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bctp Bethe Center for Theoretical Physics

Partially Composite Dark Matter in Composite Higgs Model

Masaki Asano
(Bonn University)

JHEP 1409(2014)171 **MA, Ryuichiro Kitano**
and more…

Topics of this talk

Composite Higgs

&

Dark Matter

Topics of this talk

1. Brief review of

Composite Higgs

&

2. Model with

Dark Matter

Topics of this talk

1. Brief review of

Composite Higgs

&

2. Model with

Dark Matter

produce the Higgs potential

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

↓

4 NG bosons $\pi(x)$,

Higgs!!

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

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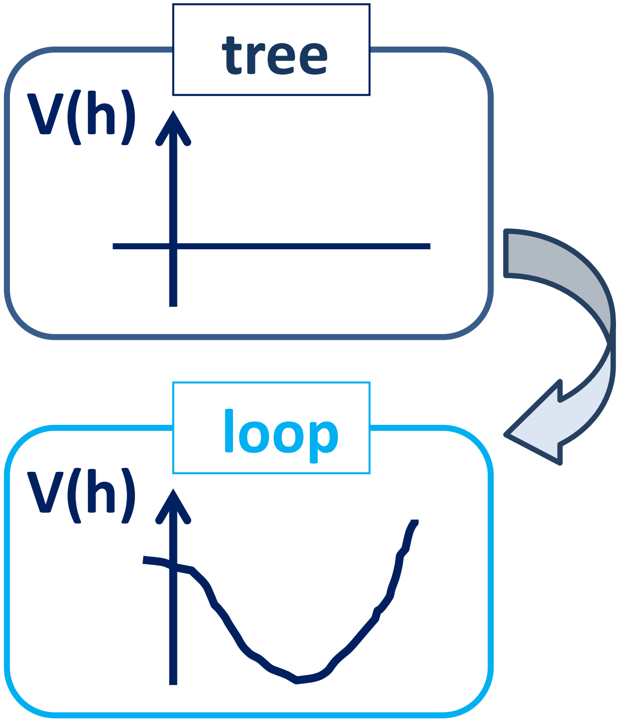
NLσM: $$\Sigma = e^{i\pi^a(x)X^a/f}\begin{pmatrix}0\\0\\0\\0\\1\end{pmatrix} = \begin{pmatrix}\frac{\sin(h/f)}{h}\times\begin{pmatrix}h_1/h\\h_2/h\\h_3/h\\h_4/h\end{pmatrix}\\ \cos(h/f)\end{pmatrix}$$

Composite Higgs

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

  - **Higgs potential is protected by the Global Symmetry.**

  - **EWSB scale is produced by the Explicit Breaking. (Yukawa & gauge couplings)**



