universitätbonn bctp Bethe Center for Theoretical Physics

Partially composite Dark Matter

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(Bonn University)

Based on JHEP 1409(2014)171

MA, Ryuichiro Kitano

Topic of this talk

Composite Higgs

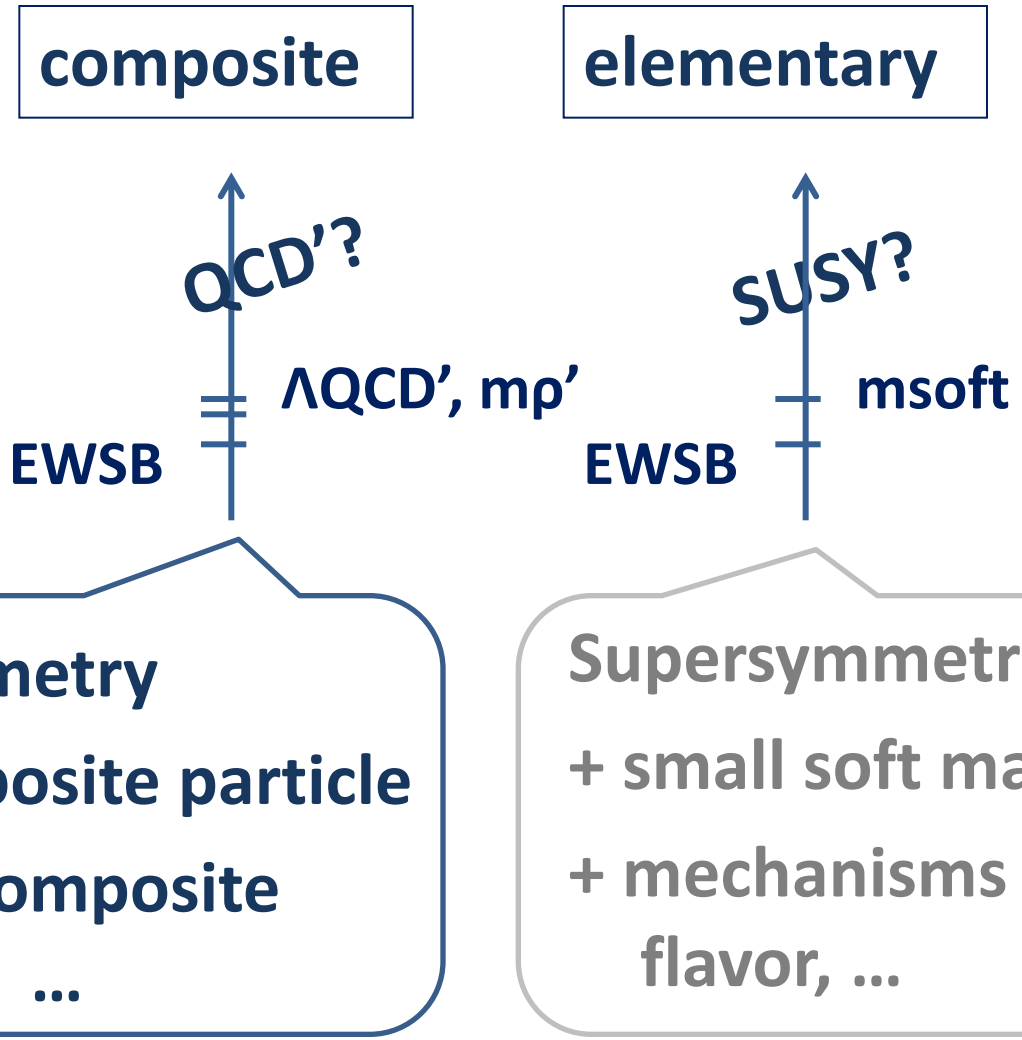
&

Dark Matter

Introduction

Higgs boson has been discovered.

Possibility



Composite Higgs

- **Higgs boson is a pseudo-NG boson**

  arising from a Global symmetry breaking.

