A two-loop Radiative seesaw with multi-component DM explaining the Gamma Excess in the Higgs Decay and at the Fermi LAT

arXiv:1302.3936

March 25 at MPI, Heidelberg

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in collaboration with
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and Hiroshi Takano(KU)

PLAN

I A brief review on radiative seesaw models and DM

II A two-loop model with two or three DM

III Byproducts:

* 135 gamma-ray line at the Fermi LAT

* Enhancement of h-> two gammas

IV Conclusion

I Radiative Seesaw and DM

Radiative Neutrino Mass Generation

(Zee,80;86; Wolfenstein,80; Babu,88, etc)

$$\nparallel$$

Radiative Seesaw Mechanism

(Kraus, Nasri + Trodden,02; Ma,06; Aoki, Kanemura+ Seto,08; etc)

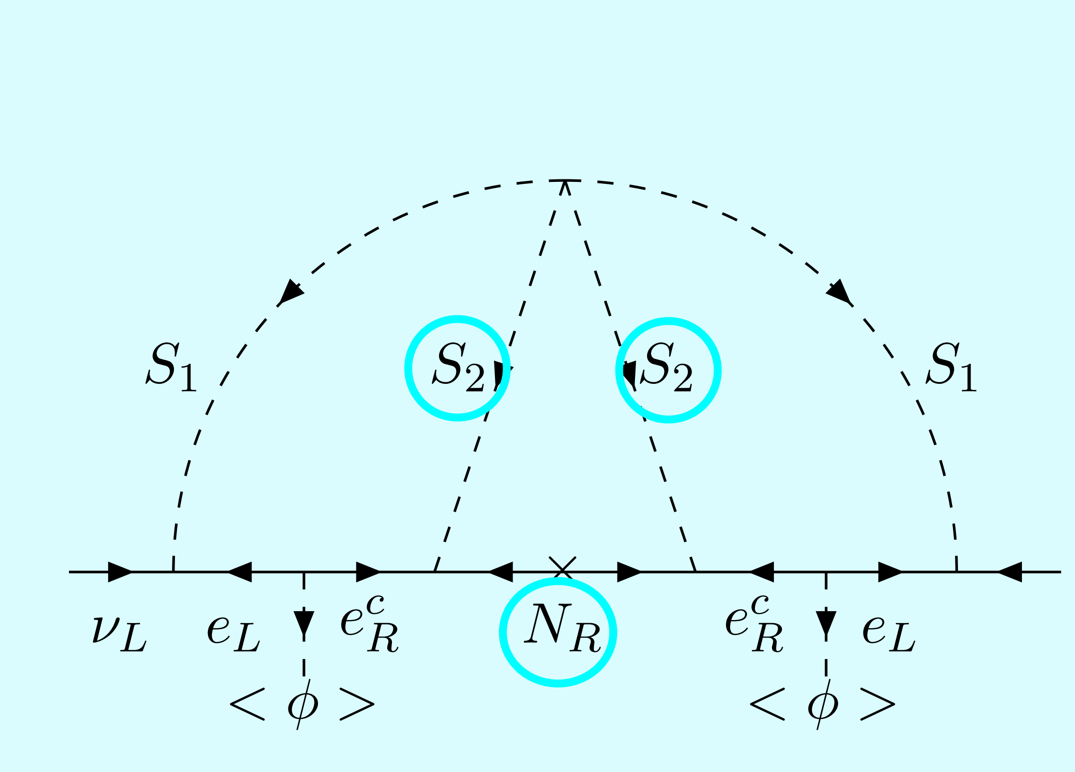
Unbroken discrete symmetry to forbid the tree-level neutrino masses

↓

N_R, Inert Higgs, etc are DM candidates.

Three-loop Model

Kraus, Nasri + Trodden, 02



Z_2 -odd *SM singlet*

N_R can be DM.

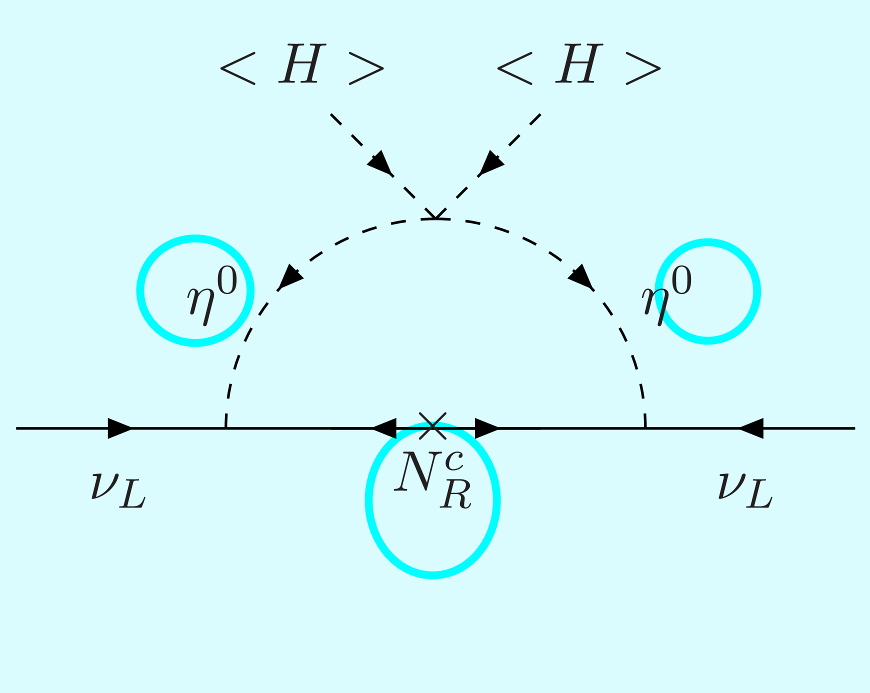
$$\mathbf{m}_\nu = \begin{pmatrix} 0 & 0 \\ 0 & M \end{pmatrix} \rightarrow \begin{pmatrix} m^2/M & 0 \\ 0 & M \end{pmatrix}$$

Radiative Seesaw

One-loop Model

Ma, 06

Z_2 -odd



Inert SU(2) doublet
Higgs

$$< \eta >= 0$$

N_R and eta are DM candidates.

Eta DM studied by

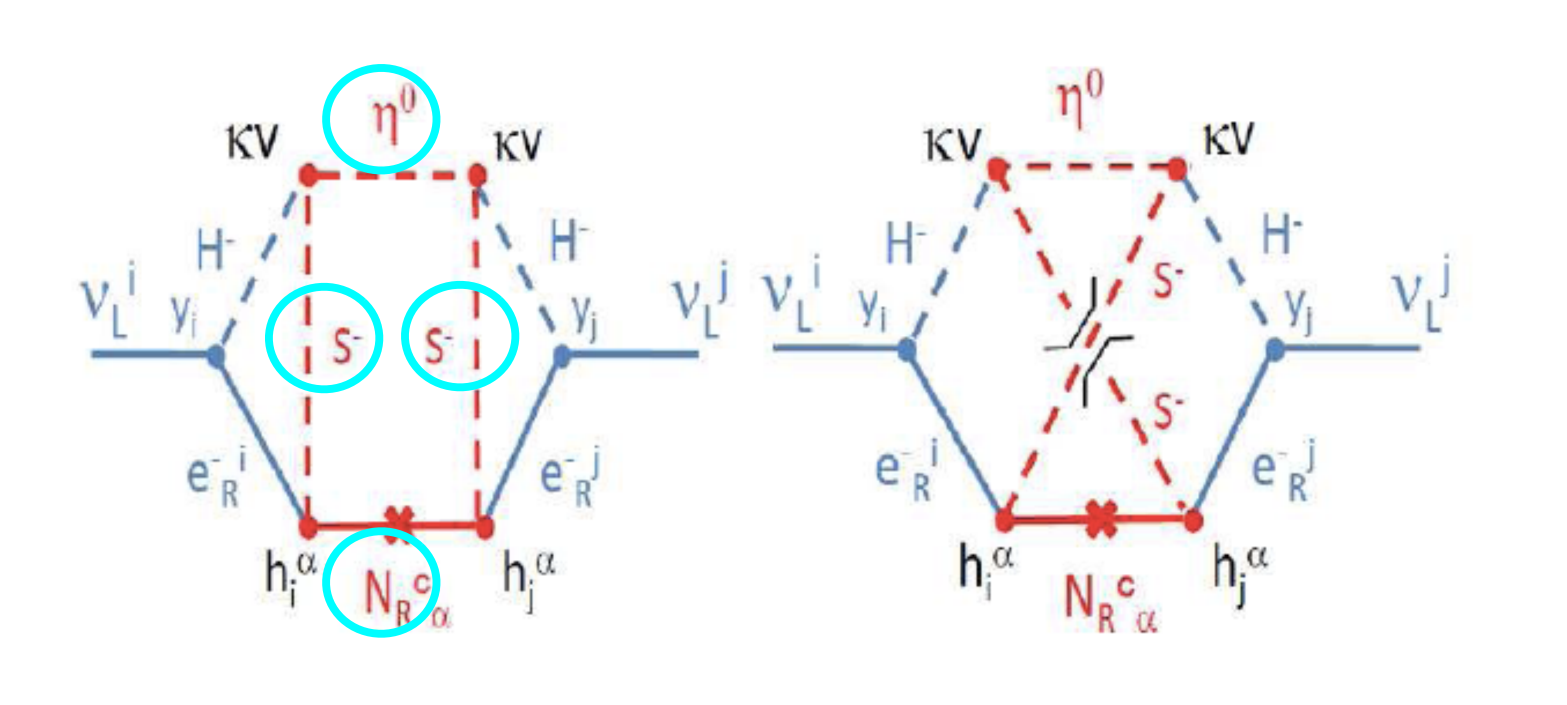
Barbieri, Hall + Rychkov, 06;
Lopez, Oliver + Tytgat,06;
Dolle + Su,09 etc

N_R DM studied by

Kubo, Ma + Suematsu, 06;
Aristizabal Sierra, Kubo, Restrepo, Suematsu +Zapata, 08;
Gelmini, Osoba+ Palomares-Ruiz, 09,
Schmidt, Schwetz +Toma, 12, etc

Three-loop Model

Aoki, Kanemura+Seto, 08



Z_2 odd

Inert SU(2) doublet Higgs

	Q^i	u_R^i	d_R^i	L^i	e_R^i	Φ_1	Φ_2	$S^\pm$	η	N_R^α
Z_2 (exact)	+	+	+	+	+	+	+	−	−	−
$\tilde{Z}_2$ (softly broken)	+	−	−	+	+	+	−	+	−	+

$$<\eta>=0$$

Non-susy Models of radiative generation of m_ν

Model	L-violating dim.	No. of loops	ν_R	No. of stable DMs
[1]	3 (tri-linear scalar coupling)	1	No	0
[2, 3, 22]	3 (tri-linear scalar coupling)	2	No	0
[16]	3 (tri-linear scalar coupling)	1	No	1
[23]	3 (tri-linear scalar coupling))	2	Yes	2
[27]	3 (tri-linear scalar coupling))	2	Yes	1
[28]	3 (tri-linear scalar coupling))	2	No	1
[4, 5, 12]	3 (Majorana mass)	3	Yes	1
[6, 8–10, 13, 15, 24, 25]	3 (Majorana mass)	1	Yes	1
[14]	3 (Majorana mass)	1	Yes ($SU(2)_L$ triplet)	1
[18]	4 (quartic scalar coupling)	1	No	1
[20]	No L-violation	1	Yes	0
[19]	Spontaneous violation	2	No	1
[21, 29, 30]	Sponataneos violation	2	Yes	1
[17]	Spontaneous violation	1	Yes	1
[11]	2 (scalar mass)	1	Yes	0
Our model	2 (scalar mass)	2	Yes	**2** or **3**

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II The model

Model	L-violating dim.	No. of loops	ν_R	No. of stable DMs
Our model	2 (scalar mass)	2	Yes	**2** or **3**

Ma

field	statistics	$SU(2)_L$	$U(1)_Y$	L	Z_2	Z_2'	D_{2N}
$L=(\nu_L, l_L)$	F	2	$-1/2$	1	$+$	$+$	$\mathbf{1}$
l_R^c	F	1	1	1	$+$	$+$	$\mathbf{1}$
N_R^c	F	1	0	0	$-$	$+$	$\mathbf{1}''$
$H=(H^+, H^0)$	B	2	$1/2$	0	$+$	$+$	$\mathbf{1}$
$\eta=(\eta^+, \eta^0)$	B	2	$1/2$	-1	$-$	$+$	$\mathbf{1}''$
χ	B	1	0	0	$+$	$-$	$\mathbf{1}'$
ϕ	B	1	0	1	$-$	$-$	$\mathbf{1}'''$

