The Decoupling Limit in the Georgi-Machacek Model

Kunal Kumar

Carleton University

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(arXiv : 1404.2640 + ongoing work with H. E. Logan and K. Hartling)

Motivation

- SM-like Higgs and no new particles discovered so far could mean we are observing the decoupling limit of a model

- The Georgi-Machacek model adds scalar triplets in way to preserve $\rho \equiv M_W/M_Z \cos\theta_W = 1$

  H. Georgi, M. Machacek [NPB 262,463];
  Chanowitz, Golden, Phys.Lett. B 165, 105

- Uncommon features : doubly-charged scalar, enhancement of hVV couplings close to the decoupling limit

- Has been incorporated into little Higgs and SUSY models

  Cort, Garcia, Quiros[PRD 88, 075010]

  Chang, Wacker [PRD 69 035002];
  S. Chang [JHEP 0312 057]

- The GM model is thus a valuable benchmark model to study Higgs properties

The Model

- Proposed in 1985 as a possible scenario for EWSB

H. Georgi, M. Machacek
[NPB 262,463 (1985)]

- SM doublet + real triplet (Y=0) + complex triplet (Y=2)

- Arranged in terms of Φ and X make global $SU(2)_L \times SU(2)_R$ apparent

$$\Phi = \begin{pmatrix} \phi^{0*} & \phi^{+} \\ -\phi^{+*} & \phi^{0} \end{pmatrix} \qquad X = \begin{pmatrix} \chi^{0*} & \xi^{+} & \chi^{++} \\ -\chi^{+*} & \xi^{0} & \chi^{+} \\ \chi^{++*} & -\xi^{+*} & \chi^{0} \end{pmatrix}$$

- where $S^{Q*} = (-1)^Q S^{-Q}$

- The scalar vevs preserve custodial SU(2)

$$\langle \Phi \rangle = \frac{v_\phi}{\sqrt{2}} \mathbb{1}_{2\times 2} \qquad \langle X \rangle = v_\chi \mathbb{1}_{3\times 3}$$

- Constrained by W and Z masses

$$v_\phi^2 + 8 v_\chi^2 \equiv v^2 = \frac{4M_W^2}{g^2} \approx (246 \text{ GeV})^2 \qquad \sin\theta_H = \frac{2\sqrt{2}\, v_\chi}{v}$$

Scalar Sector

$$\Phi = \begin{pmatrix} \phi^{0*} & \phi^{+} \\ -\phi^{+*} & \phi^{0} \end{pmatrix} \qquad X = \begin{pmatrix} \chi^{0*} & \xi^{+} & \chi^{++} \\ -\chi^{+*} & \xi^{0} & \chi^{+} \\ \chi^{++*} & -\xi^{+*} & \chi^{0} \end{pmatrix}$$

- Expanding around the minima : 3 Goldstones, 10 physical scalars
- 10 scalars arranged as custodial multiplets : 1 five-plet, 1 triplet, 2 singlets
- Masses : m_5, m_3, m_h, m_H respectively
- α controls mixing between custodial singlets H_1^0 and $H_1^{0\prime}$

$$h = \cos\alpha\, H_1^0 - \sin\alpha\, H_1^{0\prime},$$
$$H = \sin\alpha\, H_1^0 + \cos\alpha\, H_1^{0\prime}.$$

- v_χ/v controls contribution of states in X to Goldstones, custodial triplets

Scalar Potential

- Most general gauge-invariant potential that preserves $\mathrm{SU}(2)_C$:

$$V(\Phi, X) = \frac{\mu_2^2}{2}\mathrm{Tr}(\Phi^\dagger\Phi) + \frac{\mu_3{}^2}{2}\mathrm{Tr}(X^\dagger X) + \lambda_1[\mathrm{Tr}(\Phi^\dagger\Phi)]^2 + \lambda_2\mathrm{Tr}(\Phi^\dagger\Phi)\mathrm{Tr}(X^\dagger X)$$
$$+\lambda_3\mathrm{Tr}(X^\dagger X X^\dagger X) + \lambda_4[\mathrm{Tr}(X^\dagger X)]^2 - \lambda_5\mathrm{Tr}(\Phi^\dagger\tau^a\Phi\tau^b)\mathrm{Tr}(X^\dagger t^a X t^b)$$
$$-M_1\mathrm{Tr}(\Phi^\dagger\tau^a\Phi\tau^b)(UXU^\dagger)_{ab} - M_2\mathrm{Tr}(X^\dagger t^a X t^b)(UXU^\dagger)_{ab}.$$

Hartling, KK, Logan[arXiv: 1404.2640]; Aoki, Kanemura [PRD 77,095009]; Chiang, Yagyu [JHEP 1301, 026]

- μ_2 and λ_1 can be traded for v and m_h respectively and hence are not free parameters.
- Free parameters : μ_3, λ_2, λ_3, λ_4, λ_5, M_1, M_2.
- Most literature on GM model impose Z_2 symmetry for simplicity

e.g. Englert, Re, Spannowsky [PRD 87, 095014]

  - No M_1, M_2 terms in this case and all $m_i = \lambda_i v^2$
  - λ_i bounded to be $\mathcal{O}(1)$ by unitarity constraints $\implies$ $m_i < 700$ GeV
  - The Z_2 symmetric version does not possess a decoupling limit

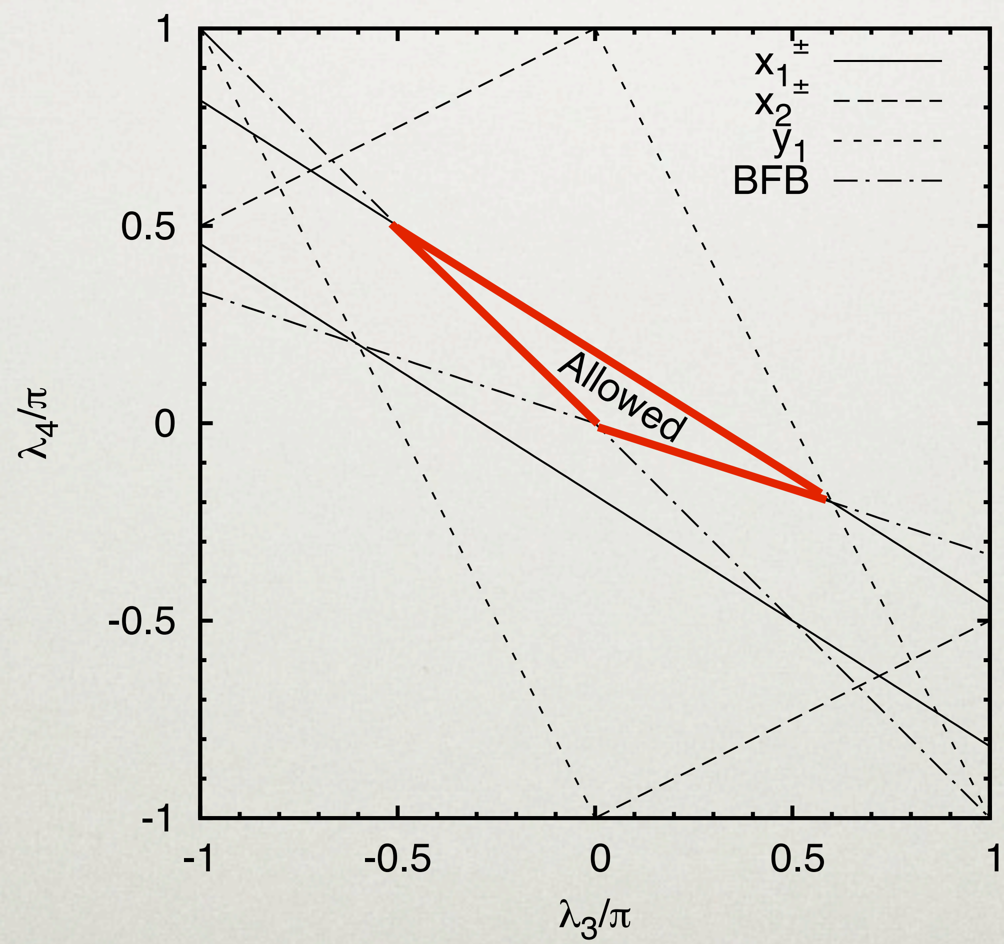
Scalar Potential

$$V(\Phi, X) = \frac{\mu_2^2}{2}\mathrm{Tr}(\Phi^\dagger\Phi) + \frac{{\mu_3}^2}{2}\mathrm{Tr}(X^\dagger X) + \lambda_1[\mathrm{Tr}(\Phi^\dagger\Phi)]^2 + \lambda_2\mathrm{Tr}(\Phi^\dagger\Phi)\mathrm{Tr}(X^\dagger X)$$
$$+\lambda_3\mathrm{Tr}(X^\dagger X X^\dagger X) + \lambda_4[\mathrm{Tr}(X^\dagger X)]^2 - \lambda_5\mathrm{Tr}(\Phi^\dagger\tau^a\Phi\tau^b)\mathrm{Tr}(X^\dagger t^a X t^b)$$
$$-M_1\mathrm{Tr}(\Phi^\dagger\tau^a\Phi\tau^b)(UXU^\dagger)_{ab} - M_2\mathrm{Tr}(X^\dagger t^a X t^b)(UXU^\dagger)_{ab}.$$

- No Z_2 symmetry allows us to write M_1 and M_2 terms
- In this scenario the GM model does have a decoupling limit!
- μ_3 defines the mass scale for new particles

Theoretical Constraints

- λ_i are constrained by unitarity limits on $2 \rightarrow 2$ scalar scattering
- We also require the scalar potential to be bounded from below for all possible field values



- We ensure that our desired vacuum is the global minimum by imposing checks to avoid alternative minima

Decoupling Behaviour

- Decoupling occurs when combinations of the three dimensional parameters : μ_3, M_1 and M_2 is taken large compared to v.

$$\lambda_1 \approx \frac{m_h^2}{8v^2} + \frac{3}{32}\frac{M_1^2}{\mu_3^2}$$

- M_1 can increase at most linearly with μ_3 because λ_1 is bounded by unitarity.

$$|M_1|/\sqrt{\mu_3^2} \lesssim 3.3$$

- M_2 can increase at most linearly with μ_3 because increasing M_2 increases v_χ which is constrained by $8v_\chi^2 < v^2$

$$|M_2|/\sqrt{\mu_3^2} \lesssim 1.2$$

Decoupling Behaviour

- Case A : μ_3 is taken large but M_1 and M_2 are fixed.

- Case B : μ_3 is taken large and M_1, M_2 increase linearly with μ_3.

