Partially composite Dark Matter

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(Bonn University)

Based on JHEP 1409(2014)171

MA, Ryuichiro Kitano

Topics of this talk

Composite Higgs

&

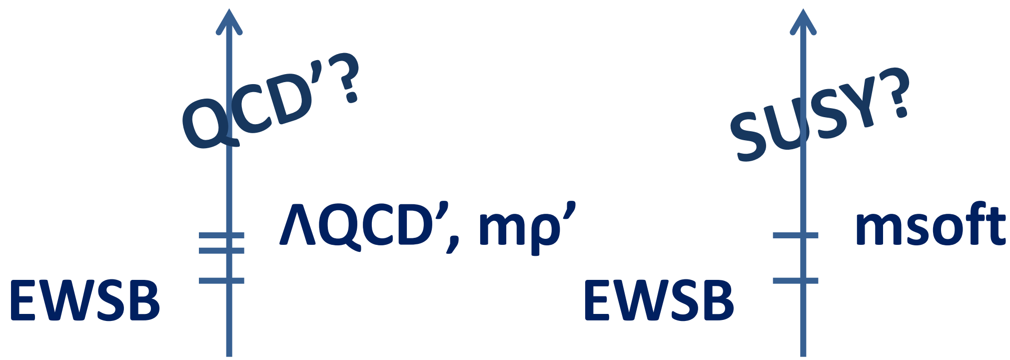
Dark Matter

Introduction

Higgs boson has been discovered.

Possibilities

composite | elementary



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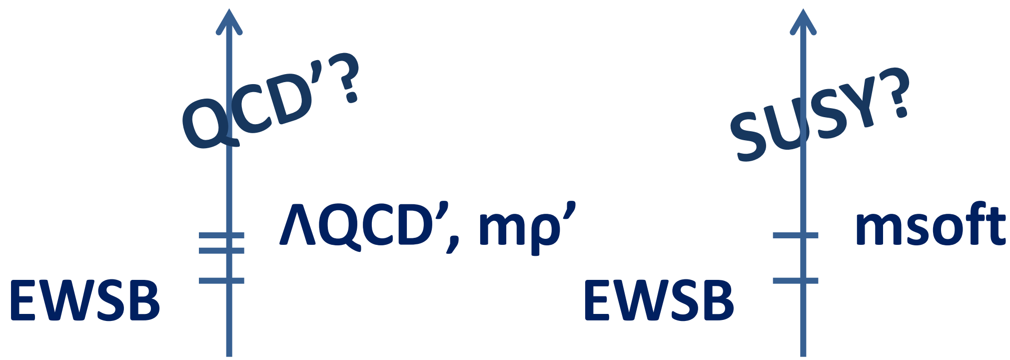

Supersymmetry

+ small soft mass

+ mechanisms for μ term,
flavor, …

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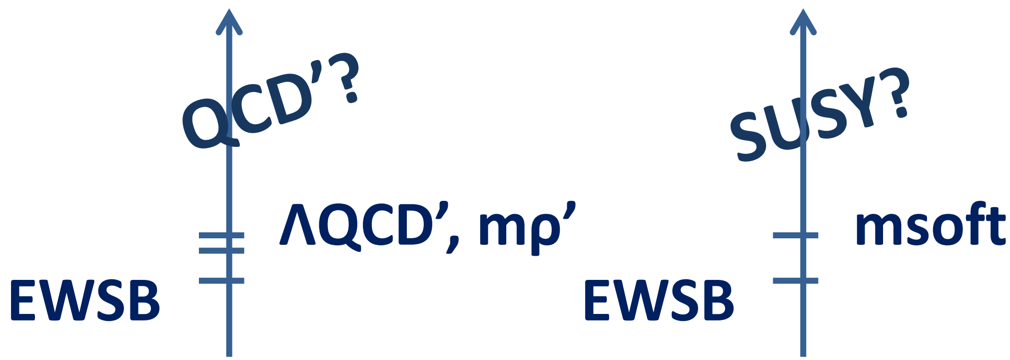
composite | **elementary**



Global symmetry

+ light composite particle

+ partially composite fermions, …

Supersymmetry

+ small soft mass

+ mechanisms for μ term, flavor, …

Composite Higgs

- **Higgs boson** is a **pseudo-NG boson**
  arising from a Global symmetry breaking.

Composite Higgs

- **Higgs boson is a pseudo-NG boson arising from a Global symmetry breaking.**

Minimal Composite Higgs Model (MCHM)

Agashe,Contino,Pomarol ’04

SO(5)/SO(4) breaking

$$SO(4) \cong SU(2)_L \times SU(2)_R$$

(custodial symmetry)

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SO(5)/SO(4) breaking

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4 NG bosons $\pi(x)$,

Higgs!!

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$\downarrow$

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Higgs!!

Generators of SO(5)/SO(4) in vector rep. 5 of SO(5)

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NLσM: $$\Sigma = \xi \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{pmatrix} = \begin{pmatrix} \dfrac{\sin(h/f)}{h} \times \begin{pmatrix} h_1/h \\ h_2/h \\ h_3/h \\ h_4/h \end{pmatrix} \\ \cos(h/f) \end{pmatrix}$$

