Aspects of the Inert Doublet Model beyond tree-level

9th IDM conference, 25/07/2012

(based on work in progress with Björn Herrmann and Oscar Stål)

Andreas Goudelis
DESY – Hamburg

Aspects of the Inert Doublet Model beyond tree-level and the ~125 GeV higgs

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Outline

- The Inert Doublet Model
- Why study higher – order effects?
- Strategy and the case of a ~125 GeV higgs.
- One-loop effects in the scalar sector masses.
- Extrapolation scale of the IDM.
- Direct detection issues.
- Conclusions and prospects.

The Inert Doublet Model

→ The Inert Doublet Model of dark matter (IDM) is a – relatively – simple extension of the SM model with a second scalar doublet which is “protected” by a discrete symmetry under which all of the SM is even and the extra doublet is odd.

- As a result, we get new particles and interactions wrt the SM

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

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

where

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

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Potential DM candidates!

The Inert Doublet Model

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it is the simplest BSM construction that can capture essentially all mechanisms that give rise to the correct DM relic density in WIMP models: coupling adjustment, resonant annihilation, coannihilation.

(although introduced for different reasons)
N. G. Deshpande, E. Ma, Phys. Rev. D18, 2574 (1978)
R. Barbieri *et al*, Phys.Rev. D74, 015007 (2006), hep-ph/0603188

All in all, the IDM introduces 3(+1) new particles and 5 new parameters to the theory :

$$(\mu_1)\,,(\mu_2,\lambda_2,\lambda_3,\lambda_4,\lambda_5)\;\leftrightarrow\;(m_h),m_{H^0},m_{A^0},m_{H^\pm},\lambda_L=1/2(\lambda_3+\lambda_4+\lambda_5),\lambda_2$$

(+ EWSB conditions)

The constraints over this parameter space have been extensively studied (see also yesterday's Sara Rydbeck's talk)

M. Gustafsson, S. Rydbeck, L. Lopez-Honorez, E Lundstrom. , arXiv:1206.6316

Why go beyond tree-level ?

- A general rule of thumb : It is meaningful to go beyond tree-level calculations when experimental uncertainties start becoming smaller than theoretical ones. Examples do exist already (e.g. in the MSSM).

- In the IDM, one expects rather “small” deviations from tree-level : weak couplings and few diagrams !

- However, in light of direct searches that seem to exclude most of the intermediate mass regime, the surviving regions rely on **resonances** and **thresholds**.

→ Corrections to masses could become important!

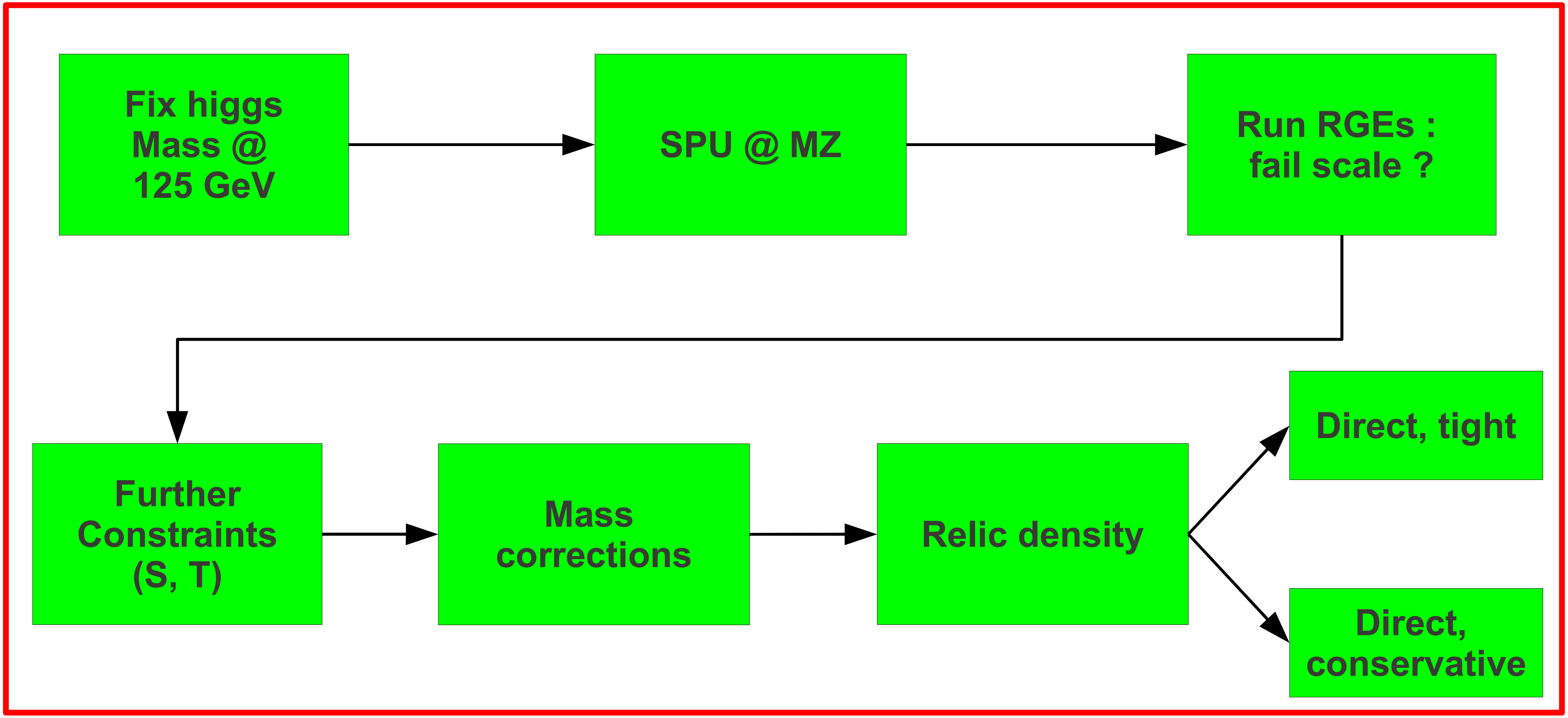
- As the LHC is placing bounds on more and more models, the mass scales are rising. It is interesting to start examining SPU constraints to higher scales!

