Dark matter from an effective couplings approach

I. Ernesto Chávez M. | J. Halim Montes de Oca Y.
Estela Garces | Ricardo Gaitán
CIT - FES Cuautitlán - UNAM

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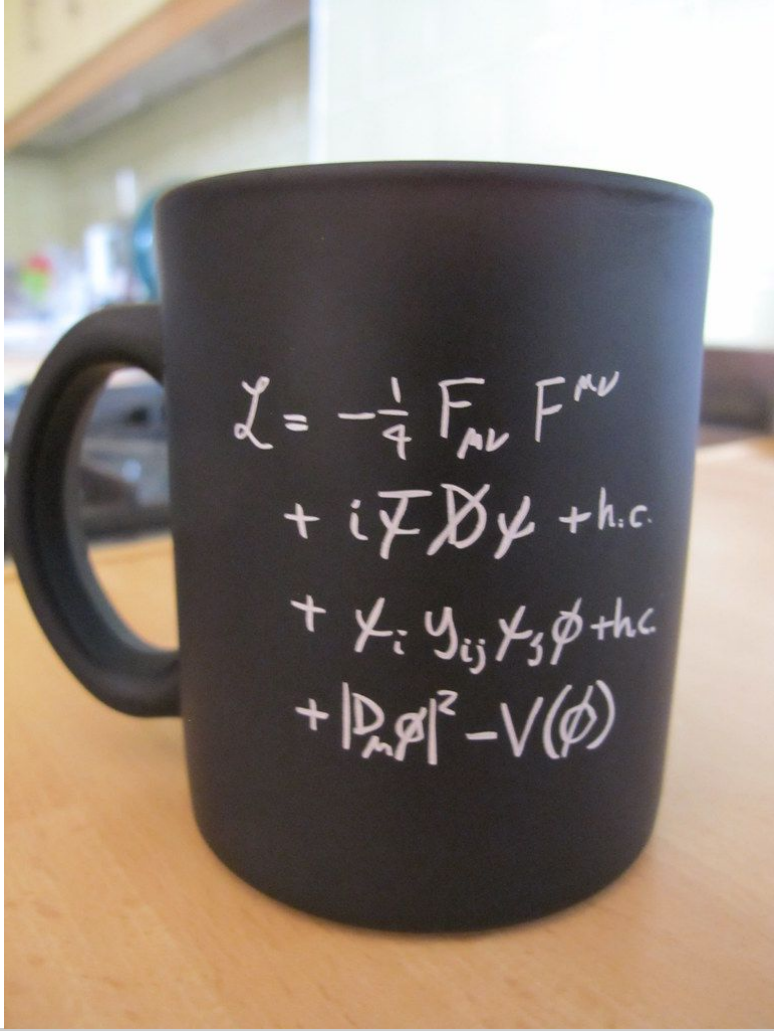
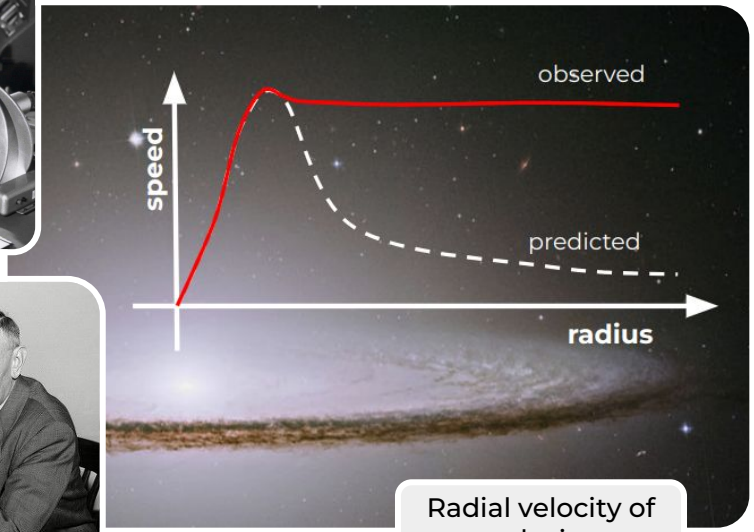
Outline

- Dark matter evidence
- What does the SM say ?
- Computer tools
- DM candidates
  - Scalar
    - H coupling
    - Z coupling
    - H, Z coupling
  - Fermion
    - H coupling
- Summary

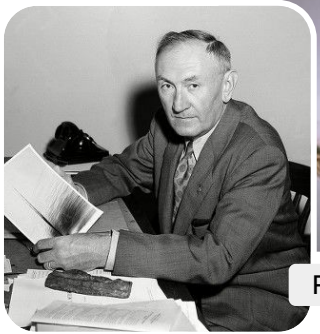


Dark matter evidence

Vera Rubin

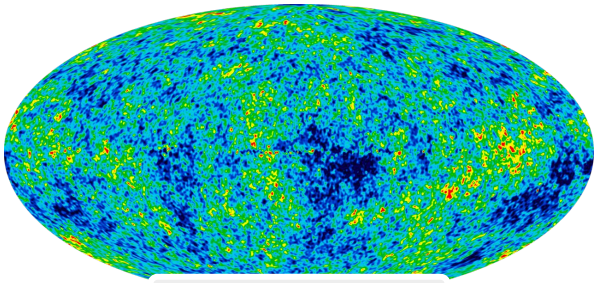


Radial velocity of galaxies



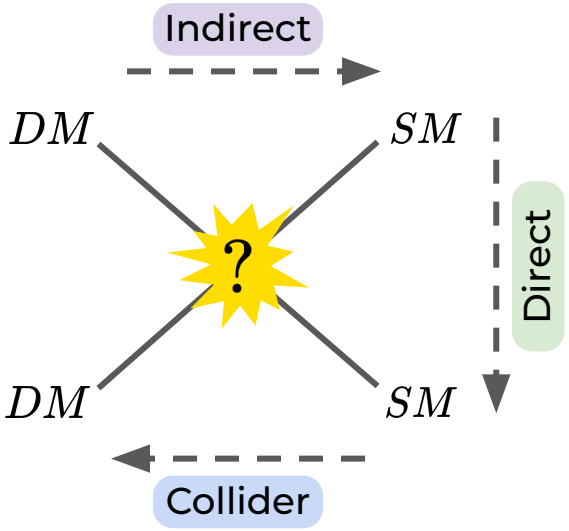
Fritz Zwicky

Gravitational lensing



CMB anisotropies

Possible detection



some experiments...

planck

CMS

ATLAS EXPERIMENT

LUX

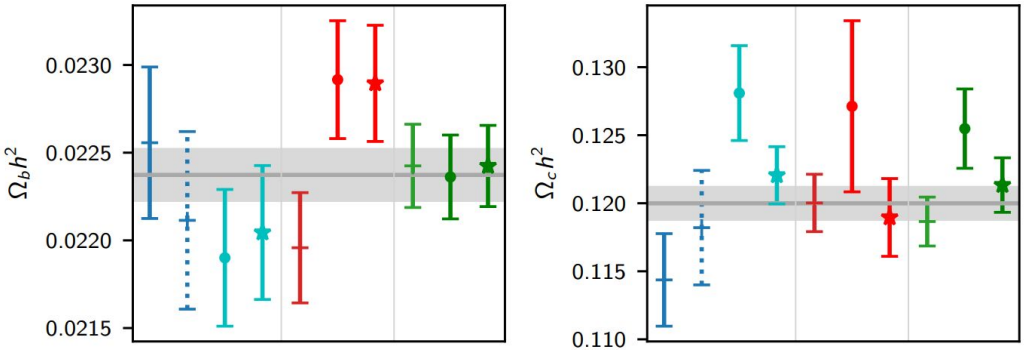
XENON

Boveia, A., Doglioni, C. (2018). Dark Matter Searches at Colliders. Annual Review of Nuclear and Particle Science, 68(1), 429–459.

Workman, R. L. (2022). Particle Data Group. Prog. Theor. Exp. Phys, 2022, 083C – 84.

