Partially composite Higgsino

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Based on arXiv:1311.6823 (appear in JHEP)

MA, Ryosuke Sato

Today’s talk

- Introduction
- Partially composite Higgs scenario in SUSY models
- Phenomenology of “partially compositeness of the Higgsino” in such models.
- Summary

Introduction

LHC: Null results in SUSY search

"mh =126 GeV"

- **High scale SUSY?**

  SM can be valid even at very high scale;

  10 GeV, 100 TeV,... or Mplanck?

or

- **TeV SUSY (but not discovered yet)**

In this case, current results are
new important hints for new physics model!

Introduction

$$V = m^2 |h|^2 + (\lambda/4)|h|^4 \quad , -2m^2 = m_h^2$$

In MSSM, the mass term can be written by these contributions

$$m^2 = \mu^2 + (m_{Hu}{}^2)_{tree} + (m_{Hu}{}^2)_{rad}$$

if one contribution is much larger than the Higgs mass ($m^2 = m_h^2/2$) → fine-tuning

Introduction

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$$m^2 = \mu^2 + (m_{Hu}{}^2)_{tree} + (m_{Hu}{}^2)_{rad}$$

- For μ term,

Requiring no 10 % tuning ($\Delta^{-1} = m_h^2/2\mu^2$ > 10 %),

$$\Rightarrow \quad |\mu| \lesssim 290 \text{ GeV}$$

Introduction

$$V = m^2 |h|^2 + (\lambda/4) |h|^4 \quad , -2 m^2 = m_h^2$$

$$m^2 = \mu^2 + (m_{Hu}{}^2)_{tree} + (m_{Hu}{}^2)_{rad}$$

- For m_{Hu} term,

$$m_{H_u}^2|_{\rm rad} \simeq -\frac{3y_t^2}{8\pi^2}(m_{Q_3}^2 + m_{U_3}^2 + |A_t|^2)\ln\left(\frac{M_{\rm mess}}{m_{\tilde t}}\right) \sim 10\ \mathrm{TeV}$$

$$m_{\tilde t} \equiv (m_{\tilde q_3} m_{\tilde u_3})^{1/2}$$

Requiring no 10 % tuning ($\Delta^{-1} \equiv m_h^2/2m_{H_u}^2|_{\rm rad}$ > 10 %),

$$m_{\tilde t} \lesssim 600\ \mathrm{GeV} \quad \text{for } |A_t| \sim 0$$

$$m_{\tilde t} \lesssim 500\ \mathrm{GeV} \quad \text{for } |A_t| \sim m_{\tilde t}$$

$$m_{\tilde t} \lesssim 350\ \mathrm{GeV} \quad \text{for } |A_t| \sim 2m_{\tilde t}$$

Introduction

126 GeV Higgs?

- large A term?

  (But, the A term also contributes the EWSB tuning...)

- Additional contribution to the Higgs mass?

Introduction

In MSSM, corrections to the Higgs potential;

$$m_{H_u}^2|_{\rm rad} \simeq -\frac{3y_t^2}{8\pi^2}(m_{Q_3}^2 + m_{U_3}^2 + |A_t|^2)\ln\left(\frac{M_{\rm mess}}{m_{\tilde{t}}}\right) \Rightarrow m^2 \propto {y_t}^2$$

$$\Updownarrow$$

$$\lambda|_{\rm rad} \sim \frac{3\,{y_t}^4}{8\,\pi^2}\ \ln\left(\frac{m\tilde{t}}{mt}\right) \Rightarrow \lambda \propto {y_t}^4$$

The larger coupling can push the Higgs mass up economically.

Partially composite Higgs

Partially composite Higgs

Higgs has semi-perturbative couplings to a strong sector:

$$W = \kappa_u^{2-d} H_u \mathcal{O}_d + \kappa_d^{2-d} H_d \mathcal{O}_u$$

$$W = \lambda_{ij} H \Psi_i \tilde{\Psi}_j$$

Fukushima, Kitano, Yamaguchi ’10
Azatov, Galloway, Luty ’11
Gherghetta, Pomarol ’11
Heckman, Kumar, Vafa, Wecht ’11
Csaki, Randall, Terning ’12
Evans, Ibe, Yanagida ’12
Kitano, Luty, Nakai ’12
…

κ : coupling (mass dim. 1), fairly strong due to 126GeV.

