Models of Yukawa interaction in the two Higgs doublet model

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Models of Yukawa interaction in the two Higgs doublet model, and their collider phenomenology
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Phys. Rev. D80 015017 (2009)

Outline

- Leptophilic Higgs bosons
- Types of Yukawa iteraction
- Higgs decays
- Experimental constraints
- Collider phenomenology (for 2HDM-X)

Introduction

- **Problems in Lepton sector?**
  - Tiny neutirno mass
  - 3 sigma excess in Muon g-2
  - Leptonic cosmic ray @ PAMELA, FERMI

  These problems can be solved by extensions of Higgs sector.

  → **Leptophilic Higgs bosons are potentially interesting**

- **Practically interesting @ LHC**
  - Clear leptonic signal @ hadron colliders
  - Avoid strong constraints from quark sector (esp., B-phys)

Two Higgs doublet models (2HDMs)

- General 2HDM → tree level FCNC

$$\mathcal{L} = Y_{e1}\overline{L}e_R\Phi_1 + Y_{e2}\overline{L}e_R\Phi_2$$

- Adding extra Z2 sym.

$$\Phi_1 \to \Phi_1, \Phi_2 \to -\Phi_2, e_R \to -e_R$$

$$\mathcal{L} = \qquad +Y_{e2}\overline{L}e_R\Phi_2$$

No FCNC

Types of 2HDMs

- There are 4 possible Z2 assignments

	Φ_1	Φ_2	u_R	d_R	ℓ_R	Q_L, L_L
Type-I	+	−	−	−	−	+
Type-II	+	−	−	+	+	+
Type-X	+	−	−	−	+	+
Type-Y	+	−	−	+	−	+

Type-I:
SM-like, universal
Φ1:none, Φ2:u,d,l (all)

Type-II:
Higgs sector of **MSSM**
Φ1:d, l, Φ2:u

Type-X:
Φ1:l (leptons)
Φ2:u,d (quarks)

H,A,H+ can be leptophilic for tanb >>1.

- **Hereafter, we take SM like limit [sin(a-b)=-1] .**
  - h (SM-like) decay is independent of types of Yukawa interaction in 2HDM. **(essetially the same as SM)**

	ξ_h^u	ξ_h^d	ξ_h^ℓ	ξ_H^u	ξ_H^d	ξ_H^ℓ	ξ_A^u	ξ_A^d	ξ_A^ℓ
Type-I	c_α/s_β	c_α/s_β	c_α/s_β	s_α/s_β	s_α/s_β	s_α/s_β	$\cot\beta$	$-\cot\beta$	$-\cot\beta$
Type-II	c_α/s_β	$-s_\alpha/c_\beta$	$-s_\alpha/c_\beta$	s_α/s_β	c_α/c_β	c_α/c_β	$\cot\beta$	$\tan\beta$	$\tan\beta$
Type-X	c_α/s_β	c_α/s_β	$-s_\alpha/c_\beta$	s_α/s_β	s_α/s_β	c_α/c_β	$\cot\beta$	$-\cot\beta$	$\tan\beta$
Type-Y	c_α/s_β	$-s_\alpha/c_\beta$	c_α/s_β	s_α/s_β	c_α/c_β	s_α/s_β	$\cot\beta$	$\tan\beta$	$-\cot\beta$

Usual tanb enhancement in SUSY models

tanb enhancement only for leptons

  - From rho-parameter constraint, **mH~mA~mH+** is favored.

→ We concentrate extra Higgs (H/A, H+) phenomenology in **Type-II (MSSM)** and **Type-X (leptophilic)** 2HDM.

