Scalar Dark Matter from the Inert Doublet Model

Laura Lopez Honorez

Universidad Autónoma de Madrid

based on *Scalar Multiplet Dark Matter*
JHEP 0907:090,2009

in collaboration with T. Hambye, F.-S. Ling and J. Rocher

Cosmo 2009 - Genève

WIMP as dark matter

Minimal DM spirit : SM + one $\mathrm{SU}(2)_L$ n-uplet see Cirelli *et* all '05-'09

- DM = neutral member of the n-uplet
- stability $\rightsquigarrow$ extra Z_2 symmetry for low n

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- Scalar multiplets H_n :
  - extra quartic coupling λ_i to Higgs H_1
  - a *range* free parameters : $\{m_{DM}, \lambda_i\}$ is compatible with Ω_{DM}^{WMAP}

Scalar DM model

- Extra n-uplet case ($n > 2$) :
  - only one coupling to the Higgs $\lambda_3 |H_1|^2 |H_n|^2$
  - no mass splittings between H_n^0 and $H_n^{\pm(\ldots\pm)}$

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- Particular case : $n = 2 \equiv$ IDM
  - three couplings to the Higgs.

$$\lambda_3 |H_1|^2 |H_2|^2 + \lambda_4 |H_1^\dagger H_2|^2 + \frac{\lambda_5}{2}\left[(H_1^\dagger H_2)^2 + h.c.\right]$$

  - non zero mass splittings :

$$H_2 = \begin{pmatrix} iH^+ \\ \frac{(H_0 - iA_0)}{\sqrt{2}} \end{pmatrix} \quad H_1 = \begin{pmatrix} 0 \\ \frac{(h + v_0)}{\sqrt{2}} \end{pmatrix}$$

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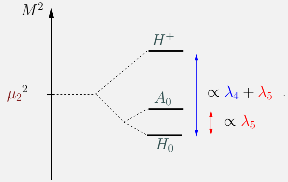
$${m_\chi}^2 = \mu_2^2 + \lambda_\chi v_0^2$$



$$\lambda_{H_c} \equiv \lambda_3/2$$

$$\lambda_{H_0,A_0} \equiv (\lambda_3 + \lambda_4 \pm \lambda_5)/2$$

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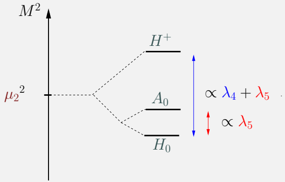
$\rightsquigarrow$ viable mass ranges ($H_0 \equiv$ DM) :

$m_{H_0} \sim \mathcal{O}(\mathrm{GeV})$, $m_{H_0} \sim m_W$ and multi-TeV

$${m_\chi}^2 = \mu_2^2 + \lambda_\chi v_0^2$$



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see also Barbieri *et* all'06, LLH *et* all '06, Cao *et* all '07, Gustafsson *et* all '07, Lundsrtom *et* all '08, Andreas *et* all '08 '09, Agrawal *et* all'08, Nezri *et* all '09

IDM in the High mass regime : Relic abundance

Standard Freeze out calculations : $\Omega_{DM} \propto \frac{1}{\langle \sigma_{\text{eff}} v \rangle}$ where

$$\langle \sigma_{\text{eff}} v \rangle \;=\; \sum_{i,j} \langle \sigma^{ij} v \rangle r_i r_j$$

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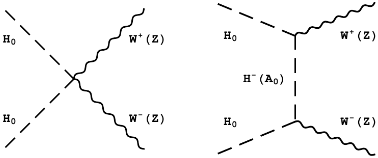
e.g. contribution to σ_g^{00} : $H_0 H_0 \to XX$



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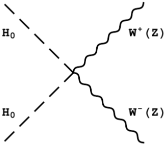

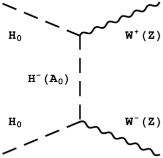

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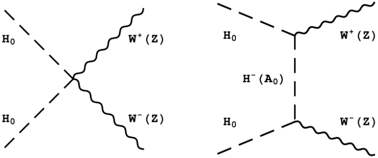

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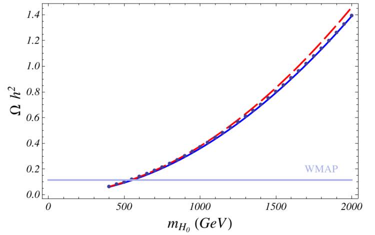

