Relic density (**and more**) with

MadDM

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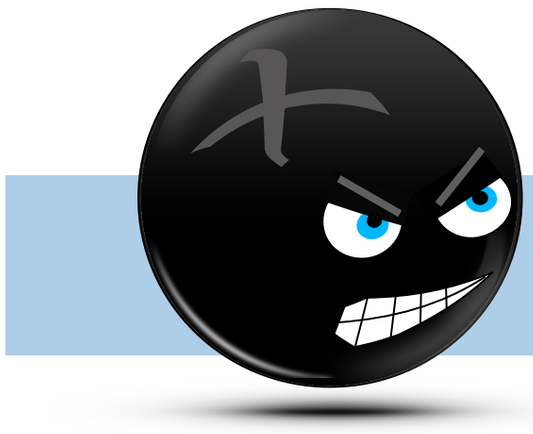
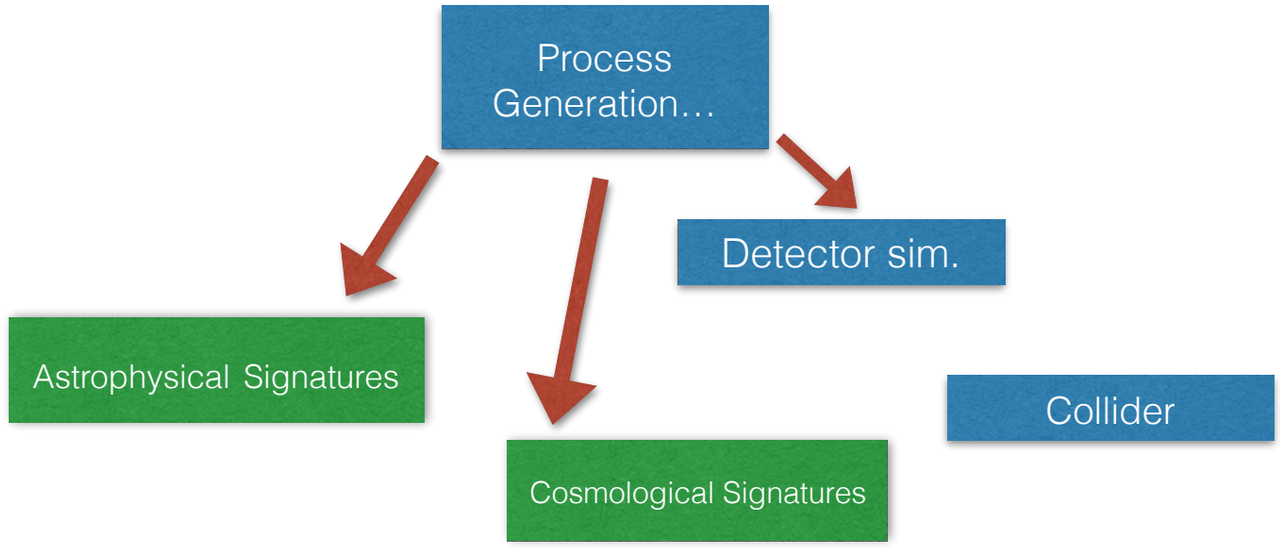


MadDM



MadDM emerged as an effort to link:

- **DM collider searches**, with
- **early cosmology** signatures (relic density) and
- **direct/indirect detection**.

Version 1.0 of MadDM focused on calculations of **DM relic density** (in a generic UFO model).

Version 2.0 of MadDM extends the functionality to **DM direct detection.**

https://launchpad.net/maddm

Some general features of MadDM

MadDM takes into account **co-annihilations as well as some scenarios of **multiple DM particles**.

** Properly treats **s-channel resonances.**

** Uses the **same model files and parameter cards** as MadGraph (UFO conventions). **(simplified models implemented in FeynRules, also at NLO for colliders)**

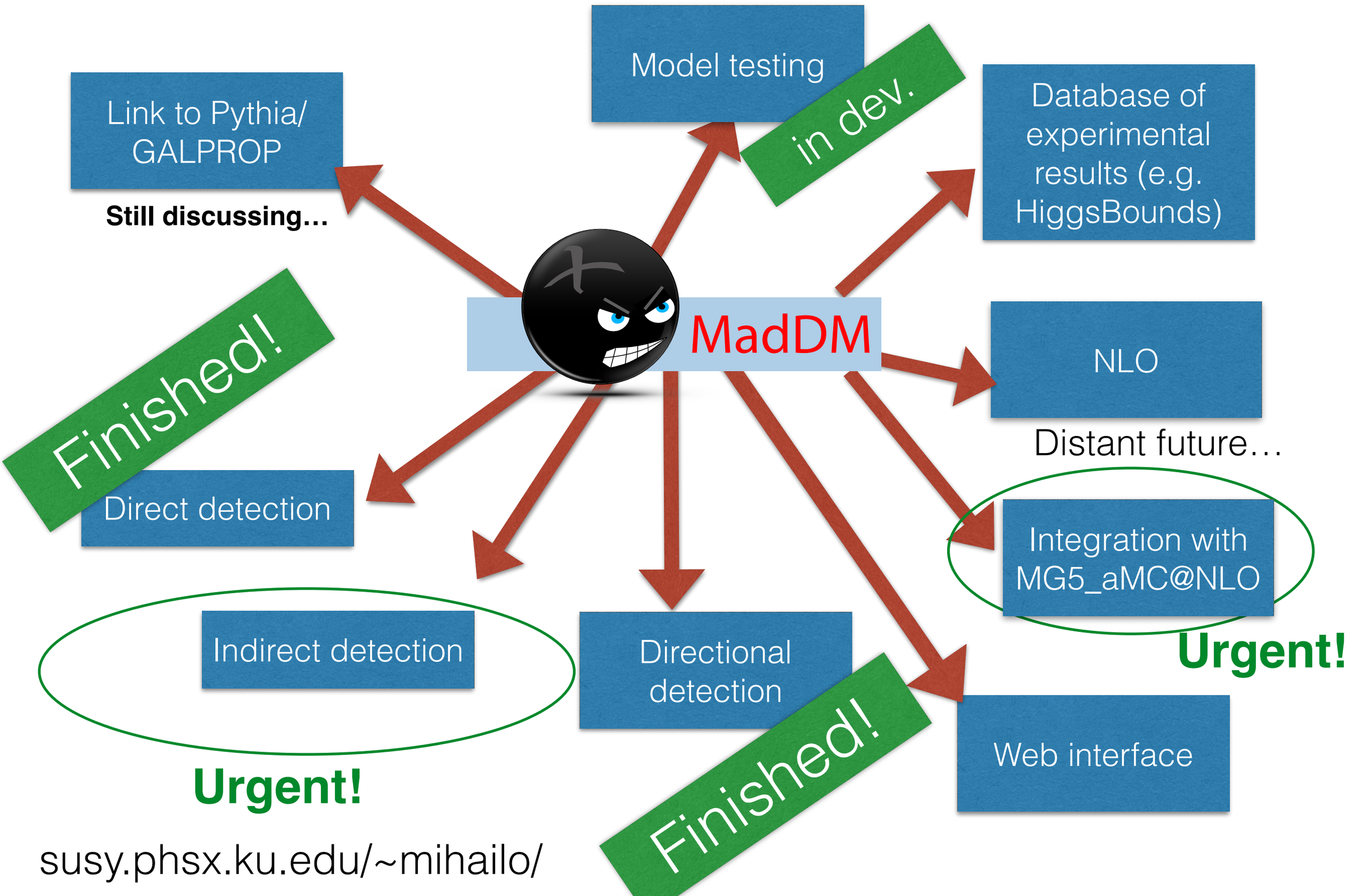
http://feynrules.irmp.ucl.ac.be/wiki/DMsimp

** Able to link to MadWidth to automatically calculate particle widths (by setting with to AUTO in parameter card).

** Comes with pre-made **parameter scanning** scripts.

** Able to calculate nucleus recoil rates both wrt. **recoil energy and angle (directional DM detection).**

Status and future plans:

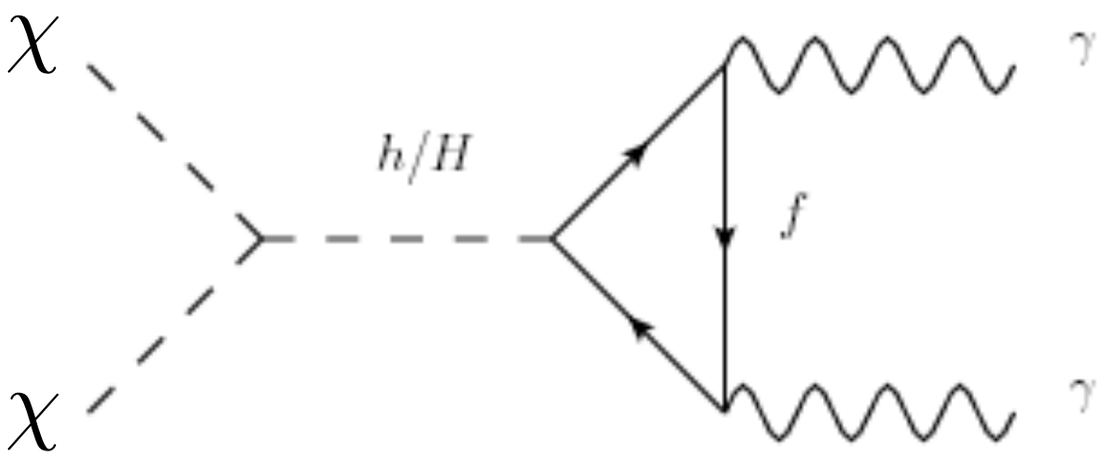


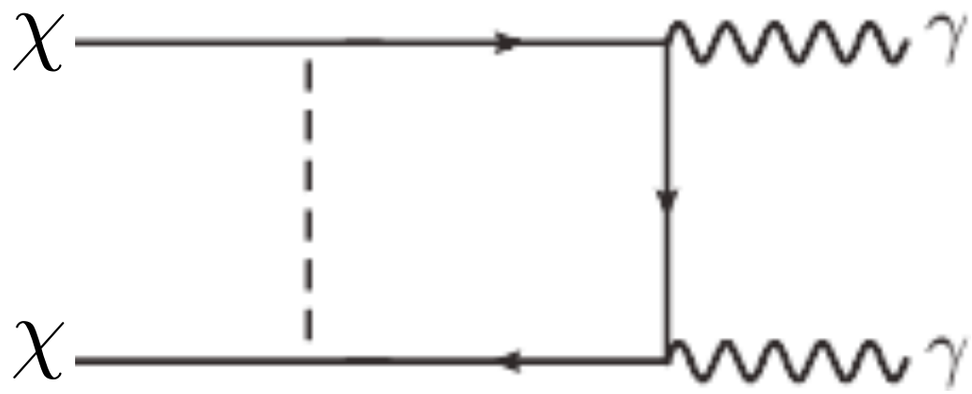
susy.phsx.ku.edu/~mihailo/

Near future plan: **indirect detection**

MG5_aMC@NLO can calculate amplitudes for loop induced processes.

- We want to exploit this and **build the first publicly available tool which will be able to calculate cosmic ray fluxes in loop induced processes in an arbitrary UFO model.**





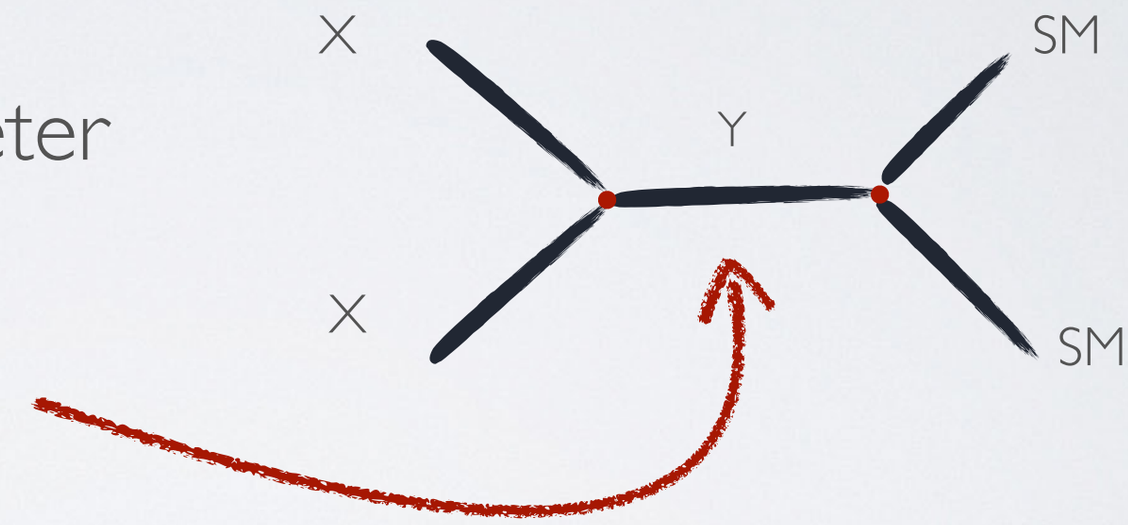
Stay tuned!

A lot of attention on **simplified models** at the LHC

A strong push for complimentarity of DM searches
(relic density, (in)direct detection, colliders…)

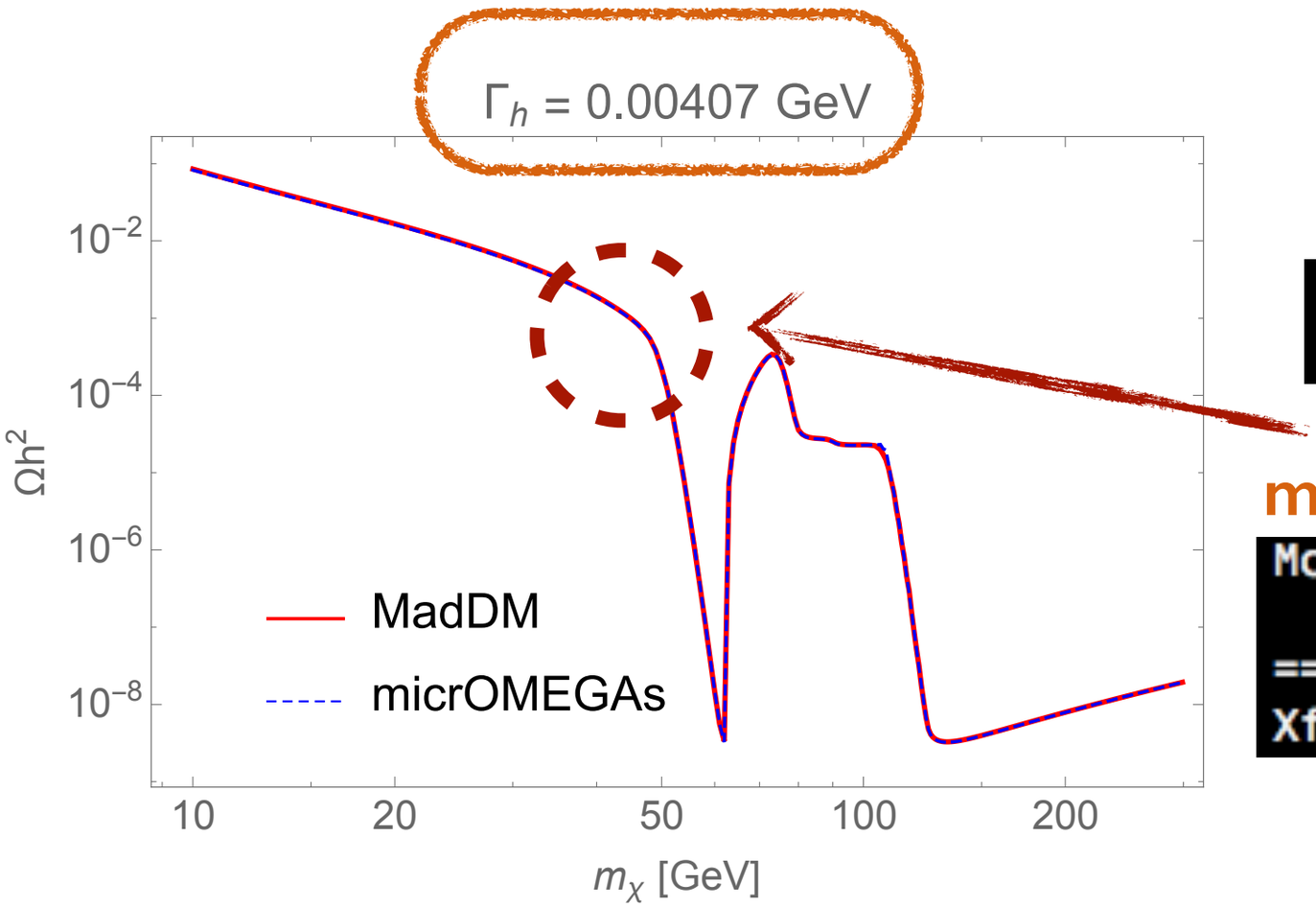
Let's talk about **relic density in the context of simplified models.**

In most of the parameter space relic density determined by an s-channel diagram



In resonant s-channel annihilation,
the total width of Y is important!

