High1 Workshop on Particle, String and Cosmology

暨南大學
JINAN UNIVERSITY

B Anomalies & SMEFT Interpretations

Fanrong Xu

Jinan University, China

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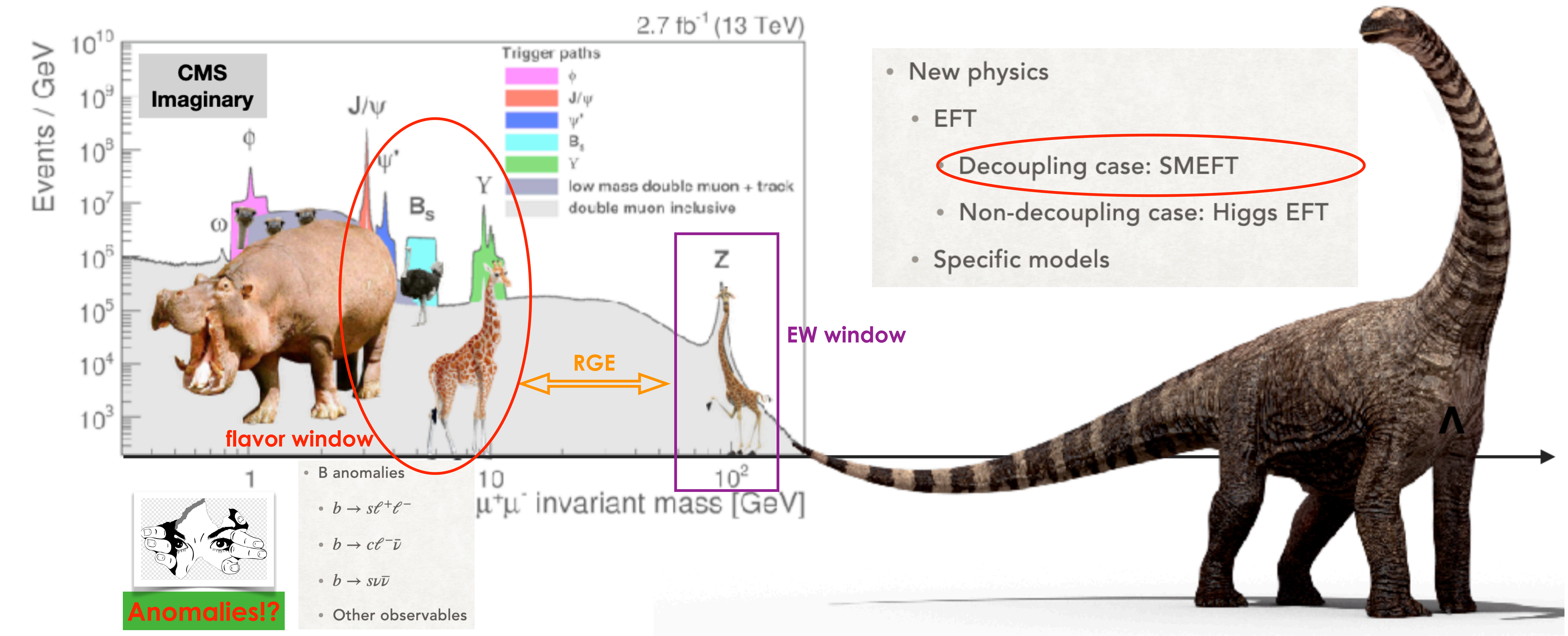
OUTLINE

- Introduction
- $b \to s\ell^+\ell^-$ and its implication
- Correlation within SMEFT
- Numerical results
- Summary

INTRODUCTION

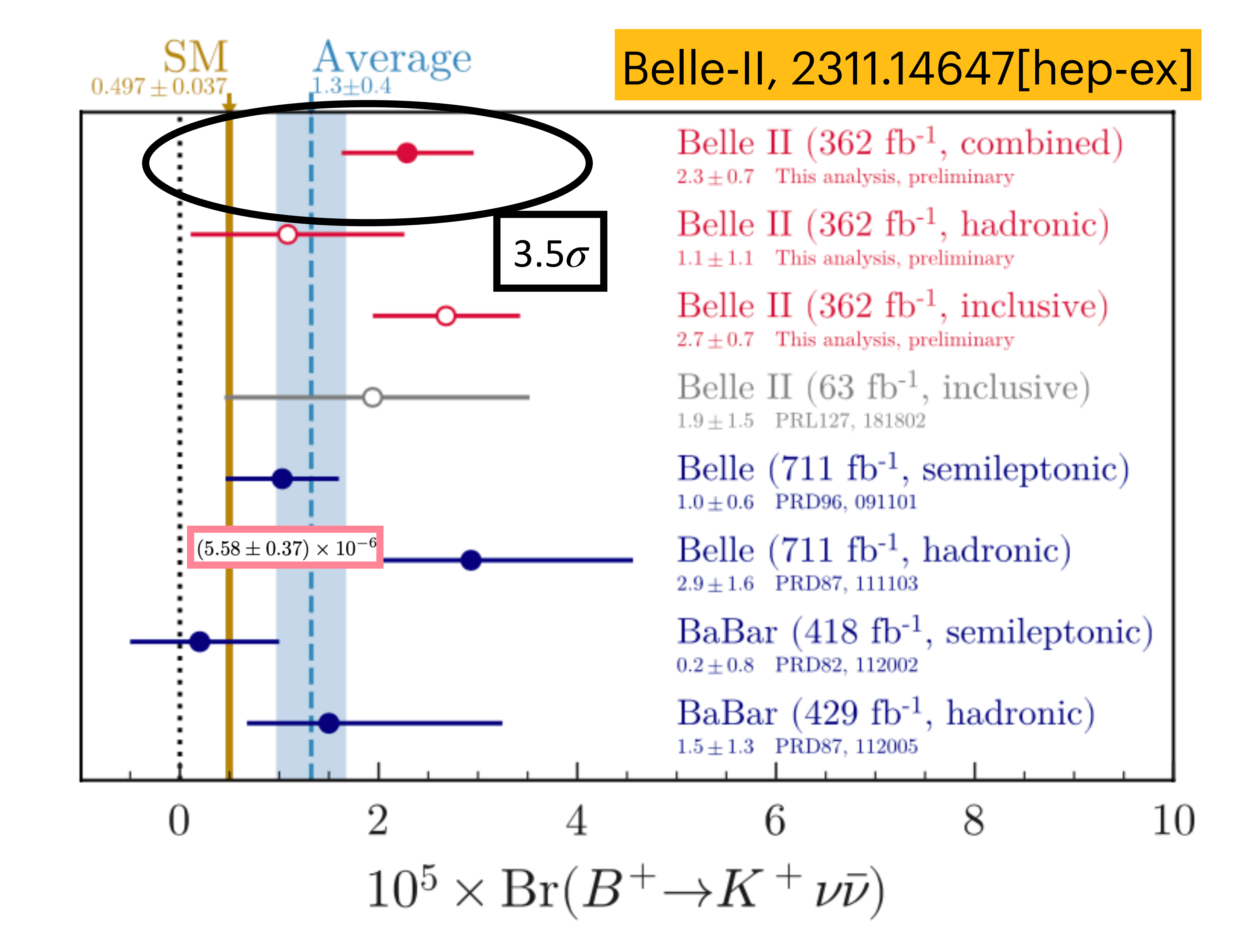
Flavor physics is an indirect probe of new physics.



- New physics
  - EFT
    - Decoupling case: SMEFT
    - Non-decoupling case: Higgs EFT
  - Specific models

- B anomalies
  - $b \to s\ell^+\ell^-$
  - $b \to c\ell^-\bar{\nu}$
  - $b \to s\nu\bar{\nu}$
  - Other observables

$B^+ \to K^+\nu\bar{\nu}$ & $B^0 \to K^{*0}\nu\bar{\nu}$



Search for $B \to h\nu\bar{\nu}$ decays with semileptonic tagging at Belle #1

Belle Collaboration • J. Grygier (KIT, Karlsruhe, EKP) et al. (Feb 10, 2017)

Published in: *Phys.Rev.D* 96 (2017) 9, 091101, *Phys.Rev.D* 97 (2018) 9, 099902 (addendum) • e-Print: 1702.03224 [hep-ex]

$$\mathcal{B}(B^0 \to K^{*0}\nu\bar{\nu})_{\rm exp} < 1.8 \times 10^{-5}$$

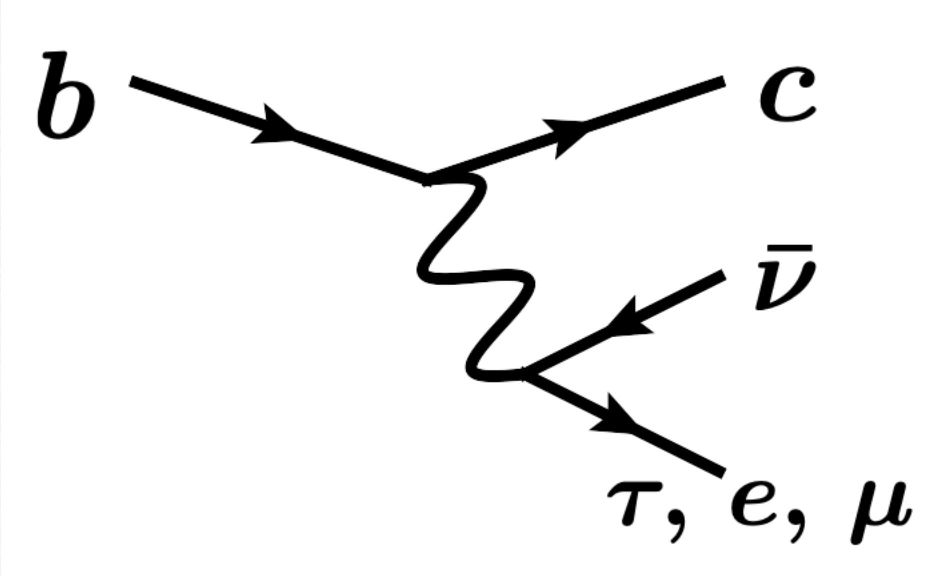
$$R\big|_{\tt exp} = \frac{\mathcal{B}(B^0 \to K^{*0}\nu\bar{\nu})\big|_{\tt exp}}{\mathcal{B}(B^+ \to K^+\nu\bar{\nu})\big|_{\tt exp}} < 0.78$$

in tension?

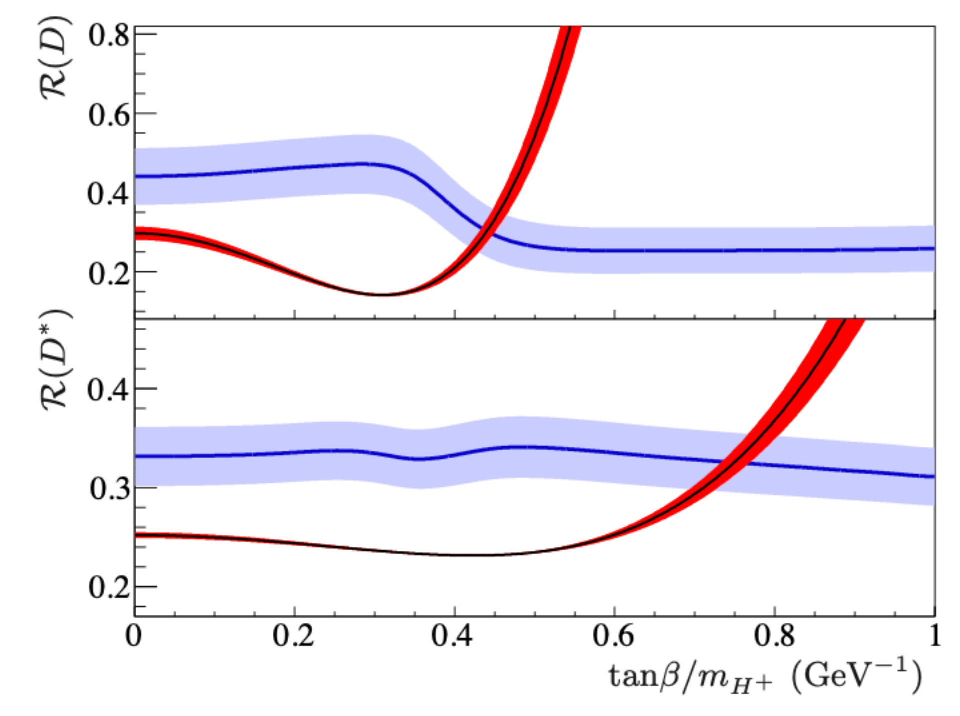
$$R\big|_{\tt SM} = \frac{\mathcal{B}(B^0 \to K^{*0}\nu\bar{\nu})\big|_{\tt SM}}{\mathcal{B}(B^+ \to K^+\nu\bar{\nu})\big|_{\tt SM}} \approx 2.37$$

$R_{D^{(*)}}$

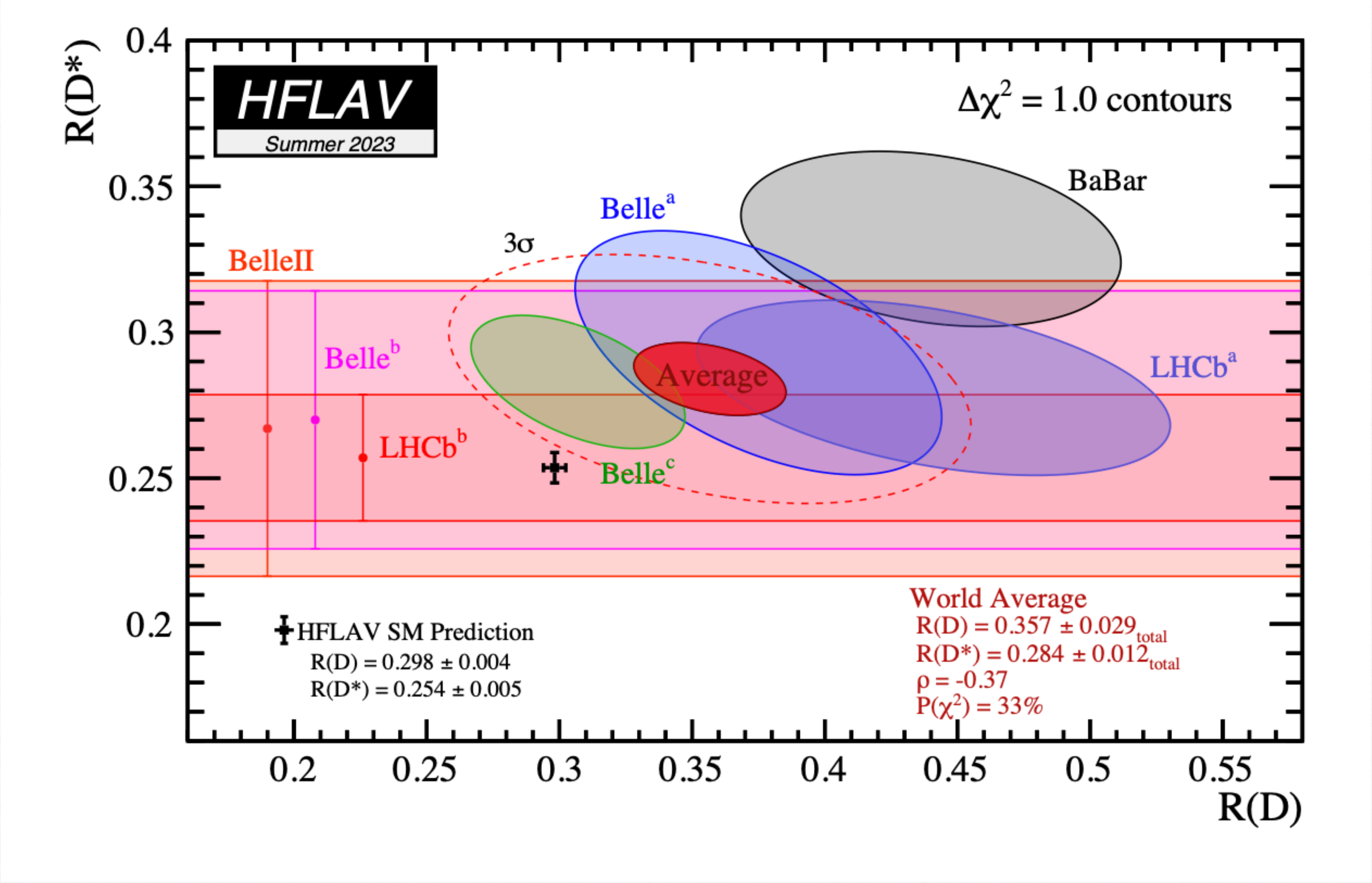
$$R_{D^{(*)}} \equiv \frac{\mathcal{B}(B \to D^{(*)}\tau\bar{\nu}_\tau)}{\mathcal{B}(B \to D^{(*)}\ell\bar{\nu}_\ell)}$$