$\rightsquigarrow$ Only $m_{H_0} = m^* \sim 534$ GeV satisfy WMAP

in agreement with Cirelli *et* all '05

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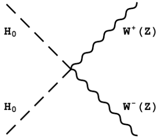

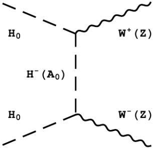

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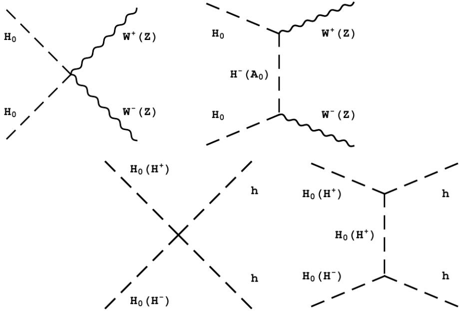

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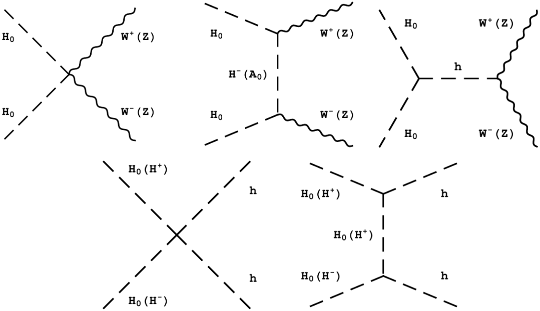

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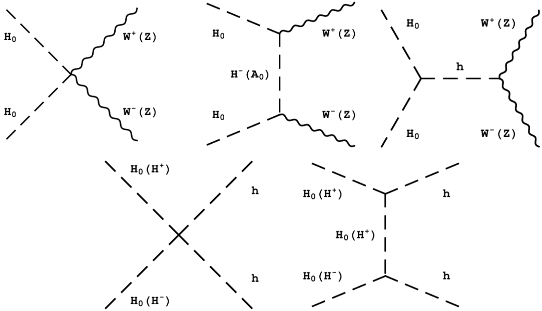

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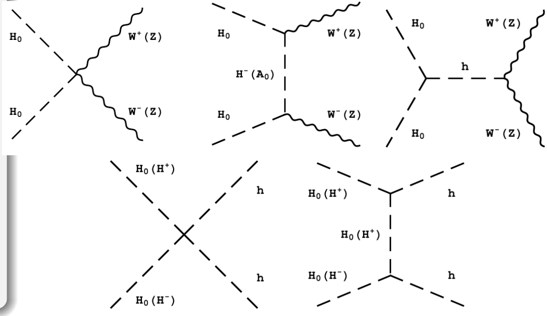

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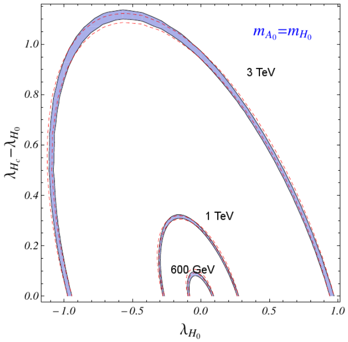

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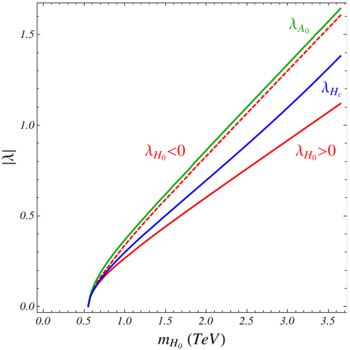

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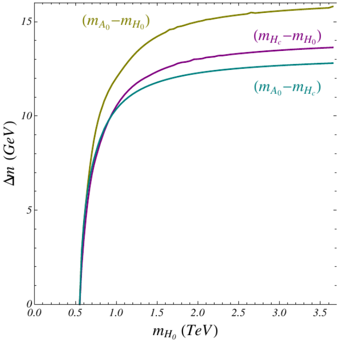
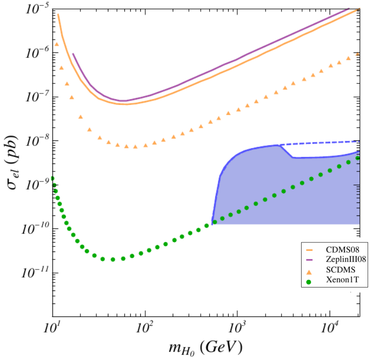
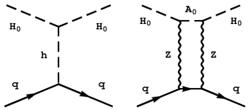


