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

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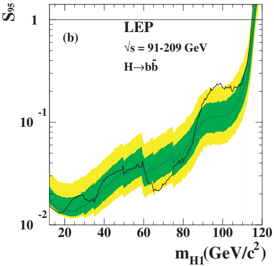
Motivation

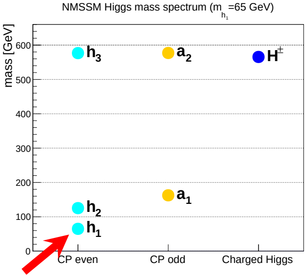
- The LHC could very well have access to light Higgs boson that were impossible to see at LEP
- Low Higgs mass range ($m_h < m_Z$) is largely unexplored at the LHC
- Certain theoretical models predict light Higgs bosons which are not excluded by existing searches
  - Important condition: Accomodate ≈ 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)]



Extended Higgs sector in the NMSSM

- 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 μ problem of the MSSM



- How to accomplish light Higgs in accord with existing measurements?
  - Identify h_2 with SM-like $H(125)$ $\rightarrow$ Small singlet component
  - h_1 should have large singlet component to evade LEP constraints

$\Rightarrow$ This is the idea of the modified P4 scenario of the NMSSM pointed out by G. Weiglein and O. Stål[1]

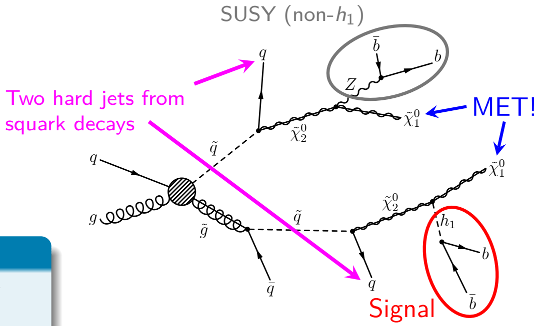
[1] O. Stål, G. Weiglein, Light NMSSM Higgs bosons in SUSY cascade decays at the LHC, *JHEP* **1201**, 071 (2012), 1108.0595.

Event selection

- Direct production of h_1?
  - Suppressed due to reduced couplings to gauge bosons and fermions

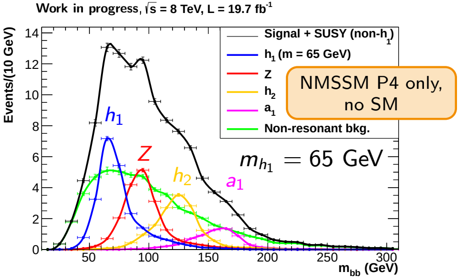
⇒ Search in SUSY cascades

- Signal
  - Peak in m_{bb} distribution at m_{h_1}



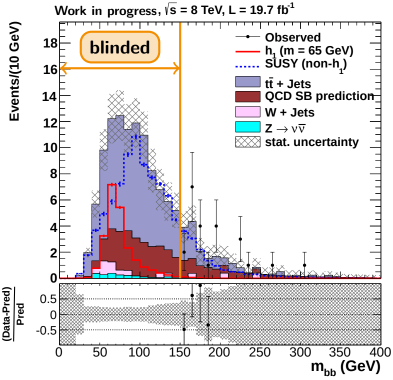
Event selection

- 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 $\Delta R(b_1, b_2) < 1.5$
- $\not{E}_T > 200$ GeV
- $\Delta\Phi(j_{1,2}, \not{E}_T) > 0.5 \Rightarrow$ QCD suppression



Background estimation

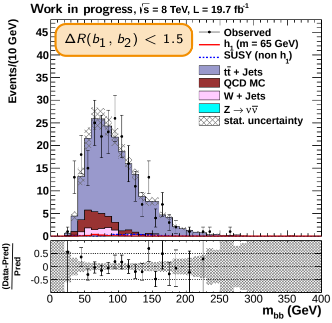
- Dominant background: $t\bar{t}$ +Jets
  - Normalization: NLO
  - Shape: MC
  - Verified in control region
- QCD Multijet
  - Normalization: data-driven
  - Shape: data-driven
  - Not shown, due to lack of time
- Minor backgrounds: $Z \to \nu\bar{\nu}$ and $W \to \ell\nu$+Jets
  - Normalization: NLO
  - Shape: MC

