Higgs production in SUSY cascades

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LHC Physics Discussion

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Outline

1. Higgs and new New physics interplay (SUSY)
2. The NMSSM with a very light Higgs boson
3. Detecting light Higgs in SUSY cascades
4. Conclusions

Higgs physics and New physics

- Even if new physics is necessary to cure SM Higgs problems, 'Higgs physics' often treated differently wrt 'New physics'

- Not completely decoupled, new physics influence:

  - Radiative corrections to Higgs masses and mixing
    $M_{h0} > M_Z$

  - Non-decoupling effects of SUSY breaking in Yukawa couplings
    Δ_b - effects in Hbb couplings

  - Explicit contributions at one-loop
    g g -> H, H -> $\gamma\,\gamma$

- SUSY -> Higgs searches in 'mh-max' scenario enough?

Higgs and new physics in conjunction

- Only changes to rates – nothing fundamentally different from SM
  Even for searches that involve the new (heavy) MSSM Higgses

- Restricting BSM Higgs searches to ‘SM-like’ scenarios
  may be too limited in the sense that

  - Lighter, non-SM like, Higgs bosons may be allowed
  - Heavy Higgs bosons may decay to new physics (or H)
  - Light 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

- These issues require Higgs physics and new physics to be treated
  in conjunction -> more “model dependence”

Example: Light H in SUSY cascades

- Production of light ($M_{H1} < M_Z$) Higgs bosons in SUSY cascades

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

$$\tilde{\chi}_2^+ \to \tilde{\chi}_1^+ H_k$$

Alternative production mechanism which should be investigated.
Event selection could benefit from hard SUSY scale (~ TeV).

Light Higgs in CP-violating MSSM ("CPX hole")
Scenario which admits very light H_1 (~ 40-45 GeV)

Full 1-loop corrections to $\chi_i^0 \to \chi_j^0 H_k$ decays

Fowler, Weiglein, arXiv:0909.5165

Higgs modes can be dominant when kinematically accessible

Theoretical Setup: The NMSSM

MSSM: two complex Higgs doublets: H_u, H_d

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

μ has mass dimension -> Natural value $\mu = M_p$
Phenomenology -> μ must be close to EW scale

NMSSM
Two Higgs doublets + complex singlet S

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

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

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

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: $H^\pm$

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

tree-level parameters increased: $\lambda, \kappa, A_\kappa, A_\lambda, v_S + \tan\beta$

$$m_A^2 = \frac{\lambda v_S}{\sin\beta\cos\beta}(A_\lambda + \kappa v_S) \qquad m_{H^\pm} \leftrightarrow A_\lambda$$

$$m_{H^\pm}^2 = m_A^2 + m_W^2 - \lambda^2 v^2$$

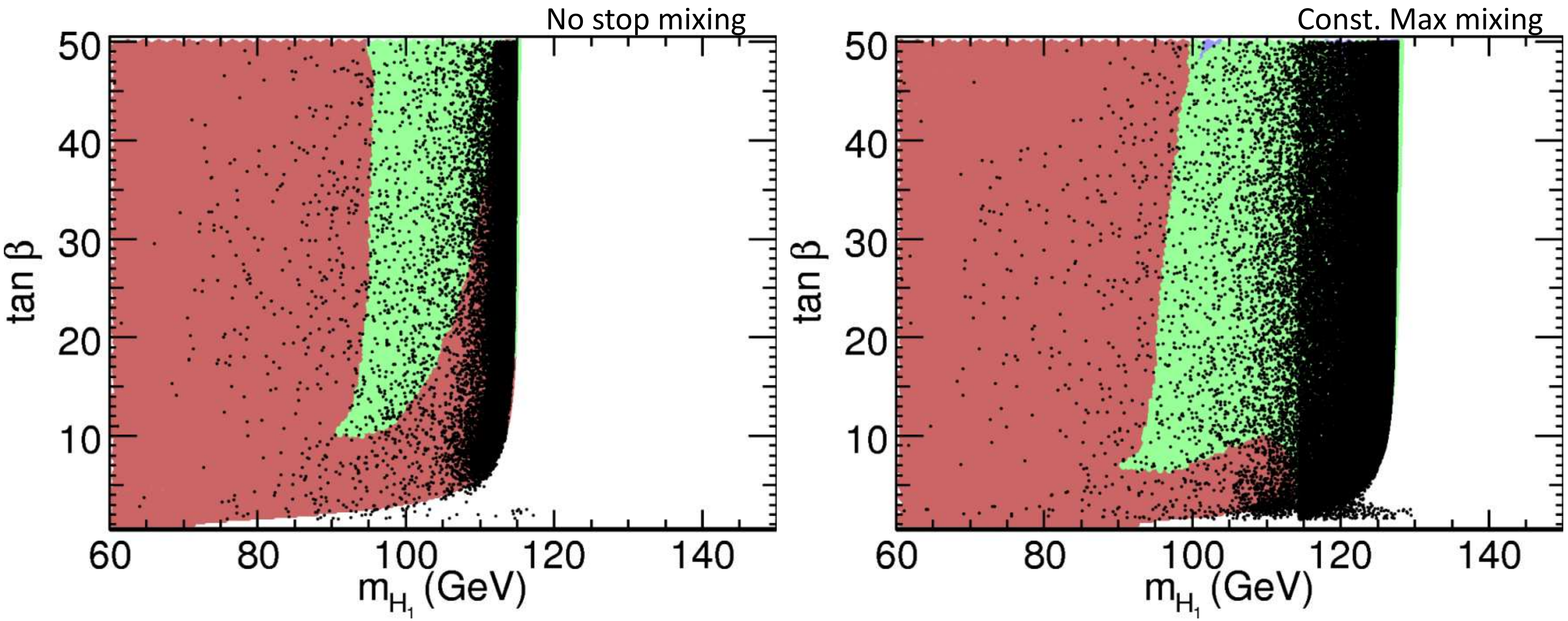
$$\mu = \lambda v_S \qquad \mu \leftrightarrow v_S$$

