Relic density of wino-like dark matter in the MSSM

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In collaboration with:

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to appear soon...

Motivations

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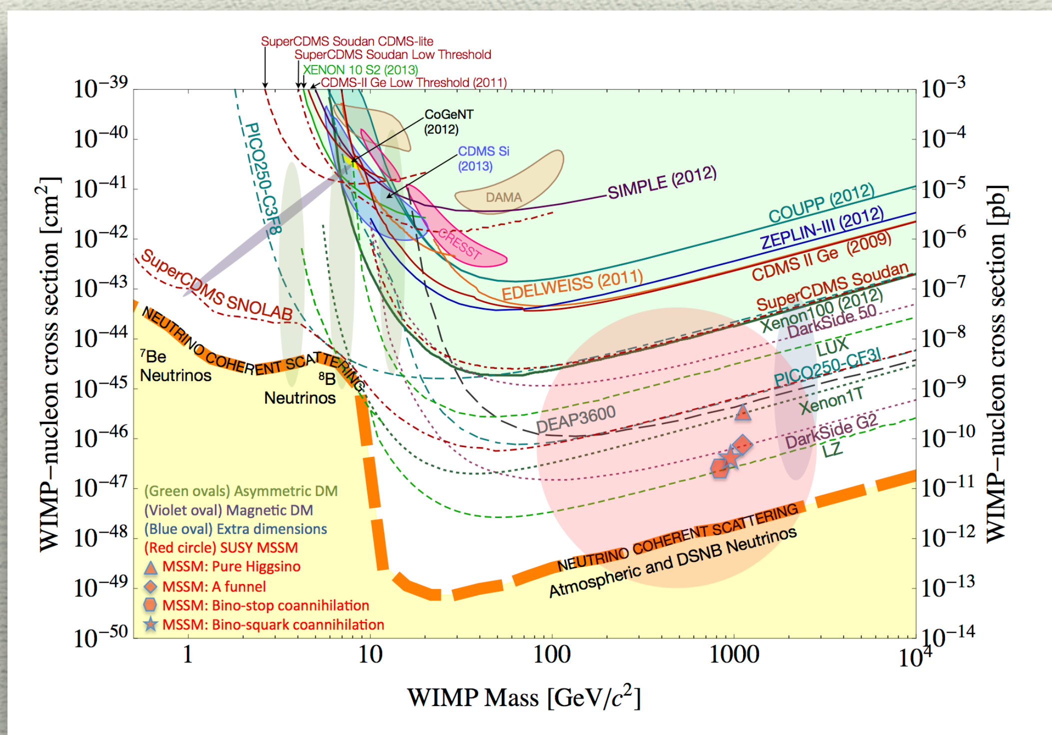
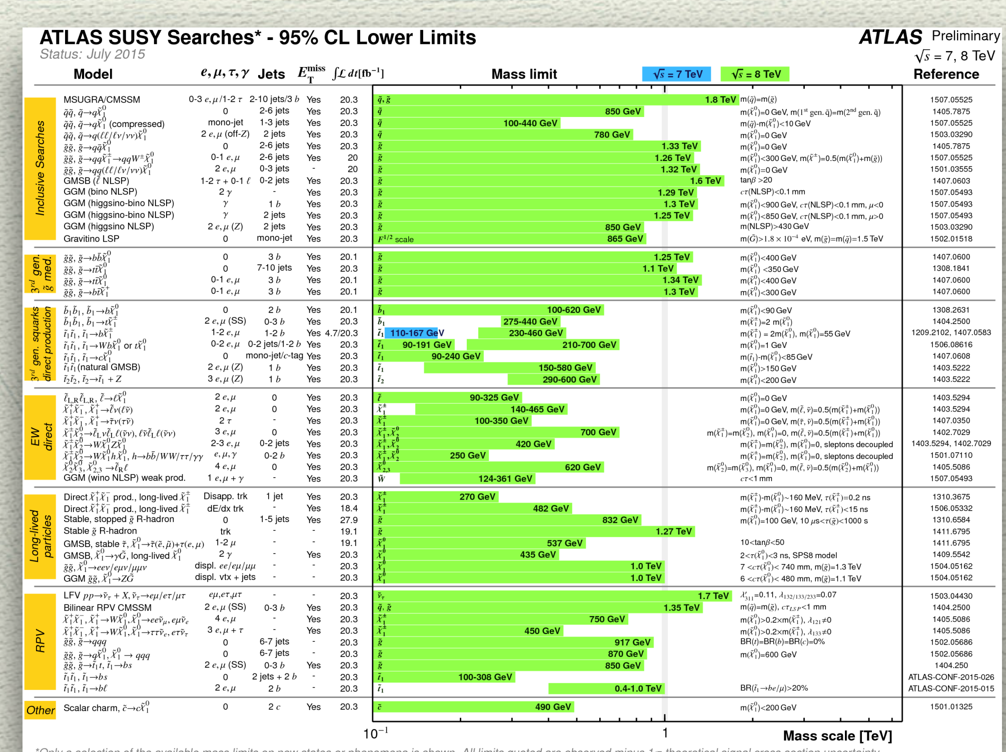
Why heavy neutralinos as dark matter?





Direct detection limits stronger for WIMP masses $\mathcal{O}(100\,\mathrm{GeV})$

No signs of new physics at the LHC

$\Longrightarrow$ In SUSY the neutralino "moves to" $\mathcal{O}(1\,\mathrm{TeV})$

Motivations

Why precision calculations are needed?

$$\Omega_{\rm CDM} h^2 = 0.1188 \pm 0.0010$$

***Planck* + lensing + BAO, '15**

$$\Downarrow$$

$$\text{uncertainty} < 1\%^{*}$$

* does not change much when varying experimantal data combinations

Motivations

Why precision calculations are needed?

$$\Omega_{\rm CDM} h^2 = 0.1188 \pm 0.0010$$

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Widely used codes e.g. DarkSUSY, micrOMEGAs have comparable numerical precision, but cross sections at tree level

$\Rightarrow$ theoretical uncertainty significantly larger!

→ loop corrections

→ LL resummation
Sommerfeld enhancement

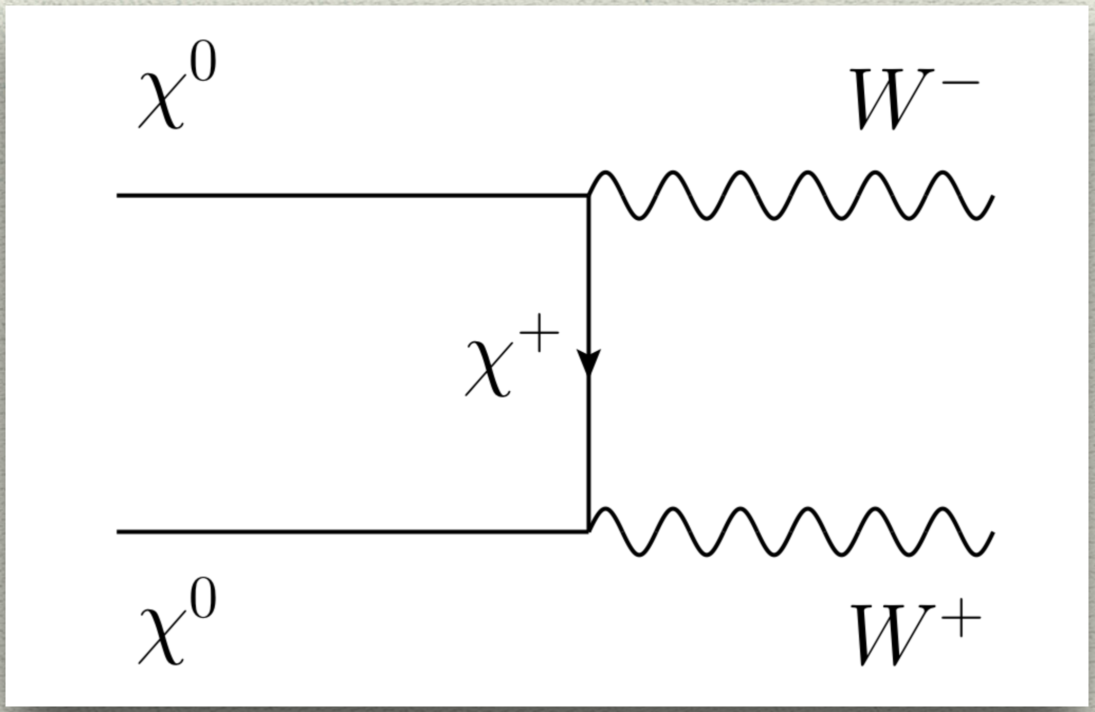
Goal: calculate relic density with Sommerfeld effect in the full MSSM

