

# Hidden dark sector and dark matter

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*arXiv:0904.1745 [hep-ph]*

*arXiv:0907.???? [hep-ph]*

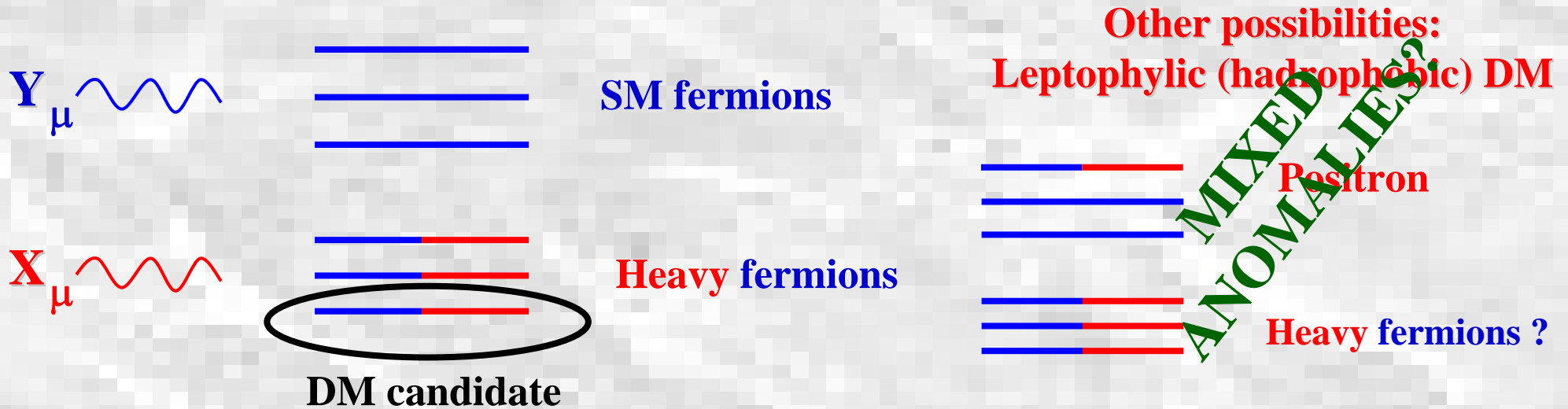
*TAUP09, Roma, July 3<sup>d</sup> 2009*

# 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

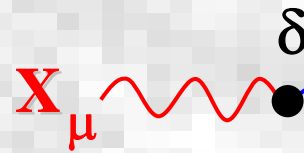


MIXED ANOMALIES?

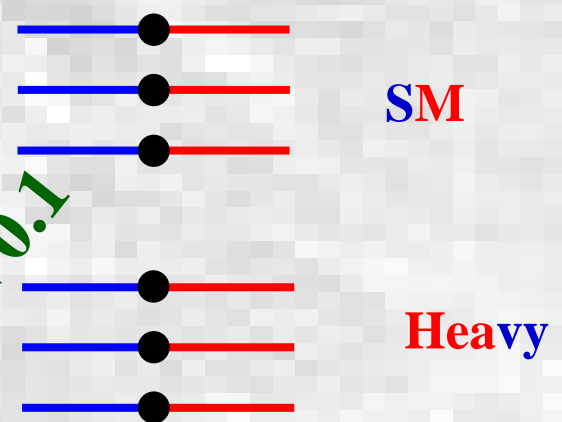
A Y-X kinetic mixing generated at loop level

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

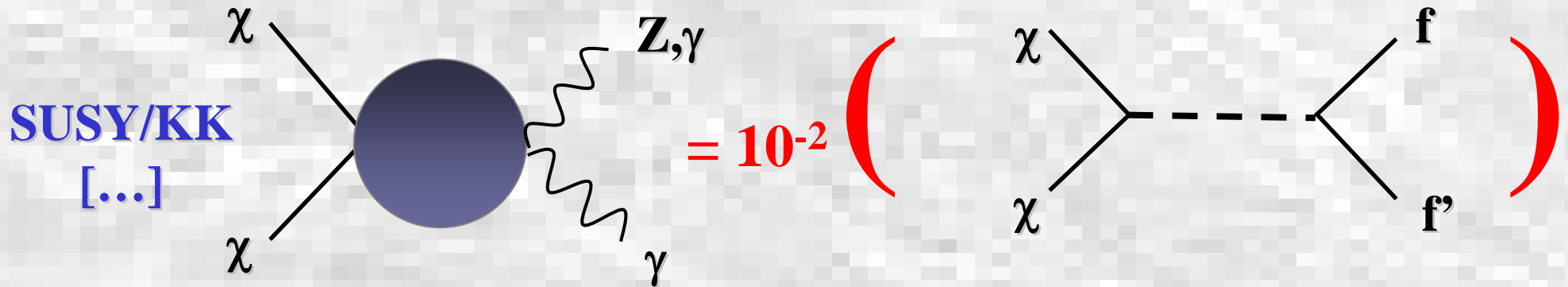
[Weiner, 08]



