LHC and ILC implications of a 125 GeV Higgs boson in supersymmetry

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KILC12

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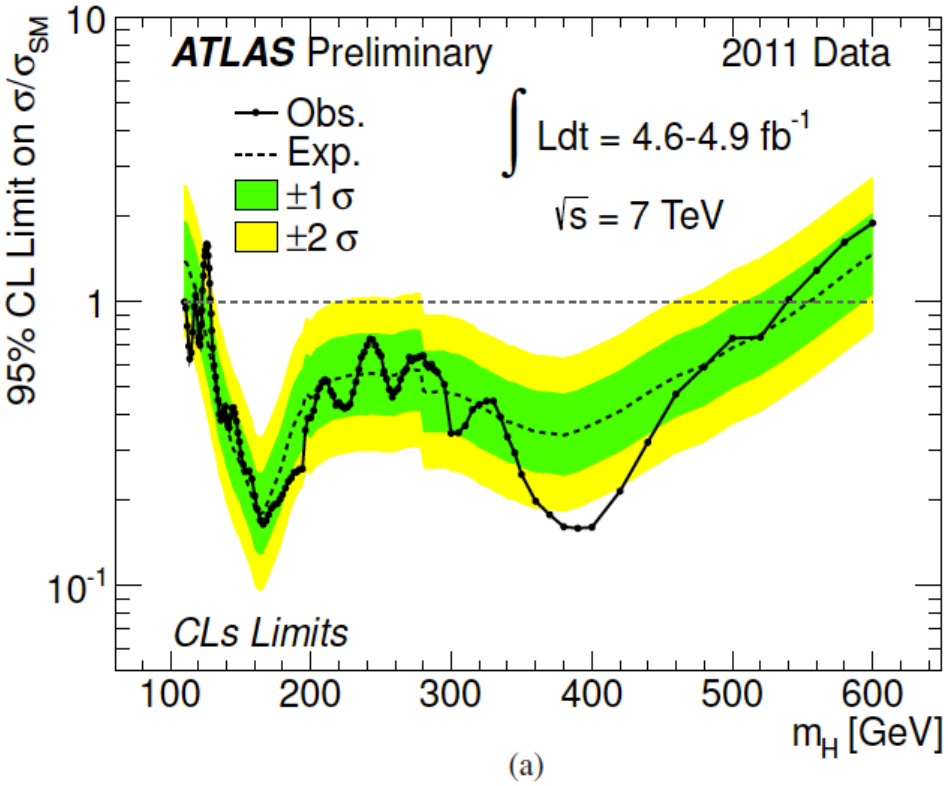
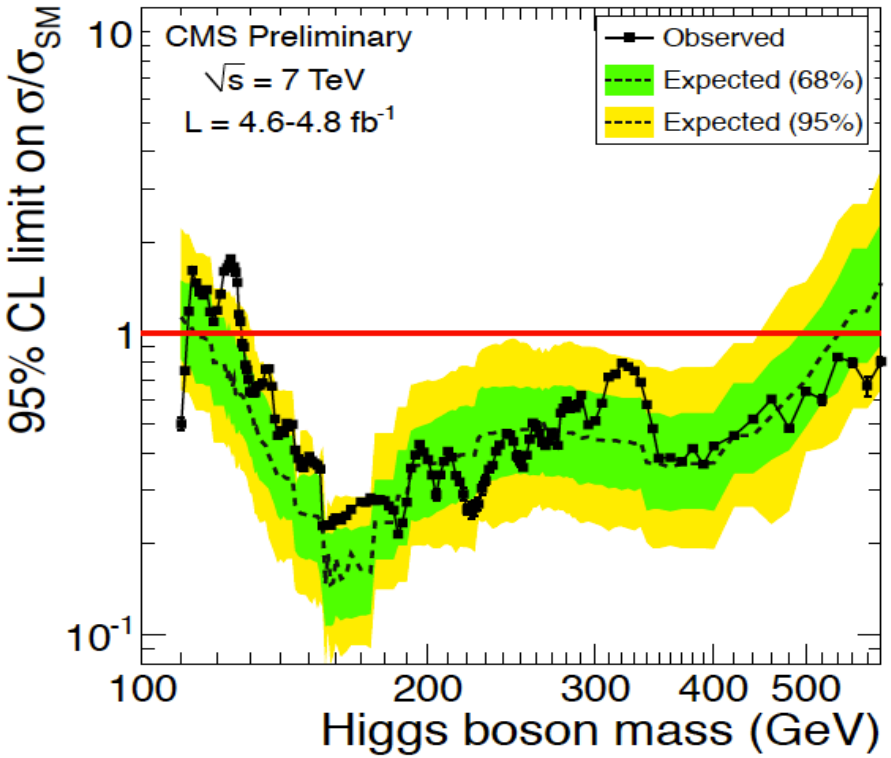
LHC Higgs Search Results

- Updated SM Higgs search results from ATLAS and CMS at Moriond using full 2011 dataset (close to 5 fb^{-1})

- SM-like Higgs excluded for $M_H > 130$ GeV -> Good news for SUSY (heavier non-SM Higgses not excluded – model-dependent bounds)





MSSM Higgs Sector

- Minimal SUSY with two complex Higgs Doublets: H_u, H_d
  -> 8 degrees of freedom, 5 physical Higgs bosons

- CP conservation: h, H (CP-even), A (CP-odd), and $H^{\pm}$

$$m_H > m_h$$

- At tree-level, the Higgs sector is determined by two parameters

$$M_A,\ \tan\beta = \frac{v_u}{v_d}$$

- Other Higgs masses are *predictions*:

$$M_h^2 = M_{h,\mathrm{tree}}^2(M_A, \tan\beta) + \Delta M_h^2\left(M_{\mathrm{SUSY}}, A_i, M_i, \ldots\right)$$

$$M_{h,\mathrm{tree}}^2 \leq M_Z^2 \cos^2 2\beta \qquad M_h \lesssim 135\,\mathrm{GeV}$$

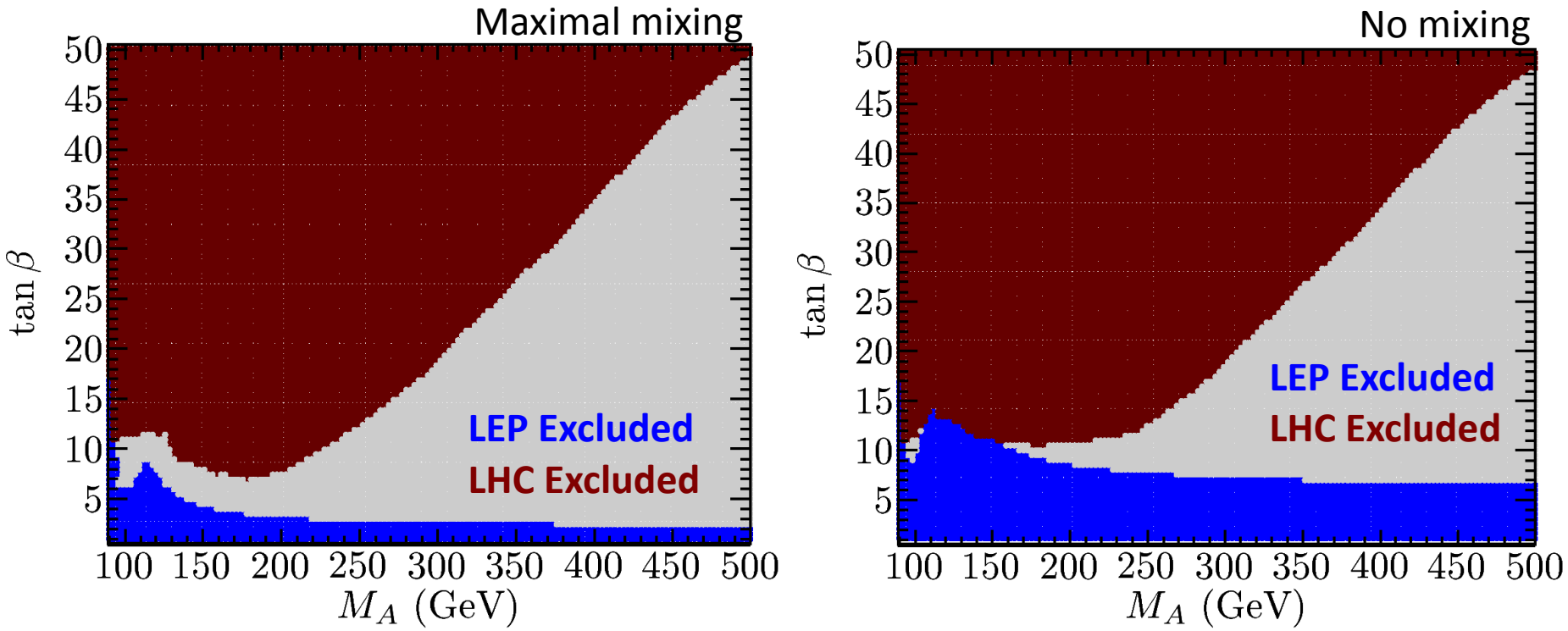
MSSM Exclusion limits

- In addition to the results for a light SM-like h, include dedicated searches for heavy SUSY Higgs, e.g. $H/A \to \tau\tau$

