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

- mysterious structure of the Standard Model

3 generations

Large mass hierarchies

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Large mass hierarchies

- Flavor symmetry exist?

discrete symmetry (S3, A4, D4, ...)
continuous symmetry (SU(3),U(1),...)

Extra scalars and large flavor-changing couplings are predicted.

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Extra scalars and large flavor-changing couplings are predicted.

- There may be hints for flavor models in the experimental results

Interesting signals

top AFB asymmetry at Tevatron

(semi)leptonic B decays (B->D(*)τν) at BABAR and Belle

(B->K*μμ at LHCb)
(Gauld, Goertz, Haisch 1308.1959;Altmannshofer,Straub,1308.1501)

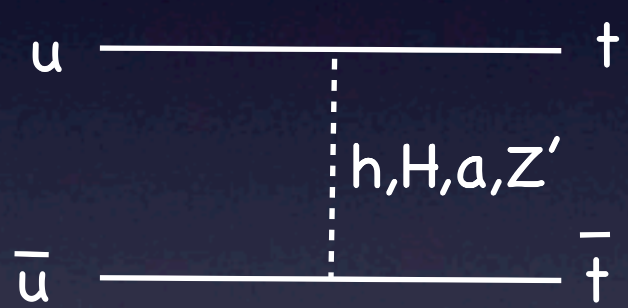
→ evidences of large FCNCs (involving t and b)???

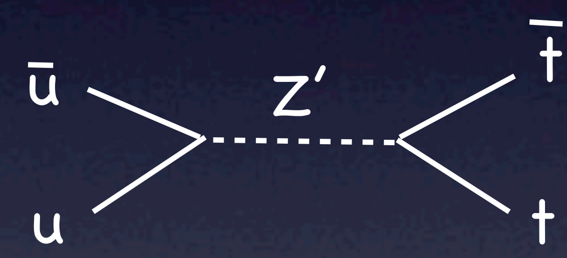
- We built a phenomenological model with U(1) flavor symmetry

(P.Ko, Y.Omura, C.Yu, 1108.0350, 1108.4005, 1205.0407)

Flavor-dependent U(1) charges are assigned to especially right-handed up sector (u,c,t).
Extra Higgs $SU(2)_L$ doublets are added for realistic mass matrix.

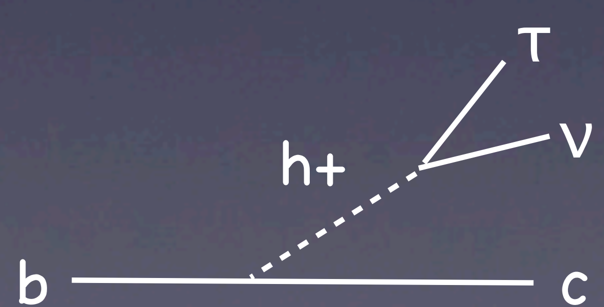
Tree-level FCNCs of extra scalars and contribute to top production

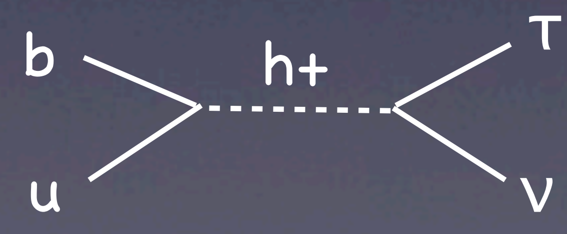




charged Higgs contributes to the B decays

(P.Ko, YO, C.Yu, 1212.4607)





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- 3. Phenomenology
- 3-1. discussion about AFB
- 3-2. (semi)leptonic B decays
- 4. Summary

2. Flavor symmetric models

- Flavor symmetry assigned to fermions

(motivated by top AFB and the BaBar discrepancies.)

Froggatt-Nielsen-type model

U(1) flavor-dependent charge assignment

	Q_L^i	U_R^i	D_R^i	L^i	E_R^i
$U(1)_{\rm flavor}$	q_i	u_i	d_i	l_i	e_i

Yukawa couplings for mass matrices

Extra scalars are required to realize realistic mass matrices

FN model

$$c_{ij}^u \left(\frac{\Phi}{\Lambda}\right)^{\frac{q_i-u_j}{q_\Phi}} \overline{Q_L^i}\widetilde{H}U_R^j$$

Φ is added, and <Φ>/Λ suppressions realize mass hierarchy and CKM

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FCNC of the neutral scalar is

$$\underline{c_{ij}^u \left(\frac{\langle\Phi\rangle}{\Lambda}\right)^{\frac{q_i - u_j}{q_\Phi}} \frac{q_i - u_j}{q_\Phi}} \left(\frac{v}{\langle\Phi\rangle}\right) \delta\Phi \overline{U_{Li}} U_{Rj}$$

same order as mass matrix

too small to contribute to ttbar production.

gauged U(1) also allow FCNCs, $g' Z'^\mu \overline{\hat{U}_R^i} \gamma_\mu \hat{U}_R^j (u_i - u_j) \times (mixing) + \ldots.$

Our model instead of Φ (P.Ko, YO, C.Yu, 1212.4607)

Extra SU(2)L doublets are added for realistic mass matrices.

When the charge assignment is $q_i = 0, Q_{U(1)}[H^j] = u^j$

$$y^u_{ij} \overline{Q^i_L} \widetilde{H^j} U^j_R.$$

$$0 \quad -u^j \quad u^j$$

Mass hierarchy may be given by the vevs of Higgs, but I do not touch this possibility in this talk.

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Mass hierarchy may be given by the vevs of Higgs, but I do not touch this possibility in this talk.

→ The (neutral) scalars in SU(2)L doublet have tree-level FCNCs after EW symmetry breaking.

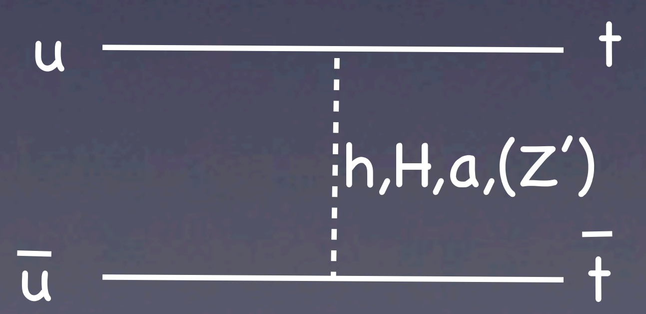
$$Y^u_{ij}\overline{\hat{U}_{Li}}\hat{U}_{Rj}h - Y^{u-}_{ij}\overline{\hat{D}_{Li}}\hat{U}_{Rj}h^- - iY^{au}_{ij}\overline{\hat{U}_{Li}}\hat{U}_{Rj}a$$

neutral scalars

(~125GeV higgs, heavy Higgs, pseudo)

