Modification of Higgs Pair Production by Stops at the LHC

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arXiv: 1705.xxxx

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Outline

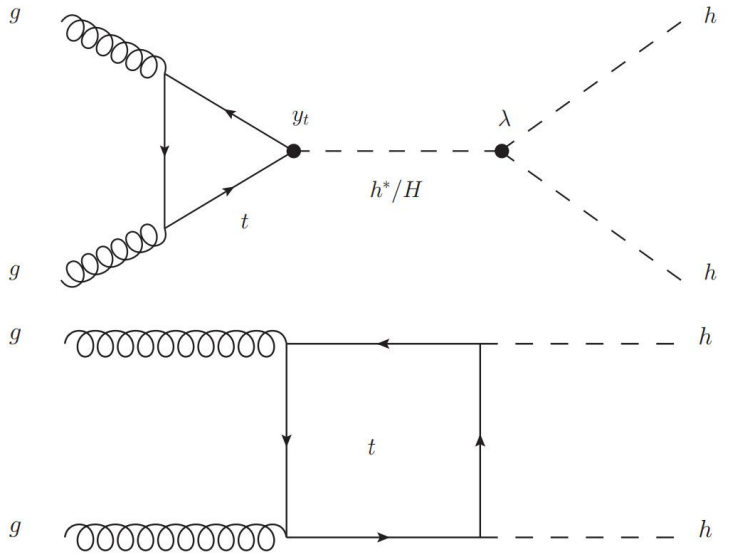
- Why enhance di-Higgs production?
- Status of Higgs couplings: 2HDM motivation
- Enhancing di-Higgs production with light colored states
- Current experimental status

Why di-Higgs?

- Cancellation between triangle and box diagrams
- Sensitivity to new physics

$$\frac{d\hat{\sigma}_{gg\to hh}}{d\hat{t}} = K\frac{G_F^2\alpha_s^2}{256(2\pi)^3} \times \left[\left|(C_\triangle F_\triangle + C_\square F_\square)\right|^2 + \left|C_\square G_\square\right|^2\right]$$

Barget et al arXiv: 1408.0003



Why di-Higgs?

- Higgs potential with non-renormalizable operators
- Direct probe of Higgs self coupling

$$\frac{d\hat{\sigma}_{gg\to hh}}{d\hat{t}} = K\frac{G_F^2\alpha_s^2}{256(2\pi)^3} \times \left[\left|(C_\triangle F_\triangle + C_\square F_\square)\right|^2 + \left|C_\square G_\square\right|^2\right]$$

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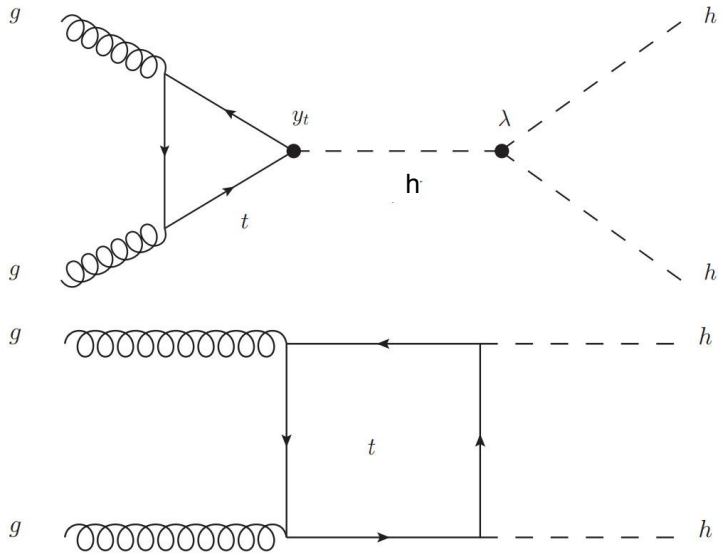


Why di-Higgs?

