Hidden dark sector and dark matter

Yann Mambrini **Laboratoire de Physique Théorique** **Orsay, Université Paris XI**

E. Dudas, S. Pokorski, A. Romagnoni

arXiv:0904.1745 [hep-ph]

arXiv:0907.2918 [hep-ph]

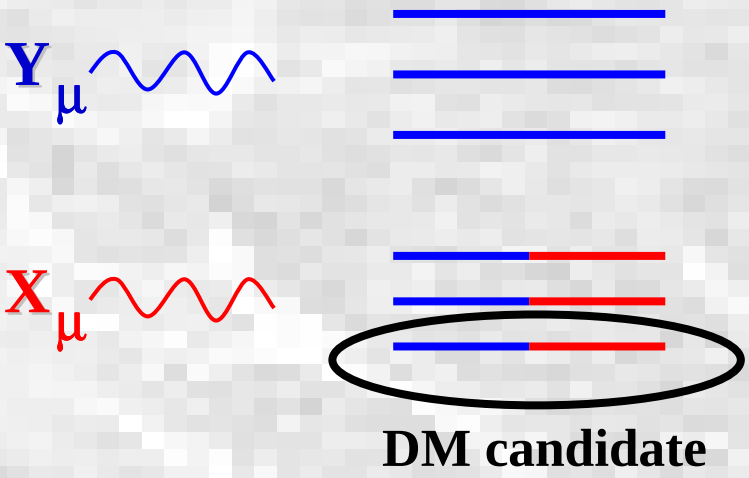
Madrid DM Workshop, September 16th 2009

Extra U(1) models

Question : is it possible to see an invisible gauge boson X?

What is an invisible X?

A boson that does not couple with SM particles

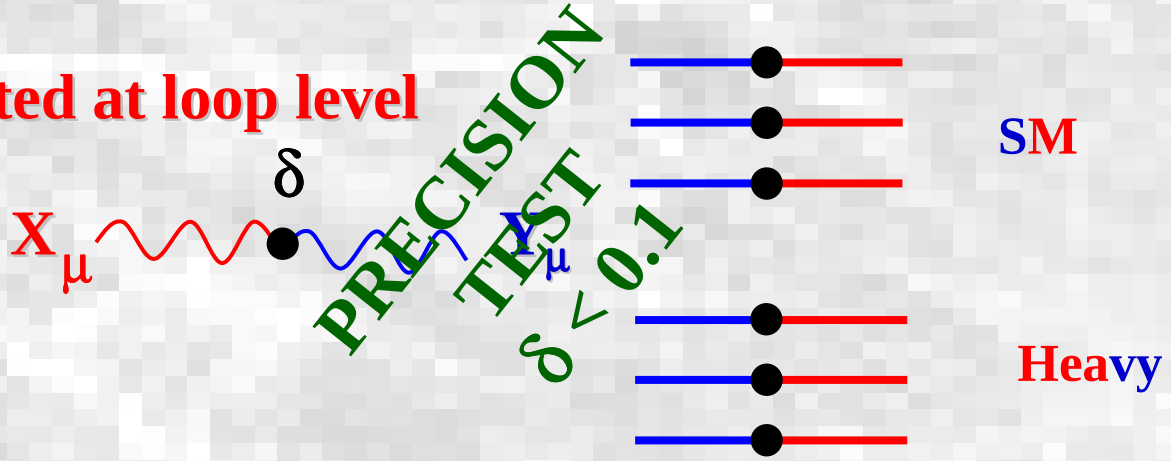


Other possibilities:
Leptophylic (hadrophobic) DM

A Y-X kinetic mixing generated at loop level

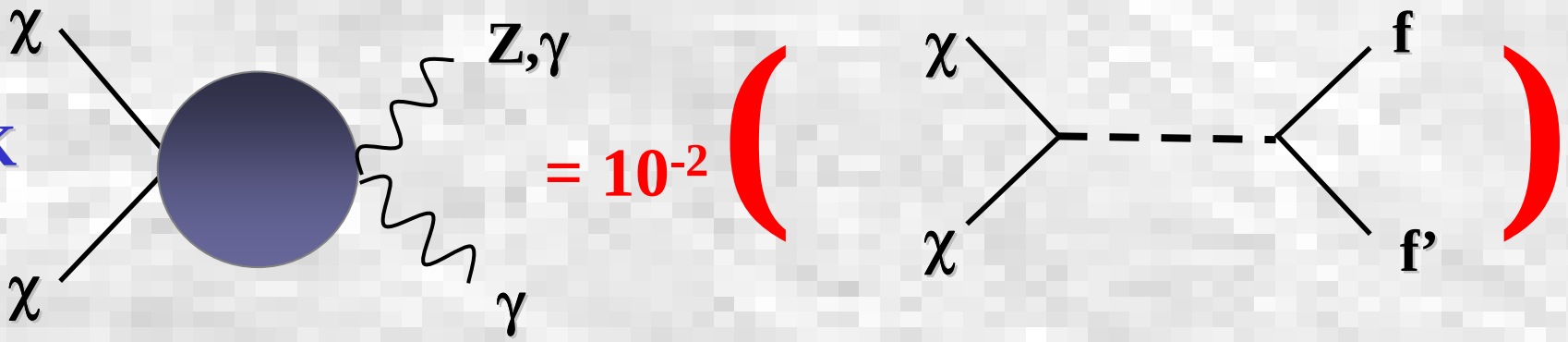
$$\mathcal{L}_{mix} = \delta\, F^{Y\mu\nu}\, F^{X}_{\mu\nu}$$

[Weiner, 08]



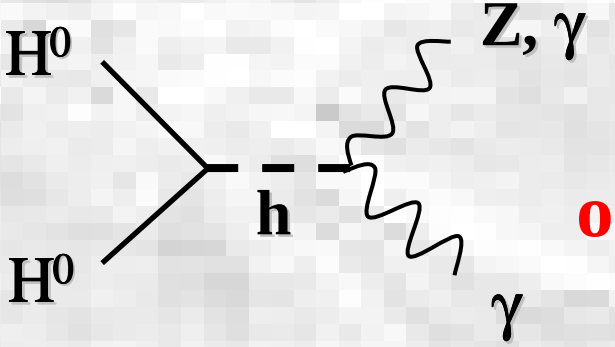
γ ray lines

SUSY/KK
[…]



