Light NMSSM Higgs bosons in SUSY cascades

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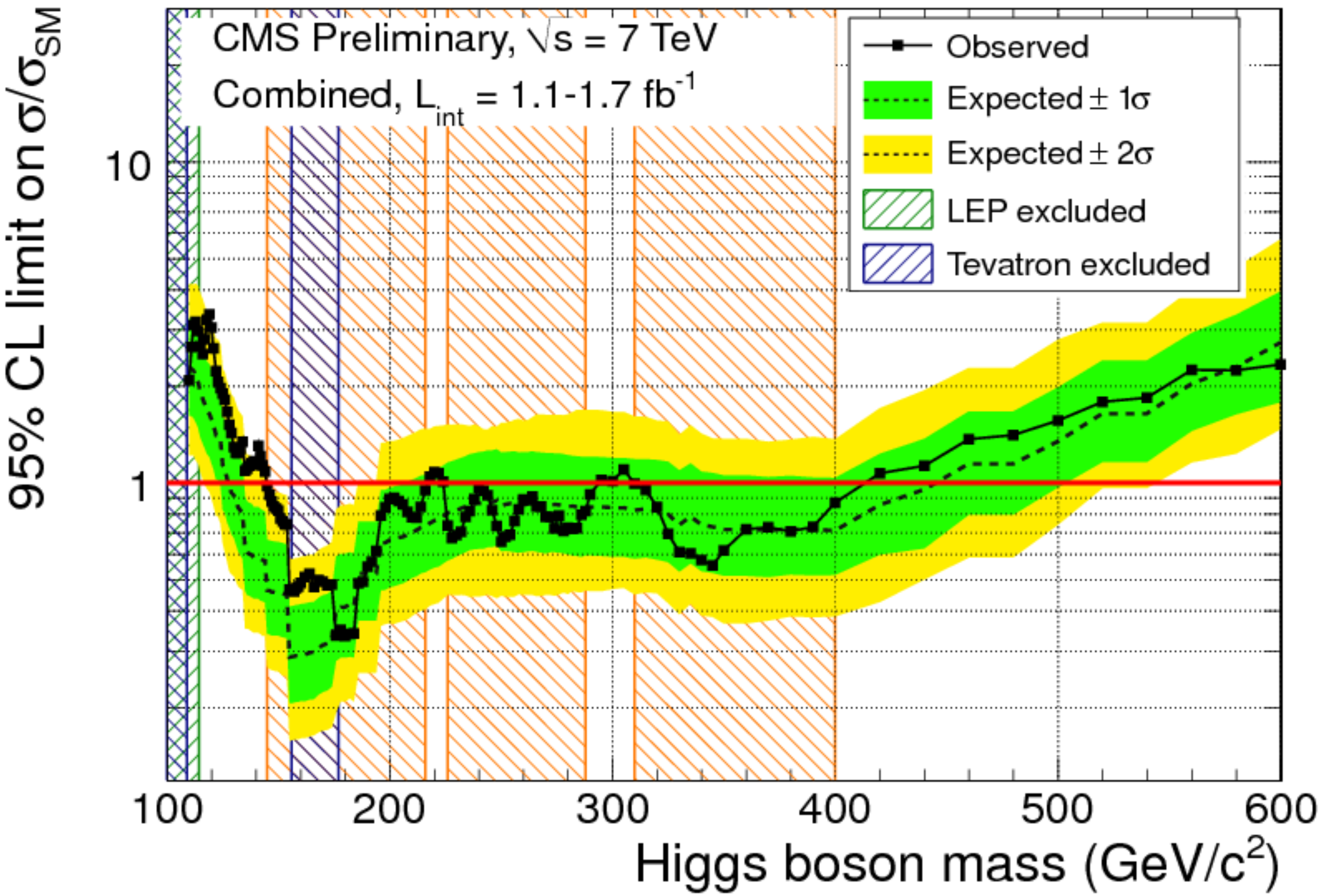
DESY Theory Workshop

