Reconstructing properties of WIMP DM

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We examine the question to what extent prospective detection of weakly interacting massive particle (WIMP) dark matter (DM) by direct (DD) and indirect (ID) detection experiments could shed light on its basic properties, *i.e.*, its mass, m_χ, annihilation cross section, $\langle \sigma v \rangle$, annihilation final states *etc.*

We then study what fraction of such WIMP DM could be generated thermally via the freeze-out process in the early Universe. We show that, in the near future and in a model-independent approach the answer to this question based on the observational results could only be achieved in a thin sliver of the parameter space. However, with additional theoretical input the hypothesis about the thermal freeze-out as the dominant mechanism for generating dark matter can potentially be verified. We illustrate this with two examples: an effective field theory of dark matter with a vector messenger and a higgsino or wino dark matter within the MSSM.

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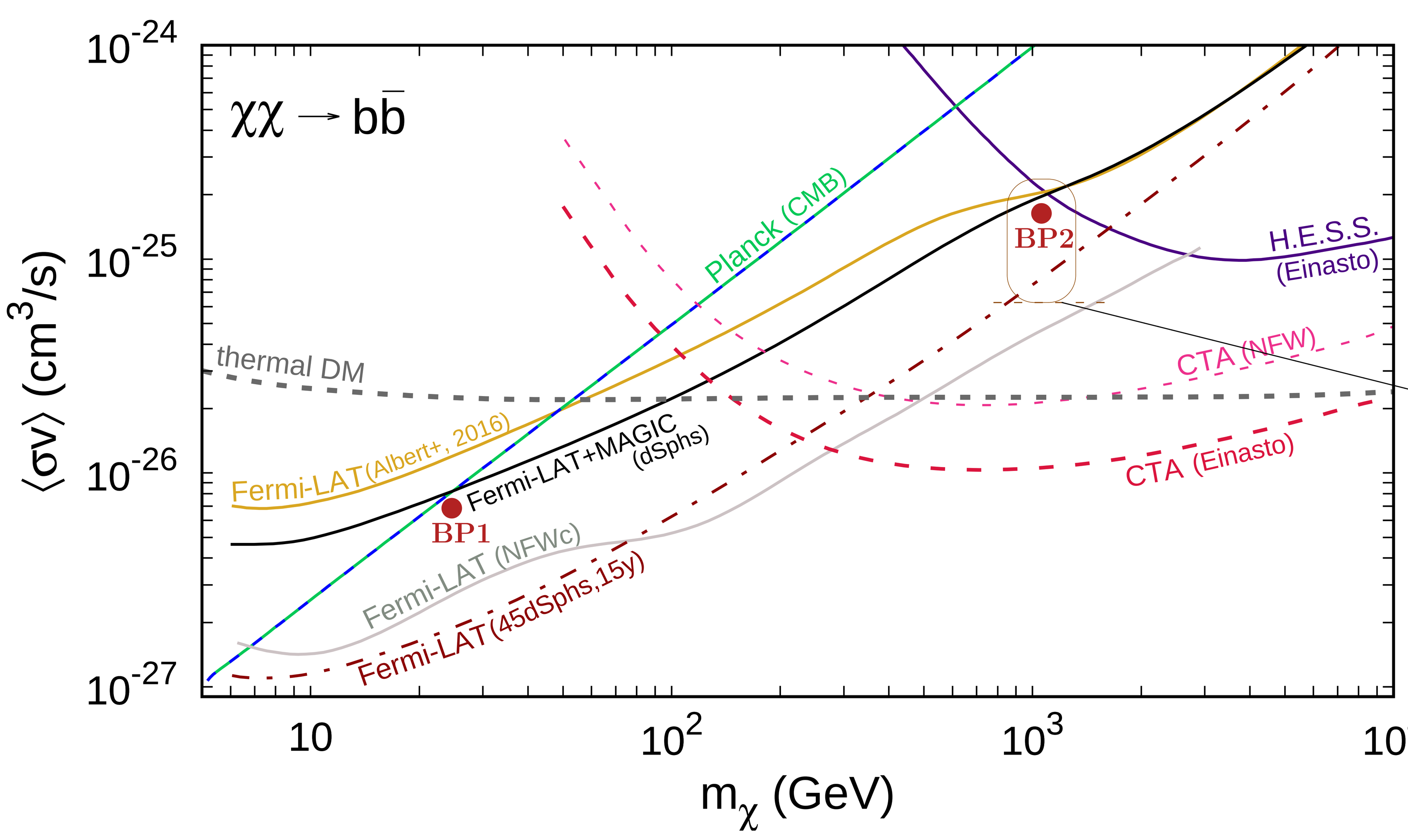
Dark matter hidden just below the current limits?

