An extended scalar sector to address the tension between a fourth generation and Higgs searches at the LHC

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B3SM 23-25/10/2011
on behalf of X.-G. He

An extended scalar sector to address the tension between a fourth generation and Higgs searches at the LHC

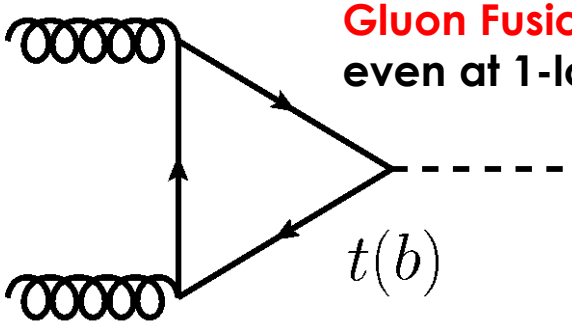
Xiao-Gang He, German Valencia, arXiv: 1108.0222

Outline

- **Higgs boson in SM3 and in SM4 (Review)**
  - gg→h cross section, Higgs decay
  - LHC result
  - (Electroweak constraint)
- **SM4 to SM4S** He, Valencia, arXiv:1108.0222
  - An extended scalar sector
  - Tension between SM4 and extra scalar
- **Summary**

Gluon fusion in SM3

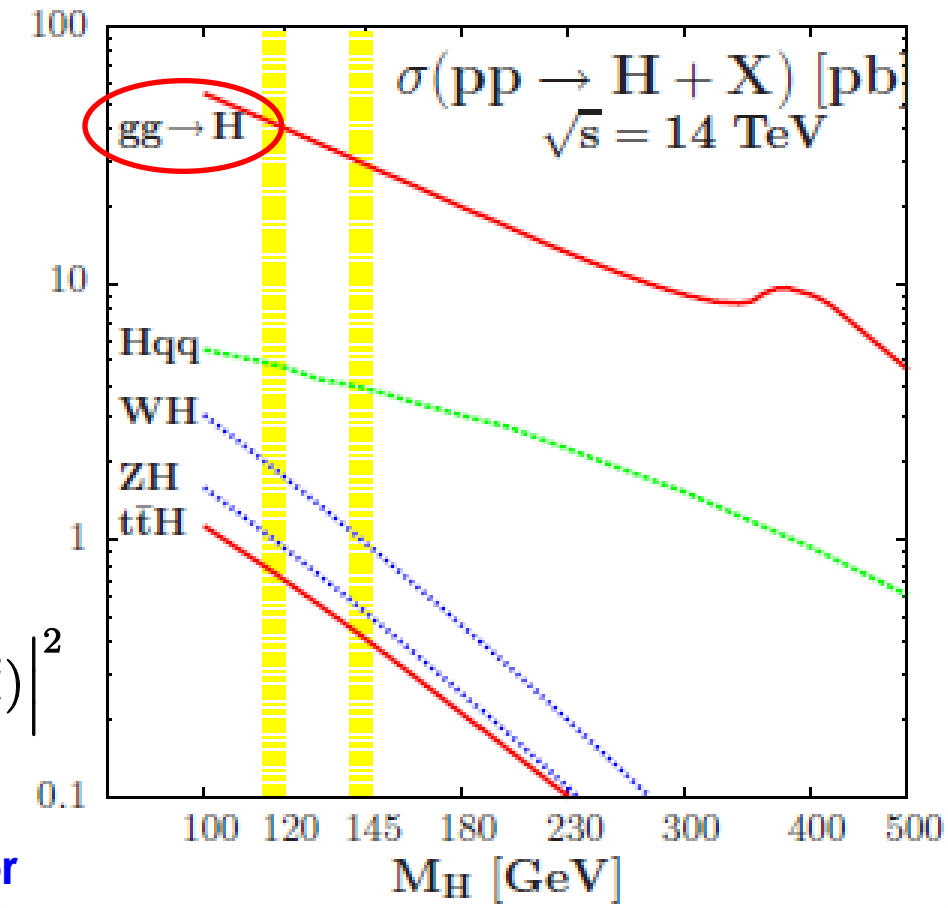
- **Gluon fusion mechanism**
  - largest cross section!!



Gluon Fusion gg→h
even at 1-loop

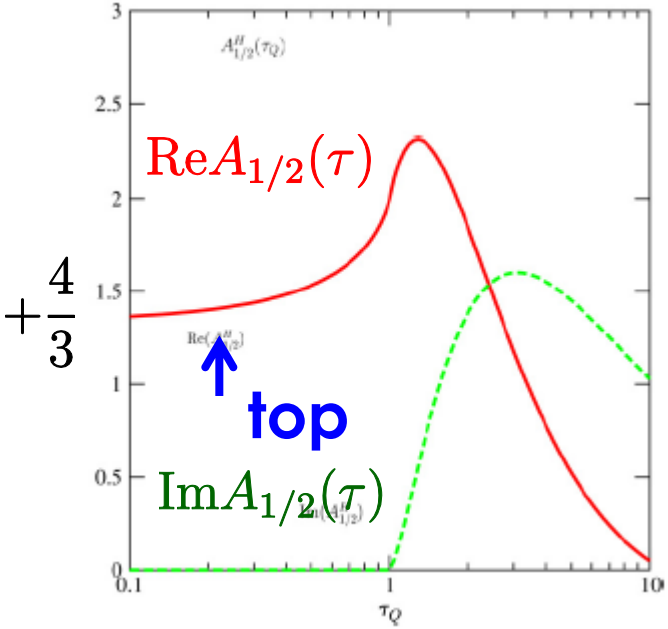
$$\sigma = \frac{\sqrt{2}G_F\alpha_s^2}{576\sqrt{2}\pi}\left|+\frac{3}{4}\sum_q A_{1/2}(m_H^2/4m_q^2)\right|^2$$