$$Y^{(a)u}_{tq} \sim \frac{m_t}{\sqrt{2}\langle H_n\rangle}(mixing)^n_{tq}$$

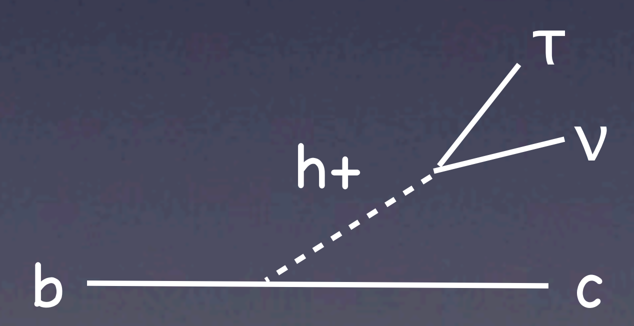
(t,u),(t,c), (t,t) elements are large

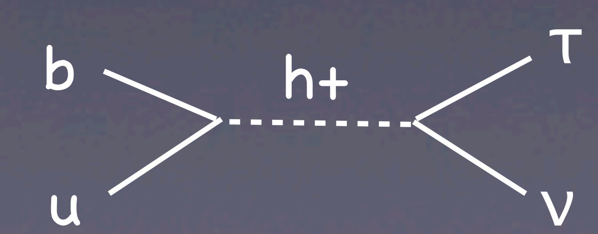


charged scalar

$$Y^{u-}_{bq} \sim (V_{CKM})^*_{tb}\frac{m^u_t}{\sqrt{2}\langle H_n\rangle}(mixing)^n_{tq}$$

(b,u),(b,c), (b,t) elements are large





For simplicity, let me fix the charge assignment and discuss complete models in phenomenology

(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
(u_1)	0	u_3	u_1	0	u_3	0

$$y_{ij}^U \overline{Q_{Li}} \widetilde{H}_j U_{Rj} + y_{ij}^D \overline{Q_{Li}} H_2 D_{Rj} + y_{ij}^E \overline{L_i} H_2 E_{Rj} .$$

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

(q1,q3)=(0,1) →2HDM   H3 does not exist

(q1,q3)=(-1,1) →3HDM   H3 exit

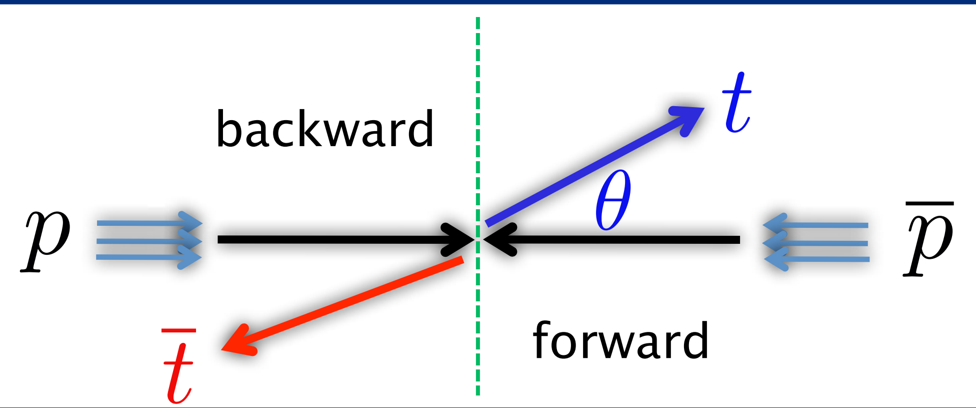
- The down (and lepton) sector Yukawas are diagonal

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

The bounds from Flavor physics are evaded.

3. phenomenology

3-1. 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

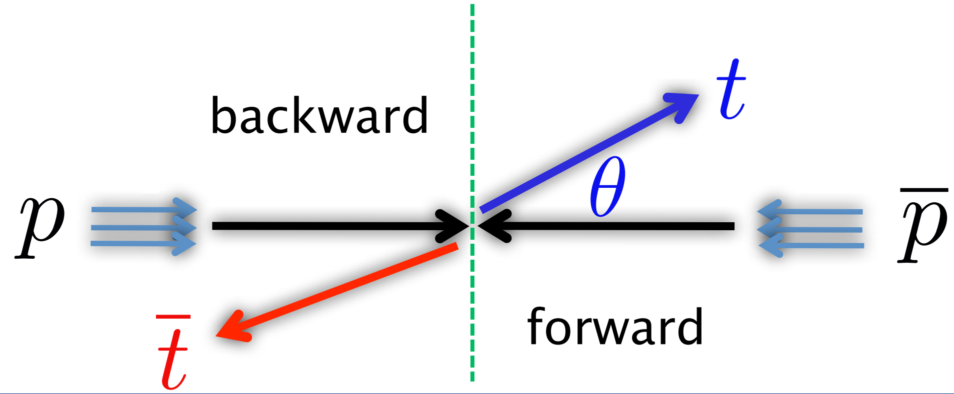
SM prediction

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

Kuhn, Rodrigo,etc.

3. phenomenology

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



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

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

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

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

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

3. phenomenology

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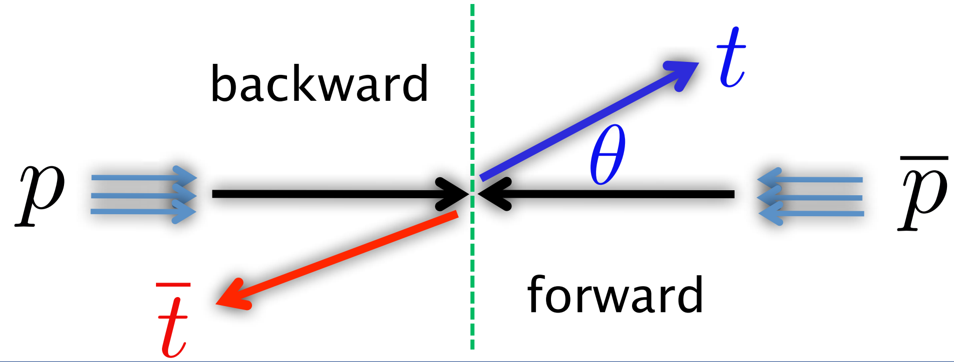

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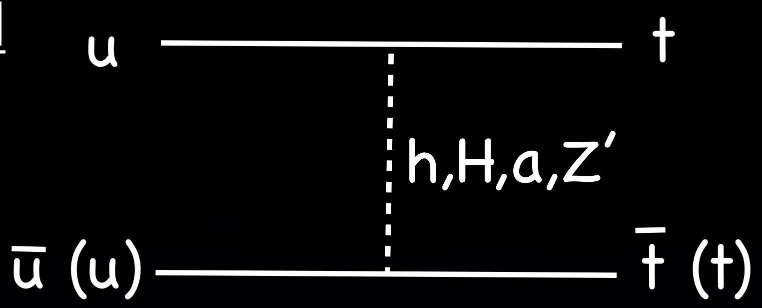
Small deviations still remain

W',Z', h in t-channel
axigluon in s-channel etc..