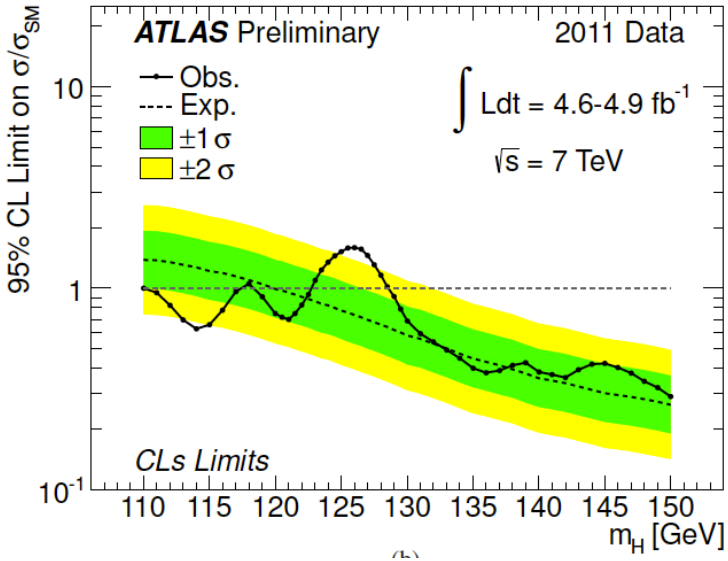
  $t \to bH^+ \to b\tau^+\nu_\tau$

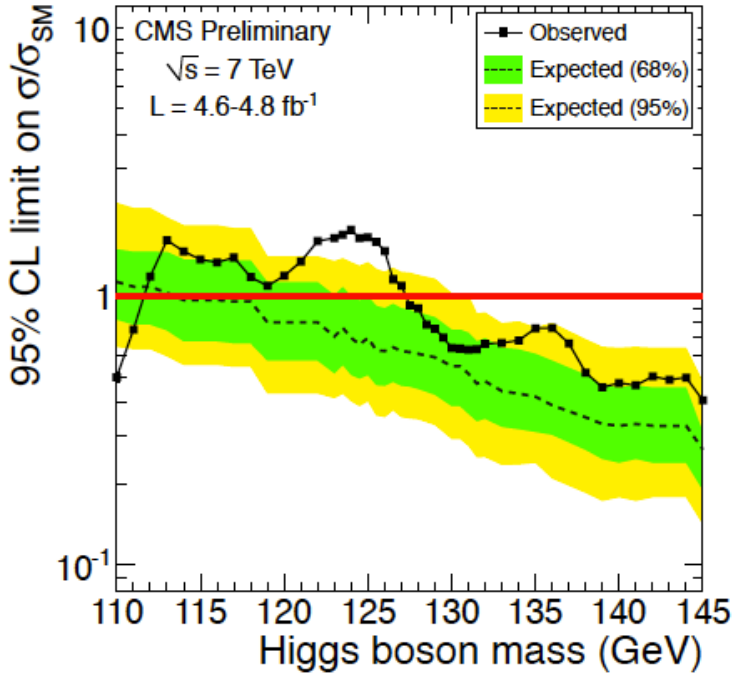
- Limits at 95% CL (no theory uncertainties on Higgs masses)

HiggsBounds: http://www.ippp.dur.ac.uk/HiggsBounds



First hint of a Higgs signal?





ATLAS

Largest excess seen at M_H = 126 GeV
Significance: 2.5 σ local (2.8 σ expected)
<2 σ including LEE

CMS

Largest excess seen at M_H = 125 GeV
Significance: 2.8 σ local, (2.8 σ expected)
2.1 σ including LEE

+ Interesting Tevatron results

First hint of a Higgs signal?

Since Dec. 13 many papers have appeared on this topic

[1112.2703], [1112.3017], [1112.3026], [1112.3028], [1112.3032], [1112.3336], [1112.3564], [1112.3645], [1112.3647], [1112.3548], [1112.4146], [1112.4391], [1112.4835], [1112.5099], [1112.5180], [1112.5666], [1201.2611], [1201.2671], [1201.2898], [1201.4338], [1201.5305], [1202.0054], [1202.3144], [1202.3262], [1202.5190], [1202.5821], [1203.3141], [1203.3207], [1203.3446], [1203.4254], [1203.5048], [1204.0080], [1204.1061], [1204.2856], …

Interpretations in the framework of
SM, pMSSM, cMSSM, NUHM, GMSB, AMSB, NMSSM,
BMSSM, UMSSM, 2HDM, RS Radions,
(insert your favorite model here)

-> No time for a review. Not even of the MSSM results.

MSSM interpretation of M_h = 125 GeV

S. Heinemeyer, OS, G. Weiglein, *Phys. Lett.* B710 (2012) 201, [1112.3026]

- We *assume* an MSSM Higgs boson signal is present in LHC data

  Experimental result: $M_h = 125 \pm 1\,\mathrm{GeV}$

- Higgs spectrum up to 2-loop order calculated with FeynHiggs.
  2 GeV theory uncertainty on M_h (e.g. from missing higher orders) added linearly:

$$122\,\mathrm{GeV} < M_h < 128\,\mathrm{GeV}$$

- SM top mass (1 σ interval) taken as parametric uncertainty

$$m_t = 173.2 \pm 0.9\,\mathrm{GeV}$$

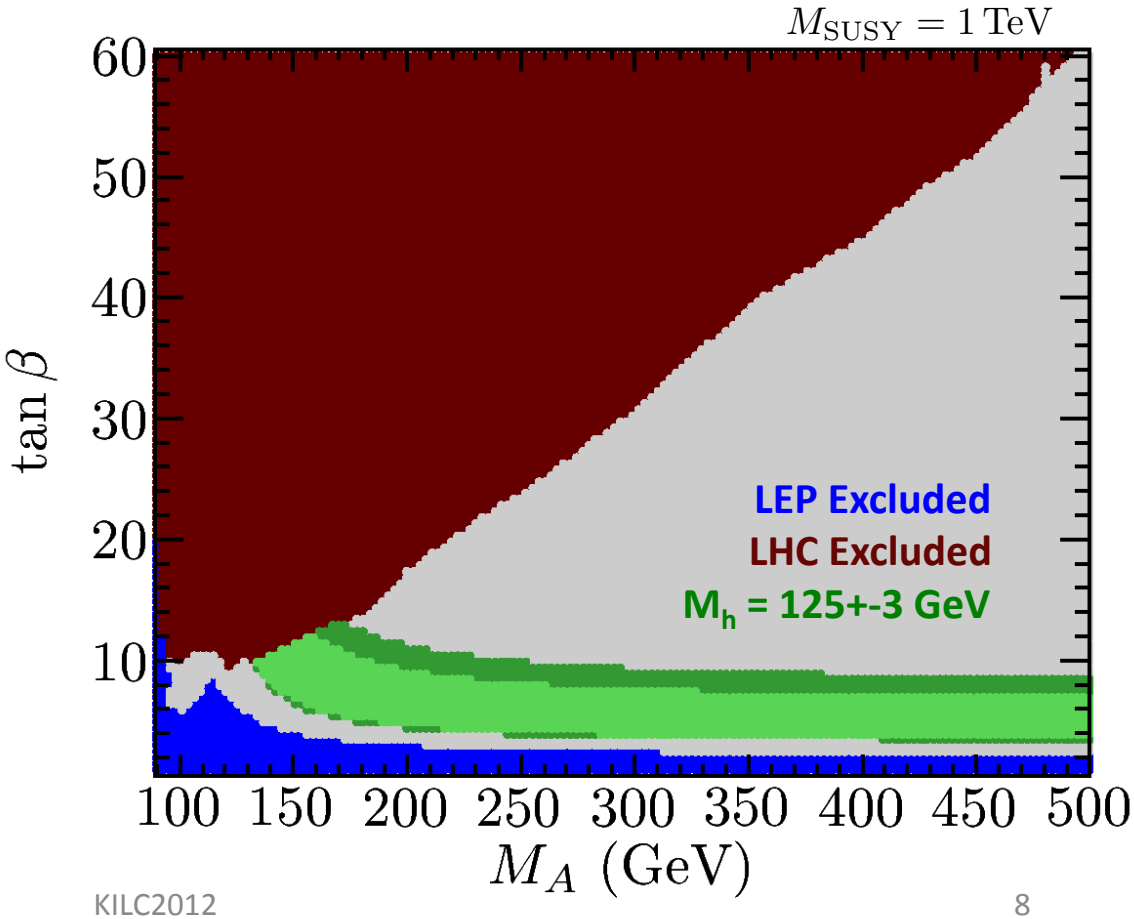
Lower limits on MSSM tree-level parameters

- M_h is increasing function of tree-level parameters

- For a given SUSY mass scale M_{SUSY}, maximize the contributions to M_h from radiative corrections -> maximal stop mixing

