New Physics at SuperKEKB/Belle II

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Introduction

B factory experiments: BaBar and Belle

EPJC74(2014)3026

Asymmetric electron-positron colliders

$e^+e^- \to \Upsilon(4\mathrm{S}) \to B\bar{B}$ boosted B pairs

$B^0\bar{B}^0$ mixing

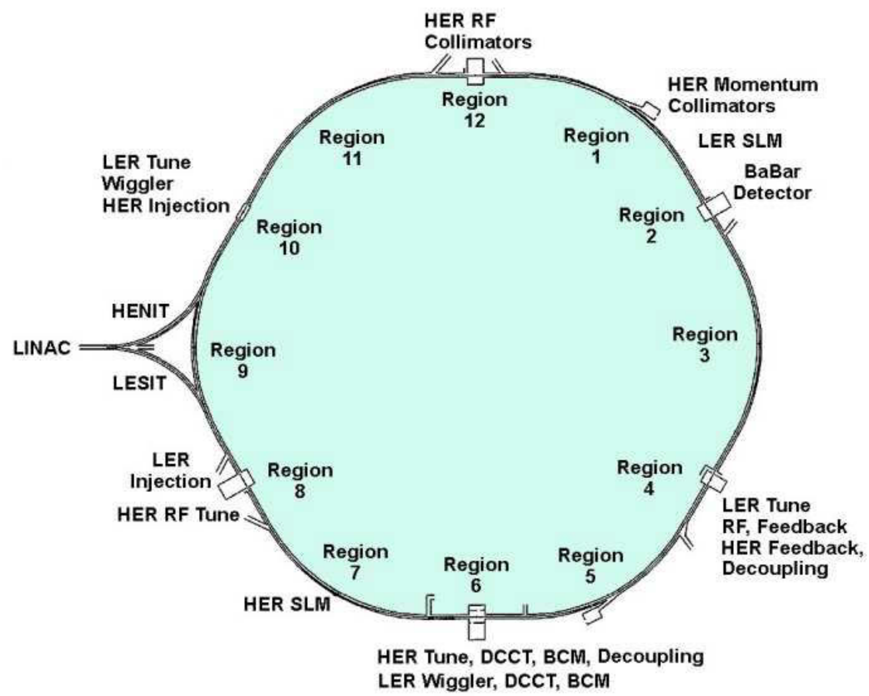
mixing-induced CP violation

time-dependent CP asymmetry

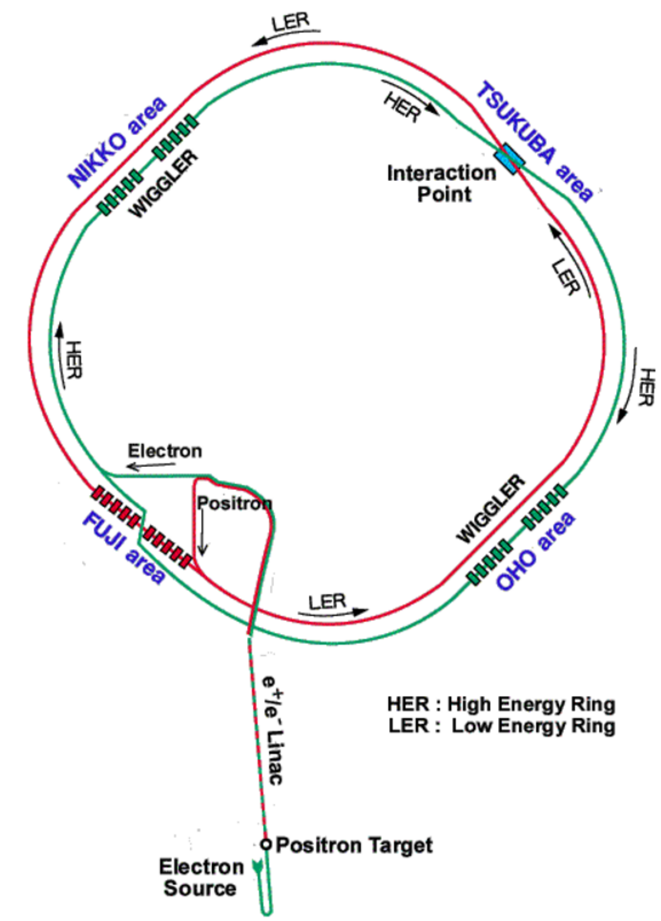
decay time ⟷ decay position

$\tau \simeq 1.6$ ps $\quad c\tau \sim 500\ \mu\mathrm{m}$

PEP-II

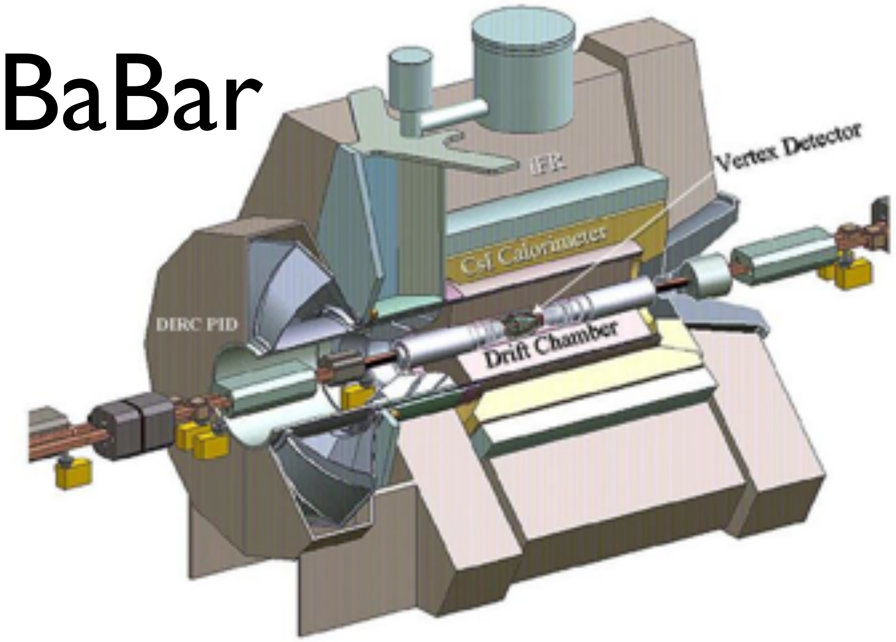


KEKB

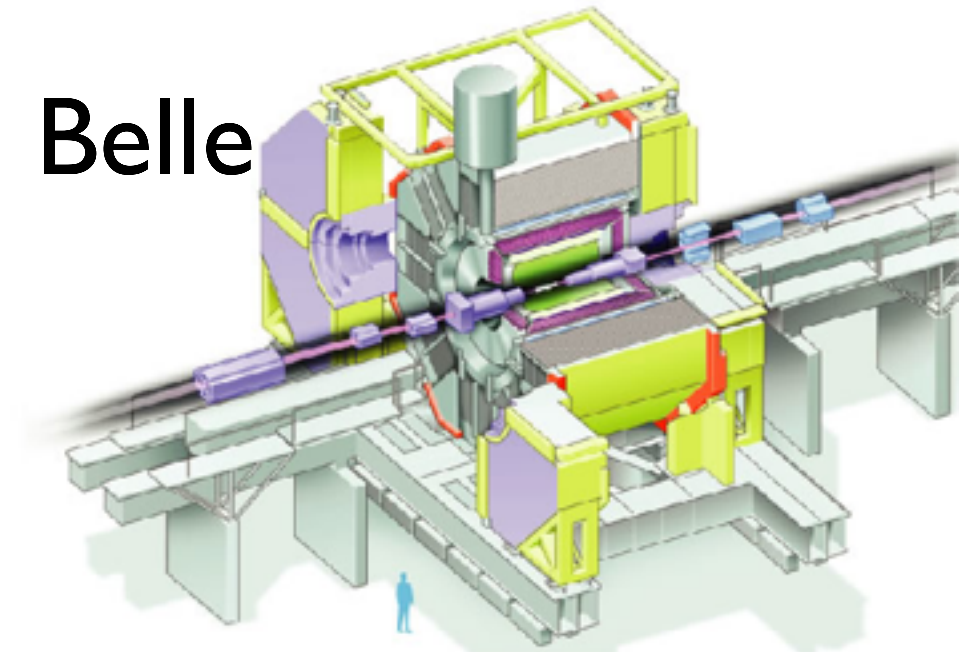


B Factory	e^- beam energy E_- (GeV)	e^+ beam energy E_+ (GeV)	Lorentz factor $\beta\gamma$	crossing angle φ (mrad)
PEP-II	9.0	3.1	0.56	0
KEKB	8.0	3.5	0.425	22

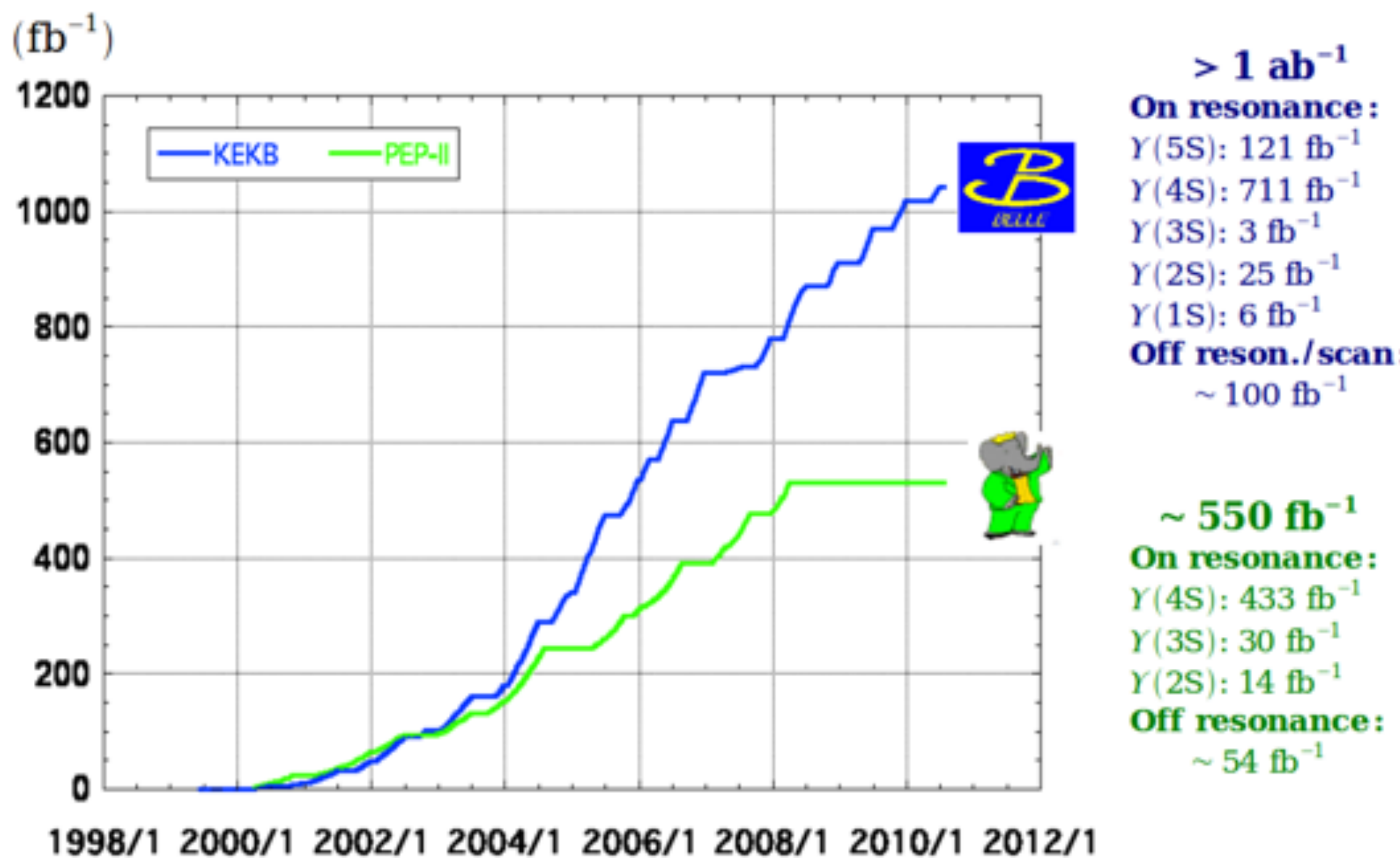
BaBar



Belle



Integrated luminosity of B factories



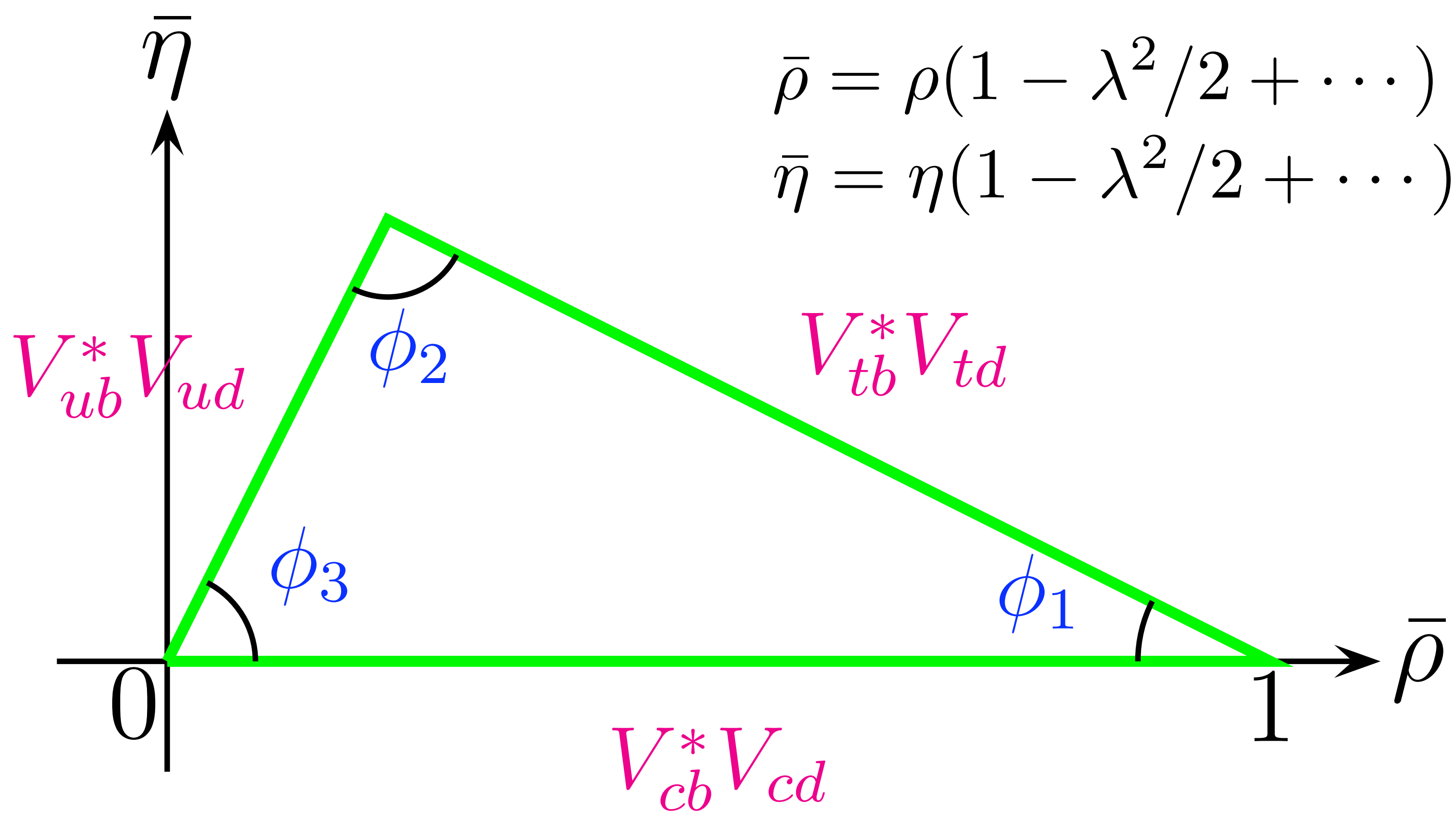
~1 /ab

Unitarity triangle

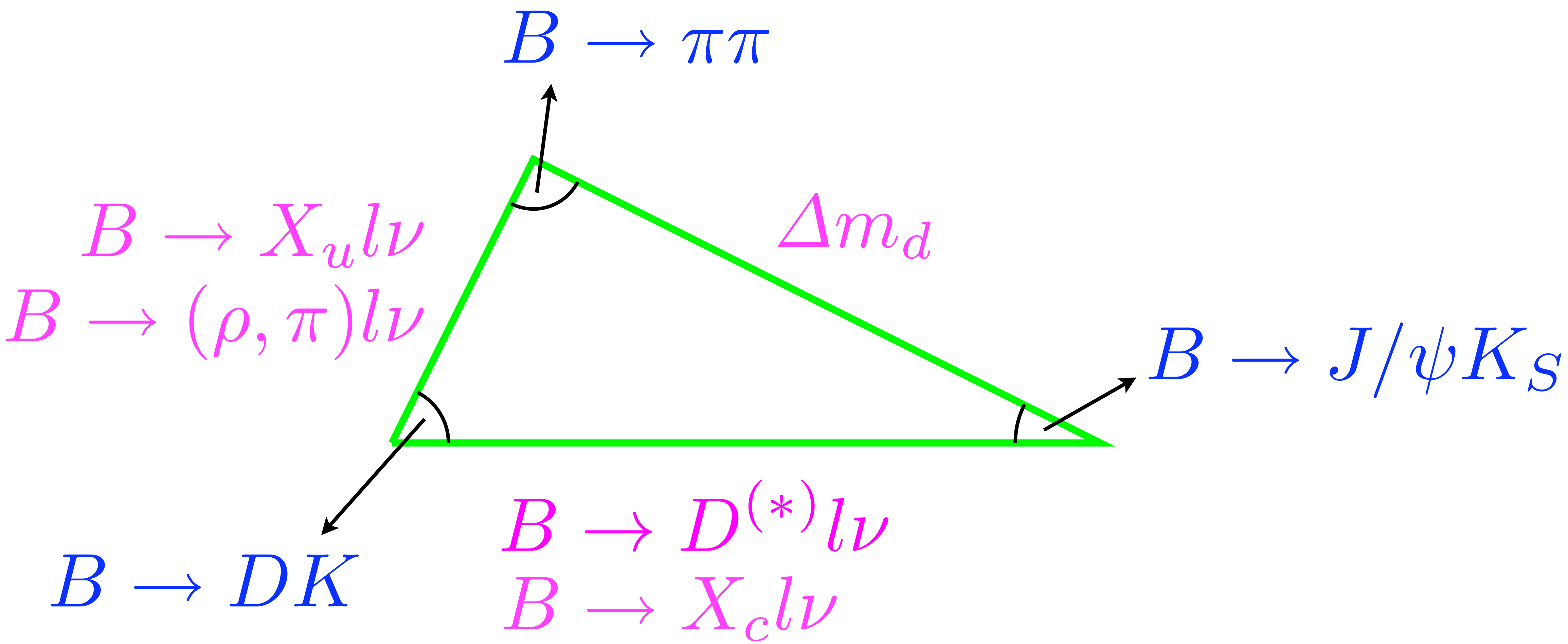
$$\mathcal{L}_{CC} = \frac{g}{\sqrt{2}} W_\mu^+ \, \bar{u}_L \gamma^\mu V_{\mathrm{CKM}} d_L + \mathrm{h.\,c.}$$

$$V_{\mathrm{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$$V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td} = 0$$