Example calculation (s-channel "Higgs" annihilation)

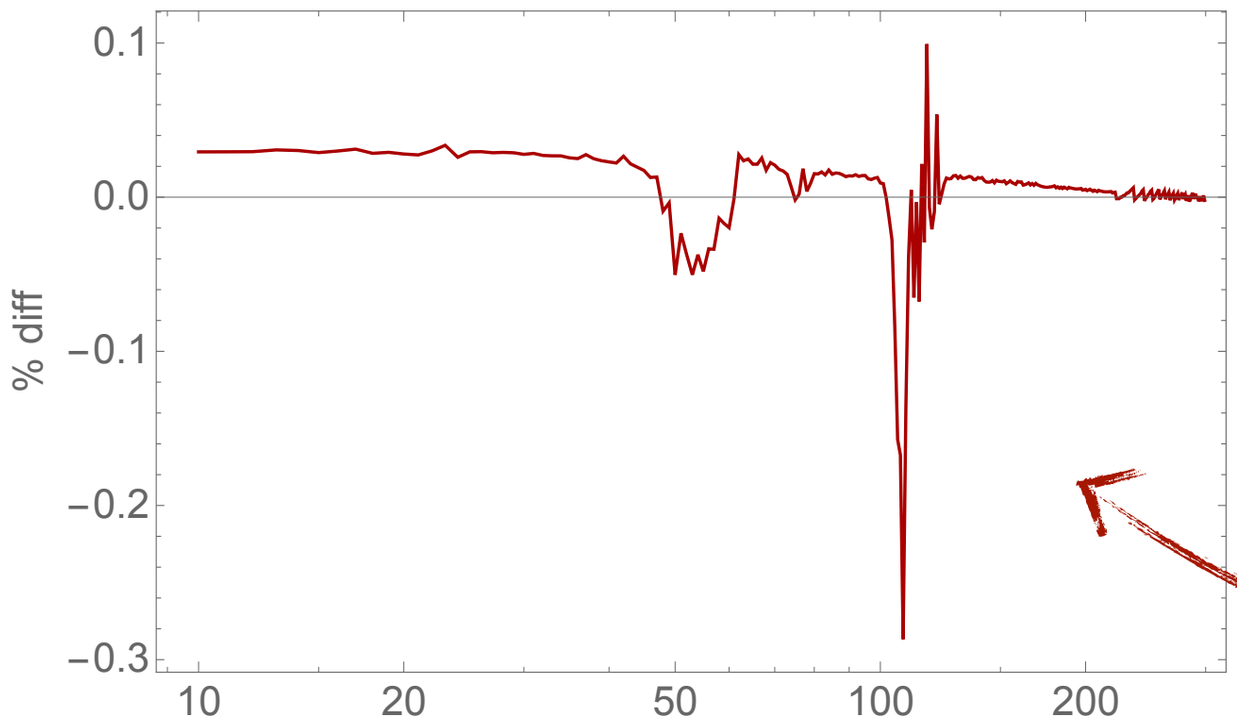


MadDM

```
Omegah^2:    2.3666186234963779E-004
x_f:    28.000000000000000
```

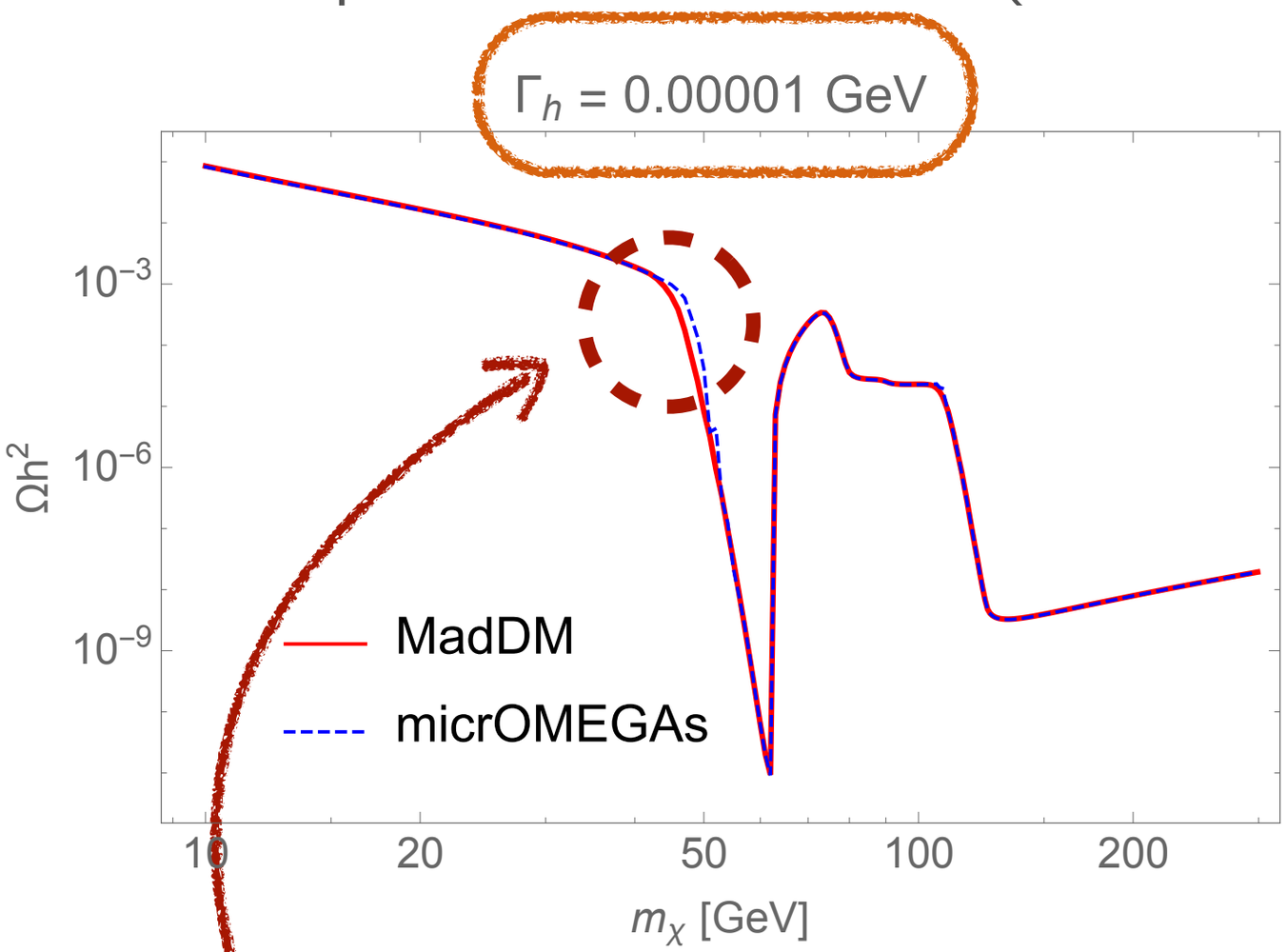
micrOMEGAs

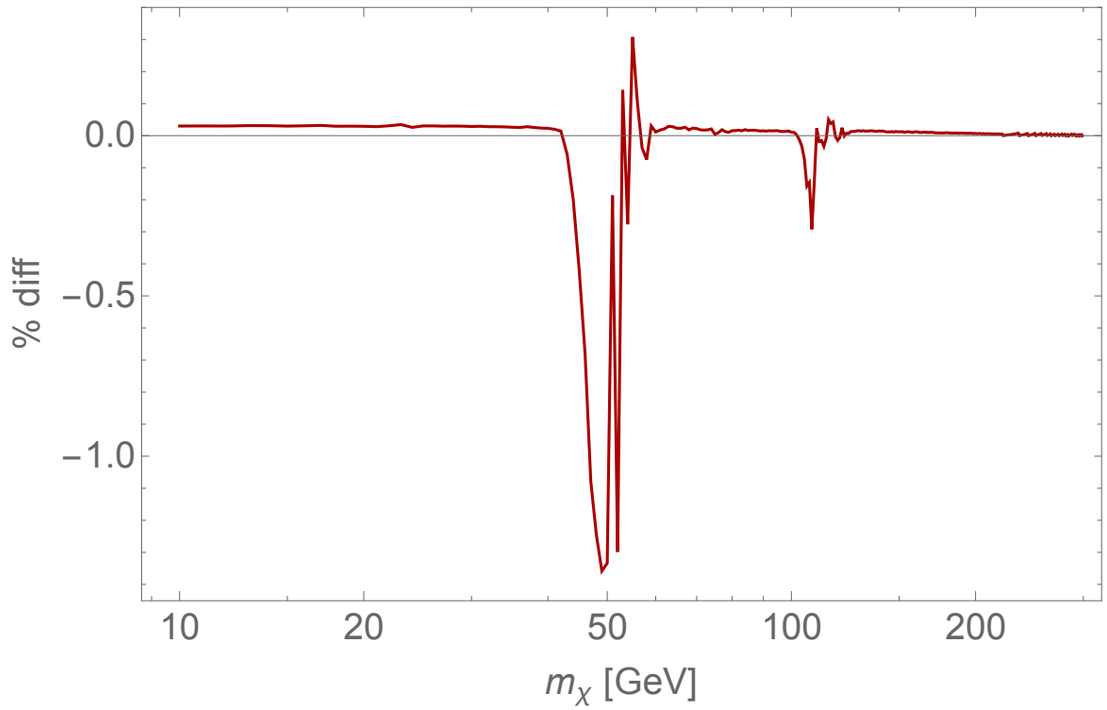
```
Mcdm = 5.00e+01

==== Calculation of relic density =====
Xf=3.31e+01 Omega=2.34e-04
```



The codes agree
to a few percent
(one point about 30% off)

Example calculation (s-channel Higgs annihilation)





