Higgs Bosons in the pMSSM

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Matthew Cahill-Rowley, JoAnne Hewett, Ahmed Ismail, Tom Rizzo

1206.5800, 1308.0297, To Appear

The p(henomenological) MSSM

- 19/20 parameter subspace of the MSSM (Neutralino/Gravitino LSP).
- Created by applying experimentally-motivated assumptions to the full MSSM lagrangian.
- “Unprejudiced” by assumptions about physics at high scales.
- Allows us to study correlations between very different observables (SUSY searches, Higgs measurements, DM, etc)

Our Methodology

General MSSM Lagrangian +

Minimal Flavor Violation
No new CP phases
Flavor-Diagonal Sparticle Mass Matrices
1st and 2nd generations degenerate
R-parity Conservation

= **19/20 weak scale parameters**

$(M_1, M_2, M_3, \mu, \tan\beta, M_A, q_{1,3}, u_{1,3}, d_{1,3}, l_{1,3}, e_{1,3}, A_{t,b,\tau}$ $\boldsymbol{+\ m_{3/2}})$

- Randomly sample the 19/20-dimensional parameter space.
- Discard points excluded by non-LHC constraints (precision EW, heavy flavor, LEP limits, Direct Detection, $\Omega_{LSP} \leq \Omega_{DM}$)
- Examine resulting model sets.

Parameter Scan Ranges

- Upper bound on masses chosen to test LHC reach.
- Log prior allows sampling of a wide range of gravitino mass scales.

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

$100 \text{ GeV} \leq |M_2, \mu| \leq 4 \text{ TeV}$

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

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

$100 \text{ GeV} \leq M_A, l, e \leq 4 \text{ TeV}$

$400 \text{ GeV} \leq q_1, u_1, d_1 \leq 4 \text{ TeV}$

$200 \text{ GeV} \leq q_3, u_3, d_3 \leq 4 \text{ TeV}$

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

$1 \text{ eV} \leq m_{3/2} \leq 1 \text{ TeV}$ (log prior)

Calculating Model Properties

- Sparticle/Higgs spectrum from SOFTSUSY, cross-checked with SuSpect.
- Calculate sparticle decays with modified SUSY-HIT, supplemented with CalcHEP and MadGraph (multi-body decays for models with a $\tilde{G}$ LSP).
- Calculate thermal relic density of LSP (if LSP is a neutralino) or NLSP (if LSP is a gravitino) with micrOMEGAs.
- Calculate light Higgs partial widths using HDECAY 5.11, normalize to HDECAY prediction for SM Higgs with the same mass

Model Constraints

- Precision EW constraints: $g - 2$, Z invisible width, $\Delta\rho$
- Flavor constraints: $b \rightarrow s\gamma$, $B_s \rightarrow \mu\mu$, $B \rightarrow \tau\nu$
- Charged sparticle masses > 100 GeV
- Impose LHC stable particle, $\Phi \rightarrow \tau\tau$ constraints
- Require $\Omega_{LSP} \leq \Omega_{DM}$
- Model independent constraints from Direct Detection experiments ($\tilde{\chi}$ LSP) or Big Bang Nucleosynthesis ($\tilde{G}$ LSP)
- Require $m_h = 126 \pm 3$ GeV (theory uncertainty dominant!)
- **Result: Two model samples**, divided by LSP type:
  - ~**45k** points with a neutralino LSP
  - ~**21k** points with a gravitino LSP

LHC SUSY Searches

- 37 LHC searches applied using PYTHIA/PGS package with custom analysis code.
- See the Monday talk on LHC pheno (“The LHC Confronts the pMSSM”) for details.
- Jets+MET, 0l and 1l stop searches simulated at the 14 TeV LHC, using projections from ATLAS-PHYS-PUB-2013-001, -002 and -004 (Jets+MET) and -011 (Stop searches)
- Luminosity scaling to extrapolate between 300 fb^{-1} and 3 ab^{-1} limits

Coupling Measurements

- Current Higgs measurements sensitive to few pMSSM models.
- Use 4 projected sensitivities as benchmarks:
  - 14 TeV LHC, 300 fb^{-1} luminosity
  - 14 TeV LHC, 3 ab^{-1} luminosity
  - 250, 500 GeV ILC, 500 fb^{-1} luminosity ("ILC-500")
  - 250,500,1000 GeV ILC, 5.25 ab^{-1} luminosity ("HL-ILC500")
- Examine constraints on individual couplings (allows direct comparison between SUSY search results and LHC/ILC Higgs measurements)
- Coupling extraction complicated for LHC! (Use global fit, assuming no new production modes and family universality)

h^0 couplings

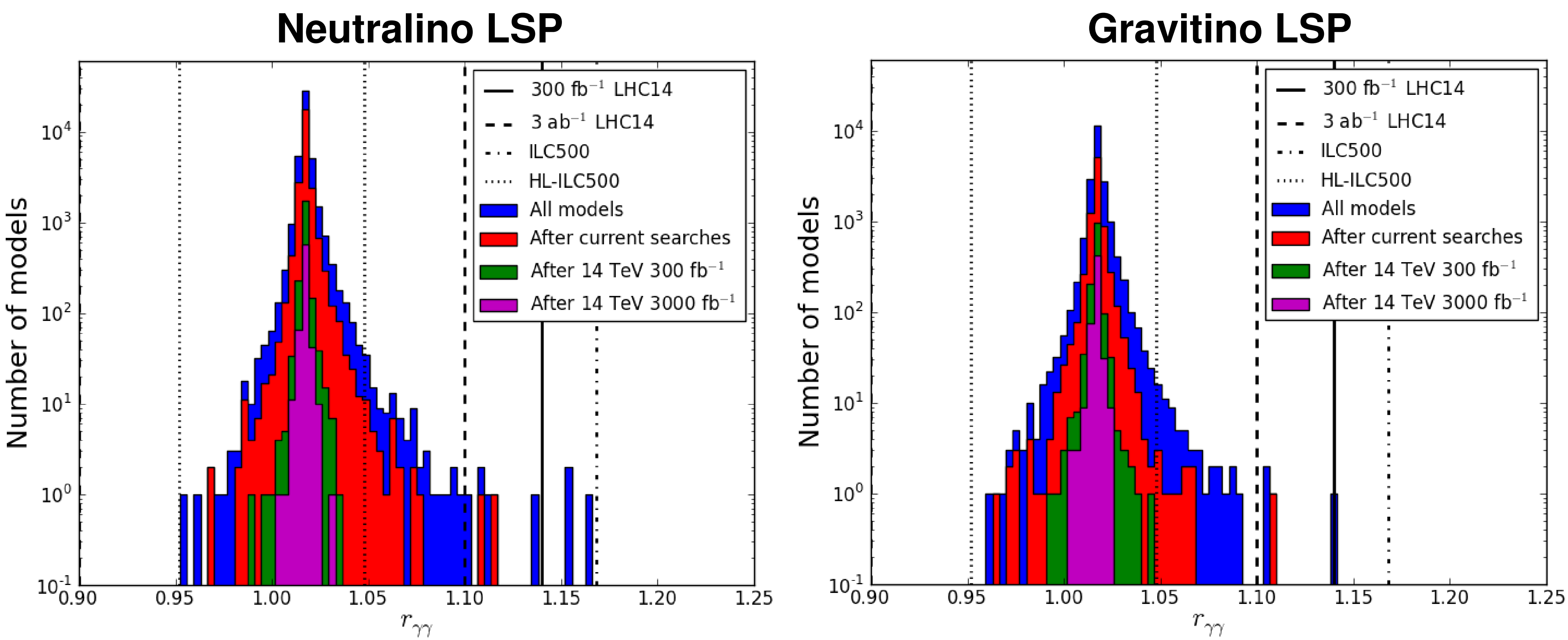
- Consider couplings of the light Higgs to bb, ττ, γγ, and gg, normalized to their SM values:

$$r_{XX} = \frac{BR(h^0 \to XX) \times \Gamma_{h^0}}{BR(h_{SM} \to XX) \times \Gamma_{h_{SM}}}$$

- Important corrections missing from Higgs couplings to vector bosons prevent their inclusion in this study.
- Important caveat: Theory uncertainties for the SM and MSSM Higgs couplings were not included in this analysis!

h^0 Couplings: h-γ-γ

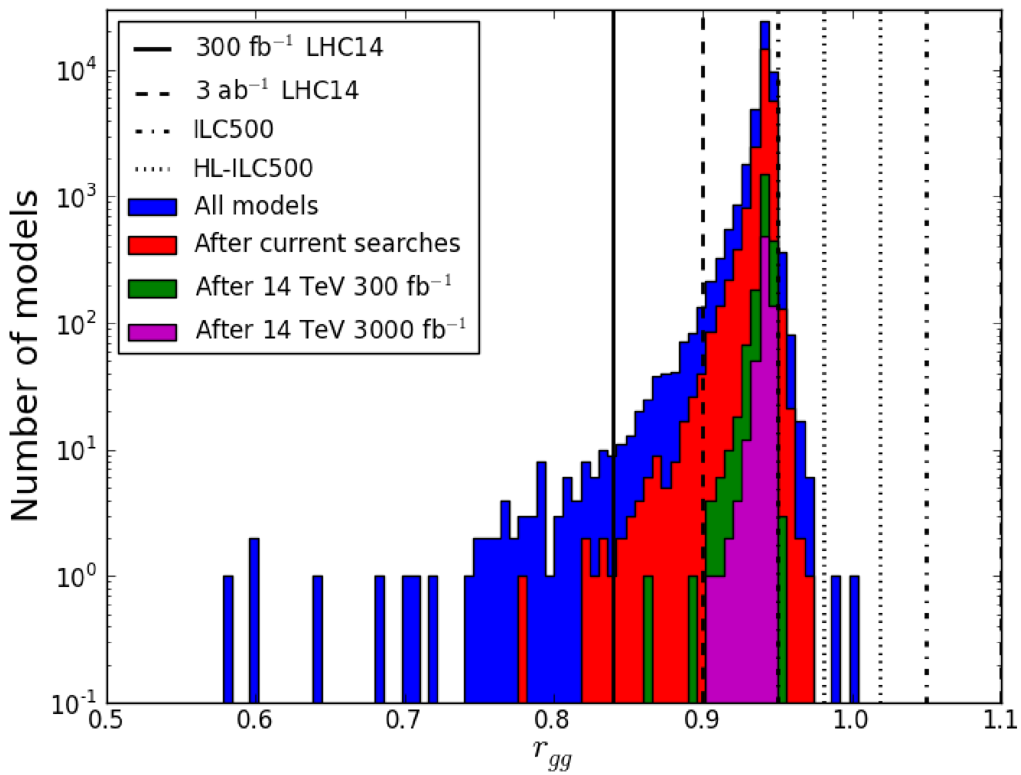
- Very light charged sparticles can modify the diphoton partial width. Smaller contributions can come from highly mixed stops (See Carena et. Al, 1303.4414).
- SUSY searches have a small impact on histogram shapes.



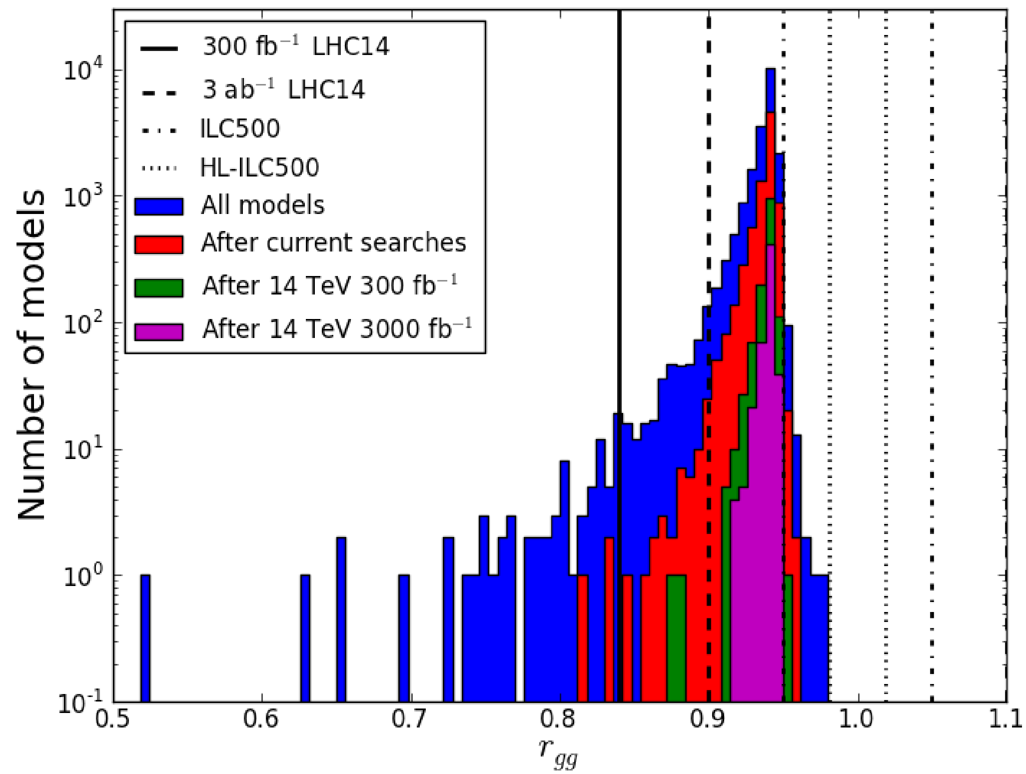
h^0 Couplings: h-g-g

- Stop loop contribution is larger than for h-γ-γ coupling and has opposite sign.
- Depending on measured central value, HL-ILC could exclude essentially all of these models!