The Sommerfeld enhancement

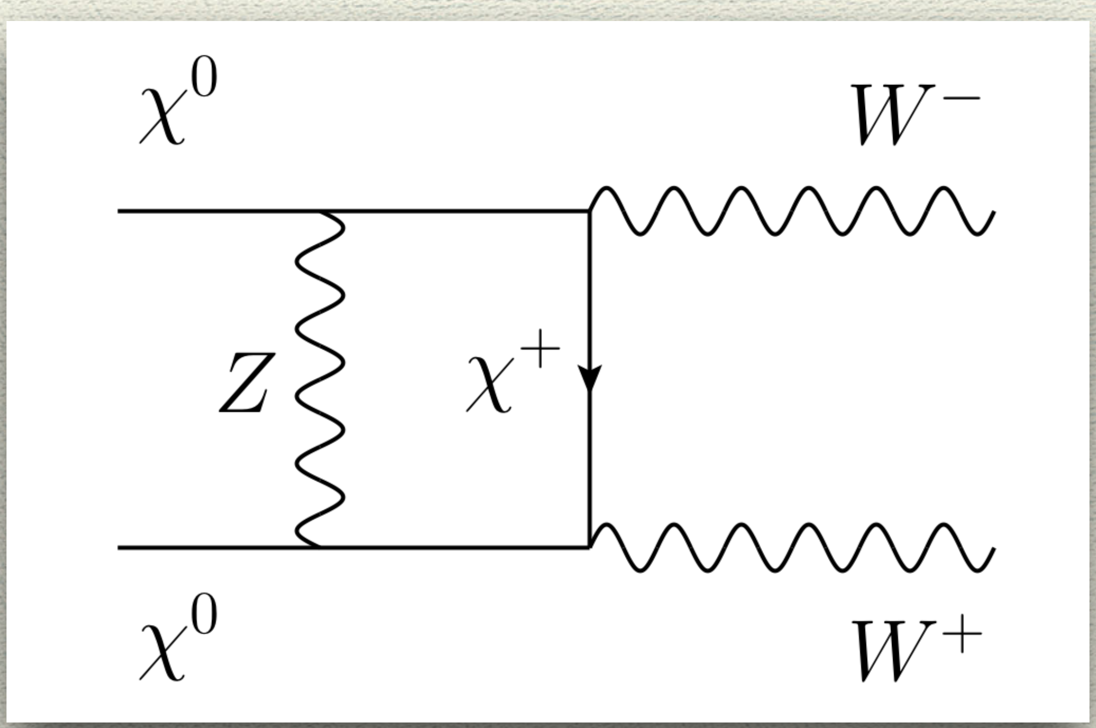
The Sommerfeld enhancement

from electroweak interaction

Tree level contribution to the cross section $\mathcal{M}_0$



1-loop correction $\mathcal{M}_1$



Non-relativistic regime: $\alpha^2 m_\chi \gtrsim m_\chi v^2$

Bohr energy | **kinetic energy**

Low mediator mass: $\frac{1}{m_Z} \gtrsim \frac{1}{\alpha\, m_\chi}$

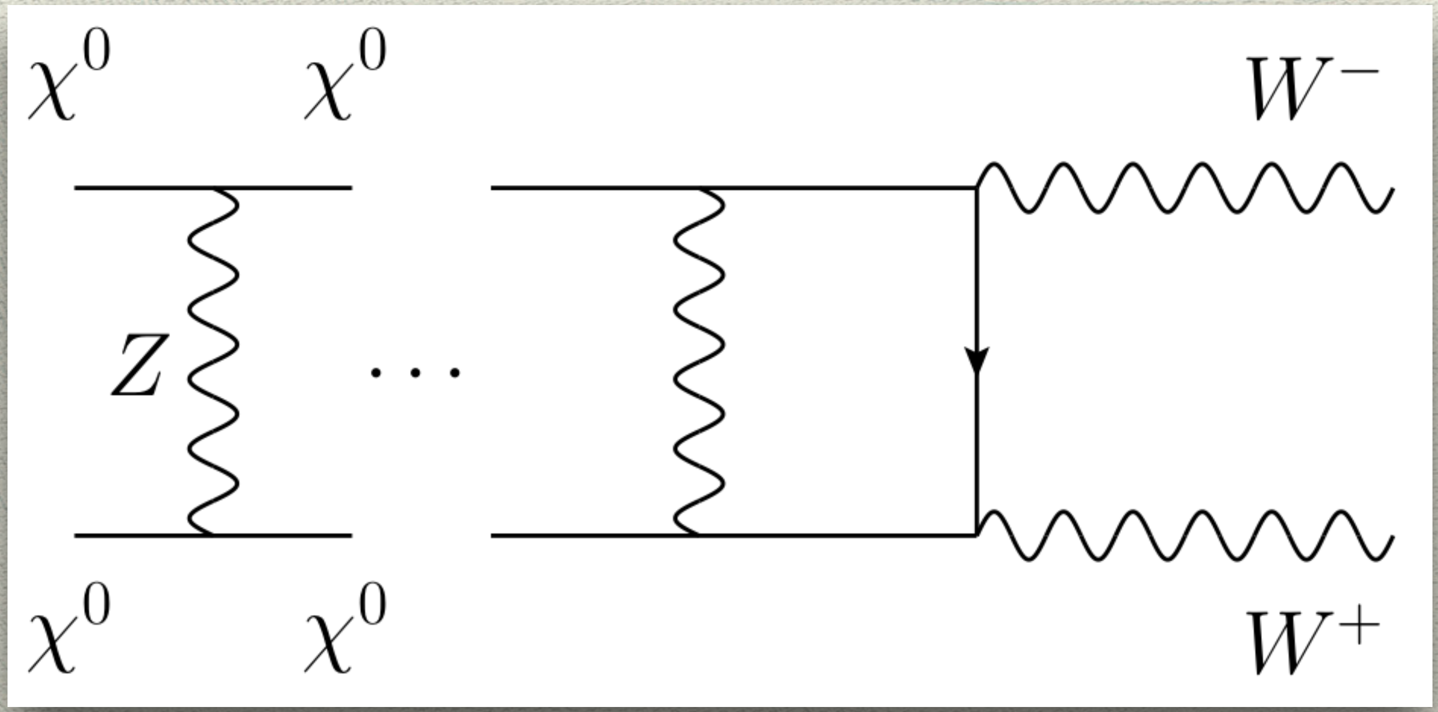
force range | **Bohr radius**

$$\Rightarrow \quad \mathcal{M}_1 \sim \left(\frac{\alpha\, m_\chi}{m_Z}\right) \mathcal{M}_0$$

O(1), no suppression!

n-loop diagram: $\mathcal{M}_n \sim \left(\frac{\alpha\, m_\chi}{m_Z}\right)^n \mathcal{M}_0$

$\Longrightarrow$ resummation of ladder diagrams is needed!



