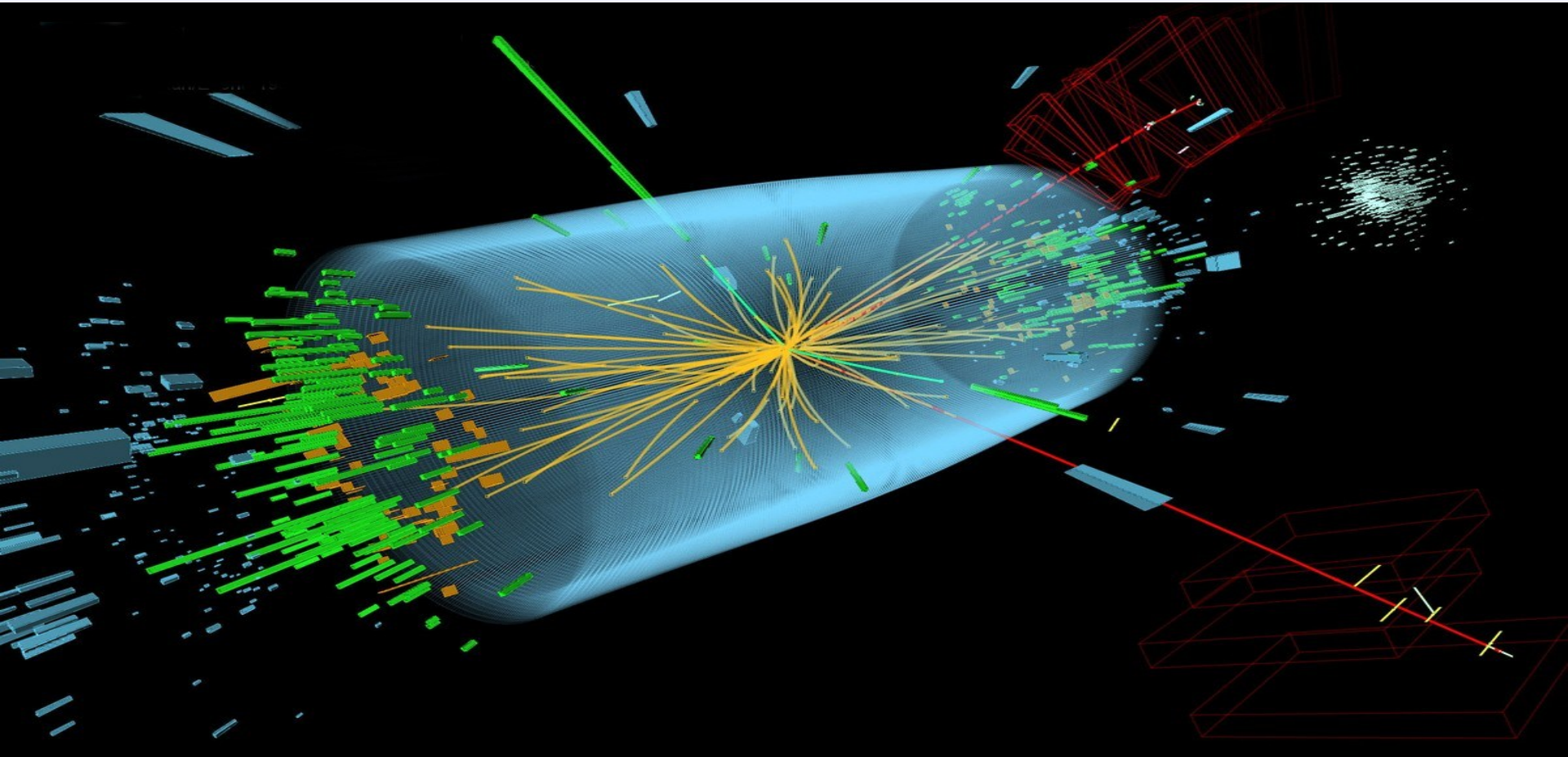


# Constraints on Higgs Properties and SUSY Partners in the pMSSM



Cahill-Rowley, JLH, Hoeche, Ismail, Rizzo 1206.4321, 1206.5800, 1211.1981,  
1211.7106, 1305.6921, 1307.8444,  
1308.0297

# The pMSSM Model Framework

- The phenomenological MSSM (pMSSM)
  - Most general CP-conserving MSSM with R-parity
  - Minimal Flavor Violation, First 2 sfermion generations are degenerate w/ negligible Yukawas
  - No GUT, SUSY-breaking, high-scale assumptions!
  - 19/20 real, weak-scale parameters (Neutralino/Gravitino LSP)

scalars:

$m_{Q_1}, m_{Q_3}, m_{u_1}, m_{d_1}, m_{u_3}, m_{d_3}, m_{L_1}, m_{L_3}, m_{e_1}, m_{e_3}$

gauginos:  $M_1, M_2, M_3$

tri-linear couplings:  $A_b, A_t, A_\tau$

Higgs/Higgsino:  $\mu, M_A, \tan\beta$

(Gravitino:  $M_G$ )

Supersymmetry without Prejudice

Berger, Gainer, JLH, Rizzo 0812.0980



# Study of the pMSSM (Neutralino/Gravitino LSP)

## Scan with Linear Priors

Perform large scan over  
Parameters

$$100 \text{ GeV} \leq m_{\text{sfermions}} \leq 4 \text{ TeV}$$

$$50 \text{ GeV} \leq |M_1, M_2, \mu| \leq 4 \text{ TeV}$$

$$400 \text{ GeV} \leq M_3 \leq 4 \text{ TeV}$$

$$100 \text{ GeV} \leq M_A \leq 4 \text{ TeV}$$

$$1 \leq \tan\beta \leq 60$$

$$|A_{t,b,\tau}| \leq 4 \text{ TeV}$$

$$(1 \text{ eV} \leq m_G \leq 1 \text{ TeV}) \text{ (log prior)}$$

Subject these points to  
Constraints from:

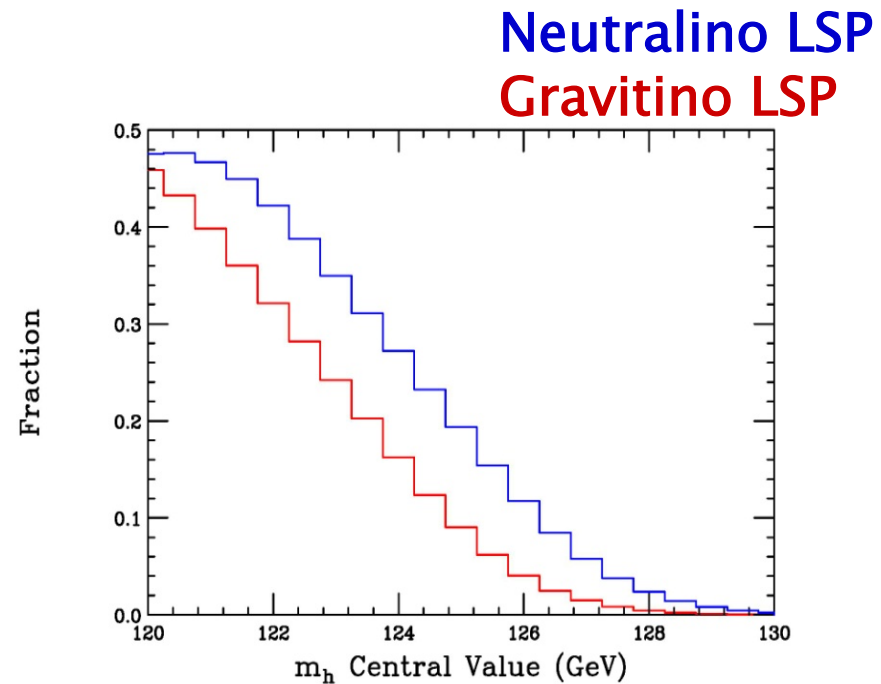
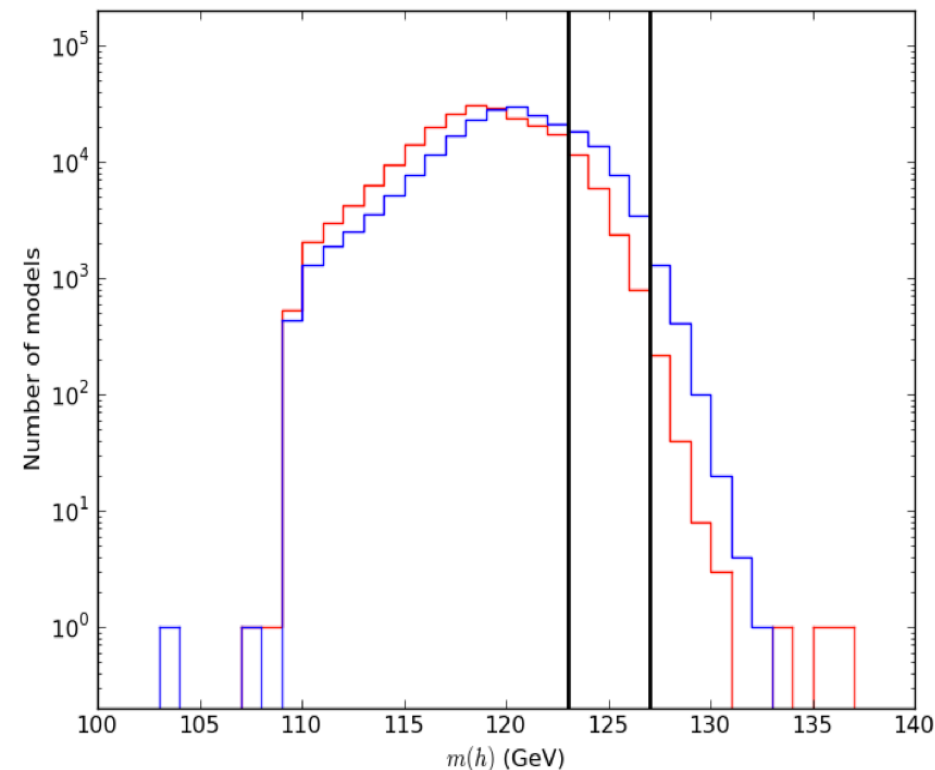
- Flavor physics
- EW precision measurements
- Collider searches
- Cosmology

~225,000 models survive constraints for each LSP type!

