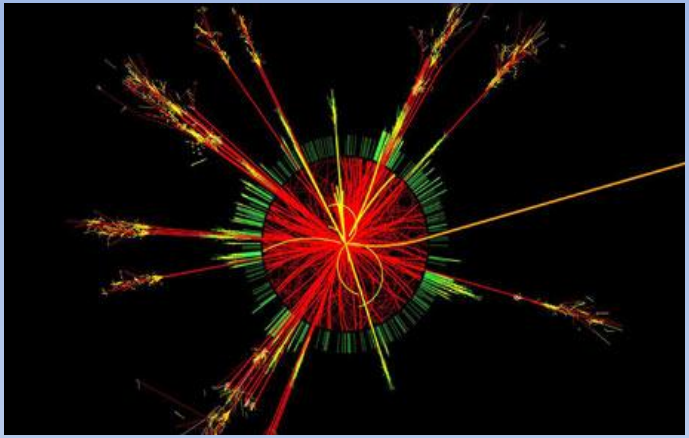

Chiral-symmetric strongly coupled sectors at the LHC

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Based on:

RP, V. Kuksa, V. Beylin, and G. Vereshkov
arXiv:1304.2081

CERN, April 11th, 2013

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- High-scale confinement: QCD analog?
- Gauged linear T-sigma model
- Physical Lagrangian
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Physical CSTC Lagrangian

$$L_{\bar{\tilde{Q}}\tilde{Q}V} = \frac{1}{\sqrt{2}} g\bar{U}\gamma^\mu D \cdot W_\mu^+ + \frac{1}{\sqrt{2}} g\bar{D}\gamma^\mu U \cdot W_\mu^- + \frac{g}{c_W} Z_\mu \sum_{f=U,D} \bar{f}\gamma^\mu (t_3^f - q_f\, s_W^2) f + e \sum_{f=U,D} q_f\, \bar{f}\gamma^\mu A_\mu f$$

$$L_{\bar{\tilde{Q}}\tilde{Q}h} + L_{\bar{\tilde{Q}}\tilde{Q}\tilde{\sigma}} + L_{\bar{\tilde{Q}}\tilde{Q}\tilde{\pi}} = -g_{\rm TC}\,(c_\theta \tilde{\sigma} + s_\theta h) \cdot (\bar{U}U + \bar{D}D) -i\sqrt{2} g_{\rm TC}\, \tilde{\pi}^+ \bar{U}\gamma_5 D - i\sqrt{2} g_{\rm TC}\, \tilde{\pi}^- \bar{D}\gamma_5 U - i g_{\rm TC}\, \tilde{\pi}^0 (\bar{U}\gamma_5 U - \bar{D}\gamma_5 D)$$

$$L_{\tilde{\pi}\tilde{\pi}V} = igW^{\mu+} \cdot (\tilde{\pi}^0 \tilde{\pi}^-_{,\mu} - \tilde{\pi}^- \tilde{\pi}^0_{,\mu}) + igW^{\mu-} \cdot (\tilde{\pi}^+ \tilde{\pi}^0_{,\mu} - \tilde{\pi}^0 \tilde{\pi}^+_{,\mu}) + ig(c_W Z_\mu + s_W A_\mu) \cdot (\tilde{\pi}^- \tilde{\pi}^+_{,\mu} - \tilde{\pi}^+ \tilde{\pi}^-_{,\mu}) + g^2\, W_\mu^+ W^{\mu-} \cdot (\tilde{\pi}^0 \tilde{\pi}^0 + \tilde{\pi}^+ \tilde{\pi}^-) + g^2\,(c_W Z_\mu + s_W A_\mu)^2 \cdot \tilde{\pi}^+ \tilde{\pi}^-$$

$$L_{\bar{f}fh} + L_{\bar{f}f\tilde{\sigma}} = -g(c_\theta h - s_\theta \tilde{\sigma}) \cdot \frac{m_f}{2M_W} \bar{f}f$$

$$L_{h\tilde{\pi}\tilde{\pi}} = -(\lambda_{\rm TC} u\, s_\theta - \lambda v c_\theta)\, h(\tilde{\pi}^0\tilde{\pi}^0 + 2\tilde{\pi}^+\tilde{\pi}^-) = -\frac{M_h^2 - m_{\tilde{\pi}}^2}{2M_{\tilde{Q}}}\, g_{\rm TC} s_\theta\, h(\tilde{\pi}^0\tilde{\pi}^0 + 2\tilde{\pi}^+\tilde{\pi}^-)$$

$$L_{hWW} + L_{hZZ} = gM_W c_\theta\, hW_\mu^+ W^{\mu-} + \frac{1}{2}(g^2 + g_1^2)^{1/2} M_Z c_\theta\, hZ_\mu Z^\mu \ .$$

$$L_{\tilde{\sigma}\tilde{\pi}\tilde{\pi}} = -(\lambda_{\rm TC} u c_\theta + \lambda v s_\theta)\, \tilde{\sigma}(\tilde{\pi}^0\tilde{\pi}^0 + 2\tilde{\pi}^+\tilde{\pi}^-) = -\frac{M_{\tilde{\sigma}}^2 - m_{\tilde{\pi}}^2}{2M_{\tilde{Q}}}\, g_{\rm TC} c_\theta\, \tilde{\sigma}(\tilde{\pi}^0\tilde{\pi}^0 + 2\tilde{\pi}^+\tilde{\pi}^-)$$

$$L_{\tilde{\sigma}WW} + L_{\tilde{\sigma}ZZ} = -gM_W s_\theta\, \tilde{\sigma} W_\mu^+ W^{\mu-} - \frac{1}{2}(g^2 + g_1^2)^{1/2} M_Z s_\theta\, \tilde{\sigma} Z_\mu Z^\mu \ .$$

+ more ….

