A Viable Four Higgs Doublet Model

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Outline

- Previous Work on Extensions of the MSSM
- Plausible Models
- Numerical Examples of Four Higgs Doublet Models

Beyond Singlets: Four 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)

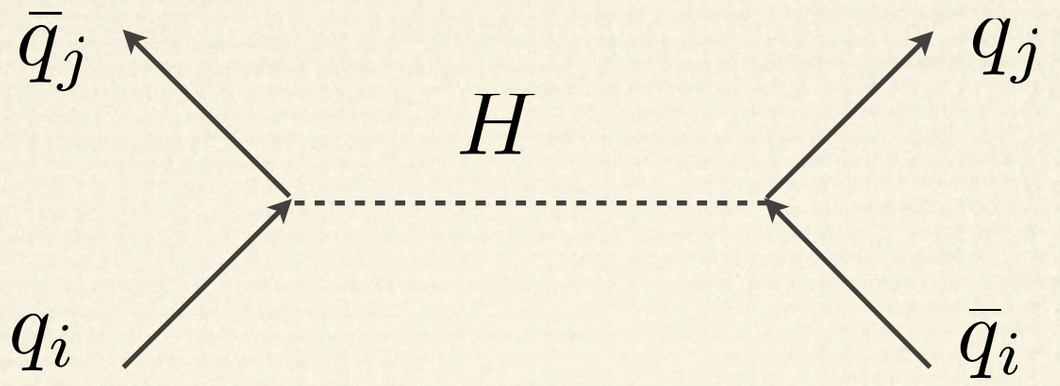
- Goal: to categorize and explore phenomenology of various extra doublet models that address the μ problem

- Observed theme: relatively difficult to get viable scenarios

  - Reason: accidental global symmetries or Flavour Changing Neutral Currents (FCNCs)

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

Flavour Changing Neutral Currents



- Can occur in the up or down sectors:

$$W = \lambda_1 S_1 H_{\textcircled{2}} \cdot H_1 + \lambda_1' S_1 H_{\textcircled{4}} \cdot H_1 + \lambda_2 S_2 H_4 \cdot H_3 + \lambda_2' S_2 H_2 \cdot H_3$$

$$W = \lambda_1 S_1 H_2 \cdot H_{\textcircled{1}} + \lambda_1' S_1 H_2 \cdot H_{\textcircled{3}} + \lambda_2 S_2 H_4 \cdot H_3 + \lambda_2' S_2 H_4 \cdot H_1$$