Sum over quark flavor



Gluon fusion in SM3

Gluon fusion mechanism

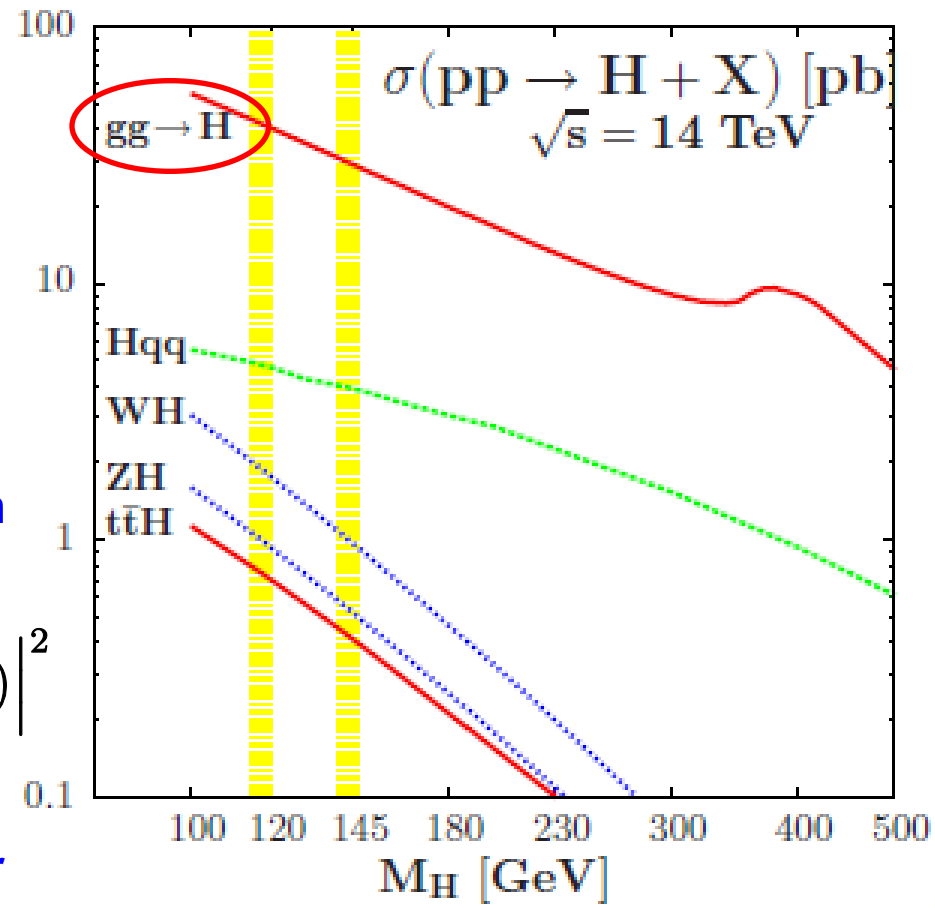


$$\tau = m_H^2/4m_q^2$$

bottom

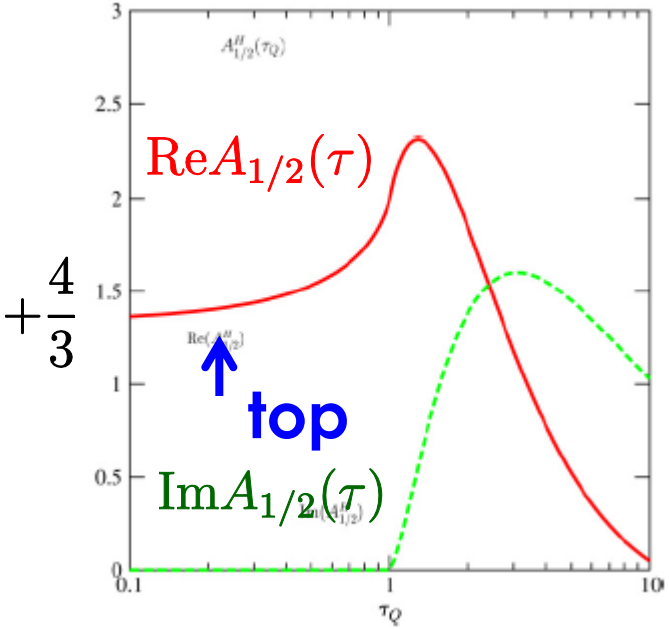
$$\sigma = \frac{\sqrt{2}G_F\alpha_s^2}{576\sqrt{2}\pi}\left|+\frac{3}{4}\sum_q A_{1/2}(m_H^2/4m_q^2)\right|^2$$

Sum over quark flavor



Gluon fusion in SM4 (sequential 4th generation)

Gluon fusion mechanism



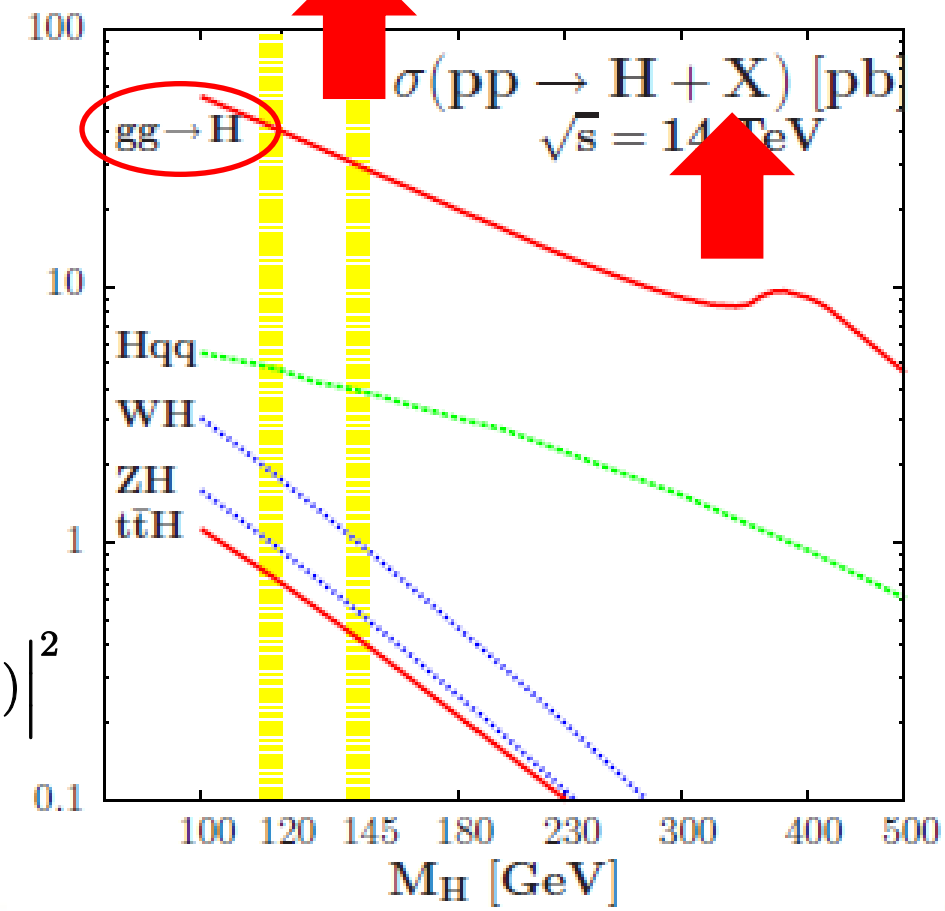
$$\tau = m_H^2/4m_q^2$$

$$\sigma = \frac{\sqrt{2}G_F\alpha_s^2}{576\sqrt{2}\pi}\left|+\frac{3}{4}\sum_{q,Q} A_{1/2}(m_H^2/4m_q^2)\right|^2$$

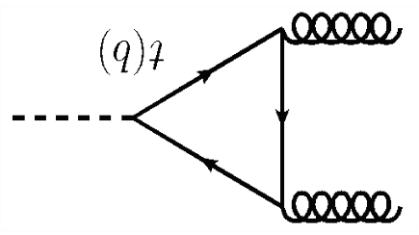
Sum over t and t', b'

