Correlation between the decays of h^0 to photon and gluon pairs in the MSSM with quark flavour violation

Helmut Eberl
HEPHY Vienna

work in progress

with K. Hidaka, E. Ginina and A. Bartl

Scalars 2017
Warsaw, Poland

Contents

- Introduction
- General quark-flavour mixing in the MSSM
- Experimental errors
- Numerics
- EFT κ – framework
- Conclusions

Introduction

- Higgs boson discovered – behaves like the Higgs boson in the SM
- Detailed study of Higgs properties – BSM physics?
- Although there is no sign of new particles yet, the MSSM is still favored as a discoverable theory beyond the SM and will be searched with high priority at LHC
- Discovered Higgs boson could be h^0 of the MSSM
- Despite the stringent constraints from B and K physics, quark-flavour violation (QFV) in the squark sector can change phenomenological observables significantly
- Loop induced decays of h^0 to $\gamma\,\gamma$ and h^0 to g g are sensitive to BSM physics
- Decay rates of these processes are studied in terms of QFV parameters
- MSSM scans done respecting all theoretical and experimental constraints
- EFT framework (in progress)
- Measurability of deviation from the SM discussed

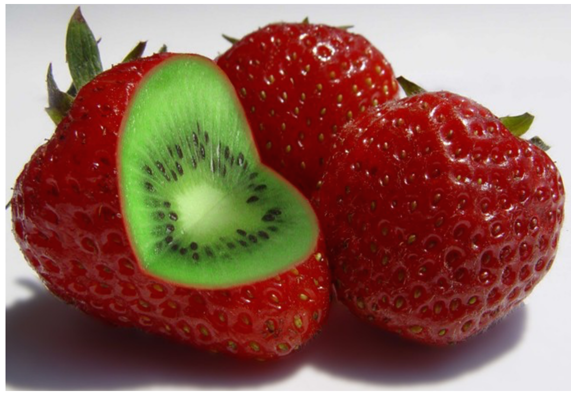
General quark-flavour mixing in the MSSM

- In the SM all QFV terms are within the CKM matrix
- In the general MSSM there are two concepts:

  * Minimal quark flavour violation - no new sources of QFV, in the super-CKM basis the squarks undergo the same rotations like the quarks, all flavour violating entries are related to the CKM matrix

  * Non-minimal quark flavour violation - new sources of QFV, independent on the CKM, considered as free parameters in the theory

- In the following we assume non-minimal quark flavour violation



- The flavour-violating terms are contained in the mass matrices of the squarks at the electroweak scale

$$\mathcal{M}^2_{\tilde{q}} = \begin{pmatrix} \mathcal{M}^2_{\tilde{q},LL} & \mathcal{M}^2_{\tilde{q},LR} \\ \mathcal{M}^2_{\tilde{q},RL} & \mathcal{M}^2_{\tilde{q},RR} \end{pmatrix}, q = u, d$$

- The 3x3 soft SUSY-breaking matrices can introduce QFV (off-diagonal) terms, e.g. in the up-squark sector

$$\begin{aligned}
(M^2_{\tilde{u}LL})_{\alpha\beta} &= M^2_{Q_u\alpha\beta} + \left[(\tfrac{1}{2} - \tfrac{2}{3}\sin^2\theta_W)\cos 2\beta\ m_Z^2 + m^2_{u_\alpha}\right]\delta_{\alpha\beta} \\
(M^2_{\tilde{u}RR})_{\alpha\beta} &= M^2_{U\alpha\beta} + \left[\tfrac{2}{3}\sin^2\theta_W\cos 2\beta\ m_Z^2 + m^2_{u_\alpha}\right]\delta_{\alpha\beta} \\
(M^2_{\tilde{u}RL})_{\alpha\beta} &= (v_2/\sqrt{2})\, T_{U\alpha\beta} - m_{u_\alpha}\mu^*\cot\beta\ \delta_{\alpha\beta}
\end{aligned}$$

- The mass eigenstates are obtained after diagonalization with a 6x6 rotation matrix

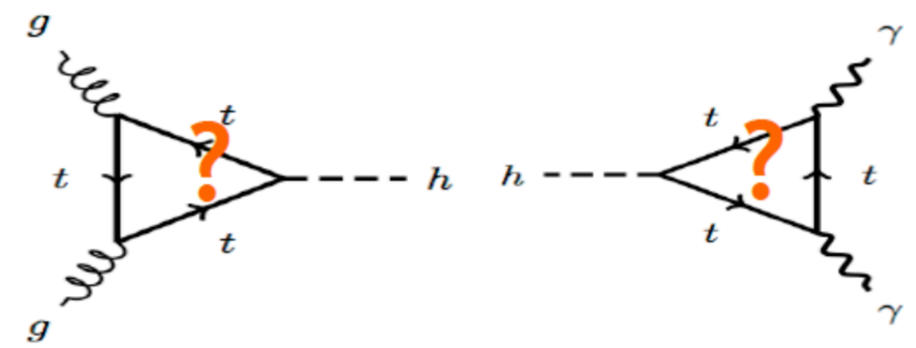
$$\begin{pmatrix} \tilde{u}_1 \\ \tilde{u}_2 \\ \tilde{u}_3 \\ \tilde{u}_4 \\ \tilde{u}_5 \\ \tilde{u}_6 \end{pmatrix} = U^{\tilde{u}}. \begin{pmatrix} \tilde{u}_L \\ \tilde{c}_L \\ \tilde{t}_L \\ \tilde{u}_R \\ \tilde{c}_R \\ \tilde{t}_R \end{pmatrix} \qquad \begin{pmatrix} \tilde{d}_1 \\ \tilde{d}_2 \\ \tilde{d}_3 \\ \tilde{d}_4 \\ \tilde{d}_5 \\ \tilde{d}_6 \end{pmatrix} = U^{\tilde{d}}. \begin{pmatrix} \tilde{d}_L \\ \tilde{s}_L \\ \tilde{b}_L \\ \tilde{d}_R \\ \tilde{s}_R \\ \tilde{b}_R \end{pmatrix}$$

