MultiHiggs Workshop 2014

Lisboa, 4.09.2014

Cancelation of quadratic divergencies in models with 2 Higgs doublets

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with Neda Darvishi,
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Bogumiła Świeżewska,
Dorota Sokołowska

Plan of the talk

Introduction

Veltman condition

Applying of cancelation of quadratic divergencies (one loop) to

- soft viol. Z_2 2HDM (Mixed vacuum)
- 2HDM +singlets (real and complex)

LHC

SM-like Higgs particle with mass~125 GeV observed at ATLAS+CMS (+Tevatron)

BROKEN SYMMETRY AND THE MASS OF GAUGE VECTOR MESONS*

F. Englert and R. Brout
Faculté des Sciences, Université Libre de Bruxelles, Bruxelles, Belgium
(Received 26 June 1964)

BROKEN SYMMETRIES, MASSLESS PARTICLES AND GAUGE FIELDS

P. W. HIGGS
Tait Institute of Mathematical Physics, University of Edinburgh, Scotland

Received 27 July 1964

Nobel 2013 (Englert, Higgs)

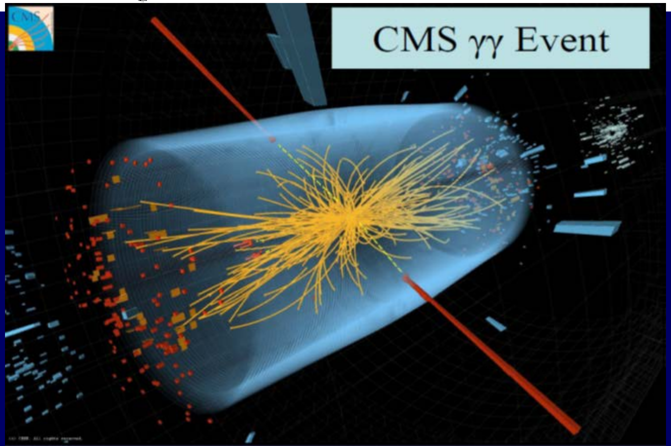
VOLUME 13, NUMBER 16 PHYSICAL REVIEW LETTERS 19 OCTOBER 1964

BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

Peter W. Higgs
Tait Institute of Mathematical Physics, University of Edinburgh, Edinburgh, Scotland
(Received 31 August 1964)

GLOBAL CONSERVATION LAWS AND MASSLESS PARTICLES*

G. S. Guralnik,† C. R. Hagen,‡ and T. W. B. Kibble
Department of Physics, Imperial College, London, England
(Received 12 October 1964)



Important loop couplings

ggH,γγH,ZγH,

125 GeV particle $\mathcal{H}$

What it is?

H_{SM} - Higgs boson of SM ?

h or a heavier scalar

(eg. H of CP-conserving 2HDM (MSSM))?

other state ?

SM-like scenario is observed - so

all measured $\mathcal{H}$ couplings are close to

the SM-prediction for *absolute value*

I. Ginzburg, MK , P. Osland 2001

2HDM

Soft viol. Z_2 symmetry

(CP conserving case)

SM-like h

H above 125 GeV, small couplings with W/Z

SM-like H

h below 125 GeV, small couplings with W/Z,

H-> hh important

Cancelation of quadratic divergencies

Veltman condition - one-loop SM

or

$$Q_1 = \lambda + \frac{1}{8}g'^2 + \frac{3}{8}g^2 - y_t^2.$$

$$Q_1' = 2Q_1 v^2 = m_H^2 + 2m_W^2 + m_Z^2 - 4m_t^2,$$

cancelation Q_1=0 ->
M_H(SM) ~ 314 GeV

2HDM: Wu, Osland, Newton ~2000; Ma, 2001

Grządkowski, Osland ~ 2010

(soft Z_2 viol, two-loop, heavy Higgses)

Our work: one-loop, 2HDM (Mixed) SM-like h, H

2HDM+singlets, IDM+singlets

(Ma 2013, Darvishi, Ilnicka 2014)

Soft Z2 violation in 2HDM

Potential

$$V = \tfrac{1}{2}\lambda_1(\Phi_1^\dagger\Phi_1)^2 + \tfrac{1}{2}\lambda_2(\Phi_2^\dagger\Phi_2)^2 + \lambda_3(\Phi_1^\dagger\Phi_1)(\Phi_2^\dagger\Phi_2)$$

$$+ \lambda_4(\Phi_1^\dagger\Phi_2)(\Phi_2^\dagger\Phi_1) + \tfrac{1}{2}\,[\lambda_5(\Phi_1^\dagger\Phi_2)^2 + h.c]$$

$$- \tfrac{1}{2}m^2_{11}(\Phi_1^\dagger\Phi_1) - \tfrac{1}{2}m^2_{22}(\Phi^\dagger\Phi_2) - \tfrac{1}{2}[m^2_{12}(\Phi_1^\dagger\Phi_2) + h.c.]$$

Z_2 symmetry under change of sign of one doublet
All parameters real -> no CP violation,

„Normal" 2HDM vacuum *Barroso,Santos,Ferreira,Venhilho,Silva..*
(mixed vacuum)

$$< \phi_1^0 >= \frac{v_1}{\sqrt{2}} \neq 0 \text{ and } < \phi_2^0 >= \frac{v_2}{\sqrt{2}} \neq 0, \text{ with } v^2 = v_1^2 + v_2^2,$$

useful parameters

$$\lambda_{345} \equiv \lambda_3 + \lambda_4 + \lambda_5\ ,\ \nu \equiv m_{12}^2/(2v_1v_2) \text{ and } \tan\beta = v_2/v_1.$$