Enhance factor 9

$$\sigma_{\mathrm{SM4}} \approx 9 \times \sigma_{\mathrm{SM}}$$

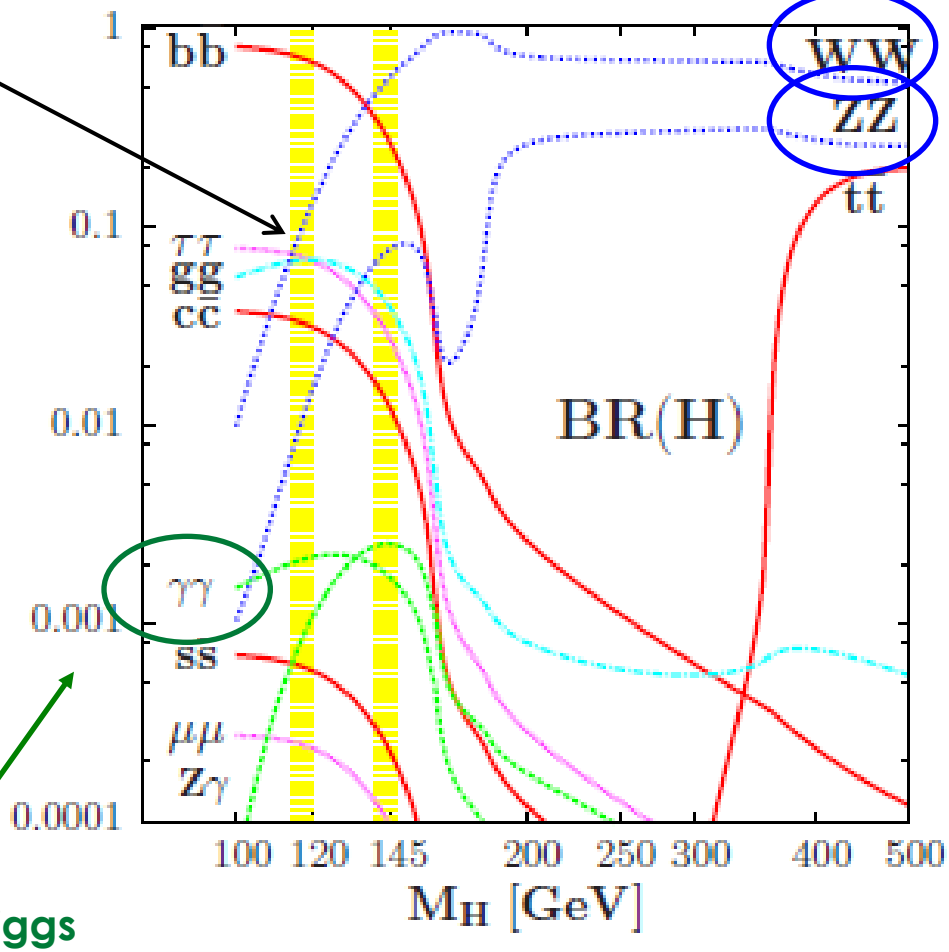


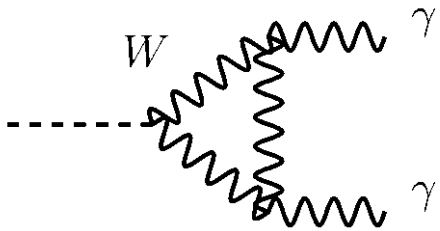
Higgs decay in SM3



B(gg) is less than 10%

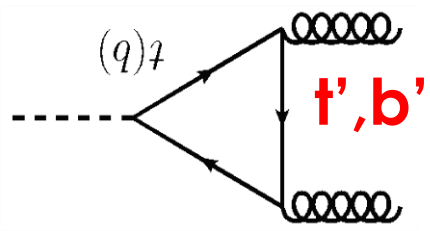
Main decay modes for heavy Higgs
Z→4l can determine mass of Higgs





Only 0.3%, but less BG events
This can determine mass of light Higgs

Higgs decay in SM4

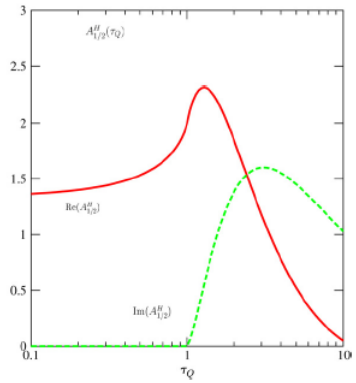


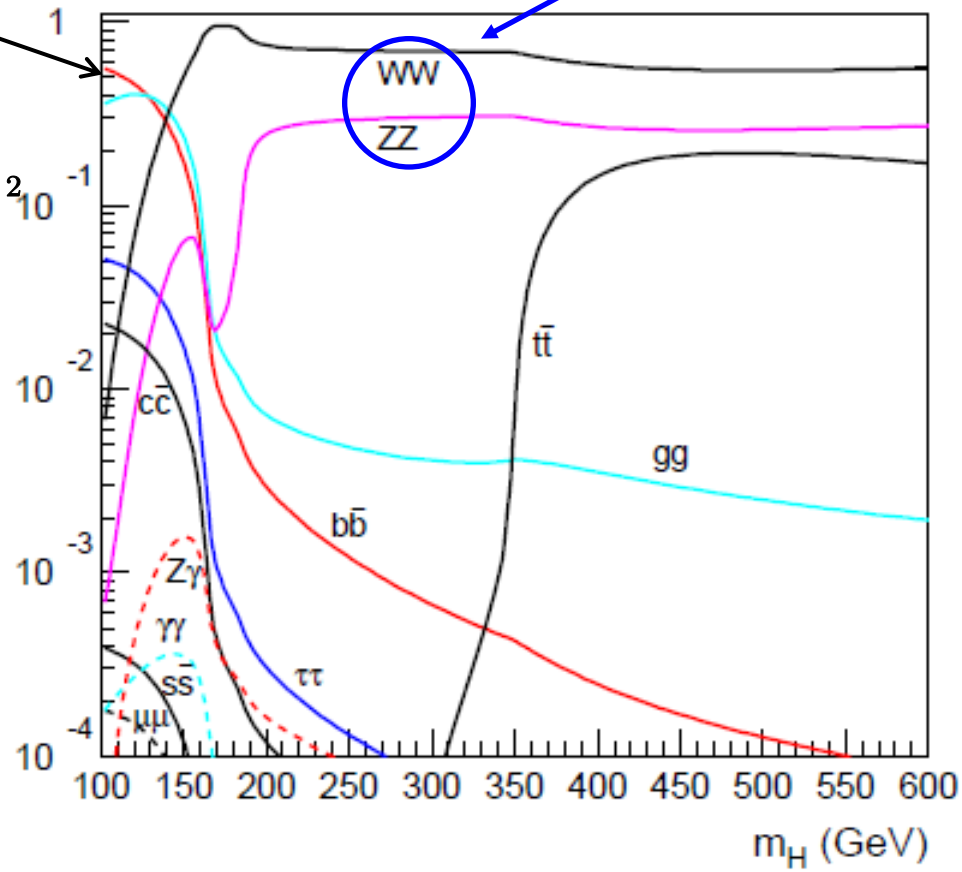
Main decay modes for heavy Higgs
Z→4l can determine mass of Higgs
Basically same as in SM3

B(gg) can be dominant in low mH region !! (40%)

$$\Gamma^{gg}_{\rm SM4} = \frac{\sqrt{2}G_F\alpha_s^2 m_H^3}{64\pi}\left|+\frac{4}{3}\sum_{q,Q} A_{1/2}(m_H^2/4m_Q^2)\right|^2$$

$$\mathcal{B}^{gg}_{\rm SM4} \approx \frac{9\times\Gamma^{gg}_{\rm SM}}{\Gamma^{others}_{\rm SM}+9\times\Gamma^{gg}_{\rm SM}}$$