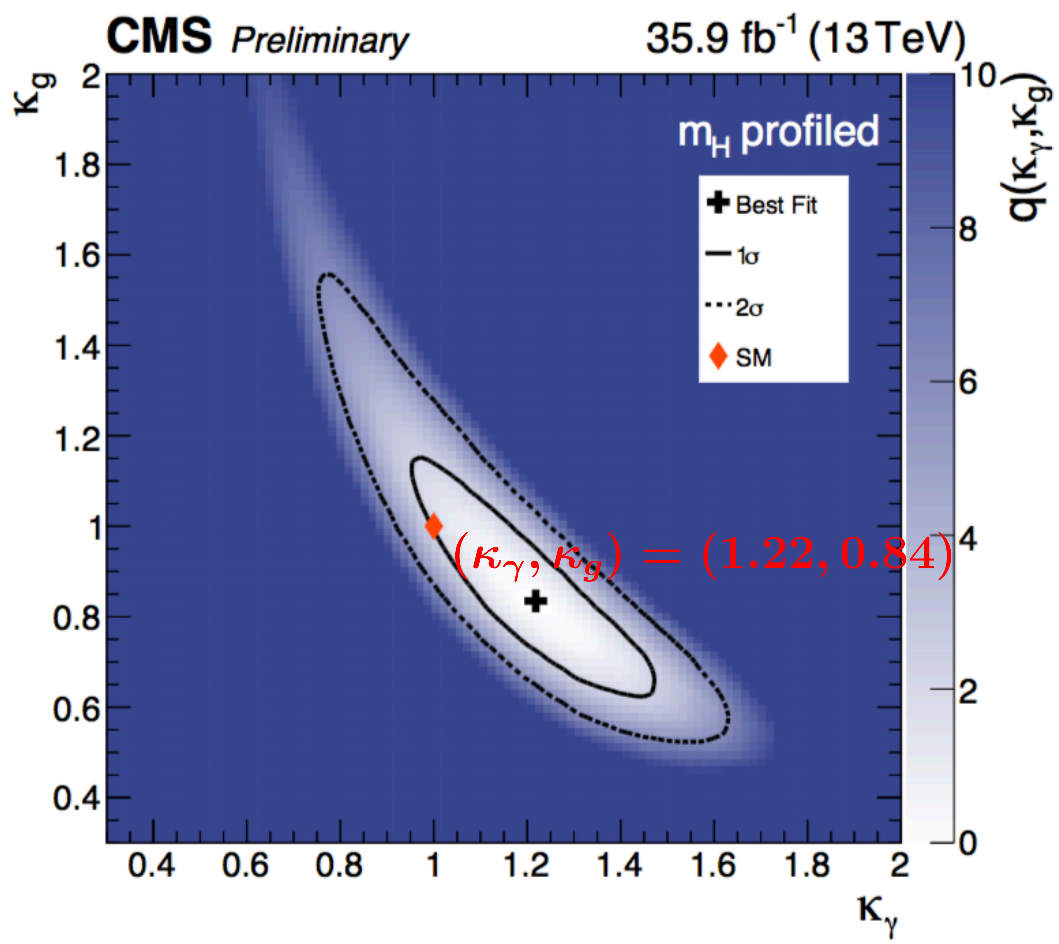
$$U^{\tilde{u}}\mathcal{M}^2_{\tilde{u}}(U^{\tilde{u}})^\dagger = \mathrm{diag}(m^2_{\tilde{u}_1}, \ldots, m^2_{\tilde{u}_6})$$

$$U^{\tilde{d}}\mathcal{M}^2_{\tilde{d}}(U^{\tilde{d}})^\dagger = \mathrm{diag}(m^2_{\tilde{d}_1}, \ldots, m^2_{\tilde{d}_6})$$

Experimental errors - LHC

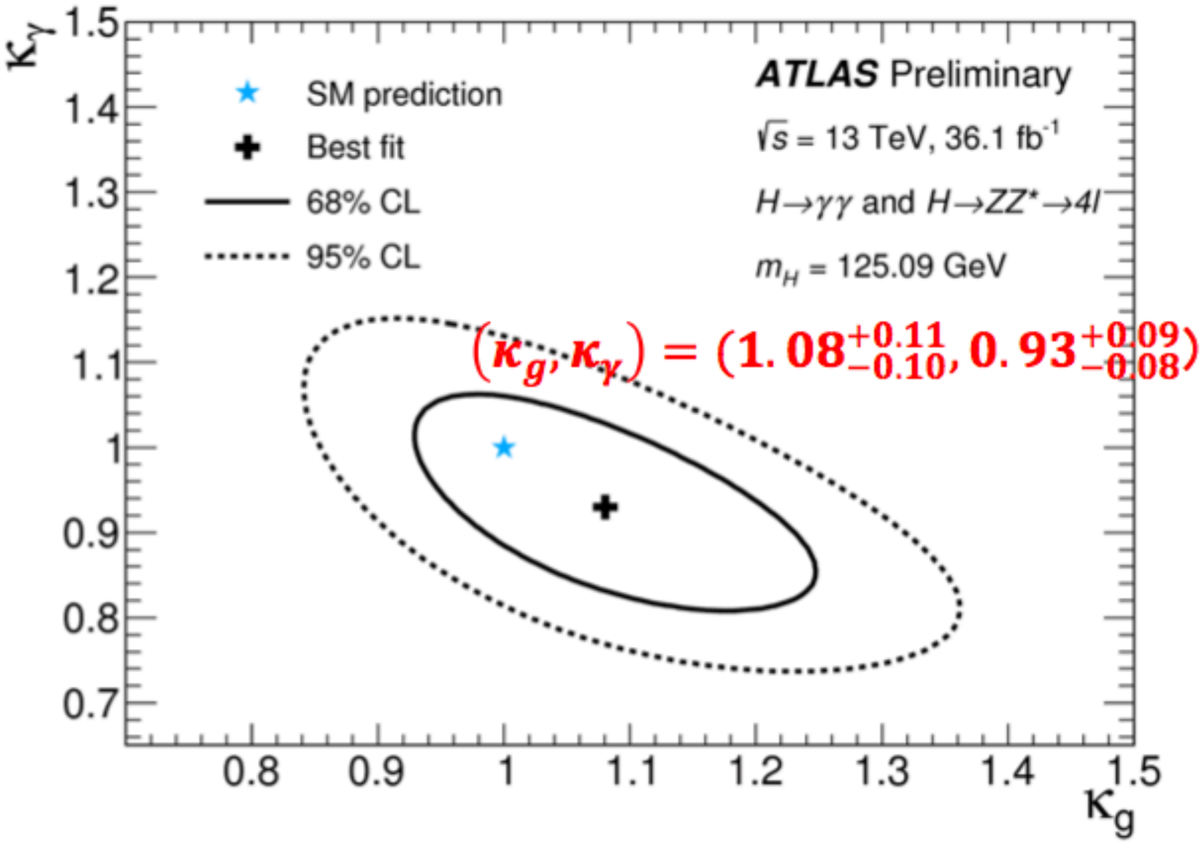
κ - framework





arXiv:1708.09215 [hep-ex]