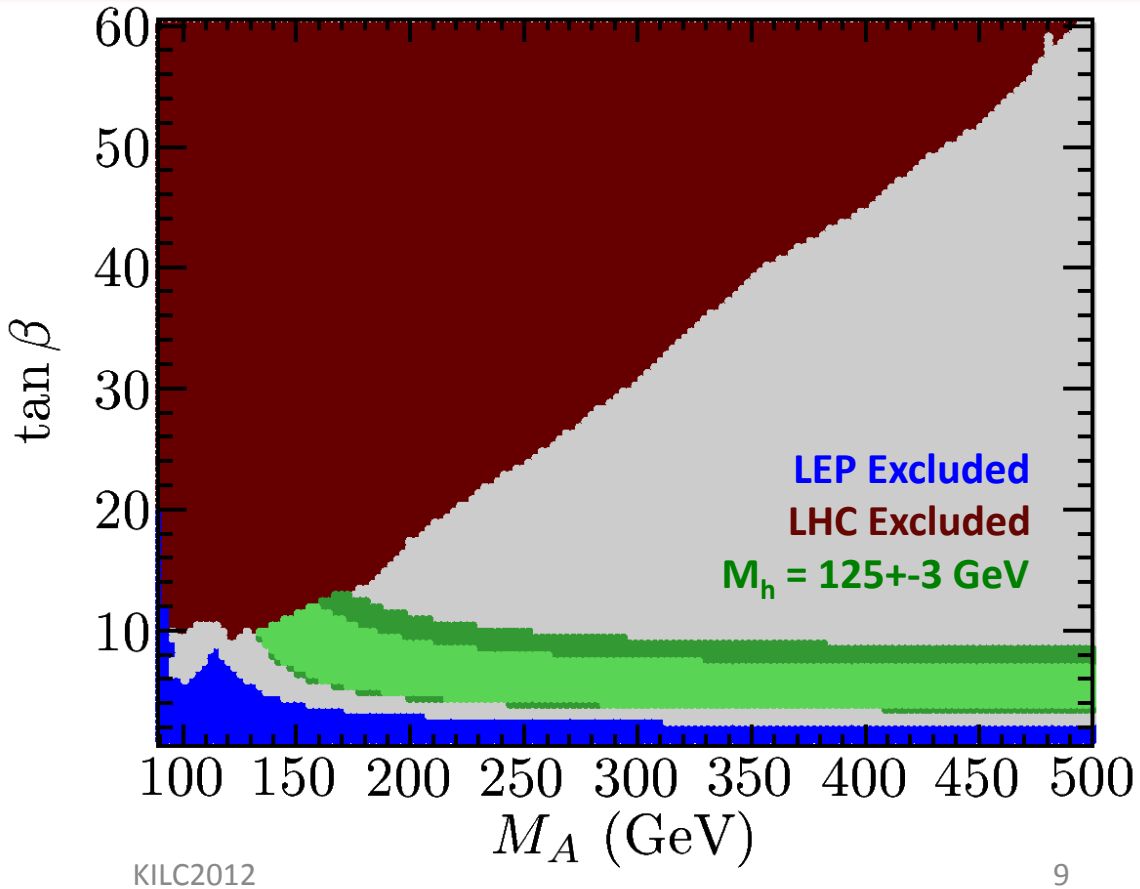
$$X_t = A_t - \mu \cot\beta = 2M_{\mathrm{SUSY}}$$

- Scenario-independent *lower* bounds on M_A, tan β



Lower limits on MSSM tree-level parameters

$M_{\rm SUSY}$ (GeV)	Limits without $M_h \sim 125$ GeV			Limits with $M_h \sim 125$ GeV		
	$\tan\beta$	M_A (GeV)	$M_{H^\pm}$ (GeV)	$\tan\beta$	M_A (GeV)	$M_{H^\pm}$ (GeV)
500	2.7	95	123	4.5	140	161
1000	2.2	95	123	3.2	133	155
2000	2.0	95	123	2.9	130	152



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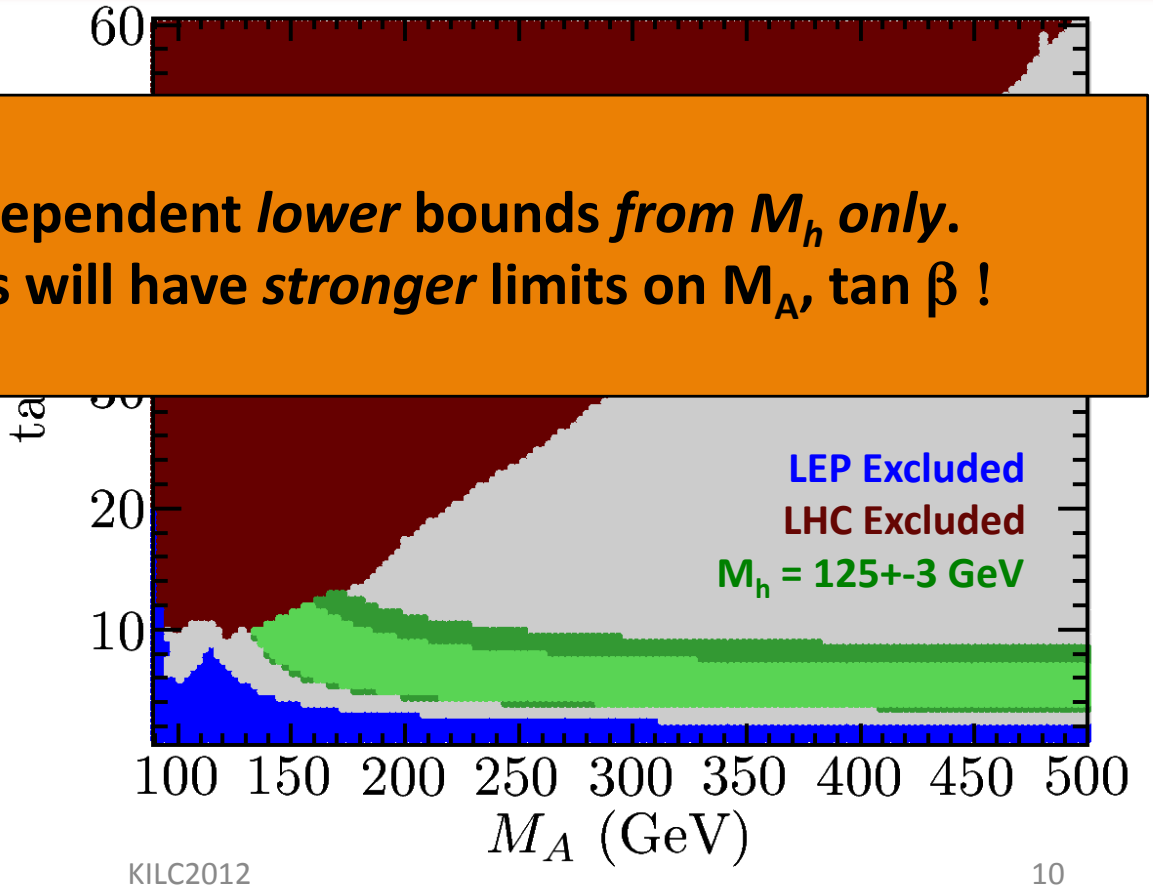
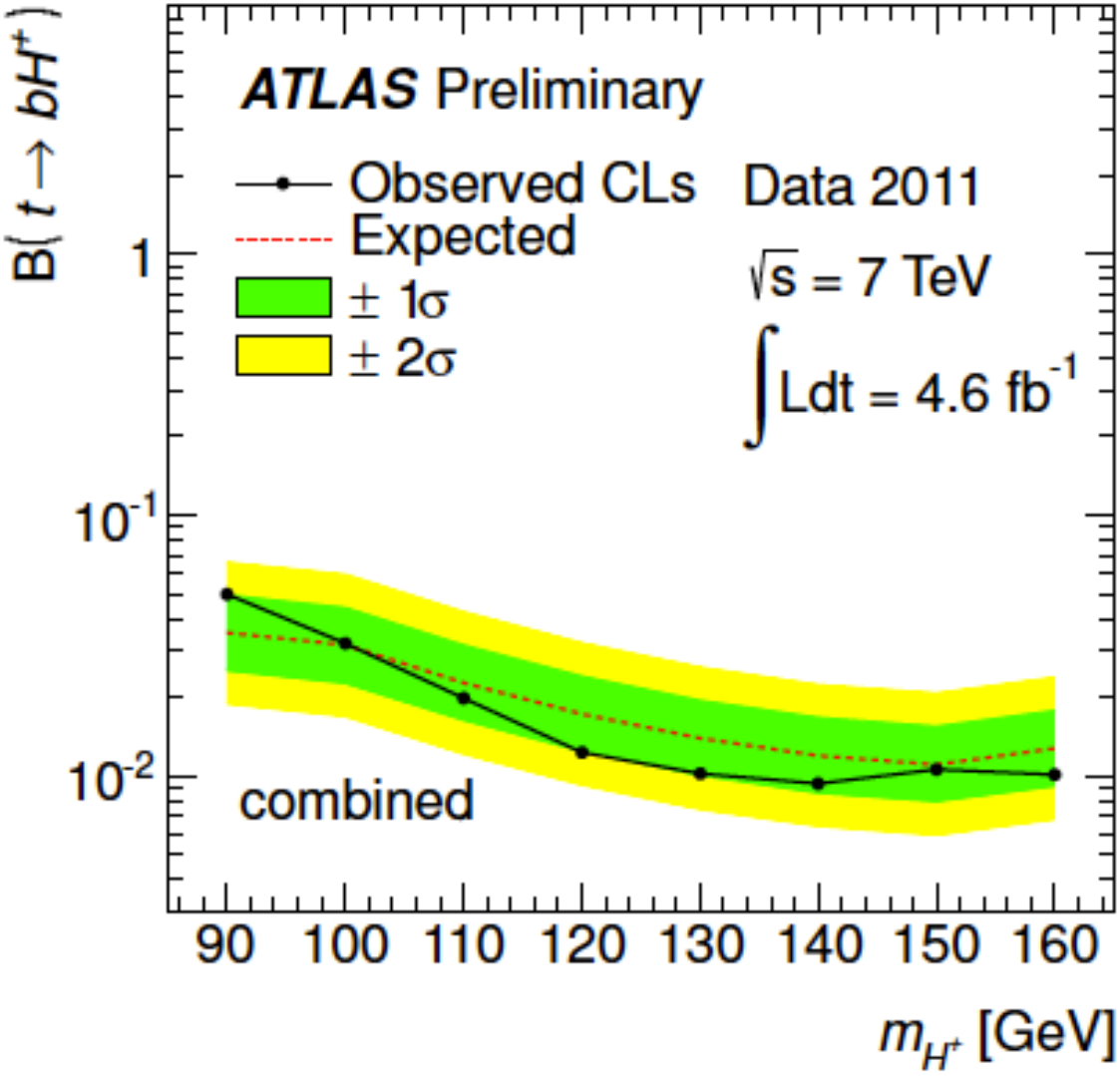
These are scenario-independent *lower* bounds *from M_h only*.
Most MSSM realizations will have *stronger* limits on M_A, tan β !