$m_{H^\pm}, \tan\beta, \mu, \lambda, \kappa, A_\kappa$

Light Higgs bosons

F. Mahmoudi, J. Rathsman, OS, L. Zeune
EPJC 71:1608 (2011), arXiv:1012.4490

LEP constraints: Higgs bosons can be lighter in NMSSM compared to corresponding CP-conserving MSSM scenarios.



New decay modes: $H_1 \to A_1 A_1 \to 4\tau \qquad m_{A_1} < 2m_b$

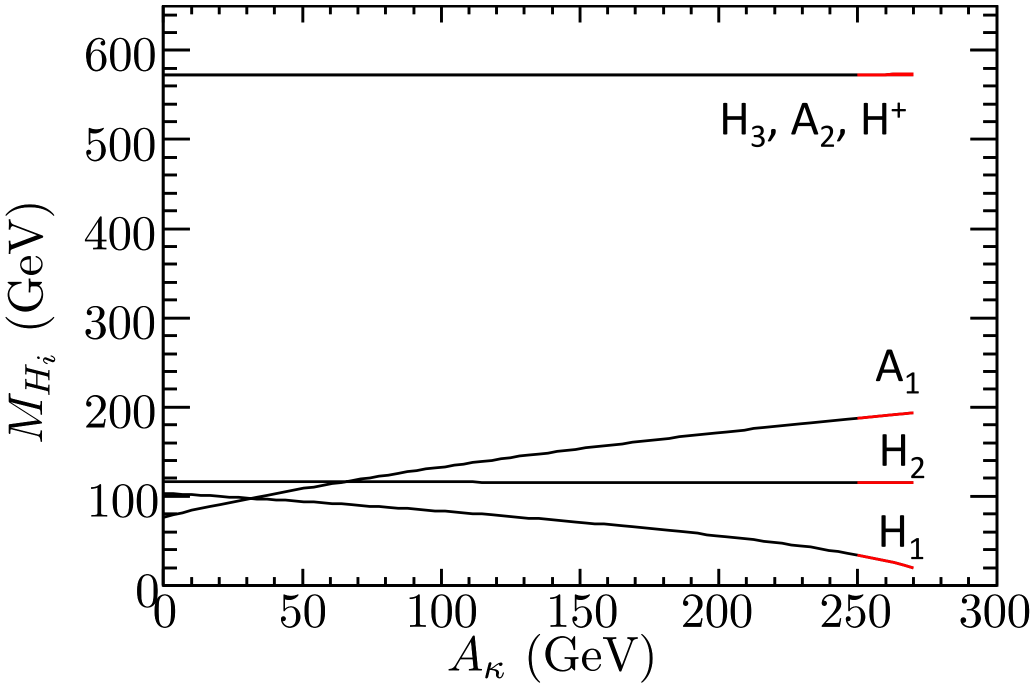
Doublet-Singlet mixing: Reduces H_1ZZ coupling

Numerical examples: 'P4' NMSSM benchmark

Djouadi et al, arXiv:0801.4321

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
Trilinear couplings					
$A_t = A_b = A_\tau = 0$ GeV					