# Predictions for Lightest Higgs Mass in the pMSSM

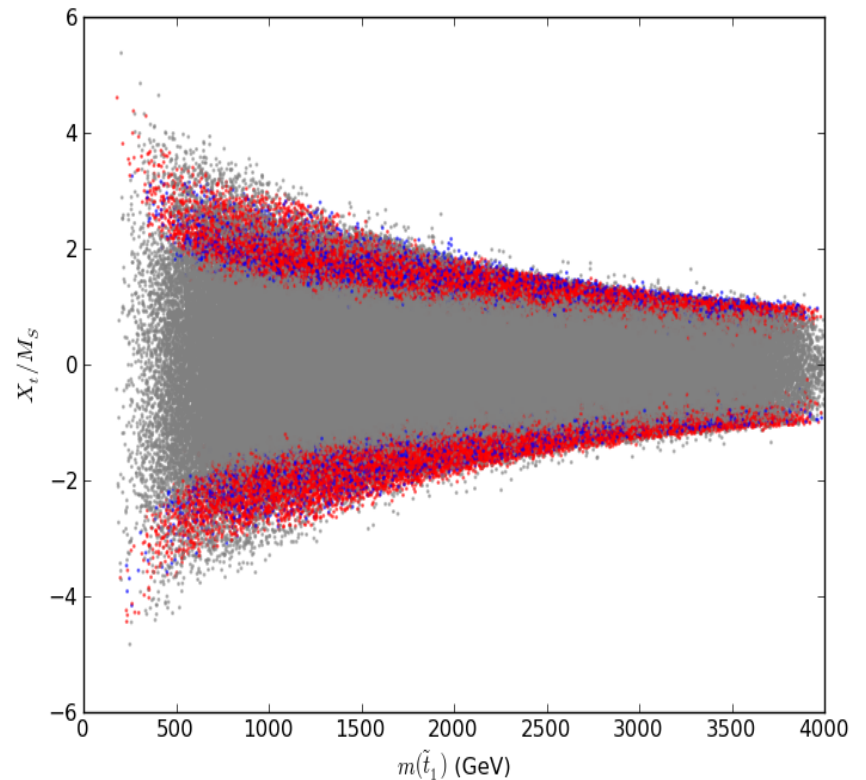
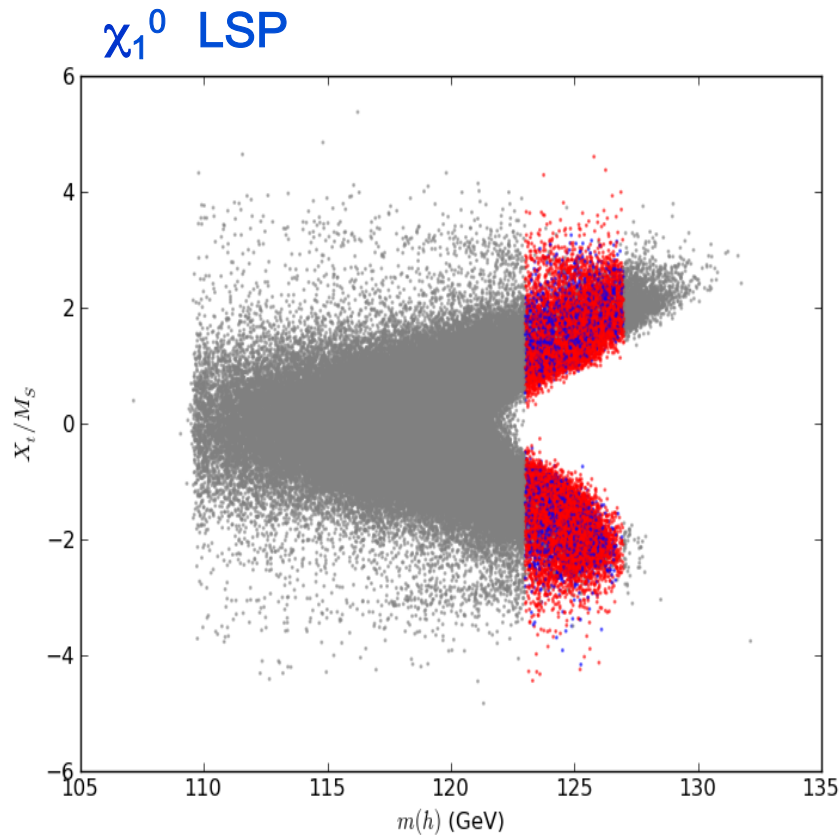
~40k Neutralino models with  $m_h = 126 \pm 3$  GeV

All results in this talk are for the Neutralino model set only with the correct Higgs mass!



# Special parameter regions needed for the 126 GeV Higgs

- Need large stop mixing:  $X_t = A_t - \mu \cot \beta$



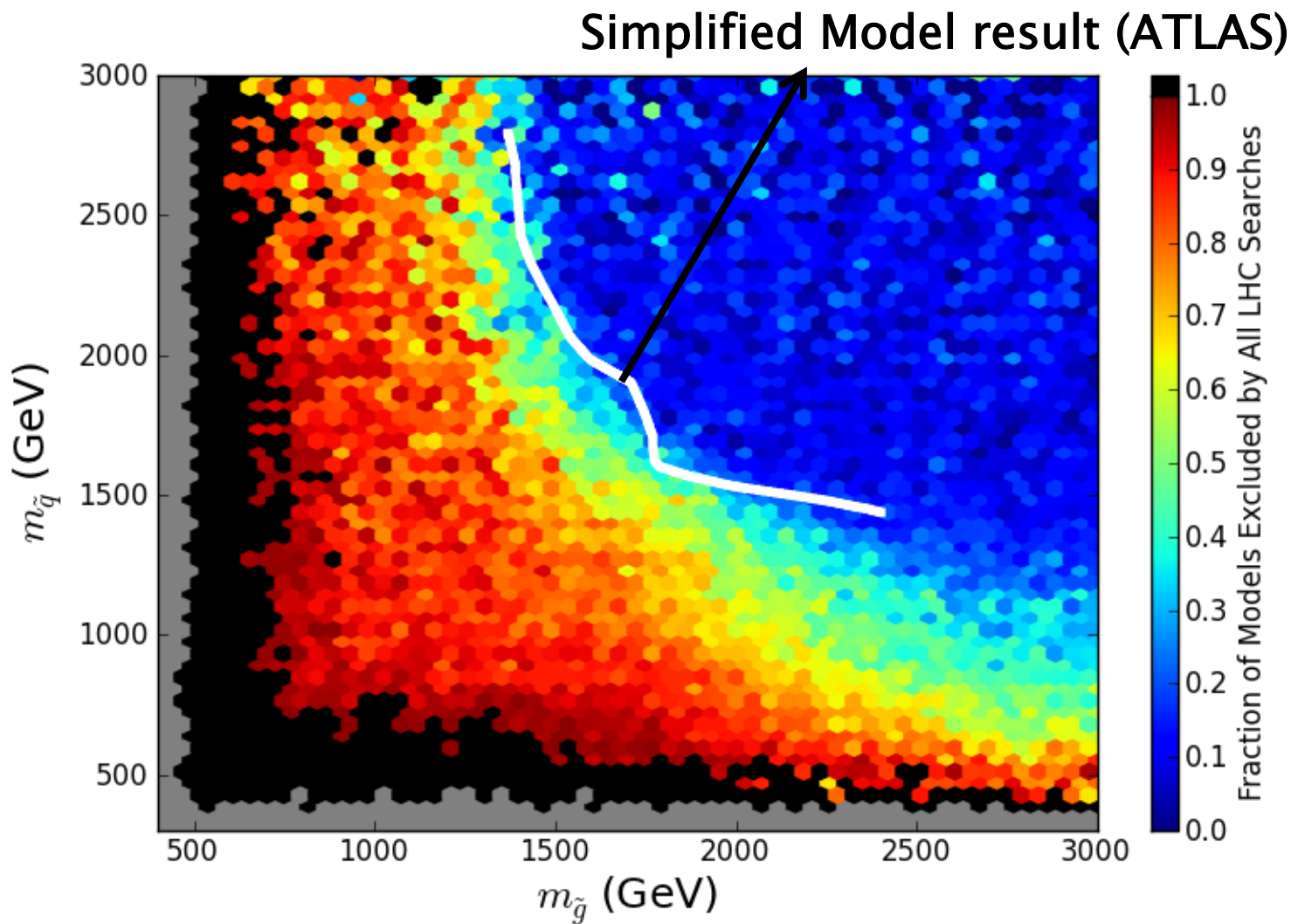


# ATLAS MET-based SUSY Analyses @ 7/8/14 TeV



- Apply the general LHC SUSY MET-based searches to our model sets
- We (almost) exclusively follow the ATLAS analysis suite as closely as possible with fast MC (modified versions of PGS, Pythia, SoftSUSY, SDECAY, HDECAY)
- Generate signal events for every model for all 85 SUSY processes ( $\sim 10^{13}$  events!) & scale to NLO with Prospino
- Validated our results with ATLAS benchmark models
- We combine the various signal regions (as ATLAS does) for  $\sim 35$  analyses: and we quote the coverage for each as well as the combined result..
- This approach is CPU intensive!!

