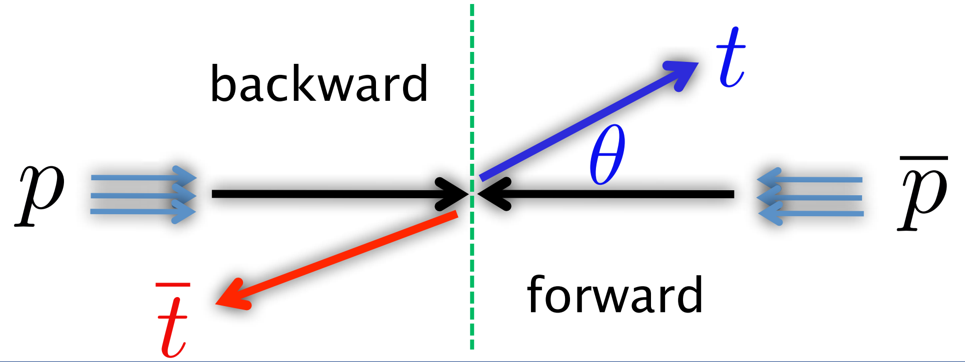
Top FB asymmetry vs. (semi)leptonic B decays in the Multi-Higgs-Doublet Models

Yuji Omura (TUM)

Based on arXiv:1108.0350, 1108.4005, 1205.0407, 1212.4607
with P. Ko and Chaehyun Yu (KIAS)

1. Introduction

- introduce BSM with extra Higgs Doublets (and Z'), originally motivated by the top forward backward asymmetry (A_{FB}) at Tevatron.



$$A_{FB} = \frac{N(t;\cos\theta > 0) - N(t;\cos\theta < 0)}{N(t;\cos\theta > 0) + N(t;\cos\theta < 0)}$$

$$A^t_{\rm FB} = \begin{cases} 0.158 \pm 0.074 & \text{(CDF, lepton+jets channel)} \\ 0.42 \pm 0.158 & \text{(CDF, dilepton channel)} \\ 0.19 \pm 0.065 & \text{(D0, lepton+jets channel)} \end{cases}$$ 1107.4995

SM prediction

$$A^t_{\rm FB} = 0.058 \pm 0.009 \text{ (NLO)}$$

Kuhn, Rodrigo,etc.

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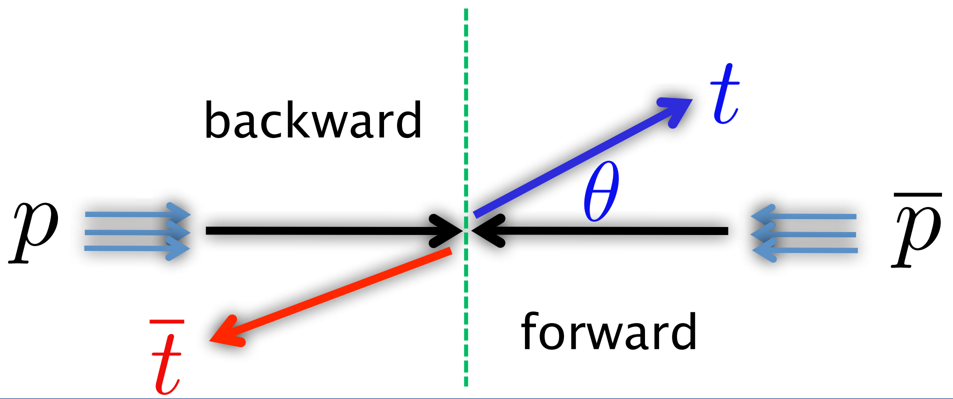

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$$A^t_{\rm FB} = 0.162 \pm 0.047 \ @\ 8.7 fb^{-1} \ ({\rm CDF,\ lepton + jets})$$ Conf.note 10807

$$A^t_{\rm FB} = 0.164 \pm 0.045 \ @\ 9.4 fb^{-1} \ ({\rm CDF,\ lepton+jets})$$ 1211.1003

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$$A^t_{\rm FB} = 0.058 \pm 0.009 \ ({\rm NLO})$$ Kuhn, Rodrigo,etc.

$$A^t_{\rm FB} = 0.072^{+0.011}_{-0.007} \ ({\rm NLO + NNLL})$$ Ahrens, Ferroglia, Neubert, Peciak, Yang, PRD84 (2011).

$$A^t_{\rm FB} = 0.087 \pm 0.010 \ ({\rm NLO + EW\ \ correction})$$

Hollik, Pagani, PRD84(2011); Kuhn, Rodrigo, JHEP1201.

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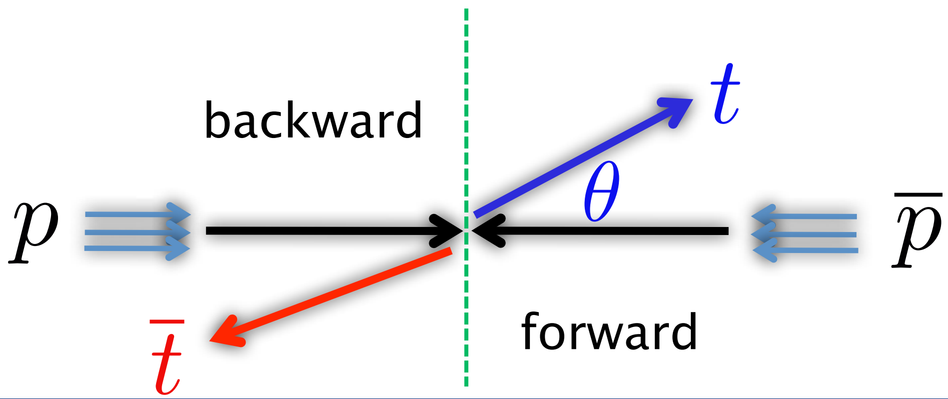

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so-called type-III-like 2HDM (3HDM),
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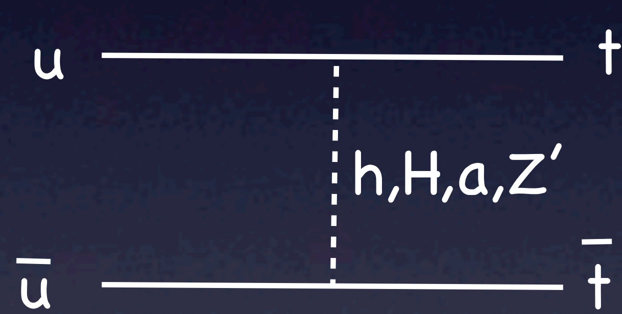

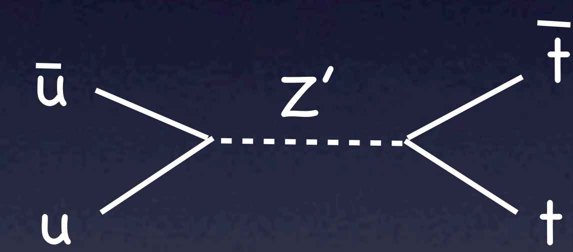

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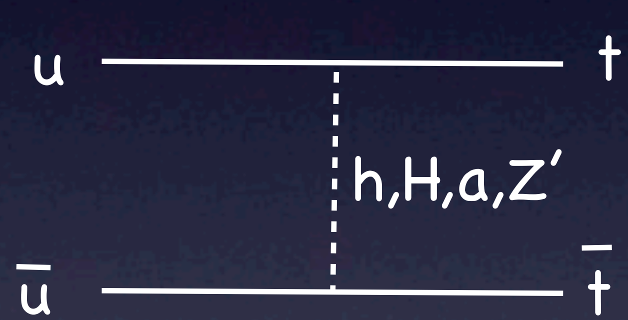
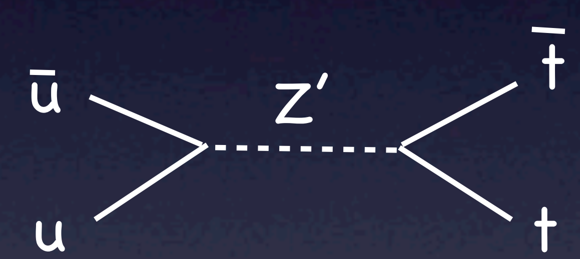