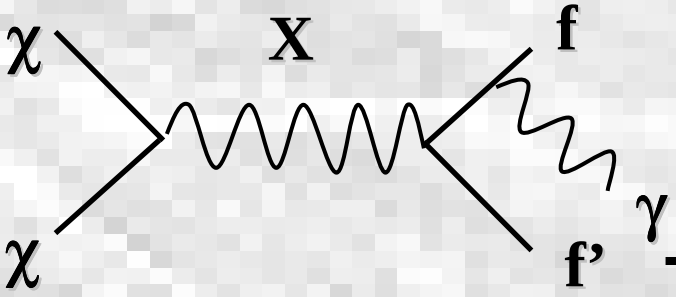
Inert Higgs Doublet
[Gustafsson et al. 07]

If $m_{H0} < M_W$



2 lines or γγ line

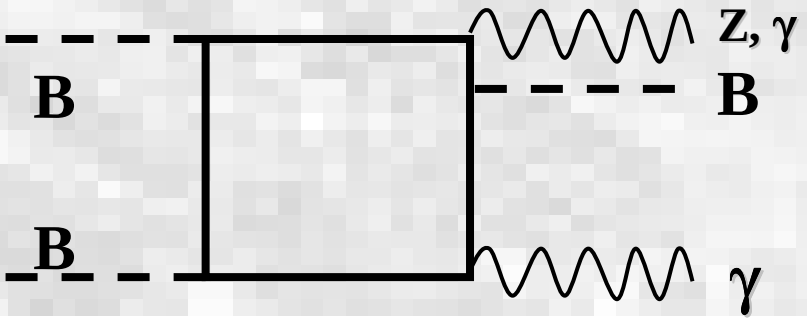
Visible X
[Cheung et al. 07]
[Baek & Ko, 08]



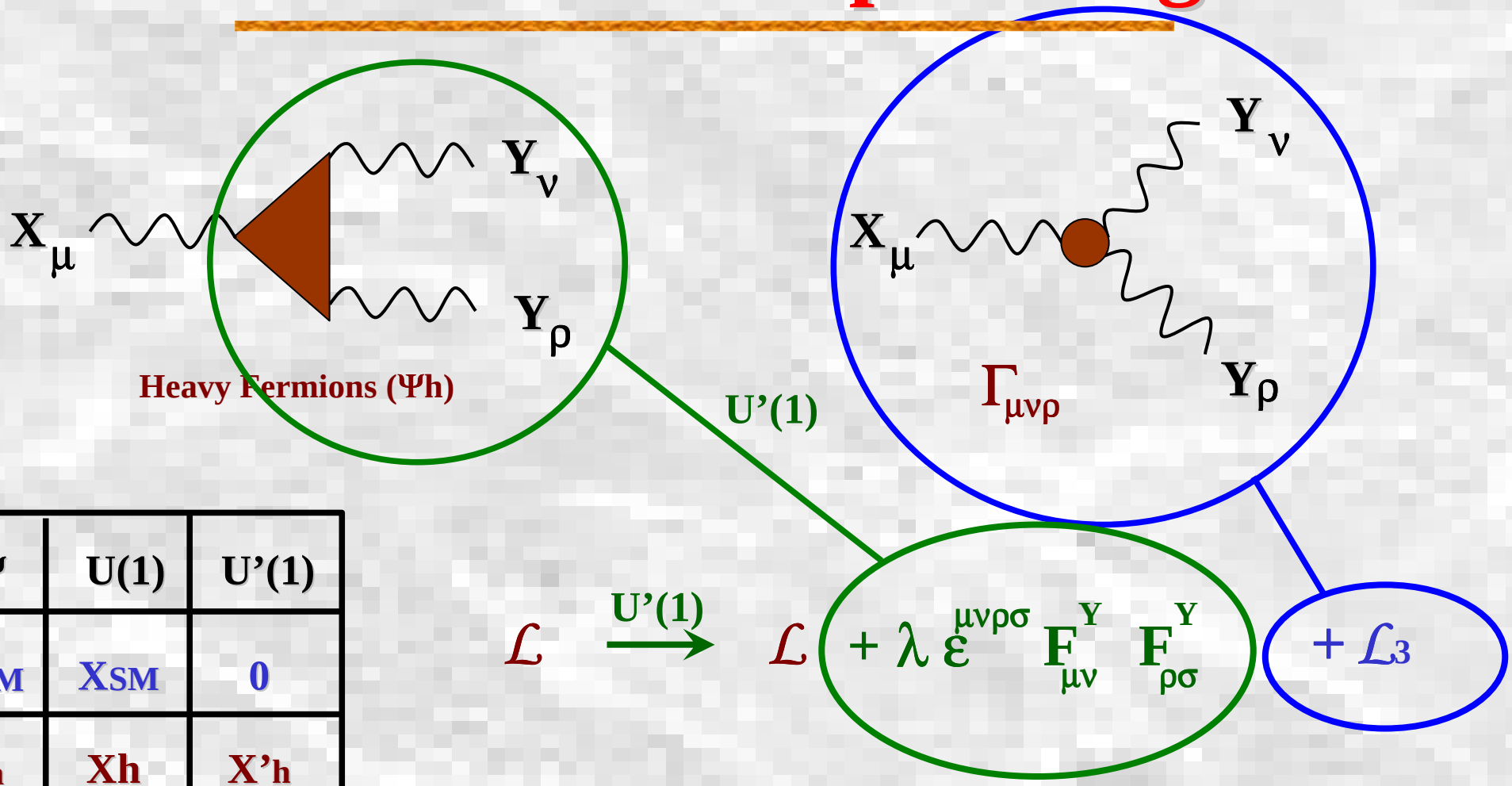
No visible line

Chiral Square
[Bertone et al. 09]

3 visible lines



Anomalies and loops triangle



Ψ	U(1)	U'(1)
Ψ_{SM}	X_{SM}	0
Ψ_h	X_h	X'_h

$$\mathcal{L} \xrightarrow{U'(1)} \mathcal{L} + \lambda\, \varepsilon^{\mu\nu\rho\sigma} F^{Y}_{\mu\nu} F^{Y}_{\rho\sigma} + \mathcal{L}_3$$

$$X_\mu \longrightarrow X_\mu + d_\mu \lambda$$

$$a \longrightarrow a - M_X \lambda$$

$$X_\mu + M_X d_\mu a \longrightarrow X_\mu + M_X d_\mu a$$

(Stuckelberg Langrangian)

