Higgs Portal Dark Matter for GeV Gamma-ray Excess

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*P. Ko,**YT**, 1407.5492(JCAP)&1504.03908*

Outline

- Introduction

  Galactic Center GeV Gamma-ray Excess

- Higgs Portal DM models

- Summary

Fermi GeV γ-ray Excess

Goodenough & Hooper 2009

Hooper & Goodenough 2011

Hooper & Linden 2011

Boyarsky+ 2011

Abazajian & Kaplinghat 2012

Gordon & Macias 2013

Macias & Gordon 2014

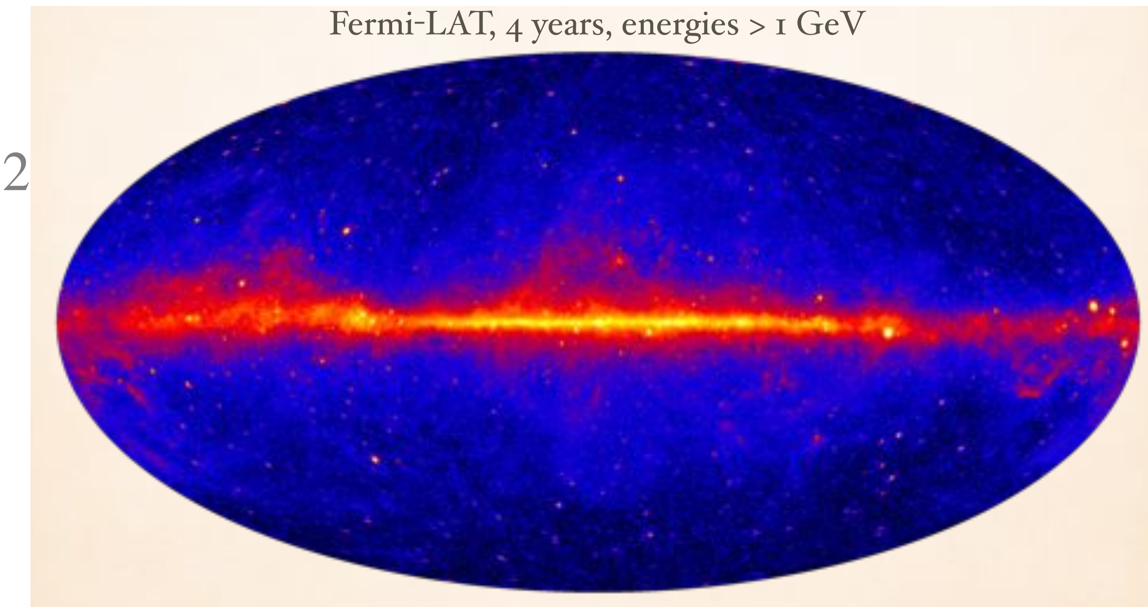
Abazajian+ 2014

Daylan+2014

Weniger+2014 (*CCW*)

…..

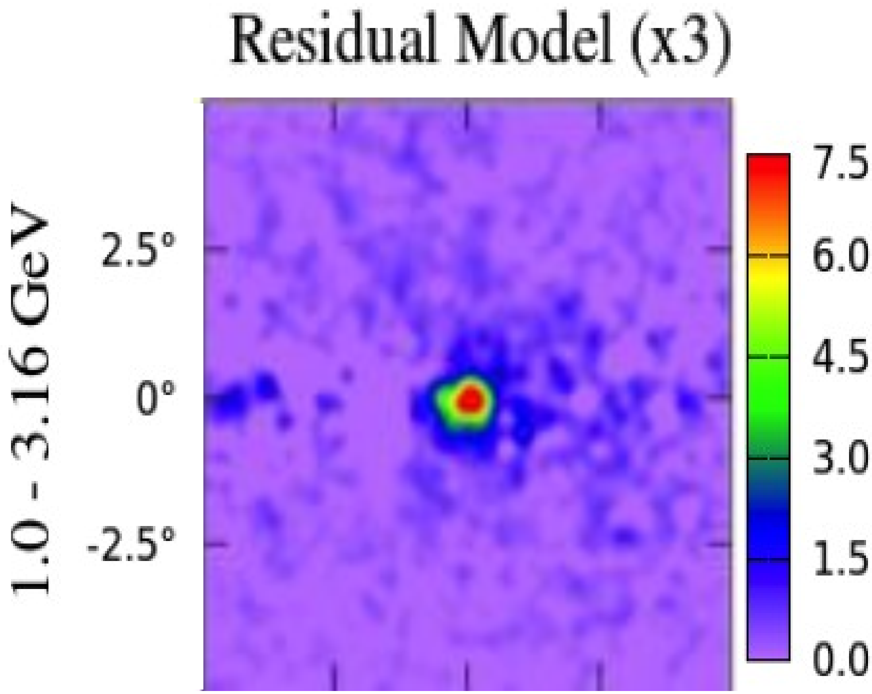
The Gamma-Ray Sky



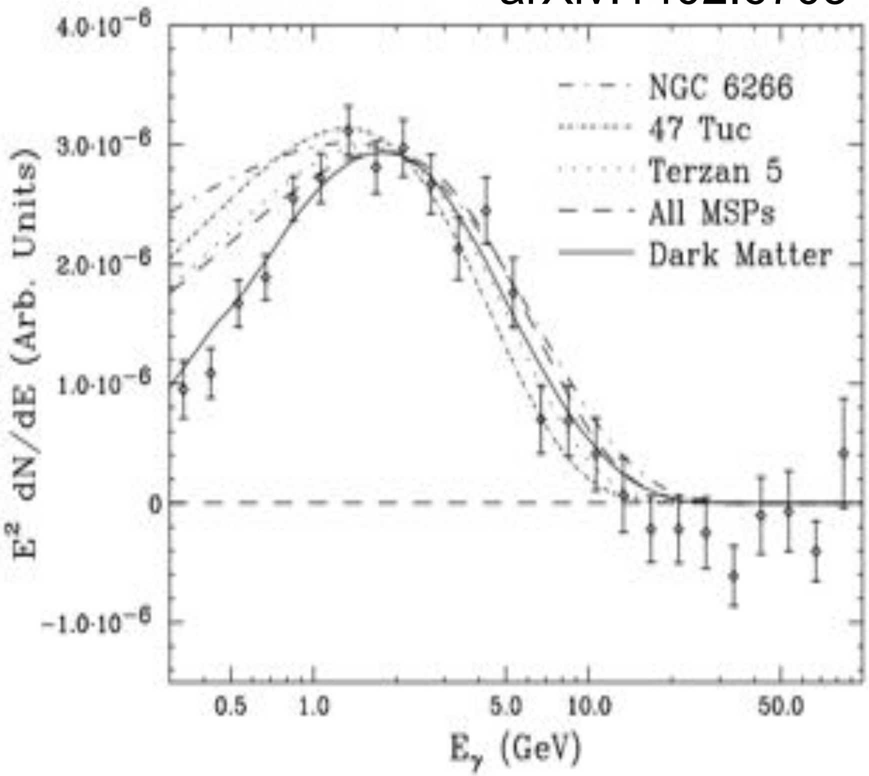
Astrophysics or Dark Matter?

The Characterization of the Gamma-Ray Signal from the Central Milky Way: A Compelling Case for Annihilating Dark Matter

Tansu Daylan,[1] Douglas P. Finkbeiner,[1,2] Dan Hooper,[3,4] Tim Linden,[5]
Stephen K. N. Portillo,[2] Nicholas L. Rodd,[6] and Tracy R. Slatyer[6,7]