Neutralino LSP



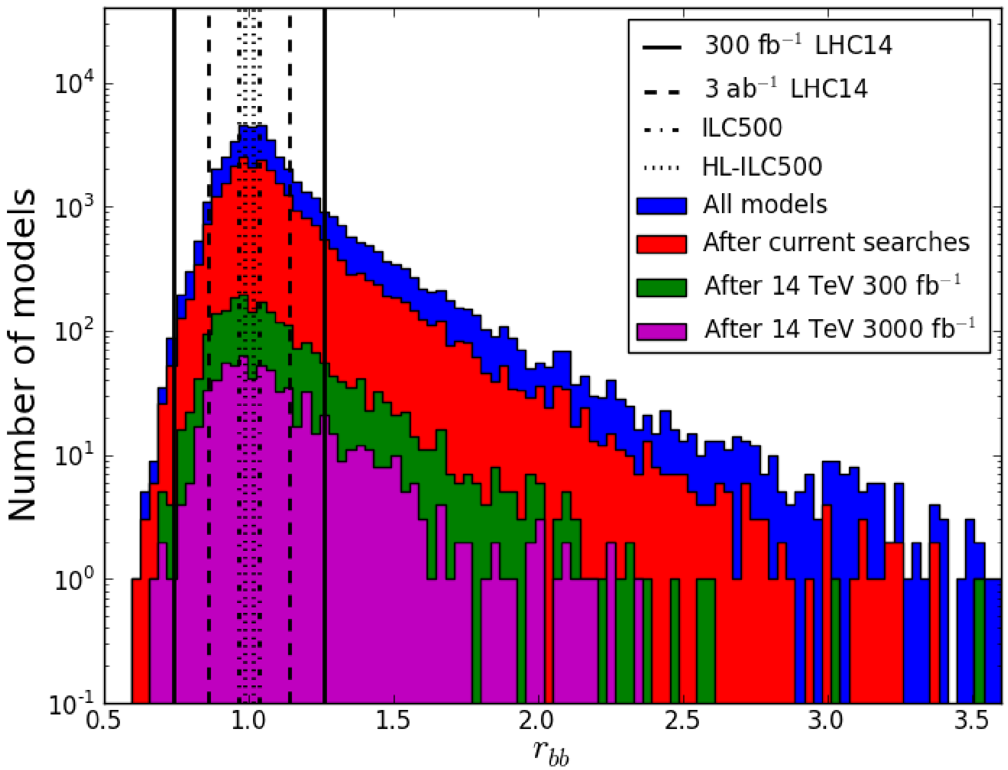
Gravitino LSP



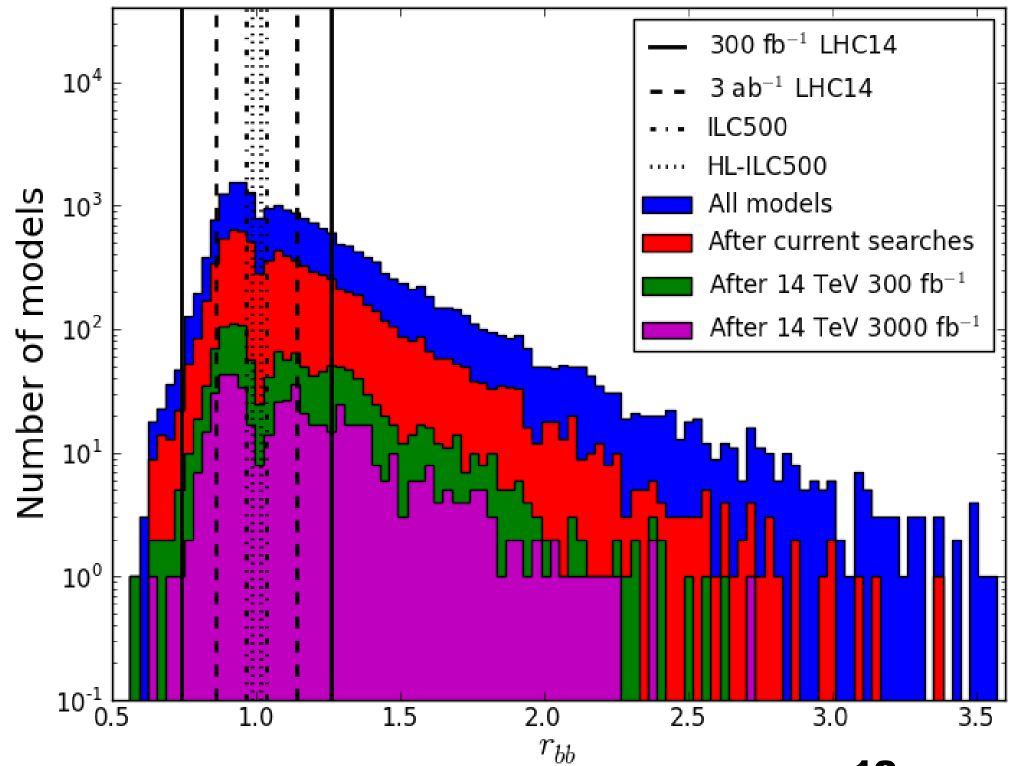
h^0 Couplings: h-b-b

- Observable tree-level deviations from SM prediction (~5% for m_A=1 TeV)
- Very large (>100%) radiative corrections possible for non-decoupled sbottoms.

