Loop effects in the Inert Doublet Model and the ~125 GeV Higgs

GDR Terascale@Paris, 6/11/2012

(based on work with Björn Herrmann and Oscar Stål, to appear soon)

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Outline

- The Inert Doublet Model
- Motivation and goals.
- 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

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

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

where

$$H = \begin{pmatrix} G^+ \\ \frac{1}{\sqrt{2}}(v + h^0 + iG^0) \end{pmatrix}, \quad \Phi = \begin{pmatrix} H^+ \\ \frac{1}{\sqrt{2}}(H^0 + iA^0) \end{pmatrix}$$

Potential DM candidates

The Inert Doublet Model

The IDM 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

Long list of references, for a recent study see, e.g.
M. Gustafsson, S. Rydbeck, L. Lopez-Honorez, E Lundstrom. , arXiv:1206.6316

The Inert Doublet Model

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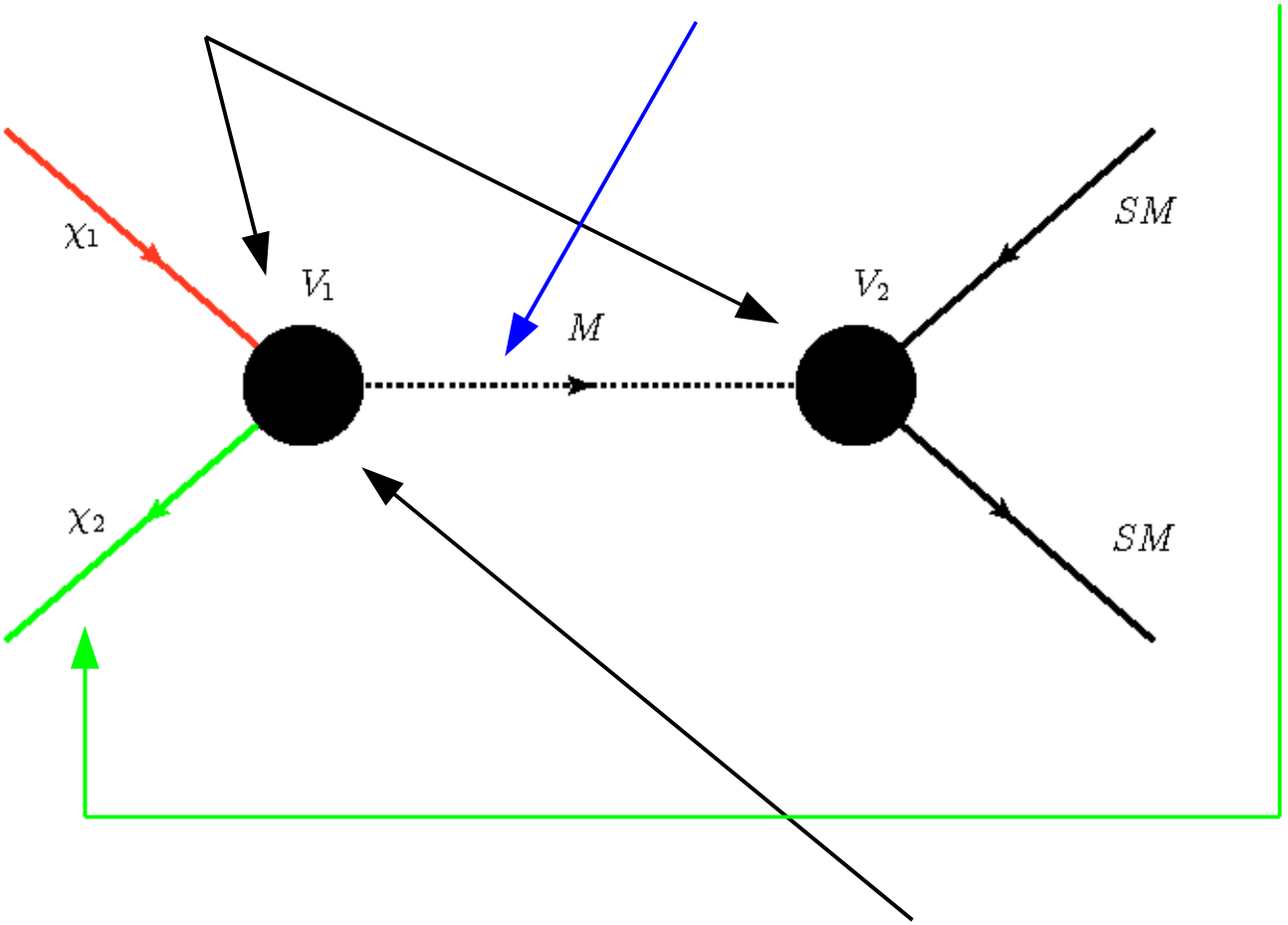

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Motivation and goals

- Rule of thumb : It is meaningful to go beyond leading order calculations when experimental uncertainties start becoming smaller than theoretical ones.

- In the IDM, one expects rather "small" loop corrections to the DM relic density : weak couplings and few diagrams (≠ e.g. MSSM).

- However, in light of XENON100 that seems put pressure on IDM masses < 120 GeV, the surviving moderate mass regions rely on **resonances** and **thresholds**.

- In particular, the IDM is also one of the simplest models where the **Higgs boson** is the basic means of communication of DM with the visible sector. And well, a Higgs boson might have been recently discovered at the LHC.

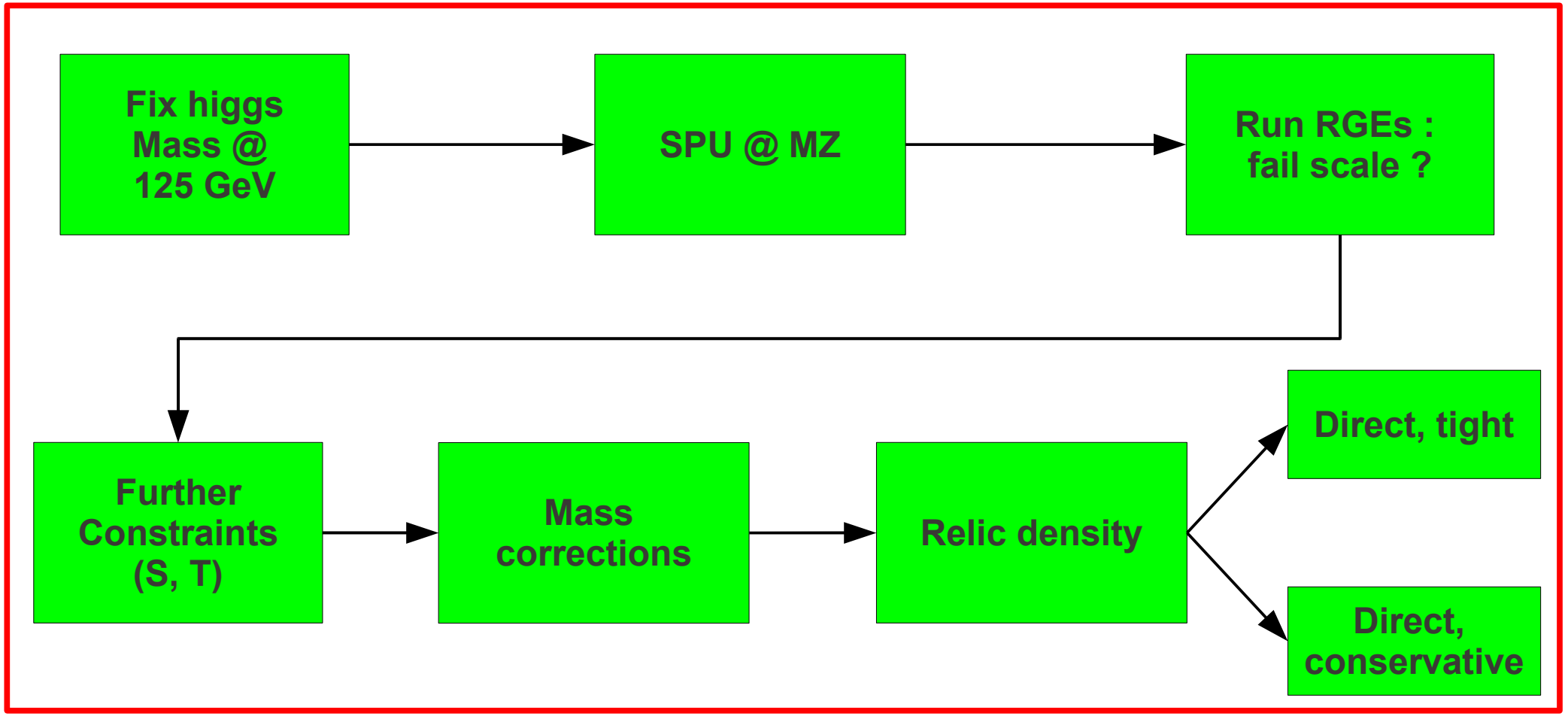
→ A simple model to start examining higgs discovery consequences for DM.

