

Gamma-ray constraints on DM annihilation to bosons in an EFT framework

Michael A. Fedderke

University of Chicago

In collaboration with

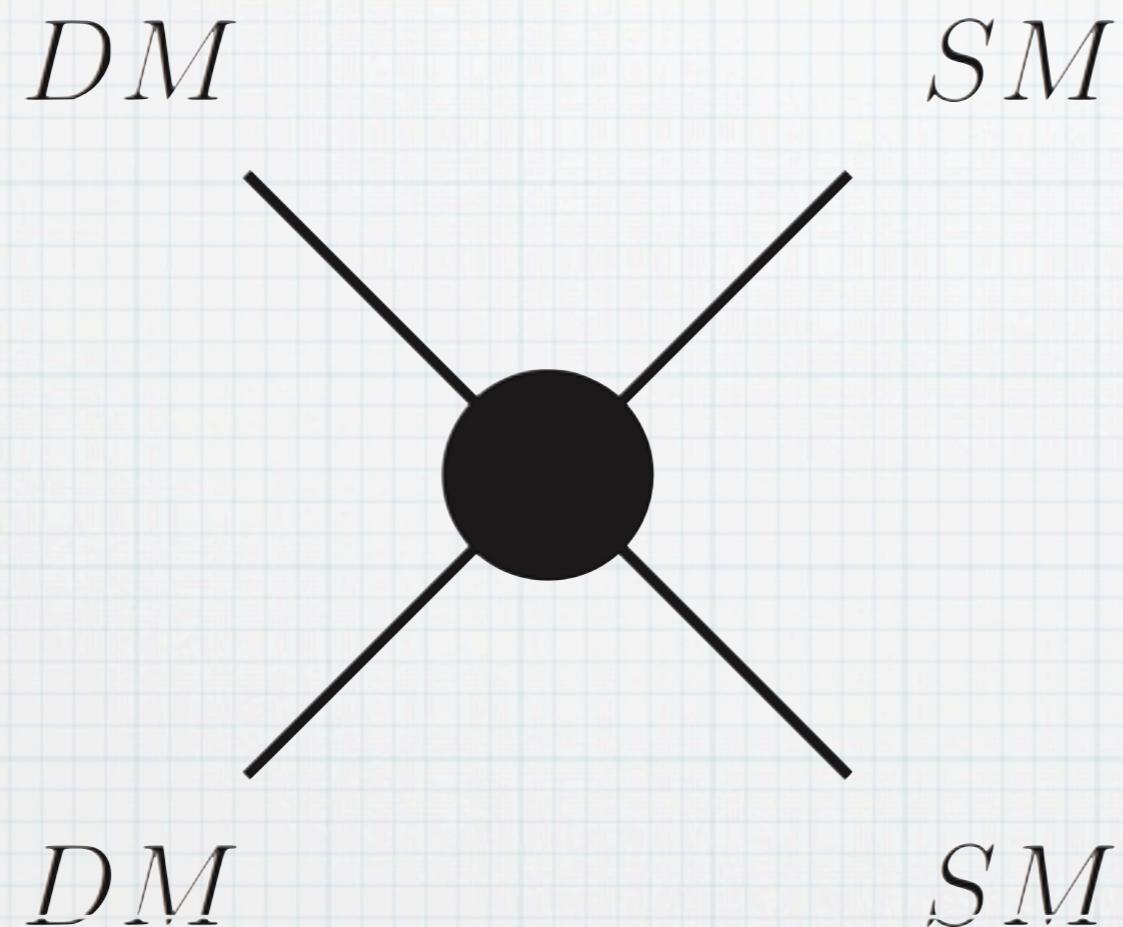
Edward W. Kolb, Tongyan Lin and Lian-Tao Wang
(in preparation)

A continuation of a study in Chen, Kolb and Wang (**CKW**) 1305.0021 [hep-ph]

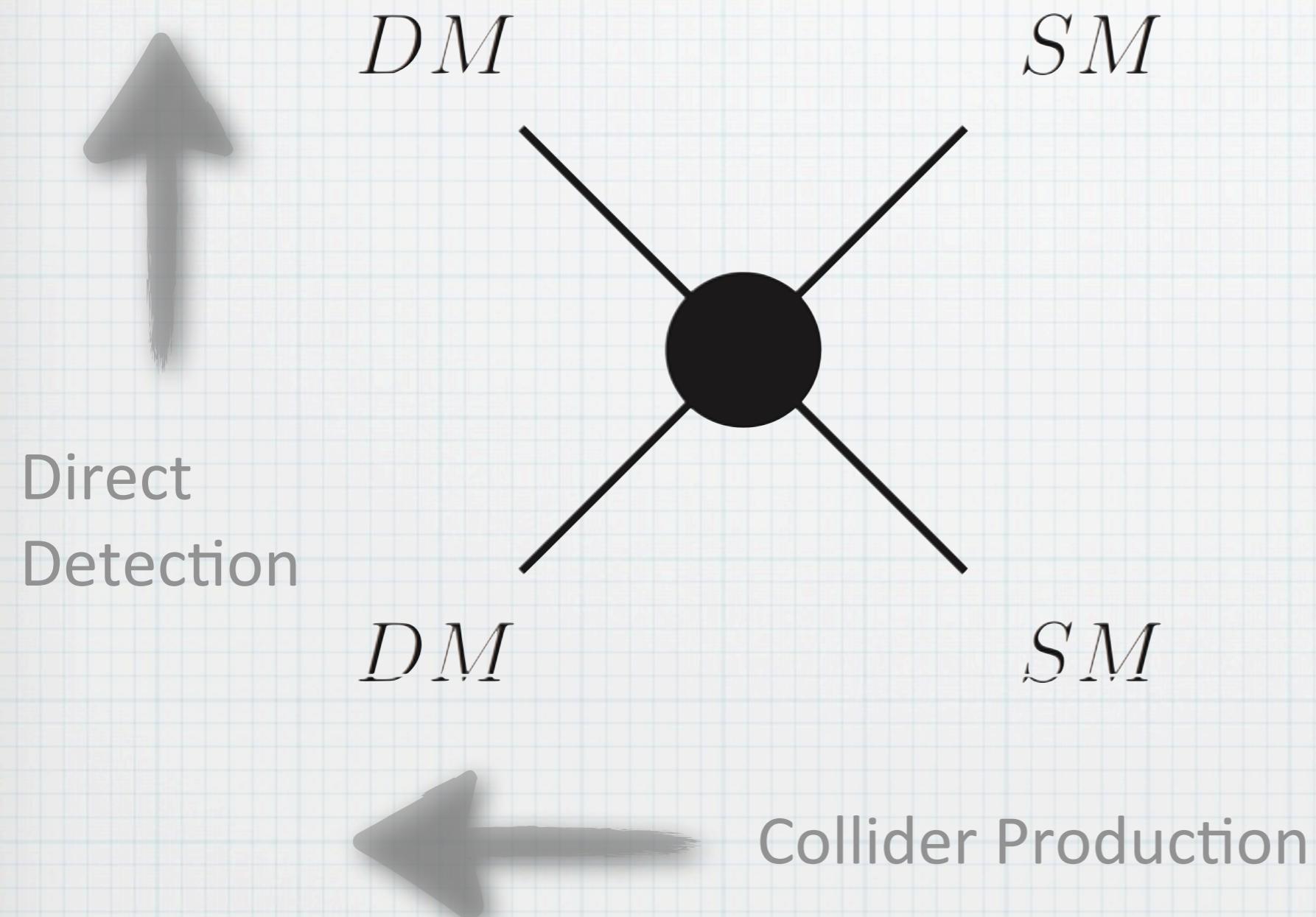


THE UNIVERSITY OF
CHICAGO

DM Detection

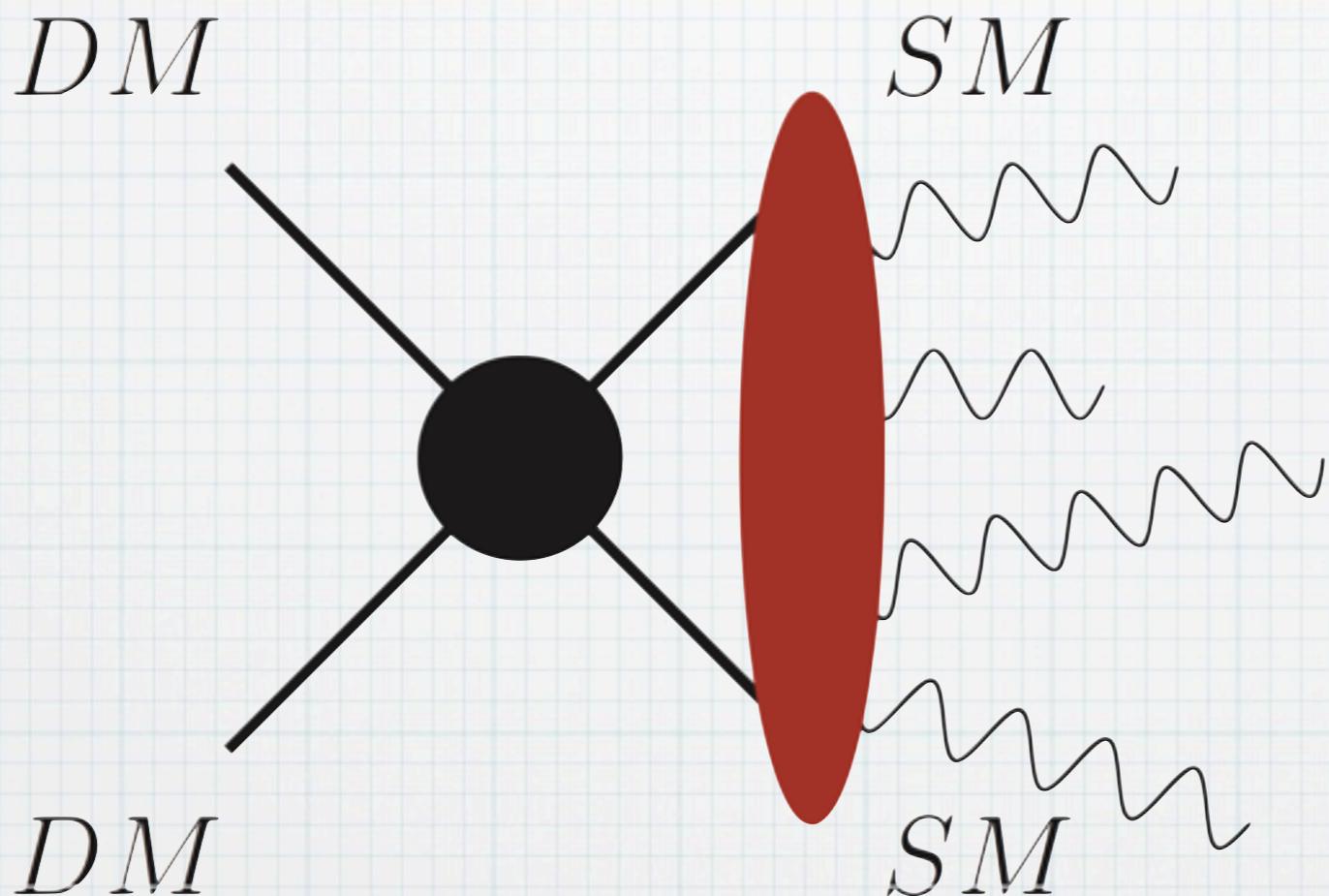
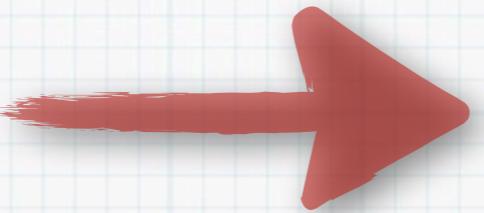


DM Detection

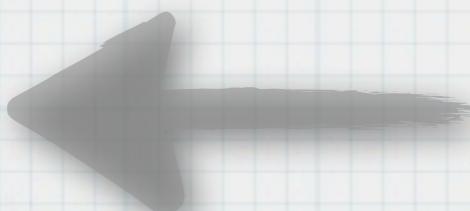


DM Detection

Indirect Detection

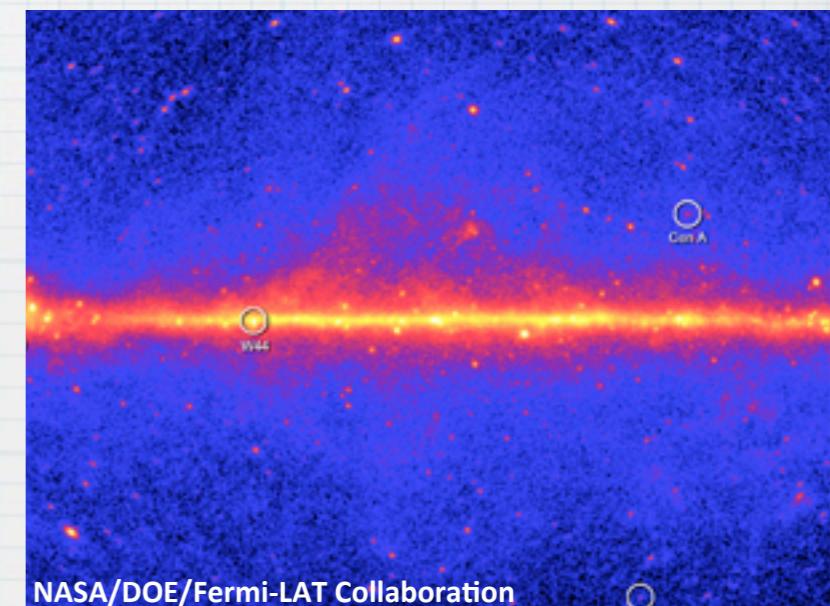


Direct
Detection



Collider Production

**Photons
from the
Galactic
Centre**



NASA/DOE/Fermi-LAT Collaboration



DM Annihilation

Annihilation cross-section from EFT (CKW, previous talk).

