

Constraint on new particle masses and couplings from Higgs measurements

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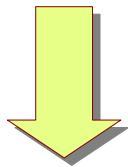
Snowmass: Seattle Energy Frontier Workshop

Seattle,

June 30th 2013

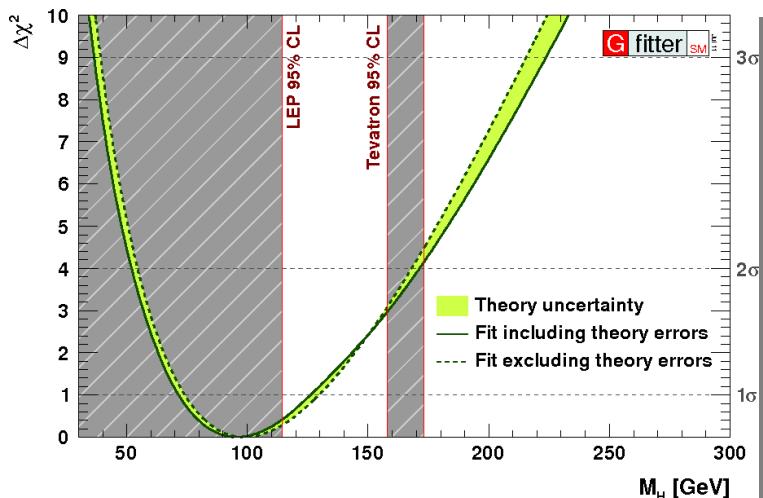
Main Idea

Precision Electroweak Measurements



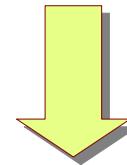
$$m_h = 91^{+30}_{-20} \text{ GeV}$$

GFitter-1107.0975



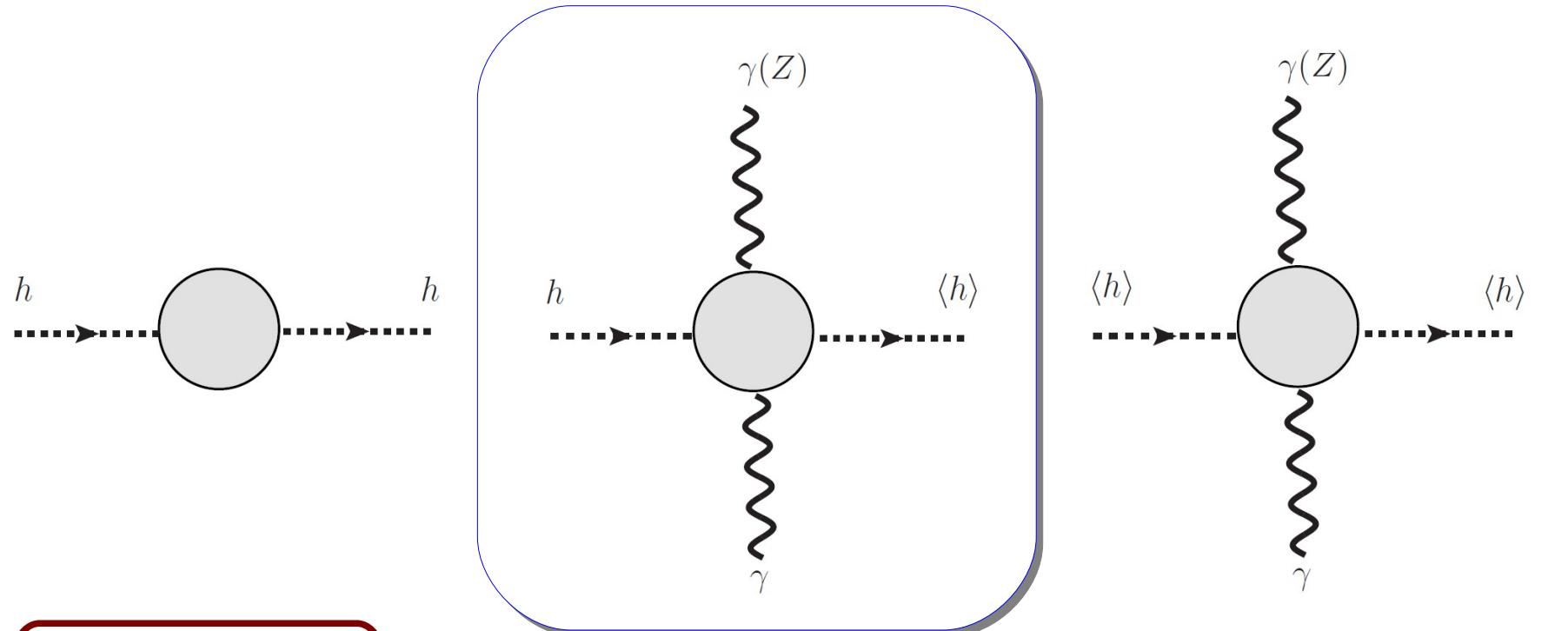
Before of its discovery

Precision measurement of the Higgs couplings

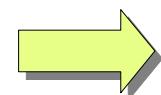


„Higgs oblique corrections“

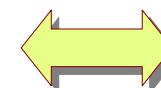
Why do we expect them?