→ Loop corrections to masses could become important!

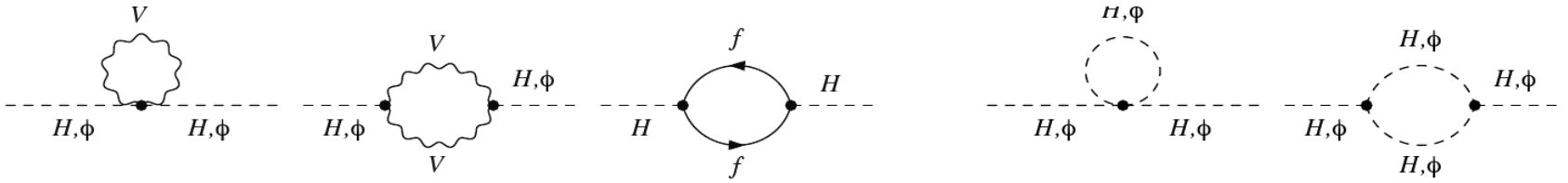
Moreover :

- 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!

Scan strategy



Radiative corrections to scalar masses



Method :

- Compute corrections to self-energies in MSbar scheme.

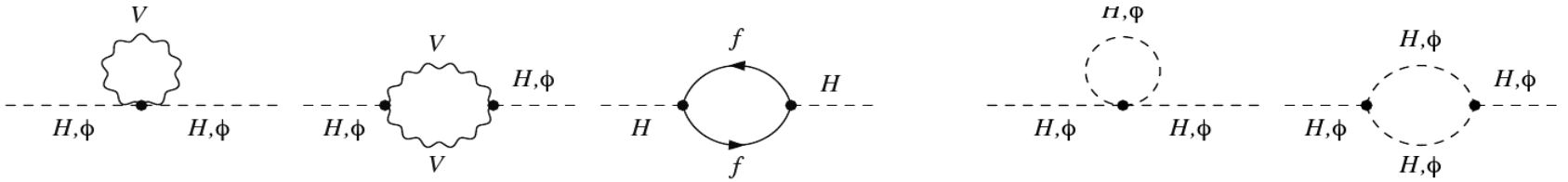
- Input some mass value, interpret it as MSbar mass.

- Compute pole mass.

- Compute corresponding tree-level mass.

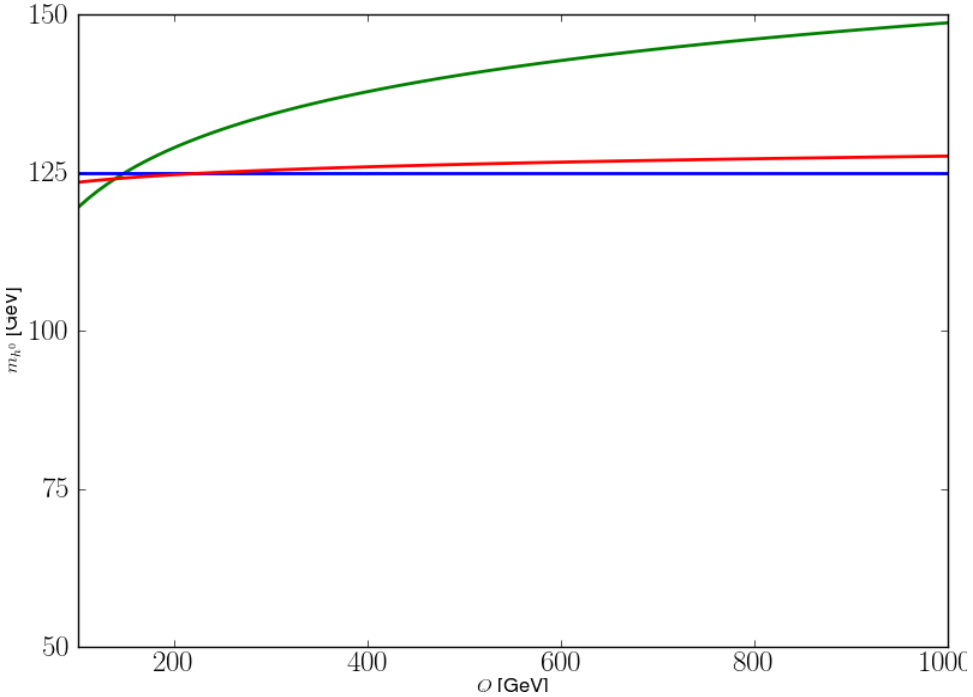
(NB : In relic density calculation, use pole mass.)

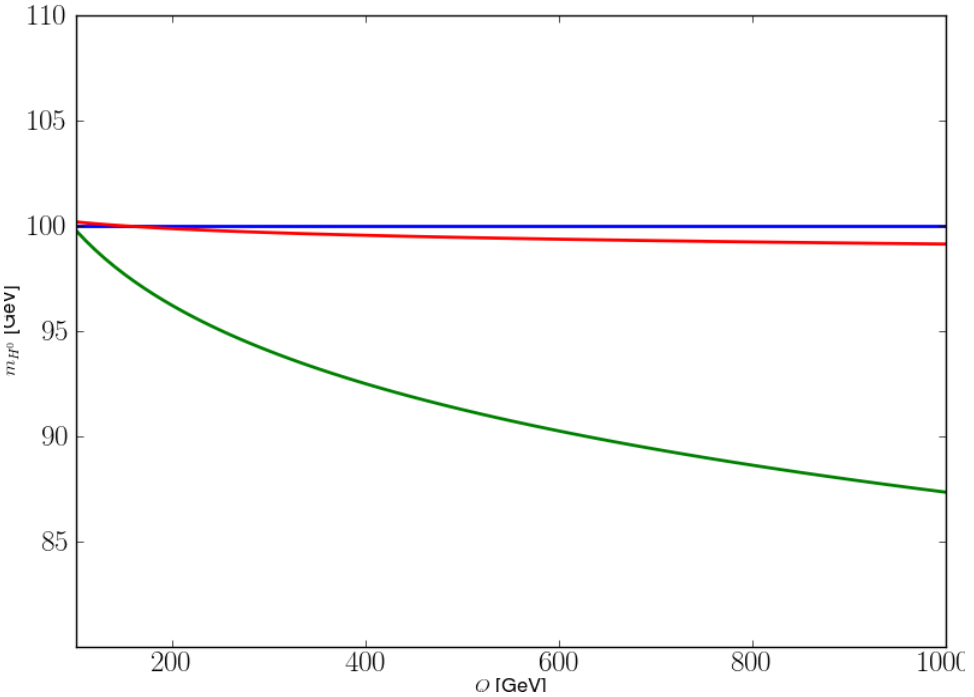
Radiative corrections to scalar masses



Approach No 1 : Fix running mass

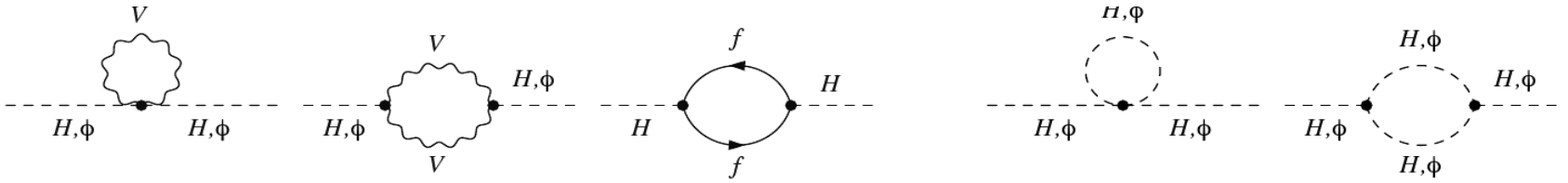
(mh = 125 GeV, mH = 100 GeV, mA = 150 GeV, mHch = 200 GeV, λL = 0.2, λ2 = 0.2)