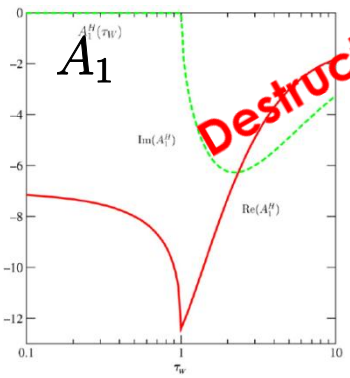
Higgs decay in SM4

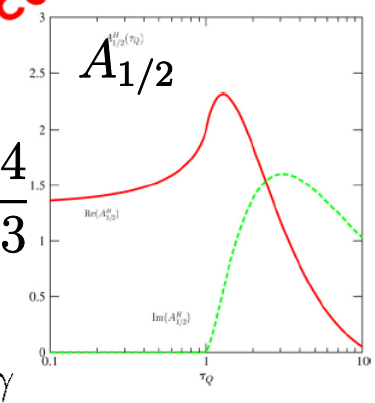
Main decay modes for heavy Higgs
Z→4l can determine mass of Higgs
Basically same as in SM3

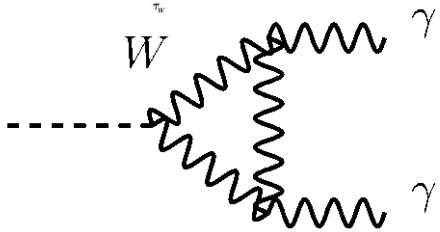
$$\Gamma^{\gamma\gamma}_{\rm SM4} = \frac{\sqrt{2}G_F\alpha^2 m_H^3}{256\pi}\left|+A_1(m_H^2/4m_W^2) + \frac{4}{3}\sum_Q N_c Q_Q^2 A_{1/2}(m_H^2/4m_Q^2)+\right|^2$$

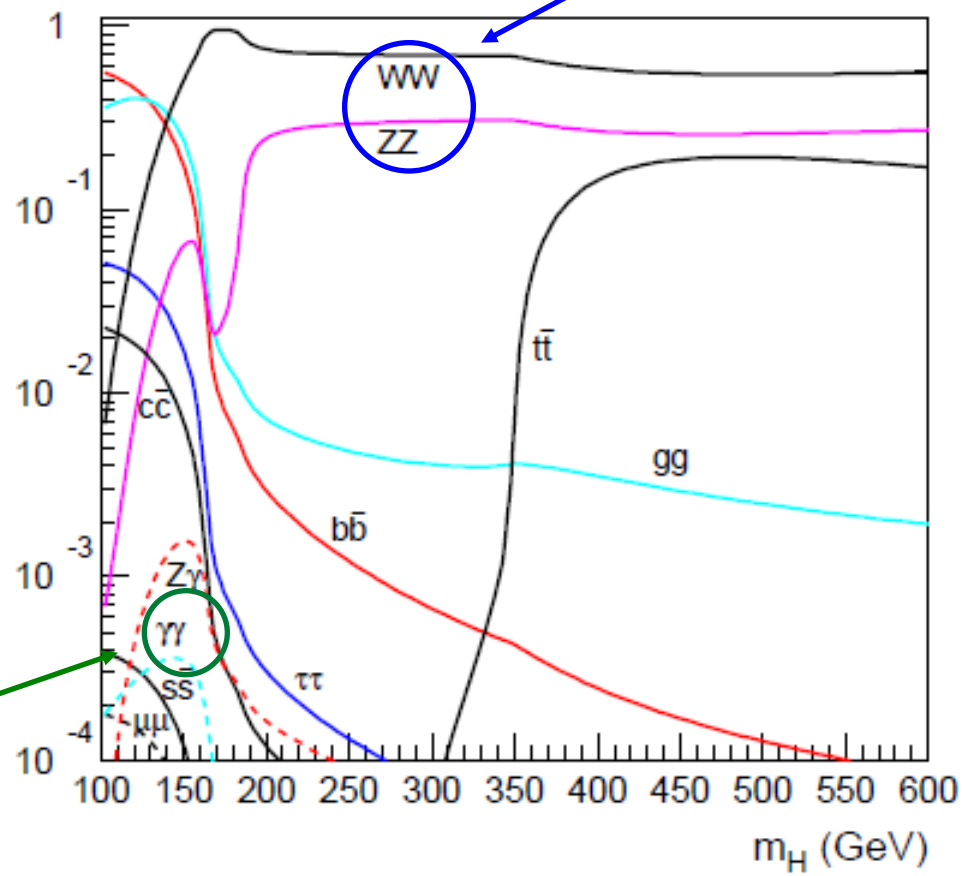
$$\mathcal{B}^{\gamma\gamma}_{\rm SM4} \approx \frac{0.2\times\Gamma^{\gamma\gamma}_{\rm SM}}{\Gamma^{others}_{\rm SM} + 9\times\Gamma^{gg}_{\rm SM}}$$

