## Singlet Boson in SUSY Model as a Mimic of the SM Higgs at the LHC

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@ ≤ TeV scale, an important discovery exists!

Is it Higgs boson?

#### Higgs boson

- is the last undiscovered particle in the SM.
- Higgs will restore the unitarity of W<sub>L</sub>W<sub>L</sub> scatt.



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http://lepewwg.web.cern.ch/LEPEWWG/plots/summer2005/s05\_stu\_contours.eps

#### **Higgs boson**

- is the last undiscovered particle in the SM.
- Higgs will restore the unitarity of W<sub>1</sub>W<sub>1</sub> scatt.
- **EWPMs (Electroweak Precision measurements**) are consistent with light Higgs boson.
- SM (light Higgs) is good for data.



#### Supersymmetry

One of the solution to the hierarchy problem.
 (Quadratic div. terms of the Higgs mass are canceled.)

Grand Unified Theory (GUT)

The theory will be valid up to GUT scale and achieve the gauge coupling unification.

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- Grand Unified Theory (GUT)
- Light Higgs

Higgs Potential gauge coupling !  $V = m_1^2 |H_1^0|^2 + m_2^2 |H_2^0|^2 + (m_3^2 H_1^0 H_2^0 + h.c.) + \frac{g^2 + g^{'2}}{8} (|H_1^0|^2 - |H_2^0|^2)^2$ 

In MSSM (Minimal Supersymmetric Standard Model), the lightest Higgs boson mass,  $m_h^{\sim}$  mZ at tree level.

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- Light Higgs
   + R-parity
  - $\rightarrow$  consistent with EWPM



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#### Sounds like a good idea!

Here, lightest neutral Higgs,  $h \sim H_u$ Other heavy Higgses,  $H \sim H_d$ , A,  $H^{\pm}$ 

# Here, lightest neutral Higgs, h ~ H<sub>u</sub> Other heavy Higgses, H ~ H<sub>d</sub>, A, H<sup>±</sup> These production & decay channel is different from the SM Higgs @ LHC.

Signal of heavy SM like Higgs does not appear at the LHC in SUSY?

- Singlet behave like a SM Higgs at LHC for wide range of the singlet mass.
- The  $\sigma_{signal}/\sigma_{SM}$  could take on a wide range of values.
- Even if heavy Higgs like signal will appear at LHC, Low-energy SUSY is not immediately excluded.

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- The  $\sigma_{signal}/\sigma_{SM}$  could take on a wide range of values.
- "SM Higgs" is excluded in this region:



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## How SM Higgs is mimicked at the LHC



# Now, the most efficient production process is the gluon fusion which induced by the top-loop diagram.







- Procudtion: vector-like matter loop.
- Decay: mixing of S & H





The ratio of the cross section,  $pp \rightarrow Higgs \rightarrow VV$ :

$$R_{VV} \equiv \frac{\sigma(pp \to \mathbf{S} \to VV)}{\sigma(pp \to h_{\rm SM} \to VV)} = \frac{\Gamma(\mathbf{S} \to \mathbf{gg}) \operatorname{Br}(\mathbf{S} \to \mathbf{VV})}{\Gamma(\mathbf{H} \to \mathbf{gg}) \operatorname{Br}(\mathbf{H} \to \mathbf{VV})}$$

The singlet can behave like a SM Higgs!

## How SM Higgs is mimicked at the LHC

more detail ...

# How SM Higgs is mimickedmore detailSimplest setupWe introduce the gauge singlet superfield: SN<sub>5</sub>-pairs of vector-like chiral multiplets: $D_i$ ( $\mathbf{3}, \mathbf{1}, -\frac{1}{3}$ ), $L_i$ ( $\mathbf{1}, \mathbf{2}, -\frac{1}{2}$ ), $\bar{D}_i$ ( $\bar{\mathbf{3}}, \mathbf{1}, \frac{1}{3}$ ), $\bar{L}_i$ ( $\mathbf{1}, \mathbf{2}, \frac{1}{2}$ ),

#### Motivated by NMSSM,

$$W \supset \lambda SH_u H_d + \frac{1}{3}\kappa S^3 + y_D S\bar{D}_i D_i + y_L S\bar{L}_i L_i$$
$$\mathcal{L}_{\text{soft}} \supset -m_{H_d}^2 |H_d|^2 - m_{H_u}^2 |H_u|^2 - m_S^2 |S|^2 - \left(\lambda A_\lambda SH_u H_d + \frac{1}{3}\kappa A_\kappa S^3 + \text{h.c.}\right)$$

