EWSB and CDM from hidden sector technicolor interaction

based on arXiv:0709.1218 [hep-ph]
with P. Ko, D.W. Jung and Jae Yong Lee
and works in preparation

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Outline

1. Why "Strongly Interacting Hidden Sector"?
2. Model I
   - EWSB and DM from strongly interacting hidden sector
3. Model II
   - Fully scale-symmetric version
4. Conclusion

Motivations for New Physics

The Standard Model gives very **successful description** of the **observed physical world**, but it is **far from being complete** yet.

- Baryon asymmetry
- Neutrino mass and mixing
- **Dark matter**
- ...

Dark Matter

Evidences and abundance of Dark Matter

- Galaxy rotation curve, Dynamics of galaxy cluster, and Gravitational Lensing
- WMAP+SDSS result :

$$\Omega_{CDM} h^2 = 0.111^{+0.011}_{-0.015} \text{ (} 2\sigma \text{ range)}$$

Required Properties of Dark Matter

- Massive, Neutral, and Stable (or long-lived)

Dark Matter Candidates in the Various Models

- MSSM R-parity: LSP
- Little Higgs T-parity: LTP
- Universal Extra Dimension KK-parity: LKP

While the extended particle spectrum provides a new massive, neutral particle, we usually need an **additional symmetry** (e.g. R-parity, T-parity) to make it **stable**.

Strongly Interacting Hidden Sector

Why Hidden Sector?

- Many GUT models have hidden sectors which are singlets under the SM gauge group $SU(3)_C \times SU(2)_L \times U(1)_Y$.
- No strong constraints from experiments.

Why Strongly Interacting Hidden Sector?

1. Stable particles from its accidental flavor symmetry without ad hoc Z_2 parity :
   Ex.)
   - Protons in SM QCD
   - Pions in SM QCD (if no EW interaction.)
2. New scale Λ_H (like Λ_{QCD}) is generated quantum mechanically by dimensional transmutation.
   $\rightarrow$ EW scale can be generated from Λ_H.

Higgs Portal to Hidden Sector

Interaction between SM and Hidden Sector

Singlet Operators in the Standard Model

$$\begin{aligned} \text{Dim } 2 \quad &: H^\dagger H \\ \text{Dim } 2.5 &: \overline{L}H \text{ (not singlet under Lorentz group)} \\ \text{Dim } 4 \quad &: (H^\dagger H)^2,\ \overline{Q}_L H d_R \text{ etc.} \end{aligned}$$

- The operator $H^\dagger H$ has lowest-mass-dimension.

We can expect that the hidden sector couples to the **Higgs sector more strongly** than **the other operators** in SM by **dimensional analysis**.

$$\mathcal{L} \ni \frac{c}{\Lambda^{d_{\mathrm{SM}}+d_{\mathrm{Hidden}}-4}} O_{\mathrm{SM}} O_{\mathrm{Hidden}}$$

Basic Set-Up


SM
Higgs
Strongly Interacting
Hidden Sector
$< \bar{Q}_h Q_h > \neq 0$
No mass parameter
(μ_H=0)
Scale Λ_H is generated from
Dimensional transmutation
EWSB
Dark Matter
π_h

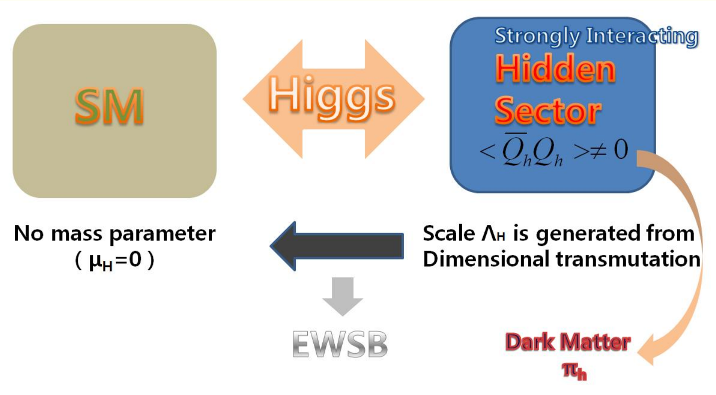
Basic Set-Up

- **Strong $SU(N_h)$ gauge group** in hidden sector with $N_{h,f}$ vector-like hidden quarks.

