Prospect talk - Physics

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What is the physics beyond the standard model?

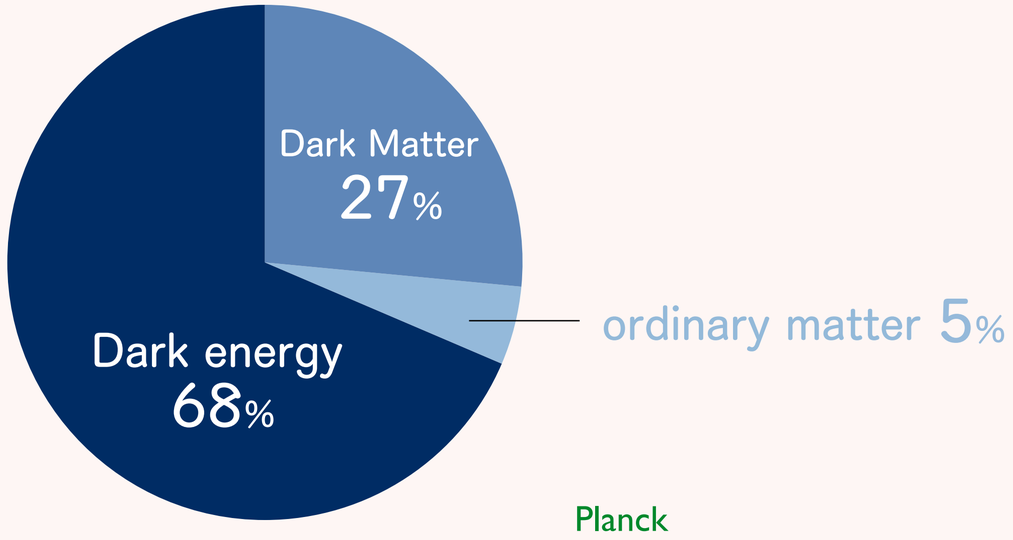
experiments

- collider
- DM direct and indirect detection
- neutrino detectors (SK, HK, …)
- EDM measurements
- g-2 measurements
- …

- We need hints from experiments
- synergy of experiments is important to test BSM models

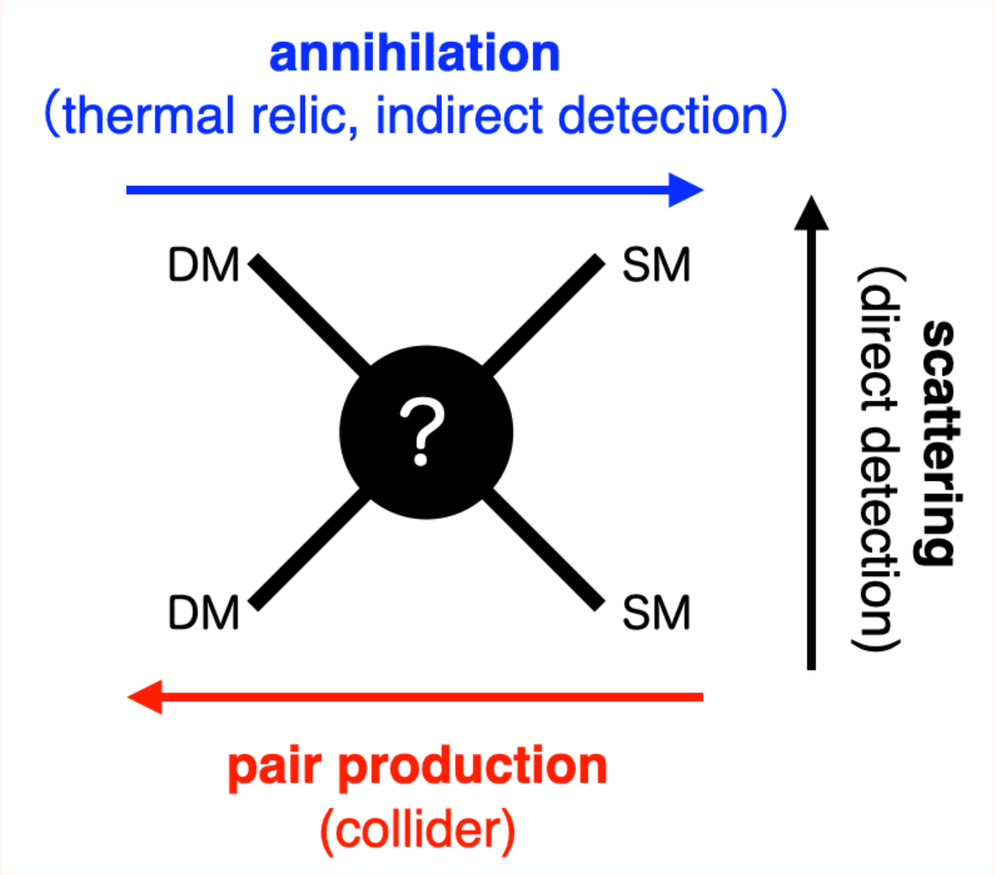
Dark matter

- Occupy 27% of the energy density of our universe (c.f. ordinary matter ~ 5%)
- many scenarios, many models