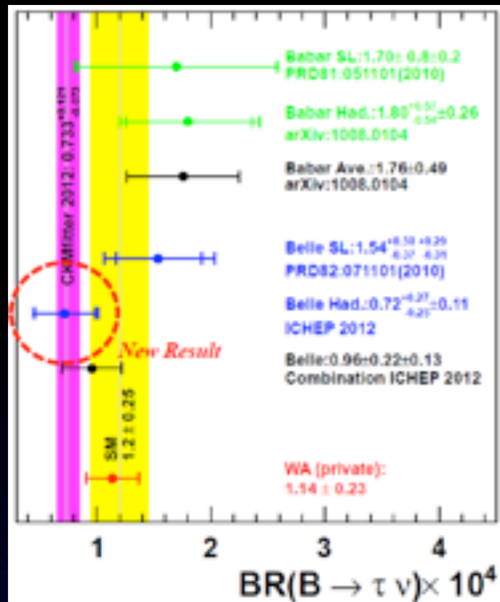
(P.Ko, YO, C.Yu, 1108.0350, 1108.4005, 1205.0407)

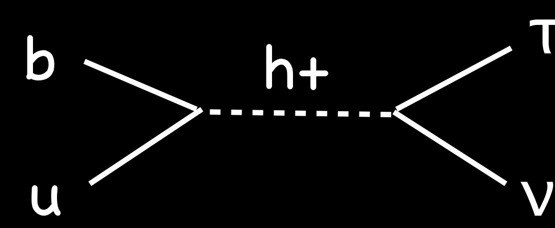
Such large (t,q) Yukawa predicts large (b,q) of charged Higgs

B-physics constrains our models (P.Ko, YO, C.Yu, 1212.4607)

(b,u) coupling

$B \to \tau\nu$





the average

$$BR(B \to \tau\nu) = (1.67 \pm 0.3) \times 10^{-4}$$ HFAG, 1010.1589

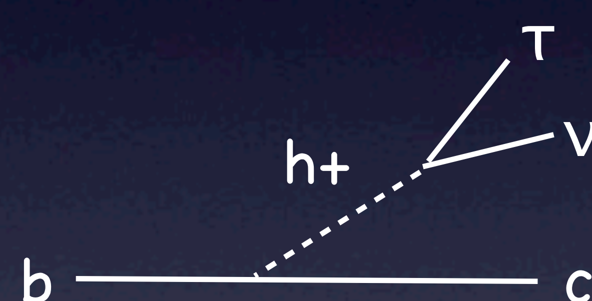
New Belle result

$$BR(B \to \tau\nu) = (0.72^{+0.27}_{-0.25} \pm 0.11) \times 10^{-4}$$ Belle, 1208.4678

(b,c) coupling

$B \to D(^*)\tau\nu$

$$R(D^{(*)}) = \frac{B(\overline{B} \to D^{(*)}\tau^-\overline{\nu}_\tau)}{B(\overline{B} \to D^{(*)}l^-\overline{\nu}_l)}$$



	$R(D)$	$R(D^*)$	
BaBar	0.440 ± 0.071	0.332 ± 0.029	BaBar, 1205.5442
	↕ 2.0σ	↕ 2.7σ	
SM	0.297 ± 0.017	0.252 ± 0.003	
	$0.316 \pm 0.012 \pm 0.007$		Fajfer, Kamenik, Nisandzic, Mescia
	(2+1 flavor lattice QCD, by Fermilab Lattice and MILC)		

combined 3.4σ

Question:

Is the enhancement of A_{FB} compatible with the (semi)leptonic B decays in our models?

Contents

2. Setup and AFB

See also C.Yu's poster

- Type-III 2HDM

$$\overline{Q_L^i}(y^1_{dij}H_1 + y^2_{dij}H_2)D^j_R + \overline{Q_L^i}(y^1_{uij}\widetilde{H}_1 + y^2_{uij}\widetilde{H}_2)U^j_R$$

⟶ neutral higgs h coupling

$$H_1 = h\cos\alpha - H\sin\alpha, H_2 = h\sin\alpha + H\cos\alpha$$

$$\{(V_L^{d\dagger}y_d^1V_R^d)_{ij}\cos\alpha + (V_L^{d\dagger}y_d^2V_R^d)_{ij}\sin\alpha\}h\overline{\hat{D}_L^i}\hat{D}_R^j$$

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too large FCNCs

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y1and y2 should be controlled by symmetry (Z2, U(1),etc.) → type-I, type-II (like SUSY), etc.

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- Our charge assignments:

Only up-sector charged flavor-dependently. Down and lepton are the same as the type-II.

H_1	H_2	H_3	U_R^1	U_R^2	U_R^3	D_R^i, Q_L^i ,L^i, E_R^i
q_1	0	q_3	q_1	0	q_3	0

H_1	H_2	H_3	U_R^1	U_R^2	U_R^3	$D_R^i,\ Q_L^i\ ,L^i,\ E_R^i$
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$$y_{ij}^U \overline{Q_{Li}} \widetilde{H}_j U_{Rj} + y_{ij}^D \overline{Q_{Li}} H_2 D_{Rj} + y_{ij}^E \overline{L_i} H_2 E_{Rj}.$$

- Depending on the charge, the num. of Higgs is different for the realistic mass matrix

(q1,q3)=(0,1) →2HDM

(q1,q3)=(-1,1) →3HDM

- The down (and lepton) sector Yukawas are diagonal

$$\delta_{ij} \tan\beta \frac{m_i^d}{v} \overline{\hat{D}_{Li}} \hat{D}_{Rj} h + i\delta_{ij} \tan\beta \frac{m_i^d}{v} \overline{\hat{D}_{Li}} \hat{D}_{Rj} a.$$

The bounds from Flavor physics are evaded.

- The only up sector has large FCNCs

$$Y^{u}_{ij}\overline{\hat{U}_{Li}}\hat{U}_{Rj}h - Y^{u-}_{ij}\overline{\hat{D}_{Li}}\hat{U}_{Rj}h^{-} - iY^{au}_{ij}\overline{\hat{U}_{Li}}\hat{U}_{Rj}a$$

The FCNCs involving top (b) are large

$$Y^{(a)}_{tq} \propto m_t, Y^{(a)}_{cq} \propto m_c, Y^{(a)}_{uq} \propto m_u$$

up-sector of neutral

$$\begin{pmatrix} \overline{u_L} & \overline{c_L} & \overline{t_L} \end{pmatrix} \begin{pmatrix} Y^{(a)}_{uu} & Y^{(a)}_{uc} & Y^{(a)}_{ut} \\ Y^{(a)}_{cu} & Y^{(a)}_{cc} & Y^{(a)}_{ct} \\ Y^{(a)}_{tu} & Y^{(a)}_{tc} & Y^{(a)}_{tt} \end{pmatrix} \begin{pmatrix} u_R \\ c_R \\ t_R \end{pmatrix} h(-ia)$$

top AFB enhanced

top mass enhance

- The only up sector has large FCNCs

$$Y^{u}_{ij}\overline{\hat{U}_{Li}}\hat{U}_{Rj}h - Y^{u-}_{ij}\overline{\hat{D}_{Li}}\hat{U}_{Rj}h^{-} - iY^{au}_{ij}\overline{\hat{U}_{Li}}\hat{U}_{Rj}a$$

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top AFB enhanced

top mass enhance

relation in 2HDM: $Y^{u-}_{ij} = \sqrt{2}(V_{CKM})^{*}_{li}Y^{au}_{lj}$.

