Indirect effects of the triplet extension of the MSSM

Based on
J. de Blas, A. Delgado, BO and M. Quiros, JHEP 1401, 177 (2014) [arXiv:1311.3654 [hep-ph]].

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Introduction

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- MSSM requires heavy third generation squarks and large stop mixing

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$$m_h^2 = m_Z^2 \cos^2 2\beta \left(1 - \frac{3}{8\pi^2}\frac{m_t^2}{v^2} t\right) + \frac{3}{4\pi^2}\frac{m_t^4}{v^2}\left[\frac{1}{2}X_t + t + \frac{1}{16\pi^2}\left(\frac{3}{2}\frac{m_t^2}{v^2} - 32\pi\alpha_3\right)\left(X_t t + t^2\right)\right]$$

$$X_t = \frac{2\widetilde{A}_t^2}{m_Q^2}\left(1 - \frac{\widetilde{A}_t^2}{12 m_Q^2}\right) \qquad t = \log\left(\frac{m_Q^2}{m_t^2}\right) \qquad \widetilde{A}_t = A_t - \frac{\mu}{\tan\beta}$$

- Introduces little hierarchy problem

Introduction

Raise the mass of the Higgs boson in another method

- Give up on minimalism in favor of naturalness (i.e. add extra particles which couple to the Higgs)
- Tree level contributions to the quartic coupling raise Higgs mass
- What happens to Electroweak observables?
- What happens to Higgs observables?
- Other non-standard MSSM phenomenology?

The Model

Give up on minimalism in favor of naturalness

- Introduce $SU(2)_L$ triplet chiral superfield with $Y = 0$
  - Two charged states, one neutral
  - Scalar and fermionic components
- $\Sigma = \begin{pmatrix} \xi^0/\sqrt{2} & -\xi_2^+ \\ \xi_1^- & -\xi^0/\sqrt{2} \end{pmatrix}$

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- $W_{Higgs-\Sigma} = \mu H_1 \cdot H_2 + \lambda H_1 \cdot \Sigma H_2 + \frac{1}{2}\mu_\Sigma \mathrm{tr}\Sigma^2$
- $\Delta V_{soft} = m_4^2 |\Sigma|^2 + \left(\frac{1}{2} B_\Sigma \mu_\Sigma \mathrm{tr}\Sigma^2 + A_\lambda \lambda H_1 \cdot \Sigma H_2 + \mathrm{h.c.}\right)$

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Contributions to the quartic coupling raise Higgs mass

- $m_{h,tree}^2 = m_Z^2 \cos^2 2\beta + \frac{\lambda^2}{2} v^2 \sin^2 2\beta$

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So what happens to Higgs observables?

Higgs Observables

- Adding an $SU(2)_L$ triplet chiral superfield to MSSM allows for heavy Higgs mass with small stop masses and mixings
- Tripletinos can alter the di-photon rate
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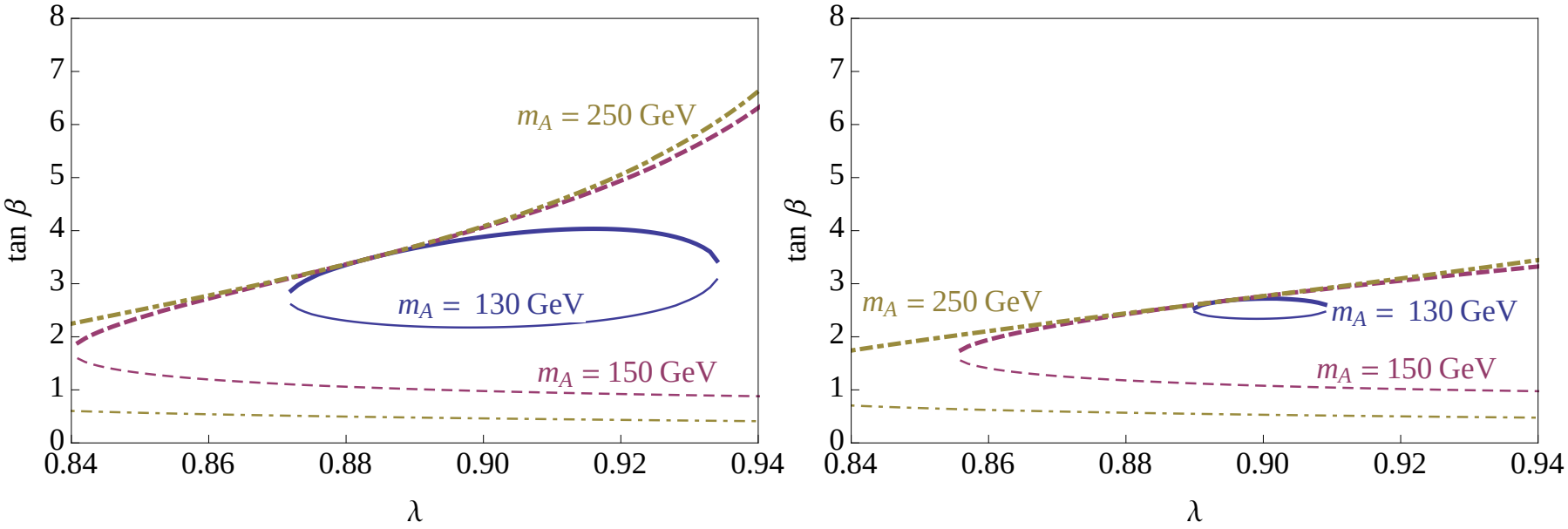
- Is there another way to distinguish the triplet model from the MSSM?
- Look for effects of the extra neutralino and chargino
- J. de Blas, A. Delgado, **BO**, and M. Quiros, JHEP **1401**, 177 (2014) [arXiv:1311.3654 [hep-ph]].

