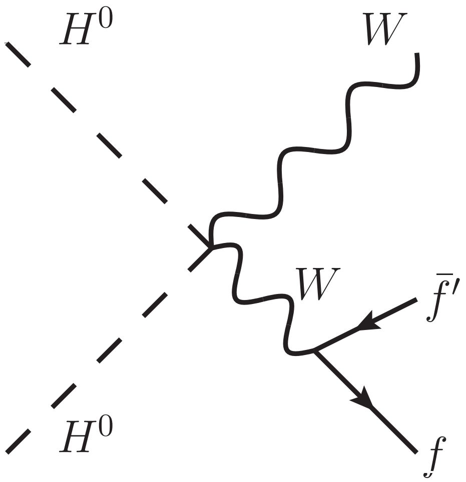
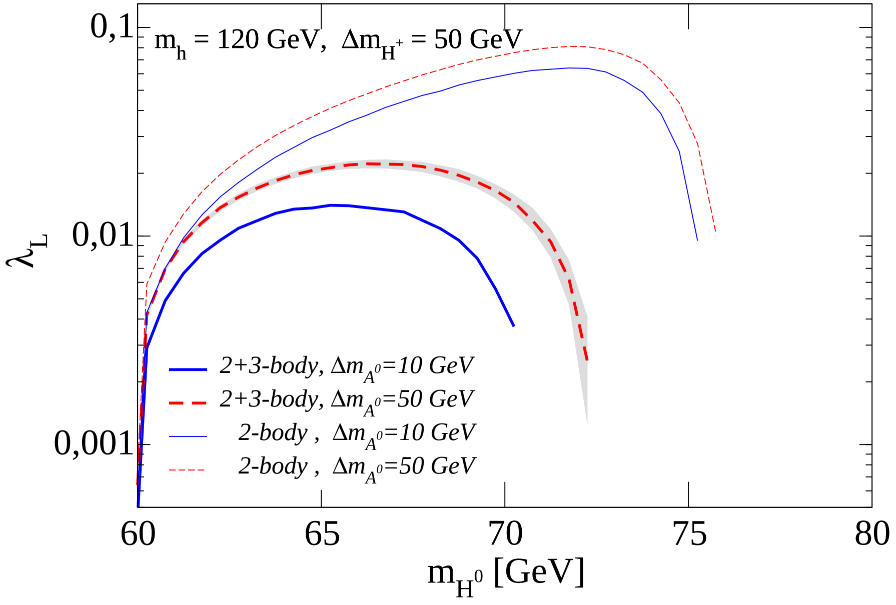
Three-body final states in dark matter annihilations and decays





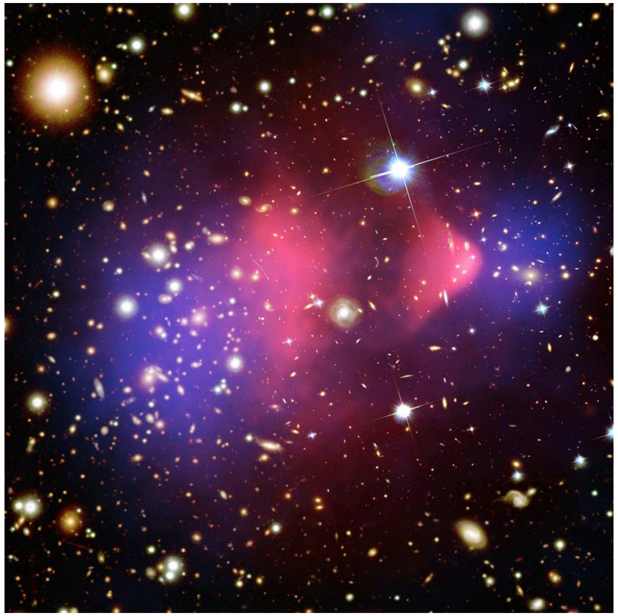
`Based on PRD81,JHEP 1009:046 (with Laura Lopez),`
`PRD82 (with Ki-Young Choi), JCAP 1010:033`
`(with D. Restrepo, O. Zapata, and K-Y Choi)`
`and work in progress`

Carlos E. Yaguna
Würzburg University

2010

Dark matter constitutes a significant fraction of the energy-density of the Universe

The evidence in favor of DM is overwhelming



Rotation curves
The Bullet Cluster
Large Scale Structure

The DM density is obtained from CMB data

$$0.097 < \Omega h^2 < 0.122$$

The existence of dark matter is a clear indication of physics beyond the Standard Model

DM candidates should be neutral and stable

Neutrinos?

Neutrinos cannot explain the dark matter

$\Omega_\nu \ll \Omega_{dm}$

ν's are not cold

The SM contains no dark matter candidates

New Physics !

Over the years several dark matter candidates have been considered in the literature

It is not yet known what the DM is

?

SUSY models are the most common scenarios

Neutralino

Gravitino

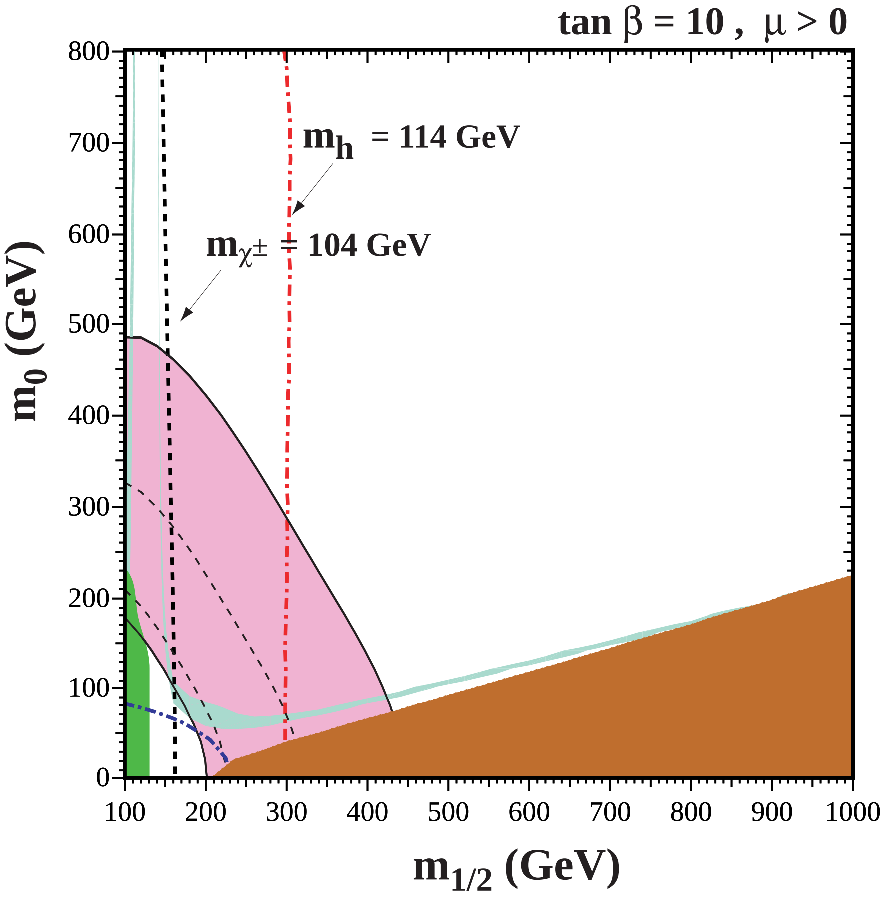
Non-SUSY candidates are also interesting