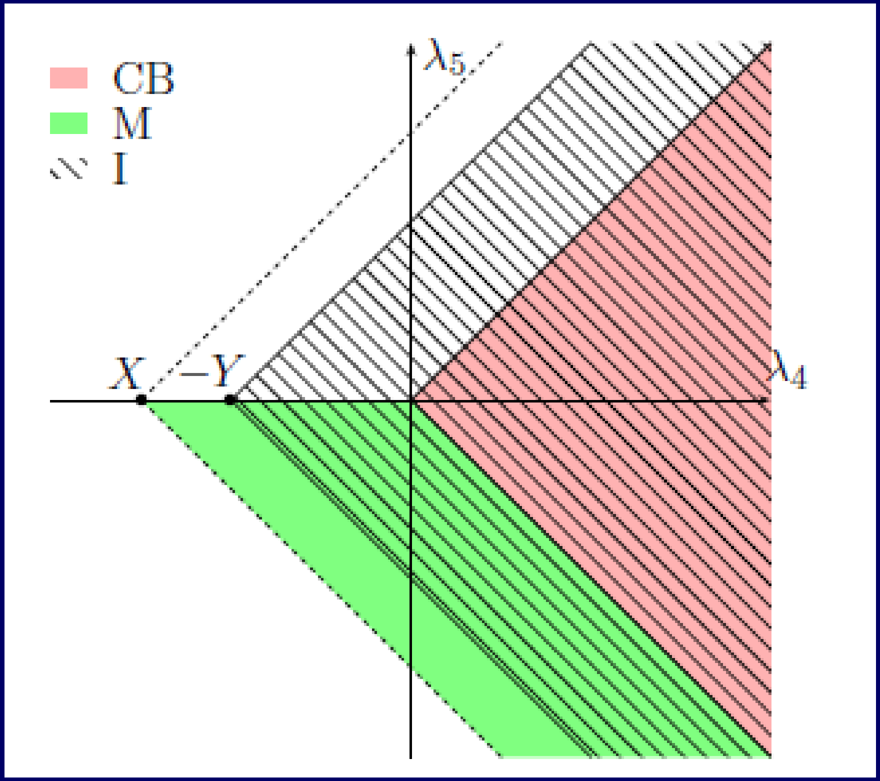
$v_1, v_2 > 0$

Vacuum states (2HDM with explicite Z_2)

Stable vacuum (positivity)

$$\lambda_1 > 0\,, \quad \lambda_2 > 0, \quad R + 1 > 0, \quad R_3 + 1 > 0$$

$$\lambda_{345} = \lambda_3 + \lambda_4 + \lambda_5, \quad R = \lambda_{345}/\sqrt{\lambda_1\lambda_2}, \quad R_3 = \lambda_3/\sqrt{\lambda_1\lambda_2}.$$



$\lambda_4 \pm \lambda_5 > -X, \quad X = \sqrt{\lambda_1\lambda_2} + \lambda_3 > 0$

$Y = M_{H+}^2\, 2/v^2|_{\text{Inert}}$

Neutral vacua

- Mixed M(v1 and v2 ≠ 0)
- Inert I1 (I2) [v1(v2) ≠ 0]

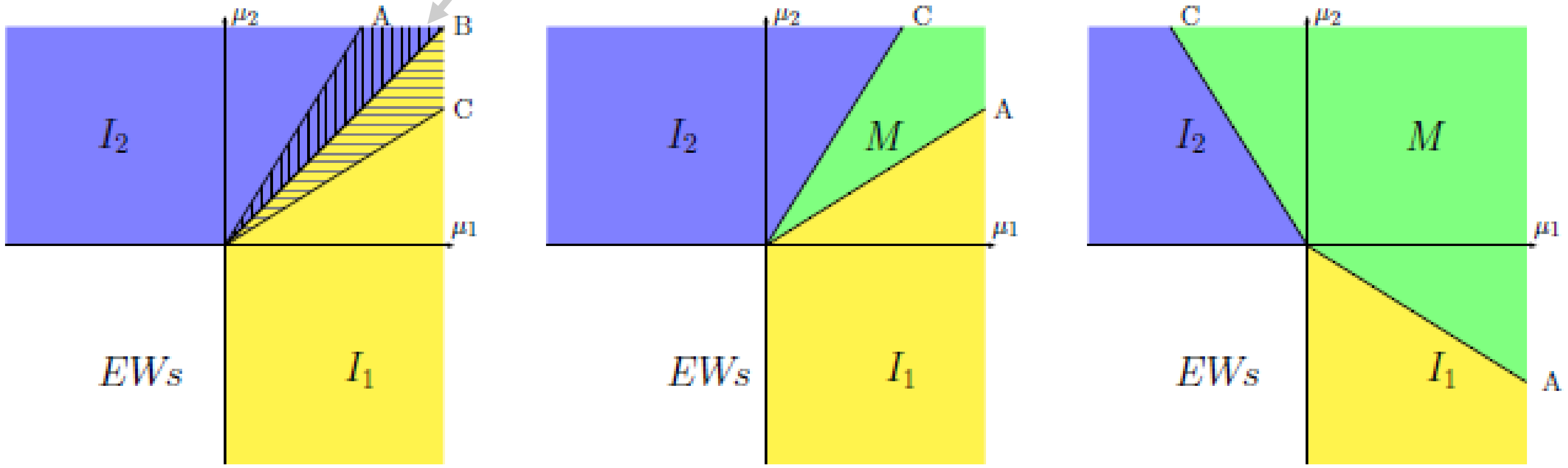
- Charged breaking vacuum CB

Inert overlaps both with Mixed and CB !

Phase diagrams Z_2-sym. V

coexistence of minima

$$\mu_1 = \frac{m_{11}^2}{\sqrt{\lambda_1}}, \quad \mu_2 = \frac{m_{22}^2}{\sqrt{\lambda_2}}.$$



(a) $R > 1$ (b) $1 > R > 0$ (c) $0 > R > -1$

$$R = \lambda_{345}/\sqrt{\lambda_1 \lambda_2},$$

Inert (I_1) vacuum for Mh=125 GeV

$$m_{22}^2 \lesssim 89 \cdot 10^3 \, \mathrm{GeV}^2.$$

Relative couplings (w.r.s SM)

For neutral Higgs particles h_i (i = 1,2,3)

$$\chi_j^{(i)} = \frac{g_j^{(i)}}{g_j^{\mathrm{SM}}} \quad j = V, u, d$$

V=Z,W+/-
u=up quarks (u,c,t)
d=down quarks (d,s,b)
and charged leptons

there are relations among couplings, eg $\Sigma_i(\chi_j^{(i)})^2 = 1,$

Haber

	χ_V(W and Z)	χ_u(up-type quarks)	χ_d(down-type quarks)
h	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)+\frac{1}{\tan\beta}\cos(\beta-\alpha)$	$\sin(\beta-\alpha)-\tan\beta\cos(\beta-\alpha)$
H	$\cos(\beta-\alpha)$	$\cos(\beta-\alpha)-\frac{1}{\tan\beta}\sin(\beta-\alpha)$	$\cos(\beta-\alpha)+\tan\beta\sin(\beta-\alpha)$
A	0	$-i\gamma_5\cot\beta$	$-i\gamma_5\tan\beta$

Masses (Mixed)

$$M_{H^\pm}^2 = (\nu - \frac{1}{2}(\lambda_4 + \lambda_5)\ )v^2,$$
$$M_A^2 = (\nu - \lambda_5)v^2.$$

$$\mathcal{M}^2 = \left[\begin{array}{cc} \cos^2\beta\lambda_1 + \sin^2\beta\nu & (\lambda_{345} - \nu)\cos\beta\sin\beta \\ (\lambda_{345} - \nu)\cos\beta\sin\beta & \sin^2\beta\lambda_2 + \cos^2\beta\nu \end{array} \right] v^2.$$

$$\mathcal{M}^2 = \left[\begin{array}{cc} M_h^2\sin^2\alpha + M_H^2\cos^2\alpha & (M_H^2 - M_h^2)\sin\alpha\cos\alpha \\ (M_H^2 - M_h^2)\sin\alpha\cos\alpha & M_H^2\sin^2\alpha + M_h^2\cos^2\alpha \end{array} \right]$$

We assume:

$M_H > M_h$, Δ M2/v2 (sin 2α /sin2β)= λ_{345}-ν

α range (- π/2, π/2) (cos α>0)

β range (0, π/2)

so β-α from –π/2 to π (in 2HDMC only to π/2 !)