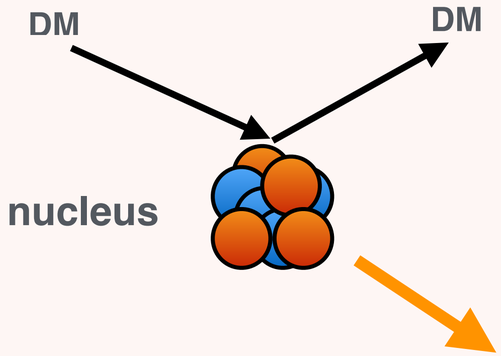


WIMP DM (thermal DM)

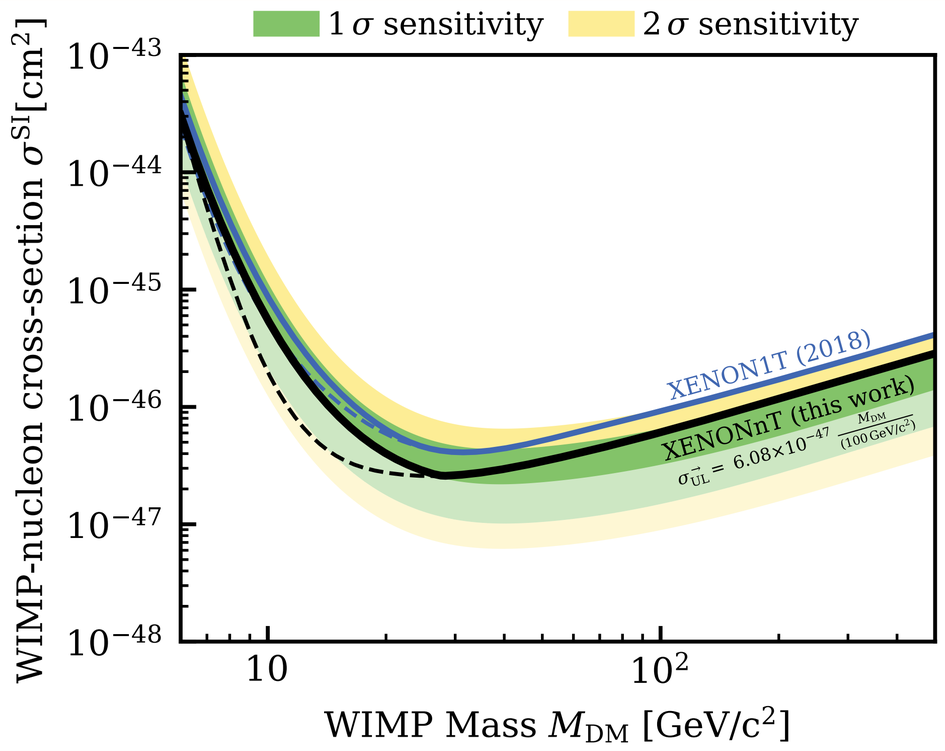
- DM has short-range interactions with the standard model particles
- energy density is explained by the freeze-out mechanism
- correlation among various processes



