LANDESEXZELLENZINITIATIVE HAMBURG

Refining dark matter calculations

Activities and research of the LEXI group
Dark Matter Theory: LHC and Cosmology

http://lapth.in2p3.fr/pg-nomin/herrmann/group/

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(on behalf of A.G., Julia Harz, Björn Herrmann)

LEXI Meeting, 11-12 October 2011 DESY

Outline

- What is dark matter ?
- Need for precision ?
- Loop corrections to DM (co-)annihilation in the MSSM
- The Inert Doublet Model and the higgs - DM connexion
- Side projects
- Conclusions

What is dark matter ?

Basically, we don't know... But we do have some ideas (surprise!!!) :

- Weakly Interacting Massive Particles (WIMPs) : SUSY, X-dim, singlets, doublets, triplets, septuplets, scalars, vectors, fermions, with excited states, fundamental, composite...

- Very weakly interacting more or less massive particles: axions, axinos, gravitinos...

- Catalyzing other processes in the universe : asymmetric dark matter

- Freezing in, freezing out, resulting from decays, decaying themselves...

...so quite a few approaches!

Dark matter physics has not only ***used*** results from BSM theories to find candidates. It has ***driven*** developments in model-building for particle physics (but also in collider searches, cf kinematic variables invented to look for missing energy signals).

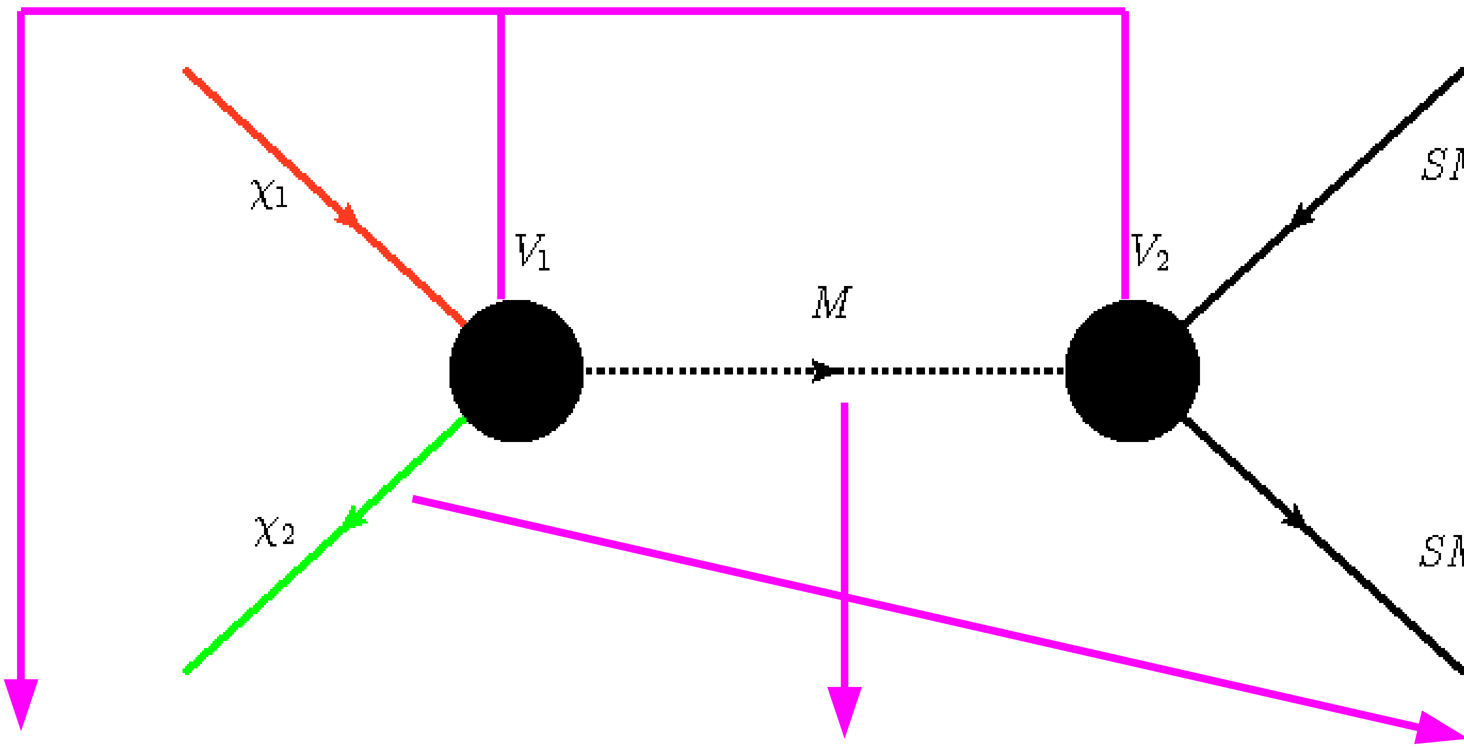
On top of all that, the WMAP limits are among the stringest bounds for BSM physics.
Experimental accuracy approaches **theoretical uncertainty**...