Small Mass Decoupling

$$m_h^2 = m_Z^2 \cos^2 2\beta + \frac{\lambda^2}{2} v^2 \sin^2 2\beta + \text{loop corrections}$$



Regions where the Higgs mass is 125.5 GeV when $\mu_\Sigma = 200$ GeV (left) and $\mu_\Sigma = 800$ GeV (right) for different values of m_A and $m_{U_3^c} = m_{Q_3} = 700$ GeV and $A_t = 0$.

Large μ_Σ decreases the region of small m_A yielding correct Higgs mass

Fermion Content

Extra chargino and neutralino are given by

$$\psi^0 = \begin{pmatrix} \widetilde{B} & \widetilde{W}^0 & \widetilde{H}_1^0 & \widetilde{H}_2^0 & \widetilde{\xi}^0 \end{pmatrix}, \; \psi^+ = \begin{pmatrix} \widetilde{W}^+ & \widetilde{H}_2^+ & \widetilde{\xi}_2^+ \end{pmatrix},$$

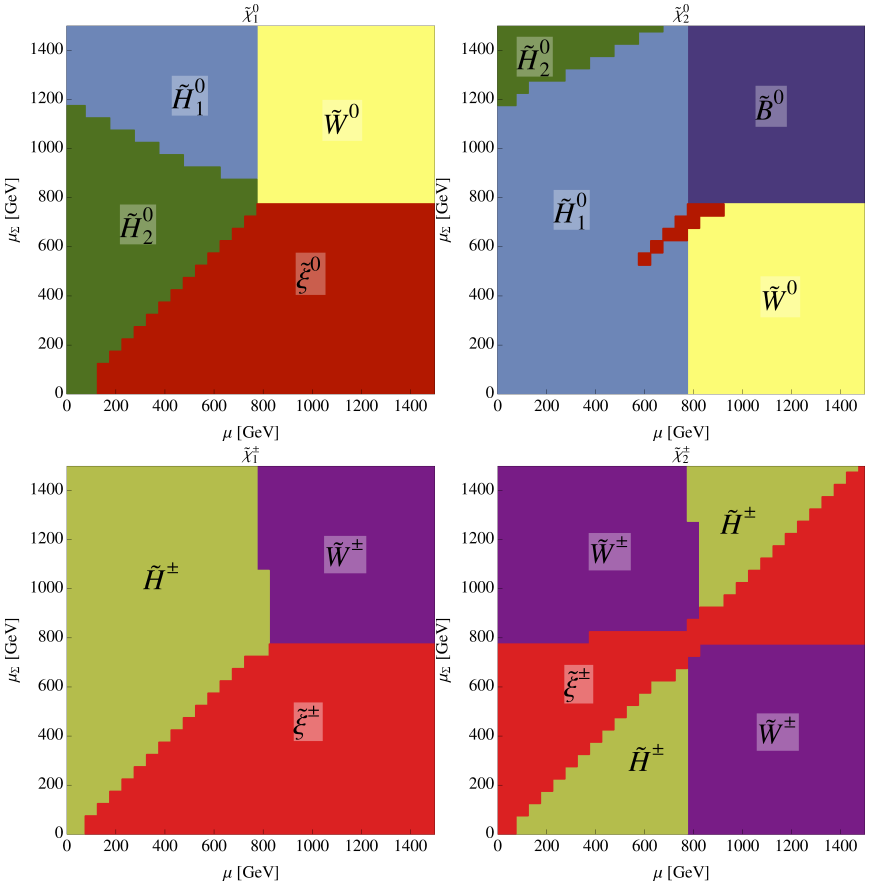
$$\psi^- = \begin{pmatrix} \widetilde{W}^- & \widetilde{H}_1^- & \widetilde{\xi}_1^- \end{pmatrix}$$