Lambdas vs masses

$$\lambda_1 v^2 = \frac{1}{\cos^2\beta}[\cos^2\alpha\, M_H^2 + \sin^2\alpha\, M_h^2 - \sin^2\beta\,\mu^2]$$

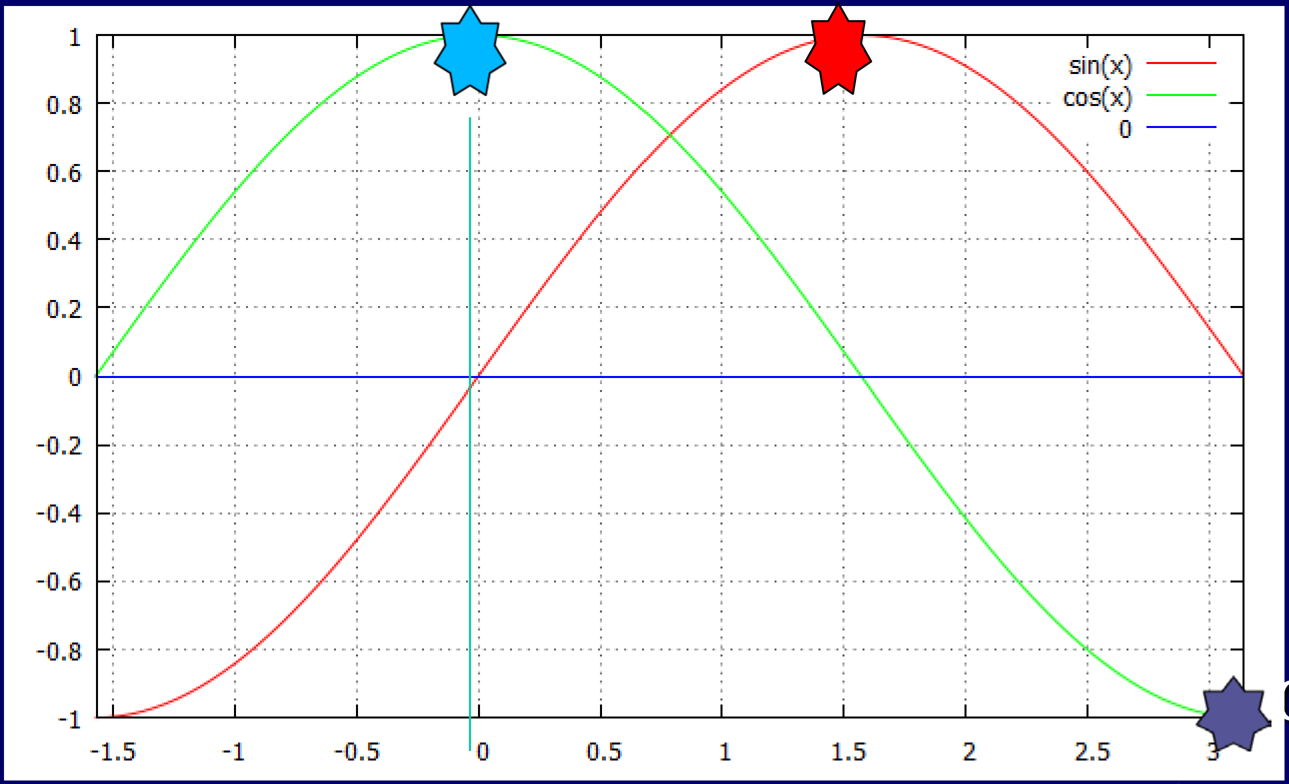
$$\lambda_2 v^2 = \frac{1}{\sin^2\beta}[\sin^2\alpha\, M_H^2 + \cos^2\alpha\, M_h^2 - \cos^2\beta\,\mu^2]$$

$$\overline{\lambda}_{345} v^2 = \frac{\sin 2\alpha}{\sin 2\beta}\,(M_H^2 - M_h^2) + \mu^2$$

$$\mu^2 = \nu v^2$$

SM-like scenarios h_+, H_+, H_-

defined by couplings to gauge bosons in terms of 'relative' couplings $\sin(\beta-\alpha)\sim +1$, $\cos(\beta-\alpha)\sim\pm 1$



β-α

$\alpha < 0$

$\beta \sim \alpha = \pi/2$

Application of Veltman condition

Veltman condition for 2HDM (II)

$$6M_W^2 + 3M_Z^2 + v^2\left(3\lambda_1 + 2\lambda_3 + \lambda_4\right) = \frac{12}{\cos^2\beta} {m_D}^2$$

$$6M_W^2 + 3M_Z^2 + v^2\left(3\lambda_2 + 2\lambda_3 + \lambda_4\right) = \frac{12}{\sin^2\beta} {m_U}^2$$

From 2HDM

$$\lambda_1 - \lambda_2 = \frac{4}{v^2}\left(\frac{m_b^2}{\cos^2\beta} - \frac{m_t^2}{\sin^2\beta}\right) = \frac{4m_b^2}{v^2}\left(1 - \frac{m_t^2/m_b^2}{\tan^2\beta}\right)\left(1 + \tan^2\beta\right).$$