Singlet scalar

Inert higgs

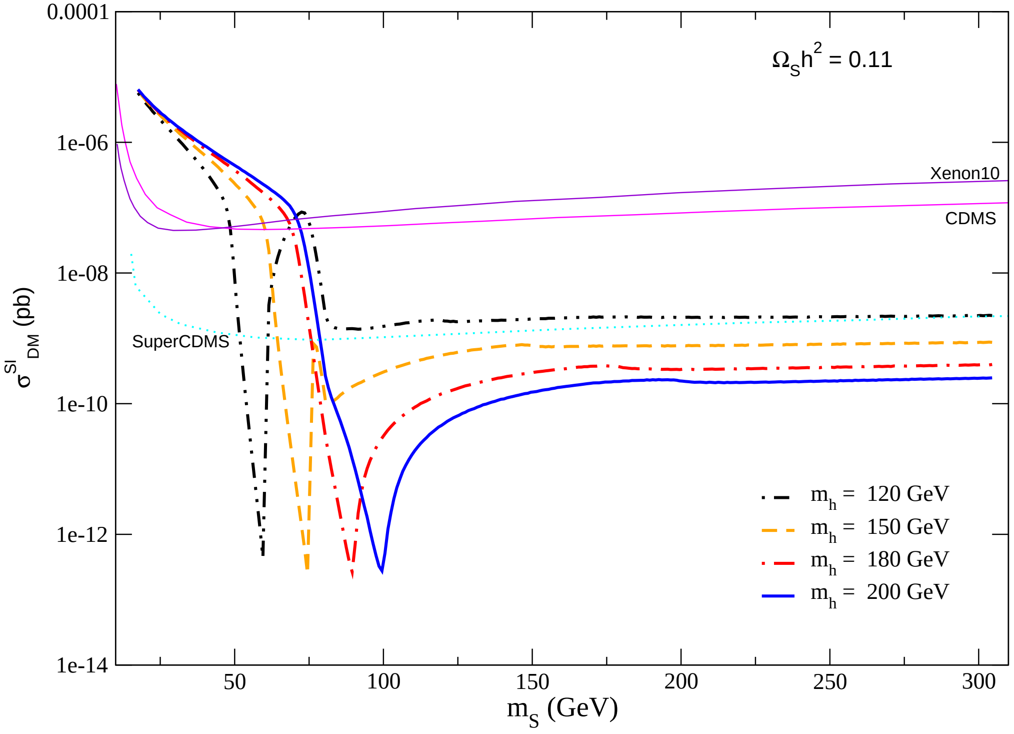
The study of dark matter models involves two main steps

Viability



Ωh^2, accelerator and precision bounds

Testability



Direct and indirect detection and accelerator searches

The annihilation rate of dark matter particles plays a crucial role in dark matter studies

It affects the prediction of the dm density

$$\dot{n} + 3Hn = -\langle \sigma v \rangle \left(n^2 - n_{eq}^2\right)$$

It modifies the viable parameter space

Dark matter constraint

It alters the dark matter detection signals

All of them

Indirect detection $\propto \sigma v$

Up to now most studies have only consider dm annihilations into two-body final states

They are all included in the calculation of Ω

$\chi_i\chi_j \rightarrow$2-bodies at tree-level

Sophisticated software is available

DarkSUSY,micrOMEGAs

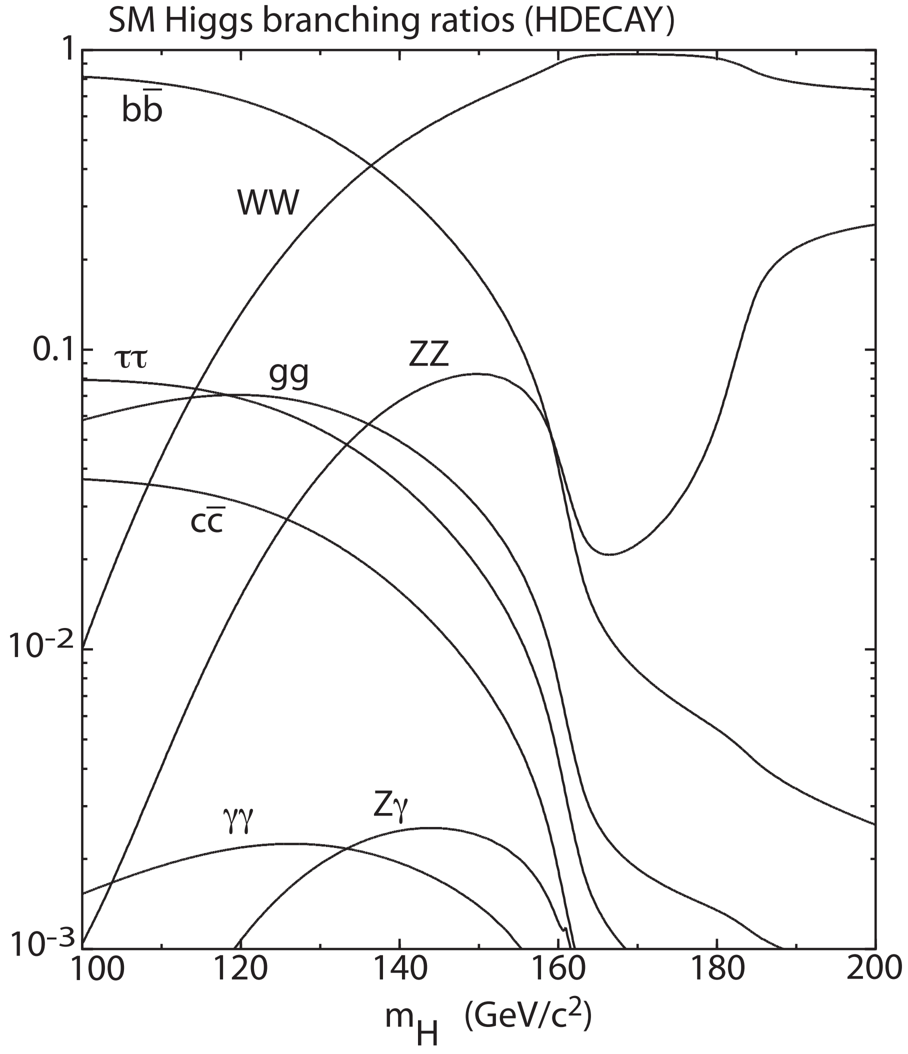
Could there be other relevant processes?

Particle physics processes can be dominated by 3-body final states

Even if 2-body final states are open

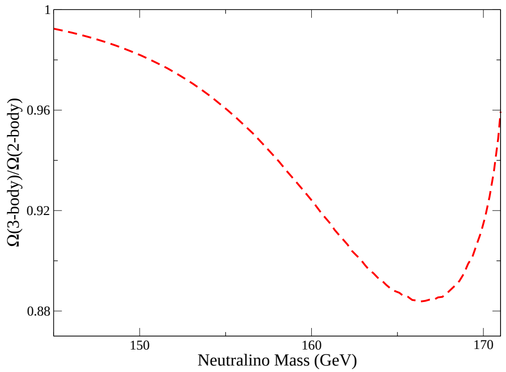
Higgs decays in the SM are a good example

Can dm particles annihilate into WW^* or $t\bar{t}^*$?



3-body final states will be shown to be relevant in well-known models of dark matter

1. Neutralinos in the MSSM



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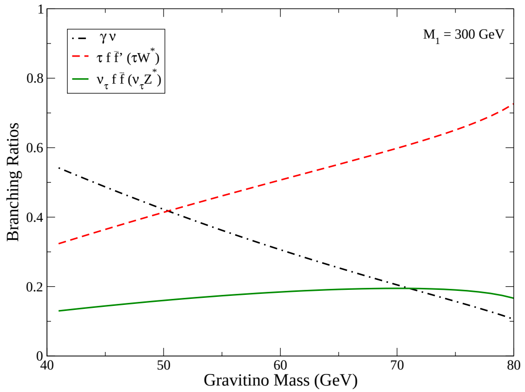
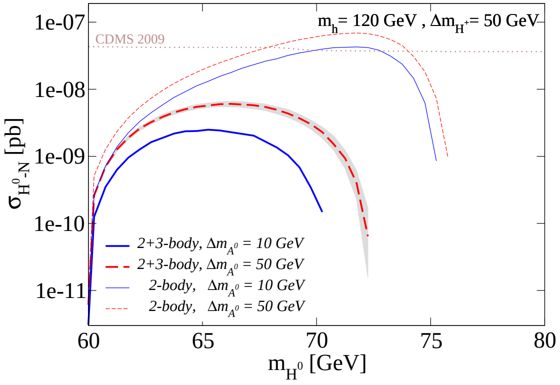
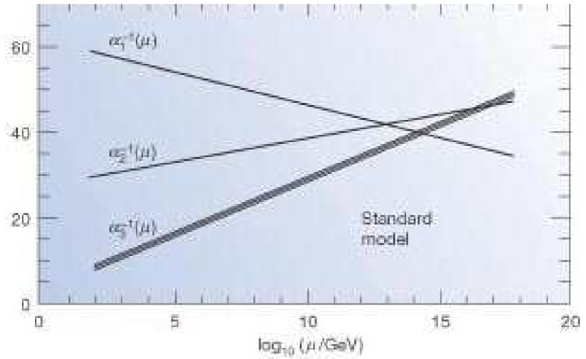