$$V(\phi, T) = \frac{m^2 + a_0 T^2}{2} \left(\phi^\dagger \phi\right) + \frac{\lambda}{4} \left(\phi^\dagger \phi\right)^2 + \frac{c_6}{8\Lambda^2} \left(\phi^\dagger \phi\right)^3$$

$$\lambda_3 = \frac{3m_h^2}{v} \left(1 + \frac{2c_6 v^4}{m_h^2 \Lambda^2}\right)$$

- For first order phase transition $\frac{2}{3} \leq \delta \leq 2.$

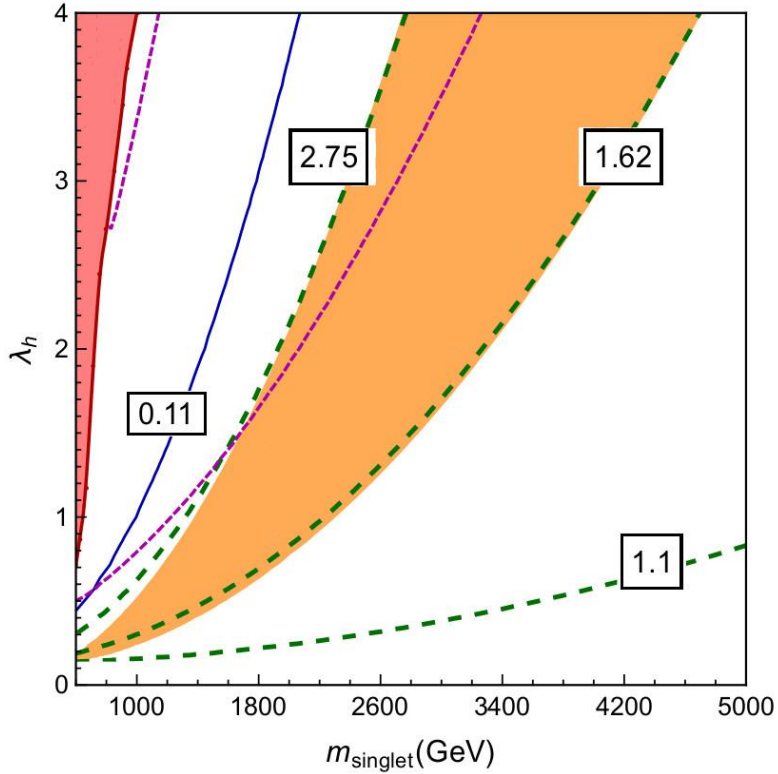
Why di-Higgs?

- For singlet extensions

$$V(\phi_h, \phi_s, T) = \frac{m_0^2 + a_0 T^2}{2}\phi_h^2 + \frac{\lambda_h}{4}\phi_h^4 + a_{hs}\phi_s\phi_h^2$$

$$+ \frac{\lambda_{hs}}{2}\phi_s^2\phi_h^2 + t_s\phi_s + \frac{m_s^2}{2}\phi_s^2 + \frac{a_s}{3}\phi_s^3 + \frac{\lambda_s}{4}\phi_s^4$$