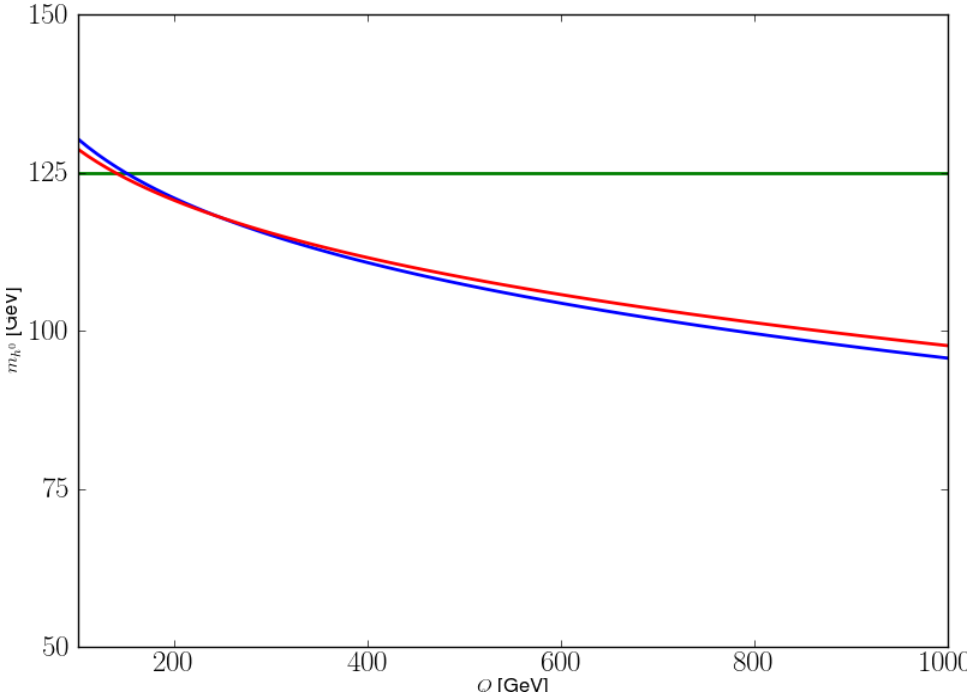
Running (MSbar), Pole, Tree

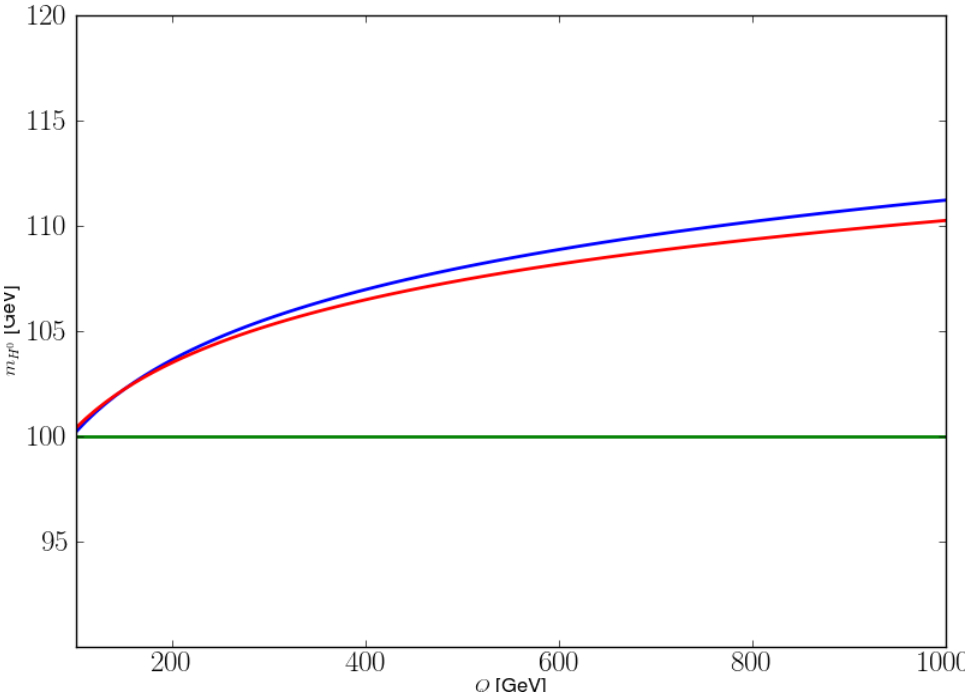
Radiative corrections to scalar masses



Approach No 2 : Fix tree-level mass

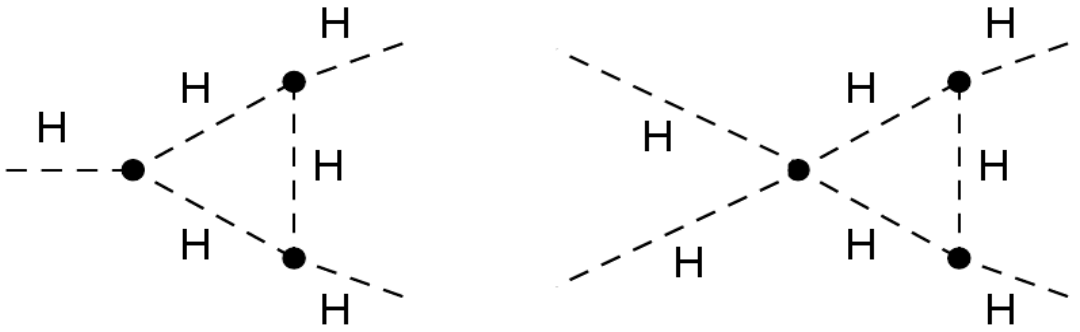
(mh = 125 GeV, mH = 100 GeV, mA = 150 GeV, mHch = 200 GeV, λL = 0.2, λ2 = 0.2)





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.