- Assumption: signal form WIMP DM will be detected in the upcoming years by one or more of the ID and DD experiments
- We simulate putative signals from such a WIMP DM that could be seen in the near future by FermiLAT (dwarfs), CTA (Galactic Center) and various DD experiments (*e.g.*, Xenon1T)
- Question: what will be the accuracy of determination of basic properties of WIMP DM based on the assumed experimental data?



Thermal or non-thermal DM?

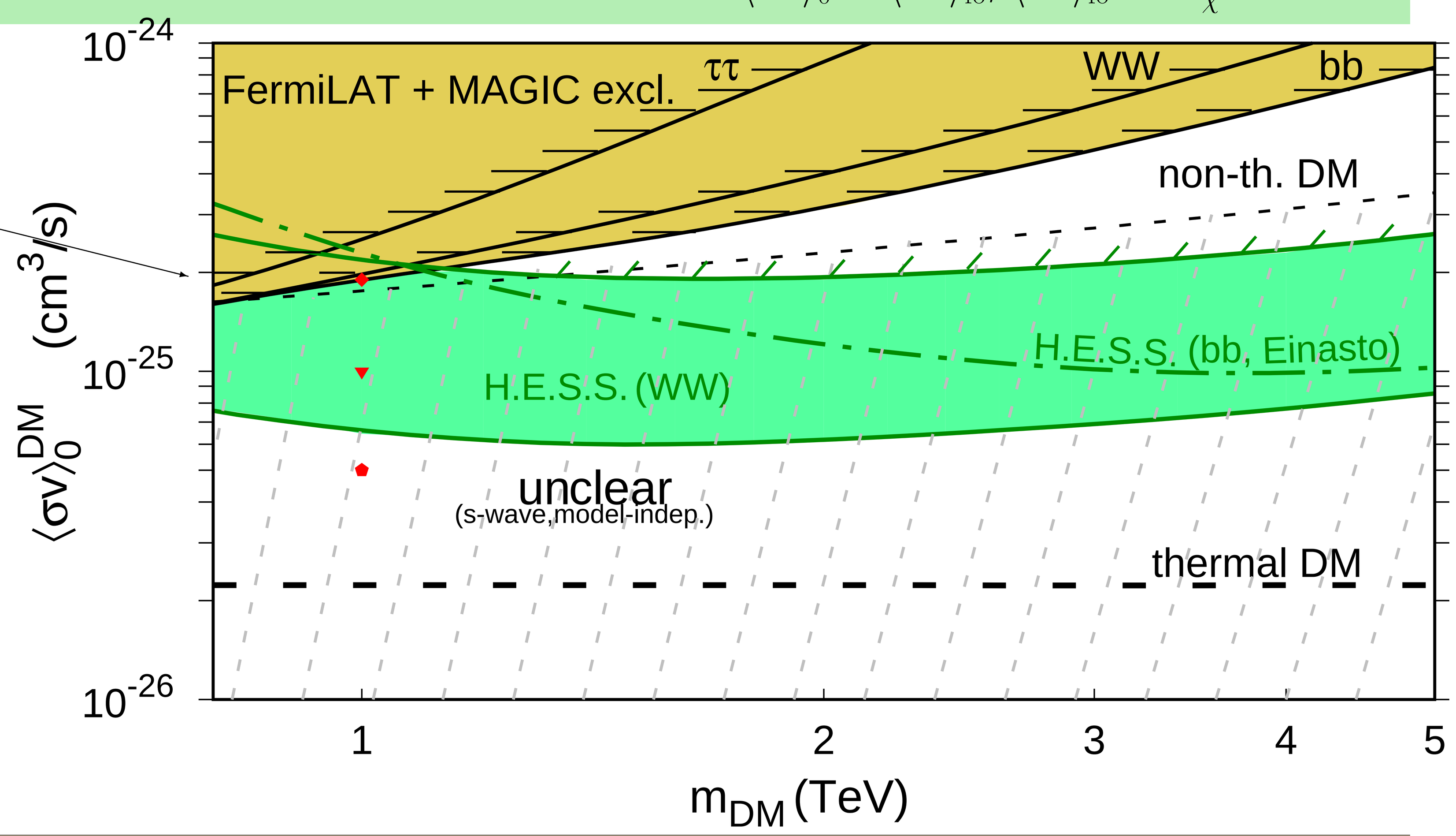
- WIMP DM relic density can contain both *thermal* (freeze-out) and *non-thermal* (e.g., late-time decays of some heavier species) contributions

