

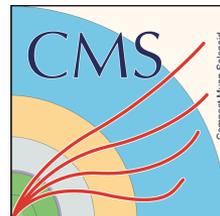
(N)MSSM $H \rightarrow b\bar{b}$ Searches at CMS

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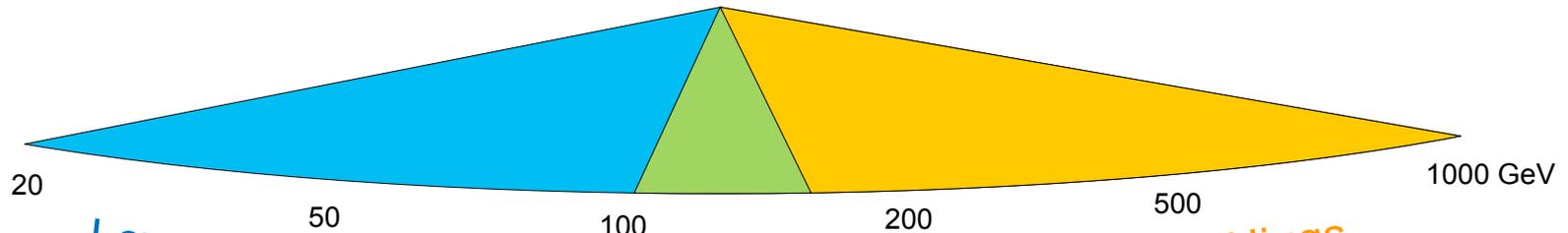
9th Annual Helmholtz Alliance Workshop on "Physics at the Terascale"

Hamburg, 18 November 2015



Model	Structure	CP-even	CP-odd	Charged
MSSM	2 doublets	h, H	A	H^\pm
NMSSM	2 doublets+1 singlet	h_1, h_2, h_3	a_1, a_2	h^\pm

$(h, H, A) \equiv \phi$



Low mass Higgs

H(125)

High mass Higgs

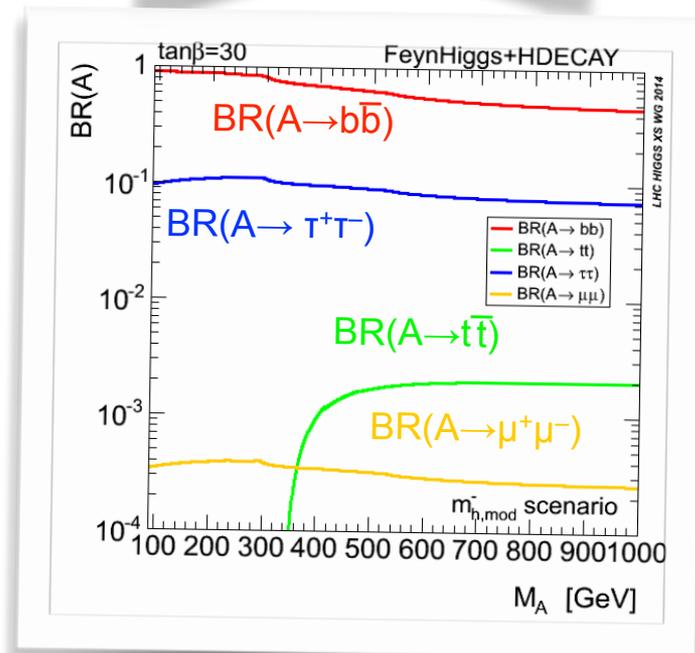
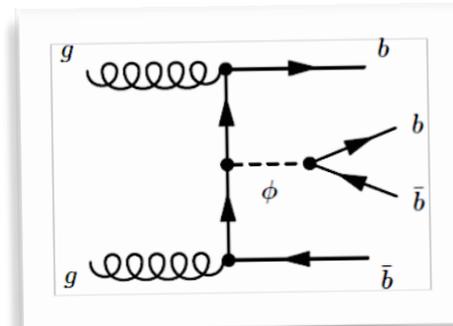
NMSSM, if existing constraints (LEP...) are avoided