50 operators $\Lambda^{4-d} J_{DM} \cdot J_{SM}$ where J_{SM}, J_{DM} gauge singlets.

Up to mass-dimension 8.

$2 \rightarrow 2$.

DM DM $\rightarrow \gamma\gamma, \gamma Z, \gamma h, W^+W^-, ZZ, Zh, hh,$ and $f\bar{f}$

σv tabulated in CKW.

s-channel Z/γ exchange



DM Annihilation

DM is **Dirac fermion or complex scalar**
(some EFT operators vanish identically for Majorana).

Annihilation proceeds by **one operator only**.

Present-day annihilation is **non-relativistic**.

Cross-section expandable in powers of relative velocity of
DM particles as $\sigma v = a + b v^2 \Rightarrow \langle \sigma v \rangle = a + 6b T/M$

Only s-wave relevant for photon signal ($T \ll M$)
34 operators. No constraints on other 16.

Fixing the EFT scale

Cross-section not uniquely fixed by operator choice:

$$a = \Lambda^{-2(d-4)} \tilde{a}(M) \quad \text{and} \quad b = \Lambda^{-2(d-4)} \tilde{b}(M)$$

Two free parameters in low-energy EFT:

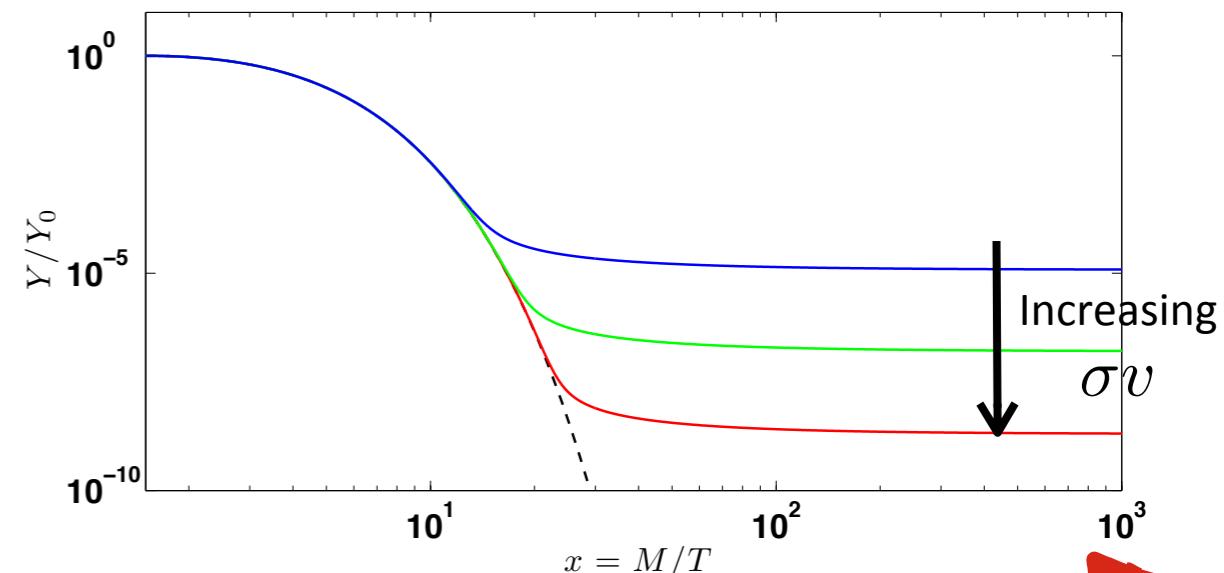
DM mass, M

EFT scale parameter, Λ

Scan over M .

Fix the EFT scale parameter:

DM is a **cold thermal relic WIMP** with $\Omega_{DM} h^2 = 0.12$.



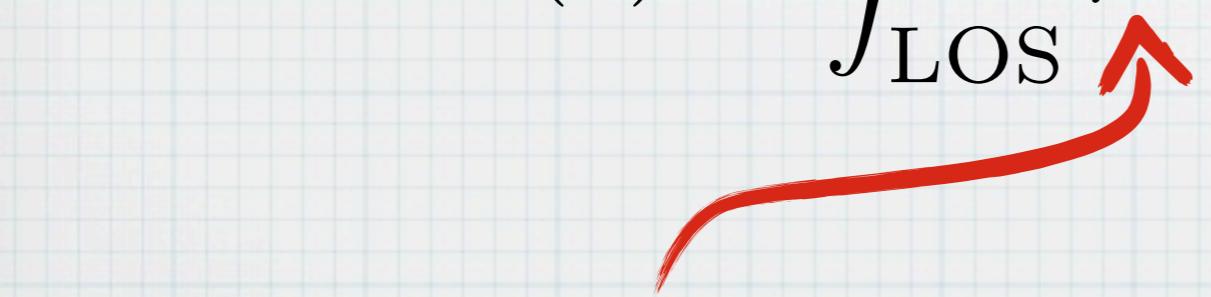
Planck [1303.5076]

Photon flux

The differential photon flux measured experimentally is

$$\frac{d\Phi}{dEd\Omega} = \frac{\langle \sigma v \rangle}{16\pi M^2} \times J(\theta) \times \frac{dN_\gamma}{dE}$$

$$J(\theta) \equiv \int_{\text{LOS}} \rho^2[r(s, l, b)] ds$$



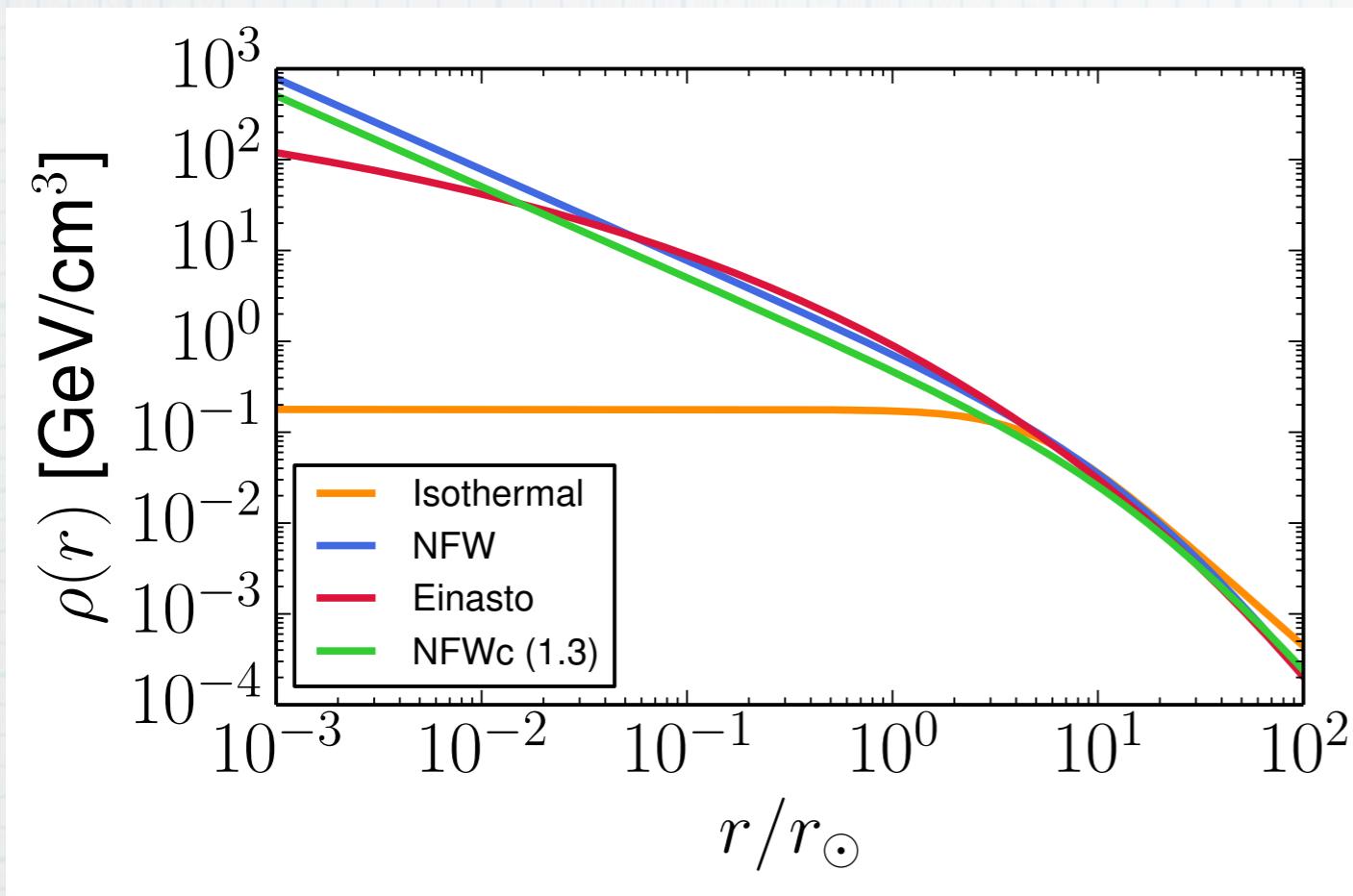
DM mass distribution (halo profile)



**Per-annihilation
photon spectrum:
From Pythia (8.176)**

DM Halo profile

Need to understand the DM distribution ρ to convert flux into a cross-section. Not very well understood:



Choice of profile and normalisation are a source of large systematic uncertainty

Normalisation from fits to galactic dynamics and microlensing data.
 [Iocco et al. 1107.5810]

Flux Limits

Lines

Applicable to cases where DM annihilates to γX ($X = \gamma, Z, h$) final states.

Fermi-LAT [1305.5597] and HESS [1301.1173] publish “line scans”: experimental lineshape + power-law background.

Only single line assumed. Some operators have two...

Strict enough to be constraining up to multi-TeV DM mass if large BR to lines.

Flux Limits (cont.)

Inclusive

$$\Phi \propto \frac{\langle \sigma v \rangle}{M^2} \int \frac{dN_\gamma}{dE_\gamma} dE_\gamma$$

Applicable to any final state giving photons.

Hooper et al. [1209.3015] gives constraints on fluxes of photons in bins 0.1-0.3GeV, 0.3-1GeV, 1-10GeV, 10-100GeV.

Higher energy bins more constraining.

Strict enough to be constraining up a (few) hundred GeV in DM mass.



Methodology

Choice of DM Mass M

Experiment

Measured flux upper limit

+

Assumed halo profile

+

Per-annihilation photon
spectrum

Upper limit



$$\langle \sigma v \rangle$$



Required value

Theory

Choice of EFT
annihilation operator

+

Cold thermal relic WIMP
assumption

Results

Results can be classified by, and understood in terms of, the structure of operators.

13 qualitatively distinct categories of limit behaviour.