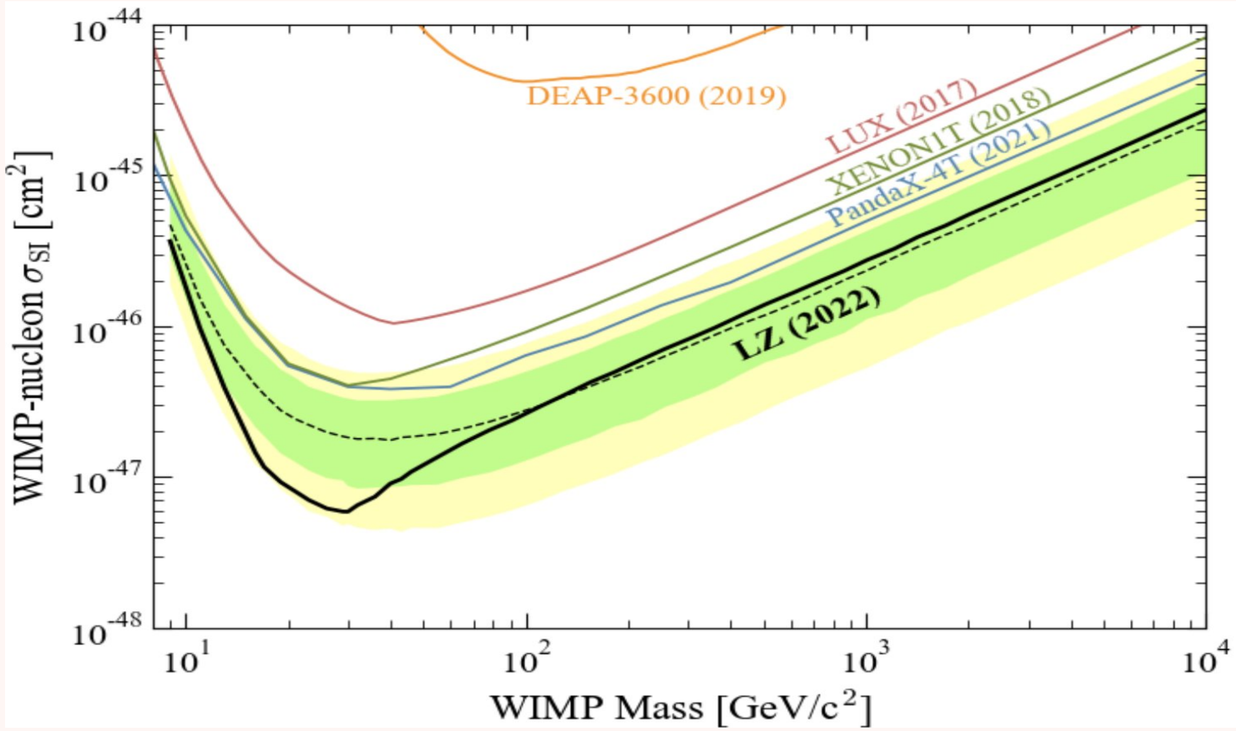
direct detection experiments



No significant signals yet

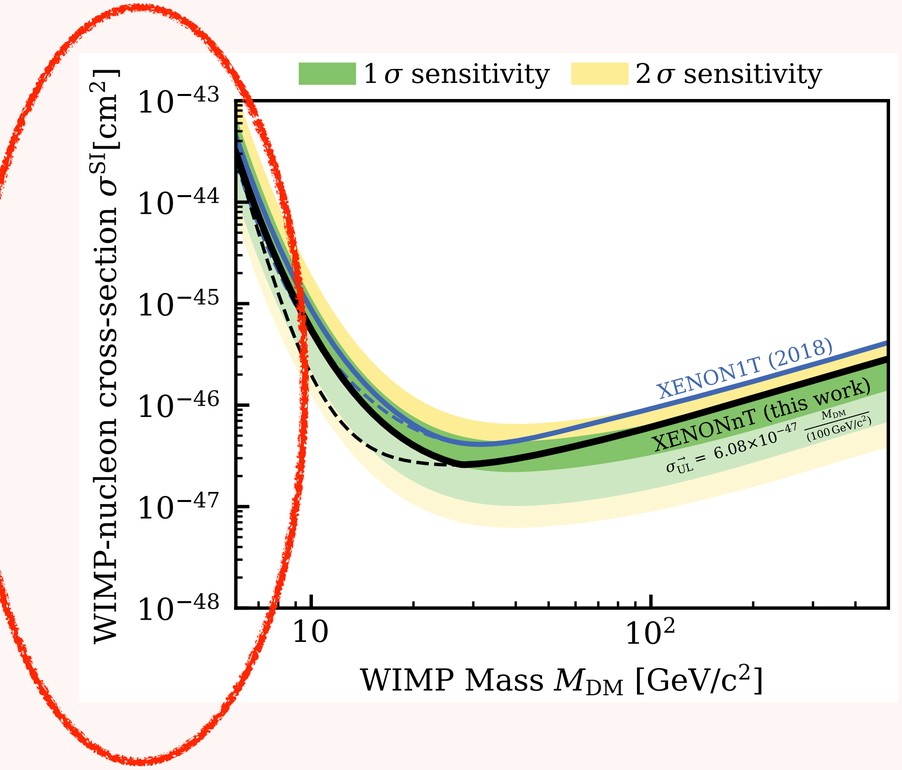


[XENON nT (’23)]



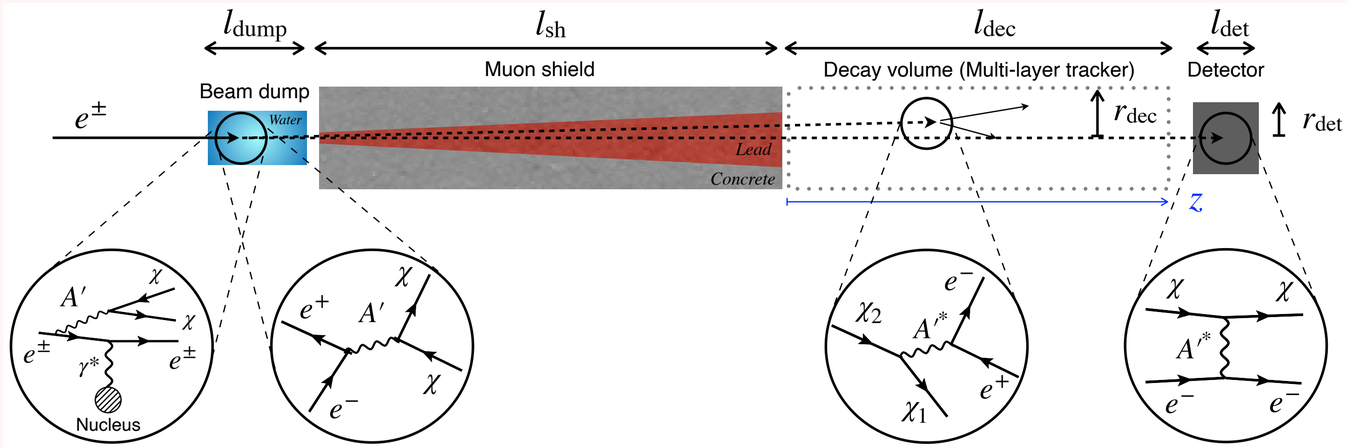
[LZ (’22)]

m_{DM} < O(1) GeV



- the weak constraint for lighter DM (due to small momentum transfer)
- light DM models typically require light and feeble particles
  - → long lived particle search
  - → beam dump experiments

[Kanemura Moroi Tanaka ('15), Ueda Sakai ('20), and more]



