CTPU, IBS, Daejeon, Korea
2014/04/30

Status on B->D(*)τν

Ryoutaro Watanabe

Based on the following:
arXiv:1401.7947, A.Soffer
Phys. Rev. D 88(2013),094012, Tanaka, et. al.
Phys. Rev. D 87(2012),034028, Tanaka &Watanabe
Phys. Rev. D 82(2010),034027, Tanaka &Watanabe

ibs 기초과학연구원
Institute for Basic Science

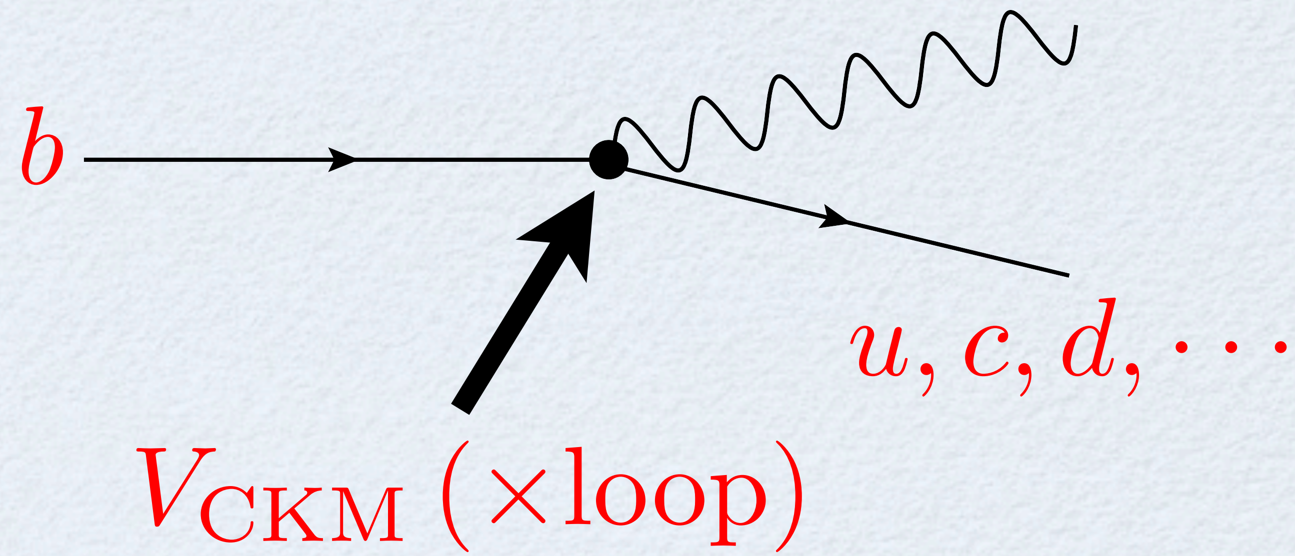
Prologue...

B meson decays are quite useful to investigate **the flavor structure** in the quark sector due to their various final states.

B^+ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Semileptonic and leptonic modes				
$\ell^+\nu_\ell$ anything	[a]	$(10.99 \pm 0.28)\%$		–
$e^+\nu_e X_c$		$(10.8 \pm 0.4)\%$		–
$D\ell^+\nu_\ell$ anything		$(9.8 \pm 0.7)\%$		–
$\overline{D}^0\ell^+\nu_\ell$	[a]	$(2.26 \pm 0.11)\%$		2310
$\overline{D}^0\tau^+\nu_\tau$		$(7.7 \pm 2.5) \times 10^{-3}$		1911
$\overline{D}^*(2007)^0\ell^+\nu_\ell$	[a]	$(5.70 \pm 0.19)\%$		2258
$\overline{D}^*(2007)^0\tau^+\nu_\tau$		$(2.04 \pm 0.30)\%$		1839
$D^-\pi^+\ell^+\nu_\ell$		$(4.2 \pm 0.5) \times 10^{-3}$		2306
$\overline{D}_0^*(2420)^0\ell^+\nu_\ell \times \mathrm{B}(\overline{D}_0^{*0} \to D^-\pi^+)$		$(2.5 \pm 0.5) \times 10^{-3}$		–
$\overline{D}_2^*(2460)^0\ell^+\nu_\ell \times \mathrm{B}(\overline{D}_2^{*0} \to D^-\pi^+)$		$(1.53 \pm 0.16) \times 10^{-3}$		2065
$D^{(*)}n\pi\ell^+\nu_\ell (n \geq 1)$		$(1.87 \pm 0.26)\%$		–
$D^{*-}\pi^+\ell^+\nu_\ell$		$(6.1 \pm 0.6) \times 10^{-3}$		2254
$D_s^{*-}K^+\ell^+\nu_\ell$		$(6.1 \pm 1.2) \times 10^{-4}$		2185
$\overline{D}_1(2420)^0\ell^+\nu_\ell \times \mathrm{B}(\overline{D}_1^0 \to D^{*-}\pi^+)$		$(3.03 \pm 0.20) \times 10^{-3}$		2084
$\overline{D}'_1(2430)^0\ell^+\nu_\ell \times \mathrm{B}(\overline{D}'^0_1 \to D^{*-}\pi^+)$		$(2.7 \pm 0.6) \times 10^{-3}$		–
$\overline{D}_2^*(2460)^0\ell^+\nu_\ell \times \mathrm{B}(\overline{D}_2^{*0} \to D^{*-}\pi^+)$		$(1.01 \pm 0.24) \times 10^{-3}$	S=2.0	2065
$\pi^0\ell^+\nu_\ell$		$(7.78 \pm 0.28) \times 10^{-5}$		2638
$\eta\ell^+\nu_\ell$		$(3.9 \pm 0.8) \times 10^{-5}$	S=1.3	2611

×30 final states

PDG (2013)



Belle & BABAR have measured a lot of processes, studied them, and then found the validity of large part of flavor structure in SM.

Prologue...

Among them, **B→D(*)τν** offer possibilities to study **NP effect**.

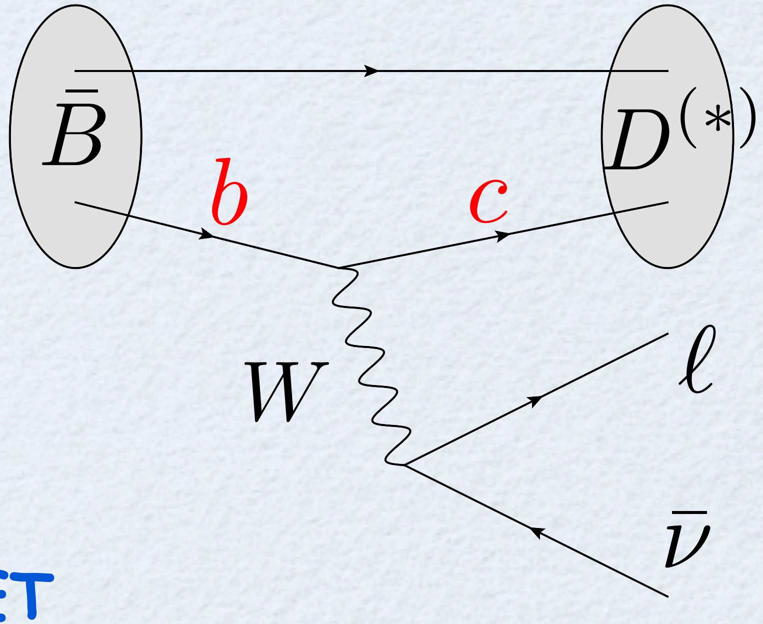
Before explaining the above, let me introduce characters:

$\bar{B} \to D\ell\bar{\nu}$ **and** $\bar{B} \to D^*\ell\bar{\nu}$ **for** $\ell = (e,\, \mu,\, \tau)$

#. B and D(*) mesons:

$$\bar{B} = B^-(\bar{u}b) \text{ or } \bar{B}^0(\bar{d}b) \qquad\qquad D^{(*)} = D^{(*)0}(\bar{u}c) \text{ or } D^{(*)+}(\bar{d}c)$$

#. D=pseudo-scalar, D*=vector



#. Tree level process via V_{cb} in the SM

#. Large Br=O(1)%

#. Well-controlled hadronic uncertainties from HQET

Prologue...

Among them, $B \to D^{(*)}\tau\nu$ offer possibilities to study **NP effect**.