Charged Higgs sector

$$\begin{pmatrix}\overline{d_L} & \overline{s_L} & \overline{b_L}\end{pmatrix}\begin{pmatrix}Y^{-}_{du} & Y^{-}_{dc} & Y^{-}_{dt}\\ Y^{-}_{su} & Y^{-}_{sc} & Y^{-}_{st}\\ Y^{-}_{bu} & Y^{-}_{bc} & Y^{-}_{bt}\end{pmatrix}\begin{pmatrix}u_R\\ c_R\\ t_R\end{pmatrix} h^{-}$$

contribute to B→τν

B→D(*)τν

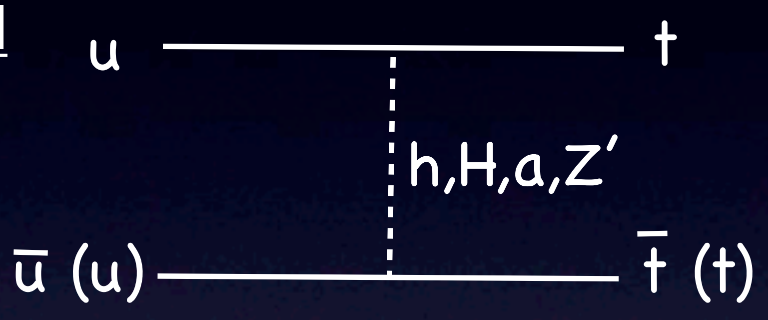
(B→X(s)γ, etc @ loop level)

3. Phenomenology

3-1. top forward-backward asymmetry (AFB) at Tevatron

Small deviations still remain

Our model



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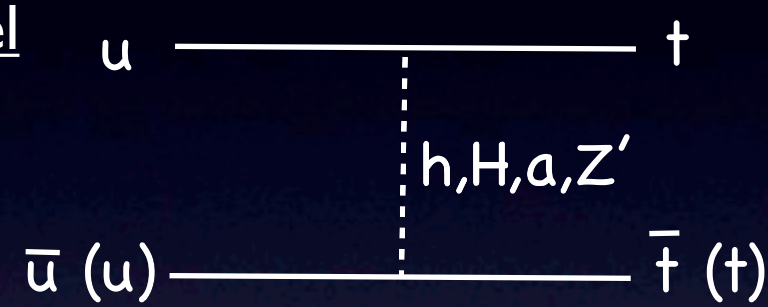
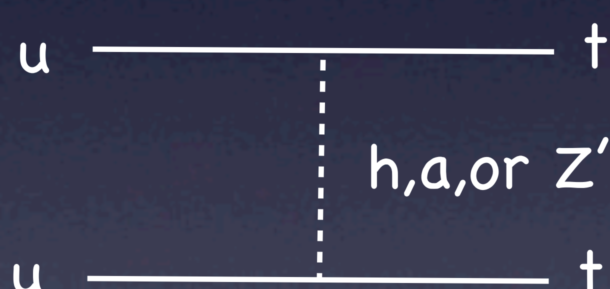


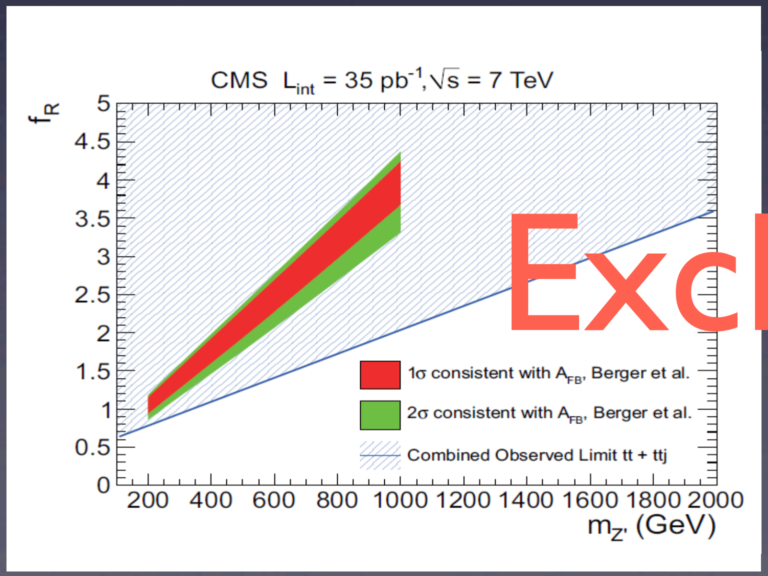
However, simple new physics scenarios (only one mediator) are excluded by uu →tt



