Detectability of light pseudoscalars in the NMSSM, 1409.8393

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NMSSM and light pseudoscalars

The Higgs sector of the NMSSM Scanning the NMSSM Scan results

LHC analyses

Cuts and backgrounds Results $H_1 = H_{SM}$ Results $H_2 = H_{SM}$

Future prospects and conclusions

Summary of results Shortcomings and possible improvements Conclusions

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The light pseudoscalar

 m_{A_1} is essentially a free parameter in the theory. Many searches $m_{A_1} < 10$ GeV. 0805.3505, 1101.1137, 1206.6326, 1210.7619. We focus mostly on $10 < m_{A_1} < m_{H_{SM}}$. Hard to detect directly: no VBF nor Higgstrahlung, gluon fusion small. Maybe associated $b\bar{b}A_1$ production? 1105.4191 Our studies shows no hope there either. We must then rely on decays from heavier particles. Our focus is $H \rightarrow A_1A_1$ and $H \rightarrow A_1Z$.

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The SM-like Higgs mass in the NMSSM

The extra scalar gives an additional contribution to the Higgs mass

 $\lambda^2 \nu^2 \sin^2(2\beta).$

It is also possible to have a mostly singlet like scalar lighter than $H_{\rm SM}$ and then the mixing gives:

$$\begin{pmatrix} M_H & m \\ m & m_S \end{pmatrix} \Rightarrow M_{H_1,H_2} = \frac{M_H - m_S}{2} \pm \sqrt{\frac{(M_H - m_S)^2}{4} + m^2}.$$

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Constraints

- ▶ 122 < m_{H_{SM}} < 129 GeV,</p>
- *m*_{A₁} ≤ 150 GeV,
- Ω_χ h² < 0.131,
 </p>
- ▶ $BR(B_s \rightarrow \mu^+ \mu^-) = (3.2 \pm 1.35 \pm 0.32) \times 10^{-9},$
- ► $BR(B_u \rightarrow \tau \nu) = (1.66 \pm 0.66 \pm 0.38) \times 10^{-4}$,
- ► BR $(b \to s\gamma) = (3.43 \pm 0.22 \pm 0.21) \times 10^{-4}$.

ATLAS: $\mu^{\gamma\gamma} = 1.57^{+0.33}_{-0.28}$, $\mu^{ZZ} = 1.44^{+0.40}_{-0.35}$. CMS: $\mu^{\gamma\gamma} = 1.13 \pm 0.24$, $\mu^{ZZ} = 1.0 \pm 0.29$.

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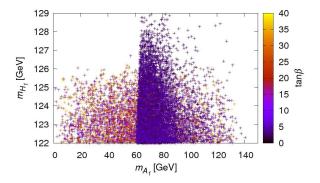
Parameter ranges

Bayesian scan using MultiNest,					
see our paper 1409.8393 for details.					
Parameter	Extended range	xtended range Reduced range			
<i>m</i> ₀ (GeV)	200 - 4000	200 – 2000			
<i>m</i> _{1/2} (GeV)	100 – 2000	100 – 1000			
A_0^{\prime} (GeV)	-5000 — 0	-3000 – 0			
$\mu_{ m eff}$ (GeV)	100 – 2000	100 – 200			
$\tan \beta$	1 – 40	1 – 6			
λ	0.01 – 0.7	0.4 – 0.7			
κ	0.01 – 0.7	0.01 – 0.7			
A_{λ} (GeV)	-2000 – 2000	-500 — 500			
A_{κ} (GeV)	-2000 – 2000	-500 — 500			

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Scan results $H_1 = H_{\rm SM}$

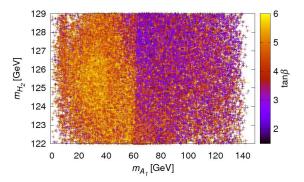


No points $m_{A_1} < m_{H_1}/2$ in naturalness limit.

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Scan results $H_2 = H_{SM}$



Easier to obtain heavy enough $H_{\rm SM}$.

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Acceptance cuts

- $|\eta| < 2.5$ for all final state objects,
- $p_T > 15$ GeV for all final state objects,
- $\Delta R \equiv \sqrt{(\Delta \eta)^2 + (\Delta \phi)^2} > 0.2$ for all *b*-quark pairs,
- $\Delta R > 0.4$ for all other pairs of final state objects.

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Backgrounds

Irreducible backgrounds obtained from MadGraph.