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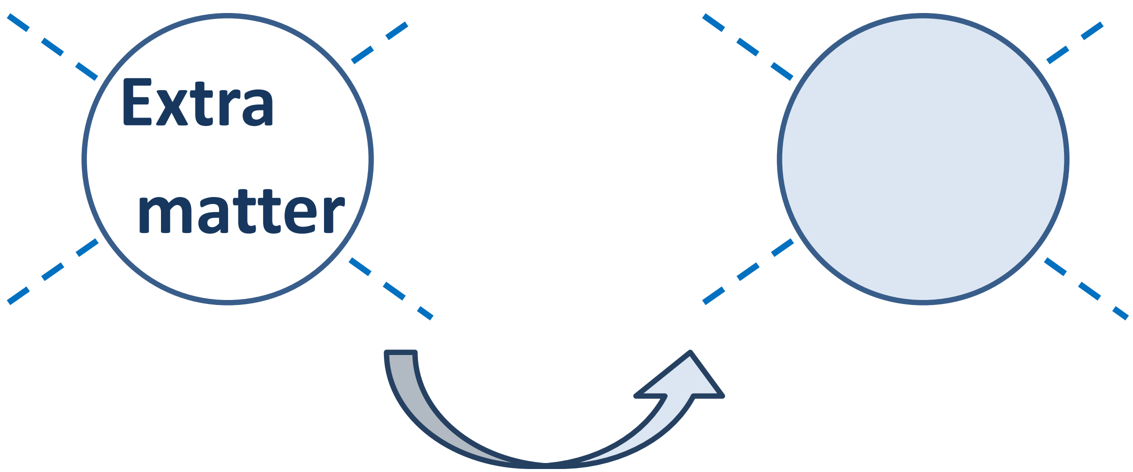

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K : coupling (mass dim. 1), fairly strong due to 126GeV.

If the strong sector is a CFT, there is no UV problem.

Relevant operator in d < 2

Compositeness:

$\epsilon_{u,d} \sim \left(\frac{\kappa_{u,d}}{\Lambda}\right)^{2-d}$: if $\epsilon_{u,d} \sim 1$, **Higgs couples strongly.**

Partially composite Higgs

- Additional Higgs potential are produced
  - Higgs mass can be 126 GeV

$$\Lambda^{6-2d}(H) \sim 16\pi^2 \kappa_u^{2-d} \kappa_d^{2-d} H_u H_d$$

$$W_{\rm dyn} \sim \frac{\Lambda^3(H)}{16\pi^2}$$ **(NDA)** **Kitano, Luty, Nakai '12**

, A term contribution, …

($\kappa_u^{2-d} A_u H_u \mathcal{O}_d + \kappa_d^{2-d} A_d H_d \mathcal{O}_u$)

⇨ There are several new contributions!

EWSB can occur by a balance between two contributions of these and tree potential.

Partially composite Higgs

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$$W_{\rm dyn} \sim \frac{\Lambda^3(H)}{16\pi^2}$$ (NDA)

Kitano, Luty, Nakai '12

$$V''_{\rm dyn} \sim \epsilon^4 \Lambda^2$$ ⇒ m_h^2

If this is dominant contribution for stabilization, required values of ε & Λ can be obtained from observed Higgs mass.

Partially composite Higgs

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$$\Lambda^{6-2d}(H) \sim 16\pi^2 \kappa_u^{2-d} \kappa_d^{2-d} H_u H_d$$

$$W_{\text{dyn}} \sim \frac{\Lambda^3(H)}{16\pi^2}$$ **(NDA)** **Kitano, Luty, Nakai '12**

$$V''_{\text{dyn}} \sim \epsilon^4 \Lambda^2$$ ⇒ m_h^2

If this is dominant contribution for stabilization,

⇒ $\epsilon \sim 0.4 \quad \Lambda \sim 800\ \text{GeV}$

⇒ $\epsilon_u \epsilon_d / \Lambda \sim 1/(10\text{TeV})$

$\epsilon_{u,d} \sim \left(\frac{\kappa_{u,d}}{\Lambda}\right)^{2-d}$ **: if** $\epsilon_{u,d} \sim 1$ **, Higgs couples strongly.**

Partially composite Higgs

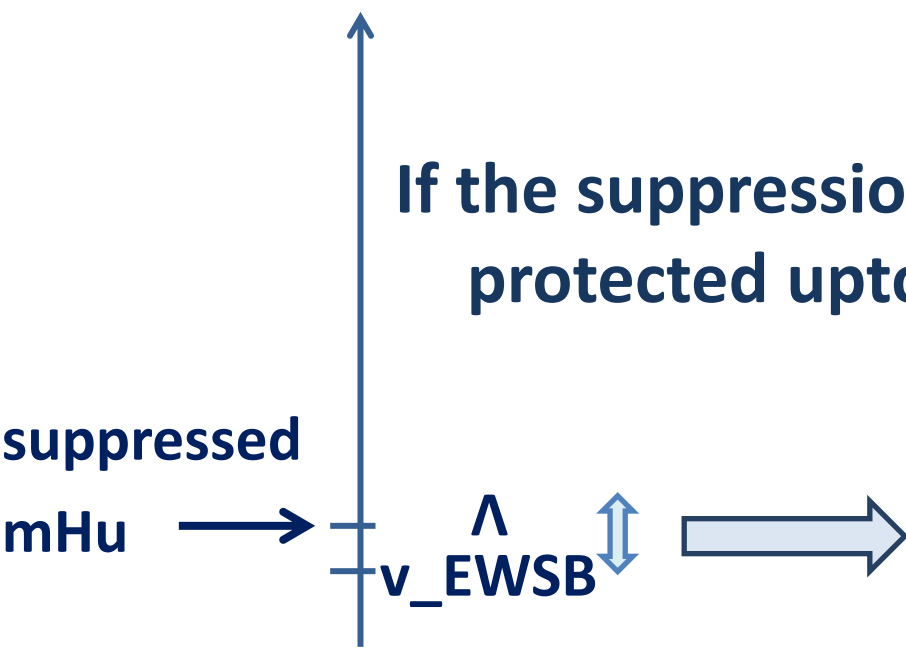
- Additional Higgs potential are produced
  - Higgs mass can be 126 GeV
  - mu-term