Naturalness



Higgs pheno



QED (QCD)
beta functions

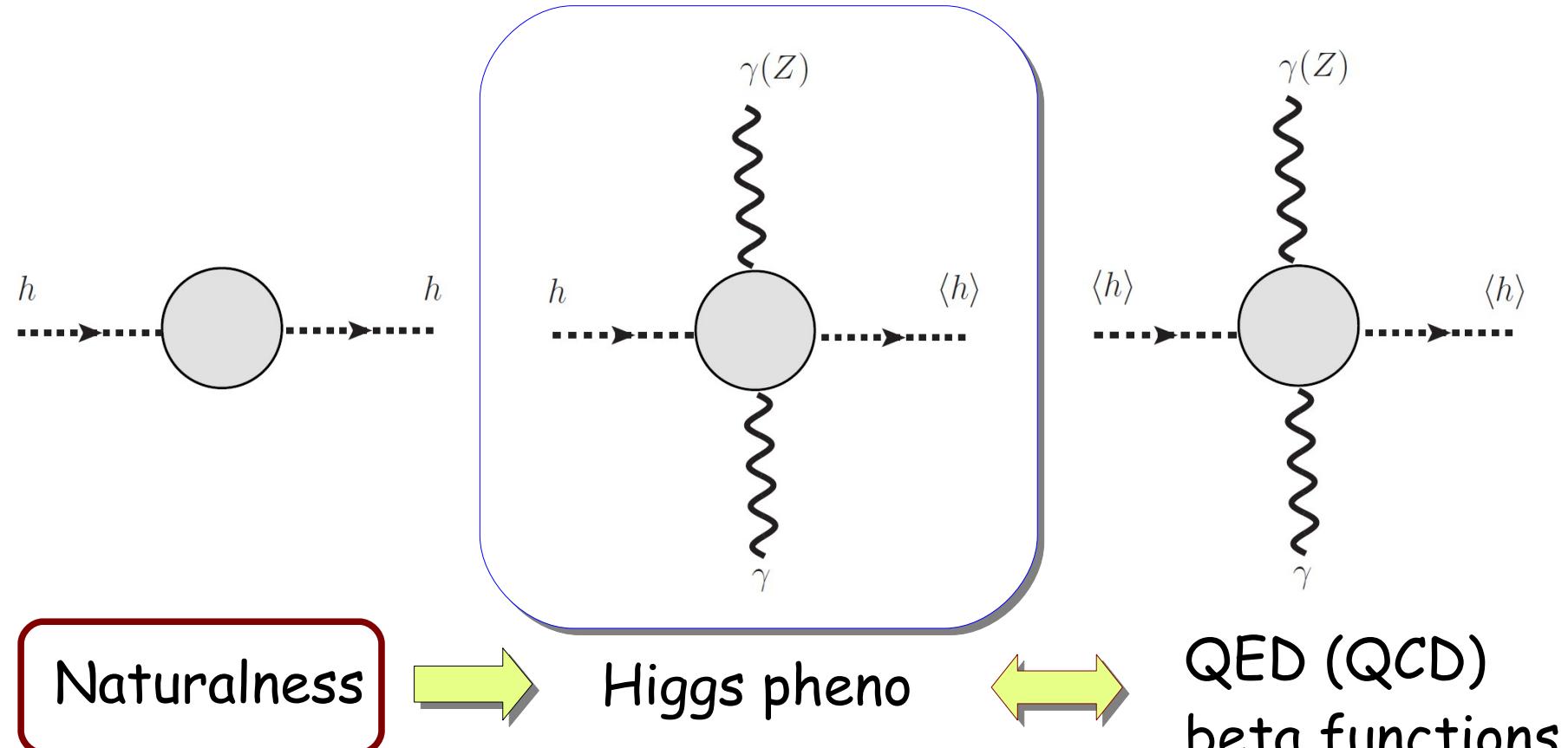
Low energy Higgs theorem

Ellis, Gaillard, Nanopoulos, 1976

Shifman, Vainshtein, Voloshin, Zakharov, 1979

„Higgs oblique corrections“

Why do we expect them?



Ellis, Gaillard, Nanopoulos, 1976
Shifman, Vainshtein, Voloshin, Zakharov, 1979

Size of the corrections: $\mathcal{O}\left(\frac{v^2}{m_{\text{NP}}^2}\right) \sim 5\%$ (dimension 6 effective operators)

Loop induced couplings in the SM

$$c_G \frac{\alpha_s}{12\pi v} h G_{\mu\nu}^a G^{\mu\nu a} + c_\gamma \frac{\alpha_{\text{em}}}{8\pi v} h F_{\mu\nu} F^{\mu\nu}$$

At the LO:

$$c_g^{(\text{SM})} = \frac{3}{4} (A_{1/2}(\tau_t) + A_{1/2}(\tau_b))$$

$$c_\gamma^{(\text{SM})} = A_1(\tau_W) + N_c Q_t^2 A_{1/2}(\tau_t)$$

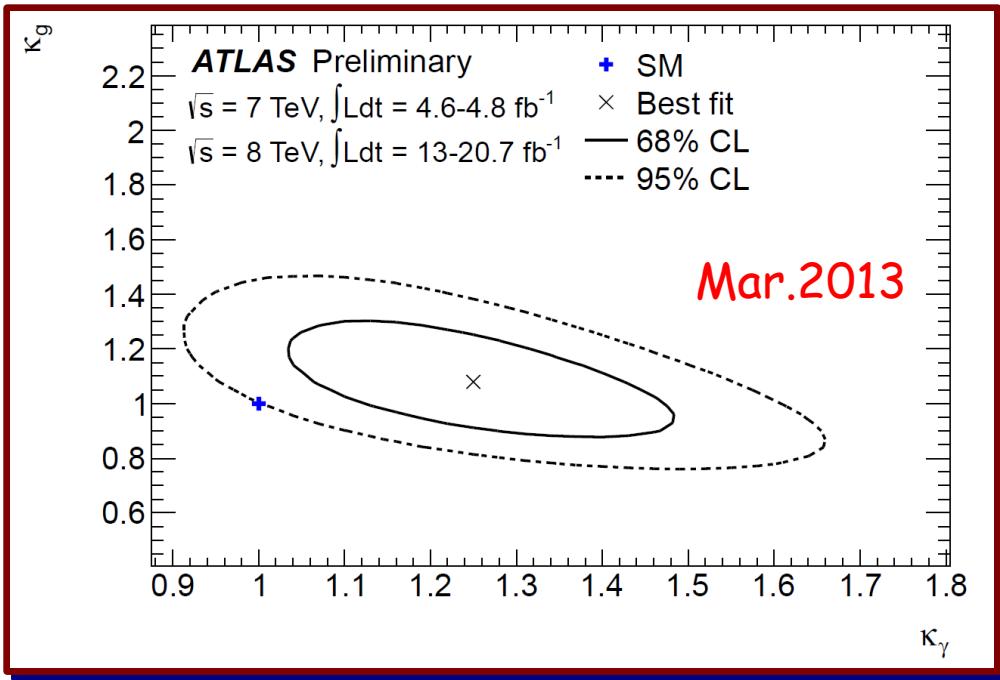
$$\tau_i \equiv 4m_i^2/m_h^2$$

Sizable higher order corrections (computed at N³LO)

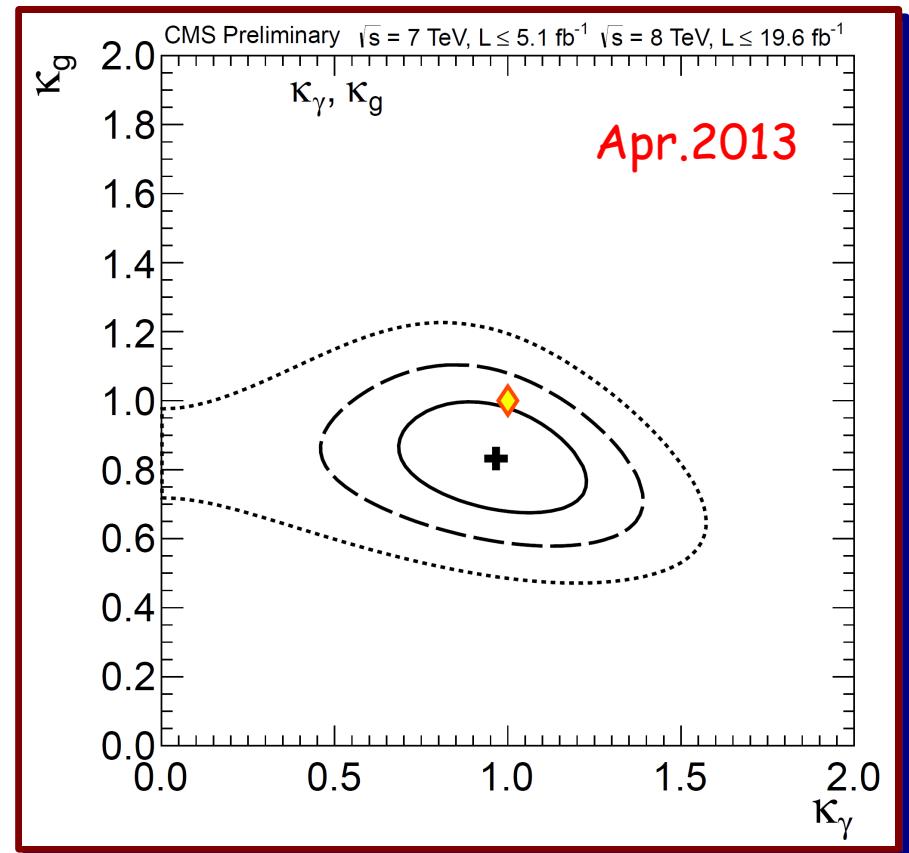
$$\begin{aligned} c_{g,\text{NLO}}^{(\text{SM})} &= 1 + \frac{11}{4} \frac{\alpha_s}{\pi} + \left[\frac{2777}{288} - N_f \frac{67}{96} + \left(\frac{19}{16} + \frac{N_f}{3} \right) \log \frac{\mu^2}{m_t^2} \right] \left(\frac{\alpha_s}{\pi} \right)^2 + \dots \\ &= 1 + 0.09891 + 0.00796 + \dots \end{aligned}$$

Djouadi, Spira, Zerwas, 1991
 Dawson, 1991
 Spira, Dawson, Graudenz, Zerwas, 1995
 Kramer, Laenen, Spira, 1998
 Chetyrkin, Kniel, Steinhauser, 1998, ...

