Higgs-portal dark matter in brane world cosmology

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Dark Matter

- Dark matter: supported by many observations; represents 26.8% of the energy density of the universe; unknown particle beyond the Standard Model (SM).

- There are many dark matter models, among which the Higgs-portal scalar dark matter is a very simple scenario.

- We discuss the Higgs-portal scalar dark matter model in the context of 5-dimensional brane-world cosmology.

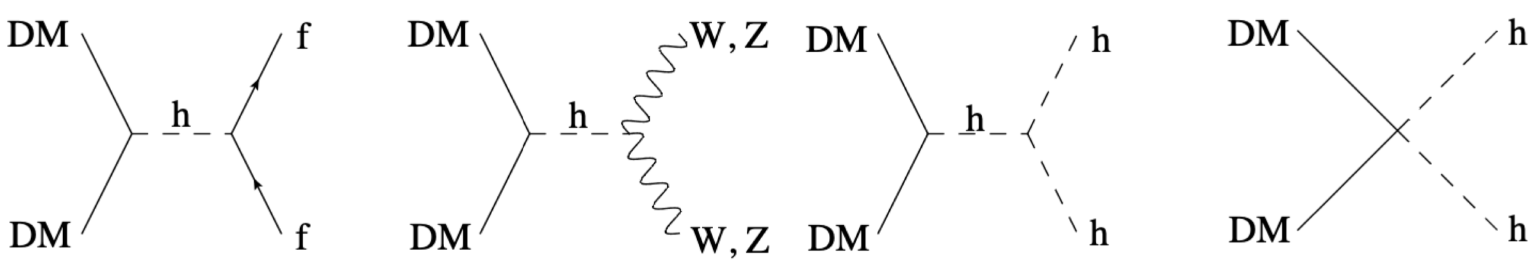
The Higgs-portal scalar dark matter

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{2}\partial_\mu S \partial^\mu S - \frac{m_0^2}{2} S^2 - \frac{\lambda_S}{4} S^4 - \lambda S^2 H^\dagger H$$

McDonald, PRD 50 (1994) 3637

This dark matter physics is controlled by only two free parameters:
λ and ${m_D}^2 = {m_0}^2 + \lambda {v_{EW}}^2$

The Higgs-portal dark matter pair annihilation processes:



Dark matter physics

1. Dark matter relic density

- Solving Boltzmann eq., with $Y \equiv \frac{n}{s(x)}$ and $x \equiv m_D/T$:

$$\frac{dY}{dx} = -\frac{x\ \mathbf{s}(x)}{H}\langle\sigma v\rangle(Y^2 - Y_{EQ}^2)$$

with the thermal average of the annihilation cross section times the relative velocity: $\langle\sigma v\rangle$

- DM relic density : (=0.12 from Planck 2018 observation)

$\rightarrow \lambda(m_D)$

$$\Omega_D h^2 = 2.74 \times 10^8\ Y_0\ m_D/\mathrm{GeV}$$ (Y_0 is Y at present)

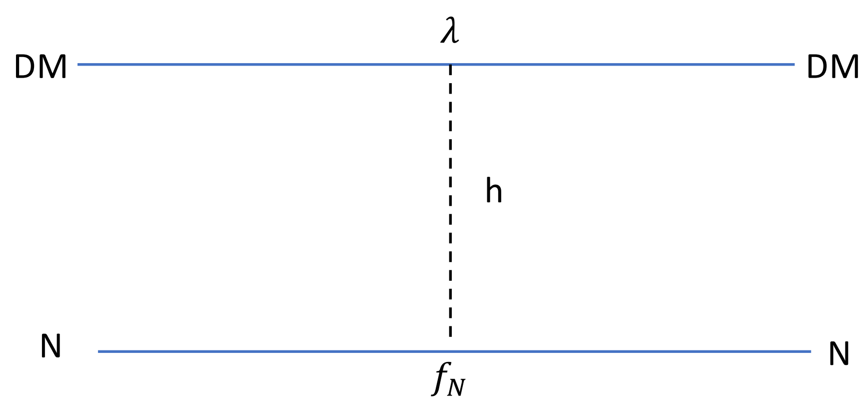
2. Direct detection of dark matter

The scattering cross section between DM and nucleon:

$$\sigma = \frac{\lambda^2}{4{m_h}^4}\frac{{m_N}^2}{\pi(m_D + m_N)^2}{f_N}^2$$

N represents proton or neutron

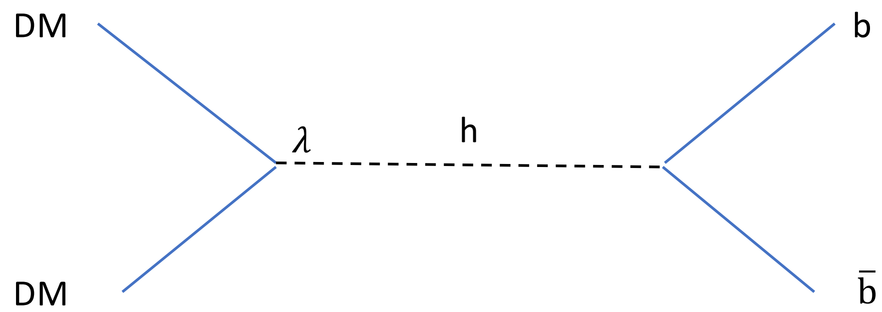
f_N is the coupling between the dark matter and N.



3. Indirect detection of dark matter

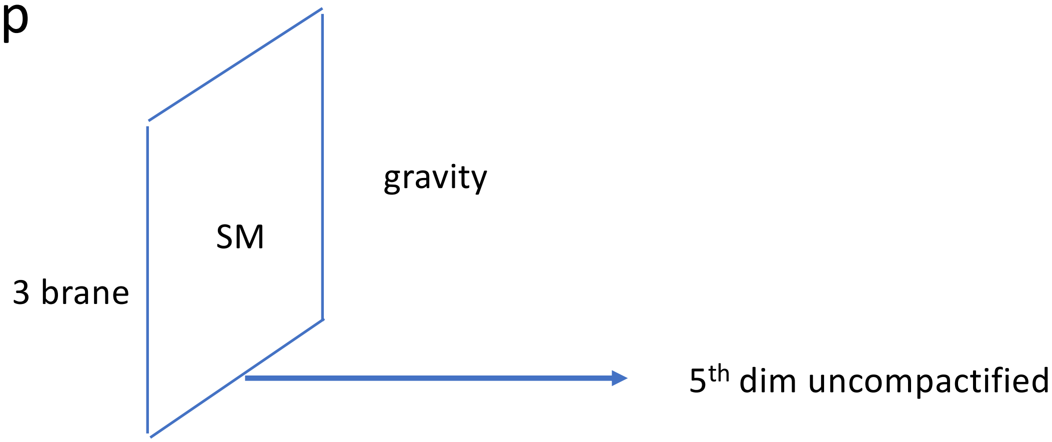
The cross section of the DM annihilation to bottom quark pair:

$$< \sigma_{bb}\, v > \approx 3\,\frac{\lambda^2 {m_b}^2}{\pi}\frac{1}{(4{m_D}^2 - {m_h}^2)^2 + {m_h}^2{\Gamma_h}^2}$$



5-D Brane World Cosmology

- Set up



- Well known realistic cosmological solutions:

  Randall-Sundrum cosmology — Randall & Sundrum, PRL 83 4690 (1999)
  For a review, see Langlois, PTP 148, 181 (2003)

  Gauss-Bonnet cosmology — Kim, Kyae, & Lee, PRD 62 045013 (2000); NP B582 296 (2000); B591, 587(E) (2000); Nojiri, Odintsov, & Ogushi, IJMP A 17, 4809 (2002); Lidsey, Nojiri, & Odintsov, JHEP 06 (2002) 026.

