HPNP2013 in Toyama
16 February 2013

B physics and Extended Higgs sectors

Ryoutaro Watanabe, Osaka University
in collaboration with Minoru Tanaka, Osaka Univ.
based on “arXiv:1212.1878”

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Tauonic B decays and 2 Higgs doublet models

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What can we do in B physics?

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My viewpoint is ...

What is sensitive to Higgs sector in B physics ?

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What can we do in B physics?

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What is sensitive to Higgs sector in B physics ?

That is ...

Tauonic B decays in terms of Charged Higgs

Today's topic !

★ Short summary

Decay processes we see

Tauonic B decay : $\bar{B} \to D^{(*)}\tau\bar{\nu}$ $\bar{B} \to \tau\bar{\nu}$

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Decay processes we see

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Problem we focus on in this talk

BABAR result implies "charged Higgs is disfavored"

★ Short summary

Decay processes we see

Tauonic B decay : $\bar{B} \to D^{(*)} \tau \bar{\nu}$ $\quad \bar{B} \to \tau \bar{\nu}$

Problem we focus on in this talk

BABAR result implies "charged Higgs is disfavored"

What we will show in this work is as follows;

"Usual" 2HDMs cannot explain the BABAR result

2HDMs allowing FCNC solves this problem

Super B factory, LHC and ILC are possible to confirm this scenario

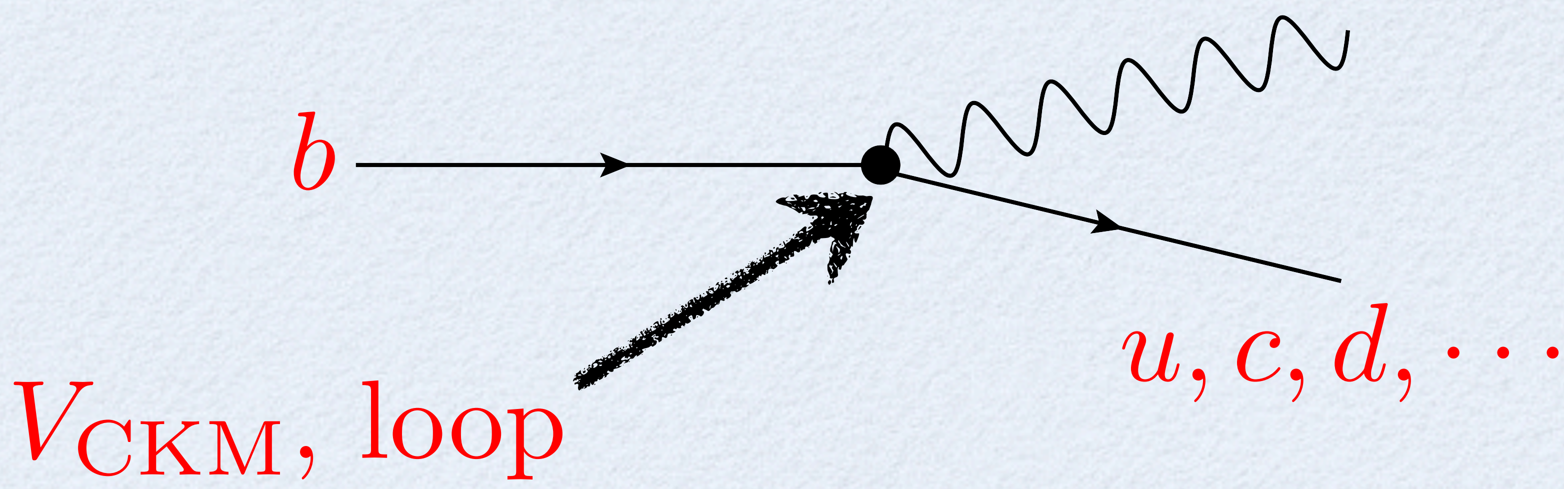
Contents

- Tauonic B decays
- Status of tauonic B decays
- Analysis
  1. 2HDMs
  2. 2HDMs allowing FCNC
  3. Future prospect : super B factory, ILC, (and LHC?)

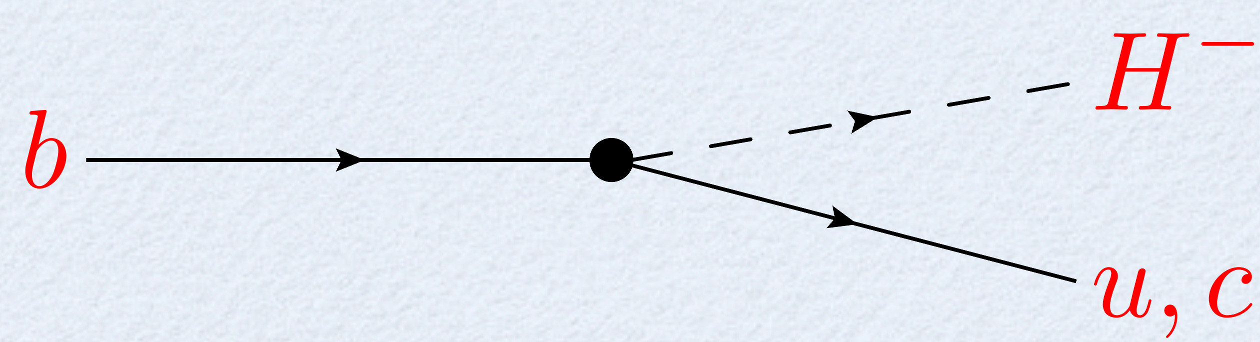
Tauonic B decay

Sensitivity to “Higgs sector”

Measuring B meson decays are suitable to investigate the flavor changing current



If a model contains charged Higgs (CH),
It contributes to flavor changing charged current



Furthermore,

CH interaction is enhanced as fermion mass is large

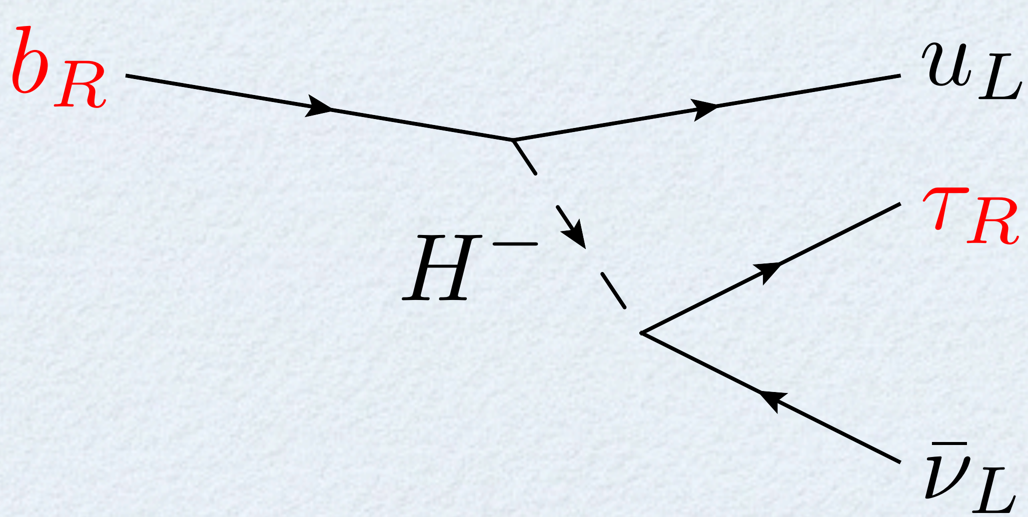
Example: 2HDM of type II

$$\mathcal{L}^{\mathrm{THDM}}_{\mathrm{yukawa}} = -\frac{\sqrt{2}V_{ud}}{v}\Big(m_u \cot\beta\, \bar{u}_R d_L H^+ + m_d \tan\beta\, \bar{u}_L d_R H^+\Big)$$

$$\boxed{m_b}$$

$$-\frac{\sqrt{2}}{v} m_l \tan\beta\, \bar{\nu}_L l_R H^+ + \mathrm{h.c.}$$

$$\boxed{m_\tau}$$



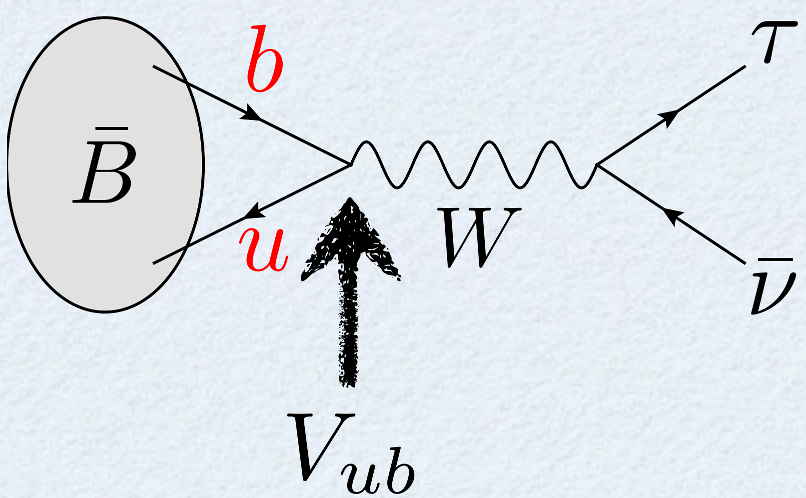
$$\propto \frac{m_\tau m_b}{m_{H^\pm}^2} \tan^2\beta$$

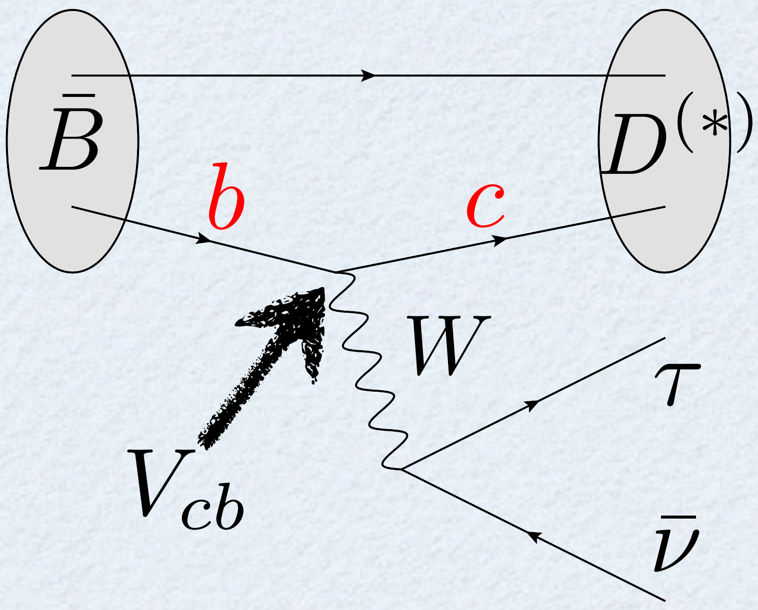
Tauonic B decay

Bottom quark decay including tau is sensitive to CH

For B meson decays : $\bar{B} \to D^{(*)}\tau\bar{\nu}$ $\quad \bar{B} \to \tau\bar{\nu}$

(Standard Model)





