Physics
OSAKA UNIVERSITY

$\bar{B}\to D^{(*)}\tau\bar{\nu}$と2HDM他

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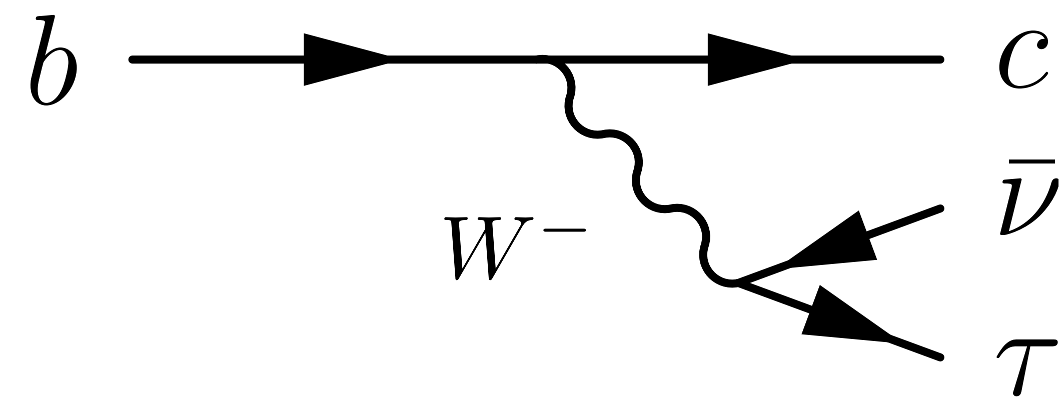
Introduction

Semi-tauonic B decays

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



Experiments

BABAR 2012 arXiv: 1205.5442

$$R(D) \equiv \frac{\mathcal{B}(\bar{B} \to D\tau\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D\ell\bar{\nu}_\ell)} = 0.440 \pm 0.058 \pm 0.042$$

$$R(D^*) \equiv \frac{\mathcal{B}(\bar{B} \to D^*\tau\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D^*\ell\bar{\nu}_\ell)} = 0.332 \pm 0.024 \pm 0.018$$

Belle 2007, 2009, 2010

Combined: $R(D) = 0.42 \pm 0.06$

$R(D^*) = 0.34 \pm 0.03$

Theory (SM)

$$R(D) = 0.297 \pm 0.017$$ (BABAR, Fajfer et al.)

$$0.302 \pm 0.015$$ (MT, Watanabe)

$$0.316 \pm 0.012 \pm 0.007$$ (Bailey et al., lattice)

$$0.31 \pm 0.02$$ (Becirevic et al.)

$$R(D^*) = 0.252 \pm 0.003$$ (BABAR, Fajfer et al.)

$$0.251 \pm 0.004$$ (MT, Watanabe)

$R(D)$ 1.9σ

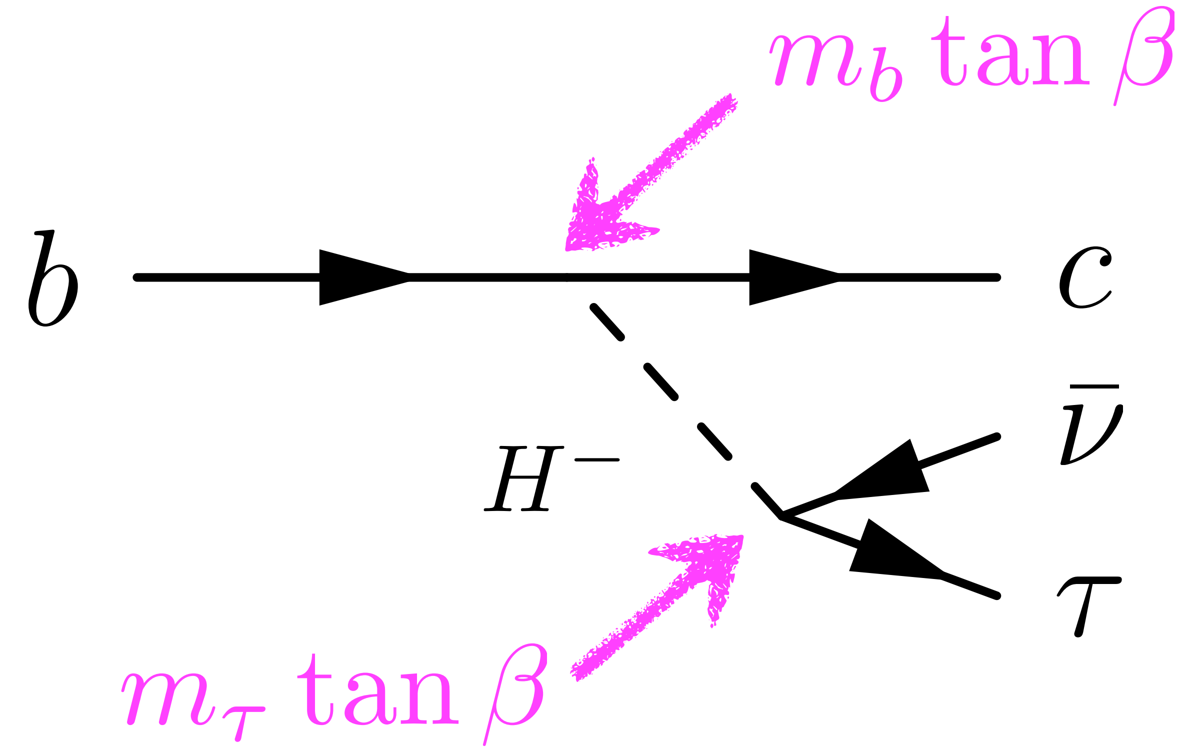
$R(D^*)$ 2.9σ

→ 3.5σ

Charged Higgs contribution

W.S. Hou and B. Grzadkowski (1992), M.T. (1995), ...