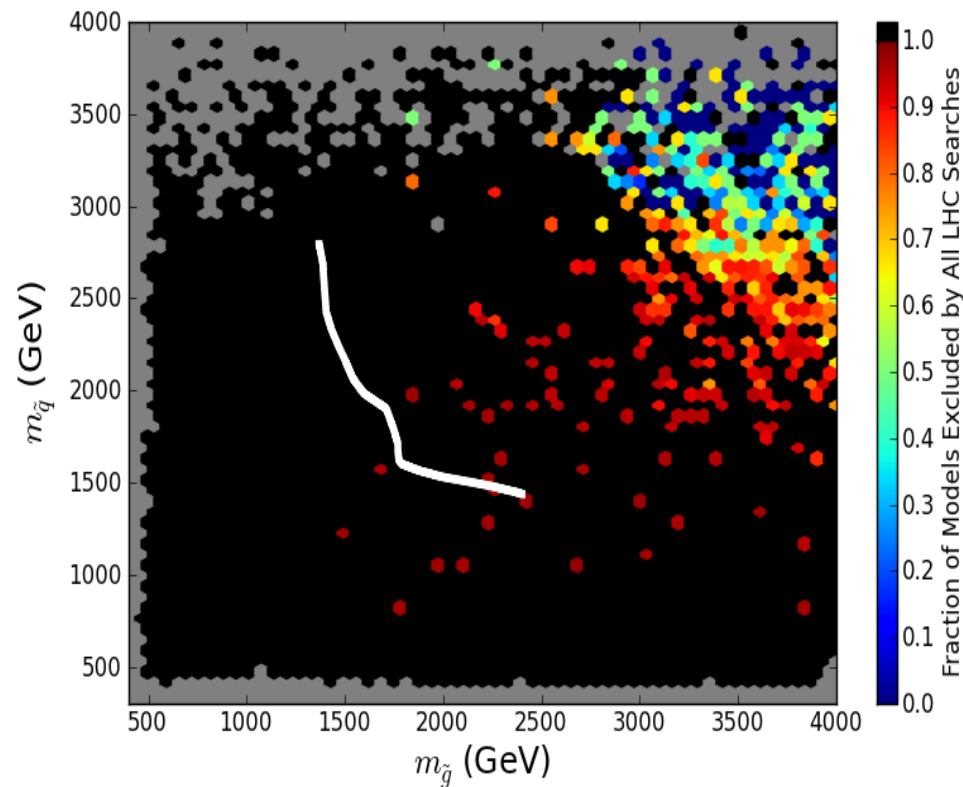
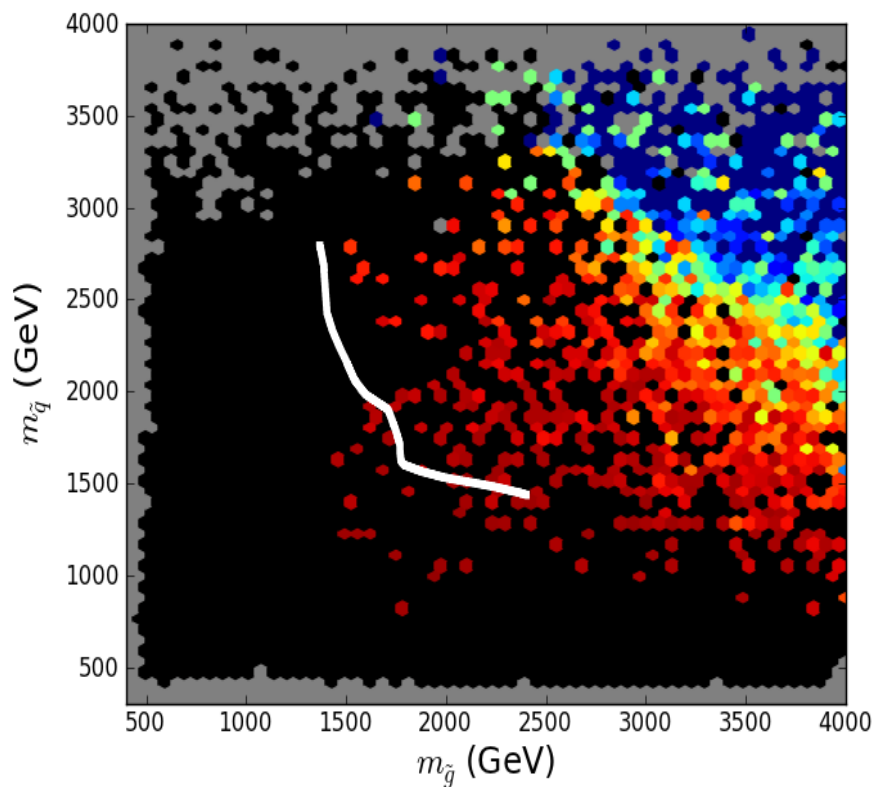
# Effects of LHC Searches on Neutralino LSP Model Set 7/8 TeV



45% of 225k model set excluded

# 14 TeV LHC pMSSM Coverage for 0.3 & 3 ab<sup>-1</sup>

Jets+MET Analysis (ATLAS European Strategy Study)  
Stop search (ATLAS Snowmass study)





# Precision Higgs Measurements

Snowmass Higgs Working Group Report: 1310.8361

CMS: current theory and sys errors: decrease by 2 and  $\sqrt{N}$

L ( $\text{fb}^{-1}$ )	$\kappa_\gamma$	$\kappa_W$	$\kappa_Z$	$\kappa_g$	$\kappa_b$	$\kappa_t$	$\kappa_\tau$	$\kappa_{Z\gamma}$	$\kappa_{\mu\mu}$	BR <sub>SM</sub>
300	[5, 7]	[4, 6]	[4, 6]	[6, 8]	[10, 13]	[14, 15]	[6, 8]	[41, 41]	[23, 23]	[14, 18]
3000	[2, 5]	[2, 5]	[2, 4]	[3, 5]	[4, 7]	[7, 10]	[2, 5]	[10, 12]	[8, 8]	[7, 11]

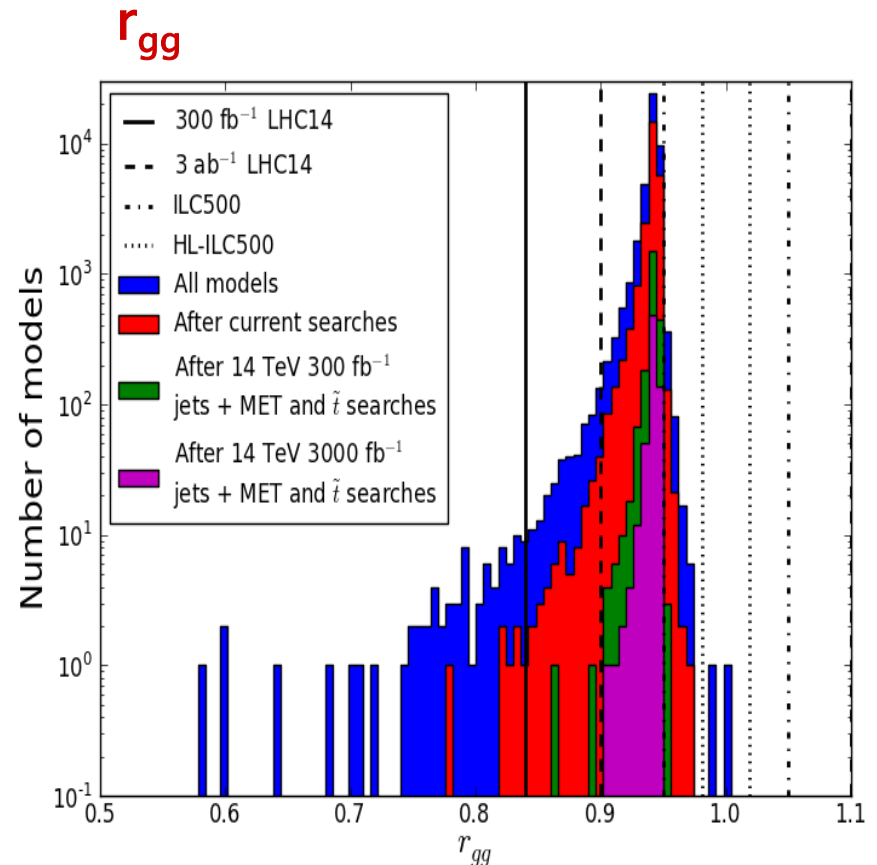
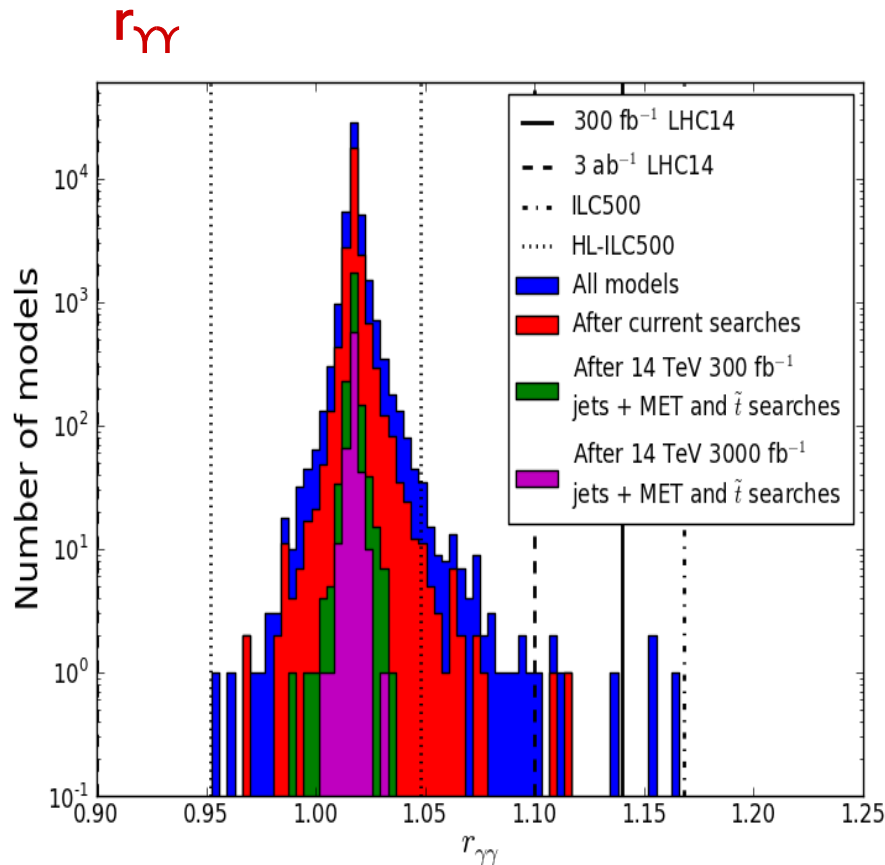
	ILC		ILC LumiUp <sup>‡</sup>	
	250/500/1000 GeV		250/500/1000 GeV	
	<i>ZH</i>	$\nu\bar{\nu}H$	<i>ZH</i>	$\nu\bar{\nu}H$
Inclusive	2.6/3.0/—%	—	1.2/1.7/—%	—
$H \rightarrow \gamma\gamma$	29-38%	—/20-26/7-10%	16/19/—%	—/13/5.4%
$H \rightarrow gg$	7/11/—%	—/4.1/2.3%	3.3/6.0/—%	—/2.3/1.4%
$H \rightarrow ZZ^*$	19/25/—%	—/8.2/4.1%	8.8/14/—%	—/4.6/2.6%
$H \rightarrow WW^*$	6.4/9.2/—%	—/2.4/1.6%	3.0/5.1/—%	—/1.3/1.0%
$H \rightarrow \tau\tau$	4.2/5.4/—%	—/9.0/3.1%	2.0/3.0/—%	—/5.0/2.0%
$H \rightarrow b\bar{b}$	1.2/1.8/—%	11/0.66/0.30%	0.56/1.0/—%	4.9/0.37/0.30%
$H \rightarrow c\bar{c}$	8.3/13/—%	—/6.2/3.1%	3.9/7.2/—%	—/3.5/2.0%
$H \rightarrow \mu\mu$	—	—/—/31%	—	—/—/20%