Before explaining the above, let me introduce characters:

For $\ell = e$ & μ

#. Very large statistics and efficiencies

#. Used to determine $|V_{cb}|$

#. Energy distributions are good agreement with SM

For $\ell = \tau$

#. Large uncertainties and low efficiencies

→ This is due to a difficulty to identify the tau lepton

#. 3rd generation in quark & lepton sector

→ This (& $B \to \tau\nu$) is only measurable among such final states

Content

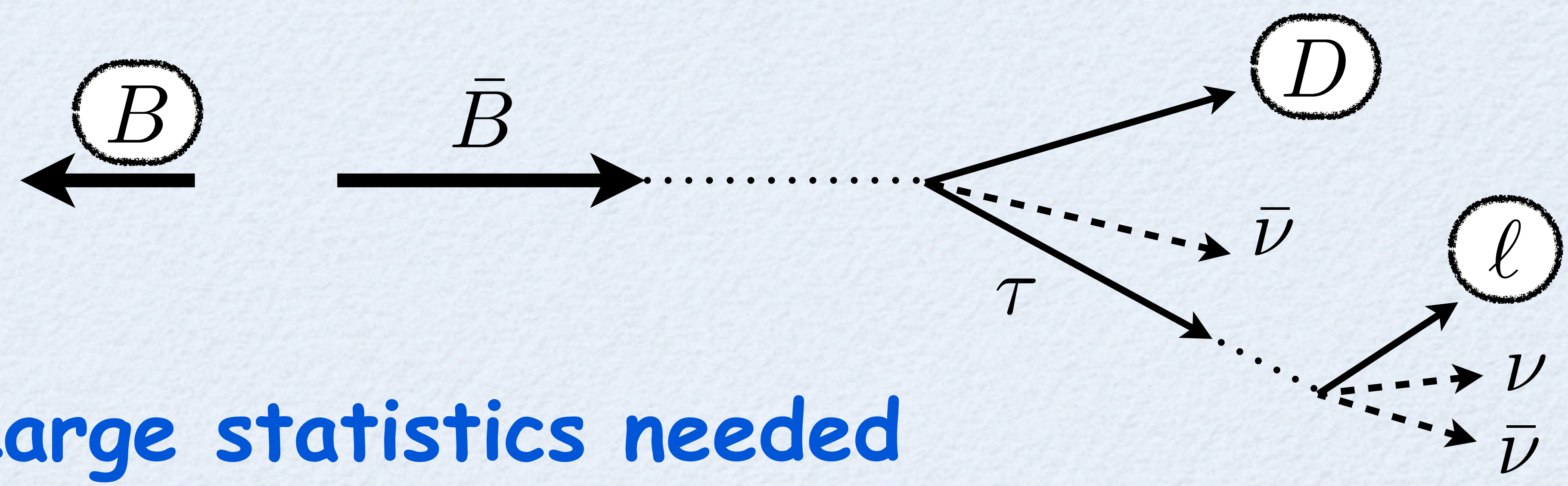
- **Prologue**
- **Experimental aspect**
  - Tau identification
  - Experimental results
- **Phenomenological status**
  - Effective operator analysis
  - New observables
- **Theoretical status (NP models)**
  - 2 Higgs doublet models
  - Leptoquark model
- **Summary**

Experimental aspect

Tau in the final state

- It is challenging to measure tauonic B meson decays, because more than 2ν appear in the detector.

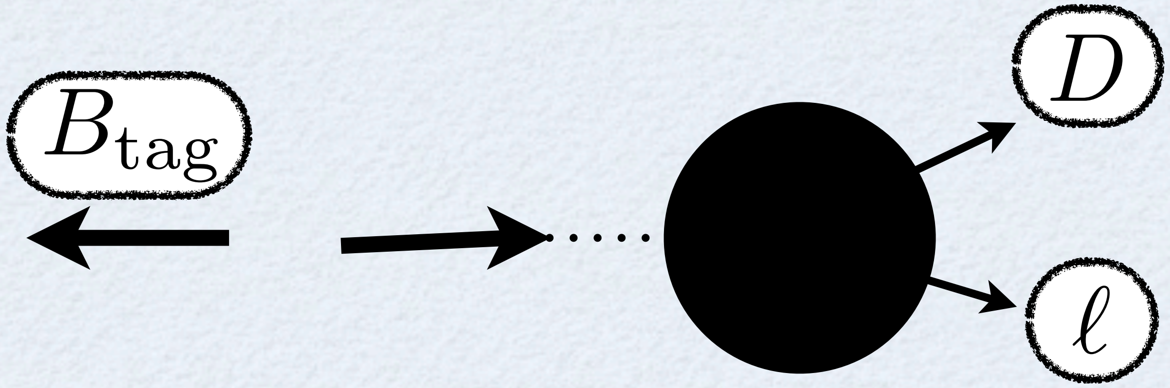
- At B factory, however, reconstructing the opposite B mesons we can compare the properties of the remaining particles to those expected for signal and background.



#. Large statistics needed

#. Expected signal required

Experimental analysis @BABAR

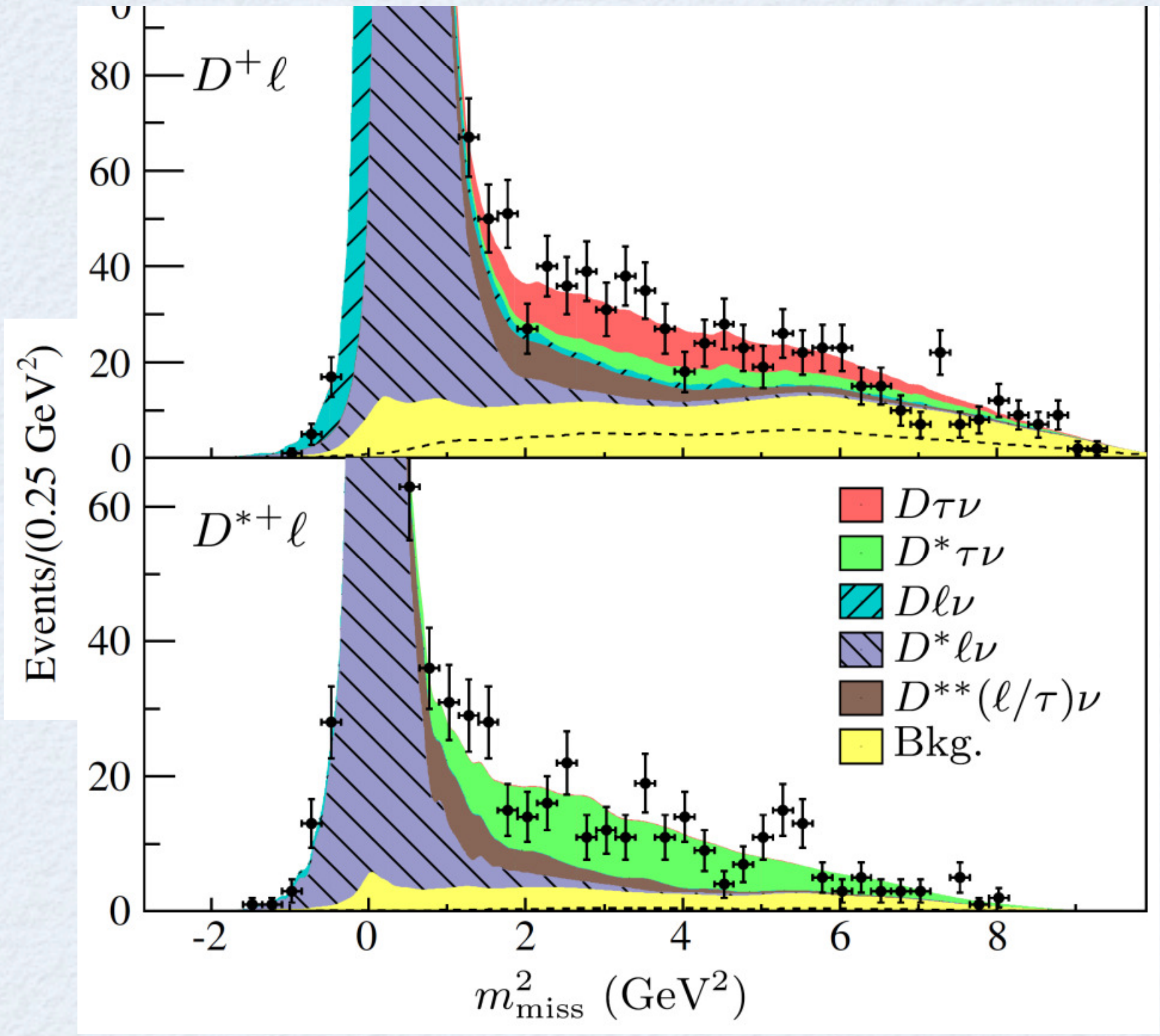


#. Decay channel BABAR analyzed:

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

#. inv. mass of missing particles:

$$m^2_{\text{miss}} = (p_{e^+e^-} - p_{\text{tag}} - p_{D^{(*)}} - p_\ell)^2$$



1. B_{tag}, $D^{(*)}$, ℓ are identified

2. m^2_{miss} distribution is measured

3. Comparing total event data with expected signal & background, signal event is extracted

BABAR, arXiv:1205.5442

Then we get the result!