The Lagrangian : Green-Schwarz mechanism

(Intersecting Brane Models)

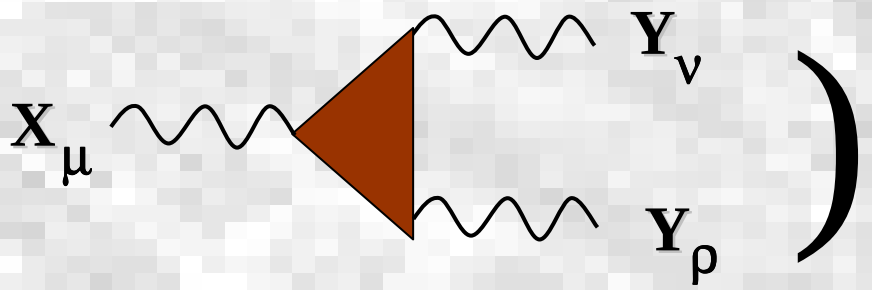
$$\mathcal{L}_{inv} = F^{Y\mu\nu} F^{Y}{}_{\mu\nu} - (d_\mu a - M_X X_\mu)^2 - i \overline{\Psi_h} \gamma^\mu D_\mu \Psi_h$$

$$\mathcal{L}_{var} = B\, a\, \varepsilon^{\mu\nu\rho\sigma} F^{Y}{}_{\mu\nu} F^{Y}{}_{\rho\sigma} + C\, \varepsilon^{\mu\nu\rho\sigma} X_\mu Y_\nu F^{Y}{}_{\rho\sigma}$$

Peccei-Quinn terms

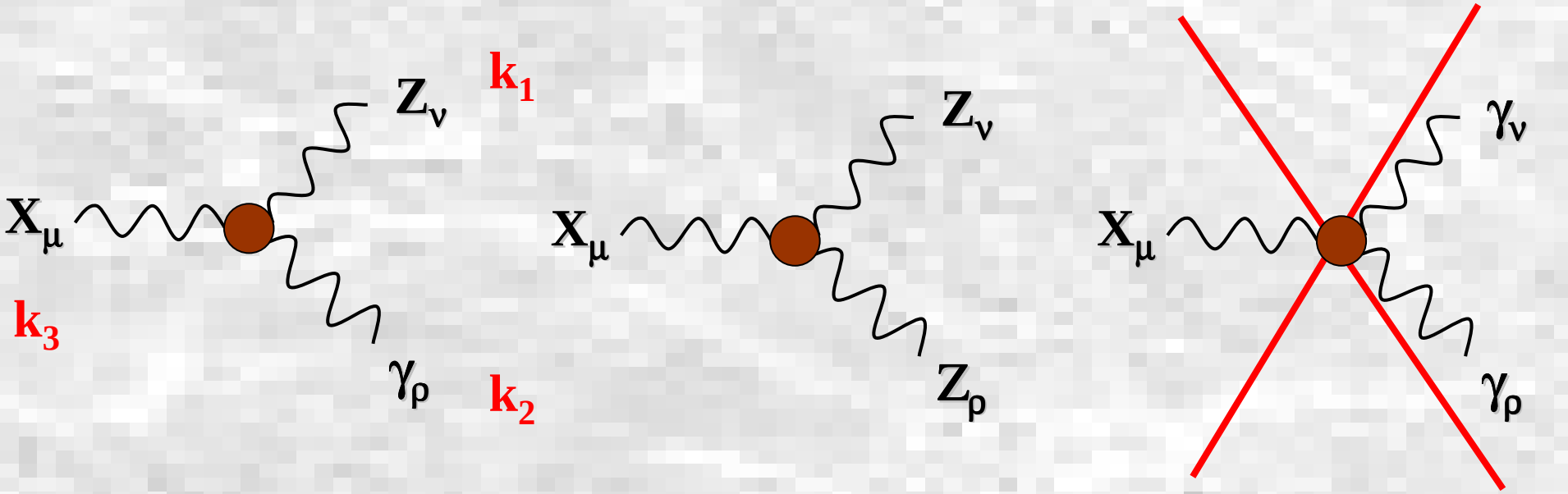
Chern-Simons terms

$$\delta \mathcal{L}_{var} = - \delta \left(\right)$$



Heavy Fermions (Ψh)

Effective couplings : $\mathcal{L}_{eff} = \mathcal{L}_{loops} + \mathcal{L}_{var}$



$$\Gamma^{\alpha}_{\mu\nu\rho} = t^{\alpha} \{ A_1\, \varepsilon^{\mu\nu\rho\sigma}\, k_{2\sigma} - A_2\, \varepsilon^{\mu\nu\rho\sigma}\, k_{1\sigma}$$
$$+ B_1\, k_{2\nu}\, \varepsilon^{\mu\rho\sigma\tau}\, k_{2\sigma}\, k_{1\tau} + B_2\, k_{1\nu}\, \varepsilon^{\mu\rho\sigma\tau}\, k_{2\sigma}\, k_{1\tau} + B_3\, k_{2\rho}\, \varepsilon^{\mu\nu\sigma\tau}\, k_{2\sigma}\, k_{1\tau} + B_4\, \varepsilon^{\mu\nu\sigma\tau}\, k_{2\sigma}\, k_{1\tau}$$
$$+ C\, k_{3\mu}/k_3^{\,2}\, \varepsilon^{\nu\rho\sigma\tau}\, k_{2\sigma}\, k_{1\tau} \qquad + D\, \varepsilon^{\mu\nu\rho\sigma}(k_{2\sigma} - k_{1\sigma})\}$$

Peccei-Quinn — Chern-Simons

[Dudas, Kiritsis 09]
[YM, 09]
[Kumar, Wells 08]

$\delta\, \mathcal{L}_{eff} = 0$ 3 Ward identities + $(k_1;k_2)$ symmetries

-> the vertex can be express as function of $|B_2 - B_1| = 1/\Lambda^2_X$

With B_1, B_2 = computable loops integrals

Cc : only 3 parameters : Λ_X [<S>] ; M_X [g_X] ; $M\chi$ [Y_{heavy}]