- DM constraints are being combined with collider ones. Precision beyond comparison!

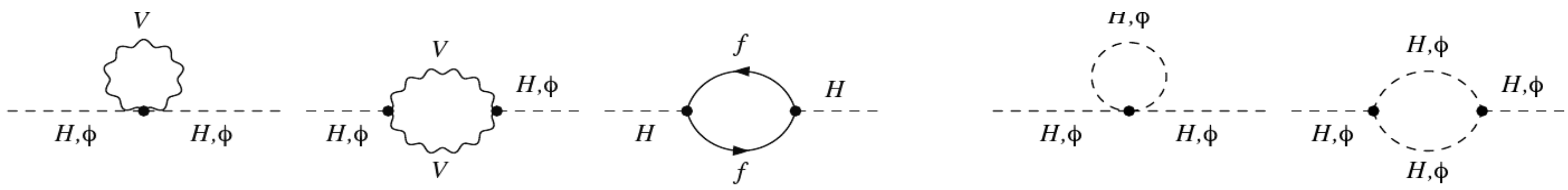
Also :

- Given the (possible) discovery of a Higgs boson, odds are that the parameters of the model are reduced by one. Consequences must be checked.

Scan strategy



Radiative corrections to scalar masses



Our strategy :

- Compute corrections to self-energies in MSbar scheme.

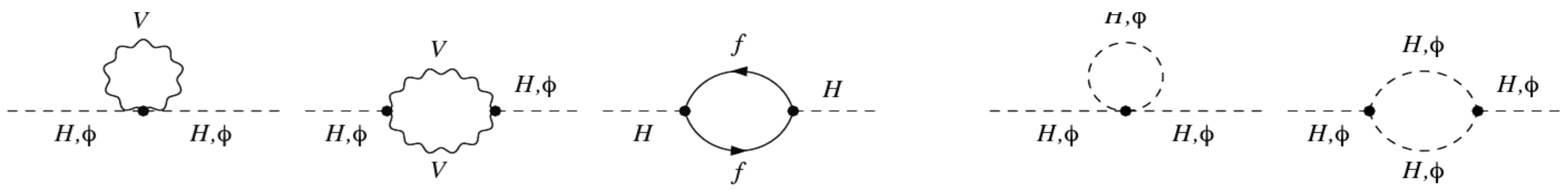
- Input some mass value, interpret it as MSbar mass.

- Compute pole mass.

- Compute corresponding tree-level mass.