$$W_{\rm dyn}(d = \tfrac{3}{2}) \sim \kappa_u^{1/2} \kappa_d^{1/2} H_u H_d$$

$$\mu_{\rm dyn} \sim \frac{\partial^2 W}{\partial H^2} \sim \frac{\Lambda^3}{(4\pi v)^2} \sim \epsilon^2 \Lambda \quad \sim \text{ O(100) GeV}$$

Partially composite Higgs

- Additional Higgs potential are produced
  - Higgs mass can be 126 GeV
  - mu-term
  - Suppression for the m_{Hu} by superconformal behavior



If the suppression works, mHu^2 can be protected upto ~ Λ.

The similar advantage as low-energy mediation

Partially composite Higgs

- Additional Higgs potential are produced
  - Higgs mass can be 126 GeV
  - mu-term
  - Suppression for the m_{Hu} by superconformal behavior

Moreover, from the view point of composite Higgs scenario,

Partially composite Higgs

- Additional Higgs potential are produced
  - Higgs mass can be 126 GeV
  - mu-term
  - Suppression for the m_{Hu} by superconformal behavior

Because of "partially" compositeness

- Advantage for flavor structure because SM particle masses can be produced by usual Yukawa coupling of elementary H.

Phenomenology

Phenomenology from compositeness

Partially compositeness would appear,

- Higgs compositeness: e.g. Higgs -> γγ
- Particle from strong sector: techni-rho meson

Higgsinos also have higher dimensional interaction

$$\int d^2\theta \int d^2\bar{\theta}\ g\frac{\epsilon_u \epsilon_d}{\Lambda^2} H_d W_\alpha e^V (D^\alpha e^{-V} H_u) \mathcal{Z}^\dagger$$

- Higgsino compositeness ?

Phenomenology from compositeness

MA, Ryosuke Sato ’13

Higgsino compositeness

- Neutralino decay (in pure Higgsino case)

Phenomenology from compositeness

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Higgsino compositeness

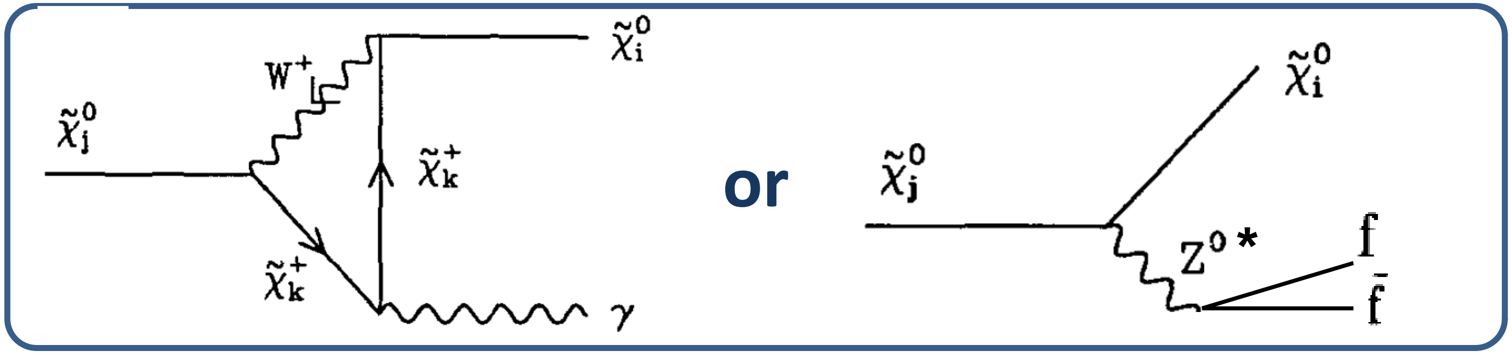
- Neutralino decay (in pure Higgsino case)

