Stable Higgs Particle as Dark Matter

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2009/09/12, 日本物理学会@甲南大学

arXiv:0908.0212 [hep-ph], to be published in PLB.

Introduction

Electro-Weak Symmetry Breaking

Higgs mechanism: Not seen yet.

Hierarchy problem: SUSY, PNGB, GHU, ...

Dark Matter

WMAP: $\Omega_{\rm CDM}h^2 = 0.1131 \pm 0.0034$

Rotation curves of galaxies: DM in galactic halo.

Both problems may be solved at once.

Stable Higgs as Dark Matter

Model

Hosotani, Oda, Ohnuma, Sakamura, PRD78,096002(2008).

$SO(5) \times U(1)$ in 5D warped space-time.

EWSB by Hosotani mechanism.

4D Higgs field: Wilson line phase,

$$\hat{\theta}_H(x) = \theta_H + \frac{H(x)}{f_H} \,. \qquad f_H \simeq 246\,\mathrm{GeV}$$

Matter: vectors (and/or tensors) of SO(5),

no spinors.

A new dynamical parity, H-parity,

$$H(x) \to -H(x) \,.$$

Effective Interactions

Integrating out KK modes,

$$\mathcal{L}_{\rm int} = -\frac{m_W^2}{f_H^2} H^2 W^{+\mu} W_\mu^- - \frac{m_Z^2}{2 f_H^2} H^2 Z^\mu Z_\mu + \sum_f \frac{m_f}{2 f_H^2} H^2 \bar{f} f + \cdots .$$

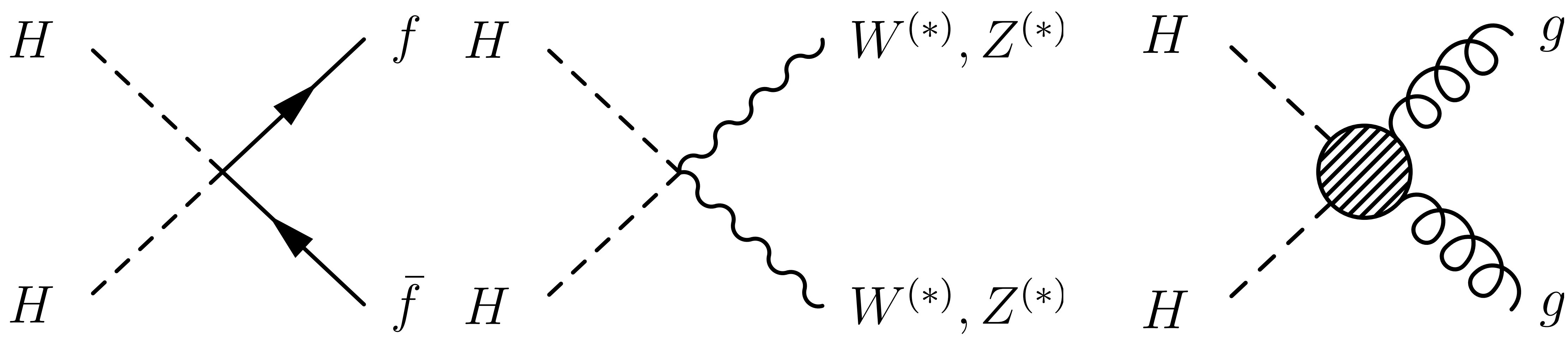
No odd powers of H .

Higgs is STABLE!

A good candidate for WIMP DM.