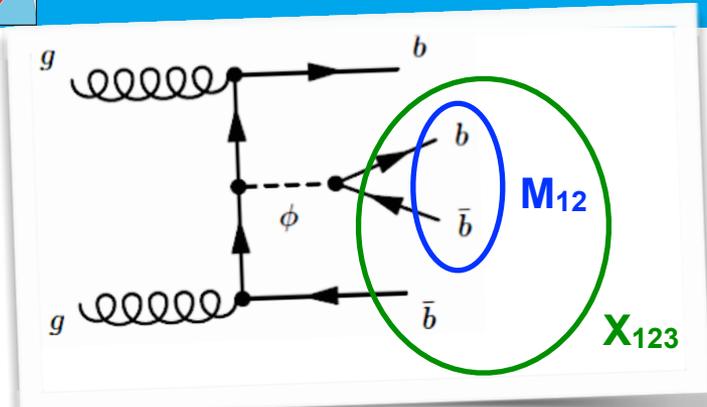
found!
 $\equiv h$ (MSSM) ?
 $\equiv h_1$ or h_2 (NMSSM) ?

(N)MSSM at large $\tan \beta$

In most scenarios the dominant decay channel of new Higgs bosons is $b\bar{b}$!

- > Search for degenerate H and A bosons.
 - > $h \equiv H(125)$ (favoured)
 - > Dominant decay channel: $H/A \rightarrow b\bar{b}$
 - > **b-associated production:**
 - > Cross section enhanced by $\sim 2 \tan^2\beta$;
 - > Better control of background
- > Huge rates from multi-jet events!
 - > Main background: **multi-jet QCD**
 - > **Dedicated trigger needed:**
 - > At least two high- p_T jets;
 - > At least two online b-tags



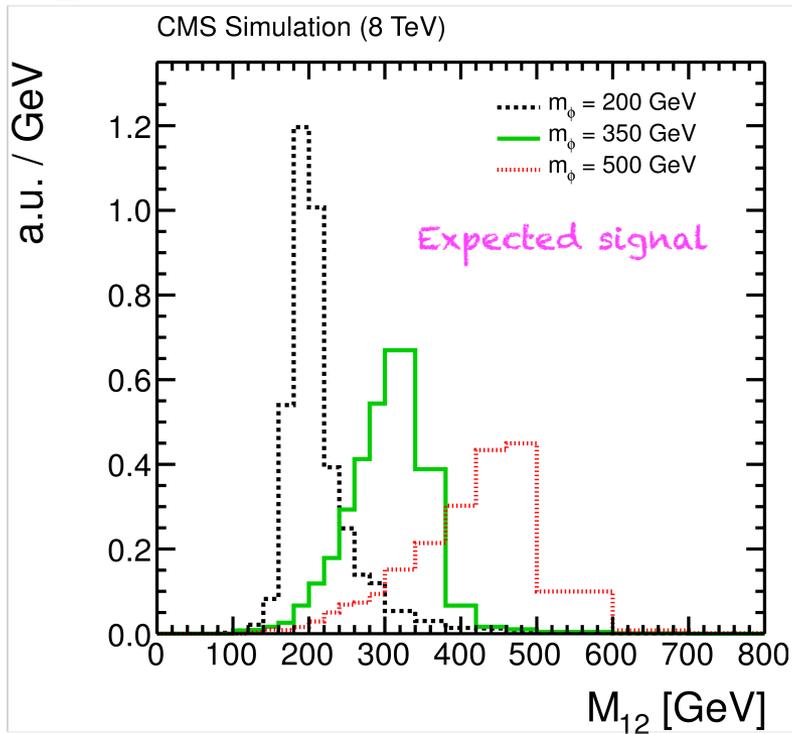


Analysis at 8 TeV

- > Three leading jets must satisfy:
 - > $p_T > (80, 70, 20)$ GeV;
 - $|\eta| < (1.65, 1.65, 2.2)$; $|\Delta\eta_{12}| < 1.4$
 - > tight **b-tag** selection (0.1% mistag)

- > Signal \rightarrow peak in the invariant mass M_{12} of the two leading jets
 - > Signal templates from MC

- > $X_{123} \rightarrow$ additional variable in the fit
 - > Event-wise b-tag estimator from the secondary vertex mass sum of the three leading jets

