Search for Light NMSSM Higgs Boson Production in bb Final States with the CMS Experiment

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Outline

1. Introduction
2. Search strategy
3. Signal vs. background simulation studies
4. Trigger studies
5. Summary

Introduction

Motivation

- After observation of the 126 GeV signal, now emphasis in Higgs context is on investigation of the nature of the new boson
  - Structure of the Higgs sector
    - Standard Model (SM)?
    - Minimal Supersymmetric Standard Model (MSSM)?
    - Next-to-Minimal Supersymmetric Standard Model (NMSSM)?
    - . . . ?
  - Are we missing any light Higgs boson?

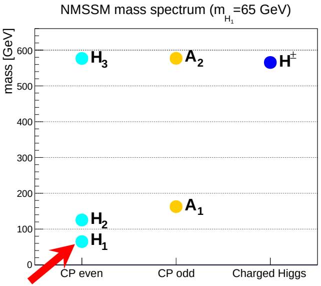
This study

- Search for "light" Higgs resonances, as e.g. possible in certain NMSSM scenarios
  - Lightest CP-even Higgs H_1
  - Decaying predominantly to bb
  - Not excluded by existing Higgs searches due to reduced couplings to gauge bosons

Extended Higgs sector in the NMSSM

NMSSM

- Simplest supersymmetric extension of MSSM
  - Additional singlet superfield
    - No gauge interactions
    - Interacts with itself and Higgs doublets
  - Resulting additional particles
    - 1 neutralino
    - 1 CP-odd Higgs
    - 1 CP-even Higgs
- Light Higgs scenarios may evade LEP constraints
- Offers a solution to the μ problem of the MSSM



μ problem of the MSSM

- $\mathcal{W}_{\mathrm{MSSM}} = \mu(\hat{H}_d \cdot \hat{H}_u) + \cdots$
- Natural scale of μ? M_{GUT}?
- EWSB yields a relation suggesting $\mu \sim M_W,\ M_Z$
- μ term created dynamically in the NMSSM

Modified "P4 benchmark scenario"

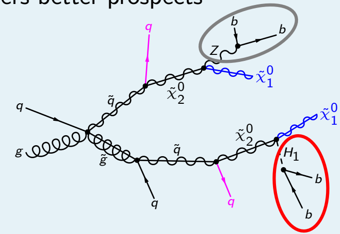
- Interesting NMSSM scenario pointed out by G. Weiglein, O. Stål [*JHEP* **1201**, 071 (2012)]
  - Lightest CP-even H_1 lighter than m_Z
    - "Signal" in this analysis
  - Second lightest CP-even H_2 is SM like
    - Can be identified with H(126 GeV)

Standard production channels (VBF, gluon fusion, associated production)

- In P4 scenario, production of H_1 is suppressed due to reduced couplings
  - Hard to find H_1, unless $H_2 \to H_1 H_1$ is kinematically allowed

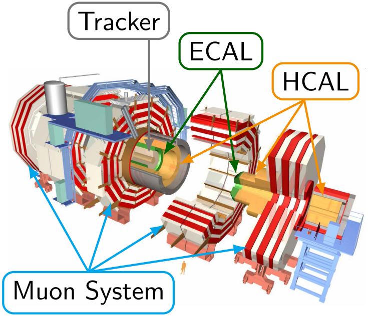
SUSY cascades

- Process related to $H_2 \to H_1 H_1$, where heavier neutralino (chargino) decays into lighter neutralino (chargino) and Higgs boson offers better prospects [1]
- Signature of squark/gluino cascade decays
  - Two hard light jets } Large H_T
  - Two b jets from H_1 decay } Large H_T
  - Large $\not\!\!E_T$ from LSPs
  - Small ΔR of the b jets due to boost from neutralino/chargino decay
  - Gives also rise to SUSY background
  - Main SM background: $t\bar{t}$, QCD



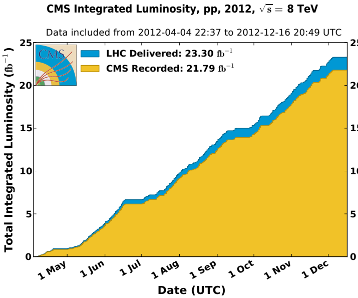
[1] O. Stål, G. Weiglein, Light NMSSM Higgs bosons in SUSY cascade decays at the LHC, *JHEP* **1201**, 071 (2012), 1108.0595.