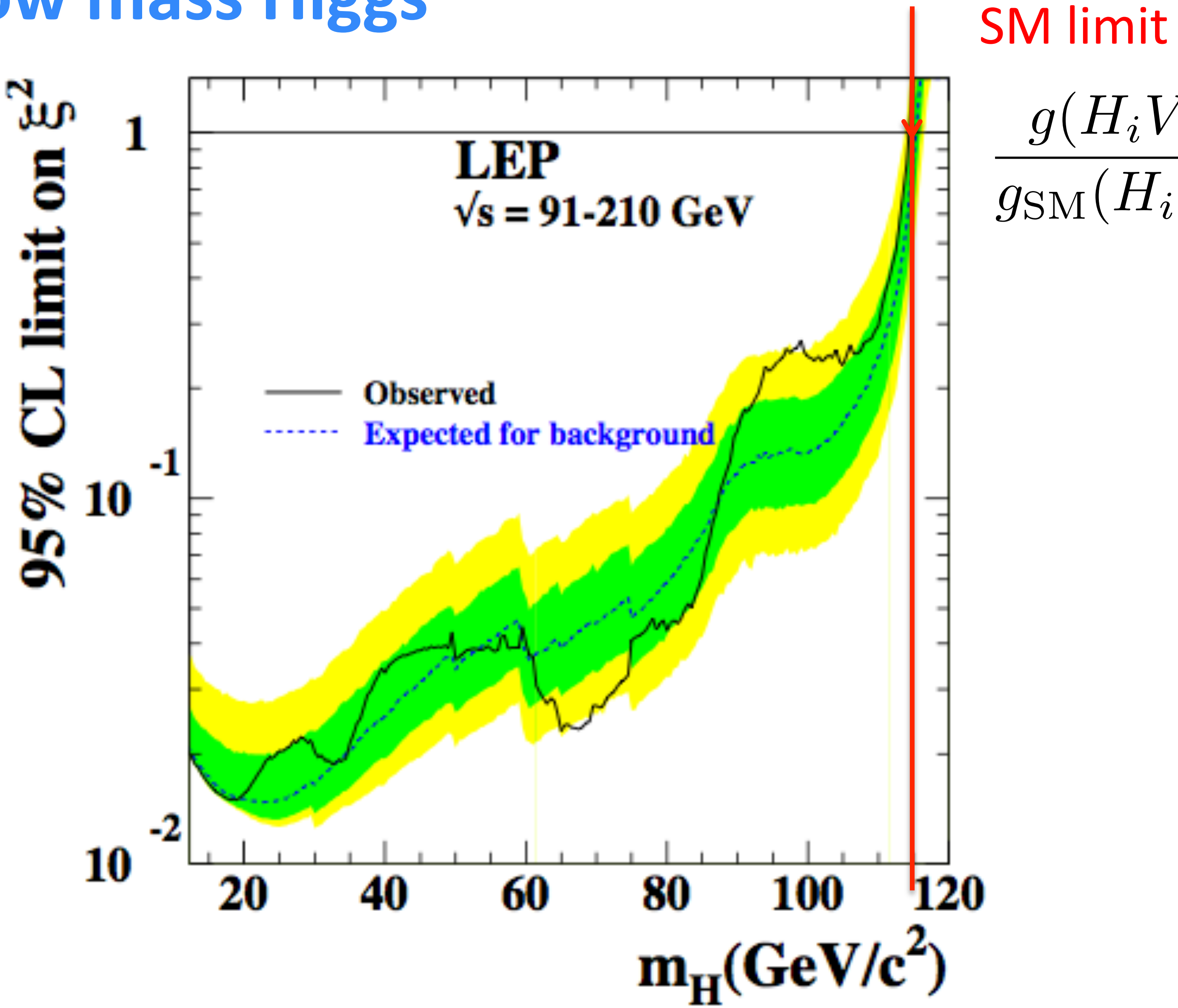
28.9 2011

SM Higgs Boson limits



- Higgs with SM-like couplings still allowed for M_H=115-150 GeV

Low mass Higgs



$$\frac{g(H_iVV)}{g_{\rm SM}(H_iVV)} \propto \xi_i$$

- Higgs with reduced couplings allowed also for $M_H < 115$ GeV

The Next-to-Minimal Supersymmetric SM

MSSM

Two complex Higgs doublets: H_u, H_d

$$W_{\mathrm{MSSM}} = Y_u \hat{Q} \cdot \hat{H}_U \hat{U} - Y_D \hat{Q} \cdot \hat{H}_d \hat{D} - Y_L \hat{L} \cdot \hat{H}_d \hat{E} + \mu \hat{H}_u \cdot \hat{H}_d$$

μ has mass dimension -> Natural value $\mu = M_p$

Phenomenology -> μ must be close to EW scale

NMSSM

Two Higgs doublets + complex singlet S

$$W = W^{(3)}_{\mathrm{MSSM}} + \lambda \hat{S} \hat{H}_u \hat{H}_d + \kappa \hat{S}^3$$

$$V_{\mathrm{soft}} = m^2_{H_u} |H_u|^2 + m^2_{H_d} |H_d|^2 + m^2_S |S|^2 + \left(\lambda A_\lambda S H_u \cdot H_d + \frac{1}{3} \kappa A_\kappa S^3 + \mathrm{h.c.} \right)$$

$$\mu_{\mathrm{eff}} = \lambda \langle S \rangle$$

Relation of μ to SUSY-breaking scale -> Naturalness problem solved

NMSSM Spectrum

Following EWSB, the NMSSM spectrum consists of:

3 CP-even Higgs bosons: H_1, H_2, H_3
2 CP-odd Higgs bosons: A_1, A_2
1 Charged Higgs pair: $H^\pm$

$$\left(\begin{array}{c} H_1 \\ H_2 \\ H_3 \end{array} \right) = \mathbf{Z^H} \left(\begin{array}{c} \mathrm{Re}(H_d^0) \\ \mathrm{Re}(H_u^0) \\ \mathrm{Re}(S^0) \end{array} \right)_{v=0}$$

Five neutralinos (additional singlino)
+ remaining sparticle spectrum similar to MSSM

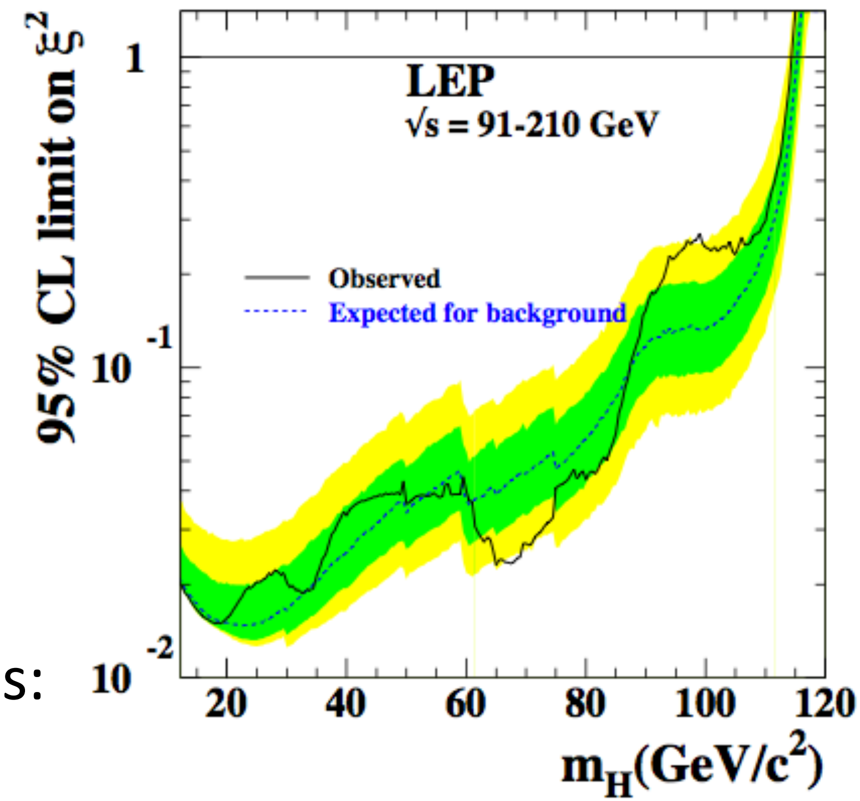
Higgs sector tree-level parameters increased:

$$\lambda, \kappa, A_\kappa, A_\lambda, v_S + \tan\beta$$

Light Higgs Bosons in the NMSSM

- If lightest Higgs is singlet dominated
  -> Avoid LEP bound on H_1

$$\frac{g(H_i VV)}{g_{\rm SM}(H_i VV)} \propto \xi_i \qquad \sum_i \xi_i^2 = 1$$



- Another interesting possibility is very light A_1: $M_{A_1} < 2m_b$
  H_1 can then explain largest LEP excess:
  "Ideal" Higgs scenarios

  Dermisek, Gunion

- In general very difficult to discover light A_1/H_1 (and other Higgses)