$\to$ Next page

BABAR result

arXiv:1205.5442

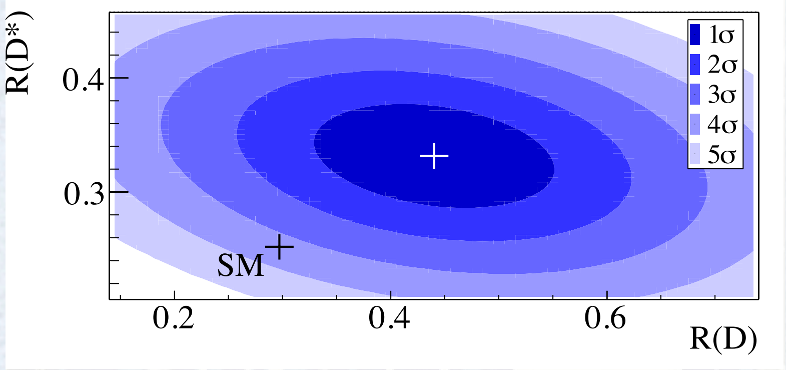
For an observable, normalized decay rate is used

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

#. ℓ is a light lepton (e or μ)

#. in order to reduce several uncertainties

	Exp. result	SM prediction
$R(D)$	$0.440 \pm 0.058 \pm 0.042$	0.297 ± 0.017
$R(D^*)$	$0.332 \pm 0.024 \pm 0.018$	0.252 ± 0.003

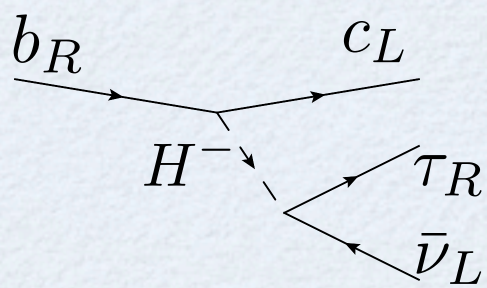


In total, 3.4σ deviation with SM!

BABAR result for 2HDM of type II

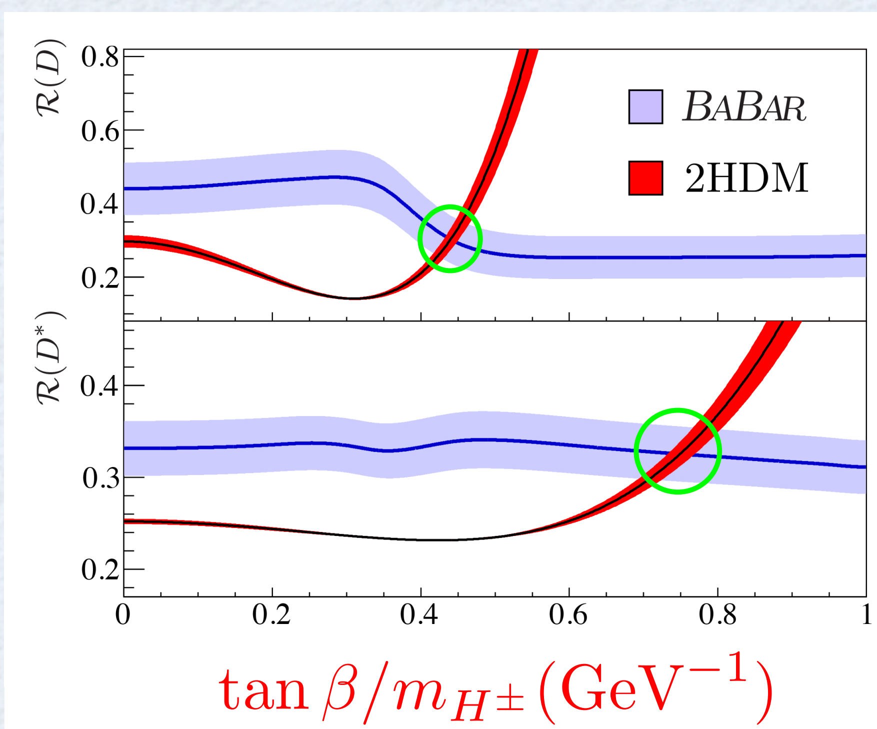
Moreover, **Type-II 2HDM is ruled out at 99.8% CL!**

#. Charged Higgs can contribute to the processes



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

#. However, it cannot explain the results at the same time



Note:
As explained, we must expect the signal event, to extract from the total event including the background event.
Thus, this result depends on the model parameters.

Belle...

- Belle result was reported, but it is not fully completed...
  We are now waiting for the upgrade.

Super KEKB

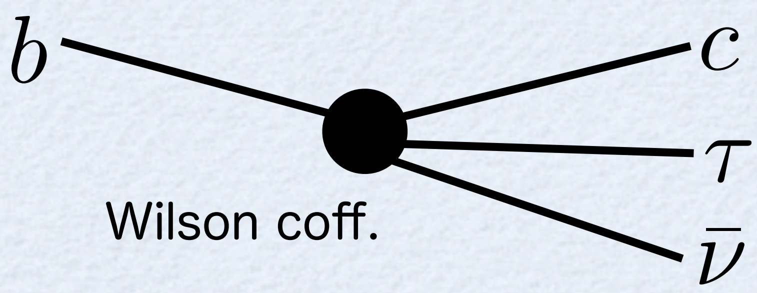
- Tauonic B meson decay is one of the golden modes
  in future super B factory, due to its large statistics.

- Large statistics enable us to measure not only total rate,
  but also some distributions & polarizations

$\rightarrow$ **will be explained later**

Phenomenological status

Model independent analysis M.Tanaka & RW (2012)



$$-\mathcal{L}_{\text{eff}} = 2\sqrt{2}G_F V_{cb}\Big[(1+C_{V_1})\mathcal{O}_{V_1} + C_{V_2}\mathcal{O}_{V_2} + C_{S_1}\mathcal{O}_{S_1} + C_{S_2}\mathcal{O}_{S_2} + C_T\mathcal{O}_T\Big]$$

Effective operators:

Vector1: $\mathcal{O}_{V_1} = \bar{c}_L\gamma^\mu b_L\,\bar{\tau}_L\gamma_\mu\nu_L$

Vector2: $\mathcal{O}_{V_2} = \bar{c}_R\gamma^\mu b_R\,\bar{\tau}_L\gamma_\mu\nu_L$

Tensor: $\mathcal{O}_T = \bar{c}_R\sigma^{\mu\nu} b_L\,\bar{\tau}_R\sigma_{\mu\nu}\nu_L$

Scalar1: $\mathcal{O}_{S_1} = \bar{c}_L b_R\,\bar{\tau}_R\nu_L$

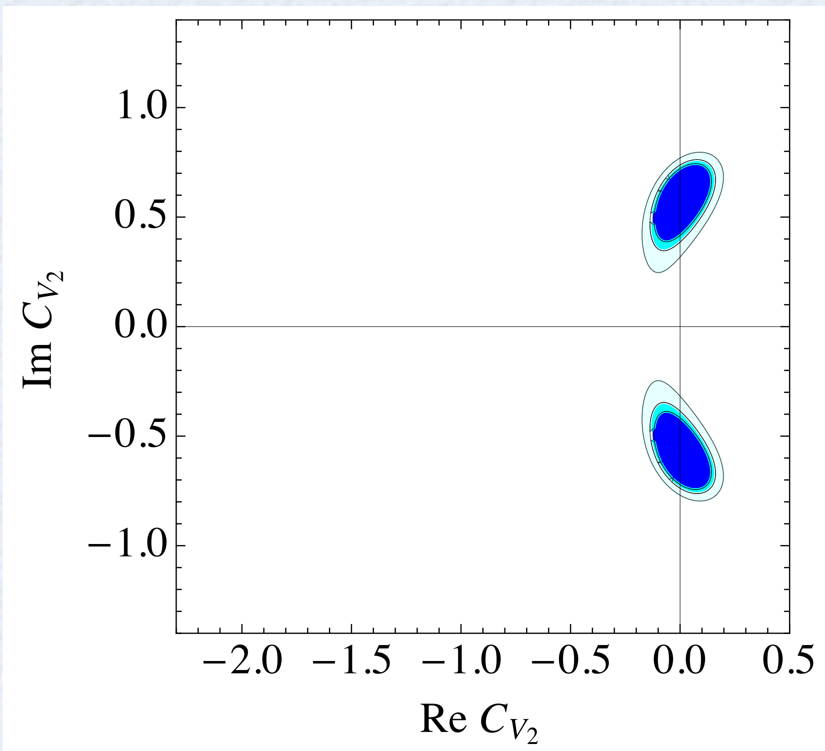
Scalar2: $\mathcal{O}_{S_2} = \bar{c}_R b_L\,\bar{\tau}_R\nu_L$

Wilson coefficients:

#. Cx represent "New Physics" contribution. In SM, all Cx=0.
#. No right-handed neutrino.
#. We assume one operator dominance. ex) $C_{S_2} \neq 0,$ others $= 0$

Bound on NP from R(D)&R(D*)

Allowed region of C_{V_2} with $C_{X\neq V_2}=0$:



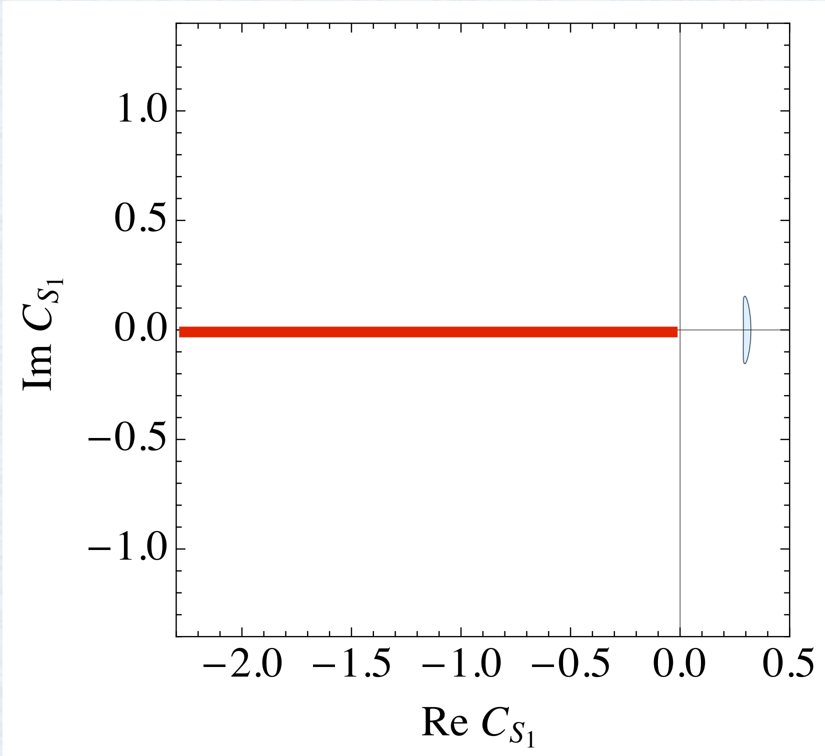
#. Colored region is allowed

90%(Light blue), 95%(Cyan), 99%(Dark blue)