Basic Set-Up

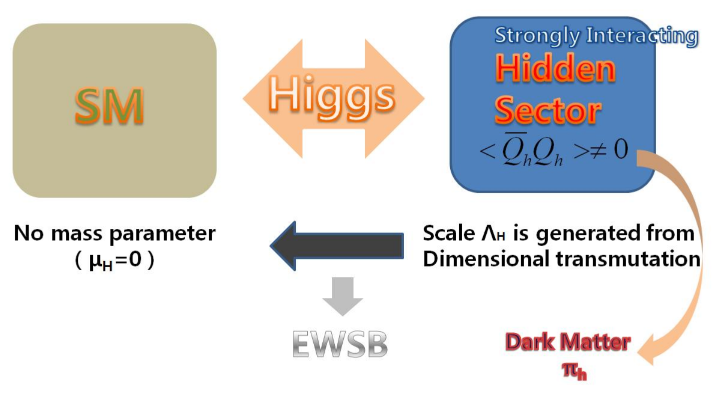
- Hidden sector **pion** π_h is (dominant) **CDM**.

Basic Set-Up



- **Higgs** is the only SM particle **interacting with hidden sector**.
  - Nonrenormalizable interaction : Model I
  - Renormalizable interaction with singlet S : Model II

Basic Set-Up



- **Classical scale symmetry**
  → No dimensionful parameter : $\mu_H^2 = \mathbf{0}$.
  → Λ_H from hidden sector strong interaction is the only source of energy scale.

Basic Set-Up

We assume :

- **Strong $SU(N_h)$ gauge group** in hidden sector with $N_{h,f}$ vector-like hidden quarks.
- Hidden sector **pion** π_h is (dominant) **CDM**.
- **Higgs** is the only SM particle **interacting with hidden sector**.
    - Nonrenormalizable interaction : Model I
    - Renormalizable interaction with singlet S : Model II
- **Classical scale symmetry**
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Model I: Lagrangian

SM sector

$$\mathcal{L}_{\rm SM} = \mathcal{L}_{\rm kin} + \mathcal{L}_{\rm Yukawa} - \frac{\lambda_1}{2}\,(H_1^\dagger H_1)^2 + \mu_1^2\; H_1^\dagger H_1$$

μ_1^2 is the only dimensionful parameter in the SM sector.

Hidden Sector

— new strong interaction with hidden quarks $\mathcal{Q}_k$

$$\mathcal{L}_{\rm hidden} = -\frac{1}{4}\mathcal{G}_{\mu\nu}\mathcal{G}^{\mu\nu} + \sum_{k=1}^{N_{h,f}} \overline{\mathcal{Q}}_k\,(iD\cdot\gamma - M_{\mathcal{Q}_k})\,\mathcal{Q}_k .$$

Messenger Sector ?

$$\mathcal{L}_{\rm mixing} = \frac{1}{\Lambda_{\rm mess}^n} H_1^\dagger H_1 \times \ldots$$

Hidden Sector
Details

$$\mathcal{L}_{\text{hidden}} = -\frac{1}{4}\mathcal{G}_{\mu\nu}\mathcal{G}^{\mu\nu} + \sum_{k=1}^{N_{h,f}} \overline{\mathcal{Q}}_k \left(iD\cdot\gamma - M_{\mathcal{Q}_k}\right)\mathcal{Q}_k .$$

- $N_{h,f} = 2$ like (u,d) system in real QCD
- Confinement occurs at the scale Λ_H
- $M_{\mathcal{Q}_k} \ll \Lambda_H$:
  Approximate global symmetry $SU(2)_L \times SU(2)_R$.

Below $\Lambda_{h,\chi} \approx 4\pi\Lambda_H$, the approximate global symmetry is broken to $SU(2)_V$, and the theory can be described by the low energy effective theory with pseudo NG bosons (pions):

Linear or Non-linear σ model

Effective Lagrangian below $\Lambda_{h,\chi}$ scale

Gell-Mann-Levy's linear σ model.

$$V(H_1,H_2) = -\mu_1^2(H_1^\dagger H_1) + \frac{\lambda_1}{2}(H_1^\dagger H_1)^2$$
$$-\mu_2^2(H_2^\dagger H_2) + \frac{\lambda_2}{2}(H_2^\dagger H_2)^2 + \lambda_3(H_1^\dagger H_1)(H_2^\dagger H_2) - \frac{a v_2^3}{2}\sigma_h$$

- $H_2 = \begin{pmatrix} \pi_h^+ \\ \frac{v_2+\sigma_h+i\pi_h^0}{\sqrt{2}} \end{pmatrix}$: meson fields from condensation of hidden quarks (SM singlet).
- If $\mu_1^2 = 0$, the SM sector has the classical scale symmetry.
- λ_3 gives effective μ_1 term when H_2 gets VEV.
- $\frac{a v_2^3}{2}\sigma_h$: the explicit chiral symmetry breaking term originated from M_{Q_i}.
  It makes the dark matter candidate (pions) massive.

