Light Higgs bosons in SUSY cascades

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Implications of LHC results for TeV-scale physiscs

1.9 2011

Motivation

- Most studies of BSM Higgs concern changes to rates – nothing fundamentally different from SM

- Obvious benefits, but restricting Higgs searches to 'SM-like' scenarios may be too limited in the sense that

  - Lighter, non-SM like, Higgs bosons could exist
  - Heavy Higgs bosons may decay to new physics (or H)
  - Higgs bosons may be produced from new particle decays
  - New physics production may be background to Higgs
  - Higgs production may be background to new physics

- Treat Higgs physics and new physics in conjunction
  ☺ Tackle some of these issues ☹ Increased model dependence

Outline

1. Scenarios with light Higgs bosons
   a) CP-violating MSSM
   b) NMSSM

2. Higgs production in SUSY cascades

3. Phenomenological LHC analysis

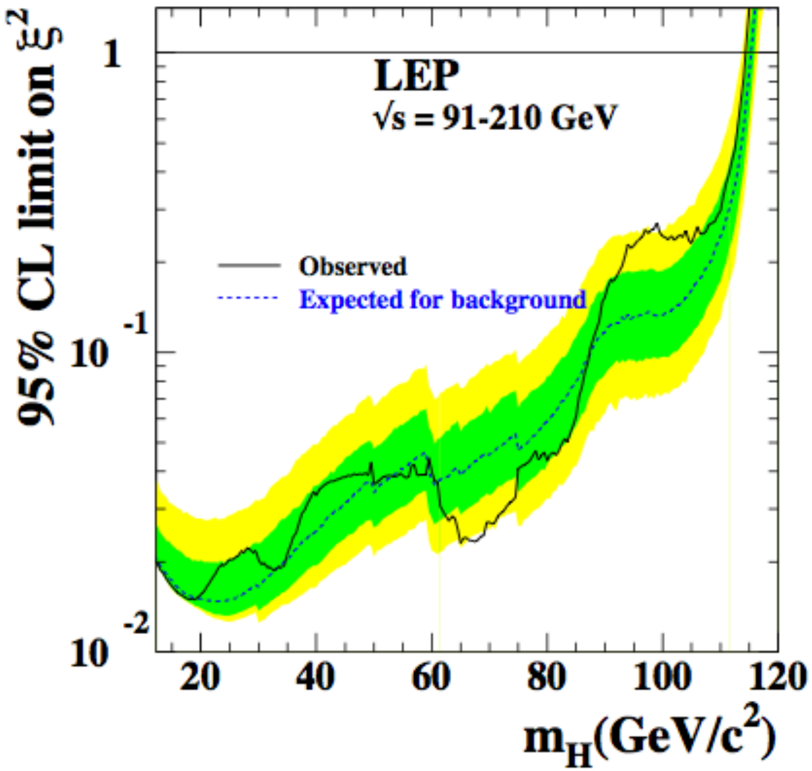
Light Higgs bosons I: MSSM

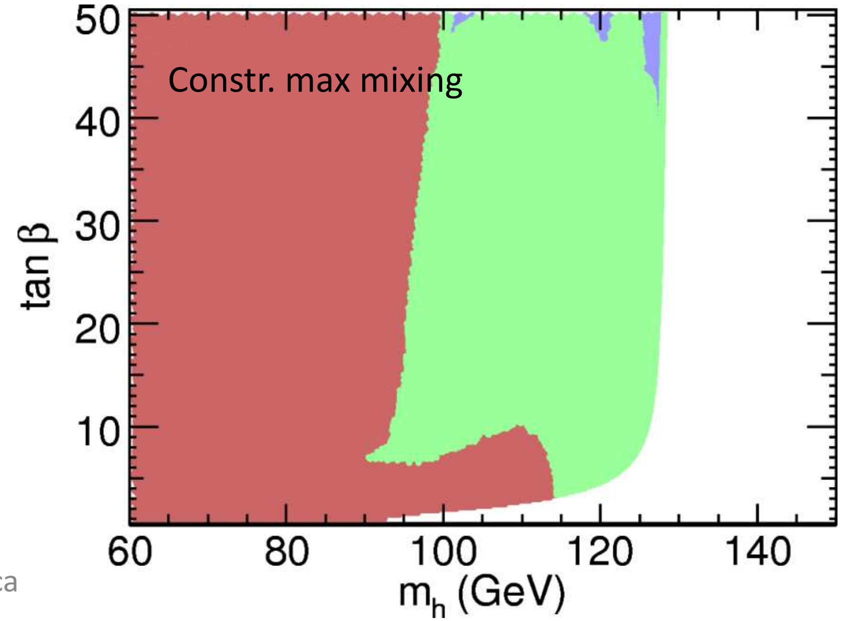
- LEP -> Lower limit on Higgs mass
- SM-like Higgs: $M_H \gtrsim 114 \text{ GeV}$
- SUSY -> two Higgs doublets
  -> 3 neutral Higgs states H_i
- CP-conserving MSSM: H_i, A^0

$$\frac{C(H_i VV)}{C(H_i VV)_{\mathrm{SM}}} \propto g_i \qquad \sum_{i=1}^{2} g_i^2 = 1$$

