Implications of LHC Higgs results for the MSSM

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03/14/16 — UC Davis — Theory Seminar

SCIPP
Santa Cruz Institute for Particle Physics

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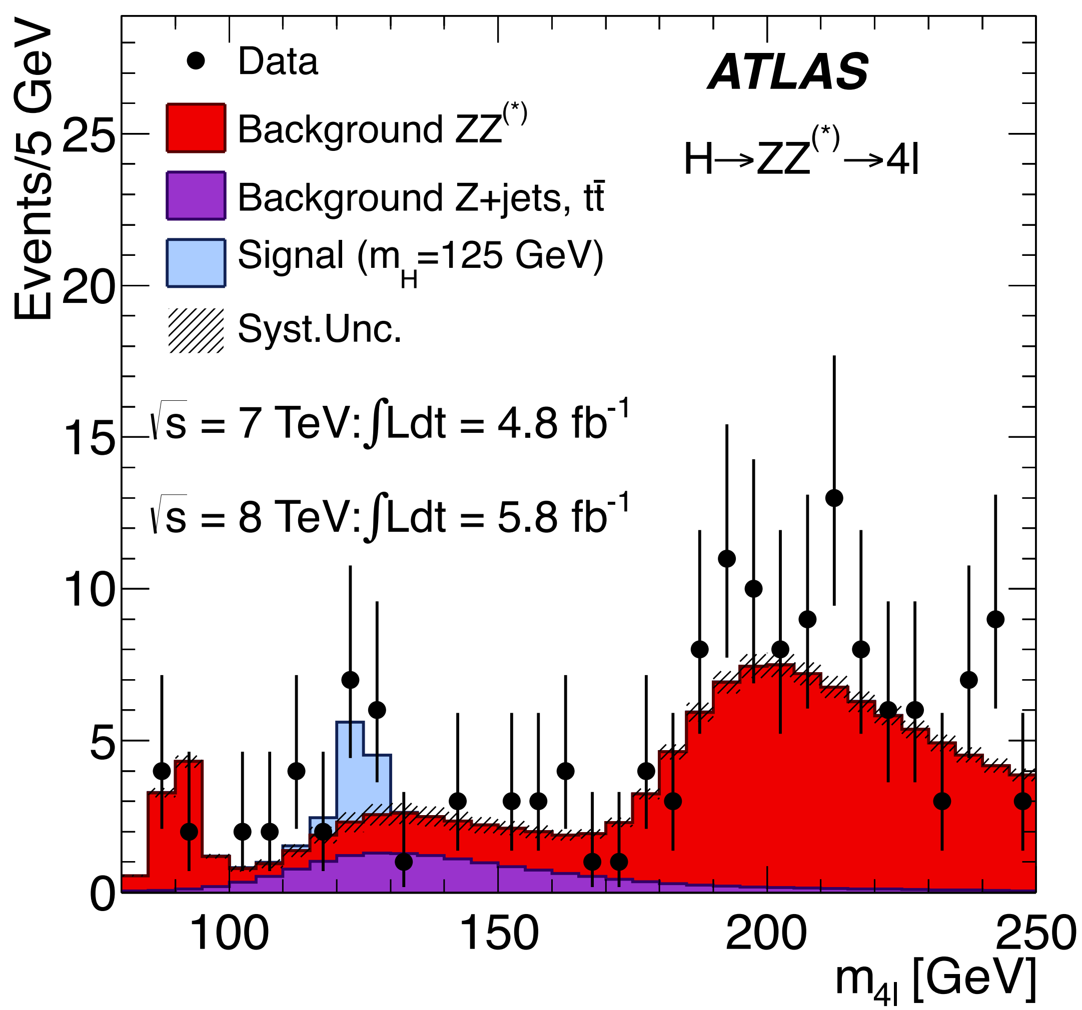
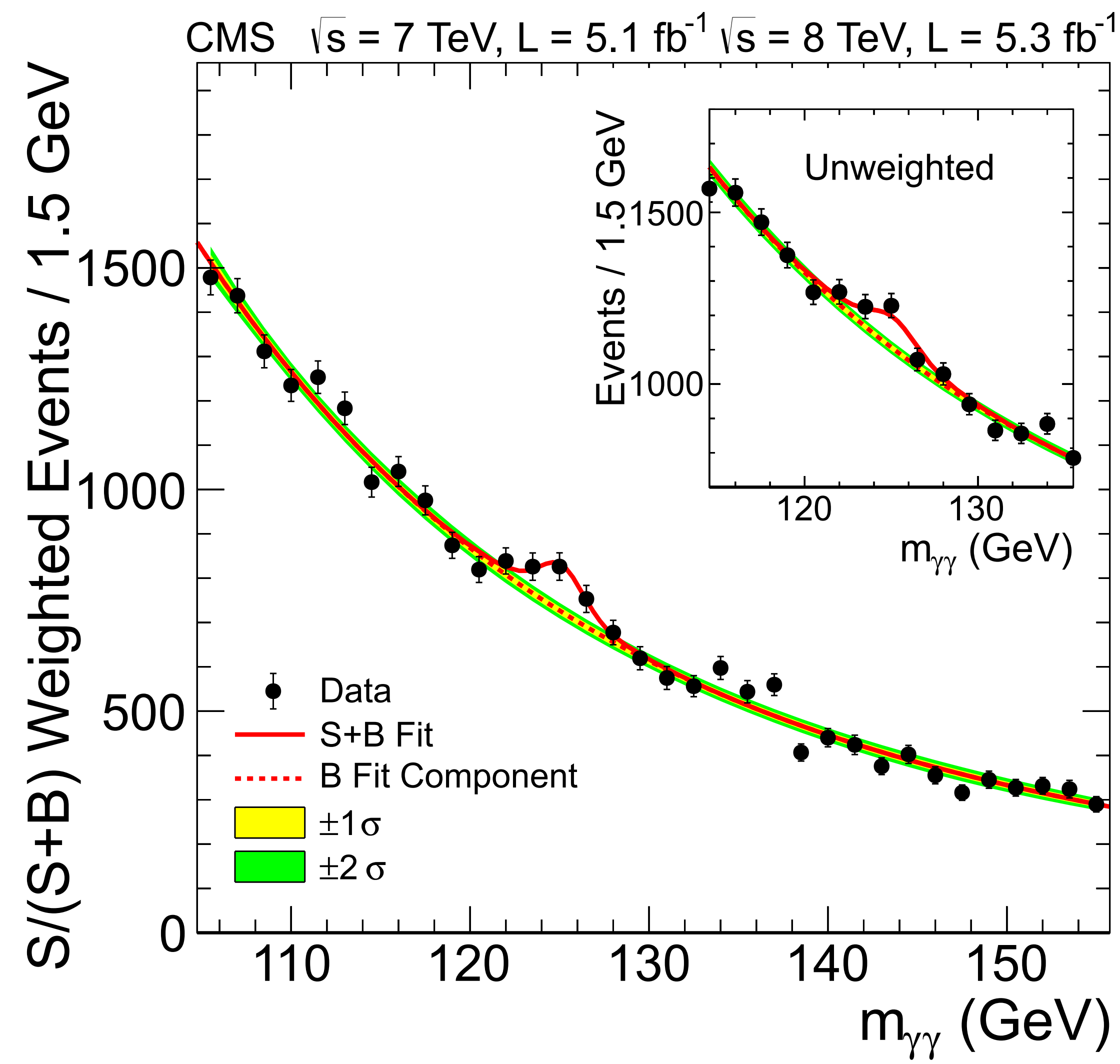
based on work with:
P. Bechtle, H. Haber, S. Heinemeyer, S. Liebler, S. Profumo, O. Stål, G. Weiglein, L. Zeune

LHC Higgs discovery

July 2012: LHC Discovery of a Higgs boson with mass 125 GeV



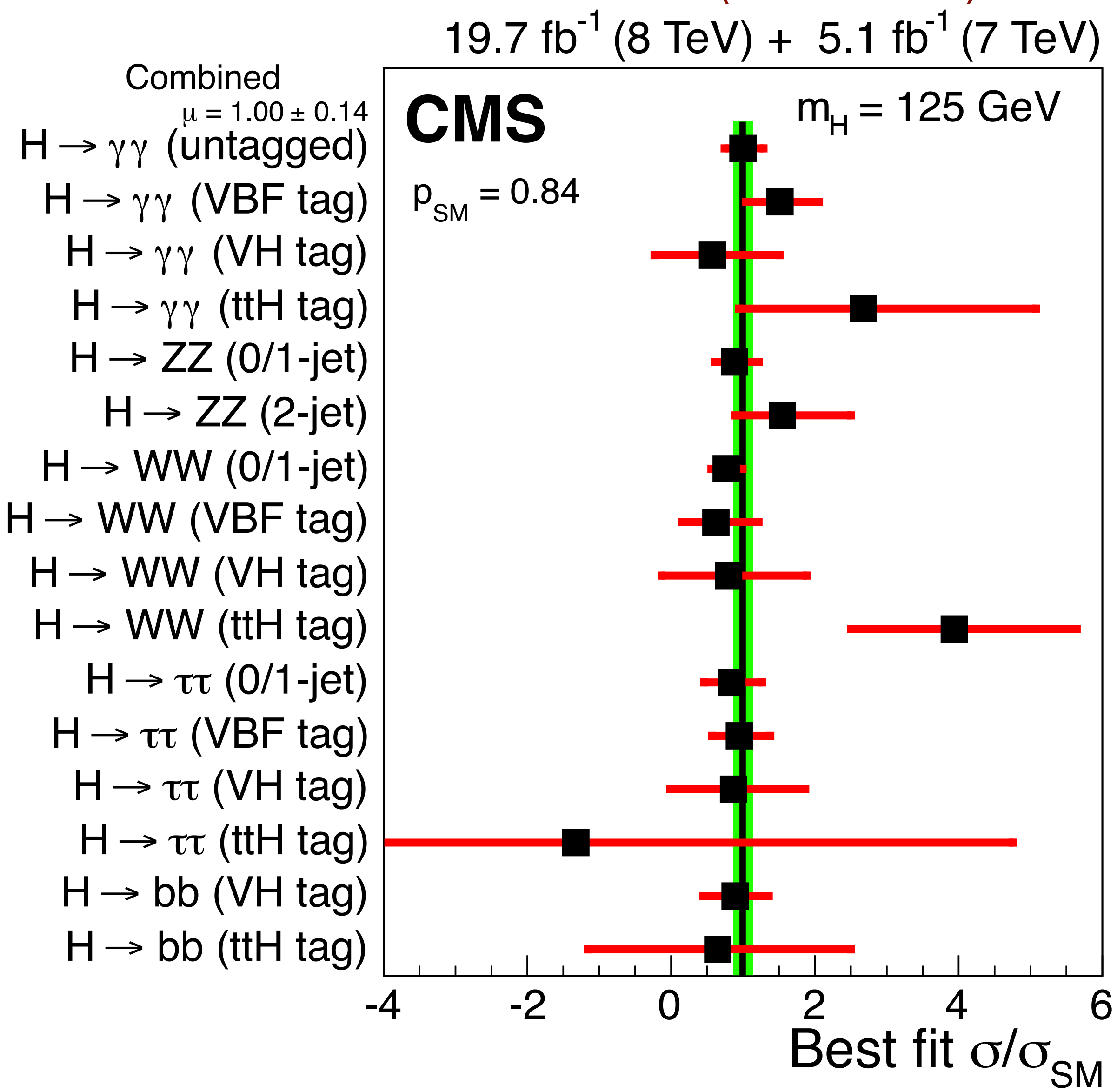


Rates, spin and CP properties in *very good agreement* with the SM Higgs hypothesis

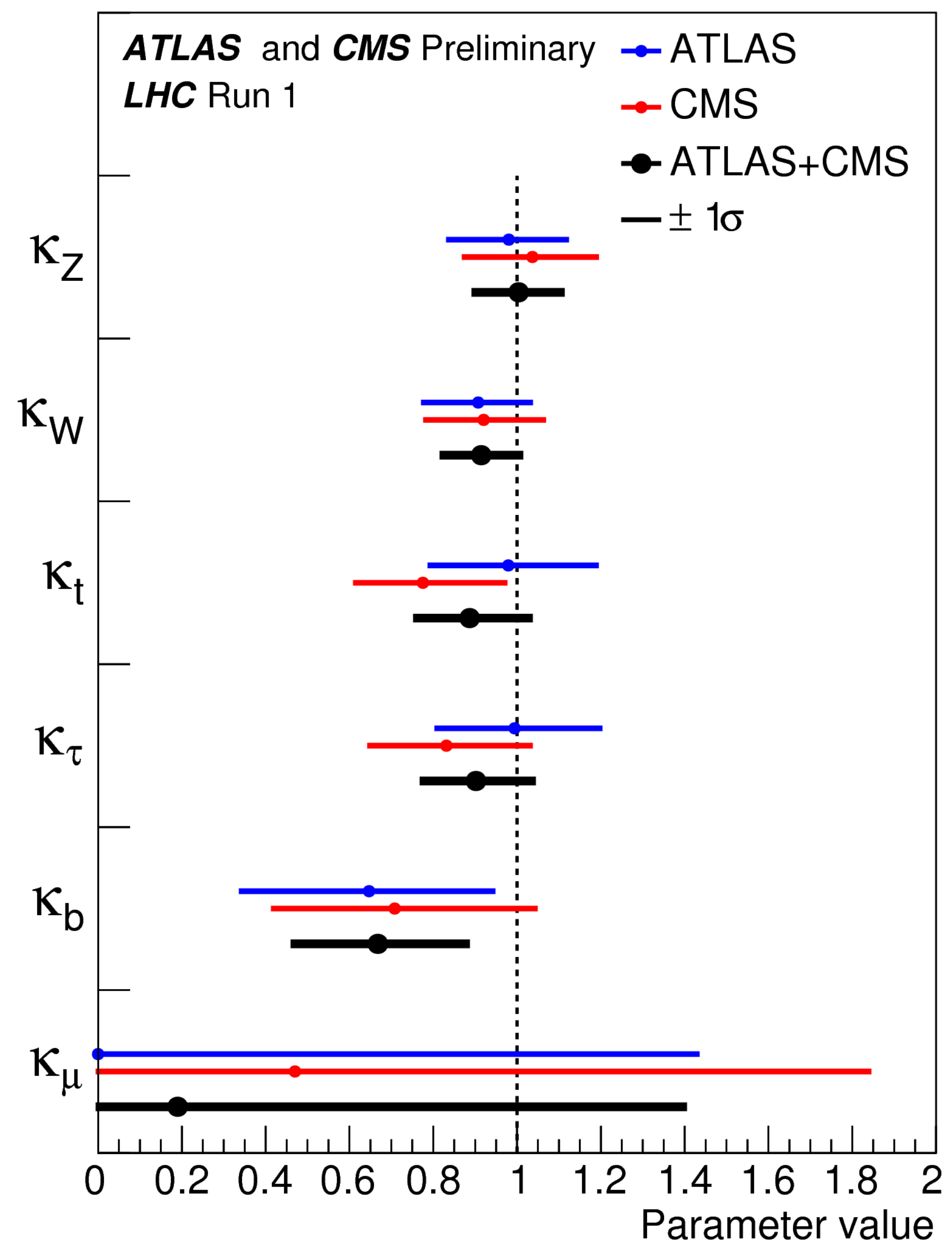
Englert, Higgs (2013)

Higgs rate measurements

CMS '14 (1412.8662)



ATLAS+CMS combination '15



LHC: Measurements of signal rates ($\sigma \times \mathrm{BR}$), *not* couplings.

Precision of SM coupling determination: at best at ~10% level.

Physics beyond the SM (BSM)

BSM physics is well motivated
(Hierarchy Problem, Baryon-Asymmetry, Dark Matter, …).

BSM theories often feature an *extended* Higgs sector:

- expect deviations in signal rates / couplings of discovered Higgs,
- additional Higgs states may be discovered in future LHC searches

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precise measurements of
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collider searches for
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precise predictions of
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predictions/model building
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Experiment		*Theory (BSM)*
precise measurements of Higgs rates and mass	HiggsSignals	*precise predictions* of Higgs rates and mass
	accurate and model-independent tools to confront Theo. vs. Exp.	
collider searches for additional Higgs states	HiggsBounds	predictions/model building for additional Higgs states

Outline

1. Introduction
2. HiggsBounds & HiggsSignals
3. Implications for the MSSM
   (I) Interpretations of the discovered Higgs boson
   (II) How light can the light top squark be?
4. Conclusions

HiggsBounds & HiggsSignals

HiggsBounds and HiggsSignals

http://higgsbounds.hepforge.org

Current Team: P. Bechtle, S. Heinemeyer, TS, G. Weiglein

Idea: Provide public tools for testing Higgs sector predictions of arbitrary BSM theories against Higgs data.

HiggsBounds: Test against 95% CL exclusion limits from LEP, Tevatron and LHC (+ exclusion likelihoods in some cases).

HiggsSignals: χ^2- test against Higgs mass and signal rate measurements from Tevatron and LHC.

- ☑ convenient to use (limits / observables come with programs),
- ☑ validated, maintained and accurate statistical procedure,
- ☑ additional checks about applicability of searches, etc..

HiggsSignals: Basic idea

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1. Take model predictions for physical quantities of given Higgs sector:

$$m_k, \quad \Gamma_k^{\mathrm{tot}}, \quad \sigma_i(pp \to H_k), \quad \mathrm{BR}(H_k \to XX),$$

with $k = 1, \ldots, N, \quad i \in \{\mathrm{ggH}, \mathrm{VBF}, WH, ZH, t\bar{t}H\}$
for N neutral Higgs bosons as the program's user input.
Optional input: Theo. uncertainties for mass, cross sections and BR's.

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2. Calculate the predicted signal strength for every observable,

$$\mu_{H\to XX} = \frac{\sum_i \epsilon^i_{\mathrm{model}}[\sigma_i(pp \to H) \times \mathrm{BR}(H \to XX)]_{\mathrm{model}}}{\sum_i \epsilon^i_{\mathrm{SM}}[\sigma_i(pp \to H) \times \mathrm{BR}(H \to XX)]_{\mathrm{SM}}}$$

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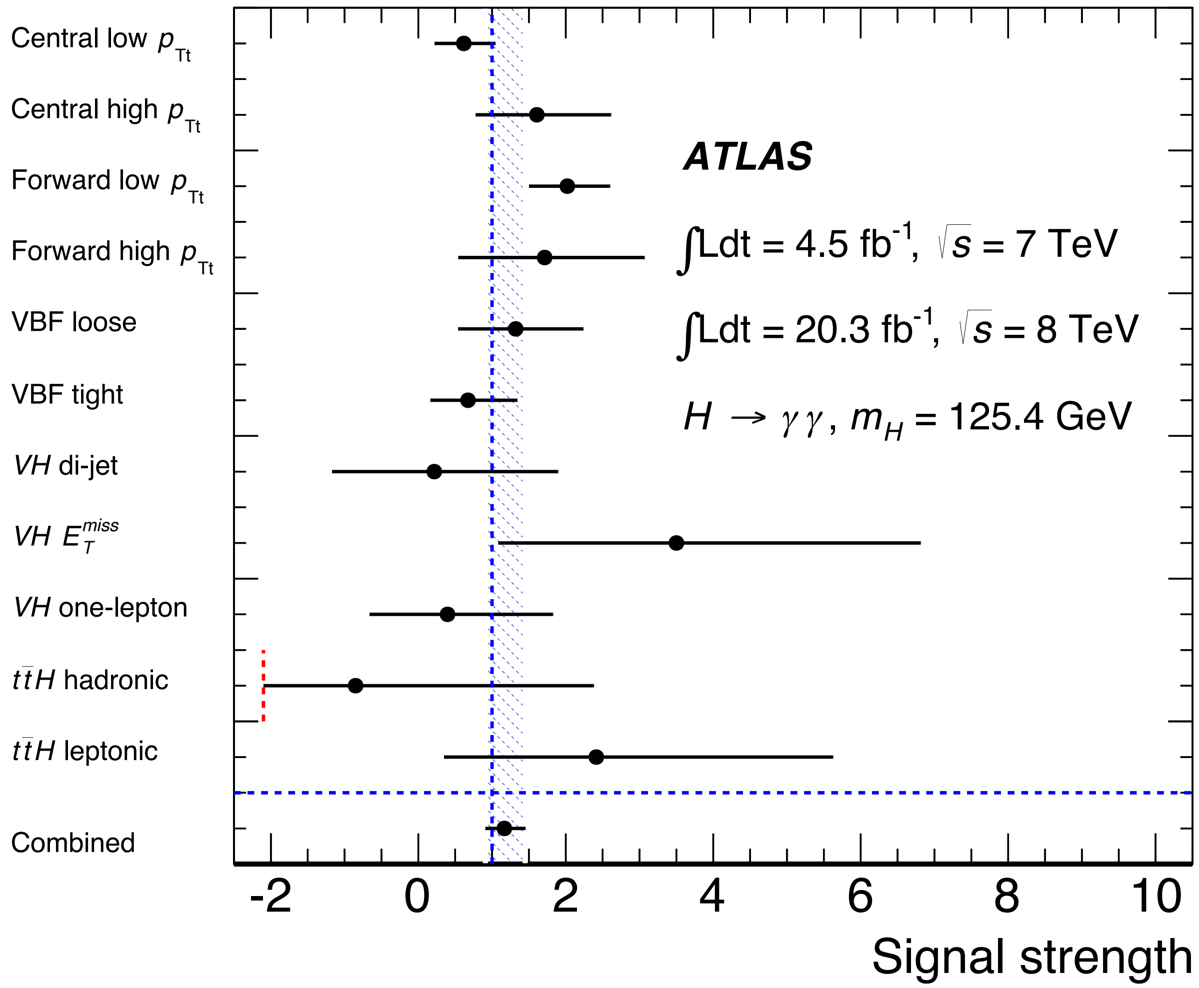
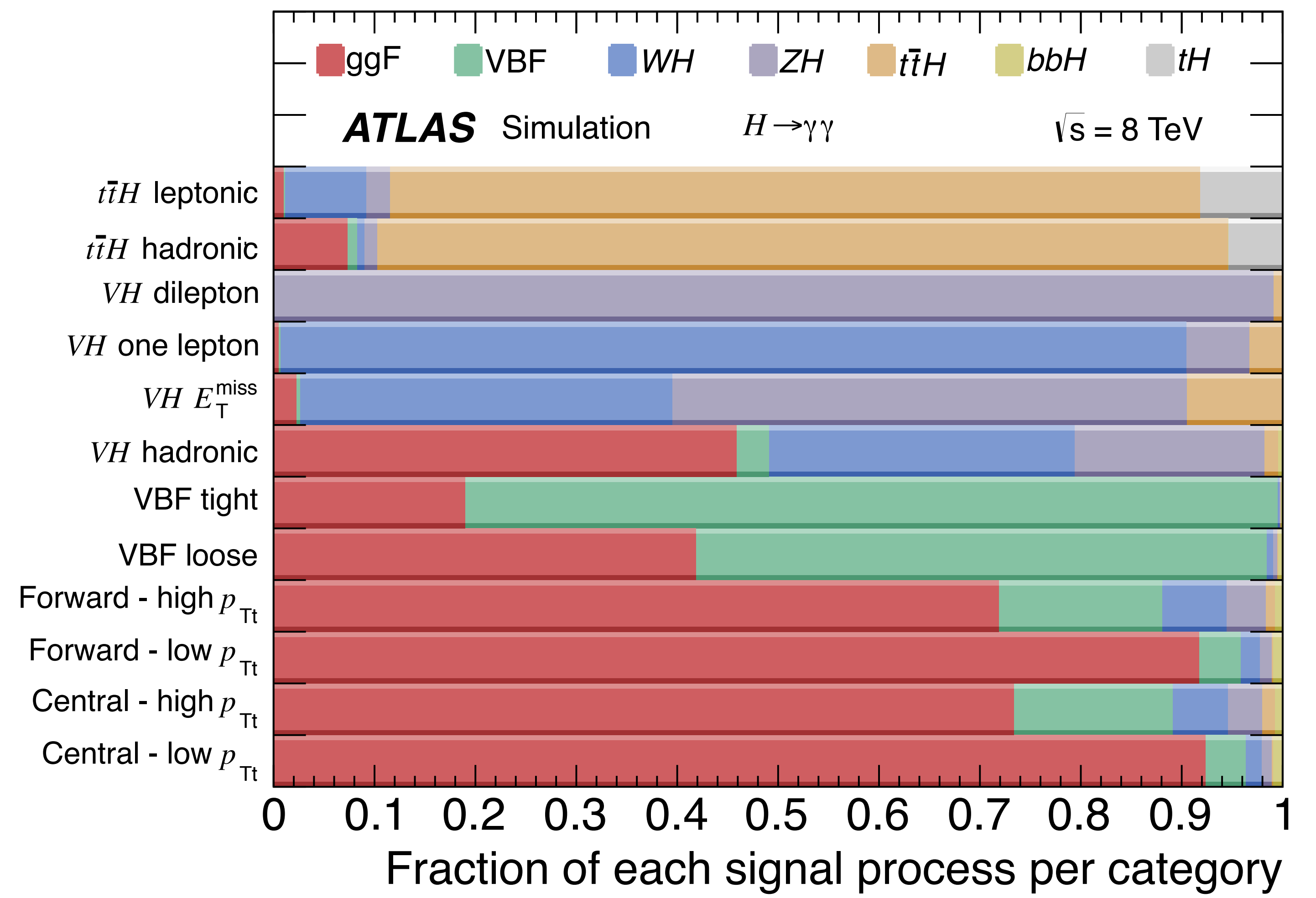
3. Perform a χ^2 test of model predictions against all available data from Tevatron and LHC, using signal rate and mass measurements.