#. Im is preferred

Best fit value: $C_{V_2}\sim 0.64\,i$

Allowed region of C_{S_1} with $C_{X\neq S_1}=0$:



#. Almost excluded

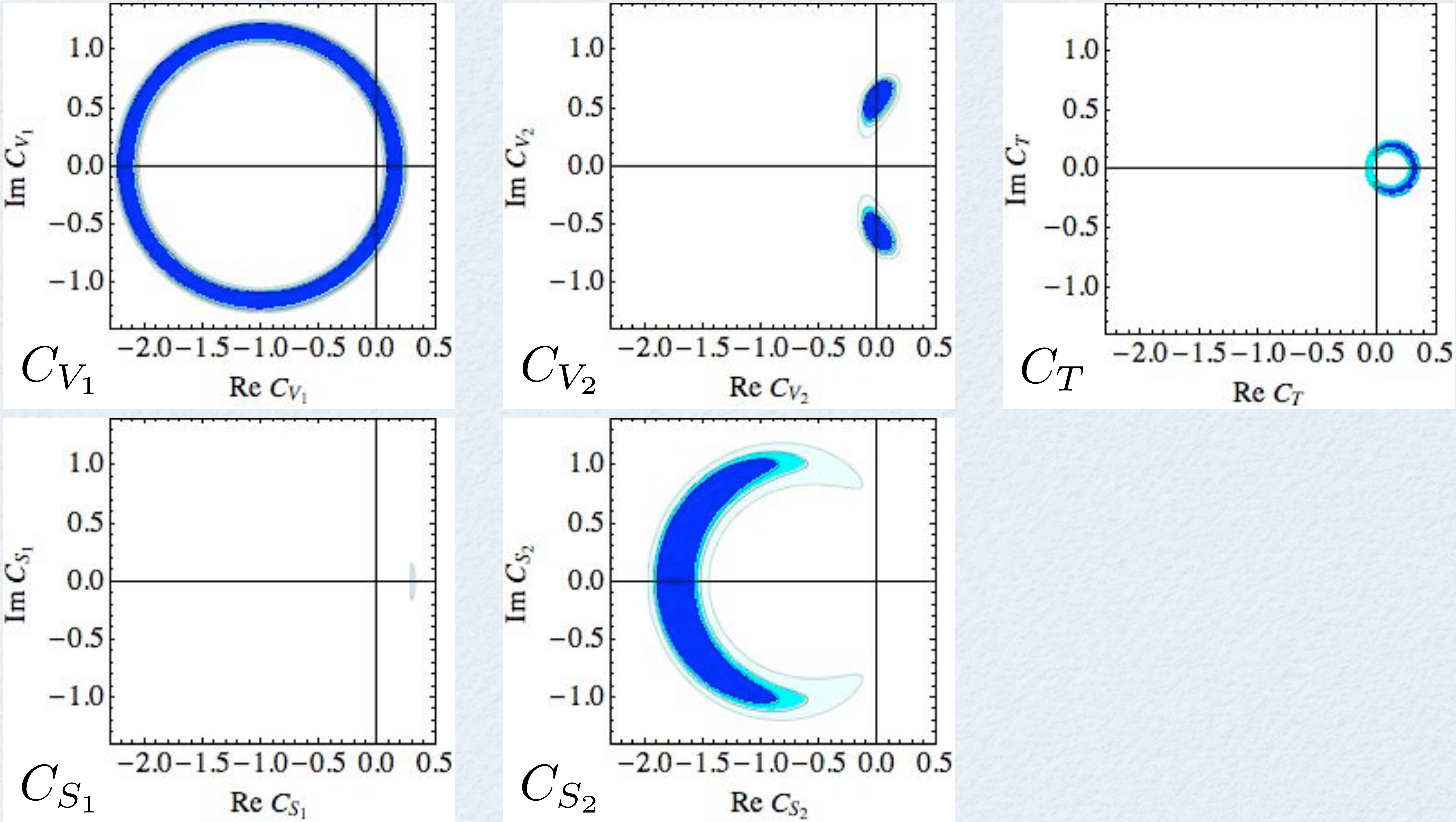
#. TypeII-2HDM (red line):

$$C_{S_1}=-\frac{m_b m_\tau}{m_{H^\pm}^2}\tan^2\beta$$

can never explain the result

Bound on NP from R(D)&R(D*)

The others:



#. V1, V2, T can explain within small Cx

#. S2 can explain but large C_{S_2}(~-1.6) is needed

#. S1 is not preferred

Tau polarization

- Tau has rich features compared with light leptons.
  Its helicity can vary depending on the type of the interaction.

#. Tau polarization on B→Dτν in SM: $P_\tau = \dfrac{\Gamma^+ - \Gamma^-}{\Gamma^+ + \Gamma^-} \simeq 0.325$

#. NP can influence the tau helicity in B→D(*)τν

#. Pτ is measurable without knowing τ momentum
& we estimated expected error δPτ~0.04 at super KEKB

M.Tanaka & RW (2010)

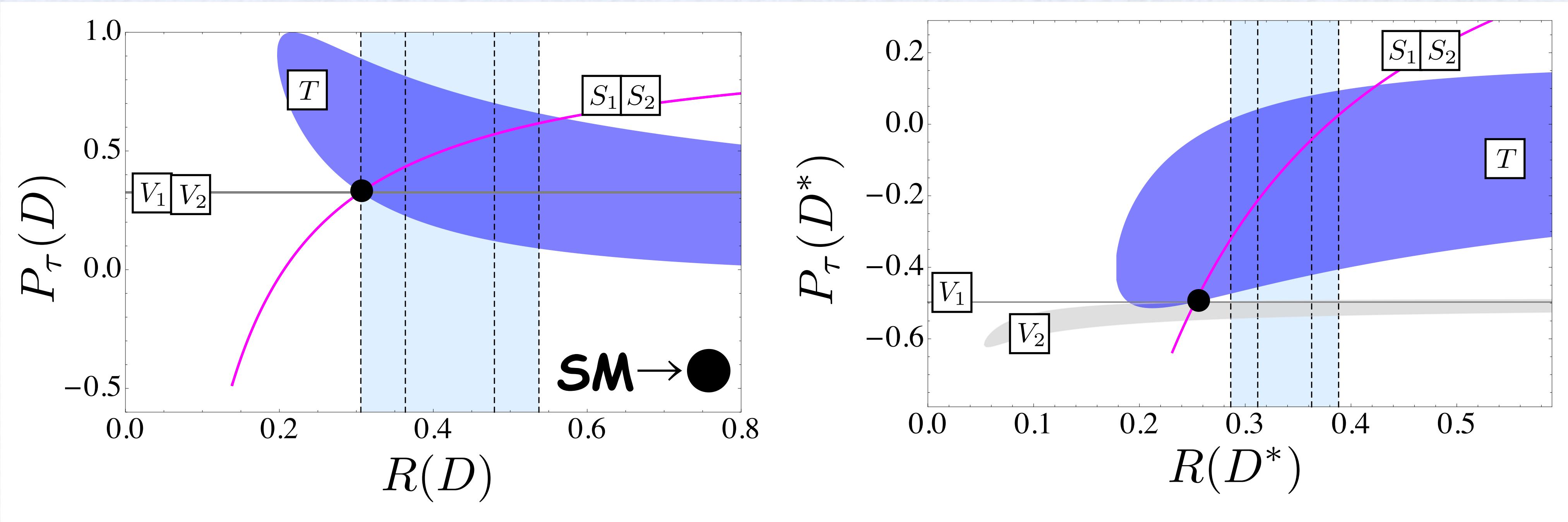
- We define them as

$$P_\tau(D) = \frac{\Gamma^+(D) - \Gamma^-(D)}{\Gamma^+(D) + \Gamma^-(D)} \qquad P_\tau(D^*) = \frac{\Gamma^+(D^*) - \Gamma^-(D^*)}{\Gamma^+(D^*) + \Gamma^-(D^*)}$$

$\Gamma^\pm(D)$ **is decay rate of B->Dτν with tau helicity to be** $\pm\frac{1}{2}$

Tau polarization

Correlation of R(D) & Pτ:



#. Pτ & R are correlated

#. Nontrivial strong correlation for $S_{1,2}$ due to spin conservation

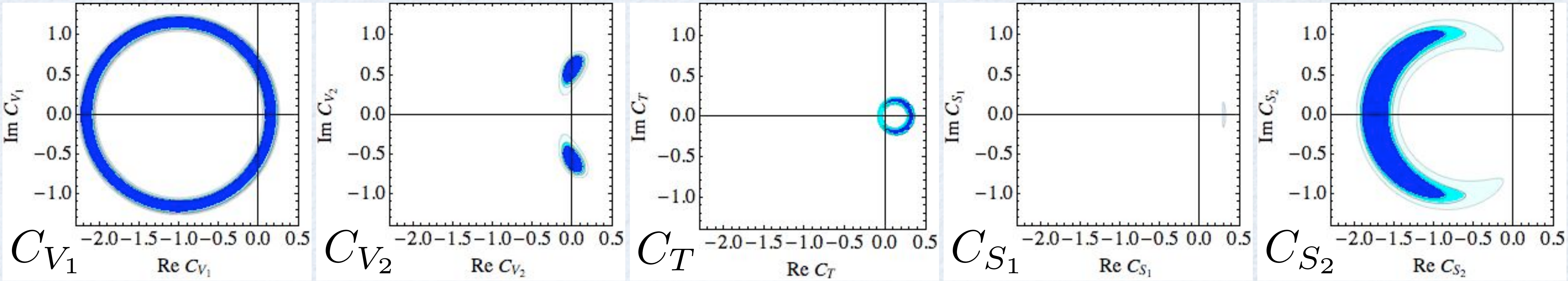
How to distinguish NP:

#. If R(D)&R(D*) are precisely measured, we can **predict Pτ** in each NP case

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

Phenomenology: summary

Constraint on Cx:

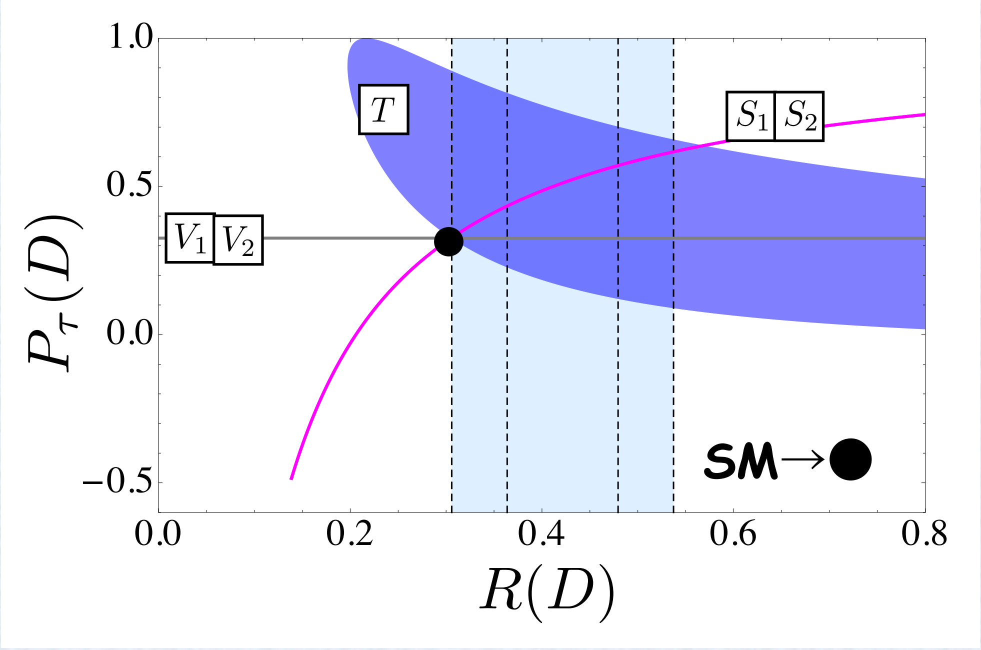


#. V1, V2, T can explain within small Cx

#. S2 can explain but large Cx is needed

#. S1 is not favored

Correlation of observables:



#. Measuring a lot of observables,
and investigating their correlations,
we can identify & distinguish NP couplings

Theoretical status: NP models

To consider NP model

- When we consider NP model, the type of interaction is specified

  #. 2 Higgs Doublet Model: V_1 V_2 S_1 S_2 T

  #. R Parity Violation: V_1 V_2 S_1 S_2 T

  #. Lepto Quark: V_1 V_2 S_1 S_2 T

- The other phenomenology could be correlated to $B \to D^{(*)} \tau \nu$.

  #. 2HDM: $\tan\beta$, $B \to \tau\nu$

  #. 2HDM with FCNC: $t \to ch$

  #. RPV & LQ: $B \to X_s \nu\nu$ (partly)

2HDM

Yukawa in 2HDM:

- In order to forbid tree level FCNC, one of the Higgs doublets must be coupled to the fermion doublet in each Yukawa term.

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

$$\boxed{H_1 \text{ or } H_2}$$

Distinct types:

- There are 4 distinct types for the Yukawa sector

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)

2HDM

Effective Lagrangian:

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

Wilson coefficient:

$$\boxed{C_{S_1} = -\frac{m_b m_\tau}{m_{H^\pm}^2} \xi_1 \qquad\qquad C_{S_2} = -\frac{m_c m_\tau}{m_{H^\pm}^2} \xi_2}$$

#. ξ depends on the type:

	Type I	Type II	Type X	Type Y
ξ_1	$\cot^2\beta$	$\tan^2\beta$	-1	-1
ξ_2	$-\cot^2\beta$	1	1	$-\cot^2\beta$

Bound on 2HDM:

#. S1 is not favored according to model independent analysis

#. Best fit $C_{S_2} \sim -1.6$, then,
TypeI & Y are unlikely, because they cannot have negative C_{S_2}
TypeII & X are disfavored, because $\xi_2 = 1, \; m_{H^\pm} \sim \mathcal{O}(1)\,\mathrm{GeV}$

2HDM with tree level FCNC

- "Usual" 2HDM cannot explain the result of R(D)&R(D*).
  But, "S2 enhancement" can be realized, if we allow FCNC

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

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

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

#. ε' is coupling that control FCNC in the weak basis

#. Constraint on FCNC in up-quark sector ε'$_u$ is rather weak

- In terms of mass basis (**ε'**→**ε**), we can have following term, which contribute as S2 type:

$$\mathcal{L}_{qq'H^\pm} = -\sin\beta\, \bar{u}_R\, \epsilon_u^\dagger V_{\rm CKM}\, d_L H^+$$

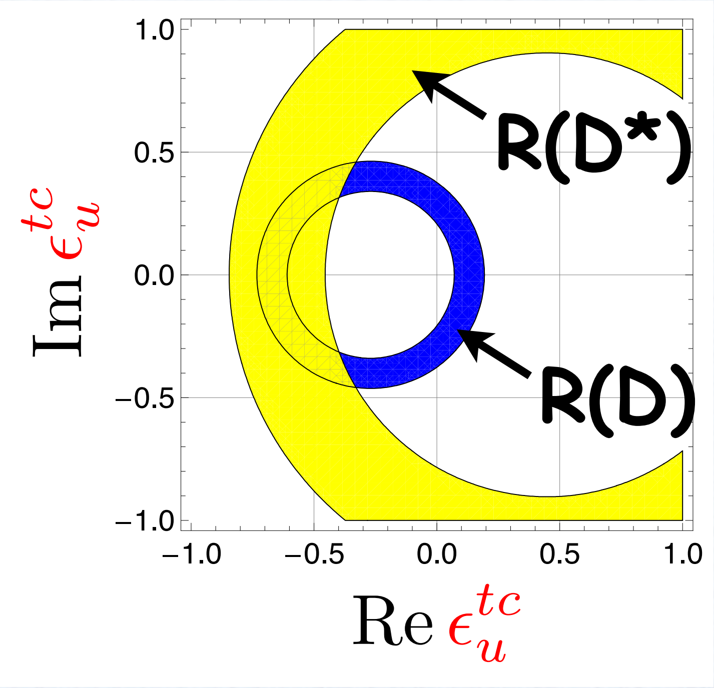
$$\downarrow$$

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

#. $(\epsilon_u^\dagger V_{\rm CKM})^{cb} = \sum_q (\epsilon_u^\dagger)^{cq} V_{qb} \simeq (\epsilon_u^*)^{tc} V_{tb}$

2HDM with tree level FCNC

Allowed region of coupling:



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

#. with fixed value: $m_{H^\pm} = 500\mathrm{GeV}, \ \tan\beta = 50$

#. the best fit value: $\epsilon_u^{tc} \sim -0.7$

#. ϵ_u^{tc} induces top quark FCNC decay, t→ch

$$\mathrm{Br}(t \to ch) \simeq 0.12 \times |\epsilon_u^{tc}|^2 \cos^2(\alpha - \beta)$$
$$\simeq 0.06 \times \cos^2(\alpha - \beta)$$

Top quark FCNC decay:

#. There are several constraints on t→ch:

$\mathrm{Br}(t \to ch) < 2.7 \times 10^{-2}$ from multi-lepton analysis, CMS(2012)

