Scenario with an extended Higgs sector

Topical Lectures *Higgs*
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Introduction

- we considered as extended Higgs sector a NMSSM model with 3 different benchmark scenarios:
  - the state at 125 GeV is not the lightest Higgs in the spectrum (Point 2)
  - the CP-even singlet state is heavier than the doublet at ~ 125 GeV (Point D)
  - the light doublet state is less than 125 GeV / 2 (Point 6)
- we use the software “NMSSMTools” for the calculation of masses, couplings and decay widths of all Higgs bosons

from "*NMSSM interpretations of the observed Higgs signal",* Florian Domingo, Georg Weiglein, arXiv:1509.07283

Benchmark Scenarios

NMSSMTools Parameters	Point 1 Decoupling limit	Point 2 Light singlet	Point 3 Low $\tan\beta$ + light s.	Point 4 2 CP-even ~ 125 GeV	Point 5 Light A $H \to 2A$	Point 6 Light doublet
λ	0.2	0.55	0.699	0.7	0.05	0.1
κ	0.6	0.45	0.1	0.1	0.05	0.25
$\tan\beta$	22.5	8	2	2	19	12.25
$\mu_{\rm eff}$ (GeV)	200	125	330	714	125	187.9
M_A (GeV)	1000	1000	801	1694	1200	130
A_κ (GeV)	-8.5	-288	-122	-176.9	-5	-1100
M_1 (GeV)	250	250	75	75	250	250
M_2 (GeV)	500	500	150	150	500	500
M_3 (TeV)	1.5	1.5	1.5	1.5	1.5	1.5
$m_{\tilde{Q}_{1,2}}$ (TeV)	1.5	1.5	1.5	1.5	1.5	1.5
$m_{\tilde{Q}_3}$ (TeV; if $\neq m_{\tilde{Q}_{1,2}}$)	1.1	1	0.5	0.5	1.2	1.1
$m_{\tilde{L}}$ (GeV)	300	200	110	110	300	250
A_t (TeV)	-2.5	-2	-0.1	-0.1	-2.5	-2.3
$A_{b,\tau}$ (TeV; if $\neq A_t$)	-1.5	-1.5	/	/	-1.5	-1.5
Higgs Spectrum						
m_{h_1} (GeV)	125.0 D	105.6 S	102.1 S	125.1 D/S	125.1 D	62.8 D
m_{h_2} (GeV)	973 D	125.0 D	125.3 D	125.2 S/D	249 S	125.6 D
m_{h_3} (GeV)	1192 S	986 D	796 D	1693 D	1174 D	605 S
m_{A_1} (GeV)	109.7 S	307 S	165.4 S	280 S	43.7 S	63.3 D
m_{A_2} (GeV)	976 D	983 D	800 D	1695 D	1174 D	1245 S
$m_{H^\pm}$ (GeV)	976	980	790	1690	1177	101.5
S^2_{13}	$\sim 0\%$	97%	91%	48.4%	0.1%	$\sim 0\%$
S^2_{23}	0.3%	1.6%	8%	51.4%	99.9%	$\sim 0\%$
S^2_{33}	99.7%	1.0%	0.9%	0.2%	$\sim 0\%$	$\sim 100\%$
P^2_{13}	99.7%	99.5%	98%	99.7%	$\sim 100\%$	$\sim 0\%$
P^2_{23}	0.3%	0.5%	1.6%	0.3%	$\sim 0\%$	$\sim 100\%$
M_W[err] (GeV)	80.372[17]	80.373[17]	80.410[20]	80.393[21]	80.371[17]	80.397[17]
χ^2 (/89 obs.)	81.2	76.1	76.0	80.5	80.2	81.4 (excl.)

we exclude this model due to the mass of the charged higgs

the light doublet scenario is then obtained using the Point2 values of the parameters, but Aκ set to -370 GeV

Benchmark Scenarios

Parameters	Point D (low $\tan\beta$)
λ	0.63
κ	0.36
$\tan\beta$	2
$\mu_{\rm eff}$ (GeV)	318
M_A (GeV)	600
A_κ (GeV)	-147
Higgs Spectrum	
m_{h_1} (GeV)	124.5 D
m_{h_2} (GeV)	333 S
m_{A_1} (GeV)	309 S
$m_{H^\pm}$ (GeV)	589
χ^2 (/89 obs.)	85.4

this model differently from the previous ones predicts 5 Higgs bosons!