Try to be as model-independent and precise as possible.

Experimental Input

ATLAS '14 (1408.7084)





- Signal efficiencies $\epsilon^i_{\rm SM}$ are very valuable information! Included in HiggsSignals if available.

- HiggsSignals contains an interface to insert model-specific relative signal efficiency scale factors, $\zeta^i = \epsilon^i_{\rm model}/\epsilon^i_{\rm SM}$.

Chi-squared test and validation

Chi-squared contribution from Higgs signal rates:

$$\chi^2_\mu = (\hat{\mu} - \mu)^T \mathbf{C}_\mu^{-1} (\hat{\mu} - \mu)$$

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Covariance matrix contains known correlations among

- luminosity uncertainties,
- theoretical rate uncertainties (assuming inclusive rate uncertainties of SM Higgs from LHC Higgs XS WG),
  LHC HXSWG '13 (1307.1347)
- other known systematic uncertainties (if information is available).

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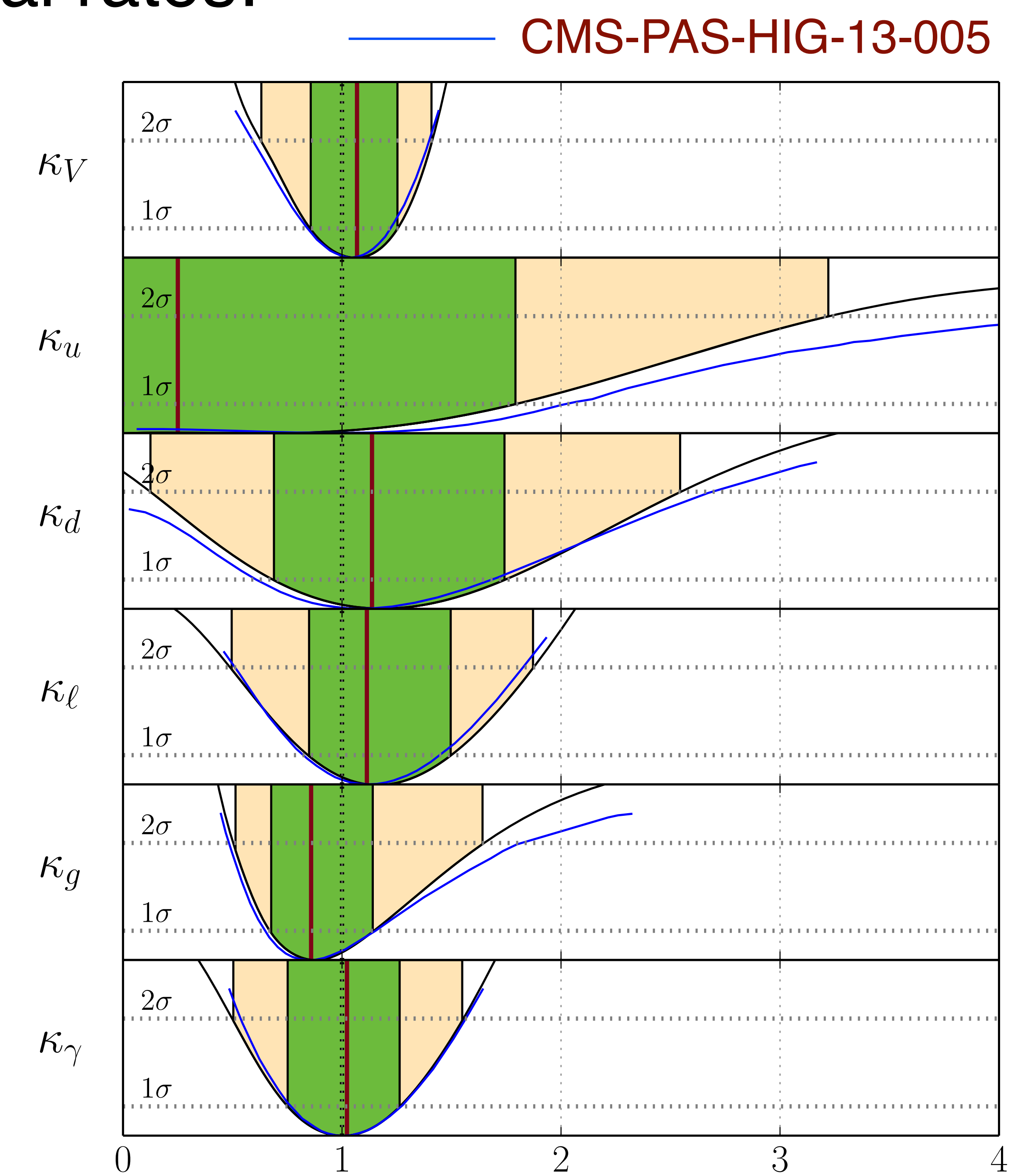
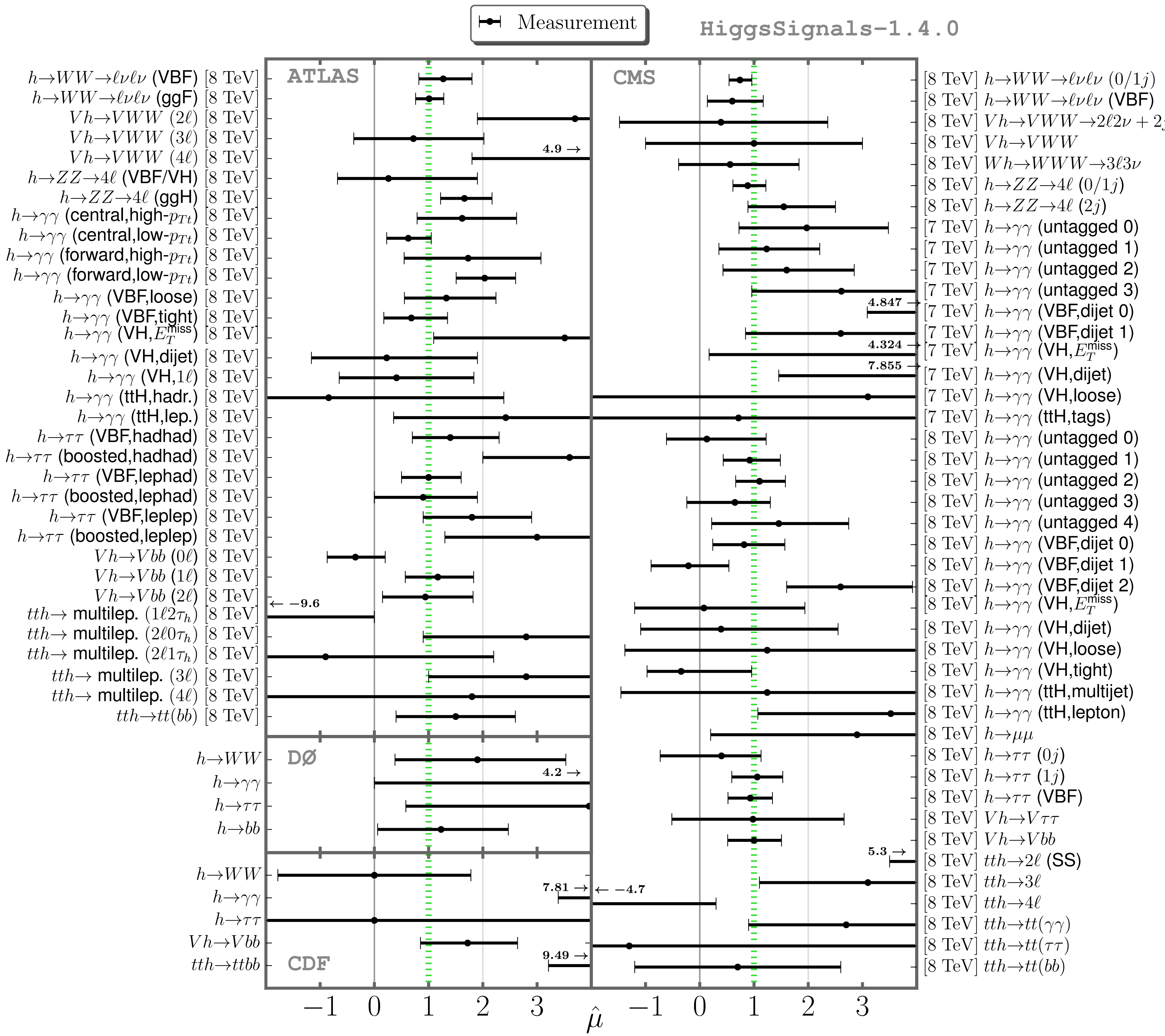


Validation: Reproduction of CMS results

Observables included in HiggsSignals-1.4.0



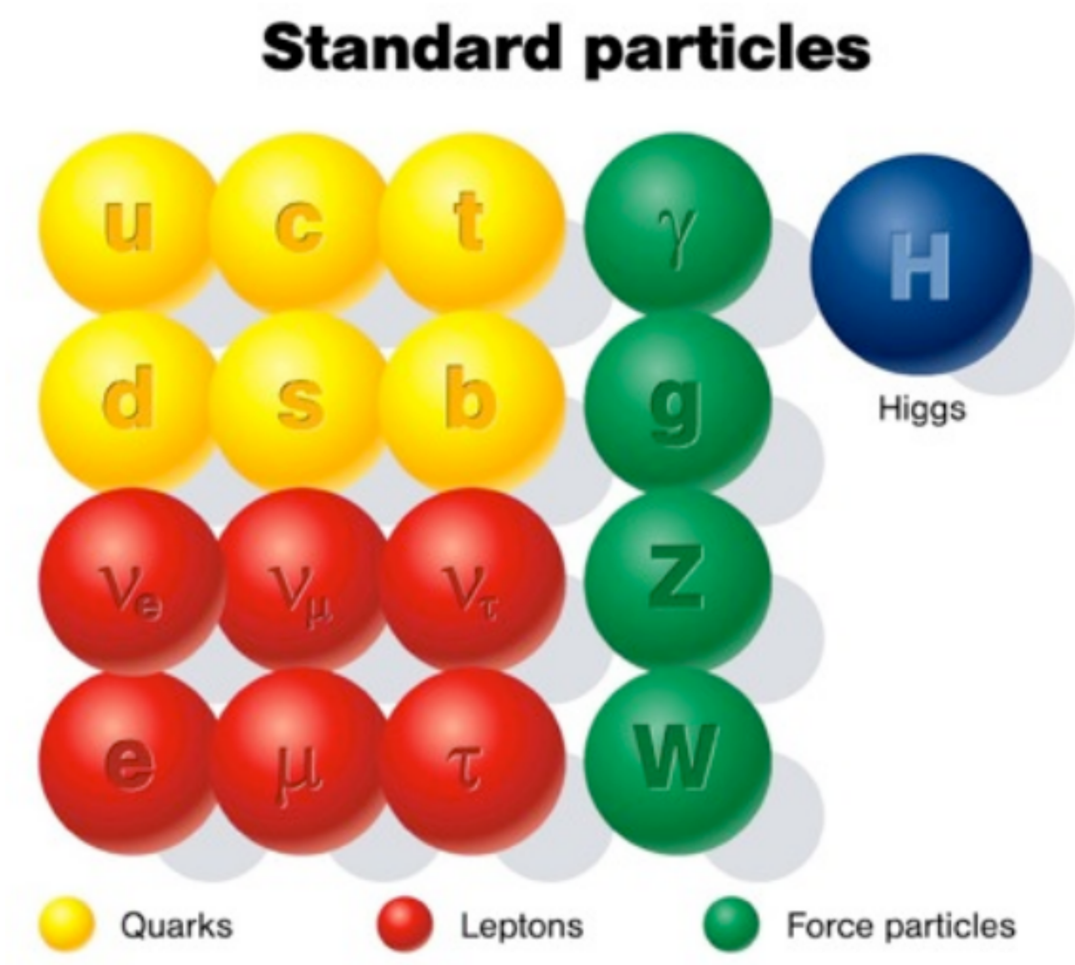
in total: 85 rate measurements, 4 mass measurements

Implications for the MSSM

Supersymmetry

SUSY: Hypothetical space-time symmetry relating fermions & bosons

⟶ introduce *superpartners* for every SM field



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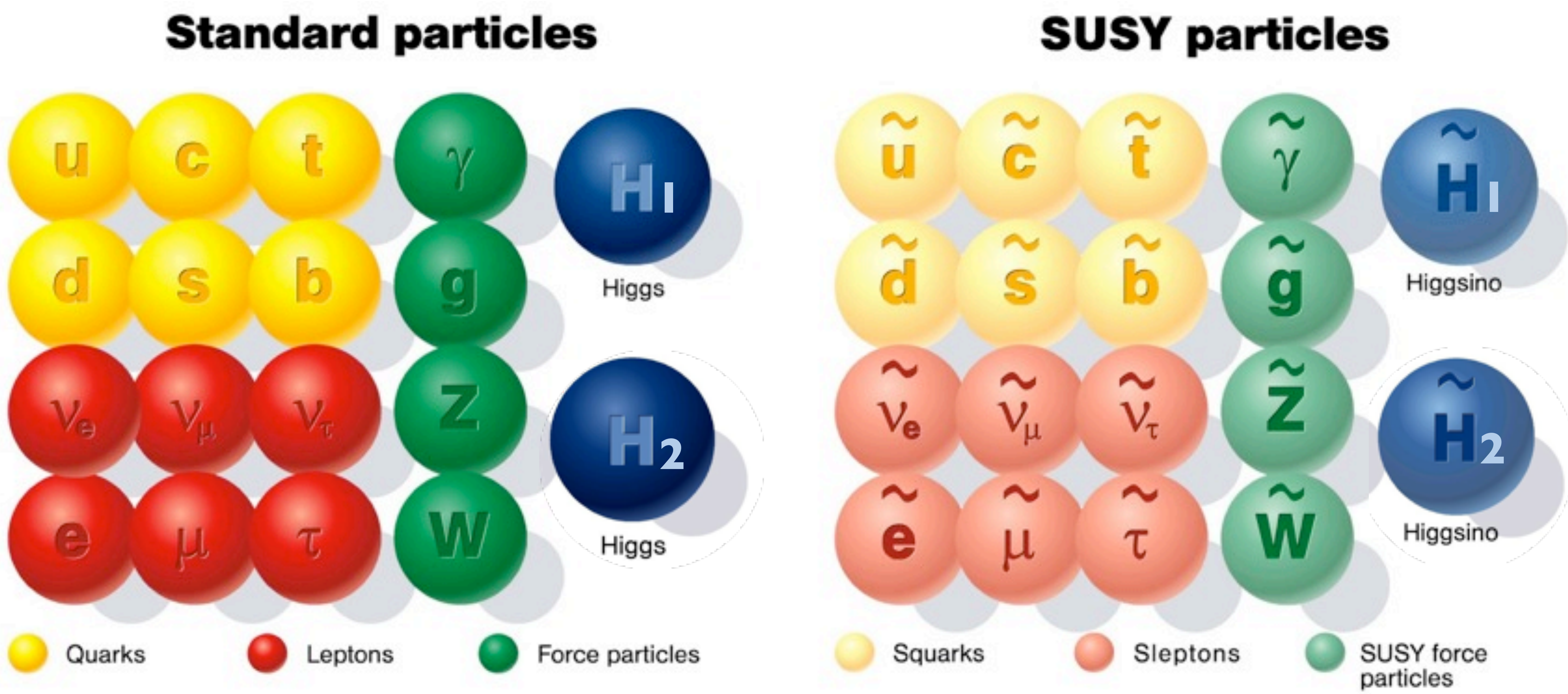

- Two Higgs doublets needed to give mass to up- and down-type fermions,
- SUSY cannot be exact. Expect SUSY masses $\sim \mathcal{O}(1~\mathrm{TeV})$.

The MSSM Higgs Sector

- 2 complex Higgs doublets H_u, H_d → 5 physical Higgs bosons ($h, H, A, H^\pm$)
- At tree-level, the Higgs sector has two parameters: $M_A, \tan\beta = v_u/v_d$

  Other Higgs boson masses are predictions:

$$M^2_{h,H} = \frac{1}{2}\left[M_A^2 + M_Z^2 \mp \sqrt{(M_A^2+M_Z^2)^2 - 4M_A^2 M_Z^2 \cos^2 2\beta}\right] \quad \Rightarrow M_h^{\text{tree}} \leq M_Z \; !$$

$$M^2_{H^\pm} = M_A^2 + M_W^2$$

- (SM-like) Higgs mass M_h receives large radiative corrections:

$$(\Delta M_h^2)^{t,\tilde{t}}_{1\text{L}} \approx \frac{3m_t^4}{2\pi^2 v^2}\left[\log\left(\frac{M_S^2}{m_t^2}\right) + \frac{X_t^2}{M_S^2}\left(1 - \frac{X_t^2}{12M_S^2}\right)\right]$$

$(M_A \gg M_Z, \tan\beta \gg 1)$ $\quad$ $(X_t = A_t - \mu/\tan\beta, M_S = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}})$

⟶ Weak scale SUSY predicts a light Higgs boson, $M_h \lesssim 135\text{ GeV}$!

The Higgs alignment limit

= One of the CP-even neutral Higgs bosons lies in the same direction (in field space) as the neutral Higgs vev.

Gunion, Haber ’02 (hep-ph/0207010)

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In the Two Higgs Doublet Model (2HDM):

Choose "Higgs basis": $\langle H_1^0 \rangle = v/\sqrt{2}$, $\langle H_2^0 \rangle = 0$

Higgs potential:

$$\mathcal{V} \supset \tfrac{1}{2} Z_1 (H_1^\dagger H_1)^2 + [Z_5 (H_1^\dagger H_2)^2 + Z_6 (H_1^\dagger H_1) H_1^\dagger H_2 + \text{h.c.}] + \ldots$$

Squared-mass matrix:

$$\mathcal{M}_H^2 = \begin{pmatrix} Z_1 v^2 & Z_6 v^2 \\ Z_6 v^2 & M_A^2 + Z_5 v^2 \end{pmatrix}$$

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1. Alignment through decoupling ($M_A^2 \gg Z_i v^2 \;\; (i = 1, 5, 6)$)
2. Alignment without decoupling ($Z_6 \to 0$)
   either light or heavy CP-even Higgs can be aligned!

