A Lighter Higgs in 2HDMs

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Institut des Origines de Lyon

ATLAS Preliminary

ATLAS SUSY Searches* - 95% CL Lower Limits

Si	tatus: August 2016	<i>е и т</i> о	<	r miss	60.100	-11 88-1-11-11		$\sqrt{s} = 7, 8, 13 \text{ TeV}$
	Model	ε,μ, ι, γ	Jets	L _T	JL at[fi		$\sqrt{s} = 7, 8 \text{ TeV}$ $\sqrt{s} = 13 \text{ TeV}$	Reference
Inclusive Searches	$\begin{array}{l} MSUGRA/CMSSM\\ \tilde{q}\tilde{q}, \tilde{q} \rightarrow \tilde{q}\tilde{\chi}_{1}^{0} \\ \tilde{q}\tilde{q}, \tilde{q} \rightarrow \tilde{q}\tilde{\chi}_{1}^{0} \\ (compressed)\\ \tilde{g}\tilde{s}, \tilde{g} \rightarrow q\tilde{q}\tilde{\chi}_{1}^{0} \\ \tilde{g}\tilde{s}, \tilde{g} \rightarrow q\tilde{q}\tilde{\chi}_{1}^{0} \\ \tilde{g}\tilde{s}, \tilde{g} \rightarrow q\tilde{q}\tilde{\chi}_{1}^{0} \\ \tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}\tilde{\chi}_{1}^{1} \rightarrow qqW^{\pm}\tilde{\chi}_{1}^{0} \\ \tilde{g}\tilde{g}, \tilde{g} \rightarrow qq\tilde{\chi}_{1}^{\ell} \rightarrow qqW^{\pm}\tilde{\chi}_{1}^{0} \\ GMSB (\ell NLSP) \\ GGM (bino NLSP) \\ GGM (higgsino-bino NLSP) \\ GGM (higgsino-bino NLSP) \\ GGM (higgsino NLSP) \\ GGM (higgsino NLSP) \\ Gravitino LSP \end{array}$	$\begin{array}{c} 0{\text{-}3} \ e, \mu/\text{1-}2 \ \tau \\ 0 \\ \text{mono-jet} \\ 0 \\ 3 \ e, \mu \\ 2 \ e, \mu \ (\text{SS}) \\ 1{\text{-}2 \ \tau + 0{\text{-}1}} \\ 2 \ \gamma \\ \gamma \\ 2 \ e, \mu \ (Z) \\ 0 \end{array}$	2-10 jets/3 <i>b</i> 2-6 jets 1-3 jets 2-6 jets 2-6 jets 4 jets 0-3 jets ℓ 0-2 jets 2 jets 2 jets 2 jets mono-jet	Yes Yes Yes Yes Yes Yes Yes Yes Yes Yes	20.3 13.3 3.2 13.3 13.3 13.2 13.2 3.2 20.3 13.3 20.3 20.3	$ \bar{q}, \bar{g} \bar{q} \bar{q} 608 GeV 1 \bar{q} 608 GeV 1 \bar{q} $	$\begin{array}{c c} \textbf{1.85 TeV} & m(\tilde{\varrho}) = m(\tilde{\varrho}) \\ \textbf{35 TeV} & m(\tilde{\chi}_1^0) < 200 \ \text{GeV}, \ m(1^{st} \ \text{gen.} \ \tilde{q}) = m(2^{nd} \ \text{gen.