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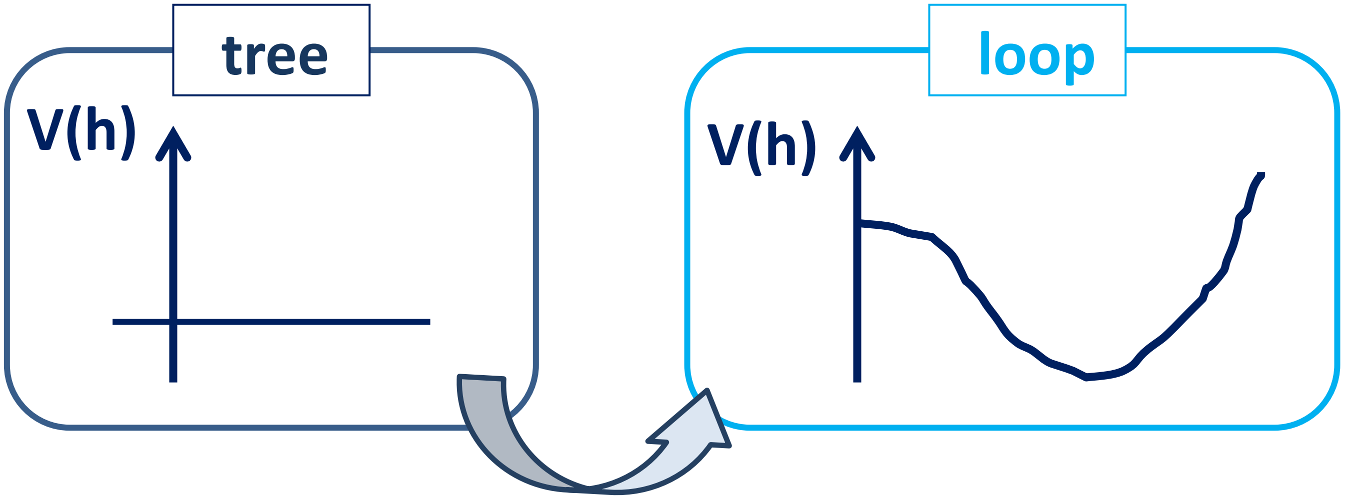
The potential is



via explicit breaking (Yukawa & gauge) couplings.

How implement the fermions?

Composite Higgs

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+ Partially composite fermions **Kaplan '91**

Elementary mix with Composite from strong sector

$$\boxed{\mathcal{L} \ni \quad \lambda_L\, \psi_L\, O_R} \qquad + (\, L \Leftrightarrow R)$$

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Explicit breaking couplings

of the global symmetry.

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Explicit breaking couplings of the global symmetry.

$\longrightarrow$ produce Yukawa coupling & Higgs potential.

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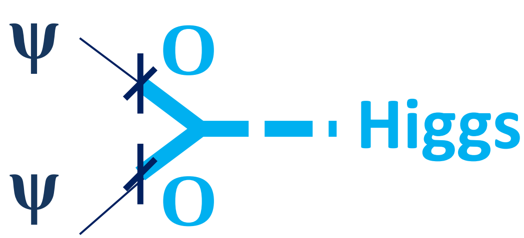
SM Yukawa



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SM Yukawa

$\longrightarrow$ **Yt ~ 1.**

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Explicit breaking couplings

Flavor constraints are mild.

(It can interpret as localization in RS via AdS/CFT correspondence.)

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Elementary mix with Composite from strong sector

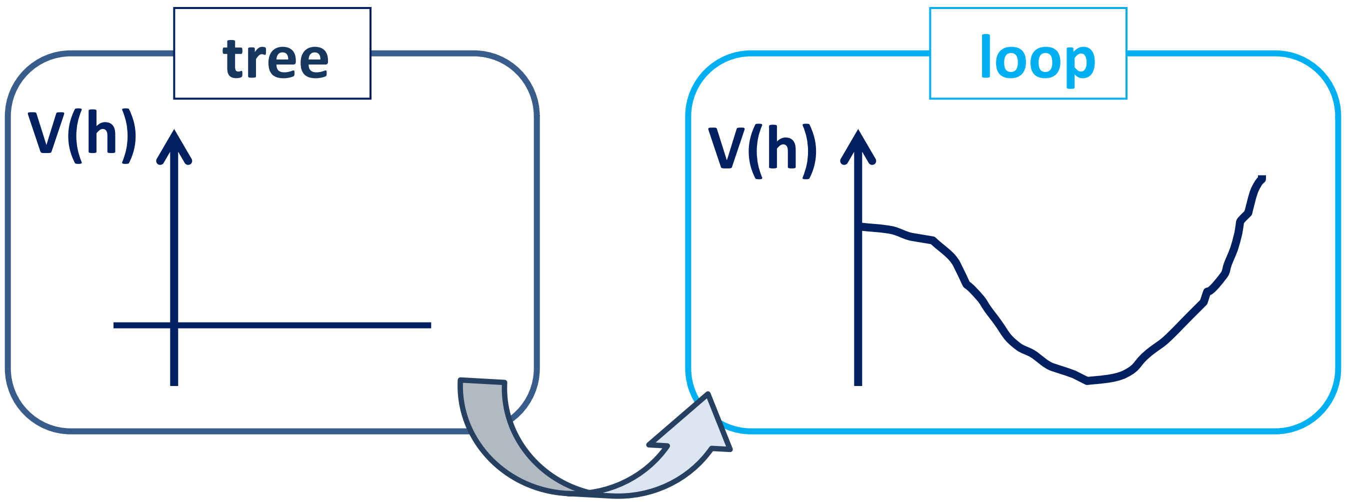
$$\boxed{\mathcal{L} \ni \lambda_L \psi_L O_R} \quad + (L \Leftrightarrow R)$$

Explicit breaking couplings

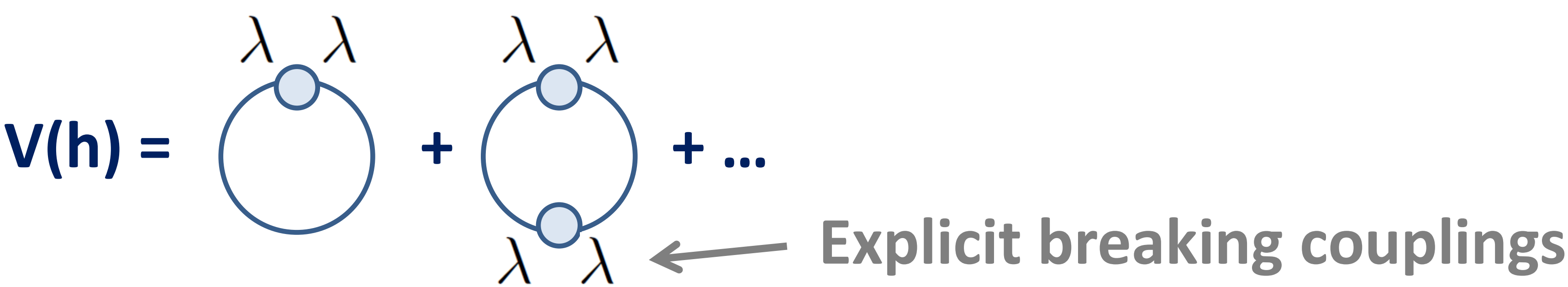
How to obtain the Higgs potential?