Case	$\mu_3 \equiv \sqrt{\lvert\mu_3^2\rvert}$	λ_1	λ_2	λ_3	λ_4	λ_5	M_1	M_2
A	300–1000 GeV	derived	0.1	0.1	0.1	0.1	100 GeV	100 GeV
B	300–1000 GeV	derived	0.1	0.1	0.1	0.1	$\mu_3/3$	$\mu_3/3$

- We shall derive expressions for masses, higgs couplings, vevs and custodial-singlet mixing angle (α) up to leading order in μ_3^{-1} (or equivalently the dimensionless quantity v/μ_3)

Decoupling Behaviour

- Case A : M_1 and M_2 fixed; Case B : $M_1 = M_2 = \mu_3/3$

- We don't consider cases where only M_1 or M_2 is fixed

- In the expansion formulae M_2 always appears with M_1

$$v_\chi \simeq \frac{M_1 v^2}{4\mu_3^2}\left[1 - (2\lambda_2 - \lambda_5)\frac{v^2}{\mu_3^2} + \frac{M_1(3M_2 - M_1)v^2}{2\mu_3^4}\right]$$

  - M_1 fixed, $M_2 \propto \mu_3 \equiv$ Case A

  - $M_1 \propto \mu_3$, M_2 fixed $\equiv$ Case B

Decoupling Behaviour

- Case A : M_1 and M_2 fixed; Case B : $M_1 = M_2 = \mu_3/3$

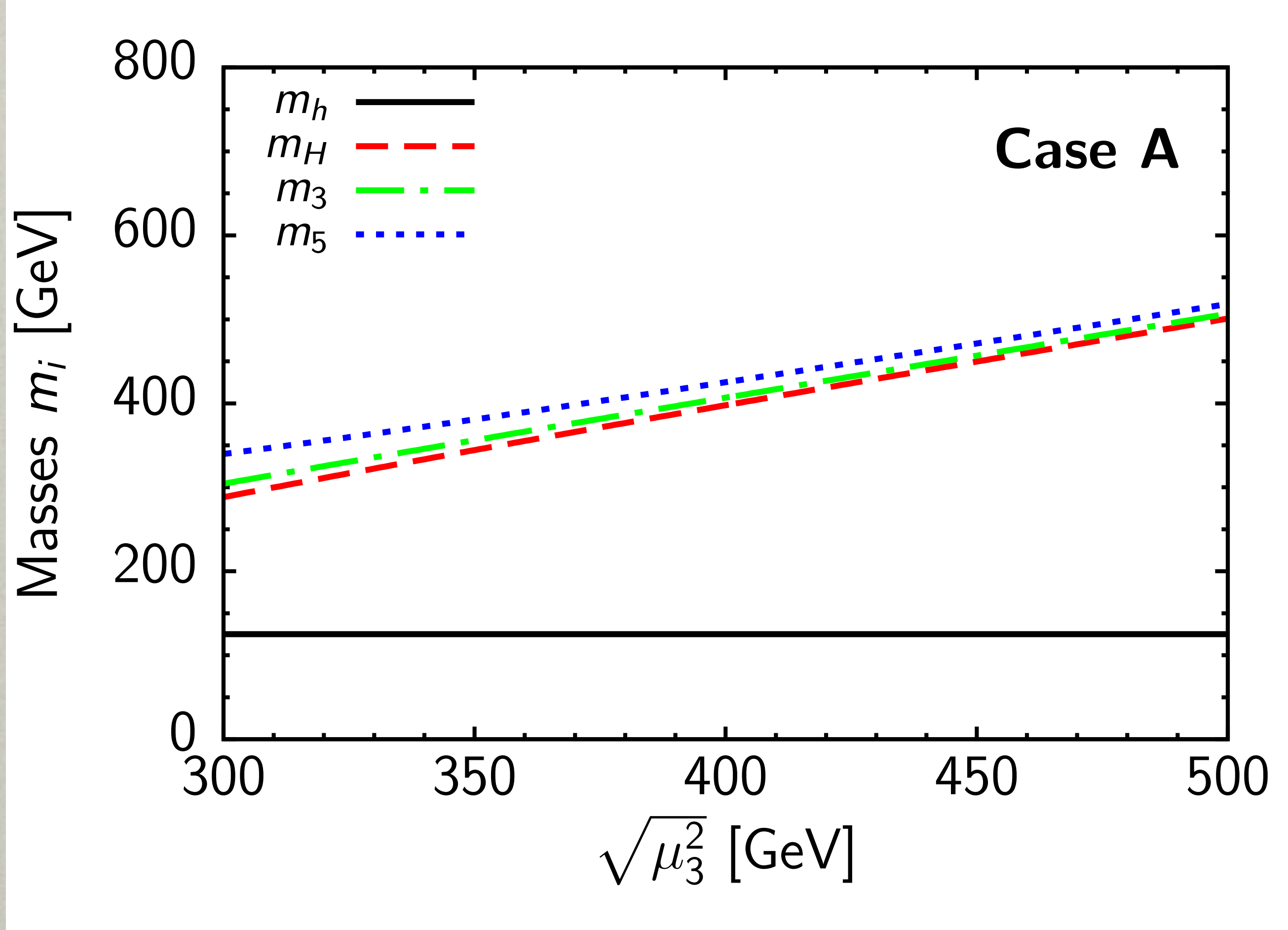
$$v_\chi \simeq \frac{M_1 v^2}{4\mu_3^2}\left[1-(2\lambda_2-\lambda_5)\frac{v^2}{\mu_3^2}+\frac{M_1(3M_2-M_1)v^2}{2\mu_3^4}\right]$$

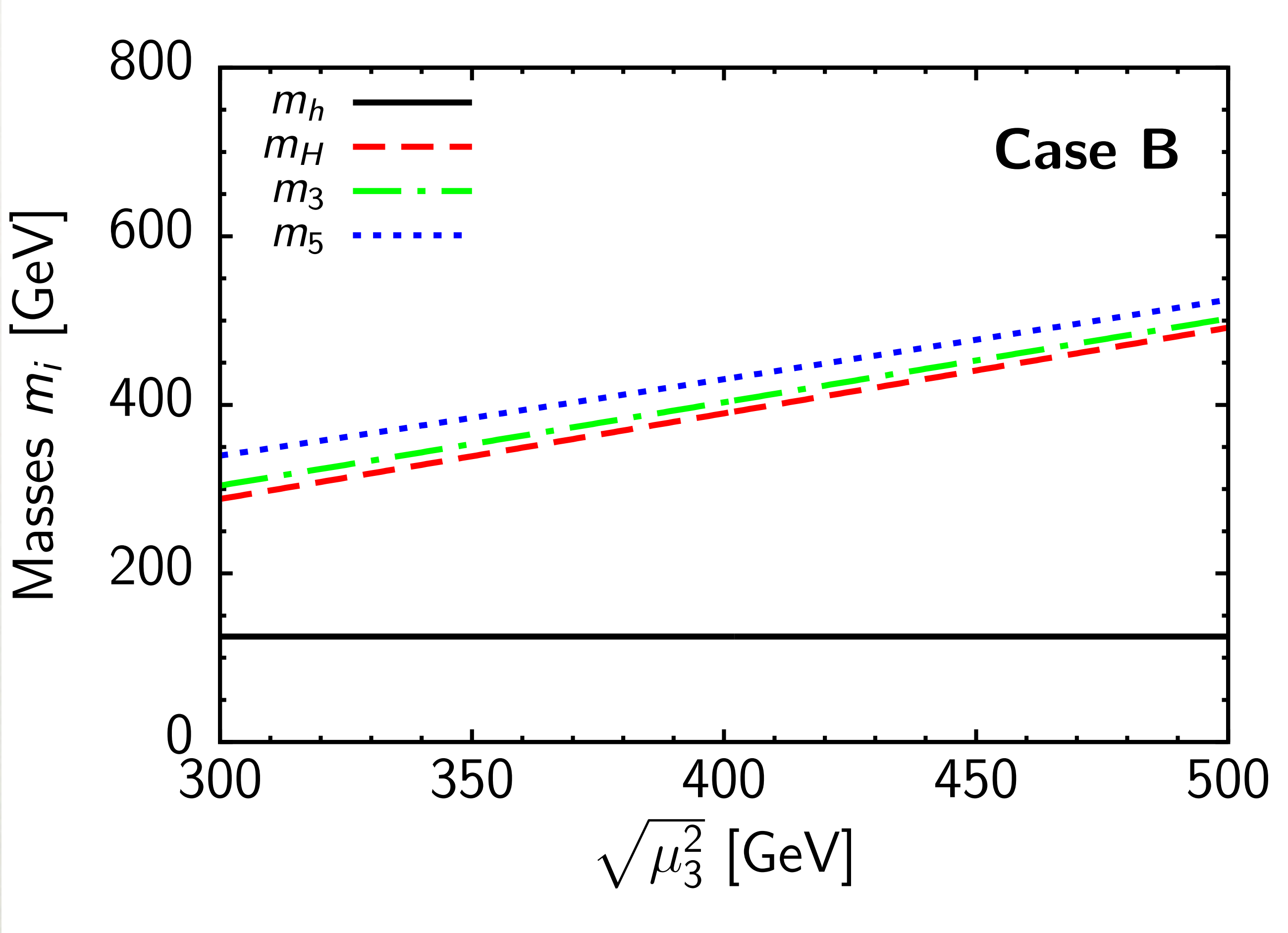
Quantity	Case A	Case B
v_χ	μ_3^{-2}	μ_3^{-1}

- In general convergence to SM is more rapid in Case A.

Decoupling Behaviour: Masses

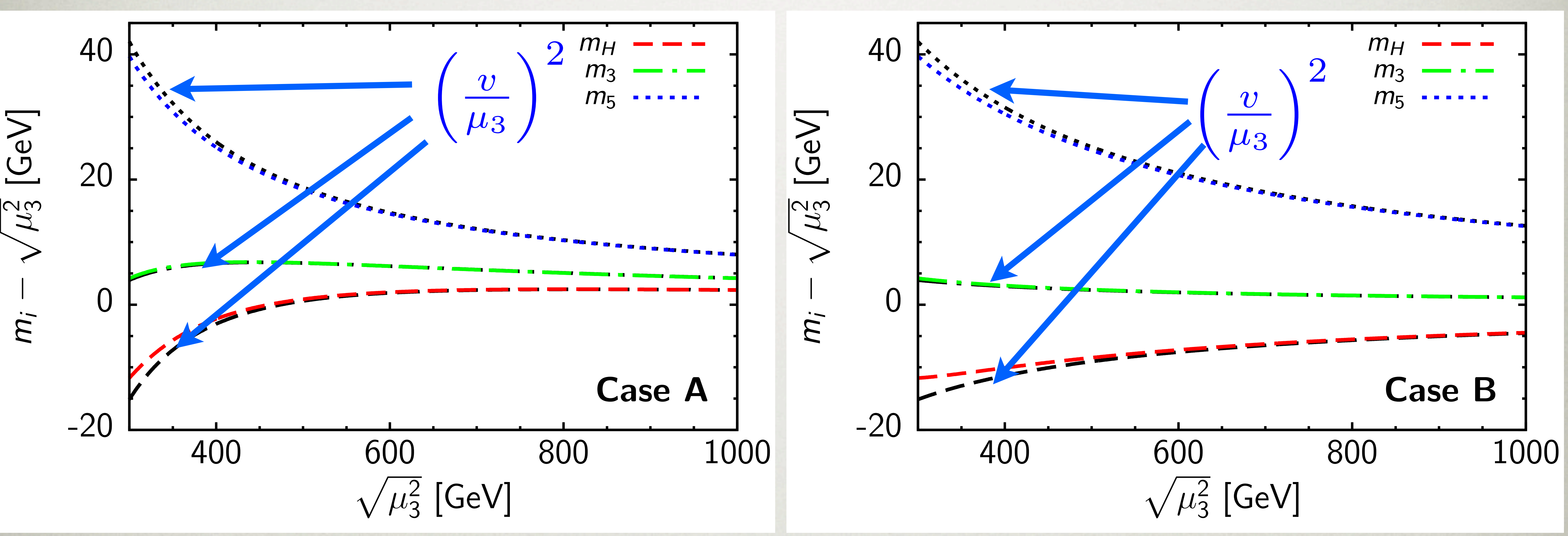
$$m_3 \simeq \mu_3 \left[1 + \left(2\lambda_2 - \frac{\lambda_5}{2}\right)\frac{v^2}{2\mu_3^2} + \frac{M_1(M_1 - 3M_2)v^2}{4\mu_3^4}\right]$$





