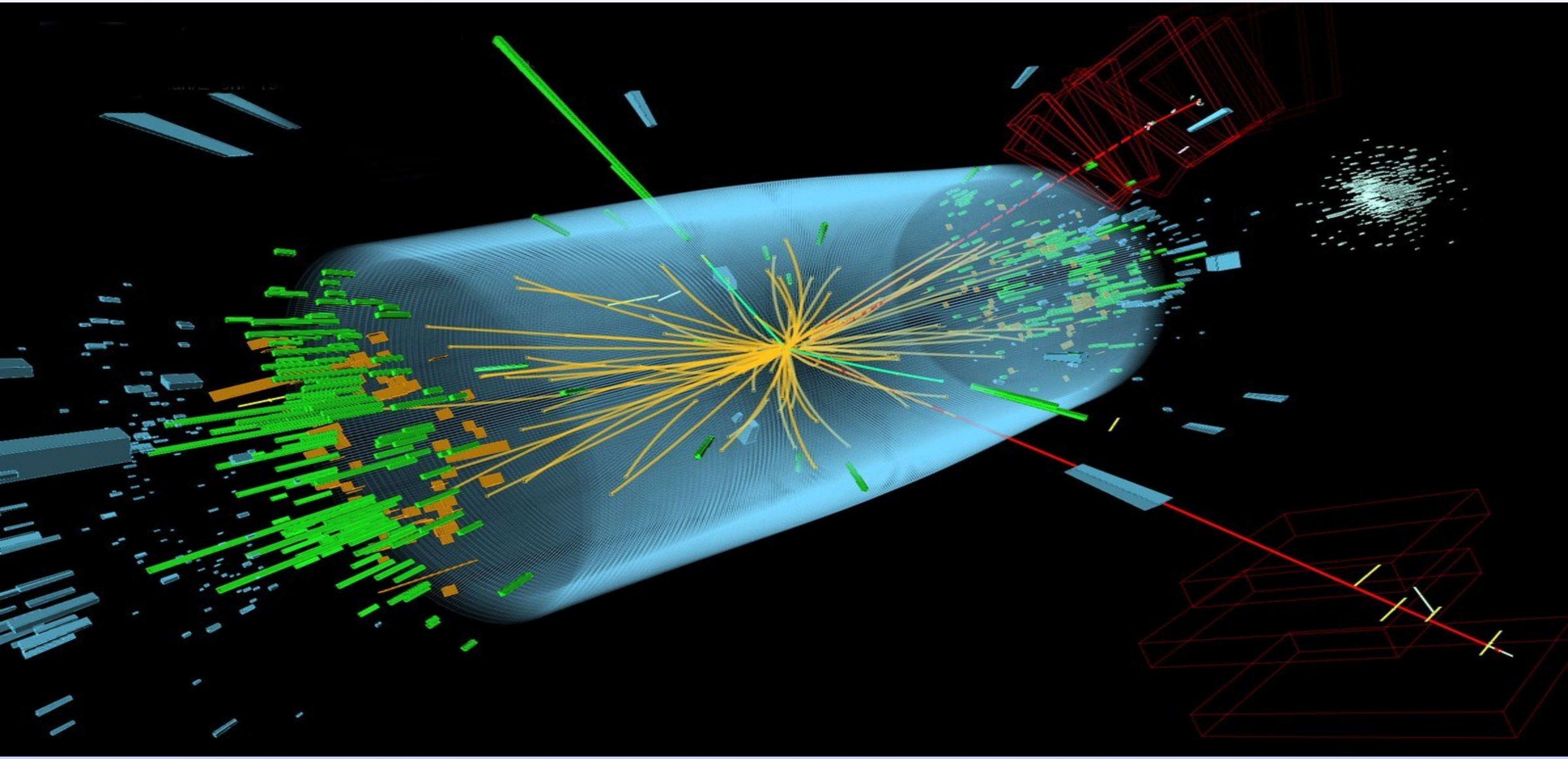
Constraints on Higgs Properties and SUSY Partners in the pMSSM



Cahill-Rowley, JLH, Hoeche, Ismail, Rizzo 1206.4321, 1206.5800, 1211.1981, 1211.7106, in preparation

SLAC NATIONAL ACCELERATOR LABORATORY

J. Hewett

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_τ

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

    (Gravitino: M_G)

Supersymmetry without Prejudice

Berger, Gainer, JLH, Rizzo 0812.0980

REMINDER:

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

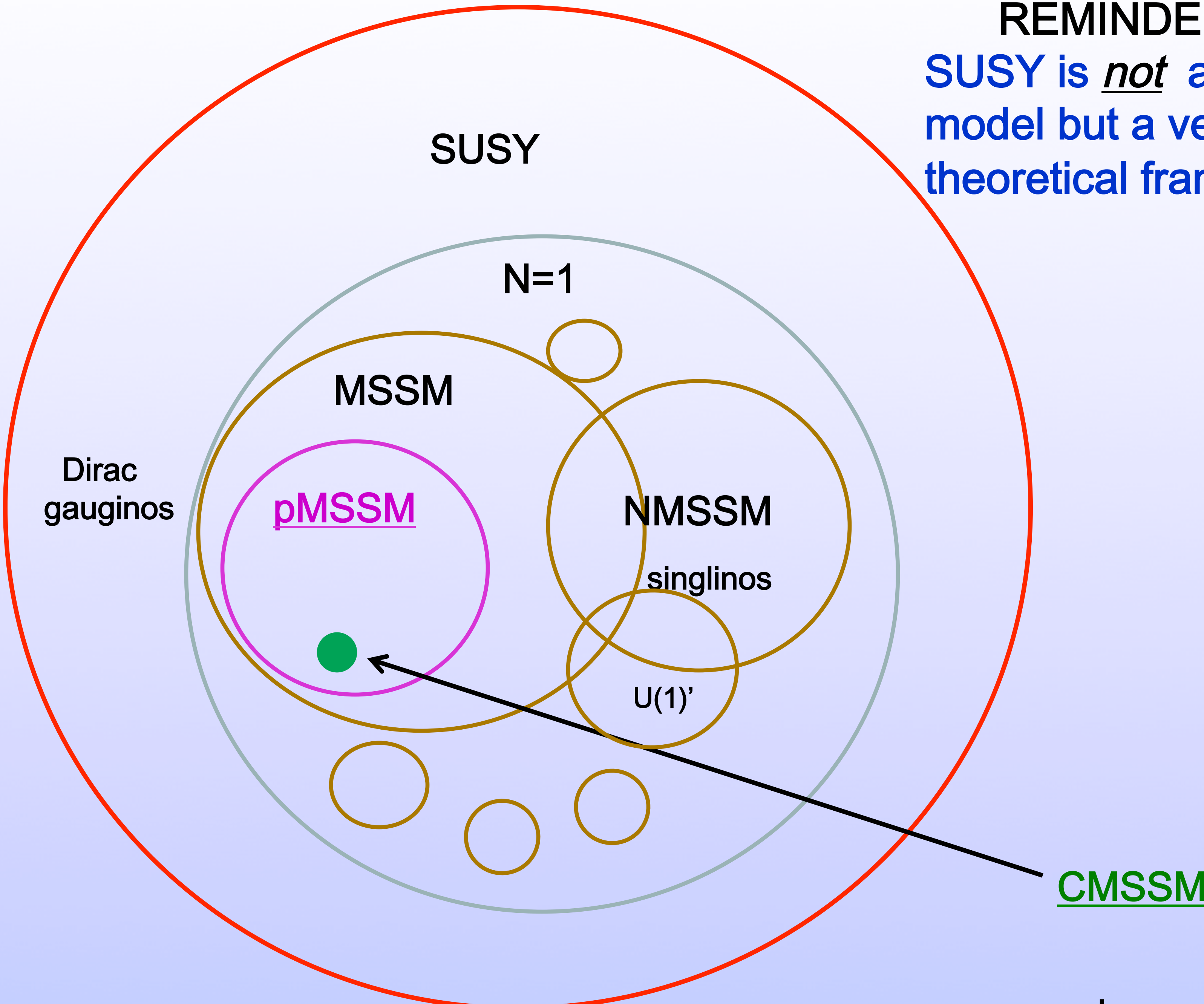


Image by T. Rizzo

Study of the pMSSM (Neutralino/Gravitino LSP)

Scan with Linear Priors

Perform large scan over Parameters

$100\ \text{GeV} \leq m_{sfermions} \leq 4\ \text{TeV}$
$50\ \text{GeV} \leq |M_1, M_2, \mu| \leq 4\ \text{TeV}$
$400\ \text{GeV} \leq M_3 \leq 4\ \text{TeV}$
$100\ \text{GeV} \leq M_A \leq 4\ \text{TeV}$
$1 \leq \tan\beta \leq 60$
$|A_{t,b,\tau}| \leq 4\ \text{TeV}$
($1\ \text{ev} \leq m_G \leq 1\ \text{TeV}$) (log prior)

Subject these points to Constraints from:

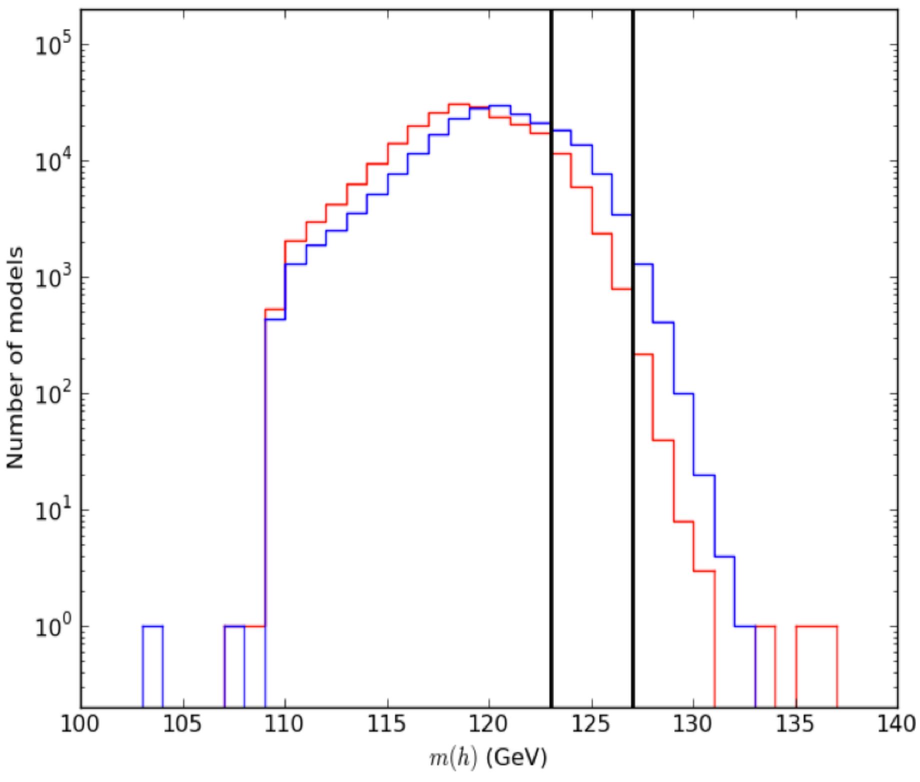
- Flavor physics
- EW precision measurements
- Collider searches
- Cosmology

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

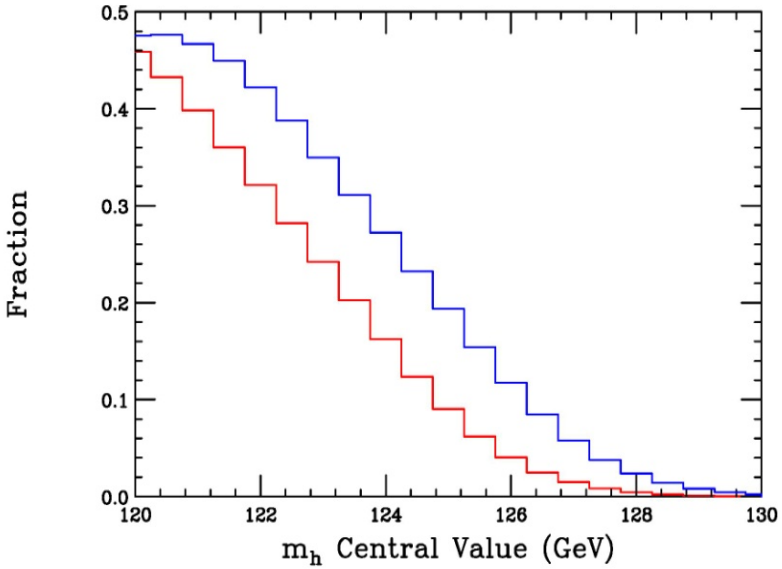
Predictions for Lightest Higgs Mass in the pMSSM