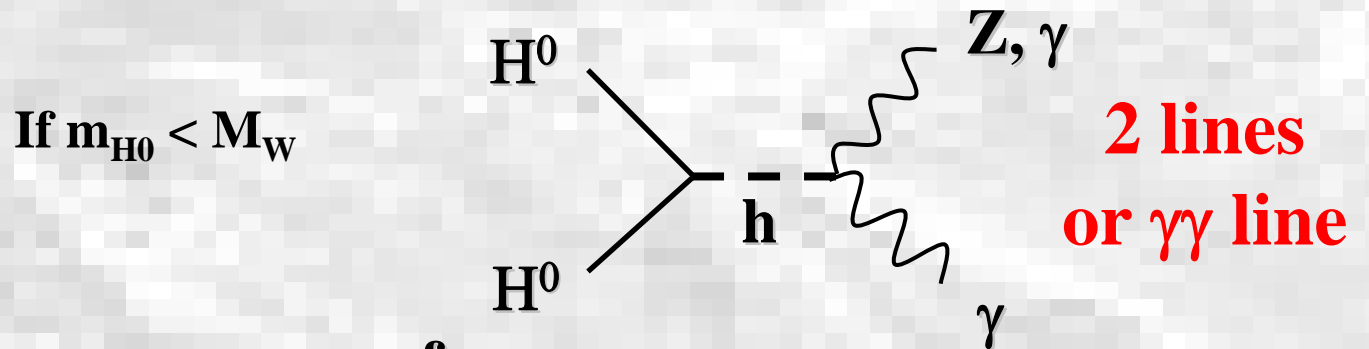
PRECISION TEST  $\delta < 0.1$



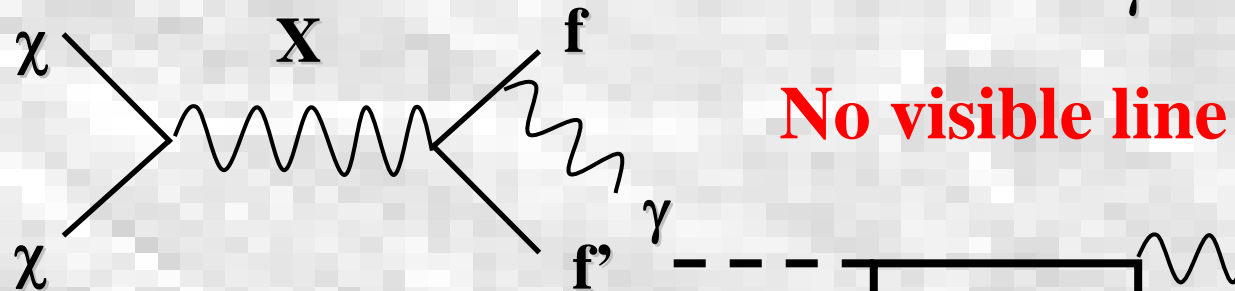
# $\gamma$ ray lines



**Inert Higgs Doublet**  
[Gustafsson et al. 2007]

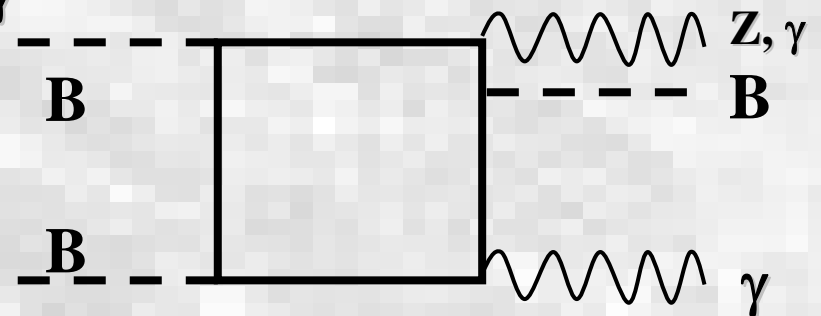


**Visible  $Z'$**   
[Cheung et al. 07]  
[Baek & Ko, 08]

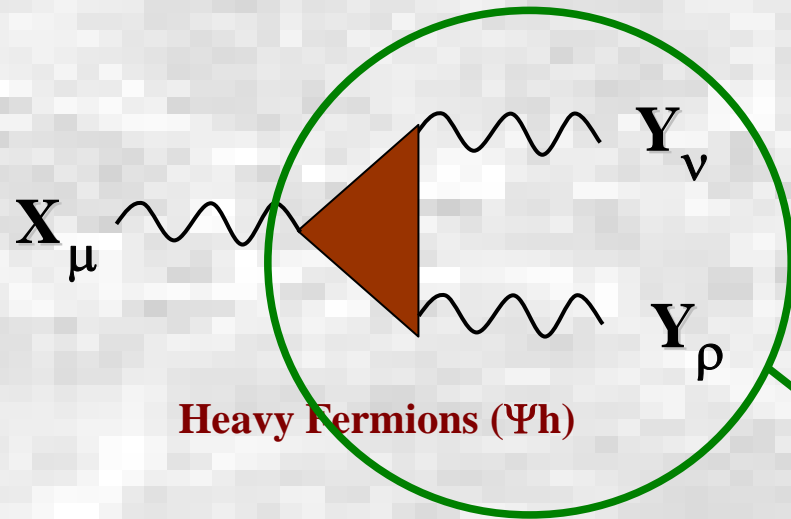


**Chiral Square**  
[Bertone et al. 2009]

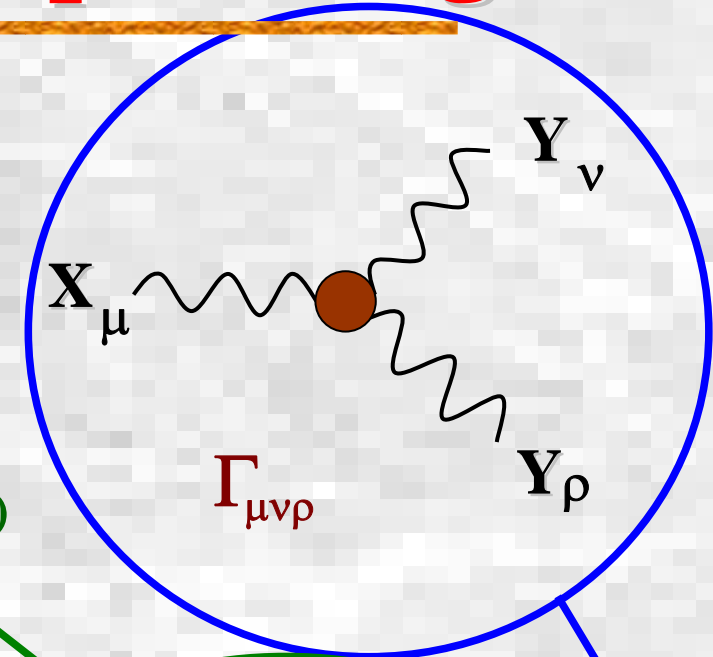
**3 visible lines**



# Anomalies and loops triangle



Heavy Fermions ( $\Psi_h$ )



$\Gamma_{\mu\nu\rho}$

$U'(1)$

$\Psi$	$U(1)$	$U'(1)$
$\Psi_{SM}$	$X_{SM}$	$0$
$\Psi_h$	$X_h$	$X'_h$

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

$$\mathbf{X}_\mu \longrightarrow \mathbf{X}_\mu + \mathbf{d}_\mu \lambda$$

$$\mathbf{a} \longrightarrow \mathbf{a} - \mathbf{M}_X \lambda$$