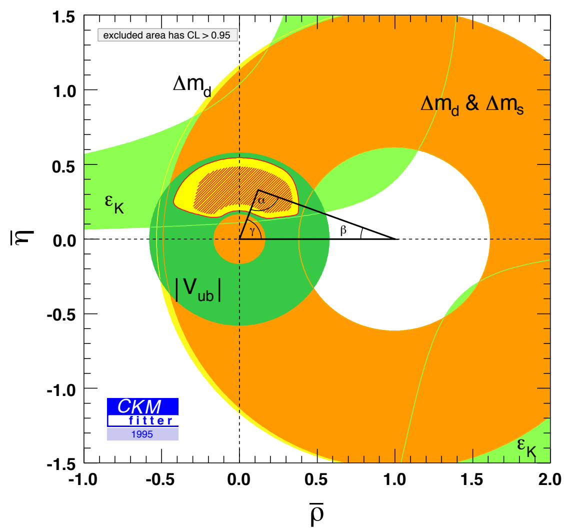


$$\bar{\rho} = \rho(1 - \lambda^2/2 + \cdots)$$
$$\bar{\eta} = \eta(1 - \lambda^2/2 + \cdots)$$

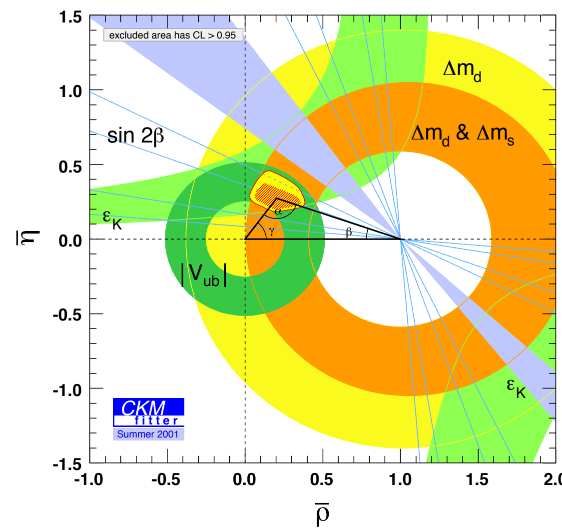

$B \to \pi\pi$
$B \to X_u l\nu$
$B \to (\rho, \pi) l\nu$
Δm_d
$B \to J/\psi K_S$
$B \to DK$
$B \to D^{(*)} l\nu$
$B \to X_c l\nu$

Two decades of CKM

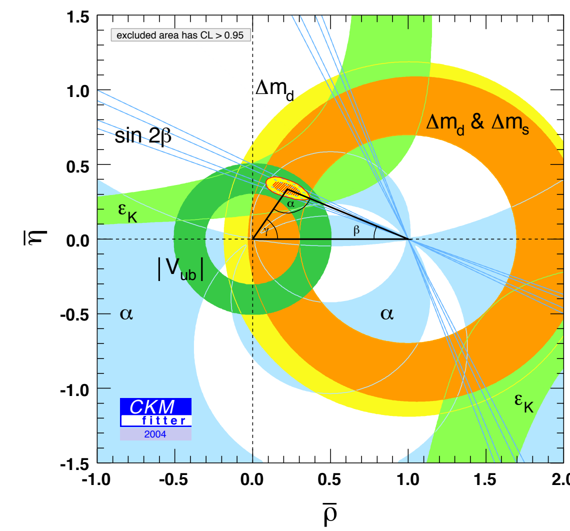
[LEP, KTeV, NA48, Babar, Belle, CDF, DØ, LHCb, CMS. . .]



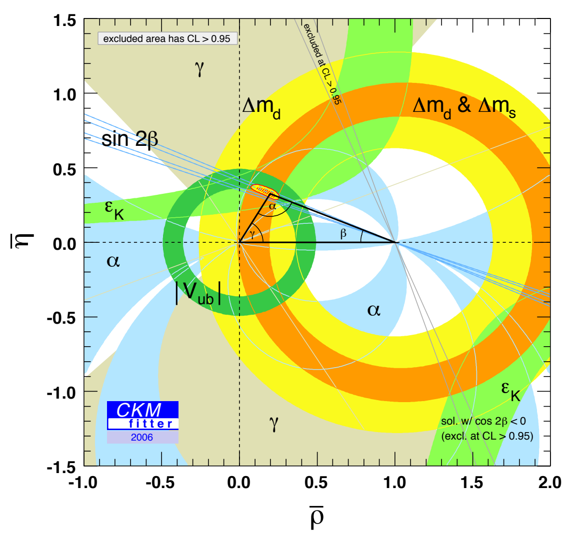
1995



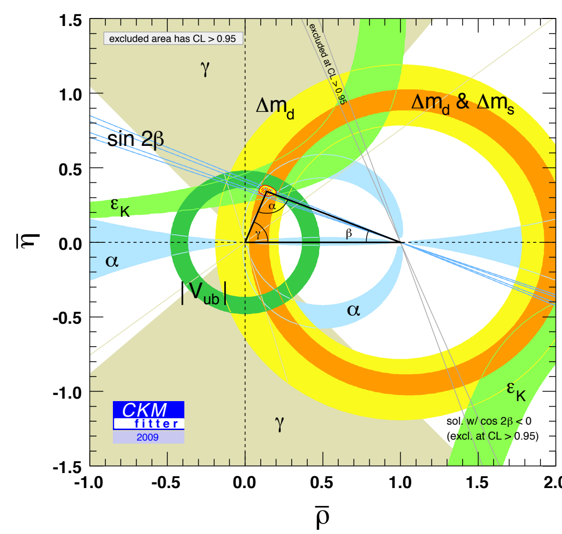
2001



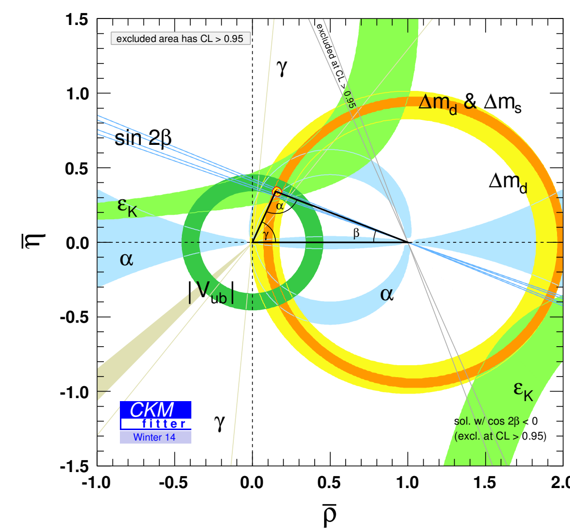
2004



2006

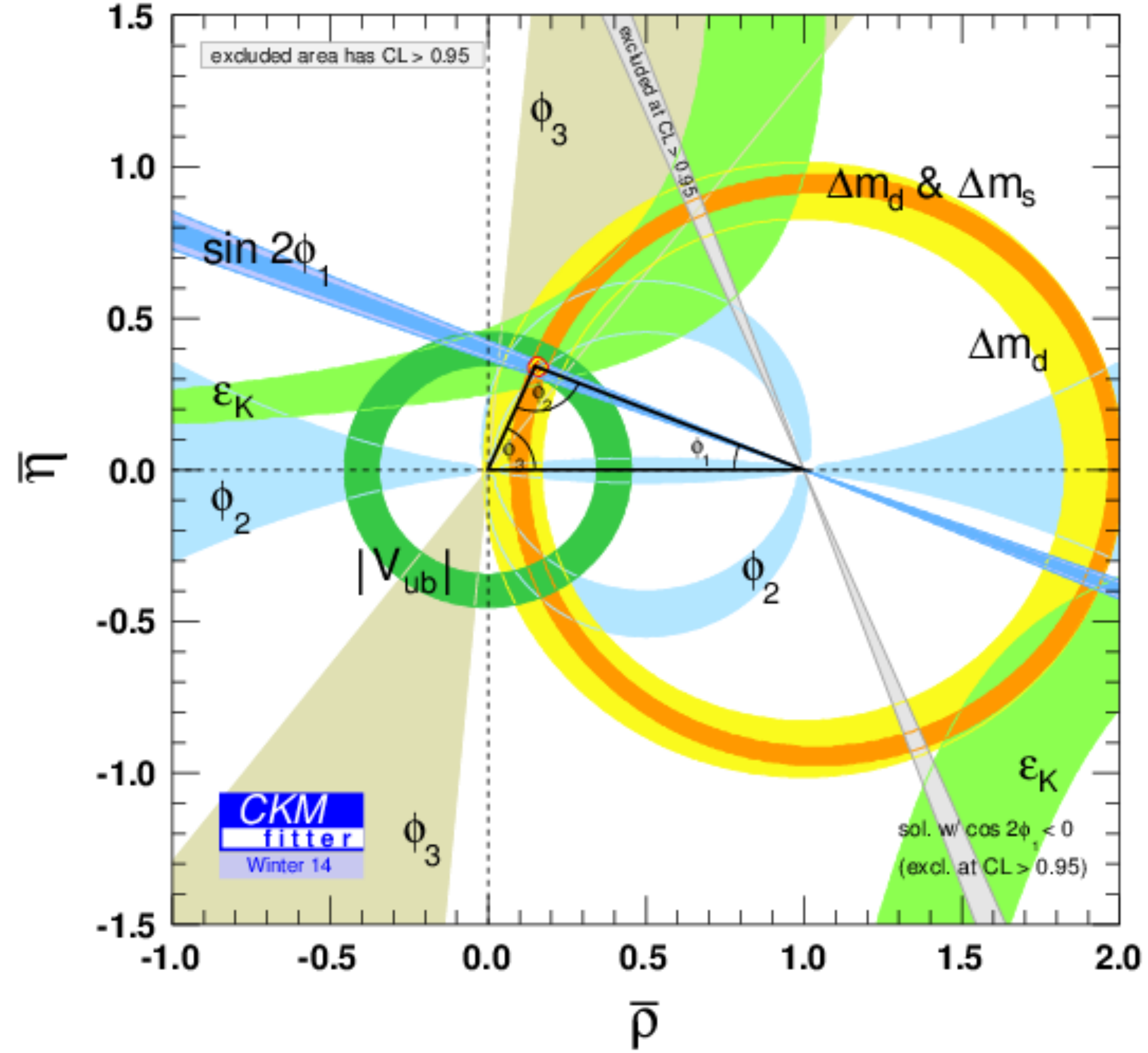


2009



2014

2014

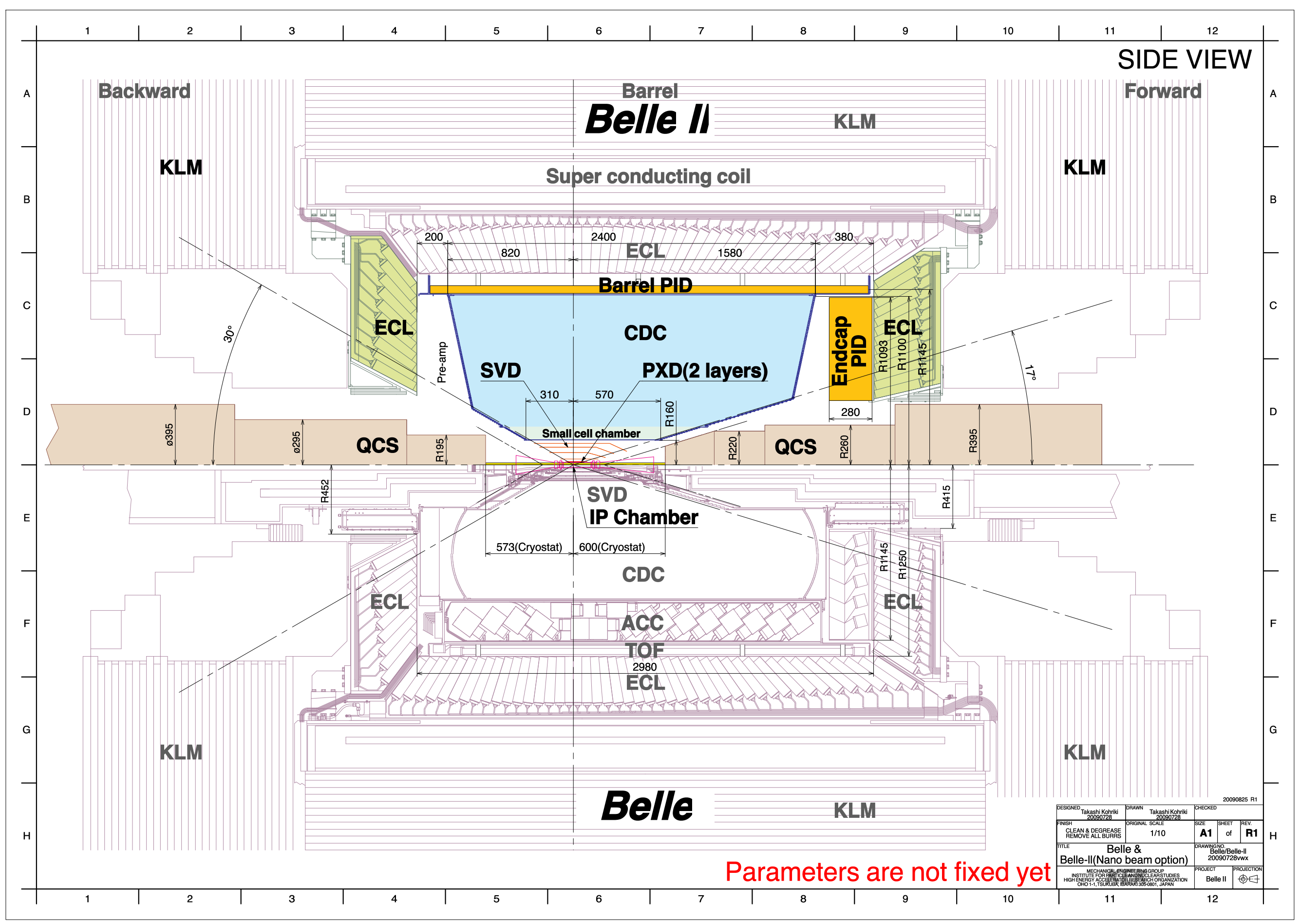


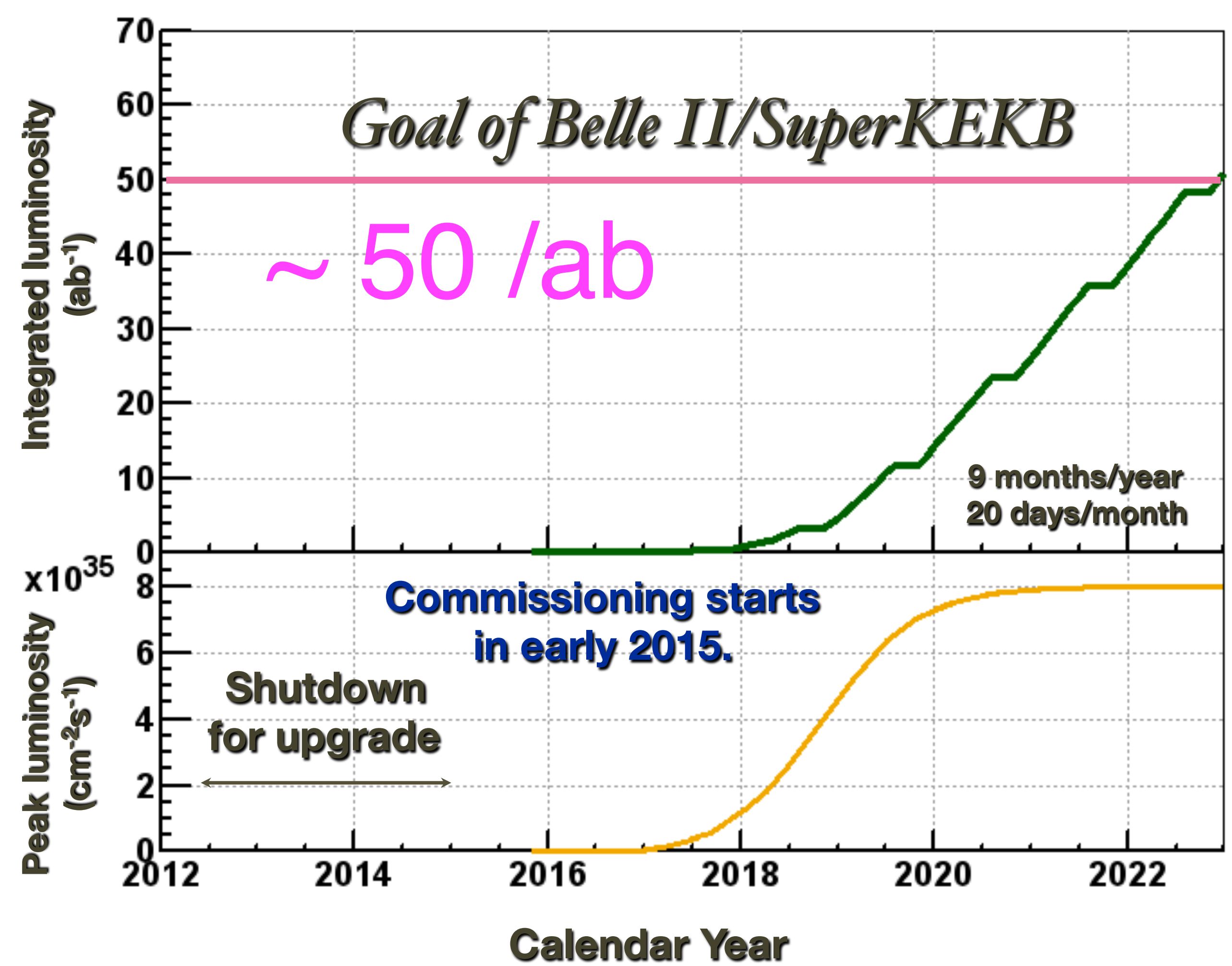
Too consistent.