Matter content
(Minimal extension)

The Z2 x Z2 x L invariant potential

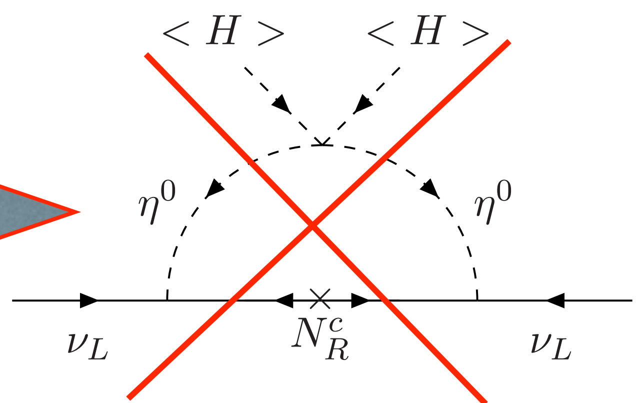
$$V_\lambda = \lambda_1(H^\dagger H)^2 + \lambda_2(\eta^\dagger\eta)^2 + \lambda_3(H^\dagger H)(\eta^\dagger\eta) + \lambda_4(H^\dagger\eta)(\eta^\dagger H)$$
$$+\frac{1}{4}\gamma_1\chi^4 + \gamma_2(H^\dagger H)\chi^2 + \gamma_3(\eta^\dagger\eta)\chi^2 + \gamma_4|\phi|^4 + \gamma_5(H^\dagger H)|\phi|^2$$
$$+\gamma_6(\eta^\dagger\eta)|\phi|^2 + \gamma_7\chi^2|\phi|^2 + \frac{\kappa}{2}[(H^\dagger\eta)\chi\phi + h.c.] .$$

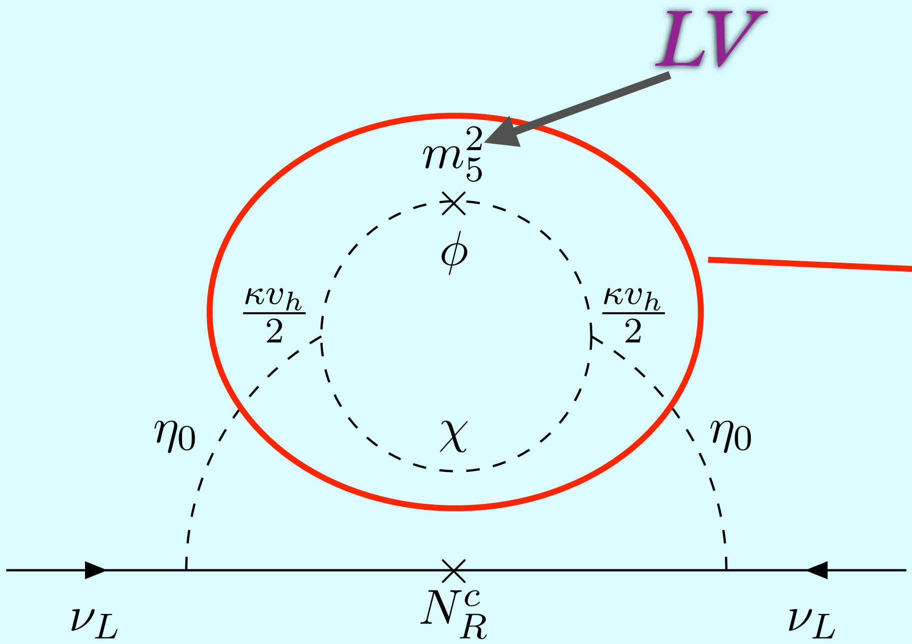
The Z2 x Z2 scalar masses

$$V_m = m_1^2 H^\dagger H + m_2^2\eta^\dagger\eta + \frac{1}{2}m_3^2\chi^2 + m_4^2|\phi|^2 + \frac{1}{2}m_5^2[\phi^2 + (\phi^*)^2]$$

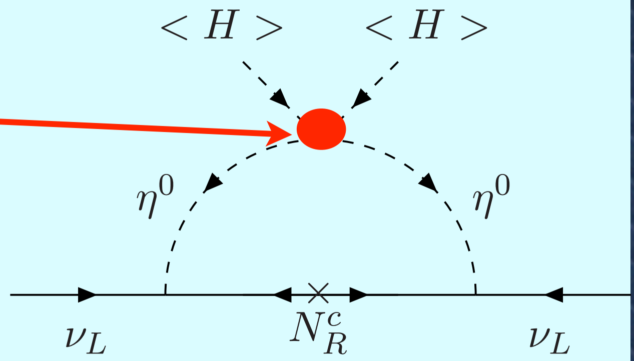
breaks L.

NO "λ_5 term", $(1/2)\lambda_5(H^\dagger\eta)^2$.





TWO LOOP SEESAW



ONE LOOP SEESAW

$$\lambda_5^{\text{eff}} = -\frac{\kappa^2}{64\pi^2}\left[\frac{m_{\phi_I}^2}{m_{\phi_I}^2 - m_\chi^2}\ln\frac{m_{\phi_I}^2}{m_\chi^2} - \frac{m_{\phi_R}^2}{m_{\phi_R}^2 - m_\chi^2}\ln\frac{m_{\phi_R}^2}{m_\chi^2}\right]$$

Neutrino mass

$$(m_\nu)_{ij} = \left(\frac{1}{16\pi^2}\right)^2 \frac{\kappa^2 v_h^2}{8} \sum_k Y^\nu_{ik} Y^\nu_{jk} M_k \int_0^\infty dx \{ B_0(-x, m_\chi, m_{\phi_R}) - B_0(-x, m_\chi, m_{\phi_I}) \}$$
$$\times \frac{x}{(x+m_\eta^2)^2 (x+M_k^2)} \quad \textbf{for } m_\eta = m_{\eta_R^0} \simeq m_{\eta_I^0}$$

Passarino-Veltman

$$m_\nu \sim \left(\frac{\kappa}{16\pi^2}\right)^2 \frac{m_D^2}{M_R} \sim 10^{-7} \frac{m_D^2}{M_R} \quad \textbf{for } \kappa = 0.1$$

MR~1 TeV is a natural scale.

Constraints:

*Perturbativity $\lambda < 4\pi$

*Stability of the Z2 x Z2 invariant vacuum

*Mu to e gamma

*Muon g-2

*Electroweak precision (T and S)

$$m_{\eta^\pm} > 70\ \mathbf{GeV}$$

$$m_{\eta_R^0} < 80\ \mathbf{GeV} \cap m_{\eta_I^0} < 100\ \mathbf{GeV} \cap m_{\eta_I^0} - m_{\eta_R^0} > 8\ \mathbf{GeV}$$

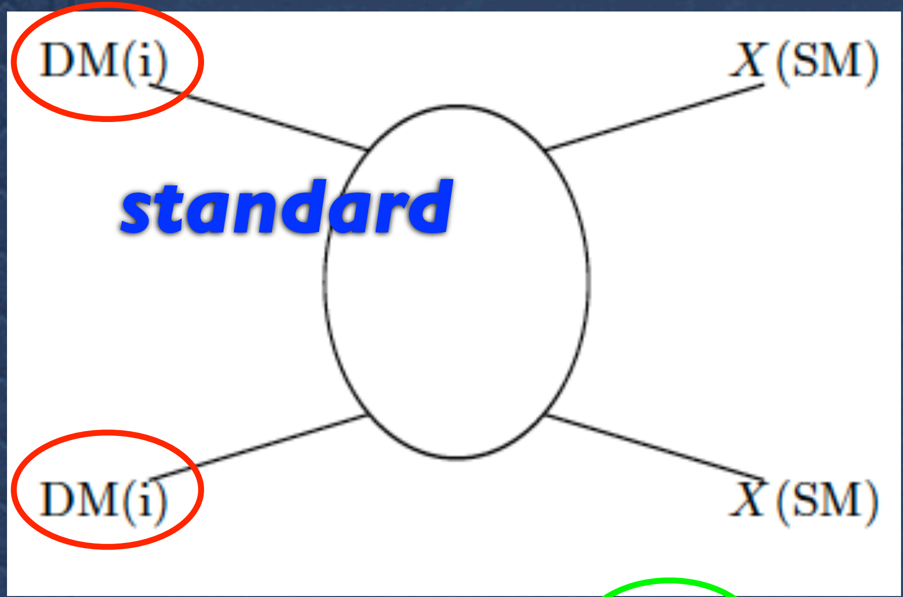
DM candidates

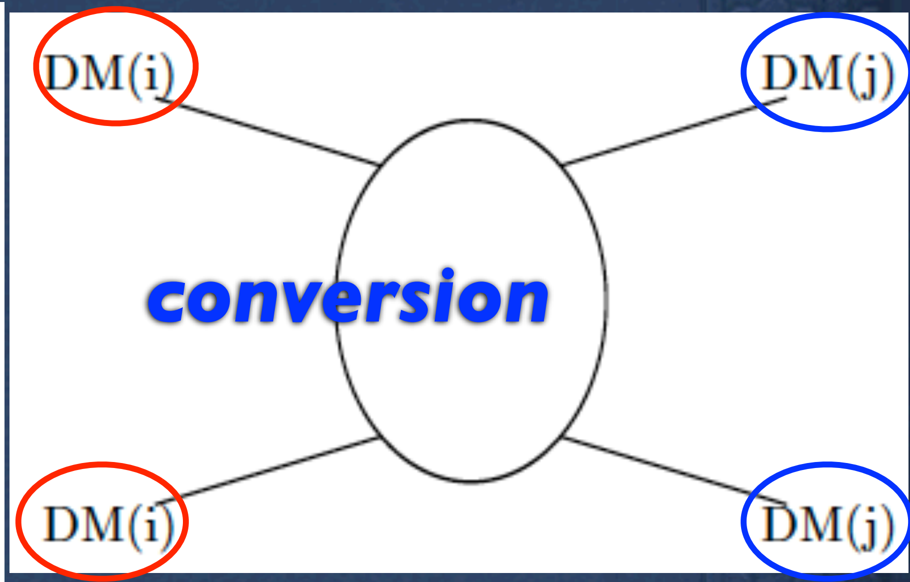
field	statistics	$SU(2)_L$	$U(1)_Y$	L	Z_2	Z_2'	D_{2N}
(ν_L, l)	F	2	$-1/2$	1	$+$	$+$	$\mathbf{1}$
l^c	F	1	1	1	$+$	$+$	$\mathbf{1}$
N_R^c	F	1	1	0	$-$	$+$	$\mathbf{1}''$
$H = (H^+, H^0)$	B	2	$1/2$	0	$+$	$+$	$\mathbf{1}$
$\eta = (\eta^+, \eta^0)$	B	2	$1/2$	-1	$-$	$+$	$\mathbf{1}''$
χ	B	1	0	0	$+$	$-$	$\mathbf{1}'$
ϕ	B	1	0	1	$-$	$-$	$\mathbf{1}'''$

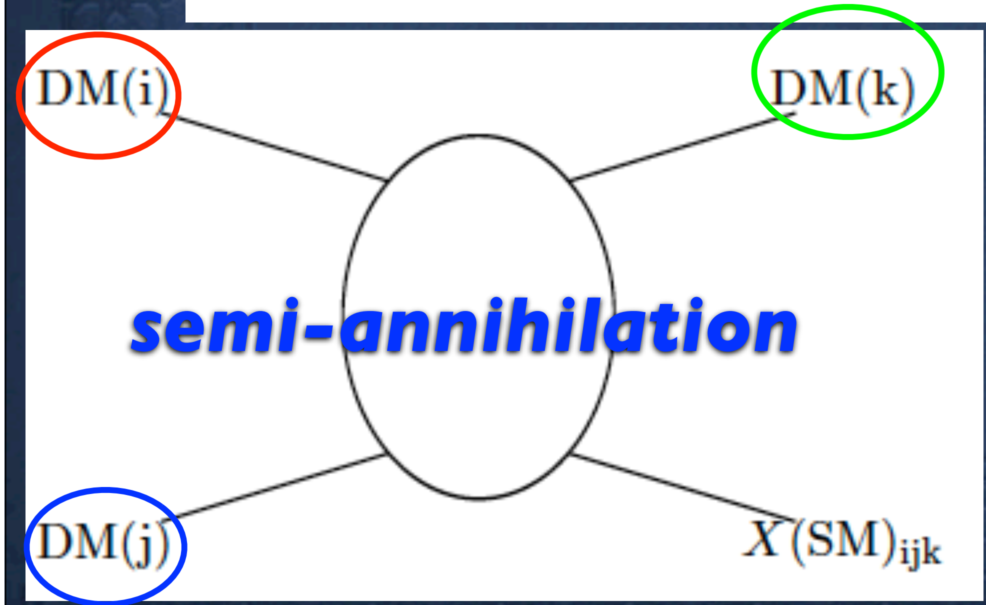
# of DMs=3: $(\eta,\ \chi,\ \phi)$ **or** $(N_R^c,\ \chi,\ \phi)$