Minimal Composite Higgs Model

Agashe,Contino,Pomarol '04

SO(5)/SO(4) breaking

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

(custodial symmetry)

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

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

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

Composite Higgs

- **Higgs boson is a pseudo-NG boson**

  arising from a Global symmetry breaking.

+ Partially composite fermions

SM fermions are partially composite.

Minimal Composite Higgs Model

Agashe,Contino,Pomarol '04

Partially composite fermions

Kaplan '91

Elementary ψ mix with Composite from strong sector

$$\mathcal{L} \ni \lambda_L \psi_L O_R + \lambda_R \psi_R O_L$$

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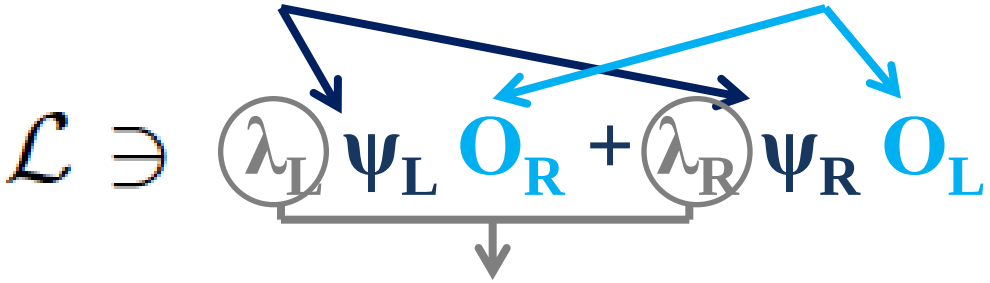

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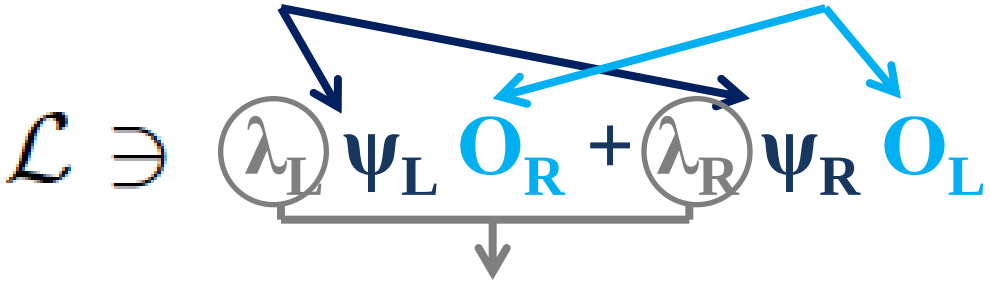

Explicit breaking couplings

of the global symmetry.

$\longrightarrow$ Yukawa coupling &

Higgs potential

are produced by this couplings.

