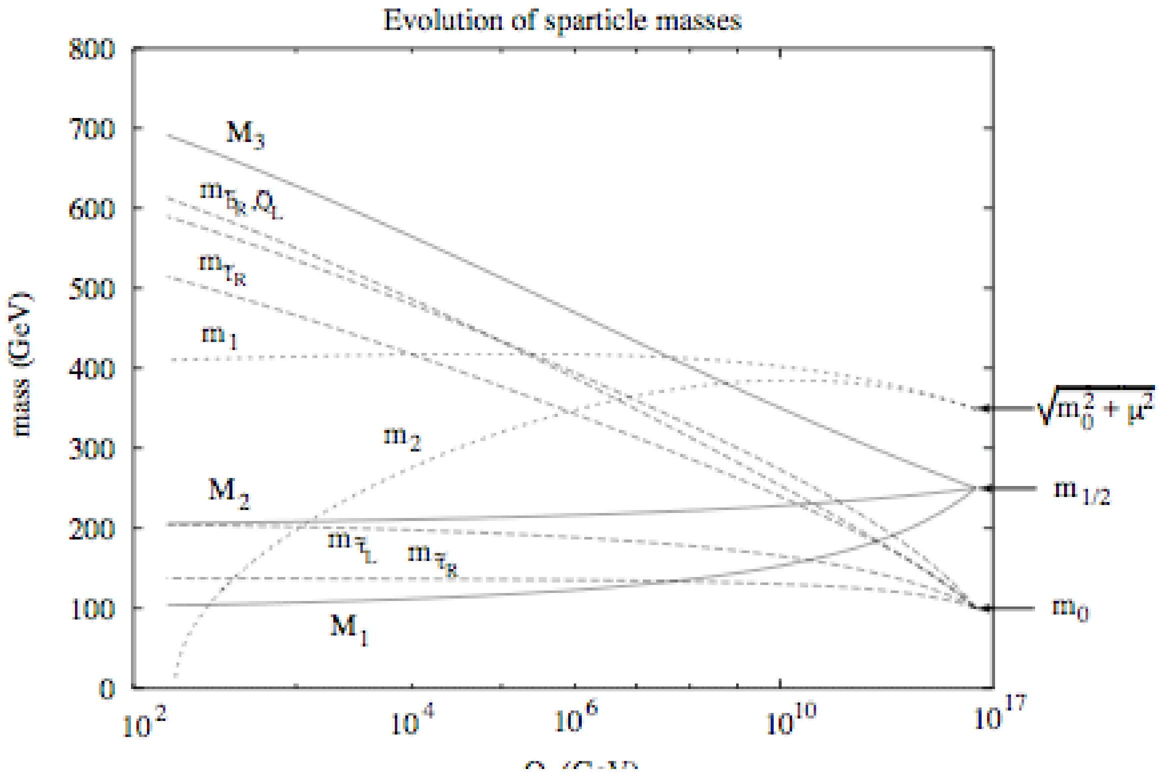
$m_0,\ m_{\frac{1}{2}},\ A_0,\ \tan\beta,\ \text{sign}(\mu)$

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:

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

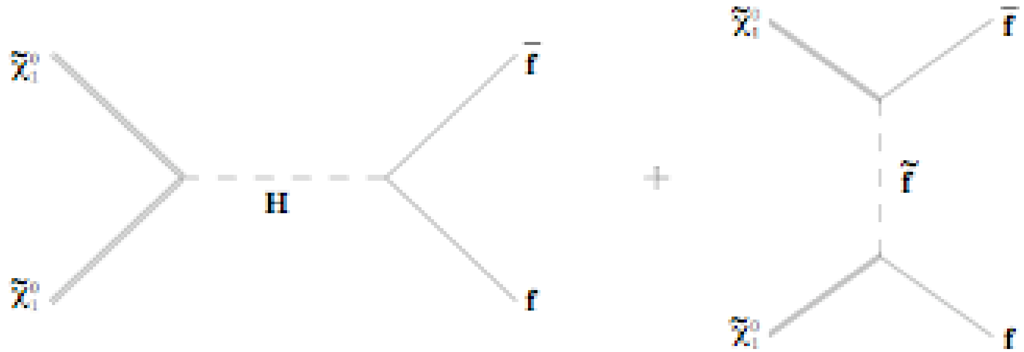


LSP, WIMP candidate

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,

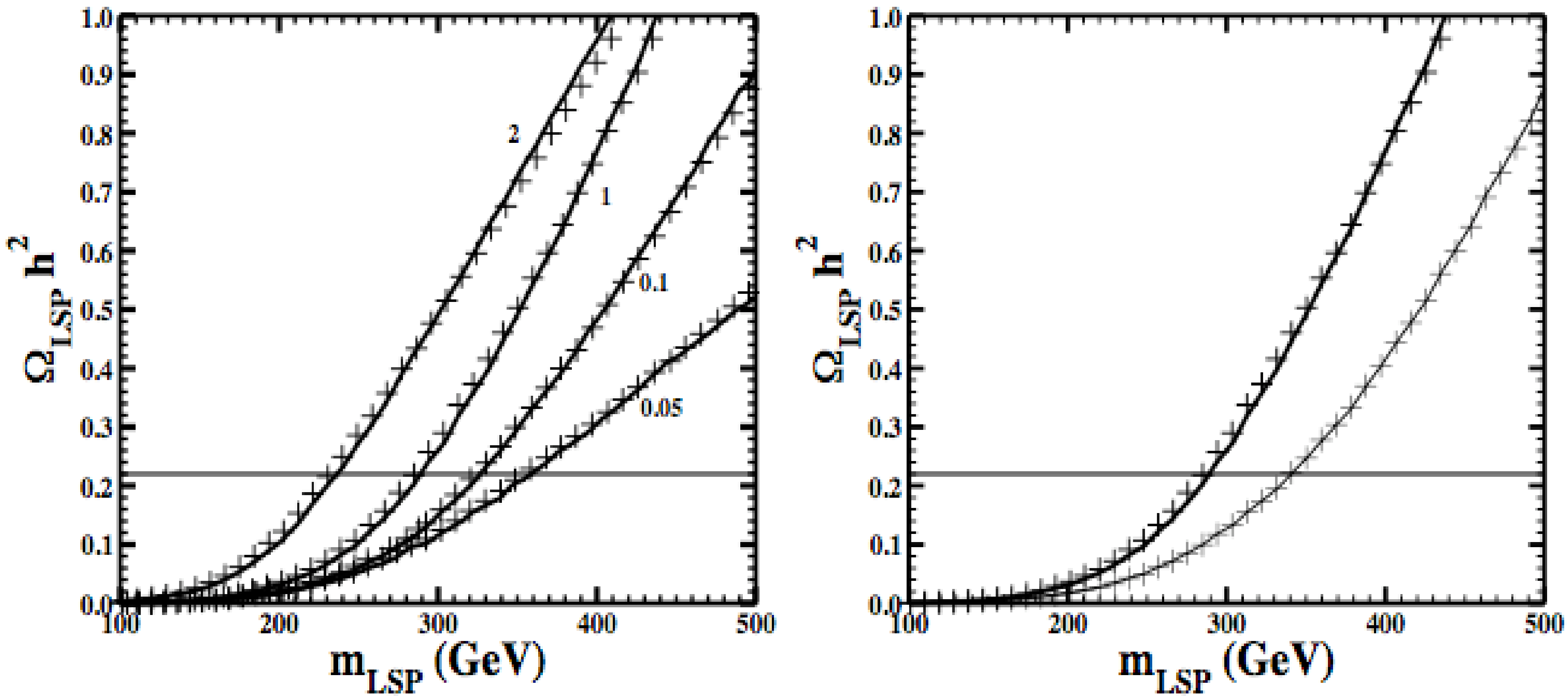
$$0{,}94 < \Omega_\chi h^2 < 0{,}129$$

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
	$t\bar{t}, b\bar{b}$	$s(h), s(H), s(\gamma), s(Z)$
	$\tau\bar{\tau}$	$s(h), s(H), s(\gamma), s(Z), t(\tilde{\chi})$