Bernon, Gunion, Haber, Jiang, Kraml '15 (1507.00933, 1511.03682)

“Alignment without Decoupling” in MSSM

The Z_i are functions of the MSSM parameters.

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In the limit $M_Z, M_A \ll M_S = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$, the leading terms $\sim \mathcal{O}(y_t^4)$ are

$$Z_6 v^2 = -s_{2\beta} \left\{ M_Z^2 c_{2\beta} - \frac{3v^2 s_\beta^2 y_t^4}{16\pi^2} \left[\ln\left(\frac{M_S^2}{m_t^2}\right) + \frac{X_t(X_t+Y_t)}{2M_S^2} - \frac{X_t^3 Y_t}{12 M_S^4} \right] \right\}$$

with $X_t = A_t - \mu^* / \tan\beta$, $Y_t = A_t + \mu^* \tan\beta$.

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with $X_t = A_t - \mu^* / \tan\beta$, $Y_t = A_t + \mu^* \tan\beta$.

Approximate 1-loop alignment condition ($\tan\beta \gg 1$):

$$\tan\beta = \frac{M_Z^2 + \frac{3v^2 y_t^4}{16\pi^2}\left[\ln\left(\frac{M_S^2}{m_t^2}\right) + \frac{2A_t^2 - \mu^2}{2M_S^2} - \frac{A_t^2(A_t^2 - 3\mu^2)}{12 M_S^4}\right]}{\frac{3v^2 y_t^4}{32\pi^2} \frac{\mu A_t}{M_S^2} \left(\frac{A_t^2}{6M_S^2} - 1\right)}$$

Alignment occurs through an accidental cancellation of tree-level and loop-level effects.

Carena, Haber, Low, Shah, Wagner '14 (1410.4969)

$$\tan\beta = \frac{M_Z^2 + \frac{3v^2y_t^4}{16\pi^2}\left[\ln\left(\frac{M_S^2}{m_t^2}\right) + \frac{2A_t^2-\mu^2}{2M_S^2} - \frac{A_t^2(A_t^2-3\mu^2)}{12M_S^4}\right]}{\frac{3v^2y_t^4}{32\pi^2}\frac{\mu A_t}{M_S^2}(\frac{A_t^2}{6M_S^2} - 1)}$$

Alignment occurs at moderate values of $\tan\beta$ only if $\mu A_t/M_S^2$ is large.

Solution exists if:

$$\mu A_t(A_t^2 - 6M_S^2) > 0$$

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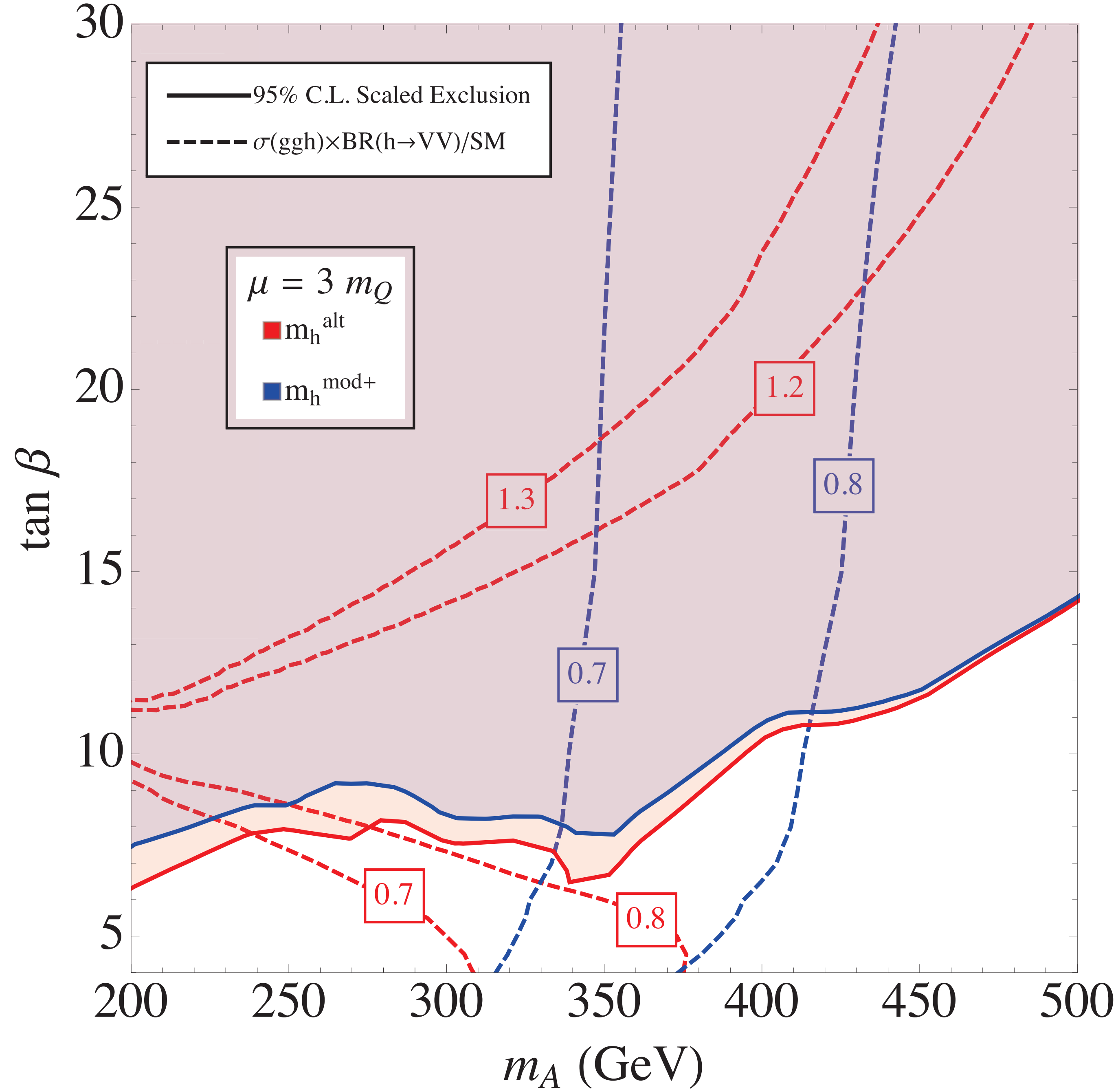
$m_h^{\rm alt}$ benchmark scenario ⟶



Complementarity between precision Higgs rate measurements and LHC $H/A \to \tau^+\tau^-$ searches.

Carena, Haber, Low, Shah, Wagner '14 (1410.4969)

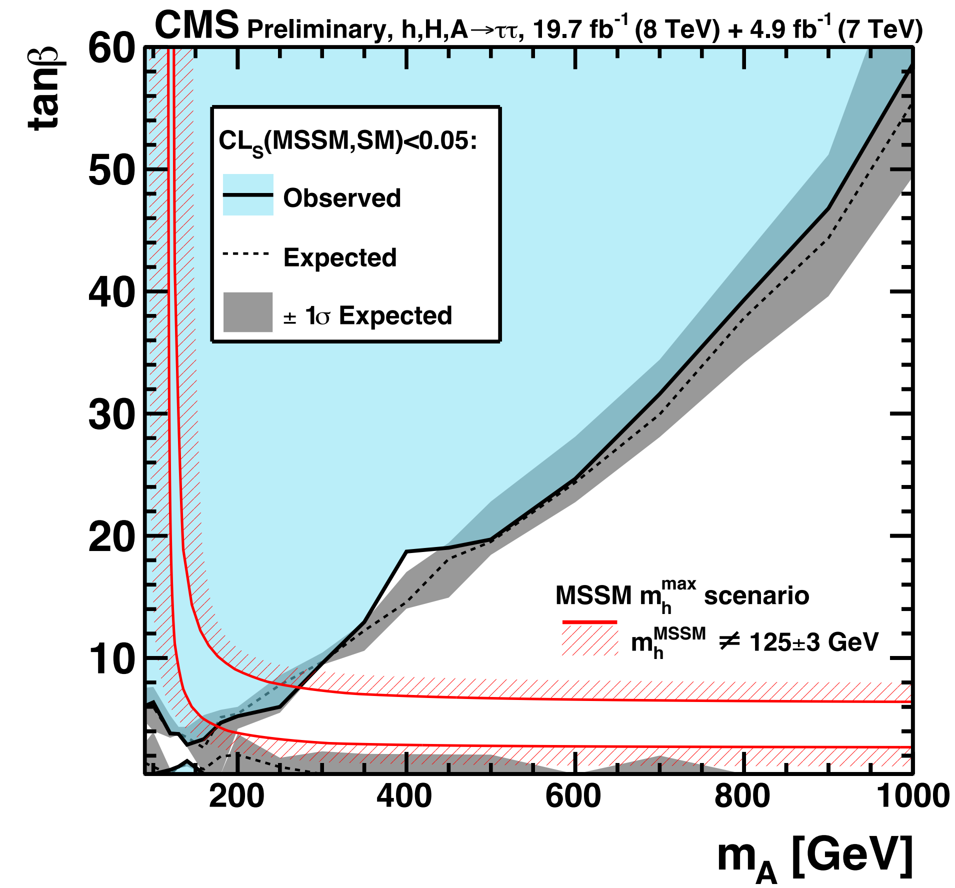
LHC searches for $h/H/A \to \tau^+\tau^-$

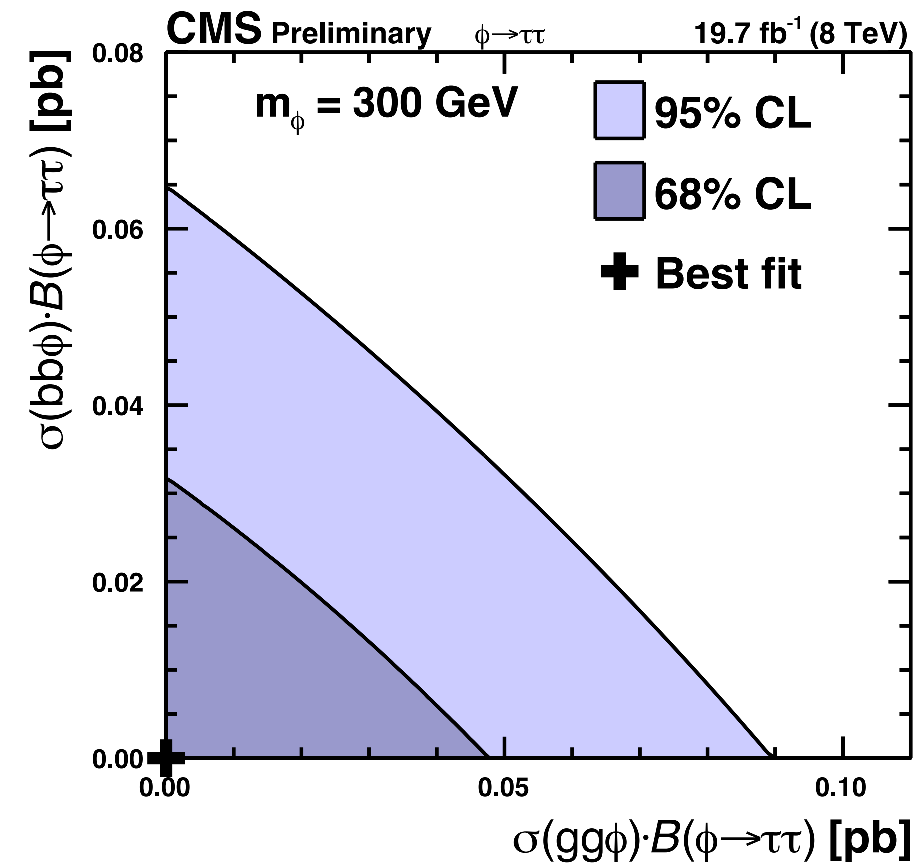
CMS published results for

- MSSM benchmark scenarios
- Single resonance toy model

⟶ exclusion likelihood in $(m_\phi, \sigma_{gg\phi}, \sigma_{b\bar{b}\phi})$

CMS-PAS-HIG-14-029





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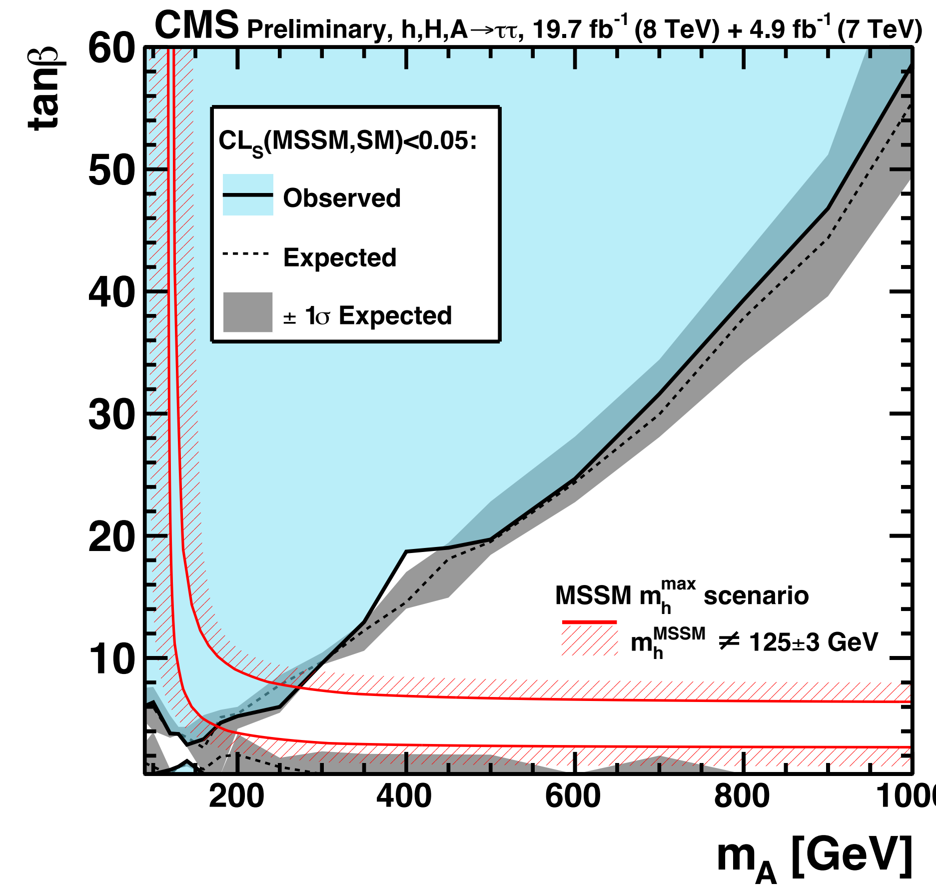
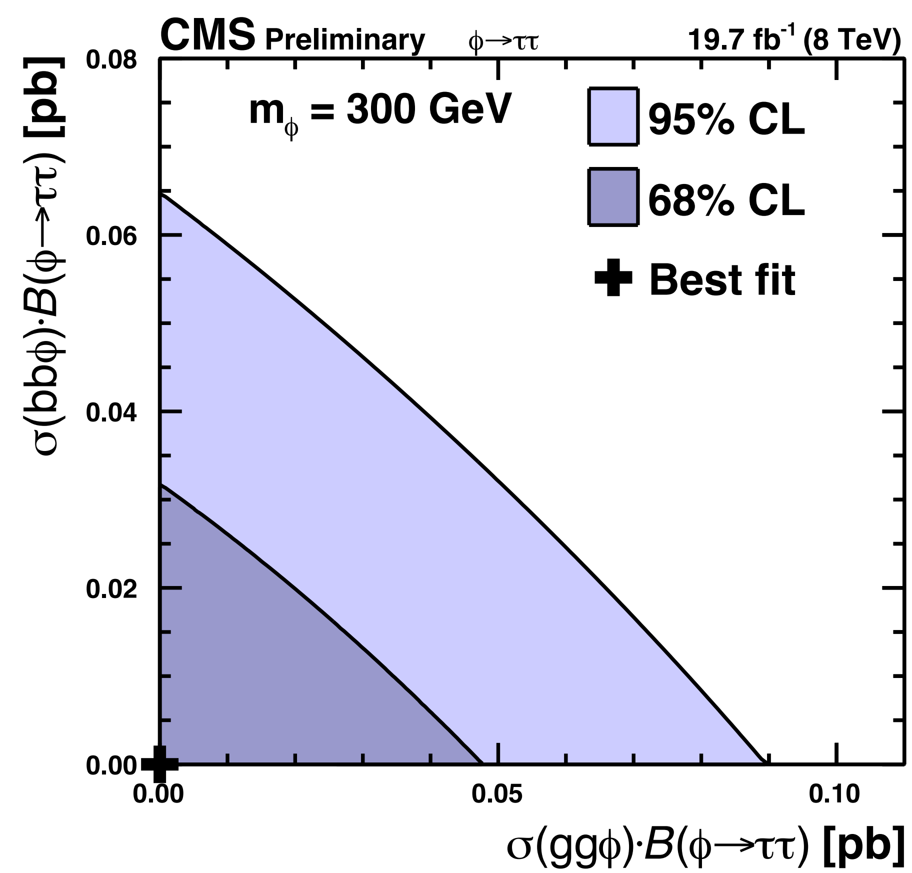


Likelihood can be mapped onto extended Higgs sectors:

(to a good approximation)

- Add Higgs boson signal rates if $(m_i - m_j)/\max(m_i, m_j) \leq 20\%$
- Determine *most sensitive* Higgs boson combination and obtain its observed exclusion likelihood.



Implemented in HiggsBounds-4.2.

P. Bechtle, S.Heinemeyer, O.Stål, TS, G. Weiglein '15 (1507.06706)

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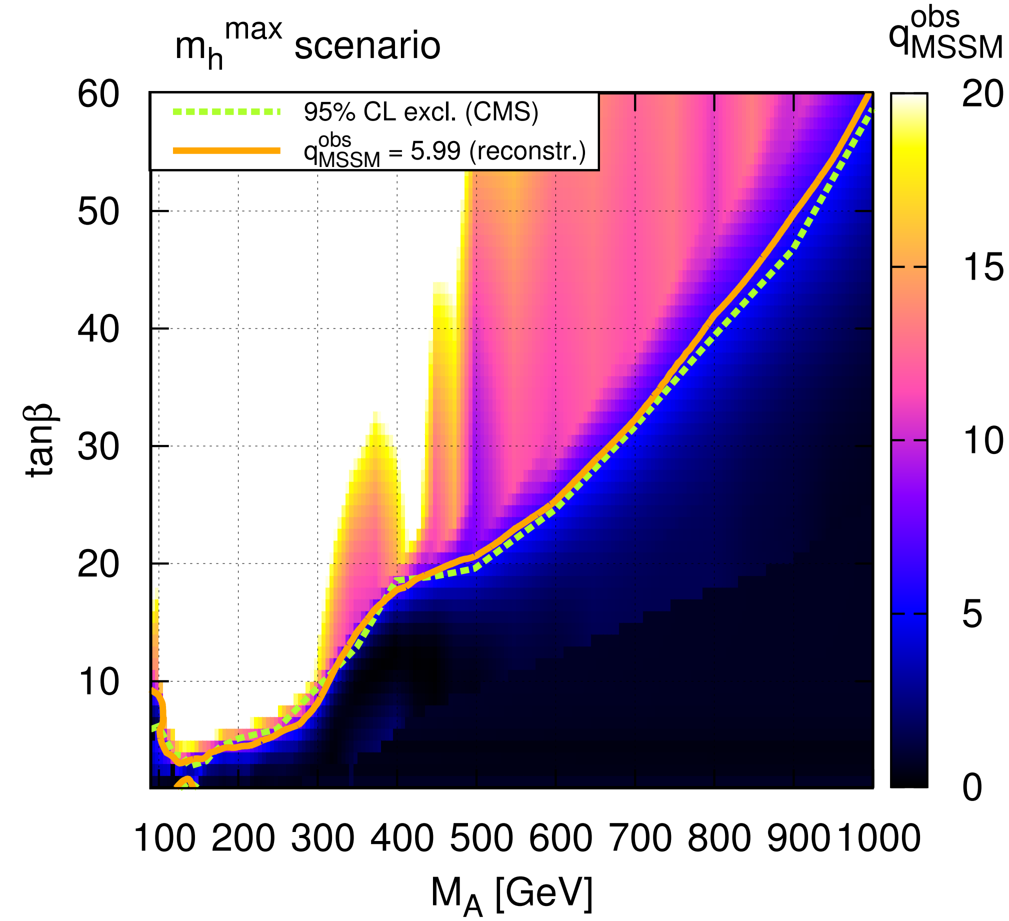