# Higgs partial widths in the pMSSM: $\Upsilon\Upsilon$ and $gg$

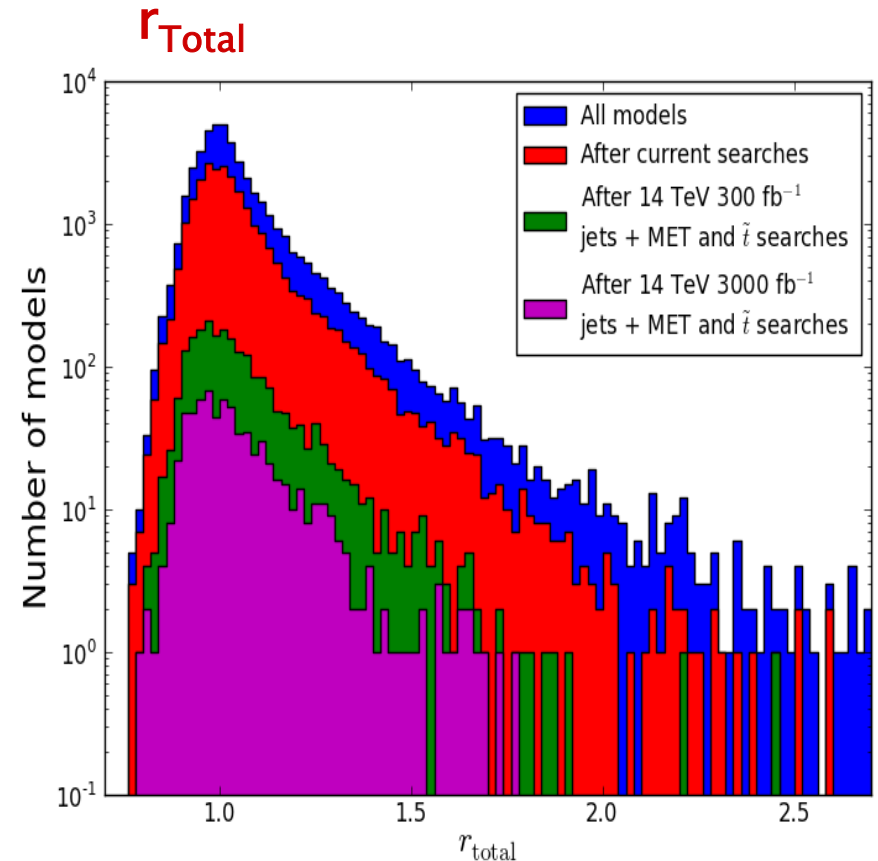
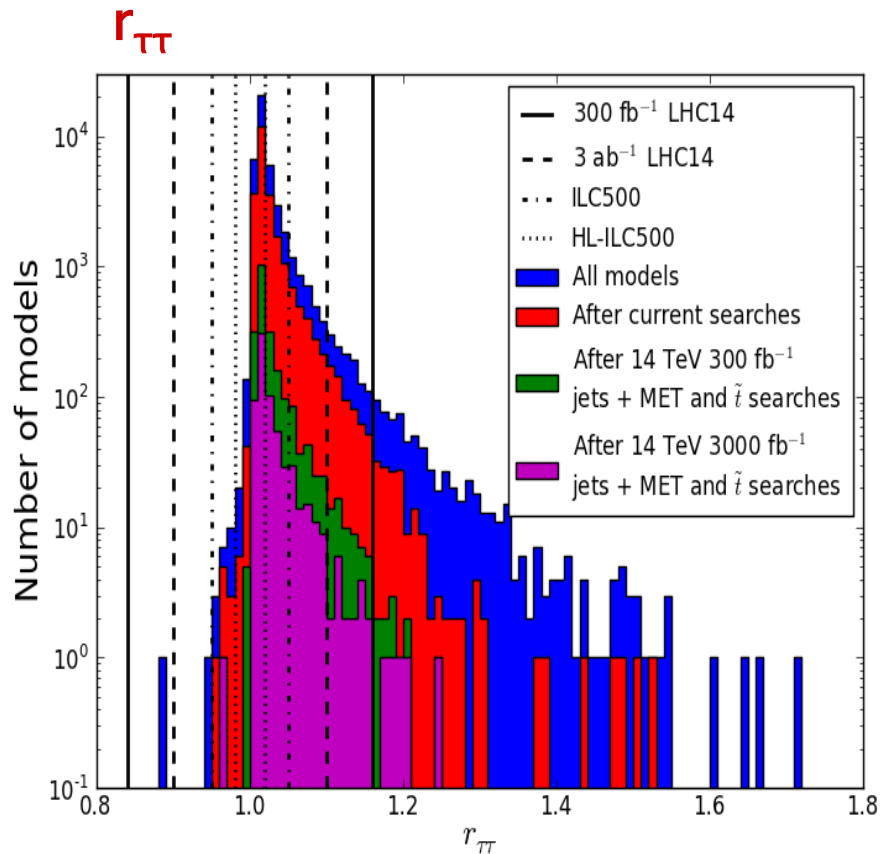
$$r_{XX} = \Gamma_{XX}|_{\text{pMSSM}} / \Gamma_{XX}|_{\text{SM}}$$

40k models with correct  $m_h$

- Requirement of large stop mixing implies non-decoupling Carena etal 1303.4414
- Results in correlated distribution peak with  $r_{\Upsilon\Upsilon} > 1$  and  $r_{gg} < 1$

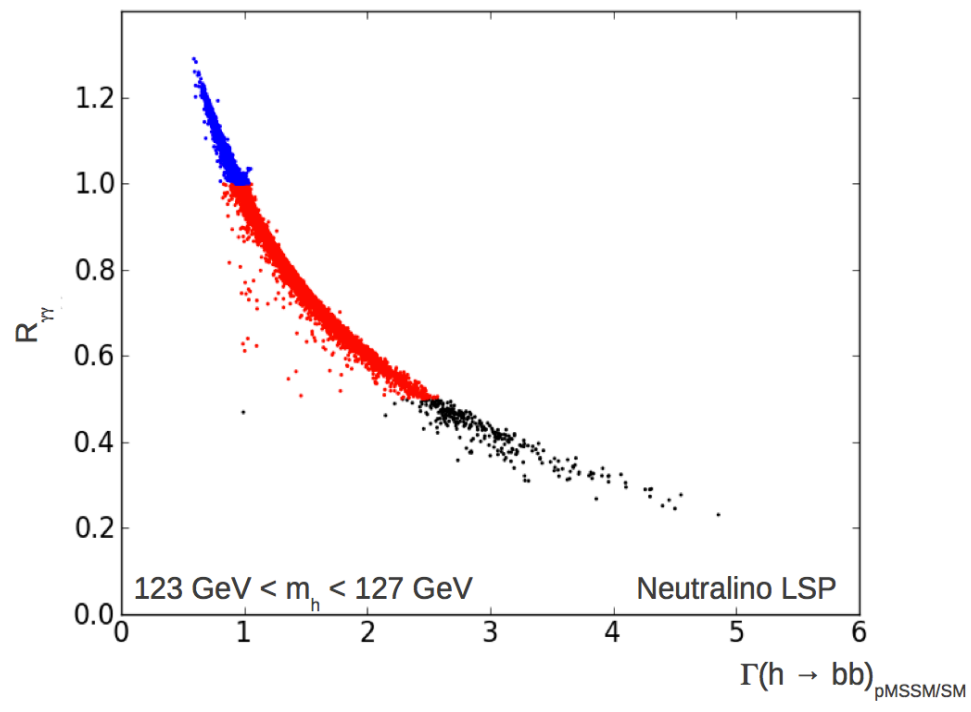
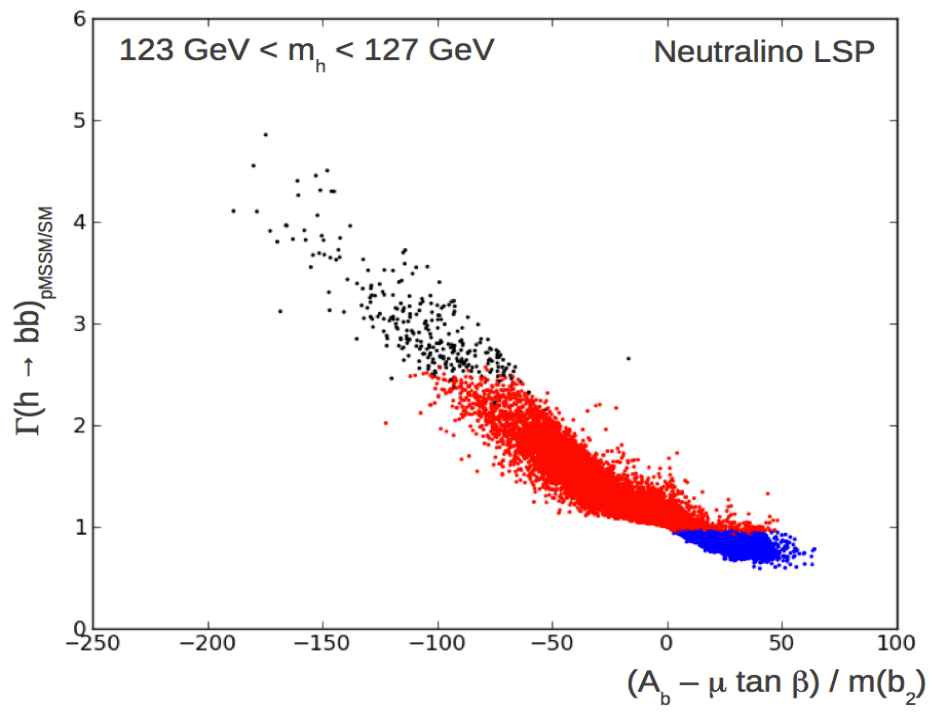