Composite Higgs

Potential of pseudo-NG boson is produced



via explicit breakings ($\lambda_{L,R}, \ldots$).



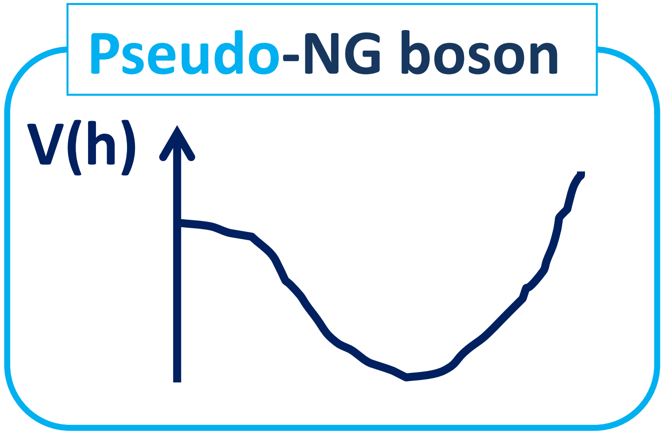
Minimal Composite Higgs Model

Agashe,Contino,Pomarol ’04

Potential

O_t: spinorial rep. 4 of SO(4)

$$V(h) \simeq \alpha_t \cos\frac{h}{f} - \beta_t \sin^2\frac{h}{f}$$



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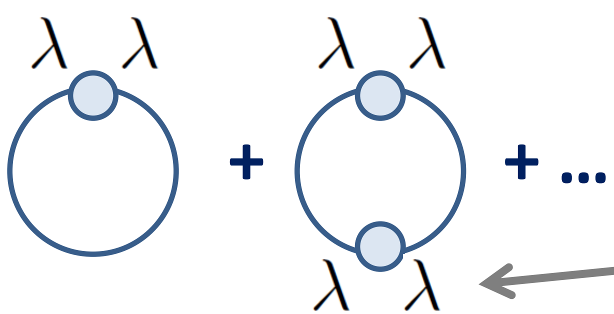

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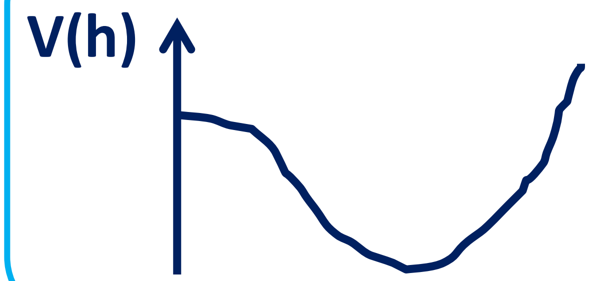

$$\alpha_t \sim \frac{\lambda^2}{(4\pi)^2}\left[\frac{m_{t'}^4}{(4\pi)^2}\right] \qquad \beta_t \sim \left(\frac{\lambda^2}{(4\pi)^2}\right)^2\left[\frac{m_{t'}^4}{(4\pi)^2}\right]$$

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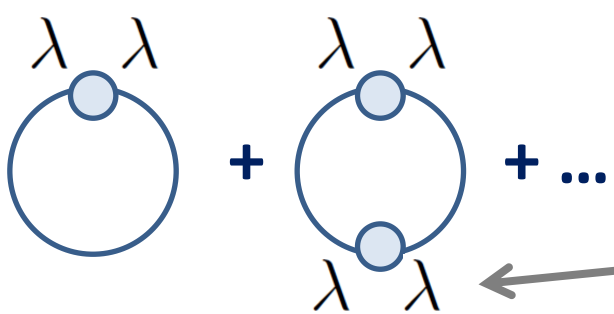

Explicit breaking couplings

Composite Higgs

- Higgs boson is a pseudo-NG boson

  arising from a Global symmetry breaking.

+ Partially composite fermions

+ light top partner

~ 1 TeV top partner is favored.

For current study with mh~ 125GeV, e.g.,
Matsedonskyi, Panico, Wulzer ’12;
Marzocca, Serone, Shu ‘12 ;…

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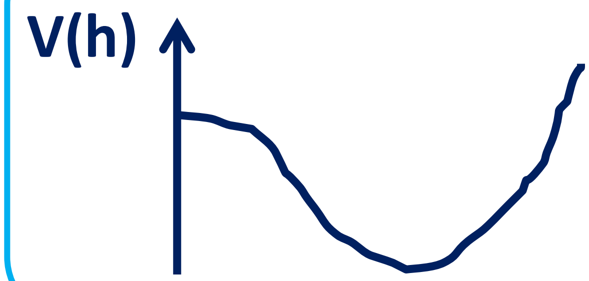

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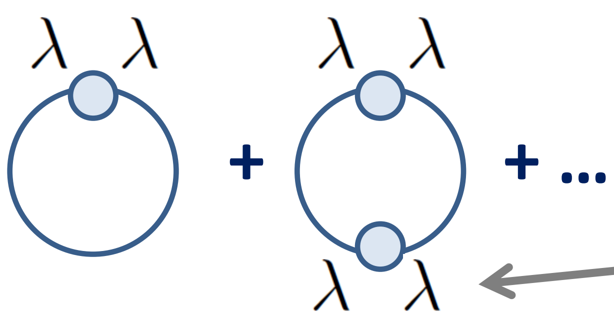

