A Global Analysis of Resonance-enhanced Light Scalar Dark Matter

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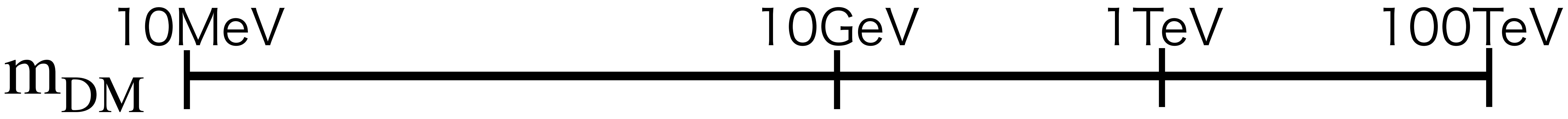
Light thermal DM

Thermal DM



Light Thermal DM

WIMP

- WIMP Miracle
- Connection to EWSB

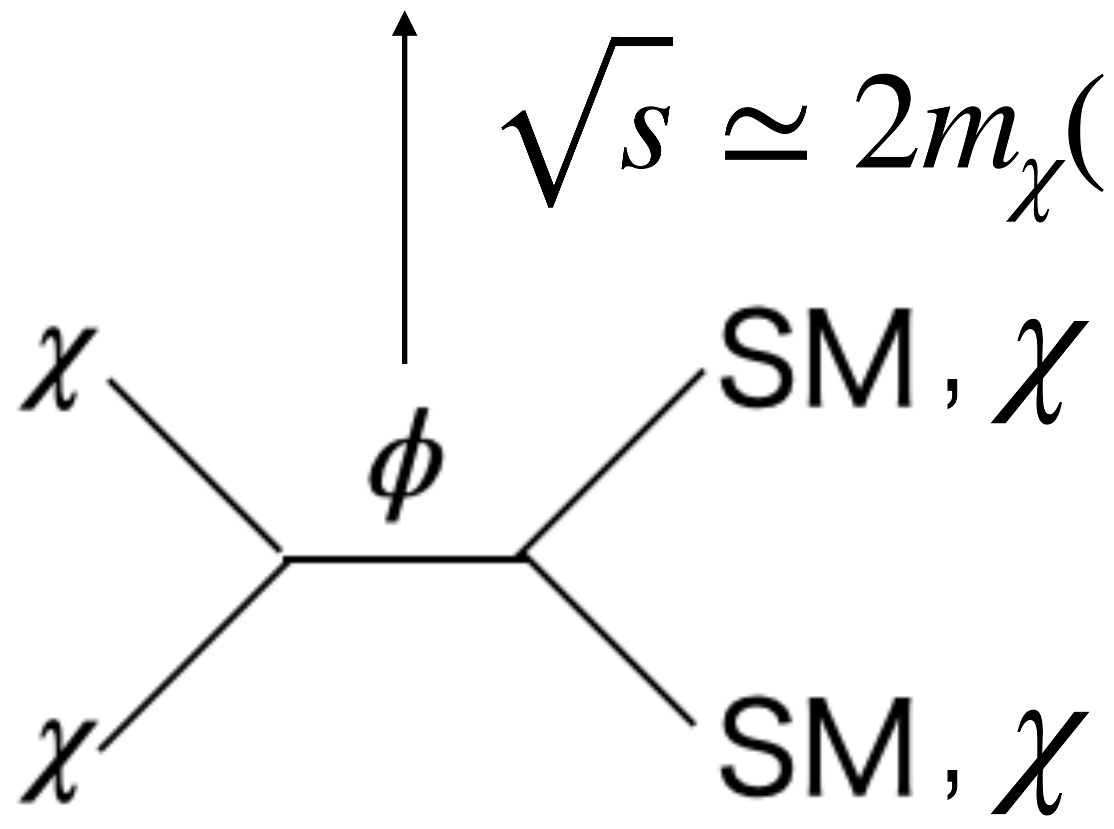
Can solve small scale problem, e.g. core-cusp

intensively searched for, but not found

Light thermal DM

$$1/(s - m_\phi^2 + i\Gamma)$$

$$\sqrt{s} \simeq 2m_\chi(1 + v^2/8)$$



- Light → singlet
  - Relic abundance → $\sigma \approx$ 1pb @ freeze-out
  - CMB → $\sigma <$ 1pb @ recommbination

→ • σ should be velocity dependent

p-wave, s-channel resonance, Sommerfeld, forbbiden…

→ • ∃singlet mediator

9 candidates; spin=0,1/2,1 for DM and mediator

We consider scalar DM and mediator

Model

- The most general renormalizable Lagrangian is

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{2}(\partial_\mu \chi)^2 - \frac{\mu_\chi^2}{2}\chi^2 - \frac{\lambda_{H\chi}}{2}|H|^2\chi^2 - \frac{\lambda_\chi}{4!}\chi^4$$
$$+ \frac{1}{2}(\partial_\mu \Phi)^2 - \frac{\mu_{\Phi\chi}}{2}\Phi\chi^2 - \frac{\lambda_{\Phi\chi}}{4}\Phi^2\chi^2 - V(\Phi, H),$$
$$V(\Phi, H) = \mu_{\Phi H}\Phi|H|^2 + \frac{\lambda_{\Phi H}}{2}\Phi^2|H|^2 + \mu_1^3\Phi + \frac{\mu_\Phi^2}{2}\Phi^2 + \frac{\mu_3}{3!}\Phi^3 + \frac{\lambda_\Phi}{4!}\Phi^4,$$

