Composite Dark Matter

Reuven Balkin
Technical University Munich

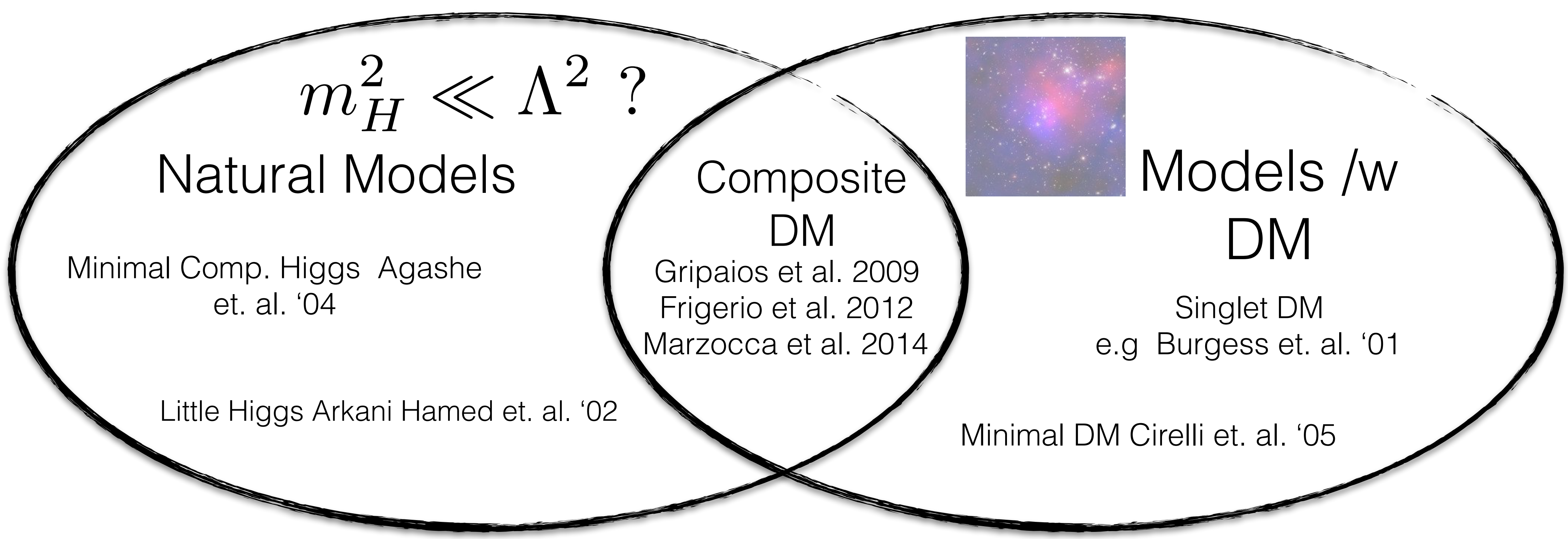
31st May, 2017
The 29th Rencontres de Blois on "Particle Physics and Cosmology"

Outline

- Motivation
- Composite Higgs framework
- Model
- DM Phenomenology
- Conclusions

Motivation

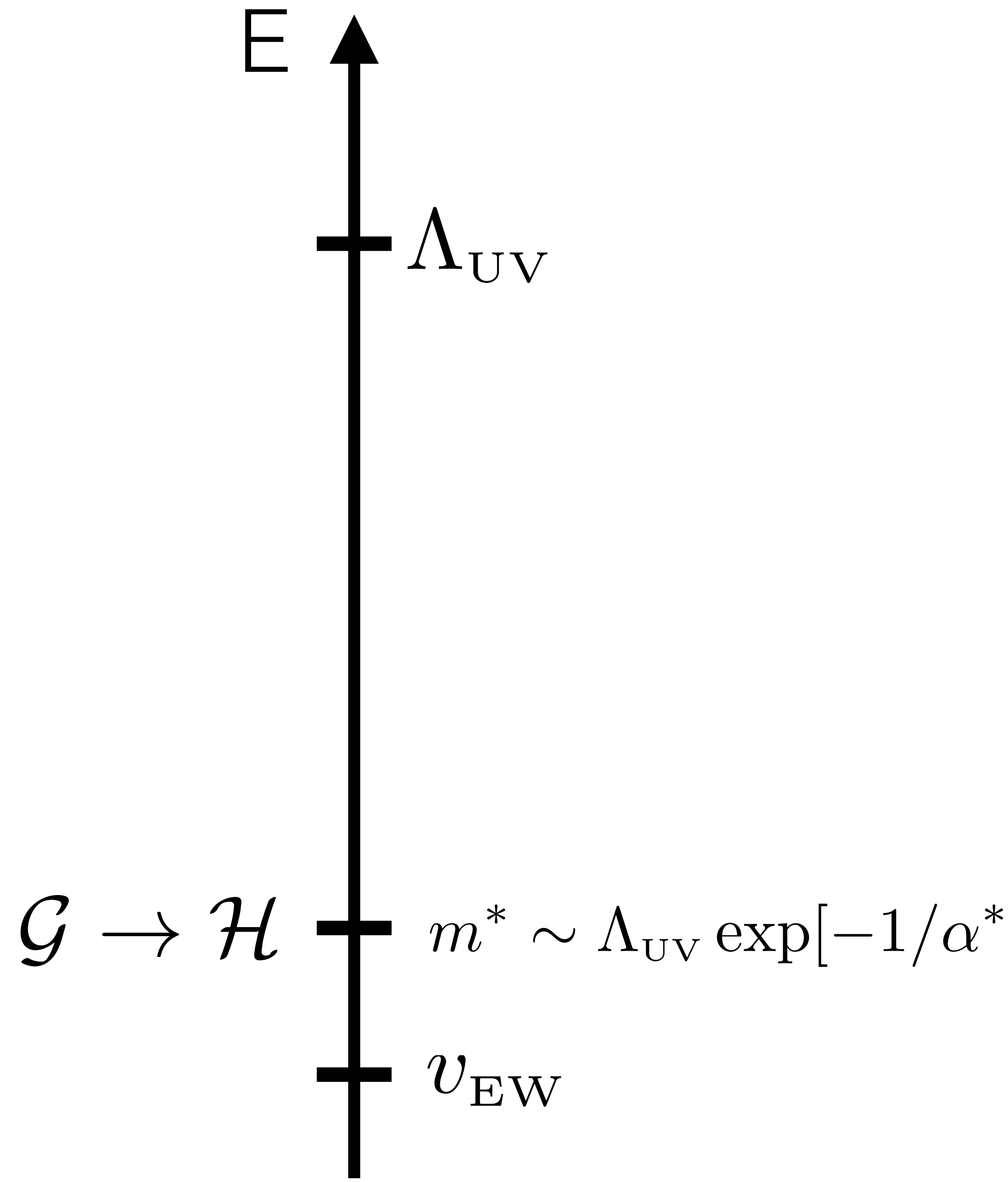
- Naturalness: no SUSY so far, maybe the Higgs is **composite**? Kaplan, Georgi ’84; Agashe, Contino, Pomarol ’04
- The Composite Higgs framework can accommodate naturally light scalar particles
- Can one of those naturally light scalars be the **Dark Matter?**