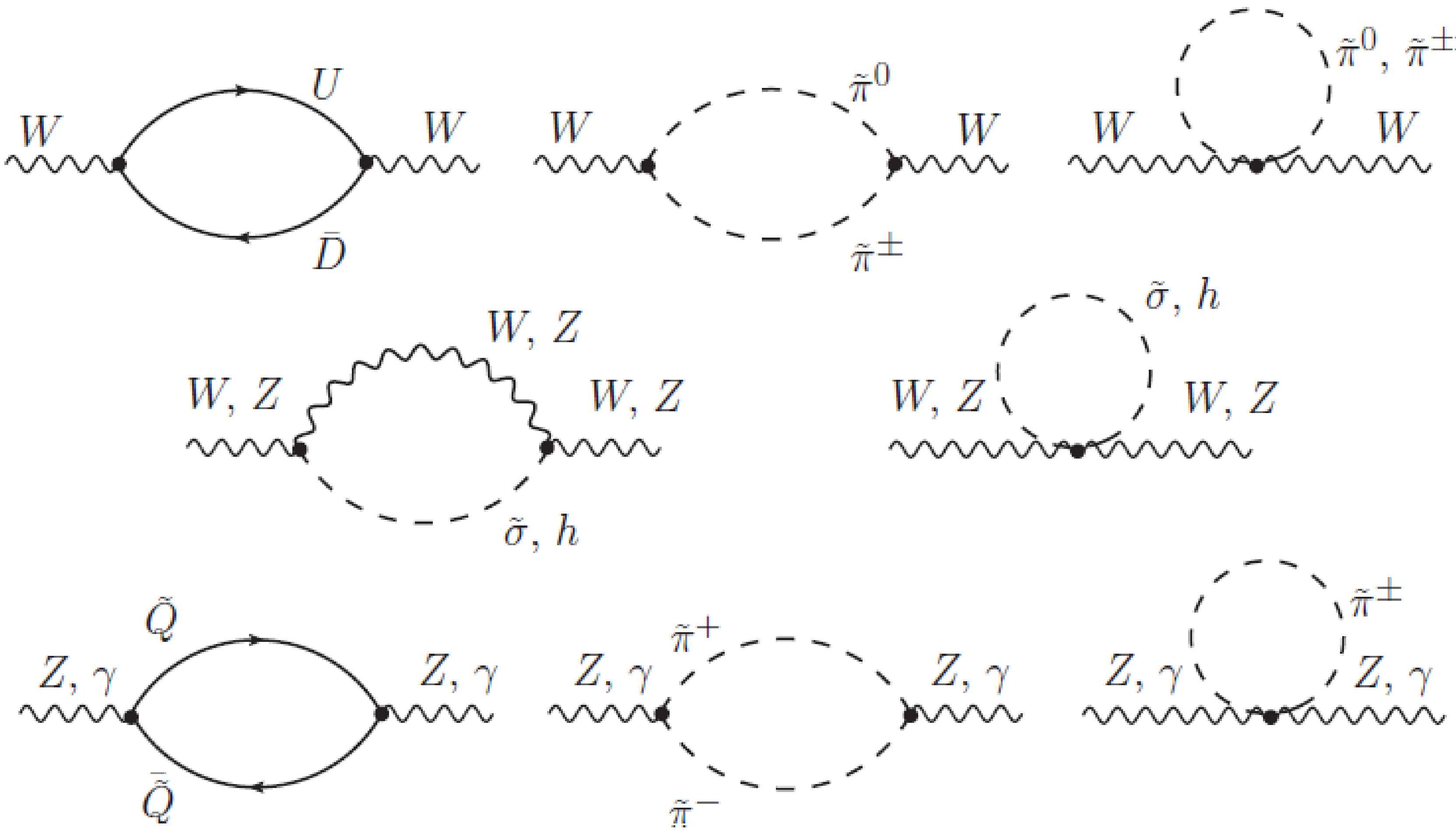
Oblique corrections: definitions

$$\delta\Pi_{\mathrm{XY}}(q^2) \equiv \Pi^{\mathrm{NP}}_{\mathrm{XY}}(q^2) - \Pi^{\mathrm{SM}}_{\mathrm{XY}}(q^2)$$

$$\begin{aligned}
\frac{\alpha}{4s_W^2c_W^2}\,S &= \frac{\delta\Pi_{ZZ}(M_Z^2)-\delta\Pi_{ZZ}(0)}{M_Z^2} - \frac{c_W^2-s_W^2}{c_Ws_W}\delta\Pi'_{Z\gamma}(0) - \delta\Pi'_{\gamma\gamma}(0)\,, \\
\alpha\,T &= \frac{\delta\Pi_{WW}(0)}{M_W^2} - \frac{\delta\Pi_{ZZ}(0)}{M_Z^2}\,, \\
\frac{\alpha}{4s_W^2}\,U &= \frac{\delta\Pi_{WW}(M_W^2)-\delta\Pi_{WW}(0)}{M_W^2} - c_W^2\,\frac{\delta\Pi_{ZZ}(M_Z^2)-\delta\Pi_{ZZ}(0)}{M_Z^2} \\
&\quad - s_W^2\delta\Pi'_{\gamma\gamma}(0) - 2c_Ws_W\delta\Pi'_{Z\gamma}(0)\,.
\end{aligned}$$

$$\begin{aligned}
\alpha V &= \delta\Pi'_{ZZ}(M_Z^2) - \frac{\delta\Pi_{ZZ}(M_Z^2)-\delta\Pi_{ZZ}(0)}{M_Z^2}\,, \\
\alpha W &= \delta\Pi'_{WW}(M_W^2) - \frac{\delta\Pi_{WW}(M_W^2)-\delta\Pi_{WW}(0)}{M_W^2}\,, \\
\alpha X &= -s_Wc_W\left[\frac{\delta\Pi_{Z\gamma}(M_Z^2)}{M_Z^2} - \delta\Pi'_{Z\gamma}(0)\right].
\end{aligned}$$

Oblique corrections: contributions



Oblique corrections: degenerated Q + "no mixing"

$$\Pi^{\tilde\pi}_{\rm XY}(q^2,m^2_{\tilde\pi}) = \frac{g^2}{24\pi^2}\,K_{\rm XY}\,F_{\tilde\pi}(q^2,m^2_{\tilde\pi})\,, \quad \Pi^{\tilde Q}_{\rm XY}(q^2,M^2_{\tilde Q}) = \frac{g^2 N_c}{24\pi^2}\,K_{\rm XY}\,\kappa_{\rm XY}\,F_{\tilde Q}(q^2,M^2_{\tilde Q})$$

$K,\ \kappa$	WW	ZZ	$\gamma\gamma$	$Z\gamma$
$K_{\rm XY}$	1	c_W^2	s_W^2	$c_W\,s_W$
$\kappa_{\rm XY},\ Y_{\tilde Q}=0$	1	1	1	1
$\kappa_{\rm XY},\ Y_{\tilde Q}=1/3$	1	$1+s_W^4/9c_W^4$	$10/9$	$1-s_W^2/9c_W^2$

$$F_{\tilde\pi}(q^2,m^2_{\tilde\pi}) = \frac{1}{3}q^2 - 2m^2_{\tilde\pi} + 2A_0(m^2_{\tilde\pi}) + \frac{1}{2}(q^2-4m^2_{\tilde\pi})B_0(q^2,m^2_{\tilde\pi},m^2_{\tilde\pi})\,,$$

$$F_{\tilde Q}(q^2,M^2_{\tilde Q}) = -\frac{1}{3}q^2 + 2M^2_{\tilde Q} - 2A_0(M^2_{\tilde Q}) + (q^2+2M^2_{\tilde Q})B_0(q^2,M^2_{\tilde Q},M^2_{\tilde Q})$$

$$B_0(0,m^2,m^2) = \frac{A_0(m^2)}{m^2} - 1\,, \qquad A_0(m^2) = m^2\left(\frac{1}{\bar\varepsilon} + 1 - \ln\frac{m^2}{\mu^2}\right)$$

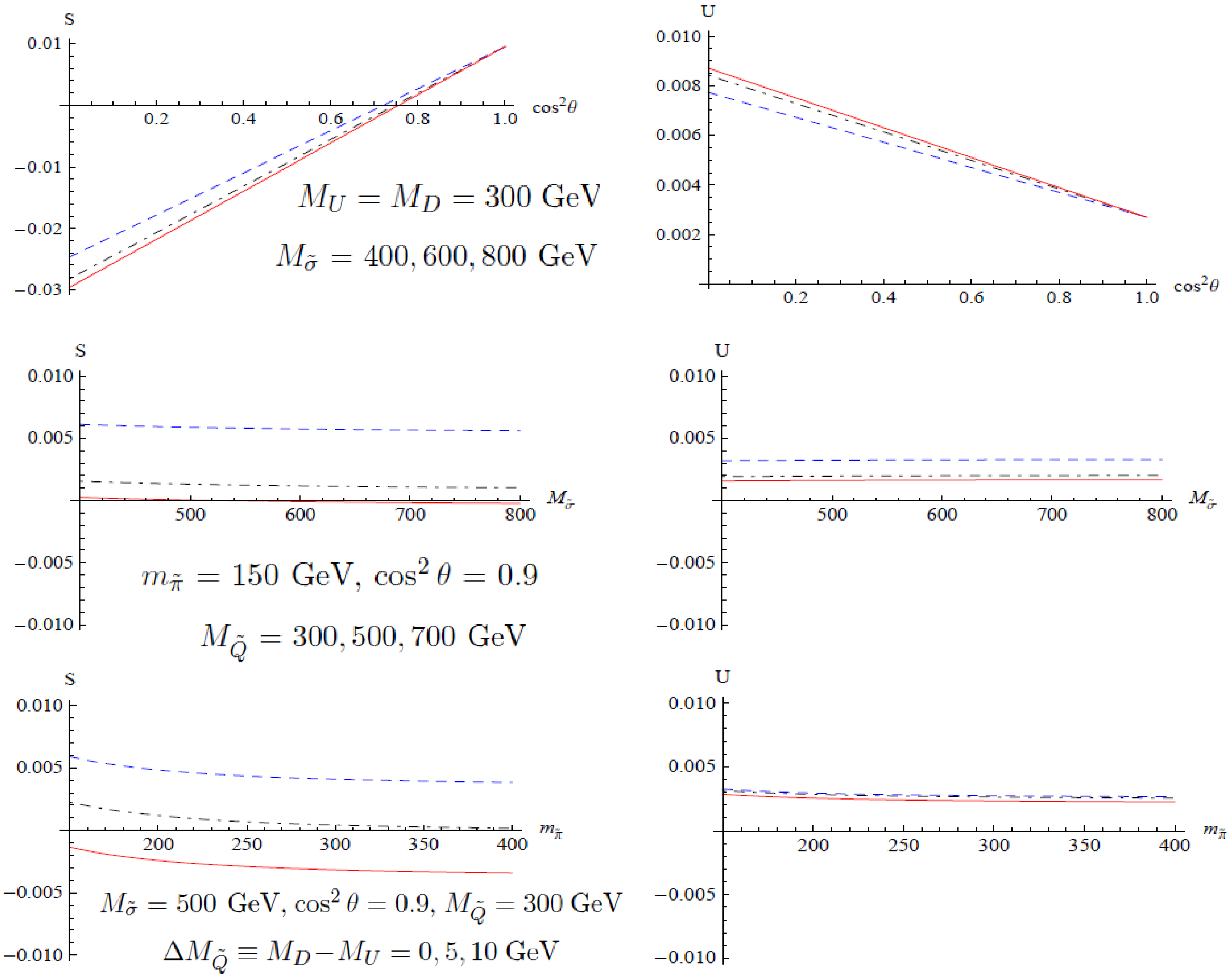
$$F_{\tilde\pi}(0,m^2_{\tilde\pi}) = 0 \text{ and } F_{\tilde Q}(0,M^2_{\tilde Q}) = 0 \qquad T^{\tilde\pi} = T^{\tilde Q} = 0$$