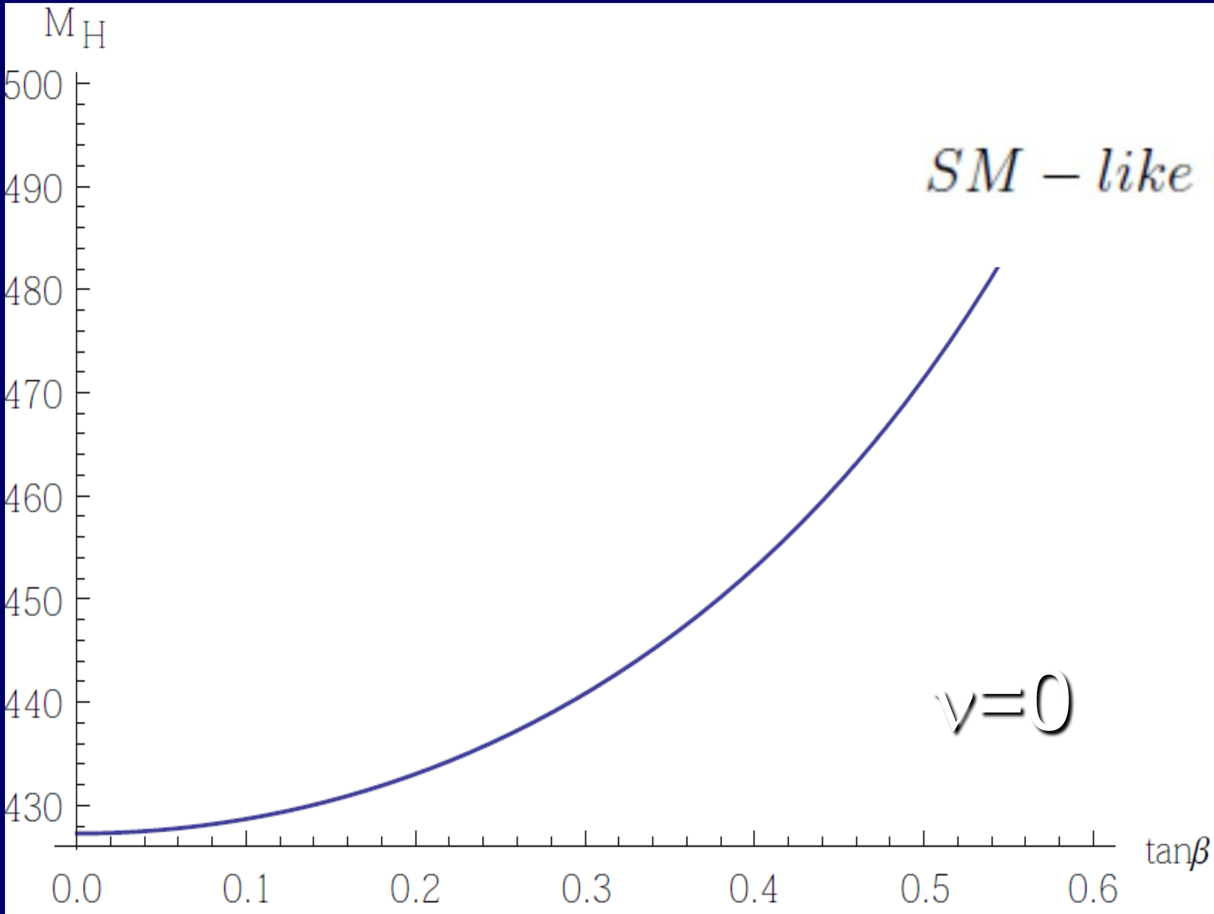
$$SM-like\ h : \lambda_1 - \lambda_2 = \left(\tan^2\beta - \frac{1}{\tan^2\beta}\right)\left(\frac{M_H^2}{v^2} - \nu\right),$$

Results for SM-like h

$$SM-like\ h : M_H^2 = 4m_b^2 \frac{\tan^2\beta - \frac{m_t^2}{m_b^2}}{\tan^2\beta - 1} + \nu v^2.$$

For SM-like H

$$M_h^2 = 4m_b^2 \frac{\tan^2\beta - \frac{m_t^2}{m_b^2}}{\tan^2\beta - 1} + \nu v^2,$$

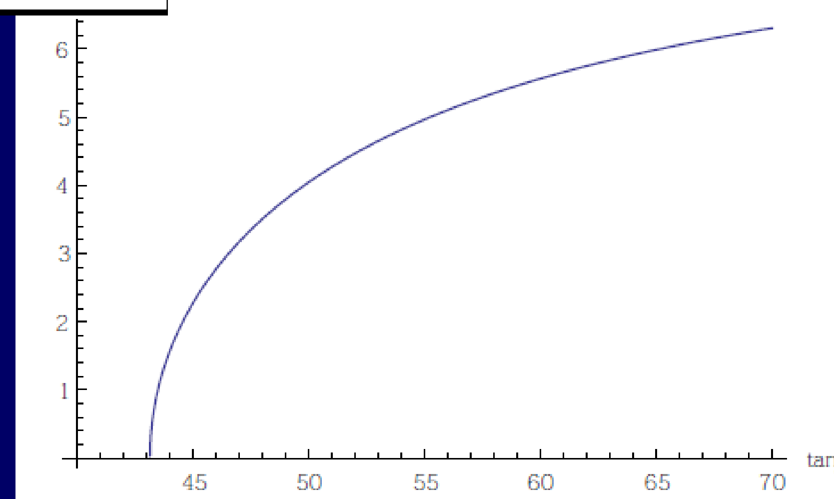


$$SM - like\ h : M_H^2 = 4m_b^2 \frac{\tan^2\beta - \frac{m_t^2}{m_b^2}}{\tan^2\beta - 1}$$

only very small tan β

ν=0

gure 2: SM-like H scenario, $m_{12} = 0$



SM-like H

$$M_h^2 = 4m_b^2 \frac{\tan^2\beta - \frac{m_t^2}{m_b^2}}{\tan^2\beta - 1}$$

only very large tan β

Scan

- SM-like h, $M_h = 125$ GeV, $\sin(\beta-\alpha) \sim +1$ $(\beta - \alpha = \pi/2)$
- SM-like H, $M_H = 125$ GeV, $\cos(\beta-\alpha) \sim +1$ $(\beta = \alpha)$
  $\cos(\beta-\alpha) \sim -1(\beta - \alpha = \pi)$ (

Scan for masses 124-127 GeV, tan beta 0.2 – 100,
$M_{\pm}$ > 300 GeV.

Mathematica and C++ (N. Darvishi)
2HDMC (not for SM-H_)

Cross check re unitarity limits on lambdas,
some exp. constraints

SM-H_+ (solution only for ν=0)

B mark	α	β	t_β	$s_{\beta-\alpha}$	$c_{\beta-\alpha}$	M_h	M_H	M_A	$M_H^\pm$
H+1	1.57000	1.5470	42.012	-0.020	0.999	2.36	126.28	230.00	310.00
H+2	1.56972	1.5515	52.012	-0.018	0.999	5.08	125.67	200.00	320.00
H+3	1.56765	1.5608	100.041	-0.006	0.999	7.31	125.84	136.50	330.00
H+4	1.56765	1.5498	47.632	-0.017	0.999	4.29	126.47	100.00	340.00
H+5	1.56765	1.5483	44.314	-0.019	0.999	3.41	124.58	136.50	335.00
H+6	1.55972	1.5470	42.012	-0.012	0.999	1.88	125.39	200.00	310.00
H+7	1.55823	1.5592	86.453	0.001	0.999	6.90	126.85	136.50	310 .00