$\sigma(tt) < 0.3pb$

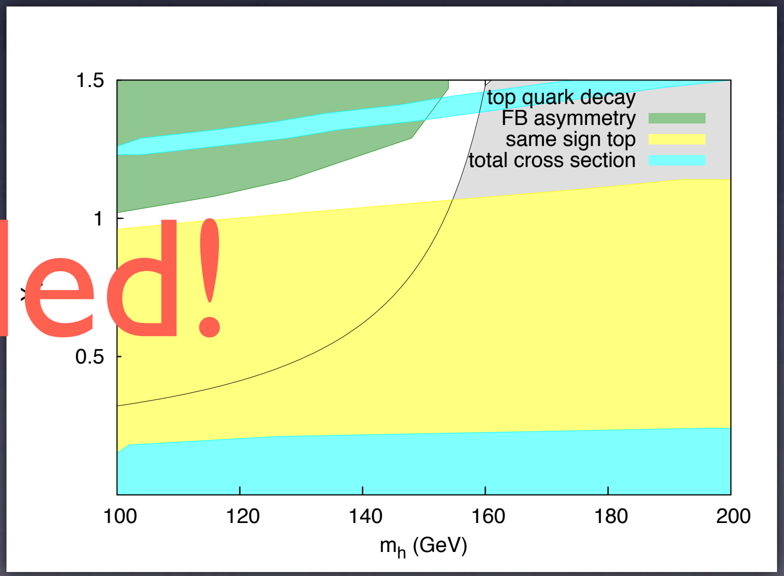
CMS, 1212.6194

only Z' scenario



CMS, 1106.2142

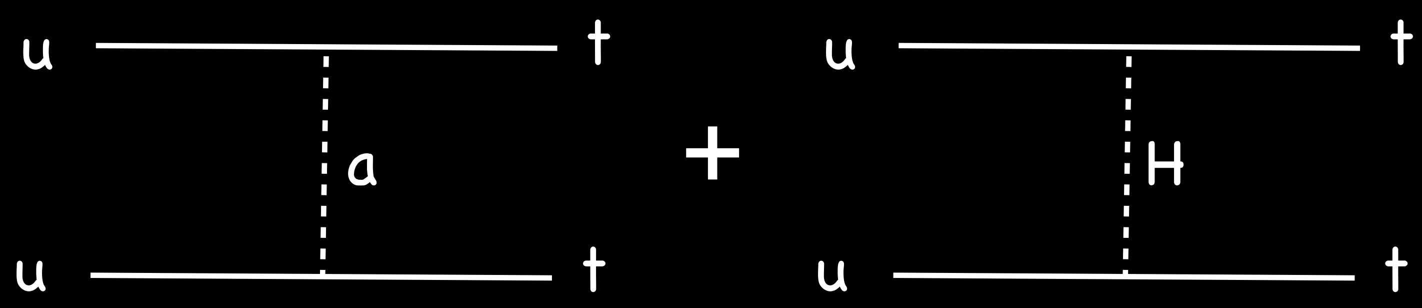
only h scenario

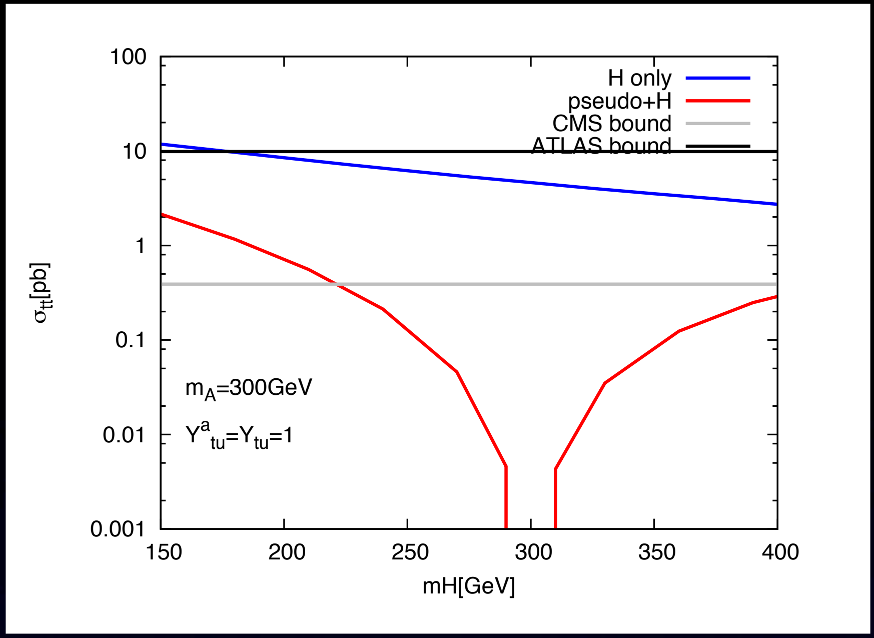


Excluded!

P.Ko,YO,C.Yu, 1108.4005

destructive interference relaxes the bound (P.Ko, YO, C.Yu, 1108.0350, 1108.4005)