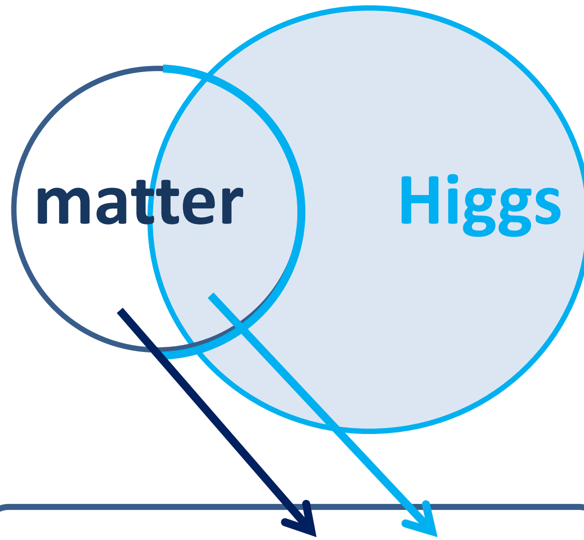
[Next] How implement the top quark? →

Composite Higgs

Top quark is implemented as

Partially composite fermions Kaplan '91

Elementary sector



Composite sector

Elementary -Composite mixing

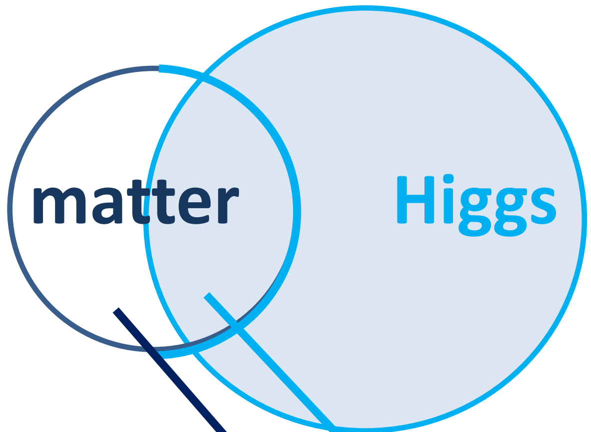
$$\mathcal{L} \ni \lambda_L \psi_L O_R \quad + (L \Leftrightarrow R)$$

Composite Higgs

Top quark is implemented as

Partially composite fermions Kaplan ’91

Elementary sector



Composite sector

Elementary -Composite mixing

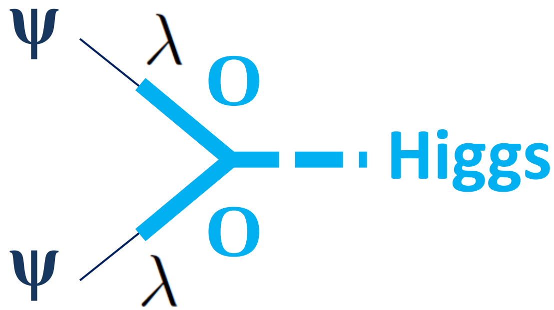
$$\mathcal{L} \ni \lambda_L \psi_L O_R + (L \Leftrightarrow R)$$

↓

Explicit breaking couplings

→ **produce Yukawa coupling & Higgs potential.**

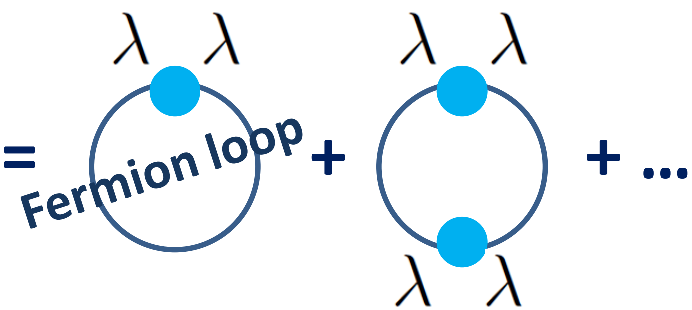
■ Yukawa coupling (very rough discussion)



$$\longrightarrow \quad y_t \sim \frac{\lambda^2}{4\pi} \sim 1$$

■ Higgs potential

V(h) =



$$\longrightarrow \quad m_h^2 \sim \frac{\lambda^4}{(16\pi^2)^2}\frac{v^2}{f^4}m_T^4$$

Light top partner (~1 TeV) is favored. $\sim \frac{y_t^2}{16\pi^2}\frac{v^2}{f^4}m_T^4$

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

Before Dark matter discussion,

We'll see how to get v ~246GeV.

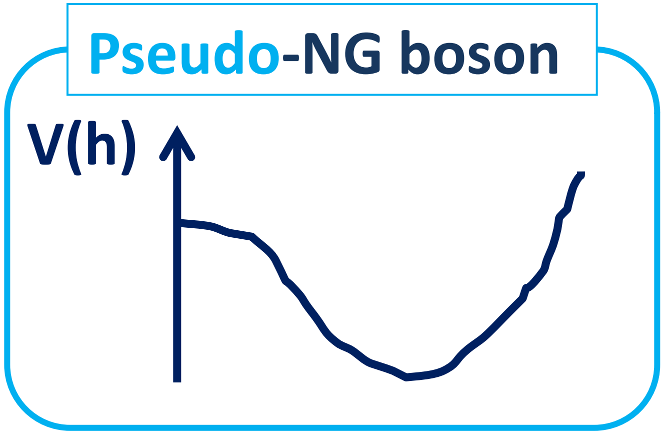
Minimal Composite Higgs Model

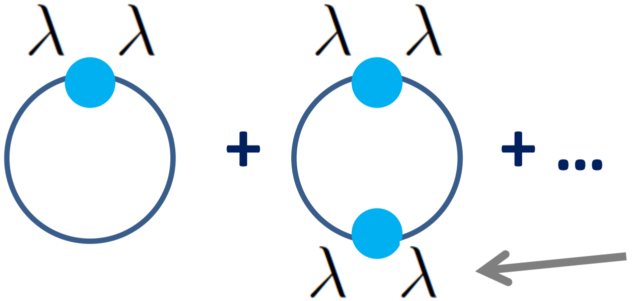
Agashe,Contino,Pomarol '04

Potential

O_t: spinorial rep. 4 of SO(4)

