Search for the lightest MSSM Higgs boson in cascades of supersymmetric particles in ATLAS

Eirik Gramstad

Experimental particle physics
Department of physics
University of Oslo

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- introduction
- lightest SUSY Higgs production
- Standard Model and SUSY background
- results
- conclusion

- Supersymmetry (SUSY) is one of the most believed *new physics* phenomena.
- need two Higgs doublets in MSSM:

$$H_u = \begin{pmatrix} h_u^+ \\ h_u^0 \end{pmatrix}, \quad H_d = \begin{pmatrix} h_d^- \\ h_d^0 \end{pmatrix},$$

  to give mass to up and down type fermions
- 8^o of freedom, so SUSY predicts 5 Higgs bosons
  - the lightest Higgs, h^0. $m_h < 135$ GeV
  - heavy CP-even Higgs, H^0
  - charged Higgs, $H^\pm$
  - CP-odd Higgs, A^0
- Ratio of vacuum expectation values (vev) of up and down field: $\tan\beta = v_u/v_d$
- gravity mediated soft SUSY breaking (mSUGRA)
  - described by five parameters at the GUT scale: common scalar (m_0) and gaugino mass ($m_{1/2}$), a common trilinear coupling (A_0) and the two Higgs parameters $\tan\beta$ and the sign of μ

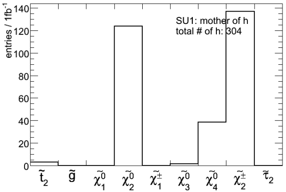
- the lightest Higgs is light (< 135 GeV) so $h^0 \to b\bar{b}$ dominates ($BR = 0.7 - 0.85$). The remaining is into $\tau^+\tau^-$
  - this motivates us to search for h^0 in SUSY cascade since the direct production (e.g. gluon-gluon fusion) will suffer from large QCD background
- most obvious channel is $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\, h$ (if open)
  - only dominant if $\tilde{\chi}_2^0 \to \tilde{l}l$ is inaccessible
  - $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\, h$ dominates $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\, Z$ due to the mostly gaugino like $\tilde{\chi}_2^0$ in mSUGRA
- also other Higgs production decays are possible
  - $\tilde{\chi}_{3,4}^0 \to \tilde{\chi}_{1,2}^0\, h$, although $\tilde{\chi}_{3,4}^0$ decays are mostly dominated by decays into $\tilde{\chi}_1^\pm$ and $W^\pm$
  - $\tilde{\chi}_2^\pm \to \tilde{\chi}_1^\pm\, h$, although $\tilde{\chi}_2^\pm$ decay are mostly dominated by decays into $\tilde{\chi}_2^0$ and $W^\pm$
  - also possible with $\tilde{t}_2 \to \tilde{t}_1\, h$ or $\tilde{\tau}_2 \to \tilde{\tau}_1\, h$

Two of the ATLAS benchmark points

	SU1	SU9
sparticle	**mass [GeV]**	
h^0	116	114
scalars	$\approx 570-760$	$\approx 730-950$
gluino	832	990
$\tilde{\chi}_1^0$ (LSP)	137	173
$\tilde{\chi}_2^0$	264	325
$\tilde{\chi}_{3,4}^0$	~ 480	~ 540
$\tilde{\chi}_1^\pm$	262	325
$\tilde{\chi}_2^\pm$	484	545
A_0	512	625
decay	**Branching Ratio [%]**	
$\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 h$	5	86
$\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 Z$	1	12
$\tilde{\chi}_2^\pm \rightarrow \tilde{\chi}_1^\pm h$	19	27
$\tilde{\chi}_2^\pm \rightarrow \tilde{\chi}_1^\pm Z$	25	22

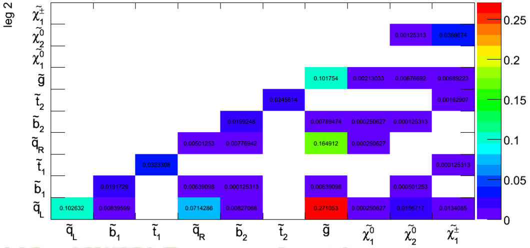
Two benchmark points are presented here
$(m_0, m_{1/2}, A_0, \tan\beta, sgn(\mu))$
SU1:
$(70, 350, 0, 10, +)$
SU9:
$(300, 425, 200, 20, +)$

mother of h^0



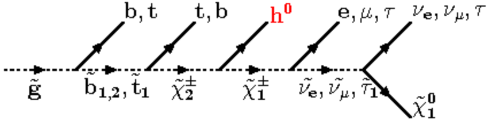
$$BR(\tilde{\chi}^\pm_2 \to \tilde{\chi}^\pm_1 h) = 0.19$$
$$BR(\tilde{\chi}^0_2 \to \tilde{\chi}^0_1 h) = 0.05$$
$$BR(\tilde{\chi}^0_3 \to \tilde{\chi}^0_1 h) = 0.02$$

initially produced sparticle pair (when h^0 prod.)



