# Composite models and their phenomenology at the LHC

Yasuhiro Okada (KEK/Sokendai)

2016 Joint Workshop of the FKPPL and TYL/FJPPL

May 18, 2016, KIAS, Seoul, Korea

# Purpose of the proposed project

- Since the discovery of the Higgs boson, focus of particle physics has shifted to understand the physics behind the electroweak symmetry breaking above the TeV regime.

- Composite models with a new strong interaction is one of such possibilities. In addition to the Higgs field, other bosons and fermions may appear as composite states.

- Our approach is mostly based on "effective theory" which is supposed to be valid at the TeV scale, and we study impacts on the LHC phenomenology

- ✓ Vector-like quarks
- ✓ Scalar for the diboson excess
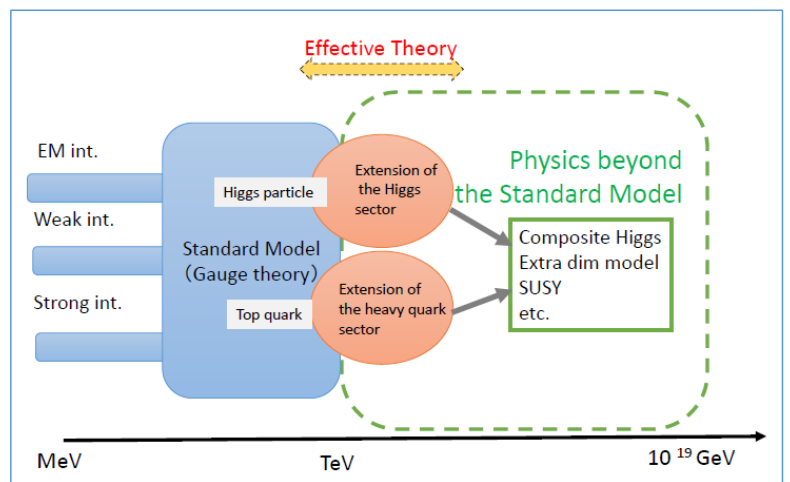
# Vector-like top partners

Vector-like quarks
Heavy quarks even without the Higgs mechanism.
Exist in various models beyond the SM
  (Composite Higgs models, Little Higgs models, extra dim models, etc. )
After the Higgs field gets VEV, vector-like quarks can mix with the SM quarks

Our group has been working on
phenomenology of "t'" quark for some time.

Constraints from
anomalous Z,
electroweak precision measurements
Flavor physics
Higgs decay
vs
Single t' production at the LJHC
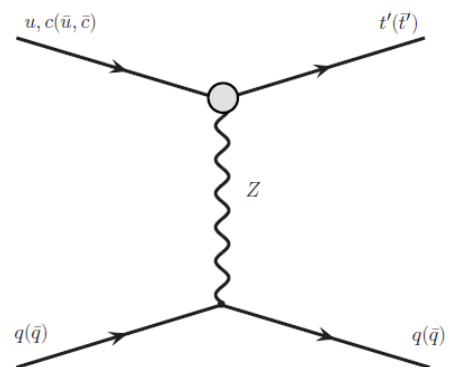