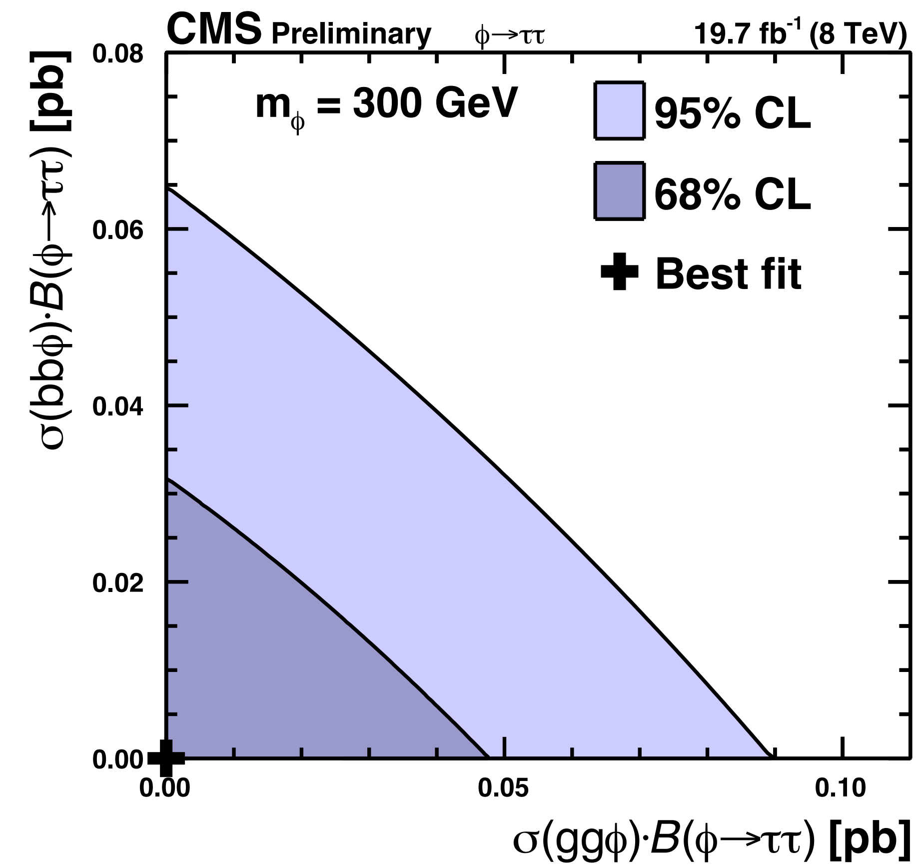

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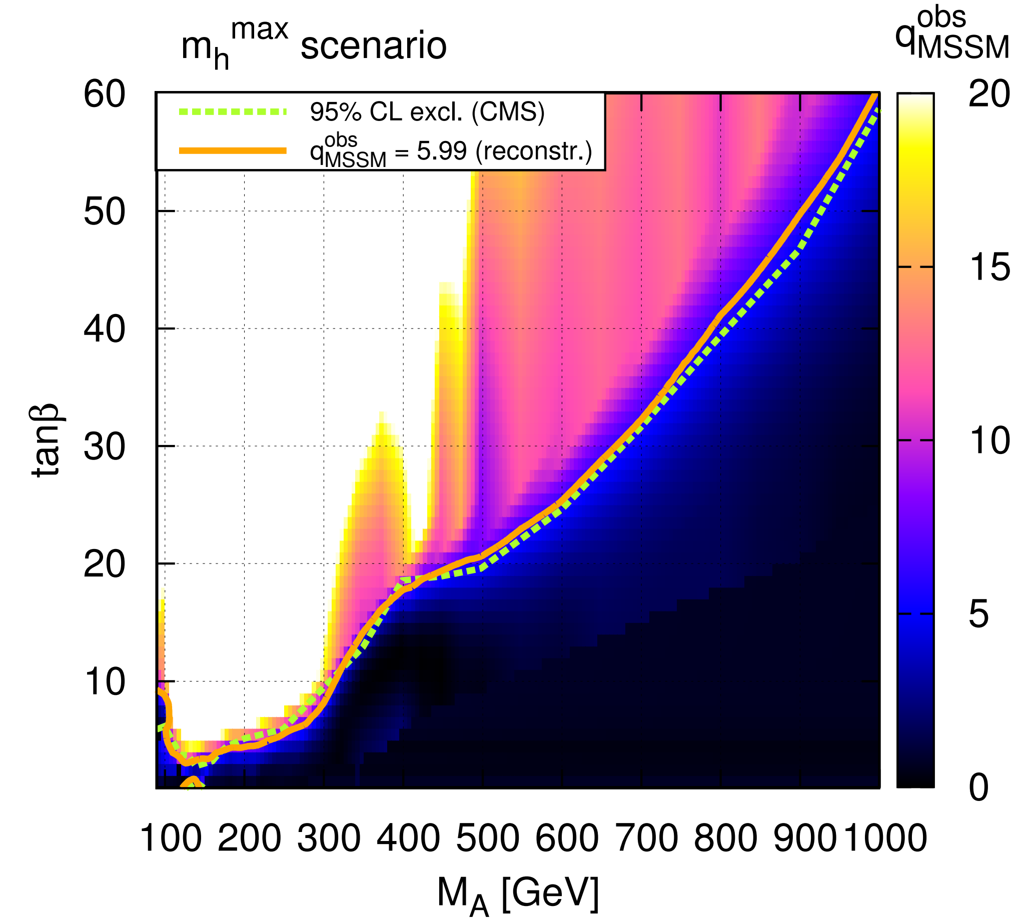

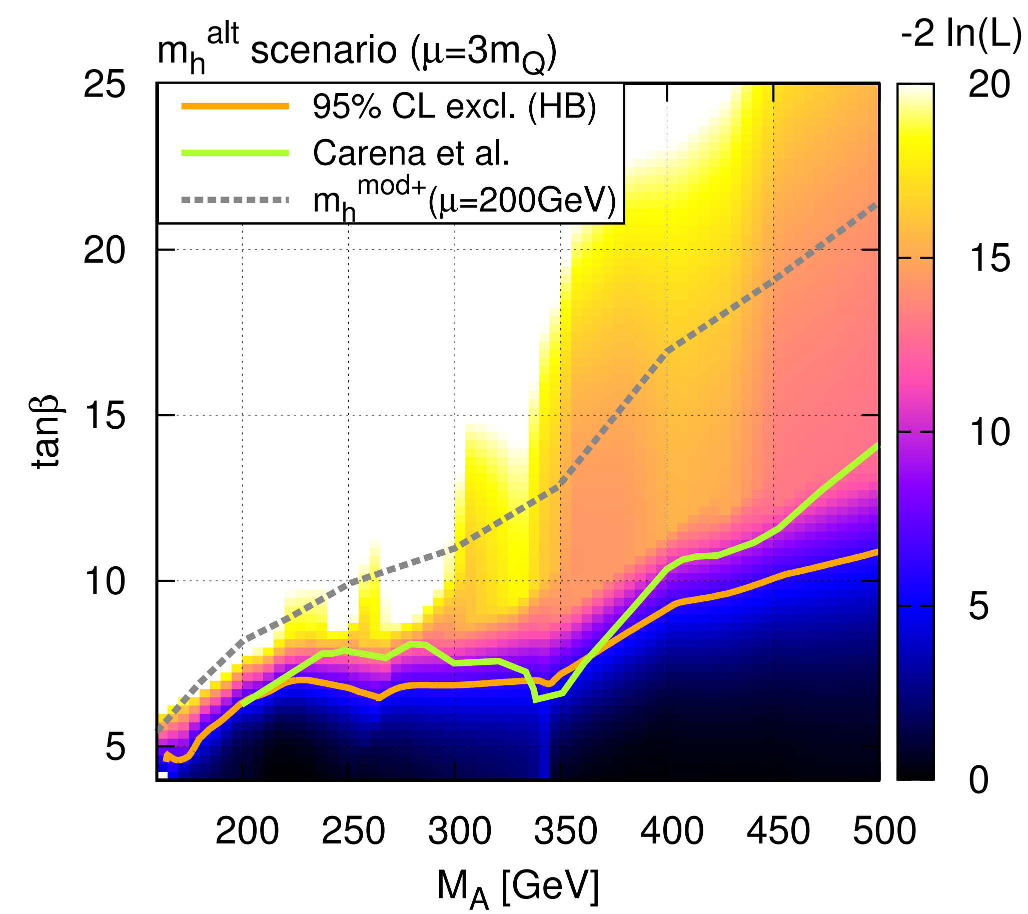

Global Fit of the phenomenological MSSM

P. Bechtle, H. Haber, S. Heinemeyer, O. Stål, TS, G. Weiglein, L. Zeune (work in progress)

Motivation:

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1) Do the three possible Higgs interpretations,

- light Higgs at 125 GeV (alignment through decoupling),
- light Higgs at 125 GeV (alignment without decoupling),
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survive the *combined constraints* from Higgs mass and signal rates, Higgs and sparticle LHC limits and low energy observables?

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2) Can they give a better description of the data than the SM?

3) What parameter regions are preferred?
What are the predictions/prospects for future LHC searches?

The setup

Perform a random scan over 8 MSSM parameters with ~10^7 points,

$$M_A,\ \tan\beta,\ \mu,\ M_{\tilde{q}_3},\ M_{\tilde{\ell}_3},\ M_{\tilde{\ell}_{1,2}},\ M_1 = M_2/2,\ A_t = A_b = A_\tau,\ (+\ m_{\text{top}})$$

using FeynHiggs and SuperIso for MSSM predictions.
(Fix other parameters, e.g. $m_{\tilde{q}_{1,2}} = m_{\tilde{g}} = 1.5\ \text{TeV}$)

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Observables and Limits:

$$\chi^2_{\mathrm{total}} = \frac{(M_{h,H} - \hat{M})^2}{\sigma^2_{\hat{M}}} + \chi^2_{\mathrm{HS}} + \sum_{i=1}^{n_{\mathrm{LEO}}} \frac{(O_i - \hat{O}_i)^2}{\sigma_i^2} - 2\ln\mathcal{L}_{\mathrm{limits}}$$

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Higgs mass
($\sigma_M^{\rm theo} = 3\ \mathrm{GeV}$)

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Higgs signal rates
(HiggsSignals)

The setup

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Low energy observables (LEO):

$\mathcal{O}_i \in \{b \to s\gamma,\ B_s \to \mu\mu,\ B_u \to \tau\nu_\tau,\ (g-2)_\mu,\ M_W\}$

The setup

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$$M_A,\ \tan\beta,\ \mu,\ M_{\tilde{q}_3},\ M_{\tilde{\ell}_3},\ M_{\tilde{\ell}_{1,2}},\ M_1 = M_2/2,\ A_t = A_b = A_\tau,\ (+\ m_{\rm top})$$

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Higgs exclusion likelihoods
(LEP, $h/H/A \to \tau^+\tau^-$)

The setup

Perform a random scan over 8 MSSM parameters with ~10^7 points,

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Hard cuts:

+ 95% CL limits from Higgs searches (HiggsBounds)
+ Direct Limits from LHC SUSY searches (Herwig++/CheckMATE)
+ require neutral lightest SUSY particle (LSP).

Results: Best-fit points

Case	full fit χ^2/ν	full fit χ^2_ν	full fit p	fit without $(g-2)_\mu$ χ^2/ν	fit without $(g-2)_\mu$ χ^2_ν	fit without $(g-2)_\mu$ p	fit without all LEOs χ^2/ν	fit without all LEOs χ^2_ν	fit without all LEOs p
SM	85.0/91	0.93	0.66	73.7/90	0.82	0.89	70.2/86	0.82	0.89
h	69.6/84	0.83	0.87	69.5/83	0.84	0.86	68.0/79	0.86	0.81
H	72.4/85	0.85	0.83	71.2/84	0.85	0.84	69.2/80	0.87	0.80

number of degrees of freedom: $\nu = n_{\mathrm{obs}} - n_{\mathrm{param}}$

- SM and MSSM light Higgs (h) and heavy Higgs (H) interpretation provide similar fit to the Higgs data.
- Including $(g-2)_\mu$: SM fit becomes worse.

Best-fit points for the full fit:

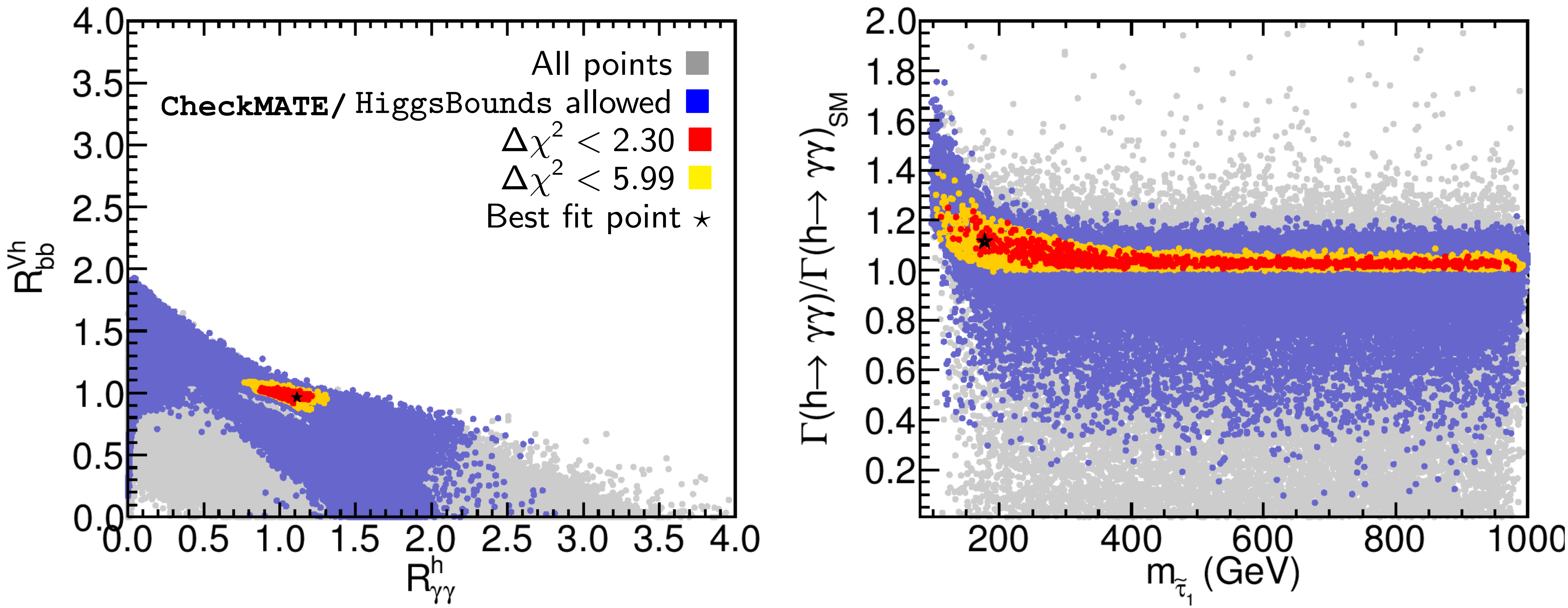
Case	M_A (GeV)	$\tan\beta$	μ (GeV)	A_t (GeV)	$M_{\tilde{q}_3}$ (GeV)	$M_{\tilde{\ell}_3}$ (GeV)	$M_{\tilde{\ell}_{1,2}}$ (GeV)	M_2 (GeV)
h	902	35.8	1297	3555	1380	325	351	239
H	160	7.0	4802	-175	662	422	303	336

Light Higgs interpretation

Higgs rates in preferred regions

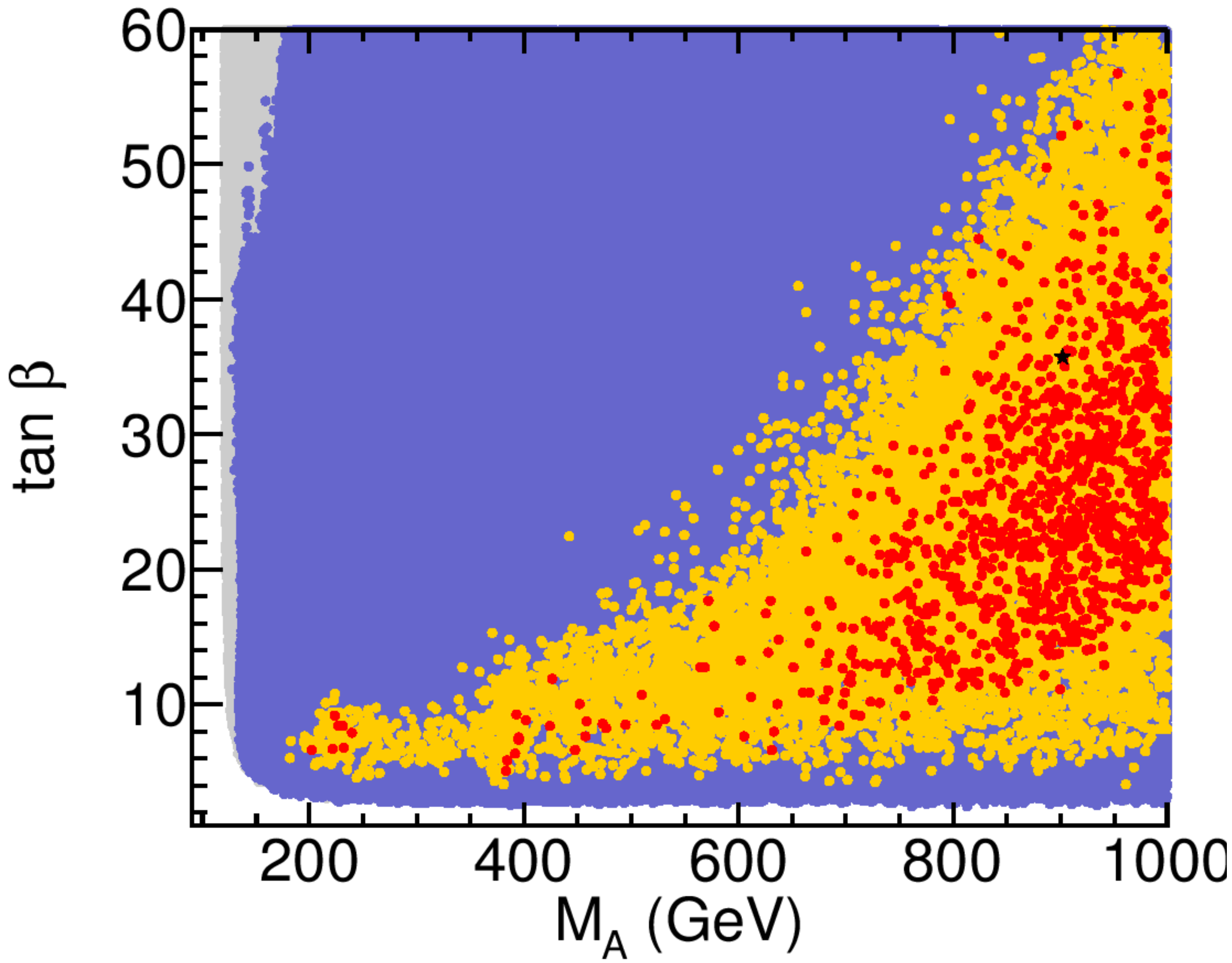
Preference for very SM Higgs-like signal rates: $R^h_{XX} = \frac{\sum_i [\sigma_i^{\rm LHC8} \times {\rm BR}(h \to XX)]_{\rm MSSM}}{\sum_i [\sigma_i^{\rm LHC8} \times {\rm BR}(h \to XX)]_{\rm SM}}$

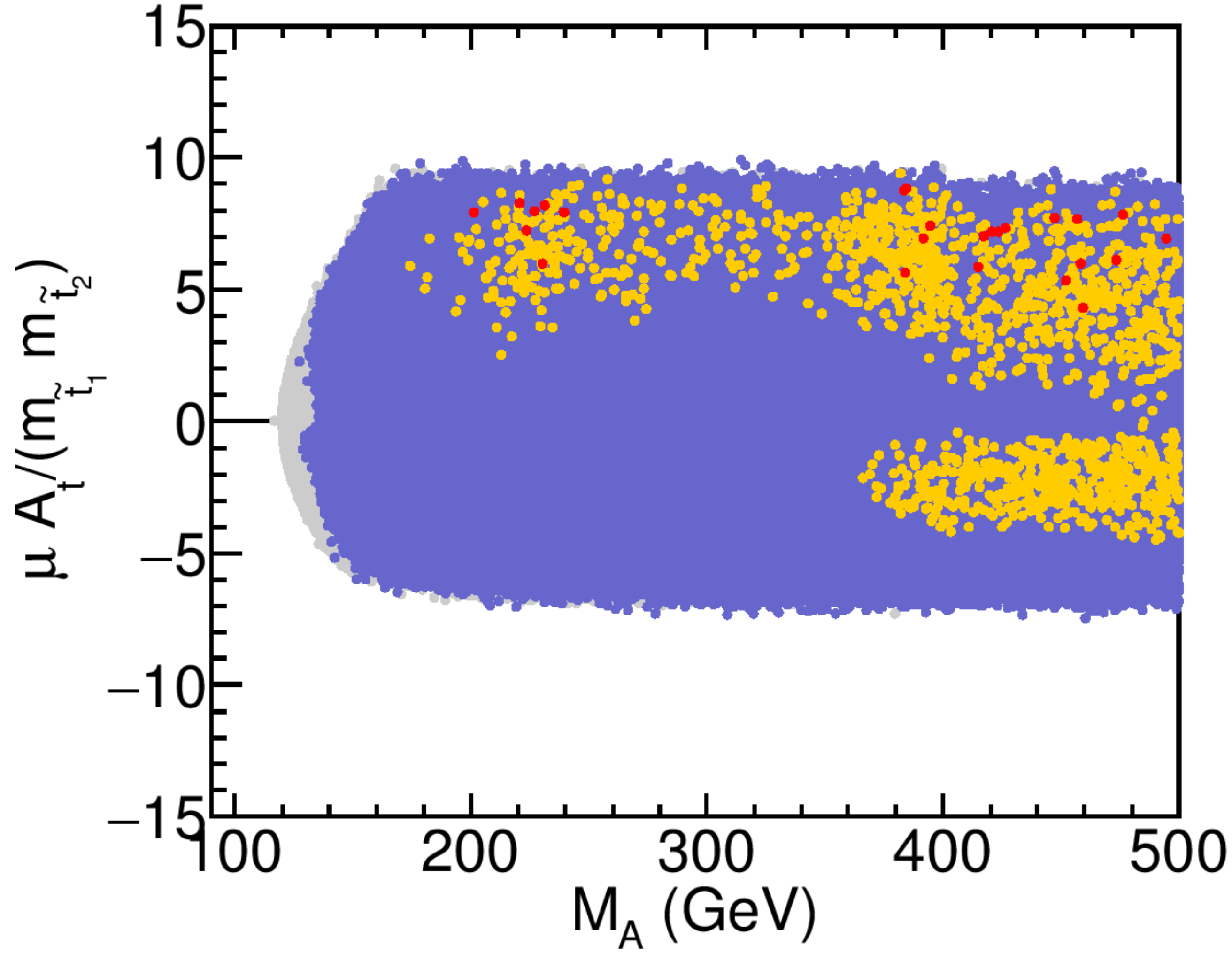
$$R^h_{VV} = 1.00^{+0.03}_{-0.12}, \quad R^h_{\gamma\gamma} = 1.12^{+0.10}_{-0.23}, \quad R^{Vh}_{bb} = 0.96^{+0.07}_{-0.01}, \quad R^h_{\tau\tau} = 0.83^{+0.22}_{-0.05}.$$



Small di-photon rate enhancement possible at small stau masses.