Decoupling Behaviour: Masses

$$m_3 \simeq \mu_3 \left[1 + \left(2\lambda_2 - \frac{\lambda_5}{2}\right)\frac{v^2}{2\mu_3^2} + \frac{M_1(M_1 - 3M_2)v^2}{4\mu_3^4}\right]$$

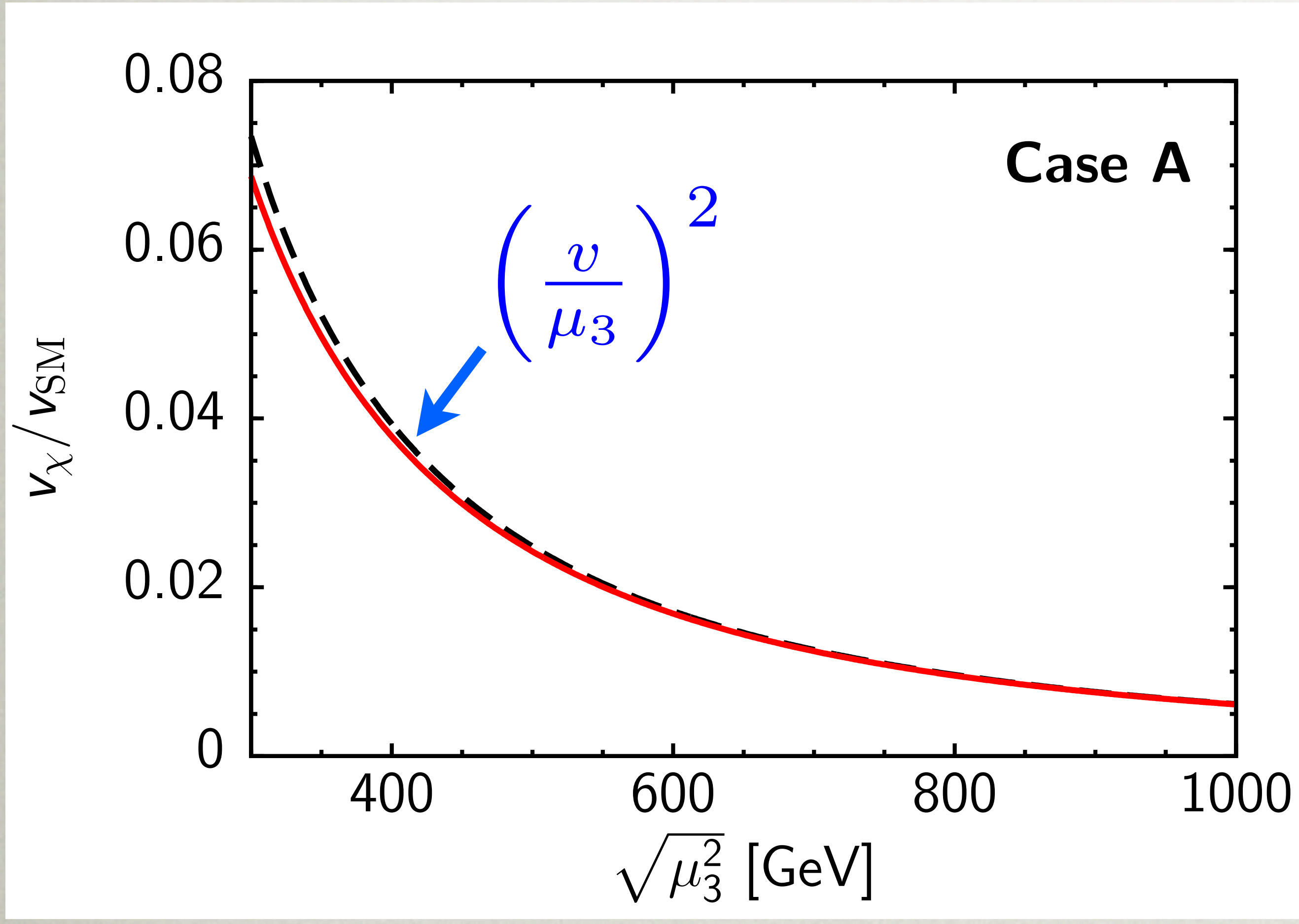


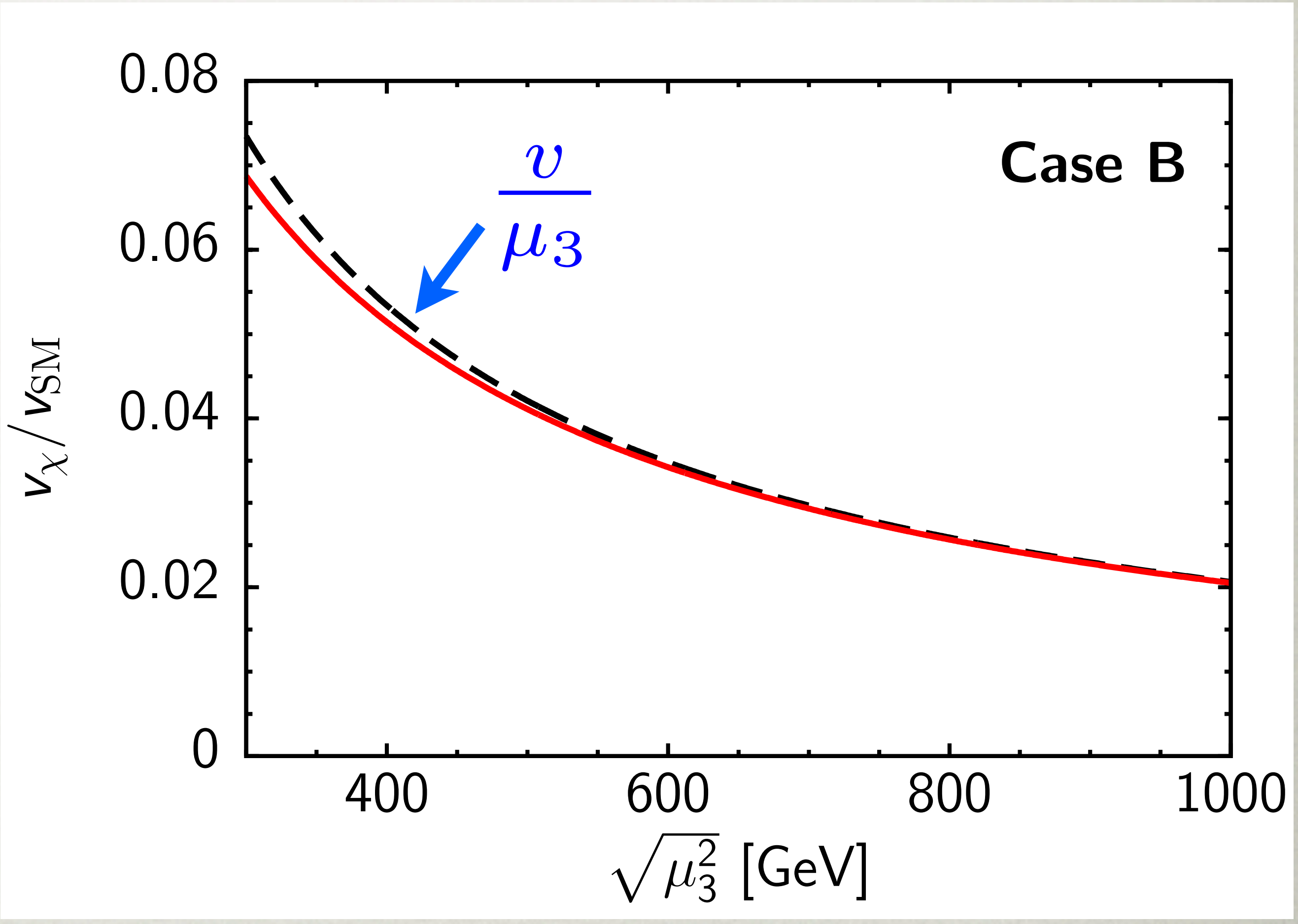
- Black curves correspond to expansions in μ_3^{-1} while colored curves are exact.

Decoupling Behaviour: vev

- triplet vev $$v_\chi \simeq \frac{M_1 v^2}{4\mu_3^2}\left[1-(2\lambda_2-\lambda_5)\frac{v^2}{\mu_3^2}+\frac{M_1(3M_2-M_1)v^2}{2\mu_3^4}\right]$$