Mass spectrum



$$A_\kappa = 238 \text{ GeV} \Rightarrow$$

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

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

$$M_{A_1} \simeq 180 \text{ GeV}$$

$$M_{H^+} \simeq 560 \text{ GeV}$$

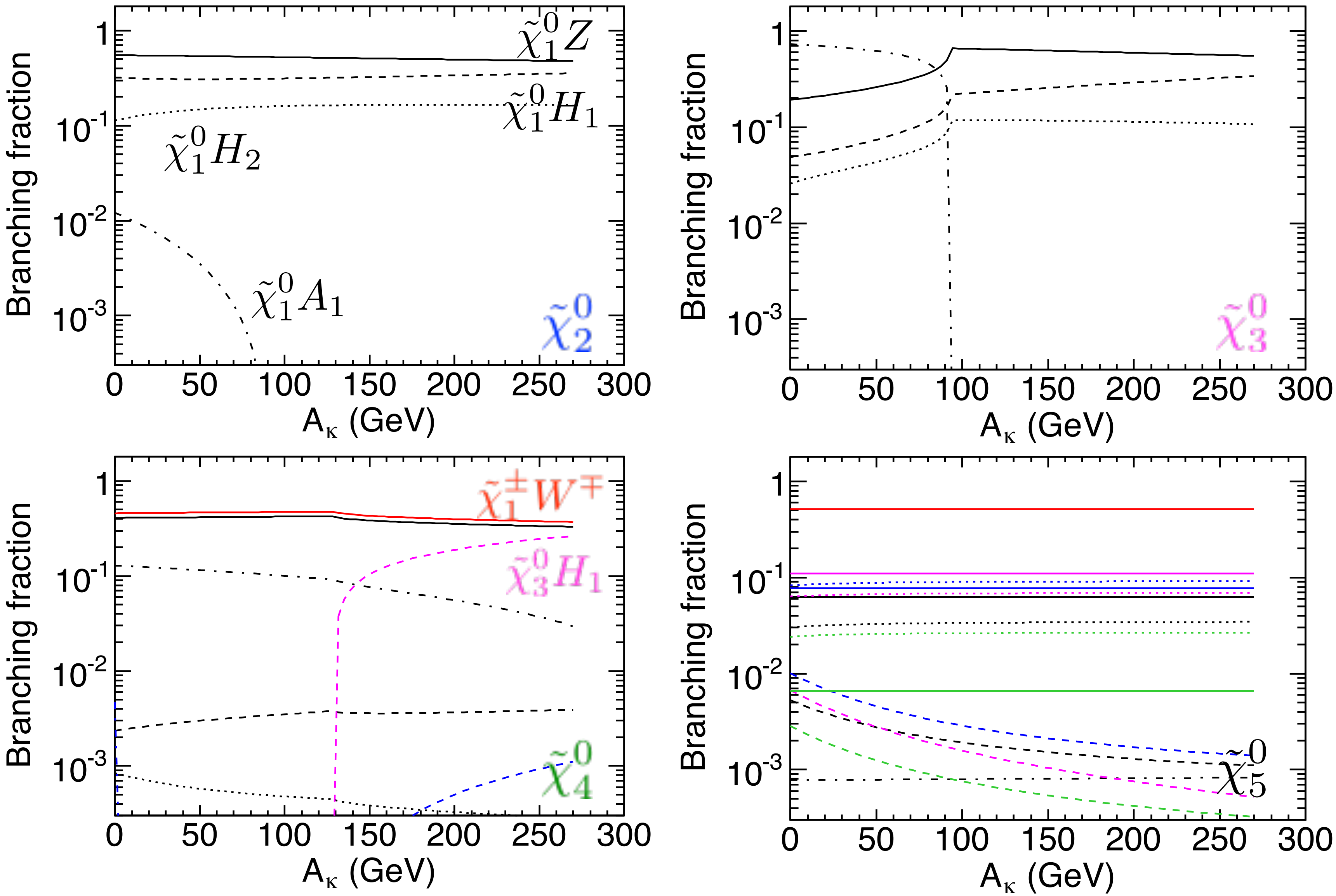
Allowed by LEP!

$$M_{\tilde{\chi}_1^0} = 97.6 \text{ GeV}, \quad M_{\tilde{\chi}_2^0} = 227 \text{ GeV}, \quad M_{\tilde{\chi}_3^0} = 228 \text{ GeV}$$

$$M_{\tilde{\chi}_4^0} = 304 \text{ GeV}, \quad M_{\tilde{\chi}_5^0} = 616 \text{ GeV}$$