$\left(D :\ J^P = 0^-\right)$

$\left(D^* :\ J^P = 1^-\right)$

Experimental results were improved last year

May : BABAR reported the results on $\bar{B} \to D^{(*)}\tau\bar{\nu}$

July : Belle reported the results on $\bar{B} \to \tau\bar{\nu}$

Status of tauonic B decays

Comparison between Experimental result and SM prediction

	SM	Result (WA)
$\mathcal{B}(\bar{B} \to \tau\bar{\nu})$	$(0.74 \pm 0.07) \times 10^{-4}$	$(1.14 \pm 0.23) \times 10^{-4}$
$R(D)$	0.302 ± 0.015	0.43 ± 0.06
$R(D^*)$	0.254 ± 0.005	0.33 ± 0.04

※Measured quantities of B→D(*) τ ν

$$R(D) = \frac{\Gamma(\bar{B} \to D\tau\bar{\nu})}{\Gamma(\bar{B} \to D\ell\bar{\nu})} \qquad R(D^*) = \frac{\Gamma(\bar{B} \to D^*\tau\bar{\nu})}{\Gamma(\bar{B} \to D^*\ell\bar{\nu})}$$

$\ell = e$, or μ

Status of tauonic B decays

Comparison between Experimental result and SM prediction

	SM		Result (WA)
$\mathcal{B}(\bar{B} \to \tau\bar{\nu})$	$(0.74 \pm 0.0$	1.7 σ deviation	$0.23) \times 10^{-4}$
$R(D)$	$0.302 \pm$	2.0 σ deviation	$\pm\, 0.06$
$R(D^*)$	$0.254 \pm$	2.7 σ deviation	$\pm\, 0.04$

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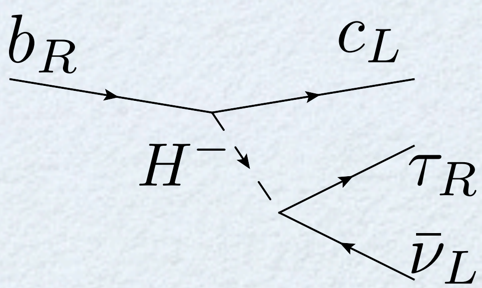
Detail

$\bar{B} \to \tau \bar{\nu}$: Belle latest result is quite consistent with SM prediction

$\bar{B} \to D^{(*)} \tau \bar{\nu}$: As a view point of quark current,

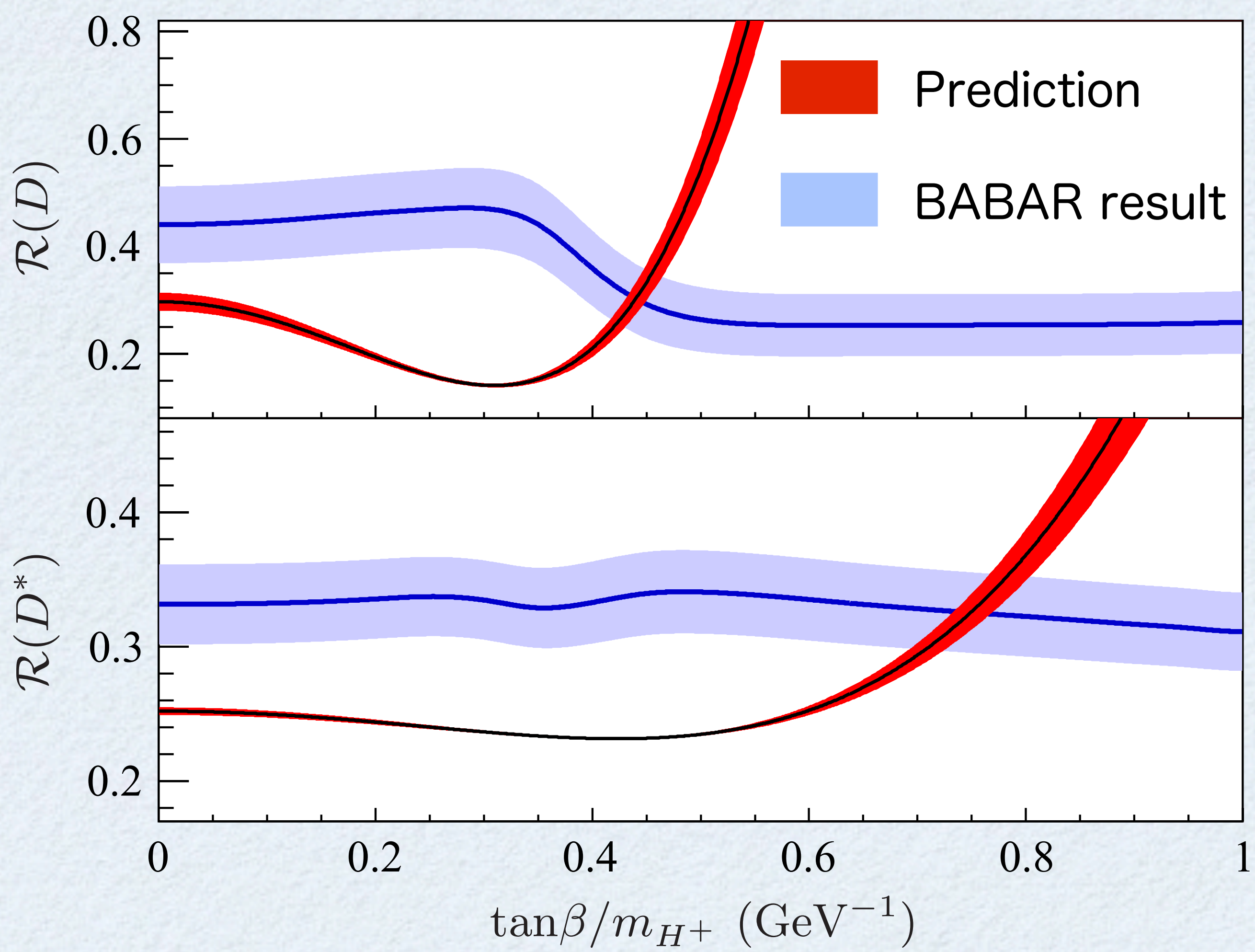
the deviation from SM prediction reach $3.4\,\sigma$

In addition, BABAR analyzed the charged Higgs effect on R(D)&R(D*)



$$\propto m_\tau m_b \frac{\tan^2\beta}{m^2_{H^\pm}}$$

BABAR, PRL109,101802(2012)



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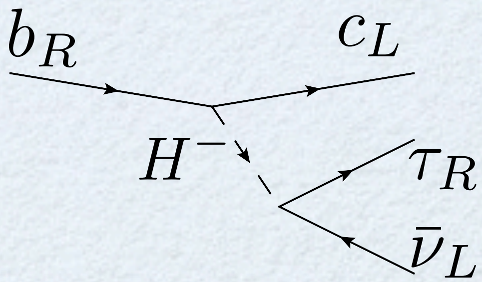

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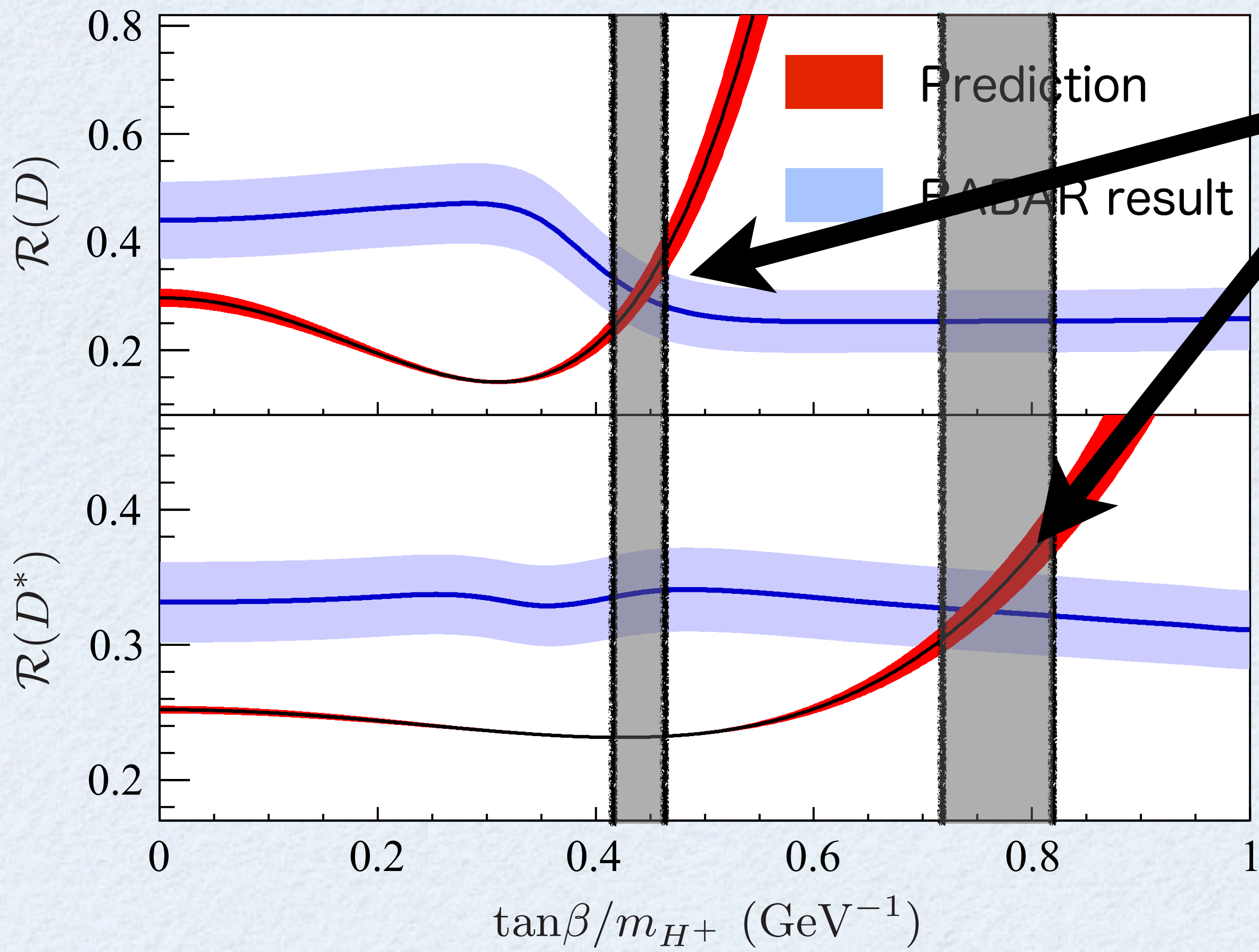

CH cannot explain both results
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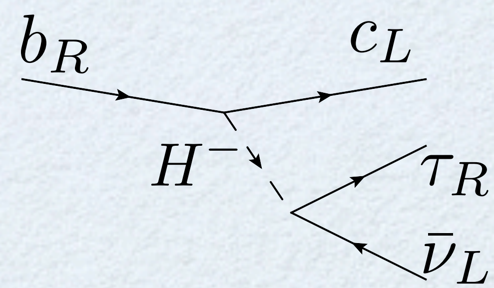