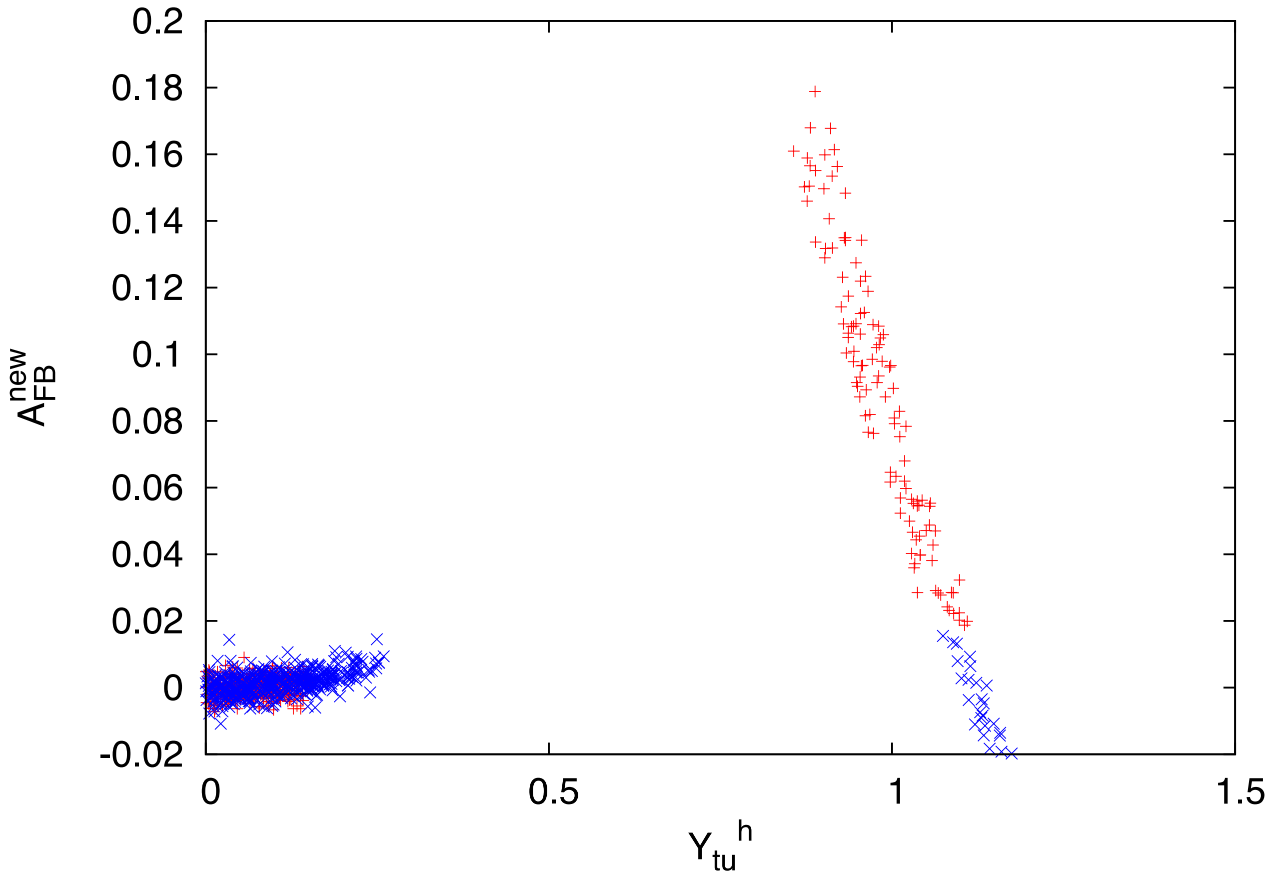


survived scenario

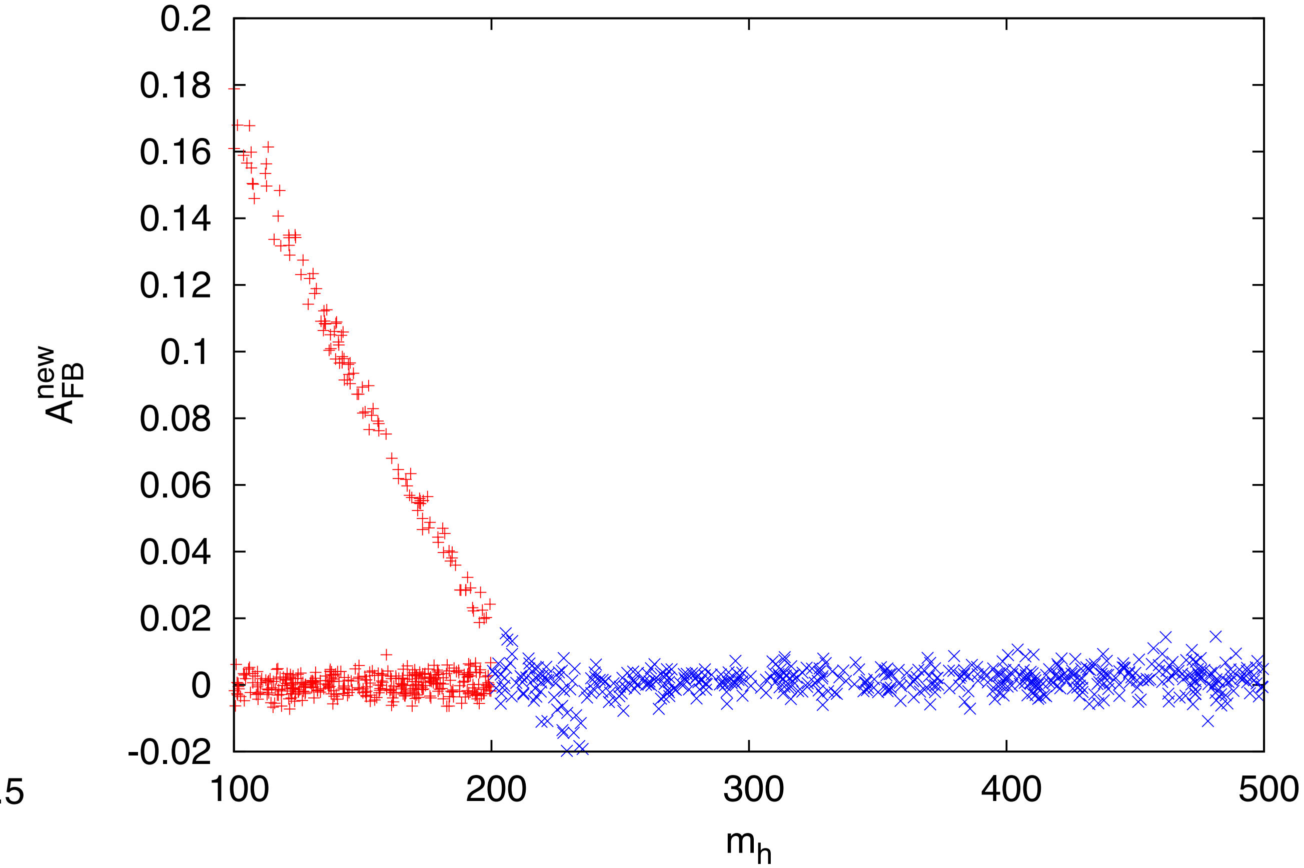
couplings and masses of pseudo and heavy scalars are almost degenerate.

the degenerate limit: $Y^H_{tu} = Y^a_{tu},\ m_H = m_a$ → $\sigma_{tt} \to 0.$

Ytu vs δAFB



mH vs δAFB



(within 1σ of $t\bar{t}$ at Tevatron)

Enhancement of AFB requires light ma and $Y^a_{tu} \sim 1.$

3-2. (Semi) leptonic B decays

discuss the bounds on such large couplings of pseudo scalar from (semi) leptonic B decays.

theoretical relation between pseudo and charged Higgs

coupling relation (in 2HDM)

$$Y^{u-}_{ij} = \sqrt{2}(V_{CKM})^{*}_{li} Y^{au}_{lj}.$$

→ large (t,q) correspond to large (b,q)

mass relation

$$m^2_{h^+} = m^2_a - \widetilde{\lambda}_{12} \frac{v^2}{2}$$

where $V(H) = \cdots + \widetilde{\lambda}_{12}(H^\dagger_1 H_2)(H^\dagger_2 H_1).$

mass difference at most weak scale

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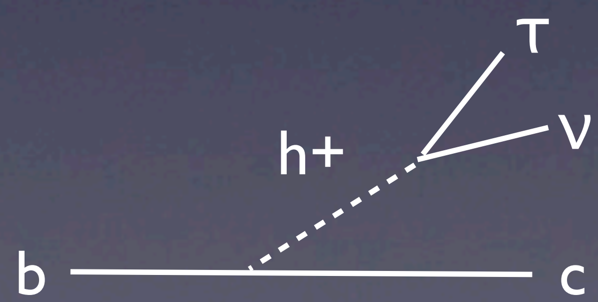
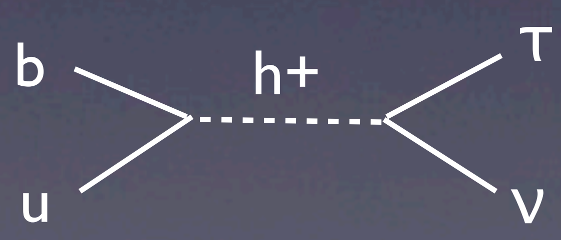
Indirectly, our scenario is tested by B physics



B→D(*)τν
BarBar discrepancies



B→τν

Our scenario for AFB favors large new physics contribution

$m_a \sim 200\text{GeV} \quad |Y^{au}_{tu}| \sim 1.$

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$m_a \sim 200\mathrm{GeV}$ $|Y^{au}_{tu}| \sim 1.$ → O(1) (b,u) and ~200 GeV charged Higgs

$Y^{u-}_{bu} \sim \sqrt{2}(V_{CKM})^*_{tb} Y^{au}_{tu}.$

predict very large new physics contribution in B physics

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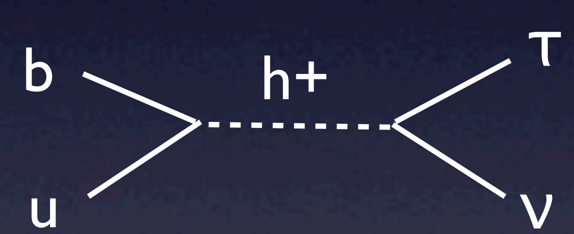
can be compatible with

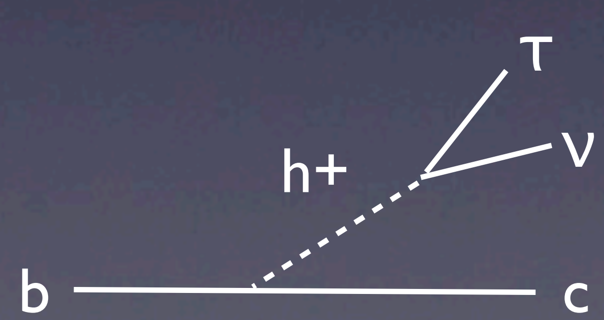
B→τν?



consistent with the SM.

requires small new physics contribution.

B→D(*)τν?



not consistent with the SM.

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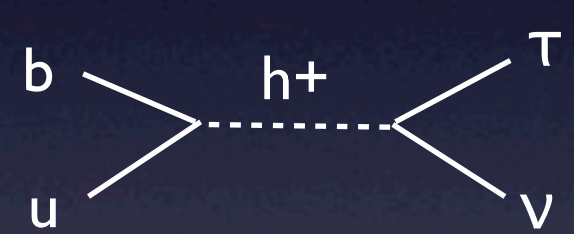
B→τν?