- 5-D cosmological solution on the 3 brane is well approximated as:

$$H = H_{ST} F\left(\frac{x_t}{x}\right),$$

where H_{ST} is the Hubble of 4-D standard cosmology

$$F\left(\frac{x_t}{x}\right) = 1 \; for \; \frac{x_t}{x} \leq 1, \qquad \left(\frac{x_t}{x}\right)^{\gamma} \; for \; \frac{x_t}{x} > 1$$

$x_t = \frac{m_D}{T_t}$: transition temperature $\quad (T_t > 1 \text{ MeV})$

$\gamma = 2$: Randall-Sundrum (RS) cosmology

$\gamma = -\frac{2}{3}$: Gauss-Bonnet (GB) cosmology

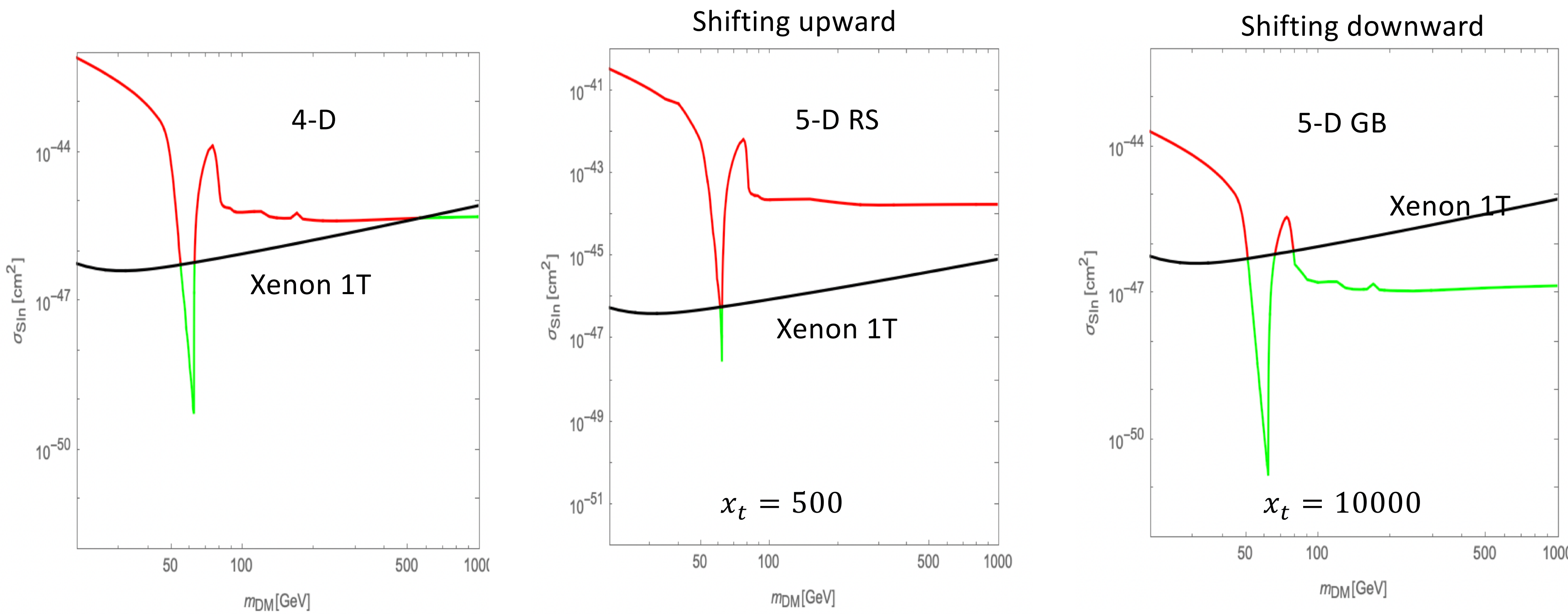
- Modification of Boltzmann eq. :

$$\frac{dY}{dx} = -\frac{c}{x^2}\left(\frac{\langle \sigma v \rangle}{F(x_t/x)}\right)(Y^2 - Y_{EQ}^2)$$