Interpretation as higher dimensional operators

[Antoniadis 09; Dudas, YM, Romagnoni 09]

$$\mathcal{L}_1 = \frac{1}{M^2} * \{ b\, \mathrm{Tr}[F^X F^Y F^Y] + c\, \varepsilon^{\mu\nu\rho\sigma} (\mathcal{D}_\mu a) (D_\nu H)^+ F^Y{}_{\rho\sigma} H \},$$

with

$$\mathcal{D}_\mu a = d_\mu a - g' X_\mu \; ; \quad D_\nu = d_\nu - ig\, Y_\nu - i\, g'\, X_\nu$$

Masses suppression coming from the fermions which decouple after U'(1) breaking

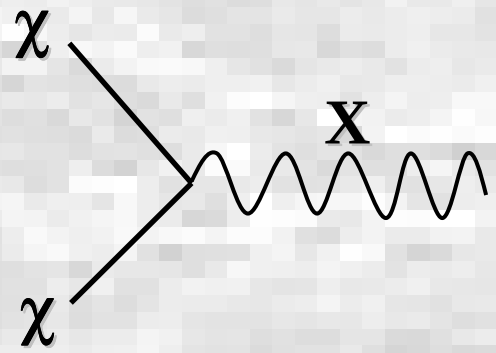
Equivalent to the D'Hoker-Farhi term

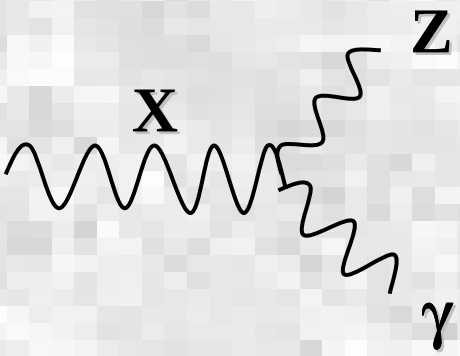
$\{1/(H^+H)\, \varepsilon^{\mu\nu\rho\sigma} (\mathcal{D}_\mu a) (D_\nu H)^+ F^Y{}_{\rho\sigma} H\}$ for SM

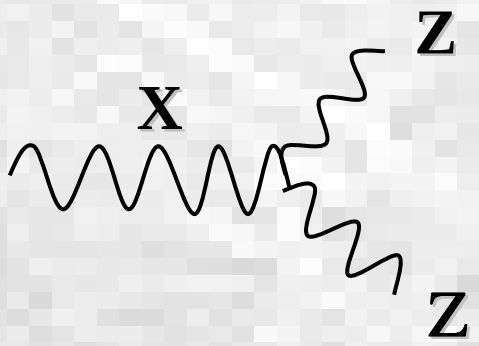
Remark :if two Z' are present, we can build an unsupressed operator,

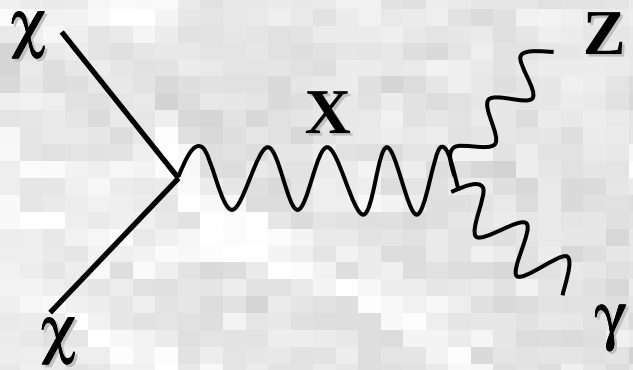
$\varepsilon^{\mu\nu\rho\sigma} (\mathcal{D}_\mu a_1) (\mathcal{D}_\nu a_2) F^Y{}_{\rho\sigma}$