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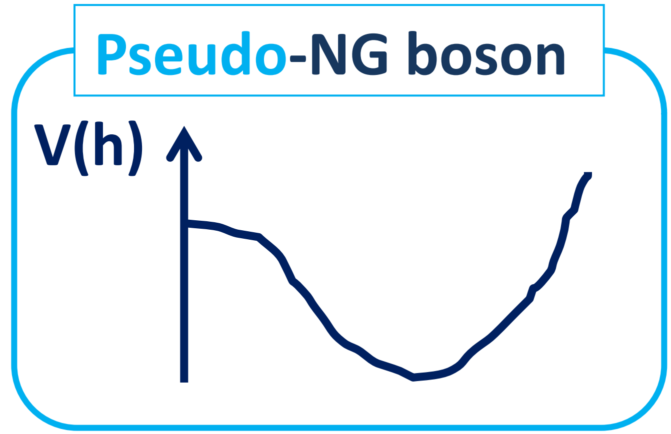

$\boxed{\text{NDA}}$ $\alpha_t \gg \beta_t$

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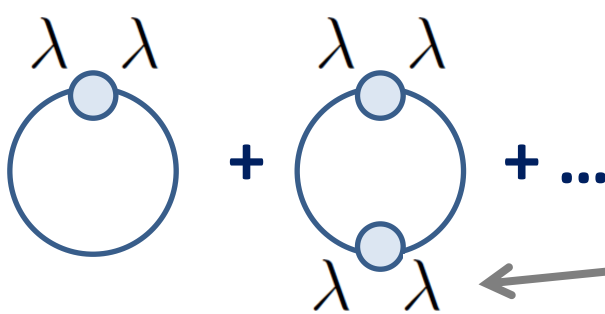

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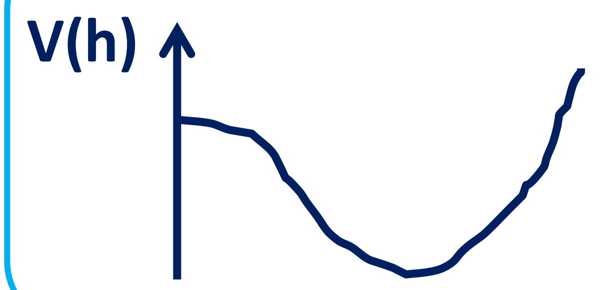
$$v = 246\ \mathrm{GeV} = \sqrt{1-\frac{\alpha_t^2}{4\beta_t^2}} \times f$$

Pseudo-NG boson



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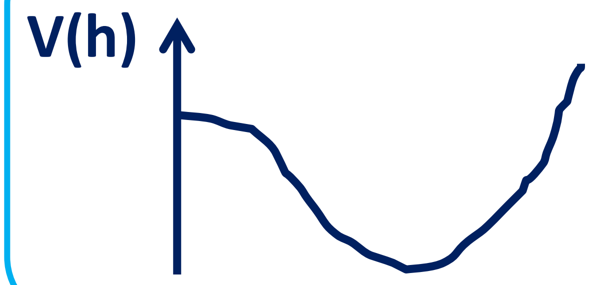

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Small $\epsilon \equiv v/f$

(i.e. v << f) is favored by experiments.

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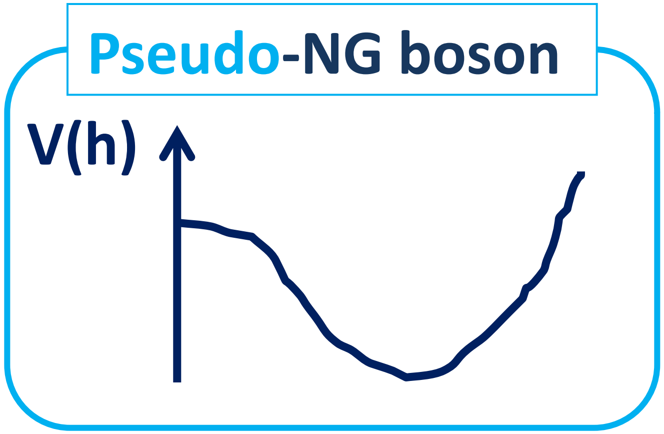
~ 1



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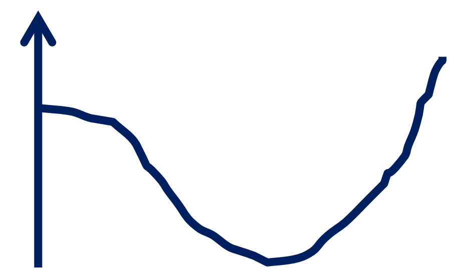

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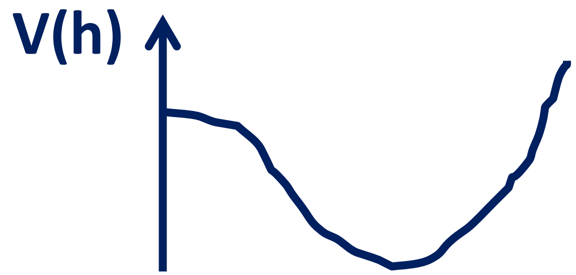

$\boxed{\epsilon \equiv v/f \ < 1}$ $\qquad \alpha_t \simeq 2\beta_t$ $\qquad$ NDA $\qquad \alpha_t \gg \beta_t$

To solve the tension,

People consider, for example, another representations,

4 -> 5 or 10 or 14 …

Dark Matter

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  - **Observed DM relic can be explained by a DM has weak scale mass & weak coupling**

MA, Kitano ’14

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DM is also partially composite fermion & the explicit breaking also contributes to Higgs potential!

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Partially composite DM

If O_{DM} is in SO(5) vector representation, 5,
the leading Dark sector contribution is $\propto \sin^2(h/f)$.