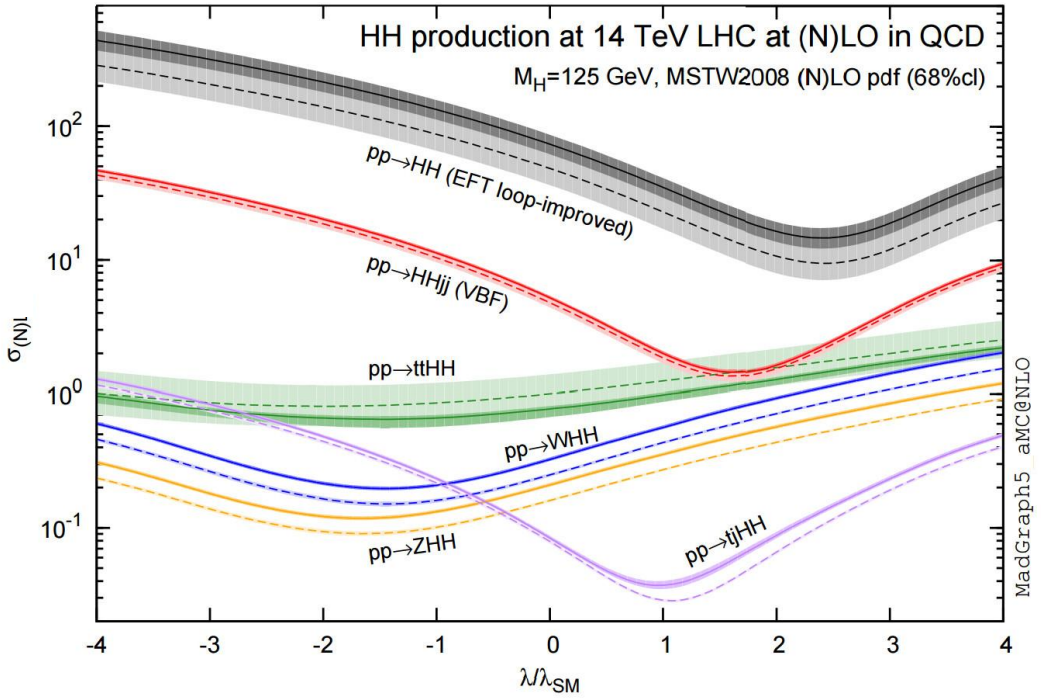
- Challenge: Reduction in cross-section



P.Huang, AJ, B. Li, C. Wagner arXiv:1512.00068

Why di-Higgs?

- About 30 fb in SM
- ~ 60 ab in $HH \to b\bar{b}\gamma\gamma$



R.Federix et al arXiv: 1401.7340

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Higgs Couplings: Current Status

- Best fit values for top yukawa ~ 1.4, bottom yukawa ~0.6
- About 2σ away from the SM values
- BR for $h \longrightarrow b\,\bar{b}$ is ~ 0.58
- Change in decay width to b will drastically modify other branching ratios
- Signal strength measured is roughly SM therefore need to reduce production
- ggh coupling best fit ~0.8

Higgs Couplings: 2HDM Motivation

- 2HDM are well motivated, present in MSSM, NMSSM
- Can easily accommodate best fits for top and bottom Yukawa
- Top Yukawa enhancement correlated with gluon fusion

$$c_t = \frac{\cos\alpha}{\sin\beta} = \sin(\beta-\alpha)\left[1+\cot\beta\cot(\beta-\alpha)\right] ,$$

$$c_b = -\frac{\sin\alpha}{\cos\beta} = \sin(\beta-\alpha)\left[1-\tan\beta\cos(\beta-\alpha)\right]$$

Higgs Couplings: 2HDM Motivation

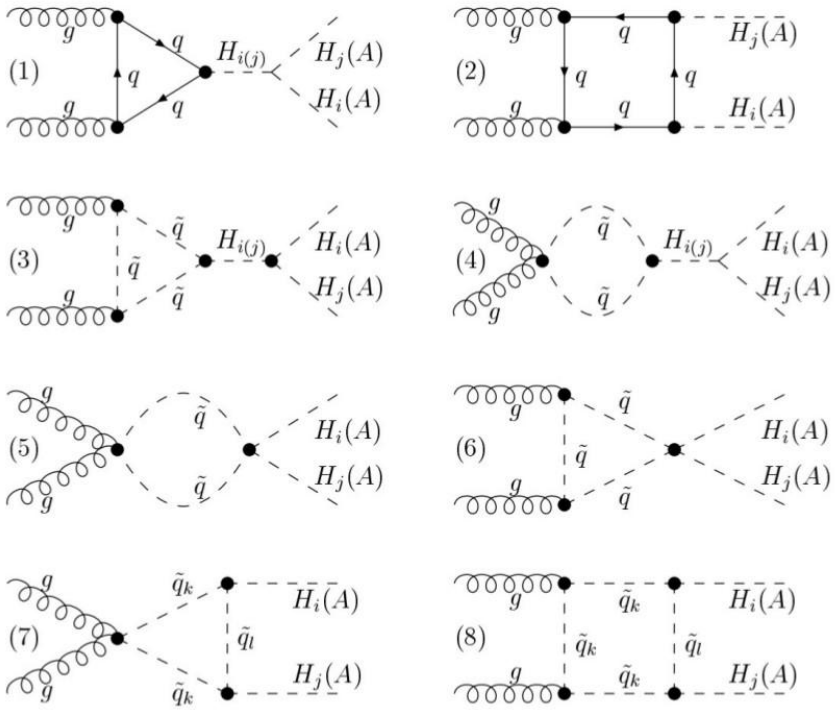
- Light colored states can alleviate this ⟶ Stops
- Mixing required to keep c_g lower