The 7-year WMAP measurements give

$$0.1018 < \Omega_{CDM} h^2 < 0.1234$$

Experimental bounds vs theoretical uncertainties (for WIMPs)

Three options to achieve the correct relic density in WIMP models :



Adjust couplings	Resonances	Coannihilation
Weak scale couplings	Low couplings	Low couplings
WMAP + Direct detection, Indirect detection, LHC	WMAP + LHC ?	WMAP + LHC ?

Experimental bounds vs theoretical uncertainties (for WIMPs)

→ WMAP is a very stringent bound ! (assuming ΛCDM)

Given the WMAP precision, radiative corrections to the relic density calculation are already known to be important in several models. So do 3-body final states.

Moreover :

- Rough trends : couplings are being pushed downwards or masses upwards.

- In the experimentally accessible regions, we might have to rely on resonances and/or coannihilation. → Corrections to masses?

- What is the role of a higgs mass measurement ? Interplay of higgs – DM sector ?

Adjust couplings	Resonances	Coannihilation
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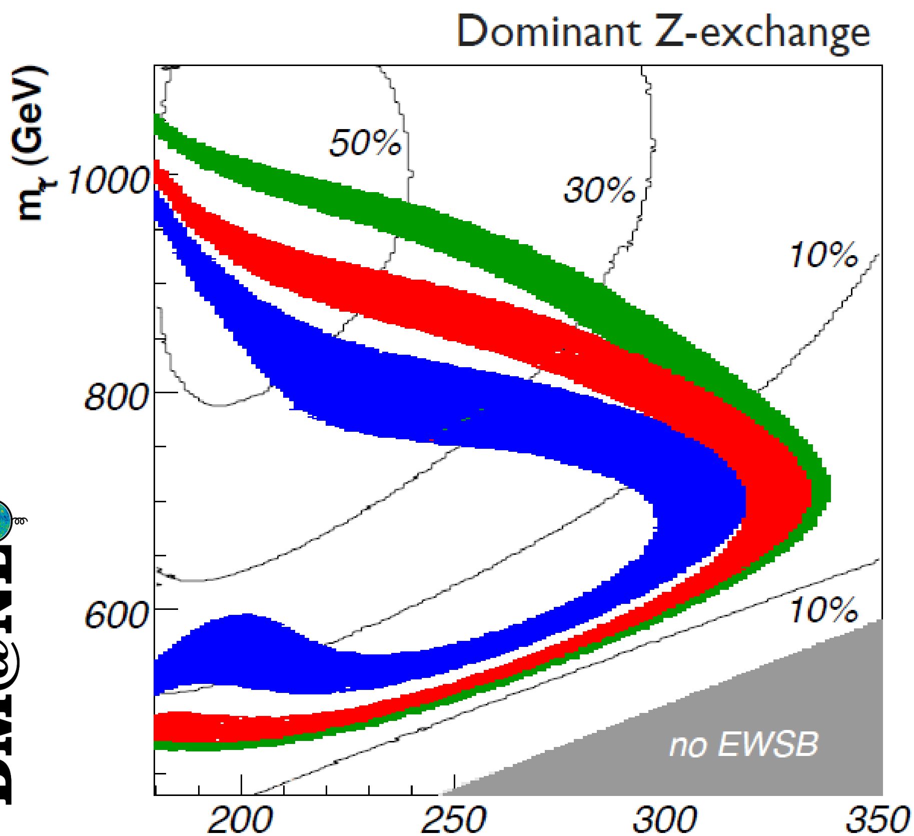
(SUSY-) QCD corrections to dark matter (co-)annihilations

- WMAP gives Ωh² with an accuracy of 10% (3σ).
- Herrmann *et al* find SUSY – QCD corrections up to O(50%).
- Boudjema *et al* even find EW corrections to be of the same order (constructive interference).

