Physics
OSAKA UNIVERSITY

New physics contributions in $B \to \pi\tau\bar{\nu}$ and $B \to \tau\bar{\nu}$

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Mini-workshop on D$^{(*)}\tau\nu$ and related topics
Nagoya U, Mar. 27-28, 2017

Introduction

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

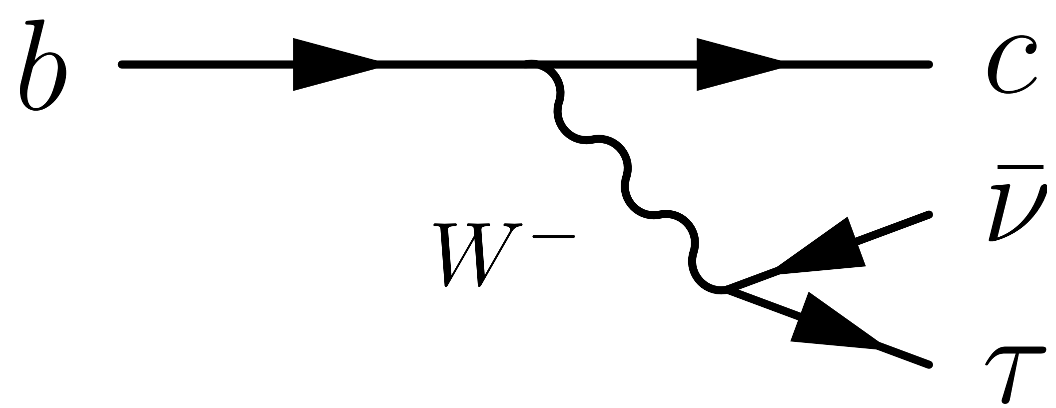
Br ~ 0.7+1.3 % in the SM

Not rare, but two or more missing neutrinos

Data available since 2007 (Belle, BABAR, LHCb)

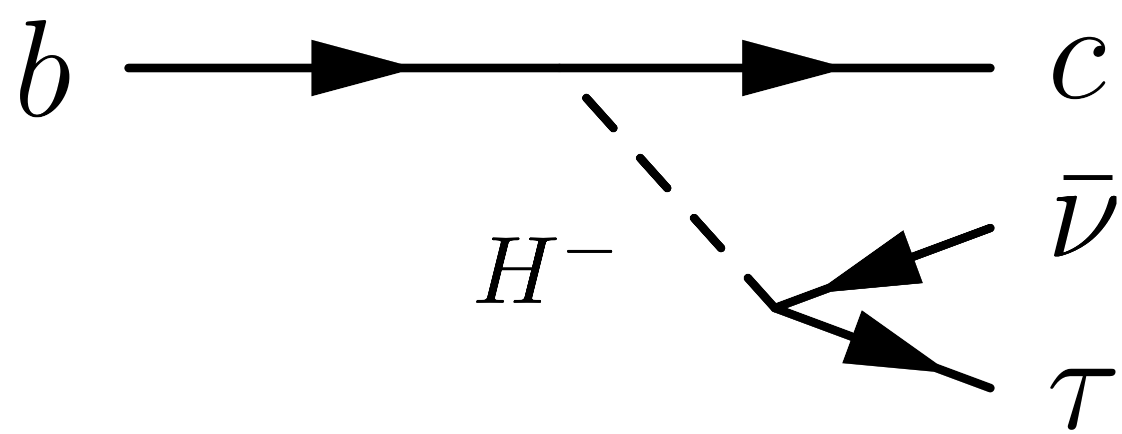
Theoretical motivation

W.S. Hou and B. Grzadkowski (1992)



SM: gauge coupling

lepton universality



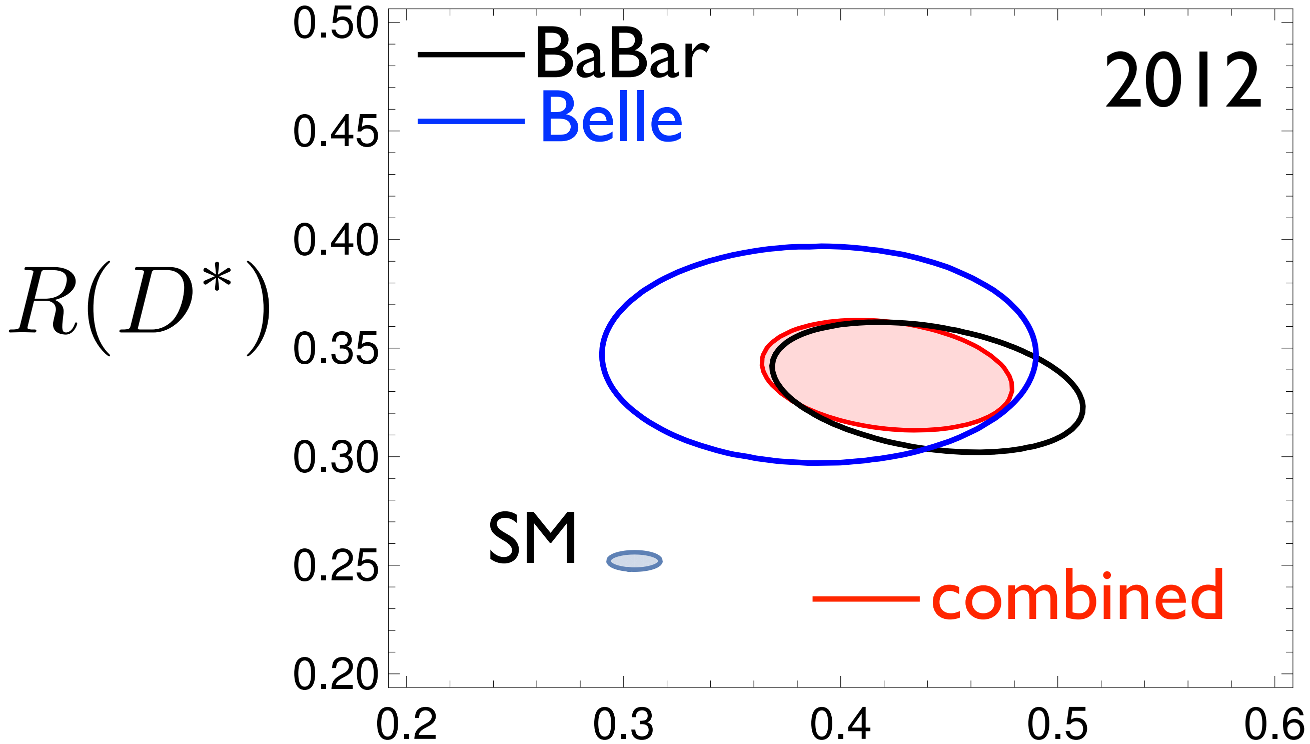
Type-II 2HDM (SUSY)