SuperKEKB/Belle II

	KEKB Achieved	SuperKEKB
Energy (GeV) (LER/HER)	3.5/8.0	4.0/7.0
ξ_y	0.129/0.090	0.090/0.088
β_y^* (mm)	5.9/5.9	0.27/0.41
I (A)	1.64/1.19	3.60/2.62
Luminosity ($10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	2.11	80

x40

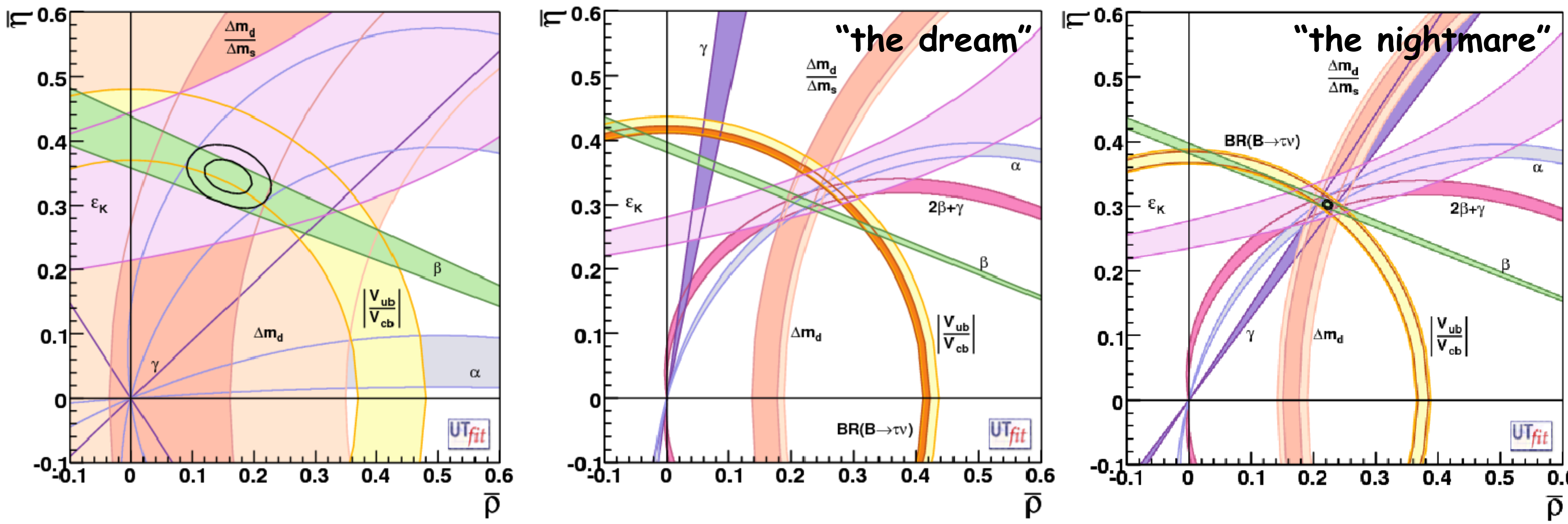




Overture: CKM matrix at 1%

Today

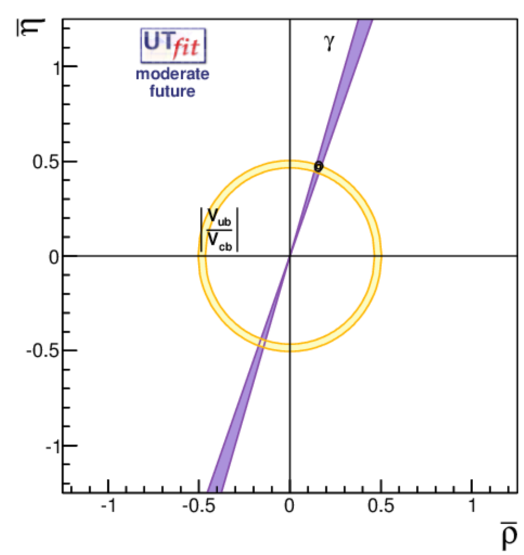
End of next-gen experiments



Generalized UT fits:

CKM at 1% in the presence of NP!

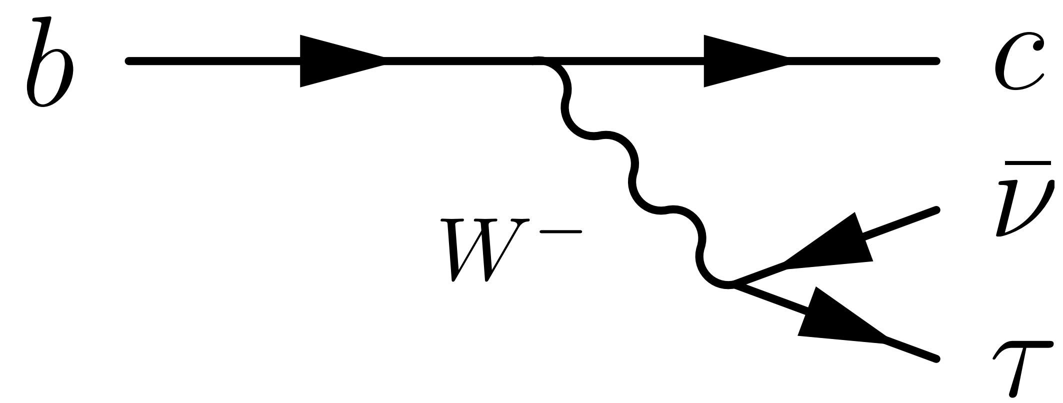
	today	future
$\bar{\rho}$	0.159±0.045	±0.008
$\bar{\eta}$	0.363±0.049	±0.010



- crucial for many NP searches

Semitauonic B decays

Present status



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

Experiments

BABAR 2012 arXiv: 1205.5442, PRL.109.101802(2012)

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

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

Belle 2007, 2009, 2010

$$R(D) = 0.390 \pm 0.100 \qquad R(D^*) = 0.347 \pm 0.050$$

Combined:

$$R(D) = 0.421 \pm 0.058$$

$$R(D^*) = 0.337 \pm 0.025 \qquad (\rho = -0.19)$$

Standard model

$$R(D) = 0.297 \pm 0.017$$ (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)

Theoretical uncertainty

Form factors

data from $\bar{B} \to D^{(*)}\ell\bar{\nu}$ $(\ell = e, \mu)$

+ heavy quark effective theory (HQET)

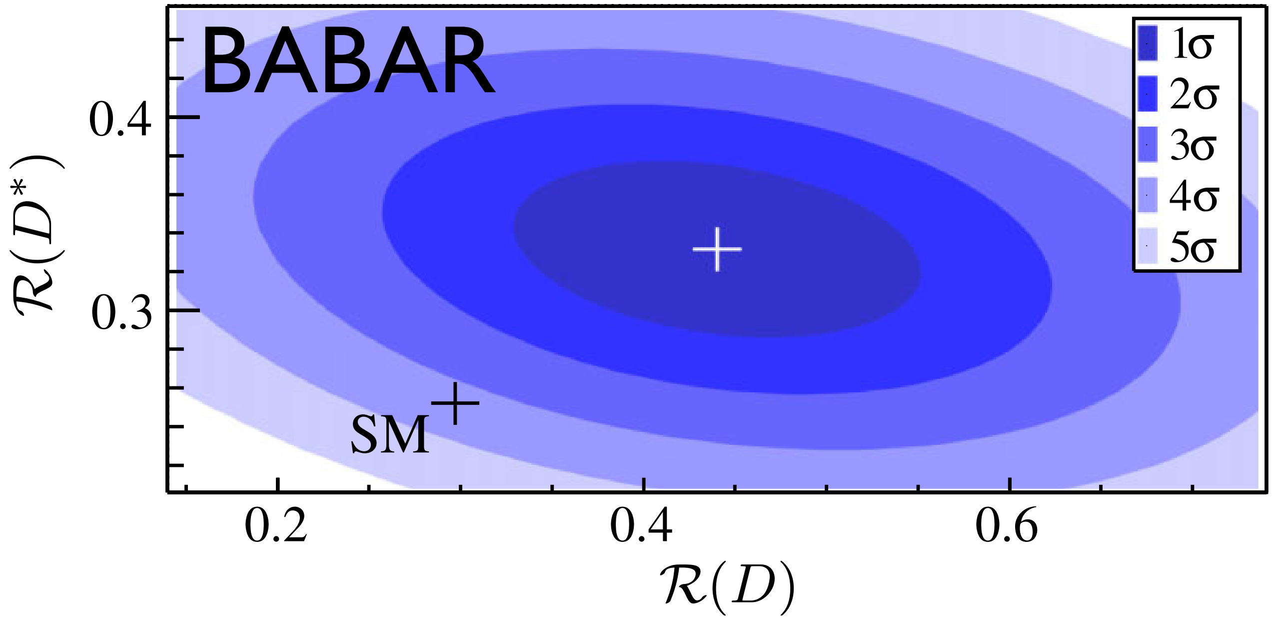
+ lattice QCD

	$R(D)$	$R(D^*)$
Exp.	0.421±0.058	0.337±0.025
SM	0.305±0.012	0.252±0.004
SD	1.9σ	2.9σ

→ 3.5σ

New physics?

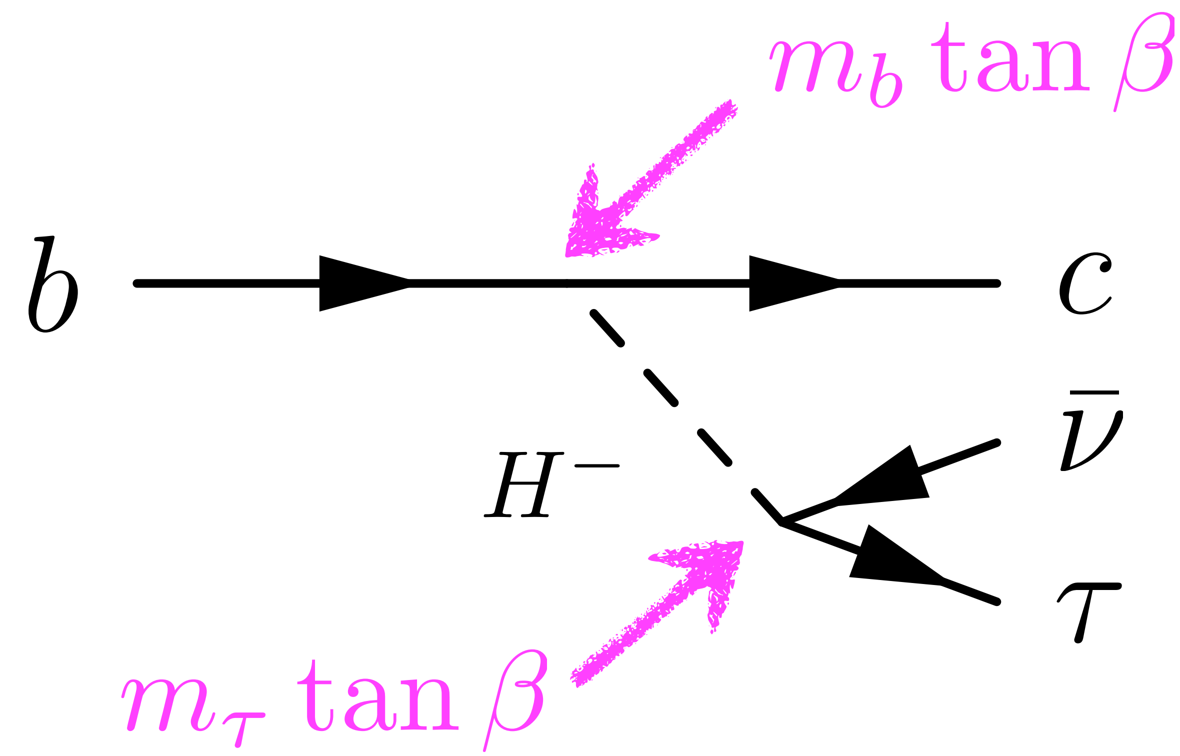
arXiv:1303.0571, PRD88.072012(2013)



Charged Higgs boson

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

Type-II 2HDM (SUSY)



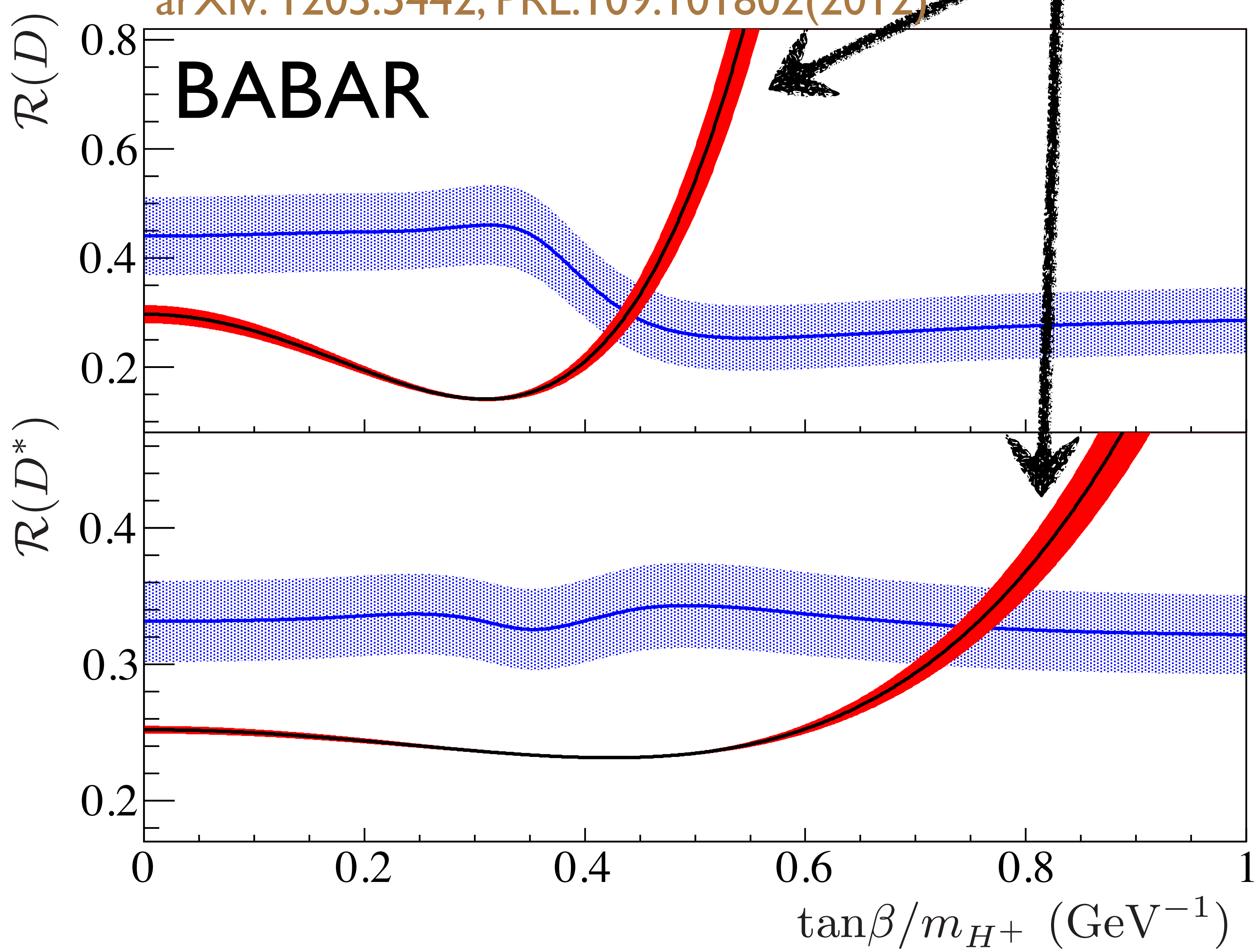
$$\propto m_b m_\tau \tan^2\beta$$

Sensitive to the charged Higgs
if tanβ is large.

But, negative interference.

predictions of 2HDM II

arXiv: 1205.5442, PRL.109.101802(2012)



Charged Higgs *excluded* at 99.8% CL

Model-independent approach

MT, R.Watanabe,arXiv1212.1878, PRD87.034028(2013).