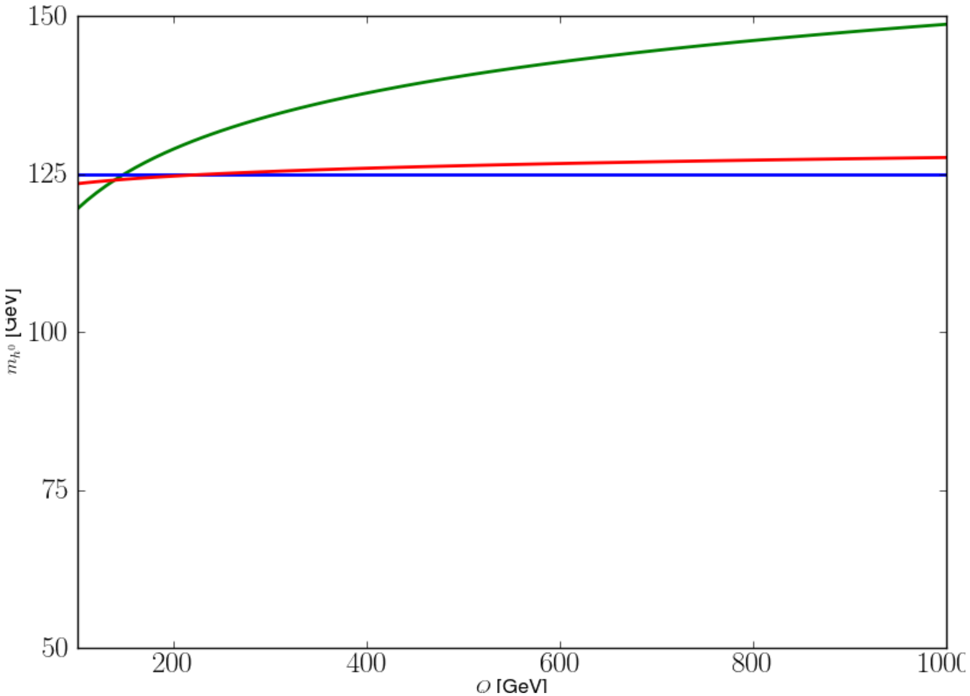
(NB : In relic density calculation, use pole mass.)

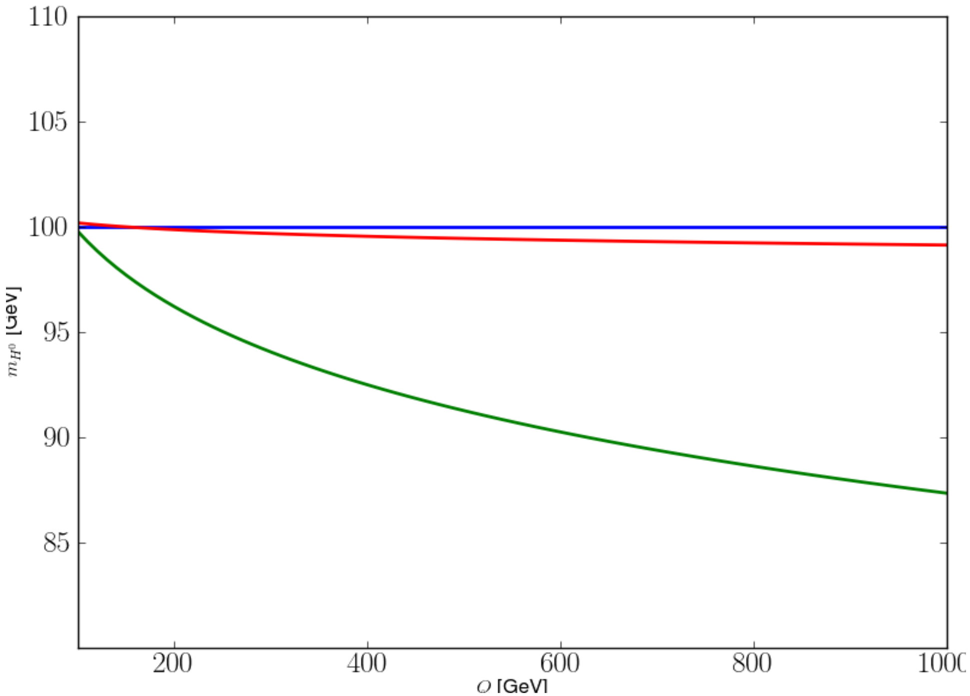
Radiative corrections to scalar masses



Approach No 1 : Fix running mass

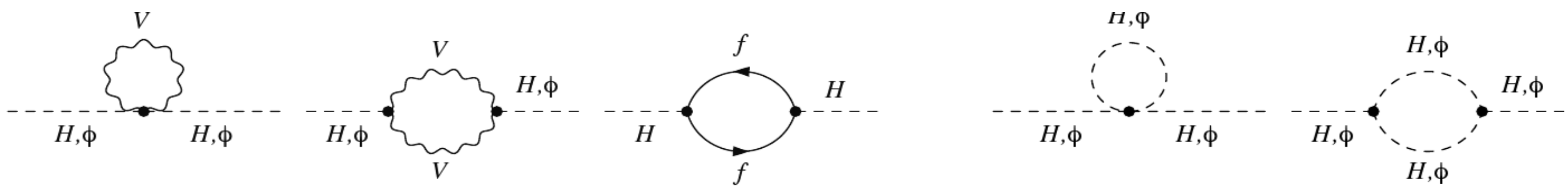
(mh = 125 GeV, mH = 100 GeV, mA = 150 GeV, mHch = 200 GeV, λL = 0.2, λ2 = 0.2)