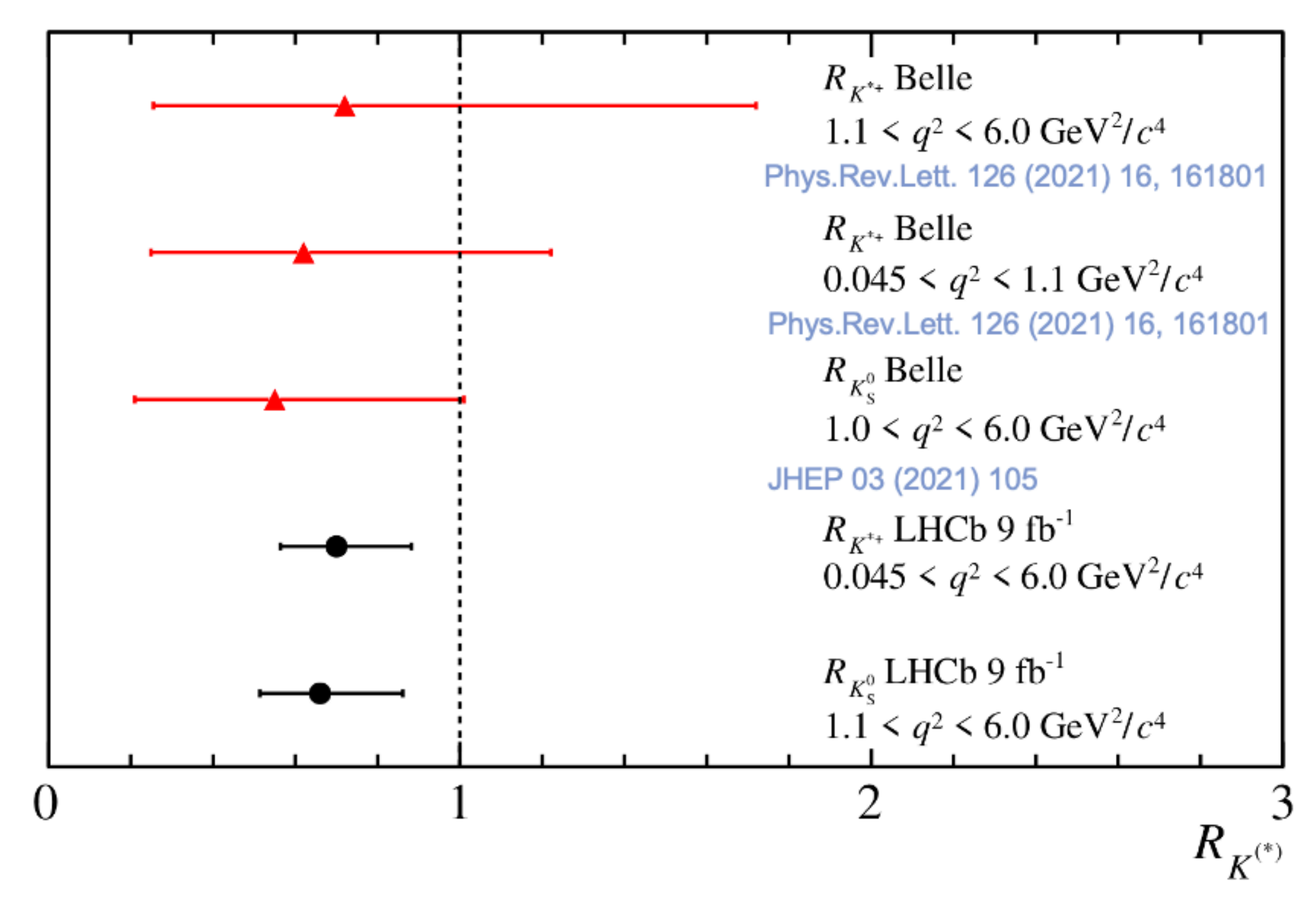
$$\mathcal{R}(D) = 0.440 \pm 0.058 \pm 0.042$$
$$\mathcal{R}(D^*) = 0.332 \pm 0.024 \pm 0.018$$



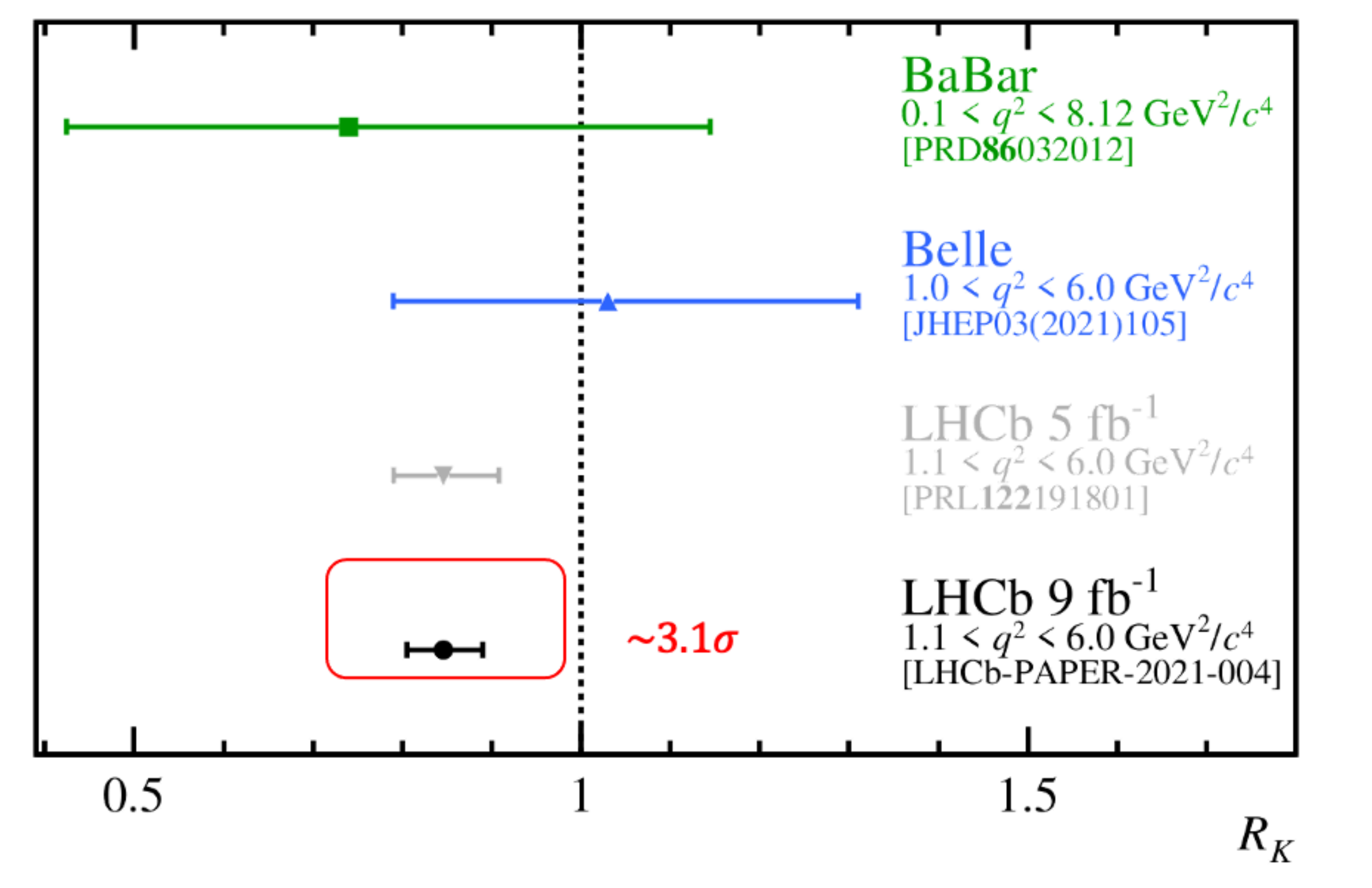
Babar, 1205.5442



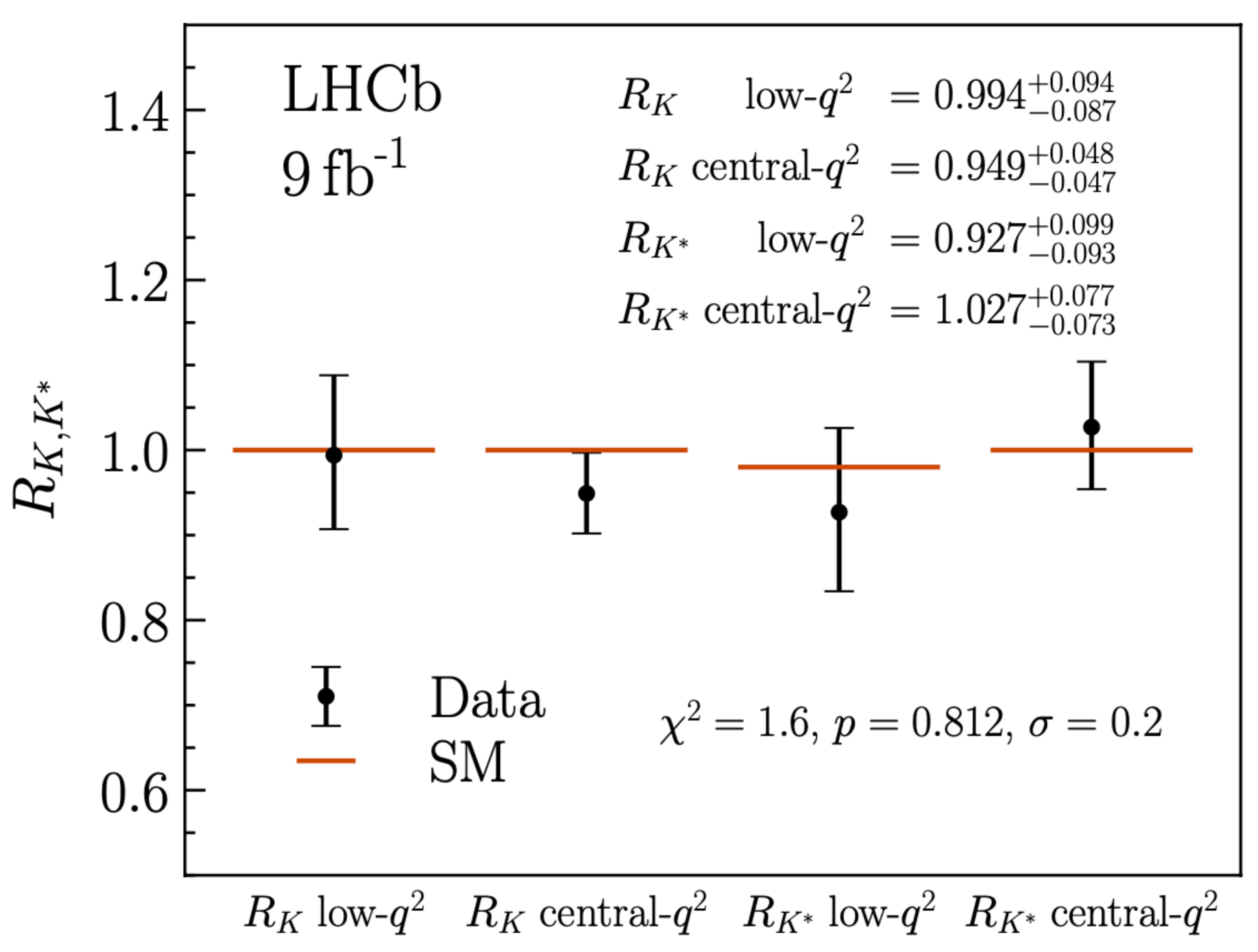
$R_{K^{(*)}}$ IN $B \to K^{(*)}\ell^+\ell^-$



LHCb, Phys.Rev.Lett. 128 (2022) 19, 191802



LHCb, Nature Physics 18, (2022) 277-282



LHCb PRD 108 (2023) 3, 032002

$$R(\mathrm{K}) = 0.78^{+0.46}_{-0.23}\,(\mathrm{stat})^{+0.09}_{-0.05}\,(\mathrm{syst}) = 0.78^{+0.47}_{-0.23}$$

CMS , 2401.0709

Standard model EFT (SMEFT)

Defined between Λ_{NP} and Λ_{EW}:

- Dynamical degrees of freedom (DoFs) restricted to SM fields;
- Symmetries – $SU(3)_C \times SU(2)_L \times U(1)_Y$, no L or B conservation requirement etc;
- Power counting – expansion in p/Λ_{NP}.

SMEFT is an infinite tower of effective interactions involving higher and higher dimensional operators:

Weinberg 1979

Lehman 2014
Liao-Ma 2016

Li et al, arXiv: 2007.07899
Liao-Ma, arXiv: 2007.08125

$$\mathscr{L}_{\mathrm{SMEFT}} = \mathscr{L}_{\mathrm{SM}} + \mathscr{L}_5 + \mathscr{L}_6 + \mathscr{L}_7 + \mathscr{L}_8 + \mathscr{L}_9 + \cdots$$

GSW 1960s

Buchmuller-Wyler 1986; ……
Grzadkowski et al 2010
– Warsaw basis

Li et al, arXiv: 2005.00008
Murphy, arXiv: 2005.00059

Latest: up to dim-12, Harlander et al, 2305.06832

SMEFT: dim-6

- Long history on basis of operators.

  Started with Buchmüller-Wyler 1986,

  Corrected and improved by efforts by many groups,

  Culminated with Warsaw basis Grzadkowski et al 2010 –

- 63 operators $\begin{cases} 59\colon \Delta B = \Delta L = 0 \\ 4\colon \Delta B = \Delta L = 1 \end{cases}$

  without counting flavors (easy with trivial flavor relations) and Hermitian conjugate.

- 1-loop RGE by UC San Diego group in 2013, 2014 Barcelona group in 2013

- Rich phenomenology, especially for LHC phys, vast literature skipped

  Commonly quoted proton decay: $p \to e^+\pi^0$

Low-energy EFT

When $E < \Lambda_{\mathrm{EW}}$, electroweak SSB manifests itself.

Heavy particles $(h, W^{\pm}, Z^0, t)$ of mass $\sim\Lambda_{\mathrm{EW}}$ are integrated out $\to$ LEFT

Defined between Λ_{EW} and $\Lambda_{\chi} \sim 1\ \mathrm{GeV}$:

- Dynamical DoFs = SM fields other than above heavy ones;
- Symmetries – $SU(3)_C \times U(1)_Q$;
- Power counting – expansion in p/Λ_{EW}.

Actually well applied in the past, e.g., in b phys, although not studied systematically.

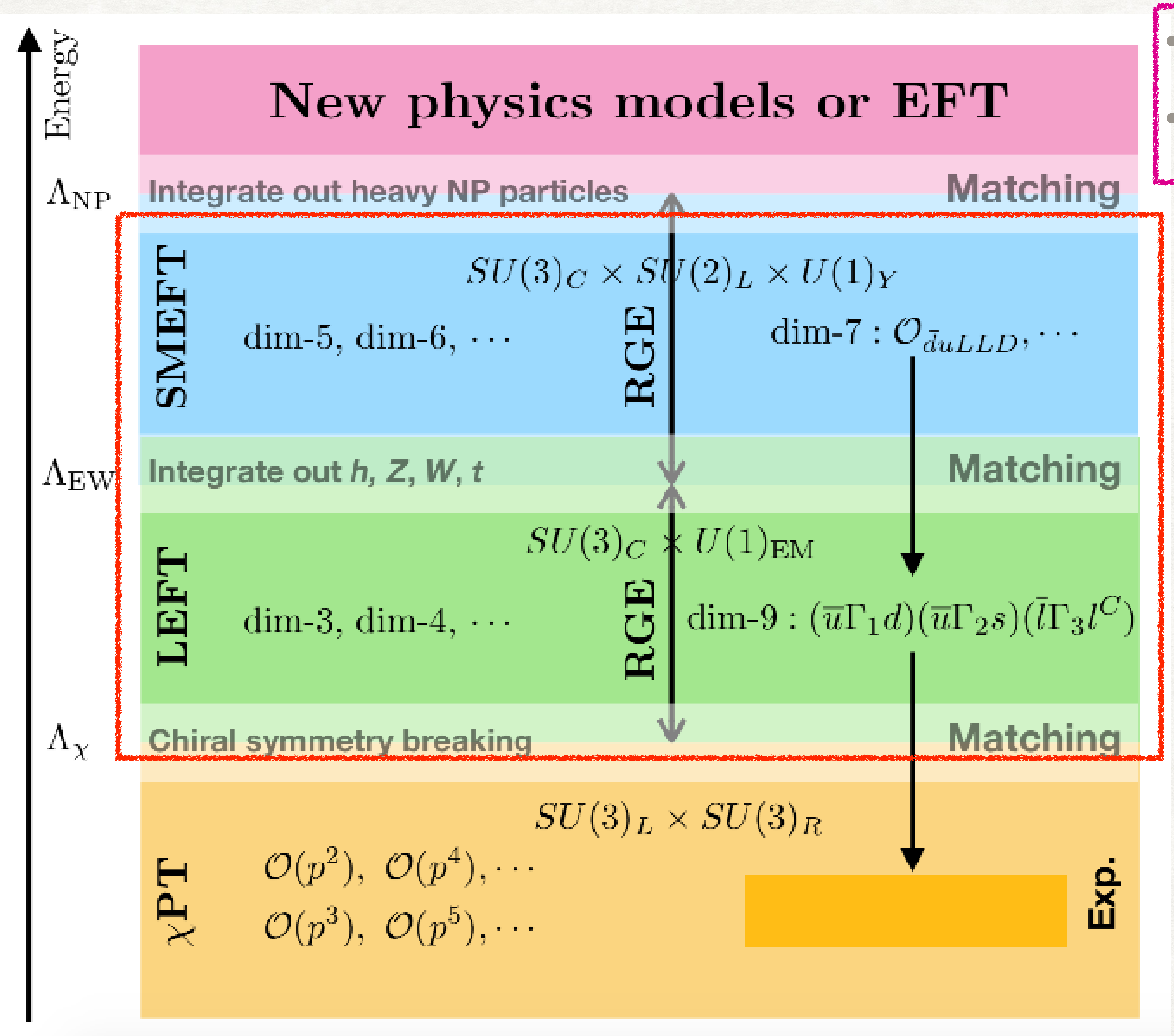
Jenkins et al, 2017 Murphy, 2020 $|\Delta L| = 2$ sector: Liao et al, 2019

$$\mathscr{L}_{\mathrm{LEFT}} = \mathscr{L}_{\mathrm{V}} + \mathscr{L}_{\mathrm{QED}} + \mathscr{L}_{\mathrm{QCD}} + \mathscr{L}_5 + \mathscr{L}_6 + \mathscr{L}_7 + \mathscr{L}_8 + \mathscr{L}_9 + \cdots$$