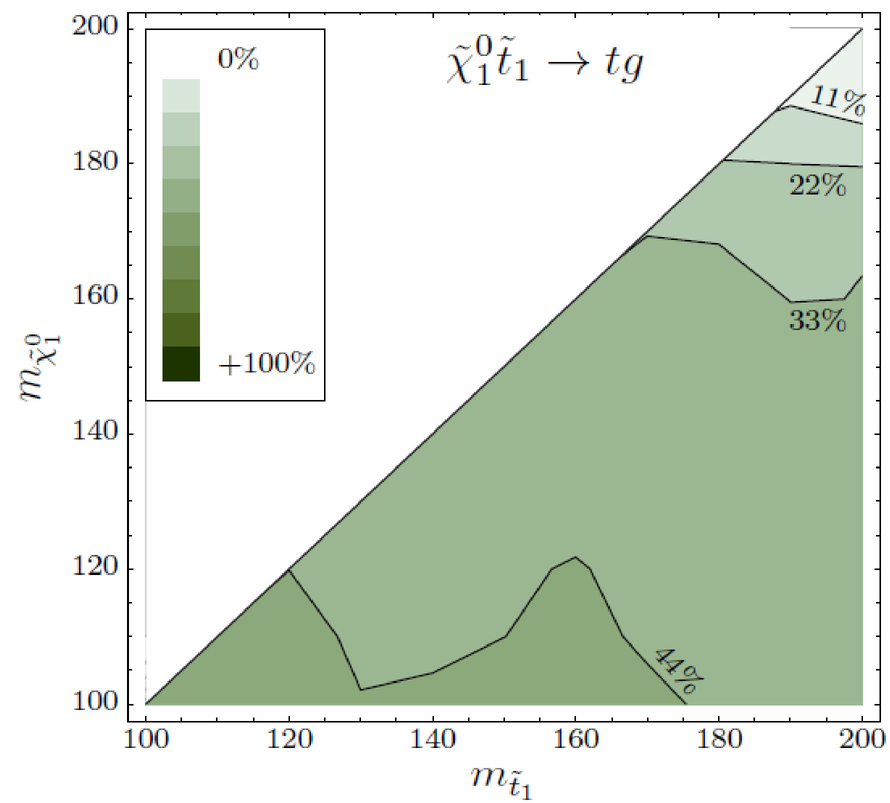
→ Radiative corrections can be larger than experimental uncertainty.

- What about coannihilation (of particular interest!)?
- Freitas finds contributions up to O(45%), once again larger than WMAP uncertainty.

→ A full calculation?



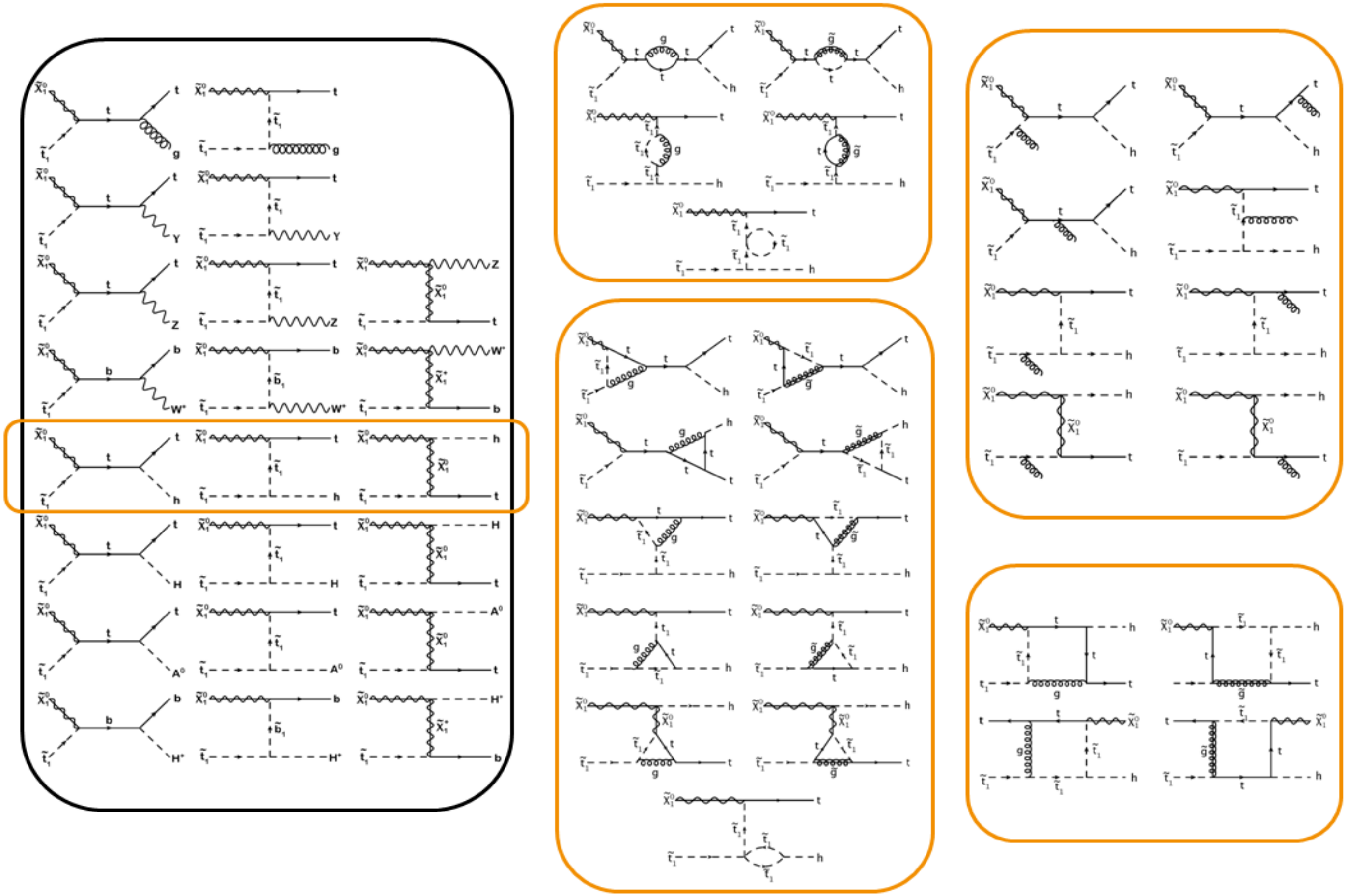
Herrmann, Klasen, Kovarik,
Phys.Rev. D80 (2009) 085025, arXiv:0907.0030



