Dark matter indirect detection limits from complete annihilation patterns

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Dark matter indirect searches

Dark matter accounts for about 26% of the energy content of our Universe

$$\Omega_{\rm CDM} h^2 = 0.1200 \pm 0.0012$$

Planck (2018)

Indirect detection invokes the dark matter annihilation cross-section

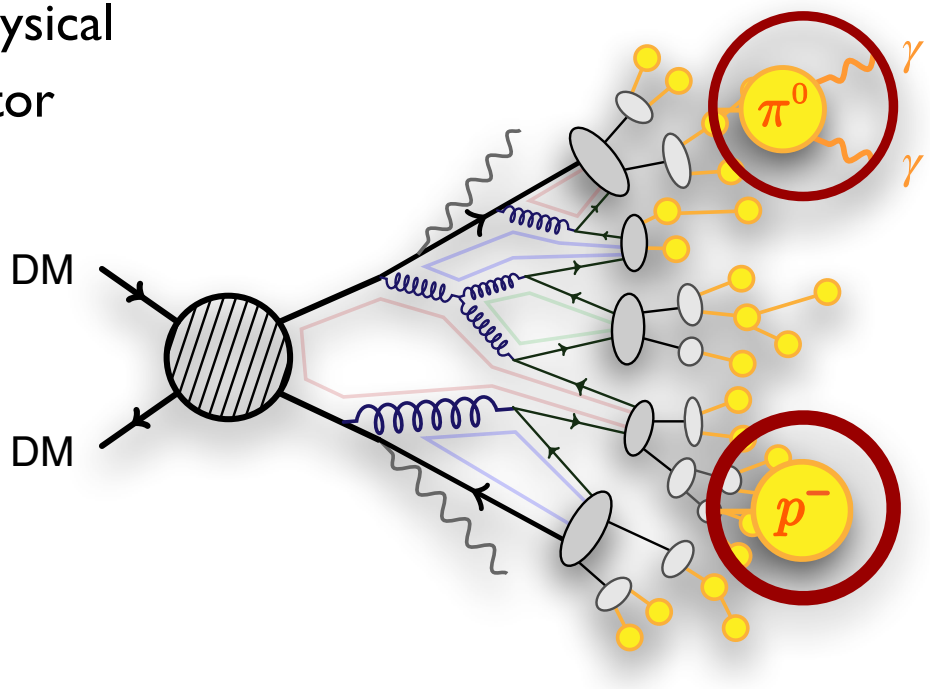
$$\frac{{\rm d}\Phi}{{\rm d}E} = \frac{1}{4\pi} \frac{\langle \sigma v \rangle}{2 m_\chi^2} \sum_f {\rm BR}_f \frac{{\rm d}N_f}{{\rm d}E} \int_{\Delta\Omega} \int_{\rm los} \rho_{\rm DM}^2 \, {\rm d}s \, {\rm d}\Omega$$

