Dark Higgs Channel for FERMI GeV γ-Ray Excess

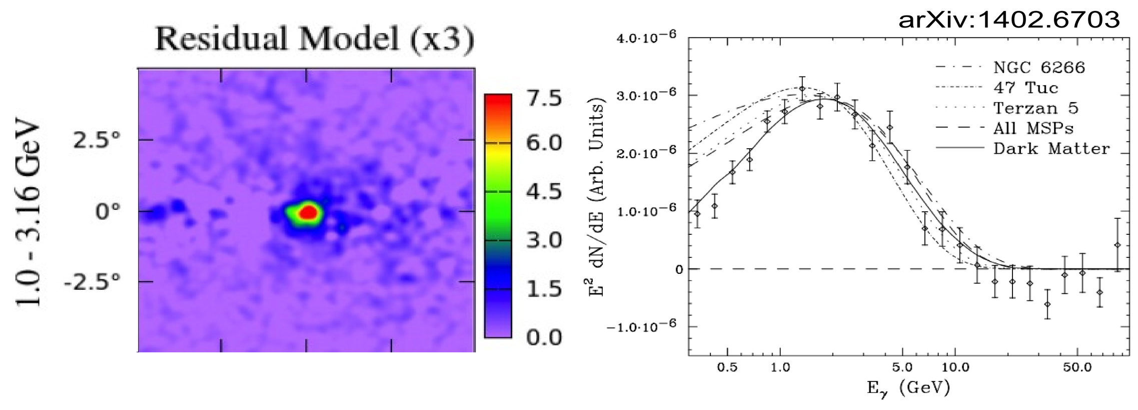
P. Ko (pko@kias.re.kr)

Korea Institute for Advanced Study

Based on [1] with Yong Tang

Motivations

Recently, several analysis showed that there are GeV γ-ray excesses from galactic center (GC), which can be interpreted as indications from dark matter annihilations.



Although it is a first step to consider the case that a pair of DM goes to two SM particles directly, from model building side, it is more natural to additional Higgs boson [1, 2, 3].

Theoretical Framework

We shall consider the following annihilation channel for self-conjugate DM X,

$$X + X \to H_2 + H_2, \quad \text{followed by}$$
$$H_2 \to SM + SM(+SM).$$

Here H_2 denotes the dark Higgs, distinguishing it from the SM-like Higgs H_1 with $M_{H_1} \simeq 125$ GeV. H_2 can decay into SM particles through its small mixing with H_1.

Dark Higgs is very generic in dark matter models with dark gauge symmetries, for example, a real scalar DM X and a complex scalar Φ can have the following interactions,

$$\mathcal{L} \supset -\lambda_{\phi X} X^2 \Phi^\dagger \Phi - \lambda_{\phi H} \Phi^\dagger \Phi H^\dagger H,$$

where H is the SM Higgs doublet. After symmetry breaking,

$$\langle H \rangle = v_h/\sqrt{2}, \ \langle \Phi \rangle = v_\phi/\sqrt{2},$$

two neutral scalars h and ϕ mix with each other, resulting in two mass eigenstates H_1 and H_2 with

$$\begin{pmatrix} H_1 \\ H_2 \end{pmatrix} = \begin{pmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} h \\ \phi \end{pmatrix}.$$

Effective operators are $X^2 H_2^2$ for scalar DM, $\bar{X}\gamma_5 X H_2^2$ for fermion or $X_\mu X^\mu H_2^2$ for vector.

Summary

We have explored a possibility that the GeV scale γ-ray excess from the GC is due to DM annihilation into a pair of dark Higgs which decays into the SM particles through its mixing with the SM Higgs boson. We find the best-fit

$$M_X \simeq 95.0\text{GeV},$$
$$M_{H_2} \simeq 86.7\text{GeV},$$
$$\langle\sigma v\rangle \simeq 4.0 \times 10^{-26}\text{cm}^3/\text{s}.$$

References

[1] P. Ko and Y. Tang, JCAP **1602**, no. 02, 011 (2016) [arXiv:1504.03908 [hep-ph]].

[2] P. Ko and Y. Tang, JCAP **1501**, 023 (2015) [arXiv:1407.5492 [hep-ph]].

[3] P. Ko, W. I. Park and Y. Tang, JCAP **1409**, 013 (2014) [arXiv:1404.5257 [hep-ph]].