MadDM

```
Omegah^2:     8.231035060471754E-006
x_f:     32.000000000000000
Wimp_Mass:     50.000000000000000        GeV
```

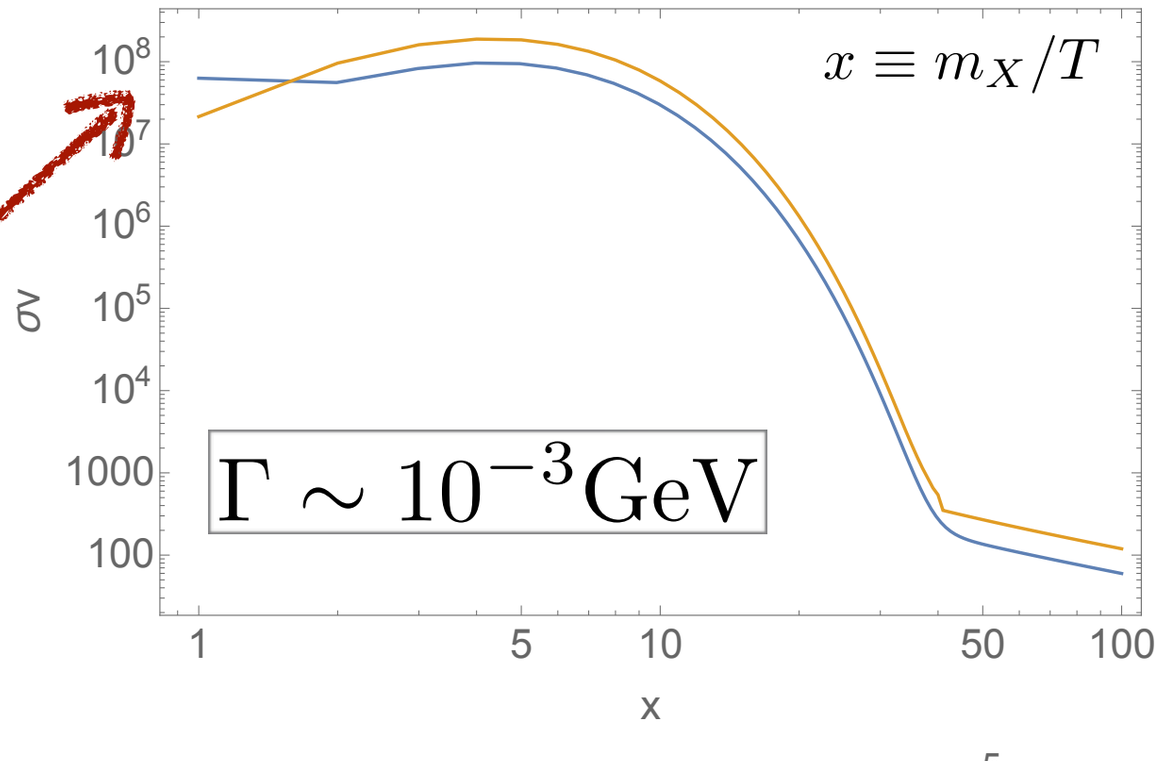
micrOMEGAs

```
Mcdm = 5.00e+01

==== Calculation of relic density =====
Xf=3.44e+01  Omega=4.12e-05
```

Large discrepancy. What's going on?

The culprit is the velocity average annihilation cross section

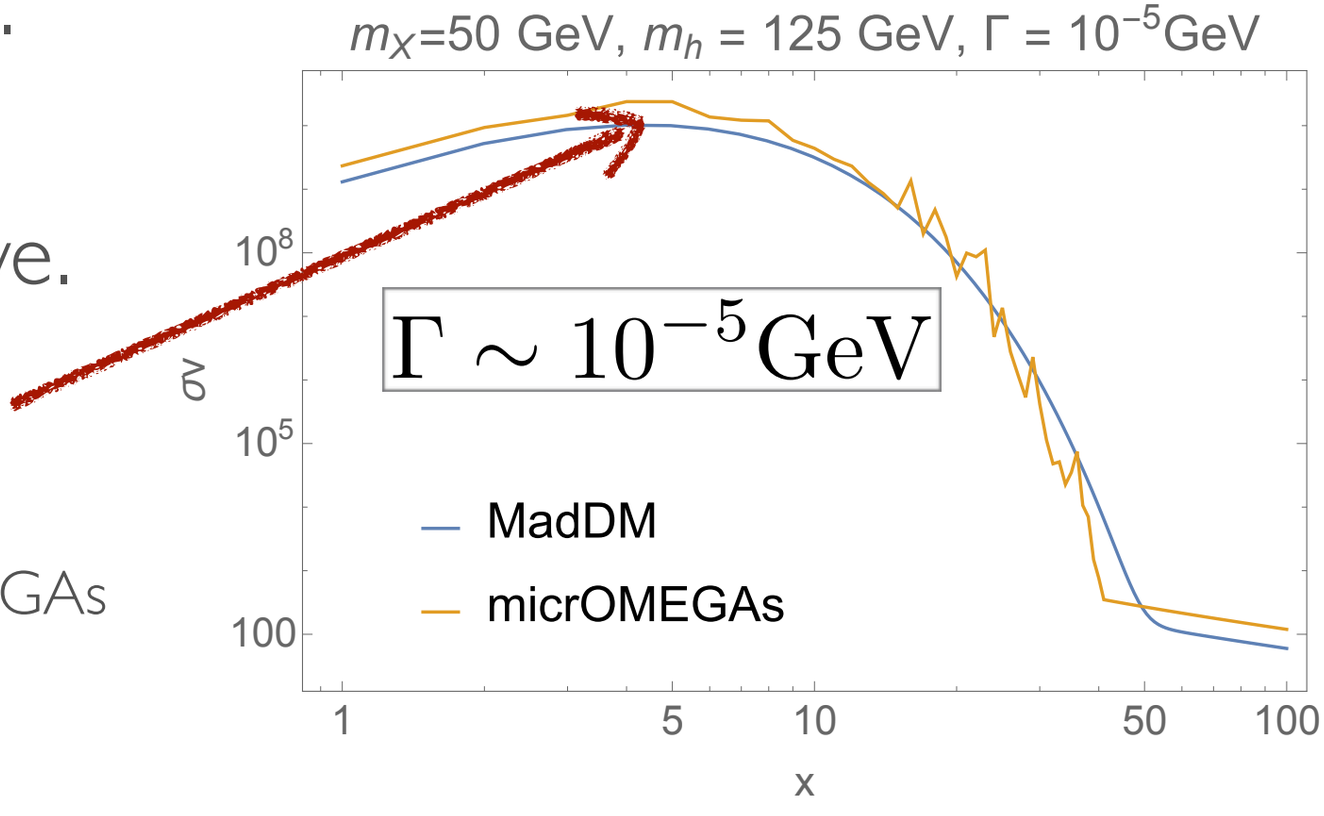
A problem mostly when the resonance is above threshold!