~40k Neutralino models with m_h = 126±3 GeV

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



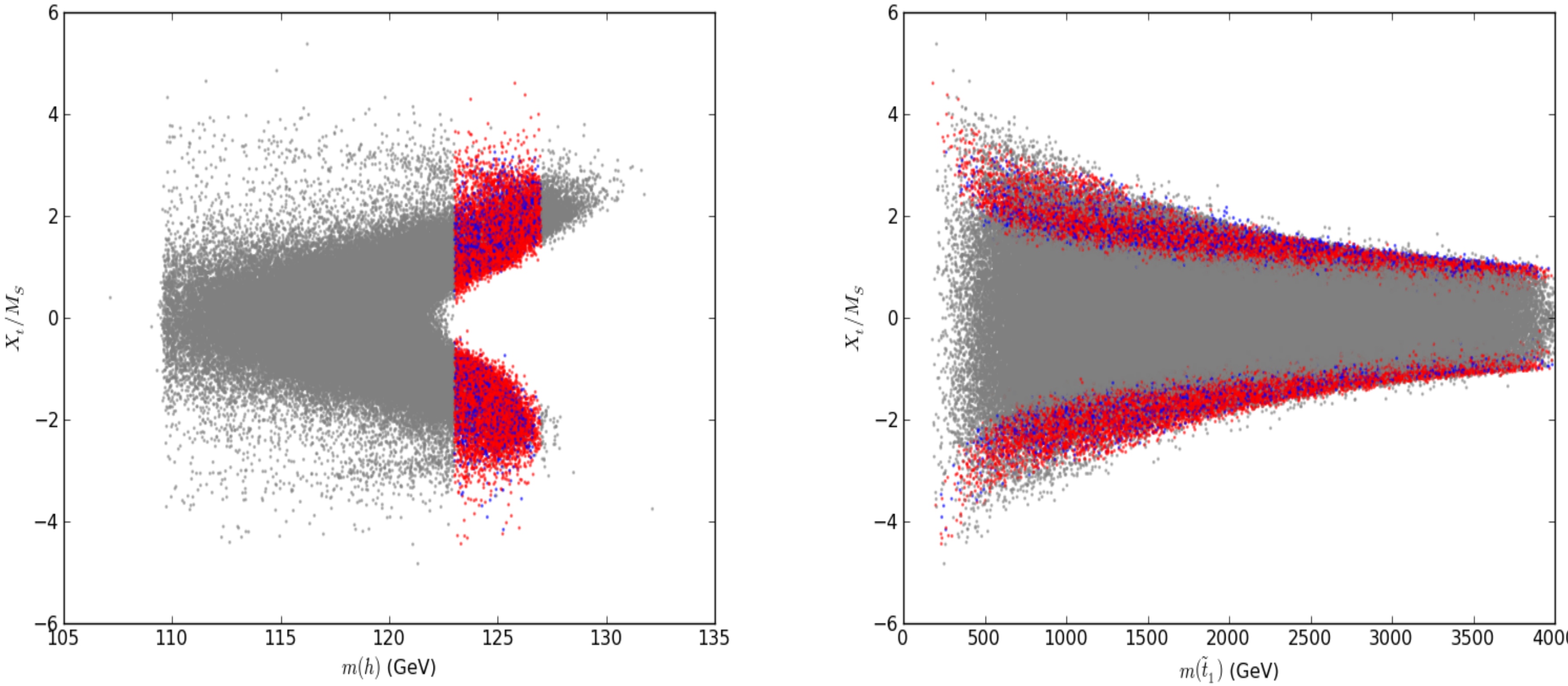
Neutralino LSP
Gravitino LSP



Special parameter regions needed for the 126 GeV Higgs

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

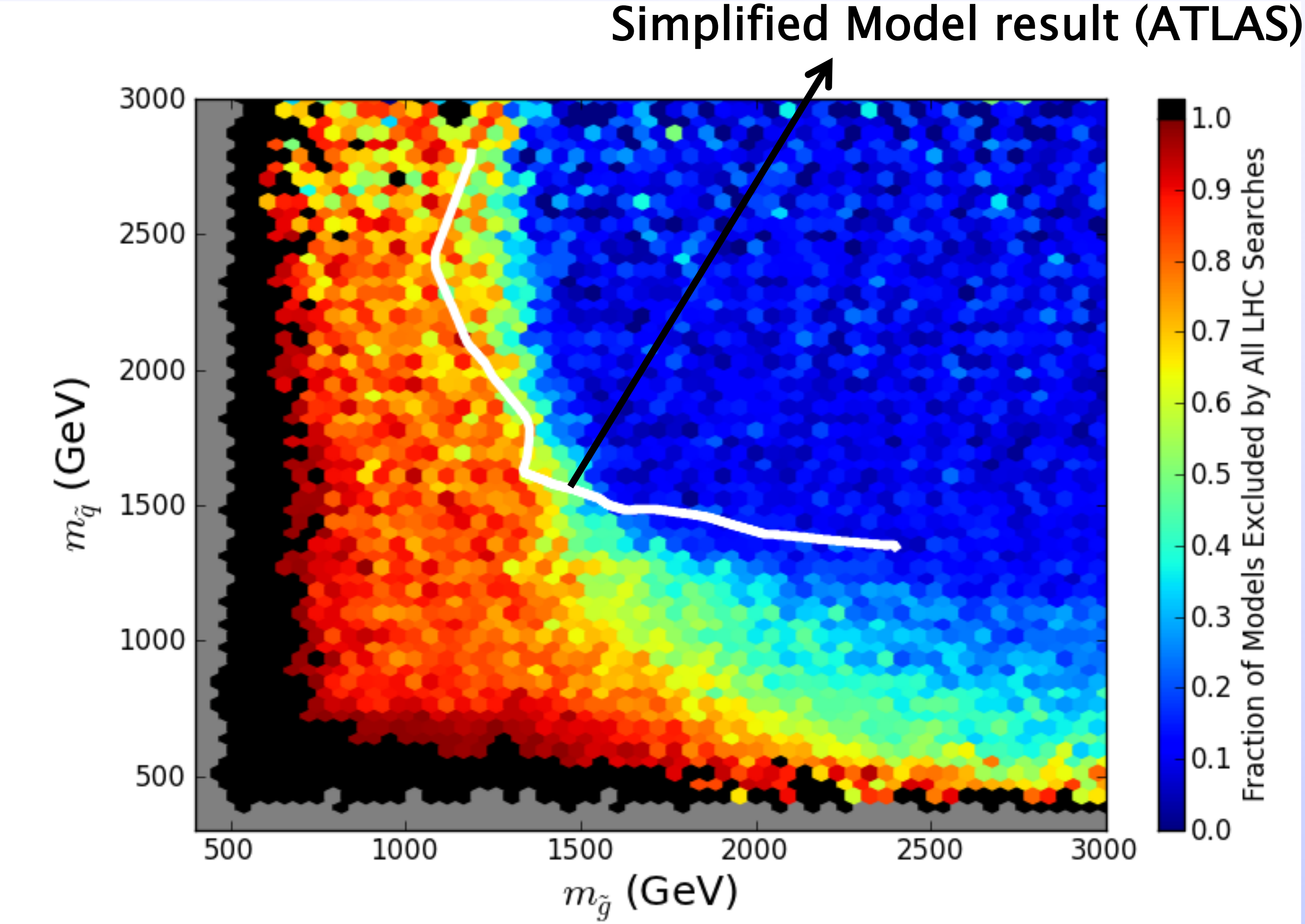
χ_1^0 LSP



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 (~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 ~ 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



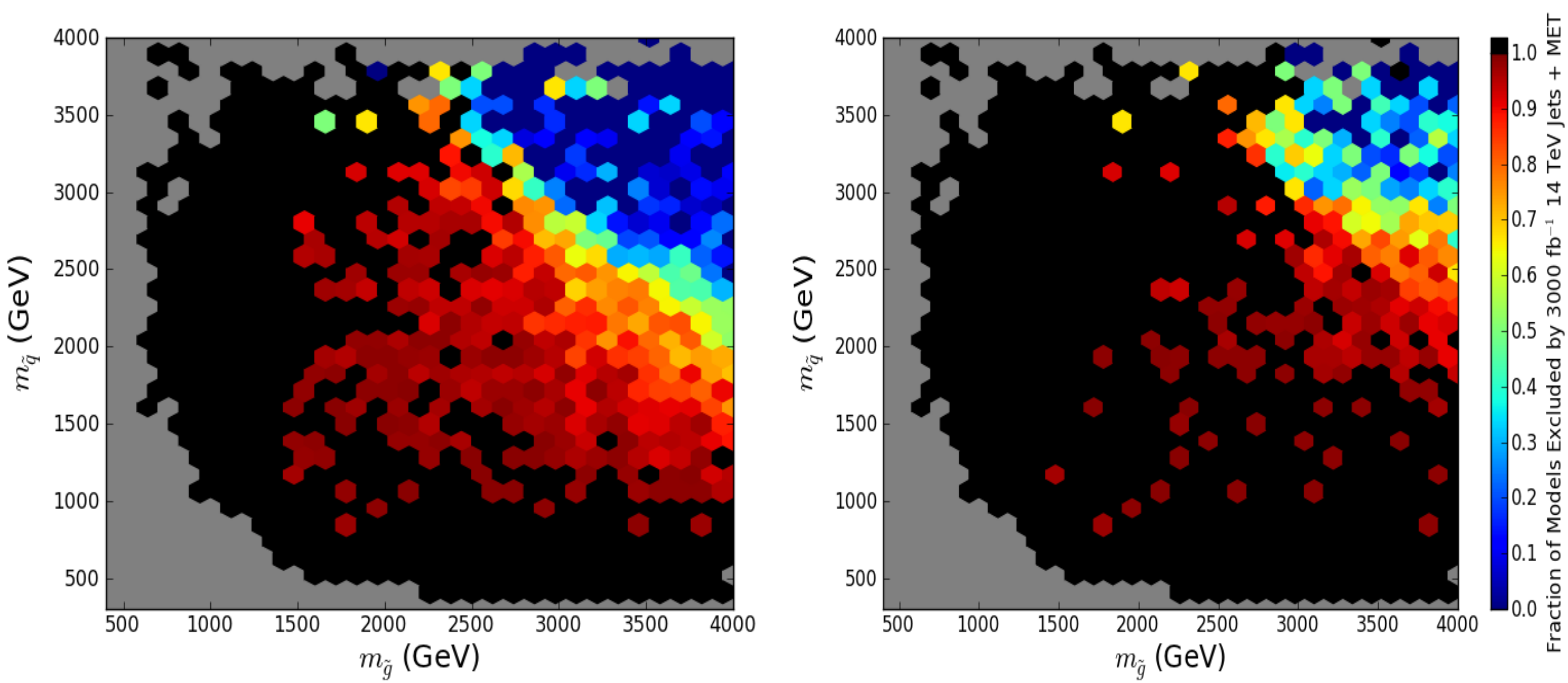
All available analyses through 3/1/13

37% of 225k model set excluded

14 TeV LHC pMSSM Coverage for 0.3 & 3 ab^{-1}

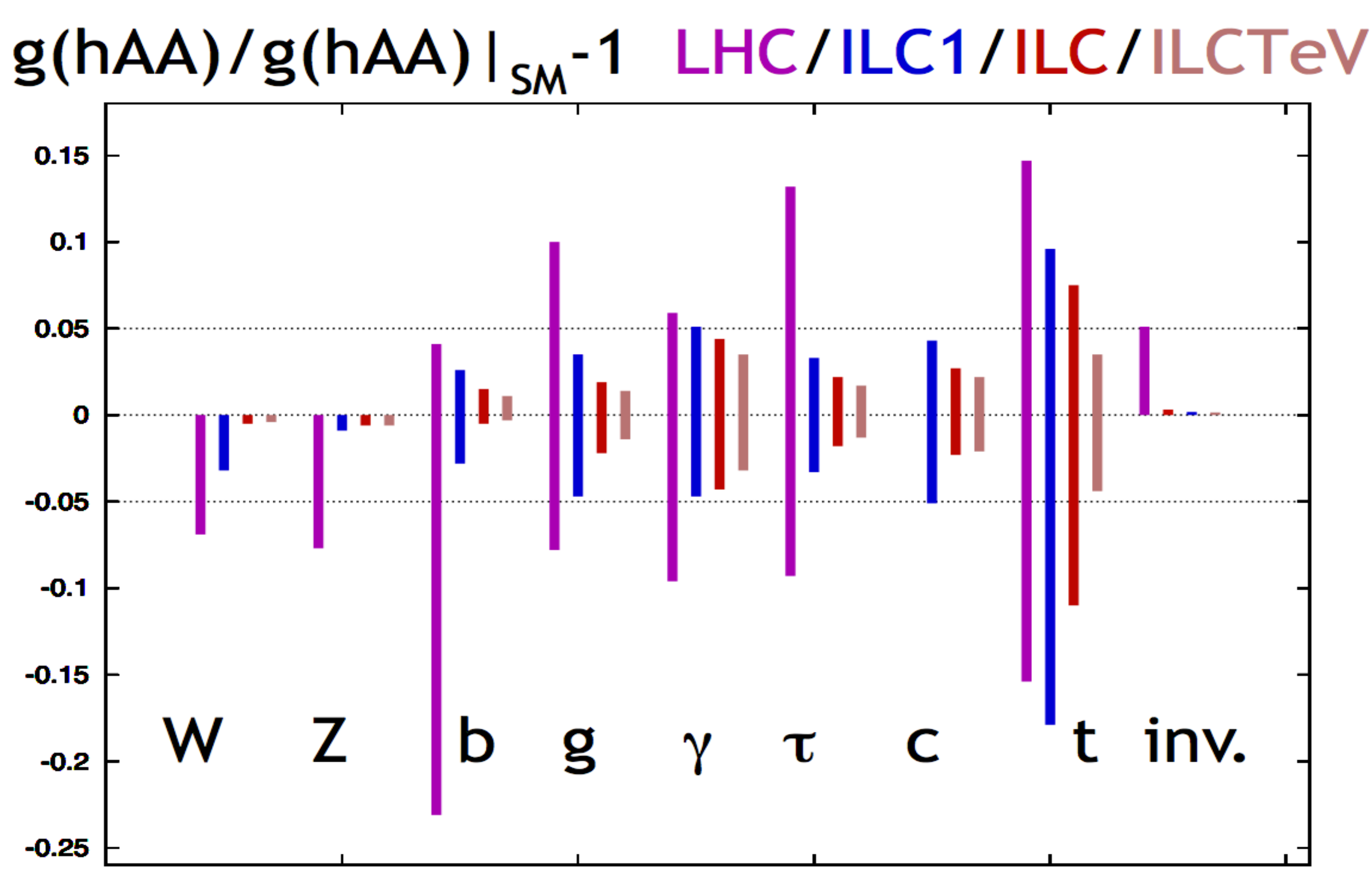
Jets+MET Analysis only (ATLAS European Strategy Study)
225k Neutralino LSP model set

300 fb^{-1}: 92.1% of models excluded 3 ab^{-1}: 97.5% of models excluded



Precision Higgs Measurements

Peskin: 1207.2516



Higgs partial widths in the pMSSM: $\gamma\gamma$ and gg

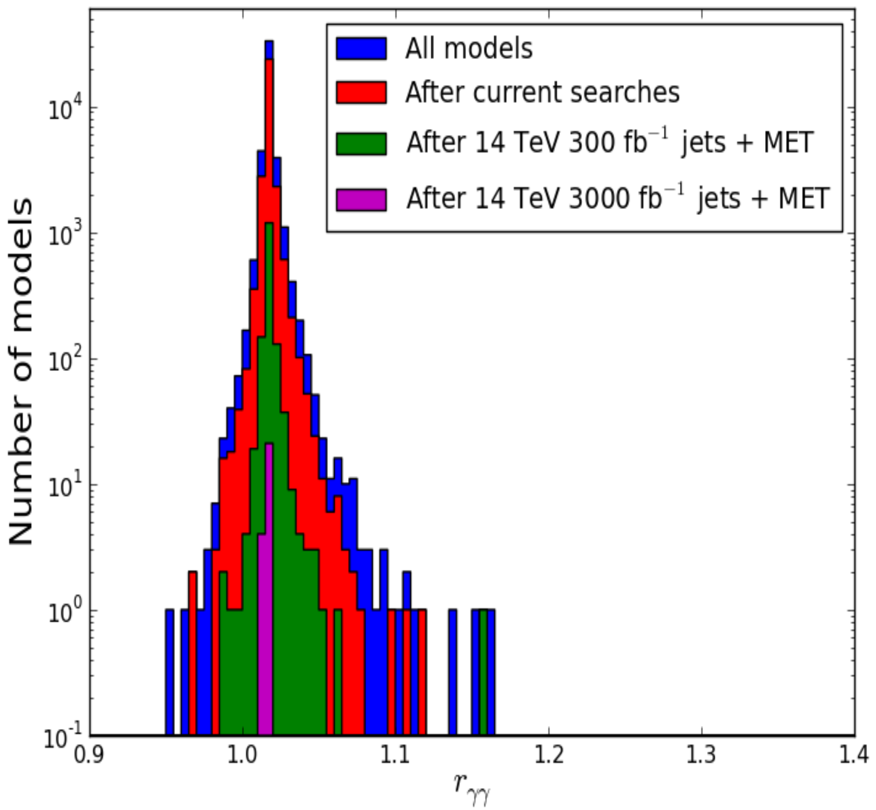
$r_{XX} = \Gamma_{XX}|_{pMSSM} \;/\; \Gamma_{XX}|_{SM}$