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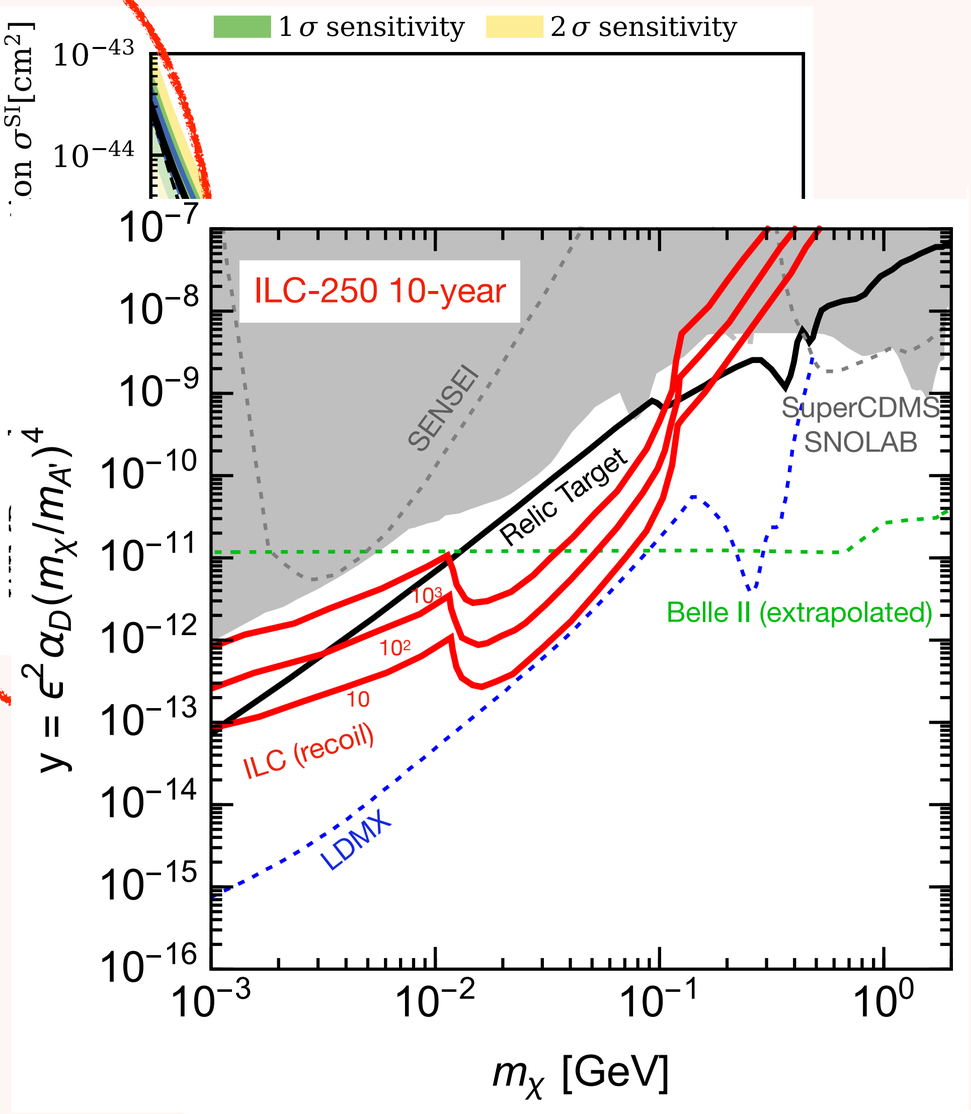

[Asai Iwamoto Perelstein Sakaki Ueda ('23)]

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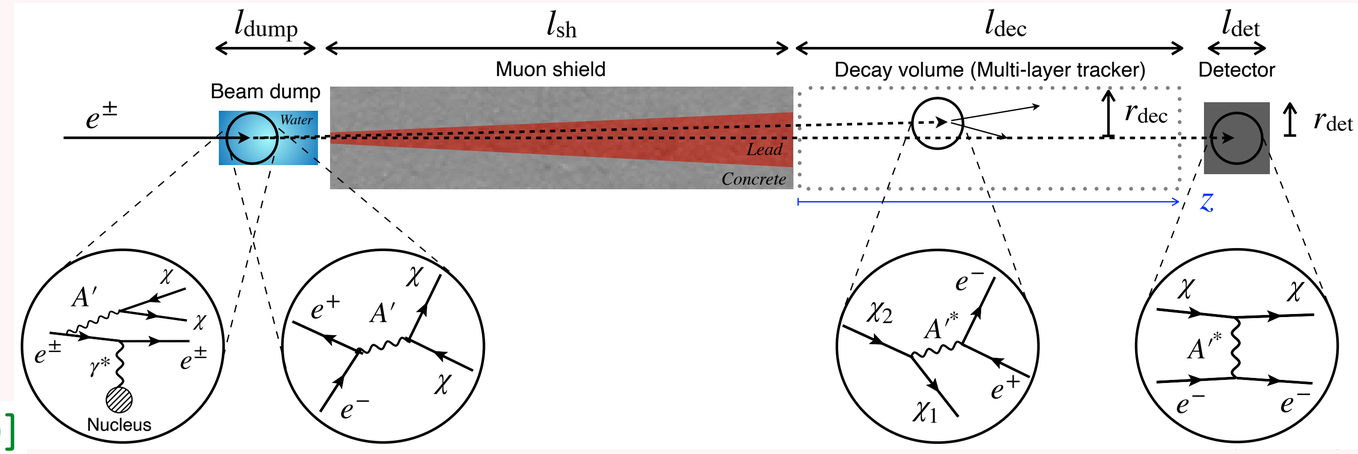

