

Minimal Asymmetric Dark Matter

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1503.01119 , with Martin Krauss & Enrico Nardi
1310.1904 , with Stefano Morisi (mini review)

Outline

- 1. DM & BAU**
- 2. DM + BAU**
- 3. MADM**

Part I
DM & BAU

Two empirical facts about matter:

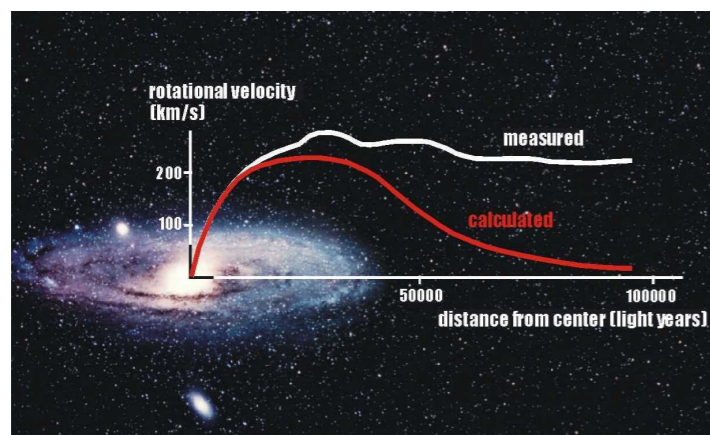
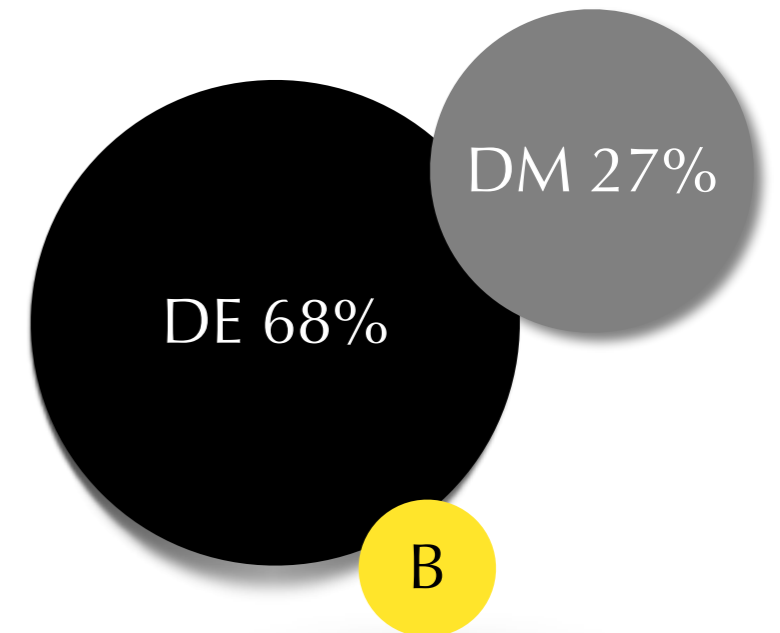
1) Our Universe is quite **dark**



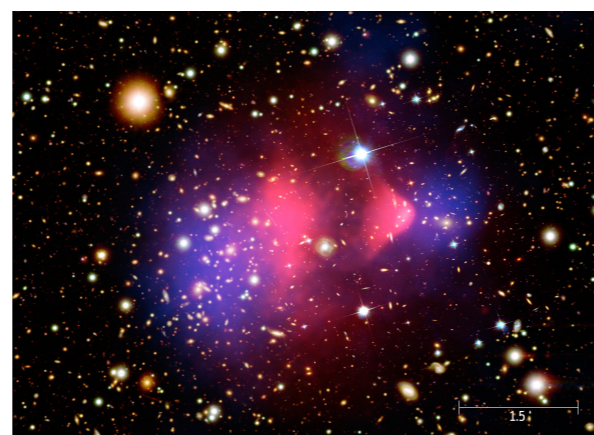
We live in a pretty dark place

By now, we have a wide array of evidences for a nonbaryonic, clustering component.

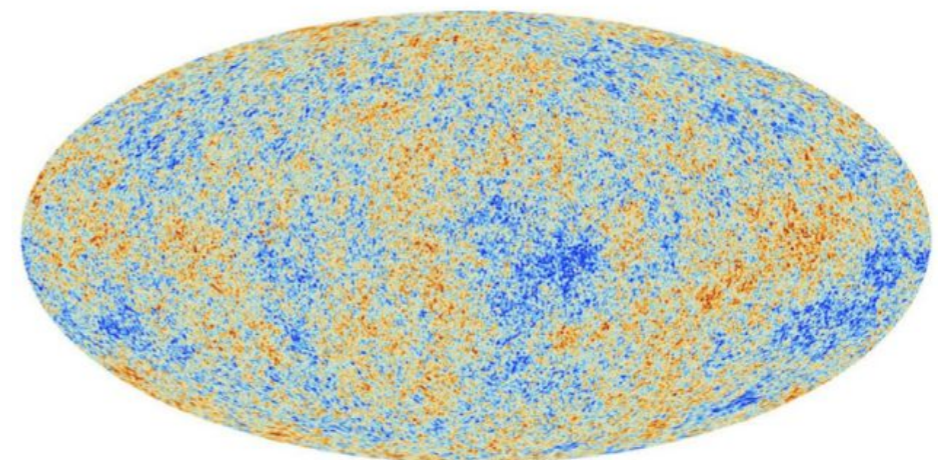
Interesting particle candidates relate DM to other BSM problems, e.g. axions, majorons, ADM, and WIMPs.



(10 kpc)



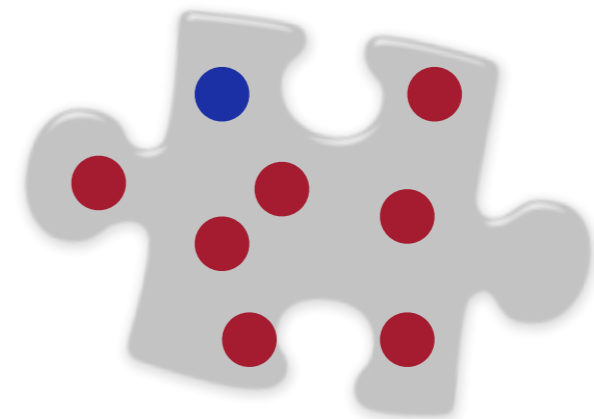
(Mpc)



(10 Gpc)