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



V(h) = 

Explicit breaking couplings

Minimal Composite Higgs Model

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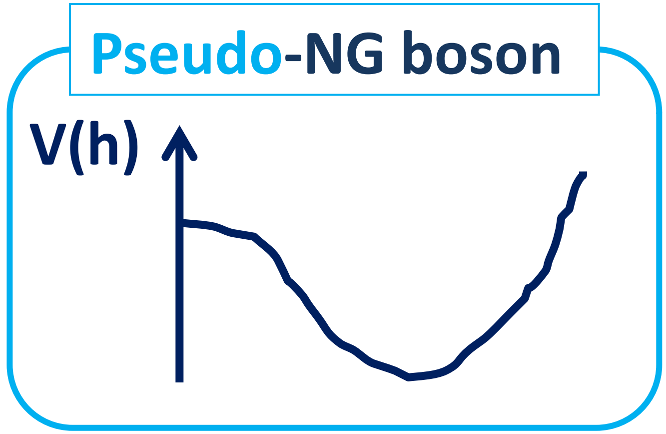
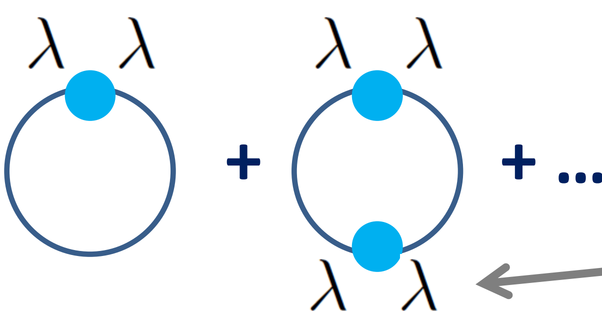


$$\alpha_t \sim \frac{\lambda^2}{(4\pi)^2}\left[\frac{m_{t'}^4}{(4\pi)^2}\right] \qquad \beta_t \sim \left(\frac{\lambda^2}{(4\pi)^2}\right)^2\left[\frac{m_{t'}^4}{(4\pi)^2}\right]$$

V(h) =



Explicit breaking couplings

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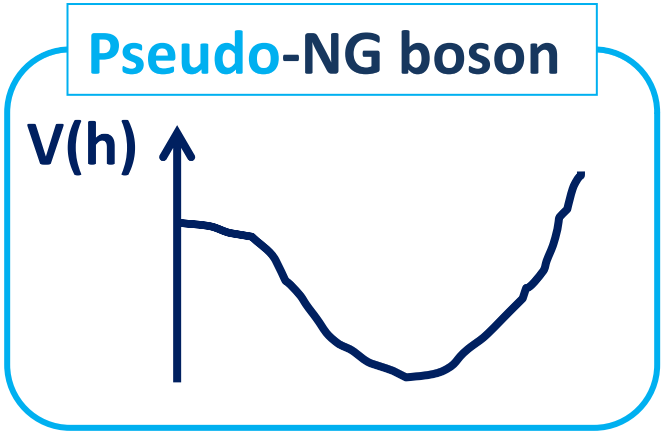
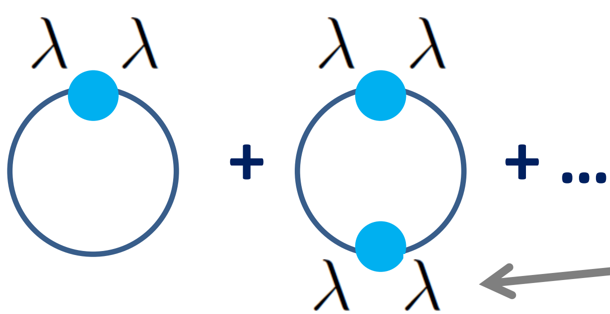