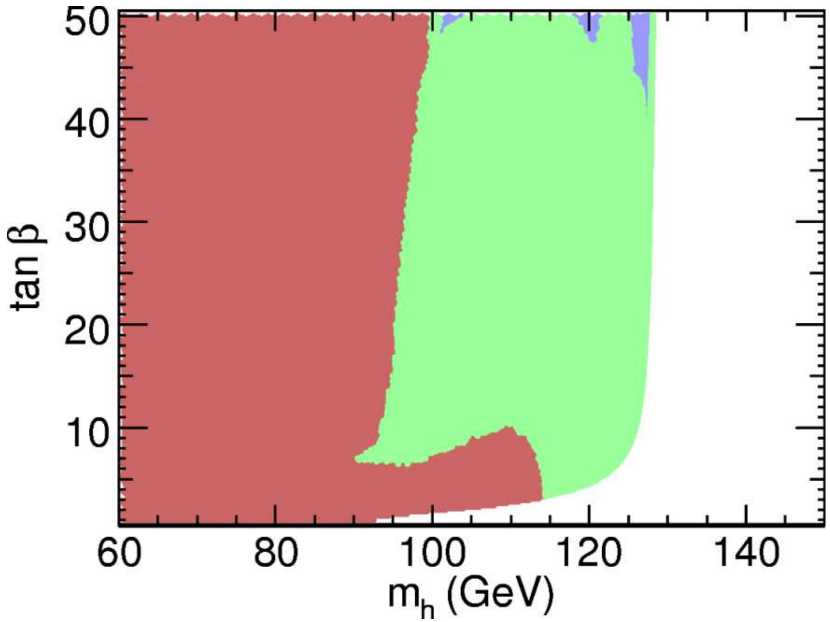
$$H_{\text{“SM”}} \to \phi\phi \to 4b, 4\tau, 2b2\tau \qquad \phi = A_1, H_1$$

MSSM -> NMSSM – Light CP-even Higgs bosons

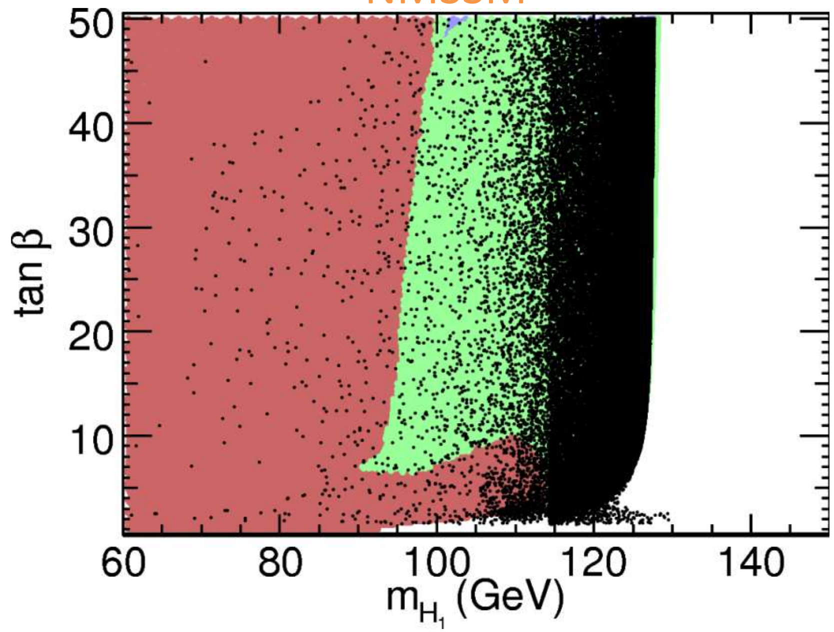
- The lightest NMSSM Higgs may be much lighter than for the corresponding MSSM scenario…

Constr. Mh-max

MSSM



NMSSM



F. Mahmoudi, J. Rathsman, OS, L. Zeune, [1012.4490]

… provided the H_1 coupling to Z bosons is suppressed by a large singlet component $\xi_1^2 \ll 1$

- Reduced production in standard channels at LHC

Higgs bosons in SUSY cascades

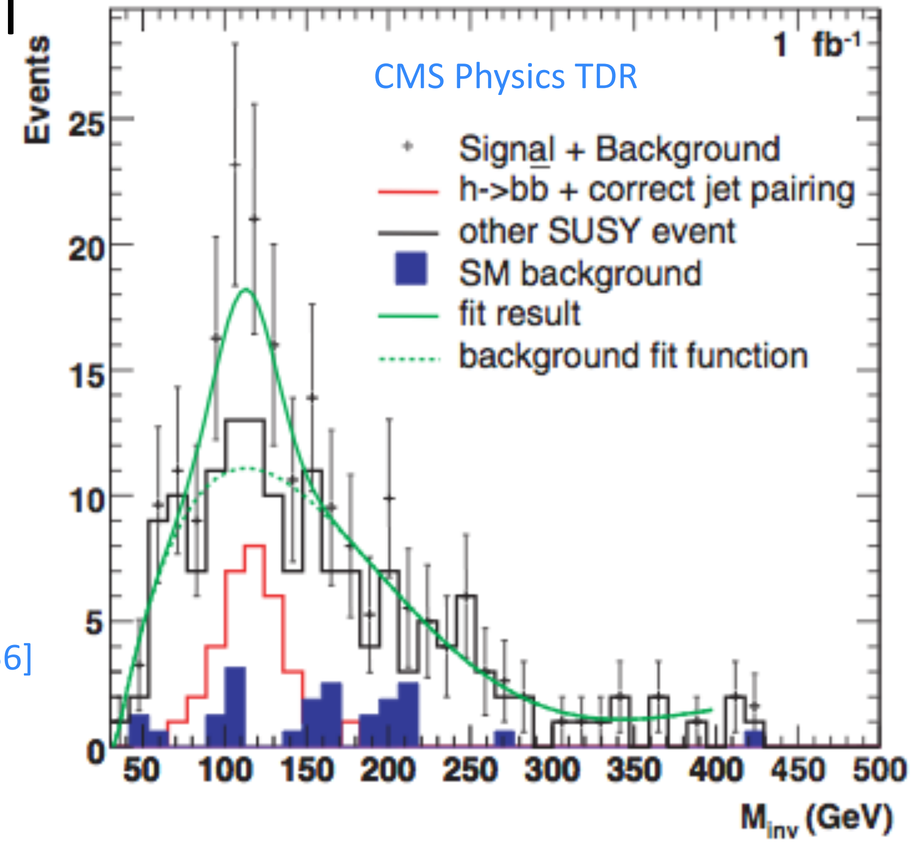
$$\tilde{q} \to q\tilde{\chi}_i^0 \to q\tilde{\chi}_j^0 H_k \to \ldots$$

- Alternative to standard production ($gg \to H$, VBF, etc.)
  - Strong cross sections - Hard scale for $H \to b\bar{b}$
  - Trigger on hard jet(s) + high MET

- CMS MC analysis of "LM5"

  $M_{H_1} \sim 116 \text{ GeV}$

  $5\,\sigma$ with 1.5 fb^{-1} (14 TeV)