Yukawa coupling

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

Experimental status

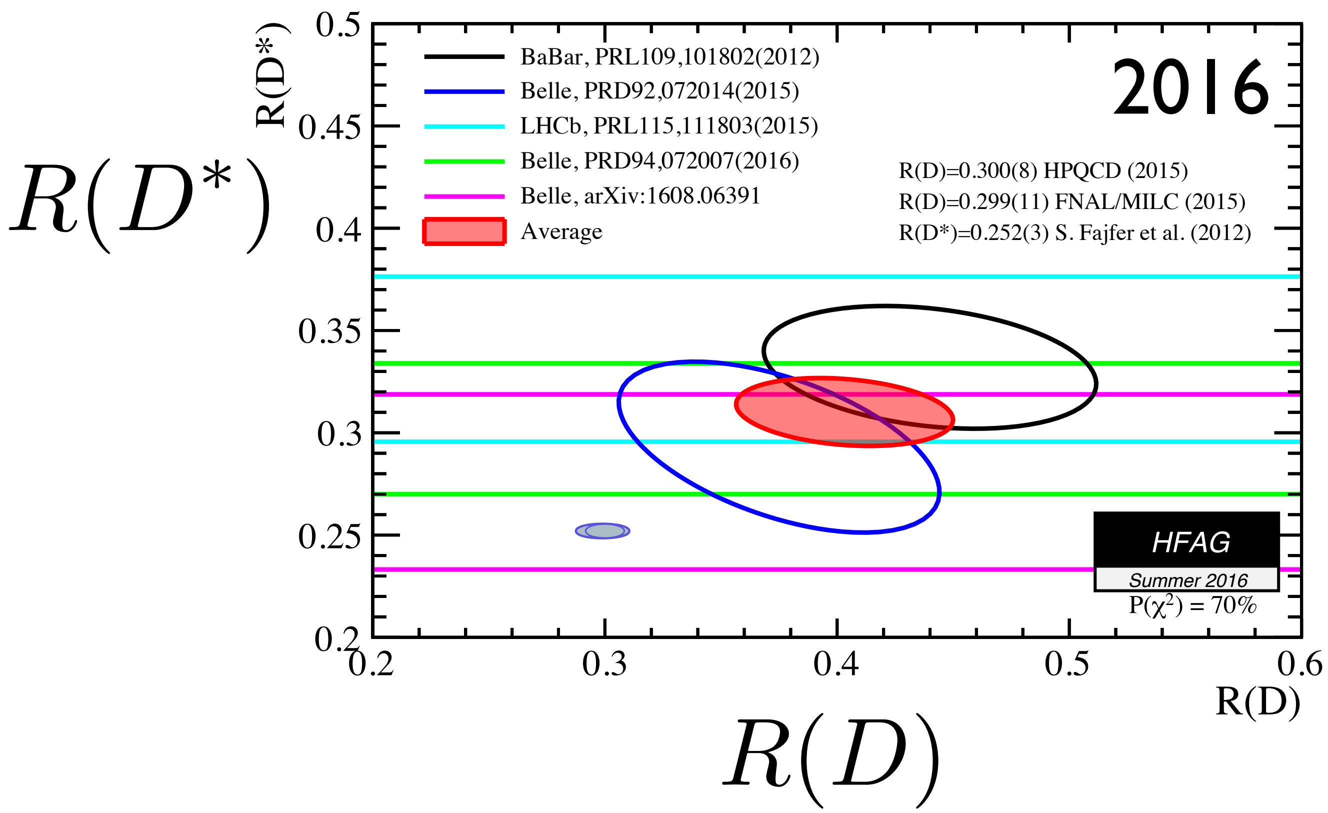
$$R(D^{(*)}) \equiv \frac{\mathcal{B}(\bar{B} \to D^{(*)}\tau\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D^{(*)}\ell\bar{\nu}_\ell)}$$



$$R(D) = 0.421 \pm 0.058$$
$$R(D^*) = 0.337 \pm 0.025$$

~3.5σ

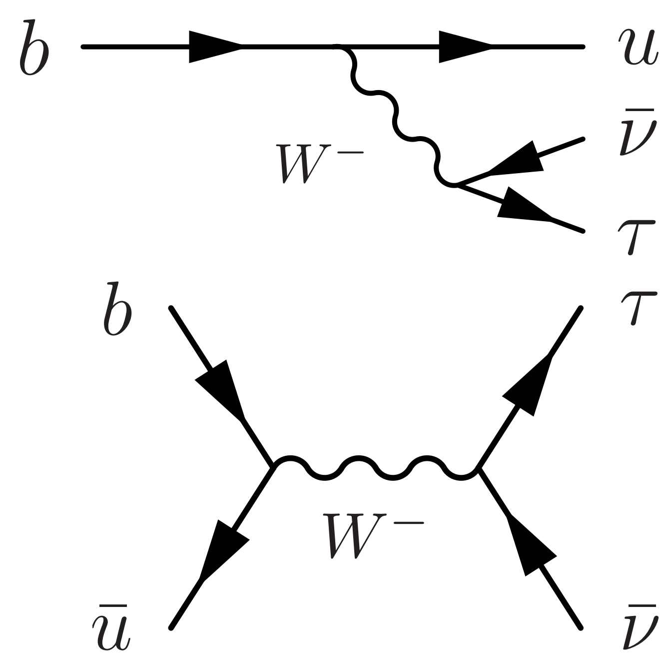
Y. Sakaki, MT, A. Tayduganov, R. Watanabe (2013)



$$R(D) = 0.403 \pm 0.040 \pm 0.024$$
$$R(D^*) = 0.310 \pm 0.015 \pm 0.008$$

~3.9σ HFAG

What about $b \to u\tau\bar{\nu}$?