$$\frac{\alpha\,S^{\tilde\pi+\tilde Q}}{4s_W^2c_W^2} = \frac{1}{M_Z^2}\,\frac{g^2}{24\pi^2}\left[F_{\tilde\pi}(q^2,m^2_{\tilde\pi}) + N_{\rm TC}\,F_{\tilde Q}(q^2,M^2_{\tilde Q})\right]\cdot\left[c_W^2 - \frac{c_W^2-s_W^2}{c_W\,s_W}\cdot c_W\,s_W - s_W^2\right] = 0,$$

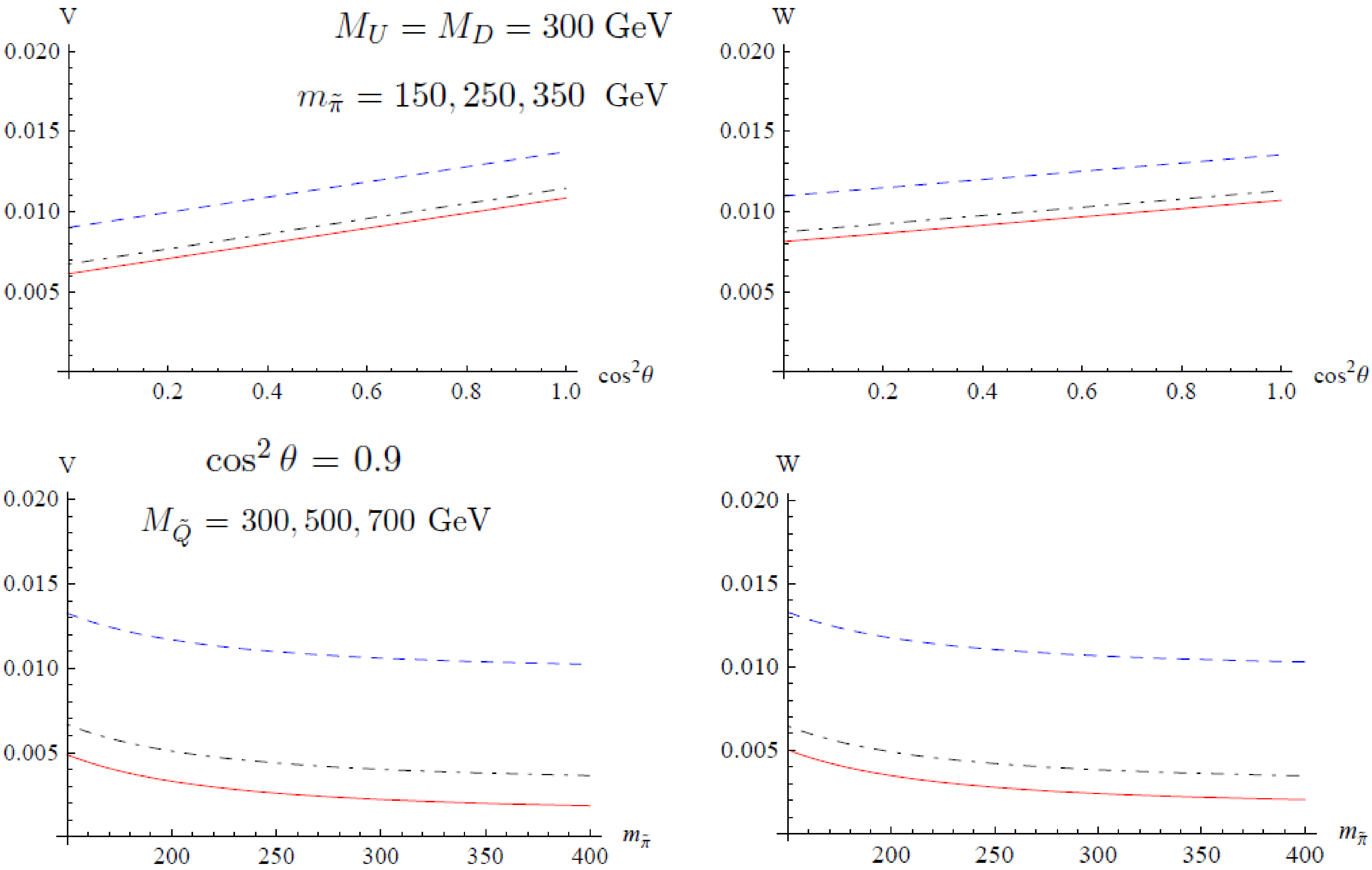
$$\frac{\alpha\,U^{\tilde\pi+\tilde Q}}{4s_W^2} = \frac{1}{M_Z^2}\,\frac{g^2}{24\pi^2}\left[F_{\tilde\pi}(q^2,m^2_{\tilde\pi}) + N_{\rm TC}\,F_{\tilde Q}(q^2,M^2_{\tilde Q})\right]\cdot\left[1 - c_W^4 - s_W^4 - 2c_W^2s_W^2\right] = 0\,.$$