Composite Higgs Framework

- Large Scale separation due to Dimensional Transmutation
- Higgs appears as a **pNGB** of the spontaneously broken global symmetry

$$H_{\rm SM} \in \mathcal{G}/\mathcal{H}$$



$m^* \sim g^* f$

The Scalar Sector

- Scalar field breaks G to H

$$\langle \Sigma \rangle : \mathcal{G} \to \mathcal{H}$$

- The SM gauge group is a subgroup of H

$$\mathcal{G}_{\rm SM} \in \mathcal{H}$$

- Low energy DOF's ("pions") contain the SM Higgs and a singlet

$$\mathcal{G}/\mathcal{H} \to \underset{H_{\rm SM}}{(1,2)_{1/2}} \oplus \underset{s}{(1,1)_0} \oplus \ldots$$

- Stabilizing symmetry

$$s \to -s$$

Model

$$\mathcal{L} = \mathcal{L}_{nl\sigma} + \mathcal{L}_{\rm top} + \mathcal{L}_{\rm scalar}$$

Low Energy DOF's described by a non-linear sigma model

$$\Sigma = e^{\frac{i\Pi}{f}} \langle\Sigma\rangle + \text{radial modes}\,,\ \Pi \equiv \pi^a X^a$$

Model

$$\mathcal{L} = \mathcal{L}_{nl\sigma} + \mathcal{L}_{\rm top} + \mathcal{L}_{\rm scalar}$$

Coupling the NGB's to SM fermions and top partners to get top Yukawa - explicitly breaks the global symmetry

Model

$$\mathcal{L} = \mathcal{L}_{nl\sigma} + \mathcal{L}_{\text{top}} + \mathcal{L}_{\text{scalar}}$$

Scalar potential is generated **radiatively** by fermion loops due to **explicit** breaking

Non-linear Sigma Model

- The non-linear sigma model fixes the **derivative couplings** between the Higgs and the singlet

$$\Sigma = e^{\frac{i\Pi}{f}} \langle \Sigma \rangle + \text{radial modes}\,, \quad \Pi \equiv \pi^a X^a$$

$$\mathcal{L}_{nl\sigma} = \frac{f^2}{N} \text{Tr}\left[(\partial_\mu \Sigma)(\partial^\mu \Sigma^\dagger) \right]$$

$$\mathcal{L}_{nl\sigma} \ni \frac{1}{f^2} \left[a_1 (\partial^\mu s)(\partial_\mu s)|H|^2 + a_2 s (\partial^\mu s) \partial_\mu (H^\dagger H) + a_3 s^2 (\partial^\mu H^\dagger)(\partial_\mu H) \right]$$

Top sector

- Various implementations of top sector - e.g partial compositeness
- Symmetries are added to protect the Higgs mass
- Generically the top sector includes a **contact term** between singlets and tops

$$\mathcal{L}_{\rm top} \ni \overline{Q}_L H t_R \left(y_t + \frac{c_{s^2\bar{t}t}}{f^2} s^2 + \ldots \right)$$

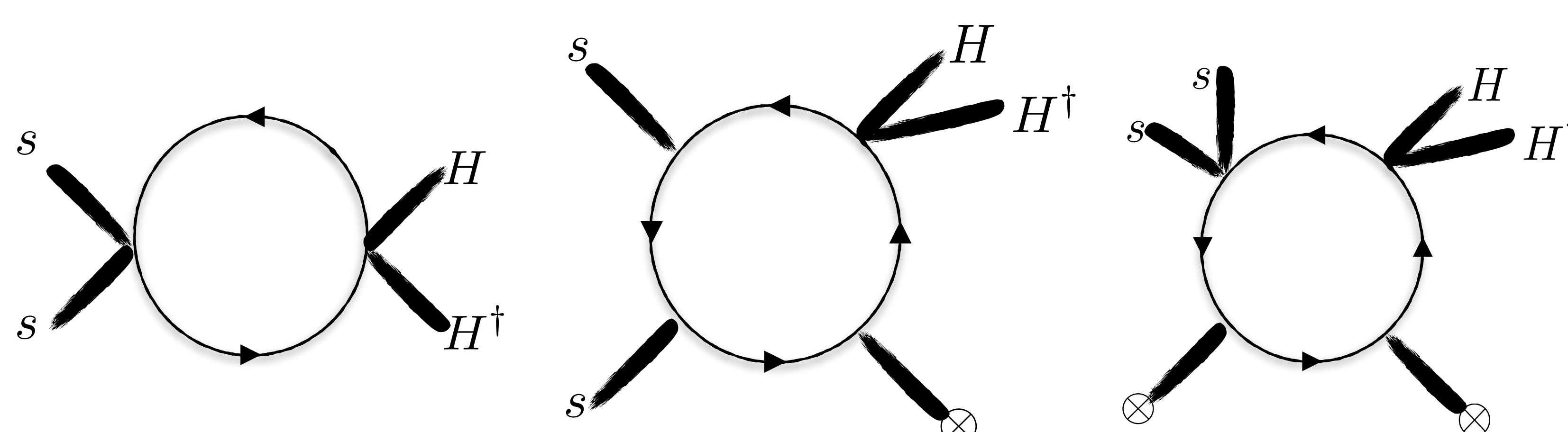
$$\mathcal{L}_{\rm top} \ni \frac{c_{s^2\bar{t}t}}{f} \sqrt{\xi}\; s^2 \bar{t}t$$