Semitauonic $\bar{B} \to (\pi, \rho, \cdots)\tau\bar{\nu}$

Pure tauonic $B^- \to \tau\bar{\nu}$

Experimental data

$$\mathcal{B}(\bar{B}^0 \to \pi^+\tau^-\bar{\nu}) = (1.52 \pm 0.72 \pm 0.13) \times 10^{-4}$$

Belle 2015

$\sim 0.7 \times 10^{-4}$ in SM

a good target of Belle II

$$\mathcal{B}(B^- \to \tau^-\bar{\nu}) = (1.14 \pm 0.22) \times 10^{-4}$$

HFAG 2014

Plan of talk

1. Introduction (3)
2. $B \to \pi\tau\bar{\nu}$ (5)
3. $B \to \tau\bar{\nu}$ (2)
4. Status and prospect (5)
5. Summary (1)

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

Model-independent analysis of $\bar{B} \to \pi\tau\bar{\nu}$

MT, R.Watanabe 1608.05207

Effective Lagrangian for $b \to u\tau\bar{\nu}$

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

SM

$\mathcal{O}_{V_1} = (\bar{u}\gamma^\mu P_L b)(\bar{\tau}\gamma_\mu P_L \nu_\tau)\,,$ SM-like, RPV, LQ,W'

$\mathcal{O}_{V_2} = (\bar{u}\gamma^\mu P_R b)(\bar{\tau}\gamma_\mu P_L \nu_\tau)\,,$ RH current

$\mathcal{O}_{S_1} = (\bar{u}P_R b)(\bar{\tau}P_L \nu_\tau)\,,$ charged Higgs II, RPV, LQ

$\mathcal{O}_{S_2} = (\bar{u}P_L b)(\bar{\tau}P_L \nu_\tau)\,,$ charged Higgs III, LQ

$\mathcal{O}_T = (\bar{u}\sigma^{\mu\nu} P_L b)(\bar{\tau}\sigma_{\mu\nu} P_L \nu_\tau)\,,$ LQ

$|V_{ub}|$ and form factors $\longrightarrow$ uncertainty

$$R_\pi = \frac{\mathcal{B}(\bar{B}^0 \to \pi^+\tau^-\bar{\nu})}{\mathcal{B}(\bar{B}^0 \to \pi^+\ell^-\bar{\nu})}$$

smaller uncertainty

Form factors

Vector: $f_+(q^2),\ f_0(q^2)$

$$\langle \pi(p_\pi)|\bar{u}\gamma^\mu b|\bar{B}(p_B)\rangle = f_+(q^2)\left[(p_B+p_\pi)^\mu - \frac{m_B^2-m_\pi^2}{q^2}q^\mu\right] + f_0(q^2)\frac{m_B^2-m_\pi^2}{q^2}q^\mu$$

$\bar{B}\to\pi\ell\bar{\nu}$ exp. data + lattice   Bailey et al. PRD92, 014024 (2015)