χ ⋯ DM

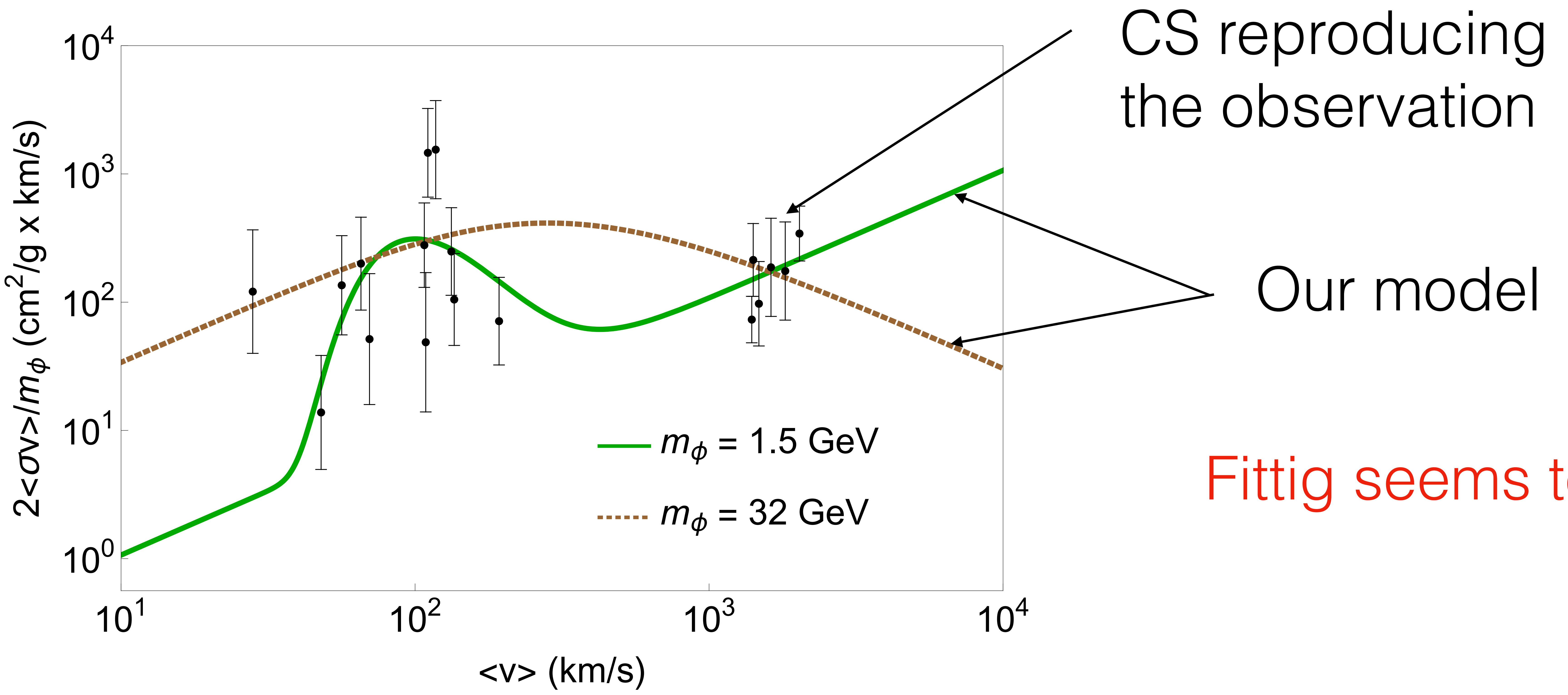
H ⋯ Higgs

Φ ⋯ mediator

Self-Scattering

- Core-cusp problem ··· mismatch of DM density profiles at GC prefered by simulation(cusp) and observation(core).

- Self-scattering of DM may solve this by thermalizing DM at GC.