# of DMs=2: $(\eta,\ \chi)$, $(\eta,\ \phi)$, $(N_R^c,\ \chi)$, $(N_R^c,\ \phi)$ **or** $(\chi,\ \phi)$

Non-standard annihilations and relic abundance

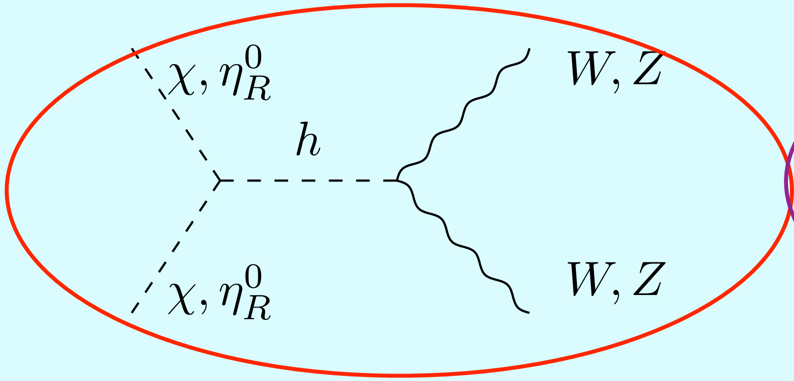


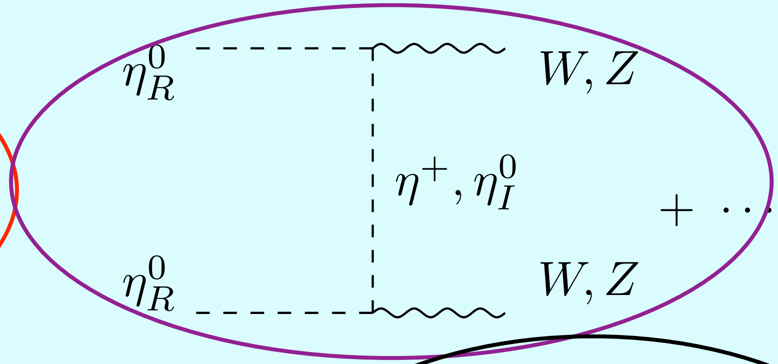




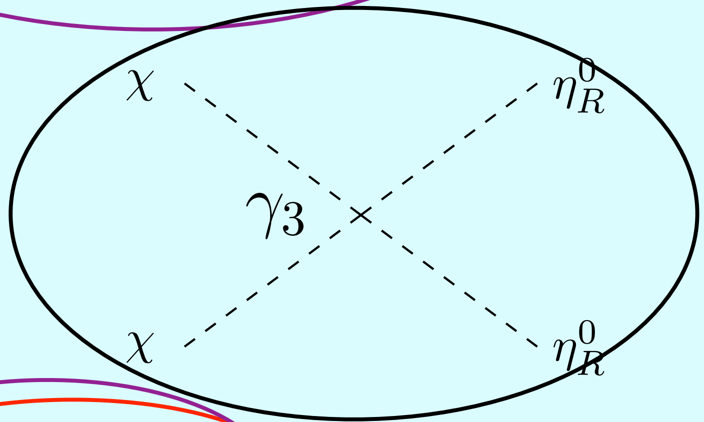
See for more details:
Aoki, Duerr, Kubo+Takano,
arXiv:1207.3318

η - χ DM system





$(2\gamma_2, \lambda_3)v_h$



Boltzmann eqs.

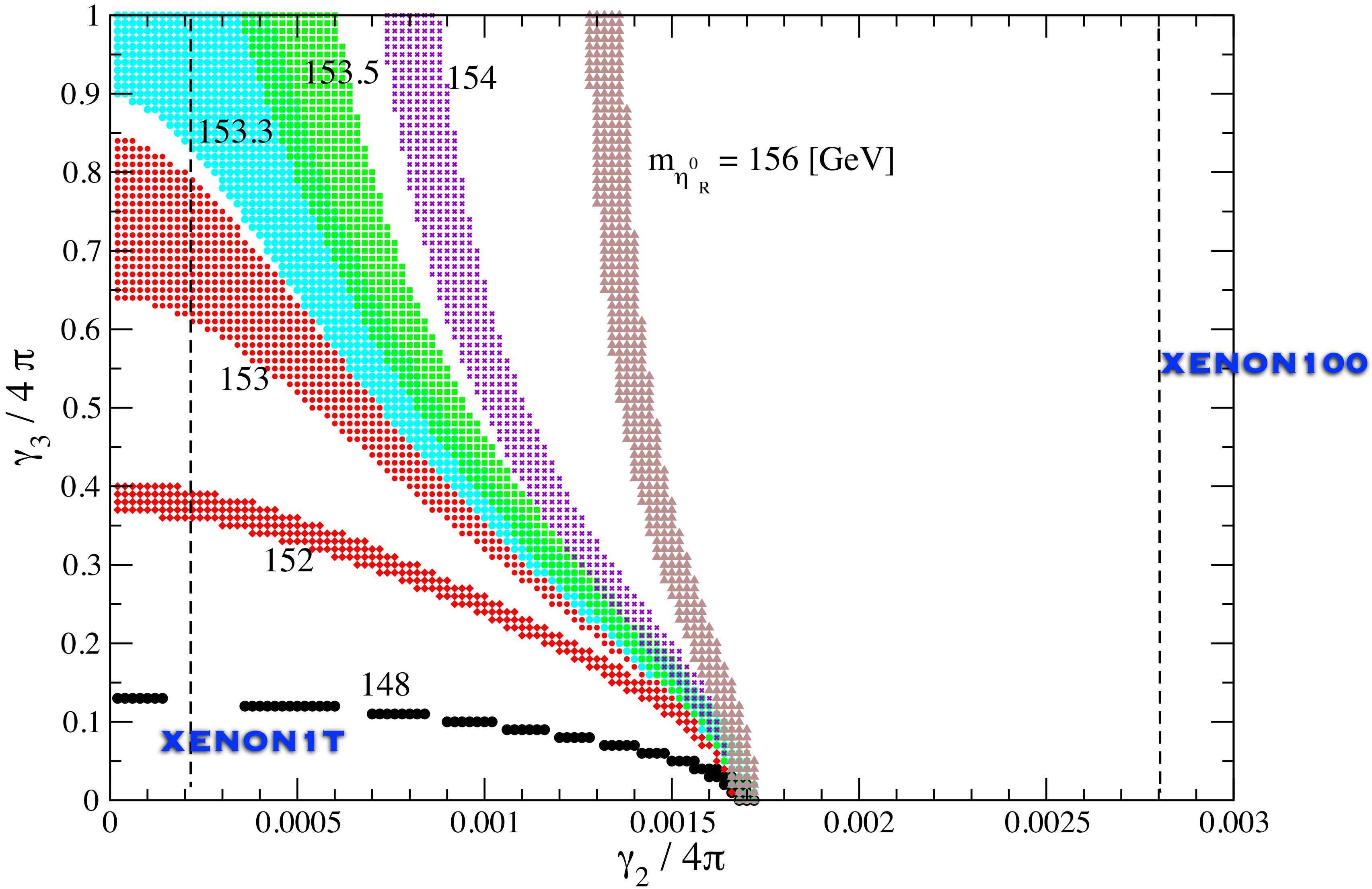
$$\frac{dY_{\eta_R^0}}{dx} = -0.264\ g_*^{1/2}\left[\frac{\mu M_{\rm PL}}{x^2}\right]\Big\{ <\sigma(\eta_R^0\eta_R^0;{\rm SM})v> \left(Y_{\eta_R^0}Y_{\eta_R^0} - \bar{Y}_{\eta_R^0}\bar{Y}_{\eta_R^0}\right)$$

$$+ <\sigma(\eta_R^0\eta_R^0;\chi\chi)v> \left(Y_{\eta_R^0}Y_{\eta_R^0} - \frac{Y_\chi Y_\chi}{\bar{Y}_\chi \bar{Y}_\chi}\bar{Y}_{\eta_R^0}\bar{Y}_{\eta_R^0}\right)\Big\}\ ,$$

$$\frac{dY_\chi}{dx} = -0.264\ g_*^{1/2}\left[\frac{\mu M_{\rm PL}}{x^2}\right]\Big\{ <\sigma(\chi\chi;{\rm SM})v> \left(Y_\chi Y_\chi - \bar{Y}_\chi \bar{Y}_\chi\right)$$

$$- <\sigma(\eta_R^0\eta_R^0;\chi\chi)v> \left(Y_{\eta_R^0}Y_{\eta_R^0} - \frac{Y_\chi Y_\chi}{\bar{Y}_\chi \bar{Y}_\chi}\bar{Y}_{\eta_R^0}\bar{Y}_{\eta_R^0}\right)\Big\}\ ,$$

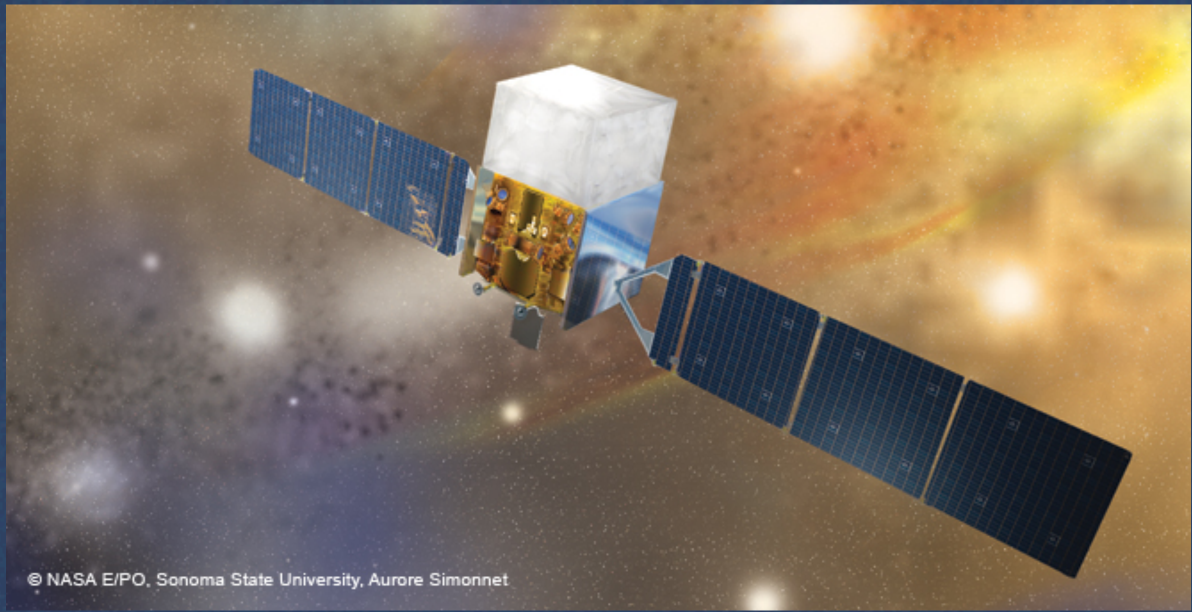
$$\Omega_T h^2 (\simeq \Omega_\chi h^2) = 0.1157 \pm 0.0046 \ (2\sigma) \quad \textit{with} \ m_\chi = 135 \ \textbf{GeV}$$