Particle physics Information

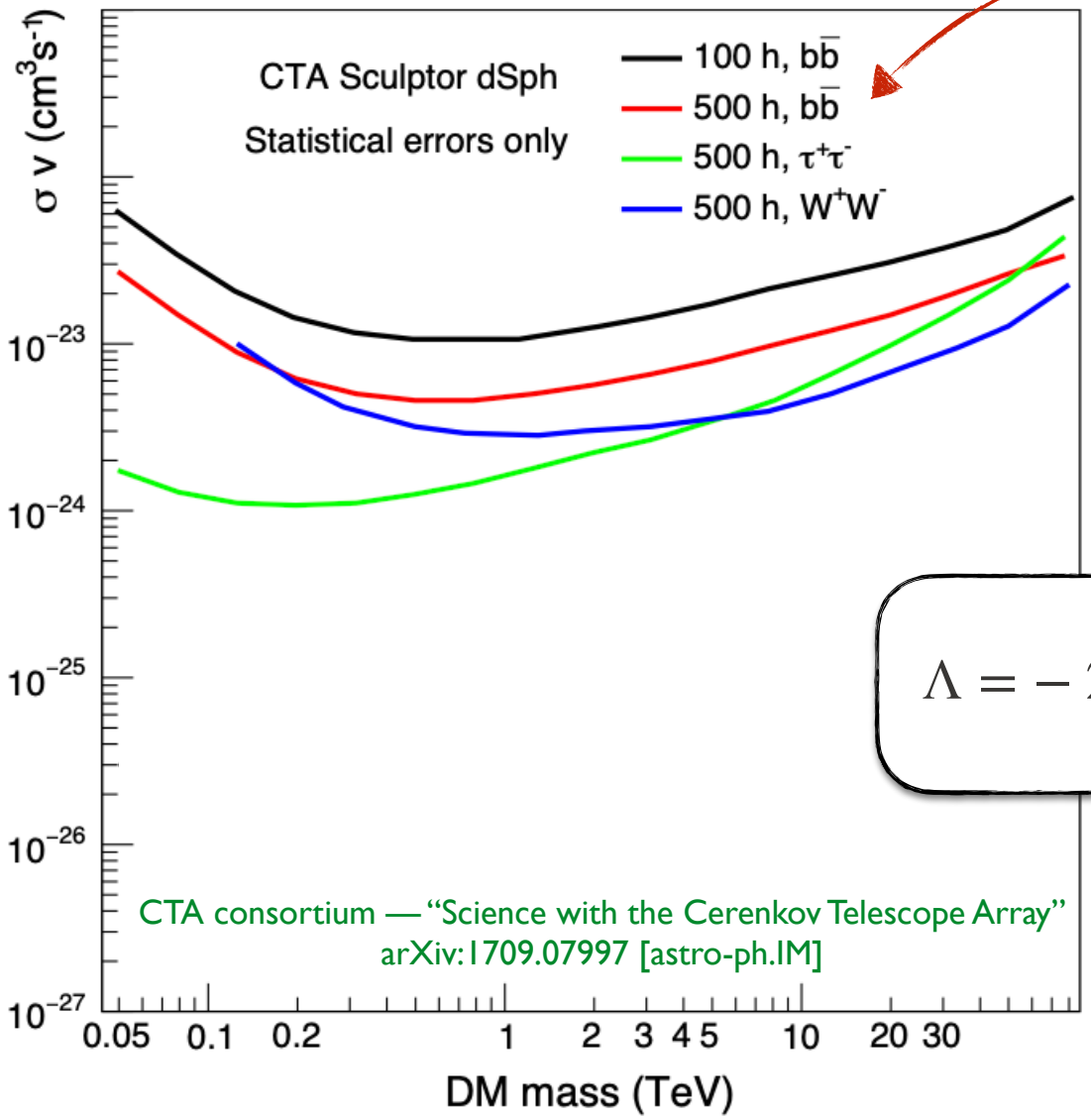
Astrophysical *J*-factor

$\langle \sigma v \rangle$, m_χ, ${\rm BR}_f$

Parameters of interest



Dark matter indirect detection limits



Assumption: **100% BR**

???

$$\Lambda = -2\ln\frac{\mathscr{L}_{H_0}}{\mathscr{L}_{H_1}} = -2\ln\frac{\mathscr{L}(\langle\sigma v\rangle_0 \,|\, \hat{N}_B, \hat{J})}{\mathscr{L}(\langle\hat{\sigma v}\rangle, \hat{N}_B, \hat{J})}$$

Log-likelihood test statistics

Cowan *et al.* (2010)

Is this hypothesis realistic…?