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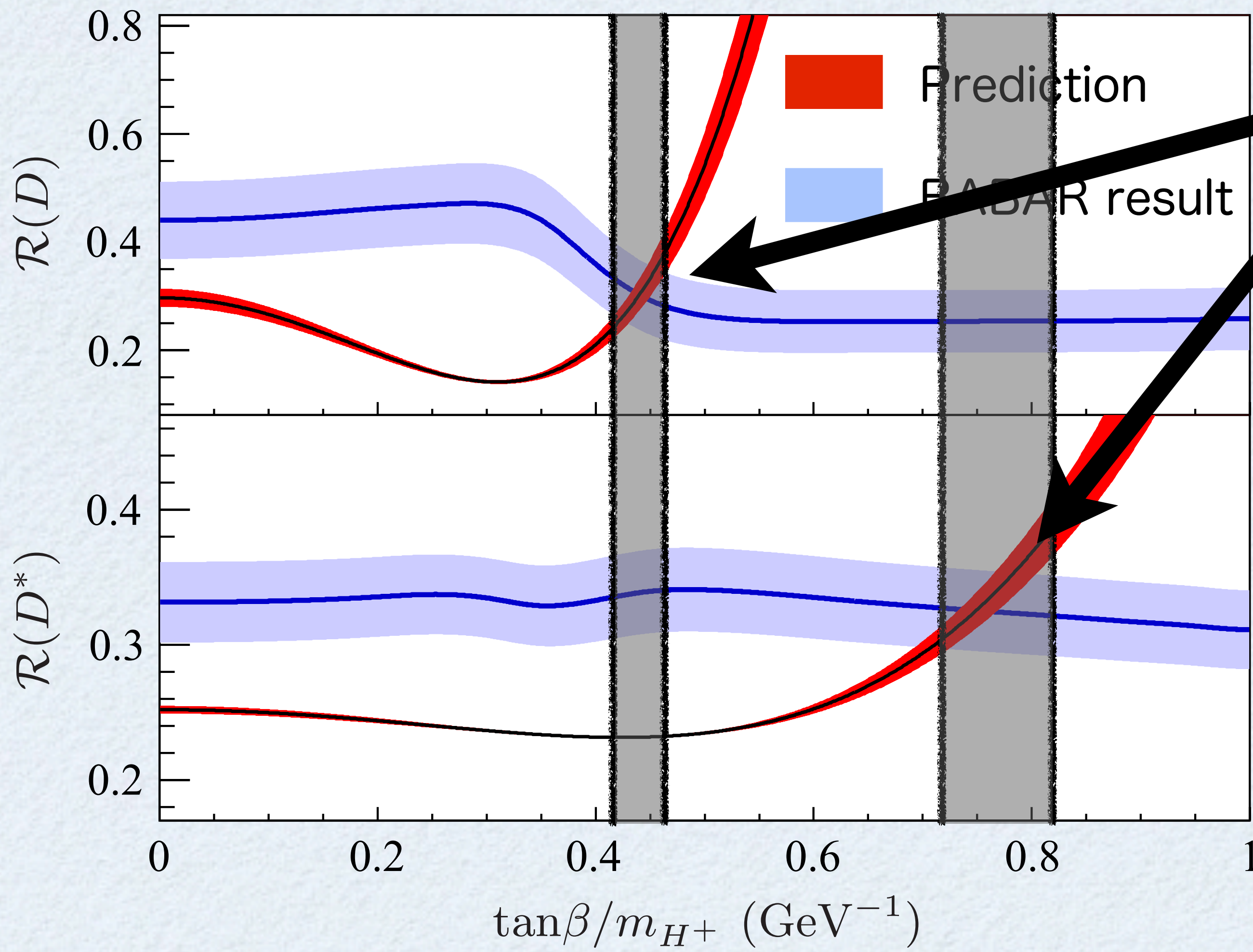

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Detail

CH boson in typeII 2HDM is excluded with 99.8%CL

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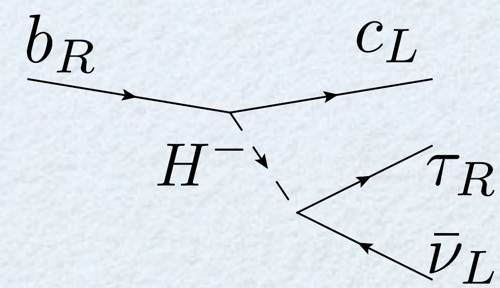

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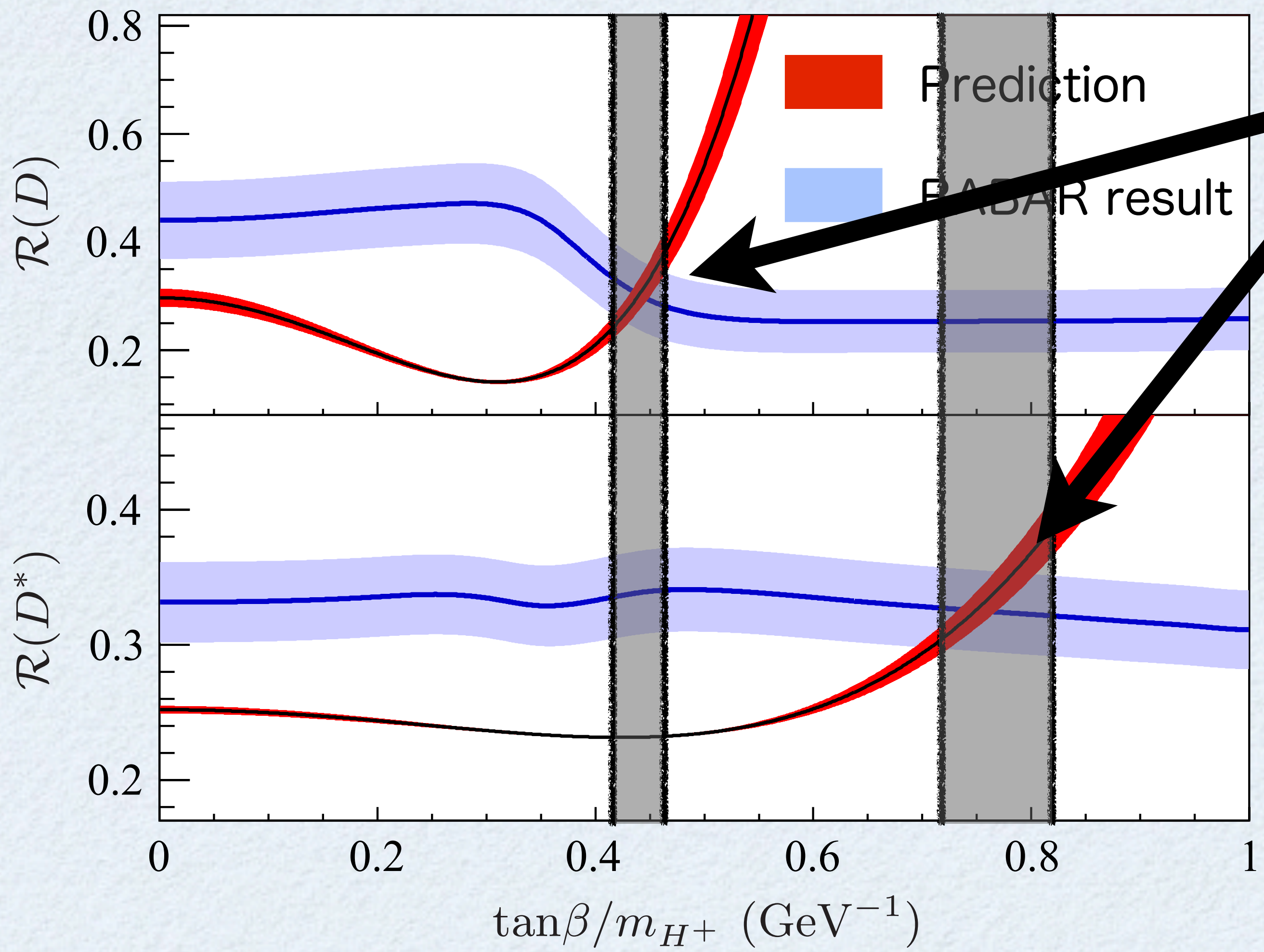


CH cannot explain both results at the same time

Technical things

Results depend on CH parameter because they include estimation of the effect of CH on R(D)&R(D*) by reweighting the simulated events at the matrix element level.

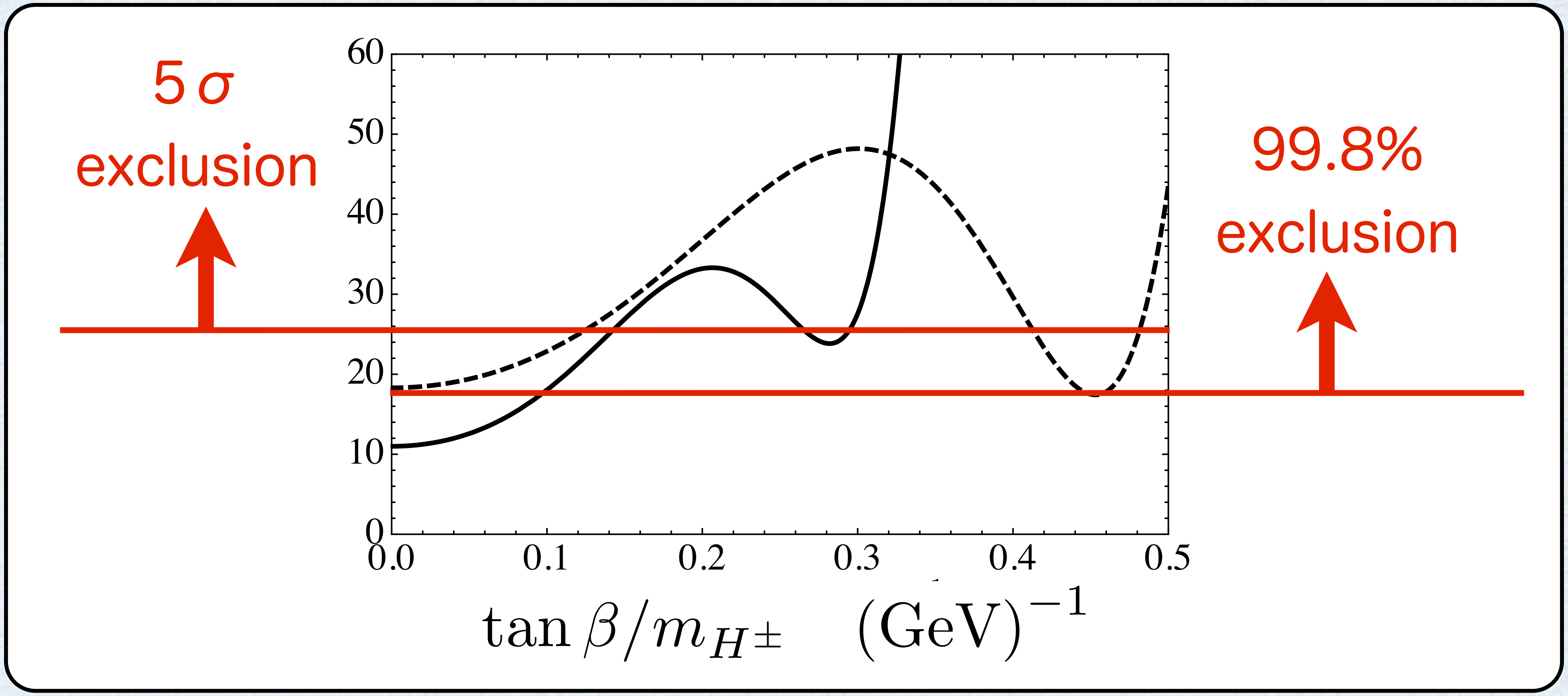
Detail

CH boson in typeII 2HDM is excluded with 99.8%CL

What happen if the result of B→$\tau\,\nu$ is included ?

