MIRROR FERMIONS SEEK FRIENDSHIP WITH HEAVY HIGGS AND INERT DOUBLET

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Portoroz 2011

OUTLINE

work with:
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- Why mirror fermions?
- Is there enough space?
- High precision: the need for an inert doublet
- Allowed parameter space
- A dark matter candidate

WHY NOT GAUGE B-L ?

Pati, Salam, 1974
Mohapatra, Pati, 1975
Senjanović, Mohapatra, 1975

- In SM: B-L number conserved

  ...gauge it !

- Gauged B-L → anomalies

  ...add a right-handed neutrino

- A rich theory emerges:

  Left-Right Symmetry → Parity restoration
  Neutrino mass

PARITY RESTORATION:

Left-Right Symmetry

$$q_L = \begin{pmatrix} u \\ d \end{pmatrix}_L \qquad u_R \qquad d_R$$

$$\ell_L = \begin{pmatrix} \nu \\ e \end{pmatrix}_L \qquad \nu_R \qquad e_R$$

$$W_L$$

PARITY RESTORATION:

Left-Right Symmetry

$$q_L = \begin{pmatrix} u \\ d \end{pmatrix}_L \qquad q_R = \begin{pmatrix} u \\ d \end{pmatrix}_R$$

$$\ell_L = \begin{pmatrix} \nu \\ e \end{pmatrix}_L \qquad \ell_R = \begin{pmatrix} \nu \\ e \end{pmatrix}_R$$

W_L W_R

Why not B and L ?

- One advantage: forbids terms that induce proton decay

$$\frac{q\,q\,q\,\ell}{M^2}$$

if you want a new physics at low scale

- Why not gauge it ?

- How to cancel B, L anomalies?

Add ***mirror fermions***

PARITY RESTORATION:

Mirror fermions

Lee, Yang, 1956

W_L

$$q_L = \begin{pmatrix} u \\ d \end{pmatrix}_L \qquad Q_L = \begin{pmatrix} U^c \\ D^c \end{pmatrix}_L$$

$$\ell_L = \begin{pmatrix} \nu \\ e \end{pmatrix}_L \qquad L_L = \begin{pmatrix} N^c \\ E^c \end{pmatrix}_L$$

W_L

u^c_L ν^c_L U_L N_L

d^c_L e^c_L D_L E_L

$(3, 2; 1/6)$

$(3^*, 2; -1/6)$

(Not the same idea:
Mirror Universe)

Okun, Kobzarev,Pomeranchuck, 1966

W_L $\quad$ γ_L $\quad$ G_L $\quad$ H

$$q_L = \begin{pmatrix} u \\ d \end{pmatrix}_L$$

$$\ell_L = \begin{pmatrix} \nu \\ e \end{pmatrix}_L$$

u_L^c $\quad$ ν_L^c

d_L^c $\quad$ e_L^c

$$Q_L = \begin{pmatrix} U^c \\ D^c \end{pmatrix}_L$$

$$L_L = \begin{pmatrix} N^c \\ E^c \end{pmatrix}_L$$

U_L $\quad$ N_L

D_L $\quad$ E_L

W'_L $\quad$ γ'_L $\quad$ G'_L $\quad$ H'

I won't be talking about these

Family Unification

SO(10) language:

16-dimensional spinor representation

$$\Psi_+ = \begin{pmatrix} u_i \\ \nu \\ e \\ d_i \\ d_i^c \\ e^c \\ \nu^c \\ u_i^c \end{pmatrix}$$

- Spinors in SO(2n) are chiral
- 2^n -dimensional $\Psi_+ \,,\, \Psi_-$

  $\mathbf{16} \,,\, \mathbf{16}^*$
- For n odd, only mass terms allowed:

$$m \, \Psi_+ \, \Psi_-$$

Unify families in $\mathrm{SO(2n)} = SO(10 + 2k) \supset \mathrm{SO(10)} \times \mathrm{SO(2k)}$?

$\mathrm{SO}(10+2\mathrm{k}) \supset \mathrm{SO}(10) \times \mathrm{SO}(2\mathrm{k})$

$$\Psi_+ = 2^{k-1}\,[16 + 16^*]$$

$$\Psi_- = 2^{k-1}\,[16 + 16^*]$$

again ***mirror fermions***

SO(14): 64-dimensional spinors: 4 families
4 mirrors

.

but: mirror-ordinary mass terms allowed always

.

Gell-Mann, Ramond, Slansky, 1979
Bagger, Dimopoulos, 1984

.

SO(18) ⊃ SO(10) x SO(8)

256 $(16, 8_+) + (16^*, 8_-)$

use symmetries to give some families large masses

Senjanović, Wilczek, Zee, 1984

end up with → 3 light families
3 light mirror families

And More...

- **Kaluza-Klein theories:** in d=11, fermions are not chiral, compactify and get mirror fermions

- **N=2 supersymmetry:** mirrors appear for each fermion

Mirror fermions:

- theoretically well-motivated
- relatively low energy (masses from EWSB)
- ... surely already eliminated by experiment ?

The Banned Extra Family

Talks by Lenz, Sannino, Melic, Košnik

An extra generation of ordinary fermions is excluded at the 6 σ level on the basis of the S parameter alone, corresponding to $N_F = 2.71 \pm 0.22$ for the number of families.

