CEPC味物理-新物理和相关探测技术研讨会

# Global Fits of $b \to s\ell^+\ell^-$

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**Jinan University**

In collab with Qiaoyi Wen, 2305.19308

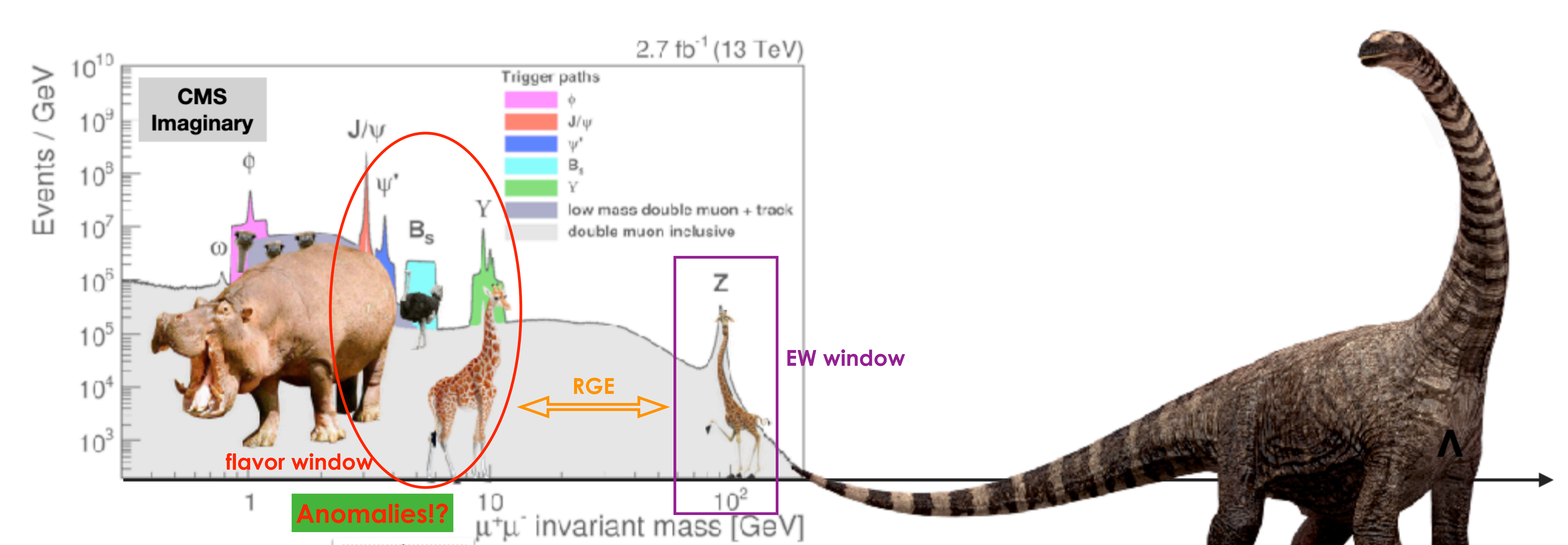
Aug. 15, 2023, Fudan University

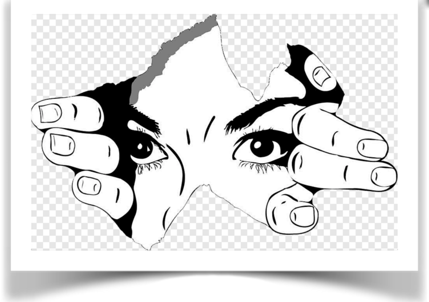
# OUTLINE

- Introduction
- Theory overview
- Fitting overview
- Our results and implications
- Summary

# INTRODUCTION

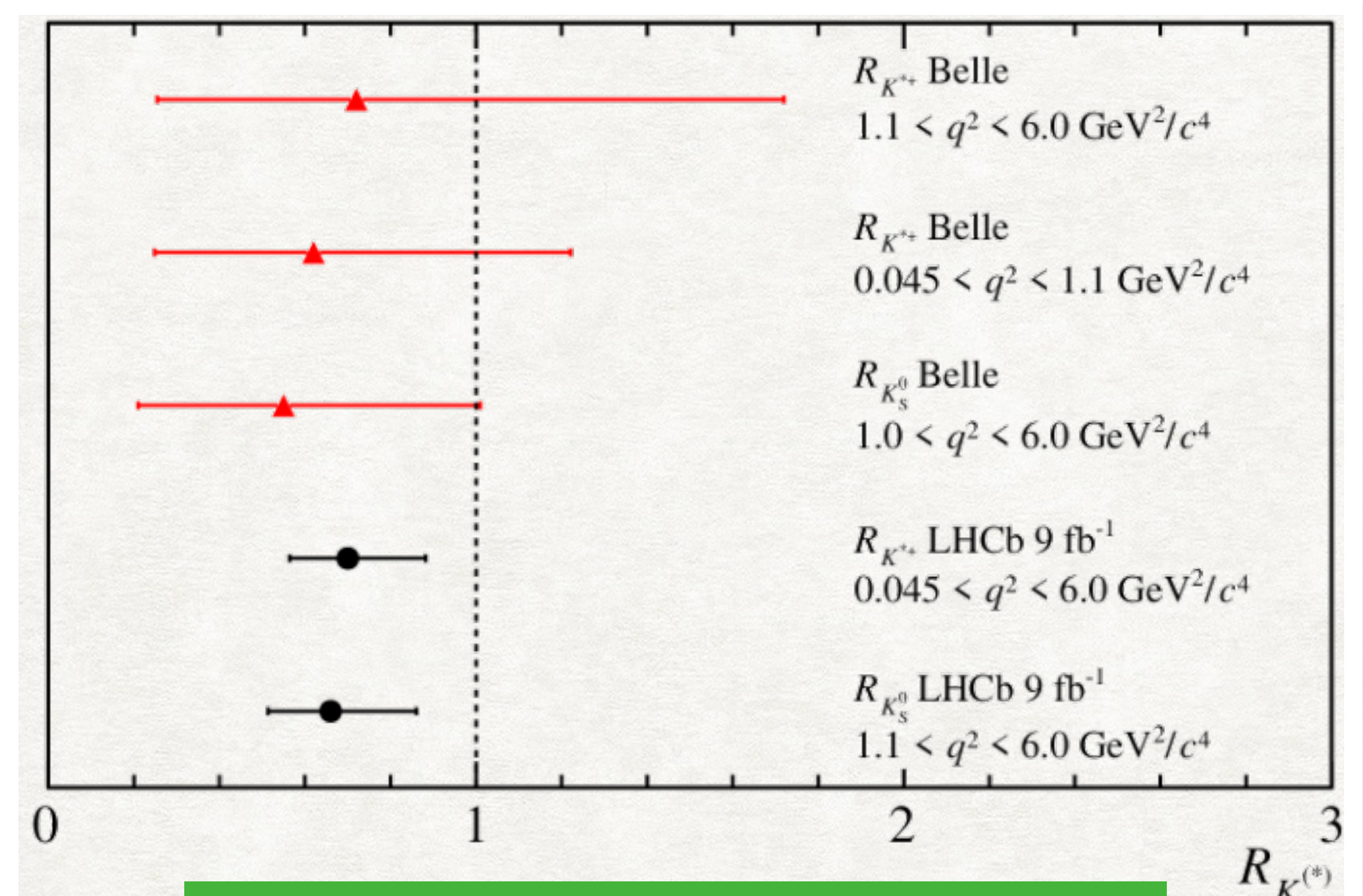
Flavor physics is a probe of new physics.