Where do we stand today?



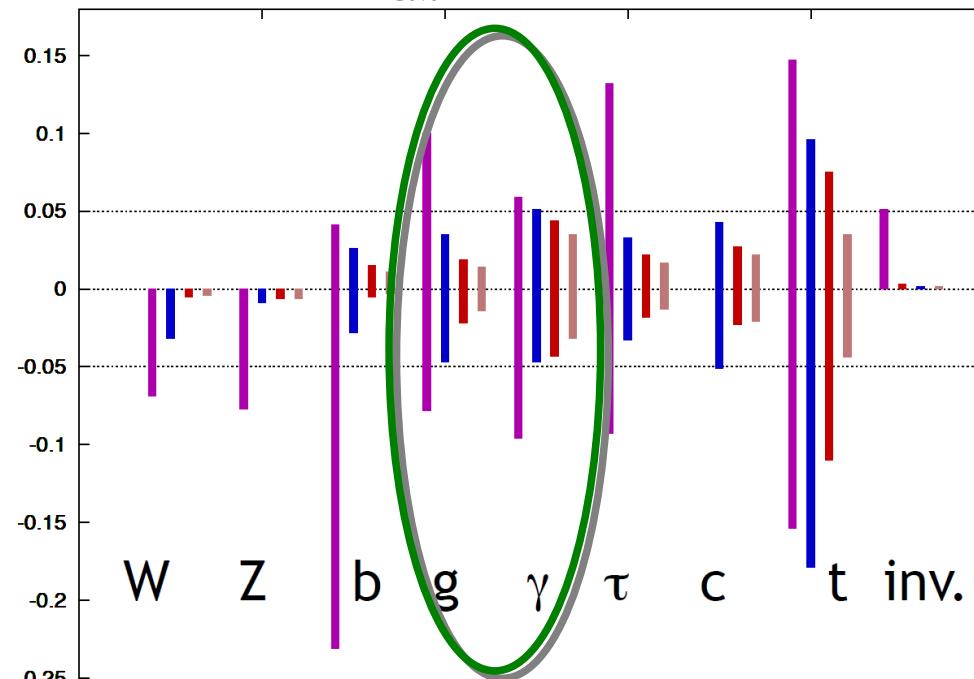
ATLAS-CONF-2013-034



CMS-PAS-HIG-13-005

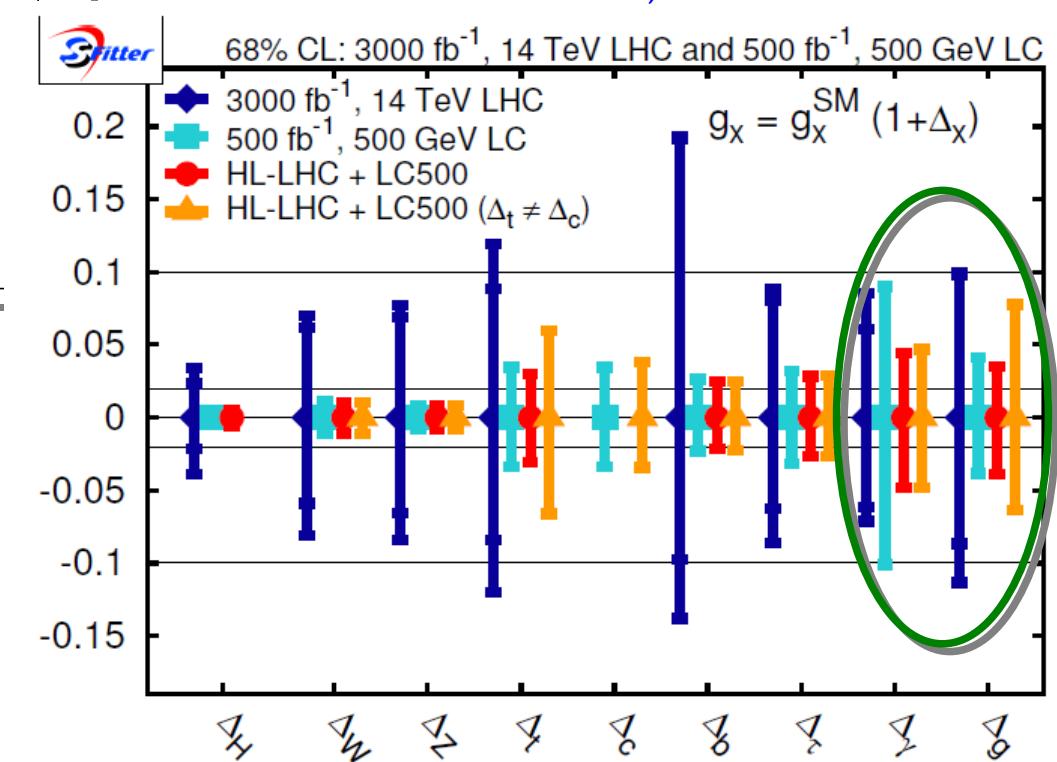
Where we might stand in the future?

$g(hAA)/g(hAA)|_{SM} - 1$ LHC/ILC1/ILC/ILCTeV

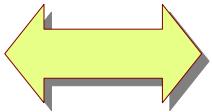


Peskin, 1207.2516

Klute, Lafaye, Plehn, Rauch,
Zerwas, 1301.1322



NP effects

Precision measurements  Precision predictions

- Low energy Higgs theorem at 2-loops

Kniehl, Spira, 1995

$$\mathcal{L}_{eff} = \mathcal{L}_{SM}^{(5)} + \frac{h}{8v} G_{\mu\nu}^a G^{a\mu\nu} \frac{\beta_{\alpha_s}}{\alpha_s} \frac{1}{1 + \gamma_m} \frac{\partial}{\partial \log v} \log m(v)^2$$

$$\begin{aligned} \frac{\beta_{\alpha_s}^{(f)}}{\alpha_s} &= \delta_R \textcolor{blue}{b_{1/2}} \frac{\alpha_s}{2\pi} T(f) \left\{ 1 + \frac{\alpha_s}{4\pi} [5C_2(G) + 3C_2(f)] \right\} \\ \frac{\beta_{\alpha_s}^{(S)}}{\alpha_s} &= \delta_R \textcolor{blue}{b_0} \frac{\alpha_s}{2\pi} T(S) \left\{ 1 + \frac{\alpha_s}{2\pi} [C_2(G) + 6C_2(S)] \right\} \end{aligned}$$