$$\mathcal{M}_{\widetilde{C}} = \begin{pmatrix} M_2 & gv\,\sin\beta & 0 \\ gv\cos\beta & \mu & -\lambda v\sin\beta \\ 0 & -\lambda v\cos\beta & -\mu_\Sigma \end{pmatrix},$$

$$\mathcal{M}_{\widetilde{N}} = \begin{pmatrix} M_1 & 0 & -\cos\beta s_W m_Z & \sin\beta s_W m_Z & 0 \\ 0 & M_2 & \cos\beta c_W m_Z & -\sin\beta c_W m_Z & 0 \\ -\cos\beta s_W m_Z & \cos\beta c_W m_Z & 0 & -\mu & \frac{\lambda}{\sqrt{2}} v\sin\beta \\ \sin\beta s_W m_Z & -\sin\beta c_W m_Z & -\mu & 0 & \frac{\lambda}{\sqrt{2}} v\cos\beta \\ 0 & 0 & \frac{\lambda}{\sqrt{2}} v\sin\beta & \frac{\lambda}{\sqrt{2}} v\cos\beta & \mu_\Sigma \end{pmatrix},$$

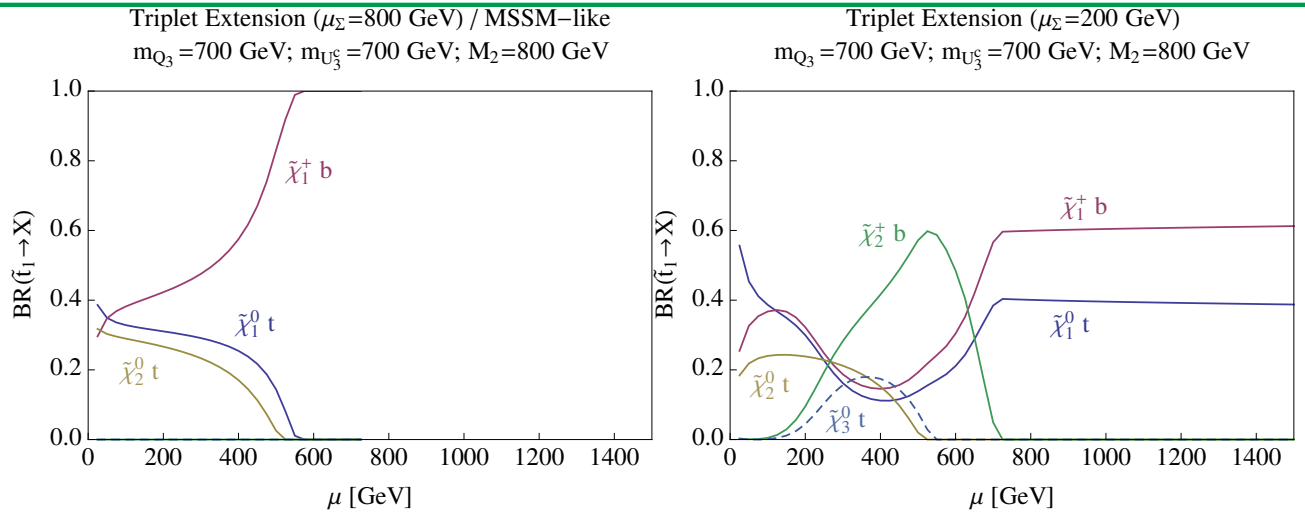
Fermion Content

- $\widetilde{\chi}_i^0 = \mathbf{N_{ij}} \widetilde{\psi}_\mathbf{j}^\mathbf{0}$
- $\widetilde{\chi}_i^\pm = \mathbf{C_{ij}} \widetilde{\psi}_\mathbf{j}^\pm$
- $M_1 = M_2 = 800$ GeV
- No stop-tripletino coupling
- Stop couples strongest to $\widetilde{H}_2$