40k models with correct m_h

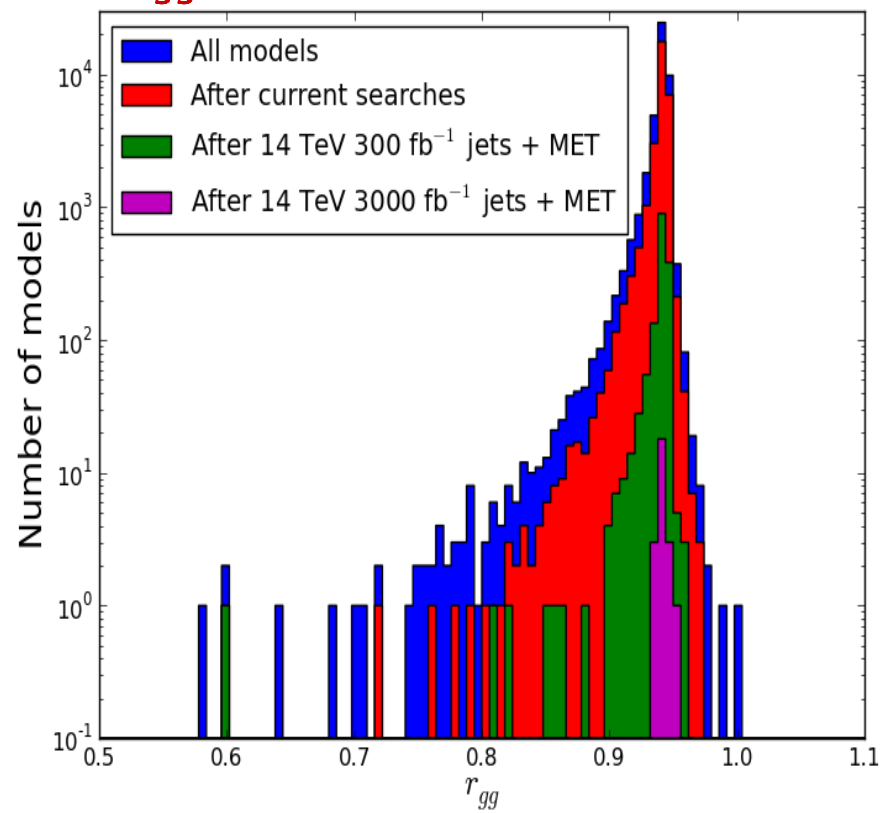
Carena etal 1303.4414

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

$r_{\gamma\gamma}$



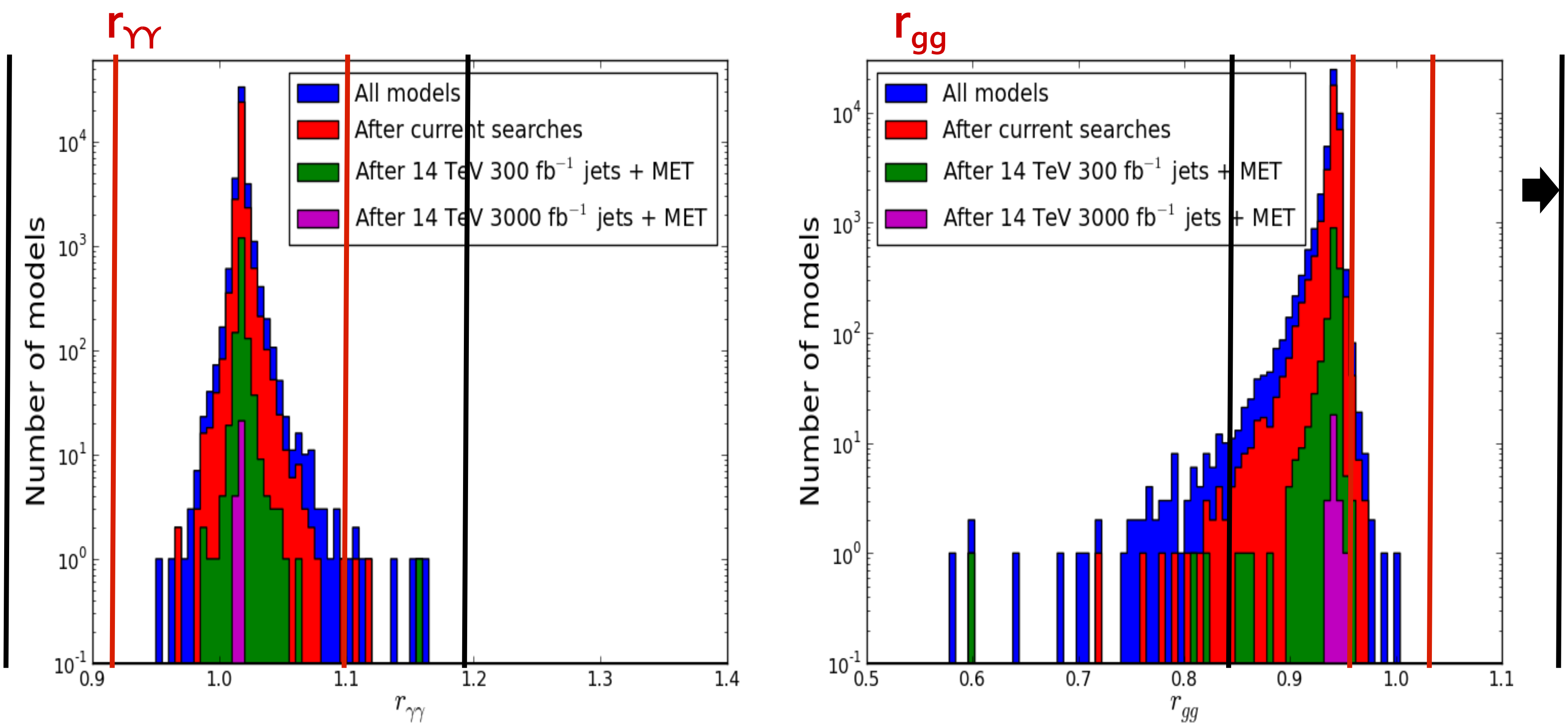
r_{gg}



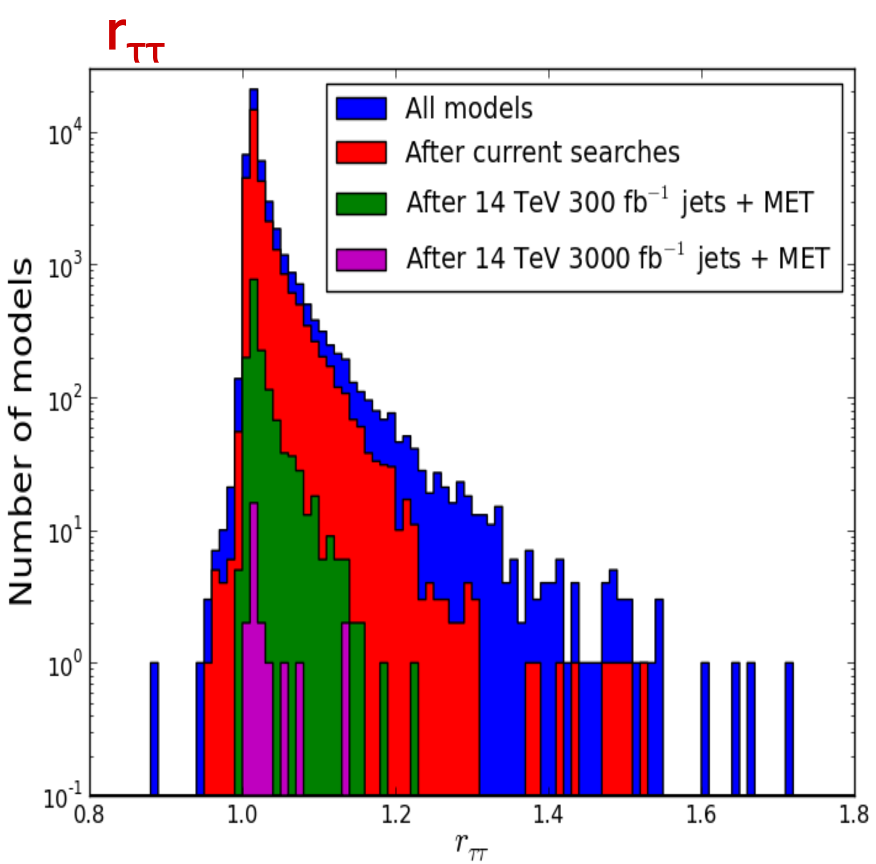
Higgs partial widths in the pMSSM: ϒϒ and gg

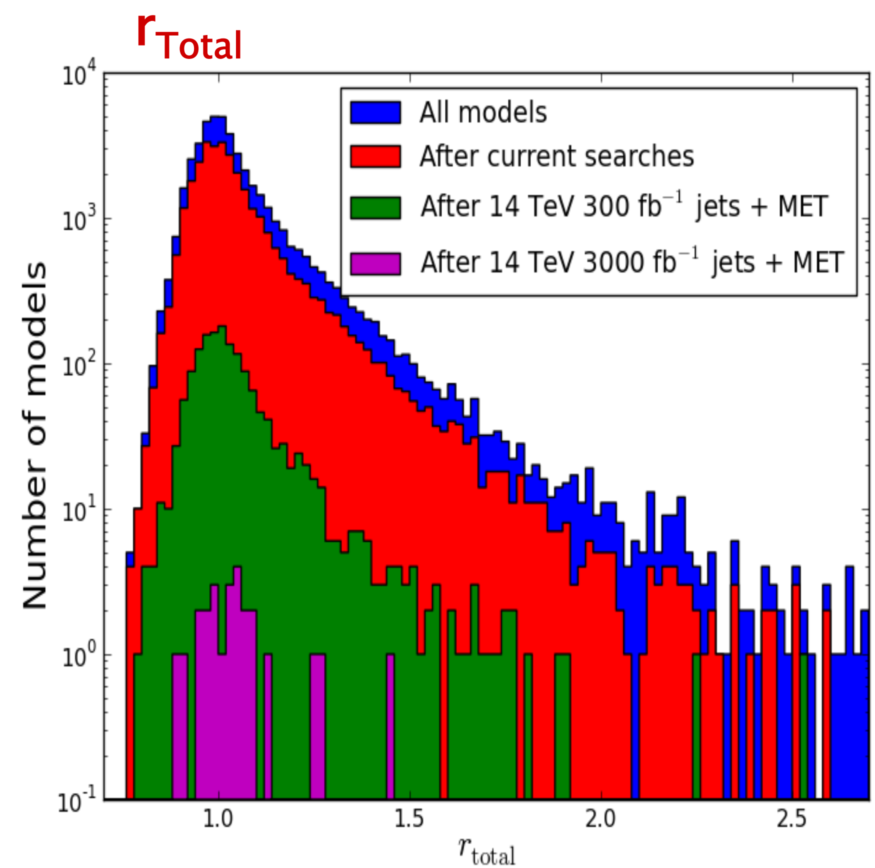
- LHC 14 TeV 300 fb^{-1} 2σ errors
- ILC 500 GeV 500 fb^{-1} 2σ errors
- Centered around 1.0 for the ratio r_{XX}

Peskin:1207.2516

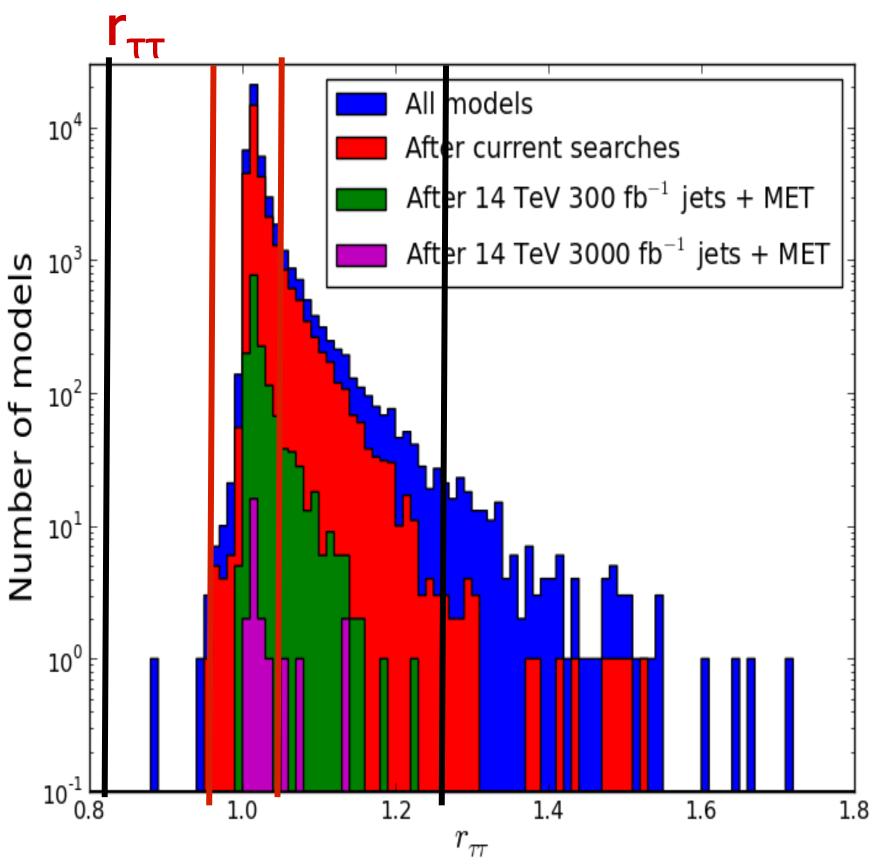


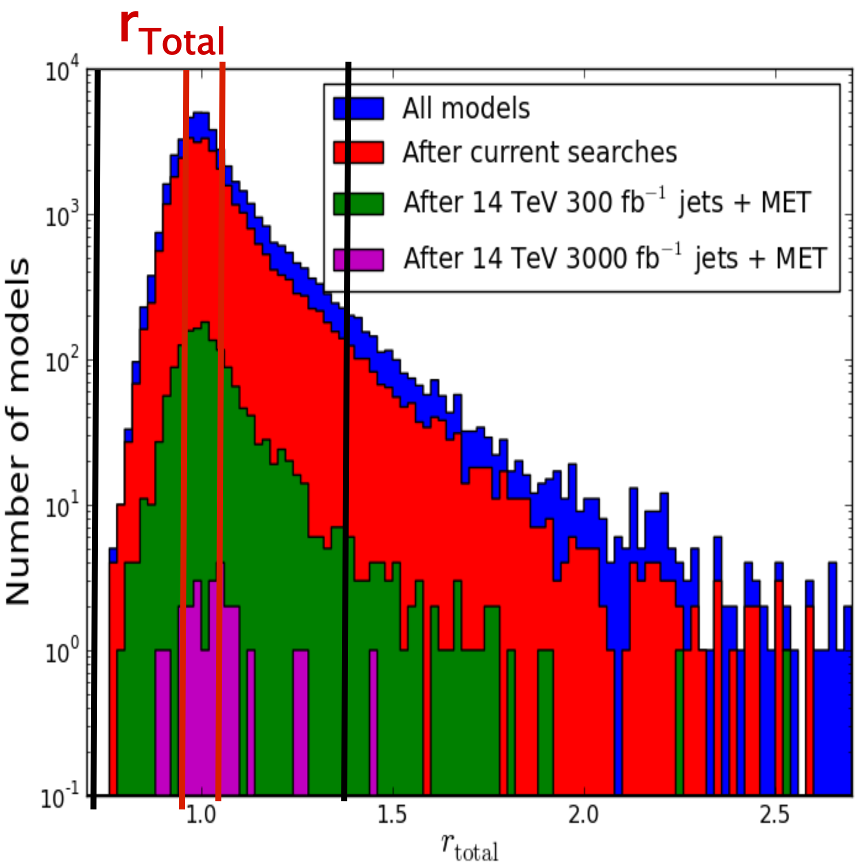
Higgs partial widths in the pMSSM: ττ and Total





Higgs partial widths in the pMSSM: ττ and Total

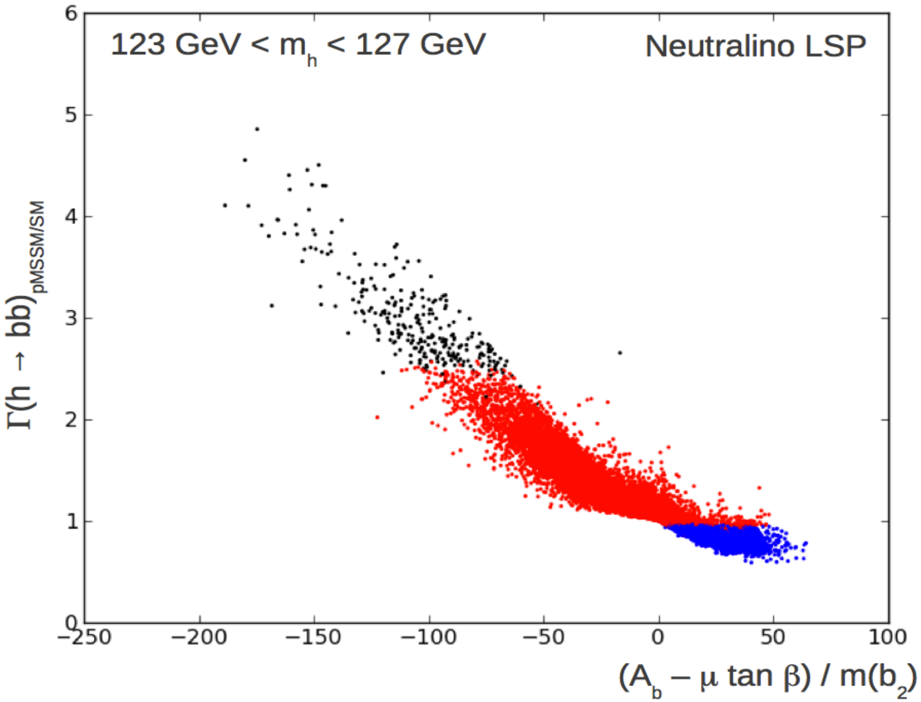


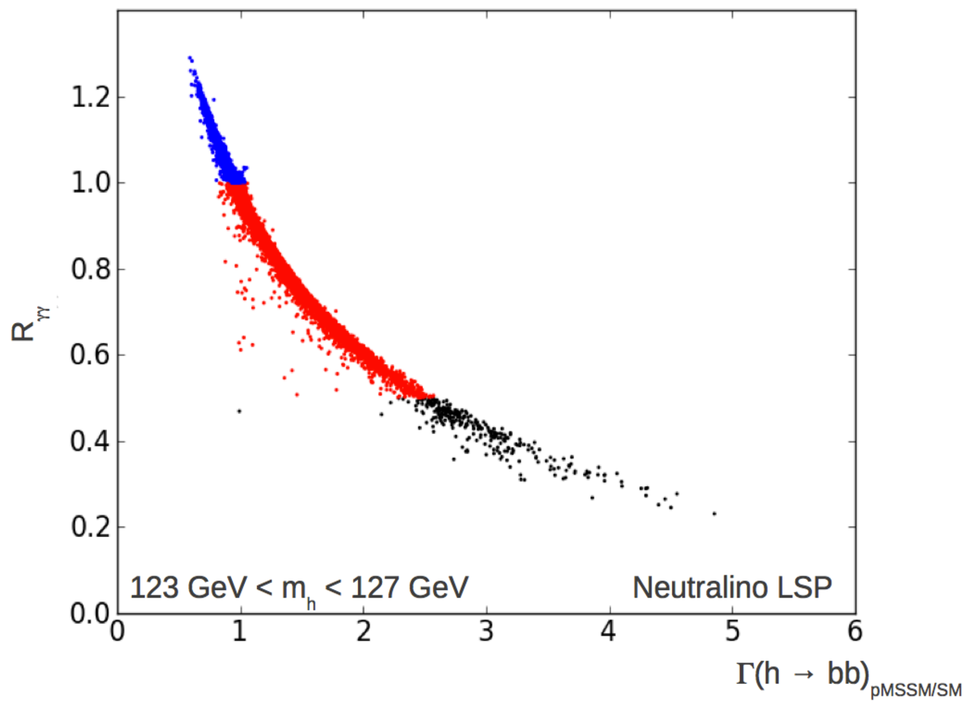


h→bb

- Large hbb coupling loop corrections decouple very slowly especially if there is large sbottom mixing (Haber etal.)