B mark	λ_1	λ_2	λ_3	λ_{345}	λ_4	λ_5
H+1	0.16	0.26	3.18	0.008	-2.30	-0.87
H+2	1.15	0.26	3.39	0.014	-2.72	-0.66
H+3	8.87	0.26	3.68	0.08	-3.29	-0.30
H+4	0.69	0.26	3.86	0.03	-3.65	-0.16
H+5	0.38	0.25	3.74	0.03	-3.40	-0.30
H+6	0.15	0.25	3.29	0.12	-2.51	-0.30
H+7	6.16	0.26	3.46	0.28	-2.86	-0.66

t b

$\frac{g_t^H}{g_t^{H\,SM}}$	$\chi_t^H(1)$	$\frac{g_b^H}{g_b^{H\,SM}}$	$\chi_b^H(1)$
1.00	0.99	0.15	0.15
1.00	0.99	0.05	0.06
1.00	0.99	0.35	0.39
0.99	0.99	0.18	0.18
1.00	0.99	0.15	0.15
1.00	0.99	0.49	0.49
0.99	0.99	1.85	1.08

t b

$\frac{g_t^h}{g_t^{h\,SM}}$	$\chi_t^h(1)$	$\frac{g_b^h}{g_b^{h\,SM}}$	$\chi_b^h(1)$
0.0058	0.0037	-72.08	-41.99
0.0014	0.0012	-75.58	-51.94
0.0043	0.0039	-88.70	-99.94
0.0058	0.0039	-71.58	-47.60
0.0043	0.0035	-69.75	-44.28
0.0203	0.0117	-76.83	-41.98
0.0291	0.0125	-119.41	-86.36

for partner h

SM-H_ (solution only for ν=0)

B mark	α	β	t_β	$s_{\beta-\alpha}$	$c_{\beta-\alpha}$	M_h	M_H	M_A	$M_{H}^{\pm}$
H-1	-1.56137	1.5609	100.03	0.019	-0.999	7.23	125.93	130	360
H-2	-1.55815	1.5560	67.98	0.027	-0.999	6.23	125.23	120	360
H-3	-1.55800	1.5541	60.06	0.029	-0.999	5.72	124.24	110	360
H-4	-1.54566	1.5556	65.81	0.040	-0.998	5.49	125.39	248	348
H-5	-1.54566	1.5484	44.81	0.047	-0.998	1.61	125.68	200	348
H-6	-1.54566	1.5482	44.31	0.047	-0.998	1.19	126.31	150	360
H-7	-1.53566	1.5569	72.00	0.049	-0.998	4.94	126.37	300	360
H-8	-1.52053	1.55923	86.45	0.061	-0.998	3.33	124.35	350	360

B mark	λ_1	λ_2	λ_3	λ_{345}	λ_4	λ_5
H-1	8.87	0.26	4.03	-0.24	-4.00	-0.27
H-2	3.12	0.25	4.06	-0.22	-4.04	-0.23
H-3	.10	0.25	4.08	-0.19	-4.08	-0.19
H-4	2.87	0.25	3.48	-0.42	-2.88	-1.02
H-5	0.41	0.26	3.70	-0.29	-3.34	-0.66
H-6	0.38	0.26	3.98	-0.29	-3.91	-0.37
H-7	3.77	0.26	3.24	-0.66	-2.42	-1.48
H-8	6.19	0.25	3.17	-1.10	-2.25	-2.02

t b

$\chi_t^H(1)$	$\chi_b^H(1)$
-0.99	0.90
-0.99	0.83
-0.99	0.74
-0.99	1.63
-0.99	1.10
-0.99	1.08
-0.99	2.53
-0.99	4.27