Erler, Langacker in PDG, 2007

However: *Maltoni, Novikov, Okun, Rosanov, Vysotski, 2000*

He, Polonsky, Su, 2001

Kribs, Plehn, Spannowsky, 2007

→ 4th. family allowed by high precision tests

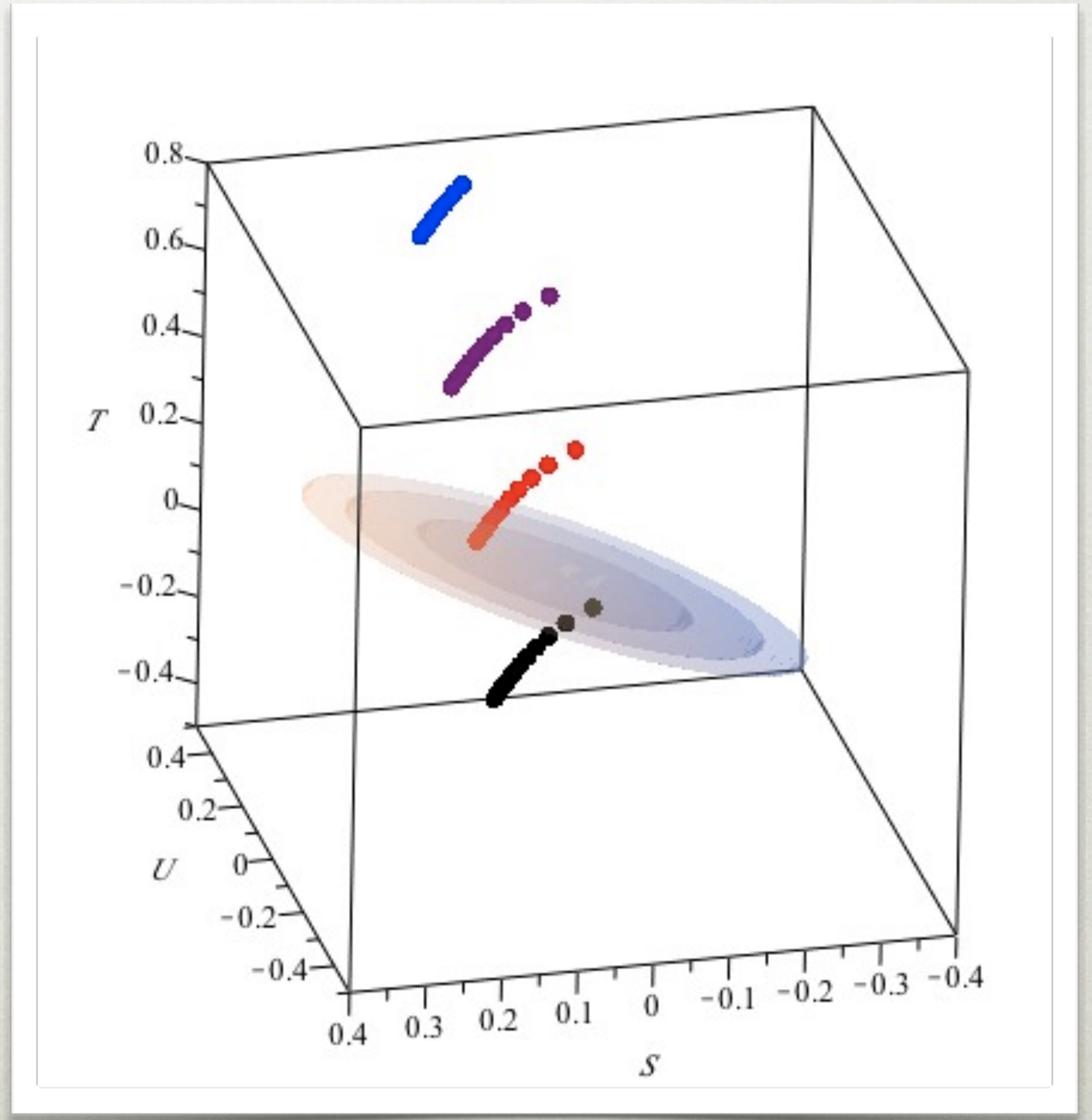
finally acknowledged in *Erler, Langacker, 2010*

Some space also for Mirrors?

- Unlikely, as space very reduced even for one extra family, and need three.

Gfitter, 2010

- High precision tests: SM better with light Higgs
- One extra family better if Higgs heavier (~350 GeV)
- More than one extra family excluded



$M_U = 420\, GeV$
$M_D = 400\, GeV$
$M_N = 46\, GeV$
$M_E = 170\, GeV$

$M_h = [100 ... 600]\, GeV$

A Mirror Higgs Doublet?

- Mirror fermions + extra Higgs doublet ?
  quite natural, as ordinary and mirror families cannot mix

$$\not{m\,\bar{f}\,F} \qquad\qquad y_{ij}\,\bar{\ell}_i \Phi e_j \quad + \quad y^M_{ij}\,\bar{L}_i \Phi^M E_j$$

- Already suggested, but before recent, stringent limits on quark masses from Tevatron

He, Polonsky, Su, 2001

Novikov et. al, 2002

- Q1: are mirror fermions + one extra doublet ***already excluded*** by EW precision tests?
- If not, Q2: what are the constraints on the new doublet?

Bounds on New Fermion Masses

- Long lived charged leptons at LEP

$$m_E \gtrsim 102.6\, GeV$$

PDG, 2008

- Neutral leptons can be light if stable: bound by Z width

$$m_N \gtrsim 45\, GeV$$

Maltoni, Novikov,
Okun, Rosanov, Vysotski, 2002
Murayama,Rentala, Shu 2010

- Quark direct searches from Tevatron, most stringent:

$$m_D \gtrsim 338\, GeV$$

CDF, 2010

$$m_D \sim m_U$$

- Perturbativity:

$$m_f < 600 GeV$$

Two Higgs Doublets

$$\Phi_1, \Phi_2 \left\{ \begin{array}{l} H^\pm \\ A^0 \\ h^0, H^0 \end{array} \right.$$

two angles: $\tan\beta = v_2/v_1$

α rotates CP-even states

S - T - U: depend on difference $\beta - \alpha$

best fits

↓

$\beta - \alpha = 0$ →

h^0 — is the SM Higgs

$H^0, A^0, H^\pm$ — components of an Inert Doublet

The Second Doublet Prefers to be Inert

- Inert Doublet Models: popular Dark Matter candidate

Deshpande, Ma , 1978
Barbieri, Hall, Rychkov, 2006

- Lower mass bounds less stringent for inert scalars:

$$m_H + m_A \gtrsim M_Z$$

  - Mass of H^0 bounded by $Z \to H^0\, H^0 Z^* \to H^0\, H^0\, f\, f$

$$m_H \gtrsim 50\, GeV$$

  - Neutralino searches in LEP II can be translated to inert scalars

Lundstrom, Gustafsson, Edsjo, 2009

$$m_A \gtrsim 100 - 120 \text{ for light } H^0$$

  - Chargino searches

$$m_{H^\pm} \gtrsim 70\, GeV$$

Pierce, Thaler, 2007

Higgs Production

- Most recent Tevatron analysis for Higgs with an extra family:

$$131\,GeV \lesssim m_h \lesssim 200GeV$$

excluded

- enhanced $g\,g \rightarrow h \rightarrow W^+\,W^-$

1 extra family: factor of 9

3 extra families: factor of 49

High Precision constraints

- Generate points in parameter space in allowed ranges (in fixed intervals first, then random points in more promising regions)