My naive estimation

R(D) & R(D*) : - - - - - -   +B→$\tau\,\nu$: ———



★CL of exclusion within small parameter region reduces, (because B→$\tau\,\nu$ is consistent with SM) while exclusion in the region $\tan\beta/m_{H^\pm} > 0.15(\mathrm{GeV})^{-1}$ almost reaches 5σ

Summary of this section

$\bar{B} \to \tau\bar{\nu}$

- Small deviation（1.7σ@WA)
  (Belle result is quite consistent with SM)

$\bar{B} \to D^{(*)}\tau\bar{\nu}$

- Large deviation（3.4σ@WA)
- CH boson in typeII 2HDM is excluded（99.8%)

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And then? → Two Possibilities to extend this analysis

(1) Other type of 2HDM

(2) Allowing FCNC in Yukawa sector

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- Tauonic B decays ✓
- Status of tauonic B decays ✓
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  1. 2HDMs
  2. 2HDMs allowing FCNC
  3. Future prospect : super B factory, ILC, (and LHC?)

Analysis

1 . 2HDMs and their constraints

$$\mathcal{L}_{\text{yukawa}} = -\bar{Q}_L Y_u \tilde{H}_u u_R - \bar{Q}_L Y_d H_d d_R - \bar{L}_L Y_\ell H_\ell \ell_R + \text{h.c.}$$

H_1 or H_2

In order to forbid tree level FCNC, One of the Higgs doublets should be coupled to the fermion doublet in each term

Type I : $H_2 = H_u = H_d = H_\ell$

Type II : $H_2 = H_u,$ $\quad H_1 = H_d = H_\ell$

Type X : $H_2 = H_u = H_d,$ $\quad H_1 = H_\ell$

Type Y : $H_2 = H_u = H_\ell,$ $\quad H_1 = H_d$

named by Aoki, Kanemura, Tsumura, Yagyu(2009)

Contribution to tauonic B decays

Parameter : $\boxed{\tan\beta = \frac{\langle h_2^0 \rangle}{\langle h_1^0 \rangle}}$ $\quad H_a = \begin{pmatrix} h_a^+ \\ h_a^0 \end{pmatrix} \quad (a = 1, 2)$

Contribution to tauonic B decays

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Contribution to tauonic B decays is summarized into Wilson coefficient,

$$C_{S_1}^u = C_{S_1}^c = -\frac{m_b m_\tau}{m_{H^\pm}^2}\xi_d$$

$$C_{S_2}^u = -\frac{m_u m_\tau}{m_{H^\pm}^2}\xi_u \quad C_{S_2}^c = -\frac{m_c m_\tau}{m_{H^\pm}^2}\xi_u$$

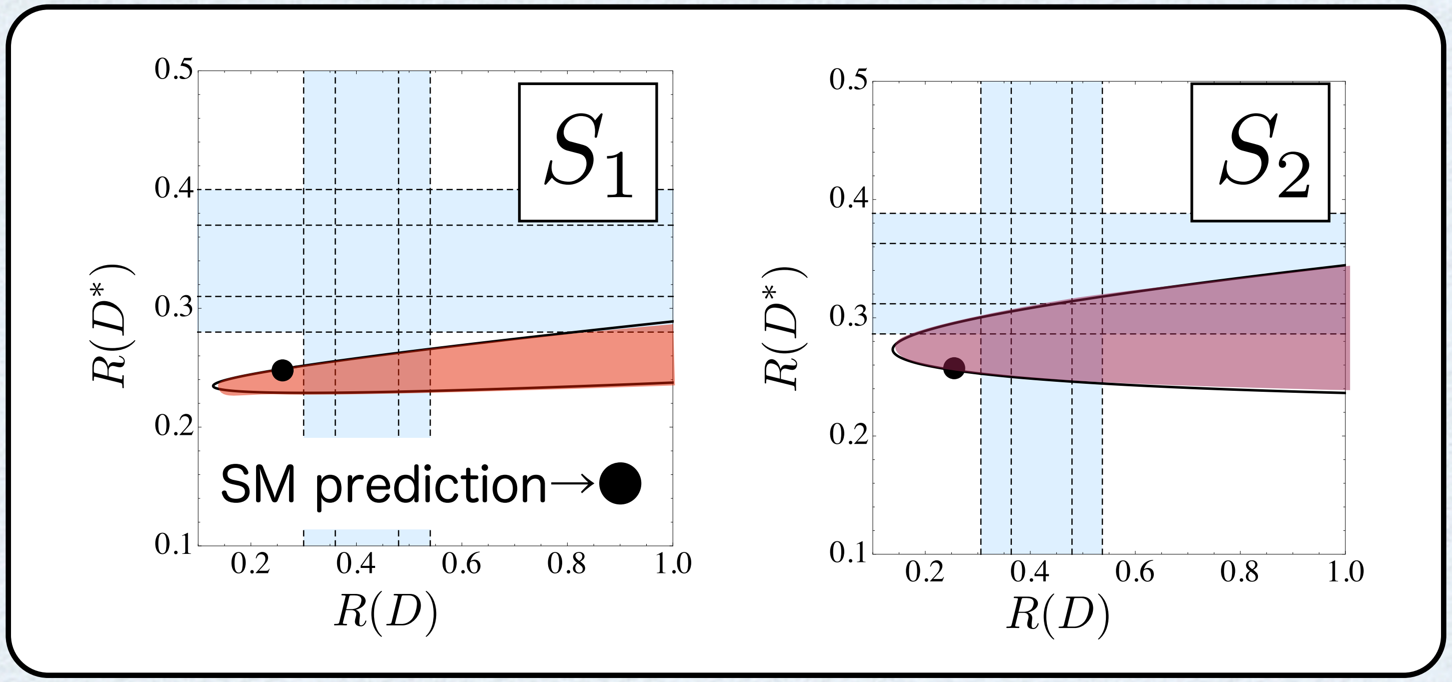
	Type I	Type II	Type X	Type Y
ξ_d	$\cot^2\beta$	$\tan^2\beta$	-1	-1
ξ_u	$-\cot^2\beta$	1	1	$-\cot^2\beta$

defined as

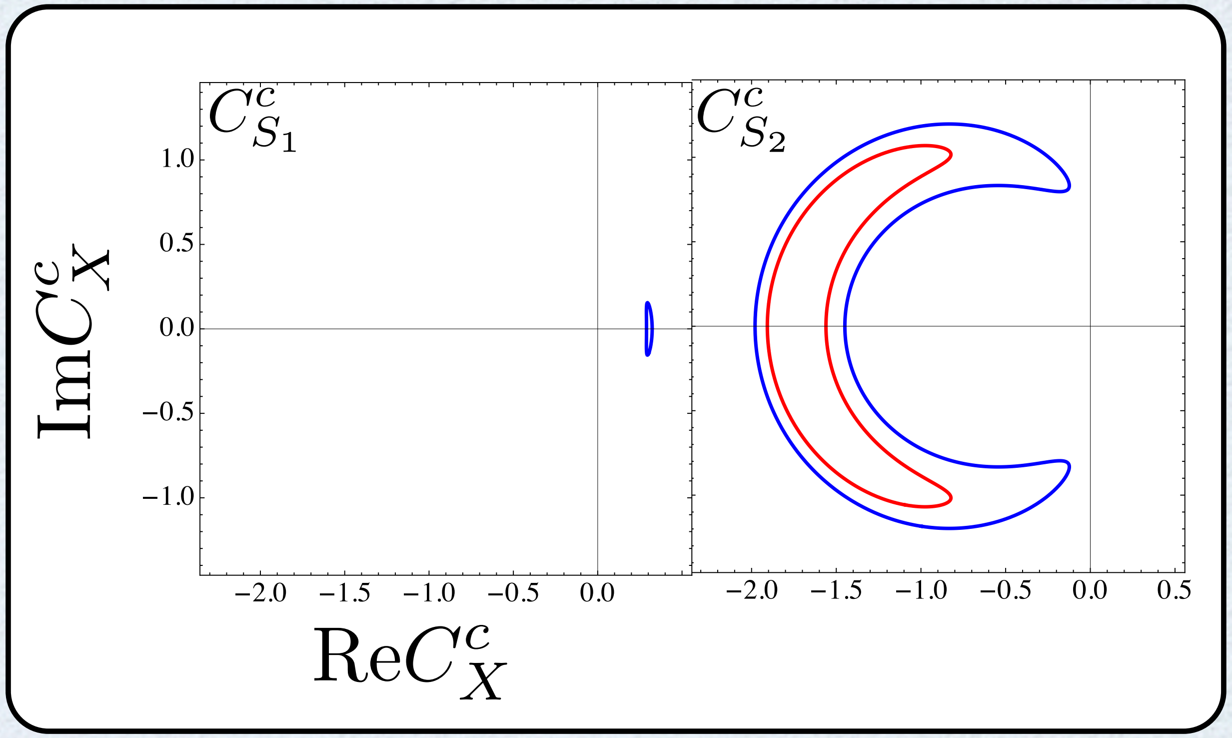
$$\mathcal{L}_{\mathrm{eff}} = -2\sqrt{2}G_F V_{qb}\Big(\bar{q}_L\gamma^\mu b_L\,\bar{\tau}_L\gamma_\mu\nu_L + C_{S_1}^q\,\bar{q}_L b_R\,\bar{\tau}_R\nu_L + C_{S_2}^q\,\bar{q}_R b_L\,\bar{\tau}_R\nu_L\Big)$$

Contribution to tauonic B decays

To begin with, let me show the study on Wilson coefficient itself in terms of effective Lagrangian approach.



Correlation between R(D)&R(D*) in the presence of S1 or S2



Constraint on C
(Exclusion@99%CL : ━━)

★S1 is not favored at all

★S2 can explain data but needs large contribution

Is it possible to have a sizable effect of S2 in 2HDM ?

Remember the contribution of S2 to B→D(*)$\tau\ \nu$

$$\boxed{C^c_{S_2} = -\frac{m_c m_\tau}{m^2_{H^\pm}}\xi_u}$$

	Type I	Type II	Type X	Type Y
ξ_u	$-\cot^2\beta$	1	1	$-\cot^2\beta$

- Charm mass is not so large compared to bottom mass
- The requirement for the top Yukawa interaction to be perturbative results in $\tan\beta \gtrsim 0.4$

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★In usual 2HDM of any type,
S2 cannot have a sizable effect on B→D(*)τ ν

Is it possible to have a sizable effect of S2 in 2HDM ?