$$\lambda_1 = 0.129 \ , \ \lambda_3 = -1.26 \ , \ \lambda_4 = -0.0205$$

III Byproducts

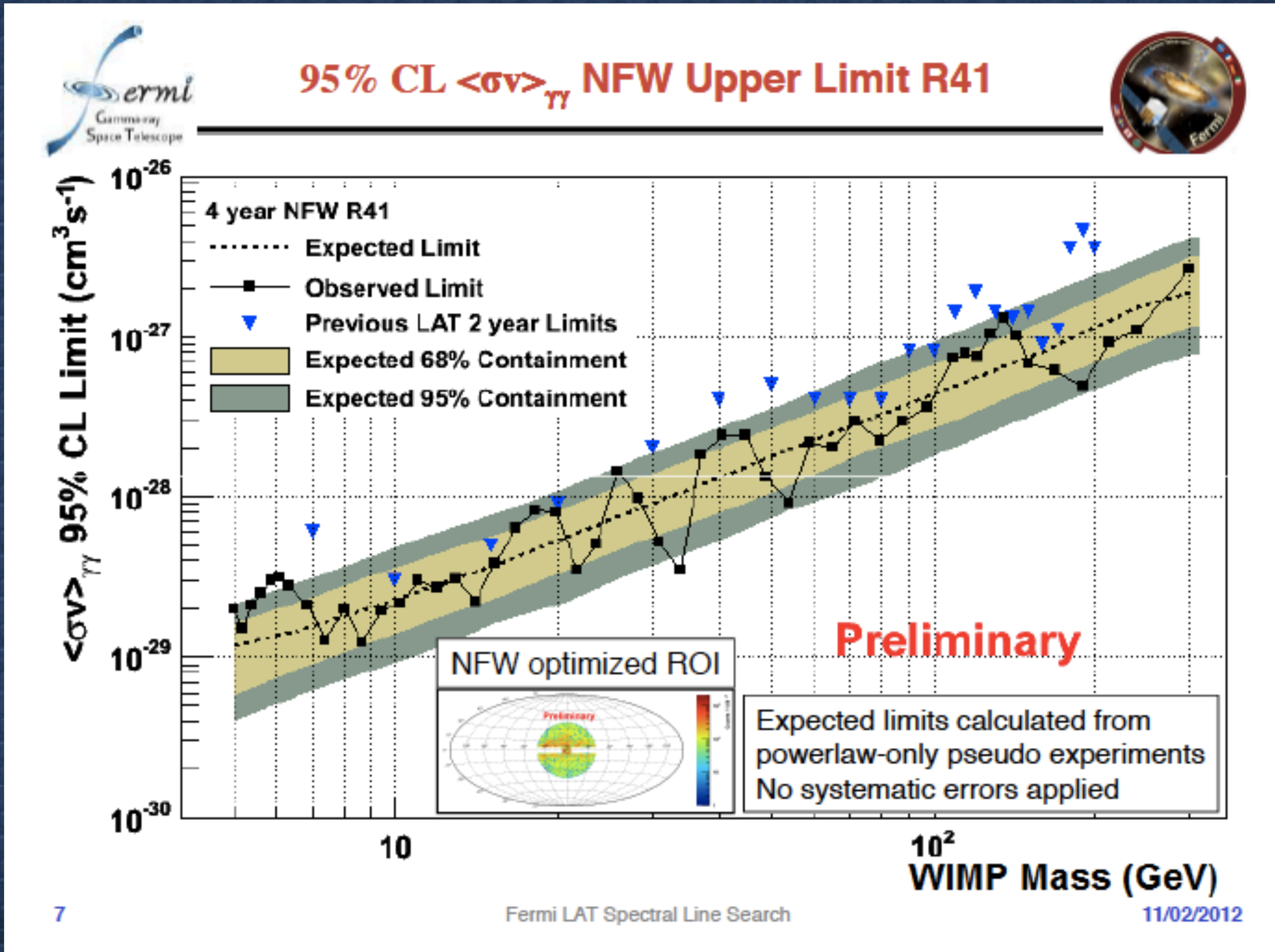
* The first byproduct: Fermi-LAT 130(135) GeV gamma-ray line



Fermi-LAT is measuring gamma rays coming from the universe since 2008.

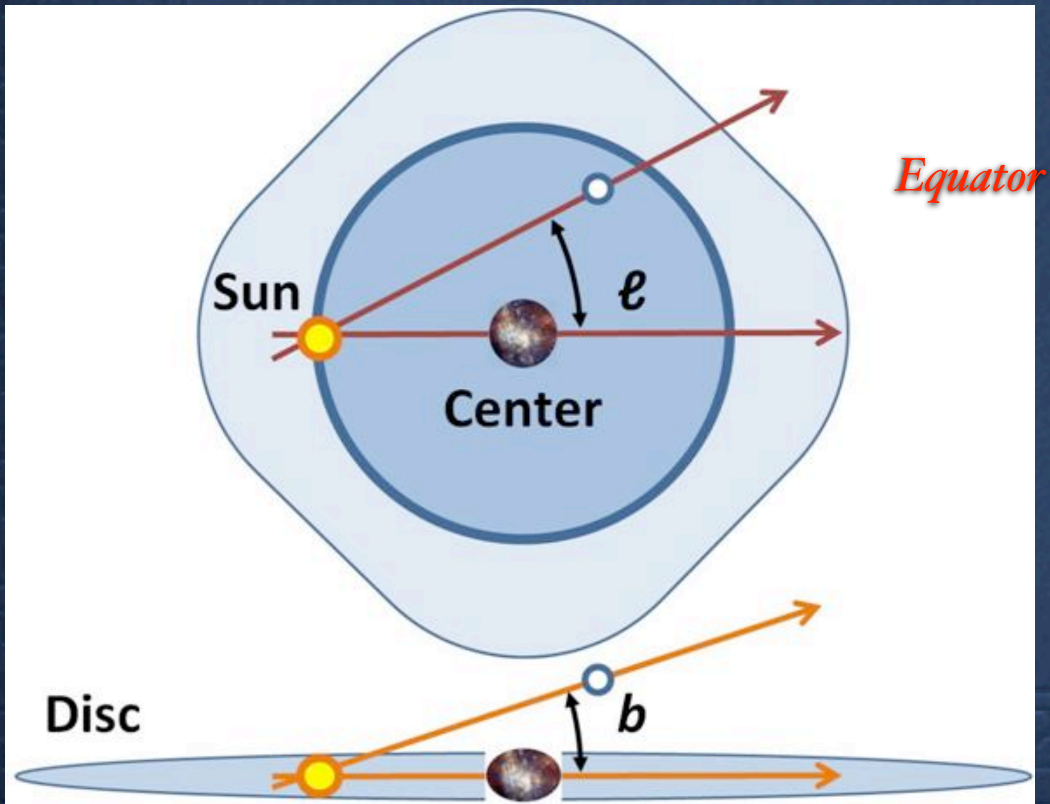
LAT Collaboration, arXiv:1205.2739; etc

If the data from the whole sky is included:



However , if you look at the center of the galaxy, something more interesting is going on.

Weniger, arXiv:1204.2797; Bringmann et al,arXiv:1203.1312; Tempel et al, arXiv:1205.1045;Rajaraman et al, arXiv:1205.4723; Su and Finkbeiner, arXiv:1206.1616; etc.

