Detectability of light pseudoscalars in the NMSSM, 1409.8393

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Outline

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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 $10 < m_{A_1} < m_{H_{\rm SM}}$.
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 $H \to A_1 A_1$ and $H \to A_1 Z$.

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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_{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

- $122 < m_{H_{\rm SM}} < 129$ GeV,
- $m_{A_1} \lesssim 150$ GeV,
- $\Omega_\chi h^2 < 0.131$,
- $\mathrm{BR}(\mathrm{B_s} \to \mu^+\mu^-) = (3.2 \pm 1.35 \pm 0.32) \times 10^{-9}$,
- $\mathrm{BR}(\mathrm{B_u} \to \tau\nu) = (1.66 \pm 0.66 \pm 0.38) \times 10^{-4}$,
- $\mathrm{BR}(b \to s\gamma) = (3.43 \pm 0.22 \pm 0.21) \times 10^{-4}$.

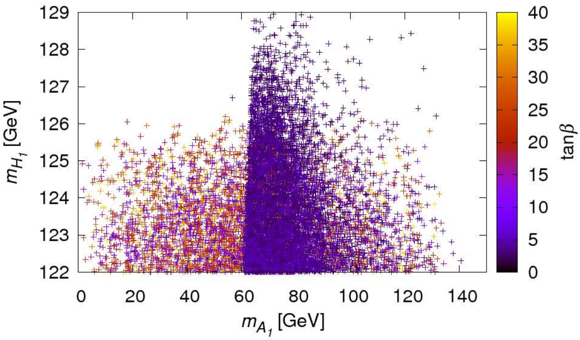
ATLAS: $\mu^{\gamma\gamma} = 1.57^{+0.33}_{-0.28}\,, \mu^{ZZ} = 1.44^{+0.40}_{-0.35}$.
CMS: $\mu^{\gamma\gamma} = 1.13 \pm 0.24\,, \mu^{ZZ} = 1.0 \pm 0.29$.

Parameter ranges

Bayesian scan using MultiNest,
see our paper 1409.8393 for details.

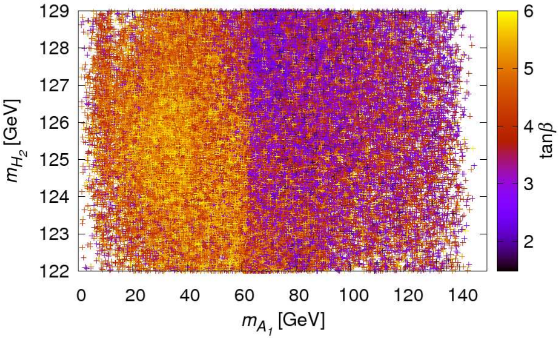
Parameter	Extended range	Reduced range
m_0 (GeV)	200 – 4000	200 – 2000
$m_{1/2}$ (GeV)	100 – 2000	100 – 1000
A_0 (GeV)	-5000 – 0	-3000 – 0
μ_{eff} (GeV)	100 – 2000	100 – 200
$\tan\beta$	1 – 40	1 – 6
λ	0.01 – 0.7	0.4 – 0.7
κ	0.01 – 0.7	0.01 – 0.7
A_λ (GeV)	-2000 – 2000	-500 – 500
A_κ (GeV)	-2000 – 2000	-500 – 500

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



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

Scan results $H_2 = H_{\rm SM}$



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

Outline

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.

Backgrounds

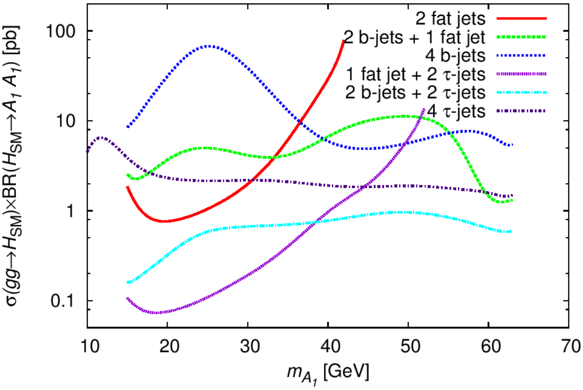
Irreducible backgrounds obtained from MadGraph.

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

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

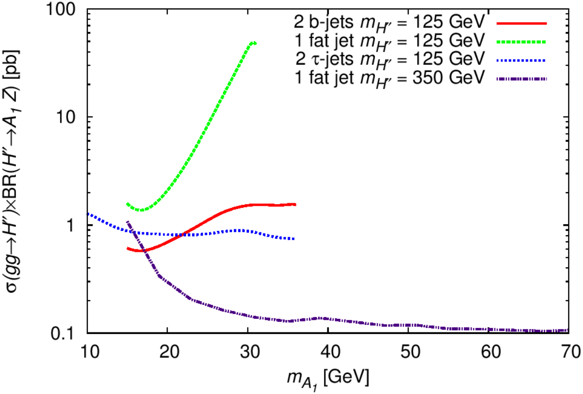
Jet substructure methods (0802.2470) used to find “fat jets” consisting of 2 b-jets.