- in principle we should use another tool
- what we did was substituting the parameter values in Point2 and consider the lightest hits we had in output

Branching Ratios for the light nMSSM Higgs

Point 2

- BR(h_1 (105.6 GeV)->b bbar) ~ 90%
- BR(h_1 (105.6 GeV)->ττ) ~ 9%
- BR(h_1 (105.6 GeV)->WW) ~ 0.1%
- BR(h_1 (105.6 GeV)->ZZ) ~ 4 10^{-3}%

- BR(h_3 (986 GeV)->h_1 h_2) ~ 15%
  this is the dominant BR among the many decay channels of h_3

Point 6

- BR(h_1 (62.8 GeV)->b bbar) ~ 91%
- BR(h_1 (62.8 GeV)->ττ) ~ 8%
- BR(h_1 (62.8 GeV)->c cbar)~ 0.07%
- BR(h_1 (62.8 GeV)->μμ) ~ 0.03%

- BR(h_3 (605 GeV)->h_1 h_2) ~ 17%
  this is the dominant BR among the many decay channels of h_3

Point D

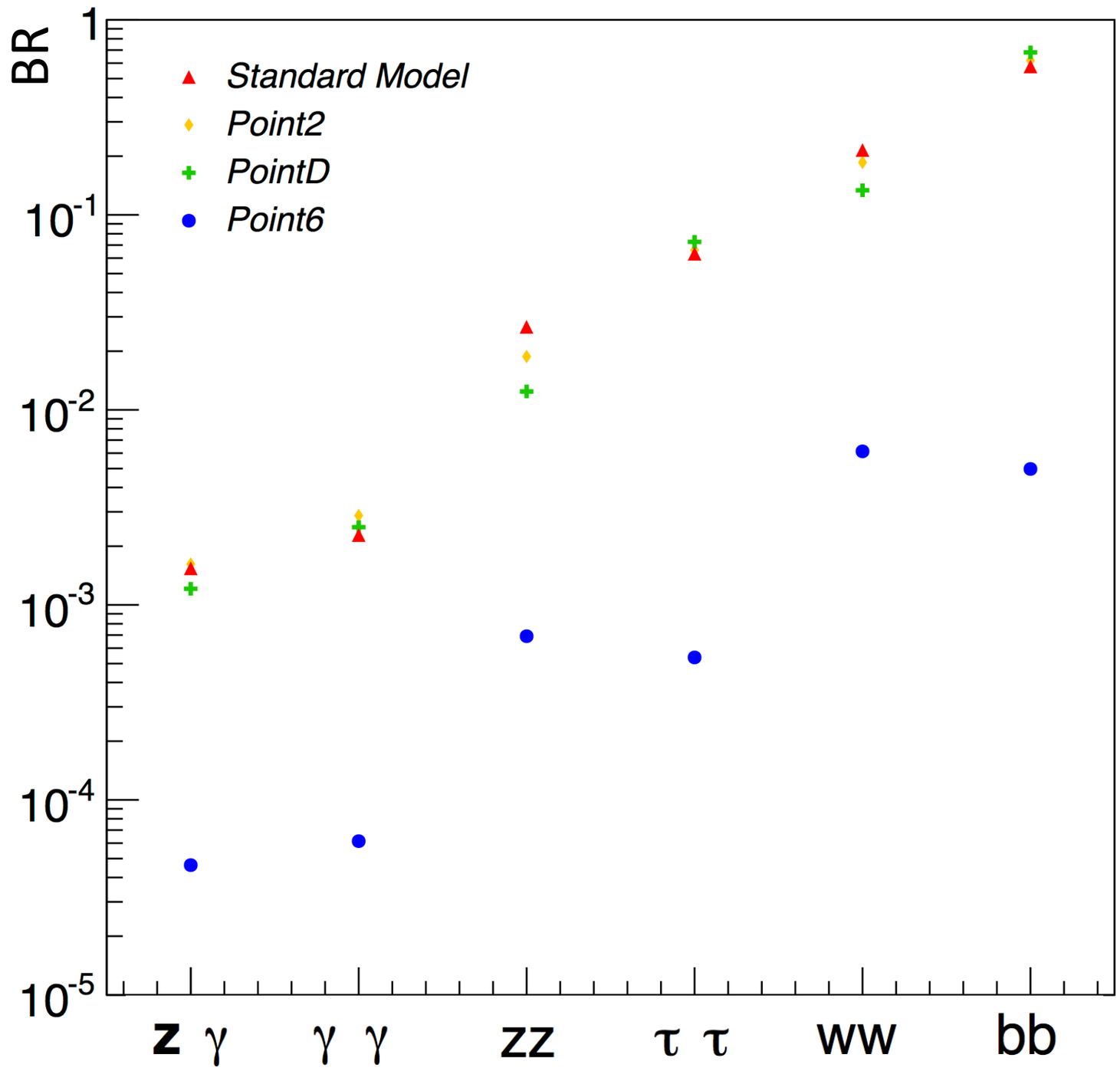
- BR(h_2 (331 GeV)->WW) ~ 45%
- BR(h_2 (331 GeV)->h_1h_1) ~ 34%
- BR(h_2 (331 GeV)->ZZ) ~ 21%