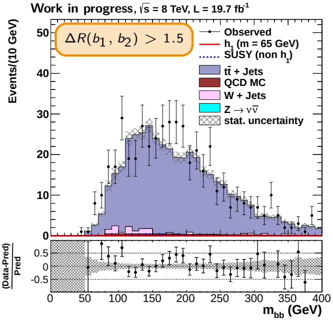


$t\bar{t}$ background

- Dominant background shown to exemplify background estimation
- m_{bb} shape is taken from MC
- Normalization from NLO
  - Verified in control region
  - E_T^{miss} sideband: $E_T^{miss} = [50,200]$ GeV + one isolated lepton (e, μ)

suppress QCD

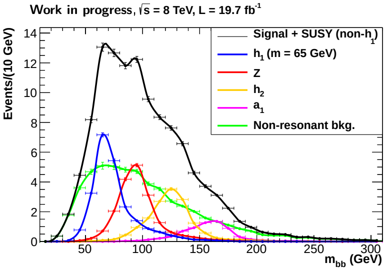


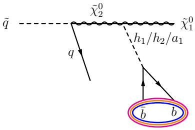


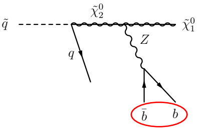
$t\bar{t}$ normalization from NLO consistent with data within errors

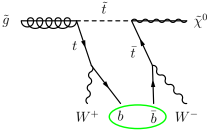
Signal modelling

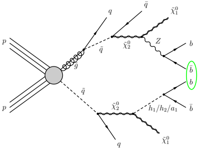
- Signal m_{bb} shape is modelled using NMSSM MC samples
  - Input created with NMSSMTools
  - PYTHIA6 used for event generation
- NMSSM contributions in the signal region
  - $h_1 \to b\bar{b}$
  - $Z \to b\bar{b}$
  - $h_2 \to b\bar{b}$
  - $a_1 \to b\bar{b}$
  - Non-resonant contributions
- Two approaches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

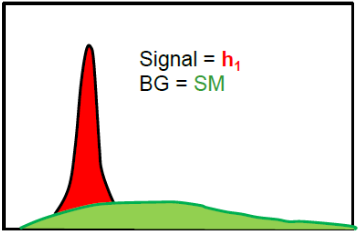


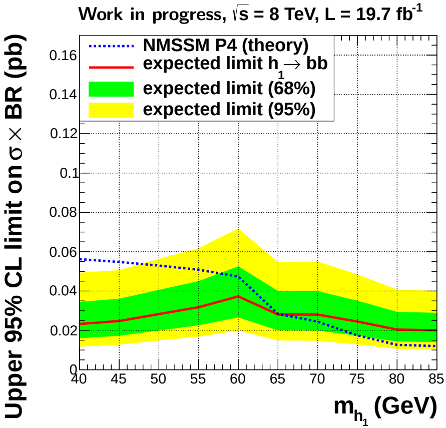








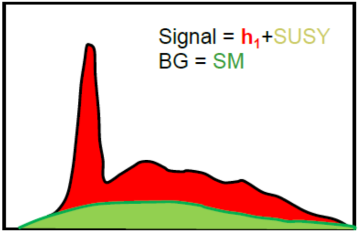




- Derived expected upper limits on $\sigma(pp \to h_1 + X) \times \mathrm{BR}(h_1 \to b\bar{b})$ in the mass range of $40 - 85$ GeV

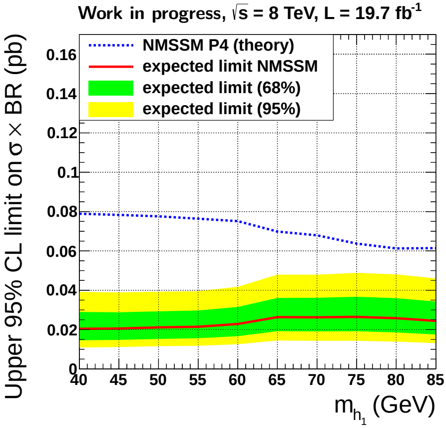
$\Rightarrow$ Below 65 GeV our limits undershoot the light Higgs production predicted by the modified P4 scenario

- 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



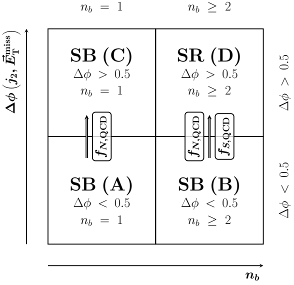
- Since the analysis is still blinded, only expected limits are shown

Summary

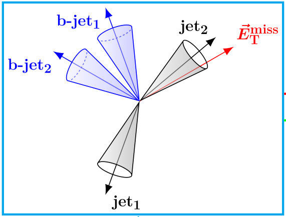
- Promising light-Higgs search
  - Probing a theoretically well motivated Higgs mass range which is to date unexplored at the LHC
- Sensitivity is estimated in terms of upper limits
  - On topological cross section $\sigma(pp \to h_1 + X) \times \mathrm{BR}(h_1 \to b\bar{b})$
  - Within the modified 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 $M_3 = M_{\mathrm{SUSY}} = 1$ TeV
- The analysis is still blinded
  - Entered CMS approval procedure
- Novel results using 8 TeV data will be public soon
  - Expect even higher sensitivity in the upcoming Run II at 13 TeV

