Closing in on mass-degenerate dark matter scenarios with antiprotons and direct detection

On the complementarity of direct and indirect detection

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Outline

- Introduction
- Particle Physics Framework
- Relic Density
- Indirect Detection
- Direct Detection
- Results
- Conclusion

Why consider compressed mass spectra?

Lets consider the case when the dark matter particle χ and the next to lightest beyond the Standard Model particle η have a similar mass

$$\Delta m = m_\chi - m_\eta \lesssim m_\chi .$$

Colliders

- minimal transverse momentum p_T is required to distinguish jet
- $p_T \approx \Delta m$
- low sensitivity to compressed mass spectra

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thermal production

- for $\frac{m_\eta}{m_\chi} \approx 1.2$ coannihilations become important

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Indirect Detection

- compressed mass spectra exhibit very characteristic features
- annihilation rates are enhanced for small Δm
- huge astrophysical uncertainties

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Direct Detection

- scattering rates are enhanced for small Δm
- less astrophysical uncertainties than in Indirect Detection
- good experimental limits

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But: We need to specify the model in order to compare observables.

Particle Physics Framework

Begin with the SM and add news physics

Particles

- Majorana fermion χ as dark matter
- a scalar η as the next to lightest beyond the Standard Model particle

Assign charges

- χ is a singlet under $SU(3) \times SU(2) \times U(1)$
- η is a triplet under $SU(3)$ and (for simplicity) a singlet under $SU(2)$
- u,d,s or b flavor quantum number for η

Interactions

- a Yukawa interaction with the quarks: $\mathcal{L}_{int} = f \bar{\chi} q_R \eta$

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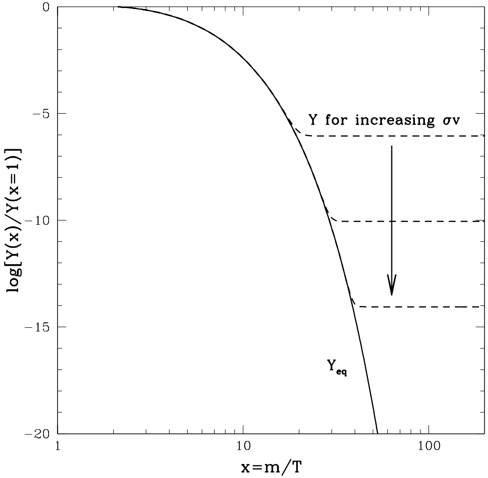
Notice: similar to SUSY with light squarks

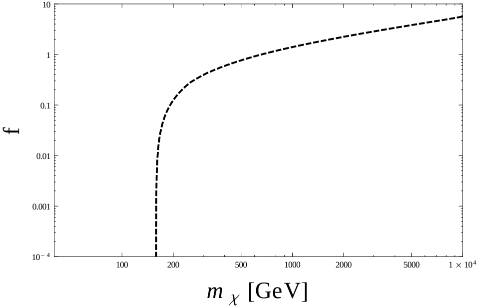
thermal freeze out

- all particles are in thermal equilibrium in the early Universe
- when temperature $T \ll m_\chi$ dark matter can't be produced anymore
  $\rightarrow$ dark matter freezes out



Coannihilations

- for $\frac{\Delta m}{m_\chi} \lesssim 1.2$ more particles need to be included in the Boltzmann equation
- we use MicrOMEGAS for the calculation of the relic density
- specifying m_χ and Δm yields constraint on f
- Example: Coupling to u and $m_\chi / m_\eta = 1.1$



- for m_χ smaller that a certain scale the relic density can not be obtained

Majorana fermions annihilating into light quarks

- thermally averaged cross section $\langle \sigma_{ann} v \rangle$ can be expanded as

$$\langle \sigma_{ann} v \rangle = a + bv^2 + \mathcal{O}(v^4)$$

- consider annihilations into quarks

- s-wave annihilation is suppressed by chirality

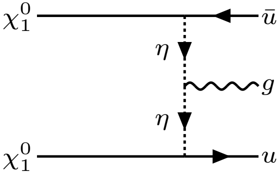
$$\langle \sigma_{ann} v \rangle \approx a \approx \frac{m_f^2}{m_{DM}^2}$$