Freitas, Phys.Lett. B652 (2007) 280-284, arXiv:0705.4027

(SUSY-) QCD corrections to dark matter (co-)annihilations

YES! Work in progress by Julia Harz, Björn Herrmann, Michael Klasen, Karol Kovarik, Quentin Le Boulc'h.



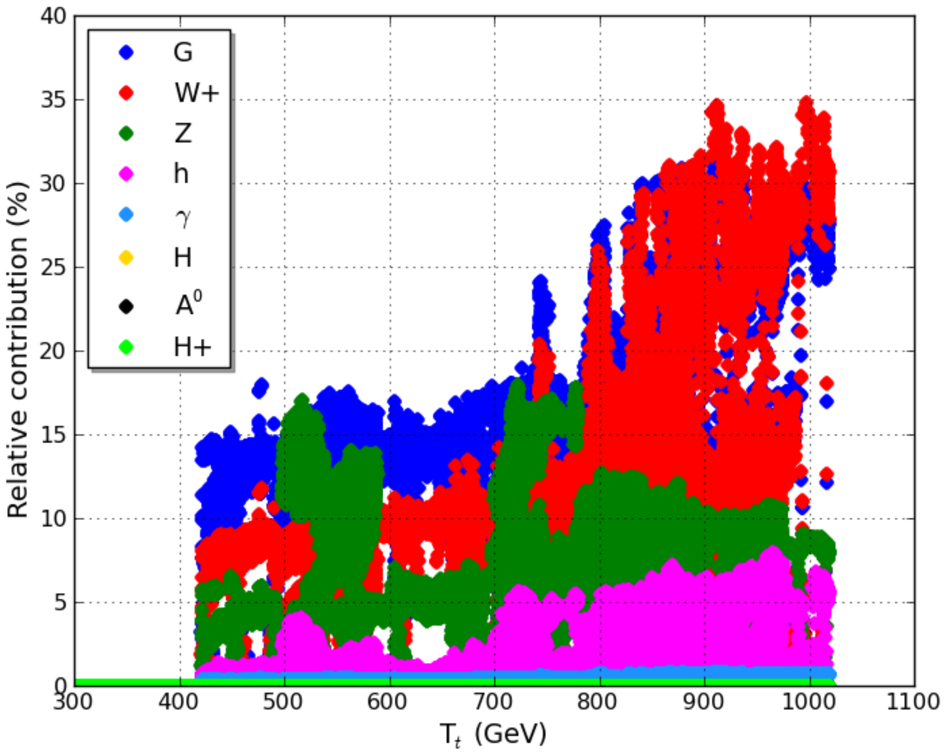
- All diagrams are calculated analytically and implemented numerically, to be soon added to the DM@NLO package for public use.
- Calculation performed for generic neutralinos, and with all EW scale parameters variable.