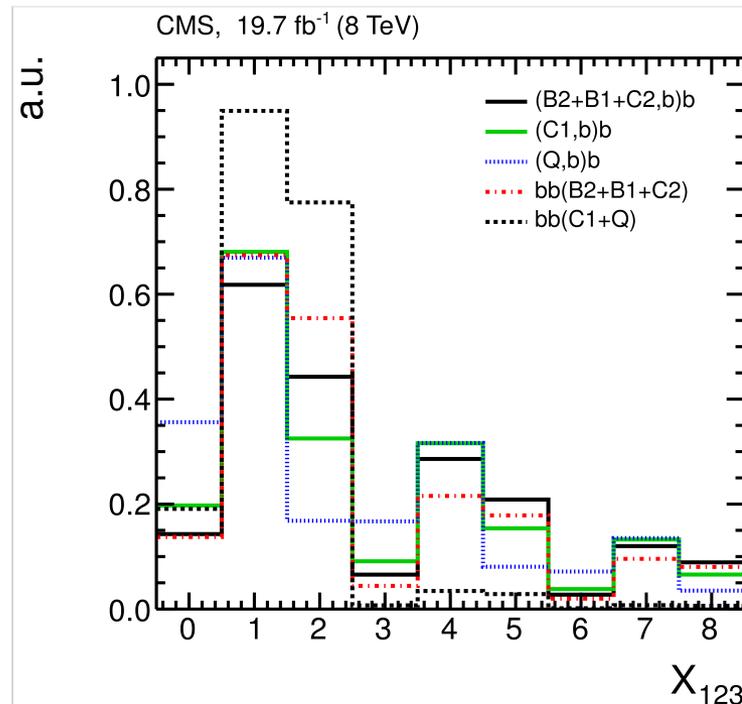
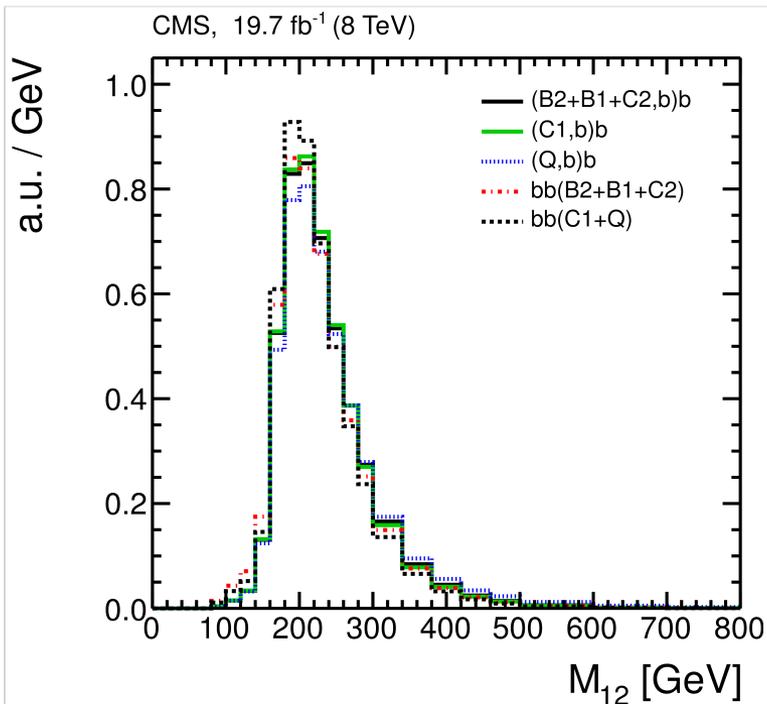


Background templates and signal extraction

- Templates for each flavour composition from **2 b-tag sample**
 - Weighted by b-tag probability of un-tagged jet
 - 5 distinct background templates
 - Binned maximum likelihood 2D fit (M_{12} , X_{123}) of the templates to the data