Particle Spectrum

Higgs Sector and Mixing

$$\begin{pmatrix} h \\ H \end{pmatrix} = \begin{pmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} h_{\rm SM} \ (\text{ from } H_1) \\ \sigma_h (\text{ from } H_2\ ) \end{pmatrix}.$$

- The couplings between SM particles and the light (heavy) Higgs is suppressed by $\cos\alpha$ ($\sin\alpha$).

Hidden Sector Pions (Dark Matter Candidate)

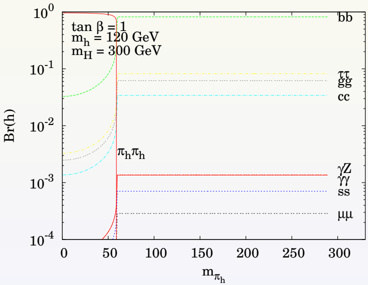
- $\pi_h^+, \pi_h^-, \pi_h^0$ (corresponding to three $SU(2)_A$ generators)
- $M_{\pi_h}^2 = \frac{a v_2^2}{2}$
- Stable from flavor symmetry of hidden quarks without ad hoc Z_2 symmetry.

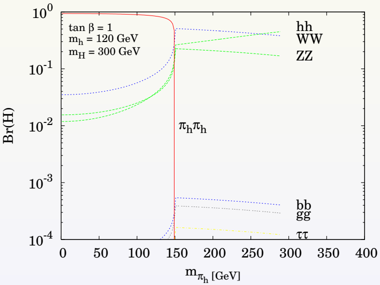
Branching Ratios of Higgs fields

($\tan\beta = 1$, $m_h = 120\text{GeV}$, $m_H = 300\text{GeV}$, and $\mu_1^2 = 0$)

Input parameters for numerical calculation

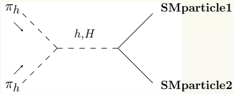
- $\tan\beta$, m_{π_h}, m_h, m_H, $\cos\alpha$ (5 parameters)
- If $\mu_1^2 = 0$, $\rightarrow \tan\beta = \frac{v_2}{v_1}$, m_{π_h}, m_h, m_H (4 parameters)

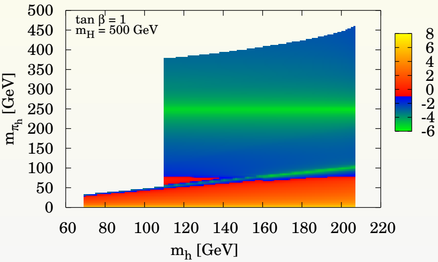




- When $2m_{\pi_h} < m_h$, channel $h \rightarrow \pi_h\pi_h$ opens, and the $Br(h \rightarrow \text{SM particles})$ is modified significantly.

Relic Density Plot
($\tan\beta = 1$, $m_H = 500$**GeV**)



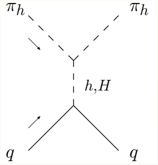


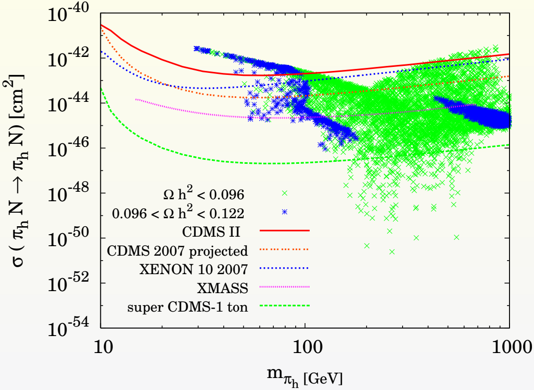
contour : $\log \Omega_{DM} h^2$

Annihilation channel

$\pi_h \pi_h \to 2$ SM particles (S channel mediated by h and H)

Direct Detection Plot
($\tan\beta = 1$)





- green : within WMAP+SDSS 2σ , blue : below WMAP+SDSS

Direct detection — $\sigma_{SI}(\pi_h p \to \pi_h p)$

$\pi_h q \to \pi_h q$ (T channel mediated by h and H)