MSSM case

$\tilde{H}^0{}_2$ decays into $\tilde{H}^0{}_1$ via

Loop induced

through virtual Z boson



Phenomenology from compositeness

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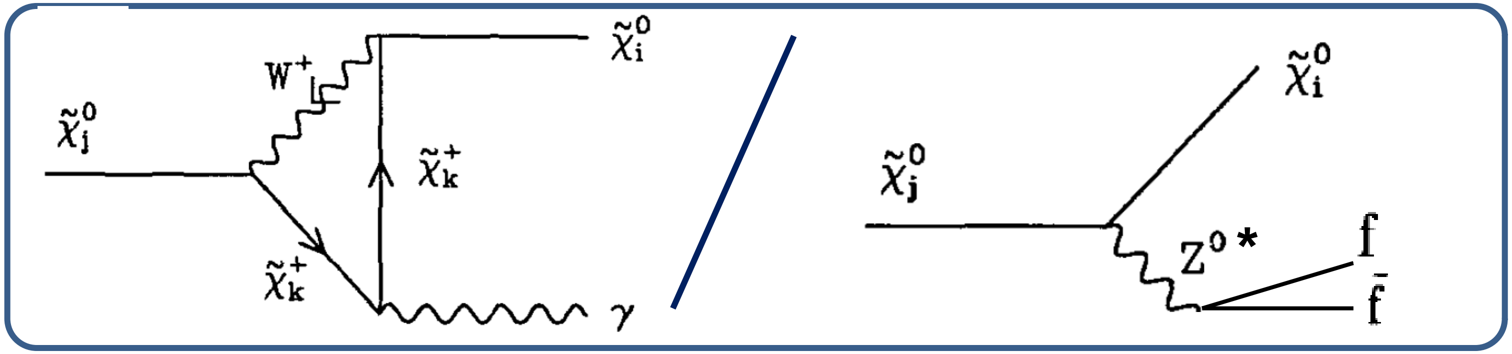
Higgsino compositeness

- **Neutralino decay (in pure Higgsino case)**

MSSM case

$$\frac{\Gamma^{\rm MSSM}_{\tilde{\chi}^0_2\to\tilde{\chi}^0_1\gamma}}{\sum_f \Gamma_{\tilde{\chi}^0_2\to\tilde{\chi}^0_1 f\bar{f}}} \sim \frac{15\alpha_{\rm em}}{2\pi\sin^4\theta_W}\frac{1}{\mu^2}\left(\frac{M_1M_2}{M_1+M_2\tan^2\theta_W}\right)^2$$

$$\times\left[C(m_W^2/\mu^2)\right]^2\times\left(\frac{40}{3}-\frac{10}{\sin^2\theta_W}+\frac{21}{4\sin^4\theta_W}\right)^{-1}$$



Phenomenology from compositeness

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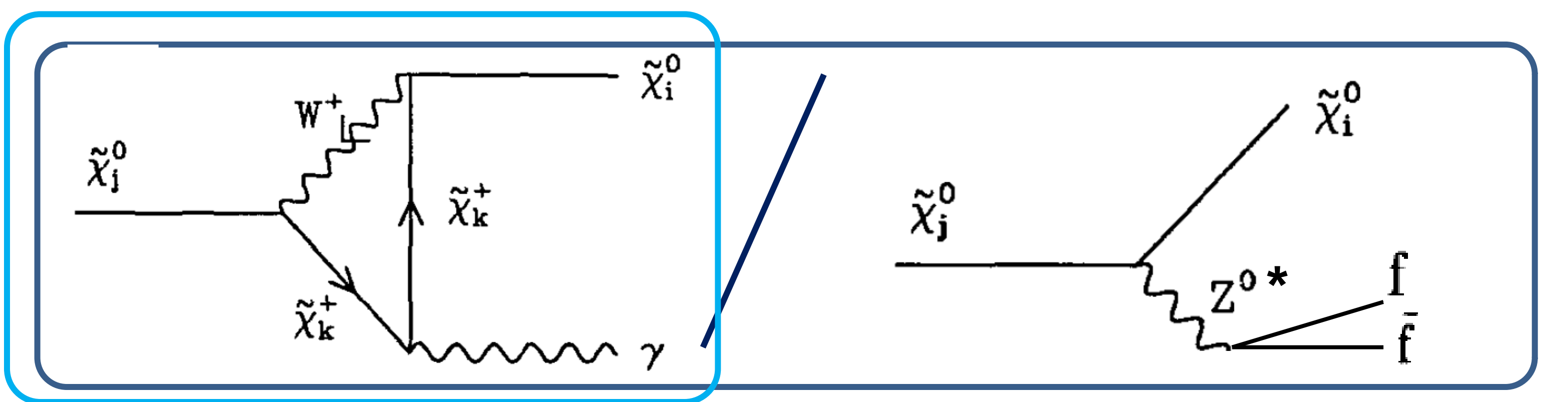
Higgsino compositeness

- Neutralino decay (in pure Higgsino case)

MSSM case

$$\frac{\Gamma^{\mathrm{MSSM}}_{\tilde{\chi}^0_2\to\tilde{\chi}^0_1\gamma}}{\sum_f \Gamma_{\tilde{\chi}^0_2\to\tilde{\chi}^0_1 f\bar{f}}} \sim \frac{15\alpha_{\mathrm{em}}}{2\pi\sin^4\theta_W}\frac{1}{\mu^2}\left(\frac{M_1M_2}{M_1+M_2\tan^2\theta_W}\right)^2 \times \text{(factors)}$$