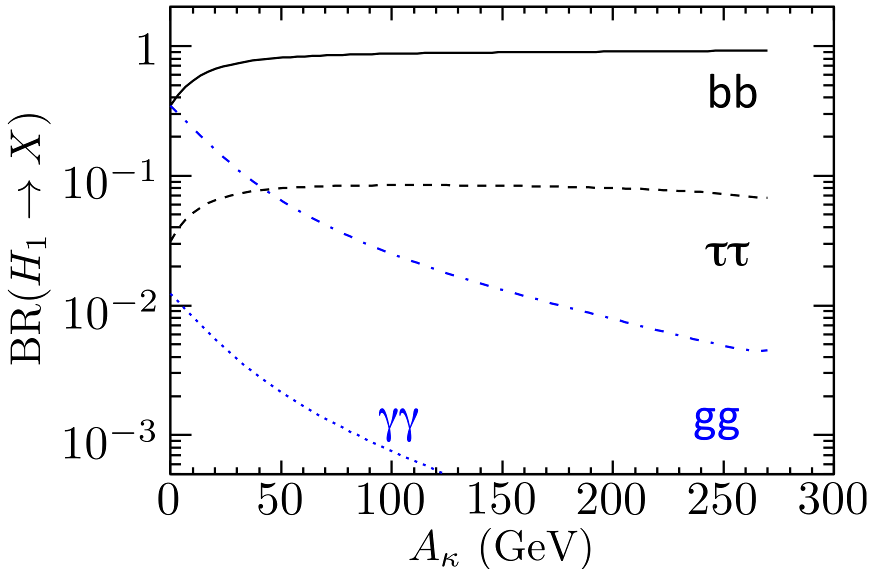
$$M_{\tilde{\chi}_1^+} = 207 \text{ GeV}, \quad M_{\tilde{\chi}_2^+} = 616 \text{ GeV}$$

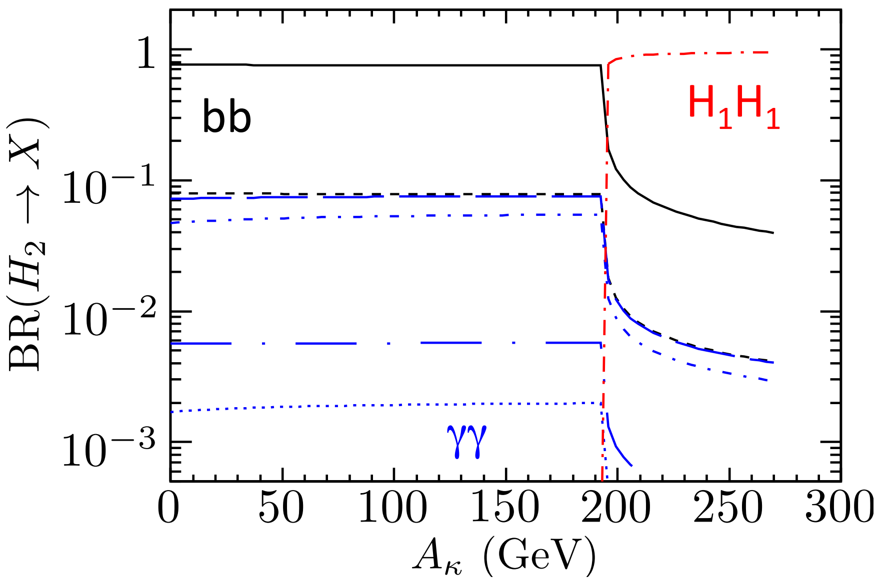
Neutralino decays

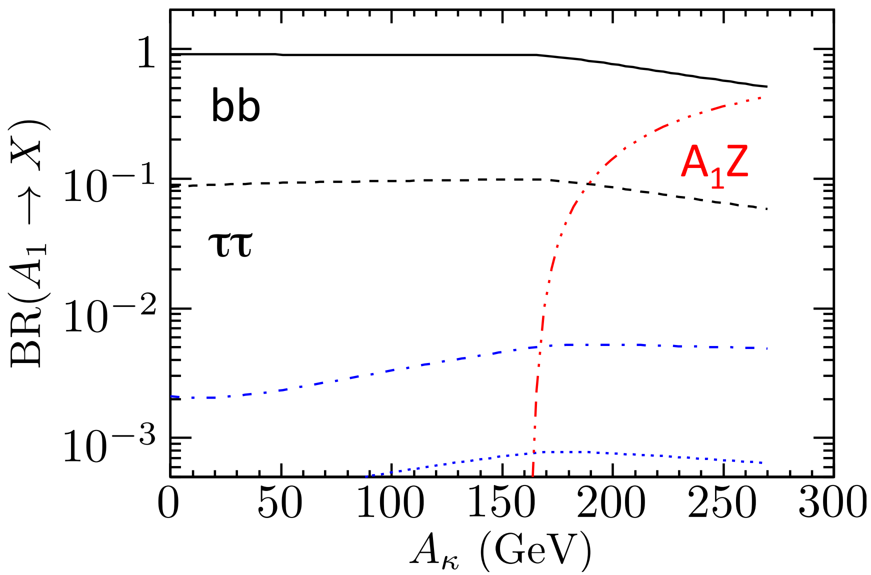


Higgs decay modes

- bb dominates for H_1
- Relevant for heavier Higgses
  – also indirectly through H_1
- Tau channel alternative
  (Not discussed further here)







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 also include charginos, W, Z, etc.