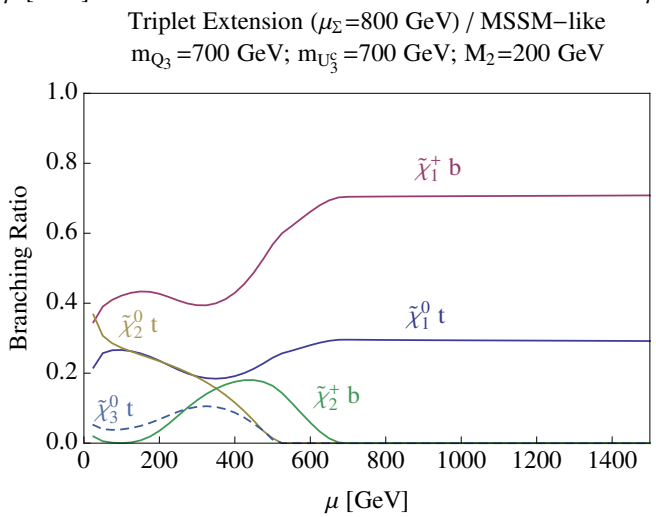


The interaction eigenstate which is the largest portion of $\widetilde{\chi}_1^0$ [lightest neutralino], $\widetilde{\chi}_2^0$ [next-to-lightest neutralino], $\widetilde{\chi}_1^\pm$ [lightest chargino], and $\widetilde{\chi}_2^\pm$ [next-to-lightest chargino].

Stop Branching Ratios

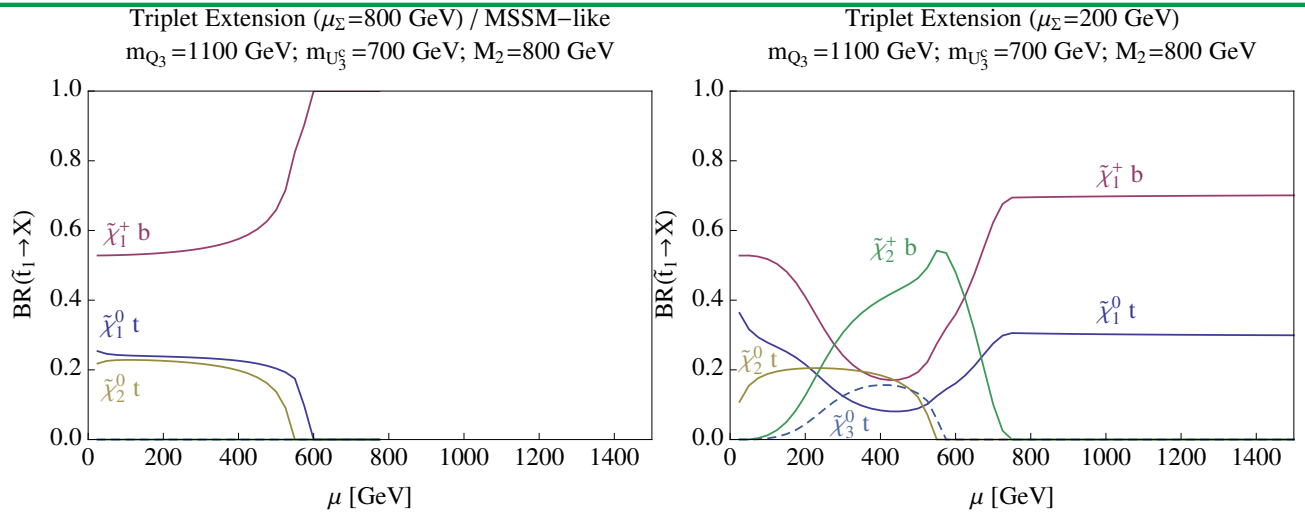


Equal mass

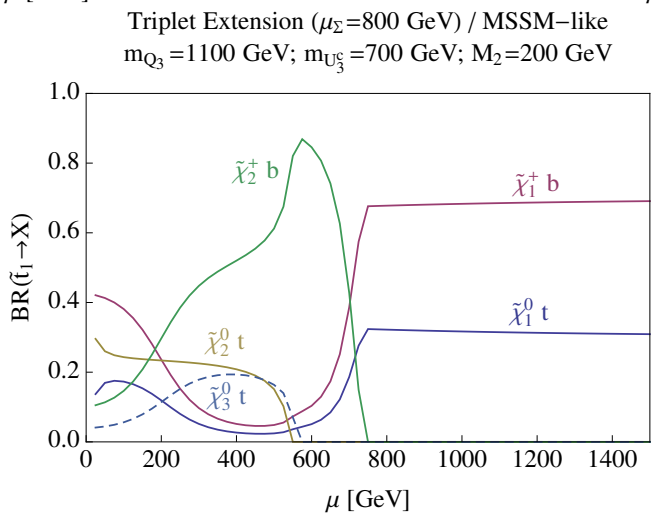


Comparison of the branching ratios (BR) of the lightest stop, as a function of μ, for *point A*: $m_{Q_3} = m_{U_3^c} = 700$ GeV. (left) In the triplet extension for $\mu_\Sigma = 800$ GeV (at the critical point). This reproduces the MSSM with $\tan\beta$ set to the same critical value of 2.67. (right) In the triplet extension with $\mu_\Sigma = 200$ GeV. In this case the critical values are $(\tan\beta_C, \lambda_C) = (3.50, 0.884)$. (bottom) The same in the MSSM-like case, with $\tan\beta = 3.50$ and $M_2 = 200$ GeV so the stop also has a light triplet state available for decays.

