

# The Inert Doublet Model: A model of dark matter

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based on hep-ph/0612275 [ JCAP(2007)]  
in collaboration with E. Nezri, J. Oliver and M.Tytgat



XLII nd Rencontres de MORIOND: Electroweak Session

# Motivations

The Inert Doublet Model (**IDM**)

≡ Standard Model (**SM**) with one Brout-Englert-Higgs doublet  $H_1$

- $\langle H_1 \rangle = v$ ,  $H_1 \rightsquigarrow h$

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+ extra “Inert” doublet  $H_2$  +  $\mathbb{Z}_2$  symmetry ( $\text{SM} \rightarrow \text{SM}$ )

- $\langle H_1 \rangle = v$ ,  $H_1 \rightsquigarrow h$ ,  $H_1 \rightarrow H_1$
- $\langle H_2 \rangle = 0$ ,  $H_2 \rightsquigarrow H_0, A_0$  and  $H^\pm$ ,  $H_2 \rightarrow -H_2$

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- Provide extra **stable** and **weakly** interacting scalars
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[Ma, Barbieri *et al*, Cirelli *et al*]

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  - For  $\Omega_{DM}^{WMAP}$ 
    - $M_{DM} \sim 60 - 75$  GeV for *Barbieri, Hall & Rychkov*
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[Ma, Barbieri *et al*, Cirelli *et al*]
- $H_2 - H_1$  interactions modify the Higgs phenomenology
  - $\rightsquigarrow$  consequences on **Higgs searches** ?

# The model

The IDM scalar potential :

$$\begin{aligned} V = & \mu_1^2 |H_1|^2 + \mu_2^2 |H_2|^2 + \lambda_1 |H_1|^4 + \lambda_2 |H_2|^4 + \lambda_3 |H_1|^2 |H_2|^2 \\ & + \lambda_4 |H_1^\dagger H_2|^2 + \frac{\lambda_5}{2} [(H_1^\dagger H_2)^2 + h.c.] \end{aligned}$$

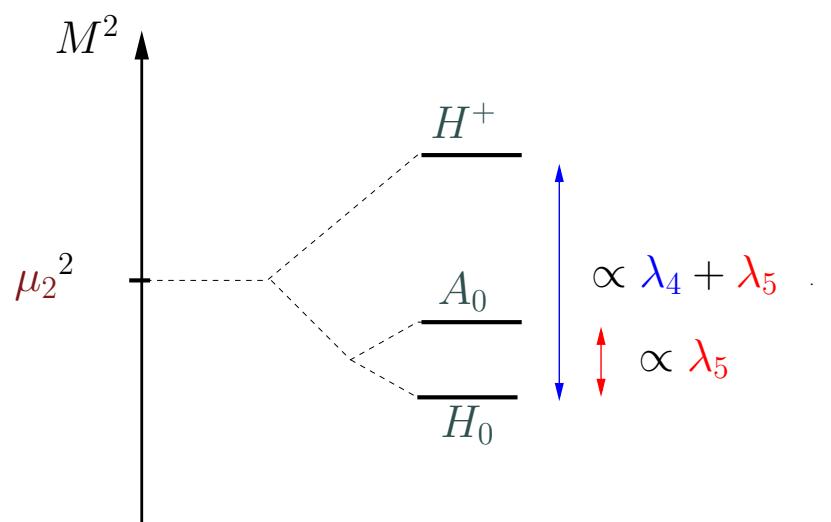
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Assuming  $H_0 \equiv \text{LZP}$   $\rightsquigarrow M_{H_0}^2 = \mu_2^2 + \lambda_L v^2$   
where  $\lambda_L = \lambda_3 + \lambda_4 + \lambda_5$

with a mass pattern e.g. :



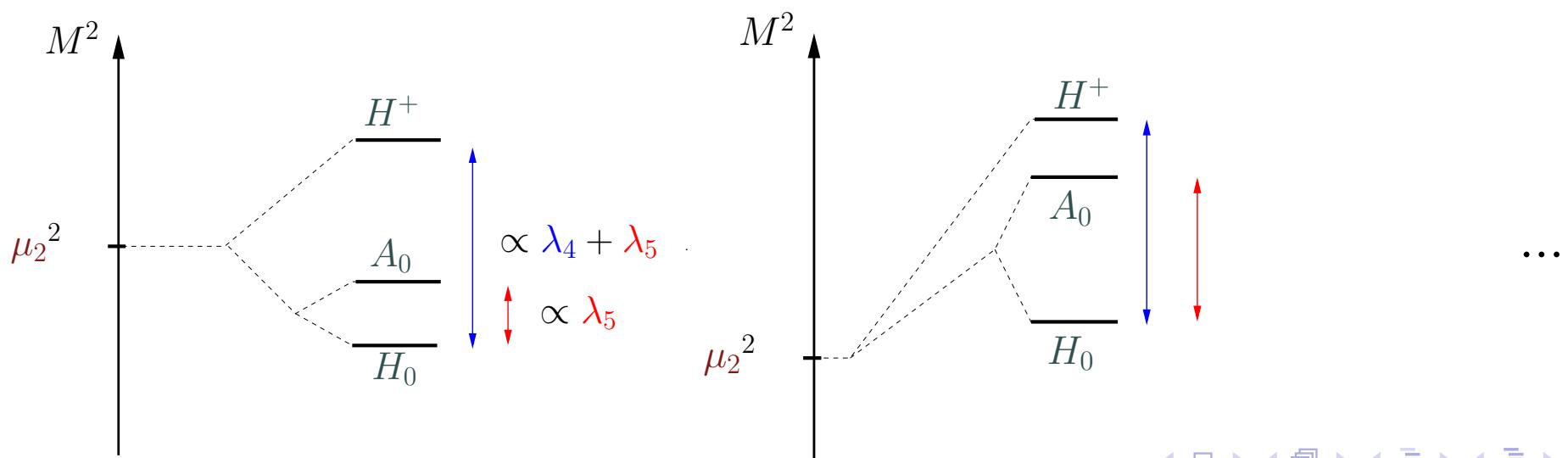
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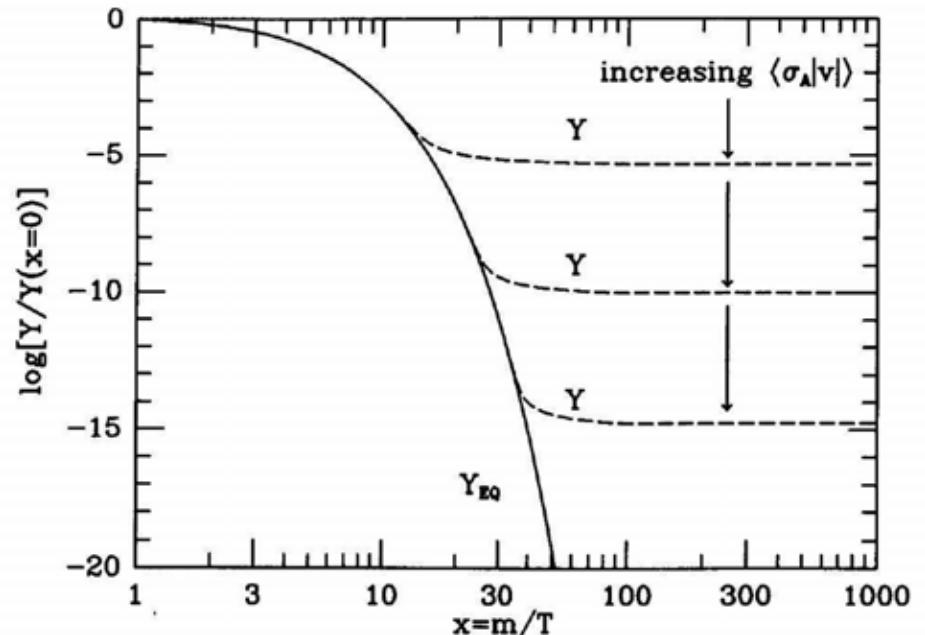


# Dark matter Abundance

Computed with [micrOMEGAs2.0](#) [Bélanger, Boudjema, Pukhov & Semenov]

**General trend :**

$$n_{DM}/s = Y \propto 1/\langle \sigma_A v \rangle$$



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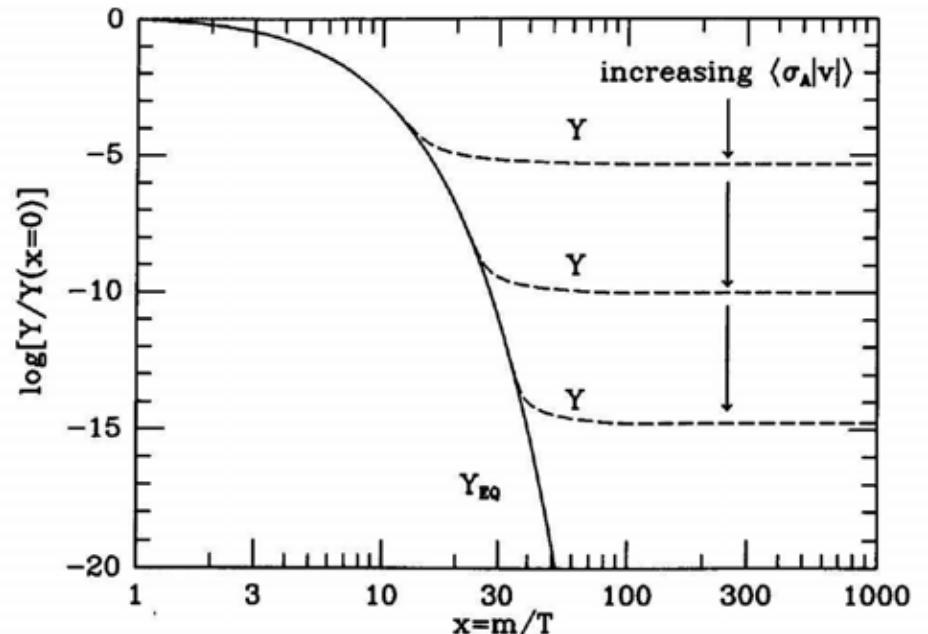
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**micrOMEGAs2.0 :**

solve Boltzmann equation  
for the LZP

$$\frac{dY}{dT} = \sqrt{\frac{\pi g_*(T)}{45}} M_{Pl} \langle\sigma_{eff} v\rangle (Y^2(T) - Y_{eq}^2(T))$$