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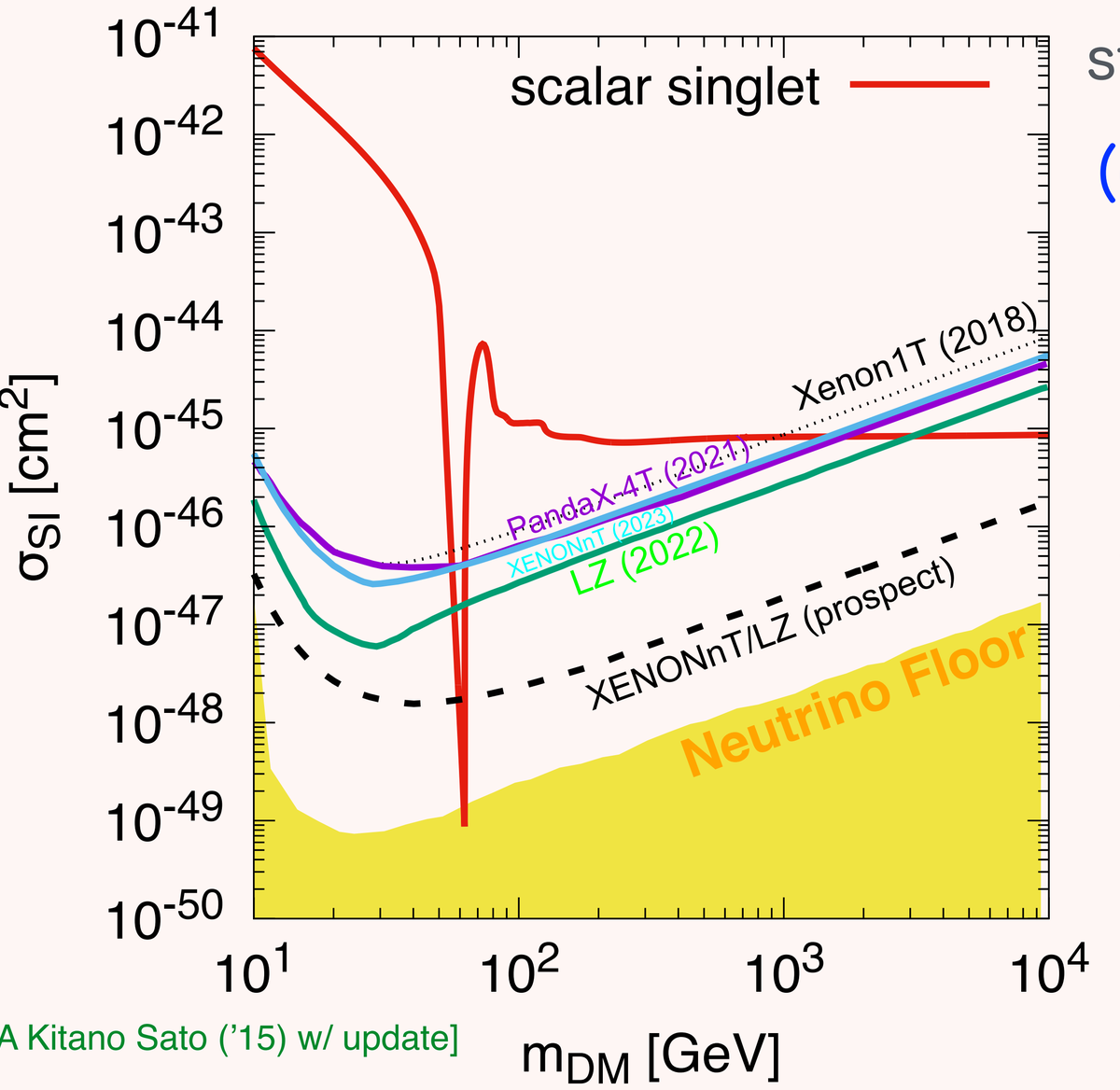


[TA Kitano Sato ('15) w/ update]

strong constraint from direct detection

(e.g) SM + a gauge singlet scalar DM

[Silveria et.al. ('85), McDonald ('94), Burgess ('01), …, Cline et.al. ('13), TA Kitano Sato ('15), … GAMBIT collaboration ('17, '19, …)]

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{2}\partial^\mu S \partial_\mu S - \frac{\mu_S^2}{2} S^2 - \frac{\lambda_S}{24} S^4 - \frac{\lambda_{hS}}{2} S^2 H^\dagger H$$

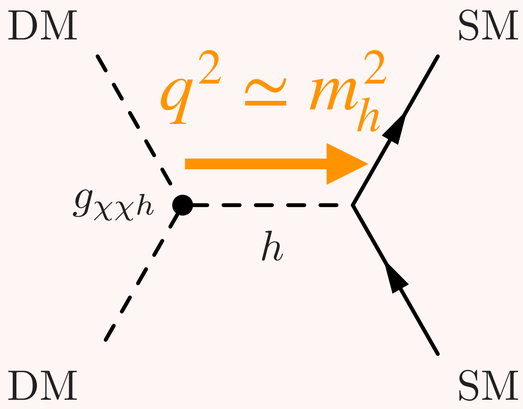
- a real scalar DM
- the SM Higgs is the mediator
- almost excluded
  - Higgs resonant region
  - heavy region
  - construct models that suppress $\sigma_{\rm SI}$