- Lightest Higgs mass

$$90 \text{ GeV} \lesssim M_h \lesssim 130 \text{ GeV}$$





Light Higgs bosons II: CP-violating MSSM

- Relaxing CP conservation, all 3 neutral Higgs bosons mix

$$\sum_{i=1}^{3} g_i^2 = 1$$

- Benchmark scenario "CPX" shows hole in excluded region

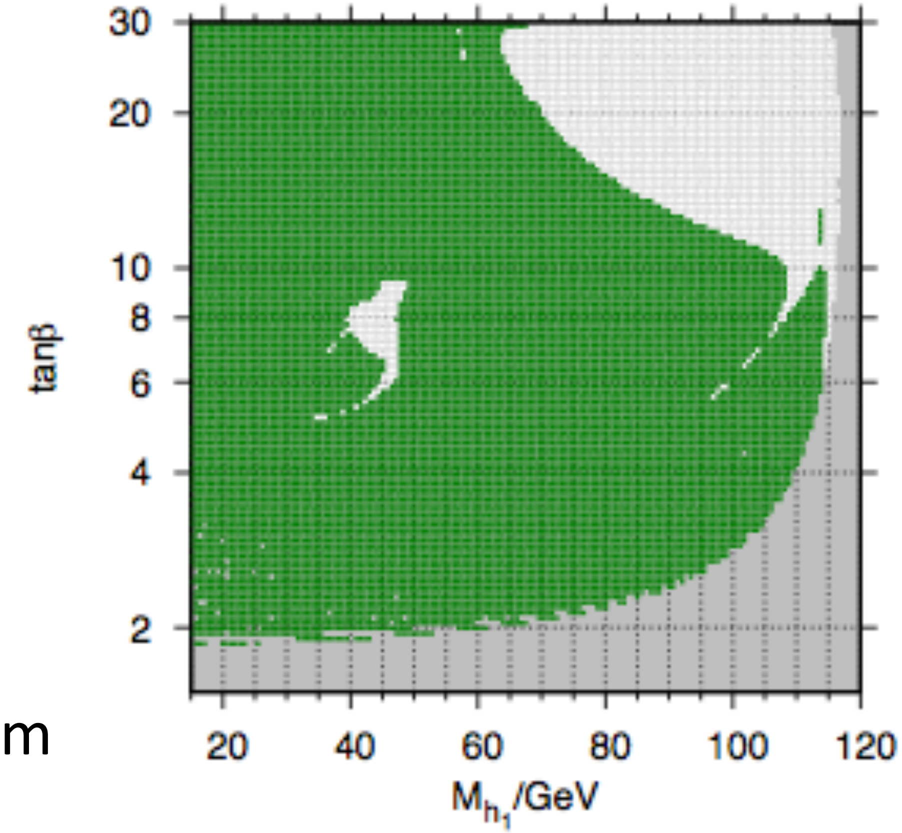
$$M_{H_1} \sim 35\text{–}45 \text{ GeV}$$

- Such light H_1 also opens for

$$H_2 \to H_1 H_1$$

-> Complicated 4f final states from SM-like Higgs

Williams, Rzehak, Weiglein, [1103.1335]



Light Higgs bosons III: The NMSSM

- The NMSSM extends the MSSM, solves μ-problem

$$W^{(2)}_{\rm MSSM} \sim \mu \hat{H}_2 \cdot \hat{H}_1 \to \lambda \hat{S} \hat{H}_2 \cdot \hat{H}_1 + \frac{1}{3}\kappa \hat{S}^3$$