Back-Up

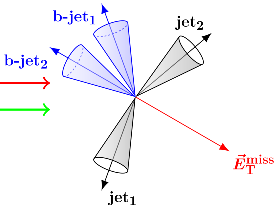
QCD Multijet background



$\Delta\phi$ sideband



$\Delta\phi$ signal region



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

Select QCD dominated sideband $\rightarrow$ $m(b_1, b_2)$ shape

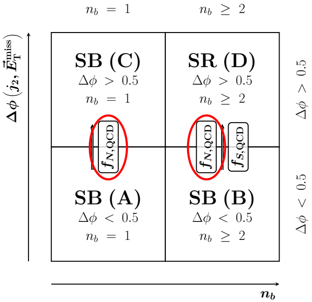
Normalization fixed by $\Delta\phi$ SignalRegion/Sideband ratio

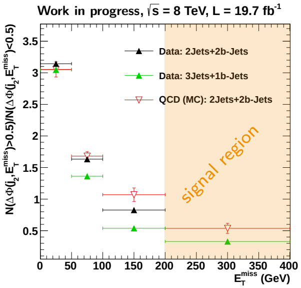
Correct $m(b_1, b_2)$ shape, since correlated with $\Delta\Phi(j_2, \vec{E}_T^{\text{miss}})$

QCD Multijet background – Normalization factor

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

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





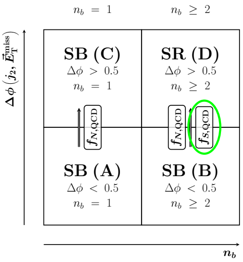
$$f_{N,\text{QCD}} = \frac{\#\text{Events with } \Delta\phi > 0.5}{\#\text{Events with } \Delta\phi < 0.5}, \quad n_b = 1$$

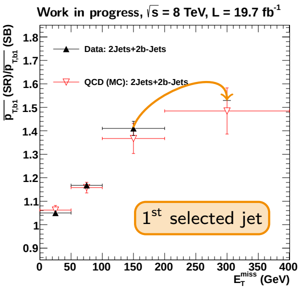
- $f_{N,\text{QCD}}$ measured in single-b sample
  - b-jet is paired with 3rd untagged jet
  - All other cuts applied
- Maximum deviation of $f_{N,\text{QCD}}(n_b = 1)$ and $f_{N,\text{QCD}}(n_b \geq 2)$ in E_T^{miss} bins < 200 GeV is used as systematic uncertainty on the normalization

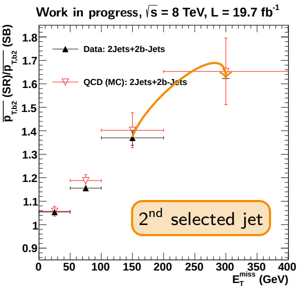
QCD Multijet background – Shape correction

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

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







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

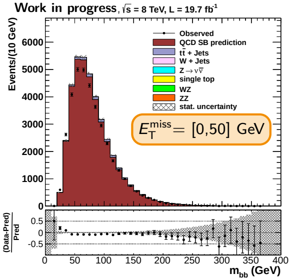
- $f_{b_i,\mathrm{QCD}}$ applied as scale factor on the two b-tagged jets
  - Correction factor for data and $E_T^{\mathrm{miss}} > 200$ GeV is extrapolated from QCD MC
- Uncertainty of these correction factors is taken into account as shape uncertainty

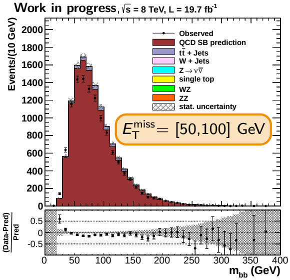
Validation in low-E_T^{miss} control region

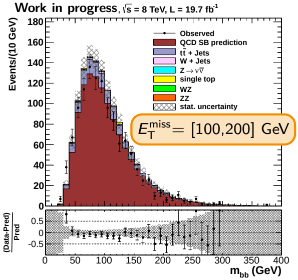
$$m(b_1,b_2)^{\mathrm{Data}}_{\Delta\phi>0.5} = \left(m(b_1,b_2)^{\mathrm{Data}} - m(b_1,b_2)^{\mathrm{MC}}_{\text{non-QCD}}\right)_{\Delta\phi<0.5} \times f_{S,\mathrm{QCD}}\left(E_T^{miss}, f_{b_j,\mathrm{QCD}}\right) \times f_{N,\mathrm{QCD}}\left(E_T^{miss}\right)$$

Closure test of the method in low MET region ($\not{E}_T < 200$ 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