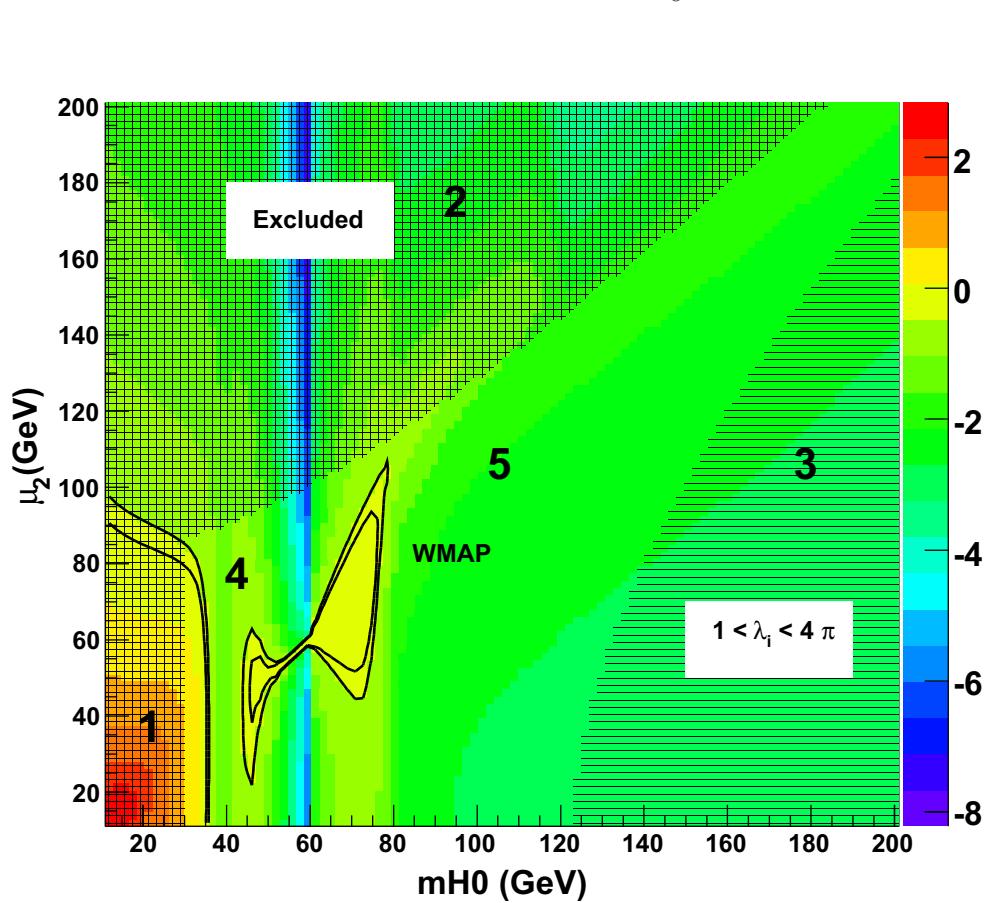
where  $\langle\sigma_{eff} v\rangle$  accounts for Annihilations and Coannihilations.

$\log_{10}(\Omega_{H_0} h^2)$  contours in the  $(M_{H_0}, \mu_2)$  plane for fixed  $\Delta M$

$$M_{H_0}^2 = \mu_2^2 + \lambda_L v^2 \text{ and } M_h = 120 \text{ GeV}$$

**Low mass regime** :  $M_{H_0} \sim M_W$

$$\Delta M_{A_0 - H_0} = 10 \text{ GeV}; \Delta M_{H^+ - H_0} = 50 \text{ GeV}$$

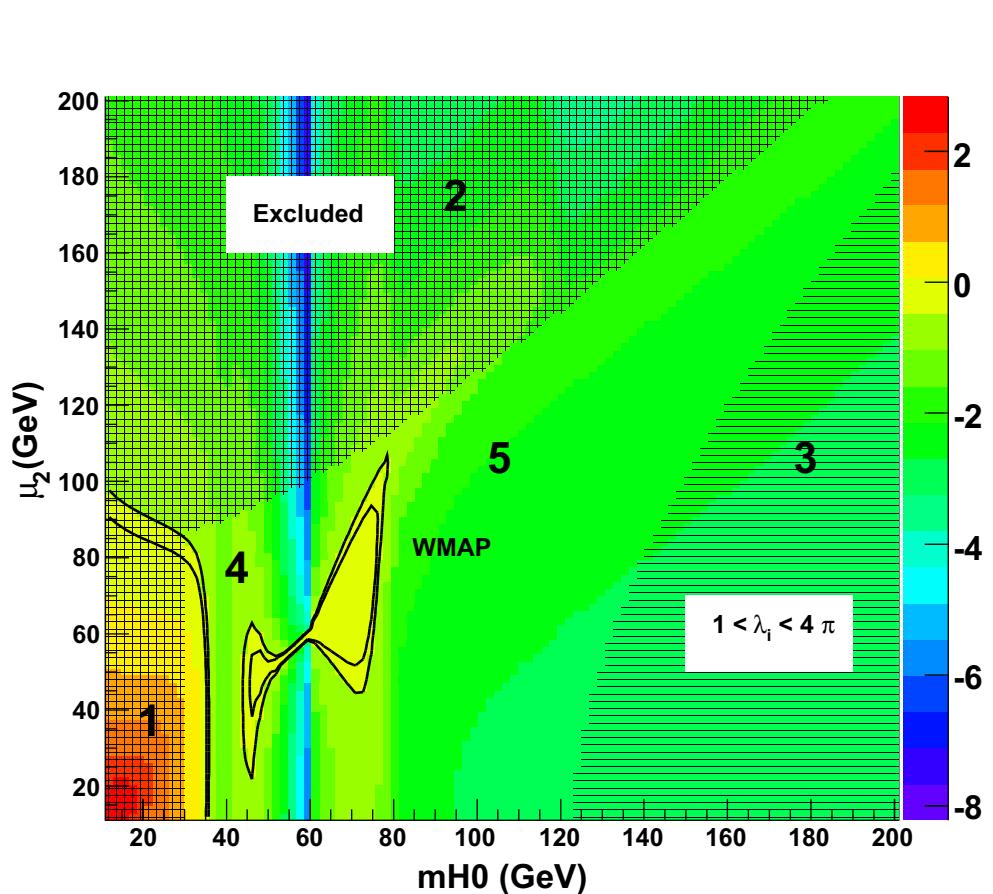


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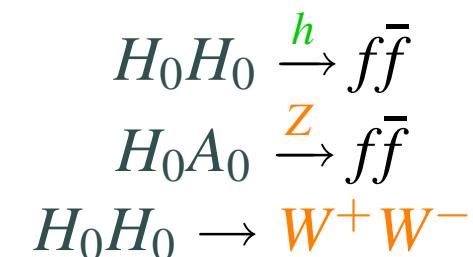
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Agreement with  $\Omega_{DM}^{WMAP}$  for  
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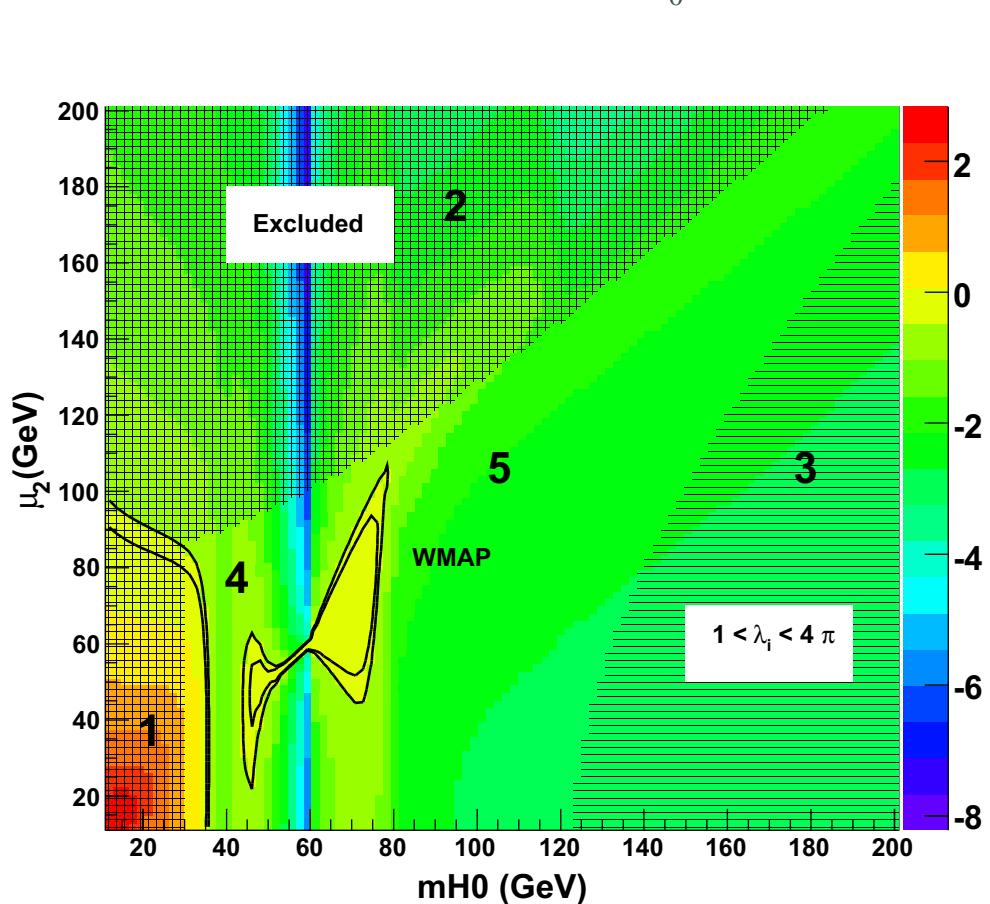