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

all possible 4f 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

$$\mathcal{O}^l_{V_1} = \bar{c}_L \gamma^\mu b_L \, \bar{\tau}_L \gamma_\mu \nu_{Ll} \,,$$ SM-like, RPV, LQ

$$\mathcal{O}^l_{V_2} = \bar{c}_R \gamma^\mu b_R \, \bar{\tau}_L \gamma_\mu \nu_{Ll} \,,$$ RH current

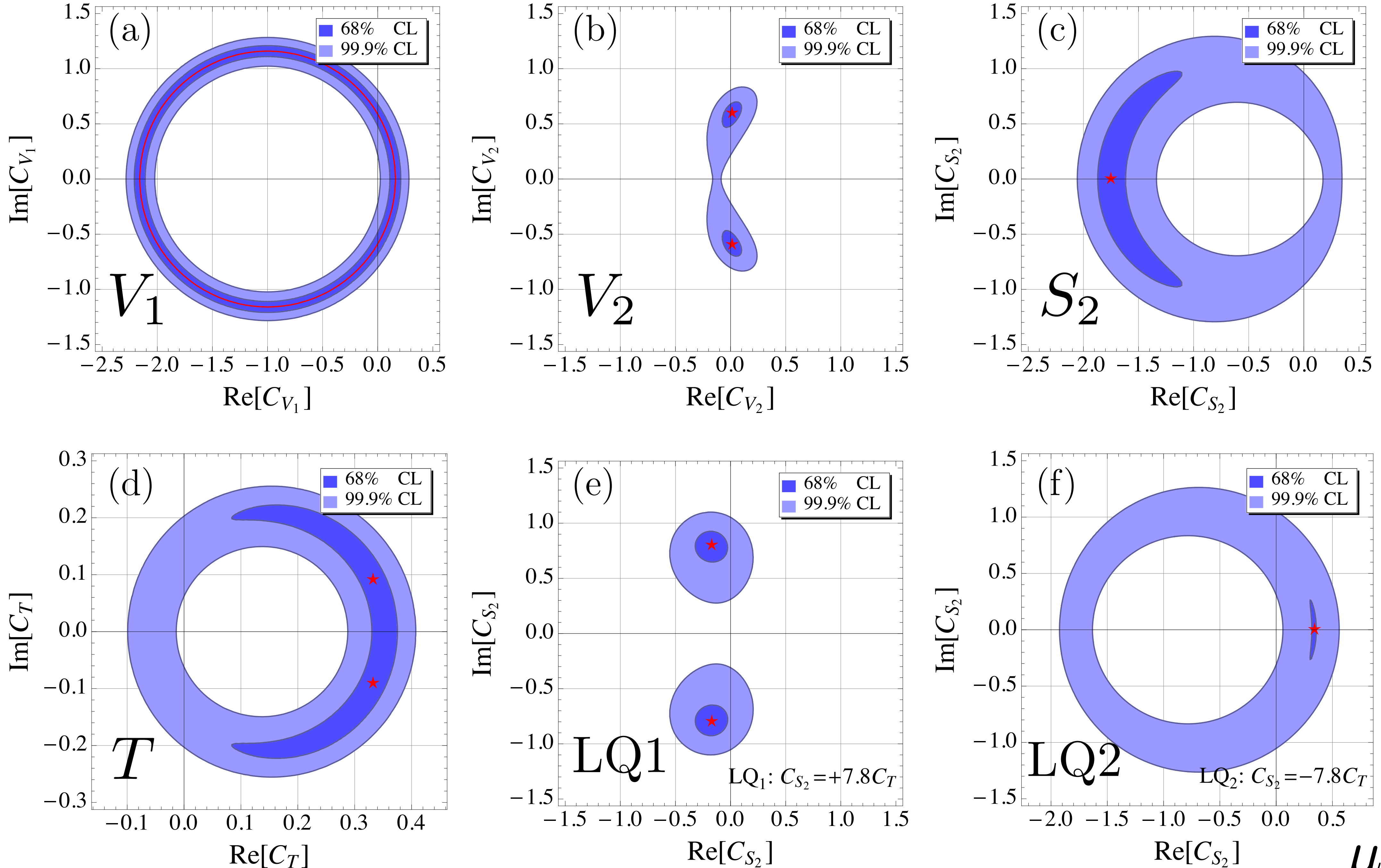
$$\mathcal{O}^l_{S_1} = \bar{c}_L b_R \, \bar{\tau}_R \nu_{Ll} \,,$$ charged Higgs II, RPV, LQ

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

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

Constraints on Wilson coefficients

Y. Sakaki, MT, A. Tayduganov, R. Watanabe, 1412.3761



$\mu = m_b$

S_1 (charged Higgs in type-II 2HDM) disfavored.

Leptoquark models

Y. Sakaki, MT, A. Tayduganov, R. Watanabe
arXiv:1309.0301, PRD88.094012(2013)

Six types of LQ possible

Buchmueller, Ruckl, Wyler (1987)

	S_1	S_3	V_2	R_2	U_1	U_3
spin	0	0	1	0	1	1
$F = 3B + L$	-2	-2	-2	0	0	0
$SU(3)_c$	3^*	3^*	3^*	3	3	3
$SU(2)_L$	1	3	2	2	1	3
$U(1)_{Y=Q-T_3}$	$1/3$	$1/3$	$5/6$	$7/6$	$2/3$	$2/3$

$$C^l_{V_1} = \frac{1}{2\sqrt{2}G_F V_{cb}} \sum_{k=1}^{3} V_{k3} \left[\frac{g^{kl}_{1L} g^{23*}_{1L}}{2M^2_{S_1^{1/3}}} - \frac{g^{kl}_{3L} g^{23*}_{3L}}{2M^2_{S_3^{1/3}}} + \frac{h^{2l}_{1L} h^{k3*}_{1L}}{M^2_{U_1^{2/3}}} - \frac{h^{2l}_{3L} h^{k3*}_{3L}}{M^2_{U_3^{2/3}}} \right],$$

constrained by $\bar{B} \to X_s \nu \bar{\nu}$

$$C^l_{V_2} = 0,$$

$$C^l_{S_1} = \frac{1}{2\sqrt{2}G_F V_{cb}} \sum_{k=1}^{3} V_{k3} \left[-\frac{2g^{kl}_{2L} g^{23*}_{2R}}{M^2_{V_2^{1/3}}} - \frac{2h^{2l}_{1L} h^{k3*}_{1R}}{M^2_{U_1^{2/3}}} \right],$$

disfavored

$$C^l_{S_2} = \frac{1}{2\sqrt{2}G_F V_{cb}} \sum_{k=1}^{3} V_{k3} \left[-\frac{g^{kl}_{1L} g^{23*}_{1R}}{2M^2_{S_1^{1/3}}} - \frac{h^{2l}_{2L} h^{k3*}_{2R}}{2M^2_{R_2^{2/3}}} \right],$$

$$C^l_T = \frac{1}{2\sqrt{2}G_F V_{cb}} \sum_{k=1}^{3} V_{k3} \left[\frac{g^{kl}_{1L} g^{23*}_{1R}}{8M^2_{S_1^{1/3}}} - \frac{h^{2l}_{2L} h^{k3*}_{2R}}{8M^2_{R_2^{2/3}}} \right],$$

$$C_{S_2}(m_{\rm LQ}) = \pm 4 C_T(m_{\rm LQ})$$

RG

$$C_{S_2}(m_b) = \pm 7.8 C_T(m_b)$$

Discrimination with the q2 distributions

Y. Sakaki, MT, A. Tayduganov, R. Watanabe, 1412.3761

Several possible NP scenarios

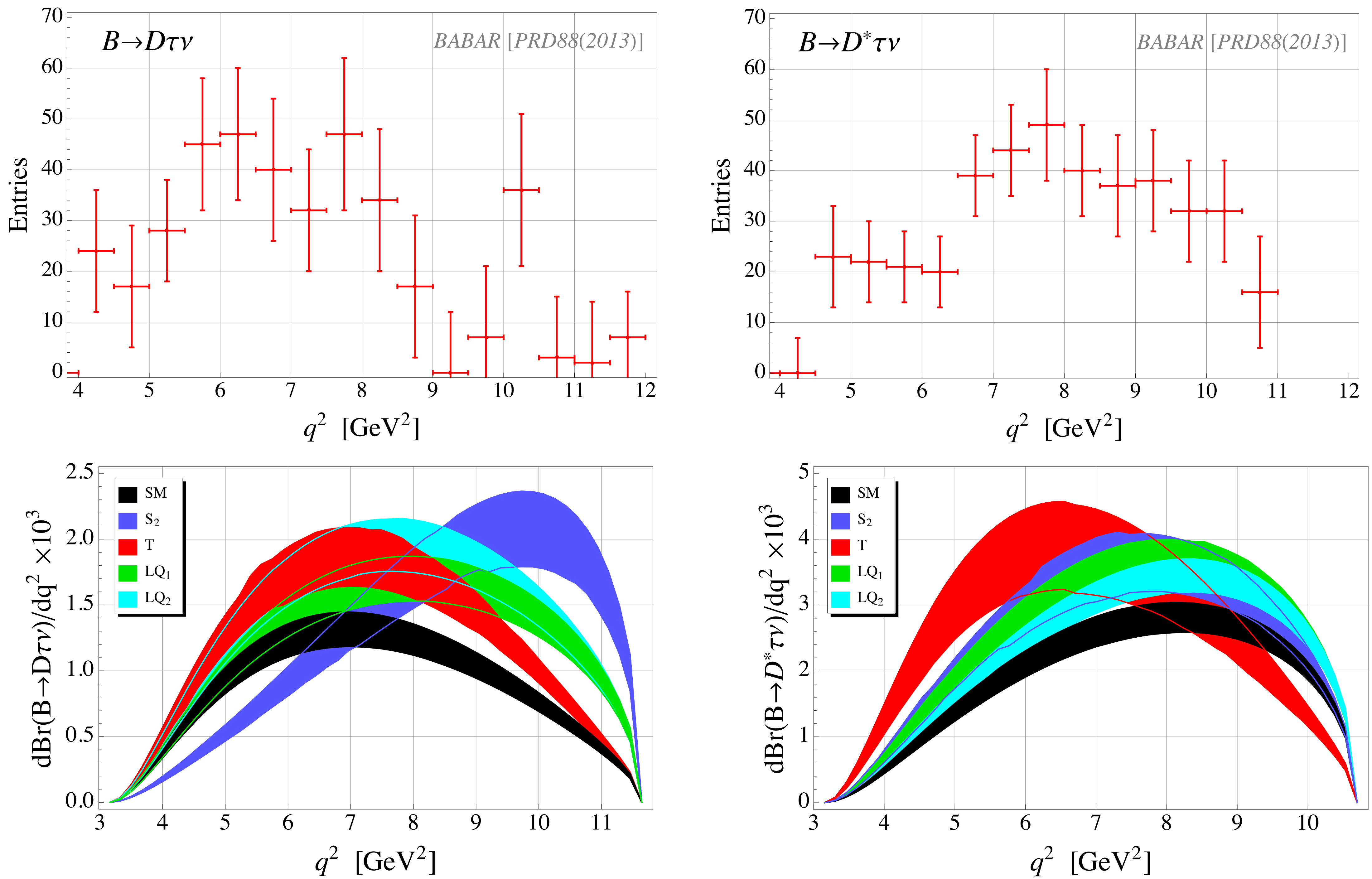
- $V_1\,:\;C_{V_1}=0.16,\;C_{X\neq V_1}=0\;\;,$
- $V_2\,:\;C_{V_2}=0.01\pm0.60i,\;C_{X\neq V_2}=0\;\;,$
- $S_2\,:\;C_{S_2}=-1.75,\;C_{X\neq S_2}=0\;\;,$
- $T\,:\;C_T=0.33\pm0.09i,\;C_{X\neq T}=0\;\;,$
- LQ_1 scenario: $C_{S_2}=7.8C_T=-0.17\pm0.80i,\;C_{X\neq S_2,T}=0\;\;,$
- LQ_2 scenario: $C_{S_2}=-7.8C_T=0.34,\;C_{X\neq S_2,T}=0\;\;.$

How to discriminate: other observables

$A_{FB},\;P_\tau,\;P_{D^*}$ rather hard to measure

$q^2=(p_B-p_{D^{(*)}})^2$ easier

Implication of the present q2 data



p value

model	$\overline{B} \to D\tau\overline{\nu}$	$\overline{B} \to D^*\tau\overline{\nu}$	$\overline{B} \to (D + D^*)\tau\overline{\nu}$
SM	54%	65%	67%
V_1	54%	65%	67%
V_2	54%	65%	67%
S_2	0.02%	37%	0.1%
T	58%	0.1%	1.0%
LQ_1	13%	58%	25%
LQ_2	21%	72%	42%

$S_2, \ T$ disfavored

$\mathrm{LQ}_{1,2}$ (combinations of $S_2, \ T$) allowed

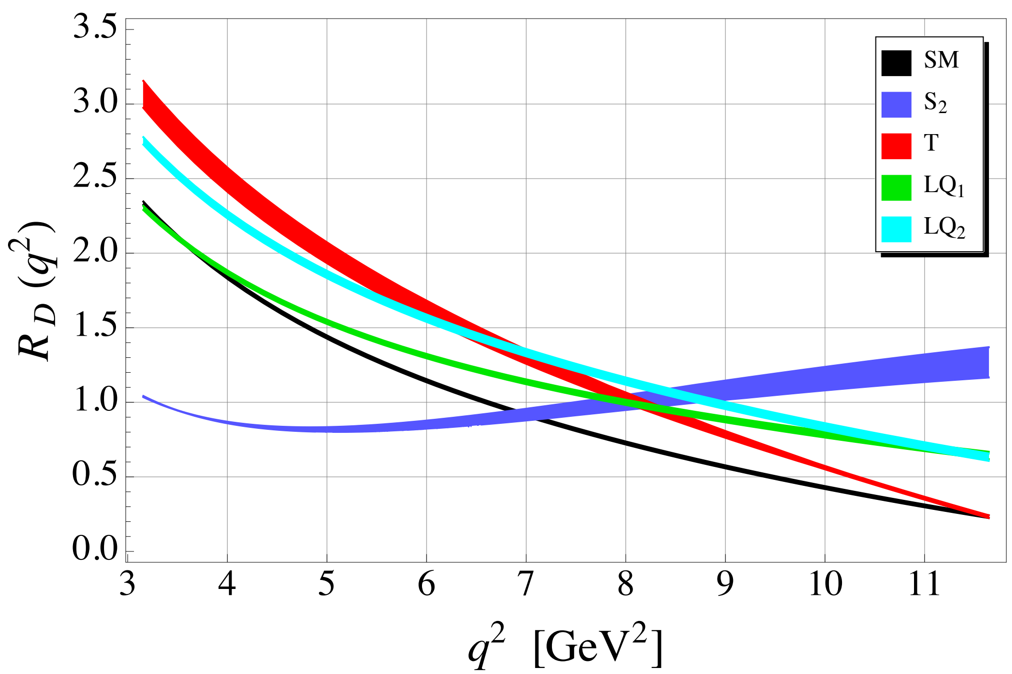
Ratio of the q2 distributions

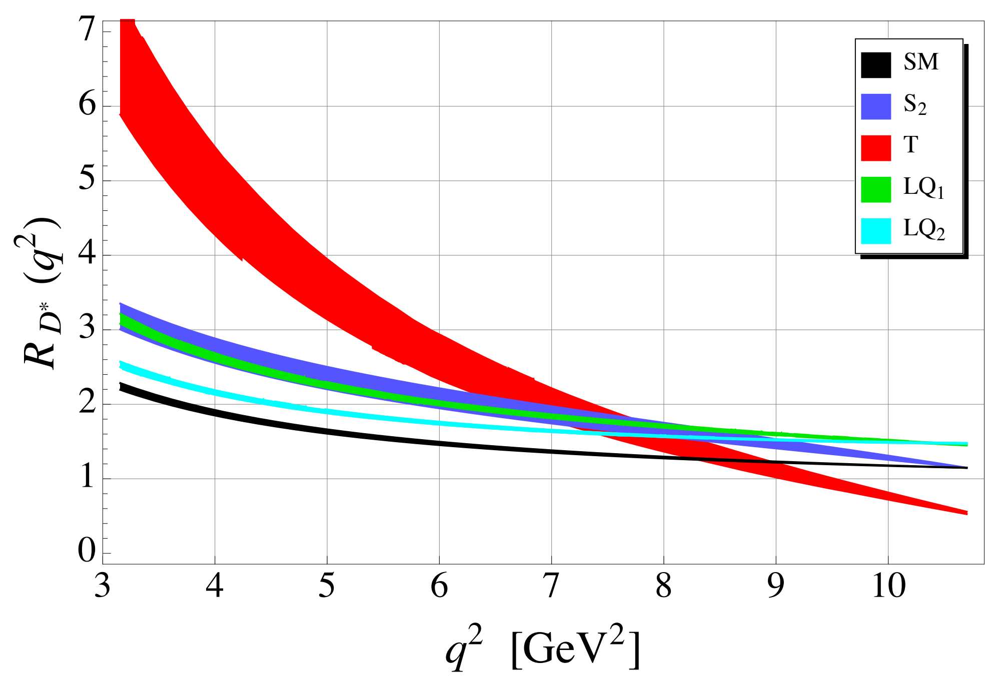
$$R_D(q^2) \equiv \frac{d\mathcal{B}(\overline{B} \to D\tau\overline{\nu})/dq^2}{d\mathcal{B}(\overline{B} \to D\ell\overline{\nu})/dq^2} \frac{\lambda_D(q^2)}{(m_B^2 - m_D^2)^2} \left(1 - \frac{m_\tau^2}{q^2}\right)^{-2}$$

$$R_{D^*}(q^2) \equiv \frac{d\mathcal{B}(\overline{B} \to D^*\tau\overline{\nu})/dq^2}{d\mathcal{B}(\overline{B} \to D^*\ell\overline{\nu})/dq^2} \left(1 - \frac{m_\tau^2}{q^2}\right)^{-2} .$$

$$\lambda_{D^{(*)}}(q^2) = ((m_B - m_{D^{(*)}})^2 - q^2)((m_B + m_{D^{(*)}})^2 - q^2)$$

No Vcb dependence, less form factor uncertainties





Simulated data vs tested models

χ^2 of the binned $R_{D^{(*)}}(q^2)$

Required luminosity to exclude the tested model

$\mathcal{L}$ [fb^{-1}]		model						
		SM	V_1	V_2	S_2	T	LQ$_1$	LQ$_2$
"data"	V_1	1170 (270)		10^6 (×)	500 (×)	900 (×)	4140 (×)	2860 (1390)
	V_2	1140 (270)	10^6 (×)		510 (×)	910 (×)	4210 (×)	3370 (1960)
	S_2	560 (290)	560 (13750)	540 (36450)		380 (×)	1310 (35720)	730 (4720)
	T	600 (270)	680 (×)	700 (×)	320 (×)		620 (×)	550 (1980)
	LQ$_1$	1010 (270)	4820 (×)	4650 (×)	1510 (×)	800 (×)		5920 (1940)
	LQ$_2$	1020 (250)	3420 (1320)	3990 (1820)	1040 (20560)	650 (4110)	5930 (1860)	