- p-wave suppressed by velocity

$$\langle \sigma_{ann} v \rangle \approx v^2 \approx 10^{-6}$$

Lifting the chirality suppression

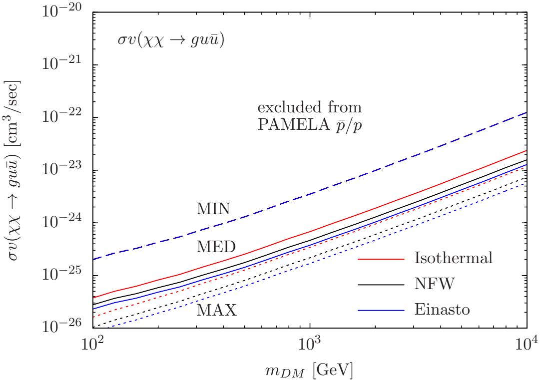
- the suppression can be lifted by the emission of a boson, i.e. γ, $W^{\pm}$, Z or a gluon



- the fragmentation of the gluon increases the production of antiprotons

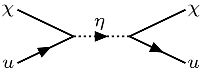
Constraints from Antiprotons

- the $\bar{p}/p$ ratio measured by Pamela constrains σv
- main uncertainty: halo model and cosmic ray propagation
- Example: $m_\eta/m_\chi = 1.1$



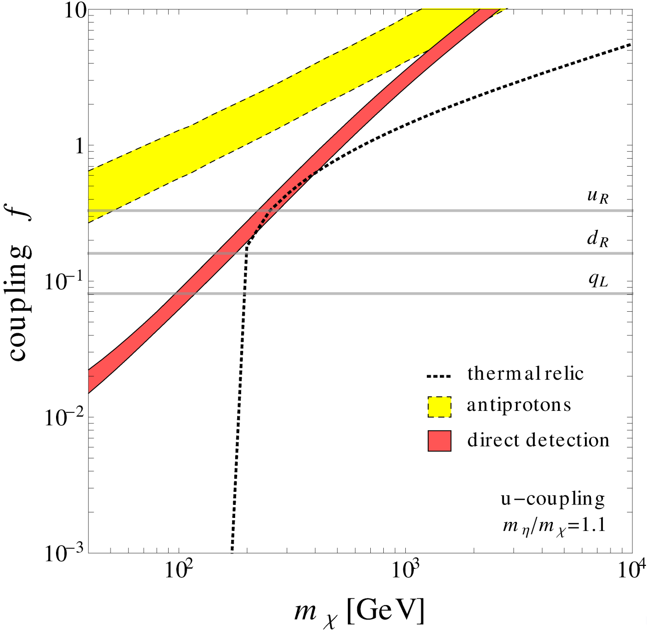
Dark Matter Nucleon Scattering

- dark matter nucleon scattering is induced microscopical by scattering of quarks and gluons in the nucleus