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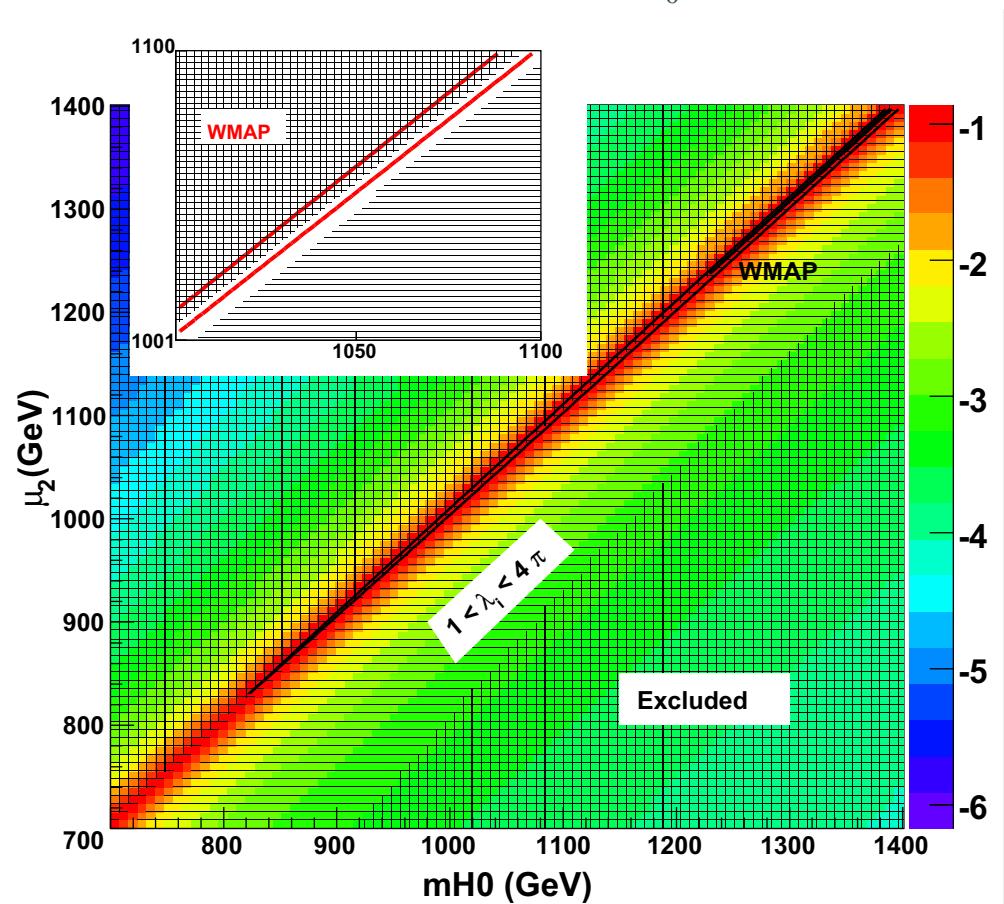
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High mass regime :  $M_{H_0} > 100 \text{ GeV}$

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Agreement with  $\Omega_{DM}^{WMAP}$  for  $M_{H_0} \gtrsim 800$  GeV thanks to :

$$H_0 H_0 \rightarrow W^+ W^-$$

$$H_0 H_0 \rightarrow ZZ$$

$$H_0 H_0 \rightarrow hh$$

Need some fine tuning :

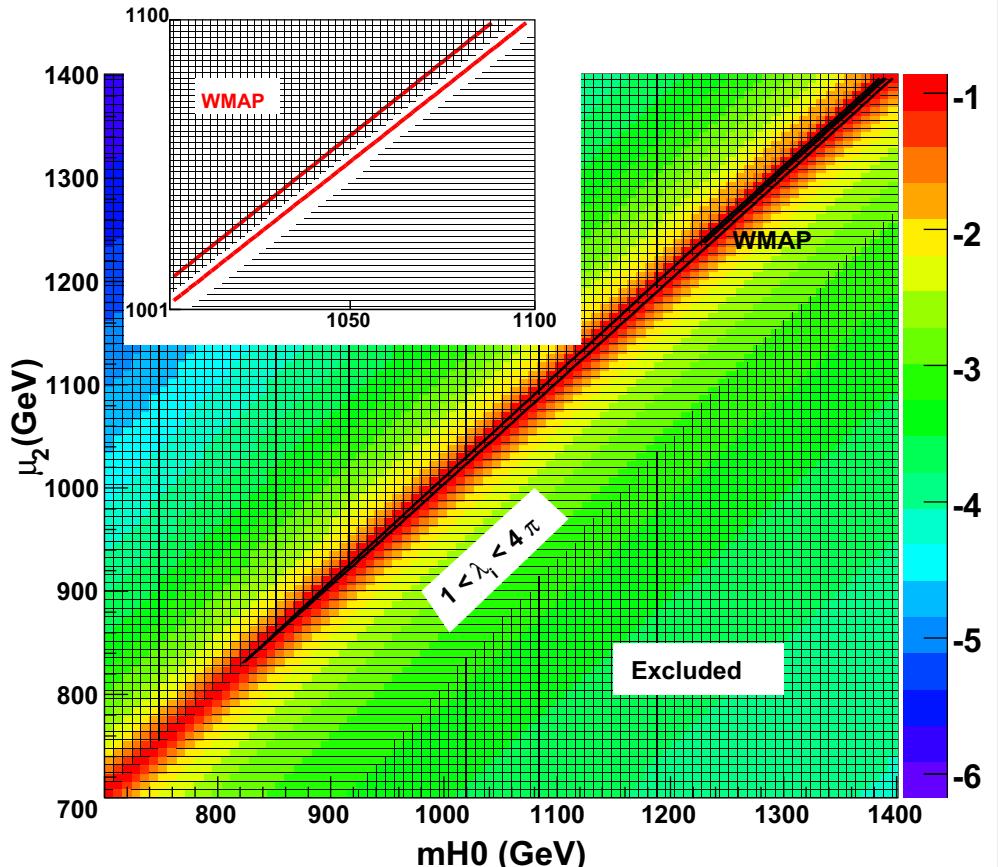
$$M_{H_0} \sim \mu_2 \sim M_{A_0} \sim M_{H^+}$$

$\Updownarrow$

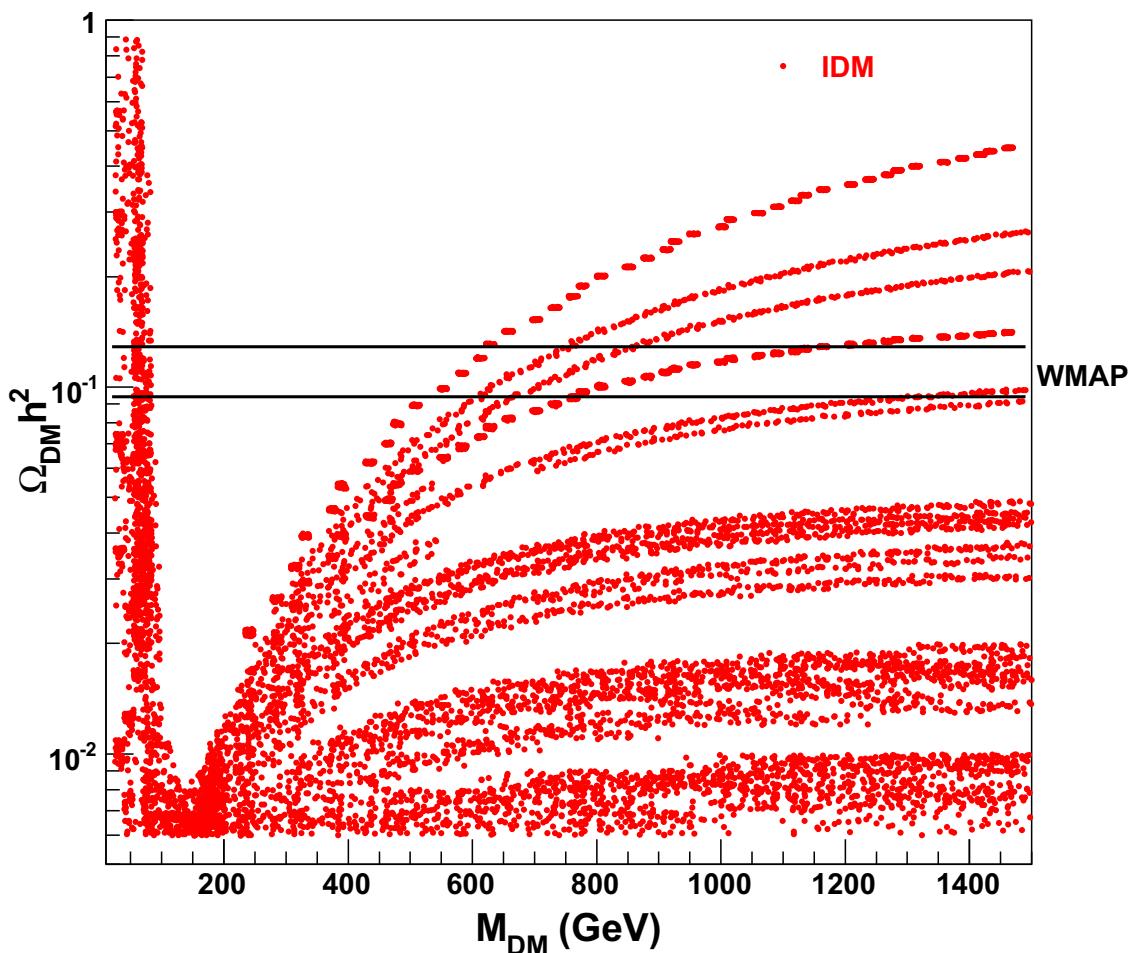
$$\lambda_L, \lambda_5, \lambda_4 \rightarrow 0$$