Neutralino LSP



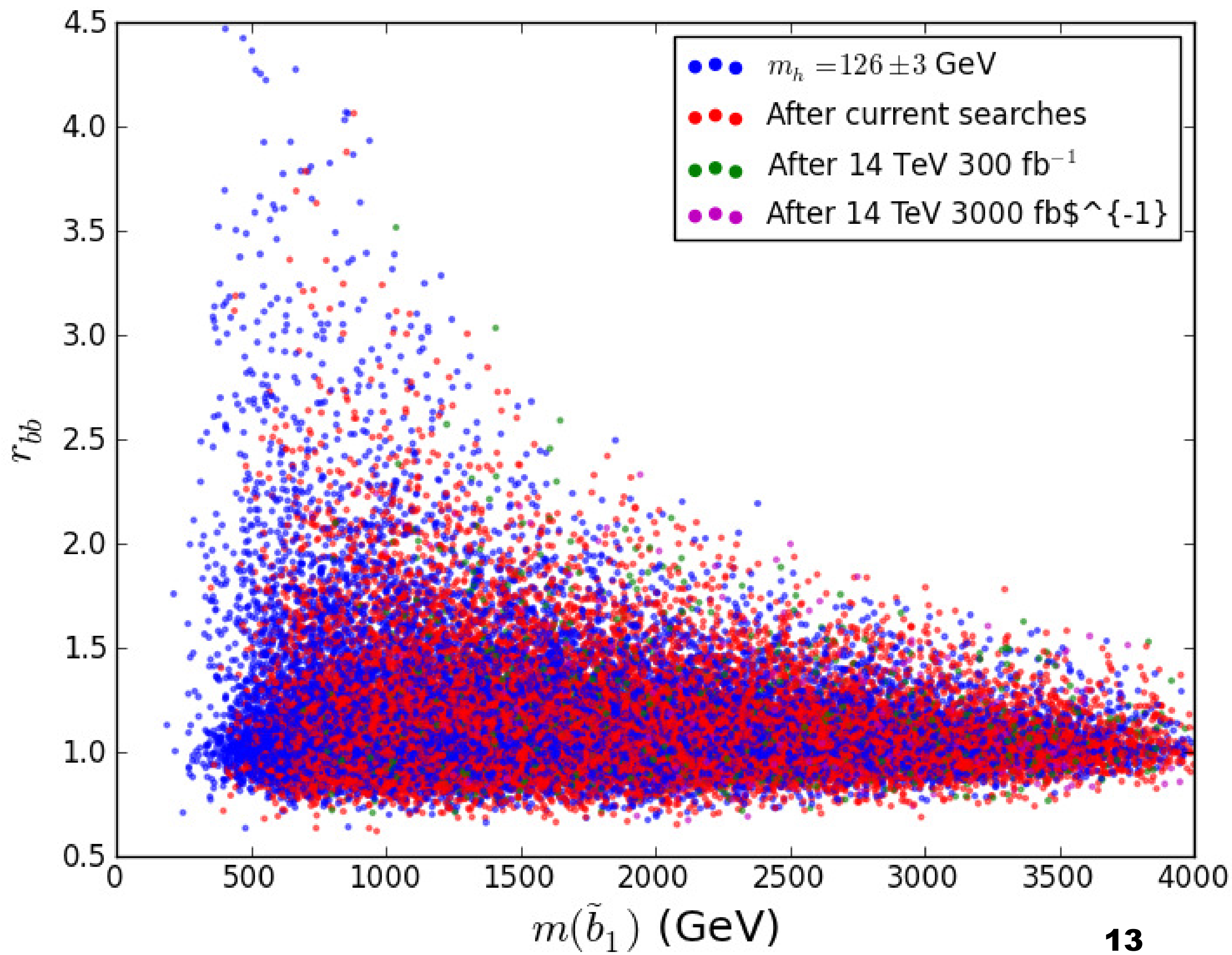
Gravitino LSP



Sbottoms and the h-b-b coupling

- Radiative corrections can be very large
- Corrections slowly decouple with increasing sbottom mass
- 100% corrections still allowed by SUSY searches

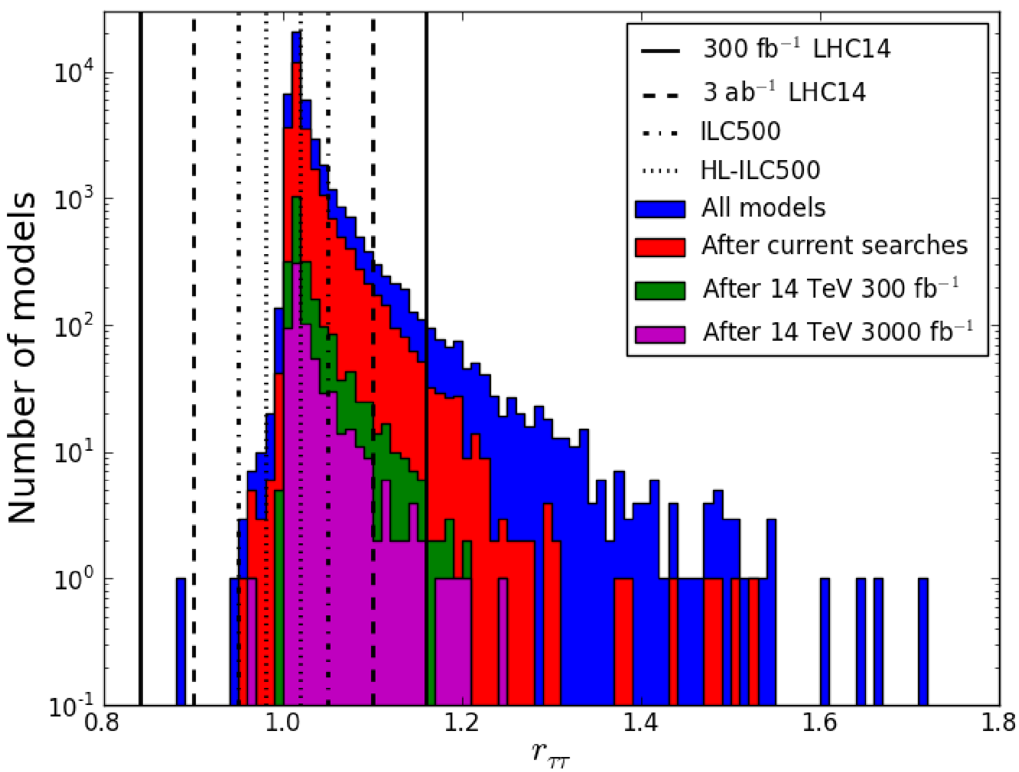
Neutralino LSP



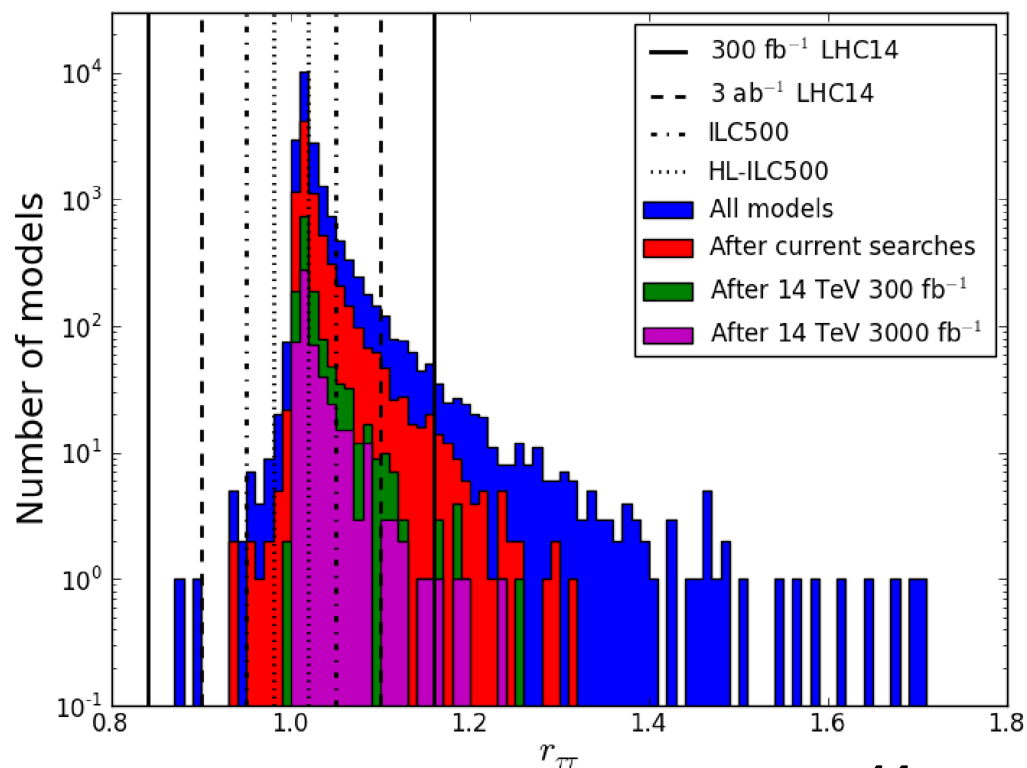
h^0 Couplings: h-τ-τ

- Same as h-b-b coupling at tree level.
- Radiative corrections are electroweak, and therefore weaker than for the h-b-b case.