Relic Abundance

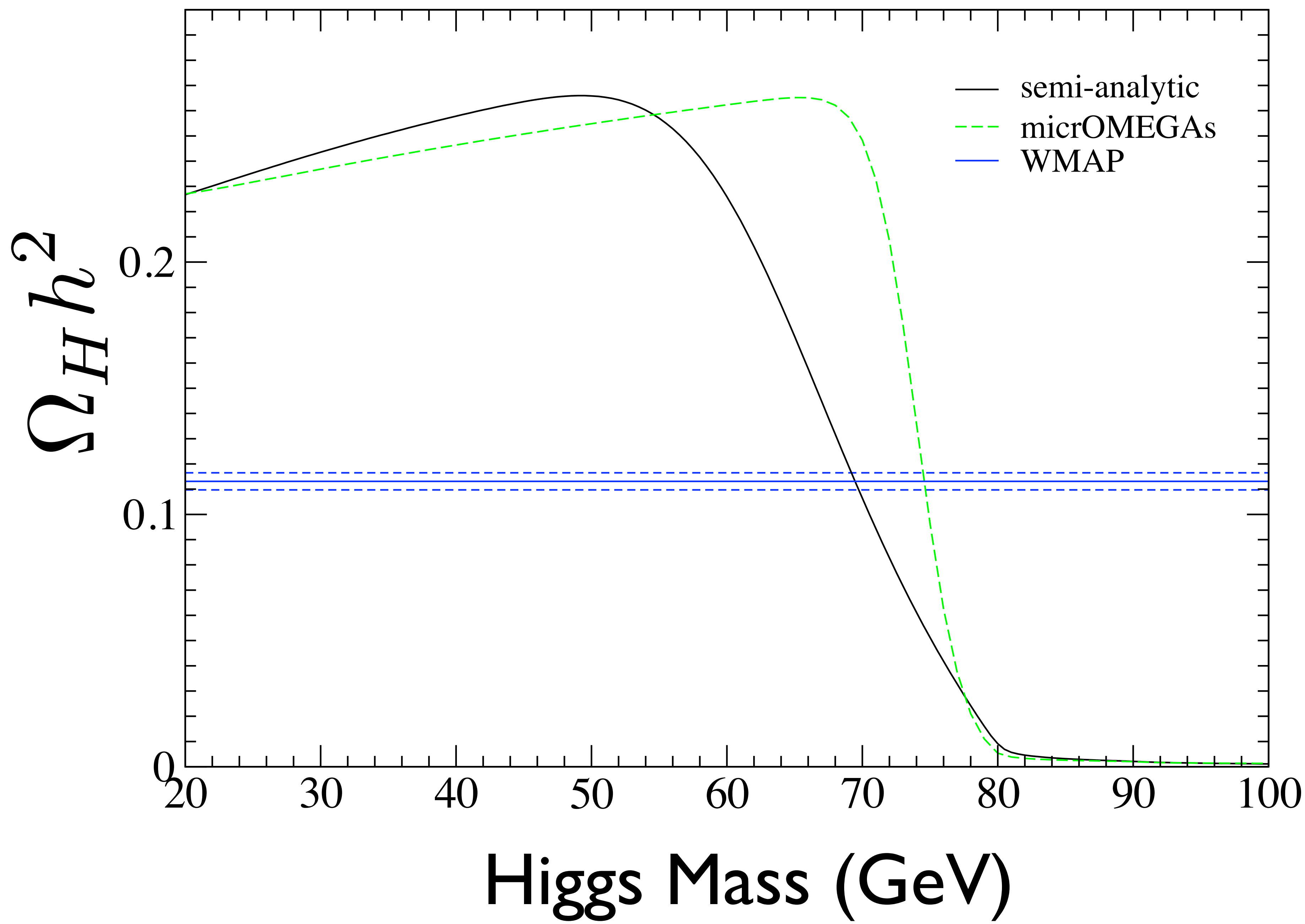
Annihilation processes:



Semi-analytic formula, e.g. Kolb and Turner

micrOMEGAs 2.2 by G. Belanger et al.