Minimal Composite Higgs Model

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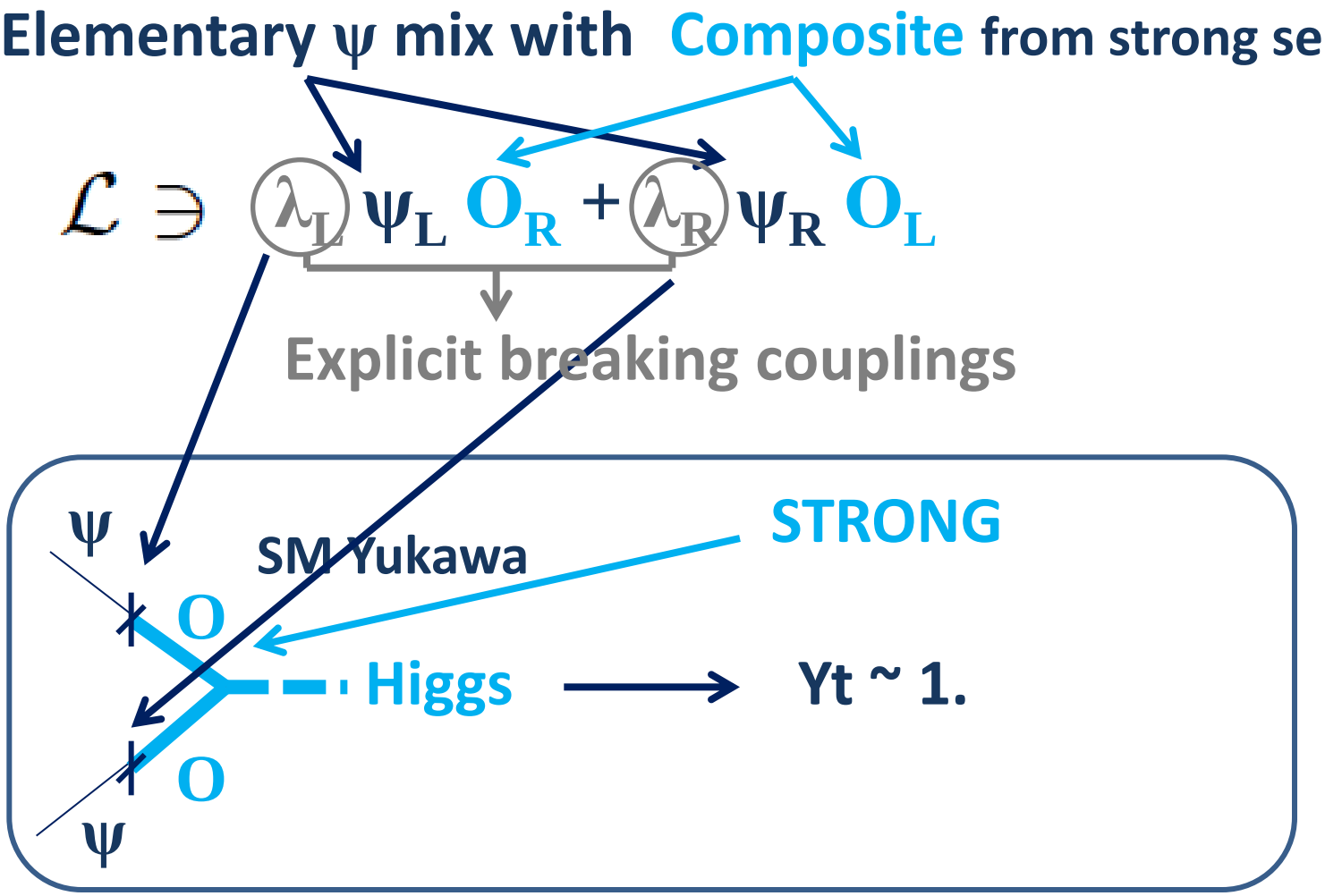

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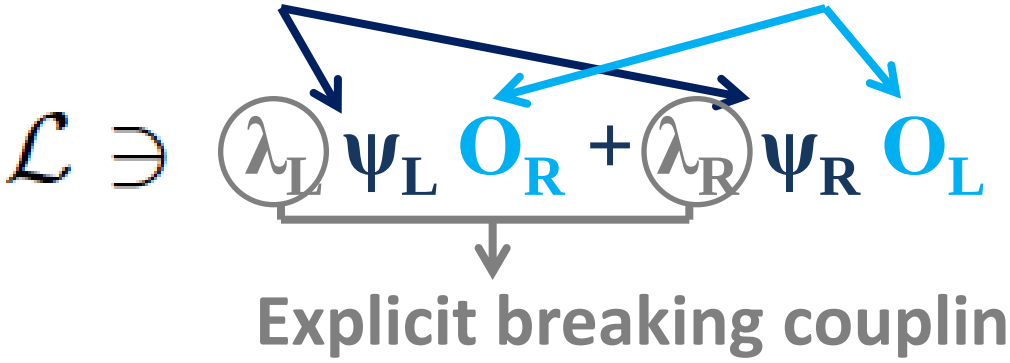


Flavor constraints are mild.

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

Composite Higgs

- **Higgs boson is a pseudo-NG boson**

  arising from a Global symmetry breaking.