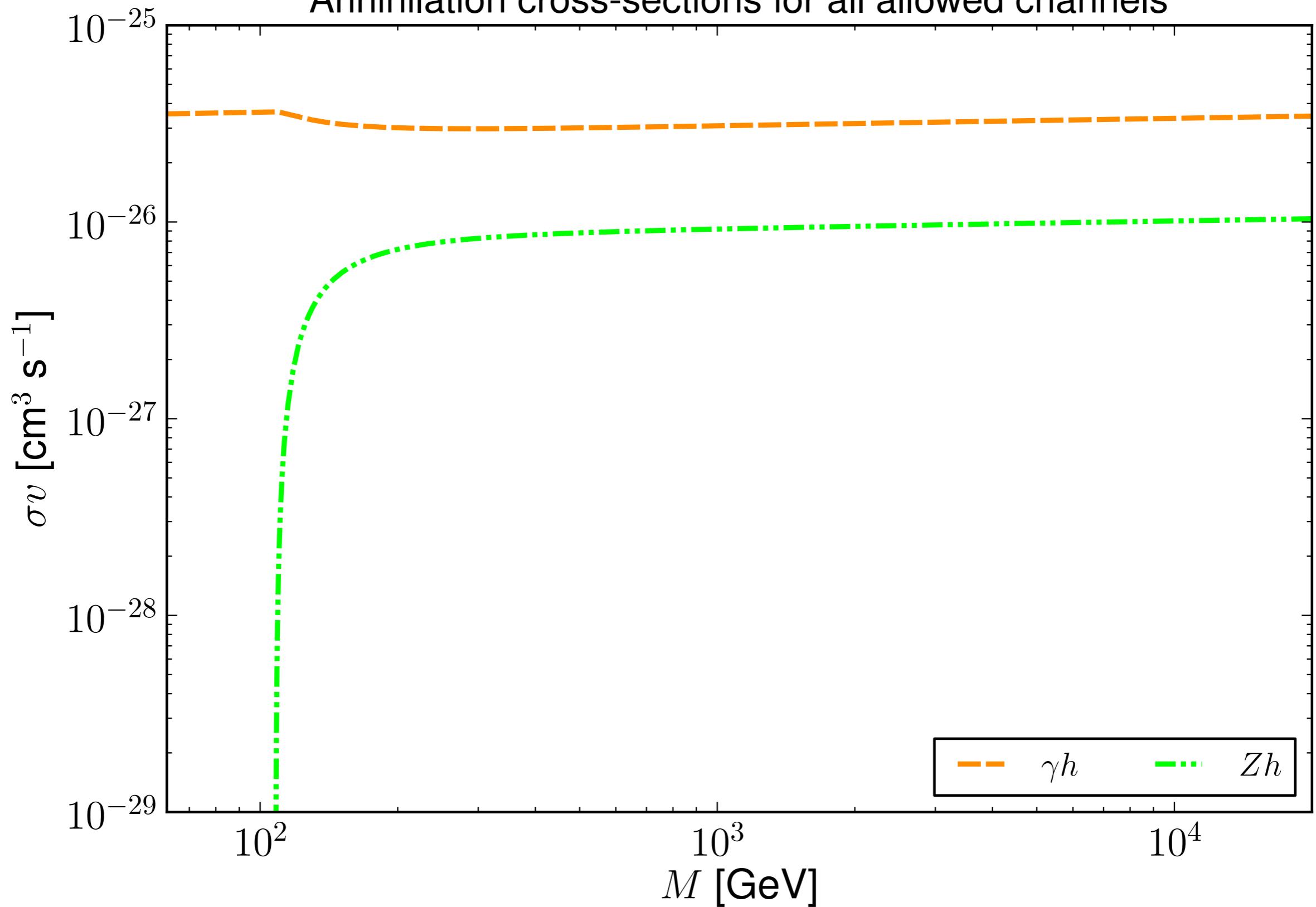
Will focus on illustrative examples of some interesting classes...

In the paper

BR, photon spectrum, Fermi-LAT line limits, HESS line limits, inclusive limits, ratio limits (not discussed here)

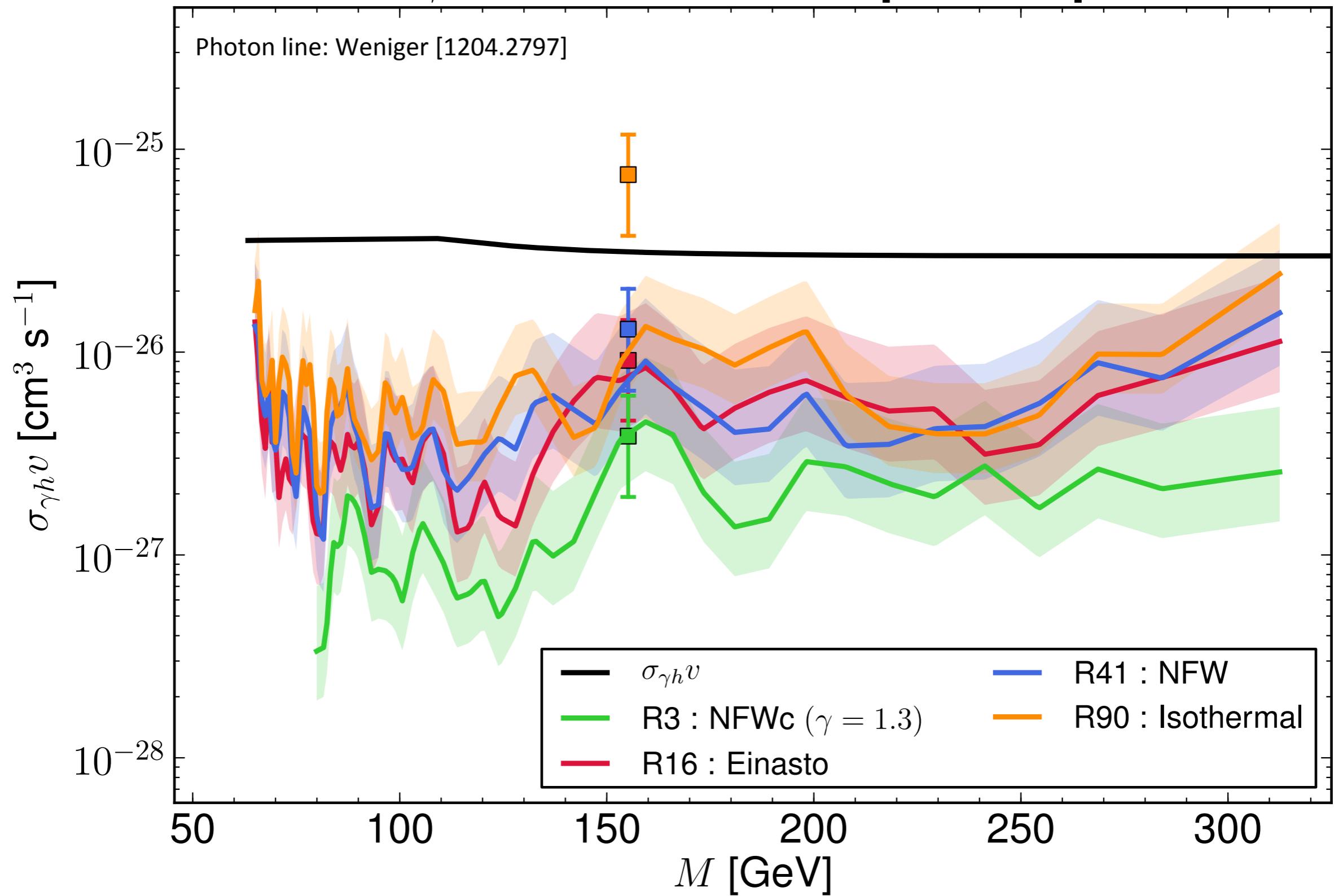
$$\Lambda^{-4} \bar{\chi} \gamma^\mu \chi \left(\tilde{B}_{\lambda\mu} Y_H H^\dagger D^\lambda H + \text{h.c.} \right)$$

Annihilation cross-sections for all allowed channels



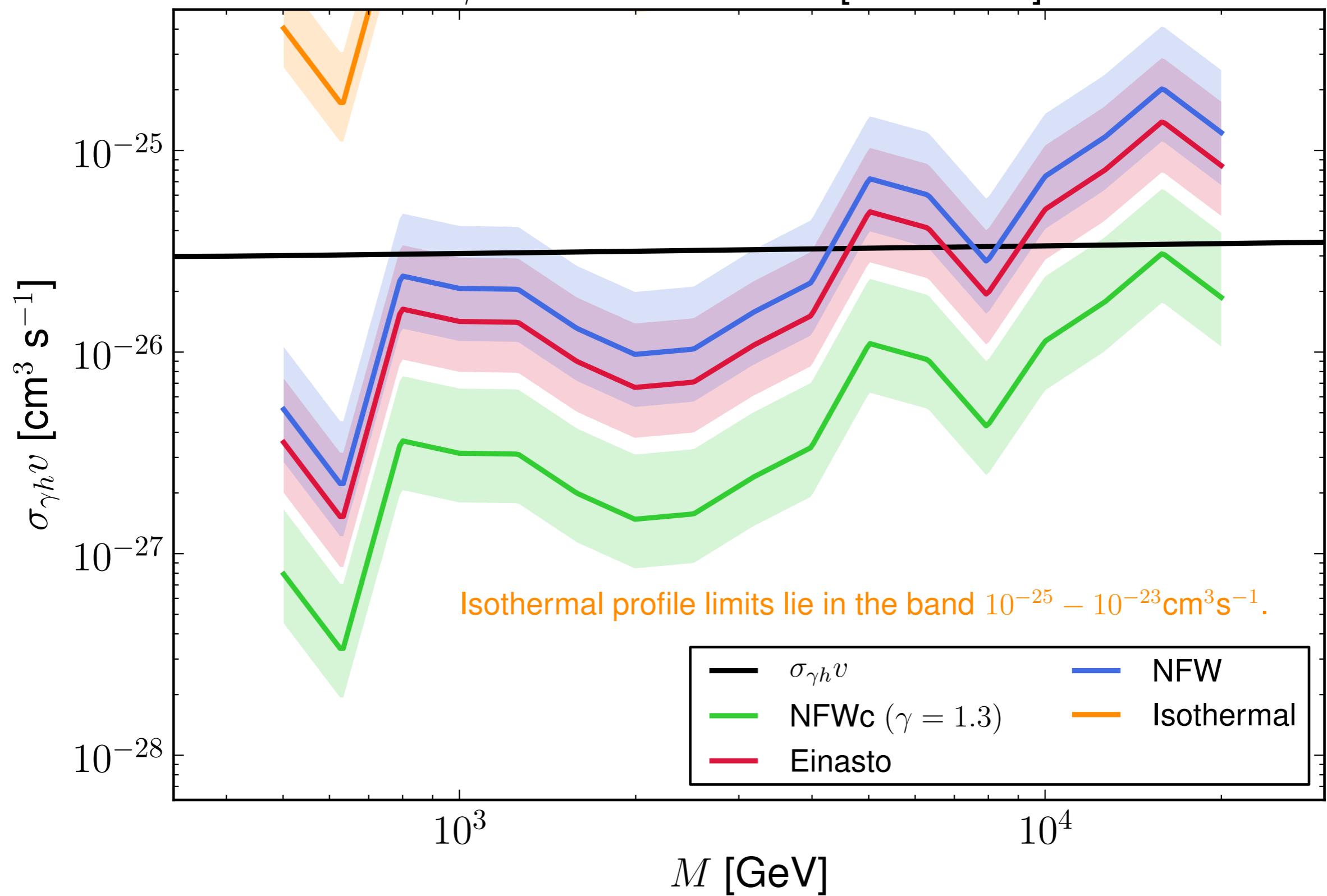
$$\Lambda^{-4} \bar{\chi} \gamma^\mu \chi \left(\tilde{B}_{\lambda\mu} Y_H H^\dagger D^\lambda H + \text{h.c.} \right)$$

γh line limits -:- Fermi-LAT [1305.5597]

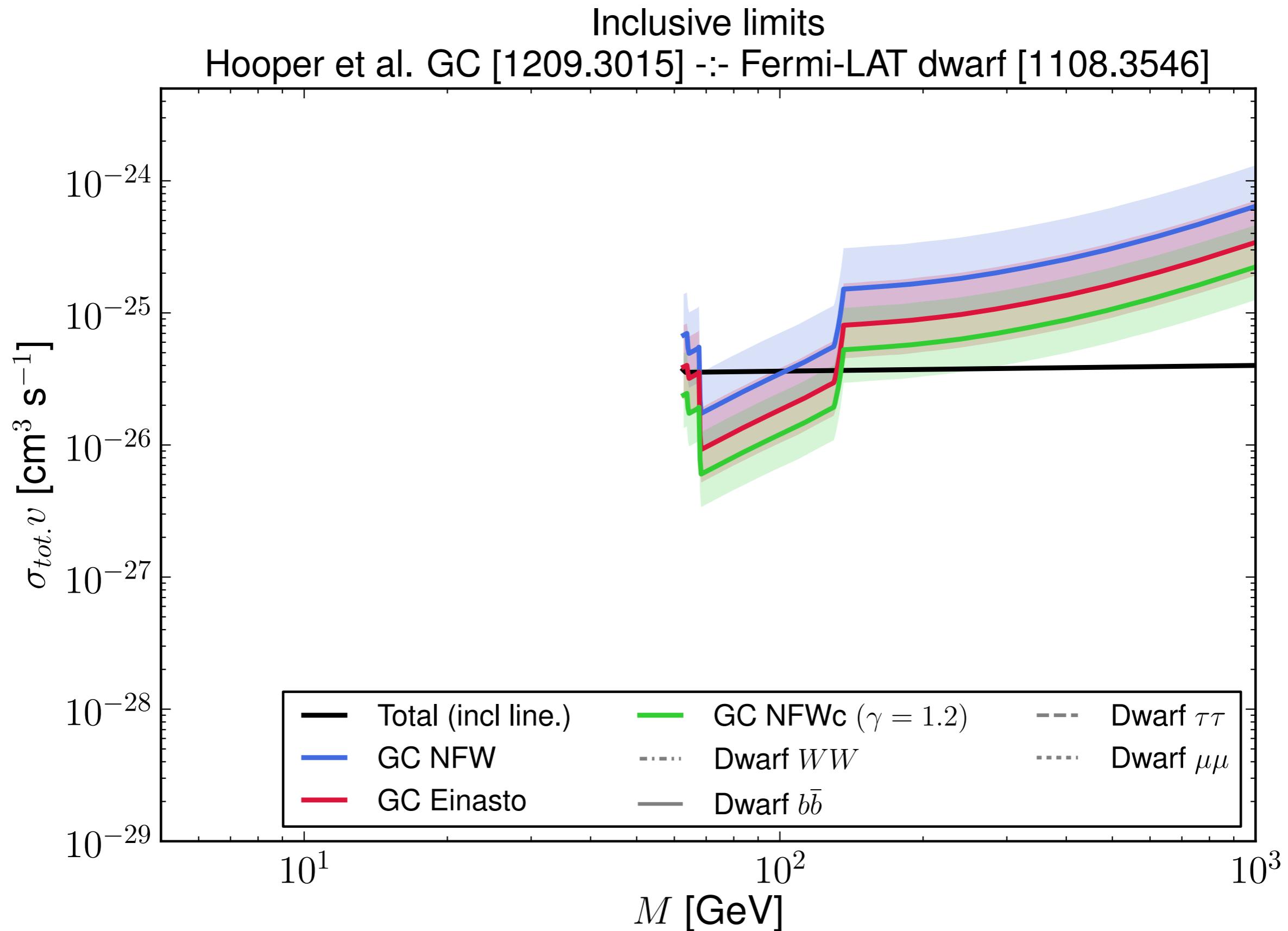


$$\Lambda^{-4} \bar{\chi} \gamma^\mu \chi \left(\tilde{B}_{\lambda\mu} Y_H H^\dagger D^\lambda H + \text{h.c.} \right)$$