(and, if not, what is the impact…?)

Singlet scalar dark matter

$$V_{\text{scalar}} = 2\lambda_H v^2 h^2 + \frac{1}{2}\mu_S^2 S^2 + \frac{1}{4}\lambda_{\text{SH}} v^2 S^2 + \frac{1}{4}\lambda_{\text{SH}} v S^2 h + \lambda_{\text{SH}} S^2 h^2 + \ldots$$

Dark matter mass

$$m_S^2 = \mu_S^2 + \frac{1}{2}\lambda_{\text{SH}} v^2$$

Dark matter coupling

("Higgs portal")

Simplest extension of the Standard Model…

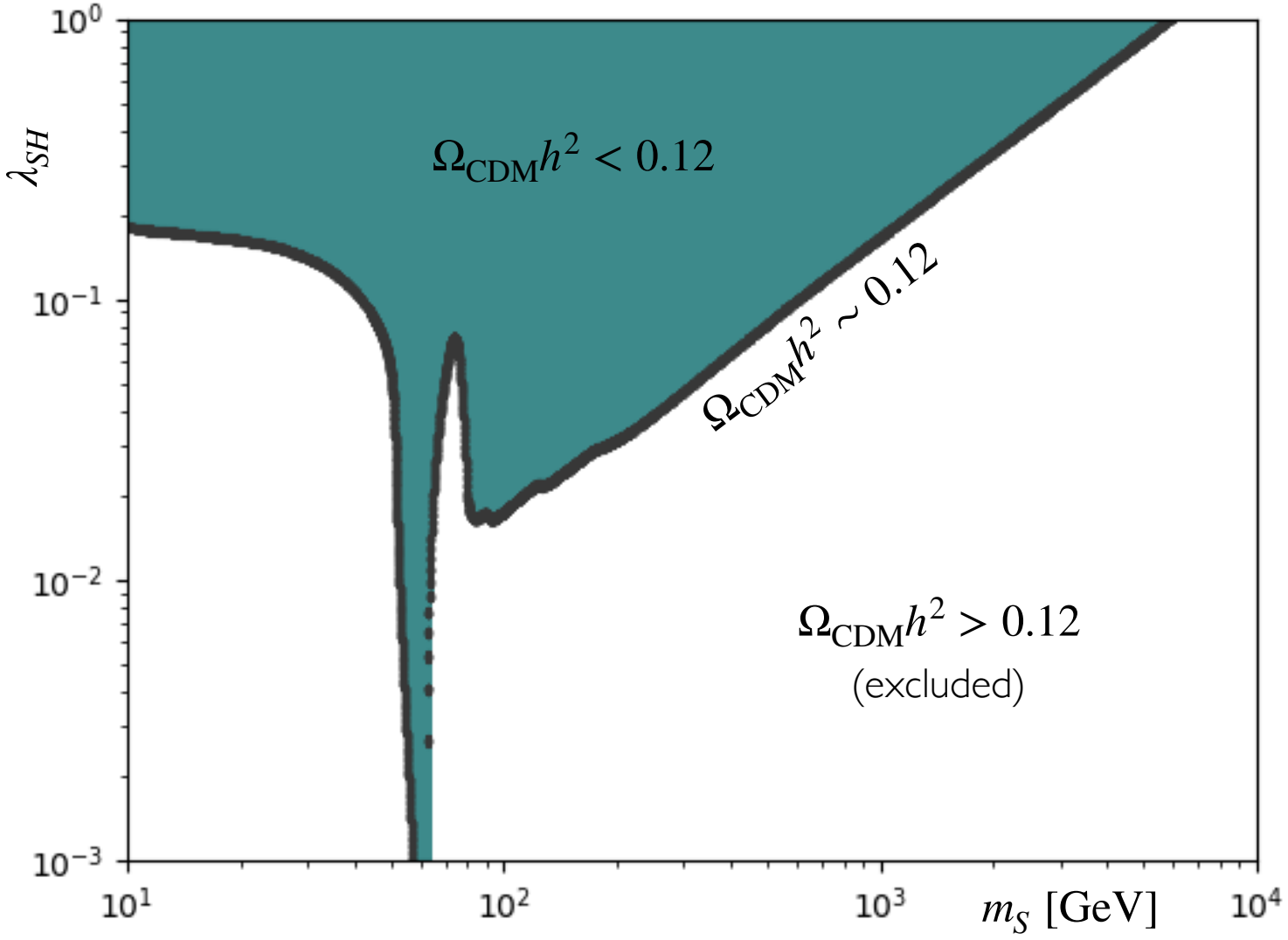
— dark matter: **real scalar singlet** (stable due to imposed $\mathbb{Z}_2$ symmetry)