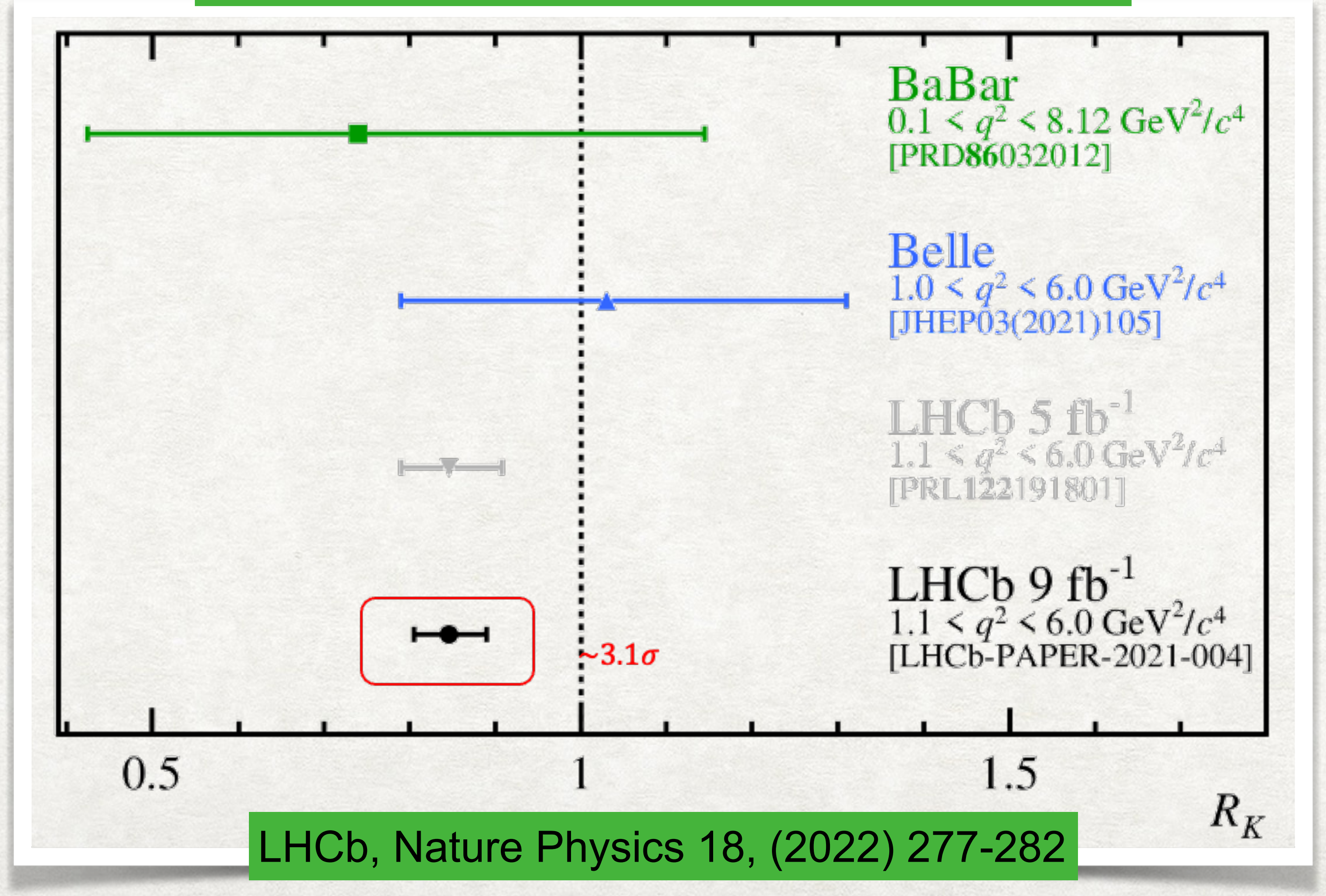



# LEPTON NON-UNIVERSALITY

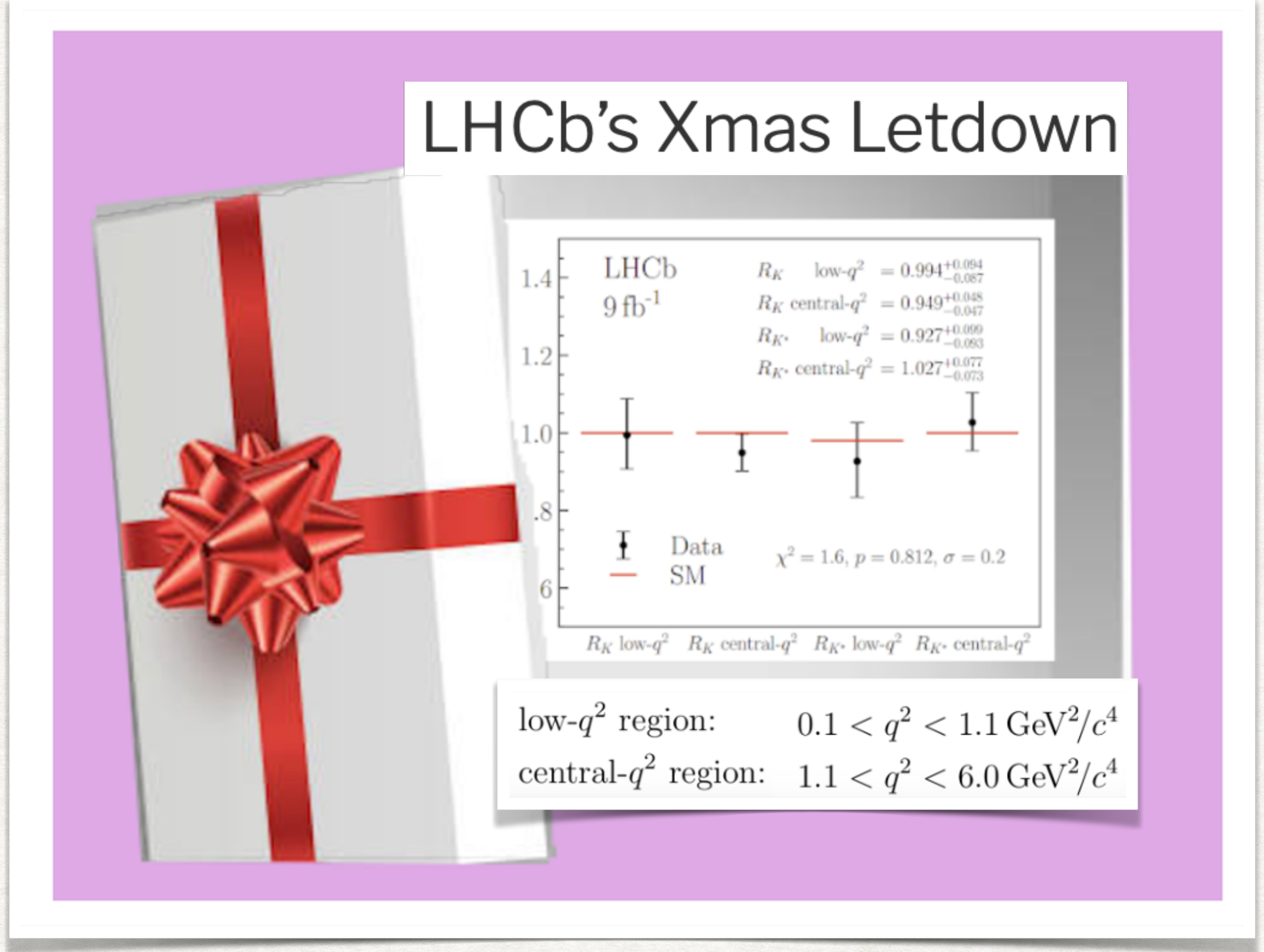
$$R_{K^*} = \frac{BR(B \to K^* \mu^+ \mu^-)}{BR(B \to K^* e^+ e^-)} \qquad R_K = \frac{BR(B \to K \mu^+ \mu^-)}{BR(B \to K e^+ e^-)}$$



