Effective models for two-component scalar dark matter with Z_8 and Z_{10} symmetries

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9th Colombian Meeting on High Energy Physics, December 2024

The Model

Two-component scalar dark matter charged under Z_{2n}:

- Complex field $\rightarrow \phi_A$
- Real field $\rightarrow \phi_B$

Associated charges: $\omega_{2n}^A = \exp(i\pi A/n)$ and $\omega_{2n}^B = \exp(i\pi)$.

The Model

- Previous work [Yaguna and Zapata, 2021] on similar scenarios.
- Potentials for Z_8 and Z_{10} either lack new terms or are redundant.
- We extent Z_8 and Z_{10} scenarios to include effective operators of up to energy dimension 6.

Used tools

Sym2Int
[Fonseca, 2017]
Operators

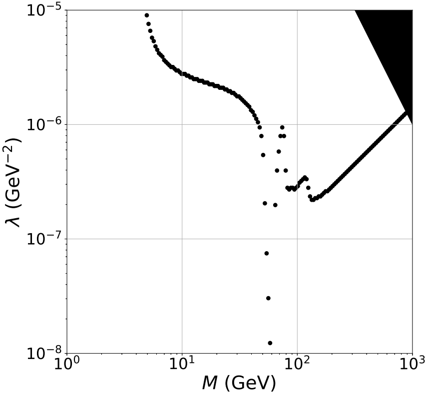
FeynRules
[Alloul et al., 2014]
Feynman Rules

micrOMEGAs
[Alguero et al., 2024]
Dark Matter observables

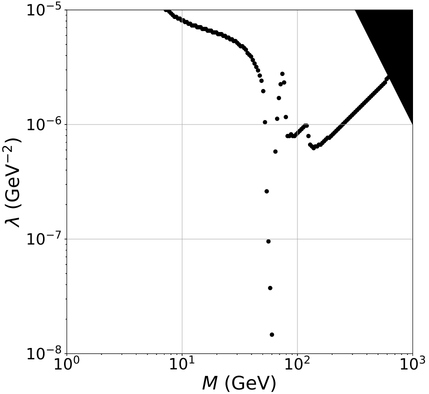
Single component case

$$\mathcal{L}_{DM} \supset M^2|\phi_{A/B}|^2/2 + \lambda|H|^4|\phi_{A/B}|^2$$

Real:

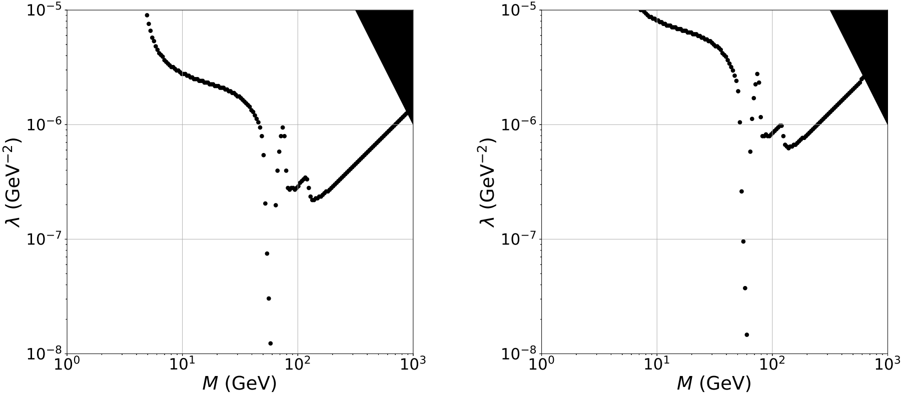


Complex:



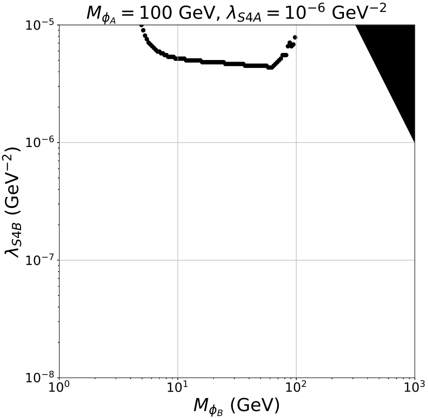
Single component case

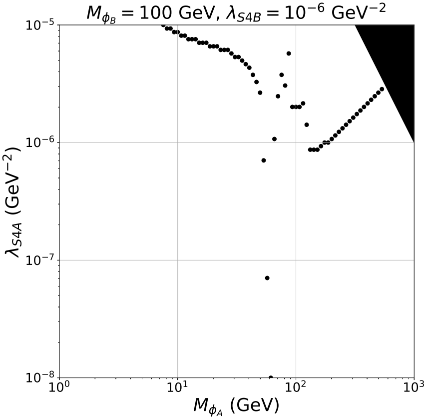
Not completely new [Criado et al., 2021]