In the MSSM: Z, W, h^0, H^0, $H^\pm$

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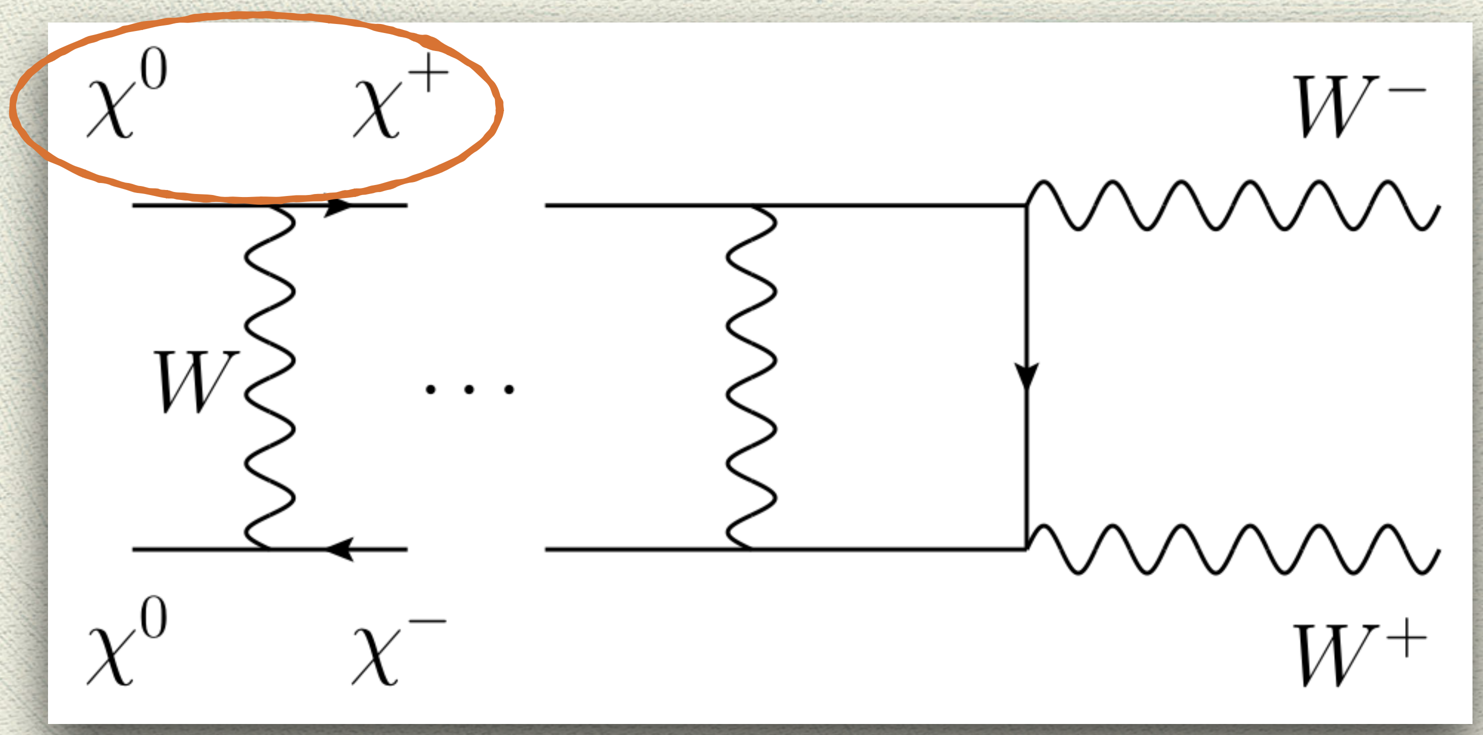

In the MSSM: $Z, W, h^0, H^0, H^\pm$

Small mass splitting: $m_{\chi^\pm} - m_\chi \lesssim \alpha^2 m_\chi$

Bohr energy

$\Longrightarrow$ off-diagonal reactions

New code (to be public):

Based on framework by Beneke, Hellmann, Ruiz-Femenia ’12, ’13, ’14

1. Full MSSM

previous results:

- pure wino, pure higgsino
  Hisano *et al*. ’04, ’06
- mixed wino-higgsino (with everything else decoupled)
  Hryczuk *et al*. ’11, **Beneke** *et al*. ’14
- stop and stau co-annihilations
  Freitas ’07, **Hryczuk** ’11, **Klasen** *et al*. ’14
- gluino co-annihilation
  Ellis *et al*. ’15
- Minimal DM model
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2. Sommerfeld effect for P- and $O(v^2)$ S-wave

3. Off-diagonal annihilation matrices

not present in DarkSE **Hryczuk,** '11 (items 2 and 3)

total effect up to O(10%)

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2. Sommerfeld effect for P- and O(v^2) S-wave
3. Off-diagonal annihilation matrices
4. Present day annihilation in the halo (for ID)
5. Accuracy at O(%) (NLO still missing...)

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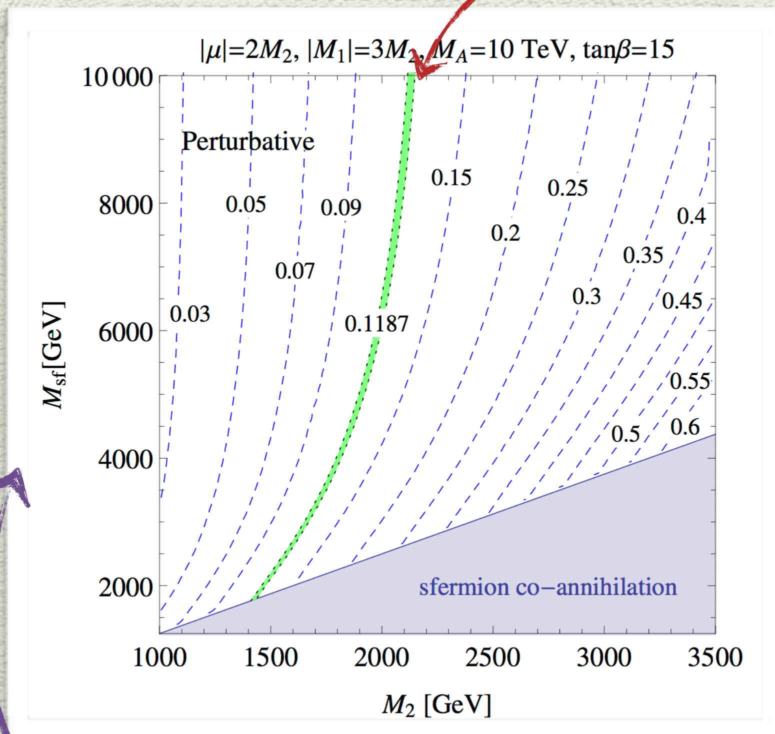
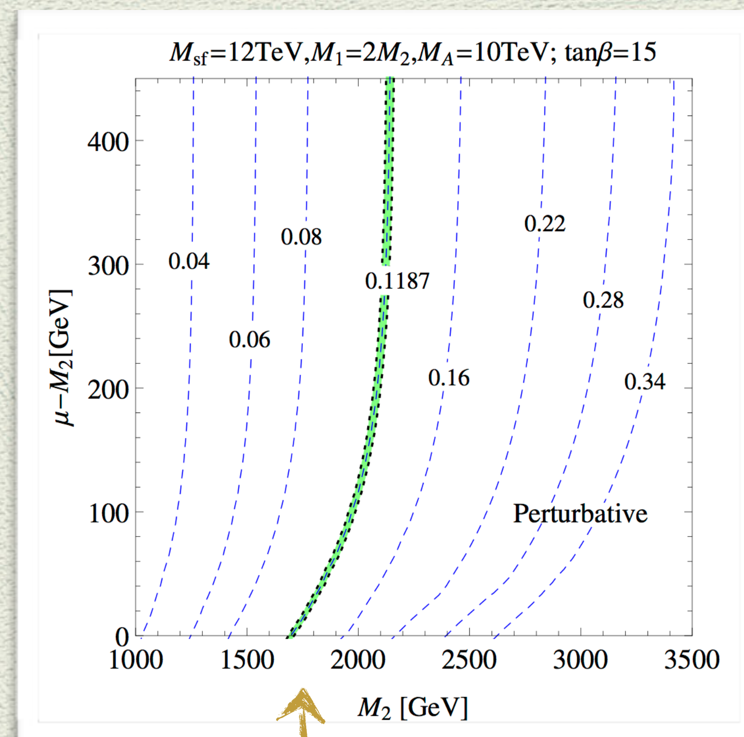
Results