[4] F. Calore, I. Cholis and C. Weniger, JCAP **1503**, 038 (2015) [arXiv:1409.0042 [astro-ph.CO]].

Dark Matter Induced γ-Ray

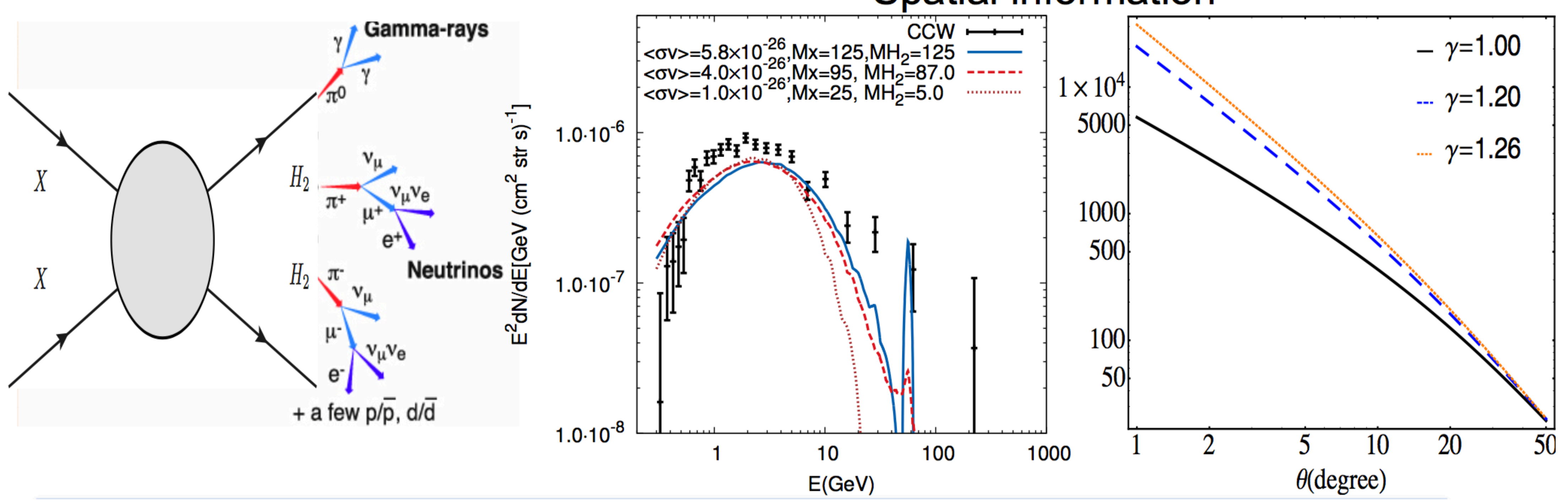
The general differential flux of γ-ray from self-conjugate DM annihilation is given by

$$\frac{d^2\Phi_\gamma}{dE_\gamma d\Omega} = \sum_i \frac{dN_\gamma^i}{dE_\gamma} \frac{\langle\sigma v\rangle_i}{8\pi M_{DM}^2} \int_{l.o.s} \rho^2\left(r(r',\theta)\right) dr'$$

prompt

Particle Physics Spectral Information

Astrophysics DM distribution Spatial information $\rho(r) = \rho_\odot \left[\frac{r_\odot}{r}\right]^\gamma \left[\frac{1+r_\odot/r_c}{1+r/r_c}\right]^{3-\gamma}$