} \ \tilde{q}) \\ & m(\tilde{\chi}_1^0) < 5 \ \text{GeV} \\ \textbf{1.86 TeV} & m(\tilde{\chi}_1^0) < 5 \ \text{GeV} \\ \textbf{1.83 TeV} & m(\tilde{\chi}_1^0) < 400 \ \text{GeV}, \ m(\tilde{\chi}^2 = 0.5(m(\tilde{\chi}_1^0) + m(\tilde{\varrho})) \\ \textbf{1.7 TeV} & m(\tilde{\chi}_1^0) < 400 \ \text{GeV}, \ m(\tilde{\chi}^2 = 0.5(m(\tilde{\chi}_1^0) + m(\tilde{\varrho})) \\ \textbf{1.6 TeV} & m(\tilde{\chi}_1^0) < 400 \ \text{GeV} \\ \textbf{1.6 TeV} & m(\tilde{\chi}_1^0) < 50 \ \text{GeV} \\ \textbf{2.0 TeV} \\ \textbf{1.65 TeV} & cr(\text{NLSP}) < 0.1 \ \text{mm} \\ \textbf{37 TeV} & m(\tilde{\chi}_1^0) < 950 \ \text{GeV}, \ cr(\text{NLSP}) < 0.1 \ \text{mm}, \ n < 0 \\ m(\text{NLSP}) > 4 \ \text{O CeV} \\ \textbf{m}(\tilde{\varrho}) > 1.8 \times 10^{-1} \ \text{eV} \\ m(\tilde{\varrho}) = m(\tilde{\varrho}) \cdot \textbf{1.8 TeV} \end{array}$	1507.05525 ATLAS-CONF-2016-078 1604.07773 ATLAS-CONF/2016-078 ATLAS-CONF/2016-078 ATLAS-CONF/2016-037 ATLAS CONF-2016-037 1607.05979 1606.09150 1507.05493 TLAS-CONF-2016-066 1503.03290 1502.01518
3 rd gen. <u>ẽ med.</u>	$\begin{array}{l} \tilde{g}\tilde{g}, \tilde{g} \rightarrow b \bar{b} \tilde{\chi}_{1}^{0} \\ \tilde{g}\tilde{g}, \tilde{g} \rightarrow t \bar{t} \tilde{\chi}_{1}^{0} \\ \tilde{g}\tilde{g}, \tilde{g} \rightarrow b \bar{t} \tilde{\chi}_{1}^{+} \end{array}$	0 0-1 <i>e</i> ,μ 0-1 <i>e</i> ,μ	3 b 3 b 3 b	Yes Yes Yes	14.8 14.8 20.1	ğ ğ ğ	$\begin{array}{c c} \textbf{1.89 TeV} & m(\tilde{\chi}_1^0) = 0 \ \text{GeV} \\ \hline \textbf{1.89 TeV} & m(\tilde{\chi}_1^0) = 0 \ \text{GeV} \\ \hline \textbf{37 TeV} & m(\tilde{\chi}_1^0) < 300 \ \text{GeV} \\ \end{array}$	ATLAS-CONF-2016-052 ATLAS-CONF-2016-052 1407.0600
3 rd gen. squarks direct production	$ \begin{split} \tilde{b}_{1}\tilde{b}_{1}, \tilde{b}_{1} \to b\tilde{\chi}_{1}^{0} \\ \tilde{b}_{1}\tilde{b}_{1}, \tilde{b}_{1} \to b\tilde{\chi}_{1}^{1} \\ \tilde{t}_{1}\tilde{i}_{1}, \tilde{t}_{1} \to b\tilde{\chi}_{1}^{\pm} \\ \tilde{t}_{1}\tilde{i}_{1}, \tilde{t}_{1} \to b\tilde{\chi}_{1}^{\pm} \\ \tilde{t}_{1}\tilde{i}_{1}, \tilde{t}_{1} \to c\tilde{\chi}_{1}^{0} \\ \tilde{t}_{1}\tilde{i}_{1}, \tilde{t}_{1} \to c\tilde{\chi}_{1}^{0} \\ \tilde{t}_{1}\tilde{i}_{1}, \tilde{t}_{1} \to c\tilde{\chi}_{1}^{0} \\ \tilde{t}_{2}\tilde{i}_{2}, \tilde{t}_{2} \to \tilde{t}_{1} + Z \\ \tilde{t}_{2}\tilde{t}_{2}, \tilde{t}_{2} \to \tilde{t}_{1} + h \end{split} $	$\begin{matrix} 0 \\ 2 \ e, \mu \ (SS) \\ 0-2 \ e, \mu \\ 0-2 \ e, \mu \\ 0 \\ 2 \ e, \mu \ (Z) \\ 3 \ e, \mu \ (Z) \\ 1 \ e, \mu \end{matrix}$	2 b 1 b 1-2 b 0-2 jets/1-2 b mono-jet 1 b 1 b 6 jets + 2 b	Yes Yes Yes 4 Yes Yes Yes Yes Yes	3.2 13.2 .7/13.3 .7/13.3 3.2 20.3 13.3 20.3	$\begin{array}{c c c c c c c c c c c c c c c c c c c $	$\begin{split} & m(\tilde{\chi}_{1}^{0}) \! < \! 100 \text{GeV} \\ & m(\tilde{\chi}_{1}^{0}) \! < \! 150 \text{GeV}, m(\tilde{\chi}_{1}^{+}) \! = \! m(\tilde{\chi}_{1}^{0}) \! + \! 100 \text{GeV} \\ & m(\tilde{\chi}_{1}^{+}) \! = \! 2m(\tilde{\chi}_{1}^{0}), m(\tilde{\chi}_{1}^{0}) \! = \! 55 \text{GeV} \\ & m(\tilde{\chi}_{1}^{0}) \! = \! 1 \text{GeV} \\ & m(\tilde{\chi}_{1}^{0}) \! = \! 1 \text{GeV} \\ & m(\tilde{\chi}_{1}^{0}) \! = \! 5 \text{GeV} \\ & m(\tilde{\chi}_{1}^{0}) \! = \! 5 \text{GeV} \\ & m(\tilde{\chi}_{1}^{0}) \! = \! 510 \text{GeV} \\ & m(\tilde{\chi}_{1}^{0}) \! = \! 10 \text{GeV} \\ & m(\tilde{\chi}_{1}^{0}) \! = \! 0 \text{GeV} \\ \end{split}$	1606.08772 ATLAS-CONF-2016-037 1209.2102, ATLAS-CONF-2016-077 1506.08616, ATLAS-CONF-2016-077 1604.07773 1403.5222 ATLAS-CONF-2016-038 1506.08616
EW direct	$ \begin{array}{l} \tilde{\ell}_{LR}\tilde{\ell}_{LR}, \tilde{\ell} \rightarrow \ell \tilde{\chi}_{1}^{0} \\ \tilde{\chi}_{1}^{+}\tilde{\chi}_{1}, \tilde{\chi}_{1}^{+} \rightarrow \tilde{\ell}\nu(\ell\tilde{\nu}) \\ \tilde{\chi}_{1}^{+}\tilde{\chi}_{1}^{-}, \tilde{\chi}_{1}^{+} \rightarrow \tilde{\tau}\nu(\tau\tilde{\nu}) \\ \tilde{\chi}_{1}^{+}\tilde{\chi}_{2}^{0} \rightarrow \tilde{\ell}_{L}\nu\tilde{\ell}_{L}\ell(\tilde{\nu}\nu), \ell\tilde{\nu}\tilde{\ell}_{L}\ell(\tilde{\nu}\nu) \\ \tilde{\chi}_{1}^{+}\tilde{\chi}_{2}^{0} \rightarrow W\tilde{\chi}_{1}^{0}Z\tilde{\chi}_{1}^{0} \\ \tilde{\chi}_{1}^{+}\tilde{\chi}_{2}^{0} \rightarrow W\tilde{\chi}_{1}^{0}h\tilde{\chi}_{1}^{0}, h \rightarrow b\bar{b}/WW/a \\ \tilde{\chi}_{2}^{0}\tilde{\chi}_{3}, \tilde{\chi}_{2,3}^{0} \rightarrow \tilde{\ell}_{R}\ell \\ \text{GGM (wino NLSP) weak prod GGM (bino NLSP) weak prod } \end{array} $	$\begin{array}{c} 2 \ e, \mu \\ 2 \ e, \mu \\ 2 \ \tau \\ 3 \ e, \mu \\ 2 \ 3 \ e, \mu \\ 2 \ 3 \ e, \mu \\ 2 \ 3 \ e, \mu \\ 1 \ e, \mu, \gamma \\ 4 \ e, \mu \\ 1 \ e, \mu + \gamma \\ 2 \ \gamma \end{array}$	0 0 - 0-2 jets 0-2 <i>b</i> 0 -	Yes Yes Yes Yes Yes Yes Yes Yes	20.3 13.3 14.8 13.3 20.3 20.3 20.3 20.3 20.3 20.3	$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	$\begin{split} m(\tilde{x}_{1}^{0}) = 0 \text{ GeV} \\ m(\tilde{x}_{1}^{0}) = 0 \text{ GeV}, m(\tilde{\ell}, \tilde{v}) = 0.5(m(\tilde{x}_{1}^{+}) + m(\tilde{x}_{1}^{0})) \\ m(\tilde{x}_{1}^{0}) = 0 \text{ GeV}, m(\tilde{\tau}, \tilde{v}) = 0.5(m(\tilde{x}_{1}^{+}) + m(\tilde{x}_{1}^{0})) \\ m(\tilde{x}_{1}^{0}) = m(\tilde{x}_{1}^{0}) = 0, m(\tilde{\ell}, \tilde{v}) = 0.5(m(\tilde{x}_{1}^{+}) + n(\tilde{x}_{1}^{0})) \\ m(\tilde{x}_{1}^{+}) = m(\tilde{x}_{1}^{0}) = 0, m(\tilde{\ell}, \tilde{v}) = 0.5(m(\tilde{x}_{1}^{+}) + n(\tilde{x}_{1}^{0})) \\ m(\tilde{x}_{1}^{+}) = m(\tilde{x}_{2}^{0}), m(\tilde{x}_{1}^{0}) = 0, m(\tilde{c}, v) = 0.5(m(\tilde{x}_{1}^{0}) + n(\tilde{x}_{1}^{0})) \\ m(\tilde{x}_{1}^{+}) = m(\tilde{x}_{2}^{0}), m(\tilde{x}_{1}^{0}) = 0, m(\tilde{c}, v) = 0.5(m(\tilde{x}_{2}^{0}) + m(\tilde{x}_{1}^{0})) \\ m(\tilde{x}_{1}^{-}) = m(\tilde{x}_{1}^{0}) = 0, m(\tilde{\ell}, \tilde{v}) = 0, m(\tilde{x}_{2}^{0}) + m(\tilde{x}_{1}^{0})) \\ c\tau < 1 mm \\ c\tau < 1 mm \end{split}$	1403.5294 ATLAS-CONF-2016-096 ATLAS-CONF-2016-093 ATLAS-CONF-2016-096 1403.5294,4402.7099 1404.0400,101 1405.5080 1507.05493 1507.05493
Long-lived particles	Direct $\tilde{\chi}_1^+ \tilde{\chi}_1^-$ prod., long-lived $\tilde{\lambda}_2^+$ Direct $\tilde{\chi}_1^+ \tilde{\chi}_1^-$ prod., long-lived $\tilde{\lambda}_2^+$ Stable, stopped \tilde{g} R-hadron Stable \tilde{g} R-hadron Metastable \tilde{g} R-hadron GMSB, stable $\tilde{\tau}, \tilde{\chi}_1^0 \rightarrow \tilde{\tau}(\tilde{e}, \tilde{\mu}) + \tau$ GMSB, $\tilde{\chi}_1^0 \rightarrow \gamma \tilde{G}$, long-lived $\tilde{\chi}_1^0$ $\tilde{g}\tilde{g}, \tilde{\chi}_1^0 \rightarrow eev/e\mu\nu/\mu\mu\nu$ GGM $\tilde{g}\tilde{g}, \tilde{\chi}_1^0 \rightarrow Z\tilde{G}$	$ \begin{array}{c} \overset{\pm}{\underset{1}{1}} & \text{Disapp. trk} \\ \overset{\pm}{\underset{1}{1}} & \text{dE/dx trk} \\ & 0 \\ & \text{trk} \\ & \text{dE/dx trk} \\ & \text{dE/dx trk} \\ & \text{c}(e,\mu) & 1\text{-}2\mu \\ & 2\gamma \\ & \text{displ. } ee/e\mu/\mu \\ & \text{displ. vtx + je} \end{array} $	1 jet - 1-5 jets - - - - μμ - ets -	Yes Yes - - Yes - Yes	20.3 18.4 27.9 3.2 3.2 19.1 20.3 20.3 20.3	$\begin{array}{c c c c c c c c c c c c c c c c c c c $	$\begin{array}{c} \mathbf{m}(\tilde{\chi}_{1}^{1})\cdot\mathbf{m}(\tilde{\chi}_{1}^{0})\sim\!\!\!160~\text{MeV},~\mathbf{r}(\tilde{\chi}_{1}^{1})\!=\!0.2~\text{ns}\\ \mathbf{m}(\tilde{\tau}_{1}^{1}\wedge\tilde{\chi}(\tilde{\chi}_{1}^{1}))\!\equiv\!50~\text{HeV},~\mathbf{r}(\tilde{\chi}_{1}^{1})\!=\!0.2~\text{ns}\\ \mathbf{m}(\tilde{\tau}_{1}^{1}\wedge\tilde{\chi}(\tilde{\chi}_{1}^{0})\!\equiv\!50~\text{HeV},~\mathbf{r}(\tilde{\chi}_{1}^{1})\!=\!100~\text{s}\\ \mathbf{1.57~\text{TeV}}\\ \mathbf{m}(\tilde{\chi}_{1}^{0})\!=\!100~\text{GeV},~\mathbf{r}\!>\!10~\text{ns}\\ 10\!<\!\tan\!\beta\!<\!50\\ 1\!<\!\mathbf{r}(\tilde{\chi}_{1}^{0})\!<\!3~\text{ns},~\text{SPS8~model}\\ 7\;<\!cr(\tilde{\chi}_{1}^{0})\!<\!740~\text{mm},~\mathbf{m}(\tilde{g})\!=\!1.3~\text{TeV}\\ 6\;<\!cr(\tilde{\chi}_{1}^{0})\!<\!480~\text{mm},~\mathbf{m}(\tilde{g})\!=\!1.1~\text{TeV}\\ \end{array}$	1310,8675 166,537 100,84 1606,05129 1604,04520 1411,6795 1409,5542 1504,05162 1504,05162
RPV	LFV $pp \rightarrow \tilde{v}_{\tau} + X, \tilde{v}_{\tau} \rightarrow e\mu/e\tau/\mu^{\tau}$ Bilinear RPV CMSSM $\tilde{\chi}_{1}^{+}\tilde{\chi}_{1}^{-}, \tilde{\chi}_{1}^{+} \rightarrow W\tilde{\chi}_{1}^{0}, \tilde{\chi}_{1}^{0} \rightarrow eev, e\mu v,$ $\tilde{\chi}_{1}^{+}\tilde{\chi}_{1}^{-}, \tilde{\chi}_{1}^{+} \rightarrow W\tilde{\chi}_{1}^{0}, \tilde{\chi}_{1}^{0} \rightarrow \tau\tau v_{e}, e\tau v$ $\tilde{g}\tilde{s}, \tilde{g} \rightarrow qq\bar{q}$ $\tilde{g}\tilde{s}, \tilde{g} \rightarrow qq\tilde{\chi}_{1}^{0}, \tilde{\chi}_{1}^{0} \rightarrow qqq$ $\tilde{g}\tilde{s}, \tilde{g} \rightarrow t\bar{t}\tilde{\chi}_{1}^{0}, \tilde{\chi}_{1}^{0} \rightarrow qqq$ $\tilde{g}\tilde{s}, \tilde{g} \rightarrow t\bar{t}, \tilde{t}, \tilde{t} \rightarrow bs$ $\tilde{t}_{1}\tilde{t}_{1}, \tilde{t}_{1} \rightarrow b\ell$	$\begin{array}{cccc} r & e\mu, e\tau, \mu\tau \\ 2 & e, \mu (SS) \\ \mu\mu\nu & 4 & e, \mu \\ \gamma_{\tau} & 3 & e, \mu+\tau \\ 0 & 4 \\ 1 & e, \mu & 4 \\ 1 & e, \mu & 4 \\ 0 \\ 2 & e, \mu \end{array}$		- Yes Yes ts - ts - b - b - -	3.2 20.3 13.3 20.3 14.8 14.8 14.8 14.8 14.8 15.4 20.3	$ \begin{array}{c c} \bar{y}_{\rm r} \\ \bar{q}, \bar{g} \\ \bar{\chi}_1^{\pm} \\ \bar{\chi}_1^{\pm} \\ \bar{\chi}_1^{\pm} \\ \bar{\chi}_1^{\pm} \\ \bar{\chi}_1^{\pm} \\ \bar{\chi}_1^{\pm} \\ \bar{g} \\ \bar{g} \\ \bar{g} \\ \bar{g} \\ \bar{f} \\ \bar{f} \\ \bar{f}_1 \\ \bar{\chi}_1 \\ \bar{\chi}_1^{\pm} \\ $	$\begin{array}{c c} \textbf{1.9 TeV} & \lambda_{311}^{*}=0.11, \lambda_{132/133/233}=0.07 \\ \textbf{1.45 TeV} & \textbf{m}(\tilde{q})=\textbf{m}(\tilde{g}), c_{TLSP}<1 \text{ mm} \\ \textbf{V} & \textbf{m}(\tilde{\chi}_{1}^{0})>400 \text{GeV}, \lambda_{12k}\neq0 \ (k=1,2) \\ \textbf{m}(\tilde{\chi}_{1}^{0})>0.2\times\textbf{m}(\tilde{\chi}_{1}^{1}), \lambda_{133}\neq0 \\ \textbf{BR}(r)=\textbf{BR}(b)=\textbf{BR}(c)=0\% \\ \textbf{1.55 TeV} & \textbf{m}(\tilde{\chi}_{1}^{0})=800 \text{ GeV} \\ \textbf{1.75 TeV} & \textbf{m}(\tilde{\chi}_{1}^{0})=700 \text{ GeV} \\ \textbf{1.4 TeV} & 625 \text{ GeV} < \textbf{BR}(\tilde{r}_{1}\rightarrow be/\mu)>20\% \end{array}$	1607.08079 1404.2500 ATLAS-CONF-2016-075 1405.5086 ATLAS-CONF-2016-057 ATLAS-CONF-2016-057 ATLAS-CONF-2016-094 ATLAS-CONF-2016-094 ATLAS-CONF-2016-094 ATLAS-CONF-2016-022, ATLAS-CONF-2016-084 ATLAS-CONF-2015-015
Other	Scalar charm, $\tilde{c} \rightarrow c \tilde{\chi}_1^0$	0	2 <i>c</i>	Yes	20.3	č 510 GeV	$m(\tilde{\chi}_1^0)$ <200 GeV	1501.01325
	*Only a selection of the states or phenomena	ie available n a is shown.	nass limits	on ne	^w 1	0 ⁻¹ 1	Mass scale [TeV]	