2HDM as an effective theory

- **Problems in Lepton sector?**
  - **Tiny neutirno mass**

    3-loop neutrino mass, light H+,
    by Aoki et al. PRL102:051805,2009

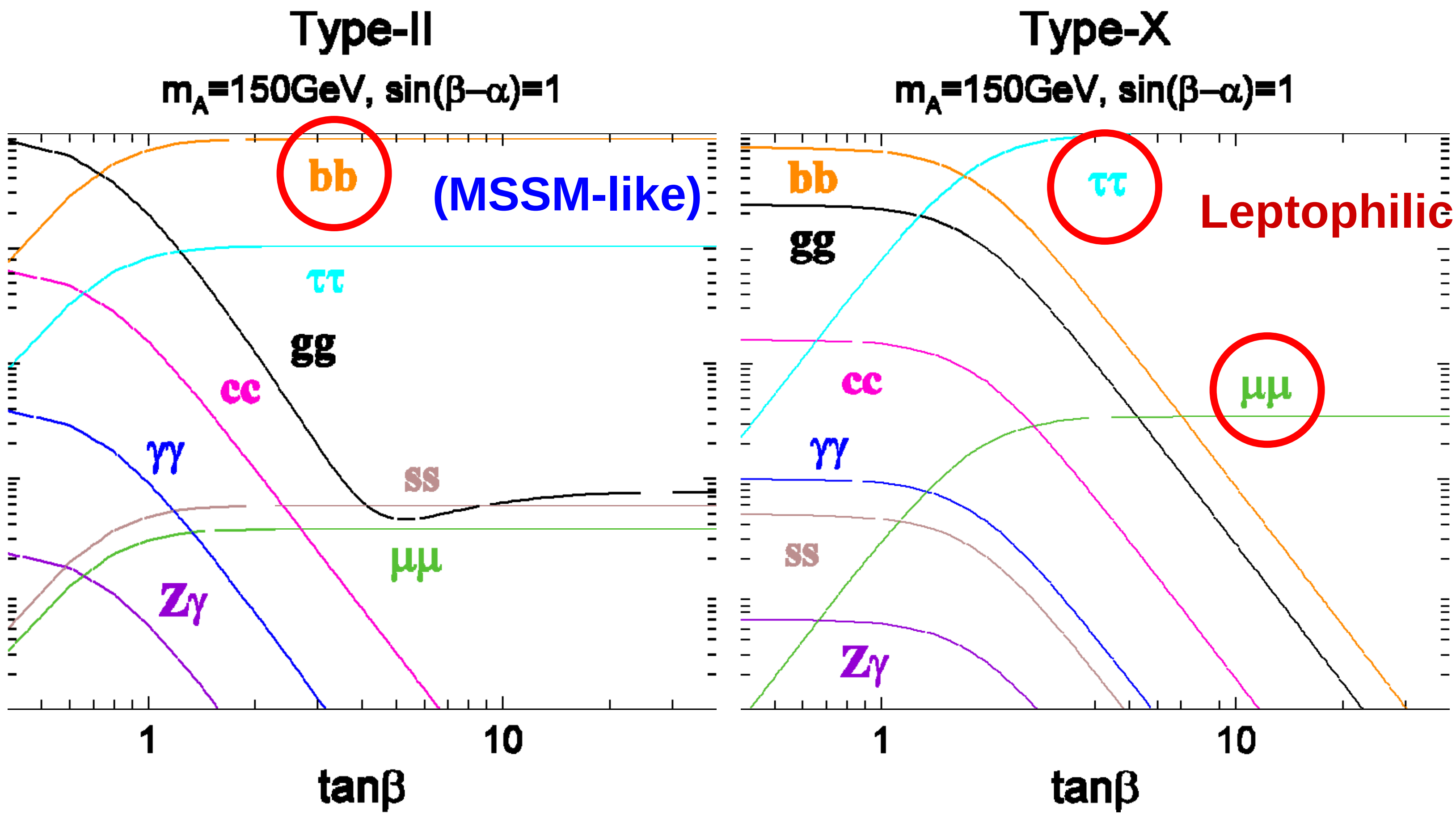
  - **3 sigma excess in Muon g-2**

    Light A with high tanb,
    by Cao et al. arXiv:0909.5148

  - **Leptonic cosmic ray @ PAMELA, FERMI**

    Higgs as a messenger of DM
    by Goh et al. JHEP 0905:097,2009

A decay



- A (H) mainly decays bb ($\tau\tau$) in Type-II (-X).

Constraints

*** Direct seacrh: typically mH,mA,mH+ > 100GeV**

*** Indirect bounds** - $b \to s \gamma$

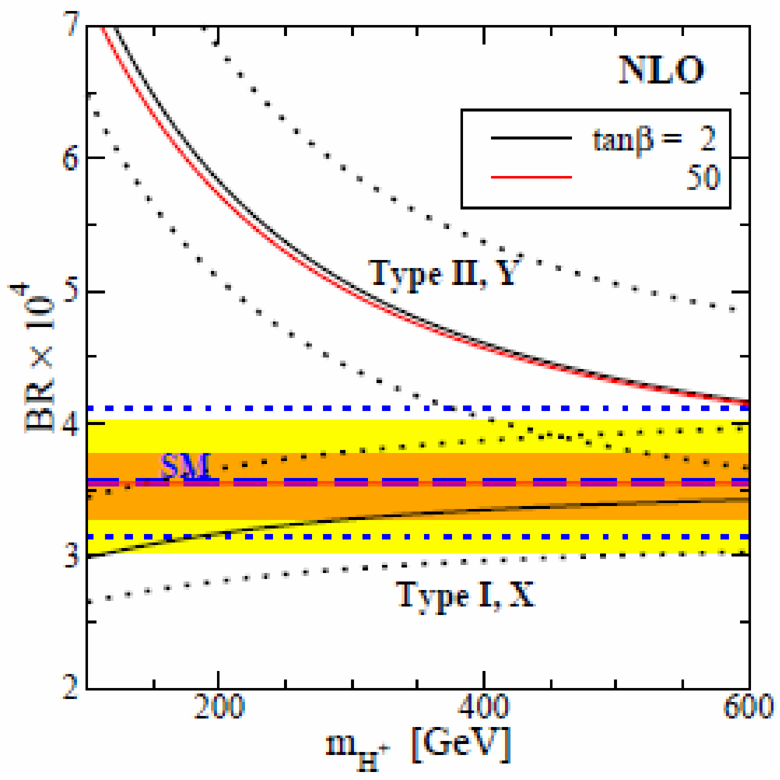
- $B \to \tau \nu$
- $\tau \to \mu \nu \nu$