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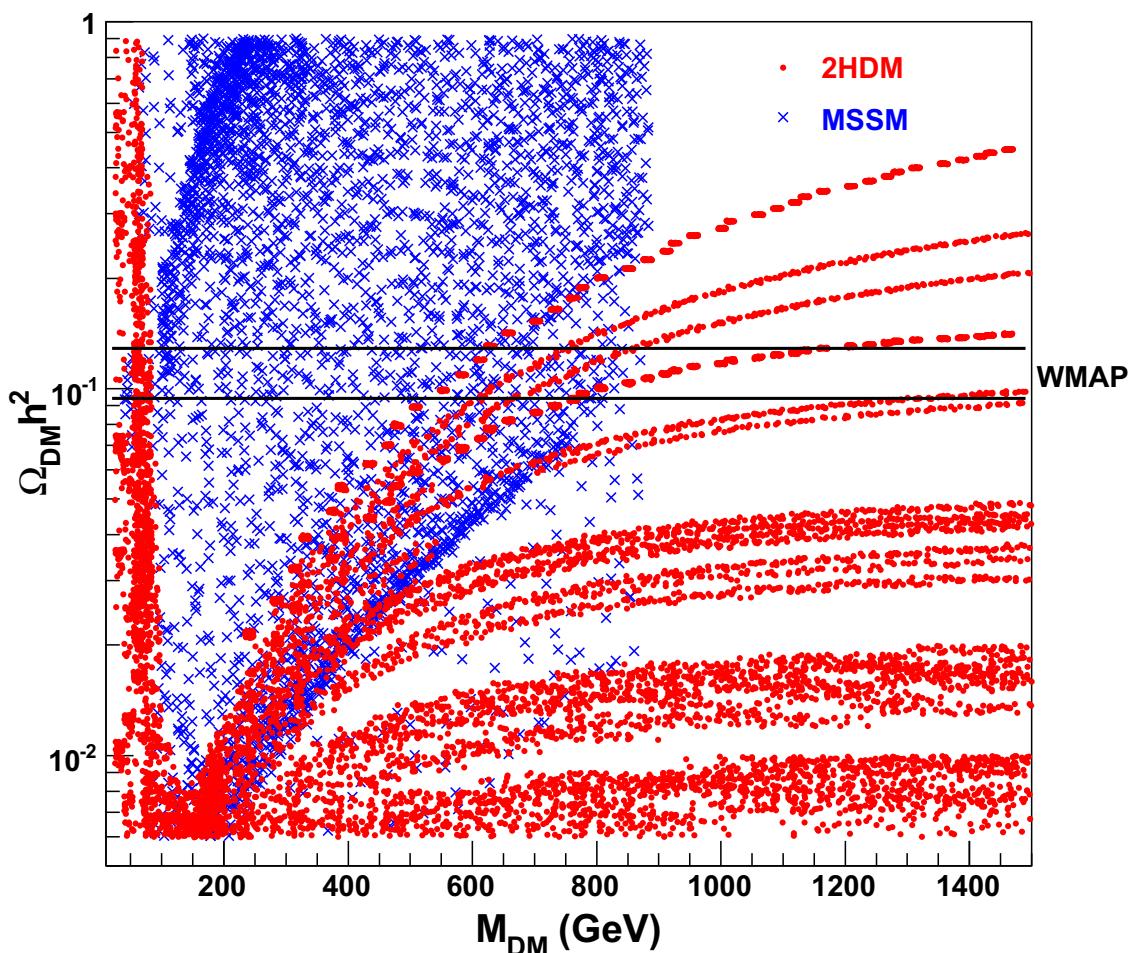
# $\Omega_{H_0} h^2$ as a function of $M_{H_0}$ for a sample of models



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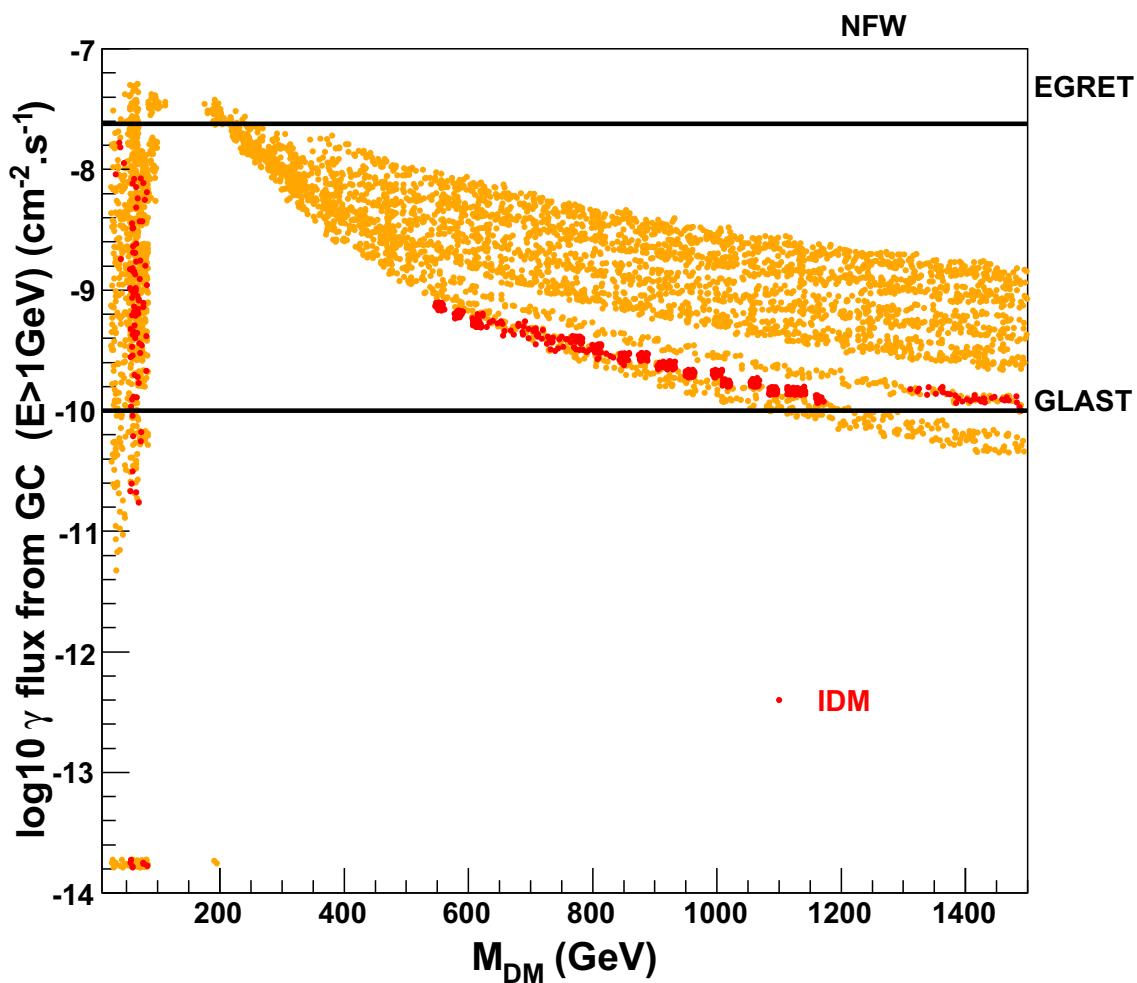