$M_{\mathrm{gaugino}} \gg |\mu|$ → >>1, $\tilde{\chi}^0_2 \to \tilde{\chi}^0_1\gamma$ become dominant



Phenomenology from compositeness

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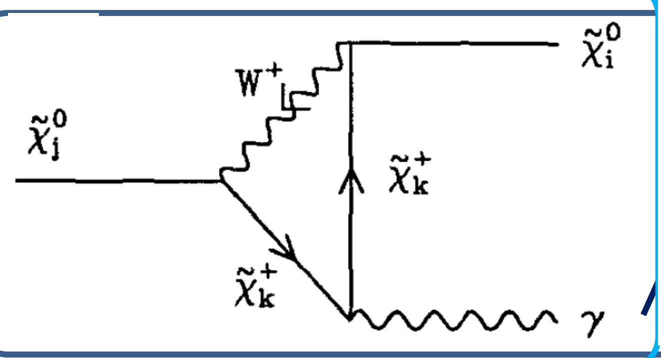
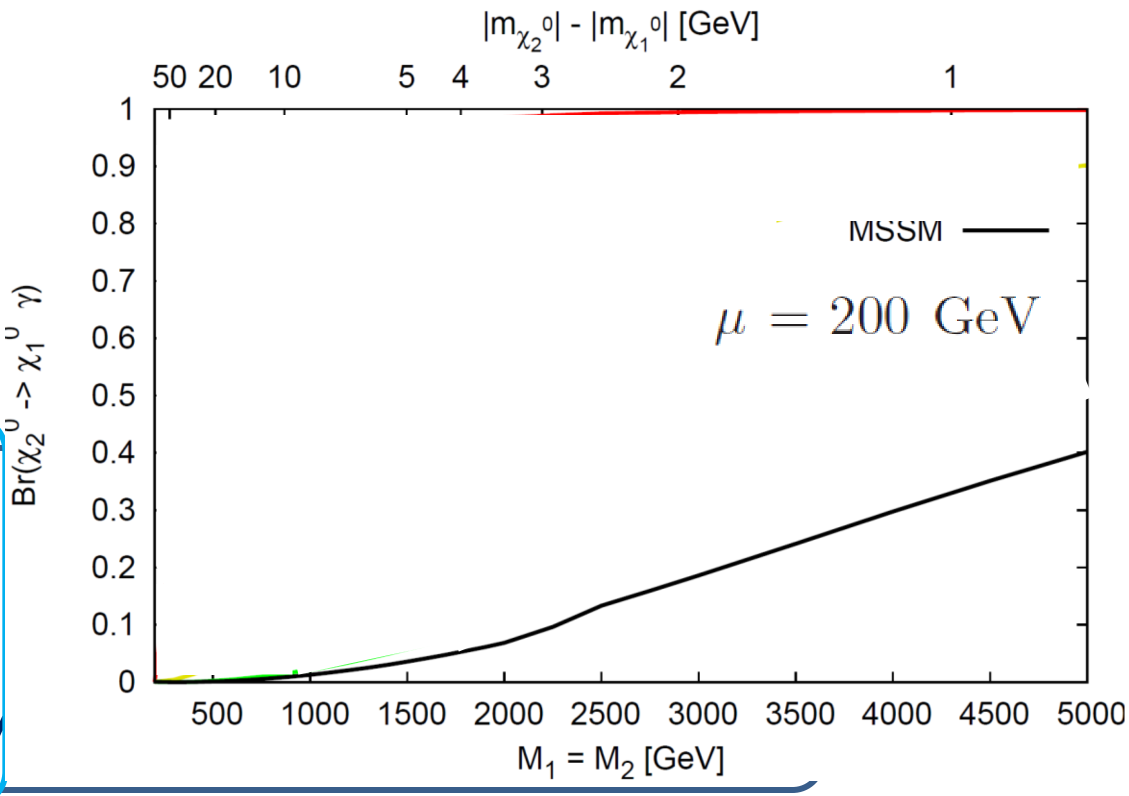
Higgsino compositeness