Preferred parameter regions



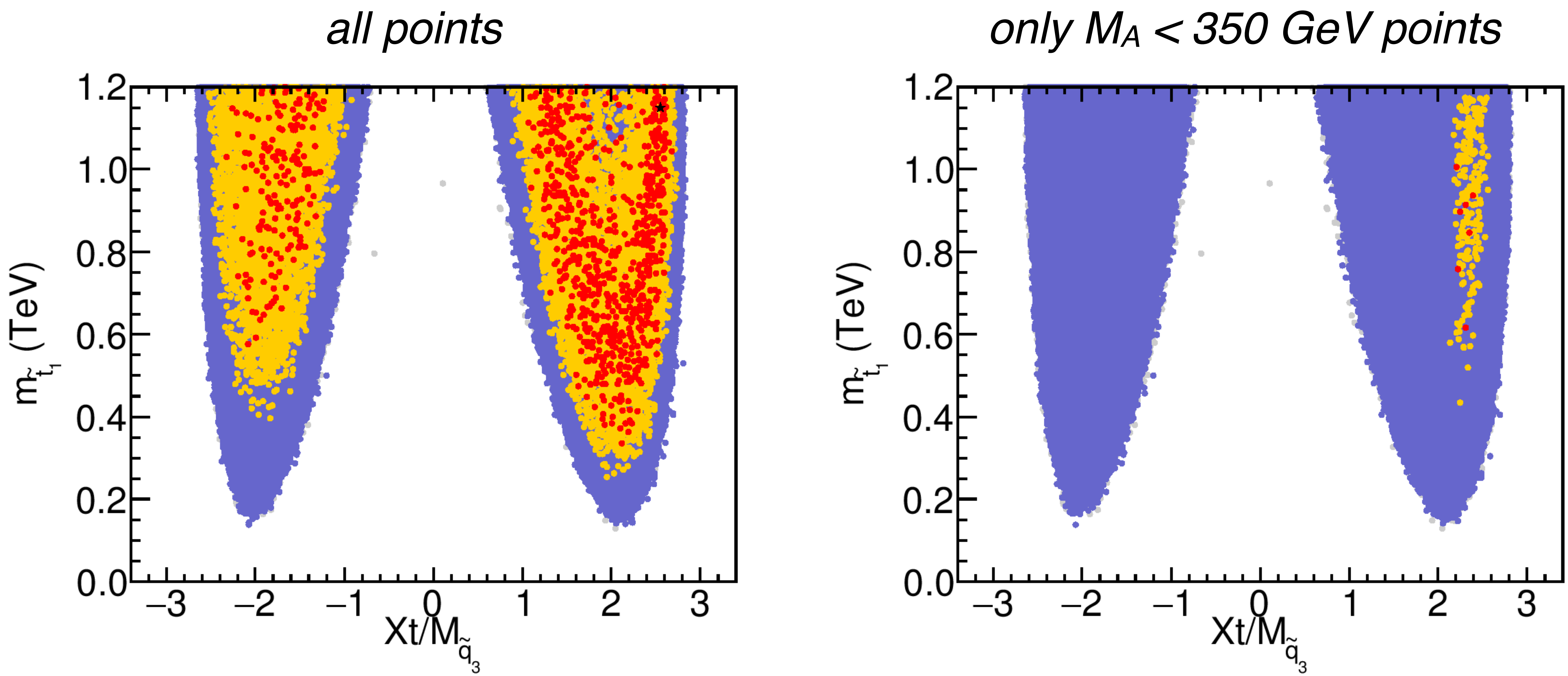


- Bulk of favored points have $M_A > 350$ GeV ⟶ decoupling limit
- Points survive down to $M_A \sim 200$ GeV ⟶ alignment w/o decoupling

Recall: $\tan\beta_{\mathrm{align}} \sim 1/\frac{\mu A_t}{M_S^2}\left(\frac{A_t^2}{6M_S^2} - 1\right)$

⟶ low M_A points are allowed for large, positive $\mu A_t/M_S^2$.

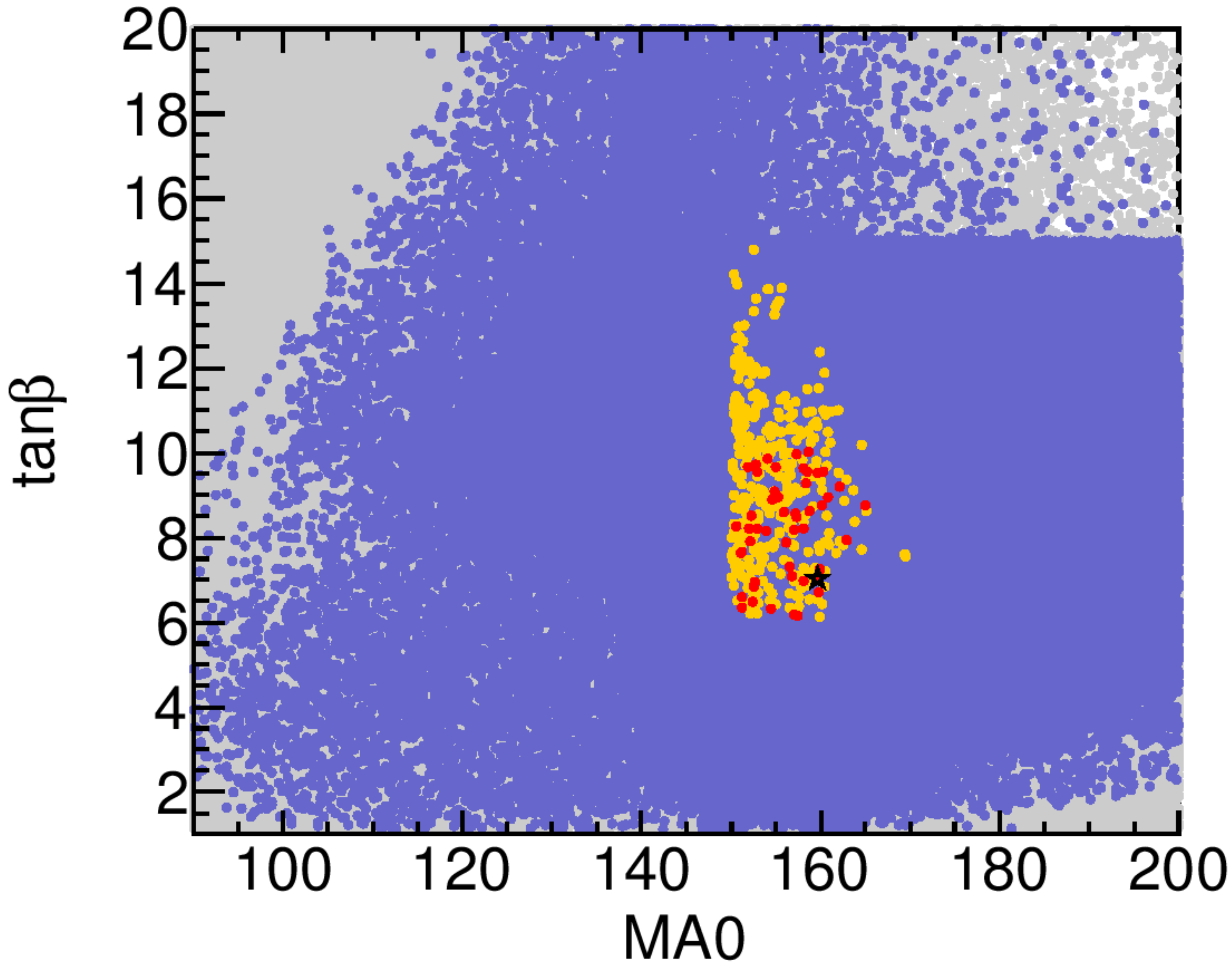
Implications for the stop sector



- Light stops down to ~ 300 GeV possible at large stop mixing,
- Alignment region prefers positive X_t branch ($\mu > 0, A_t > 0$) (negative μ disfavored by $b \to s\gamma$ and $(g-2)_\mu$).

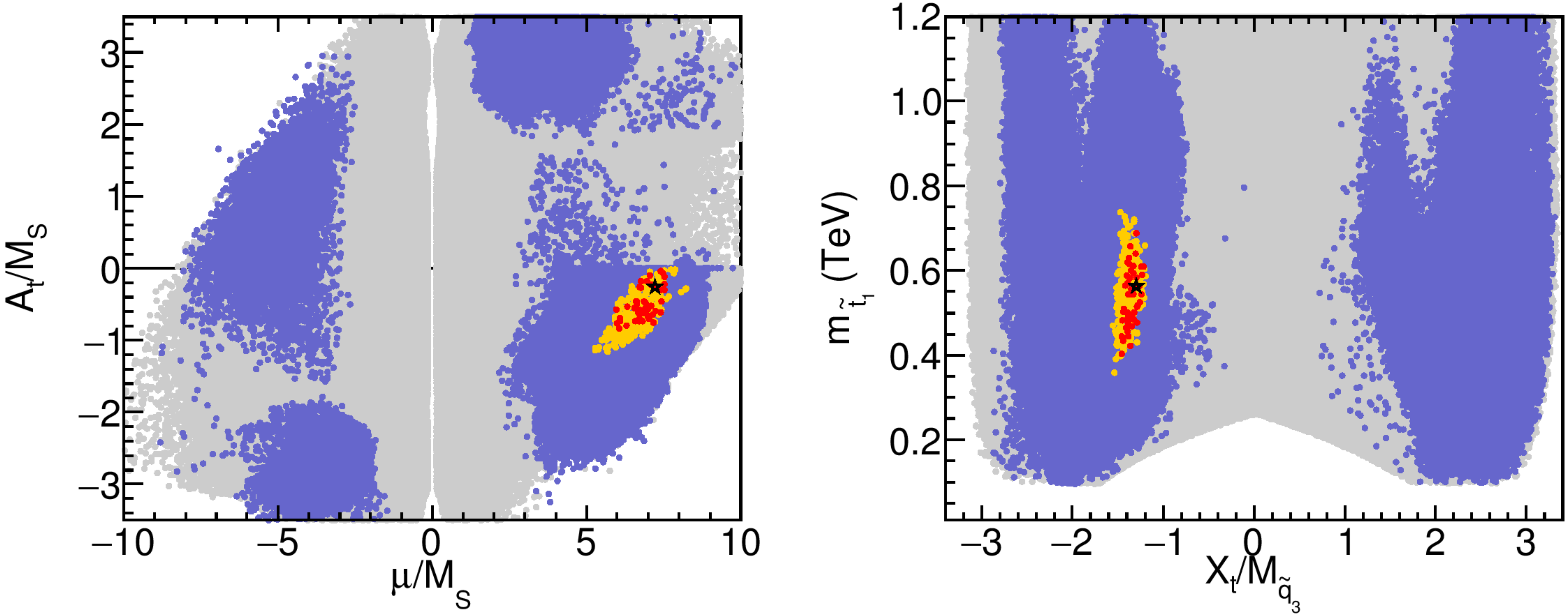
Heavy Higgs interpretation

Favored parameter region



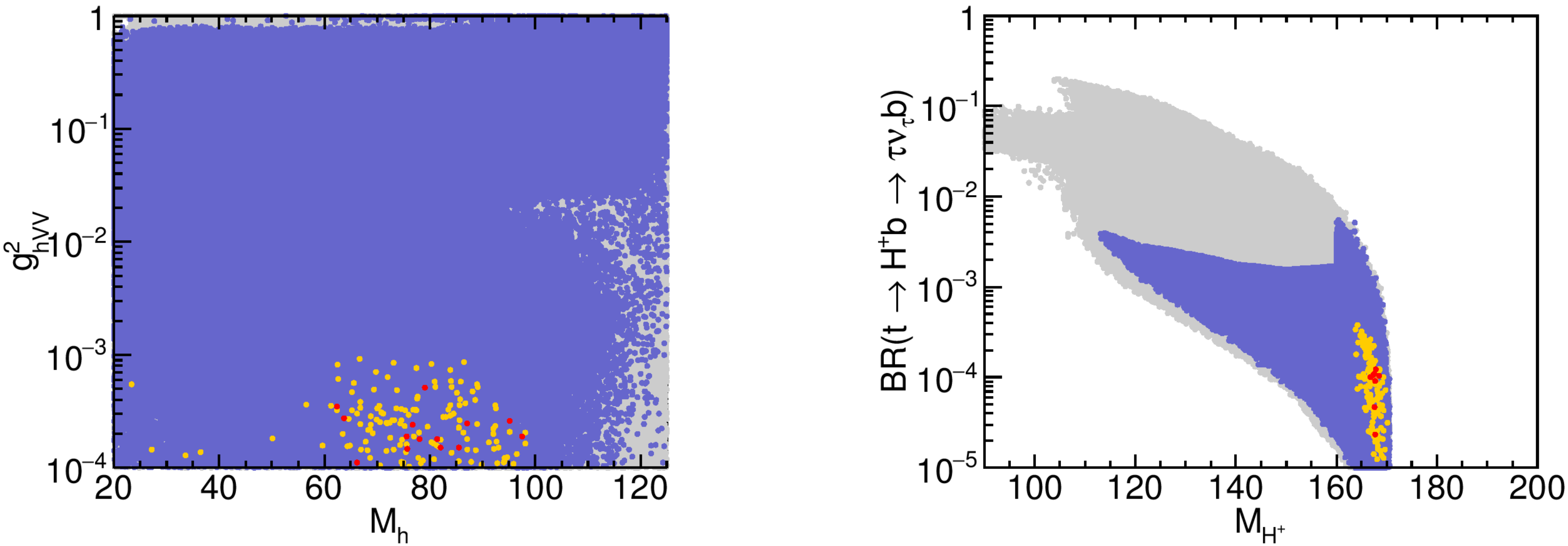
- Allowed parameter region is very limited,
- below $M_A \sim 150$ GeV, the process $A \to \tau\tau$ contaminates the observed Higgs signal, leading to a *too high* signal rate.

Favored parameter region



- Prefers negative X_t and (too?) large positive $\mu > 5\ M_S$,
- Light Stop masses ~ (350 - 750) GeV preferred.

Where are the other Higgs states?



- Light Higgs *h* with mass ~(60 - 100) GeV has extremely reduced couplings to vector bosons $\longrightarrow$ *beyond LEP reach*!
- Charged Higgs *H+* lies at kinematic threshold (or above) of the top decay $t \to H^+ b$. $H^+ \to \tau^+\nu_\tau$ decay rate suppressed by competing decay $H^+ \to hW^+$.

How light can the light stop be?

S. Liebler, S. Profumo, TS ‘15 (1512.09172)

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Motivation:

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Electroweak Baryogenesis:

Need *very light stop* for a strongly-enough first-order phase transition
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Perturbative calculations

(finite temperature effective potential)

$$m_{\tilde{t}_1} \lesssim (110 - 120)\ \mathrm{GeV}$$

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Two complementary paths to obtain light stop mass limits from LHC:

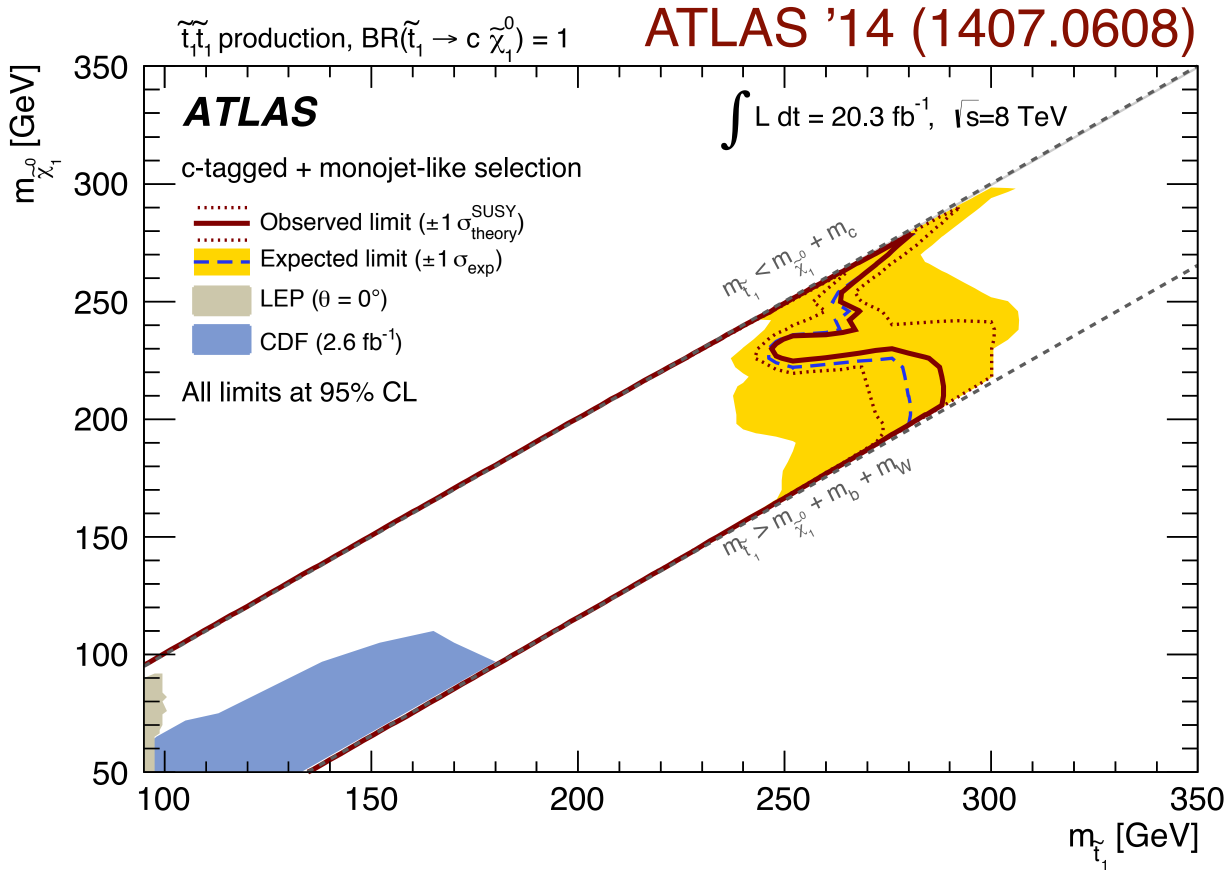
Direct LHC searches

Indirect Constraints from Higgs data

Status of direct LHC constraints

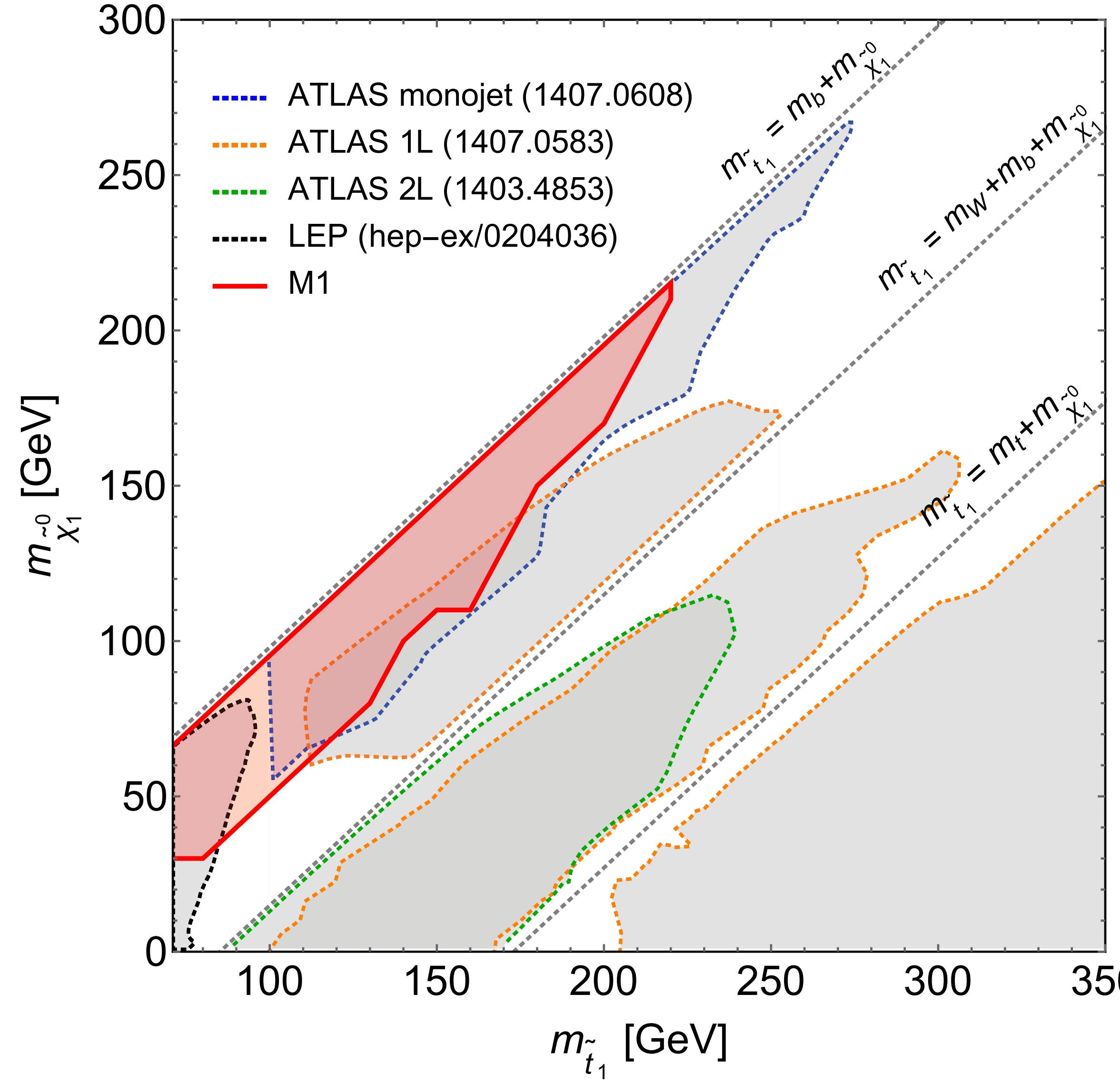
Two-body stop decay, $\tilde{t}_1 \to c\tilde{\chi}_1^0$

ATLAS '14 (1407.0608)



Four body stop decay

Ferretti, Franceschini, Petersson, Torre '15 (1502.01721)



Direct LHC limits are strongly dependent on assumed decay-mode(s) and mass spectrum.