**How SM Higgs is mimicked** more detail Simplest setup We introduce the gauge singlet superfield: S N<sub>5</sub>-pairs of vector-like chiral multiplets:  $D_i$  (3, 1,  $-\frac{1}{3}$ ),  $L_i$  (1, 2,  $-\frac{1}{2}$ ),  $\bar{D}_i \ (\bar{\mathbf{3}}, \mathbf{1}, \frac{1}{3}), \ \bar{L}_i \ (\mathbf{1}, \mathbf{2}, \frac{1}{2}),$ Motivated by NMSSM, **Vector-like matter** mass:  $m_D = y_D v_s$  $W \supset \lambda SH_u H_d + \frac{1}{3}\kappa S^3 + y_D S\bar{D}_i D_i + y_L S\bar{L}_i L_i$  $v_s = \langle S \rangle$  $\mathcal{L}_{\text{soft}} \supset -m_{H_d}^2 |H_d|^2 - m_{H_u}^2 |H_u|^2 - m_S^2 |S|^2 - \left(\lambda A_\lambda S H_u H_d + \frac{1}{3} \kappa A_\kappa S^3 + \text{h.c.}\right)$ 

Assuming the perturbativity of the Yukawa coupling constant, the colored fermions are expected to be lighter than  $\sim v_s$ 

#### How SM Higgs is mimicked more detail Simplest setup We introduce the gauge singlet superfield: S N<sub>5</sub>-pairs of vector-like chiral multiplets: $D_i$ (3, 1, $-\frac{1}{3}$ ), $L_i$ (1, 2, $-\frac{1}{2}$ ), $\bar{D}_i \ (\bar{\mathbf{3}}, \mathbf{1}, \frac{1}{3}), \ \bar{L}_i \ (\mathbf{1}, \mathbf{2}, \frac{1}{2}),$ **Motivated** mu parameter in MSSM: $\mu_{\mathrm{eff}} = \lambda v_s$ **Vector-like matter** mass: $m_D = y_D v_s$ $W \supset \lambda S H_u H_d + \frac{1}{3} \kappa S^3 + y_D S \bar{D}_i D_i + y_L S \bar{L}_i L_i$ $v_s = \langle S \rangle$ $\mathcal{L}_{\text{soft}} \supset -m_{H_d}^2 |H_d|^2 - m_{H_u}^2 |H_u|^2 - m_S^2 |S|^2 - \left(\lambda A_\lambda S H_u H_d + \frac{1}{3} \kappa A_\kappa S^3 + \text{h.c.}\right)$

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#### **Parameters:**

$$A_{\lambda}, A_{\kappa}, \lambda, \kappa, m_{H_d}^2, m_{H_u}^2, m_S^2$$

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## How SM Higgs is mimicked at the LHC

**Numerical results** 

## How SM Higgs is mimicked at the LHC

## **Numerical results**

#### **Parameters:**

$$A_{\lambda}, A_{\kappa}, m_Z, \tan\beta, v_s, \mu_{\text{eff}}, m_{h_2}$$

 $A_{\lambda} = 500 \text{ GeV}, A_{\kappa} = -100 \text{ GeV}$ 



Contours of constant  $R_{ZZ}$ , lightest Higgs boson mass (The behavior of  $\mathbf{R}_{WW}$  is almost identical)



Contours of constant  $R_{ZZ}$ , lightest Higgs boson mass (The behavior of  $\mathbf{R}_{WW}$  is almost identical)



The SM-Higgs-like signal at the LHC can be mimicked by the singlet scalar for wide range of the singlet mass. (the R<sub>vv</sub> take also on a wide range of values.)

#### summary

When Higgs signals are discovered at LHC, can we identify that it is really Higgs discovery? (If it is heavy, is low-energy SUSY immediately excluded?)

It is possible that the singlet may behave as SM Higgs for wide range of the singlet mass. (e.g. NMSSM + vector-like matter)

SUSY is not excluded immediately.

- Lightest neutral Higgs will also discovered.
- vector-like matter exists.

## Thank you!

## backup