— phenomenology (at the tree-level) governed by only **two parameters**:

$$m_S \sim 10\,\text{GeV} - 10\,\text{TeV}$$
$$\lambda_{\text{SH}} \sim 10^{-4} - 1$$

Dark matter annihilation into: gauge bosons, Higgs bosons, quarks, leptons

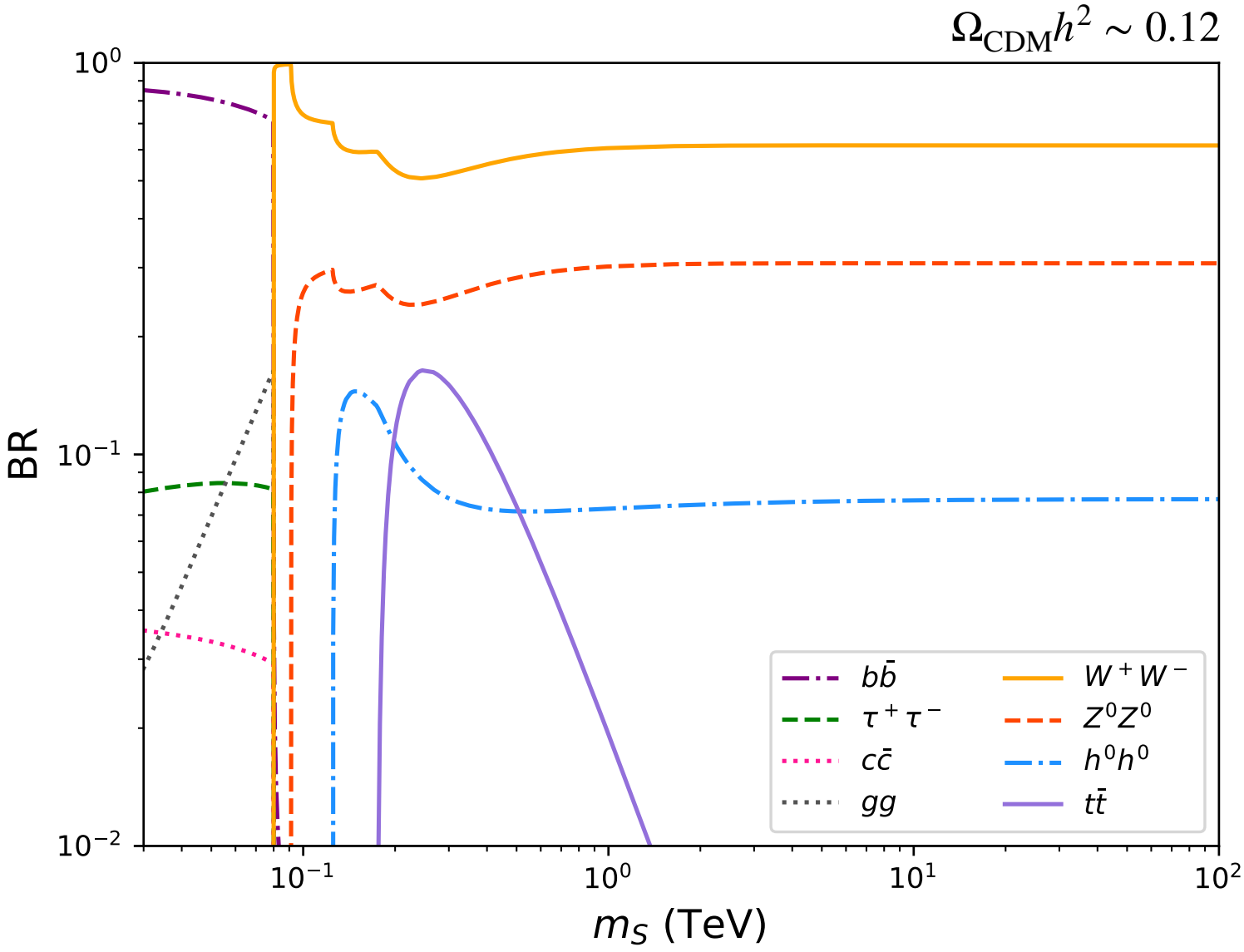
Singlet scalar dark matter



Dark matter relic density / annihilation channels computed using micrOMEGAs

G. Bélanger, A. Pukhov *et al.* (2003-2023)

Singlet scalar dark matter

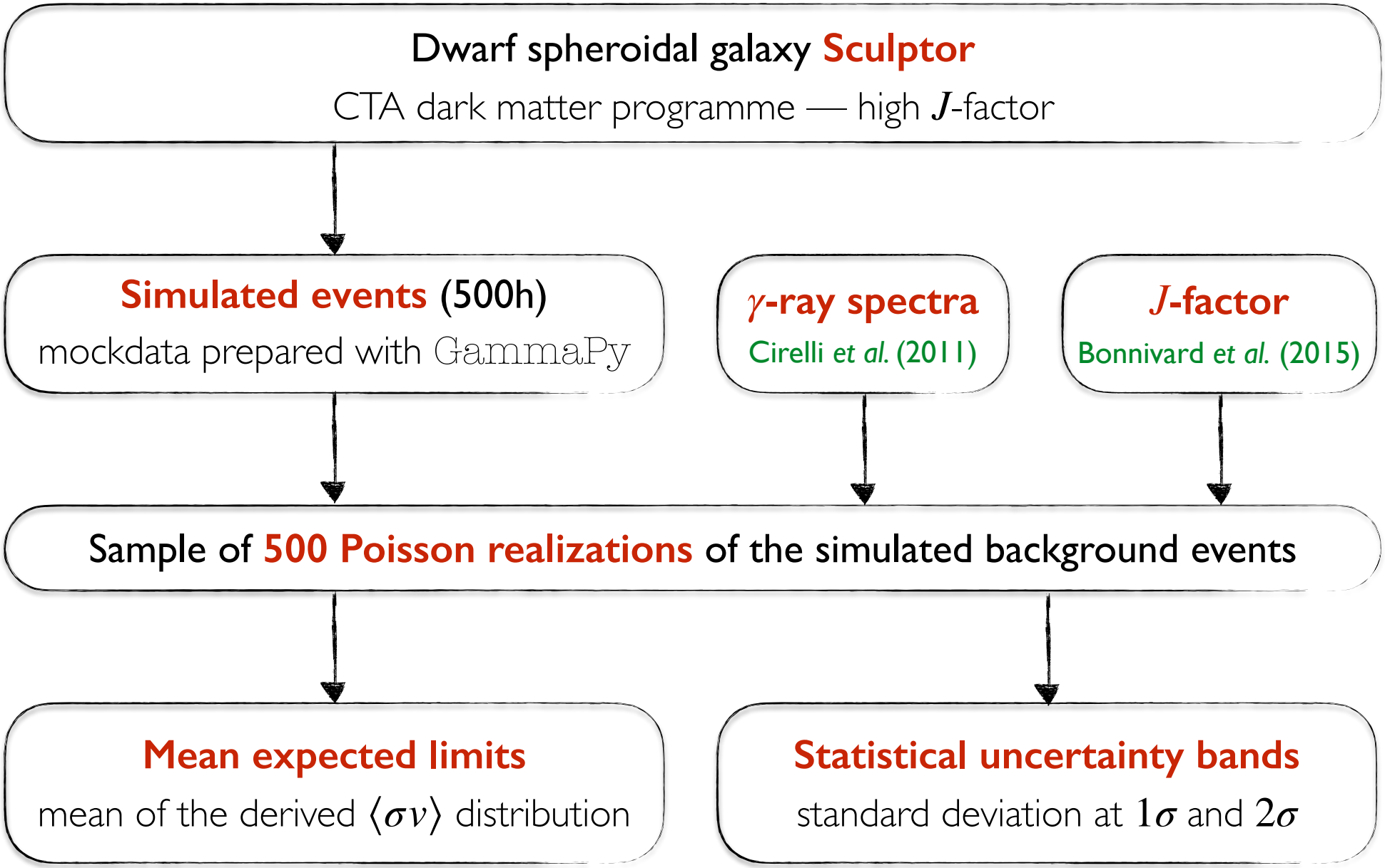


⟶ Hypothesis of a single annihilation channel (almost) never satisfied !!!