- Additional singlet -> 3 CP-even, 2 CP-odd Higgs states

$$\sum_{i=1}^{3} g_i^2 = 1$$

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

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

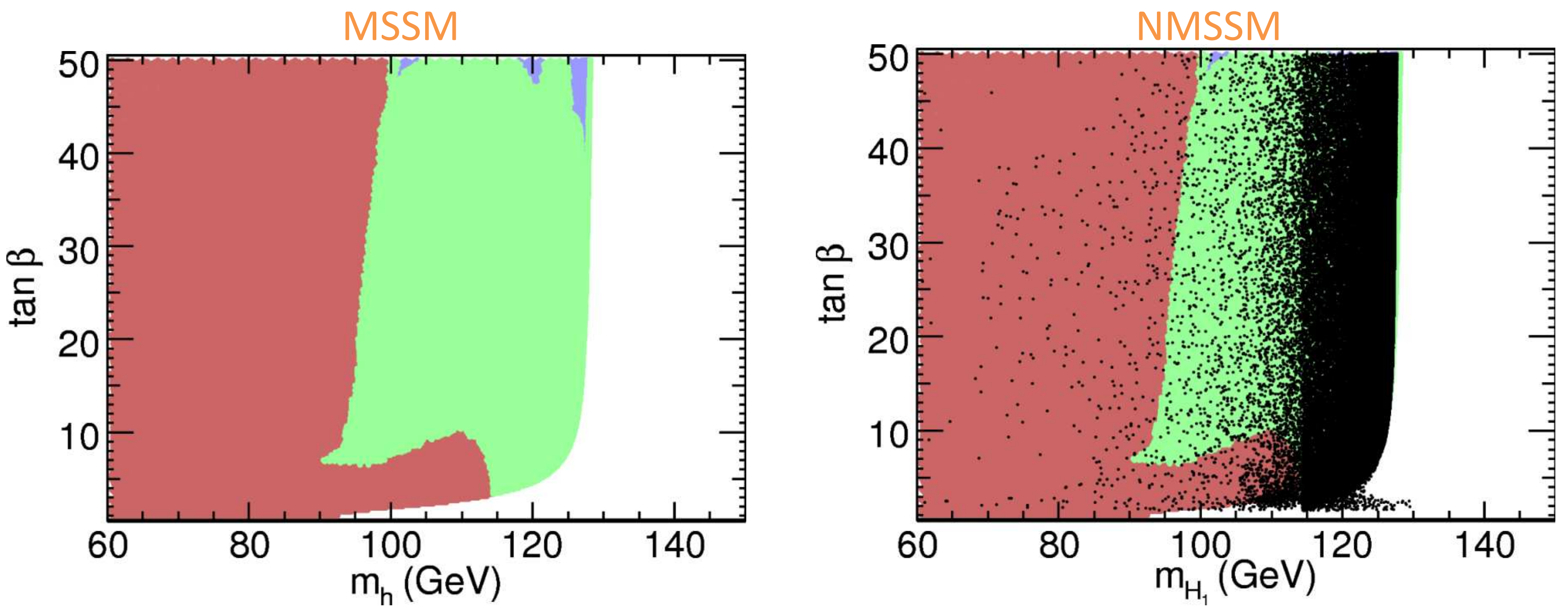
Dermisek, Gunion

- Difficult to discover light A_1/H_1 at LHC, and also "H_{SM}" since

$$H_{\rm SM} \to \phi\phi \to 4b, 4\tau, 2b2\tau$$
$$\phi = A_1, H_1$$

MSSM -> NMSSM – Light CP-even Higgs bosons

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



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

… provided the H_1 coupling to Z bosons is suppressed by a large singlet component

- This also means reduced production in standard channels at LHC

Searching for 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

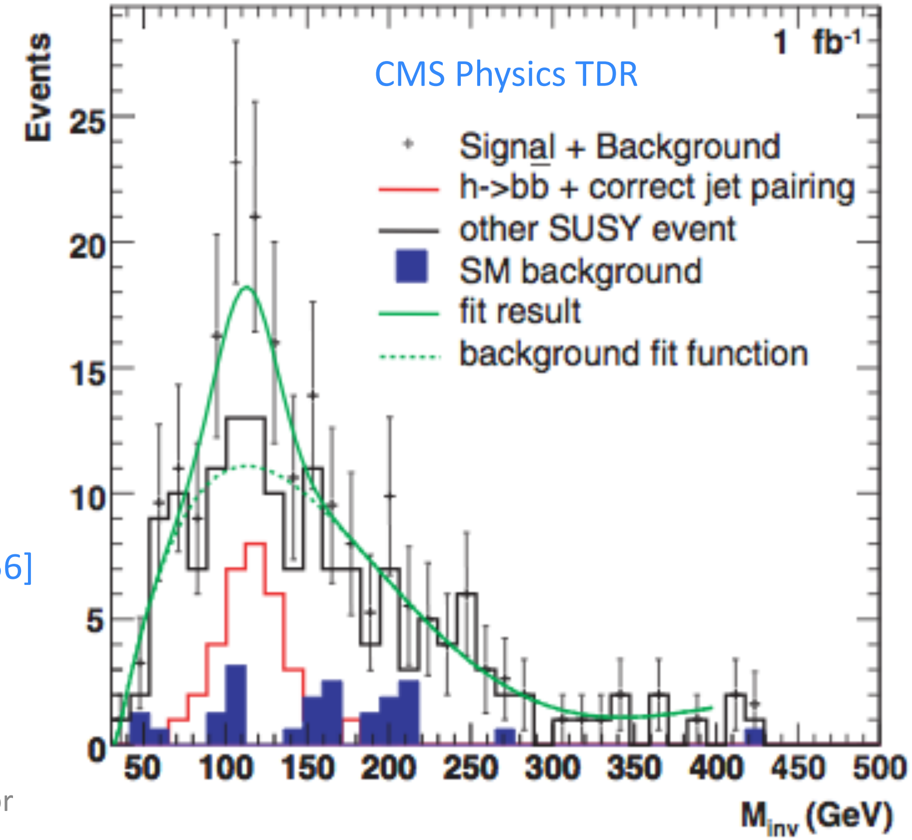
- CMS MC analysis of "LM5"