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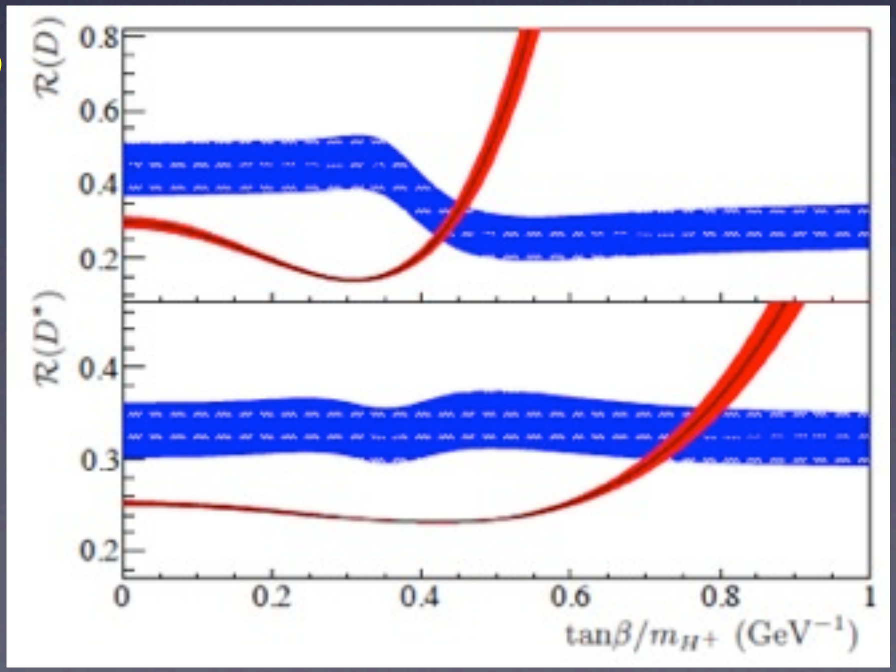


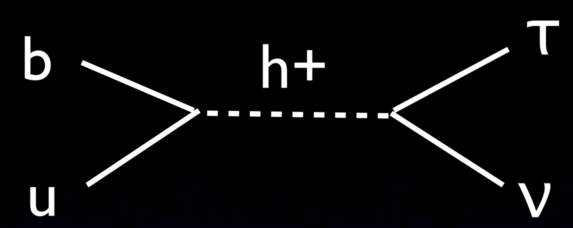
not consistent with the SM.

requires large new physics contribution.

Type-II 2HDM cannot explain.

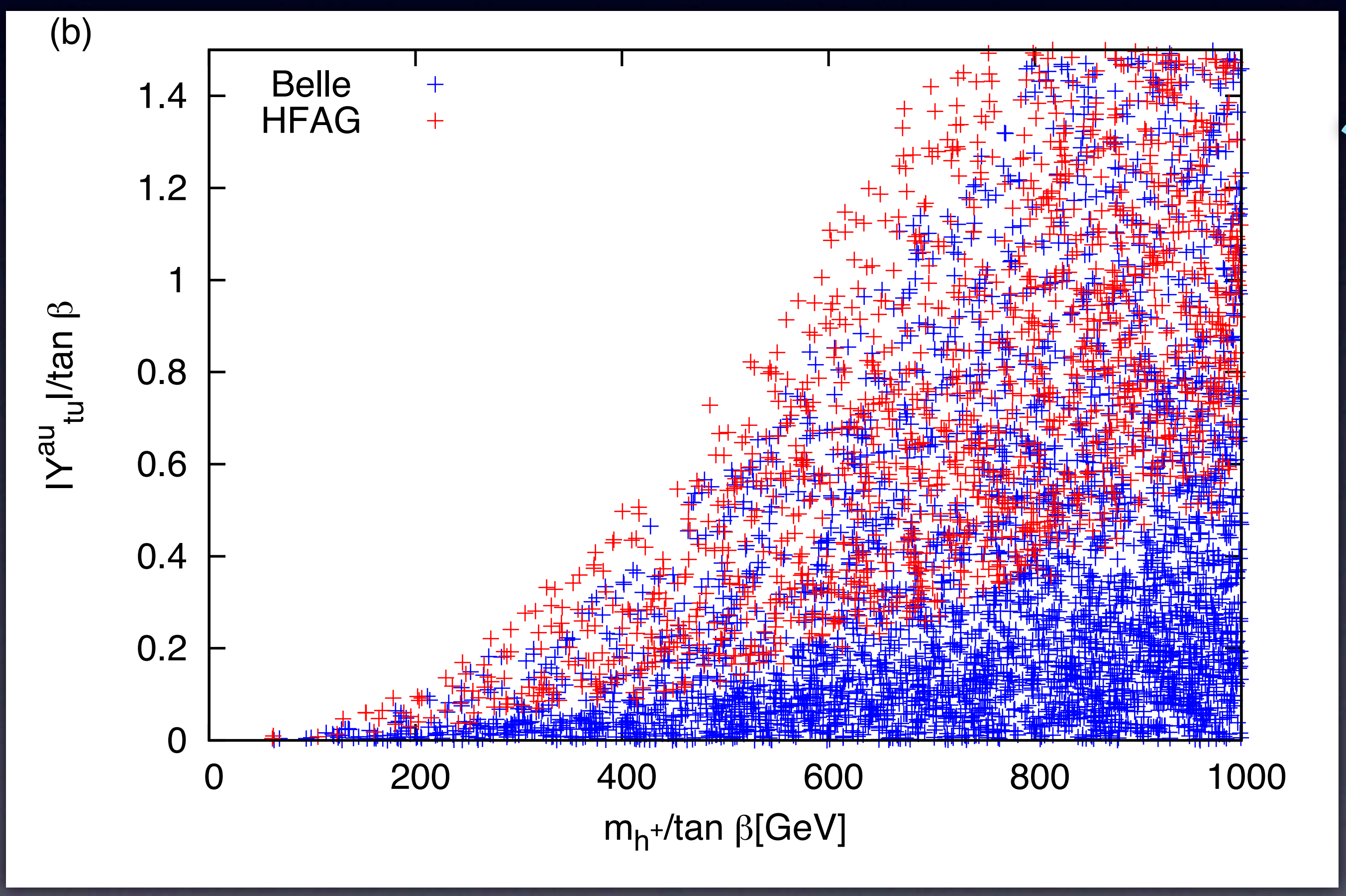
BaBar, 1205.5442; Crivellin, Greub, Kokulu, 1206.2634; Fajfer, Kamenik, Nisandzic, Zupan, 1206.1872; M. Tanaka, R. Watanabe, 1212.1878

Constraint on B→τν decay in our 2HDM



$$-Y^{-u}_{bu} h^- \overline{b_L} u_R + Y^{+d}_{ub} h^+ \overline{u_L} b_R$$

In our 2HDM



coupling relation

$$Y^{u-}_{bu} \sim \sqrt{2}(V_{CKM})^*_{tb} Y^{au}_{tu}.$$

$$Y^{d+}_{ub} = \sqrt{2}(V_{CKM})_{ub} \frac{m_b \tan\beta}{v}$$

mass relation

$$m^2_{h+} = m^2_a - \widetilde{\lambda}_{12} \frac{v^2}{2}$$

where $V(H) = \cdots + \widetilde{\lambda}_{12}(H_1^\dagger H_2)(H_2^\dagger H_1).$