Prospects for Direct and Indirect detection

Direct detection through Elastic Scattering ($m_{A_0} - m_{H_0}$ >100 keV)





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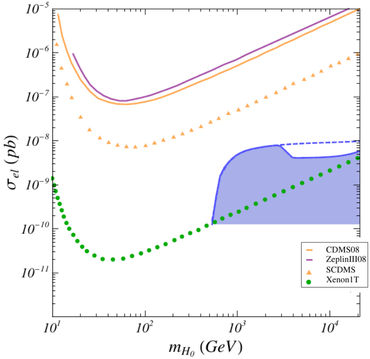

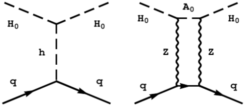

- $\sigma_{el} \propto \left(\frac{\lambda_{H_0}}{M_{H_0} M_h^2}\right)^2 \rightsquigarrow \sigma_{el} < 9.410^{-9}$ pb
  bounded $\lambda_{H_0} \rightsquigarrow$ absolute upper bound
- lower bound from one loop gauge processes : $\sigma_{el} > 10^{-10} pb$

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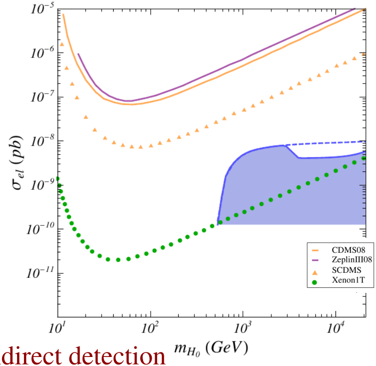

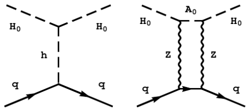

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Indirect detection

- γ and ν : $\Phi^{NFW}_{\gamma,\nu} \propto \frac{\langle \sigma v \rangle}{2m^2_{\rm DM}} N_{\gamma,\nu}$ within the reach of FERMI for $m_{H_0} \lesssim$ 1TeV for γ
  and generally bellow KM3net sensitivity for ν
  (see also Andreas *et* all '09)
- $\bar{p}$ and e^+ fluxes lie at least 3-4 order of magnitude below the signal
  (see also Nezri *et* all '09)

Conclusion

The Inert Doublet Model is WIMP model is a rich Scalar DM model

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In the high mass regime ($m \gg m_W$), without fine tuning, the neutral component H_0 can account for WMAP :

- with $m_{H_0}^{min} = 532$ fixed by pure gauge interactions
- for each $m_{H_0} > m^*$ with an upper bound on λ
- and with an upper bound on dark sector mass splittings $|\Delta m_{ij}| < 17.6$ GeV

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Direct and Indirect detection :

- upper bound on $\lambda_{H_0} \rightsquigarrow$ upper bound on σ_{el} of $9.4\,10^{-9}$ pb within the reach of Xenon 1T
- prospects for indirect detection are quite poor even for rather cuspy profiles as NFW (a part for $m_{H_0} \lesssim$ 1TeV)

This is the End

Thank you for your attention ! !

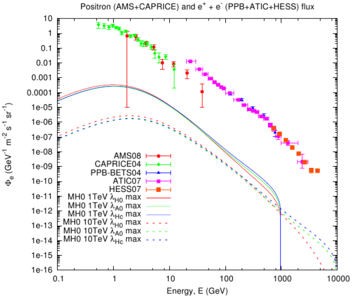
Backup

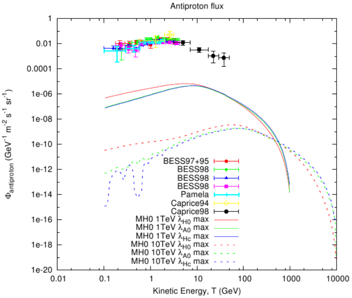
Indirect detection prospects

γ and ν signals : $\Phi_{\gamma,\nu}(\Delta\Omega) = \frac{\langle\sigma v\rangle}{2m^2_{\rm DM}} N_{\gamma,\nu} \times \frac{\Delta\Omega\,\rho_0^2\,R_0}{4\pi}\,\bar{J}(\Delta\Omega)$,