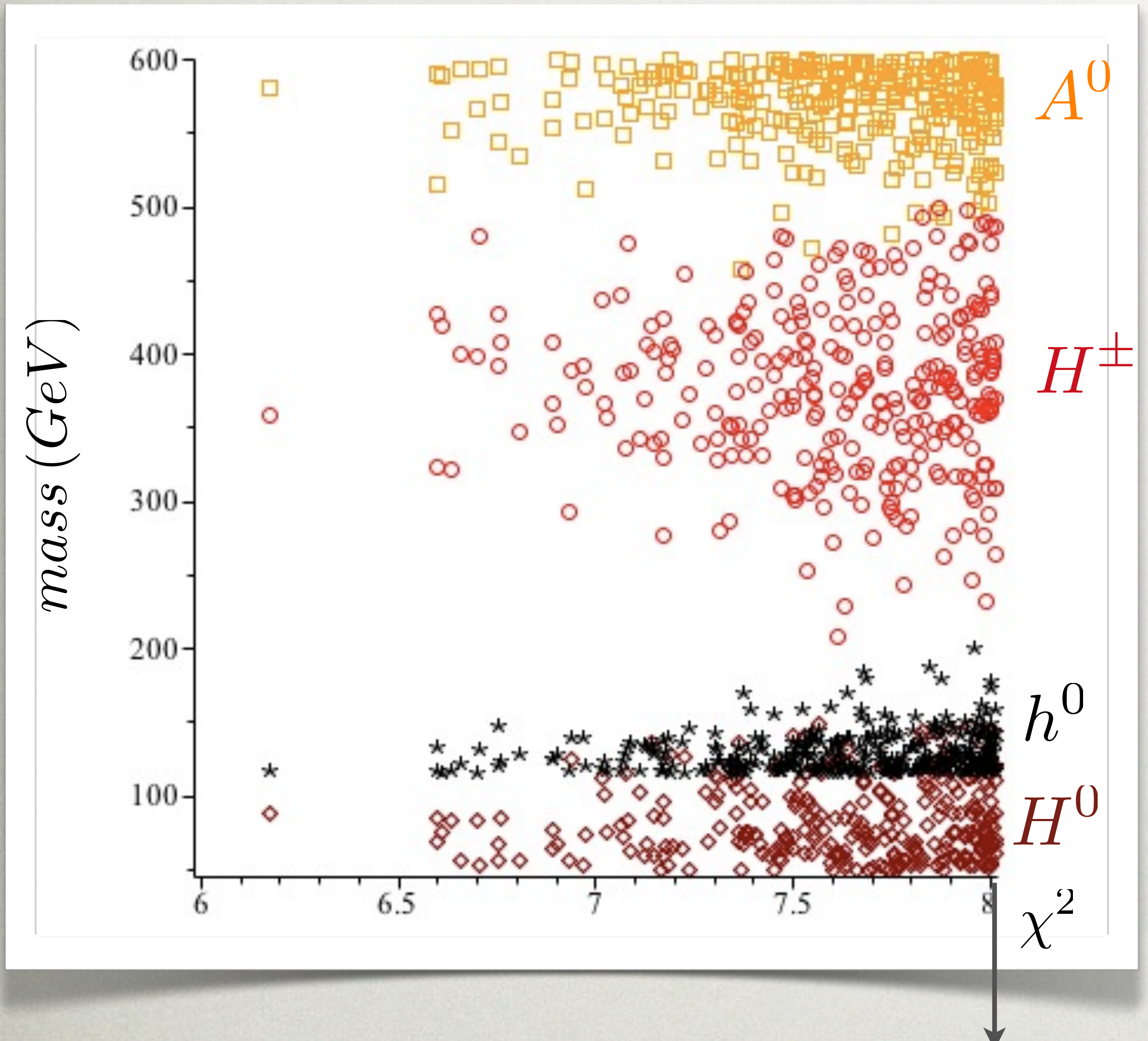
- Calculate S,T, U

  Grimus, Lavoura, Ogreid, Osland, 2008

- Compare with best fit form experiment

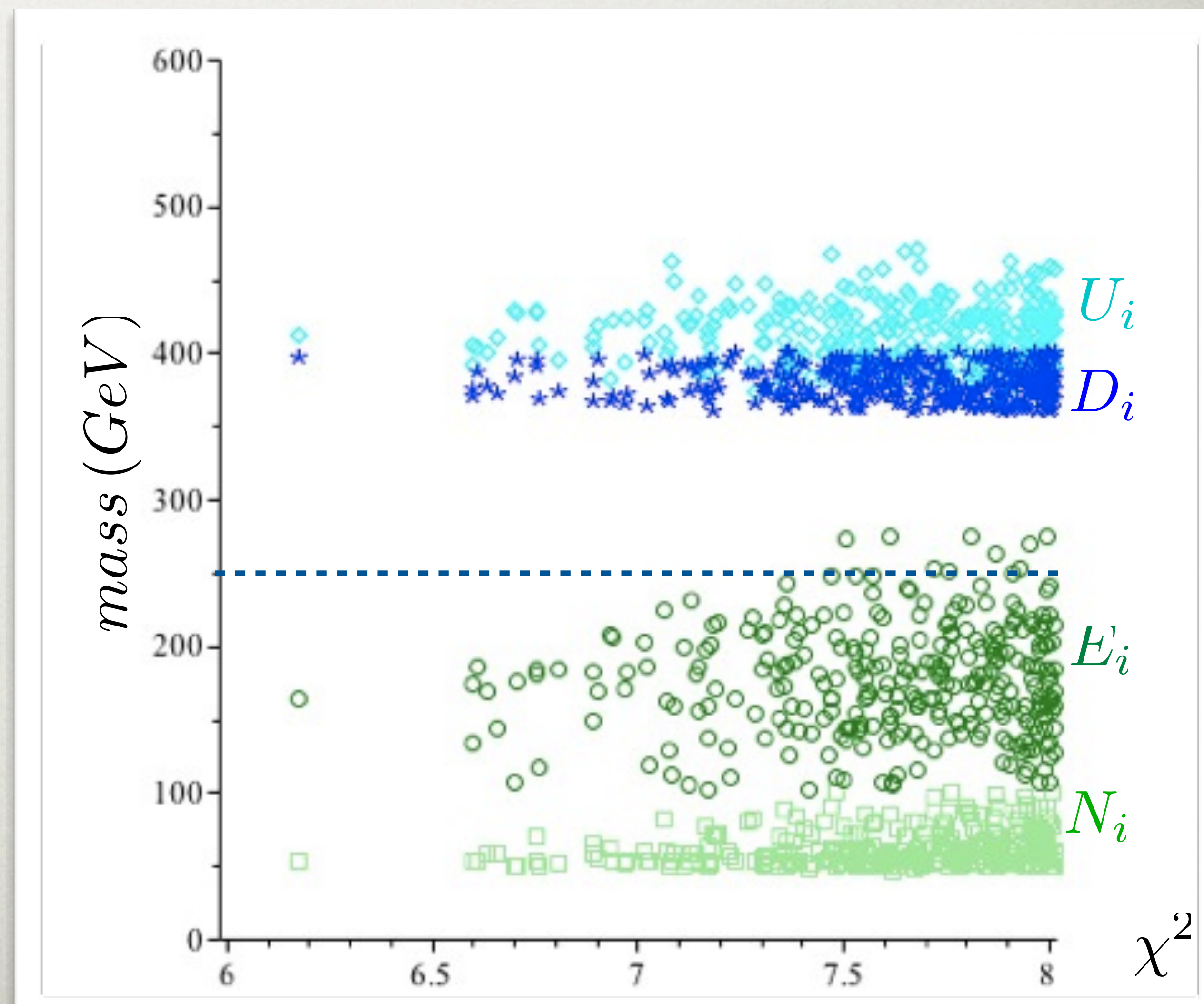
  Gfitter, 2010

Case I: Low mass SM Higgs



Scalars

Fermions

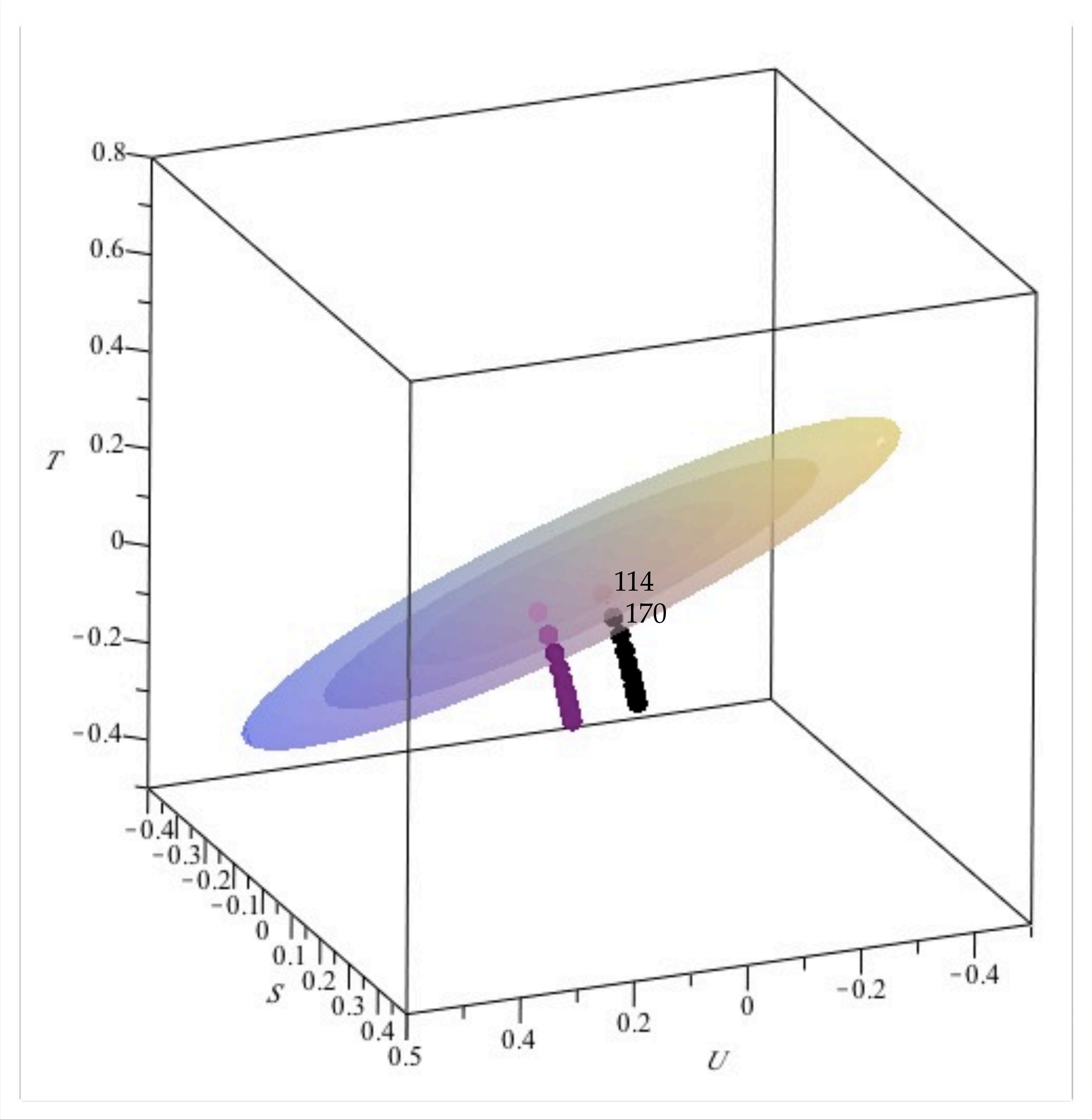


Carpenter, 2010

Case I: Low mass SM Higgs

Standard Model

m_h : [114...550]



Standard Model
+ 3 families
+ inert doublet

m_h : [114..550]

$m_H = 87$

$m_A = 580$

$m_{H^\pm} = 357$

$m_N = (53, 52, 61)$

$m_E = (164, 157, 162)$

$m_D = (396, 399, 365)$

$m_U = (412, 455, 431)$

BUT...