QCD beta function
 $\beta_{\alpha_s} = \partial \alpha_s / \partial \log \mu$
 $\gamma_m = -\partial \log m / \partial \log \mu$

Mass anomalous dimension

$$A_{1/2}(\tau) \rightarrow \textcolor{blue}{b_{1/2}} = \frac{4}{3},$$

$$A_0(\tau) \rightarrow \textcolor{blue}{b_0} = \frac{1}{3}$$

- Keeping only LO corrections to the hyy coupling

$$\mathcal{L}_{eff} = \mathcal{L}_{SM}^{(5)} + \frac{h}{8v} F_{\mu\nu} F^{\mu\nu} \frac{\beta_{\alpha_{em}}}{\alpha_{em}} \frac{\partial}{\partial \log v} \log m(v)^2$$

Example scenarios (hgg)

$$\Gamma_{hgg} = \frac{\alpha_s^2 m_h^3}{128\pi^3} \kappa_{soft}^{NLO} \left| \delta_R T(V) \frac{g_{hVV}}{m_V^2} A_1(\tau_V) c_{g,V}^{NLO} + T(f) \frac{2g_{hff\bar{f}}}{m_f} A_{1/2}(\tau_f) c_{g,f}^{NLO} + \delta_R T(R) \frac{g_{hSS}}{m_S^2} A_0(\tau_S) c_{g,S}^{NLO} \right|^2$$

$$\kappa_{soft}^{NLO} = 1 + \frac{\alpha_s}{\pi} \left(\frac{73}{4} - \frac{7}{6} N_f \right) = 1 + 0.427$$

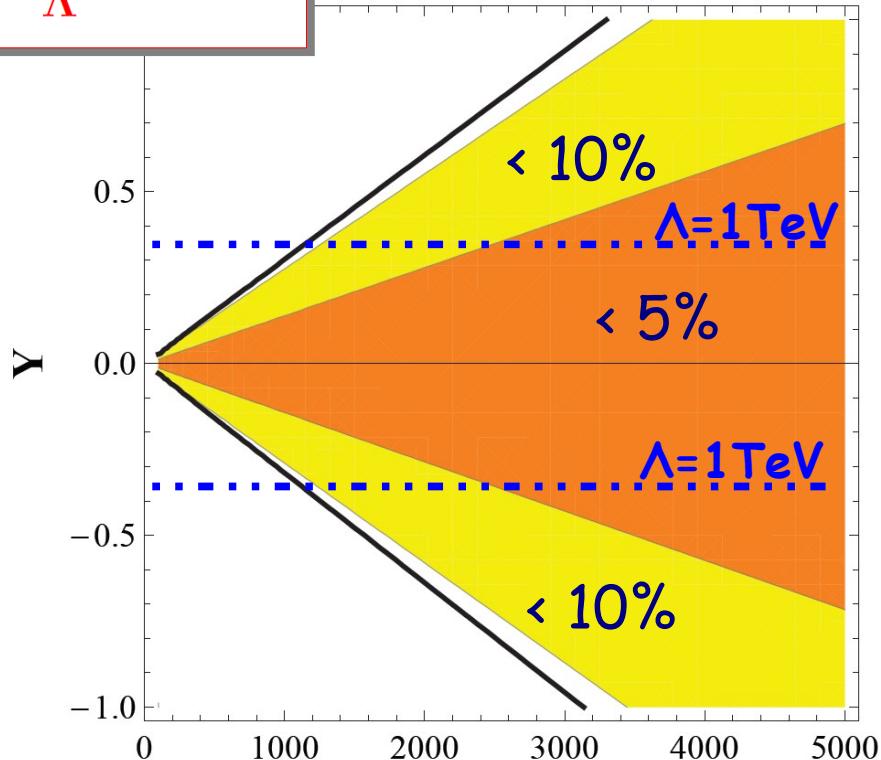
Good approximation.
Theoretical error $\sim 2\%$

Example scenarios (hgg)

$$\Gamma_{hgg} = \frac{\alpha_s^2 m_h^3}{128\pi^3} \kappa_{soft}^{NLO} \left| \delta_R T(V) \frac{g_{hVV}}{m_V^2} A_1(\tau_V) c_{g,V}^{NLO} + T(f) \frac{2g_{hff}}{m_f} A_{1/2}(\tau_f) c_{g,f}^{NLO} + \delta_R T(R) \frac{g_{hSS}}{m_S^2} A_0(\tau_S) c_{g,S}^{NLO} \right|^2$$

$$\mathcal{O}_f = \frac{c_f}{\Lambda} H^\dagger H f \bar{f}$$

Fermion, Fundamental

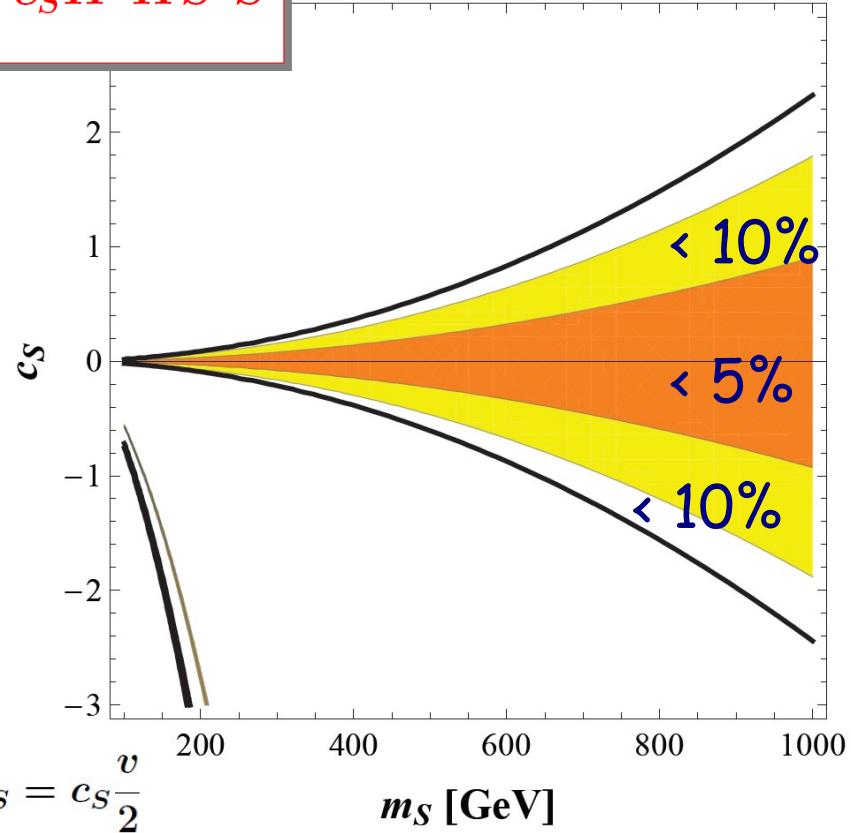


$$g_{hff} = c_f \frac{v}{\Lambda} \equiv \frac{Y}{\sqrt{2}}$$

$$c_{g,f,(3)}^{NLO} = 1 + \frac{11}{4} \frac{\alpha_s}{\pi}$$

$$\mathcal{O}_S = c_S H^\dagger H S^\dagger S$$

Real scalar, Adjoint



$$g_{hSS} = c_S \frac{v}{2}$$

$$c_{g,S,(8)}^{NLO} = 1 + \frac{33}{4} \frac{\alpha_s}{\pi}$$

(neglecting the scalar quartic coupling)