$$\mathbf{X}_\mu + \mathbf{M}_X \mathbf{d}_\mu \mathbf{a} \longrightarrow \mathbf{X}_\mu + \mathbf{M}_X \mathbf{d}_\mu \mathbf{a}$$

(Stueckelberg Lagrangian)

# The Lagrangian :

## Green-Schwarz mechanism

(Intersecting Brane Models)

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

$$\mathcal{L}_{var} = \underbrace{B a \varepsilon^{\mu\nu\rho\sigma} F^Y_{\mu\nu} F^Y_{\rho\sigma}}_{\text{Peccei-Quinn terms}} + \underbrace{C \varepsilon^{\mu\nu\rho\sigma} X_\mu Y_\nu F^Y_{\rho\sigma}}_{\text{Chern-Simons terms}}$$

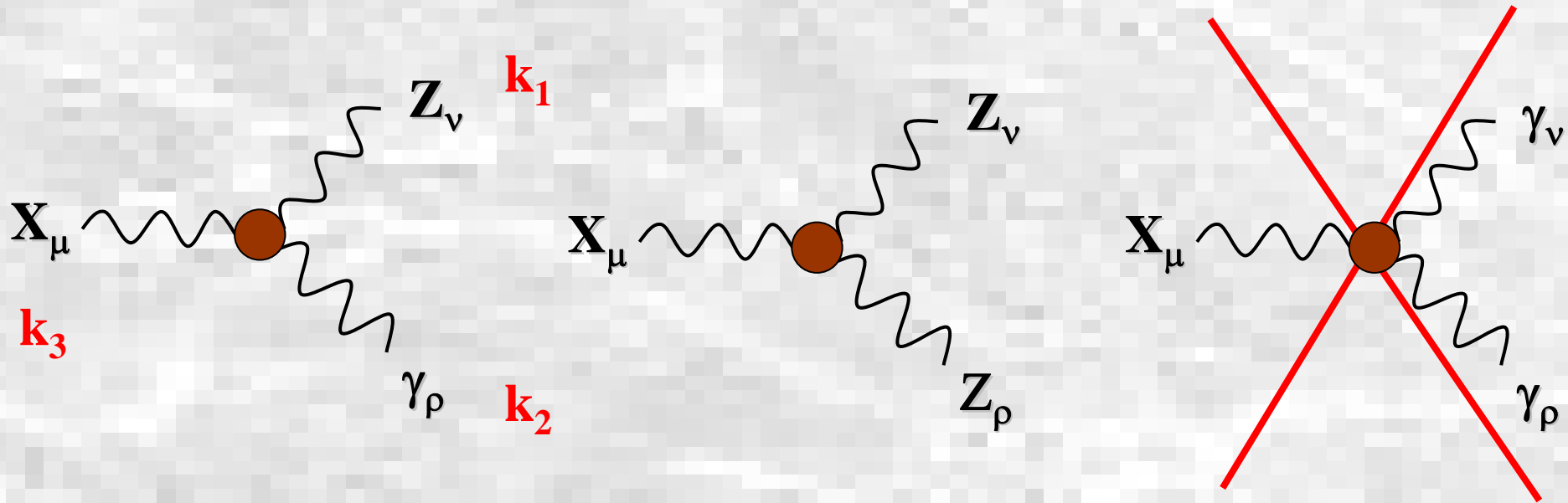
Peccei-Quinn terms

Chern-Simons terms

$$\delta \mathcal{L}_{var} = - \delta \left( \begin{array}{c} X_\mu \text{ wavy line} \\ \text{triangle} \\ Y_\nu \text{ wavy line} \\ Y_\rho \text{ wavy line} \end{array} \right)$$

Heavy Fermions ( $\Psi_h$ )