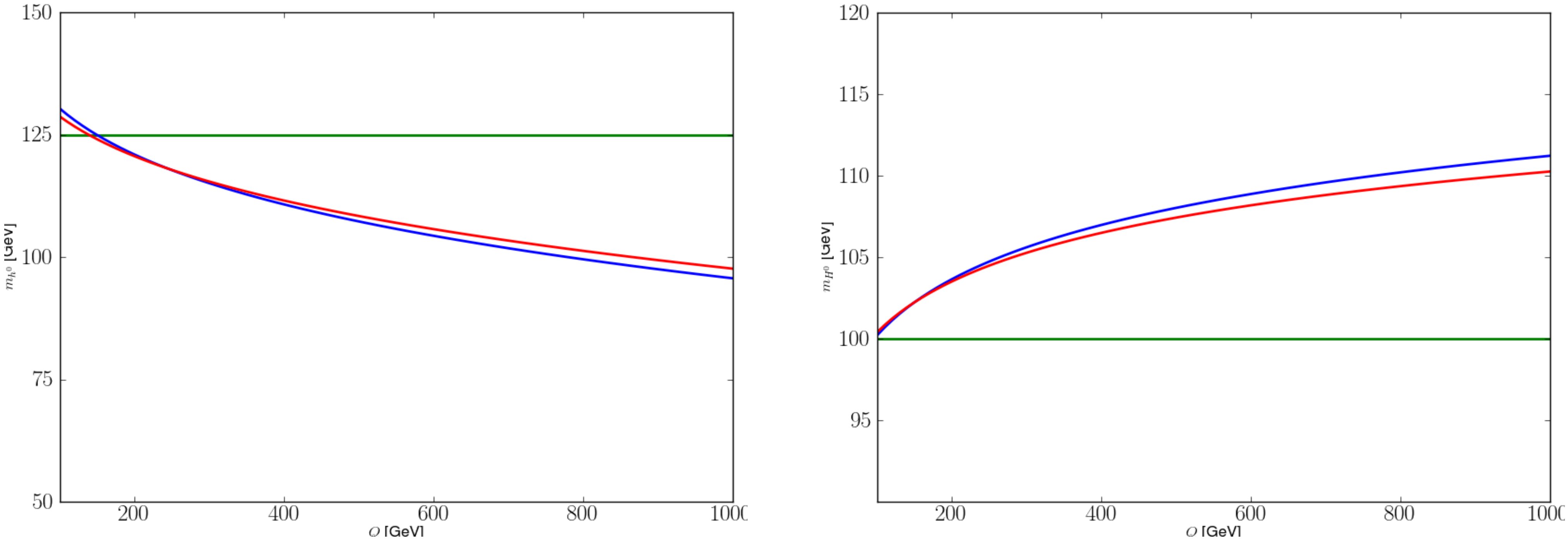
Running (MSbar), Pole, Tree

Radiative corrections to scalar masses



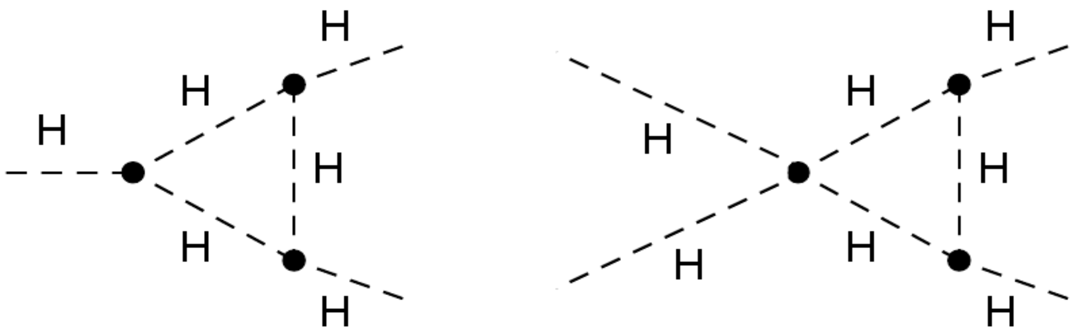
Approach No 2 : Fix tree-level mass

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



Running (MSbar), Pole, Tree

Extrapolation scale of the IDM



Our strategy :

- Compute the beta functions for all couplings.

- Scan the parameter space demanding Stability, Perturbativity, Unitarity (SPU) @ the input scale (MZ). Mass input interpreted as MSbar mass to match RGE computation.

- Numerically solve the RGEs up to the scale where S, P or U fail.

- In parallel, compute additional constraints (oblique parameters, LEP).

→ Calculation performed through adaptation of 2HDMC code.