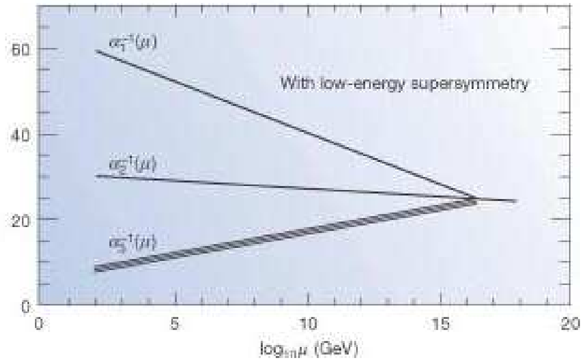
3. Inert doublet model



Low energy supersymmetry is one of the best motivated extensions of the standard model

Gauge couplings unify in the MSSM





The lightest susy particle is stable: R_p

The neutralino is a viable dark matter candidate

$$\chi_1 = N_{11}\tilde{B}^0 + N_{12}\tilde{W}^0 + N_{13}\tilde{H}_d^0 + N_{14}\tilde{H}_u^0$$

For neutralino dark matter, the most relevant 3-body final state is $t\bar{t}^*$

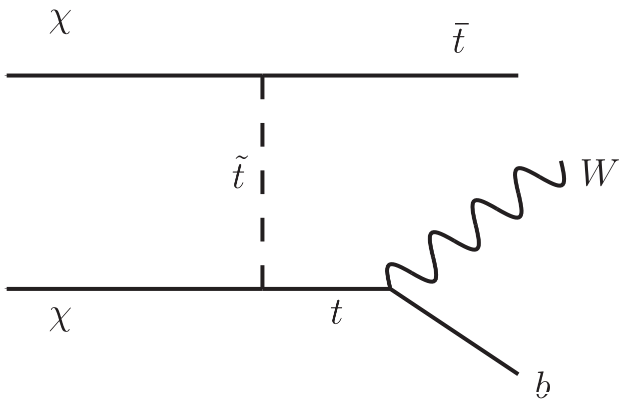
These effects are present if $m_\chi < m_t$

$$\chi\chi \not\to WW, ZZ$$
$$\chi\chi \to f\bar{f}$$

The dominant 2-body final state is $b\bar{b}$

$$\sigma v(\chi\chi \to f\bar{f}) \propto m_f^2$$

$\chi\chi \to t\bar{t}^* \to tW\bar{b}$ can also be sizable

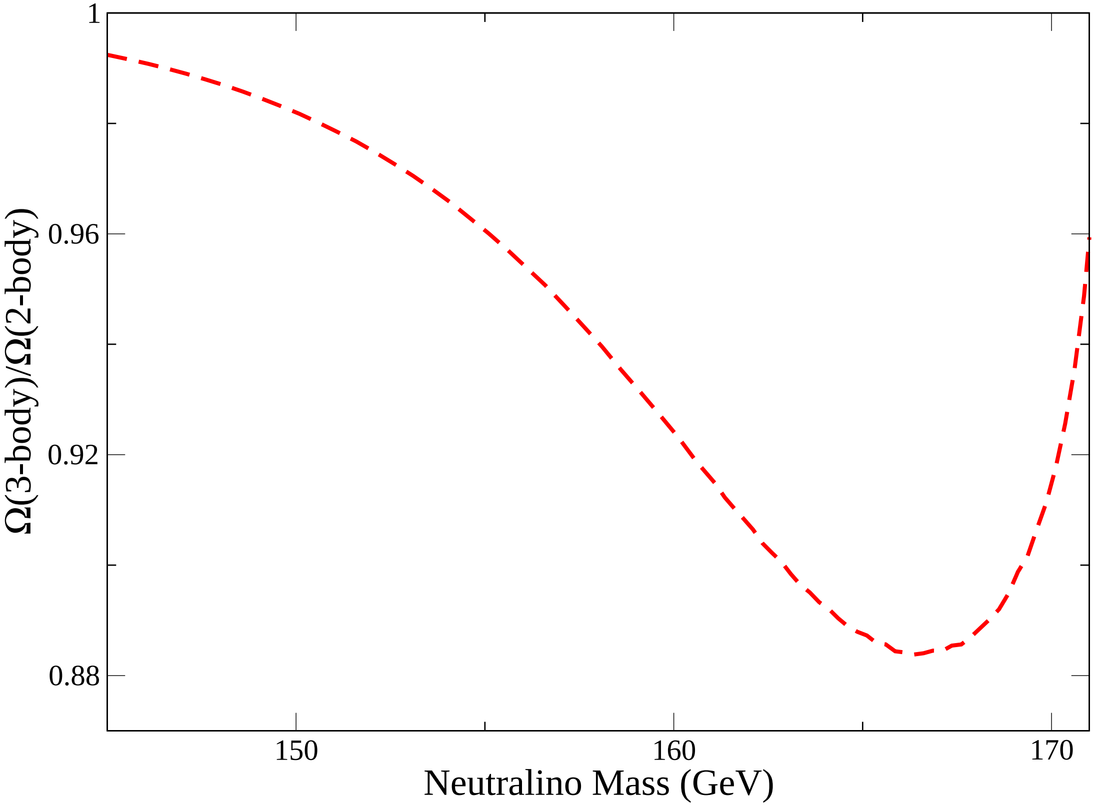


The χ relic density is smaller than that obtained for 2-body final states only

The effect in Ω is largest few GeVs below m_t

It could be more than 10% smaller

DarkSUSY claims a 1% accuracy in Ω

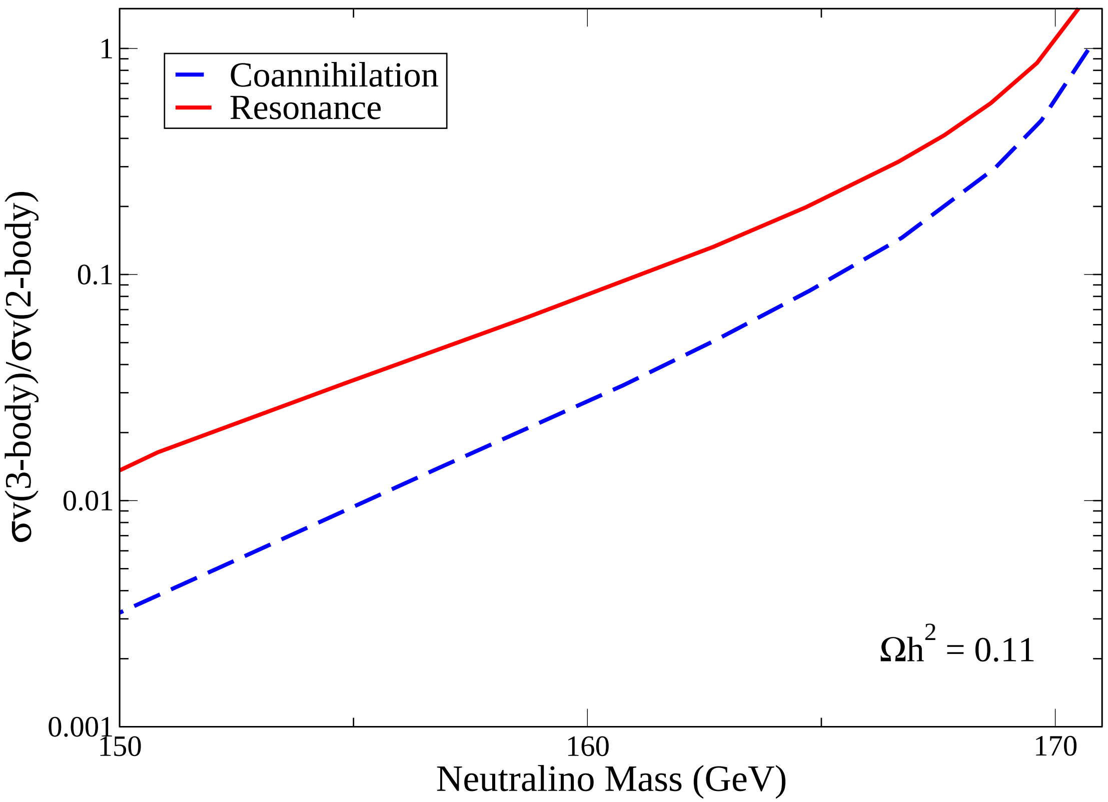


The 3-body neutralino annihilation cross section can be larger than the 2-body one