No room for a light charged Higgs boson

ATLAS-CONF-2012-011



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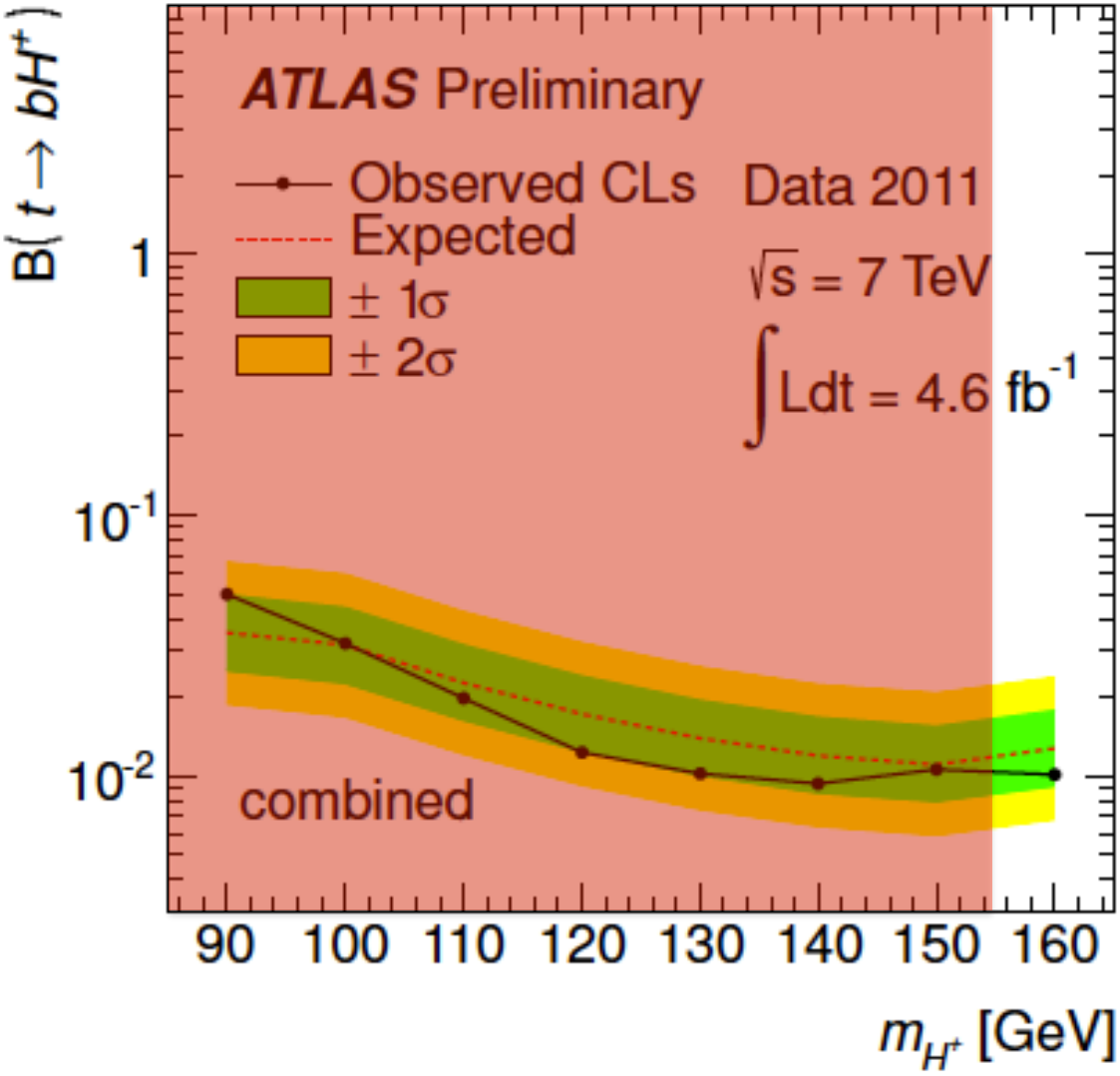
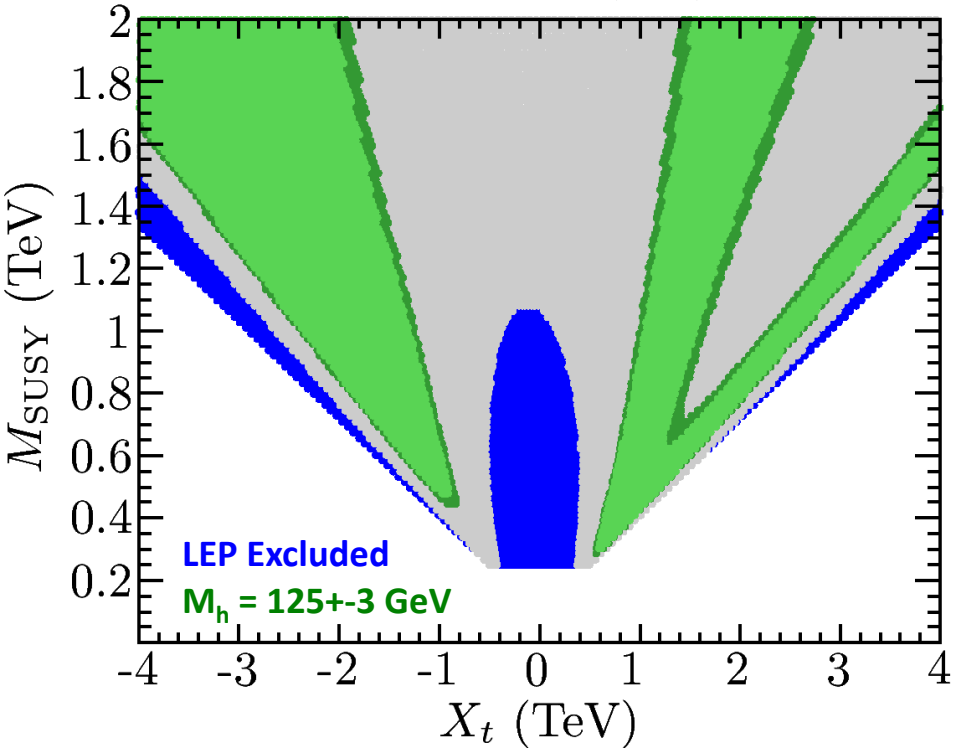


Constraints on stop sector parameters

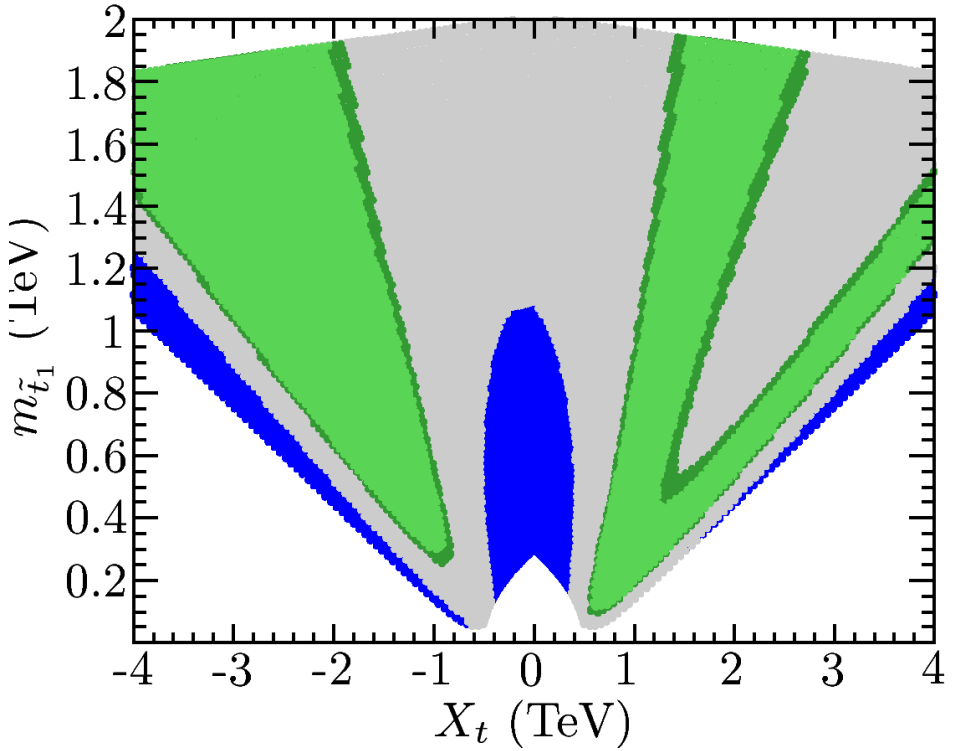
- We can also ask for a lower limit on the amount of radiative corrections by maximizing $M_{h,\mathrm{tree}} \to M_Z$ (decoupling limit)