arXiv:1402.6703

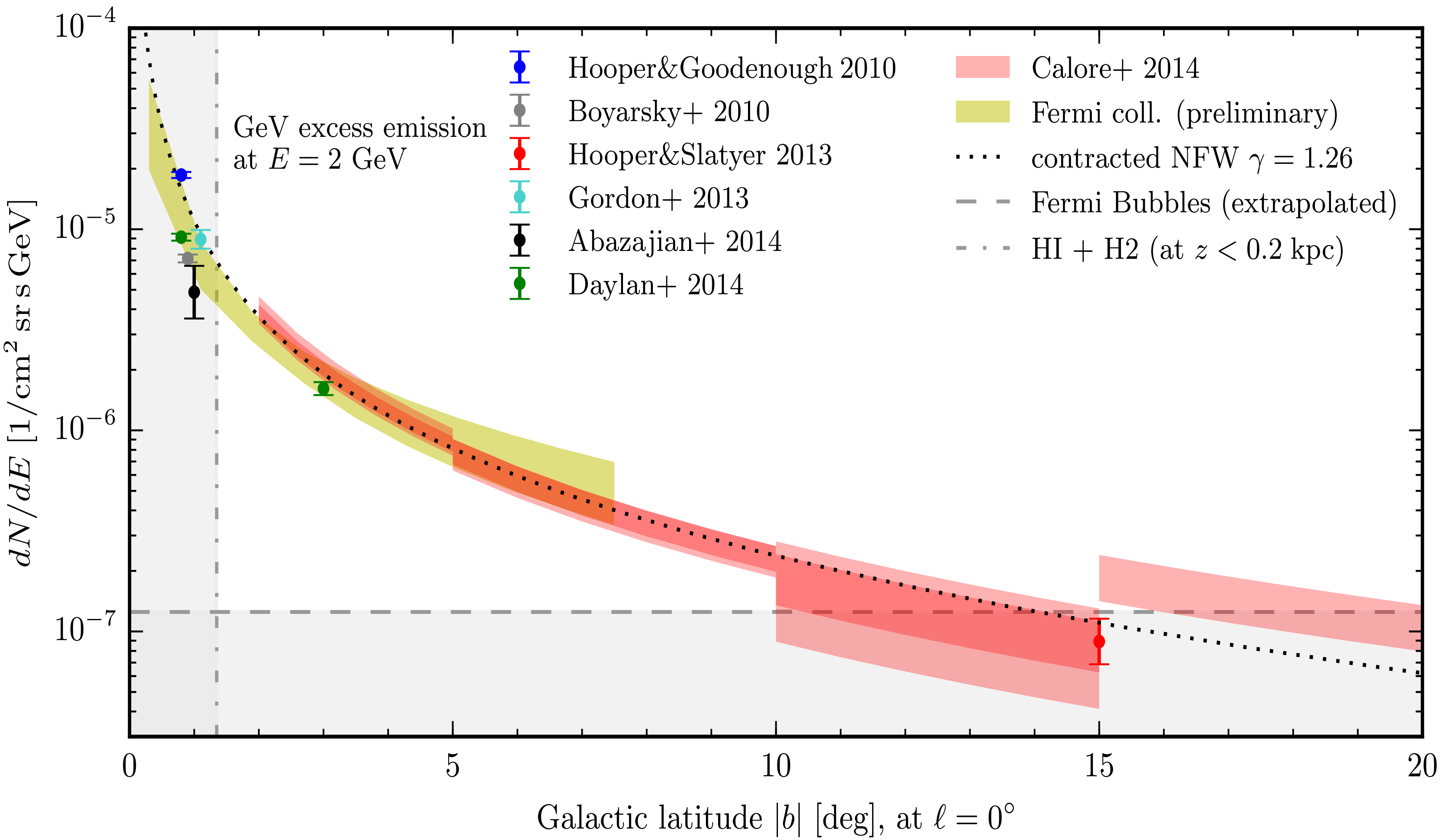


[Daylan+ 2014]

PHYSICAL REVIEW D **91,** 063003 (2015)

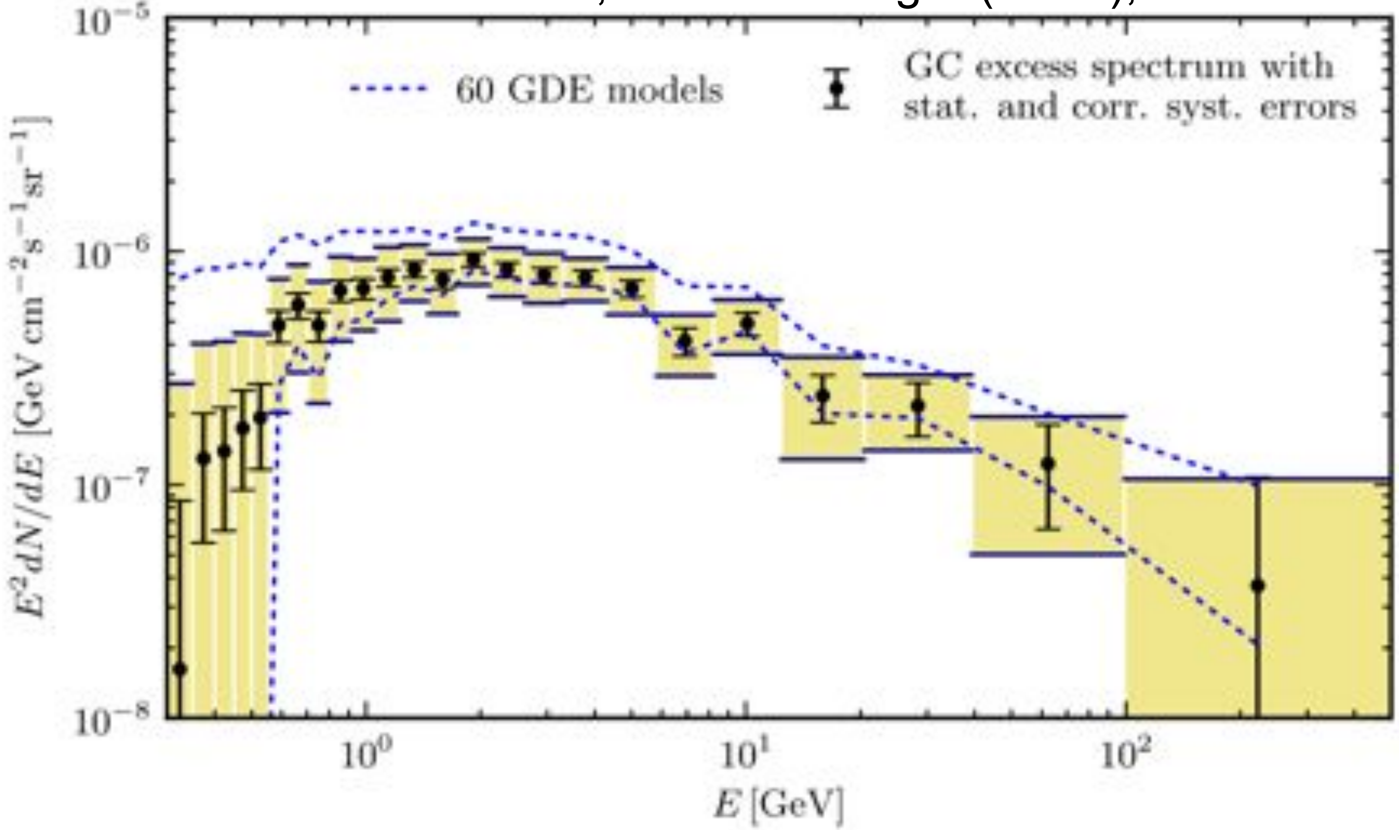
A tale of tails: Dark matter interpretations of the Fermi GeV excess in light of background model systematics

Francesca Calore,[1,*] Ilias Cholis,[2,†] Christopher McCabe,[1,‡] and Christoph Weniger[1,§]



Background Uncertainties

Calore, Cholis&Weniger (*CCW*), 1409.0042



Empirical model uncertainties (yellow) and theoretical model uncertainties (blue lines) are significantly larger than the statistical error over the entire energy range.

Evidence for DM

- Rotation Curves of Galaxies
- Gravitational Lensing
- Large Scale Structure
- CMB anisotropies
- ……

These evidences all come from gravitational interaction
CDM: velocity is negligible for structure formation,
a popular candidate, WIMP,
M ~ O(GeV) -- O(TeV), $\langle \sigma v \rangle_{ann} \sim 3 \times 10^{-26} cm^3/s$

DM-Induced Gamma Rays

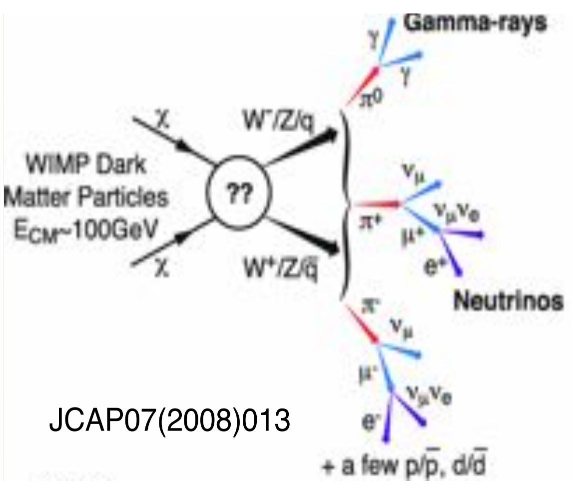
$$\frac{d^2\Phi_\gamma}{dE_\gamma d\Omega} = \sum_i \frac{dN_\gamma^i}{dE_\gamma} \frac{\langle\sigma v\rangle_i}{8\pi M_{DM}^2} \int_{l.o.s} \rho^2\left(r(r',\theta)\right) dr'$$