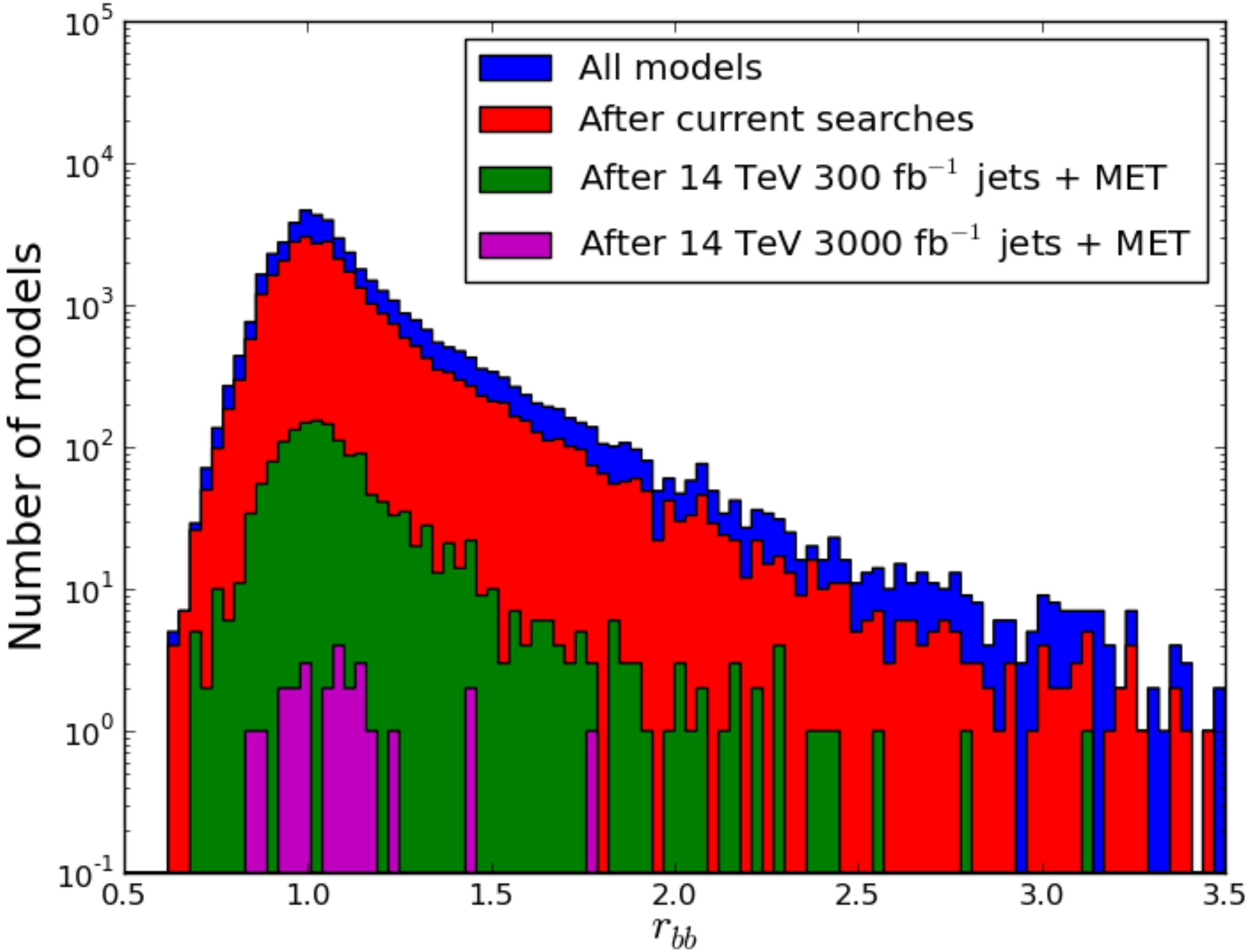
- These lead to a significant Higgs width increase/decrease since it is the dominant decay mode