Dark matter: Annihilation channels

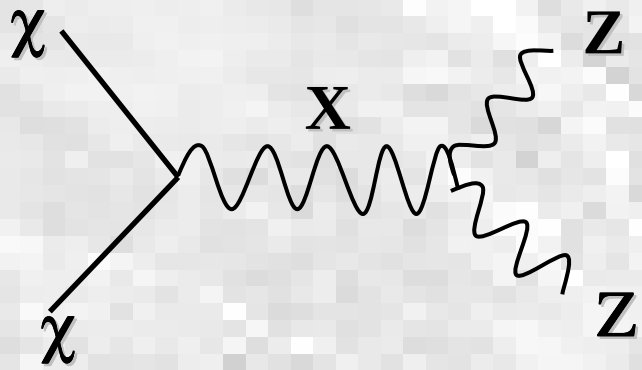


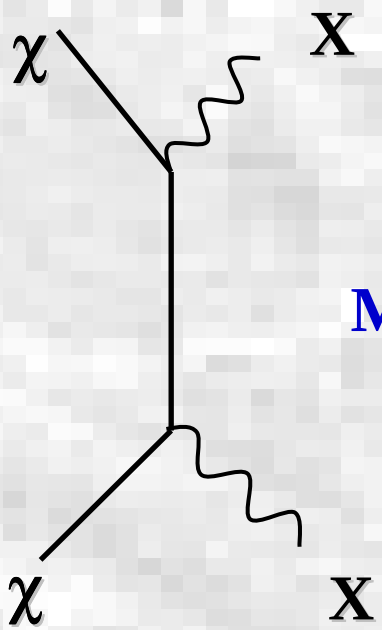






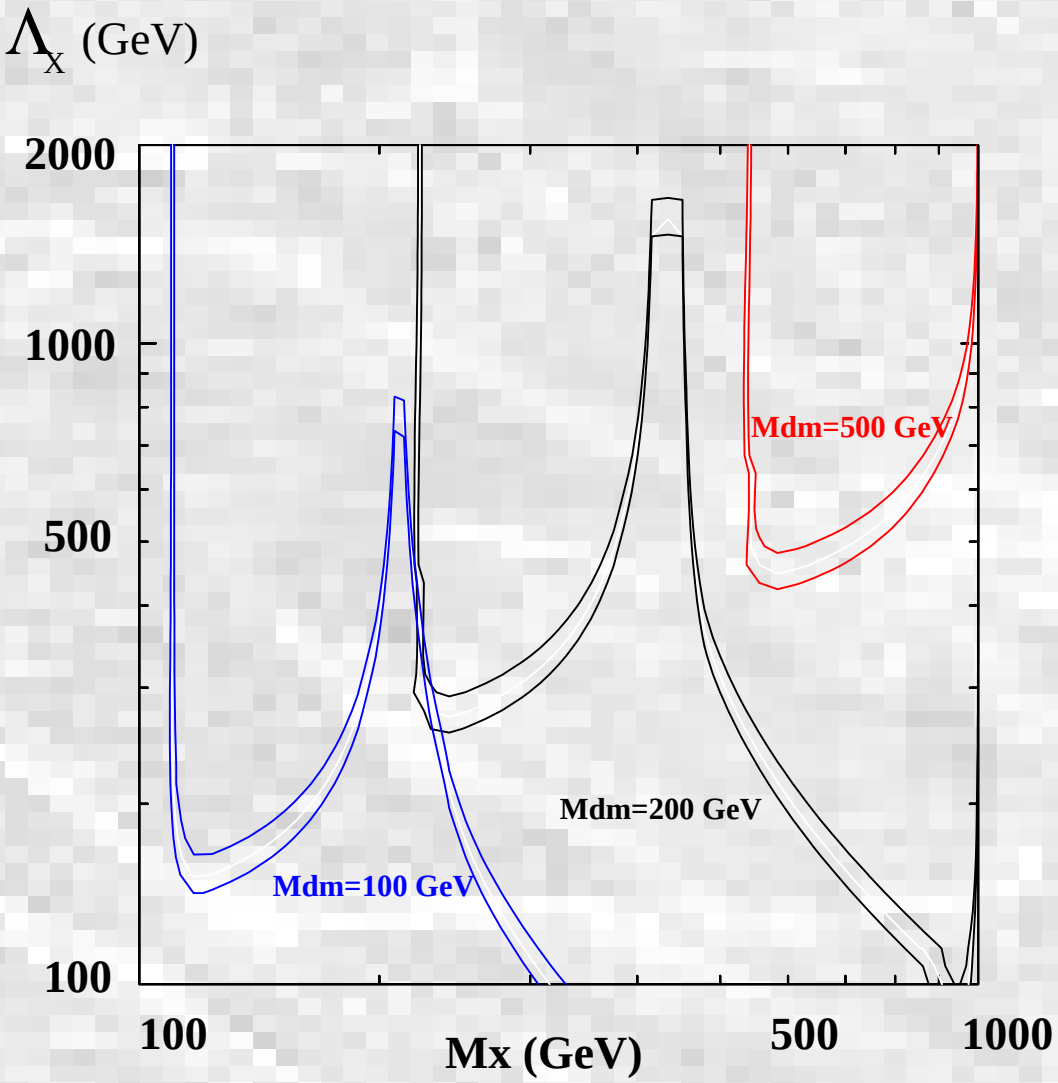
$M_X > M\chi$ (natural)





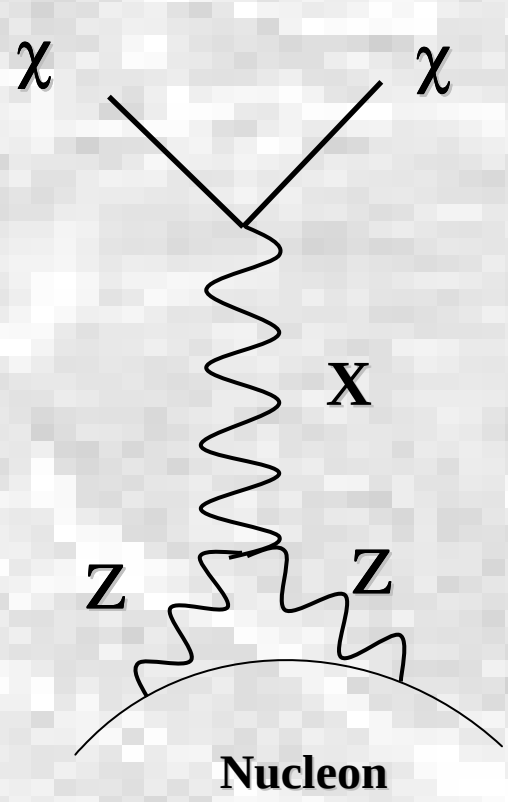
$M_X < M\chi$ (unatural)

The relic density

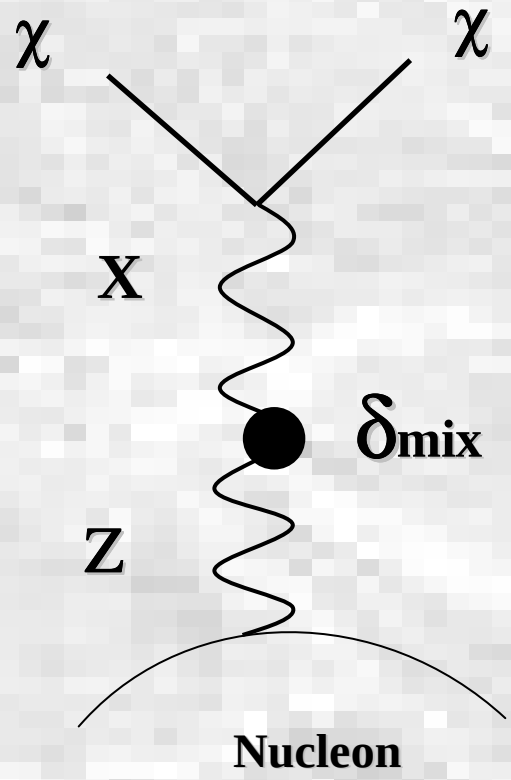


$$\Lambda^2_X = |B_2 - B_1| = g_h * g^2/(8\pi^2) * \mathrm{Tr}[X' X^2/M^2_{heavy}] * \mathrm{Integral}$$