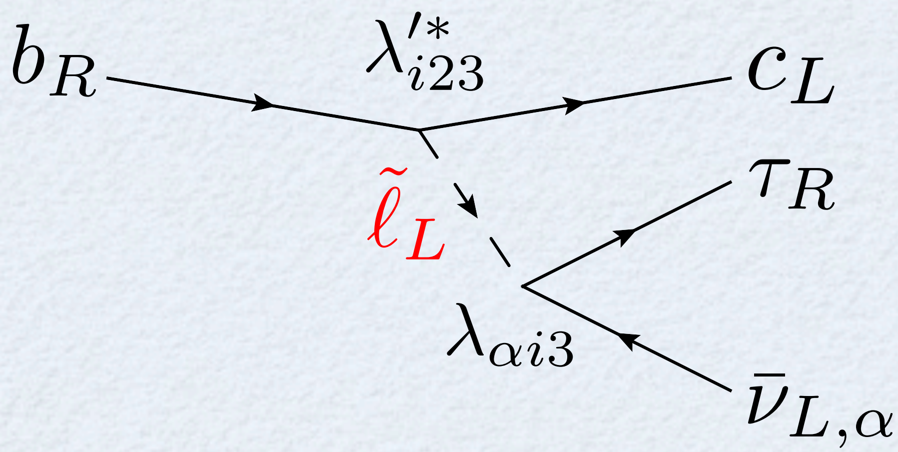
$\mathrm{Br}(t \to ch) < 2.5 \times 10^{-3}$ from Z measurement, F.Larios et.al.(2004)

#. Observed limit at 14TeV LHC:

$\mathrm{Br}(t \to ch) < 4.1 \times 10^{-5}$ with 14TeV, 100fb^-1

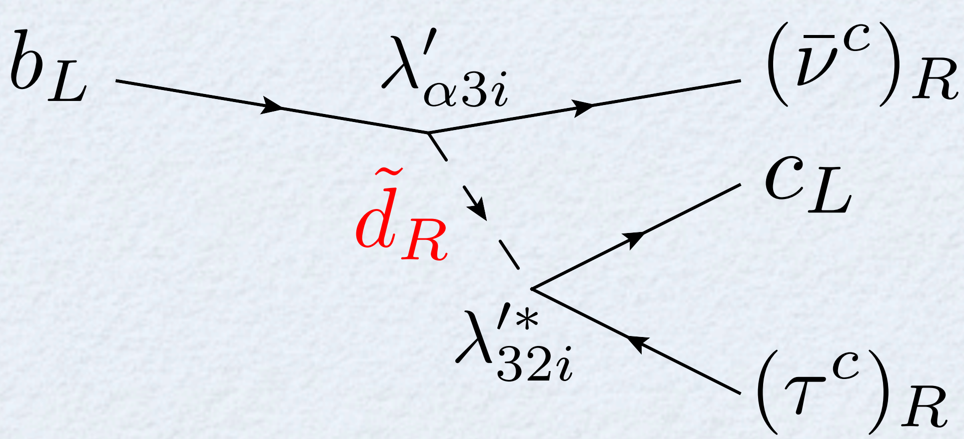
RPV

Superpotential: $W_{\rm RPV} = \frac{1}{2}\lambda_{ijk} L_i L_j E^c_k + \lambda'_{ijk} L_i Q_j D^c_k$



#. correspond to S1,
then this is disfavored

$$2\sqrt{2} G_F V_{cb}\, C_{S_1} = \sum_{j=1}^{3} \frac{\lambda_{3j3}\lambda'^*_{j23}}{2m^2_{\tilde{l}^j_L}}$$



#. correspond to V1,
likely to explain the results,
but incompatible with B→X$_s$νν.

$$2\sqrt{2} G_F V_{cb}\, C_{V_1} = -\sum_{j=1}^{3} \frac{\lambda'_{33j}\lambda'^*_{32j}}{16 m^2_{\tilde{d}^j_R}}$$

$$\mathcal{B}(B \to X_s \nu\bar{\nu}) < 6.4 \times 10^{-4}$$

LQ

- LQs are particles, carrying both baryon & lepton number. Thus, they couple to quark-lepton pair.
- LQ particles are expected to exist in various NP models; ex) SU(5)-GUT, SO(10)-GUT, composite models, and so on.

#. Mass bounds on LQs from LHC

Scalar LQ: $M_{\mathrm{SLQ}_3} \gtrsim 530\mathrm{GeV}$ ATLAS & CMS (2013)

Vector LQ: $M_{\mathrm{VLQ}_3} \gtrsim 760\mathrm{GeV}$ CMS (2012)

#. Lagrangian relevant for b->cτν, with general dimensionless SU(3)xSU(2)xU(1) invariant couplings of scalar & vector LQs:

$$\mathcal{L}^{\mathrm{LQ}}_{F=0} = \left(h^{ij}_{1L}\,\overline{Q}_{iL}\gamma^\mu L_{jL} + h^{ij}_{1R}\,\overline{d}_{iR}\gamma^\mu \ell_{jR}\right) U_{1\mu} + h^{ij}_{3L}\,\overline{Q}_{iL}\boldsymbol{\sigma}\gamma^\mu L_{jL}\boldsymbol{U}_{3\mu}$$
$$+ \left(h^{ij}_{2L}\,\overline{u}_{iR}L_{jL} + h^{ij}_{2R}\,\overline{Q}_{iL}i\sigma_2\ell_{jR}\right) R_2\,,$$

$$\mathcal{L}^{\mathrm{LQ}}_{F=-2} = \left(g^{ij}_{1L}\,\overline{Q}^c_{iL}i\sigma_2 L_{jL} + g^{ij}_{1R}\,\overline{u}^c_{iR}\ell_{jR}\right) S_1 + g^{ij}_{3L}\,\overline{Q}^c_{iL}i\sigma_2\boldsymbol{\sigma}L_{jL}\boldsymbol{S}_3$$
$$+ \left(g^{ij}_{2L}\,\overline{d}^c_{iR}\gamma^\mu L_{jL} + g^{ij}_{2R}\,\overline{Q}^c_{iL}\gamma^\mu \ell_{jR}\right) V_{2\mu}\,,$$

S,R: scalar LQ
U,V: vector LQ

LQ

Classification of interaction: 4 independent types generated

#. Scalar1: disfavored according to model indep. analysis

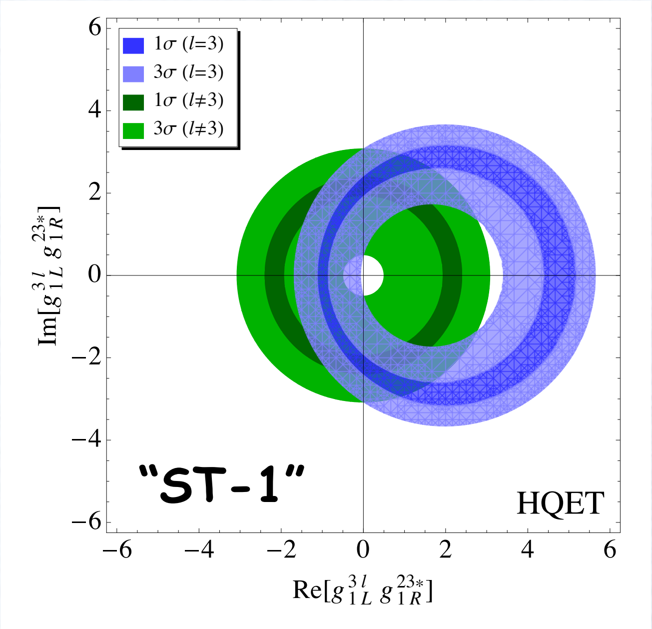
#. Vector1: incompatible with B->$X_s\nu\nu$, as well as RPV

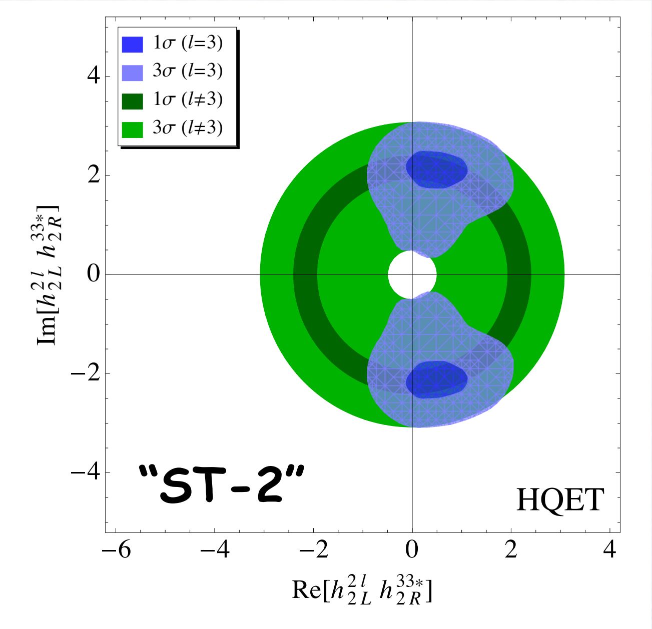
#. Scalar2-Tensor: both C_{S_2}&C_T appear at the same time

"ST-1" $$C^{\ell}_{S_2} = 4C^{\ell}_T = \frac{1}{2\sqrt{2}G_F V_{cb}} \sum_{k=1}^{3} \frac{-V_{k3}\, h^{2\ell}_{2L} h^{k3*}_{2R}}{2M^2_{R_2^{2/3}}} \qquad (\mu = M_{\mathrm{LQ}})$$

