Tools for frozen-in dark matter

LHC Dark Matter Working Group meeting

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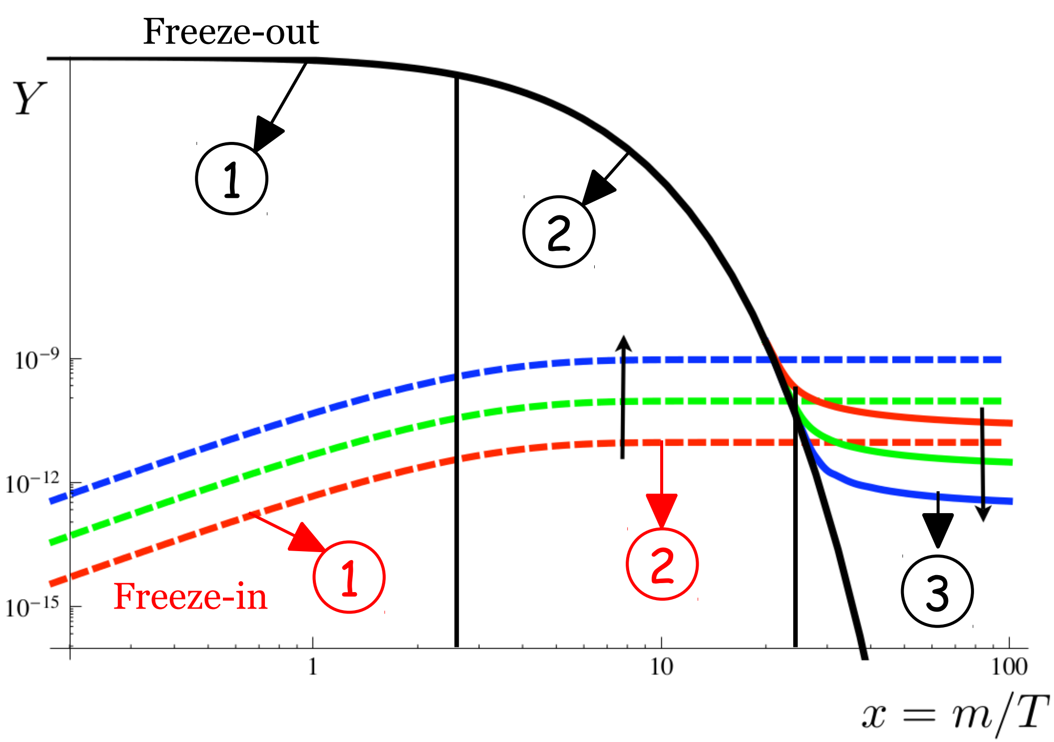
What is freeze-in?

Dark matter abundance evolution as a function of temperature :

arXiv:hep-ph/0106249
arXiv:0911.1120
arXiv:1706.07442...



Freeze-in requires *very* weak interactions with the visible sector

Freeze-out :

1. DM + DM ↔ SM + SM efficient in both directions.

   Interactions strong enough → Equilibrium

2. DM + DM ← SM + SM disfavoured.

3. n_{DM} <σv> < H : Equilibrium lost → Freeze-out.

Freeze-in :

1. DM only produced from thermal bath.

   Feeble interactions/density → No equilibrium

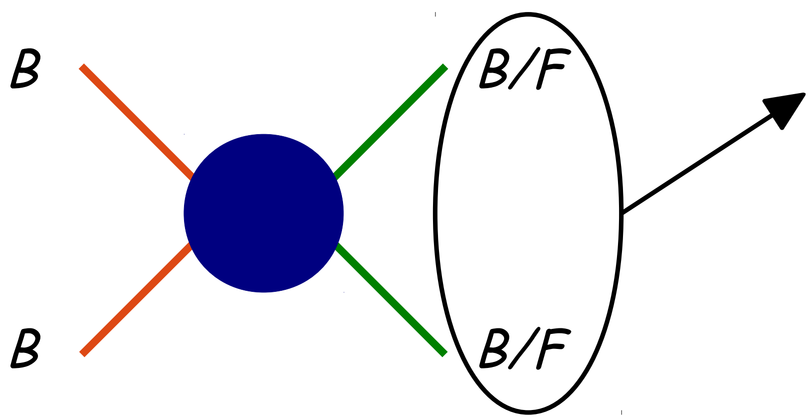
2. n_{Bath} <σv> < H : DM Production stops

Types of freeze-in

We can imagine at least two mechanisms for freeze-in DM production :

· Annihilation of bath particles into DM (pairs?).