- Choose up-type FCNC option

A Numerical Example

- Superpotential

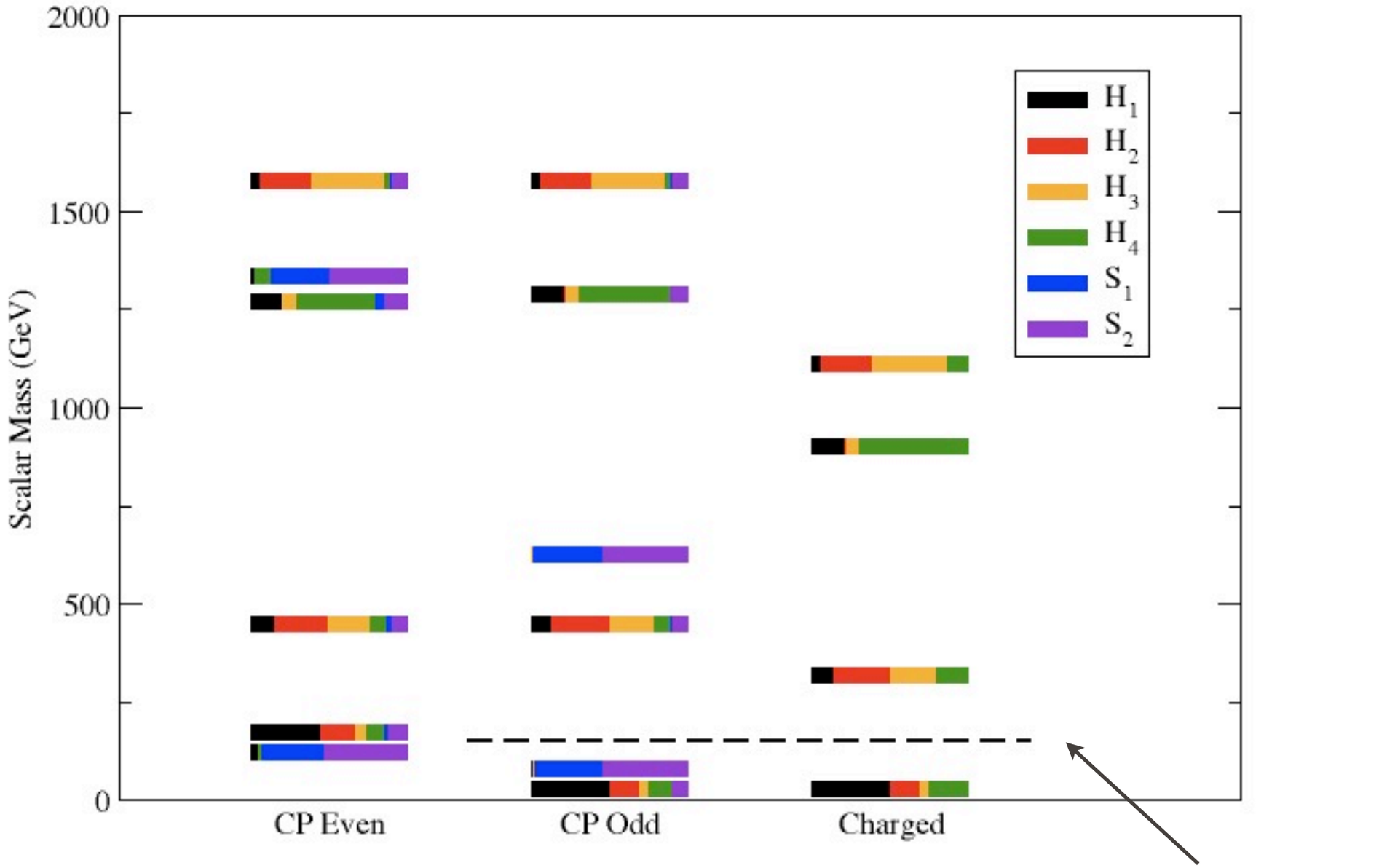
$$\begin{aligned} W &= \lambda_1 S_1 H_2 \cdot H_1 + \lambda_1' S_1 H_4 \cdot H_1 \\ &+ \lambda_2 S_2 H_4 \cdot H_3 + \lambda_2' S_2 H_2 \cdot H_3 \\ &+ \tilde{\mu} S_1 S_2 \end{aligned}$$