The call for New Physics mainly comes
 from the Higgs sector (and DM?)

It's a logical possibility to have weakly coupled light states:

"Non-minimal" composite Higgs models! EW-inos in SUSY

Axions (R-axion...)

multi-TeV horizon

The Martin

Light stuff may still be there!



2 Higgs Doublet Models

Minimal extension of the SM Higgs sector

$$\begin{split} V =& m_{11}^2 \phi_1^{\dagger} \phi_1 + m_{22}^2 \phi_2^{\dagger} \phi_2 - m_{12}^2 \left(\phi_1^{\dagger} \phi_2 + \phi_2^{\dagger} \phi_1 \right) + \frac{\lambda_1}{2} \left(\phi_1^{\dagger} \phi_1 \right)^2 + \frac{\lambda_2}{2} \left(\phi_2^{\dagger} \phi_2 \right)^2 + \\ \lambda_3 \left(\phi_1^{\dagger} \phi_1 \right) \left(\phi_2^{\dagger} \phi_2 \right) + \lambda_4 \left(\phi_1^{\dagger} \phi_2 \right) \left(\phi_2^{\dagger} \phi_1 \right) + \frac{\lambda_5}{2} \left[\left(\phi_1^{\dagger} \phi_2 \right)^2 + \left(\phi_2^{\dagger} \phi_1 \right)^2 \right], \end{split}$$

Z2 symmetric (except m12)

 $\tan\beta = \frac{v_2}{v_1}$

 $lpha \Rightarrow h \leftrightarrow H$ mixing

2 Higgs Doublet Models

 Couplings to fermions define 4 flavoursafe scenarios

		Type I	Type II	Flipped	Lepton Specific		
	h	$\frac{\cos \alpha}{\sin \beta}$					
Up-Type quark	Η	$\frac{\sin \alpha}{\sin \beta}$					
	Α	$\cot eta$					
	h	$\frac{\cos \alpha}{\sin \beta}$	$-\frac{\sin \alpha}{\cos \beta}$	$-\frac{\sin \alpha}{\cos \beta}$	$\frac{\cos \alpha}{\sin \beta}$		
Down-Type quark	Η	$\frac{\sin \alpha}{\sin \beta}$	$\frac{\cos \alpha}{\cos \beta}$	$\frac{\cos \alpha}{\cos \beta}$	$\frac{\sin \alpha}{\sin \beta}$		
	Α	$\cot eta$	aneta	aneta	\coteta		
	h	$\frac{\cos \alpha}{\sin \beta}$	$-\frac{\sin \alpha}{\cos \beta}$	$\frac{\cos \alpha}{\sin \beta}$	$-\frac{\sin \alpha}{\cos \beta}$		
Lepton	Η	$\frac{\sin \alpha}{\sin \beta}$	$\frac{\cos \alpha}{\cos \beta}$	$\frac{\sin \alpha}{\sin \beta}$	$\frac{\cos \alpha}{\cos \beta}$		
	Α	$\cot eta$	aneta	\coteta	aneta		
	h	$egin{array}{c} \sin(eta-lpha) & extsf{Higg}\ \cos(eta-lpha) & extsf{couplit}\ 0 & extsf{couplit} \end{array}$			Higgs		
WW and ZZ	Η				countinos		
	Α				coupenigs		

A Lighter Higgs?

The spectrum may contain a lighter Higgs-like state:



1607.08653 (JHEP)

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strategy:

Preliminary scan of the parameter space

$m_h~({ m GeV})$	$m_H~({ m GeV})$	$m_A~({ m GeV})$	$m_{H^{\pm}}~({ m GeV})$	$\sin(eta-lpha)$	aneta	$m^2_{12} \; ({ m GeV})^2$
[80;110]	125	[60;1000]	[80;1000]	[-1;1]	[1/50;50]	$[-(300)^2;+(200)^2]$



Strategy:

- · Preliminary scan of the parameter space
- Impose existing constraints (using existing tools):

1* Indirect constraints 2* LEP bounds (on scalars) 3* LHC bounds (on Higgs couplings)

1* Indirect constraints

- EWPTs (S and T parameters) 2 sigma limit
- stability of the potential, and perturbativity of all couplings