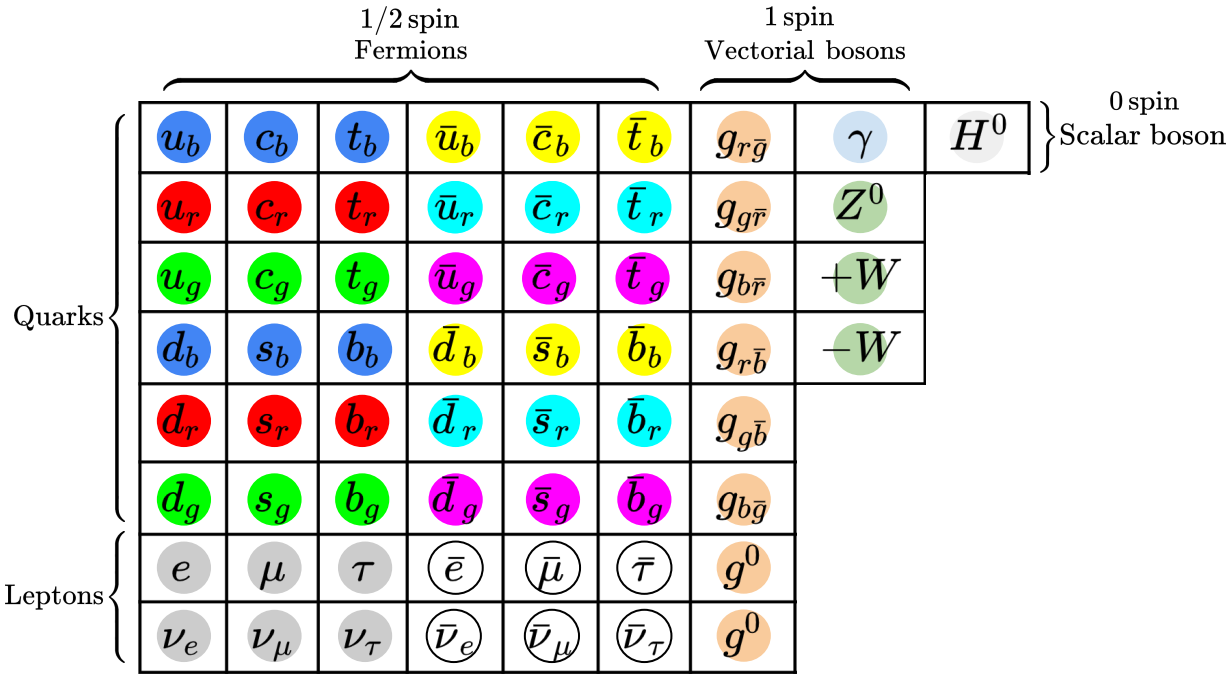
Indirect detection

$$\Lambda\text{CDM}\begin{cases} \Omega_{\text{DM}}h^2 = 0.120 \pm 0.001 & \longleftarrow \text{Dark matter Relic density} \\ \Omega_{\text{B}}h^2 = 0.0224 \pm 0.0001 & \longleftarrow \text{Baryonic Relic density} \\ \Rightarrow \Omega_{\text{DM}}h^2 \sim 5.3571\ \Omega_{\text{B}}h^2 \end{cases}$$



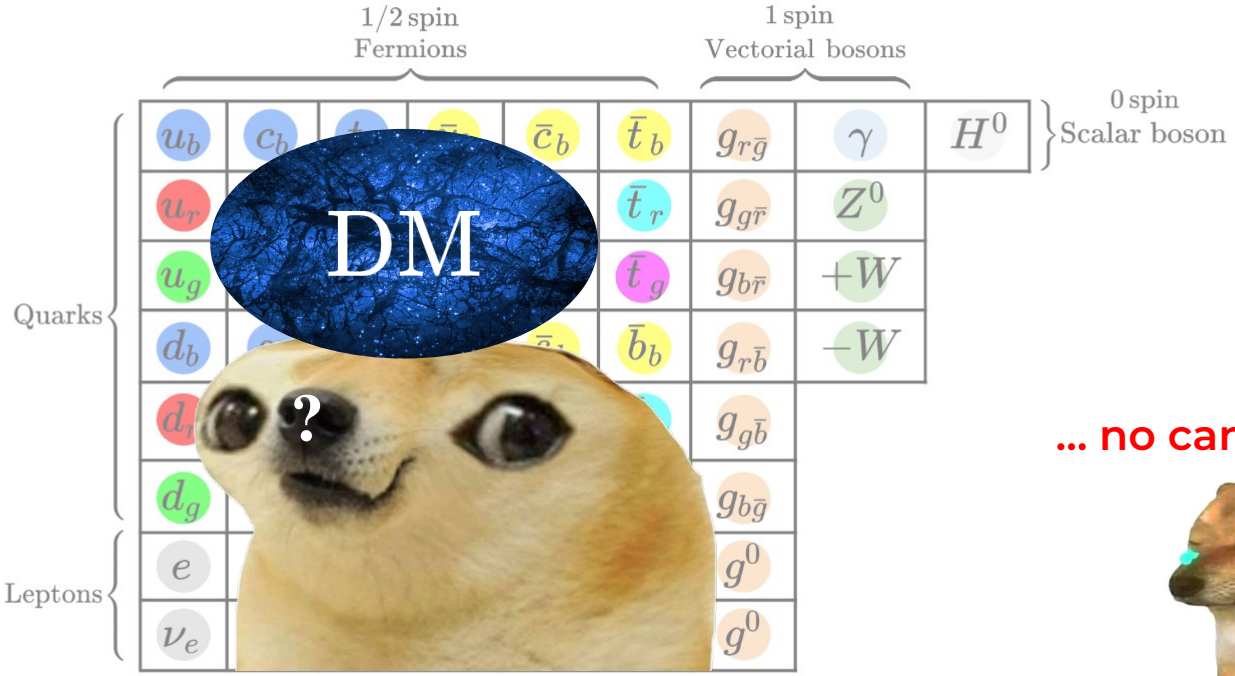
Planck Collaboration, Aghanim, N. et al. (2018). Planck 2018 results. VI. Cosmological parameters. **arXiv: 1807.06209**

What does the Standard Model say ?



$$\mathcal{L}_{\text{SM}} = \mathcal{L}_{\text{Gauge}} + \mathcal{L}_{\text{Fermions}} + \mathcal{L}_{\text{Scalar}} + \mathcal{L}_{\text{Yukawa}}$$

What does the Standard Model say ?



... no candidates

$$\mathcal{L}_{\mathrm{SM}} = \mathcal{L}_{\mathrm{Gauge}} + \mathcal{L}_{\mathrm{Fermions}} + \mathcal{L}_{\mathrm{Scalar}} + \mathcal{L}_{\mathrm{Yukawa}} + \ldots ?$$

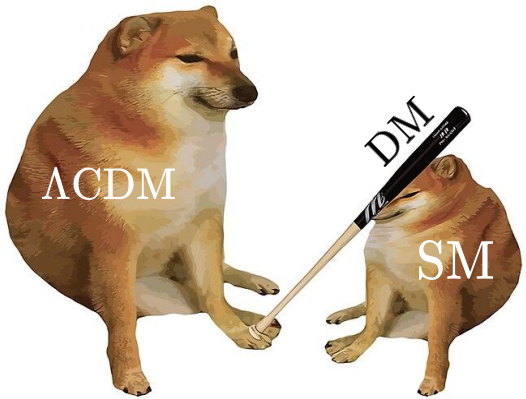
... constrictions of potential candidates