D. Eriksson, J. Rathsman, O. Stål, Comput.Phys.Commun. 181 (2010)

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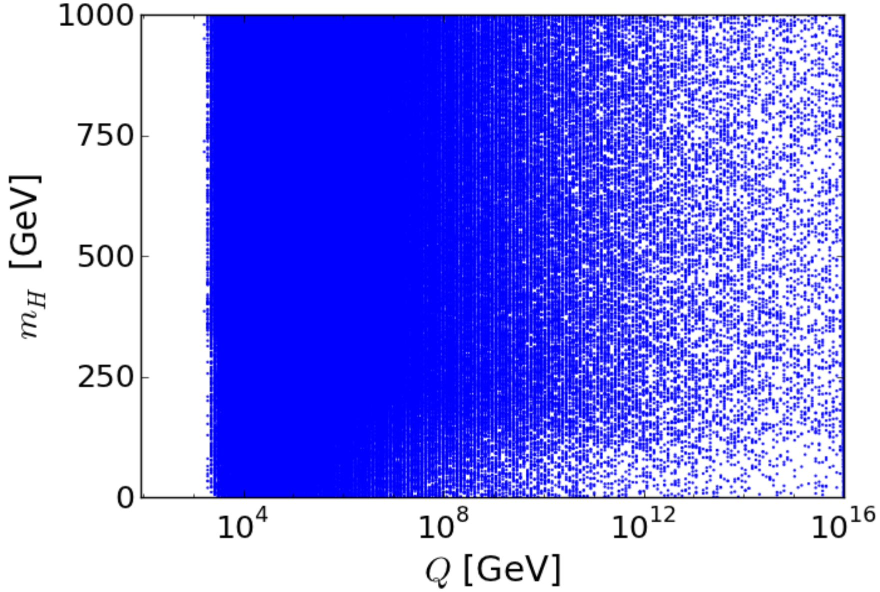