γh line limits :- HESS [1301.1173]

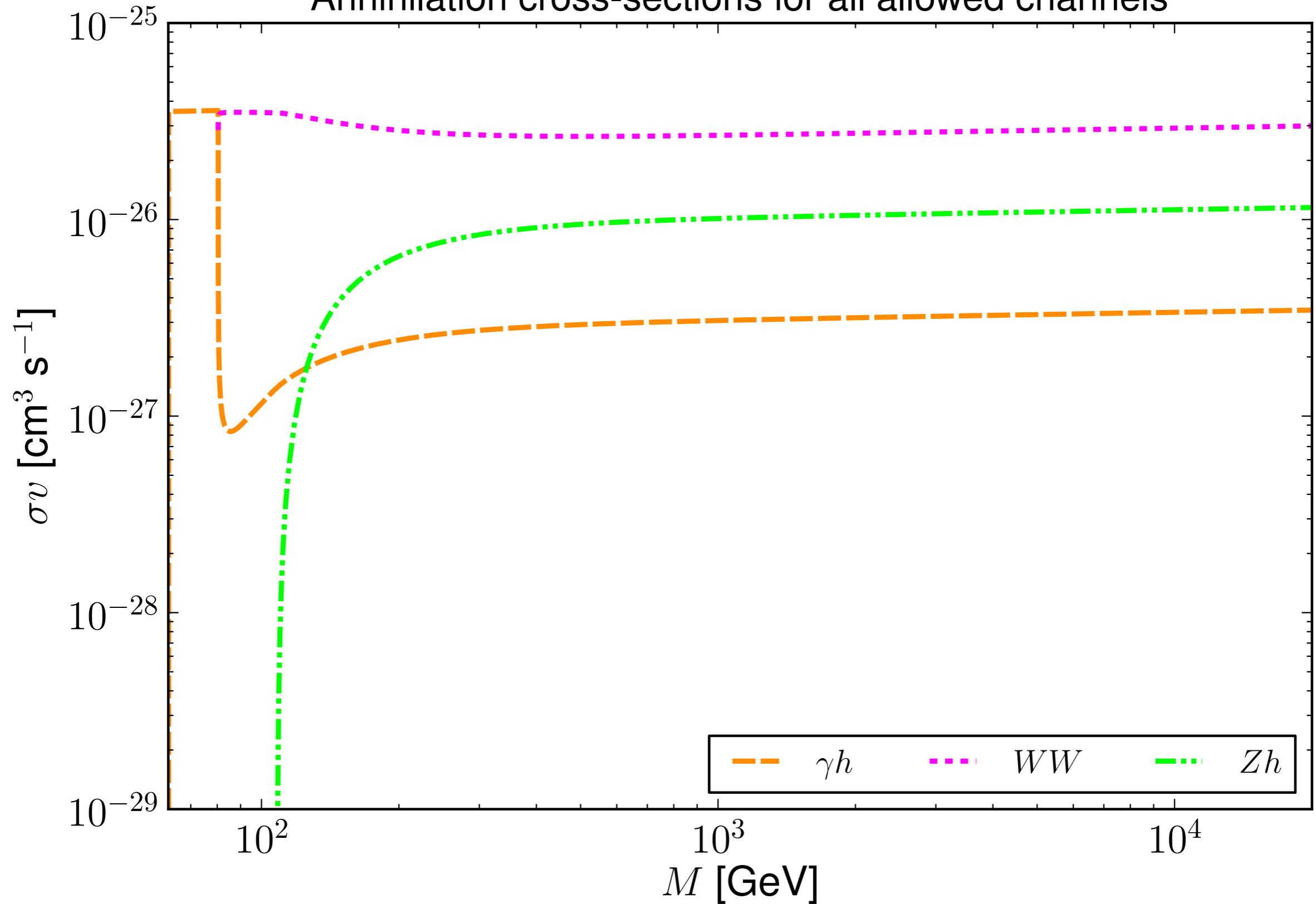


$$\Lambda^{-4} \bar{\chi} \gamma^\mu \chi \left(\tilde{B}_{\lambda\mu} Y_H H^\dagger D^\lambda H + \text{h.c.} \right)$$



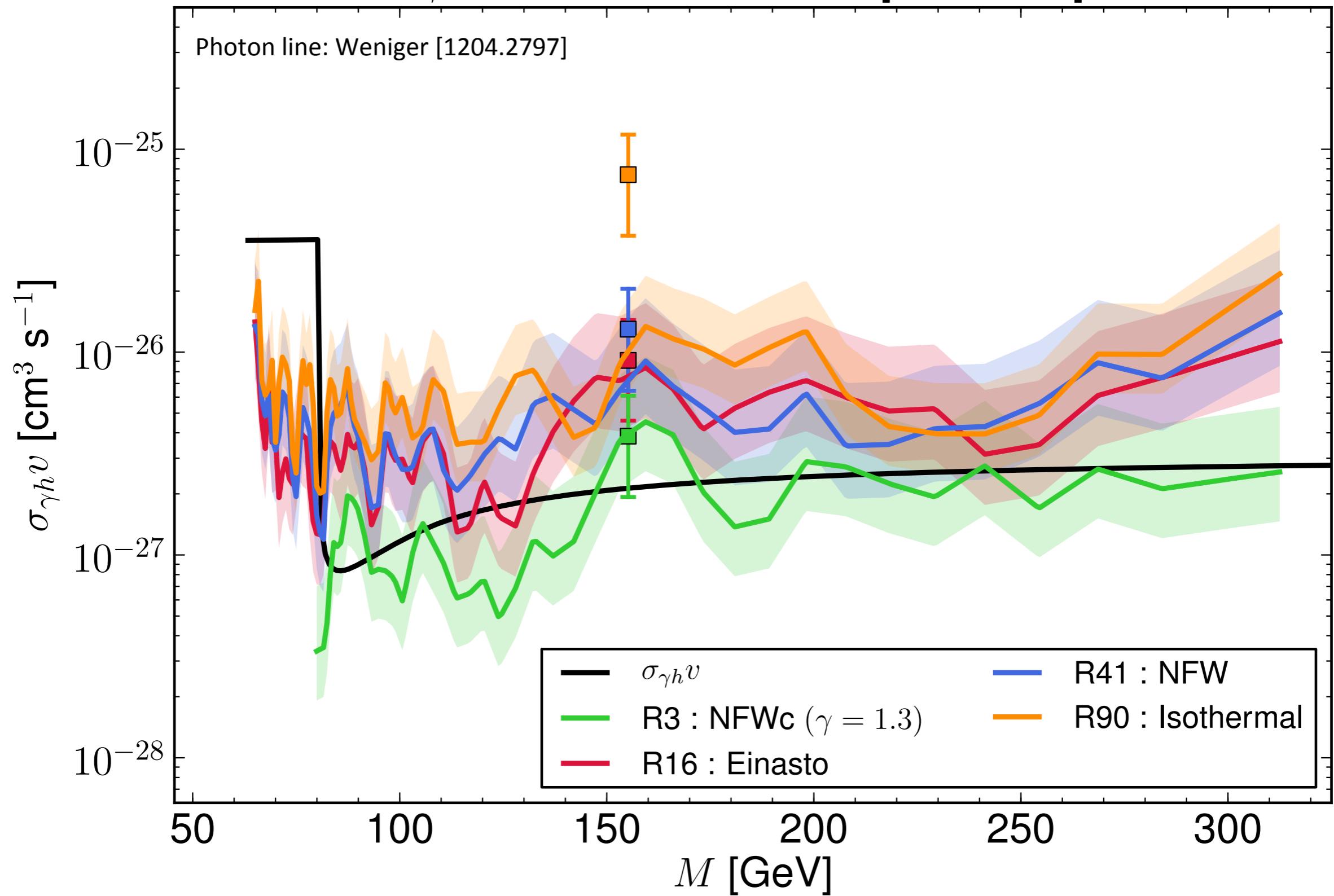
$$\Lambda^{-4} \bar{\chi} \gamma^\mu \chi \left(\widetilde{W}_{\lambda\mu}^a H^\dagger t^a D^\lambda H + \text{h.c.} \right)$$

Annihilation cross-sections for all allowed channels

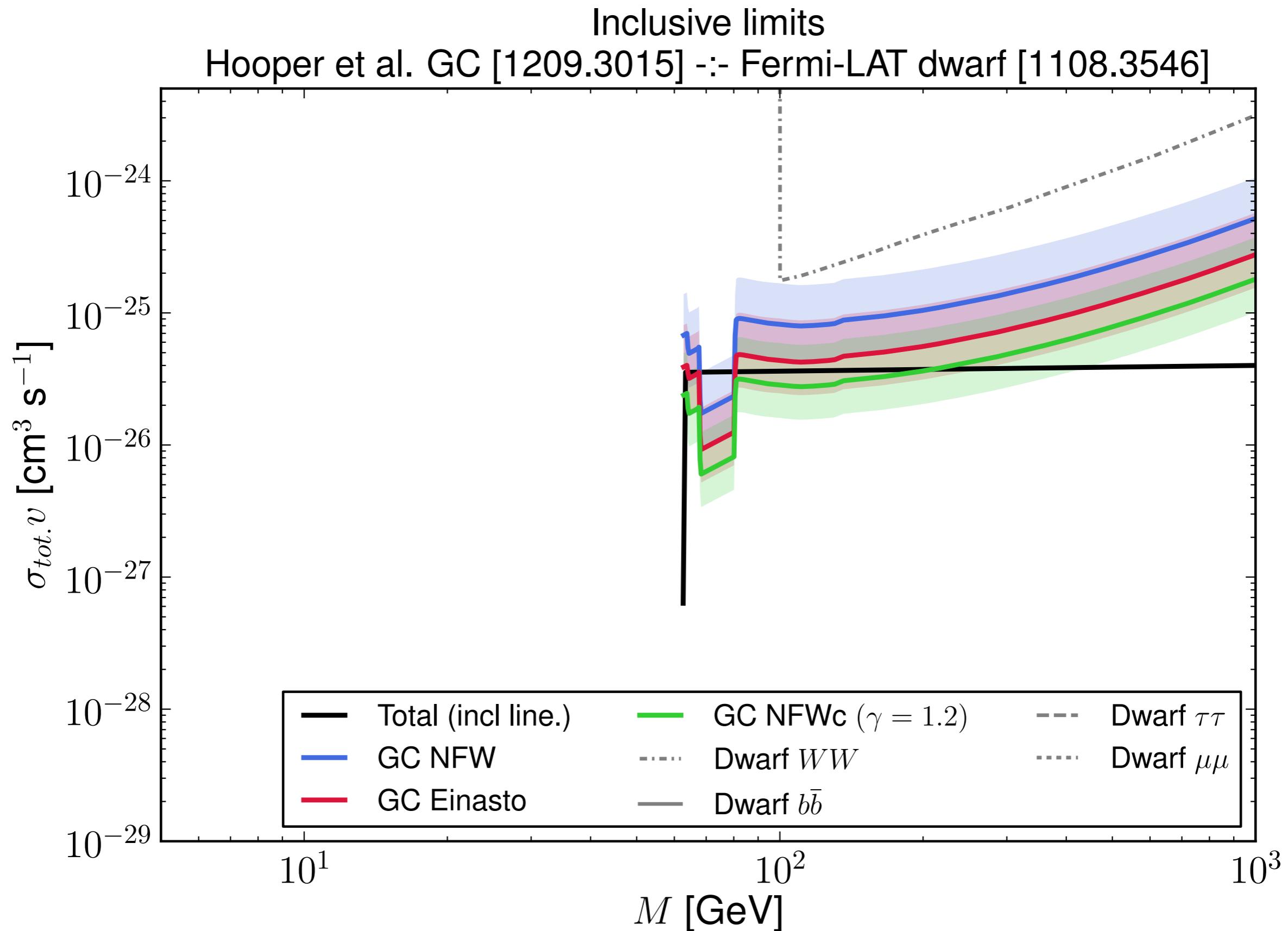


$$\Lambda^{-4} \bar{\chi} \gamma^\mu \chi \left(\widetilde{W}_{\lambda\mu}^a H^\dagger t^a D^\lambda H + \text{h.c.} \right)$$