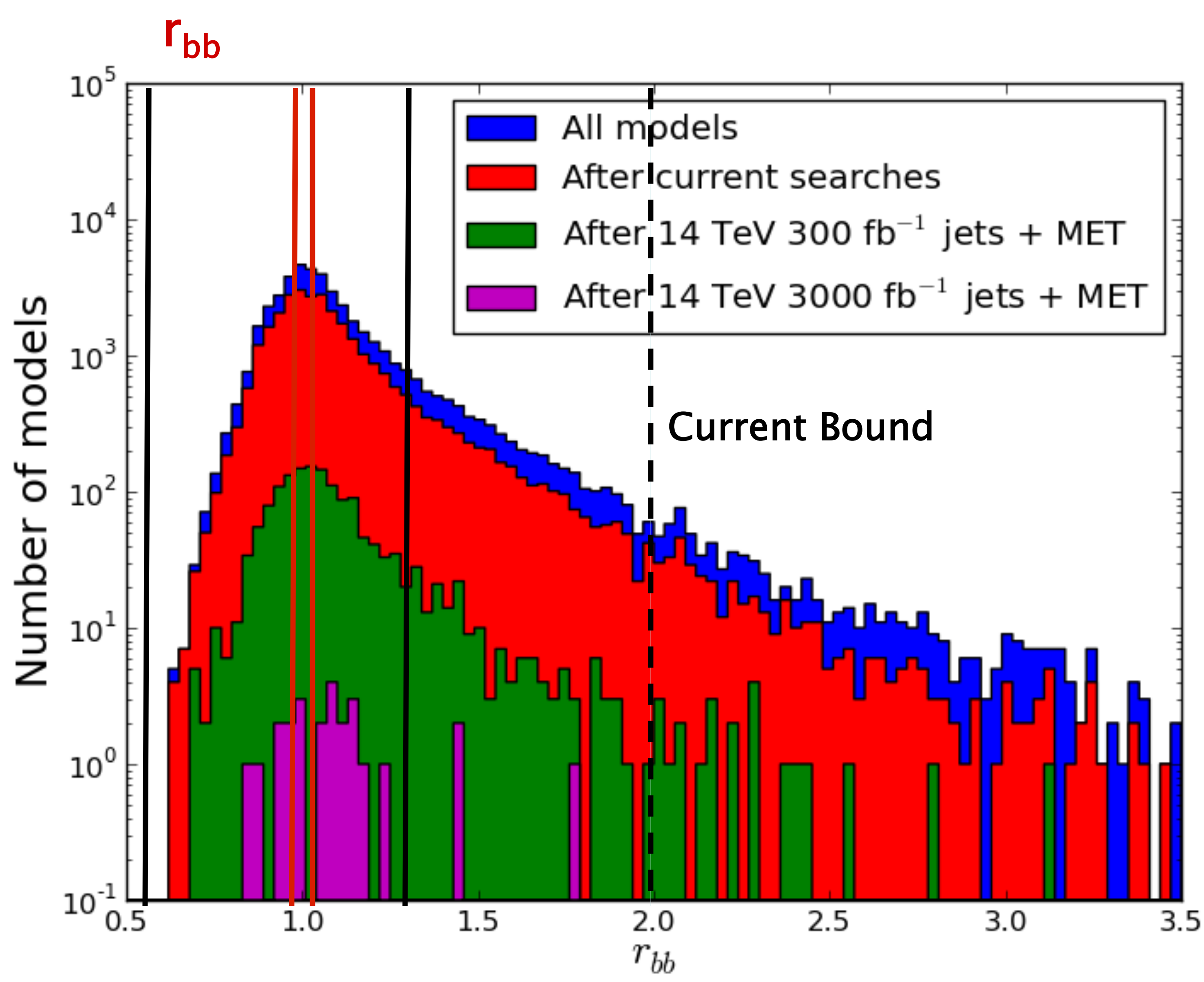


Higgs partial widths in the pMSSM: $b\bar{b}$

r_{bb}

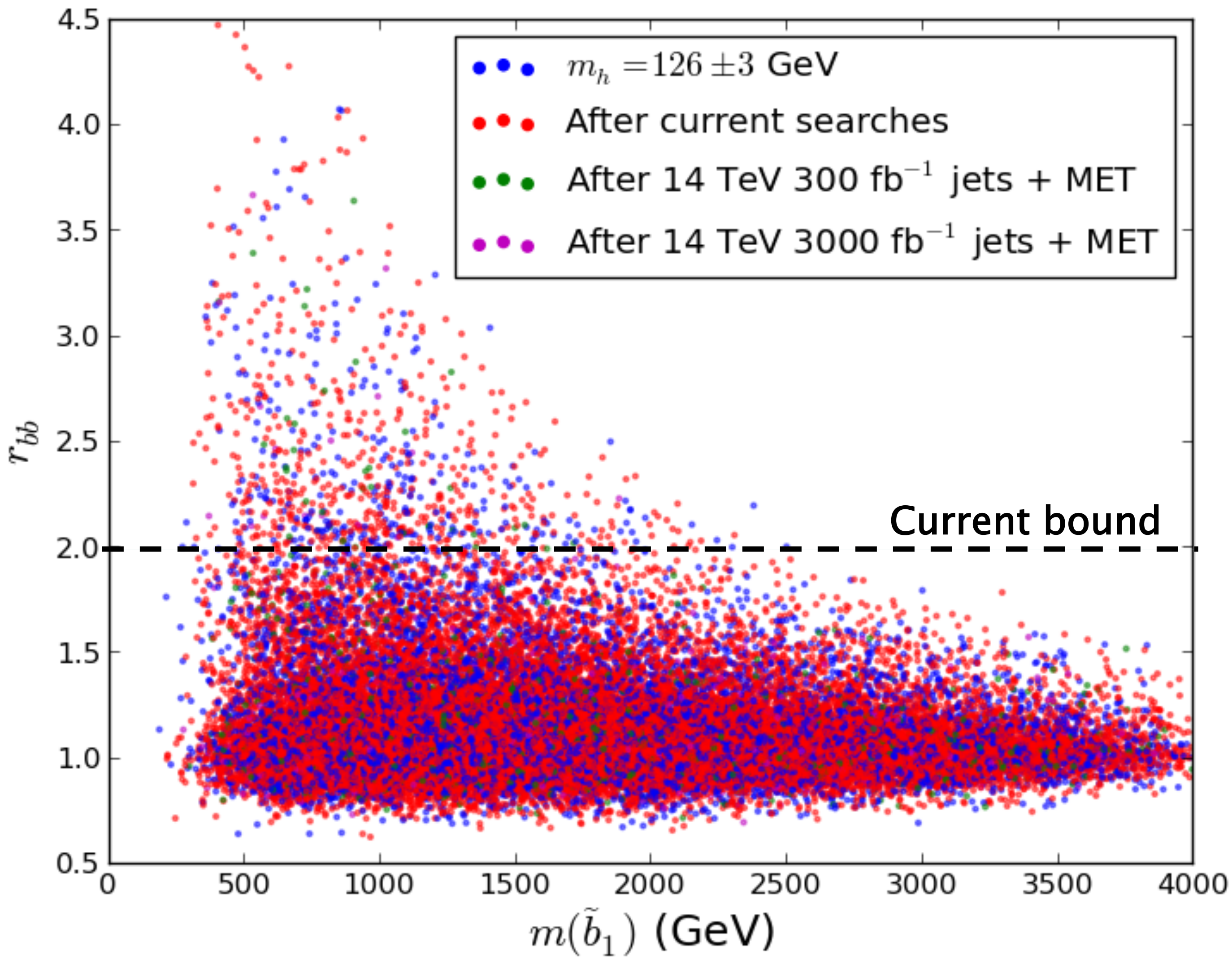


Higgs partial widths in the pMSSM: $b\bar{b}$

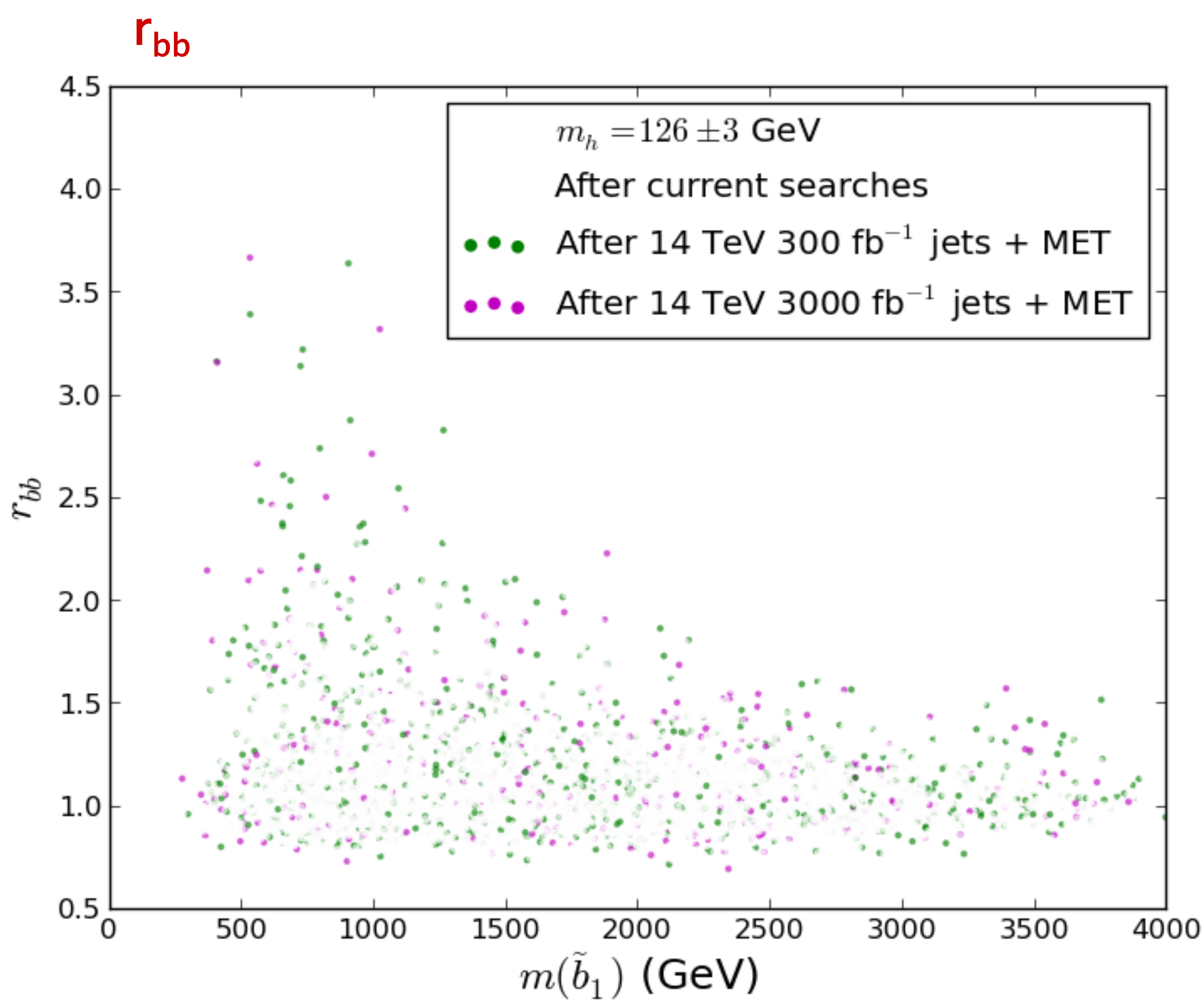


Higgs partial widths in the pMSSM: $b\bar{b}$

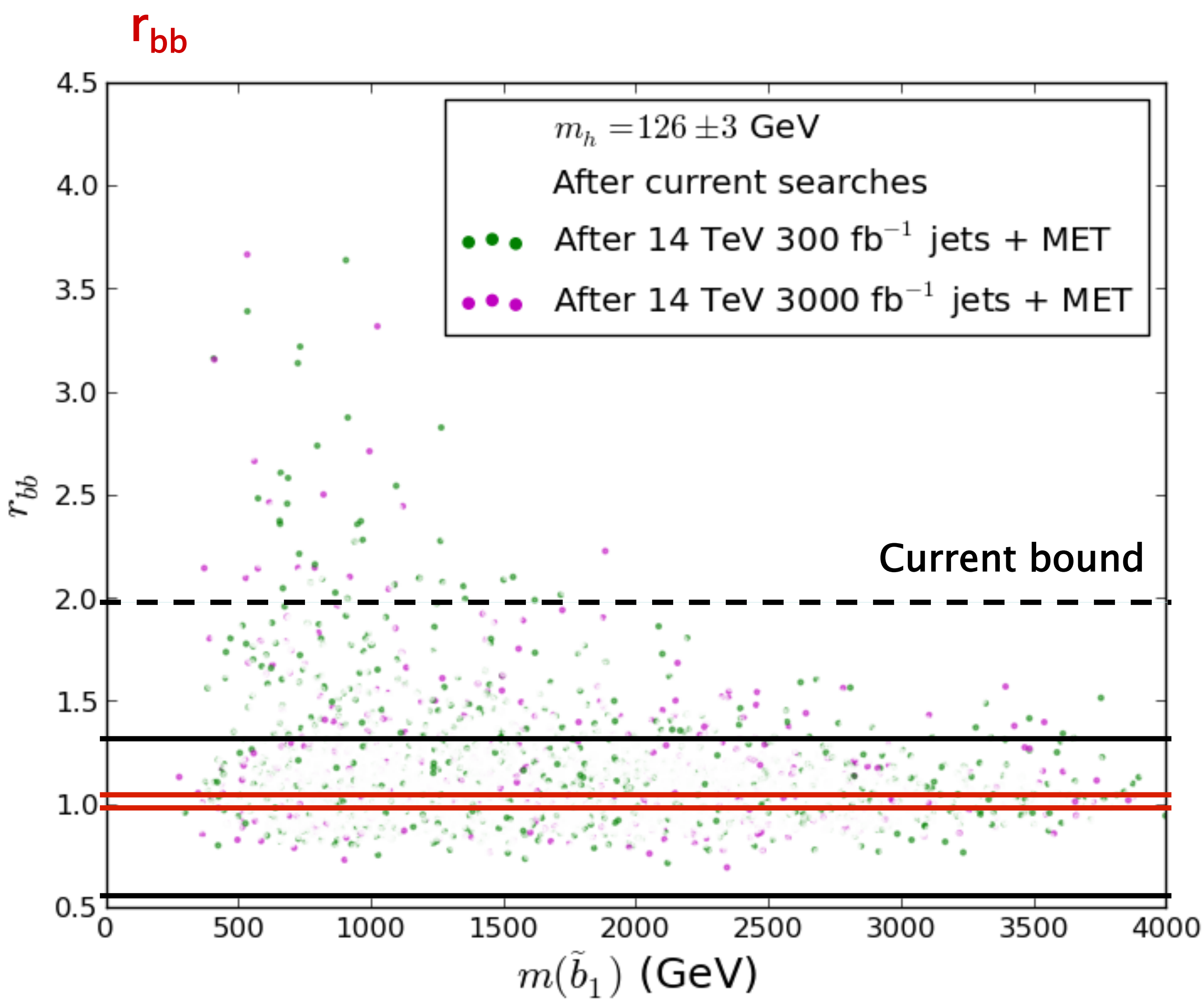
r_{bb}



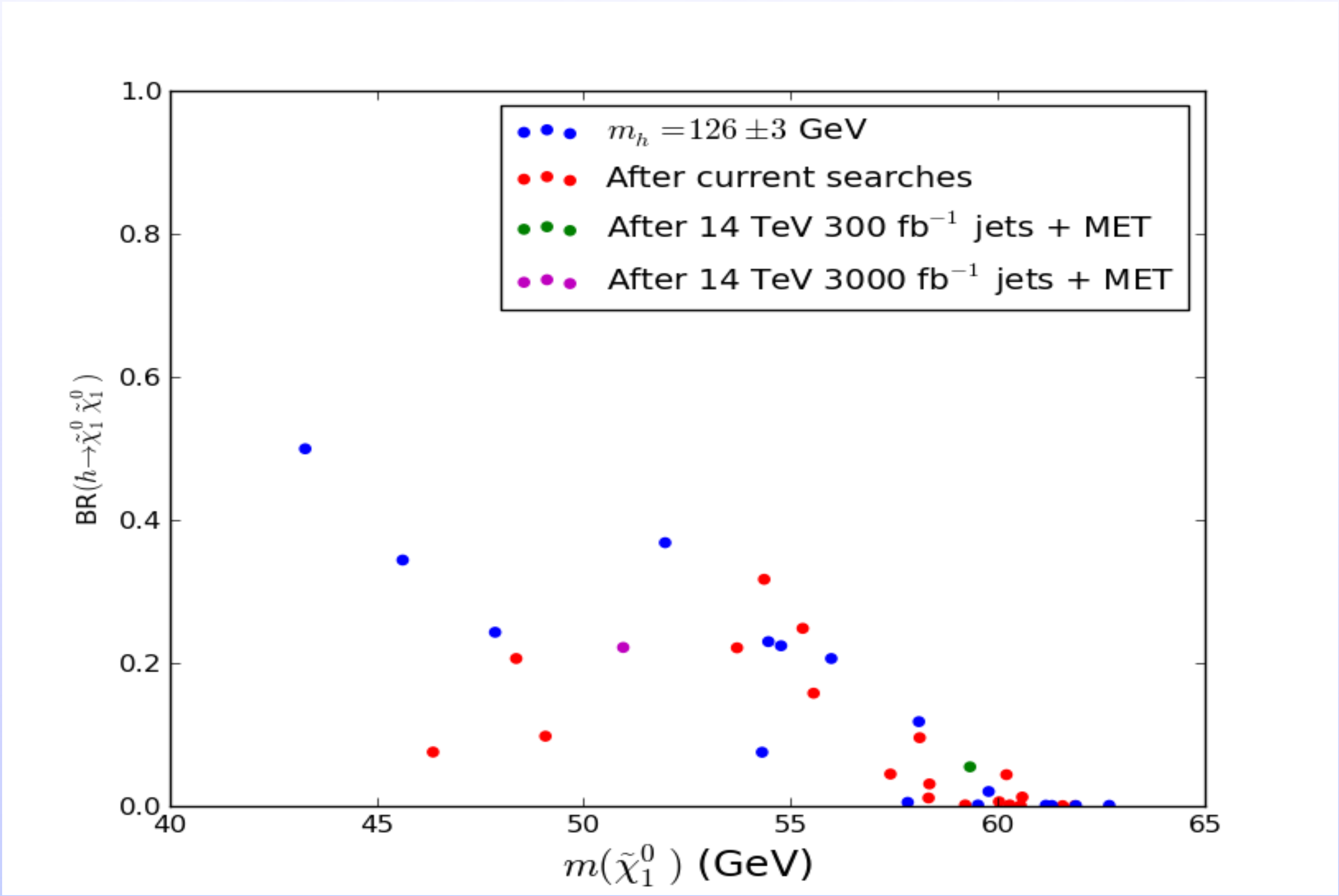
Higgs partial widths in the pMSSM: $b\bar{b}$



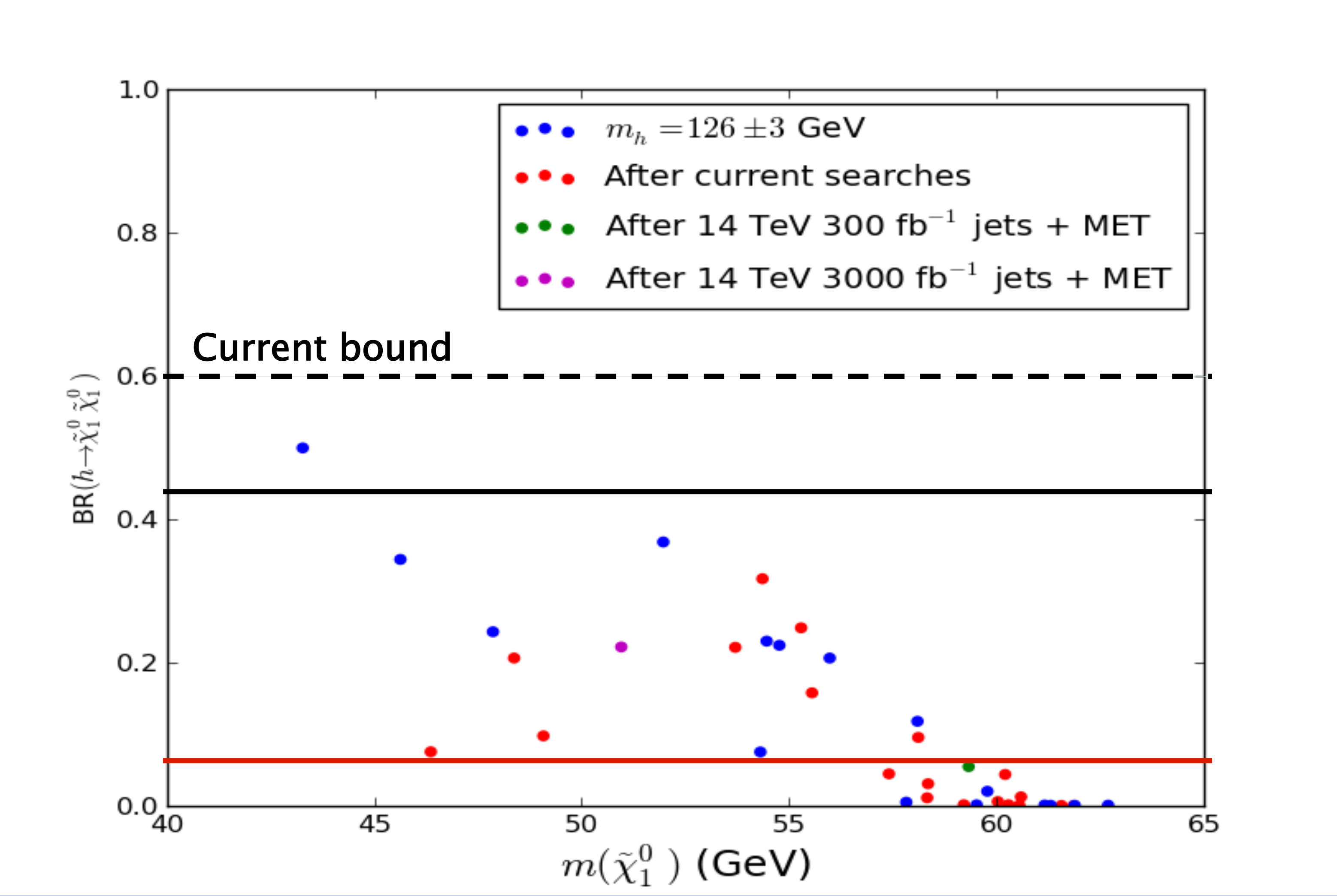
Higgs partial widths in the pMSSM: $b\bar{b}$



Invisible Width of the Higgs



Invisible Width of the Higgs



Conclusions

- Relatively easy to accommodate 126±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

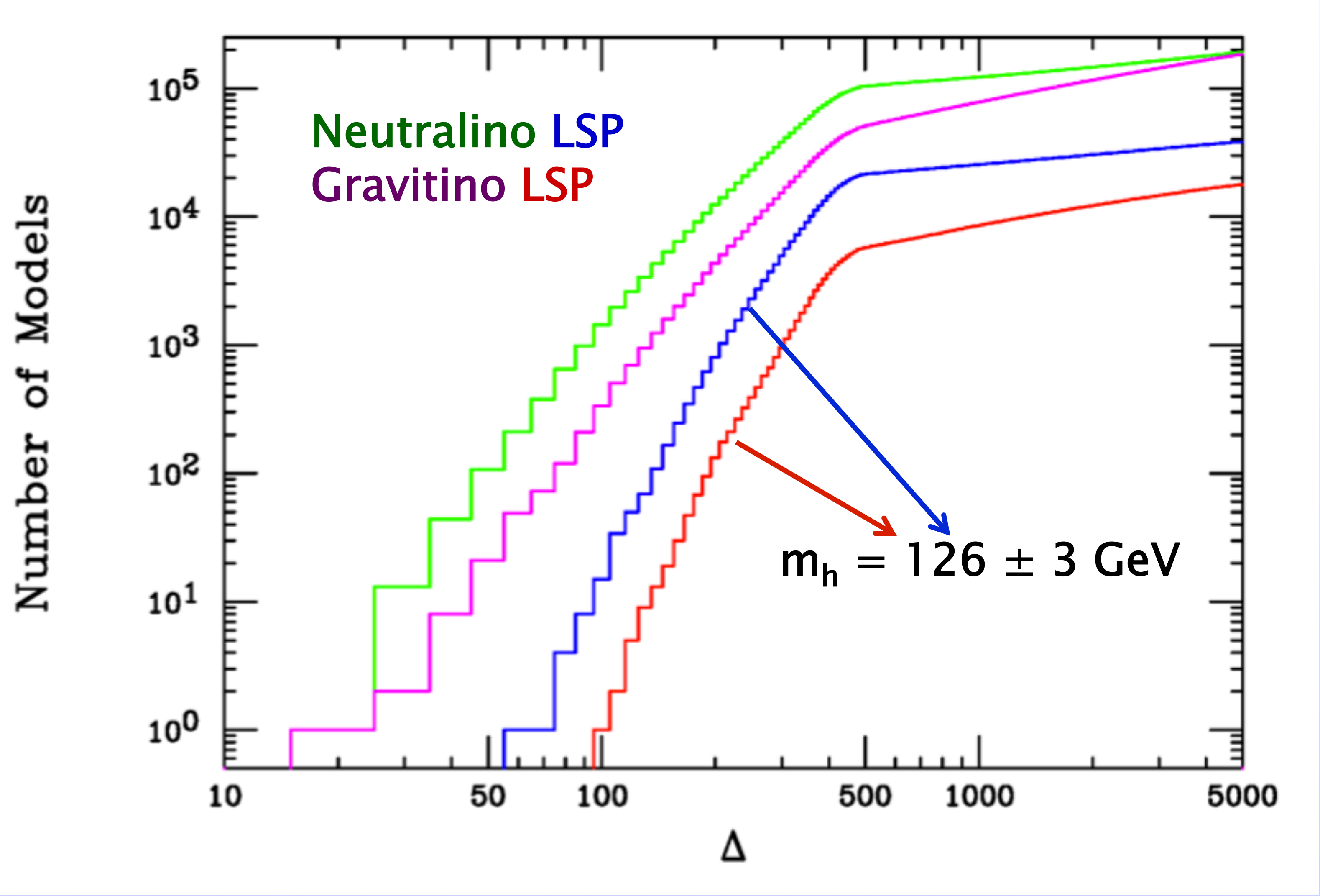
Backup

Model Constraints

- $\Delta\rho$ / W–mass
- $\Gamma(Z \to$ invisible$)$
- $\Delta(g-2)_\mu$
- $b \to s\,\gamma$
- Meson–Antimeson Mixing
- $B \to \tau\nu$
- $B_s \to \mu\mu$

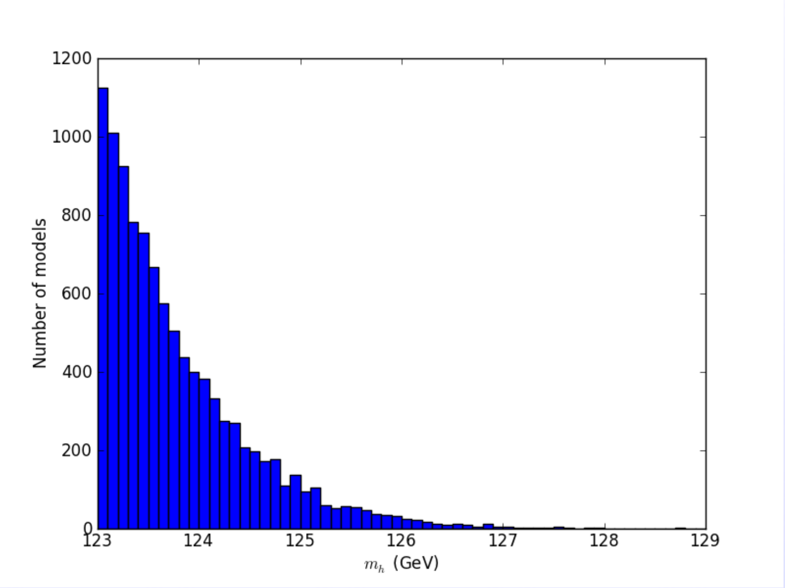
- Direct Detection of Dark Matter (SI & SD)
- WMAP Dark Matter density upper bound
- BBN energy deposition for gravitinos
- Relic ν's & diffuse photon bounds
- LEP and Tevatron Direct Higgs & SUSY searches
- LHC stable sparticle searches
- No tachyons or color/charge breaking minima
- Stable vacua only