Both codes give smooth curves which are in agreement if the width is large enough.

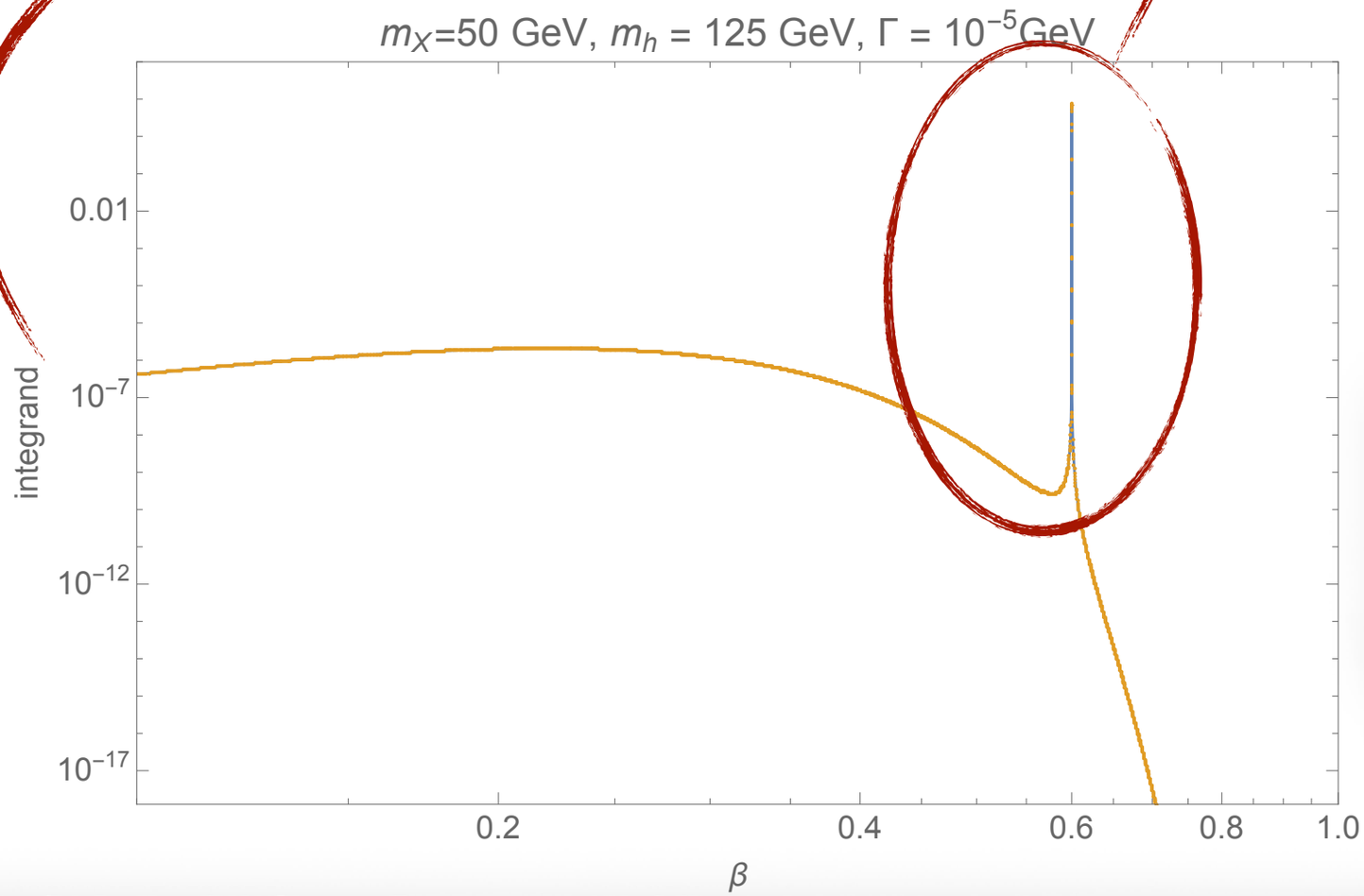
MadDM gives a smooth curve. micrOMEGAs has some numerical instabilities.

*** used Beps = 10E-10 in micrOMEGAs



Why numerical instabilities?!

$$\langle \sigma v \rangle \sim \int_0^1 d\beta \, |M_{XX \to xx}|^2 \Phi(\beta), \quad x \equiv SM$$



99.999….% of the area in the spike!

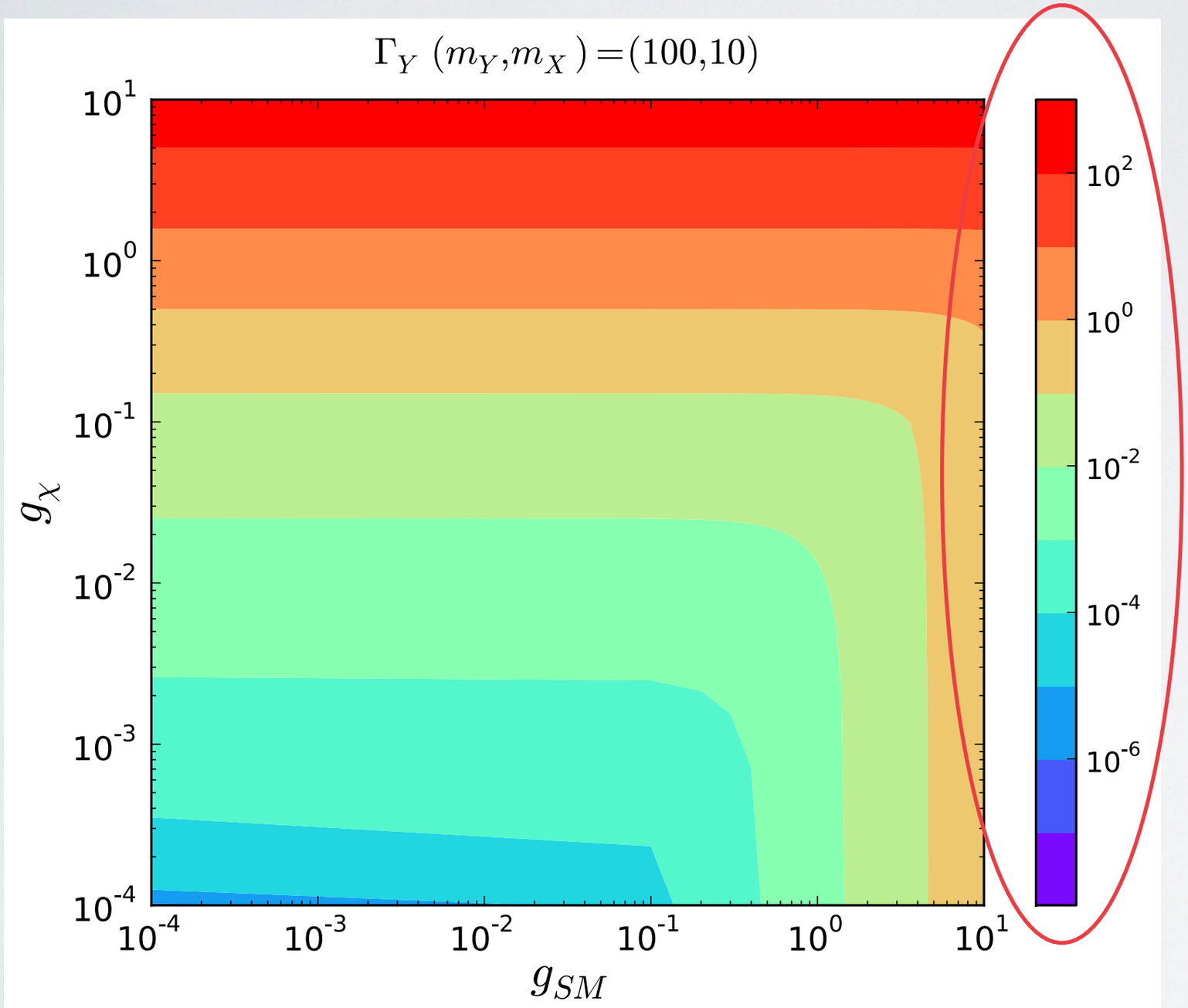
The integrating routines must be both **adaptive and flexible!**

Users should have control over the precision parameters!