- 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

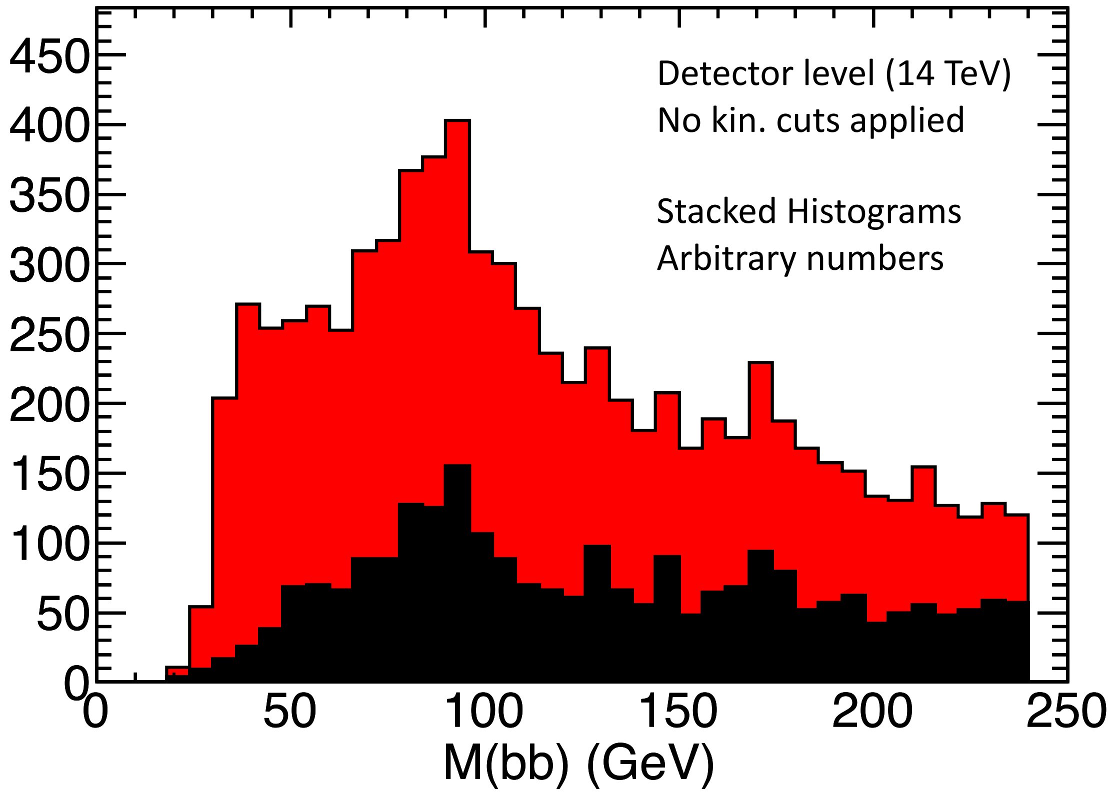
$$pp \to \tilde{g}\tilde{g}, \tilde{q}\tilde{q}, \tilde{g}\tilde{q}, \tilde{q}\tilde{\bar{q}}$$

- (S)QCD corrections sizable -> NLO

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

Energy $\sqrt{s}$	Masses (GeV) $M_{\tilde{g}}$	$M_{\tilde{q}}$	σ_{NLO} (pb) $\tilde{g}\tilde{g}$	$\tilde{q}\tilde{q}$	$\tilde{g}\tilde{q}$	$\tilde{q}\tilde{q}^*$	Σ
7 TeV	750	750	0.073	0.27	0.39	0.79	0.82
7 TeV	1000	750	0.006	0.21	0.10	0.07	0.39
7 TeV	1000	1000	0.005	0.036	0.036	0.006	0.084
14 TeV	750	750	2.21	2.06	6.78	1.53	12.6
14 TeV	1000	750	0.32	1.59	2.44	1.34	5.69
14 TeV	1000	1000	0.31	0.51	1.19	0.26	2.27