(...): integrated quantities

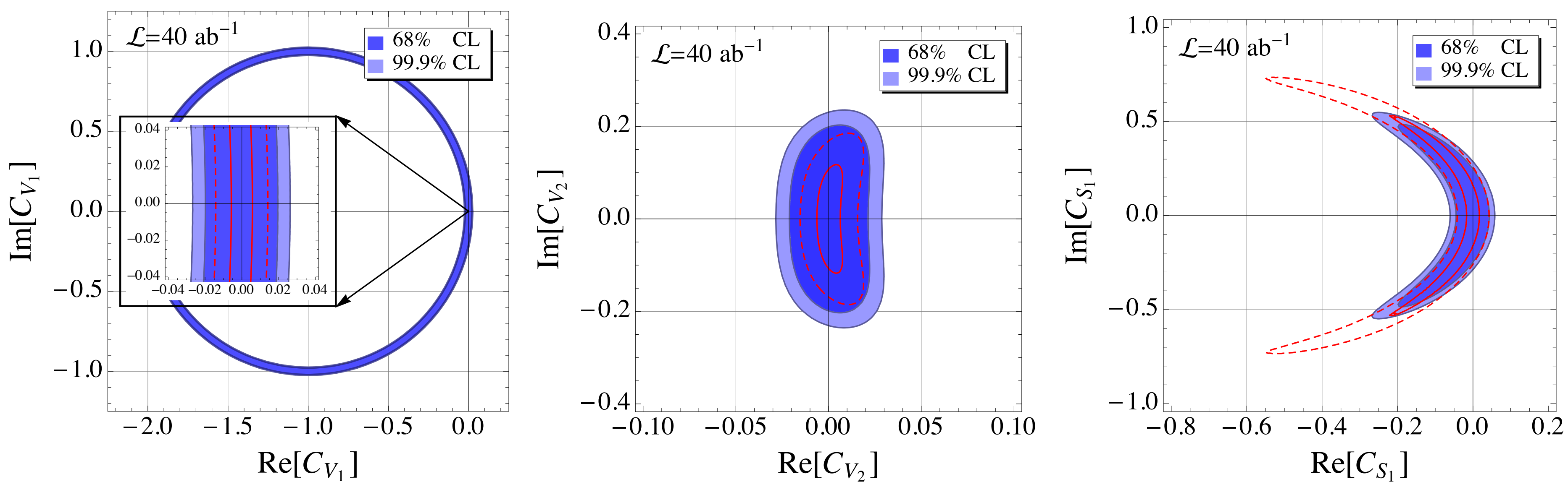
99.9 % CL

$L \lesssim 6\ \mathrm{ab}^{-1}$ in most cases

→ A good target at an earlier stage of Belle II

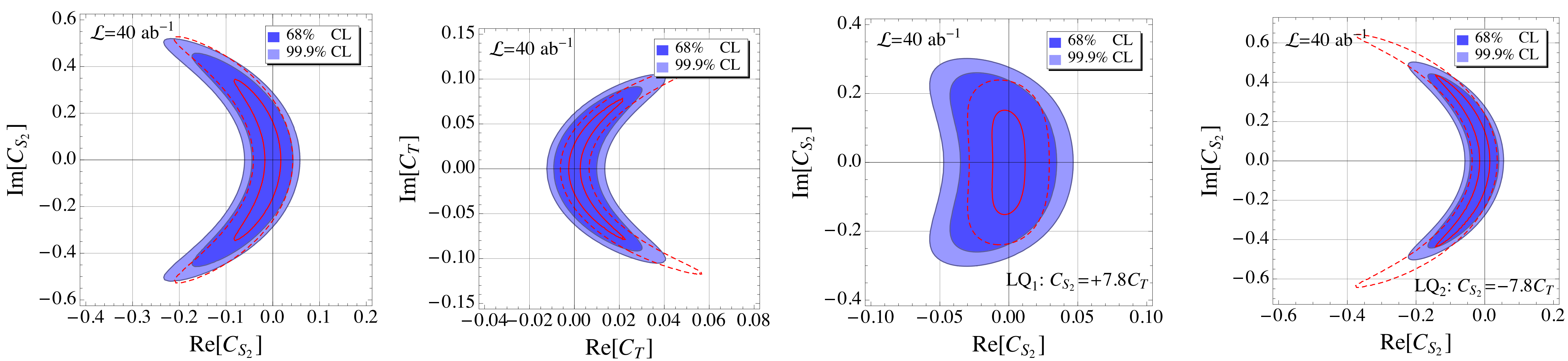
Ultimate Belle II sensitivity

Assuming exp. = SM for $R(D),\ R(D^*)$



blue $R_{D^{(*)}}(q^2)$

red $R(D^{(*)})$



$$M_{\rm NP} \gtrsim \underset{V_{1,2}}{5(7)},\ \underset{S_{1,2}}{5(6)},\ \underset{T}{7(10)},\ \underset{\rm LQ_1}{5(7)},\ \underset{\rm LQ_2}{5(6)}$$

Right-handed b to u current

1411.1177, T. Enomoto, MT

Flavor structure in the quark sector

Standard Model:

Yukawa couplings ⇒ charged current

$$\mathcal{L}_{CC} = \frac{g}{\sqrt{2}} W_\mu^+ \, \bar{u}_L \gamma^\mu V_{\mathrm{CKM}} d_L + \mathrm{h.\,c.}$$

$$V_{\mathrm{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

New Physics:

Minimal Flavor Violation

No other flavor violation

Non-MFV

New source(s) of flavor violation

Hierarchy

$$V_{\rm CKM} = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & \boxed{\lambda^3 A(\rho - i\eta)} \\ -\lambda & 1-\frac{\lambda^2}{2} & \lambda^2 A \\ \lambda^3 A(1-\rho-i\eta) & -\lambda^2 A & 1 \end{pmatrix}$$

$$= \begin{pmatrix} 0.97428 \pm 0.00015 & 0.2253 \pm 0.0007 & \boxed{0.00347^{+0.00016}_{-0.00012}} \\ 0.2252 \pm 0.0007 & 0.97345^{+0.00015}_{-0.00016} & 0.0410^{+0.0011}_{-0.0007} \\ 0.00862^{+0.00026}_{-0.00020} & 0.0403^{+0.0011}_{-0.0007} & 0.999152^{+0.000030}_{-0.000045} \end{pmatrix}$$

V_{ub} the smallest element

may be affected by Non-MFV new physics

Right-handed current in b→u

Model-indep. effective Lagrangian of dim. 6

$$\mathcal{L}_6 = \frac{C}{\Lambda^2}\bar{u}_R\gamma^\mu b_R\,\tilde{\Phi}^\dagger iD_\mu\Phi + \mathrm{h.\,c.}$$

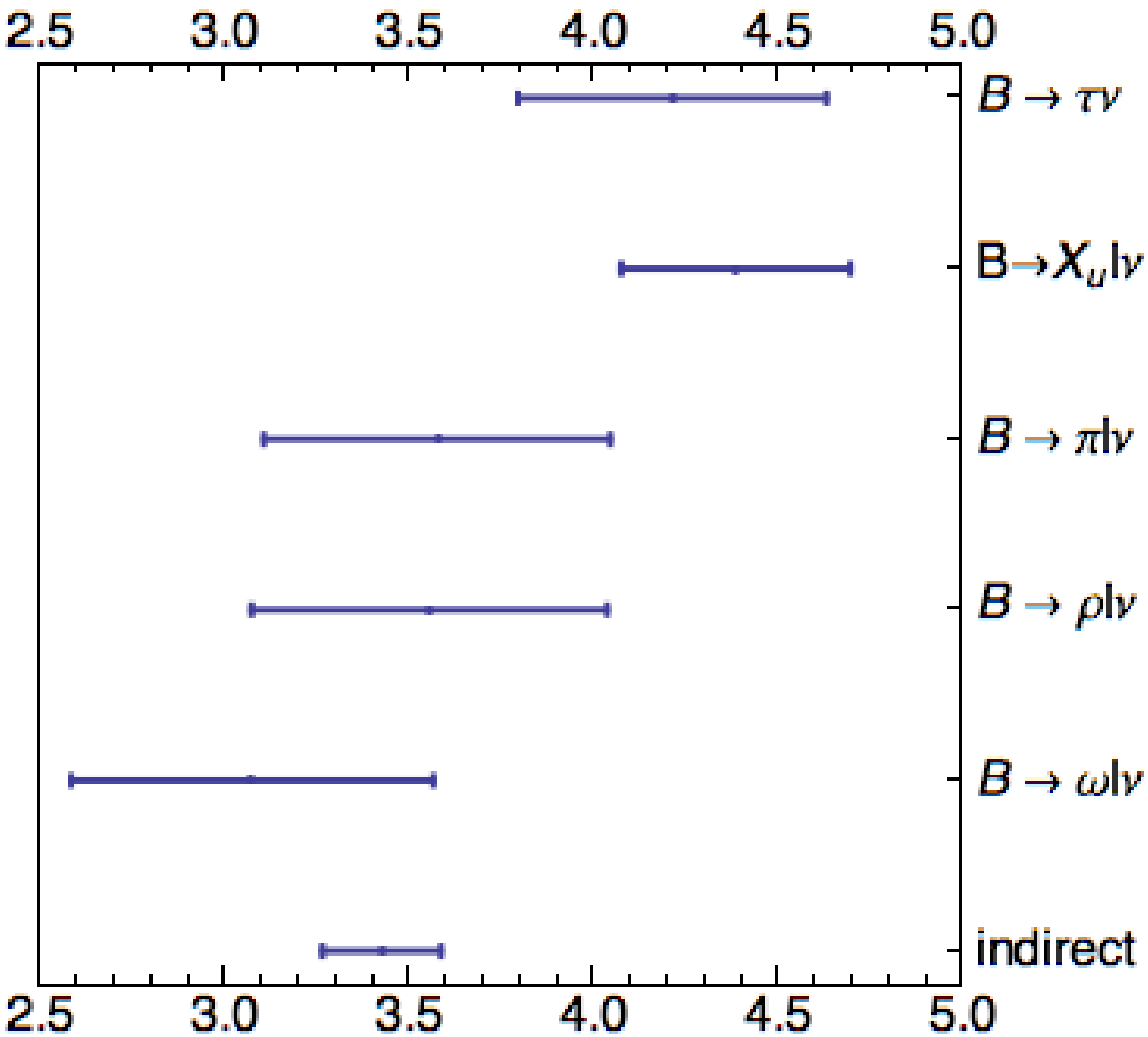
→ Effective charged current interaction

$$\mathcal{L}_{\rm cc}^{\rm eff} = -\frac{g}{\sqrt{2}}\left[V_{ub}^L\bar{u}_L\gamma^\mu b_L + V_{ub}^R\bar{u}_R\gamma^\mu b_R\right]W_\mu^+ + \mathrm{h.\,c.}$$

$$V_{ub}^R = C\frac{v^2}{2\Lambda^2} \sim 3\times 10^{-2}C\left(\frac{1\mathrm{TeV}}{\Lambda}\right)^2$$

$\sim \lambda^3$ possible

Present status of |Vub| determination



$|V_{ub}^L| \times 10^3$

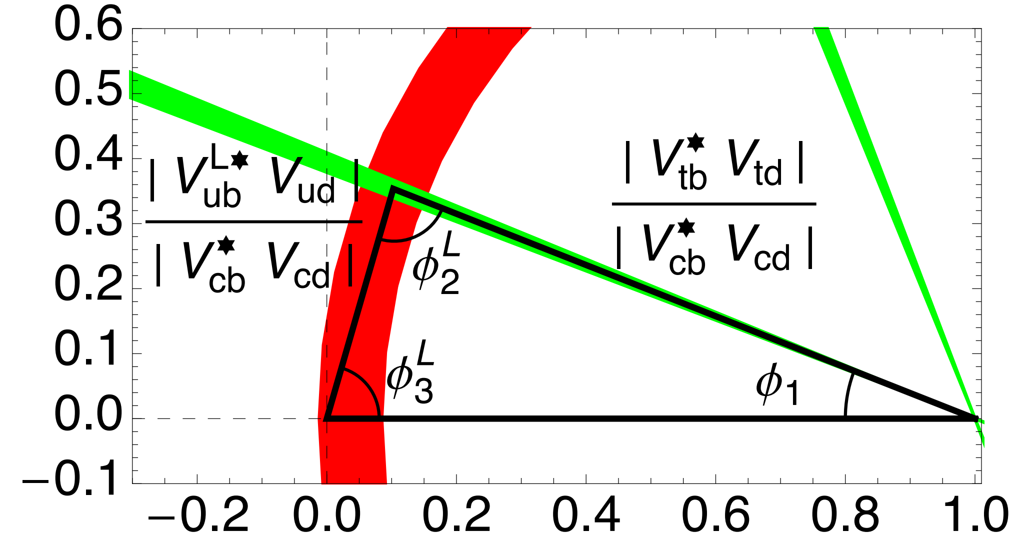
Average

$|V_{ub}| = 3.64 \times 10^{-3}$

$\chi^2/\mathrm{dof} = 2.16$

$(p = 0.055)$

CKM unitarity



$$\phi_3^L = \arg V_{ub}^{L*} = 73.8^\circ \pm 7.5^\circ$$

Effects of the right-handed current

$B \to \tau\nu$ axial vector current only

$$|V_{ub}^{\exp}|^2 = |V_{ub}^L - V_{ub}^R|^2 = |V_{ub}^L|^2 \left[1 - 2\mathrm{Re}\left(\frac{V_{ub}^R}{V_{ub}^L}\right) + \left|\frac{V_{ub}^R}{V_{ub}^L}\right|^2 \right]$$

$B \to \pi\ell\nu$ vector current only

$$|V_{ub}^{\exp}|^2 = |V_{ub}^L + V_{ub}^R|^2 = |V_{ub}^L|^2 \left[1 + 2\mathrm{Re}\left(\frac{V_{ub}^R}{V_{ub}^L}\right) + \left|\frac{V_{ub}^R}{V_{ub}^L}\right|^2 \right]$$

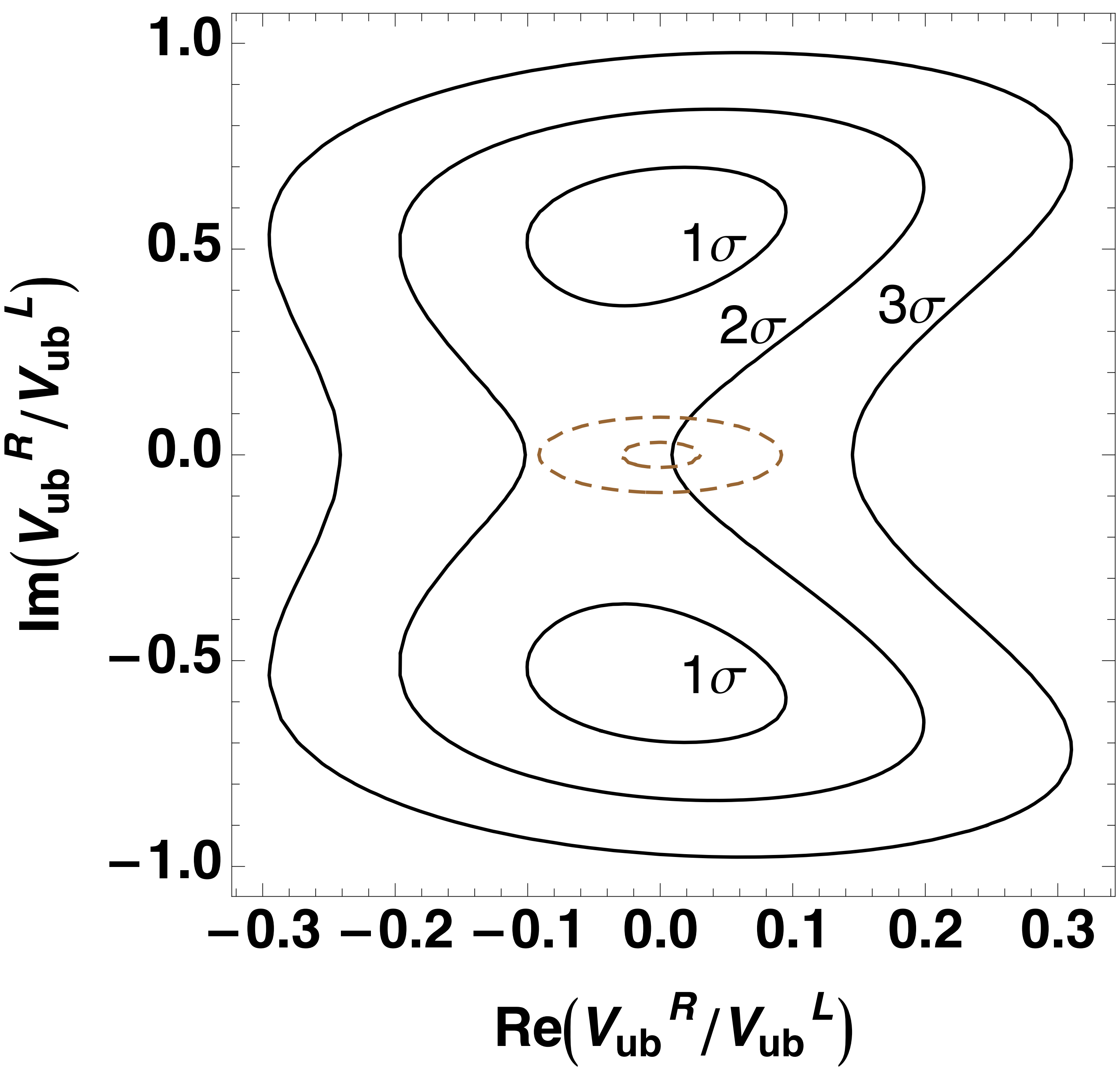
$B \to X_u\ell\nu$ no interference $m_u \simeq 0$

$$|V_{ub}^{\exp}|^2 = |V_{ub}^L|^2 + |V_{ub}^R|^2 = |V_{ub}^L|^2 \left[1 + \left|\frac{V_{ub}^R}{V_{ub}^L}\right|^2 \right]$$

$B \to \rho(\omega)\ell\nu$ vector and axial vector

$$|V_{ub}^{\exp}|^2 = |V_{ub}^L|^2 \left[1 - 1.18(1.25)\,\mathrm{Re}\left(\frac{V_{ub}^R}{V_{ub}^L}\right) + \left|\frac{V_{ub}^R}{V_{ub}^L}\right|^2 \right]$$