Light SM Higgs + heavy Inert Doublet components:

- Perturbativity concerns:

  strong coupling regime already at 600 GeV

- Vacuum instability danger:

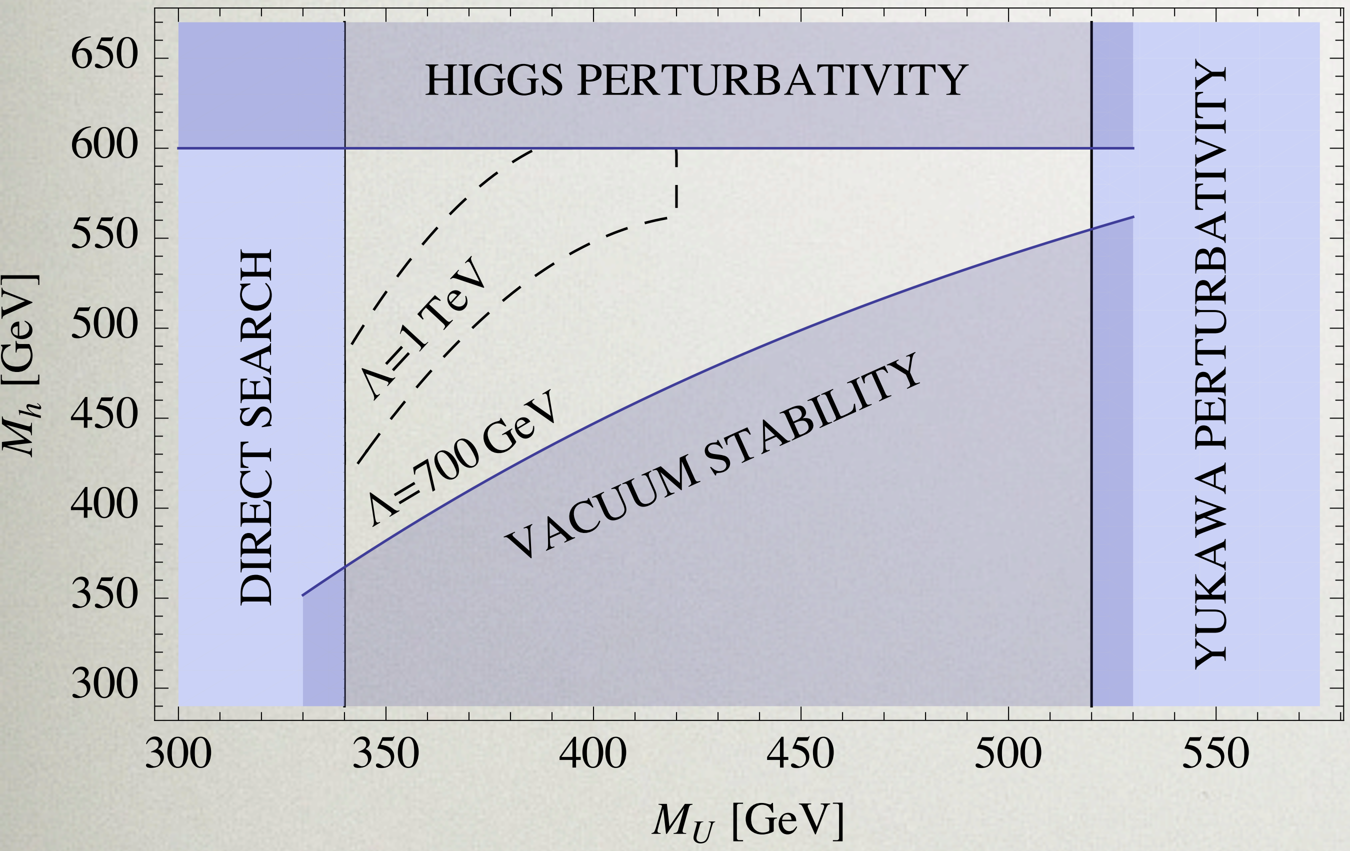
  extra doublet couplings drive SM Higgs self coupling to negative values