Stop Branching Ratios

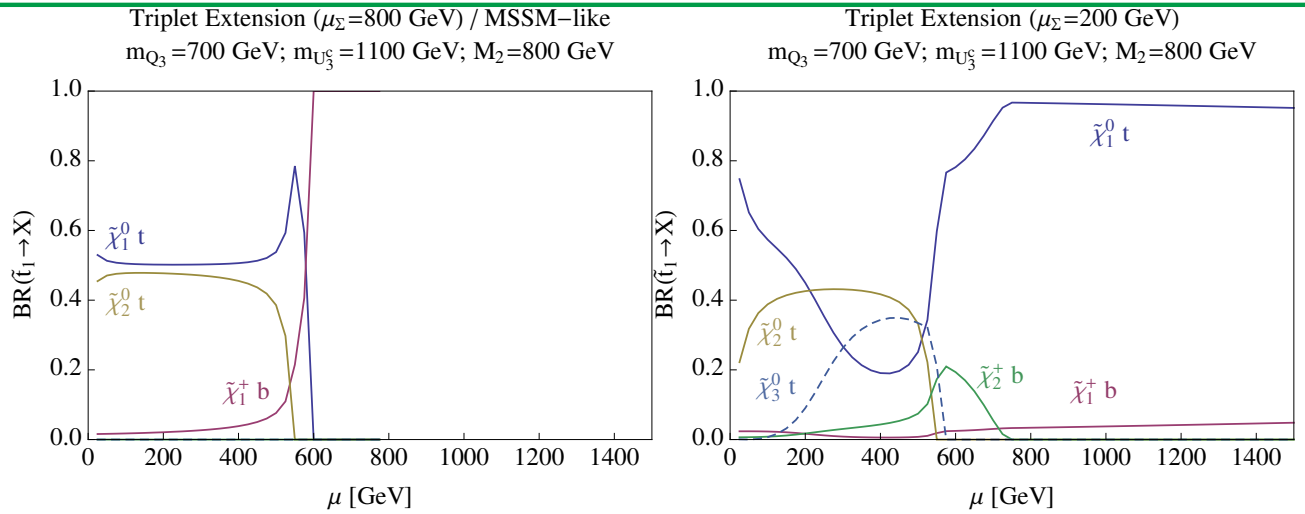


Light Right

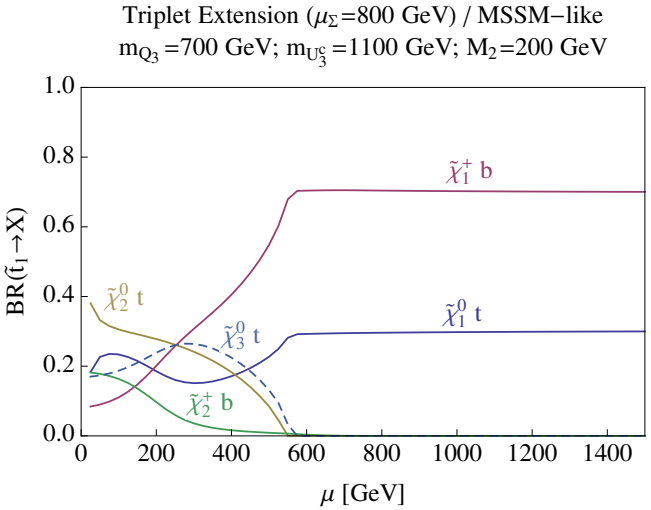


Comparison of the branching ratios of the lightest stop, as a function of μ, for *point B*: $m_{Q_3} = 1100$ GeV, $m_{U_3^c} = 700$ GeV. (left) In the triplet extension for $\mu_\Sigma = 800$ GeV (at the critical point) or, equivalently, the MSSM with $\tan\beta = 3.48$. (right) In the triplet extension with $\mu_\Sigma = 200$ GeV. In this case the critical values are $(\tan\beta_C, \lambda_C) = (5.99, 0.876)$. (bottom) The same in the MSSM-like case, with $\tan\beta = 5.99$ and $M_2 = 200$ GeV so the stop also has a light triplet state available for decays.