Summary - Model I

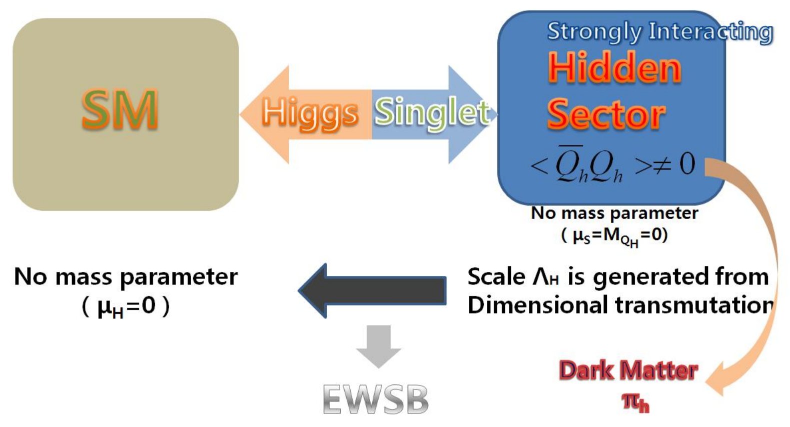
- The strongly interacting hidden sector can give **successful EWSB** **without** any dimensionful parameters in the SM sector.
- The hidden sector pion can be **a good CDM**.
  - The pion is stable without ad hoc Z_2 parity.
  - Some parameter sets are allowed by current experimental constraints : relic density and direct detection rate.

Something unsatisfactory yet :

- The SM and the hidden sector are interacting with nonrenormalizable term.
  $\rightarrow$ UV completion of the model ?
- The hidden sector does not have the classical scale symmetry. (because of hidden quark mass $M_{\mathcal{Q}_k}$)

$\rightarrow$ Model II (singlet-extended version)

Model II : Singlet Extended Model



We will ignore N_R which can directly couple to the singlet.

Lagrangian

Additional real singlet S with classical scale symmetry

SM Sector (without $\mu^2_{H_1}$ term)

$$\mathcal{L}_{\rm SM} = \mathcal{L}_{\rm kin} + \mathcal{L}_{\rm Yukawa} - \frac{\lambda_1}{2}\left(H_1^\dagger H_1\right)^2$$

Hidden Sector (without μ^2_S term and $M_{\mathcal{Q}_k}$)
— Singlet + new strong interaction with hidden quarks

$$\mathcal{L}_{\rm hidden} = -\frac{1}{4}\mathcal{G}_{\mu\nu}\mathcal{G}^{\mu\nu} + \sum_{k=1}^{N_{h,f}} \overline{\mathcal{Q}}_k \left(iD\cdot\gamma - \lambda_k S\right)\mathcal{Q}_k - \frac{\lambda_S}{8}S^4$$

Renormalizable Mixing Term

$$\mathcal{L}_{\rm mixing} = -\frac{\lambda_{1S}}{2}(H_1^\dagger H_1)S^2$$

Low Energy Effective Lagrangian below $\Lambda_{h,\chi}$

$$
\begin{aligned}
\mathcal{L}^{\rm eff}_{\rm hidden} &= \frac{v_h^2}{4}\mathrm{Tr}[\partial_\mu\Sigma_h\partial^\mu\Sigma_h^\dagger] + \frac{v_h^2}{2}\mathrm{Tr}[\lambda S\mu_h(\Sigma_h+\Sigma_h^\dagger)] - \frac{\lambda_S}{8}S^4 \\
\mathcal{L}_{\rm mixing} &= -\frac{\lambda_{1S}}{2}H_1^\dagger H_1 S^2 \\
&\quad -v_h^2\Lambda_h^2[\kappa_H\frac{H_1^\dagger H_1}{\Lambda_h^2} + \kappa_S\frac{S^2}{\Lambda_h^2} + \kappa_S'\frac{S}{\Lambda_h} + O(\frac{SH_1^\dagger H_1}{\Lambda_h^3}, \frac{S^3}{\Lambda_h^3})] \\
&\approx -\frac{\lambda_{1S}}{2}H_1^\dagger H_1 S^2 - v_h^2[\kappa_H H_1^\dagger H_1 + \kappa_S S^2 + \Lambda_h\kappa_S' S]
\end{aligned}
$$

Σ field

$$
\Sigma_h(x) = e^{2i\Pi(x)/v_h}, \quad \Pi(x) = \pi_a\frac{\sigma_a}{2} = \begin{pmatrix} \frac{\pi^0}{2} & \frac{\pi^+}{\sqrt{2}} \\ \frac{\pi^-}{\sqrt{2}} & \frac{-\pi^0}{2} \end{pmatrix}
$$

For simplicity, we assume all κ_H, κ_S, and κ_S' are zero.