# Higgs partial widths in the pMSSM: $\tau\tau$ and Total

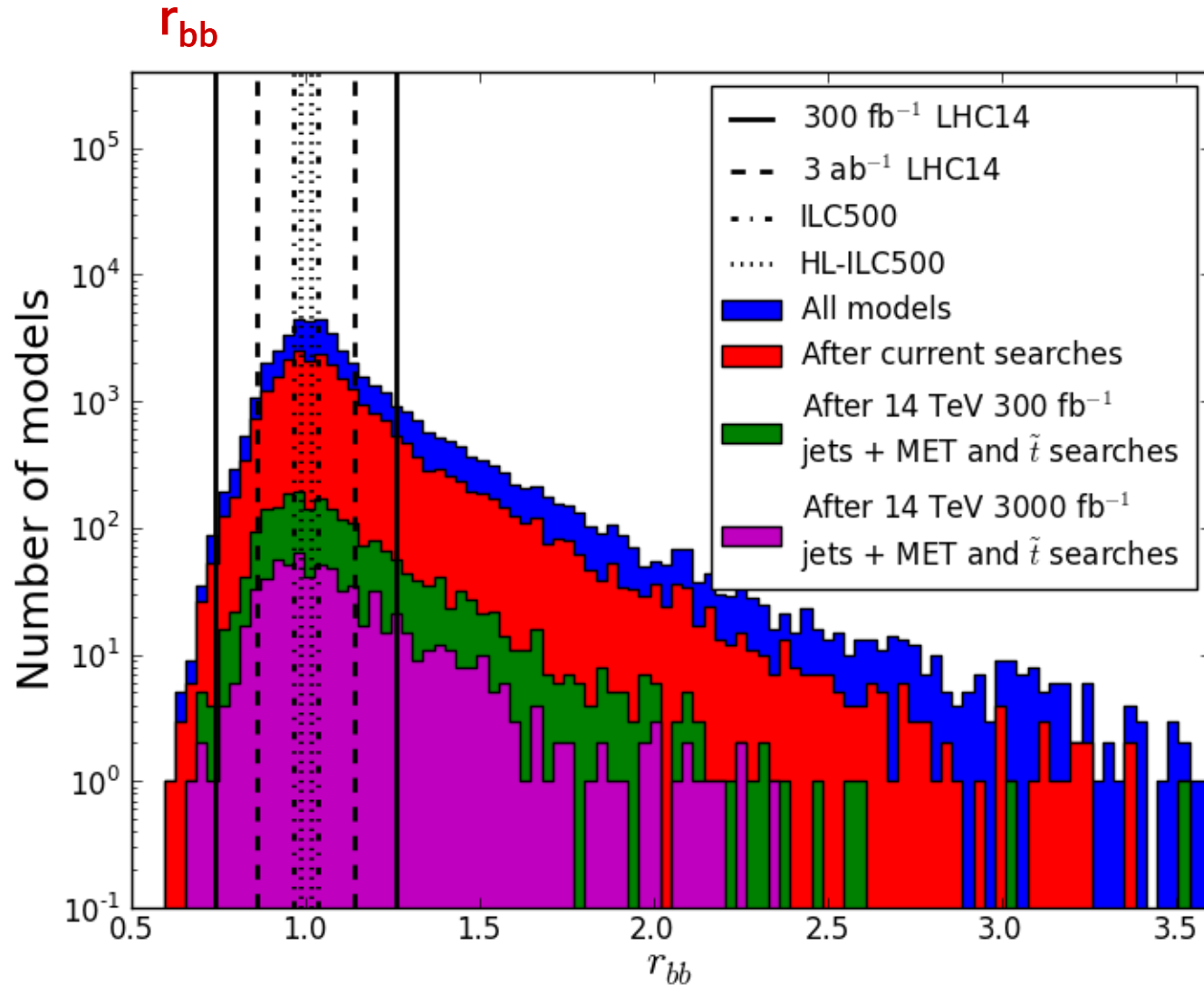


# $h \rightarrow bb$

- Large  $hbb$  coupling loop corrections decouple very slowly especially if there is large sbottom mixing (Haber et al.)
- These lead to a significant Higgs width increase/decrease since it is the dominant decay mode