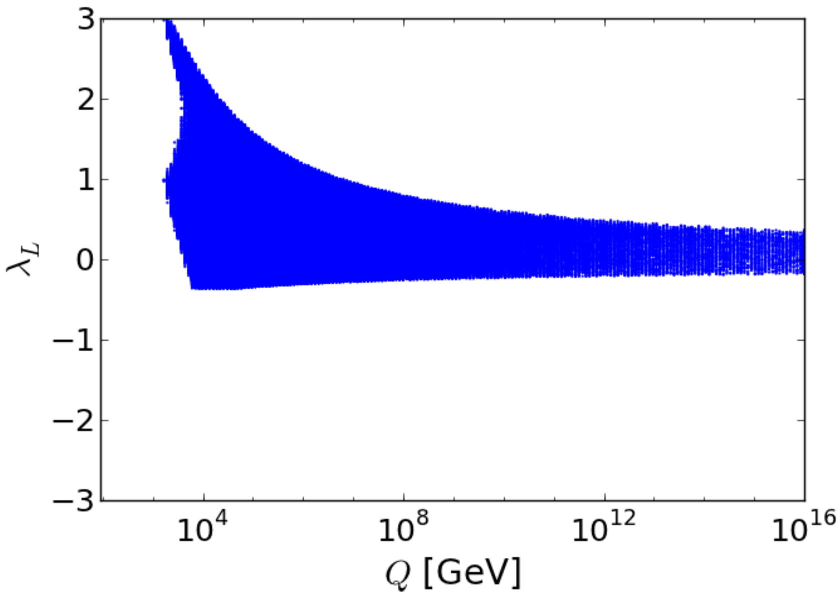
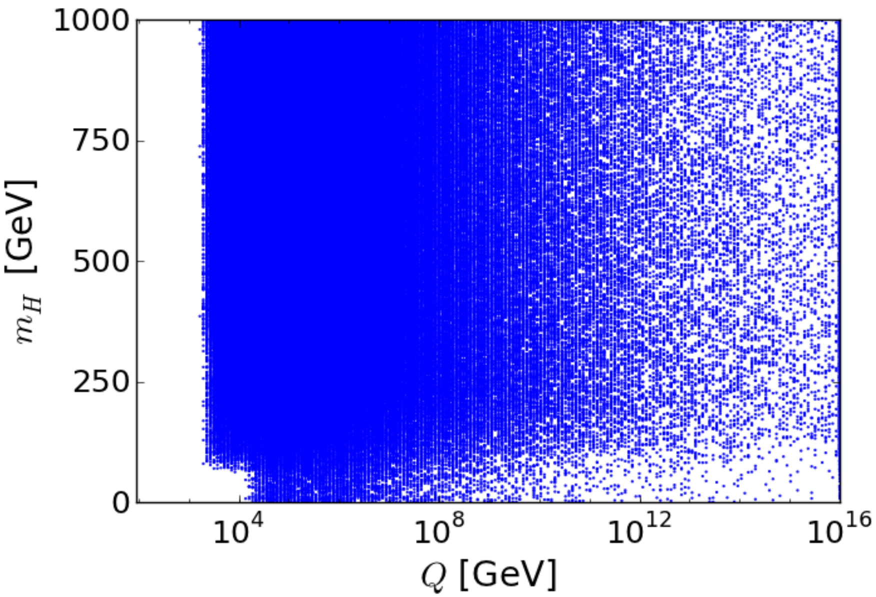
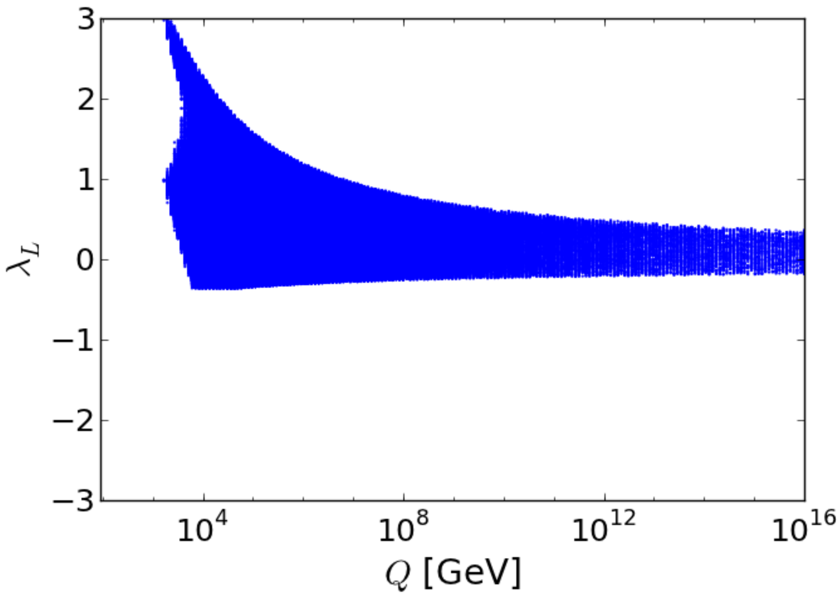