$$\sqrt{\xi} \equiv \frac{v}{f} \sim \frac{1}{3} - \frac{1}{6}$$

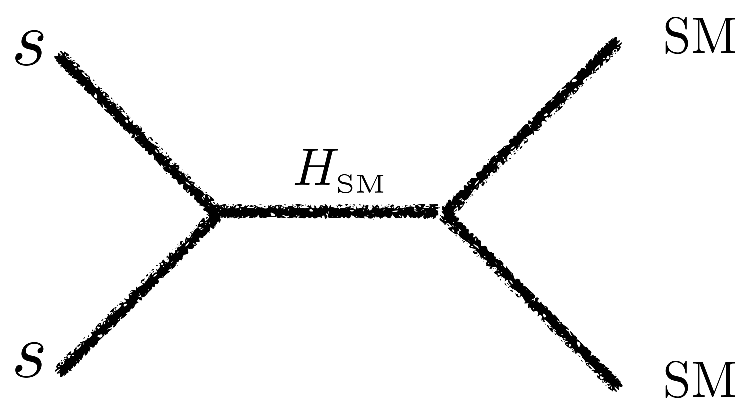
Scalar Potential

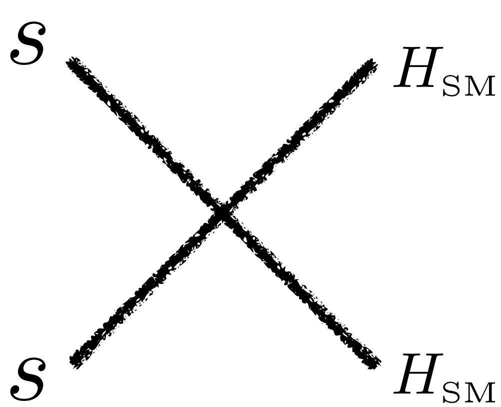
- Scalar potential generated radiatively due to explicit symmetry breaking, including the **Higgs portal** coupling
- Calculability of couplings depends on implementation of top sector

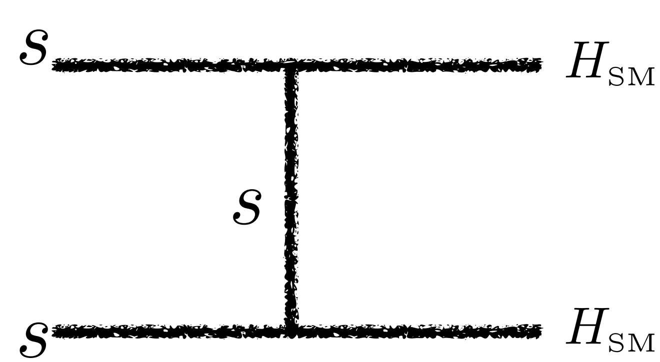
$$-\mathcal{L}_{\rm scalar} = -\mu^2|H|^2 + \lambda|H|^4 + \frac{1}{2}\tilde{m}_s^2 s^2 + \lambda_{\rm DM} s^2 H^\dagger H + \ldots$$