Stop Branching Ratios



Light Left



Comparison of the branching ratios of the lightest stop, as a function of μ, for *point C*: $m_{Q_3} = 700$ GeV, $m_{U_3^c} = 1100$ GeV. (left) In the triplet extension for $\mu_\Sigma = 800$ GeV (at the critical point) or, equivalently, the MSSM with $\tan\beta = 3.48$. (right) In the triplet extension with $\mu_\Sigma = 200$ GeV. In this case the critical values are $(\tan\beta_C, \lambda_C) = (5.99, 0.876)$. (bottom) The same in the MSSM-like case, with $\tan\beta = 5.99$ and $M_2 = 200$ GeV so the stop also has a light triplet state available for decays.

LHC Considerations

- Look at points with $\mu = 600$ GeV

$$m_{\tilde{\chi}^0_{1,2}} \approx \begin{cases} 570,\ 600\,\mathrm{GeV} & \mathrm{MSSM}_{800} \\ 200,\ 580\,\mathrm{GeV} & \text{Triplet Ext.} \\ 190,\ 600\,\mathrm{GeV} & \mathrm{MSSM}_{200} \end{cases}, \quad m_{\tilde{\chi}^\pm_{1,2}} \approx \begin{cases} 580,\ 820\,\mathrm{GeV} & \mathrm{MSSM}_{800} \\ 200,\ 600\,\mathrm{GeV} & \text{Triplet Ext.} \\ 190,\ 610\,\mathrm{GeV} & \mathrm{MSSM}_{200} \end{cases}$$

$$m_{\tilde{t}_{1,2}} \approx \begin{cases} 700,\ 740\,\mathrm{GeV} & \text{Point A} \\ 720,\ 1110\,\mathrm{GeV} & \text{Points B \& C} \end{cases}, \quad \theta_t \approx \begin{cases} 46^\circ & \text{Point A} \\ 4^\circ & \text{Point B} \\ 1^\circ & \text{Point C} \end{cases}$$

- All MSSM_{800} points have 100 % decay to chargino + sbottom
- Triplet Ext. Branching ratios given by

$$\mathrm{BR}(\tilde{t}_1 \to \tilde{\chi}^0_1\, t) \approx \begin{cases} 0.2 & \text{Points A \& B} \\ 0.8 & \text{Point C} \end{cases}$$

$$\mathrm{BR}(\tilde{t}_1 \to \tilde{\chi}^\pm_{1,2}\, b) \approx \begin{cases} 0.3,\ 0.5 & \text{Points A \& B} \\ 0\ \ ,\ 0.2 & \text{Point C} \end{cases}.$$

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PGS detector level counts. The figure under every jet count is the percentage of the events which contain the given number of jets.

Model	Point	# of Jet Counts 3	4	5	≥ 6
MSSM_{800} (M_2=800GeV)	A, B, C	25	23-25	16-17	17-19
Triplet Extension (μ_Σ=200GeV, M_2=800GeV)	A, B, C	8-9	14	18-19	54-57
MSSM_{200} (M_2=200GeV)	A, B C	11-13 7	18-19 13	20-21 17	43-46 60

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PGS detector level counts. The figure under every lepton count is the percentage of the events which contain the given number of leptons.

Model	Point	# of Lepton Counts 0	1	2	≥ 3
MSSM_{800} (M_2=800GeV)	A, B, C	81-82	17	1-2	0
Triplet Extension (μ_Σ=200GeV, M_2=800GeV)	A, B, C	53-57	34-37	8-9	1
MSSM_{200} (M_2=200GeV)	A, B C	65 53	30 35	5 10	1 2

Conclusion

- Introducing a $Y = 0$, $SU(2)_L$ triplet chiral superfield into MSSM has promising feautes
  - Alleviates naturalness by raising Higgs mass
  - Can modify $h\gamma\gamma$ coupling
  - Critical points where decoupling limit is reached at low m_A
- If SUSY found, effects could be seen in stop sector
  - Modify the dominant decay mode of the stop

Backup Slides

Higgs Observables

What happens to Higgs observables?

$$R_{\gamma\gamma} = \left| 1 + \frac{\frac{4}{3}\frac{\partial}{\partial \log v} \log\det \mathcal{M}_{ch}(v)}{A_1(\tau_W) + \frac{4}{3}A_{1/2}(\tau_t)} \right|^2$$

$$\frac{\partial}{\partial \log v} \log\det \mathcal{M}_{ch}(v) = -\frac{\sin 2\beta v^2(\lambda^2 M_2 + g^2\mu_\Sigma)}{M_2\mu\mu_\Sigma - \frac{1}{2}\sin 2\beta v^2(\lambda^2 M_2 + g^2\mu_\Sigma)}$$