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# Indirect detection

Seeking for Gamma rays resulting from DM annihilation at Galactic Center

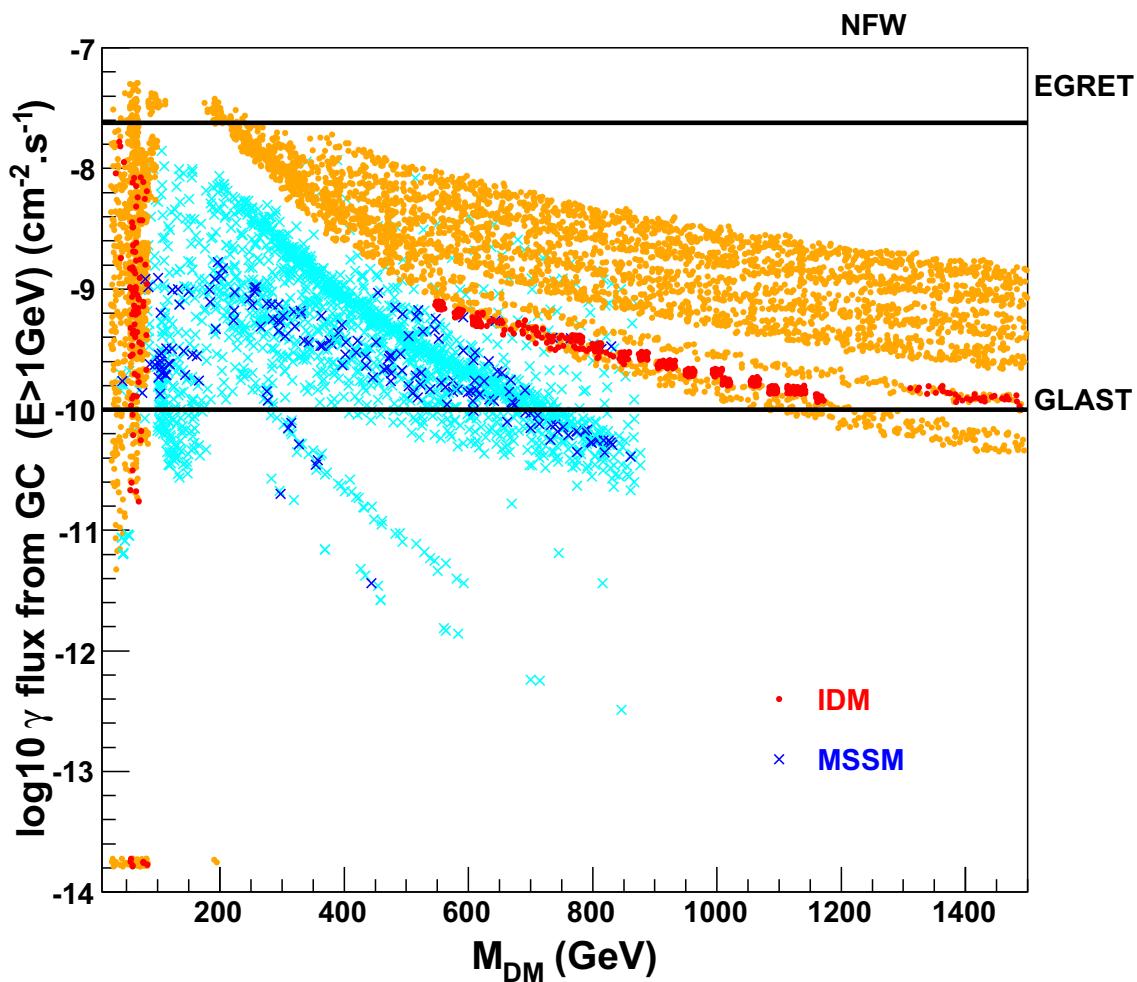


Gamma ray flux depend on :

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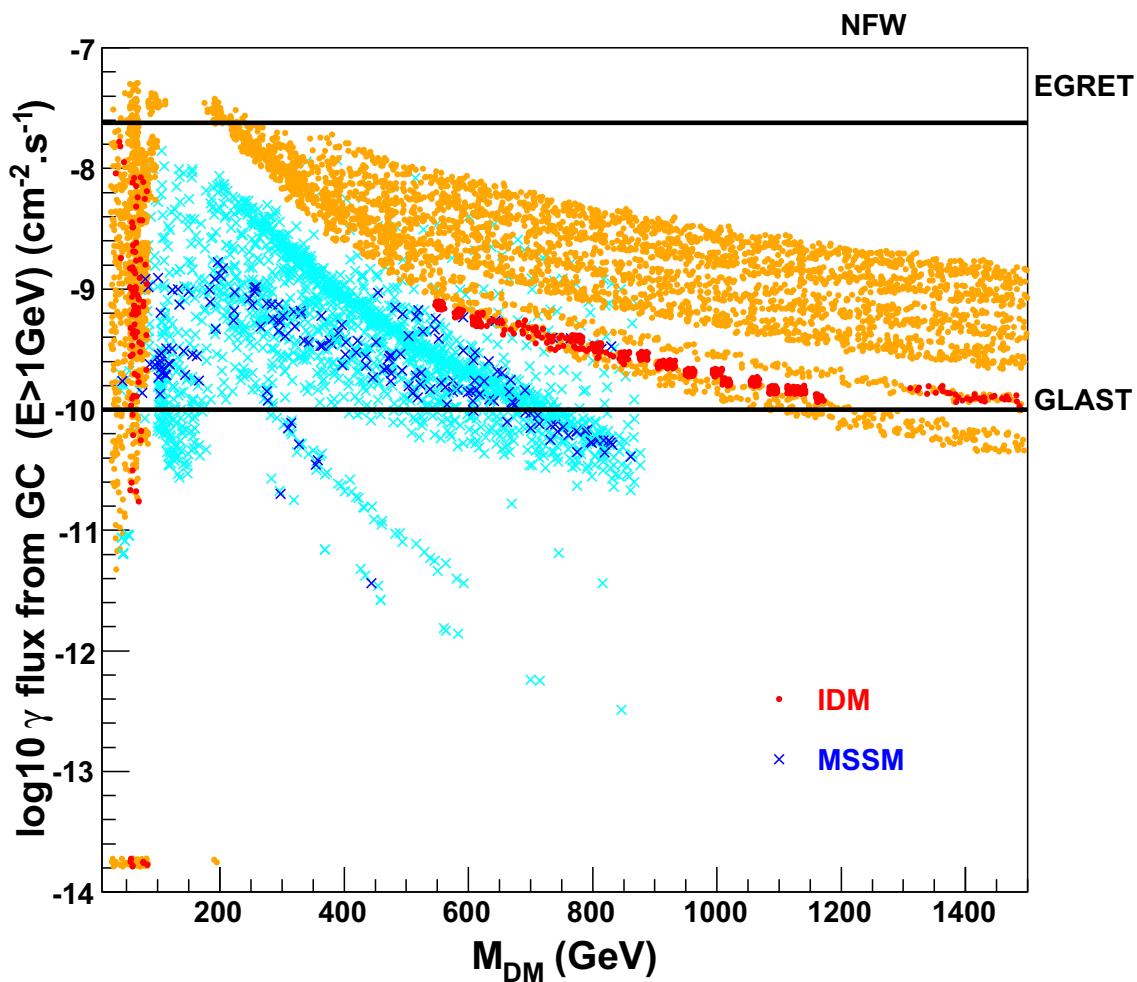


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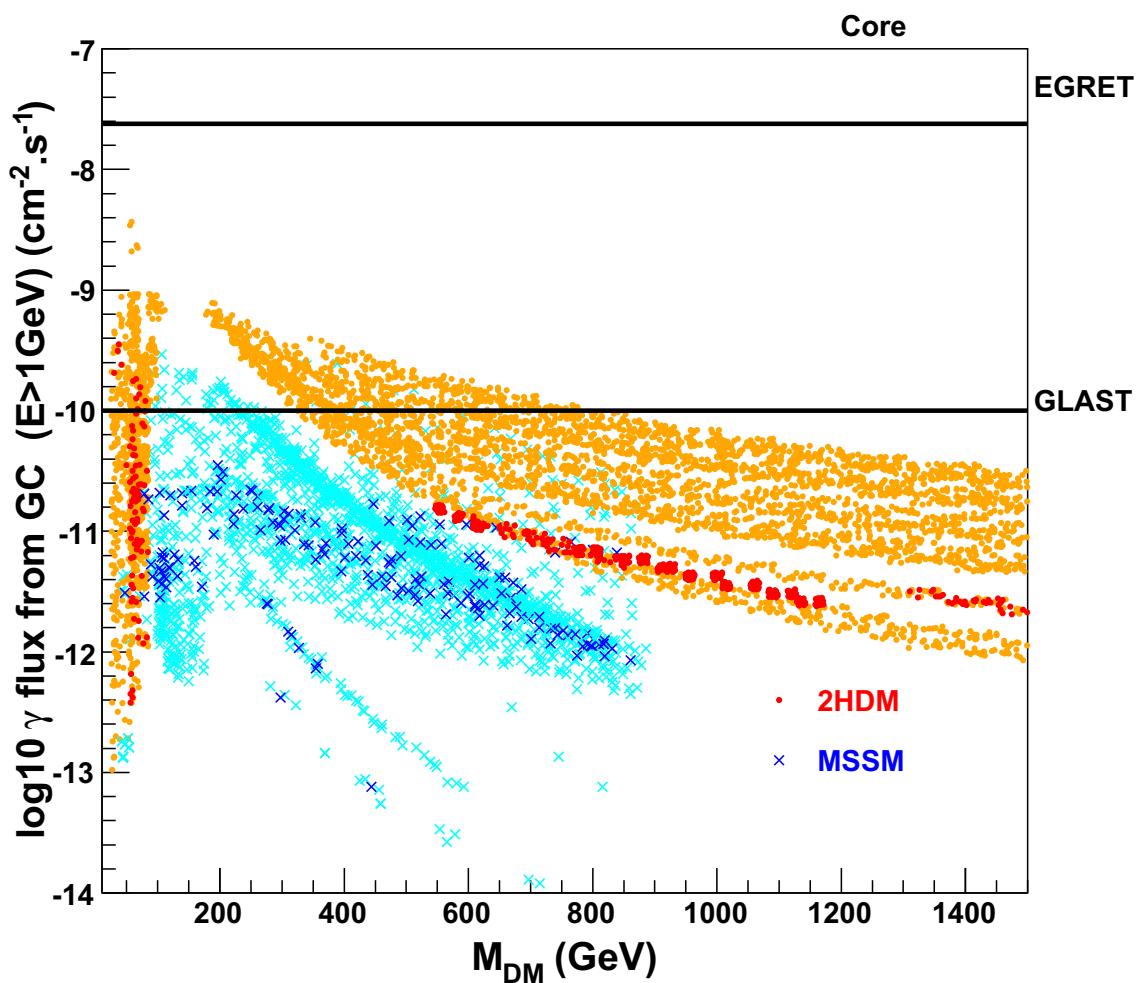


