

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

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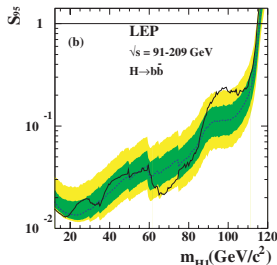
<sup>3</sup>now at Stockholm University (SU)

8th Annual Meeting of the Helmholtz Alliance “Physics at the Terascale”  
2 December 2014

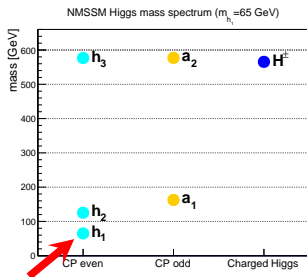


- ▶ The LHC could very well have access to light Higgs boson that were impossible to see at LEP
- ▶ Low Higgs mass range ( $m_h < m_Z$ ) is largely unexplored at the LHC
- ▶ Certain theoretical models predict light Higgs bosons which are not excluded by existing searches
  - Important condition: Accomodate  $\approx$  SM-like  $H(125)$
  - Disfavored in the MSSM by charged Higgs measurements
- ▶ This analysis is a search for light SUSY-Higgs resonances, as e.g. possible in certain NMSSM scenarios
- ▶ Using data recorded with the CMS experiment at  $\sqrt{s} = 8$  TeV during 2012 data taking

[Eur.Phys.J. C47, 547 (2006)]



- ▶ NMSSM is extension of the 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
- ▶ Offers a solution to the  $\mu$  problem of the MSSM



- ▶ How to accomplish light Higgs in accord with existing measurements?
  - Identify  $h_2$  with SM-like  $H(125)$  → Small singlet component
  - $h_1$  should have large singlet component to evade LEP constraints
- ▶ This is the idea of the modified P4 scenario of the NMSSM pointed out by G. Weiglein and O. Stål<sup>1</sup>

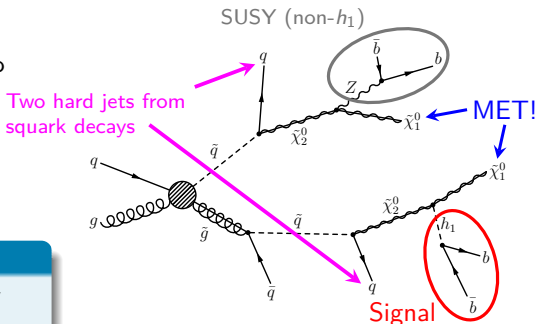
<sup>1</sup>O. Stål, G. Weiglein, Light NMSSM Higgs bosons in SUSY cascade decays at the LHC, *JHEP* **1201**, 071 (2012), 1108.0595.

# Event selection

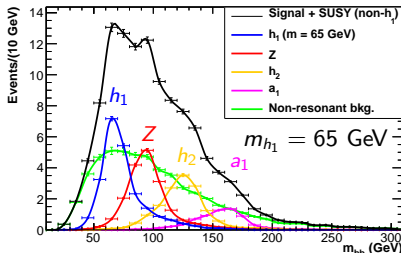
- ▶ Direct production of  $h_1$ ?
  - Suppressed due to reduced to gauge bosons and fermions
- ⇒ Search in SUSY cascades
- ▶ Signal
  - Peak in  $m_{bb}$  distribution at  $m_{h_1}$

## Event selection

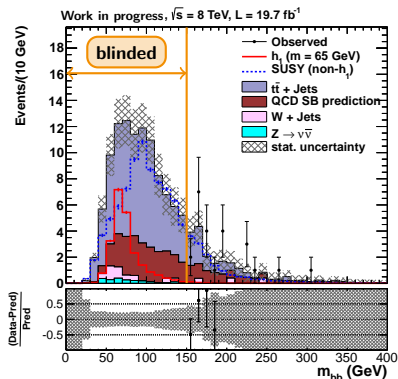
- ▶  $H_T$ -trigger with threshold of 650 GeV
- ▶  $H_T > 750$  GeV
- ▶ At least 4 jets (250,100,25,25)
- ▶ At least 2 b-tagged jets (not leading two)
- ▶ Select two b-tagged jets with minimal  $\Delta R(b_1, b_2)$
- ▶  $\min \Delta R(b_1, b_2) < 1.5$
- ▶  $\cancel{E}_T > 200$  GeV
- ▶  $\Delta\Phi(j_{1,2}, \cancel{E}_T) > 0.5 \Rightarrow$  QCD suppression