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



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

Peccei-Quinn

Chern-Simons

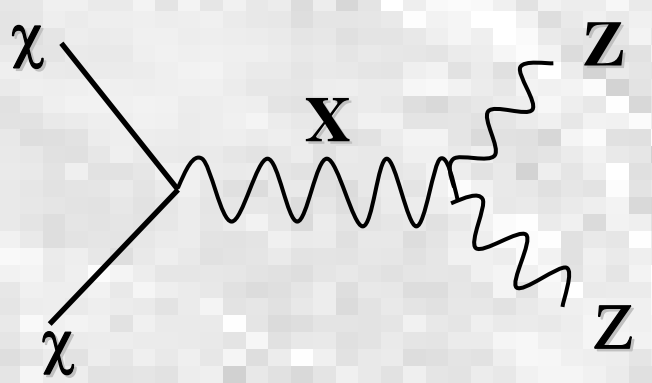
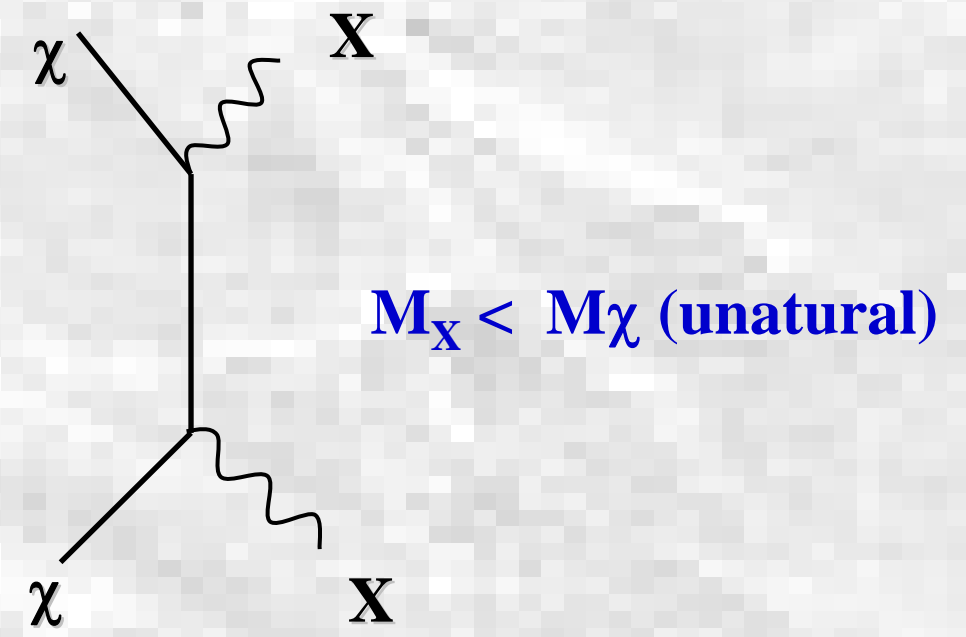
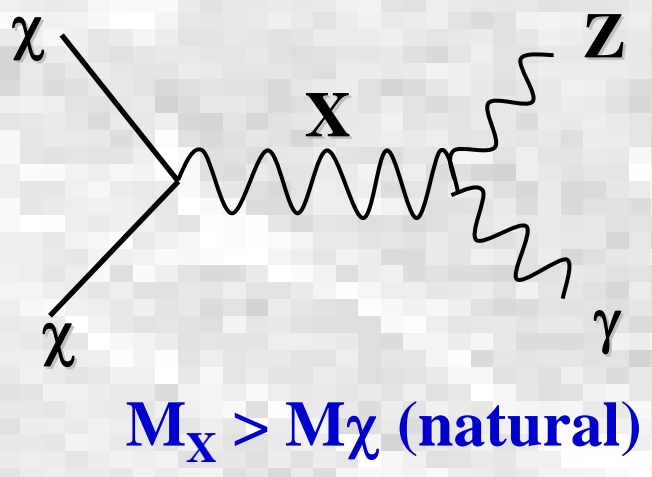
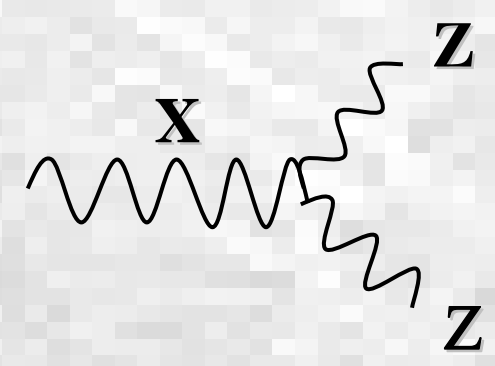
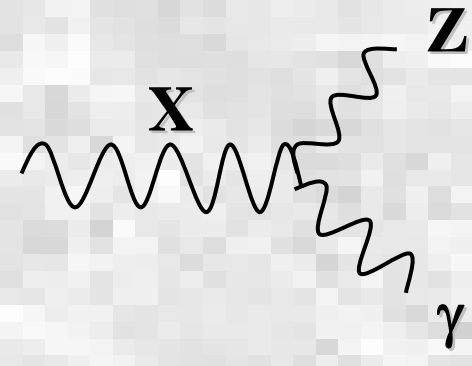
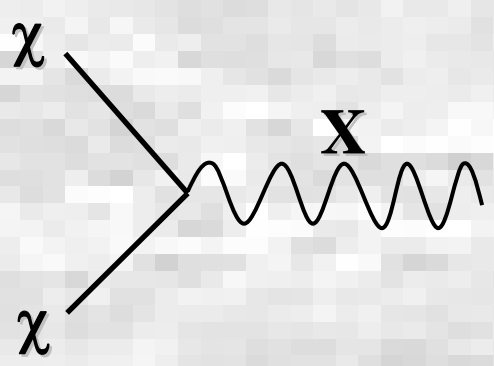
$\delta \mathcal{L}_{eff} = 0$  3 Ward identities +  $(\mathbf{k}_1; \mathbf{k}_2)$  symmetries  
 $\rightarrow$  the vertex can be express as function of  $|B_2 - B_1| = 1/\Lambda_X^2$