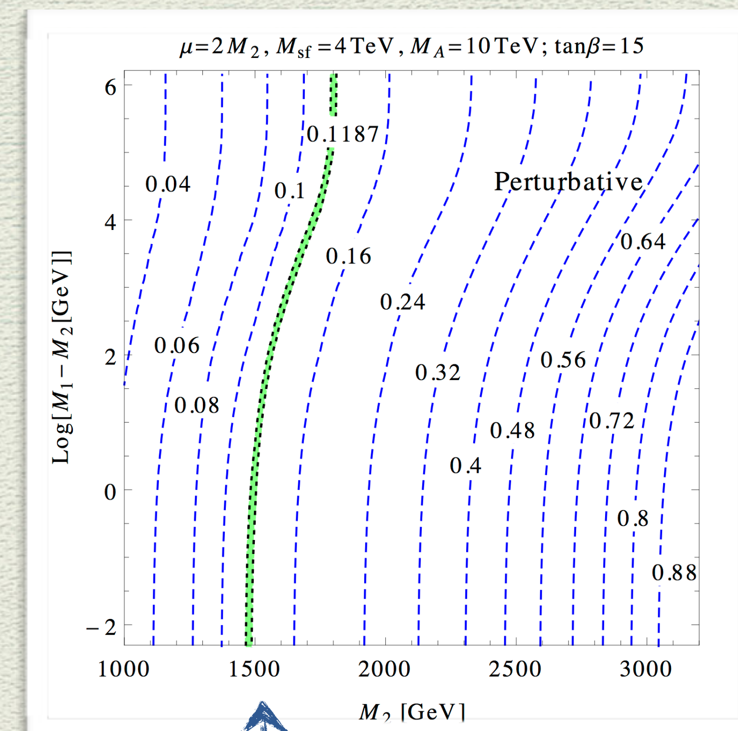
Tree level results

Wino-like neutralino with higgsino or bino admixtures

"pure wino" 2.2 TeV







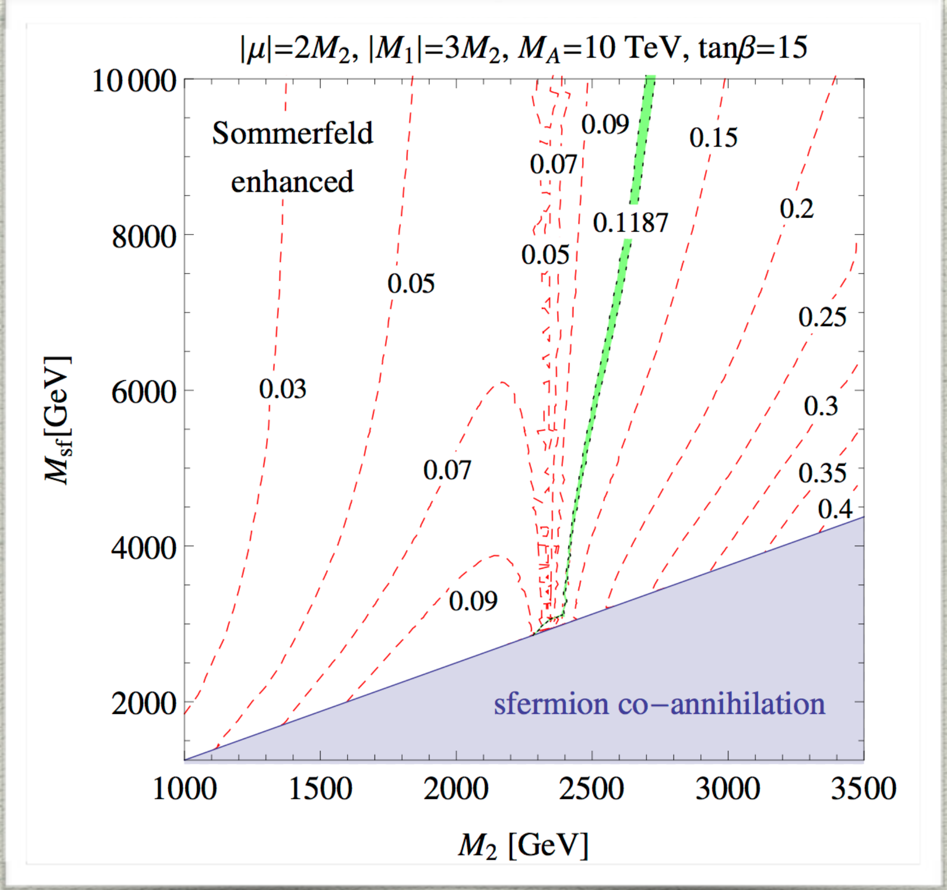
As the sfermion mass decreases the effective annihilation rate is suppressed due to t-channel interference - the correct relic abundance is obtained for masses of around 1.4 TeV*

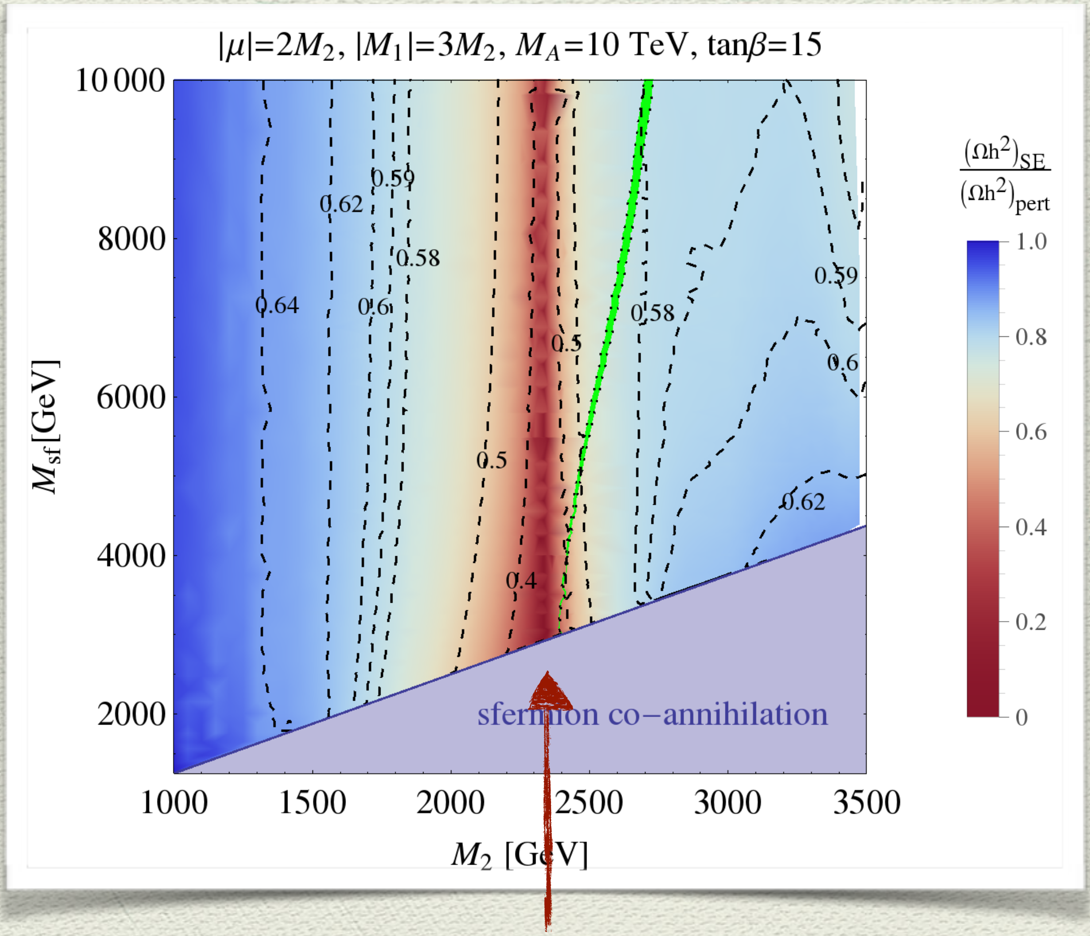
Higgsino and bino annihilate less strongly - dilute the wino annihilation and reduce the mass to 1.7 and 1.5 TeV respectively*