Type-II 2HDM (SUSY)

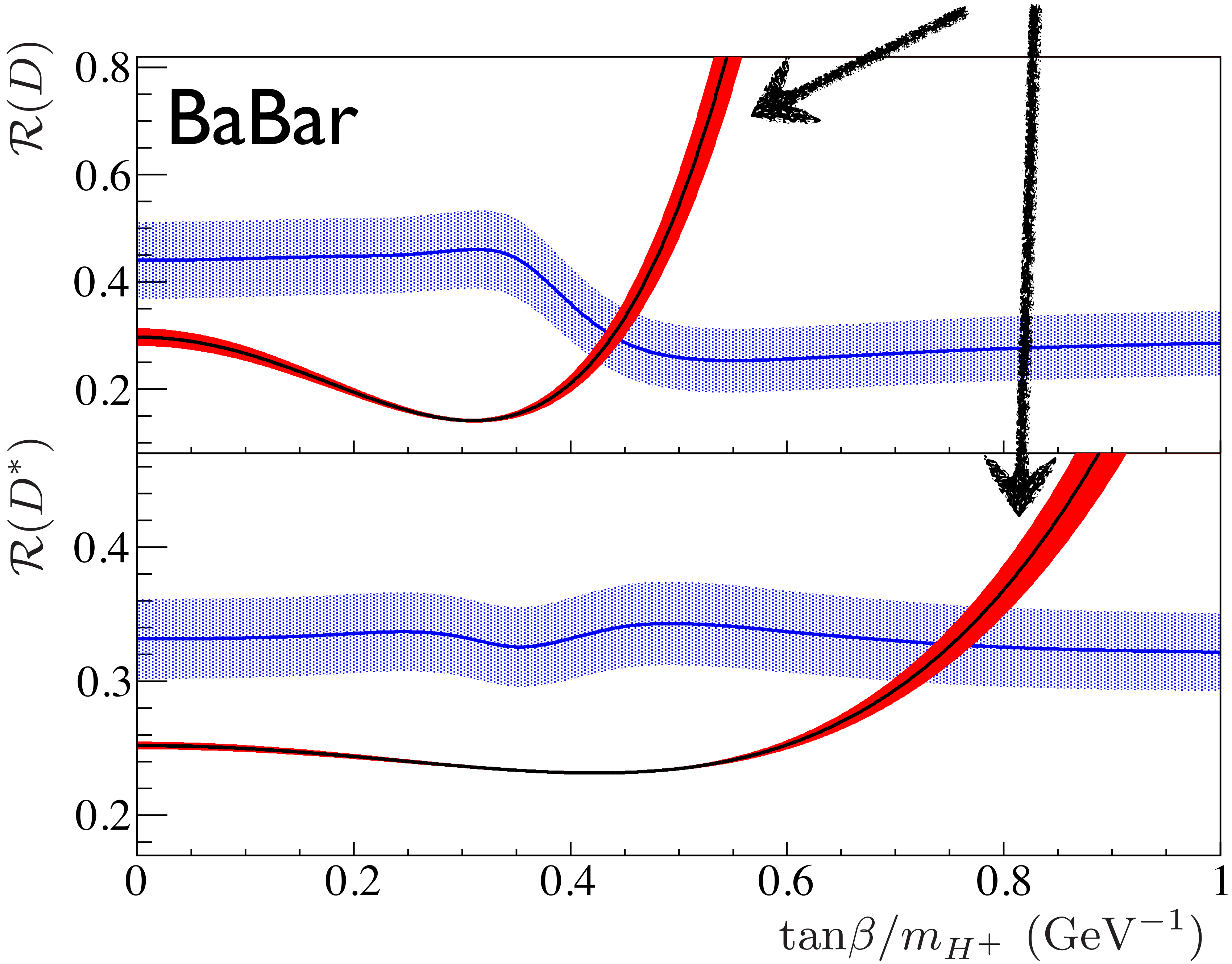


$$\propto m_b m_\tau \tan^2\beta$$

Sensitive to the charged Higgs if tanβ is large.

But, negative interference.

predictions of 2HDM II



charged Higgs *excluded* at 99.8% CL

Model-independent approach

Effective Lagrangian for $b \longrightarrow c\tau\bar{\nu}$

all possible 4-fermi operators with LH neutrinos

$$-\mathcal{L}_{\rm eff} = 2\sqrt{2}G_F V_{cb} \sum_{l=e,\mu,\tau} \left[(\delta_{l\tau} + C^l_{V_1})\mathcal{O}^l_{V_1} + C^l_{V_2}\mathcal{O}^l_{V_2} + C^l_{S_1}\mathcal{O}^l_{S_1} + C^l_{S_2}\mathcal{O}^l_{S_2} + C^l_T\mathcal{O}^l_T\right]$$

SM

$\mathcal{O}^l_{V_1} = \bar{c}_L\gamma^\mu b_L\,\bar{\tau}_L\gamma_\mu\nu_{Ll}\,,$	V−A	SM-like
$\mathcal{O}^l_{V_2} = \bar{c}_R\gamma^\mu b_R\,\bar{\tau}_L\gamma_\mu\nu_{Ll}\,,$	V+A	RH current
$\mathcal{O}^l_{S_1} = \bar{c}_L b_R\,\bar{\tau}_R\nu_{Ll}\,,$	S+P	charged Higgs (II)
$\mathcal{O}^l_{S_2} = \bar{c}_R b_L\,\bar{\tau}_R\nu_{Ll}\,,$	S−P	charged Higgs
$\mathcal{O}^l_T = \bar{c}_R\sigma^{\mu\nu} b_L\,\bar{\tau}_R\sigma_{\mu\nu}\nu_{Ll}$	Tensor	GUT?

Observables

branching fractions

$$R(D) \equiv \frac{\mathcal{B}(\bar{B} \to D\tau\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D\ell\bar{\nu}_\ell)} \qquad R(D^*) \equiv \frac{\mathcal{B}(\bar{B} \to D^*\tau\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D^*\ell\bar{\nu}_\ell)}$$

tau longitudinal polarizations

$$P_L(D),\ P_L(D^*) \qquad \delta P_L = \frac{1}{\sqrt{N}S}$$

sensitivity S: $P_L(D)$ $S(\tau \to \pi\nu) \simeq 0.60$

$S(\tau \to \ell\nu\bar{\nu}) \simeq 0.23$

$P_L(D^*)$ no estimation yet

$\tau \to \ell\nu\bar{\nu}$ is used in BaBar 2012.

D* polarization

$$P_{D^*} = \frac{\Gamma(D_L^*)}{\Gamma(D_L^*) + \Gamma(D_T^*)} \qquad S(D^* \to D\pi) \simeq 0.66$$