Higgs resonant region ($m_{DM} \sim m_h/2$)

correlation in three observables

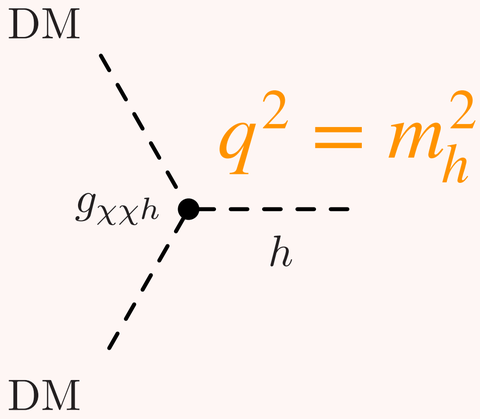
relic abundance

$$\Omega h^2 \propto \frac{1}{\langle \sigma v \rangle} \propto \frac{1}{g_{\chi\chi h}^2}$$



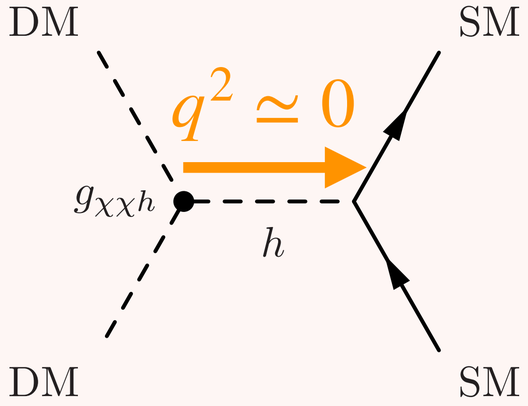
Higgs invisible decay

$$\Gamma(h \to \chi\chi) \propto g_{\chi\chi h}^2$$



direct detection

$$\sigma_{\rm SI} \propto g_{\chi\chi h}^2$$



Calculation is not trivial in some models

- early kinetic decoupling [Binder Bringmann Gustafsson Hryczuk ('17), TA ('20, '21)]
- temperature of dark sector can be different from temperature of the thermal bath ($T_\chi \neq T$)

Higgs re ic h/2)

correlation in three

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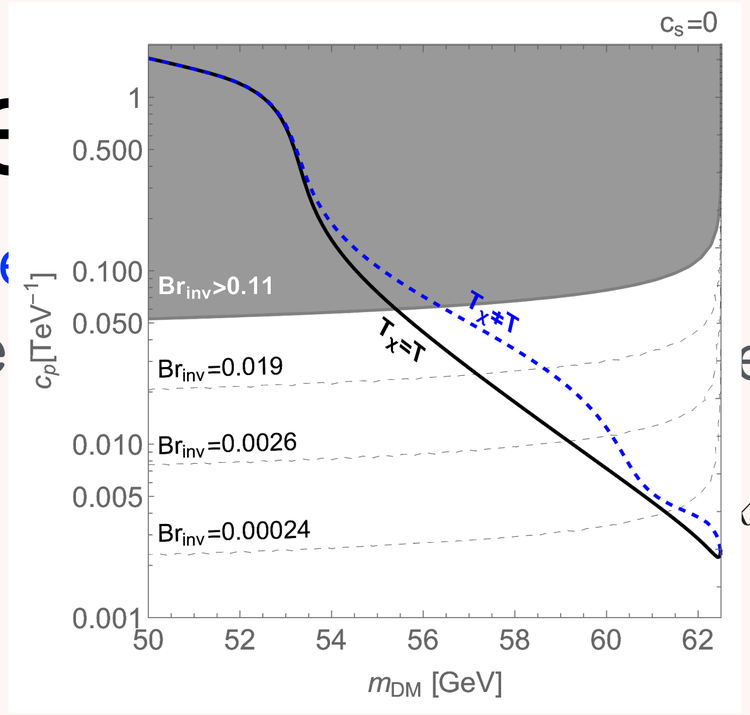