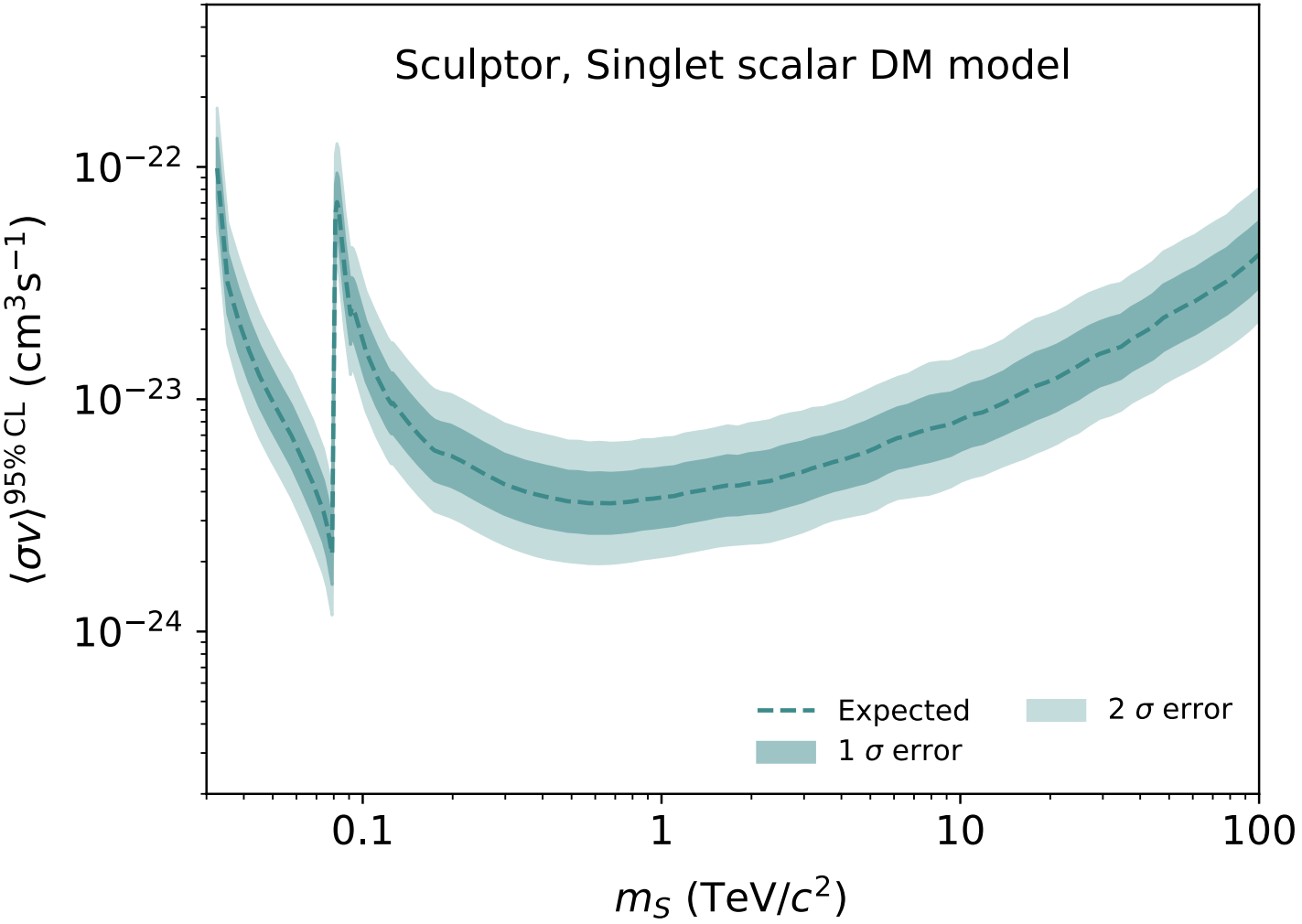
Even in such a simple setup,
the "100% hypothesis" is not justified...

More complex (i.e. more realistic) frameworks
invoke an even richer phenomenology…