G.Cacciapaglia et al
JHEP11(2010) 159, JHEP03(2012)070

## Interplay of vector-like top partner multiplets in a realistic mixing set-up

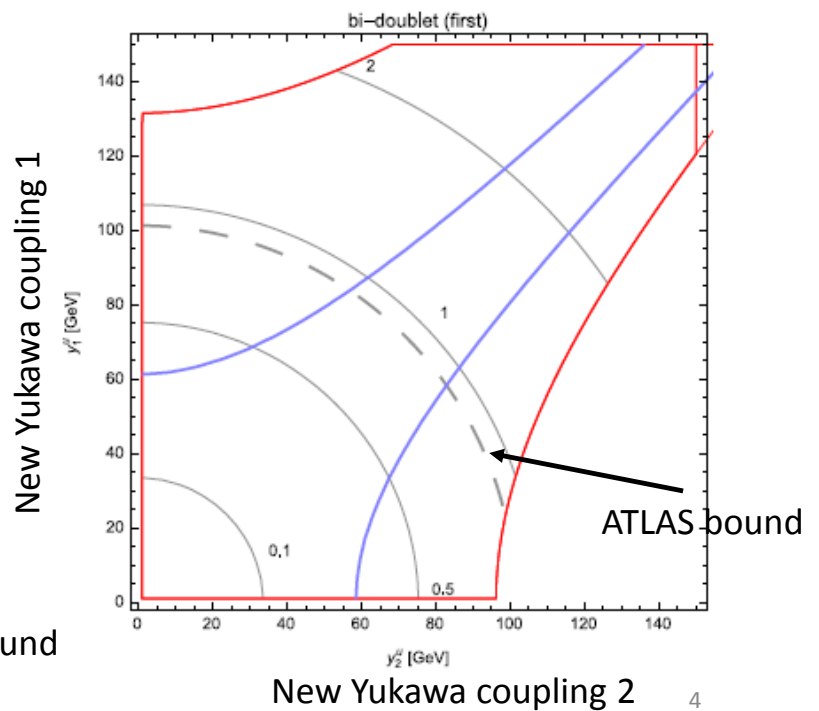G.Cacciapaglia, A.Deandrea, N.Gaur. D.Harada, Y.Okada and L.Panizzi
JHEP09 (2015)012

T+jet production cross section
at 14 TeV LHC in pb (bi-doublet case)

We have extended our previous
analysis to the case of two top partners

Four cases are considered

- Singlet $(Y = 2/3)$ + Doublet $(Y = 7/6)$;

- Doublet $(Y = 7/6)$ + Triplet $(Y = 5/3)$;

- Singlet $(Y = 2/3)$ + Doublet $(Y = 1/6)$;

- Doublet $(Y = 1/6)$ + Doublet $(Y = 7/6)$.



New Yukawa coupling 1

ATLAS bound

Red: EW precision bound
Blue: Tree-level Z coupling bound

New Yukawa coupling 2

A new weak singlet pseudoscalar particle is introduced to explain excess of
resonant diboson (WW/ZZ/WZ) production around 2 TeV reported by ATLAS and CMS
last year.

If strong dynamics is behind the new particle, coupling to gauge bosons could be
determined anomaly term of the effective Lagrangian.

$$\mathcal{L}_{\eta gg} = \kappa_g^\eta \frac{g_3^2}{32\pi^2} \frac{\eta_{WZ}}{F_\eta} \epsilon^{\mu\nu\rho\sigma} G_{\mu\nu}^a G_{\rho\sigma}^a,$$
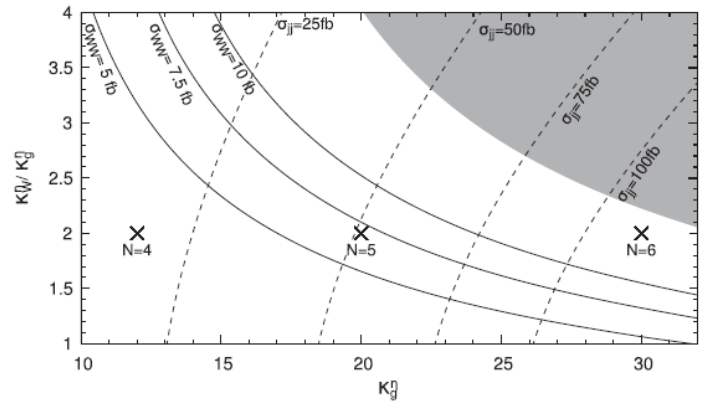
$$\mathcal{L}_{\eta WW} = \kappa_W^\eta \frac{g_2^2}{32\pi^2} \frac{\eta_{WZ}}{F_\eta} \epsilon^{\mu\nu\rho\sigma} W_{\mu\nu}^i W_{\rho\sigma}^i,$$

$$\mathcal{L}_{\eta BB} = \kappa_B^\eta \frac{g_Y^2}{32\pi^2} \frac{\eta_{WZ}}{F_\eta} \epsilon^{\mu\nu\rho\sigma} B_{\mu\nu} B_{\rho\sigma},$$