- $v_\chi \to 0$ as $\mu_3 \to \infty$

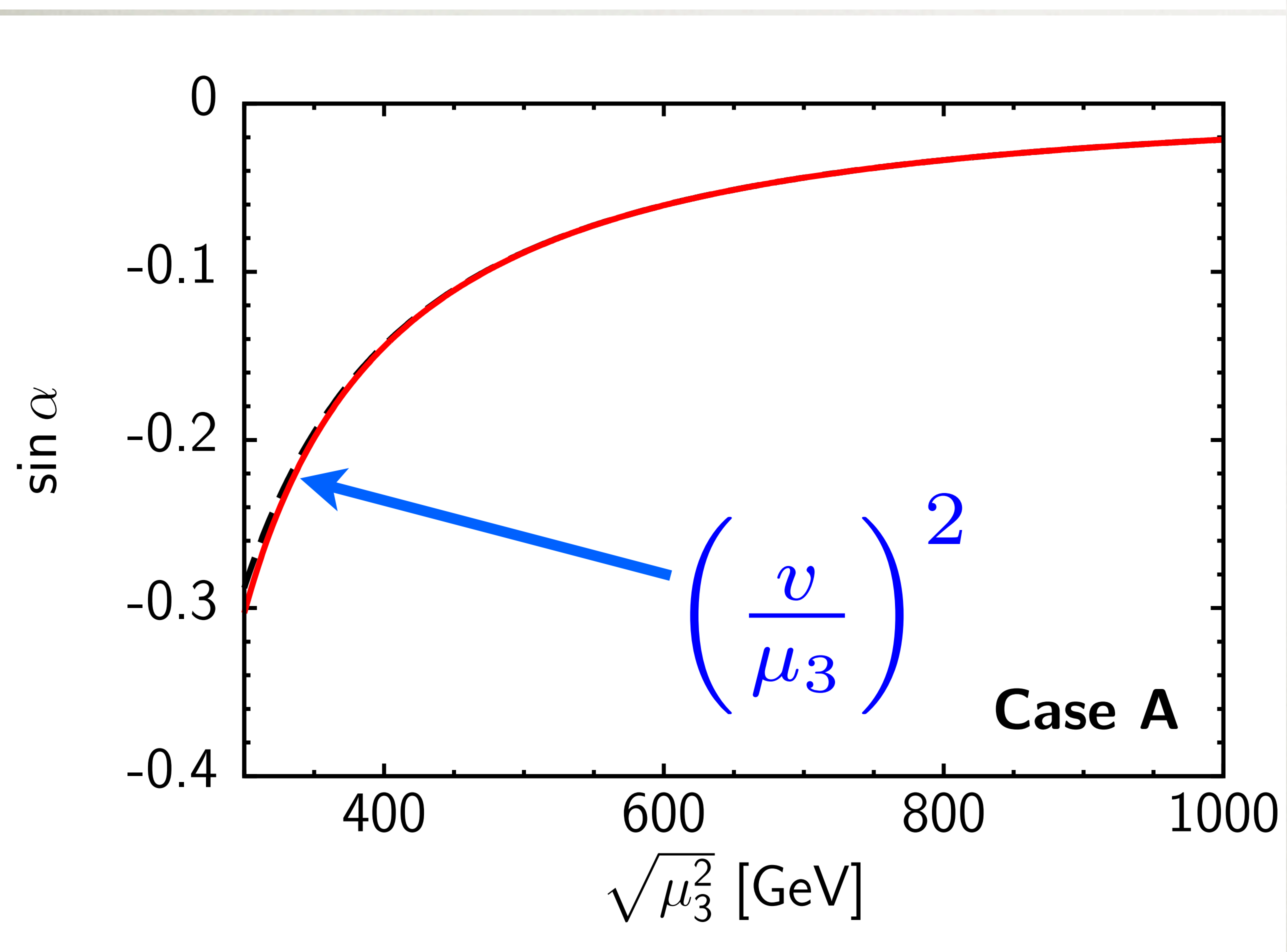


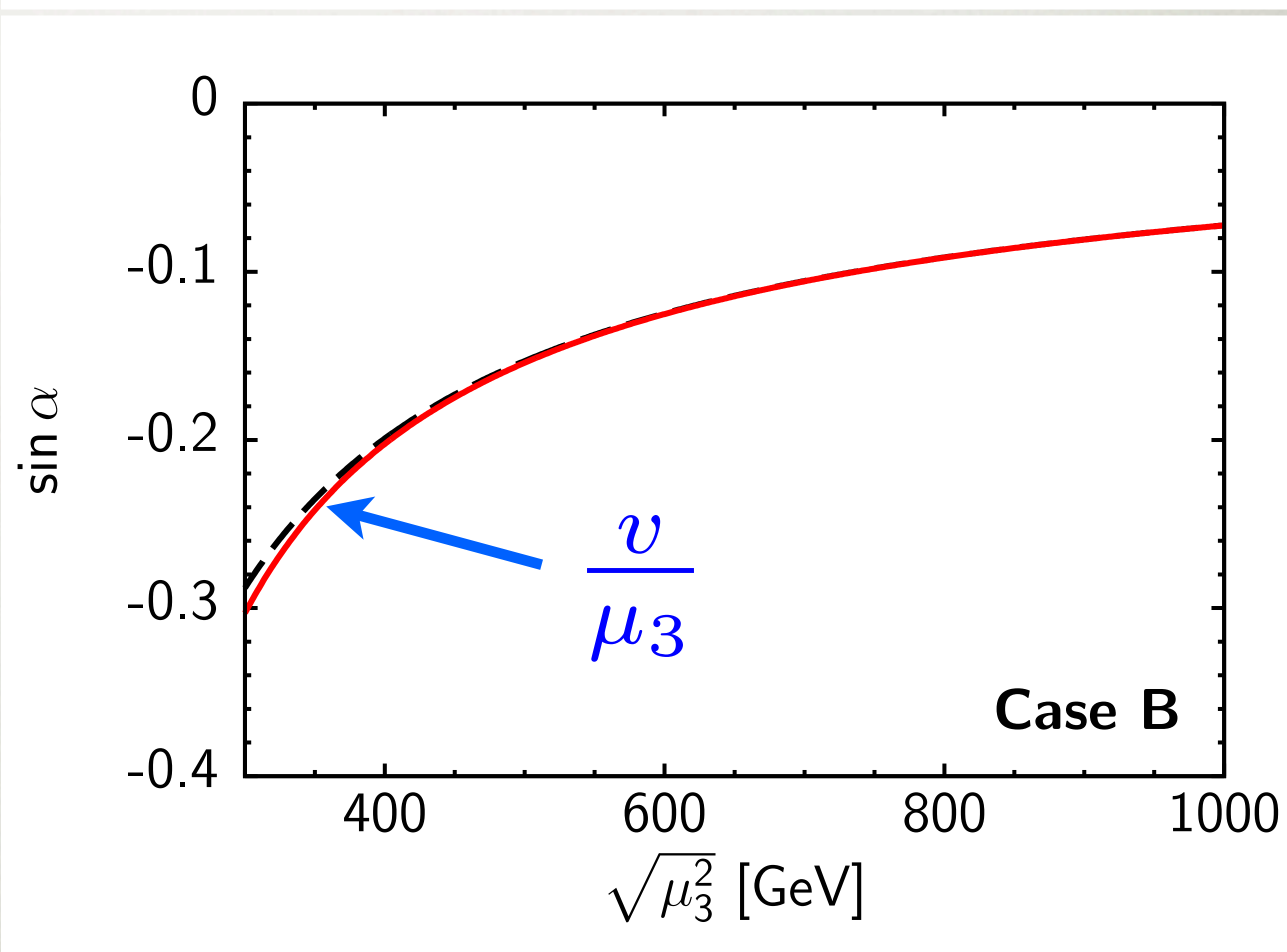


Decoupling Behaviour: mixing angle

- custodial-singlet mixing angle

$$\sin\alpha \simeq -\frac{\sqrt{3}M_1 v}{2\mu_3^2}\left[1 - 2(2\lambda_2 - \lambda_5)\frac{v^2}{\mu_3^2} + \frac{m_h^2}{\mu_3^2} + \frac{M_1(24M_2 - 5M_1)v^2}{8\mu_3^4}\right]$$





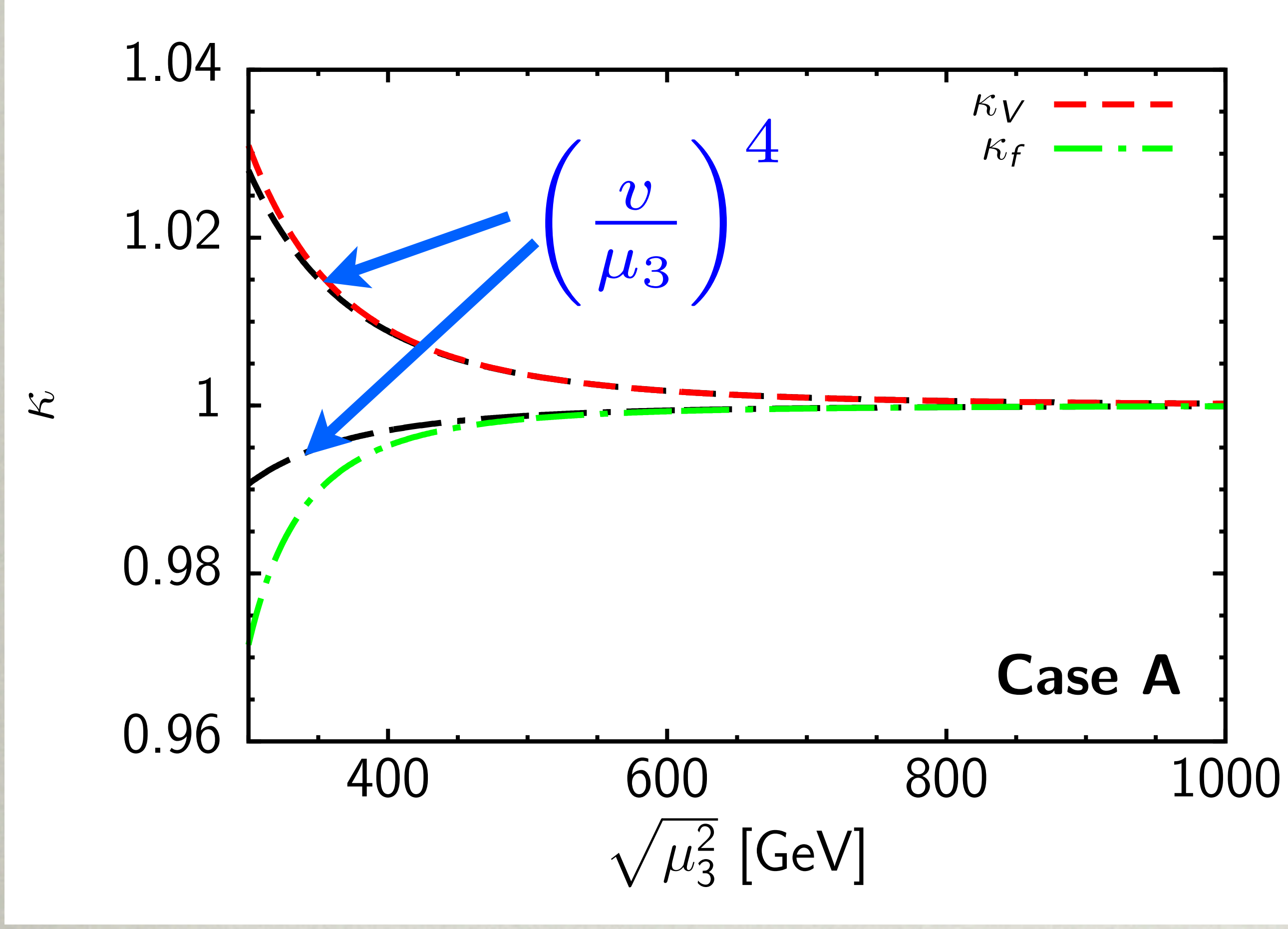
- $\sin\alpha \to 0$ as $\mu_3 \to \infty$