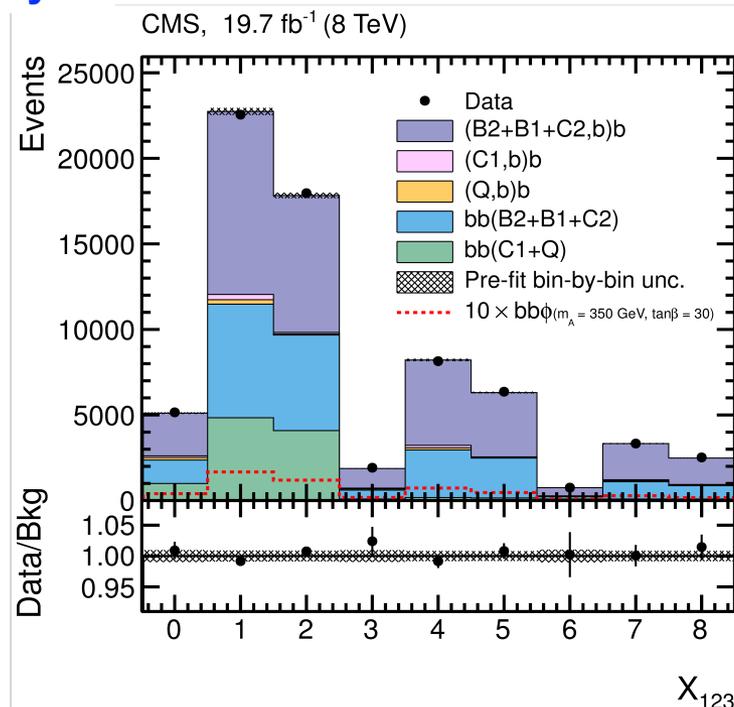
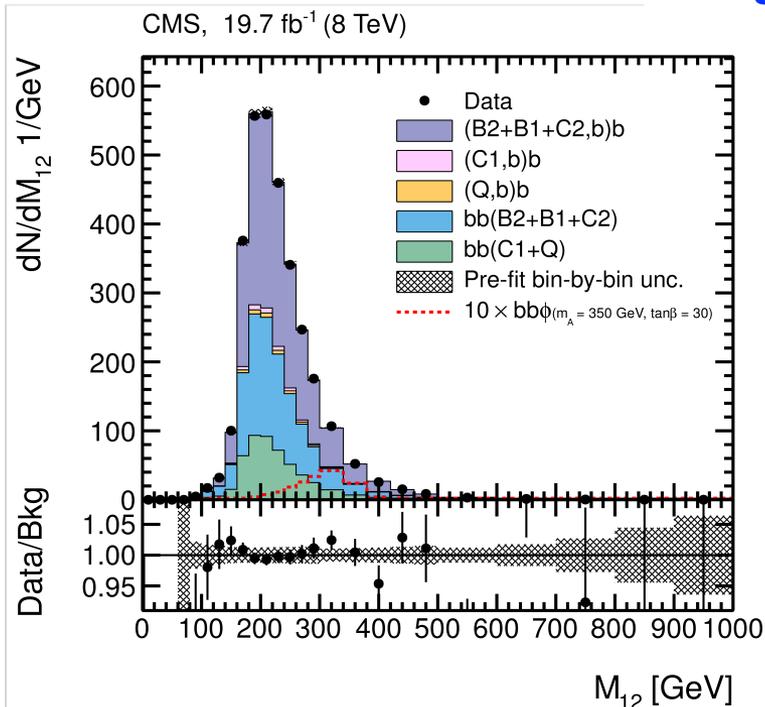
Flavour definitions

