Proposal: Benchmark Point with low-mass CP-odd Higgs A with strong couplings to leptons and top quarks

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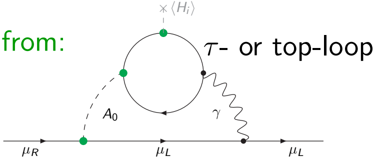
Overview

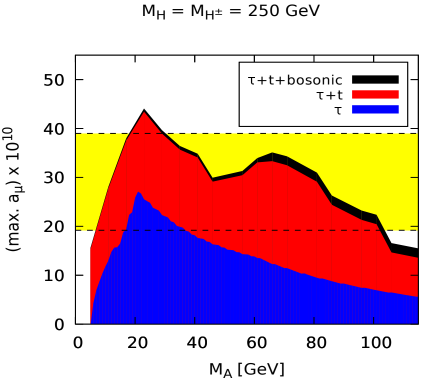
- We propose benchmarks points for the search for a new light (CP-odd) Higgs A with the following properties
  - mass $20 \ldots 90$ GeV
  - small/negligible couplings to W, Z
  - large couplings to leptons ($\sim 50\times$ SM)
  - large couplings to top-quarks ($\mathcal{O}$(SM))
- Motivation:
  - new light particles should be searched for comprehensively
  - several "anomalies" in low-E observables, dark matter $\rightsquigarrow$ light new states?
  - specifically: muon $g-2$ can be explained by such light A
  - the scenario can be realized in the 2HDM, we have delineated the range of A-couplings allowed be existing constraints
- Existing studies:
  - theory investigation of constraints on masses/couplings/$g-2$ [Cherchiglia,Stöckinger,Stöckinger-Kim'17]
  - ATLAS study on possible reach of LHC searches [Mader,Moder,Straessner]

a_μ in the 2-Higgs doublet model? [Cherchiglia,DS,Stöckinger-Kim '17]

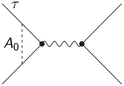
- $(g-2)_\mu$: 3–4σ discrepancy, not easy to explain ($\rightsquigarrow$ SUSY limits!)
- promising: 2HDM with light A_0, large couplings to τ (and top) can explain $(g-2)_\mu$ via 2-loop diagrams

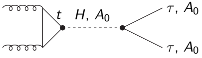
a_μ from:





Constraints: τ, b, Z-physics, LHC





$\Rightarrow$ 2HDM can explain a_μ for $M_A = 20\ldots100$ GeV.

$\Rightarrow$ Need largest possible lepton couplings and top couplings

$\Rightarrow$ Suppress couplings to W, Z and suppress $h \to AA$ if $M_A < 62.5$ GeV

Two-Higgs Doublet Model couplings

- Yukawa couplings ($\times$SM) in general "aligned" model [Pich,Tuzon]

$$
\begin{aligned}
Y^A_{d,l;u} &= \mp\zeta_{d,l;u} \\
Y^h_f &= s_{\beta-\alpha} + c_{\beta-\alpha}\zeta_f \\
Y^H_f &= c_{\beta-\alpha} - s_{\beta-\alpha}\zeta_f
\end{aligned}
$$

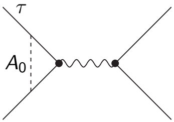
Compare with:

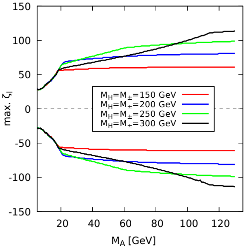
MSSM/Type 2:	$\zeta_{d,l} = -\tan\beta$,	$\zeta_u = 1/\tan\beta$
Type X (lepton-specific):	$\zeta_l = -\tan\beta$,	$\zeta_{d,u} = 1/\tan\beta$

Analysis of [Cherchiglia,DS,Stöckinger-Kim'17] for $M_A = 20\ldots100$ GeV:
general limits $|\zeta_l| < 50\ldots100$, $|\zeta_u| <\sim 0.5$ — details below

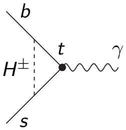
constraints on A-couplings to tau/top [Cherchiglia,DS,Stöckinger-Kim'17]

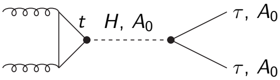
$Z \to \tau\tau$, τ-decay, LEP $e^+e^- \to 4\tau$ constraints on ζ_L!