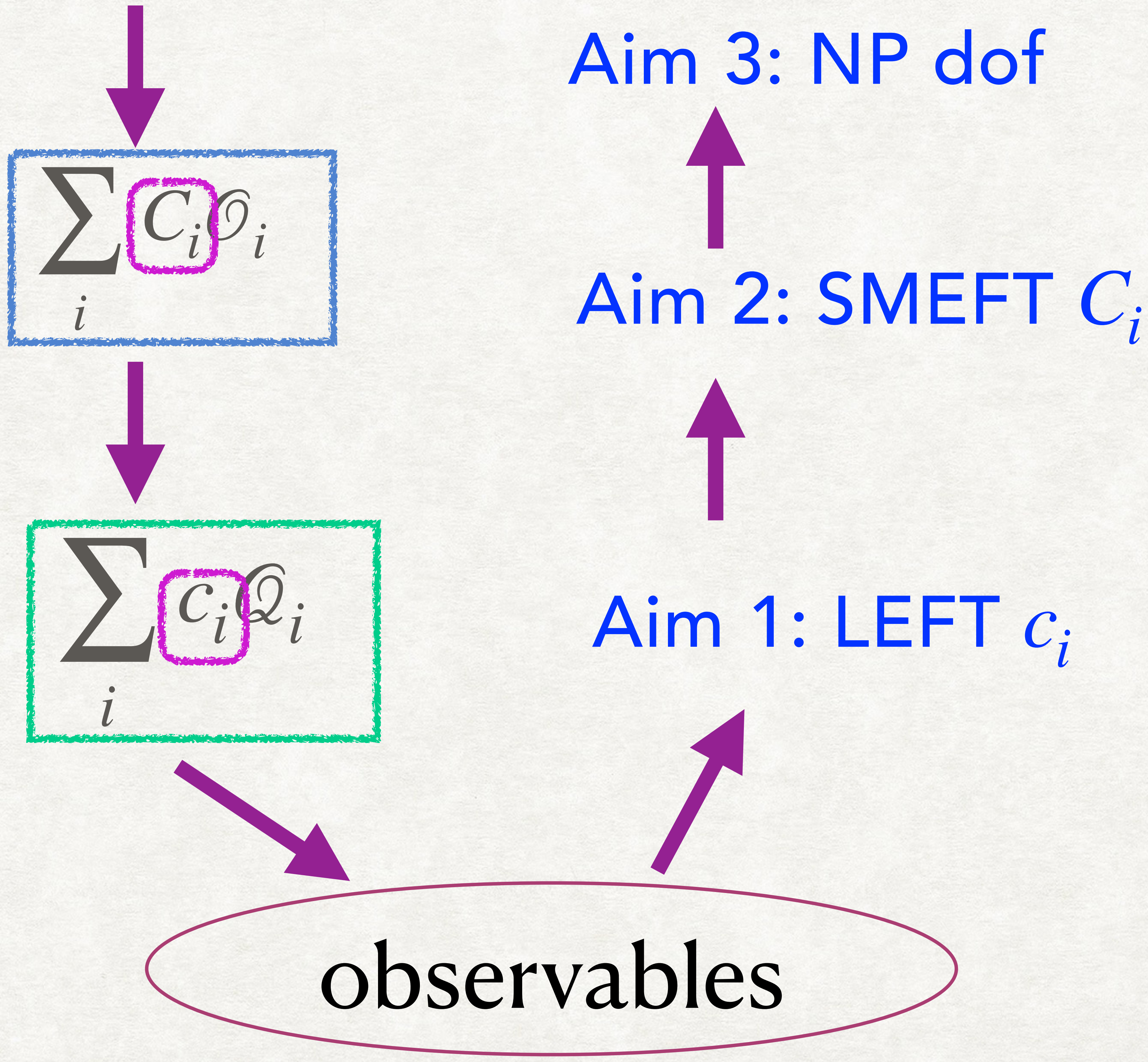
Liao et al, 2020 Li et al, 2020

Attention: combined power counting in $1/\Lambda_{\mathrm{EW}}$ and $1/\Lambda_{\mathrm{NP}}$

EFT & DATA



- NP degrees of freedom far above EW integrated out
- Spontaneous symmetry breaking



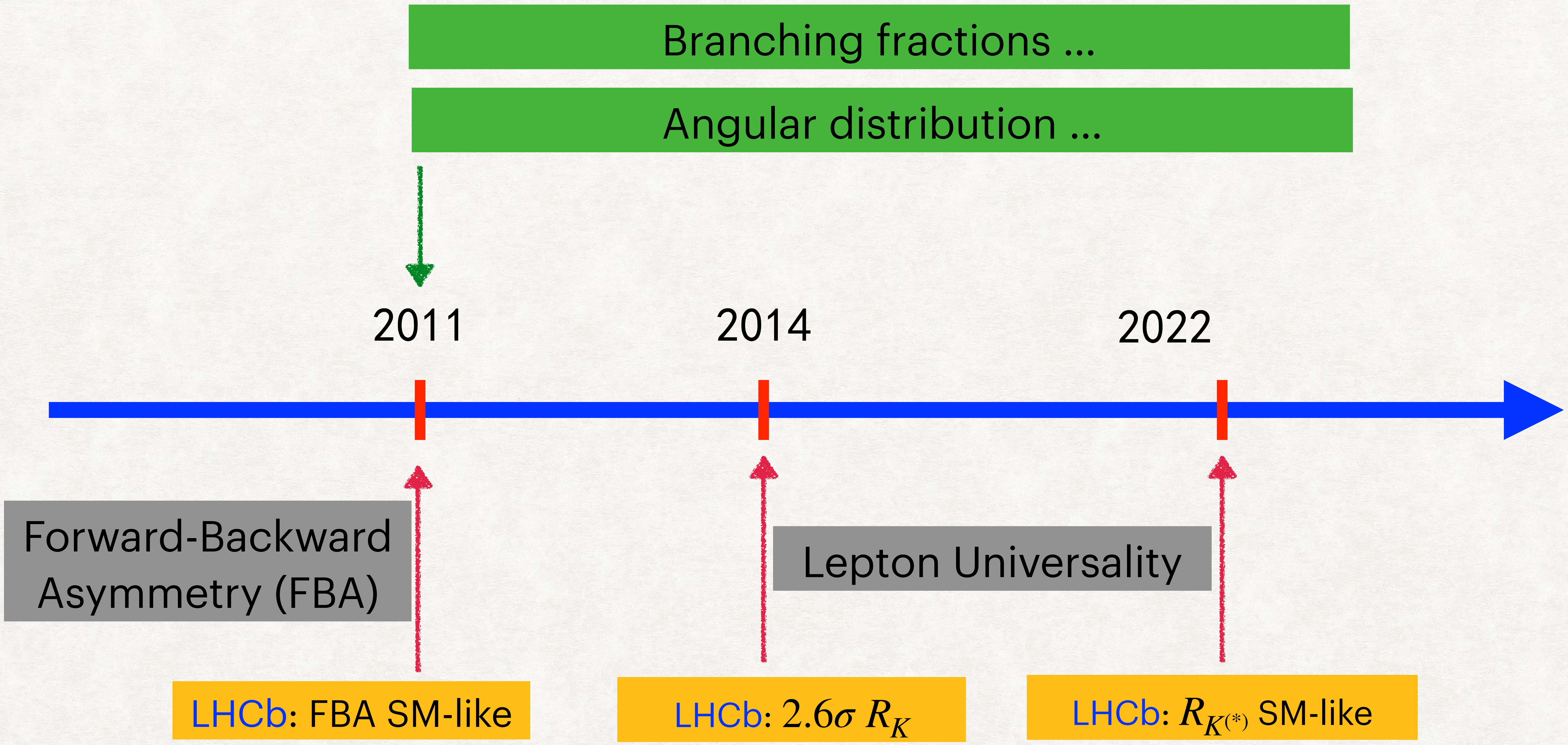
To be answered in LEFT level

1. Is NP really ruled out by $R_{K^{(*)}}$?
2. Is lepton flavor distinguishable ?

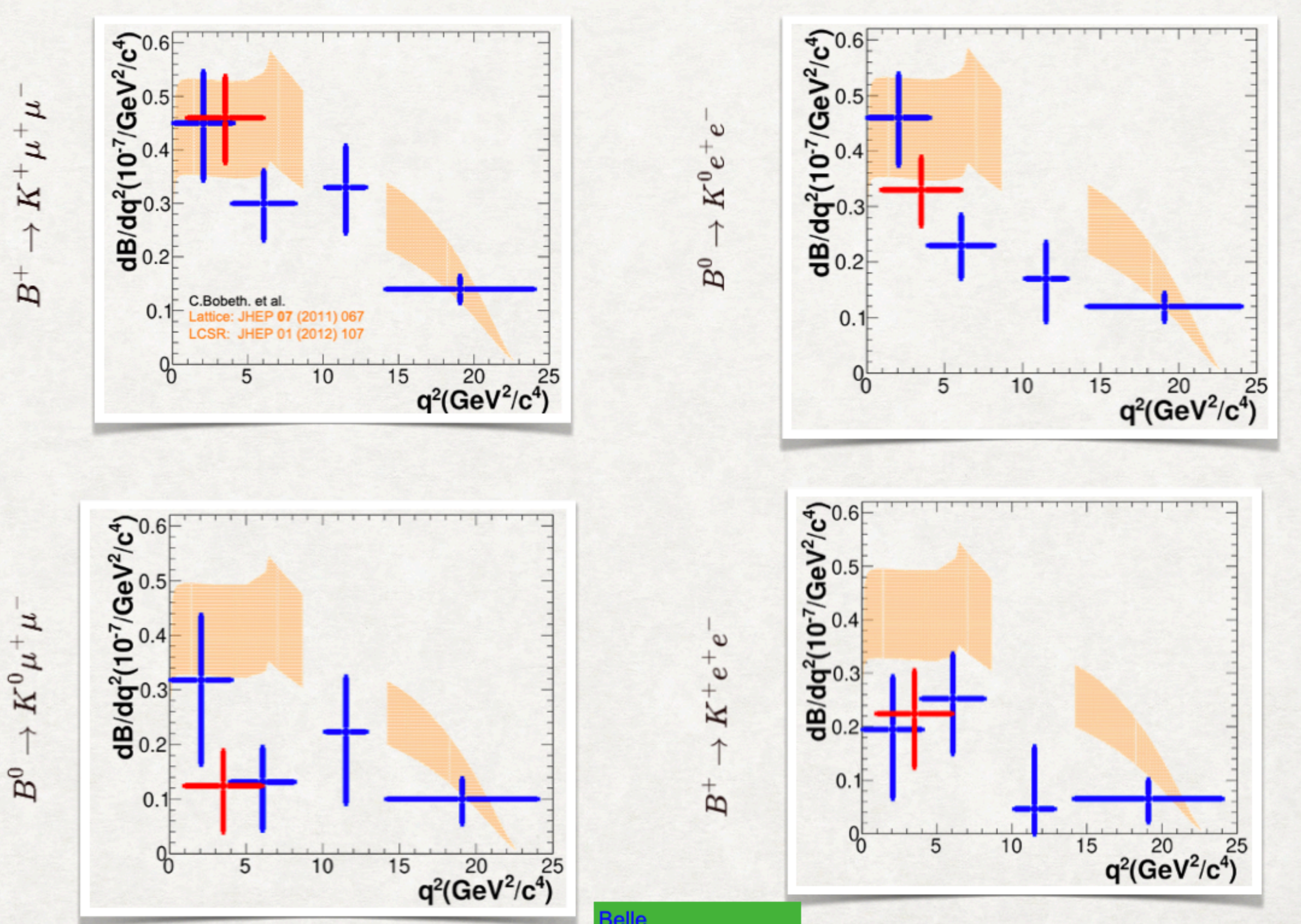
$$b \to s\ell^+\ell^-$$

Qiaoyi Wen, FX, PRD 108 (2023), 095038

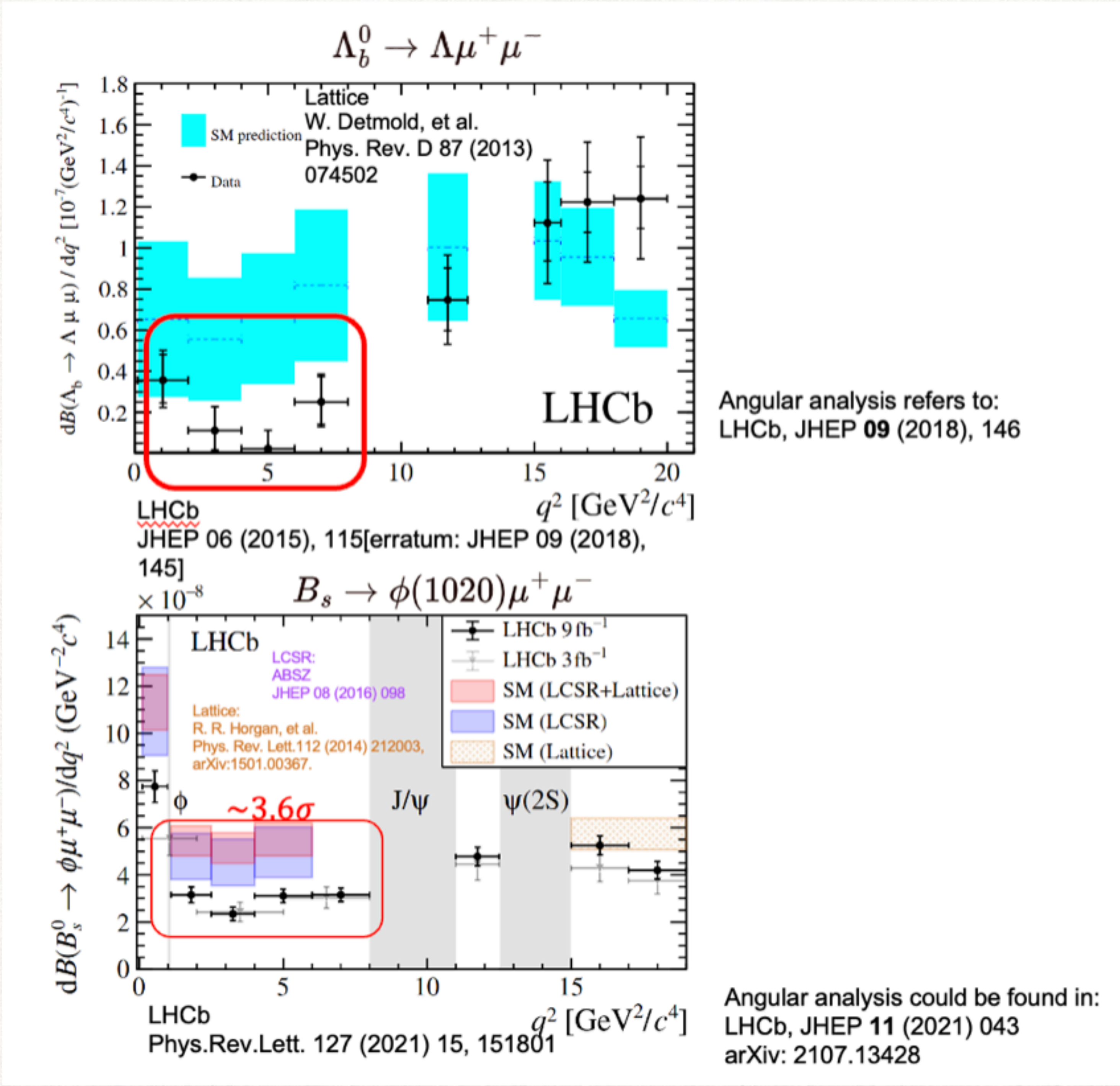
TIME EVOLUTION OF "ANOMALIES" IN $b \to s\ell^+\ell^-$