$b \to s\gamma$

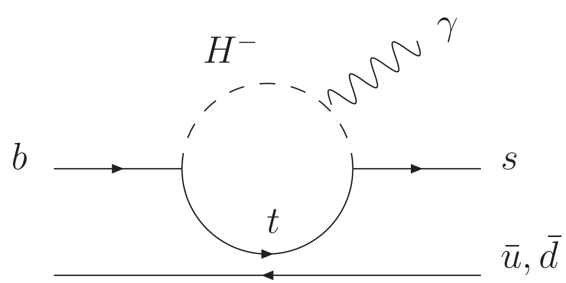
In addition to C7W (SM W boson loop),

Constant for wide range of tanb.

$$C_7^{H^\pm} = 2\sqrt{2}G_F \left\{ \frac{1}{\tan^2\beta} F\left(\frac{m_t^2}{m_{H^\pm}^2}\right) + \frac{1}{\tan\beta} \tan\beta\, G\left(\frac{m_t^2}{m_{H^\pm}^2}\right) \right\}$$



Type-II



mH+ > 300GeV

Light H+ is disfavored for Type-II.

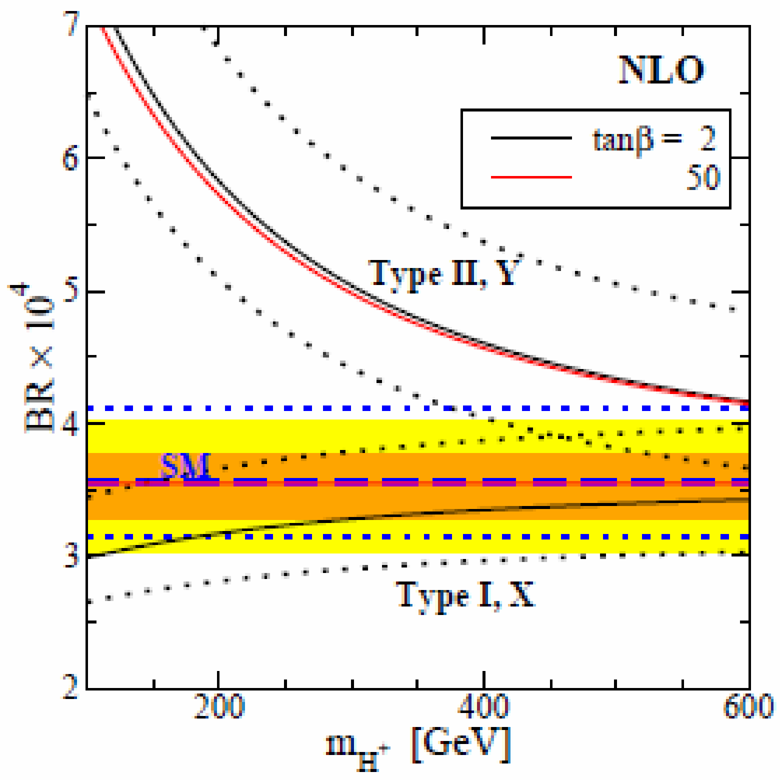
chargino−stop loop can cancel this contribution in MSSM

→ Light charged Higgs boson is still possible **for MSSM.**

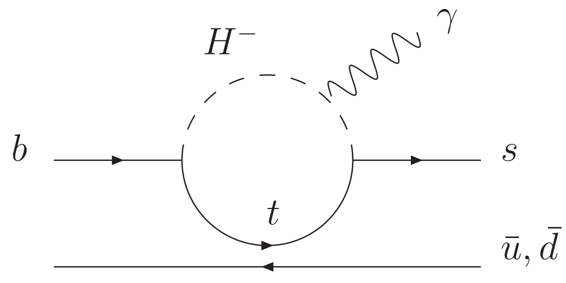
$b \to s\,\gamma$

In addition to C7W (SM W boson loop), small contrib. for tanb>2.

$$C_7^{H^\pm} = 2\sqrt{2}G_F\left\{\frac{1}{\tan^2\beta}F\left(\frac{m_t^2}{m_{H^\pm}^2}\right) + \frac{1}{\tan\beta}\frac{1}{\tan\beta}G\left(\frac{m_t^2}{m_{H^\pm}^2}\right)\right\}$$