+ Partially composite fermions

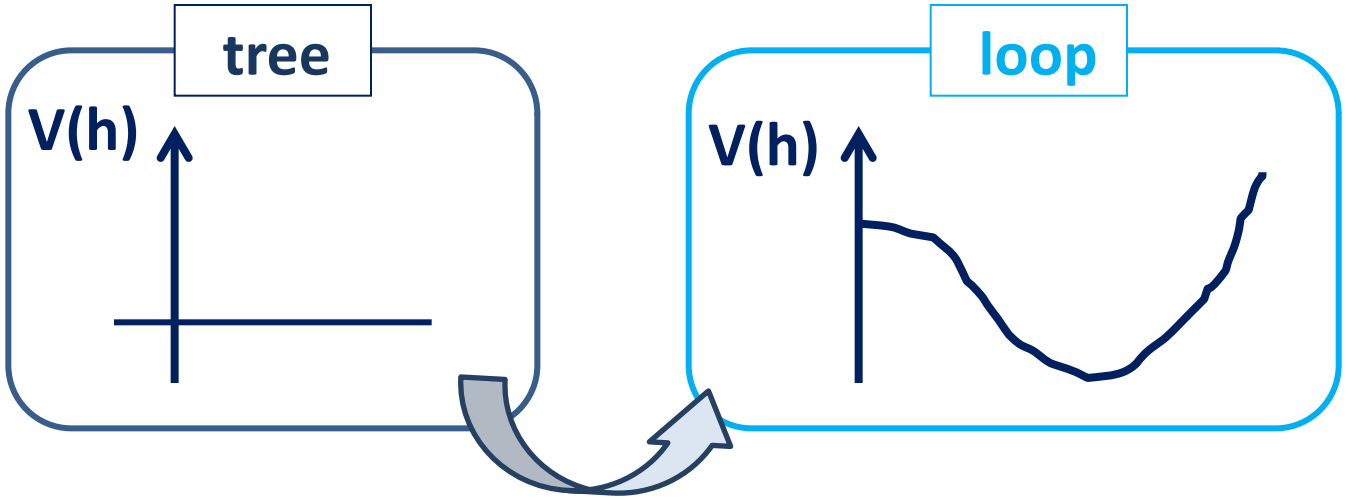
+ light composite partner

It is required to provide realistic Higgs potential.

Minimal Composite Higgs Model

Agashe,Contino,Pomarol '04

Potential of pseudo-NG boson is produced



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

Top sector contribution is important because of the large coupling.