Two-component cases

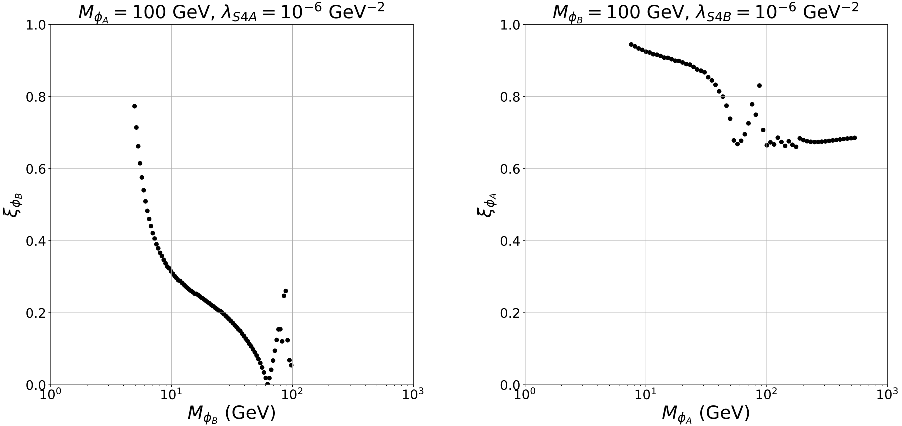
$$M_{\phi_A}^2|\phi_A|^2 + \frac{1}{2}M_{\phi_B}^2\phi_B^2 + \lambda_{S4A}|H|^4|\phi_A|^2 + \lambda_{S4B}|H|^4\phi_B^2$$





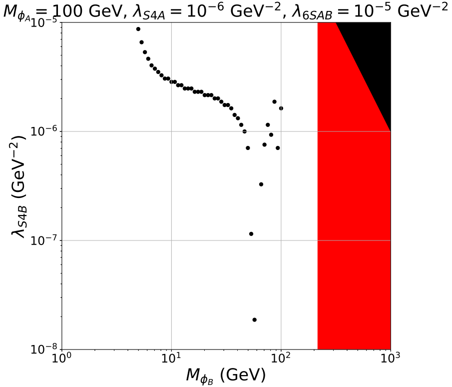
Two-component cases

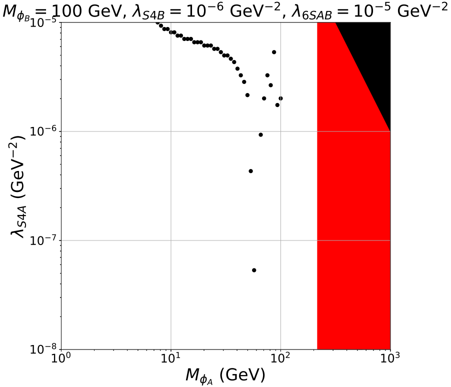
$$\xi_{\phi_i} = \Omega_{\phi_i}/\Omega_{DM}$$



Two-component cases

$$M_{\phi_A}^2|\phi_A|^2+\frac{1}{2}M_{\phi_B}^2\phi_B^2+\lambda_{S4A}|H|^4|\phi_A|^2+\lambda_{S4B}|H|^4\phi_B^2+\lambda_{6SAB}|H|^2|\phi_A|^2\phi_B^2$$