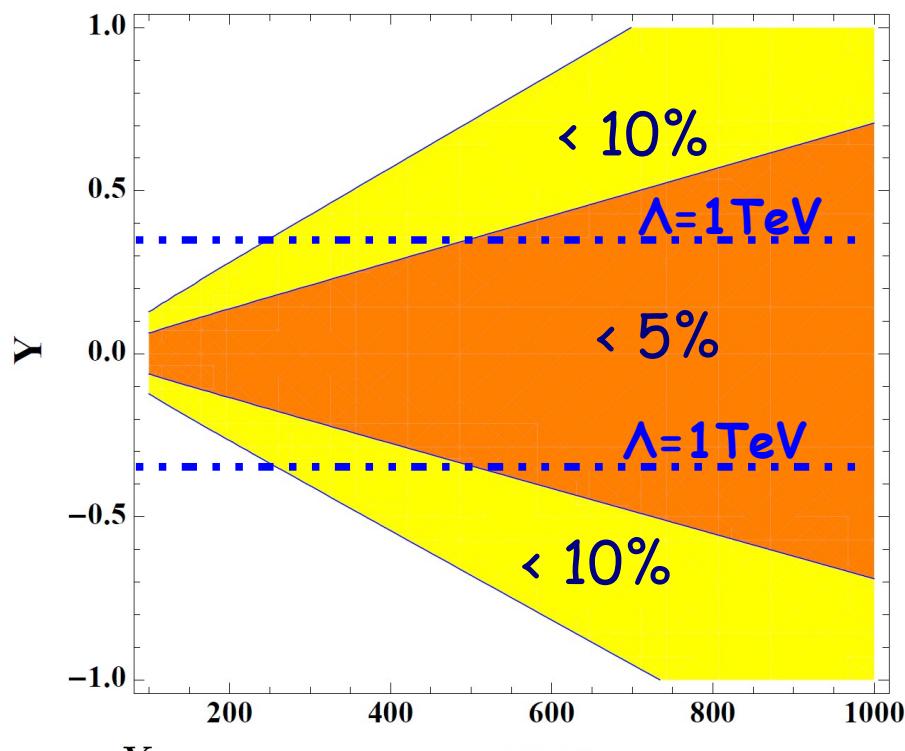
SG, Low, 1307.xxx

Example scenarios ($h\gamma\gamma$)

$$\Gamma_{h\gamma\gamma} = \frac{\alpha_{\text{em}}^2 m_h^3}{1024\pi^3} \left| \frac{g_{hVV}}{m_V^2} Q_V^2 A_1(\tau_V) + \frac{2g_{hff}}{m_f} N_{c,f} Q_f^2 A_{1/2}(\tau_f) + N_{c,S} Q_S^2 \frac{g_{hSS}}{m_S^2} A_0(\tau_S) \right|^2$$

$$\mathcal{O}_f = \frac{c_f}{\Lambda} H^\dagger H f \bar{f}$$

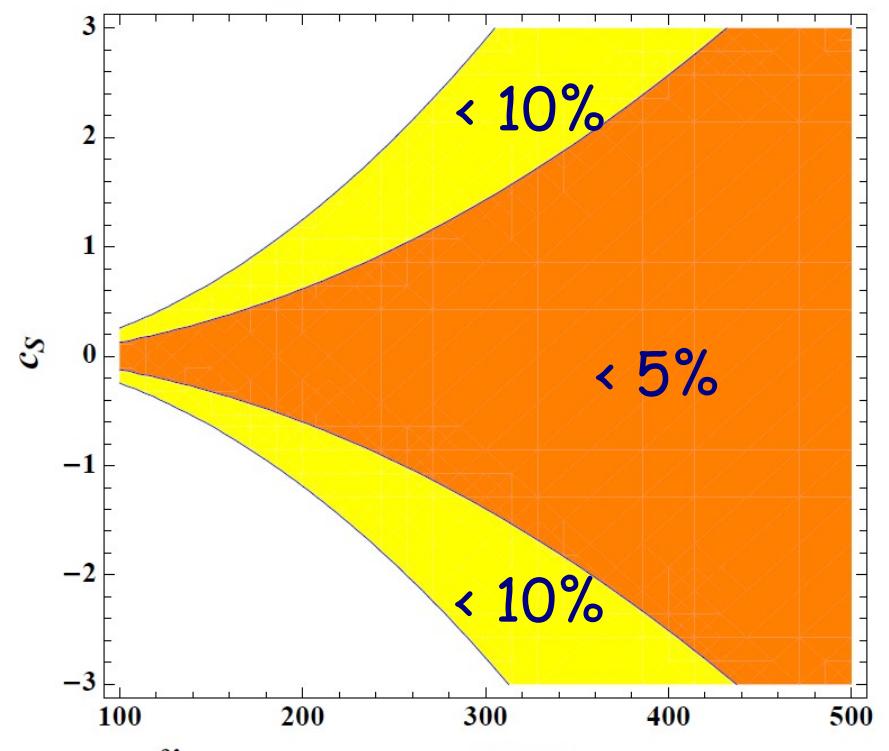
$R_{\gamma\gamma}$ for singly charged fermion