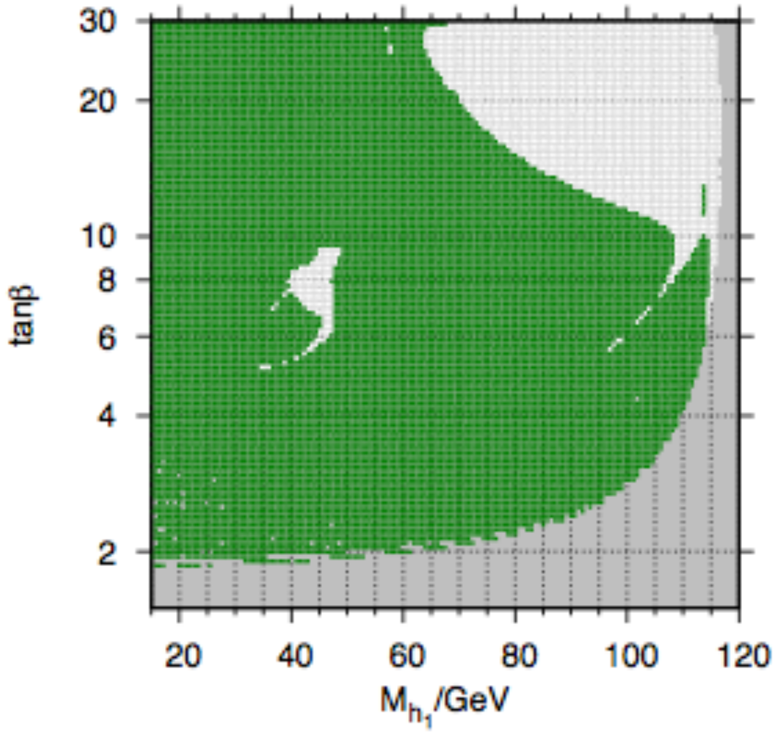


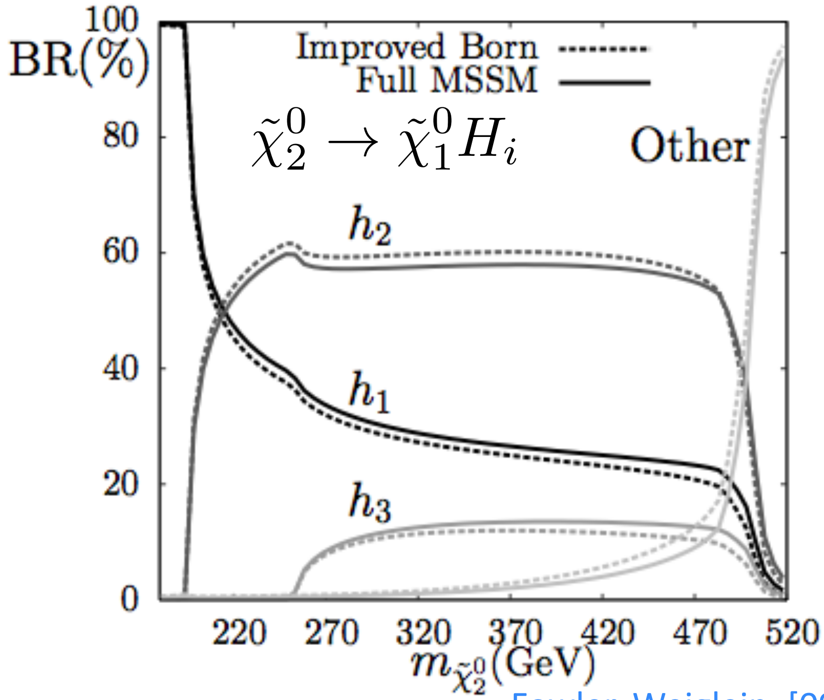
- Boosting the bb analysis

Kribs, Roy, Martin, Spannowsky,, [0912.4731], [1006.1656]
Gori, Schwaller, Wagner [1103.4138]

Cascades for light Higgs scenarios

- Higgs modes can be dominant when kinematically accessible
  Full 1-loop corrections to $\tilde{\chi}_i^0 \to \tilde{\chi}_j^0 H_k$ decays in CPV MSSM





Fowler, Weiglein, [0909.5165]
Bandyopadhyay, [1008.3339]

- Also in the NMSSM the relevant decays have been studied at the level of BR

Kraml, Porod, [hep-ph/0507055]
Choi, Miller, Zerwas, [hep-ph/0407209]
Cheung, Hou, [0809.1122]

Phenomenological LHC analysis

OS, G. Weiglein, [1108.0595]

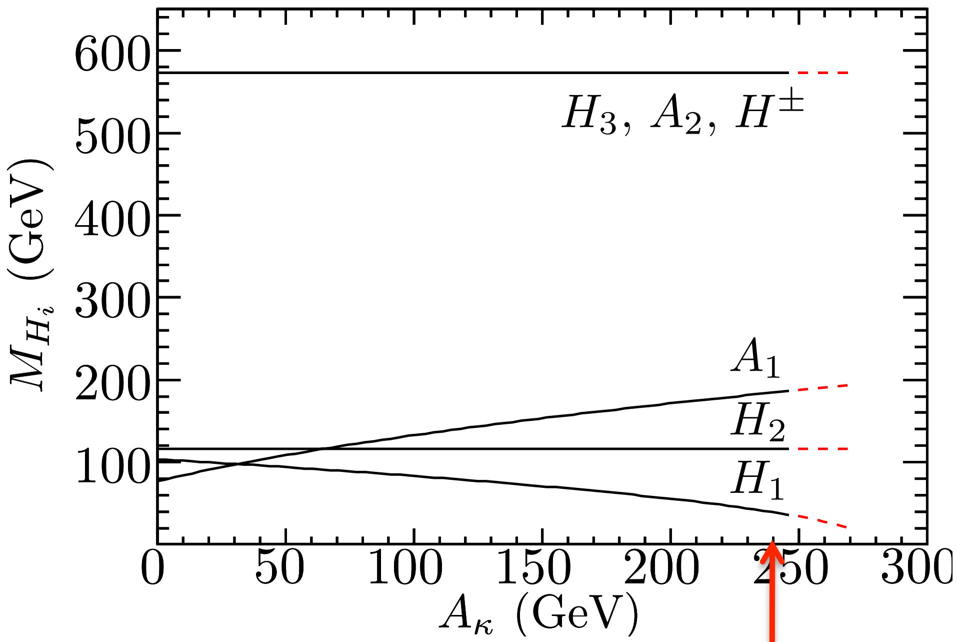
- Starting point: NMSSM “P4” benchmark (light singlet H_1)…