<u>Our model</u>



uu->tt is predicted.

New physics tested by other observables at LHC!

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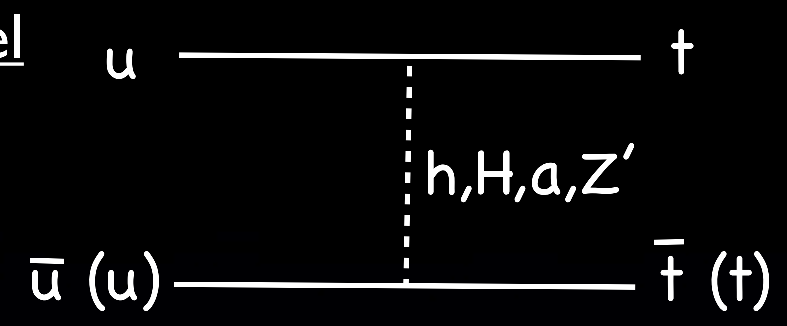

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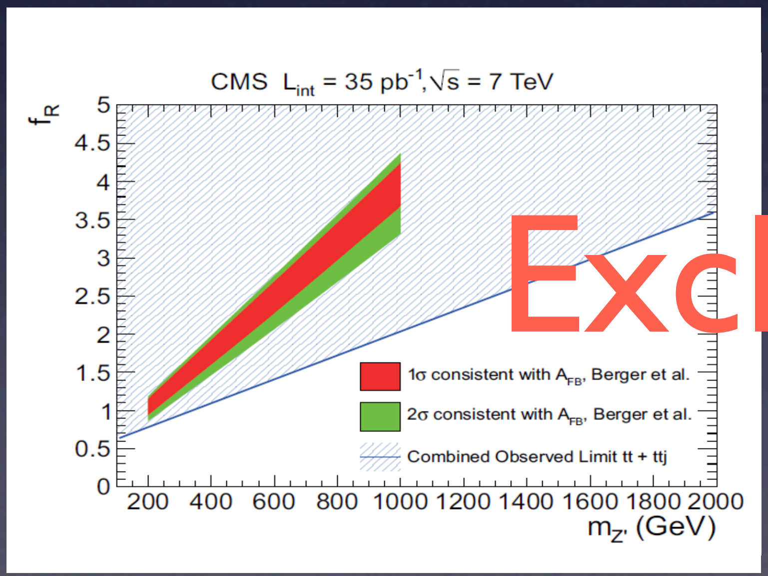
uu->tt at LHC

$\sigma(tt) < 0.3pb$

CMS, 1212.6194,
PAS SUS-12-029

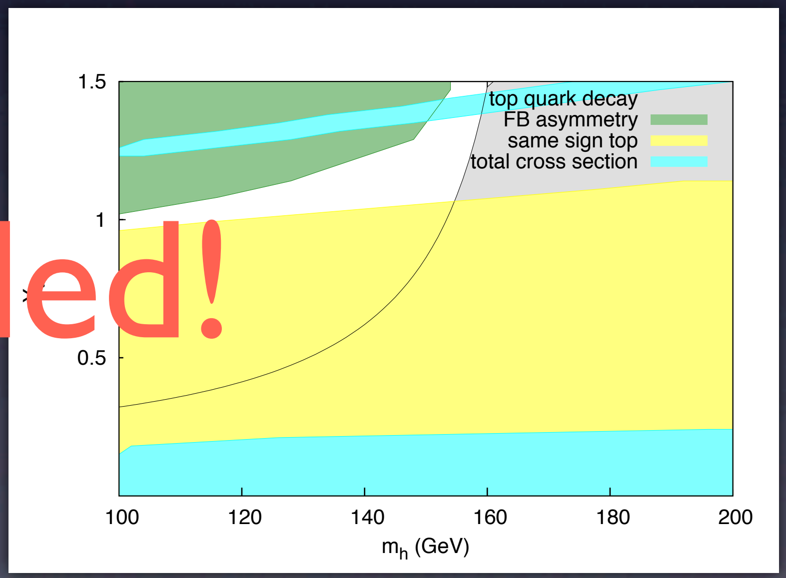
only Z’ scenario



Excluded!

CMS, 1106.2142

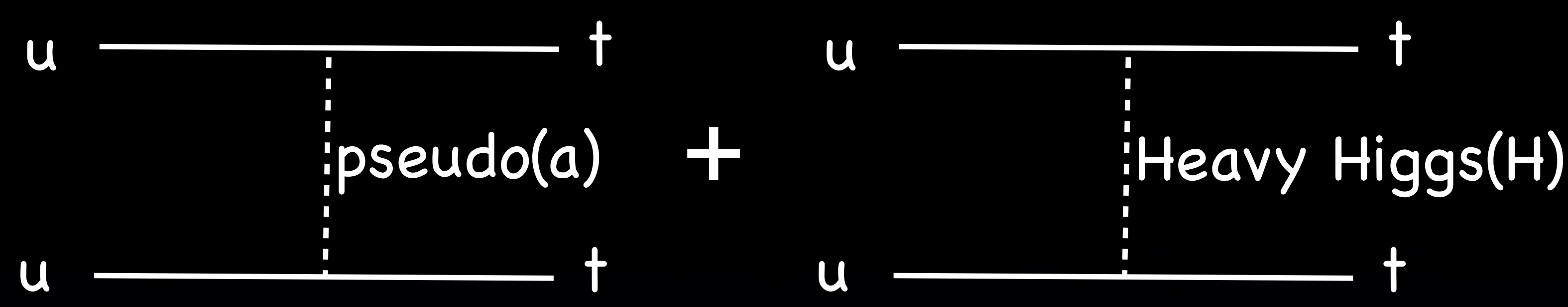
only h scenario

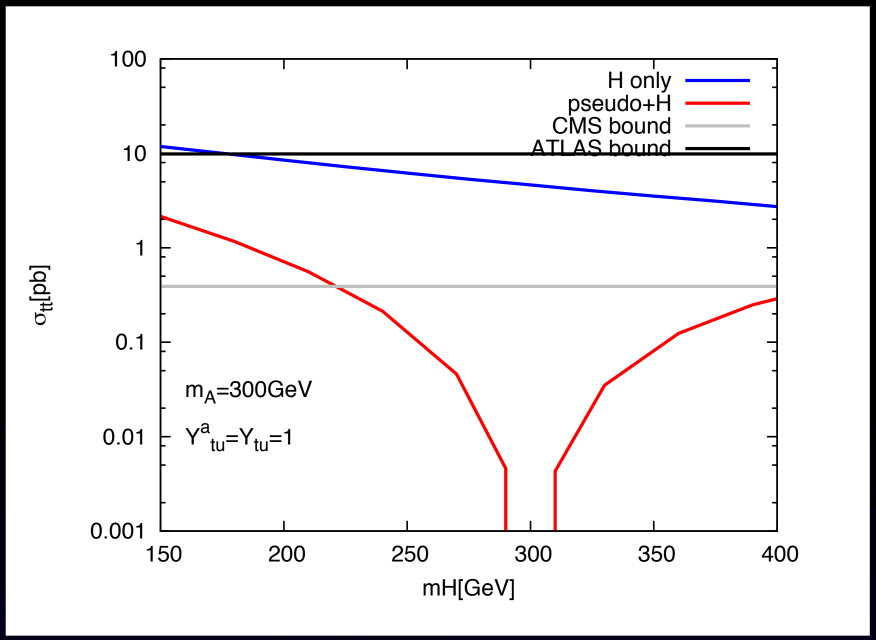


P.Ko,YO,C.Yu, 1108.4005

uu->tt should be forbidden.