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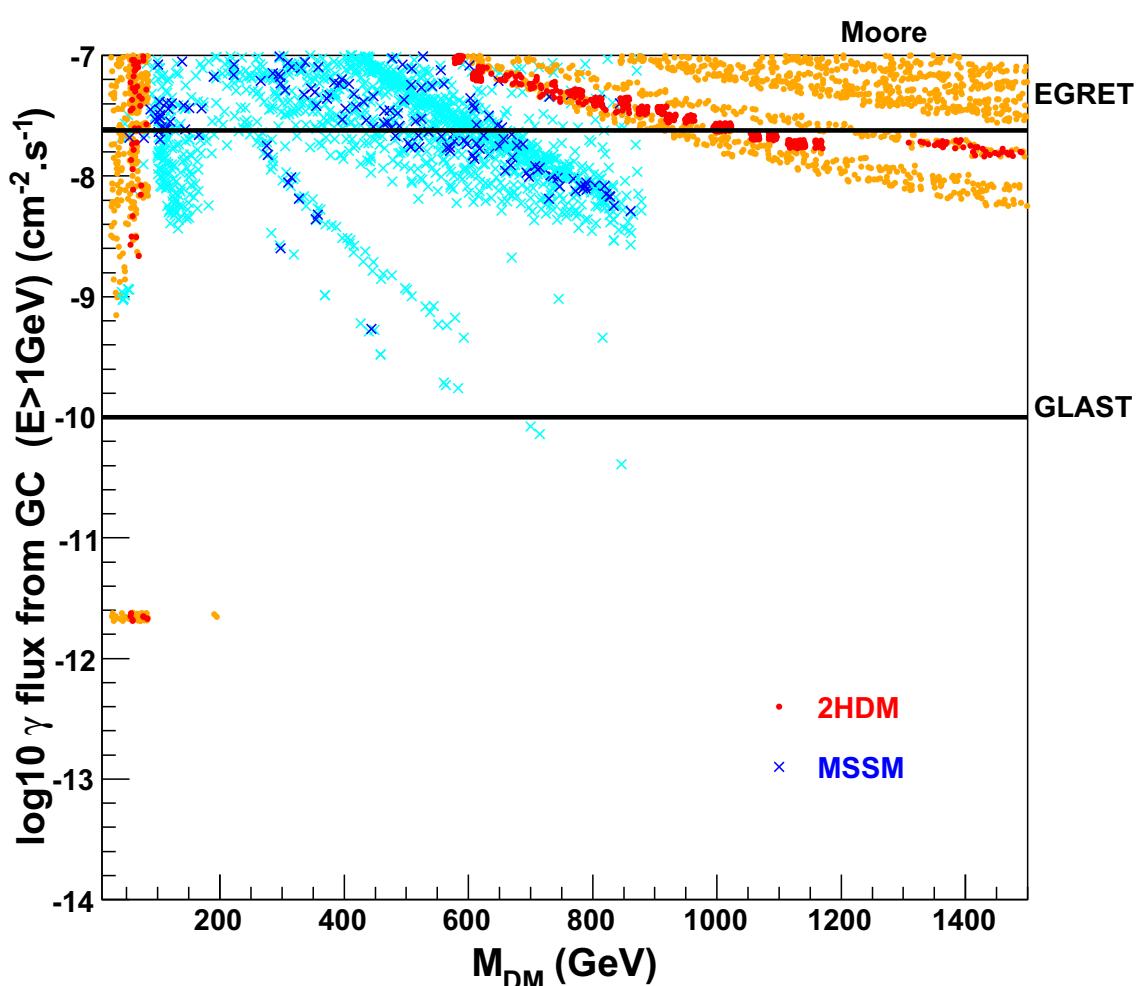


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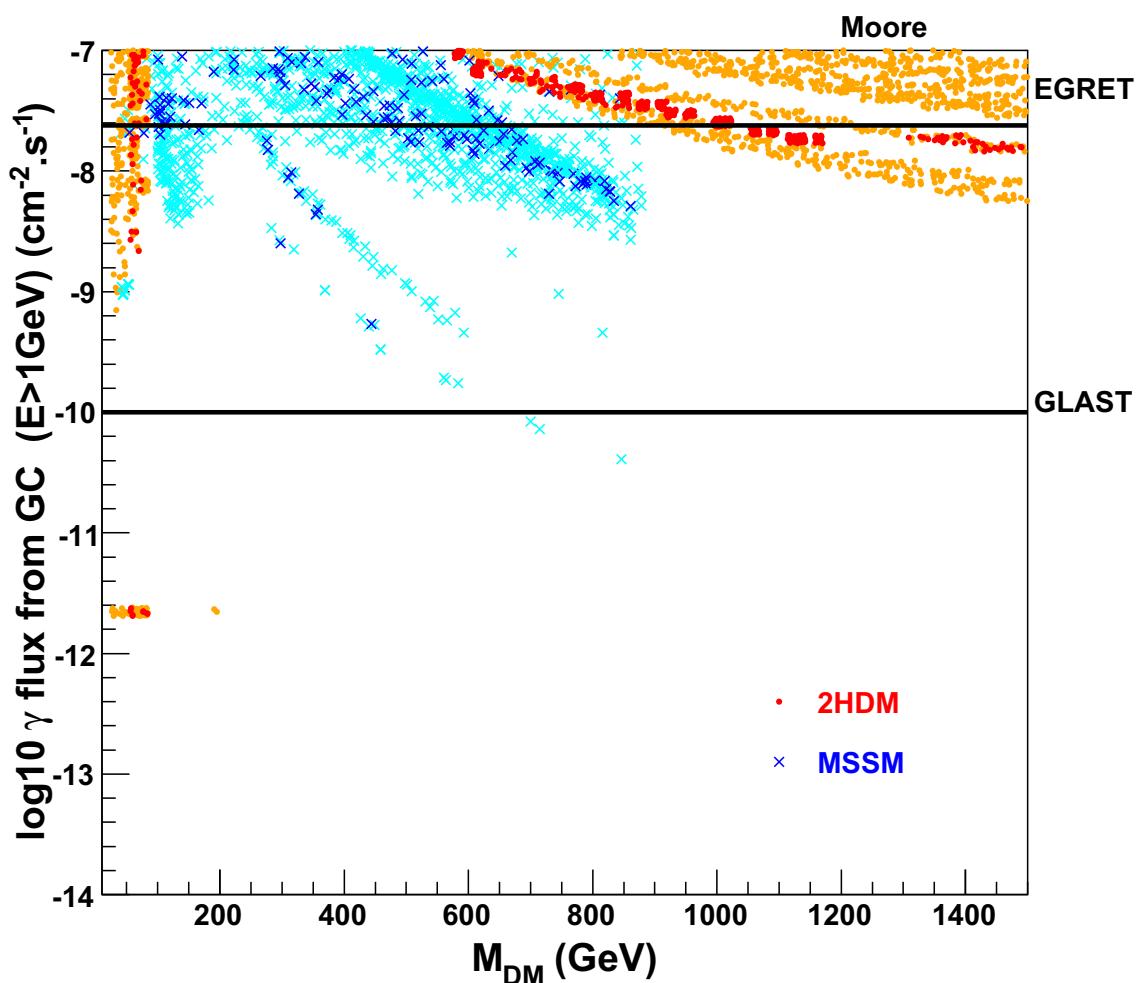


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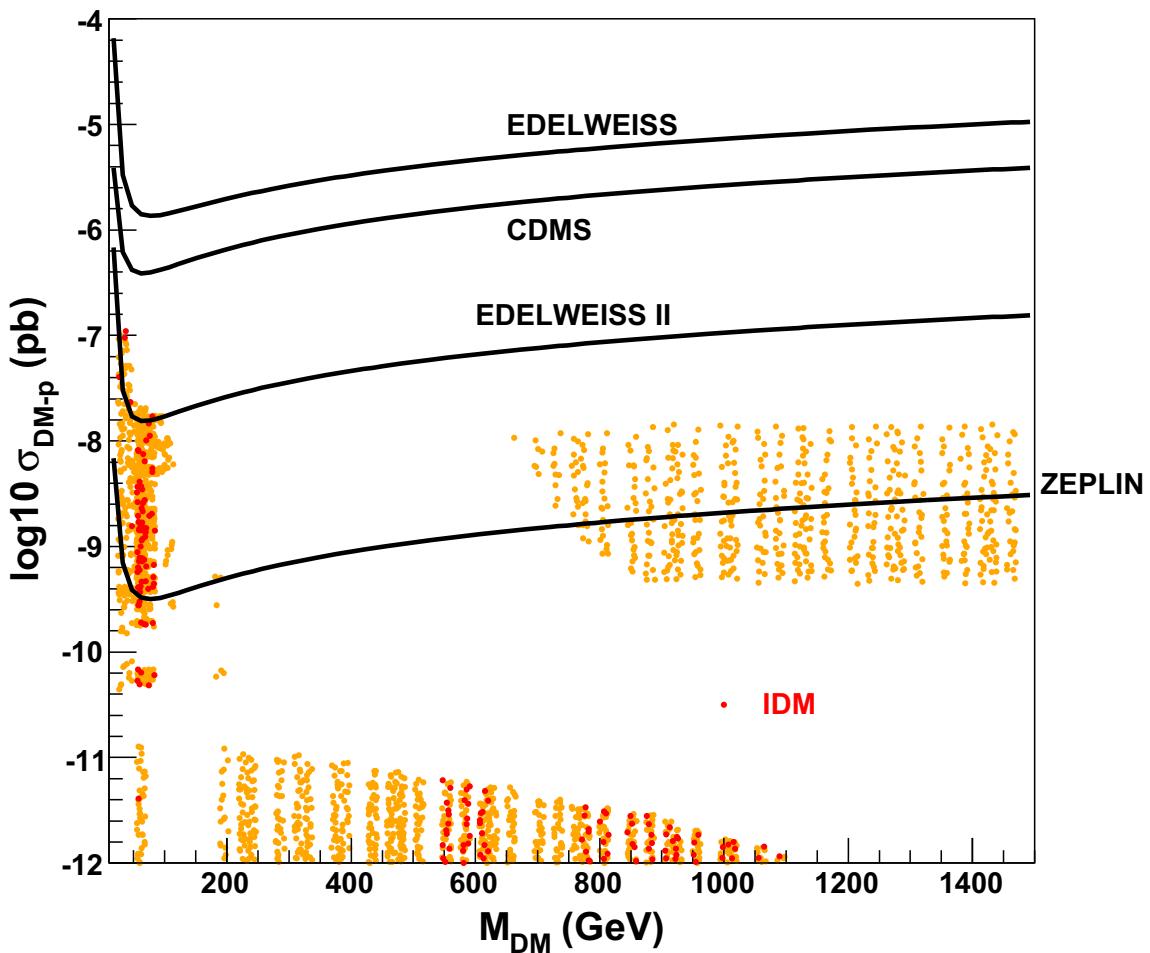
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Results

