Higgs Doublet and Complex Singlet and U(1)′ Extensions to the MSSM

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Outline

- Doublet Extensions to MSSM
- Nelson-Randall Model
- Examples
- Conclusions

Beyond Singlets:
4 Higgs Doublets and Singlets

- work in progress with Barger, Everett, McCaskey

Fields	$SU(3)_C, SU(2)_L, U(1)_Y, U(1)'$
H_1, H_3	$(\mathbf{1}, \mathbf{2}, -1/2, Q_{1,3})$
H_2, H_4	$(\mathbf{1}, \mathbf{2}, 1/2, Q_{2,4})$
S_i	$(\mathbf{1}, \mathbf{1}, 0, Q_{S_i})$

- Singlets added as needed to solve μ problem(s)

Motivation

- Top-down models
  - String theory: often has many doublets and singlets
- "natural" large $tan\beta$ with mixed terms

$$H_2 \cdot H_3, H_4 \cdot H_1$$

(A. Nelson and L. Randall; hep-ph/9308277)

As yet unstudied...

- not necessary for EW breaking
- issue of gauge unification
  - extra exotics (GUTs)
  - gauge unification not fundamental (string models)

As yet unstudied...

$$W = \mu H_2 \cdot H_1 + h_{ui}\bar{u}_i Q_i \cdot H_2 - h_{di}\bar{d}_i Q_i \cdot H_1 - h_{ei}\bar{e}_i L_i \cdot H_1$$

- A major concern: >1 Higgs couples to up-type or down-type quarks
  - tree level FCNCs

$$W \supset h_{d_i}\bar{d}_i Q_i \cdot H_1 + h'_{d_i}\bar{d}_i Q_i \cdot H_3$$

- We'll address this on a case-by-case basis...

Misiak, Pokorski and Rosiek; hep-ph/9703442

S.L. Glashow and S. Weinberg; Natural Conservation Laws for Neutral Currents: Phys. Rev. D, 1977 (ID 10.1103/PhysRevD.15.1958)

- Goal: to categorize and explore phenomenology of various extra doublet models that address the μ problem

- Observed theme: relatively difficult to get viable scenarios

- Reason: accidental global symmetries

- Challenge: to minimally break symmetries without reintroducing μ problem(s)

Nelson-Randall Model

$$W = \mu_{41} H_4 \cdot H_1 + \mu_{23} H_2 \cdot H_3$$

- doesn't solve the μ problem
- Naive extension: $W = a_1 S H_4 \cdot H_1 + a_2 S H_2 \cdot H_3$
  - problem: 1 extra accidental symmetry
    - 1 Goldstone boson after SSB
    - 1 unobserved axion or extra force

Aside

- problem was already observed for models with many singlets and a $U(1)'$
(P. Langacker, G. Paz, I. Yavin arXiv:0811.1196)

$$V(S_1 ... S_N) = \sum_i m_i^2 |S_i|^2 + \frac{g'^2}{2} (\sum_i Q_i |S_i|^2)^2$$

  - N-1 accidental symmetries to be broken by superpotential singlet terms
    - bilinear terms: easiest, but new μ problem
    - trilinear: harder to obtain by gauge invariance

- Now we have doublets as well
  -> even more constrained in field combinations

- Goal: to explore this issue systematically

- Are there any viable scenarios?

- Naive Nelson-Randall extension is out...

2 Singlet Superpotentials

- 2 singlet N-R model $W = a_1 S_1 H_4 \cdot H_1 + a_2 S_2 H_2 \cdot H_3$
  - 2 Goldstone bosons
- What about adding 2 extended N-R models?

$$W = a_1 S_1 H_2 \cdot H_1 + a_2 S_1 H_4 \cdot H_3 + a_3 S_2 H_4 \cdot H_1 + a_4 S_2 H_2 \cdot H_3$$

- 2 Goldstone bosons -> only 1 can be broken by trilinear $S_1^2 S_2, S_1 S_2^2$ or bilinear $S_1 S_2$

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- Correct mass behaviour, what about FCNCs?

- Gauge invariance -> $Q_1 = Q_3$, $Q_{S_1} = -Q_{S_2}$, $Q_2 = Q_4 + 2Q_{S_2}$
- Can only prevent FCNC from up-type or down-type, not both

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Superpotential

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- Cases:
  - all different $S_1 \neq S_2 \neq S_3 \neq S_4$
  - 3 different $S_i = S_j \neq S_k \neq S_l$
  - only 2 singlets $S_i = S_j \neq S_k = S_l$
  - only 1 singlet $S_1 = S_2 = S_3 = S_4$

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- all or 3 different: 4 or 3 Goldstone bosons
- only 2 singlets:
  - S_1=S_3 or S_1=S_4: extra Goldstone boson
  - S_1=S_2: correct Goldstone bosons
- only 1 singlet: correct Goldstone bosons
- Consequences: possible FCNCs

Observations so far...

- Global symmetries -> breaking in superpotential restricts $U(1)'$ charges
- In progress: study viable scenarios and examine FCNC problem in more detail
- Future:
  - RGEs: connect to top down models
  - Anomalies and GUT embedding consequences

Summary

- global symmetries: issues for multi scalar Higgs sectors
- previously studied for singlet extended models
- In progress: search for viable scenarios, including Z′ and FCNC constraints
- stay tuned!

References

- Cvetic, M. et al. arXiv: hep-ph/9703317
- Dawson, S. arXiv: hep-ph/9712464
- Martin, S. arXiv: hep-ph/9709356

Thank you!