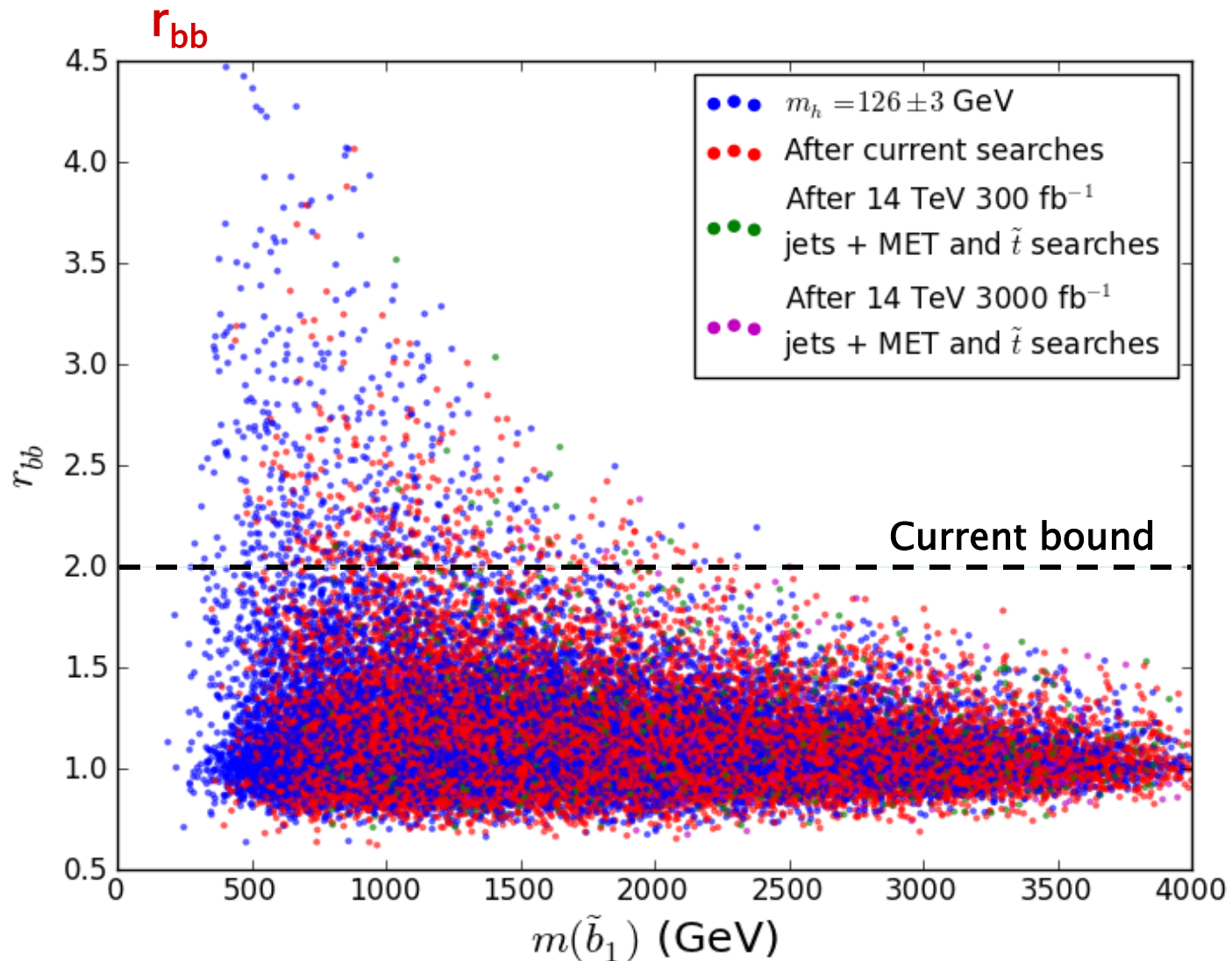


# Higgs partial widths in the pMSSM: $b\bar{b}$

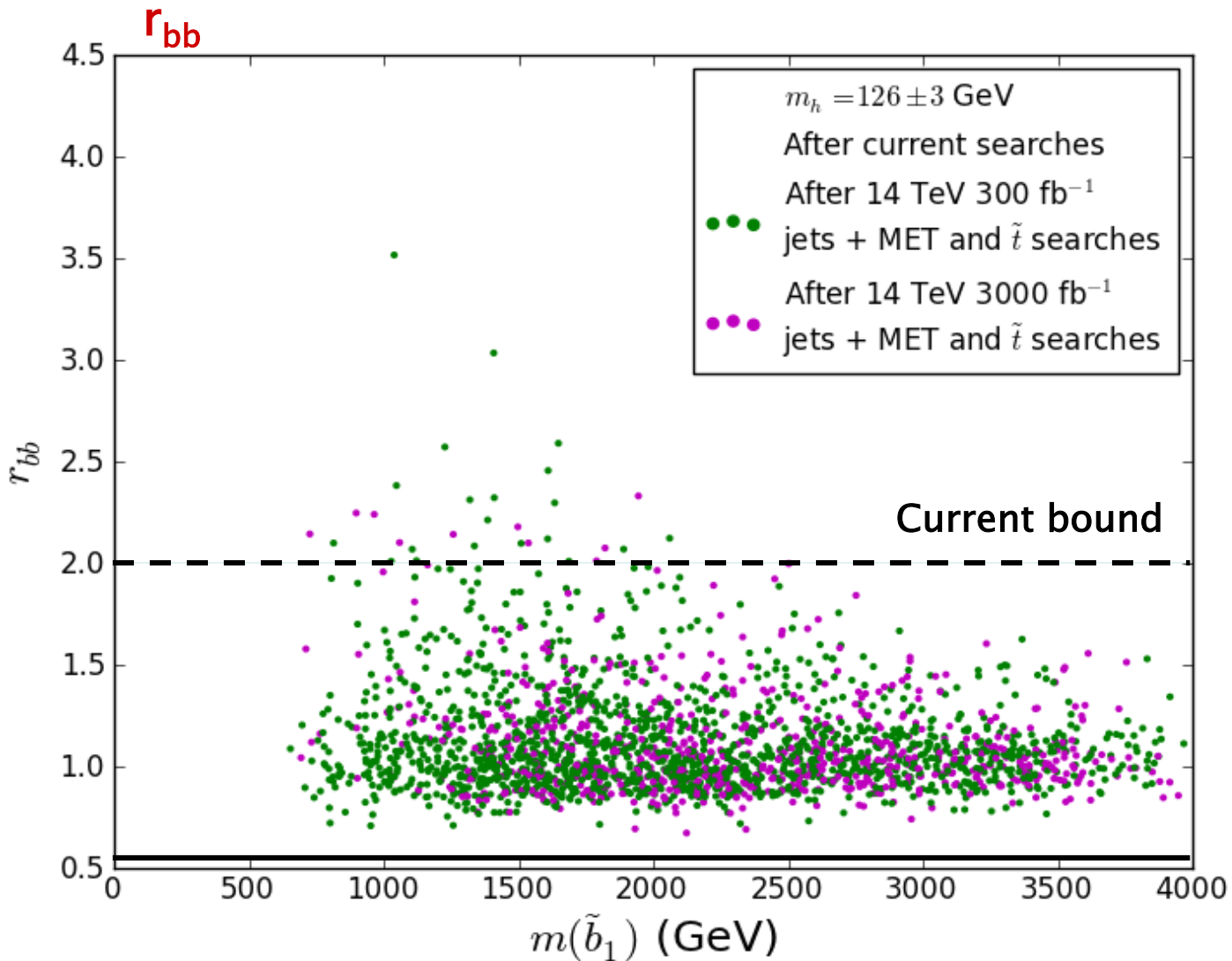




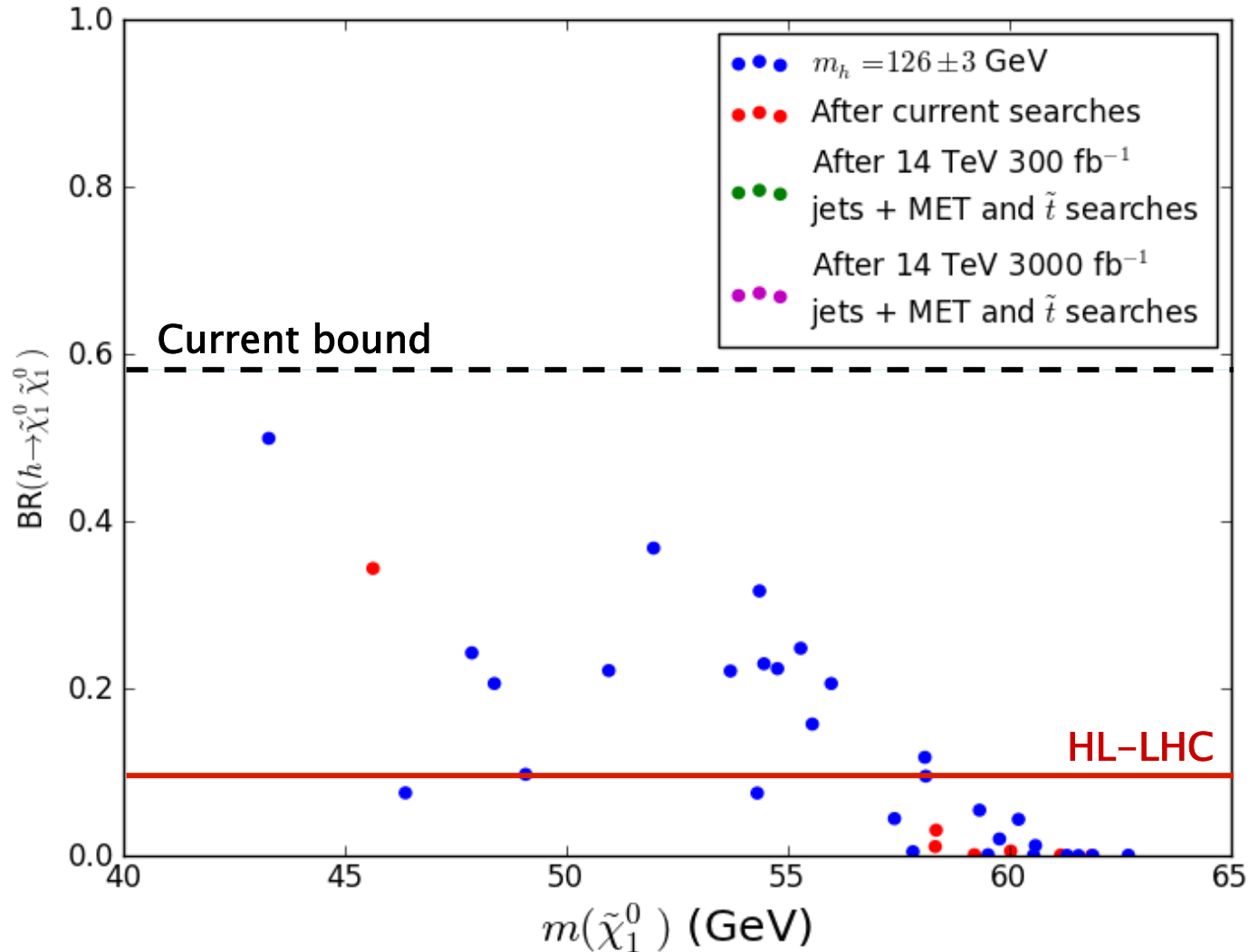
# Higgs partial widths in the pMSSM: $b\bar{b}$