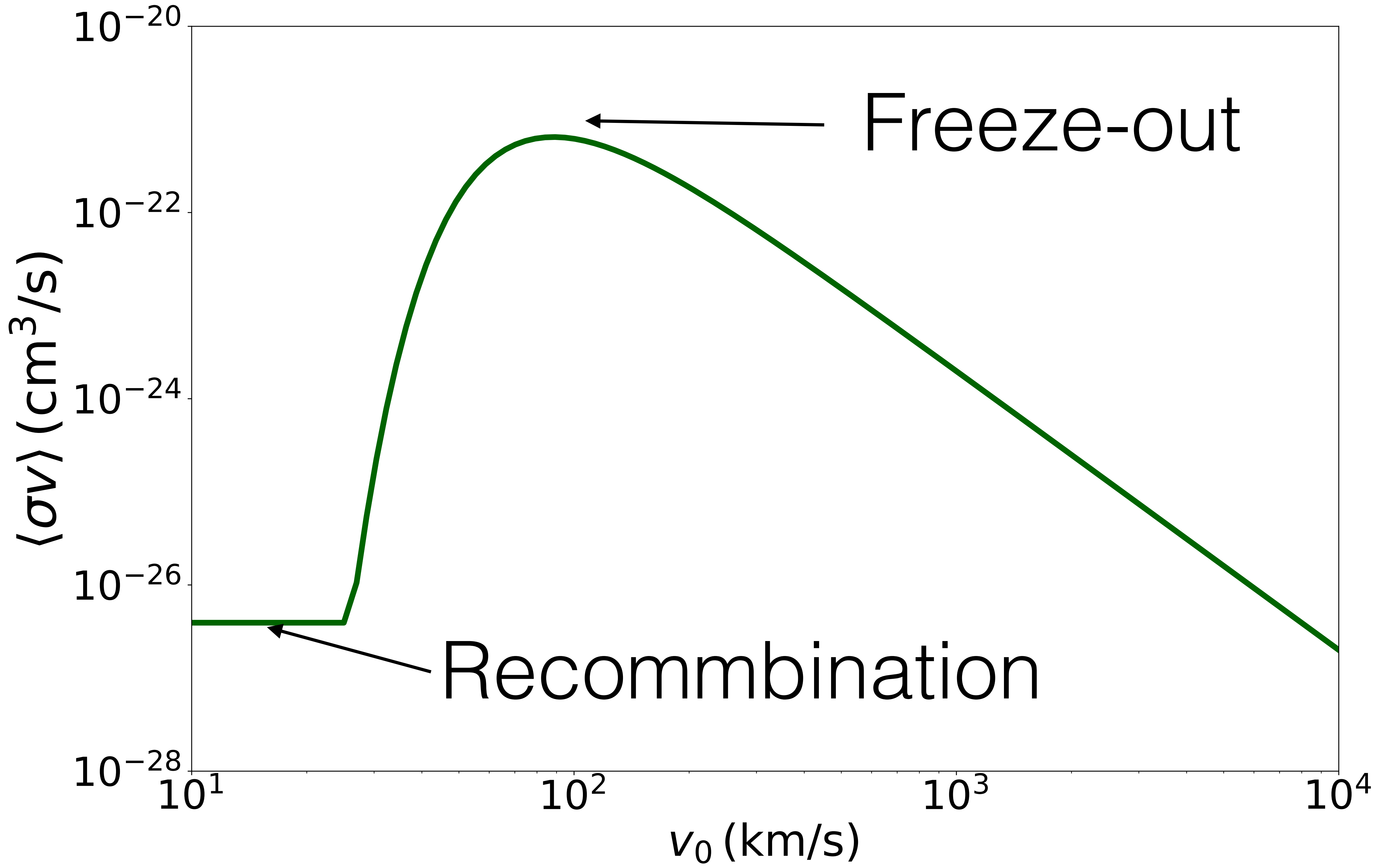


Fittig seems to be good.

CMB

- DM decoupling after ν decoupling alters expansion rate of universe. $N_{eff} \simeq 3 \rightarrow m_{DM} \gtrsim 10$ MeV

- Annihilation of DM into primordial plasma may modify anisotropy of the CMB $\rightarrow f_{eff} \langle \sigma v \rangle / m_\chi < 4.1 \times 10^{-28} \mathrm{cm}^3/\mathrm{s}/\mathrm{GeV}$