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

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

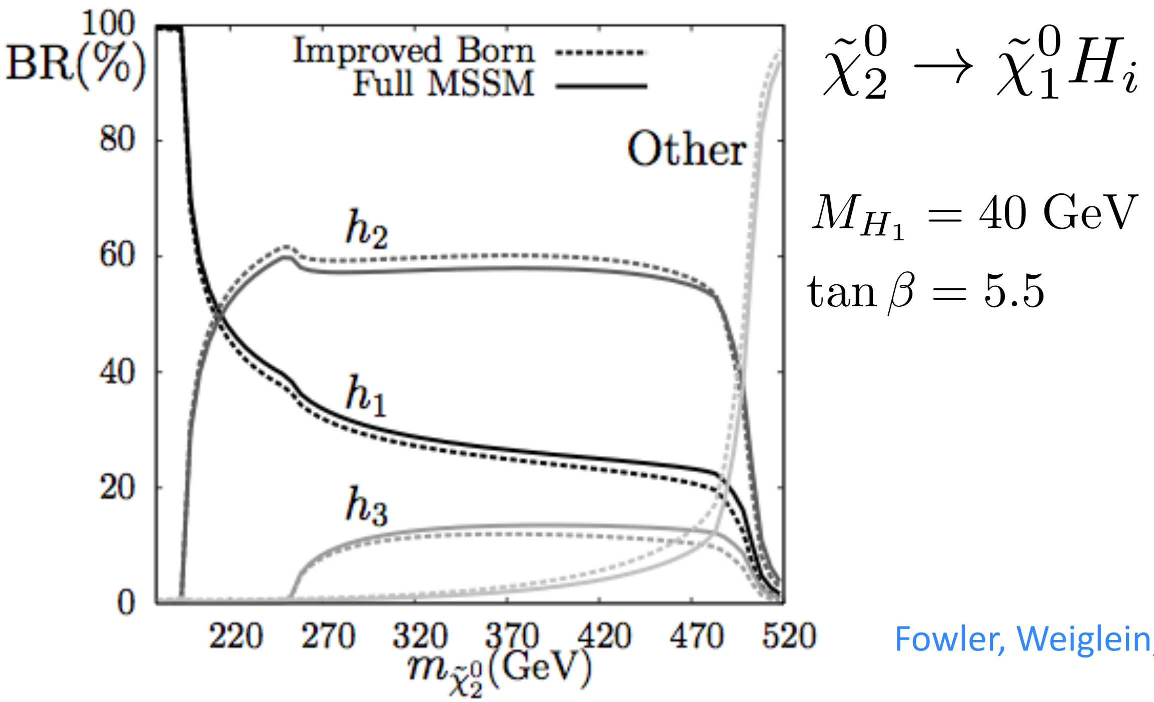
- Boosting the bb analysis

  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)…

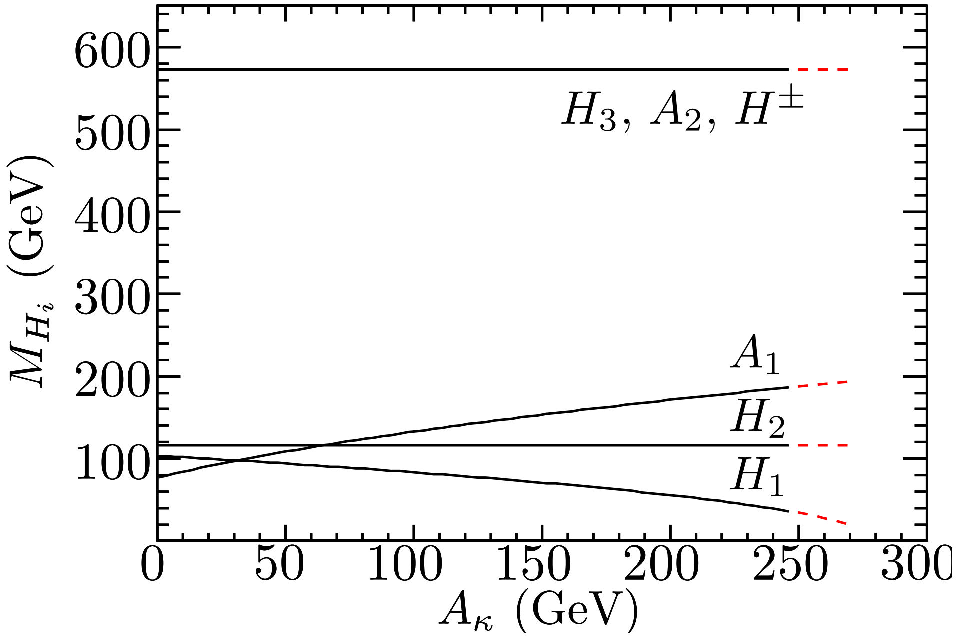
A. Djouadi et al, [0801.4321]