$$\Omega_\chi h^2 = \Omega_\chi^{\rm fo} h^2 + \Omega_\chi^{\rm non\text{-}th.} h^2$$

- Interpreting the ID results in terms of the thermal contribution to $\Omega_\chi h^2$ requires assuming some relation between the annihilation cross section today and around DM freeze-out
- The simplest relation of this kind (Sommerfeld enh. and multicomponent DM also discussed in the article)

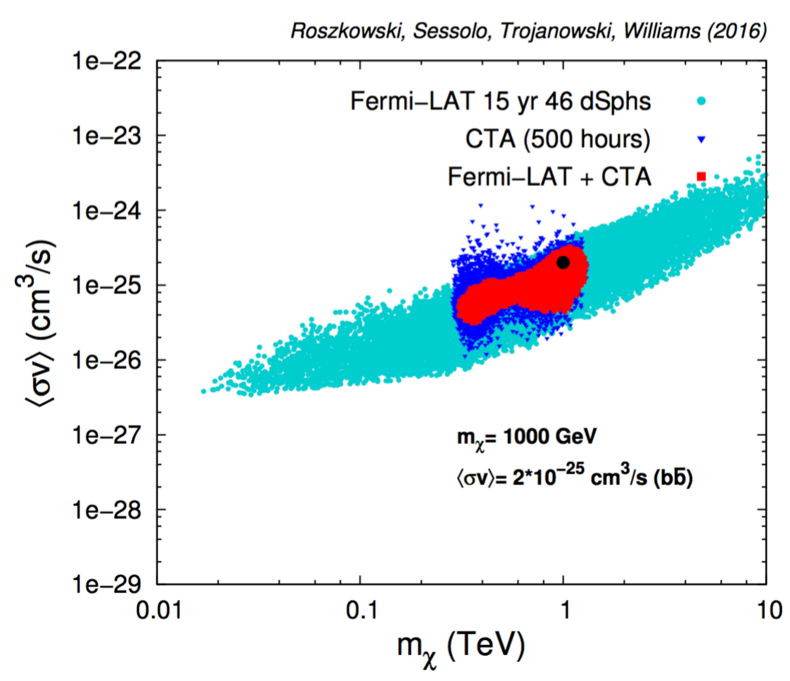
$$\langle \sigma v \rangle = \frac{\alpha_s + (T/m_\chi)\,\alpha_p}{m_\chi^2}$$