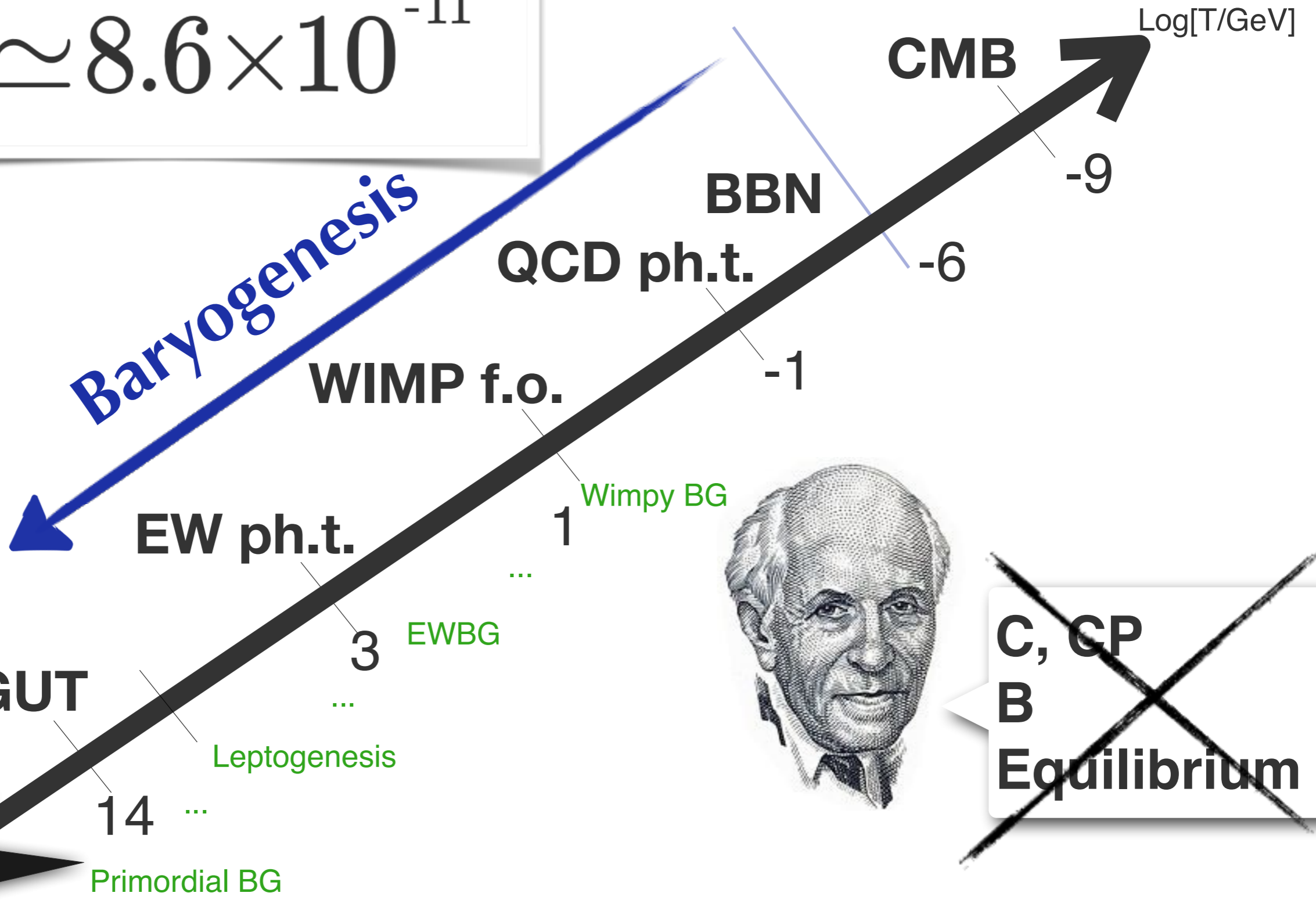
Two empirical facts about matter:

- 1) Our Universe is quite **dark**
- 2) Its visible part is quite **asymmetric**



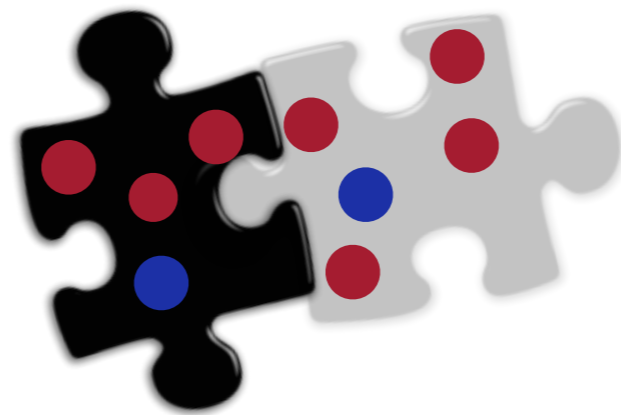
..and pretty asymmetric too

$$\eta_B \simeq 8.6 \times 10^{-11}$$



Two empirical facts about matter:

- 1) Our Universe is quite **dark**
- 2) Its visible part is quite **asymmetric**



**Are the dark and the asymmetric
Universe related to each other?**

Part II

DM + BAU

What if $\Omega_\chi = 5\Omega_B$ is not just a coincidence?

In a nutshell, ADM theories set DM abundance via its chemical potential; they relate number densities.

$$M_\chi n_\chi \sim 5 M_p n_p$$


E.g. sphalerons or transfer operators

DM asymmetry is protected thanks to extra charge → no annihilation signal. Also, DM mass is a free parameter.

ADM vs. WIMP

ADM

Relation between dark and visible densities; link to baryogenesis; not so great pheno

WIMP

Very rich pheno; link to weak scale; no explanation for the 'coincidence'

ADM ⁺~~vs.~~ WIMP

ADM

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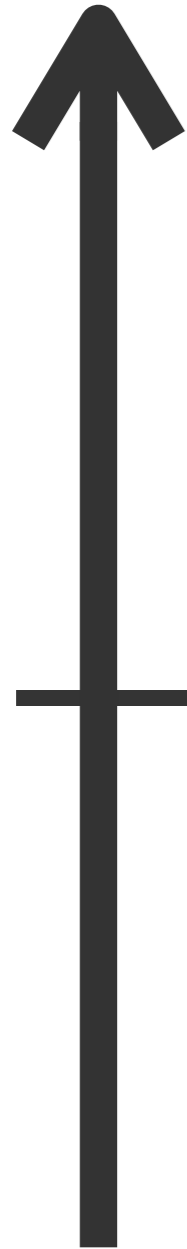
Combine advantages of both!

Remember that:

1) Any particle carrying a conserved charge and in eq. with thermal bath acquires an asymmetry

2) Hypercharge is a conserved quantum number that is spontaneously broken at weak scale

Temperature



EWSB



ADM

WIMP



ADM horse

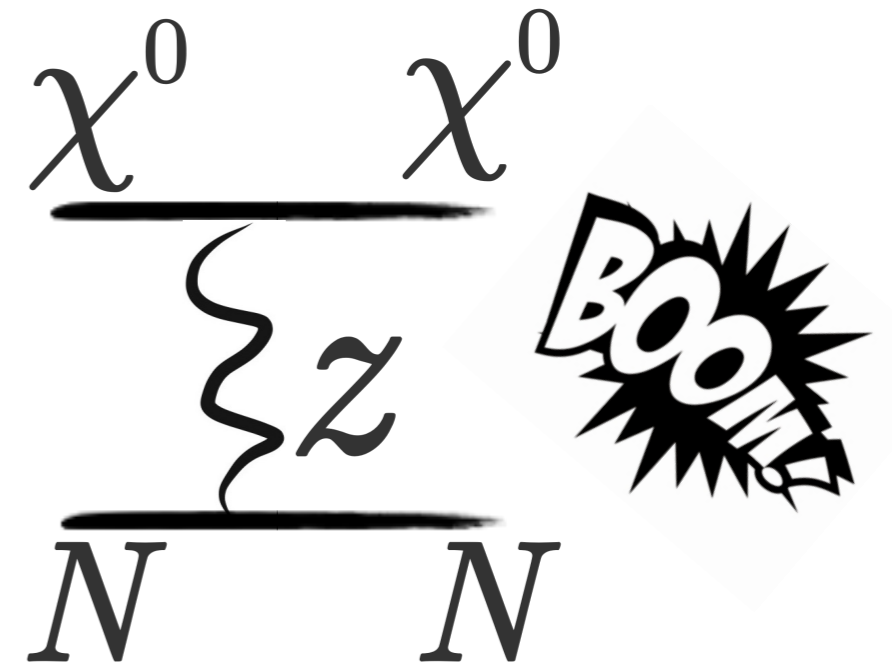
**Asymmetric WIMP via
'Hypercharge portal'?**

Some direct consequences

Hypercharged DM:

- $SU(2)_L$ multiplet
- Z mediated interactions
- Direct detection problem
- Very high DM mass ($\sim EeV$),