NDA $\alpha_t \gg \beta_t$

V(h) = 

Explicit breaking couplings

Minimal Composite Higgs Model

Agashe,Contino,Pomarol ’04

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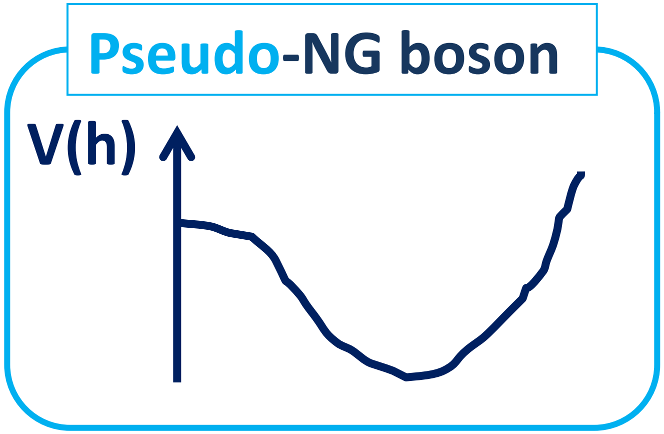
O_t: spinorial rep. 4 of SO(4)

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

$$\frac{\partial V}{\partial h} = 0$$

$$v/f = \sqrt{1 - \frac{\alpha_t^2}{4\beta_t^2}} \equiv \epsilon$$



NDA $\alpha_t \gg \beta_t$

Small ϵ (i.e. v << f)

is favored by experiments.

Minimal Composite Higgs Model

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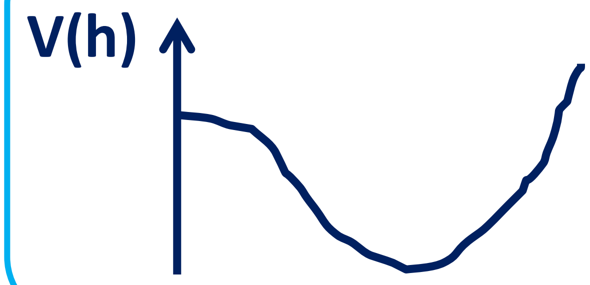
Pseudo-NG boson



$\epsilon \equiv v/f$ **< 1** $\qquad \alpha_t \simeq 2\beta_t$

NDA $\qquad \alpha_t \gg \beta_t$

$$v/f = \sqrt{1 - \frac{\alpha_t^2}{4\beta_t^2}} \equiv \epsilon$$

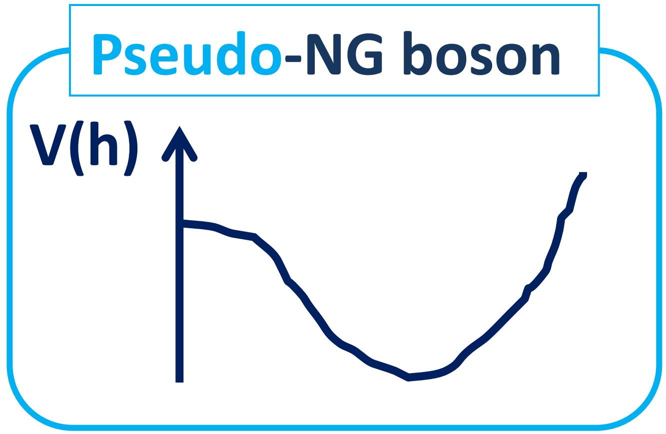
Small ϵ (i.e. v << f) is favored by experiments.

$\frac{\alpha_t^2}{4\beta_t^2}$ → **~ 1**

Minimal Composite Higgs Model

Agashe, Contino, Pomarol '04

Potential



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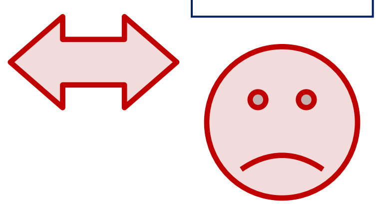

NDA $\quad \alpha_t \gg \beta_t$

To solve the tension,

People consider, for example, another representations,

4 -> 5 or 10 or 14 … ← Panico, Redi Tesi, Wulzer '12

The situation can change

by considering Dark matter!