*for the chosen set of parameters

Results with Sommerfeld effect

I) Wino with non-decoupled sfermions





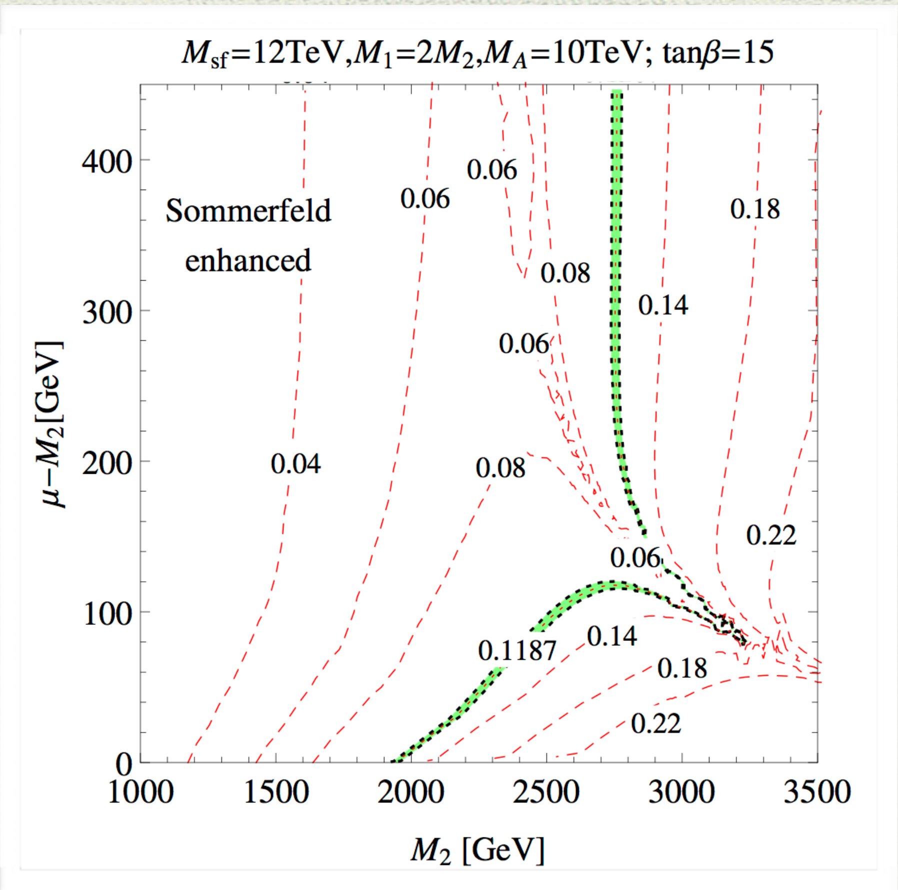
The correct relic density is moved from 1.4-2.2 TeV up to 2.4-2.8 TeV

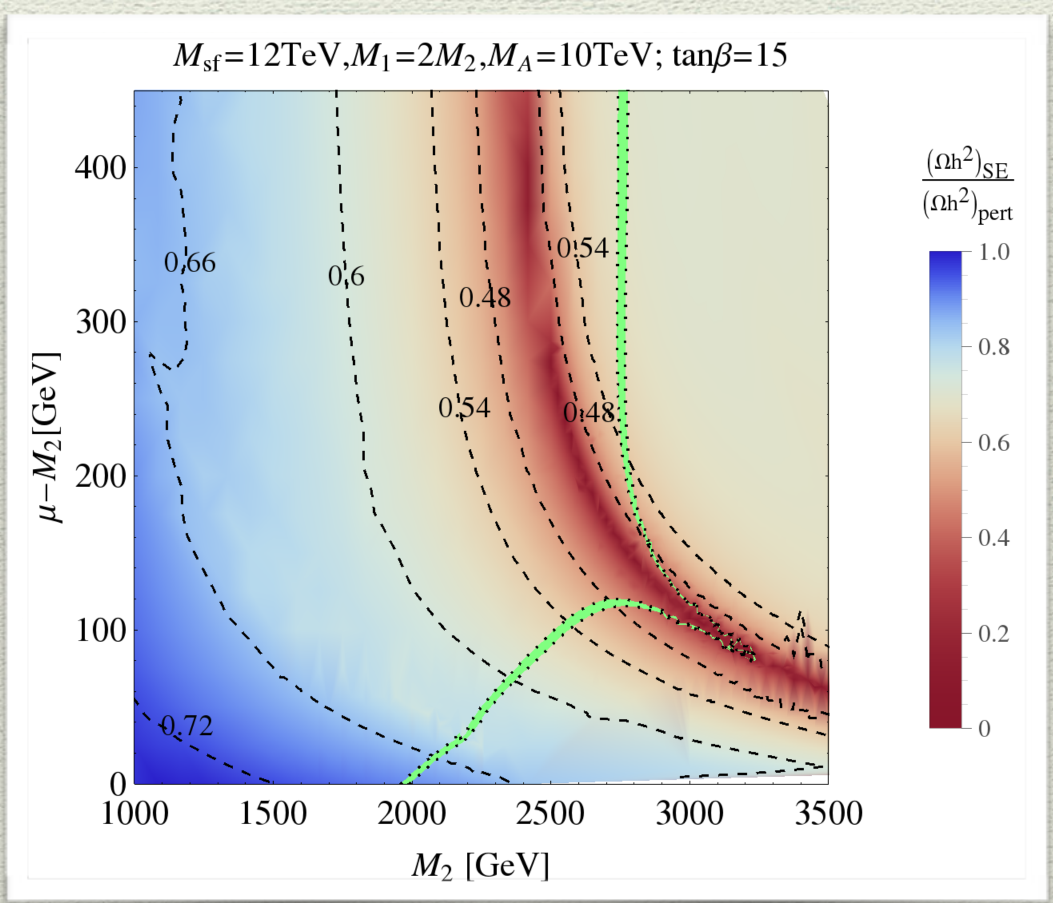
At 2.4 TeV resonance occurs, for low sfermion masses region with correct RD is resonant