Close to m_t, σv is about twice as large

The χ indirect detection signals will be affected

Large 3-body effects are not generic in the MSSM



3-body final states will be shown to be relevant in well-known models of dark matter

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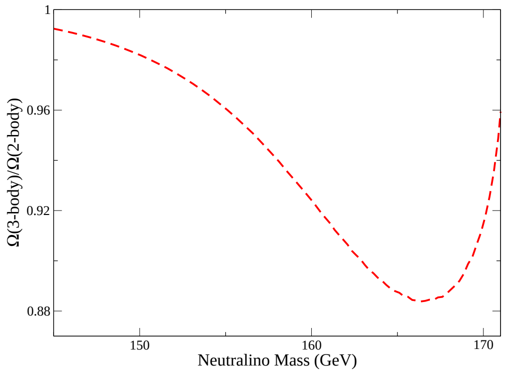

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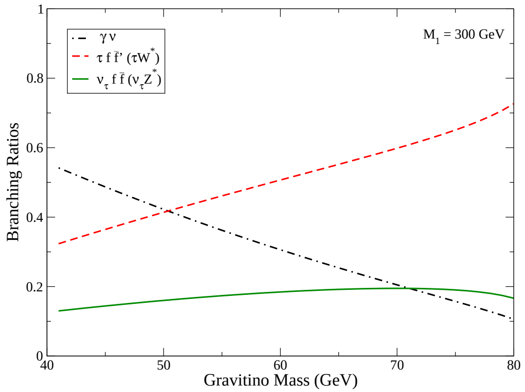

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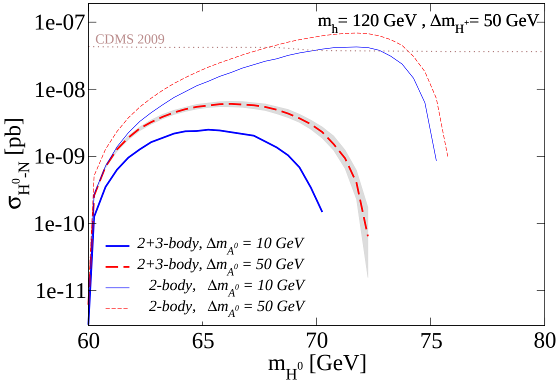


In susy models with broken R-parity the gravitino is the only viable dm candidate

The LSP becomes unstable	Neutralino is not a viable dm candidate
If $\widetilde{G}$ is the LSP, it is a dm candidate	$\widetilde{G}$ lifetime $\gg$ age of the Universe
We consider bilinear $\not{R}_p$: $\langle \tilde{\nu} \rangle \neq 0$	Buchmuller, Covi, Ibarra, Moroi, Muñoz, etc

The dominant 2-body decay modes of the gravitino are $\gamma\nu$ and $W\ell$

$\widetilde{G}$ decays are determined by $M_i, m_{\widetilde{G}}, \langle\tilde{\nu}\rangle$

For $m_{\widetilde{G}} < M_W$, $\gamma\nu$ is the only possible 2-body fs

The final states $W^*\ell$ and $Z^*\nu$ may be important

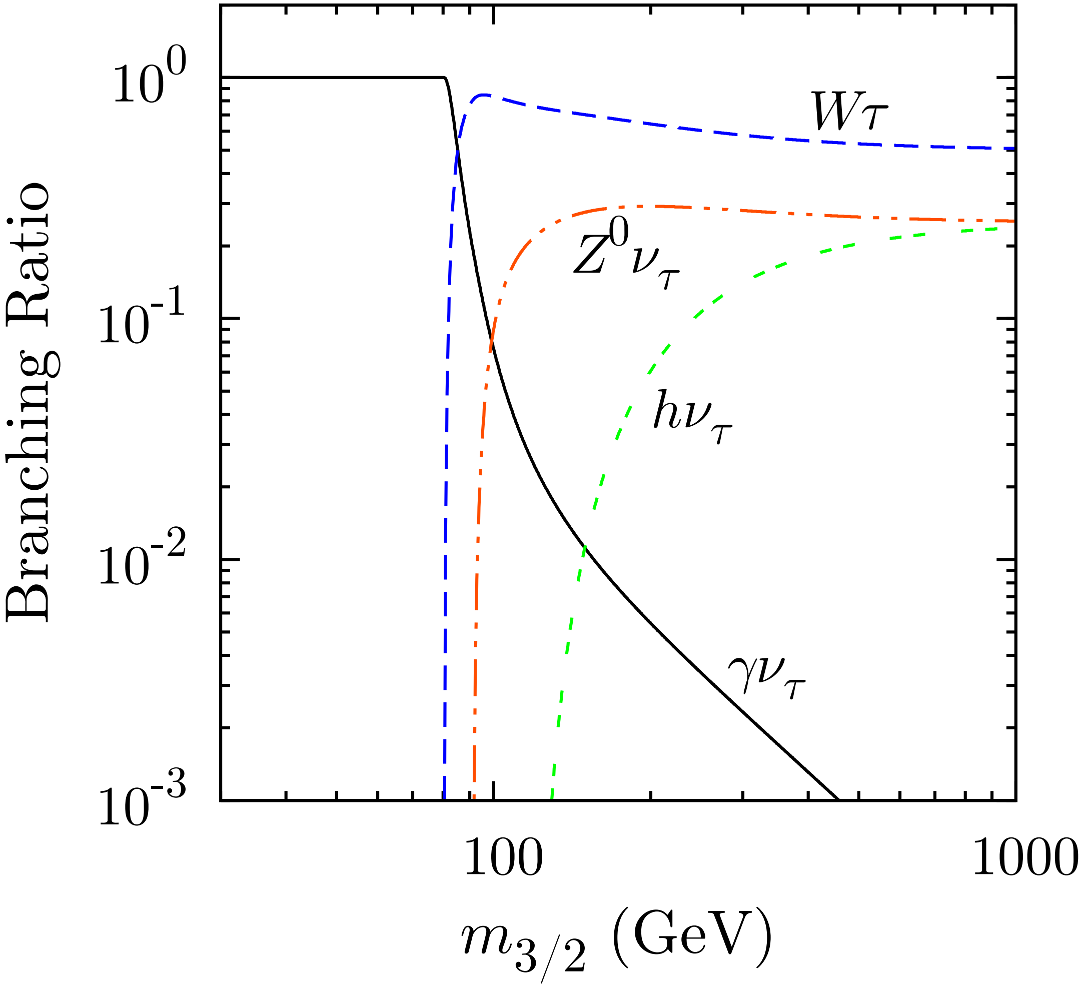
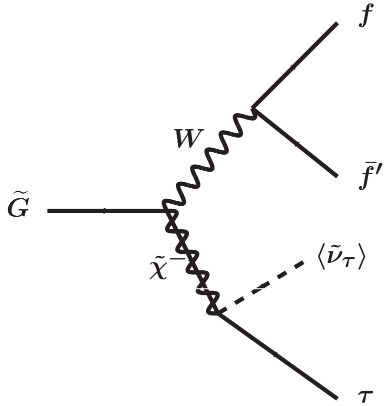


figure from 0809.5030 by Covi et al

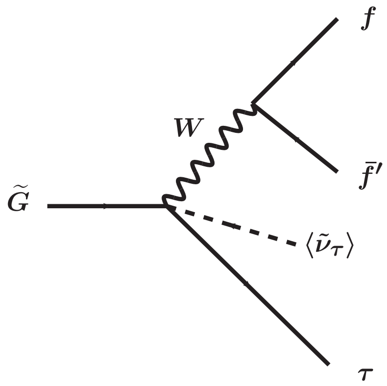
Three-body gravitino decays into $W^*\ell$ and $Z^*\nu$ had not been considered before