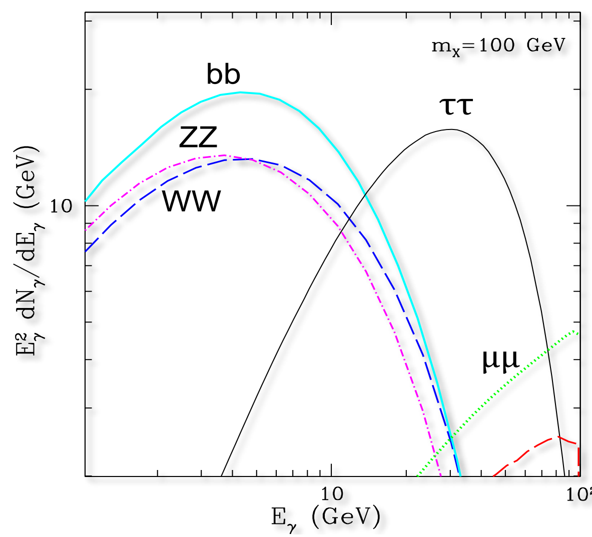
prompt

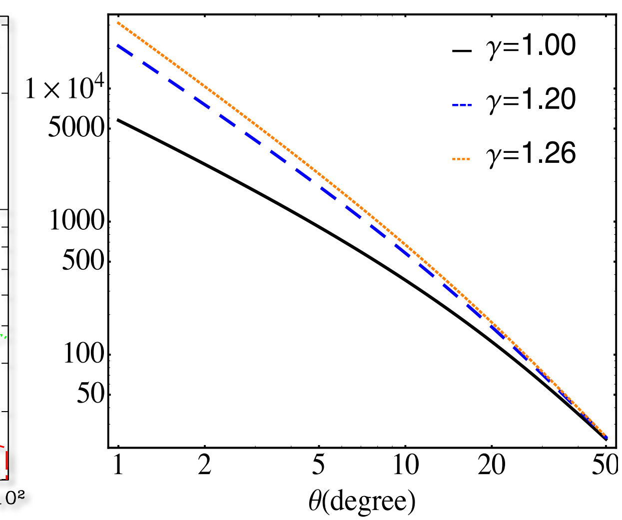
Particle Physics
Spectral Information

Astrophysics
DM distribution
Spatial information

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

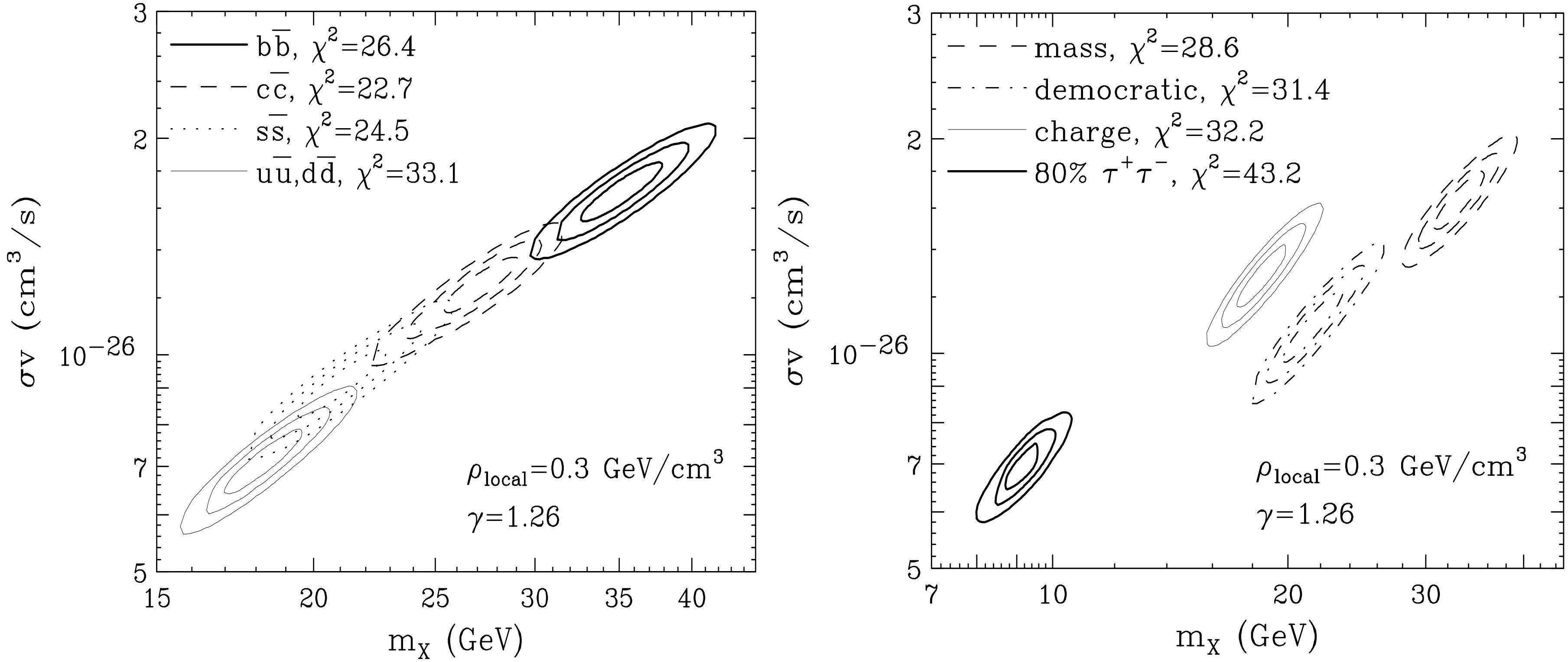






Channels

Daylan+2014



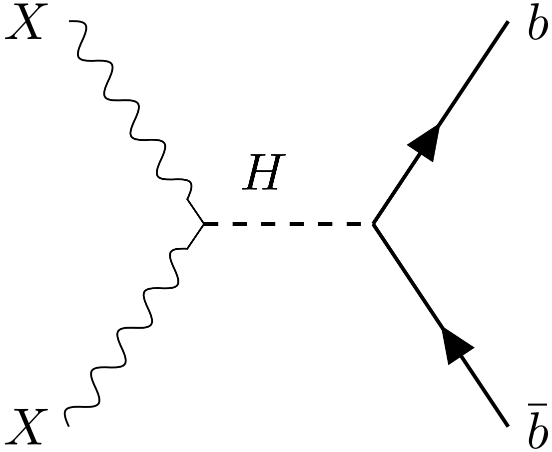
- heavy quark channel are favored,
- Naturally higgs-like couplings?

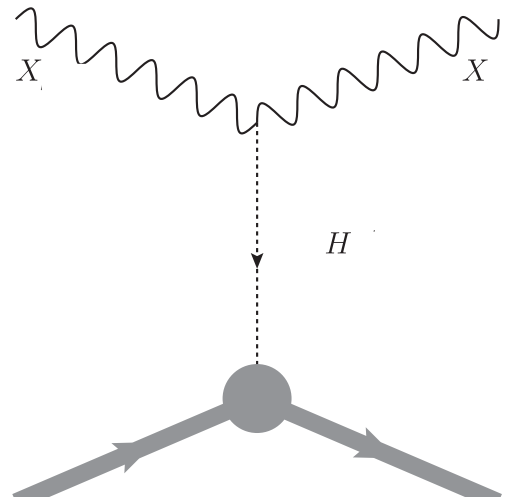
Higgs Portal DM

$$\Delta\mathcal{L}_S = -\frac{1}{2}m_S^2 S^2 - \frac{1}{4}\lambda_S S^4 - \frac{1}{4}\lambda_{hSS} H^\dagger H S^2\ ,$$

$$\Delta\mathcal{L}_V = \frac{1}{2}m_V^2 V_\mu V^\mu + \frac{1}{4}\lambda_V (V_\mu V^\mu)^2 + \frac{1}{4}\lambda_{hVV} H^\dagger H V_\mu V^\mu,$$