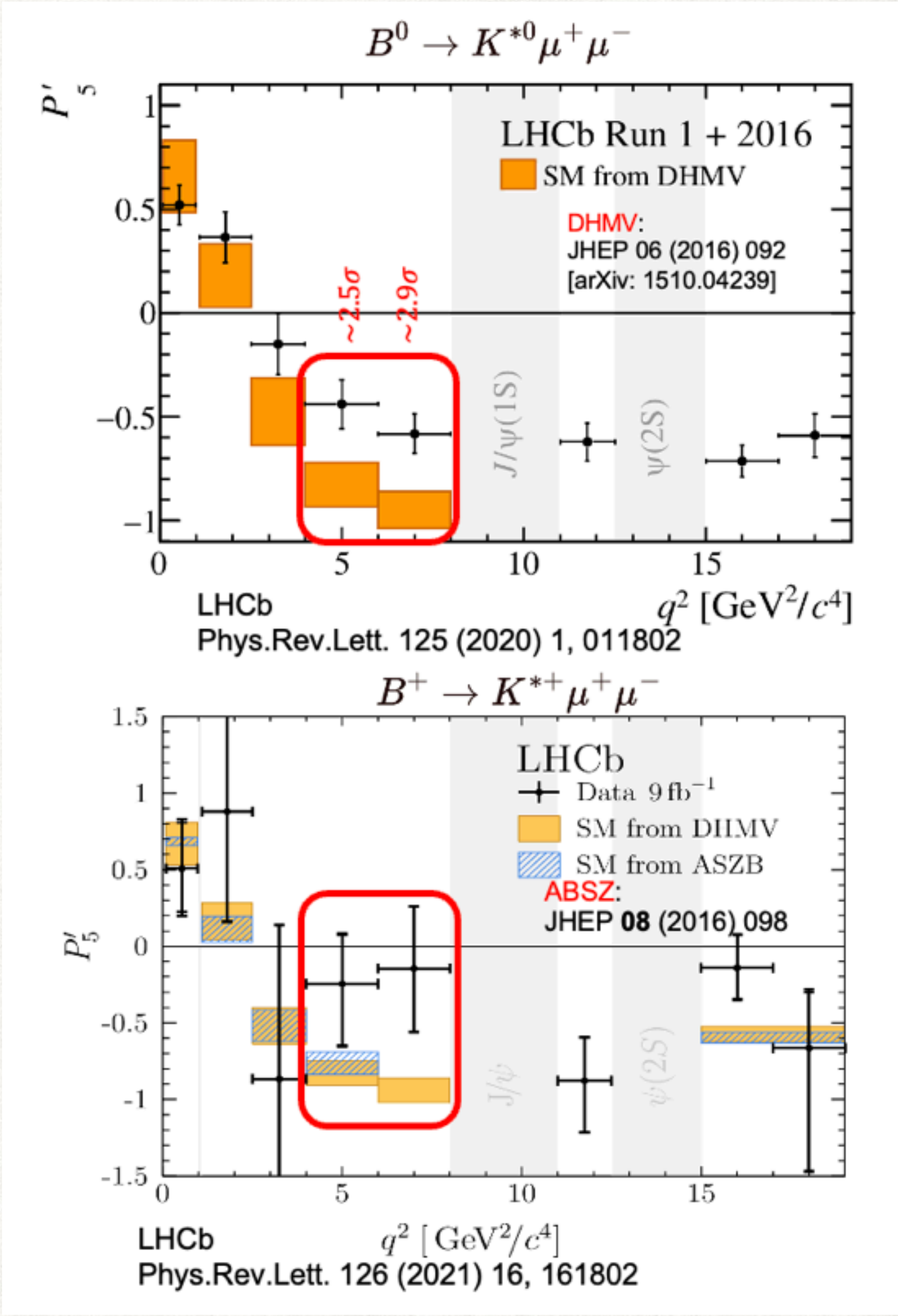


THE REMAINING CANDY IN $b \to s\ell^+\ell^-$



Belle
JHEP **03** (2021) 105





THEORETICAL SKELETON OF FCNC PROCESS $b \to s$

effective Hamiltonian:

$$\mathscr{H} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{e^2}{16\pi^2} \sum_i \left(\boxed{C_i} \mathcal{O}_i + C_i' \mathcal{O}_i' \right) + h.c.$$

high energy information

$$C_i^{(\prime)\ell} = C_i^{(\prime)\ell;\mathrm{SM}} + \Delta C_i^{(\prime)\ell;\mathrm{NP}} = C_i^{(\prime)\ell;\mathrm{SM}} + \Delta C_i^{(\prime)\ell}$$

SM

$$\mathcal{O}_7 = \frac{m_b}{e}(\bar{s}\sigma_{\mu\nu}P_R b)F^{\mu\nu}, \qquad \mathcal{O}_7' = \frac{m_b}{e}(\bar{s}\sigma_{\mu\nu}P_L b)F^{\mu\nu},$$

$$\mathcal{O}_8 = \frac{g_s m_b}{e^2}(\bar{s}\sigma_{\mu\nu}T^a P_R b)G_a^{\mu\nu}, \qquad \mathcal{O}_8' = \frac{g_s m_b}{e^2}(\bar{s}\sigma_{\mu\nu}T^a P_L b)G_a^{\mu\nu},$$

$$\mathcal{O}_9 = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell), \qquad \mathcal{O}_9' = (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \ell),$$

$$\mathcal{O}_{10} = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma_5 \ell), \qquad \mathcal{O}_{10}' = (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \gamma_5 \ell),$$

$$\mathcal{O}_S = m_b(\bar{s}P_R b)(\bar{\ell}\ell), \qquad \mathcal{O}_S' = m_b(\bar{s}P_L b)(\bar{\ell}\ell),$$

$$\mathcal{O}_P = m_b(\bar{s}P_R b)(\bar{\ell}\gamma_5\ell), \qquad \mathcal{O}_P' = m_b(\bar{s}P_L b)(\bar{\ell}\gamma_5\ell).$$

QCDF

decay amplitude:

$$\mathcal{M}(\bar{B} \to P\ell^+\ell^-) = \frac{G_F \alpha}{2\sqrt{2}\pi} c_P^{-1} \xi_P \left[\left(\lambda_t \boxed{\mathcal{C}_{9,P}^{(t)}} + \lambda_u \boxed{\mathcal{C}_{9,P}^{(u)}} \right) (p^\mu + p'^\mu)(\bar{\ell}\gamma_\mu \ell) + \lambda_t C_{10} (p^\mu + p'^\mu)(\bar{\ell}\gamma_\mu \gamma_5 \ell) \right]$$

$$\mathcal{C}_{9,P}^{(t)}(q^2) = C_9 + \frac{2m_b}{M_B} \frac{\boxed{\mathcal{T}_P^{(t)}(q^2)}}{\xi_P(q^2)}$$

$$\mathcal{C}_{9,P}^{(u)}(q^2) = \frac{2m_b}{M_B} \frac{\boxed{\mathcal{T}_P^{(u)}(q^2)}}{\xi_P(q^2)}.$$

$$\mathcal{T}_P^{(i)} = \xi_P C_P^{(i)} + \frac{\pi^2 f_B f_P}{N_c M_B} \sum_\pm \int_0^\infty \frac{d\omega}{\omega} \Phi_{B,\pm}(\omega) \int_0^1 du\, \phi_P(u) T_{P,\pm}^{(i)}(u,\omega)$$

observables:

$$\frac{d\mathcal{B}}{dq^2}(\bar{B} \to P\ell^+\ell^-) = S_P \tau_B \frac{G_F^2 M_B^3}{96\pi^3} \left(\frac{\alpha}{4\pi}\right)^2 \lambda(q^2, m_P^2)^3 \xi_P(q^2)^2 \left(\left| \lambda_t \mathcal{C}_{9,P}^{(t)}(q^2) + \lambda_u \mathcal{C}_{9,P}^{(u)}(q^2) \right|^2 + |\lambda_t|^2 C_{10}^2 \right)$$

PHYSICS FROM EW SCALE

- High energy information: Wilson coefficients in SM
  - EW scale
    - $C_{9,10}$: NNLL;
    - $C_{1-6}, C_{7,8}$: NLL
    - 2-loop matching: C. Bobeth, M. Misiak, J. Urban, NPB 574, 291 (2000)
  - RGE running
    - 3-loop anomalous dimension matrix:

      K.G. Chetyrkin, M. Misiak, M. Munz, PLB 400, 206 (1997); 425, 414(E) (1998);

      P. Gambino, M. Gorbahn, U. Haisch, NPB673, 238 (2003);

      M. Gorbahn, U. Haisch, NPB713, 291 (2005);

TABLE III. The SM Wilson coefficients at the scale $\mu = 4.6$ GeV in leading logarithmic (LL), next-to-leading logarithmic (NLL) and next-to-next-to-leading logarithmic order (NNLL). Input parameters listed in Table II are used.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7^{eff}	C_8^{eff}	C_9	C_{10}
LL	−0.5093	1.0256	−0.0050	−0.0686	0.0005	0.0010	−0.3189	−0.1505	2.0111	0
NLL	−0.3001	1.0080	−0.0047	−0.0827	0.0003	0.0009	−0.2969	−0.1642	4.1869	−4.3973
NNLL	–	–	–	–	–	–	–	–	4.2607	−4.2453

THE ENCODED NEW PHYSICS

- New physics effect
  - Deviations from SM Wilson coefficients

$$C_i^{(\prime)\ell} = C_i^{(\prime)\ell;\mathrm{SM}} + \Delta C_i^{(\prime)\ell;\mathrm{NP}} = C_i^{(\prime)\ell;\mathrm{SM}} + \boxed{\Delta C_i^{(\prime)\ell}}$$

  - BSM operators

$$\begin{aligned}
\mathcal{O}_7 &= \frac{m_b}{e}(\bar{s}\sigma_{\mu\nu}P_R b)F^{\mu\nu}, & \mathcal{O}'_7 &= \frac{m_b}{e}(\bar{s}\sigma_{\mu\nu}P_L b)F^{\mu\nu},\\
\mathcal{O}_8 &= \frac{g_s m_b}{e^2}(\bar{s}\sigma_{\mu\nu}T^a P_R b)G_a^{\mu\nu}, & \mathcal{O}'_8 &= \frac{g_s m_b}{e^2}(\bar{s}\sigma_{\mu\nu}T^a P_L b)G_a^{\mu\nu},\\
\mathcal{O}_9 &= (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell), & \mathcal{O}'_9 &= (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \ell),\\
\mathcal{O}_{10} &= (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma_5 \ell), & \mathcal{O}'_{10} &= (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \gamma_5 \ell),\\
\mathcal{O}_S &= m_b(\bar{s}P_R b)(\bar{\ell}\ell), & \mathcal{O}'_S &= m_b(\bar{s}P_L b)(\bar{\ell}\ell),\\
\mathcal{O}_P &= m_b(\bar{s}P_R b)(\bar{\ell}\gamma_5 \ell), & \mathcal{O}'_P &= m_b(\bar{s}P_L b)(\bar{\ell}\gamma_5 \ell).
\end{aligned}$$

Scenario I: muon-specific

$$\Delta C^{(\prime)e}_{9,10,S,P} = 0$$

Scenario II: lepton-universal

$$\Delta C^{(\prime)\mu}_{9,10,S,P} = \Delta C^{(\prime)e}_{9,10,S,P}$$

Scenario III: lepton-specific

all parameters are taken except C7,C8

Scenario IV: full scenario

all parameters are taken

THE $b \to s$ PROCESSES

- B meson leptonic decays
- B meson radiative decays
- B meson inclusive semi-leptonic decay
- B meson exclusive semi-leptonic decay: **QCDF approach**
  - $B \to P\ell^+\ell^-$
  - $B \to V\ell^+\ell^-$
- Bottomed baryon semi-leptonic decays: **naive factorization**

KINEMATICS & OBSERVABLES

- Kinematics

$$\frac{d^4\Gamma}{dq^2\, d\cos\theta_l\, d\cos\theta_{K^*}\, d\phi} = \frac{9}{32\pi} I(q^2, \theta_l, \theta_{K^*}, \phi)$$

$$\begin{aligned} I(q^2,\theta_l,\theta_{K^*},\phi) &= I_1^s \sin^2\theta_{K^*} + I_1^c \cos^2\theta_{K^*} + (I_2^s \sin^2\theta_{K^*} + I_2^c \cos^2\theta_{K^*})\cos 2\theta_l \\ &+ I_3 \sin^2\theta_{K^*} \sin^2\theta_l \cos 2\phi + I_4 \sin 2\theta_{K^*} \sin 2\theta_l \cos\phi \\ &+ I_5 \sin 2\theta_{K^*} \sin\theta_l \cos\phi \\ &+ (I_6^s \sin^2\theta_{K^*} + I_6^c \cos^2\theta_{K^*}) \cos\theta_l + I_7 \sin 2\theta_{K^*} \sin\theta_l \sin\phi \\ &+ I_8 \sin 2\theta_{K^*} \sin 2\theta_l \sin\phi + I_9 \sin^2\theta_{K^*} \sin^2\theta_l \sin 2\phi\,. \end{aligned}$$

  - transversity amplitude

W. Altmannshofer, P. Ball, A. Bharucha, A.J. Buras, D. Straub, M. Wick, 0811.1214

$$\begin{aligned} I_1^s &= \frac{(2+\beta_\mu^2)}{4}\left[|A_\perp^L|^2 + |A_\parallel^L|^2 + (L \to R)\right] + \frac{4m_\mu^2}{q^2}\mathrm{Re}\left(A_\perp^L A_\perp^{R*} + A_\parallel^L A_\parallel^{R*}\right) \\ I_1^c &= |A_0^L|^2 + |A_0^R|^2 + \frac{4m_\mu^2}{q^2}\left[|A_t|^2 + 2\mathrm{Re}(A_0^L A_0^{R*})\right] + \beta_\mu^2 |A_S|^2, \\ I_2^s &= \frac{\beta_\mu^2}{4}\left[|A_\perp^L|^2 + |A_\parallel^L|^2 + (L \to R)\right], \\ I_2^c &= -\beta_\mu^2\left[|A_0^L|^2 + (L \to R)\right], \\ I_3 &= \frac{1}{2}\beta_\mu^2\left[|A_\perp^L|^2 - |A_\parallel^L|^2 + (L \to R)\right], \\ I_4 &= \frac{1}{\sqrt{2}}\beta_\mu^2\left[\mathrm{Re}(A_0^L A_\parallel^{L*}) + (L \to R)\right], \end{aligned}$$

$$\begin{aligned} A_{\parallel L,R} &= -N\sqrt{2}(m_B^2 - m_{K^*}^2)\left[\left[(C_9^{\mathrm{eff}} - C_9^{\mathrm{eff}\prime}) \mp (C_{10}^{\mathrm{eff}} - C_{10}^{\mathrm{eff}\prime})\right]\frac{A_1(q^2)}{m_B - m_{K^*}} \right. \\ &\quad \left. + \frac{2m_b}{q^2}(C_7^{\mathrm{eff}} - C_7^{\mathrm{eff}\prime})T_2(q^2)\right], \\ A_{0L,R} &= -\frac{N}{2m_{K^*}\sqrt{q^2}}\left\{\left[(C_9^{\mathrm{eff}} - C_9^{\mathrm{eff}\prime}) \mp (C_{10}^{\mathrm{eff}} - C_{10}^{\mathrm{eff}\prime})\right] \right. \\ &\quad \times \left[(m_B^2 - m_{K^*}^2 - q^2)(m_B + m_{K^*})A_1(q^2) - \lambda\frac{A_2(q^2)}{m_B + m_{K^*}}\right] \\ &\quad \left. + 2m_b(C_7^{\mathrm{eff}} - C_7^{\mathrm{eff}\prime})\left[(m_B^2 + 3m_{K^*}^2 - q^2)T_2(q^2) - \frac{\lambda}{m_B^2 - m_{K^*}^2}T_3(q^2)\right]\right\}, \\ A_t &= \frac{N}{\sqrt{q^2}}\lambda^{1/2}\left[2(C_{10}^{\mathrm{eff}} - C_{10}^{\mathrm{eff}\prime}) + \frac{q^2}{m_\mu}(C_P - C_P')\right]A_0(q^2), \\ A_S &= -2N\lambda^{1/2}(C_S - C_S')A_0(q^2), \end{aligned}$$

  - helicity amplitude

S. Jager, J. M. Camalich 1212.2263

$$\begin{aligned} I_1^c &= F\left\{\frac{1}{2}\left(|H_V^0|^2 + |H_A^0|^2\right) + |H_P|^2 + \frac{2m_\ell^2}{q^2}\left(|H_V^0|^2 - |H_A^0|^2\right) + \beta^2|H_S|^2\right\}, \\ I_1^s &= F\left\{\frac{\beta^2+2}{8}\left(|H_V^+|^2 + |H_V^-|^2 + (V \to A)\right) + \frac{m_\ell^2}{q^2}\left(|H_V^+|^2 + |H_V^-|^2 - (V \to A)\right)\right\} \\ I_2^c &= -F\frac{\beta^2}{2}\left(|H_V^0|^2 + |H_A^0|^2\right), \\ I_2^s &= F\frac{\beta^2}{8}\left(|H_V^+|^2 + |H_V^-|^2\right) + (V \to A), \\ I_3 &= -\frac{F}{2}\mathrm{Re}\left[H_V^+(H_V^-)^*\right] + (V \to A), \end{aligned}$$

$$\begin{aligned} H_V(\lambda) &= -i\,N\left\{C_9\tilde{V}_{L\lambda} + C_9'\tilde{V}_{R\lambda} + \frac{m_B^2}{q^2}\left[\frac{2\,\hat{m}_b}{m_B}(C_7\tilde{T}_{L\lambda} + C_7'\tilde{T}_{R\lambda}) - 16\pi^2 h_\lambda\right]\right\}, \\ H_A(\lambda) &= -i\,N(C_{10}\tilde{V}_{L\lambda} + C_{10}'\tilde{V}_{R\lambda}), \\ H_{TR}(\lambda) &= -i\,N\frac{4\,\hat{m}_b\,m_B}{m_W\sqrt{q^2}}C_T\tilde{T}_{L\lambda}, \\ H_{TL}(\lambda) &= -i\,N\frac{4\,\hat{m}_b\,m_B}{m_W\sqrt{q^2}}C_T'\tilde{T}_{R\lambda}, \\ H_S &= i\,N\frac{\hat{m}_b}{m_W}(C_S\tilde{S}_L + C_S'\tilde{S}_R), \\ H_P &= i\,N\left\{\frac{\hat{m}_b}{m_W}(C_P\tilde{S}_L + C_P'\tilde{S}_R) \right. \\ &\quad \left. + \frac{2\,m_\ell\hat{m}_b}{q^2}\left[C_{10}\left(\tilde{S}_L - \frac{m_s}{m_b}\tilde{S}_R\right) + C_{10}'\left(\tilde{S}_R - \frac{m_s}{m_b}\tilde{S}_L\right)\right]\right\} \end{aligned}$$