Particle Spectrum

Higgs Sector

- Almost same structure with the Model I.
- h and H are mixtures of H_1 and S.
- The couplings between SM particles and the light (heavy) Higgs is suppressed by $\cos\alpha$ $(\sin\alpha)$.
- The $Br(h \to \text{SM particles})$ also modified significantly if $h \to \pi_h \pi_h$ opens.

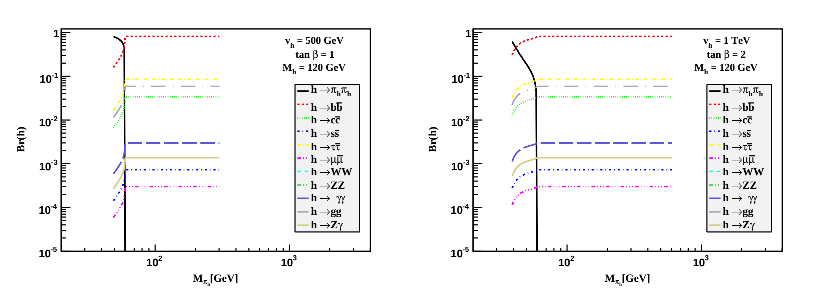
Hidden Sector Pions (Dark Matter Candidate)

- $\pi_h^+, \pi_h^-, \pi_h^0$ (corresponding to three $SU(2)_A$ generators)
- Stable without ad hoc Z_2 symmetry.

Branching Ratios of Higgs

Input parameters for numerical calculation

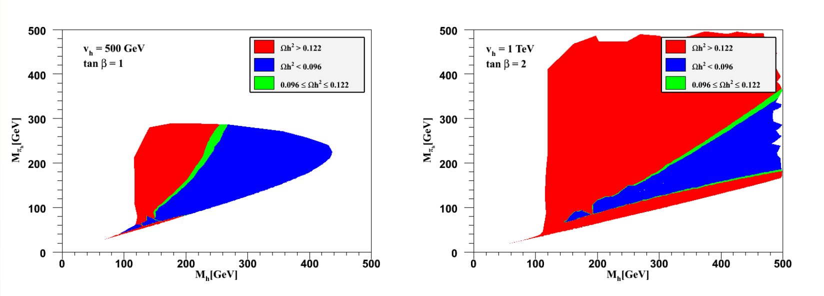
- $\tan\beta = \frac{v_s}{v_1}$, v_h, m_{π_h}, m_h : 4 parameters



1. m_h=120GeV, v_h = 500GeV, and $\tan\beta$=1
2. m_h=120GeV, v_h = 1TeV, and $\tan\beta$=2

Relic Density of π_h (Ωh^2)

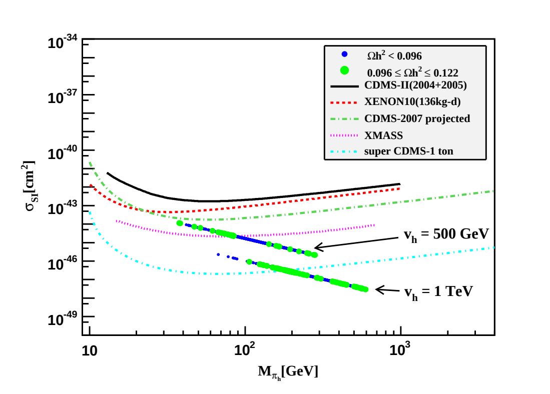
(m_h, m_{π_h}) plane



1. v_h = 500GeV, and tan β=1
2. v_h = 1TeV, and tan β=2

Direct Detection Rates

$\sigma_{SI}(\pi_h, p \to \pi_h, p)$



The cross-section is a function of M_{π_h} and v_h only.

1. $v_h = 500\text{GeV}$
2. $v_h = 1\text{TeV}$

Summary

- **The lightest particle (π_h)** in the strongly interacting hidden sector can be **a good dark matter candidate**.
- **Without any dimensionful parameters** in the fundamental lagrangian, **all the mass scales** can be generated from the scale symmetry breaking in the hidden sector.
- Future Works ?
  - Extension of the model with additional gauge symmetry
  - Radiative corrections to the scalar potential
  - Gauge coupling unification of two sectors.
  - Supersymmetric version of this model ?

- END -

Thank you!