No SM interactions

- Electrically neutral
- Non baryonic
- Not very interactive

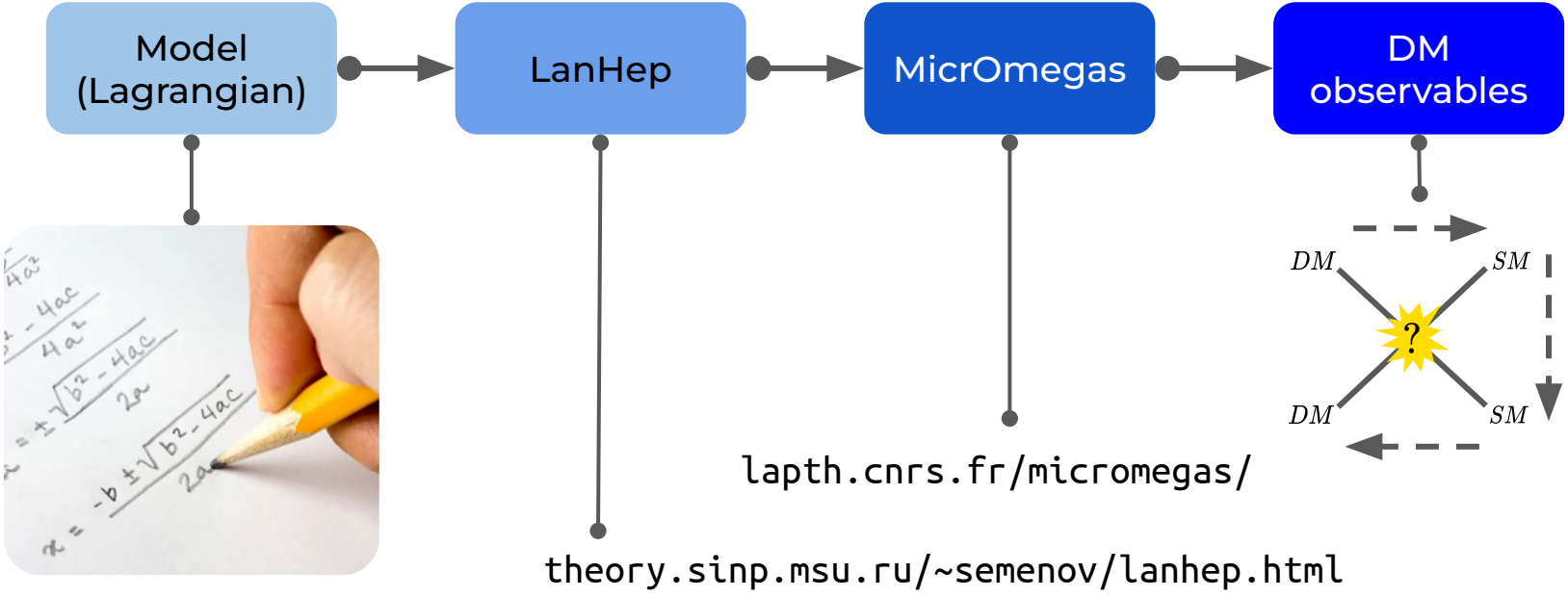
Large Scale Structure

- Massive
- Stable or very long lived
- Non relativistic



Taoso, M., Bertone, G., & Masiero, A. (2007). Dark Matter candidates: A ten-point test. **arXiv: 0711.4996**

Computer tools



Feynman rules generator using the lagrangian formalism

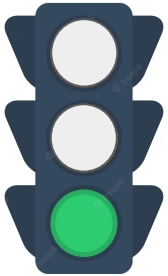
Used to calculate Dark matter properties including the Relic Density

LanHep

$$Z, \chi_{\,mass-\text{in}} = Z, \chi_{\,mass-\text{out}}$$

MicrOmegas

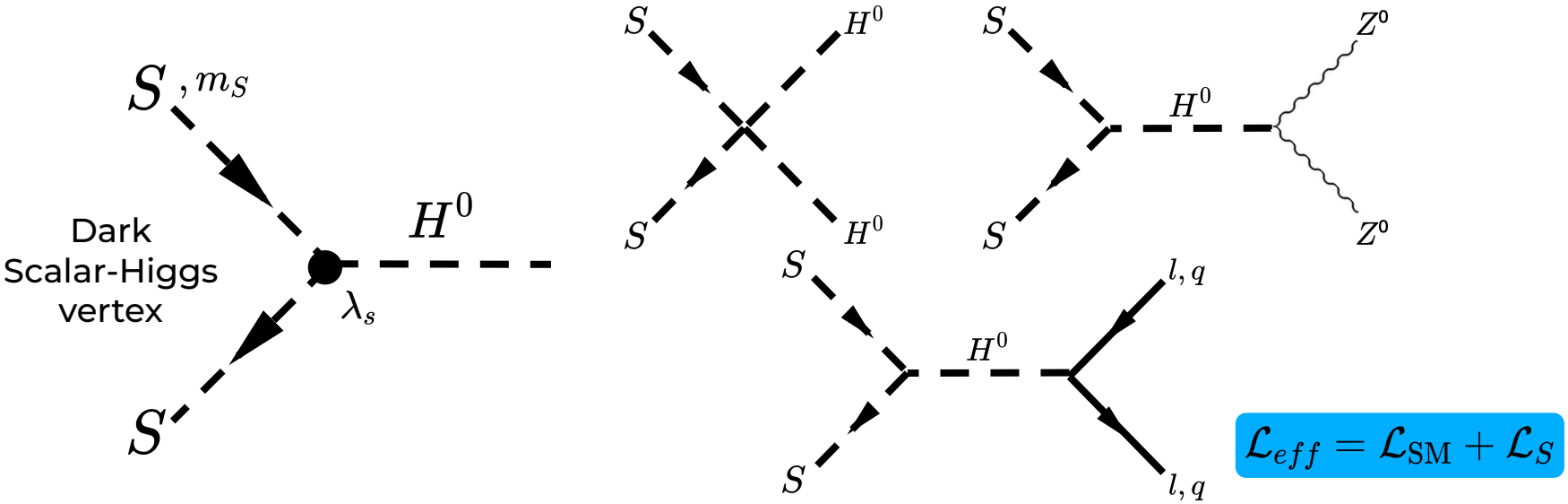
- leaves the SM unchanged
- reproduces masses successfully



Using a program to calculate candidates that reproduce Relic Density

Scalar DM candidate $\rightarrow S$

(Higgs coupling)



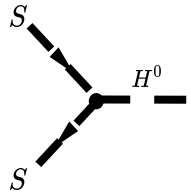
$$\mathcal{L}_{eff} = \mathcal{L}_{\mathrm{SM}} + \mathcal{L}_S$$

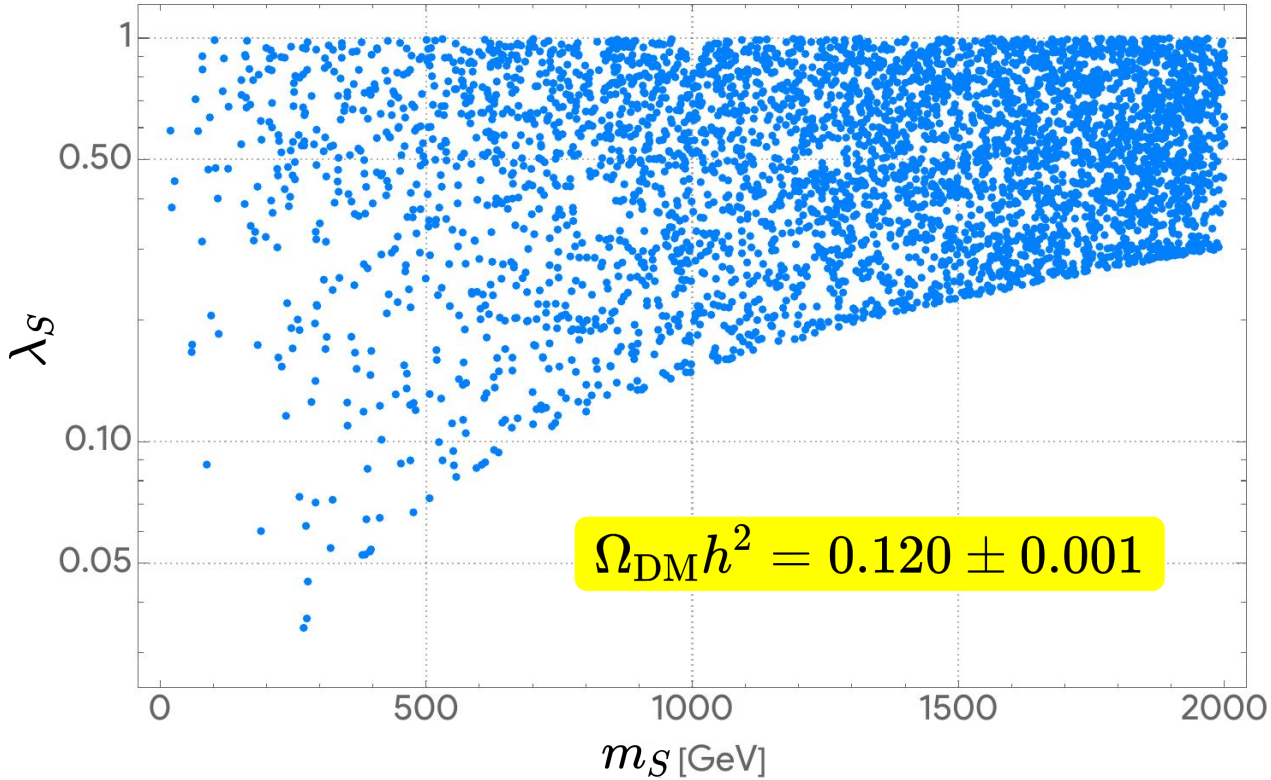
$$\mathcal{L}_{S,H} = D_\mu S^* D^\mu S - \tfrac{1}{2} m_S^2 S^* S - \lambda_s S^* S v^2 - \lambda_s S^* S \left(H + \frac{v}{\sqrt{2}} \right)^2$$