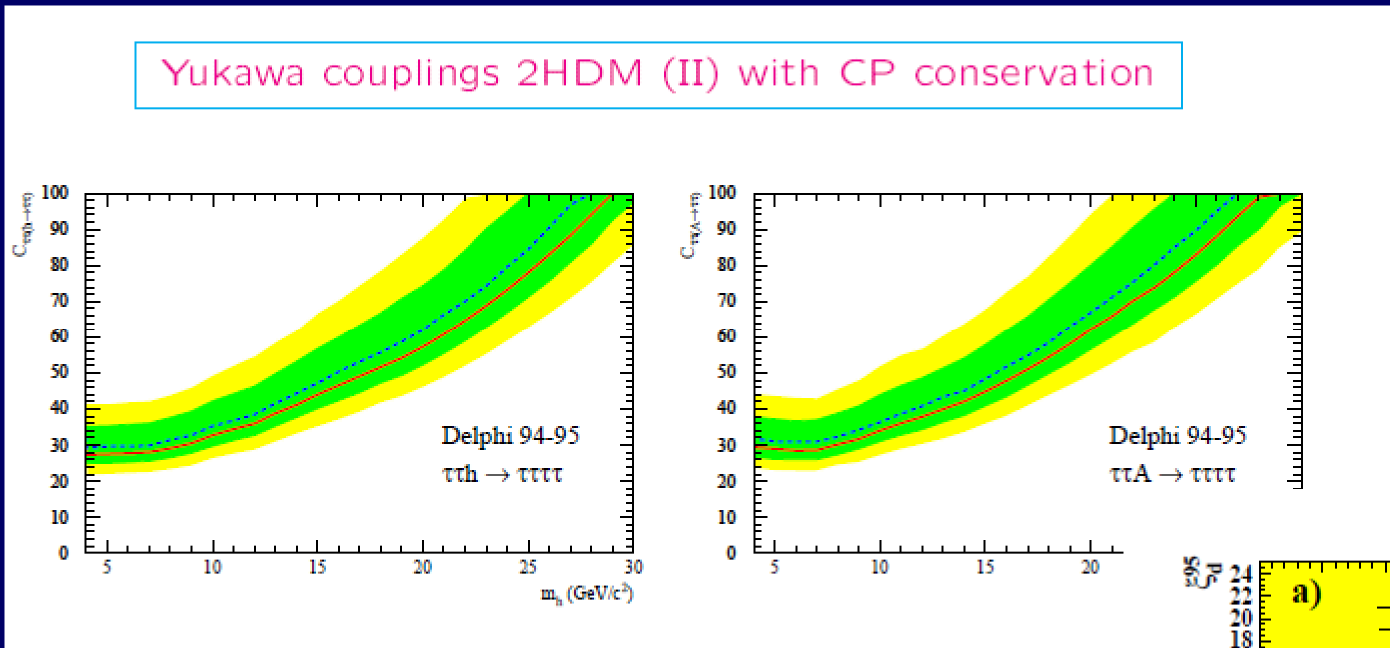
wrong sign Htt

t b

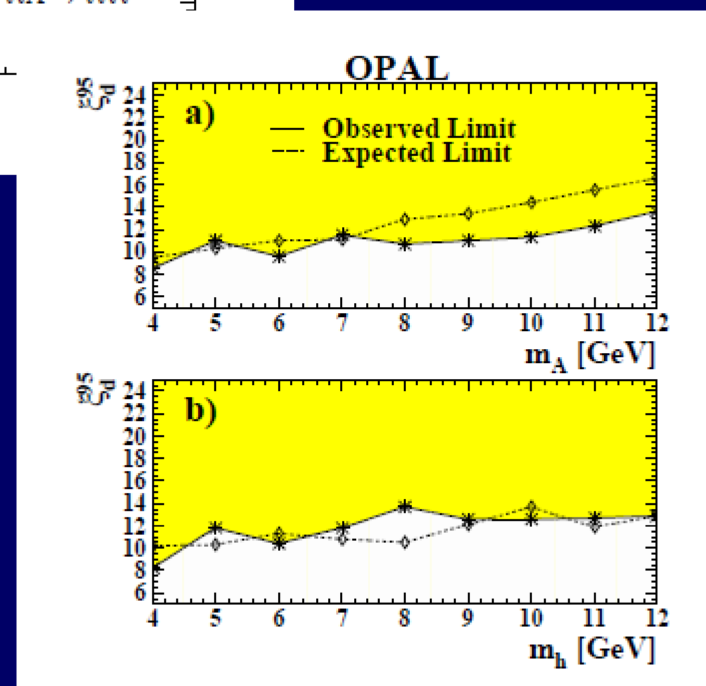
$\chi_t^h(1)$	$\chi_b^h(1)$
0.009	99.94
0.012	67.93
0.012	60.02
0.024	64.72
0.024	44.76
0.024	44.26
0.035	71.90
0.049	86.33

for partner h

LEP



Yukawa couplings 2HDM (II) with CP conservation
Delphi 94-95
ττh → ττττ
Delphi 94-95
ττA → ττττ
m_h (GeV/c^2)



OPAL
a)
Observed Limit
Expected Limit
m_A [GeV]
b)
m_h [GeV]

SM-like h (solutions only for $\nu>0$)

B mark	α	t_β	$s_{\beta-\alpha}$	$c_{\beta-\alpha}$	M_h	M_H	M_A	$M_H^\pm$	$\lvert m_{12}\rvert$	ν
h+1	-1.15	0.36	0.99	0.07	125.24	445.91	136.5	360	178	0.82
h+2	-1.05	0.48	0.99	0.07	125.56	489.89	136.5	360	223	1.05
h+3	-0.85	0.68	0.99	0.12	124.71	711.74	136.5	360	342	2.07
h+4	-0.85	0.68	0.99	0.12	126.55	739.21	300.0	360	377	2.52
h+5	-0.85	0.68	0.99	0.12	124.89	795.49	500.0	360	443	3.48

B mark	λ_1	λ_2	λ_3	λ_{345}	λ_4	λ_5
h+1	0.75	17.89	-0.07	-2.71	-3.15	0.51
h+2	1.20	11.70	-0.86	-3.04	-2.92	0.74
h+3	4.58	10.80	-6.44	-6.57	-1.89	1.77
h+4	4.80	11.02	-7.58	-6.82	-0.27	1.03
h+5	5.26	11.48	-10.07	-7.38	3.33	-0.64

t b

$\frac{g_t^h}{g_t^{h_{SM}}}$	$\chi_t^h(1)$	$\frac{g_b^h}{g_b^{h_{SM}}}$	$\chi_b^h(1)$
1.38	1.18	0.91	0.96
1.28	1.13	0.91	0.95
1.19	1.16	0.83	0.90
1.19	1.16	0.83	0.90
1.19	1.16	0.83	0.90

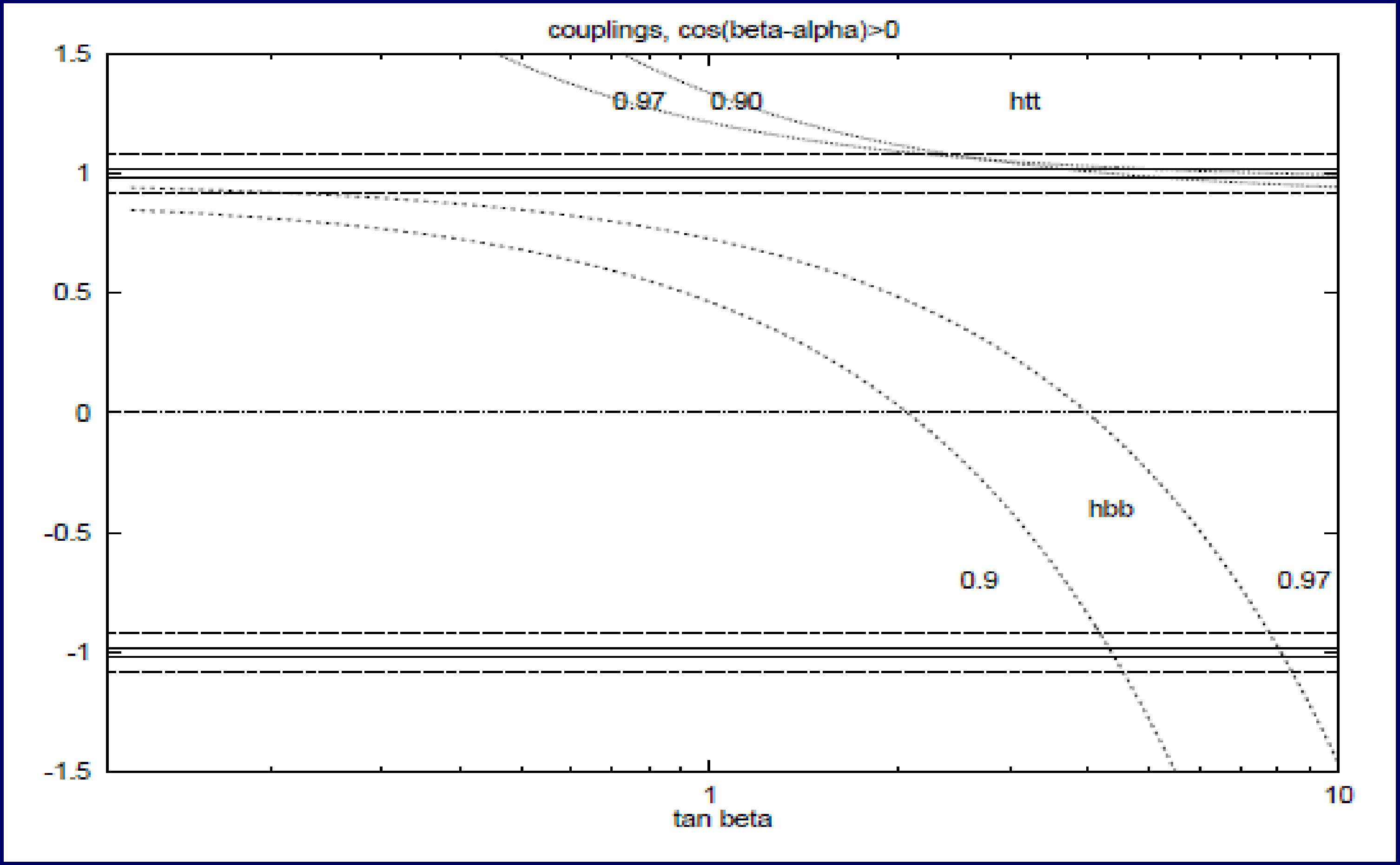
$\frac{\Gamma(h\to\gamma\gamma)}{\Gamma(h_{SM}\to\gamma\gamma)}$	$\frac{\Gamma(h\to Z\gamma)}{\Gamma(h_{SM}\to Z\gamma)}$	$\frac{\Gamma(h\to gg)}{\Gamma(h_{SM}\to gg)}$	$\frac{\Gamma_h^{tot}}{\Gamma_h^{tot\,SM}}$
0.78	0.86	1.55	0.99
0.86	0.98	1.72	0.98
0.89	0.92	1.46	0.90
0.88	1.09	1.16	0.95
0.89	0.94	1.11	0.90