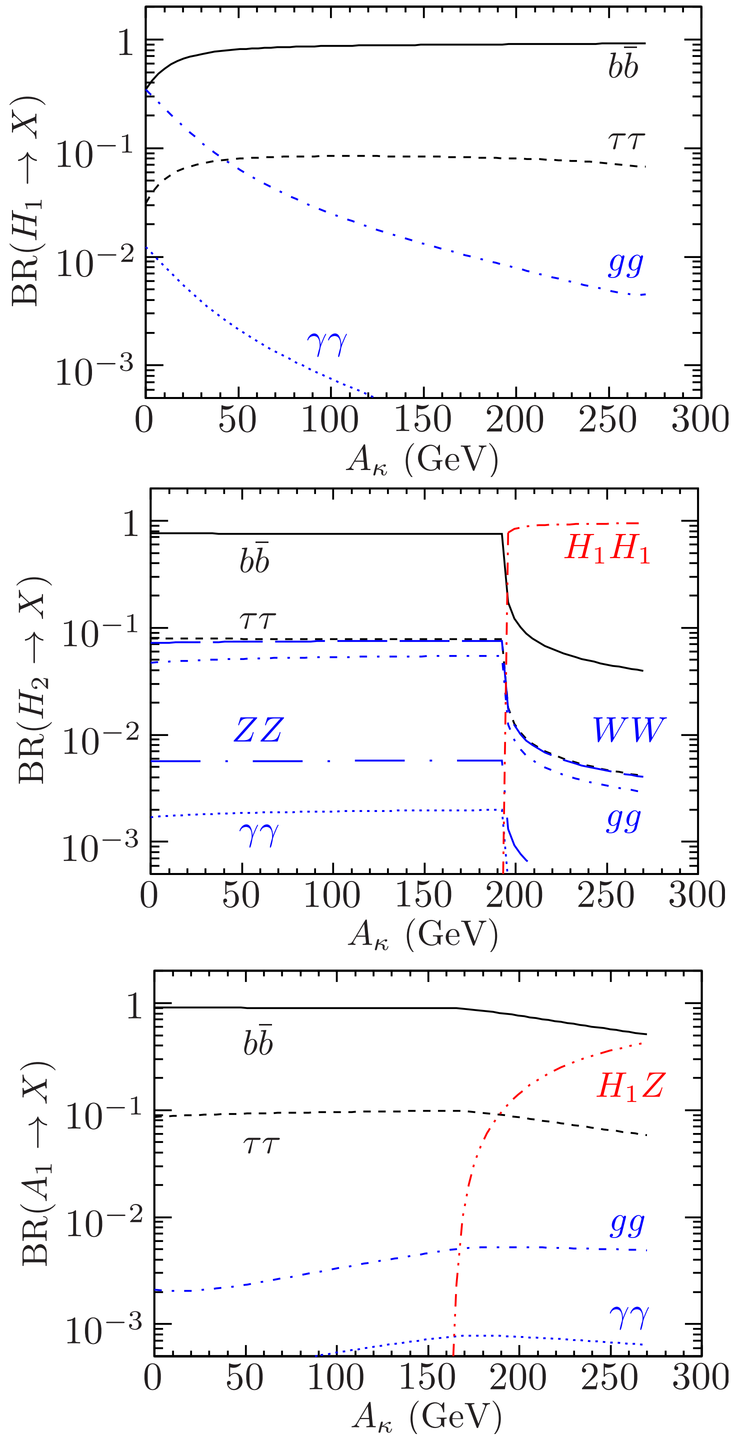
A. Djouadi et al, [0801.4321]

… slightly modified to allow for varying lightest Higgs mass

Higgs sector parameters					
λ	0.6		κ	0.12	
$\tan\beta$	2.6		μ_{eff}	-200	GeV
A_λ	-510	GeV	A_κ	$0-300$	GeV
Gaugino masses					
M_1	300	GeV	M_2	600	GeV
M_3	1000	GeV			
Trilinear couplings					
$A_t = A_b = A_\tau = 0$ GeV					
Soft scalar mass					
$M_{\mathrm{SUSY}} = 750$ GeV, 1 TeV					