Work in progress,  $\sqrt{s} = 8$  TeV,  $L = 19.7$  fb $^{-1}$

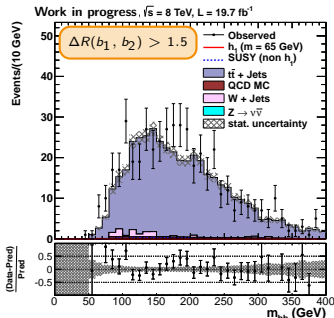
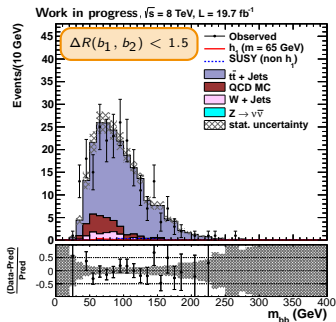


- ▶ Dominant background:  $t\bar{t} + \text{Jets}$ 
  - Normalization: NLO
    - ▶ Verified in control region
  - Shape: MC
- ▶ QCD Multijet
  - Normalization: data-driven
  - Shape: data-driven
- ▶ Minor backgrounds:  $Z \rightarrow \nu\bar{\nu}$  and  $W \rightarrow \ell\nu + \text{Jets}$ 
  - Normalization: NLO
  - Shape: MC



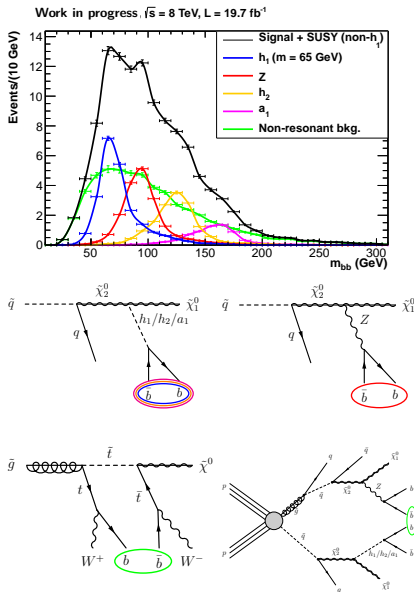


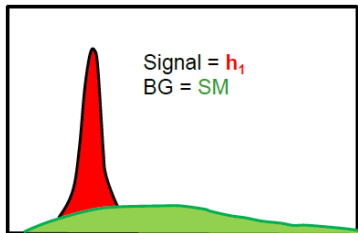
- ▶  $m_{bb}$  shape is taken from MC
- ▶ Normalization from NLO
  - Verified in control region
  - $E_T^{\text{miss}}$  sideband:  $E_T^{\text{miss}} = [50, 200] \text{ GeV} +$  one isolated lepton ( $e, \mu$ ) suppress QCD



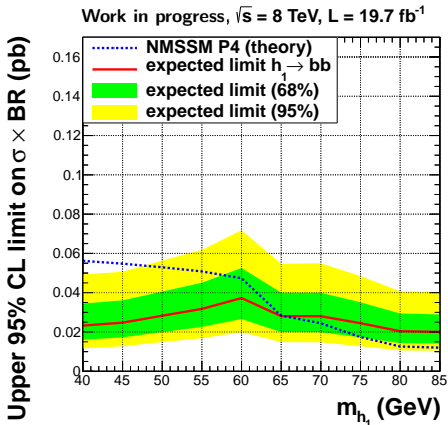
$t\bar{t}$  normalization  
from NLO  
consistent  
with data  
within errors

- ▶ Signal  $m_{bb}$  shape is modelled using NMSSM MC samples
  - Input created with NMSSMTools
  - PYTHIA6 used for event generation
- ▶ NMSSM contributions in the signal region
  - $h_1 \rightarrow b\bar{b}$
  - $Z \rightarrow b\bar{b}$
  - $h_2 \rightarrow b\bar{b}$
  - $a_1 \rightarrow b\bar{b}$
  - Non-resonant contributions
- ▶ Two approaches considered
  - Search for an  $h_1$ -peak over the SM expectations
  - Include non- $h_1$  contributions for NMSSM-specific interpretation



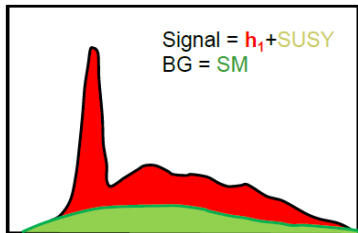


- ▶ Derived expected upper limits on  $\sigma(pp \rightarrow h_1 + X) \times BR(h_1 \rightarrow b\bar{b})$  in the mass range of 40 – 85 GeV
- ▶ Below 65 GeV our limits undershoot the light Higgs production predicted by the modified P4 scenario