S	T	U
-0.006	-0.288	-0.03
-0.001	0.438	-0.004
0.015	-1.113	-0.008
0.023	-0.366	-0.002
0.032	1.009	0.004

exp. 3

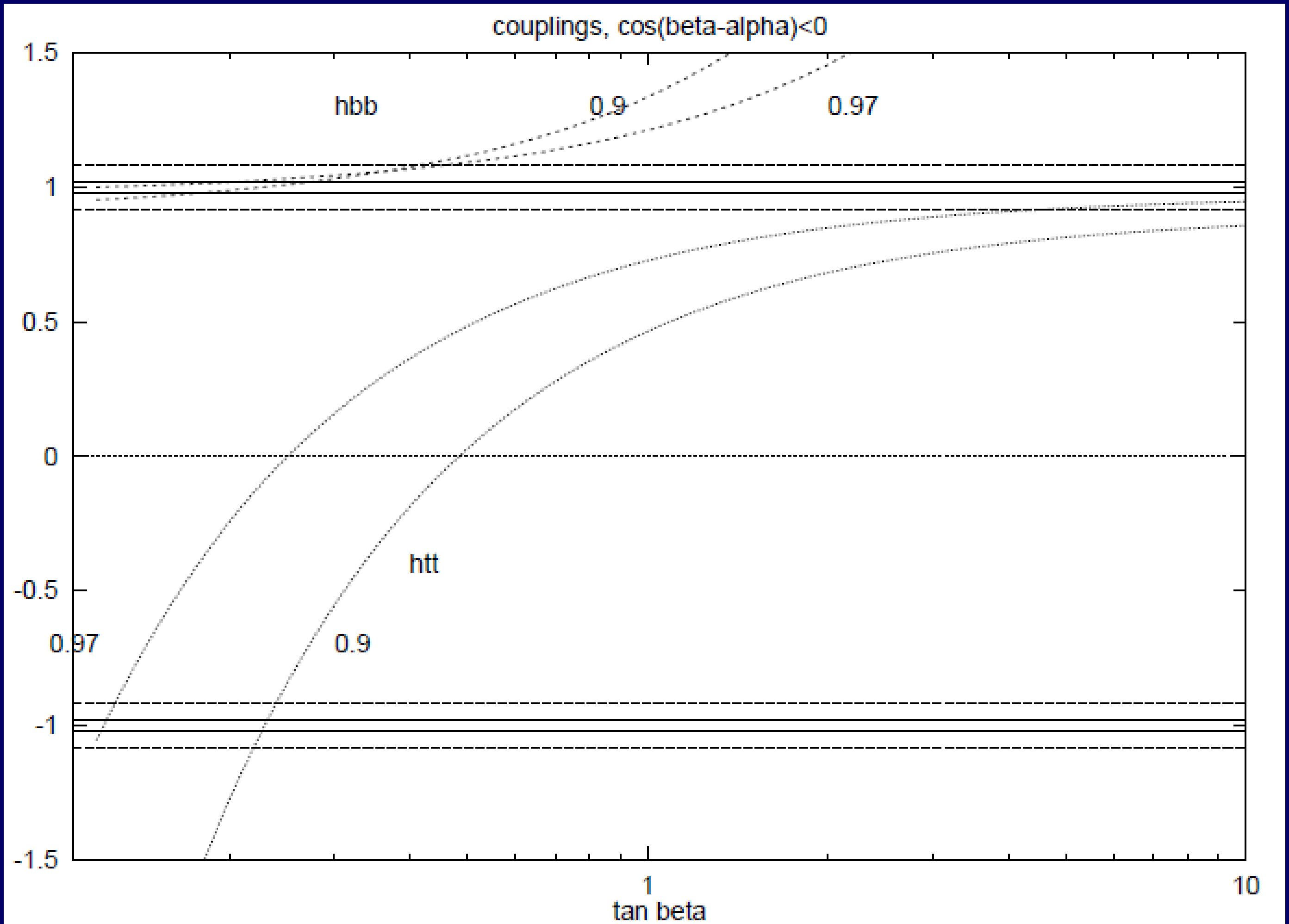
$-0.27 \leq S \leq 0.33,$
$-0.31 \leq T \leq 0.41,$
$-0.26 \leq U \leq 0.40.$

For SM-like h $\chi_V \sim 0.90\text{-}0.97$



wrong
sign
hbb

For SM-like h $\chi_V \sim 0.90\text{-}0.97$



wrong sign htt

SM-like h

in GeV

t b

B mark	$\frac{g_t^H}{g_t^{H\,SM}}$	$\chi_t^H(1)$	$\frac{g_b^H}{g_b^{H\,SM}}$	$\chi_b^H(1)$
h+1	-2.35	-2.68	0.41	0.42
h+2	-1.72	-1.99	0.50	0.54
h+3	-1.14	-1.33	0.66	0.79
h+4	-1.14	-1.33	0.66	0.79
h+5	-1.14	-1.33	0.66	0.79

$\Gamma(H \to \gamma\gamma)$	$\Gamma(H \to Z\gamma)$	$\Gamma(H \to gg)$	$\Gamma(H \to hh)$	Γ_H^{tot}
8.19e-4	3.04e-4	0.22	0.53	1.32
5.58e-4	2.29e-4	0.14	0.58	1.07
5.38e-4	2.96e-4	0.09	1.40	2.60
8.28e-4	5.09e-4	0.10	1.57	2.56
1.01e-3	6.55e-4	0.10	1.94	2.71

for partner H

Summary of results of application of Veltman condition for 2HDM (II)

SM-like $H_\pm$: solutions only for $\nu=0, |\chi_V| \sim 0.999$,

very light h (1- 8 GeV), $\tan\beta > 40$

- H_+ M_H 124.6-126.8 GeV, Mh 1.9-7.3 GeV
  M_A 100-230 GeV, $M_\pm < 310$-340 GeV,
  $\tan\beta > 42.4$
- H_- M_H 124.2-126.3 GeV, Mh 1.2-7.2 GeV
  M_A 110-350 GeV, $M_\pm$ 350-360 GeV $\tan\beta > 44$

Problem with couplings to b both for SM-like H and a partner h – excluded !!