New analysis with complete annihilation pattern

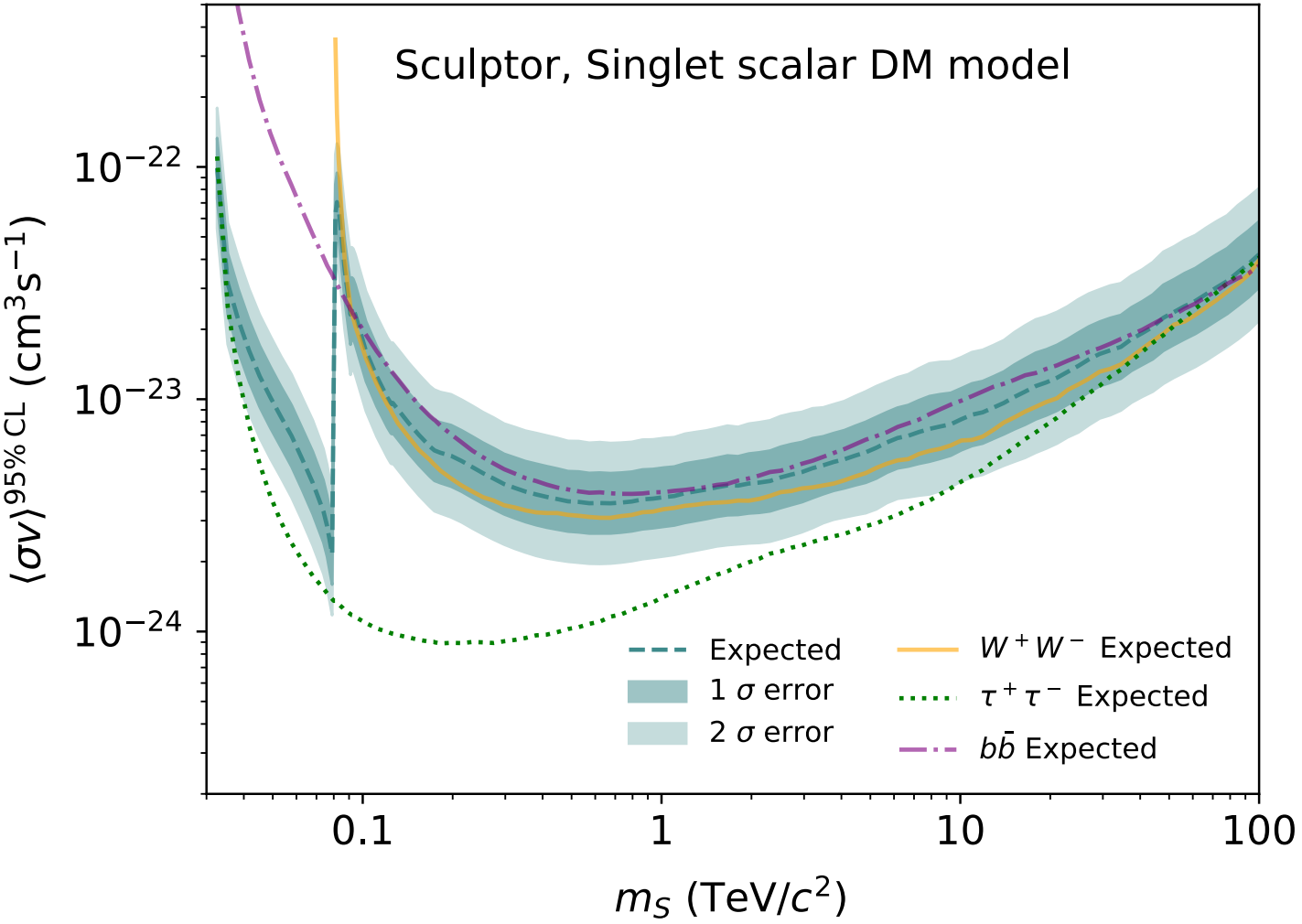


Results for singlet scalar dark matter



Shape of exclusion limit influenced by **Higgs resonance** (inflection point) and the opening of **additional channels** (e.g. WW final state)

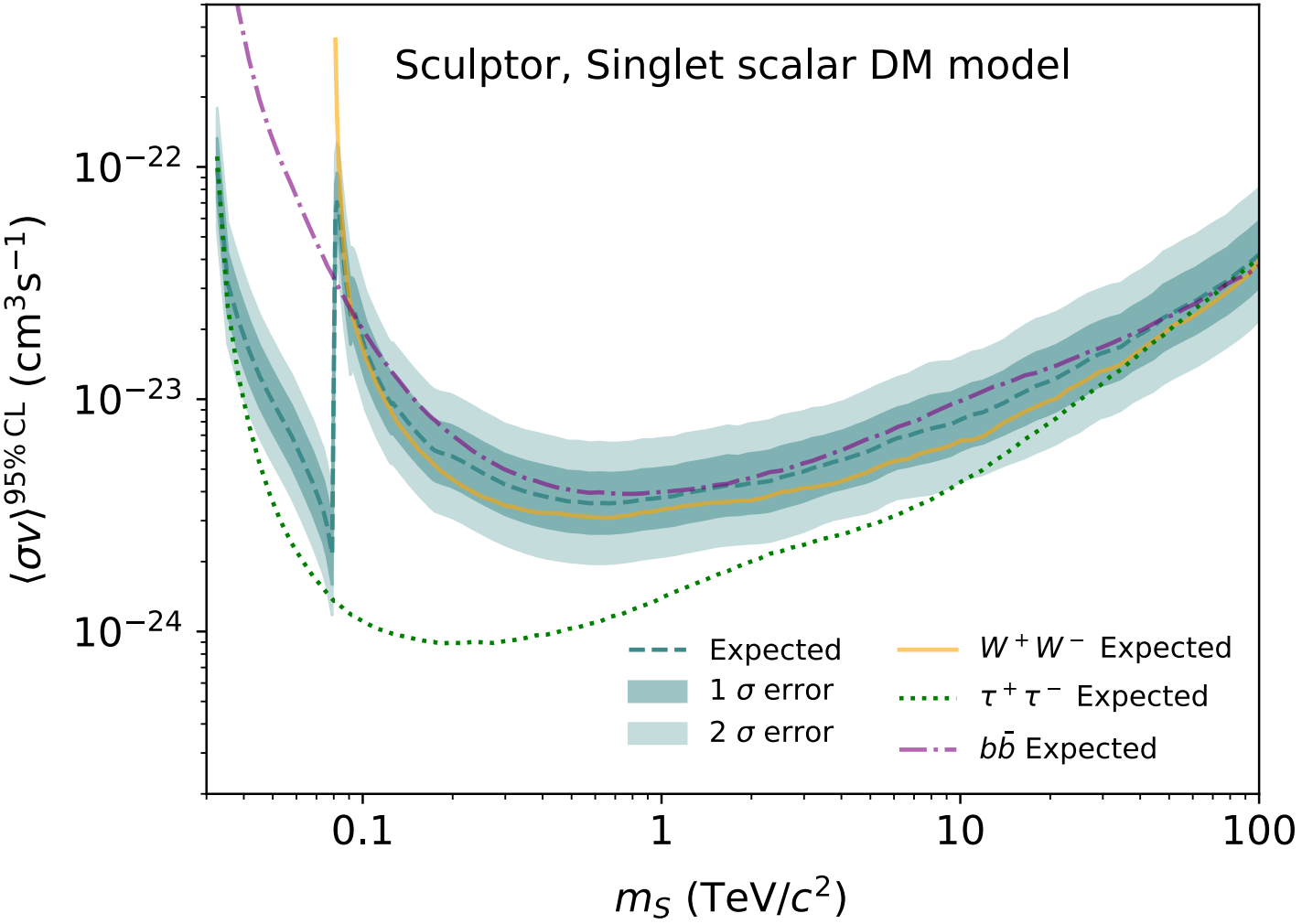
Comparison with single-channel analysis (W^+W^-)