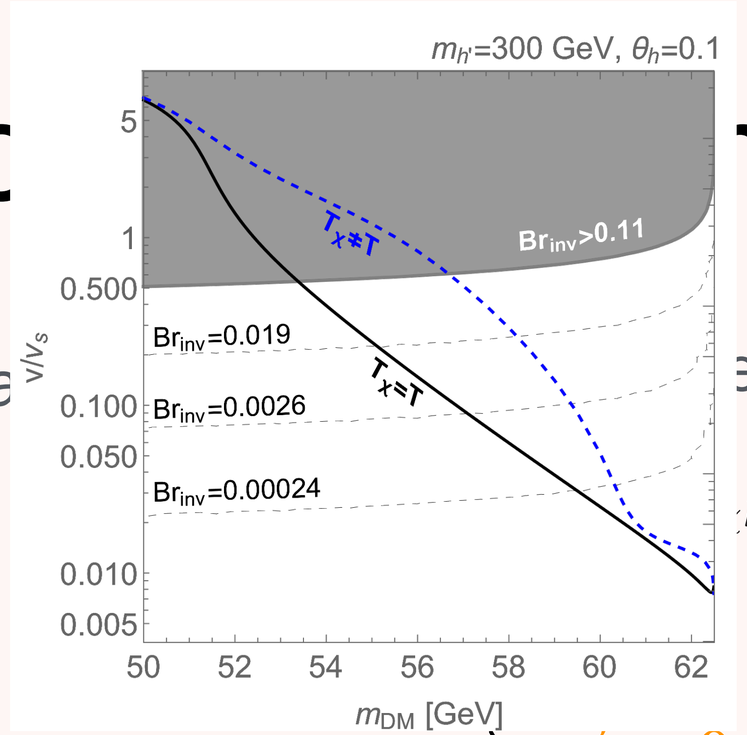

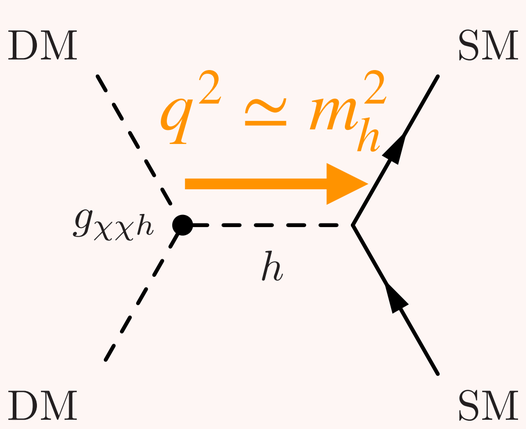

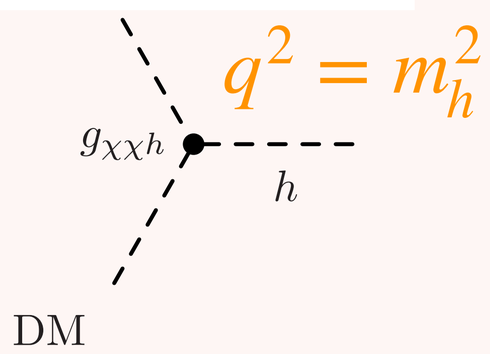

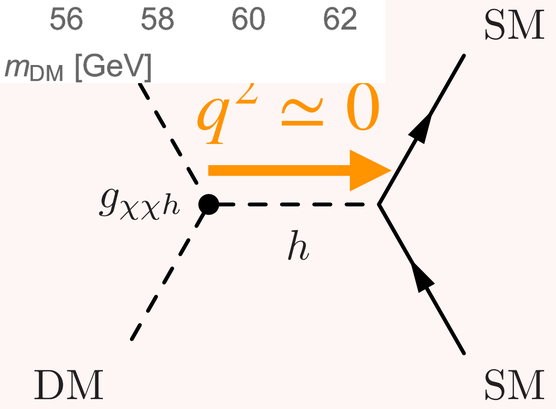

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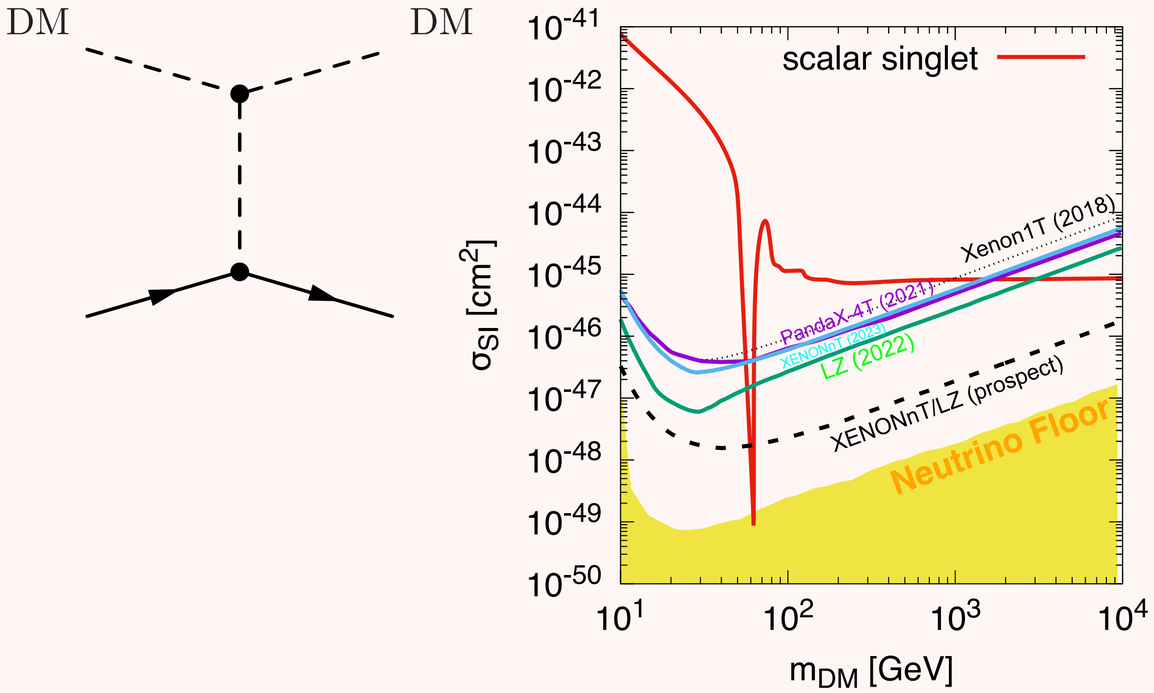
- temperature of dark sector can be different from temperature of the thermal bath ($T_\chi \neq T$)