mass difference at most weak scale

$O(100) \lesssim m_{h+}/\tan\beta$ ⟶ can be $|Y^{au}_{tu}| \sim 1.$

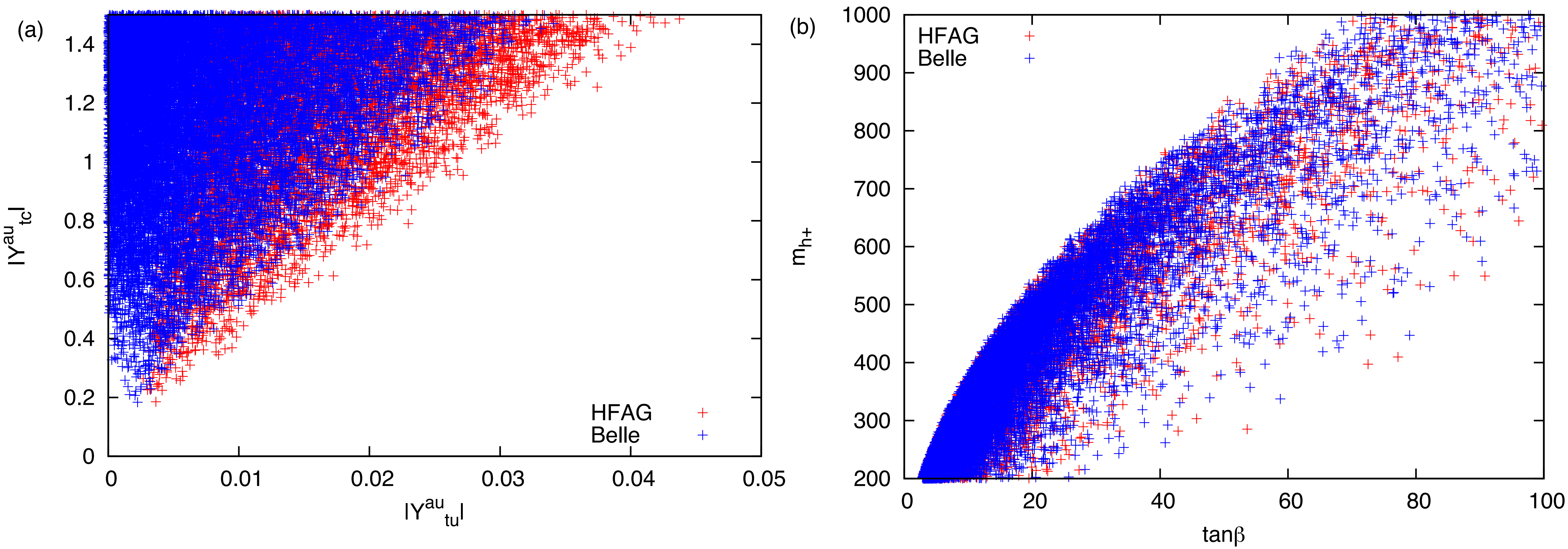
(pseudo scalar may be heavy.)

Constraints from B→D(*)τν and B→τν in 2HDM

parameter region within 1 σ of B->D(*)τν at BaBar and B->τν.

Ytc vs Ytu of pseudo scalar

mH+ vs tan β



The BaBar discrepancies require large charged Higgs contribution,

$$0.2 \lesssim |Y^{au}_{tc}|, \;\; m_{h+}/\tan\beta \lesssim O(10).$$

→ B->τν requires small (t,u) coupling, $|Y^{au}_{tu}| \lesssim 0.03.$ cannot achieve enhancement AFB.

If the deviation is relaxed, (t,u) can be large.
(pseudo scalar should be heavy for B->τν in 2HDM.)

- To enhance AFB and be consistent with the semi-leptonic and leptonic B decays, 3HDM is favored.

difference between 2HDM and 3HDM.

U_R^1	U_R^2	U_R^3
0	0	q

2HDM

→

U_R^1	U_R^2	U_R^3
$-q$	0	q

3HDM

2HDM:

$$y^u_{i1}\overline{Q_{Li}}\widetilde{H_2}U_{R1} + y^u_{i2}\overline{Q_{Li}}\widetilde{H_2}U_{R2} + y^u_{i3}\overline{Q_{Li}}\widetilde{H_1}U_{R3}$$

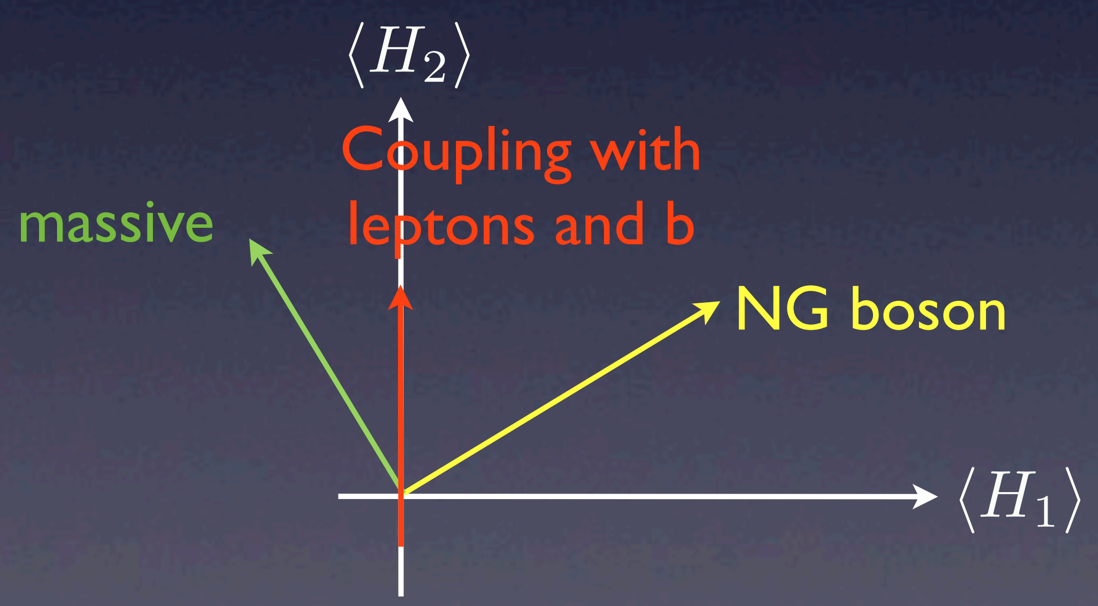
$$y^d_{ij}\overline{Q_i}H_2D_{Rj} + y^e_{ij}\overline{Q_i}H_2E_{Rj}$$

3HDM:

$$y^u_{i1}\overline{Q_i}\widetilde{H_1}U_{R1} + y^u_{i2}\overline{Q_i}\widetilde{H_2}U_{R2} + y^u_{i3}\overline{Q_i}\widetilde{H_3}U_{R3}$$

$$y^d_{ij}\overline{Q_i}H_2D_{Rj} + y^e_{ij}\overline{Q_i}H_2E_{Rj}$$

pseudoscalar and charged Higgs directions in 2HDM



- To enhance AFB and be consistent with the semi-leptonic and leptonic B decays, 3HDM is favored.

difference between 2HDM and 3HDM.

U_R^1	U_R^2	U_R^3
0	0	q

2HDM

U_R^1	U_R^2	U_R^3
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3HDM

2HDM:

$$y_{i1}^u \overline{Q_{Li}} \widetilde{H_2} U_{R1} + y_{i2}^u \overline{Q_{Li}} \widetilde{H_2} U_{R2} + y_{i3}^u \overline{Q_{Li}} \widetilde{H_1} U_{R3}$$