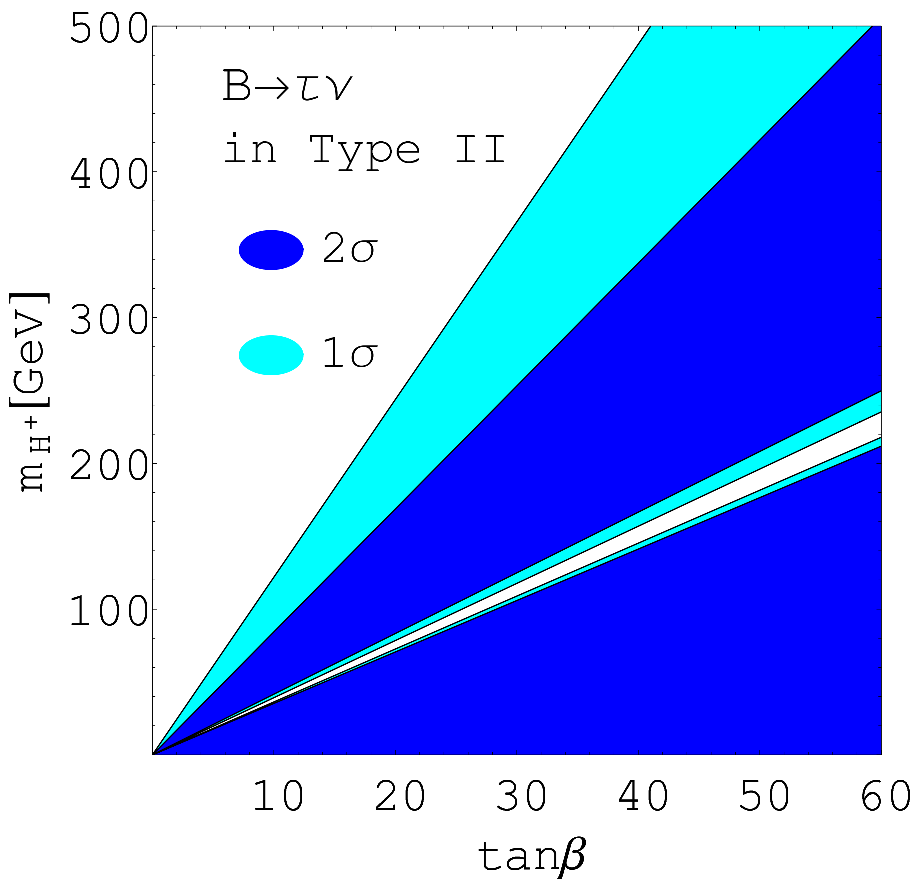


Type-X

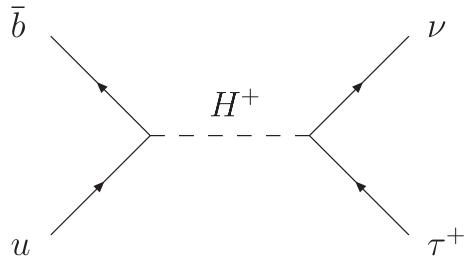


Light charged Higgs is allowed
for Type-X in tanb>2.

B → τ ν



Stringent constraint
on only for Type-II

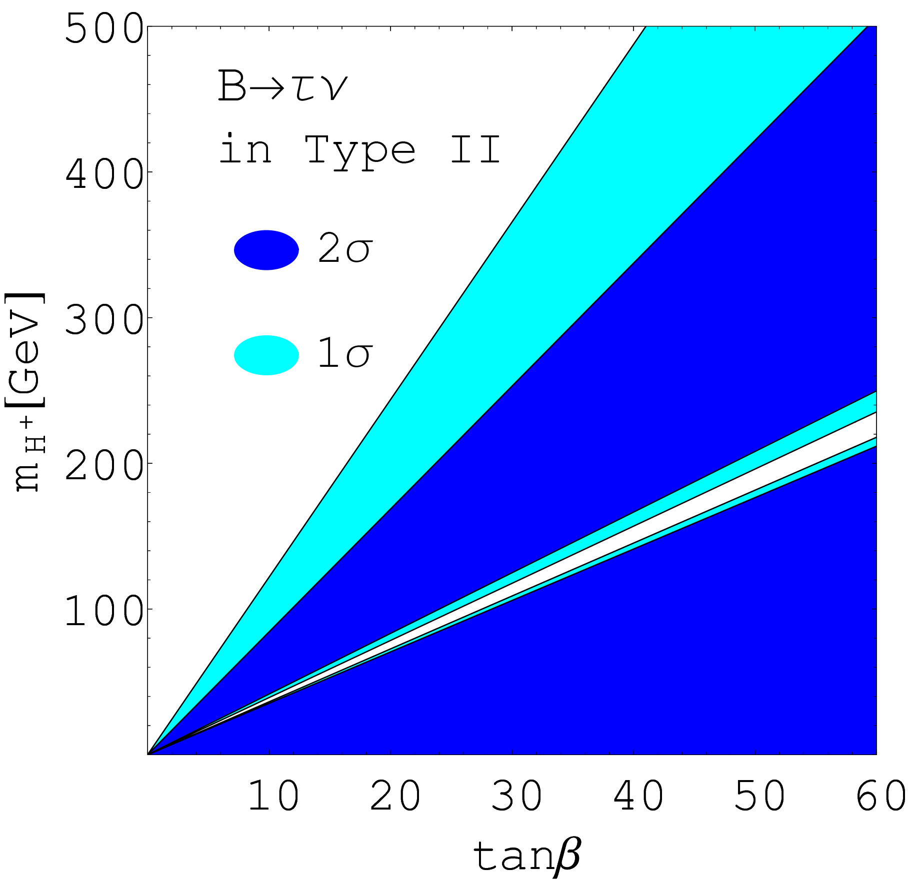


Type-II

$$\frac{\mathcal{B}^{2\mathrm{HDM}}}{\mathcal{B}^{\mathrm{SM}}} \approx \left[1 - \frac{m_B^2}{m_{H^\pm}^2}\tan\beta\tan\beta\right]^2$$

tanb^2 enhancement!!