McDonald, J. (2007). Gauge singlet scalars as cold dark matter. **arXiv: 0702143**

Candidates constrain to $\Omega_{DM}h^2$

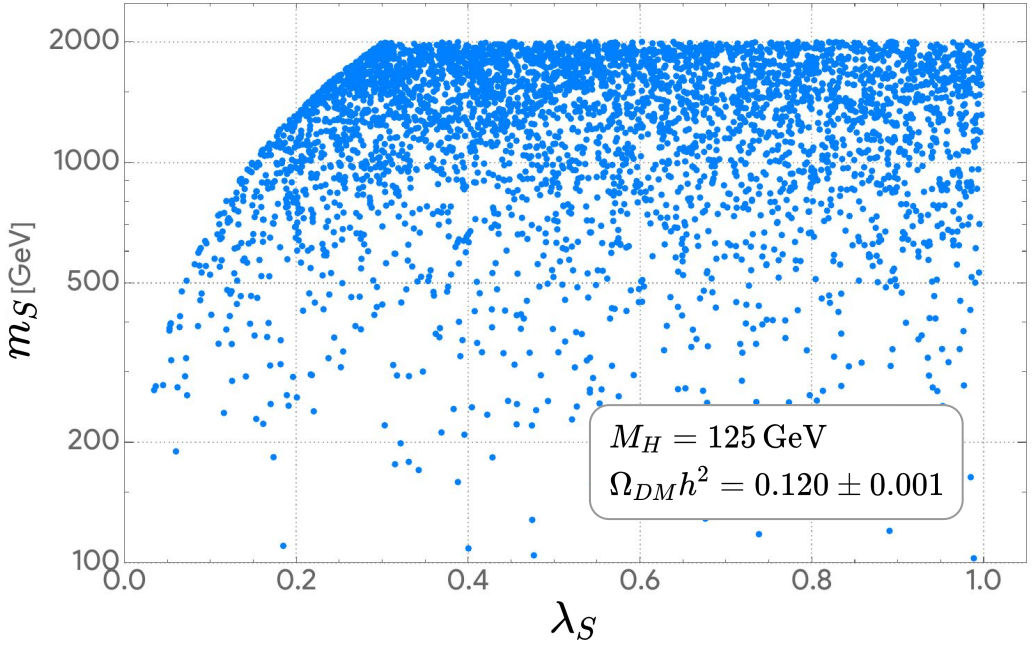
(Higgs coupling)

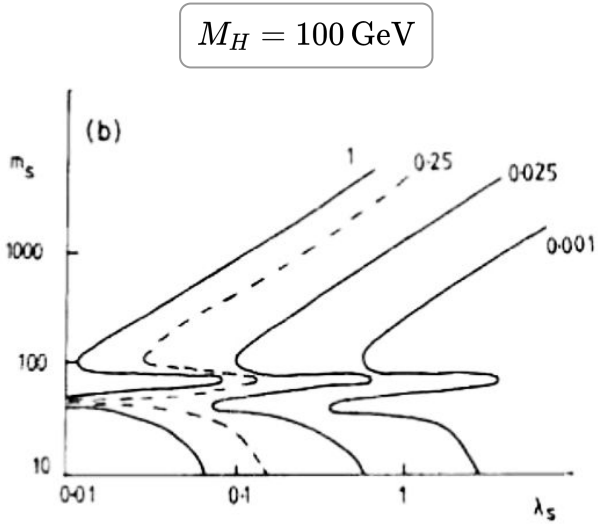




Compare with McDonald results

(Higgs coupling)