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・Charm mass to bottom mass

・The requirem teraction to be perturbative

★In usual 2H

S2 cannot t on B→D(*) $\tau\ \nu$

2 . 2HDMs allowing FCNC

A possible solution to have a large S2 contribution within 2HDMs

CASE : type II + FCNC

$$\mathcal{L}_{\rm yukawa} = -\bar{Q}_L Y_u \tilde{H}_2 u_R - \bar{Q}_L Y_d H_1 d_R - \bar{L}_L Y_\ell H_1 \ell_R + \text{h.c.}$$

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$$-\bar{Q}_L \epsilon'_u \tilde{H}_1 u_R - \bar{Q}_L \epsilon'_d H_2 d_R + \text{h.c.}$$

- $\epsilon'_{u,d}$ is parameter that control FCNC (in the weak basis)

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- $\epsilon'_{u,d}$ is parameter that control FCNC (in the weak basis)
- In terms of mass eigenstate, one of CH-q-q terms is written as

$$-\sin\beta\, \bar{u}_R\, \epsilon_u^\dagger V_{\text{CKM}}\, d_L$$ ($\epsilon_{u,d}$ is that in the mass eigenstate)

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$$-\sin\beta\, \bar{u}_R\, \epsilon_u^\dagger V_{\text{CKM}}\, d_L$$

($\epsilon_{u,d}$ is that in the mass eigenstate)

$$\boxed{C_{S_2}^c \simeq \frac{V_{tb}}{\sqrt{2}V_{cb}} \frac{v m_\tau}{m_{H^\pm}^2} (\epsilon_u^*)^{ct} \sin\beta \tan\beta}$$

How about the other types ?

CASE : type I + FCNC

CASE : type Y + FCNC

No “reasonable” sizable contribution

(To explain data, $\epsilon_u^{ct} >> 1$ is needed)

CASE : type II + FCNC

CASE : type X + FCNC

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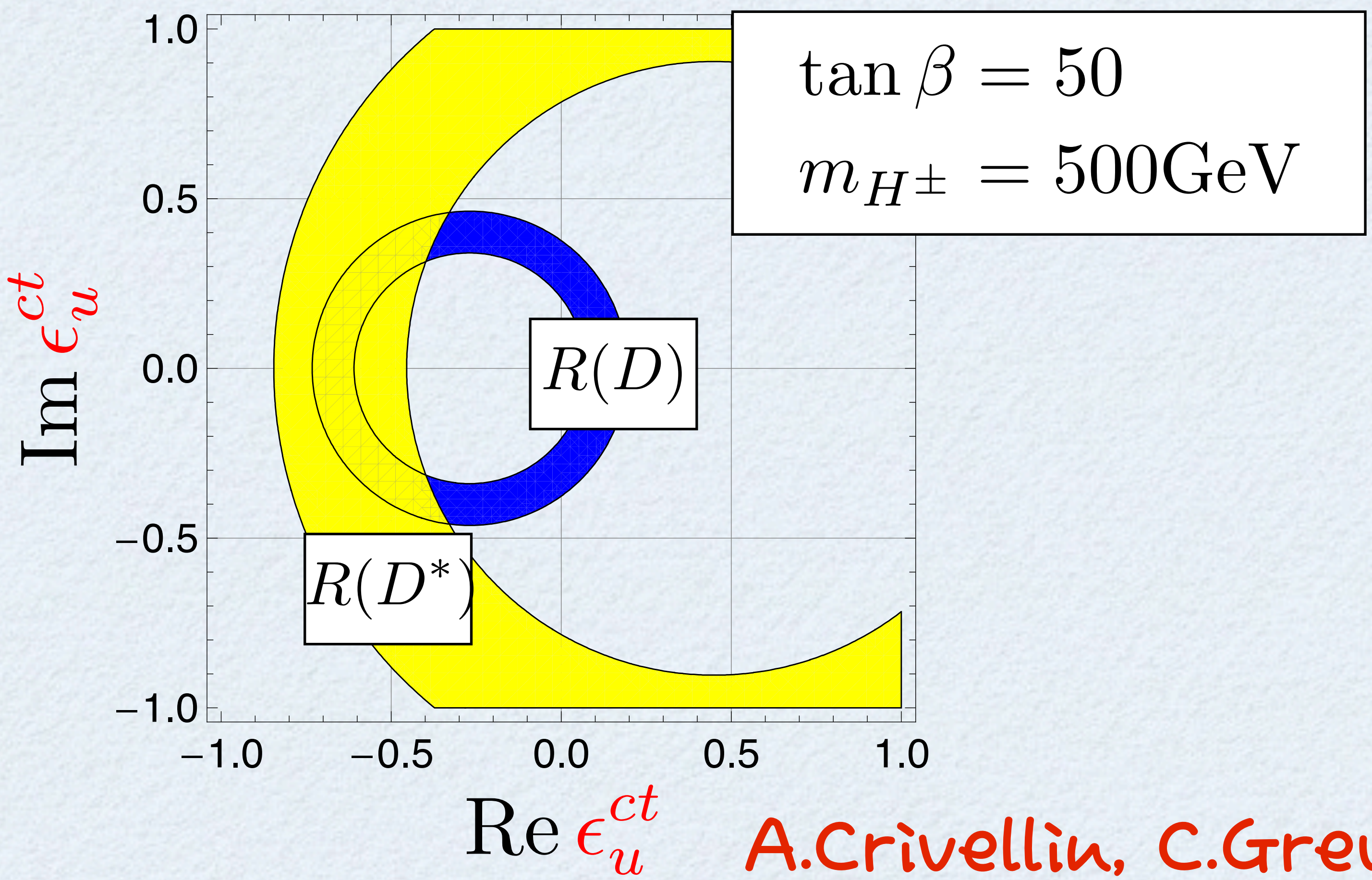

A.Crivellin, C.Greub & A.Kokulu (2012)

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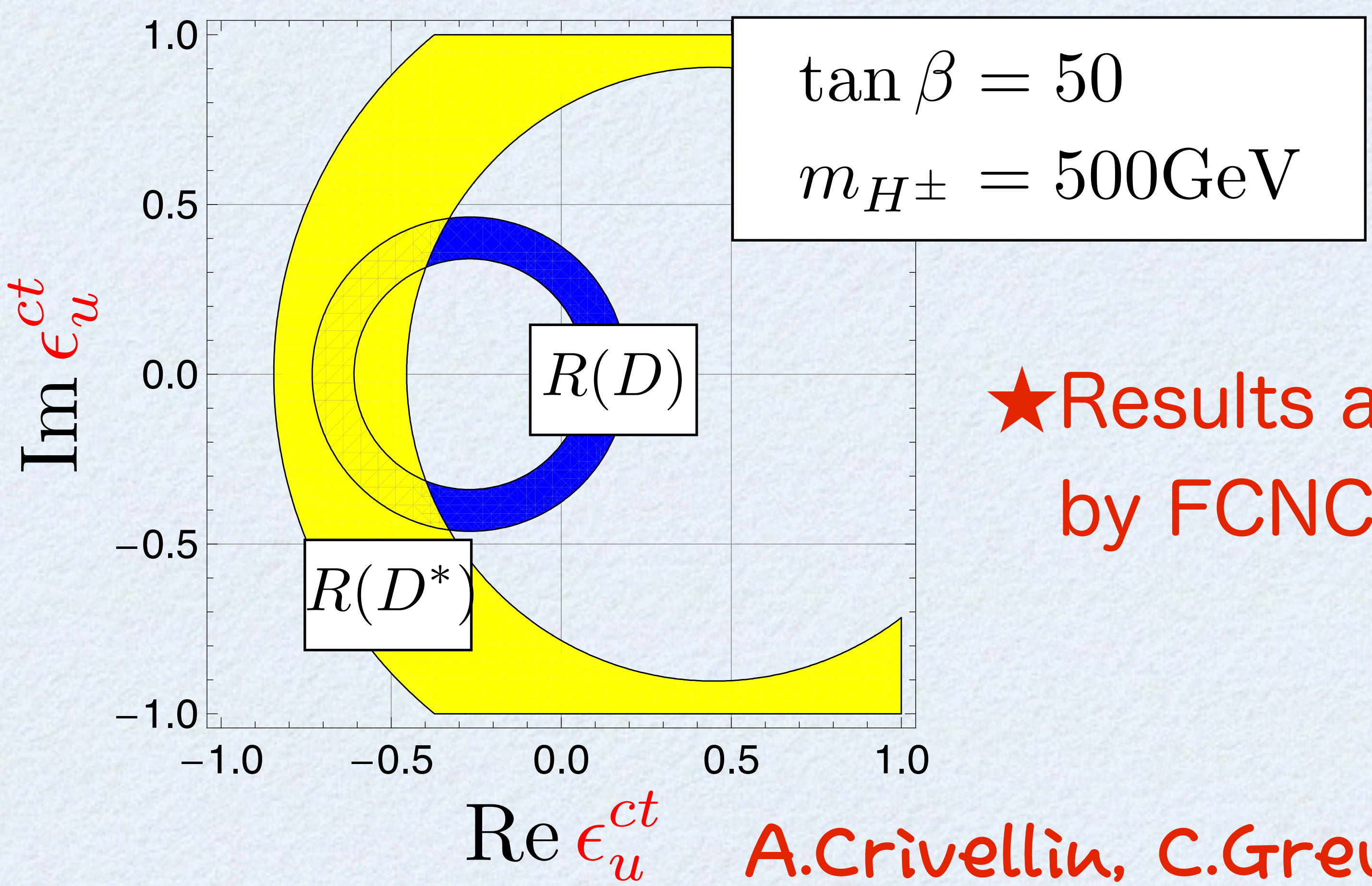

★Results are explained at the same time by FCNC parameter to be $\epsilon_u^{ct} \sim \mathcal{O}(1)$

A.Crivellin, C.Greub & A.Kokulu (2012)

Summary of this section

1 . 2HDMs without FCNC

★Not favored at all

2 . 2HDMs allowing FCNC

★Type II and X are possible to explain data at the cost of sizable FCNC in Yukawa term

Is there no constraint from the other observables ?

Not yet.

For more detail $\rightarrow$ 3 . Future prospects

3 . Future prospects：LHC&ILC

Of course, such models induce direct FCNC process

★FCNC induced by ϵ_d is highly limited from B physics, while constraints on ϵ_u are rather weak.

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Of course, such models induce direct FCNC process

★FCNC induced by ϵ_d is highly limited from B physics,

while constraints on ϵ_u are rather weak.

★In particular, ϵ_u^{ct} is only constrained from $t \to c\,(h, H, A)$.

For example, decay rate of t → c h turns out to be

$$\frac{\Gamma(t \to ch)}{\Gamma(t \to bW)} \simeq 0.12 \frac{|\epsilon_u^{tc}|^2 \cos^2(\alpha - \beta)}{\sin^2 \beta}$$

3 . Future prospects：LHC&ILC

FCNC process @ LHC

★It might be challenging for LHC (I don't know detail)

$3\,\sigma$ discovery limits for top FCN interactions at LHC, for an integrated luminosity of 100 fb^{-1}. The limits are expressed in terms of top decay branching ratios.