LCSR Ball, Zwicky



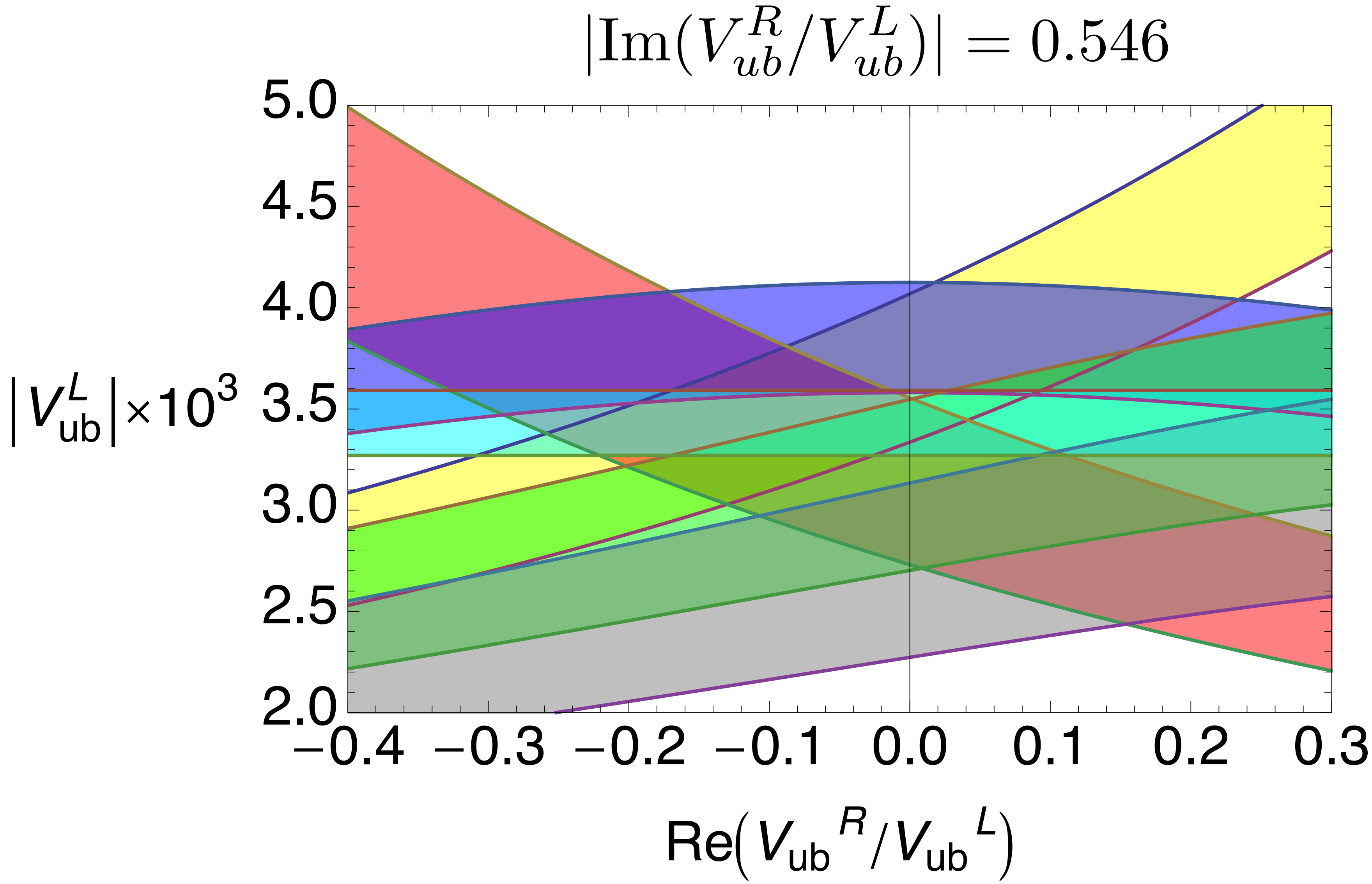
Best fit

$$|V_{ub}^{L}| = 3.43 \times 10^{-3}$$

$$\mathrm{Re}\left(\frac{V_{ub}^{R}}{V_{ub}^{L}}\right) = -4.21 \times 10^{-3}$$

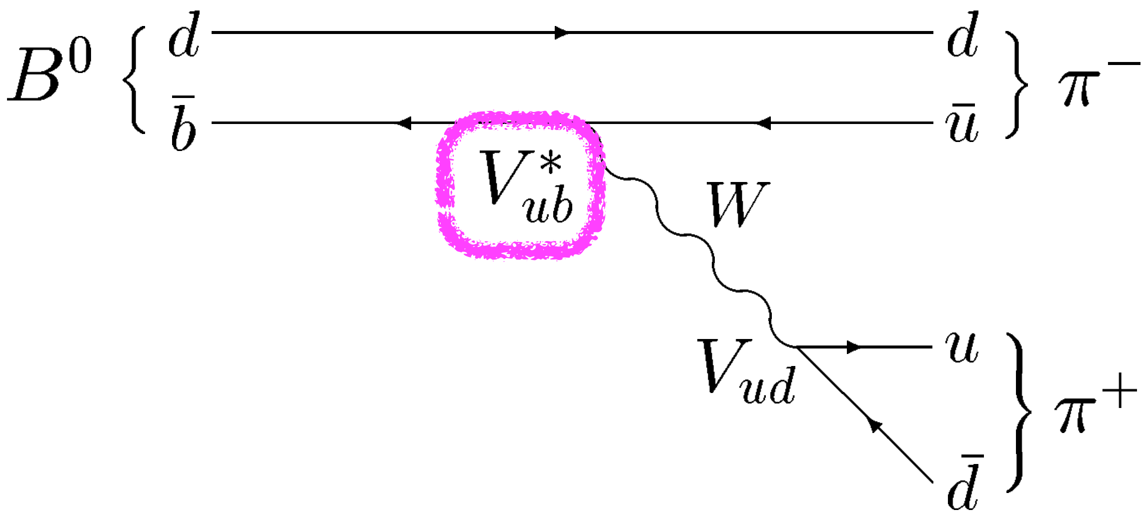
$$\left|\mathrm{Im}\left(\frac{V_{ub}^{R}}{V_{ub}^{L}}\right)\right| = 0.551$$

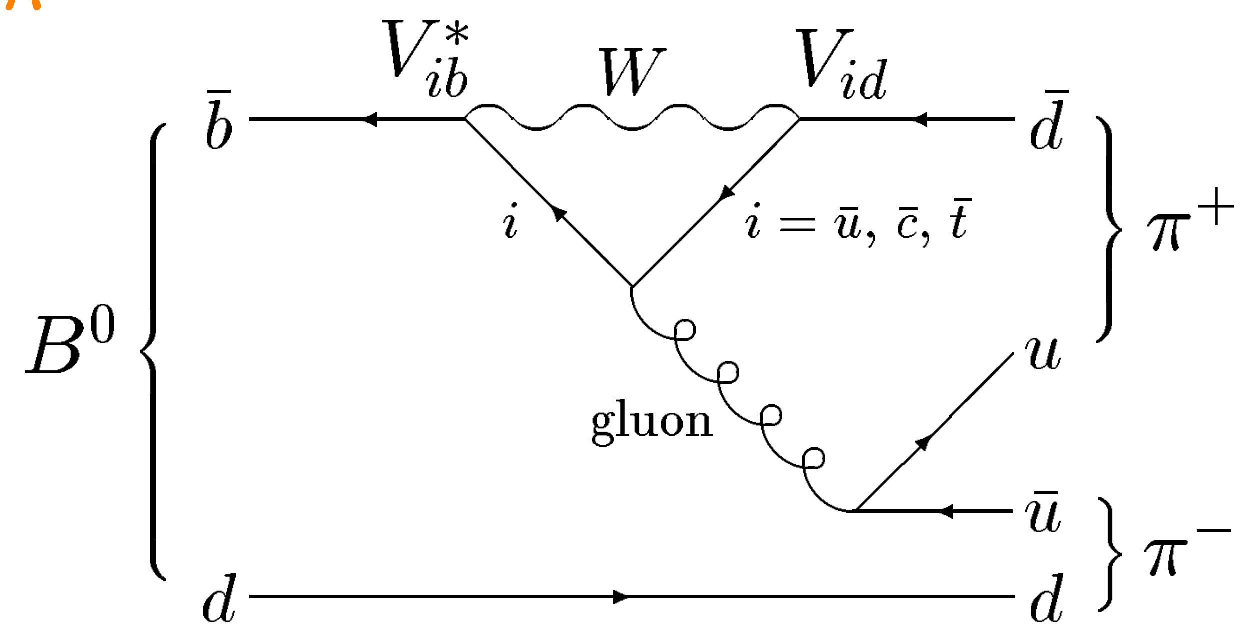
$$\chi^2/\mathrm{dof} = 2.27 \quad (p = 0.078)$$



Yellow: B->τν
Blue: B->Xulν
Red: B->πlν
LightBlue: indirect
LightGreen: B->ρlν
Gray: B->ωlν

CP violation in $B \to \pi\pi$





$$I = 0, 2 \qquad\qquad I = 0$$

Isospin analysis for ϕ_2

$$A_I = \langle(\pi\pi)_I|B^0\rangle \qquad \bar{A}_I = \langle(\pi\pi)_I|\bar{B}^0\rangle$$

$$A(B^+ \to \pi^+\pi^0) = A(B^0 \to \pi^+\pi^-)/\sqrt{2} + A(B^0 \to \pi^0\pi^0)$$

$$\Rightarrow \quad z = \sqrt{2}A_0/A_2,\ \bar{z} = \sqrt{2}\bar{A}_0/\bar{A}_2$$

determined from BR's

Observables

Branching ratios

$$\mathrm{BR}(B \to \pi^+\pi^-),\ \mathrm{BR}(B \to \pi^0\pi^0),\ \mathrm{BR}(B^\pm \to \pi^\pm\pi^0)$$

Time-dependent CP asymmetry

$$\frac{\Gamma(B^0 \to \pi^+\pi^-) - \Gamma(\bar{B}^0 \to \pi^+\pi^-)}{\Gamma(B^0 \to \pi^+\pi^-) + \Gamma(\bar{B}^0 \to \pi^+\pi^-)} = C_{\pi^+\pi^-} \cos(\Delta M_{B_d} t) - S_{\pi^+\pi^-} \sin(\Delta M_{B_d} t)$$

$$C_{\pi^+\pi^-},\ S_{\pi^+\pi^-}$$

Time-integrated CP asymmetry

$$C_{\pi^0\pi^0}$$

Direct CP asymmetry in charged B decays

$$A_{CP}(B^+ \to \pi^+\pi^0)$$

Experimental values

$C_{\pi^+\pi^-}$	-0.31 ± 0.05
$S_{\pi^+\pi^-}$	-0.66 ± 0.06
$C_{\pi^0\pi^0}$	-0.43 ± 0.24
$A_{CP}(B^+ \to \pi^+\pi^0)$	-0.026 ± 0.039
$\mathrm{BR}(B \to \pi^+\pi^-)$	$(5.10 \pm 0.19) \times 10^{-6}$
$\mathrm{BR}(B \to \pi^0\pi^0)$	$(1.91 \pm 0.225) \times 10^{-6}$
$\mathrm{BR}(B^\pm \to \pi^\pm\pi^0)$	$(5.48 \pm 0.345) \times 10^{-6}$

Effect of the right-handed current

$$A_2 = A_{2L} + A_{2R}, \ \bar{A}_2 = \bar{A}_{2L} + \bar{A}_{2R}$$

$$R_{\pi\pi} \equiv \frac{1 + \bar{A}_{2R}/\bar{A}_{2L}}{1 + A_{2R}/A_{2L}} \qquad \frac{A_{2R}}{A_{2L}} \simeq 1.56 \frac{V_{ub}^{R*}}{V_{ub}^{L*}} e^{i\delta_{\pi\pi}}$$

RGE
factorization

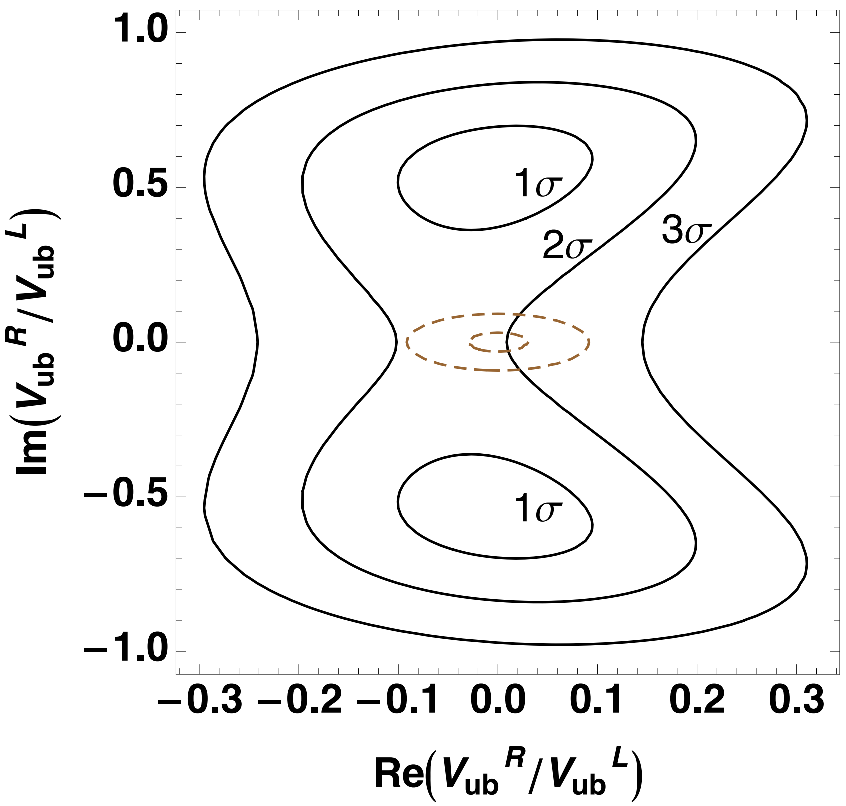
$$C_{\pi^+\pi^-} = \left(1 - |R_{\pi\pi}|^2 \left|\frac{1+\bar{z}}{1+z}\right|^2\right) \Big/ \left(1 + |R_{\pi\pi}|^2 \left|\frac{1+\bar{z}}{1+z}\right|^2\right)$$

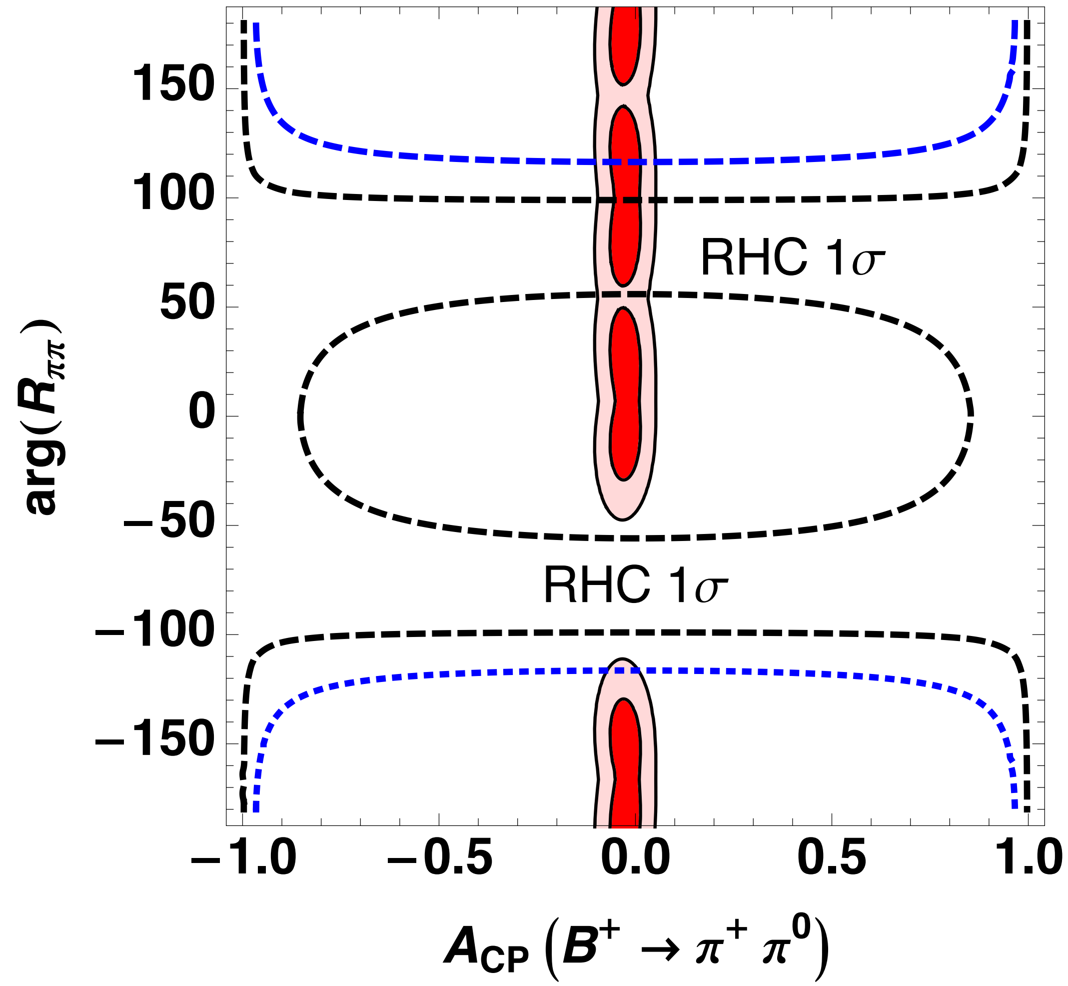
$$S_{\pi^+\pi^-} = \sqrt{1 - C_{\pi^+\pi^-}^2}\ \sin\left(2\phi_2^L + \arg\left(R_{\pi\pi}\right) + \arg\left(\frac{1+\bar{z}}{1+z}\right)\right)$$