FITS BEFORE XMAS 2022

$b \to s\ell^+\ell^-$ Global Fits after R_{K_S} and $R_{K^{*+}}$

Marcel Algueró[a,b,*], Bernat Capdevila[c], Sébastien Descotes-Genon[d], Joaquim Matias[a,b], Martín Novoa-Brunet[d,e]

[a] *Grup de Física Teòrica (Departament de Física), Universitat Autònoma de Barcelona, E-08193 Bellaterra (Barcelona), Catalunya.*
[b] *Institut de Física d'Altes Energies (IFAE), The Barcelona Institute of Science and Technology, Campus UAB, E-08193 Bellaterra (Barcelona), Catalunya.*
[c] *Università di Torino and INFN Sezione di Torino, Via P. Giuria 1, Torino I-10125, Italy.*
[d] *Université Paris-Saclay, CNRS/IN2P3, IJCLab, 91405 Orsay, France.*
[e] *Istituto Nazionale di Fisica Nucleare, Sezione di Bari, Via Orabona 4, I-70126 Bari, Italy*

private code

ACDMN, 2104.08921

Implications of new evidence for lepton-universality violation in $b \to s\ell^+\ell^-$ decays

Li-Sheng Geng,[1,2] Benjamín Grinstein,[3] Sebastian Jäger,[4] Shuang-Yi Li,[5] Jorge Martin Camalich,[6,7] and Rui-Xiang Shi[5]

[1] *School of Physics & Beijing Key Laboratory of Advanced Nuclear Materials and Physics, Beihang University, Beijing 102206, China*
[2] *School of Physics and Microelectronics, Zhengzhou University, Zhengzhou, Henan 450001, China*
[3] *Department of Physics, University of California, San Diego, La Jolla, California, 92093, USA*
[4] *Department of Physics and Astronomy, University of Sussex, Brighton BN1 9QH, United Kingdom*
[5] *School of Physics, Beihang University, Beijing 102206, China*
[6] *Instituto de Astrofisica de Canarias, C/ Via Lactea, s/n E38205 - La Laguna (Tenerife), Spain*
[7] *Universidad de La Laguna, Departamento de Astrofisica, La Laguna, Tenerife E-38205, Spain*

private code

GGJLCS, 2103.12378

New Physics in Rare B Decays after Moriond 2021

Wolfgang Altmannshofer[a], Peter Stangl[b]

[a] *Department of Physics and Santa Cruz Institute for Particle Physics, University of California, Santa Cruz, 1156 High Street, Santa Cruz, CA 95064, United States*
[b] *Albert Einstein Center for Fundamental Physics, Institute for Theoretical Physics, University of Bern, Sidlerstrasse 5, CH-3012 Bern, Switzerland*

Flavio

AS, 2103.13370

Neutral current B-decay anomalies

T. Hurth[a], F. Mahmoudi[b,c], D. Martínez Santos[d], S. Neshatpour[e]

[a] *PRISMA+ Cluster of Excellence and Institute for Physics (THEP), Johannes Gutenberg University, D-55099 Mainz, Germany*
[b] *Université de Lyon, Université Claude Bernard Lyon 1, CNRS/IN2P3, Institut de Physique des 2 Infinis de Lyon, UMR 5822, F-69622, Villeurbanne, France*
[c] *CERN, Theoretical Physics Department, CH-1211 Geneva 23, Switzerland,*
[d] *Instituto Galego de Física de Altas Enerxías, Universidade de Santiago de Compostela, Spain*
[e] *INFN-Sezione di Napoli, Complesso Universitario di Monte S. Angelo, Via Cintia Edificio 6, 80126 Napoli, Italy*

HMMN, 2210.07221

SuperIso

FITTING PACKAGES ON THE MARKET

Brands	flavio	Smelli	HEPfit	EOS	SuperIso
Developers	David M. Straub, Peter Stangl, Jason Aebischer, Jacky Kumar et al.		Jorge de Blas, Debtosh Chowdhury, Marco Ciuchini et al.	Danny van Dyk, Christoph Bobeth, Frederik Beaujean et al.	Farvah Nazila Mahmoudi, A. Arbey et al.
Related works (& Manuals)	arXiv:**1810.08132** 1704.07397 1608.02556 1704.07397	arXiv:**1810.07698** 1911.07866 2103.13370 2212.10497	arXiv: **1910.14012** 1902.05564 1512.07157 1306.4644	arXiv: **2111.15428** 2305.06301 2208.08937 1912.09335	arXiv: **0710.2067** **0808.3144** 1410.4545 1806.11489
First edition (as far as we know)	v0.1.3 (2016.2)	(2018.10)	SUSYfit (2013.06)	D. van Dyk, thesis, 2011	2007.10 2008.08
latest update (as far as we know)	v2.5.5 (2023.6.1)	v2.4.0 (2023.4.27)	v1.0 (2023.5.19)	v1.0.9 (2023.8.8)	v4.1 (2020.11.4)
Code PL	Pure Python3	Based on Flavio	Pure C++11	C++20 with python API	C
Statistic FrameWork	**MLE** (Bayesian Estimation can be self-defined)	Same as flavio	**Bayesian Estimation**	**Bayesian Estimation**	**MLE**
Scientific Library	NumPy, SciPy, iminuit, matplotlib, PyMC, emcee	flavio, wilson	BAT (Bayesian Analysis Toolkit), GSL, boost, ROOT Data Analysis Framework	boost, GSL	GSL

OUR HOME-MADE FIT

- Statistics: Bayesian statistics
  - weak prior dependence confirmed
  - relied package: emcee
- Theoretical framework: dynamics
  - most generic WEFT/LEFT operator basis (tensor to be added)
  - self-controllable Wilson coefficients
  - the up-to-date FF parameterization
- Observables & kinematics
  - transversity amplitude convention adopted
  - all observables (Br, ADO, LFU…) have been encompassed

OUR RESULTS (I)

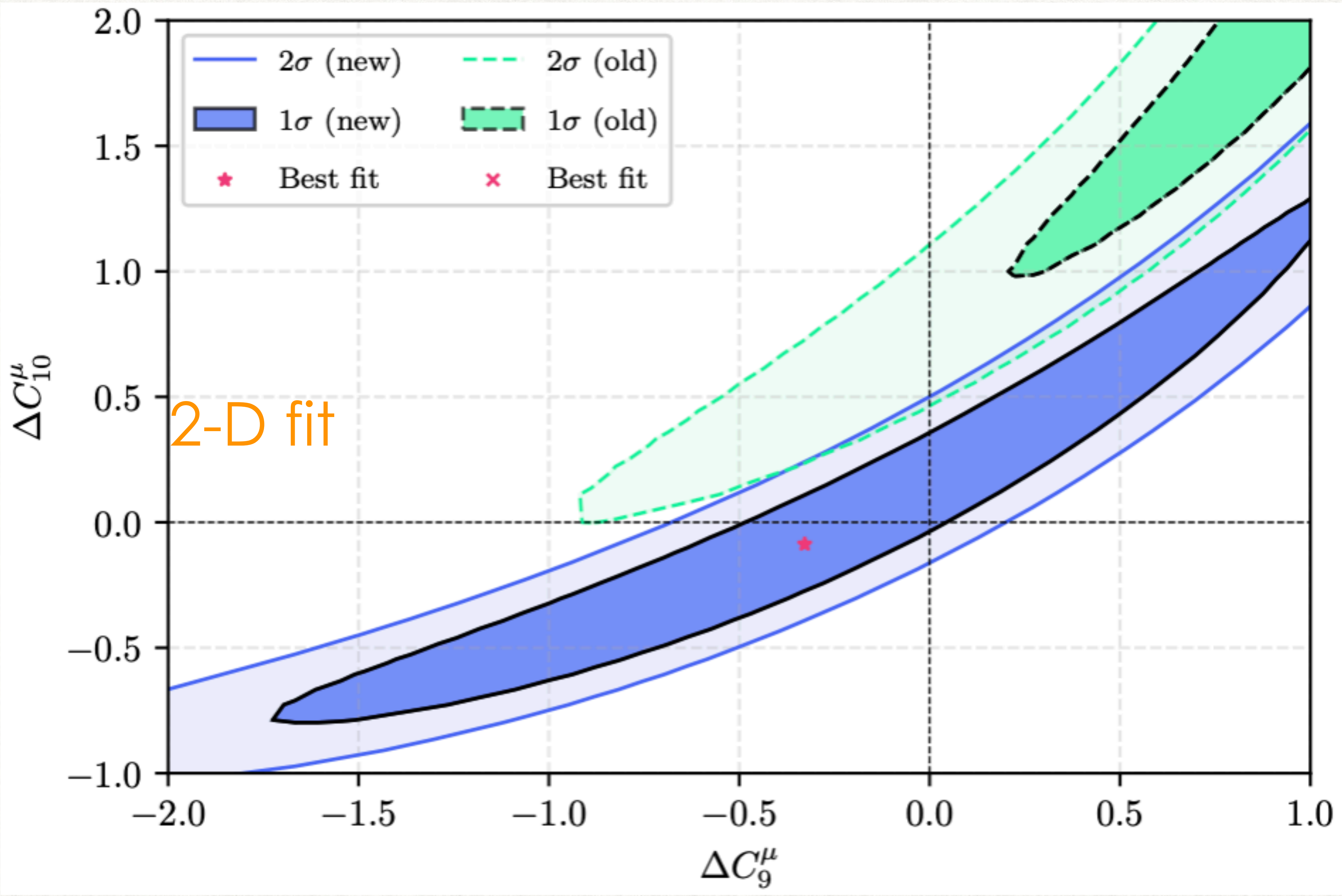
Params	S-I'	S-II'	S-III'	S-IV'	S-I	S-II	S-III	S-IV	ADCMN [23]	AS [24]	HMMN [25]	GGJLCS [26]
Reduced χ^2	183.404/(n-12)	197.556/(n-12)	182.869/(n-16)	176.807/(n-20)	190.044/(n-12)	177.891/(n-12)	185.386/(n-16)	178.953/(n-20)	260.66/(254-6)		179.1/(183-20)	96.88/90
$\chi^2_{\min}$/d.o.f	= 0.970	= 1.045	= 0.988	= 0.977	= 0.995	= 0.931	= 0.991	= 0.978	= 1.05		= 1.1	= 1.08
ΔC_7	$-0.003^{+0.020}_{-0.019}$	$-0.001^{+0.015}_{-0.015}$	$\cdots$	$0.001^{+0.016}_{-0.015}$	$-0.000^{+0.020}_{-0.020}$	$-0.001^{+0.015}_{-0.015}$	$\cdots$	$-0.000^{+0.016}_{-0.015}$	$0.00^{+0.01}_{-0.02}$	$\cdots$	$0.06^{-0.03}_{+0.03}$	$\cdots$
$\Delta C_7'$	$0.017^{+0.018}_{-0.019}$	$0.020^{+0.014}_{-0.015}$	$\cdots$	$0.020^{+0.014}_{-0.014}$	$0.017^{+0.020}_{-0.018}$	$0.020^{+0.015}_{-0.014}$	$\cdots$	$0.023^{+0.014}_{-0.016}$	$+0.00^{+0.02}_{-0.01}$	$\cdots$	$-0.01^{-0.01}_{+0.01}$	$\cdots$
ΔC_8	$-0.788^{+0.595}_{-0.514}$	$-0.885^{+0.435}_{-0.398}$	$\cdots$	$-0.773^{+0.451}_{-0.449}$	$-0.995^{+0.540}_{-0.463}$	$-0.921^{+0.443}_{-0.378}$	$\cdots$	$-0.773^{+0.465}_{-0.424}$	$\cdots$	$\cdots$	$-0.80^{-0.40}_{+0.40}$	$\cdots$
$\Delta C_8'$	$-0.073^{+1.089}_{-1.000}$	$-0.093^{+0.921}_{-0.831}$	$\cdots$	$-0.089^{+0.996}_{-0.922}$	$-0.080^{+1.046}_{-0.942}$	$-0.076^{+0.893}_{-0.833}$	$\cdots$	$-0.258^{+1.007}_{-0.802}$	$\cdots$	$\cdots$	$-0.30^{+1.30}_{-1.30}$	$\cdots$
ΔC_9^μ	$-0.806^{+0.257}_{-0.272}$	$-0.795^{+0.205}_{-0.210}$	$-1.068^{+0.161}_{-0.164}$	$-0.863^{+0.214}_{-0.227}$	$-0.752^{+0.262}_{-0.265}$	$-0.789^{+0.198}_{-0.210}$	$-1.054^{+0.163}_{-0.171}$	$-0.872^{+0.215}_{-0.215}$	$-1.08^{+0.18}_{-0.17}$	$-0.82^{+0.23}_{-0.23}$	$-1.14^{-0.19}_{+0.19}$	$-1.07^{+0.29}_{-0.29}$
$\Delta C_9'^\mu$	$0.194^{+0.395}_{-0.416}$	$0.056^{+0.338}_{-0.342}$	$0.112^{+0.393}_{-0.397}$	$0.020^{+0.346}_{-0.362}$	$0.174^{+0.434}_{-0.441}$	$0.048^{+0.338}_{-0.348}$	$0.130^{+0.439}_{-0.437}$	$0.088^{+0.342}_{-0.378}$	$0.16^{+0.37}_{-0.36}$	$-0.10^{+0.34}_{-0.34}$	$0.05^{+0.32}_{-0.32}$	$0.32^{-0.21}_{+0.21}$
ΔC_{10}^μ	$0.236^{+0.216}_{-0.193}$	$0.145^{+0.166}_{-0.156}$	$0.164^{+0.181}_{-0.180}$	$0.213^{+0.166}_{-0.155}$	$-0.019^{+0.206}_{-0.175}$	$0.163^{+0.165}_{-0.160}$	$0.112^{+0.166}_{-0.184}$	$0.171^{+0.157}_{-0.175}$	$0.15^{+0.13}_{-0.13}$	$+0.14^{+0.23}_{-0.23}$	$0.21^{-0.20}_{+0.20}$	$0.21^{-0.14}_{+0.14}$
$\Delta C_{10}'^\mu$	$-0.096^{+0.251}_{-0.237}$	$-0.108^{+0.186}_{-0.177}$	$-0.115^{+0.200}_{-0.198}$	$-0.089^{+0.177}_{-0.176}$	$-0.118^{+0.266}_{-0.247}$	$-0.093^{+0.183}_{-0.179}$	$-0.115^{+0.215}_{-0.213}$	$-0.062^{+0.197}_{-0.180}$	$-0.18^{+0.20}_{-0.18}$	$-0.33^{+0.23}_{-0.23}$	$-0.03^{+0.19}_{-0.19}$	$-0.26^{-0.14}_{+0.14}$
ΔC_S^μ	$0.066^{+1.091}_{-1.142}$	$-0.004^{+1.102}_{-1.131}$	$-0.008^{+0.883}_{-0.899}$	$-0.043^{+0.842}_{-0.875}$	$0.023^{+1.064}_{-1.097}$	$0.060^{+1.188}_{-1.230}$	$-0.066^{+0.944}_{-0.929}$	$0.009^{+0.858}_{-0.845}$	$\cdots$	$\cdots$	$0.01^{+0.05}_{-0.05}$	$\cdots$
$\Delta C_S'^\mu$	$0.065^{+1.087}_{-1.140}$	$0.003^{+1.103}_{-1.126}$	$-0.002^{+0.873}_{-0.936}$	$-0.059^{+0.844}_{-0.869}$	$0.014^{+1.064}_{-1.086}$	$0.061^{+1.188}_{-1.225}$	$-0.070^{+0.957}_{-0.930}$	$0.012^{+0.858}_{-0.862}$	$\cdots$	$\cdots$	$-0.01^{+0.05}_{-0.05}$	$\cdots$
ΔC_P^μ	$0.167^{+1.172}_{-1.225}$	$1.017^{+0.735}_{-0.816}$	$0.092^{+1.076}_{-0.994}$	$0.117^{+0.847}_{-0.894}$	$0.079^{+1.159}_{-1.146}$	$0.478^{+0.808}_{-0.899}$	$0.189^{+1.018}_{-1.028}$	$0.124^{+0.902}_{-0.910}$	$\cdots$	$\cdots$	$-0.04^{+0.02}_{-0.02}$	$\cdots$
$\Delta C_P'^\mu$	$0.053^{+1.169}_{-1.227}$	$0.891^{+0.729}_{-0.812}$	$0.010^{+1.083}_{-1.002}$	$0.040^{+0.854}_{-0.895}$	$-0.032^{+1.158}_{-1.145}$	$0.370^{+0.803}_{-0.897}$	$0.098^{+1.009}_{-1.024}$	$0.038^{+0.894}_{-0.913}$	$\cdots$	$\cdots$	$-0.04^{+0.02}_{-0.02}$	$\cdots$
ΔC_9^e	$\cdots$	$-0.795^{+0.205}_{-0.210}$	$-1.753^{+0.781}_{-0.772}$	$-1.551^{+0.627}_{-0.599}$	$\cdots$	$-0.789^{+0.198}_{-0.210}$	$-1.623^{+0.662}_{-0.734}$	$-1.511^{+0.561}_{-0.533}$	$\cdots$	$-0.24^{+1.17}_{-1.17}$	$-6.50^{+1.90}_{-1.90}$	$\cdots$
$\Delta C_9'^e$	$\cdots$	$0.056^{+0.338}_{-0.342}$	$1.725^{+1.724}_{-2.286}$	$1.710^{+1.466}_{-1.764}$	$\cdots$	$0.048^{+0.338}_{-0.348}$	$1.090^{+1.610}_{-1.793}$	$0.864^{+1.483}_{-1.608}$	$\cdots$	$\cdots$	$1.40^{+2.30}_{-2.30}$	$\cdots$
ΔC_{10}^e	$\cdots$	$0.145^{+0.166}_{-0.156}$	$0.108^{+1.456}_{-0.661}$	$0.058^{+1.193}_{-0.661}$	$\cdots$	$0.163^{+0.165}_{-0.160}$	$0.555^{+1.042}_{-0.576}$	$0.383^{+0.840}_{-0.424}$	$\cdots$	$-0.24^{+0.78}_{-0.78}$	~ 0	$\cdots$
$\Delta C_{10}'^e$	$\cdots$	$-0.108^{+0.186}_{-0.177}$	$0.600^{+1.208}_{-1.099}$	$0.655^{+0.958}_{-0.841}$	$\cdots$	$-0.093^{+0.183}_{-0.179}$	$0.088^{+0.969}_{-0.956}$	$0.002^{+0.881}_{-0.815}$	$\cdots$	$\cdots$	~ 0	$\cdots$
ΔC_S^e	$\cdots$	$-0.004^{+1.102}_{-1.131}$	$-0.719^{+1.861}_{-1.227}$	$-0.549^{+1.602}_{-1.232}$	$\cdots$	$0.060^{+1.188}_{-1.230}$	$-0.952^{+2.122}_{-1.139}$	$-0.806^{+1.900}_{-1.238}$	$\cdots$	$\cdots$	$-0.38^{+0.41}_{-0.41}$	$\cdots$
$\Delta C_S'^e$	$\cdots$	$0.003^{+1.103}_{-1.126}$	$-0.699^{+1.837}_{-1.224}$	$-0.550^{+1.618}_{-1.326}$	$\cdots$	$0.061^{+1.188}_{-1.225}$	$-1.051^{+2.251}_{-1.075}$	$-0.803^{+1.861}_{-1.194}$	$\cdots$	$\cdots$	$-0.36^{+0.50}_{-0.50}$	$\cdots$
ΔC_P^e	$\cdots$	$1.017^{+0.735}_{-0.816}$	$-1.592^{+1.552}_{-1.079}$	$-1.688^{+1.366}_{-0.978}$	$\cdots$	$0.478^{+0.808}_{-0.899}$	$-1.568^{+1.544}_{-1.149}$	$-1.837^{+1.376}_{-0.930}$	$\cdots$	$\cdots$	$-0.98^{+0.21}_{-0.21}$	$\cdots$
$\Delta C_P'^e$	$\cdots$	$0.891^{+0.729}_{-0.812}$	$-1.360^{+1.318}_{-1.149}$	$-1.431^{+1.212}_{-1.017}$	$\cdots$	$0.370^{+0.803}_{-0.897}$	$-1.477^{+1.409}_{-1.083}$	$-1.652^{+1.200}_{-0.979}$	$\cdots$	$\cdots$	$-0.95^{+0.29}_{-0.29}$	$\cdots$