… 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

NMSSMTools 2.3.5



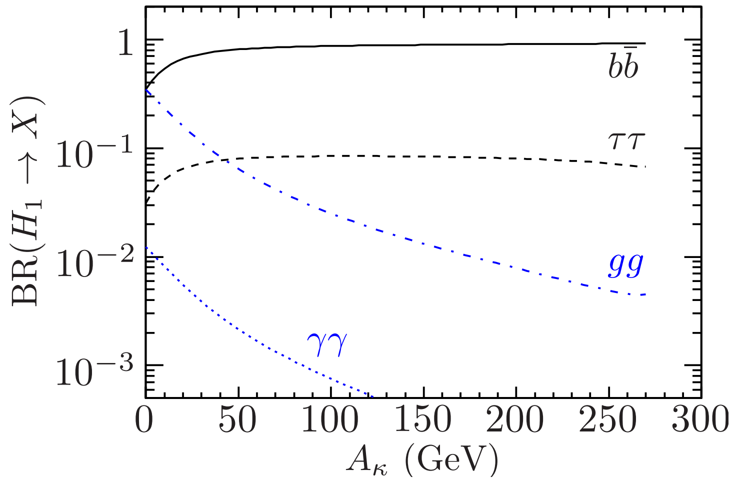
- Example working point

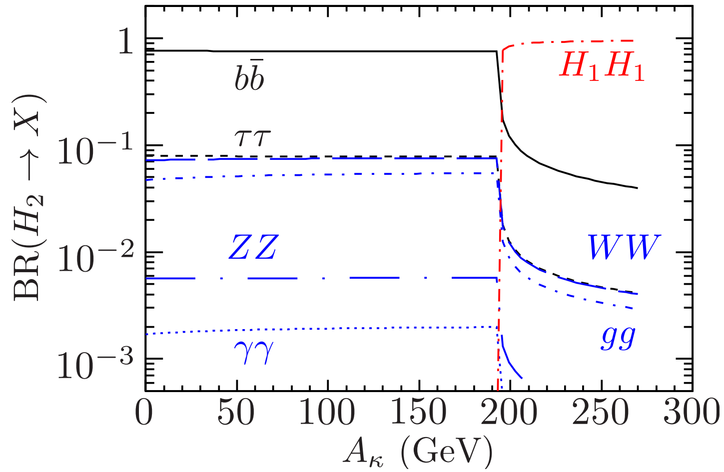
$$M_{H_1} = 40 \text{ GeV}$$

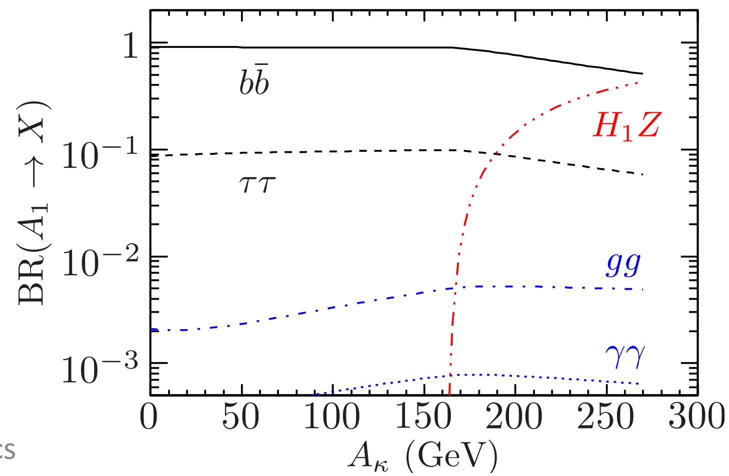
$$M_{H_2} = 116 \text{ GeV}$$

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

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

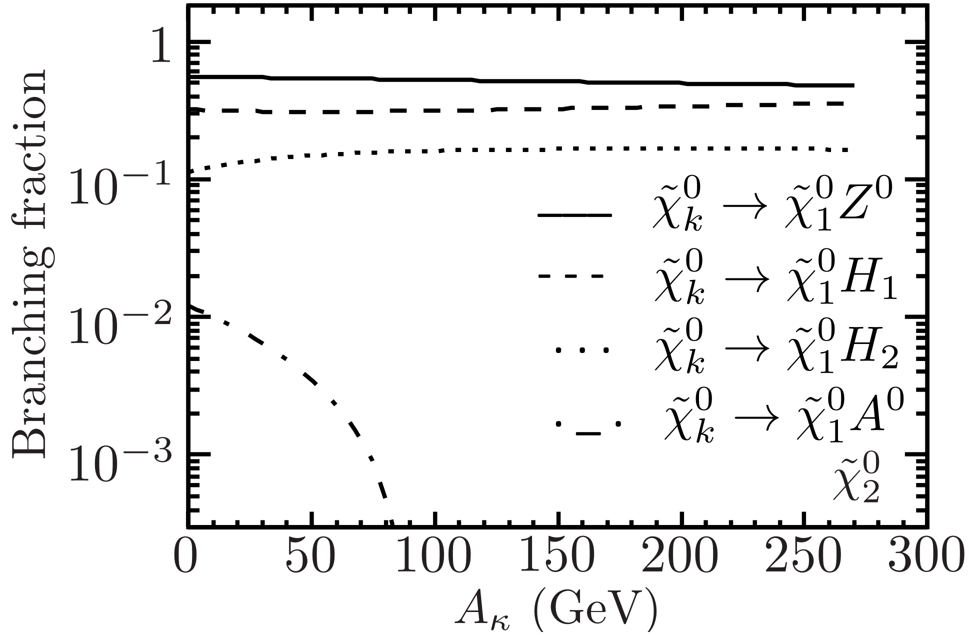