The CMS Experiment

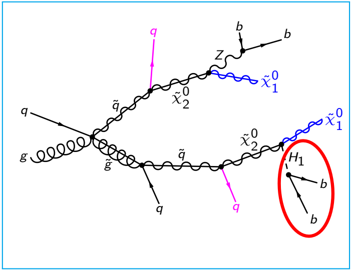


- CMS is one of the large multi-purpose experiments at the CERN LHC
  - Total weight: 12500 t
  - Overall diameter: 15 m
  - Overall length: 21.6 m
  - Magnetic field: 3.8 T

- Particle flow technique for optimised reconstruction of all particles in the event
  - Extensive combination of all CMS detector systems
- Recorded *pp* data at $\sqrt{s} = 8$ TeV: $\int \mathcal{L}dt = 21.79\ \mathrm{fb}^{-1}$



Baseline selection

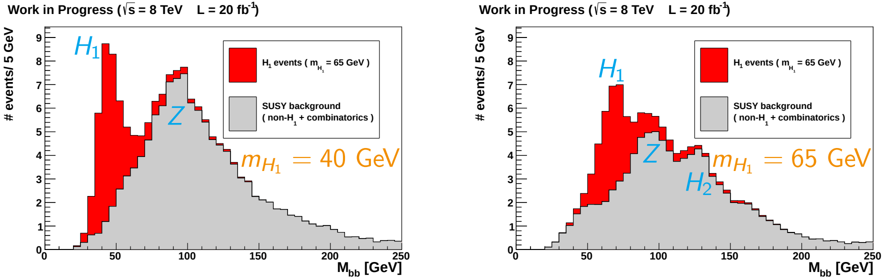


- Applied offline cuts (motivated by [2])
  - General cuts on jets
    - $p_\mathrm{T} > 25$ GeV
    - $|\eta| < 2.5$
  - Require minimum #jets
    - 2 light jets
    - 2 b jets
  - $p_\mathrm{T}^{\mathrm{Lead},1} > 250$ GeV
  - $p_\mathrm{T}^{\mathrm{Lead},2} > 100$ GeV

  } Considering only non-b tagged jets
  - $\not{E}_\mathrm{T} > 150$ GeV
  - $\min\left[\Delta R(bb)\right] < 1.5$
    - Exploits correlation of b jets emanating from H_1
- Select two b-jets with minimum ΔR

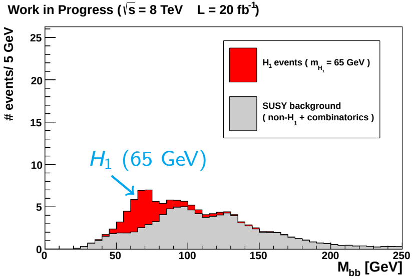
[2] O. Stål, G. Weiglein, Light NMSSM Higgs bosons in SUSY cascade decays at the LHC, *JHEP* **1201**, 071 (2012), 1108.0595.

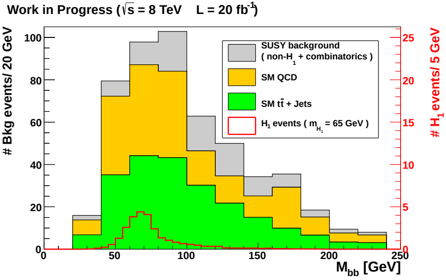
Signal studies



- Simulated squark-gluino production/decay
  - Used PYTHIA6 with NMSSM-specific input
    - Parameters, masses, branching ratios
- Colour coding
  - Signal $\rightarrow$ The selected b-jets stem from the same H_1
  - SUSY background $\rightarrow$ Non-H_1 events or combinatorial background
- Right plot has an additional peak in the background spectrum
  - $H_2 \rightarrow$ SM-like, decays predominantly into bb
  - Not visible in the left plot, since $H_2 \rightarrow H_1 H_1$ dominates over $H_2 \rightarrow bb$

Signal vs. background simulation studies





- Squark-Gluino events yield
  - H_1 signal
  - SUSY background
- Standard model backgrounds
  - $t\bar{t}$
  - QCD

  Rebinned due to limited statistics

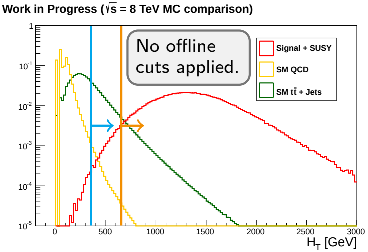
Signal vs. background simulation studies