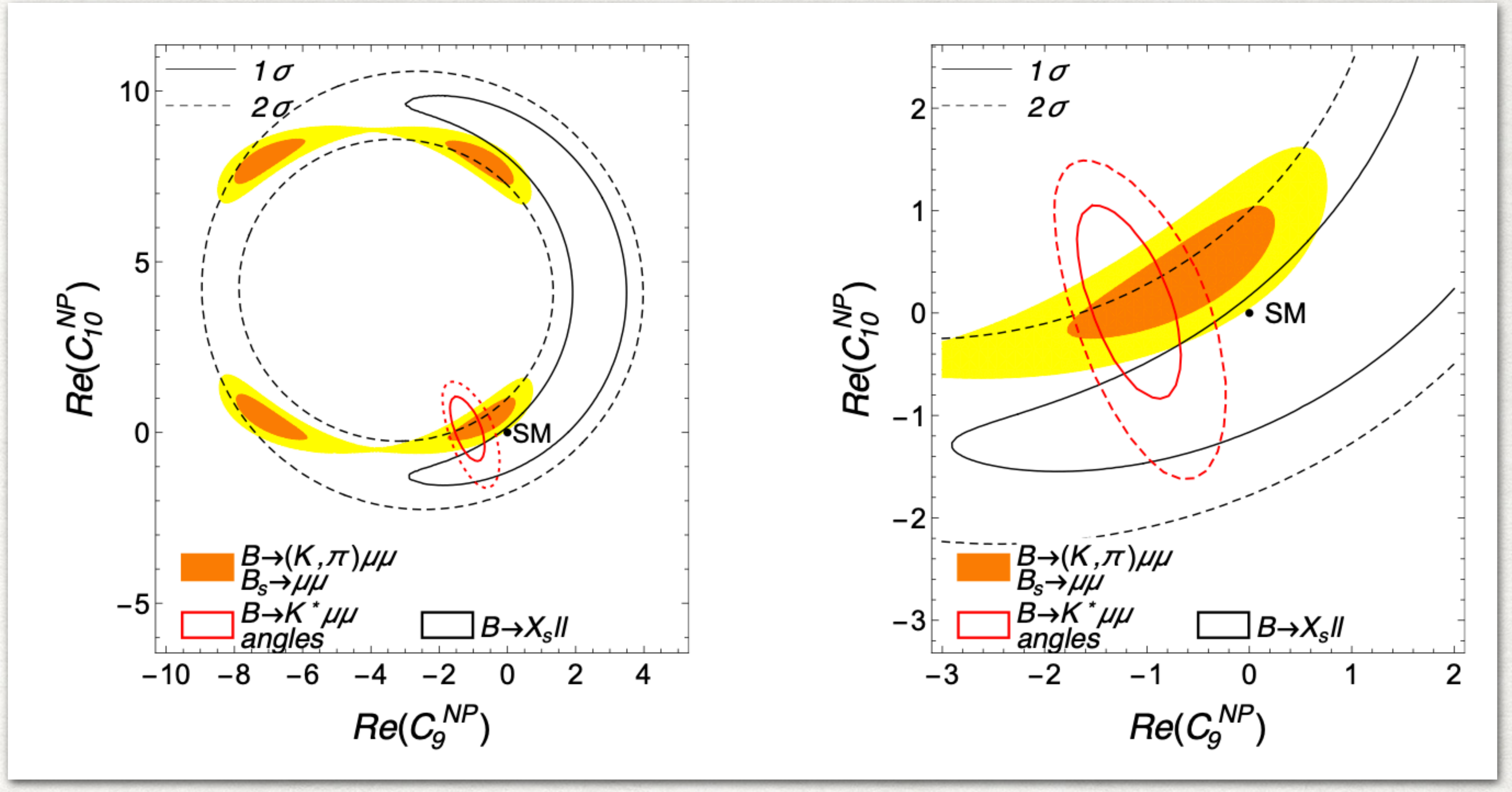
Before Dec. 2022

After Dec. 2022

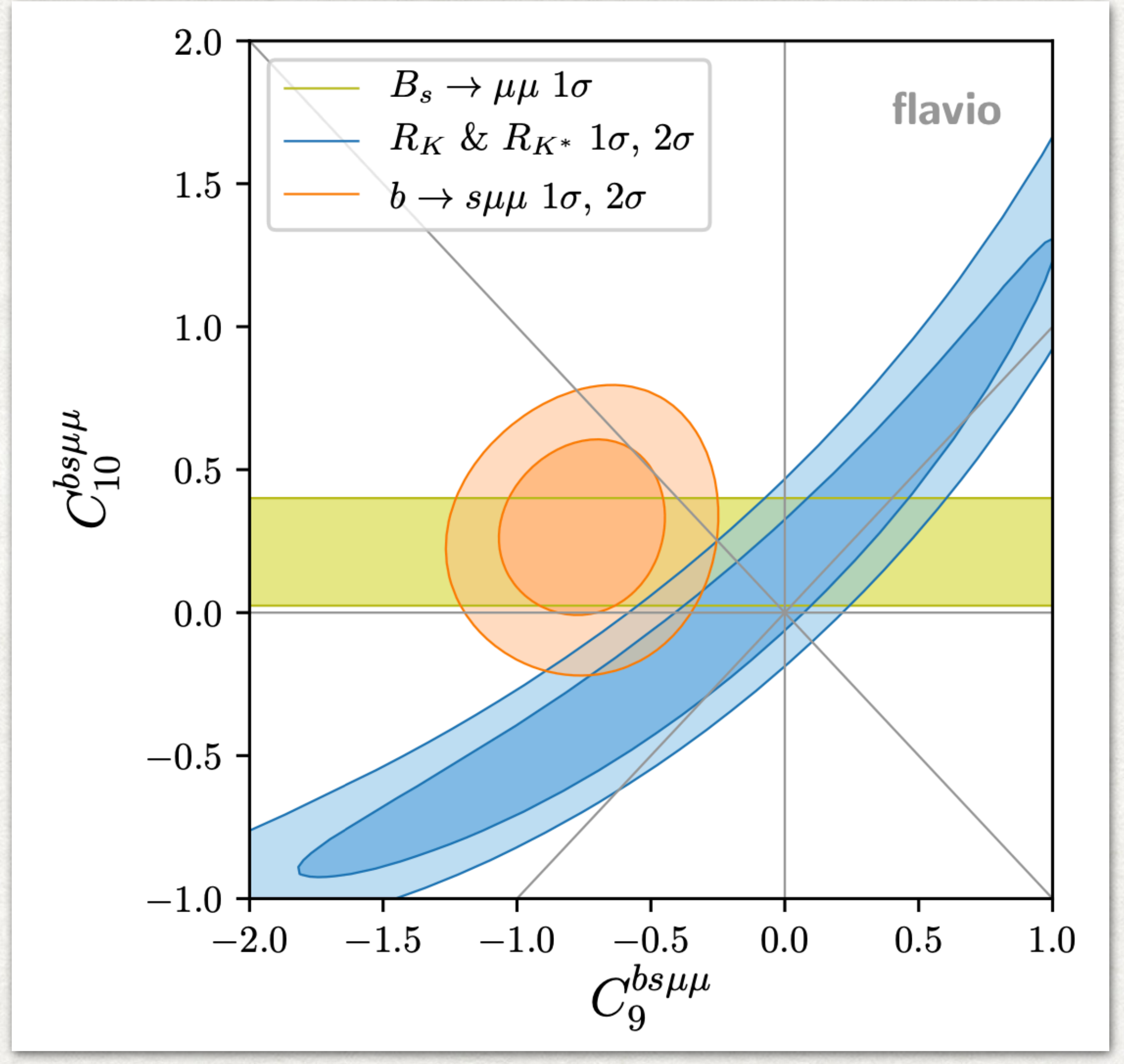
- we carried out a 20-D fit
- fitting results depend on the numbers of fitting d.o.f.
- both old and new fits imply NP exists in ΔC_9^μ in various fitting scenarios
- both old and new fits imply: NP possibility in ΔC_{10}^μ is less hopeful
- new fits implies: NP may be hidden in ΔC_9^e, and its inverse process $e^+e^- \to bs$ calls for **CEPC**

UNDERSTANDING THE ROLE OF $R_{K^{(*)}}$





Daping Du, et.al. 1510.02349



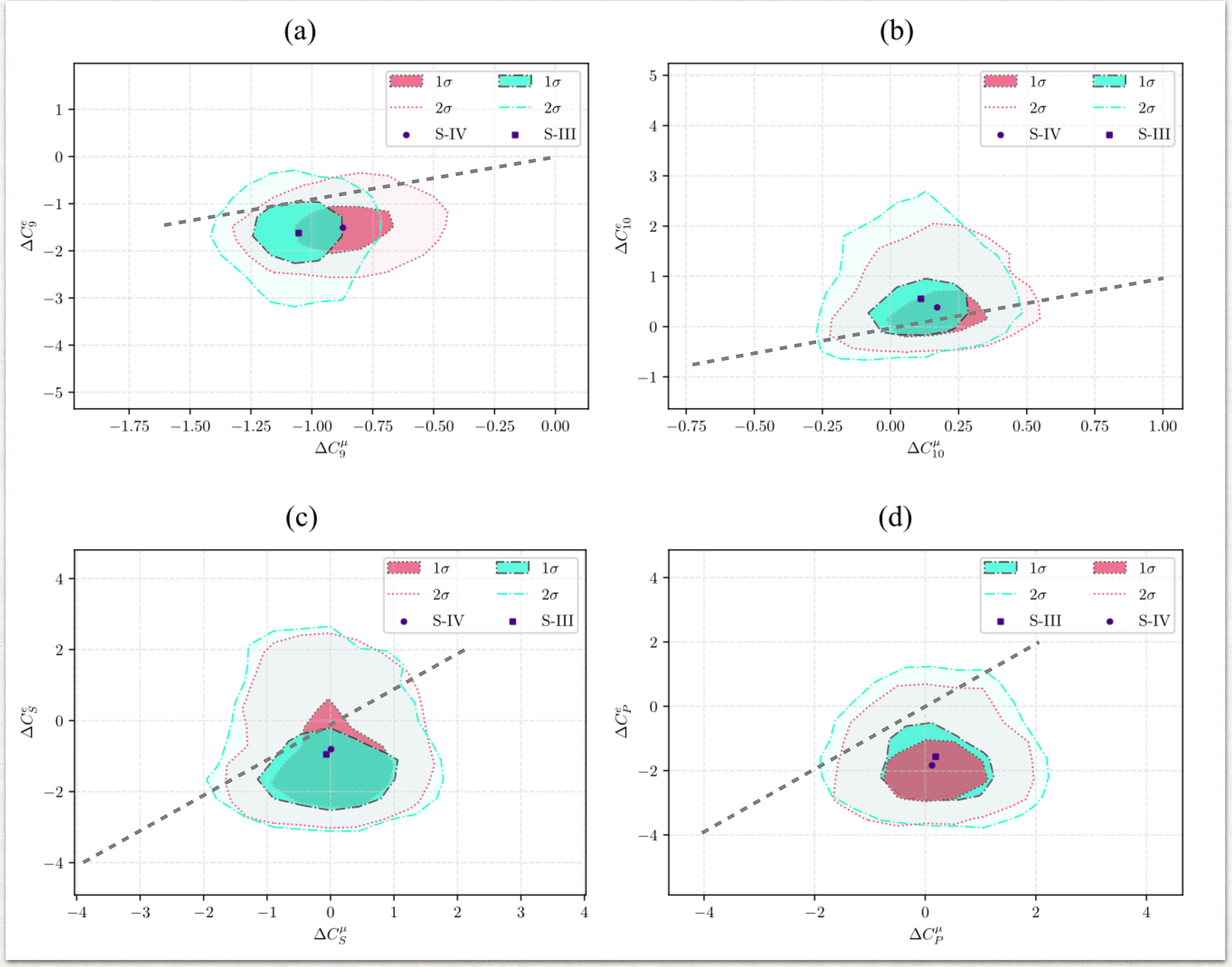
Admir Greljo, et.al. 2212.10497

Pure $R_{K^{(*)}}$ constraints on $(\Delta C_9^{\mu}, \Delta C_{10}^{\mu})$:

still with large uncertainty

$R_{K^{(*)}}$ is not main determiner of ΔC_9^{μ} , slightly shift ΔC_{10}^{μ}

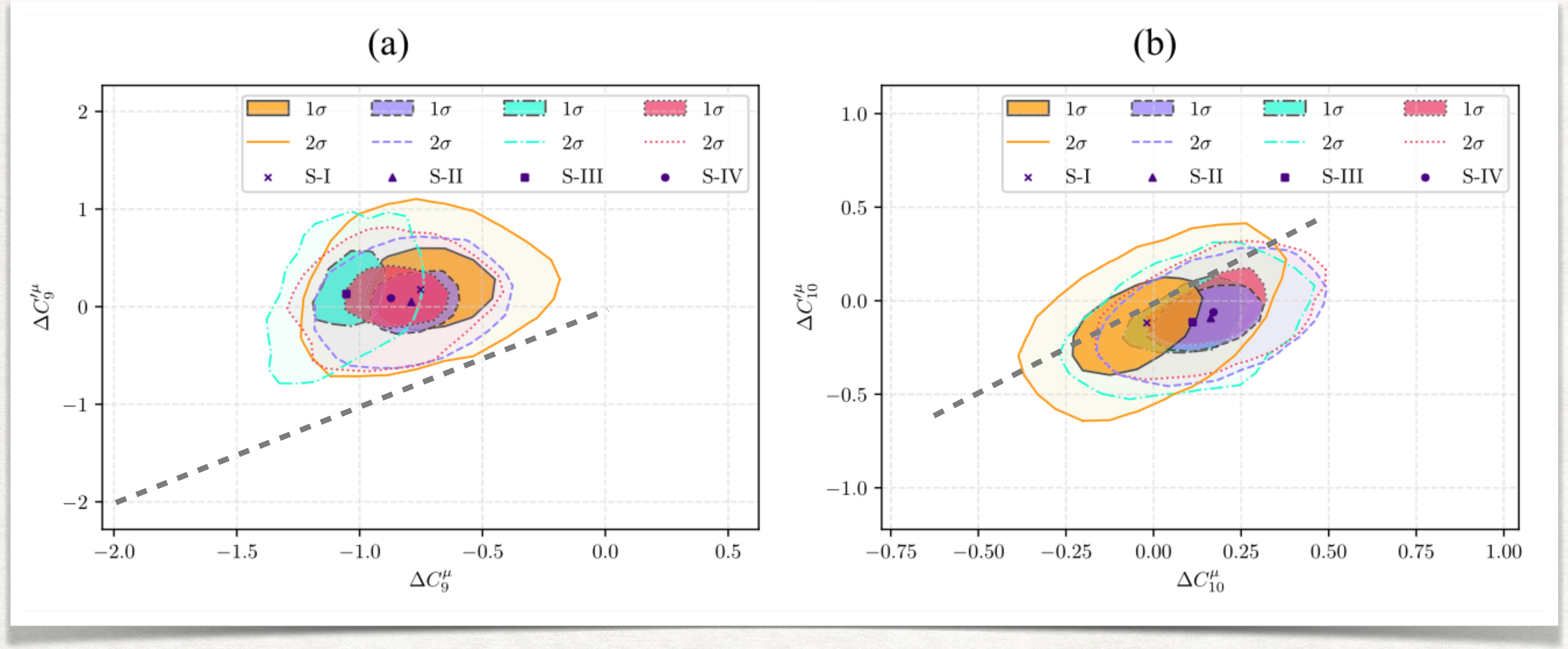
OUR RESULTS (II): FLAVOR CORRELATION

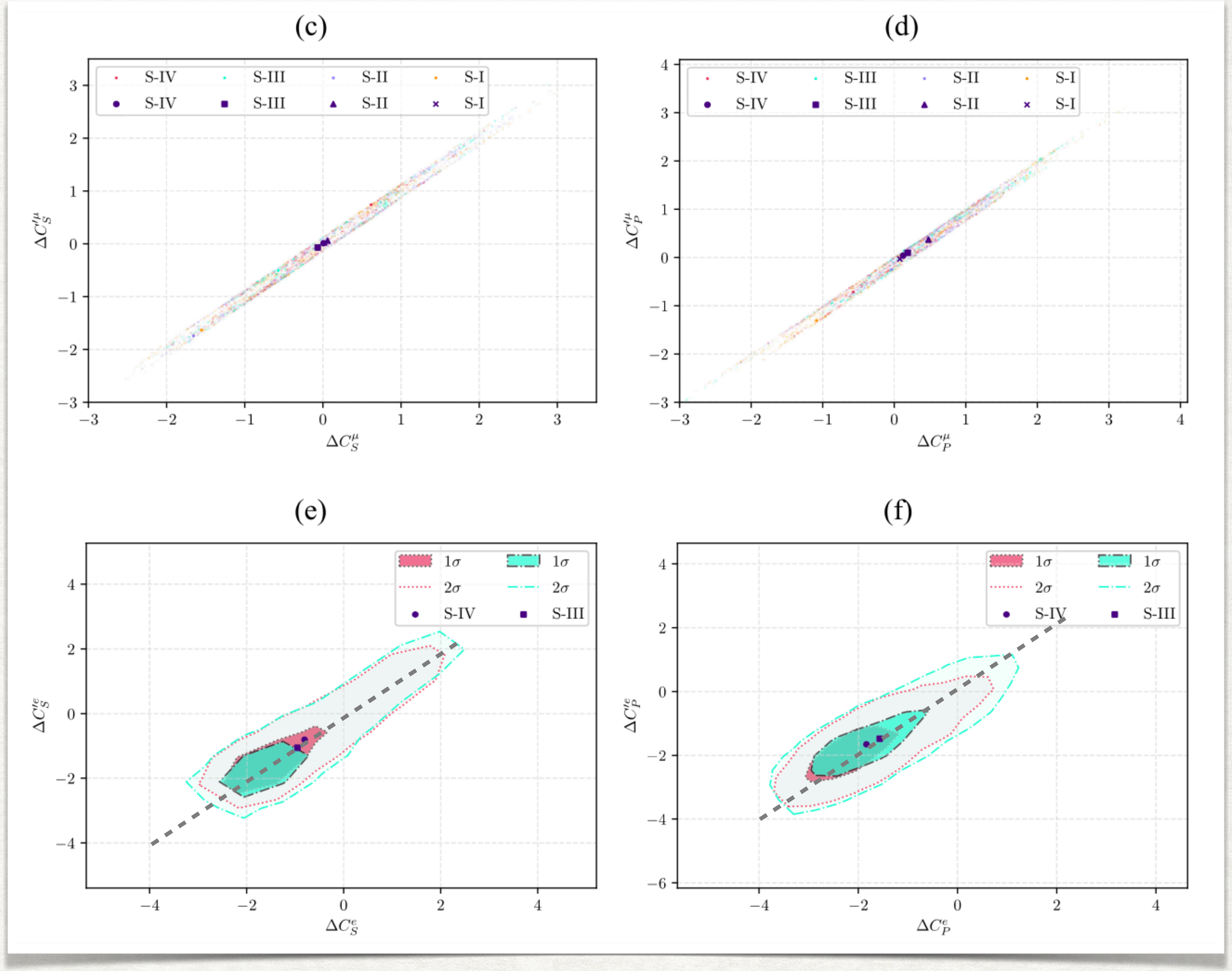


Muon-type operator as an example

- The lepton flavor for ΔC_{10}^{μ} is indistinguishable at 1σ level.
- All WCs are flavor identical at 2σ level

OUR RESULTS (III): CHIRAL CORRELATION





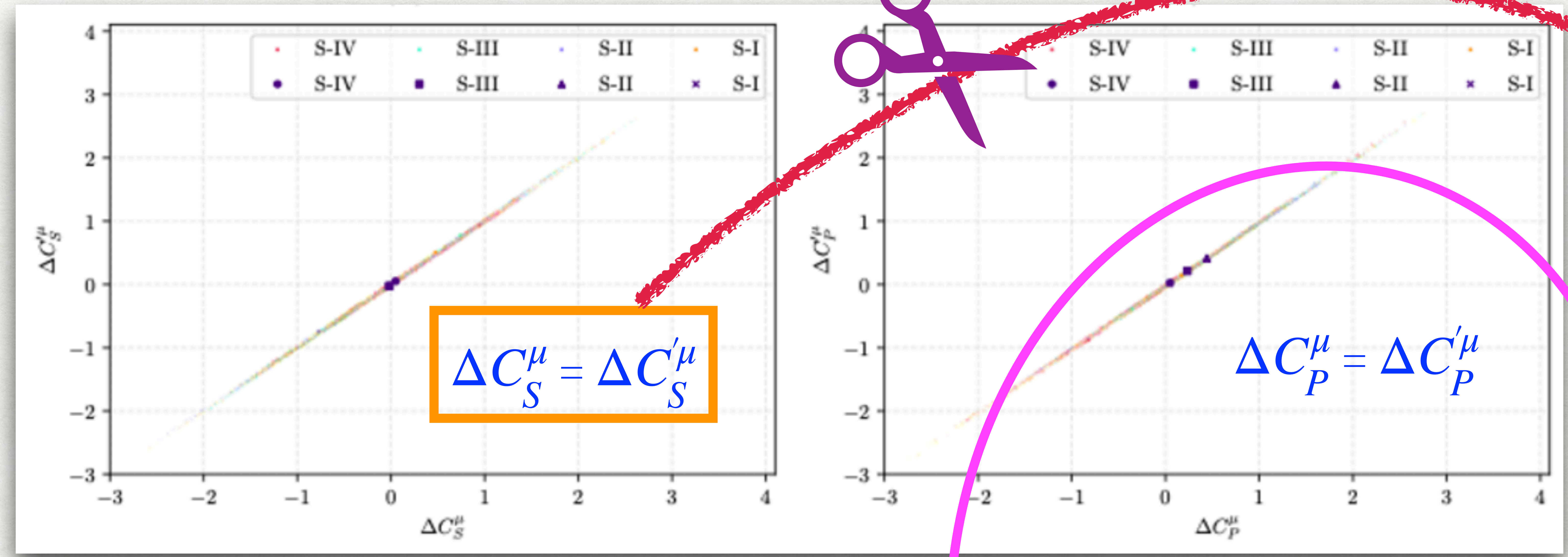
- ΔC_9^μ deviates from its chiral dual one more than 2σ level, while ΔC_{10}^μ is within 1σ region which is scenario dependent.

- scalar WCs have better chiral identity, and muon type is strictly respected.

IMPLICATIONS TO SMEFT

Two options:

- Non-SMEFT NP
- SMEFT: vanishing scalar operator



$$\boxed{\Delta C_S^{\mu} = \Delta C_S^{\prime\mu}}$$

$$\Delta C_P^{\mu} = \Delta C_P^{\prime\mu}$$

$$\Delta C_S^{\mu} = -\Delta C_S^{\prime\mu}$$

- SMEFT (Jenkins, Manohar and Stoffer, 1709.04486)

$$
\begin{aligned}
\lambda_1 C_7 &= c_7\,, & \lambda_1 C_7' &= c_7'\,,\\
\lambda_2 C_9 &= c_\ell^{V,LL} + c_\ell^{\prime V,LR}\,, & \lambda_2 C_{10} &= -c_\ell^{V,LL} + c_\ell^{\prime V,LR}\,,\\
\lambda_2 C_9' &= c_\ell^{V,LR} + c_\ell^{V,RR}\,, & \lambda_2 C_{10}' &= -c_\ell^{V,LR} + c_\ell^{V,RR}\,,\\
\lambda_2 C_S &= \cancel{c_\ell^{S,RR}} + c_\ell^{\prime S,RL}\,, & \lambda_2 C_P &= \cancel{c_\ell^{S,RR}} - c_\ell^{\prime S,RL}\,,\\
\lambda_2 C_S' &= c_\ell^{S,RL} + \cancel{c_\ell^{\prime S,RR}}\,, & \lambda_2 C_P' &= c_\ell^{S,RL} - \cancel{c_\ell^{\prime S,RR}}\,,\\
\lambda_2 C_T &= c_\ell^{\prime T,RR} + c_\ell^{T,RR}\,, & \lambda_2 C_{T5} &= -c_\ell^{\prime T,RR} + c_\ell^{T,RR}\,,
\end{aligned}
$$

$$\boxed{C_S + C_P = 0\,, \qquad C_S' - C_P' = 0\,, \qquad C_T = 0\,, \qquad C_{T5} = 0\,.}$$

To be answered in SMEFT level

1. Can all the old and new flavor problems be accommodated?
2. What is the economic way?

CORRELATION WITHIN SMEFT

Feng-Zhi Chen, Qiaoyi Wen, FX, 2401.11552

LEFT DESCRIPTIONS

$$\mathcal{L}_{\rm eff}^{b\to s\nu\bar\nu} = \frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^* \frac{\alpha}{4\pi} \sum_\ell \left(C_L^{\nu_\ell}\mathcal{O}_L^{\nu_\ell} + C_R^{\nu_\ell}\mathcal{O}_R^{\nu_\ell}\right) + \text{h.c.}$$

$$\mathcal{B}(B^+ \to K^+\nu\bar\nu) = 3.46\times 10^{-8} \left|C_L^{\nu_\ell} + C_R^{\nu_\ell}\right|^2 ,$$

$$\mathcal{B}(B^0 \to K^*\nu\bar\nu) = 6.84\times 10^{-8} \left|\underline{C_L^{\nu_\ell} - C_R^{\nu_\ell}}\right|^2 + 1.36\times 10^{-8} \left|\underline{C_L^{\nu_\ell} + C_R^{\nu_\ell}}\right|^2$$

If $C_R^{\nu_\ell}$ absent:

$$R = \frac{8.20\times 10^{-8}\left|C_L^{\nu_\ell}\right|^2}{3.46\times 10^{-8}\left|C_L^{\nu_\ell}\right|^2} \simeq 2.37$$

$$\mathcal{L}_{\rm eff}^{b\to s\ell^+\ell^-} = \frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^* \frac{\alpha}{4\pi} \sum_{i=9}^{10} \left(C_i^\ell\mathcal{O}_i^\ell + C_i^{\ell\prime}\mathcal{O}_i^{\ell\prime}\right) + \text{h.c.}$$

$$\underline{\Delta C_9^e = \Delta C_9^\mu} = -0.789^{+0.198}_{-0.210}$$

Scenario II in our global fits

LEFT DESCRIPTIONS

$$\mathcal{L}_{\text{eff}}^{c\to u} = \frac{4G_F}{\sqrt{2}}\frac{\alpha}{4\pi}\left[C_L^{U\nu_\ell}(\bar{u}\gamma_\mu P_L c)(\bar{\nu}_\ell\gamma^\mu P_L \nu_\ell) + C_L^{U\ell}(\bar{u}\gamma_\mu P_L c)(\bar{\ell}\gamma^\mu P_L \ell)\right] + \text{h.c.}$$

$$\mathcal{B}(D\to P\nu\bar{\nu}) = A_+^{DP}\left|\Delta C_L^{U\nu_\tau}\right|^2$$

$$\mathcal{L}_{\text{eff}}^{d_j\to u_i\ell\nu_\ell} = -\frac{4G_F}{\sqrt{2}}V_{ij}(1+\Delta C_L^{ij\ell})(\bar{u}_i\gamma_\mu P_L d_j)(\bar{\ell}\gamma^\mu P_L \nu_\ell) + \text{h.c.}$$

$$R_D = R_D^{\text{SM}}\left|1+\underline{\Delta C_L^{cb\tau}}\right|^2 \qquad R_{D^*} = R_{D^*}^{\text{SM}}\left|1+\underline{\Delta C_L^{cb\tau}}\right|^2$$

$$\mathcal{B}(D_s^+\to\tau^+\nu_\tau) = \tau_{D_s^+}\frac{G_F^2}{8\pi}|V_{cs}|^2 f_{D_s^+}^2 m_\tau^2 m_{D_s^+}\left(1-\frac{m_\tau^2}{m_{D_s^+}^2}\right)^2|1+\Delta C_L^{cs\tau}|^2$$

MATCHING LEFT TO SMEFT

$$\mathcal{L}_{\rm SMEFT} \supset \frac{1}{\Lambda^2}\Big[[C_{\ell d}]_{prst}(\bar{L}_p\gamma^\mu L_r)(\bar{d}_{Rs}\gamma_\mu d_{Rt}) + [C^{(1)}_{\ell q}]_{prst}(\bar{L}_p\gamma^\mu L_r)(\bar{Q}_s\gamma_\mu Q_t)$$
$$+[C^{(3)}_{\ell q}]_{prst}(\bar{L}_p\gamma^\mu\tau^I L_r)(\bar{Q}_s\gamma_\mu\tau^I Q_t)\Big]\,,$$

Scalar interaction has been excluded from previous fits.

$$\mathcal{L}_{\rm SMEFT} \supset \frac{1}{\Lambda^2}\Big\{[C_{\ell d}]_{prst}\Big[(\bar{\nu}_{Lp}\gamma^\mu\nu_{Lr})(\bar{d}_{Rs}\gamma_\mu d_{Rt}) + (\bar{\ell}_{Lp}\gamma^\mu\ell_{Lr})(\bar{d}_{Rs}\gamma_\mu d_{Rt})\Big]$$
$$+[C^{(1)}_{\ell q}]_{prst}\Big[(\bar{\nu}_{Lp}\gamma^\mu\nu_{Lr})(\bar{d}_{Ls}\gamma_\mu d_{Lt}) + (\bar{\ell}_{Lp}\gamma^\mu\ell_{Lr})(\bar{d}_{Ls}\gamma_\mu d_{Lt})$$
$$+V_{is}V^*_{jt}\big[(\bar{\nu}_{Lp}\gamma^\mu\nu_{Lr})(\bar{u}_{Li}\gamma_\mu u_{Lj}) + (\bar{\ell}_{Lp}\gamma^\mu\ell_{Lr})(\bar{u}_{Li}\gamma_\mu u_{Lj})\big]\Big]$$
$$+[C^{(3)}_{\ell q}]_{prst}\Big[-(\bar{\nu}_{Lp}\gamma^\mu\nu_{Lr})(\bar{d}_{Ls}\gamma_\mu d_{Lt}) + (\bar{\ell}_{Lp}\gamma^\mu\ell_{Lr})(\bar{d}_{Ls}\gamma_\mu d_{Lt})$$
$$+2V_{is}(\bar{\ell}_{Lp}\gamma^\mu\nu_{Lr})(\bar{u}_{Li}\gamma_\mu d_{Lt}) + 2V^*_{jt}(\bar{\nu}_{Lp}\gamma^\mu\ell_{Lr})(\bar{d}_{Ls}\gamma_\mu u_{Lj})$$
$$+V_{is}V^*_{jt}\big((\bar{\nu}_{Lp}\gamma^\mu\nu_{Lr})(\bar{u}_{Li}\gamma_\mu u_{Lj}) - (\bar{\ell}_{Lp}\gamma^\mu\ell_{Lr})(\bar{u}_{Li}\gamma_\mu u_{Lj})\big)\Big]\Big\}\,,$$

$$\frac{8G_F}{\sqrt{2}}V_{tb}V^*_{ts}\frac{\alpha}{4\pi}\Delta C^{\nu_\ell}_L = \frac{[C^{(1)}_{\ell q}]_{\ell\ell 23} - [C^{(3)}_{\ell q}]_{\ell\ell 23}}{\Lambda^2}\,,$$
$$\frac{8G_F}{\sqrt{2}}V_{tb}V^*_{ts}\frac{\alpha}{4\pi}\Delta C^{\nu_\ell}_R = \frac{[C_{\ell d}]_{\ell\ell 23}}{\Lambda^2}\,,$$
$$\frac{4G_F}{\sqrt{2}}V_{tb}V^*_{ts}\frac{\alpha}{4\pi}(\Delta C^\ell_9 - \Delta C^\ell_{10}) = \frac{[C^{(1)}_{\ell q}]_{\ell\ell 23} + [C^{(3)}_{\ell q}]_{\ell\ell 23}}{\Lambda^2}\,,$$
$$\frac{4G_F}{\sqrt{2}}V_{tb}V^*_{ts}\frac{\alpha}{4\pi}(\Delta C^{\ell\prime}_9 - \Delta C^{\ell\prime}_{10}) = \frac{[C_{\ell d}]_{\ell\ell 23}}{\Lambda^2}\,,$$
$$-\frac{4G_F}{\sqrt{2}}\frac{V^*_{ib}}{2V_{is}}\Delta C^{ib\ell *}_L = \frac{[C^{(3)}_{\ell q}]_{\ell\ell 23}}{\Lambda^2}\,,$$
$$-\frac{4G_F}{\sqrt{2}}\frac{V_{js}}{2V^*_{jb}}\Delta C^{js\ell}_L = \frac{[C^{(3)}_{\ell q}]_{\ell\ell 23}}{\Lambda^2}\,,$$
$$\frac{4G_F}{\sqrt{2}}\frac{\alpha}{4\pi}\frac{1}{V_{is}V^*_{jb}}\Delta C^{U\nu_\ell}_L = \frac{[C^{(1)}_{\ell q}]_{\ell\ell 23} + [C^{(3)}_{\ell q}]_{\ell\ell 23}}{\Lambda^2}\,,$$
$$\frac{4G_F}{\sqrt{2}}\frac{\alpha}{4\pi}\frac{1}{V_{is}V^*_{jb}}\Delta C^{U\ell}_L = \frac{[C^{(1)}_{\ell q}]_{\ell\ell 23} - [C^{(3)}_{\ell q}]_{\ell\ell 23}}{\Lambda^2}$$