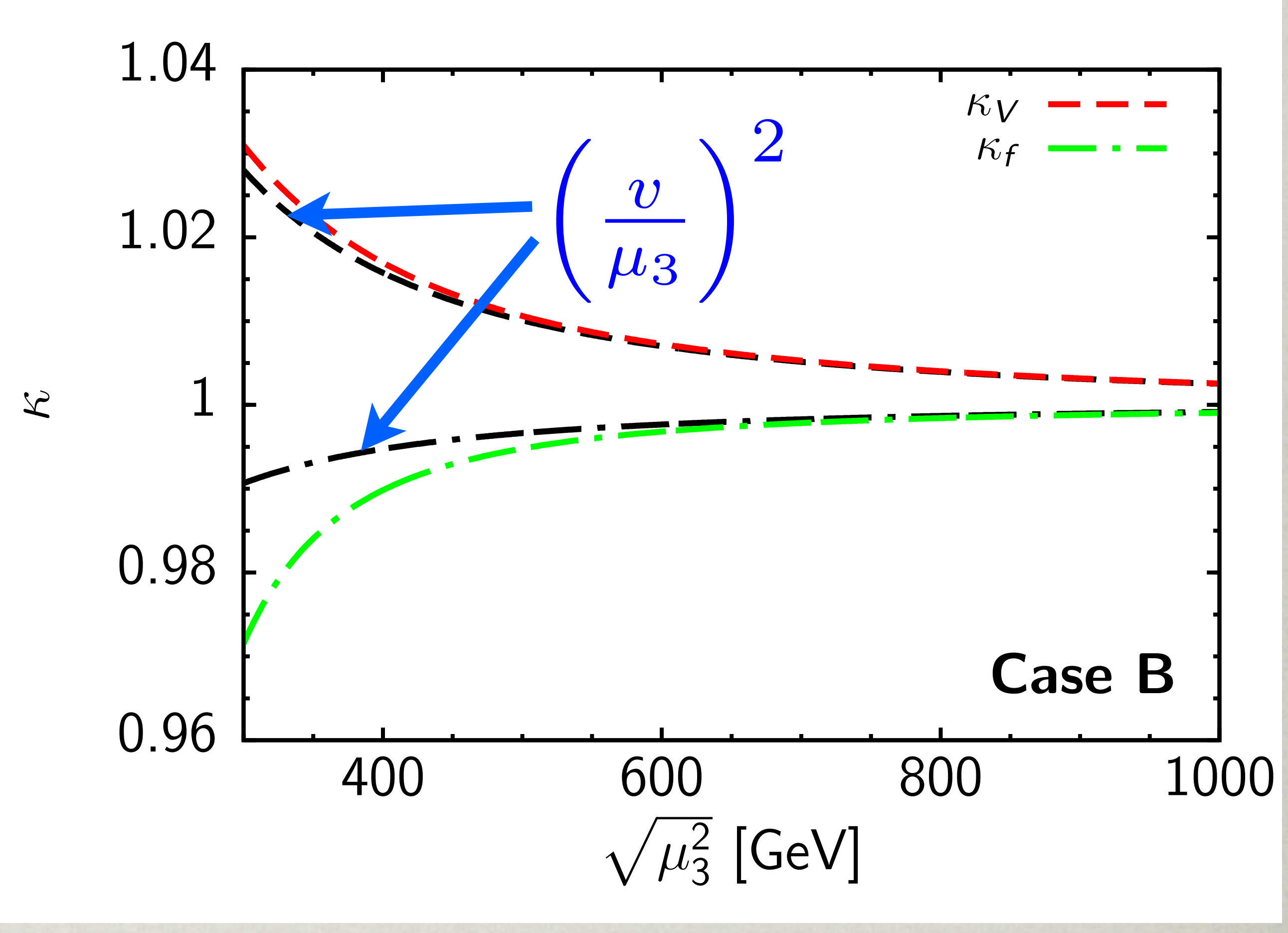
Decoupling Behaviour: hVV, hff

κ : ratio of a coupling to its SM value

$$\kappa_V = \cos\alpha \frac{v_\phi}{v} - \frac{8}{\sqrt{3}} \sin\alpha \frac{v_\chi}{v} \simeq 1 + \frac{3}{8} \frac{M_1^2 v^2}{\mu_3^4},$$

$$\kappa_f = \cos\alpha \frac{v}{v_\phi} \simeq 1 - \frac{1}{8} \frac{M_1^2 v^2}{\mu_3^4},$$

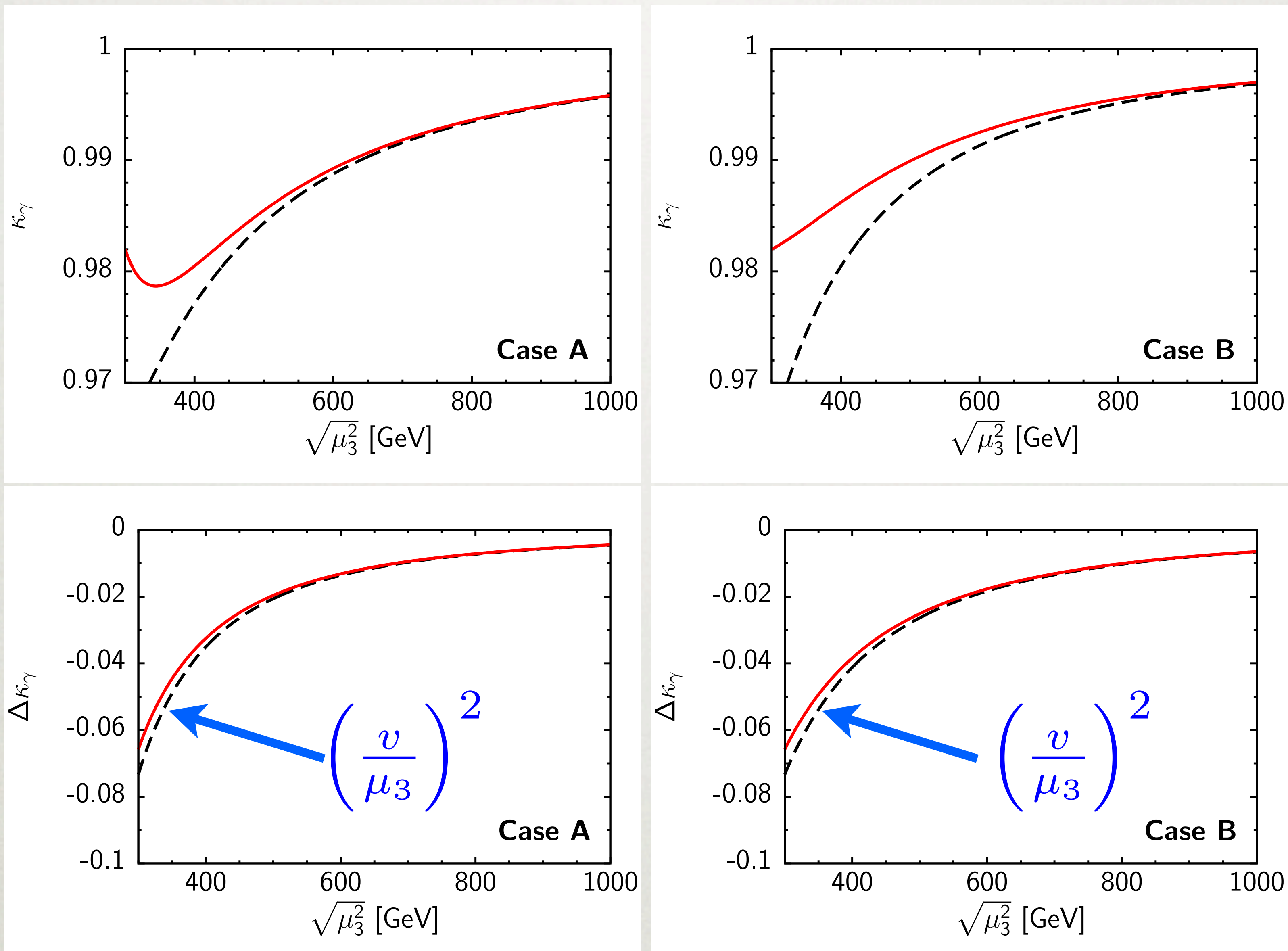




- Expansion formulae are not a very good approximation in the case of κ_f for $\mu_3 \lesssim 400$

Decoupling Behaviour: $h\gamma\gamma$

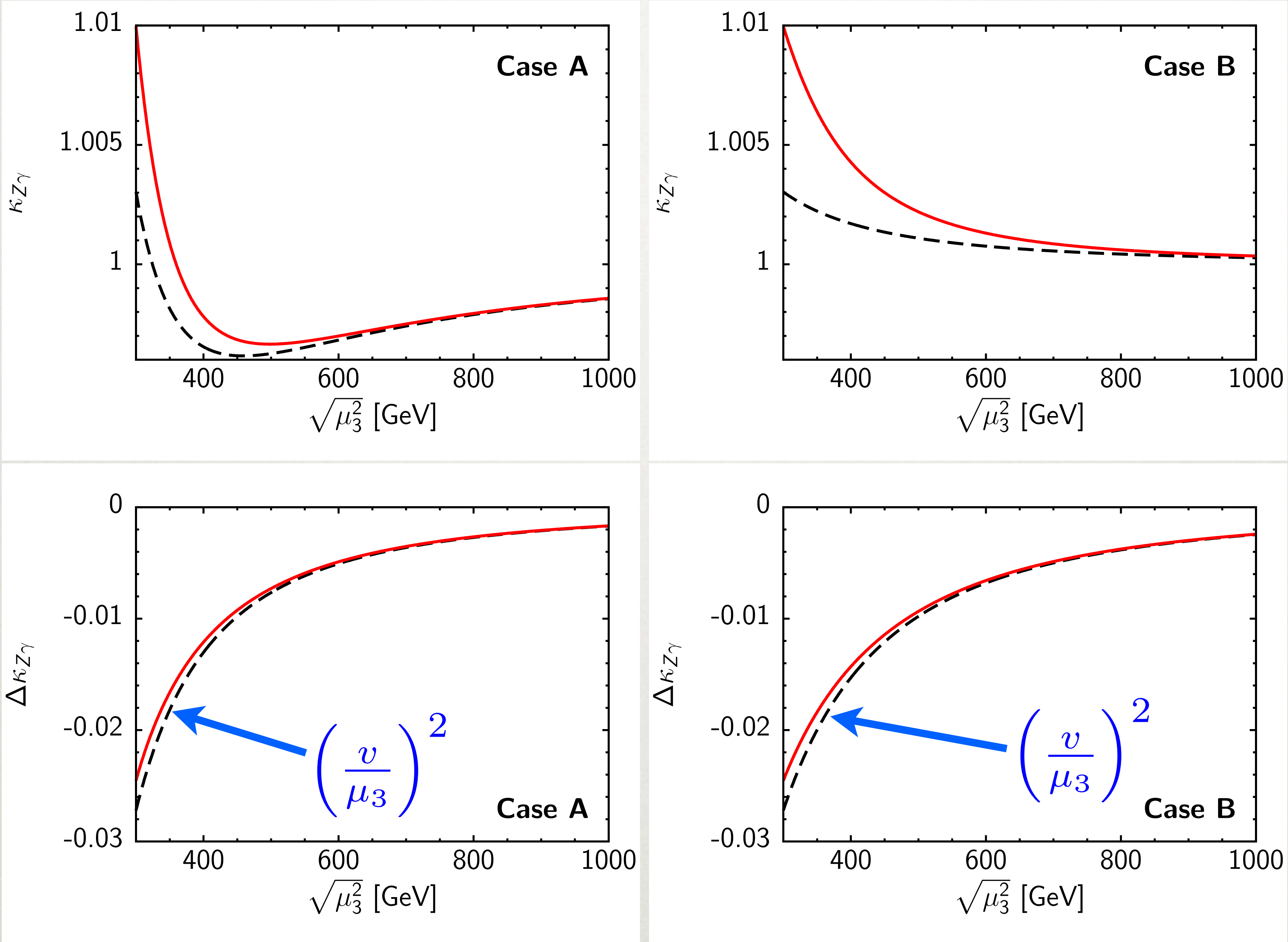
- Loop induced couplings: affected by changes to hVV and hff, new charged scalars in the loop



$$\Delta\kappa_\gamma \simeq -\frac{1}{F_1(M_W) + \frac{4}{3}F_{1/2}(m_t)}\frac{2v^2}{3\mu_3^2}\left[6\lambda_2 + \lambda_5 + \frac{M_1^2 + 12M_1M_2}{4\mu_3^2}\right]$$