Ot: spinorial rep. 4 of SO(4)

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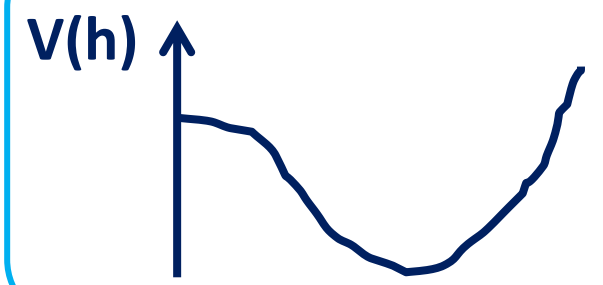

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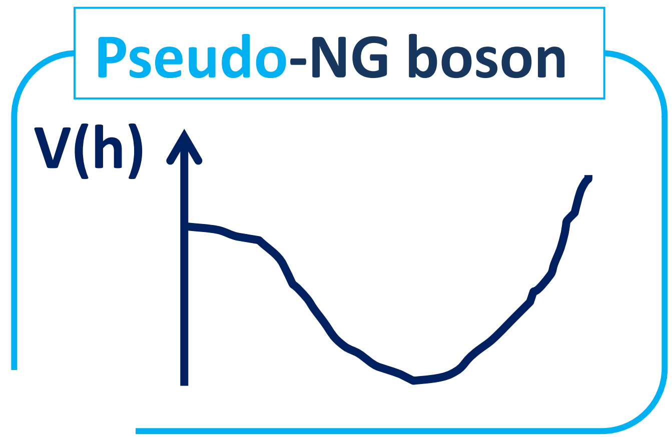

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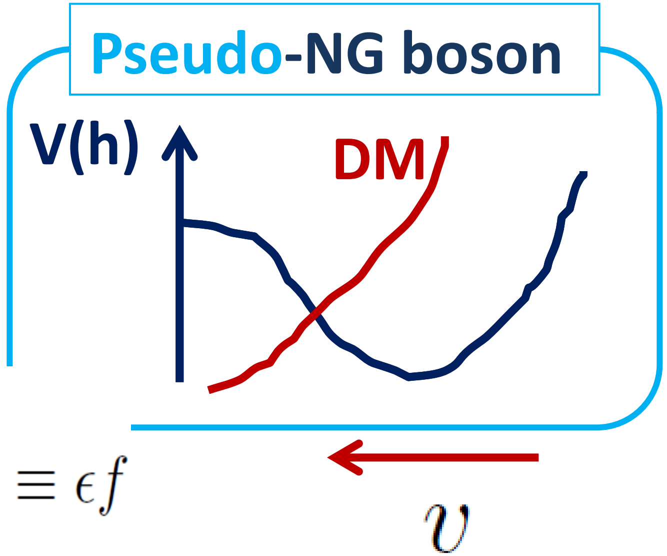

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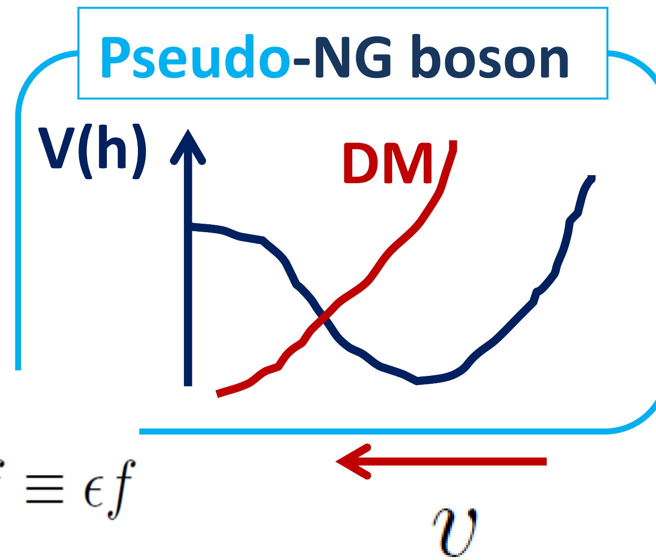

NDA $\alpha_t \gg \beta_t$

The parameter space is also consistent with observed Higgs mass & DM relic!

Partially composite DM

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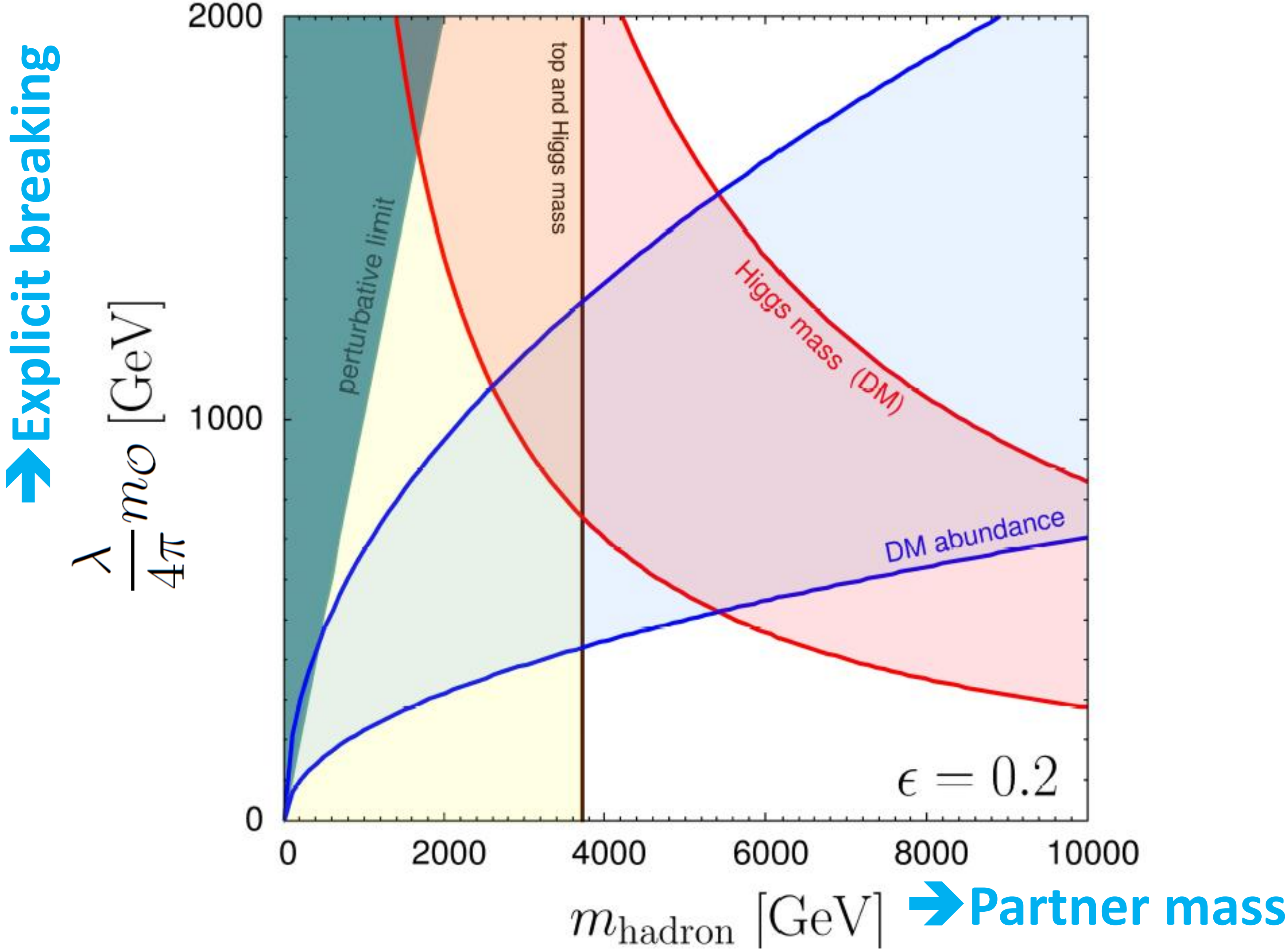