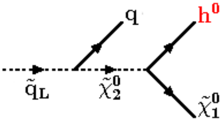
- mostly **g**lui**no** and light **s**quark production
- seldom production of **s**top and **s**bottom

main decay through $\tilde{\chi}_2^{\pm}$:



$BR = 0.014\,(\tilde{b}_{1,2}),\; BR = 0.004\,(\tilde{t}_1)$

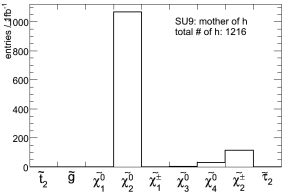
main decay through $\tilde{\chi}_2^0$:

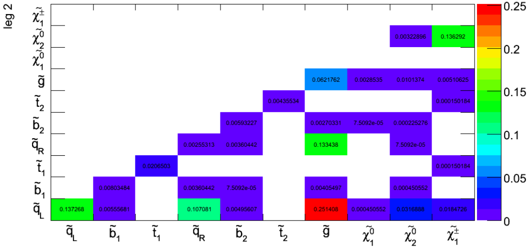


$BR = 0.030\,(\tilde{q}_L),\; BR = 0.017\,(\tilde{b}_{1,2}),\; BR = 0.007\,(\tilde{t}_1)$

initially produced sparticle pair (when h^0 prod.)

mother of h^0



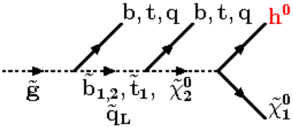


$$BR(\tilde{\chi}_2^\pm \to \tilde{\chi}_1^\pm h) = 0.22$$
$$BR(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 h) = 0.86$$

- mostly **gluino** and light **squark** production
- seldom production of **stop** and **sbottom**
- also initially production of $\tilde{\chi}_2^0$

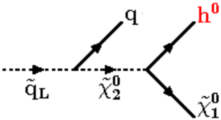
(almost) only h^0 production through $\tilde{\chi}_2^0$

long cascade:



$BR = 0.022\,(\tilde{q}_L)$, $BR = 0.007\,(\tilde{b}_{1,2})$, $BR = 0.036\,(\tilde{t}_1)$

short cascade:

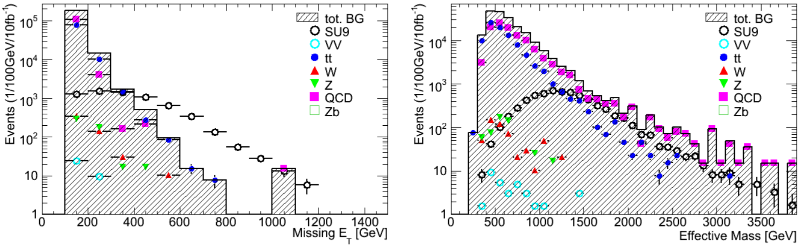


$BR = 0.82\,(\tilde{q}_L)$, $BR = 0.21\,(\tilde{b}_{1,2})$, $BR = 0.12\,(\tilde{t}_2)$

	SU1	SU9
number of Higgs ($\mathcal{L} = 1fb^{-1}$)	304	1216
typical final state	b or light jets, leptons, $\not{E}_T$	light jets, $\not{E}_T$

- Standard Model is not the biggest challenge, can be rejected by using the $\not{E}_T$ and effective mass:

$$M_{eff} = \sum_{i}^{N_{jets}} p_T^i + \not{E}_T .$$



..., however the SUSY background is problematic

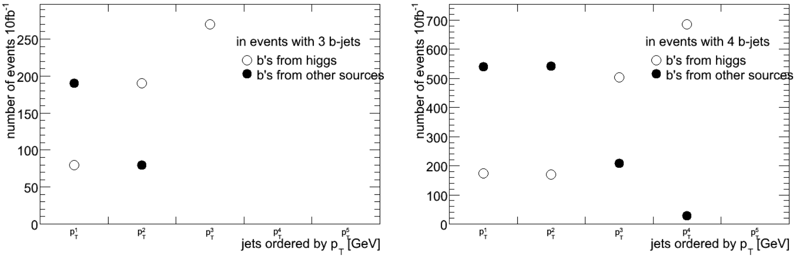
$$\tilde{g} \rightarrow b\,\tilde{b}_{1,2} \rightarrow b\,b\,\widetilde{\chi}^0_{1,2,3,4}$$
$$\tilde{g} \rightarrow b\,\tilde{b}_{1,2} \rightarrow b\,t\,\widetilde{\chi}^{\pm}_{1,2}$$
$$\tilde{g} \rightarrow t\,\tilde{t}_1 \rightarrow t\,b\,\widetilde{\chi}^{\pm}_{1,2}$$
$$\tilde{g} \rightarrow t\,\tilde{t}_1 \rightarrow t\,t\,\widetilde{\chi}^0_{1,2,3,4}$$