- **Neutralino decay (in pure Higgsino case)**





Phenomenology from compositeness

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Higgsino compositeness

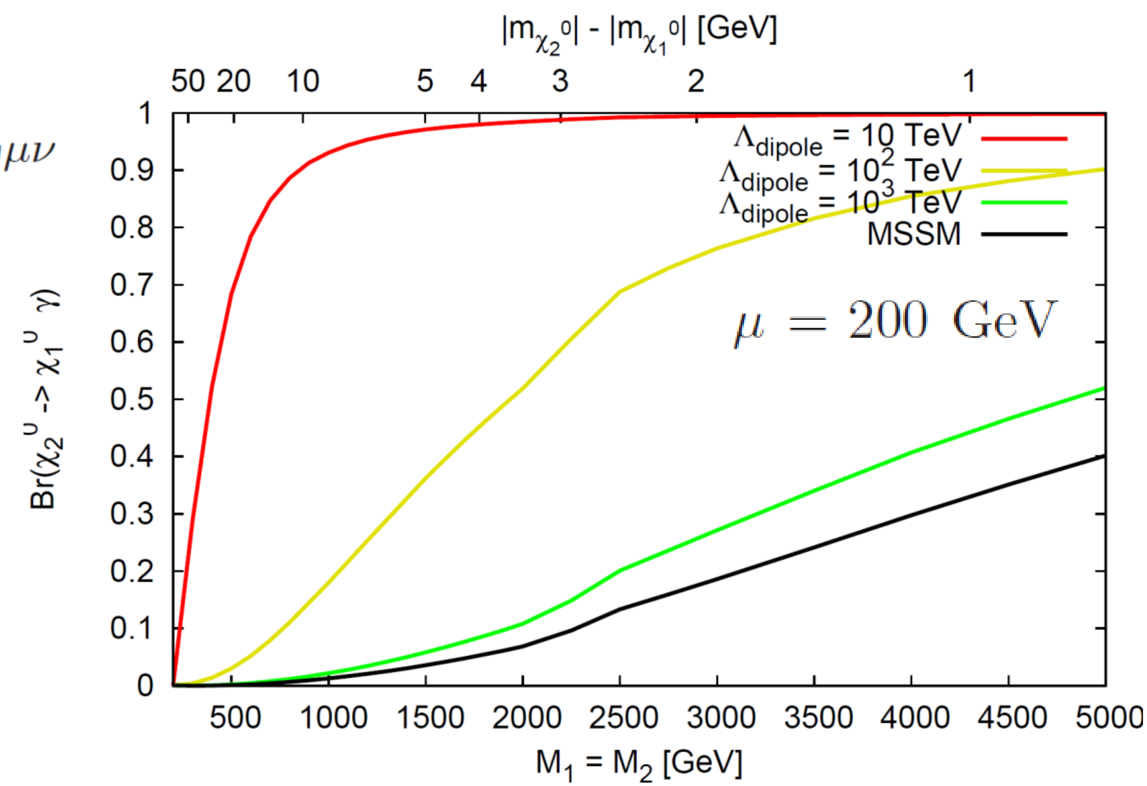
- **Neutralino decay (in pure Higgsino case)**

If there is the

additional operator,

$$\mathcal{L} = \frac{e}{\Lambda_{\rm dipole}} \bar{\tilde{\chi}}_1^0 \sigma_{\mu\nu} \tilde{\chi}_2^0 F^{\mu\nu}$$

two body decay Br. can be larger than MSSM case →



Phenomenology from compositeness

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Higgsino compositeness

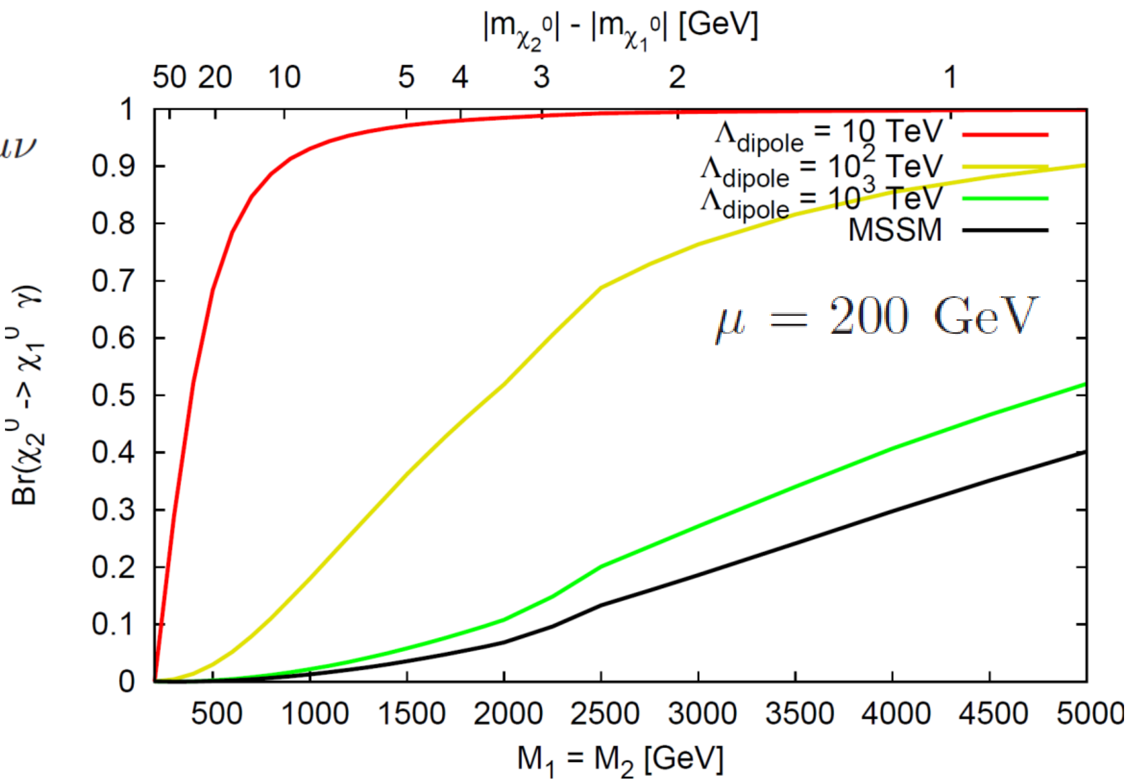
- **Neutralino decay (in pure Higgsino case)**