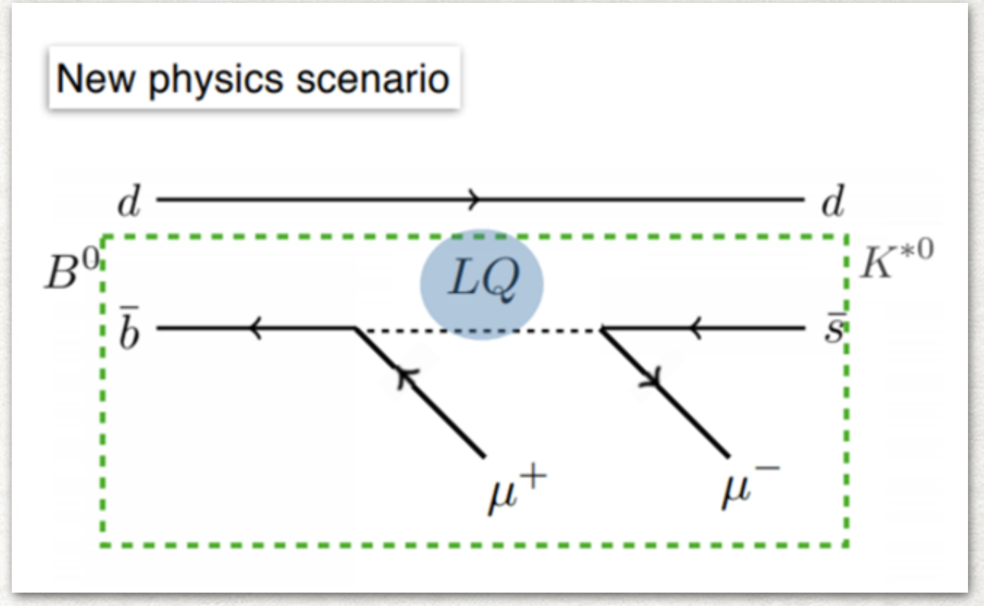

LHCb, Phys.Rev.Lett. 128 (2022) 19, 191802




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

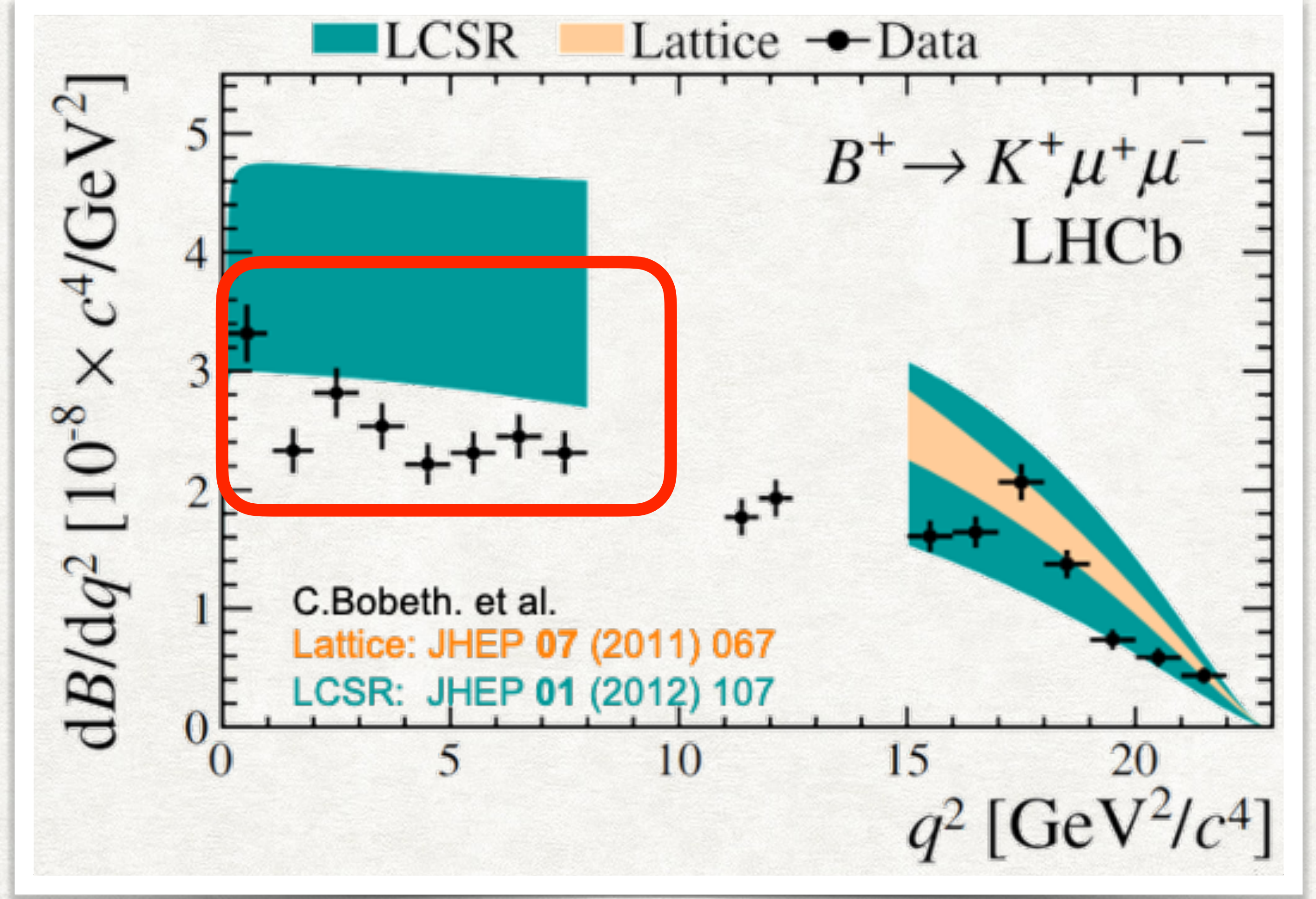



LHCb , arXiv: 2212.09153V1

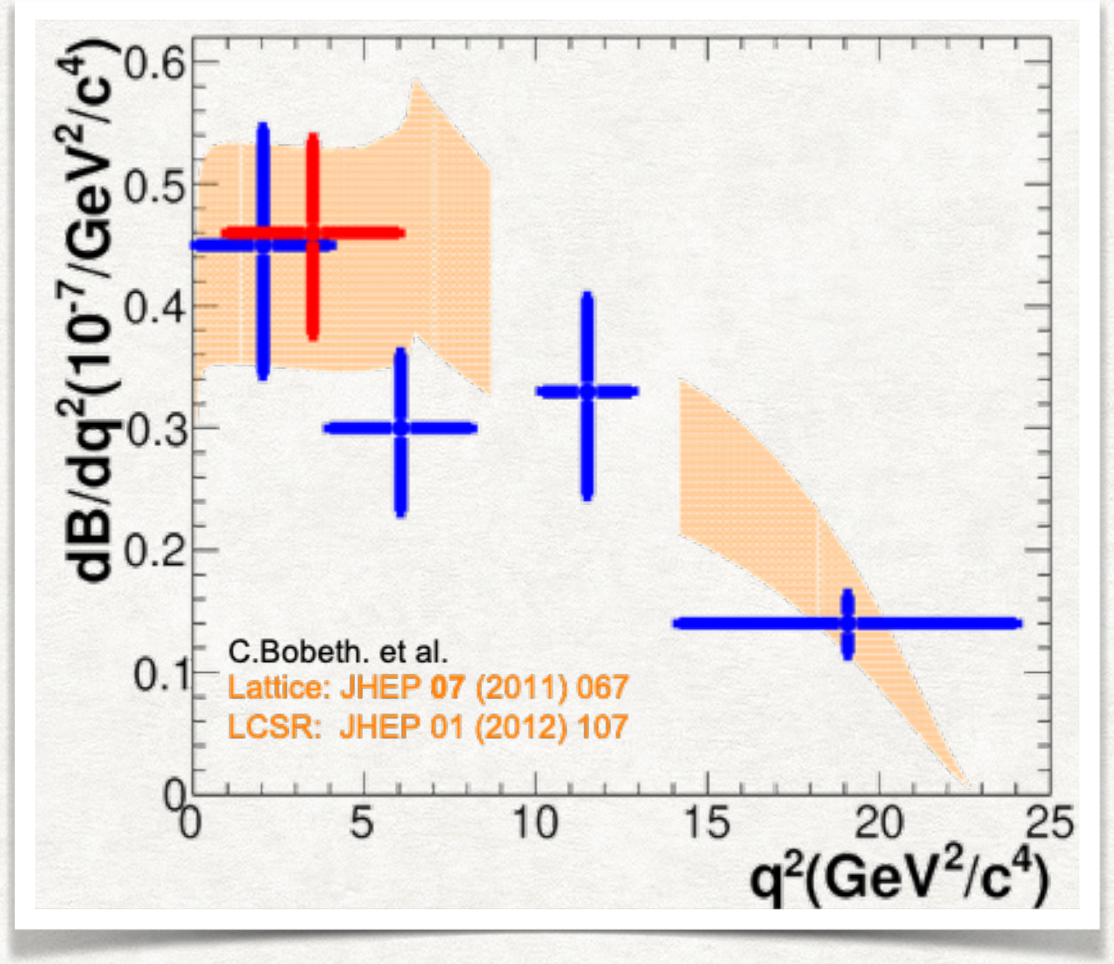



# BRANCHING FRACTION

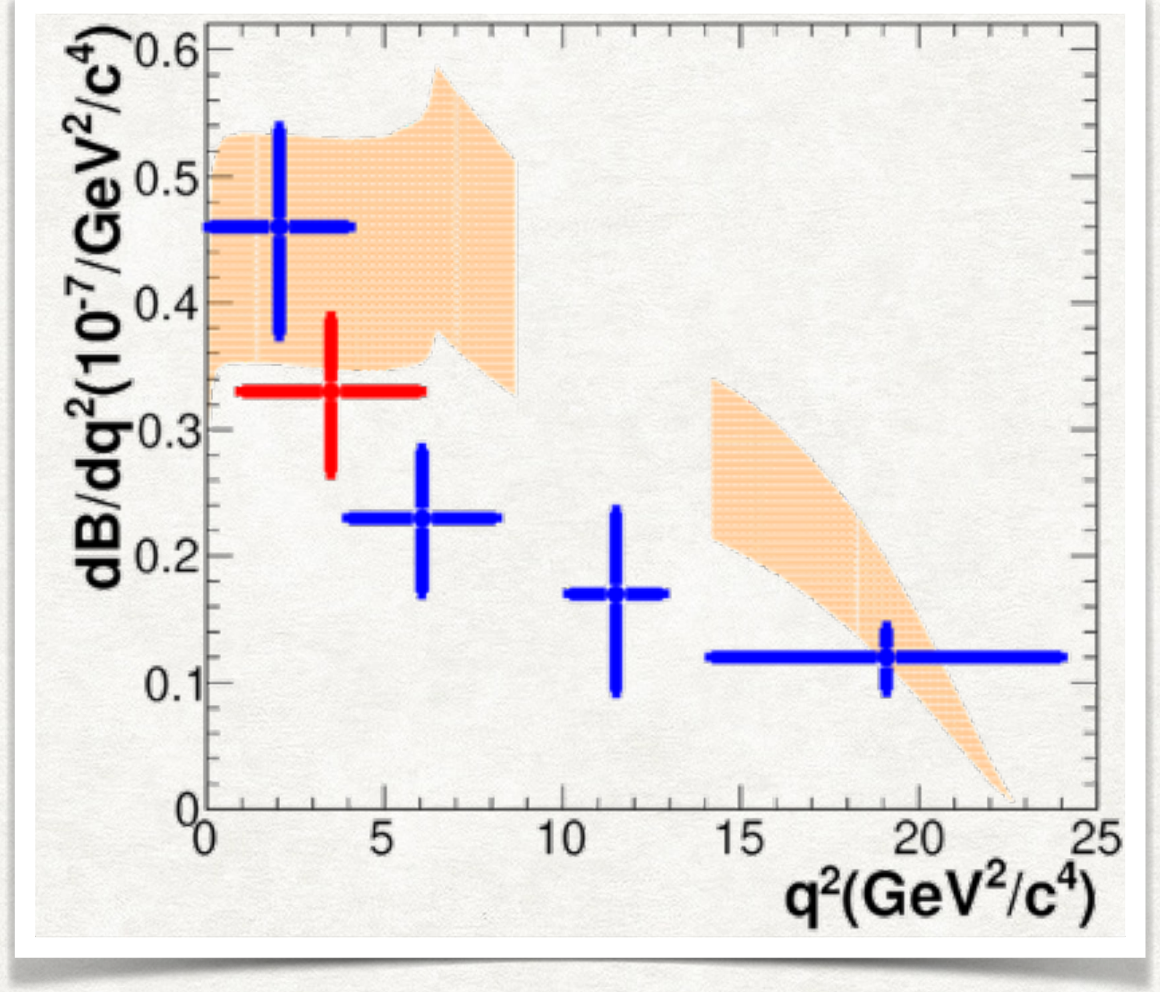
$B^+ \to K^+\mu^+\mu^-$



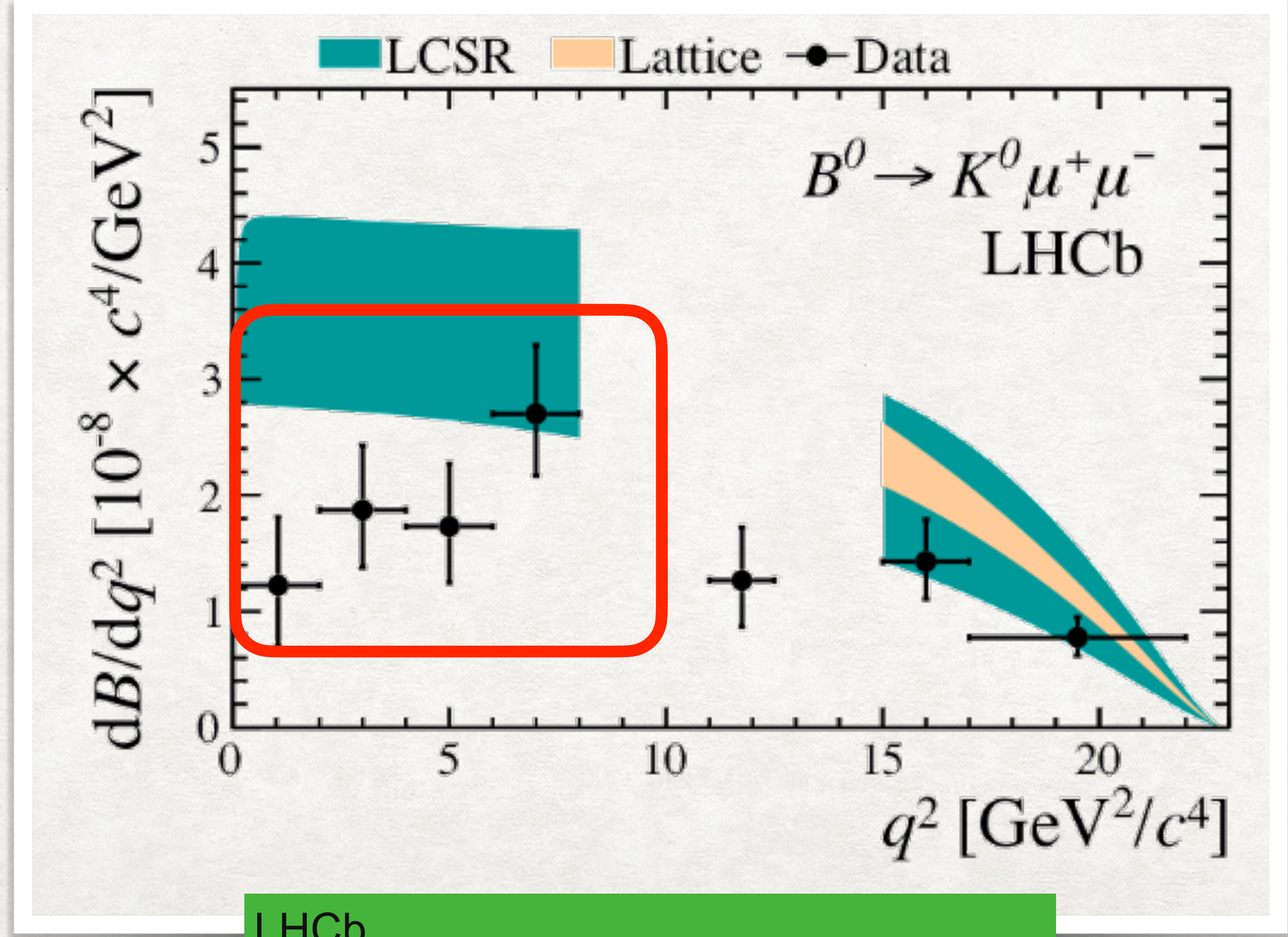

$B^+ \to K^+\mu^+\mu^-$



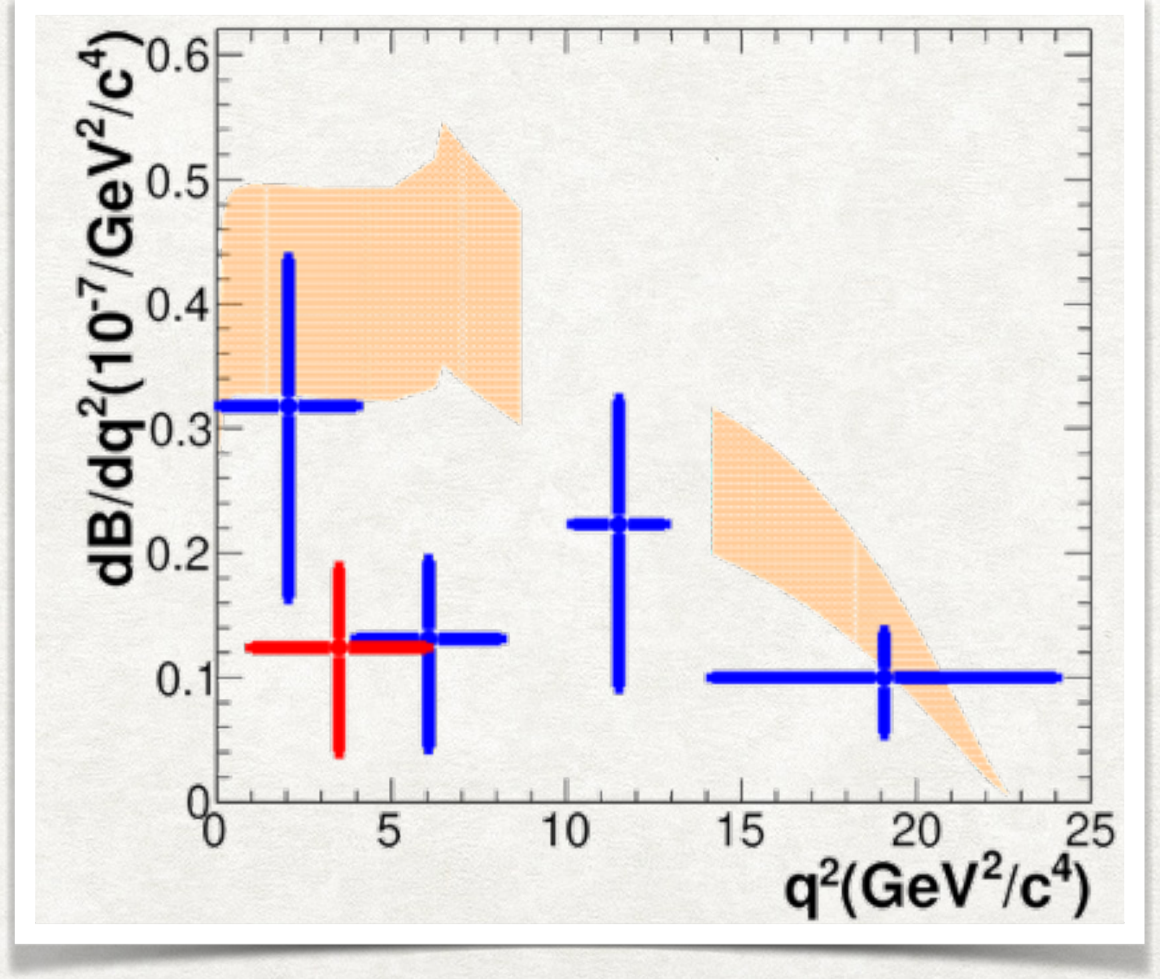