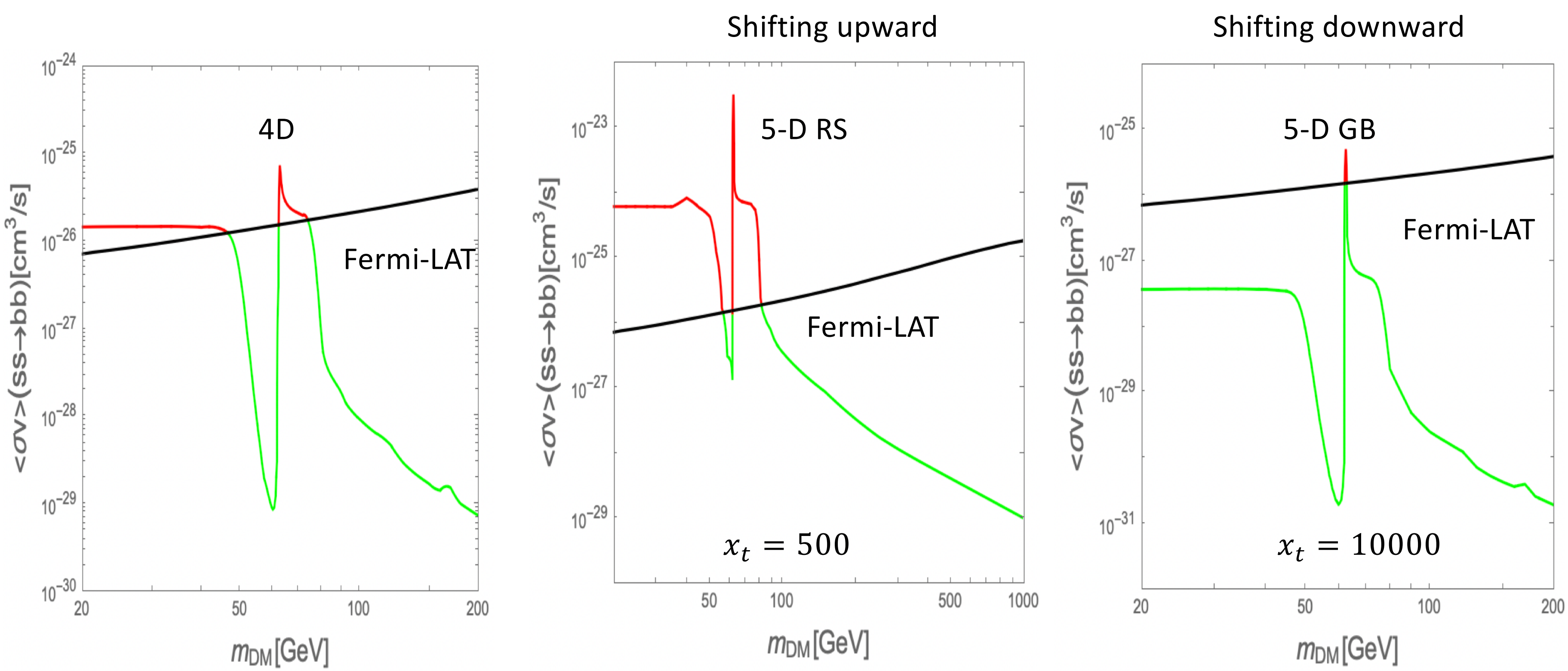
N. Okada & S. Okada, PRD 79 (2009) 103528

Brane world cosmology effects along with direct detection constraints (Xenon 1T 2018)