Two diagrams contribute to these decays



$\propto U_{\widetilde{W}\widetilde{W}}$

The four-vertex diagram $\not\propto U_{\widetilde{W}\widetilde{W}} \sim M_W/M_2$



The decay into $\gamma\nu$ tends to be suppressed

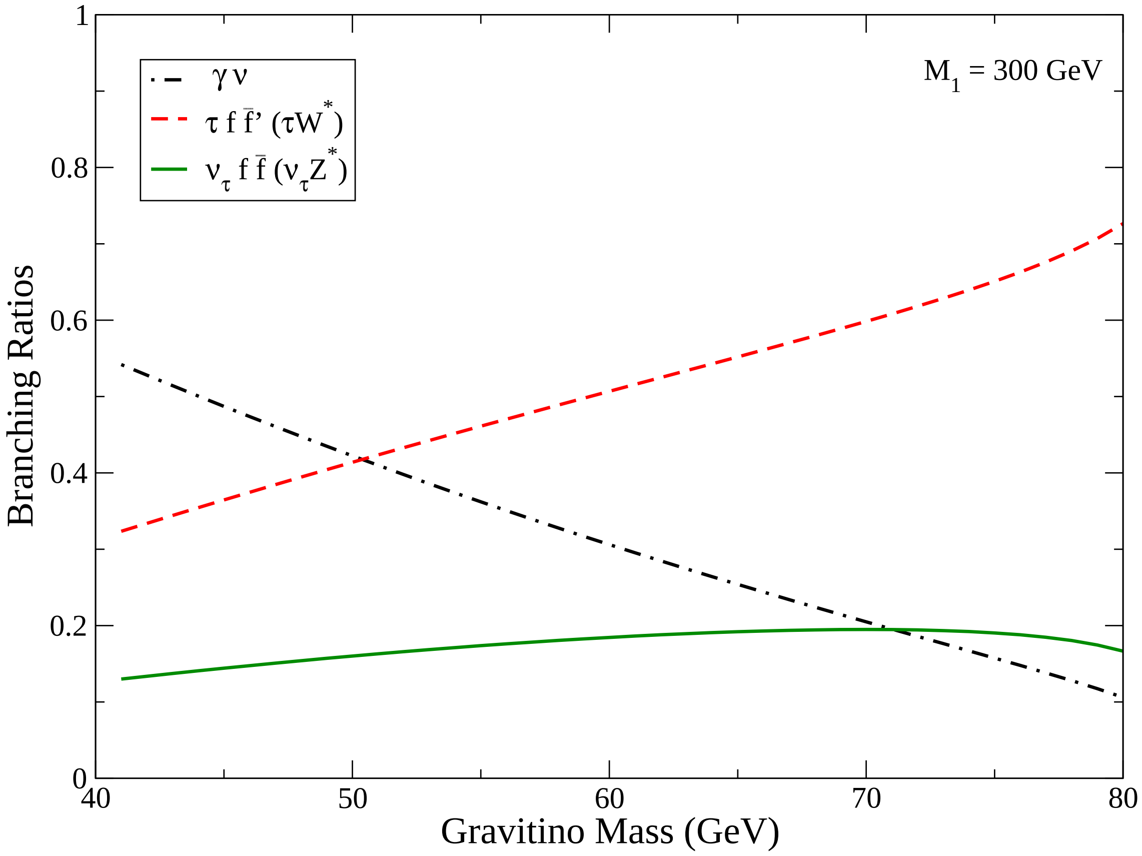
$$\Gamma(\widetilde{G} \to \gamma\nu_\tau) = \frac{\xi_\tau^2 m_{\widetilde{G}}{}^3}{64\pi M_P^2}|U_{\widetilde{\gamma}\widetilde{Z}}|^2 \propto 1/M_2^2$$