$$Y_{\tilde Q} = 0$$

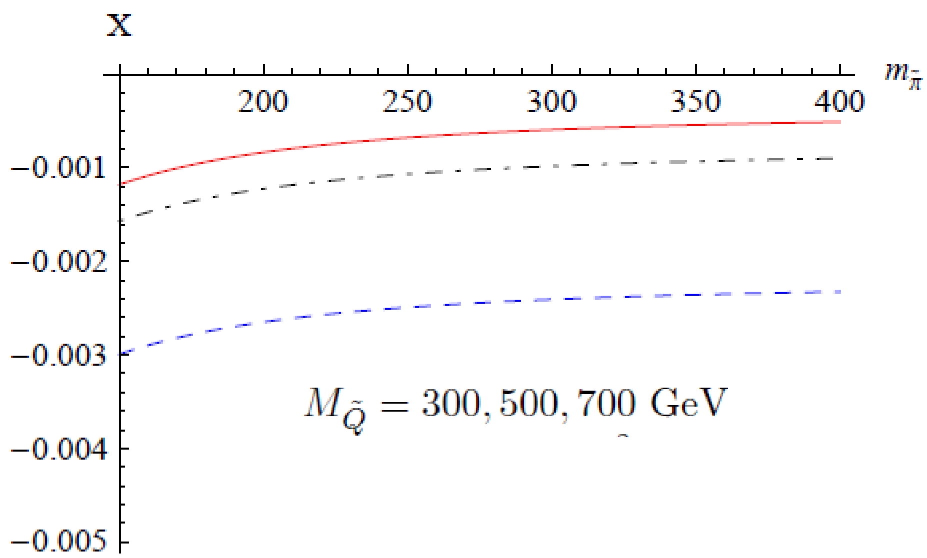
Oblique corrections: complete Y_Q=1/3

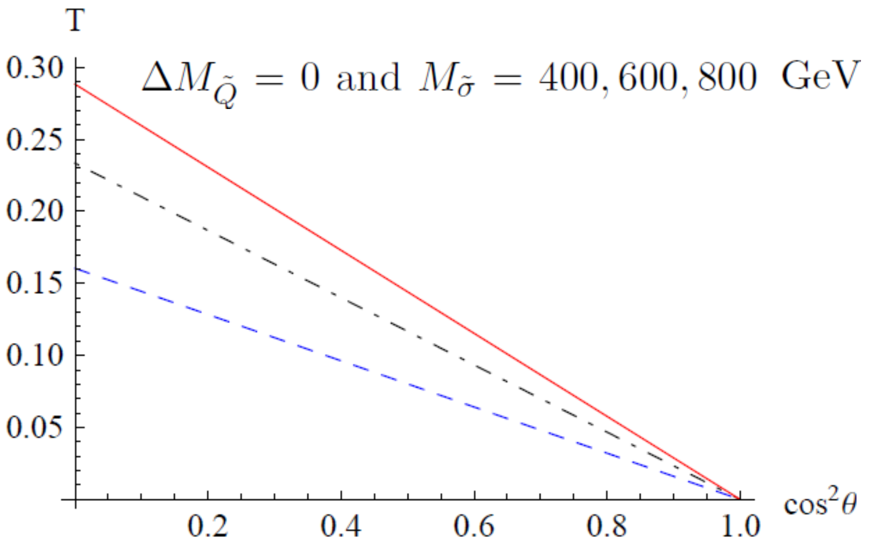


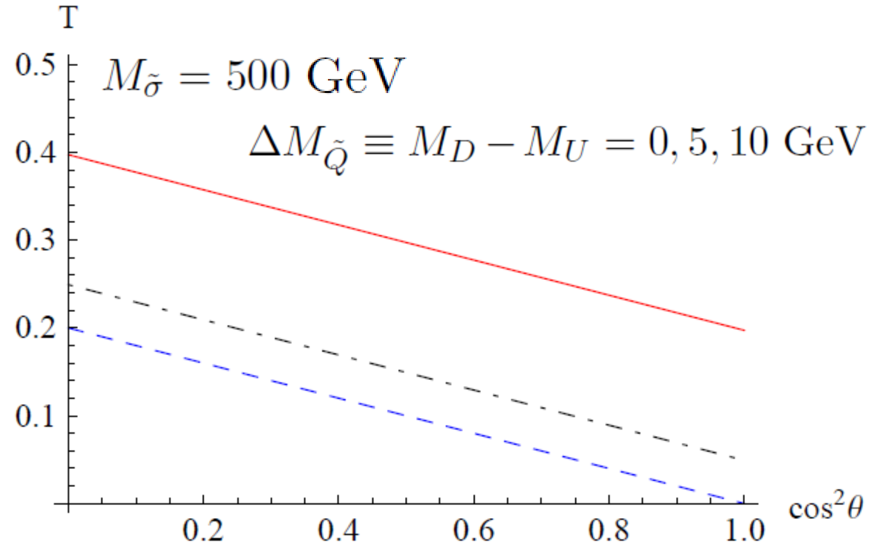
Oblique corrections: complete Y_Q=1/3



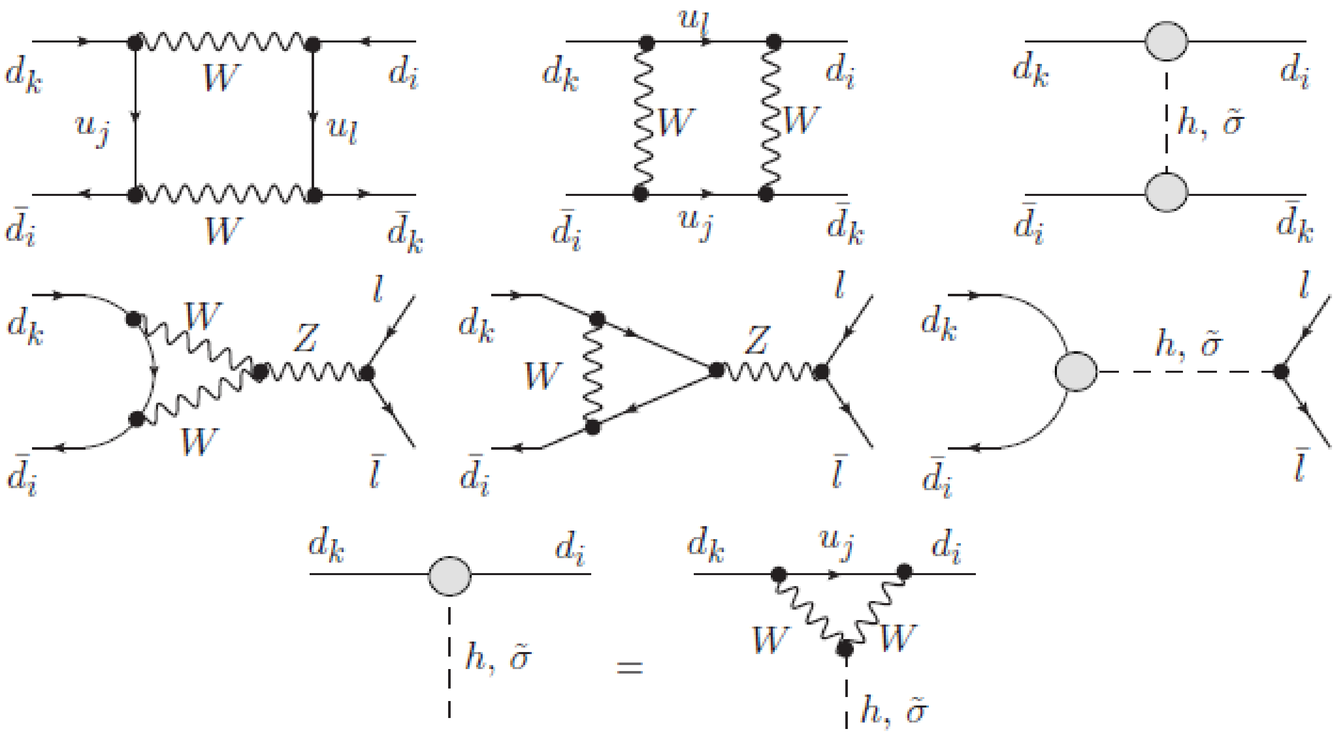
Oblique corrections: complete Y_Q=1/3







FCNC



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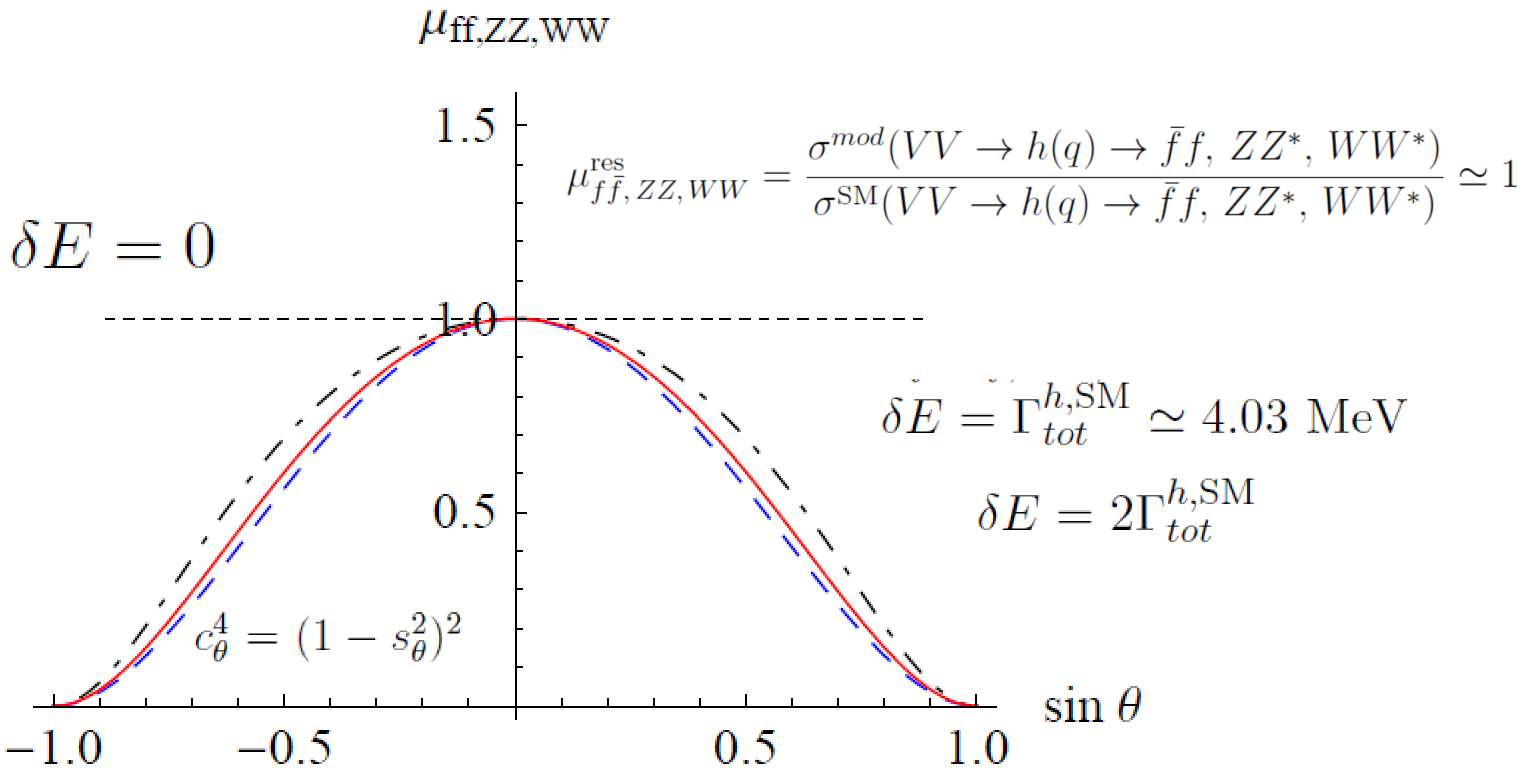
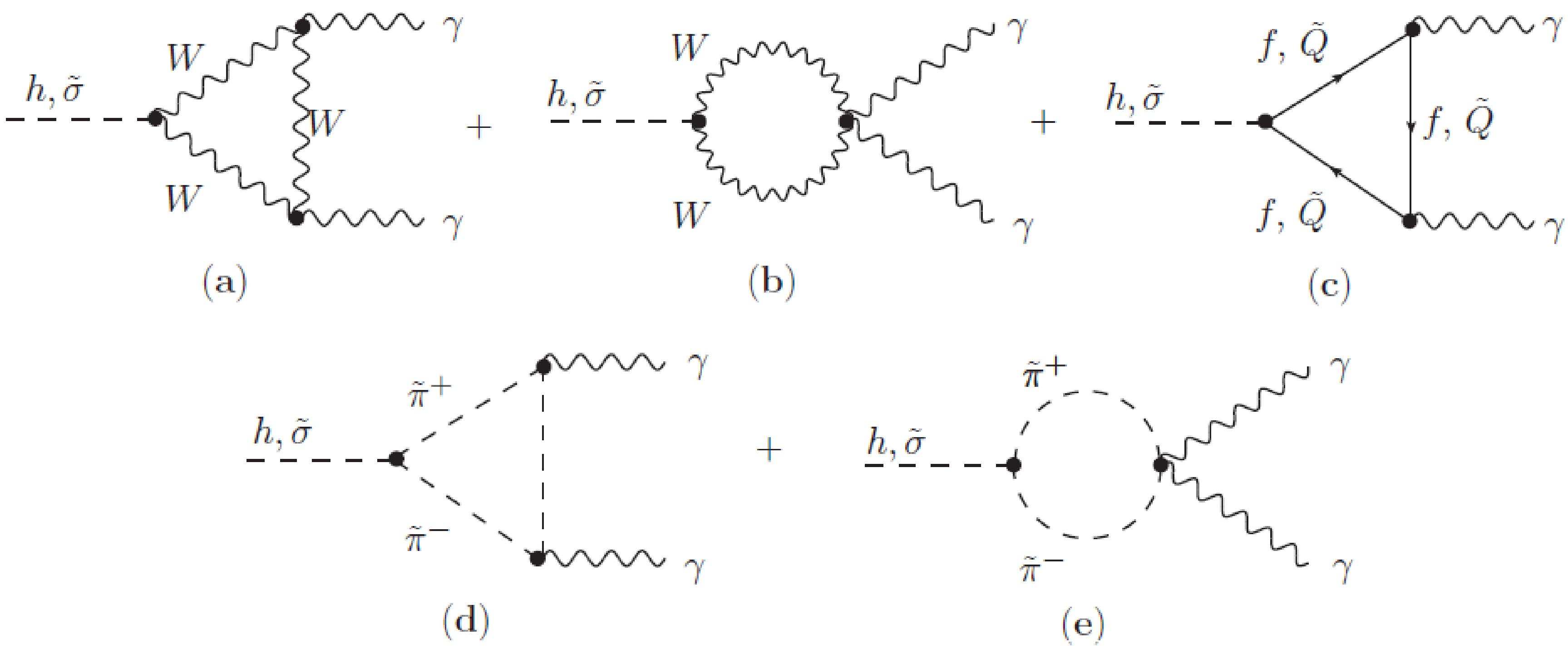
Higgs signal strength: Born channels



$$\mu_{\rm XY}(\delta E) = \frac{\int_{M_h-\delta E}^{M_h+\delta E} \sigma^{mod}_{\rm XY}(q)dq}{\int_{M_h-\delta E}^{M_h+\delta E} \sigma^{\rm SM}_{\rm XY}(q)dq}$$

Higgs signal strength: loop-induced γγ

$$\mu_{\gamma\gamma}^{\rm res} = \frac{\sigma^{mod}(h \to \gamma\gamma)}{\sigma^{\rm SM}(h \to \gamma\gamma)} \simeq \frac{1}{c_\theta^2}\frac{\Gamma^{mod}(h \to \gamma\gamma)}{\Gamma^{\rm SM}(h \to \gamma\gamma)} \simeq \frac{1}{c_\theta^2}\frac{|A_W + A_f + A_{\tilde{\pi}} + A_{\tilde{Q}}|^2}{|A_W^{\rm SM} + A_f^{\rm SM}|^2}$$



Higgs signal strength: loop-induced γγ

$$\Gamma^{mod}(h \to \gamma\gamma) = \frac{\alpha^2 M_h}{16\pi^3} \cdot |F_W + F_{top} + F_{\tilde{\pi}} + F_{\tilde{Q}}|^2$$

$$F_W = \frac{1}{8}\, g\, c_\theta\, \frac{M_h}{M_W} \cdot \left[2 + 3\beta_W + 3\beta_W(2 - \beta_W) f(\beta_W)\right],$$