Destructive cancellation

-7 

$+\frac{4}{3}$ 

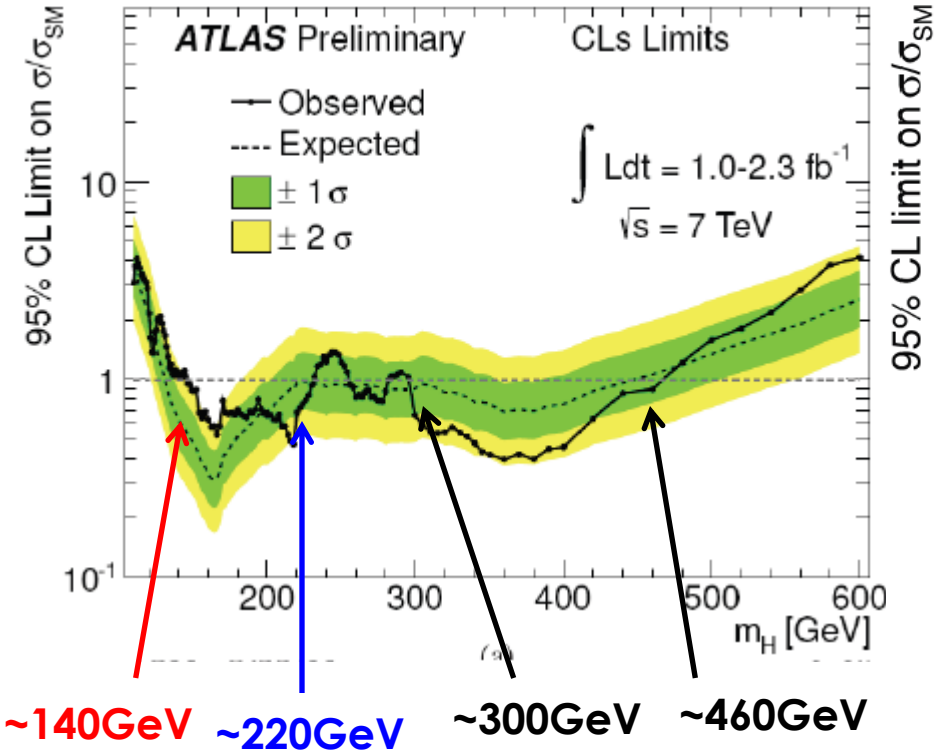


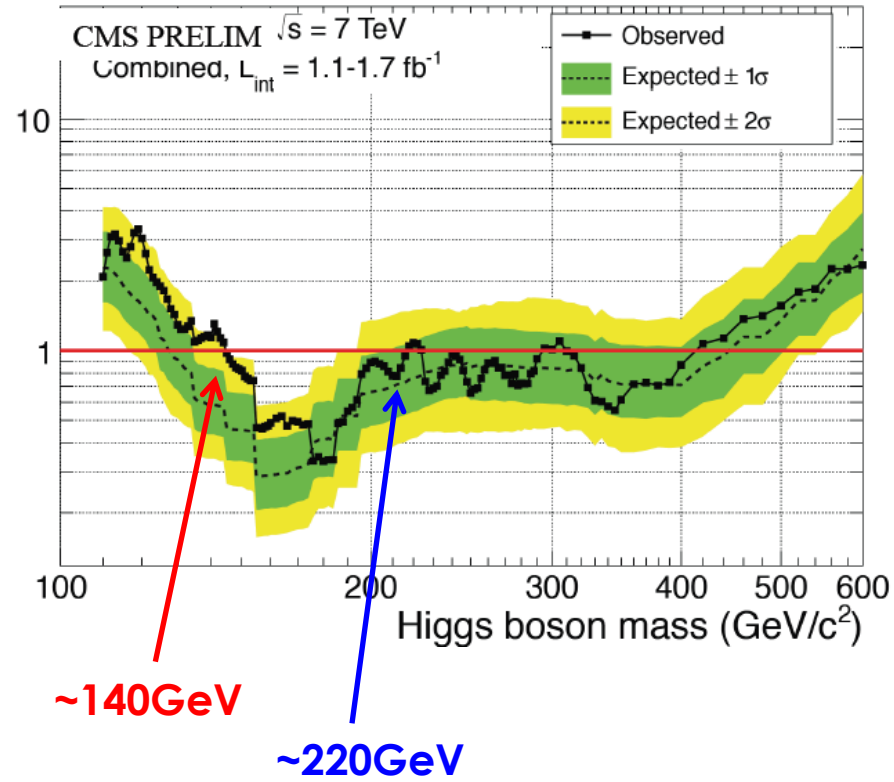


Reduce to 0.03% from 0.3%.
Enhance tot. width, cancellation in $\Gamma(\gamma\gamma)$.

Present status of Higgs boson search in SM3

- The results given @ LP2011

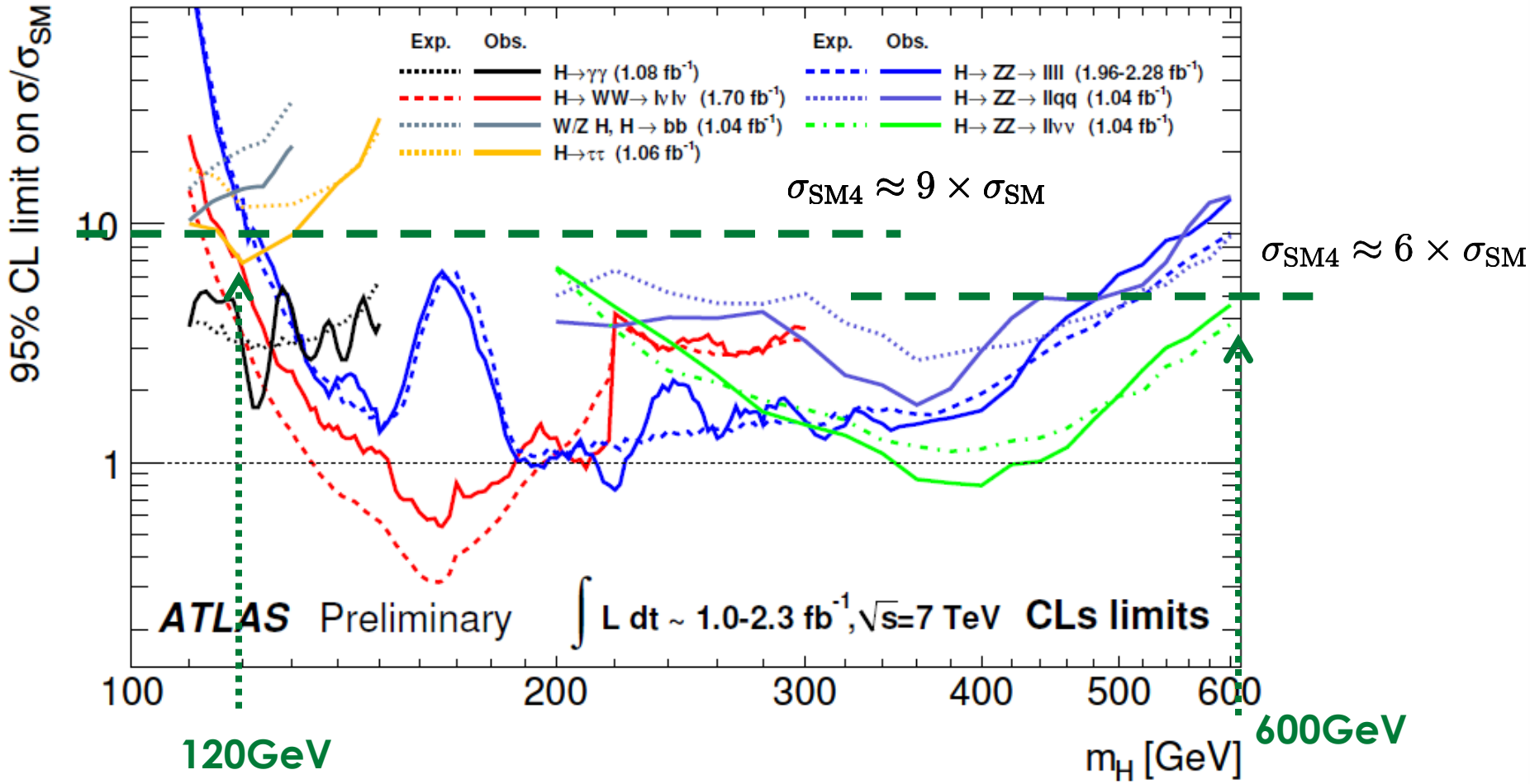




- Roughly speaking, mH=140-450GeV is excluded !!