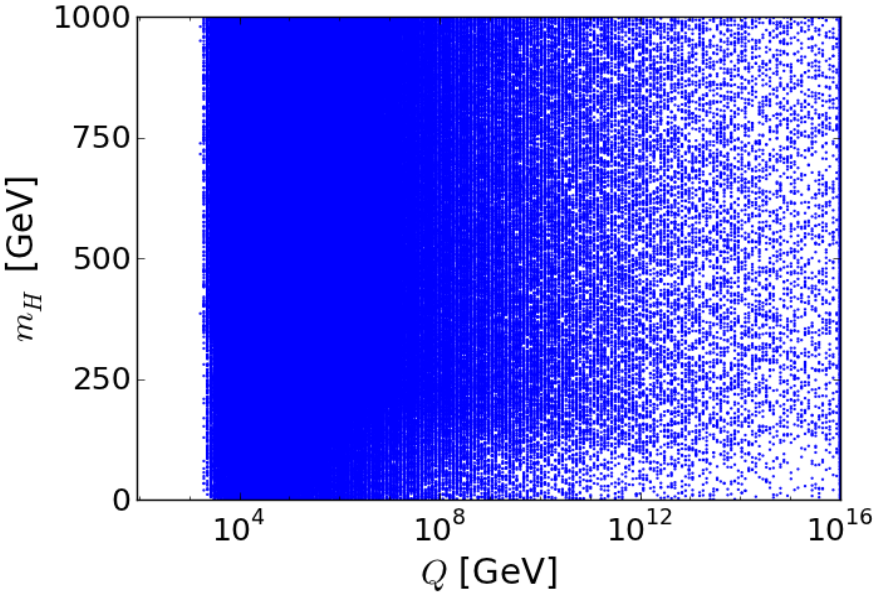
- Numerically solve the RGEs up to the scale where S, P or U fail.

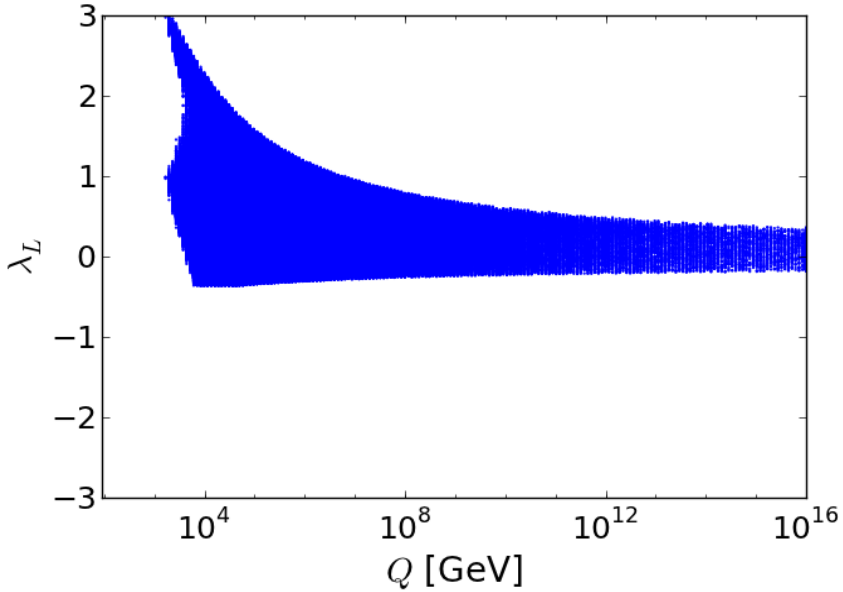
- In parallel, compute additional constraints (oblique parameters, LEP).

→ Calculation performed through adaptation of 2HDMC code.

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

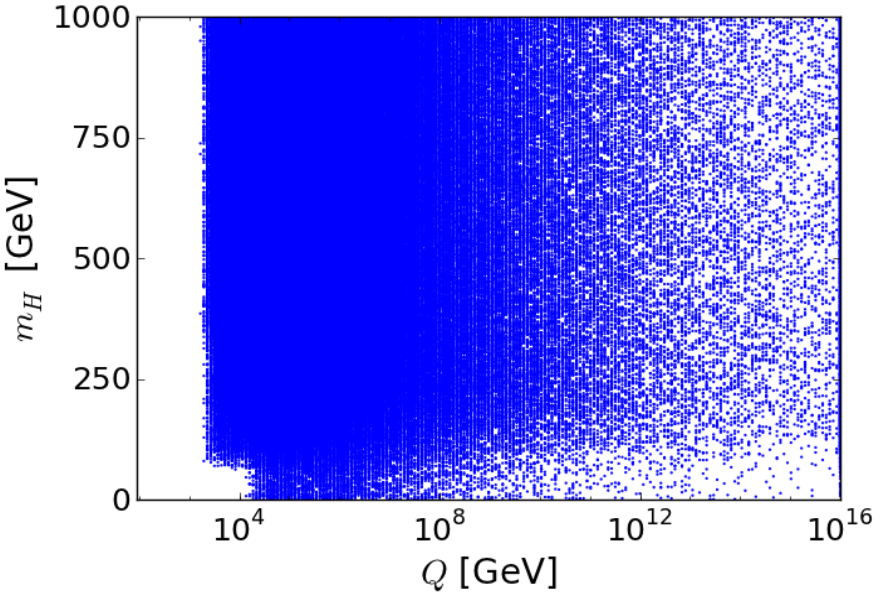
Extrapolation scale of the IDM

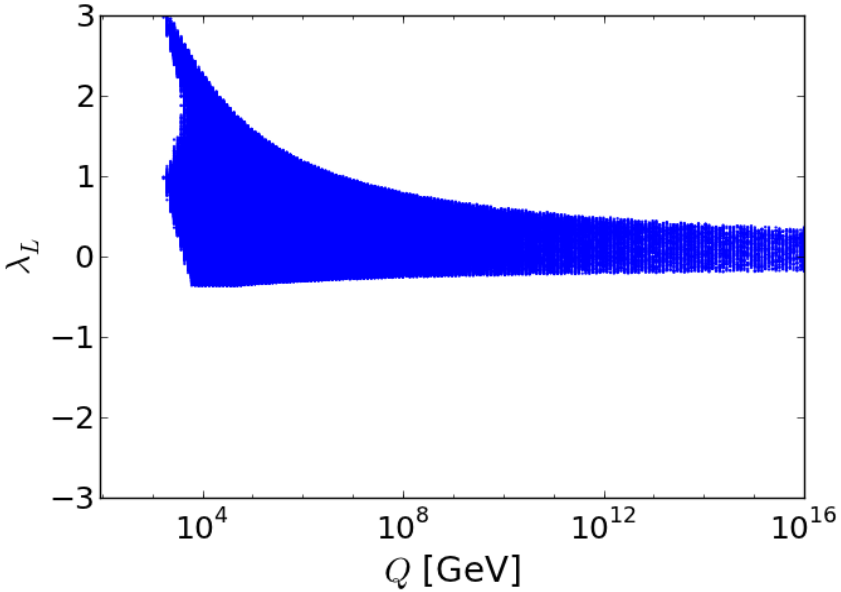




- Higgs mass fixed @ 125 GeV : Inert scalar mass basically unconstrained, small λL needed (perturbativity).