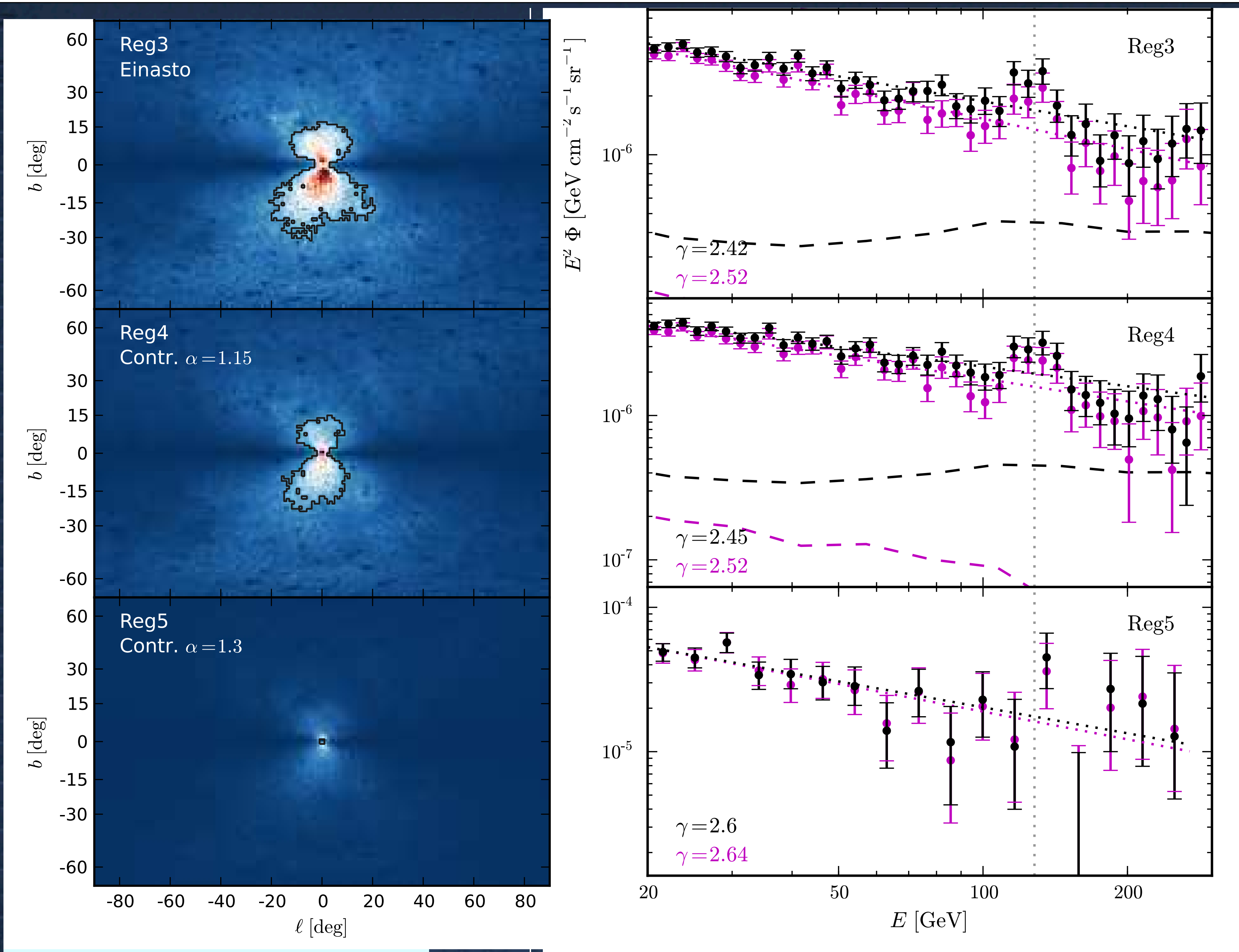


Galactic Coordinates

l: longitude

b: latitude

The center: l=b=0

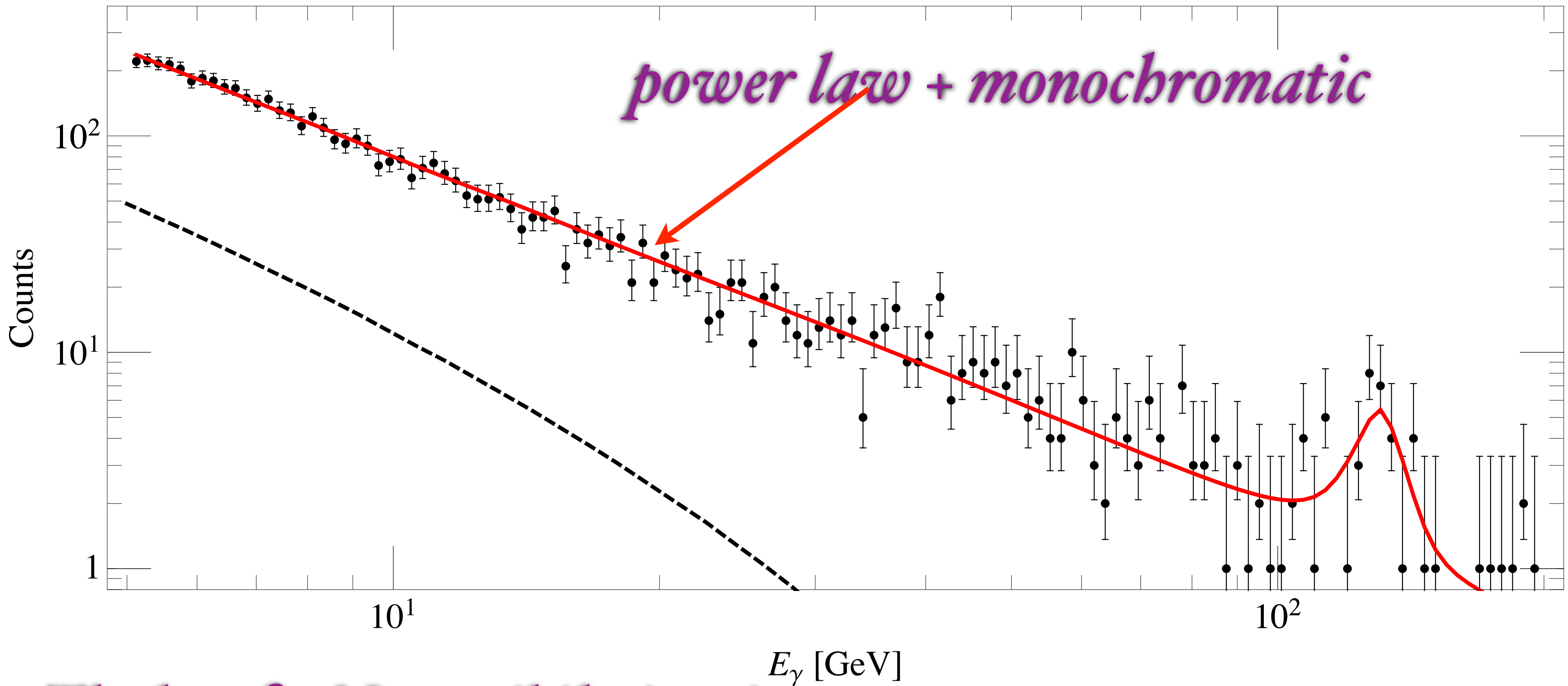


$$v\sigma_{\gamma\gamma} \simeq 10^{-27}\ \mathbf{cm^3 s^{-1}}$$

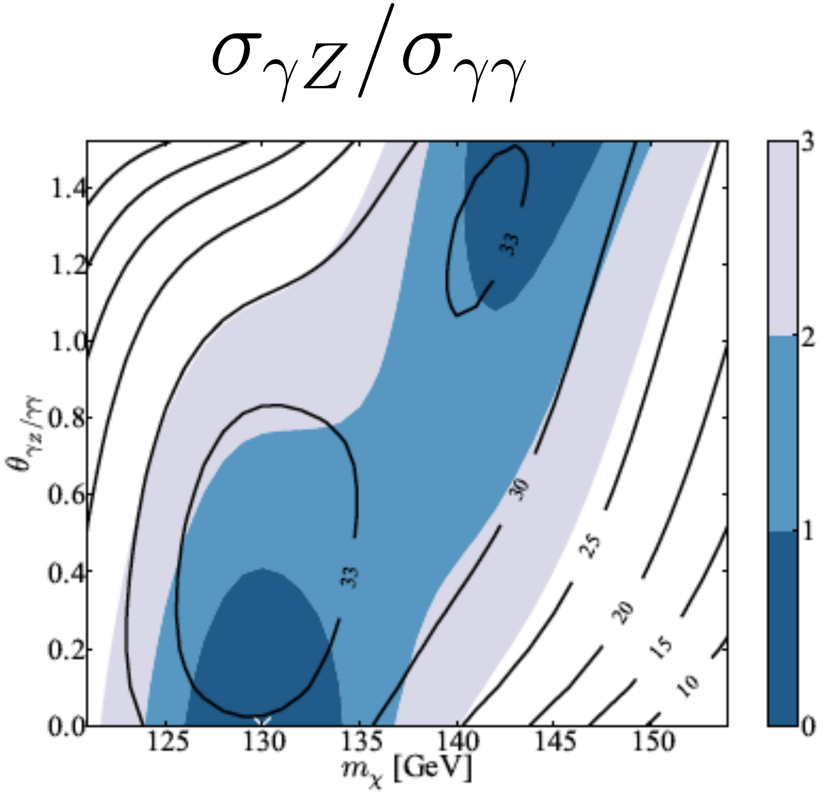
Weniger, JCAP 1208 (2012) 007

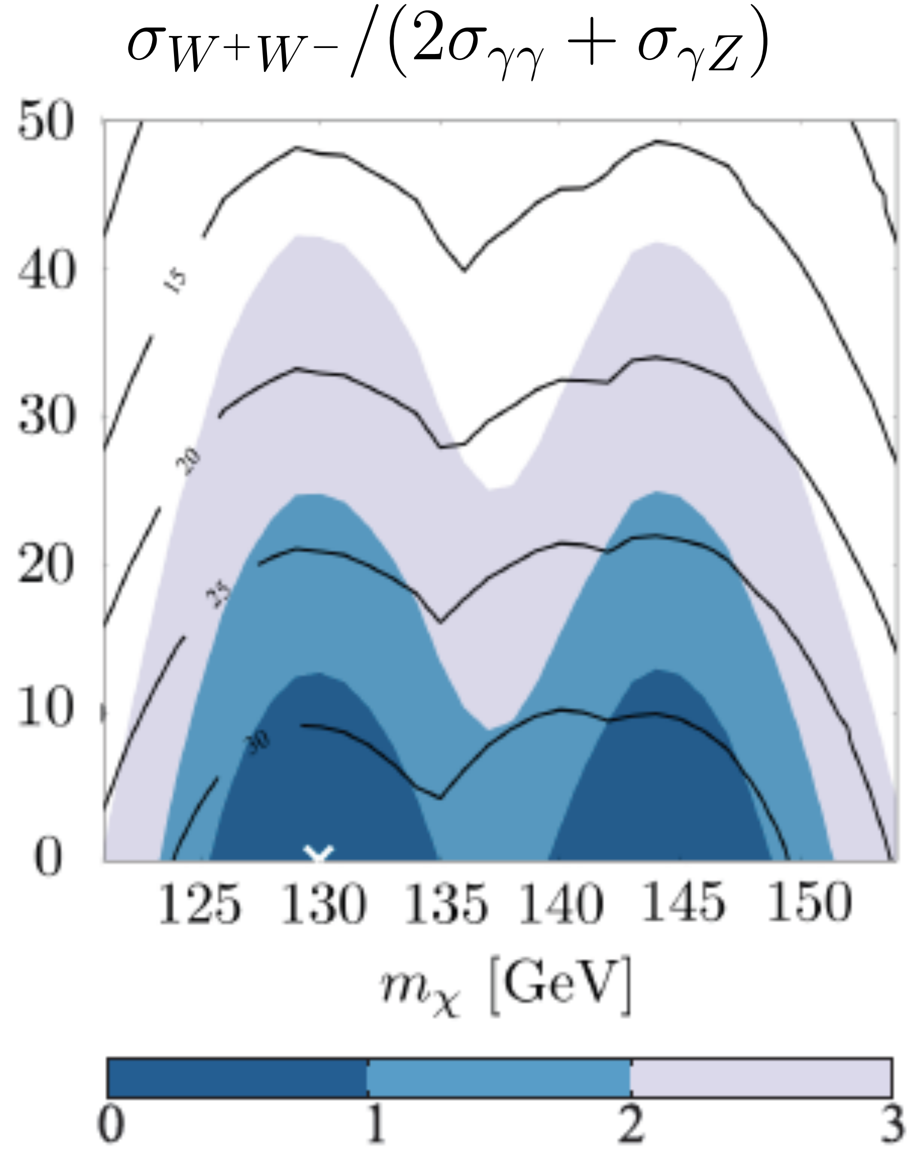
looking at the center more in detail.
(inner 3 degree radius around the center)

Cohen et al, arXiv:1207.0800



The best fit: No annihilations into W^+W^- , ZZ , $Z\gamma$ *etc.*





Cohen et al, arXiv:1207.0800

Dilemma

* **Monochromatic gamma**

$$v\sigma_{\gamma\gamma} \simeq 10^{-27}\ \mathbf{cm^3 s^{-1}}$$ *(loop effect)*

* **Continuum gamma**

$$v\sigma(\mathbf{DMDM} \to \mathbf{SM}), i.e. v\sigma(\mathbf{DMDM} \to W^+W^-)\ \mathbf{etc}$$

$$\lesssim 10 \times v\sigma(\mathbf{DMDM} \to \gamma\gamma) \sim 10^{-26}\ \mathbf{cm^3 s^{-1}}$$ *(tree level)*

* **Observed relic density** $\Omega_T h^2 = 0.116$

$$v\sigma(\mathbf{DMDM}) \simeq 10^{-26}\ \mathbf{cm^3 s^{-1}}$$

SUSY

Higgsino:

$$\sigma_{\gamma\gamma} v \simeq 1.1 \times 10^{-28}\ \text{cm}^3/\text{s}$$
$$\sigma_{\gamma Z} v \simeq 3.7 \times 10^{-28}\ \text{cm}^3/\text{s}$$
$$\sigma_{\text{ann}} v \simeq \sigma_{WW} v + \sigma_{ZZ} v \simeq 4.2 \times 10^{-25}\ \text{cm}^3/\text{s}$$

Wino:

$$\sigma_{\gamma\gamma} v \simeq 2.5 \times 10^{-27}\ \text{cm}^3/\text{s}$$
$$\sigma_{\gamma Z} v \simeq 1.4 \times 10^{-26}\ \text{cm}^3/\text{s}$$
$$\sigma_{\text{ann}} v \simeq \sigma_{WW} v \simeq 4.0 \times 10^{-24}\ \text{cm}^3/\text{s}$$

Bino:

$$\sigma_{\gamma\gamma} v \simeq \text{few} \times 10^{-30}\ \text{cm}^3/\text{s};$$
$$\sigma_{\gamma Z} v \simeq \text{few} \times 10^{-31}\ \text{cm}^3/\text{s};$$
$$\sigma_{\text{ann}} v \simeq \sigma_{\ell\bar{\ell}} v \simeq \text{few} \times 10^{-27}\ \text{cm}^3/\text{s}.$$

Neutralino DM can not explain the 130 gamma ray line.

Buchmüller+Garny, JCAP 1208 (2012)035;
Cohen et al, arXiv:1207.0800

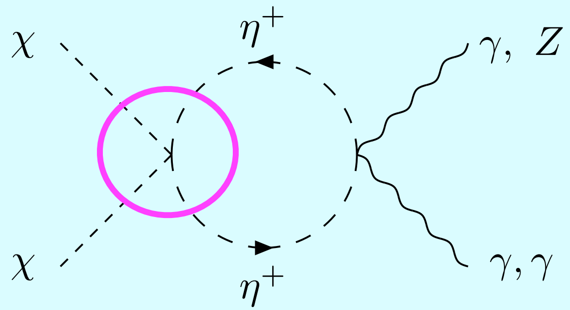
GOOD NEWS

ONE-LOOP ->

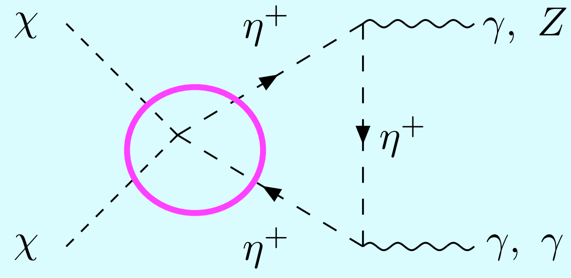
$$v\sigma(\mathbf{DMDM} \to \gamma\gamma) \sim \lambda^2 \frac{1}{\pi}\frac{1}{m_{DM}^2}\left(\frac{e^2}{16\pi^2}\right)^2 \simeq 1.2\left(\frac{\lambda}{4\pi}\right)^2 \times 10^{-26}\ \mathbf{cm}^3\mathbf{s}^{-1}$$

$$\textbf{for } m_{\mathrm{DM}} = 135\ \textbf{GeV}$$

In our model:



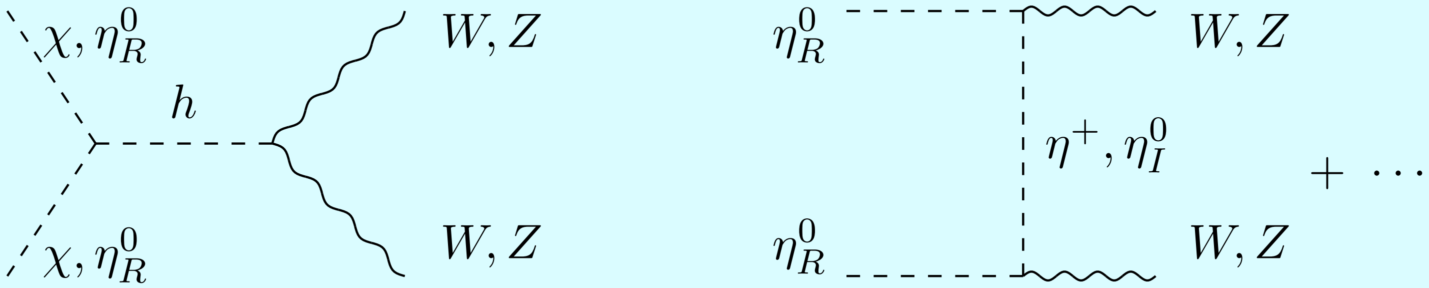
$+$



γ_3 γ_3

How to realize a large σ at the freeze out, while suppressing σ in the galaxy, i.e. at low temperature.