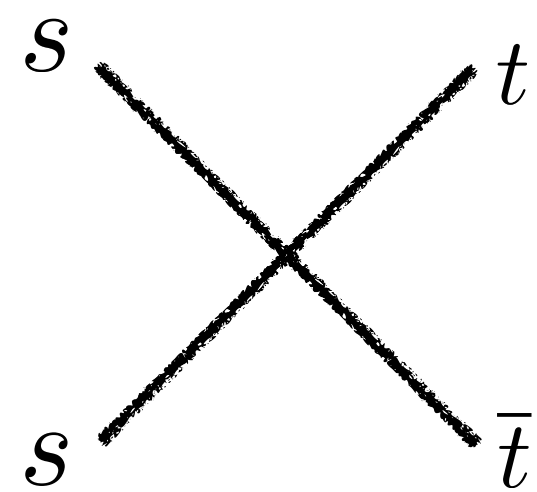


Annihilation Channels









$$\lambda_{\rm DM} s^2 H^\dagger H$$

$$\frac{1}{f^2} s(\partial_\mu s)\partial^\mu (H^\dagger H) + ..$$

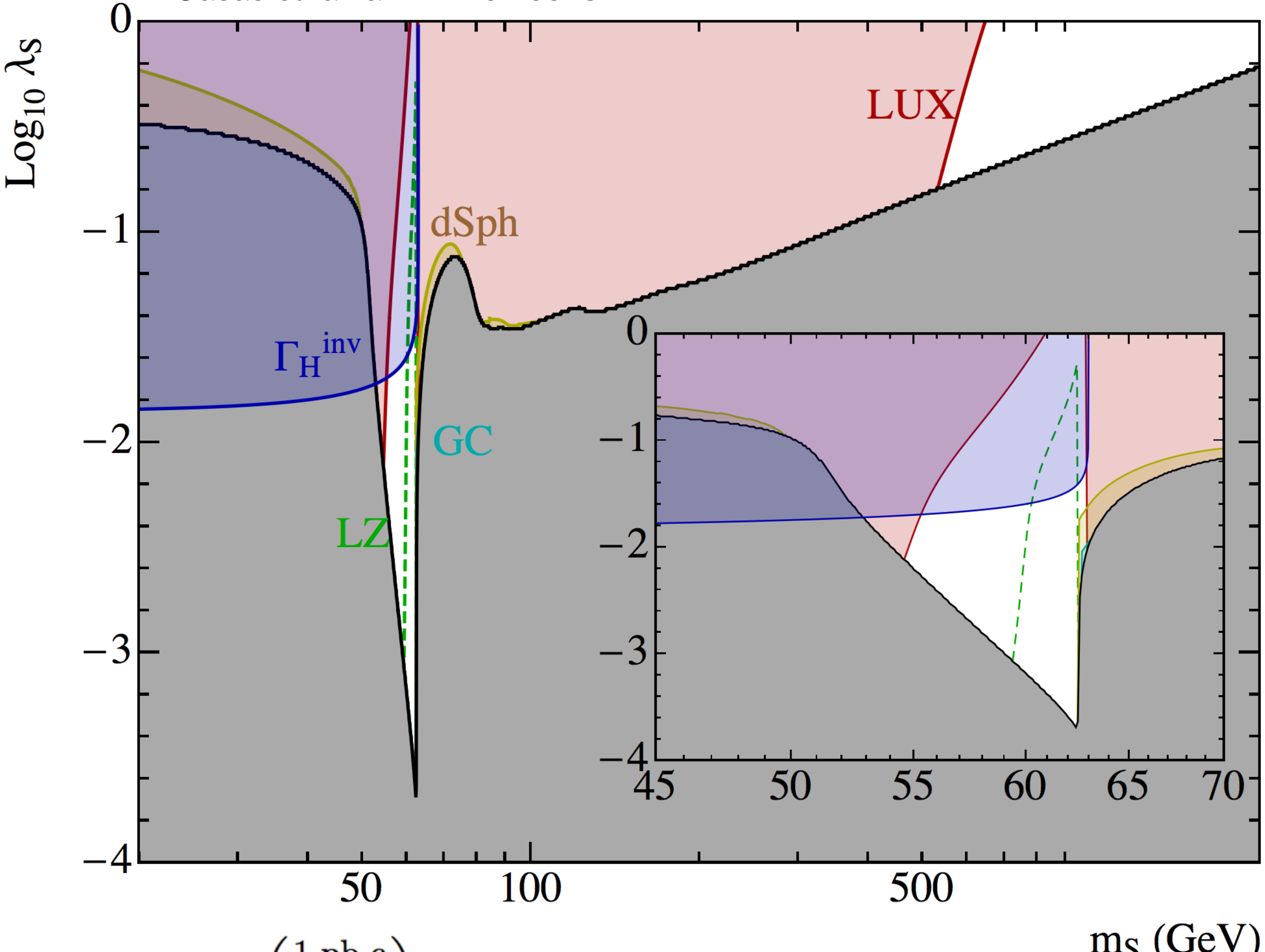
$$\frac{c_{s^2\bar{t}t}}{f} s^2 \bar{t}t$$

$$\dot{n}_s + 3Hn_s = -\langle \sigma v \rangle \left(n_s^2 - (n_s^{\rm EQ})^2\right)$$

$$\Omega_s h^2 \approx 0.12 \left(\frac{3 \times 10^{-26}\ {\rm cm}^3\ {\rm s}^{-1}}{\langle \sigma v \rangle} \right)$$

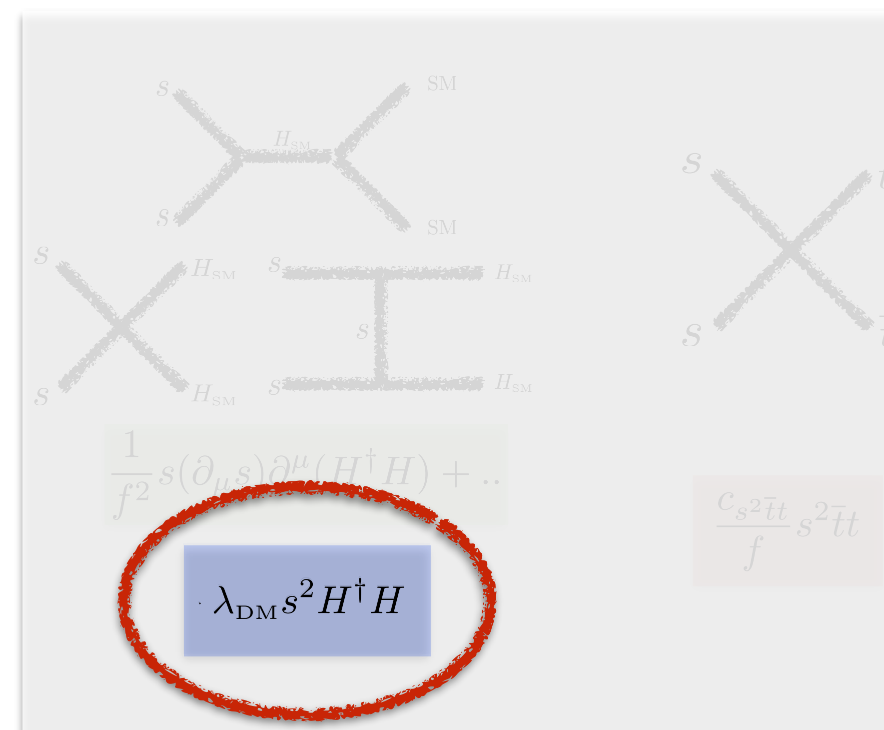
“Elementary” Singlet DM

Casas et. al. arXiv:1701.08134



$$m_s \lll f$$

$$m_s^2 = \tilde{m}_s^2 + \lambda v^2$$



$$\Omega_s h^2 \approx 0.12 \left(\frac{1 \text{ pb c}}{\langle \sigma v \rangle} \right)$$