Relic Density Channels

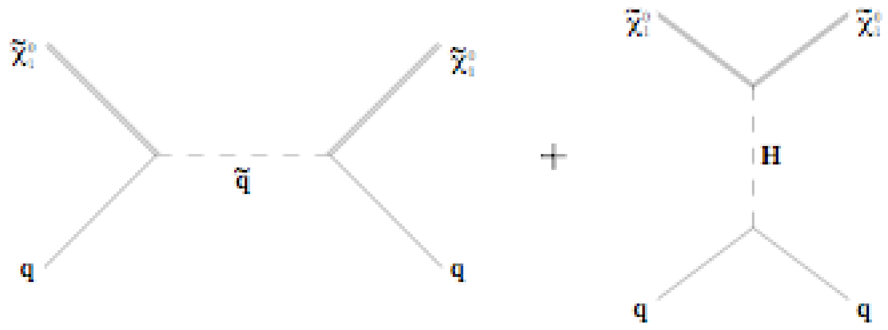


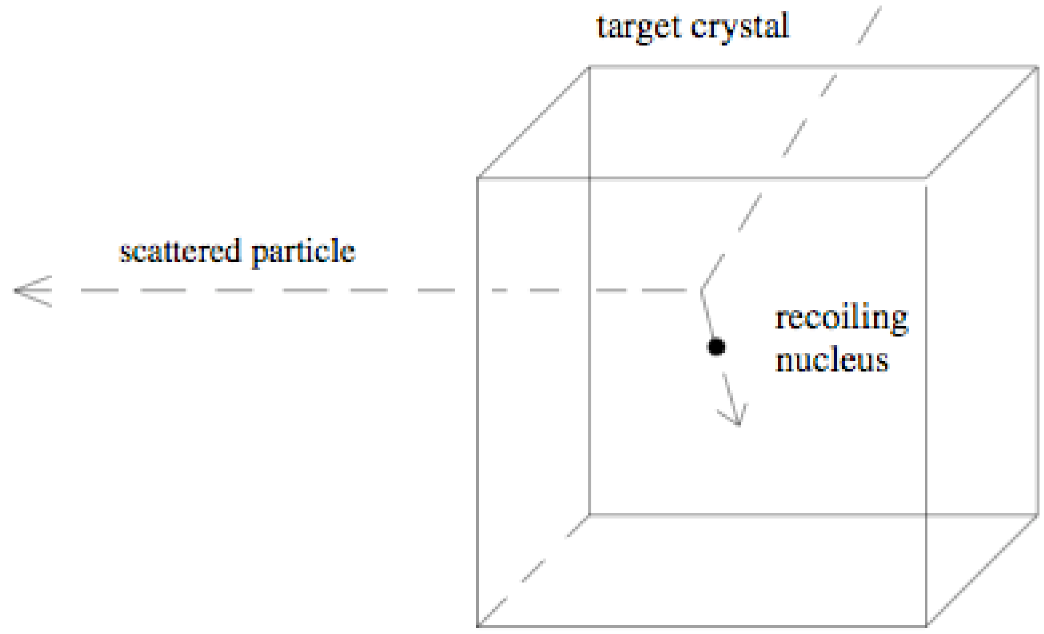
Gondolo,Edsjo 1997, Lazarides, Pallis , M.E.G.

Very good public codes MICROMEGAS (Belanger et al), DarkSusy (Gondolo et al.)

Neutralino Direct Detection

Neutralino-Matter interaction is very weak





Experimental Prostpects

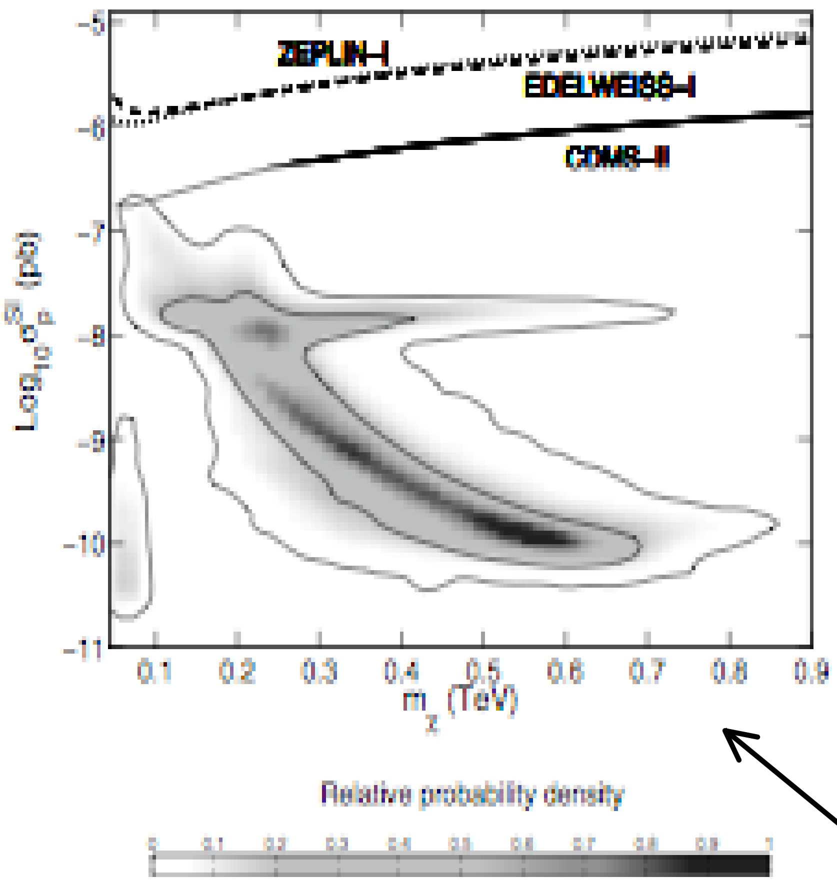
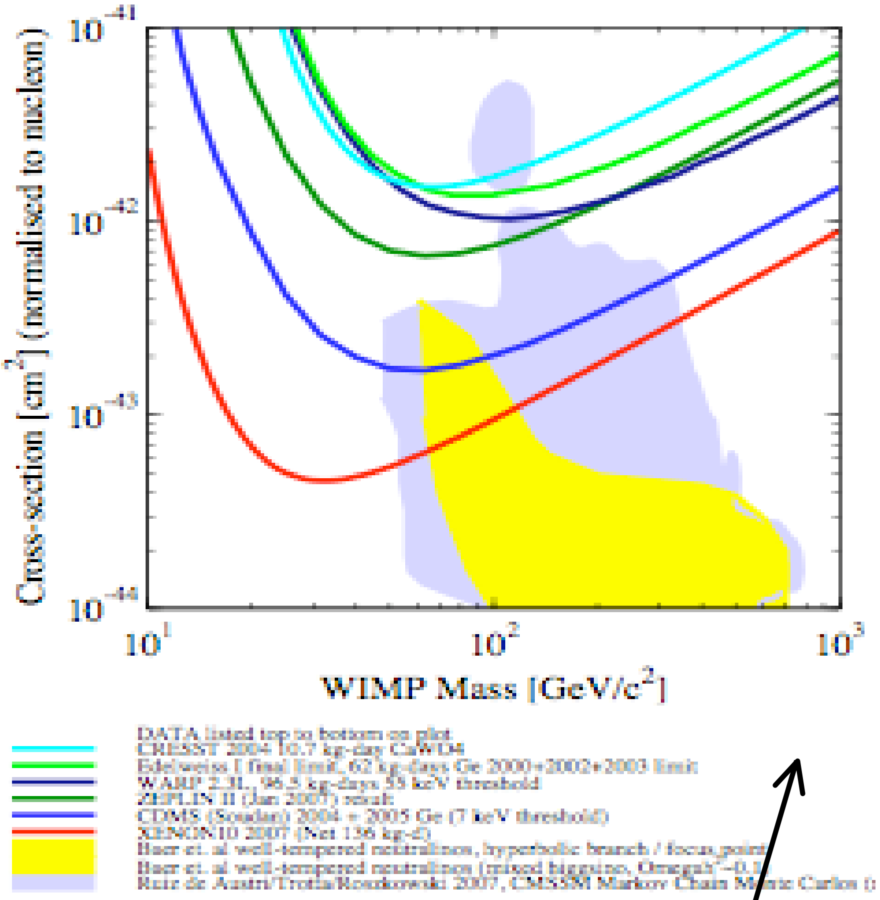