In our model:



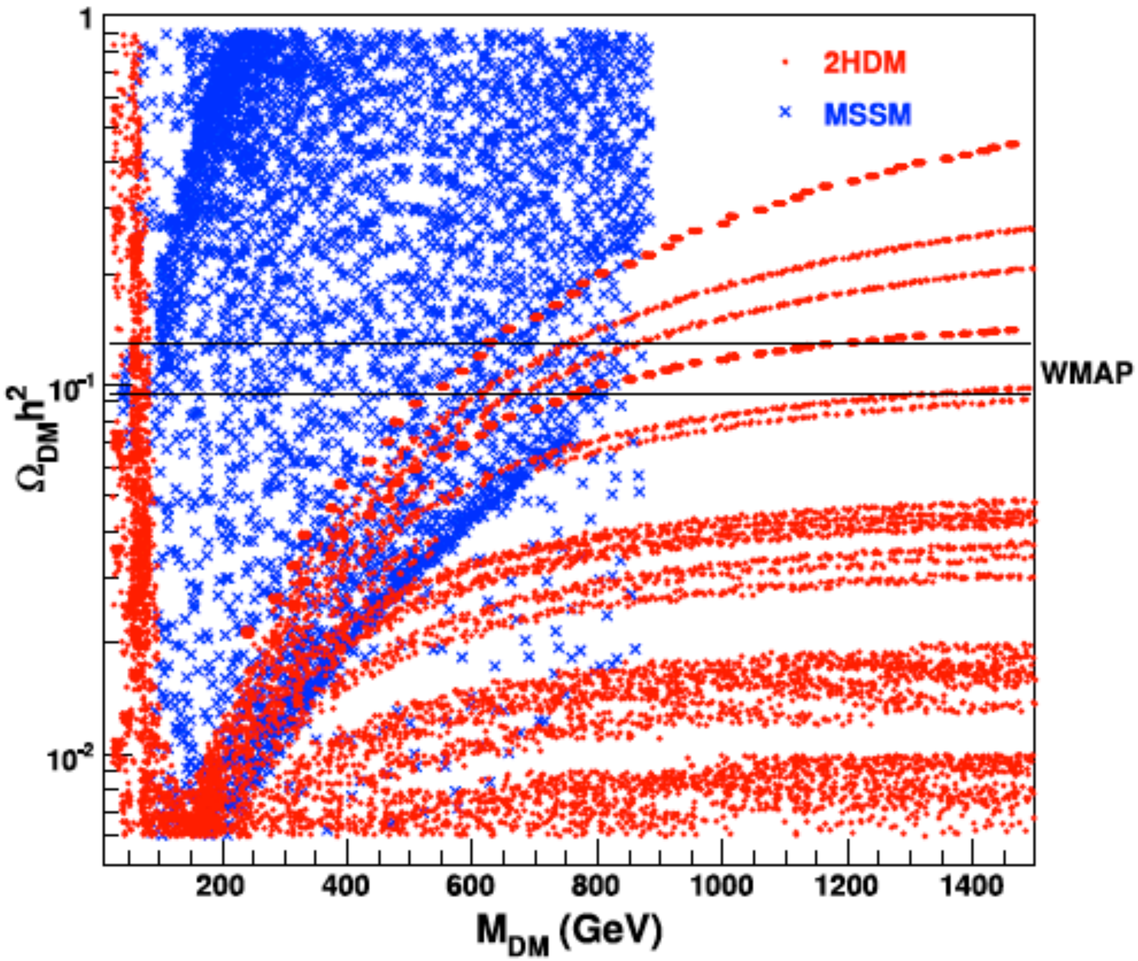
$(2\gamma_2, \lambda_3)v_h$

To make the continuum gammas small:

For chi DM: small γ_2

For eta DM: small Ω_η

Relic abundance of eta DM

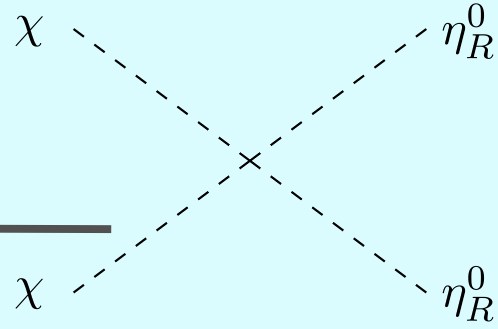


Lopez, Oliver and Tytgat,'06

TEMPERATURE DEPENDENT CROSS SECTION:

$$\frac{dY_\chi}{dx} = -0.264\; g_*^{1/2}\left[\frac{\mu M_{\rm PL}}{x^2}\right]\Big\{<\sigma(\chi\chi;{\rm SM})v>\left(Y_\chi Y_\chi - \bar{Y}_\chi \bar{Y}_\chi\right)$$

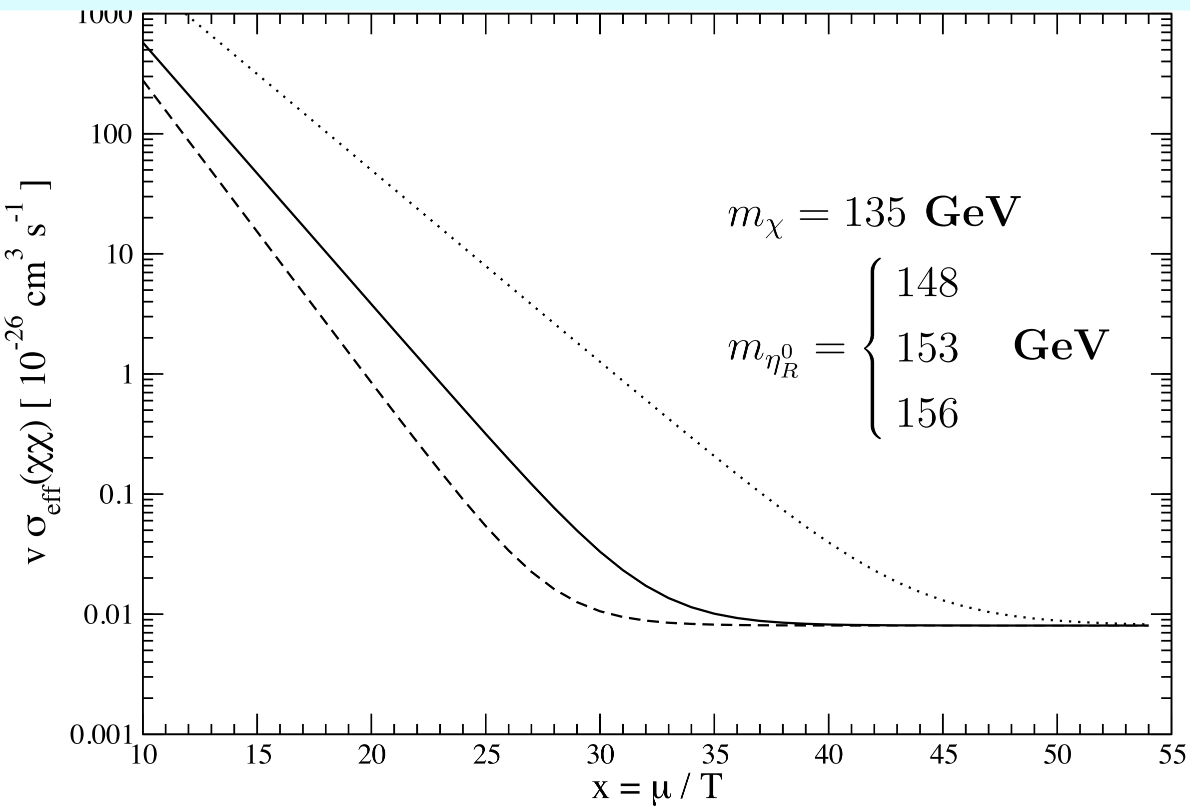
$$- <\sigma(\eta_R^0\eta_R^0;\chi\chi)v>\left(Y_{\eta_R^0}Y_{\eta_R^0} - \frac{Y_\chi Y_\chi}{\bar{Y}_\chi \bar{Y}_\chi}\bar{Y}_{\eta_R^0}\bar{Y}_{\eta_R^0}\right)\Big\},$$



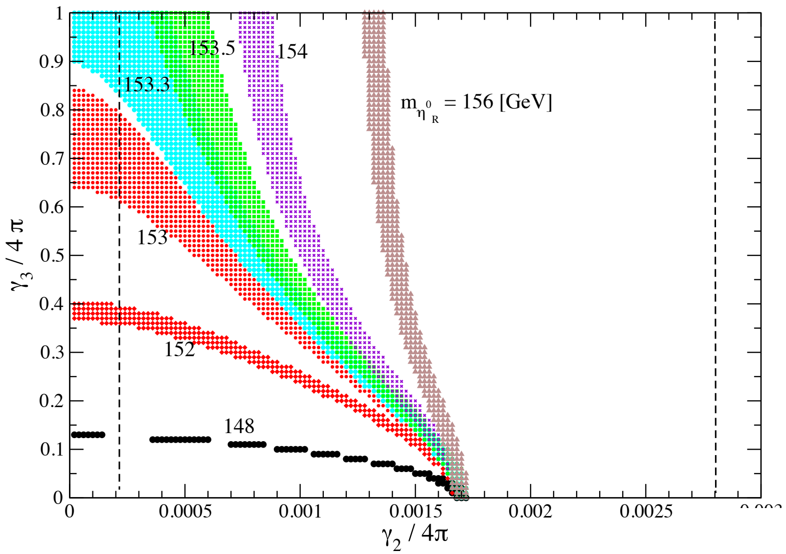
DM conversion

σ_{eff}

$$\left[<\sigma(\chi\chi;{\rm SM})v> + <\sigma(\eta_R^0\eta_R^0;\chi\chi)v>\frac{m_{\eta_R^0}^3}{m_\chi^3}\exp 2\left(\frac{m_\chi^2 - m_{\eta_R^0}^2}{m_\chi m_{\eta_R^0}}\right)x\right]\left(Y_\chi Y_\chi - \bar{Y}_\chi \bar{Y}_\chi\right)$$