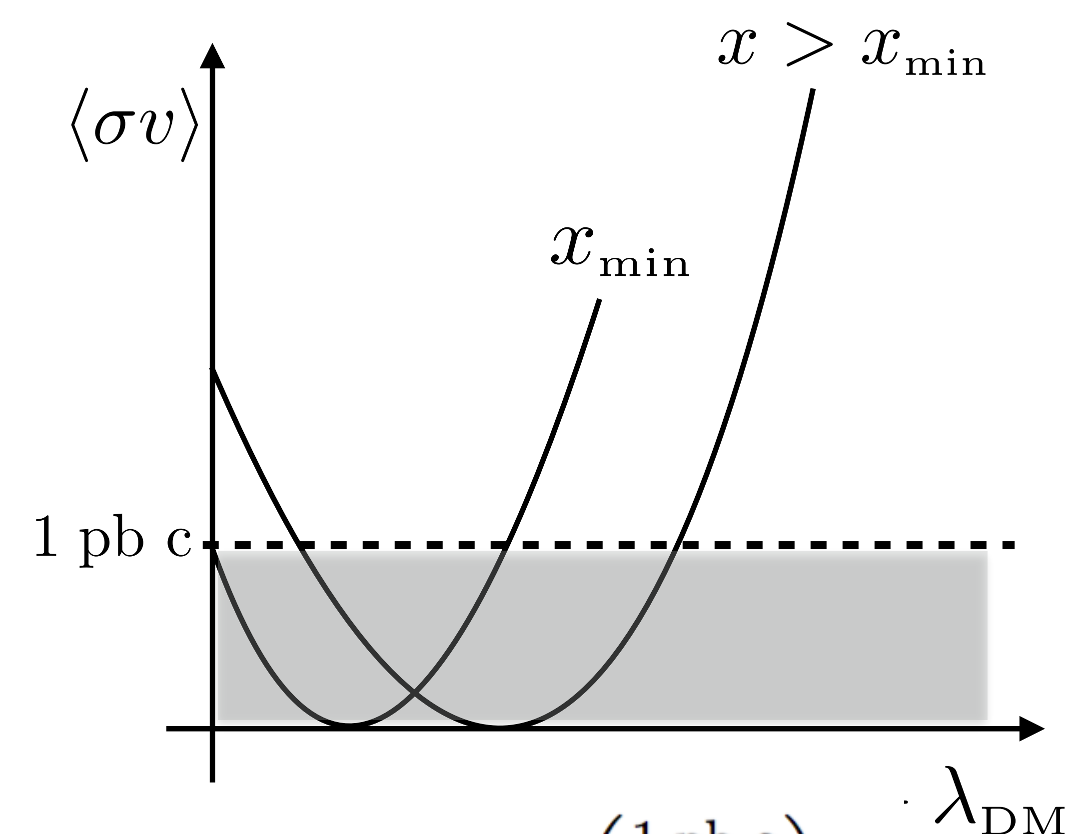
Composite DM Phenomenology I

$$m_s \sim \sqrt{\lambda_{\rm DM}} f \quad \text{and} \quad m_s < m_t$$

$$x \equiv \frac{m_s}{f}$$

$$\langle \sigma v \rangle = \sigma_0(x)\left(\lambda_{\rm DM} - f_1(x)\right)^2$$

$$\lambda_{{\rm DM}\pm} \approx \pm\sqrt{\frac{1 \text{ pb c}}{\sigma_0(x)}} + f_1(x)$$



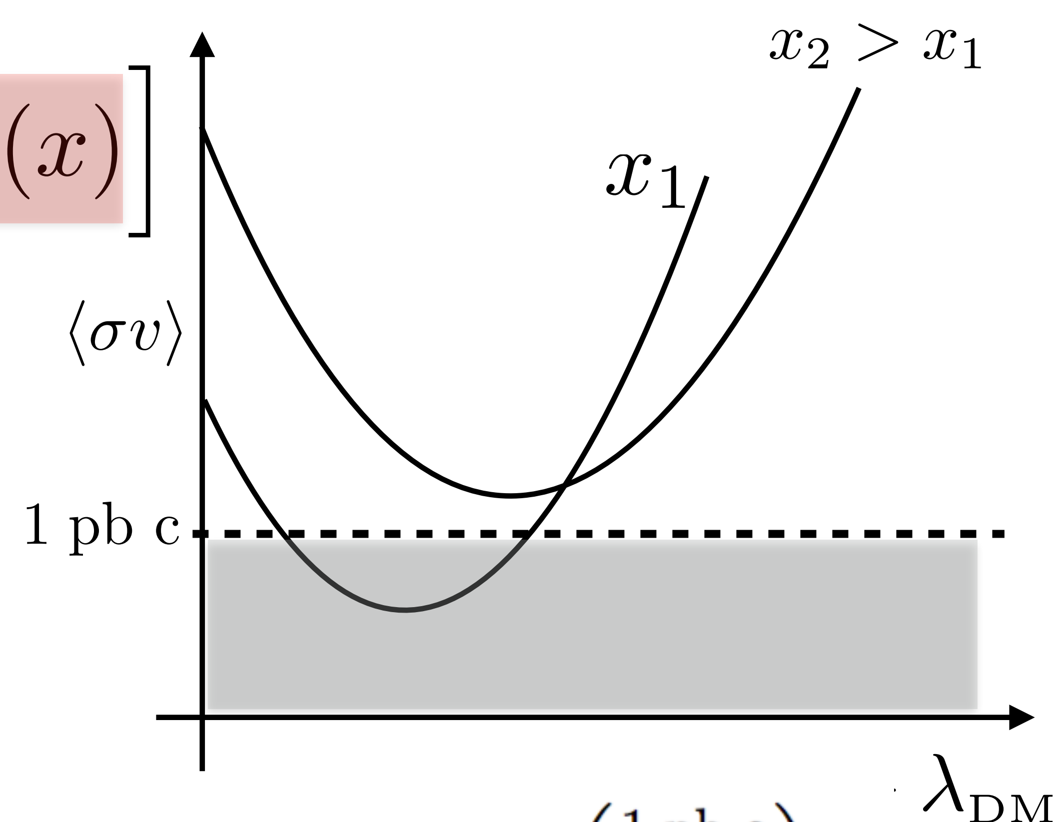
$$\Omega_s h^2 \approx 0.12\left(\frac{1 \text{ pb c}}{\langle \sigma v \rangle}\right)$$