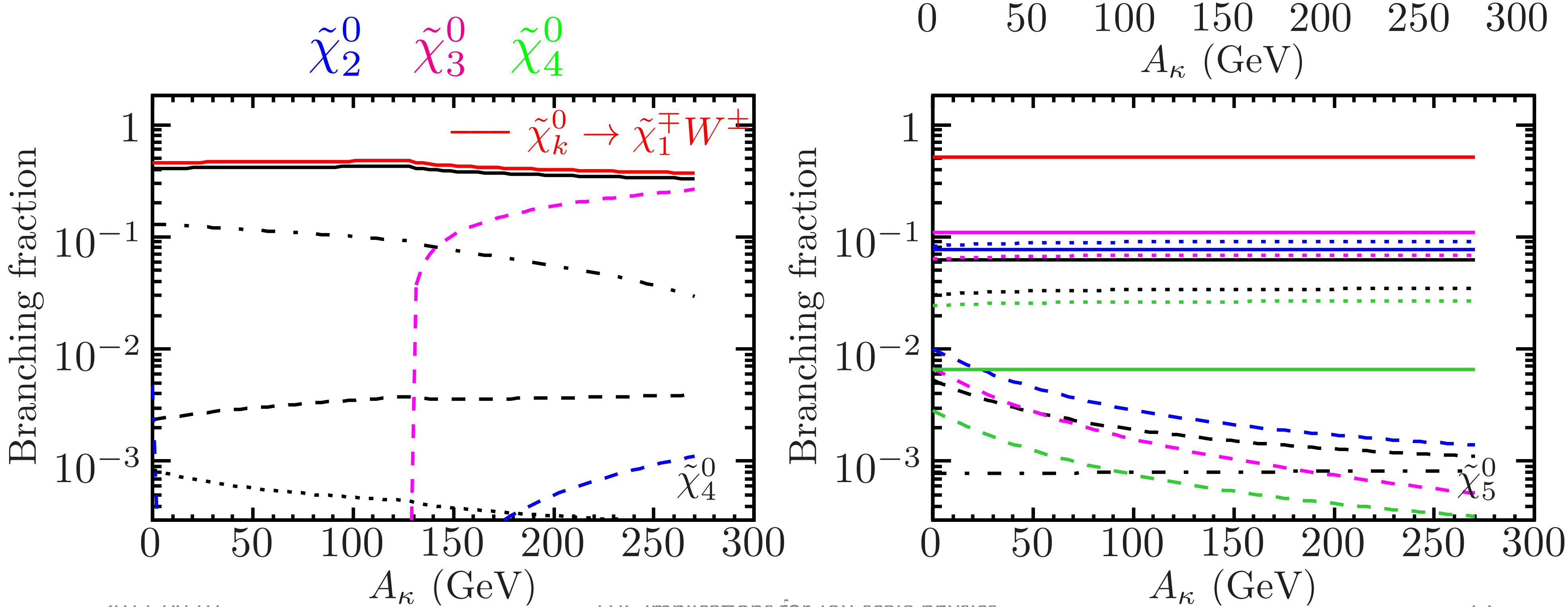




Neutralino sector

$\tilde{\chi}_1^0$	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

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

- 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

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

- (S)QCD corrections <u>sizable</u> -> NLO

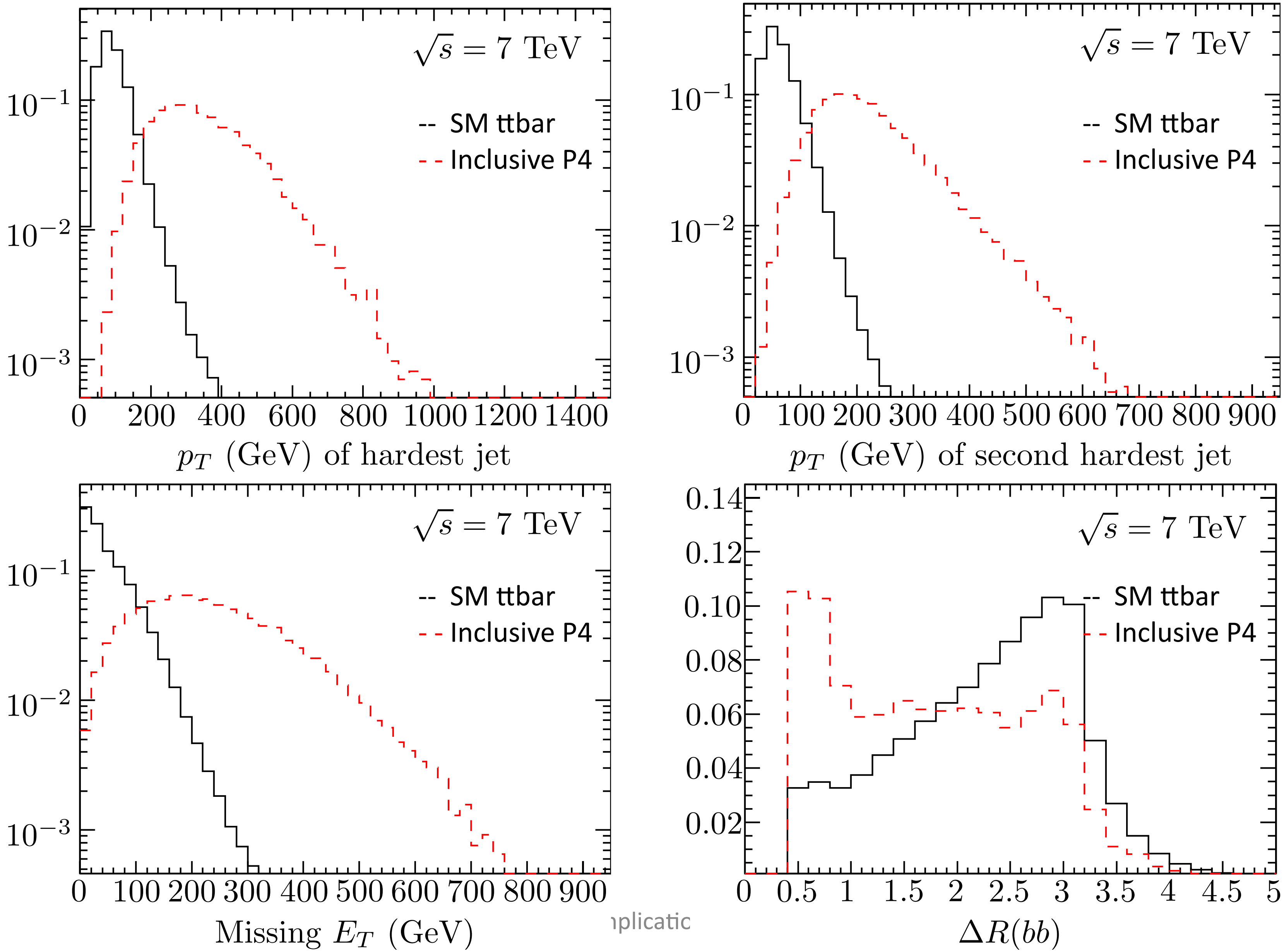
W. Beenakker, R. Höpker, M. Spira, P. M. Zerwas, [hep-ph/9610490]
T. Plehn, Prospino