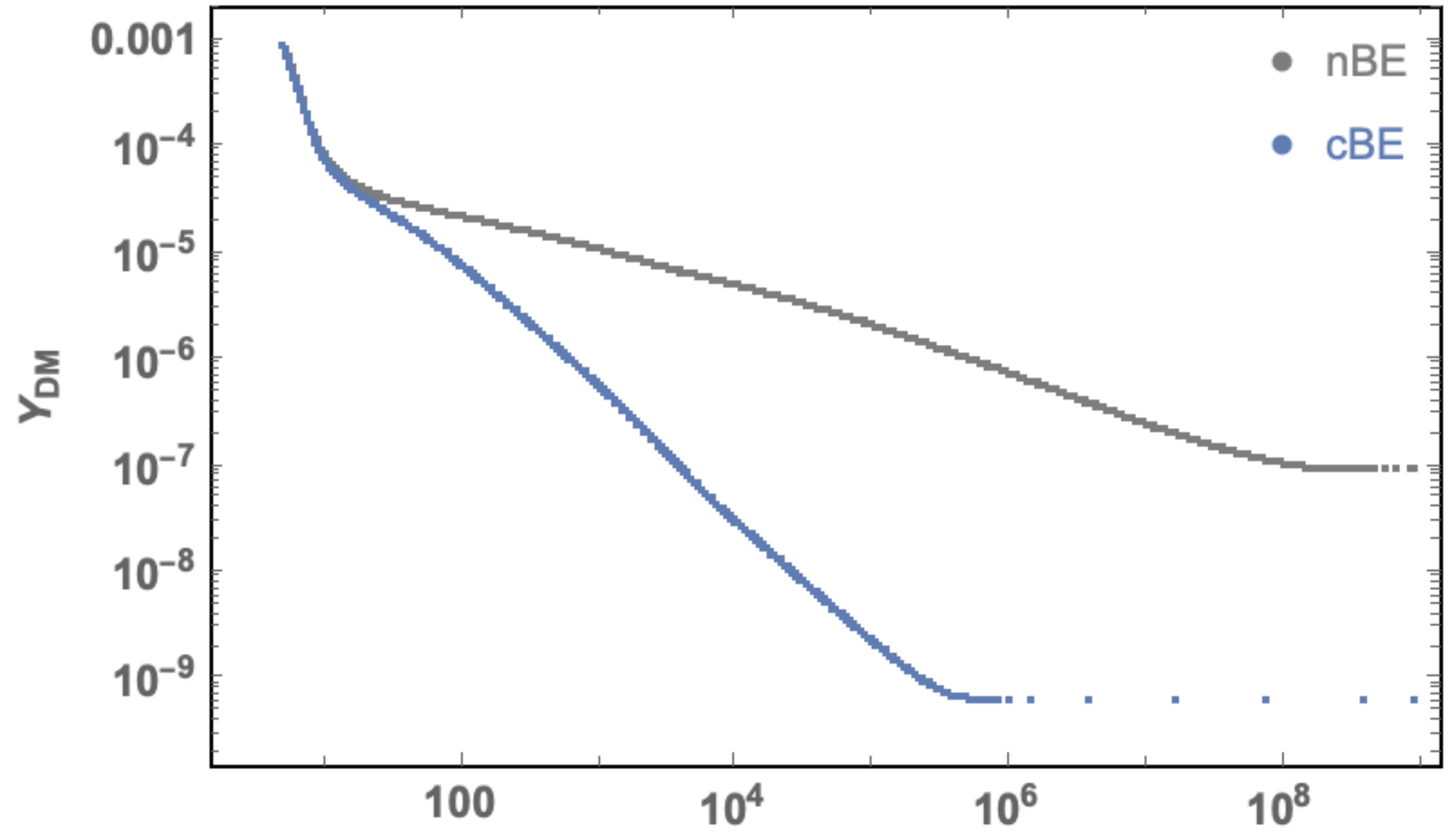


$\langle \sigma v \rangle$ can be enhanced(suppressed) at freeze-out(recommbination)

Relic abundance

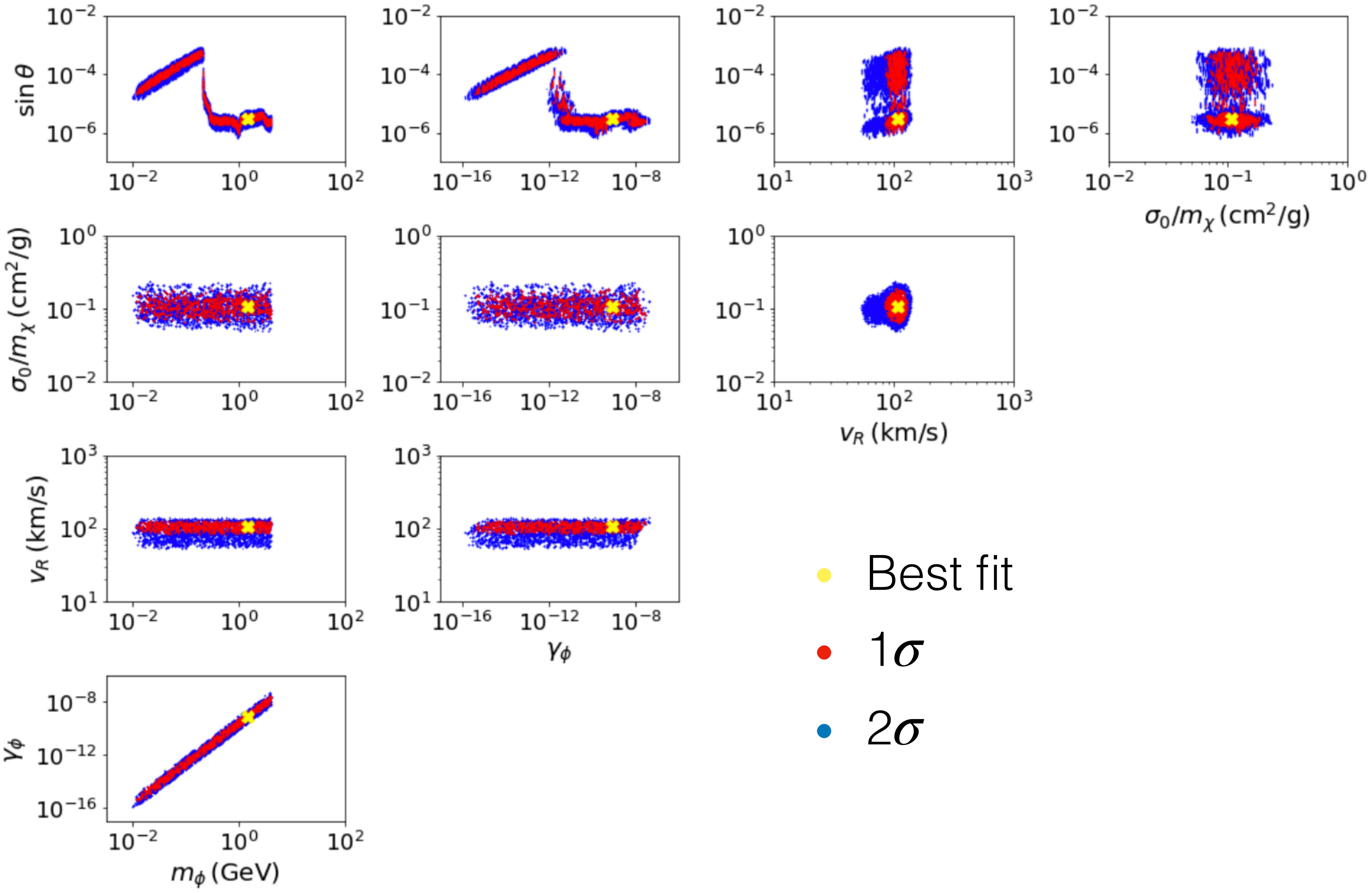
- We required that abundance of DM is thermally produced.