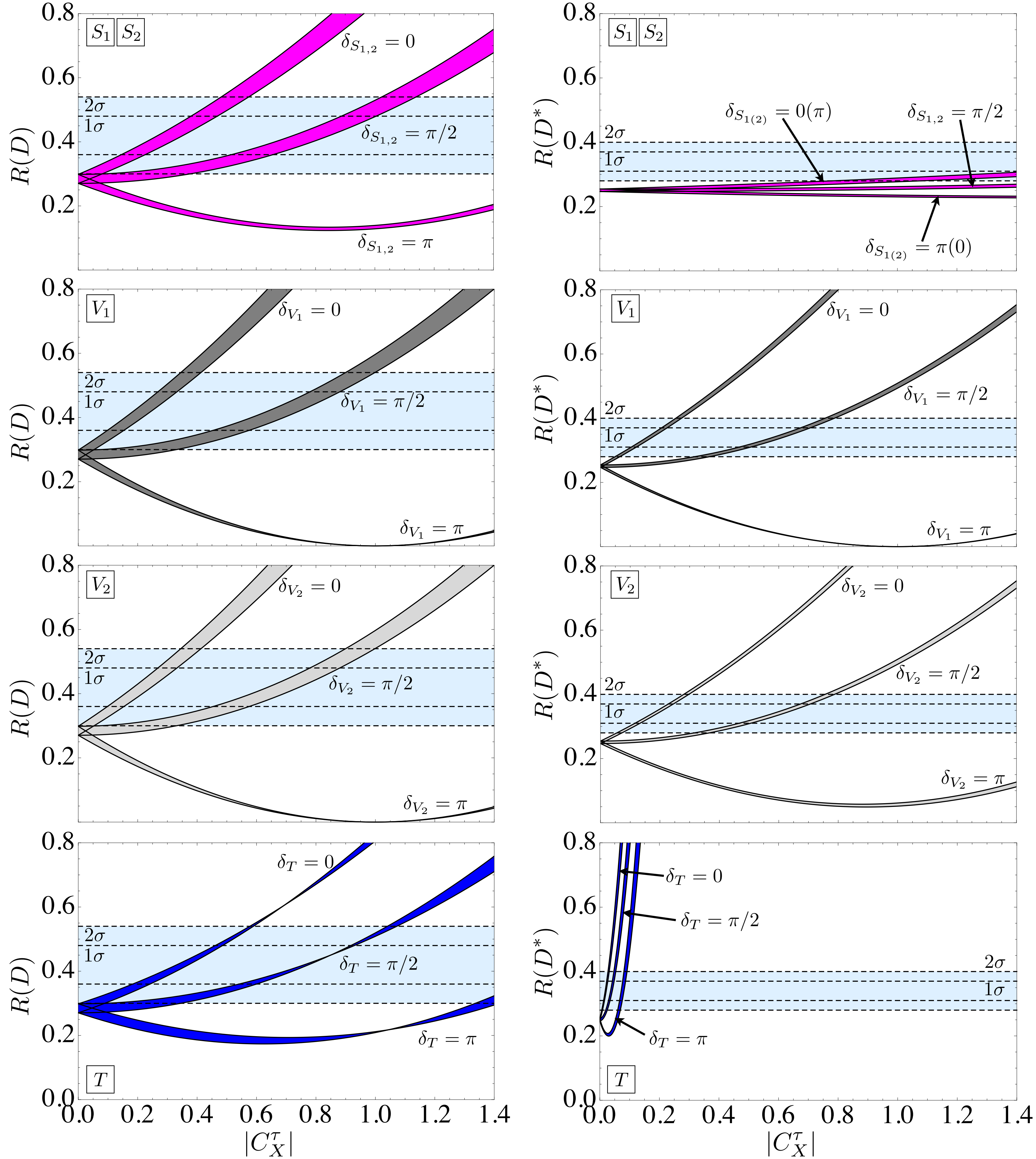
q2 distribution

$$\frac{1}{\Gamma}\frac{d\Gamma}{dq^2}$$ (needed in polarization measurements)

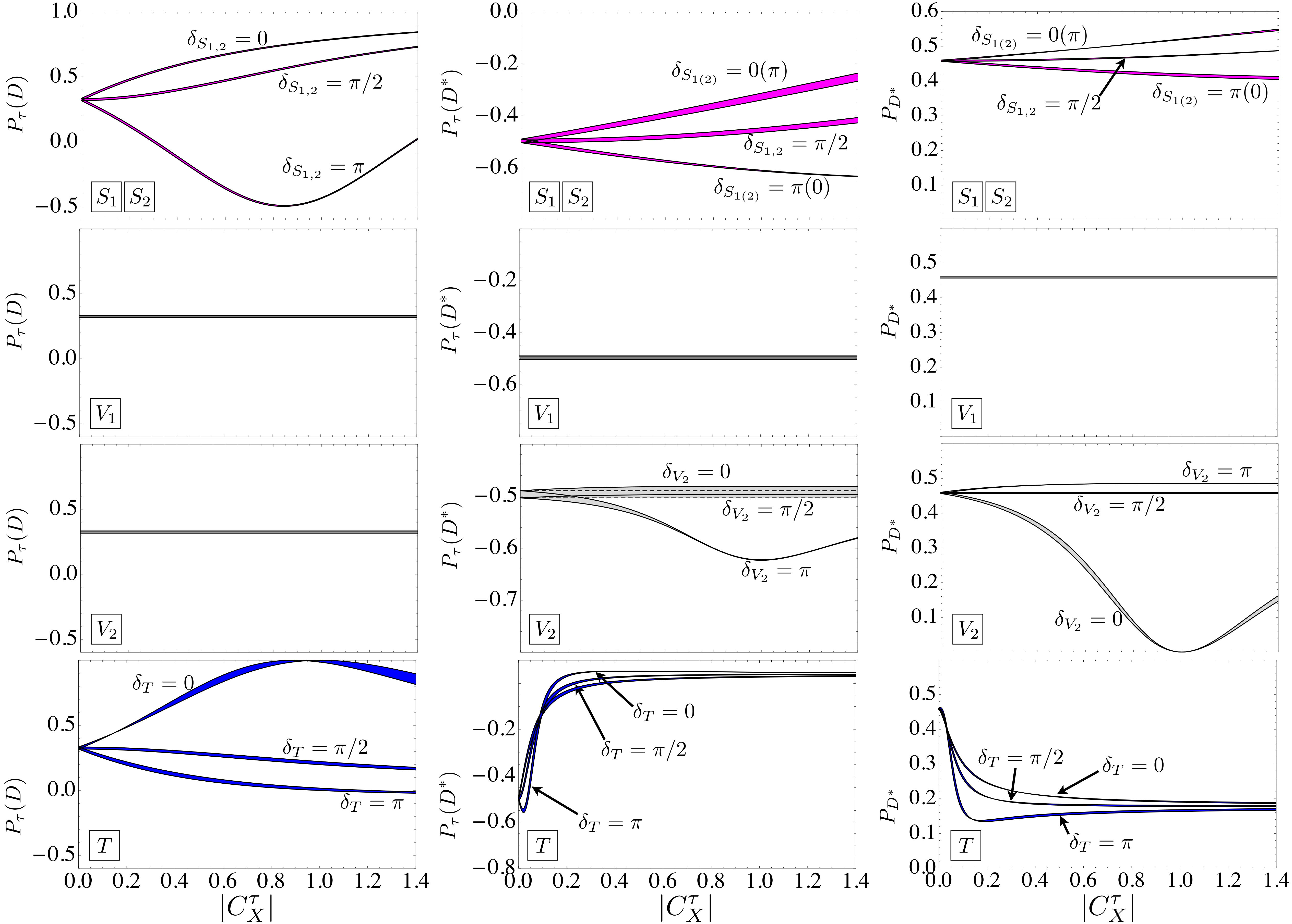
Effects of NP operators

Assumption: SM + one NP op.