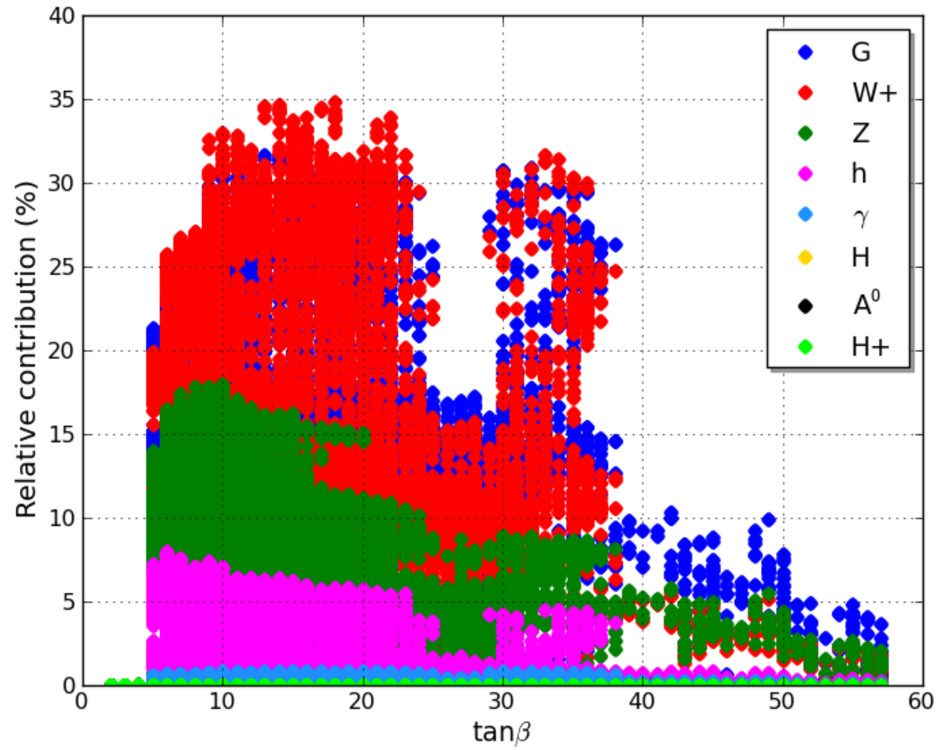
→ A modular computation to suit all our MSSM DM needs!

http://dmnlo.hepforge.org

(SUSY-) QCD corrections to dark matter (co-)annihilations

Scanning the pMSSM8 :