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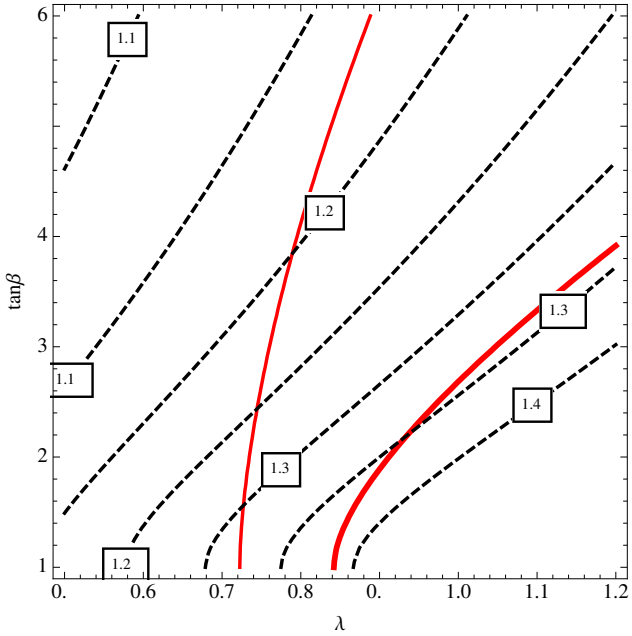
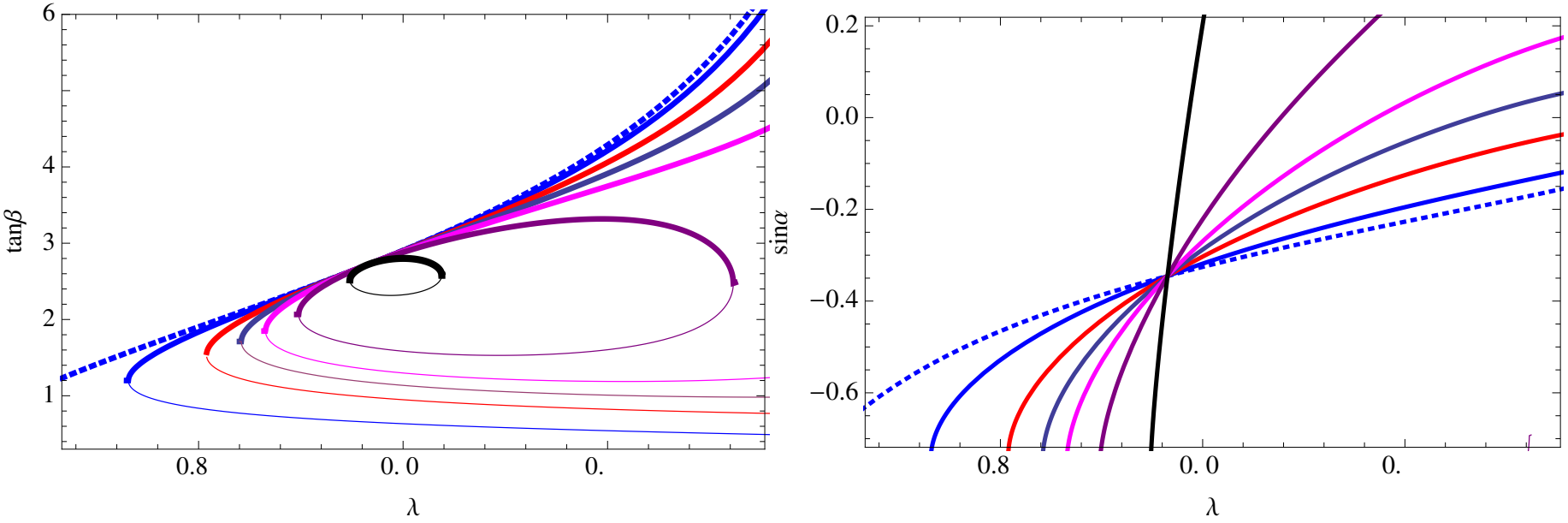
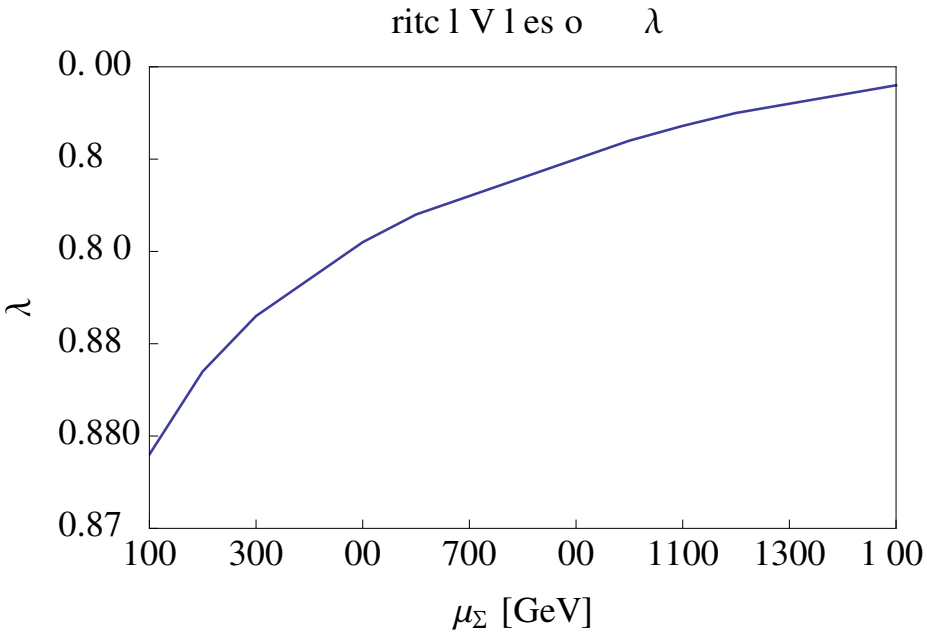