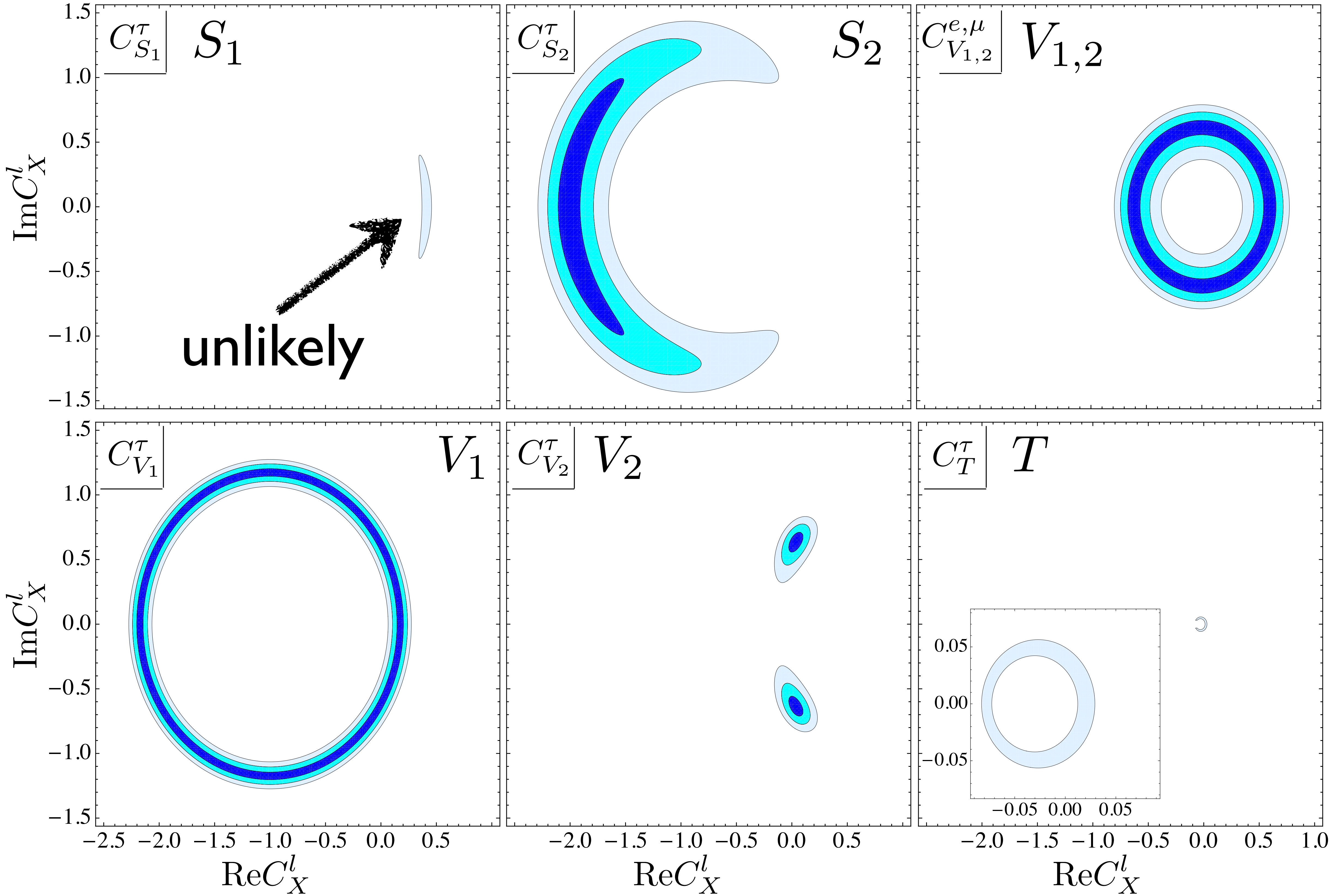
$$C_X^\tau = |C_X^\tau| e^{i\delta_X}$$



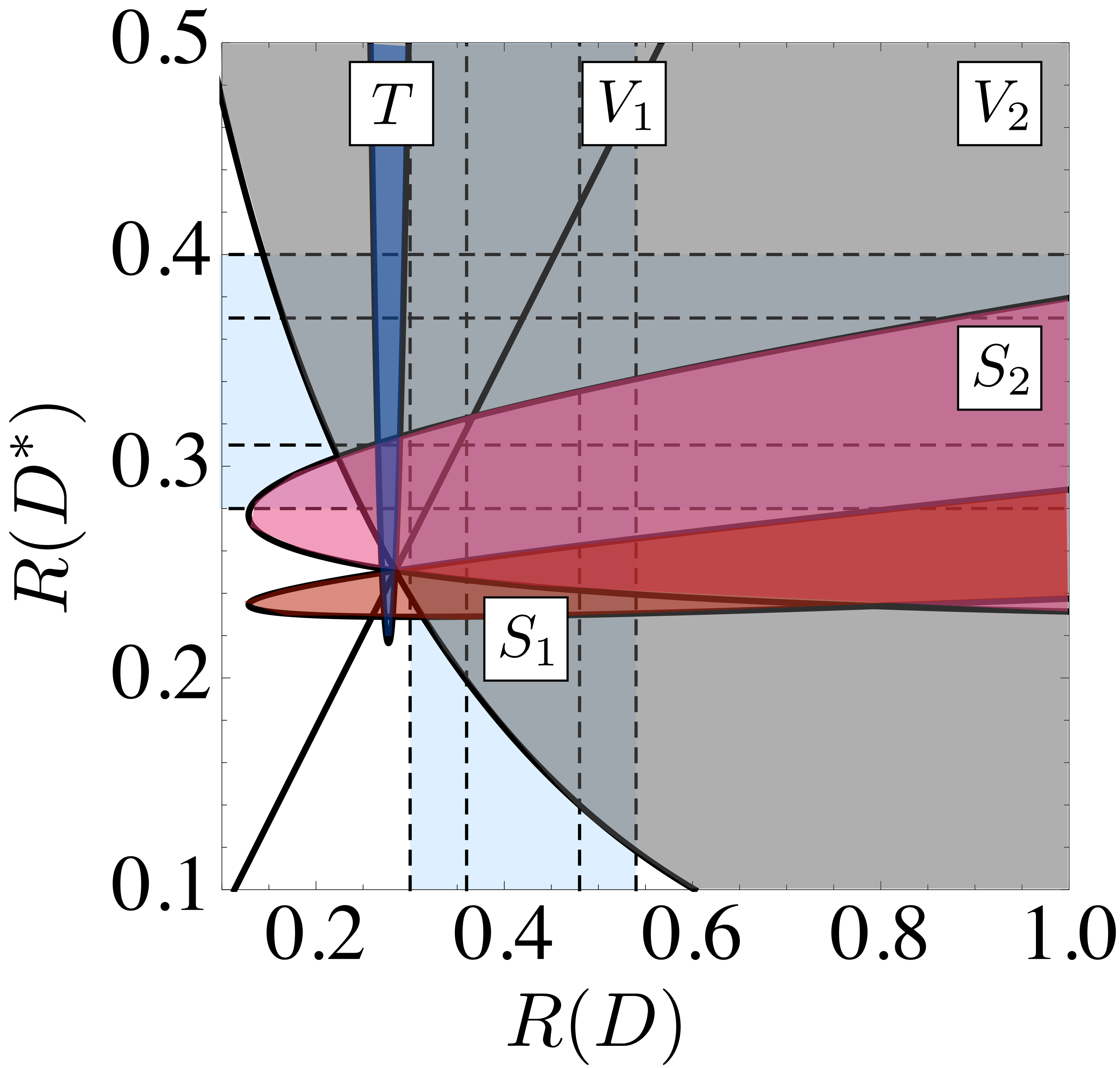
S_1 S_2
$\delta_{S_{1,2}}=0$
$\delta_{S_{1,2}}=\pi/2$
$\delta_{S_{1,2}}=\pi$
$\delta_{S_{1(2)}}=0(\pi)$
$\delta_{S_{1(2)}}=\pi(0)$
V_1
$\delta_{V_1}=0$
$\delta_{V_1}=\pi/2$
$\delta_{V_1}=\pi$
V_2
$\delta_{V_2}=0$
$\delta_{V_2}=\pi/2$
$\delta_{V_2}=\pi$
T
$\delta_T=0$
$\delta_T=\pi/2$
$\delta_T=\pi$
2σ
1σ
$R(D)$
$R(D^*)$
$|C_X^\tau|$