	Top decay	Single top
$t \to uZ(\gamma_\mu)$	3.6×10^{-5}	8.0×10^{-5}
$t \to uZ(\sigma_{\mu\nu})$	3.6×10^{-5}	2.3×10^{-5}
$t \to u\gamma$	1.2×10^{-5}	3.1×10^{-6}
$t \to ug$	–	2.5×10^{-6}
$t \to uH$	5.8×10^{-5}	5.1×10^{-4}

	Top decay	Single top
$t \to cZ(\gamma_\mu)$	3.6×10^{-5}	3.9×10^{-4}
$t \to cZ(\sigma_{\mu\nu})$	3.6×10^{-5}	1.4×10^{-4}
$t \to c\gamma$	1.2×10^{-5}	2.8×10^{-5}
$t \to cg$	–	1.6×10^{-5}
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Acta Physica Polonica B (2004)

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Acta Physica Polonica B (2004)

FCNC process @ ILC

★If the excesses in R(D)&R(D*) will remain in future,
Please try to measure THIS

3 . Future prospects：super B factory

Tauonic B decays are good target for super B factory

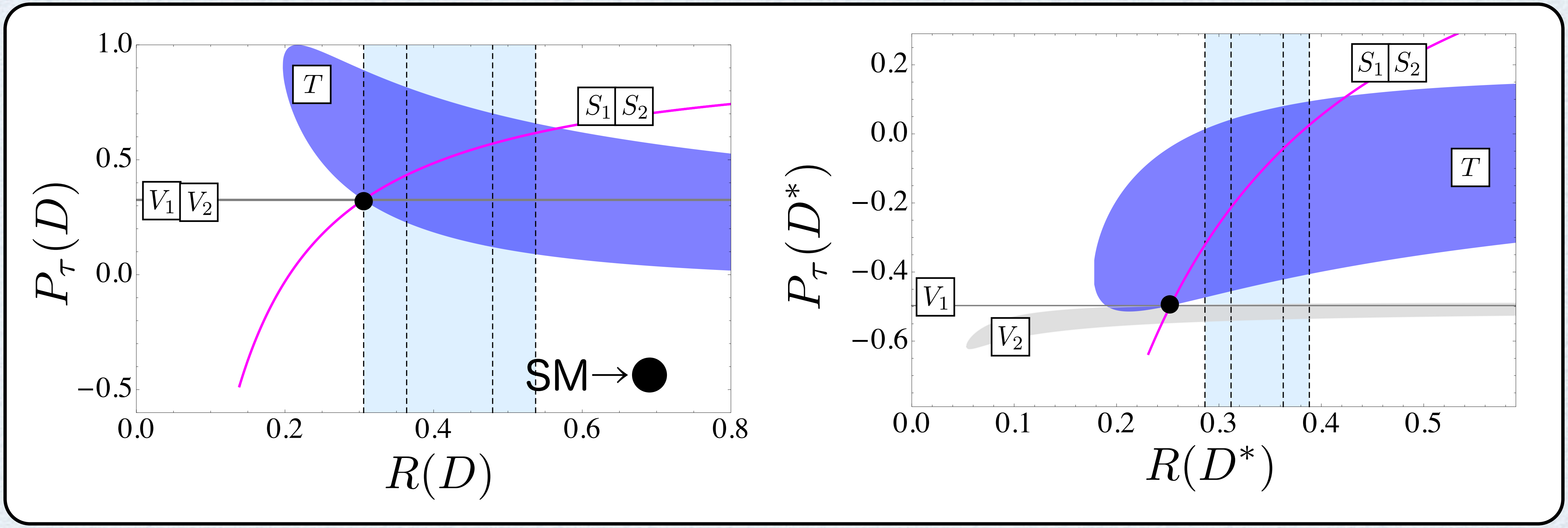
★Super B factory will reduce statistical error in R(D)&R(D*)

3 . Future prospects : super B factory

Tauonic B decays are good target for super B factory

★Super B factory will reduce statistical error in R(D)&R(D*)

★Furthermore, large number of signal events allow us to measure tau polarization, which is useful to confirm the NP interaction to be SCALAR or NOT



M.Tanaka and RW (2012)

Contents

- Tauonic B decays ✓
- Status of tauonic B decays ✓
- Analysis ✓

    1. 2HDMs
    2. 2HDMs allowing FCNC
    3. Future prospect : super B factory, ILC, (and LHC?)

★ Short summary

Decay processes we see

Tauonic B decay : $\bar{B} \to D^{(*)}\tau\bar{\nu}$ $\bar{B} \to \tau\bar{\nu}$

Problem we focus on in this talk

BABAR result implies "charged Higgs is disfavored"

What we have shown

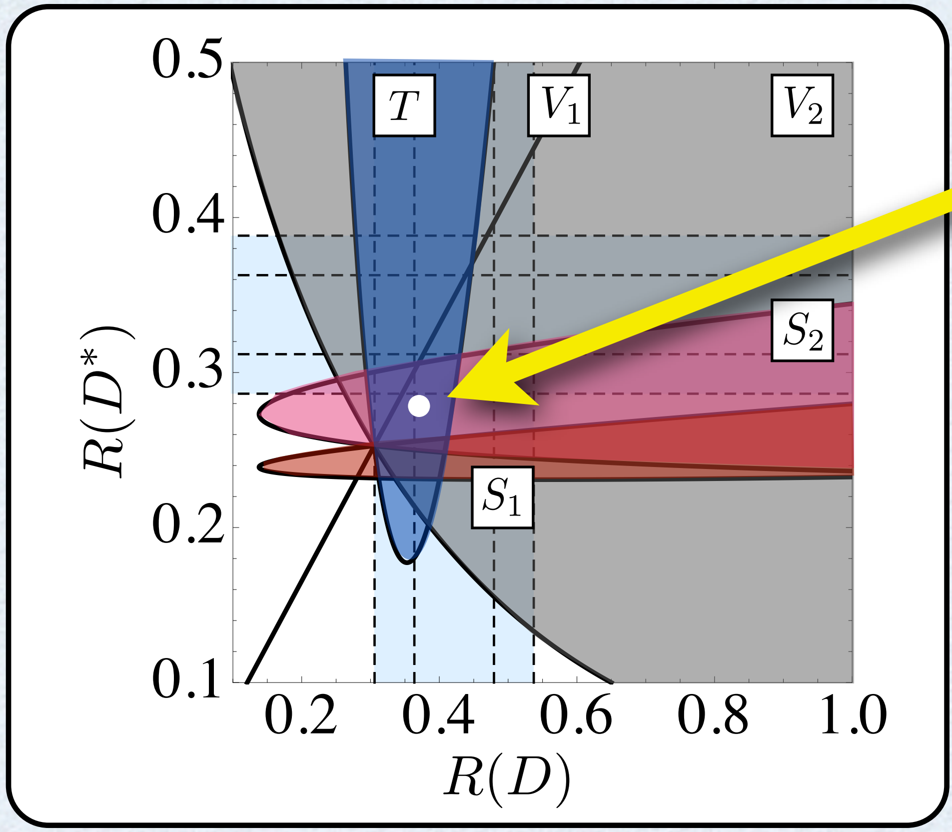
Usual 2HDMs cannot explain the BABAR result

2HDM allowing FCNC (type II & X) solves this problem

Super B factory, LHC and ILC are possible to confirm this scenario

Back up

Prediction on polarization (Appendix)



【Ex】 R(D)&R(D*) are measured here

We can predict polarization from the measured values of R(D)&R(D*)

$(R(D), R(D^*))$	$(0.37, 0.28)$		
X	S_2	V_2	T
C_X^c	$-0.81 \pm i\,0.87$	$0.03 \pm i\,0.40$	$0.16 \pm i\,0.14$
$P_\tau(D)$	0.44	0.33	0.22
$P_\tau(D^*)$	-0.35	-0.50	-0.26
P_{D^*}	0.51	0.45	0.32

Detailed representation (Appendix)

$$\mathcal{L}_{H^\pm} = \left(\bar{u}_R Z_u^\dagger V_{\rm CKM} d_L + \bar{u}_L V_{\rm CKM} Z_d d_R\right) H^+ + {\rm h.c.}$$

	Z_u	Z_d
Type I & X	$\frac{\sqrt{2}M_u}{v}\cot\beta - \epsilon_u \sin\beta(1+\cot^2\beta)$	$-\frac{\sqrt{2}M_d}{v}\cot\beta + \epsilon_d \sin\beta(1+\cot^2\beta)$
Type II & Y	$\frac{\sqrt{2}M_u}{v}\cot\beta - \epsilon_u \cos\beta(\tan\beta+\cot\beta)$	$\frac{\sqrt{2}M_d}{v}\tan\beta - \epsilon_d \sin\beta(\tan\beta+\cot\beta)$

Is it consistent with B$\to\tau\ \nu$? (Appendix)

Component of FCNC matrix is different

$$C^{u}_{S_2} \simeq \frac{V_{tb}}{\sqrt{2}V_{ub}}\frac{vm_\tau}{m^2_{H^\pm}}(\epsilon^*_u)^{ut}\sin\beta\tan\beta$$

$$C^{c}_{S_2} \simeq \frac{V_{tb}}{\sqrt{2}V_{cb}}\frac{vm_\tau}{m^2_{H^\pm}}(\epsilon^*_u)^{ct}\sin\beta\tan\beta$$

Effective Lagrangian : b→q τ ν

$$\mathcal{L}_{\rm eff}^{\rm SM} = C_{\rm SM}^{q} \bar{q}_L \gamma^\mu b_L \bar{\tau}_L \gamma_\mu \nu_L \qquad \left(C_{\rm SM}^{q} = -2\sqrt{2} G_F V_{qb} \right)$$

Input parameter :

$\bar{B} \to \tau\bar{\nu}$

Electroweak

$$V_{ub}$$

Strong

B meson decay constant :

$$f_B$$

$\bar{B} \to D^{(*)}\tau\bar{\nu}$

Electroweak

$$V_{cb}$$

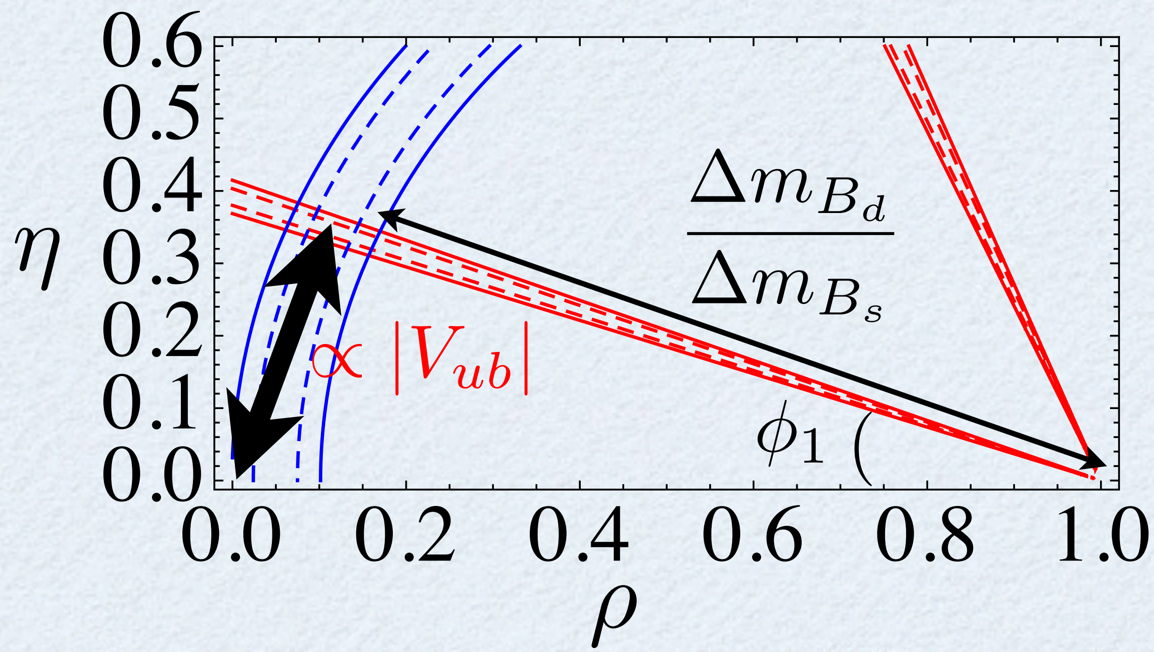
Strong

B→D(*) form factors :

$$\underset{(\bar{B} \to D)}{V_1,\ S_1,} \qquad \underset{(\bar{B} \to D^*)}{A_1,\ R_{1,2,3}}$$