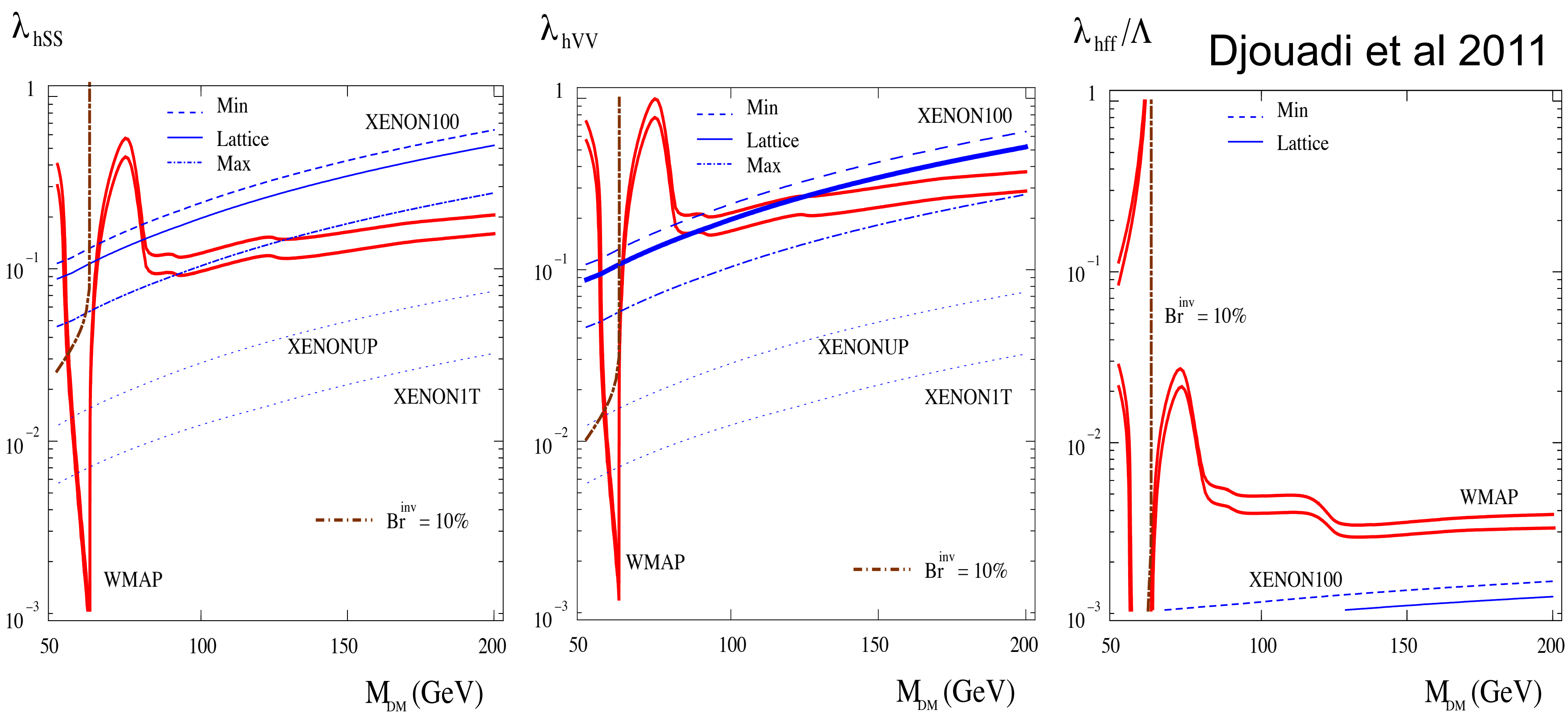
$$\Delta\mathcal{L}_f = -\frac{1}{2}m_f \bar{\chi}\chi - \frac{1}{4}\frac{\lambda_{hff}}{\Lambda} H^\dagger H \bar{\chi}\chi.$$





Direct Detection Bounds

Highly constrained, GeV favored region excluded.



Djouadi et al 2011

$U(1)_X$ Vector DM

P.Ko, W-I.Park, YT,1404.5257(JCAP)

- U(1) dark gauge symmetry,

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

$$-\lambda_{H\Phi}\left(H^\dagger H - \frac{v_H^2}{2}\right)\left(\Phi^\dagger\Phi - \frac{v_\Phi^2}{2}\right) - \lambda_H\left(H^\dagger H - \frac{v_H^2}{2}\right)^2 + \mathcal{L}_{\rm SM}.$$

- dark Higgs field

$$D_\mu\Phi = (\partial_\mu + ig_X Q_\Phi X_\mu)\Phi,$$

- symmetry breaking

$$\Phi(x) = \frac{1}{\sqrt{2}}\left(v_\Phi + \varphi(x)\right),$$

Particle spectrum

- Massive gauge boson X is the Dark Matter
- Mixed two scalars

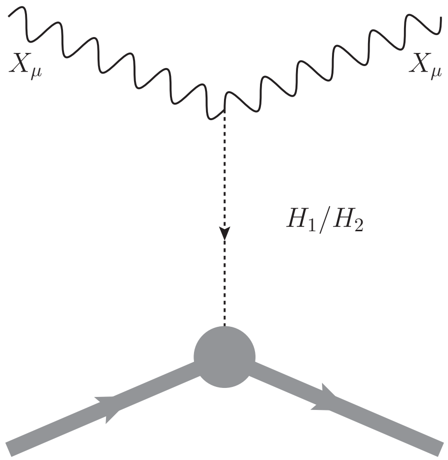
$$\begin{pmatrix} h \\ \varphi \end{pmatrix} = \begin{pmatrix} c_\alpha & s_\alpha \\ -s_\alpha & c_\alpha \end{pmatrix} \begin{pmatrix} H_1 \\ H_2 \end{pmatrix} \equiv O \begin{pmatrix} H_1 \\ H_2 \end{pmatrix}$$

- mixing angle $s_\alpha(c_\alpha) \equiv \sin\alpha(\cos\alpha)$

$$\mathcal{M} \equiv \begin{pmatrix} 2\lambda_H v_H^2 & \lambda_{H\Phi} v_H v_\Phi \\ \lambda_{H\Phi} v_H v_\Phi & 2\lambda_\Phi v_\Phi^2 \end{pmatrix} = \begin{pmatrix} M_{H_1}^2 c_\alpha^2 + M_{H_2}^2 s_\alpha^2 & \left(M_{H_2}^2 - M_{H_1}^2\right) s_\alpha c_\alpha \\ \left(M_{H_2}^2 - M_{H_1}^2\right) s_\alpha c_\alpha & M_{H_1}^2 s_\alpha^2 + M_{H_2}^2 c_\alpha^2 \end{pmatrix}.$$

$$\tan 2\alpha = \frac{2\mathcal{M}_{12}}{\mathcal{M}_{22} - \mathcal{M}_{11}}, \text{ or } \sin 2\alpha = \frac{2\lambda_{H\Phi} v_H v_\Phi}{M_{H_2}^2 - M_{H_1}^2}.$$

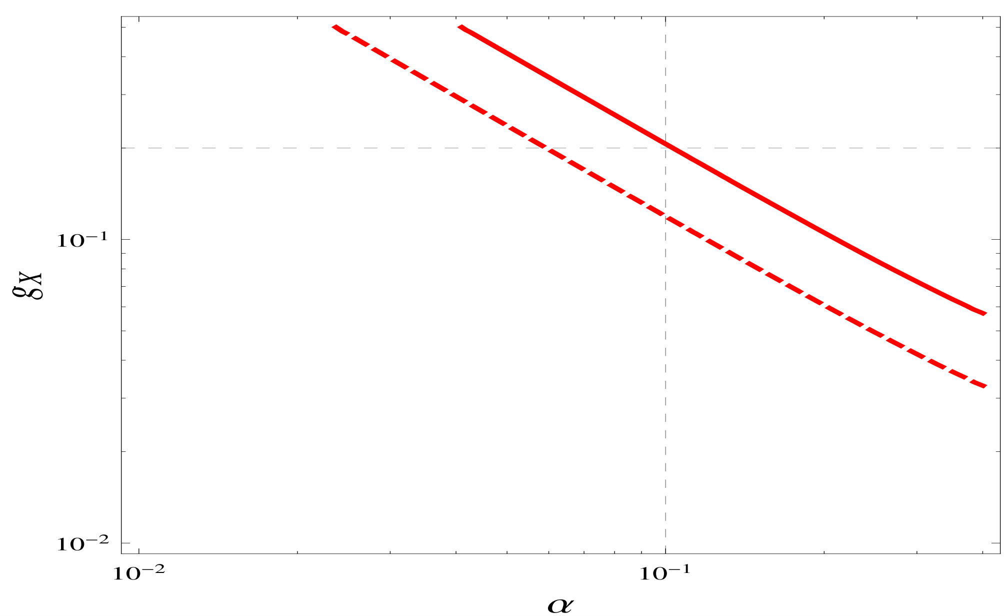
Direct Detection

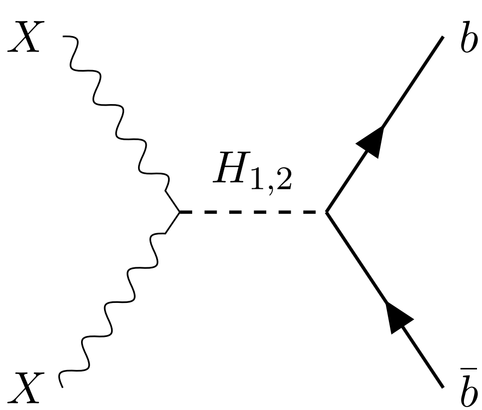


$$\sigma_p^{\rm SI} = \frac{4\mu_V^2}{\pi}\left(\frac{g_X s_\alpha c_\alpha m_p}{2v_H}\right)^2\left(\frac{1}{m_{H_1}^2}-\frac{1}{m_{H_2}^2}\right)^2 f_p^2,$$