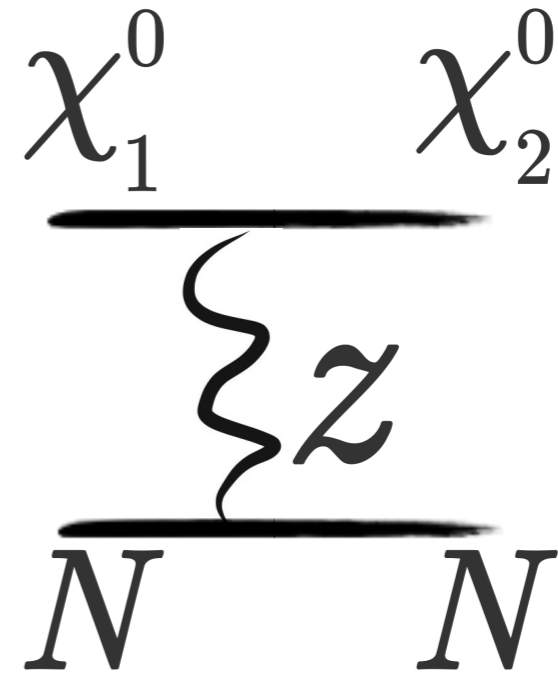
singlet admixture, or **non hermitian mass operators**



Some direct consequences

Hypercharged DM:

- $SU(2)_L$ multiplet
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- ~~Very high DM mass ($\sim EeV$),~~
Can't be WIMP-like
~~singlet admixture, or non hermitian mass operators~~
Not so nice

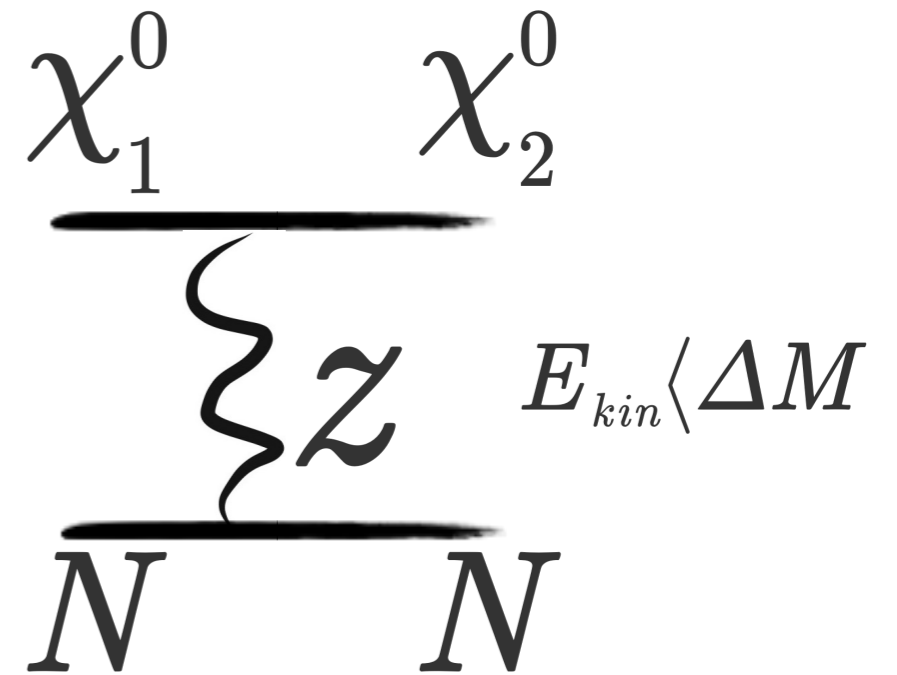


→ $E_{kin} \ll \Delta M$

Some direct consequences

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Not so nice



On the other hand, asymmetries can be transferred via **non hermitian operators**.

Part III
MADM

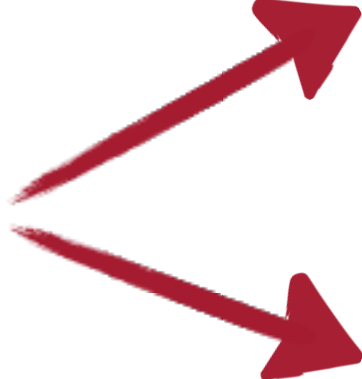
Minimal ADM

MADM is a framework based on an extension of SM by hypercharged $SU(2)_L$ multiplets and an effective interaction playing two roles:

$$\frac{1}{\Lambda^{4y+2(s-1)}} \chi\chi\phi^{4y}$$

Spin

Higgs ($y=-1/2$)



At high T , it transfers asymmetries between SM & DM (**ADM**)

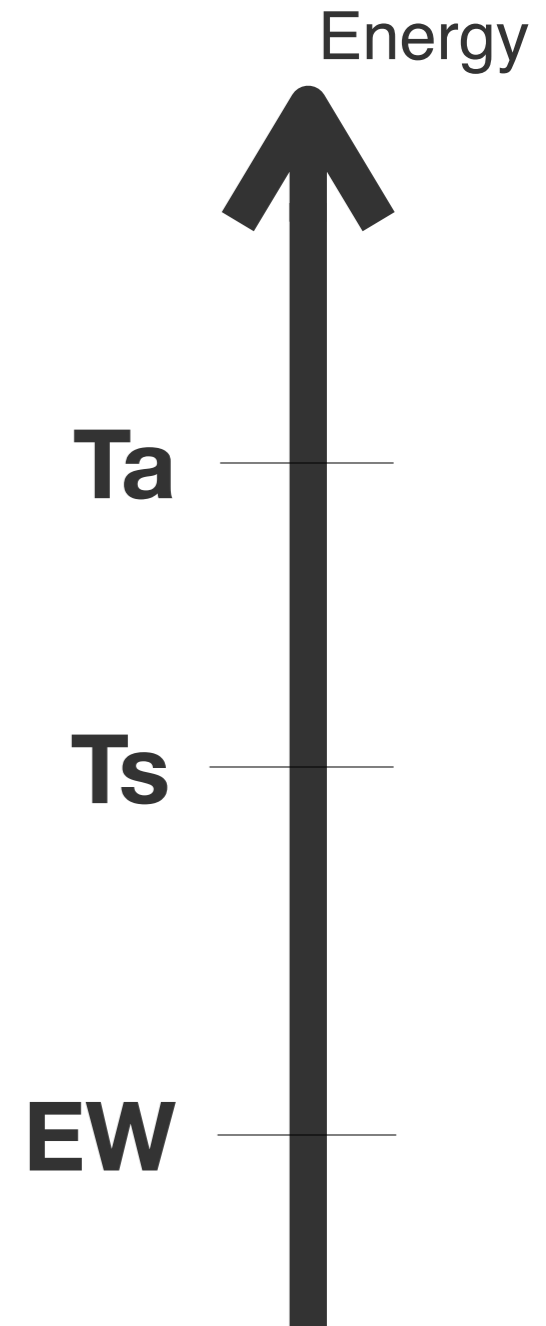
After EWSB, it splits the d.o.f. of the neutral state, and regenerates the symmetry (**WIMP**)

MADM proceeds through 3 steps

1) the effective interactions transfer asymmetries between dark and visible sectors, until freeze out at **T_a**