Direct detection



<<

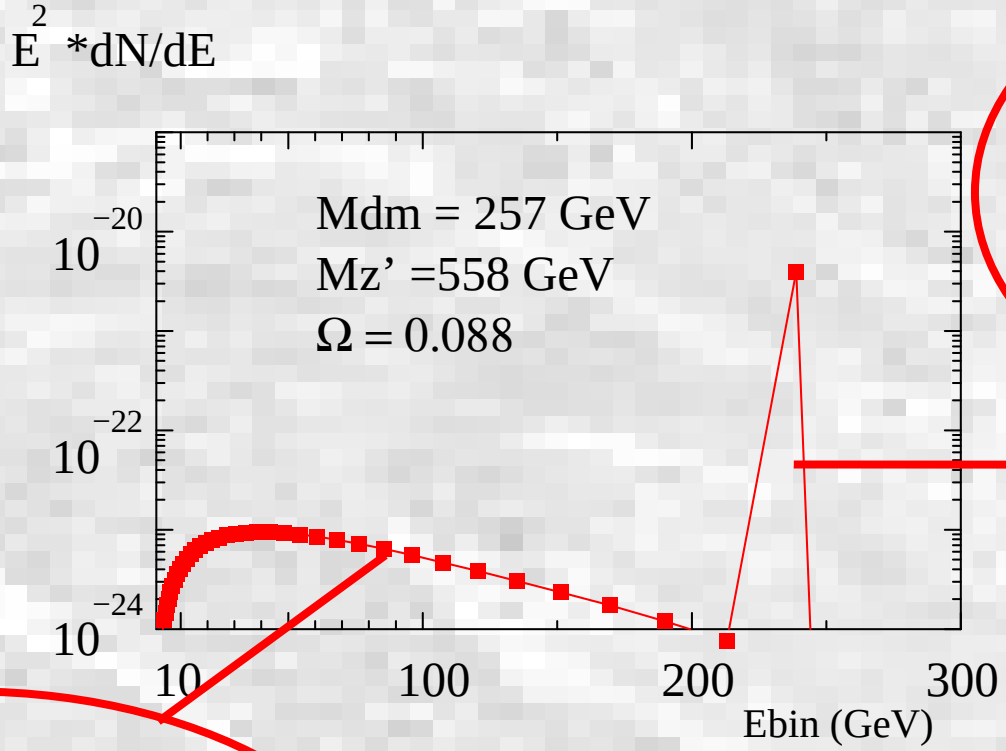


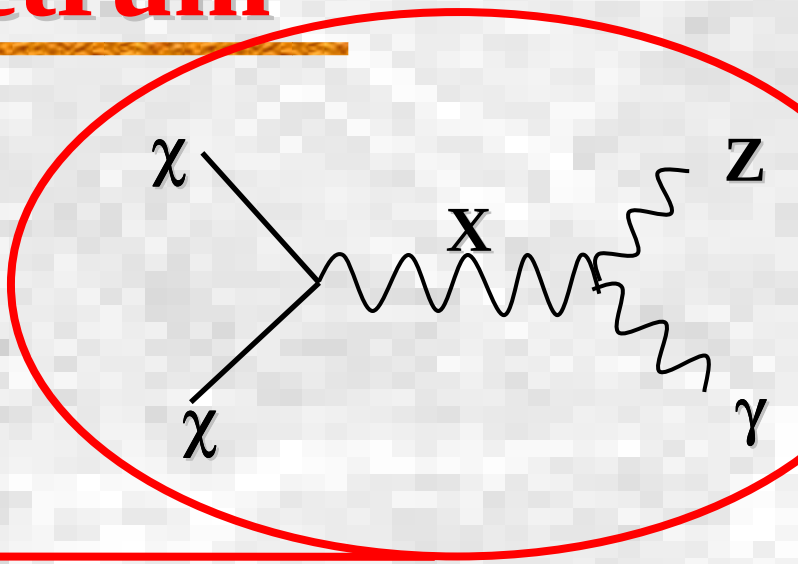
$$\mathcal{L}_{mix} = \delta_{mix} F_{\mu\nu} F'_{\mu\nu}$$