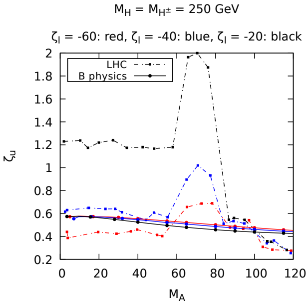




$b \to s\gamma$, $B_s \to \mu\mu$, LHC constraints!







Benchmark points and LHC predictions

The scenario of low-mass A is motivated — it should be tested/found or excluded at the LHC! We suggest two points at border of allowed parameter space [Khasianevich, Stöckinger, Stöckinger-Kim, Mader, Moder, Straessner]:

Point 1:	Point 2:
$M_A = 50$ GeV	$M_A = 80$ GeV
$\zeta_l = -40$	$\zeta_l = -60$
$\zeta_u = 0.5$	$\zeta_u = 0.5$
$C_{hAA} = 0$	$C_{hAA} = 0$
$\cos(\beta-\alpha) = 0$	$\cos(\beta-\alpha) = 0$

BR$(A \to \tau\tau) \approx 100\%$ and $f_\sigma \equiv \frac{\sigma(gg\to A)}{\sigma(gg\to h_{\text{SM-like}})} \approx 0.6\ldots 0.7$ (uncertainty: LO and ζ_d unknown)

study for ATLAS-reach on $f_\sigma \equiv \frac{\sigma(gg\to A)}{\sigma(gg\to h_{\text{SM-like}})}$ has been carried out — shows that exclusion down to $f_\sigma \approx 0.2$ can be possible! [Mader,Moder,Straessner]

Details of ATLAS-study [Mader,Moder,Straessner]

SM-like Higgs cross section:

Mass [GeV]	XSec [pb]			
	LO	NLO	NNLO	N^3LO
60	43.897	109.278	151.238	166.827
70	35.0192	85.44	117.398	129.316
80	28.5669	68.6164	93.6927	103.082
90	23.7323	56.2314	76.4134	83.9884

Table 0.1: Cross-section for a Standard Model Higgs boson with different mass and orders, calculated with ggHiggs (https://www.ge.infn.it/~bonvini/higgs/)

Trigger choices:

	$m_A = 60$ GeV	$m_A = 70$ GeV	$m_A = 80$ GeV	$m_A = 90$ GeV
Baseline Selection	# of μ = # of $e = 1$ and $q_\mu \cdot q_e = -1$ $p_T^\mu > 25$ GeV, $p_T^e > 8$ GeV # of b-jets $= 0$ with $p_T^{jet} > 20$ GeV			
Individual Event Selection	$m_T^{tot} < 55$ GeV $m_{ll} < 40$ GeV $m_{MMC} < 65$ GeV $\Delta\eta_{ll} < 1.6$ $\Delta R_{ll} < 2.3$	$m_T^{tot} < 65$ GeV $m_{ll} < 40$ GeV $m_{MMC} < 75$ GeV $\Delta\eta_{ll} < 1.8$ $\Delta R_{ll} < 3.1$	$m_T^{tot} < 75$ GeV $m_{ll} < 50$ GeV $m_{MMC} < 85$ GeV $\Delta\eta_{ll} < 1.8$ $\Delta R_{ll} < 3.0$	$m_T^{tot} < 85$ GeV $m_{ll} < 60$ GeV $m_{MMC} < 100$ GeV $\Delta\eta_{ll} < 2.4$ $\Delta R_{ll} < 3.1$

Table 0.2: Complete list of cuts for all different signal processes

Resulting expected upper limits for the scaling factor $f_\sigma = \frac{\sigma(gg\to A)}{\sigma(gg\to h_{\text{SM-like}})}$:

[limits are in the range $f_\sigma < 0.2 \ldots 0.4$ for M_A between 60 . . . 90 GeV (Master thesis Paul Moder)]