Composite DM Phenomenology II

$$m_s \sim \sqrt{\lambda_{\rm DM}} f \quad \text{and} \quad m_s > m_t$$

$$\langle \sigma v \rangle = \sigma_0(x) \left[\left(\lambda_{\rm DM} - f_1(x) \right)^2 + f_2(x) \right]$$

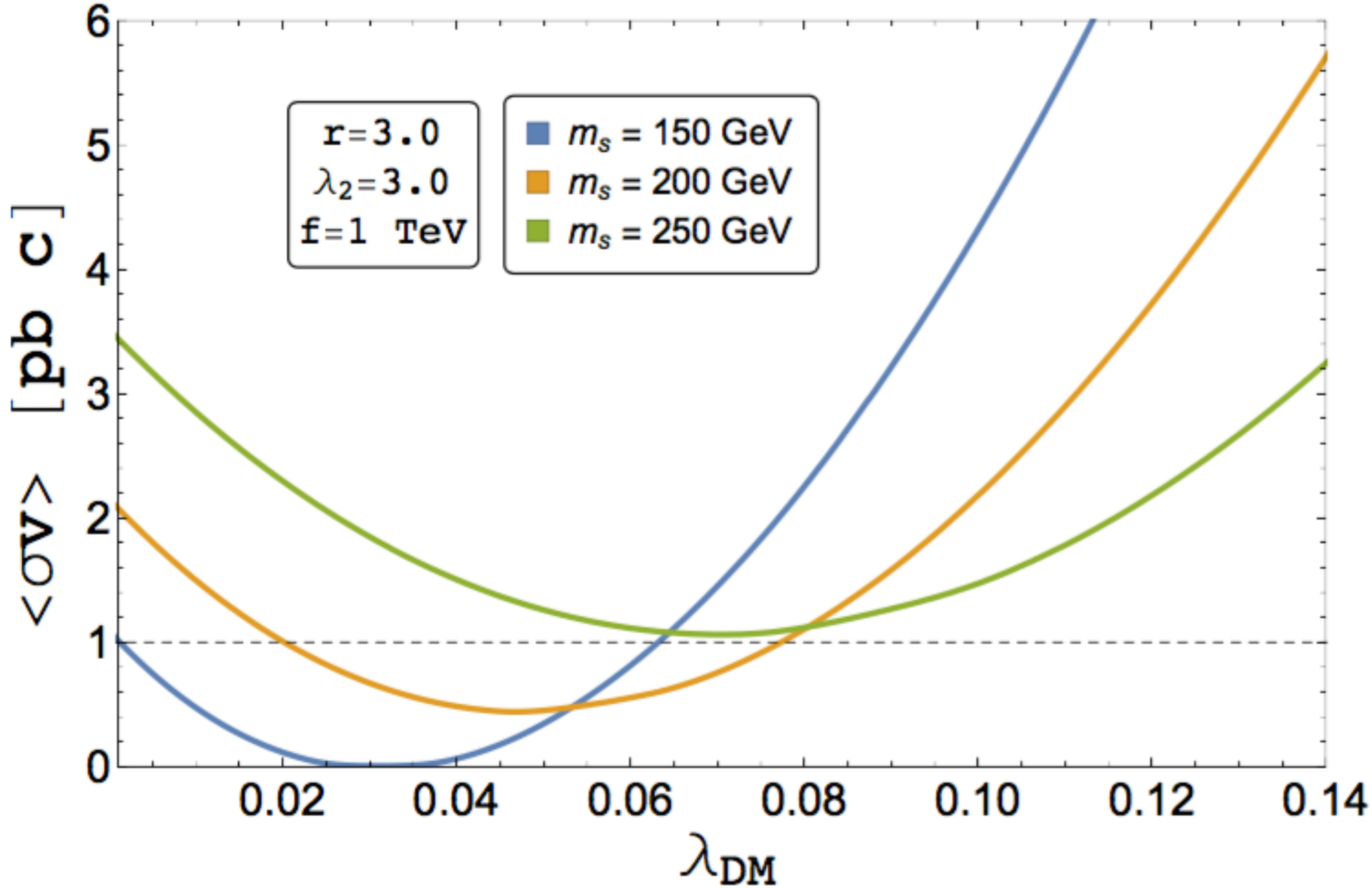
$$\lambda_{\rm DM\pm} \approx \pm \sqrt{\frac{1 \text{ pb c}}{\sigma_0(x)} - f_2(x)} + f_1(x)$$



$$\Omega_s h^2 \approx 0.12 \left(\frac{1 \text{ pb c}}{\langle \sigma v \rangle} \right)$$