Relic Abundance

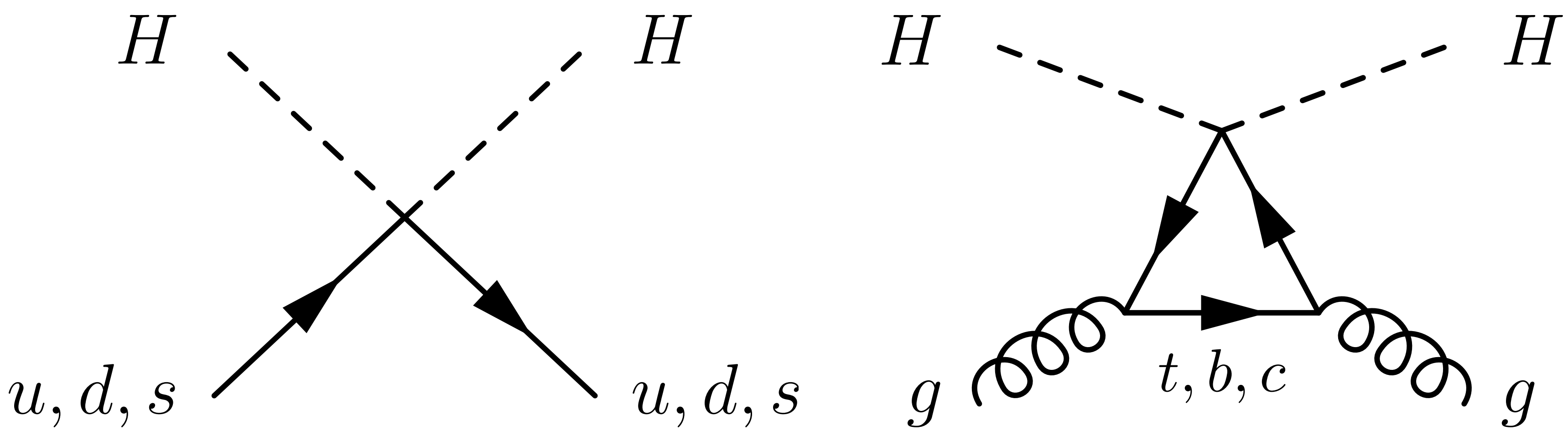


$m_H \sim 70\,\mathrm{GeV}$ favored.

$T_f \sim 3\,\mathrm{GeV}$

$10^{-27}\mathrm{cm}^3/\mathrm{s}$	$b\bar{b}$	$W^{(*)}W^{(*)}$	$Z^{(*)}Z^{(*)}$
$\sigma v\|_{v\to 0}$	7.3	11	1.5