Figure 1. The 2-dimensional probability density in the neutralino mass and spin-independent cross section plane in the CMSSM (all other parameters marginalized) with the contours containing 68% and 95% probability also marked. Current 90% experimental upper limits are also shown. A large fraction of 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: ≈ 0.1°

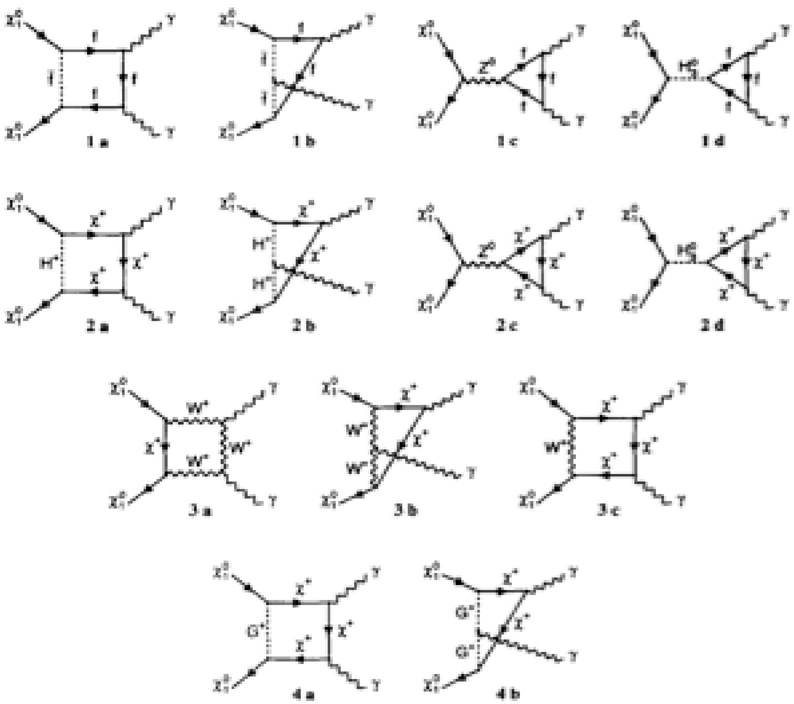
LSP Anihilation into Gammas

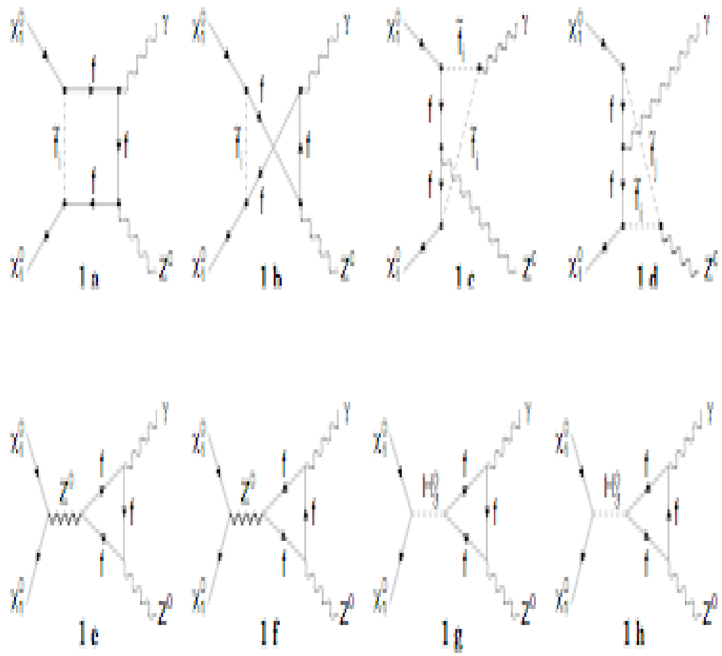
Subdominant channels because:

❖**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

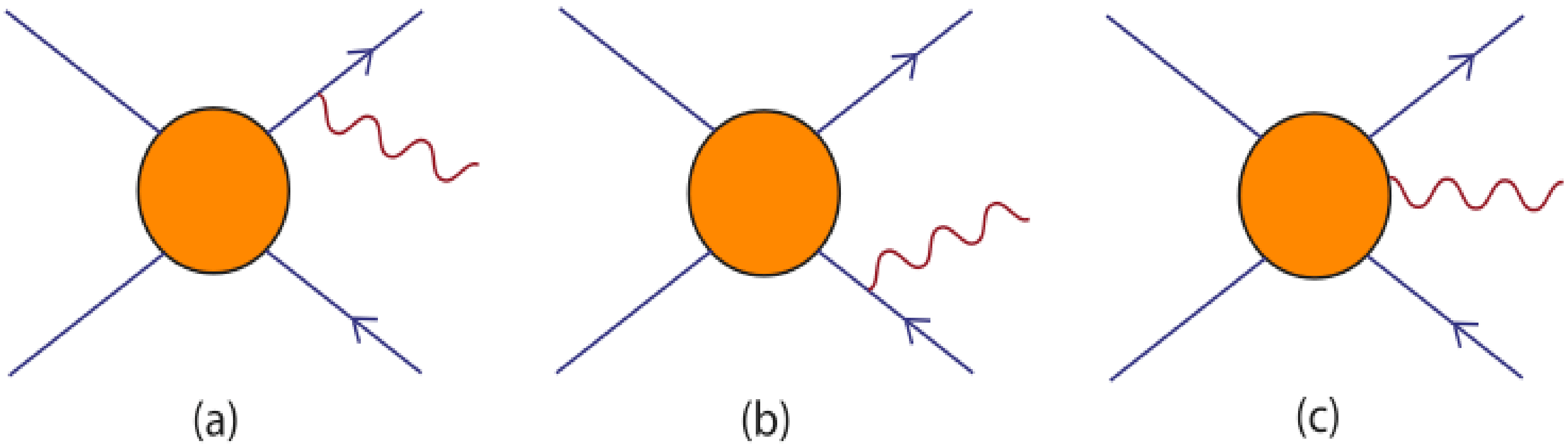
- Secondary Gamma's from annihilation's:

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

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

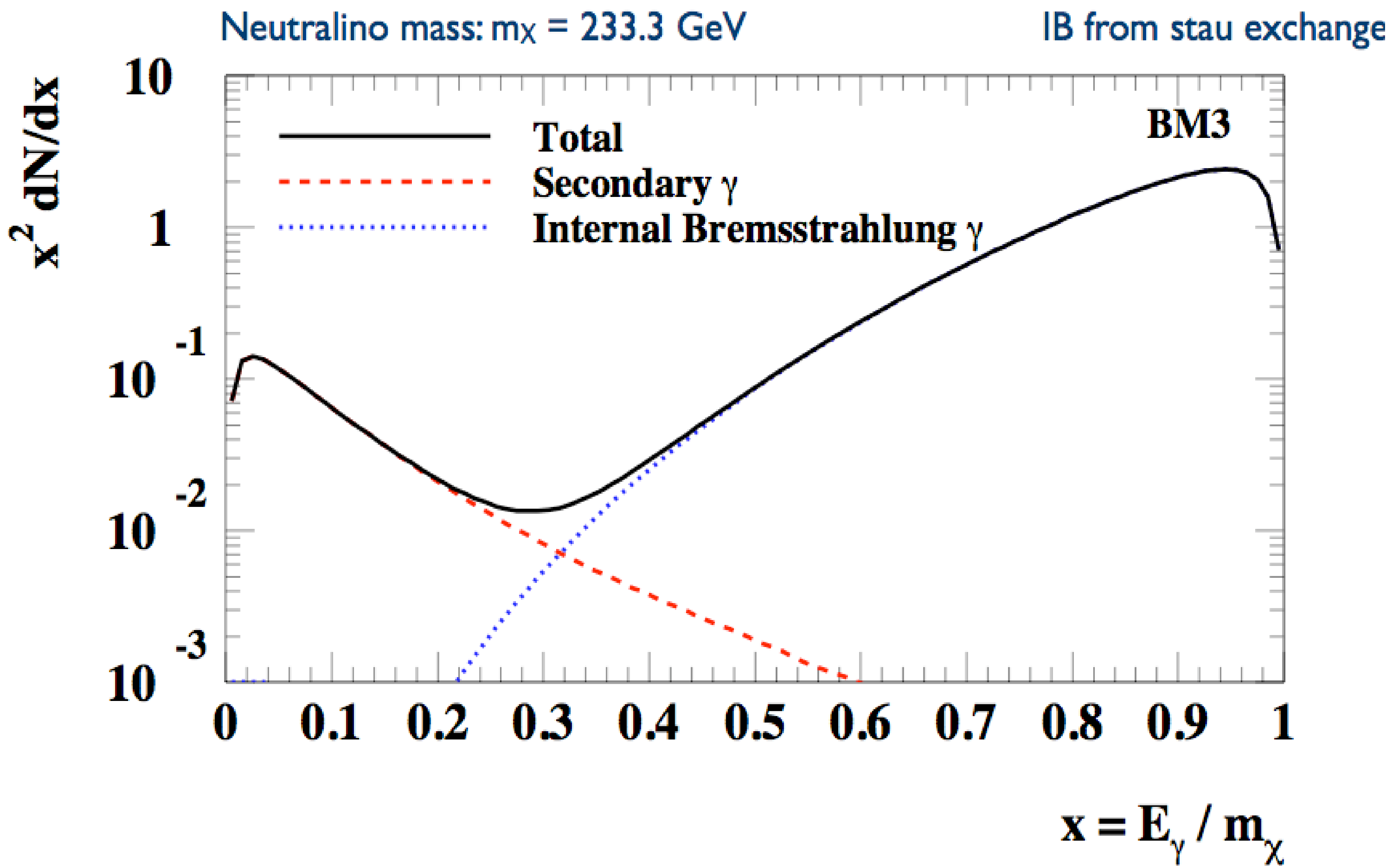
Internal Bremsstrahlung

From annihilation channels with charged particles on the final state:



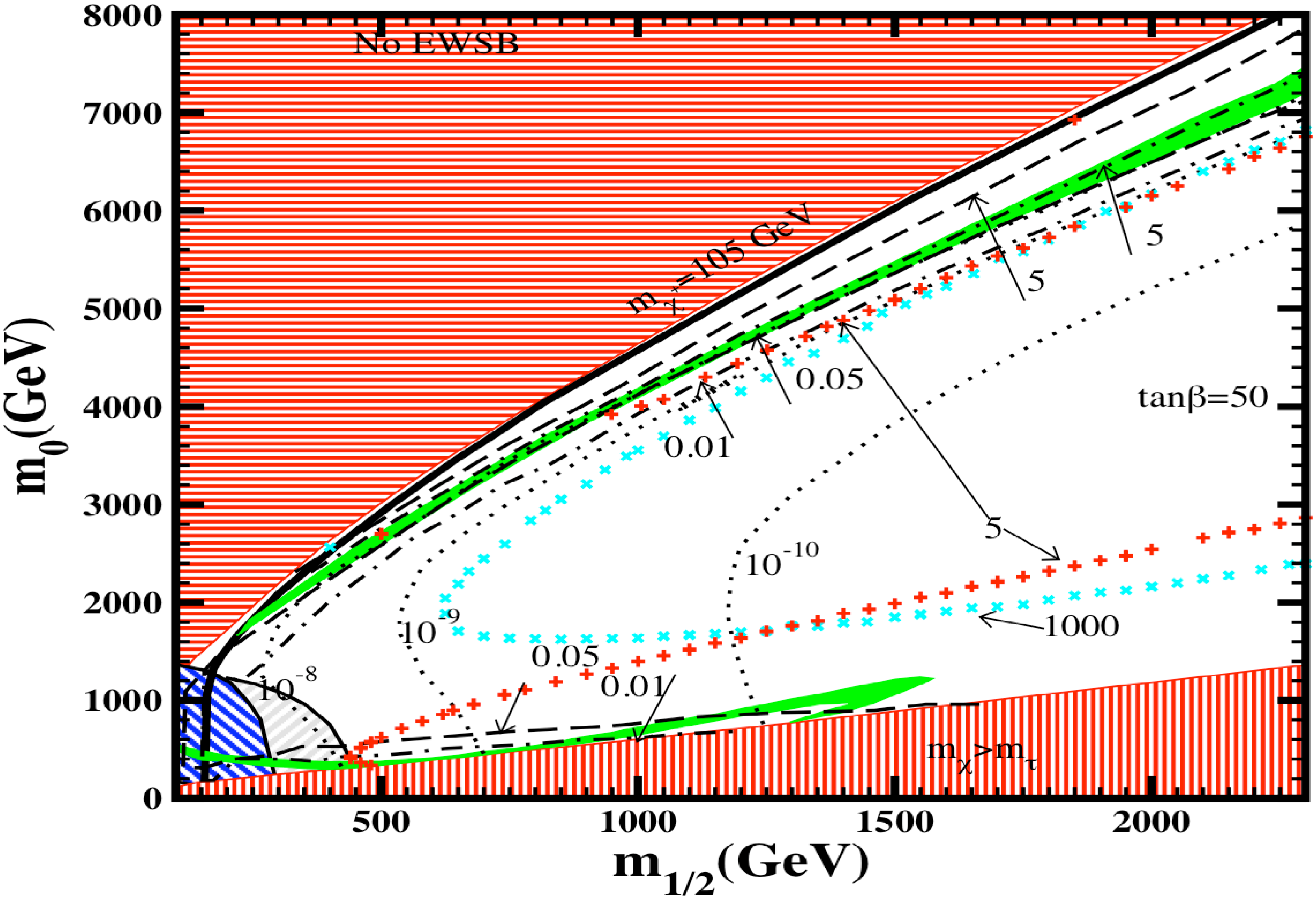
Bringmann, Bergstrom, Edsjo 2008
and references there in.