Computed with 2HDMC

a flavour bounds (charged Higgs) Computed with <u>SuperIso</u>

Process	Experimental values	Theoretical computation	Combined error at 1σ
$\mathcal{BR}(\overline{B} \to X_s \gamma)$	$(3.43 \pm 0.22) \times 10^{-4}$ [20]	$(3.40 \pm 0.19) \times 10^{-4}$ [21]	$0.29 imes10^{-4}$
$\mathcal{BR}(B_s \to \mu^+ \mu^-)$	$(2.9 \pm 0.7) \times 10^{-9}$ [22, 23]	$(3.54 \pm 0.27) \times 10^{-9}$ [21]	$0.8 imes10^{-9}$
$\Delta_0(B \to K^* \gamma)$	$(5.2 \pm 2.6) \times 10^{-2}$ [24]	$(5.1 \pm 1.5) \times 10^{-2}$ [21]	$3.0 imes10^{-2}$
ΔM_d	$0.510 \pm 0.003 \text{ ps}^{-1}$ [20]	$0.543 \pm 0.091 \text{ ps}^{-1} \text{ [25]}$	$0.091 \ {\rm ps}^{-1}$

2* LEP constraints

@ Direct bounds on scalars (HiggsBounds at 95% C.L.)

3* LHC constraints

Fit of signal strengths using kappa's (8TeV legacy data - 1606.02266)

 $\kappa_{XY}^2 = \frac{\Gamma(H \to YX)}{\Gamma^{\rm SM}(H \to XY)} \qquad \text{N.S.} \quad \kappa_{WW} = \kappa_{ZZ} = \cos(\beta - \alpha)$

o Gaussian fit of signal strengths (1504.07919)



Figure 2: Relevance of the hypothesis of a Gaussian likelihood: comparison of experimental 95% C.L. exclusion contours with contours extrapolated from the 68% C.L. fit (ATLAS only). Colour code per final state: yellow: $\gamma\gamma$, green: $\tau\tau$, red: WW, blue: ZZ. Gray rhombus: SM

 $\kappa_{XY}^2 = \frac{\Gamma(H \to YX)}{\Gamma^{\rm SM}(H \to XY)} \qquad \text{N.S.} \quad \kappa_{WW} = \kappa_{ZZ} = \cos(\beta - \alpha)$

o Gaussian fit of signal strengths (1504.07919)

Cross section calculation

We use the same "kappa trick" to calculate
 production cross sections for the lighter Higgs.

 $\kappa_{XY}^2 = \frac{\Gamma(h \to YX)}{\Gamma^{\rm SM}(H \to XY)}$

Approximate cross sections

 $\sigma(gg \to h) = \kappa_{gg}^2 \times \sigma^{\rm SM}$

 $\sigma(VBF + Vh) = \kappa_{VV}^2 \times \sigma^{\rm SM}$

compared with SusHi

N.B.: no VBF nor Vh in Sushi!

N.B. $\kappa_{VV}^{\text{light}} = \sin(\beta - \alpha)$



Results



Results Di-photon signal (type I)



• Search sensitive to VBF+Vh for $-0.3 \lesssim \sin(eta-lpha) \lesssim 0$

Results Di-photon signal (type II)



Very far from sensitivity! We focus on Type I!

Focused scan

$m_h~({ m GeV})$	$m_H~({ m GeV})$	$m_A~({ m GeV})$	$m_{H^{\pm}}~({ m GeV})$	$\sin(eta-lpha)$	aneta	$m12^{2}$
[80;110]	125	[60;650]	[80;630]	[-0.3; -0.05]	[2;12]	$[-(100)^2;+(100)^2]$

Comparison with CMS cross section bounds.





Note: no VBF optimisation, but simple recast!

Focused scan



Exclusion driven by large BR (h-> photons)

Conclusions

- @ 2HDMs still allow for a light CP-even Higgs
- We found that in Type-I, large diphoton
 signal can be obtained in VBF+Vh channel
- We also checked the pseudoscalar (no large signal)
- 2HDM Type-I is a good benchmark model for the search!
- Note: optimisation for VBF+Vh will help!

Light pseudo-scalar

[80; 110]