Masses (GeV)		σ_{LO} (pb)					σ_{NLO} (pb)					
$M_{\tilde{g}}$	$M_{\tilde{q}}$	$\tilde{g}\tilde{g}$	$\tilde{q}\tilde{q}$	$\tilde{g}\tilde{q}$	$\tilde{q}\bar{\tilde{q}}$	Σ	$\tilde{g}\tilde{g}$	$\tilde{q}\tilde{q}$	$\tilde{g}\tilde{q}$	$\tilde{q}\bar{\tilde{q}}$	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

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

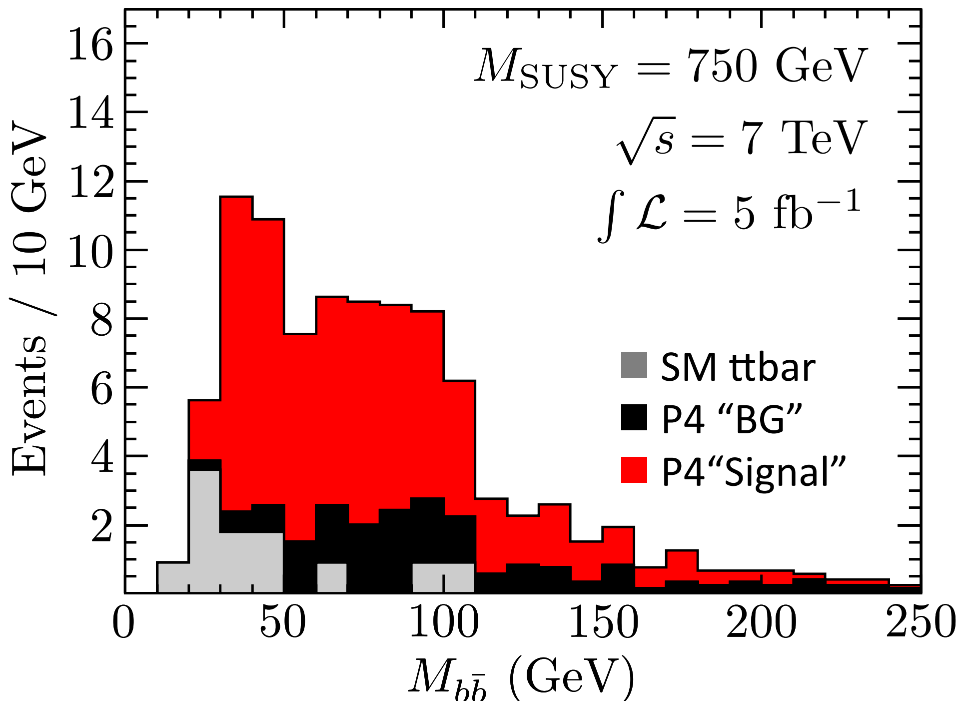
All histograms normalized to unity

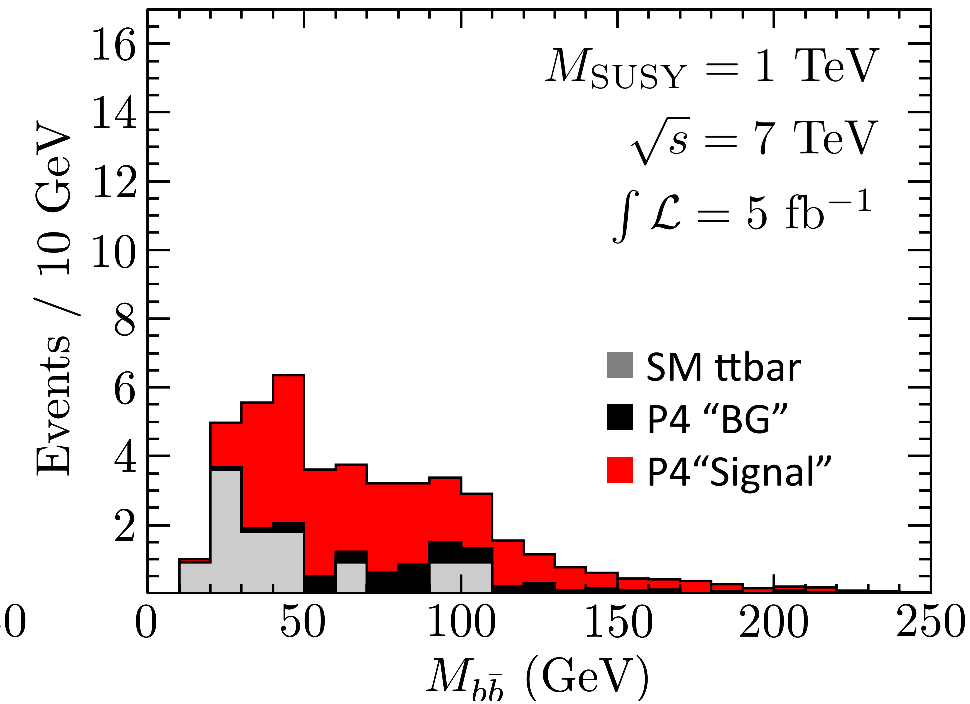


Results for LHC@7 TeV

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

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