Input values to use here $\bar{B} \to \tau\bar{\nu}$

EW $|V_{ub}|$ is determined by the fit to CKM unitarity triangle



$$|V_{ub}| = (3.38 \pm 0.15) \times 10^{-3}$$

Strong f_B is obtained from Lattice study

$$\langle 0|\bar{u}\gamma^\mu\gamma^5 b|\bar{B}\rangle = f_B p^\mu$$

(HPQCD2012) $f_B = (191 \pm 9)\mathrm{MeV}$

Summary $$\mathcal{B}(\bar{B} \to \tau\bar{\nu}) = \frac{\tau_B}{8\pi} G_F^2 |V_{ub}|^2 f_B^2 m_B m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2$$

Input values to use here $\bar{B} \to D^{(*)}\tau\bar{\nu}$

$\boxed{\bar{B} \to D\ell\bar{\nu}}$

$$\frac{d\Gamma}{dw}(\bar{B} \to D\ell\bar{\nu}) = \frac{G_F m_B^5}{48\pi^3} r^3 (1+r)^2 (w^2-1)^{3/2} V_1(w)^2 |V_{cb}|^2$$

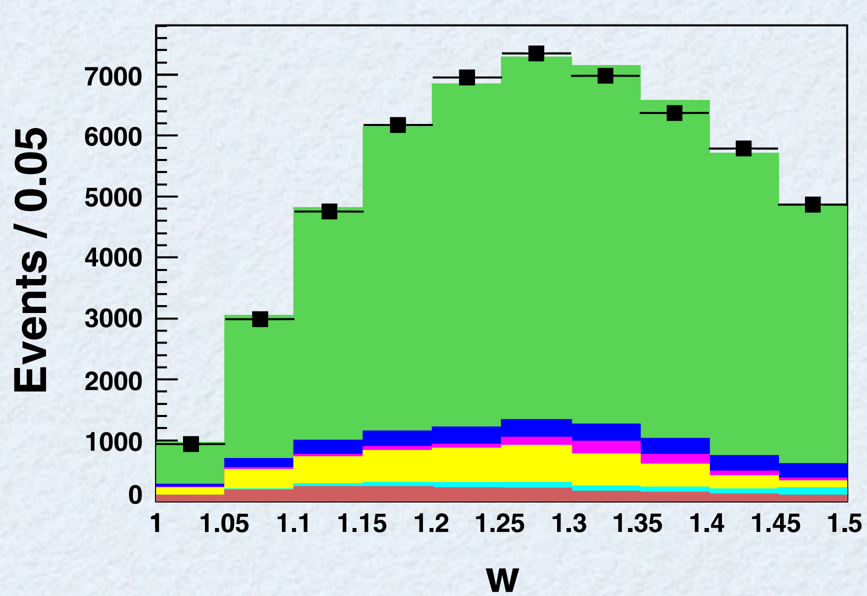
- Shape is parametrized as "slope parameter"

Caprini et.al.(1996)

Shape : $V_1(w) = V_1(1)\left[1 - 8\rho_1^2 z + (51\rho_1^2 - 10)z^2 - (252\rho_1^2 - 84)z^3\right]$

Hight : $V_1(1)|V_{cb}|$

$$\left(z = \frac{\sqrt{w+1}-\sqrt{2}}{\sqrt{w+1}+\sqrt{2}}\right)$$



$$V_1(1)|V_{cb}| = (4.26 \pm 0.07 \pm 0.14) \times 10^{-2}$$

$$\rho_1^2 = 1.186 \pm 0.055$$

2. 評価・予言・計算のための予備知識

Input values to use here $\bar{B} \to D^{(*)}\tau\bar{\nu}$

HQET

$\bar{B} \to D\tau\bar{\nu}$ contains new form factor $S_1(w)$

$S_1(w)$ is estimated by using HQET

$$\frac{S_1(w)}{V_1(w)} \simeq 0.981 + 0.041(w-1) - 0.015(w-1)^2$$

Summary

Input : $V_1(1)|V_{cb}|$ and ρ_1^2 . Taking the ratio, $V_1(1)|V_{cb}|$ is canceled

$$R(D) = \frac{\Gamma(\bar{B} \to D\tau\bar{\nu})}{\Gamma(\bar{B} \to D\ell\bar{\nu})} \qquad R(D^*) = \frac{\Gamma(\bar{B} \to D^*\tau\bar{\nu})}{\Gamma(\bar{B} \to D^*\ell\bar{\nu})}$$

$R(D)$
Meas.
0.440
-1 σ
SM
0.305
30%
17%
$R(D^*)$
Meas.
0.352
-1 σ
SM
0.252
24%
17%

(Appendix)

- $471 \times 10^6 B\bar{B}$ pairs

$$\downarrow$$

- After "full reconstruction" and "Tau tagging" :

Decay	N_{sig}	N_{norm}	$\varepsilon_{\text{sig}}/\varepsilon_{\text{norm}}$	$\mathcal{R}(D^{(*)})$	$\mathcal{B}(B \to D^{(*)}\tau\nu)$ (%)	Σ_{stat}	Σ_{tot}
$B^- \to D^0\tau^-\overline{\nu}_\tau$	314 ± 60	1995 ± 55	0.367 ± 0.011	$0.429 \pm 0.082 \pm 0.052$	$0.99 \pm 0.19 \pm 0.13$	5.5	4.7
$B^- \to D^{*0}\tau^-\overline{\nu}_\tau$	639 ± 62	8766 ± 104	0.227 ± 0.004	$0.322 \pm 0.032 \pm 0.022$	$1.71 \pm 0.17 \pm 0.13$	11.3	9.4
$\overline{B}^0 \to D^+\tau^-\overline{\nu}_\tau$	177 ± 31	986 ± 35	0.384 ± 0.014	$0.469 \pm 0.084 \pm 0.053$	$1.01 \pm 0.18 \pm 0.12$	6.1	5.2
$\overline{B}^0 \to D^{*+}\tau^-\overline{\nu}_\tau$	245 ± 27	3186 ± 61	0.217 ± 0.005	$0.355 \pm 0.039 \pm 0.021$	$1.74 \pm 0.19 \pm 0.12$	11.6	10.4
$\overline{B} \to D\tau^-\overline{\nu}_\tau$	489 ± 63	2981 ± 65	0.372 ± 0.010	$0.440 \pm 0.058 \pm 0.042$	$1.02 \pm 0.13 \pm 0.11$	8.4	6.8
$\overline{B} \to D^*\tau^-\overline{\nu}_\tau$	888 ± 63	11953 ± 122	0.224 ± 0.004	$0.332 \pm 0.024 \pm 0.018$	$1.76 \pm 0.13 \pm 0.12$	16.4	13.2

BaBar, arXiv:1205.5442

	SM prediction	Exp. result
$\bar{B} \to D\tau\bar{\nu}$	0.302 ± 0.015	0.43 ± 0.06
$\bar{B} \to D^*\tau\bar{\nu}$	0.254 ± 0.005	0.33 ± 0.04

MSSM：コメントだけ

基本的に、
・Treeだと「type II」
・Loopを考慮すると「type II ＋ FCNC」

つまり、$\boxed{C^c_{S_2} \simeq \frac{V_{tb}}{\sqrt{2}V_{cb}} \frac{v m_\tau}{m^2_{H^\pm}} (\epsilon^*_u)^{ct} \sin\beta \tan\beta}$ が有力候補になる

ϵ^{tc}_u はSUSY粒子のループから出てきて、だいたい

$$\epsilon^{tc}_u \sim \frac{\alpha_s}{4\pi} \times f(\mathrm{MSSM\ parameter})$$

コメント：

・cMSSMなどの“自然な”シナリオではϵ^{tc}_uを大きくできない
・何でもアリにすると何でもアリ？

MSSM

$$C_{S_1} = -\frac{m_b m_\tau}{m_{H^\pm}^2} \cdot \frac{\tan^2\beta}{(1+\Delta_e \tan\beta)(1+\Delta_d \tan\beta)}$$

$$C_{S_2} = -\frac{m_c m_\tau}{m_{H^\pm}^2} \cdot \frac{1}{1+\Delta_e \tan\beta}$$

Itoh, Komine, Okada (2010)

$$\Delta_e = \frac{m_Z^2 - m_W^2}{4v^2\pi^2}\,\mu M_{\tilde{B}}\, f(M_{\tilde{B}}, M_{\tilde{L}_L}, M_{\tilde{L}_R})$$

$$\Delta_d = \frac{2\alpha_s}{3\pi}\,\mu^* M_{\tilde{g}}\, f(M_{\tilde{g}}, M_{\tilde{D}_L}, M_{\tilde{D}_R})$$

$$f(a,b,c) = \frac{a^2 b^2 \ln\frac{a^2}{b^2} + b^2 c^2 \ln\frac{b^2}{c^2} + c^2 a^2 \ln\frac{c^2}{a^2}}{(a^2-b^2)(b^2-c^2)(c^2-a^2)}$$

Vector operators

$\mathcal{O}_{V_1} = \bar{c}_L \gamma^\mu b_L \, \bar{\tau}_L \gamma_\mu \nu_L$ $\qquad$ $\mathcal{O}_{V_2} = \bar{c}_R \gamma^\mu b_R \, \bar{\tau}_L \gamma_\mu \nu_L$

$\boxed{\bar{B} \to D\tau\bar{\nu}}$

$$\langle D|\bar{c}\gamma^\mu\gamma^5 b|\bar{B}\rangle = 0 \quad \longrightarrow \quad \boxed{\langle D\tau\bar{\nu}|\mathcal{O}_{V_1}|\bar{B}\rangle = \langle D\tau\bar{\nu}|\mathcal{O}_{V_2}|\bar{B}\rangle}$$

$\boxed{\bar{B} \to D^*\tau\bar{\nu}}$

$$\langle D^*|\bar{c}\gamma^\mu\gamma^5 b|\bar{B}\rangle \gg \langle D^*|\bar{c}\gamma^\mu b|\bar{B}\rangle$$

$$\longrightarrow \quad \boxed{\langle D^*\tau\bar{\nu}|\mathcal{O}_{V_1}|\bar{B}\rangle \sim -\langle D^*\tau\bar{\nu}|\mathcal{O}_{V_2}|\bar{B}\rangle}$$

Scalar operators $\qquad \mathcal{O}_{S_1} = \bar{c}_L b_R \, \bar{\tau}_R \nu_L \qquad \mathcal{O}_{S_2} = \bar{c}_R b_L \, \bar{\tau}_R \nu_L$

$\boxed{\bar{B} \to D\tau\bar{\nu}}$

$$\langle D|\bar{c}\gamma^5 b|\bar{B}\rangle = 0 \quad \longrightarrow \quad \boxed{\langle D\tau\bar{\nu}|\mathcal{O}_{S_1}|\bar{B}\rangle = \langle D\tau\bar{\nu}|\mathcal{O}_{S_2}|\bar{B}\rangle}$$

$\boxed{\bar{B} \to D^*\tau\bar{\nu}}$

$$\langle D^*|\bar{c}b|\bar{B}\rangle = 0 \quad \longrightarrow \quad \boxed{\langle D^*\tau\bar{\nu}|\mathcal{O}_{S_1}|\bar{B}\rangle = -\langle D^*\tau\bar{\nu}|\mathcal{O}_{S_2}|\bar{B}\rangle}$$

Tau polarization is useful but,

- How is it measured ?
- Capability of new physics search ?