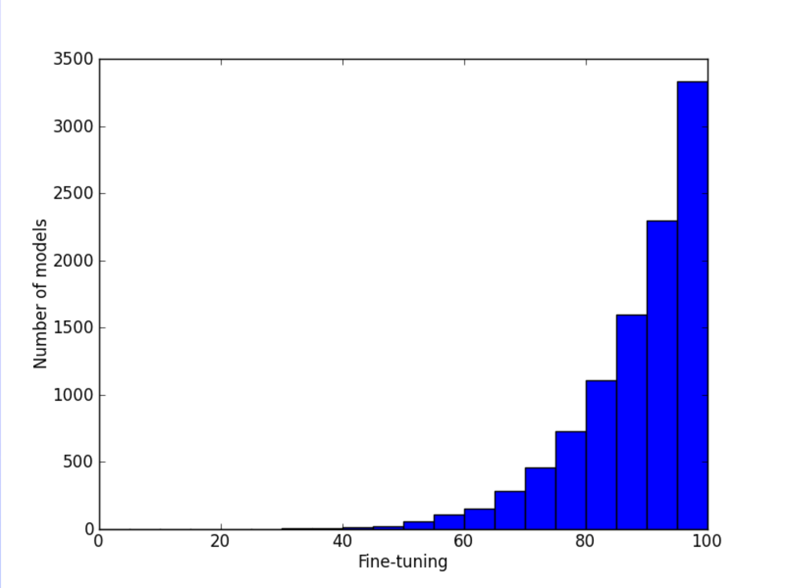
Fine-Tuning in the pMSSM

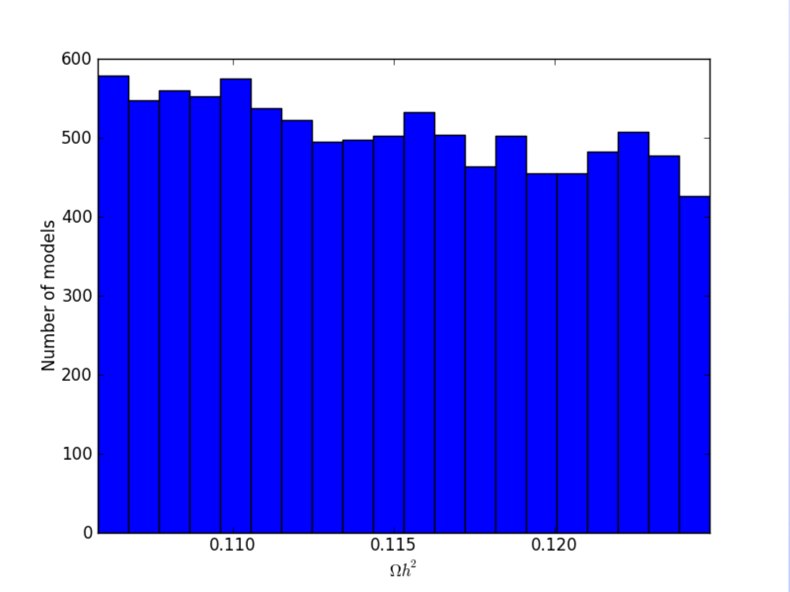


pMSSM Special Low-FT Neutralino LSP Model Set

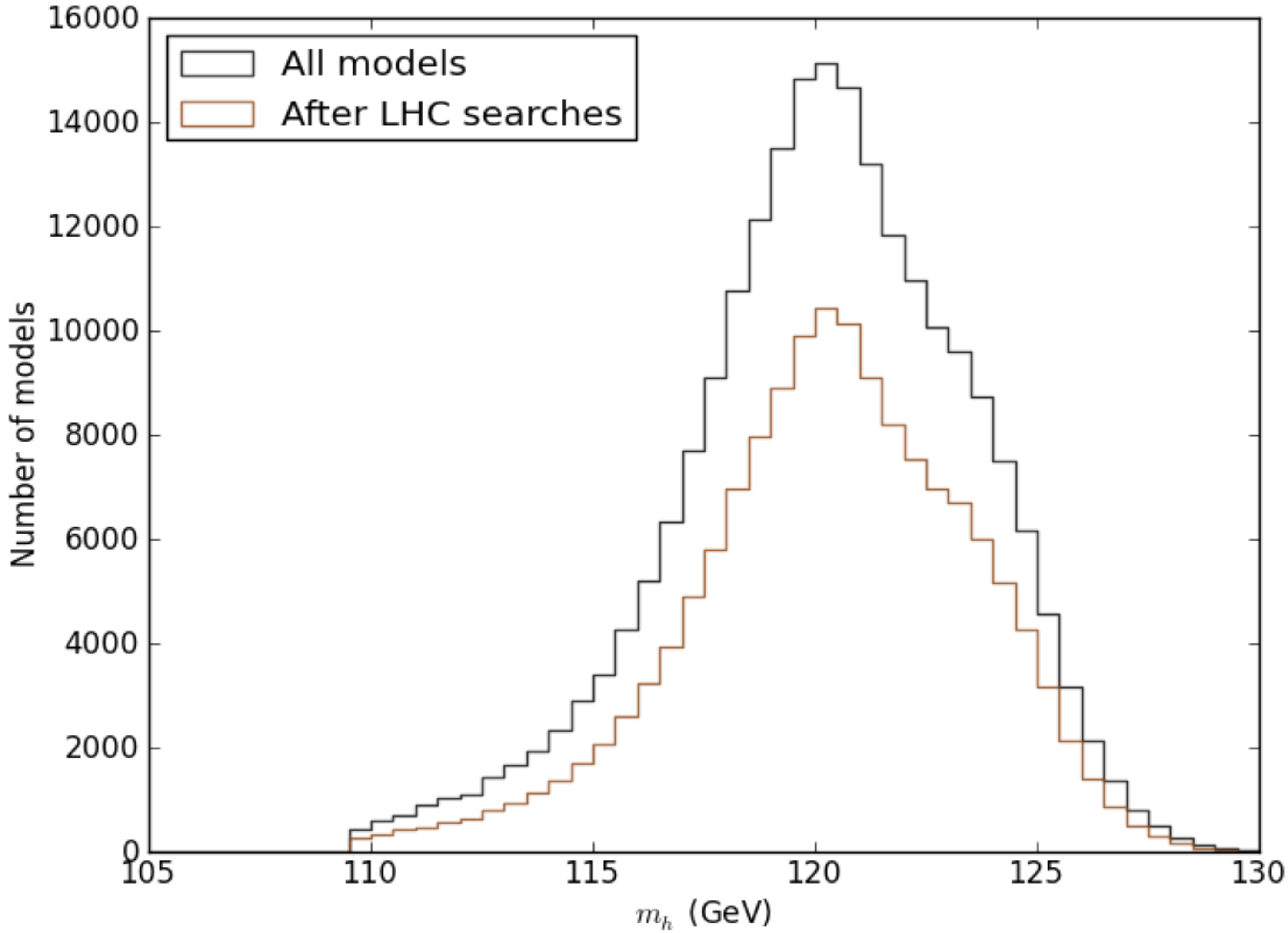
- m_h = 126 ± 3 GeV
- $\Omega h^2|_{DM}$ = 0.1153 ± 0.0095
- FT better than 1%
- ~10k model points







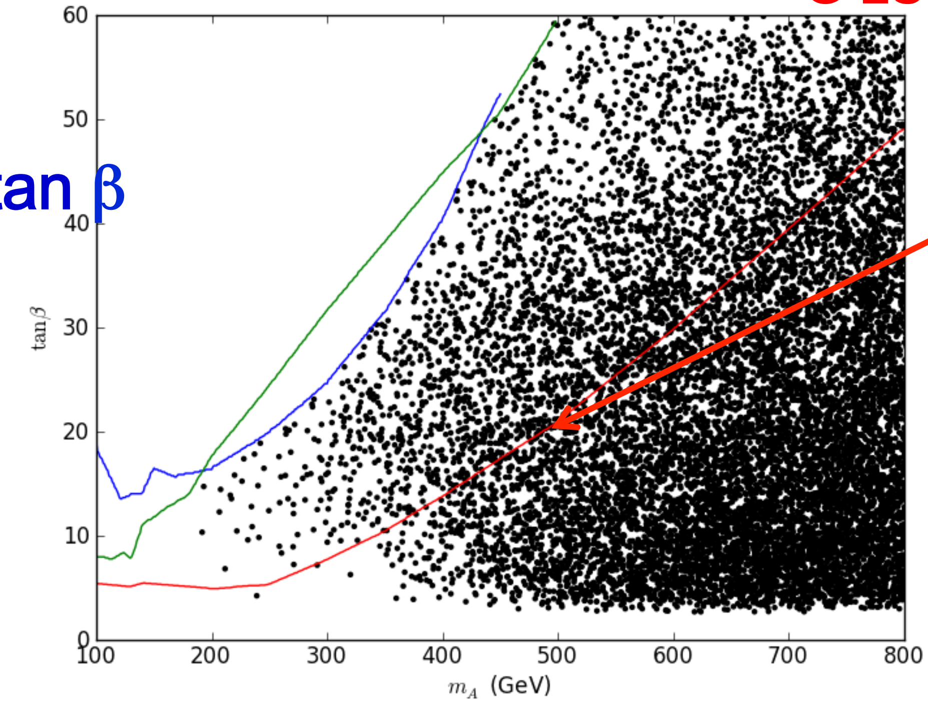
The MET-based searches are roughly independent of the of the Higgs mass: the predicted mass of the Higgs is roughly independent of the SUSY searches



Impact of A,H →ττ Searches

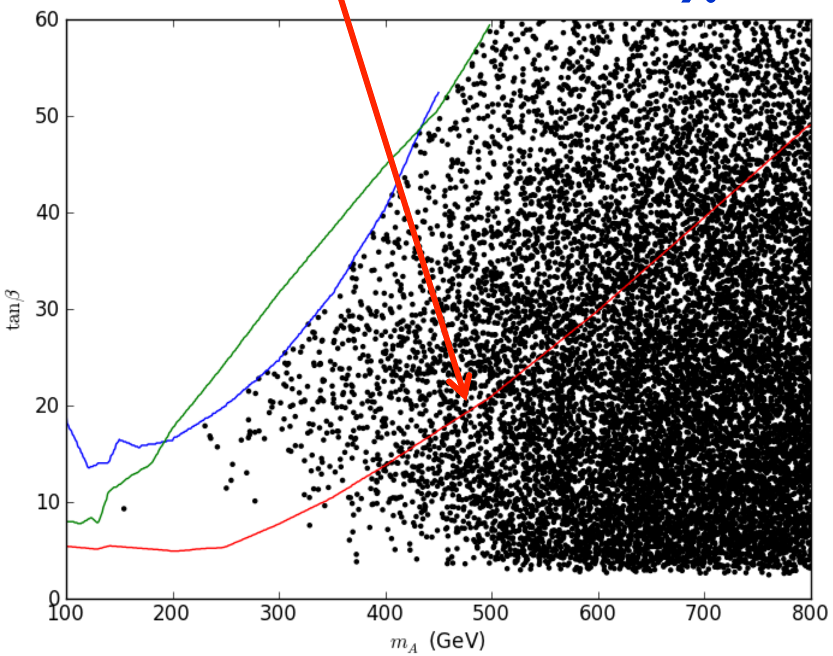
G LSP

tan β



CMS 13 fb^{-1}

χ LSP



M_A

3671(3309) models removed from the χ (G) LSP set…

Preliminary Model Set Fractions Excluded by ATLAS Searches @ 7 TeV

Search	Reference	Neutralino	Gravitino	Low-FT
2-6 jets	ATLAS-CONF-2012-033	21.2%	17.8%	37.4%
multijets	ATLAS-CONF-2012-037	1.6%	2.3%	11.3%
1-lepton	ATLAS-CONF-2012-041	3.2%	5.3%	19.4%
HSCP	1205.0272	4.0%	16.9%	<0.1%
Disappearing Track	ATLAS-CONF-2012-111	2.6%	1.1%	<0.1%
Gluino $\to$ Stop/Sbottom	1207.4686	4.9%	4.1%	21.9%
Very Light Stop	ATLAS-CONF-2012-059	<0.1%	0.03%	0.3%
Medium Stop	ATLAS-CONF-2012-071	0.3%	4.9%	2.6%
Heavy Stop (0l)	1208.1447	3.7%	3.3%	17.9%
Heavy Stop (1l)	1208.2590	2.0%	2.3%	13.5%
GMSB Direct Stop	1204.6736	<0.1%	0.05%	0.8%
Direct Sbottom	ATLAS-CONF-2012-106	2.5%	2.8%	5.5%
3 leptons	ATLAS-CONF-2012-108	1.1%	5.9%	18.3%
1-2 leptons	1208.4688	4.1%	8.2%	21.3%
Direct slepton/gaugino (2l)	1208.2884	0.1%	1.2%	1.0%
Direct gaugino (3l)	1208.3144	0.4%	5.5%	8.0%
4 leptons	1210.4457	0.7%		15.5%
1 lepton + many jets	ATLAS-CONF-2012-140	1.3%		12.4%
1 lepton + γ	ATLAS-CONF-2012-144	<0.1%		<0.1%
γ + b	1211.1167	<0.1%		0.3%
$\gamma\gamma$ + MET	1209.0753	<0.1%		<0.1%
$B_s \to \mu\mu$	1211.2674	0.8%	3.1%	*
$A/H \to \tau\tau$	CMS-PAS-HIG-12-050	1.6%	0.07%	*

This is useful for comparing searches and model sets

Preliminary Model Set Fractions Excluded by ATLAS Searches @ 8 TeV

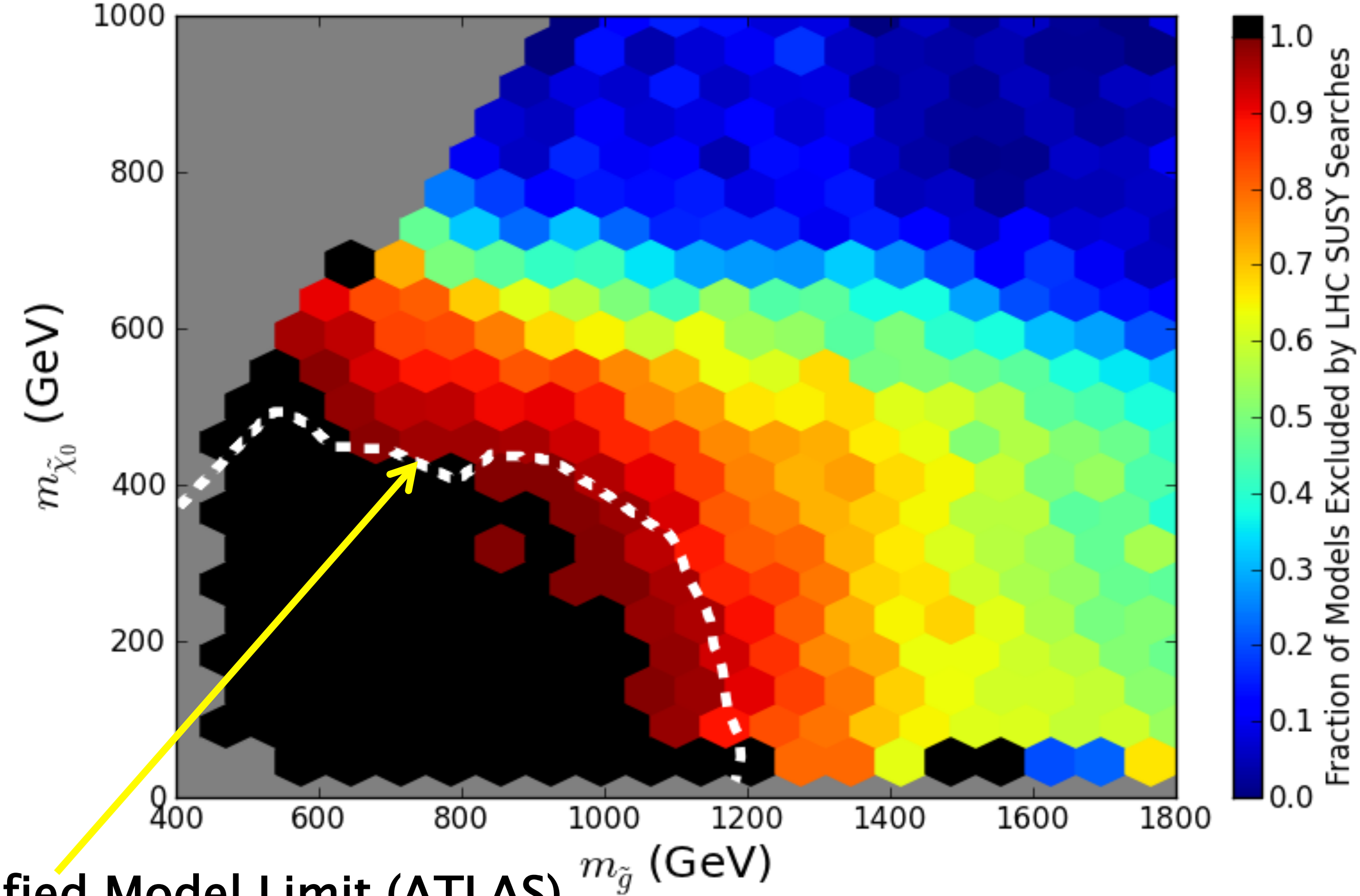
Search	Reference	Neutralino	Gravitino	Low-FT
2-6 jets	ATLAS-CONF-2012-109	26.7%	21.8%	49.8%
multijets	ATLAS-CONF-2012-103	3.3%	4.1%	27.0%
1-lepton	ATLAS-CONF-2012-104	3.3%	5.4%	27.7%
SS dileptons	ATLAS-CONF-2012-105	4.9%	11.5%	42.8%
Medium Stop (2l)	ATLAS-CONF-2012-167	0.6%		9.4%
Medium/Heavy Stop (1l)	ATLAS-CONF-2012-166	3.8%		28.7%
Direct Sbottom (2b)	ATLAS-CONF-2012-165	6.2%		17.4%
3rd Generation Squarks (3b)	ATLAS-CONF-2012-145	10.8%		47.2%
3rd Generation Squarks (3l)	ATLAS-CONF-2012-151	1.9%		32.8%
3 leptons	ATLAS-CONF-2012-154	1.4%		38.5%
4 leptons	ATLAS-CONF-2012-153	3.0%		52.4%
Z + jets + MET	ATLAS-CONF-2012-152	0.3%		12.2%

Total Exclusions: ~37% ~46% ~73%

→ ~15 MORE analyses coming 'soon' bringing us up to date with all public ATLAS results as of 6/25/2013