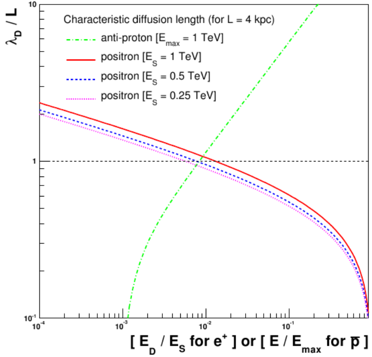
- $\Phi^{\rm NFW}_{\gamma}(\Delta\Omega = 10^{-3}) \simeq \mathcal{O}(1) \times 2.3 \cdot 10^{-10}\,(m_{DM}/1\ TeV)^{-2}$ $[{\rm ph\,cm^{-2}\,s^{-1}}]$
  within the reach of FERMI-LAT for low masses.
- $\Phi^{\rm NFW}_{\nu}(\Delta\Omega = 10^{-3}) \simeq \mathcal{O}(1) \times 1.5 \cdot 10^{-12}\,\left(E^{min}_{\nu}/100\ GeV\right)^{-1}$ $[\nu\,{\rm cm^{-2}\,s^{-1}}]$,
  $<$ KM3net sensitivity for pt. source

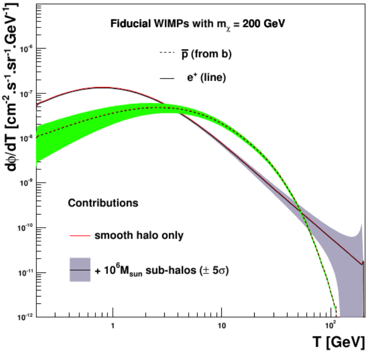
Charged antimatter cosmic ray signals





Diffusion length and Clumpiness





Lavalle *et* all

'08

IDM : Mass Ranges

Mass Ranges	main contributions to σ_{eff}	mass splittings	main Refs
$m_{H_0} \ll m_W(\mathcal{O}(GeV))$	$H_0H_0 \to h^* \to \bar{f}f$	$\Delta m_{ij} \gtrsim m_Z - m_{H_0} \sim 90$ GeV	Andreas *et* all '08
$m_{H_0} \lesssim m_W$	$H_0H_0 \to h^* \to \bar{f}f$ $H_0A_0(H^+) \to Z^*(W^*) \to \bar{f}f^{(')}$	$\Delta m_{ij} \gtrsim m_Z - m_{H_0} \gtrsim 7$ GeV	Barbieri *et* all '06 LLH *et* all '06
$m_{H_0} \gg m_W(\mathcal{O}(TeV))$	$H_0H_0 \to ZZ, WW, hh$ coannihil into bosons	$\Delta m_{ij} \lesssim 17.6$ GeV	Hambye *et* all '09

IDM : Potential - constraints

- Full Potential

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

- Dark scalars couplings to Higgs and masses :

$$\tfrac{1}{2}\left(\lambda_{H_0}H_0^2+\lambda_{A_0}A_0^2+2\lambda_{H_c}H^+H^-\right)\left(2v_0h+h^2\right)$$
$$m_h^2=2\lambda_1 v_0^2\ , \quad m_i^2=\mu_2^2+\lambda_i v_0^2.$$

- Stability constraint

$$\begin{aligned} \lambda_{1,2} &> 0 \quad , \\ \lambda_{H0}\ , \quad \lambda_{A_0}\ , \quad \lambda_{H_c} &> -\sqrt{\lambda_1\lambda_2}\ . \end{aligned}$$

- EWPT measurements : $\Delta T \approx \frac{1}{12\pi^2\alpha v^2}(m_{H^+}-m_{A_0})(m_{H^+}-m_{H_0})$

n-uplets : Potential - constraints

- Full Potential

$$
\begin{aligned}
V(H_n, H_1) \quad = \quad & V_1(H_1) + \mu^2 H_n^\dagger H_n + \frac{\lambda_2}{2}\left(H_n^\dagger H_n\right)^2 + \lambda_3 \left(H_1^\dagger H_1\right)\left(H_n^\dagger H_n\right) \\
& + \frac{\lambda_4}{2}\left(H_n^\dagger \tau_a^{(n)} H_n\right)^2 + \lambda_5 \left(H_1^\dagger \tau_a^{(2)} H_1\right)\left(H_n^\dagger \tau_a^{(n)} H_n\right) \quad ,
\end{aligned}
$$