Sommerfeld effect > O(30%), up to O(1) close to resonance

Results with Sommerfeld effect

II) Wino-higgsino admixture



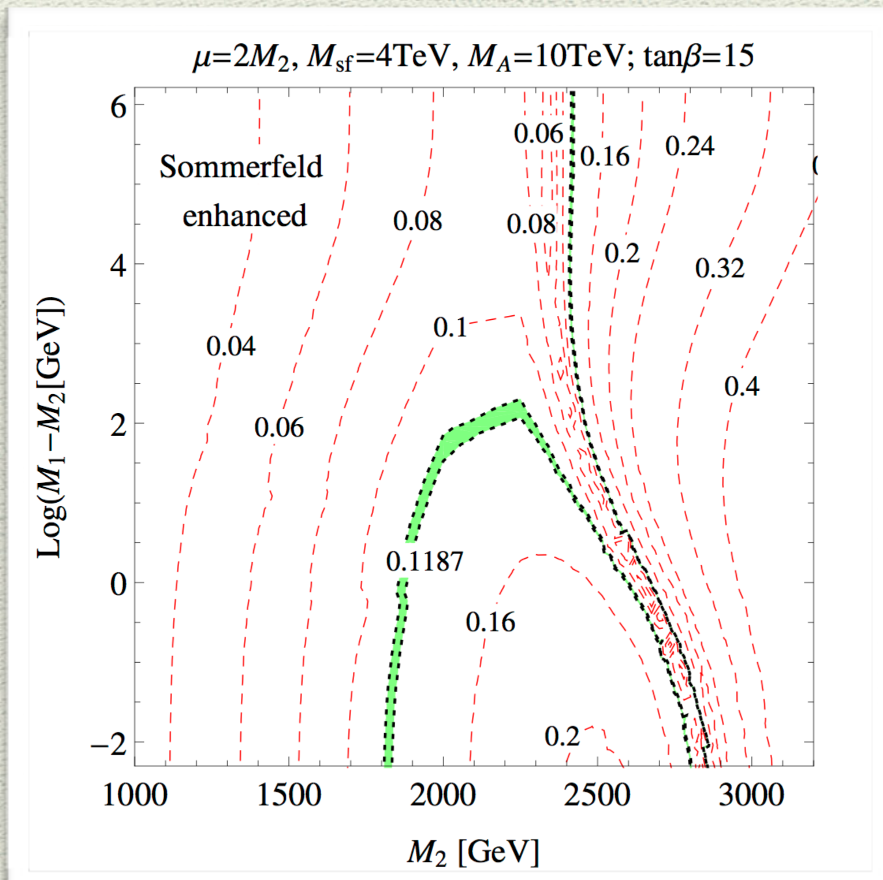


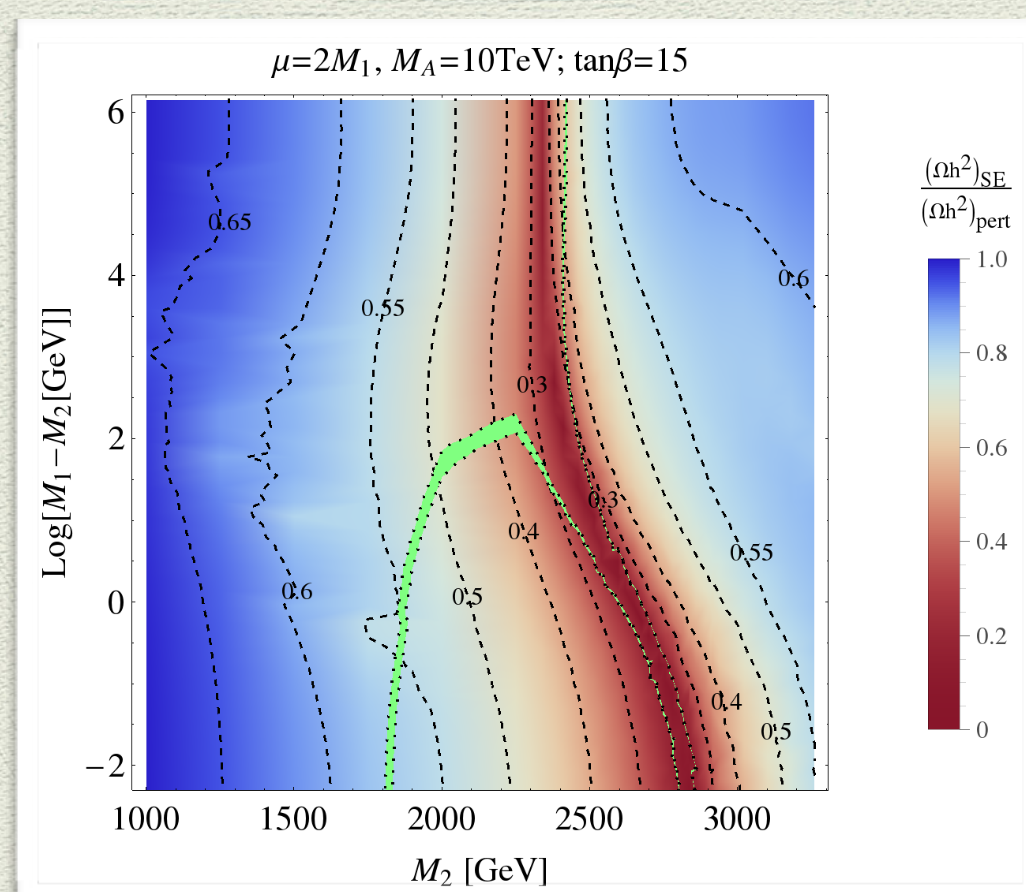
The correct relic density is moved from 1.7-2.2 TeV up to 1.9-3.3 TeV

The position of the resonance is strongly μ-dependent

Results with Sommerfeld effect

III) Wino-bino admixture



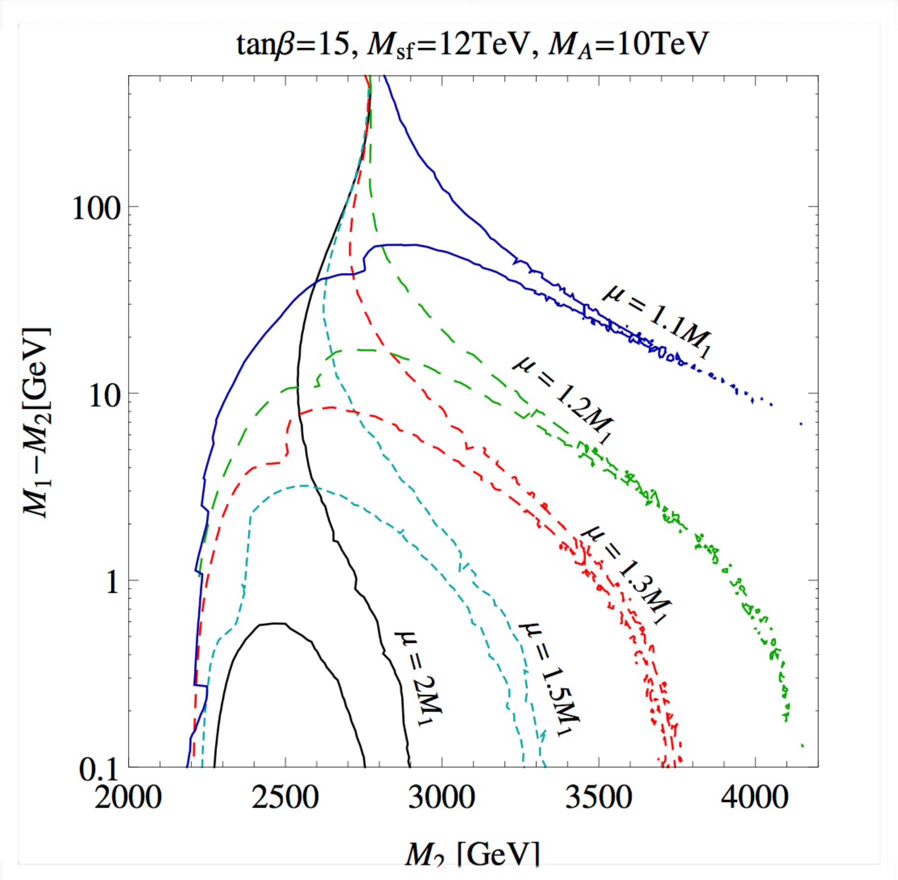


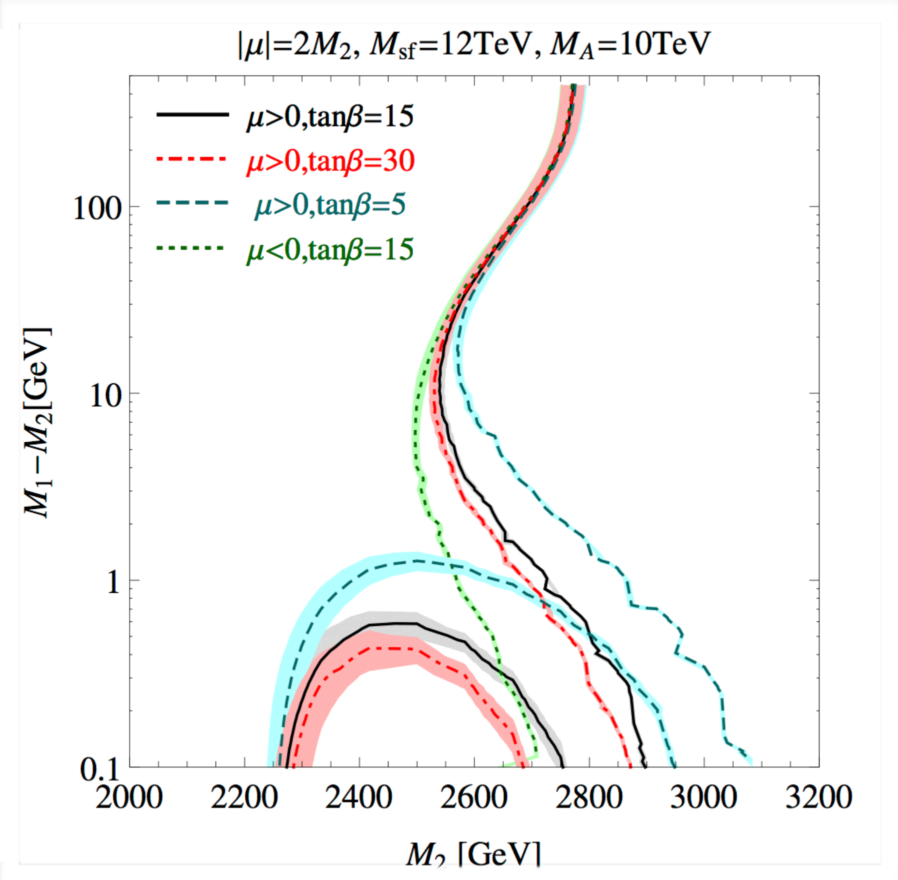
The correct relic density is moved from 1.5-1.8 TeV up to 1.8-2.9 TeV

The position of the resonance is strongly M_1-dependent

Results with Sommerfeld effect

III) Wino-bino admixture: dependence on residual parameters





All contours have correct relic density

The position of the resonance strongly depends on the wino-bino mixing (μ , $\tan\beta$)