$$\mathbf{M}_{\tilde{\mathbf{t}}}^{\mathbf{2}} = \begin{pmatrix} m_Q^2 + m_t^2 & m_t X_t \\ m_t X_t & m_U^2 + m_t^2 \end{pmatrix}$$

$$\frac{c_g}{c_g^{\rm SM}} = c_t + \frac{m_t^2}{4}\left[c_t\left(\frac{1}{m_{\tilde{t}_1}^2} + \frac{1}{m_{\tilde{t}_2}^2}\right) - \frac{\tilde{X}_t^2}{m_{\tilde{t}_1}^2\, m_{\tilde{t}_2}^2}\right]$$

$$\tilde{X}_t^2 \equiv X_t\left(A_t \frac{\cos\alpha}{\sin\beta} + \mu\frac{\sin\alpha}{\sin\beta}\right) \qquad X_t \equiv A_t - \mu/\tan\beta$$

Contributions to gg → hh



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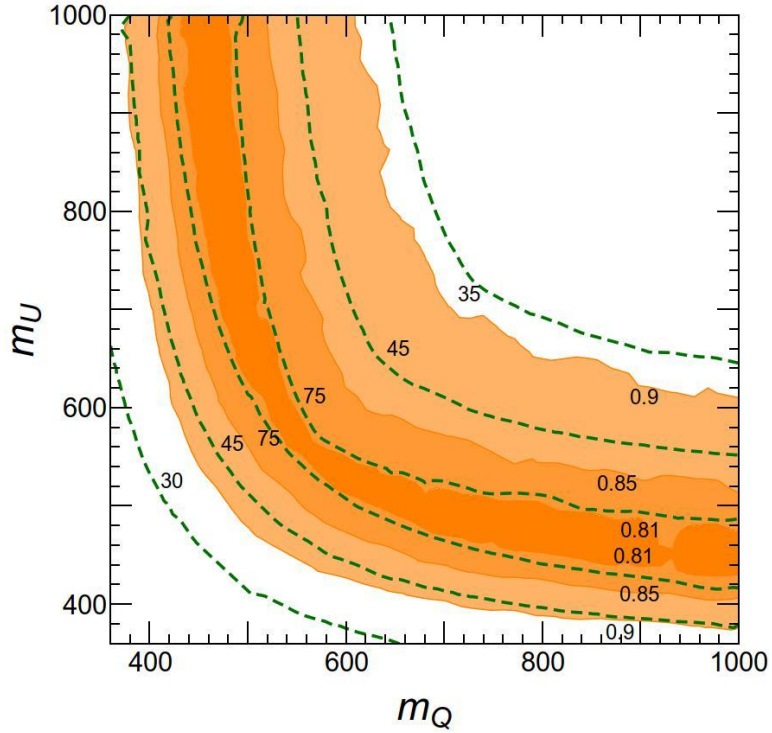
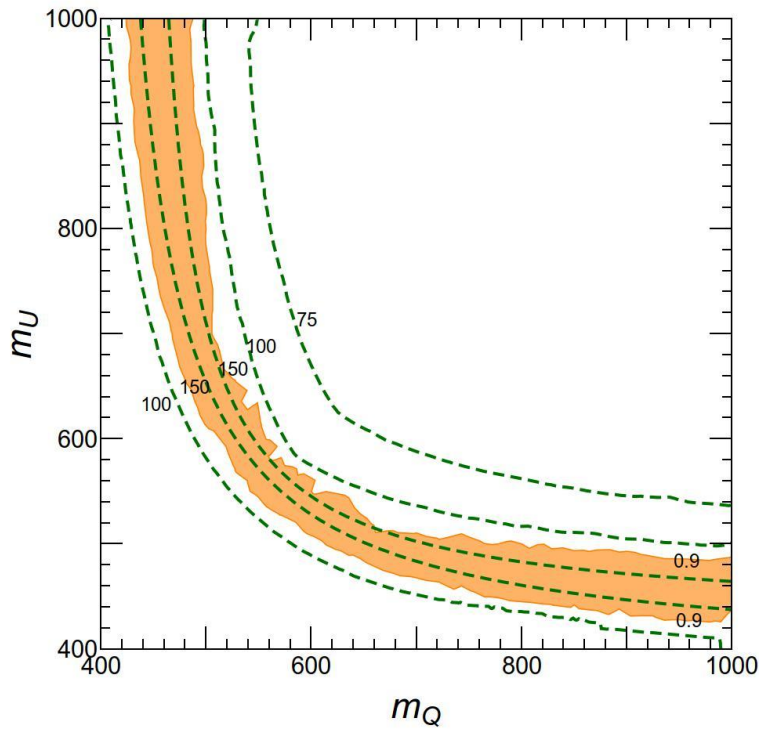
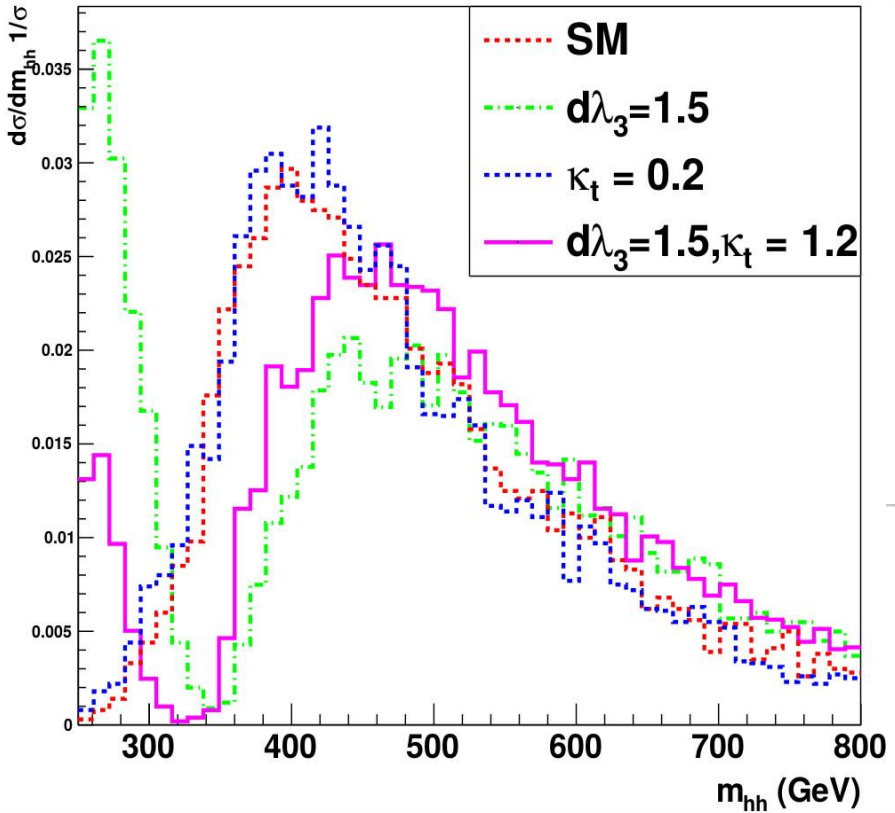
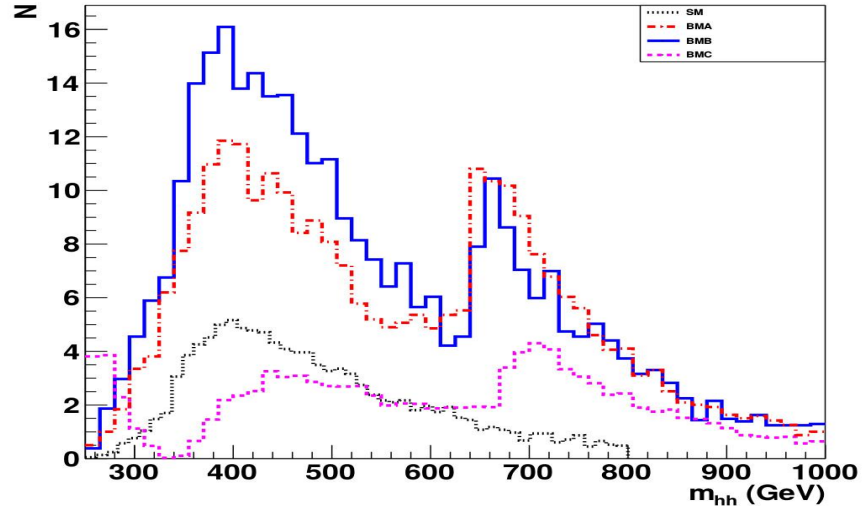
Enhanced di-Higgs production