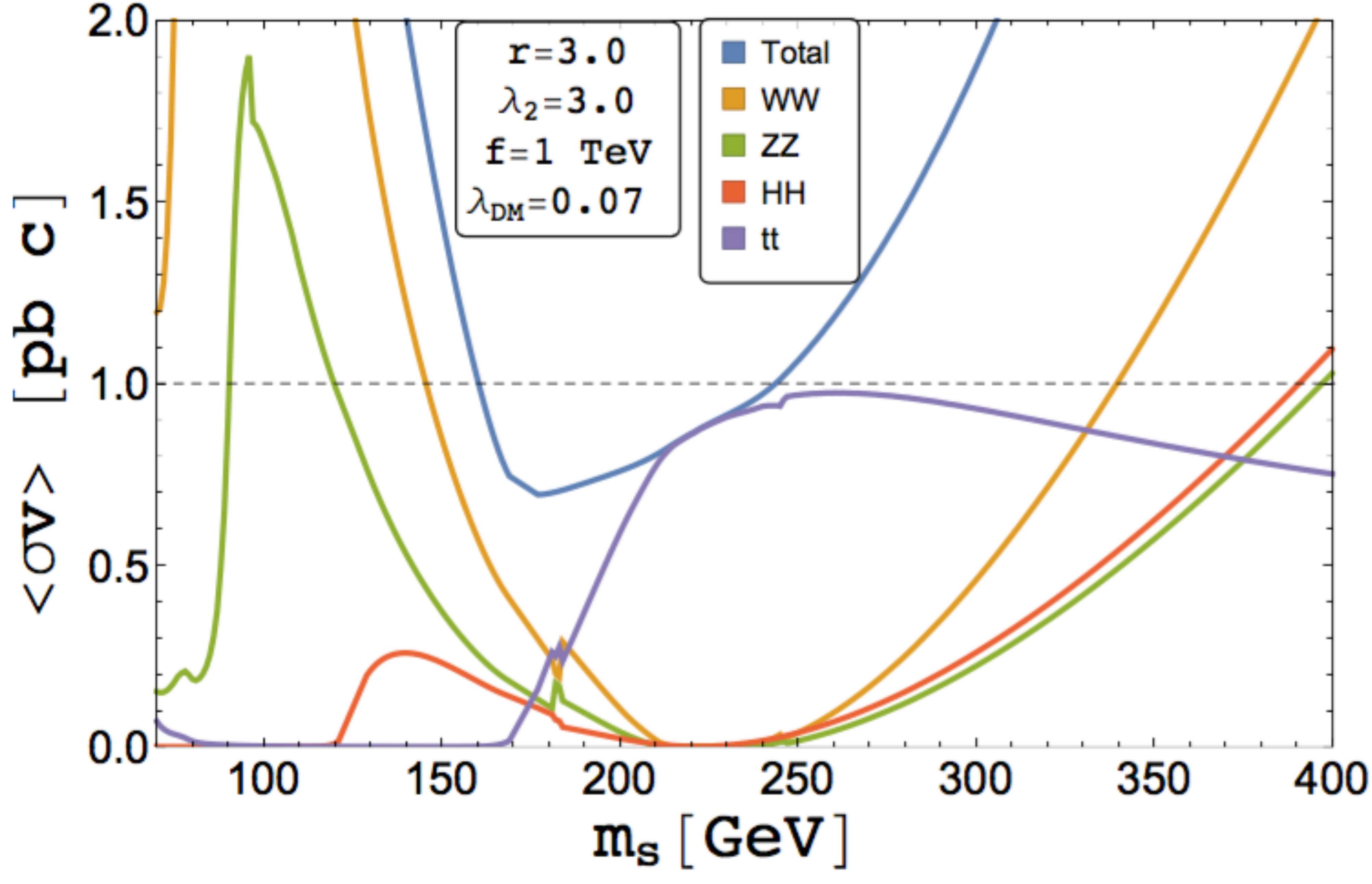
Annihilation Cross Sections

RB, Perez, Weiler 1706.XXXX



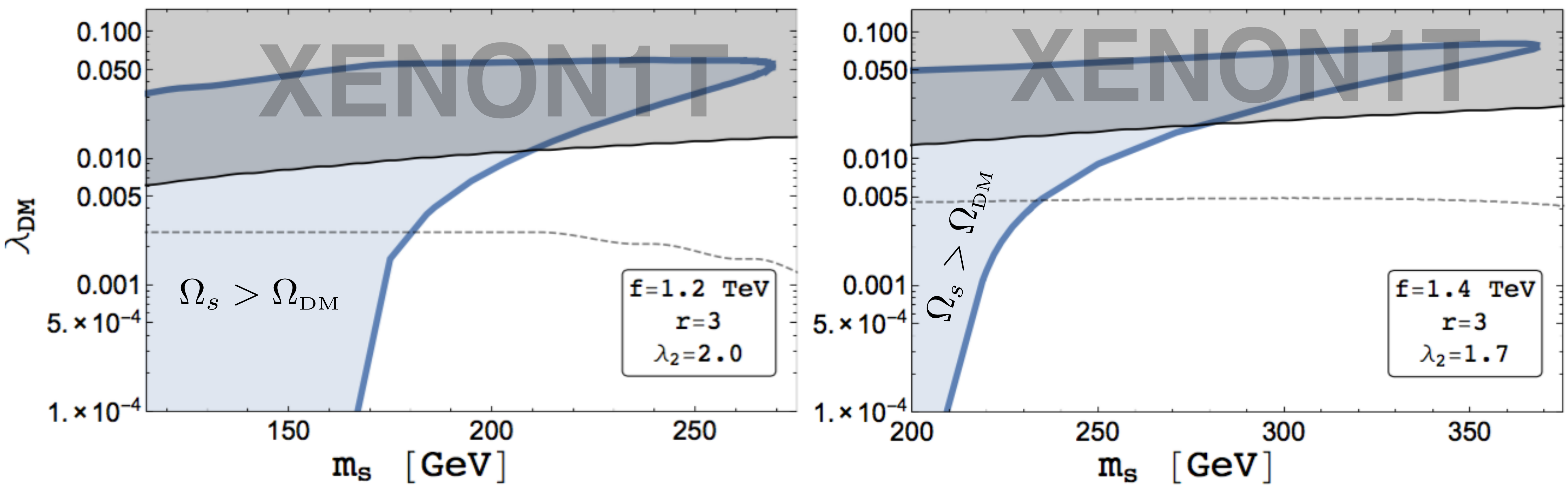
Annihilation Channels

RB, Perez, Weiler 1706.XXXX



Relic Abundance

RB, Perez, Weiler 1706.XXXX



XENON1T : arXiv:1705.06655

Conclusions and Outlook

- Composite singlet DM with EW mass evades current direct detection with percent-level portal coupling
- Small portal coupling requires some tuning, possible to do in realistic models
- Other interesting aspects that I did not discuss : collider pheno. , model building and symmetries, stabilizing symmetries
- Charged scalar DM RB, Ruhdorfer, Salvioni, Weiler 1706.XXXX