Identification of tau

τ in $\bar{B} \to D\tau\bar{\nu}_\tau$ is identified by $\tau \to \pi\nu$ or $\tau \to l\nu\bar{\nu}$

$$\longrightarrow \quad \tau \to \pi\nu \ : \ N \sim 70$$

$$\tau \to l\nu\bar{\nu} \ : \ N \sim 100$$

@B factory

BABAR(2008), Belle (2009)

How to measure tau polarization

$$\frac{d\Gamma}{dq^2 dz}(\bar{B} \to D\tau\bar{\nu} \to \cdots) = \frac{d\Gamma}{dq^2}(\bar{B} \to D\tau\bar{\nu}) \times \underline{F(\cdots)}$$

$$\boxed{\begin{array}{c} \tau \to \pi\nu \\ \tau \to l\nu\bar{\nu} \end{array}}$$

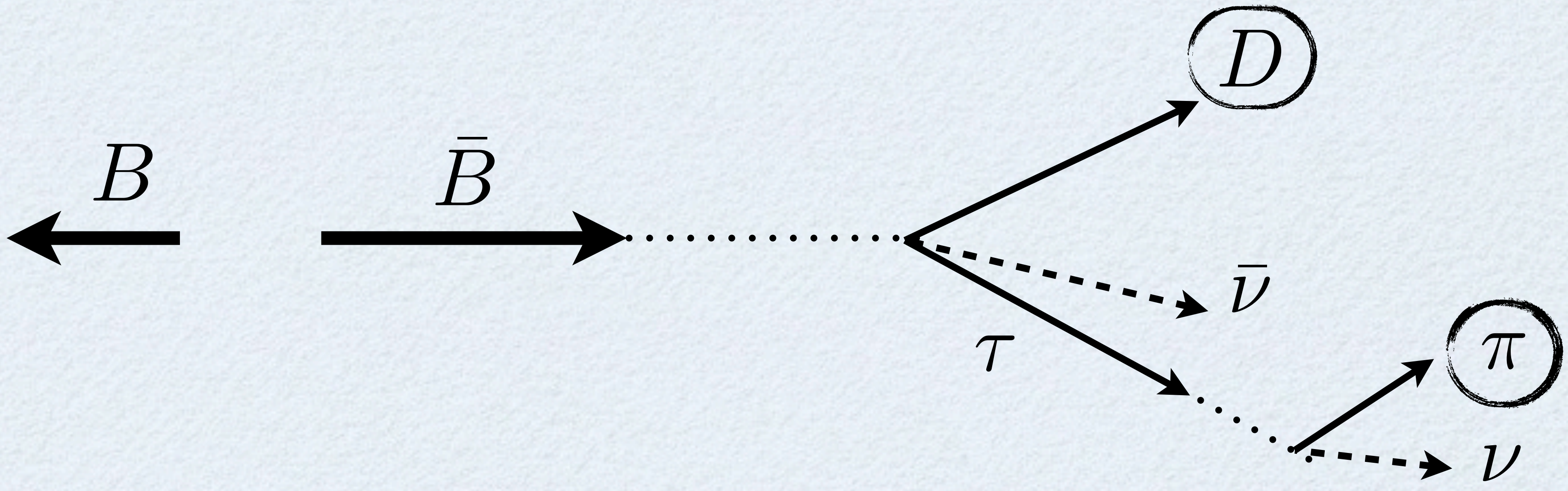
$$q^2 = (p_B - p_D)^2$$

$$z = \frac{E_{\pi(l)}}{E_\tau}$$

We know it in rest frame of q^2

$$\underline{F(\cdots)} = Br(\cdots)\Big[f(z, q^2) + P_\tau(q^2) g(z, q^2)\Big]$$

$$\boxed{\int f(z, q^2) dz = 1, \quad \int g(z, q^2) dz = 0}$$



- In rest frame of q^μ
- $p^\mu_{\bar{B}},\ p^\mu_D \ \rightarrow\ q^2,\ E_\tau$
- $E_\tau,\ E_{\pi(l)} \ \rightarrow\ z$

$\Downarrow$

Tau polarization can be determined by pion (or lepton) energy distribution of the decay rate of this chain.

Estimation of statistical error of tau polarization

$$\delta P_\tau = \frac{1}{S\sqrt{N}} \qquad P_\tau = P_{\tau 0} \pm \delta P_\tau$$

N : # of event for $\bar{B} \to D\tau\bar{\nu} \to \cdots$

$N_{(\pi)} \sim 70, \quad N_{(l)} \sim 100$ ← B factory

$N_{(\pi)} \sim 2000, \quad N_{(l)} \sim 3000$ ← super B factory

S : "sensitivity"

$$S^2 = \int dz \frac{g^2}{f + P_\tau g}$$

$$\boxed{S_{(\pi)} \sim 0.6, \quad S_{(l)} \sim 0.2}$$

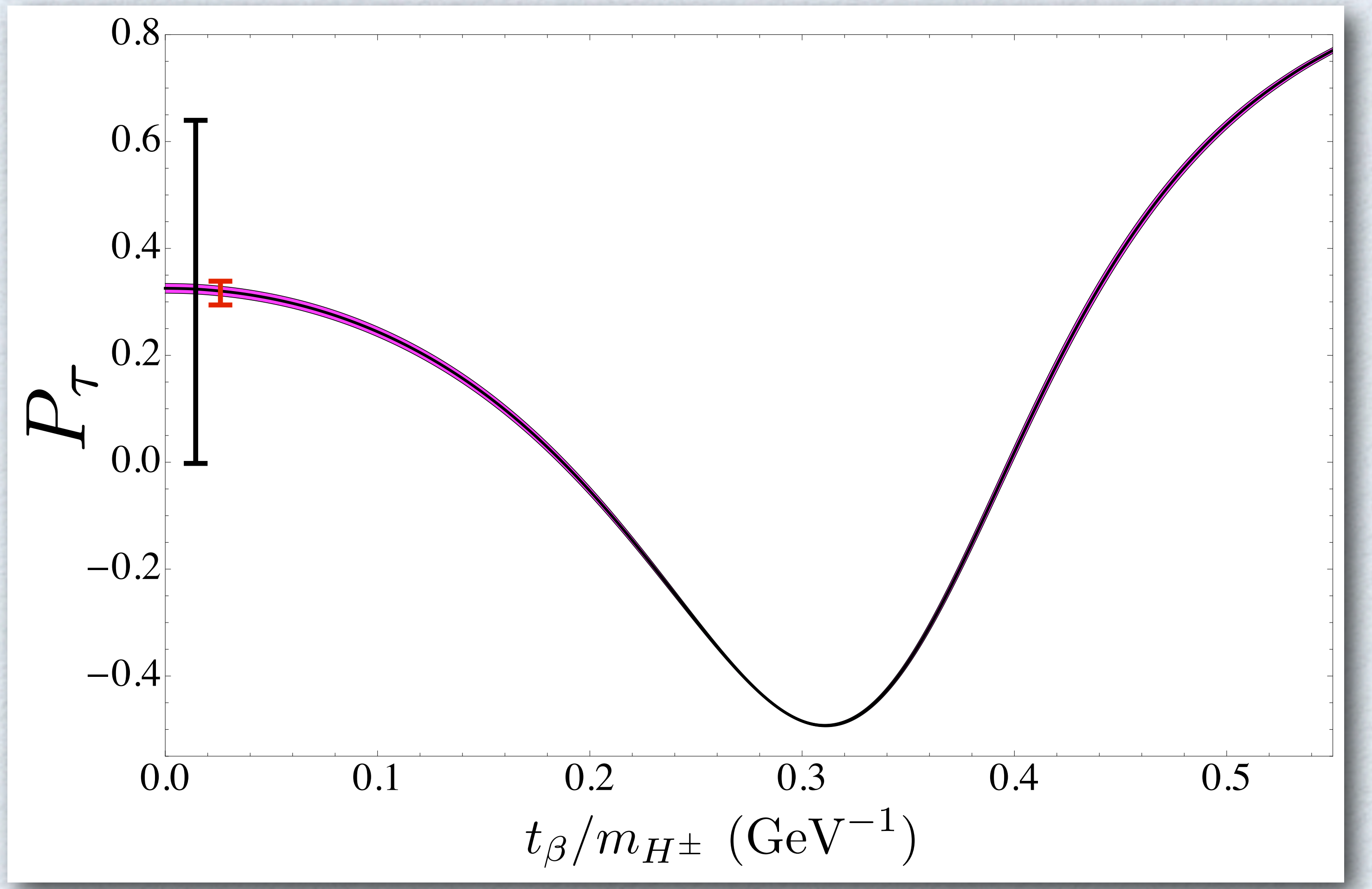
Estimation of statistical error of tau polarization

$$\delta P_\tau = \frac{1}{S\sqrt{N}} \qquad\qquad P_\tau = P_{\tau 0} \pm \delta P_\tau$$

Super B factory :

$\delta P_{\tau(\pi)} \sim 0.04,\ \delta P_{\tau(l)} \sim 0.08$

We may see $H^\pm$effect



: Error @ B factory

: Error @ super B factory

Form Factors (Tensor)

$\bar{B} \to D\tau\bar{\nu}$

$$\langle D(p_D)|\bar{c}\sigma^{\mu\nu}b|\bar{B}(p_B)\rangle = iT(q^2)(p_B^\mu p_D^\nu - p_B^\nu p_D^\mu)$$

$$\langle D(p_D)|\bar{c}\sigma^{\mu\nu}\gamma^5 b|\bar{B}(p_B)\rangle = T(q^2)\epsilon^{\mu\nu\alpha\beta}p_{D\alpha}p_{B\beta}$$

$\bar{B} \to D^*\tau\bar{\nu}$

$$\langle D^*(p_D)|\bar{c}\sigma^{\mu\nu}b|\bar{B}(p)\rangle = \epsilon^{\mu\nu\alpha\beta}[T_1\varepsilon^*_\alpha p_{B\beta} + T_2\varepsilon^*_\alpha p_{D\beta} + T_3(\varepsilon^*\cdot p_B)p_{B\alpha}p_{D\beta}]$$

$$\langle D^*(p_D)|\bar{c}\sigma^{\mu\nu}\gamma^5 b|\bar{B}(p)\rangle = \cdots$$

EOM

$$i\partial_\mu\Big\{\bar{c}[\gamma^\mu,\gamma^\nu]b\Big\} = -2(m_b+m_c)\bar{c}\gamma^\nu b - 2(i\partial^\nu\bar{c})b + 2\bar{c}(i\partial^\nu b)$$

$$\Downarrow$$

$$T(q^2) = \frac{2\sqrt{r}}{q^2}\Big\{m_B^2\frac{1-r}{m_b-m_c}(w+1)S_1(q^2) - \frac{m_b+m_c}{1+r}2V_1(q^2)\Big\}$$