B1	b
B2	bb (merged)
C1	c
C2	cc (merged)
Q	udsg



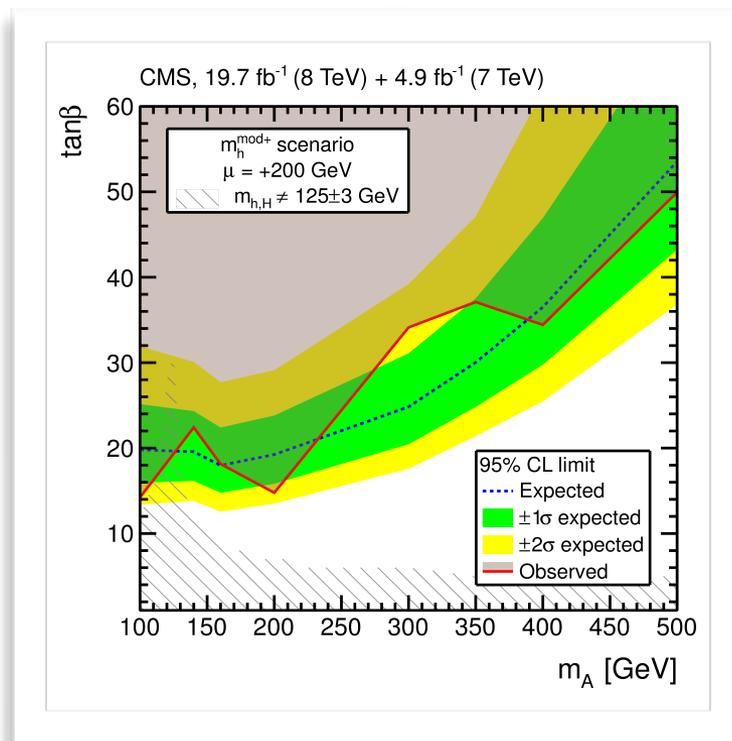
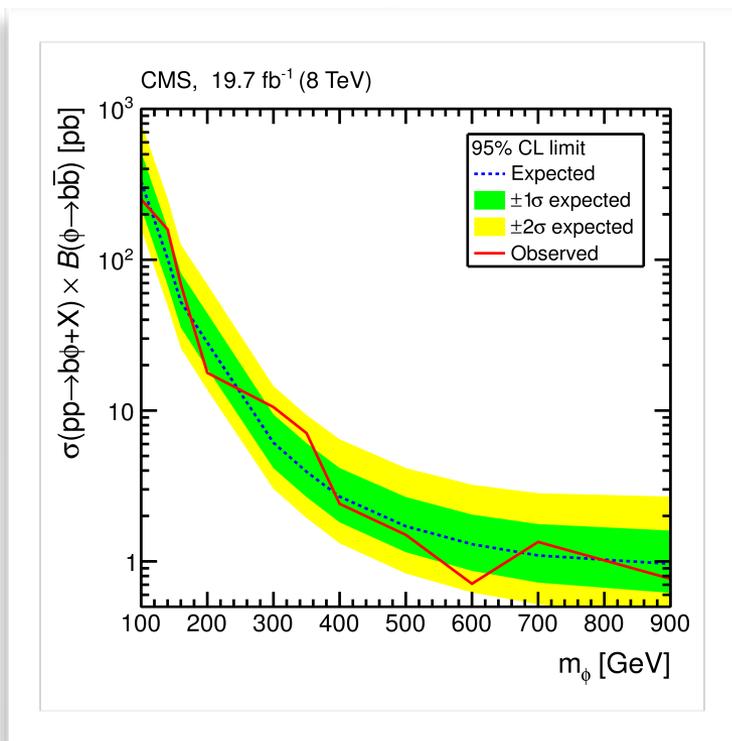
Fit results

background-only fit



- Background fits perfectly to the data → No evidence of signal 🙄
- Background from triple b-jets is dominant (~80%), as expected.

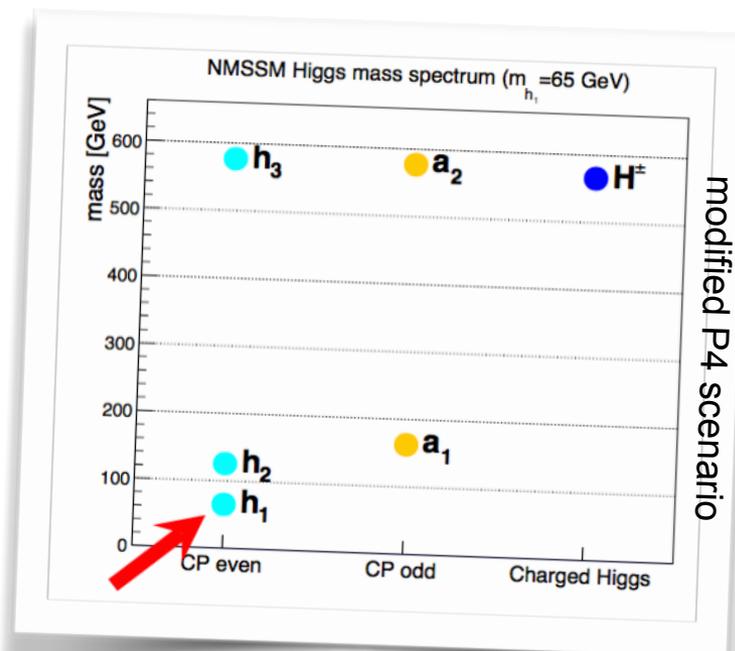
Upper Limits



- Largest systematic uncertainty from b-tagging.
- Upper limits on $\tan\beta$ from 14–50, significant improvement wrt 7 TeV analysis.
- World's best limits and the only LHC measurement in this channel!