Sensitivity $A_1 A_1$



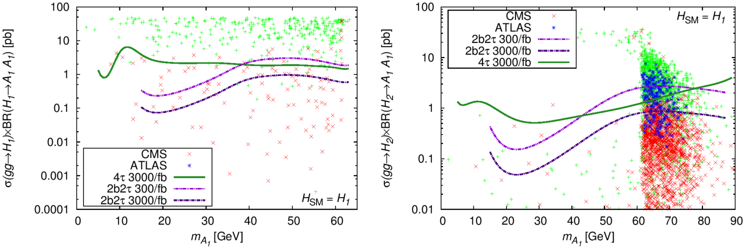
The $b\bar{b}\tau^+\tau^-$ channel most promising.

Sensitivity $A_1 Z$



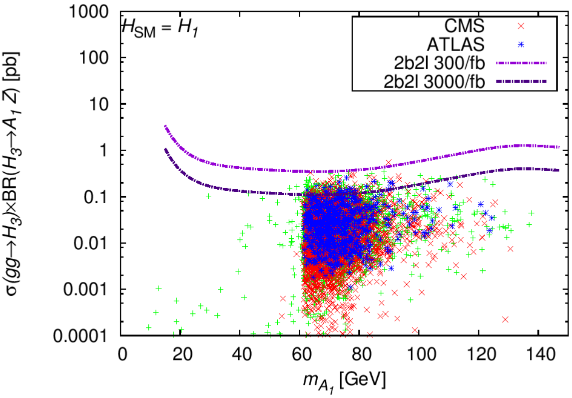
Most efficient for a heavier scalar.

Sensitivity in $A_1 A_1$ channel



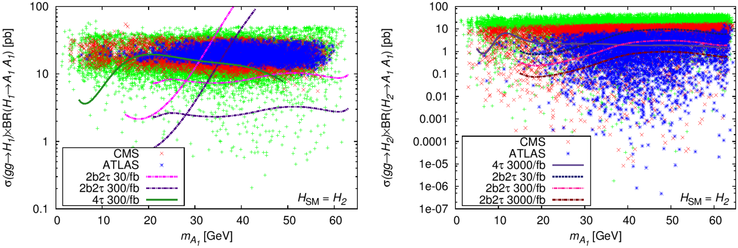
Some hope for detection but limited number of points.

Sensitivity in $A_1 Z$ channel



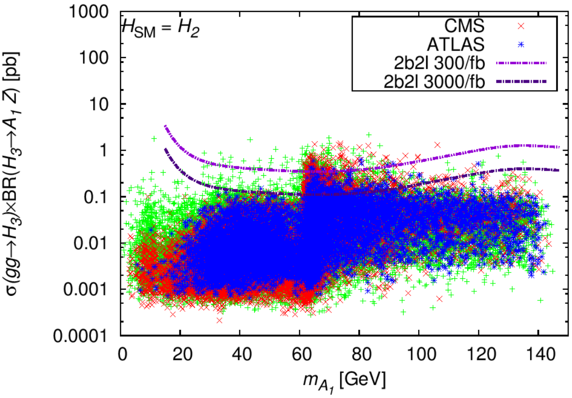
At least HL-LHC may discover something.

Sensitivity in $A_1 A_1$ channel



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

Sensitivity in $A_1 Z$ channel



Enough detectable points to motivate further study.

Outline

Detectability ranges

Production mode	Final states	Accessibility	Range (GeV)
$b\bar{b}A_1$	$4b$, $2b2\tau$	x	
$H_1 \to A_1A_1$ (H_1)	$4b$, $2b2\tau$, 4τ	✓ 300/fb	$m_{A_1} < 63$
$H_1 \to A_1A_1$ (H_2)	$4b$, $2b2\tau$, 4τ	✓ 30/fb	$m_{A_1} < 60$
$H_1 \to A_1Z$	$2b2\ell$, $2\tau2\ell$	x	
$H_2 \to A_1A_1$ (H_1)	$4b$, $2b2\tau$, 4τ	✓ 300/fb	$60 < m_{A_1} < 80$
$H_2 \to A_1A_1$ (H_2)	$4b$, $2b2\tau$, 4τ	✓ 30/fb	$m_{A_1} < 63$
$H_2 \to A_1Z$	$2b2\ell$, $2\tau2\ell$	x	
$H_3 \to A_1A_1$	$4b$, $2b2\tau$, 4τ	x	
$H_3 \to A_1Z$	$2b2\ell$, $2\tau2\ell$	✓ 300/fb	$60 < m_{A_1} < 120$

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 $H_3 \to A_1 Z$, 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 $\tan\beta$) the LHC will practically exclude $m_{A_1} < 60$ GeV.
- For somewhat heavier pseudoscalars, $H_3 \rightarrow A_1 Z$ is a very interesting channel.