Conclusions

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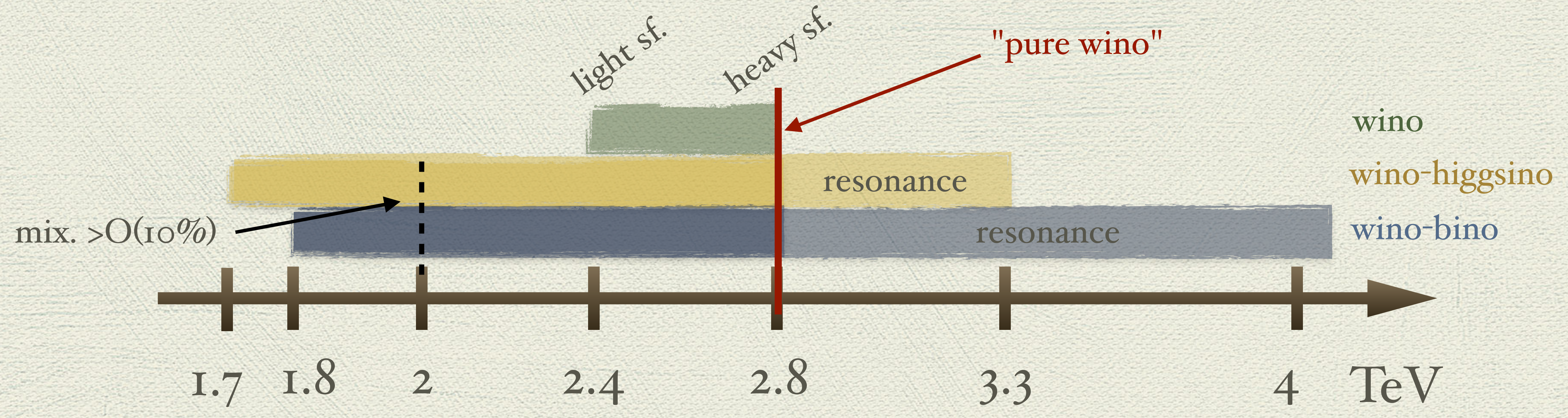
1. Correct relic density for wino-like neutralino in MSSM is obtained for wide range of masses:



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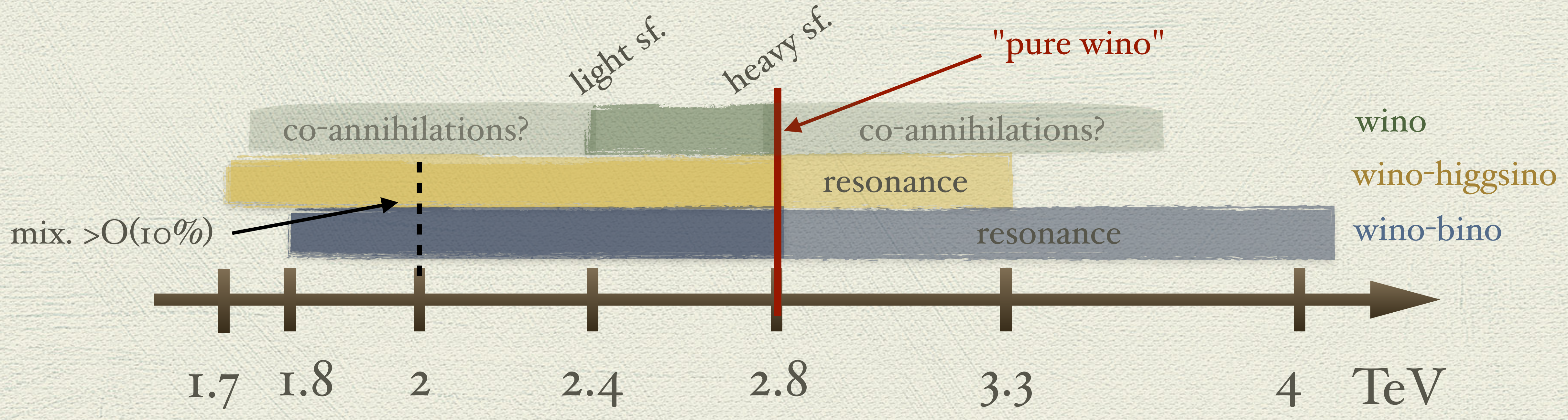

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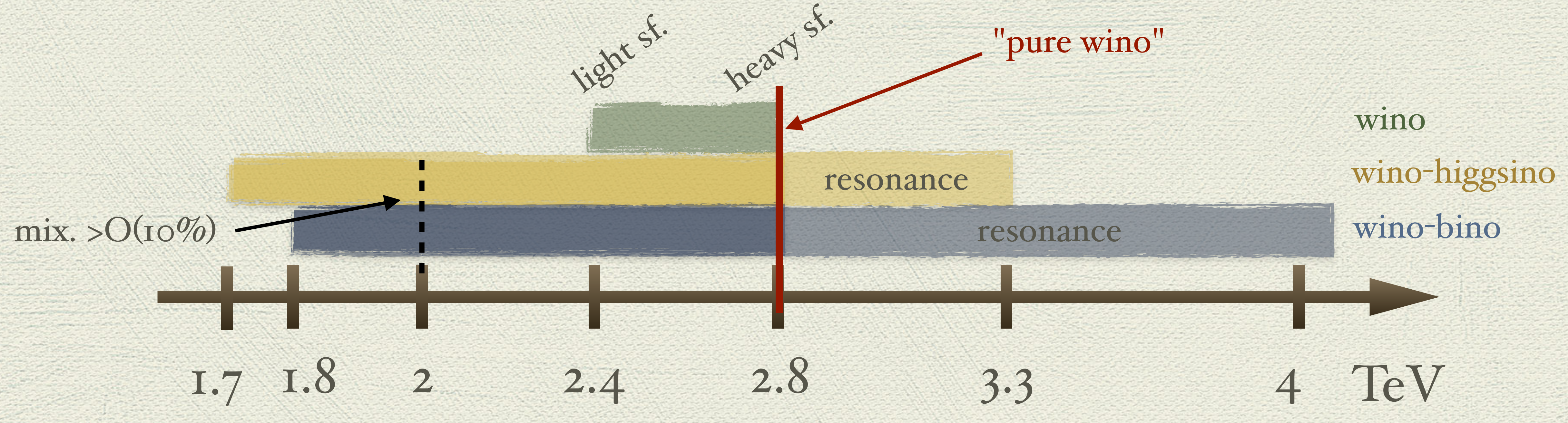

2. SE effect > O(30%) plus resonance ⇒ large ID signals

(already constrained - work in progress...)

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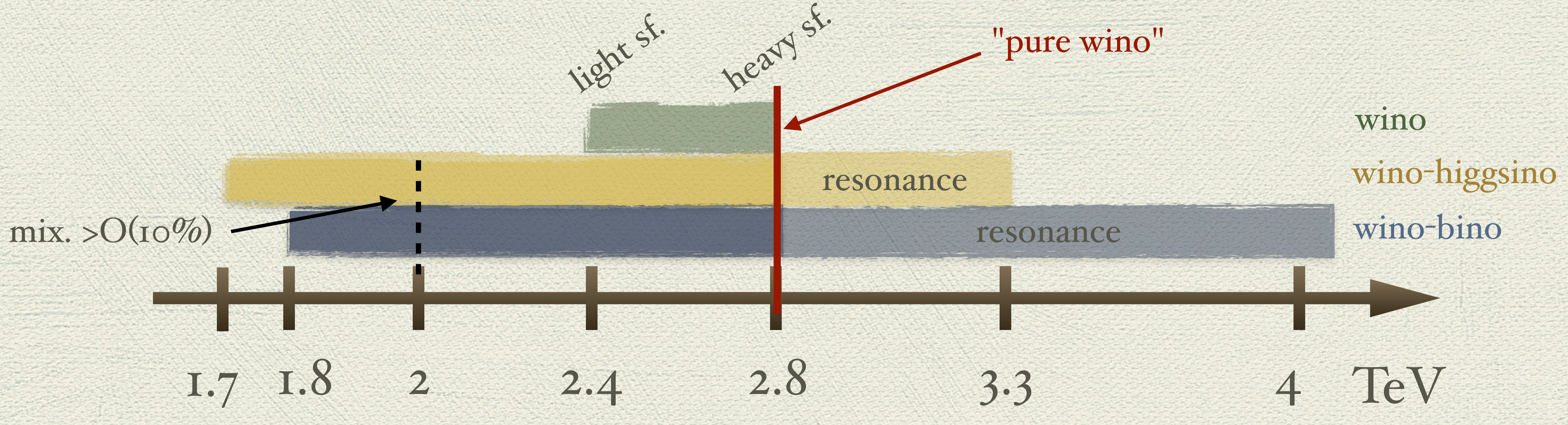