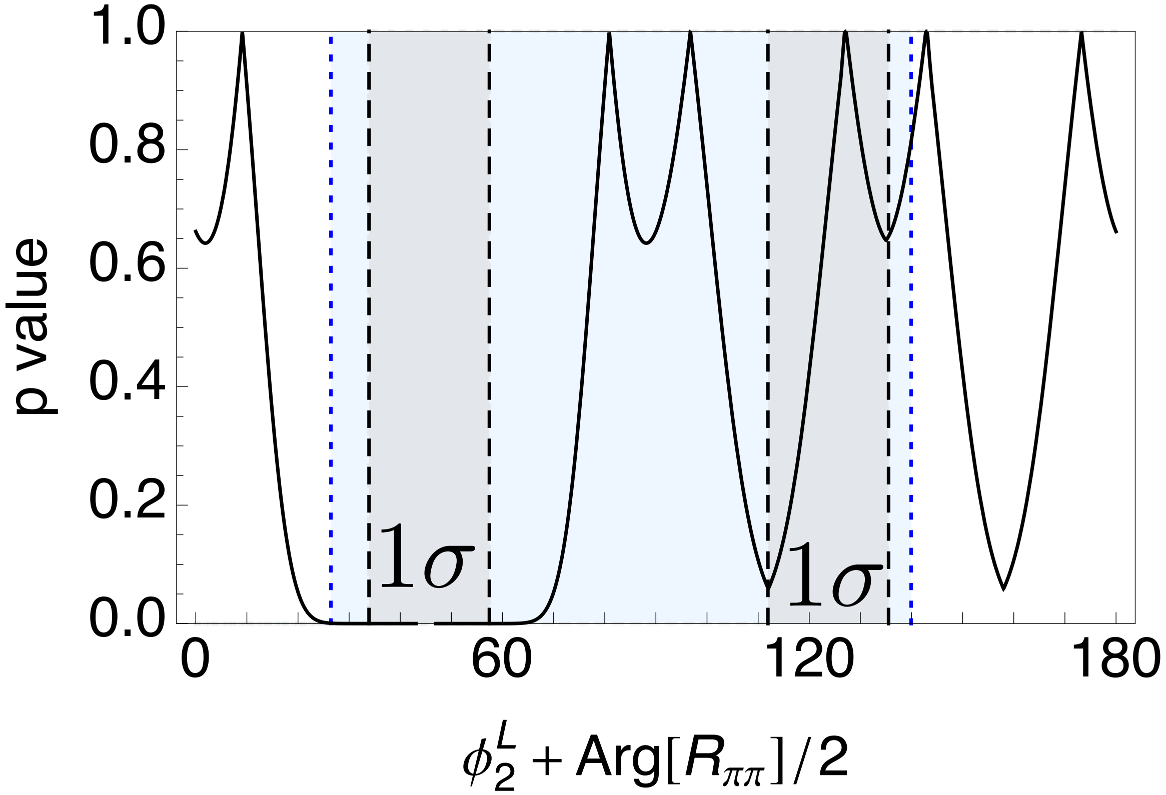
$$C_{\pi^0\pi^0} = \left(1 - |R_{\pi\pi}|^2 \left|\frac{2-\bar{z}}{2-z}\right|^2\right) \Big/ \left(1 + |R_{\pi\pi}|^2 \left|\frac{2-\bar{z}}{2-z}\right|^2\right)$$

$$A_{CP}(B^+ \to \pi^+\pi^0) = \frac{1 - |R_{\pi\pi}|^2}{1 + |R_{\pi\pi}|^2}$$

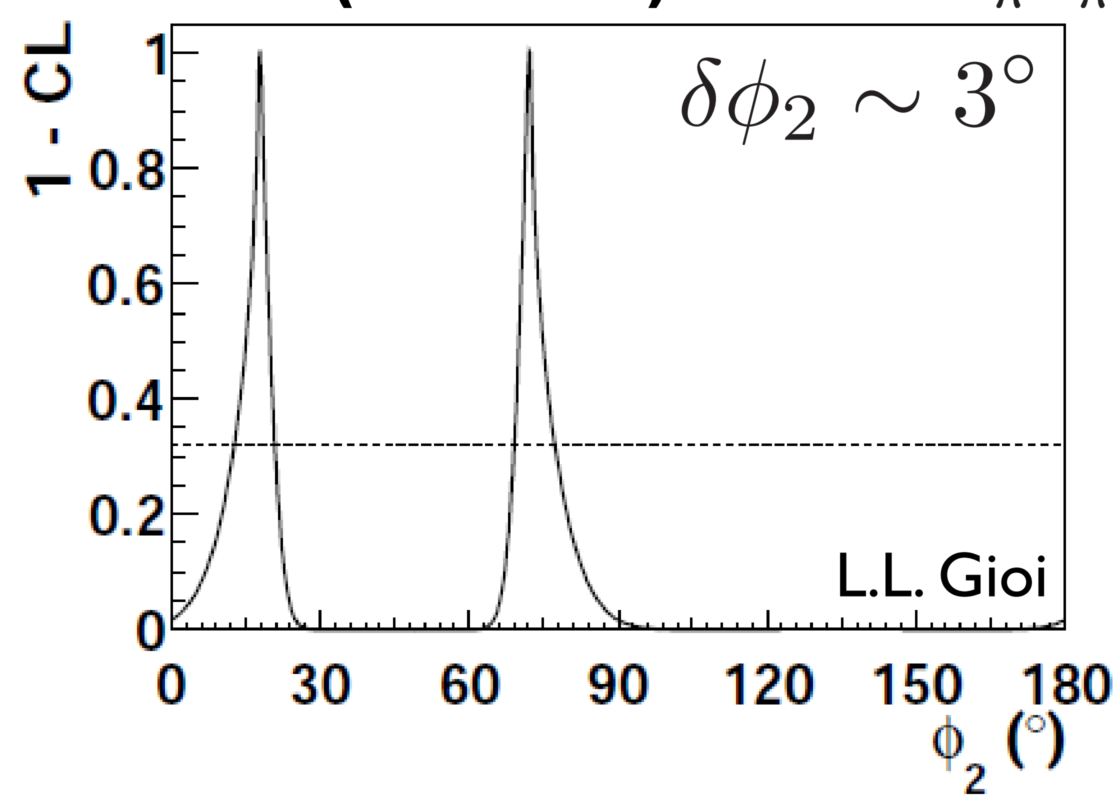
$$\phi_2^L = 84.7^\circ \pm 7.5^\circ$$







Belle II (50 /ab) with $S_{\pi^0\pi^0}$

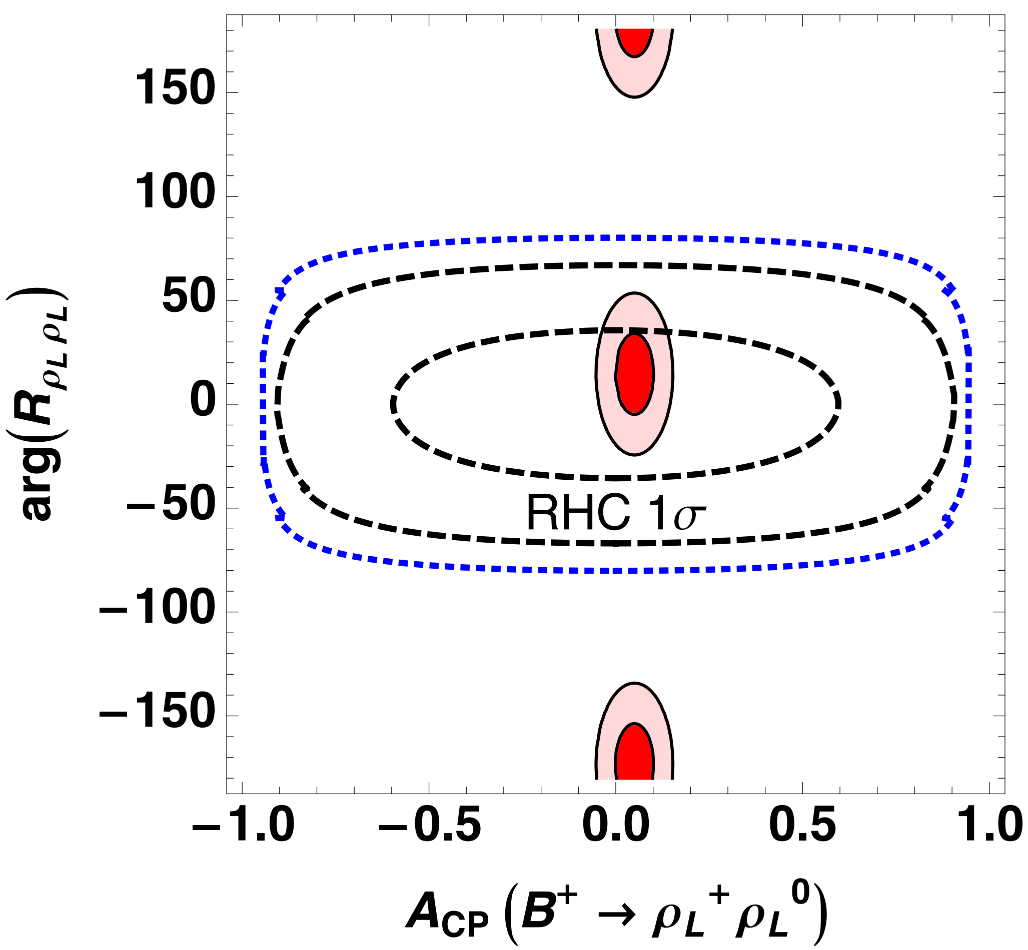


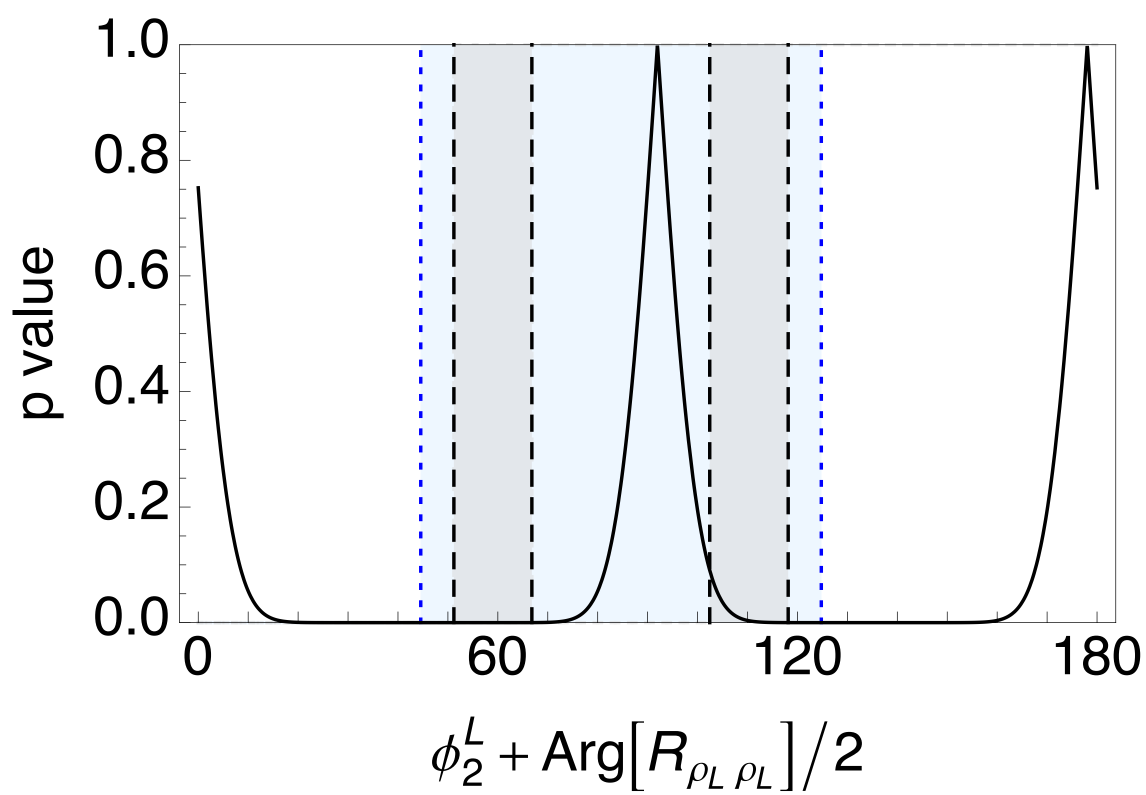
CP violation in $B \to \rho\rho$

$\rho_L \rho_L$ CP even, $I = 0, 2$

Isospin analysis as the two-pion mode

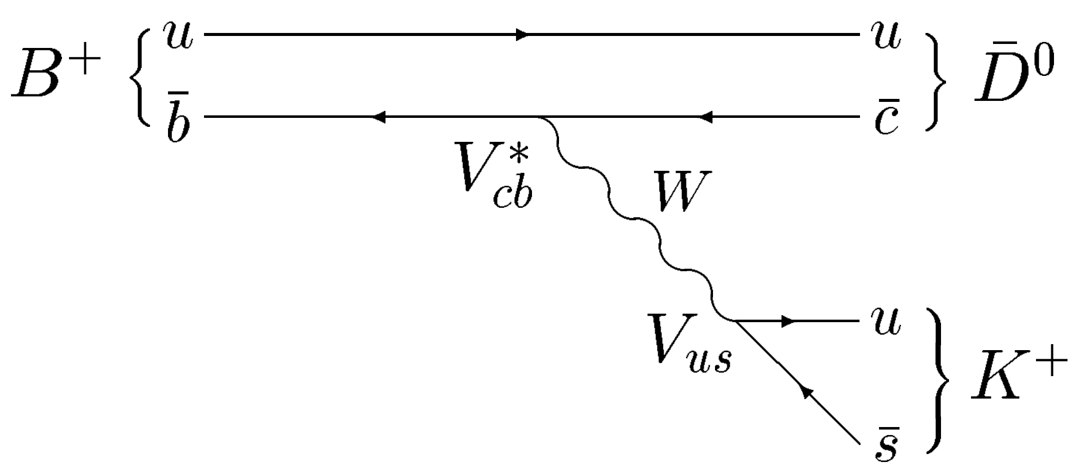
$$\frac{A_{2R}}{A_{2L}} \simeq -0.91 \frac{V_{ub}^{R*}}{V_{ub}^{L*}} e^{i\delta_{\rho_L \rho_L}}$$

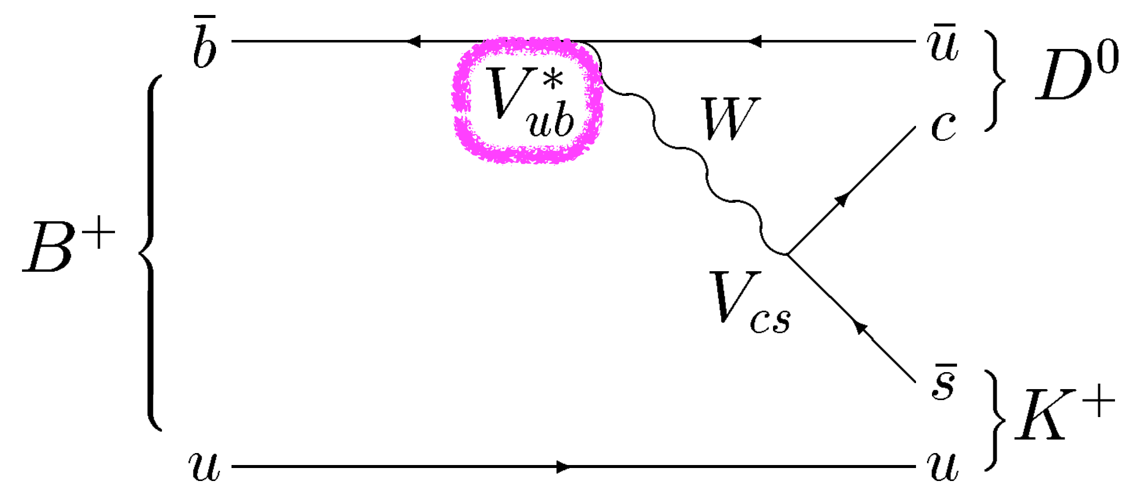




$\delta\phi_2 \sim 3^\circ$ at Belle II

CP violation in $B \to DK$





Dalitz plot method $\quad D \to K_s \pi^+ \pi^-$

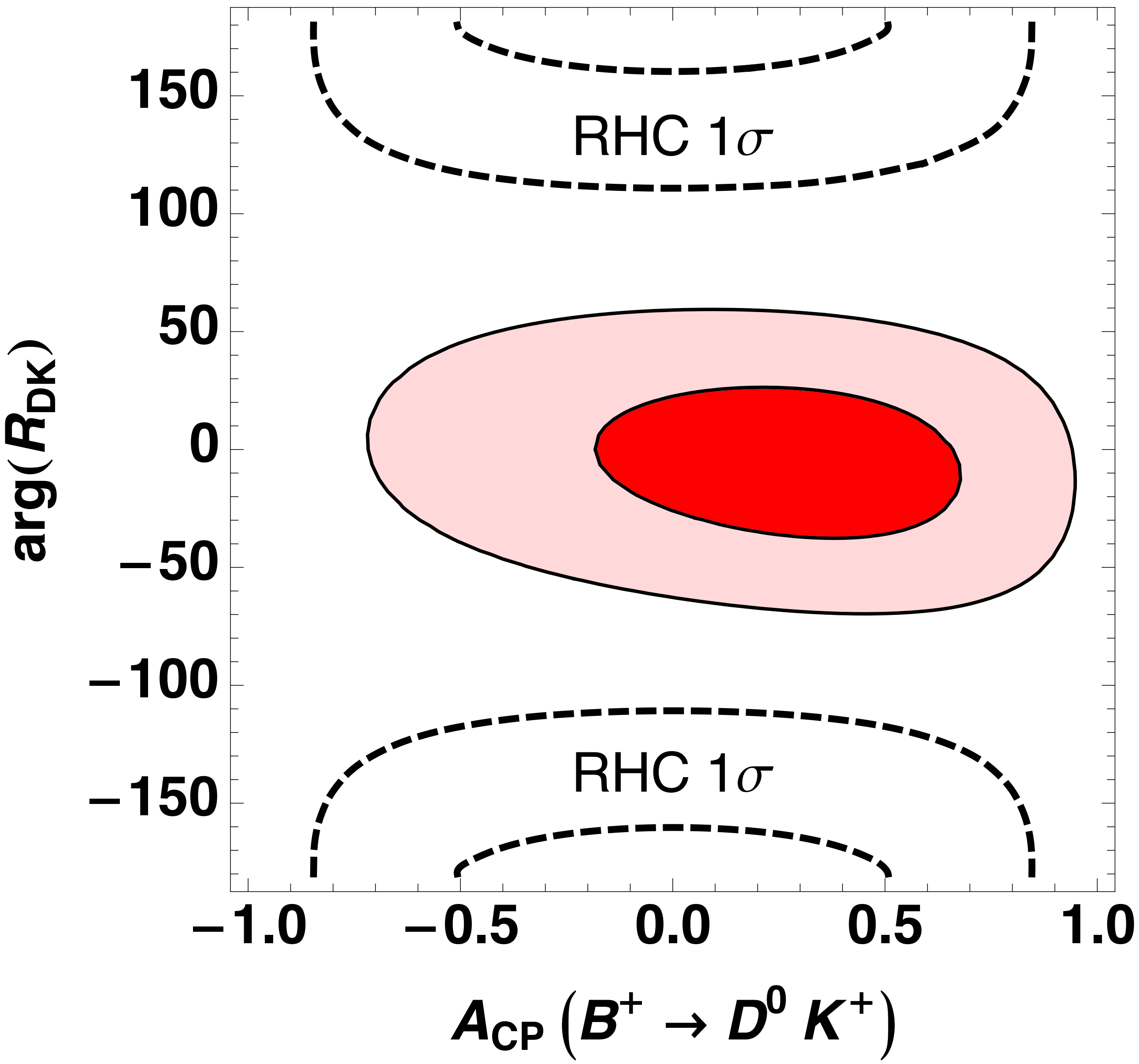
Effect of the right-handed current

$$\phi_3^{L(R)} = \arg(V_{ub}^{L(R)*})$$

$$A(B^+ \to D^0 K^+) = |A_L| e^{i(\phi_3^L + \delta_L)} + |A_R| e^{i(\phi_3^R + \delta_R)}$$

$$R_{DK} = e^{2i\phi_3^L} \frac{A(B^- \to \bar{D}^0 K^-)}{A(B^+ \to D^0 K^+)} = \frac{1 + |A_R/A_L| e^{i(-\phi_3^R + \phi_3^L + \delta)}}{1 + |A_R/A_L| e^{i(\phi_3^R - \phi_3^L + \delta)}}$$

$$|A_R/A_L| = 4.99 |V_{ub}^R / V_{ub}^L|$$



Belle II

$$\delta\phi_3 \sim 1.7^\circ$$

Tau lepton flavor violation

1412.2530, T. Goto, Y. Okada, T. Shindou, MT, R. Watanabe

Lepton flavor violation

Neutrino oscillation $\nu_i \to \nu_j$

→ Lepton flavors are NOT conserved.