$$g_{hff} = c_f \frac{v}{\Lambda} \equiv \frac{Y}{\sqrt{2}}$$

$$\mathcal{O}_S = c_S H^\dagger H S^\dagger S$$

$R_{\gamma\gamma}$ for singly charged scalar

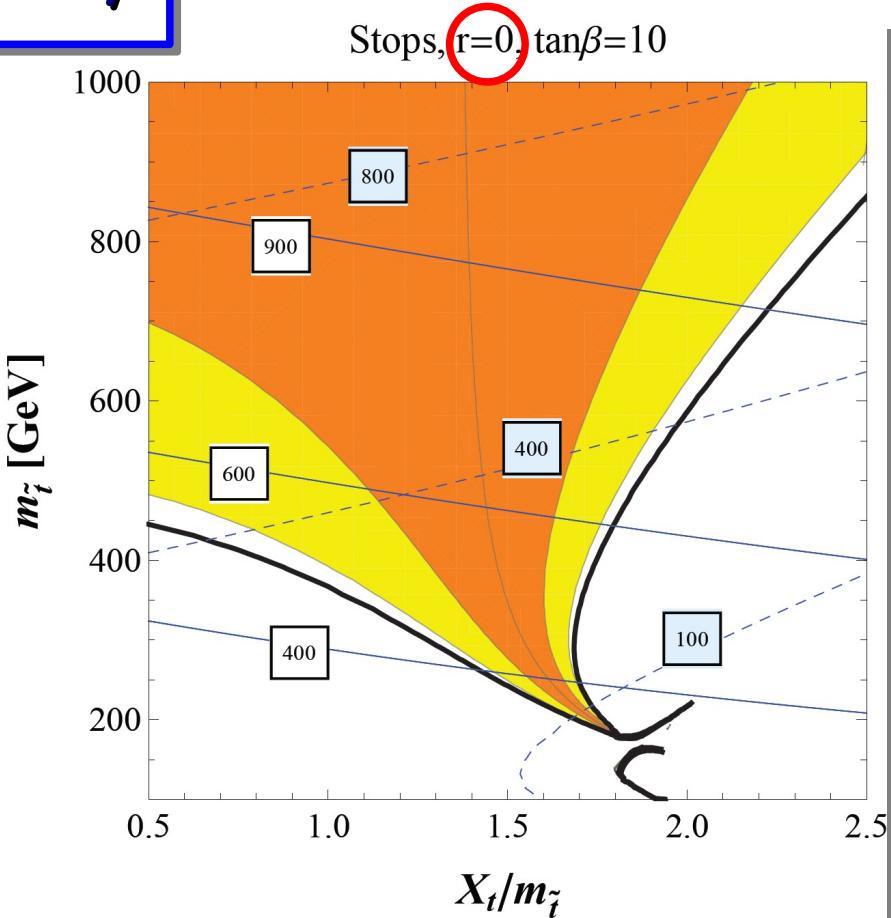


$$g_{hSS} = c_S \frac{v}{2}$$

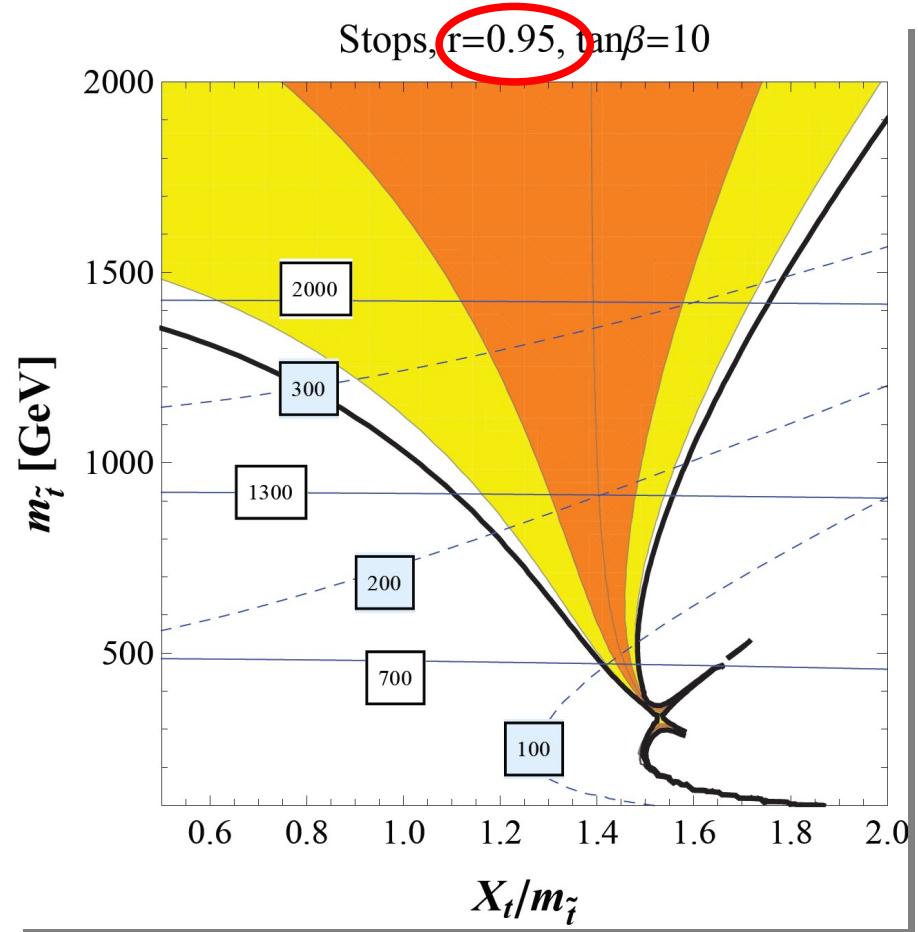
SG, Low, 1307.xxx

Specific NP models (hgg)

Susy



SG, Low, 1307.xxx

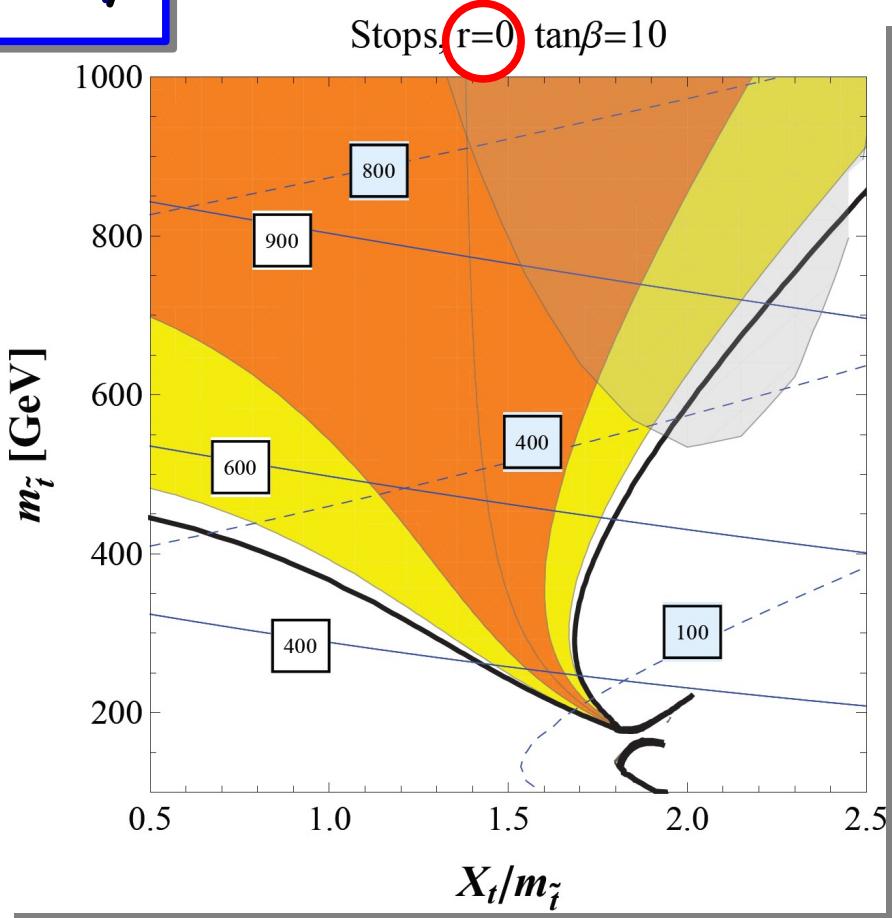


$$m_{\tilde{t}}^2 \equiv \frac{m_{Q_3}^2 + m_{U_3}^2}{2}, \quad r \equiv \frac{m_{Q_3}^2 - m_{U_3}^2}{m_{Q_3}^2 + m_{U_3}^2}$$