Tradeoff between precision and speed!

Should you care about tiny widths?

Scalar mediator, couplings to all quarks



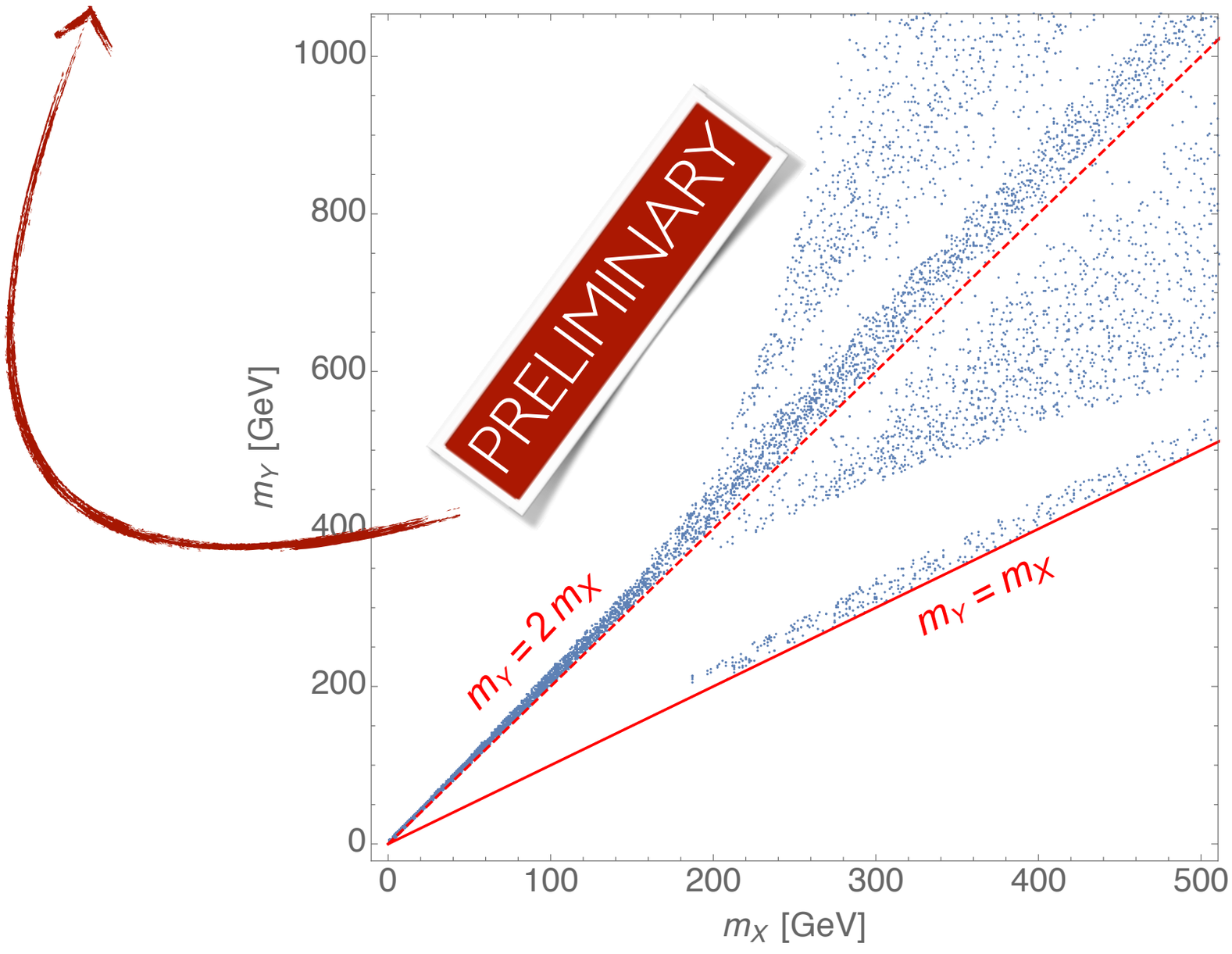
Small widths are quite generic!

4D scan on relic density and direct detection

$$m_X, m_Y, g_{YXX}, g_{YSM}$$

only free parameters in the
simplest simplified model

All points require the model to be consistent with direct detection exclusion bounds and total relic density



4D scan on relic density and direct detection

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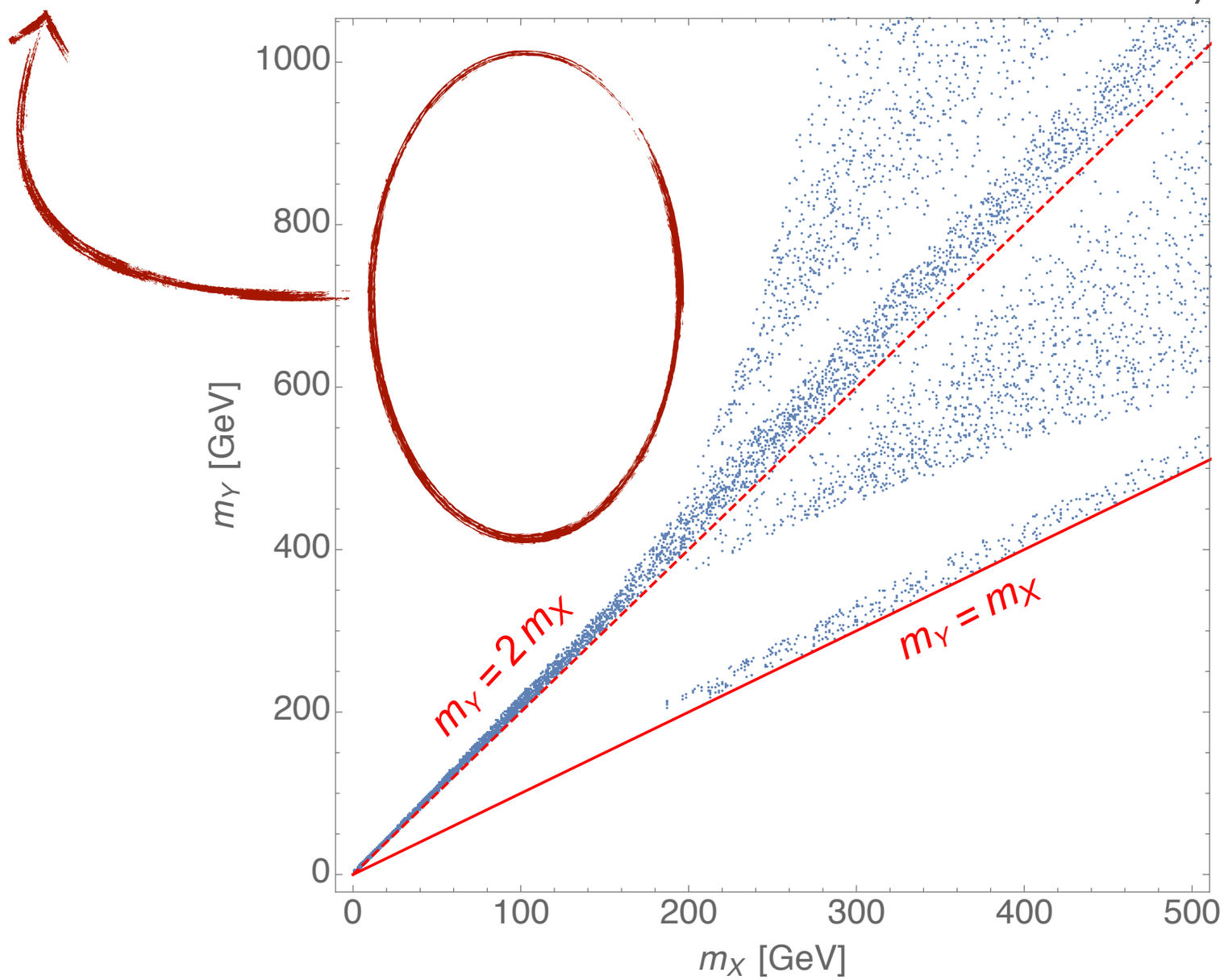
Low DM, high mediator mass regions are inconsistent with direct detection and relic density