- also b-jets from $W^{\pm}$ and Z-decays
- since all SUSY events contain two LSPs, $\not{E}_T$ can not be used to reduce SUSY background
- in case of $SU9$ a lepton veto could be efficient, remove some of the background, both SM and SUSY
- ... however; not good for SU1

lepton veto after cuts: $\not{E}_T > 100$ GeV and ≥ 2 jets, $p_T^{1/2} > 100/50$:

$\mathcal{L} = 10fb^-1$	$SU1$		$SU9$	
	S	B	S	B
no lep. veto	165	116875	1413	115030
lep. veto	101	95618	1121	94855
efficiency(ε),rejection(R)	0.6,0.18		0.80,0.18	

- there are often produced b-jets in SUSY cascades
- might have high p_T since they come from decays of heavy **s**quarks or glu**inos**



From this:

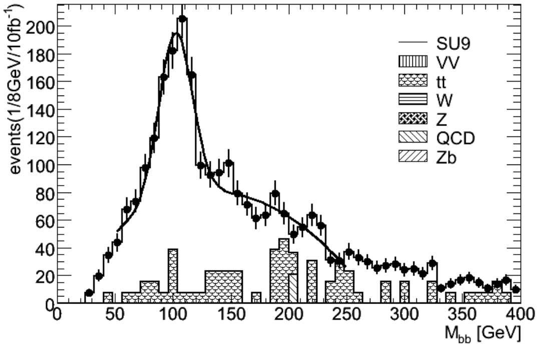
- omitting the hardest (and second hardest) b-jet(s) in events with 3 (> 3) b-jets we remove some of the wrong b-jet combinations in the M_{bb} calculation

Final cut used:

CUT #	VALUE
CUT 1	2 b-jets with $p_T^{1,2} > 50, 20$ GeV
CUT 2	omit hardest (and sec. hardest) b-jet in events with 3 ($>$ 3) b-jets from M_{bb} calculation
CUT 3	$\not{E}_T > 300$ GeV
CUT 4	$M_{\rm eff} > 800$ GeV
CUT 5	$\geq$ 2 additional jets $p_T^{1,2} > 100, 100$ GeV

***b*-tagging efficiency**: 60% $\Rightarrow$ efficiency of 36% per b-jet pair.

$\mathscr{L} = \mathbf{10fb}^{-1}$

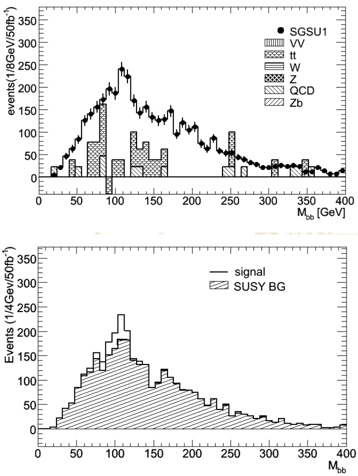


- have required the two additional jets to be light flavored
- see a clear signal above SUSY + SM background
- fitted with a Gaussian superimposed to a second degree polynomial

Number of events in $\pm 1\sigma$**:**

	signal	SUSY BG	SM BG	significance
events	681	777	426	15.1

$\mathscr{L} = 50\text{fb}^{-1}$



- have required one of the two additional jets to be b-jet
- more difficult to extract a resonance over the SUSY background
  - however in $SU1$ we see a signal with $\mathscr{L} = 50fb^{-1}$

- lightest MSSM Higgs boson is light (< 135 GeV) so $h \to b\bar{b}$ dominates
- when $\tilde{\chi}_2^0 \to \tilde{l}l$ is not kinematically allowed, $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 h$ dominates
    - if not: h^0 is produced mainly through chargino and heavy neutralino decays
        - these decays are never dominated by the decay into h^0, leading to few Higgses
- Standard Model background not the main challenge ($\not{E}_T$ and M_{eff})
- the SUSY events contain many b-jets and is the main background, some is removed by:
    - omit the hardest (and second hardest) b-jet in the M_{bb} calculation in events with 3 (> 3) b-jets
    - require more jets with specific flavors
- in all SUX samples except $SU9$ the $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 h$ is suppressed and to extract a Higgs resonance one will need high luminosity and/or more sophisticated methods