Two-component cases

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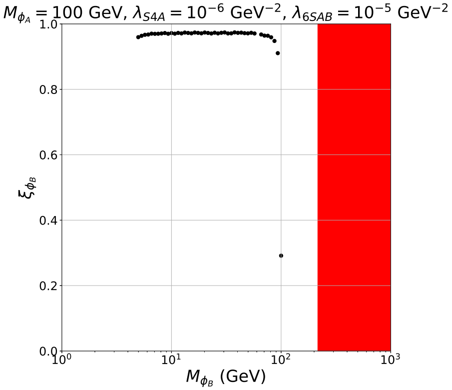
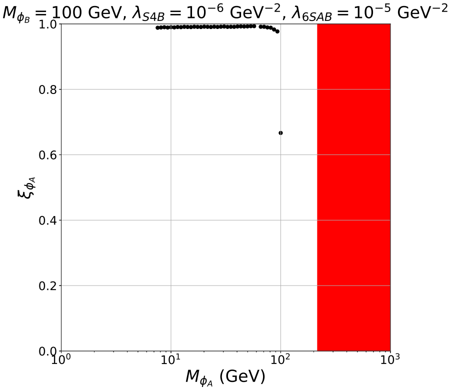
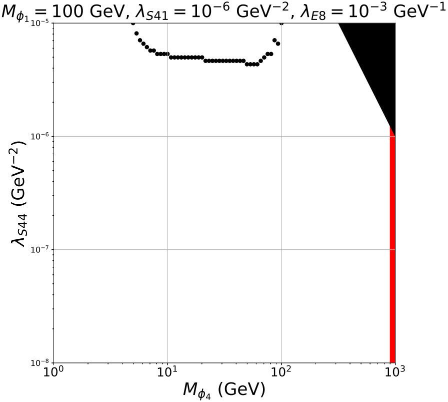
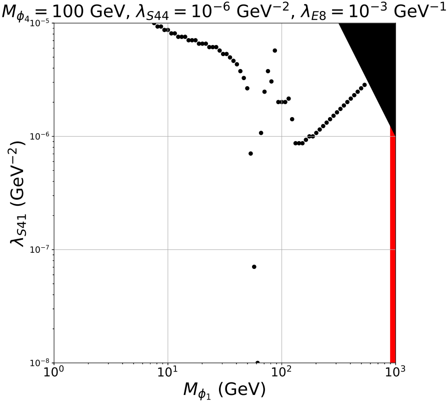




Two-component cases

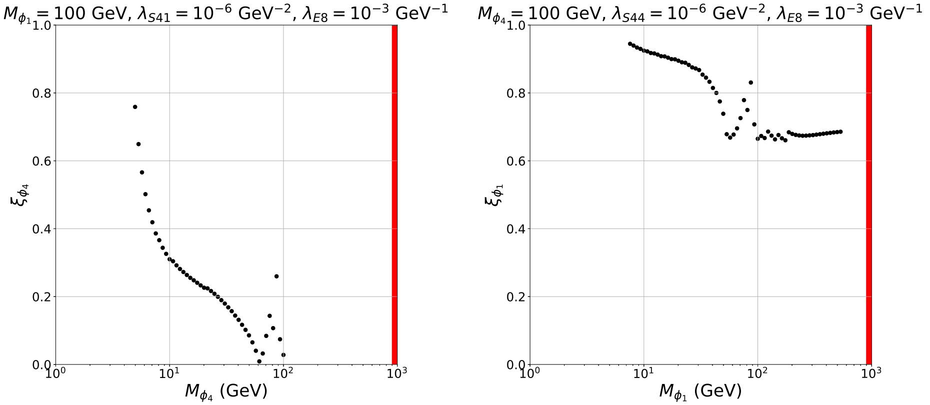
$$Z_8 : M_{\phi_1}^2|\phi_1|^2 + \frac{1}{2}M_{\phi_4}^2\phi_4^2 + \lambda_{S41}|H|^4|\phi_1|^2 + \lambda_{S44}|H|^4\phi_4^2 + \lambda_{E8}\phi_1^4\phi_4 + \text{h.c.}$$





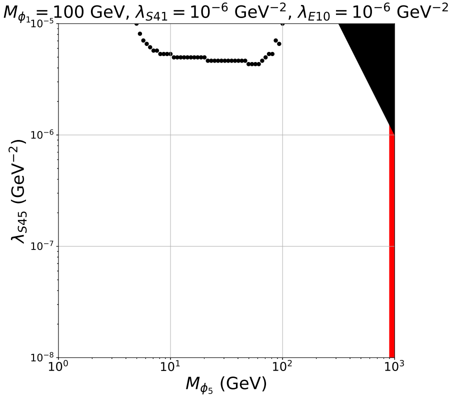
Two-component cases

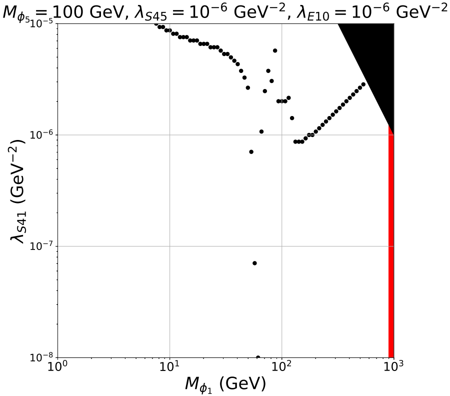
$$Z_8 : M_{\phi_1}^2|\phi_1|^2 + \frac{1}{2}M_{\phi_4}^2\phi_4^2 + \lambda_{S41}|H|^4|\phi_1|^2 + \lambda_{S44}|H|^4\phi_4^2 + \lambda_{E8}\phi_1^4\phi_4 + \text{h.c.}$$