Neutralino LSP

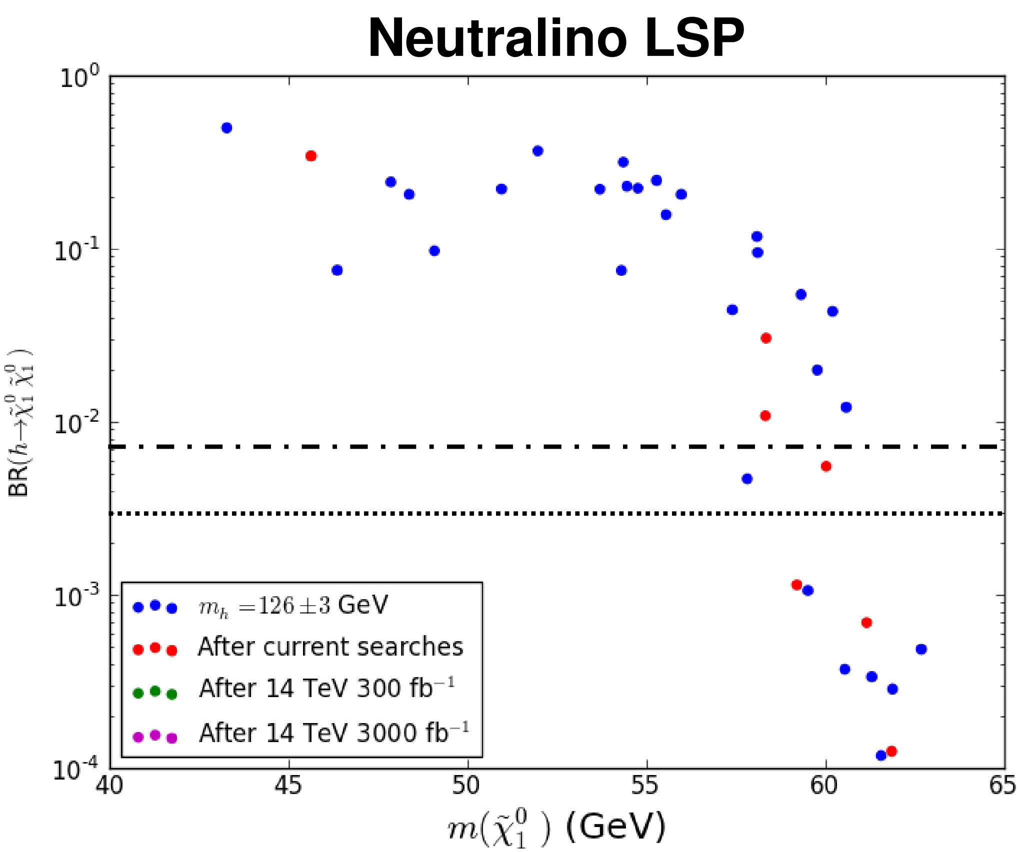


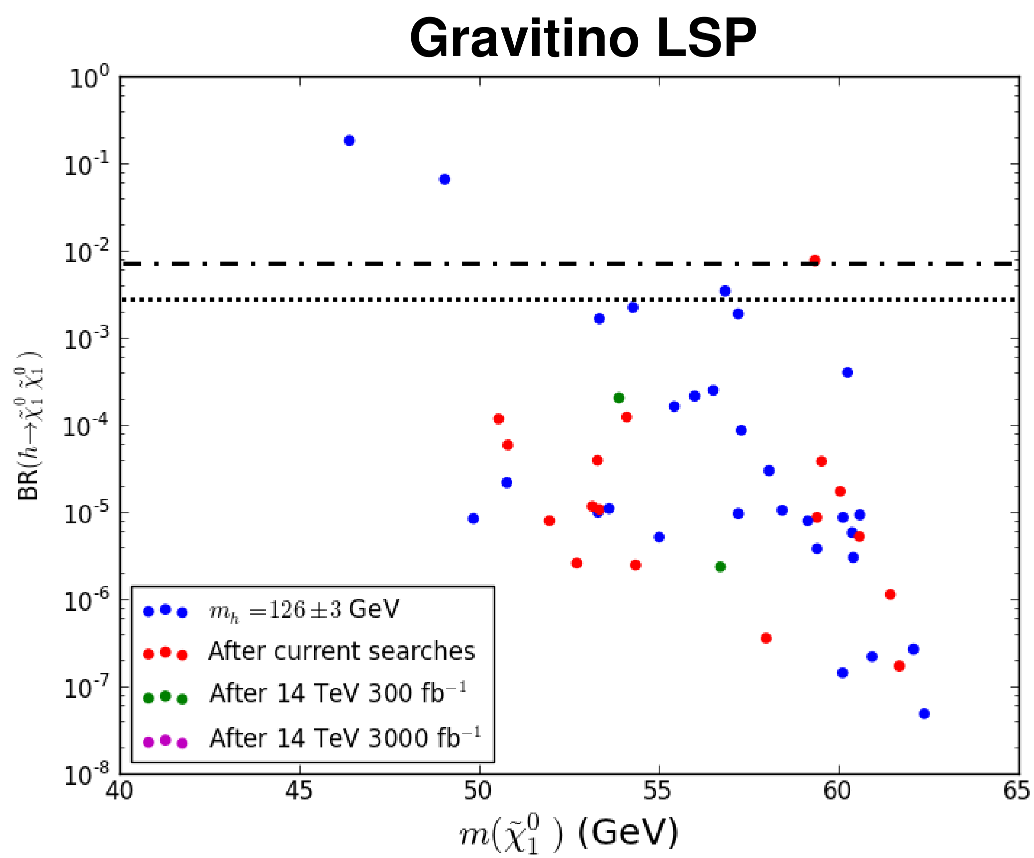
Gravitino LSP



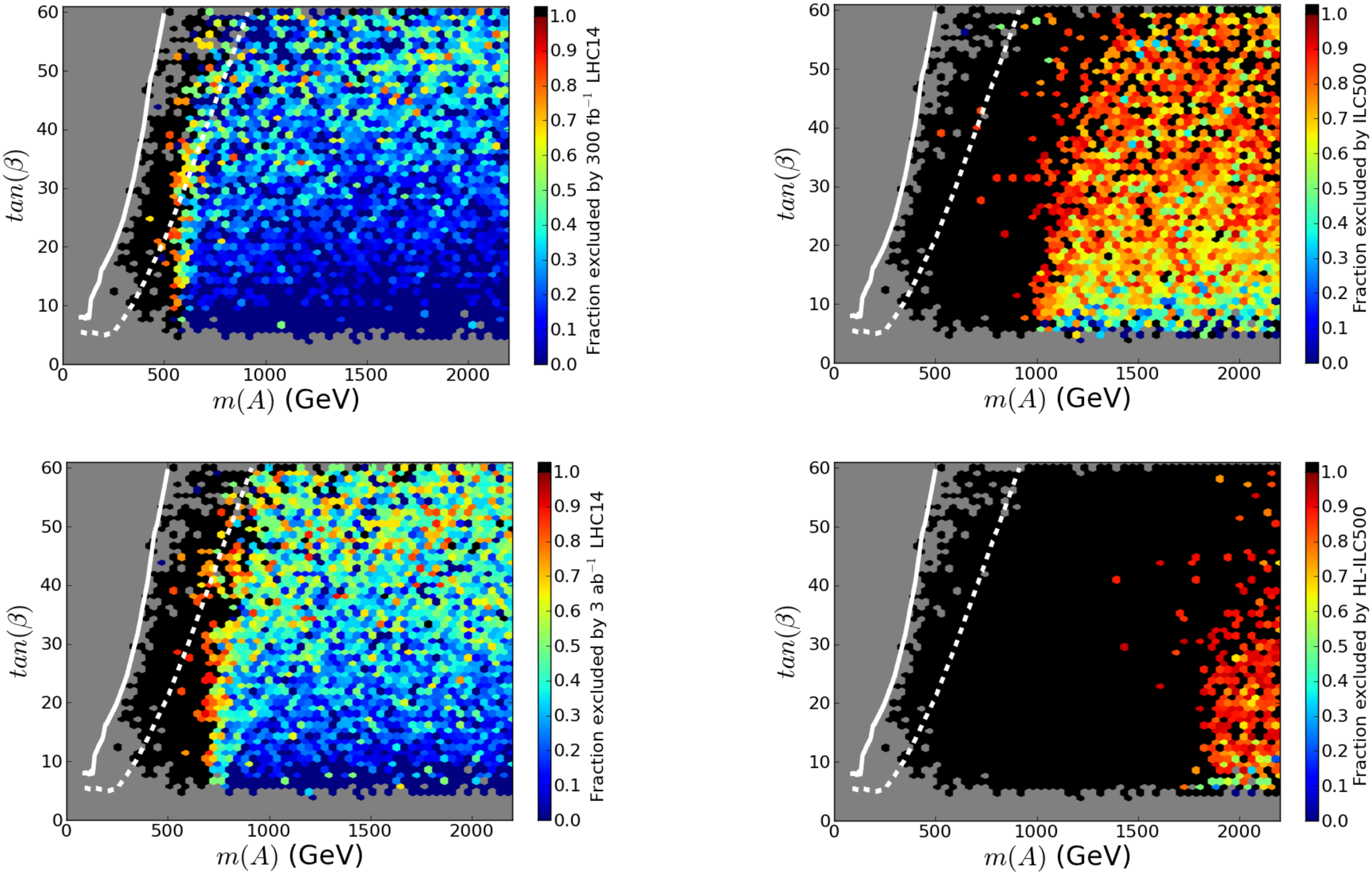
h^0 invisible width

- Bino-like neutralino can be lighter than $m_h/2 \rightarrow$ invisible decays.
- Neutralino LSP: Thermal freeze-out sets minimum $h\chi\chi$ coupling.
- Gravitino LSP: $h\chi\chi$ coupling can be very small without overclosing.