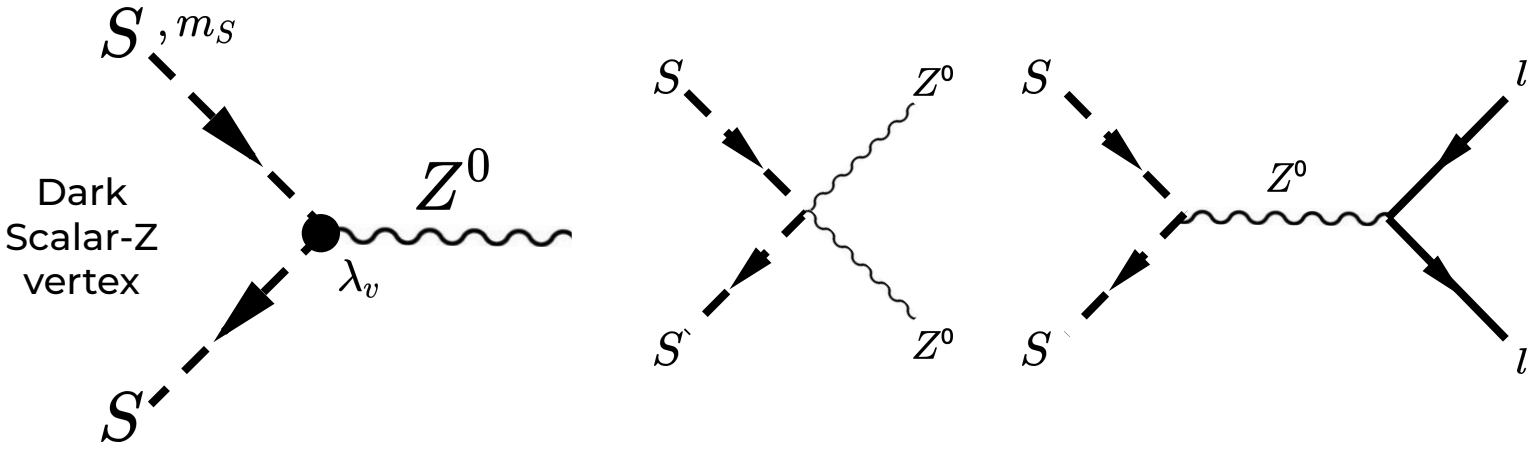




arXiv: 0702143

Scalar DM candidate $\rightarrow S$

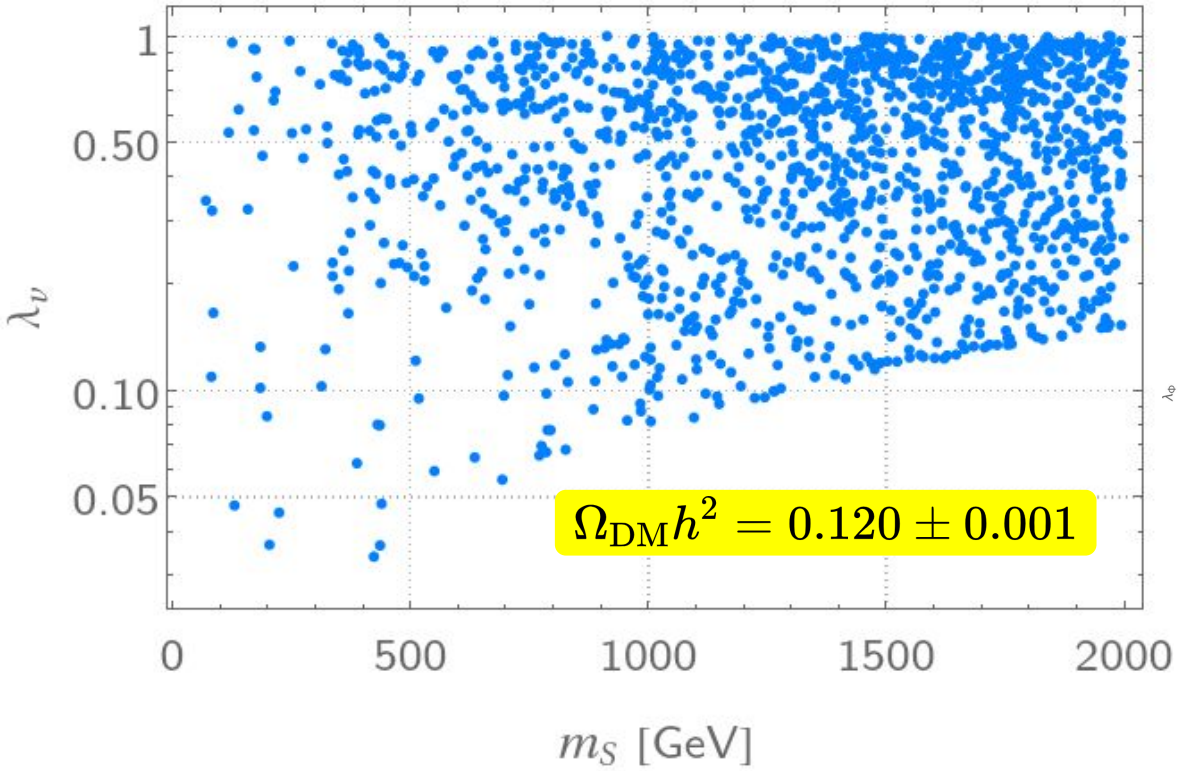
(Z coupling)



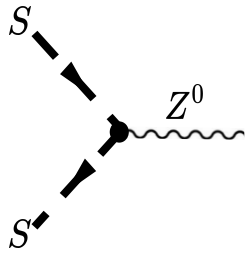
$$\mathcal{L}_{S,Z} = D_\mu S^* D_\mu S - \tfrac{1}{2} m_S^2 S^* S - \lambda_v S^* S Z_\mu Z^\mu$$

$$\mathcal{L}_{eff} = \mathcal{L}_{\mathrm{SM}} + \mathcal{L}_S$$

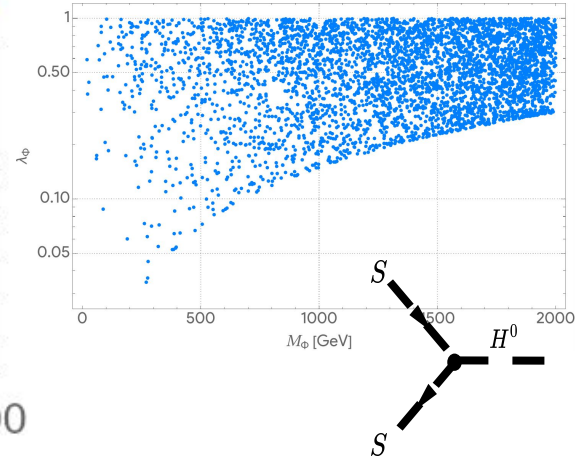
Candidates constrain to $\Omega_{DM}h^2$

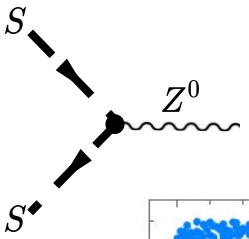


$\Omega_{\rm DM}h^2 = 0.120 \pm 0.001$



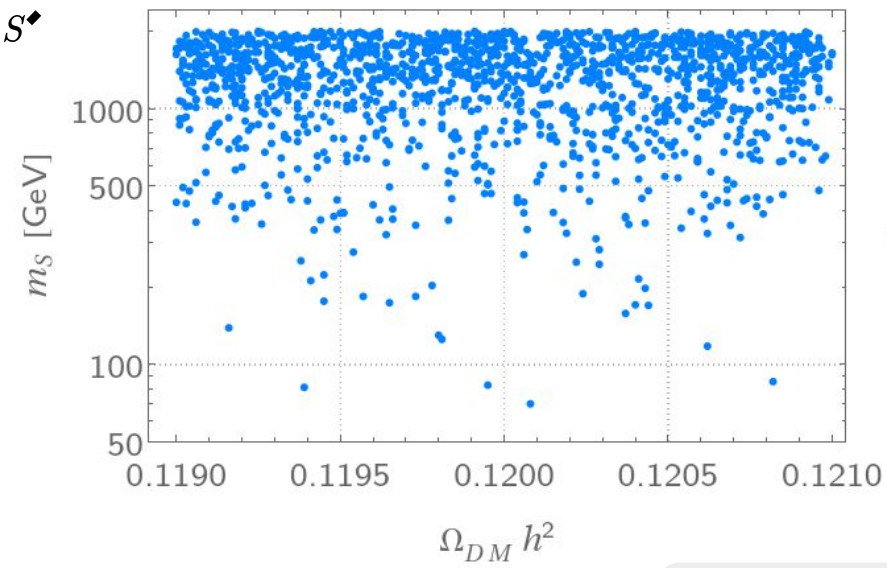
(Z coupling)

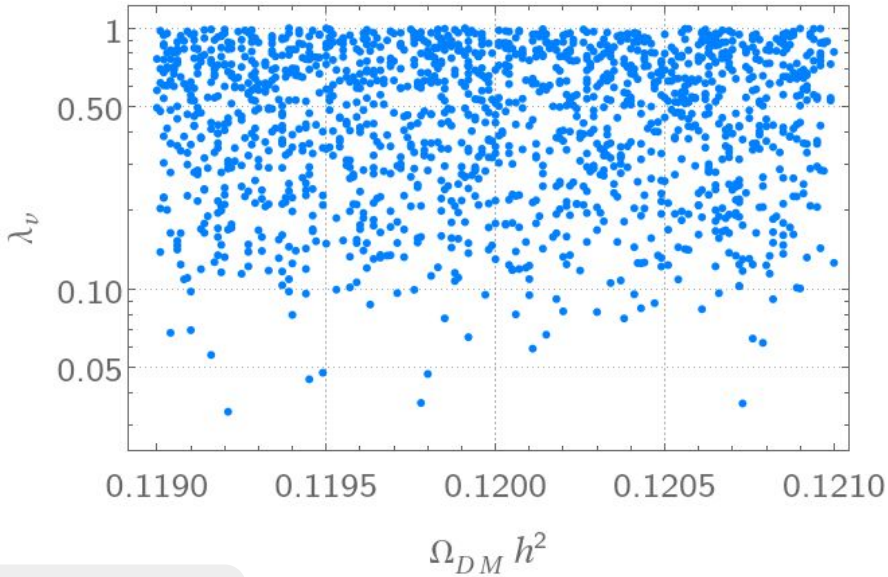




(Z coupling)