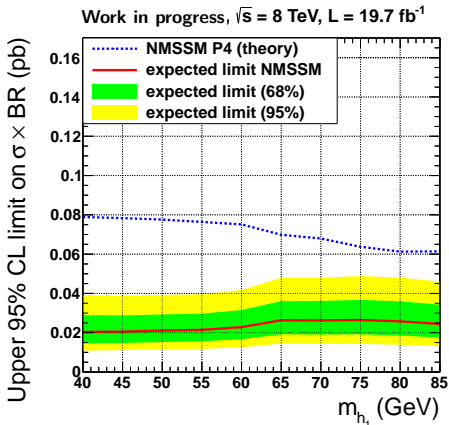


- ▶ Since the analysis is still blinded, only expected limits are shown





- ▶ Derived expected upper limits using also non- $h_1$  contributions to the  $m(b_1, b_2)$ -spectrum
  - Model-dependent interpretation within the NMSSM P4 scenario
- ▶ Analysis is sensitive to the modified NMSSM P4 scenario with a scale of 1 TeV for coloured SUSY particles

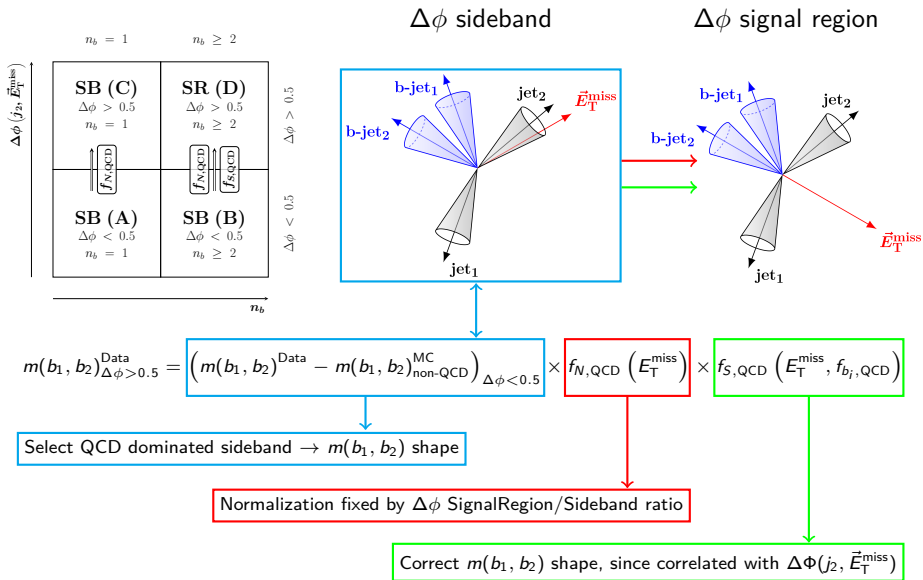


- ▶ Since the analysis is still blinded, only expected limits are shown



- ▶ Presented a promising light-Higgs search
  - Probing a theoretically well motivated Higgs mass range which is to date unexplored at the LHC
- ▶ Sensitivity is estimated in terms of upper limits
  - On topological cross section  $\sigma(pp \rightarrow h_1 + X) \times \text{BR}(h_1 \rightarrow b\bar{b})$
  - Within the modified NMSSM P4 scenario
  - In a detailed scan within the decoupled squarks scenario (not shown)
- ▶ Analysis sensitivity is in the range of the NMSSM P4 scenario with  $M_3 = M_{\text{SUSY}} = 1 \text{ TeV}$
- ▶ The analysis is still blinded
  - Entering CMS approval procedure
- ▶ Expect even higher sensitivity in the upcoming Run II at 13 TeV

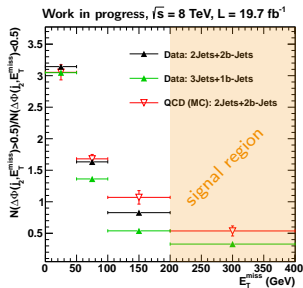
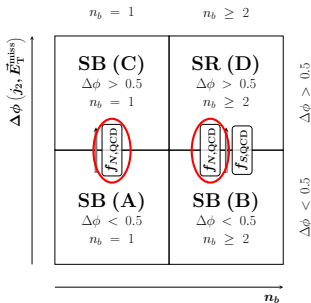
Back-Up



# QCD Multijet background – Normalization factor

$$m(b_1, b_2)_{\Delta\phi > 0.5}^{\text{Data}} = \left( m(b_1, b_2)^{\text{Data}} - m(b_1, b_2)^{\text{MC}}_{\text{non-QCD}} \right)_{\Delta\phi < 0.5} \times f_{N,\text{QCD}}(E_T^{\text{miss}}) \times f_{S,\text{QCD}}(E_T^{\text{miss}}, f_{b_i,\text{QCD}})$$