Enhanced di-Higgs production





σ_A = 70 fb, σ_B = 80 fb, σ_C = 27 fb

c_{gA}=0.83, c_{gB}=0.98, c_{gC}=0.94

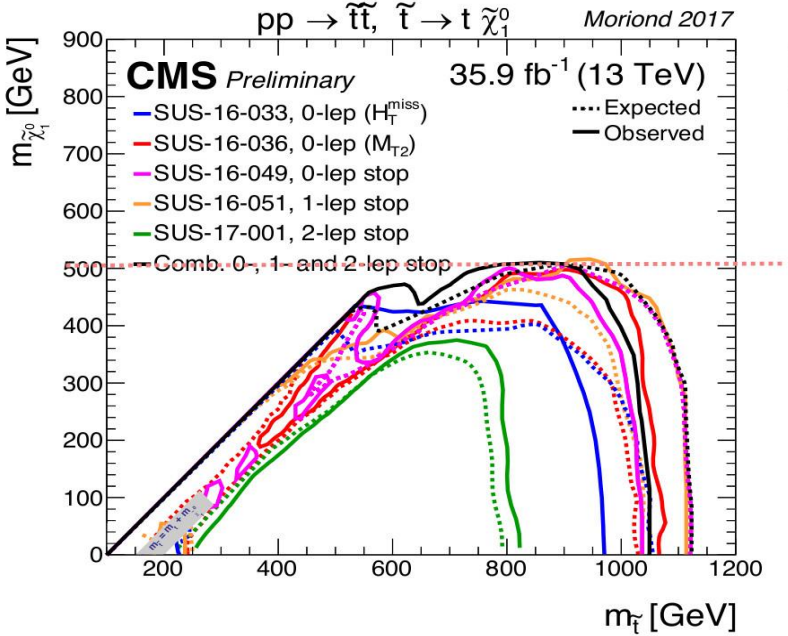
Enhanced di-Higgs production

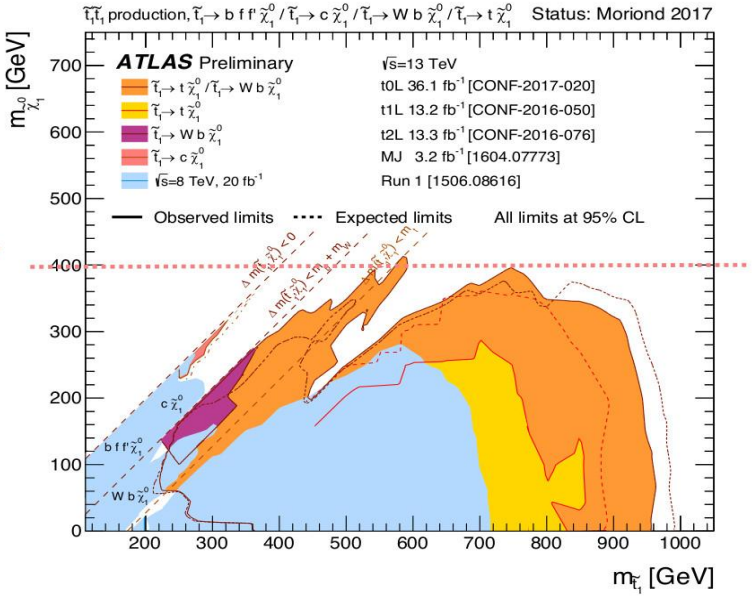
At 3 ab^{-1} of integrated luminosity at 14 TeV LHC

- For BMA: Stat. significance obtained is 7.7σ
- For BMB: Stat. significance obtained is 8.8σ
- For BMC: Stat. significance obtained is 3.4σ

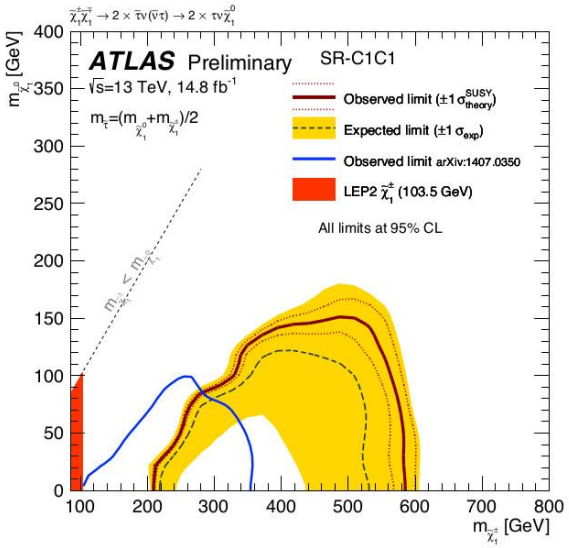
Hiding Stops

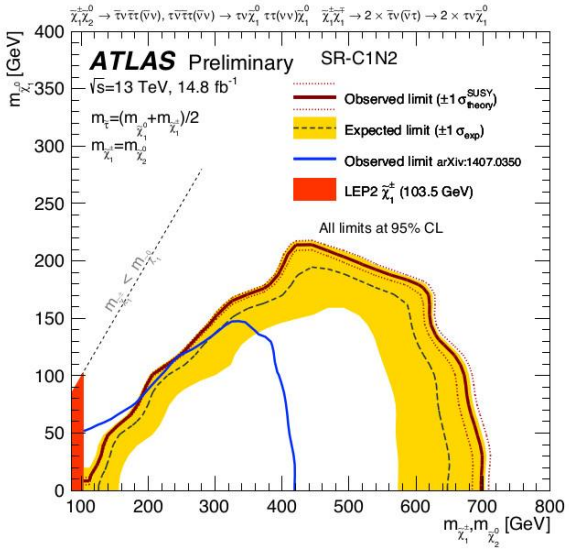
Weak constraints when stops are heavier than 500 GeV

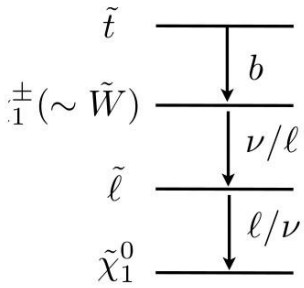




Hiding Stops







Constraints can be further lowered with a light stau

Conclusions

- For best fit values of Higgs couplings 2HDM can account for potential deviation in top and bottom Yukawas
- Reduction in bottom yukawa requires reduction in single Higgs production
- Light colored scalars such as stops can achieve that with mixing
- Large enhancement of di-HIggs production cross section can still be obtained for stops of masses higher than 300 GeV with sufficient mixing
- Light staus can possibly avoid current tight bounds post-moriond on the light stop masses