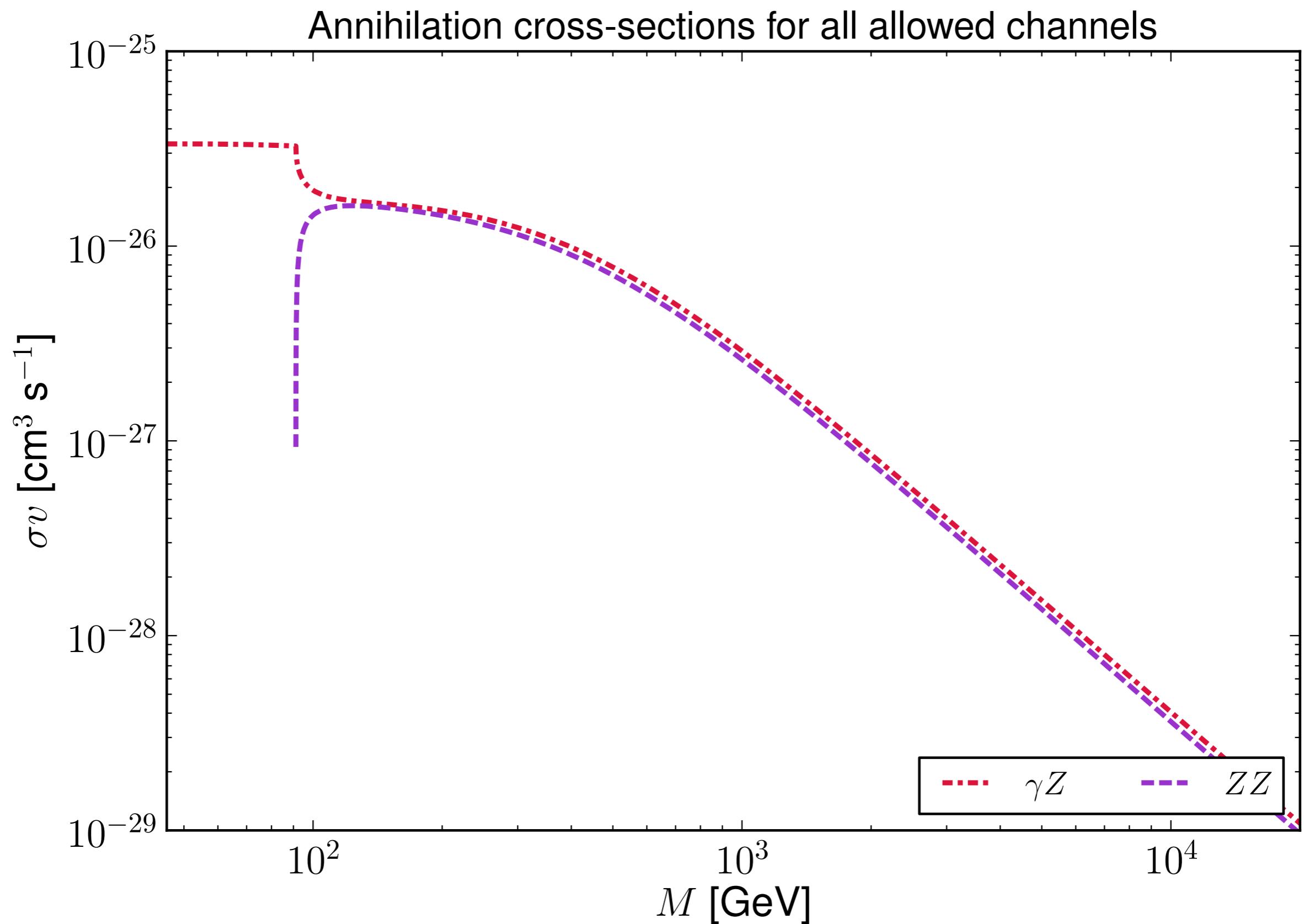
γh line limits -:- Fermi-LAT [1305.5597]



$$\Lambda^{-4} \bar{\chi} \gamma^\mu \chi \left(\widetilde{W}_{\lambda\mu}^a H^\dagger t^a D^\lambda H + \text{h.c.} \right)$$

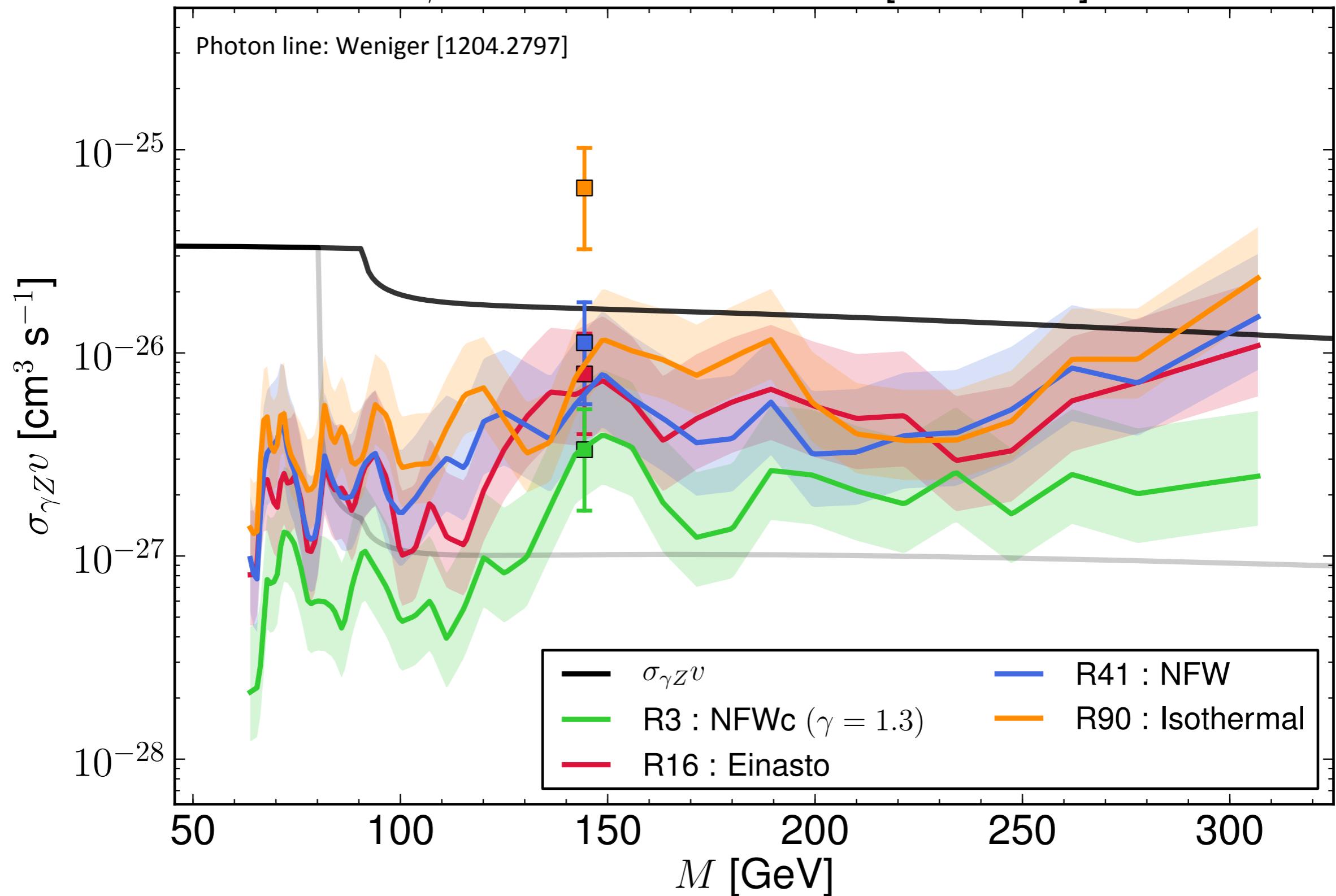


$$\Lambda^{-4} \bar{\chi} \gamma^{\mu 5} \chi i (B_{\lambda\mu} Y_H H^\dagger D^\lambda H - \text{h.c.})$$



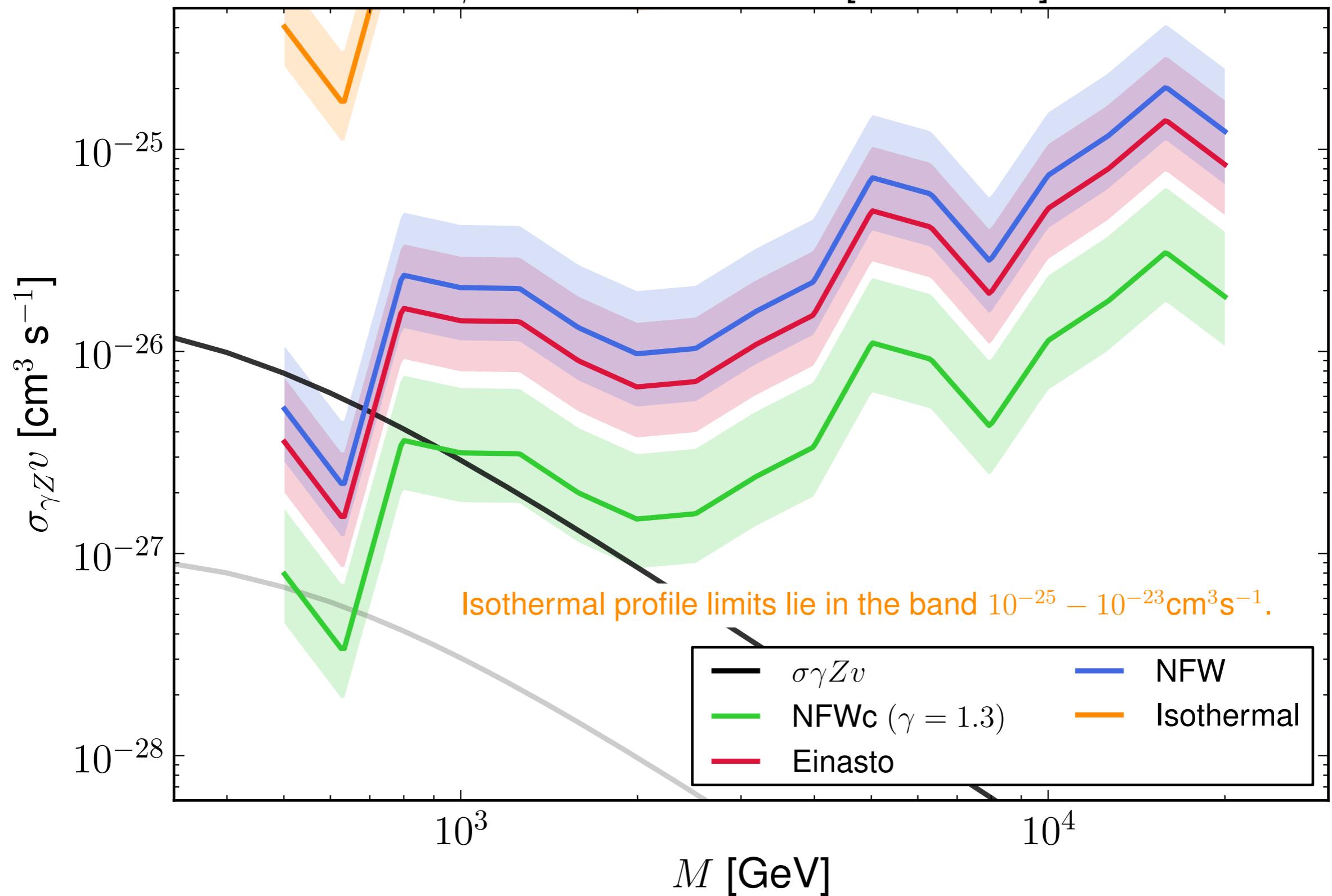
$$\Lambda^{-4} \bar{\chi} \gamma^{\mu 5} \chi i (B_{\lambda\mu} Y_H H^\dagger D^\lambda H - \text{h.c.})$$

γZ line limits -:- Fermi-LAT [1305.5597]