- High SUSY mass scale and/or large stop mixing required
  Can also be interpreted as a lower limit on the lightest stop mass

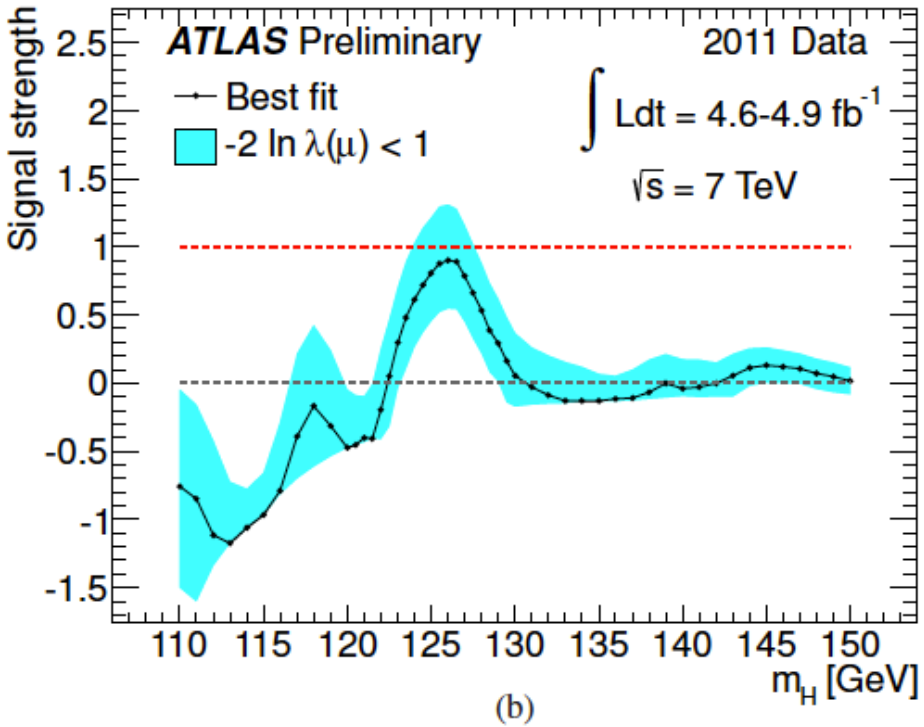
$M_{\mathrm{SUSY}} > 300\,\mathrm{GeV}, |X_t| > 600\,\mathrm{GeV}$

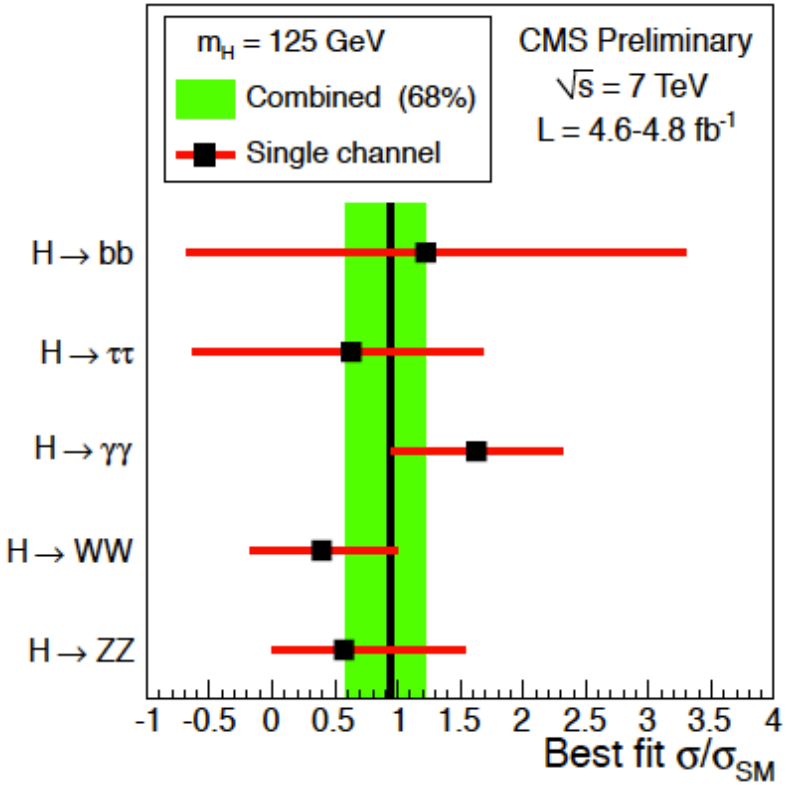


$m_{\tilde{t}_1} \gtrsim 100\,\mathrm{GeV}$



Including rate information





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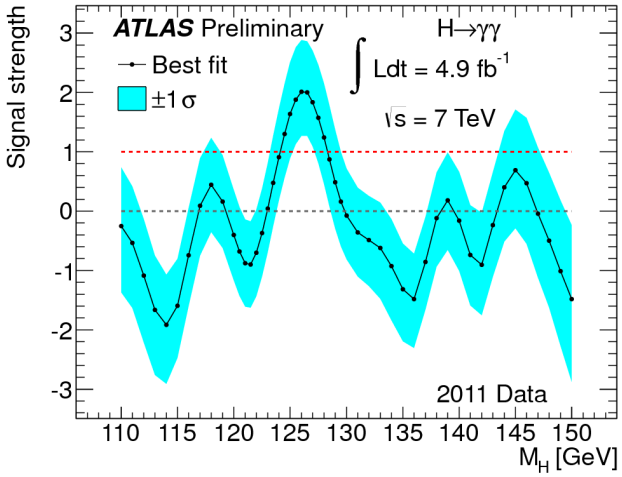


- Best fit signal strength is compatible with SM, with possible room for an enhanced γγ

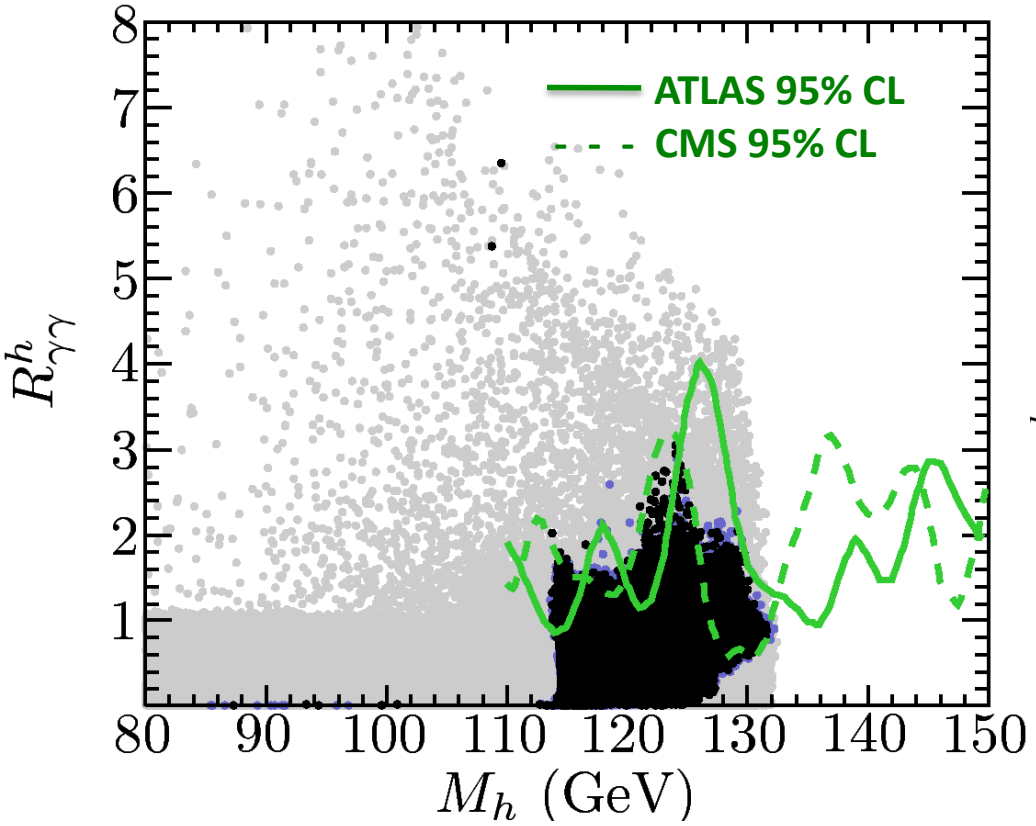
$$R_{\gamma\gamma}^{h_i} = \frac{\sigma(pp \to h_i) \times \mathrm{BR}(h_i \to \gamma\gamma)}{\sigma(pp \to h_i)_{\mathrm{SM}} \times \mathrm{BR}(h_i \to \gamma\gamma)_{\mathrm{SM}}} \gtrsim 1$$