With  $B_1, B_2 =$  computable loops integrals

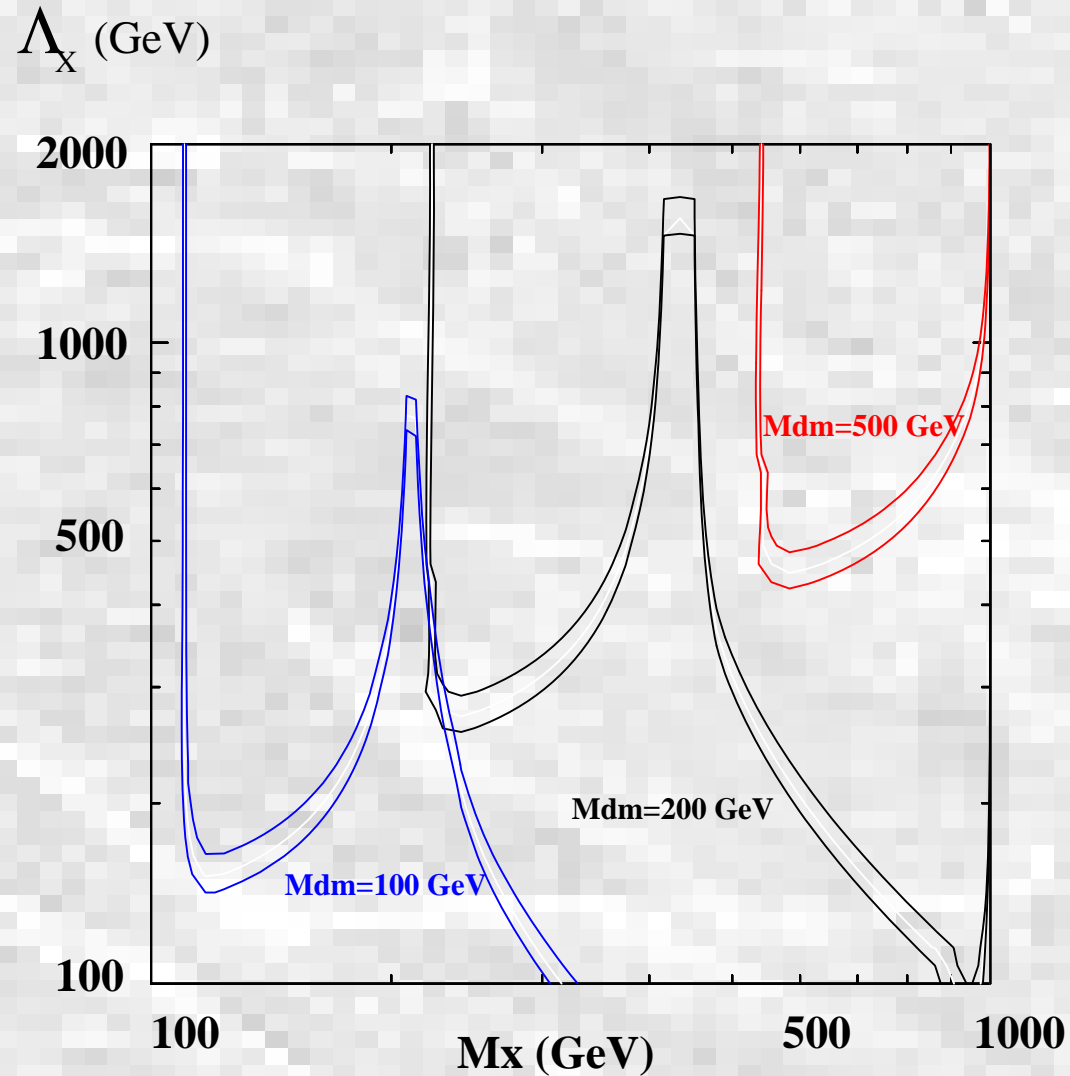
Cc : only 3 parameters :  $\Lambda_X [ <S> ] ; M_X [g_X] ; M_{\chi} [Y_{heavy}]$