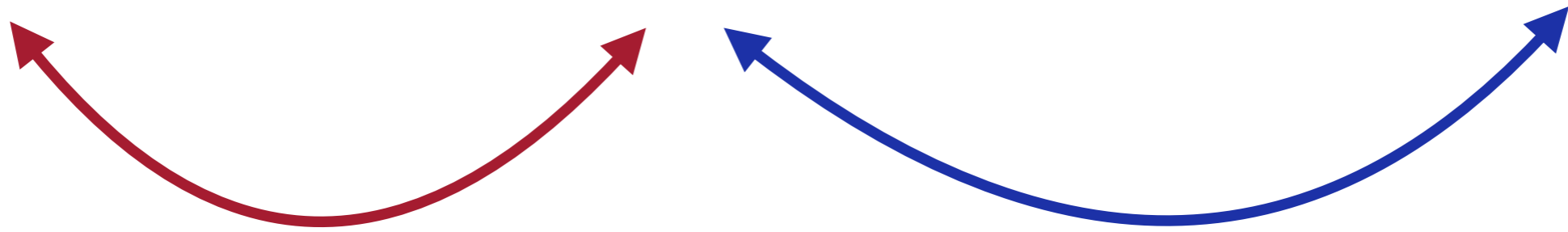
2) symmetric part is cancelled away at **T_s**

3) after **EWSB**, neutral d.o.f are split, and WIMP-like phenomenology is recovered



Step 1: asymmetrical birth

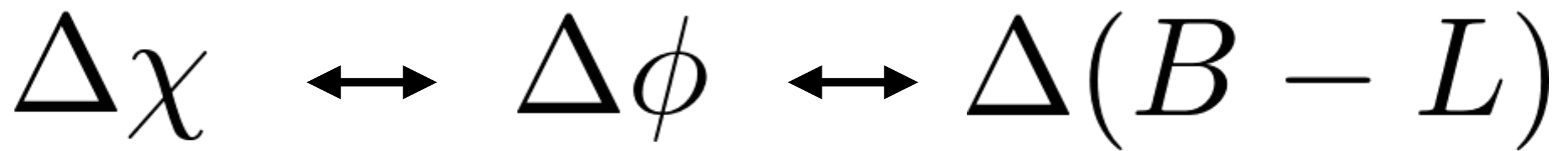
$$\Delta\chi \leftrightarrow \Delta\phi \leftrightarrow \Delta(B - L)$$



Operator

Sphalerons

Step 1: asymmetrical birth



$$Y_{\Delta\chi} = -2y \frac{n_{\chi}^{eq}}{n_{\phi}} Y_{\Delta\phi}$$

$$Y_{\Delta\phi} = -\frac{8}{79} Y_{\Delta_{B-L}}$$

Step 1: asymmetrical birth

$$\Gamma \left(\begin{array}{c} \chi \\ \chi \end{array} \begin{array}{c} \phi \\ \vdots \\ \phi \end{array} ; \begin{array}{c} \chi \\ \phi^* \end{array} \begin{array}{c} \bar{\chi} \\ \vdots \\ \phi \end{array} \right) \sim H(T_a)$$

$$n_{\chi}^{eq} \langle \sigma | v | \rangle_{\chi\chi} \propto e^{-\frac{M_{\chi}}{T}} T^3 \frac{1}{M_{\chi}^2} \left(\frac{M_{\chi}}{\Lambda} \right)^{4(2y-1)} \left(\frac{M_{\chi}}{\Lambda} \right)^{4s}$$

Step 1: asymmetrical birth

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$$n_{\phi}^{eq} \langle \sigma | v | \rangle_{\chi\phi} \propto T^3 \frac{1}{T^2} \left(\frac{T}{\Lambda} \right)^{4(2y-1)} \left(\frac{M_{\chi}}{\Lambda} \right)^{4s}$$

Dominates for $y=1/2$ only

Step 2: symmetrical apocalypse

It is crucial that MADM mass is $<$ WIMP mass that saturates the Universe

y	n	M_{χ}^{wimp} [TeV]	
0	3	~ 3.2	inc. Sommerfeld effects, Cohen et al. JCAP 2013, Hryczuk et al. JCAP 2014
1	3	~ 2.8	Estimate
0	5	~ 10	inc. Sommerfeld effects, Cirelli et al. Nuc.Phys.B 2007
1	5	$\mathcal{O}(10)$	Estimate

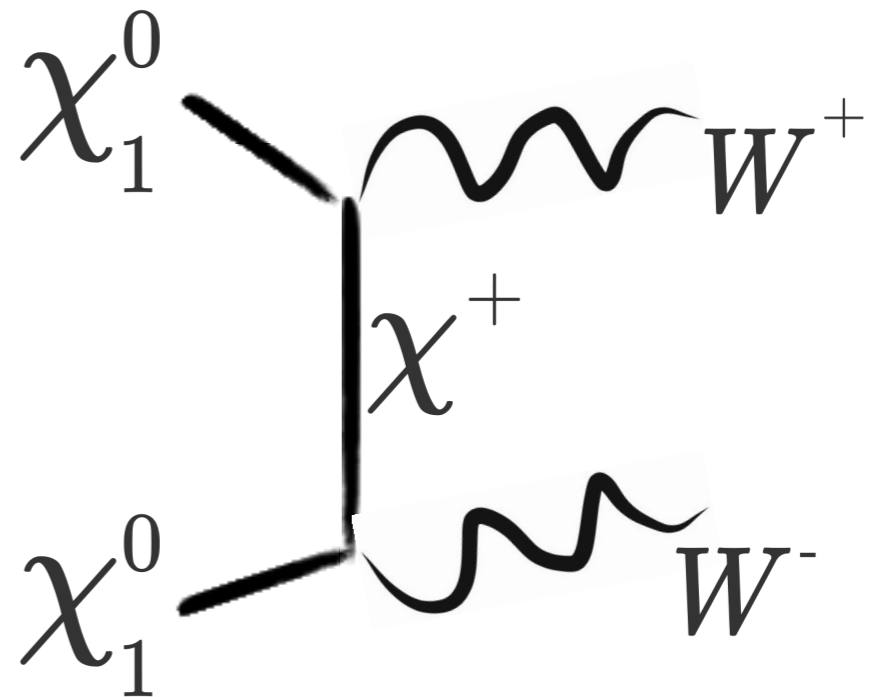
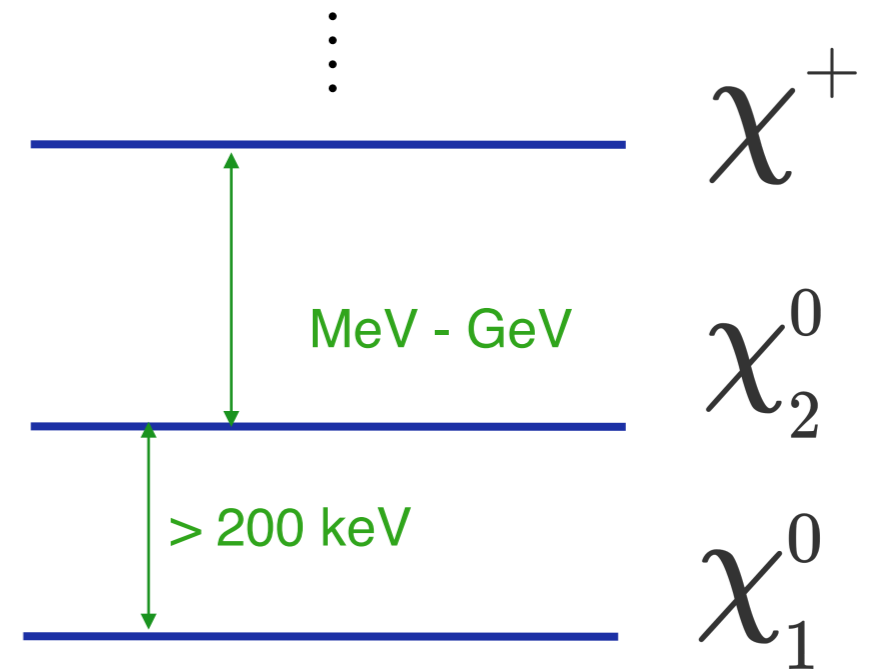
Step 3: WIMP reincarnation