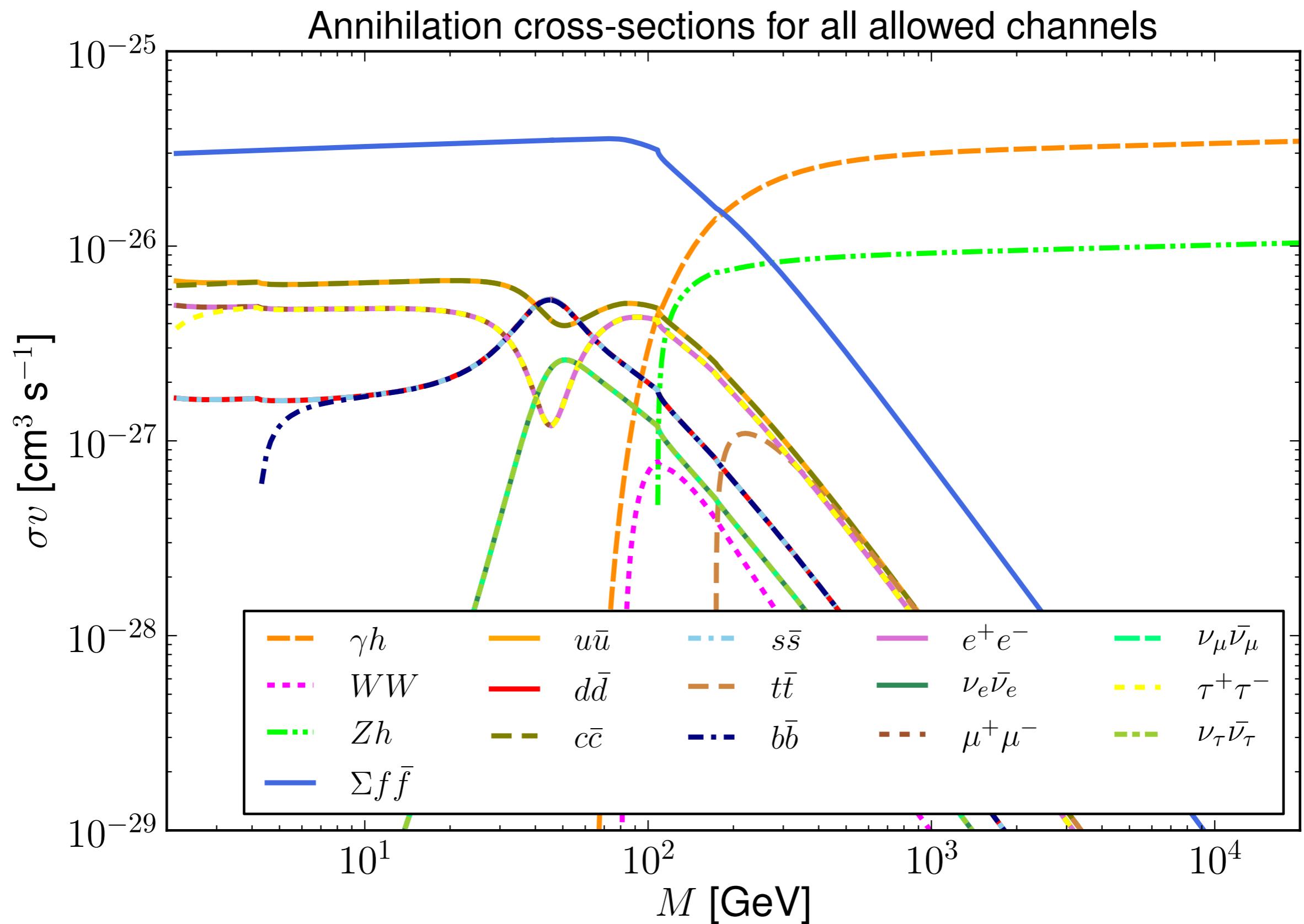


$$\Lambda^{-4} \bar{\chi} \gamma^{\mu 5} \chi i (B_{\lambda\mu} Y_H H^\dagger D^\lambda H - \text{h.c.})$$

γZ line limits -- HESS [1301.1173]

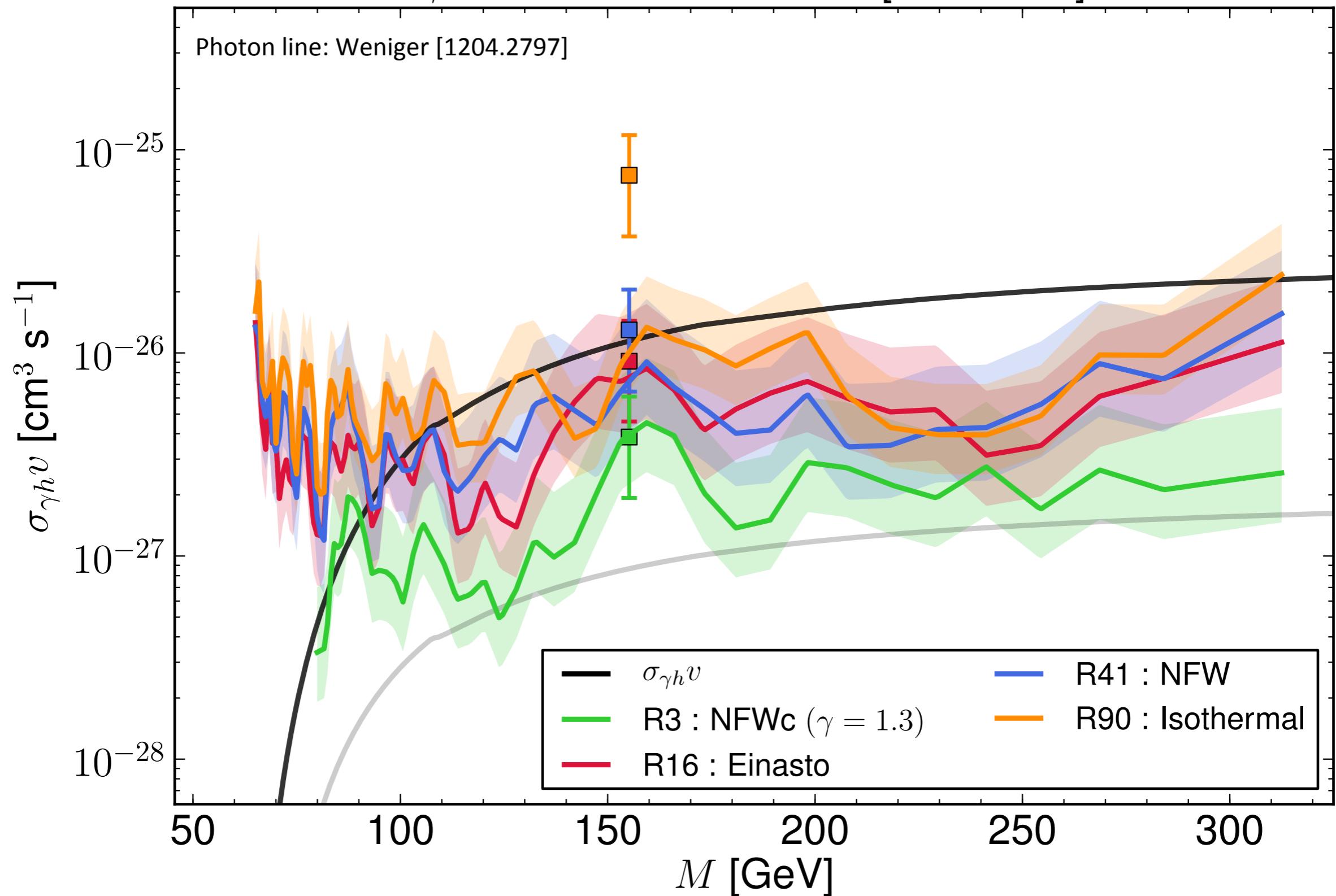


$$\Lambda^{-3} \bar{\chi} \gamma^{\mu\nu} \chi B_{\mu\nu} Y_H H^\dagger H$$

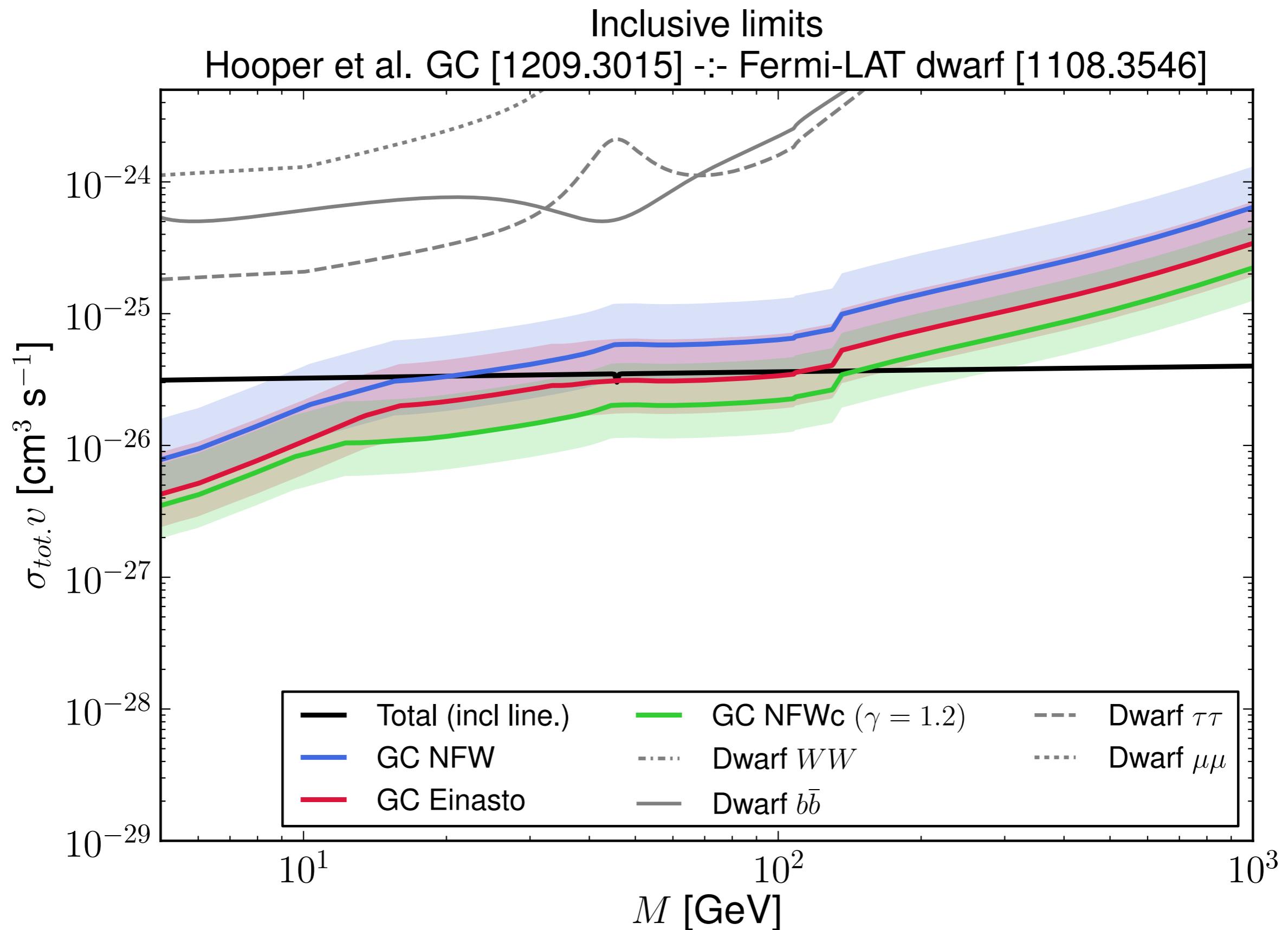


$$\Lambda^{-3} \bar{\chi} \gamma^{\mu\nu} \chi B_{\mu\nu} Y_H H^\dagger H$$

γh line limits -:- Fermi-LAT [1305.5597]



$$\Lambda^{-3} \bar{\chi} \gamma^{\mu\nu} \chi B_{\mu\nu} Y_H H^\dagger H$$



Conclusions

Examined GC photon constraints on 34 EFT operators.

Limit results depend on structure of operator.

Line limits already quite constraining on applicable operators.

Inclusive limits weaker, but beginning to reach required sensitivity.