$B^0 \to K^0e^+e^-$



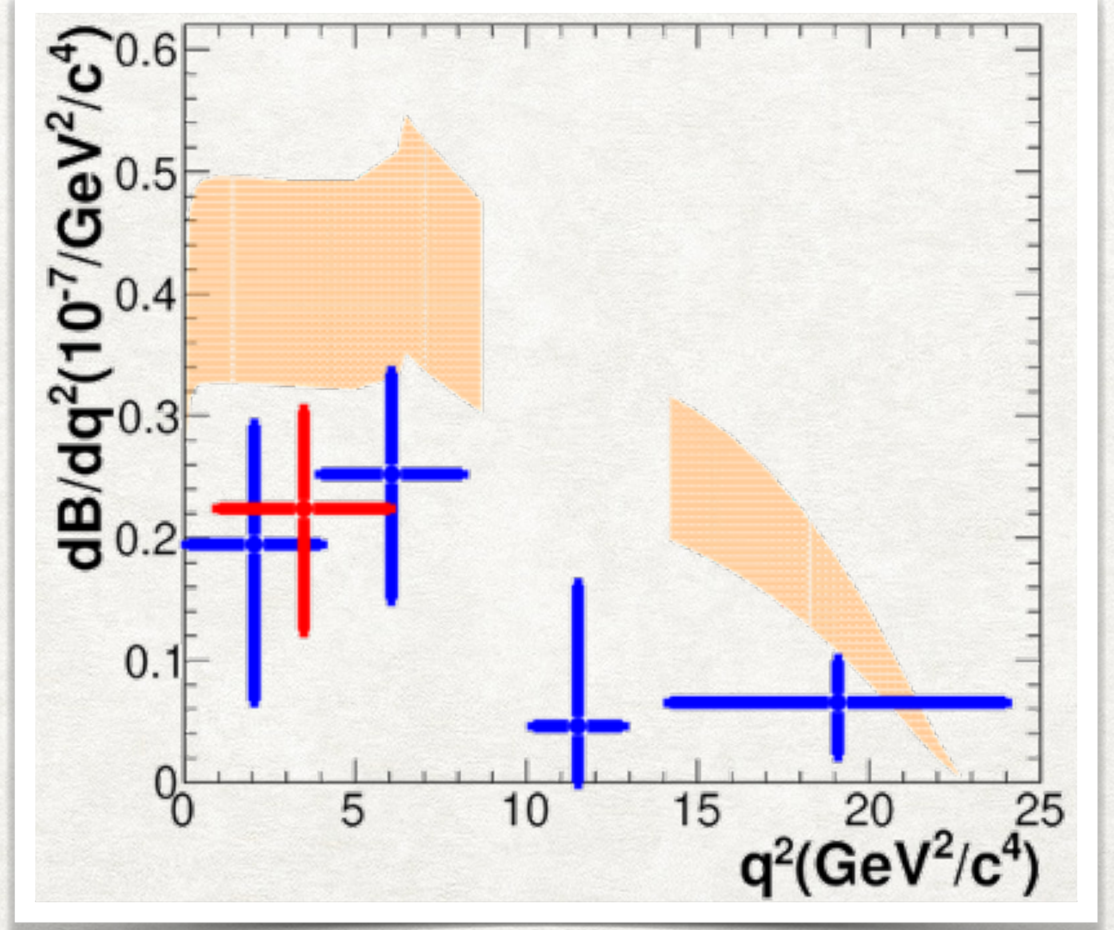

$B^0 \to K^0\mu^+\mu^-$




$B^0 \to K^0\mu^+\mu^-$



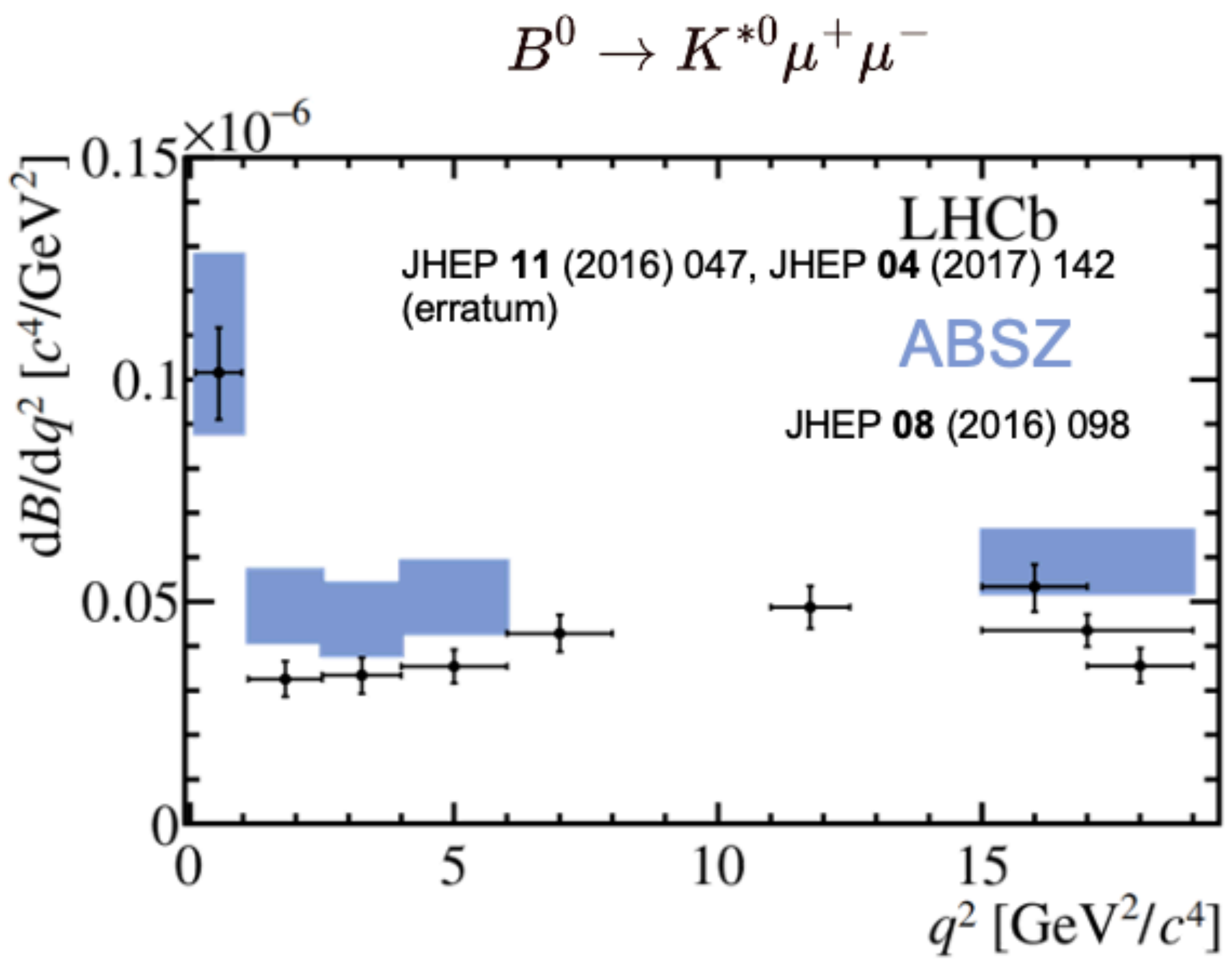

$B^+ \to K^+e^+e^-$

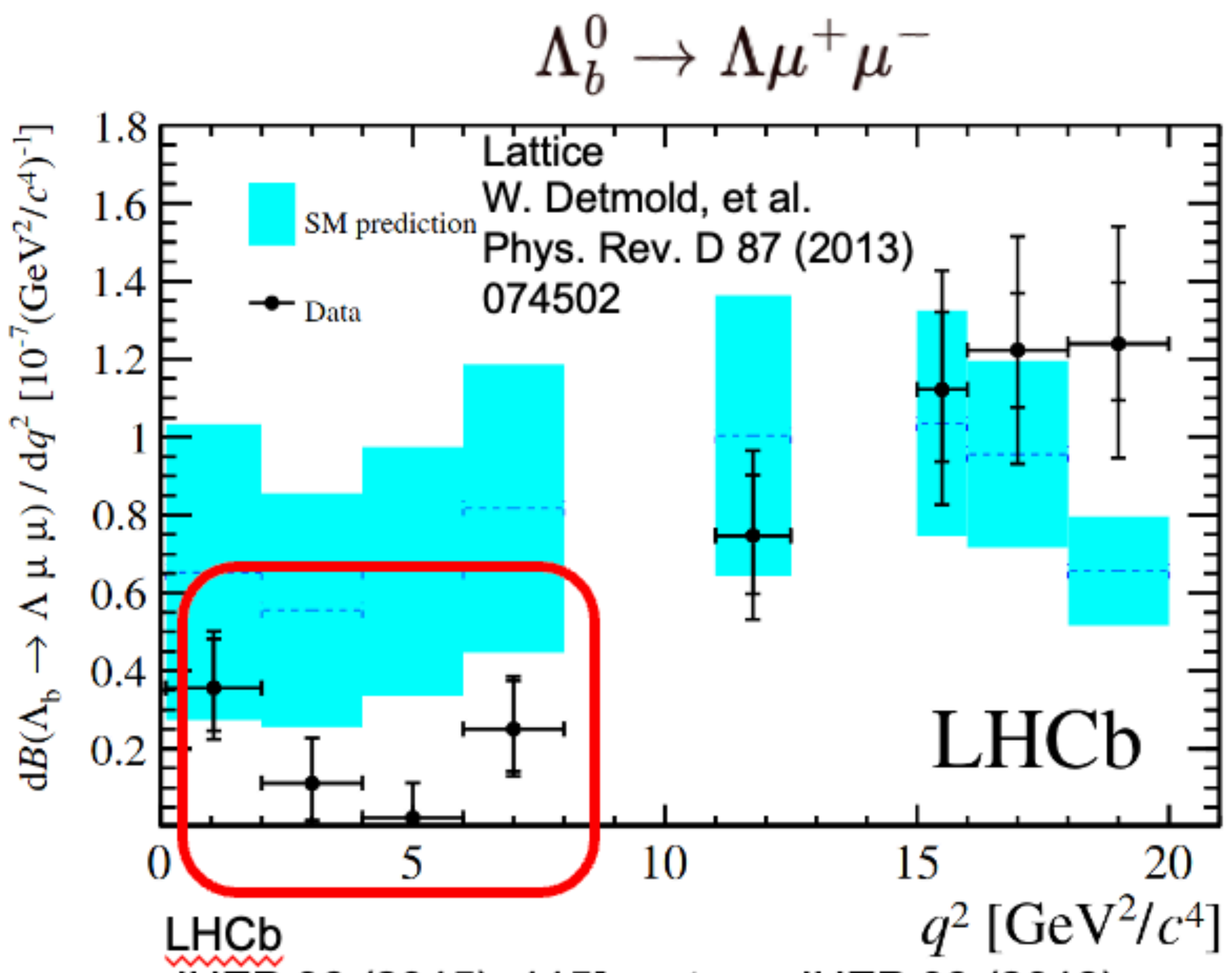



LHCb
JHEP **06** (2014) 133 arXiv: 1403.8044v1

Belle
JHEP **03** (2021) 105

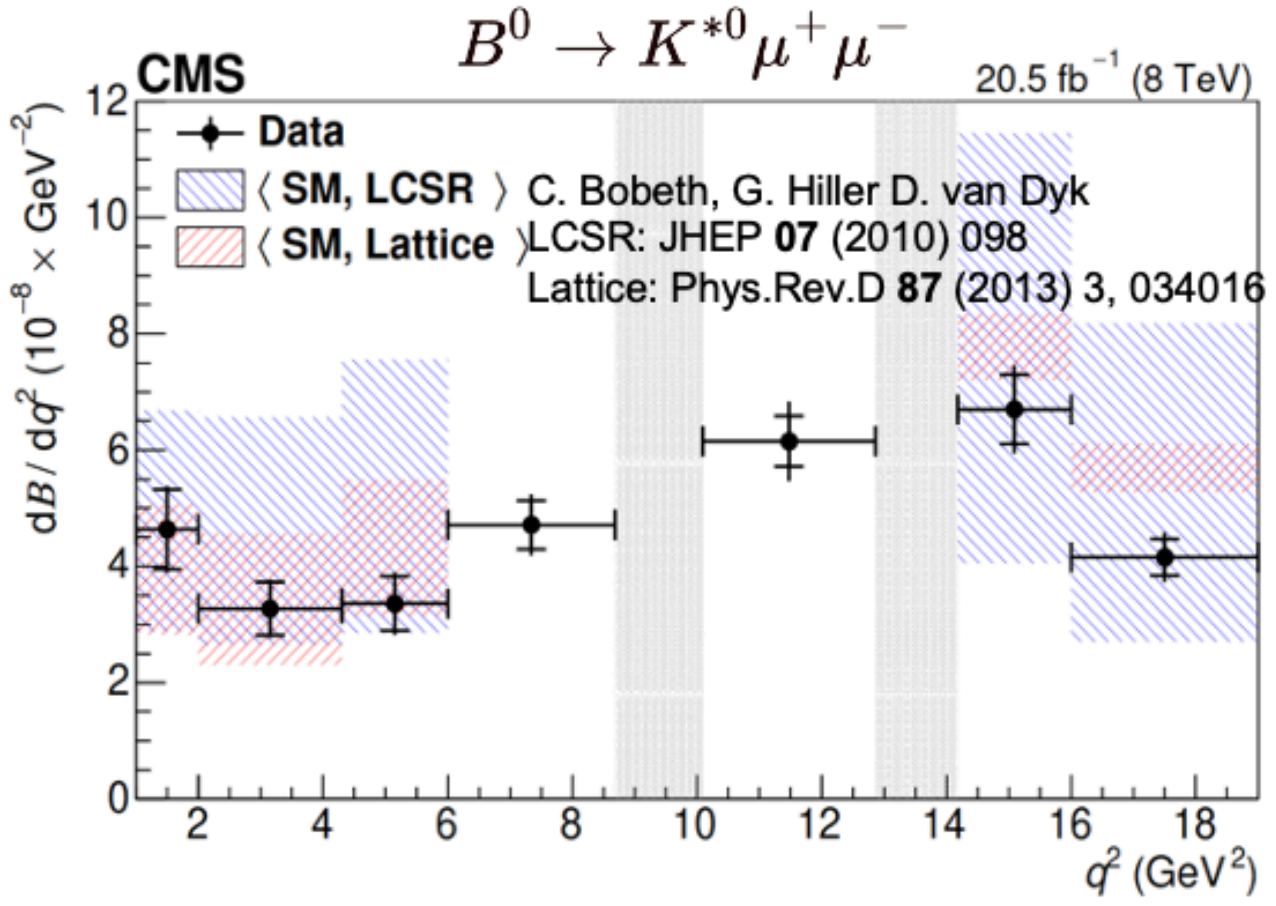
# BRANCHING FRACTION



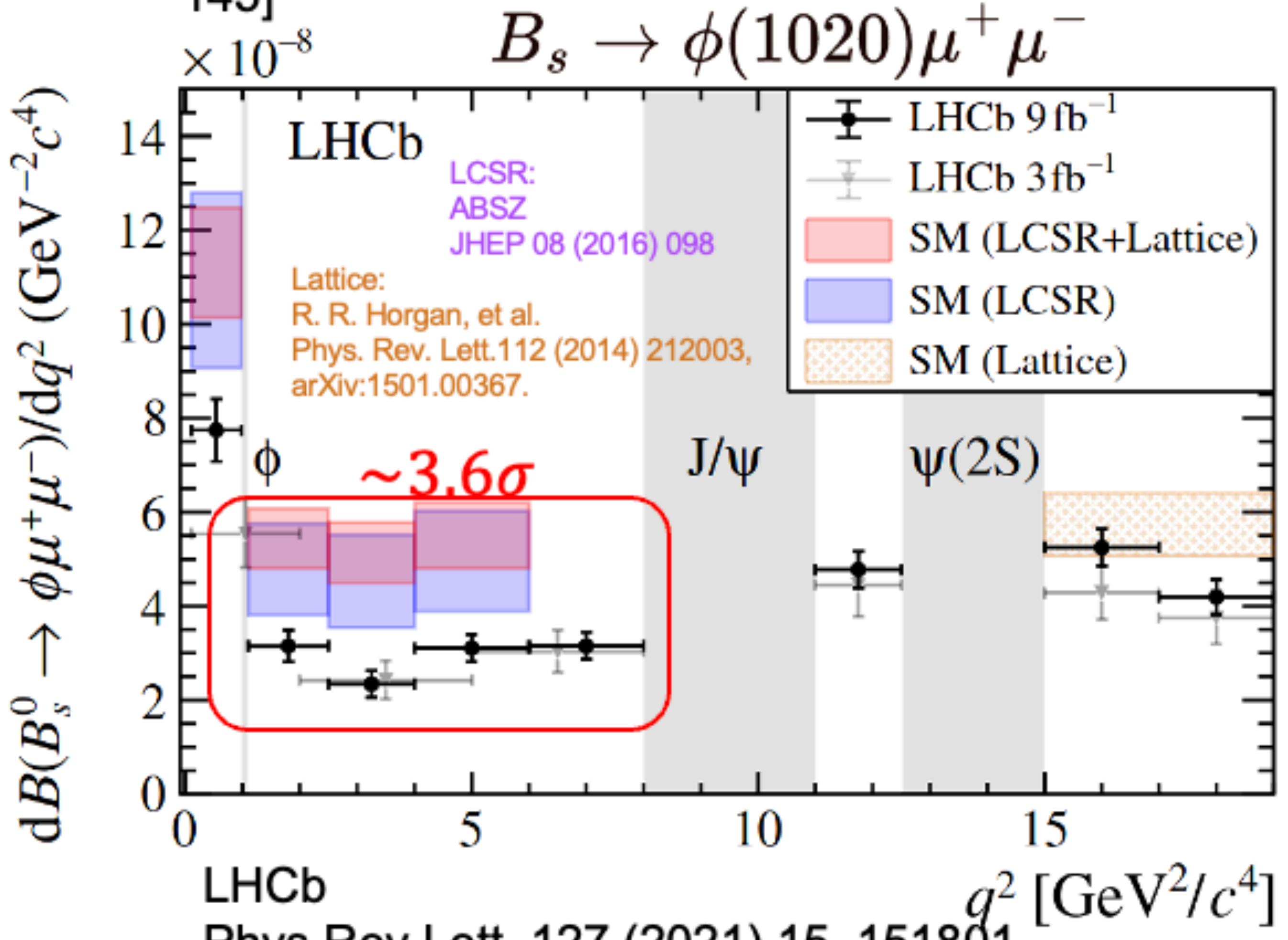




LHCb
JHEP 06 (2015), 115[erratum: JHEP 09 (2018), 145]