- S-channel resonance → Abundance continues to dicrease even after freeze-out.



- S-channel is enhanced, however t,u-channel are not enhanced.
  →Early kinetic decoupling

Favored parameter region



Experiments

1. Collider

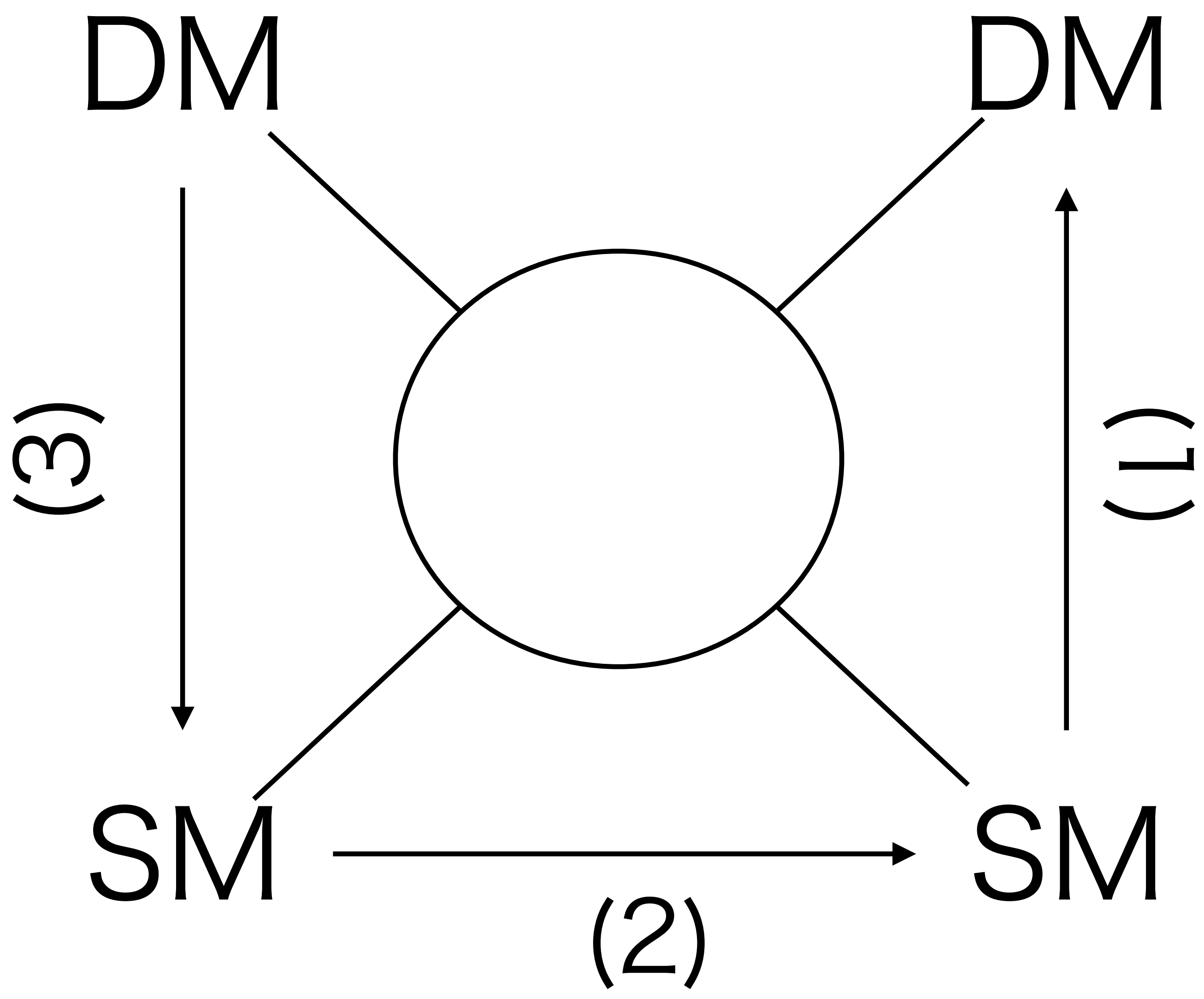
   Produce DM by collision of
   high energy SM particles