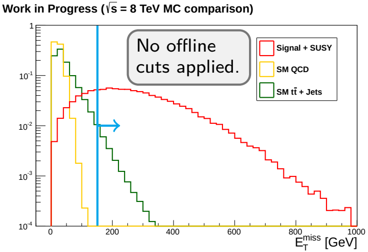
Expected event counts for $\int \mathcal{L} dt = 20\ \text{fb}^{-1}$

m_{H_1} [GeV]	N_{H_1}	$N_{\text{Non-}H_1}$	$N_{t\bar{t}}$	N_{QCD}	S/B	$S/\sqrt{B}$	$S/\sqrt{S+B}$
40	130	27	223	211	0.27	5.90	5.24
65	64	59	223	211	0.12	2.83	2.67
80	26	70	223	211	0.05	1.15	1.13

- Counted over the full mass range $\rightarrow M_{bb} \in [0, \infty)$
- With full 2012 statistics a statement about the existence of H_1 according to P4 scenario is within reach
- Outcome of the analysis will constrain NMSSM parameter space

Trigger studies





- Hadronic activity H_T
  - Scalar sum of all jet-$\vec{p}_T$
  - CMS triggers for 2012
    - Use particle flow methods
    - Correct for pile-up
- Missing transverse energy $\not{E}_T$
  - Magnitude of the vectorial sum of all jet–$\vec{p}_T$
  - CMS triggers for 2012
    - Use particle flow methods
- Considered trigger selection
  - $H_T > 650$ GeV
  - $H_T > 350$ GeV, $\not{E}_T > 100$ GeV
- Both are 100% efficient for signal relative to the current offline selection

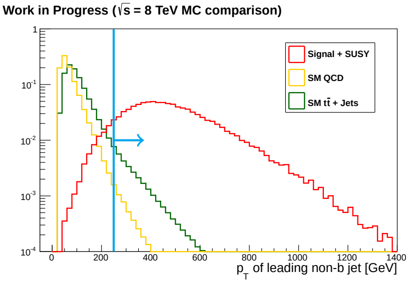
Summary

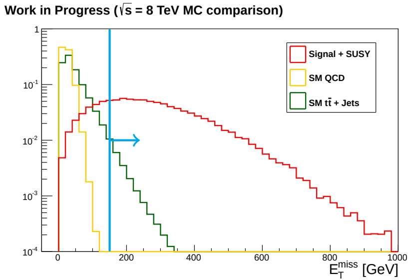
- This analysis searches for light Higgs bosons produced in SUSY cascades as feasible in certain NMSSM scenarios
- Initial studies of signal and background have been performed
- With the full 8 TeV data, reasonable sensitivity is expected
  - Foundation for future analysis at 13 TeV

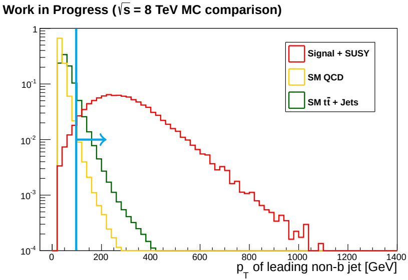
- Next steps
  - Optimization of selection and signal significance
  - Aim for further reduction of QCD background
  - Modelling of background and signal
  - Signal extraction

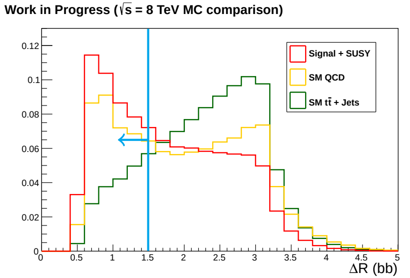
Back-Up

Kinematical distributions









Signal vs. background studies using simulation

- Counted over the full mass range ($M_{bb} \in [0, \infty]$)

SUSY background

m_{H_1} [GeV]	S/B	$S/\sqrt{B}$	$S/\sqrt{S+B}$
40	4.87	25.15	10.38
65	1.09	8.37	5.79
80	0.05	1.17	1.14

SUSY + $t\bar{t}$ background

m_{H_1} [GeV]	S/B	$S/\sqrt{B}$	$S/\sqrt{S+B}$
40	0.48	7.87	6.47
65	0.21	3.68	3.34
80	0.08	1.49	1.43

SUSY + QCD background

m_{H_1} [GeV]	S/B	$S/\sqrt{B}$	$S/\sqrt{S+B}$
40	0.59	8.76	6.94
65	0.26	4.05	3.61
80	0.10	1.63	1.56