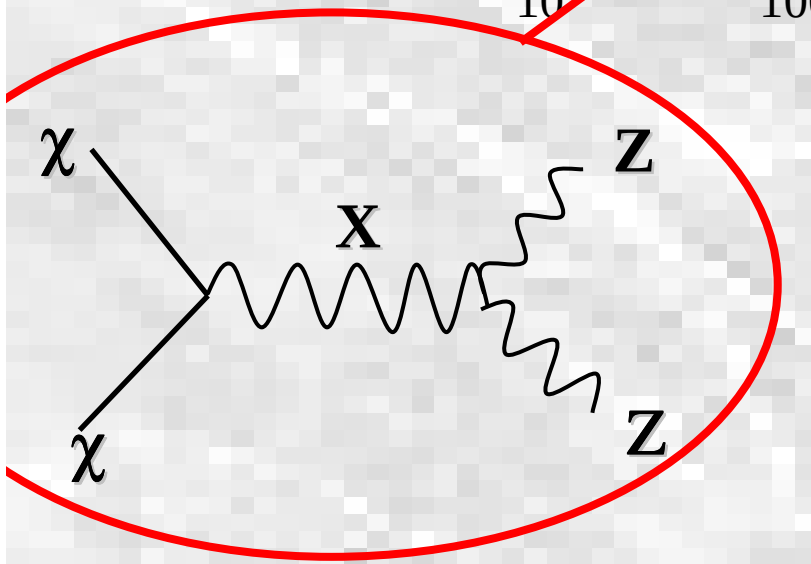
Millicharged DM,

XENON ➡ $\delta_{mix} < 0.01$

Indirect detection: examples of spectrum

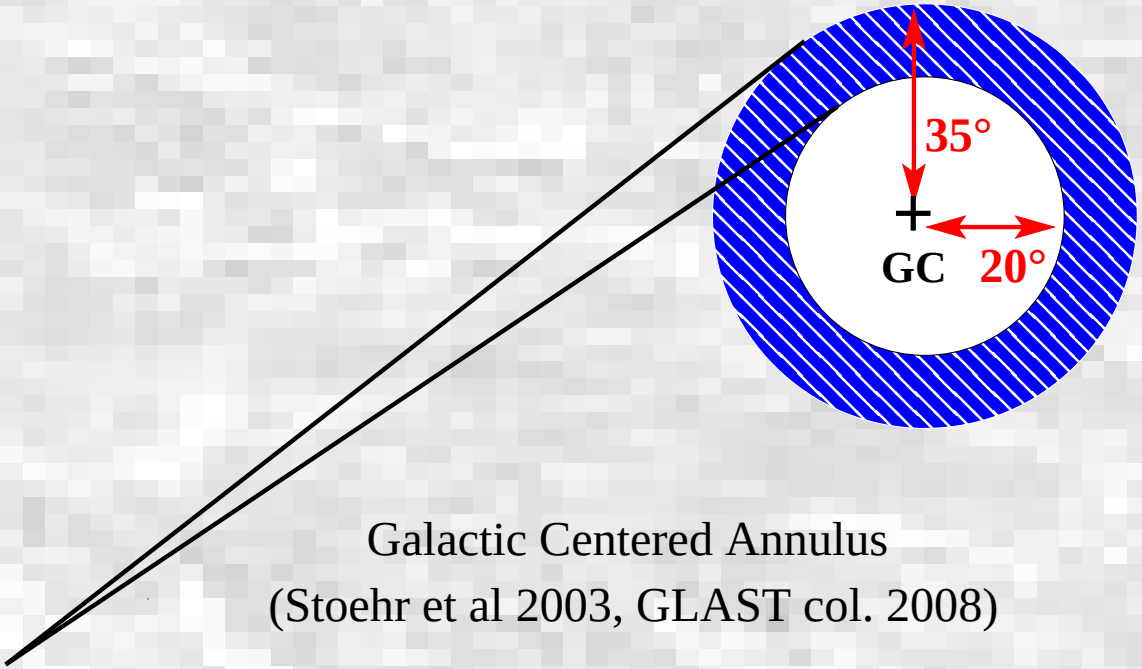






$$E_\gamma = M_\chi \left[1 - (M_Z/2M_\chi)^2\right]$$

Indirect detection astro-parameters



Galactic Centered Annulus
(Stoehr et al 2003, GLAST col. 2008)

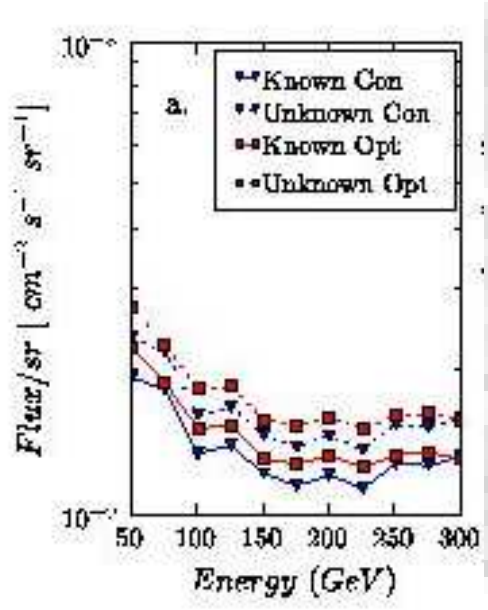
Signal to noise ratio 12 time greater than GC

Independant of the Galactic profile

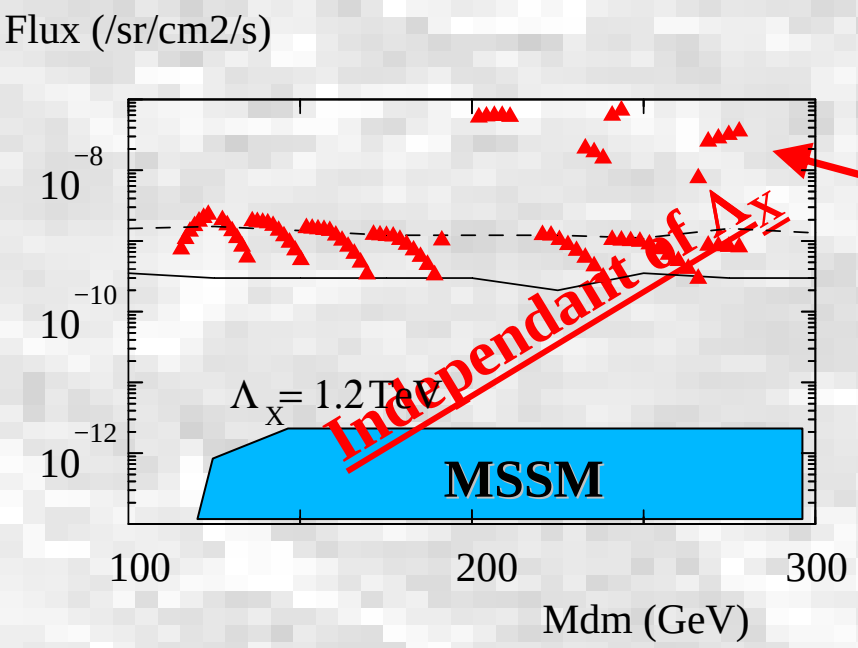
$J\,\Delta\Omega \sim 10$

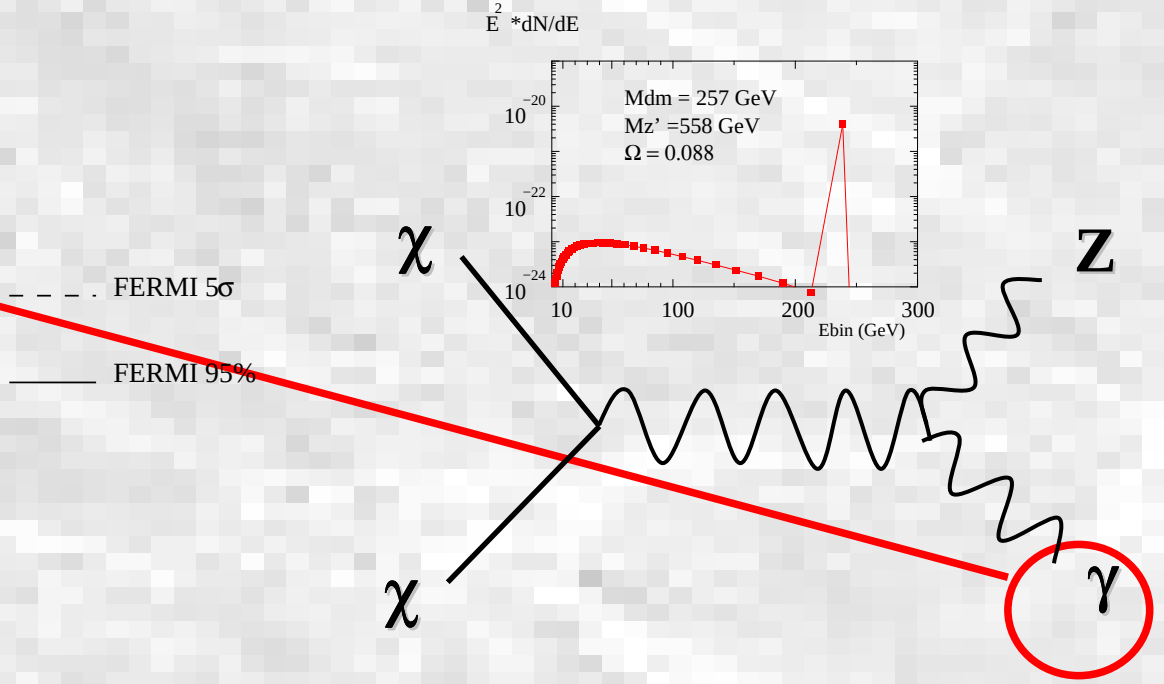
Galprop conventional model for the background