$\delta_{S_{1,2}} = 0$
$\delta_{S_{1,2}} = \pi/2$
$\delta_{S_{1,2}} = \pi$
$\delta_{S_{1(2)}} = 0(\pi)$
$\delta_{S_{1(2)}} = \pi(0)$
S_1 S_2
V_1
V_2
$\delta_{V_2} = 0$
$\delta_{V_2} = \pi/2$
$\delta_{V_2} = \pi$
T
$\delta_T = 0$
$\delta_T = \pi/2$
$\delta_T = \pi$
$P_\tau(D)$
$P_\tau(D^*)$
P_{D^*}
$|C_X^\tau|$

Allowed regions by R(D) and R(D*)



Correlations: rates

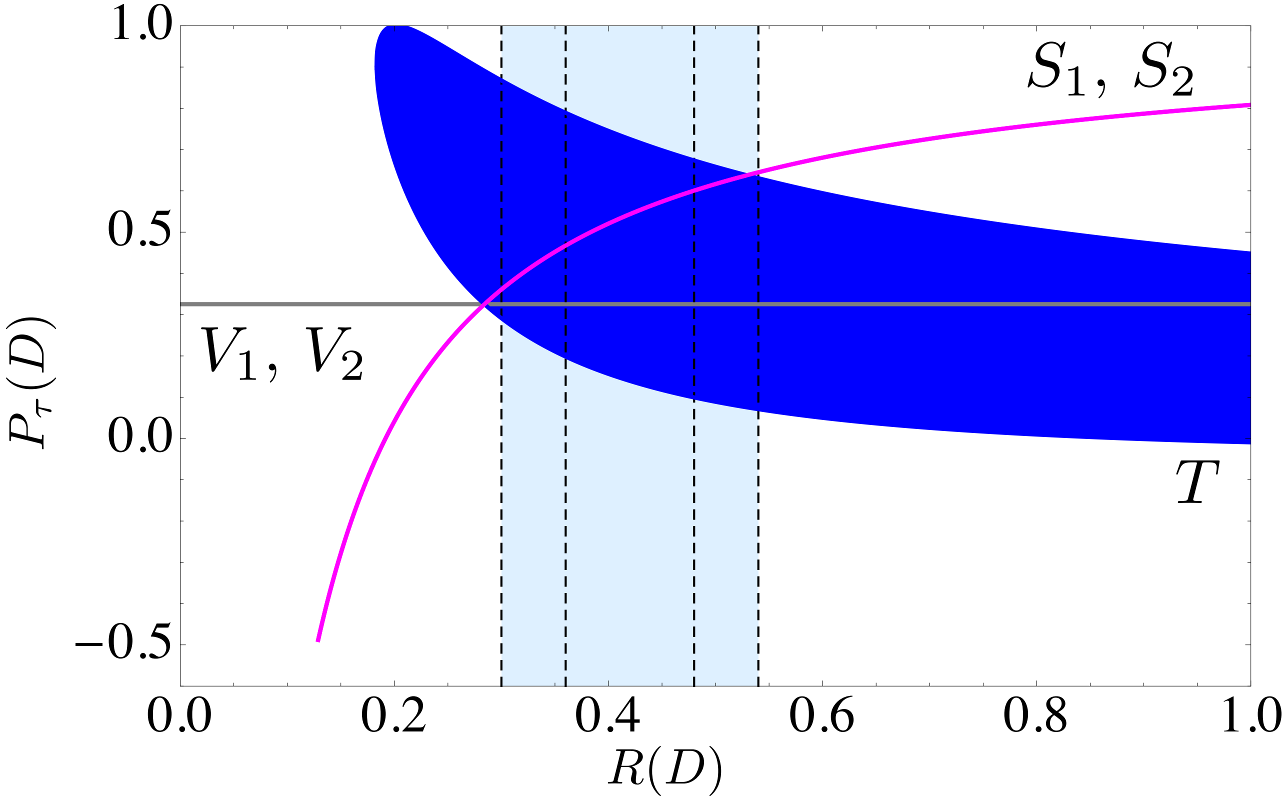


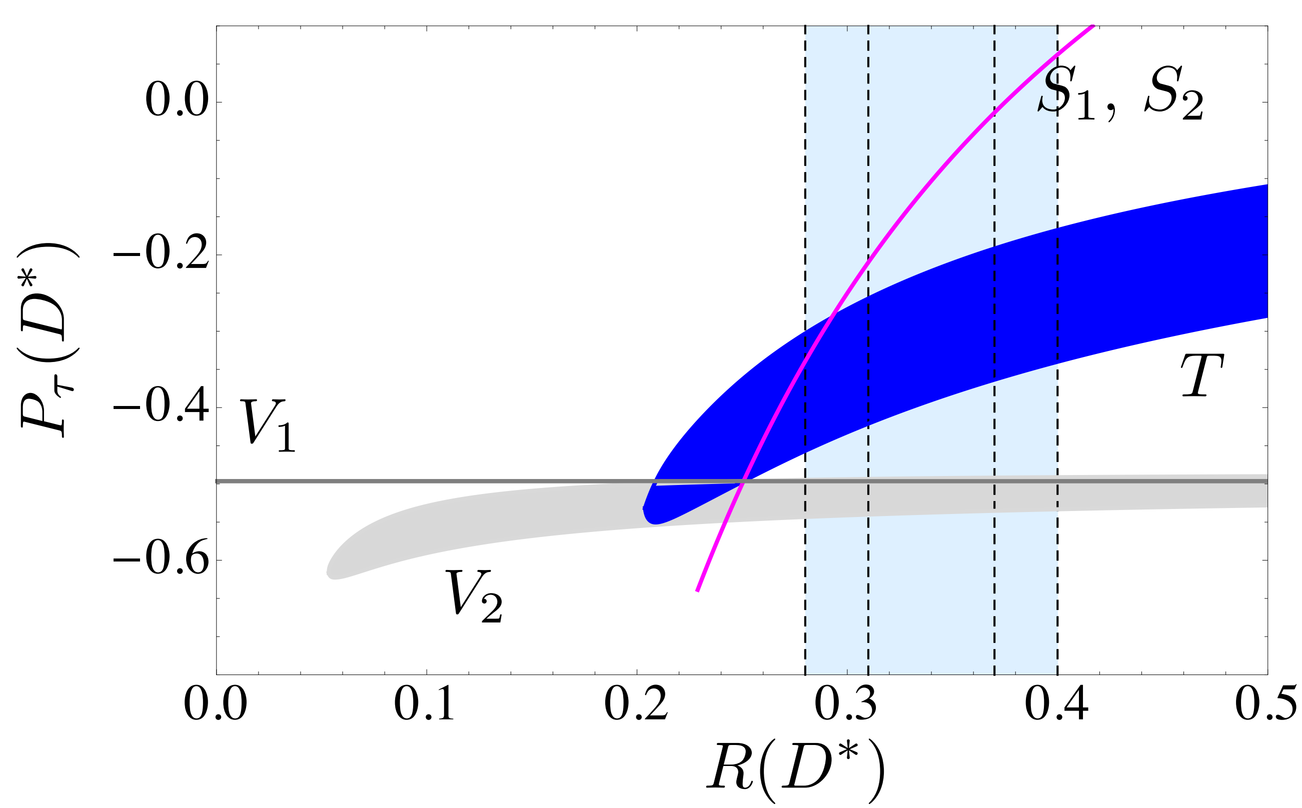
$V_1,\ V_2,\ S_2$ favored

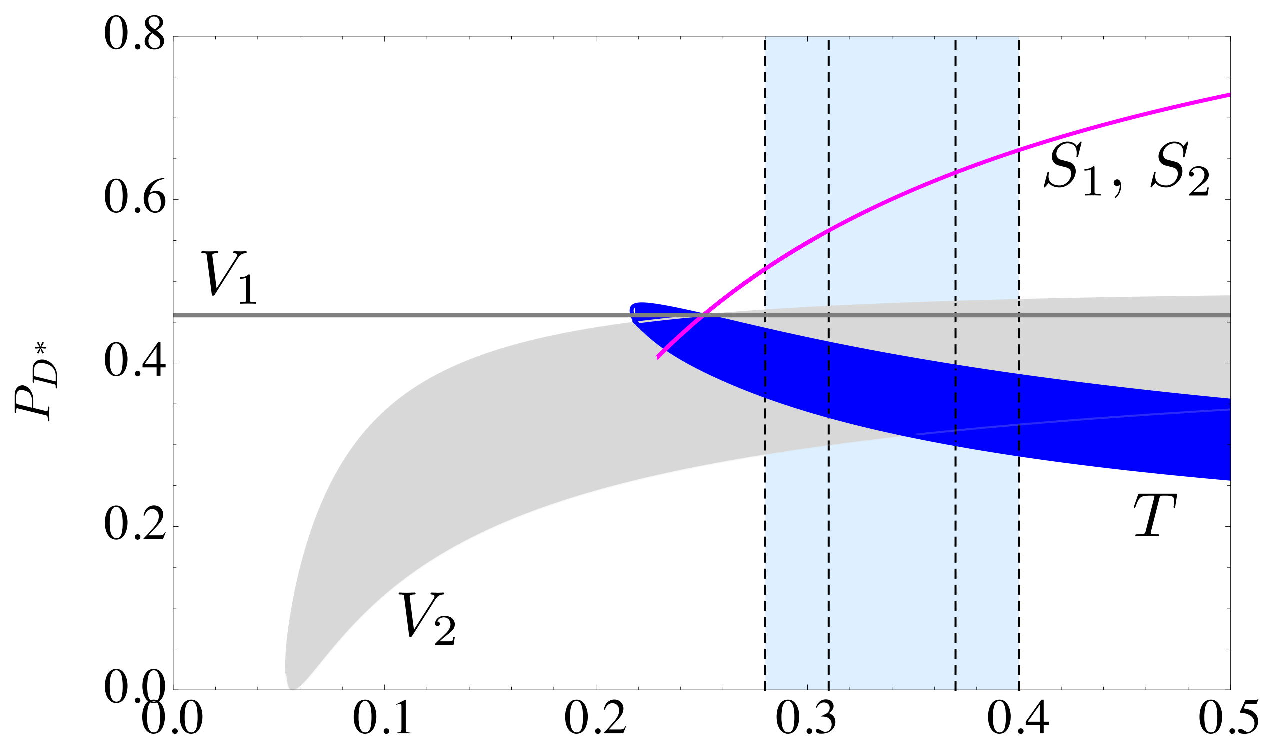
$S_1,\ T$ disfavored