Extrapolation scale of the IDM

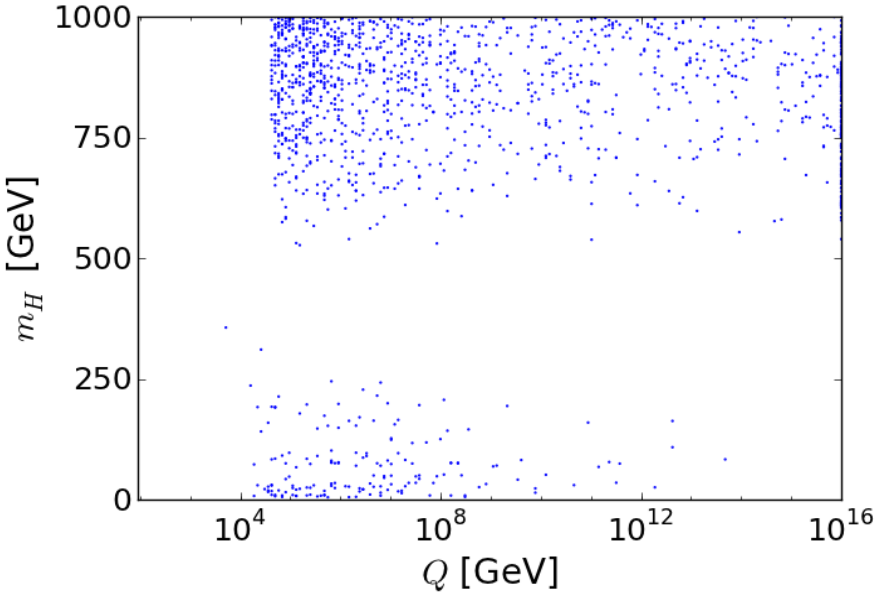


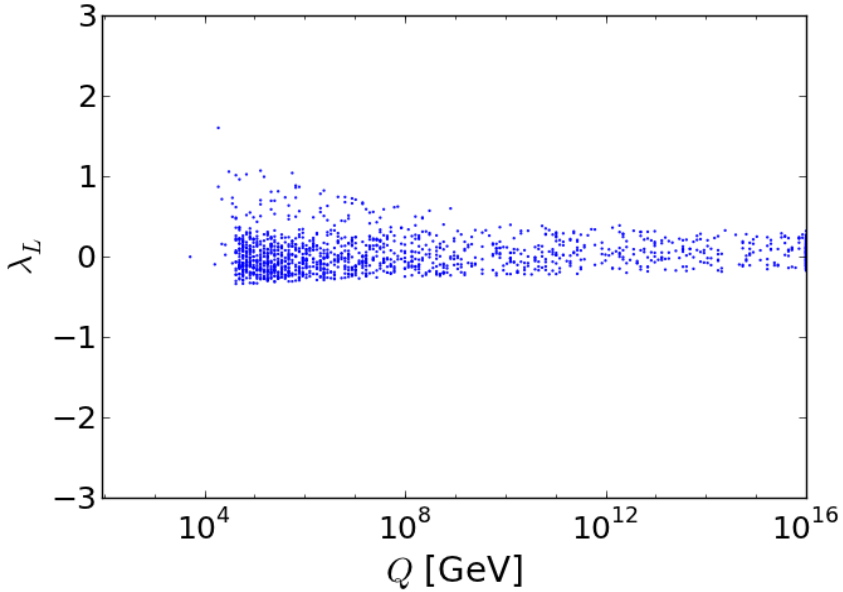


- Higgs mass fixed @ 125 GeV : Inert scalar mass basically unconstrained, small λL needed (perturbativity).

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

Extrapolation scale of the IDM



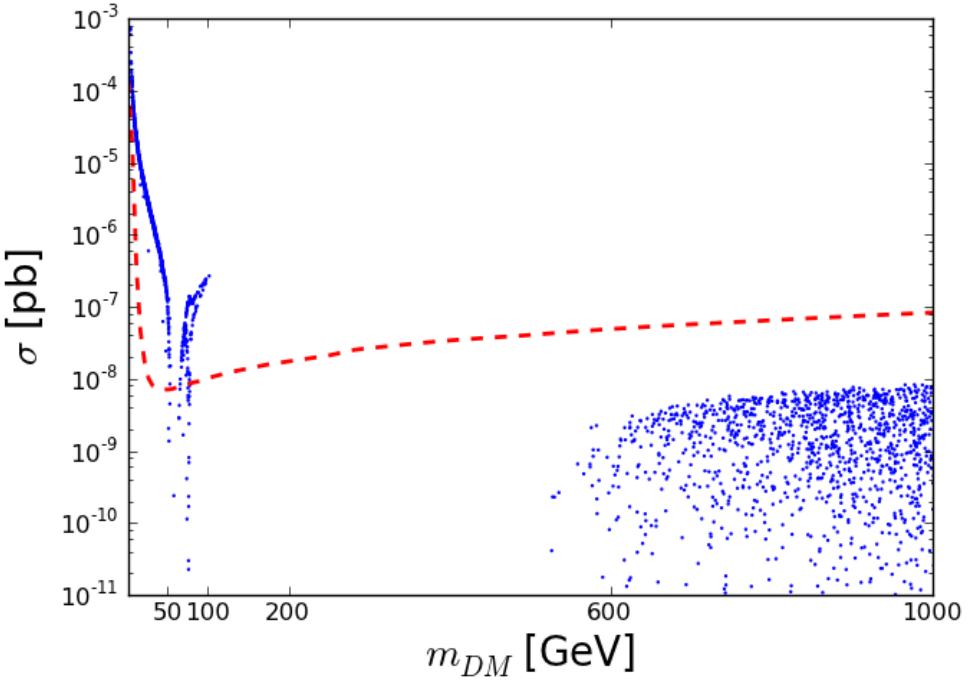


- Higgs mass fixed @ 125 GeV : Inert scalar mass basically unconstrained, small λL needed (perturbativity).

- 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.

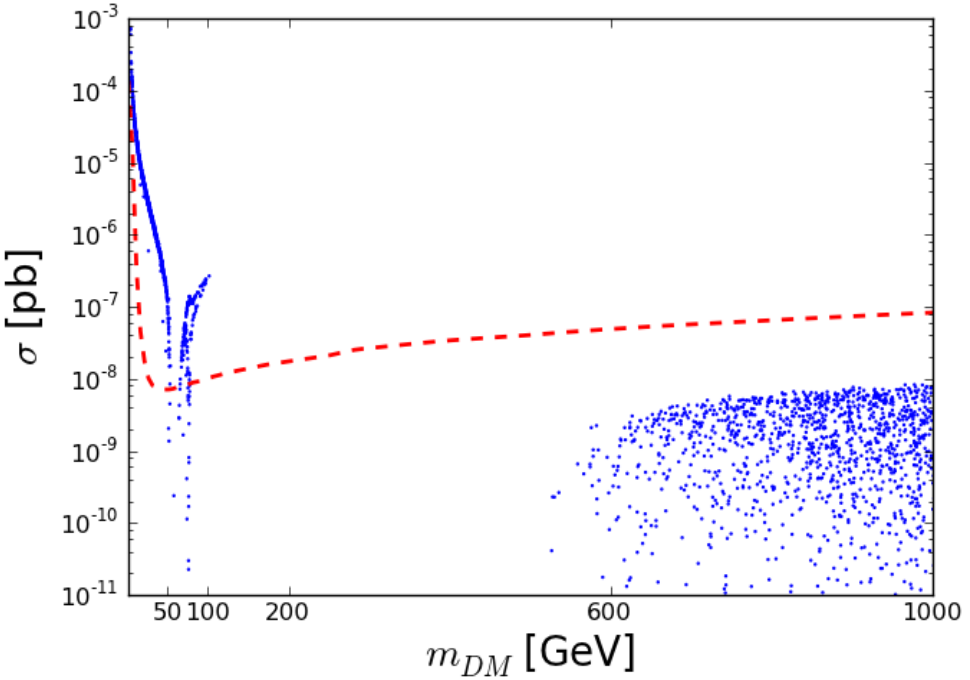
Direct detection



- 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.

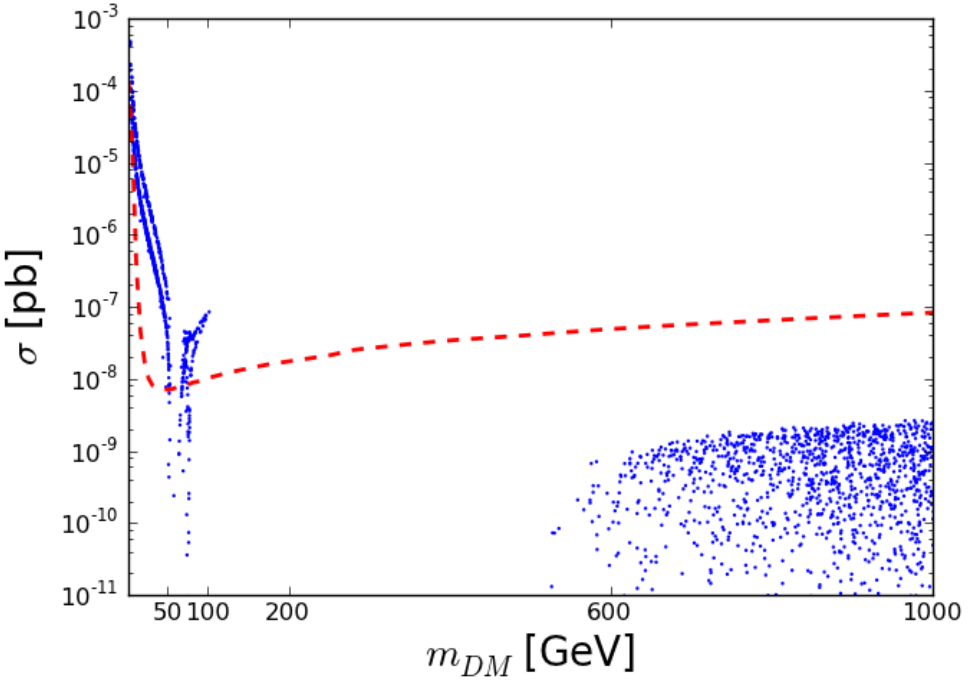
Direct detection : out with the old...