CMS-HIG-14-030

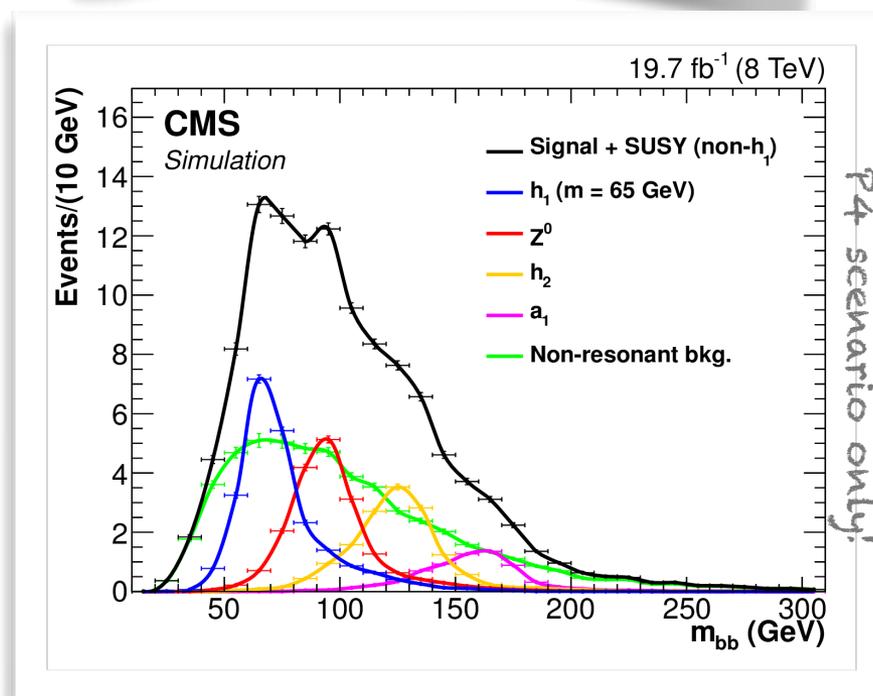
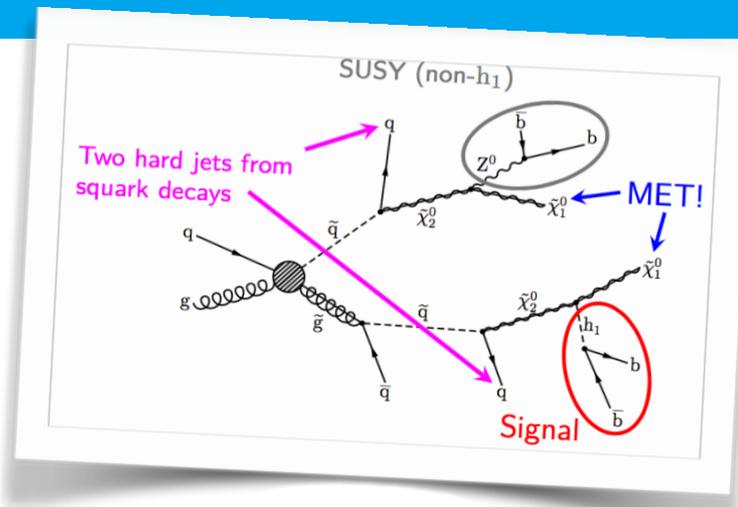
- > NMSSM: two Higgs doublets + additional singlet (no gauge interactions)
- > Well motivated SUSY model
 - > Solves the μ problem of the MSSM
- > Compatibility with existing measurements and H(125) discovery:
 - > $h_2 \equiv H(125)$, has small singlet component;
 - > h_1 : large singlet component (not seen at LEP); mass < 100 GeV
 - > Implemented in the modified P4 scenario*



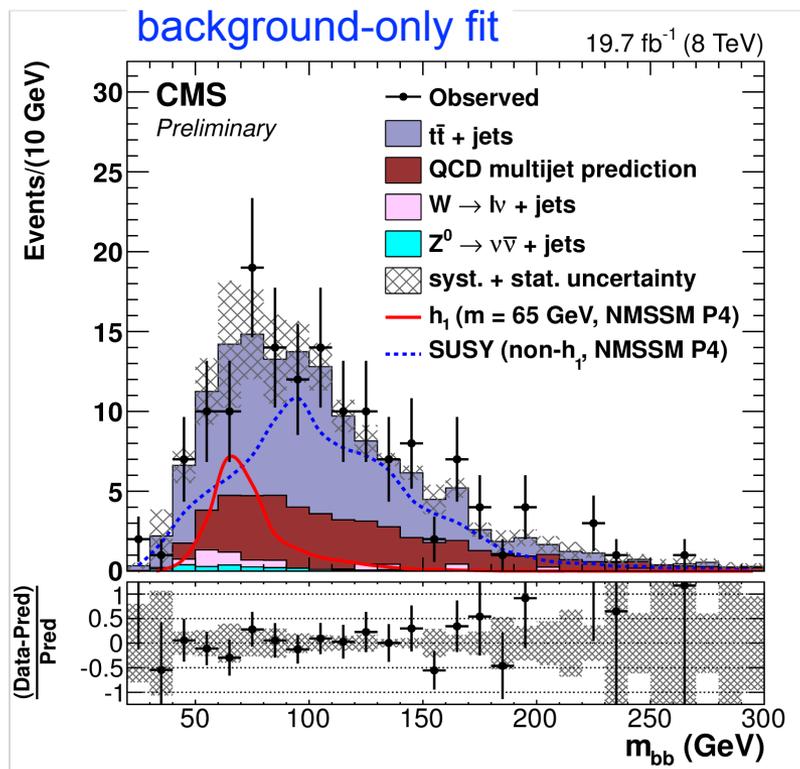
* O. Stål, G. Weiglein, Light NMSSM Higgs bosons in SUSY cascade decays at the LHC, JHEP 1201, 071 (2012), 1108.0595.