(q == test statistic, equal to twice the negative log likelihood ratio)



T. V. Schröder, talk at EPS-HEP2017

Expected experimental errors - ILC

see LCC Physics Working Group, arXiv:1710.07621

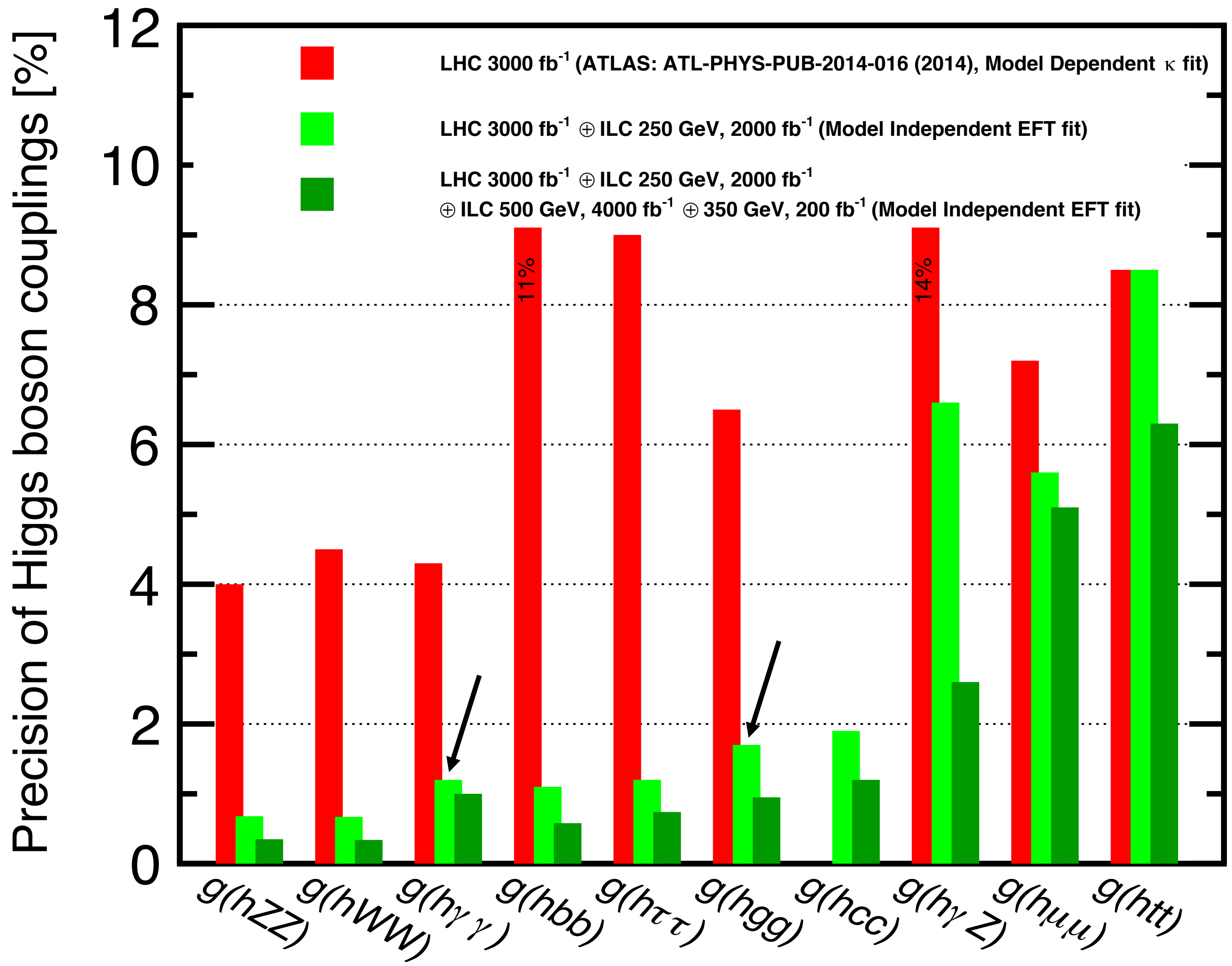
(most general set of SU(3) × SU(2) × U(1)-invariant dimension-6 operators)

Based on EFT fits we use at ILC 250 GeV stage, 2000 fb^{-1}:

g(h_photon_photon): 1.2%

g(h_gluon_gluon): 1.7%

g(h_photon_photon)/g(h_gluon_gluon): 1.8%



Numerical results

preliminary

DEV(X) and DEV(X/Y)

We compute the loop-induced decay widths $\Gamma(h^0 \to \gamma\gamma)$ and $\Gamma(h^0 \to gg)$ by using the public code *SPheno-v3.3.8*.

The computation includes

(LO 1-loop contributions) + (gluonic 2-loop corrections)$_{QCD-loops}$, where

$$\begin{aligned}\text{(LO 1-loop contributions)} &= \text{(SM particle loops)} + \text{(SUSY particle loops)} \\ &= \text{(top-loop + ...)} + \text{(stop-loop + ...)}.\end{aligned}$$

The **deviation of the width** from the SM prediction is defined as:

$$DEV(X) = \frac{\Gamma(h^0 \to XX)_{MSSM}}{\Gamma(h^0 \to XX)_{SM}} - 1$$

$$X = \gamma, g$$

The **deviation of the width ratio** from the SM prediction is defined as:

$$DEV(X/Y) = \frac{[\Gamma(X)/\Gamma(Y)]_{MSSM}}{[\Gamma(X)/\Gamma(Y)]_{SM}} - 1$$

The SM predictions are as follows [Almeida et al. 2014]:
$\Gamma(h^0 \to \gamma\gamma)_{SM} = 1.08 \cdot 10^{-5}$ GeV, $\Gamma(h^0 \to gg)_{SM} = 3.61 \cdot 10^{-4}$ GeV.

Constraints

B-physics: Exp. data + theor. uncertainty 95% CL

ΔM_{B_s}	$(17.757 \pm 3.3)\ \mathrm{ps}^{-1}$
$\mathrm{B}(b \to s\gamma)$	$(3.41 \pm 0.54)10^{-4}$
$\mathrm{B}(b \to s\ l^+l^-)$	$(1.60\ ^{+0.97}_{-0.91})10^{-6}$ $(l = e \text{ or } \mu)$
$\mathrm{B}(B_s \to \mu^+\mu^-)$	$(2.80\ ^{+1.44}_{-1.26})10^{-9}$
$\mathrm{B}(B^+ \to \tau^+\nu)$	$(1.14 \pm 0.78)10^{-4}$

Higgs mass:

m_{h^0} [GeV] (125.09 ± 3.48) GeV

others:

The LHC limits on the squark and gluino masses

The electroweak ρ parameter: $\Delta\rho$ (SUSY) < 0.0012.