Two-component cases

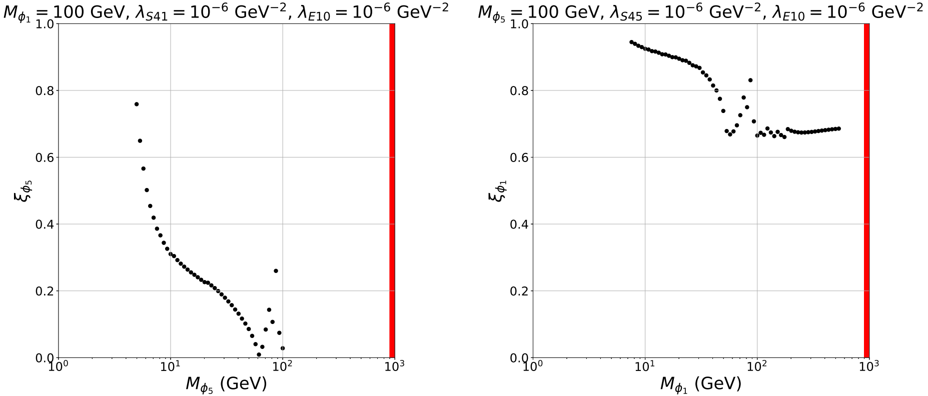
$$Z_{10}: M_{\phi_1}^2|\phi_1|^2 + \frac{1}{2}M_{\phi_5}^2\phi_5^2 + \lambda_{S41}|H|^4|\phi_1|^2 + \lambda_{S45}|H|^4\phi_5^2 + \lambda_{E10}\phi_1^5\phi_5 + \text{h.c.}$$





Two-component cases

$$Z_{10}: M_{\phi_1}^2|\phi_1|^2 + \frac{1}{2}M_{\phi_5}^2\phi_5^2 + \lambda_{S41}|H|^4|\phi_1|^2 + \lambda_{S45}|H|^4\phi_5^2 + \lambda_{E10}\phi_1^5\phi_5 + \text{h.c.}$$



Conclusions

- Generated correct dark matter abundances for single component real and complex DM with effective operators.
- Constructed a two-component scenario combining both real and complex fields.
- Effective operators such as $|H|^4|\phi_{A/B}|^2$ and $|H|^2|\phi_A|^2\phi_B^2$ change the outlook for generating correct DM abundance.
- Operators $\phi_1^4\phi_4$ and $\phi_1^5\phi_5$ do not seem to meaningfully affect the DM abundances but more work is required.

References

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The End

BU: Cut-Off energy of the EFT

For an effective operator of dimension D its coupling c:

$$c = \frac{1}{\Lambda^{D-4}} \Rightarrow \Lambda = c^{-1/(D-4)}$$

With E the typical energy scale of a DM process we say that the EFT breaks down at $E \sim \Lambda$.
For effective operators that involve one field we take the typical energy of a DM process as $E \sim M_{DM}$:

$$M_{DM} < c^{-1/(D-4)}$$

For effective operator involving both DM fields we take the sum of the masses instead:

$$\sum M_{DM} < c^{-1/(D-4)}$$

BU: Charges under Z_{2n}

In principle for Z_8 we can have $A = 1, 2, 3$:

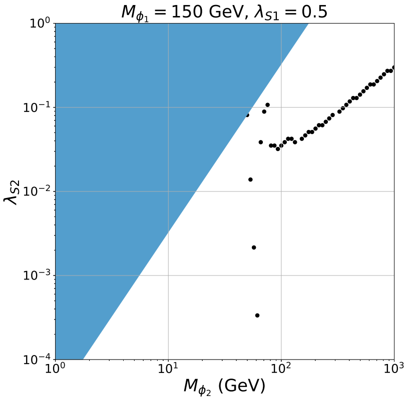
- $A = 2$ is analogous to $Z_4(12)$.
- $A = 1, 3$ allow the same operators up to dim 6 so we only show $Z_8(14)$ and drop the (14).