2. Direct detection

   Observe DM-SM scattering in
   underground laboratory

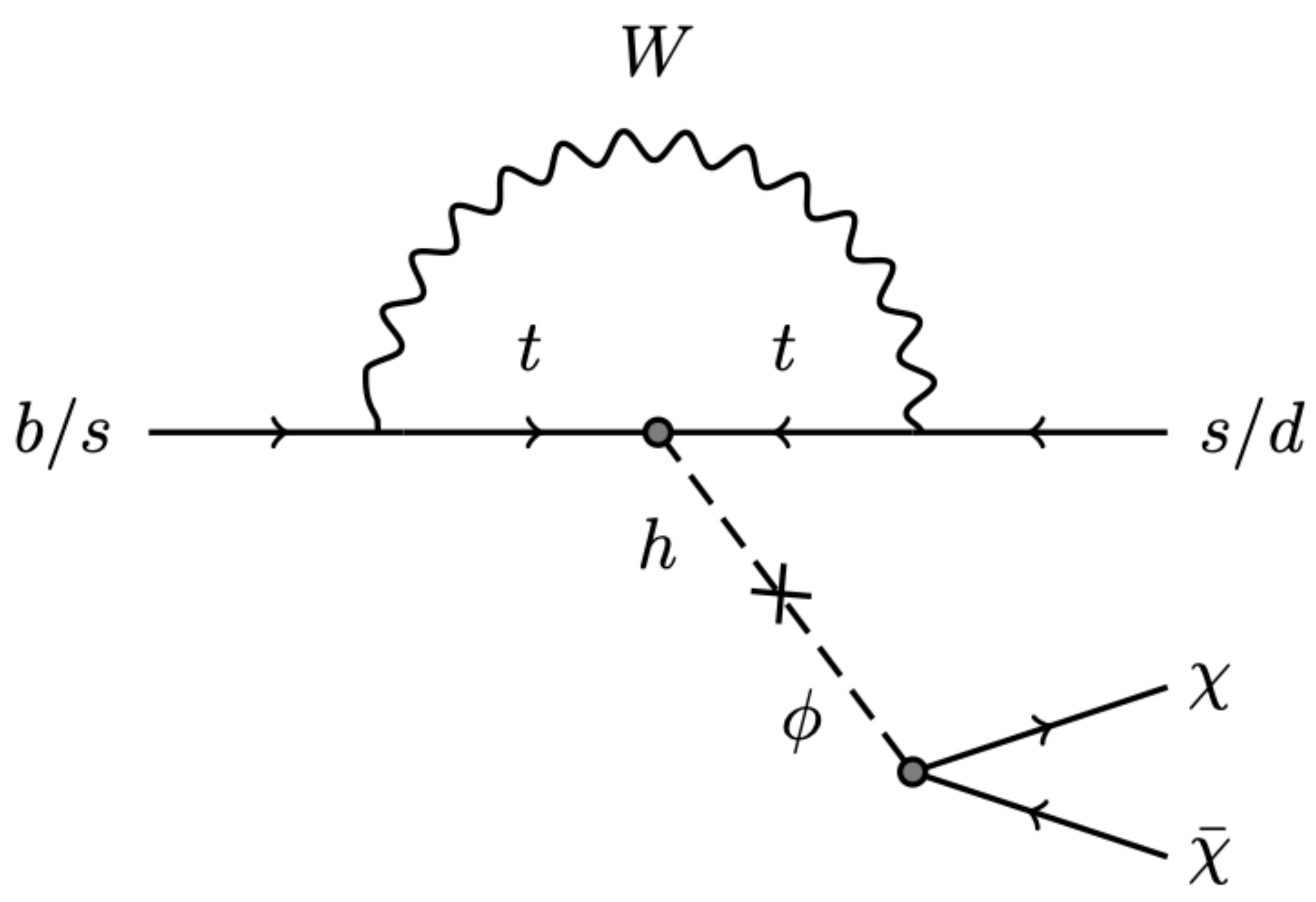
3. Indirect detection

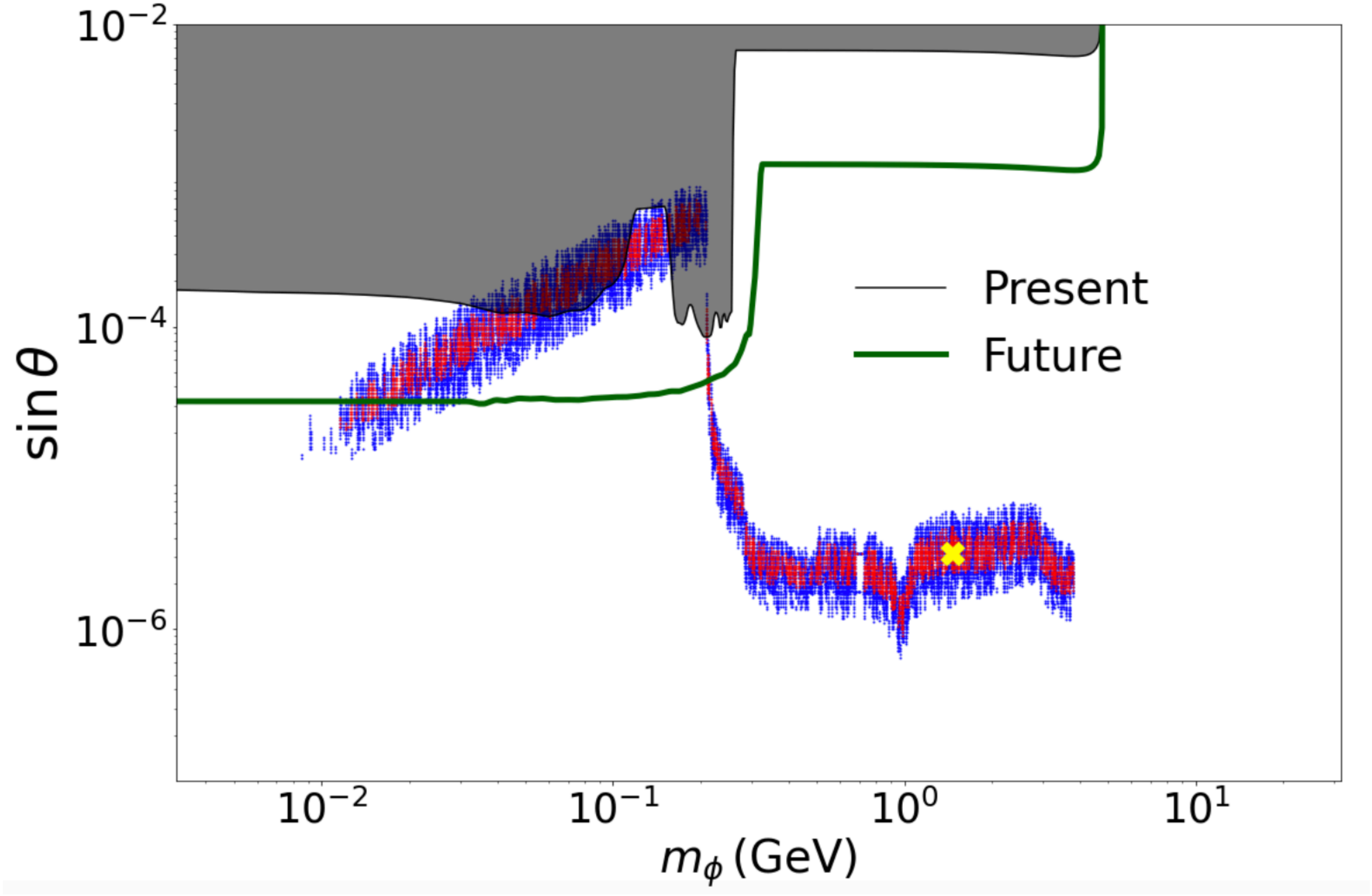
   Observe SM particles prodused
   by annihilations of DM