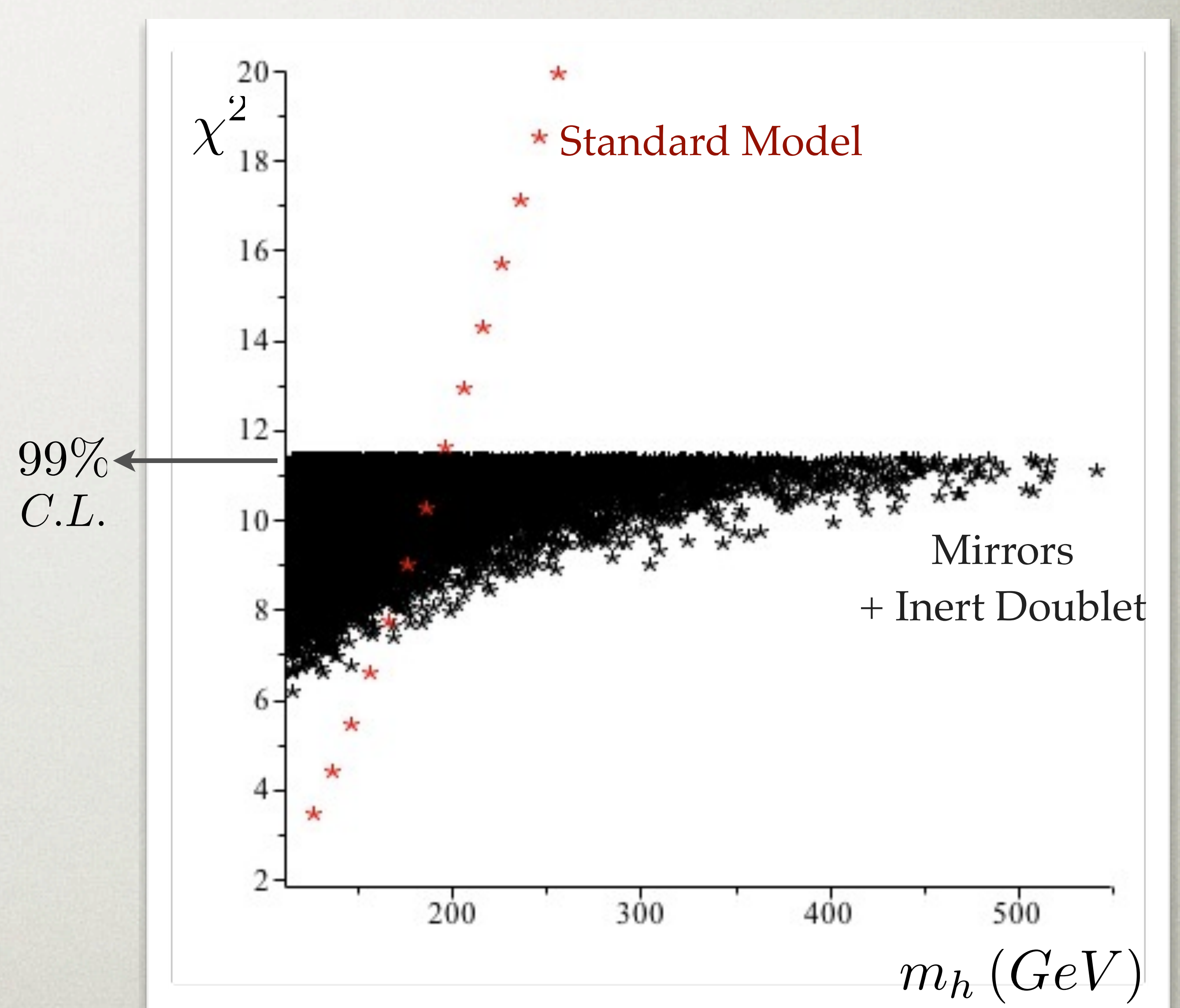
situation not clear: under study

A.M., Nemevšek, Nesti, Senjanović, Zhang

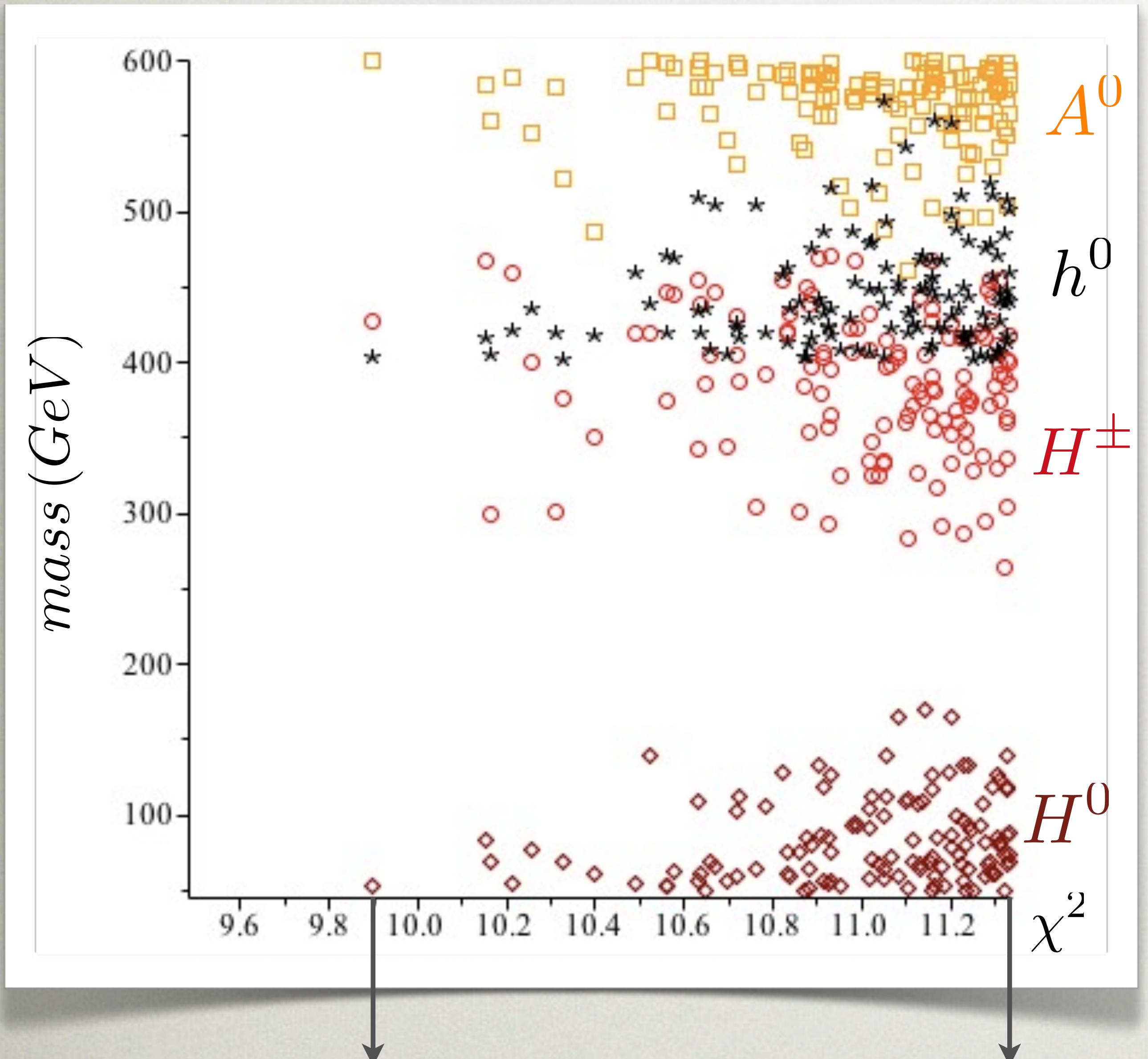
Heavy Higgs?