- $\Sigma v_i^2 = (246 GeV)^2$

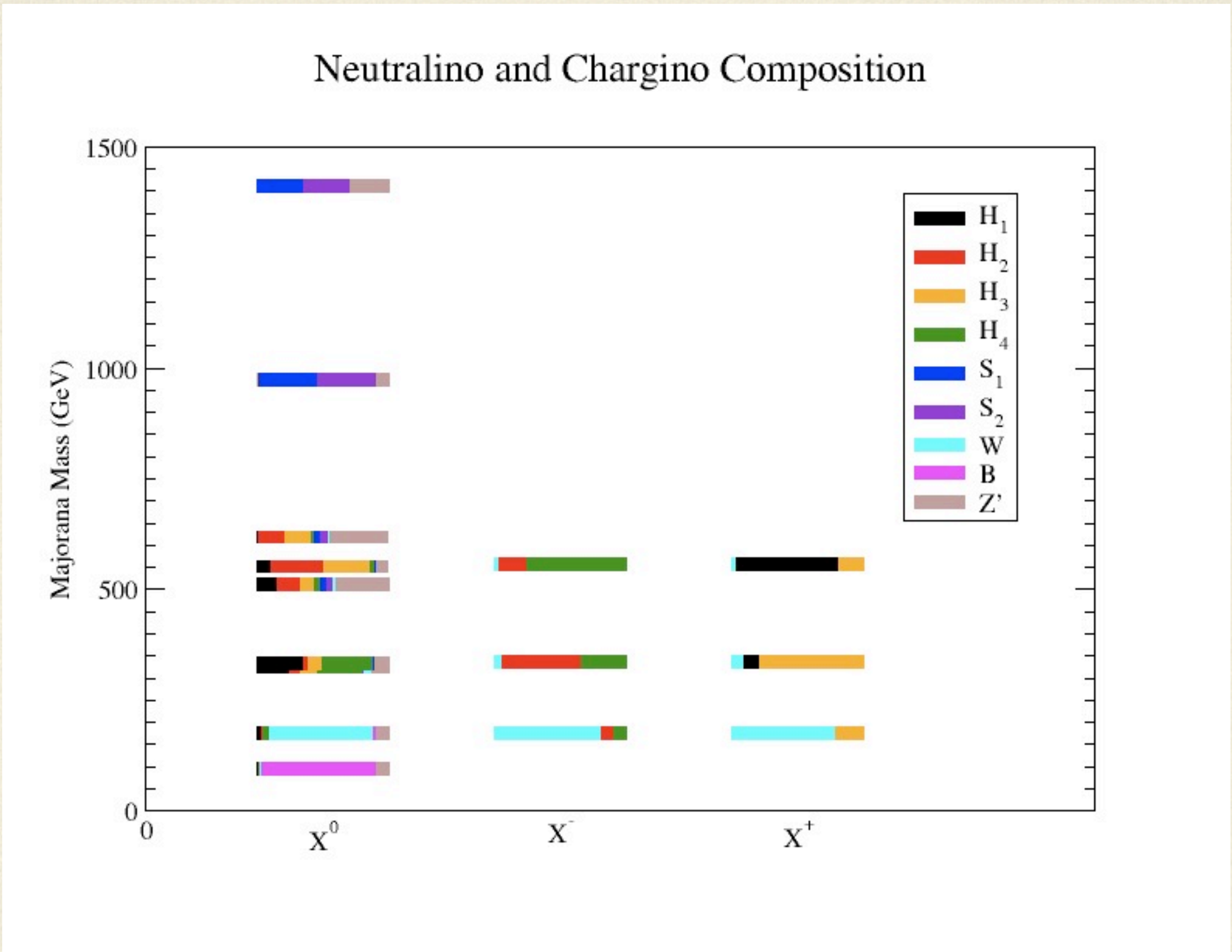
- $M_{Z'} = 827 GeV$

Parameters	VEVs
$\lambda_1 = 0.263$	$s_1 = 826$ GeV
$\lambda_1' = 0.595$	$s_2 = 826$ GeV
$\lambda_2 = 0.009$	$v_1 = 184$ GeV
$\lambda_2' = 0.867$	$v_2 = 112$ GeV
$\tilde{\mu} = 966$ GeV	$v_3 = 60$ GeV
	$v_4 = 101$ GeV

Scalar Masses and Composition



- States below dashed line are Goldstone bosons


Neutralino and Chargino Composition
1500
1000
500
0
Majorana Mass (GeV)
0
X0
X-
X+
H1
H2
H3
H4
S1
S2
W
B
Z'

Conclusions

- More complex than singlet-only extensions
- Accidental symmetries versus FCNCs
- Electroweak scale is rich
- Parameter space needs exploration
- Thank you!

References

- Cvetic, M. *et al.* arXiv: hep-ph/9703317
- Dawson, S. arXiv: hep-ph/9712464
- Martin, S. arXiv: hep-ph/9709356
- Nelson, A. arXiv: hep-ph/9308277
- Petrov, A. arXiv:1003.0906v1 [hep-ph]

Accidental Symmetries and $U(1)'$.

- Each gauge boson can eat one massless degree of freedom
- Only singlets couple to additional $U(1)$ symmetries
- Additional $U(1)$ symmetries are inadequate solutions