# Dark matter: Annihilation channels

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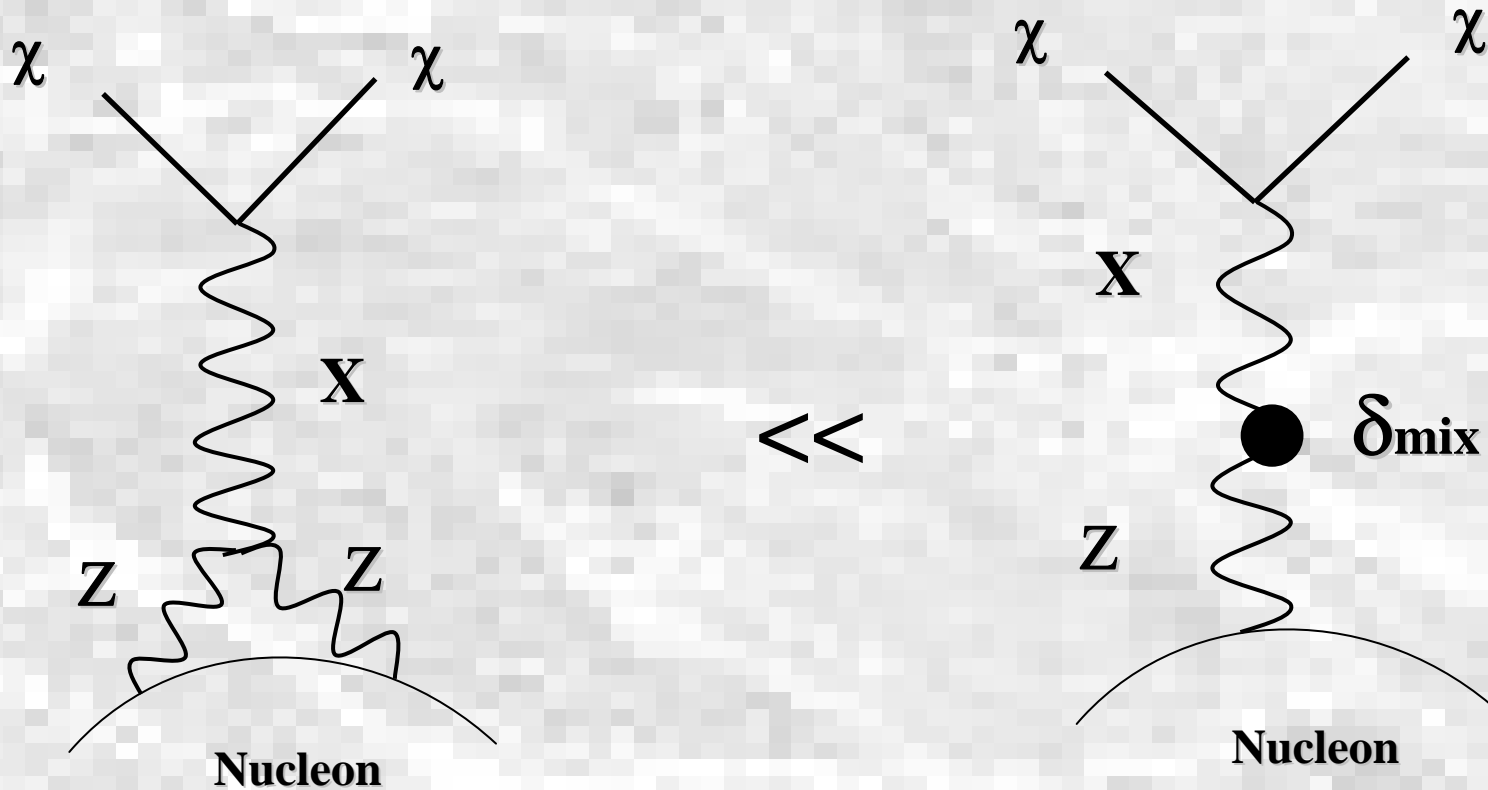
# The relic density



$$\Lambda_X^2 = |\mathbf{B}_2 - \mathbf{B}_1| = g_h * g^2 / (8\pi^2) * \text{Tr}[\mathbf{X}' \mathbf{X}^2 / M_{heavy}^2] * \text{Integral}$$



# Direct detection

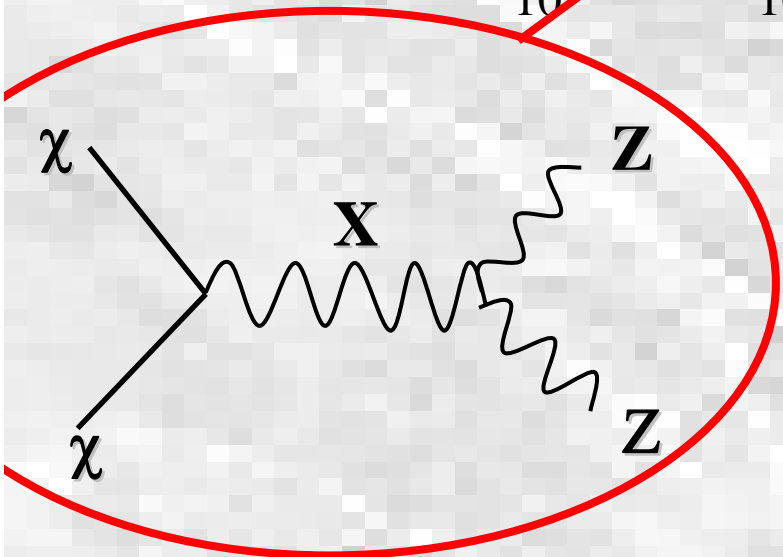
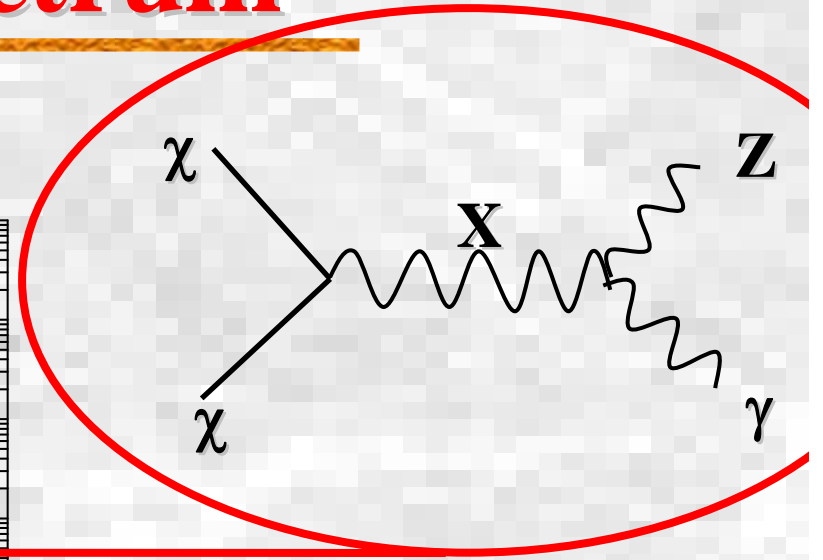
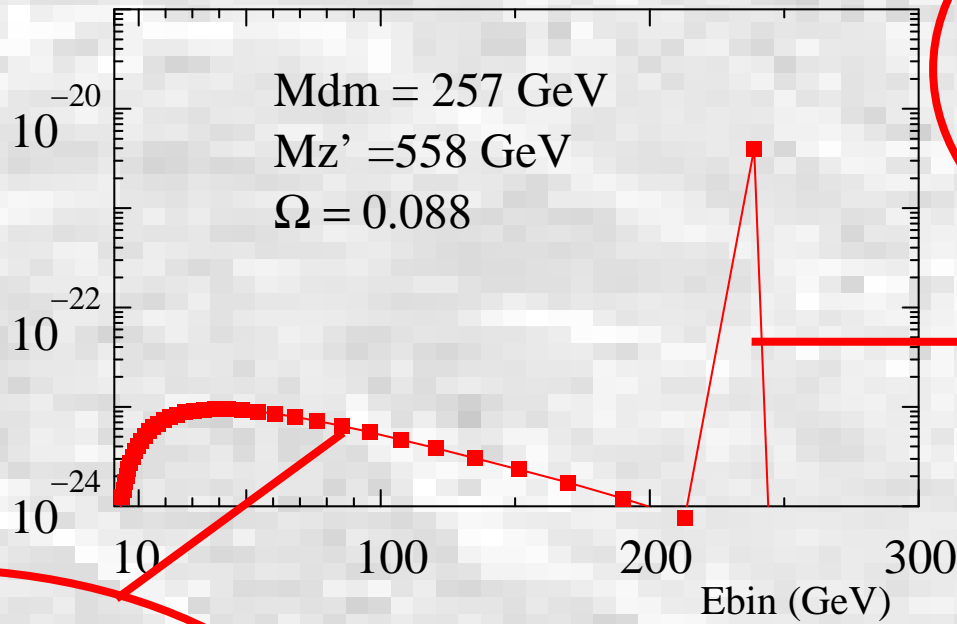