Theoretical constraints from the vacuum stability conditions for the trilinear coupling matrices

Parameters of numerical Scan A

Parameter	$\tan\beta$	M_1	M_2	M_3	μ	$m_A(pole)$
Range	$10 \div 30$	$300 \div 2500$	$300 \div 2500$	$2500 \div 5000$	$100 \div 2500$	$800 \div 3000$

Parameter	M^2_{Q22}	M^2_{Q33}	$\lvert M^2_{Q23}\rvert$	M^2_{U22}	M^2_{U33}	$\lvert M^2_{U23}\rvert$
Range	$2500^2 \div 4000^2$	$2500^2 \div 4000^2$	$< 1000^2$	$2500^2 \div 4000^2$	$1000^2 \div 3000^2$	$< 1000^2$

Parameter	M^2_{D22}	M^2_{D33}	$\lvert M^2_{D23}\rvert$	$\lvert T_{U23}\rvert$	$\lvert T_{U32}\rvert$	$\lvert T_{U33}\rvert$
Range	$2500^2 \div 4000^2$	$1000^2 \div 3000^2$	$< 1000^2$	< 3000	< 3000	< 4000

Parameter	$\lvert T_{D23}\rvert$	$\lvert T_{D32}\rvert$	$T_{D33}\rvert$	$\lvert T_{E33}\rvert$
Range	< 1000	< 1000	< 1000	< 500

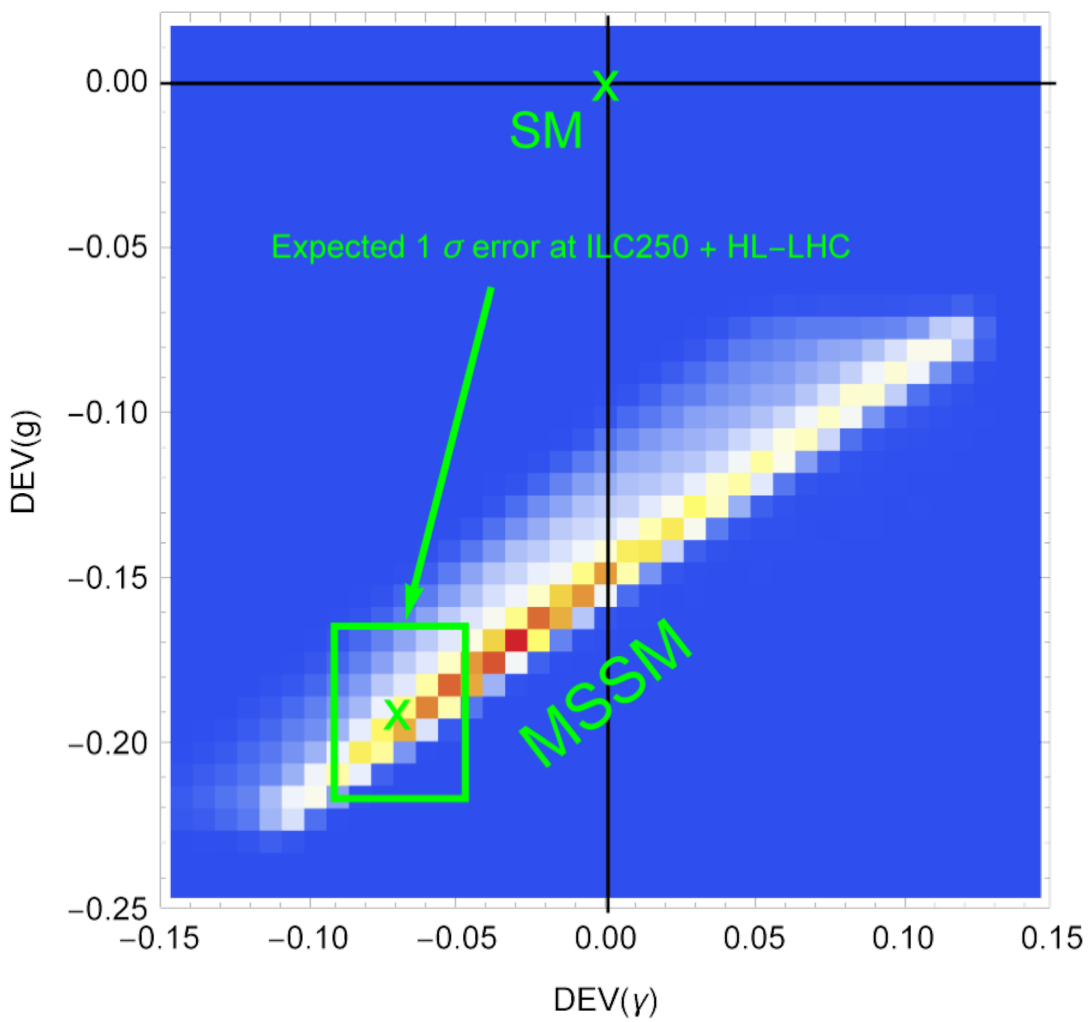
Parameter	M^2_{Q11}	M^2_{U11}	M^2_{D11}	M^2_{L11}	M^2_{L22}	M^2_{L33}	M^2_{E11}	M^2_{E22}	M^2_{E33}
Value	4000^2	4000^2	4000^2	1500^2	1500^2	1500^2	1500^2	1500^2	1500^2