- For cuspy profile : EGRET rule out most of IDM
- For flatter profile : GLAST will probe the IDM

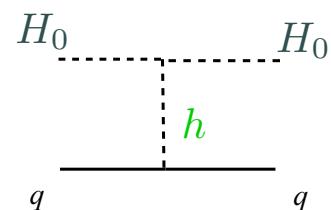
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On the track of  $H_0$  scattering with nuclei in low background detectors



Relevant spin independent processes for  $M_{A_0} \neq M_{H_0}$ :

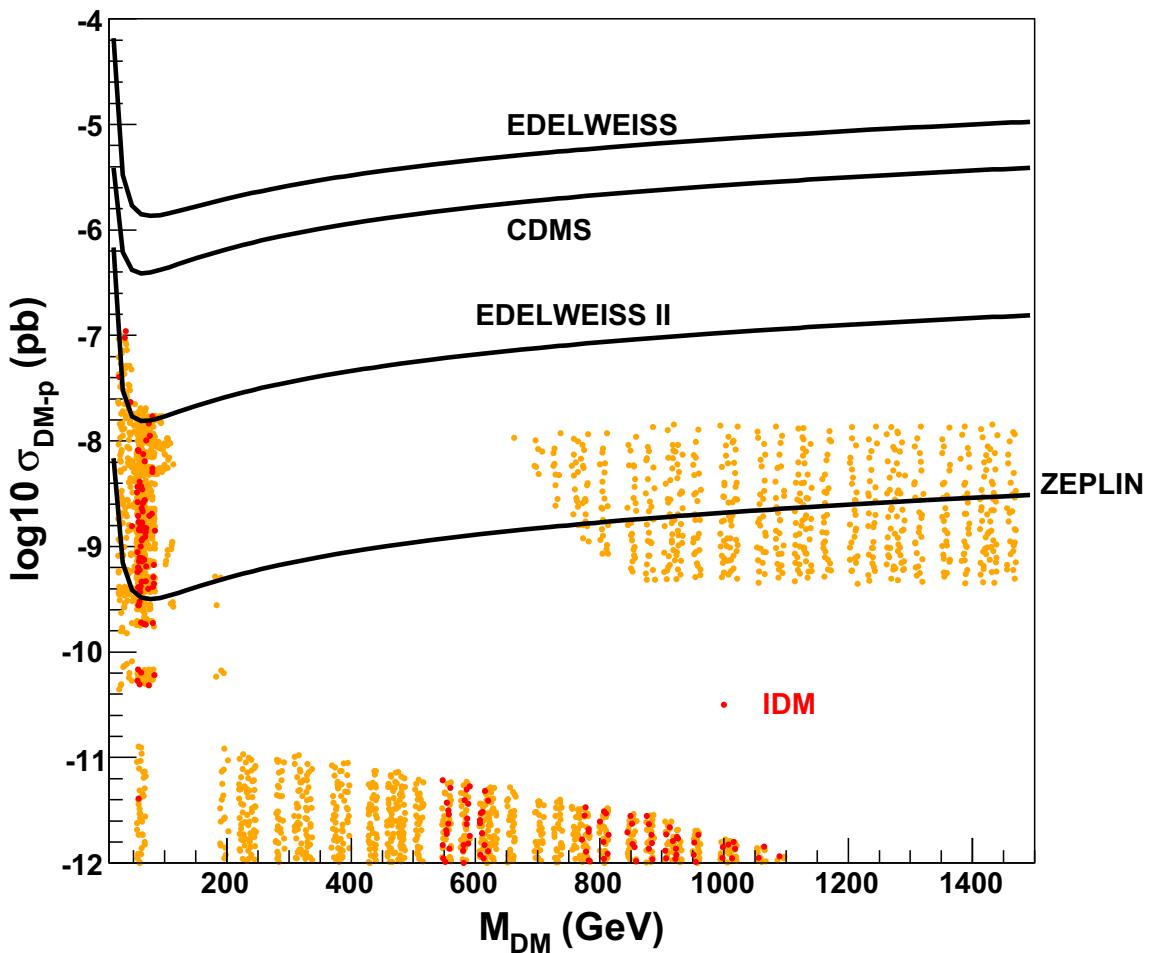
[Barbieri *et al*]



$$\sigma_{H_0-p} \propto \left( \frac{\lambda_L}{M_{H_0} M_h} \right)^2$$

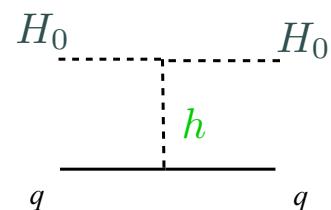
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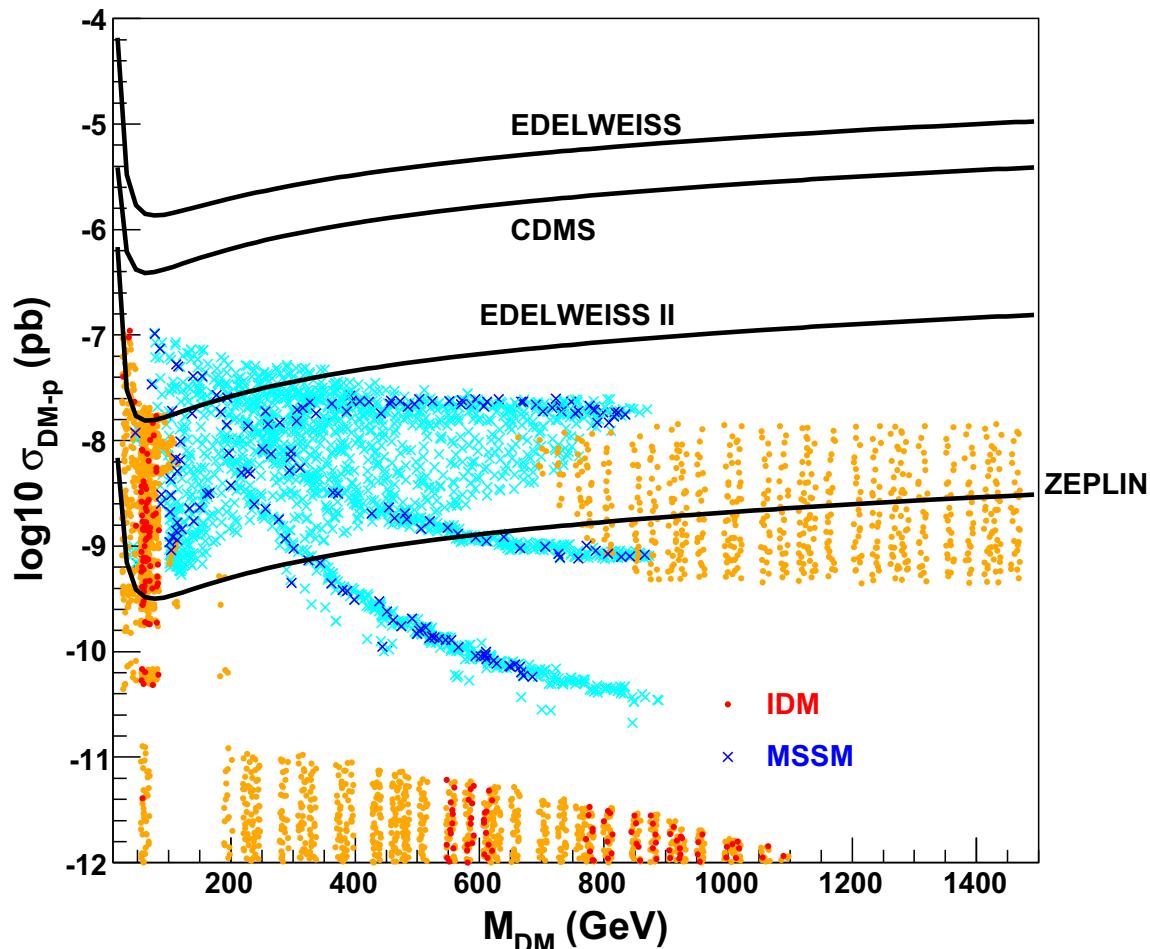