B → τ ν



Stringent constraint
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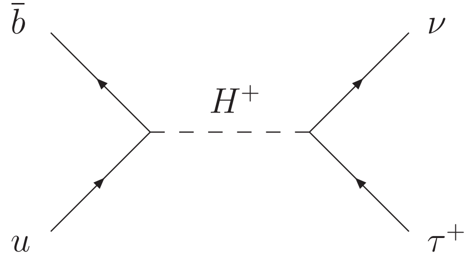
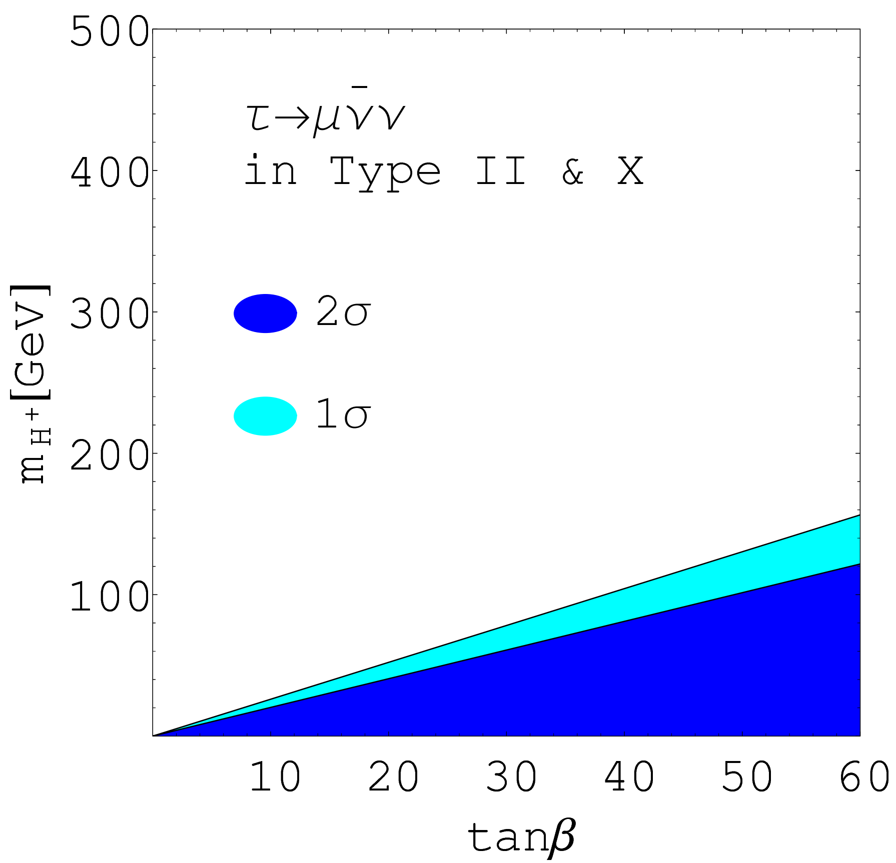
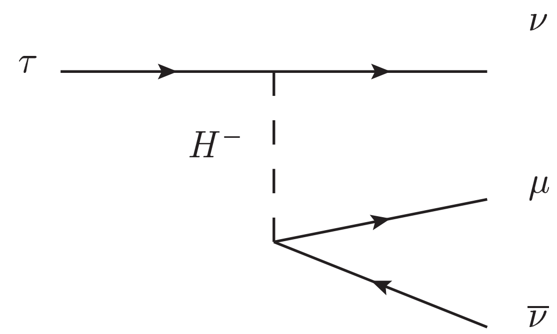


For Type-X, no bounds

$$\frac{\mathcal{B}^{2\mathrm{HDM}}}{\mathcal{B}^{\mathrm{SM}}} \approx \left[1 - \frac{m_B^2}{m_{H^\pm}^2}\tan\beta\frac{1}{\tan\beta}\right]^2$$

τ leptonic decay





$$\frac{\Gamma^{2\mathrm{HDM}}}{\Gamma^{\mathrm{SM}}} \simeq 1 - \frac{2m_\mu^2}{m_{H\pm}^2} \tan^2\beta$$

milder bounds
for both Type-II and -X

Light charged Higgs
(mH+ ~ 100GeV)
is allowed for Type-X

Collider signals

* $t \rightarrow H^+ b$ (light charged Higgs boson)

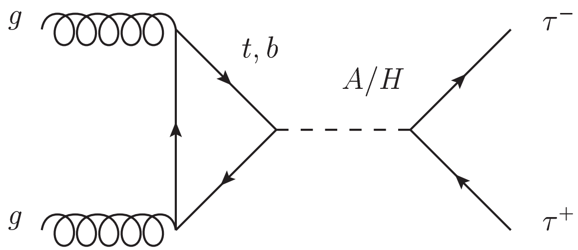
* $gg \rightarrow A/H \rightarrow \tau\tau$

* $qq/gg \rightarrow bbA/bbH$

* $qq \rightarrow AH \rightarrow \tau\tau\tau\tau$

* $qq' \rightarrow AH^+ \rightarrow \tau\tau\tau\tau$

gg → A/H → ττ



Production

$$t\text{-loop}\quad m_t/\tan\beta \rightarrow m_t/\tan\beta$$

$$b\text{-loop}\quad m_b\tan\beta \rightarrow m_b/\tan\beta$$

MSSM: significant for both small and large tanb
Type-X: xsec. becomes small for large tanb.