- Higgs mass fixed @ 125 GeV : Inert scalar mass basically unconstrained, small λL needed (perturbativity).

Extrapolation scale of the IDM

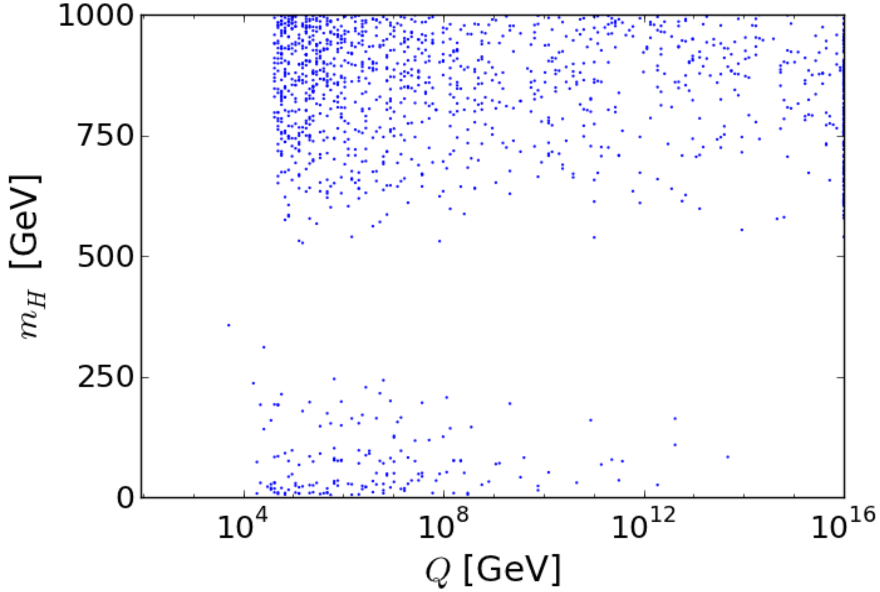


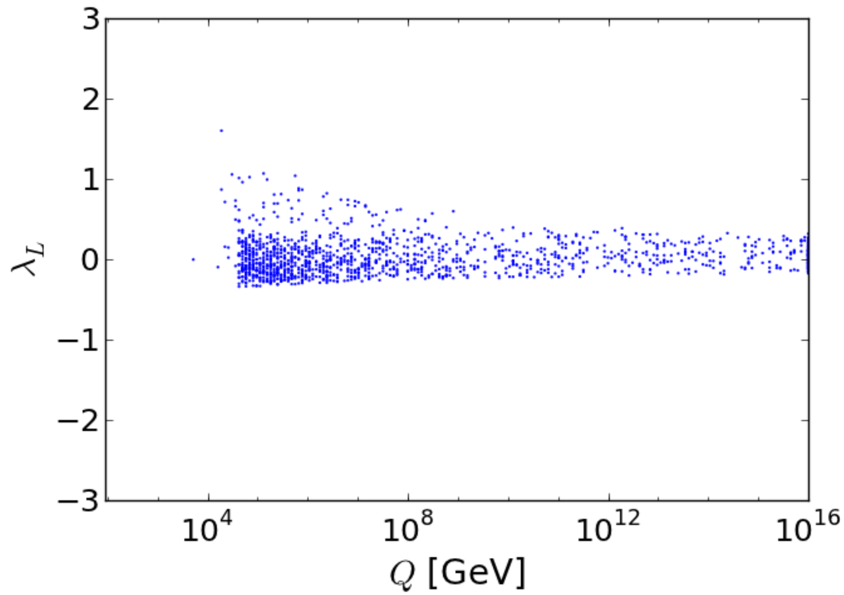


- Higgs mass fixed @ 125 GeV : Inert scalar mass basically unconstrained, small λL needed (perturbativity).

- Impose oblique, LEP constraints : The picture doesn't change dramatically (O(8%) point rejection).

Extrapolation scale of the IDM



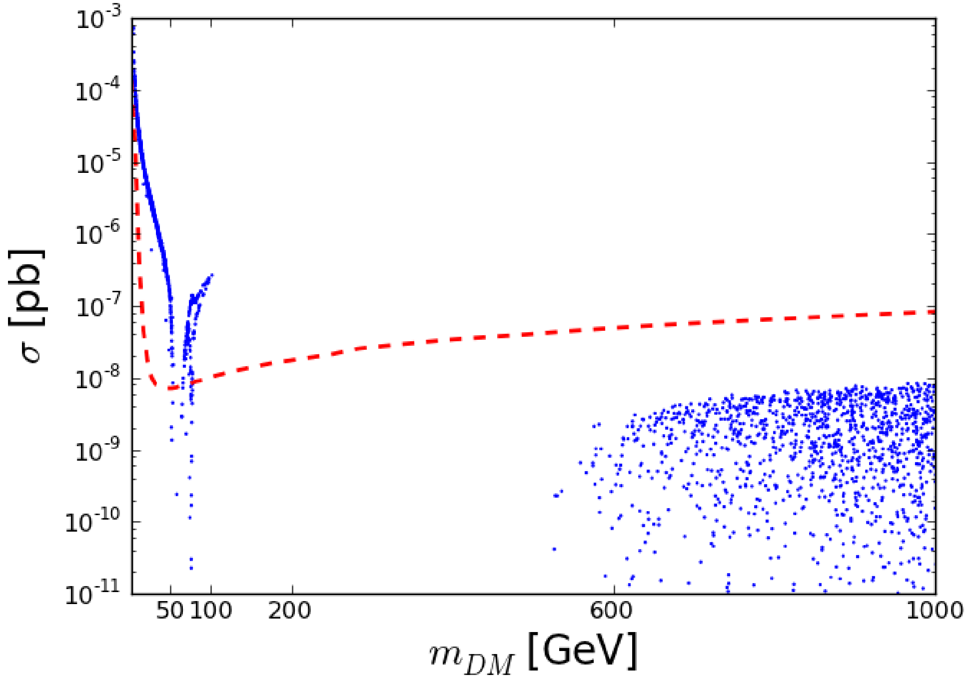


- Higgs mass fixed @ 125 GeV : Inert scalar mass basically unconstrained, small λL needed (perturbativity).

- Impose oblique, LEP constraints : The picture doesn't change dramatically. (*O*(8%) point rejection)

- Impose relic density constraint : Pretty dramatic change! (*O*(99.8%) point rejection!). However, model can still be extrapolated up to GUT scale.