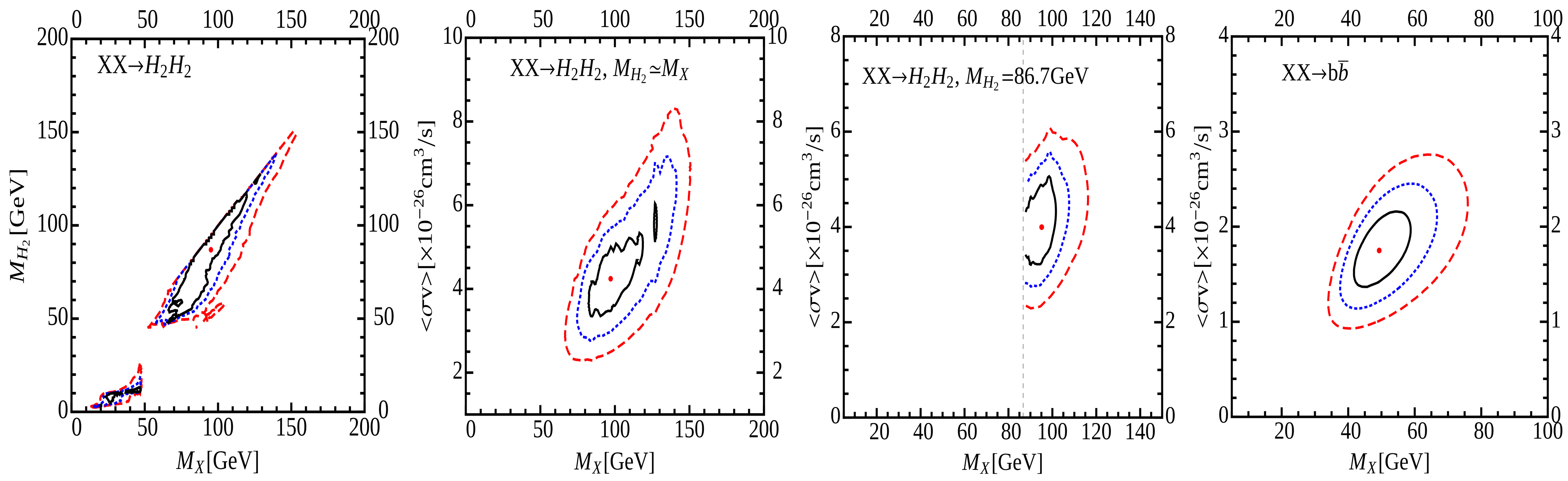
CCW above is referred to the paper [4].

Numerical Results

We use the χ^2 function to find out the favored parameter space,

$$\chi^2\left(M_X, M_{H_2}, \langle\sigma v\rangle\right) = \sum_{i,j} (\mu_i - f_i)\,\Sigma_{ij}^{-1}\,(\mu_j - f_j),$$

where μ_i and f_i are the predicted and measured fluxes in the i-th energy bin respectively, and Σ is the 24×24 covariance matrix. We take the numerical values for f_i and Σ from CCW [4]. Minimizing the χ^2 against f_i with respect to M_X, M_{H_2} and $\langle\sigma v\rangle$ gives the best-fit points, and then two-dimensional 1σ, 2σ and 3σ contours are defined at $\Delta\chi^2 \equiv \chi^2 - \chi^2_{\text{min}} = 2.3$, 6.2 and 11.8, respectively.



The best-fit parameter points and their associated χ^2_{min} and p-value:

Channels	Best-fit parameters	χ^2_{min}/d.o.f.	p-value
$XX \to H_2H_2$ (with $M_{H_2} \neq M_X$)	$M_X \simeq 95.0$GeV, $M_{H_2} \simeq 86.7$GeV $\langle\sigma v\rangle \simeq 4.0 \times 10^{-26}$cm^3/s	22.0/21	0.40
$XX \to H_2H_2$ (with $M_{H_2} = M_X$)	$M_X \simeq 97.1$GeV $\langle\sigma v\rangle \simeq 4.2 \times 10^{-26}$cm^3/s	22.5/22	0.43
$XX \to H_1H_1$ (with $M_{H_1} = 125$GeV)	$M_X \simeq 125$GeV $\langle\sigma v\rangle \simeq 5.5 \times 10^{-26}$cm^3/s	24.8/22	0.30
$XX \to b\bar{b}$	$M_X \simeq 49.4$GeV $\langle\sigma v\rangle \simeq 1.75 \times 10^{-26}$cm^3/s	24.4/22	0.34

An ultraviolet complete model [3]:

$$\mathcal{L} = -\frac{1}{4}X_{\mu\nu}X^{\mu\nu} + (D_\mu\Phi)^\dagger(D^\mu\Phi) - \lambda_\Phi\left(\Phi^\dagger\Phi - v_\Phi^2/2\right)^2 - \lambda_{\Phi H}\left(\Phi^\dagger\Phi - v_\Phi^2/2\right)\left(H^\dagger H - v_H^2/2\right).$$

After symmetry breaking, the gauge boson will be massive, stable and a dark matter candidate. Detailed phenomenologies can be found in Ref. [3].

Acknowledgements

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