Branching Ratio comparison with SM

BR	Point 2: next to lightest particle mH=122.4GeV	Point D: lightest particle mH=120.1GeV	Point 6: next to lightest particle mH=126.2GeV	SM Higgs	Ratios Point2/ SM	Ratios Point D/SM	Ratios Point 6/SM
H->WW	0,18589	0,13372	0,03655	0,21500	1,39017	0,62195	0,17001
H->ZZ	0,01877	0,01243	0,00415	0,02640	1,51009	0,47084	0,15720
H->γγ	0,00287	0,00250	0,00040	0,00228	1,14671	1,09786	0,17408
H->bb	0,61938	0,68099	0,09550	0,57700	0,90953	1,18023	0,16551
H->ττ	0,06597	0,07271	0,00988	0,06320	0,90725	1,15046	0,15633
H->Zγ	0,00162	0,00121	0,00028	0,00154	1,33791	0,78550	0,18480

$BR(h_2 \to h_1 h_1) \sim 84\%$

SM like Higgs



Couplings

arXiv:1509.07283

Couplings^2/SM	Point 2
h_1WW	0.017
h_1ZZ	0.017
h_1gg	0.015
$h_1\gamma\gamma$	0.001
$h_1t\bar{t}$	0.014
$h_1b\bar{b}$	0.853
$h_1\tau\bar{\tau}$	0.855
h_2WW	0.983
h_2ZZ	0.983
h_2gg	0.973
$h_2\gamma\gamma$	1.023
$h_2t\bar{t}$	0.986
$h_2b\bar{b}$	0.800
$h_2\tau\bar{\tau}$	0.800
h_3WW	$6 \cdot 10^{-6}$
h_3ZZ	$6 \cdot 10^{-6}$
h_3gg	0.013
$h_3\gamma\gamma$	0.089
$h_3t\bar{t}$	0.016
$h_3b\bar{b}$	63.2
$h_3\tau\bar{\tau}$	63.3
A_1WW	0
A_1ZZ	0
A_1gg	$1 \cdot 10^{-4}$
$A_1\gamma\gamma$	1.455
$A_1t\bar{t}$	$8 \cdot 10^{-4}$
$A_1b\bar{b}$	0.325
$A_1\tau\bar{\tau}$	0.326
A_2WW	0
A_2ZZ	0
A_2gg	0.028
$A_2\gamma\gamma$	0.098
$A_2t\bar{t}$	0.016
$A_2b\bar{b}$	63.5
$A_2\tau\bar{\tau}$	63.7

Couplings^2 /SM	Point 2
Higgs(1)-W-W	0,019
Higgs(1)-Z-Z	0,019
Higgs(1)-gluon-gluon	0,014
Higgs(1)-gamma-gamma	0,001
Higgs(1)-top-top	0,015
Higgs(1)-b-b	0,849
Higgs(1)-tau-tau	0,874
Higgs(2)-W-W	0,981
Higgs(2)-Z-Z	0,981
Higgs(2)-gluon-gluon	0,994
Higgs(2)-gamma-gamma	1,018
Higgs(2)-top-top	0,985
Higgs(2)-b-b	0,790
Higgs(2)-tau-tau	0,787
Higgs(3)-W-W	5,90E-07
Higgs(3)-Z-Z	5,90E-07
Higgs(3)-gluon-gluon	0,013
Higgs(3)-gamma-gamma	0,095
Higgs(3)-top-top	0,016
Higgs(3)-b-b	61,227
Higgs(3)-tau-tau	63,339
A(1)-W-W	0,000
A(1)-Z-Z	0,000
A(1)-gluon-gluon	1,06E-04
A(1)-gamma-gamma	1,543
A(1)-top-top	0,000
A(1)-b-b	0,313
A(1)-tau-tau	0,324
A(2)-W-W	0,000
A(2)-Z-Z	0,000
A(2)-gluon-gluon	0,027
A(2)-gamma-gamma	0,097
A(2)-top-top	0,016
A(2)-b-b	61,586
A(2)-tau-tau	63,676

Conclusions

- We studied three different scenarios
  - We observed deviations of the properties of h(125) from the SM Higgs → BR, couplings
- Searches for heavy NMSSM Higgs scalar bosons can be performed in the channels
  - point 2: h_3 (986 GeV)->h_1 (105 GeV) h_2 (125 GeV)
  - point D:
    - h_2 (331 GeV)->WW
    - h_2 (331 GeV)->h_1 (124.5 GeV) h_1 (125 GeV)
  - point 6: h_3 (605 GeV)->h_1 (62.8 GeV) h_2 (125 GeV)
    - This theory can be excluded as h_2->h_1h_1 would have been the main decay. So we would not have seen the h_2