MSSM-like 2HDM

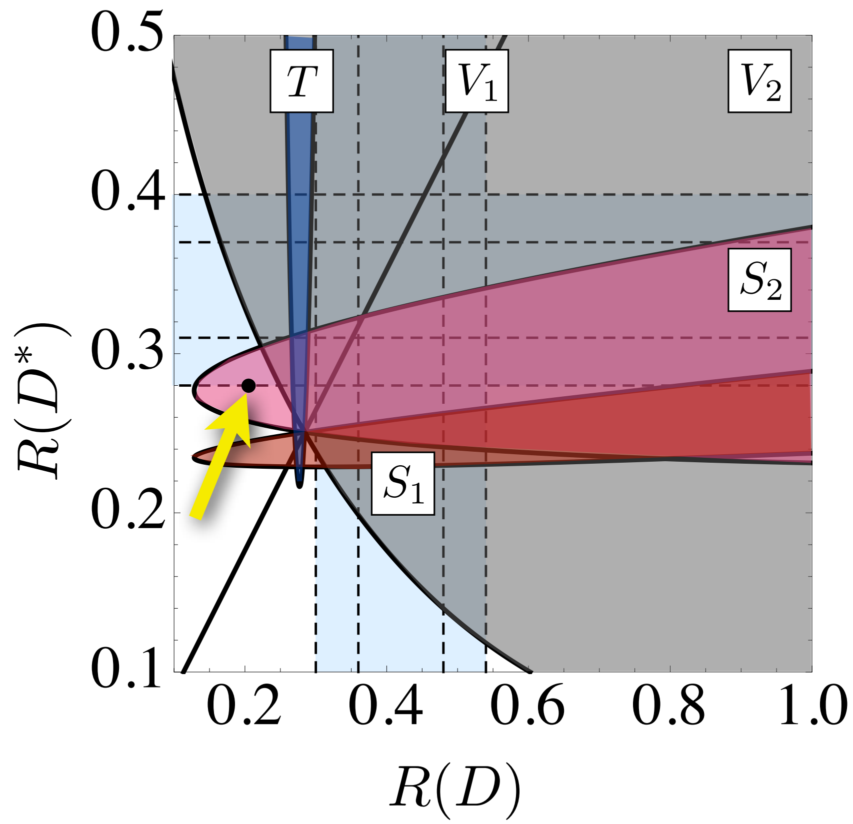
Correlations: rate and polarization





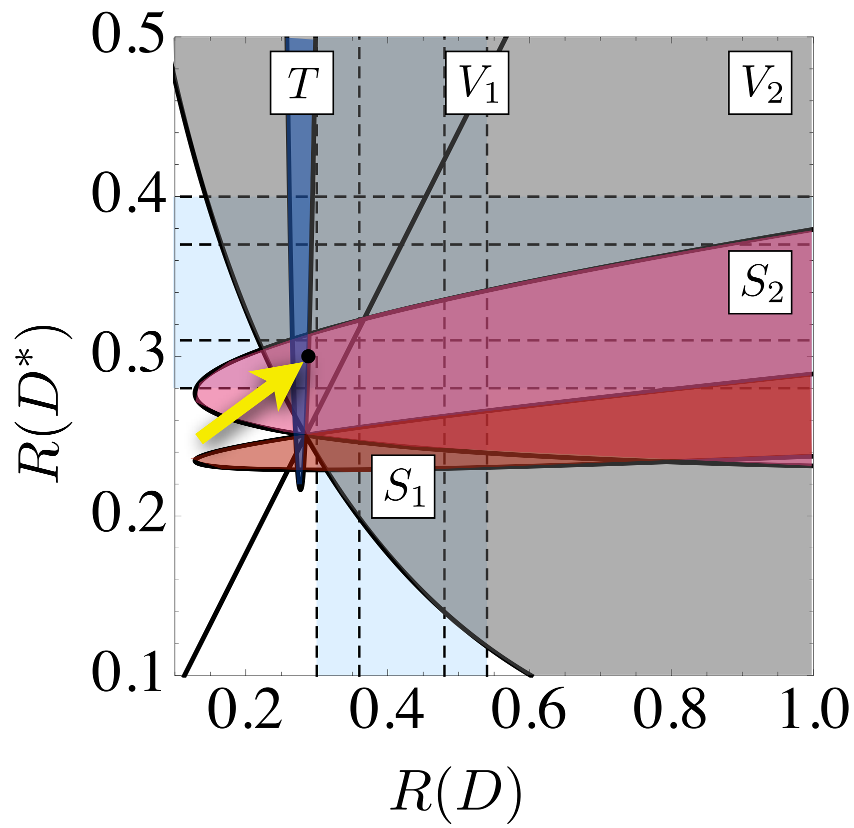


An illustration



identified as S_2

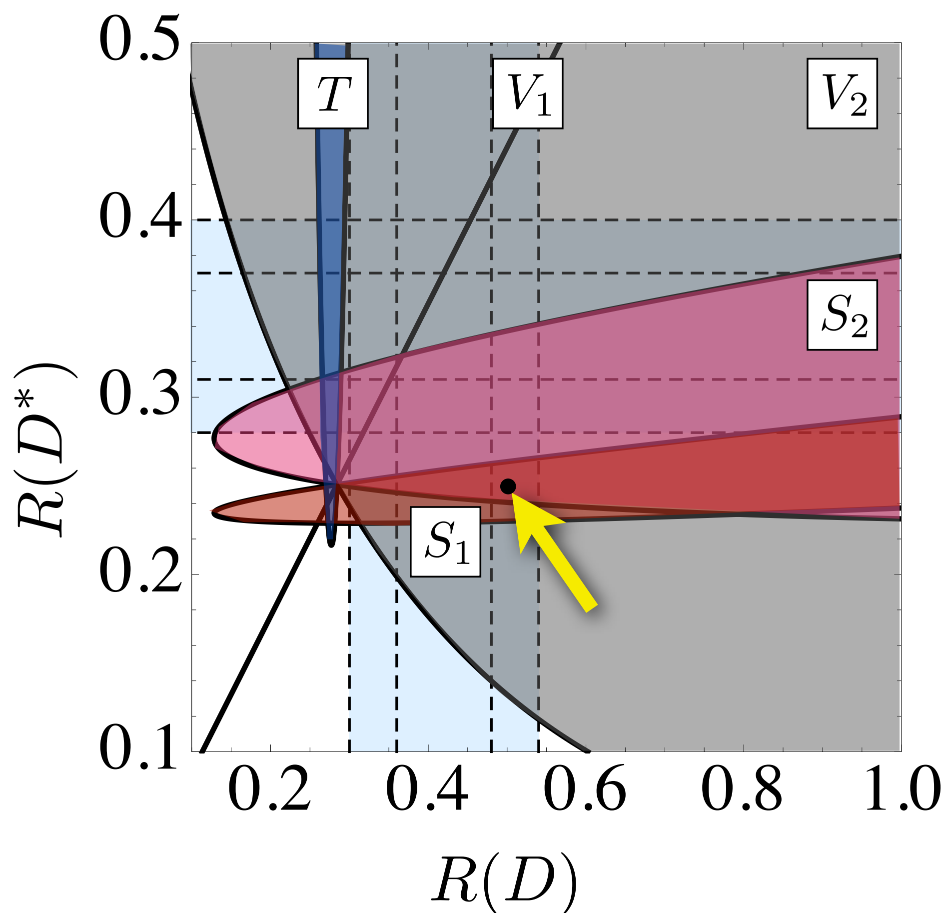
pols. for cross-check



$S_2, V_2,$ or T

Use pols.