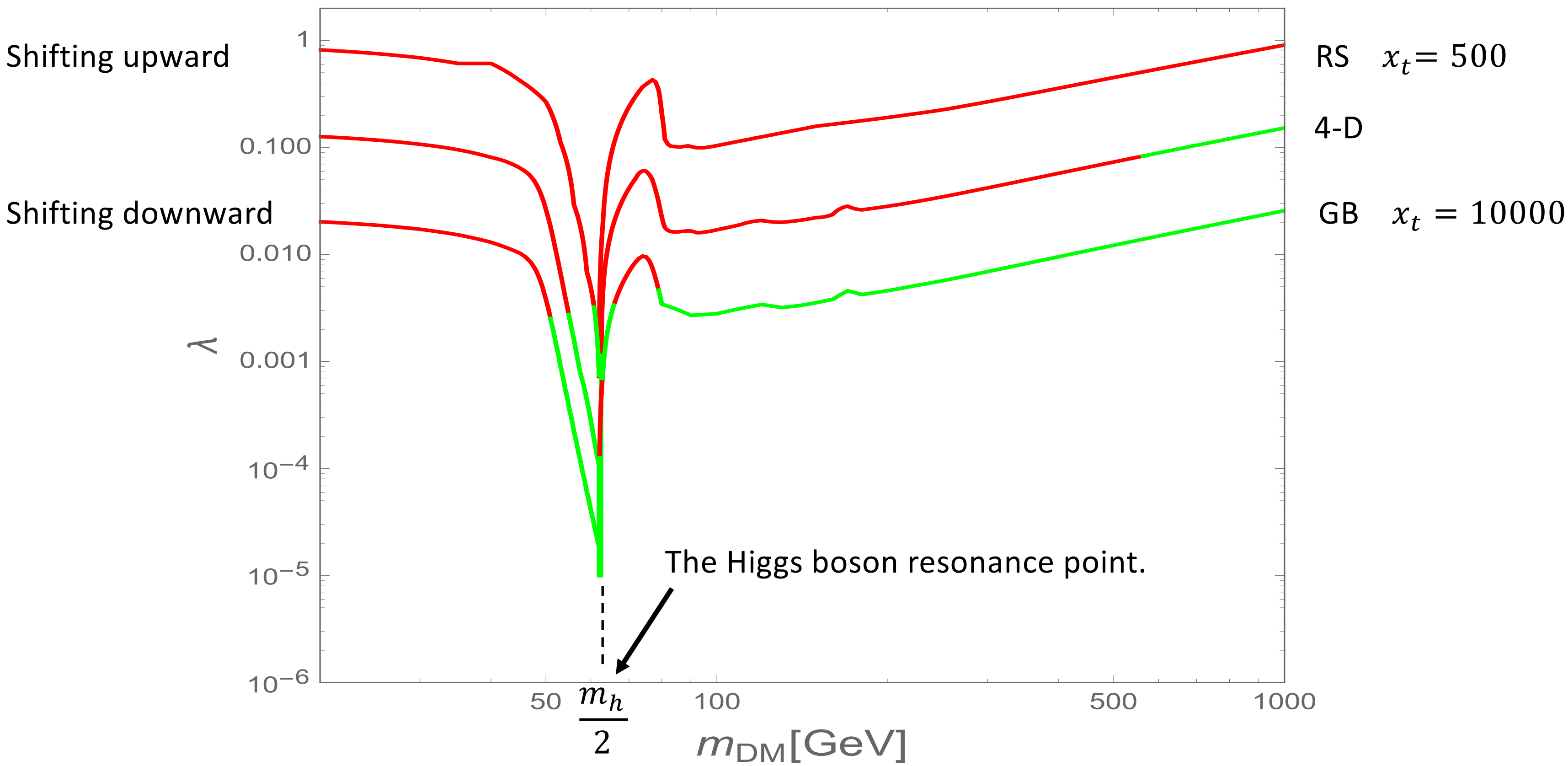
Annihilation cross section effectively change: $<\sigma v> \to <\sigma v>/F(x_t/x)$



Brane world cosmology effects along with indirect detection constrains (Fermi-LAT)



Combining the relic density, direct and indirect detection constraints



Conclusion

- We have considered the Higgs-portal scalar DM model in 5-D brane-world cosmology (Randall-Sundrum & Gauss-Bonnet).

- We have identified the allowed parameter region by considering the observed DM relic density, direct and indirect DM detection constraints.

- Comparing with the 4-D standard cosmology case, RS case allowed region more limited, while the allowed region is enlarged for the GB case.