Dark Matter

- **Dark matter exists** $\Omega_{\rm DM}h^2 = 0.12$

- **We know "WIMP Miracle"**
  - **Observed DM relic can be explained by a DM has weak scale mass & weak coupling**

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

DM may also couple to Higgs weakly.

Dark Matter

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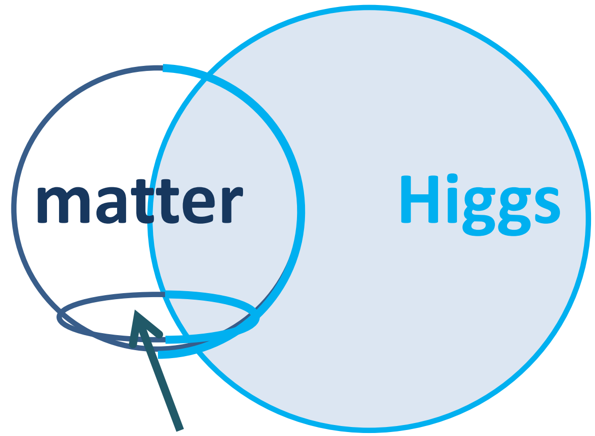
- **We know "WIMP Miracle"**
  - **Observed DM relic can be explained by a DM has weak scale mass & weak coupling**

DM may also couple to Higgs (i.e. strong sector) weakly.

MA, Kitano '14

Dark Matter

Elementary sector



Composite sector

Dark Matter

$$\mathcal{L} \ni \lambda \, \psi_{DM} \, O$$

Elementary (ψ_{DM}) Composite (O)

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

MA, Kitano ’14

Partially composite DM

Ot: 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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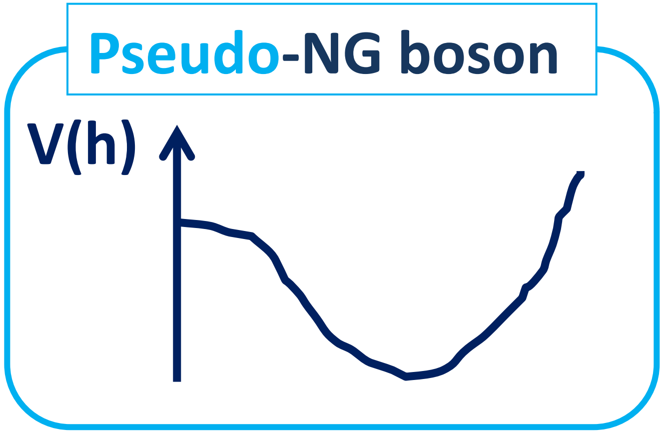

$\epsilon \equiv v/f$ **< 1** $\quad \alpha_t \simeq 2\beta_t$ ⟺ **NDA** $\quad \alpha_t \gg \beta_t$

MA, Kitano ’14

Partially composite DM

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

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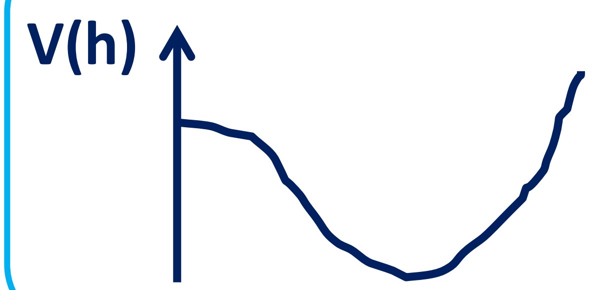
Pseudo-NG boson



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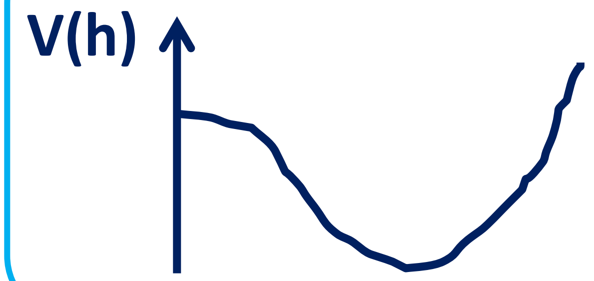