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



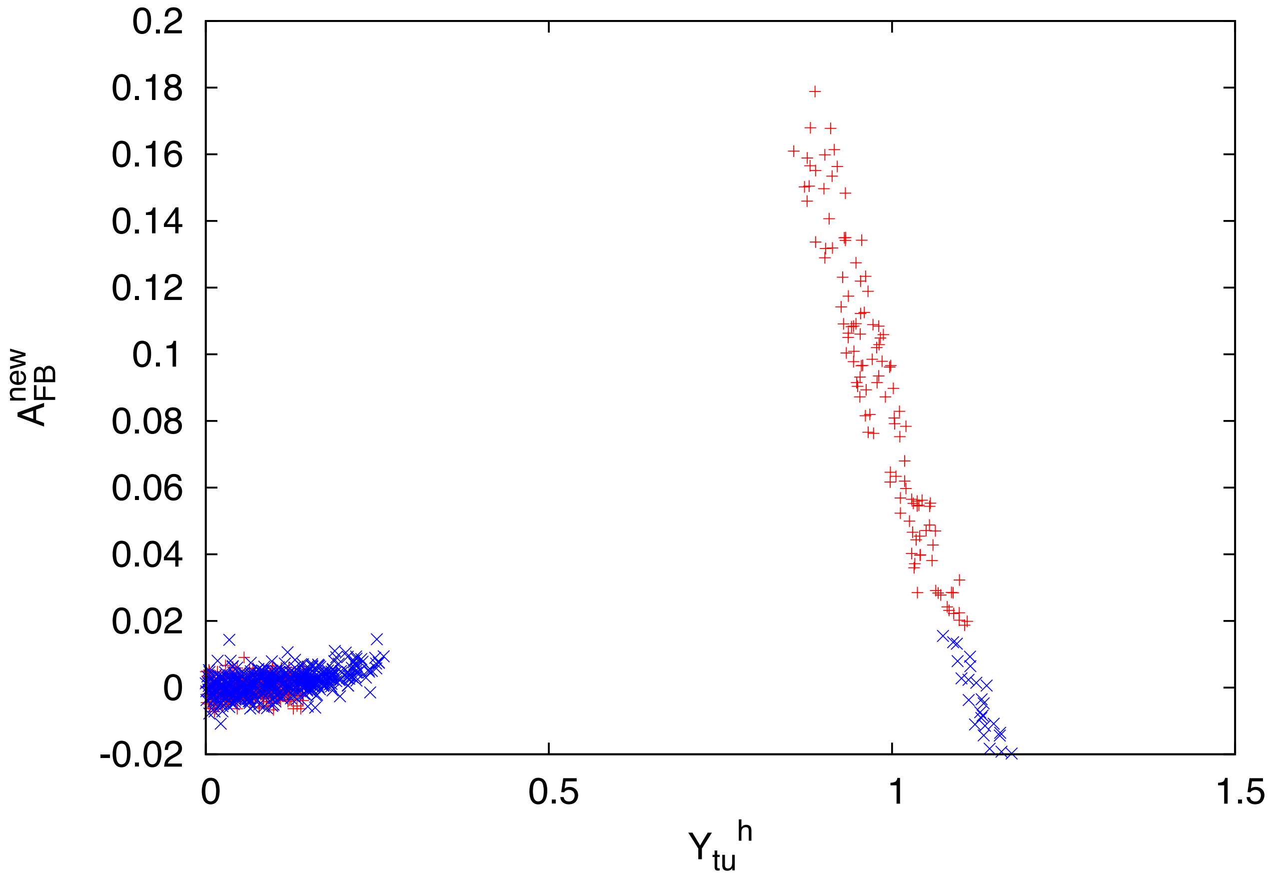


survived scenario

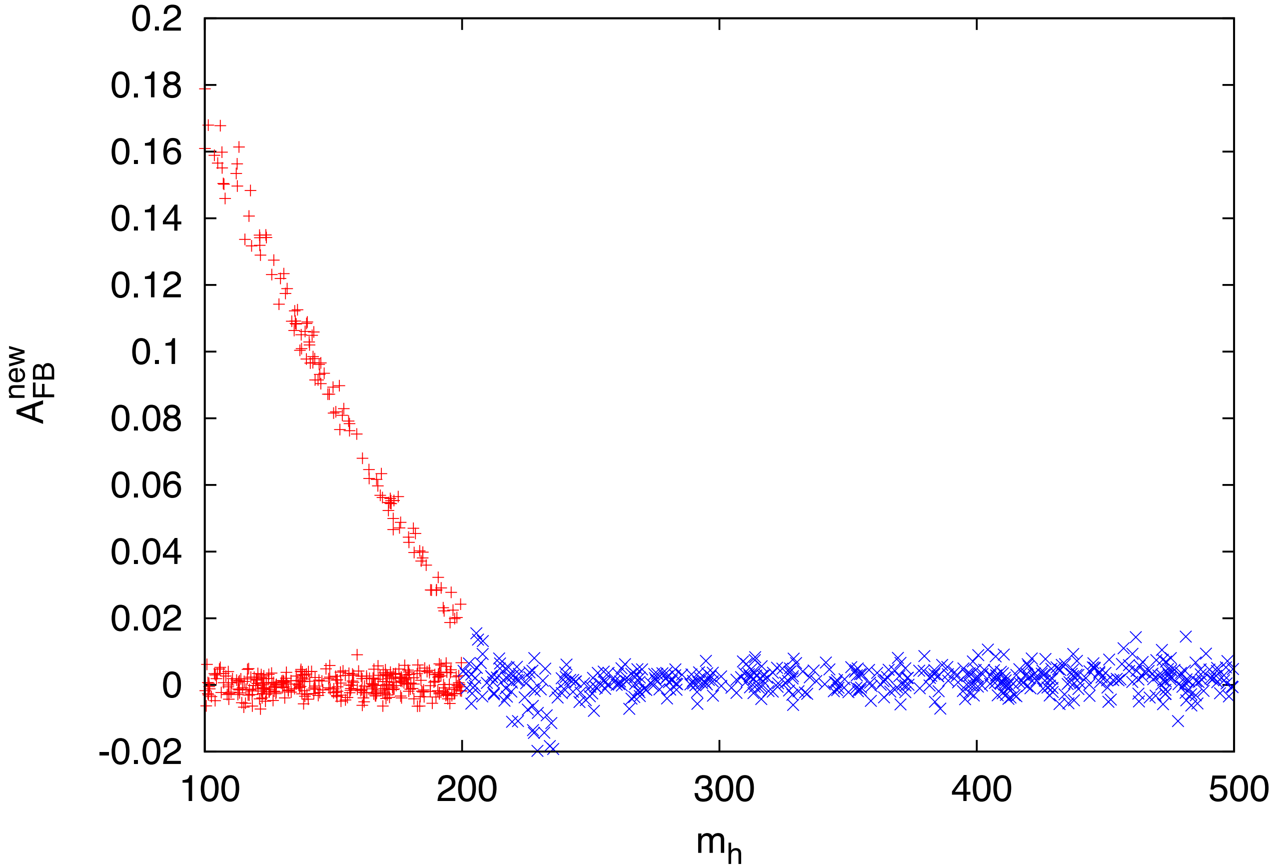
couplings and masses of pseudo and heavy scalars are almost degenerate.