Dijet ($\sigma$jj)and diboson ($\sigma$WW) cross section



$\kappa$ 's are parameters calculable once
fundamental theory is specified

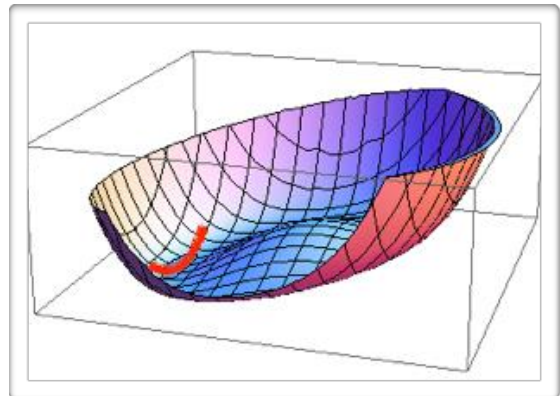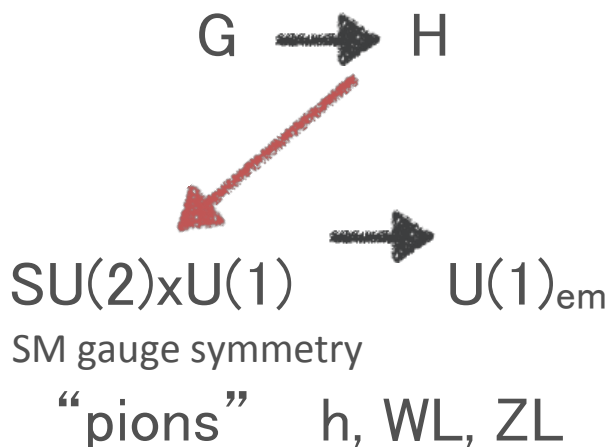This kind of models may be relevant also for the 750GeV diphoton excess.

5

# Research plan for 2016-2017

We continue to study "strong dynamics in the EW sector" and
Its implications to LHC phenomenology.

Global symmetry:

G ➔ H

SU(2)xU(1) ➔ U(1)$_{em}$

SM gauge symmetry

"pions"    h, WL, ZL



Higgs boson light as pNGB of the broken symmetry of the strong sector,
parameterisation with an effective chiral Lagrangian, detailed computations in
terms of the fundamental fermionic states

- **Scalars in TeV strong dynamics**

  ✓ Higgs: pNGB or mixture pNGB-Composite (see 1402.0233)

  ✓ Composite scalars can be lighter than vectors (indications from lattice calculations with specific strong dynamics)

  ✓ A pseudo-scalar η with WZW anomaly couplings is present in the spectrum and can be in the TeV range.

  ✓ Couplings are calculable in terms of the dynamics

  ✓ Fermiophobic η is a realistic case in composite models

- **Vector-like quarks in strong dynamics**

  ✓ They come in complete multiplets (not only singlets)

  ✓ In some models not too heavy mass scale M (∼TeV) and mainly coupling to the 3rd generation

  ✓ Present LHC mass bounds ∼ 800 GeV

  ✓ Mixings bounded by EWPT, flavor…

  ✓ Note: in realistic composite models also scalars and vectors are expected.

- **Perspective for Run 2**
- ✓ Strong dynamics: which resonances?
- ✓ Diboson/diphoton excesses:
- ✓ Search for new (composite) scalars
- ✓ Search for vector-like fermions
- ✓ Spin 1 resonances typically more massive

- **Project key points**
- ✓ Study of vector-like and scalar resonances from a strong electroweak sector at the LHC Run 2
- ✓ Effects in the Yukawa couplings from the strong EW sector: either modification of the SM ones or new ones and bounds in the Higgs observables
- ✓ Non-perturbative techniques inspired from QCD for extracting information on the strong dynamics and comparison with numerical (lattice) techniques when available.

# Members and communications

2015-2016

Fiscal year April 1 ,2016 - March 31 2017

### Title: Composite models and their phenomenology at the LHC

| French Group | | | Japanese Group | | |
|---|---|---|---|---|---|
| Name | Title | Lab./Organis. | Name | Title | Lab/Organis. |
| **DEANDREA Aldo** | Professor | IPNL/Lyon 1 | OKADA Yasuhiro | Professor | KEK/SOKENDAI |
| CACCIAPAGLIA Giacomo | Researcher | IPNL/CNRS | HASHIMOTO Michio | Associate Professor | Chubu University |
| LESPINASSE Mickael | PhD student | IPNL/Lyon 1 | HARADA Daisuke | associated | KEK |
| LE CORRE Solène | PhD student | IPNL/Lyon 1 | | | |

France-> KEK
1 travel (+1 travel by another source)

Japan->Lyon
2 travels

2016-2017

We would like to arrange two travels on both sides.