Results for SM-h

SM-h: solutions only for $\nu > 0$, $\chi_V \sim 0.99$,

heavy H > 450 GeV, $\tan\beta < 1$

- M_h 124.7-125.6 GeV, M_H 446- 795 GeV
  M_A 135.6-500 GeV, $M_\pm$ ~360 GeV,
  m_{12} 178-443 GeV, $\tan\beta$ <0.68,
  at 3σ in agreement with S,T,U

OK ?

Veltman condition for other models

Two scalar doublets (2,1) of SU(2)xU(1)

One singlet (1,Y_φ) of SU(2)xU(1)

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Potential (2 doublet + real singlet)

V= V_2HDM(soft viol.Z_2) + $m\varphi^2 \varphi^2$

$$+ \lambda_\varphi \varphi^4 + \eta_1 \varphi^2 \Phi_1^\dagger \Phi_1 + \eta_2 \varphi^2 \Phi_2^\dagger \Phi_2 + etc(\varphi)$$

if complex singlet $\varphi^2 \to \varphi^\dagger \varphi$

Vacuum structure

Mixed(s)

$$< \phi_1^0 >= \frac{v_1}{\sqrt{2}} \neq 0 \text{ and } < \phi_2^0 >= \frac{v_2}{\sqrt{2}} \neq 0,$$

$$\langle \varphi \rangle = 0 \quad \text{or} \quad \langle \varphi \rangle = \frac{v_\varphi}{\sqrt{2}}$$

Inert(s)

$$< \phi_1^0 >= \frac{v_1}{\sqrt{2}} \neq 0 \text{ and } < \phi_2^0 >= 0$$

$$\langle \varphi \rangle = 0 \quad \text{or} \quad \langle \varphi \rangle = \frac{v_\varphi}{\sqrt{2}}$$

For Inert case Z_2 symmetry $\Phi_2 \to -\Phi_2$
for singlet with zero vev Z_2'

Positivity conditions

$$\lambda_1 > 0\,, \quad \lambda_2 > 0, \quad R + 1 > 0, \quad R_3 + 1 > 0$$

$$\lambda_{345} = \lambda_3 + \lambda_4 + \lambda_5, \quad R = \lambda_{345}/\sqrt{\lambda_1 \lambda_2}, \quad R_3 = \lambda_3/\sqrt{\lambda_1 \lambda_2}.$$

$$\lambda_\varphi \geq 0 \;\;\&\;\; \eta_1, \eta_2 \geq 0$$

Veltman condition

$$(\frac{3}{2}\lambda_1 + \lambda_3 + \frac{1}{2}\lambda_4 + \frac{1}{2}\eta_1)\frac{v^2}{2} + \frac{3}{4}(2m_W^2 + m_Z^2) = 3(\frac{m_t^2}{\cos^2\beta} + \frac{m_b^2}{\cos^2\beta})$$

$$(\frac{3}{2}\lambda_2 + \lambda_3 + \frac{1}{2}\lambda_4 + \frac{1}{2}\eta_2)\frac{v^2}{2} + \frac{3}{4}(2m_W^2 + m_Z^2) = 0$$

$$\Rightarrow \quad 3\lambda_\varphi + \eta_1 + \eta_2 = 0$$

Mixed(s)
Type I
(real s)

$$(\frac{3}{2}\lambda_1 + \lambda_3 + \frac{1}{2}\lambda_4 + \frac{1}{2}\eta_1)\frac{v^2}{2} + \frac{3}{4}(2m_W^2 + m_Z^2) = 3\frac{m_b^2}{\cos^2\beta}$$

$$(\frac{3}{2}\lambda_2 + \lambda_3 + \frac{1}{2}\lambda_4 + \frac{1}{2}\eta_2)\frac{v^2}{2} + \frac{3}{4}(2m_W^2 + m_Z^2) = 3\frac{m_t^2}{\sin^2\beta}$$

$$\Rightarrow \quad 3\lambda_\varphi + \eta_1 + \eta_2 = 0$$

Mixed(s)
Type II
(real s)

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Veltman condition

$$(\frac{3}{2}\lambda_1 + \lambda_3 + \frac{1}{2}\lambda_4 + \frac{1}{2}\eta_1)\frac{v^2}{2} + \frac{3}{4}(2m_W^2 + m_Z^2) = (m_t^2 + m_b^2) \cdot 3$$

$$(\frac{3}{2}\lambda_2 + \lambda_3 + \frac{1}{2}\lambda_4 + \frac{1}{2}\eta_2)\frac{v^2}{2} + \frac{3}{4}(2m_W^2 + m_Z^2) = 0$$

$\Uparrow$ ALSO CONTRADICTION

$$(\lambda_3 + \frac{1}{2}\lambda_4) \geq \frac{2}{v^2}((m_t^2 + m_b^2) \cdot 3 - \frac{3}{4}m_h^2 - \frac{3}{4}(2m_W^2 + m_Z^2)) = 1.86$$

$3\lambda_\varphi + \eta_1 + \eta_2 = 0 \Leftarrow$ CONTRADICTION (positivity conditions)

Inert(s) real singlet

Veltman condition

Case of two doublets with complex singlet

- The conditions for cancellation of quadratic divergences for doublets stay the same
- Two additional neutral scalars ($Y_\varphi = 0, v_\varphi \neq 0$) or charged scalars ($Y_\varphi \neq 0, v_\varphi = 0$)
- For charged particles with non-zero hypercharge:

$$3\lambda_\varphi + \eta_1 + \eta_2 + \frac{3}{4}(g' Y_\varphi)^2 = 0 \Leftarrow \text{STILL CONTRADICTION}$$

Conclusions

We investigated consequences of cancelation of quadratic divergencies (Veltman condition) at one loop

- for SM-like scenarios for Mixed 2HDM
  with ~125 GeV h for χ_V ~ 1 OK
  ~125 GeV H for χ_V ~ +1, -1 NO
- difficult to get solution for other models with two doublets and singlets