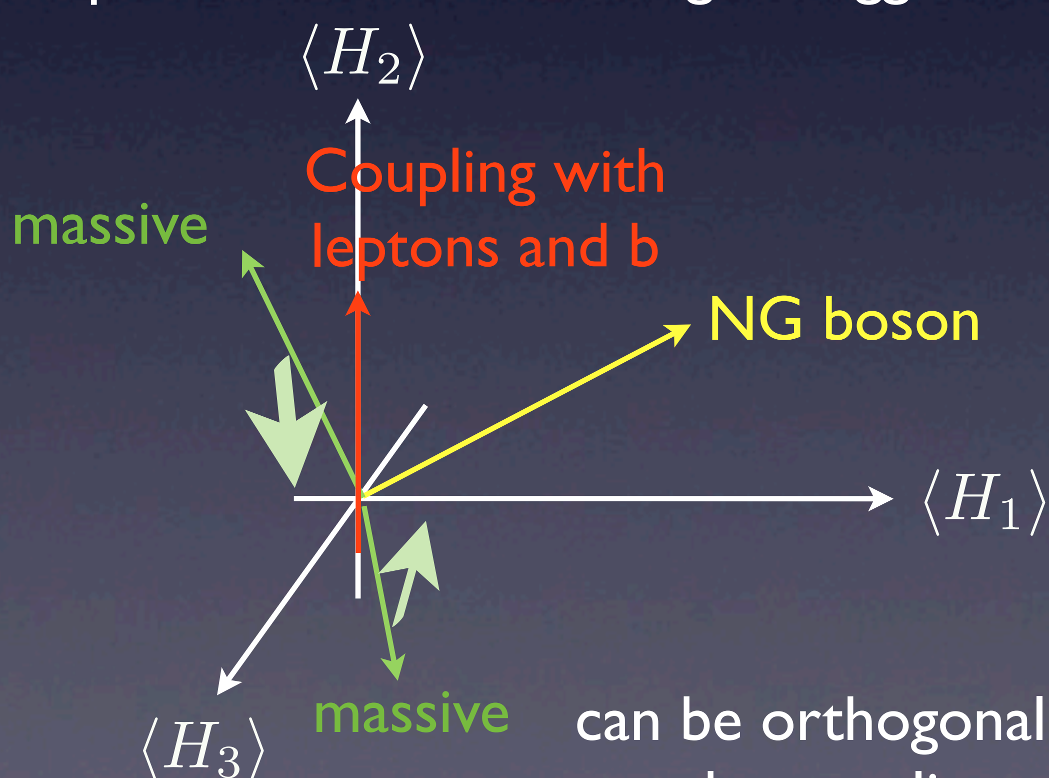
$$y_{ij}^d \overline{Q_i} H_2 D_{Rj} + y_{ij}^e \overline{Q_i} H_2 E_{Rj}$$

3HDM:

$$y_{i1}^u \overline{Q_i} \widetilde{H_1} U_{R1} + y_{i2}^u \overline{Q_i} \widetilde{H_2} U_{R2} + y_{i3}^u \overline{Q_i} \widetilde{H_3} U_{R3}$$

$$y_{ij}^d \overline{Q_i} H_2 D_{Rj} + y_{ij}^e \overline{Q_i} H_2 E_{Rj}$$

pseudoscalars and charged Higgs directions in 3HDM



can be orthogonal to the coupling.

One of the charged Higgs (pseudoscalar) can decouple with leptons and do not contribute to (semi)leptonic B decay

→ The limit corresponds to the fine-tuning in Higgs potential

$$m_{12}^2 \tan\gamma = m_{23}^2 \cos\gamma \qquad \widetilde{\lambda}_{12} = \widetilde{\lambda}_{23}$$

where $\langle H_3 \rangle / \langle H_1 \rangle = \tan\gamma$ and

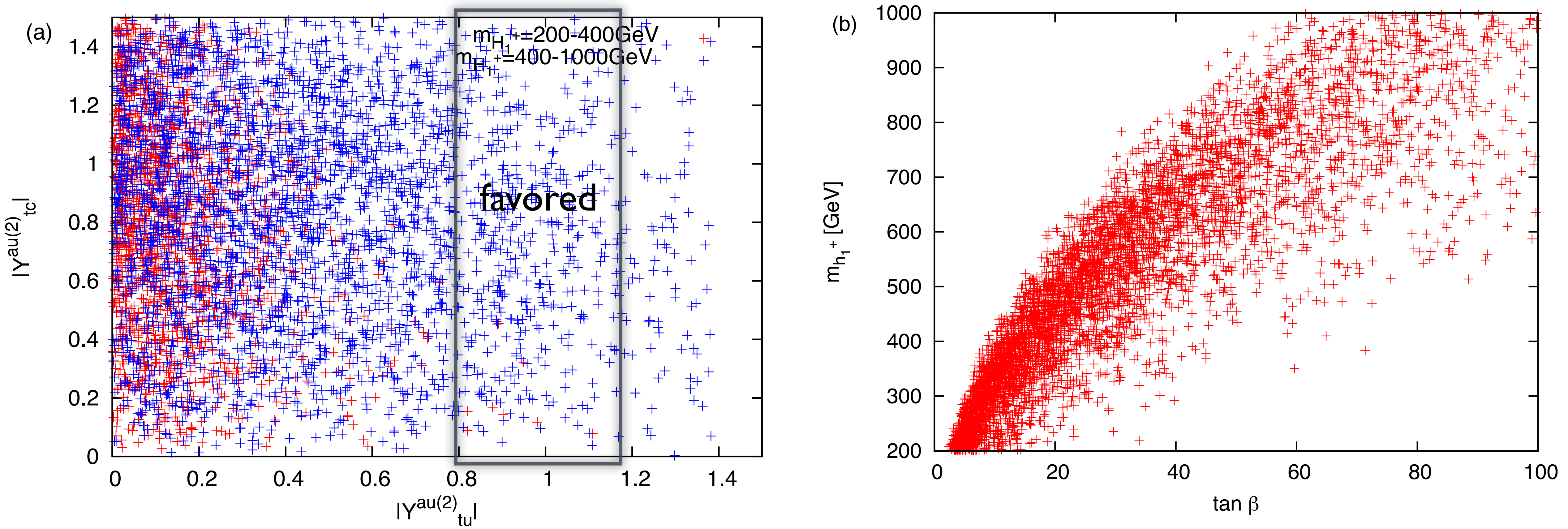
$$V(H) = \ldots m_{ij}^2 H_i^\dagger H_j + \widetilde{\lambda}_{ij} (H_i^\dagger H_j)(H_j^\dagger H_i).$$

- **Concrete analysis for other cases in 3HDM** P.Ko, YO, C.Yu, 1212.4607

parameter spaces are large, so we could expect some allowed region without the fine-tuning

but not so large, because of the bound from $D_0 - \overline{D_0}$ mixing.

ex) degenerate case $m_{h_1^+} = m_{h_2^+}$



$+ \ \ldots \ 200\text{GeV} \leq m_{h_1^+} \leq 400\text{GeV}$

$+ \ \ldots \ 400\text{GeV} \leq m_{h_1^+} \leq 1000\text{GeV}$

4. Summary

- I introduced 2HDM and 3HDM, where gauged U(1) controls the FCNC.
- There are tree-level FCNCs:especially (t,q) in neutral and (b,q) in charged Higgs are large because of top mass.
- Large (t,u) enhance AFB and can be consistent with LHC results according to destructive interference between CP-even scalar and CP-odd scalar. One good point is CP-even (-odd) mass ~200GeV and the Yukawa coupling ~1.
- We discussed whether the enhancement of AFB is compatible with the (semi)leptonic B decay at the BaBar and Belle experiments.
- AFB and B->D(*)τν requires large new physics effects, but B->τν requires the small effect. It is difficult to achieve all.
- Requirement of 2HDM to achieve B->D(*)τν at BaBar and B->τν:

$$|Y^{au}_{tu}| \lesssim 0.03. \quad 0.2 \lesssim |Y^{au}_{tc}|, \quad m_{h+}/\tan\beta \lesssim O(10).$$ →difficult to enhance AFB.

- In 3HDM, we can describe the scenario that one of charged Higgs decouples with the (semi)leptonic B decays. It is possible to achieve AFB, the BaBar discrepancies, and B->τν.

Thank you