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

Ytu vs δAFB



mH vs δAFB



(within 1σ of $t\bar{t}$ at Tevatron)

Enhancement of AFB requires light ma (~200GeV) and $Y^a_{tu} \sim 1.$

3-2.B-physics

our FCNCs: $Y^u_{ij}\overline{\hat{U}_{Li}}\hat{U}_{Rj}H + Y'^u_{ij}\overline{\hat{U}_{Li}}\hat{U}_{Rj}h - Y^{u-}_{ij}\overline{\hat{D}_{Li}}\hat{U}_{Rj}h^- - iY^{au}_{ij}\overline{\hat{U}_{Li}}\hat{U}_{Rj}a$

Large (t,q) elements

$$Y^{(a)u}_{tq} \sim \frac{m_t}{\sqrt{2}\langle H_n\rangle}(mixing)$$

Our scenario for AFB

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

3-2.B-physics

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Large (t,q) elements → Large (b,q) elements

$$Y^{(a)u}_{tq} \sim \frac{m_t}{\sqrt{2}\langle H_n\rangle}(mixing) \qquad Y^{u-}_{bq} \sim \sqrt{2}(V_{CKM})^{*}_{tb}Y^{au}_{tq}$$

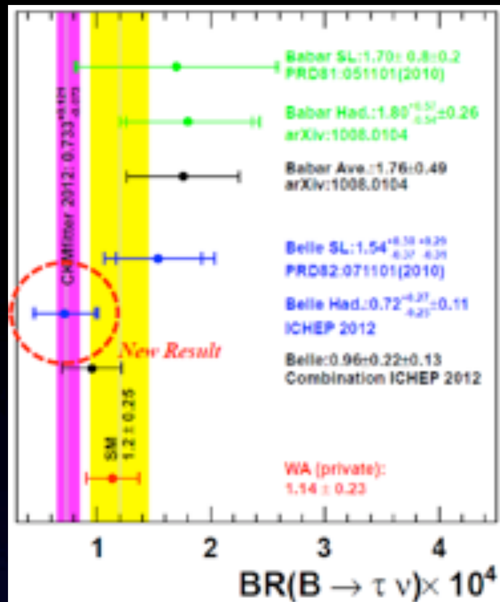
Our scenario for AFB → O(1) (b,u) element and ~200 GeV charged Higgs

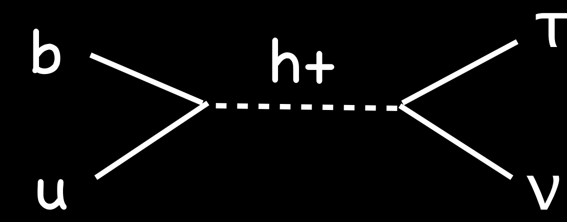
$$m_H \sim \ m_a \sim 200\mathrm{GeV} \ \ |Y^{au}_{tu}| \sim 1.$$

predict very large new physics contribution in B physics

(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

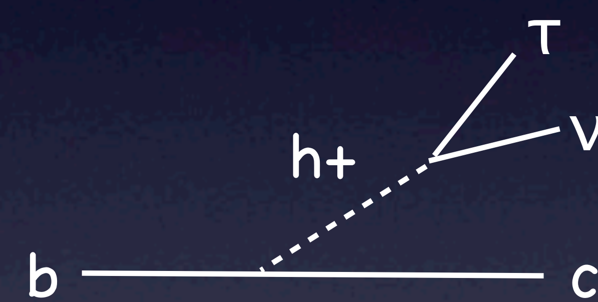
New Belle result

$$BR(B \to \tau\nu) = (0.72^{+0.27}_{-0.25} \pm 0.11) \times 10^{-4}$$ 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, 1303.0571
	↕ 2.0σ	↕ 2.7σ	
SM	0.297 ± 0.017	0.252 ± 0.003	
	$0.316 \pm 0.012 \pm 0.007$ (2+1 flavor lattice QCD, by Fermilab Lattice and MILC)		Fajfer, Kamenik, Nisandzic, Mescia, 1203.2654; BABAR, 1303.0571

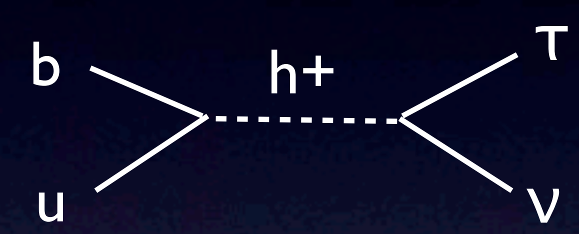
combined 3.4σ

Our scenario for AFB

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

can be compatible with

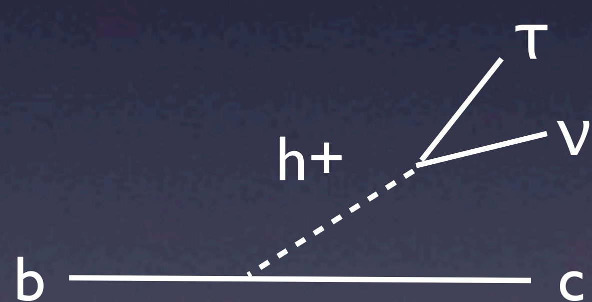
B→τν?



consistent with the SM.

requires small new physics contribution.

B→D(*)τν?



not consistent with the SM.