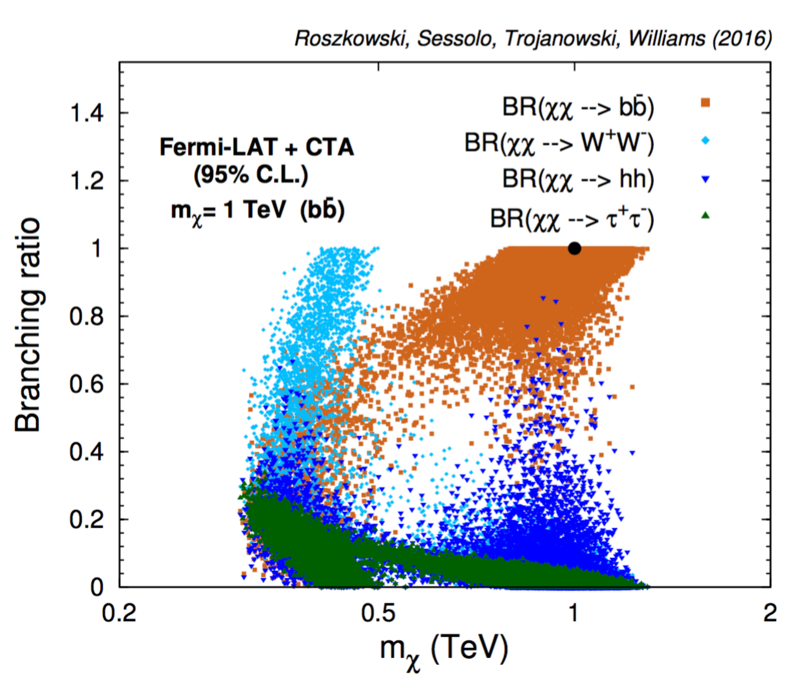
- Often s-wave contribution dominates in which case $\langle \sigma v \rangle_0 \simeq \langle \sigma v \rangle_{\rm fo}$, $\langle \sigma v \rangle_{\rm fo} \to \Omega_\chi^{\rm th} h^2$