Channel	Background cross section	
bbbb	3400 pb	
$bar{b} au^+ au^-$	3.1 pb	
$\tau^+ \tau^- \tau^+ \tau^-$	5.4 fb	
bbZ	126 pb	
$ au^+ au^- Z$	0.46 pb	

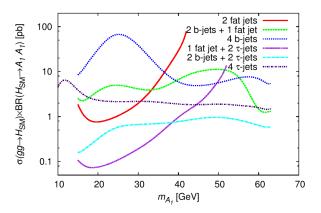
Signal and (parton level) background hadronised and clustered in Pythia.

Jet substructure methods (0802.2470) used to find "fat jets" consisting of 2 b-jets.

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Sensitivity A₁A₁



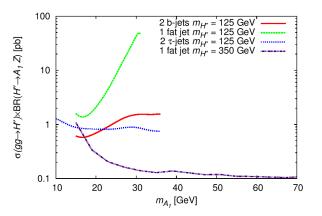
The $b\bar{b}\tau^+\tau^-$ channel most promising.

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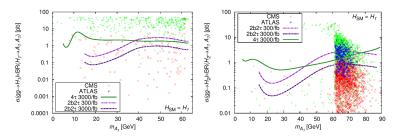
Sensitivity A₁Z



Most efficient for a heavier scalar.

Cuts and backgrounds **Results** $H_1 = H_{SM}$ Results $H_2 = H_{SM}$

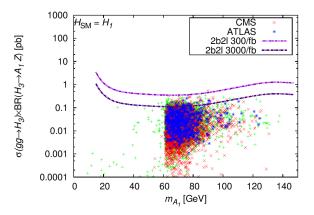
Sensitivity in A_1A_1 channel



Some hope for detection but limited number of points.

Cuts and background: Results $H_1 = H_{SM}$ Results $H_2 = H_{SM}$

Sensitivity in A_1Z channel

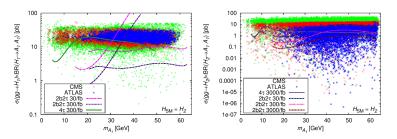


At least HL-LHC may discover something.

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Cuts and backgrounds Results $H_1 = H_{SM}$ Results $H_2 = H_{SM}$

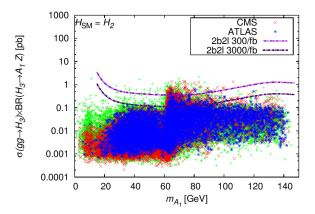
Sensitivity in A_1A_1 channel



The LHC should exclude $m_{A_1} \lesssim 60$ GeV.

Cuts and backgrounds Results $H_1 = H_{SM}$ Results $H_2 = H_{SM}$

Sensitivity in A_1Z channel



Enough detectable points to motivate further study.

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Detectability ranges

Production mode	Final states	Accessibility	Range (GeV)
b̄bA ₁	4b, 2b $2 au$	X	
$H_1 \rightarrow A_1 A_1 (H_1)$	4b, 2b $2 au$, 4 $ au$	🗸 300/fb	<i>m</i> _{A1} < 63
$H_1 ightarrow A_1 A_1 (H_2)$	4b, 2b $2 au$, 4 $ au$	✓ 30/fb	$m_{A_1} < 60$
$H_1 ightarrow A_1 Z$	2b2 ℓ , 2 $ au$ 2 ℓ	X	
$H_2 \rightarrow A_1 A_1 (H_1)$	4b, 2b $2 au$, 4 $ au$	✓ 300/fb	$60 < m_{A_1} < 80$
$H_2 ightarrow A_1 A_1 (H_2)$	4b, 2b $2 au$, 4 $ au$	✓ 30/fb	<i>m</i> _{A1} < 63
$H_2 ightarrow A_1 Z$	2b2 ℓ , 2 $ au$ 2 ℓ	X	
$H_3 ightarrow A_1 A_1$	4b, 2b $2 au$, 4 $ au$	X	
$H_3 ightarrow A_1 Z$	2b2 ℓ , 2 $ au$ 2 ℓ	✓ 300/fb	$60 < m_{A_1} < 120$

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Some points for future studies

- The "tagging" is done from MC truth with average efficiencies added as factors on *σ*.
- Only irreducible backgrounds included, e.g. no $t\bar{t}$.
- No detector effects nor triggering are included.
- ► Cuts are not optimised. Especially for H₃ → A₁Z, harder cuts may improve sensitivity.
- Maybe improved jet substructure technics.
- Improved tau reconstruction, e.g. collinear approximation.
- Fitting to kinematic distributions, rather than just using S/\sqrt{B} per bin.

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Conclusions

- Due to the extra singlet, the NMSSM may feature a very light pseudoscalar.
- In the most natural region (large λ, small tan β) the LHC will practically exclude m_{A1} < 60 GeV.</p>
- For somewhat heavier pseudoscalars, H₃ → A₁Z is a very interesting channel.

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