- $\Delta\kappa$: Ratio of contribution from non-SM particles in loop to SM coupling

Decoupling Behaviour: $hZ\gamma$



$$\Delta\kappa_{Z\gamma} \simeq \frac{1}{2(A_W + A_f)} \frac{1 - 2s_W^2}{s_W c_W} \frac{2v^2}{3\mu_3^2} \left[6\lambda_2 + \lambda_5 + \frac{M_1^2 + 12 M_1 M_2}{4\mu_3^2} \right]$$

- $\Delta\kappa$: Ratio of contribution from non-SM particles in loop to SM coupling

Comparison with Type-II 2HDM

Type-II 2HDM

$$\kappa_V^{\rm 2HDM} \simeq 1 - \frac{\hat{\lambda}^2 v^4}{2\, m_A^4},$$

$$\kappa_f^{\rm 2HDM} \simeq 1 + \frac{\hat{\lambda} v^2}{m_A^2} \times \begin{cases} \cot\beta & \text{for up type fermions} \\ -\tan\beta & \text{for down type fermions,} \end{cases}$$

$$g_{hhh}^{\rm 2HDM} \simeq \frac{3m_h^2}{v}\left[1 - \frac{3\hat{\lambda}^2 v^2}{\lambda m_A^2}\right],$$

J.F. Gunion, H.E. Haber [PRD 67, 075019]

Georgi-Machacek

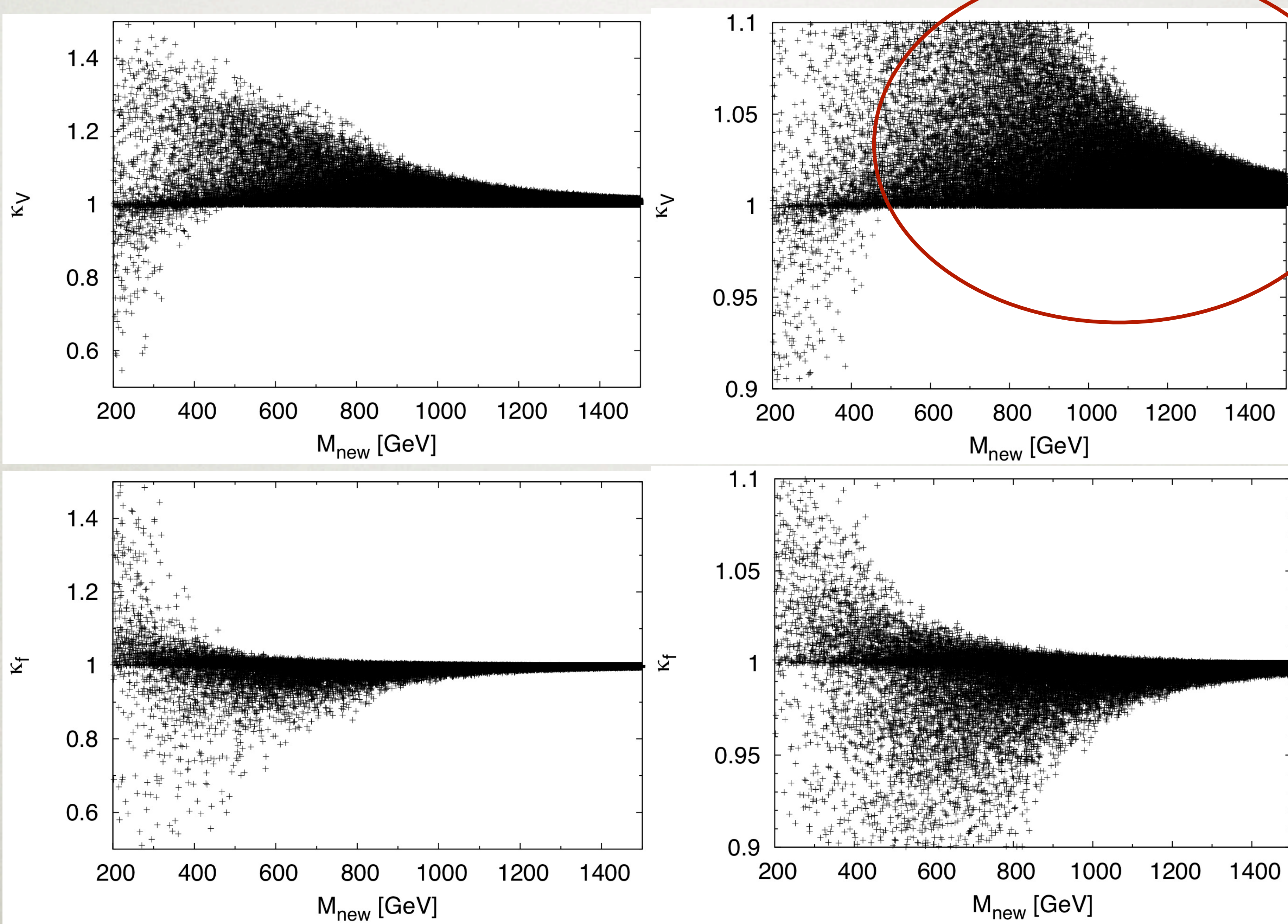
Quantity	Case A	Case B
$\kappa_V - 1$	μ_3^{-4}	μ_3^{-2}
$\kappa_f - 1$	μ_3^{-4}	μ_3^{-2}
$g_{hhh}/g_{hhh}^{\rm SM} - 1$	μ_3^{-4}	μ_3^{-2}

- relatively large deviations in all couplings would favor GM Case B
- relatively large deviations fermion and trilinear couplings, but SM like vector couplings favors 2HDM
- Another distinguishing feature is the κ_V is enhanced in the decoupling limit of the GM model

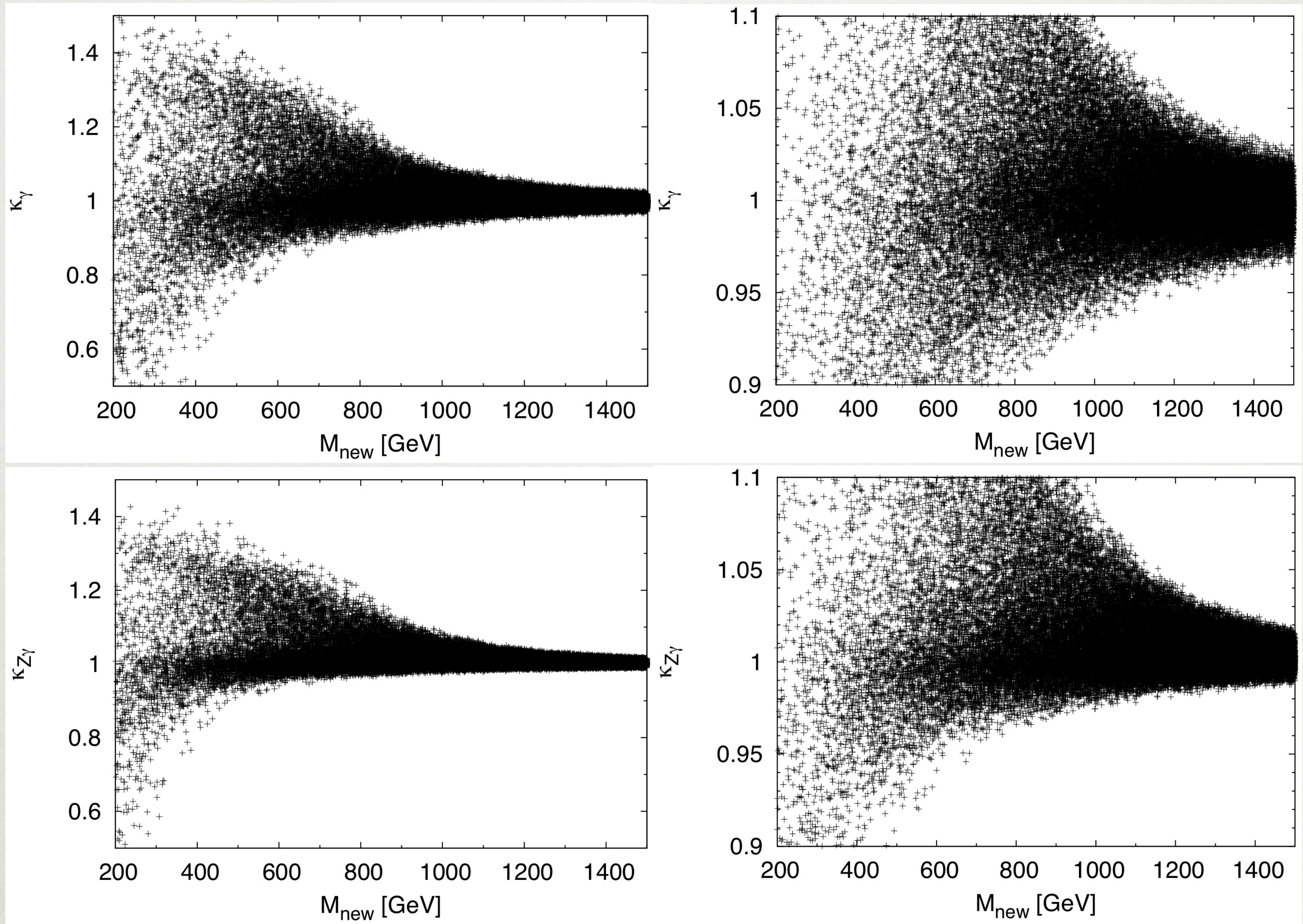
$$\kappa_V = \cos\alpha \frac{v_\phi}{v} - \frac{8}{\sqrt{3}} \sin\alpha \frac{v_\chi}{v} \simeq 1 + \frac{3}{8}\frac{M_1^2 v^2}{\mu_3^4},$$

Numerical Scans

- Numerical scans to examine accessible range of couplings
- We allow all the free parameters to vary and impose theoretical constraints.