Parameter space adjust to $\Omega_{DM}h^2$

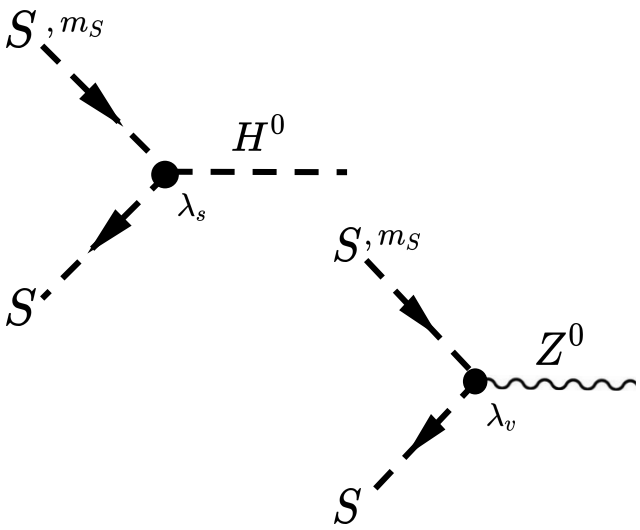


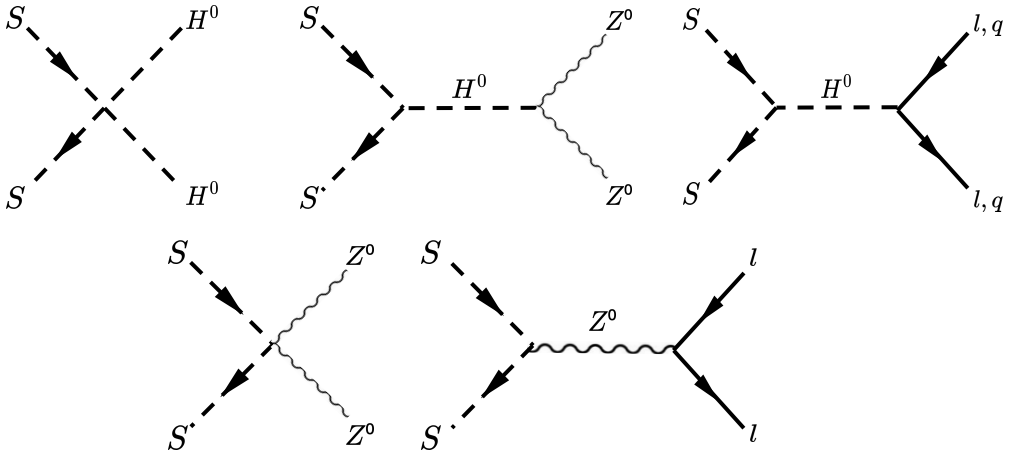


Low values → Less candidates

Scalar DM candidate $\rightarrow S$

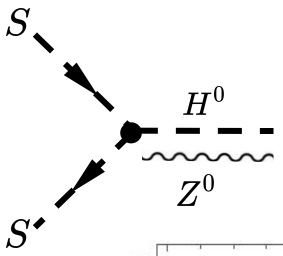
(Higgs and Z coupling)





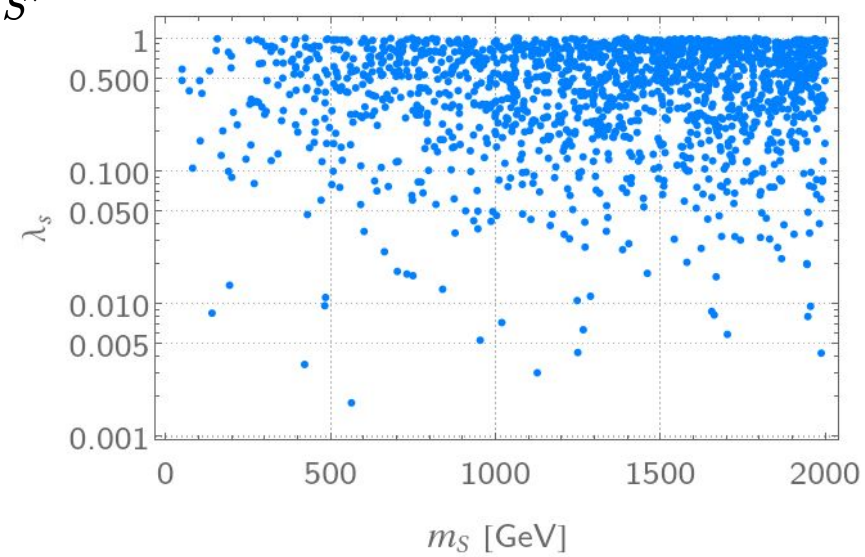
$$\mathcal{L}_{eff} = \mathcal{L}_{\text{SM}} + \mathcal{L}_S$$

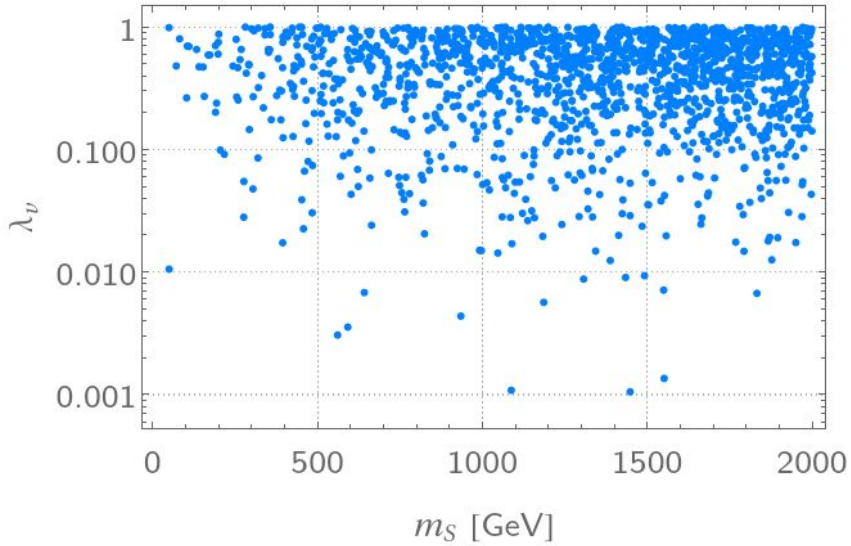
$$\mathcal{L}_S = D_\mu S^* D^\mu S - \tfrac{1}{2} m_S^2 S^* S - \lambda_s S^* S v^2 - \lambda_s S^* S \left(H + \tfrac{v}{\sqrt{2}}\right)^2 - \lambda_v S^* S \, Z_\mu Z^\mu$$



(Higgs and Z coupling)

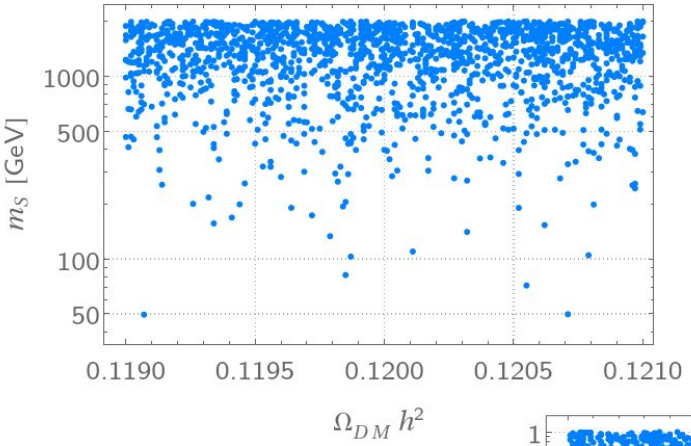
Candidates constrain to $\Omega_{DM}h^2$