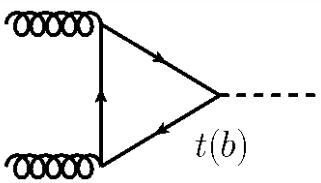
Present status of Higgs boson search in SM3 → SM4

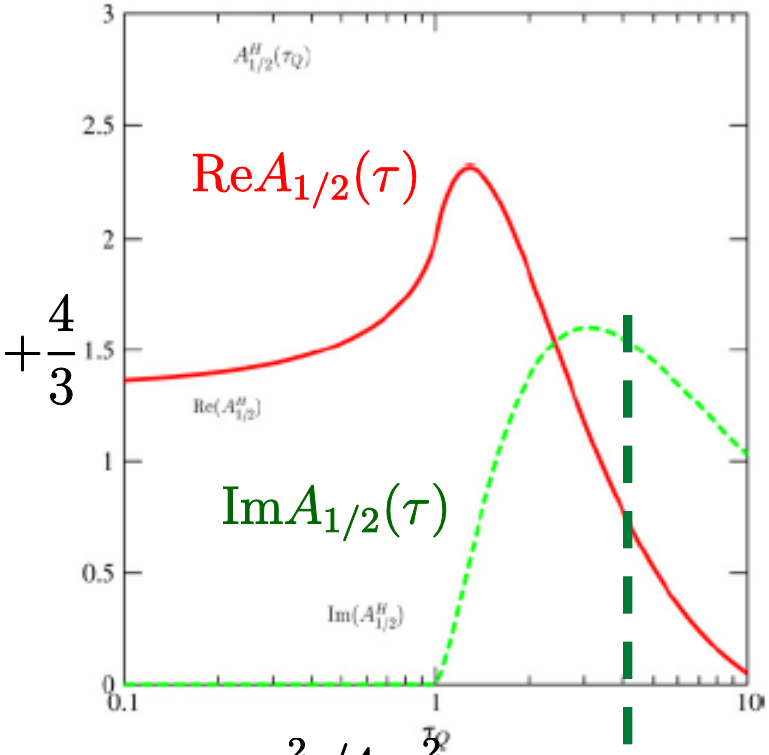
- The results given @ LP2011 (in separate modes)



Gluon fusion revisited

- **Factor of 9?**





$m_H \approx 4m_t$

$$\sigma_{\mathrm{SM4}} \approx |1+2|^2\sigma_{\mathrm{SM}} = 9\sigma_{\mathrm{SM}}$$

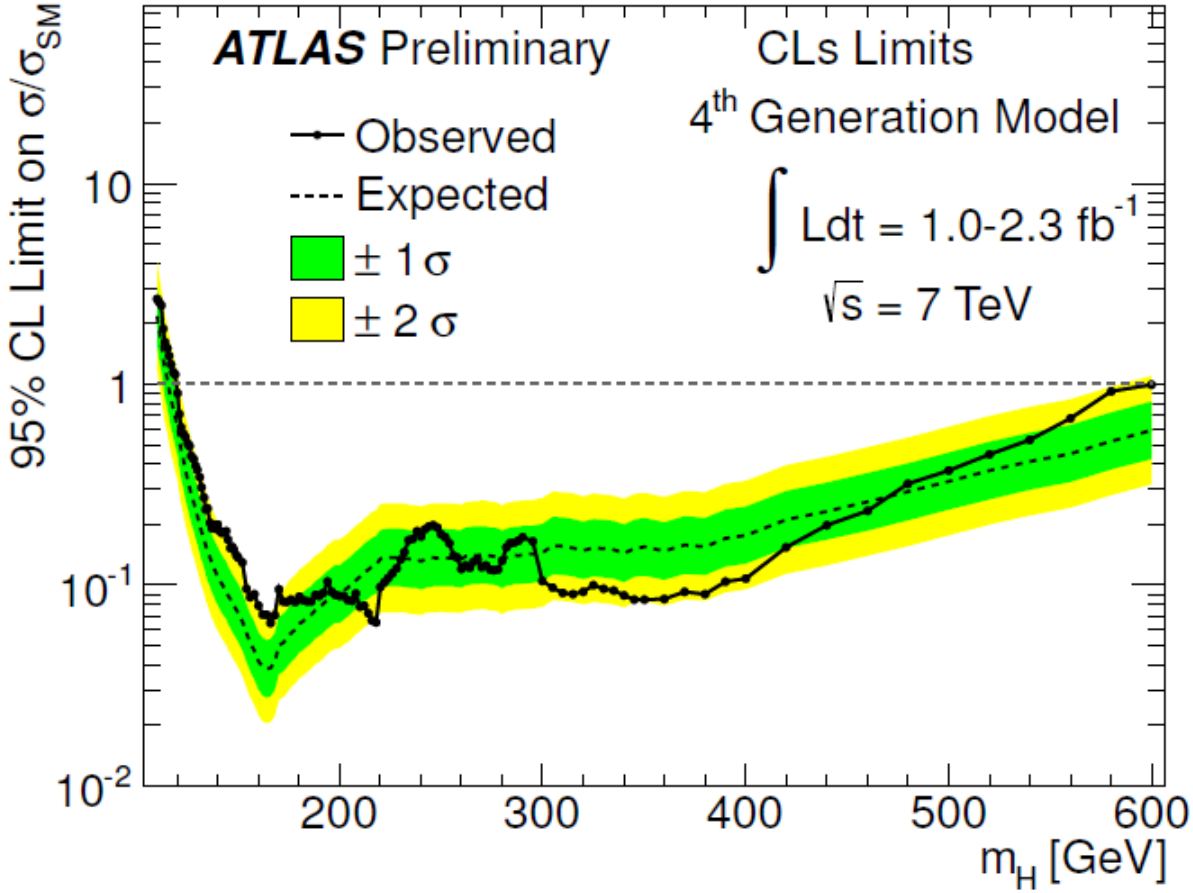
For low mass Higgs boson,
top and t', b' give constant contributions.

$$\sigma_{\mathrm{SM4}} \approx (|1/3+2|^2 + |1+0|^2)\sigma_{\mathrm{SM}} \approx 6\sigma_{\mathrm{SM}}$$

For high mass Higgs boson,
top gives imaginary contribution and
t', b' give real constant contributions.

Present status of Higgs boson search in SM4

- **The results given @ LP2011**



- **In SM4, mH=119-593GeV is excluded !!**

What do we learn from Review?

→ **Tension @ one-loop level.**

$$\sigma = \frac{\sqrt{2}G_F\alpha_s^2}{576\sqrt{2}\pi}\left|+\frac{3}{4}\sum_{q,Q}A_{1/2}(m_H^2/4m_q^2)+\cdots\right|^2$$

SM4+X

He, Valencia, arXiv:1108.0222

SM4 to SM4S (Smart?, Survive?, Simple?, Scalar?)

- **New colored scalar**

  He, Valencia, arXiv:1108.0222

  Gresham, Wise, PRD76,075003(2007)

  - QCD production: Testable new scalar @ LHC
  - Color triplet scalar (→ squarks); skip in this talk
  - **<u>Color octet scalar</u>** [SU(2) doublet] Manohar, Wise, PRD74,035009(2006)
    - Rich flavor pheno. due to Yukawa int.

$$Y_d\, Q_L(\bar{\mathbf{3}})\, \Phi(\mathbf{1} \text{ or } \mathbf{8})\, d_R(\mathbf{3})$$

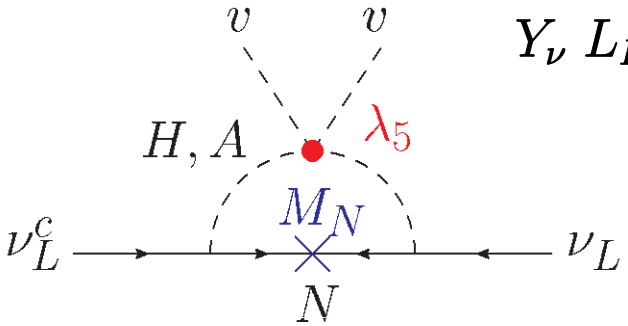
Color octet

    - New physics model → loop induced neutrino mass

$$Y_\nu\, L_L(\bar{\mathbf{3}})\, \Phi(\mathbf{1} \text{ or } \mathbf{8})\, N_R(\mathbf{8}) + M_N\, \overline{N_R^c}(\mathbf{8})\, N_R(\mathbf{8})$$