Collider

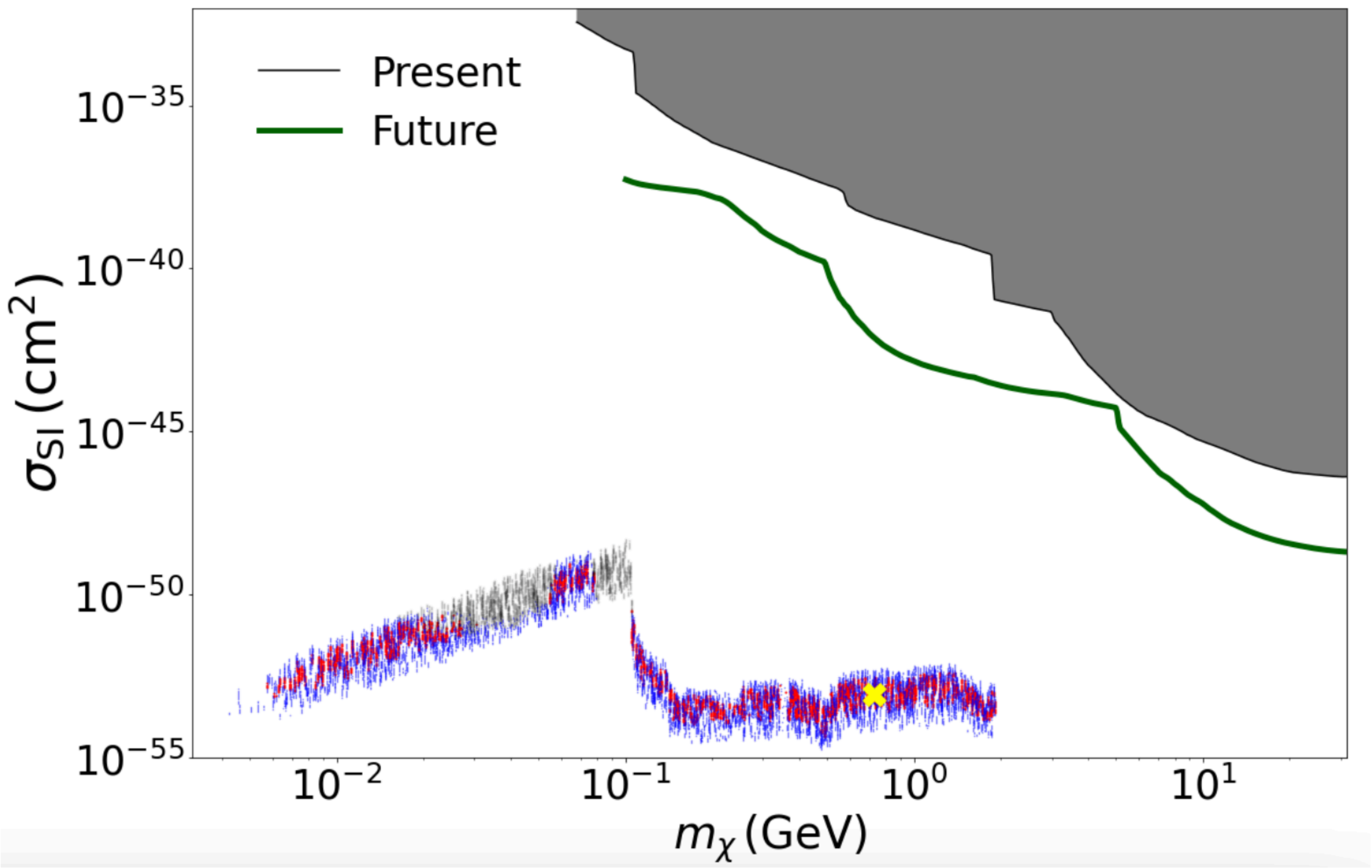
- $B^{\pm}, K^{\pm}, K_L \to K^{\pm}, \pi^{\pm}, \pi^0 + \Phi(\to \text{missing})$





- Several parameter sets are constrained.