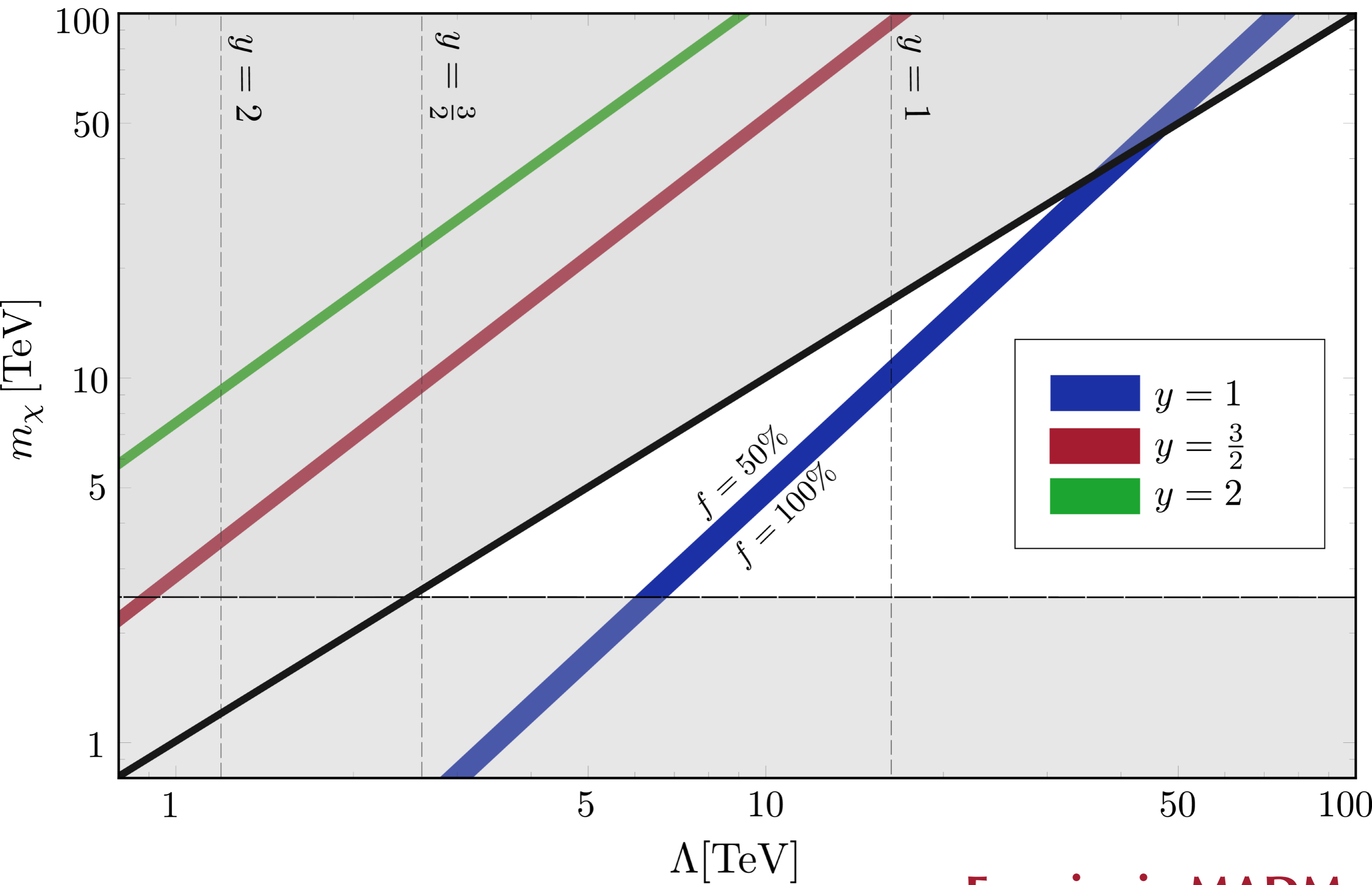
After EWSB, the components of the multiplet are split:

$$\Delta M = 2M_\chi \left(\frac{v}{\Lambda}\right)^{4y} \left(\frac{\Lambda}{2m_\chi}\right)^{2(1-s)} \gtrsim 200 \text{ keV}$$

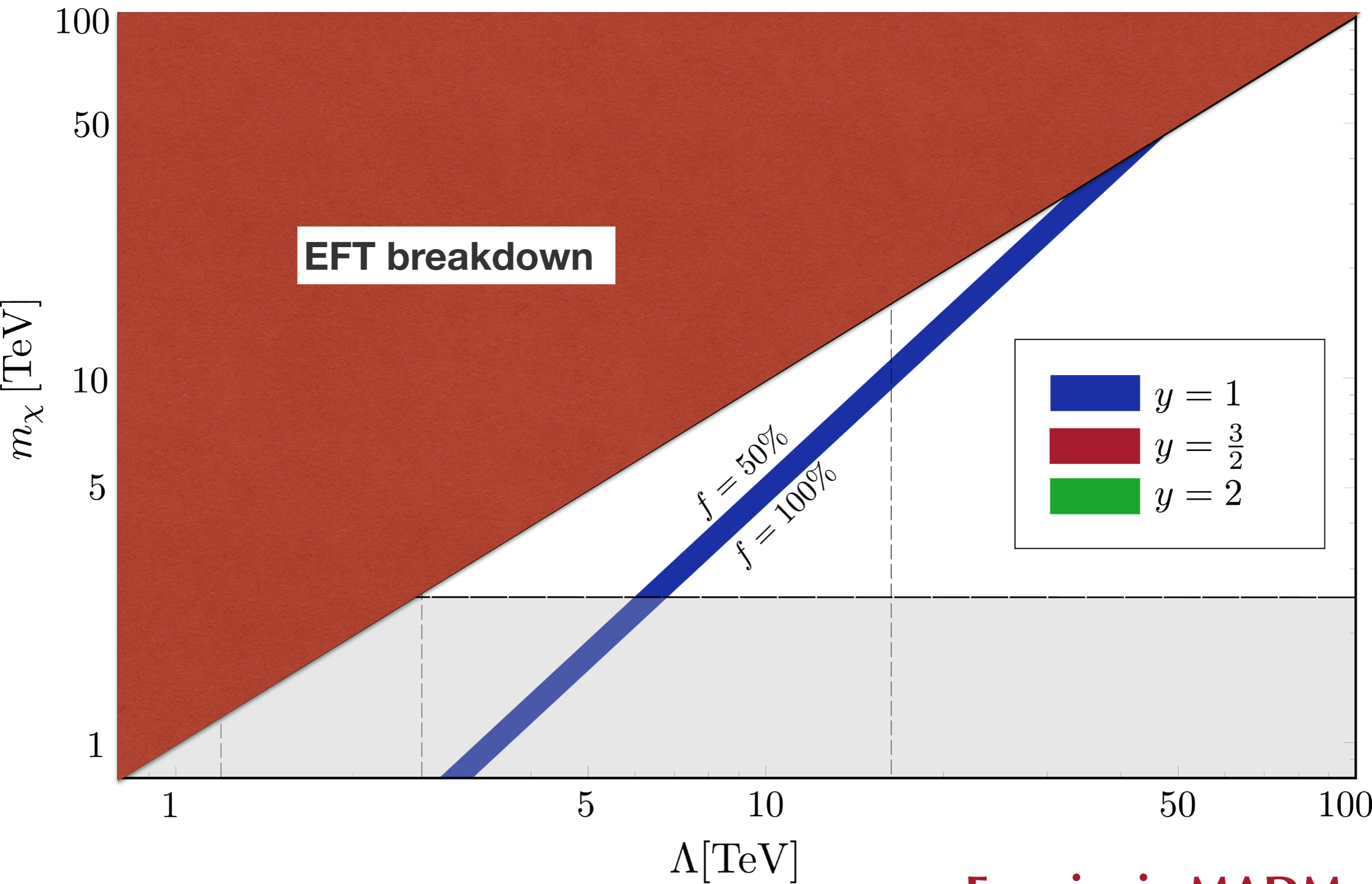
Implies upper bound on scale of new physics

Annihilating DM is revamped!