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Dark matter phenomenology

Partially composite DM

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Majorana DM: $\mathcal{L} \ni -\frac{m}{2}\bar{\psi}_S\psi_S + \lambda\bar{\psi}_S\underline{\mathcal{O}_5} + i\lambda'\bar{\psi}_S\gamma_5\underline{\mathcal{O}_5}$

After integrating out **Composite O,**

$$\boxed{\mathcal{L}_{\text{eff}} = -\frac{m_{\text{DM}}}{2}\bar{\psi}_S\psi_S + \frac{\kappa}{2}\bar{\psi}_S\psi_S\sin^2\frac{h}{f} + \frac{i\kappa_5}{2}\bar{\psi}_S\gamma_5\psi_S\sin^2\frac{h}{f}}$$

⇨ **Higgs portal DM**

$$m_{\text{DM}} \sim \kappa \sim \kappa_5 = c\left(\frac{\lambda}{4\pi}\right)^2 m_{\mathcal{O}}$$

Partially composite DM

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- Annihilation cross section

$\boxed{\text{If only } \boxed{\kappa}}$

$$\langle \sigma_{\text{ann.}} v \rangle \propto (\kappa^2 \ \text{v}^2 \ \ \text{term}) \longrightarrow \text{large } \kappa$$

- Direct detection cross section

$$\sigma_{\text{SI}} \propto \underline{\kappa^2} \longrightarrow$$

Strong constraints from DM direct detection

$$\boxed{\mathcal{L}_{\text{eff}} = -\frac{m_{\text{DM}}}{2}\bar{\psi}_S\psi_S + \frac{\kappa}{2}\bar{\psi}_S\psi_S \sin^2\frac{h}{f} + \frac{i\kappa_5}{2}\bar{\psi}_S\gamma_5\psi_S \sin^2\frac{h}{f}}$$

Partially composite DM

MA, Kitano '14

- **Annihilation cross section**

$$\langle \sigma_{\mathrm{ann.}} v \rangle \propto (\ \kappa^2\ \mathrm{v}^2\ \ \mathrm{term}\ ) + \underline{\kappa_5^2}$$

- **Direct detection cross section**

$$\sigma_{\mathrm{SI}} \propto \underline{\kappa^2} + (\ \kappa_5^2\ \mathrm{v}^2\ \ \mathrm{term}\ )$$

$$\mathcal{L}_{\mathrm{eff}} = -\frac{m_{\mathrm{DM}}}{2}\bar{\psi}_S\psi_S + \frac{\kappa}{2}\bar{\psi}_S\psi_S \sin^2\frac{h}{f} + \frac{i\kappa_5}{2}\bar{\psi}_S\gamma_5\psi_S \sin^2\frac{h}{f}$$

Partially composite DM

MA, Kitano '14

- Annihilation cross section

$$\langle \sigma_{\mathrm{ann.}} v \rangle \propto (\kappa^2 \mathrm{v}^2 \ \mathrm{term}) + \underline{\kappa_5^2}$$

- Direct detection cross section

$$\sigma_{\mathrm{SI}} \propto \underline{\kappa^2} + (\kappa_5^2 \mathrm{v}^2 \ \mathrm{term})$$

If $\cancel{CP}$ in strong sector, $\kappa \sim \kappa_5$, large κ is not required to explain observed DM relic, then, constraints from direct detection can be mild.