Example

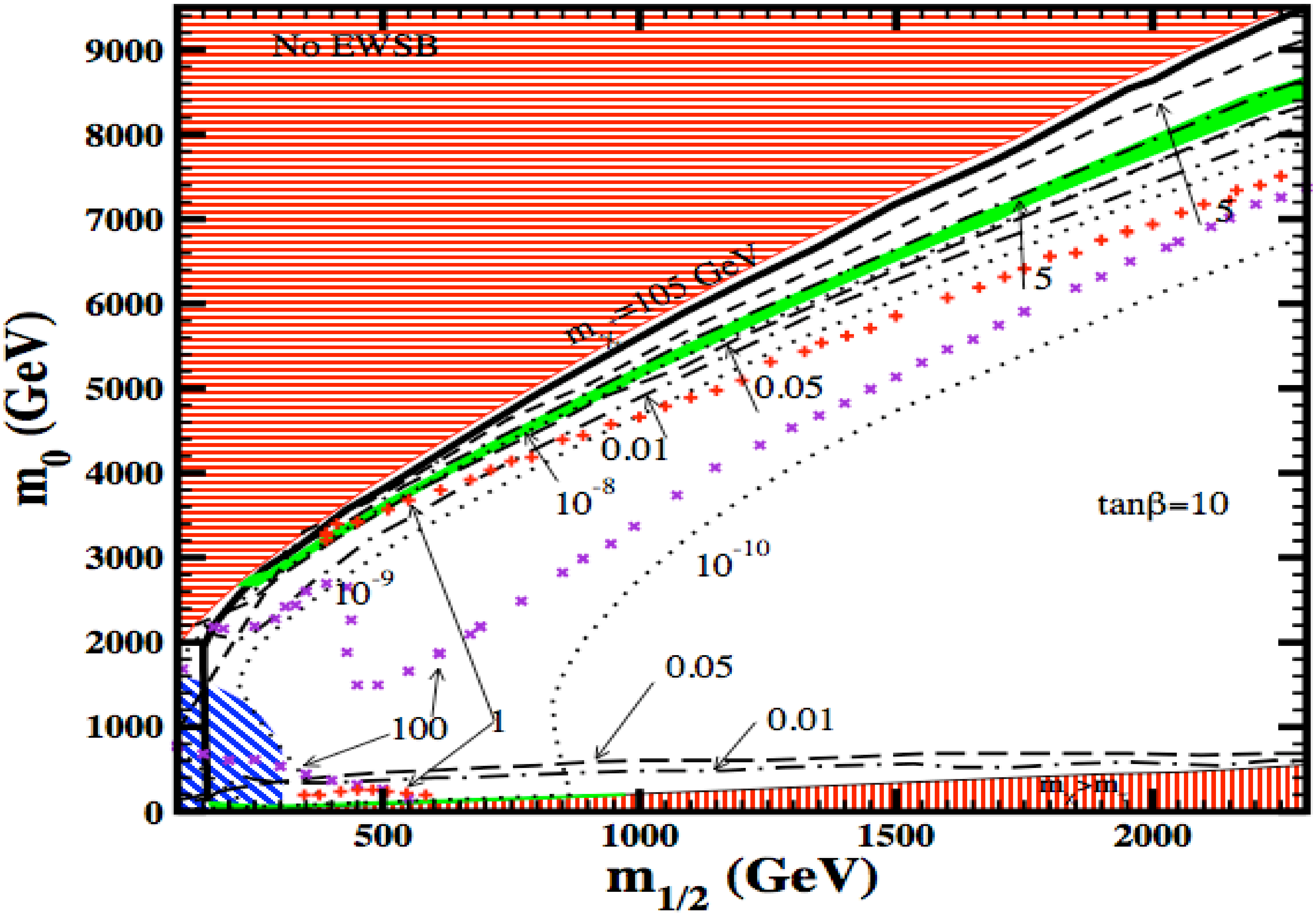


T. Bringmann, L. Bergstrom and J. Edsjo, JHEP 01 (2008) 049

mSUGRA Parameter Space, Large tanβ



Parameter Space Low tanβ



THE GAMMA-RAY FLUX IN IACT'S

Flux above a certain E_{th}:

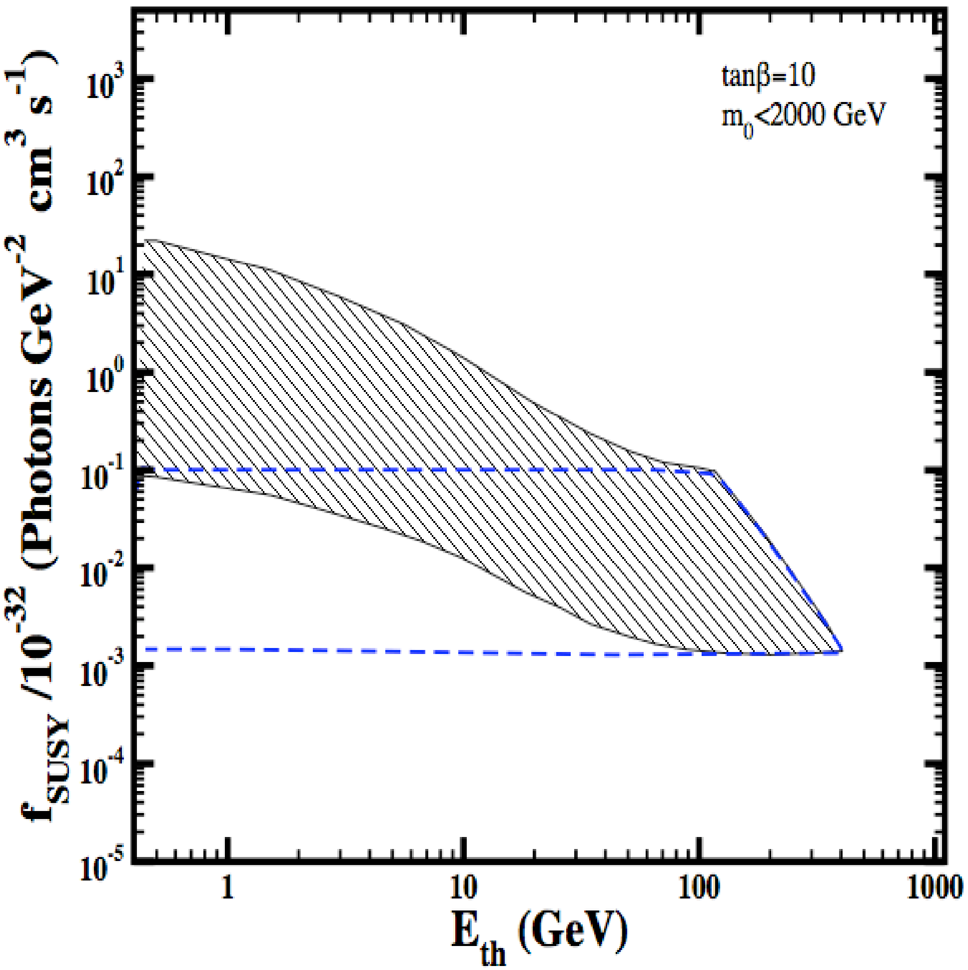
$$F(E > E_{th}) = \frac{1}{4\pi} f_{SUSY} \cdot U(\Psi_0)$$

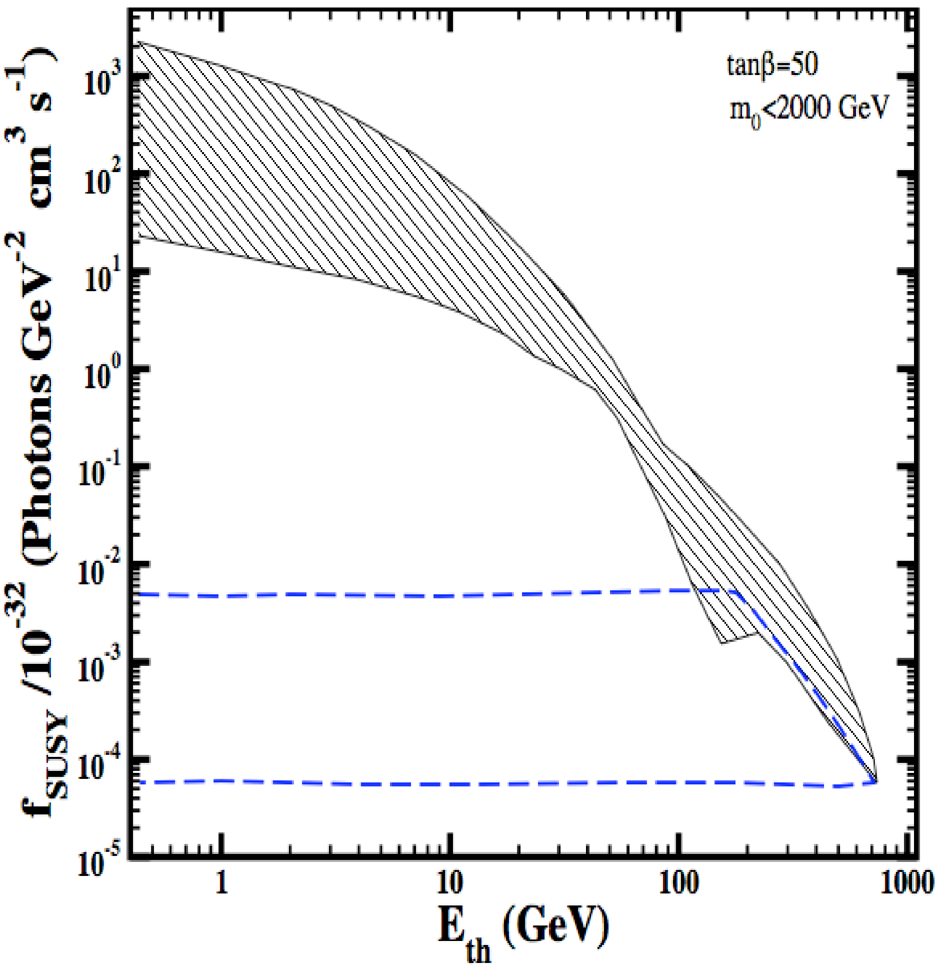
Particle Physics

Astrophysical

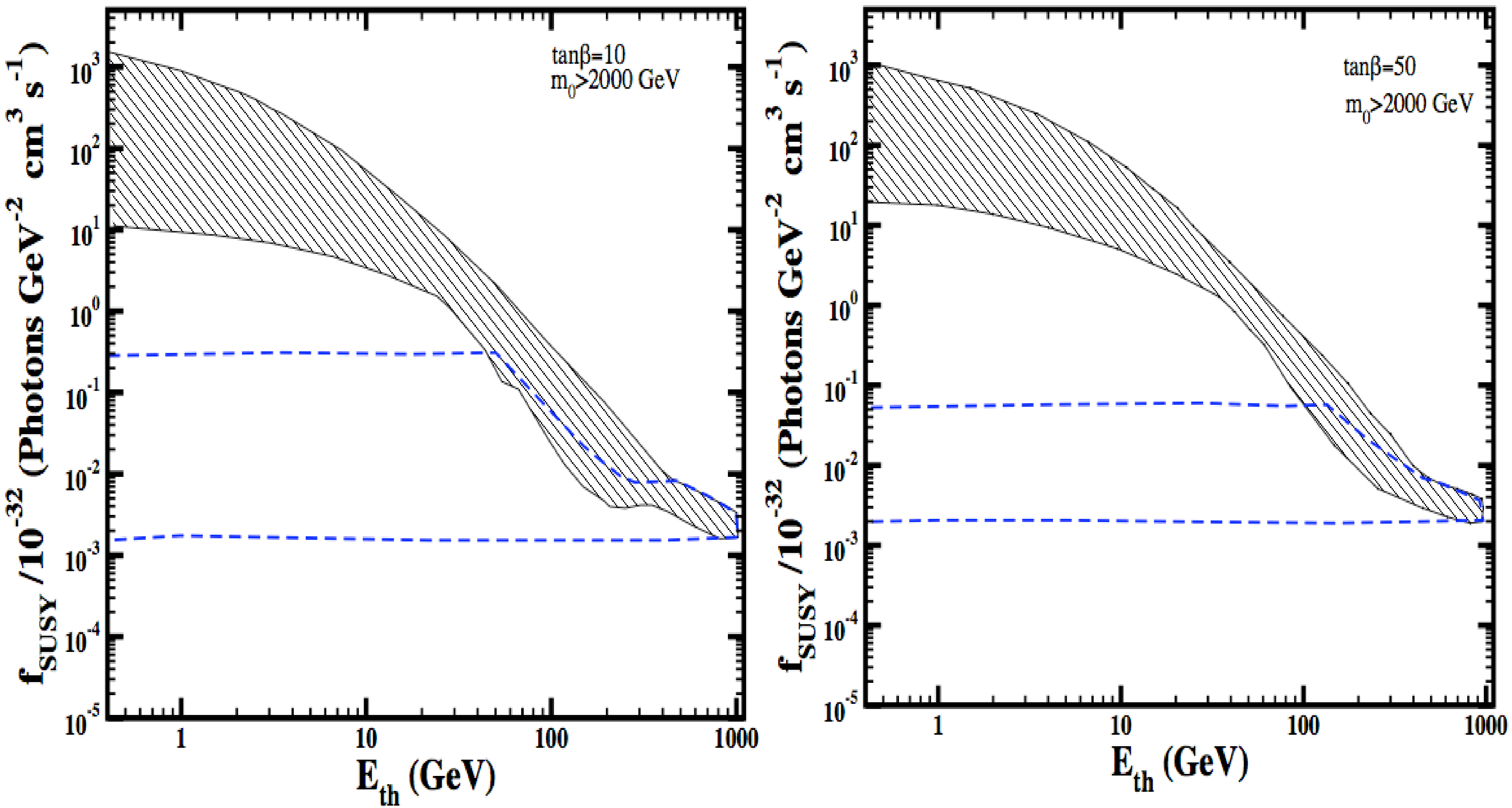
$$f_{SUSY} = \frac{\theta(E_{th} > m_\chi) \cdot 2(v\sigma_{\gamma\gamma})}{2m_\chi^2} + \frac{\theta(E_{th} > m_\chi - \frac{m_Z^2}{4m_\chi}) \cdot (v\sigma_{\gamma Z}) + k(v\sigma_{cont.})}{2m_\chi^2}$$