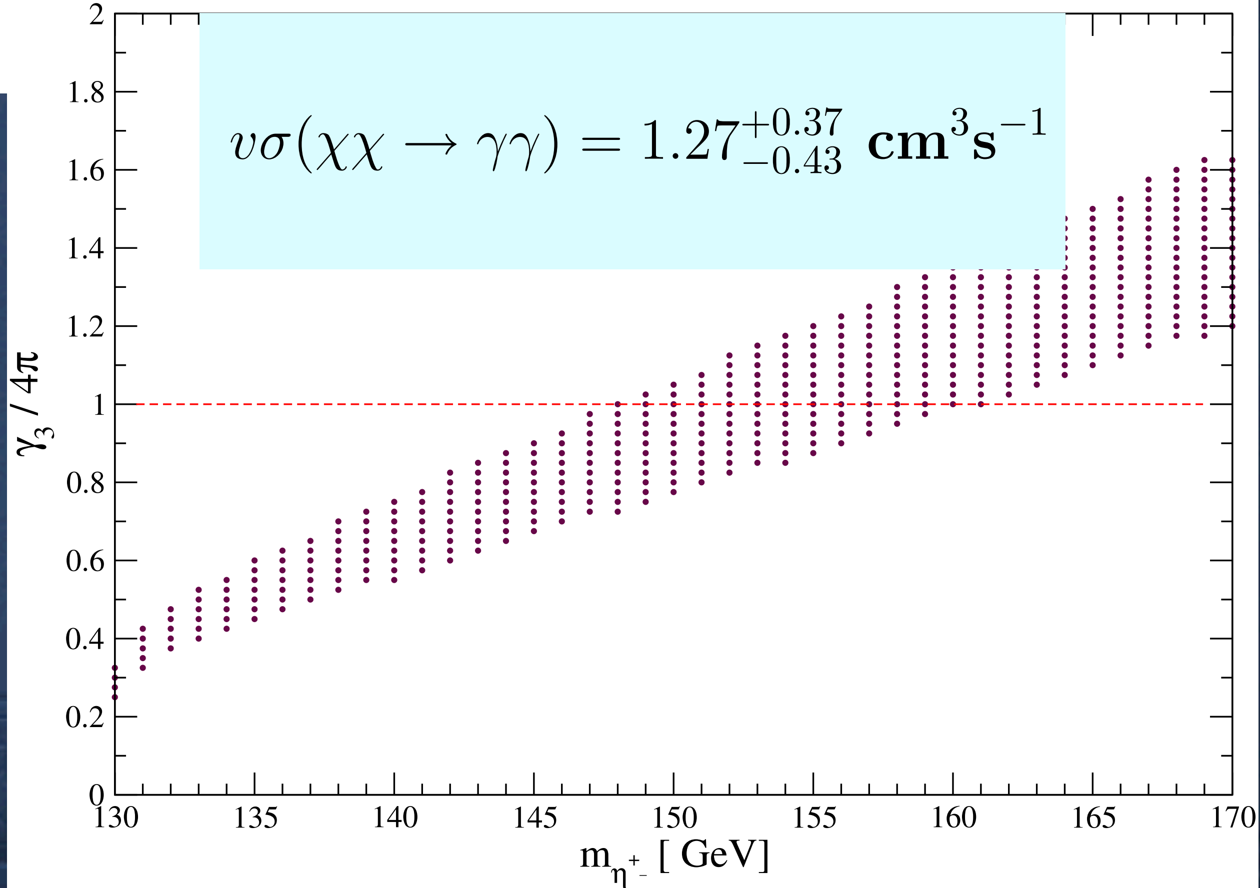


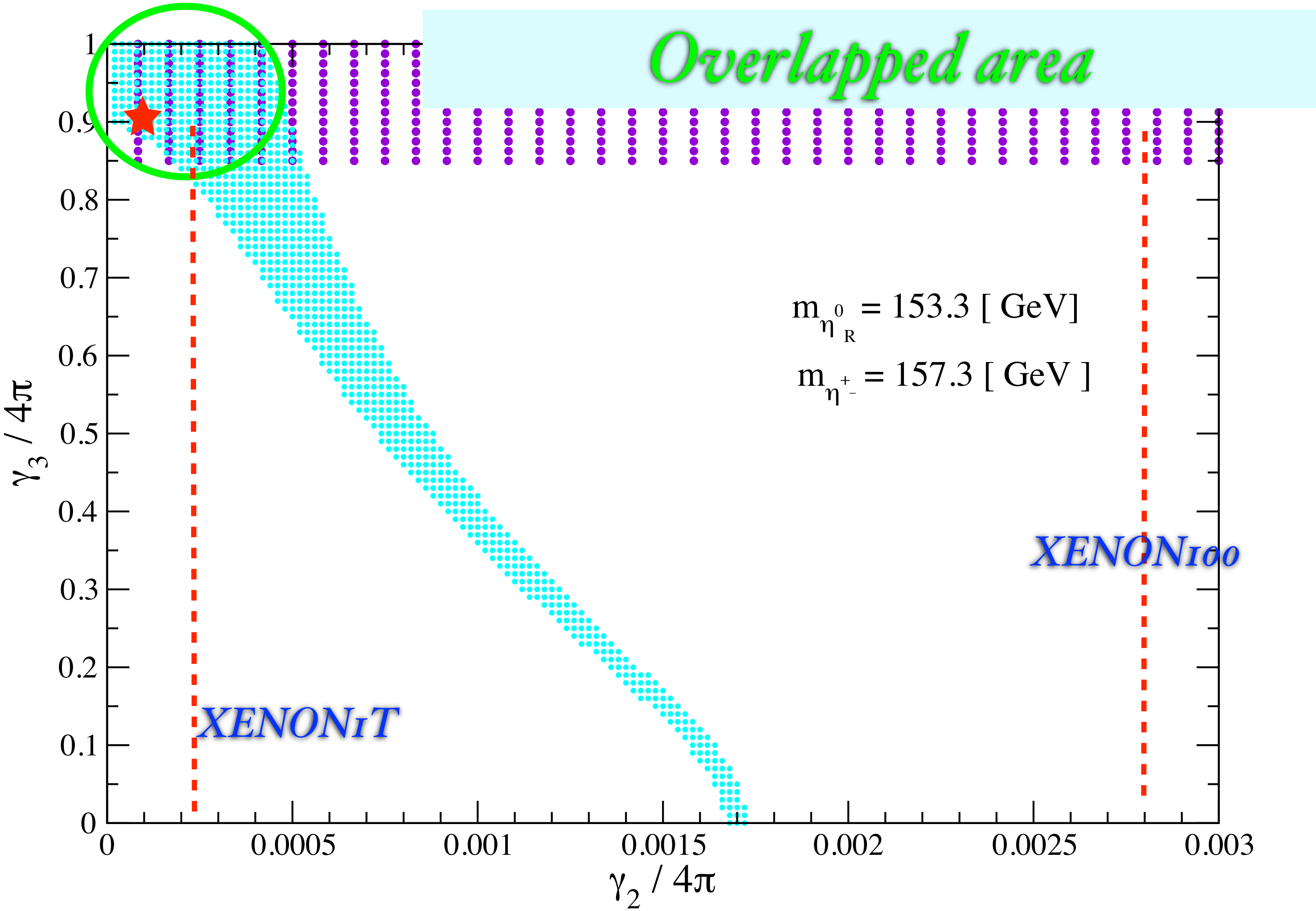
Griest, 91;
Tulin, Yu and Zurek, 12
Baek, Ko+Senaha, 12



$$\Omega_T = 0.1157 \pm 0.0046(2\sigma)$$

$$v\sigma(\chi\chi \to \gamma\gamma) = 1.27^{+0.37}_{-0.43}\ \mathbf{cm^3 s^{-1}}$$





$$v\sigma(\chi\chi \to \mathrm{SM}) \simeq 8.0 \times 10^{-29}\ \mathrm{cm^3 s^{-1}}$$

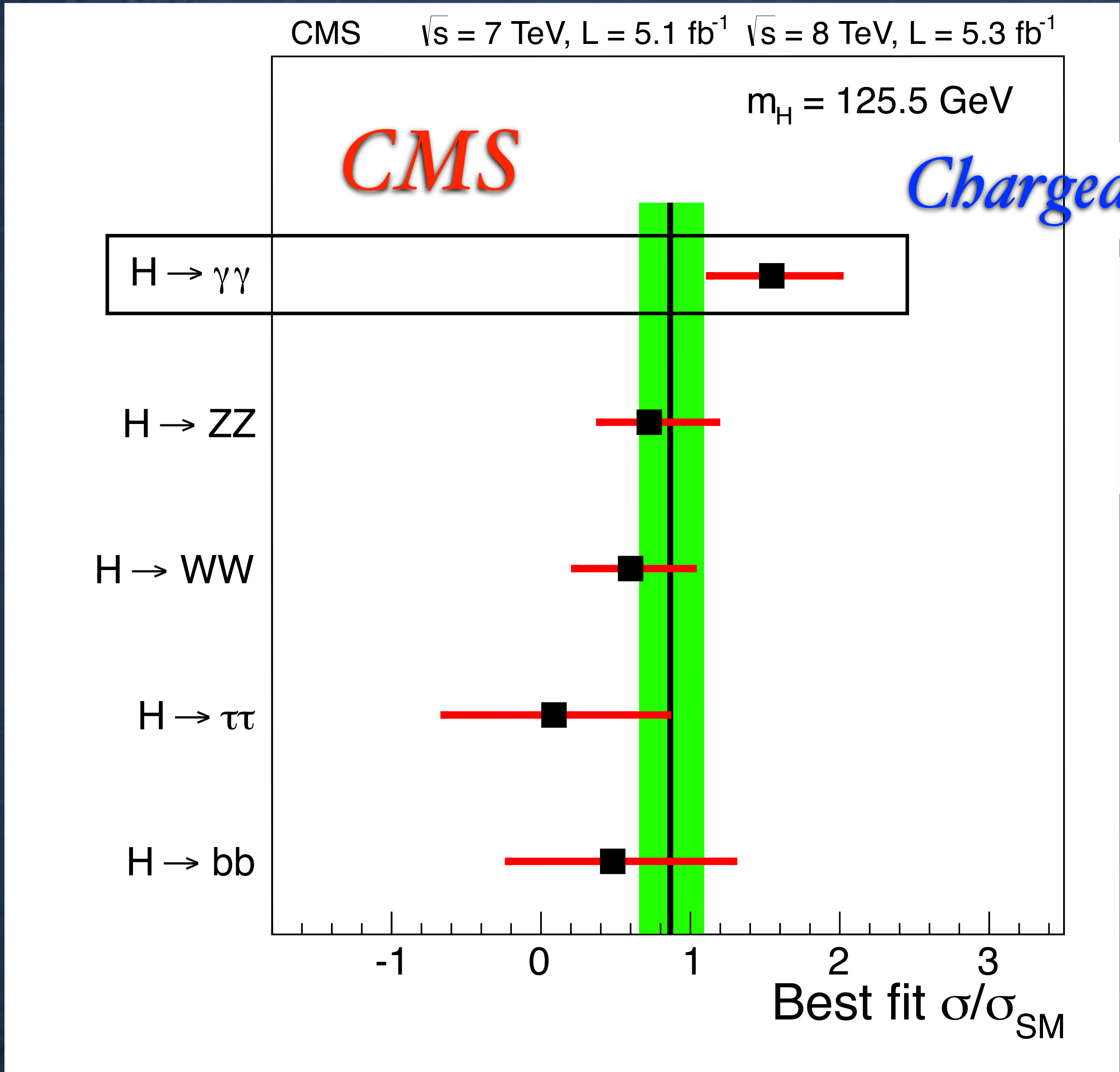
$$v\sigma(\chi\chi \to W^+W^-) \simeq 3.9 \times 10^{-29}\ \mathrm{cm^3 s^{-1}}$$

★ $$v\sigma(\chi\chi \to ZZ) \simeq 1.7 \times 10^{-29}\ \mathrm{cm^3 s^{-1}}$$

$$v\sigma(\chi\chi \to hh) \simeq 2.5 \times 10^{-29}\ \mathrm{cm^3 s^{-1}}$$

$$v\sigma(\chi\chi \to f\bar{f}) \simeq 1.1 \times 10^{-31}\ \mathrm{cm^3 s^{-1}}$$

* Yet another byproduct:

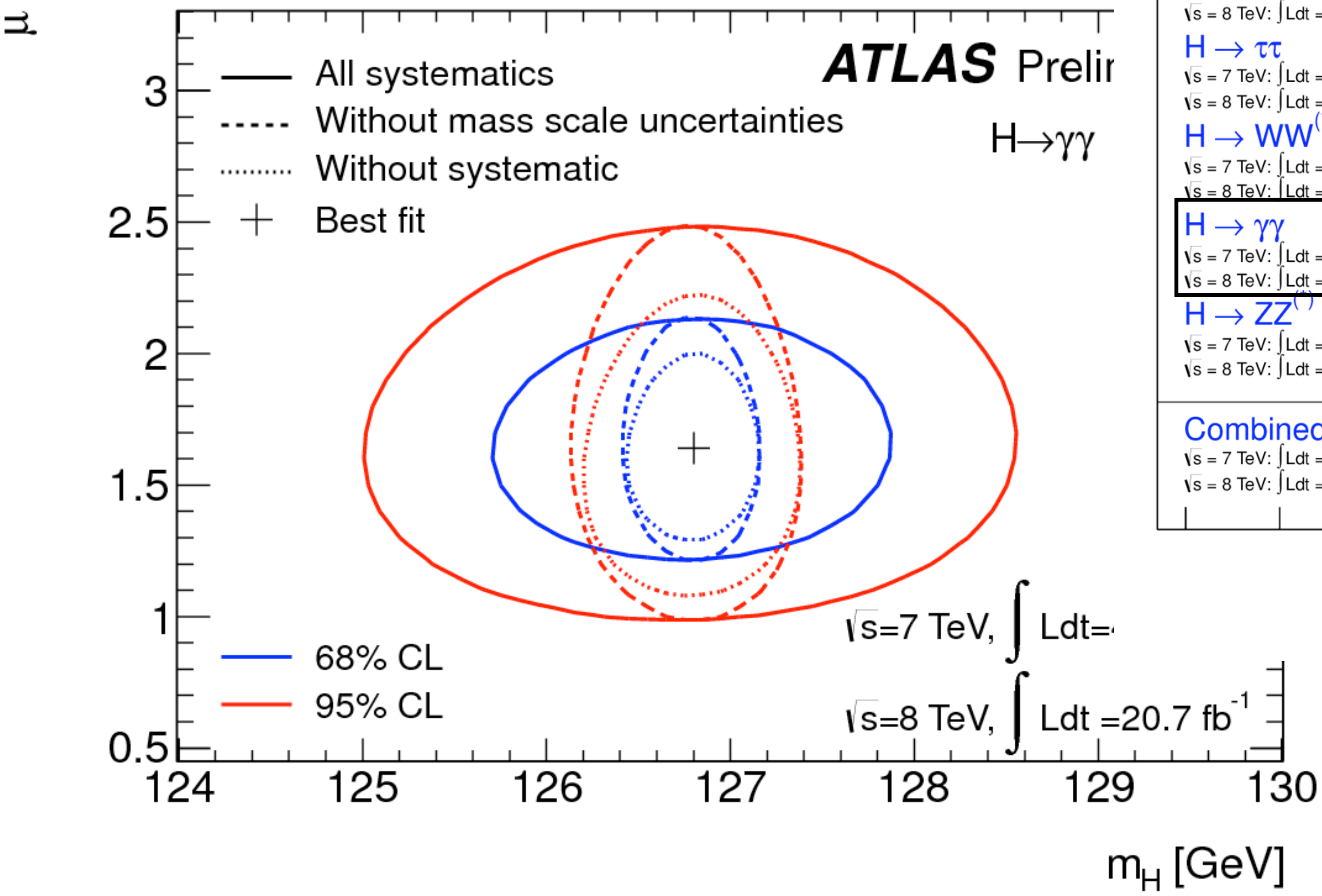


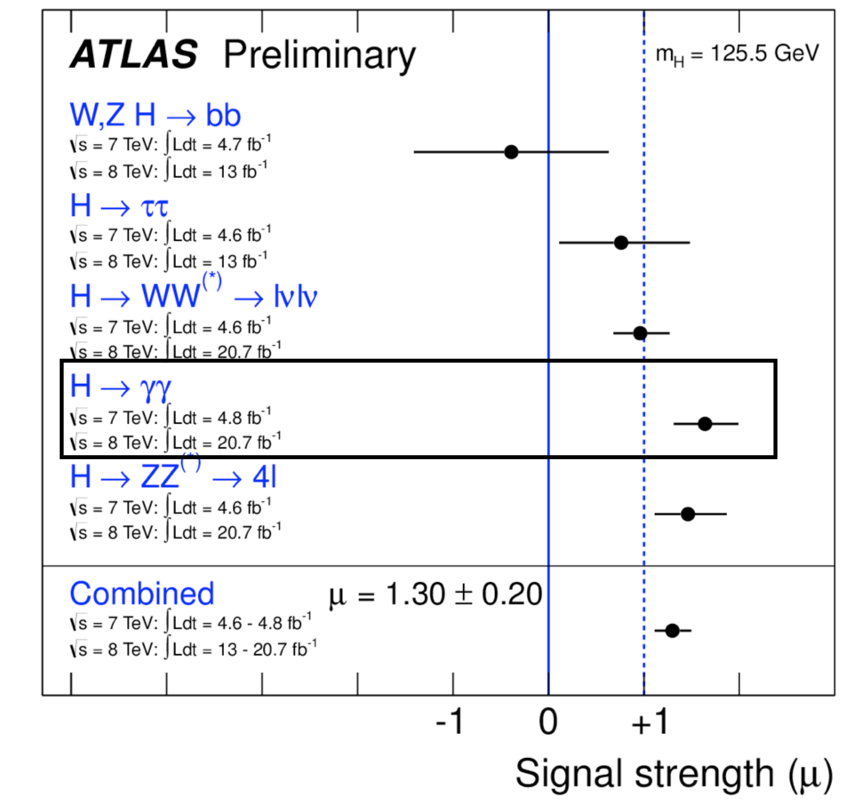
Charged Higgs contributes:

$$\sigma^{MCDM}/\sigma^{\rm SM} = 1.6 \pm 0.4$$

CMS

CMS Collaboration, ArXiv:1207.7235





- Best fit of signal strength @ this mass $\mu = 1.65^{+0.34}_{-0.30} = 1.65 \pm 0.24\ \text{(stat)}\ ^{+0.25}_{-0.18}\ \text{(syst)}$
  [consistent across various categories]

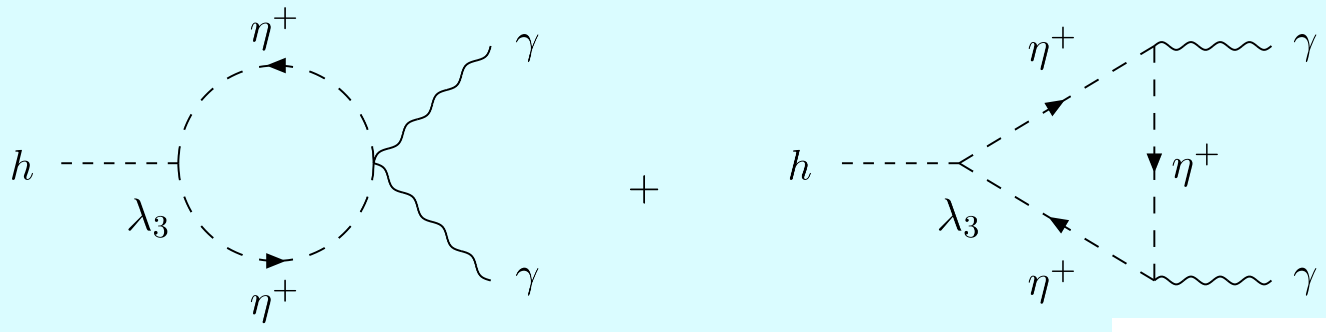
➔ 2.3σ from SM Higgs + background hypothesis

by Hubaut at Moriond2013

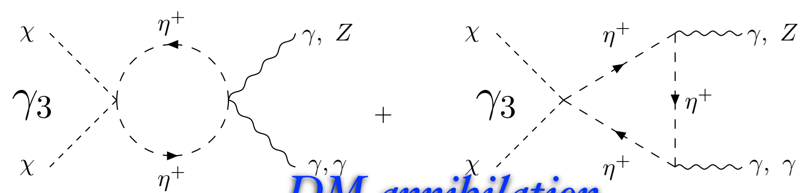
Higgs decay into two gammas

$$R_{\gamma\gamma} = \frac{\sigma(pp \to h \to \gamma\gamma)}{\sigma(pp \to h \to \gamma\gamma)^{\rm SM}} \simeq \frac{\sigma(gg \to h \to \gamma\gamma)}{\sigma(gg \to h \to \gamma\gamma)^{\rm SM}}$$

$$\simeq \frac{\sigma(gg \to h) B(h \to \gamma\gamma)}{\sigma(gg \to h)^{\rm SM} B(h \to \gamma\gamma)^{\rm SM}} = \frac{B(h \to \gamma\gamma)}{B(h \to \gamma\gamma)^{\rm SM}}$$

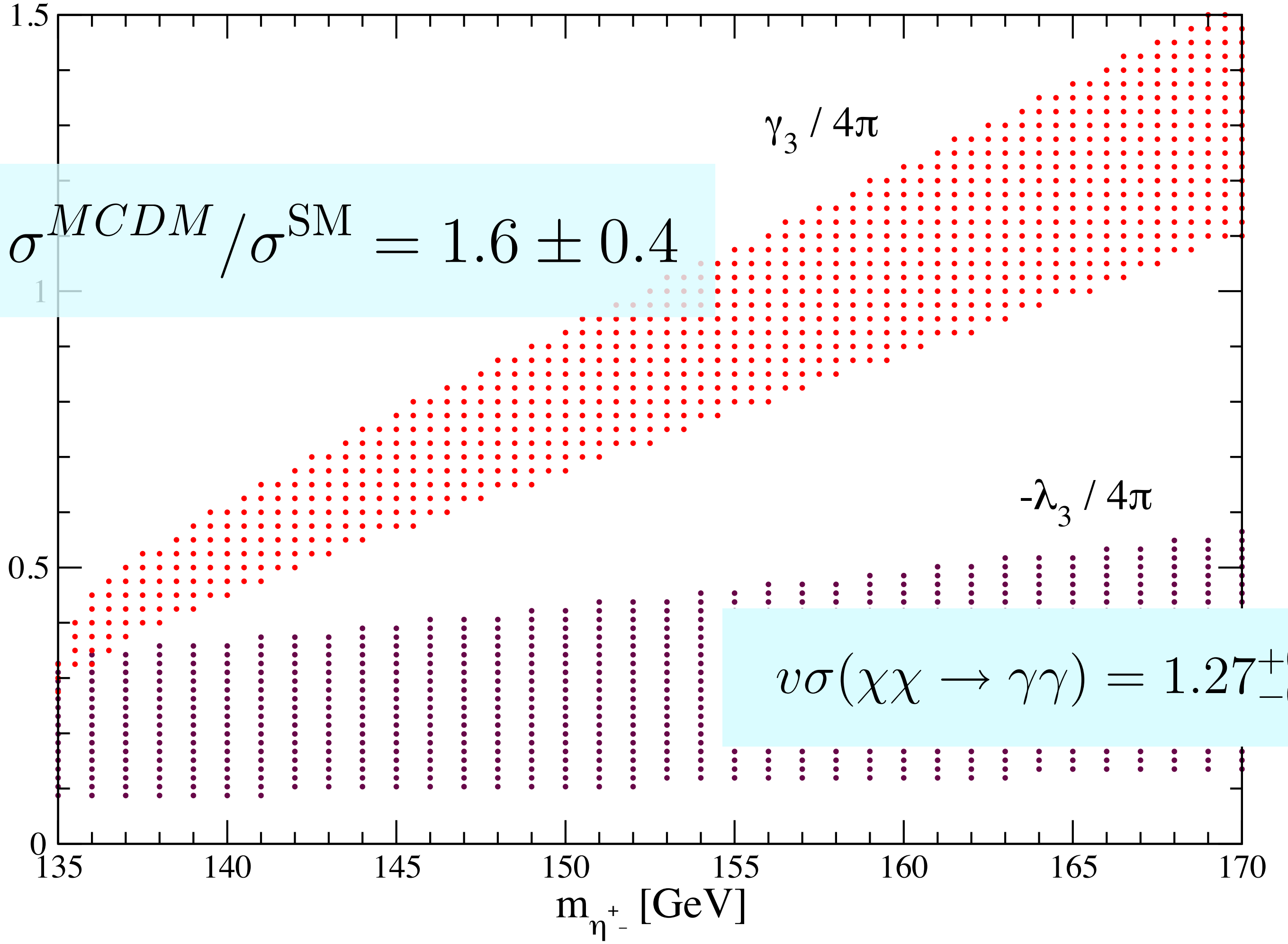


Cao, Ma+rajasekaran; Posch; Arhrib, Benbrik + Gaur; Swiezewska + Krawczyk; etc



DM annihilation

$$\sigma^{MCDM}/\sigma^{\mathrm{SM}} = 1.6 \pm 0.4$$



$$v\sigma(\chi\chi \to \gamma\gamma) = 1.27^{+0.37}_{-0.43}\ \mathbf{cm^3 s^{-1}}$$

Attempts to explain gamma excesses both in the Higgs decay and Fermi spectrum

1.Wang and Han,`130 GeV gamma-ray line and enhancement of h \to \gamma \gamma in the Higgs triplet model plus a scalar dark matter," arXiv:1209.0376 [hep-ph].

2.. Baek, Ko and Senaha,``Can Zee-Babu model implemented with scalar dark matter explain both Fermi/LAT 130 GeV gamma-ray excess and neutrino physics ?," arXiv: 1209.1685 [hep-ph].

3. Bai et al, ``2HDM Portal Dark Matter: LHC data and the Fermi-LAT 135 GeV Line," arXiv:1212.5604 [hep-ph].

4. Kopp et al, ``From gamma ray line signals of dark matter to theLHC," arXiv:1301.1683 [hep-ph].

5.Fan and Reece,``Probing Charged Matter Through Higgs Diphoton Decay, Gamma Ray Lines, and EDMs," arXiv:1301.2597 [hep-ph].

6. Biswas e tal,``Two Component Dark Matter : A Possible Explanation of 130 GeV gamma-Ray Line from the Galactic Centre," arXiv:1301.3668 [hep-ph].

IV Conclusion

1 *A Two-loop seesaw model is proposed;*

* *L is softly violated by a dim. 2 operator,*

* *Z_2 x Z_2 is the unbroken symmetry, and*

* *the Higgs sector is minimal.*

2 *With* η_R^0 **and** χ *as DM the model has a potential to explain:*

* *135 GeV gamma-ray line observed at the Fermi LAT and*

* *enhancement of* $h \to \gamma\gamma$ *observed at LHC.*

Danke schön.