Inclusive bb mass spectrum



- Inclusive SUSY (no Higgs) is "bg"

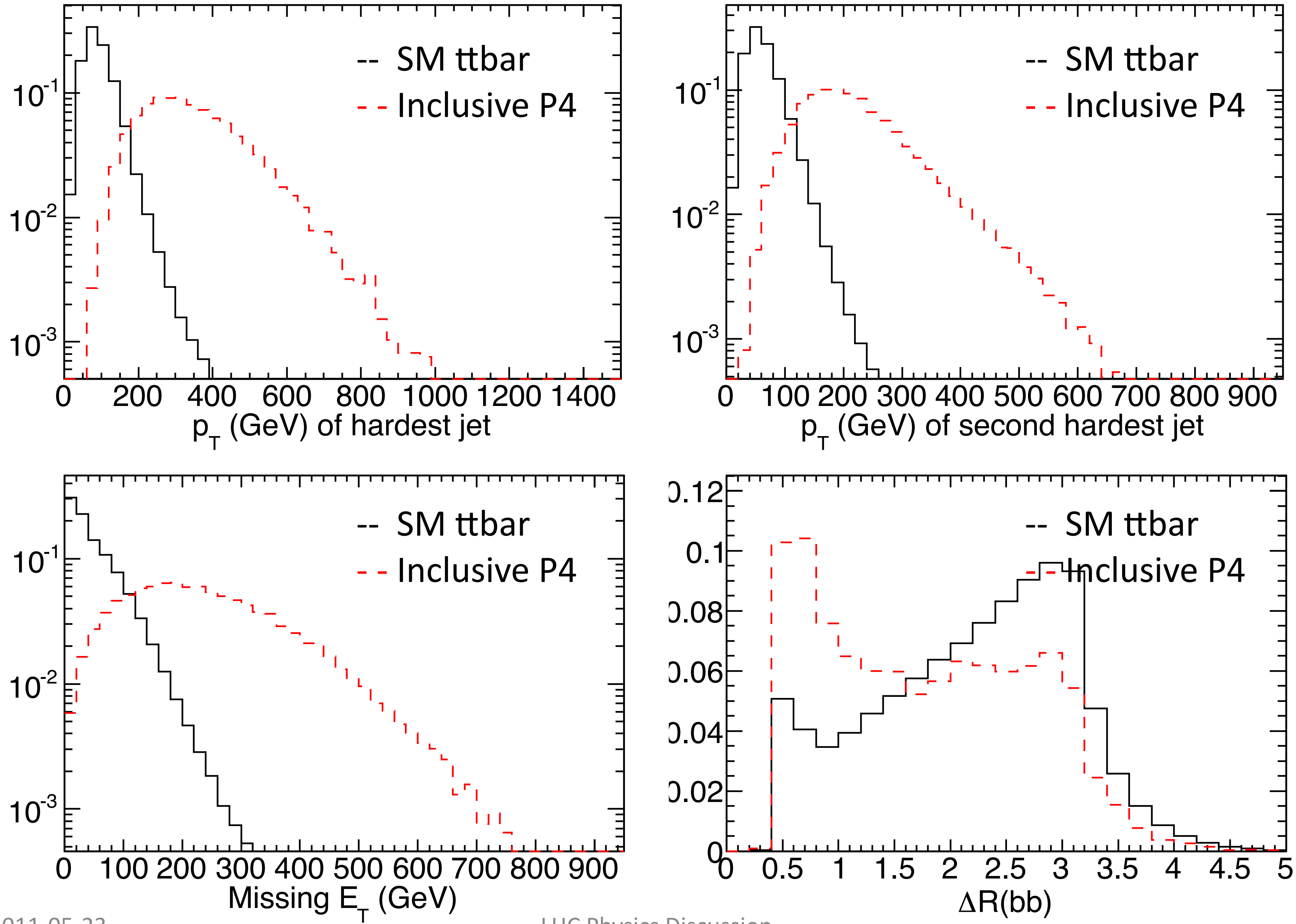
■ Incl. sample with 0 Higgses
■ Events with ≥1 Higgs boson