Angular analysis refers to:
LHCb, JHEP **09** (2018), 146




CMS
Phys.Lett.B 753 (2016) 424-448

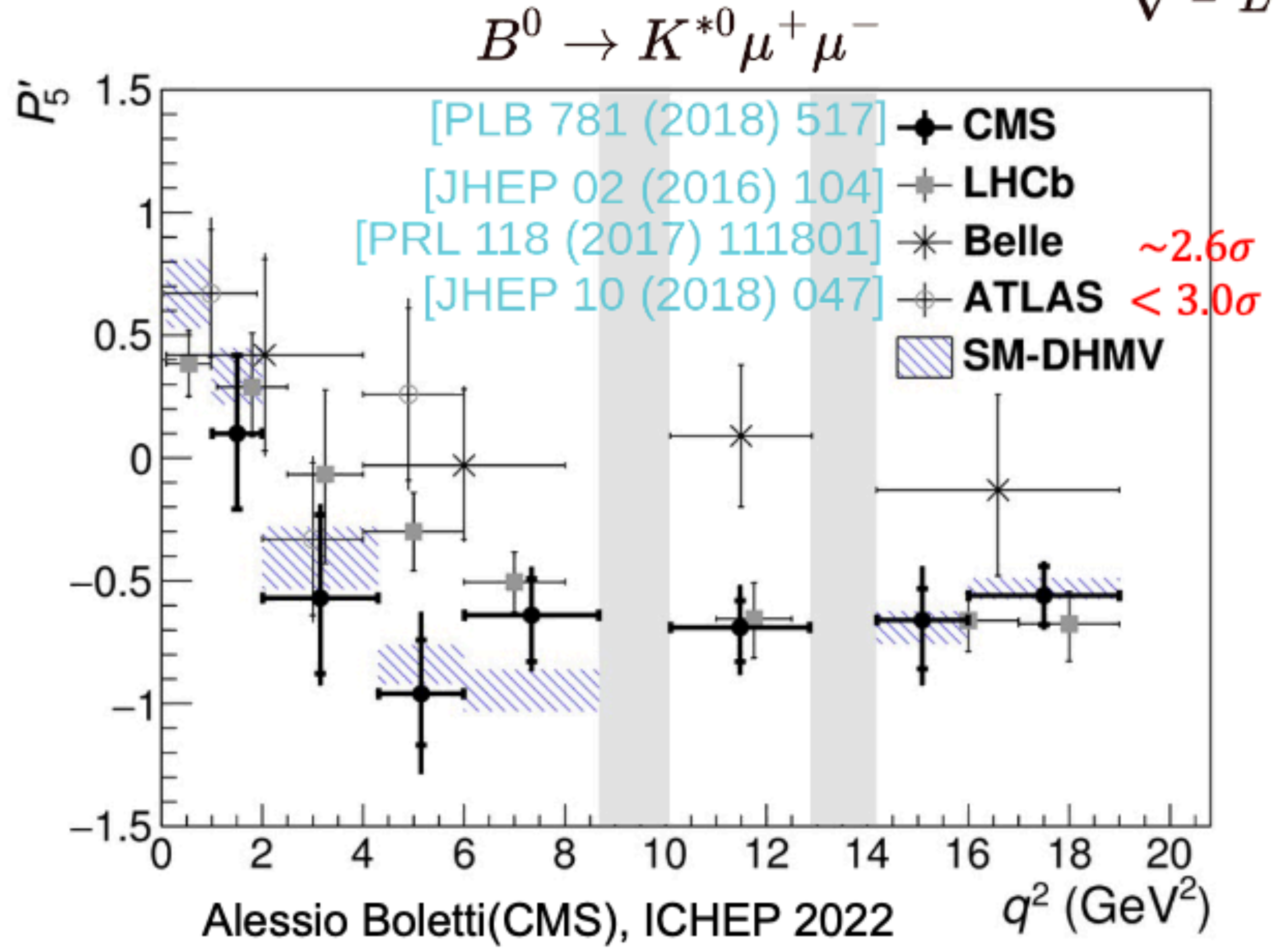



LHCb
Phys.Rev.Lett. 127 (2021) 15, 151801

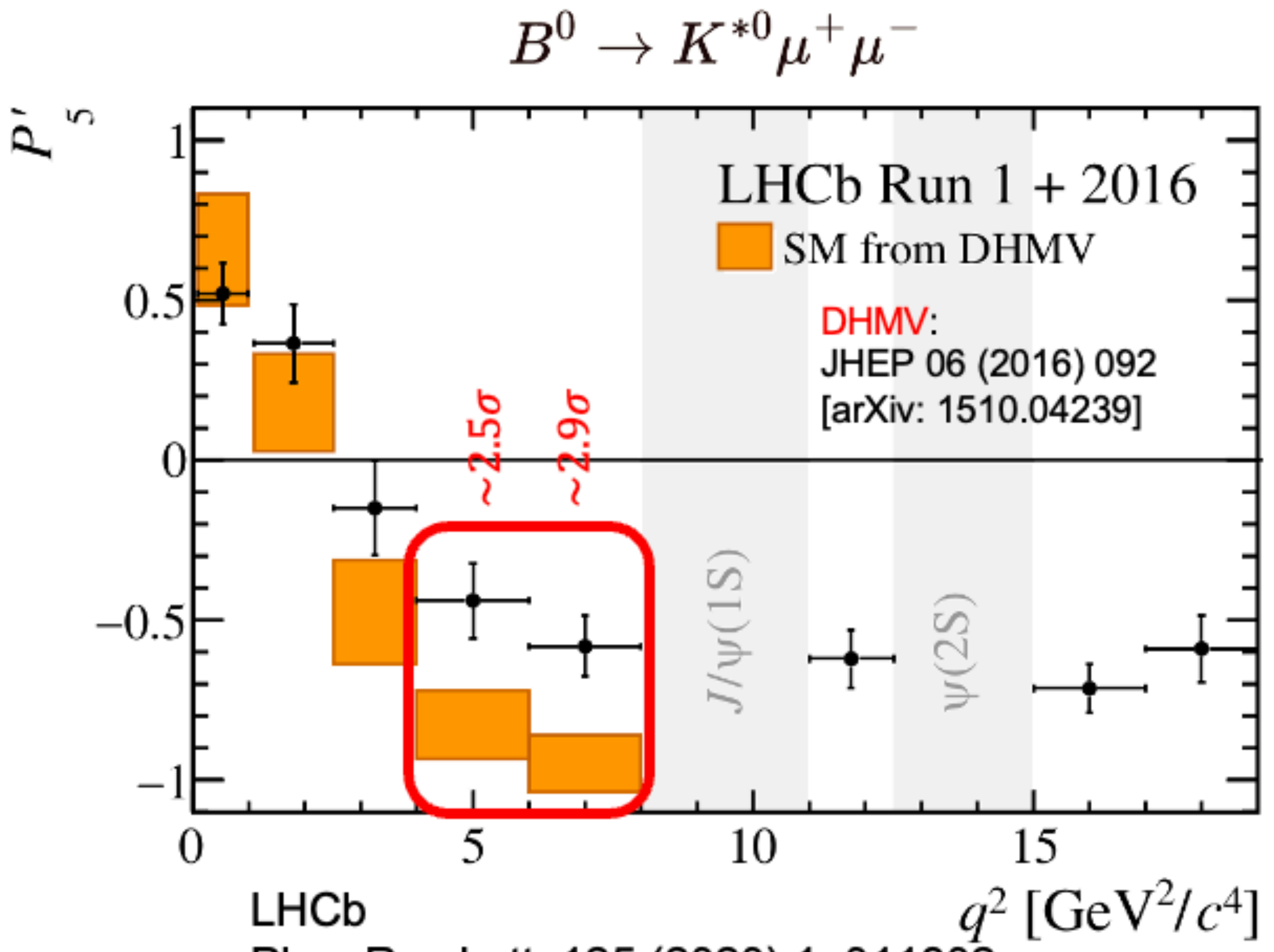
Angular analysis could be found in:
LHCb, JHEP **11** (2021) 043
arXiv: 2107.13428

# ANGULAR DISTRIBUTION

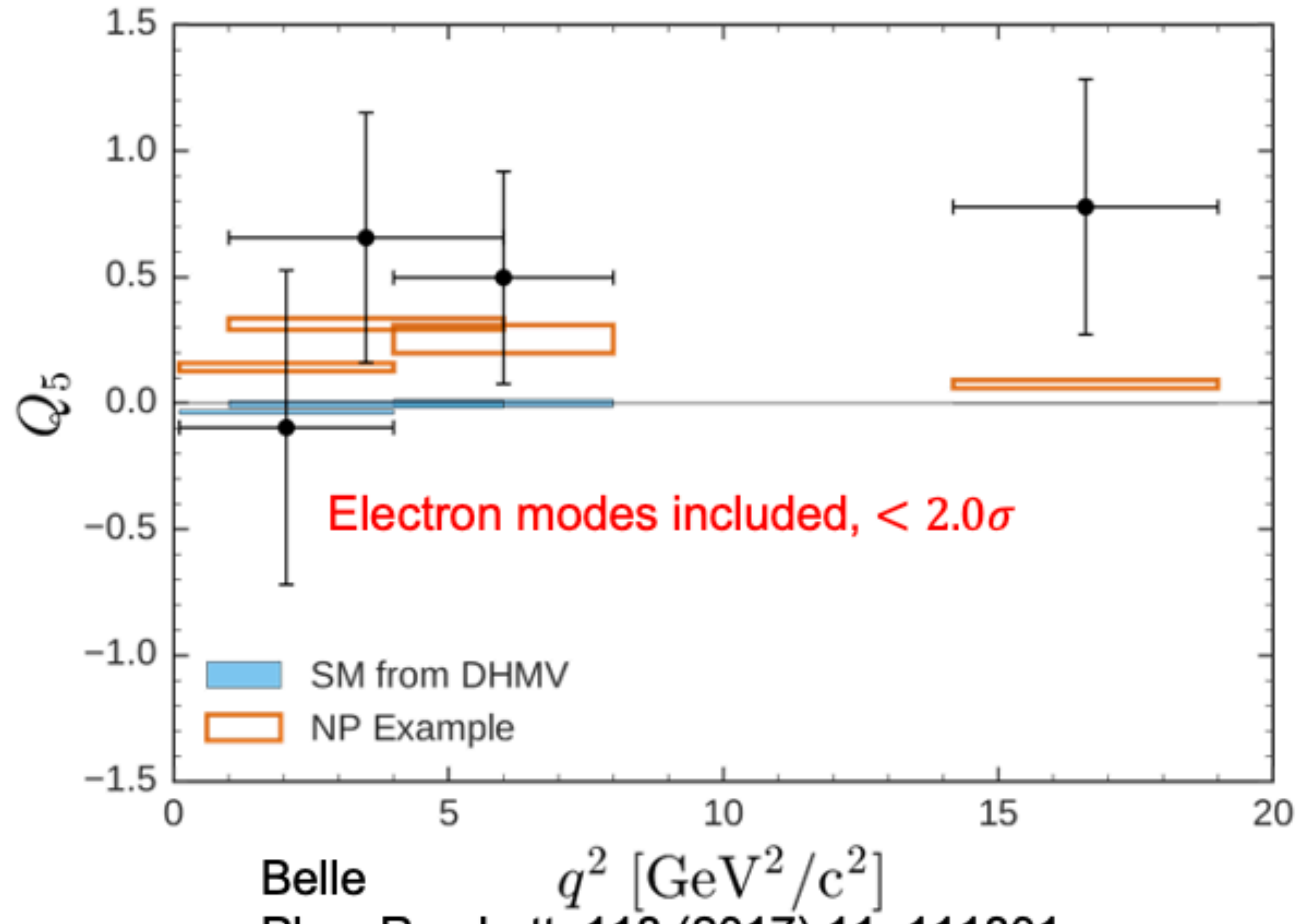
$$P_5' = \frac{S_5}{\sqrt{F_L(1-F_L)}} \qquad Q_5 = P_i'^{\mu} - P_i'^{e}$$