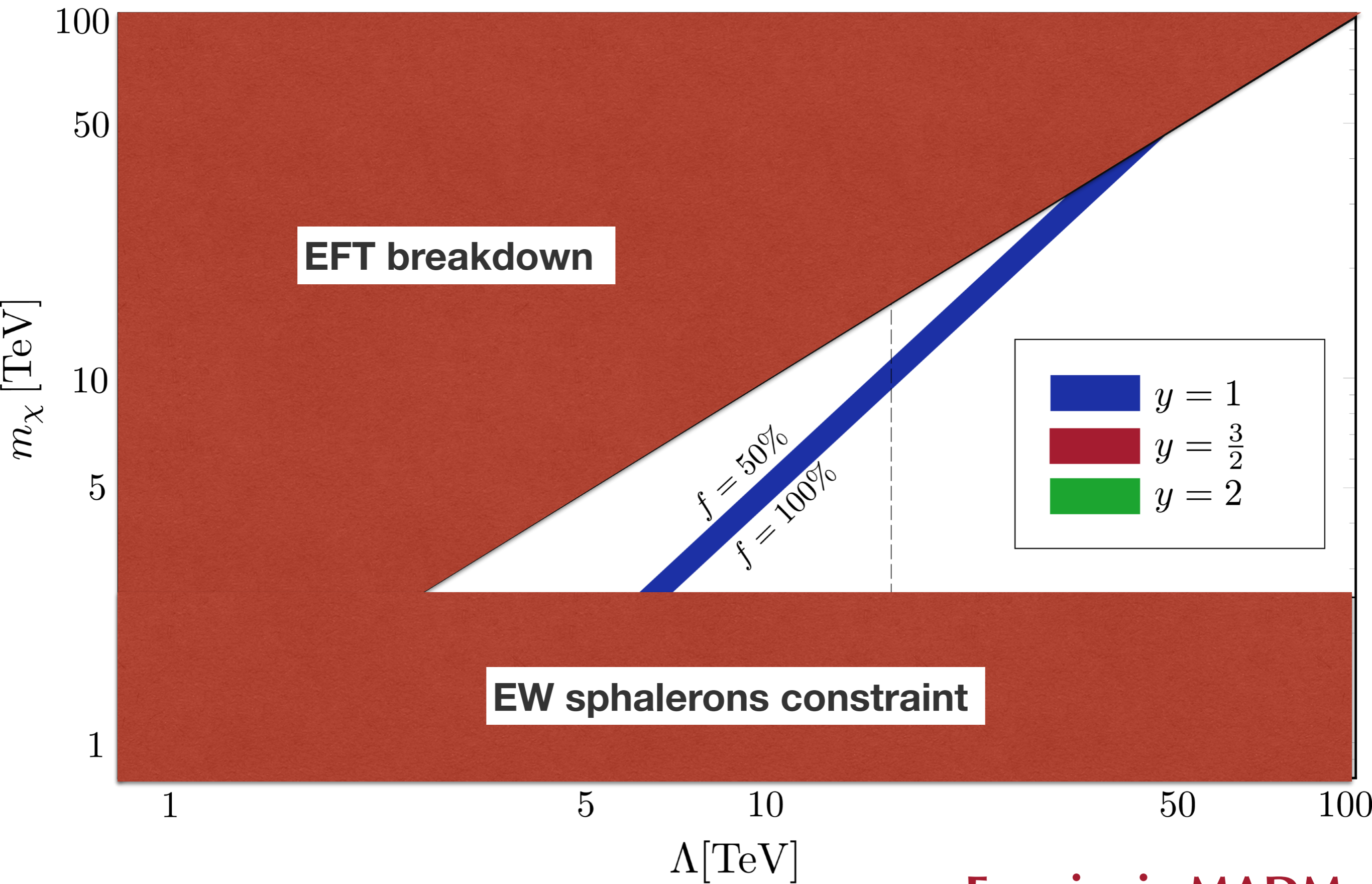


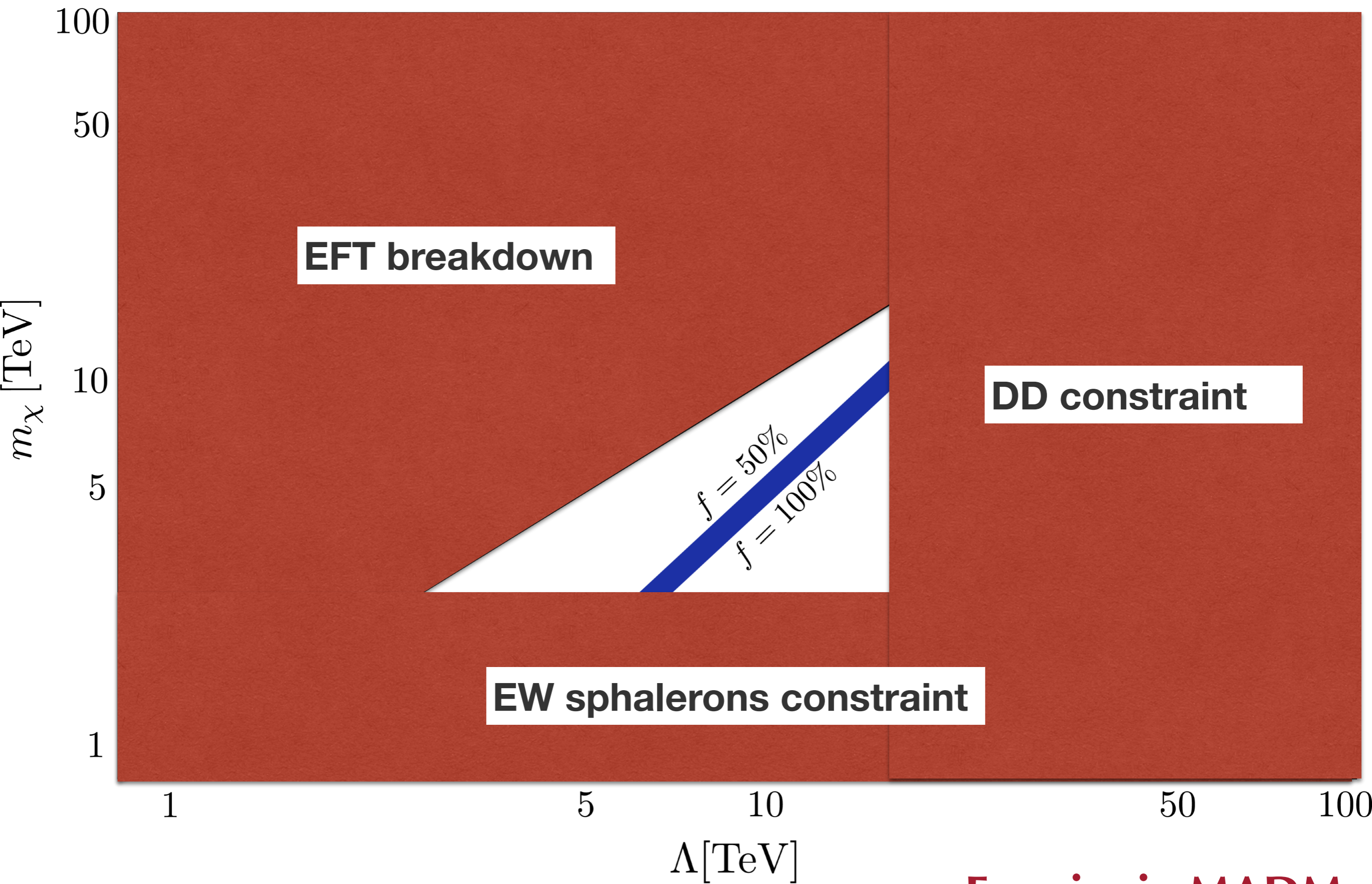


Fermionic MADM

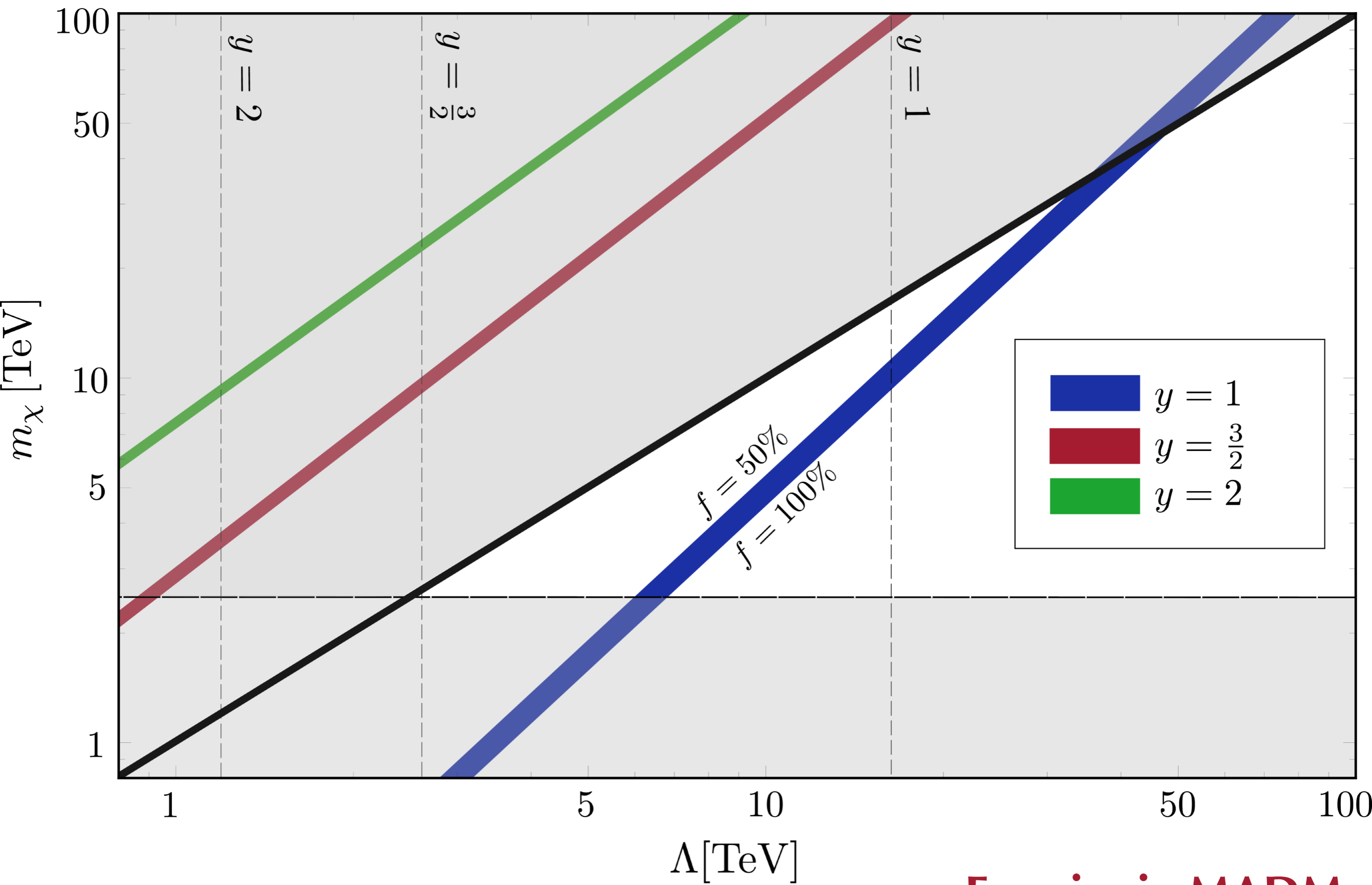


Fermionic MADM

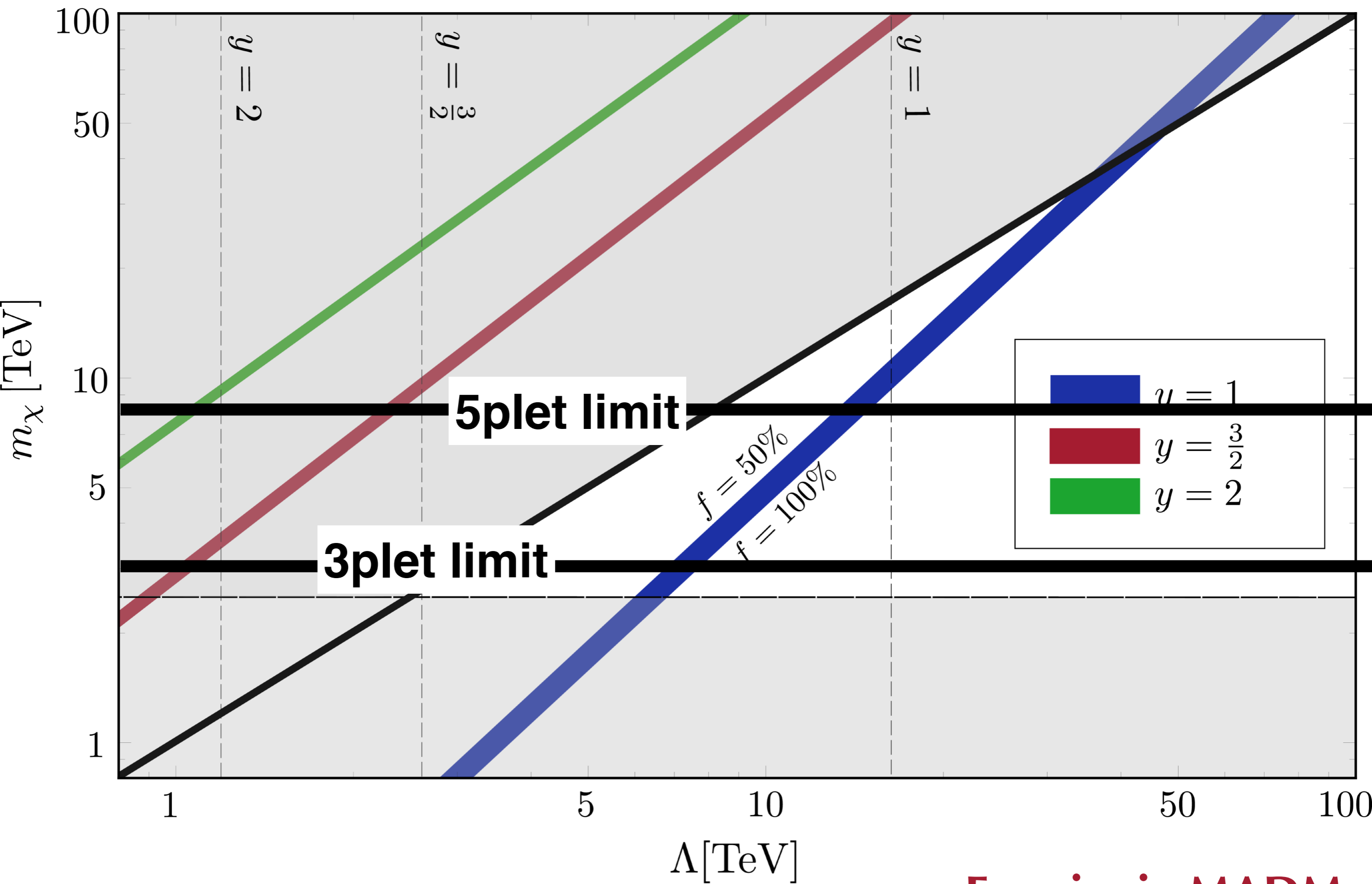




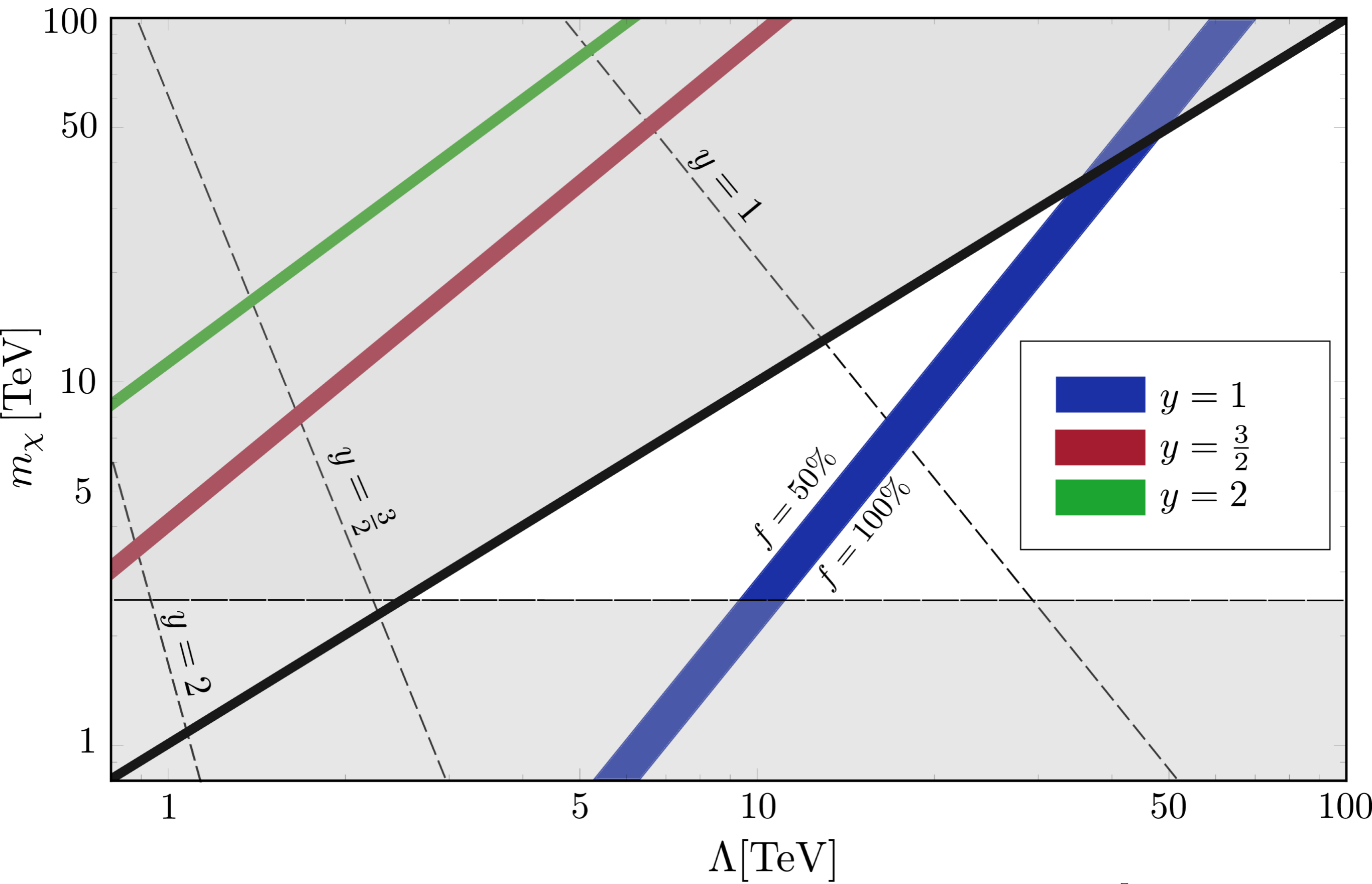
Fermionic MADM



Fermionic MADM



Fermionic MADM



Scalar MADM

Doublets are special


$$\lambda \chi \chi \phi \phi$$

**Direct
detection:**

$$\frac{M_\chi}{\lambda} \lesssim 8 \times 10^4 \text{ TeV}$$

**Asymmetry
Transfer:**

$$\frac{M_\chi}{\lambda} \gtrsim 4.1 \times 10^5 \left(\frac{T_a}{100 \text{ GeV}} \right)^{1/2} \text{ TeV}$$

(holds for any scalar multiplet with $y=1/2$)

Doublets are special ^{Out}



(Same conclusion reached for fermions with $y=1/2$)

Conclusions