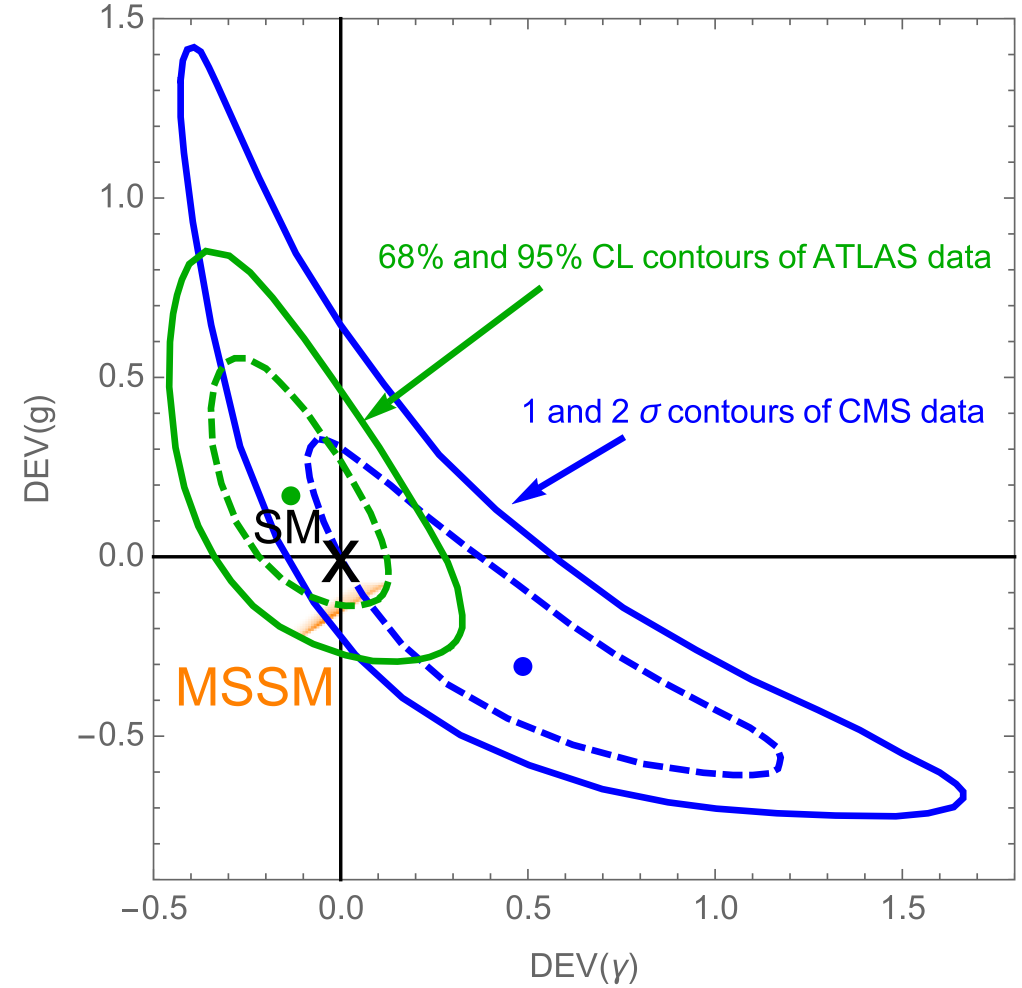
in units of GeV or GeV^2, except for $\tan\beta$

All MSSM parameters not shown here are set to be zero.

DEV(γ) – DEV(g)