# Higgs partial widths in the pMSSM: $b\bar{b}$



# Invisible Width of the Higgs



# Conclusions

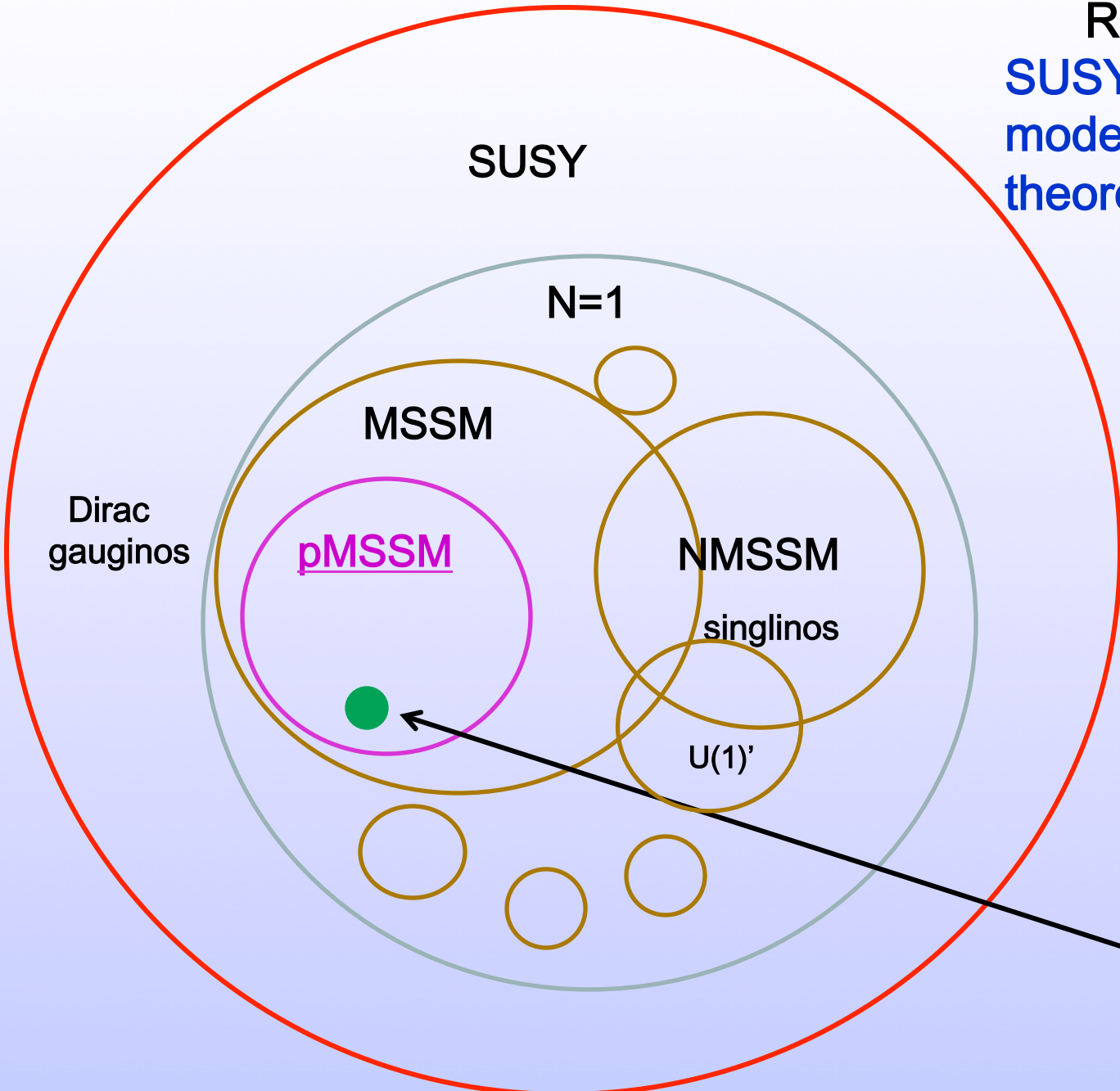
- Relatively easy to accommodate  $126 \pm 3$  GeV Higgs in the pMSSM
- SUSY EW corrections need to be performed for WW/ZZ modes in order to compare with future exp'ts
- Cannot make predictions for Higgs couplings from non-observation of SUSY direct production
- ILC precision on Higgs couplings allows for new physics observation/exclusion beyond LHC reach
  - Channel dependent

Searching for new physics via precision Higgs measurements is complementary to direct searches at LHC

**Backup**



REMINDER:  
SUSY is *not* a single model but a very large theoretical framework

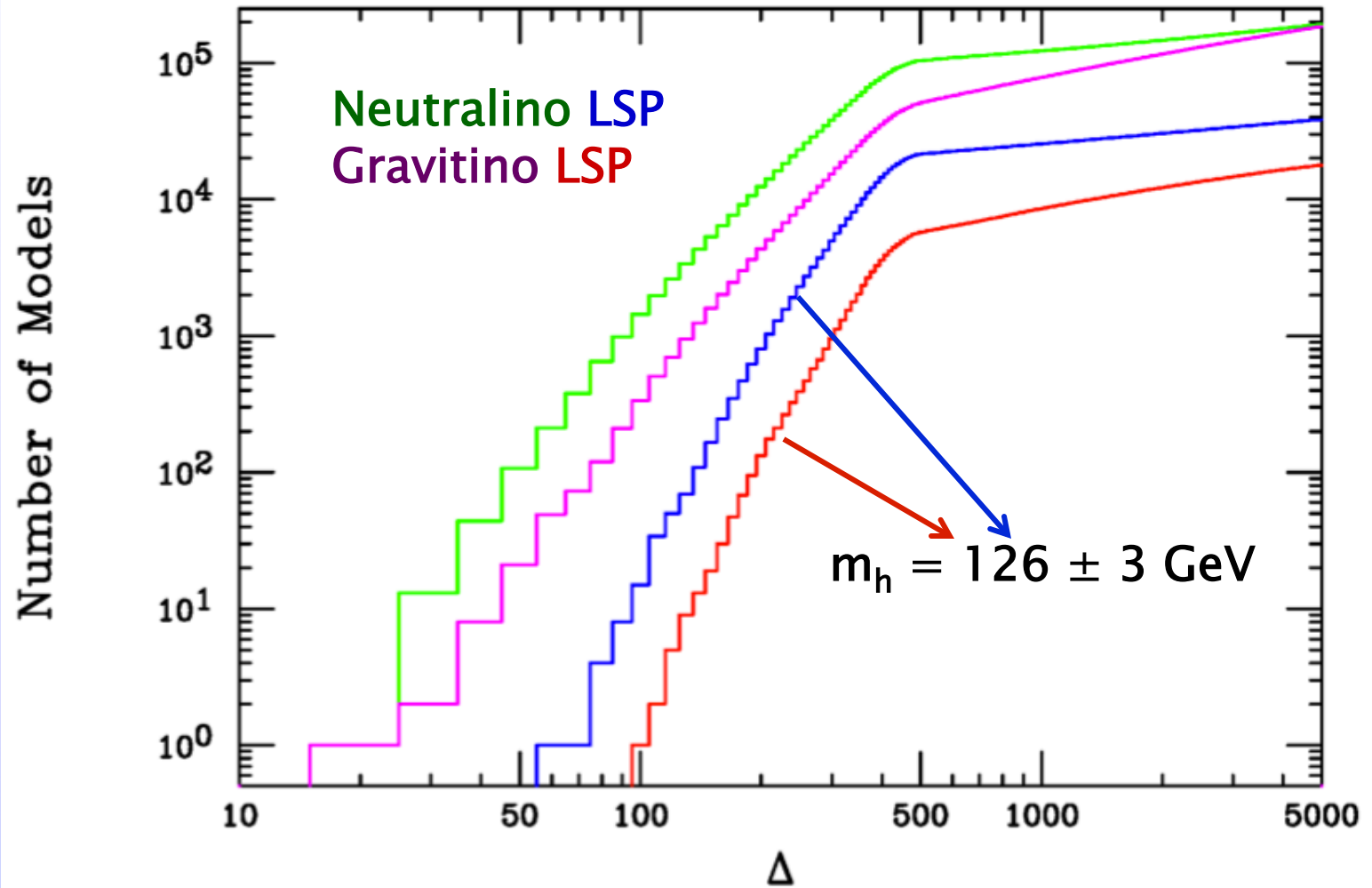


CMSSM

# Model Constraints

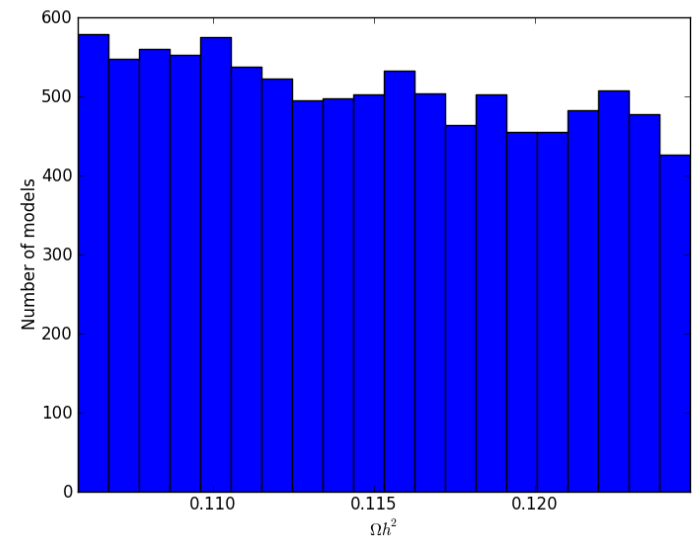
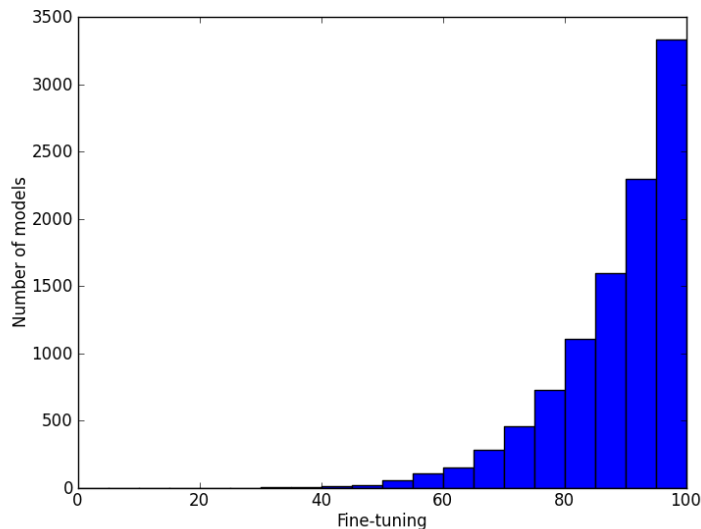
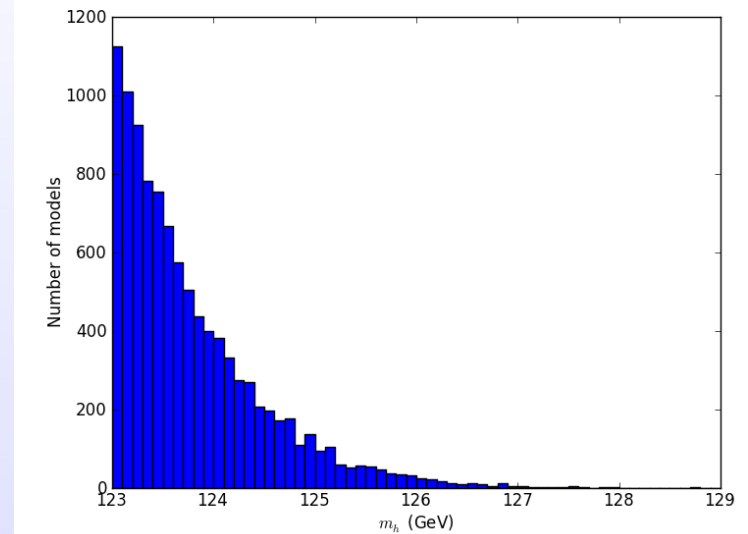
- $\Delta\rho$  / W-mass
- $\Gamma(Z \rightarrow \text{invisible})$
- $\Delta(g-2)_\mu$
- $b \rightarrow s \gamma$
- Meson-Antimeson Mixing
- $B \rightarrow \tau \nu$
- $B_s \rightarrow \mu\mu$
- Direct Detection of Dark Matter (SI & SD)
- WMAP Dark Matter density upper bound
- BBN energy deposition for gravitinos
- Relic  $\nu$ 's & diffuse photon bounds
- LEP and Tevatron Direct Higgs & SUSY searches
- LHC stable sparticle searches
- No tachyons or color/charge breaking minima
- Stable vacua only