Constraining the m_A – tan(β) plane



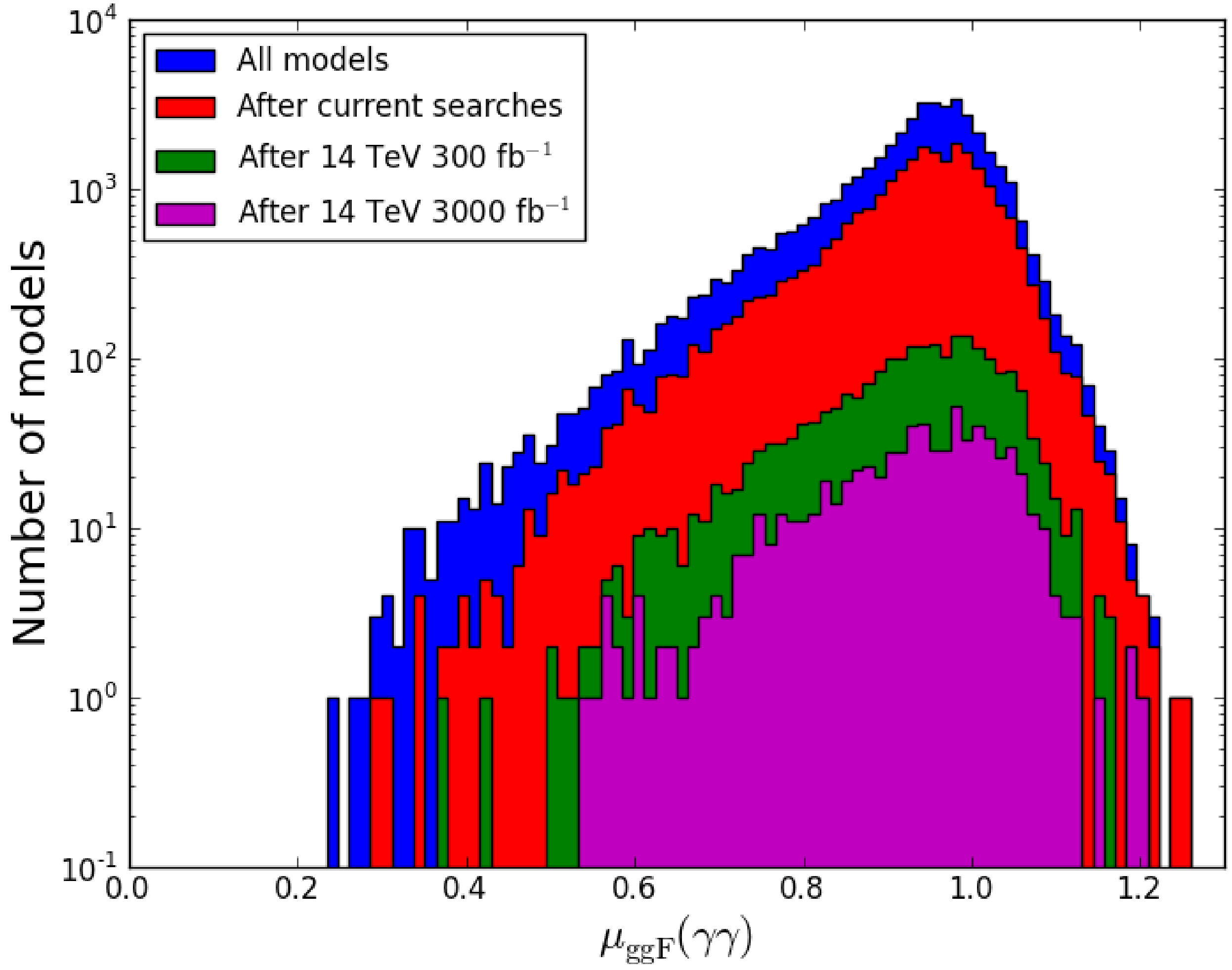
Conclusions

- Precision Higgs measurements at the LHC and ILC are a powerful and essential probe of the MSSM.
- Null SUSY search results have a small effect on the range of expected Higgs couplings (large deviations from SM prediction are still allowed).
- Combined search program provides many opportunities for discovery!