SUSY + QCD + $t\bar{t}$ background

m_{H_1} [GeV]	S/B	$S/\sqrt{B}$	$S/\sqrt{S+B}$	
40	0.28	6.02	5.32	
65	0.13	2.88	2.71	**Favoured!**
80	0.05	1.17	1.14	

- With full 2012 statistics a statement about the existence of H_1 according to P4 scenario is within reach
- If no signal: Constrain NMSSM parameter space (A_κ)

Modified P4 scenario (Example parameter point)

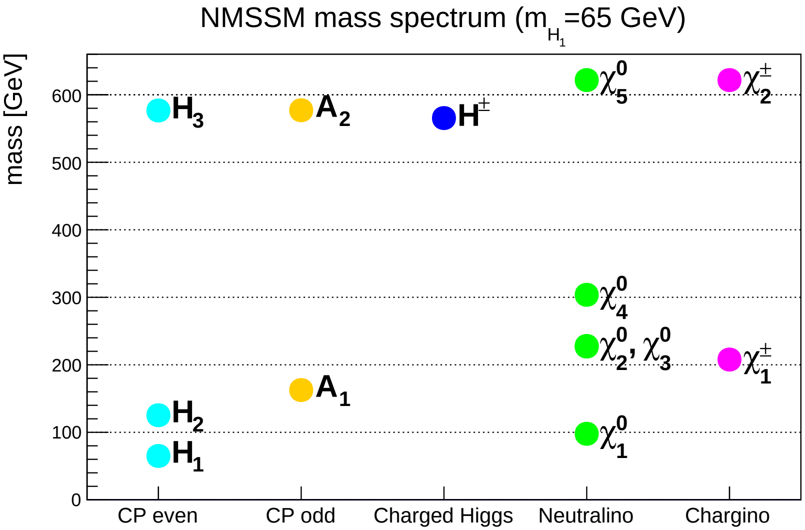
Higgs sector parameters

- $\tan\beta = 2.6$
- $\lambda = 0.6$
- $A_\lambda = -510$ GeV
- $\kappa = 0.12$
- $A_\kappa = 161$ GeV
- $\mu_{\text{eff}} = -200$ GeV

Higgs masses		Neutralino & Chargino masses	
M_{H_1}	65 GeV	$\tilde{\chi}_1^0$	98 GeV
M_{H_2}	125 GeV	$\tilde{\chi}_2^0$	227 GeV
M_{H_3}	577 GeV	$\tilde{\chi}_3^0$	228 GeV
M_{A_1}	163 GeV	$\tilde{\chi}_4^0$	304 GeV
M_{A_2}	577 GeV	$\tilde{\chi}_5^0$	622 GeV
$M_{H^\pm}$	566 GeV	$\tilde{\chi}_1^\pm$	208 GeV
		$\tilde{\chi}_2^\pm$	622 GeV

Non-Higgs sector parameters (as a reference)

M_1	300 GeV	A_t	1145 GeV	M_{SUSY}	1 TeV
M_2	600 GeV	A_b	1145 GeV		
M_3	1 TeV	A_τ	1145 GeV		


NMSSM mass spectrum (m_{H_1}=65 GeV)
mass [GeV]
0
100
200
300
400
500
600
H_3
A_2
$H^\pm$
χ_5^0
$\chi_2^\pm$
χ_4^0
χ_2^0, χ_3^0
$\chi_1^\pm$
A_1
H_2
H_1
χ_1^0
CP even
CP odd
Charged Higgs
Neutralino
Chargino

μ problem[3]

Problem

- $\mathcal{W}_{\text{MSSM}} = \mu(\hat{H}_d \cdot \hat{H}_u) + \cdots$
- Which is the natural scale of the dimensionful coupling μ?
  - Expected to be $\sim M_{\text{GUT}}$
  - But EWSB yields relation that suggests μ to be $\sim M_W$, M_Z

Solution: NMSSM

- Additional singlet superfield $\hat{S}$
- μ term created dynamically from $\mathcal{W}_{\text{NMSSM}} = \lambda\hat{S}(\hat{H}_d \cdot \hat{H}_u)$
  - Scalar component of $\hat{S}$ obtains a VEV: $\langle s \rangle = \frac{v_s}{\sqrt{2}}$
  - $\mathcal{W}_{\text{NMSSM}} = \lambda\hat{S}(\hat{H}_d \cdot \hat{H}_u) = -\mu_{\text{eff}}(\tilde{h}_d \cdot \tilde{h}_u) + \cdots$

[3] J. E. Kim, H. P. Nilles; The μ Problem and the Strong CP Problem; *Phys.Lett.* **B138**, 150 (1984).