Gravitino decays can easily be dominated by three-body final states

$W^*\tau$ is dominant for
$M_W > m_{\tilde{G}} > 50$ GeV

Even $Z^*\nu_\tau$ can be more important than $\gamma\nu$

3-body gravitino decays cannot be neglected

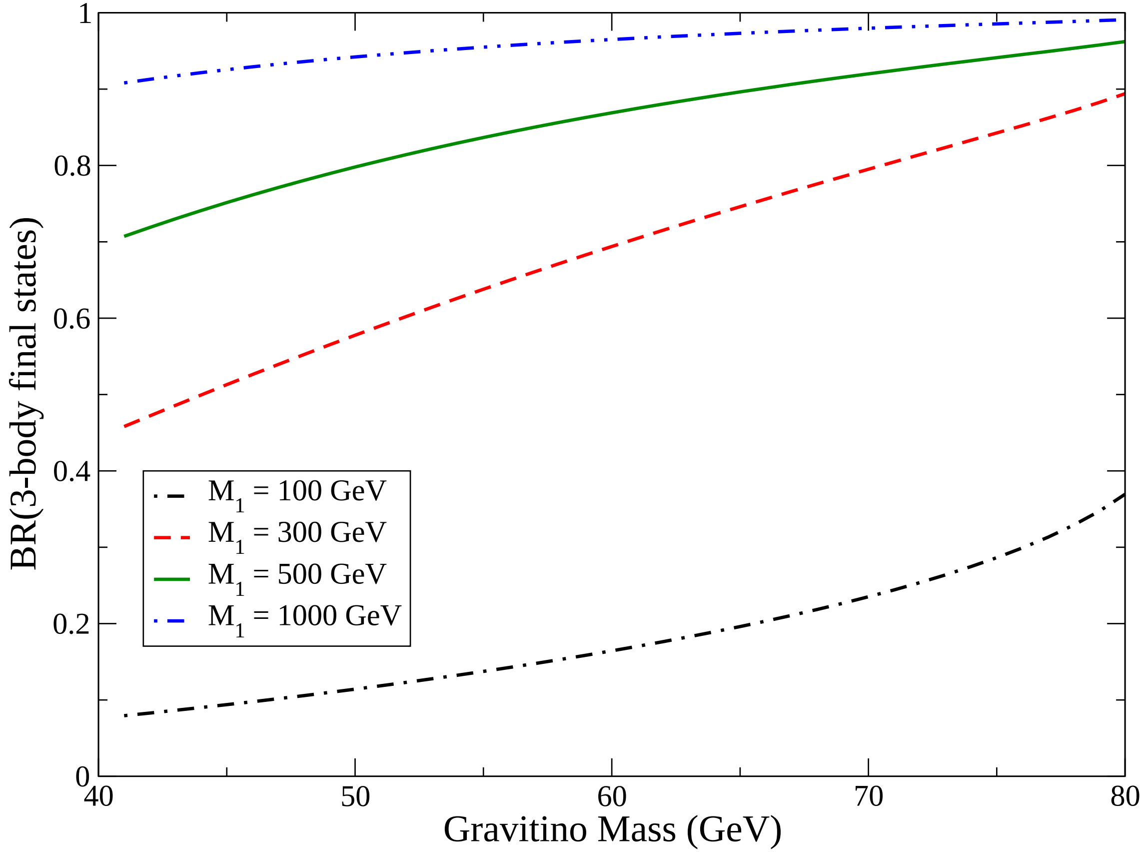


The 3-body final states become more relevant for larger gaugino masses

They can dominate over a wide range of $\widetilde{G}$ masses

The effect is significant even for small M_i

For large M_i, $\widetilde{G} \to \gamma\nu$ becomes negligible

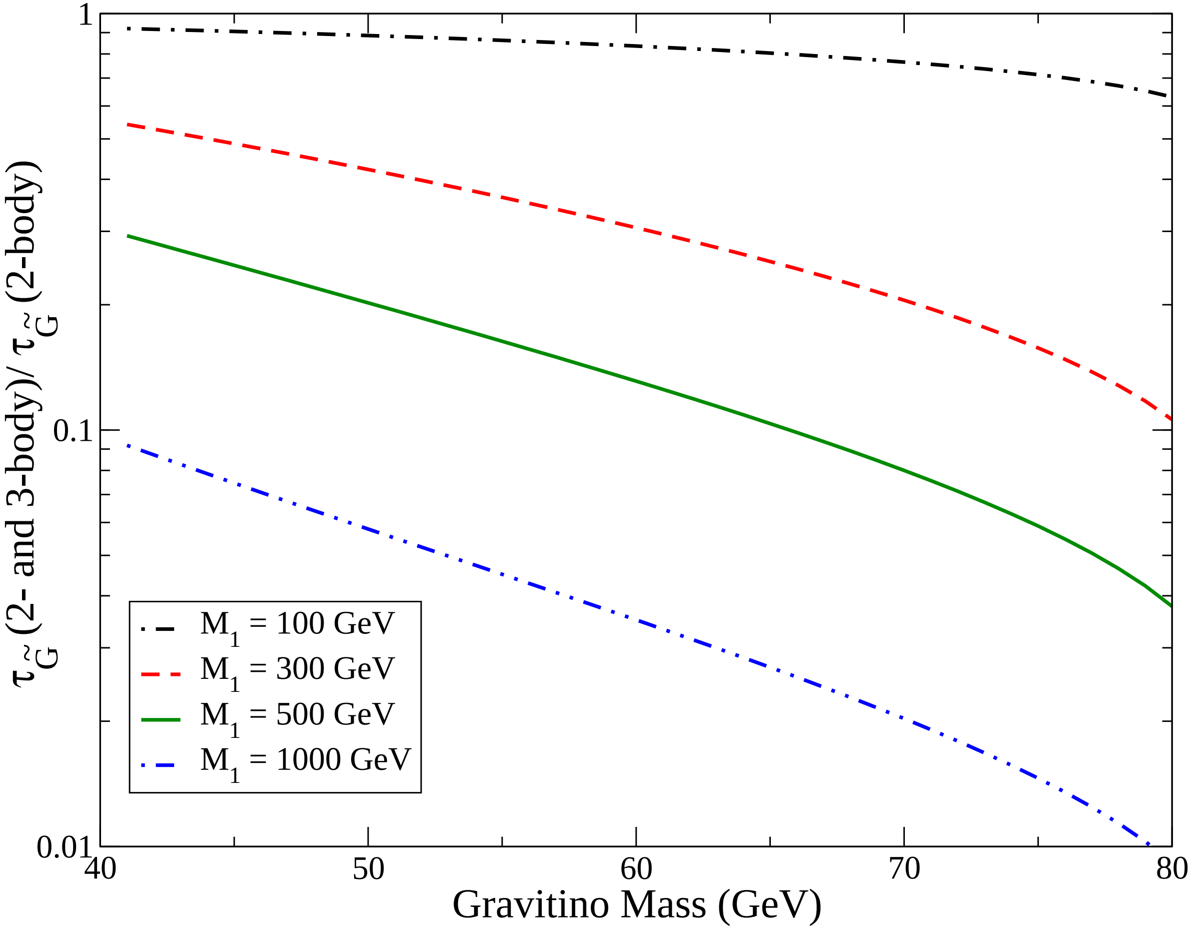


The gravitino lifetime is significantly affected by these new decay modes

It could be more than 100 times smaller

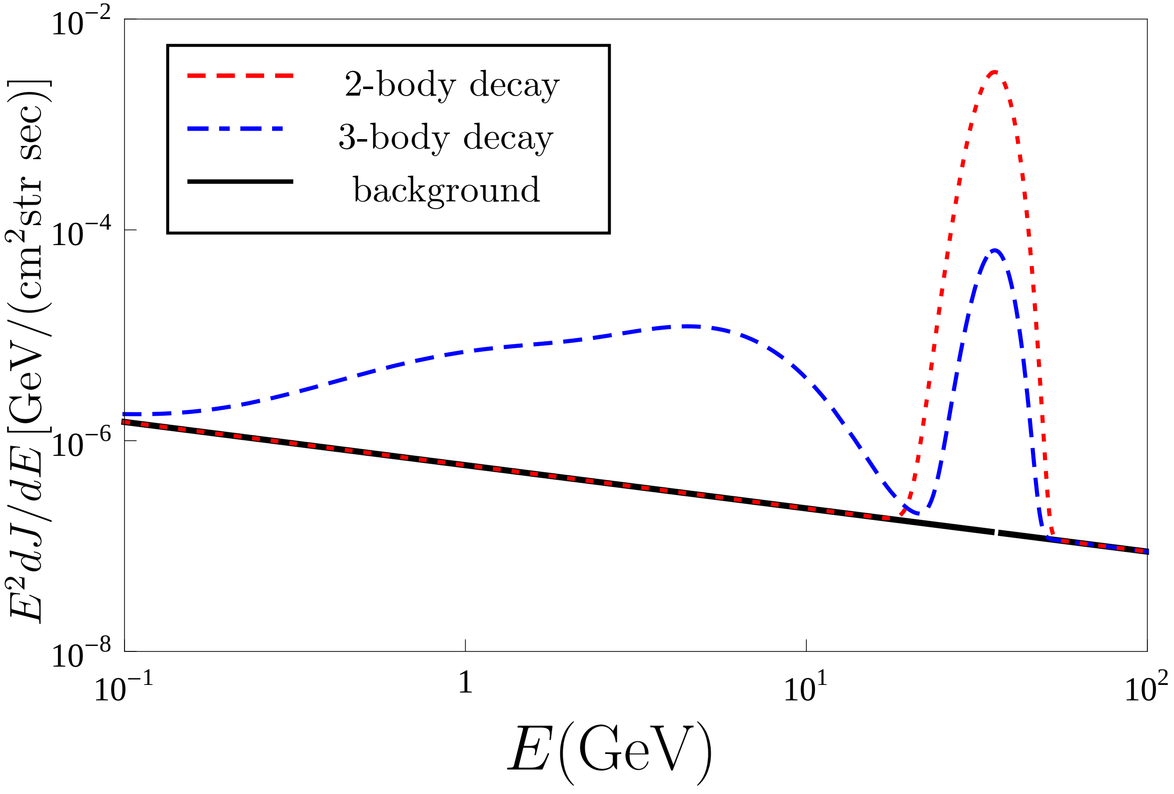
Indirect detection of $\widetilde{G}$ dm is strongly affected:

Suppressed γ, ν lines
New continuum of γs
New antimatter signals



The expected gamma ray flux from gravitino decays is significantly altered

The γ line is less apparent



The new γ continuum could be observed

These effects are typically sizable

3-body final states will be shown to be relevant in well-known models of dark matter

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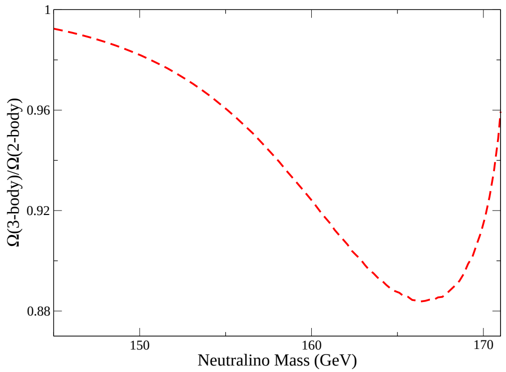

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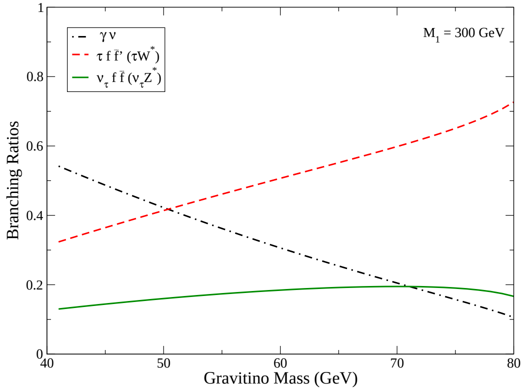
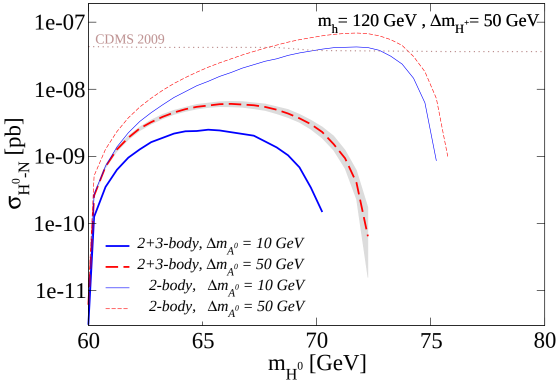