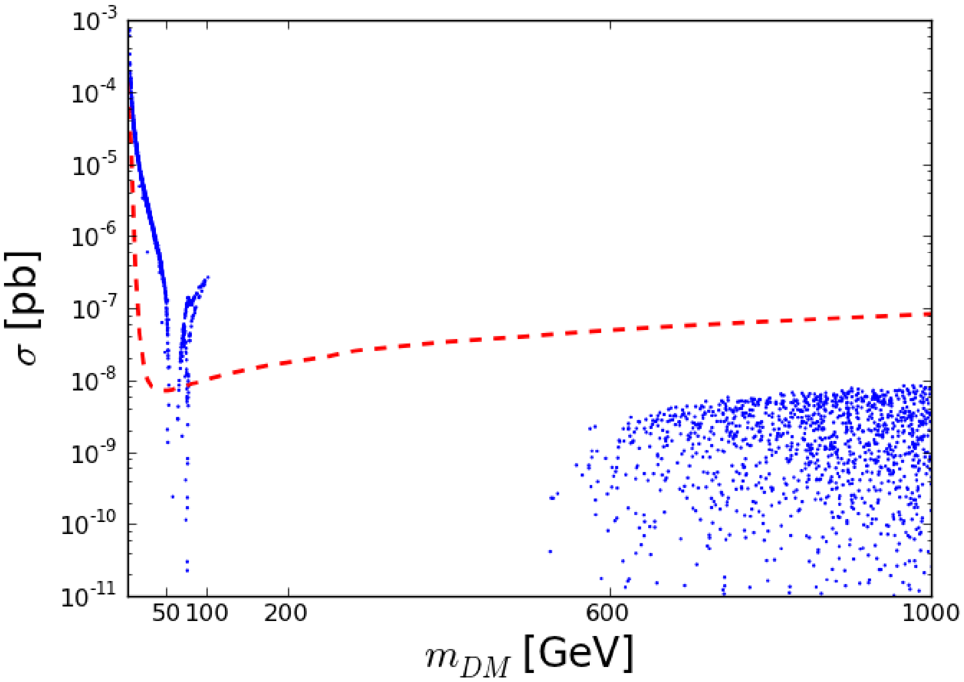
Direct detection



- XENON is placing very strong bounds especially on the intermediate mass regime.

- Appearance of “funnel structure” with two distinct branches around half the higgs mass.

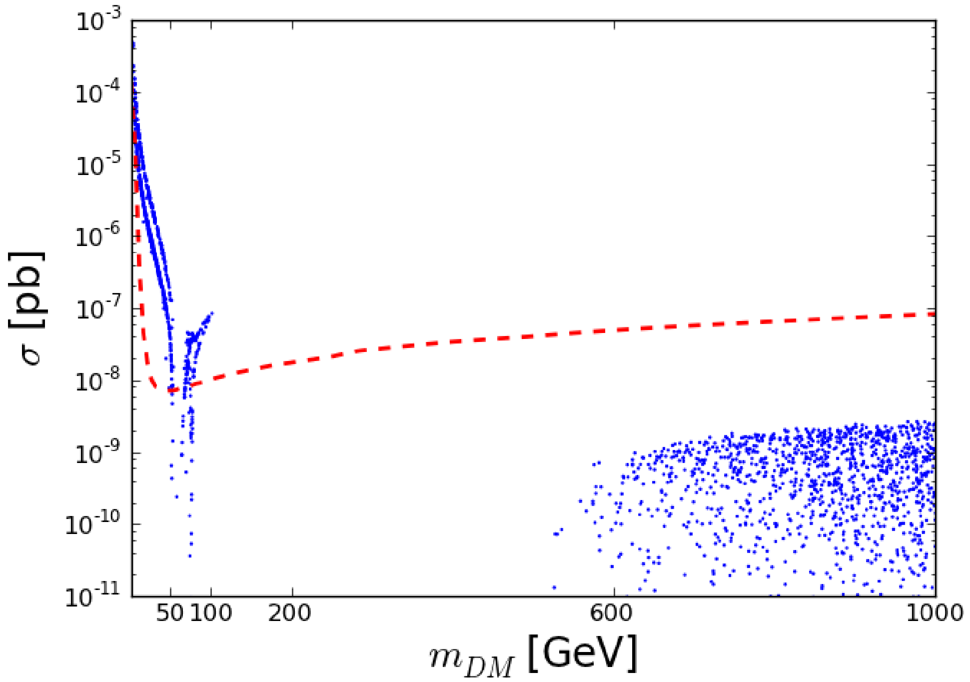
Direct detection : out with the old...



- However, this calculation is based on the old default values for nucleon form factors coming with micrOMEGAs, f_{T_s}= 0.2594 (even higher in DarkSUSY).

- In the absence of a precise measurement of $\sigma_{\pi N}$, we rely on lattice results. They point to a much lower value for f_{T_s}!

Direct detection : in with the new !



- Calculation performed with f_{T_s}= 0.014, according to Twisted Mass collaboration results. This is *not* the most conservative estimate in the literature.

- Future micrOMEGAs default is f_{T_s}= 0.0277.

- A crucial uncertainty for direct detection. It's *not* playing with parameters, it's an uncertainty !

Conclusions and outlook

- We examined the consequences of fixing the Higgs mass at ~125 GeV motivated by the recent LHC findings. Basic regions of the IDM qualitatively remain but with restricted features (e.g. appearance of funnel structure).

- We computed the 1-loop corrections to the scalar masses. They can be non-negligible, of the order of 3 – 5 GeV. Overall consequences? Full 1-loop calculation of relic density probably needed, work in progress!

- We examined the extrapolation scale of the IDM by actually solving the 1-loop RGEs. After imposition of the relic density bound, the model can still be extrapolated up to the GUT scale (modulo direct detection constraints).

- We quantified the effect of hadronic uncertainties on the direct detection bounds. The effect is there, although a significant part of the parameter space remains excluded.

- These uncertainties also influence more complicated models (xMSSM) and should be accounted for, especially given the precision of all other calculations when constraining models!

Merci !