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

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

Direct detection : in with the new !



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

- Future micrOMEGAs default is $f_{\mathrm{T_s}}$= 0.014.

- 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!

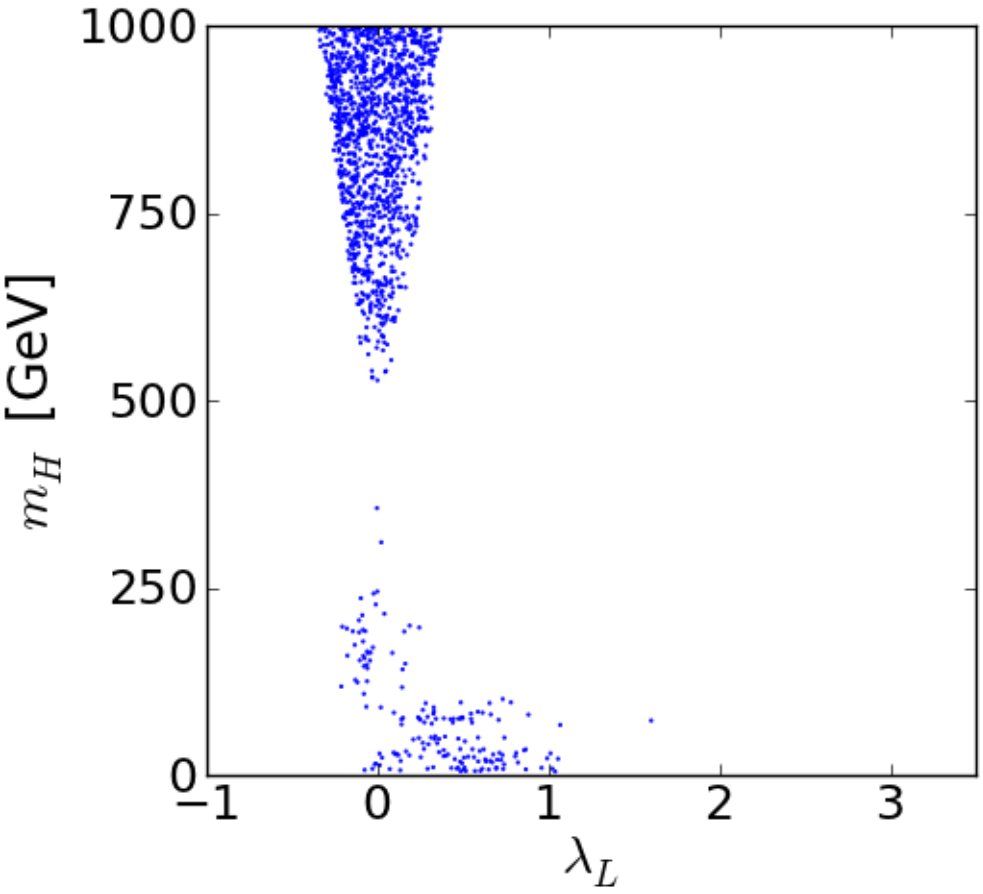
- We examined the extrapolation scale of the IDM by actually solving the 1-loop RGEs. After imposition of the relic density bound, the model can still be extrapolated up to the GUT scale.

- 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.

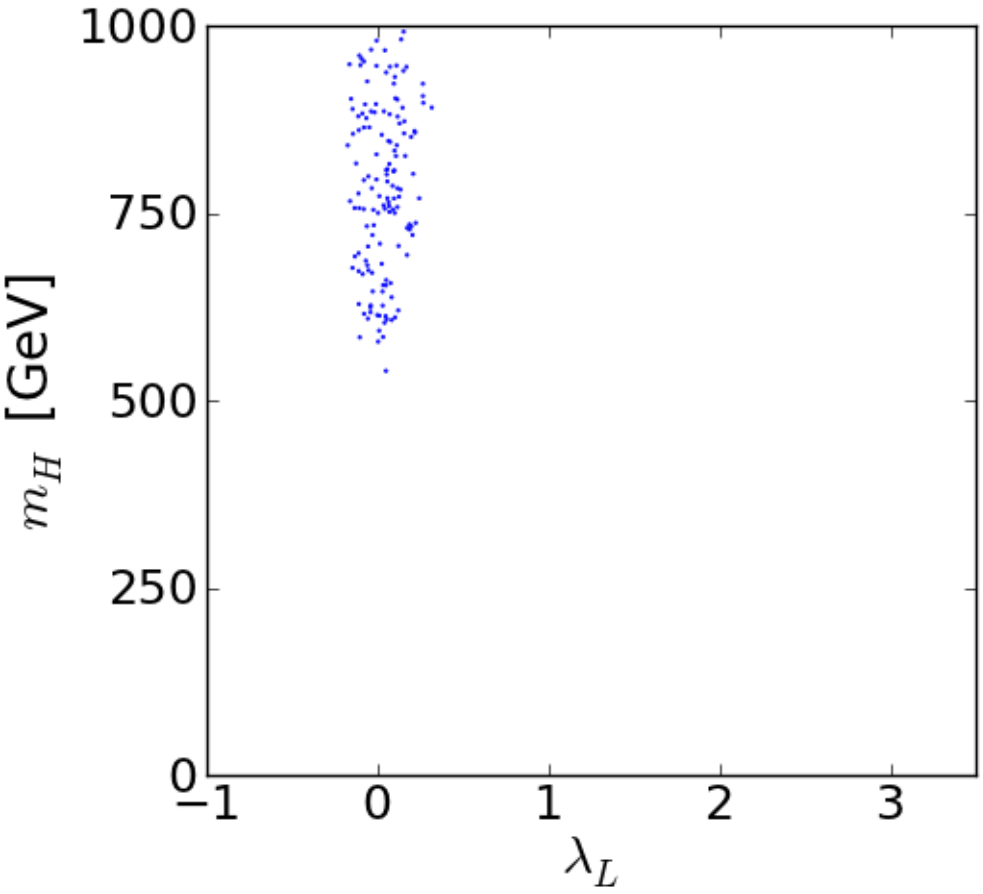
- These uncertainties also influence more complicated models (xMSSM) and should be accounted for, especially given the precision of all other calculations when constraining models!

Merci !