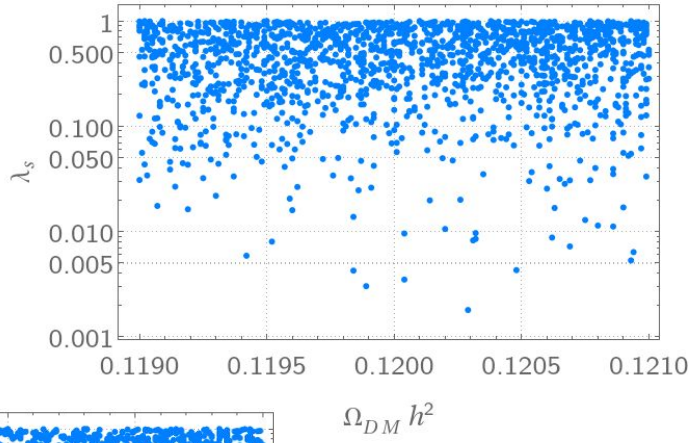


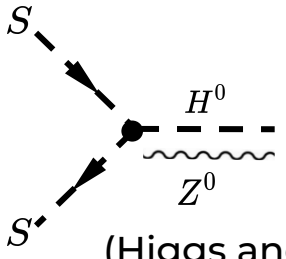


$$\Omega_{\mathrm{DM}}h^2 = 0.120 \pm 0.001$$

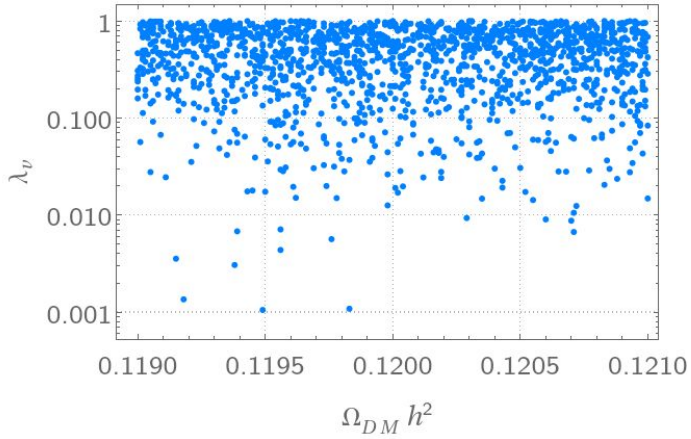
Parameter space adjust to $\Omega_{DM}h^2$







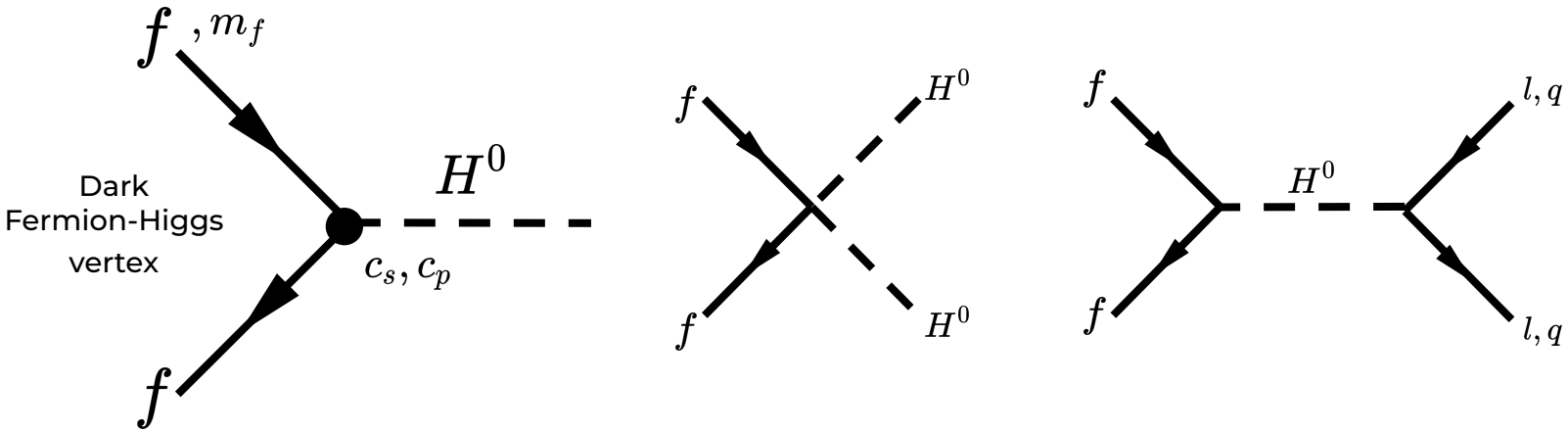
(Higgs and Z coupling)



Low values $\rightarrow$ Less candidates

Fermion DM candidate $\rightarrow f$

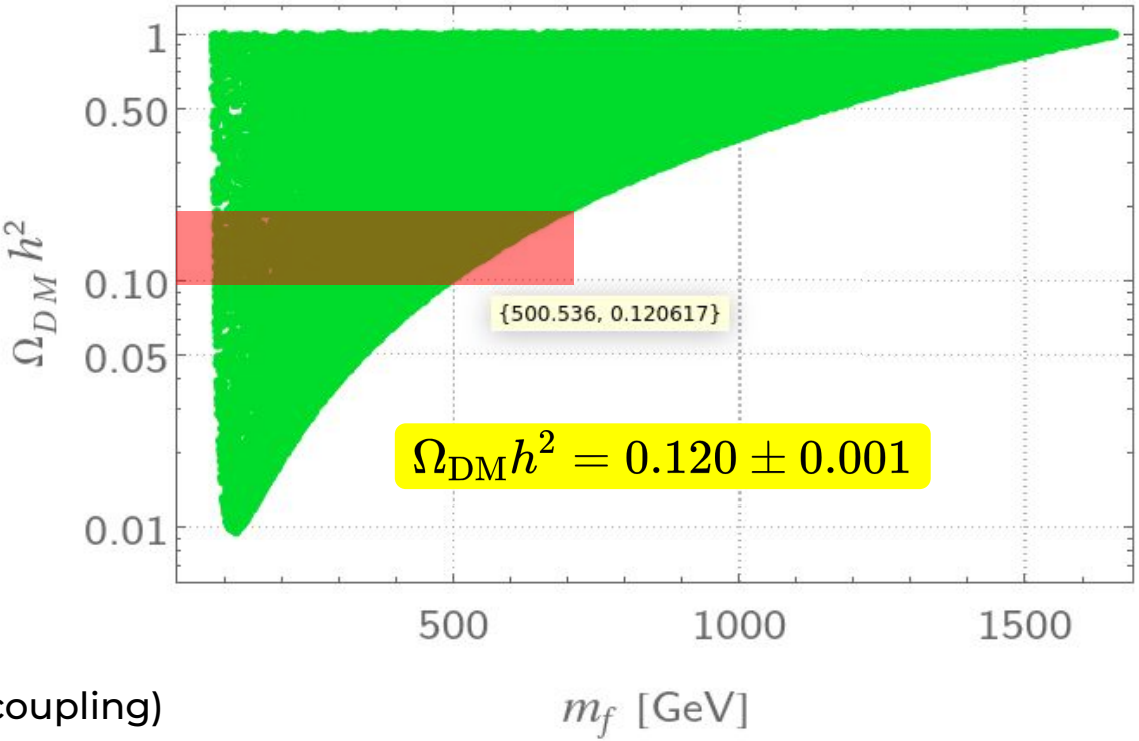
(Higgs coupling)

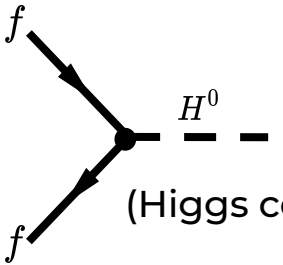


$$\mathcal{L}_{f,H} = \bar{f}\, i\gamma^{\mu} \frac{\left(1+\gamma^5\right)}{2} \partial_{\mu} f - \frac{1}{2}\bar{f}\, m_f f + \bar{f}\left(c_{sc} + c_{ps}\gamma^5\right) f\, H$$

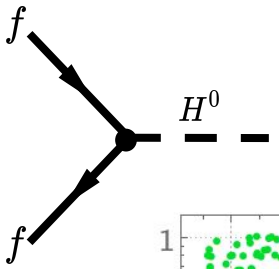
$$\mathcal{L}_{eff} = \mathcal{L}_{\mathrm{SM}} + \mathcal{L}_f$$