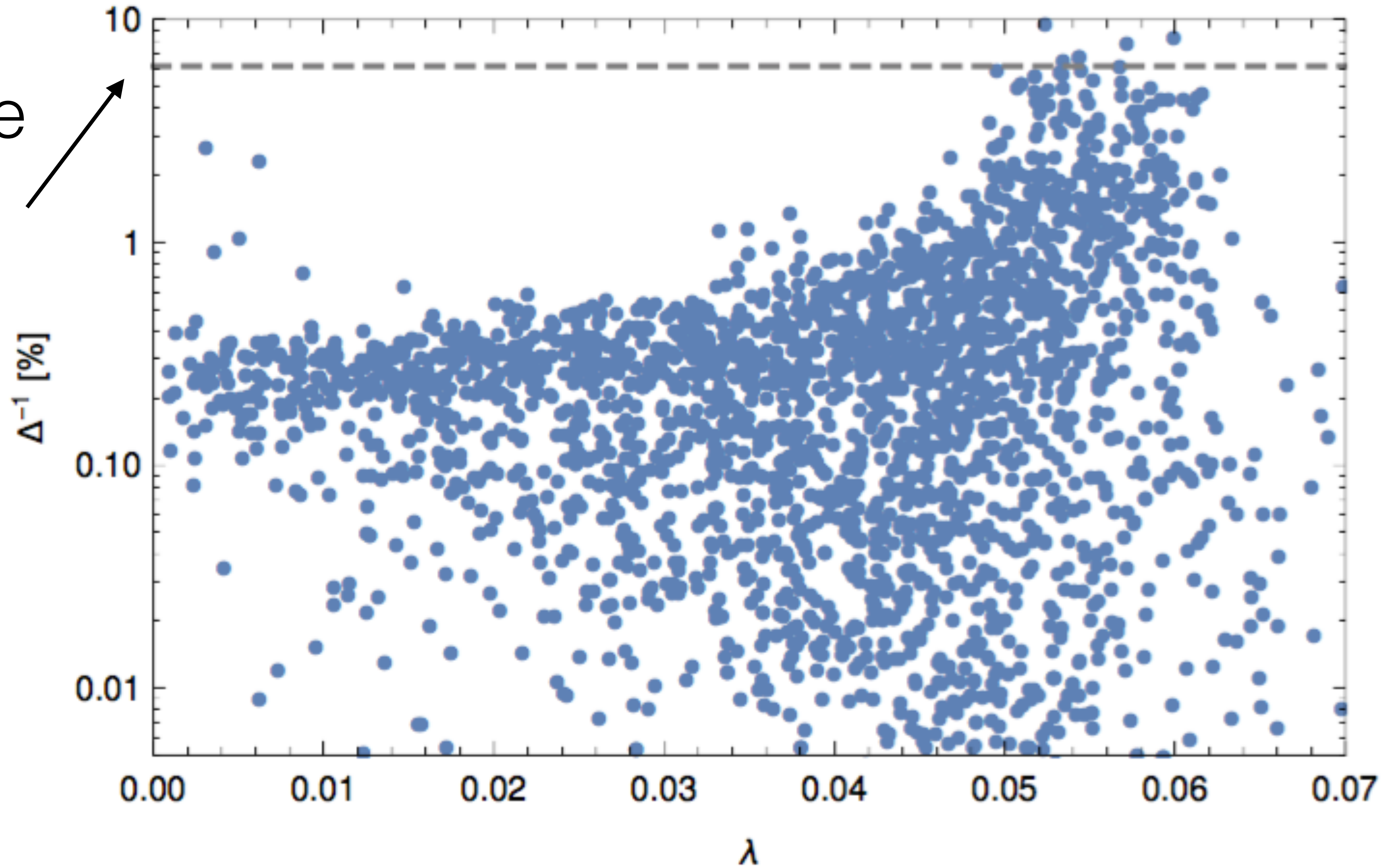
Thank you.

Backup

Fine Tuning

Usual estimate

$\Delta^{-1} \sim \xi \sim 5\%$

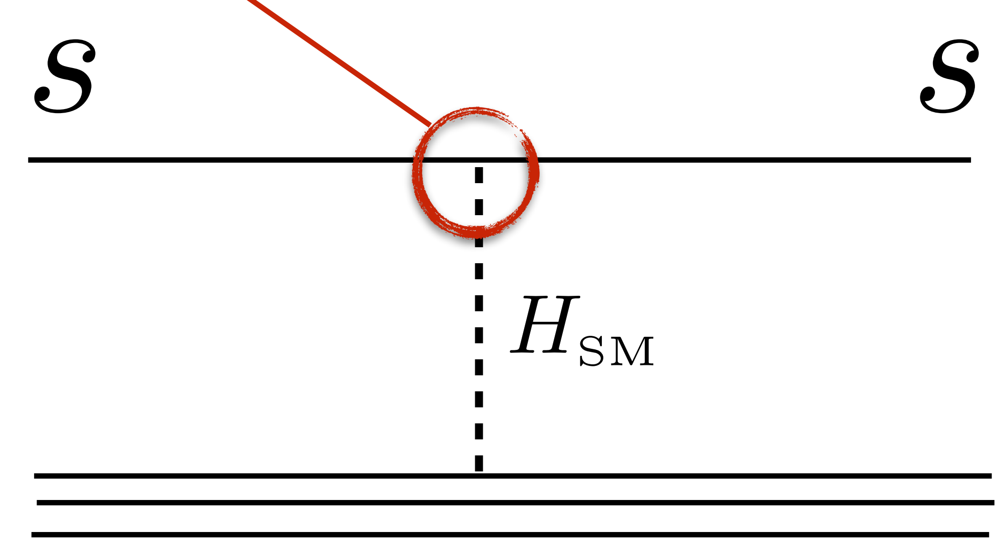


RB, Ruhdorfer, Salvioni, Weiler 1706.XXXX

Direct Detection

$$iv\left(2a_1\frac{m_s^2}{f^2} - \lambda_{\rm DM} - (a_2 - a_1)\frac{q^2}{f^2}\right)$$

$$E_{\rm recoil} \ll f$$



$$\lambda_{\rm DM} s^2 H^\dagger H$$

$$\mathcal{L}_{nl\sigma} \ni \frac{1}{f^2}\left[a_1(\partial^\mu s)(\partial_\mu s)|H|^2 + a_2 s(\partial^\mu s)\partial_\mu(H^\dagger H) + a_3 s^2(\partial^\mu H^\dagger)(\partial_\mu H)\right]$$