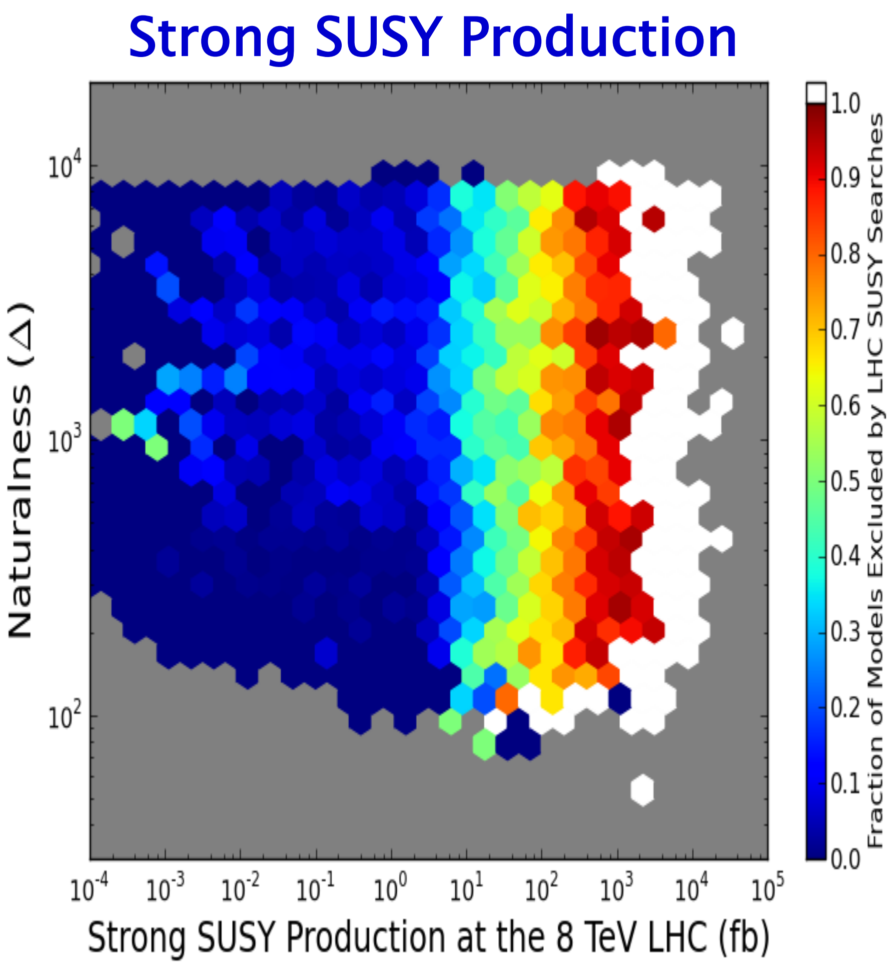
Of course search efficiency plots are much more interesting…

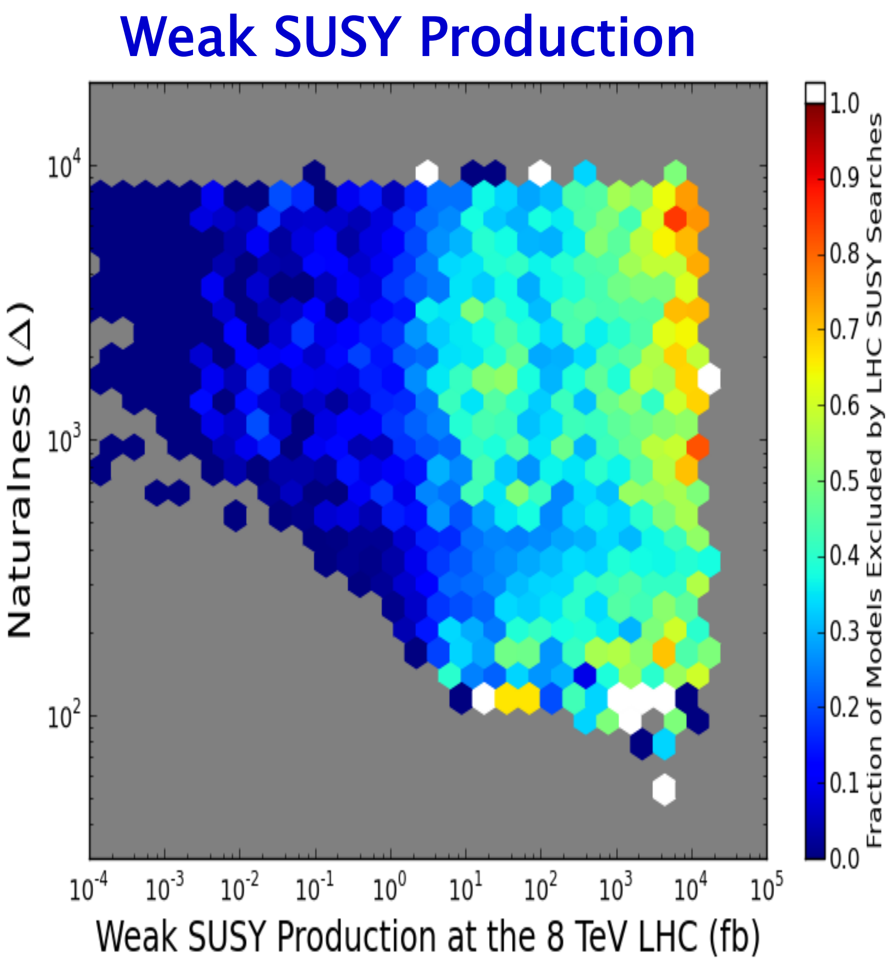
Effects of LHC Searches on Neutralino LSP Sample



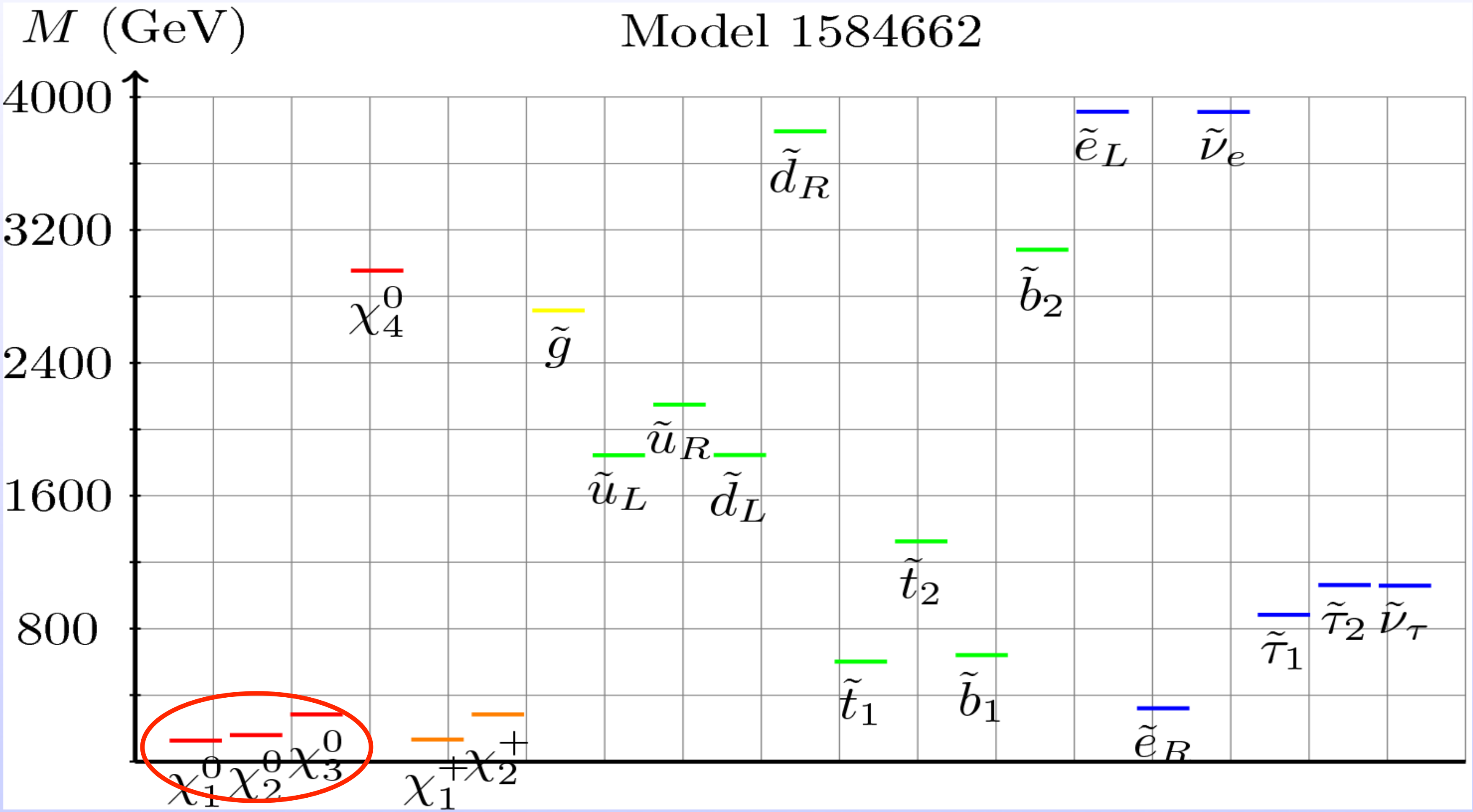
Simplified Model Limit (ATLAS)