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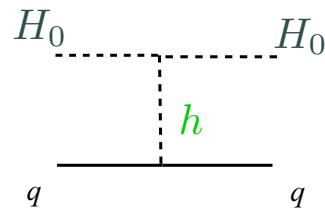
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- GLAST can bound  $\langle \sigma_A v \rangle$  depending on  $\rho_{DM}$
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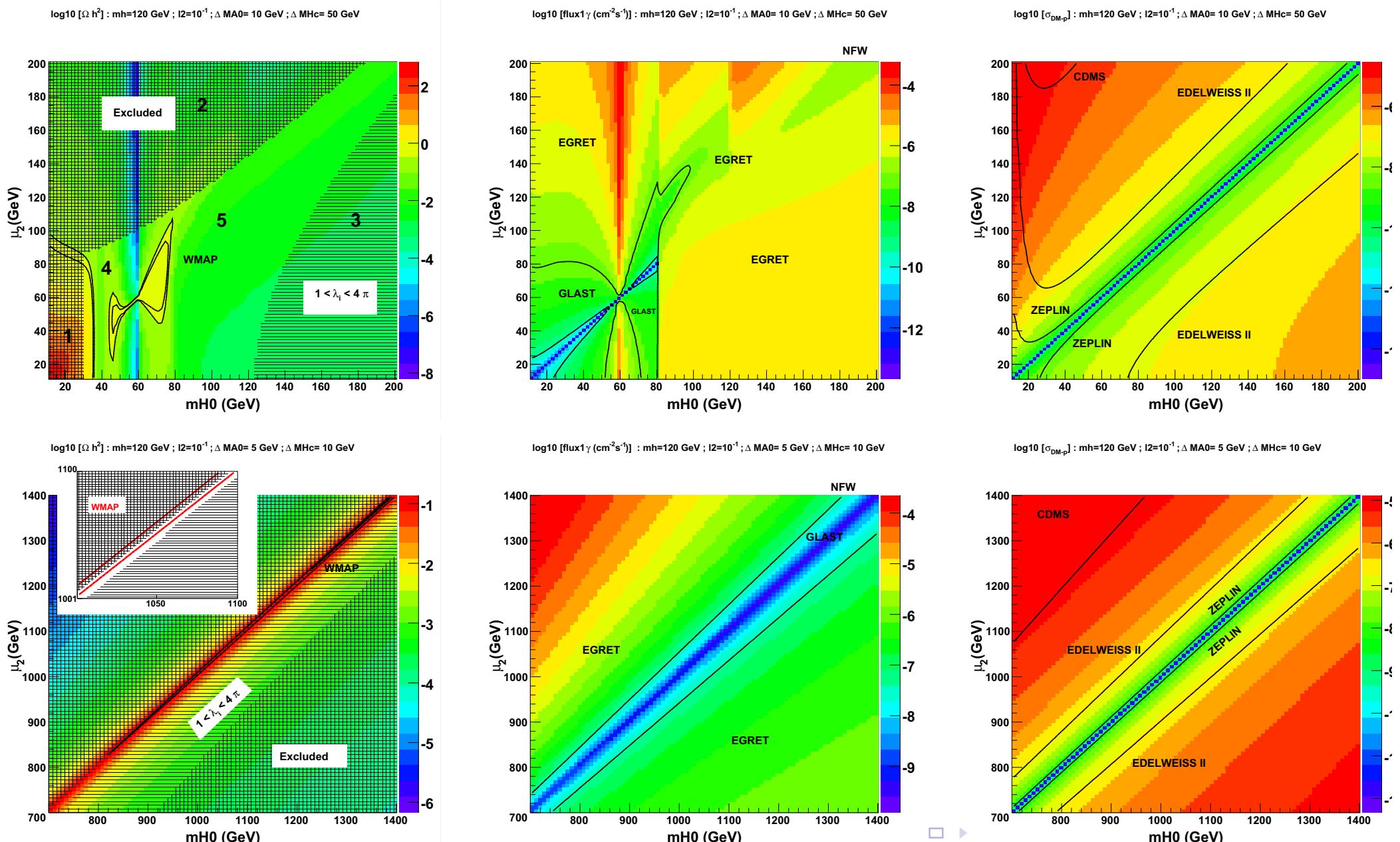
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## Perspectives

- More indirect detection probes : neutrinos, positrons and antiprotons
- Consequences on  $h$  searches at colliders
- Add Majorana particles [Ma] : systematic analysis

# Backup

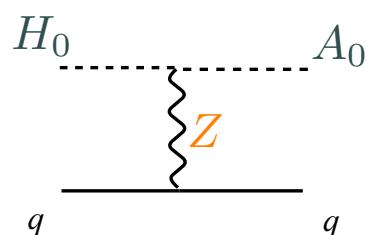
# Relic density, Indirect and Direct detection for fixed $\Delta M$



# More details on direct detection

Relevant spin independent processes :

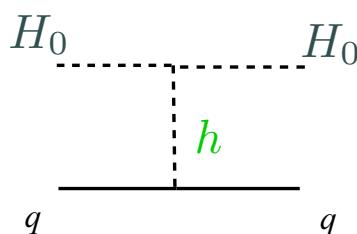
$$m_r = \frac{m_{H_0} m_N}{m_{H_0} + m_N}$$



$$\sigma_{H_0-p}^Z = \frac{G_F^2 m_r^2}{2\pi} \left( N - (1 - 4 \sin^2 \theta_W) Z \right)^2$$

↔ orders of magnitude over present direct detection  
bounds

Kinematically excluded for  $M_{A_0} - M_{H_0} > 100$  keV



$$\sigma_{H_0-p}^h = \frac{m_r^2}{4\pi} \left( \frac{\lambda_L}{M_{H_0} M_h^2} \right)^2 f^2 m_p^2$$

# More details on indirect detection

The produced **gamma ray flux** from dark matter annihilation

$$\frac{\Phi_\gamma}{d\Omega dE} = \sum_i \frac{dN_\gamma^i}{dE_\gamma} \langle \sigma_{Ai} v \rangle \frac{1}{4\pi m_{DM}^2} \int_{\text{l.o.s.}} \rho_{DM}^2 \, dl$$

where  $dN_\gamma^i/dE_\gamma$  is the differential gamma spectrum per annihilation coming from the decay of annihilation products of final state  $i$ .

The dark matter **density profile** :

$$\rho_{DM}(r) = \rho_{\text{local}} \left( \frac{R_0}{r} \right)^\gamma \left( \frac{1 + (R_0/a)^\alpha}{1 + (r/a)^\alpha} \right)^{(\beta - \gamma)/\alpha}$$

$$R_0 = 8.5 \text{ kpc}$$

$$\rho_{\text{local}} = 0.3 \text{ GeV/cm}^3$$

	$\alpha$	$\beta$	$\gamma$	a (kpc)
Iso	2.0	2.0	0	3.5
NFW	1.0	3.0	1.0	20
Moore	1.5	3.0	1.5	28.0

## Relevant Annihilation and Coannihilation processes :

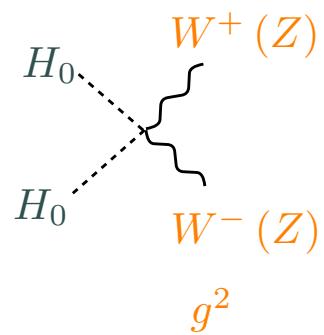
For all  $M_{H_0}$



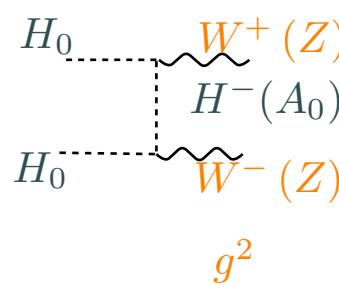
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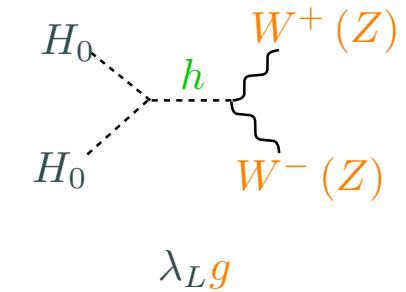
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$$g^2$$

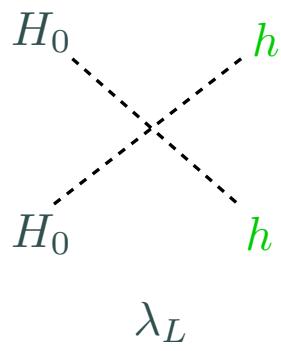


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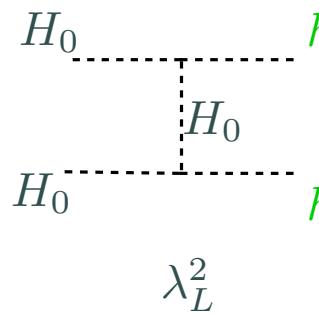


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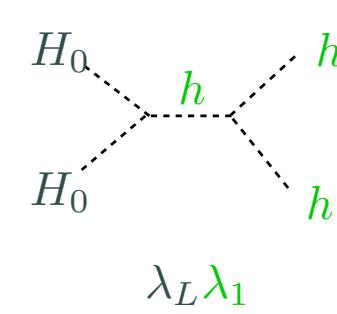
For  $M_{H_0} > M_h$



$$\lambda_L$$



$$\lambda_L^2$$



$$\lambda_L \lambda_1$$