Normalization fixed by  $\Delta\phi$  SignalRegion/Sideband ratio



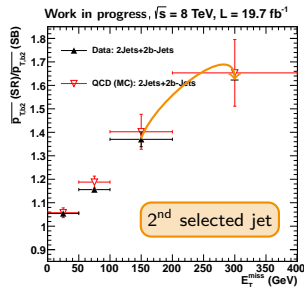
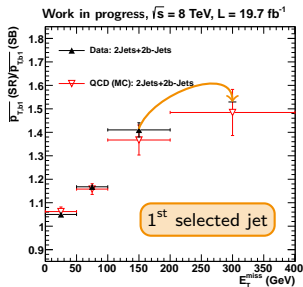
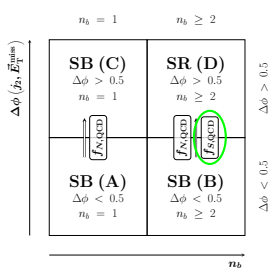
$$f_{N,\text{QCD}} = \frac{\# \text{Events with } \Delta\phi > 0.5}{\# \text{Events with } \Delta\phi < 0.5}, \quad n_b = 1$$

- ▶  $f_{N,\text{QCD}}$  measured in **single-b sample**
  - b-jet is paired with 3rd untagged jet
  - All other cuts applied
- ▶ Maximum deviation of  $f_{N,\text{QCD}}(n_b = 1)$  and  $f_{N,\text{QCD}}(n_b \geq 2)$  in  $E_T^{\text{miss}}$  bins  $< 200 \text{ GeV}$  is used as systematic uncertainty on the normalization

# QCD Multijet background – Shape correction

$$m(b_1, b_2)_{\Delta\phi > 0.5}^{\text{Data}} = \left( m(b_1, b_2)^{\text{Data}} - m(b_1, b_2)^{\text{MC}_{\text{non-QCD}}} \right)_{\Delta\phi < 0.5} \times f_{N, \text{QCD}}(E_T^{\text{miss}}) \times f_{S, \text{QCD}}(E_T^{\text{miss}}, f_{b_i, \text{QCD}})$$

Correct  $m(b_1, b_2)$  shape, since correlated with  $\Delta\Phi(j_2, \vec{E}_T^{\text{miss}})$



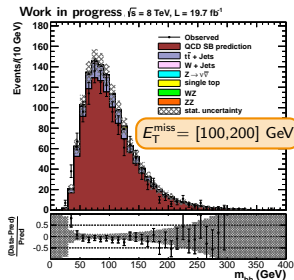
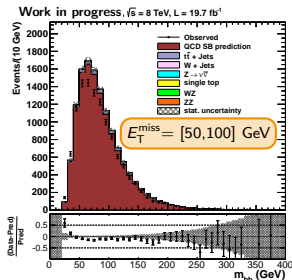
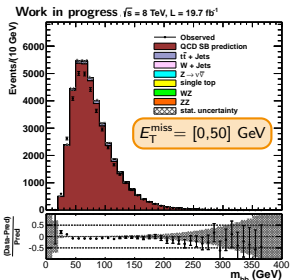
$$f_{b_i, \text{QCD}} = \frac{\overline{p_{T, b_i}}(\# \text{Events with } \Delta\phi > 0.5)}{\overline{p_{T, b_i}}(\# \text{Events with } \Delta\phi < 0.5)}$$

- ▶  $f_{b_i, \text{QCD}}$  applied as scale factor on the two b-tagged jets
  - Correction factor for data and  $E_T^{\text{miss}} > 200 \text{ GeV}$  is **extrapolated from QCD MC**
- ▶ Uncertainty of these correction factors is taken into account as shape uncertainty

# Validation in low- $E_T^{\text{miss}}$ control region

$$m(b_1, b_2)_{\Delta\phi > 0.5}^{\text{Data}} = \left( m(b_1, b_2)_{\Delta\phi < 0.5}^{\text{Data}} - m(b_1, b_2)_{\Delta\phi < 0.5}^{\text{MC}_{\text{non-QCD}}} \right) \times f_{S, \text{QCD}}(E_T^{\text{miss}}, f_{b_i, \text{QCD}}) \times f_{N, \text{QCD}}(E_T^{\text{miss}})$$

Closure test of the method in low MET region ( $\cancel{E}_T < 200$  GeV)  
(veto isolated leptons, highly QCD dominated)



- The  $m_{bb}$  shape is well described by the method in the QCD enriched control regions



# $t\bar{t}$ control distributions