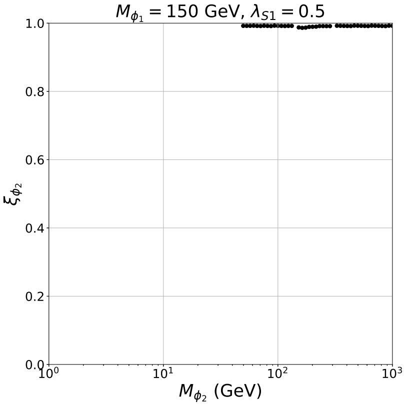
For Z_{10} it is possible to have $A = 1, 2, 3, 4$:

- $A = 1, 3$ allow the same operators up to dim 6 so we only show $Z_{10}(15)$ and drop the (15).
- $A = 2, 4$ allow for a ϕ_1^5 term we have not considered yet.

BU: Other Benchmark

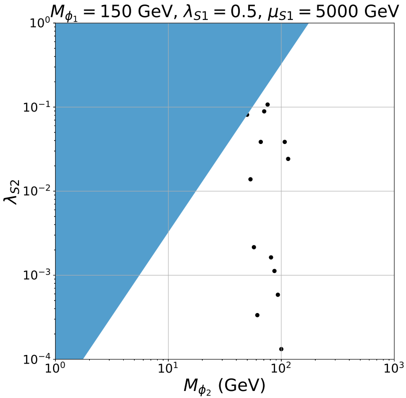
$$\mu_A^2|\phi_A|^2 + \frac{1}{2}\mu_B^2\phi_B^2 + \lambda_{SA}|H|^2|\phi_A|^2 + \lambda_{SB}|H|^2\phi_B^2$$

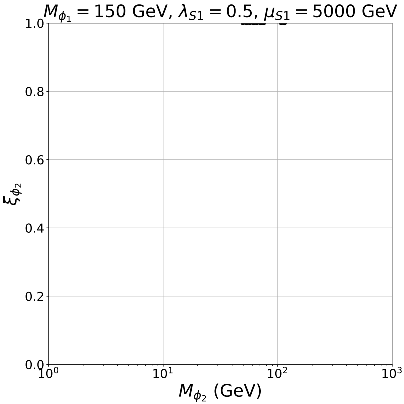




BU: Other Benchmark

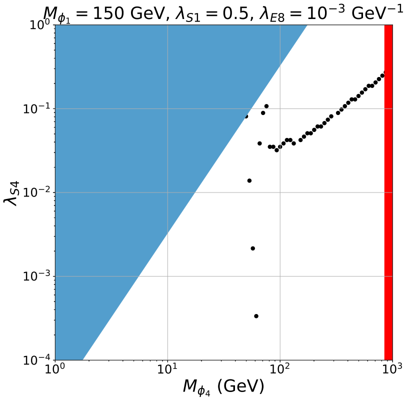
$$Z_4 : \mu_1^2|\phi_1|^2 + \frac{1}{2}\mu_2^2\phi_2^2 + \lambda_{S1}|H|^2|\phi_1|^2 + \lambda_{S2}|H|^2\phi_2^2 + \mu_{S1}\phi_1^2\phi_2 + h.c.$$

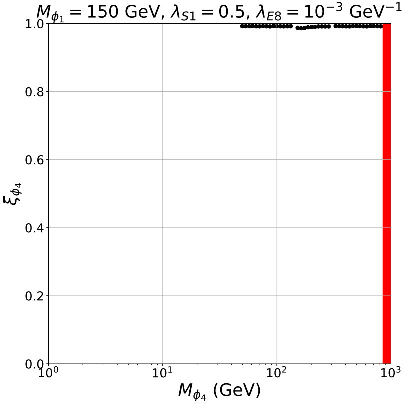




BU: Other Benchmark

$$Z_8 : \mu_1^2|\phi_1|^2 + \frac{1}{2}\mu_4^2\phi_4^2 + \lambda_{S1}|H|^2|\phi_1|^2 + \lambda_{S4}|H|^2\phi_4^2 + \lambda_{E8}\phi_1^4\phi_4 + \text{h.c.}$$





BU: Other Benchmark

$$Z_{10} : \mu_1^2|\phi_1|^2 + \frac{1}{2}\mu_5^2\phi_5^2 + \lambda_{S1}|H|^{2}|\phi_1|^2 + \lambda_{S5}|H|^{2}\phi_5^2 + \lambda_{E10}\phi_1^5\phi_5 + \text{h.c.}$$