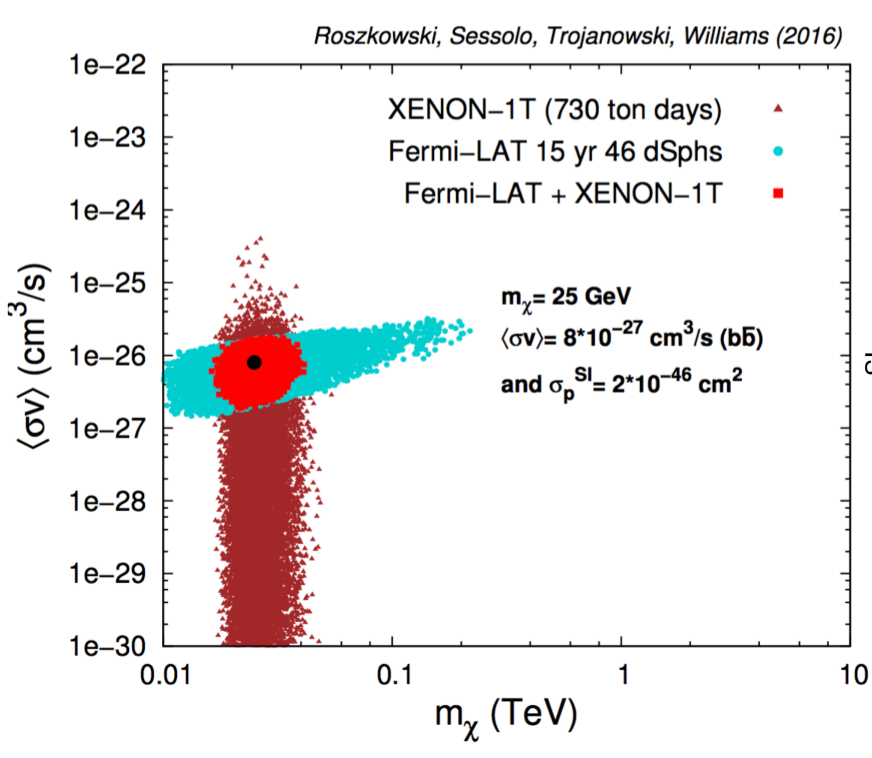
Quality of reconstruction

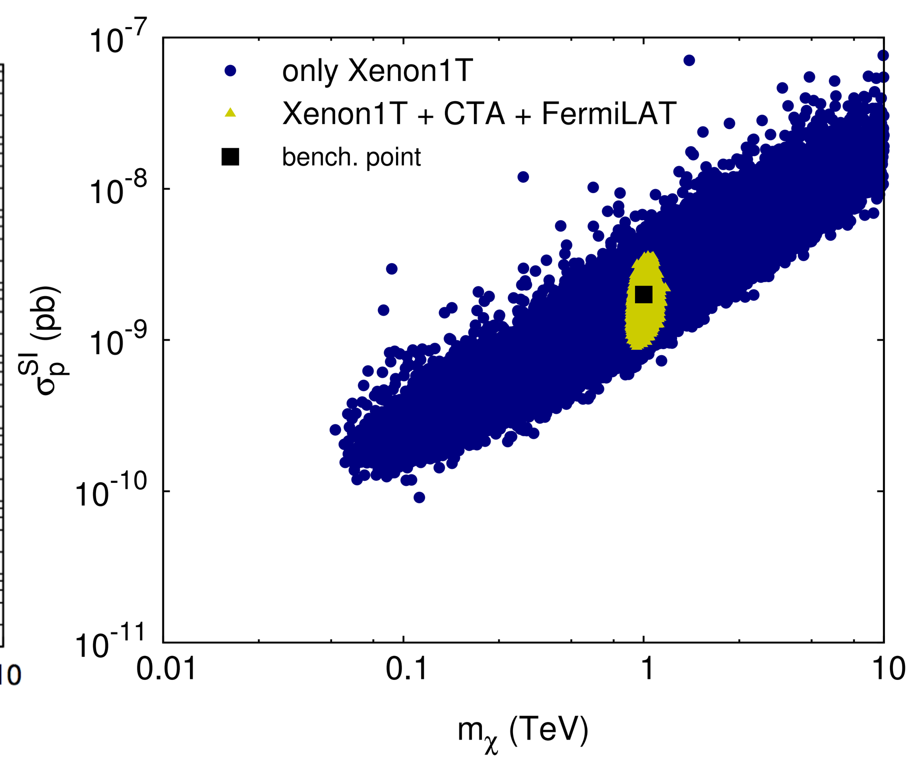
- It depends on the actual value of $\langle \sigma v \rangle_0$, DM mass m_χ and the annihilation final states
- Significant improvement can be obtained thanks to even small monochromatic-like signal (*e.g.*, from $\chi\chi \to \gamma\gamma$ or $\chi\chi \to W^+W^-$ and $W^\pm \to W^\pm\gamma$ splitting)
- Possible mixed final states need to be taken into account for realistic reconstruction





- Degeneracy of the annihilation spectra for different final states can be partly overcome if m_χ is reconstructed more accurately, *e.g.*, thanks to DD (for low enough DM mass)
- For large DM mass, $m_\chi > 100$ GeV, DD cannot help with the reconstruction of m_χ due to $\sigma_p^{\rm SI}/m_\chi$ degeneracy, but. . .
- . . . possible good DM mass reconstruction in the ID can help to constrain allowed values of $\sigma_p^{\rm SI}$