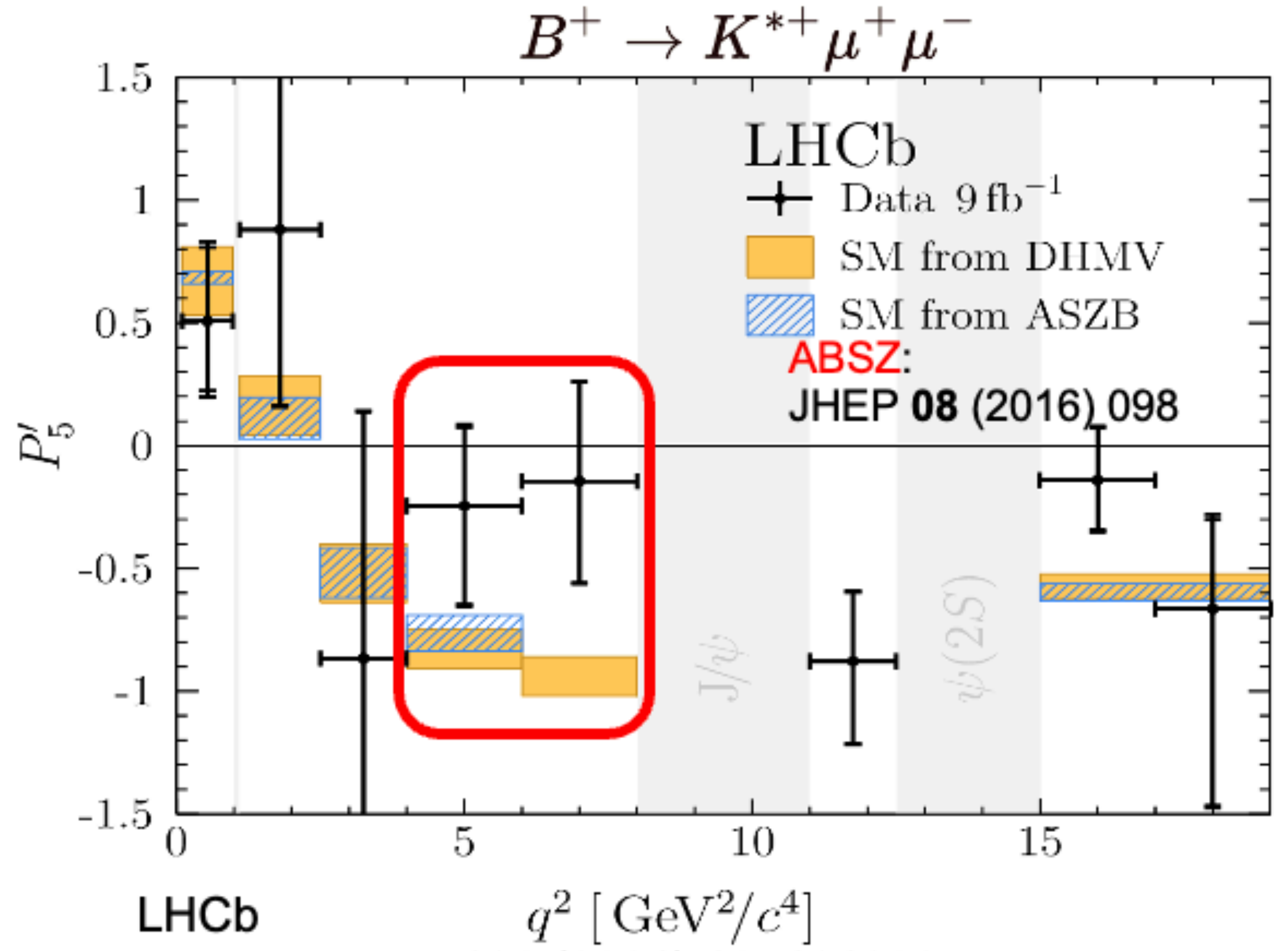

Alessio Boletti(CMS), ICHEP 2022
https://agenda.infn.it/event/28874/contributions/169340/




LHCb
Phys.Rev.Lett. 125 (2020) 1, 011802




Belle
Phys.Rev.Lett. 118 (2017) 11, 111801




LHCb
Phys.Rev.Lett. 126 (2021) 16, 161802

# THEORETICAL SKELETON OF FCNC PROCESS $b \to s$

effective Hamiltonian:

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

SM

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

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

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

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

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

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

high energy information

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

QCDF

decay amplitude:

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

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

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

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

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.

| | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ | $C_7^{\text{eff}}$ | $C_8^{\text{eff}}$ | $C_9$ | $C_{10}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 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

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

  - BSM operators

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

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

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

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

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

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

**Scenario I: muon-specific**

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

**Scenario II: lepton-universal**

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

**Scenario III: lepton-specific**

all parameters are taken except C7

**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

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

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

  - helicity amplitude

S. Jager, J. M. Camalich 1212.2263

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

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

# FITS BEFORE XMAS 2022

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

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private code

ACDMN, 2104.08921

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

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private code

GGJLCS, 2103.12378

## New Physics in Rare *B* Decays after Moriond 2021

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Flavio

AS, 2103.13370

## Neutral current *B*-decay anomalies

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SuperIso

HMMN, 2210.07221

# 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**<br>1704.07397<br>1608.02556<br>1704.07397 | arXiv:**1810.07698**<br>1911.07866<br>2103.13370<br>2212.10497 | arXiv: **1910.14012**<br>1902.05564<br>1512.07157<br>1306.4644 | arXiv: **2111.15428**<br>2305.06301<br>2208.08937<br>1912.09335 | arXiv: **0710.2067**<br>**0808.3144**<br>1410.4545<br>1806.11489 |
| First edition (as far as we know) | v0.1.3<br>(2016.2) | (2018.10) | SUSYfit<br>(2013.06) | D. van Dyk,<br>thesis, 2011 | 2007.10<br>2008.08 |
| latest update (as far as we know) | v2.5.5<br>(2023.6.1) | v2.4.0<br>(2023.4.27) | v1.0<br>(2023.5.19) | v1.0.9<br>(2023.8.8) | v4.1<br>(2020.11.4) |
| Code PL | Pure Python3 | Based on Flavio | Pure C++11 | C++20 with python API | C |
| Statistic FrameWork | **MLE**<br>(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 |

# FITTING PACKAGES ON THE MARKET

| Brands | flavio | Smelli | HEPfit | EOS | SuperIso |
|---|---|---|---|---|---|
| Theo. FrameWork | **WEFT** (below EW scale) **SMEFT(dim-6)** (above EW scale) | **SMEFT(dim-6)** (above EW scale) | 1. **WEFT/SMEFT(dim6)** 2. **2HDM/MSSM** 3. **Georgi-Machacek model** | **WEFT** (below EW scale) | 1. **WEFT/SMEFT(dim6)** 2. **2HDM** 3. **Different scenarios in MSSM** |
| Basis of WEFT | **arXiv: 1606.00916** (with tensor Operators?) | **arXiv: 1606.00916** (with tensor Operators?) | **arXiv: 1903.09632** (no tensor Operators) | **arXiv: 2107.04822** (with tensor Operators?) | **arXiv: 0808.3144** (no tensor Operators) |
| FFs (part of it) | (Heavy to light) **B -> Vll** **arXiv: 1503.05534, etc.** **B -> Pll** **arXiv: 1811.00983, etc.** **Lambda_b -> Lambda ll** **arXiv: 1602.01399** (Heavy to Heavy) **B -> D^{(*)} l nu** arXiv:1703.05330 (HQET) | Same as flavio | (Heavy to light) **B -> Vll** **arXiv: 1503.05534** **B -> Pll** **arXiv: hep-ph/0406232** | (Heavy to light) **B -> Vll** **arXiv: 1503.05534, etc.** **B -> Pll** **arXiv: 1004.3249, etc.** **Lambda_b -> Lambda ll** **arXiv: 1602.01399, etc.** (Heavy to Heavy) **B -> D^{(*)} l nu** arXiv: 1503.07237, etc. | (Heavy to light) **B -> Vll** **arXiv: 1503.05534, etc.** **B -> Pll** **arXiv: 1811.00983, etc.** |
| Focused Processes | More than 1400 observables. Observables library. Higgs production/decays, b/c/s hadron decays, dipole moments, W/Z decays, nucleon decays, EWPO, etc. | EWPO, FCCC, FCNC, LFV processes, Z decays, tau muon decays, meson mixing, Higgs signal strengths. | EWPO, oblique parameter, Higgs observables (strengths and direct searches). Flavour observables. | Mainly flavour observables | FCNC, LFU, $B \to V(P)ll$, $b \to s\gamma$, $B \to X_s ll$, g-2. |