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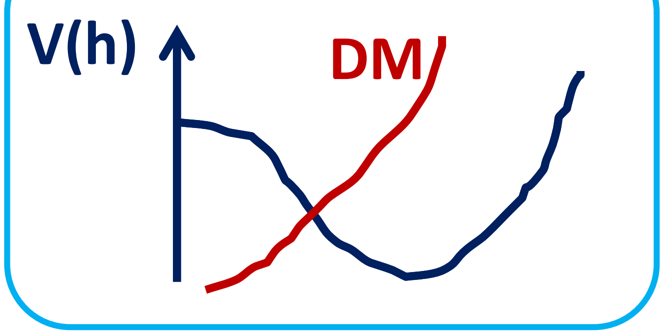
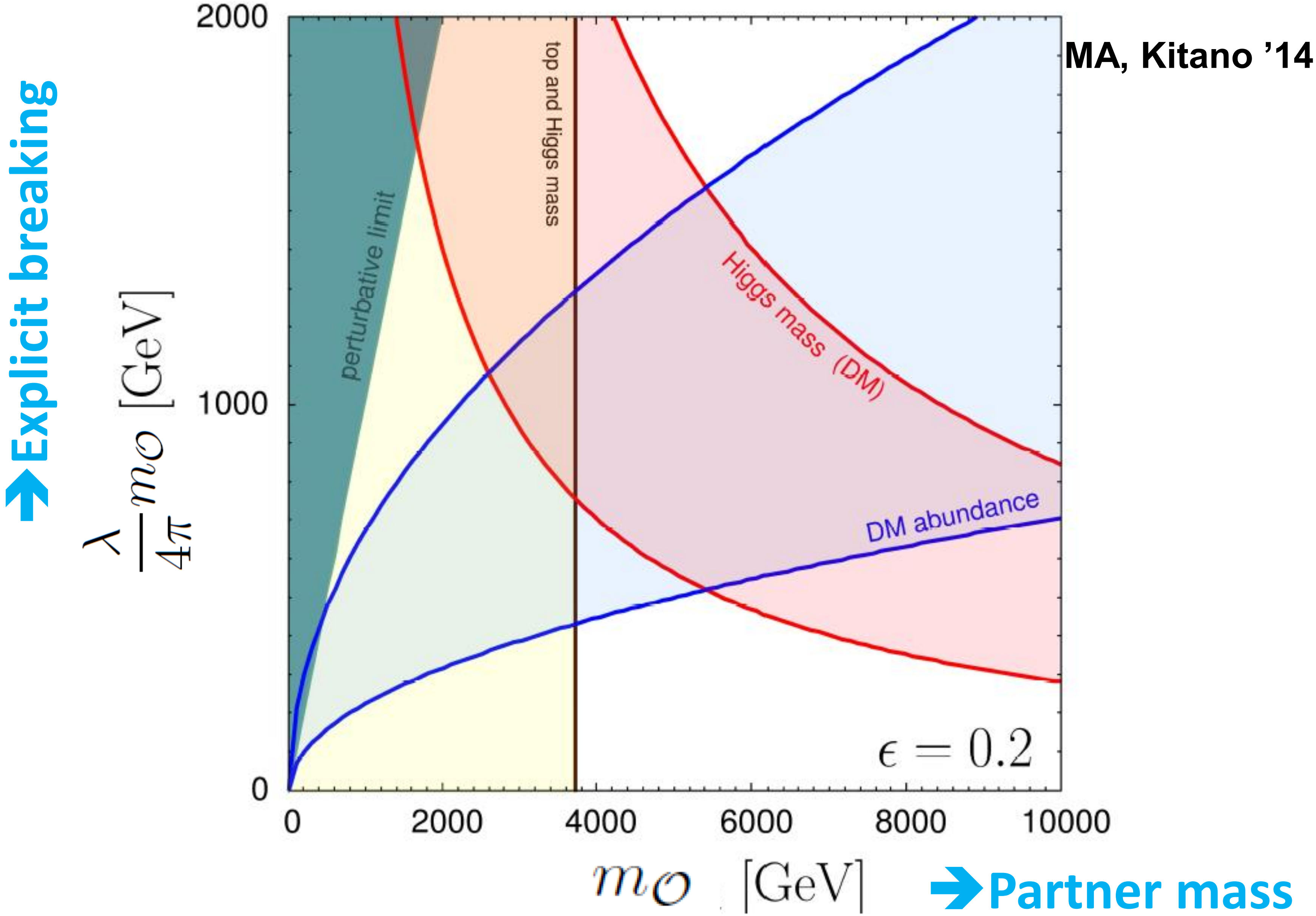


