Strong phase transition and dark matter from a simple hidden sector

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T. Alanne, K. Tuominen, and V. Vaskonen, Nucl. Phys. B 889 (2014) 692, [arXiv:1407.0688 [hep-ph]].

Introduction

- Motivation: Dark matter and baryon asymmetry.
- Extended scalar potential could provide a strong first order phase transition and a portal between dark and the visible sectors.
- Model: extend SM scalar sector with a singlet s, dark sector consists of a singlet fermion ψ.

Model

Scalar potential of the model is

$$V(\phi, s) = \mu_\phi^2 \phi^\dagger \phi + \lambda_\phi (\phi^\dagger \phi)^2 + \mu_1 s + \frac{\mu_s^2}{2} s^2 + \frac{\mu_3}{3} s^3 + \frac{\lambda_s}{4} s^4 + \mu_{\phi s} (\phi^\dagger \phi) s + \frac{\lambda_{\phi s}}{2} (\phi^\dagger \phi) s^2 .$$

s: real scalar field, SM singlet,

ϕ: SM doublet

$$\phi = \begin{pmatrix} \chi^+ \\ \frac{1}{\sqrt{2}}(v + h + \mathrm{i}\chi) \end{pmatrix} .$$

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$$\phi = \begin{pmatrix} \chi^+ \\ \frac{1}{\sqrt{2}}(v + h + \mathrm{i}\chi) \end{pmatrix}.$$

Choose $\langle s \rangle_{T=0} = 0 \implies \mu_1 = -v^2 \mu_{\phi s}/2$, $\mu_\phi^2 = -v^2 \lambda_\phi$.

Stability $\implies \lambda_\phi > 0, \quad \lambda_s > 0, \quad \lambda_{\phi s} > -2\sqrt{\lambda_\phi \lambda_s}$.

$\mu_{\phi s}$ determines the mixing between h and s:

$$V \ni \begin{pmatrix} h & s \end{pmatrix} \begin{pmatrix} 2v^2\lambda_\phi & v\mu_{\phi s} \\ v\mu_{\phi s} & \frac{v^2\lambda_{\phi s}}{2} + \mu_s^2 \end{pmatrix} \begin{pmatrix} h \\ s \end{pmatrix}.$$

The mass eigenstates are

$$H = h\cos\beta + s\sin\beta, \quad S = -h\sin\beta + s\cos\beta,$$

$m_H = 126\,\mathrm{GeV}.$

The dark matter candidate is a SM singlet fermion ψ:

$$\mathcal{L}_{\rm DM} = \bar{\psi}(i\partial\!\!\!/ - m_\psi)\psi + g_s s\bar{\psi}\psi.$$

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The model contains 7 free parameters:

$$m_S, m_\psi, \cos\beta, \lambda_s, \lambda_{\phi s}, \mu_3, g_s.$$

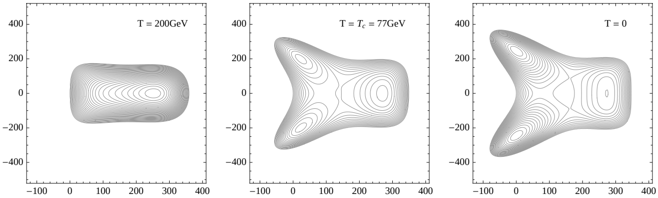
Constraints from colliders

- We perform a Monte Carlo scan of the parameter space with stability and perturbativity constraints.
- Constrain the parameter space with LHC Higgs coupling data and electroweak precision measurements using S and T parameters.

Strong phase transition

To study the electroweak phase transition, we need to include the finite-temperature corrections:

$$\mu_1(T) = \mu_1 + c_1 T^2,\ \mu_s(T)^2 = \mu_s^2 + c_s T^2,\ \mu_\phi(T)^2 = \mu_\phi^2 + c_\phi T^2.$$



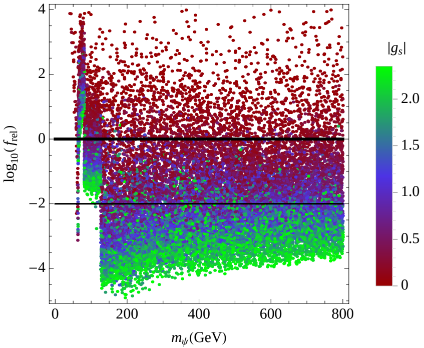
We calculate the critical temperature and constrain $v(T_c)/T_c > 1$.

Dark matter

We calculate the dark matter relic abundance using the freeze-out formalism,

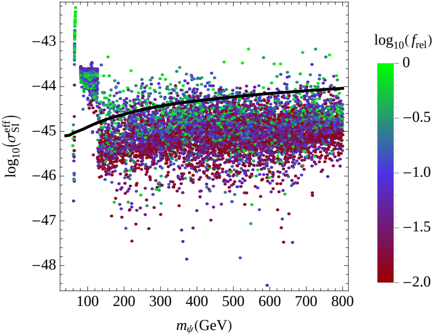
$$\dot{n}_\psi + 3Hn_\psi = -\sum_{a,b} \langle \sigma_{\psi\overline{\psi}\to ab}|v| \rangle \left(n_\psi^2 - (n_\psi^{\rm eq})^2 \right),$$

define $f_{\rm rel} = \Omega h^2/0.12$ and require that $0.01 < f_{\rm rel} \leq 1$.



The LUX experiment constrains the dark matter scattering on nuclei:

$$\sigma_{\rm SI}^{\rm eff} = f_{\rm rel}\frac{\mu_N^2 f_N^2 m_N^2}{\pi v^2} g_s^2 \sin^2\beta\cos^2\beta\left(\frac{1}{m_S^2}-\frac{1}{m_H^2}\right)^2 .$$



Conclusions

- It is possible to explain observed DM abundance and obtain strong EWPT from a simple hidden sector.
- The model is compatible with LHC and direct search results.
- Can remain perturbative and stable up to $M_{\rm Planck}$ (see Alanne et al.).
- In progress: analysis of self interacting DM via freeze-in mechanism.

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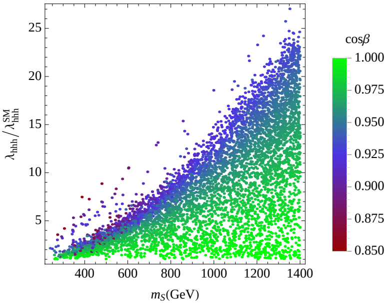

25
20
15
10
5
400
600
800
1000
1200
1400
m_S(GeV)
$\lambda_{hhh}/\lambda_{hhh}^{SM}$
$\cos\beta$
1.000
0.975
0.950
0.925
0.900
0.875
0.850