- Dark scalars couplings to Higgs and masses :

$\frac{\lambda_3}{2}\left(\frac{1}{2}\Delta^{(0)\,2} + \sum_{0<Q\leq j_n} \Delta^{(Q)}\Delta^{(-Q)}\right)(2v_0 h + h^2)$

mass of all components : $\quad m_0^2 = \mu^2 + \frac{\lambda_3 v_0^2}{2}$

at one-loop (Cirelli'05) : $\quad m\left(\Delta^{(Q)}\right) - m\left(\Delta^{(0)}\right) = Q^2 \Delta M_g$

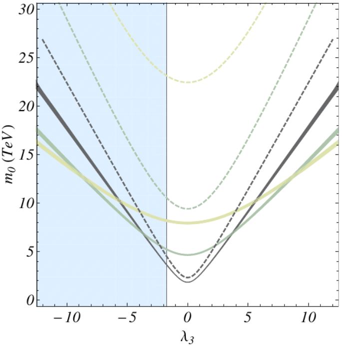
with $\quad \Delta M_g = g M_W \sin^2\frac{\theta_W}{2} \simeq (166 \pm 1)$ MeV

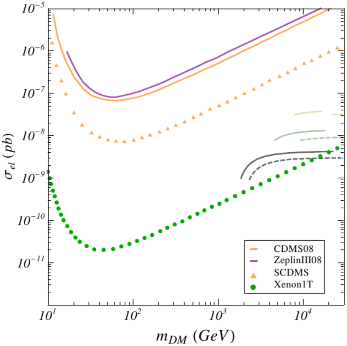
- Stability constraint

$$
\begin{aligned}
\lambda_{1,2} \quad &> \quad 0 \quad , \\
\lambda_3 \quad &> \quad -\sqrt{2\lambda_1\lambda_2} \quad .
\end{aligned}
$$

Multiplets : Relic density-Direct detection

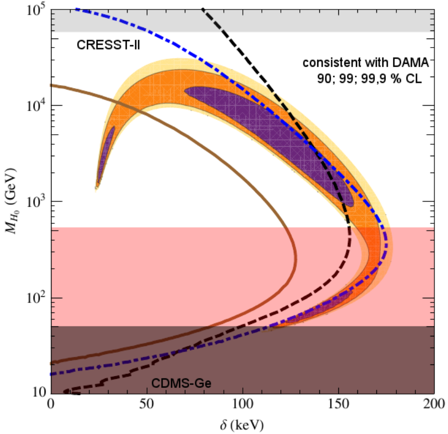
Models	$\lambda_3 = 0$	$\lambda_3 = 2\pi$	$\lambda_3 = 4\pi$	$\lambda_3 = 0$ (SE)	$\lambda_3 = 4\pi$ (SE)
Real Triplet	1.826 ± 0.028	11.1	21.9	2.3	28.1
Real Quintuplet	4.642 ± 0.072	9.6	17.4	9.4	35.7
Real Septuplet	7.935 ± 0.12	10.6	16.1	22.4	46.3

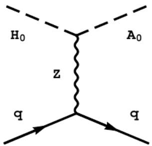




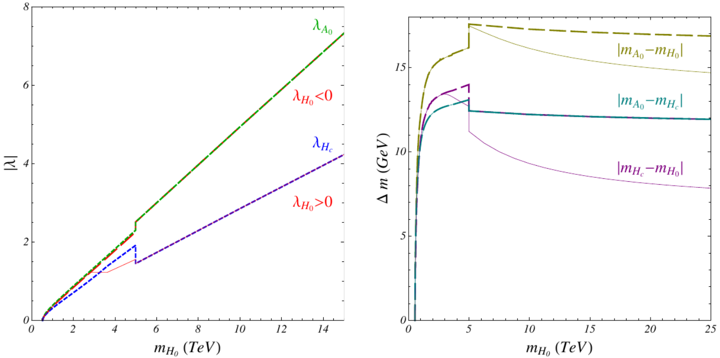
Inelastic Scattering (Arina *et* all '09)

$$m_{A_0} - m_{H_0} = \delta$$





Bounded λ and Δm high mass



for freeze-out assumed in the unbroken phase for $m_{H_0} < 5$ TeV and taking into account the stability constraints ruling out $\lambda_{H_0}^{\max} < -\sqrt{\lambda_1 \lambda_2}$

This is the End