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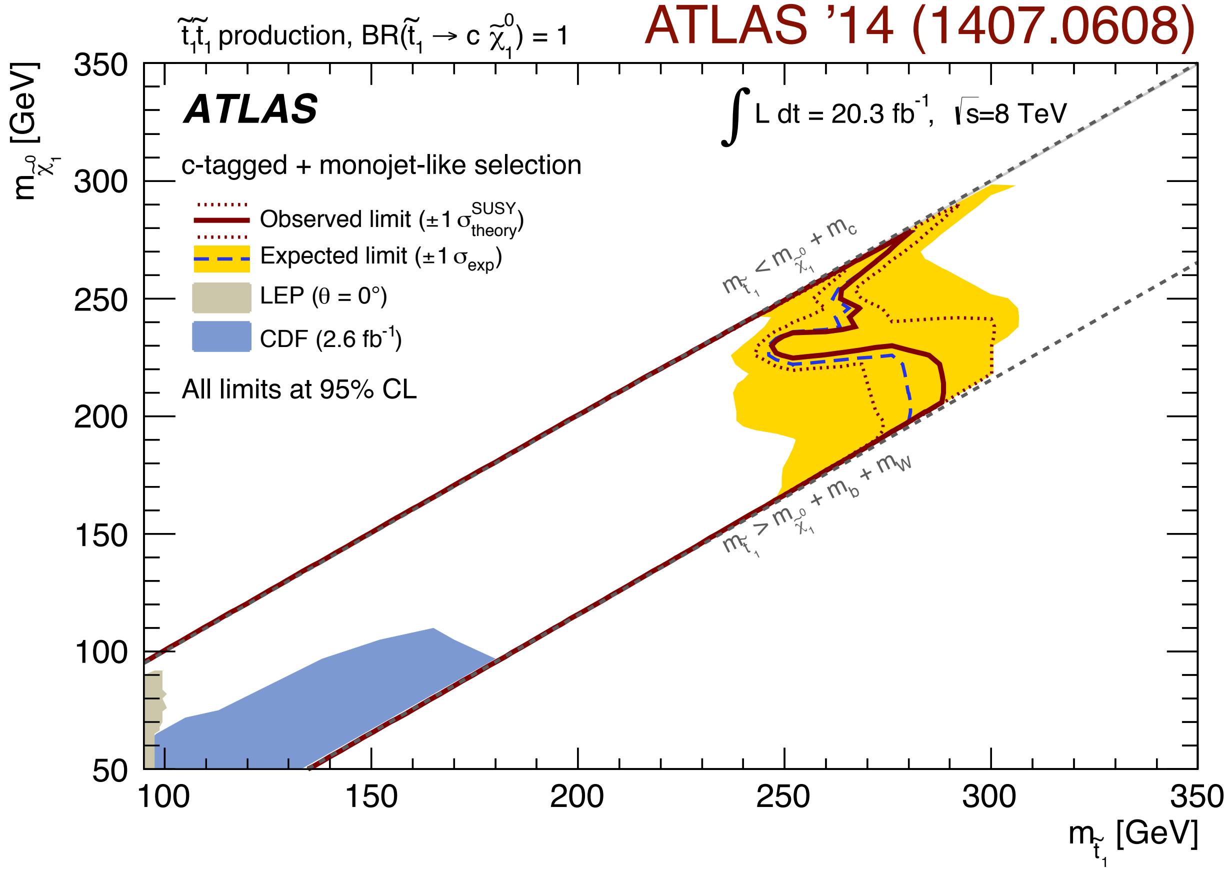

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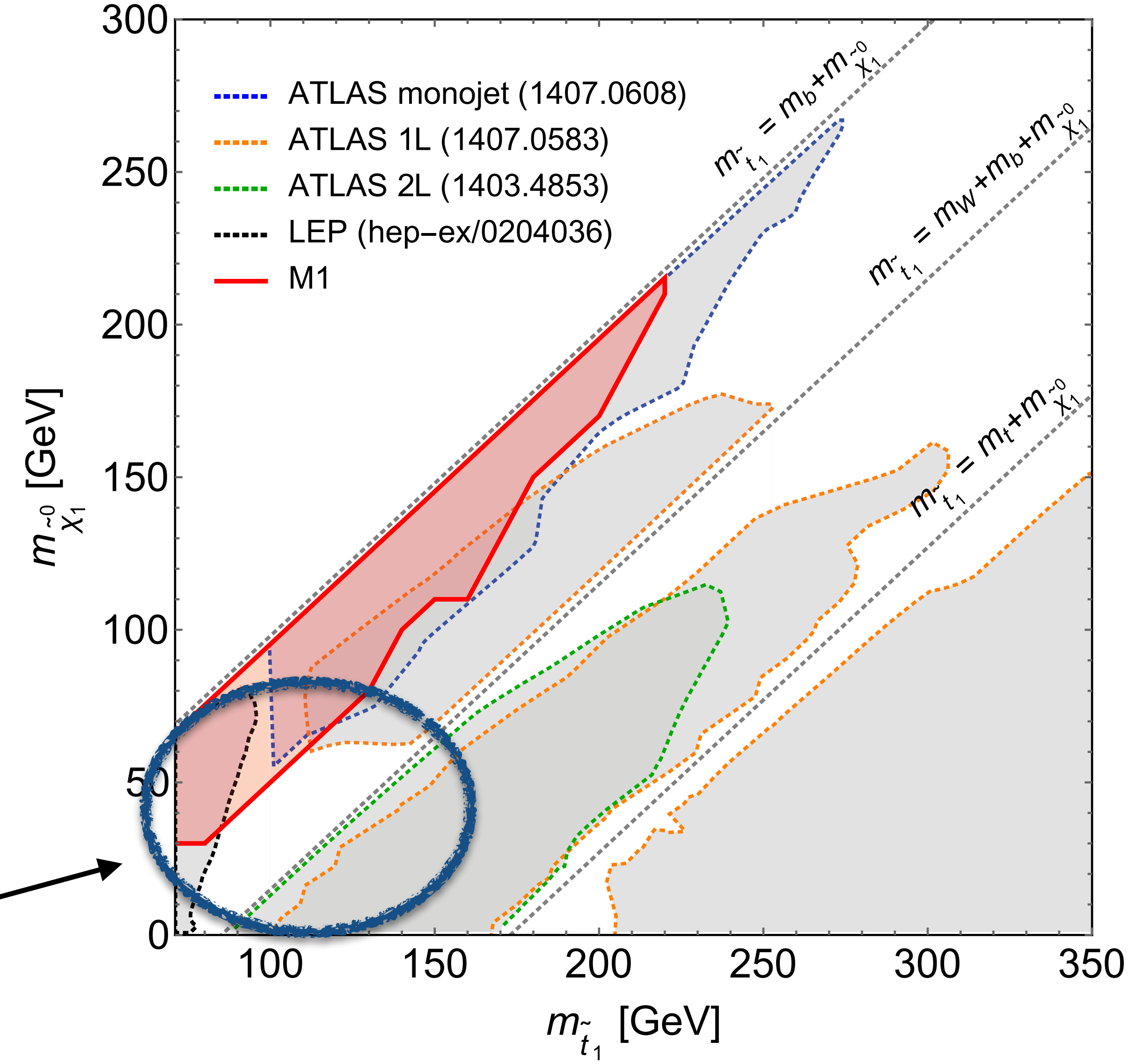


Room for a light stop?

Direct LHC limits are strongly dependent on assumed decay-mode(s) and mass spectrum.

A very light stop in the MSSM?

Need large radiative corrections to light Higgs mass:

$$(\Delta m_h^2)_{1L}^{(t,\tilde{t})} \approx \frac{3m_t^4}{2\pi^2 v^2}\left(\log\left(\frac{M_S^2}{m_t^2}\right) + \frac{X_t^2}{M_S^2} - \frac{X_t^4}{12 M_S^4}\right)$$

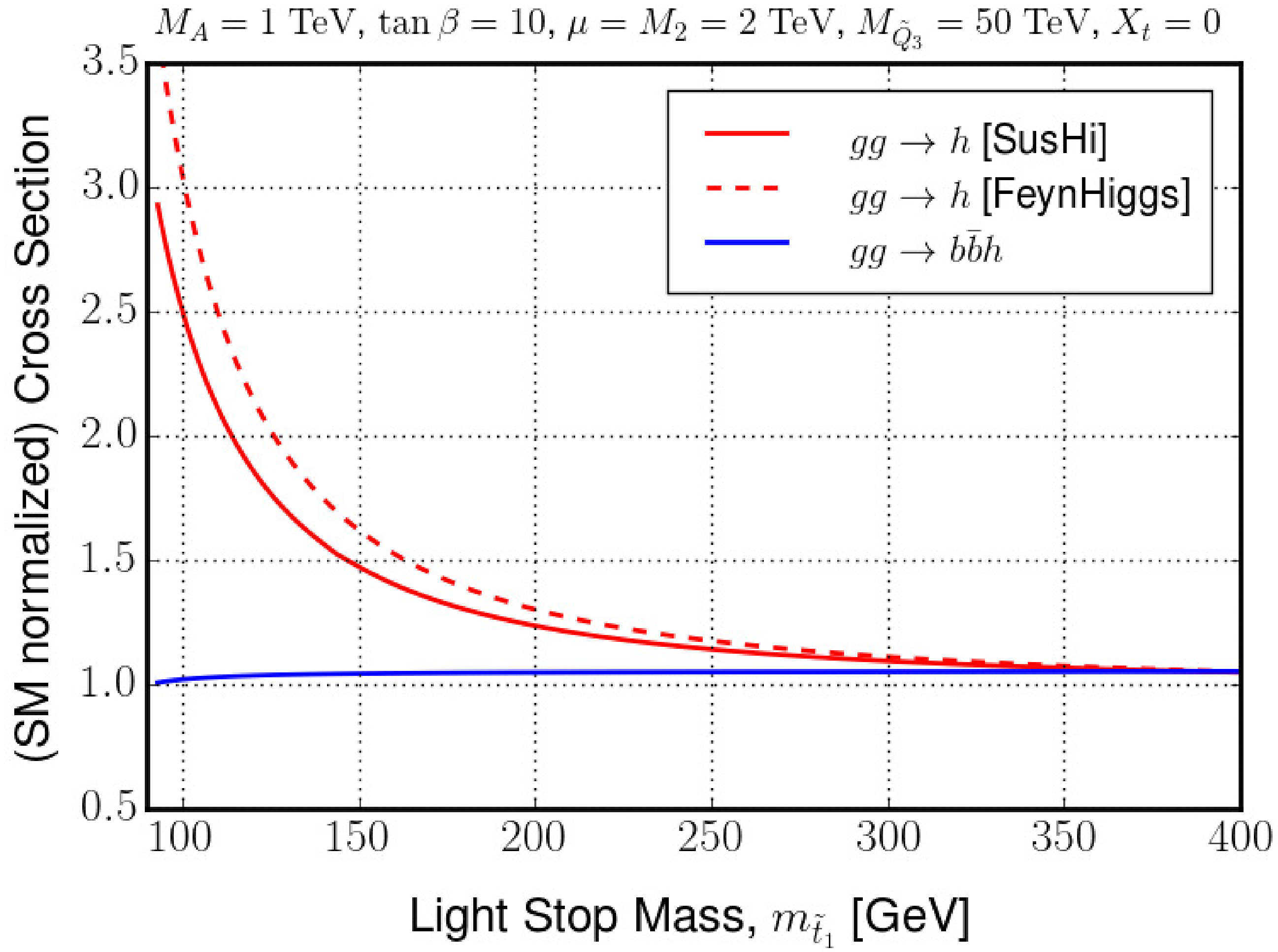
with $M_S = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}} \approx \sqrt{M_{\tilde{U}_3} M_{\tilde{Q}_3}}$.

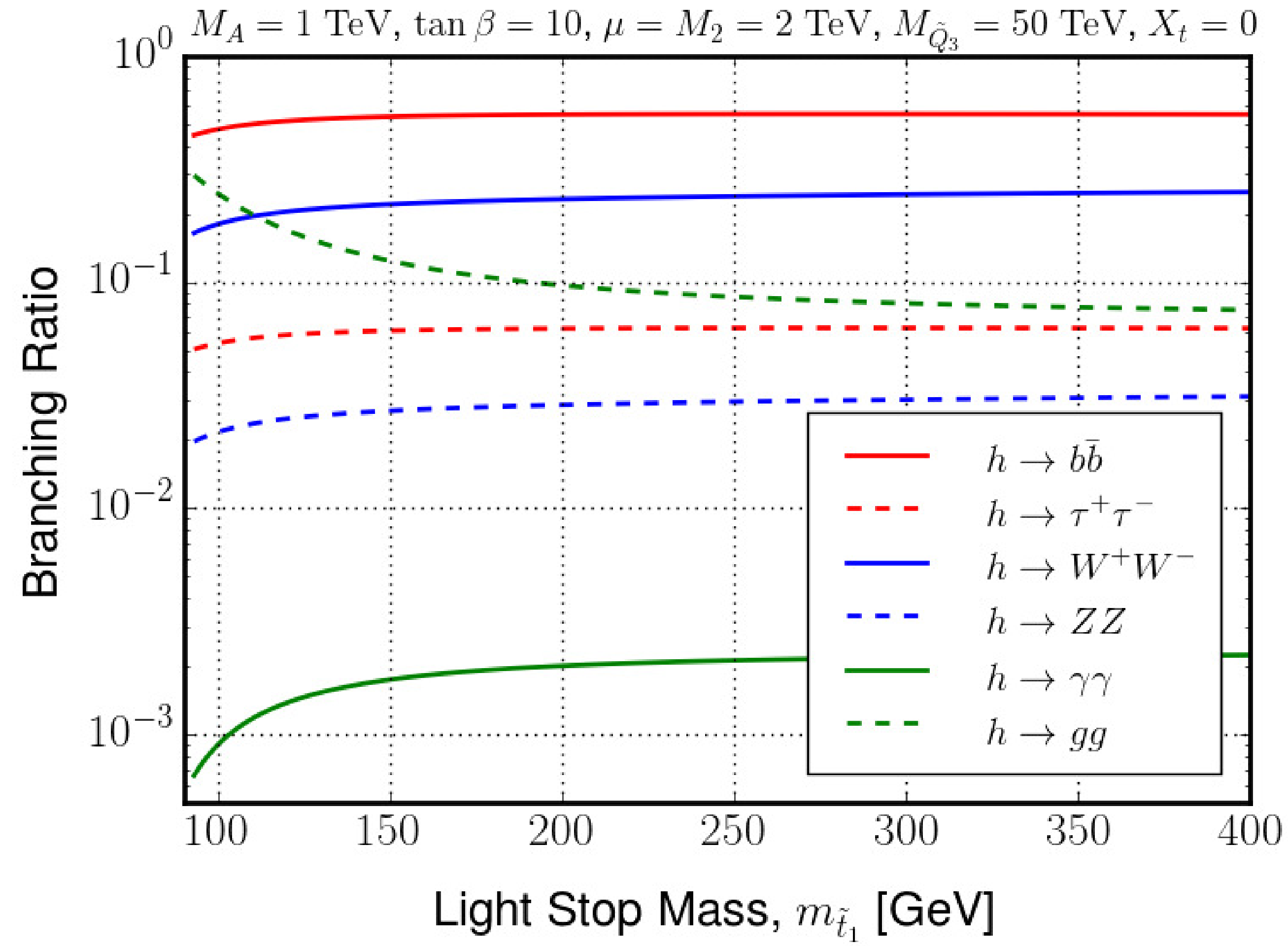
For a light stop mass below the top mass, we need

⟶ Large stop mass splitting, $M_{\tilde{U}_3} \ll M_{\tilde{Q}_3}$,

⟶ Small stop mixing, $X_t / M_{\tilde{Q}_3} \approx 0$.

Light stop influence on Higgs rates





The light stop (with $X_t \sim 0$)

- strongly enhances the Higgs gluon fusion cross section,
- enhances $\Gamma(h \to gg)$ and reduces $\Gamma(h \to \gamma\gamma)$.

Strategy

Higgs signal rate measurements $\longrightarrow$ indirect lower stop mass limits

Tune the heavy SUSY scale $M_{\tilde{Q}_3}$ to obtain correct Higgs mass.

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Consider several scenarios:

1. Decoupling Limit + light stop
2. Decoupling Limit + light stop + light stau
3. Decoupling Limit + light stop + light chargino
4. Non-Decoupling Effects + light stop + light stau

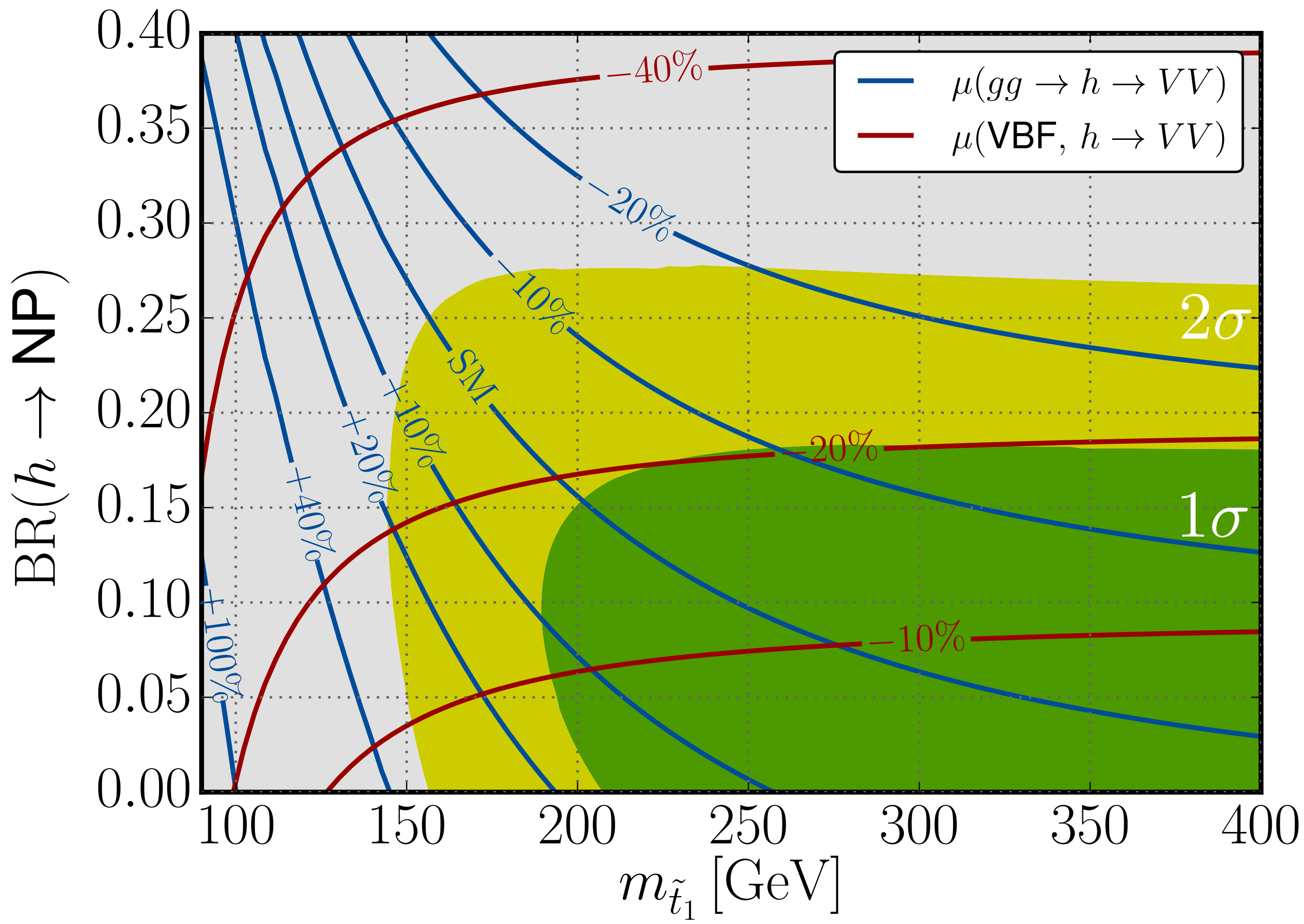
In scenarios 1 - 3 we allow for a generic "Higgs to new physics (NP)" decay, $\mathrm{BR}(h \to \mathrm{NP})$.

(E.g. $\mathrm{BR}(h \to \tilde{\chi}_1^0 \tilde{\chi}_1^0)$ or something *beyond* the MSSM)

Current best limit on invisible Higgs decay: $\mathrm{BR}(h \to \mathrm{inv}) \leq 28\%$

ATLAS '15 (1508.07869)

1) Decoupling + light stop



- $\mathrm{BR}(h \to \mathrm{NP})$ partially compensates $\sigma(gg \to h)$ enhancement,
- Splitting between signal rates of $gg \to h$ and VBF/Vh channels remains, in disagreement with Higgs measurements.