Stability: safe for
SM Higgs above 400 GeV





Case II: High Mass SM Higgs

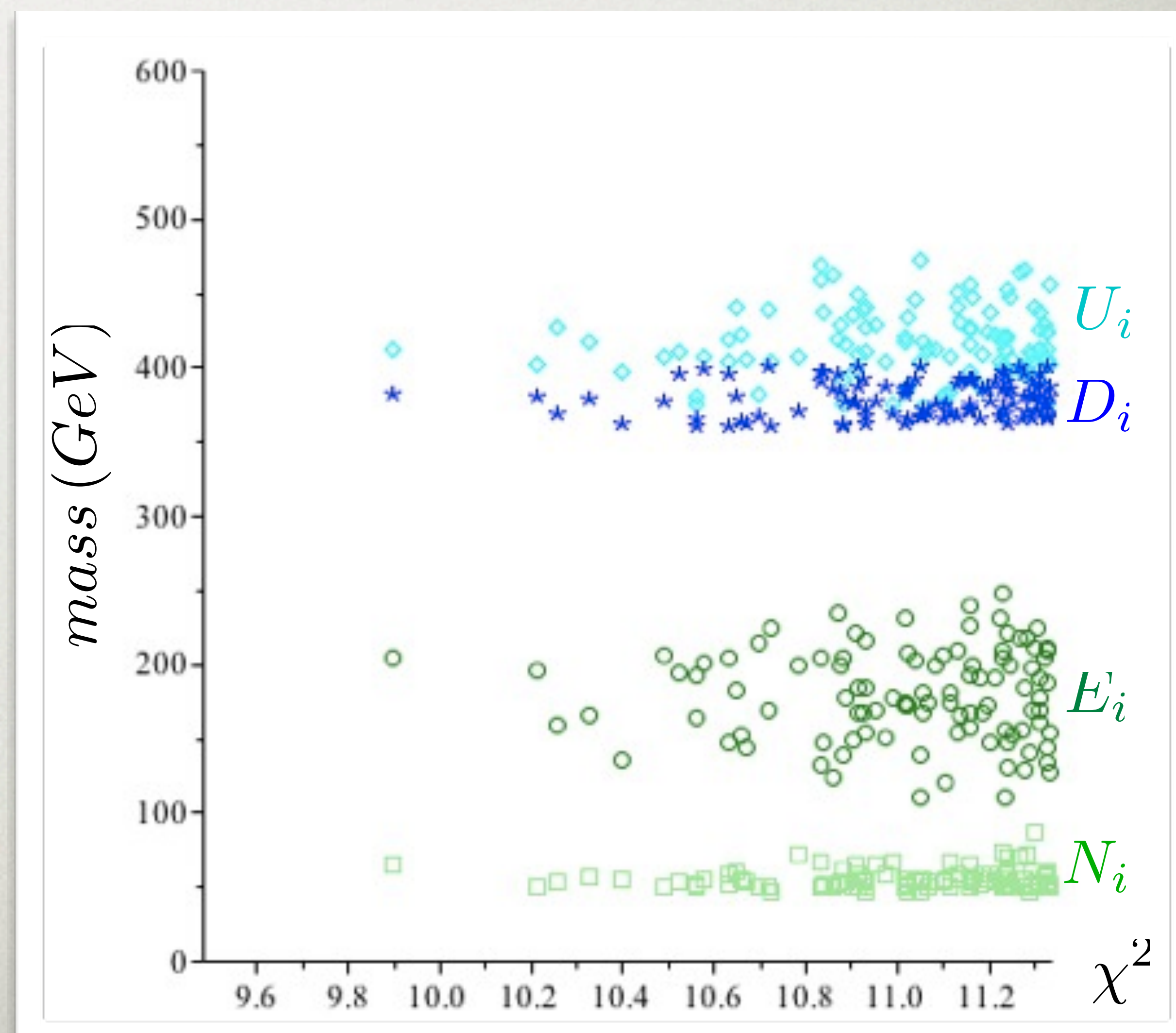


2.3σ

$99\%_{C.L.}$

Scalars

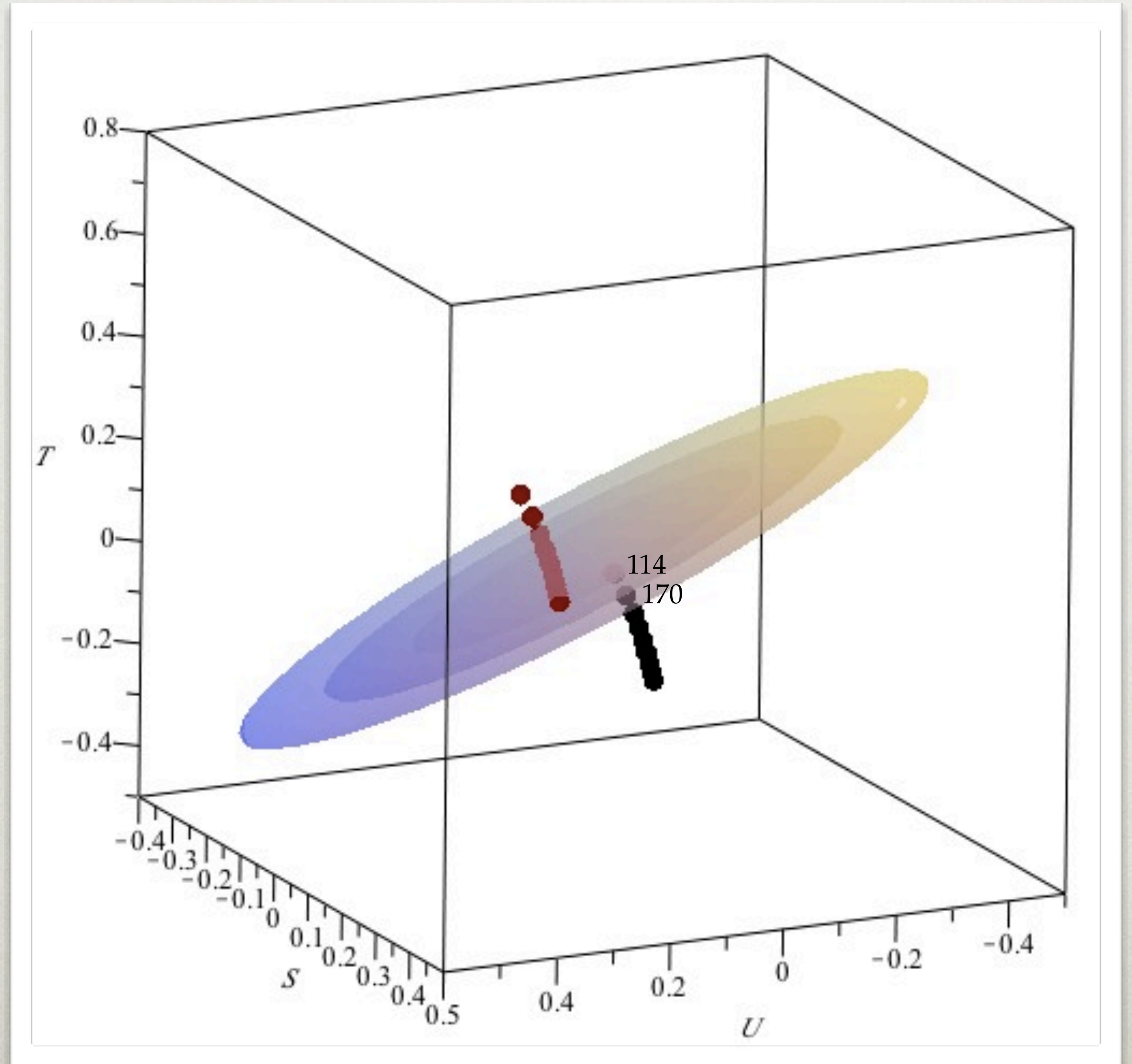
Fermions



Case II: High Mass SM Higgs

Standard Model

$m_h : [114...550]$



Standard Model
+ 3 families
+ inert doublet

$m_h : [114..550]$

$m_H = 53$

$m_A = 600$

$m_{H^\pm} = 427$

$m_N = (64, 53, 51)$

$m_E = (203, 202, 169)$

$m_U = (411, 413, 404)$

$m_D = (381, 382, 361)$

Inert Doublet as Dark Matter

Deshpande, Ma, 1978
Barbieri, Hall, Rychkov, 2006
Lopez-Honorez, Nezri, Oliver, 2007
Hambye et al. 2009
Nezri, Tytgat, Vertgonen, 2009
Dolle, Su, 2009