We obtain a **more conservative limit** (due to additional contributions)

Shape similar to W^+W^- alone (hh and ZZ final states lead to similar gamma-ray spectra)

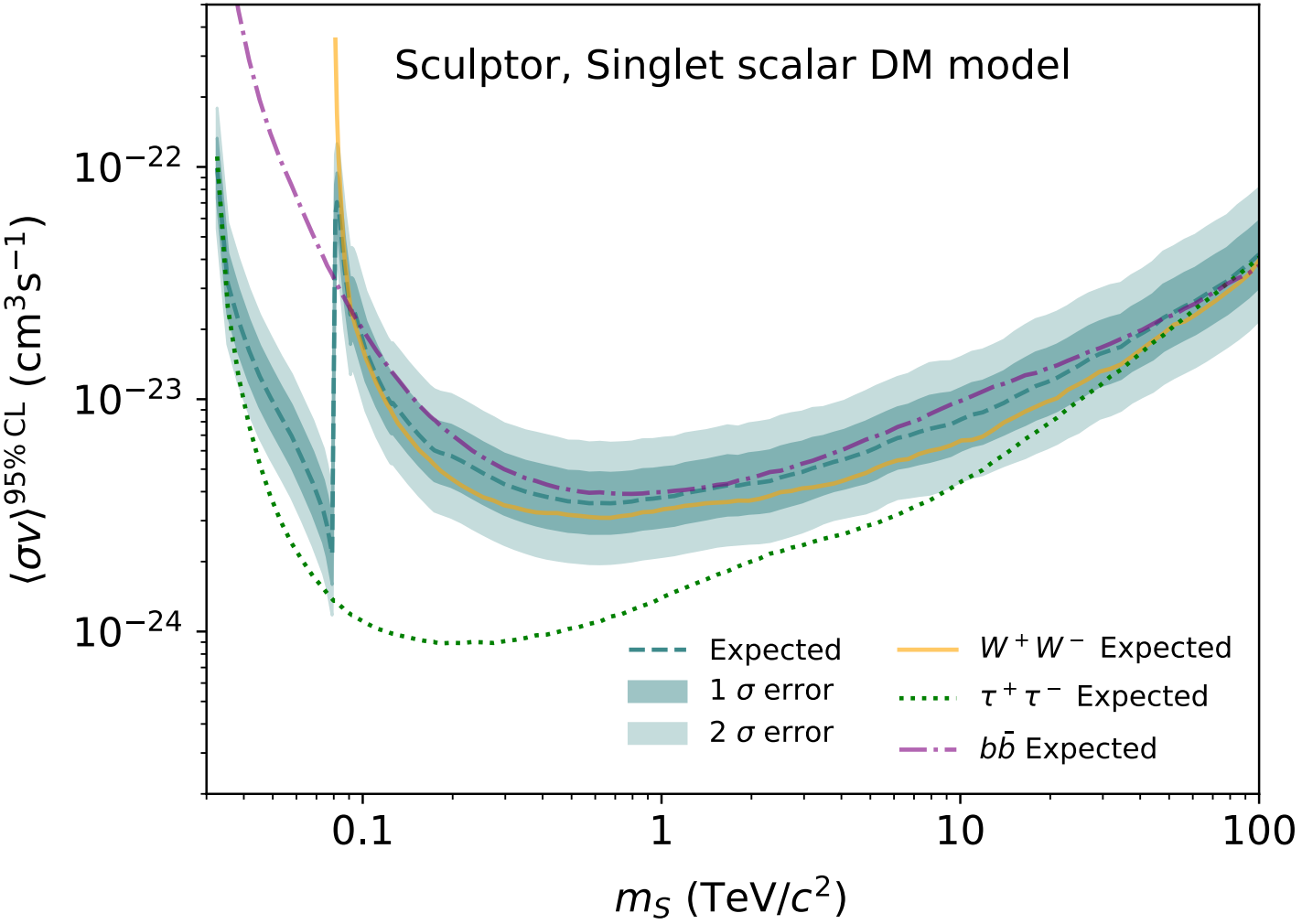
Comparison with single-channel analysis $(\tau^+\tau^-)$