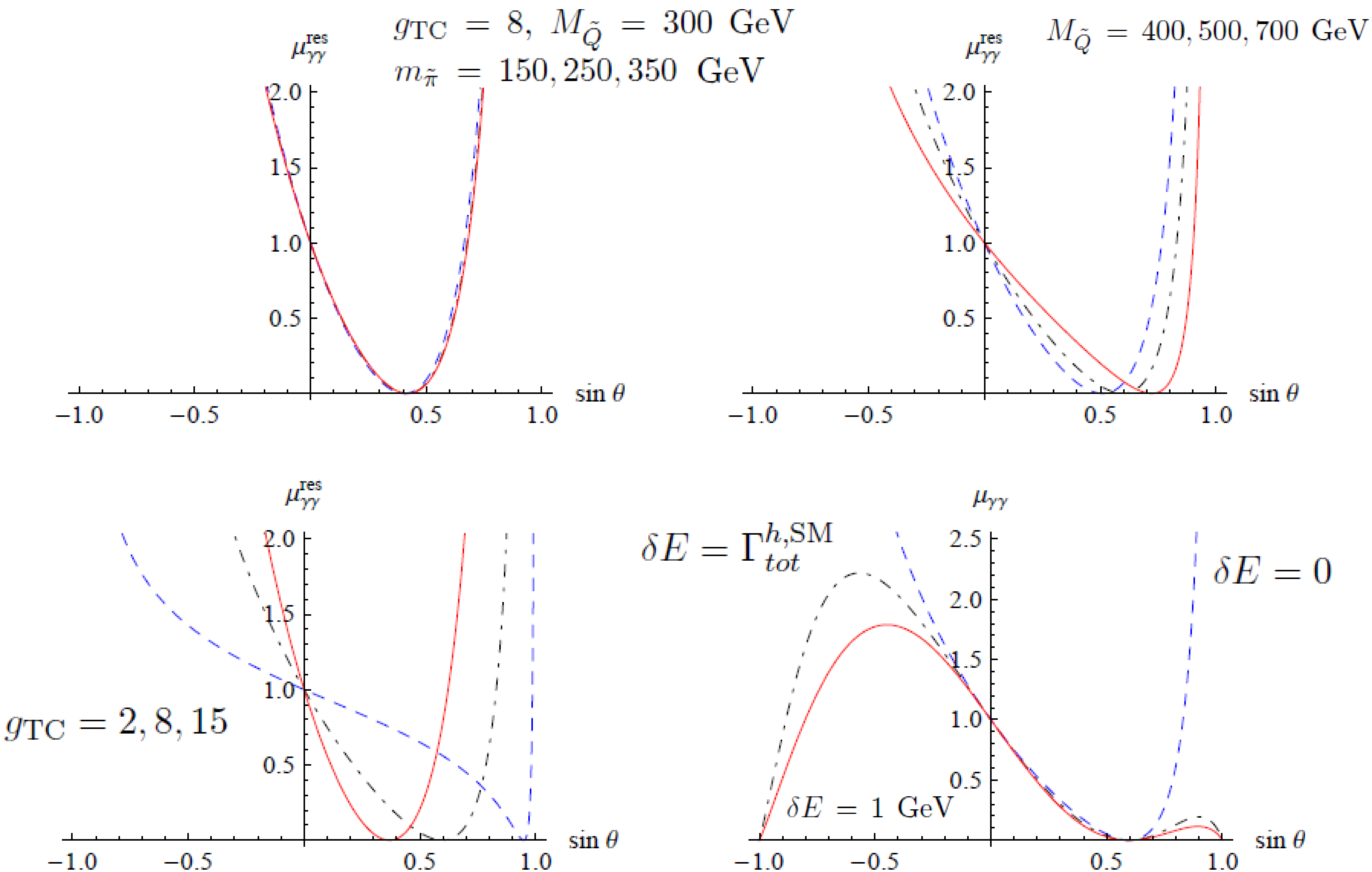
$$F_{top} = -\frac{4}{3}\, g\, c_\theta\, \frac{m_{top}^2}{M_h M_W} \left[1 + (1 - \beta_{top}) f(\beta_{top})\right],$$

$$F_{\tilde{\pi}} = -\frac{g_{h\tilde{\pi}}}{2M_h} \left[1 - \beta_{\tilde{\pi}} f(\beta_{\tilde{\pi}})\right], \qquad g_{h\tilde{\pi}} = -2(\lambda_{\mathrm{TC}}\, u s_\theta - \lambda\, v c_\theta),$$

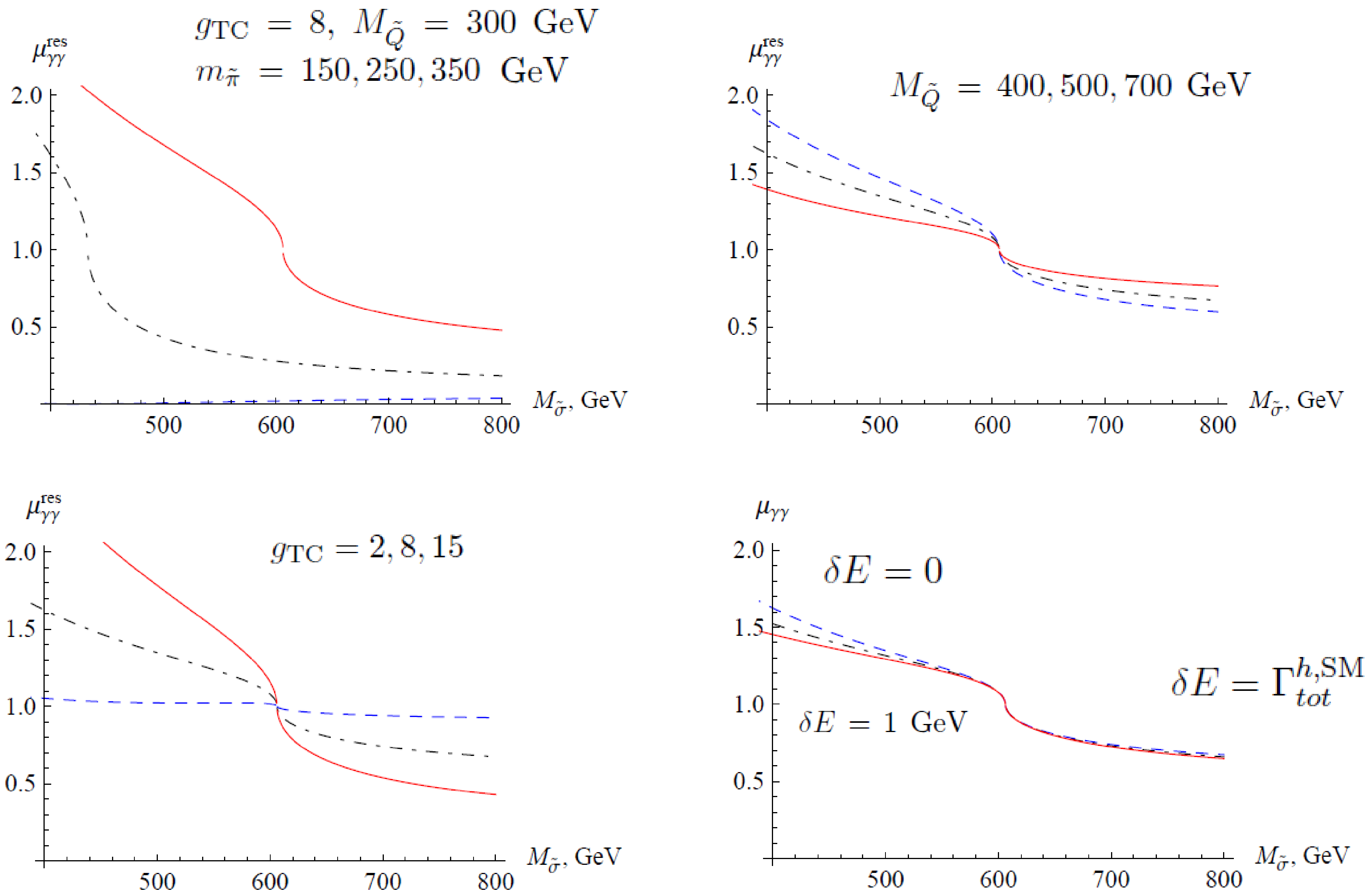
$$F_{\tilde{Q}} = -2N_{\mathrm{TC}}(q_U^2 + q_D^2)\, g_{\mathrm{TC}}\, s_\theta\, \frac{M_{\tilde{Q}}}{M_h} \left[1 + (1 - \beta_{\tilde{Q}}) f(\beta_{\tilde{Q}})\right],$$

$$f(\beta) = \arcsin^2 \frac{1}{\sqrt{\beta}} \qquad \beta_X = \frac{4m_X^2}{M_h^2}, \qquad X = W,\ \mathrm{top},\ \tilde{\pi},\ \tilde{Q}$$