# 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)

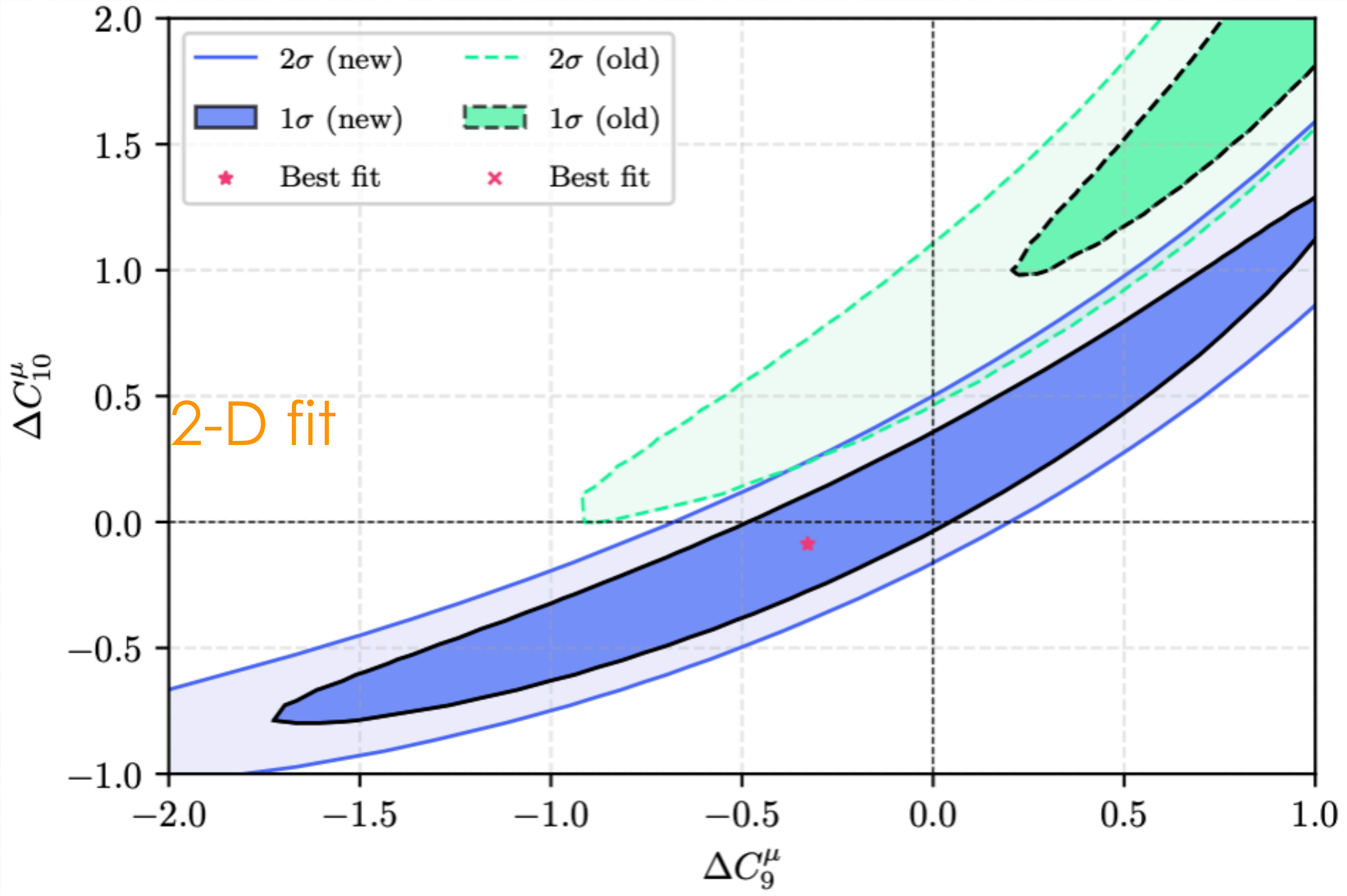
to be improved

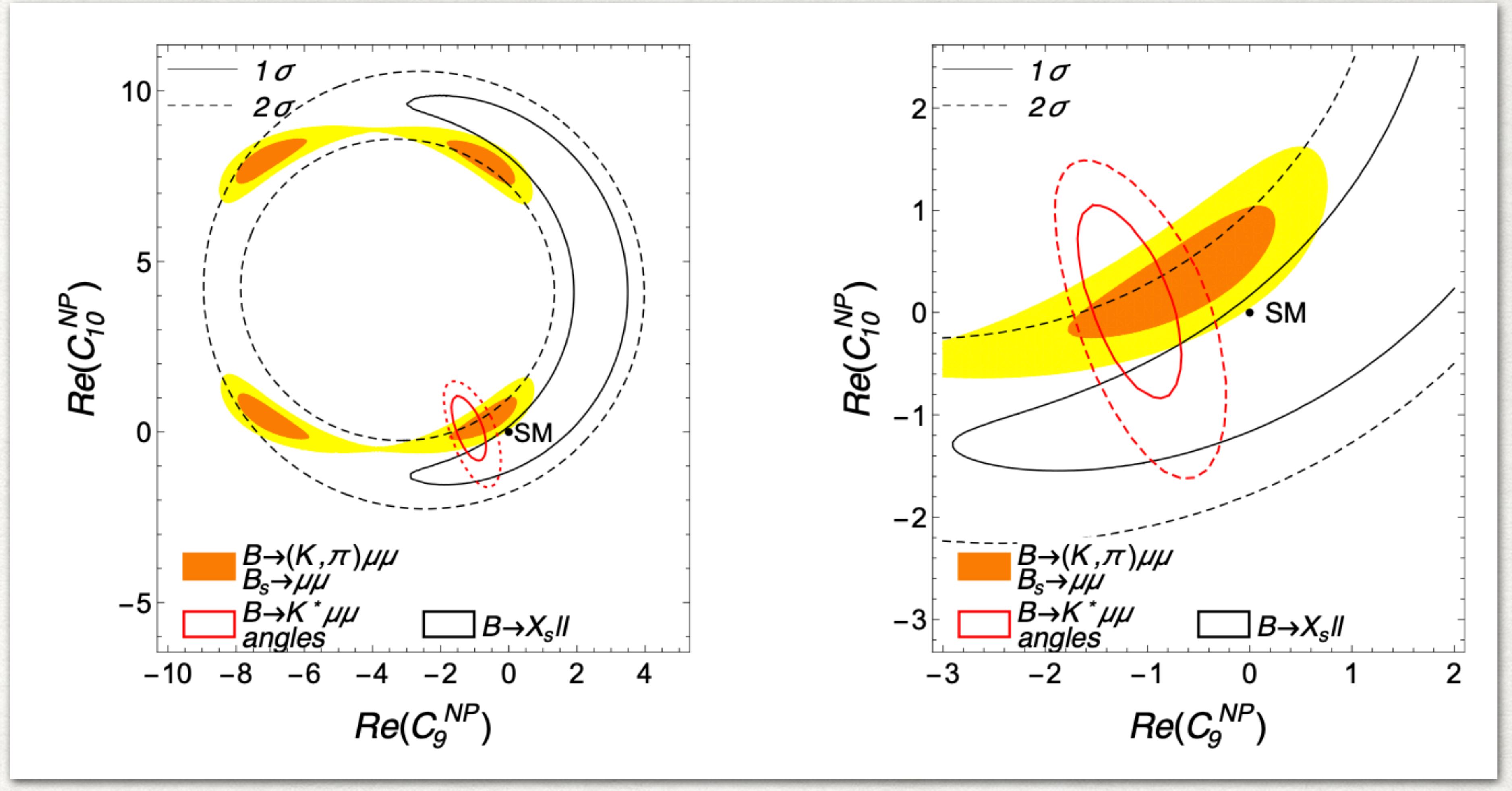
| Params | S-I' | S-II' | S-III' | S-IV' | S-I | S-II | S-III | S-IV | ADCMN[24] | AS[25] | HMMN[26] | GGJLCS[27] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reduced $\chi^2$ | 175.637/(n-12) | 188.921/(n-12) | 169.408/(n-18) | 168.368/(n-20) | 192.396/(n-12) | 168.852/(n-12) | 171.999/(n-18) | 169.327/(n-20) | 260.66/(254-6) | | 179.1/(183-20) | 96.88/90 |
| $\chi^2_{\rm min}$/d.o.f | = 0.965 | = 1.038 | = 0.963 | = 0.968 | = 1.046 | = 0.918 | = 0.966 | = 0.962 | = 1.05 | | = 1.1 | = 1.08 |
| $\Delta C_7$ | $-0.006^{+0.023}_{-0.020}$ | $-0.002^{+0.018}_{-0.017}$ | - | $0.006^{+0.020}_{-0.018}$ | $-0.005^{+0.023}_{-0.020}$ | $-0.001^{+0.019}_{-0.017}$ | - | $0.002^{+0.020}_{-0.017}$ | $0.00^{+0.01}_{-0.02}$ | - | $0.06^{-0.03}_{+0.03}$ | - |
| $\Delta C_7'$ | $0.028^{+0.042}_{-0.042}$ | $0.065^{+0.038}_{-0.036}$ | - | $0.077^{+0.040}_{-0.039}$ | $0.036^{+0.042}_{-0.042}$ | $0.064^{+0.038}_{-0.036}$ | - | $0.073^{+0.041}_{-0.039}$ | $+0.00^{+0.02}_{-0.01}$ | - | $-0.01^{-0.01}_{+0.01}$ | - |
| $\Delta C_8$ | $-0.477^{+0.562}_{-0.530}$ | $-0.400^{+0.448}_{-0.427}$ | $-0.402^{+0.458}_{-0.437}$ | $-0.387^{+0.428}_{-0.415}$ | $-0.738^{+0.530}_{-0.494}$ | $-0.451^{+0.440}_{-0.410}$ | $-0.502^{+0.471}_{-0.426}$ | $-0.357^{+0.455}_{-0.450}$ | - | - | $-0.80^{-0.40}_{+0.40}$ | - |
| $\Delta C_8'$ | $-0.039^{+0.843}_{-0.807}$ | $-0.046^{+0.686}_{-0.658}$ | $-0.054^{+0.722}_{-0.748}$ | $-0.049^{+0.753}_{-0.709}$ | $-0.031^{+0.802}_{-0.800}$ | $-0.027^{+0.692}_{-0.658}$ | $-0.001^{+0.758}_{-0.752}$ | $0.017^{+0.656}_{-0.698}$ | - | - | $-0.30^{+1.30}_{-1.30}$ | - |
| $\Delta C_9^\mu$ | $-0.970^{+0.273}_{-0.279}$ | $-1.138^{+0.240}_{-0.256}$ | $-1.028^{+0.194}_{-0.194}$ | $-1.263^{+0.244}_{-0.276}$ | $-0.914^{+0.282}_{-0.289}$ | $-1.127^{+0.235}_{-0.246}$ | $-0.988^{+0.192}_{-0.202}$ | $-1.223^{+0.256}_{-0.295}$ | $-1.08^{+0.18}_{-0.17}$ | $-0.82^{+0.23}_{-0.23}$ | $-1.14^{-0.19}_{+0.19}$ | $-1.07^{+0.29}_{-0.29}$ |
| $\Delta C_9'^\mu$ | $0.474^{+0.424}_{-0.448}$ | $0.113^{+0.344}_{-0.375}$ | $0.321^{+0.351}_{-0.348}$ | $0.033^{+0.355}_{-0.390}$ | $0.457^{+0.453}_{-0.492}$ | $0.116^{+0.353}_{-0.363}$ | $0.311^{+0.387}_{-0.354}$ | $0.088^{+0.395}_{-0.450}$ | $0.16^{+0.37}_{-0.36}$ | $-0.10^{+0.34}_{-0.34}$ | $0.05^{+0.32}_{-0.32}$ | $0.32^{-0.21}_{+0.21}$ |
| $\Delta C_{10}^\mu$ | $0.399^{+0.229}_{-0.208}$ | $0.367^{+0.171}_{-0.162}$ | $0.487^{+0.177}_{-0.166}$ | $0.388^{+0.179}_{-0.170}$ | $0.117^{+0.223}_{-0.203}$ | $0.378^{+0.173}_{-0.165}$ | $0.459^{+0.172}_{-0.172}$ | $0.370^{+0.172}_{-0.171}$ | $0.15^{+0.13}_{-0.13}$ | $+0.14^{+0.23}_{-0.23}$ | $0.21^{-0.20}_{+0.20}$ | $0.21^{-0.14}_{+0.14}$ |
| $\Delta C_{10}'^\mu$ | $-0.021^{+0.245}_{-0.249}$ | $-0.006^{+0.166}_{-0.170}$ | $0.037^{+0.200}_{-0.180}$ | $-0.002^{+0.184}_{-0.180}$ | $-0.053^{+0.269}_{-0.265}$ | $-0.002^{+0.174}_{-0.174}$ | $0.034^{+0.207}_{-0.190}$ | $-0.001^{+0.191}_{-0.181}$ | $-0.18^{+0.20}_{-0.18}$ | $-0.33^{+0.23}_{-0.23}$ | $-0.03^{+0.19}_{-0.19}$ | $-0.26^{-0.14}_{+0.14}$ |
| $\Delta C_S^\mu$ | $-0.001^{+1.098}_{-1.121}$ | $0.035^{+1.073}_{-1.098}$ | $0.035^{+0.932}_{-0.958}$ | $0.020^{+0.829}_{-0.834}$ | $-0.020^{+1.090}_{-1.066}$ | $-0.016^{+1.153}_{-1.134}$ | $-0.023^{+0.922}_{-0.876}$ | $0.048^{+0.829}_{-0.841}$ | - | - | $0.01^{+0.05}_{-0.05}$ | - |
| $\Delta C_S'^\mu$ | $-0.001^{+1.098}_{-1.120}$ | $0.038^{+1.071}_{-1.098}$ | $0.030^{+0.934}_{-0.959}$ | $0.025^{+0.831}_{-0.836}$ | $-0.020^{+1.088}_{-1.069}$ | $-0.015^{+1.153}_{-1.135}$ | $-0.026^{+0.921}_{-0.873}$ | $0.051^{+0.831}_{-0.842}$ | - | - | $-0.01^{+0.05}_{-0.05}$ | - |
| $\Delta C_P^\mu$ | $0.017^{+1.223}_{-1.203}$ | $0.964^{+0.747}_{-0.835}$ | $0.109^{+0.918}_{-0.940}$ | $0.047^{+0.908}_{-0.888}$ | $0.046^{+1.136}_{-1.168}$ | $0.441^{+0.822}_{-0.878}$ | $0.233^{+0.883}_{-1.026}$ | $0.049^{+0.917}_{-0.882}$ | - | - | $-0.04^{+0.02}_{-0.02}$ | - |
| $\Delta C_P'^\mu$ | $-0.010^{+1.219}_{-1.205}$ | $0.935^{+0.746}_{-0.834}$ | $0.084^{+0.916}_{-0.943}$ | $0.017^{+0.907}_{-0.888}$ | $0.015^{+1.136}_{-1.168}$ | $0.413^{+0.820}_{-0.876}$ | $0.212^{+0.883}_{-1.027}$ | $0.024^{+0.919}_{-0.885}$ | - | - | $-0.04^{+0.02}_{-0.02}$ | - |
| $\Delta C_9^e$ | - | $\Delta C_9^\mu$ | $-1.656^{+0.683}_{-0.696}$ | $-1.882^{+0.584}_{-0.598}$ | - | $\Delta C_9^\mu$ | $-1.657^{+0.618}_{-0.602}$ | $-1.739^{+0.548}_{-0.545}$ | - | $-0.24^{+1.17}_{-1.17}$ | $-6.50^{+1.90}_{-1.90}$ | - |
| $\Delta C_9'^e$ | - | $\Delta C_9'^\mu$ | $0.889^{+1.922}_{-2.013}$ | $1.196^{+1.439}_{-1.830}$ | - | $\Delta C_9'^\mu$ | $0.446^{+1.692}_{-1.436}$ | $0.657^{+1.213}_{-1.336}$ | - | - | $1.40^{+2.30}_{-2.30}$ | - |
| $\Delta C_{10}^e$ | - | $\Delta C_{10}^\mu$ | $0.153^{+0.944}_{-0.542}$ | $0.074^{+0.915}_{-0.535}$ | - | $\Delta C_{10}^\mu$ | $0.720^{+0.694}_{-0.442}$ | $0.610^{+0.634}_{-0.415}$ | - | $-0.24^{+0.78}_{-0.78}$ | $\sim 0$ | - |
| $\Delta C_{10}'^e$ | - | $\Delta C_{10}'^\mu$ | $0.299^{+1.013}_{-1.015}$ | $0.480^{+0.809}_{-0.828}$ | - | $\Delta C_{10}'^\mu$ | $-0.315^{+1.014}_{-0.853}$ | $-0.103^{+0.761}_{-0.677}$ | - | - | $\sim 0$ | - |
| $\Delta C_S^e$ | - | $\Delta C_S^\mu$ | $-0.793^{+1.647}_{-1.191}$ | $-0.674^{+1.614}_{-1.232}$ | - | $\Delta C_S^\mu$ | $-1.142^{+1.841}_{-1.026}$ | $-1.044^{+1.744}_{-1.075}$ | - | - | $-0.38^{+0.41}_{-0.41}$ | - |
| $\Delta C_S'^e$ | - | $\Delta C_S'^\mu$ | $-0.810^{+1.626}_{-1.184}$ | $-0.632^{+1.667}_{-1.207}$ | - | $\Delta C_S'^\mu$ | $-1.159^{+1.824}_{-1.018}$ | $-1.068^{+1.794}_{-1.078}$ | - | - | $-0.36^{+0.50}_{-0.50}$ | - |
| $\Delta C_P^e$ | - | $\Delta C_P^\mu$ | $-1.544^{+1.419}_{-1.090}$ | $-1.468^{+1.310}_{-1.038}$ | - | $\Delta C_P^\mu$ | $-1.657^{+1.326}_{-1.051}$ | $-1.726^{+1.261}_{-1.024}$ | - | - | $-0.98^{+0.21}_{-0.21}$ | - |
| $\Delta C_P'^e$ | - | $\Delta C_P'^\mu$ | $-1.251^{+1.148}_{-1.075}$ | $-1.305^{+1.199}_{-1.100}$ | - | $\Delta C_P'^\mu$ | $-1.534^{+1.283}_{-1.098}$ | $-1.512^{+1.173}_{-1.048}$ | - | - | $-0.95^{+0.29}_{-0.29}$ | - |