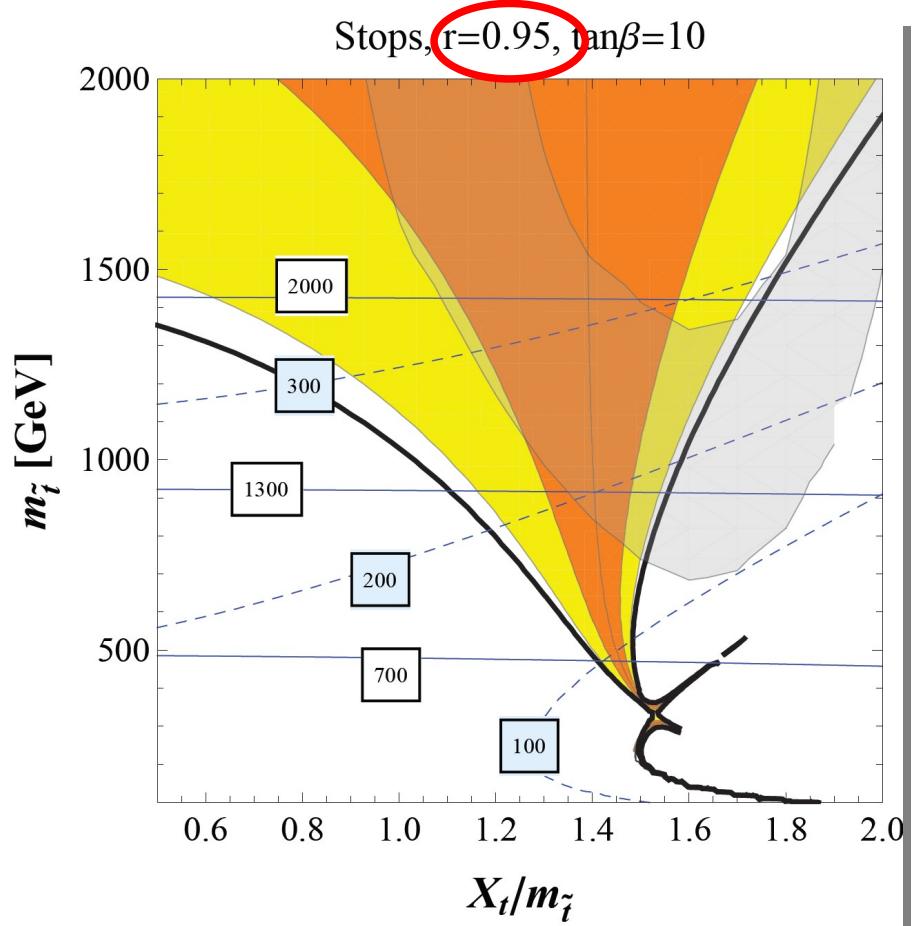
$$\mathcal{M}_{stop}^2 = \begin{pmatrix} m_{Q_3}^2 + m_t^2 + D_L & m_t X_t \\ m_t X_t & m_{u_3}^2 + m_t^2 + D_R \end{pmatrix}$$

Specific NP models (hgg)

Susy



SG, Low, 1307.xxx



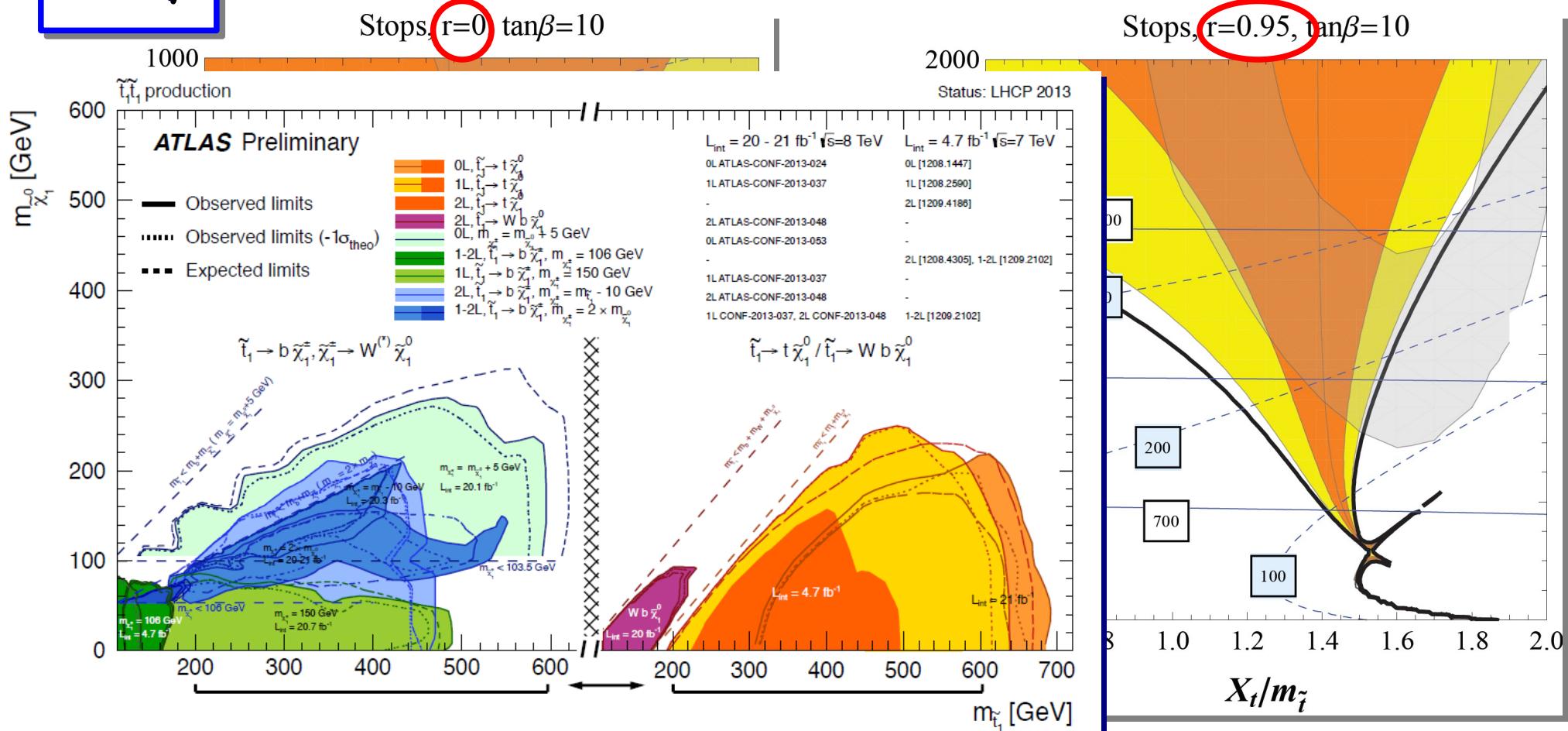
$$m_{\tilde{t}}^2 \equiv \frac{m_{Q_3}^2 + m_{U_3}^2}{2}, \quad r \equiv \frac{m_{Q_3}^2 - m_{U_3}^2}{m_{Q_3}^2 + m_{U_3}^2}$$

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Specific NP models (hgg)