Scalar: $f_S(q^2)$

$$\langle \pi(p_\pi)|\bar{u}b|\bar{B}(p_B)\rangle = (m_B+m_\pi)f_S(q^2)$$

eq. of motion $\quad f_S(q^2) = \dfrac{m_B-m_\pi}{m_b-m_u}f_0(q^2)$

$m_b \simeq 4.2\ \mathrm{GeV}$

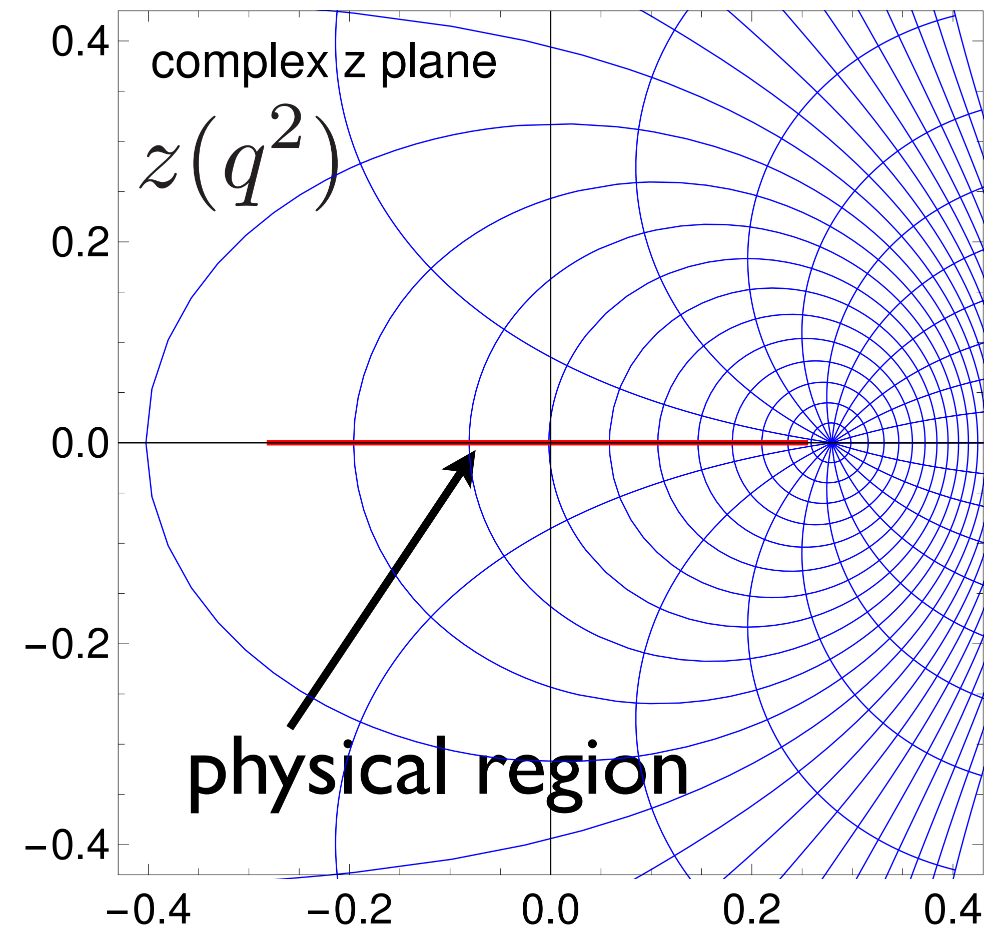
Tensor: $f_T(q^2)$

$$\langle \pi(p_\pi)|\bar{u}\,i\sigma^{\mu\nu}\,b|B(p_B)\rangle = \frac{2}{m_B+m_\pi}f_T(q^2)\left[p_B^\mu p_\pi^\nu - p_B^\nu p_\pi^\mu\right]$$

lattice   Bailey et al. PRL115, 152002 (2015)

BCL expansion

Bourrely, Caprini, Lellouch, PRD79, 013008 (2009)



Series expansion in terms of

$$z := \frac{\sqrt{t_+ - q^2} - \sqrt{t_+ - t_0}}{\sqrt{t_+ - q^2} + \sqrt{t_+ - t_0}}$$

$$t_+ := (m_B + m_\pi)^2$$

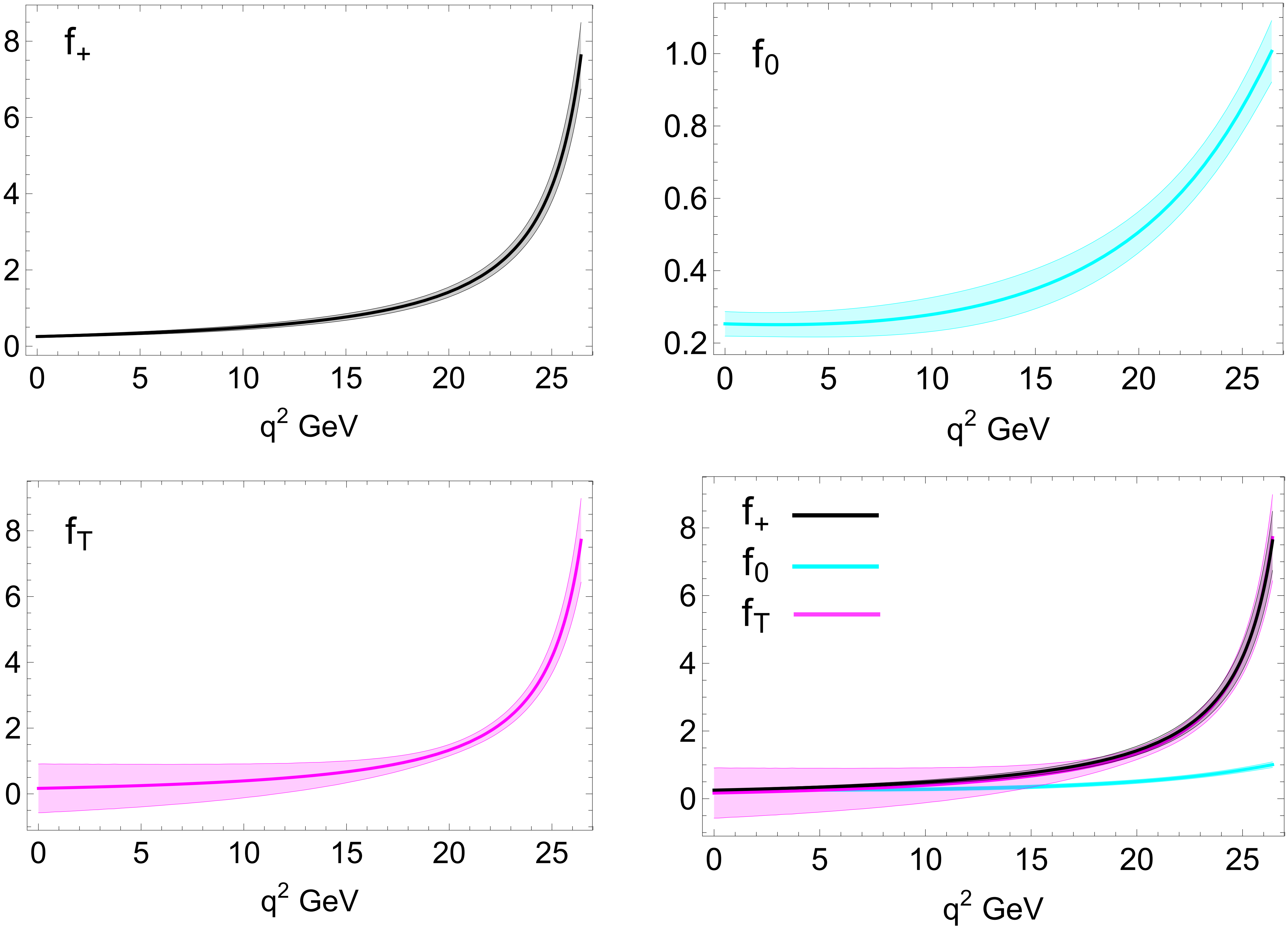
$$t_0 := (m_B + m_\pi)(\sqrt{m_B} - \sqrt{m_\pi})^2$$

$$f_j(q^2) = \frac{1}{1 - q^2/m_{B^*}^2} \sum_{n=0}^{N_z - 1} b_n^j \left[z^n - (-1)^{n-N_z} \frac{n}{N_z} z^{N_z} \right] \qquad j = +, T \quad N_z = 4$$

B* pole $\quad m_{B^*} = 5.325\,\mathrm{GeV}$

$$f_0(q^2) = \sum_{n=0}^{N_z - 1} b_n^0 z^n$$

12 b's given with errors and correlations Bailey et al.