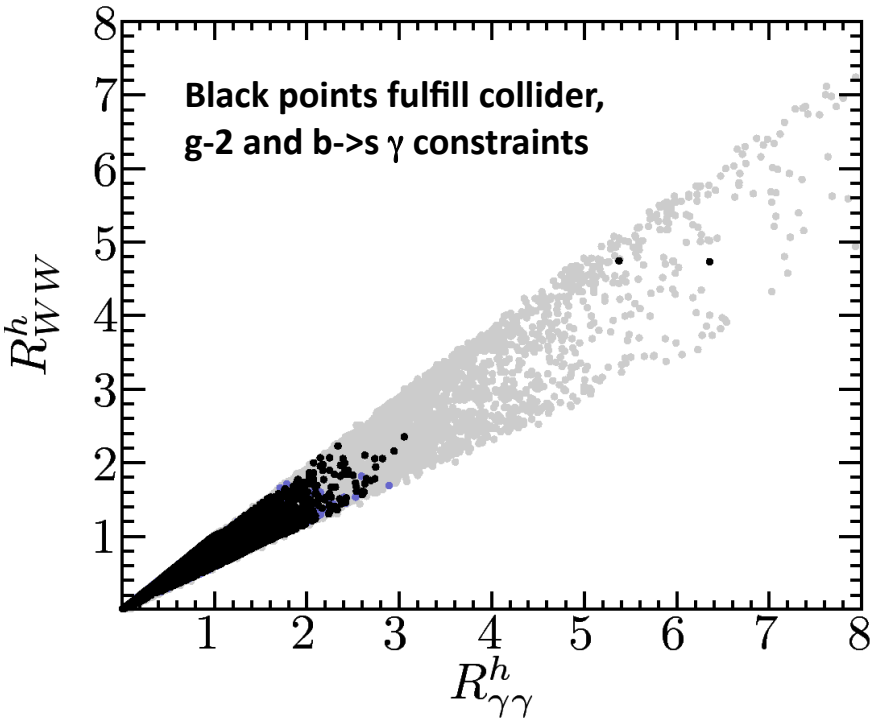
MSSM Higgs scenarios with enhanced γγ rates

R. Benbrik, S. Heinemeyer, M. Gomez, OS, G. Weiglein, L. Zeune, in preparation

- "Easy" solution: Decoupling limit -> SM-like lightest Higgs

- Here: scan over broad range of (low-energy) MSSM parameters to find possible enhancements





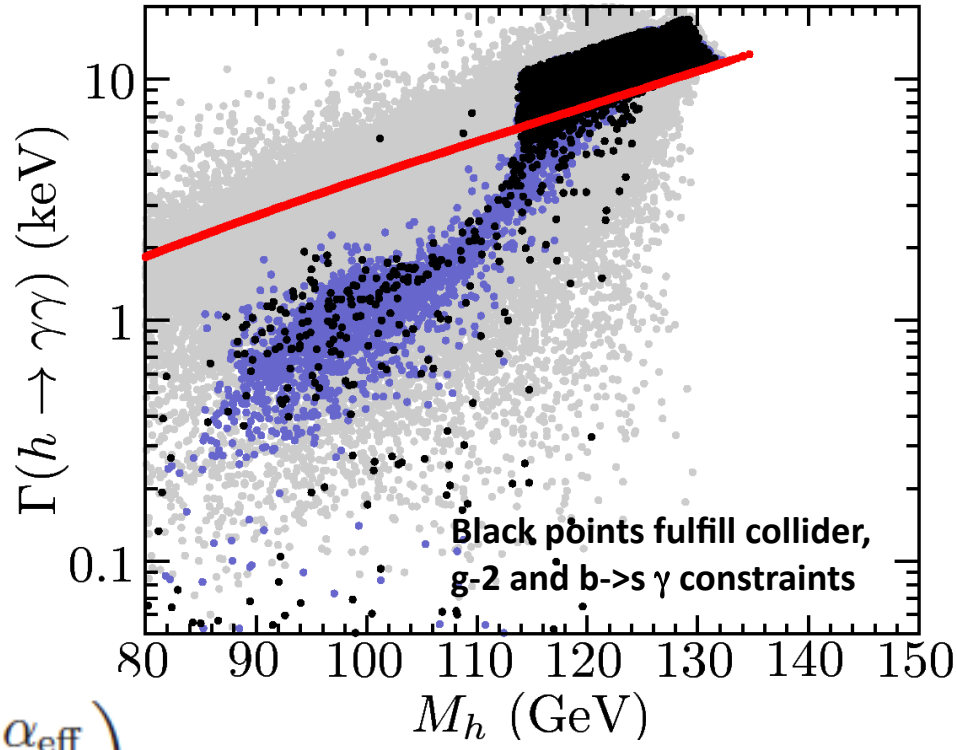
MSSM enhancement of the two photon mode

- Two mechanisms can enhance the MSSM h -> γγ branching ratio

Contribution from light staus can give ~40% enhancement

Carena, Gori, Shah, Wagner, [1112.3336]

-> Implies lightest stau mass close to current (PDG) bound



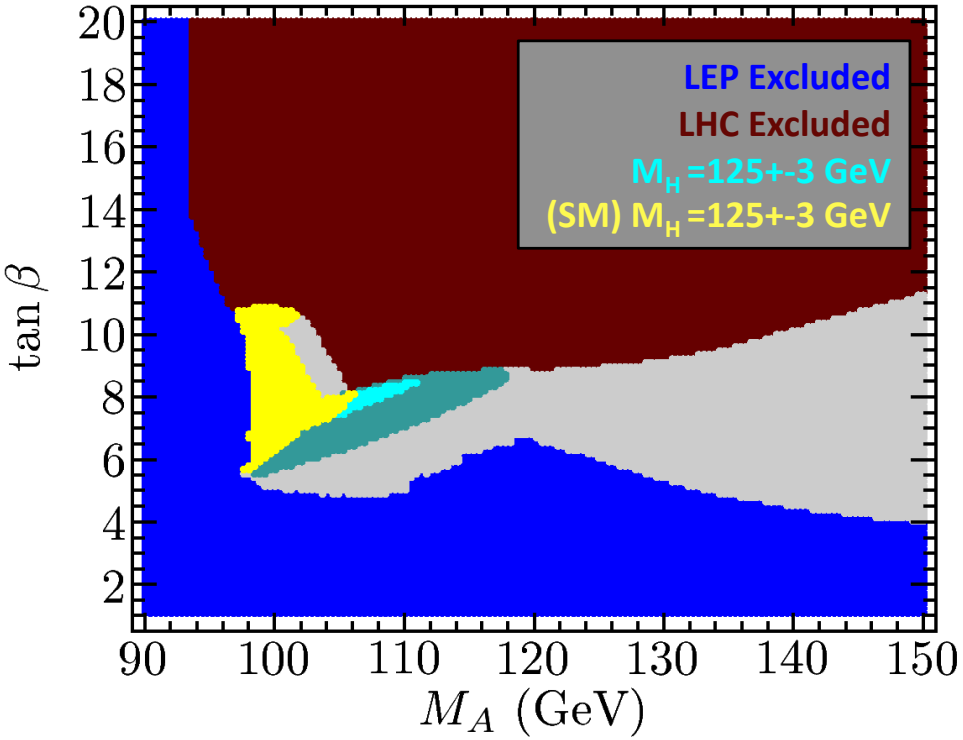
- Reduction of hbb coupling by Higgs mixing (small α_{eff})

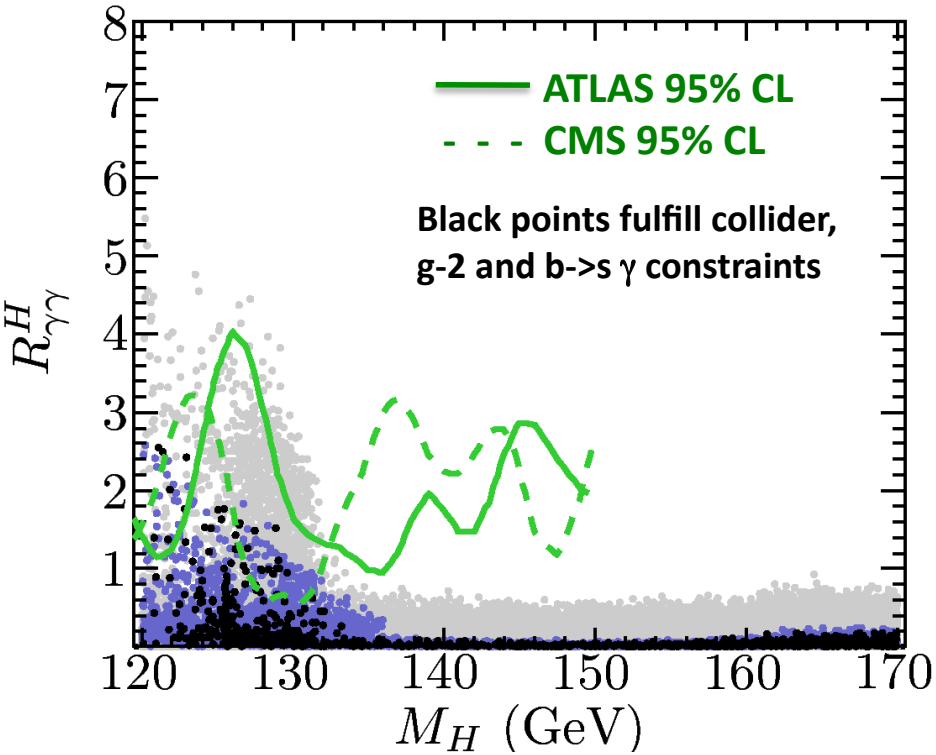
$$\frac{g_{hb\bar{b}}}{g_{H_{\text{SM}}b\bar{b}}} = \frac{1}{1+\Delta_b}\left(-\frac{\sin\alpha_{\text{eff}}}{\cos\beta} + \Delta_b \frac{\cos\alpha_{\text{eff}}}{\sin\beta}\right)$$