SUSY spectrum unknown -> Do not try to suppress SUSY BG

Kinematic distributions

$\sqrt{s} = 7\ \mathrm{TeV}$

All histograms normalized to unity

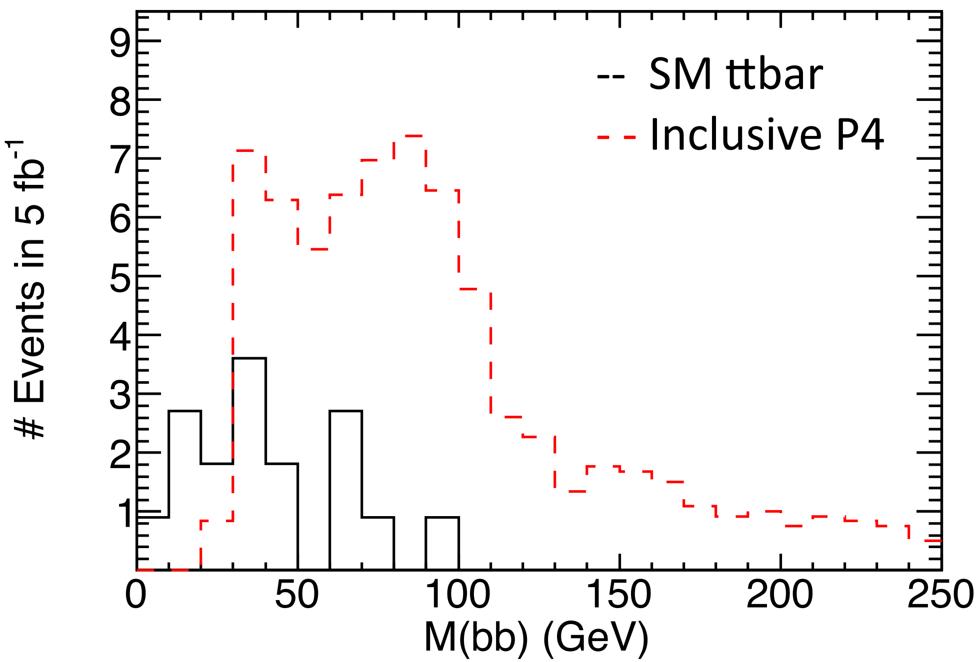


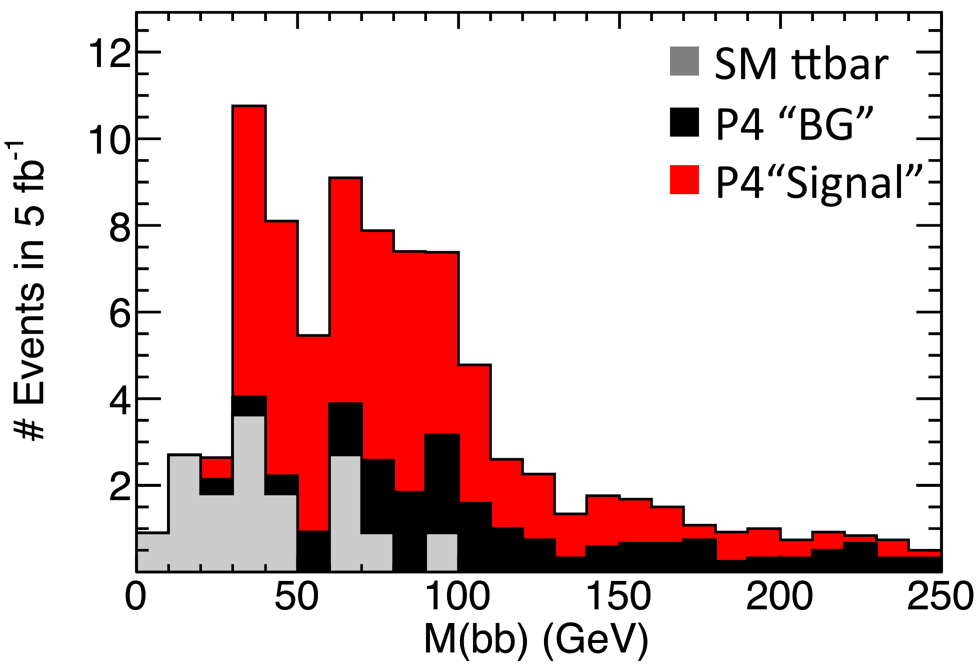
Preliminary results: 7 TeV

$N_{\text{jets}} \geq 4$ $N_b \geq 2$ $E_T^{\text{miss}} > 150$ GeV

$p_T(\text{jet1}) > 200$ GeV $\Delta R(b\bar{b}) < 1.5$

$p_T(\text{jet2}) > 100$ GeV



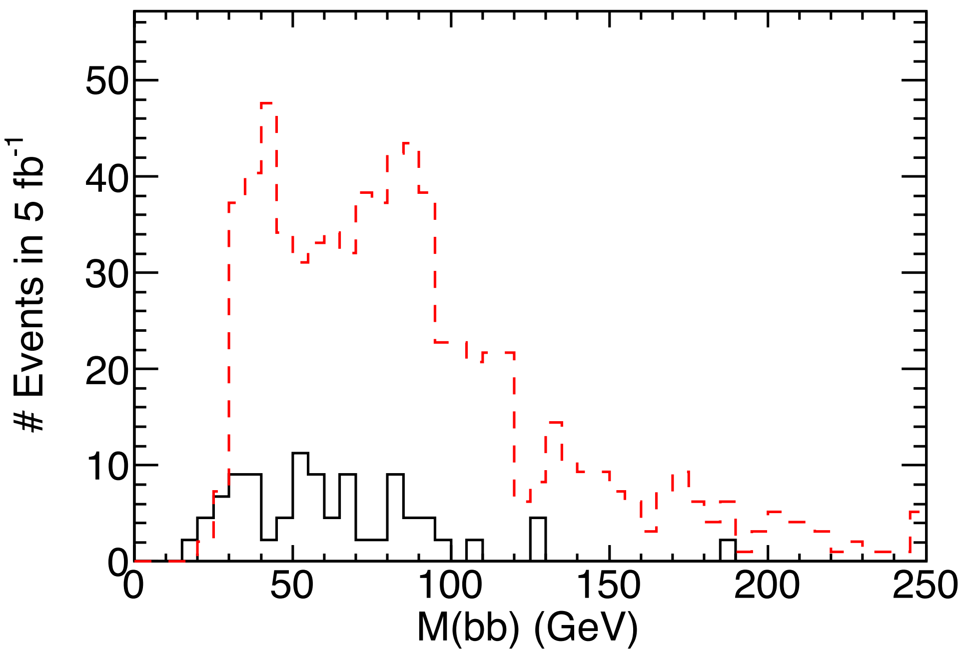


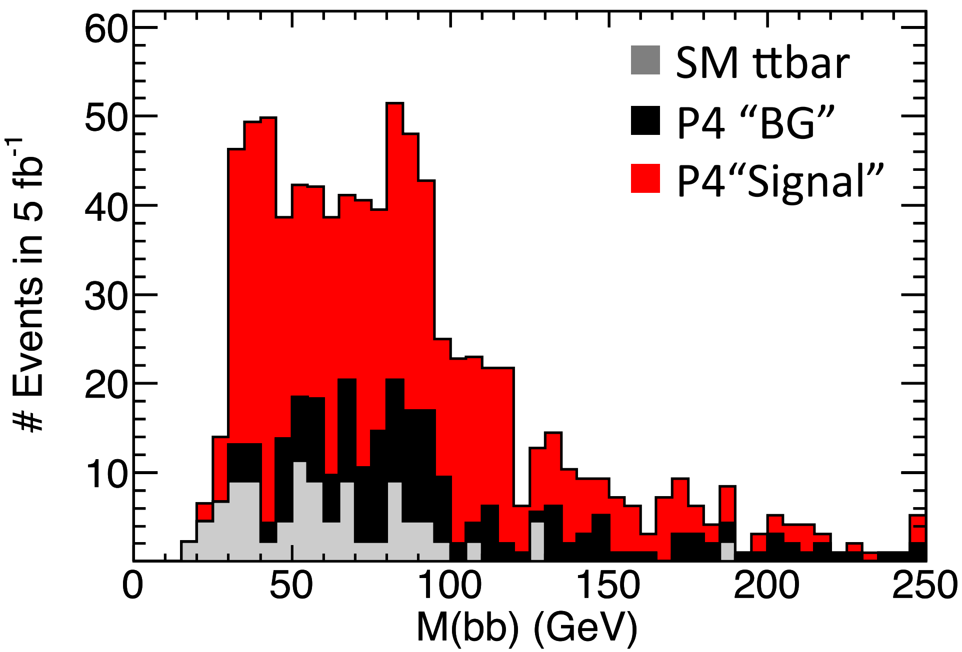
Preliminary results: 14 TeV

$N_{\text{jets}} \geq 4$ $\quad N_b \geq 2$ $\quad E_T^{\text{miss}} > 200$ GeV

$p_T(\text{jet1}) > 200$ GeV $\quad \Delta R(b\bar{b}) < 1.2$

$p_T(\text{jet2}) > 100$ GeV





Conclusions

- Higgs physics is by tradition separate from `new physics'
- We emphasize the possible interplay, leading to phenomena beyond rescaling of SM results such as
  -> New modes of Higgs production and decay at the LHC
  -> Additional backgrounds
- Example: Light singlet Higgs in cascades (NMSSM)
- Higgs bosons with mass below 90 GeV are not excluded
- Present in large fraction of 2b-events with SUSY-type selection
- Simulations show promising signal at 7 (14) TeV with 5 fb^{-1}