f_+
f_0
f_T
q^2 GeV
0 5 10 15 20 25
0 2 4 6 8
0.2 0.4 0.6 0.8 1.0

Ratio of branching fraction

$$R_\pi = \frac{\mathcal{B}(\bar{B}^0 \to \pi^+ \tau^- \bar{\nu})}{\mathcal{B}(\bar{B}^0 \to \pi^+ \ell^- \bar{\nu})}$$

$$R_\pi^{\rm exp} = 1.05 \pm 0.51$$

$$\mathcal{B}(B \to \pi \ell \bar{\nu}) = (1.45 \pm 0.02 \pm 0.04) \times 10^{-4}$$

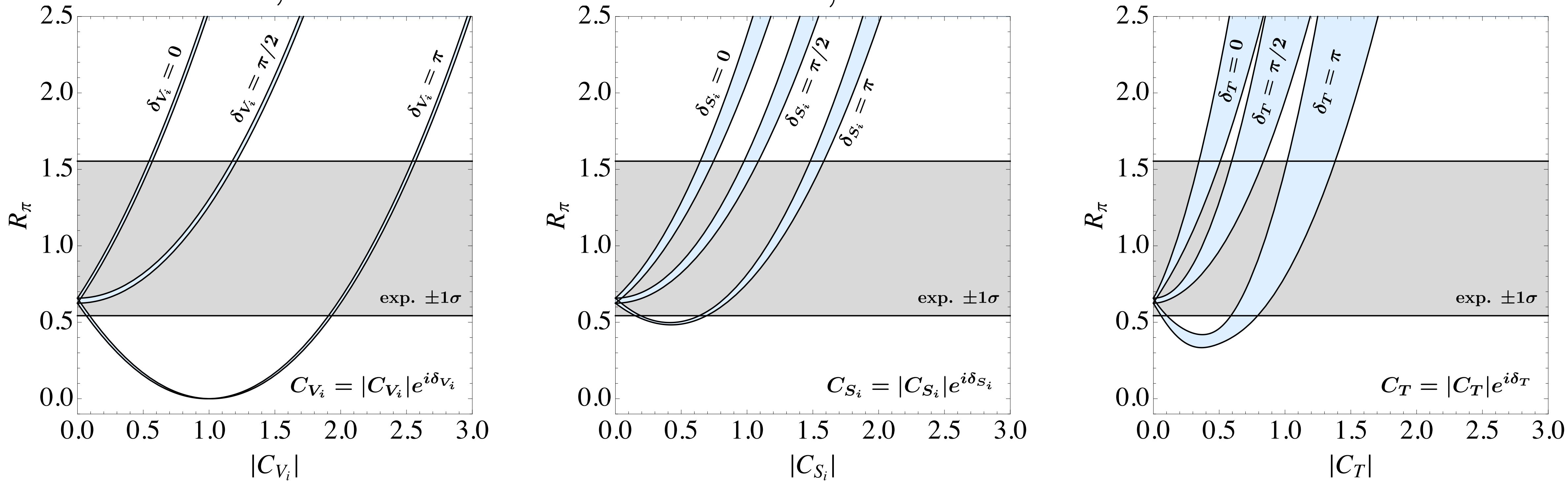
HFAG

$$R_\pi^{\rm SM} = 0.641 \pm 0.016$$

Bernlochner, PRD92, 115019 (2015)

$V_{1,2}$ $\quad$ $S_{1,2}$ $\quad$ T

R_π



$|C_{V_{1,2}}|$ $\quad$ $|C_{S_{1,2}}|$ $\quad$ $|C_T|$

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

Pure- to semi- leptonic ratio

$B^- \to \tau^- \bar{\nu}$ **described by** $\mathcal{L}_{\rm eff}(b \to u\tau\bar{\nu})$

$$\mathcal{B}(B \to \tau\bar{\nu}_\tau) = \frac{\tau_{B^-} G_F^2 |V_{ub}|^2 f_B^2}{8\pi} m_B m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 |1 + r_{\rm NP}|^2$$

$$r_{\rm NP} = C_{V_1} - C_{V_2} + \frac{m_B^2}{m_b m_\tau}(C_{S_1} - C_{S_2})$$ No tensor contrib.

Uncertainties: $|V_{ub}|, \ f_B$

Taking a ratio to eliminate $|V_{ub}|$

$$R_{\rm ps} = \frac{\Gamma(B^- \to \tau^- \bar{\nu}_\tau)}{\Gamma(\bar{B}^0 \to \pi^+ \ell^- \bar{\nu}_\ell)} = \frac{\tau_{B^0}}{\tau_{B^-}} \frac{\mathcal{B}(B^- \to \tau^- \bar{\nu}_\tau)}{\mathcal{B}(\bar{B}^0 \to \pi^+ \ell^- \bar{\nu}_\ell)}$$

Fajfer et al. PRL109, 161801(2012)

+ lattice $f_B = 192.0 \pm 4.3 \ {\rm MeV}$ FLAG 1607.00299

$R_{\rm ps}^{\rm SM} = 0.574 \pm 0.046$ $R_{\rm ps}^{\rm exp} = 0.73 \pm 0.14$

$\mathcal{B}(B^- \to \tau^- \bar{\nu}) = (1.14 \pm 0.22) \times 10^{-4}$

HFAG 2014

Another ratio

$$R_{\rm pl} = \frac{\mathcal{B}(B \to \tau\bar{\nu}_\tau)}{\mathcal{B}(B \to \mu\bar{\nu}_\mu)} = \frac{m_\tau^2}{m_\mu^2} \frac{(1 - m_\tau^2/m_B^2)^2}{(1 - m_\mu^2/m_B^2)^2} |1 + r_{\rm NP}|^2 \simeq 222\, |1 + r_{\rm NP}|^2$$