MADM mixes **ADM** and **WIMP** physics to provide a phenomenologically rich framework connecting different BSM sectors

Only $y=1$ is allowed; preferentially $SU(2)_L$ 5plet

Outlook: MADM offers unique indirect detection signatures that have to be investigated

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Thanks!

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Outlook: MADM offers unique indirect detection signatures that have to be investigated

Thanks!

Backup

Multiplets structure

$$\begin{pmatrix} \vdots \\ \chi^+ \\ \chi^0 \end{pmatrix}$$

$$\begin{pmatrix} \vdots \\ \chi^0 \\ \chi^- \end{pmatrix}$$

.....

doublet, $y=1/2$

4plet, $y=1/2$

3plet, $y=1$

5plet, $y=1$

4plet, $y=3/2$

...

5plet, $y=2$

...

Step 1: asymmetrical birth

$$\Gamma \left(\begin{array}{c} \chi \\ \chi \end{array} \text{ (red) } \rightarrow \text{ (red) } \begin{array}{c} \phi \\ \vdots \\ \phi \end{array} ; \begin{array}{c} \chi \\ \phi^* \end{array} \text{ (blue) } \rightarrow \text{ (blue) } \begin{array}{c} \bar{\chi} \\ \vdots \\ \phi \end{array} \right) \sim H(T_a)$$

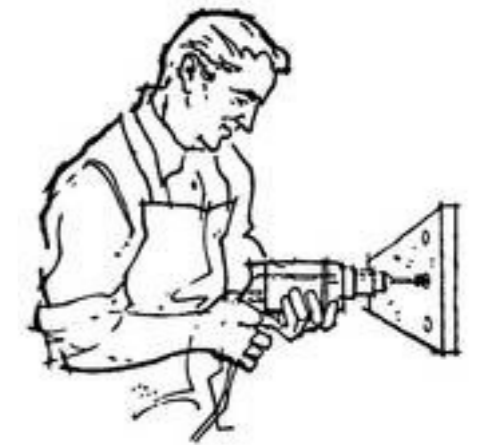


$$m_\chi^{-2} z_a^{-1} \left(\frac{M_\chi}{\Lambda} \right)^{8y+4(s-1)} \lesssim 6.1 \frac{y}{\eta_{PS}} \times 10^{-19} \text{ GeV}^{-2}$$

↑
MDM $\sim 7 \text{ Ta}$

ADM model building 101

- Pick up the symmetries of the model
- Realize/assume baryogenesis in one of the sectors, or both. In former cases, consider transfer mechanism
- Make sure that the symmetric parts will cancel away



* No particular order is assumed

The mass is 'predicted' from relation between densities.