Numerical Scans



- All couplings can show 10% deviations even when the mass of the lightest scalar is around 800 GeV.

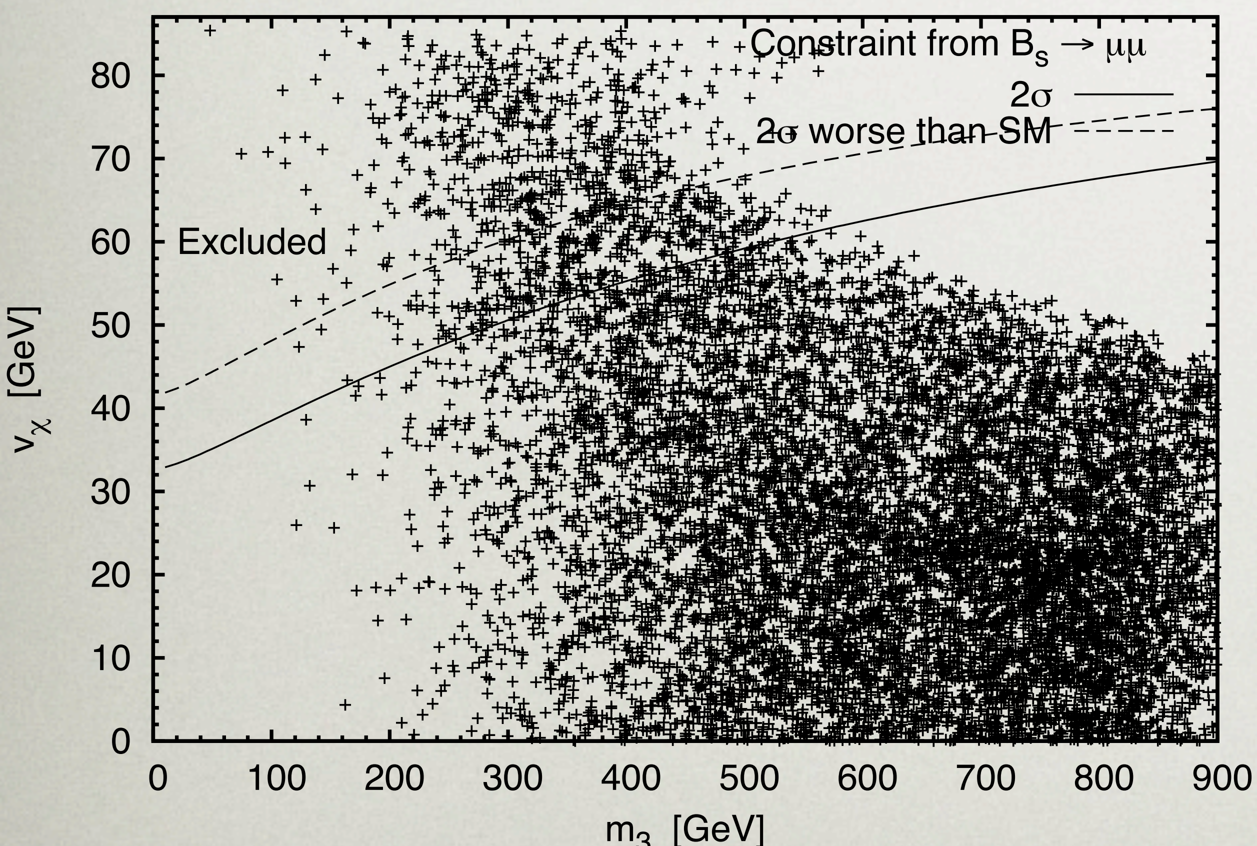
- The 1σ allowed regions of higgs couplings measured at the LHC can be populated fully by the GM model with scalar masses below $400-600$ GeV.

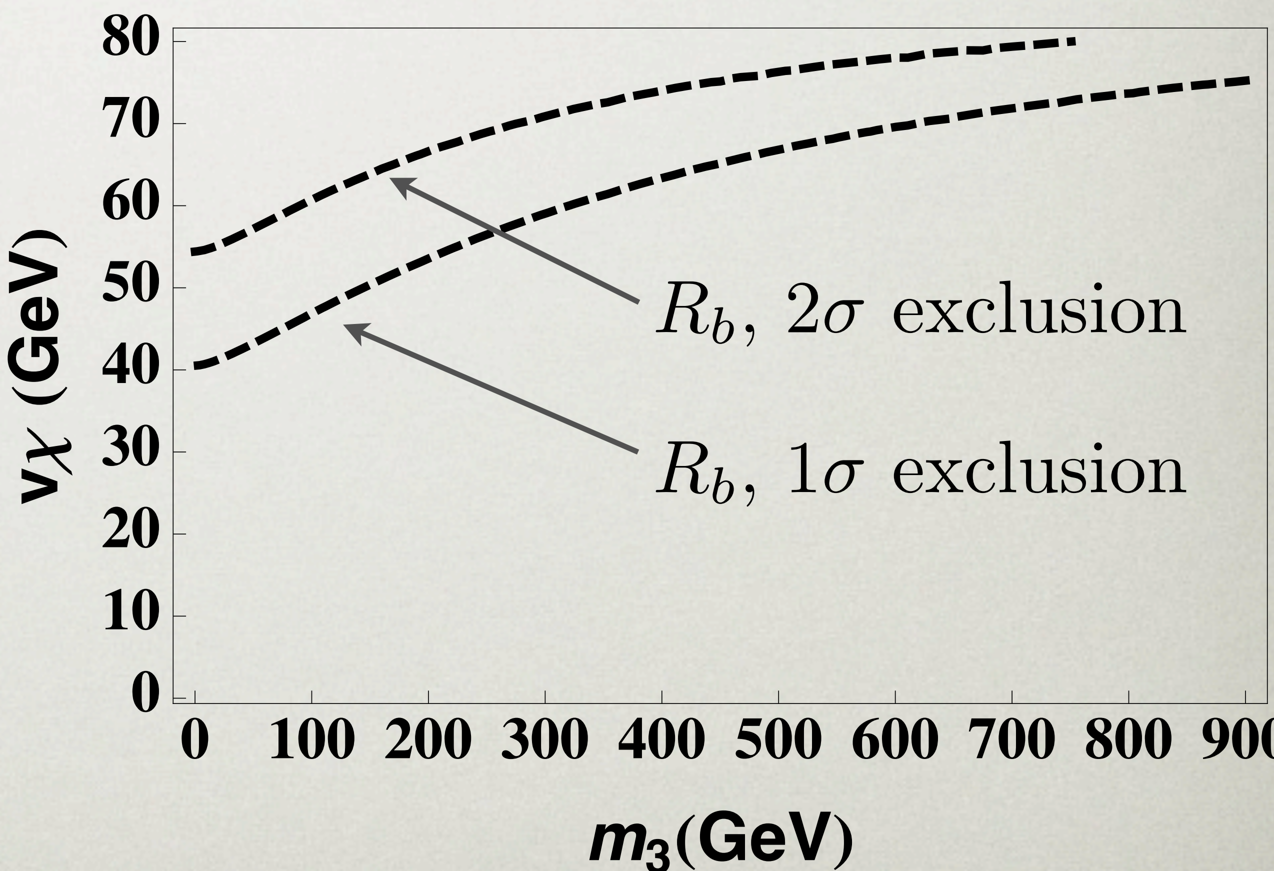
Indirect Constraints

- Include constraints from : B meson mixing, $B_s \to \mu\mu$, R_b, $b \to s\gamma$,Oblique parameters (ongoing)

- Most stringent constraint comes from $B_s \to \mu\mu$

Preliminary Result





Indirect Constraints

- At one-loop level $\rho \neq 1$ and we require a counterterm to cancel the singularities in the T parameter Gunion, Vega, Wudka [PRD 43, 2322]

- We could approach the constraint from oblique parameters in the following ways:
  - Apply the constraint only from the S parameter
  - Perform the one-loop calculations with the required counterterm
  - Minimize χ^2 with respect to T and use $T_{\min}$ to obtain the constraint

$$\chi^2 = \frac{1}{(1-\rho_{ST}^2)}\left[\frac{(S-S_{\exp})^2}{(\Delta S_{\exp})^2} + \frac{(T-T_{\exp})^2}{(\Delta T_{\exp})^2} - \frac{2\,(S-S_{\exp})\,(T-T_{\exp})}{\Delta S_{\exp}\Delta T_{\exp}}\right]$$

$$T_{\min} = T_{\exp} + (S - S_{\exp})\frac{\Delta T_{\exp}}{\Delta S_{\exp}}$$

Conclusions

- GM model with most general gauge-invariant and $SU(2)_C$ preserving potential does possess a decoupling limit
- Approach to the SM is in general faster when M_1 and M_2 are fixed as compared to $M_1 = M_2 = \mu_3/3$
- Numerical scans show that 10% coupling deviations are possible for new scalars even as heavy as 800 GeV
- GM model can fully populate the allowed 1σ ranges of Higgs couplings when the new scalars are lighter than 400-600 GeV.
- Improved measurements of higgs couplings can help distinguish GM model from other extensions such as the 2HDM.

Future Work

- Including exclusion due to oblique parameters.