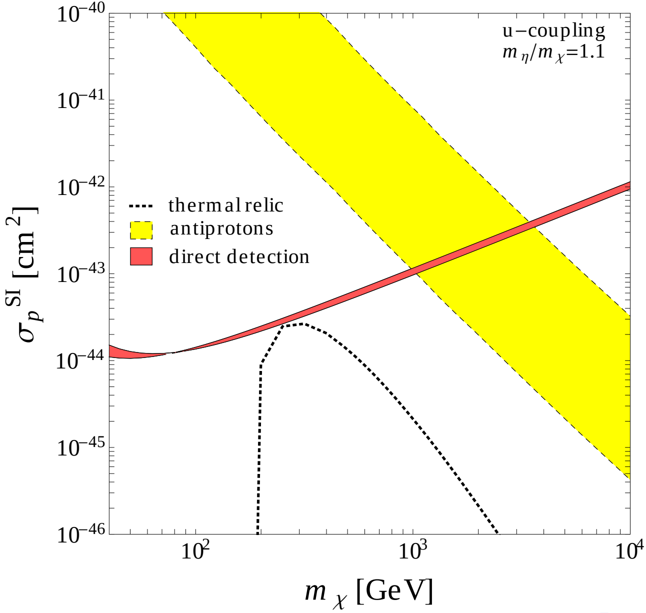


- interactions can be described in terms of effective Lagrangian
- suppression scale $\Lambda = m_\eta^2 - (m_\chi + m_q)^2$
- compressed spectrum $\rightarrow$ small Λ
- recoil rate is enhanced
- uncertainties: astrophysics (mainly neglected here) and composition of the nucleon

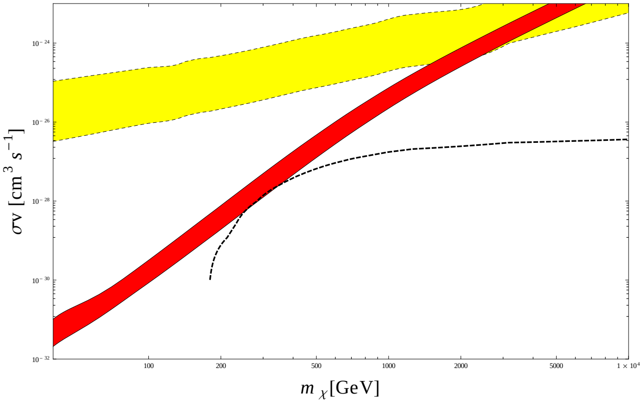
Putting everything together



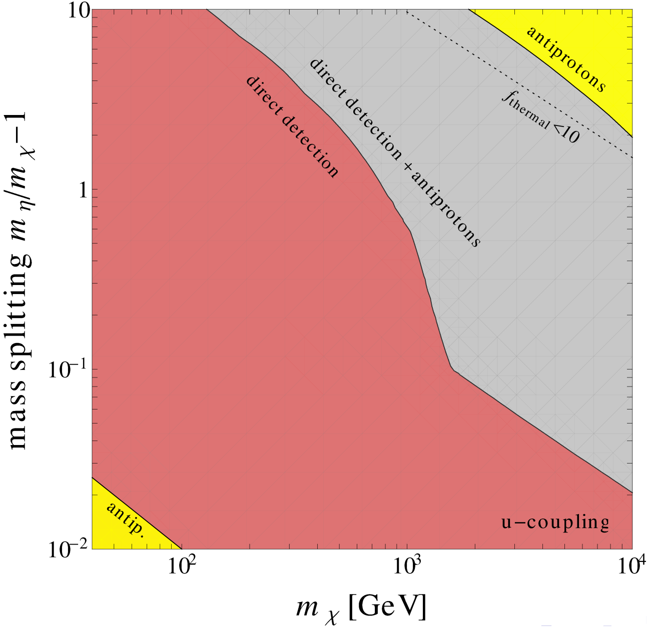
The Direct Detection Plane



The Indirect Detection Plane



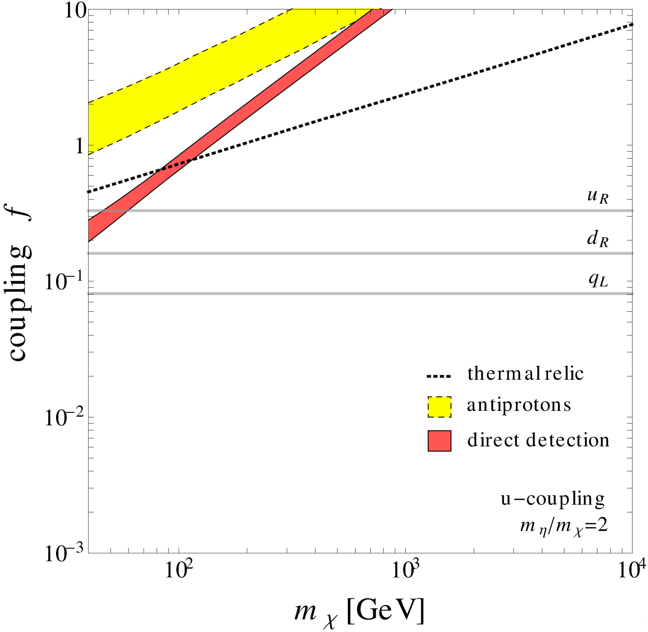
Which constraint is strongest?