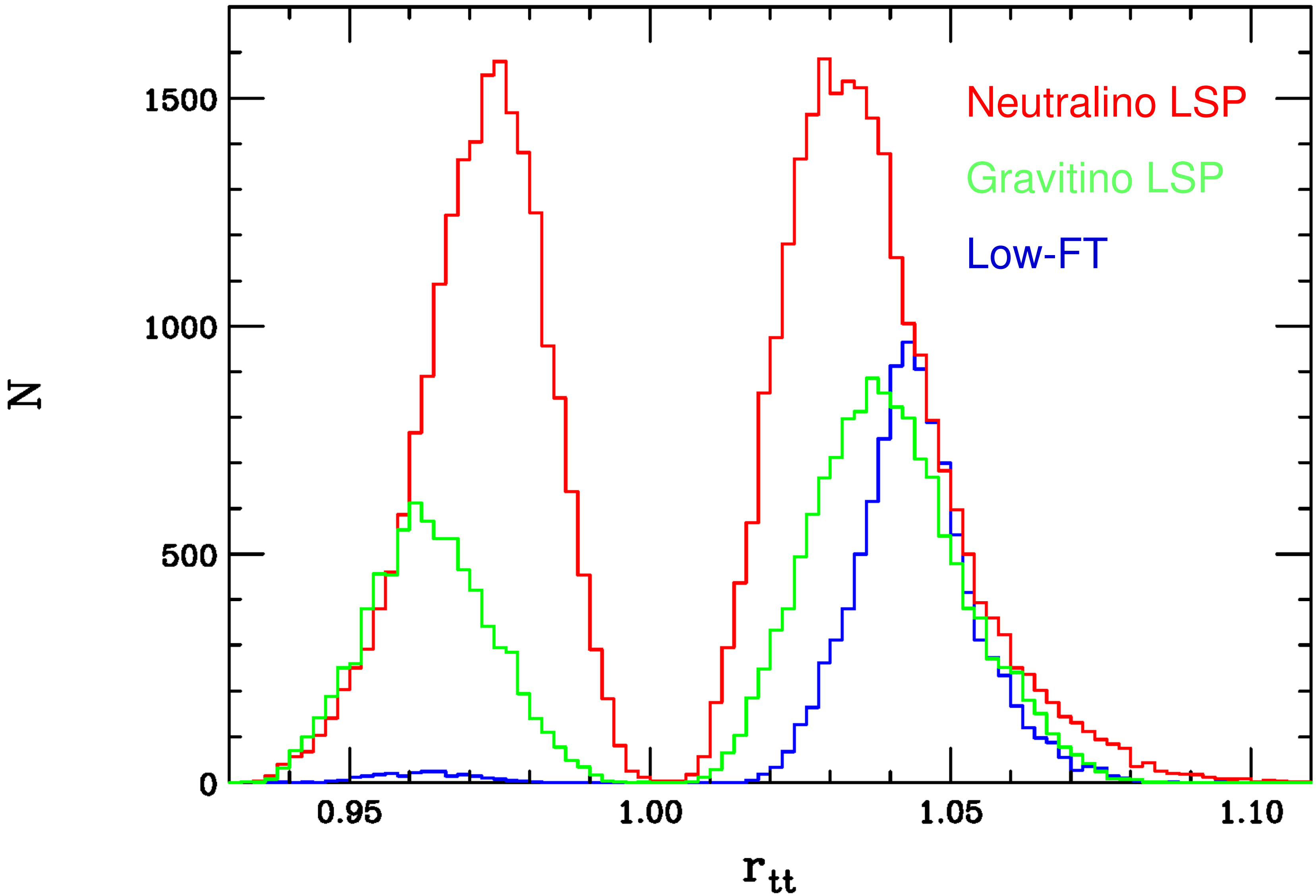
Backup Slides

- Precision Higgs measurements at the LHC and ILC are a powerful and essential probe of the MSSM.
- Null SUSY search results have a small effect on the range of expected Higgs couplings (large deviations from SM prediction are still allowed).