Perez, Wise, PRD80, 053006(2009)

Color octet

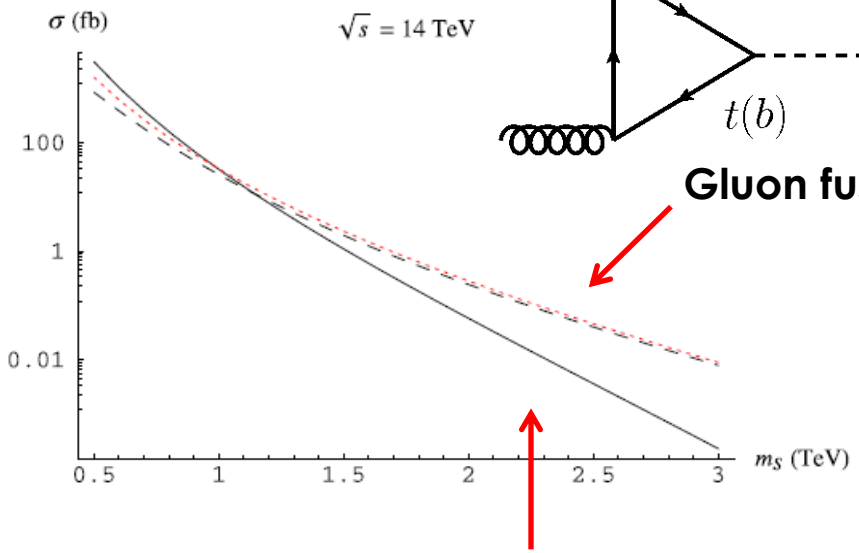


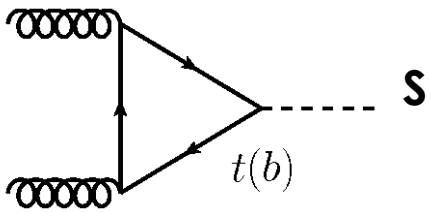
Exp. bound on octet

- **Flavor data** Manohar, Wise, PRD74,035009(2006)
  - K→μe, Bs→ Xs γ, μ→e γ

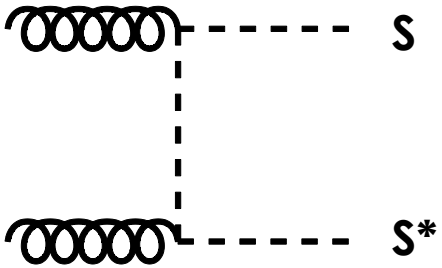
  → [Minimal flavor violation] or [**small** Yukawa coupling]

- **Gluon fusion, and pair production** Gresham, Wise, PRD76,075003(2007)





Gluon fusion (for Yt=1), No constraint for small Yukawa.



Pair production, complicated final states (not yet constrained)

Scalar potential in SM4S

Scalar potential

Manohar, Wise, PRD74,035009(2006)

$$V = +\lambda\left(\Phi_a^\dagger\Phi_a - \frac{v^2}{2}\right)^2 + 2M^2\,\mathrm{Tr}S_a^\dagger S_a + \lambda_1\Phi_a^\dagger\Phi_a\,\mathrm{Tr}S_a^\dagger S_a$$
$$+\lambda_2\Phi_a^\dagger\Phi_b\,\mathrm{Tr}S_b^\dagger S_a + \left[\lambda_3\Phi_a^\dagger\Phi_b^\dagger\,\mathrm{Tr}S_aS_b + \mathrm{H.c.}\right] + \cdots$$

λ2=2λ3 (Custodial)

Scalar Mass and Higgs coupling

$$m_{S^\pm}^2 = M^2 + \frac{\lambda_1 v^2}{4} \qquad \lambda_{hS^+S^-} = 2\lambda_1$$
$$m_{S_R}^2 = M^2 + \frac{(\lambda_1+\lambda_2+2\lambda_3)v^2}{4} \qquad \lambda_{hS_RS_R} = \lambda_1+\lambda_2+2\lambda_3$$
$$m_{S_I}^2 = M^2 + \frac{(\lambda_1+\lambda_2-2\lambda_3)v^2}{4} \qquad \lambda_{hS_IS_I} = \lambda_1+\lambda_2-2\lambda_3$$

Tension between SM4 and extra scalar

Effective Lagrangian

He, Valencia, arXiv:1108.0222

$$\mathcal{L} = \frac{\alpha_s}{12\pi\, v} G^A_{\mu\nu} G^{A\,\mu\nu} h \left[\#\text{ of heavy fermions} + \frac{v^2}{m_S^2}\frac{3}{8}(2\lambda_1 + \lambda_2) \right]$$

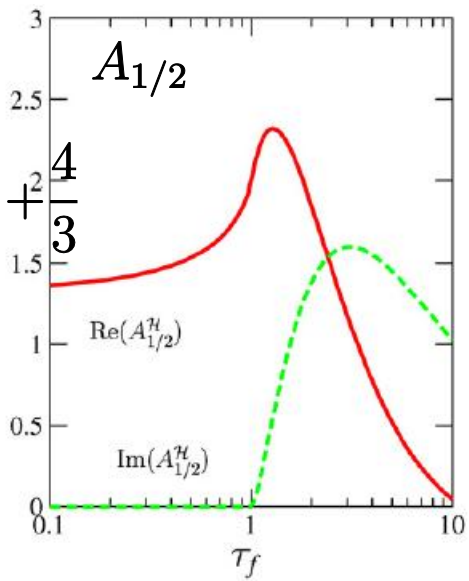
Sum of S_R, S_I, S^+ contributions.

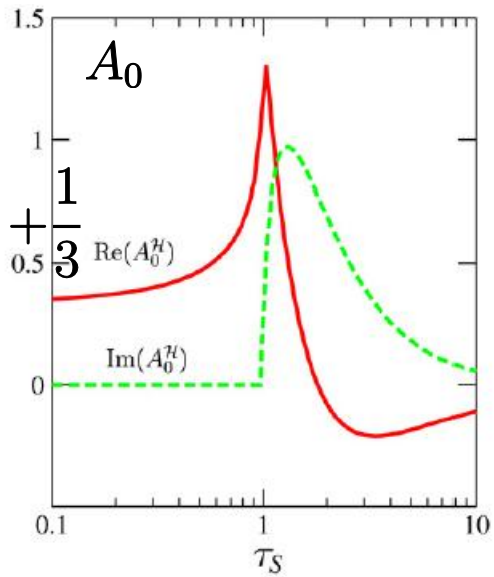
Over all sign can be flipped by λ couplings