Partially composite DM

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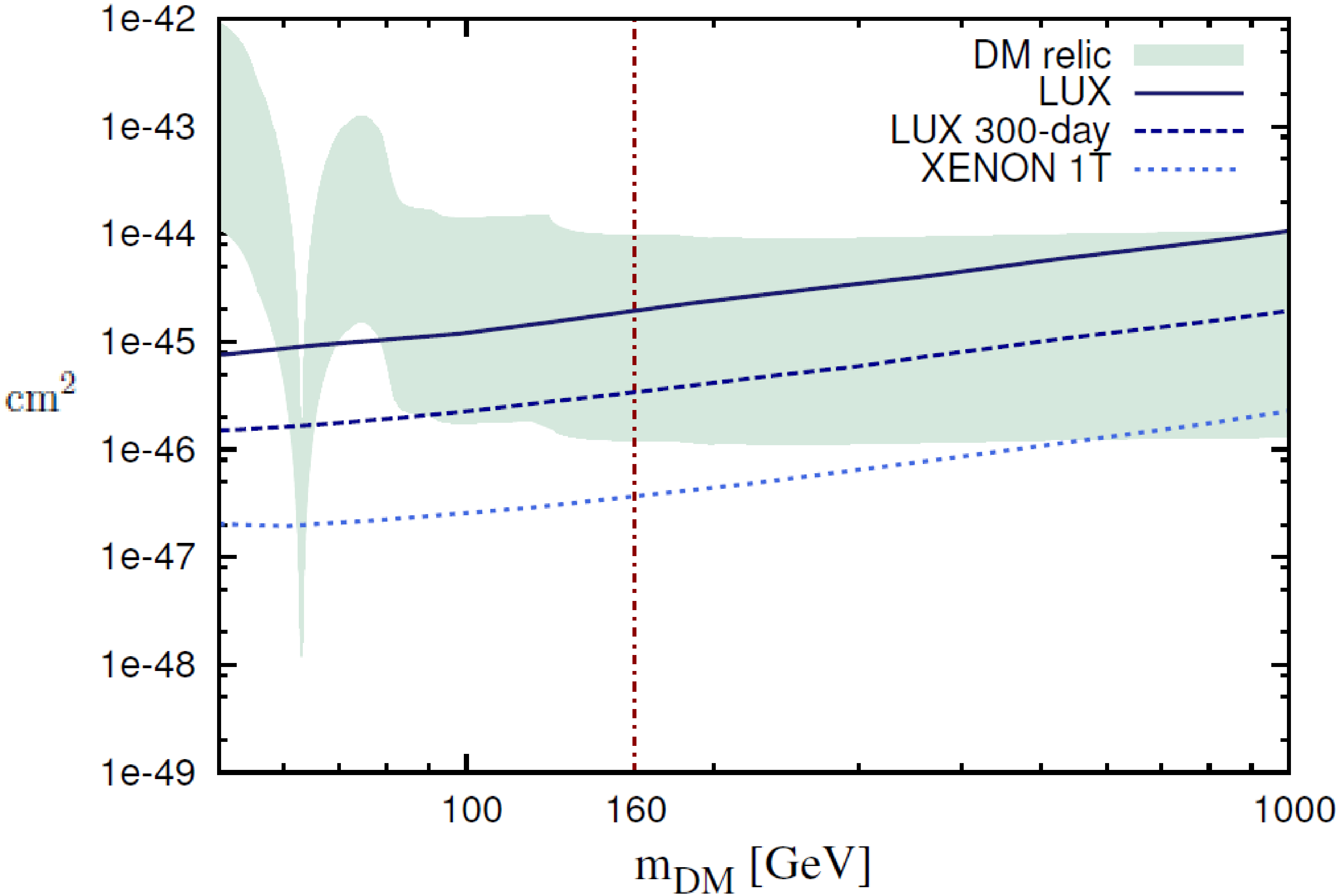


$$1/3 < \kappa_{\cdot}/\kappa_5 < 3$$

Partially composite DM

Other prediction:

Higgs physics

As other composite Higgs model, there are deviations from SM coupling.

Direct search for top partner

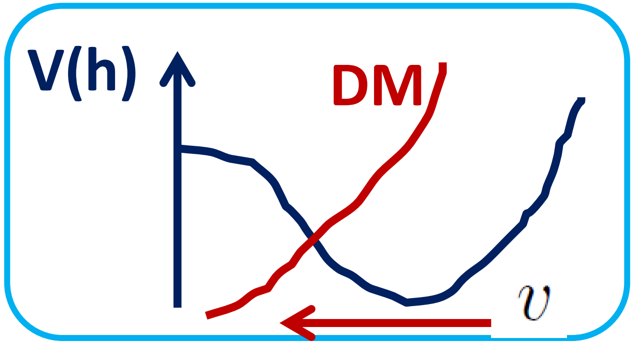
Current bound is roughly mt’< 700 GeV.

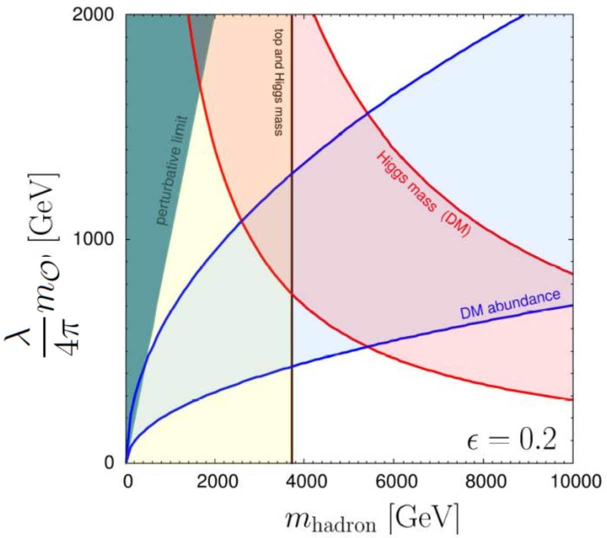
Summary

Summary

We consider a composite Higgs scenario in which Dark matter is also a partially composite fermion.