We obtain a **less constraining limit** ($\tau^+\tau^-$ final state never dominant in this model…)

Assuming 100% $\tau^+\tau^-$ leads to over-estimation of the contribution…

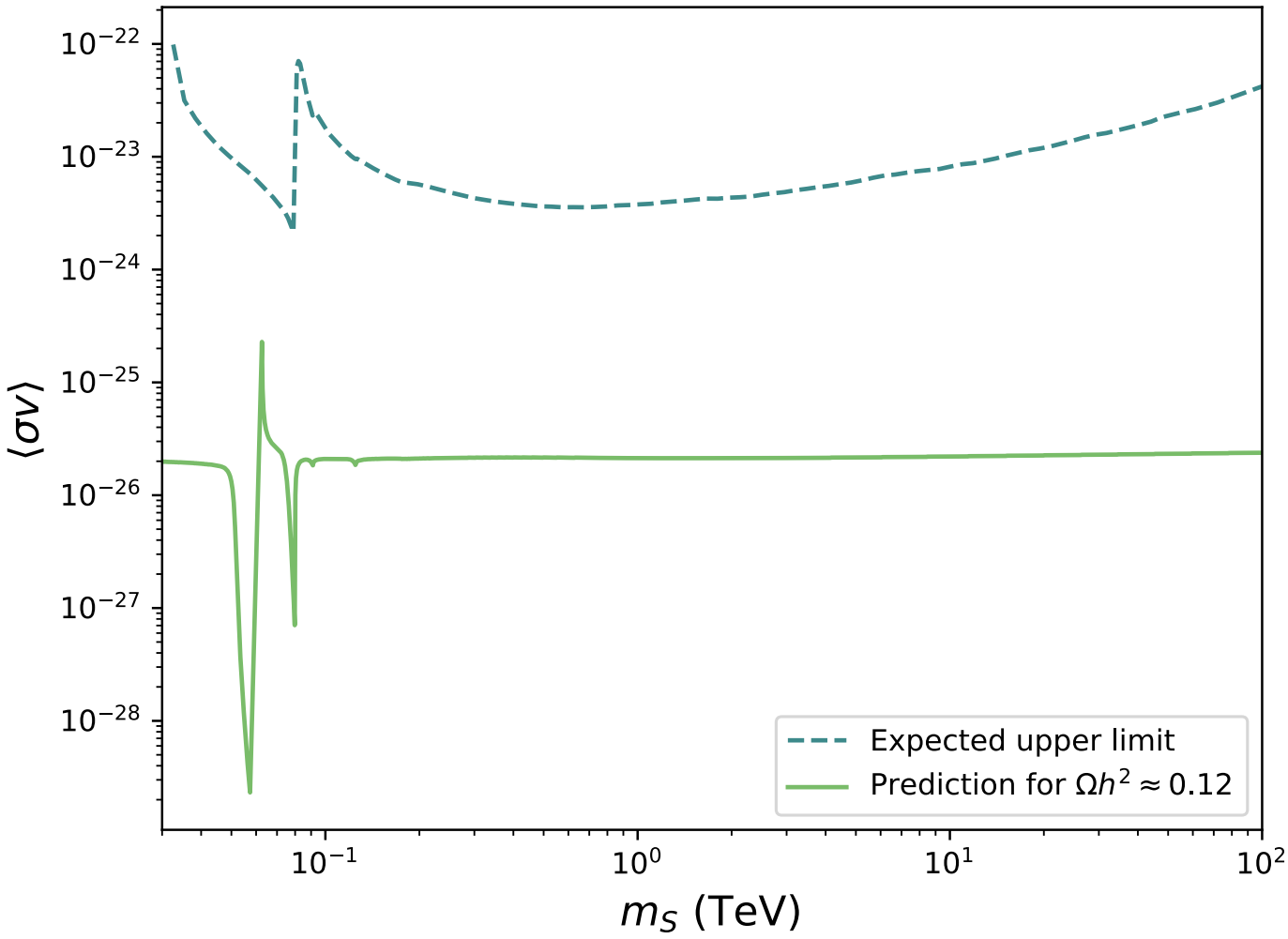
Comparison with single-channel analysis $(b\bar{b})$



$m_S < m_W$: subdominant $\tau^+\tau^-$… we obtain **more constraining upper limit**

$m_S > m_W$: $b\bar{b}$ channel suppressed…

Exclusion limit for singlet scalar dark matter



Singlet scalar DM **not excluded** by our analysis

Resonances and **kinematical thresholds** influence the exclusion limit… !!!

Conclusion

Indirect dark matter searches provide important limits on new physics models

However, the hypothesis of a single annihilation channel is typically not satisfied…

— example of singlet scalar dark matter…

— same behaviour expected in more complete particle models!

Including the complete annihilation pattern may impact the obtained limits…

— under/over-estimation of given channels!

— complete analysis for singlet scalar dark matter assuming CTA observation of Sculptor

Recommendation: **Include full annihilation pattern when deriving limits in a specific particle physics model…**

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