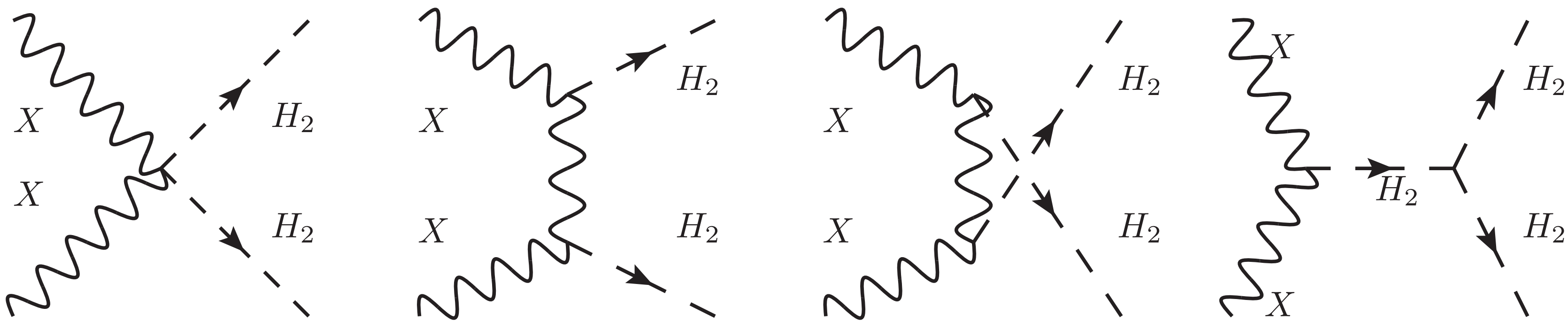
$$\simeq 2.2\times 10^{-45}{\rm cm}^2\left(\frac{g_X s_\alpha c_\alpha}{10^{-2}}\right)^2\left(\frac{75\,{\rm GeV}}{m_{H_2}}\right)^4\left(1-\frac{m_{H_2}^2}{m_{H_1}^2}\right)^2$$

$m_X = 80GeV, m_{H_2} = 75GeV$



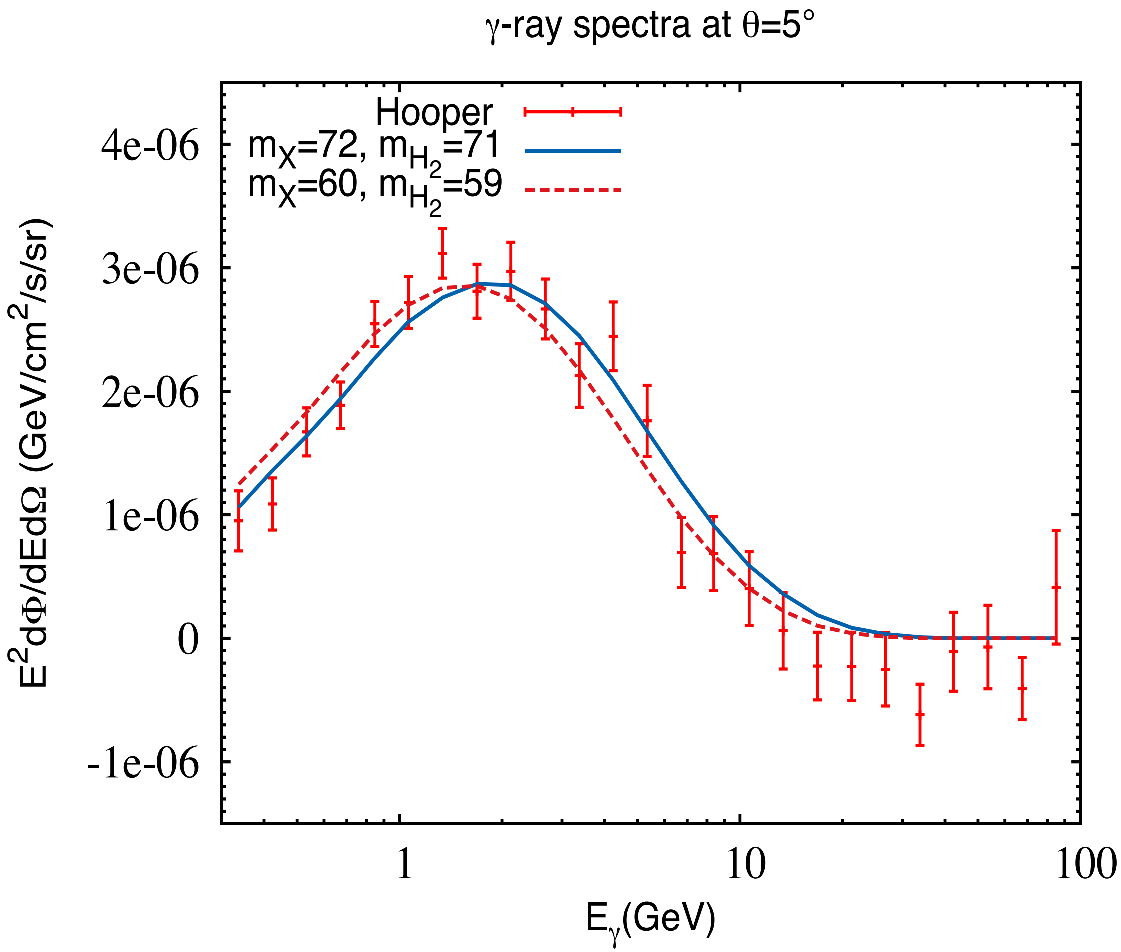


Annihilation



- These are the dominant annihilating processes,
- The *on-shell* final particles decay into standard model fermions,
- mostly bb for dark Higgs with mass *<130* GeV

Gamma-Ray spectrum



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Extensions: Hidden sector DM

- hidden sector for DM with gauge symmetry
- residual symmetry, dark Higgs, new gauge boson(s), and they decay into SM fermions through *Higgs portal* and kinetic mixing,
- Example: Z_3

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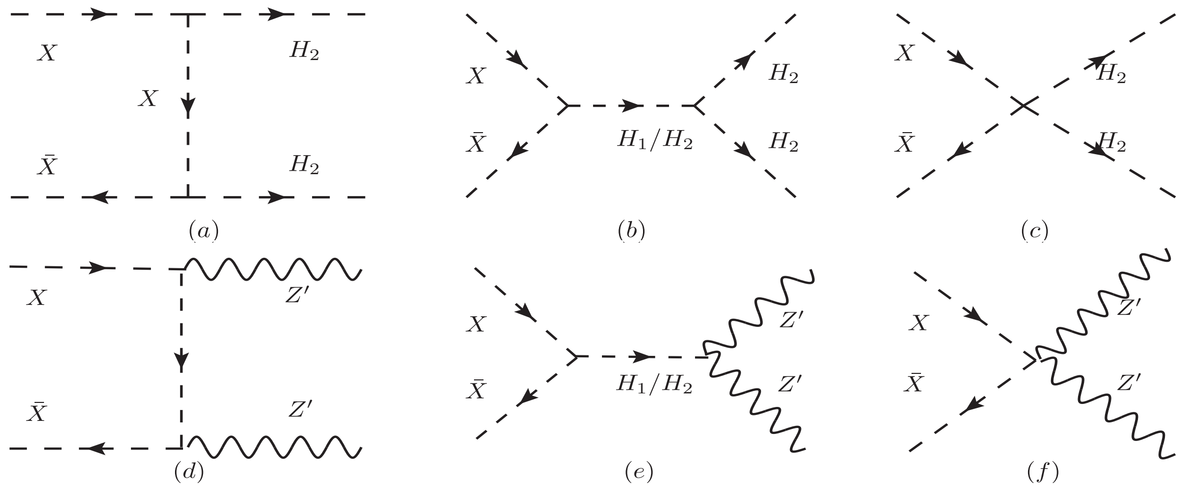
$$\mathcal{L} = \mathcal{L}_{\rm SM} - \frac{1}{4}\tilde{X}_{\mu\nu}\tilde{X}^{\mu\nu} - \frac{1}{2}\sin\epsilon\tilde{X}_{\mu\nu}\tilde{B}^{\mu\nu} + D_\mu\phi_X^\dagger D^\mu\phi_X + D_\mu X^\dagger D^\mu X - V,$$

$$V = -\mu_H^2 H^\dagger H + \lambda_H\left(H^\dagger H\right)^2 - \mu_\phi^2\phi_X^\dagger\phi_X + \lambda_\phi\left(\phi_X^\dagger\phi_X\right)^2 + \mu_X^2 X^\dagger X + \lambda_X\left(X^\dagger X\right)^2$$