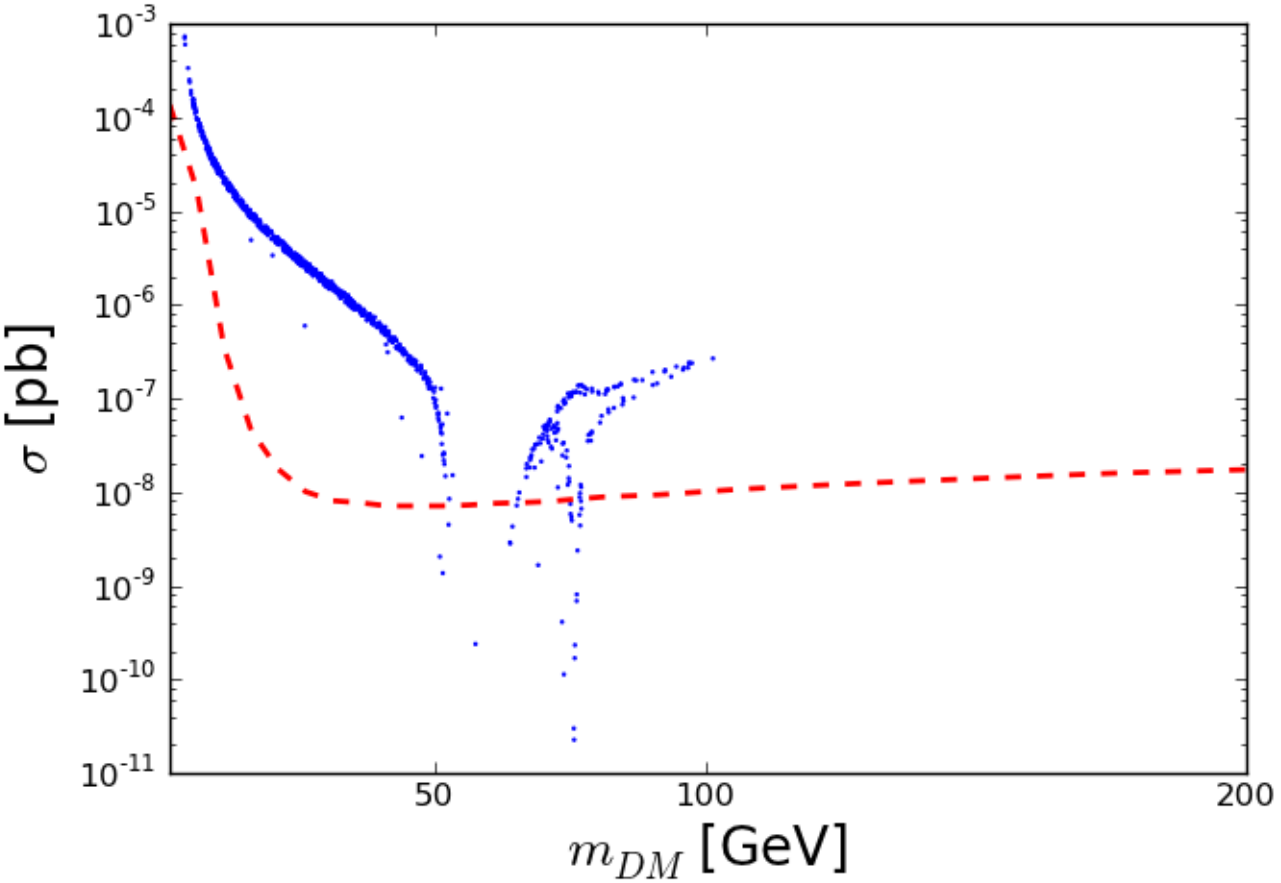
2D all constraints



2D all constraints + extrapolation to M_{GUT}



Zoom in the intermediate region, old fTs



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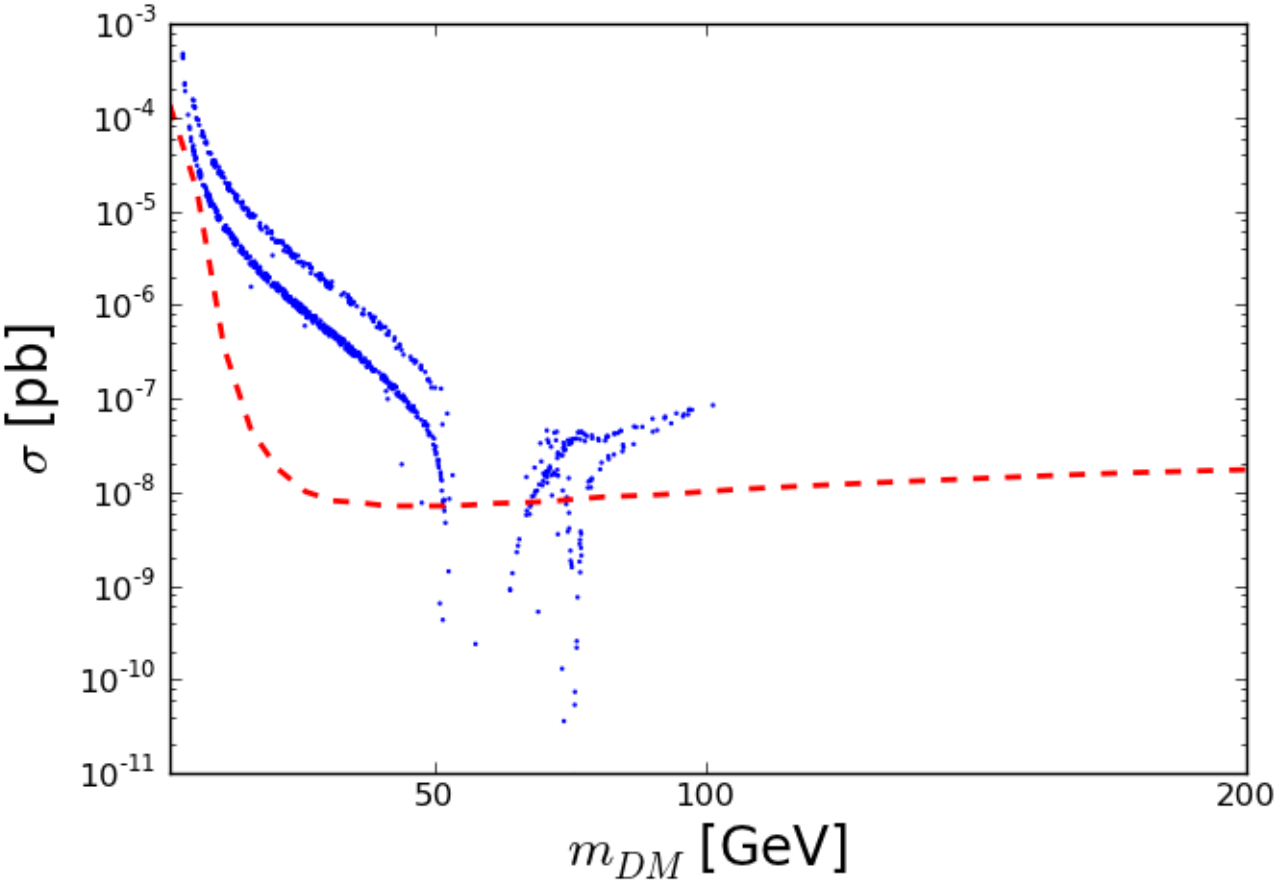