BACKUP SLIDES

Theoretical Constraints : Unitarity

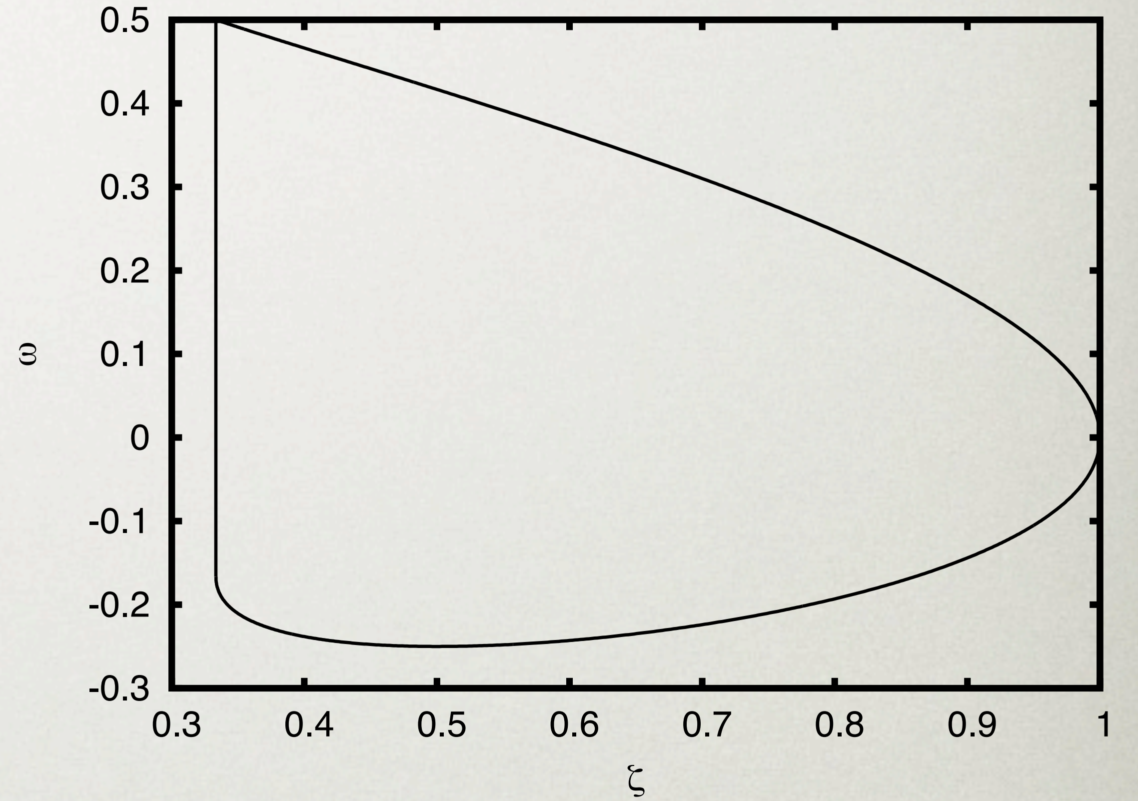
Q	Y	Basis states	Eigenvalues
0	0	$[\chi^{++*}\chi^{++}, \chi^{+*}\chi^{+}, \xi^{+*}\xi^{+}, \phi^{+*}\phi^{+}, \chi^{0*}\chi^{0}, \frac{\xi^0\xi^0}{\sqrt{2}}, \phi^{0*}\phi^{0}]$	$x_1^+, x_1^-, x_2^+, x_2^-, y_1, y_1, y_2$
0	1	$[\phi^{+}\xi^{+*}, \phi^{0}\xi^{0}, \chi^{+}\phi^{+*}, \chi^{0}\phi^{0*}]$	y_3, y_4, y_4, y_5
0	2	$[\frac{\phi^0\phi^0}{\sqrt{2}}, \chi^{0}\xi^{0}, \chi^{+}\xi^{+*}]$	x_2^+, x_2^-, y_2
0	3	$[\phi^{0}\chi^{0}]$	y_3
0	4	$[\frac{\chi^0\chi^0}{\sqrt{2}}]$	y_2
1	-2	$[\xi^{+}\chi^{0*}]$	y_2
1	-1	$[\phi^{+}\chi^{0*}, \xi^{+}\phi^{0*}]$	y_3, y_4
1	0	$[\xi^{+}\xi^{0}, \chi^{+*}\chi^{++}, \phi^{+}\phi^{0*}, \chi^{0*}\chi^{+}]$	x_2^+, x_2^-, y_1, y_2
1	1	$[\phi^{0}\xi^{+}, \phi^{+}\xi^{0}, \phi^{+*}\chi^{++}, \phi^{0*}\chi^{+}]$	y_3, y_4, y_4, y_5
1	2	$[\phi^{+}\phi^{0}, \chi^{+}\xi^{0}, \chi^{++}\xi^{+*}, \chi^{0}\xi^{+}]$	x_2^+, x_2^-, y_1, y_2
1	3	$[\phi^{+}\chi^{0}, \phi^{0}\chi^{+}]$	y_3, y_4
1	4	$[\chi^{+}\chi^{0}]$	y_2
2	0	$[\chi^{++}\chi^{0*}, \frac{\xi^+\xi^+}{\sqrt{2}}]$	y_1, y_2
2	1	$[\phi^{+}\xi^{+}, \chi^{++}\phi^{0*}]$	y_3, y_4
2	2	$[\frac{\phi^+\phi^+}{\sqrt{2}}, \chi^{++}\xi^{0}, \chi^{+}\xi^{+}]$	x_2^+, x_2^-, y_2
2	3	$[\phi^{+}\chi^{+}, \phi^{0}\chi^{++}]$	y_3, y_4
2	4	$[\chi^{++}\chi^{0}, \frac{\chi^+\chi^+}{\sqrt{2}}]$	y_1, y_2
3	2	$[\chi^{++}\xi^{+}]$	y_2
3	3	$[\chi^{++}\phi^{+}]$	y_3
3	4	$[\chi^{++}\chi^{+}]$	y_2
4	4	$[\frac{\chi^{++}\chi^{++}}{\sqrt{2}}]$	y_2

$$|x_i^{\pm}| < 8\pi \text{ and } |y_i| < 8\pi$$

Theoretical Constraints : BFB

$$r \equiv \sqrt{\mathrm{Tr}(\Phi^\dagger \Phi) + \mathrm{Tr}(X^\dagger X)},$$
$$r^2 \cos^2\gamma \equiv \mathrm{Tr}(\Phi^\dagger \Phi),$$
$$r^2 \sin^2\gamma \equiv \mathrm{Tr}(X^\dagger X),$$
$$\zeta \equiv \frac{\mathrm{Tr}(X^\dagger X X^\dagger X)}{[\mathrm{Tr}(X^\dagger X)]^2},$$
$$\omega \equiv \frac{\mathrm{Tr}(\Phi^\dagger \tau^a \Phi \tau^b)\mathrm{Tr}(X^\dagger t^a X t^b)}{\mathrm{Tr}(\Phi^\dagger \Phi)\mathrm{Tr}(X^\dagger X)}$$

$$r \in [0, \infty), \quad \gamma \in \left[0, \frac{\pi}{2}\right]$$
$$\zeta \in \left[\frac{1}{3}, 1\right] \quad \text{and} \quad \omega \in \left[-\frac{1}{4}, \frac{1}{2}\right]$$



$$[a + by^2 + \bar{c}y^4] \quad a > 0, \qquad c > 0, \qquad \text{and} \quad b + 2\sqrt{ac} > 0.$$

quartic terms in the potential

$$V^{(4)}(r, \tan\gamma, \zeta, \omega) = \frac{r^4}{(1+\tan^2\gamma)^2}\left[\lambda_1 + (\lambda_2 - \omega\lambda_5)\tan^2\gamma + (\zeta\lambda_3 + \lambda_4)\tan^4\gamma\right]$$

bounded-from-below conditions

$$\lambda_1 > 0, \qquad \zeta\lambda_3 + \lambda_4 > 0, \qquad \text{and} \quad \lambda_2 - \omega\lambda_5 + 2\sqrt{\lambda_1(\zeta\lambda_3 + \lambda_4)} > 0.$$

Theoretical Constraints

- Maximum Ranges :

$$\lambda_1 \in \left(0, \frac{1}{3}\pi\right) \simeq (0, 1.05)$$

$$\lambda_2 \in \left(-\frac{2}{3}\pi, \frac{2}{3}\pi\right) \simeq (-2.09, 2.09)$$

$$\lambda_3 \in \left(-\frac{1}{2}\pi, \frac{3}{5}\pi\right) \simeq (-1.57, 1.88)$$

$$\lambda_4 \in \left(-\frac{1}{5}\pi, \frac{1}{2}\pi\right) \simeq (-0.628, 1.57)$$

$$\lambda_5 \in \left(-\frac{8}{3}\pi, \frac{8}{3}\pi\right) \simeq (-8.38, 8.38)$$

- Within these ranges the following conditions need to be satisfied :

$$\lambda_4 > \begin{cases} -\frac{1}{3}\lambda_3 & \text{for } \lambda_3 \geq 0, \\ -\lambda_3 & \text{for } \lambda_3 < 0, \end{cases}$$

$$\lambda_2 > \begin{cases} \frac{1}{2}\lambda_5 - 2\sqrt{\lambda_1\left(\frac{1}{3}\lambda_3 + \lambda_4\right)} & \text{for } \lambda_5 \geq 0 \text{ and } \lambda_3 \geq 0, \\ \omega_+(\zeta)\lambda_5 - 2\sqrt{\lambda_1(\zeta\lambda_3 + \lambda_4)} & \text{for } \lambda_5 \geq 0 \text{ and } \lambda_3 < 0, \\ \omega_-(\zeta)\lambda_5 - 2\sqrt{\lambda_1(\zeta\lambda_3 + \lambda_4)} & \text{for } \lambda_5 < 0. \end{cases}$$

Theoretical Constraints : Alternative Minima

$$V = \frac{r^2}{(1+\tan^2\gamma)}\frac{1}{2}\left[\mu_2^2 + \mu_3^2\tan^2\gamma\right]$$
$$+\frac{r^4}{(1+\tan^2\gamma)^2}\left[\lambda_1 + (\lambda_2 - \omega\lambda_5)\tan^2\gamma + (\zeta\lambda_3 + \lambda_4)\tan^4\gamma\right]$$
$$+\frac{r^3}{(1+\tan^2\gamma)^{3/2}}\tan\gamma\left[-\sigma M_1 - \rho M_2\tan^2\gamma\right],$$

$$\sigma \equiv \frac{\mathrm{Tr}(\Phi^\dagger\tau^a\Phi\tau^b)(UXU^\dagger)_{ab}}{\mathrm{Tr}(\Phi^\dagger\Phi)[\mathrm{Tr}(X^\dagger X)]^{1/2}},$$
$$\rho \equiv \frac{\mathrm{Tr}(X^\dagger t^a X t^b)(UXU^\dagger)_{ab}}{[\mathrm{Tr}(X^\dagger X)]^{3/2}}.$$

Decoupling Behaviour

Case	$\mu_3 \equiv \sqrt{\|\mu_3^2\|}$	λ_1	λ_2	λ_3	λ_4	λ_5	M_1	M_2
A	300–1000 GeV	derived	0.1	0.1	0.1	0.1	100 GeV	100 GeV
B	300–1000 GeV	derived	0.1	0.1	0.1	0.1	$\mu_3/3$	$\mu_3/3$

Quantity	Case A	Case B
$\frac{m_{H,3,5}}{\mu_3} - 1$	μ_3^{-2}	μ_3^{-2}
v_χ	μ_3^{-2}	μ_3^{-1}
$\sin\alpha$	μ_3^{-2}	μ_3^{-1}
$\kappa_V - 1$	μ_3^{-4}	μ_3^{-2}
$\kappa_f - 1$	μ_3^{-4}	μ_3^{-2}
$g_{hhVV}/g_{hhVV}^{\rm SM} - 1$	μ_3^{-4}	μ_3^{-2}
$g_{hhh}/g_{hhh}^{\rm SM} - 1$	μ_3^{-4}	μ_3^{-2}
$\Delta\kappa_\gamma$	μ_3^{-2}	μ_3^{-2}
$\Delta\kappa_{Z\gamma}$	μ_3^{-2}	μ_3^{-2}