v

$\epsilon \equiv v/f$ < 1

$\beta \simeq \alpha_t \gg \beta_t$

NDA $\alpha_t \gg \beta_t$



It's also consistent with DM relic!

MA, Kitano ’14

Dark matter phenomenology

Partially composite DM

MA, Kitano '14

After integrating out Composite O,
we obtain the low-energy effective theory as

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

⇒ This is similar to "Higgs portal DM model".

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

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

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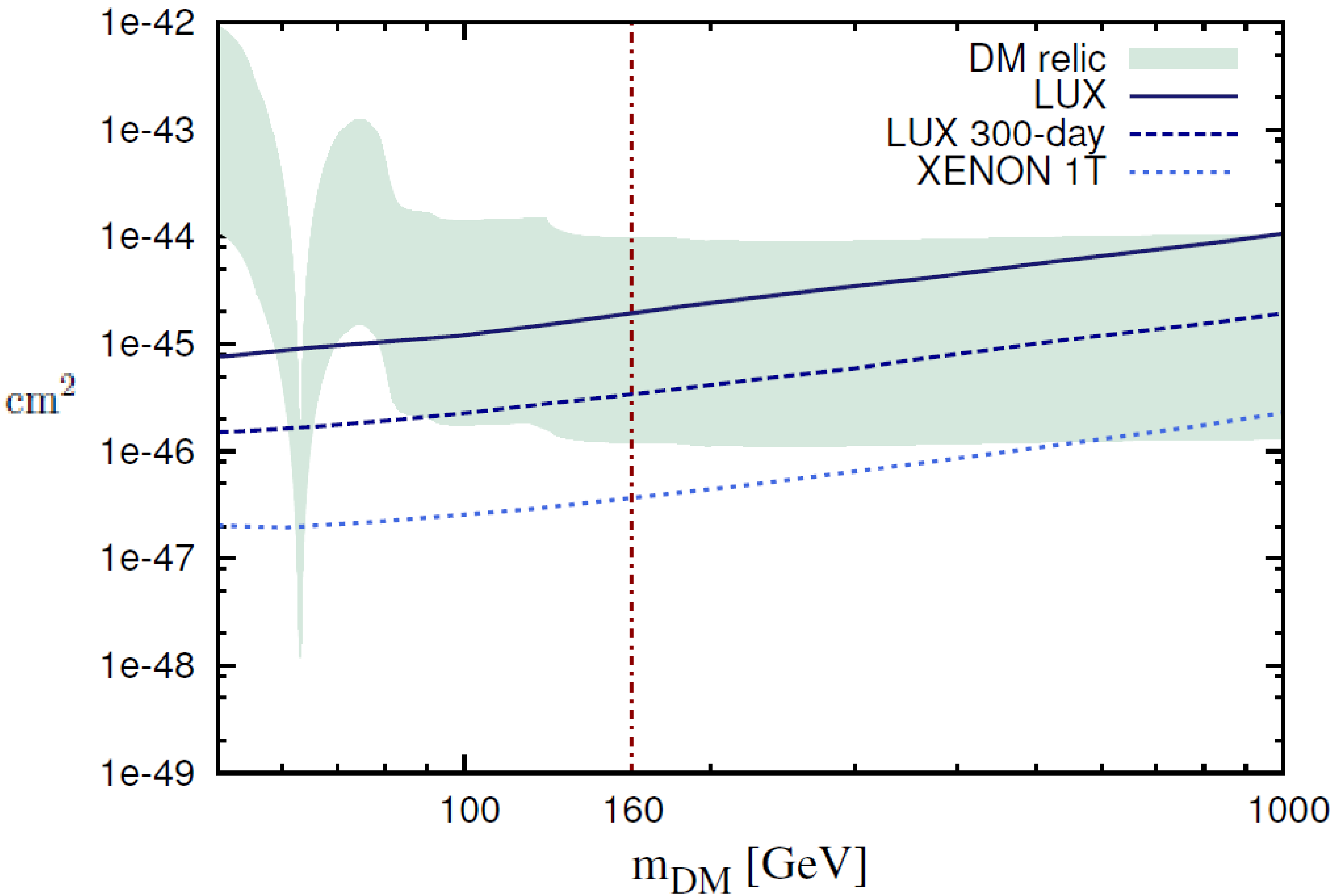
- Direct detection cross section