NDA $\left(g\left(\frac{\epsilon_u\epsilon_d}{\Lambda}\right)\left(\frac{m_{\rm SUSY}}{\Lambda}\right)\left[H_d W_\alpha e^V (D^\alpha e^{-V} H_u)\right]|_{\theta^2} \right)$

$$\mathcal{L} = \frac{e}{\Lambda_{\rm dipole}} \bar{\tilde{\chi}}_1^0 \sigma_{\mu\nu} \tilde{\chi}_2^0 F^{\mu\nu}$$

$$1/\Lambda_{\rm dipole} \sim \left(\frac{\epsilon_u\epsilon_d}{\Lambda}\right)\left(\frac{m_{\rm SUSY}}{\Lambda}\right)$$

$$\epsilon_u\epsilon_d/\Lambda \sim 1/(10{\rm TeV})$$



Phenomenology from compositeness

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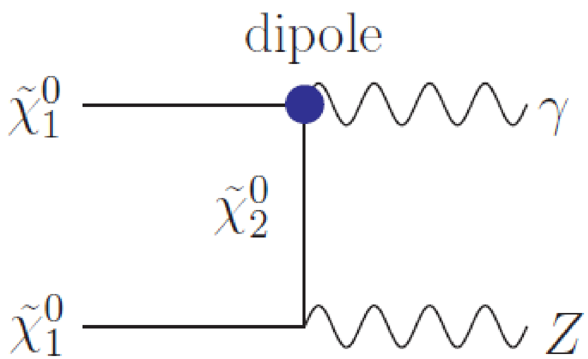
Higgsino compositeness

- Neutralino decay
- Annihilation cross section



Line-gamma signal can also be enhanced in indirect dark matter detection.

Phenomenology from compositeness

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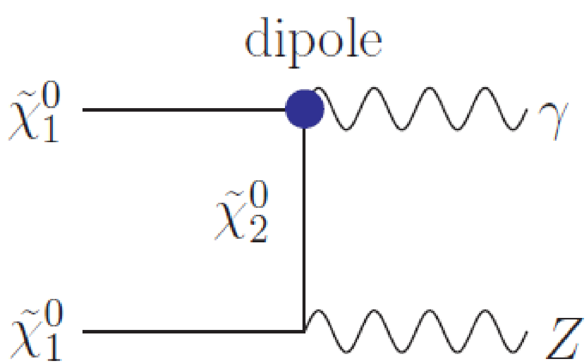
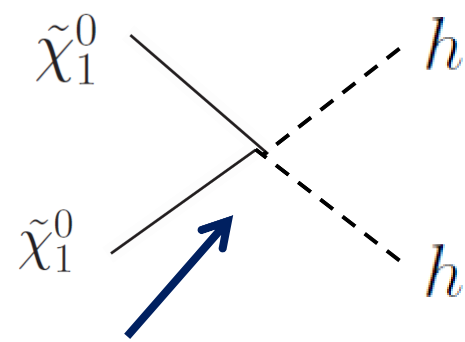
Higgsino compositeness

- Neutralino decay
- Annihilation cross section





For annihilation, there are also other contributions.

$$W_{\rm BMSSM} = \frac{\lambda_1}{M}(H_u H_d)^2$$

Cheung, Choi, Song ’09
Bernal, Blum, Nir, Losada ’09 …

Phenomenology from compositeness

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Higgsino compositeness

- Neutralino decay
- Annihilation cross section
- Additional contribution to off diagonal in neutralino mass matrix

due to the kinetic mixing between gaugino and Higgsino.

$$\int d^4\theta \mathcal{Z}^\dagger H_d W_Y^\alpha e^V (D_\alpha e^{-V} H_u) \longrightarrow \sqrt{2} i H_d \tilde{H}_u \sigma^\mu \partial_\mu \tilde{B}^\dagger$$

(& also the contribution from HHHH …)