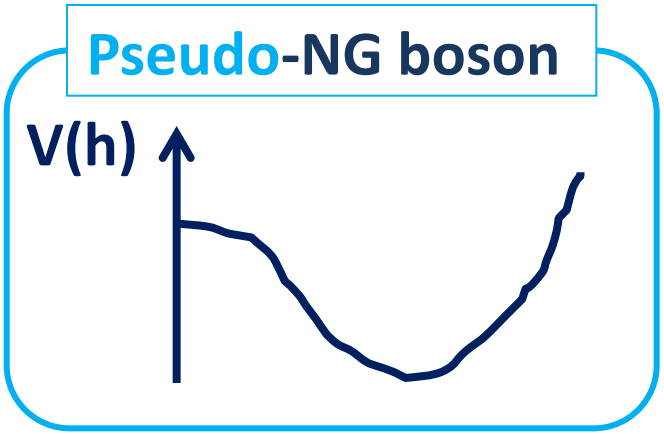
Minimal Composite Higgs Model

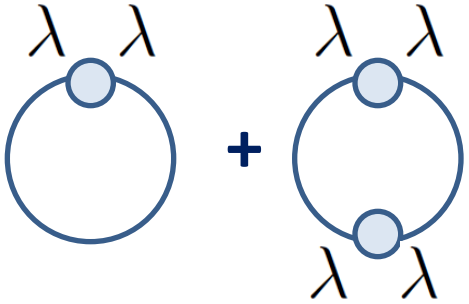
Agashe,Contino,Pomarol '04

Potential

$\mathbf{O_t}$: 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 breakings

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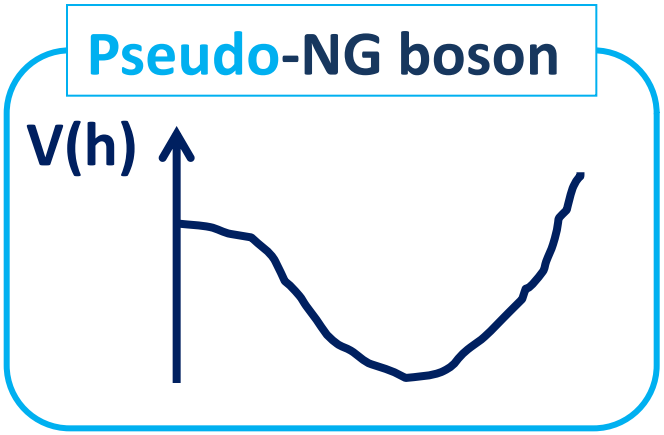
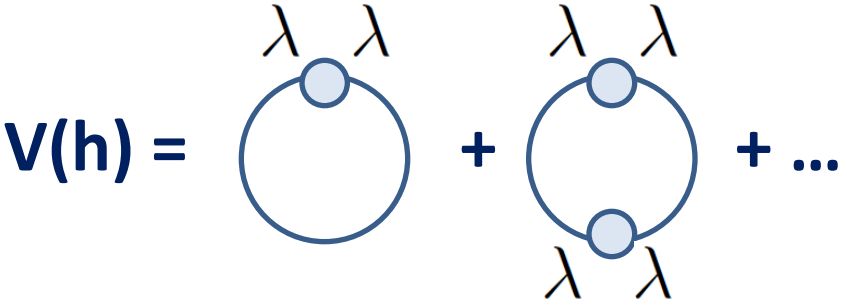
$$\alpha_t \sim \frac{\lambda^2}{(4\pi)^2}\left[\frac{m_{t'}^4}{(4\pi)^2}\right]$$

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





explicit breakings

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 ;…

Minimal Composite Higgs Model

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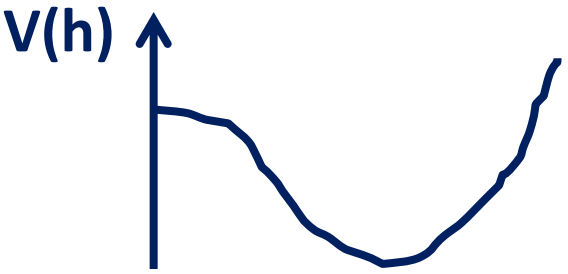
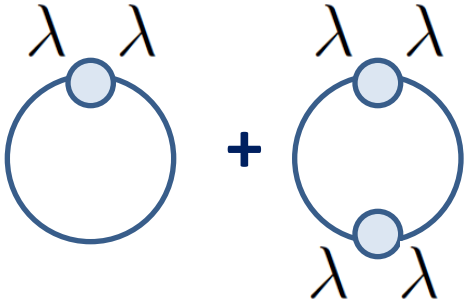
Pseudo-NG boson



NDA $\quad \alpha_t \gg \beta_t$

V(h) =



+ + …

explicit breakings

Minimal Composite Higgs Model

Agashe,Contino,Pomarol '04

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

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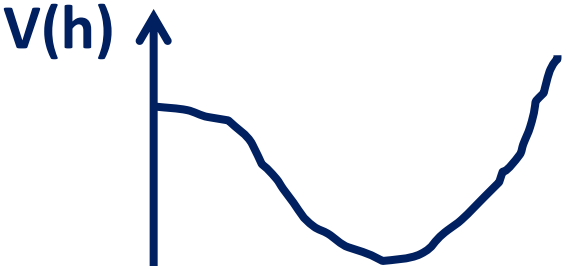

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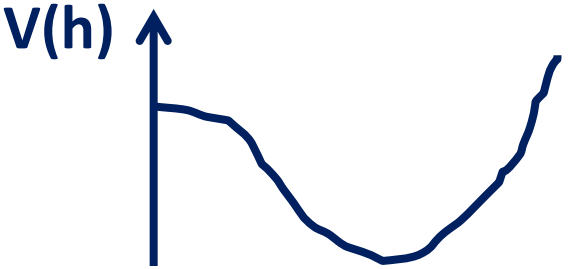