Direct Detection $HN \to HN$

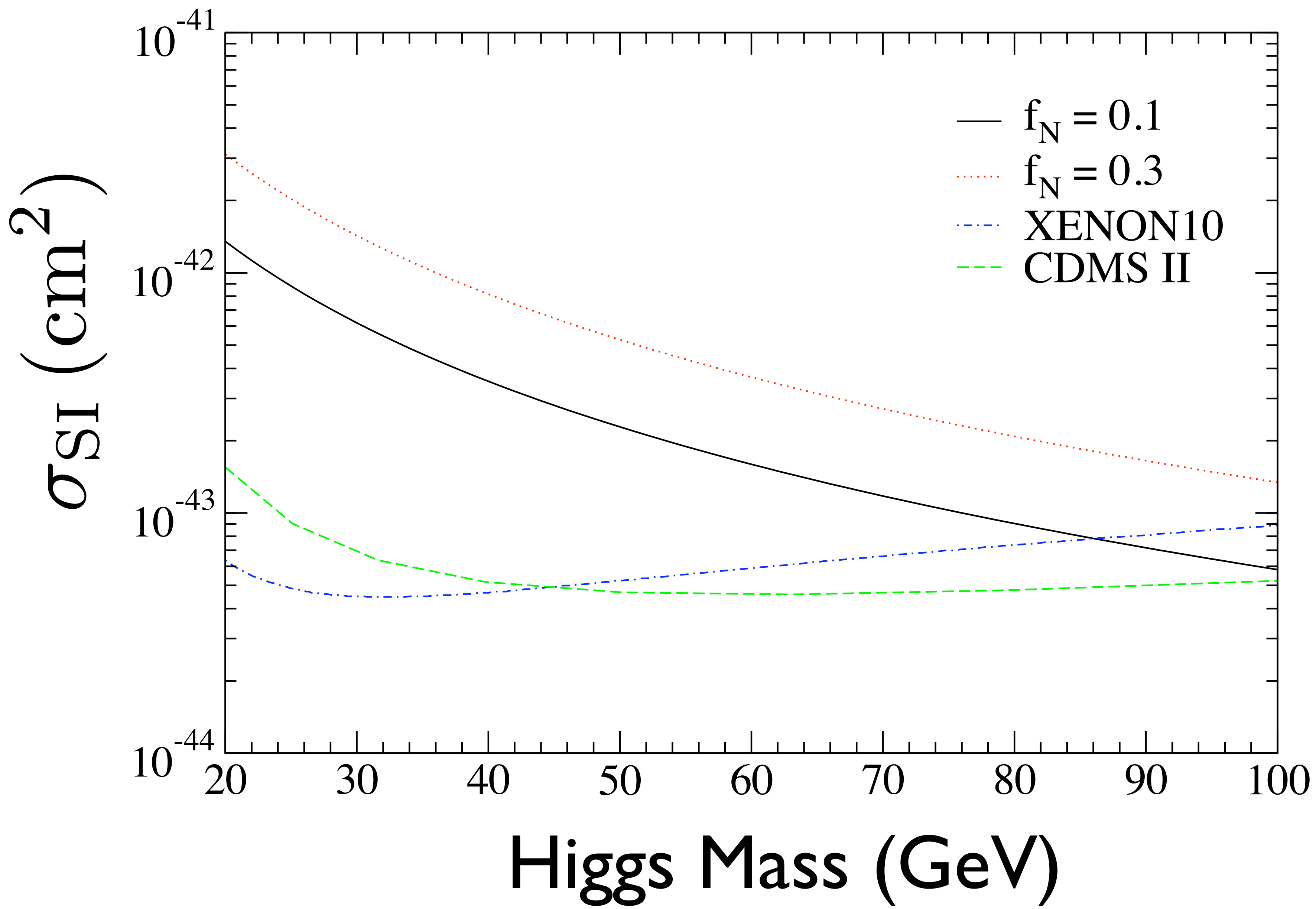


$$\mathcal{L}_{\rm eff} \simeq \frac{H^2}{2f_H^2}\left[\sum_{q=u,d,s} m_q \bar{q}q - \frac{\alpha_s}{4\pi} G^a_{\mu\nu} G^{a\,\mu\nu}\right]$$

$$\mathcal{L}_{HN} \simeq \frac{2+7f_N}{9}\,\frac{m_N}{2f_H^2}\,H^2 \bar{N}N$$

$$f_N = \sum_{q=u,d,s} \langle N | m_q \bar{q}q | N\rangle / m_N \simeq 0.1 \sim 0.3$$

Spin-Independent Cross Section



Local DM density $\rho_0 = 0.3\,{\rm GeV/cm}^3$ assumed in exps.

For $m_H = 70\,{\rm GeV}$

Prediction: $\sigma_{\rm SI} \simeq (1.2 - 2.7) \times 10^{-43}\,{\rm cm}^2$

Exp. bound: $\sigma_{\rm SI} \lesssim 5 \times 10^{-44}\,{\rm cm}^2$

Conclusion

- Stable Higgs is a viable candidate of dark matter.
- $m_H \sim 70\,\mathrm{GeV}$ is predicted.
- Direct detection is likely.