Modified P4 Higgs spectrum





- Example working point

$$M_{H_1} = 40\ \text{GeV}$$

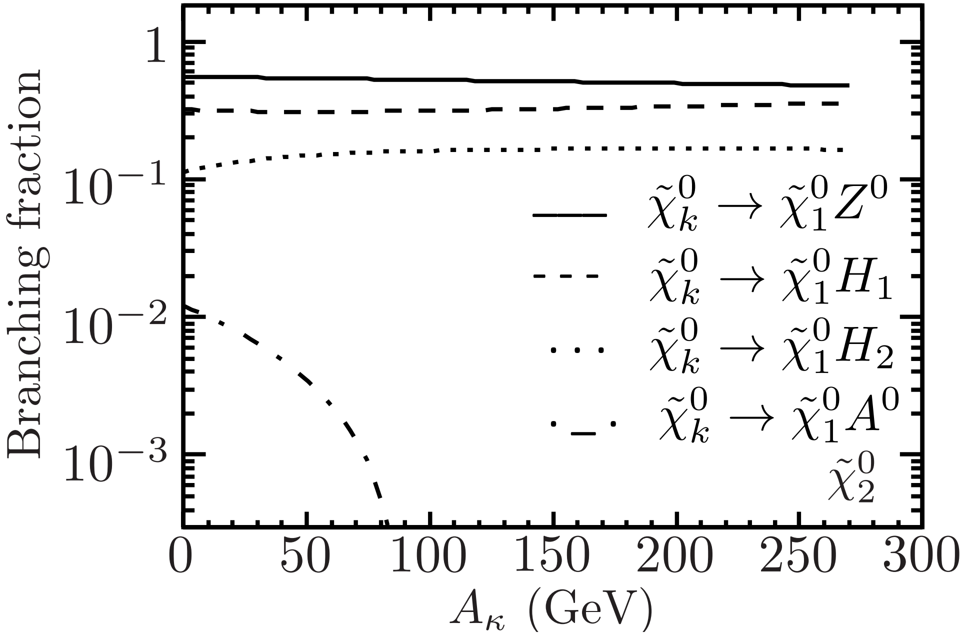
$$M_{H_2} = 116\ \text{GeV}$$

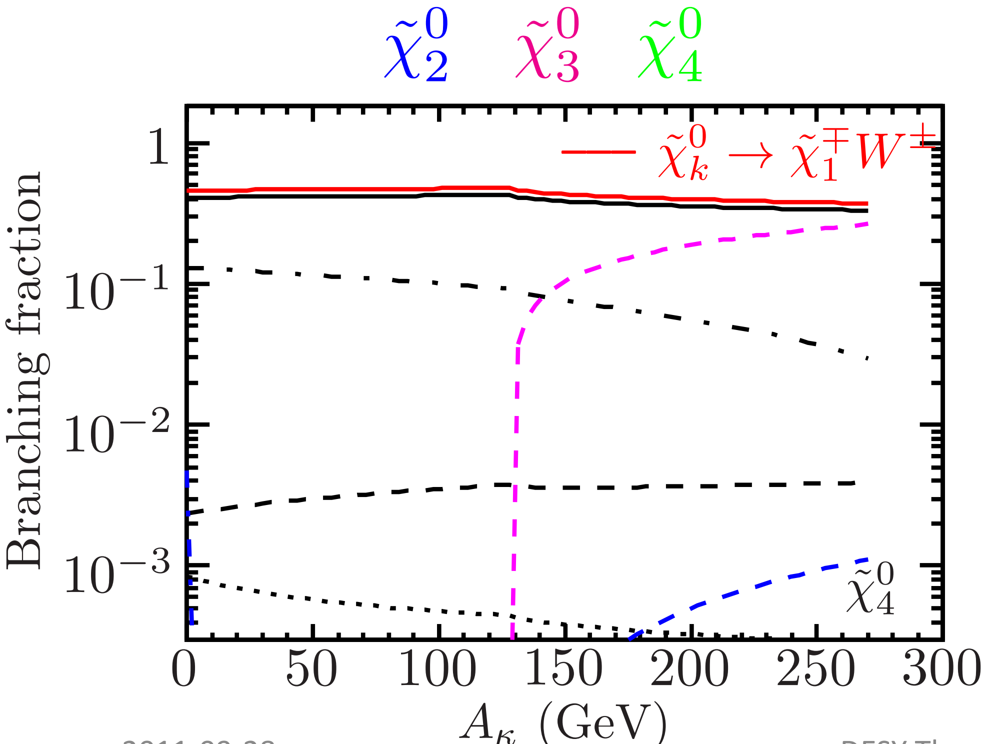
$$M_{A_1} = 184\ \text{GeV}$$

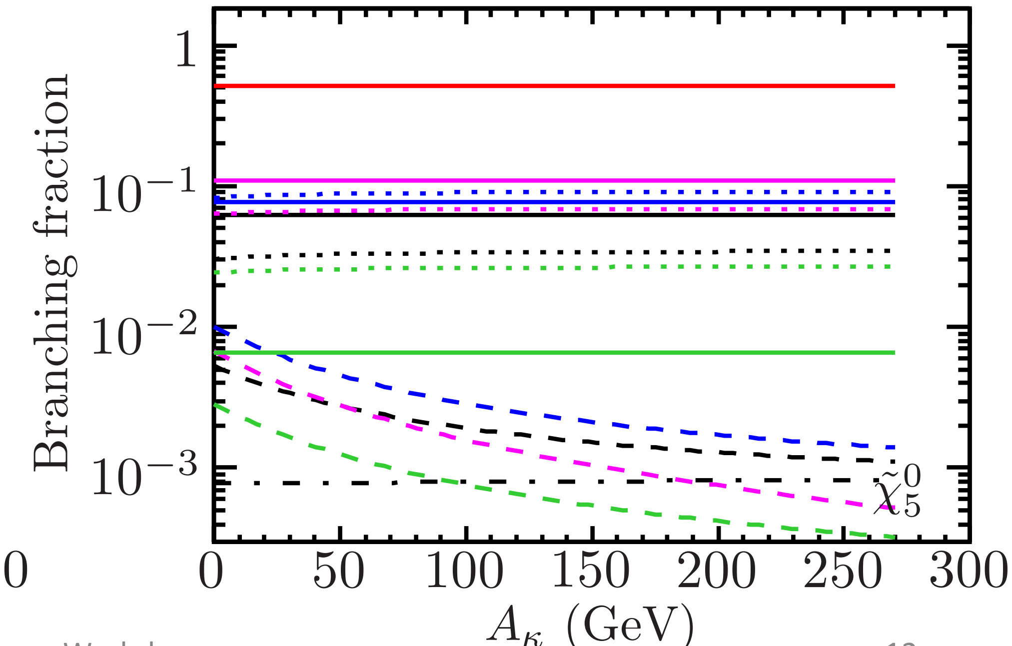
$$M_{H^\pm} \simeq 570\ \text{GeV}\,(\simeq M_{H_3} \simeq M_{A_2})$$

Neutralino sector

$\tilde{\chi}_1^0$	97.6 GeV	$\tilde{S}, \tilde{H}$
$\tilde{\chi}_2^0$	227 GeV	$\tilde{H}$
$\tilde{\chi}_3^0$	228 GeV	$\tilde{H}$
$\tilde{\chi}_4^0$	304 GeV	$\tilde{B}$
$\tilde{\chi}_5^0$	616 GeV	$\tilde{W}$







LHC analysis: MC simulation strategy

- SUSY-QCD matrix elements: MadGraph/MadEvent

$$pp \to \tilde{g}\tilde{g}, \tilde{q}\tilde{q}, \tilde{g}\tilde{q}, \tilde{q}\tilde{\bar{q}}$$

- NMSSM resonance decays (external BR) Pythia

$$\tilde{q} \to q\chi_i^0 \to q\chi_1^0 H_k \to q\chi_1^0 b\bar{b}, \qquad n_j \geq 1, \quad n_b \geq 2,$$

$$\tilde{g} \to g\tilde{q} \to gq\chi_i^0 \to gq\chi_1^0 H_k \to gq\chi_1^0 b\bar{b}, \qquad n_j \geq 2, \quad n_b \geq 2$$

cascades may include charginos, W, Z, …

- ISR, FSR, Fragmentation, MPI Pythia

- Energy Smearing, fast `ATLAS' detector simulation Delphes

$$P(\mathrm{btag}|b) = 60\% \qquad P(\mathrm{btag}|c) = 10\% \qquad P(\mathrm{btag}|q) = 1\%$$

Squark/Gluino production

- Production of colored sparticles unchanged wrt MSSM

$$pp \to \tilde{g}\tilde{g}, \tilde{q}\tilde{q}, \tilde{g}\tilde{q}, \tilde{q}\tilde{\bar{q}}$$