Phenomenology from compositeness

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Higgsino compositeness

- Neutralino decay
- Annihilation cross section
- Additional contribution to off diagonal

$$\begin{pmatrix} M_1 & 0 & -m_Z s_W c_\beta(1+\delta_{13}) & m_Z s_W s_\beta(1+\delta_{14}) \\ 0 & M_2 & m_Z c_W c_\beta(1+\delta_{23}) & -m_Z c_W s_\beta(1+\delta_{24}) \\ -m_Z s_W c_\beta(1+\delta_{13}) & m_Z c_W c_\beta(1+\delta_{23}) & 0 & -\mu_{\rm eff.} \\ m_Z s_W s_\beta(1+\delta_{14}) & -m_Z c_W s_\beta(1+\delta_{24}) & -\mu_{\rm eff.} & 0 \end{pmatrix}$$

$$\begin{aligned} \mu_{\rm eff.} &= -\mu - \frac{\epsilon_u\epsilon_d\bar{C}m_Z^2 c_{2\beta}}{2\Lambda}, \\ \delta_{13} &= \frac{2C_{g',d}\epsilon_u\epsilon_d}{\Lambda}\left(-M_1 t_\beta+\mu\right), \qquad \delta_{14} = \frac{2C_{g',u}\epsilon_u\epsilon_d}{\Lambda}\left(-M_1 t_\beta^{-1}+\mu\right), \\ \delta_{23} &= \frac{2C_{g,d}\epsilon_u\epsilon_d}{\Lambda}\left(-M_2 t_\beta+\mu\right), \qquad \delta_{24} = \frac{2C_{g,u}\epsilon_u\epsilon_d}{\Lambda}\left(-M_2 t_\beta^{-1}+\mu\right). \end{aligned}$$

Summary

Summary

One of the possibility to realize the viable Higgs potential

→ Partially composite Higgs scenario:

Higgs potential can be produced by strong dynamics.

Partially compositeness would appear,

- Higgs compositeness: Higgs -> photon
- Particle from strong sector: techni-rho meson
- Higgsino compositeness
  - ☐ Higgsino decay
  - ☐ Higgsino annihilation
  - ☐ Mixing

In some case,

it may also appear as Higgsino compositeness.

Partially composite Higgs

- Additional Higgs potential are produced.
  - Higgs mass can be 126 GeV.

many scenarios are proposed:

Fukushima, Kitano, Yamaguchi ’10
Azatov, Galloway, Luty ’11
Gherghetta, Pomarol ’11
Heckman, Kumar, Vafa, Wecht ’11
Csaki, Randall, Terning ’12
Evans, Ibe, Yanagida ’12
Kitano, Luty, Nakai ’12
…

- EWSB are achieves only by <H>.

or

- EWSB are also achieves by strong sector.

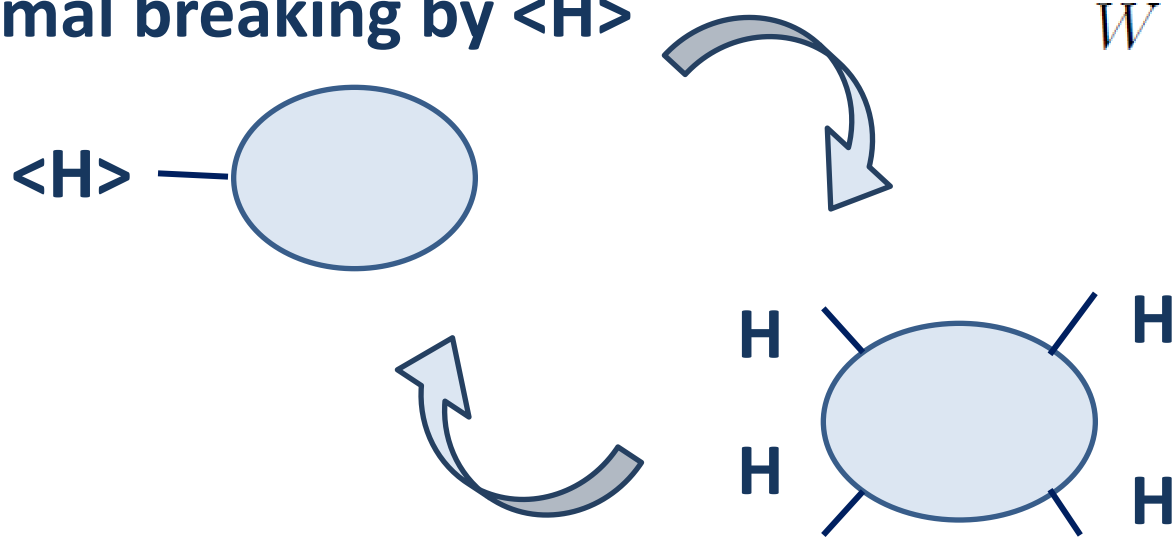
Partially composite Higgs

- Additional Higgs potential are produced.
  - Higgs mass can be 126 GeV.

For example, Higgs bootstrap: Kitano, Luty, Nakai ’12

Conformal breaking by <H>

$$W = \lambda_{ij} H \Psi_i \tilde{\Psi}_j$$



Higgs potential provides <H>