$$\mathcal{L}_{\text{mix}} = \delta_{\text{mix}} \mathbf{F}_{\mu\nu} \mathbf{F}'_{\mu\nu}$$

Millicharged DM,  
XENON  $\Rightarrow \delta_{\text{mix}} < 0.01$

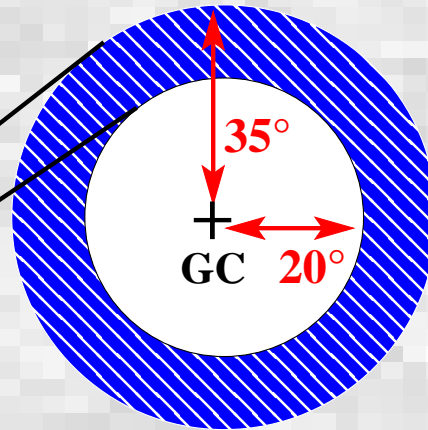
# Indirect detection: examples of spectrum

$E^2 * dN/dE$



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

# Indirect detection astro-parameters



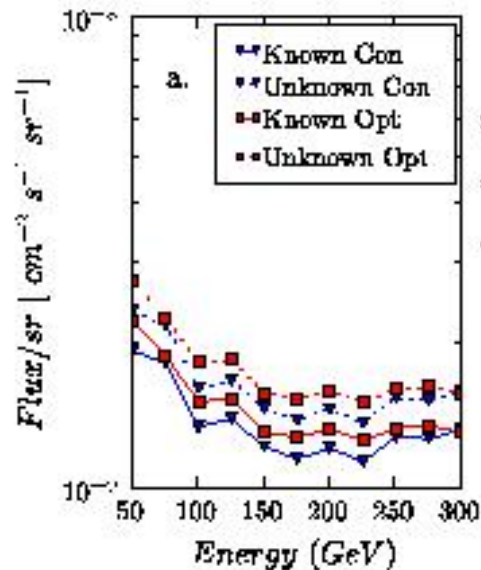
Signal to noise ratio  
12 time greater than  
GC

Independant of the Galactic profile

Galactic Centered Annulus

(Stoehr et al 2003, GLAST col. 2008)