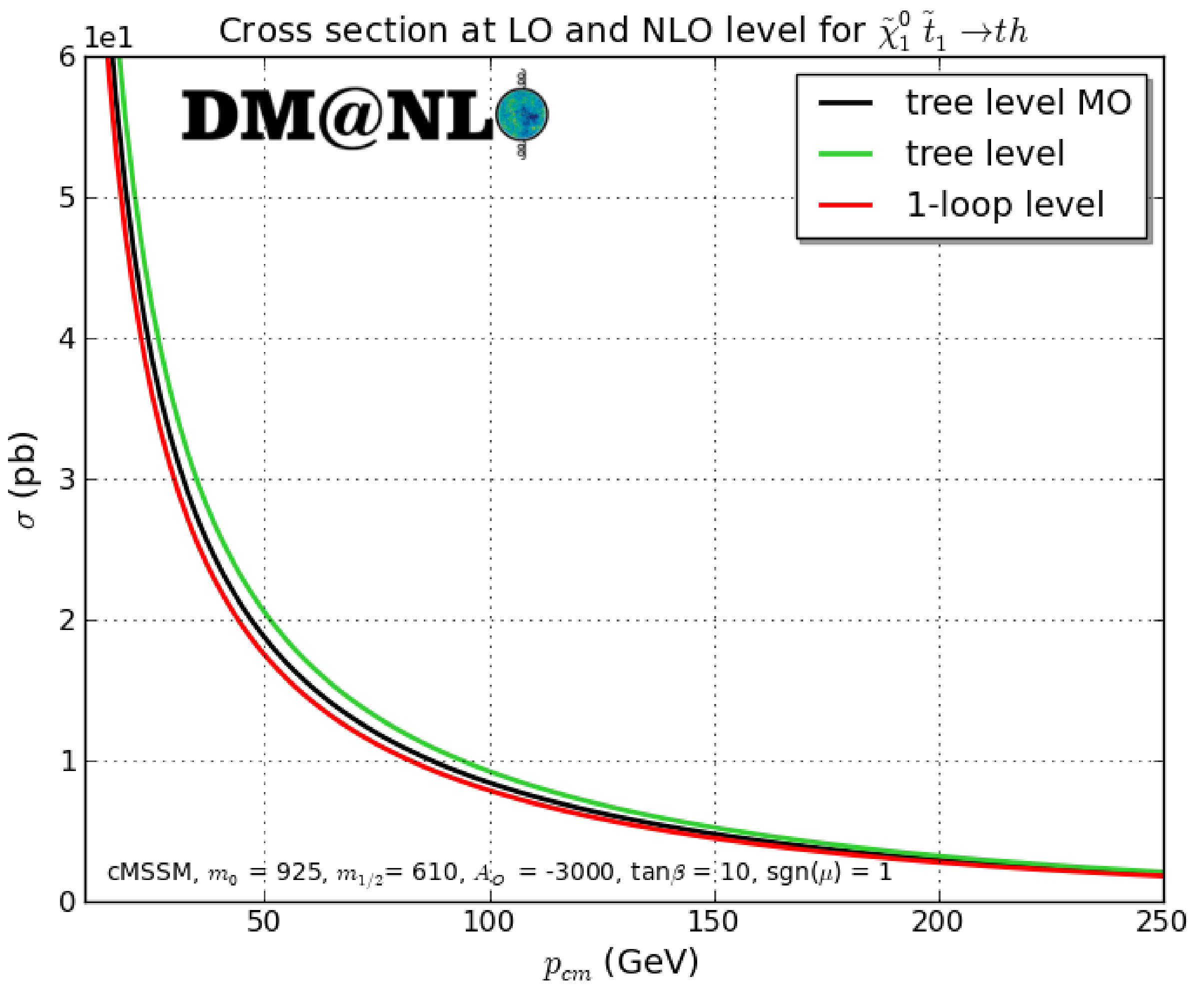


- Coannihilation becomes dominant for large trilinear coupling values and up to quite high tanβ.
- Work in progress, some minor issues with vector boson final states are being resolved, gluon final state contributions cooking, results to appear soon.

(SUSY-) QCD corrections to dark matter (co-)annihilations

An example for the top + light higgs final state :
- Corrections to pure tree-level calculation can reach O(20%). Deviations can be even larger and in more dominant channels.
- MicrOMEGAs can handle some corrections, but that's NOT what you get out of the box for a new model.

→ Stay tuned for full results!



The Inert Doublet Model and the higgs - DM connexion

The Inert Doublet Model (IDM) is a simple extension of the SM by an additional scalar doublet, protected by a discrete Z2 symmetry under which the SM is even and the new doublet is odd.

$$H = \begin{pmatrix} G^+ \\ \frac{1}{\sqrt{2}}\left(v + h^0 + \mathrm{i}G^0\right) \end{pmatrix}, \quad \Phi = \begin{pmatrix} H^+ \\ \frac{1}{\sqrt{2}}\left(H^0 + \mathrm{i}A^0\right) \end{pmatrix}$$

DM candidates

$$\mathcal{L}_{\text{cov}} = (D_\mu H)^\dagger (D^\mu H) + (D_\mu \Phi)^\dagger (D^\mu \Phi)$$

$$V_0 = \mu_1^2 |H|^2 + \mu_2^2 |\Phi|^2 + \lambda_1 |H|^4 + \lambda_2 |\Phi|^4 + \lambda_3 |H|^2 |\Phi|^2 + \lambda_4 |H^\dagger \Phi|^2 + \frac{\lambda_5}{2}\left[(H^\dagger \Phi)^2 + \text{h.c.}\right]$$

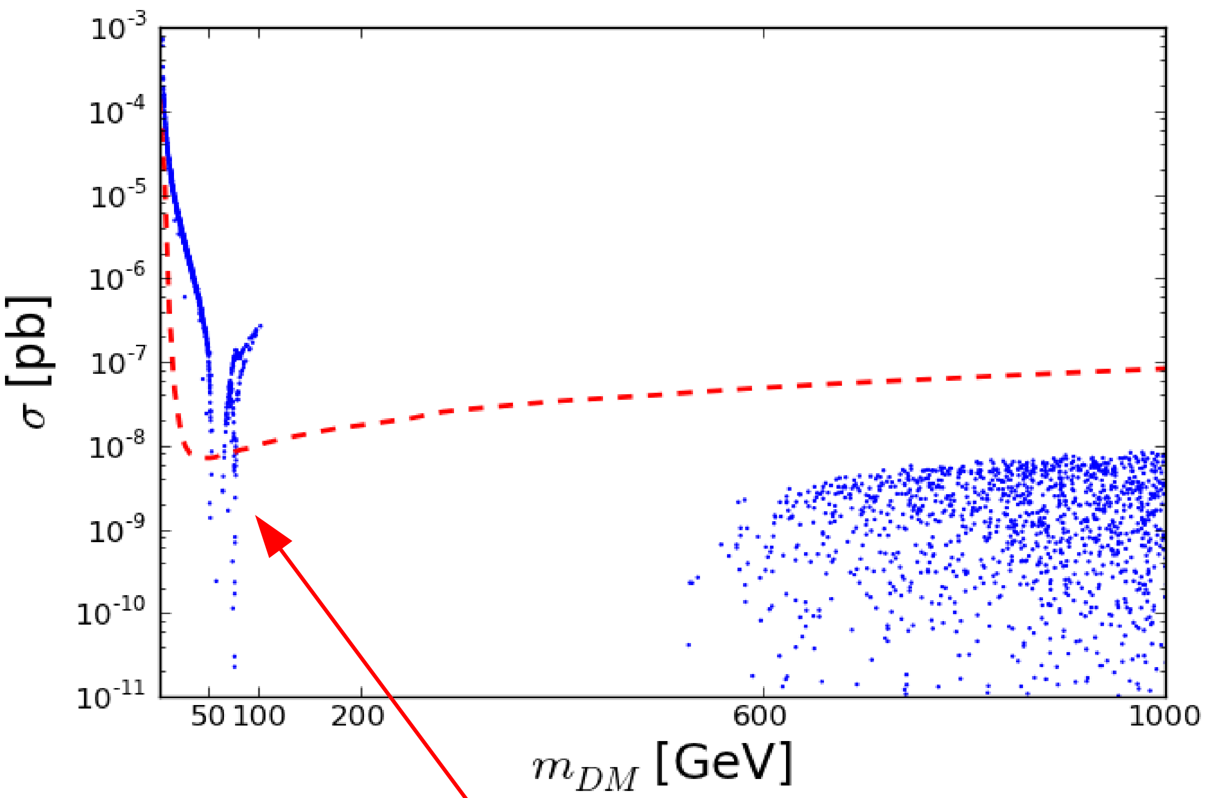
- The higgs sector is the basic means of communication between the visible sector and DM.
- It is only natural to wonder what happens if the observed ~125 GeV particle is the Higgs boson.