- Amply studied on its own
  "archetype WIMP"

- Can give WMAP abundace if the lightest component is in the mass windows:

$$40GeV \lesssim m_S \lesssim 80GeV$$

$$80GeV \lesssim m_S \lesssim 160GeV$$

Lopez-Honorez, Yaguna, 2010

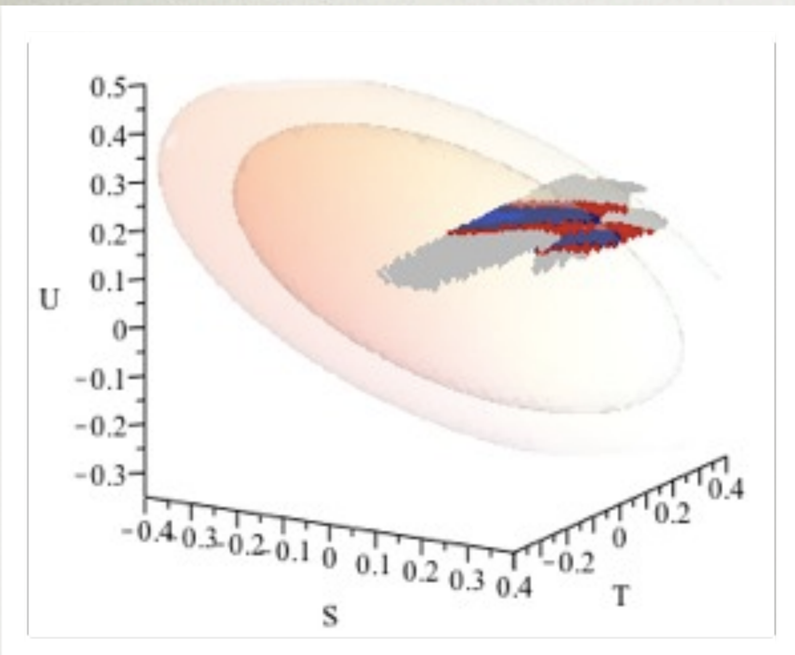
$$m_S \gtrsim 600GeV$$

- Hopes for direct detection
  (extra quarks enhance scattering off nuclei)

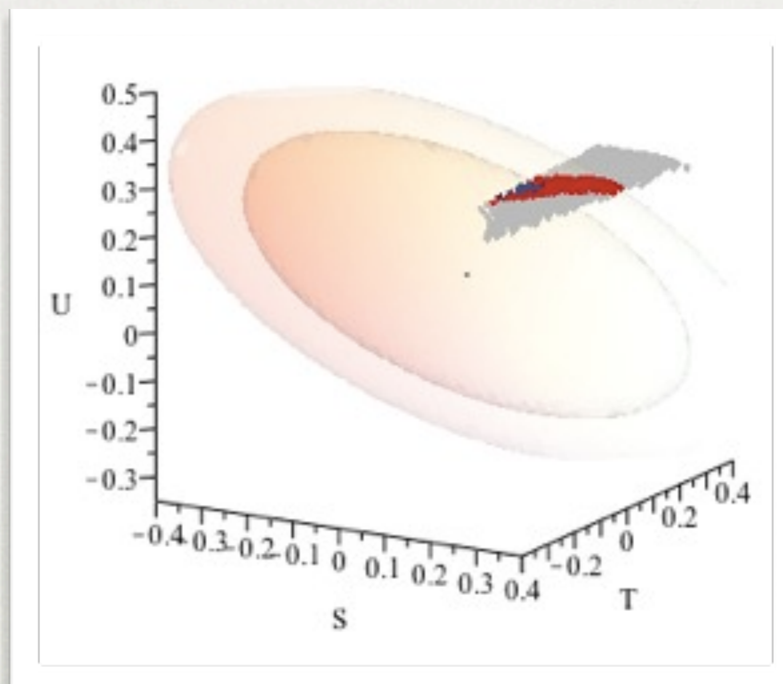
- ...work in progress

A.M., Nemevšek, Nesti, Senjanović, Zhang

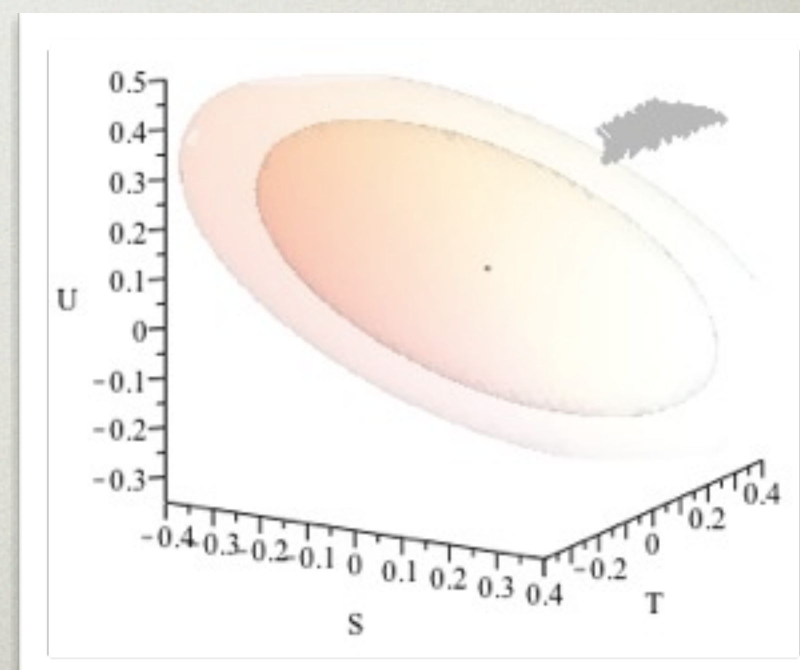
Even More Families?



3 + 2 families



3 + 3 families



3 + 4 families

Conclusions

- Mirror fermion idea still possible with most recent data
- Prefer a SM Higgs in the window $114GeV \lesssim m_h \lesssim 130GeV$
- But can also accomodate $m_h \gtrsim 400GeV$
- Requires existence of an Inert Doublet with lightest component in right mass range for dark matter
- Extra charged leptons light $100GeV \lesssim m_E \lesssim 300GeV$
- Light, stable extra neutral leptons $45GeV \lesssim m_N \lesssim 120GeV$
- Space for extra quarks getting smaller $360GeV \lesssim m_Q \lesssim 600GeV$
- Can be explored by LHC