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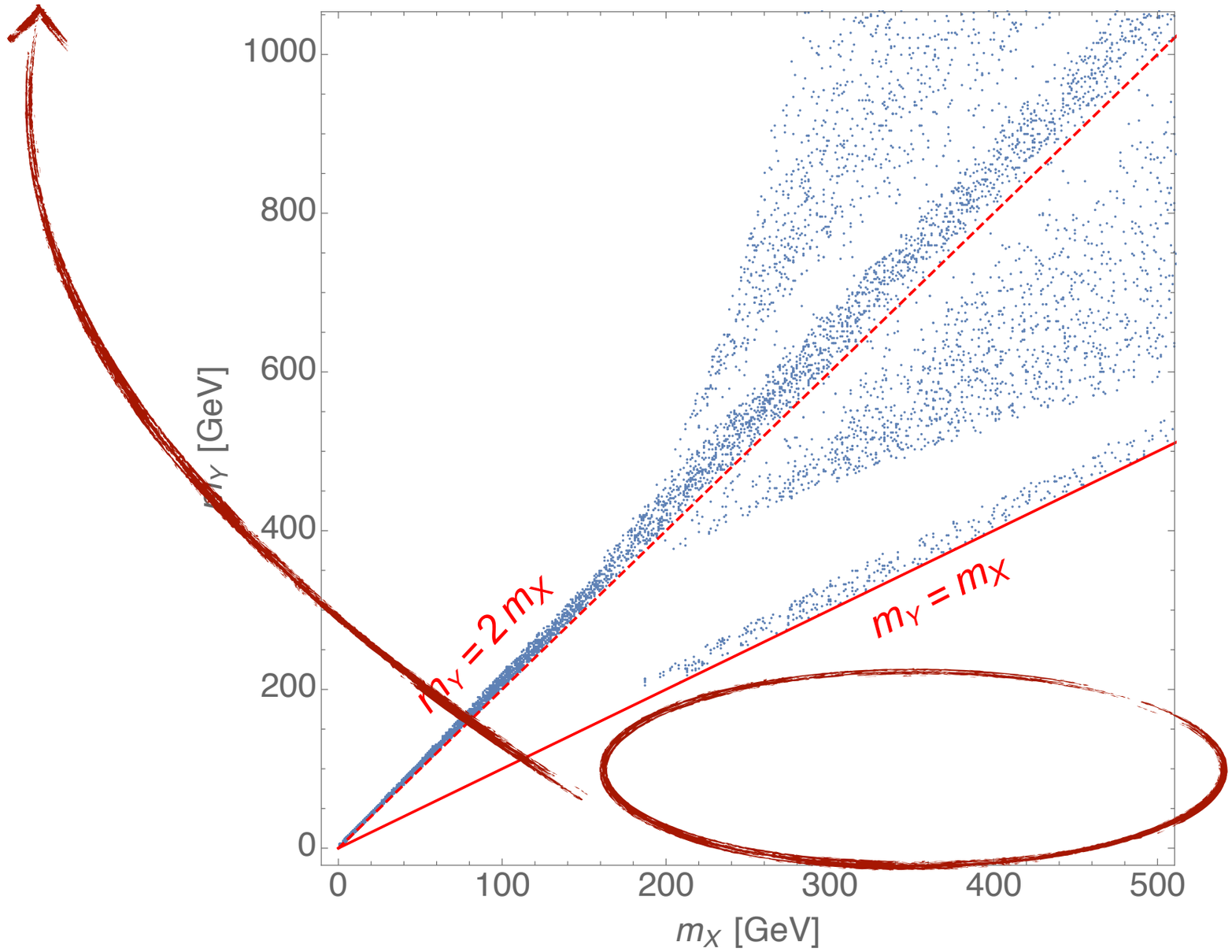

4D scan on relic density and direct detection

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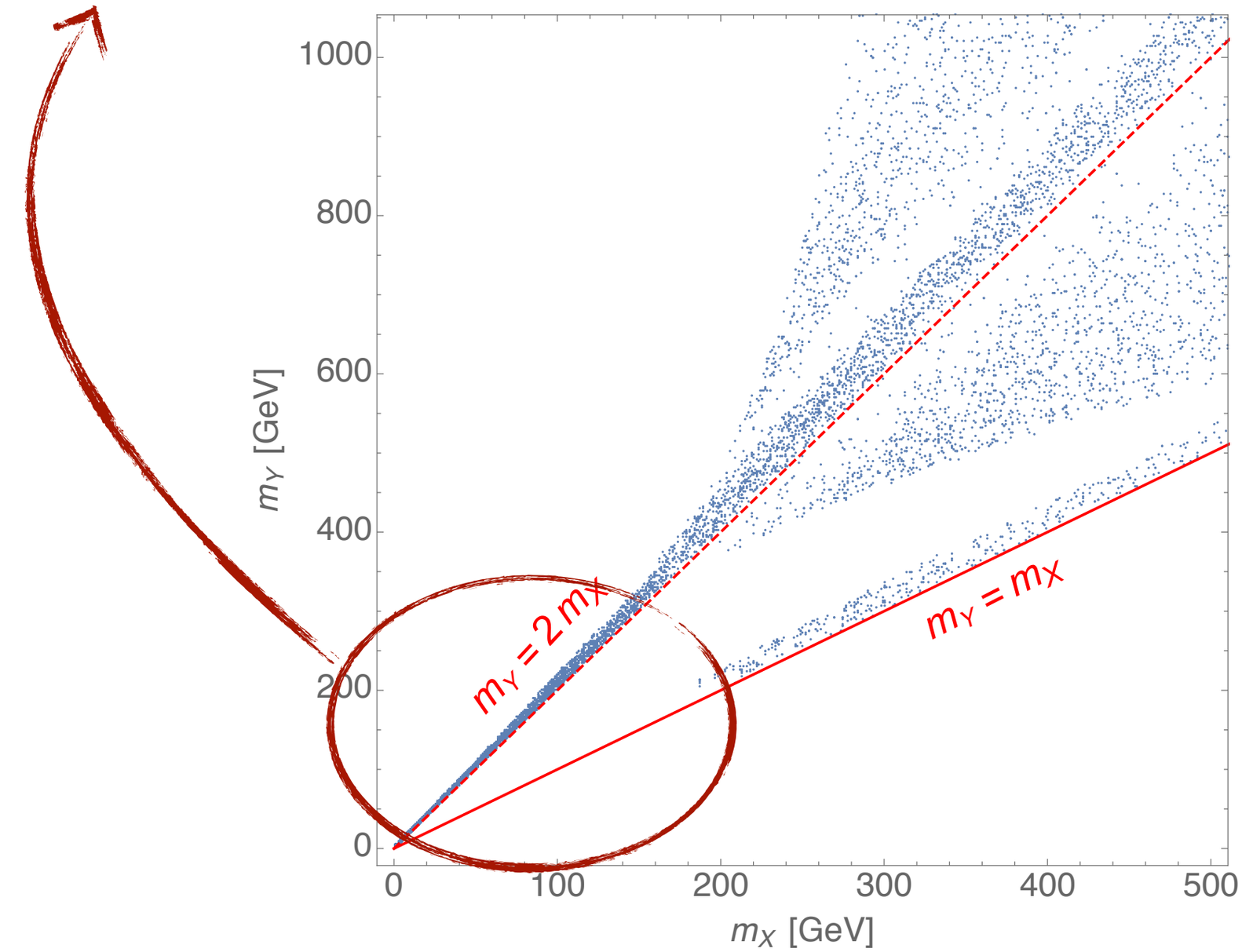
Low DM and mediator masses only work in the finely tuned scenario of **mY ~ 2mX**