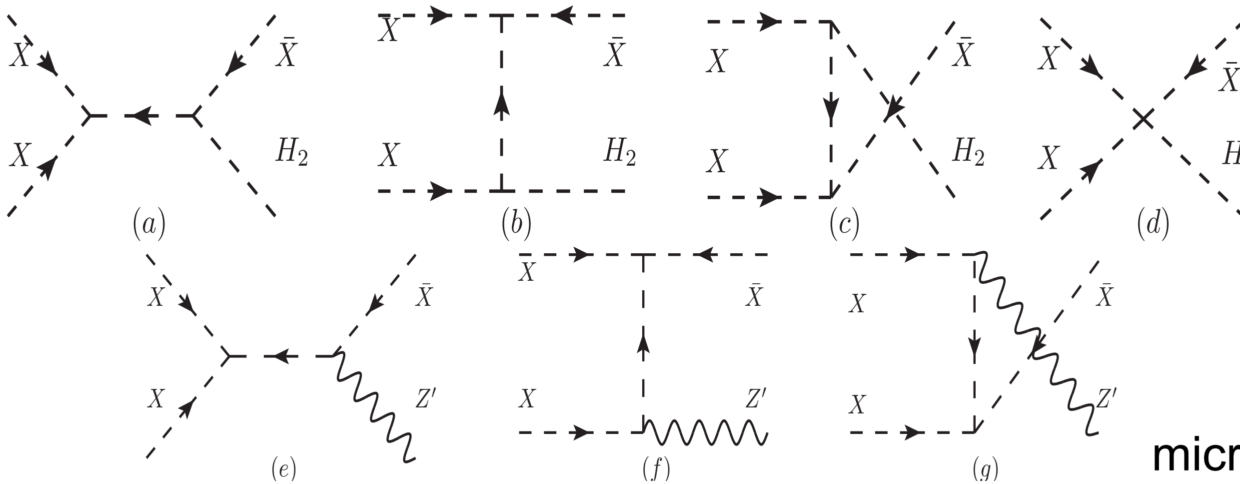
$$+ \lambda_{\phi H}\phi_X^\dagger\phi_X H^\dagger H + \lambda_{\phi X}X^\dagger X\phi_X^\dagger\phi_X + \lambda_{HX}X^\dagger X H^\dagger H + \left(\lambda_3 X^3\phi_X^\dagger + H.c.\right),$$