practically no uncertainty in the SM prediction

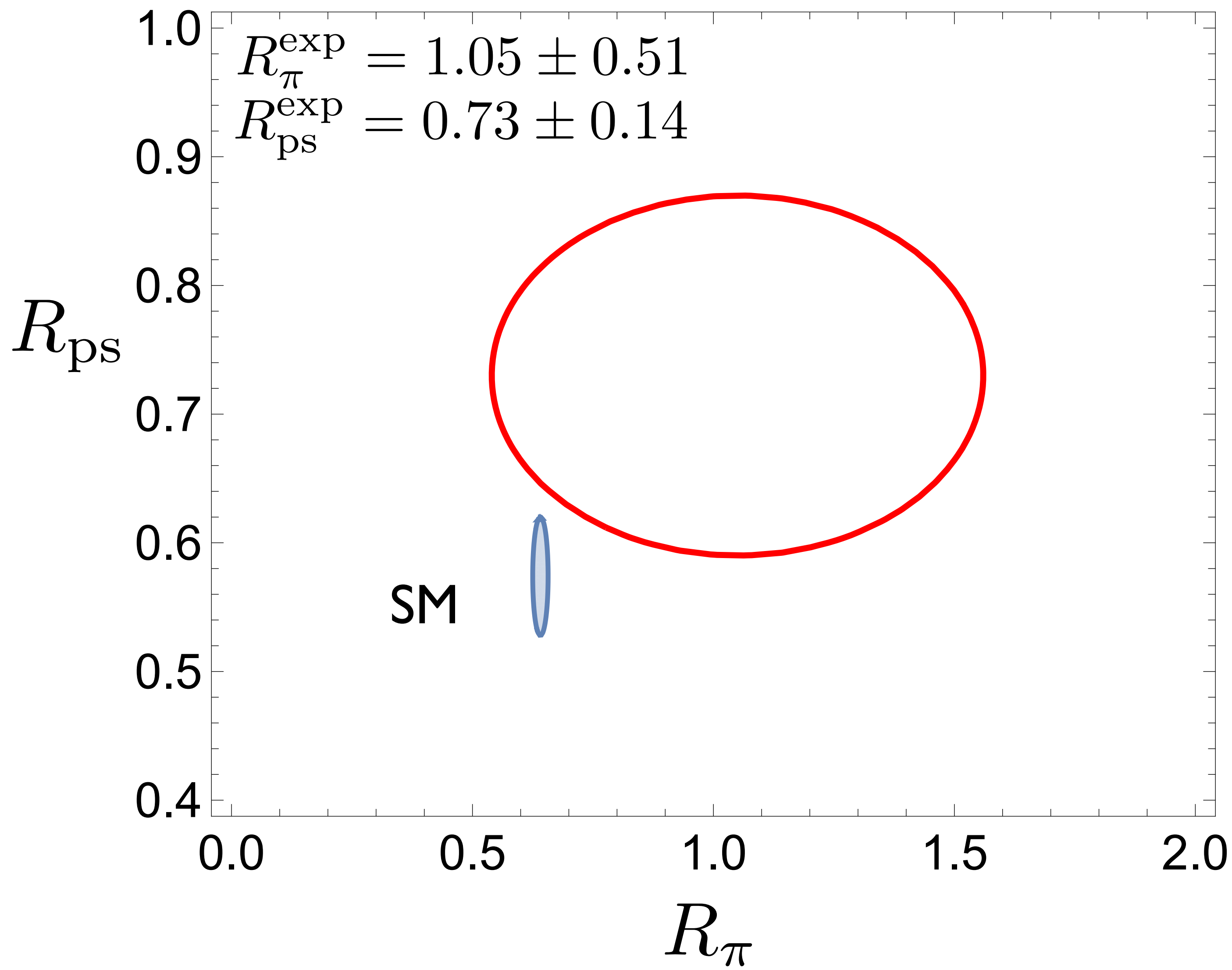
$$\mathcal{B}(B \to \mu\bar{\nu}_\mu)^{\rm exp.} < 1 \times 10^{-6} \ \text{ at } \ 90\% \ \text{ CL}$$ BaBar, Belle

$$\mathcal{B}(B \to \mu\bar{\nu}_\mu)^{\rm SM} = (0.41 \pm 0.05) \times 10^{-6}$$