-> Minimizing α_{eff} requires large μ and stop mixing, reduces h -> bb and h -> τ τ (ATLAS: OK, CMS: no, Tevatron: no)

Alternative interpretation: M_H = 125 GeV

- Viable to have the heavier CP-even MSSM Higgs boson at 125 GeV? -> Yes, but in a limited region of parameter space!





- In these scenarios the lightest Higgs is always *below* the LEP limit (with reduced couplings) -> LHC limits for lower M_h interesting

125 GeV Higgs: future prospects

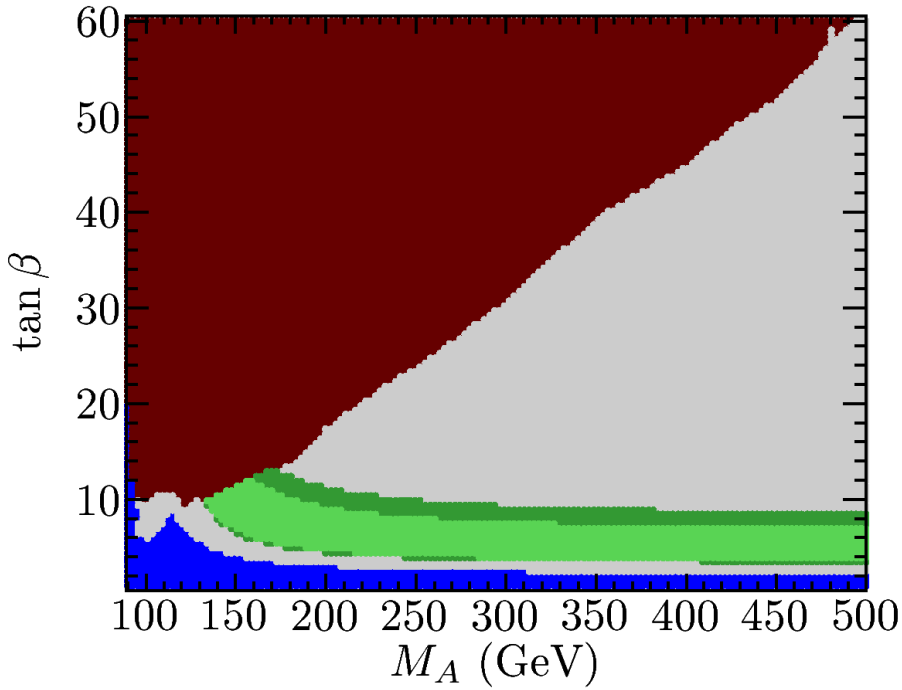
- Assuming something interesting at 125 GeV: Higgs? SM? MSSM?

Establishing Higgs mechanism

Mass	LHC
Quantum numbers	LHC
Couplings	(LHC)/ILC
Self-couplings	(ILC)

Identifying SUSY

Direct obs.	LHC
(Heavy) Higgs obs.	LHC
Properties	ILC
Indirect meas. (M_W, …)	ILC

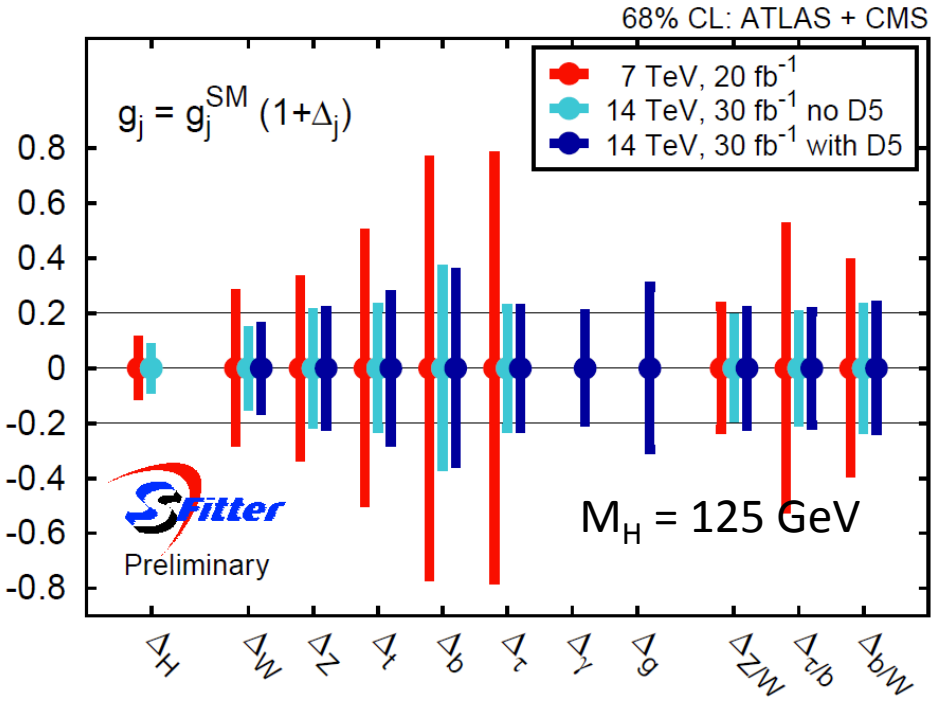


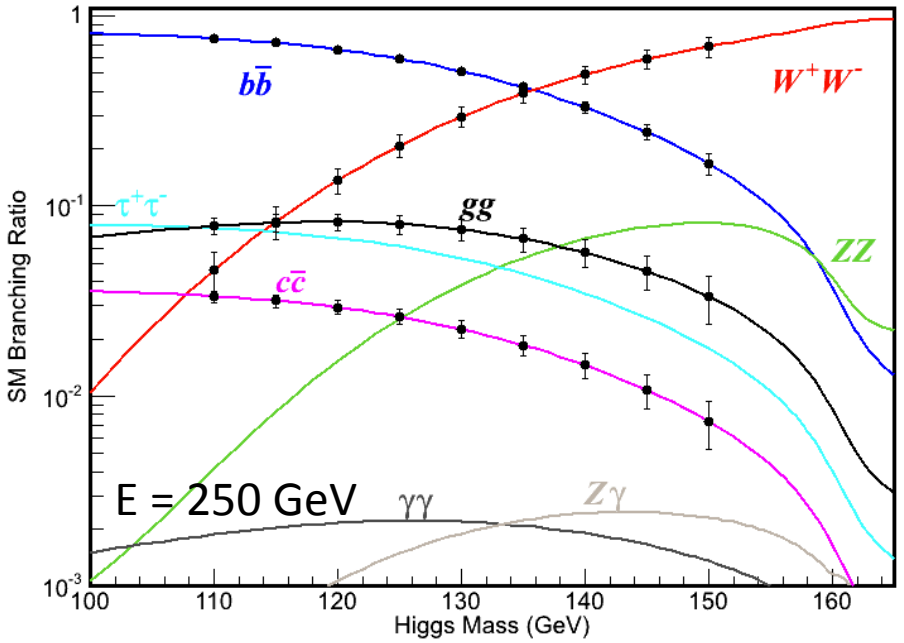
125 GeV Higgs: couplings

- A Higgs boson at 125 GeV is great news both for the LHC and the ILC(250). Wide range of modes accessible.