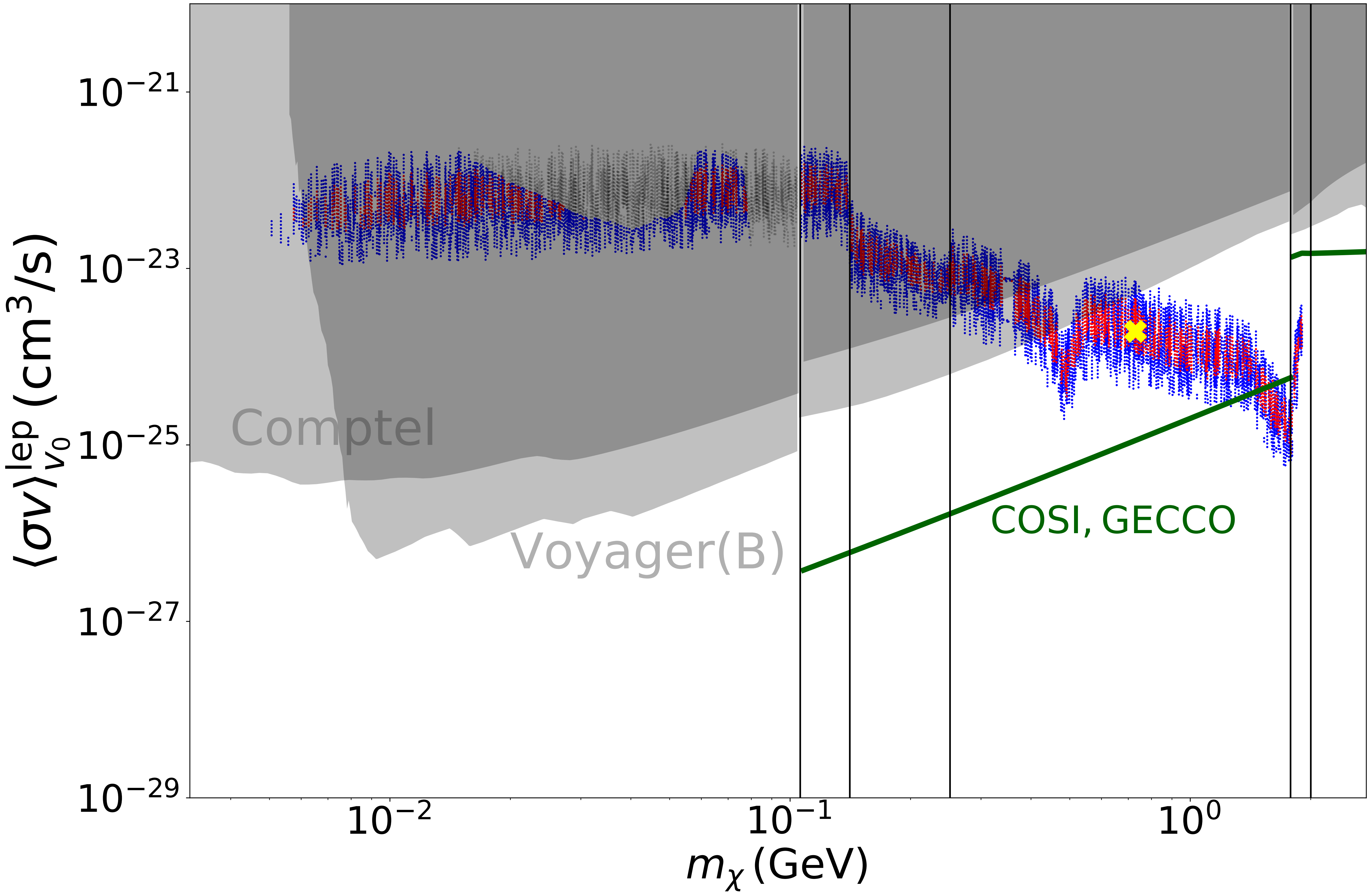
Direct detection



- Constraints are too weak because t,u-channel diagrams are not enhanced.

Indirect detection

- COMPTEL gives the most straingent constraint to γ.
- Voyager can observe $e^{\pm}$ produced by annihilation of DM.



- Several parameter survives at present.
- Almost all of them can be excluded in the near future.

MeV gap and huge uncertainties; J-factor, hadrons.

Summary

- **Light thermal DM with velocity-dependent $\langle \sigma v \rangle$** is an attractive DM candidate.

- As an example, we studied the model with **scalar singlet DM and mediator**.

- A part of attractive regions in which DM can solve core-cusp problem, explain the relic density and overcome the constraint from CMB is still **surviving** from constraints **at present** concerning the uncertainties.

- **Almost all** of these will be **constrained** by **near future** MeV γ-ray observations e.g. GECCO and COSI.