3. Inert doublet model



In the inert doublet model (IDM) the SM is extended with a second higgs doublet

The idm contains 3 new scalars

$$H_2 = \begin{pmatrix} H^+ \\ (H^0 + iA^0)/\sqrt{2} \end{pmatrix}$$

H_2 is odd under a new Z_2 symmetry

Lightest component is stable

No coupling to fermions

This model features a rich phenomenology

Barbieri, Bergstrom, Gustaffson, Ma, Tytgat, etc

The inert doublet model can account for the dark matter of the Universe

It includes a viable dm candidate

The lightest odd particle: H^0

H^0 has gauge and scalar interactions

$$V = \mu_1^2|H_1|^2 + \mu_2^2|H_2^2| + \lambda_1|H_1|^4 + \lambda_2|H_2|^4$$
$$+\lambda_3|H_1|^2|H_2|^2 + \lambda_4|H_1^\dagger H_2|^2$$
$$+\tfrac{\lambda_5}{2}\left[(H_1^\dagger H_2)^2 + \text{h.c.}\right]$$

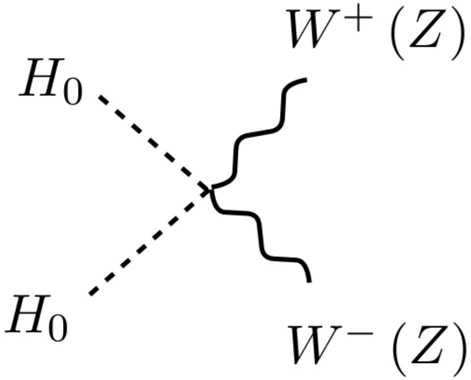
The parameter space is rather simple

$$m_{H^0}, m_{A^0}, m_{H^\pm}$$

$$\lambda_L \equiv \tfrac{1}{2}(\lambda_3 + \lambda_4 + \lambda_5)$$

In the IDM the viable parameter space coincides with the region where $H^0H^0 \to WW^*$ is important

$H^0H^0 \to W^+W^-$ has a purely gauge contribution

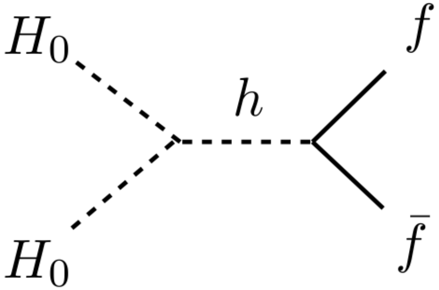


$\propto g^2$

The viable parameter space is $m_{H^0} < M_W$

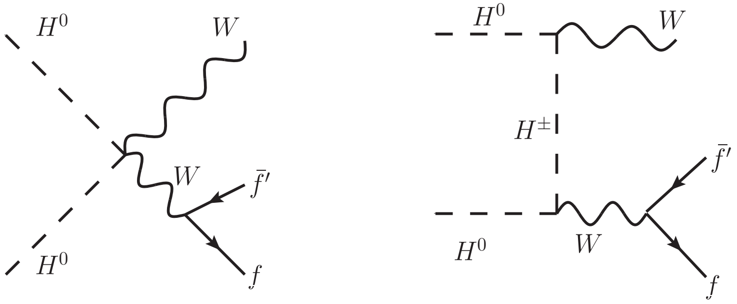
or $m_{H^0} > 500$ GeV

In that region, $b\bar{b}$ is the dominant 2-b final state



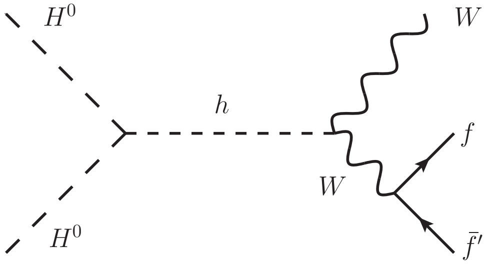
Three different diagrams contribute to $H^0H^0 \to WW^* \to Wf\bar{f}'$ in the IDM