Search in SUSY cascades

- > Direct production suppressed due to reduced couplings to SM particles.
- > **SUSY cascades** signature:
 - > Large hadronic activity
 - > High- p_T jets from squark/gluino
 - > Large missing transverse energy
- > **Signal** \rightarrow look at $m_{b\bar{b}}$ distribution!
 - > Includes non- h_1 SUSY contribution.
- > **SM Backgrounds:**
 - > $t\bar{t}$ + jets (from MC)
 - > QCD multi-jet (data-driven; largest systematic)
 - > Electroweak (from MC)



Analysis + Fit results



> Selection

- > $HT > 750$ GeV (trigger > 650 GeV)
- > At least 4 jets $p_T > (250, 100, 25, 25)$ GeV
- > $\cancel{E}_T > 200$ GeV
- > At least 2 b-tag jets (not leading)
- > b-tag jets with $\min \Delta R(b_1, b_2)$
- > $\min \Delta R(b_1, b_2) < 1.5$
- > $\Delta\Phi(j_{12}, \vec{E}_T) > 0.5$ (suppress QCD)

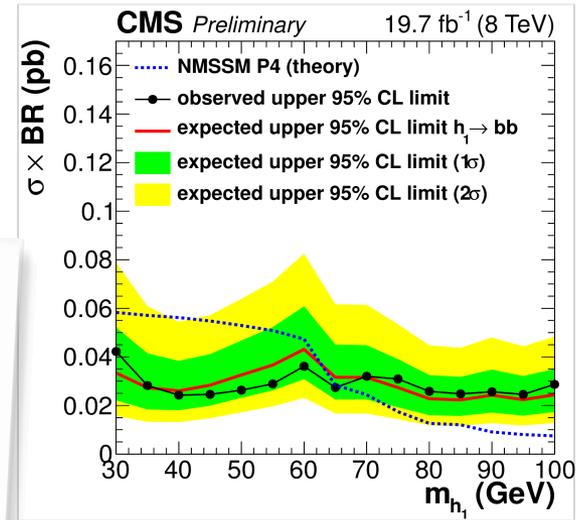
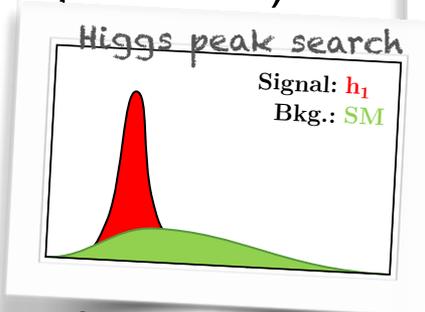
> Data well described by the background