→ A simple model to study the DM - Higgs connexion.

(For a nice recent study see also M. Gustafsson, S. Rydbeck, L. Lopez-Honorez, E Lundstrom, arXiv:1206.6316)

The Inert Doublet Model and the higgs - DM connexion

→ So why calculate radiative corrections in a weakly coupled model with few diagrams?



- Interesting region from an LHC point of view, DM is pretty light.
- With the higgs mass fixed, funnel structure appears.

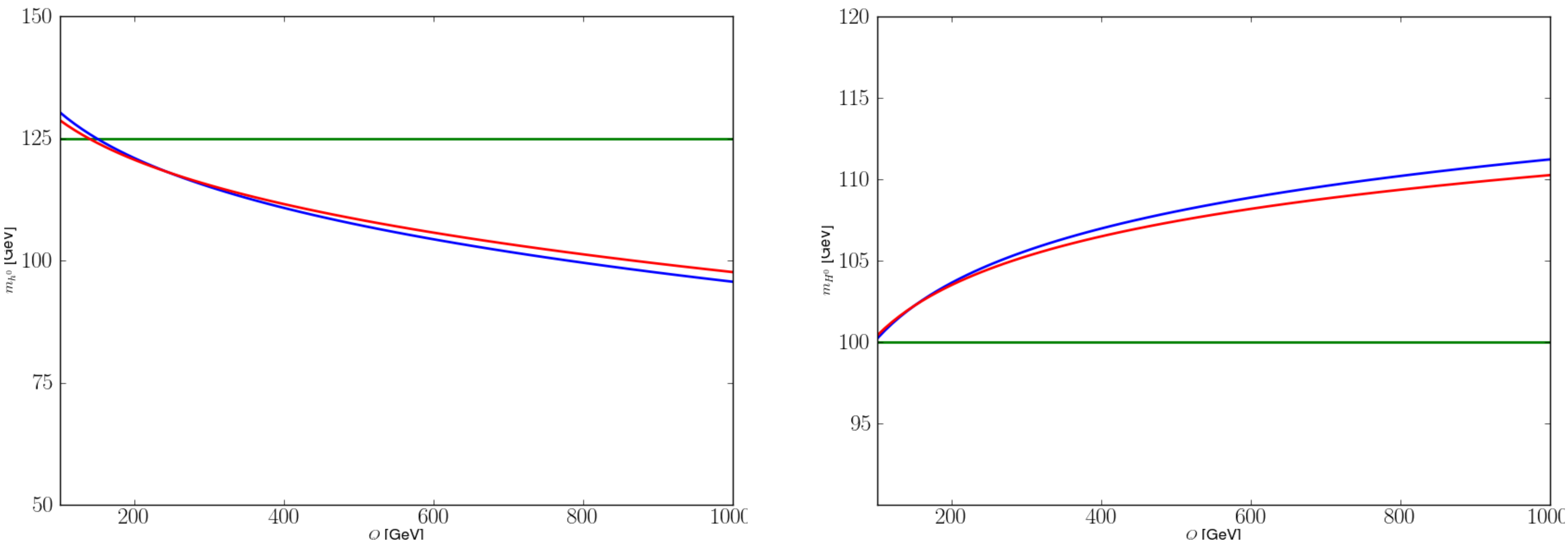
→ Small corrections could be crucial for the viability of parameter space points!