Scan A, 286k points allowed from 1080k input points

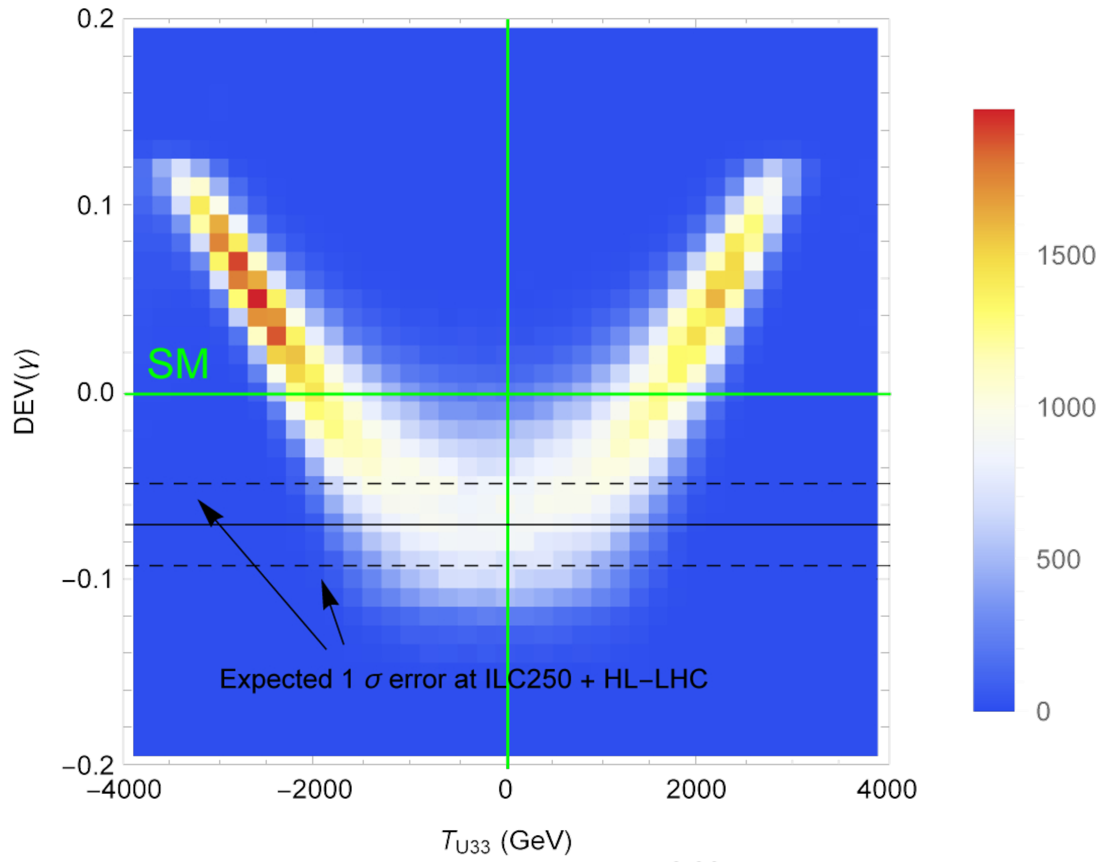


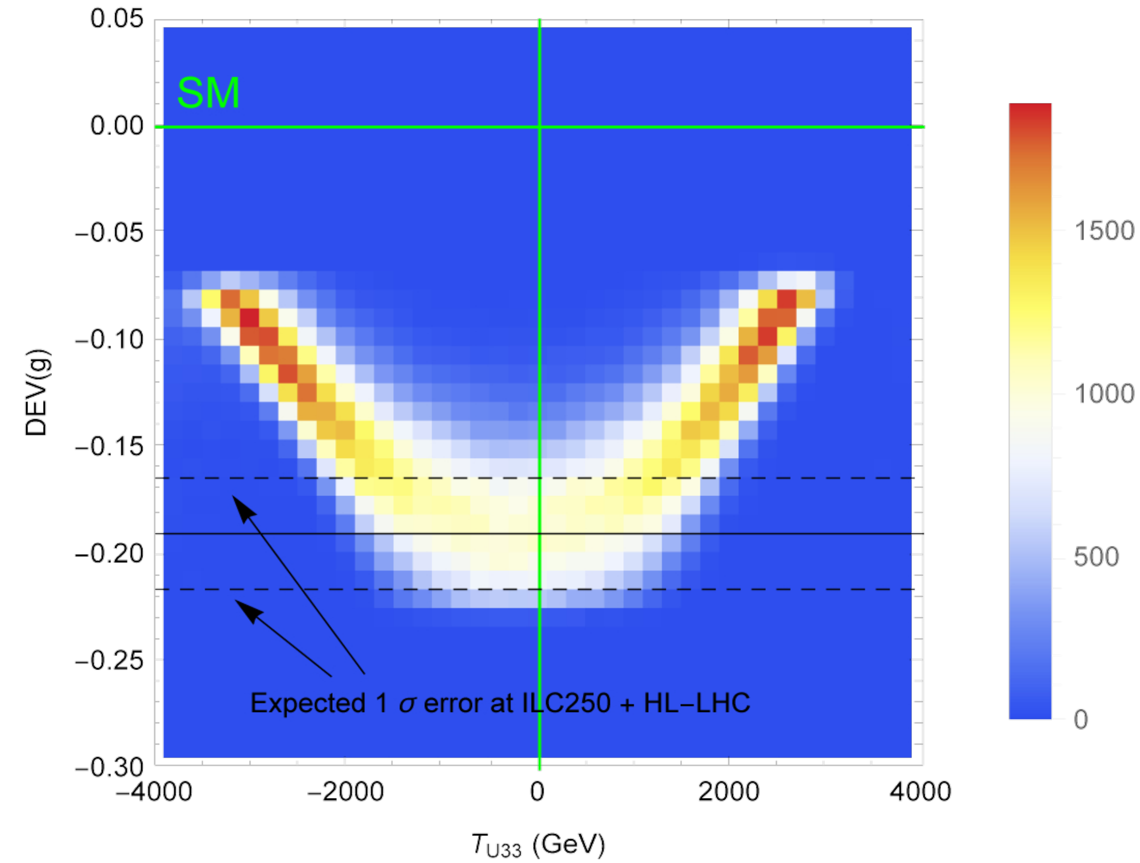


40 x 40 bins

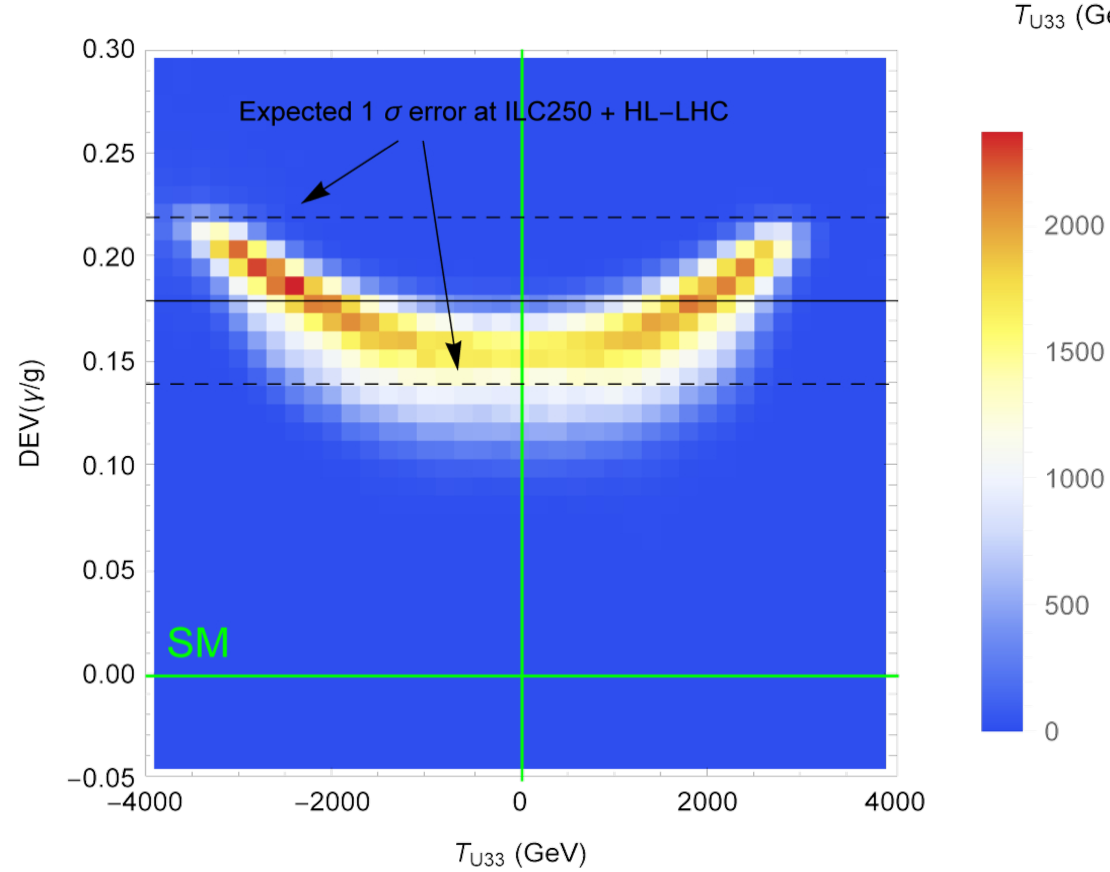
Scan A

Dependences on T_{U33}



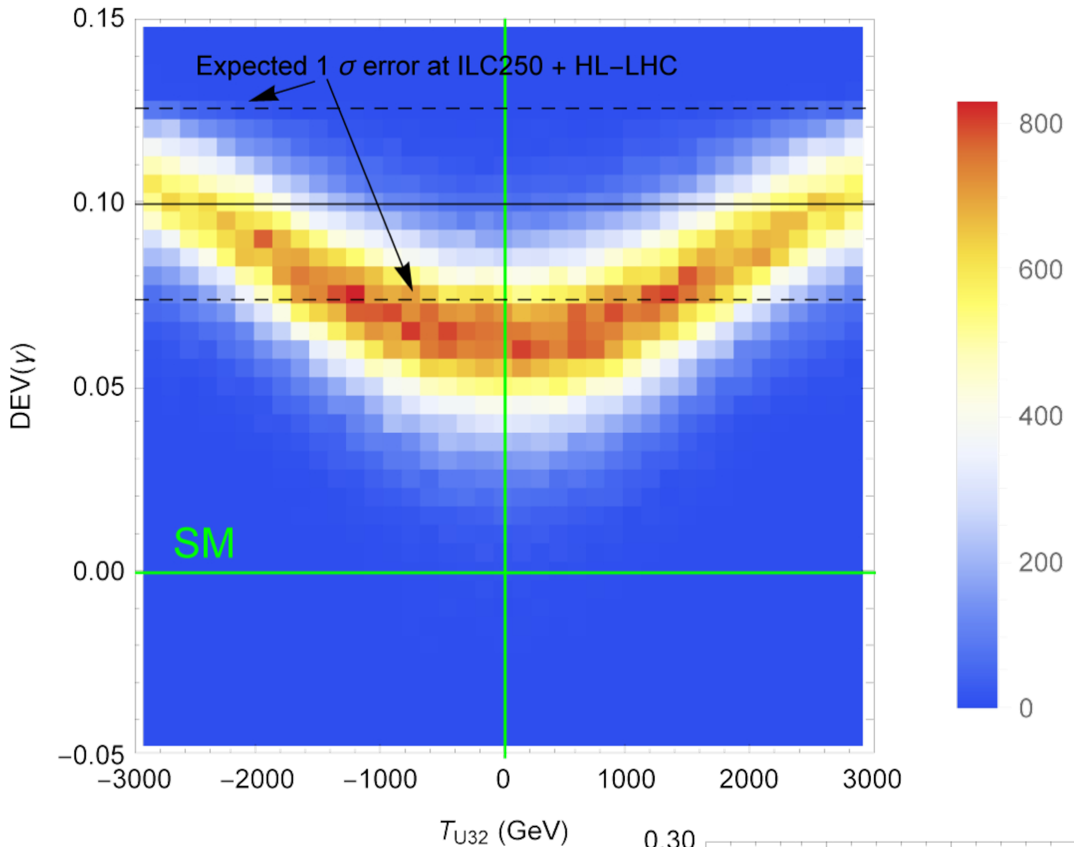


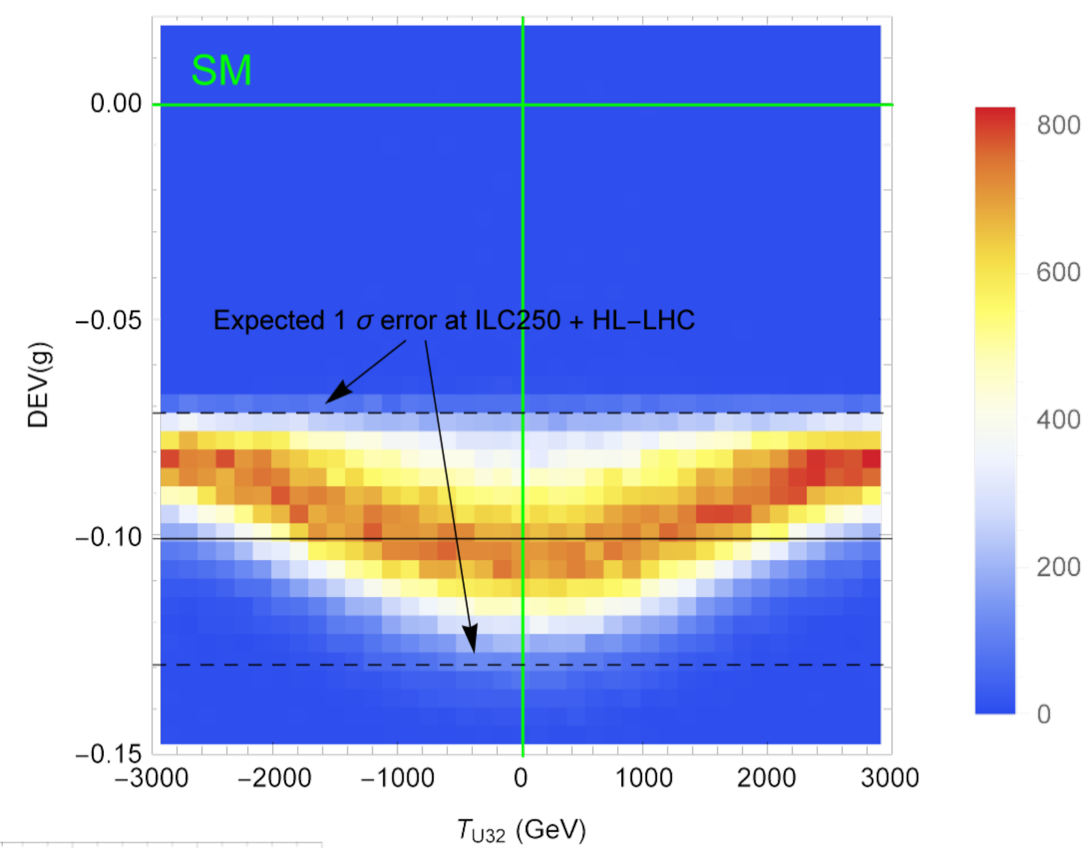
40 x 40 bins



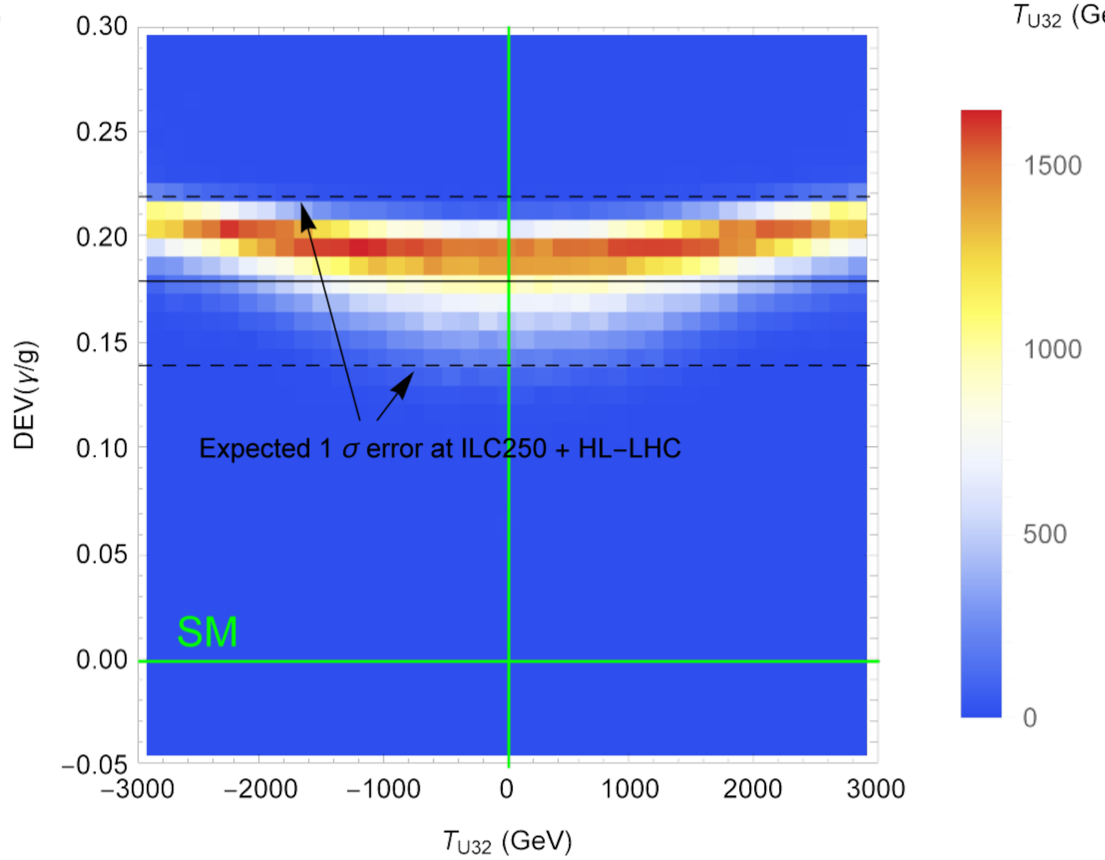
Dependences on T_{U32}

Scan B = Scan A with fixed TU33 (= 2500 GeV), 218k points allowed from 708k input points





40 x 40 bins



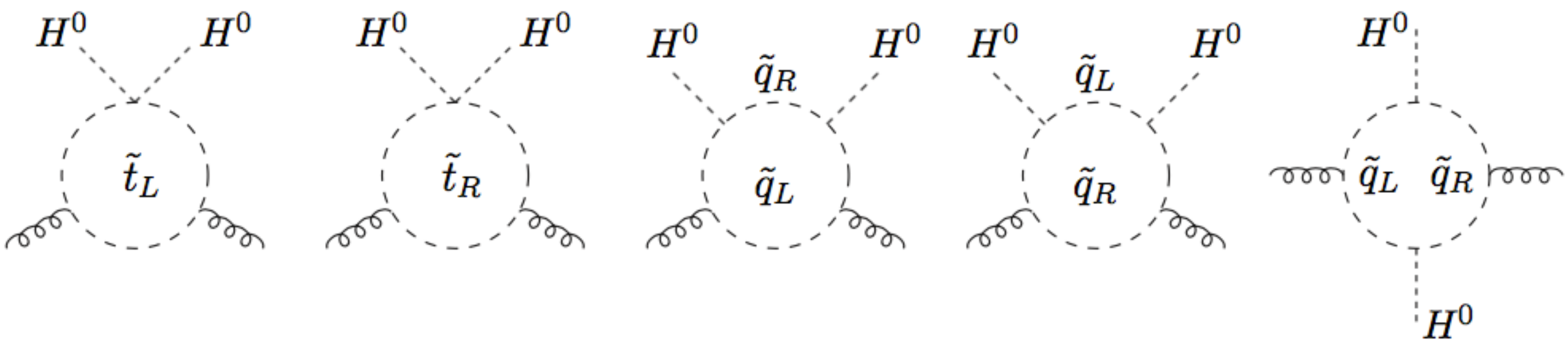
EFT κ – framework

A. Brignole (2015)

$$\frac{\sigma(gg\to h)}{\sigma^{\rm SM}(gg\to h)} \simeq \frac{\Gamma(h\to gg)}{\Gamma^{\rm SM}(h\to gg)} = \kappa_g^2 \qquad \frac{\Gamma(h\to\gamma\gamma)}{\Gamma^{\rm SM}(h\to\gamma\gamma)} = \kappa_\gamma^2 \qquad \kappa_g = 1+\delta\kappa_g \text{ and } \kappa_\gamma = 1+\delta\kappa_\gamma$$