M_0 <2000 GeV

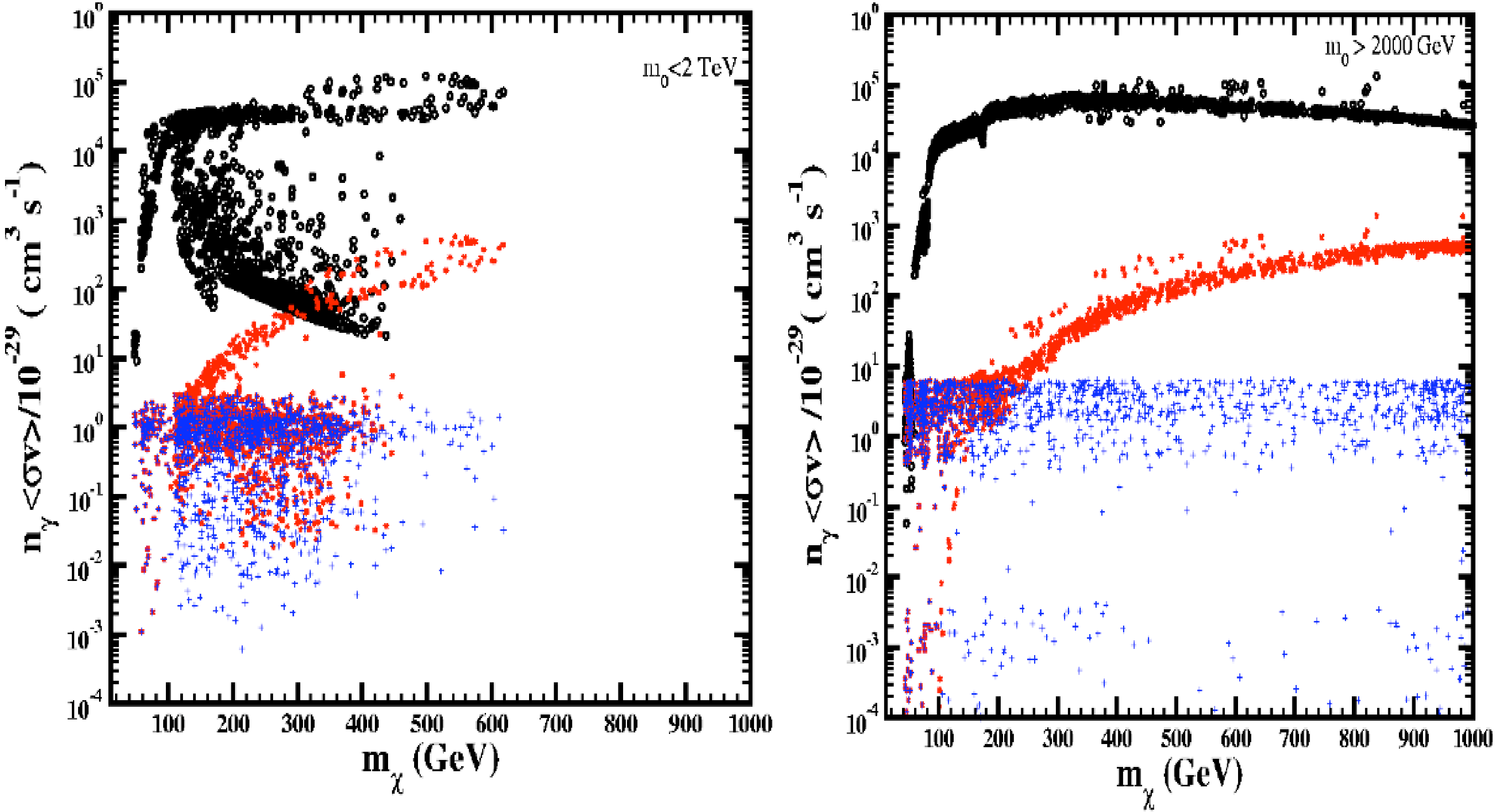

tanβ=10
m0<2000 GeV
fSUSY /10-32 (Photons GeV-2 cm3 s-1)
Eth (GeV)
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
1
10
100
1000


tanβ=50
m0<2000 GeV
fSUSY /10-32 (Photons GeV-2 cm3 s-1)
Eth (GeV)
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
1
10
100
1000