Annihilation Channels

- Standard

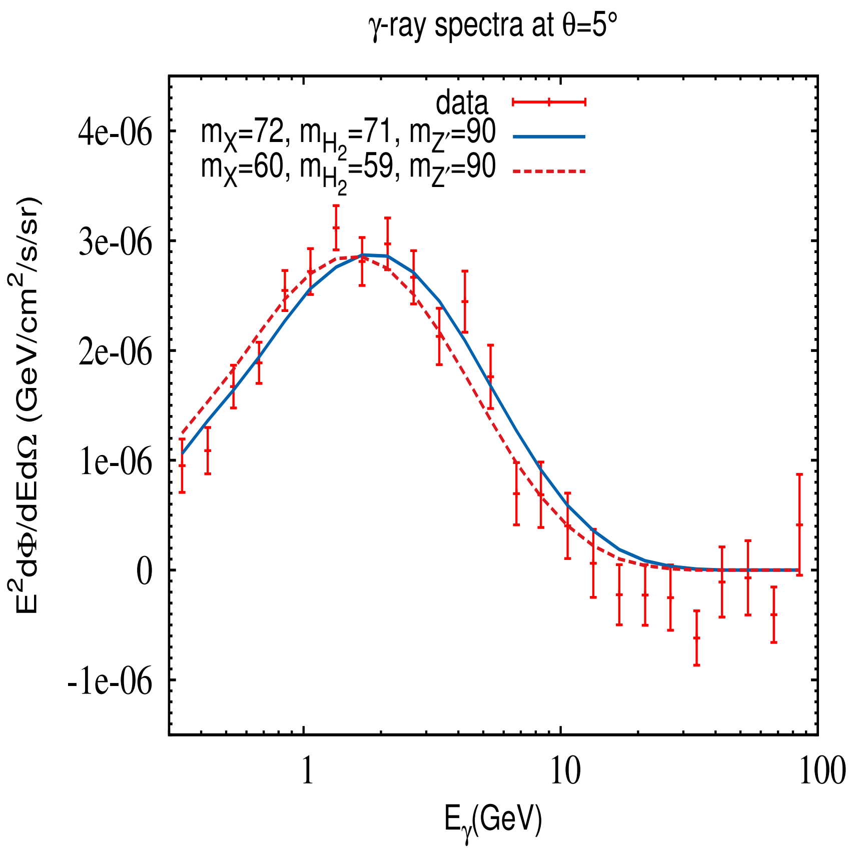


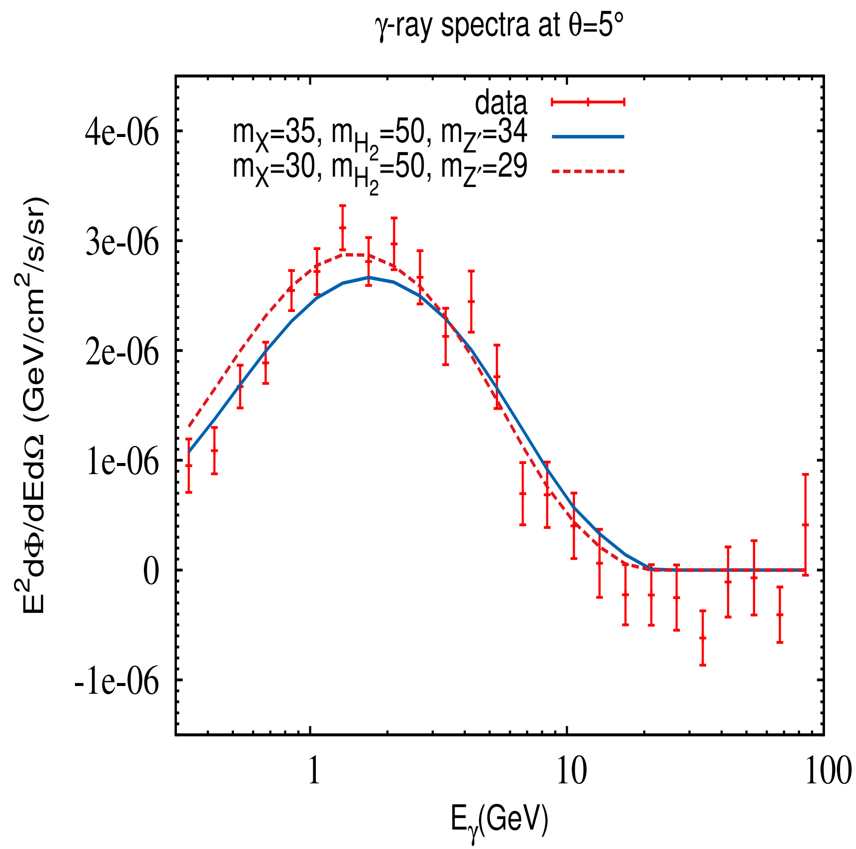
- *Semi-Annihilation*



micrOMEGAs-3

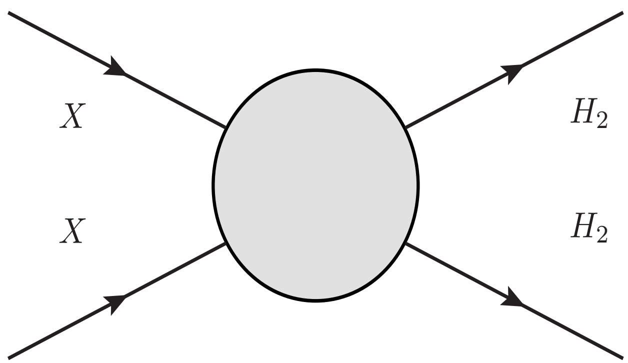
γ-ray spectra





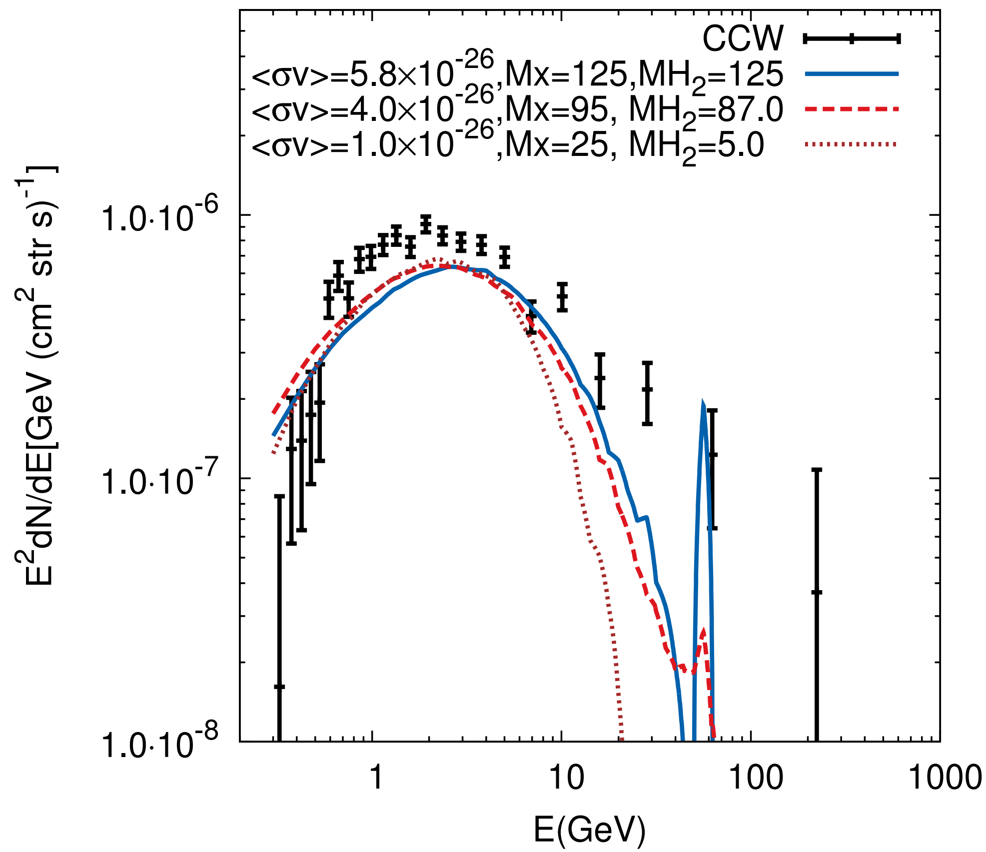
Model-Independent

- Assume dark matter annihilate into *dark higgs*



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

X can be *scalar*, *fermion* and *vector*



Numeric Analysis

$$E^2 \frac{dN}{dE} \equiv E_\gamma^2 \frac{1}{\Delta\Omega} \int_{\Delta\Omega} \frac{d^2\Phi}{dE_\gamma d\Omega},$$

We now use the χ^2 function and find its minimum to find out the best fit:

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

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. 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 $\Delta\chi^2 \equiv \chi^2 - \chi^2_{\rm min} = 2.3$, 6.2 and 11.8, respectively.

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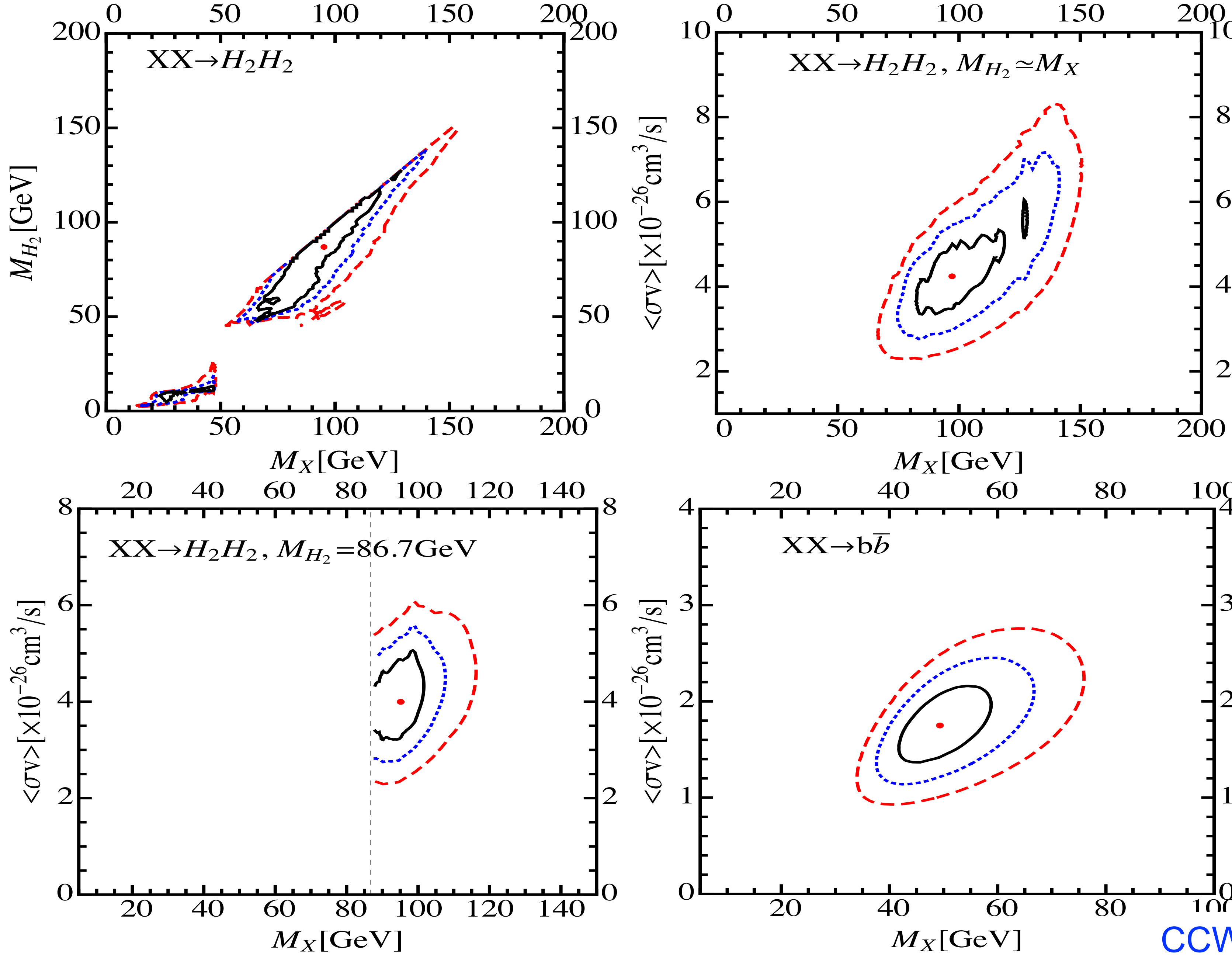