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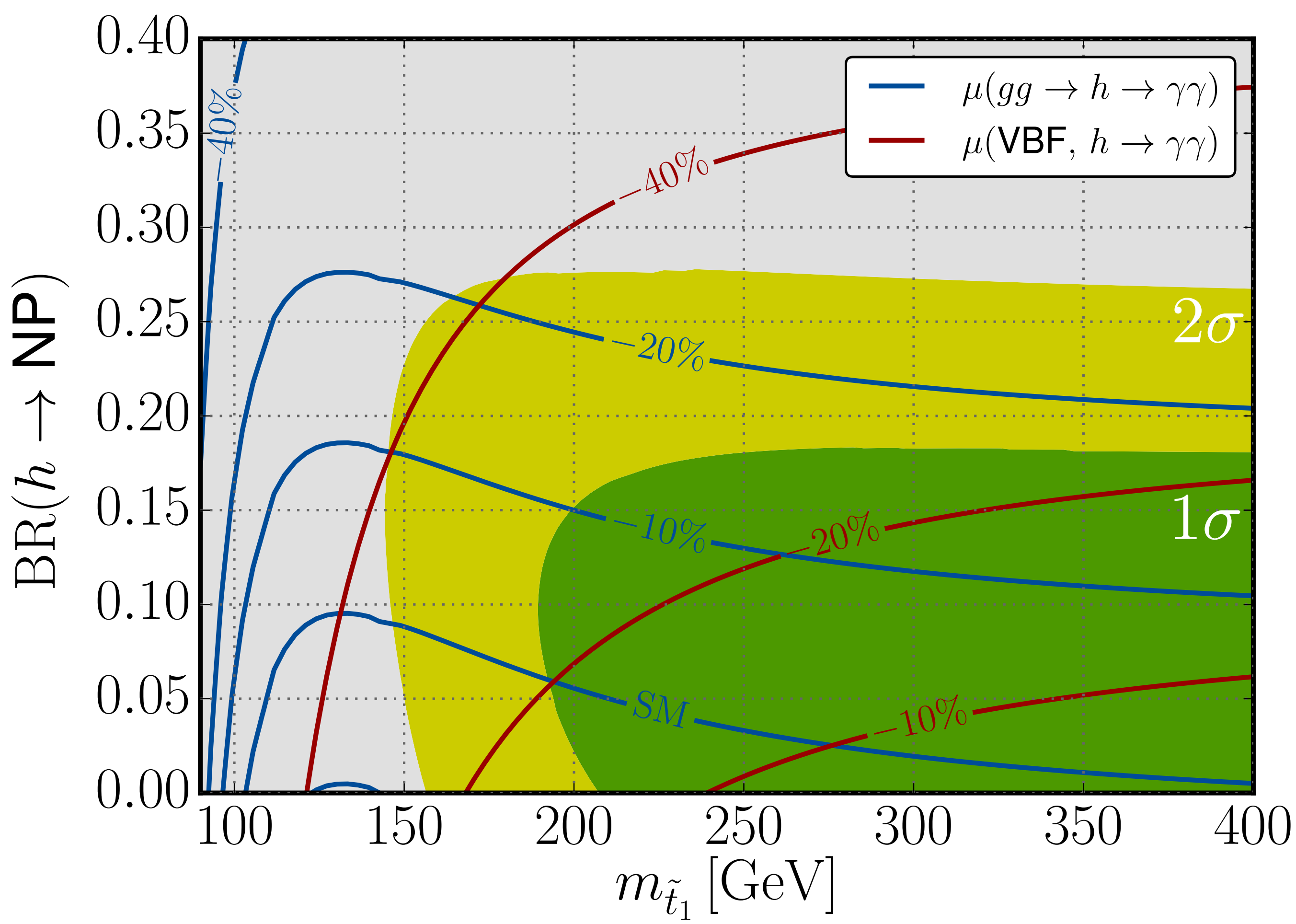

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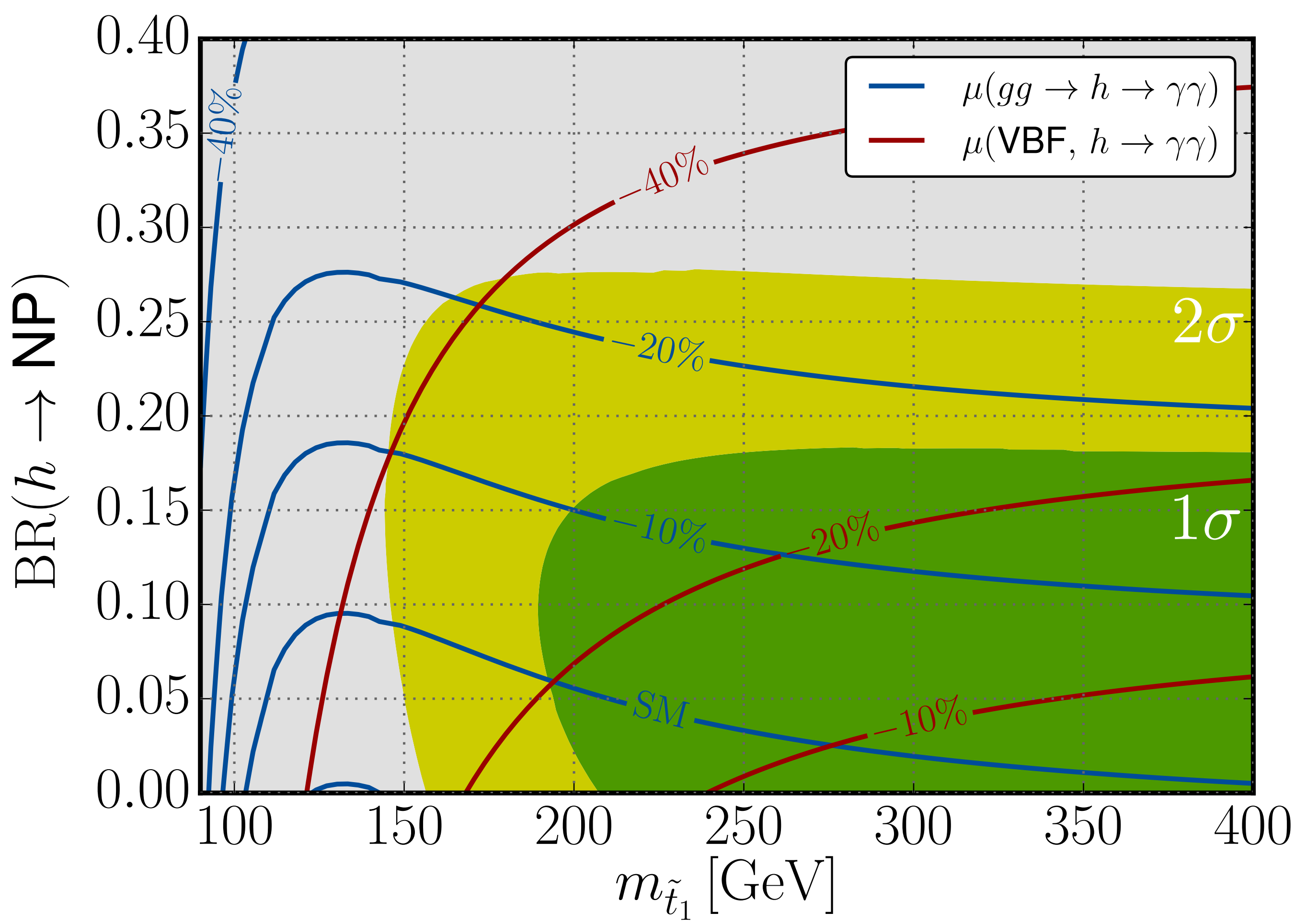

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$\longrightarrow$ $m_{\tilde{t}_R} \geq 144$ GeV (at 95% C.L.)

2) Decoupling + light stop + light stau

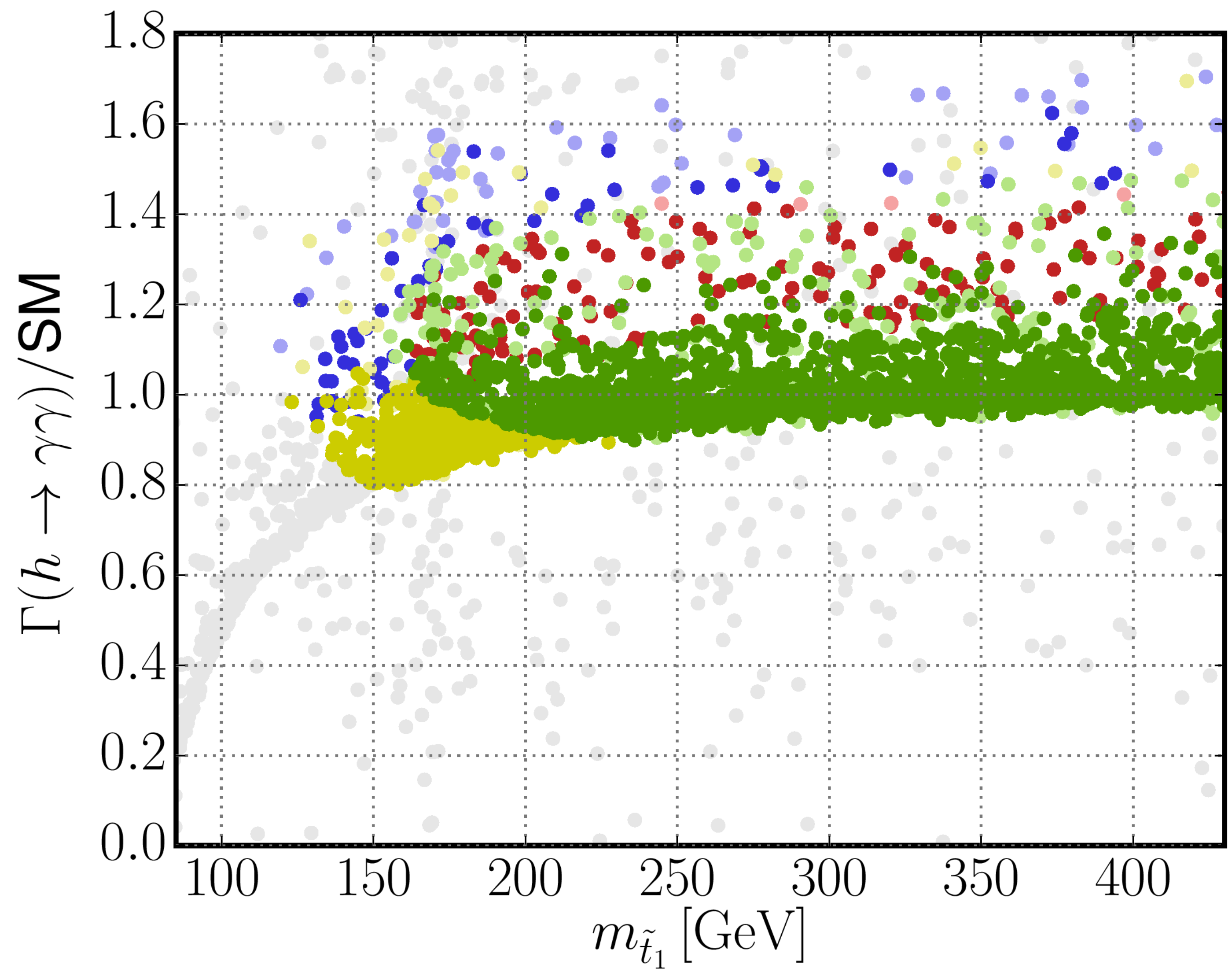
Large positive contributions to $\Gamma(h \to \gamma\gamma)$ at small stau masses and large $\mu \tan\beta$.

Vacuum metastability constraints relevant at large $\mu \tan\beta$. Here, use an approximate formula.

Hisano, Sugiyama '11 (1011.0260)

LEP stau mass limit:

$$m_{\tilde{\tau}_1} \gtrsim 90 \text{ GeV}$$



68% C.L.
95% C.L. fulfill metastability requirement

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$$\longrightarrow m_{\tilde{t}_R} \gtrsim 123 \text{ GeV (at 95\% C.L.)}$$

+ *faint colors violate LEP stau mass limit*

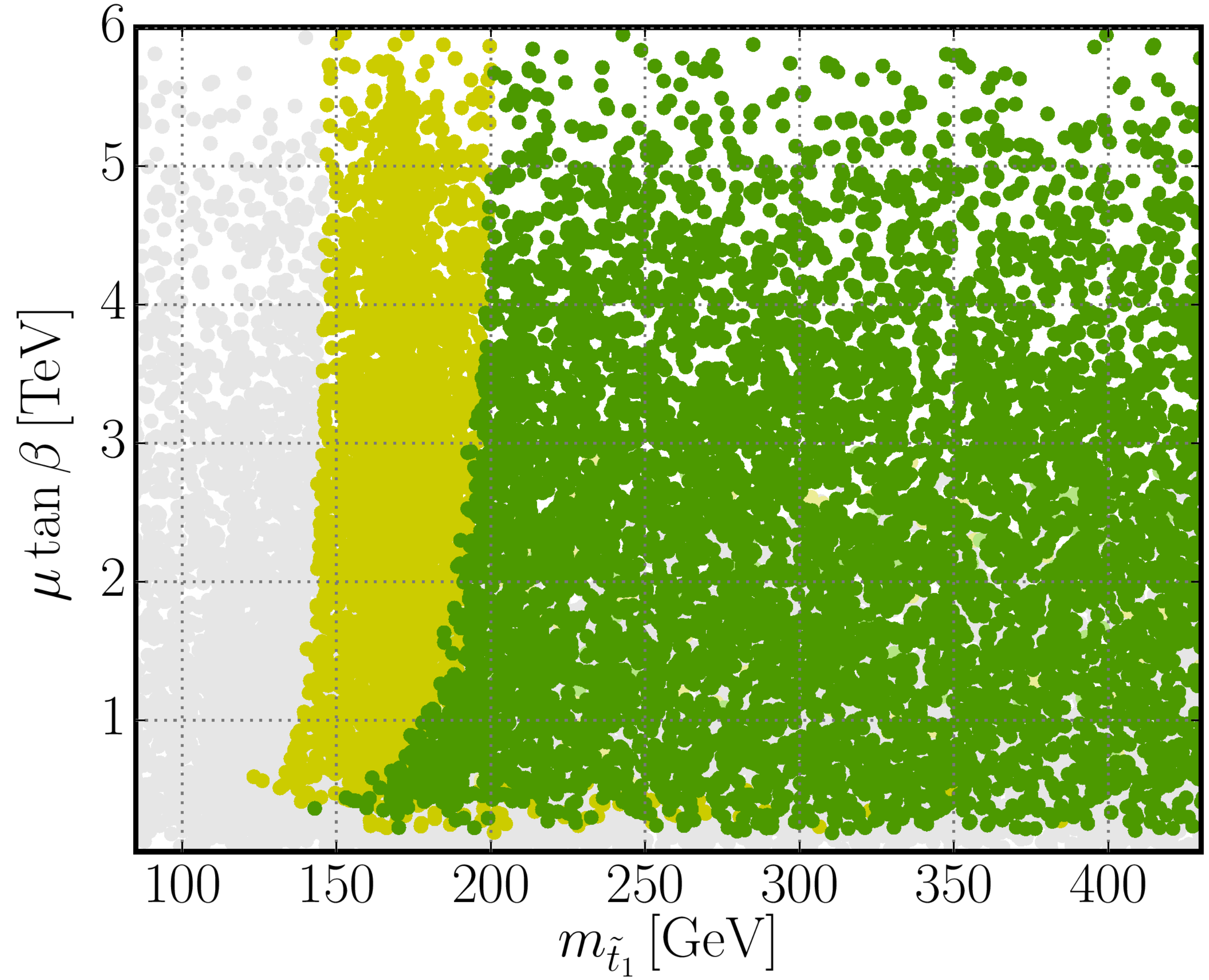
3) Decoupling + light stop + light chargino

Large positive contributions to $\Gamma(h \to \gamma\gamma)$ at small chargino mass and large wino-Higgsino mixing.

$\longrightarrow$ maximal at low $\tan\beta$ and assume $\mu = M_2$.

LEP chargino mass limit:

$$m_{\tilde{\chi}_1^\pm} \geq 103.5 \text{ GeV}$$



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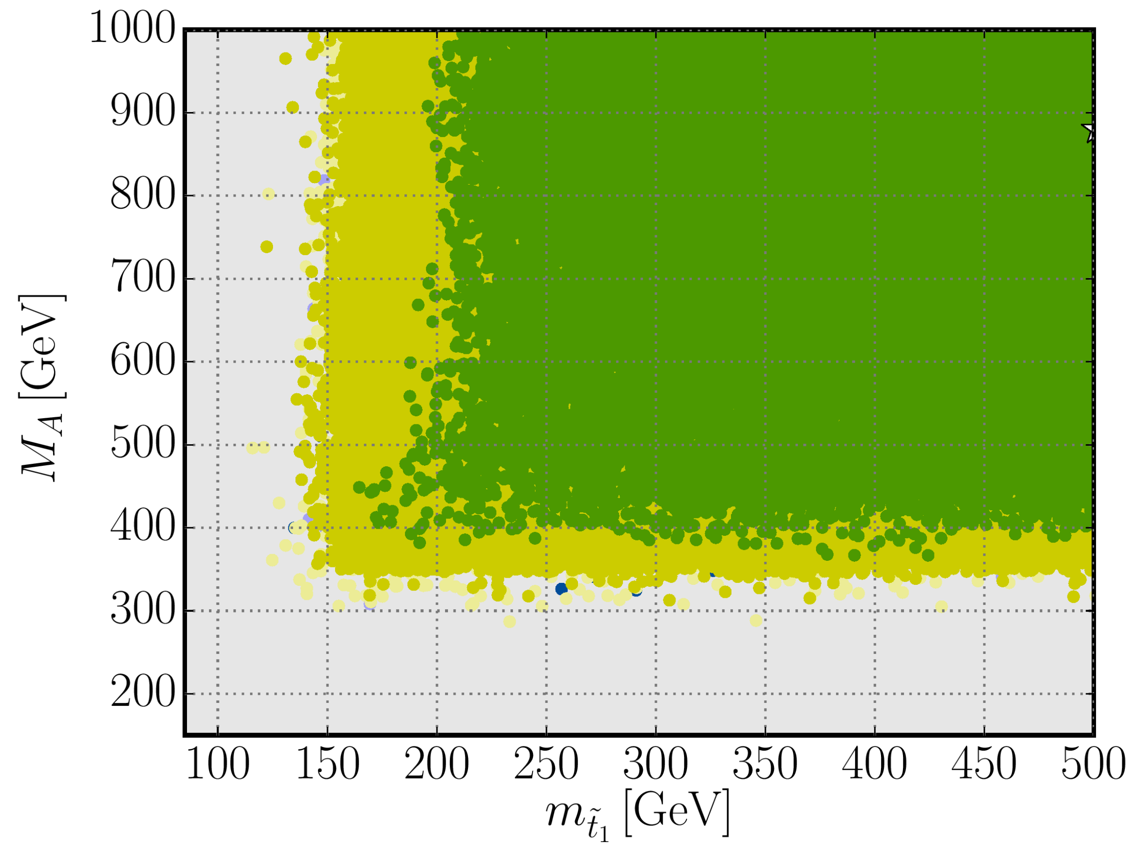
Instead of $\mathrm{BR}(h \to \mathrm{NP})$, let an enhancement of relatively poorly measured channels, $h \to bb, \tau\tau$, suppress the well measured decay rates and thus compensate the $\sigma(gg \to H)$ enhancement.