# Fine-Tuning in the pMSSM

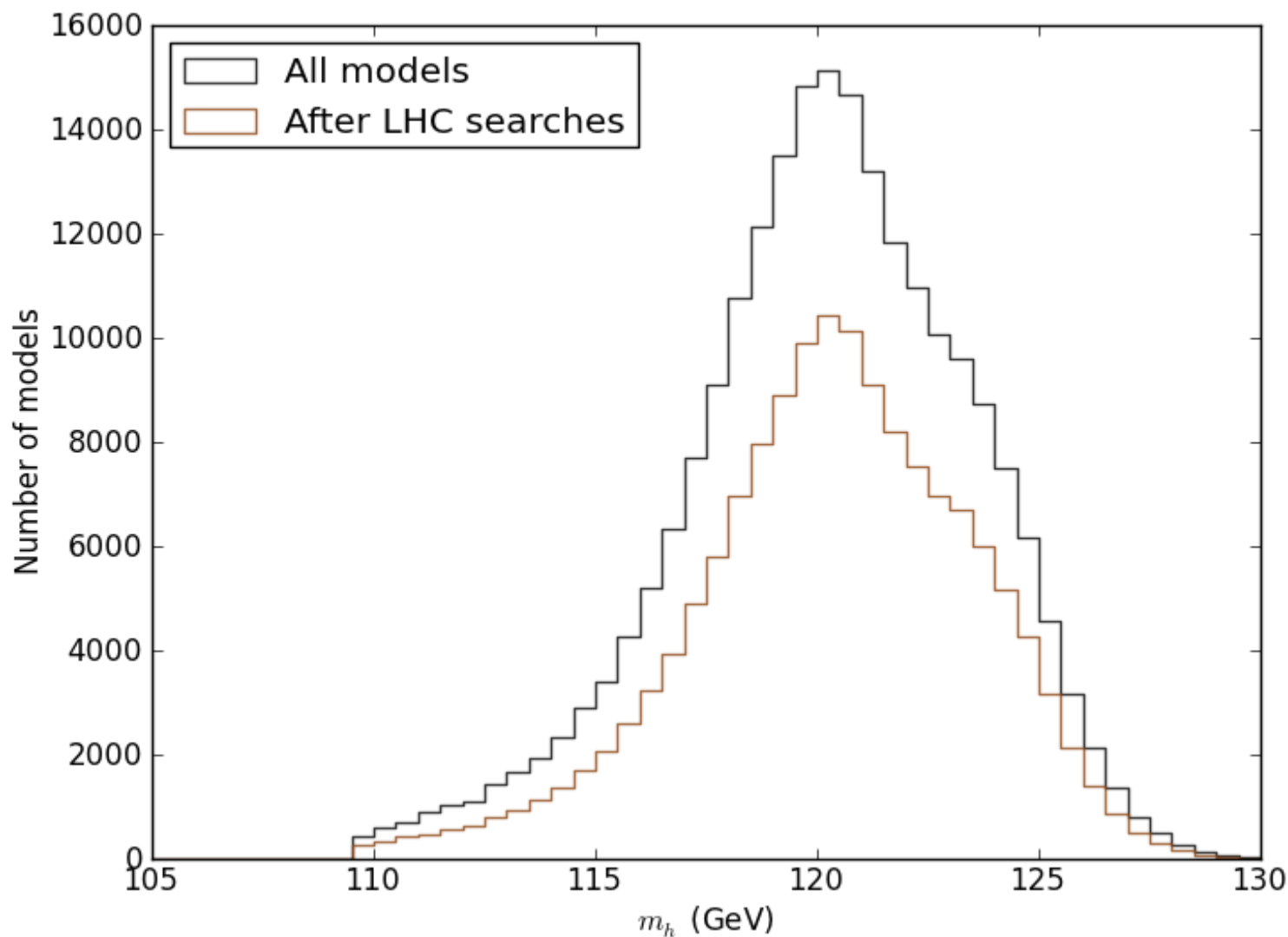


# pMSSM **Special** Low-FT Neutralino LSP Model Set

- $m_h = 126 \pm 3$  GeV
- $\Omega h^2|_{\text{DM}} = 0.1153 \pm 0.0095$
- FT better than 1%
- **~10k model points**

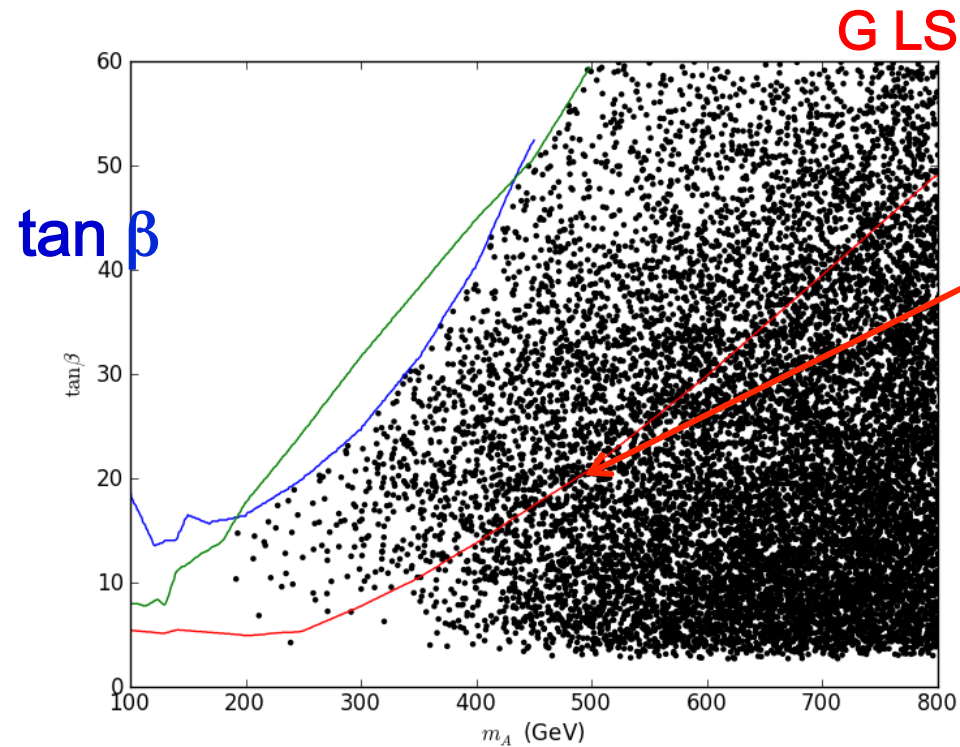


The MET-based searches are roughly independent of the of the Higgs mass: the predicted mass of the Higgs is roughly independent of the SUSY searches





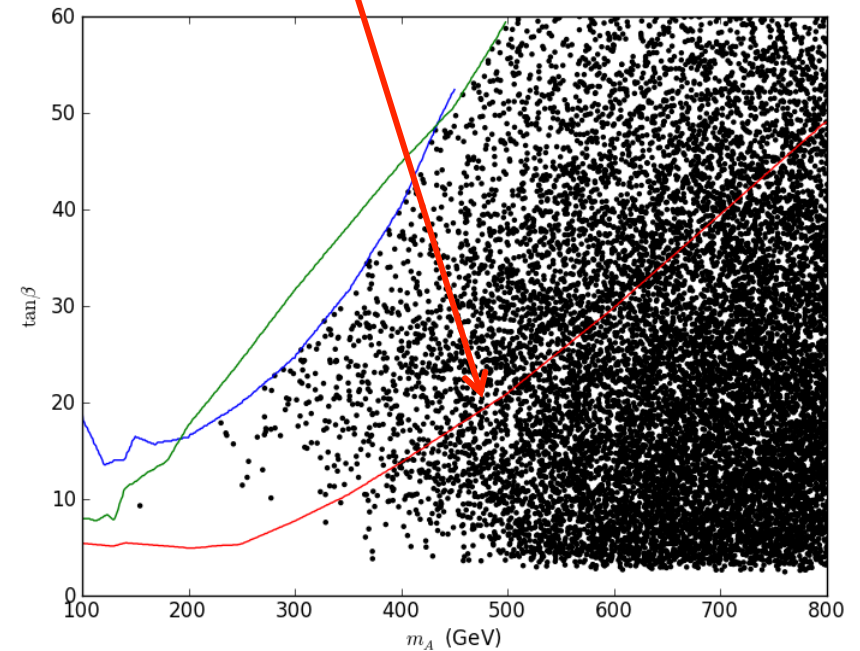
# Impact of $A, H \rightarrow \tau\tau$ Searches



G LSP

CMS 13 fb<sup>-1</sup>

$\chi$  LSP



$M_A$

3671(3309) models removed from the  $\chi$  (G) LSP set...

# $h \rightarrow bb$ decoupling

- $\Gamma = \Gamma_0 (1 + 2 \delta g^{\text{QCD}} / g + 2 \delta g^{\text{SQCD}} / g)$
- $\delta g^{\text{SQCD}}$  receives contributions from vertex correction, b wave function renormalization, and hbb counterterm