Detection mode is A/H → ττ.

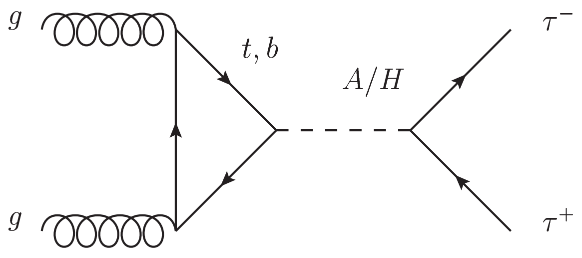
A/H-decay

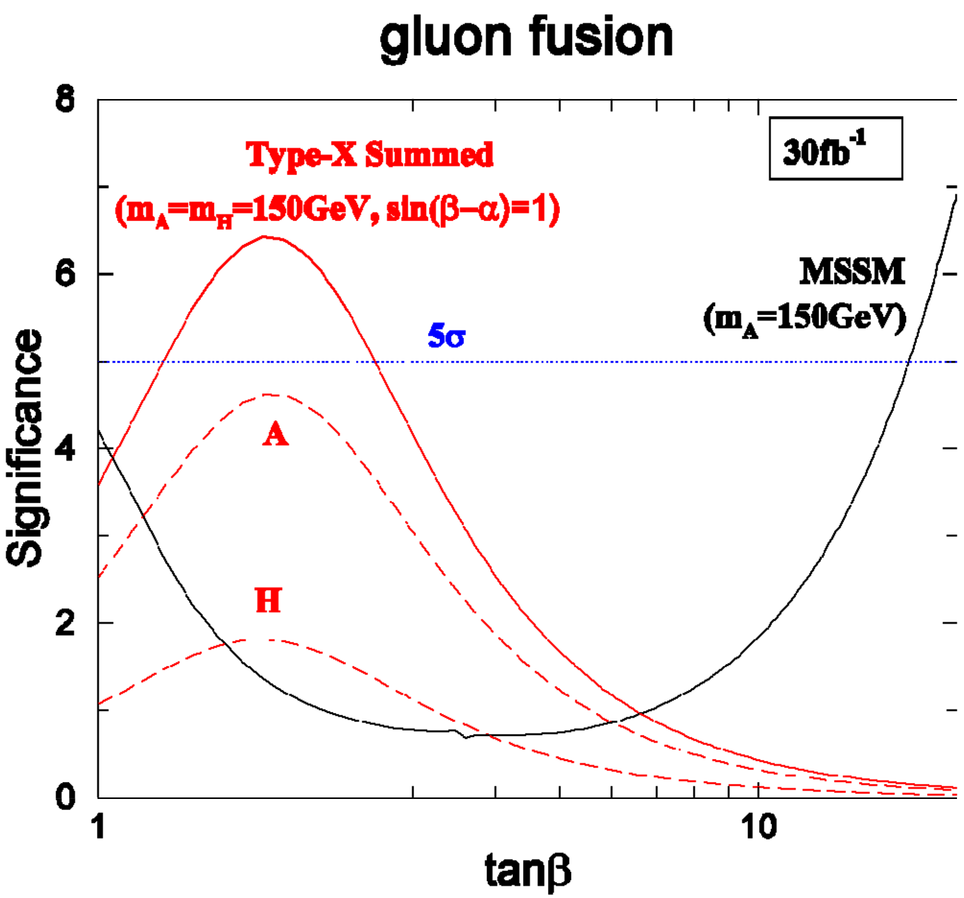
$$\Gamma_{bb} \propto N_c m_b^2 \tan^2\beta \rightarrow N_c m_b^2/\tan^2\beta$$

$$\Gamma_{\tau\tau} \propto m_\tau^2 \tan^2\beta \rightarrow m_\tau^2 \tan^2\beta$$

MSSM: A/H→bb.
Type-X: A/H→ ττ for tanb>2.

gg → A/H → ττ

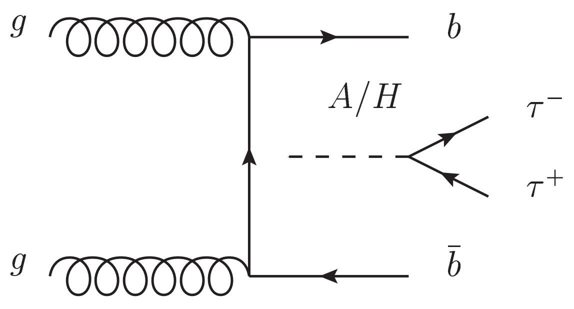




- Type-X with small tanb(~2) and

MSSM with large (or very small) tanb can be identified. (30fb^-1)

qq/gg -> bbA/bbH -> bb tau tau



Production

$$m_b \tan\beta \to m_b / \tan\beta$$

MSSM: enhanced by tanb
Type-X: suppressed by tanb.