There are two gauge diagrams



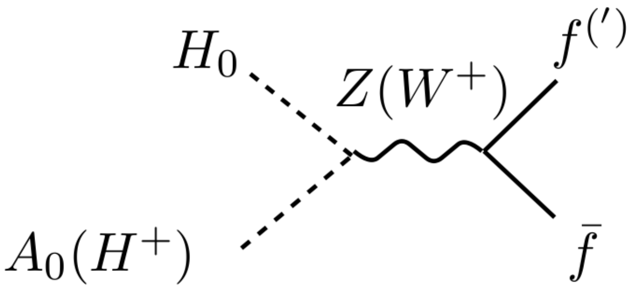
$\propto g^3$

And a higgs mediated diagram



$\propto g^2\lambda_L$

Coannihilations may also affect Ω

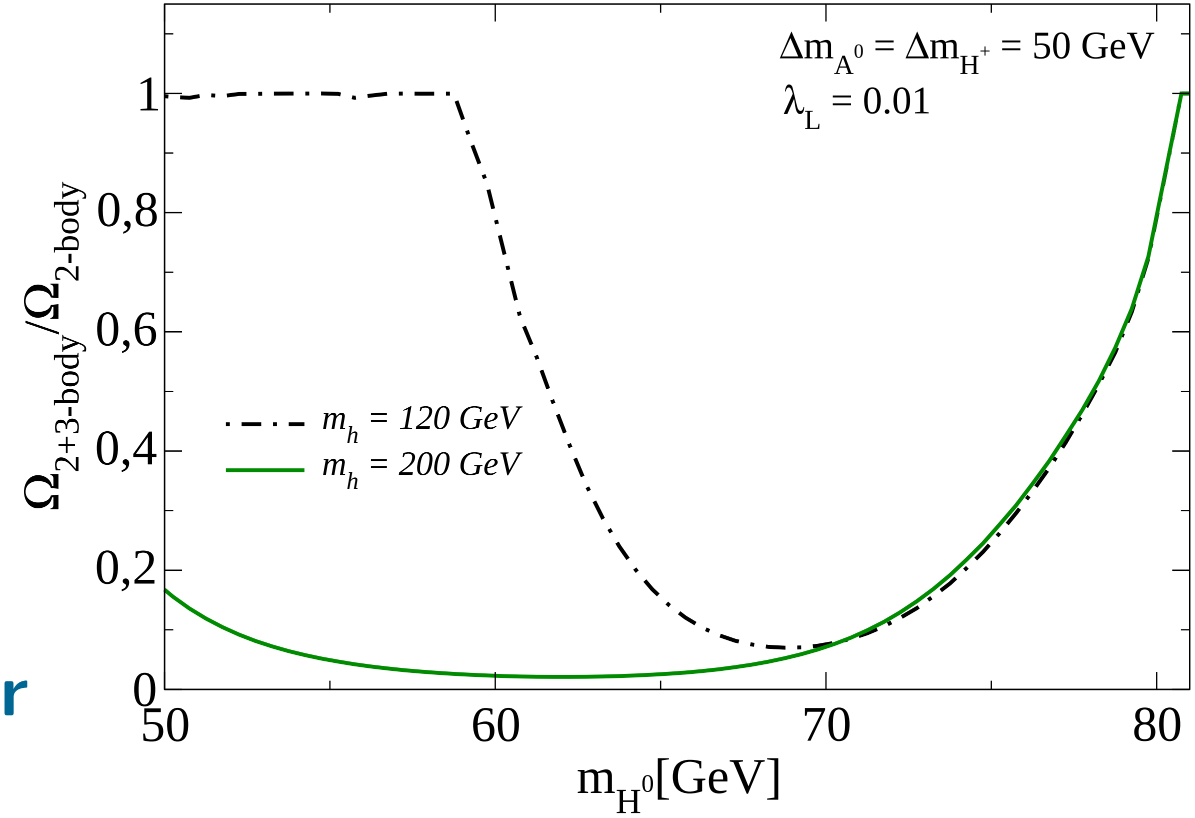


The H^0 relic density is strongly reduced by annihilations into WW^*

This suppression depends on the higgs mass

Ω could be 10 times smaller

Ω(3-body) $\ll$ Ω(2-body) over a wide m_{H^0} range

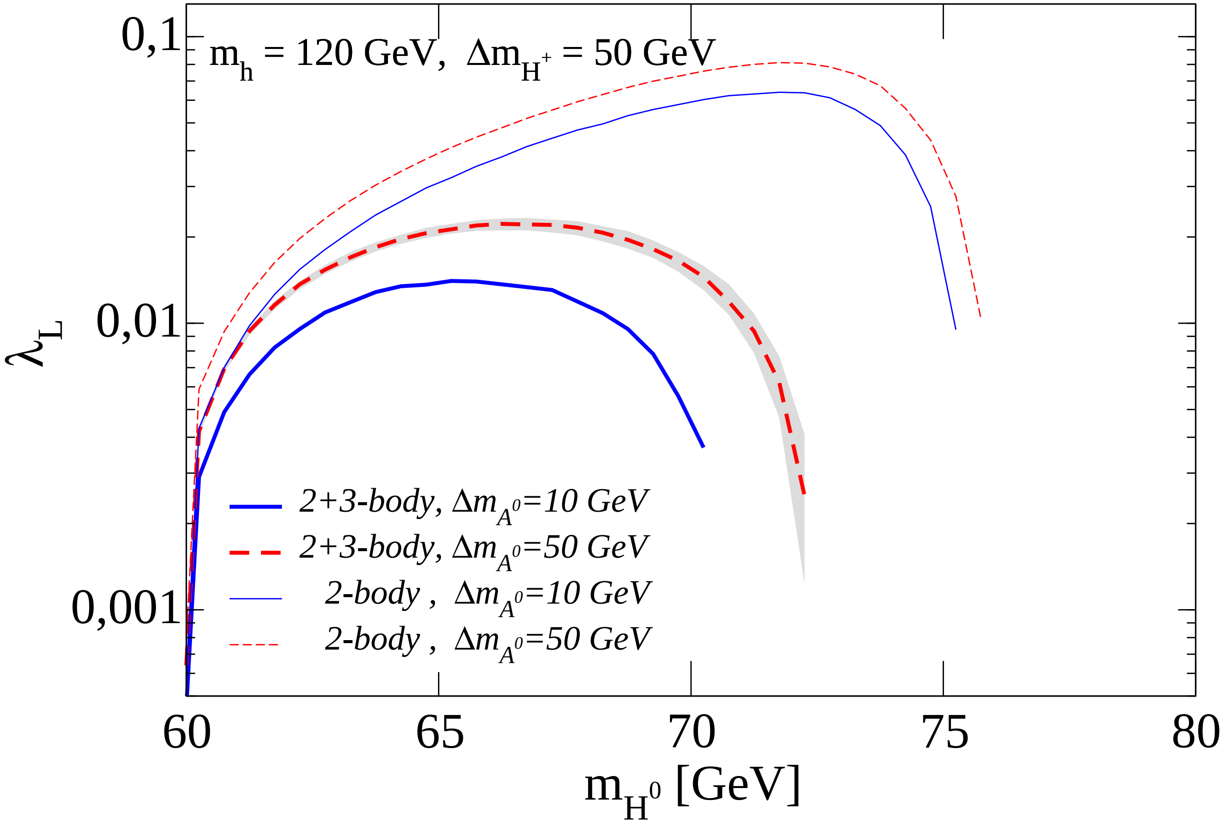


Due to 3-body final states, the viable parameter space of the IDM is substantially modified

The required value of λ_L may be much smaller

The maximum allowed m_{H^0} decreases

The effect is rather generic in the IDM

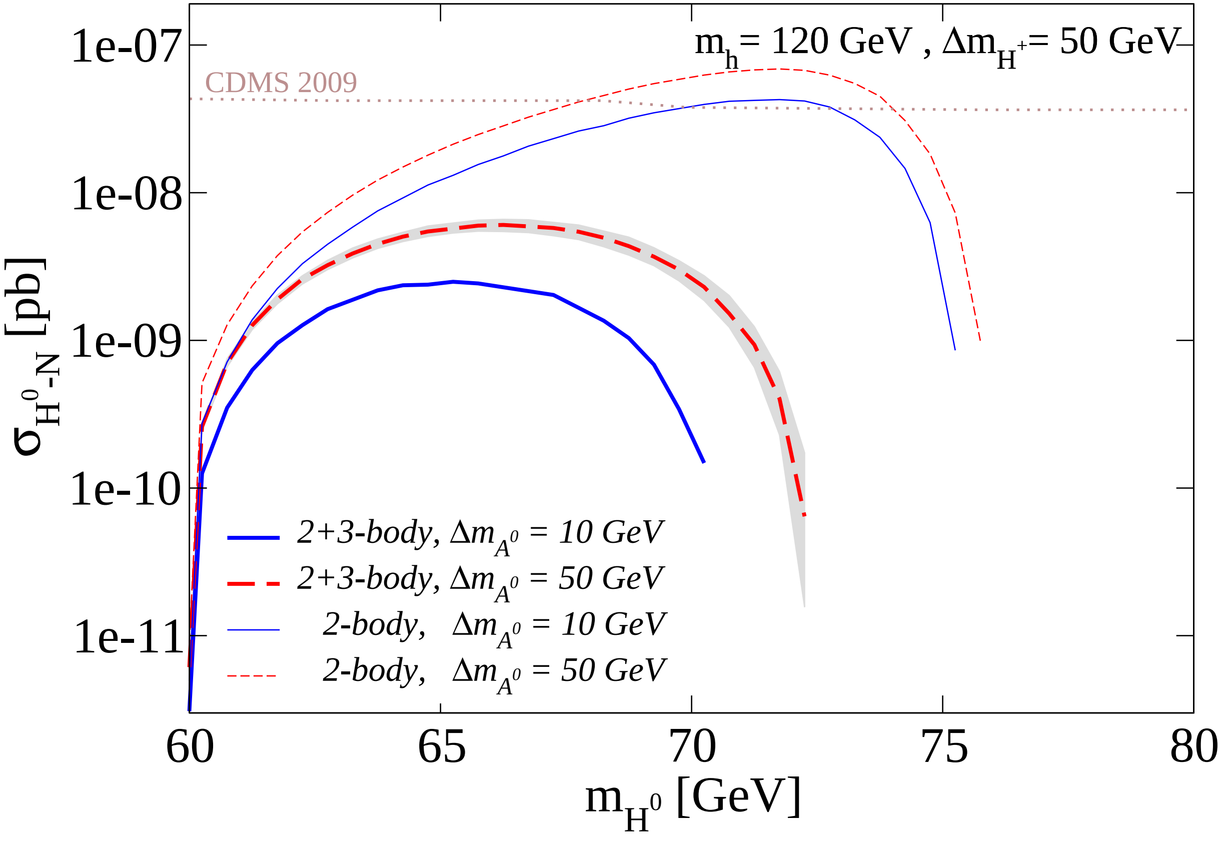


The inert higgs direct detection cross section is much smaller than previously believed

The dd cross section is proportional to λ_L^2

The new σ_{H^0-N} is up to 100 times smaller

Indirect detection signals are also affected



3-body final states are relevant in well-known dark matter models

They modify the viable parameter space

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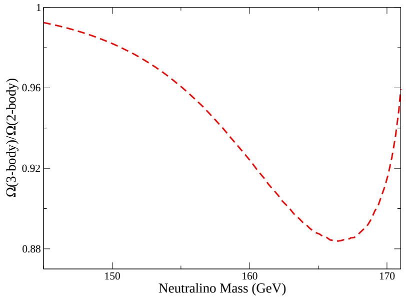

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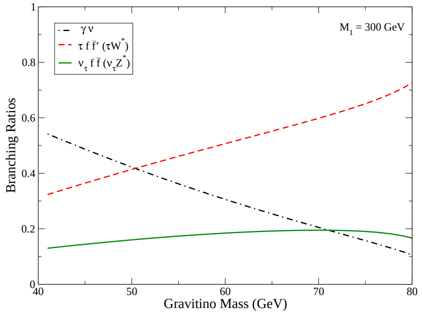
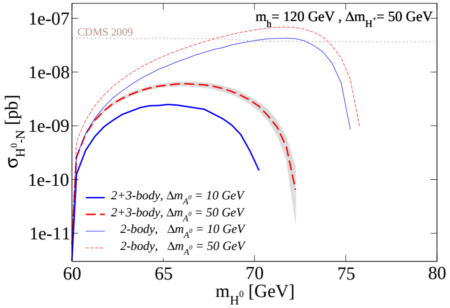


They alter the dm detection prospects

3. Inert doublet model



They induce large corrections