$J \Delta\Omega \sim 10$

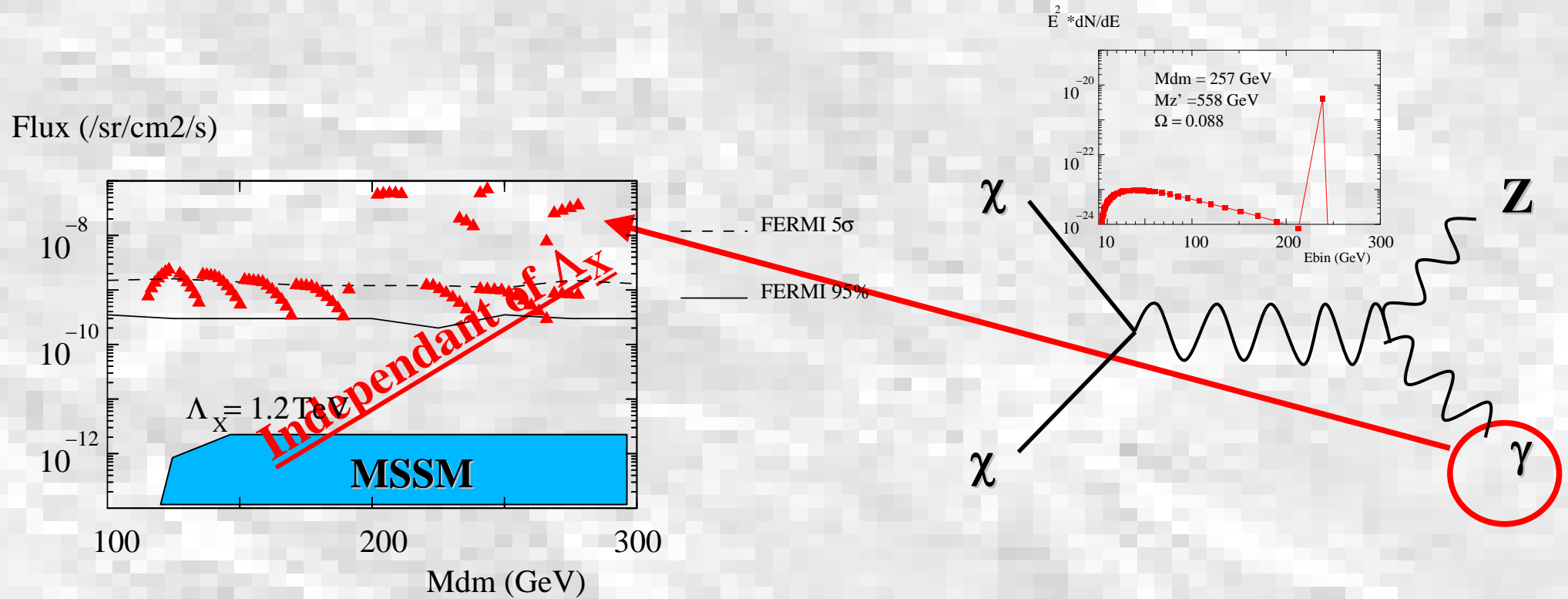


Galprop conventional model  
for the background

5 years of data, signals at  $5\sigma$  and  
95% CL

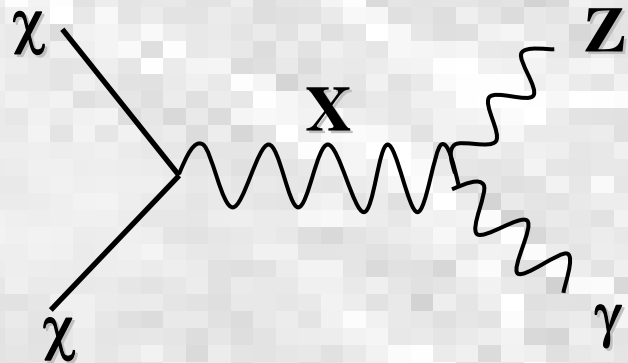
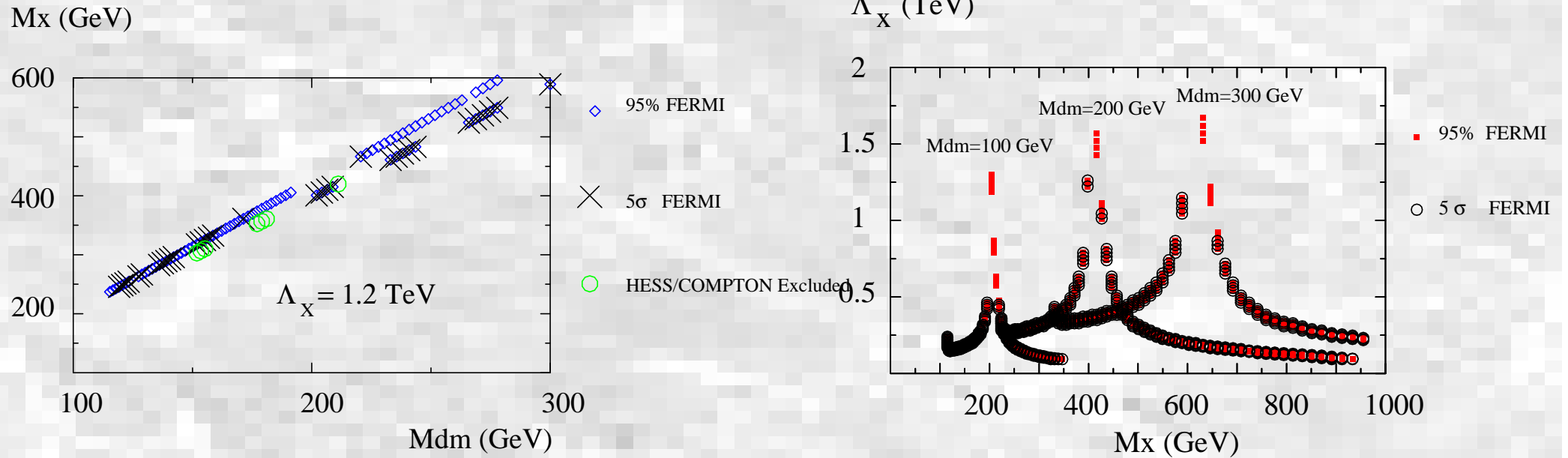
[FERMI estimates, Morselli et al. 08]

# Observability



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

# Consequences on $M_x$ and $M_{chi}$



# Comparison with other models

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

# Conclusions

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**An (In)visible  $Z'$  can be quite visible**

**Indirect detection would be THE ONLY WAY to observe it**

**1  $\gamma$  ray line is a smoking gun signal distinguishing it clearly from other constructions**

**Possibility to test up to 1TeV BSM scale**