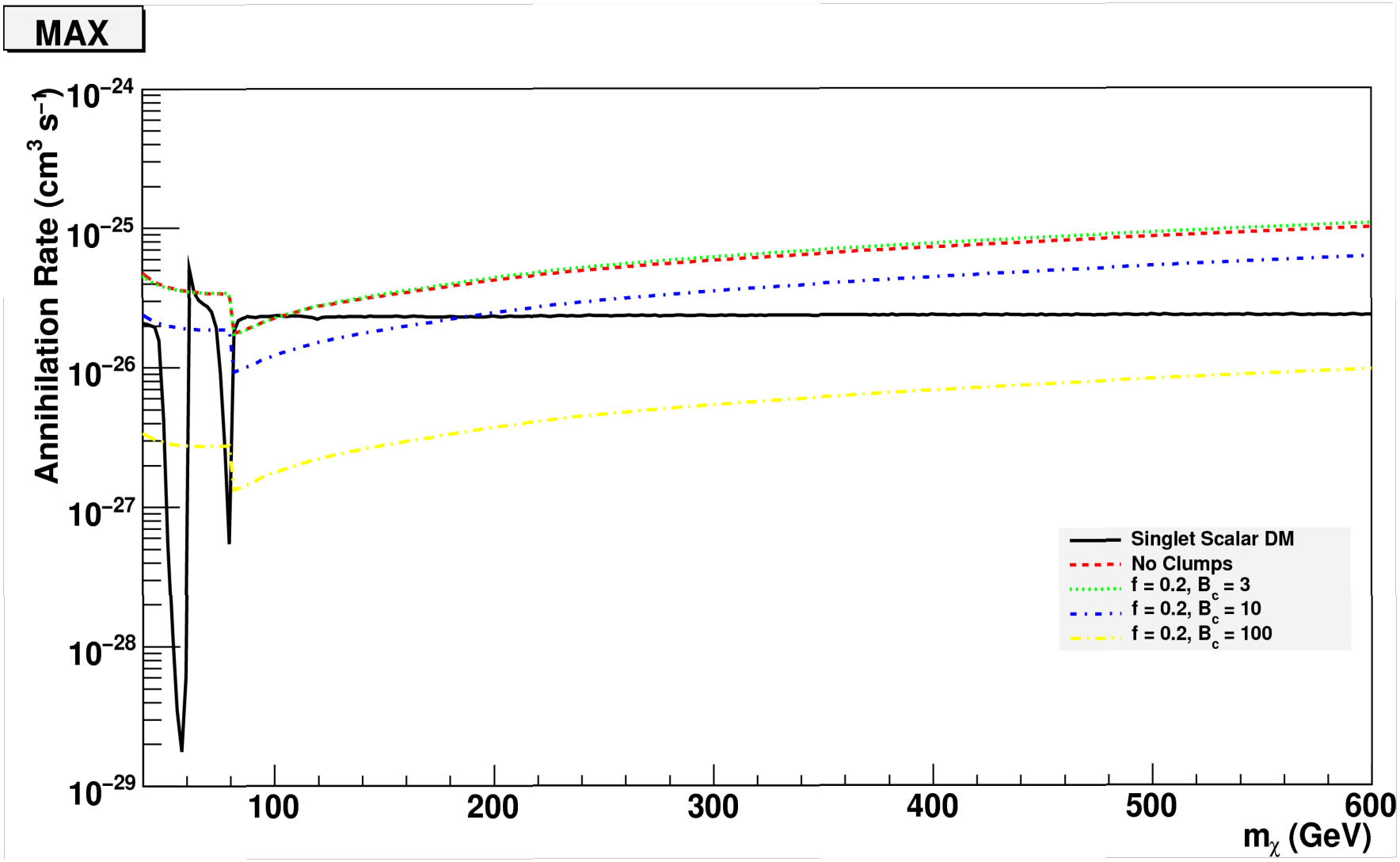
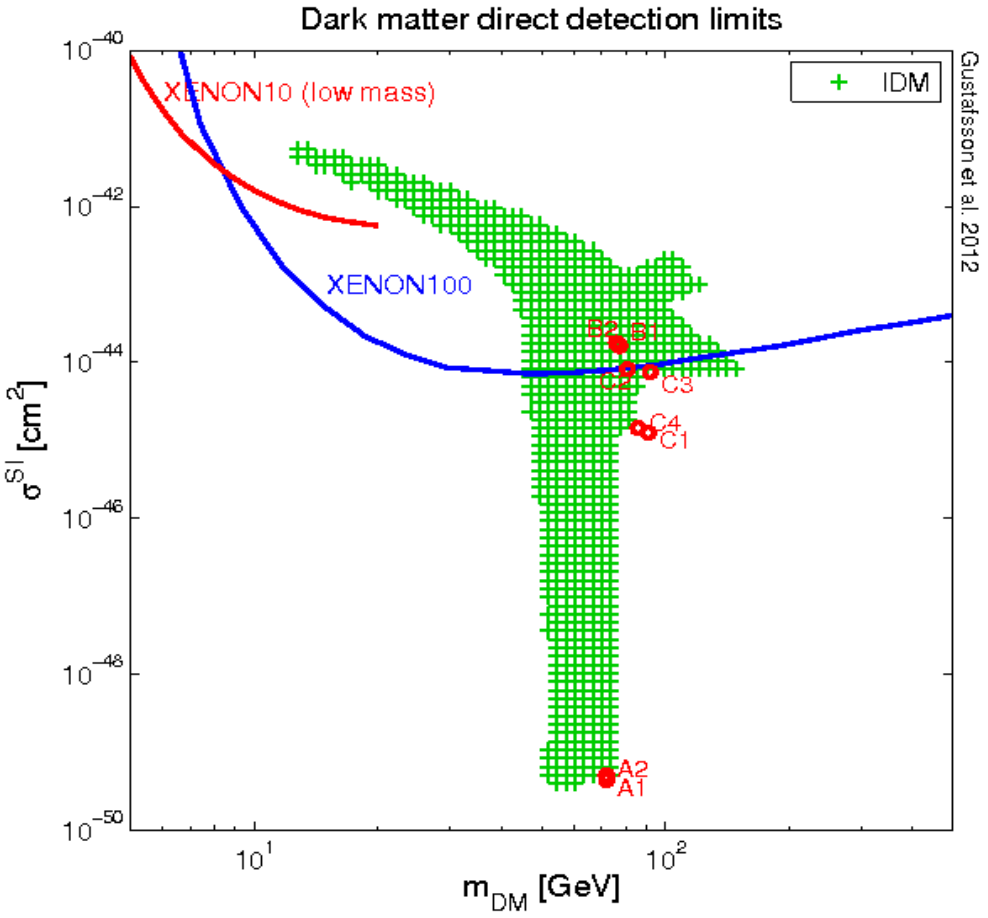
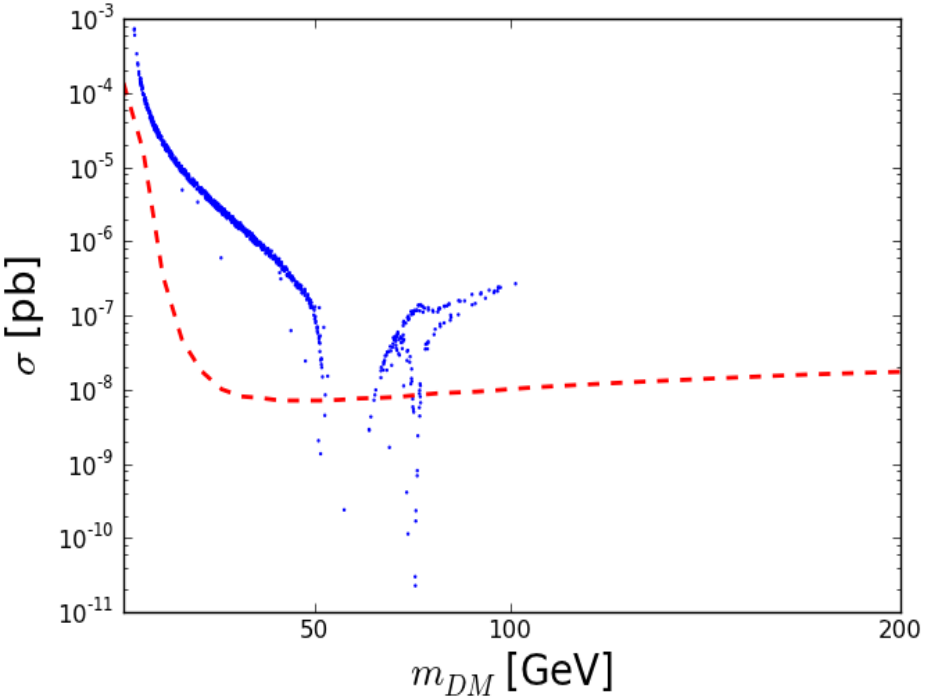


Non - exotic cross – section enhancement



Direct detection comparison