- (S)QCD corrections sizable -> NLO

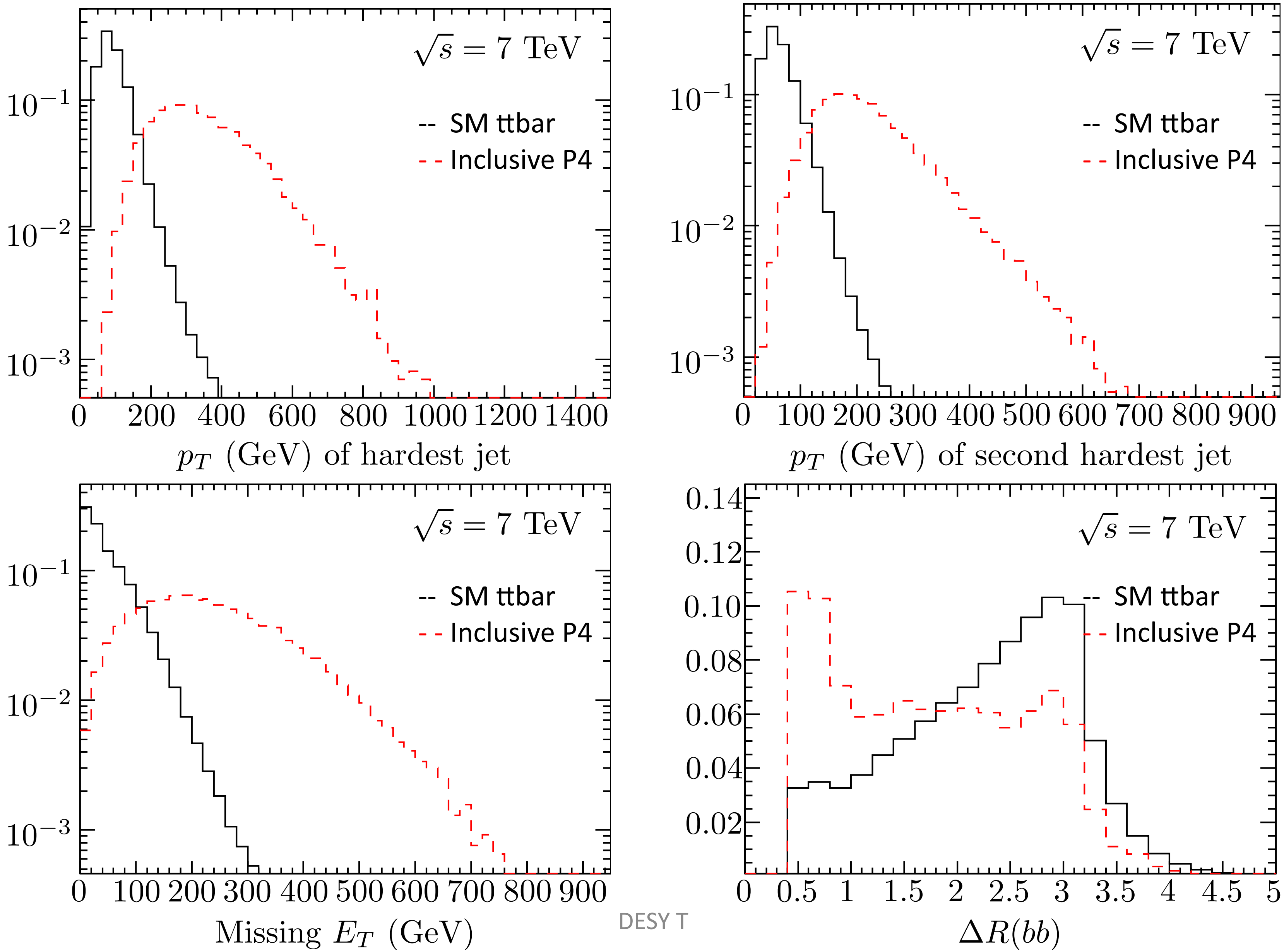
W. Beenakker, R. Höpker, M. Spira, P. M. Zerwas, [hep-ph/9610490]
T. Plehn, Prospino

Masses (GeV)		σ_{LO} (pb)					σ_{NLO} (pb)				
$M_{\tilde{g}}$	$M_{\tilde{q}}$	$\tilde{g}\tilde{g}$	$\tilde{q}\tilde{q}$	$\tilde{g}\tilde{q}$	$\tilde{q}\tilde{\bar{q}}$	Σ	$\tilde{g}\tilde{g}$	$\tilde{q}\tilde{q}$	$\tilde{g}\tilde{q}$	$\tilde{q}\tilde{\bar{q}}$	Σ
$\sqrt{s} = 7$ TeV											
750	750	0.03	0.23	0.25	0.05	0.56	0.07	0.27	0.39	0.08	0.82
1000	750	0.002	0.19	0.06	0.05	0.31	0.006	0.21	0.10	0.07	0.39 ←
1000	1000	0.001	0.03	0.02	0.004	0.06	0.005	0.04	0.04	0.006	0.08 ←
$\sqrt{s} = 14$ TeV											
750	750	1.18	1.67	5.20	1.06	9.11	2.21	2.06	6.78	1.53	12.6
1000	750	0.15	1.41	1.86	0.96	4.38	0.32	1.59	2.44	1.34	5.69 ←
1000	1000	0.14	0.42	0.87	0.18	1.61	0.31	0.51	1.19	0.26	2.27 ←
1500	1500	0.01	0.04	0.05	0.01	0.10	0.01	0.05	0.07	0.02	0.15