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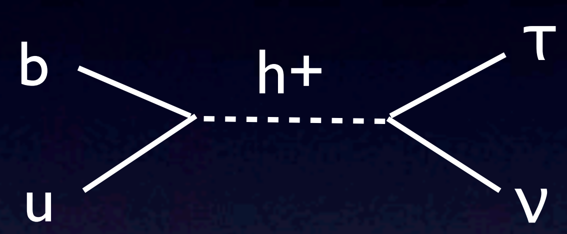

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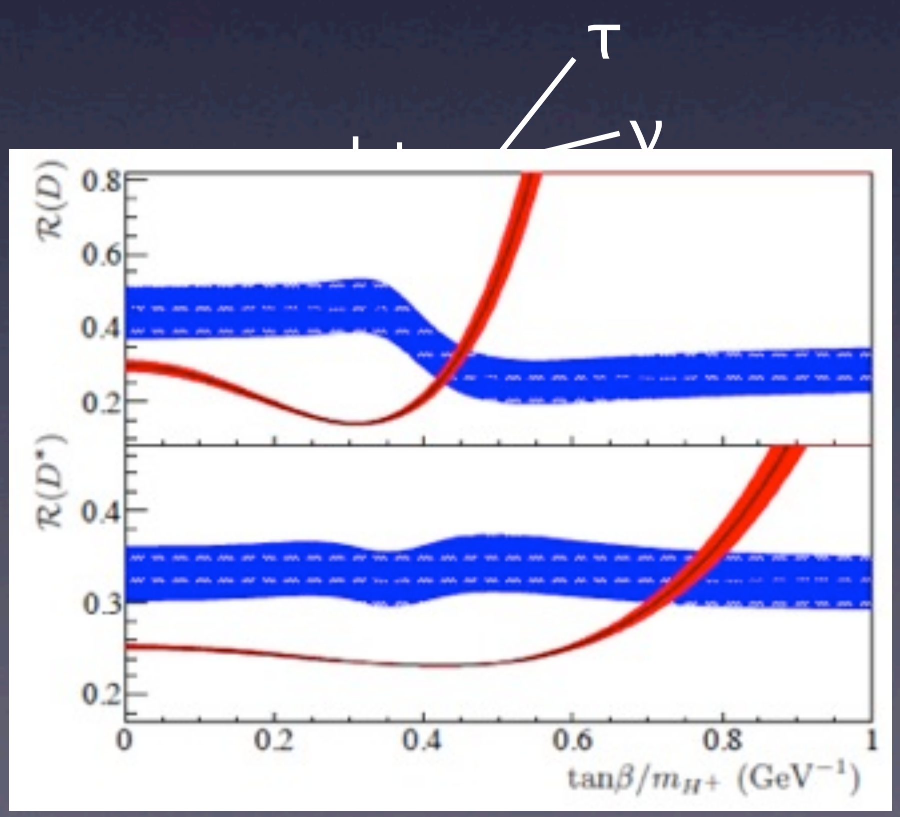
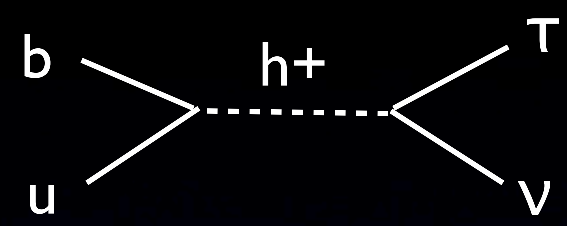


Type-II 2HDM cannot explain.

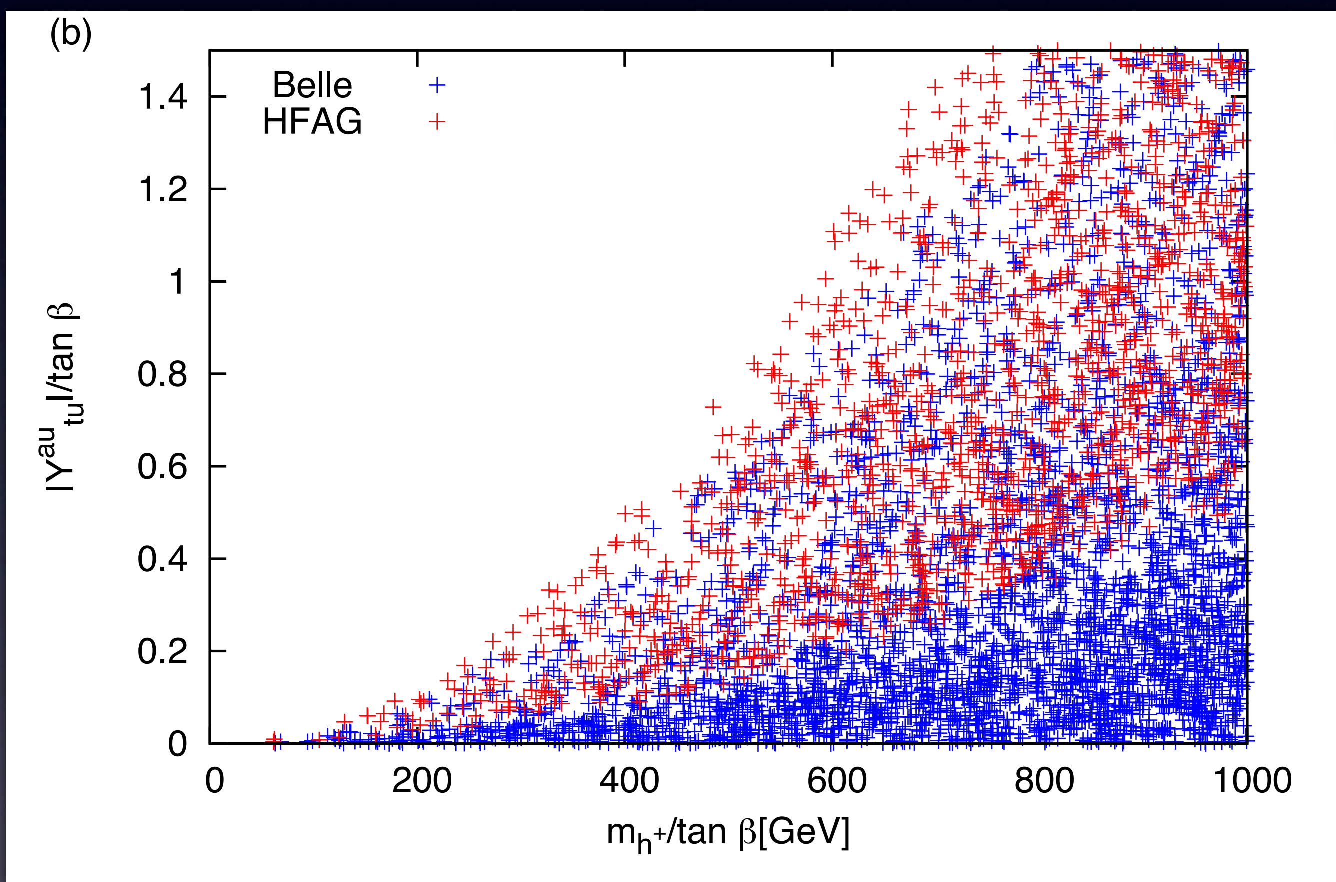
BaBar, 1205.5442, 1303.0571;
Crivellin, Greub, Kokulu, 1206.2634;
Fajfer, Kamenik, Nisandzic, Zupan, 1206.1872;
M.Tanaka, R.Watanabe, 1212.1878