- Precise coupling measurements crucial test of SM/BSM

- SUSY is more than just MSSM (e.g. additional singlet as in NMSSM)



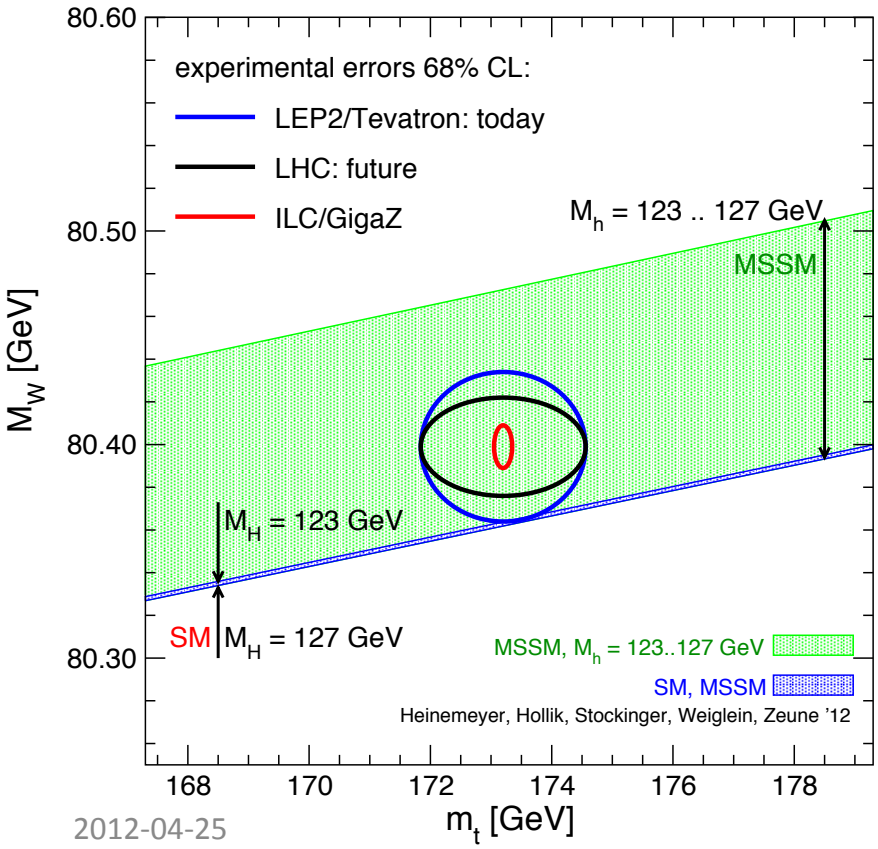


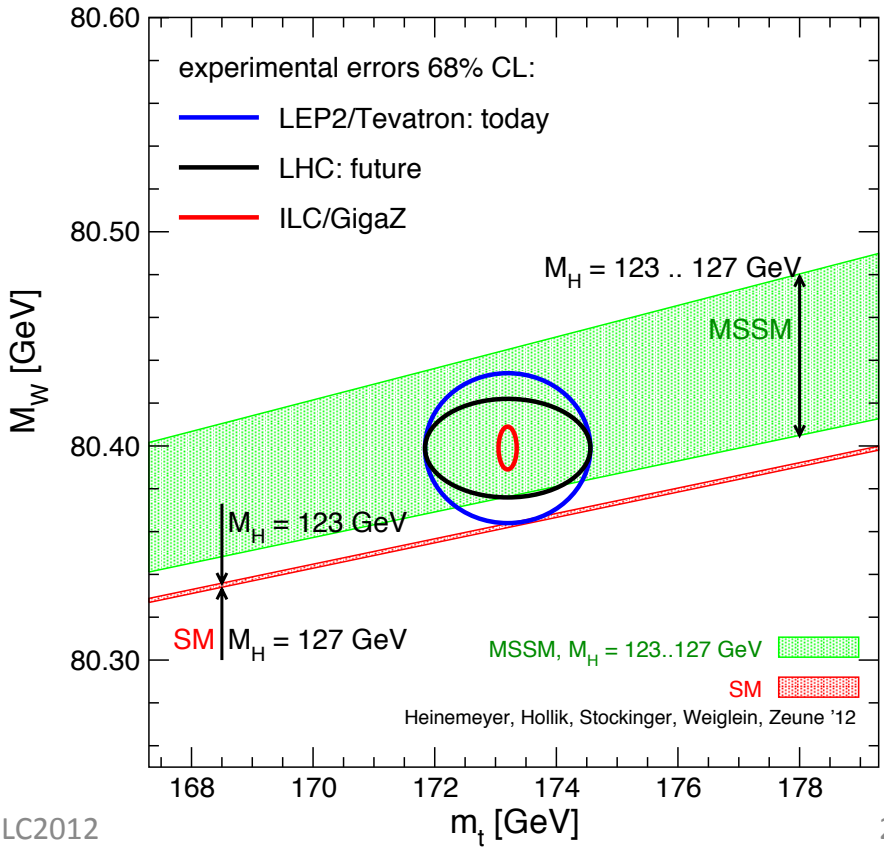
R. Pöschl, talk at LCFORUM, DESY (2012)

Precision measurements: M_W

- Indirect measurements can point the way beyond the SM even in the case of "only" a light Higgs discovery at the LHC

- 2-loop M_W evaluation in MSSM, scan over 14 parameters
  Current experimental bounds + "Higgs signal" applied





Conclusions

- LHC Higgs searches are rapidly becoming interesting to probe physics beyond the Standard Model.
  A large part of the MSSM (m_A, tan β) plane is already excluded

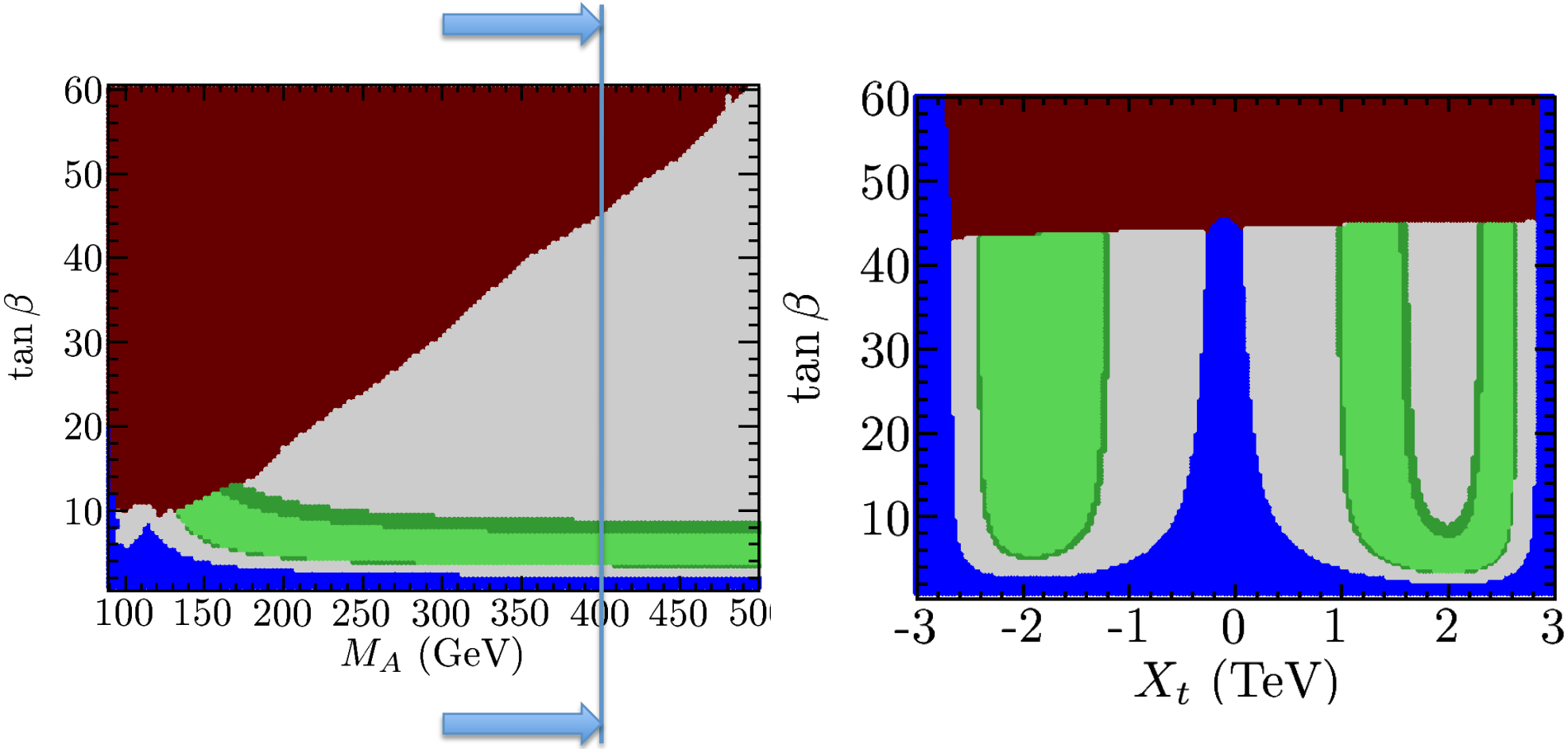
- Two possible MSSM interpretations of a 125 GeV excess:
  M_h = 125 GeV -> New lower limits on tree-level parameters
  M_H = 125 GeV -> Small corner of parameter space still viable

- Observed rates compatible with SM, suggests decoupling limit
  Enhanced h -> $\gamma\gamma$ still an open possibility in the MSSM

- At 125 GeV, the LHC has access to several Higgs couplings.
  The ILC could provide precision for model discrimination.

- No new physics at LHC -> precision measurements

Upper limit on tree-level parameters?



Maximal mixing gives the model-independent lower bound on tan β, but the most stringent upper bound possible.

Parameter ranges MSSM scan

Parameter	Minimum	Maximum
M_{SUSY}	750	1500
$M_2 \simeq 2M_1$	200	500
$A_t = A_b = A_\tau$	-2400	2400
μ	200	3000
M_A	100	600
$\tan\beta$	1	60