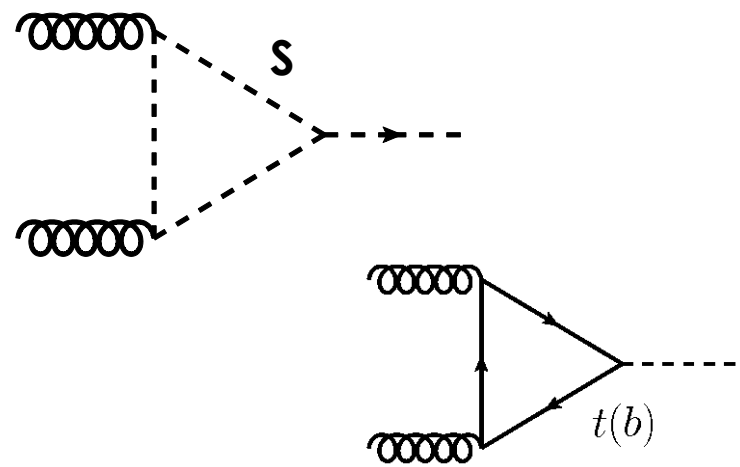
$$\lambda_{hS^+S^-} + \lambda_{hS_RS_R} + \lambda_{hS_IS_I} = 2(2\lambda_1 + \lambda_2)$$

$$m_S^2 \sim M^2 \sim m_{S^\pm}^2 \sim m_{S_R}^2 \sim m_{S_I}^2$$

Loop functions







Gluon fusion in SM4S

He, Valencia, arXiv:1108.0222

- **Tension between SM4 and extra scalar**

$$\sigma = \frac{\sqrt{2}G_F\alpha_s^2}{576\sqrt{2}\pi}\left|+\frac{3v^2}{8m_S^2}(2\lambda_1+\lambda_2)+\frac{3}{4}\sum_{q,Q}A_{1/2}(m_H^2/4m_q^2)\right|^2$$

Can be negative

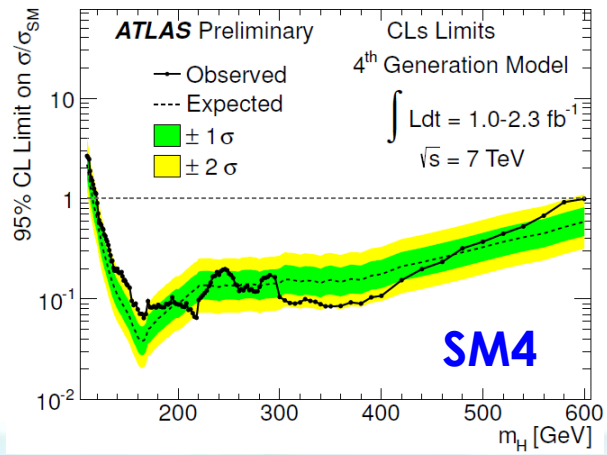
- **Clearly, scalar contributions can be destructive!!**
- **How big?**
  - **For $\lambda 1$=-8, mS~2v,**

    the first term ~ -1 (comparable to one 4G quark)

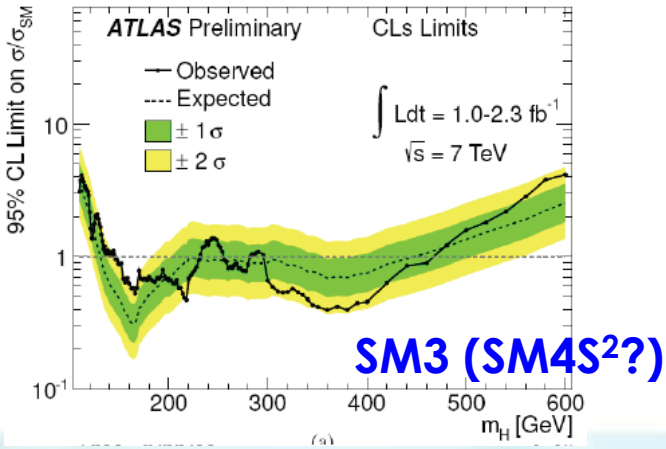
    M ~ 1(top) +2(t',b') -1(colored scalar) +(…)
- **You may add more "exotic" colored scalars.**

Summary

- **Higgs boson in SM3 and in SM4 (Review)**
  - gg→h cross section, Higgs decay
  - LHC result
  - (Electroweak constraint)
- **SM4 to SM4S** He, Valencia, arXiv:1108.0222
  - An extended scalar sector $\sigma = \frac{\sqrt{2}G_F\alpha_s^2}{576\sqrt{2}\pi}\left|+\frac{3v^2}{8m_S^2}(2\lambda_1+\lambda_2)+\frac{3}{4}\sum_{q,Q}A_{1/2}(m_H^2/4m_q^2)\right|^2$
  - Tension between SM4 and extra scalar



Back to SM3



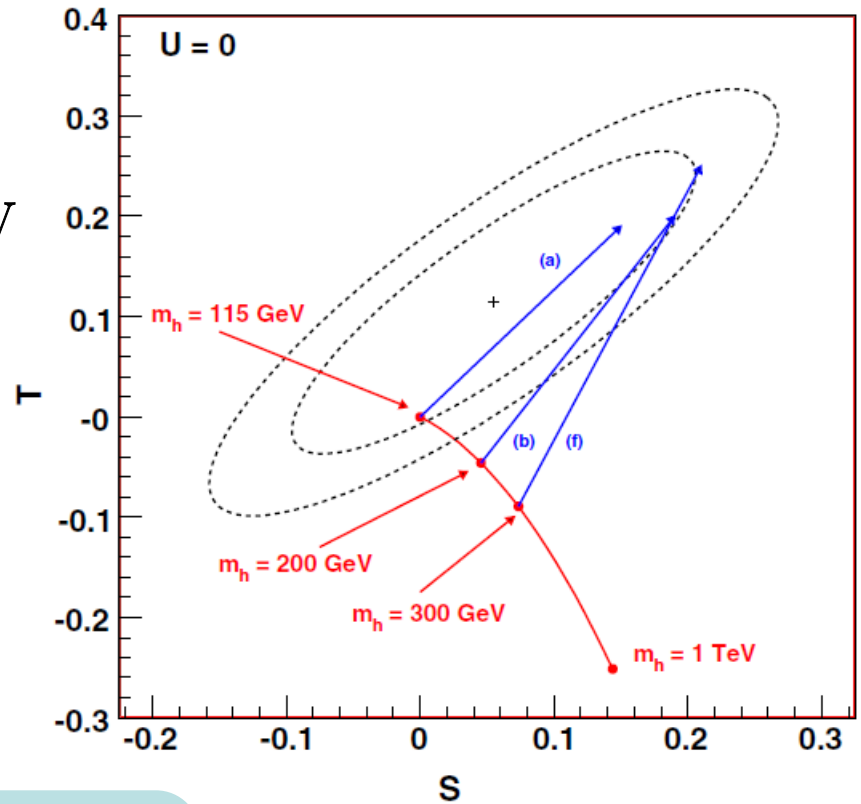
Backup

Kribs, Plehn, Spannowsky, Tait, PRD76,075016(2007)

Electroweak constraint

- Small splitting with mt'>mb'

$$m_{t'} - m_{b'} \approx \left[50 - 10 \ln \frac{m_H}{115\mathrm{GeV}}\right]\mathrm{GeV}$$



$$S = +\frac{N_c}{6\pi}\left(1 - \tfrac{1}{3}\ln\frac{m_{t'}^2}{m_{b'}^2}\right)$$

$$T \approx +\frac{\sqrt{2}G_F N_c}{12\pi^2\alpha_{EM}}(m_{t'} - m_{b'})^2 - \frac{3\sqrt{2}G_F m_Z^2 s_W^2}{16\pi\alpha_{EM}}\left(\ln\frac{m_H^2}{m_W^2} - \frac{5}{6}\right)$$