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

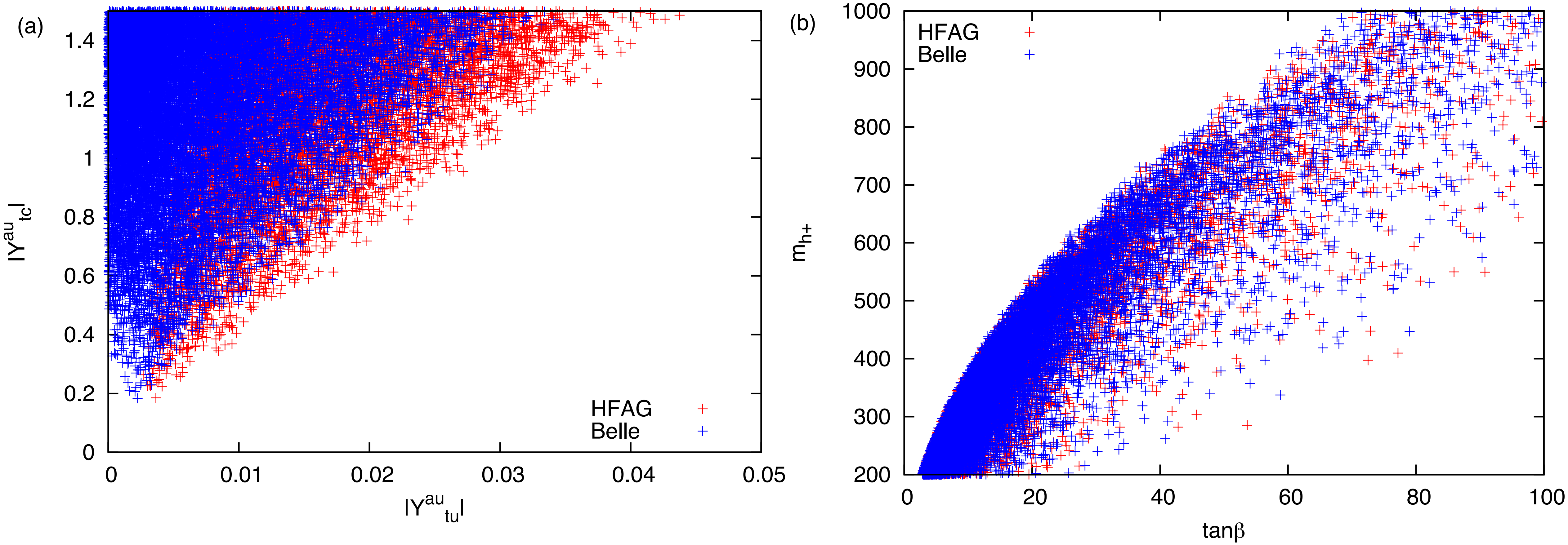
$O(100) \lesssim m_{h+}/\tan\beta$ $\longrightarrow$ can be $|Y^{au}_{tu}| \sim 1.$

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.)

- To enhance AFB and be consistent with the semi-leptonic and leptonic B decays, we need more complex model such as 3HDM.

difference between 2HDM and 3HDM.

$$\begin{array}{ccc} U_R^1 & U_R^2 & U_R^3 \\ \hline 0 & 0 & q \end{array} \quad \longrightarrow \quad \begin{array}{ccc} U_R^1 & U_R^2 & U_R^3 \\ \hline -q & 0 & q \end{array}$$

2HDM

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

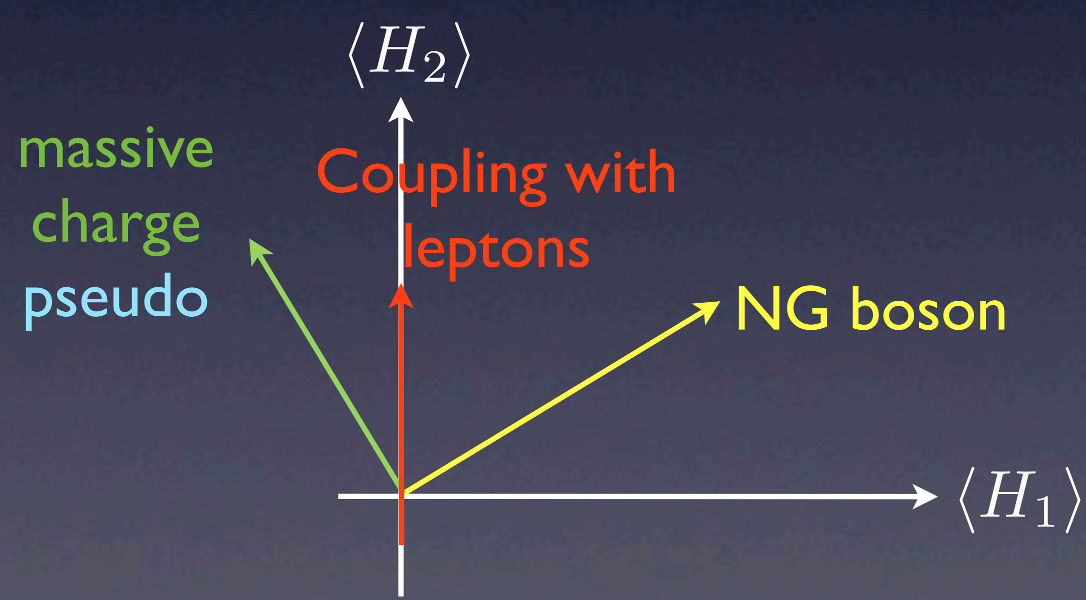
$$y^d_{ij}\overline{Q_i}H_2D_{Rj} + y^e_{ij}\overline{Q_i}H_2E_{Rj}$$

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



strong relation between pseudo and charged Yukawa

$$Y^a_{tq} \sim Y^-_{bq}$$

- To enhance AFB and be consistent with the semi-leptonic and leptonic B decays, we need more complex model such as 3HDM.

difference between 2HDM and 3HDM.