· Decays of heavier particles into DM (pairs?).



B : Bath particles
F : Feebly coupled particles

Dark matter or other particles that subsequently decay into DM.

In all cases, need to solve a different set of Boltzmann Eqs. wrt the usual freeze-out case

Also: If the final state particles are feebly coupled, need to write down Boltzmann Eqs. for them too.
→ For complicated models the problem can get involved!

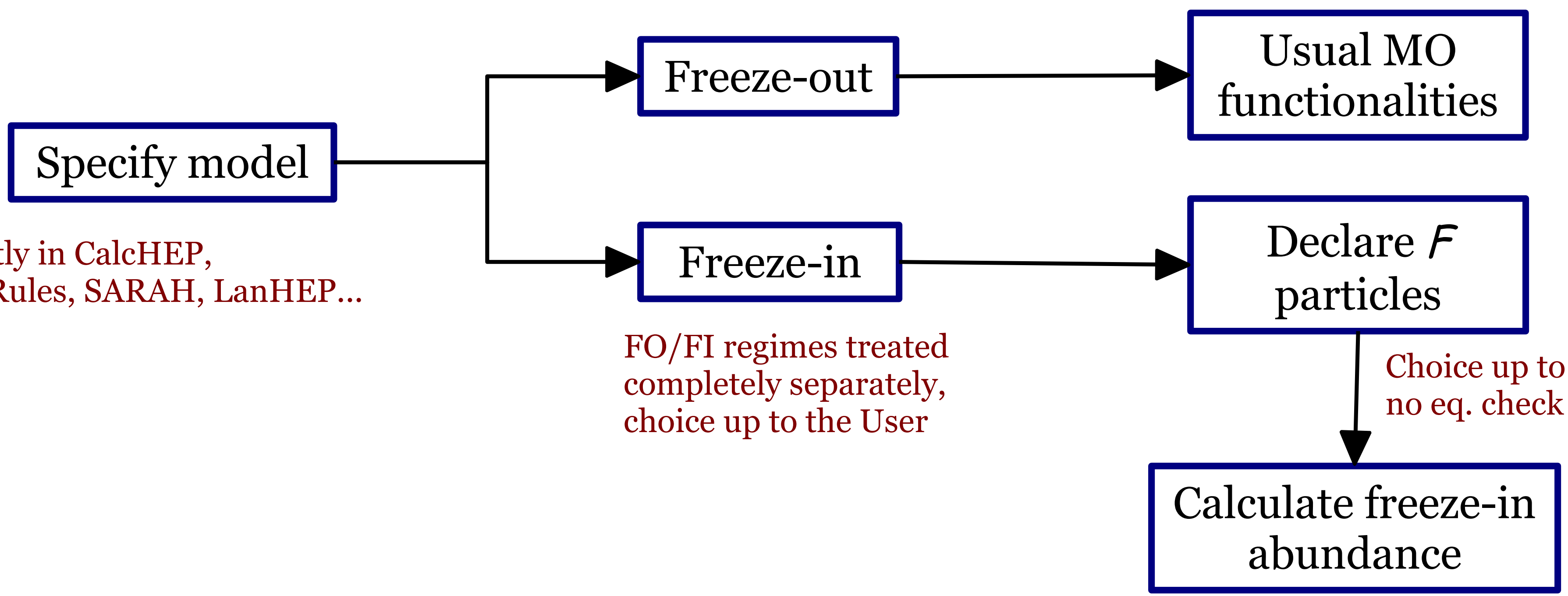
So far there exists no public code to tackle the problem for a general BSM scenario.

Freeze-in in micrOMEGAs

Over the last year or so, we have been preparing a major upgrade of micrOMEGAs to render it capable of computing the DM abundance in freeze-in scenarios.

G. Bélanger, F. Boudjema, A. G.,
S. Pukhov, B. Zaldivar, *to appear soon!*

General idea :



i.e. the code requires some intuition by the user.

NB: this is not a novelty, to my knowledge all DM codes *assume* equilibrium!

In practice

Once the User specifies a model, there are two basic steps to be taken :

· `toFeebleList(particle_name)`: specify all feebly coupled particles in the spectrum.

All particles not in this list are assigned their equilibrium distributions

If you want to do things manually :

· `darkOmegaFiDecay(TR, Name, KE, plot)`: calculates the DM abundance from the decay of the particle `Name` into all odd feeble particles, assuming kinetic equilibrium (`KE` = 1) or not (`KE` = 0) with the Standard Model.