Effects of LHC Searches on Neutralino LSP Sample

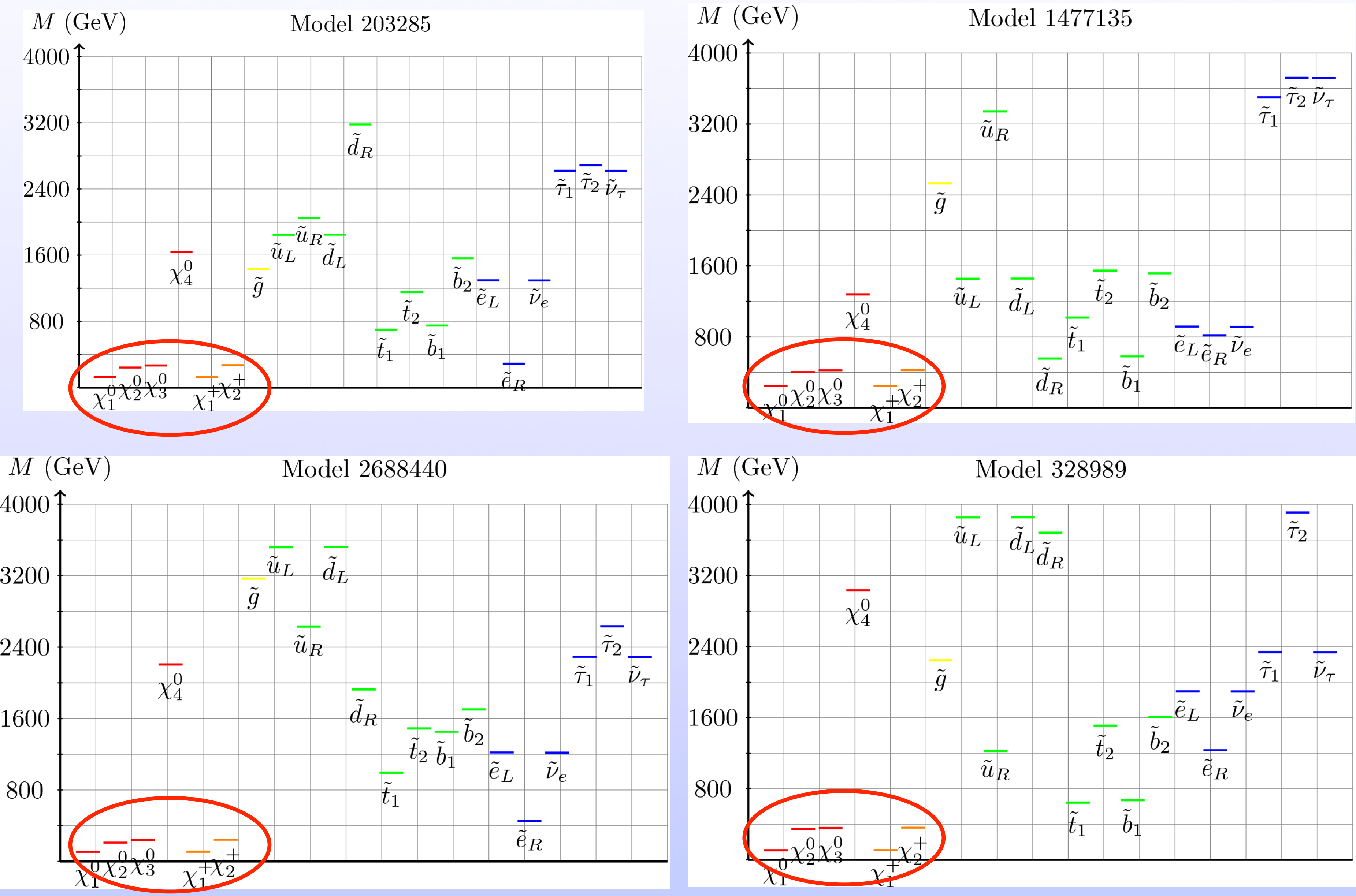




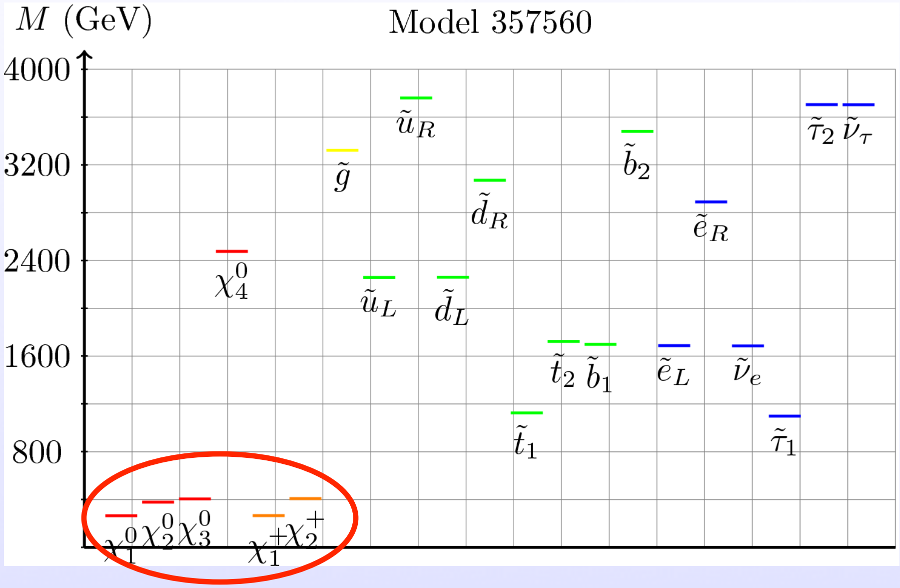
Low Fine-Tuning Model Spectra I

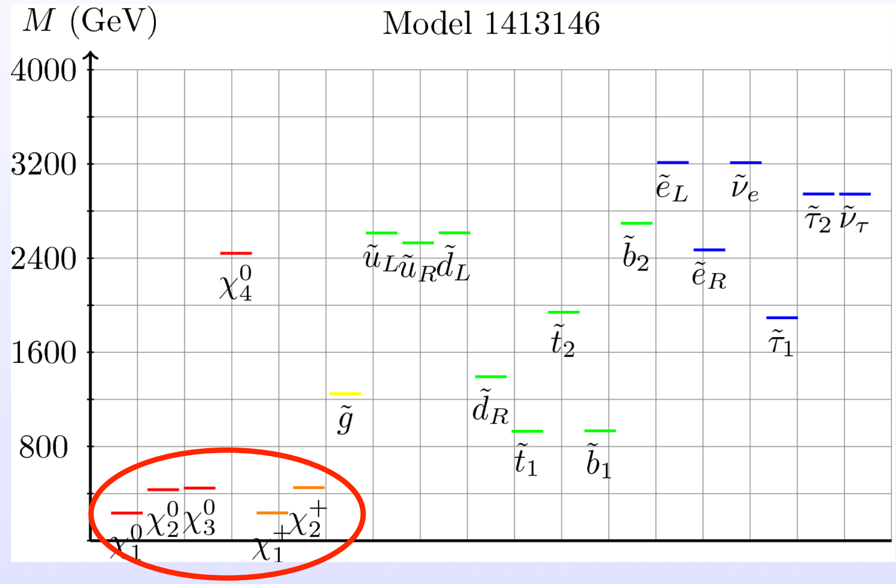


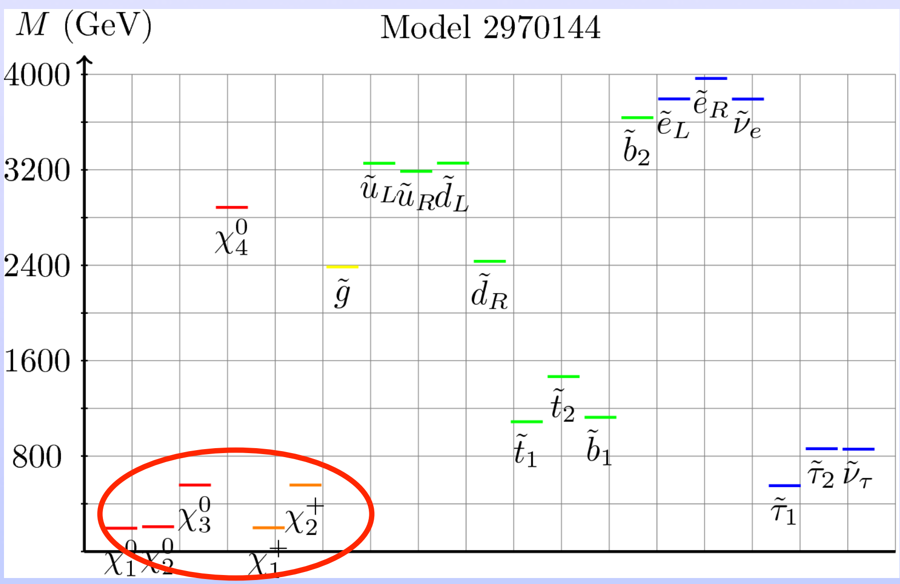
Low Fine-Tuning Model Spectra I

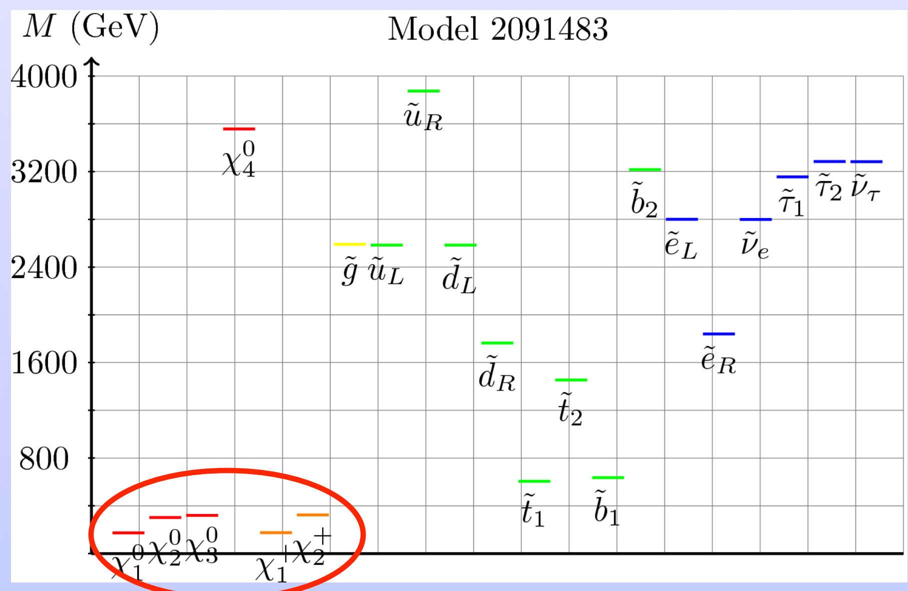


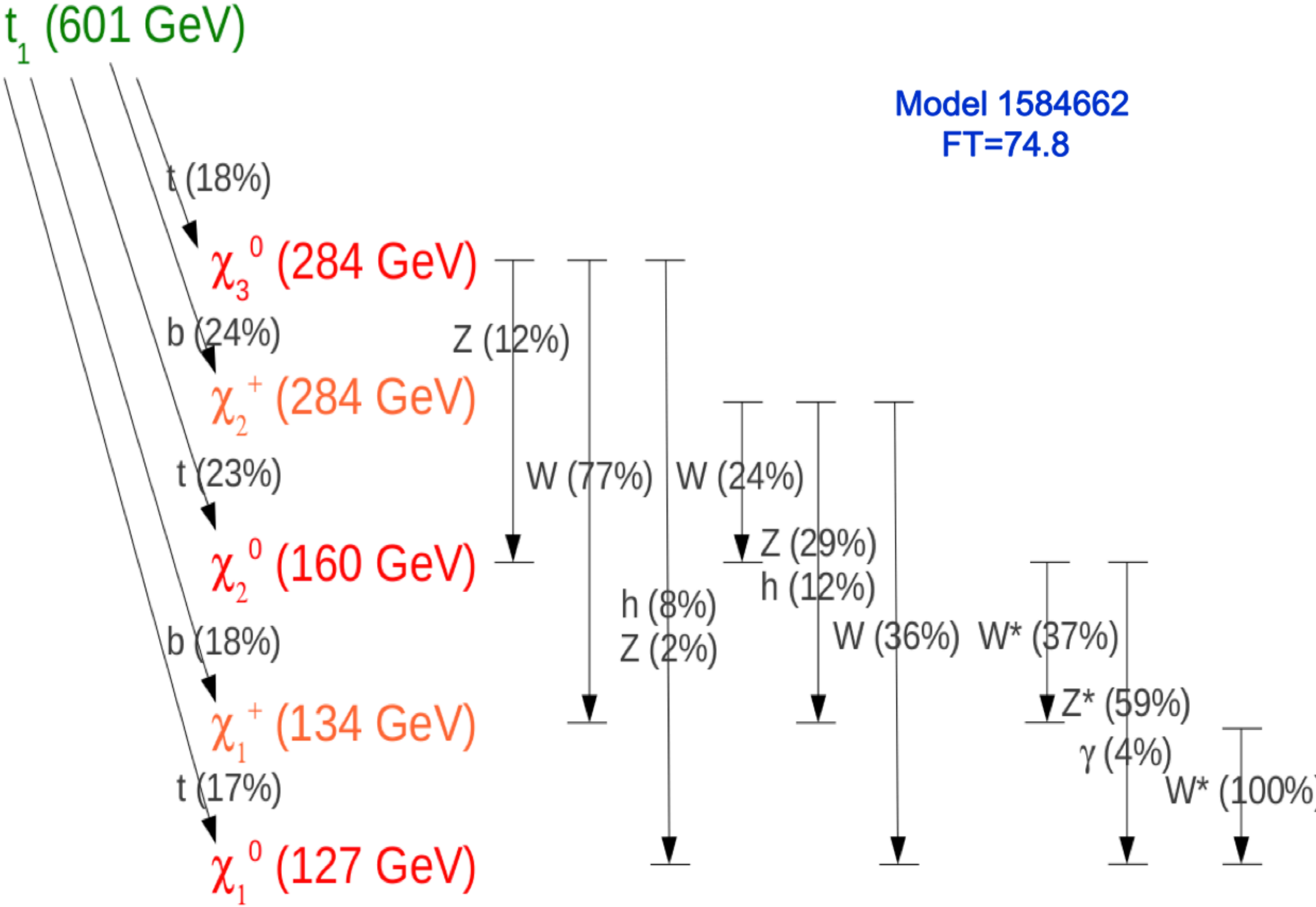
Low Fine-Tuning Model Spectra II



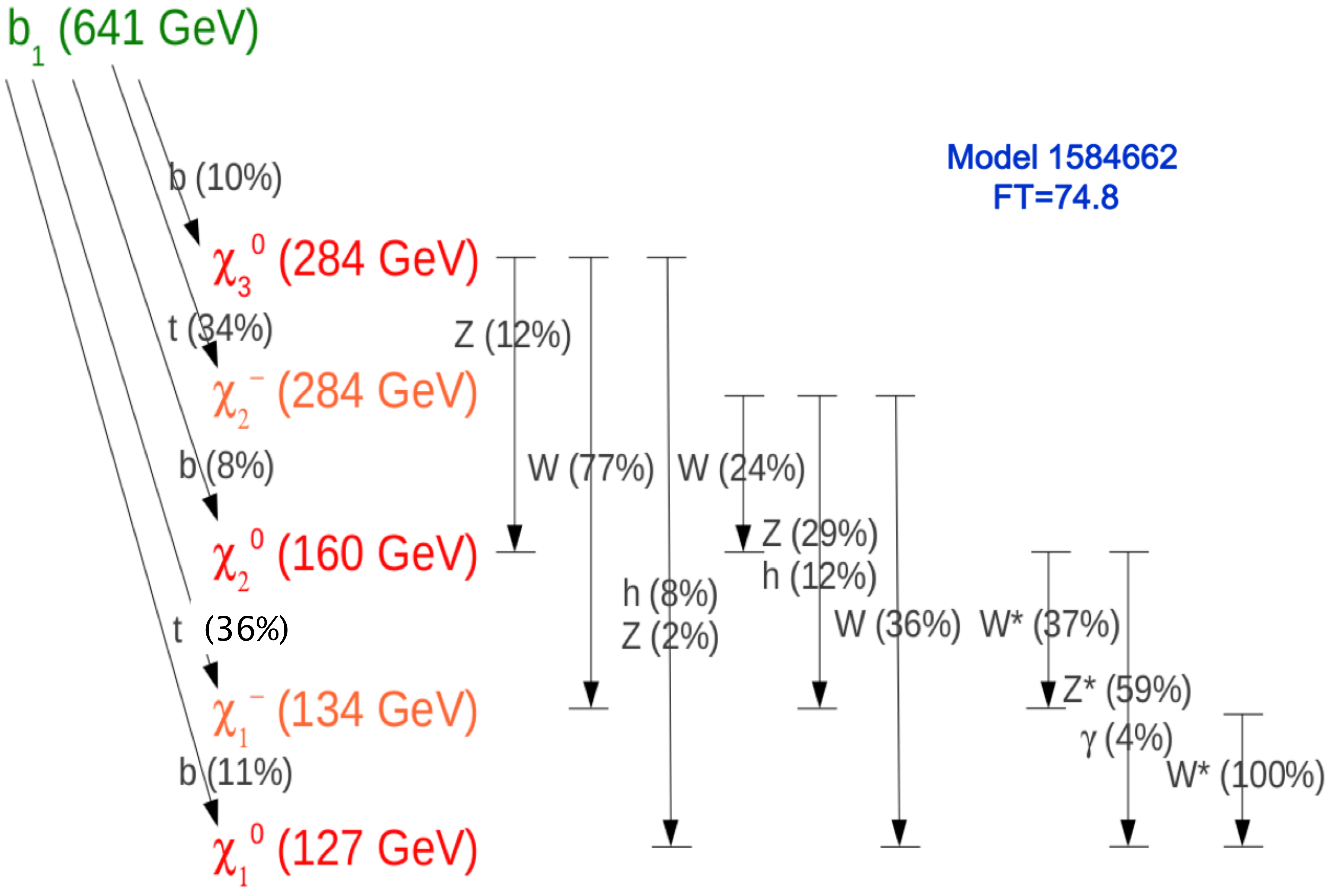








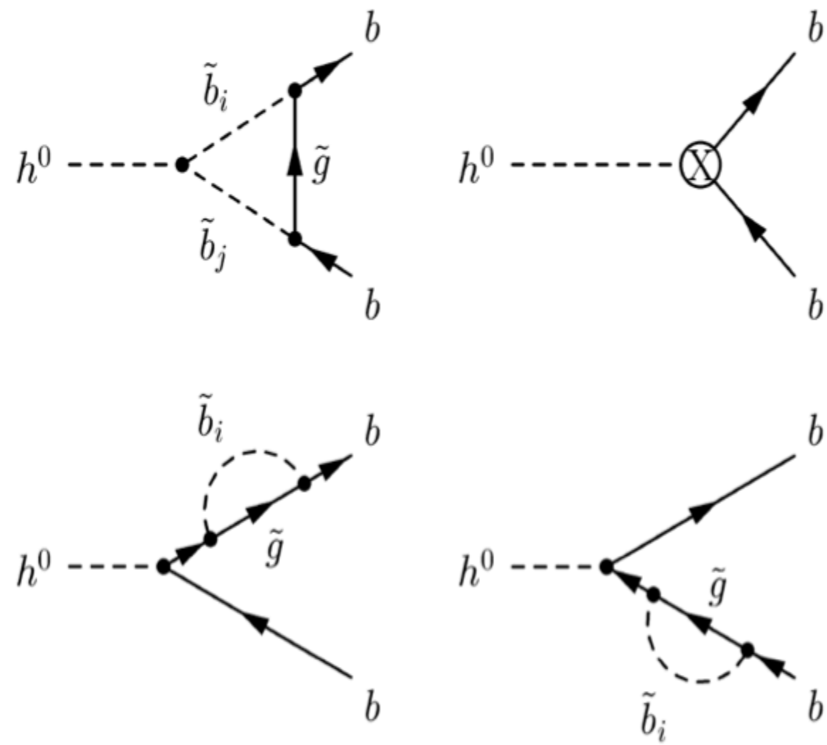
t1 (601 GeV)
Model 1584662
FT=74.8
t (18%)
χ3 0 (284 GeV)
b (24%)
Z (12%)
χ2 + (284 GeV)
t (23%)
W (77%)
W (24%)
Z (29%)
χ2 0 (160 GeV)
h (12%)
h (8%)
Z (2%)
b (18%)
W (36%)
W* (37%)
Z* (59%)
χ1 + (134 GeV)
γ (4%)
t (17%)
W* (100%)
χ1 0 (127 GeV)



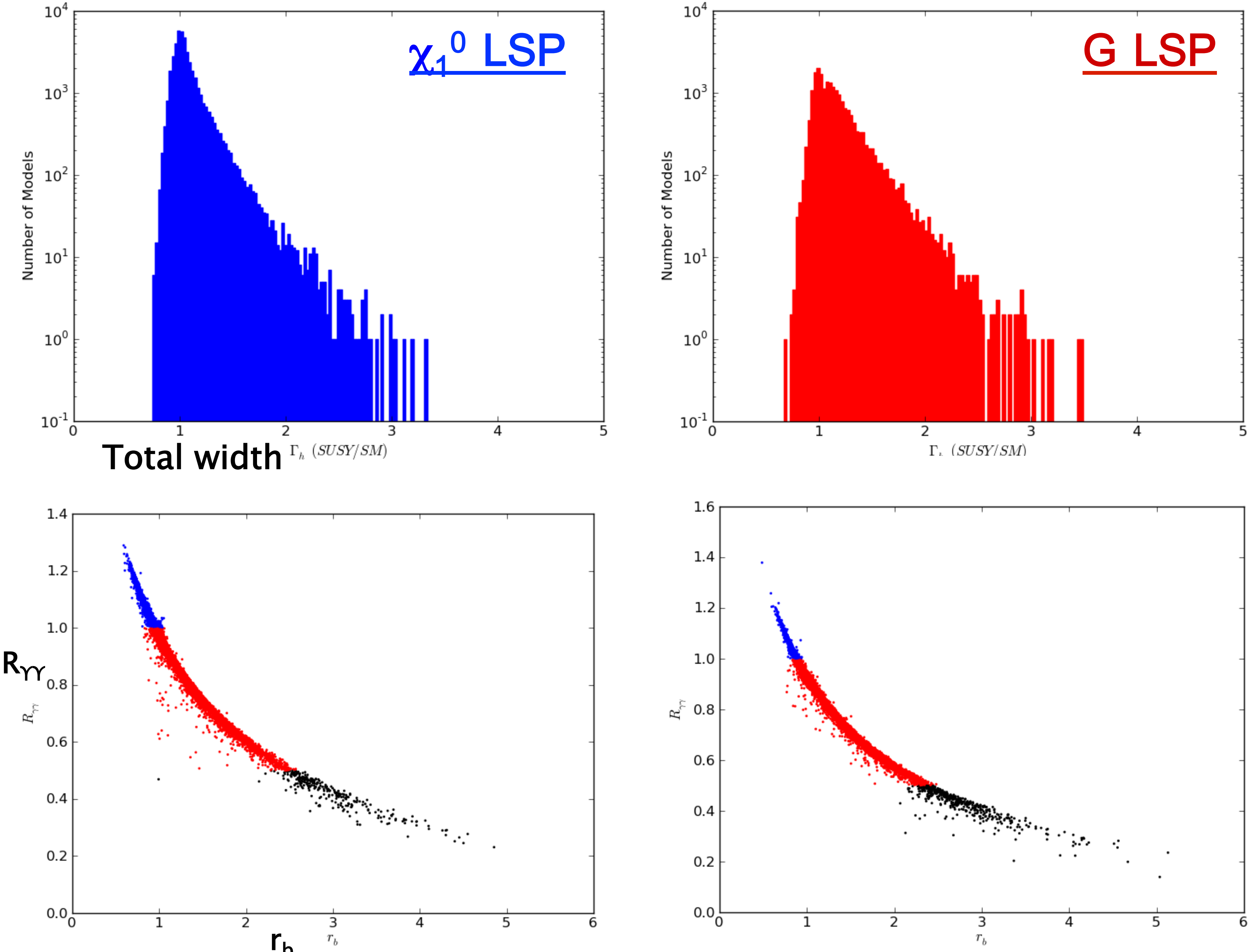
b1 (641 GeV)
Model 1584662
FT=74.8
b (10%)
χ3 0 (284 GeV)
t (34%)
Z (12%)
χ2 − (284 GeV)
b (8%)
W (77%)
W (24%)
Z (29%)
χ2 0 (160 GeV)
h (12%)
h (8%)
Z (2%)
t (36%)
W (36%)
W* (37%)
Z* (59%)
χ1 − (134 GeV)
γ (4%)
b (11%)
W* (100%)
χ1 0 (127 GeV)

$h \rightarrow bb$ decoupling

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



Haber et al., hep-ph/0007006



χ1 0 LSP
G LSP
Number of Models
Total width
Γh (SUSY/SM)
Rγγ
rb