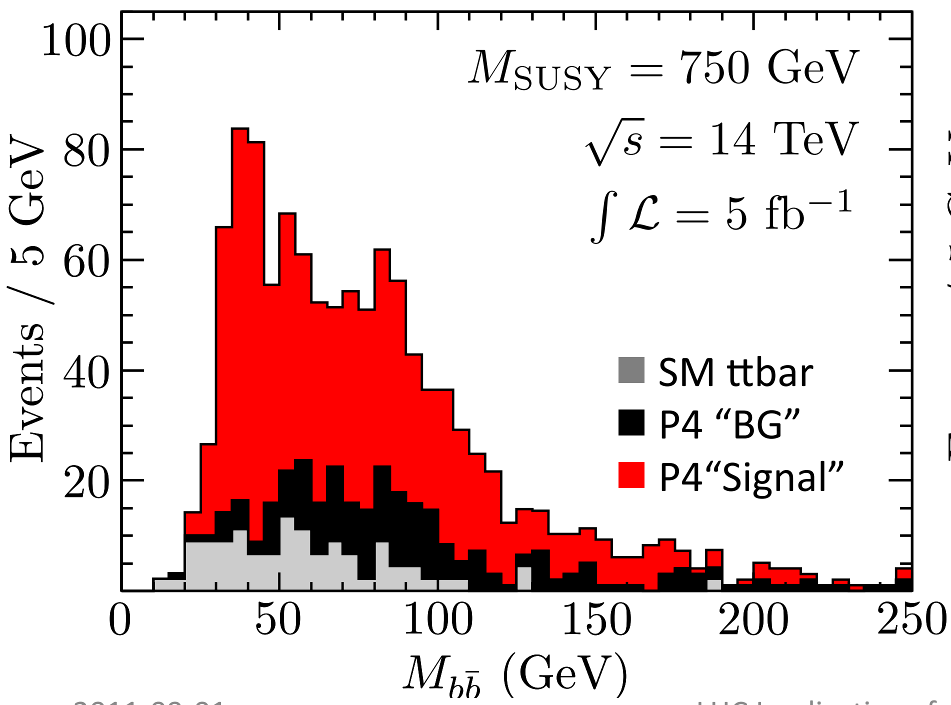


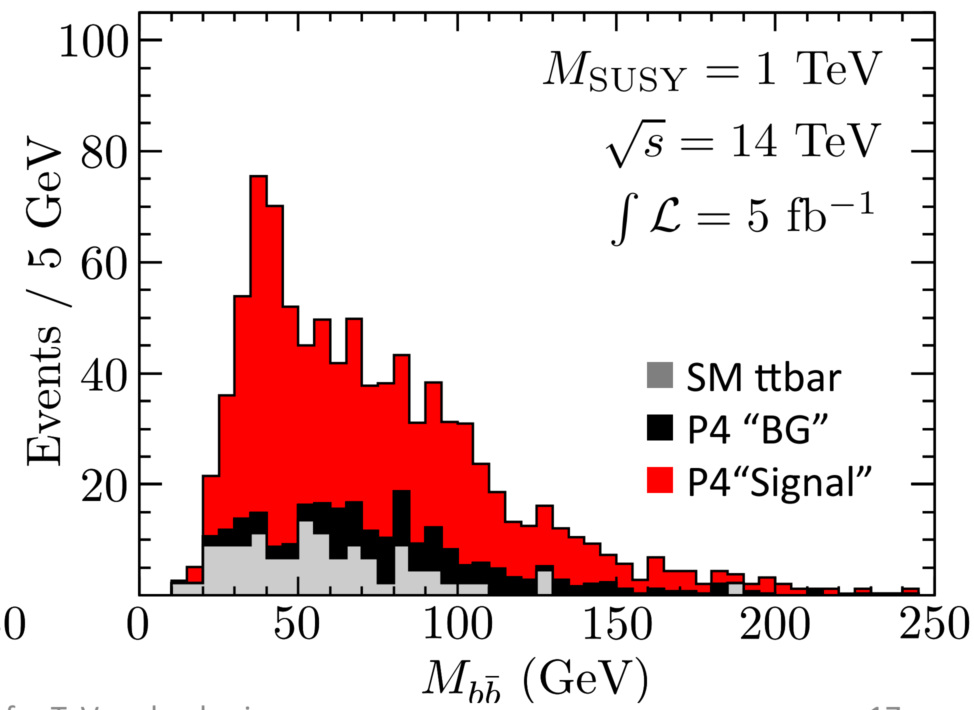


Outlook: LHC@14 TeV

- Statistics greatly improved
- Clear signal also for 1 TeV 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 ($M_H < M_Z$) compatible with constraints can exist in CP-violating MSSM and the NMSSM

- One method to search for light Higgses at the LHC could be through their production in SUSY cascades

- Several studies have shown that SUSY cascades have potential to aid Higgs searches in otherwise difficult channels

- We have worked out one NMSSM example in some detail
  -> 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