"ST-2" $$C^{\ell}_{S_2} = -4C^{\ell}_T = \frac{1}{2\sqrt{2}G_F V_{cb}} \sum_{k=1}^{3} \frac{-V_{k3}\, g^{k\ell}_{1L} g^{23*}_{1R}}{2M^2_{S_1^{1/3}}} \qquad (\mu = M_{\mathrm{LQ}})$$

Allowed region of LQ couplings (gg & hh) with M_{LQ}=1TeV:





#. O(1) couplings are needed

#. Green: $\nu_{\ell\neq\tau}$ Blue: ν_τ

#. No other constraint

Model analysis: summary

#. 2 Higgs Doublet Model: V_1 V_2 S_1 S_2 T

- Usual 2HDM cannot explain the recent R(D)&R(D*)
- FCNC induced S2 can explain them

#. R Parity Violation: V_1 V_2 S_1 S_2 T

- S1 type is generated, and is disfavored
- V1 type is generated, but it is incompatible with $B \to X_s \nu\nu$

#. Lepto Quark: V_1 V_2 S_1 S_2 T

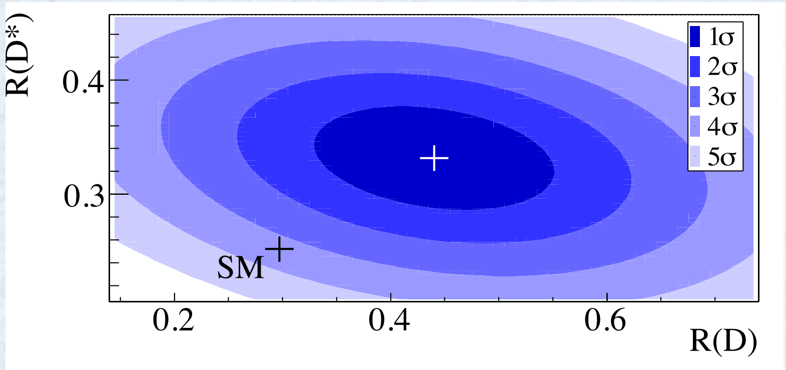
- S1&V1 type are generated and disfavored as well as RPV
- S2-T types are generated and likely to explain the results

Summary

Experiments

BABAR result: arXiv:1205.5442

	Exp. result	SM prediction
$R(D)$	$0.440 \pm 0.058 \pm 0.042$	0.297 ± 0.017
$R(D^*)$	$0.332 \pm 0.024 \pm 0.018$	0.252 ± 0.003



Belle result:

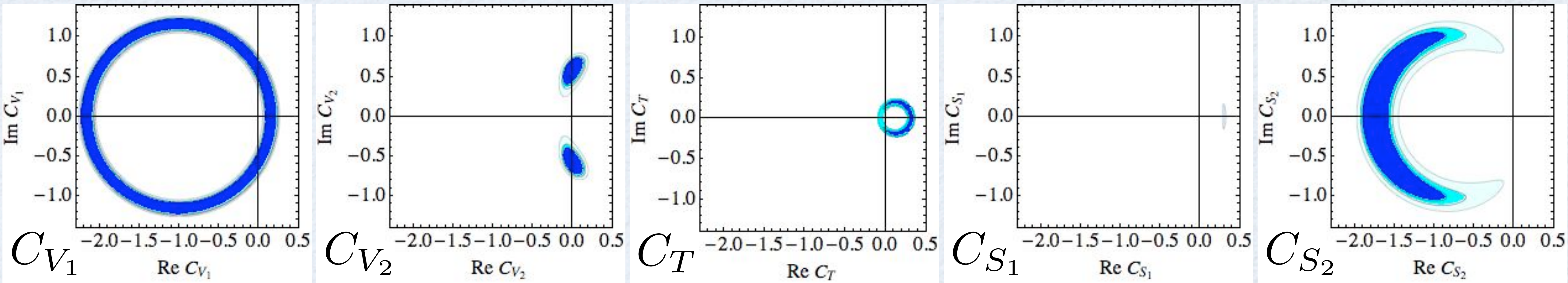
- They did not use full data set yet
- They are now analyzing

Super B factory:

- Large statistics enable us to measure not only total rate, but also some distributions & polarizations

Phenomenology: summary

Constraint on Cx:

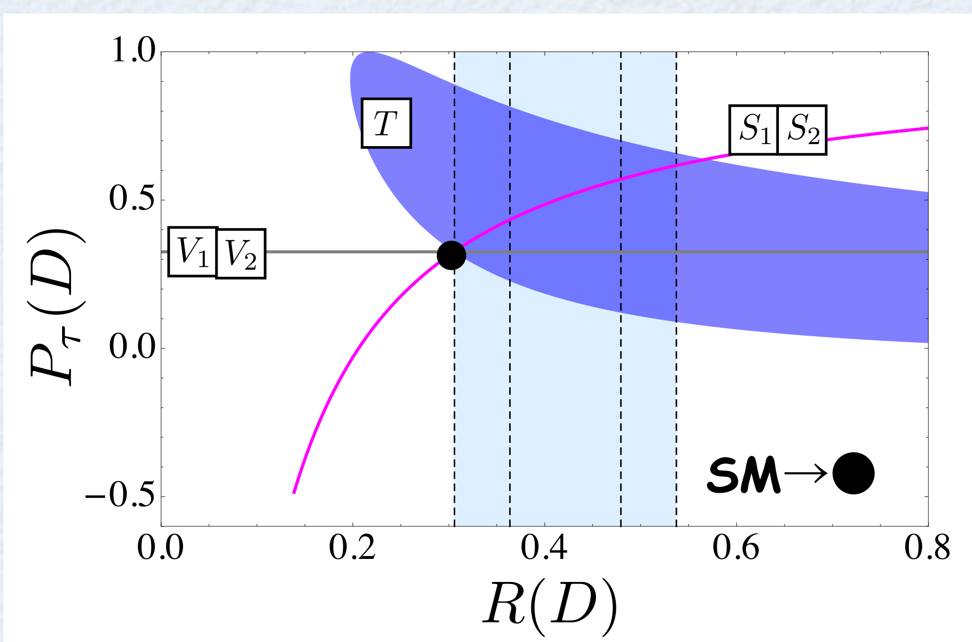


#. V1, V2, T can explain within small Cx

#. S2 can explain but large Cx is needed

#. S1 is not favored

Correlation of observables:



#. Measuring a lot of observables,
and investigating their correlations,
we can identify & distinguish NP couplings

Model analysis: summary

#. 2 Higgs Doublet Model: V_1 V_2 S_1 S_2 T

- Usual 2HDM cannot explain the recent R(D)&R(D*)
- FCNC induced S2 can explain them

#. R Parity Violation: V_1 V_2 S_1 S_2 T

- S1 type is generated, and is disfavored
- V1 type is generated, but it is incompatible with $B \to X_s \nu\nu$

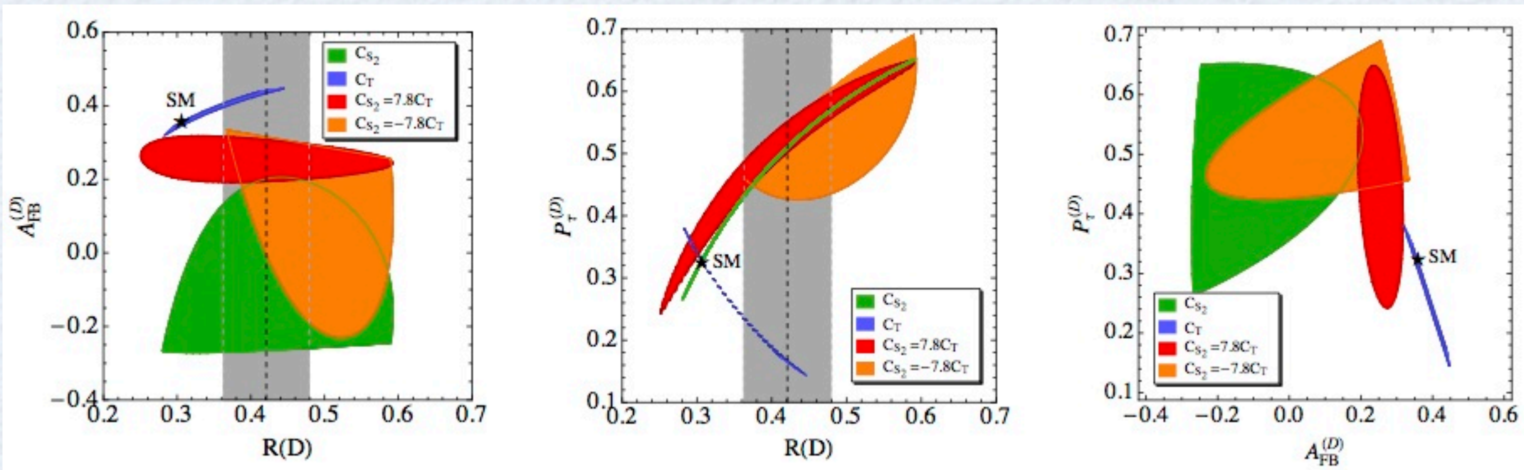
#. Lepto Quark: V_1 V_2 S_1 S_2 T

- S1&V1 type are generated and disfavored as well as RPV
- S2-T types are generated and likely to explain the results