  Exp. limits depend on the local DM density, ρ_0 .

  $$\rho_0 \simeq 0.04 \sim 0.6\,\mathrm{GeV/cm^3}$$

- Cosmic rays from Higgs pair annihilation may be observed.

  $$HH \to \gamma\gamma,\ \gamma Z \qquad E_\gamma \sim 70\,,\ 40\,\mathrm{GeV}$$

Backup Slides

Effective Lagrangian at the Weak Scale

$$\mathcal{L}_{\rm eff} = -V_{\rm eff}(\hat\theta_H) + m_W^2(\hat\theta_H) W^{+\mu} W^-_\mu + \frac{1}{2} m_Z^2(\hat\theta_H) Z^\mu Z_\mu - \sum_f m_f(\hat\theta_H) \bar f f$$

$$m_W(\hat\theta_H) \sim \cos\theta_W m_Z(\hat\theta_H) \sim \frac{1}{2} g f_H \sin\hat\theta_H \ ,$$

$$m_a^F(\hat\theta_H) \sim \lambda_a \sin\hat\theta_H \ ,$$

Symmetry implication:

$$V_{\rm eff}(\hat\theta_H + \pi) = V_{\rm eff}(\hat\theta_H) = V_{\rm eff}(-\hat\theta_H) \, ,$$

$$m_{W,Z}^2(\hat\theta_H + \pi) = m_{W,Z}^2(\hat\theta_H) = m_{W,Z}^2(-\hat\theta_H) \, ,$$

$$m_f(\hat\theta_H + \pi) = -m_f(\hat\theta_H) = m_f(-\hat\theta_H) \, .$$

Vacuum: $\theta_H = \pi/2 \, .$

→ Parity inv. under $H(x) \to -H(x) \, .$

Uncertainties in the direct detection

Local density of CDM (not measured)

$\rho_0 = 0.3\,\mathrm{GeV/cm^3}$

assumed in the experiments.

$\rho_0 = 0.2 \sim 0.6\,\mathrm{GeV/cm^3}$

reasonable for smooth halo.

$\rho_0 \sim 0.04\,\mathrm{GeV/cm^3}$ (Kamionkowski and Koushiappas)

possible for non-smooth halo.

Effective Higgs coupling $HH\bar{f}f$

may be altered in more general models.