Explore the mass parameter around $\Omega_{DM}h^2$



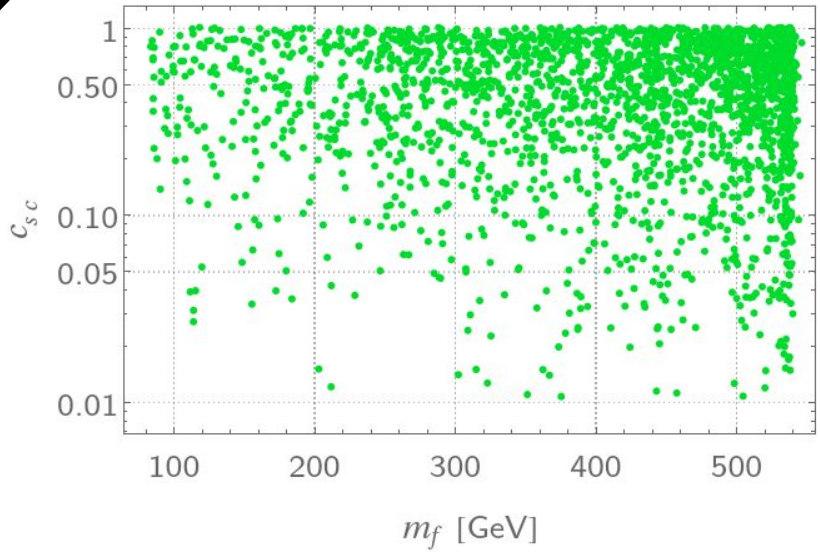


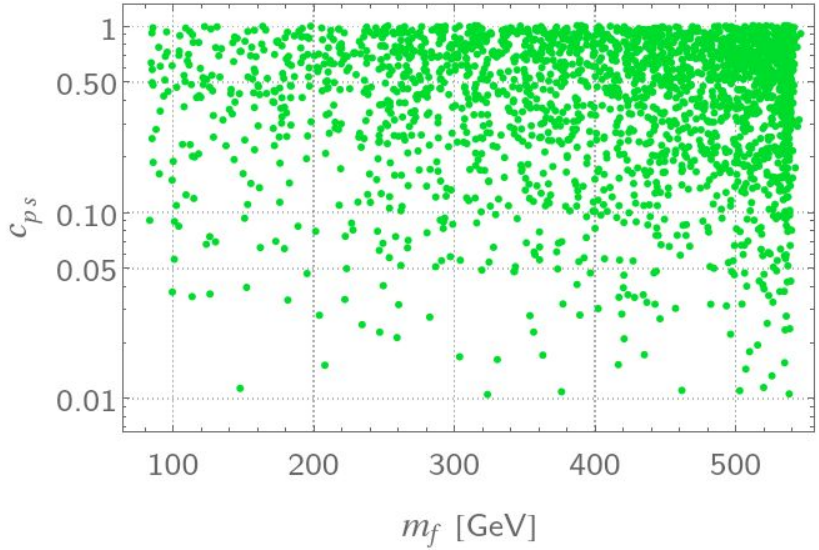
(Higgs coupling)



(Higgs coupling)

Candidates constrain to $\Omega_{DM}h^2$



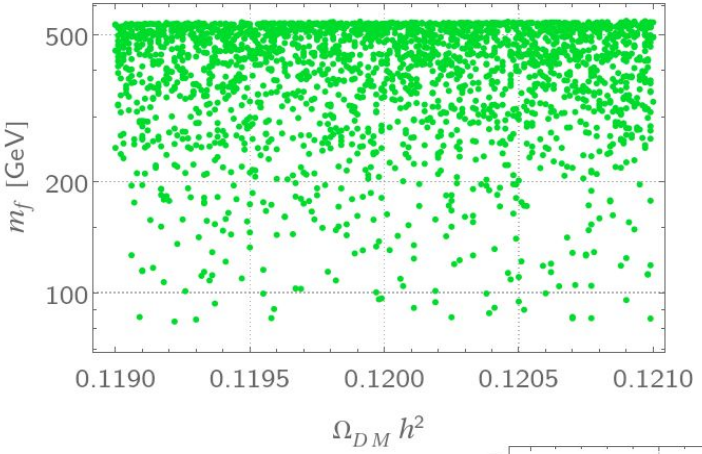


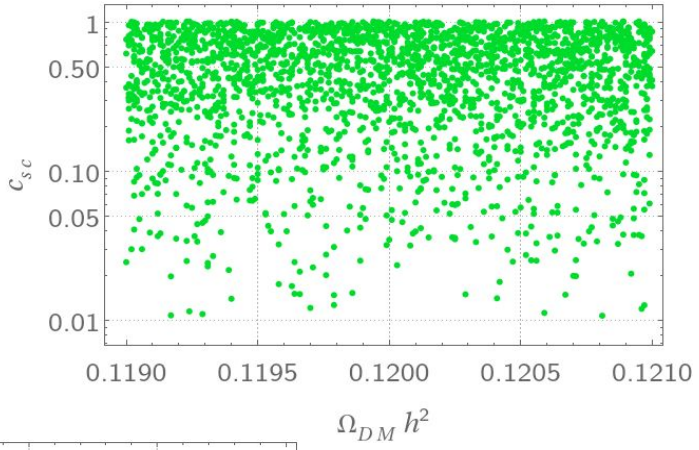
No strong correlation :(

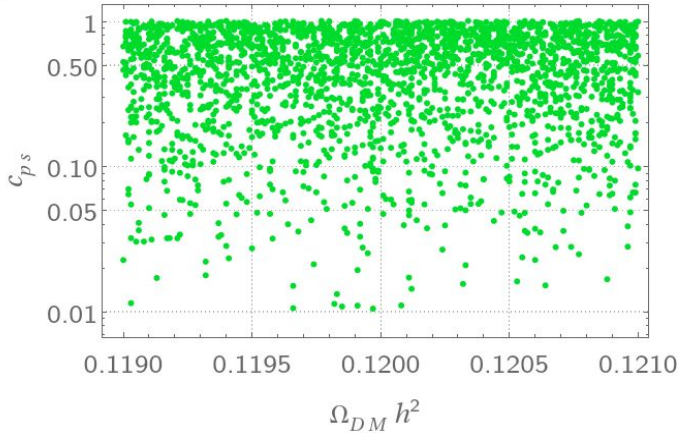
$$\Omega_{\mathrm{DM}}h^2 = 0.120 \pm 0.001$$

Low values $\rightarrow$ Less candidates

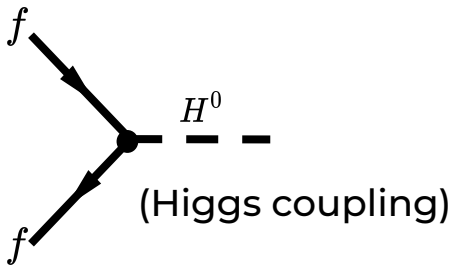
Parameter space adjust to $\Omega_{DM}h^2$







... opportunity area

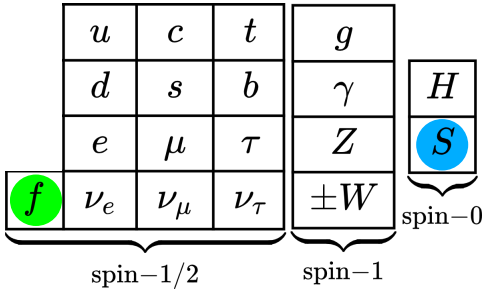


Summary

- This academic exercise allows me learn to use computational tools in HEP.
- DM Relic density is an important cosmological measure that allows to calculate effective models according to observables.
- **LanHep** allows SM extensions, using the lagrangian formalism.
- **MicrOmegas** allows the calculation of cosmological constraints and detection data.

Perspectives

- Find new DM candidates in other particle fields and with other types of couplings.
- Obtain direct and collider detection parameters.



Thanks for your attention !

Contact info:
inti.ernesto.chavez@gmail.com
josehalim@gmail.com
regaitan@gmail.com
estela.garces@gmail.com