Back up

Other observables

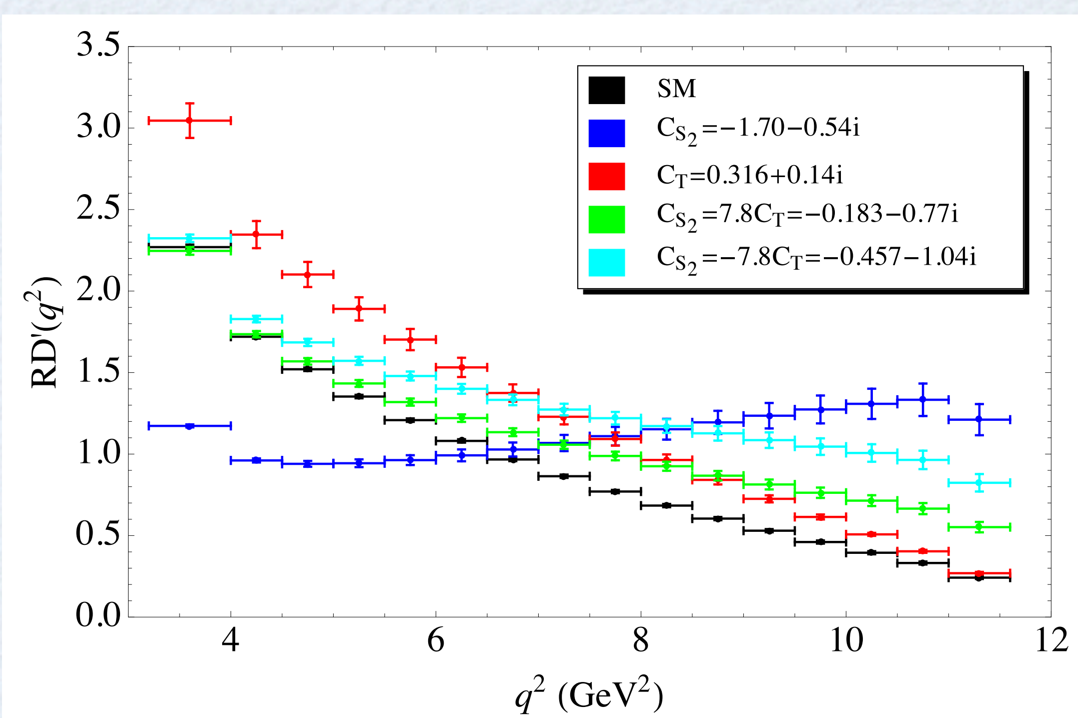
- D* polarization & τ FB-asymmetry are also helpful.
  Correlations of them are important.



#. Colored range allowed
from R(D)&R(D*) within 3σ

Given by Andrey

- We are now investigating q^2 distribution, $q^2 = (p_B - p_{D^{(*)}})^2$,
  which will be available at super B factory.

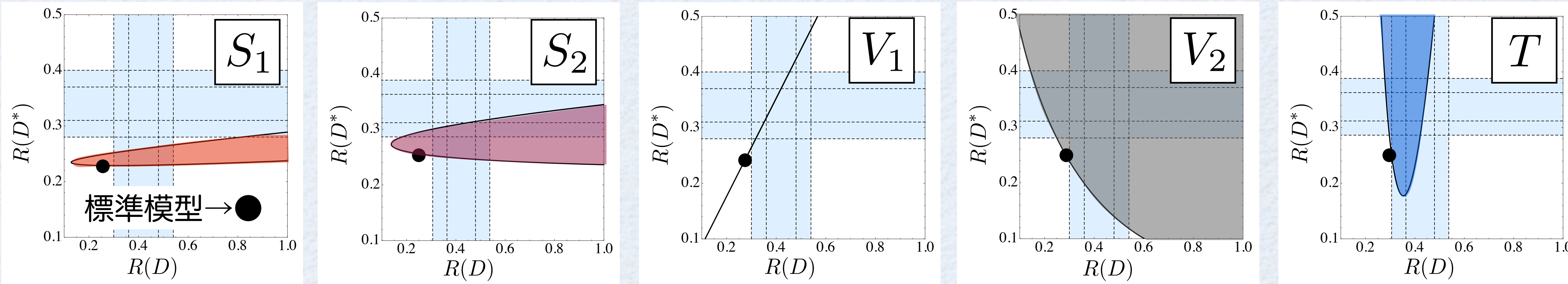


#. Same R(D(*)) but
different distribution can happen

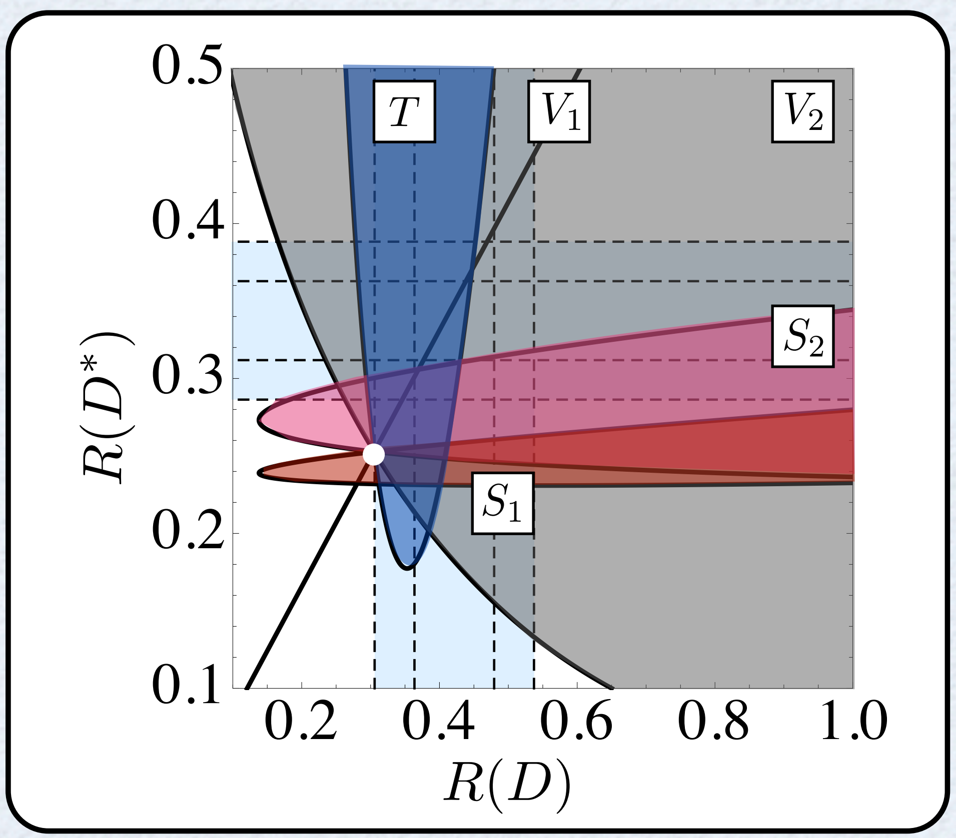
#. We are discussing
1. ability to distinguish
2. expected uncertainties

Preliminary

Correlation of R(D) & R(D*)



Sensitive to R(D) Same to R(D*)



We can distinguish the type in part if we measure them more precisely.

$|V_{cb}|$ determination

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

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

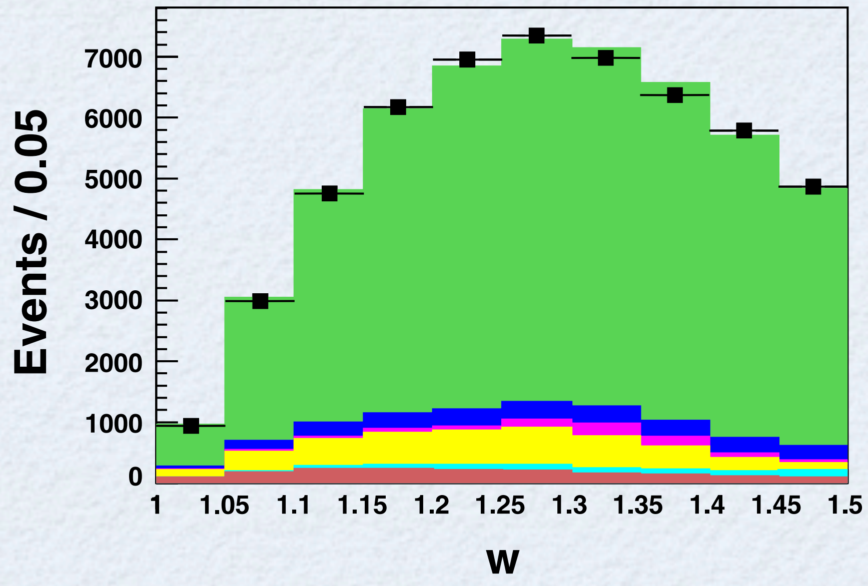
- Fit the shape (=interaction type) and the hight (=coupling)
- Shape is parametrized by HQET

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

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



Fit result:

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

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

How to measure Tau polarization

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

$$\tau \to \pi\nu$$

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

$q^2 = (p_B - p_D)^2$ and $z = \dfrac{E_{\pi(l)}}{E_\tau}$ are available

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

determined from kinematics