The Inert Doublet Model and the higgs - DM connexion

- Loop corrections to masses in different schemes (MSbar, on-shell).
- Extrapolation scale based on Perturbativity, Vacuum Stability, Unitarity constraints.
- Other experimental constraints (collider, oblique parameters).
- Relic density in view of all these constraints with fixed higgs mass.
- Impact of hadronic uncertainties on direct detection constraints.
- h → γγ

(To appear, A.G., B. Herrmann, O. Stal)

(mh = 125 GeV, mH = 100 GeV, mA = 150 GeV, mHch = 200 GeV, λL = 0.2, λ2 = 0.2)



Running (MSbar), Pole, Tree

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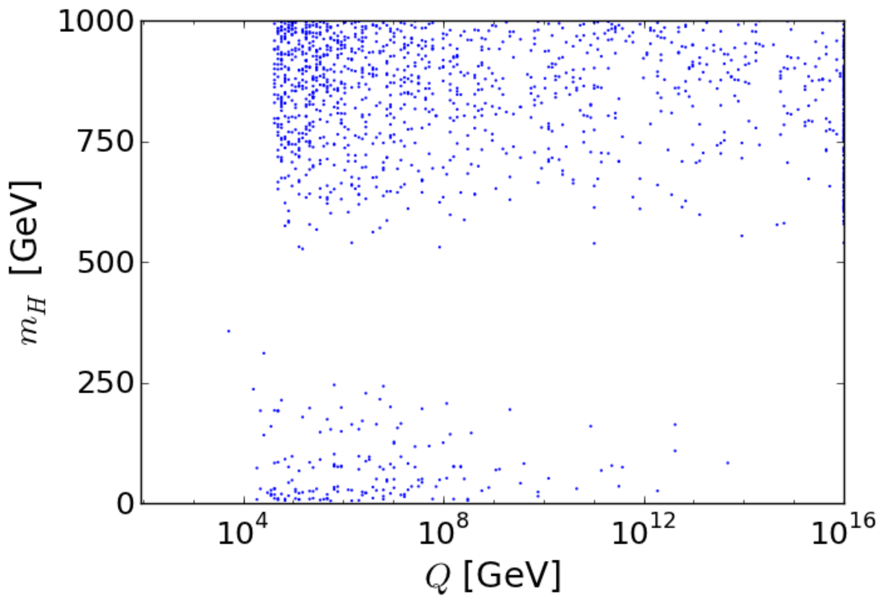

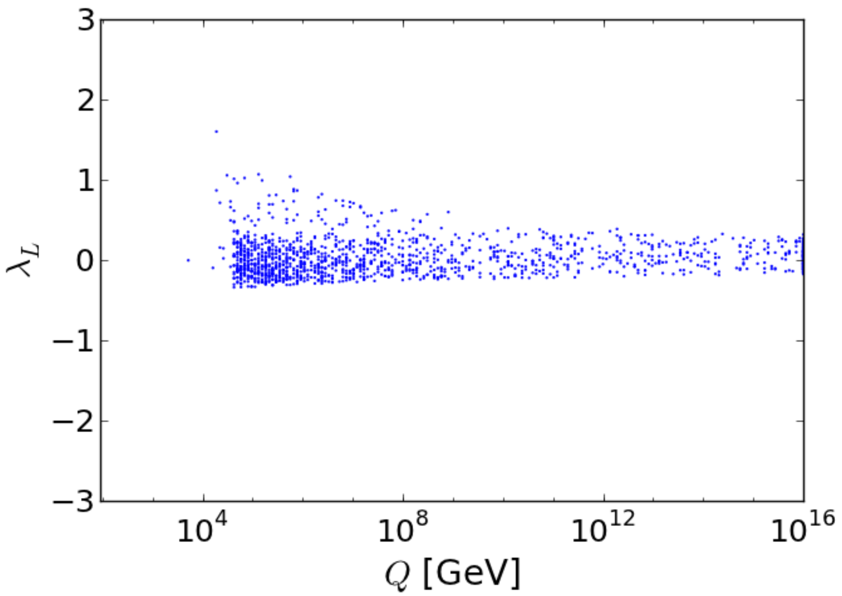

Other activities of the group

Further activities have mostly focused on flavor violation.

- In the squark sector, in SUSY models relaxing the MFV assumption, with signatures for the LHC and impact on the relic density of DM.

B. Herrmann, M. Klasen, Q. Le Boulc'h, Phys.Rev. D84 (2011) 095007
A. Bartl, H. Eberl, E. Ginina, B. Herrmann, K. Hidaka, W. Majerotto, W. Porod, Phys. Rev. D 84: 115026 (2011)

- In the lepton sector due to higgs interactions for quite generic models and providing an interpretation of the lepton mass hierarchy.

A.G., O. Lebedev, J.-h. Park, Phys.Lett. B707 (2012) 369-374

...and more ideas are on the way :)

Summary

- Dark matter is one of the main ingredients of new physics models. Up to this day, it remains one of the most solid pieces of evidence for BSM physics.

- With experimental data improving in quality and precision, theoretical calculations might also require refinement.

- In particular, SUSY – QCD (but also EW) corrections to DM annihilations can be important and should be taken into account.

- Our models now might have one less free parameter! The higgs mass measurement could be of relevance for DM and its implications should be addressed.

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Thank you !