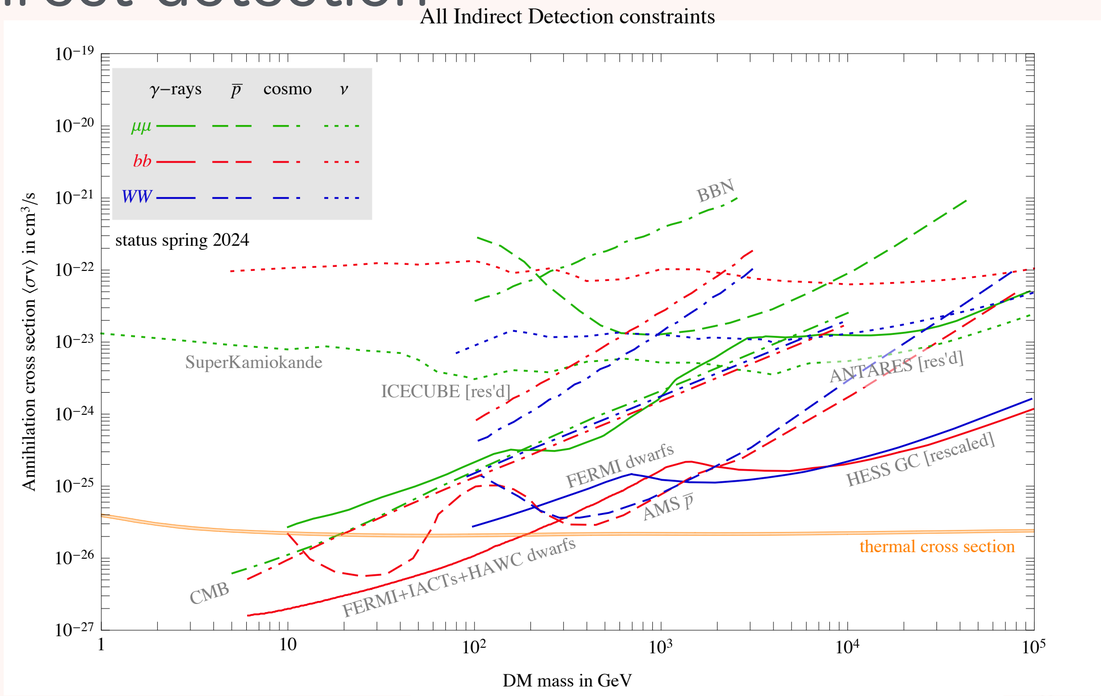
Heavy DM ($m_{DM} \gtrsim$ O(1) TeV)

- constraints from direct detection are weak now (due to small number density)
- heavy particles (e.g. W' and Z') associated with the dark sector → collider search

Higgs (or scalar) mediator
→ direct detection



weak boson mediator (such as wino)
→ indirect detection

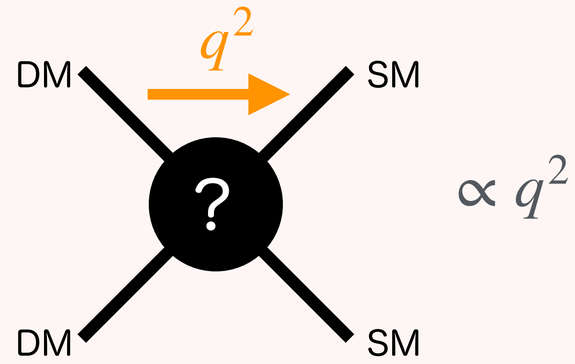


[Cirelli Strumia Zupan 2406.01705]

Suppression in $\sigma_{\rm SI}$

・momentum transfer is small in DM-nucleon scattering

・if scattering amplitude is proportional to momentum transfer, then $\sigma_{\rm SI}$ is suppressed

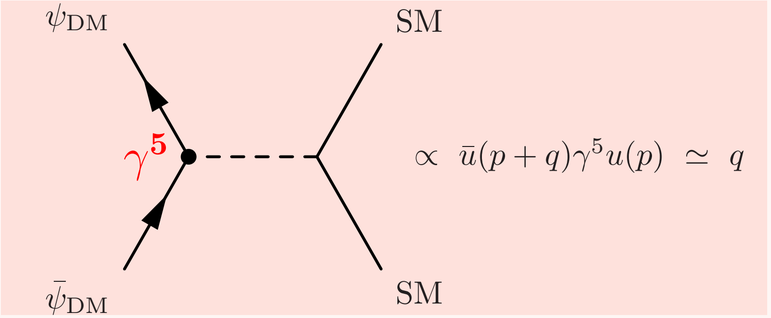


realization

・fermionic DM + scalar mediator with pseudo-scalar interaction

(e.g.) THDM+a [Ipek McKeen Nelson ('14), LHC Dark Matter Working Group 1810.09420, ⋯, TA Fujiwara Hisano ('19), ⋯]

singlet-doublet model with CPV [Mahbubani Senatore ('05), D'Eramo ('07), Enberg+ ('07), ⋯, TA Kitano Sato ('14), TA ('17), TA Sato ('19), ⋯.]



・pseudo-Nambu-Goldstone dark matter

[Gross Lebedev Toma ('17), Abe Toma Tsumura ('20, '21), Okada Raut Shafi ('20, '21), Liu Chi Jian Yu Zhang ('22), TA Hamada ('22), Otsuka Shimomura Tsumura Uchida Yamatsu ('22), TA Hamada Tsumura ('24), ⋯]

Summary

SubGeV ($m_{DM} \lesssim$ O(1) GeV)

- constraints from direct detection experiments are weak
- light and feeble particles → beam dump experiments

Higgs resonant region ($m_{DM} \sim m_h/2$)

- strong correlations in relic abundance, Higgs invisible decay, direct detection
- need careful evaluation (early kinetic decoupling, loop corrections, ⋯)

Heavy ($m_{DM} \gtrsim$ O(1) TeV)

- direct detection, indirect detection
- heavy particle associated with DM search in collider experiments

suppress σ_{SI} by momentum dependent scattering amplitude

- fermonic DM + scalar mediator with pseudo scalar interaction
- pseudo-Nambu-Goldstone DM models