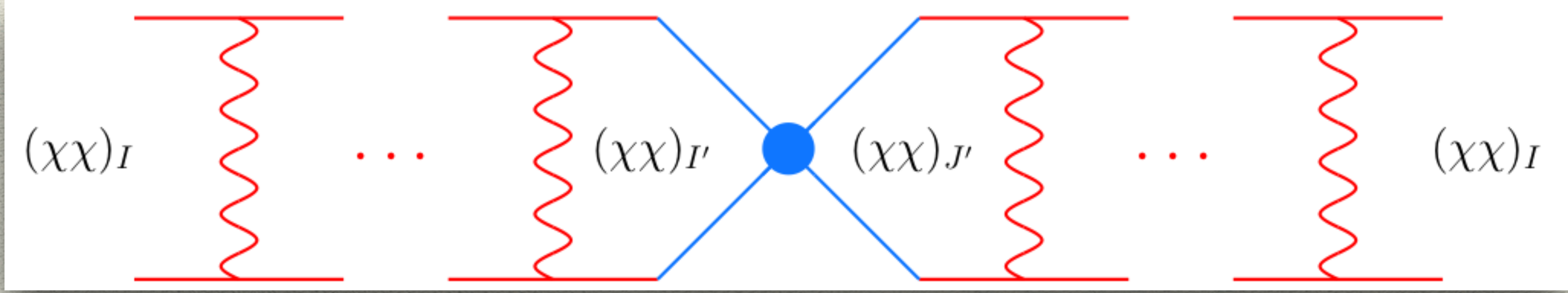
2. SE effect > O(30%) plus resonance $\Rightarrow$ large ID signals

(already constrained - work in progress…)

Public code including full SE in the MSSM with accuracy for relic density O(%) and running time O(min) to become available

Backup slides

Optical theorem + effective field theory lead to:



$$\sigma^{(\chi\chi)_I \to \text{light}} v_{\text{rel}} = \sum_{wave} S_I(wave)\, \hat{f}_{II}(wave)$$

$$S_I = \frac{[\psi_{II'}]^* \hat{f}_{I'J'} [\psi_{J'I}]}{\hat{f}_{II}}$$

Long-range potential
- energy scale $m_\chi v^2$
- non-perturbative effect
- solve a Schrödinger eq.

Short-range annihilation
- energy scale m_χ
- NR effective theory
- Wilson coeffs. of local operators
- off-diagonal reactions needed

The Sommerfeld enhancement

What is known?

- pure wino, pure higgsino

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- mixed wino-higgsino (with everything else decoupled)

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Only available tool for the MSSM:

DarkSE package

Hryczuk, '11

The Sommerfeld enhancement

New framework by Beneke, Hellmann, Ruiz-Femenia '12, '13, '14

1. the Sommerfeld effect for P- and $O(v^2)$ S-wave
2. off-diagonal annihilation matrices

not present in DarkSE
total effect up to O(10%)

New code (to be public):

- suitable for full MSSM
- using EFT computation of annihilation matrices
- one-loop on-shell mass splittings and running couplings
- present day annihilation in the halo (for ID)
- accuracy at O(%), dominated by theoretical uncertainties of EFT

caveat: still no NLO effects...

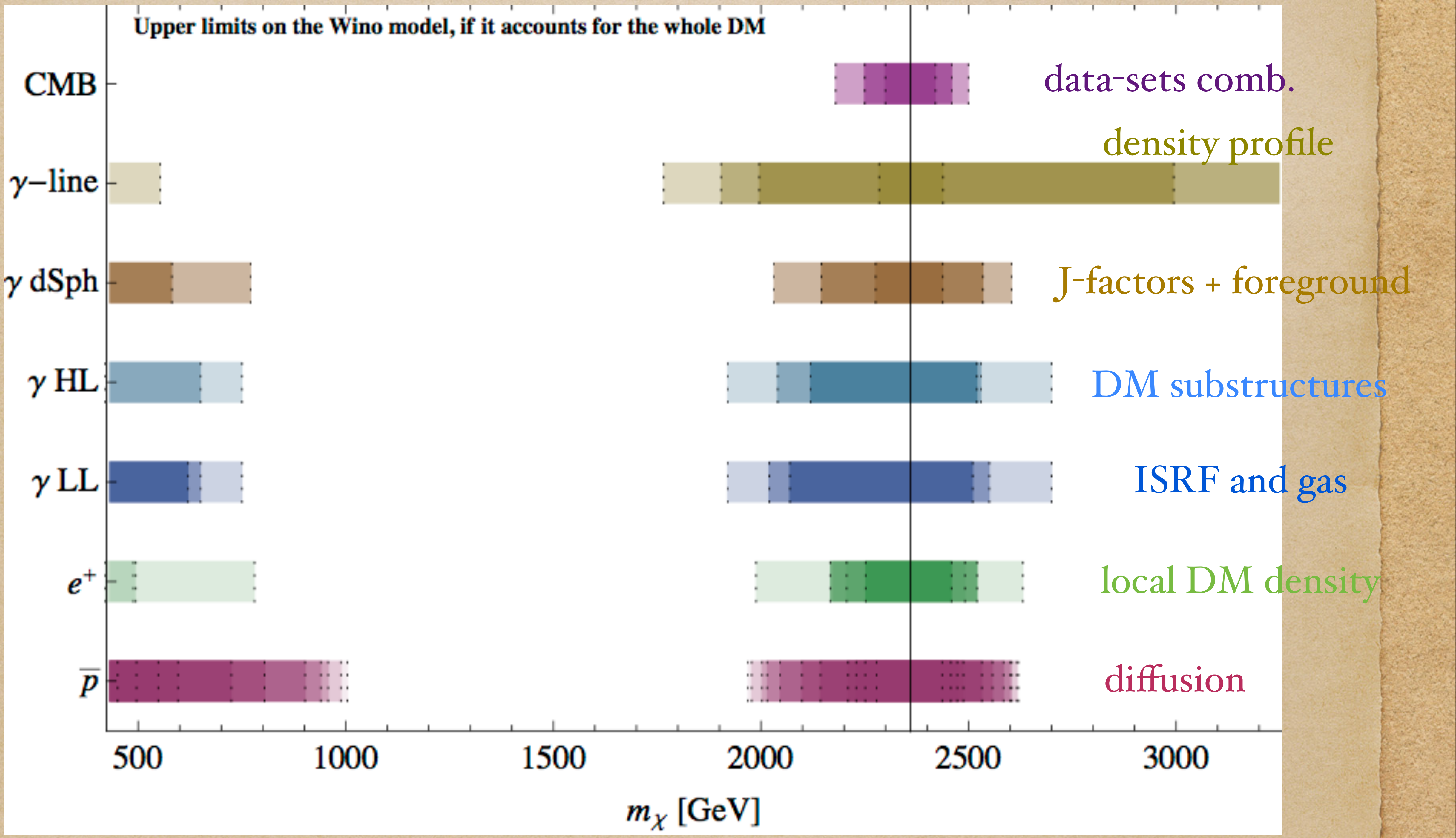
Parameter ranges

Parameter	Range
M_2	1 - 5 TeV
$\|\mu\| - M_2$	0 - 500 GeV
$\|M_1\| - M_2$	0 - 500 GeV
$M_{\rm sf}$	1.25 M_2 - 12 TeV
$\|A_f\|$	1 - 10 TeV
$\tan\beta$	5 - 30
M_{A^0}	0 - 8 TeV
M_3	1.25 M_2 - 8 TeV

Central parameters
wino-like LSP mass
higgsino and bino fractions
common sfermion mass

Residual parameters

LIMITS ON WINO DM
UNCERTAINTIES



AH, I. Cholis, R. Iengo, M. Tavakoli, P. Ullio; JCAP 1407 (2014) 031