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Small $\epsilon \equiv v/f$

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

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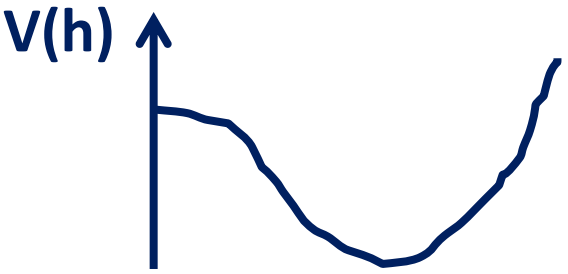

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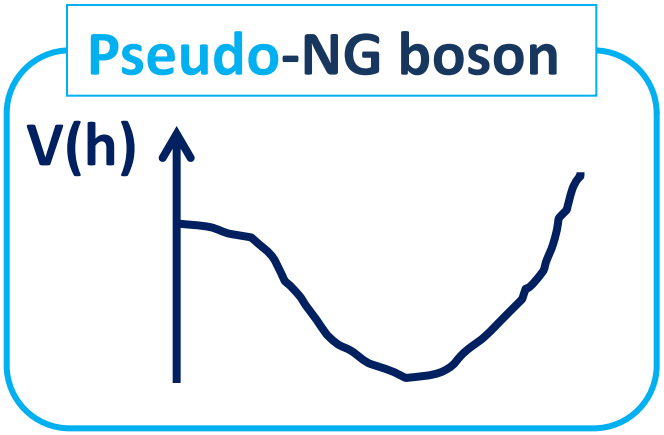

$\epsilon \equiv v/f$ < 1 $\quad \alpha_t \simeq 2\beta_t$ NDA $\quad \alpha_t \gg \beta_t$

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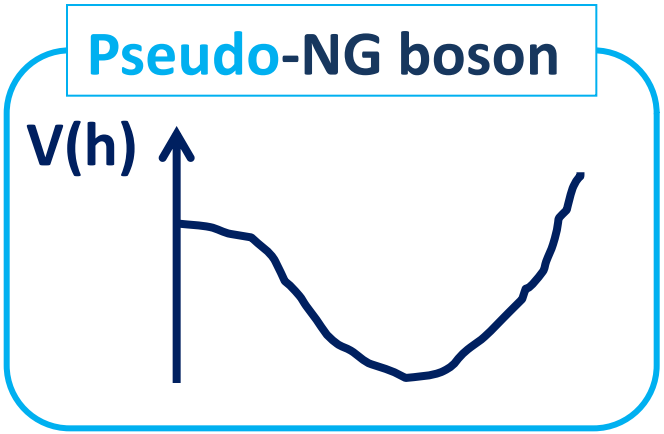

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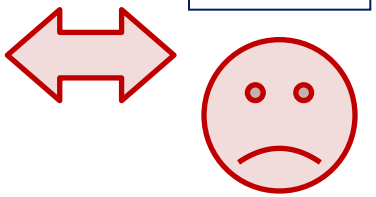

To solve the tension,

People consider, for example, another representations,

4 -> 5 or 10 or 14 …

Dark Matter

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

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**

MA, Kitano '14

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It is plausible that
DM also couple to Higgs weakly.

MA, Kitano '14

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    It is plausible that

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

MA, Kitano '14

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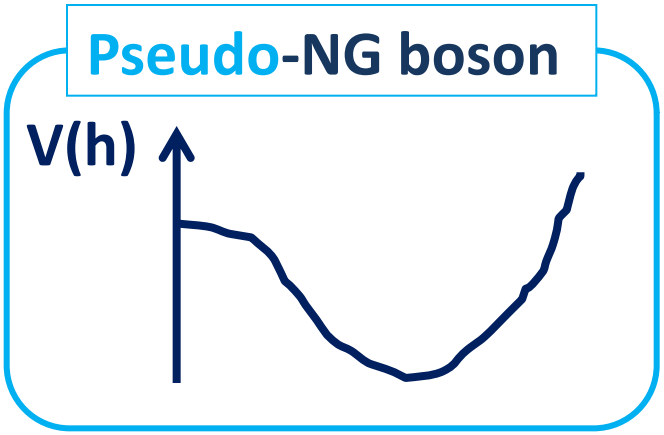
DM also couple to Higgs (i.e. strong sector) weakly.