· `darkOmegaFi22(TR, Process, vegas, plot, &err)`: freeze-in through scattering for a given `Process`.

Routines also useful for checks etc.

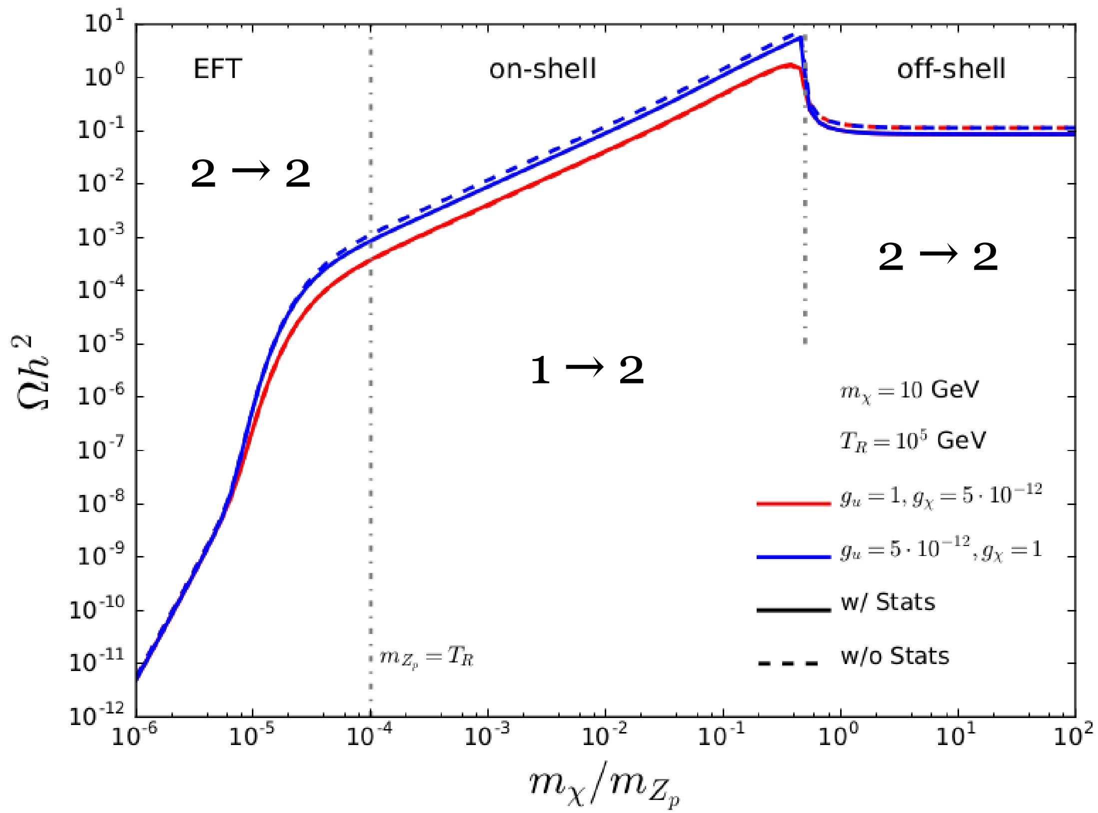
Or simply :

· `darkOmegaFi(TR)`: DM abundance after summing over all $2 \to 2$ processes involving particles in the bath in the initial state and at least one feeble particle in in the final state.

A simple example

Consider a simple vector portal model

$$\mathcal{L}_{\text{int}} = -g_\chi Z'_\mu \bar{\chi}\gamma^\mu \chi - \sum_q g_q Z'_\mu \bar{q}\gamma^\mu q$$



Statistics *do* matter and are taken into account in micrOMEGAs. Can easily lead to factor 2 differences.

Outlook

· micrOMEGAs 5.0 will be able to handle feebly coupled dark matter candidates and compute their predicted abundance according to the freeze-in mechanism. Statistical distributions of bath particles are fully taken into account and are found to matter.

· Most major freeze-in scenarios will be covered.

· Our hope is that this will facilitate phenomenological studies (and model-building endeavours!) and help establish stronger connections between the early Universe phenomenology of FIMPs and their observational signatures.

· To appear really soon!

The ultimate goal (for the next versions): a unified treatment of all cases,with a smooth passage amongst the various regimes.

aka the most general form of the Boltzmann equation