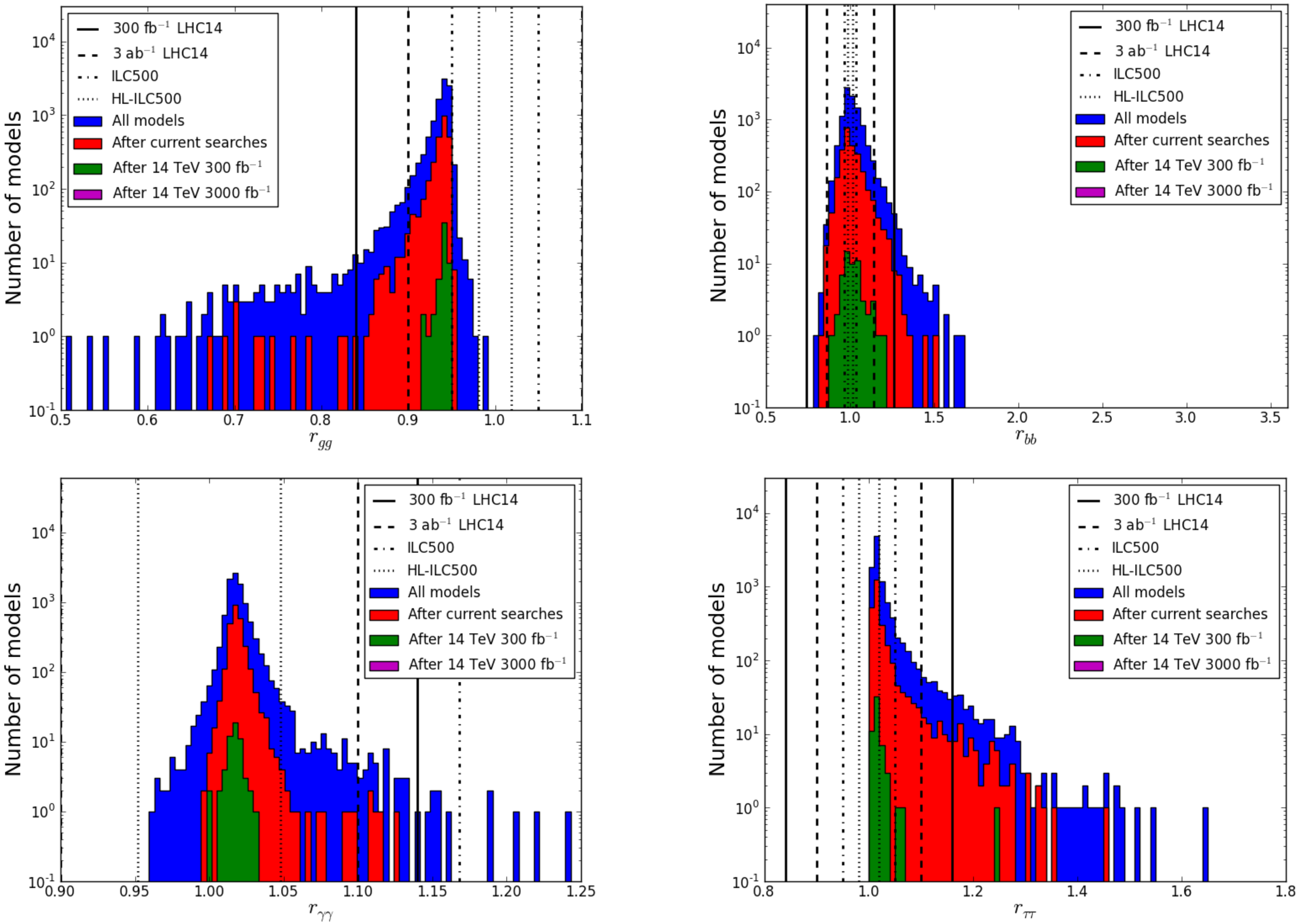
Diphoton signal strength



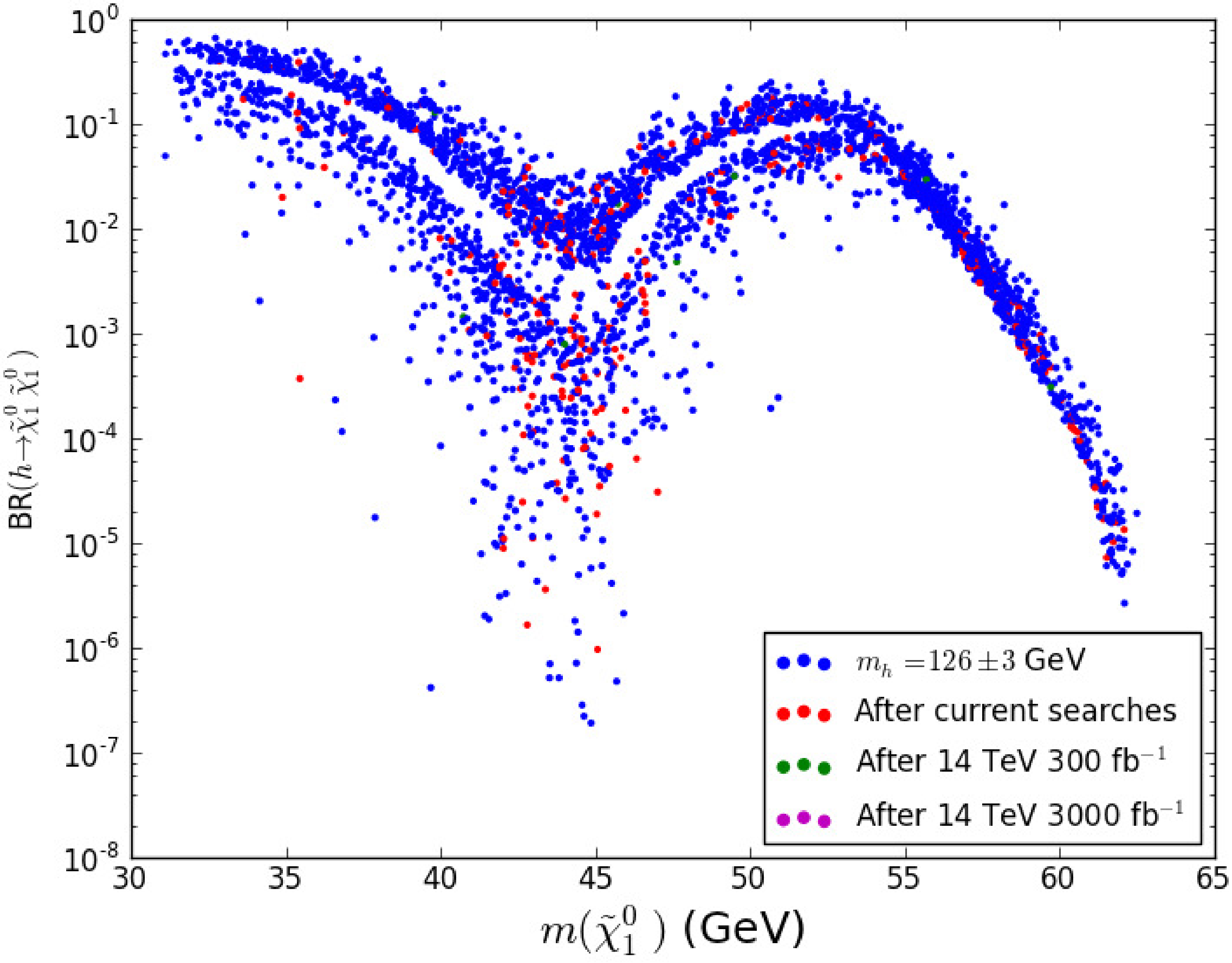
h^0-t-t Coupling



Low-FT Distributions



Low-FT invisible width



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Excluded Fractions For Models Surviving Current LHC Searches:

Channel	300 fb^{-1} LHC	3 ab^{-1} LHC	500 GeV ILC	HL 500 GeV ILC
$b\bar{b}$	16.6 (27.7, 0.5)	33.4 (48.5, 5.5)	78.4 (88.8, 49.1)	91.1 (95.8, 77.3)
$\tau\tau$	0.7 (0.8, 2.9)	3.1 (2.7, 5.7)	11.5 (9.9, 11.9)	36.9 (34.2, 32.9)
gg	0.02 (0.04, 0.5)	0.5 (0.6, 3.1)	99.4 (99.7, 99.7)	100.0 (100.0, 100.0)
$\gamma\gamma$	0.02 (0.07, 0)	0.02 (0.09, 0.2)	0.02 (0.07, 0)	0.1 (0.2, 0.6)
Invisible	0 (0, 0)	0 (0, 0)	0.01 (0.01, 6.2)	0.02 (0.01, 7.5)
All	17.1 (28.2, 3.8)	34.9 (49.6, 11.1)	99.8 (99.96, 99.92)	100.0 (100.0, 100.0)