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

Top contribution

Ot: spinorial rep. 4 of SO(4)

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



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

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

If O_{DM} is in SO(5) vector representation, 5, the dominant contribution is proportional to $\sin^2$(h/f).

Top contribution

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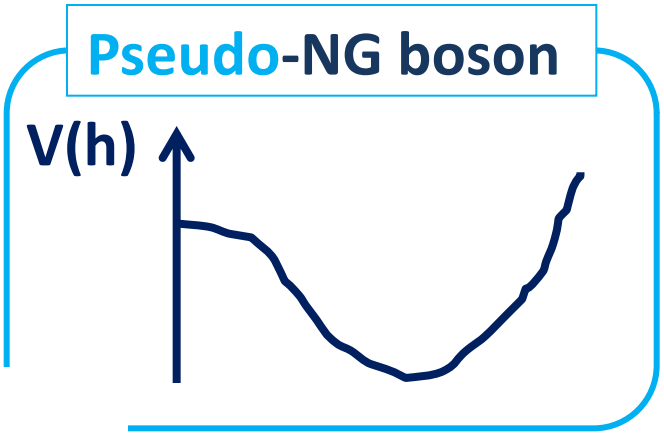

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$\epsilon \equiv v/f$ **< 1**

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

NDA $\alpha_t \gg \beta_t$

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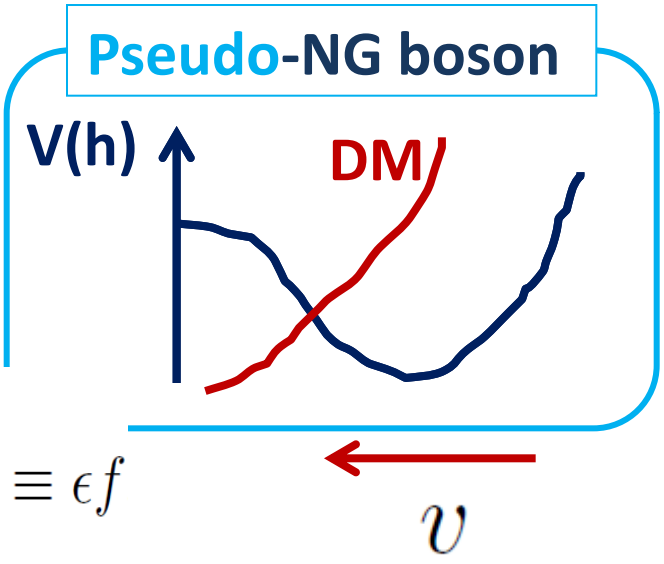

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Partially composite DM

MA, Kitano '14

We add Majorana DM:

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

After integrating out composites,

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

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

⇨ **Higgs portal DM**

Partially composite DM

MA, Kitano '14

- **Annihilation cross section**

If only κ

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

- **Direct detection cross section**

$$\sigma_{\rm SI} \propto \kappa^2 \longrightarrow$$

Strong constraints from DM direct detection

Partially composite DM

MA, Kitano '14

- **Annihilation cross section**

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

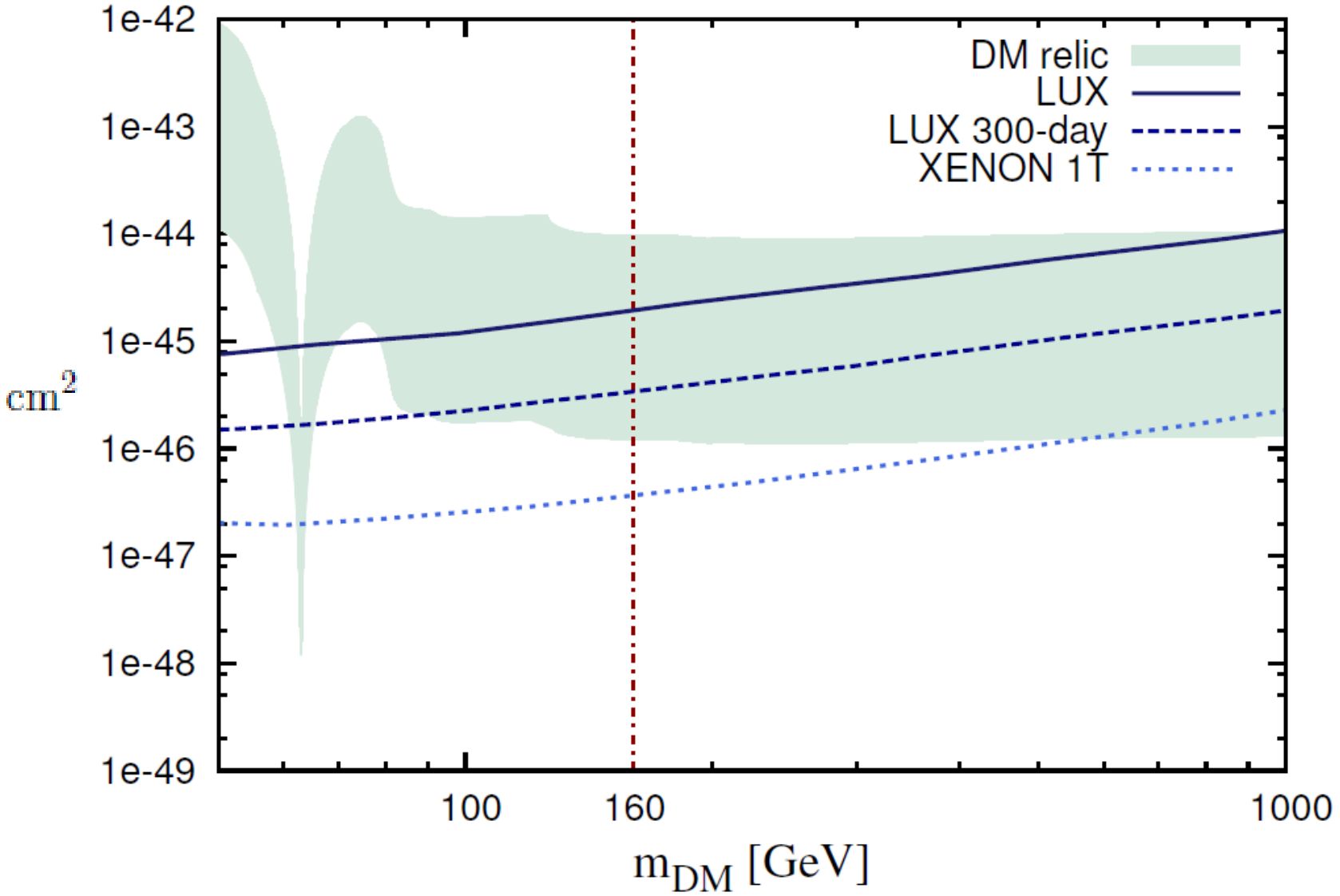
- **Direct detection cross section**

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

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

Other prediction:

Higgs physics

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

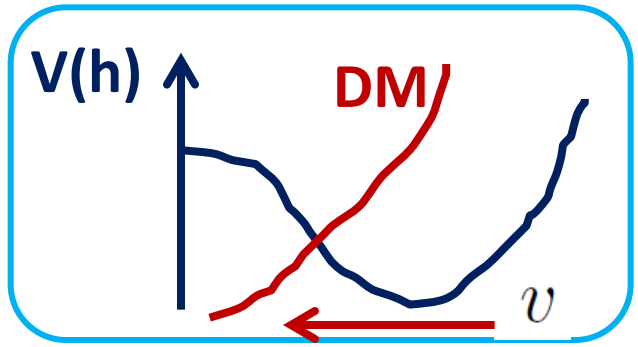
Direct search for top partner

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.