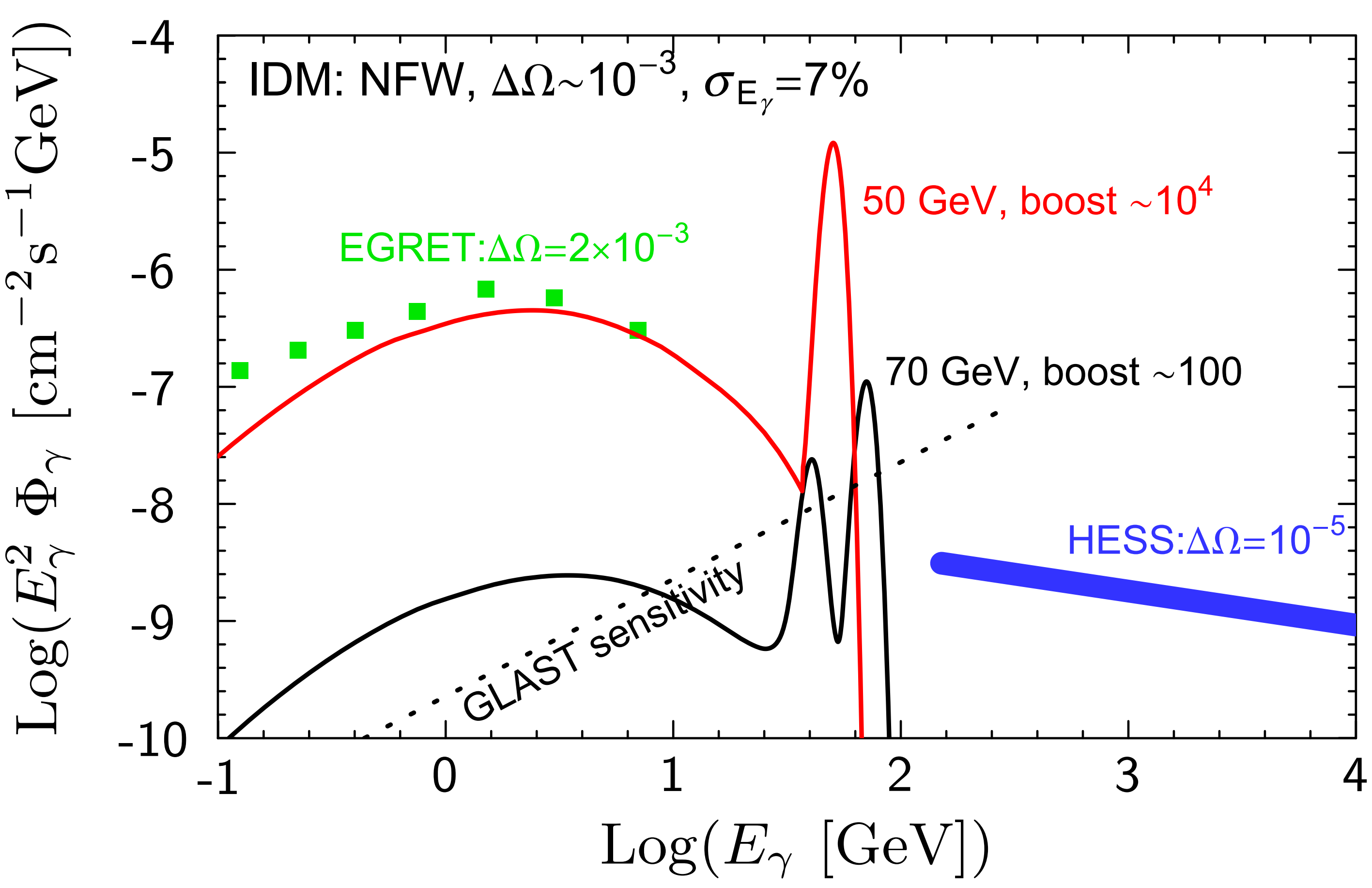
Astrophysical Signals

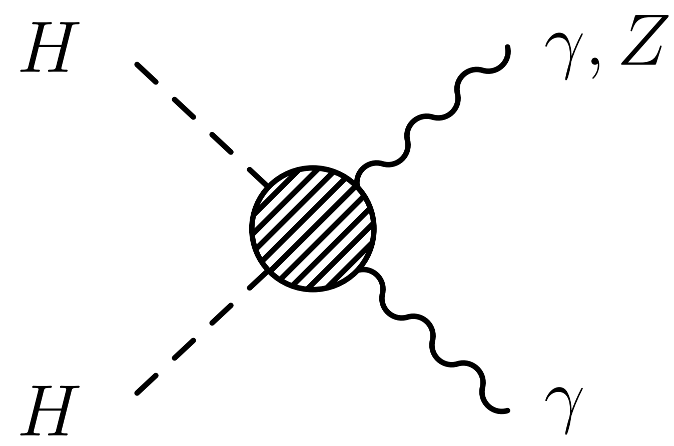
$HH \rightarrow \gamma\gamma,\ \gamma Z$ in the Galactic halo.

Two (nearly) monochromatic gamma lines.

$$E_\gamma = m_H (\simeq 70\mathrm{GeV})\,, m_H - m_Z^2/(4m_H)(\simeq 40\mathrm{GeV})$$

$$\sigma_{\gamma\gamma(\gamma Z)}\, v|_{v\to 0} \simeq 4.3(5.4)\times 10^{-29}\mathrm{cm}^3/\mathrm{s}$$





cf. Inert Doublet Model

← Gustafsson et al.