CCW 2014

Favored Parameters

P.Ko, YT, 1504.03908

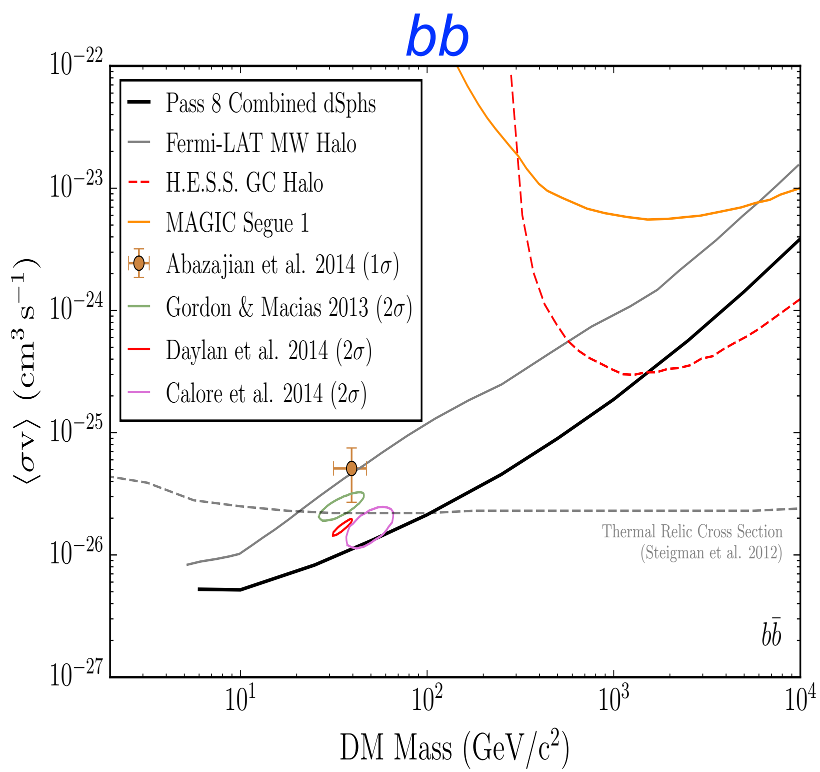
- Based on *CCW*

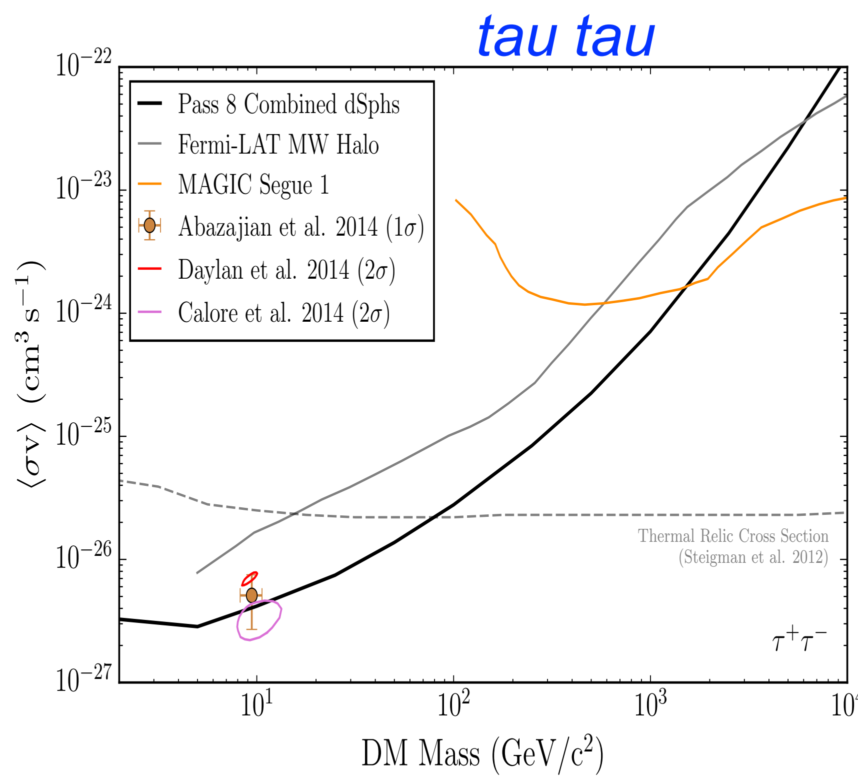
Channels	Best-fit parameters	$\chi^2_{\rm min}$/d.o.f.	p-value
$XX \to H_2H_2$ (with $M_{H_2} \neq M_X$)	$M_X \simeq 95.0$GeV, $M_{H_2} \simeq 86.7$GeV $\langle\sigma v\rangle \simeq 4.0 \times 10^{-26}{\rm cm}^3/{\rm s}$	22.0/21	0.40
$XX \to H_2H_2$ (with $M_{H_2} = M_X$)	$M_X \simeq 97.1$GeV $\langle\sigma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

TABLE I: Summary table for the best fits with three different assumptions.

Searching for Dark Matter Annihilation from Milky Way Dwarf Spheroidal Galaxies with Six Years of Fermi-LAT Data

Fermi-LAT Collaboration, 1503.02641





Contours do not fully consider uncertainties in the DM profile

A broader range of DM masses and annihilation channels

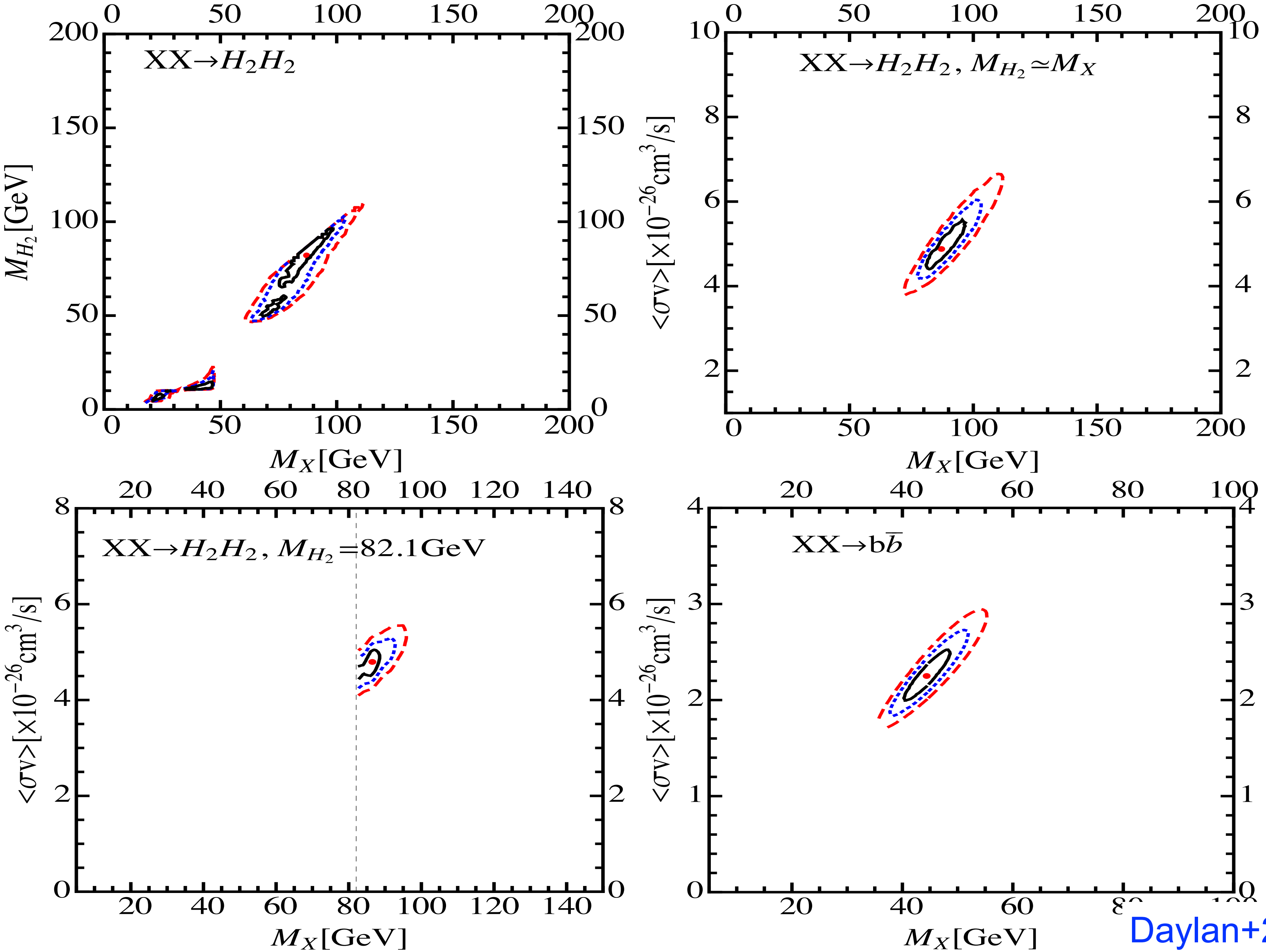
Summary

- We have briefly introduced the GeV gamma-ray excess from galactic center.
- Simple DM models with *gauge symmetries* are fully capable of providing the needed signal.
- We have specifically discussed a vector dark matter model, and a scalar dark matter with Z_3 symmetry and conducted a *model-independent* analysis.

Thanks for your attention.

Backup

P.Ko, YT, 1504.03908



Daylan+2014