Higgs signal strength: loop-induced γγ

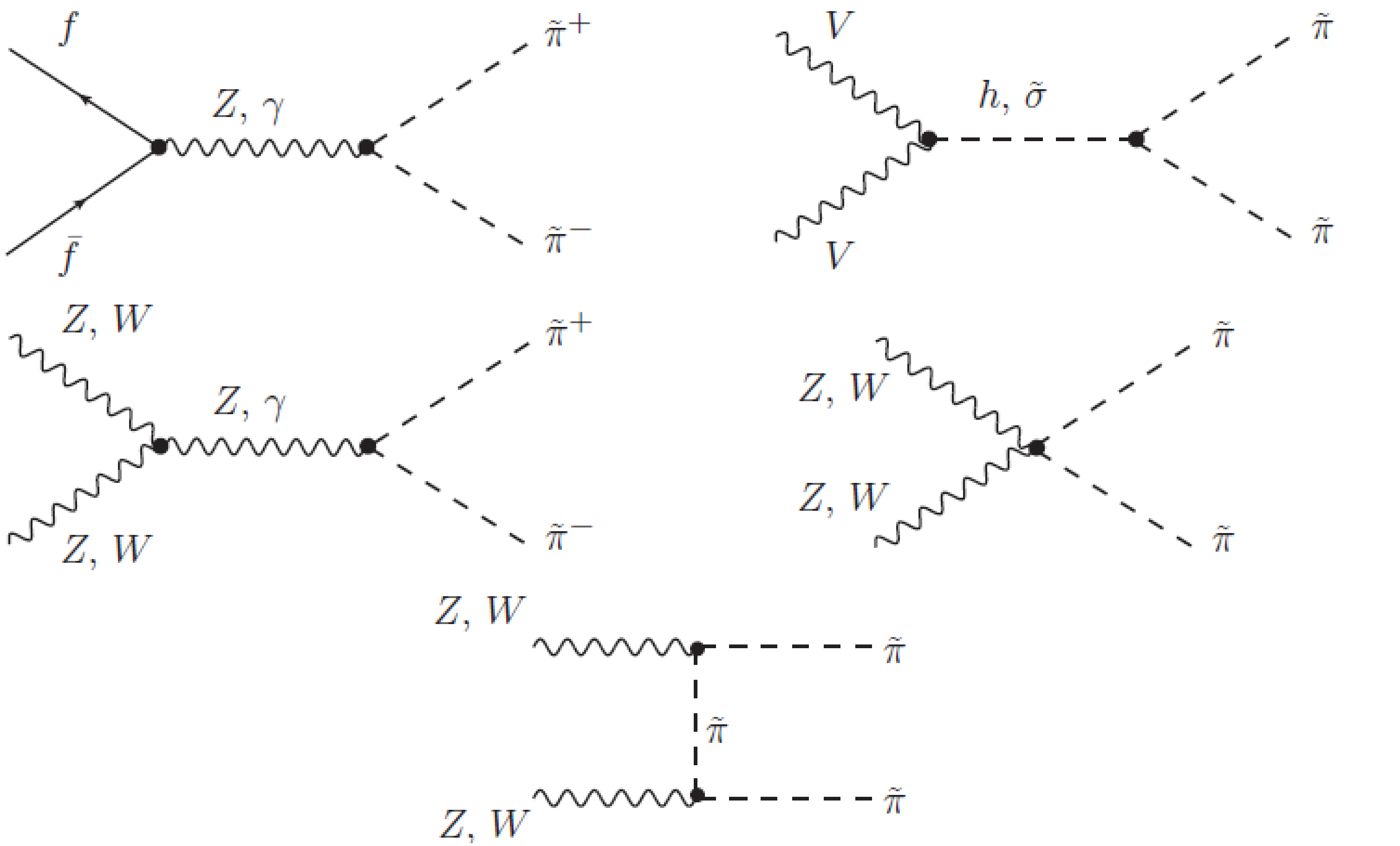


Higgs signal strength: loop-induced γγ (minimal CSTC)



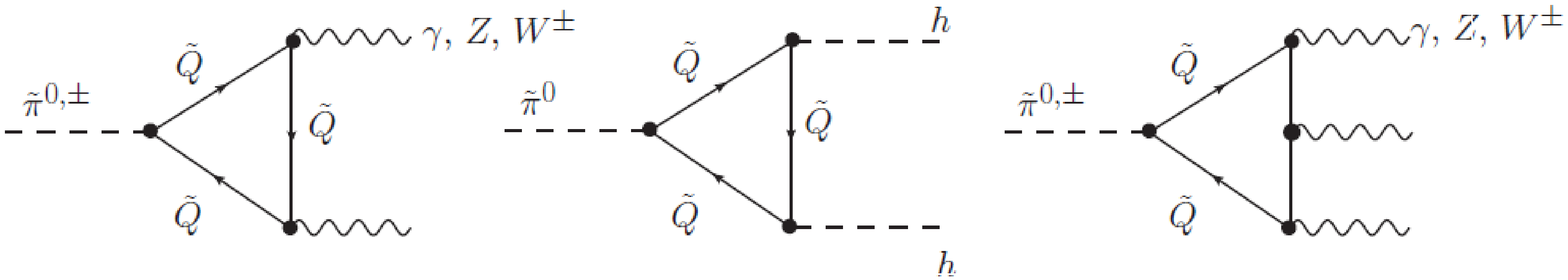
T-Pion production

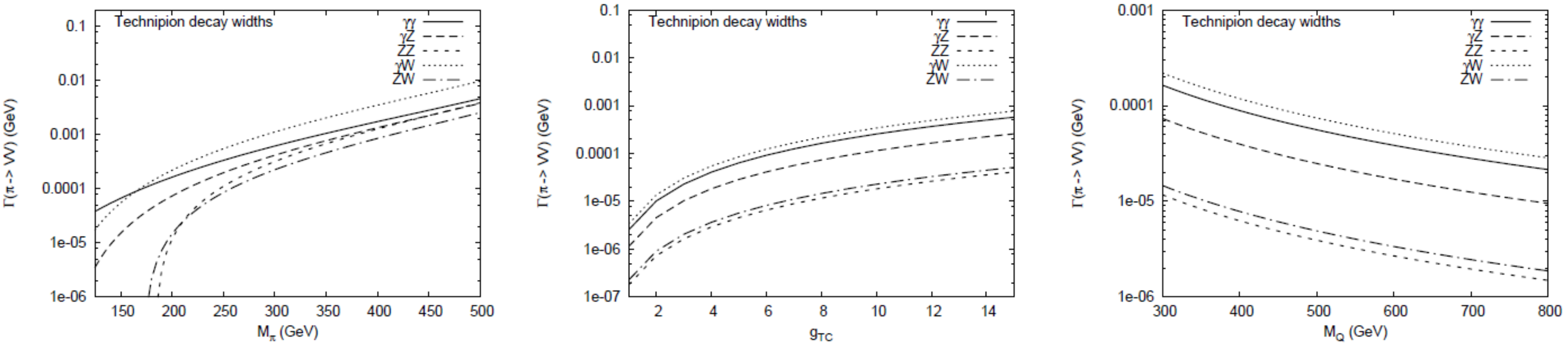
$$s_\theta^2 \ll 1 \qquad g_{\tilde{\pi}\tilde{\pi}\tilde{\sigma}} = -g_{\mathrm{TC}} c_\theta \frac{M_\sigma^2 - M_{\tilde{\pi}}}{2M_{\tilde{Q}}}$$