κ's encode corrections from new physics, $\mathcal{A} \equiv$ amplitude, $\delta\kappa_x = \frac{\delta\mathcal{A}_{hxx}}{\mathcal{A}^{\rm SM}_{hxx}}$, $x = g, \gamma$

dimension 6 operators $|H^0|^2 G_{\mu\nu}G^{\mu\nu}$ and $|H^0|^2 F_{\mu\nu}F^{\mu\nu}$



diagrams with stop, scharm to $\delta\kappa_g$ and $\delta\kappa_\gamma$, $\mathcal{O}(y_t^2)$

with gluons, SM $\simeq$ top loop:

$$\delta\kappa_g \simeq \frac{m_t^2}{4}\left[\frac{1}{\tilde{m}^2_{t_L}}\left(1-\frac{|A_{ct}|^2}{\tilde{m}^2_{c_R}}\right)+\frac{1}{\tilde{m}^2_{t_R}}\left(1-\frac{|A_{tc}|^2}{\tilde{m}^2_{c_L}}\right)-\frac{|X_t|^2}{\tilde{m}^2_{t_L}\tilde{m}^2_{t_R}}\right]$$

our notation: $X_t \simeq \frac{T_{U33}}{y_t}$, $A_{ct} = \frac{T_{U23}}{y_t}$, $A_{tc} = \frac{T_{U32}}{y_t}$

since $\mathcal{A}^{top}_{h\gamma\gamma} \simeq -0.3\mathcal{A}^{\rm SM}_{h\gamma\gamma}$, $\delta\kappa_\gamma \simeq -0.3\,\delta\kappa_g$

Conclusions

- We have studied the correlation between the loop-induced decays h^0 (125GeV) $\rightarrow$ photon photon and gluon gluon in the MSSM with QFV.

- Performing a full parameter scan, we have found out:
  - There is a strong correlation between $DEV(h^0 \rightarrow \text{photon photon})$ and $DEV(h^0 \rightarrow \text{gluon gluon})$!
  - The deviation of the width ratio $\Gamma(h^0 \rightarrow \text{photon photon})$ / $\Gamma(h^0 \rightarrow \text{gluon gluon})$ from the SM value is large (roughly +10% to +23%) in the scanned parameter ranges!

- Comparison with EFT results - in progress

- In case the deviation patterns shown here are really observed at ILC, then it would strongly suggest the discovery of SUSY (MSSM)!

Thank you!