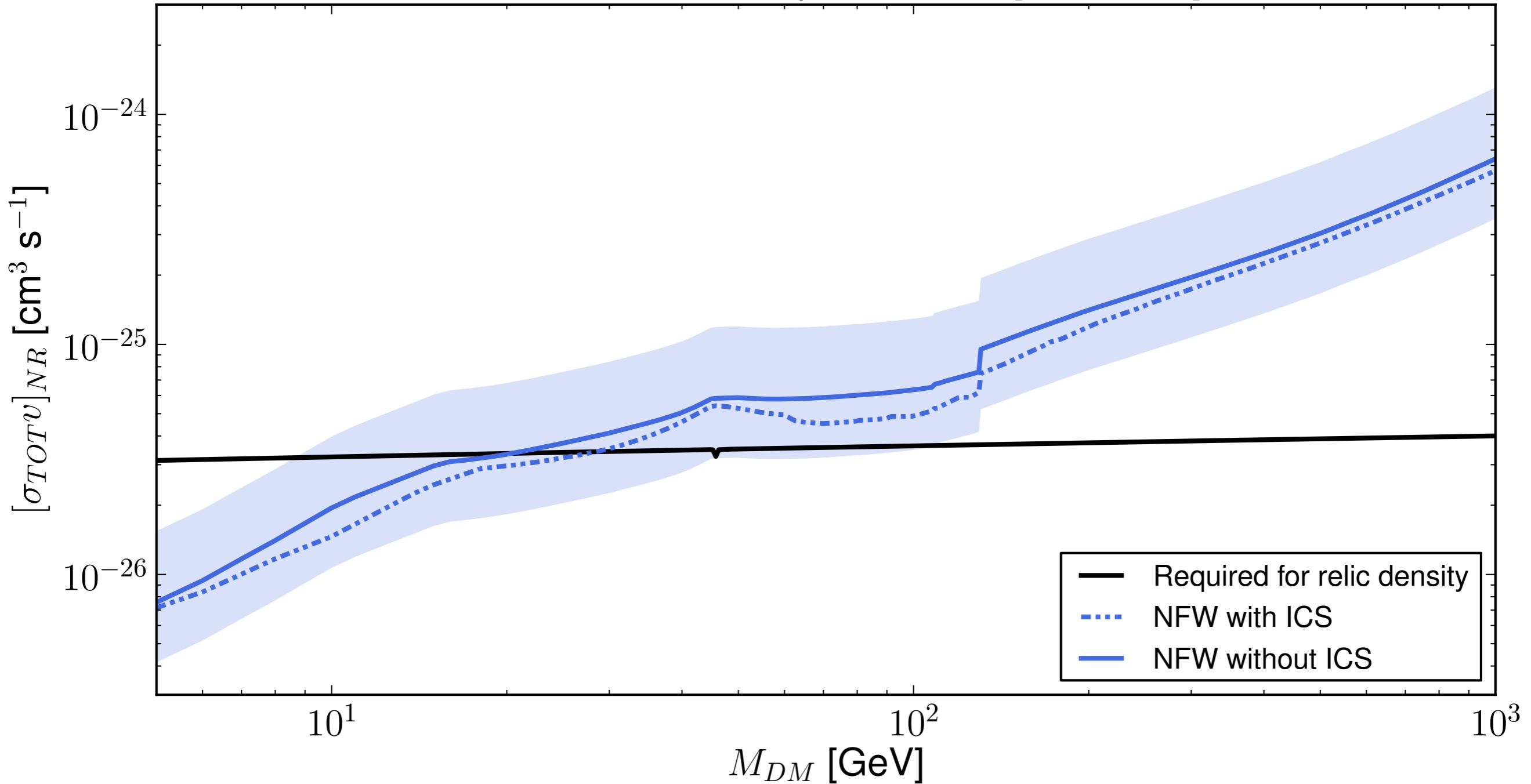
Some operators ruled out, but many operators remain viable...
look at complementary searches.

Reach projections: factor of 3-5 improvement in next generation.
Will be able to rule out larger mass ranges. [Bergström et al 1207.6773]

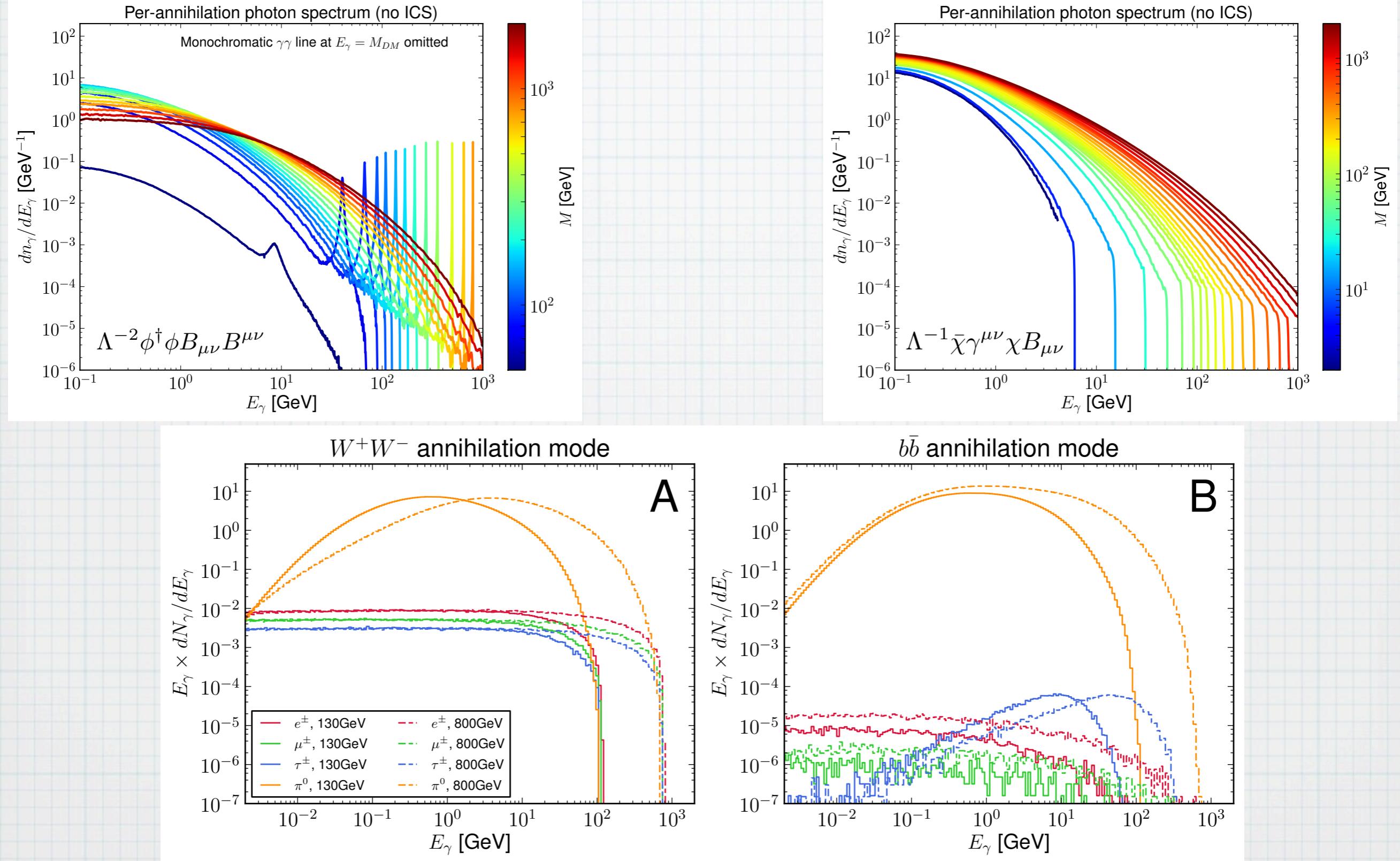
Backup

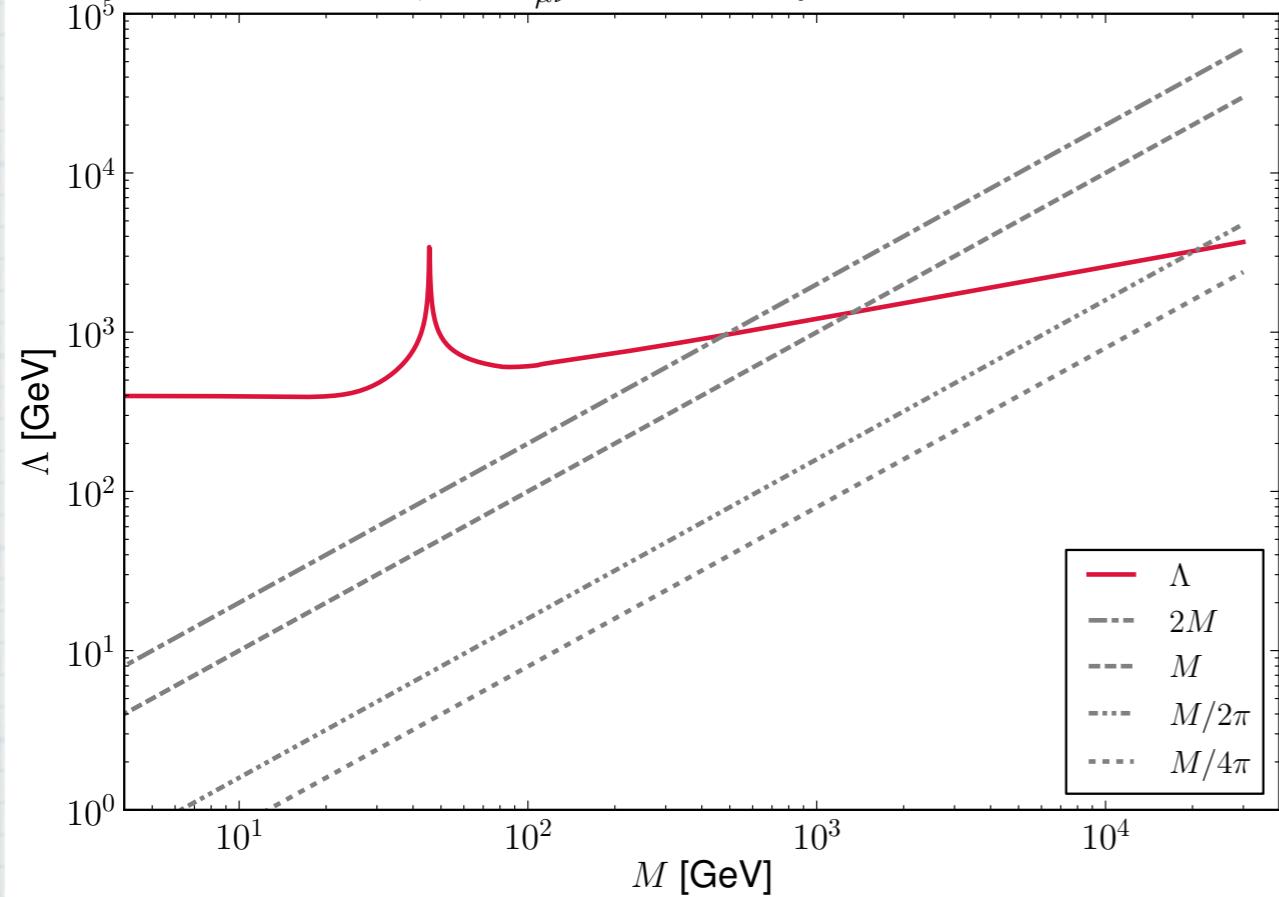
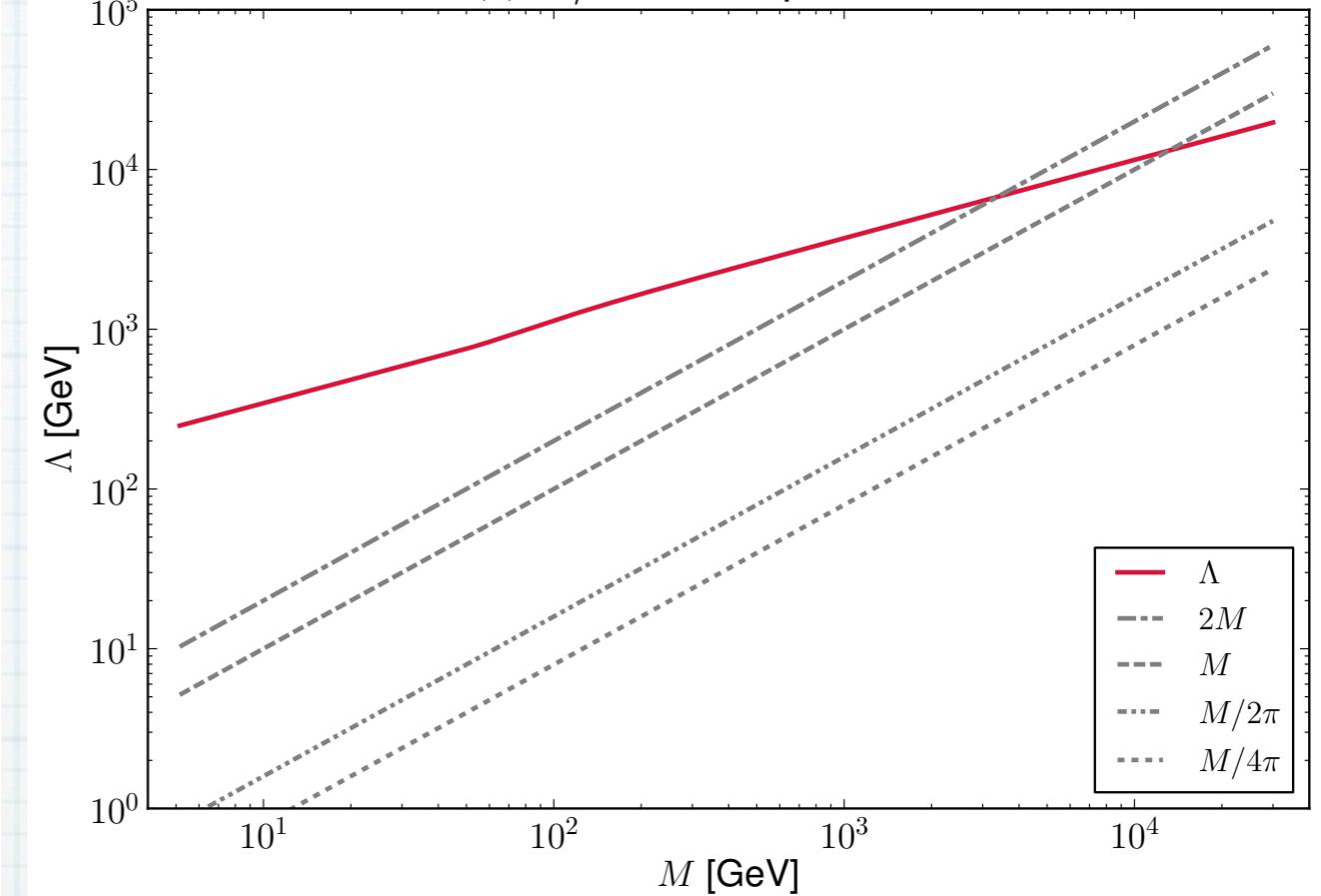
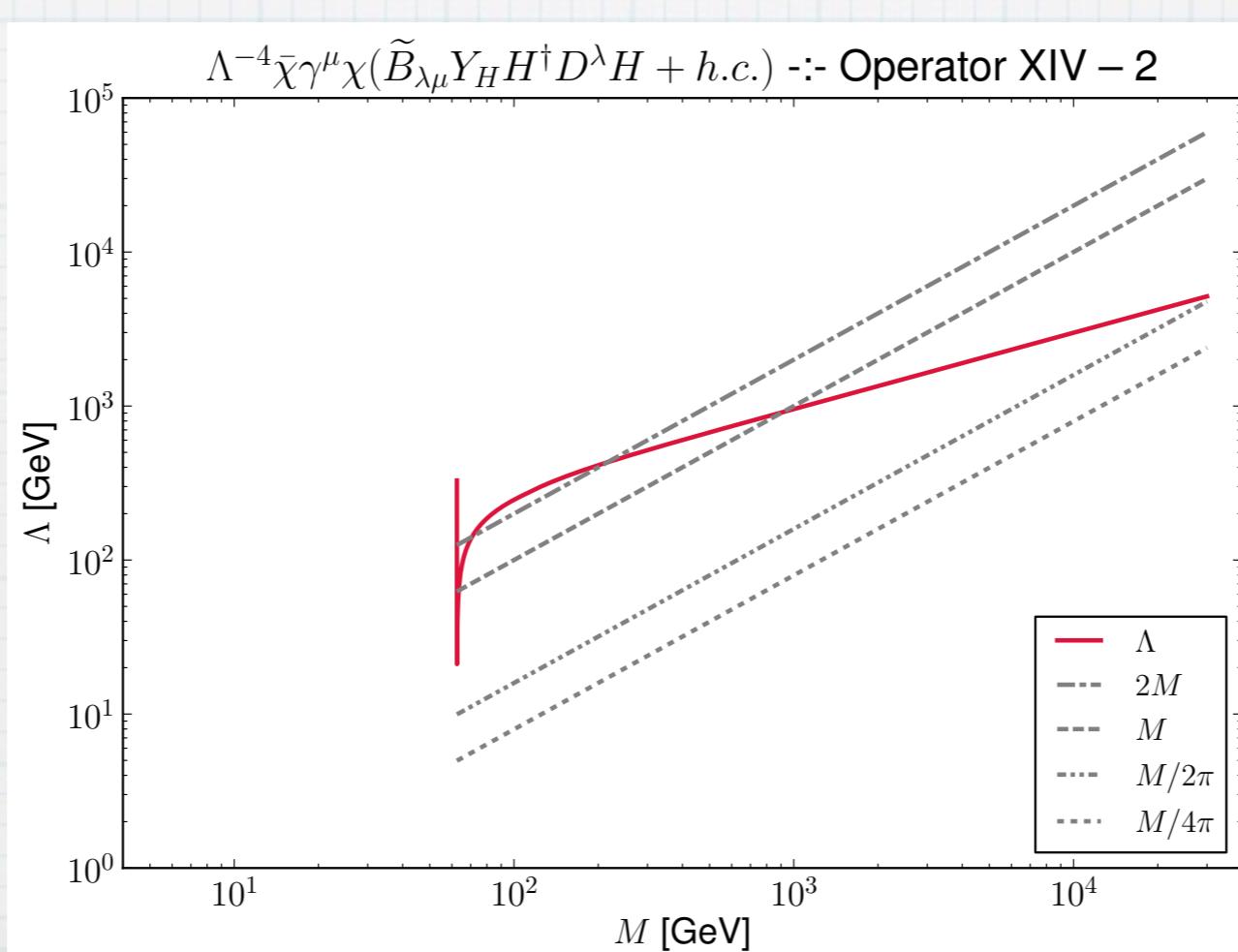
Inverse Compton Scattering