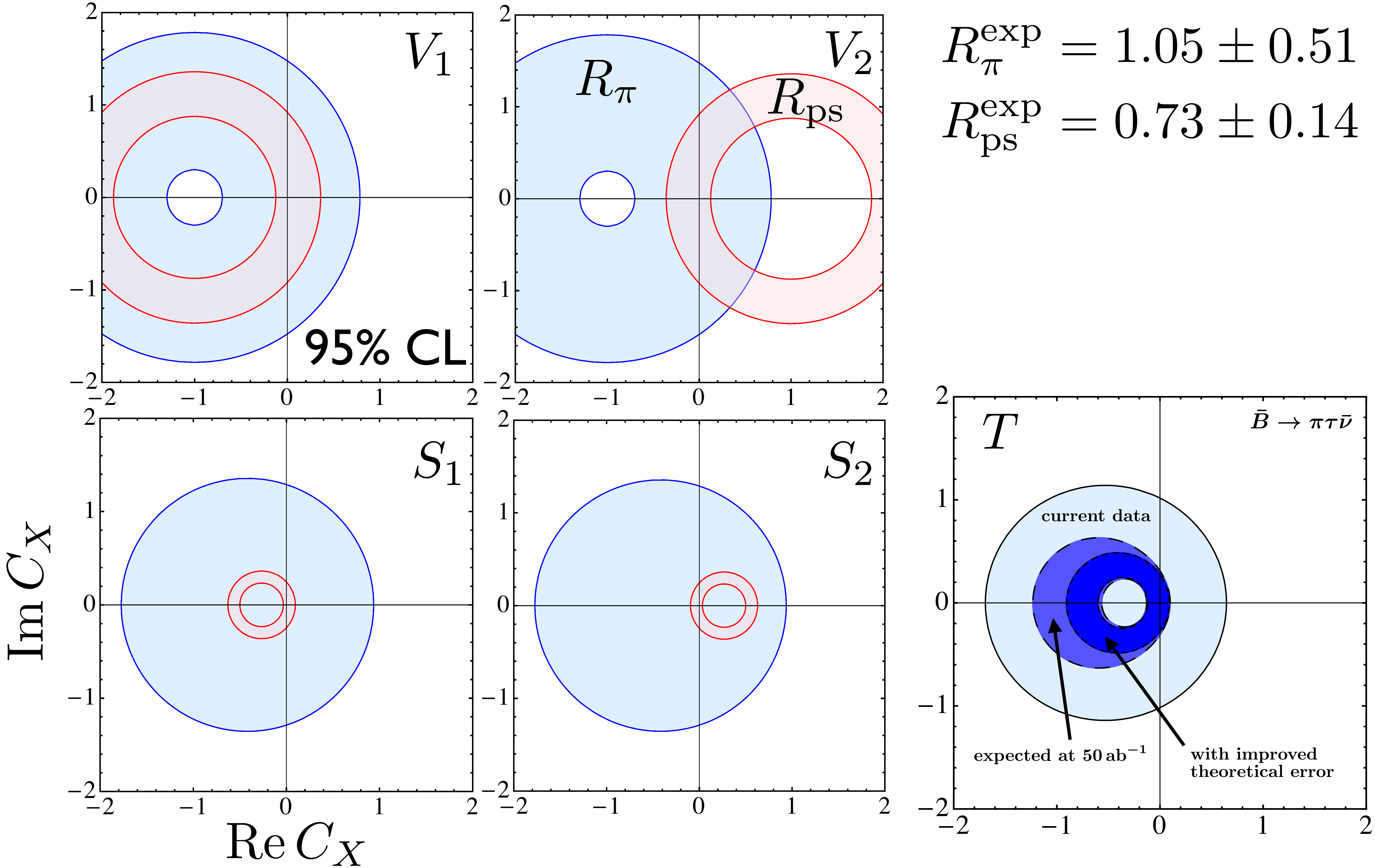
likely to be observed at Belle II

Status and prospect

Summary of the status in 2016



Present constraint

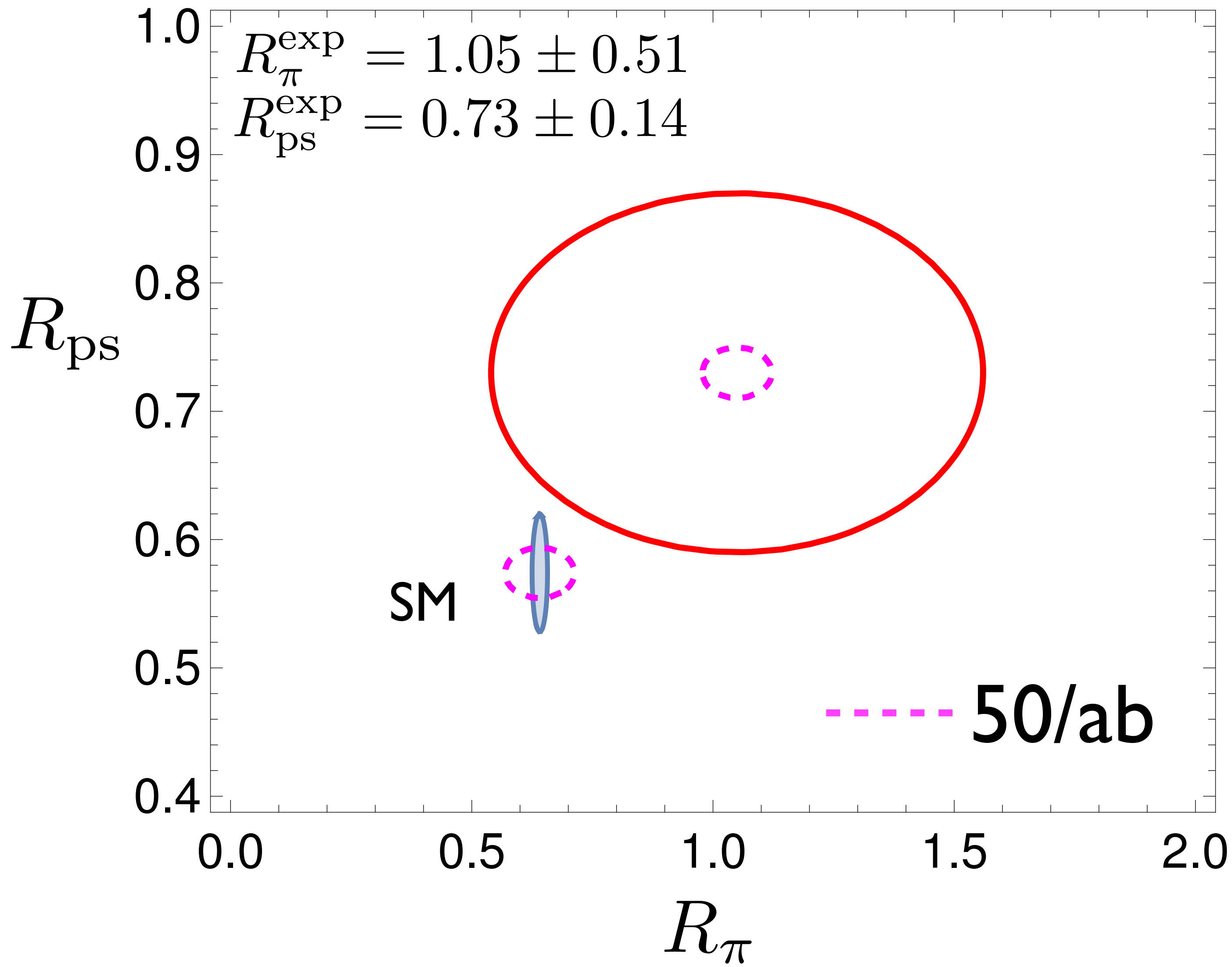


$$R_\pi^{\rm exp} = 1.05 \pm 0.51$$
$$R_{\rm ps}^{\rm exp} = 0.73 \pm 0.14$$

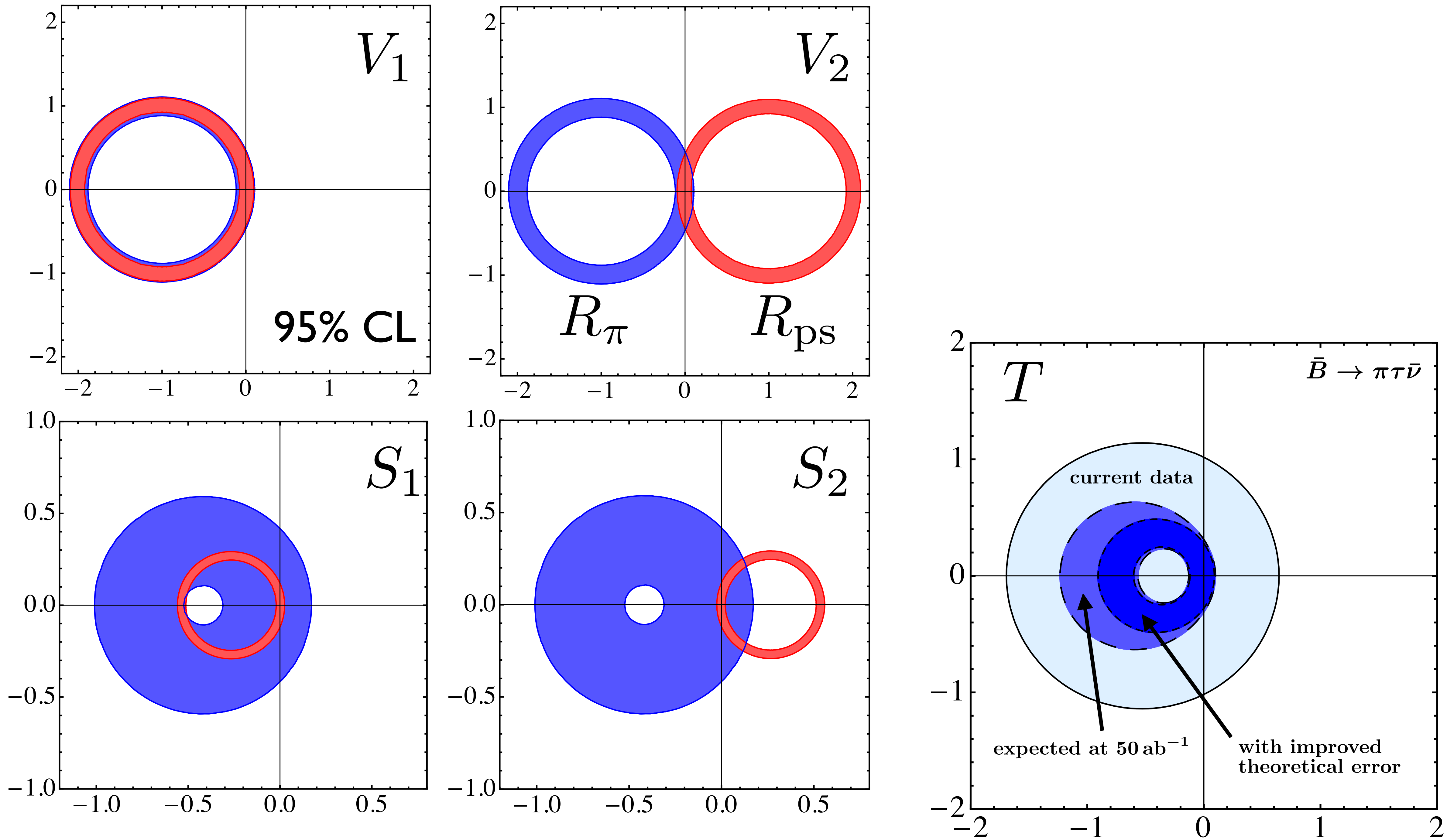
Future prospect

Belle II ~50/ab   cf. Belle ~ 1/ab

Scaling the present errors as $1/\sqrt{\mathcal{L}}$



Belle II (L~50/ab), the central values = SM



Real Cx case

NP scenario	$R_\pi^{\text{Belle II}} = 0.641 \pm 0.071$ and $R_{\text{ps}}^{\text{Belle II}} = 0.574 \pm 0.020$	$R_{\text{pl}}^{\text{Belle II}} = 222 \pm 47$
C_{V_1}	$[-0.08, 0.09]; [-2.09, -1.92]$	$[-0.23, 0.19]; [-2.19, -1.77]$
C_{V_2}	$[-0.09, 0.08]$	$[-0.19, 0.23]; \quad [1.77, 2.19]$
C_{S_1}	$[-0.03, 0.03]; [-0.55, -0.52]$	$[-0.06, 0.05]; [-0.58, -0.47]$