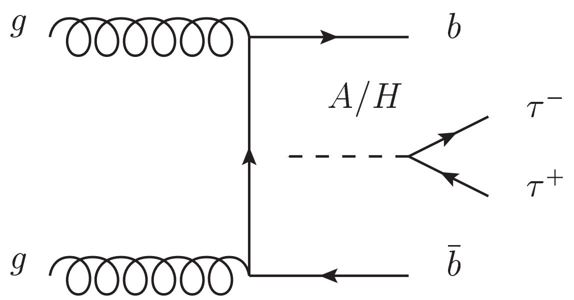
A/H-decay

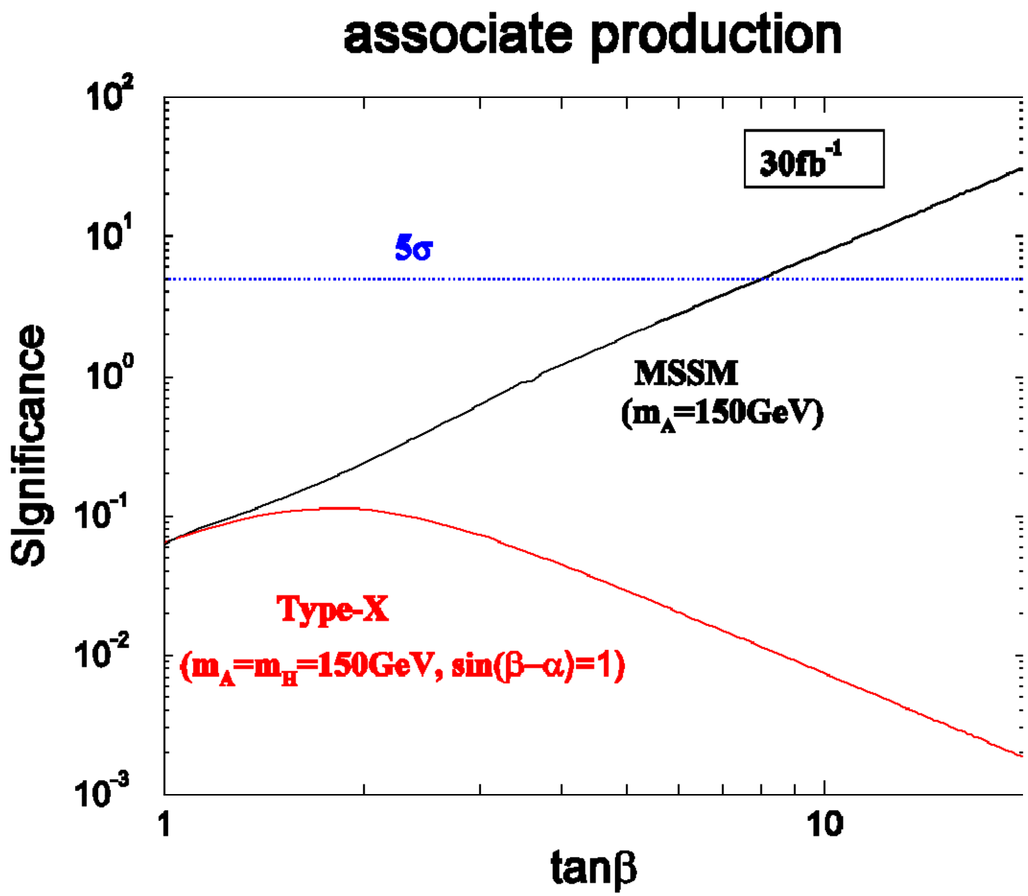
$$\Gamma_{bb} \propto N_c m_b^2 \tan^2\beta \to N_c m_b^2 / \tan^2\beta$$

$$\Gamma_{\tau\tau} \propto m_\tau^2 \tan^2\beta \to m_\tau^2 \tan^2\beta$$

MSSM: A/H→bb.
Type-X: A/H→ ττ for tanb>2.