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

If ~~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

MA, Kitano '14



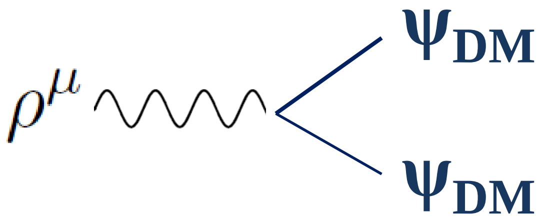
$1/3 < \kappa_{.}/\kappa_5 < 3$

Partially composite DM

$$\mathbf{5_0} = (\mathbf{2}, \mathbf{2})_\mathbf{0} + (\mathbf{1}, \mathbf{1})_\mathbf{0}$$

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

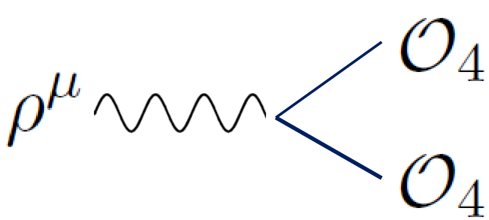
Spin-1 resonance ρ^μ



$$\sim g_\rho \epsilon^2 \left(\frac{\lambda}{4\pi}\right)^2 \gamma_5$$

Due to the ε² supression, this Br is small.

If it is kinematically allowed,



$$\sim g_\rho$$

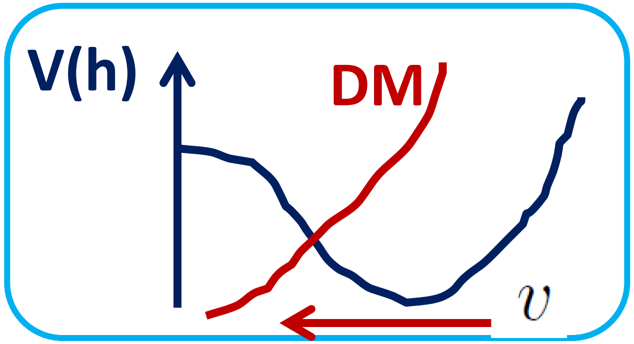
Summary

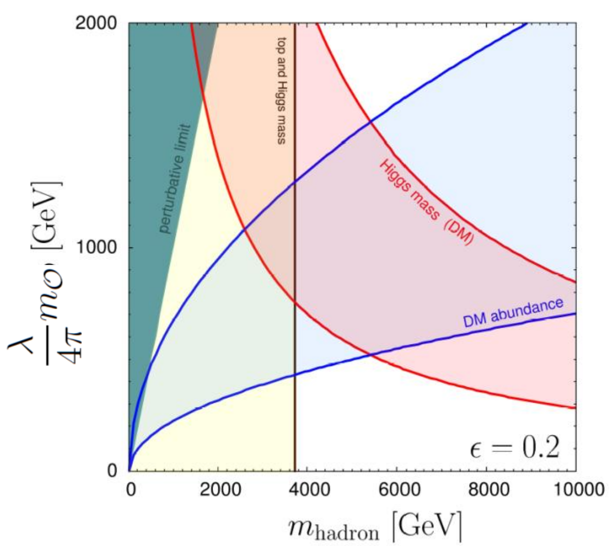
Summary

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

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

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

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

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

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

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

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

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

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

decompose Π's

in terms of the unbroken $SO(4)$

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

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, $i = 1, \ldots 5$, are the gamma matrices for SO(5)