	S_2	V_2	T
$P_\tau(D)$	0.32	0.33	0.34
$P_\tau(D^*)$	-0.25	-0.50	-0.41
P_{D^*}	0.55	0.46	0.40

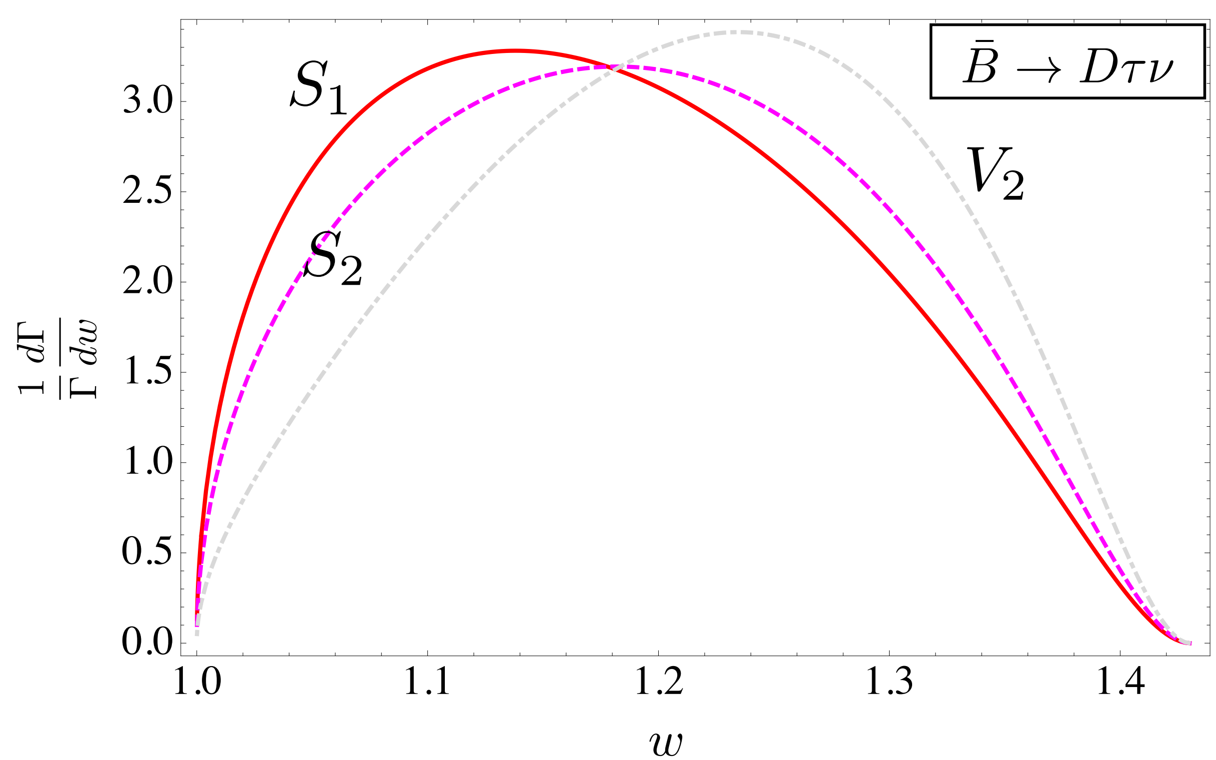


$S_1,\ S_2,$ or V_2

pols.

	$S_{1,2}$	V_2
$P_\tau(D)$	0.62	0.33
$P_\tau(D^*)$	−0.50	−0.50
P_{D^*}	0.46	0.43

q2 dist.



Models

2HDMs

Aoki et al., PRD80, 015017(2009)

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

No FCNC

	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	$-\cot^2\beta$

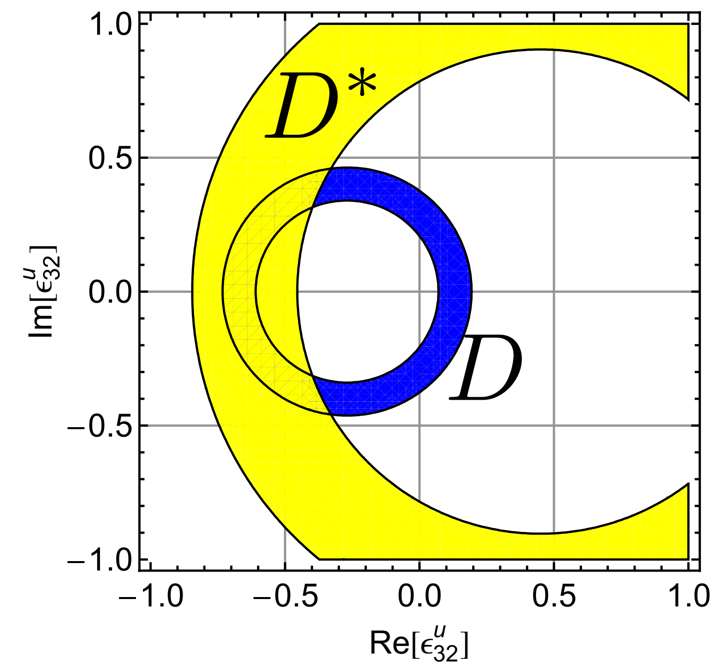
$$C_{S_1}^{\tau} = -\frac{m_b m_\tau}{m_{H^\pm}^2}\xi_d$$

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

Type III 2HDM: allowing FCNC in the up sector

Crivellin et al., PRD86, 054014(2012)

$$C^{\tau}_{s_2} \simeq \frac{\epsilon_{tc}}{2V_{cb}} \frac{v m_\tau}{m^2_{H^\pm}} \tan\beta \sim O(1)$$



Scalar leptoquark

J.P. Lee, PLB526, 61(2002)

$$\mathcal{L}_{\mathrm{LQ}} = (\lambda_{ij} \bar{Q}_i e_{Rj} + \lambda'_{ij} \bar{u}_{Ri} L_j) S_{\mathrm{LQ}} + \mathrm{h.c.}$$

(3,2,7/6)

$$\mathcal{O}^l_{S_2} = \bar{c}_R b_L \, \bar{\tau}_R \nu_{Ll}$$

$$\mathcal{O}^l_T = \bar{c}_R \sigma^{\mu\nu} b_L \, \bar{\tau}_R \sigma_{\mu\nu} \nu_{Ll}$$

MSSM

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

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

could be large ?

$\Delta_e \tan\beta \sim -1$

RPV SUSY （渡邉君の話）

$$W_{\mathrm{RPV}} = \frac{1}{2}\lambda_{ijk} L_i L_j E_k^c + \lambda'_{ijk} L_i Q_j D_k^c$$

Summary

Observables

$R(D^{(*)})$, $P_\tau(D^{(*)})$, P_{D^*}

q^2 dist., etc.

input

output

Effective Lagrangian

C_X^ℓ

constraint

prediction

Models

2HDM's, MSSM,

RPV, LQ, etc.

Further study

- Better use of distributions

  q2 dist.

- Combination with other processes

  $$B^- \to \tau\bar{\nu},\ B \to X\tau\bar{\tau},\ B \to X\nu\bar{\nu}$$

- More on models

- Expected accuracy at Belle, Belle II