RUNNING FROM SMEFT TO LEFT

small QED anomalous dimension dominates evolution:

$$\frac{dC^{\nu_\ell}_{L(R)}}{d\log\mu} = 0\,, \qquad \frac{dC^{D\ell}_{L(R)}}{d\log\mu} = \left(\frac{4}{3}q_e^2 + (-)12q_d q_e\right)\frac{\alpha}{4\pi}C^{D\ell}_{L(R)}\,, \qquad \frac{dC^{ij\ell}_{L}}{d\log\mu} = 6q_u q_e\frac{\alpha}{4\pi}C^{ij\ell}_{L}\,,$$

$$\frac{dC^{U\nu_\ell}_{L}}{d\log\mu} = 0\,, \qquad \frac{dC^{U\ell}_{L}}{d\log\mu} = \left(\frac{4}{3}q_e^2 + 12q_u q_e\right)\frac{\alpha}{4\pi}C^{U\ell}_{L}$$

RGE effect is negligible

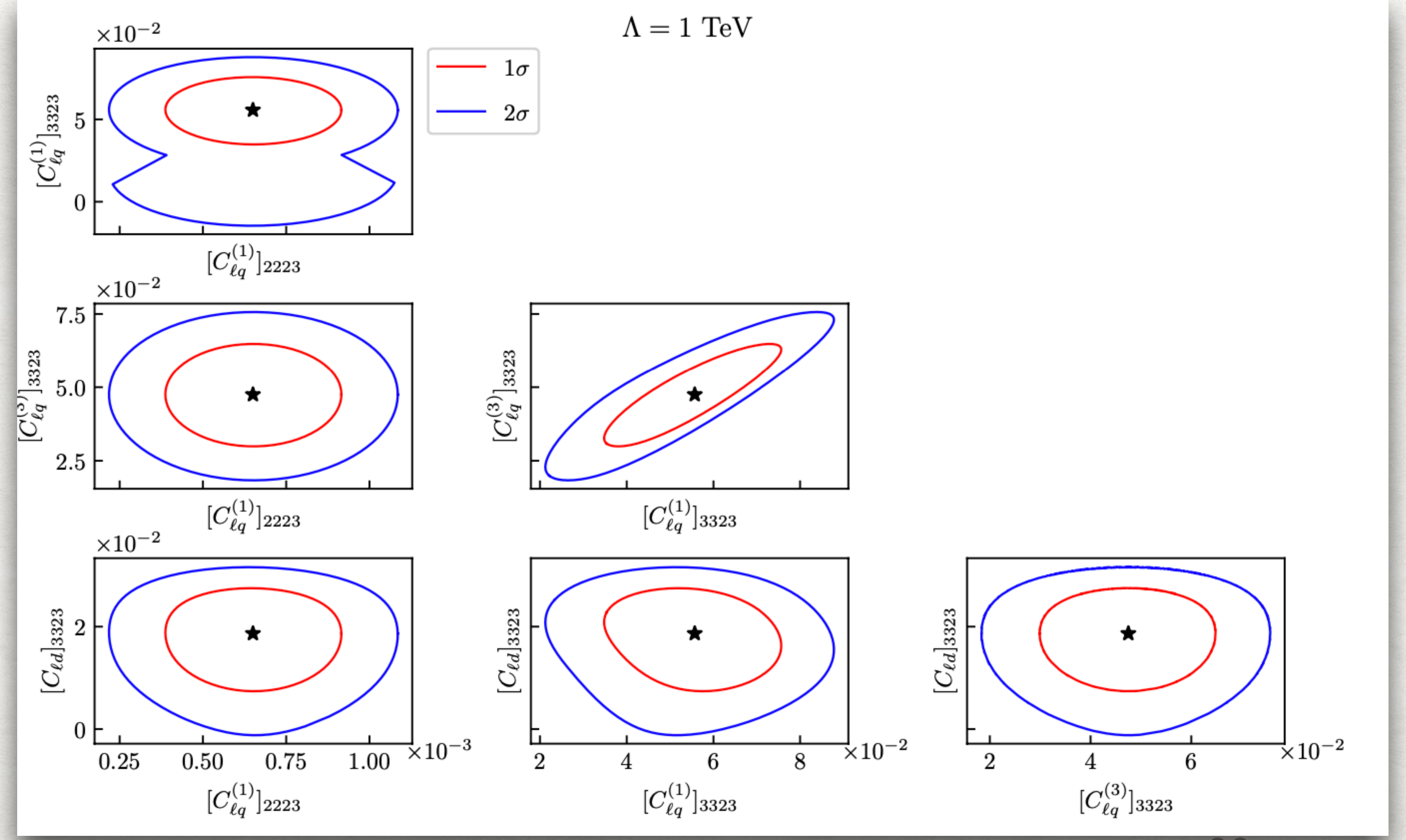
SOME RESULTS

CONSTRAINTS ON SMEFT COEFFICIENTS

$$\chi^2(\vec{\theta}) = (\mathcal{O}_{\text{the.}}(\vec{\theta}) - \mathcal{O}_{\text{exp.}})^\top V^{-1} (\mathcal{O}_{\text{the.}}(\vec{\theta}) - \mathcal{O}_{\text{exp.}})$$

$$\vec{\theta} = \left([C_{\ell q}^{(1)}]_{2223} \, , [C_{\ell q}^{(1)}]_{3323} \, , [C_{\ell q}^{(3)}]_{3323} \, , [C_{\ell d}]_{3323} \right)$$

$$\mathcal{O} = \left(\mathcal{B}(B^+ \to K^+ \nu\bar{\nu}), \; \mathcal{B}(B^0 \to K^{*0} \nu\bar{\nu}), \; R_D, \; R_{D^*}, \; \Delta C_9^\mu \right)$$



$$[C_{\ell q}^{(1)}]_{2223} = 6.50^{+1.76}_{-1.73} \times 10^{-4} \, ,$$
$$[C_{\ell q}^{(3)}]_{3323} = 4.75^{+1.15}_{-1.16} \times 10^{-2} \, ,$$

$$[C_{\ell q}^{(1)}]_{3323} = 5.57^{+1.37}_{-1.37} \times 10^{-2} \, ,$$
$$[C_{\ell d}]_{3323} = 1.87^{+0.63}_{-0.74} \times 10^{-2} \, ,$$

CONSTRAINTS ON SMEFT COEFFICIENTS

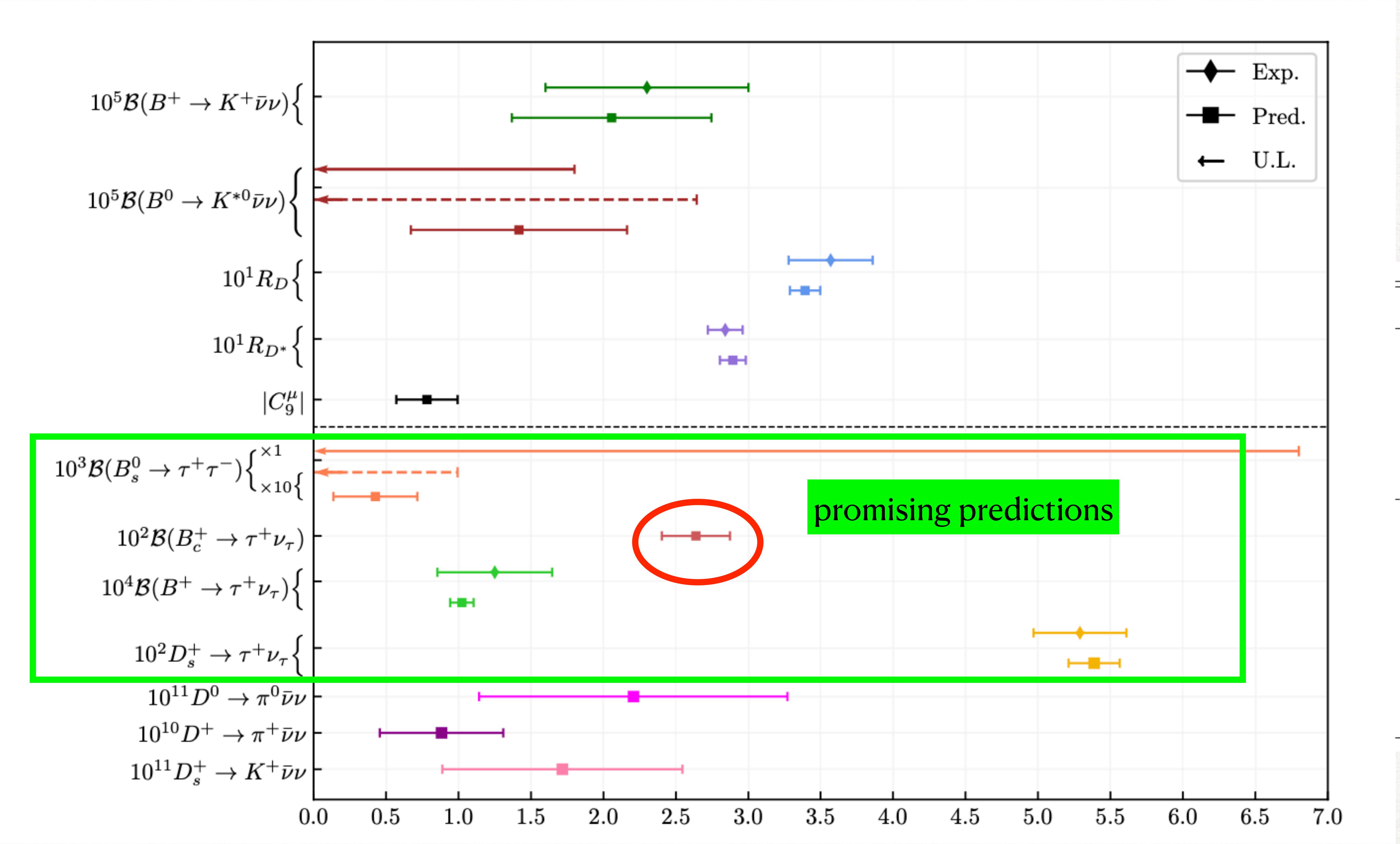
Wilson coefficient	$[C_{\ell q}^{(1)}]_{2223}$	$[C_{\ell q}^{(1)}]_{3323}$	$[C_{\ell q}^{(3)}]_{3323}$	$[C_{\ell d}]_{3323}$
This work	$(6.50^{+1.76}_{-1.73}) \times 10^{-4}$	$(5.57^{+1.34}_{-1.37}) \times 10^{-2}$	$(4.75^{+1.15}_{-1.16}) \times 10^{-2}$	$(1.87^{+0.63}_{-0.74}) \times 10^{-2}$
HLY[74]	—	—	-0.0679 ± 0.0150	—
CFFPSV[75]	$[4.78, 9.33] \times 10^{-4}$	—	—	—
Drell-Yan tails[76]	$[-0.066, 0.071]$	—	—	—
$b \to q\ell\ell$[76]	$[7.71, 51.86] \times 10^{-5}$	—	—	—
$b \to q\nu\nu$[76]	$[-0.038, 0.017]$	—	—	—
95% C.L. LHC[77]	$[-0.14, 0.12]$	$[-0.30, 0.27]$	$[-0.13, 0.15]$	$[-0.29, 0.29]$
ABPRS muon-specific[10]	$[0.0129, 0.0134]$	—	—	—
ABPRS flavor universal[10]	$[0.012, 0.013]$	$[0.012, 0.013]$	—	—
ABPRS tau-specific[10]	—	—	$[-0.015, -0.013] \cup [0.033, 0.036]$	—

[10] L. Allwicher, D. Becirevic, G. Piazza, S. Rosauro-Alcaraz, and O. Sumensari, *Understanding the first measurement of $\mathcal{B}(B \to K\nu\bar{\nu})$*, *Phys. Lett. B* **848** (2024) 138411, [arXiv:2309.02246].

Recently, Belle II reported on the first measurement of $\mathcal{B}(B^\pm \to K^\pm\nu\bar{\nu})$ which appears to be almost 3σ larger than predicted in the Standard Model. We point out the important correlation with $\mathcal{B}(B \to K^*\nu\bar{\nu})$ so that the measurement of that decay mode could help restrain the possible options for building the model of New Physics. We interpret this new experimental result in terms of physics beyond the Standard Model by using SMEFT and find that a scenario with coupling only to τ can accommodate the current experimental constraints but fails in getting a desired $R_{D^{(*)}}^{\text{exp}}/R_{D^{(*)}}^{\text{SM}}$, unless one turns the other SMEFT operators that are not related to $b \to s\ell\ell$ or/and $b \to s\nu\nu$.

[76] A. Greljo, J. Salko, A. Smolkovič, and P. Stangl, *Rare b decays meet high-mass Drell-Yan*, *JHEP* **05** (2023) 087, [arXiv:2212.10497].

PREDICTIONS ON OBSERVABLES



Observable	prediction with NP	Experiment	
$\mathcal{B}(B^+ \to K^+\nu\bar{\nu})$	$(2.06 \pm 0.69) \times 10^{-5}$	$(2.3 \pm 0.7) \times 10^{-5}$	[1]
$\mathcal{B}(B^0 \to K^{*0}\nu\bar{\nu})$	$(1.42 \pm 0.74) \times 10^{-5}$	$< 1.8 \times 10^{-5}$	[27]
R_D	0.339 ± 0.010	0.358 ± 0.028	[38]
R_{D^*}	0.289 ± 0.009	0.285 ± 0.013	[38]
ΔC_9^μ	-0.782 ± 0.212	$-0.789^{+0.198}_{-0.210}$	[25]
$\mathcal{B}(B^+ \to \tau^+\nu)$	$(1.02 \pm 0.08) \times 10^{-4}$	$(1.09 \pm 0.24) \times 10^{-4}$	[56]
$\mathcal{B}(B_c^+ \to \tau^+\nu)$	$(2.64 \pm 0.23) \times 10^{-2}$	—	
$\mathcal{B}(B_s \to \tau^+\tau^-)$	$(4.26 \pm 2.85) \times 10^{-4}$	$< 6.8 \times 10^{-3}$	[64]
$\mathcal{B}(D_s^+ \to \tau^+\nu_\tau)$	$(5.39 \pm 0.18) \times 10^{-2}$	$(5.37 \pm 0.23) \times 10^{-2}$	[68]
$\mathcal{B}(D^0 \to \pi^0\nu\bar{\nu})$	$(2.21 \pm 1.05) \times 10^{-11}$	$< 2.1 \times 10^{-4}$	[71]
$\mathcal{B}(D^+ \to \pi^+\nu\bar{\nu})$	$(8.83 \pm 4.19) \times 10^{-11}$	—	
$\mathcal{B}(D_s^+ \to K^+\nu\bar{\nu})$	$(1.72 \pm 0.82) \times 10^{-11}$	—	

SUMMARY

- NP opportunity in $b \to s\ell^+\ell^-$ exists in C_9. Efforts from both QCD and experiment are further needed.
- The recent tension in $b \to s\nu\bar{\nu}$, 10-year-old $R_{D^{(*)}}$, not-yet-disappeared $b \to s\ell^-\ell^+$ anomaly can be accommodated by 3 SMEFT operators (3 tau flavor + 1 muon flavor).
- More low energy observables can be correlated within SMEFT.
- Based on stringent constraints for SMEFT operators, other predictions can be made:
  - prediction consistent with measured value: $B^+ \to \tau^+\nu$, $D_s \to \tau^+\nu_\tau$
  - forecast for anticipated process yet to be measured: $B_c^+ \to \tau^+\nu$, $B_s \to \tau^+\tau^-$