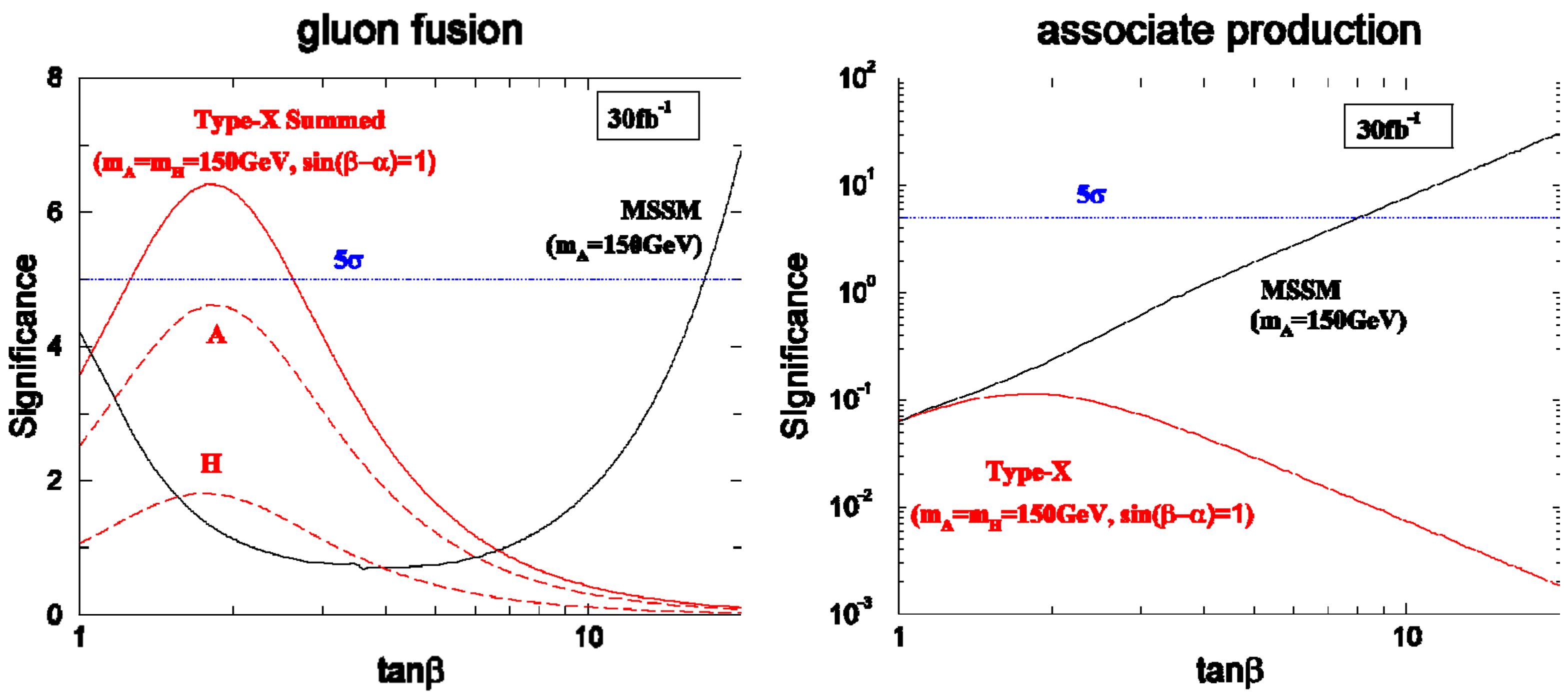
qq/gg -> bbA/bbH -> bb tau tau





- Signal can be found only in MSSM with large tanb. (30fb^-1)

Complementality



- Type-X with small tanb can be distinguished from MSSM (with large tanb)
- In Type-X with moderate (and large) tanb, we must go other processes, such as qq → AH (AH+) → ττττ (τττν).

Summary

- Type-X (leptophilic) 2HDM might be interesting.
- Light charged Higgs boson is allowed.
- Characteristic signals can be found at the LHC!!

(leptonic decays are enhanced !!)

ρ-parameter

- In the SM (top-bottom, Higgs-gauge loop)

$$\Delta\rho_t = \frac{3G_F m_t^2}{8\sqrt{2}\pi^2 m_W^2}, \qquad \Delta\rho_h = -\frac{3G_F m_Z^2 s_W^2}{8\sqrt{2}\pi^2}\left(\ln\frac{m_h^2}{m_W^2} - \frac{5}{6}\right)$$

- In the 2HDM (in addition, Higgs-Higgs loop)

$$\Delta\rho_H = \frac{g^2}{64\pi^2 m_W^2}\left[F_{\Delta\rho}(m_{H^+}^2, m_A^2) + F_{\Delta\rho}(m_{H^+}^2, m_H^2)s_{\beta-\alpha}^2 + F_{\Delta\rho}(m_{H^+}^2, m_h^2)c_{\beta-\alpha}^2 \right.$$
$$\left. - F_{\Delta\rho}(m_A^2, m_H^2)s_{\beta-\alpha}^2 - F_{\Delta\rho}(m_A^2, m_h^2)c_{\beta-\alpha}^2\right]$$
$$F_{\Delta\rho}(m_1^2, m_2^2) = \frac{1}{2}(m_1^2 + m_2^2) - \frac{m_1^2 m_2^2}{m_1^2 - m_2^2}\ln\frac{m_1^2}{m_2^2}$$

Favorable parameter region

1) $m_{H^\pm} \simeq m_A$
2) $m_{H^\pm} \simeq m_H$ with $\sin^2(\alpha-\beta) \simeq 1$
3) $m_{H^\pm} \simeq m_h$ with $\cos^2(\alpha-\beta) \simeq 1$