2HDM

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

→

3HDM

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

2HDM:

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

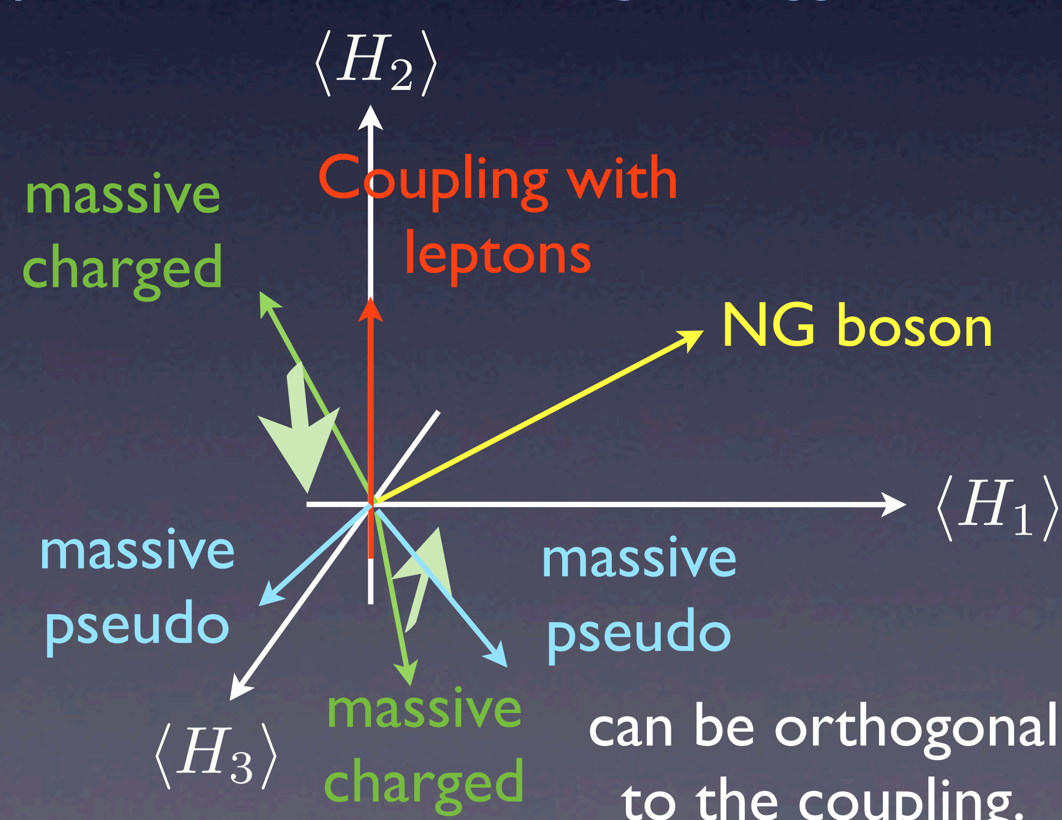
$$y^d_{ij}\overline{Q_i}H_2D_{Rj} + y^e_{ij}\overline{Q_i}H_2E_{Rj}$$

3HDM:

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

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

pseudoscalars and charged Higgs directions in 3HDM



massive 2 pseudo + massive 2 charged

no strong relation between pseudo and charged Yukawa

$$Y^a_{tq} \not\sim Y^-_{bq}$$

large (t,u) pseudo does not mean large (b,u) of charged

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

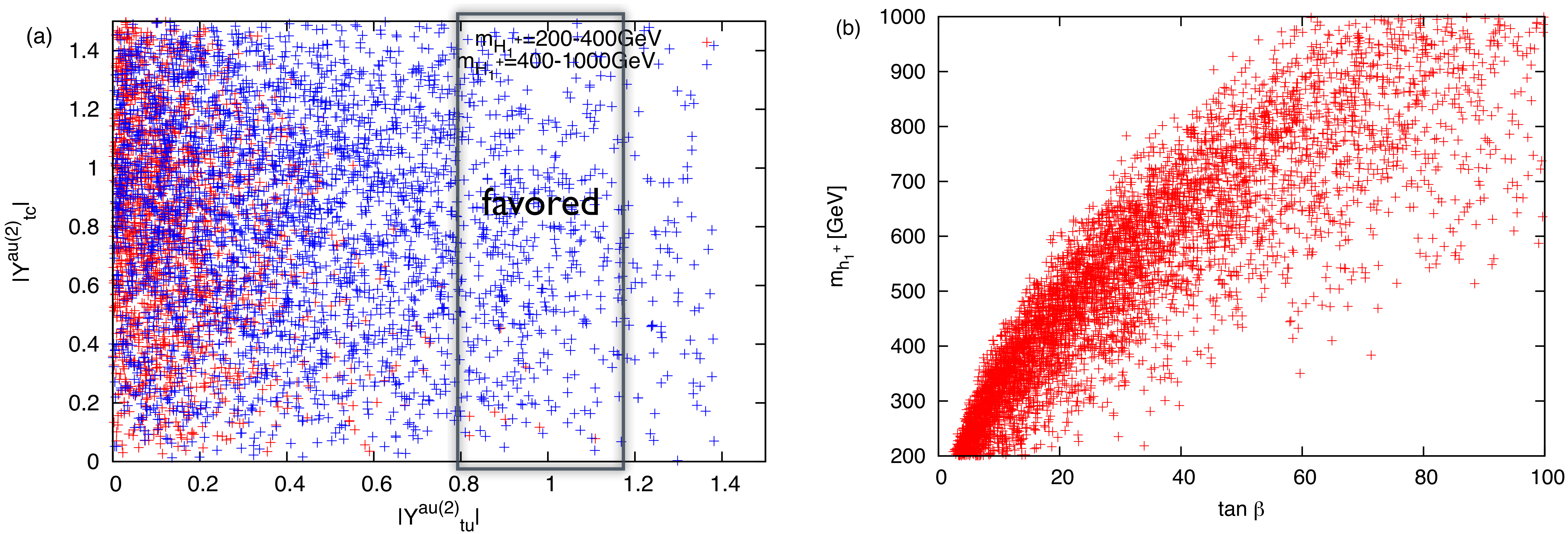
• Allowed points in 3HDM

P.Ko, YO, C.Yu, 1212.4607

many points consistent with (semi)leptonic B decays,

but points with large (t,u) and light mass of pseudo are not so many,
because of the bound from $D_0 - \overline{D_0}$ mixing.

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



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

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

4. Summary

- I introduced phenomenological models: 2HDM and 3HDM, where $U(1)_{\text{Flavor}}$ are assigned.
- 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 A_{FB} and can be consistent with LHC results according to destructive interference between CP-even scalar and CP-odd scalar. Favored scalars are CP-even (-odd) mass ~200GeV and the Yukawa coupling ~1.
- A_{FB} and B->D(*)τν requires large new physics effects, but B->τν requires the small effect. It is difficult to achieve all.
- Requirement for B->D(*)τν at BABAR and B->τν in 2HDM:

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

- In 3HDM, it may be possible to achieve A_{FB}, the BABAR discrepancies, and B->τν.
- We will discuss the consistency with Higgs search and EWPOs.
- Parity violation will test our scenario (Gresham, Kim, Tulin, Zurek 1203.1320).

Thank you