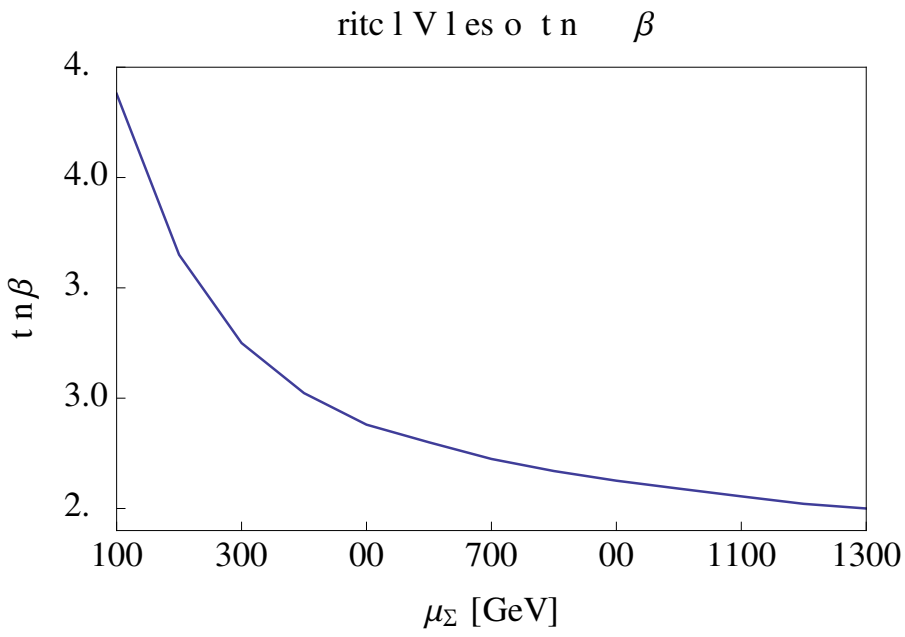
- $m_{\tilde{Q}} = 700$ GeV
- $M_2 = 750$ GeV
- $\mu = \mu_\Sigma$
- $m_{\tilde{\chi}_1^+} \in [95, 110]$ GeV; $m_{\tilde{\chi}_2^+} \in [217, 302]$ GeV
- $m_h(m_{\tilde{Q}}, \beta, \lambda) = 126$ GeV

Higgs Observables



Left panel: $\tan\beta$ *as a function of* λ *providing* $m_h = 126$ *GeV in the decoupling limit or large* m_A *(blue dotted) and for* $m_A = 200$ *GeV (blue solid), 155 GeV (red solid), 145 GeV (grey solid), 140 GeV (magenta solid), 135 GeV (purple solid) and 130 GeV (black solid). Right panel: The same but for* $\sin\alpha$ *as a function of* λ.





The critical values of λ (left) and $\tan\beta$ (right) as a function of μ_Σ for $m_{U_3^c} = m_{Q_3} = 700$ GeV and $A_t = 0$.