Inclusive limits -- Hooper et al. GC [1209.3015]



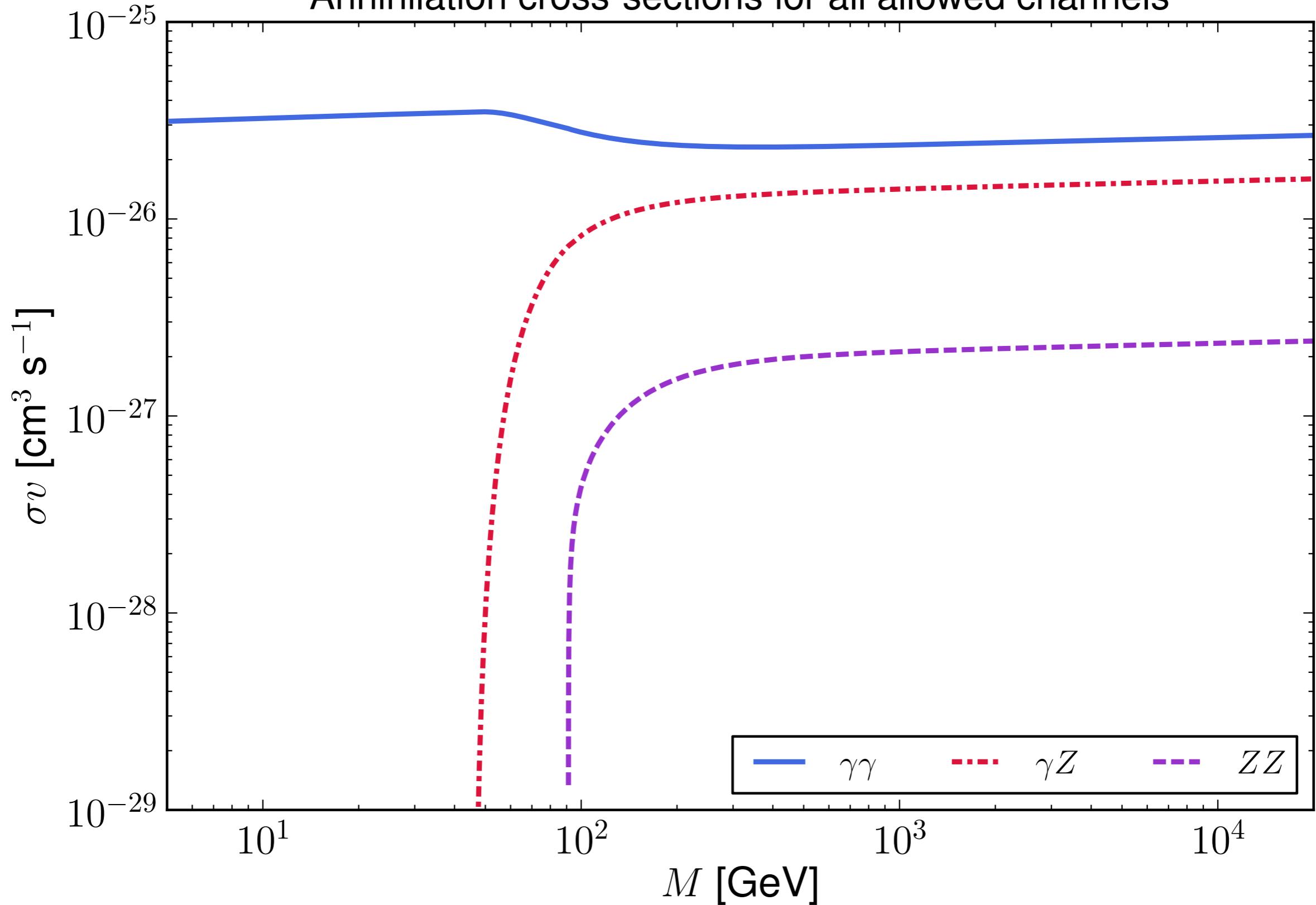
Photon Spectra



$\Lambda^{-3}\bar{\chi}\gamma^{\mu\nu}\chi W_{\mu\nu}^a H^\dagger t^a H$:- Operator XIX – 1 $\Lambda^{-2}\phi\phi^\dagger B_{\mu\nu}B^{\mu\nu}$:- Operator VI – 1 $\Lambda^{-4}\bar{\chi}\gamma^\mu\chi(\tilde{B}_{\lambda\mu}Y_H H^\dagger D^\lambda H + h.c.)$:- Operator XIV – 2

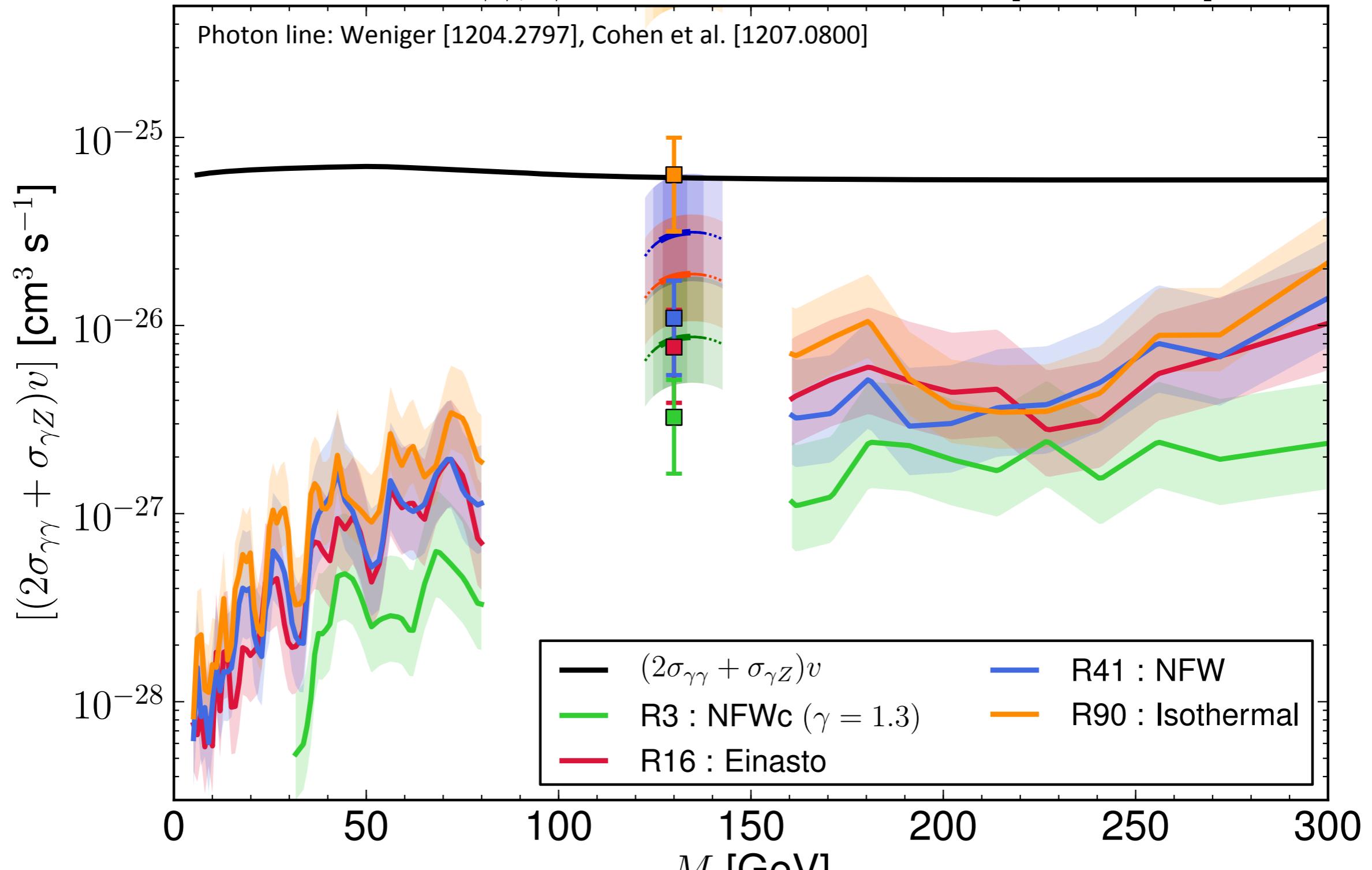
$$\Lambda^{-3} \bar{\chi} i\gamma^5 \chi B_{\mu\nu} B^{\mu\nu}$$

Annihilation cross-sections for all allowed channels



$$\Lambda^{-3} \bar{\chi} i\gamma^5 \chi B_{\mu\nu} B^{\mu\nu}$$

Combined $\gamma\gamma$, γZ line limits -:- Fermi-LAT [1305.5597]



$$\Lambda^{-3} \bar{\chi} i\gamma^5 \chi B_{\mu\nu} B^{\mu\nu}$$