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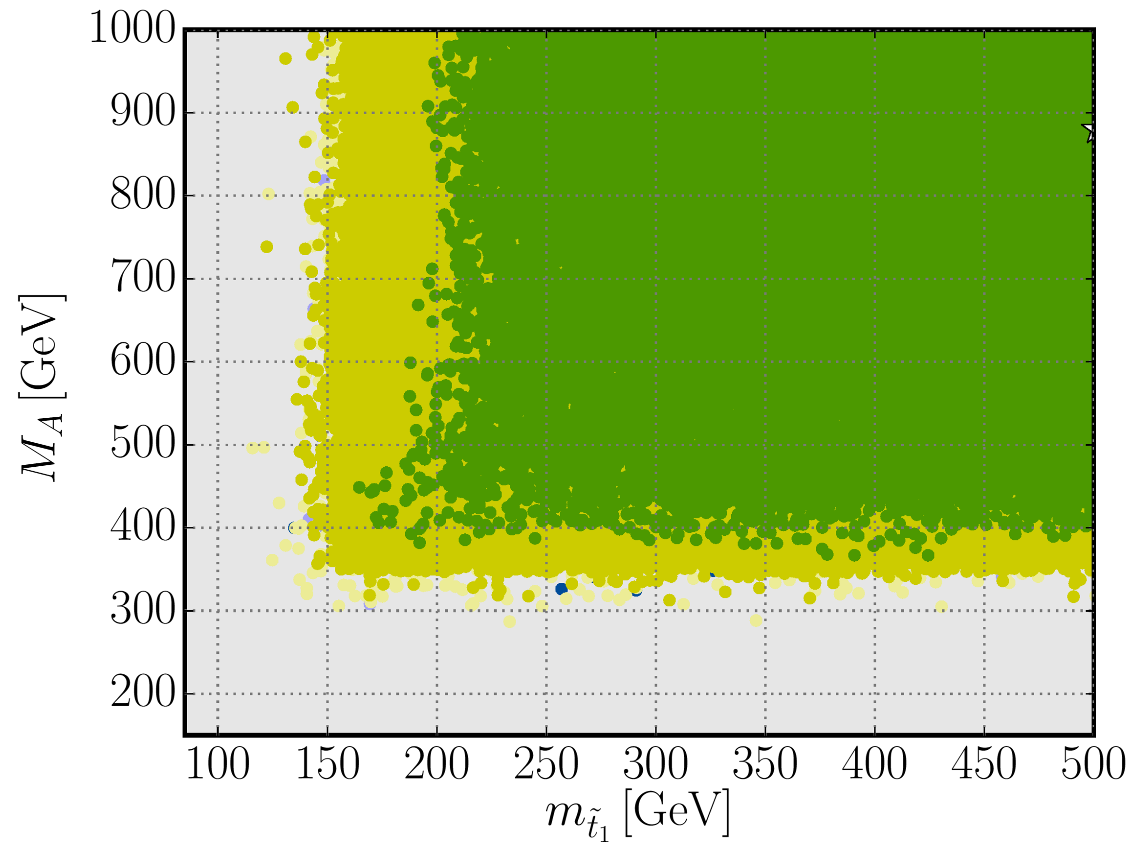
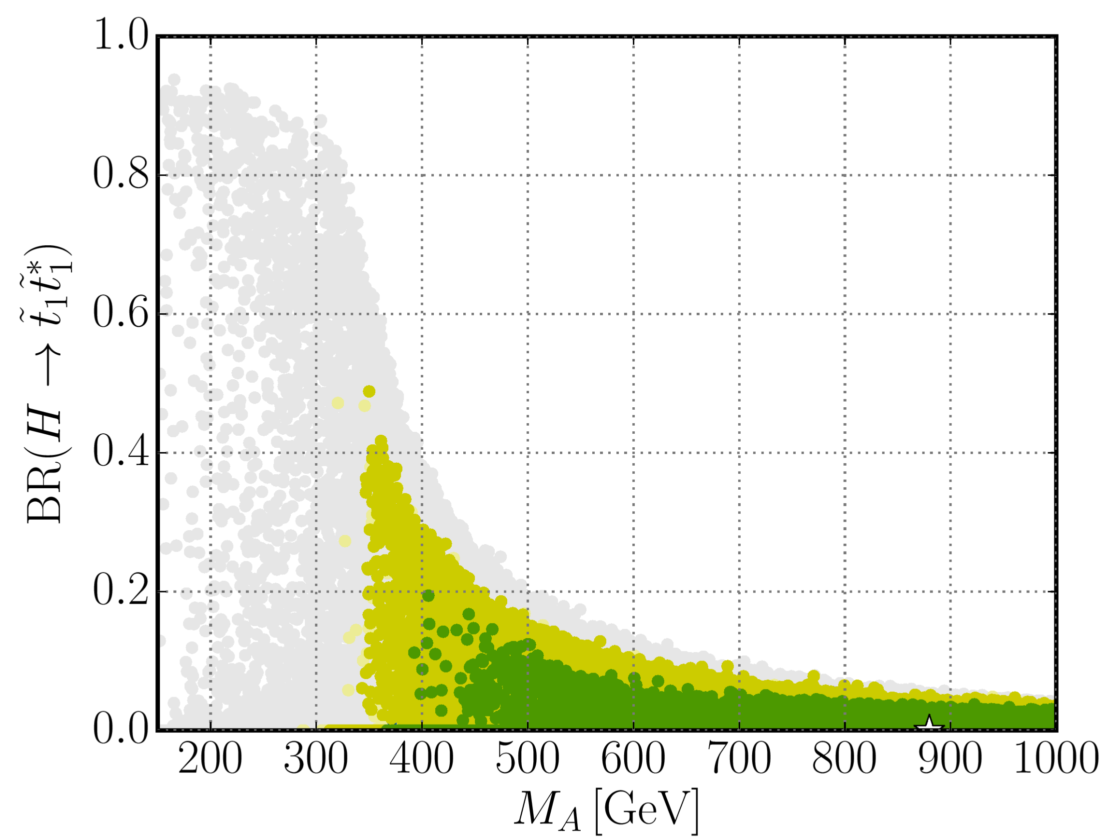
Interesting new LHC signature:

$$pp \to H \to \tilde{t}_1 \tilde{t}_1^*$$





Summary & Conclusions

HiggsBounds and HiggsSignals are convenient and accurate tools to confront Higgs sector predictions with Higgs data from the LHC.

http://higgsbounds.hepforge.org

All three possible MSSM interpretations of the Higgs boson,

- light Higgs in the decoupling limit,
- light Higgs in the "alignment without decoupling" limit,
- heavy Higgs at 125 GeV,

provide a very good fit to Higgs data + low energy observables!

A light stop with $m_{\tilde{t}_1} \gtrsim 120\ \mathrm{GeV}$ is allowed by Higgs data in a split-stop-mass scenario with additional light charged states (staus or charginos).

$\longrightarrow$ leaves a (small) window for successful electroweak baryogenesis.

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Thanks for your attention!

Backup Slides

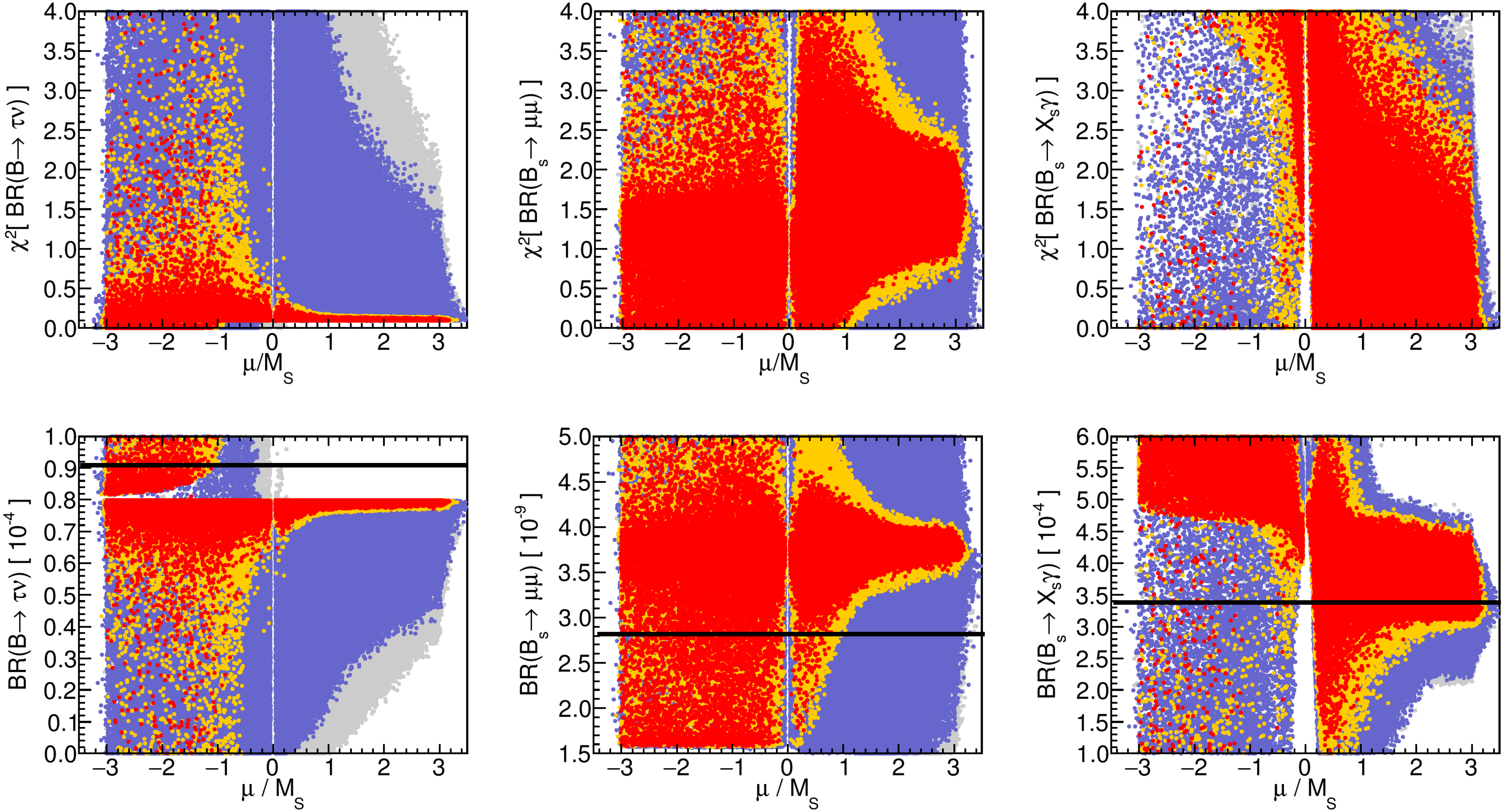
Scan ranges

	Light Higgs case		Heavy Higgs case	
Parameter	Minimum	Maximum	Minimum	Maximum
M_A [GeV]	90	1000	90	200
$\tan\beta$	1	60	1	20
$M_{\tilde{q}_3}$ [GeV]	200	5000	200	1500
$M_{\tilde{\ell}_3}$ [GeV]	200	1000	200	1000
$M_{\tilde{\ell}_{1,2}}$ [GeV]	200	1000	200	1000
μ [GeV]	$-3\,M_{\tilde{q}_3}$	$3\,M_{\tilde{q}_3}$	200	5000
A_f [GeV]	$-3\,M_{\tilde{q}_3}$	$3\,M_{\tilde{q}_3}$	$-3\,M_{\tilde{q}_3}$	$3\,M_{\tilde{q}_3}$
M_2 [GeV]	200	500	200	500

Low energy observables

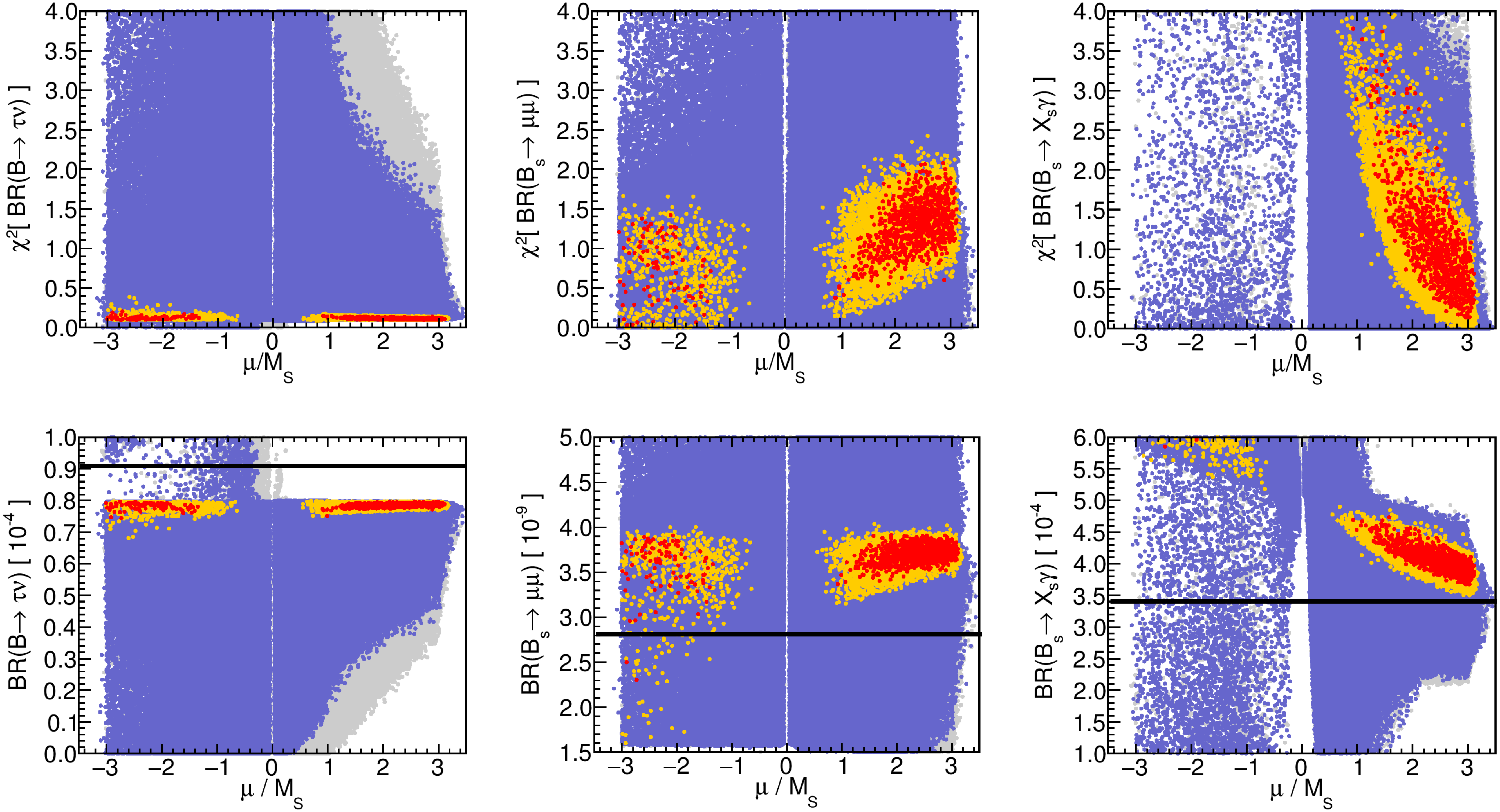
Observable	Experimental value	SM value	MSSM uncertainty
$\mathrm{BR}(B \to X_s\gamma)$	$(3.43 \pm 0.21 \pm 0.07) \times 10^{-4}$	$(3.09 \pm 0.22) \times 10^{-4}$	$\pm\, 0.15 \times 10^{-4}$
$\mathrm{BR}(B_s \to \mu^+\mu^-)$	$(2.8 \pm 0.7) \times 10^{-9}$	$(3.90 \pm 0.2) \times 10^{-9}$	–
$\mathrm{BR}(B^+ \to \tau^+\nu_\tau)$	$(9.1 \pm 1.9 \pm 1.1) \times 10^{-5}$	$(8.01 \pm 0.7) \times 10^{-5}$	–
δa_μ	$(30.2 \pm 9.0) \times 10^{-10}$	–	–
M_W	(80.385 ± 0.015) GeV	(80.358 ± 0.007) GeV	$\pm\, 0.003$ GeV

μ dependence of flavor observables



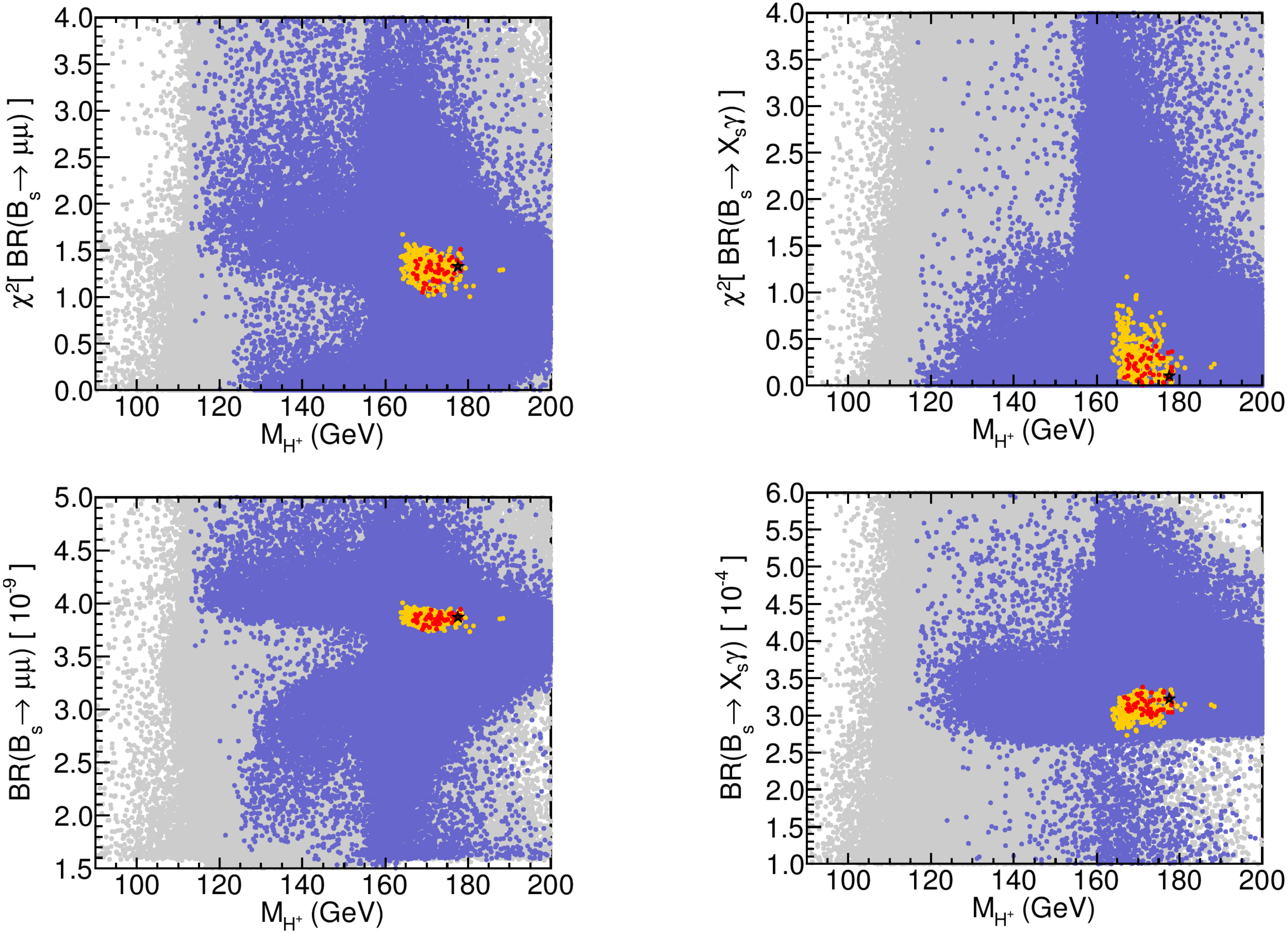
all points, color coding shows preferred points before LEOs are included

μ dependence of flavor observables



low M_A points, color coding shows preferred points before LEOs are included

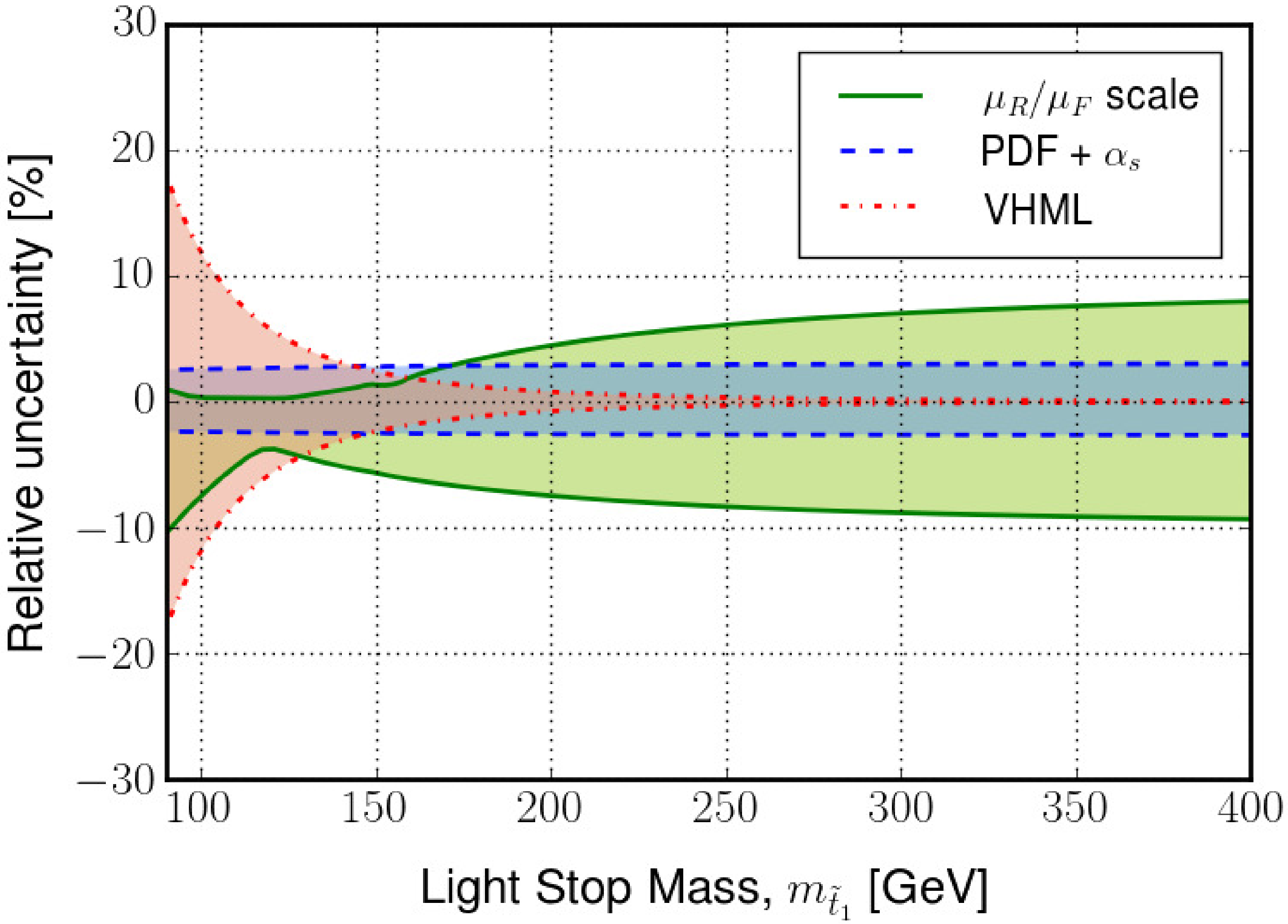
Heavy Higgs case: Flavor observables



Theoretical uncertainties of $\sigma(gg \to h)$

2-loop and approximate 3-loop stop contributions are based on "vanishing Higgs mass limit" (VHML) assumption, $4m_{\tilde{t}_1}^2/m_h^2 \gg 1$.

Estimate uncertainty by multiplying these amplitude contributions by a test factor $t = \mathcal{A}_{\tilde{t}_1}^{\mathrm{LO}}/\mathcal{A}_{\tilde{t}_1}^{\mathrm{LO,VHML}}$.



VHML uncertainty as function of stop mass properly incorporated in HiggsSignals.