- **DM also contribute making Higgs potential.**
- **Parameter space consists with both Higgs & DM observables.**
- **It would be measure by DM DD in near future.**





Partially composite DM

MA, Kitano '14

$$\Omega_{\mathrm{DM}} h^2 = 0.12 \qquad \kappa_5 = 160 \text{ GeV} \left(\frac{\epsilon}{0.2}\right)^{-2}$$

$$\Rightarrow \quad \lambda f_{\mathcal{O}} = 900 \text{ GeV} \cdot c_{\kappa_5}^{-1/2} \left(\frac{m_{\mathcal{O}}}{5 \text{ TeV}}\right)^{1/2} \left(\frac{\epsilon}{0.2}\right)^{-1}$$

$$\Rightarrow \quad m_{\mathrm{DM}} = 160 \text{ GeV} \left(\frac{c_{\mathrm{DM}}}{c_{\kappa_5}}\right) \left(\frac{\epsilon}{0.2}\right)^{-2}$$

$$\Rightarrow \quad \sigma_{\mathrm{SI}} \simeq 1.2 \times 10^{-45} \mathrm{cm}^2 \left(\frac{c_\kappa}{c_{\kappa_5}}\right)^2$$

Partially composite DM

MA, Kitano '14

$$m_h^2 = (126\ \mathrm{GeV})^2 = \frac{2(\beta + \beta_t)\epsilon^2}{f^2}$$

$$m_{\mathcal{O}} = 4.9\ \mathrm{TeV} \cdot c_\beta^{-1/2} \left(\frac{\lambda f_{\mathcal{O}}}{1\ \mathrm{TeV}}\right)^{-1} \left(\frac{\epsilon}{0.2}\right)^{-2}$$

$$m_{t'} = 2.4\ \mathrm{TeV} \left(\frac{c_t \cdot 2\lambda_q \lambda_u}{c_q \lambda_q^2 + c_u \lambda_u^2}\right)^{1/3} \left(\frac{\epsilon}{0.2}\right)^{-1}$$

$$\leq 2.4\ \mathrm{TeV} \left(\frac{c_t}{\sqrt{c_q c_u}}\right)^{1/3} \left(\frac{\epsilon}{0.2}\right)^{-1}$$

$$\frac{\lambda_q \lambda_u f_{t'}^2}{m_{t'}^2} = 0.5 \cdot c_t^{-1} \left(\frac{\epsilon}{0.2}\right)^{-1} \left(\frac{m_{t'}}{2.4\ \mathrm{TeV}}\right)^{-1}$$

Partially composite DM

MA, Kitano '14

$$\mathcal{L} \ni -\frac{m}{2}\bar{\psi}_S\psi_S + \lambda\bar{\psi}_S\mathcal{O}_5 + i\lambda'\bar{\psi}_S\gamma_5\mathcal{O}_5$$

$$\mathcal{O} = \begin{pmatrix} \mathcal{O}_1 \\ \mathcal{O}_2 \\ \mathcal{O}_3 \\ \mathcal{O}_4 \\ \mathcal{O}_5 \end{pmatrix}$$

$$\langle\psi_S(x)\bar{\psi}_S(0)\rangle = -\int\frac{d^4k}{i(2\pi)^4}\frac{e^{-ikx}}{\not{k} + \lambda^2\Pi_{55}(k)},$$

$$\begin{aligned}\Pi_{ij}(q) &= i\int d^4x\langle\mathcal{O}_i(x)\bar{\mathcal{O}}_j(0)\rangle e^{iqx} \\ &= \Pi_4(q)(\delta_{ij} - \Sigma_i\Sigma_j) + \Pi_1(q)\Sigma_i\Sigma_j.\end{aligned}$$

decompose Π's

in terms of the unbroken $SO(4)$

$$\begin{aligned}V(h) &= -\frac{1}{2}\int\frac{d^4k}{i(2\pi)^4}\mathrm{Tr}\log[\not{k} + \lambda^2\Pi_{55}(k) + i\epsilon] \\ &= \mathrm{const.} - \frac{1}{2}\int\frac{d^4k}{i(2\pi)^4}\mathrm{Tr}\left[\frac{-\lambda^2}{\not{k} + i\epsilon}(\Pi_4(k) - \Pi_1(k))\Sigma_5\Sigma_5\right] + O(\lambda^4) \\ &\equiv \mathrm{const.} - \beta\sin^2\frac{h}{f} + O(\lambda^4),\end{aligned}$$

Minimal Composite Higgs Model

Agashe,Contino,Pomarol '04

Top sector

A spinorial representation of SO(5), a **4** of SO(5), contains two (complex) doublets, one transforming under $\mathrm{SU}(2)_L$, the other transforming under $\mathrm{SU}(2)_R$.

$$\Psi_q = \begin{bmatrix} q_L \\ Q_L \end{bmatrix}, \qquad \Psi_u = \begin{bmatrix} q_R^u \\ \begin{pmatrix} u_R \\ d'_R \end{pmatrix} \end{bmatrix}, \qquad \Psi_d = \begin{bmatrix} q_R^d \\ \begin{pmatrix} u'_R \\ d_R \end{pmatrix} \end{bmatrix}$$

$$\mathcal{L}_{\rm eff} = $$

$$\sum_{r=q,u,d} \bar{\Psi}_r \, \not{p} \left[\Pi_0^r(p) + \Pi_1^r(p) \, \Gamma^i \Sigma_i \right] \Psi_r + \sum_{r=u,d} \bar{\Psi}_q \left[M_0^r(p) + M_1^r(p) \, \Gamma^i \Sigma_i \right] \Psi_r$$

$P_{\mu\nu} = \eta_{\mu\nu} - p_\mu p_\nu / p^2$ and Γ^i, $i = 1, \dots 5$, are the gamma matrices for SO(5)

Minimal Composite Higgs Model

Agashe,Contino,Pomarol ’04

SO(5)/SO(4) breaking

$$SO(4) \cong SU(2)_L \times SU(2)_R$$

$\longrightarrow$ **4 NG bosons** $\pi(x)$, $\xi(x) = e^{i\pi^a(x)X^a/f}$

Generators of SO(5)/SO(4) in vector rep. 5 of SO(5)

Higgs field

$$\Sigma(x) = \xi(x) \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{pmatrix} = \begin{pmatrix} \underline{\sin(h/f)} \times \begin{pmatrix} h_1/h \\ h_2/h \\ h_3/h \\ h_4/h \end{pmatrix} \\ \underline{\cos(h/f)} \end{pmatrix}$$

$$h^2 = h_1^2 + h_2^2 + h_3^2 + h_4^2 \qquad \langle h \rangle = \langle h_3 \rangle \neq 0$$