C_{S_2}	$[-0.03, 0.03]$	$[-0.05, 0.06]; \quad [0.47, 0.58]$
C_T	$[-0.13, 0.10]; [-1.23, -0.56]$	-

SM like

large negative interference

vectors, tensor ~ O(0.1)

scalars ~ 0.03

Summary

- Model-independent analysis of $b \to u\tau\bar{\nu}$

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

- Observables of less uncertainties

$$R_{\rm ps} = \frac{\tau_{B^0}}{\tau_{B^-}} \frac{\mathcal{B}(B^- \to \tau^- \bar{\nu}_\tau)}{\mathcal{B}(\bar{B}^0 \to \pi^+ \ell^- \bar{\nu}_\ell)}$$ most sensitive

$$R_\pi = \frac{\mathcal{B}(\bar{B}^0 \to \pi^+ \tau^- \bar{\nu})}{\mathcal{B}(\bar{B}^0 \to \pi^+ \ell^- \bar{\nu})}$$ sensitive to tensor
complementary to $R_{\rm ps}$

$$R_{\rm pl} = \frac{\mathcal{B}(B \to \tau\bar{\nu}_\tau)}{\mathcal{B}(B \to \mu\bar{\nu}_\mu)}$$ no theoretical uncertainty
need more statistics ?

- Other observables

  q[2] distribution, $B \to \rho\tau\bar{\nu}$