Conclusions

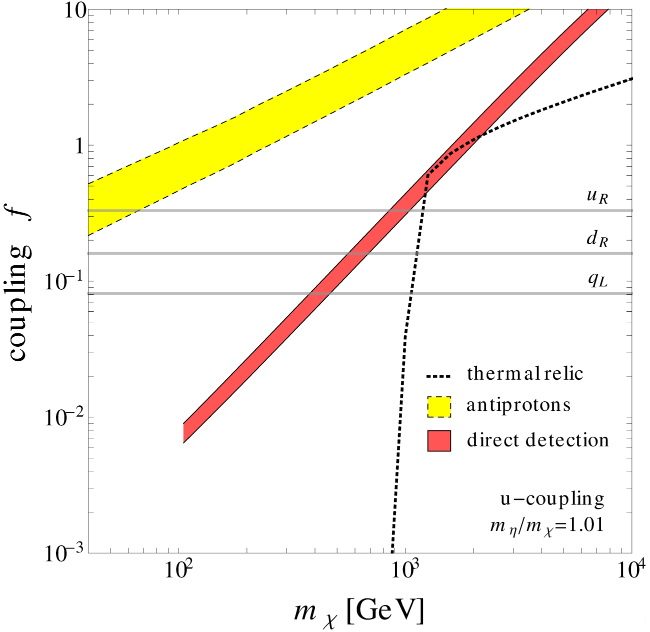
- compressed mass spectra lead to enhanced signals for dark matter detection experiments
- probes region of parameter space inaccessible at colliders
- direct detection experiments are cutting into the parameter space allowed by thermal production

Backup



10
1
10^{-1}
10^{-2}
10^{-3}
10^2
10^3
10^4
coupling f
m_χ [GeV]
u_R
d_R
q_L
thermal relic
antiprotons
direct detection
u−coupling
m_η/m_χ=2

Backup



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thermal relic
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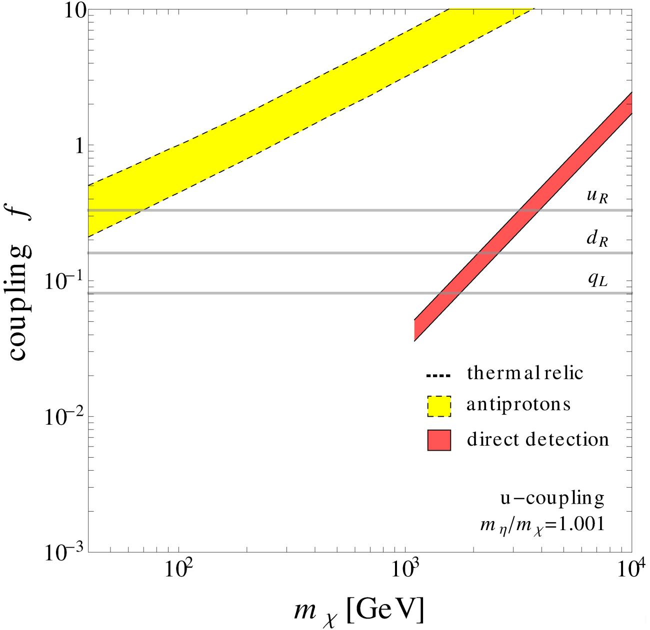
u−coupling
m_η/m_χ=1.01

Backup



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m_η/m_χ=1.001