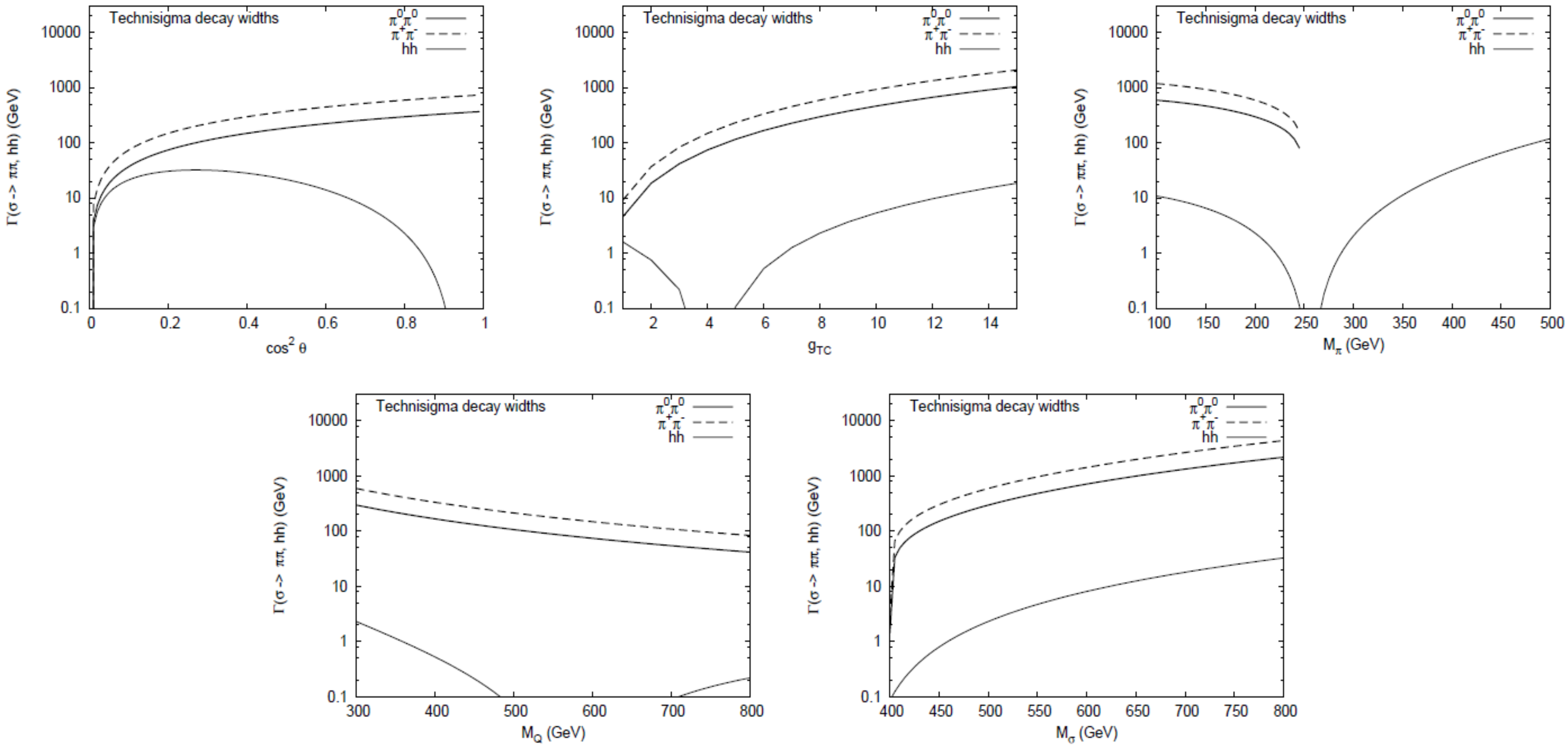
T-Pion decay

$$Y_{\tilde{Q}} = 0$$



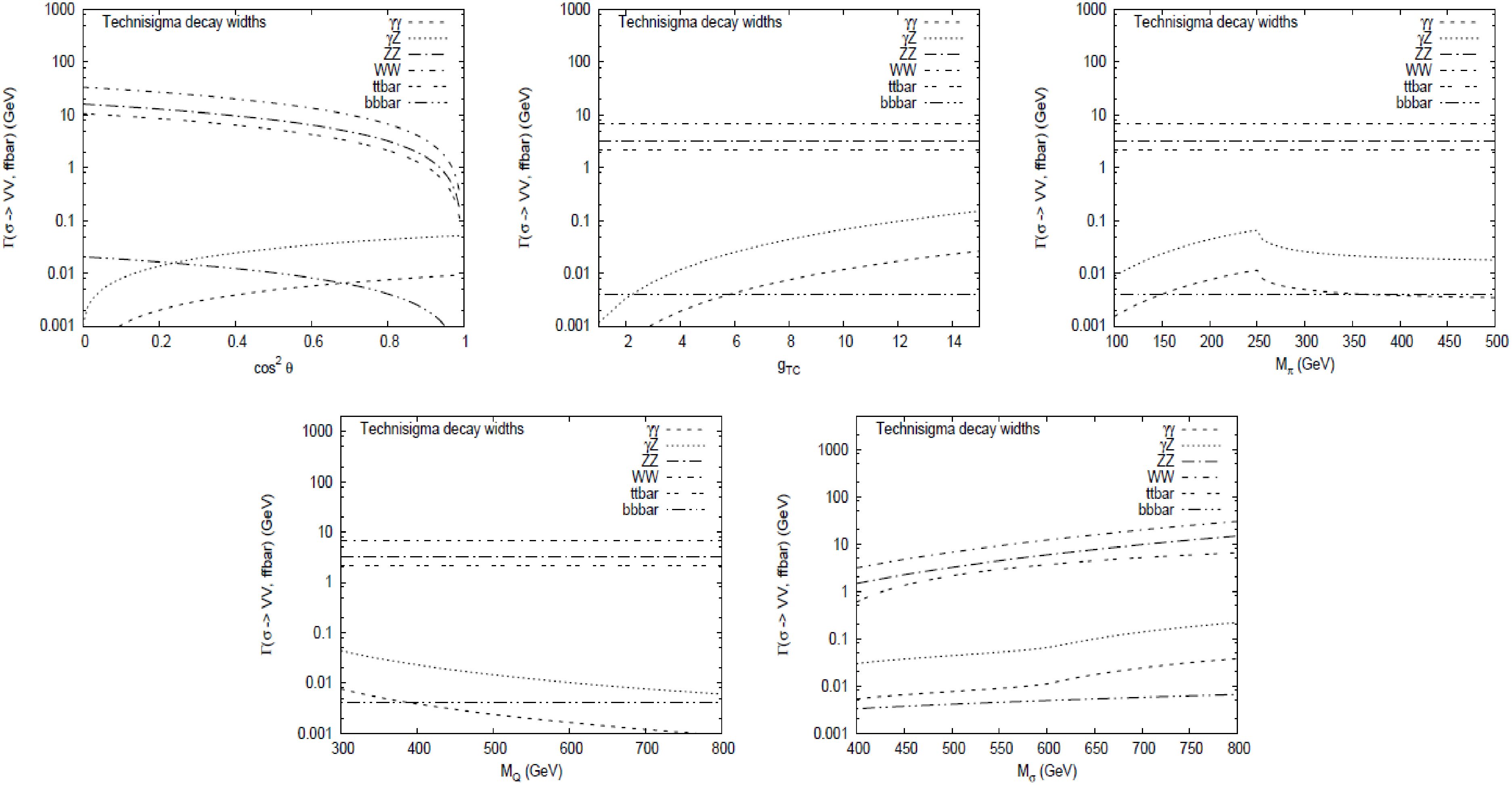


T-sigma decay



$$m_{\tilde{\pi}} = 200 \text{ GeV},\ M_{\tilde{Q}} = 300 \text{ GeV},\ M_{\tilde{\sigma}} = 500 \text{ GeV},\ c_\theta^2 = 0.8 \quad g_{\rm TC} = 8$$

T-sigma decay



$$m_{\tilde{\pi}} = 200 \text{ GeV},\ M_{\tilde{Q}} = 300 \text{ GeV},\ M_{\tilde{\sigma}} = 500 \text{ GeV},\ c_\theta^2 = 0.8 \quad g_{\text{TC}} = 8$$

....discussions

- The CSTC with light T-pions and T-sigma has been considered. It is based on an assumption about the existence of the strongly-coupled sector at LHC energy scales. It preserves standard Higgs mechanism of the SM;
- The model survives EW precision/FCNC/SM-like Higgs observations;
- Higgs-like vacuum condensates might have a TC origin. They can be expressed through T-fermion condensates;
- T-sigma – Higgs mixing/T-fermions may lead to a modification of the SM Higgs boson couplings and consistent with current data;
- The model provides rich TC phenomenology at the LHC by means of T-pions/T-sigma production and decays, as well as loop-induced effects from T-fermion loops;
- There is an interesting possibility to identify the neutral lightest T-hadron (T-baryon) state as a Dark Matter candidate.