- > No indication of a signal 😞

Upper limits $\sigma(pp \rightarrow h_1 + X) \times B(h_1 \rightarrow b\bar{b})$

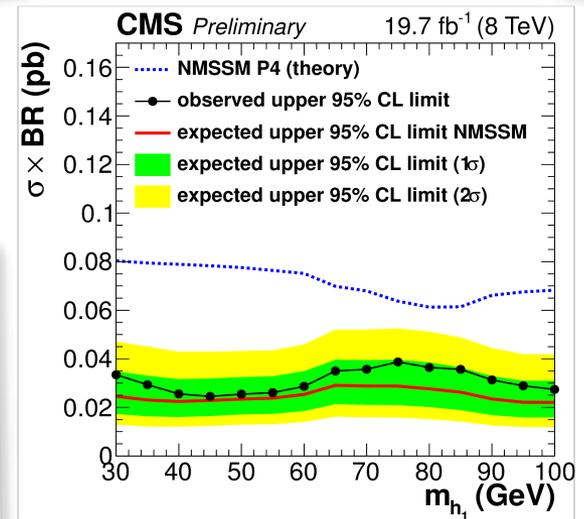
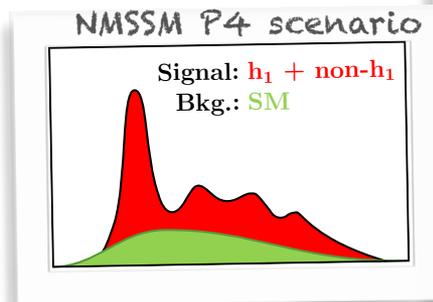
> Higgs peak search (model “independent”)

- > Upper limits in the range $30 < m_{b\bar{b}} < 100$ GeV
- > $m_{b\bar{b}} < 65$ GeV, limits undershoot the light Higgs production in modified P4 scenario

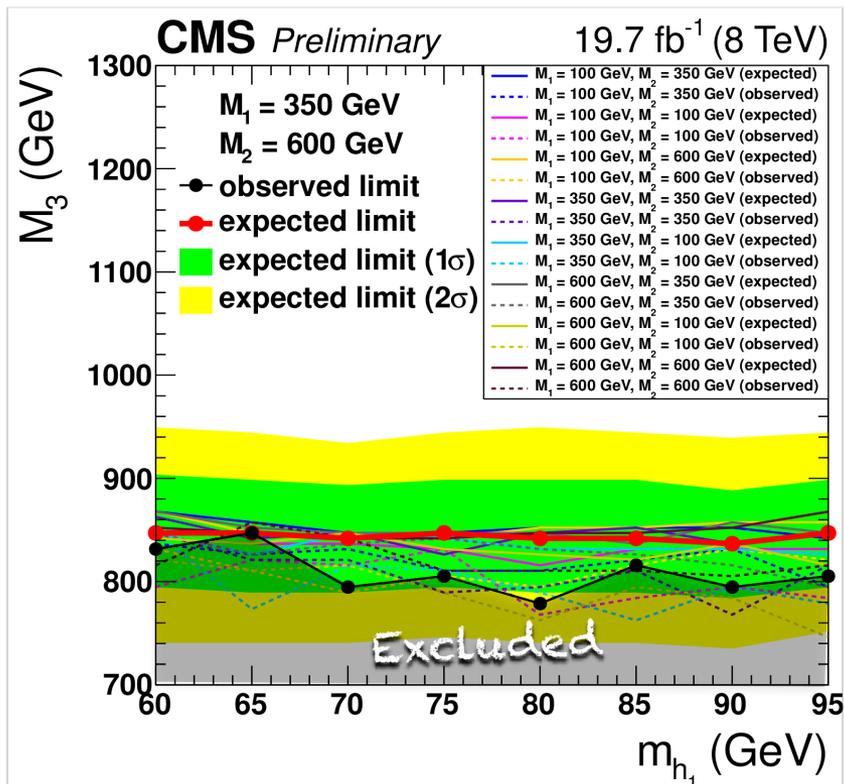


> NMSSM P4 scenario

- > Takes non- h_1 contributions into account.
- > **Modified NMSSM P4 scenario excluded!** with $M_3 = M_{SUSY} = 1$ TeV



Decoupled squarks scenario



- > Parameter space scan.
- > Cross section largely dependent on gluino mass parameter M_3 ; mild dependence on gaugino mass parameters M_1 and M_2 , and the higgs mass M_{h_1}

- > Extended Higgs sectors has been probed by CMS in the $b\bar{b}$ channel
 - > Searches for states lighter and heavier than H(125)

- > The one and only MSSM $\Phi \rightarrow b\bar{b}$ search at LHC with the 8 TeV data
 - > No evidence of signal: upper limits in $\sigma \times \text{BR}$ and MSSM $\tan \beta$
 - > World's best sensitivity in this channel!

- > First search for light NMSSM Higgs in SUSY cascades at LHC
 - > No evidence of signal: upper limits in $\sigma \times \text{BR}$ and gluino mass parameter M_3 (decoupled squarks scenario)
 - > Modified P4 scenario excluded for $M_3 = M_{\text{SUSY}} = 1 \text{ TeV}$

- > No evidence of a BSM Higgs at 8 TeV...
but the collisions at 13 TeV have just started. Stay tuned!