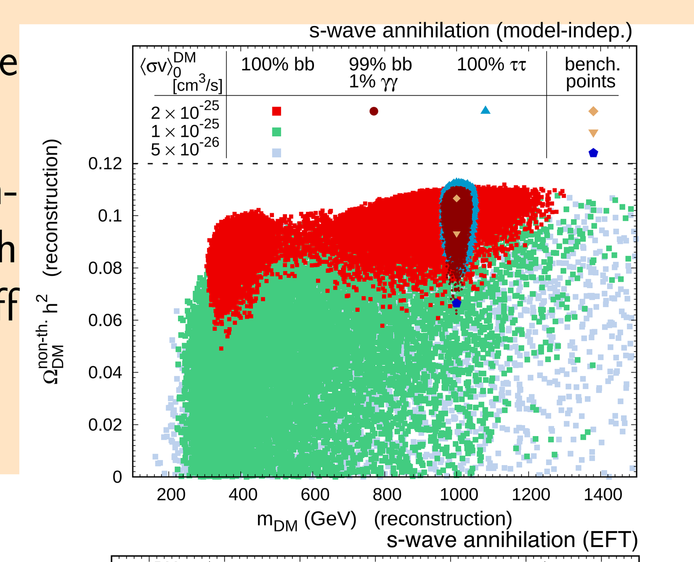


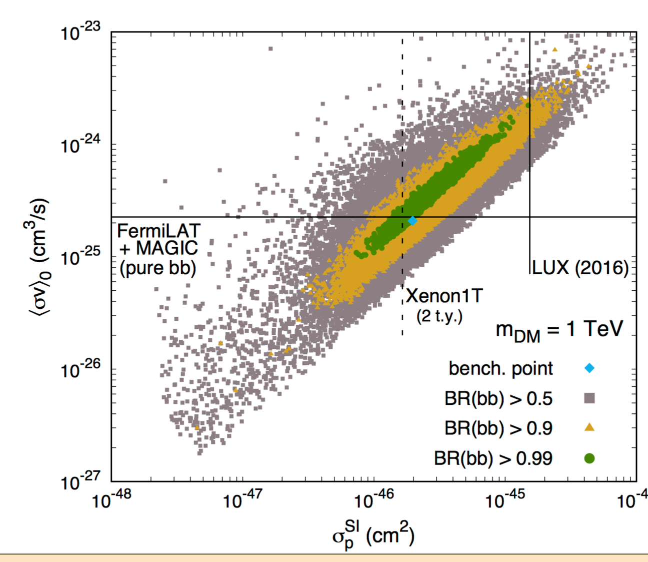
DD vs ID interplay (EFT)

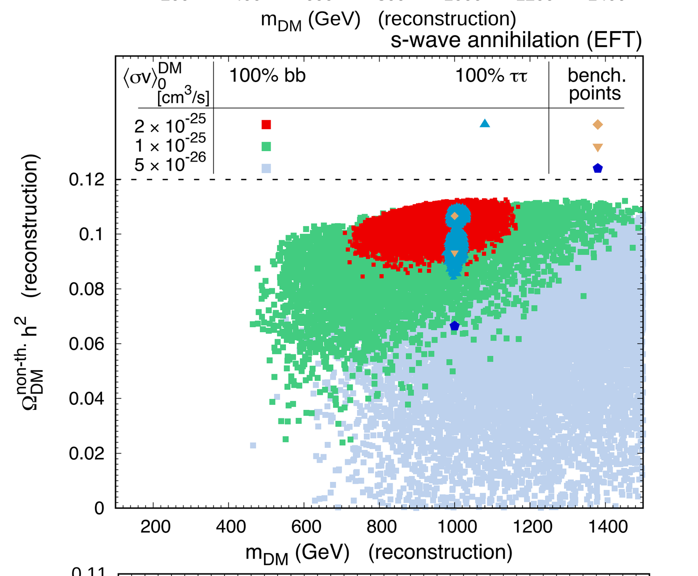
- We illustrate this for a simple EFT model with vector-like couplings between DM and the SM particles (3rd gen)

$$\mathcal{L}_{\rm eff} = \frac{1}{\Lambda^2}\,(\bar{\chi}\gamma^\mu\chi)\,\{c_{q,3}\,\bar{q}_L^3\gamma_\mu q_L^3 + c_{u,3}\,\bar{u}_R^3\gamma_\mu u_R^3 + c_{d,3}\,\bar{d}_R^3\gamma_\mu d_R^3 + c_{l,3}\,\bar{l}_L^3\gamma_\mu l_L^3 + c_{e,3}\,\bar{e}_R^3\gamma_\mu e_R^3\}$$

- DD signal is generated thanks to RGE running of the Wilson coefficients for u and d quarks
- **strong ID-DD correlation:** if ID can help to reconstruct the mass and the annihilation final states, then both ID and DD rates depend essentially only on the cut-off scale Λ
- this correlation further improves the reconstruction







Coannihilations (SUSY)

- If coannihilations are important around DM freeze-out, the relation between $\langle \sigma v \rangle_0$ and $\langle \sigma v \rangle_{\rm fo}$ becomes more complicated
- However, in specific models the reconstruction of $\Omega_\chi^{\rm th} h^2$ is still possible. . .
- . . . we illustrate this for neutralino DM in the MSSM