4D scan on relic density and direct detection

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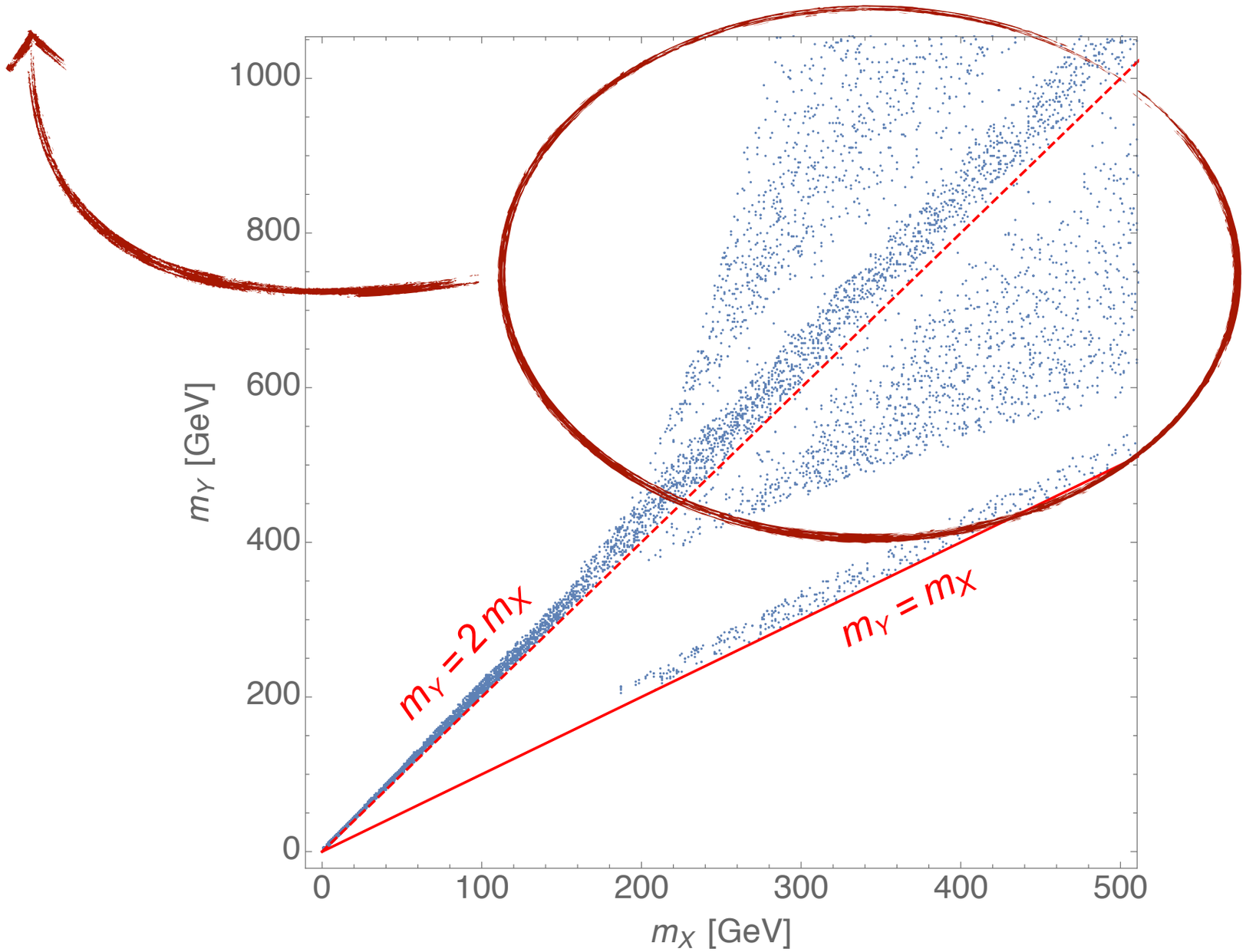
The bulk of "consistent" parameter space is for heavy DM and mediators.



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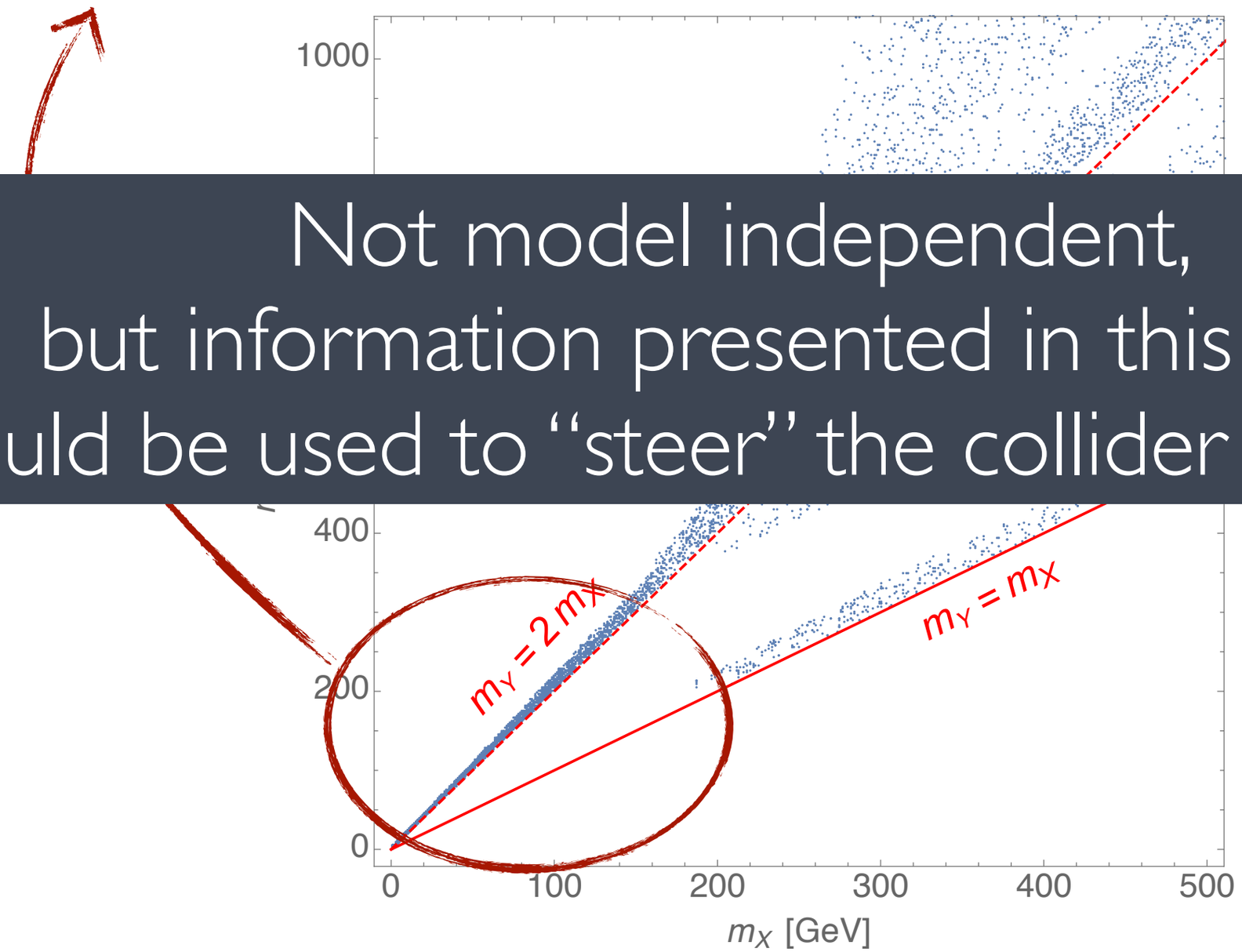

Not model independent,
but information presented in this form
could be used to "steer" the collider searches

Conclusions:

- Mediator widths are important in calculation of relic density!

- Extra care should be taken when treating widths in numerical codes (**maybe we should do more to give results with numerical errors**)

- Users should have more control over choosing precision vs. speed of calculation!

- Cosmological and astro-physical constraints favor certain regions of parameter space. Should this be a theoretical factor in LHC searches?