5 years of data, signals at 5σ and 95% CL
[FERMI estimates, Morselli et al. 08]



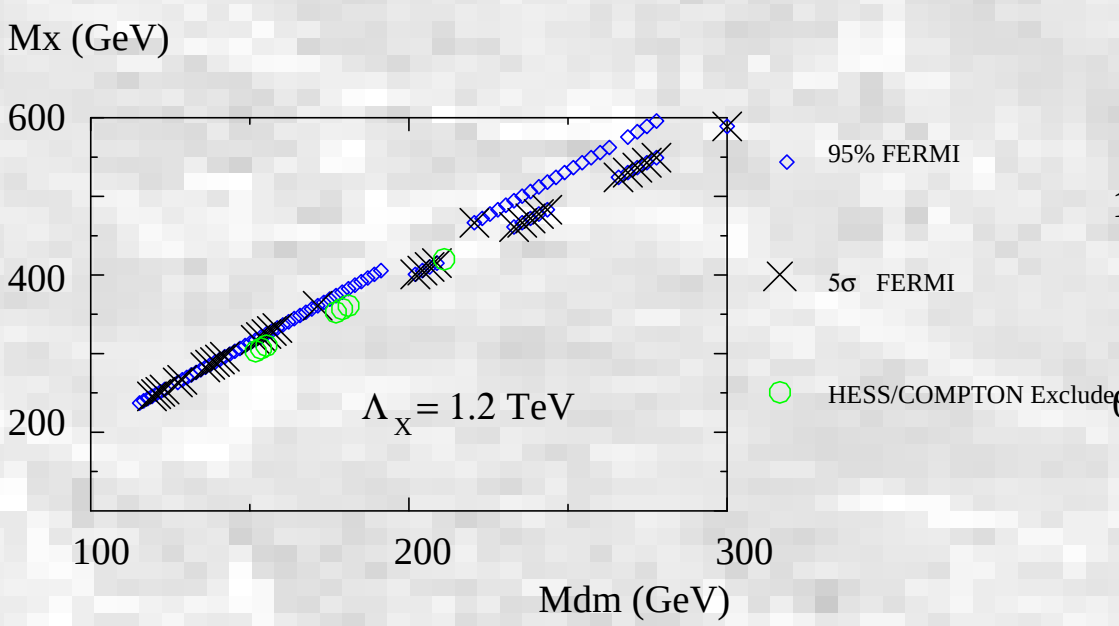
Observability

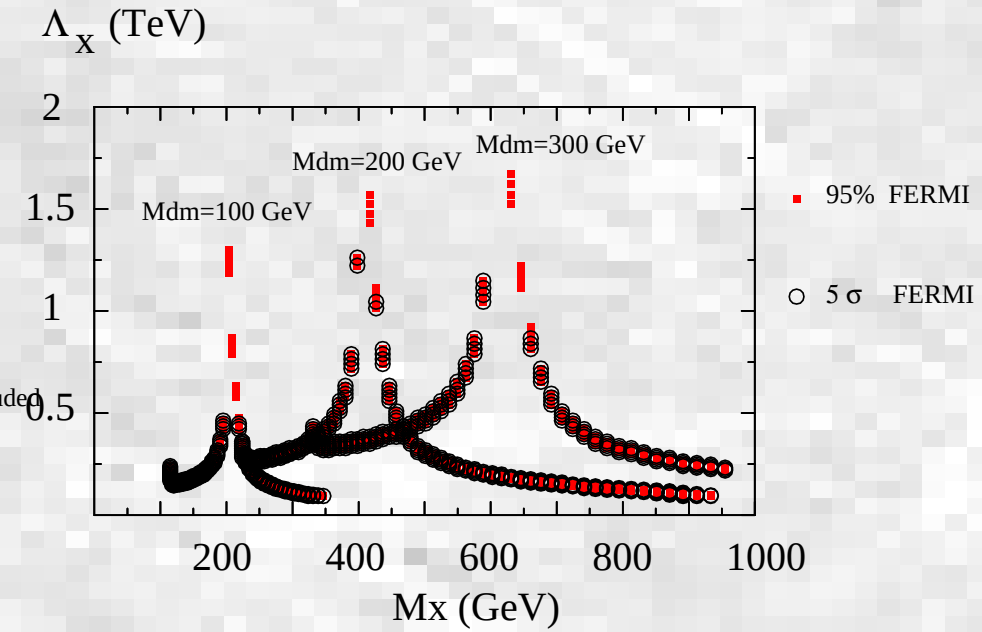


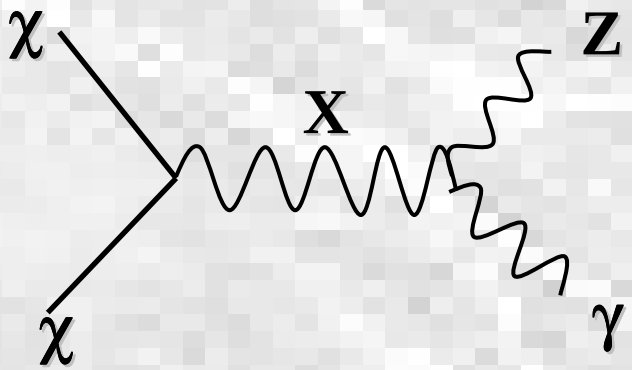


No excess with courent constraints (EGRET, HESS.. [Jacques, Bell 08])

Consequences on Mx and Mchi







Comparison with other models

Masse	Direct detection	Indirect detection	LHC
SUSY/KK	Yes	No line	Yes
Chiral Square	Yes	3 lines	?
Inert HiggsModel	Yes	2 lines	Yes
Milli-charged	Yes	No line	Yes
(In)visible X	No	1 line	No

Conclusions

An (In)visible Z' can be quite visible

Indirect detection would be THE ONLY WAY to observe it

1 γ ray line is a smoking gun signal distinguishing it clearly from other constructions

Possibility to test up to 1TeV BSM scale