M0 >2000 GeV


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

mSUGRA



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).*

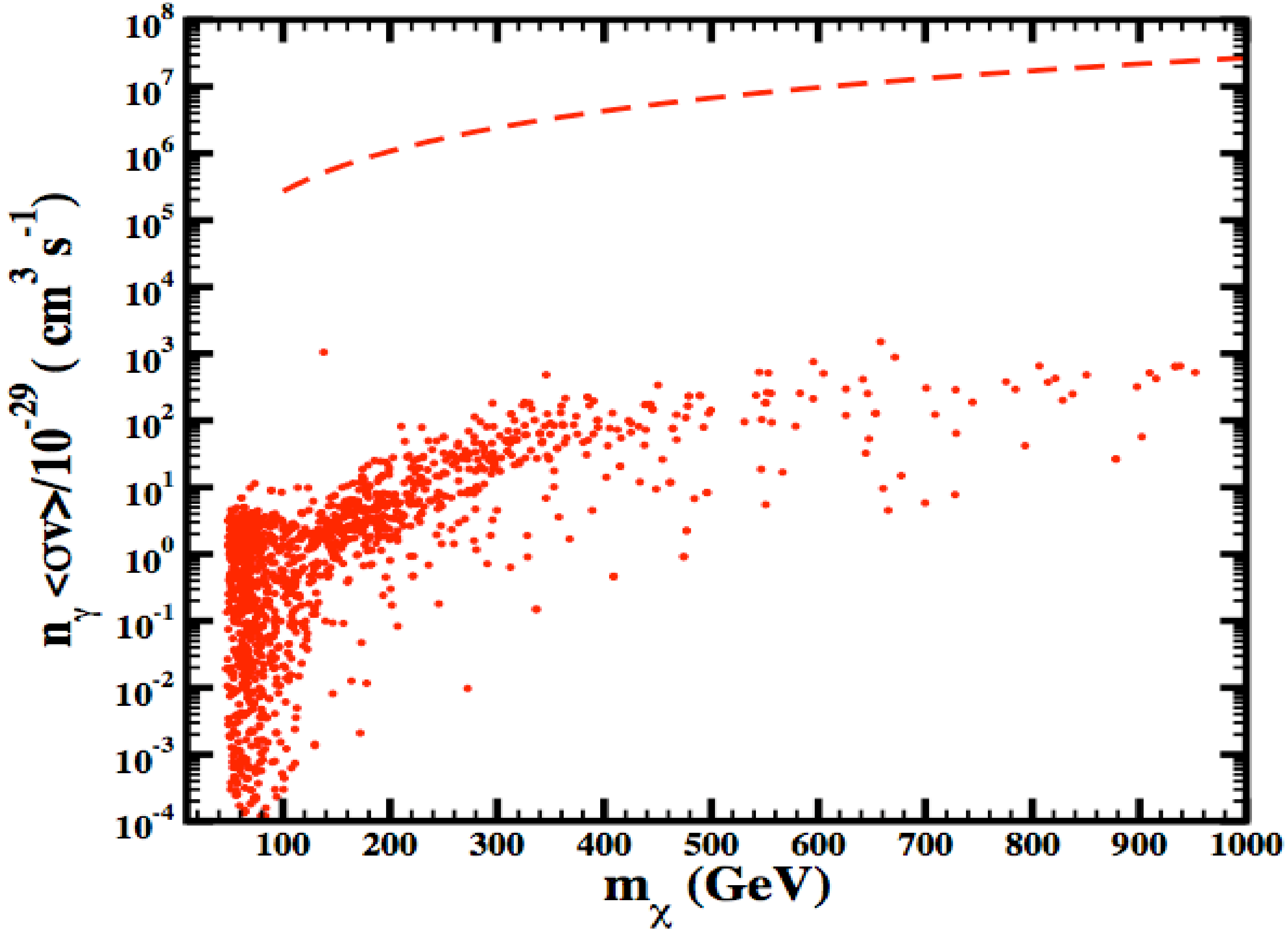
- *M/L ~ 300*

- *High in the Northern Sky --> suitable for MAGIC*

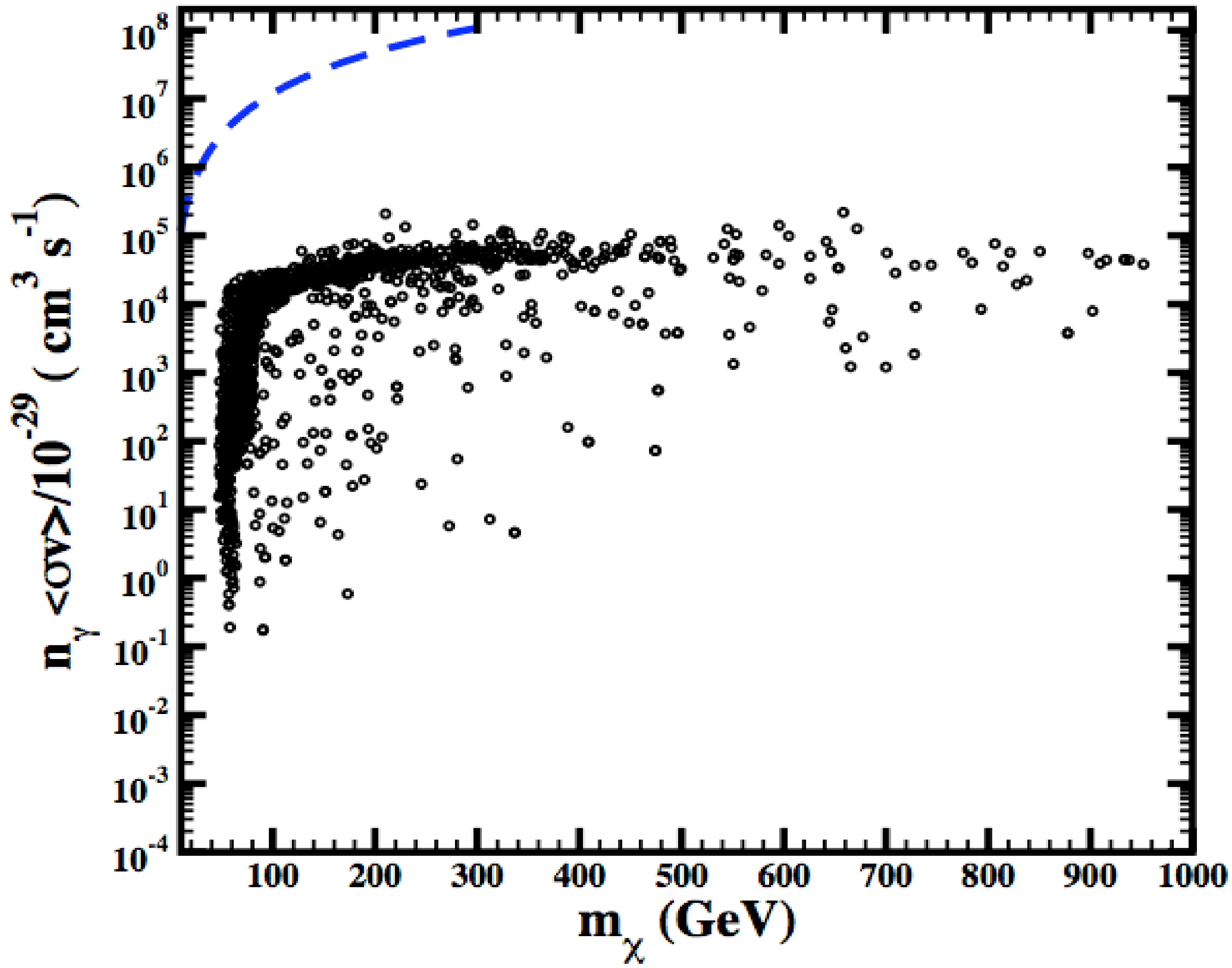
MAGIC observations and analysis

- 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



Result from GLAST



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 more than 3 orders of magnitude above the detection limits.