Kinematic distributions

$M_{\text{SUSY}} = 750\ \text{GeV}$

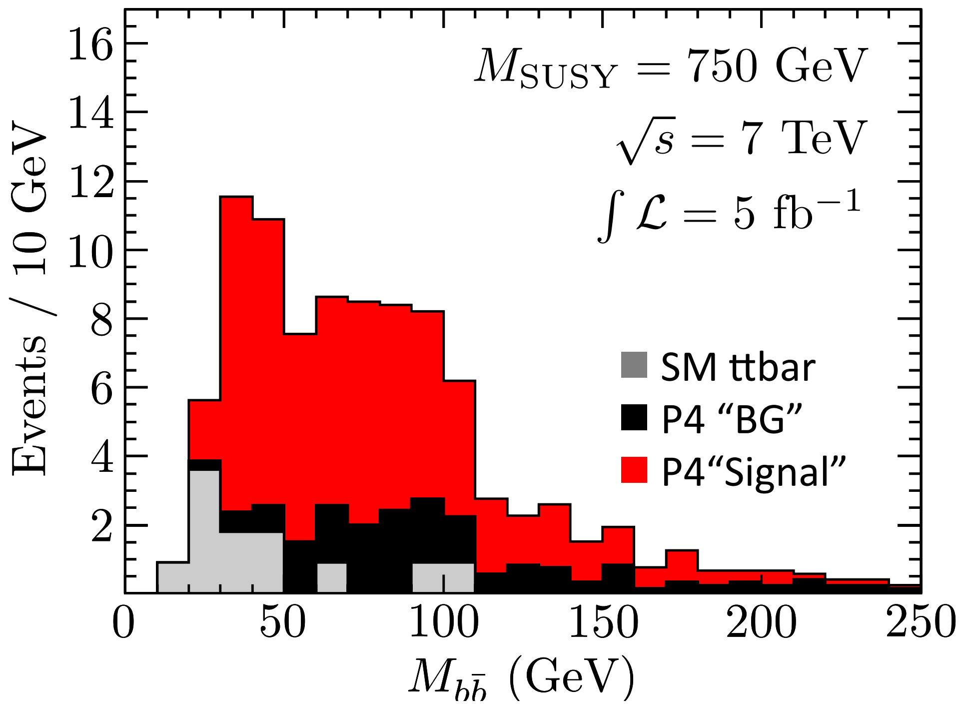
All histograms normalized to unity

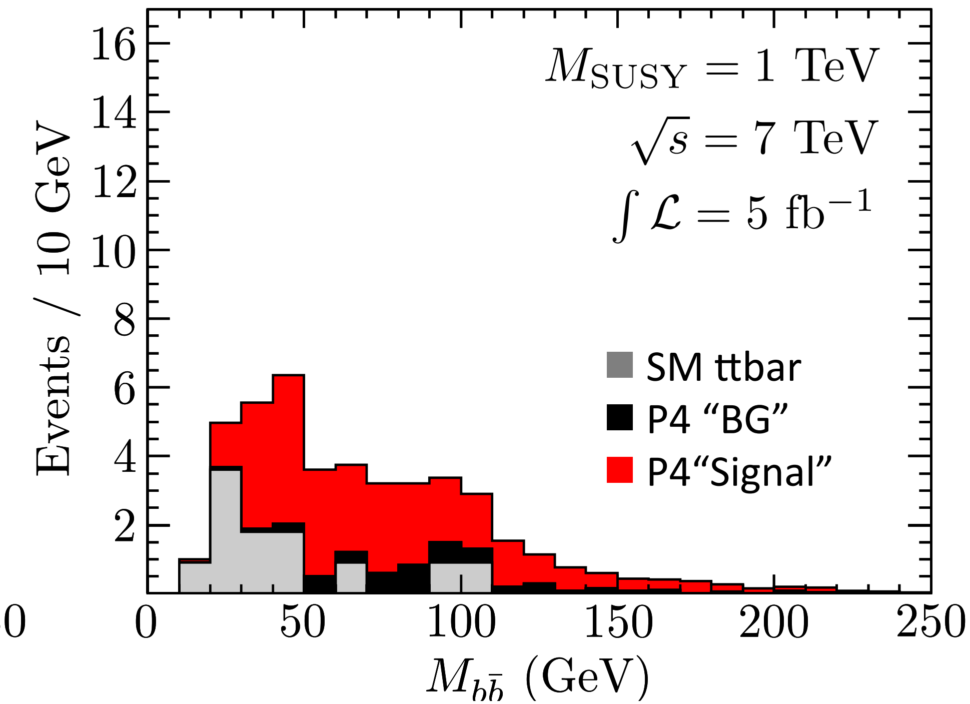


Results for LHC@7 TeV

- Cuts-based analysis to suppress SM tt background
- ΔR cut selects b-jet pairs from H_1 SUSY BG suppressed by N_b

$$N_{\text{jets}} \geq 4 \qquad N_b \geq 2$$
$$p_T(\text{jet1}) > 250 \text{ GeV}$$
$$p_T(\text{jet2}) > 100 \text{ GeV}$$
$$E_T^{\text{miss}} > 150 \text{ GeV}$$
$$\min \Delta R(b\bar{b}) < 1.5$$

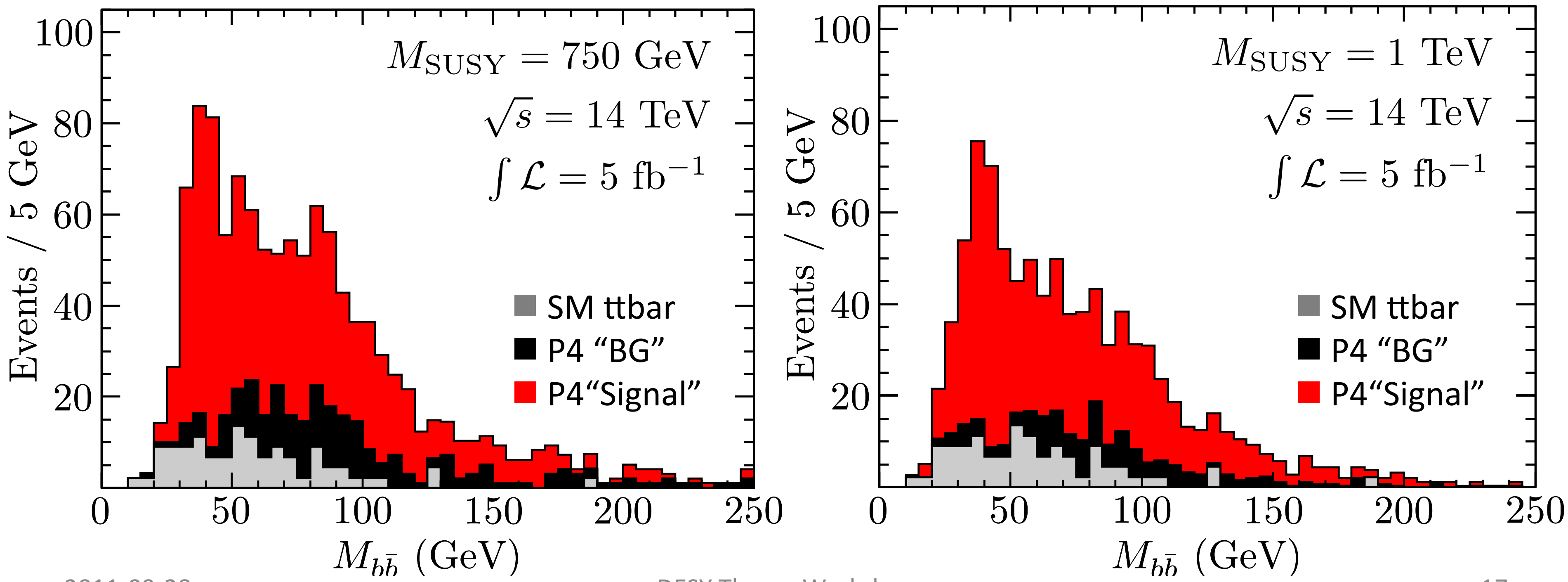




Outlook: LHC@14 TeV

- Statistics improve greatly
- Clear signal also for 1 TeV squark case

$$N_{\text{jets}} \geq 4 \qquad N_b \geq 2$$
$$p_T(\text{jet1}) > 250 \text{ GeV}$$
$$p_T(\text{jet2}) > 100 \text{ GeV}$$
$$E_T^{\text{miss}} > 200 \text{ GeV}$$
$$\min\Delta R(b\bar{b}) < 1.2$$



Conclusions

- Light Higgs bosons ($M_H < M_Z$) still compatible with constraints in extended models

- The NMSSM is an appealing scenario where this can be realized

- One method to search for these difficult light Higgses at the LHC is through production in SUSY cascades

- We have performed MC study of the light NMSSM Higgs case:
  -> Still meaningful to do Higgs searches in SUSY cascades at 7 TeV
  with squarks and/or gluinos close to present bounds
  -> Prospects at 14 TeV promising for even higher masses

- Interesting to know LHC/Tevatron prospects to probe light Higgs scenario also in other (standard) channels