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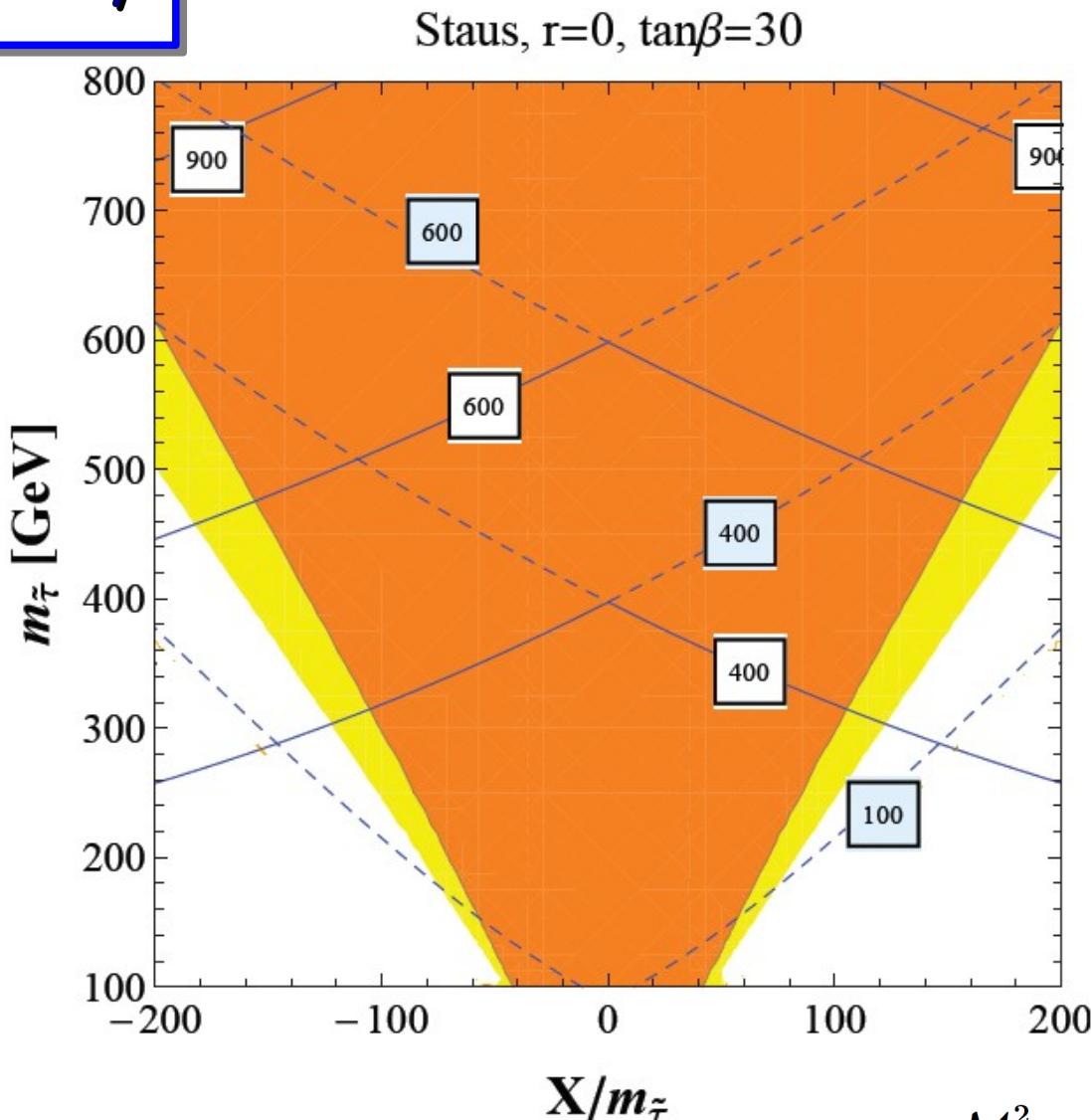
$$m_{\tilde{t}}^2 \equiv \frac{m_{Q_3}^2 + m_{U_3}^2}{2}, \quad r \equiv \frac{m_{Q_3}^2 - m_{U_3}^2}{m_{Q_3}^2 + m_{U_3}^2}$$

$$\mathcal{M}_{stop}^2 = \begin{pmatrix} m_{Q_3}^2 + m_t^2 + D_L & m_t X_t \\ m_t X_t & m_{u_3}^2 + m_t^2 + D_R \end{pmatrix}$$

Specific NP models (hgg)

SG, Low, 1307.xxx

Susy



Important constraints
on the stau parameter
space

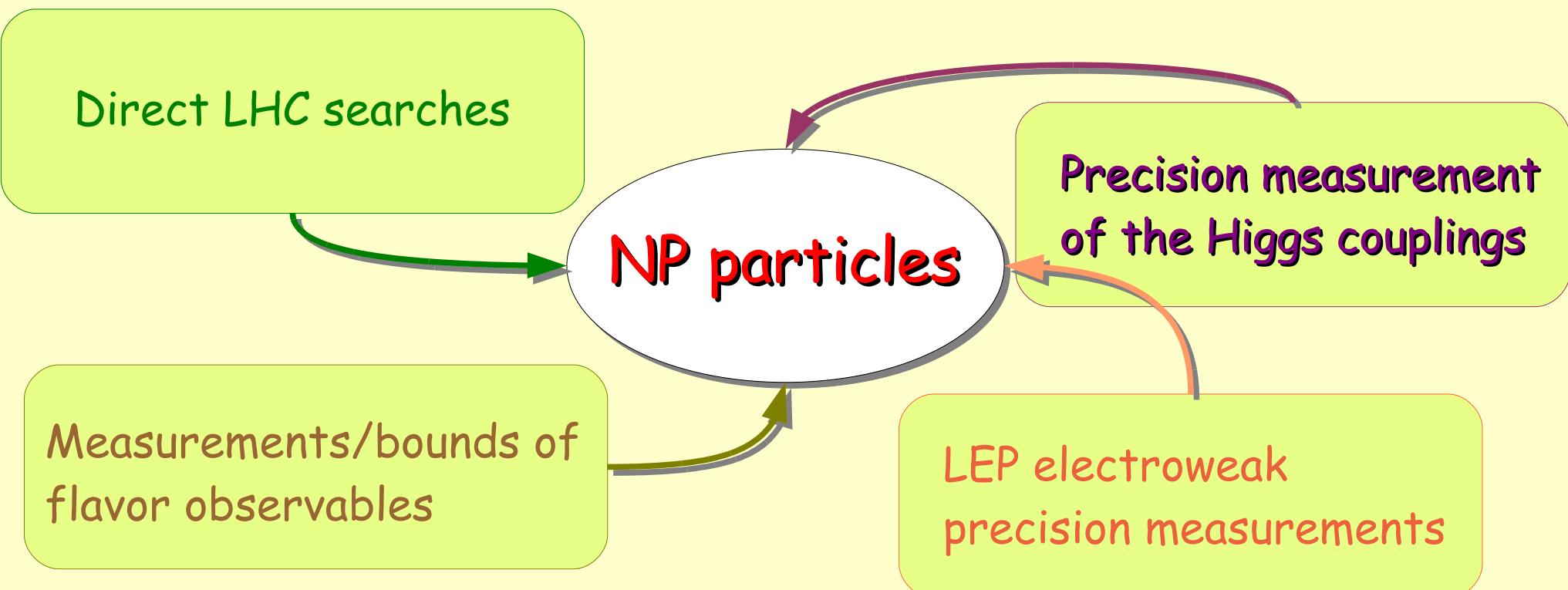


$$\mathcal{M}_{\tilde{\tau}}^2 \simeq \begin{pmatrix} m_{L_3}^2 + m_{\tau}^2 + D_L^{\tau} & m_{\tau}(A_{\tau} - \mu \tan \beta) \\ m_{\tau}(A_{\tau} - \mu \tan \beta) & m_{E_3}^2 + m_{\tau}^2 + D_R^{\tau} \end{pmatrix}$$

Conclusions

A lot of physics can be learned from the precision measurement of the Higgs (loop induced) couplings

The strength of the complementarity



Overconstraining New Physics

1. Direct production of new particles

Several assumptions

Probe for m_{NP} , decay mode, mass of the daughter particles, ...

2. Precision measurement of the hgg and $hy\gamma$ couplings

Probe for m_{NP} , hPP coupling

3. Decays of these new particles into a Higgs + X

$$pp \rightarrow (NP)(NP) \rightarrow (hX)(hX)$$

Probe for m_{NP} , hPP coupling, ...