Charged lepton sector $\mu \to e\gamma,\ \tau \to \mu\gamma, \cdots$

suppressed by the small neutrino masses

$$\mathrm{BR} \sim (m_\nu / m_W)^4 \lesssim 10^{-54}$$

Supersymmetric models

flavor mixing among scalar leptons

→ new source of LFV at SUSY mass scale

LFV experiments

$\mu \to e\gamma$

MEG $\mathrm{BR}(\mu \to e\gamma) < 5.7 \times 10^{-13}$

MEG II (expectation) $\sim 5 \times 10^{-14}$

$\tau \to \mu\gamma$

BaBar $\mathrm{BR}(\tau \to \mu\gamma) < 4.4 \times 10^{-8}$

Belle II (expectation) $\sim 10^{-9}$

Supersymmetric seesaw model

MSSM + type-I seesaw + minimal SUGRA

$$W_{\text{lepton}} = Y_E^{ij} E_i^c L_j H_1 + Y_N^{ij} N_i^c L_j H_2 + \frac{1}{2} M_N^{ij} N_i^c N_j^c$$

$$-\mathcal{L}_{\text{soft}}^{\text{lepton}} = (m_L^2)^{ij} \tilde{\ell}_i^\dagger \tilde{\ell}_j + (m_E^2)^{ij} \tilde{e}_i^\dagger \tilde{e}_j + (m_N^2)^{ij} \tilde{\nu}_i^\dagger \tilde{\nu}_j + (T_E^{ij} \tilde{e}_i^\dagger \tilde{\ell}_j h_1 + T_N^{ij} \tilde{\nu}_i \tilde{\ell}_j h_2 + \text{h.c.})$$

$$(m_L^2)^{ij} = (m_E^2)^{ij} = (m_N^2)^{ij} = M_0^2 \delta^{ij} \,, \quad T_N^{ij} = M_0 A_0 Y_N^{ij} \,, \quad T_E^{ij} = M_0 A_0 Y_E^{ij}$$

at GUT scale

Source of LFV

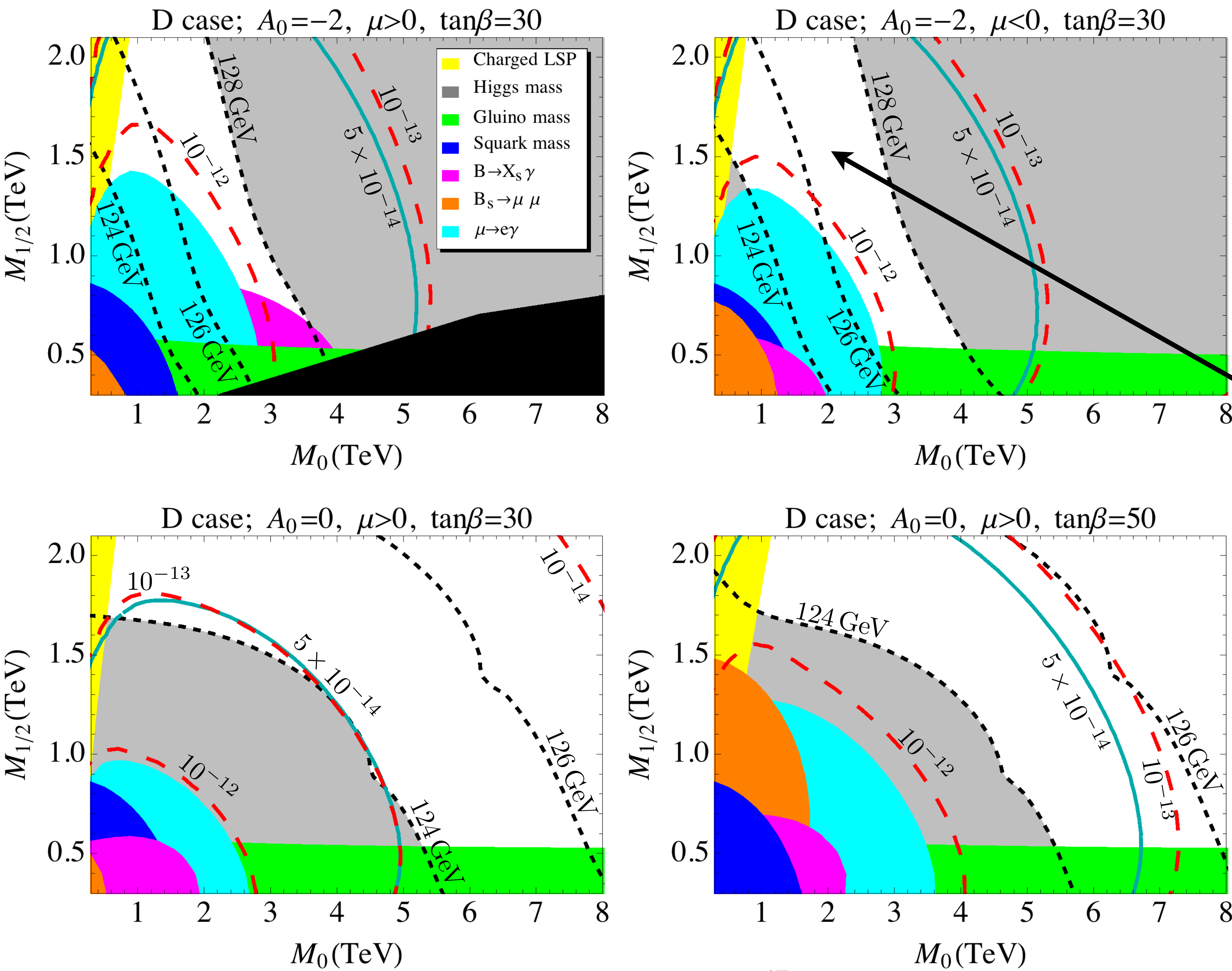
18 parameters in $Y_N, \ M_N$

9 in the light neutrino masses and PMNS

18-9=9 left for cLFV

Degenerate case w/o CPV

$M_N \propto 1$



$\tau \to \mu\gamma$

$\mu \to e\gamma$

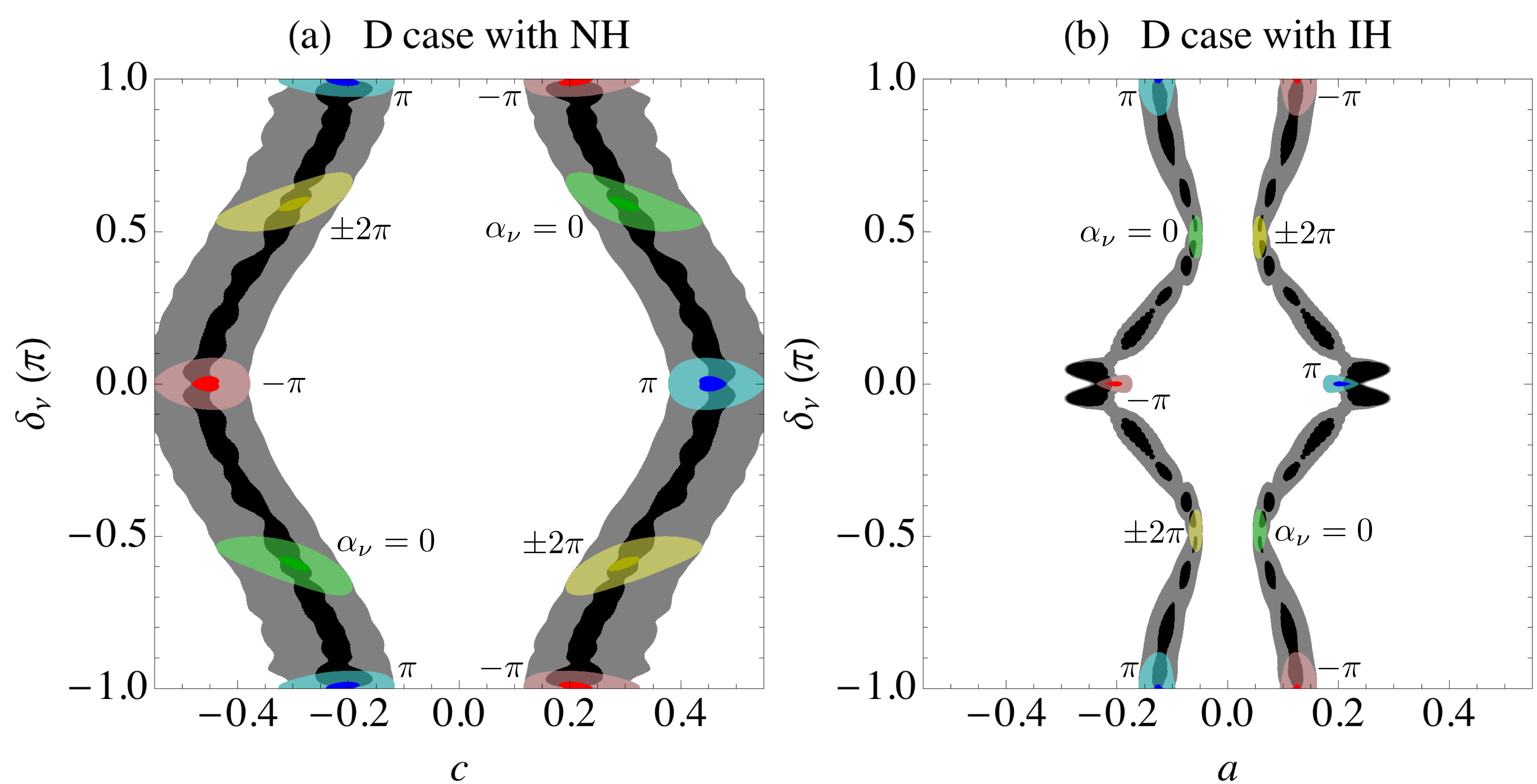
allowed

Degenerate case with CPV

$$Y_N = \frac{\sqrt{\tilde{M}_N}}{v \sin\beta} e^{iA_N} \begin{pmatrix} \sqrt{m_{\nu_1}} & & \\ & \sqrt{m_{\nu_2}} & \\ & & \sqrt{m_{\nu_3}} \end{pmatrix} U_\nu^\dagger$$

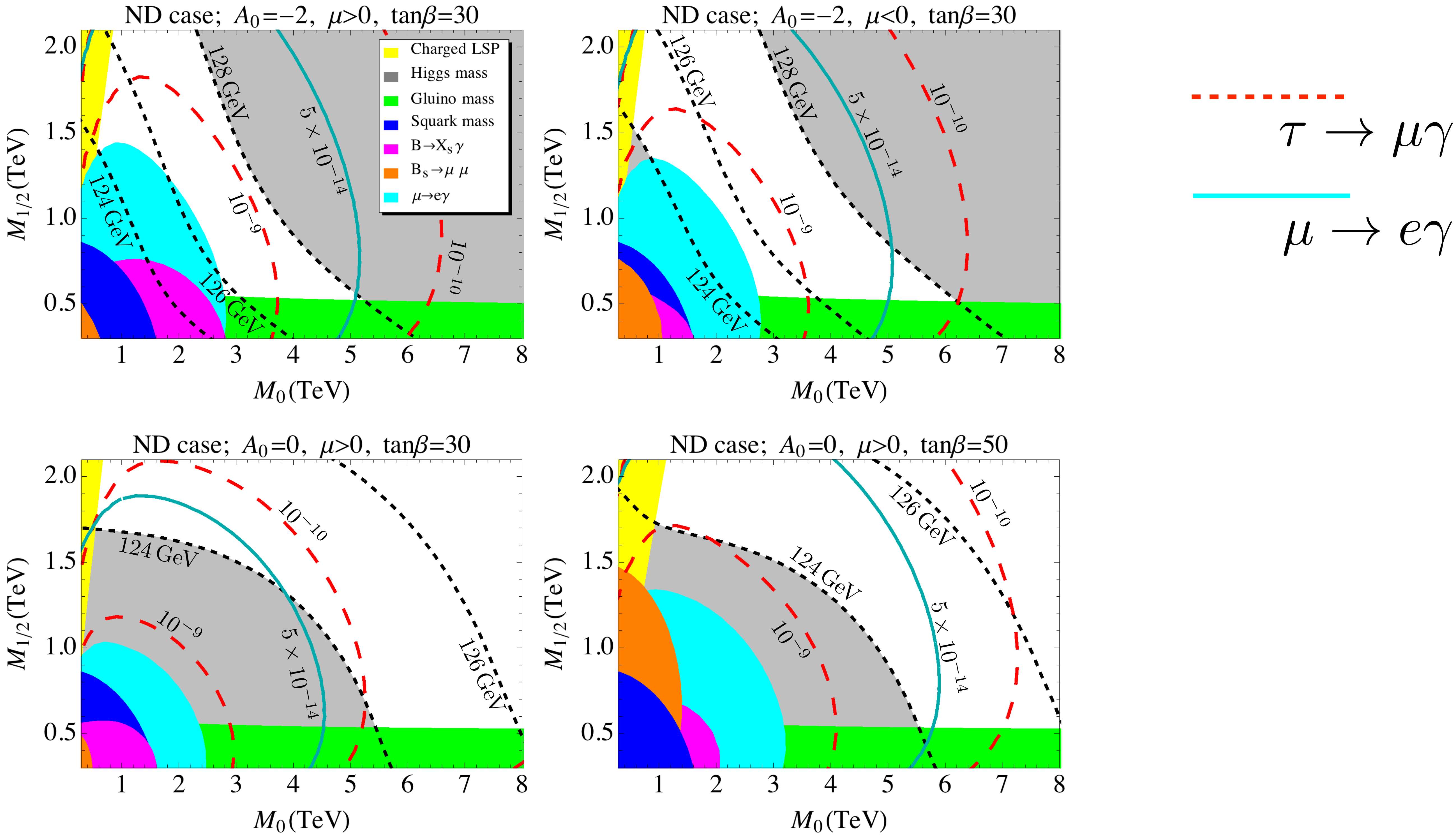
Belle II reach

$$\mathrm{BR}(\tau \to \mu\gamma)/\mathrm{BR}(\mu \to e\gamma) > 1800(100)$$



Nondegenerate case

$$Y_N = \begin{pmatrix} y_1 & & \\ & y_2 & \\ & & y_3 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & \sin\theta \\ 0 & -\sin\theta & \cos\theta \end{pmatrix}$$



Summary

- Belle II

  40 times (or more) larger statistics

  A few % error in UT

  Indirect search for new physics

- LHCb

  Competition and complementarity

- Excess of semitauonic B decays

  Testing NP with the q2 distribution

  A good target of an earlier stage of Belle II

  5-10 /ab

  LHCb can do $B \to D^* \tau \nu$.

- Right-handed b to u current

  Shifts in UT phases $\phi_2,\ \phi_3$

  New direct CP asymmetries

- LFV

  Both MEG II and Belle II have possibilities to observe LFV.

    Large A term?

- ....

  Many other issues to be discussed

B2TIP

Belle II Theory Interface Platform

https://belle2.cc.kek.jp/~twiki/bin/view/Public/B2TIP

WG 1: Semileptonic & leptonic decays

WG 2: Radiative & EW penguins

WG 3: phi1 & phi2

WG 4: phi3

WG 5: Charmless hadronic B decays

WG 6: Charm

WG 7: Quarkonium

WG 8: Tau, low multiplicity & EW

WG 9: New Physics

Table of golden modes

https://belle2.cc.kek.jp/~twiki/bin/view/Public/B2TIPGoldenModes

Home | Public Web | View | Edit | Account

Jump | Search

Group	Observable	Mode	SM or fit Expectation	Belle 2014	Babar 2014	Belle II 5/ab	Belle II 50/ab	LHCb 2014	LHCb 8/fb	LHCb 50/fb
ϕ_1/ϕ_2 WG page	$\sin(2\phi_1)$	$B \to J/\psi K_S$		$0.667 \pm 0.023 \pm 0.012 (1.4^\circ)$		0.7°	0.4°		1.6°	0.6°
	S	$B \to \phi K_S^0$		$0.90^{+0.09}_{-0.19}$		0.053	0.018		0.2	0.04
		$B \to \eta' K_S^0$		$0.68 \pm 0.07 \pm 0.03$		0.028	0.011			
		$B \to K_S^0 K_S^0 K_S^0$		$0.30 \pm 0.32 \pm 0.08$		0.100	0.033			
		$B \to \pi\pi$, $B \to \rho\pi$,		$(85 \pm 4)^\circ$ (Belle + Babar)		2°	1°			
ϕ_3 WG page	ϕ_3	)		(		6°	1.5°			
Hadronic B WG page	A			–		0.07	0.04			
Semileptonic & Leptonic WG page	$V_{cb}[10^{-}$ inclusive			$41.6(1 \pm 0.024_{fit})$		1.2%				
	$V_{cb}[10^{-3}]$ exclusive	$B \to D^* \ell \nu$				1.8%	1.4%			
	$V_{ub}[10^{-3}]$ inclusive	$B \to X_u \ell \nu$				3.4%	3.0%			
	$V_{ub}[10^{-3}]$ exclusive	$B \to \pi \ell \nu$ (Hadronic tag)				4.4%	2.3%			
	$\mathcal{B}[10^{-6}]$	$B \to \tau \nu$ (Hadronic tag)		$96(1 \pm 0.26)$		10%	5%			

Decide maximum of 5 key observable leaving a few spaces for new ideas

Please tell us the responsible person for each process !

Theorists to fill!

Detailed explanation can be added to the linked page.

Experimentalists to fill!

Simulation result can be added to the linked page.

Lots to do. Please join us.

Future External Workshops

Next meeting is at Krakow !

B2TiP 2nd Workshop

27-29th April 2015

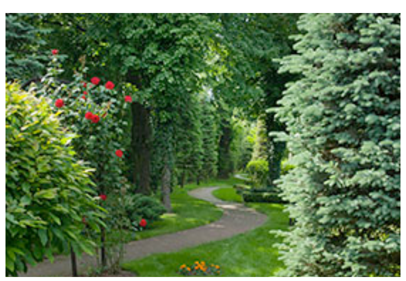
Crown Piast Hotel

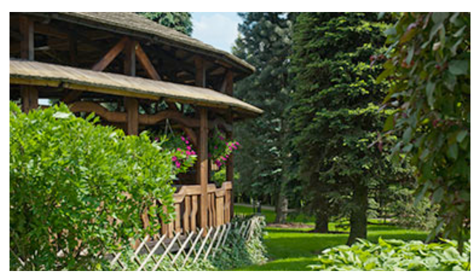
-15mins from city
-In front of the institute

The timetable is typically,

- One day equivalent of plenary session
- Two days equivalent of parallel session

See you there!





North America 2016 (~April/May). USA colleagues are looking into funding options and locations.

P. Urquijo, B2TiP, Closing Remarks 9

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