Before Dec. 2022 — After Dec. 2022

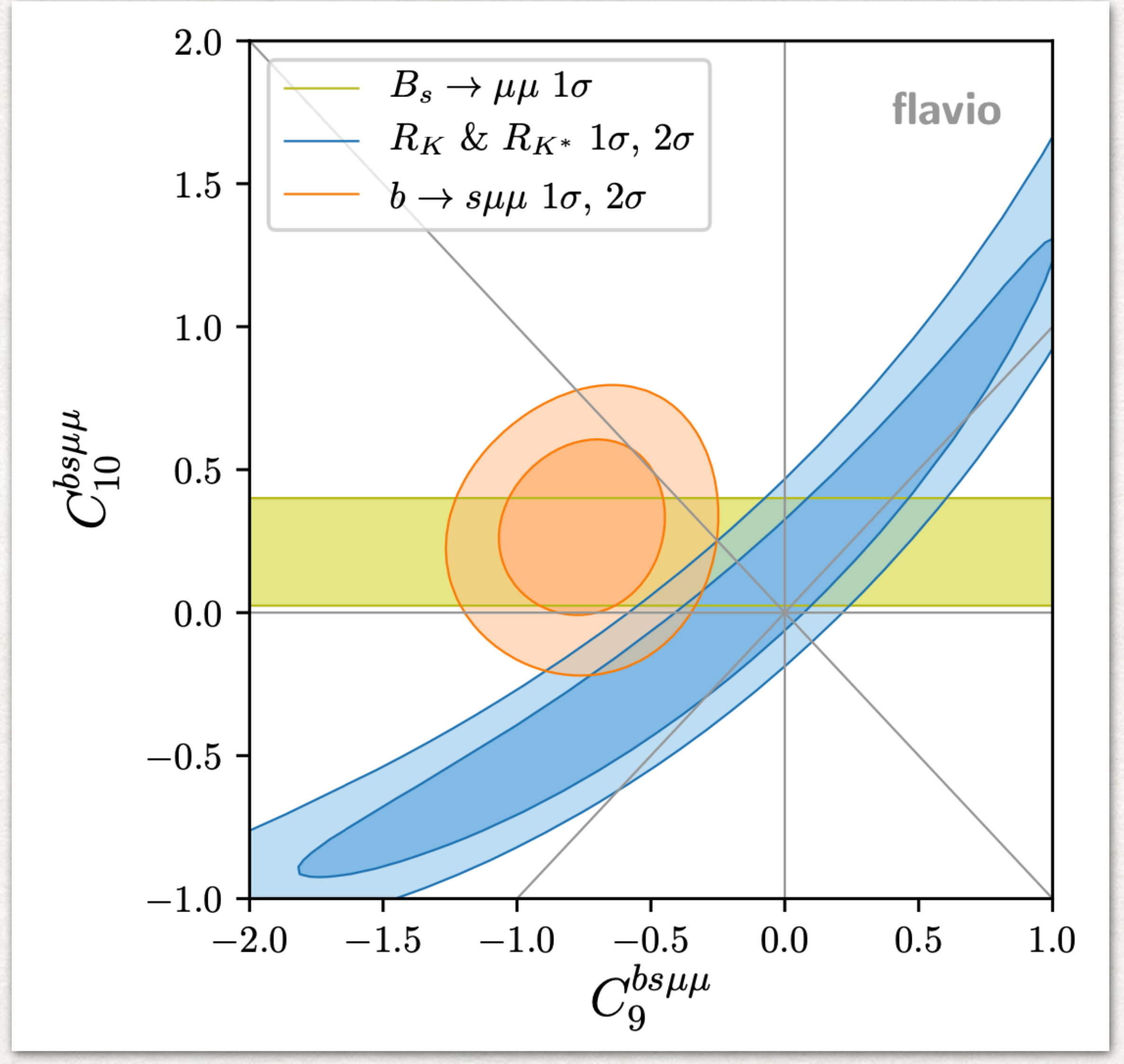
- we carried out a 20-D fit
- fitting results depend on the numbers of fitting d.o.f.
- both old and new fits imply NP exists in $\Delta C_9^\mu$ in various fitting scenarios
- both old and new fits imply: possible NP in $\Delta C_{10}^\mu$ is scenario dependent
- new fits implies: NP may be hidden in $\Delta C_9^e$, and its inverse process $e^+e^- \to bs$ calls for **CEPC**

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




Daping Du, et.al. 1510.02349



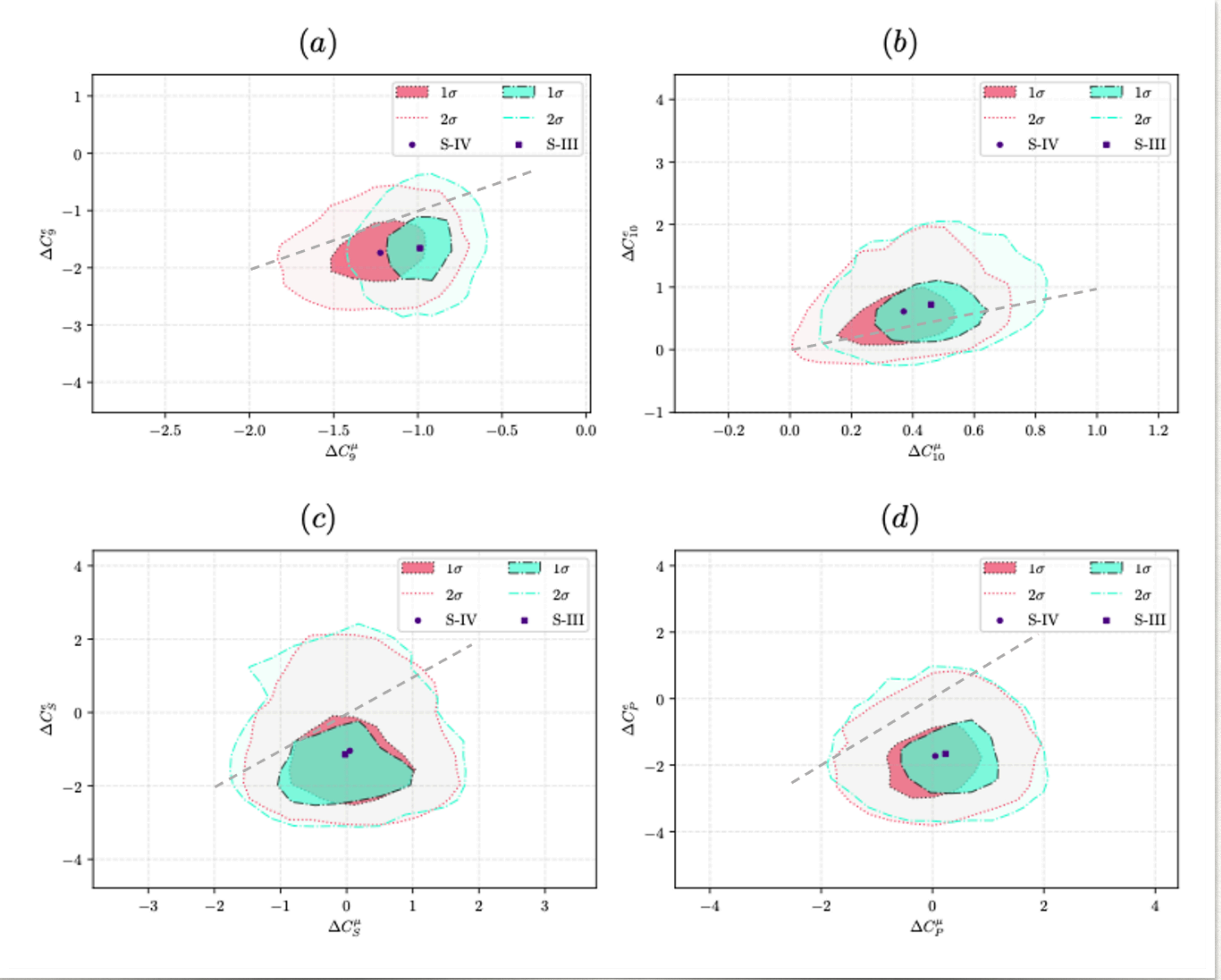

Admir Greljo, et.al. 2212.10497

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

still with large uncertainty

$R_{K^{(*)}}$ is not main determiner of $\Delta C_9^{\mu}$ !

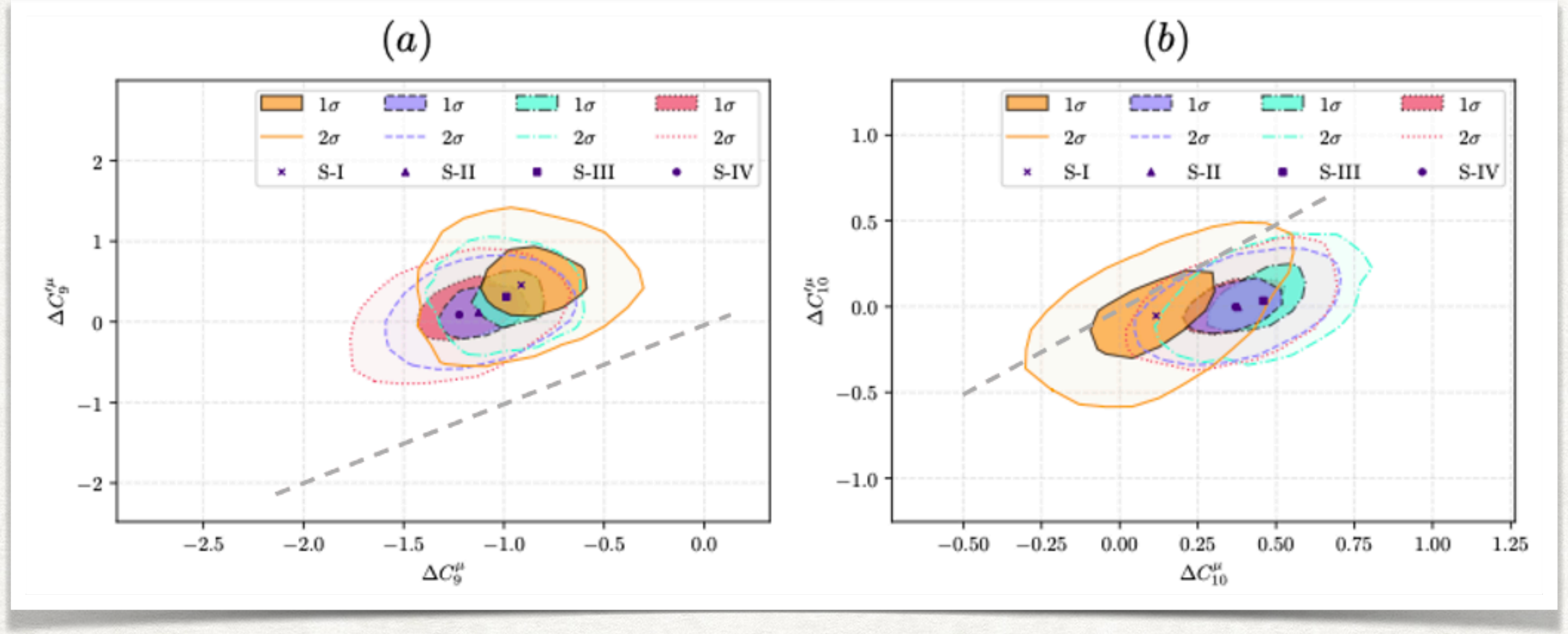
# OUR RESULTS (II): FLAVOR CORRELATION

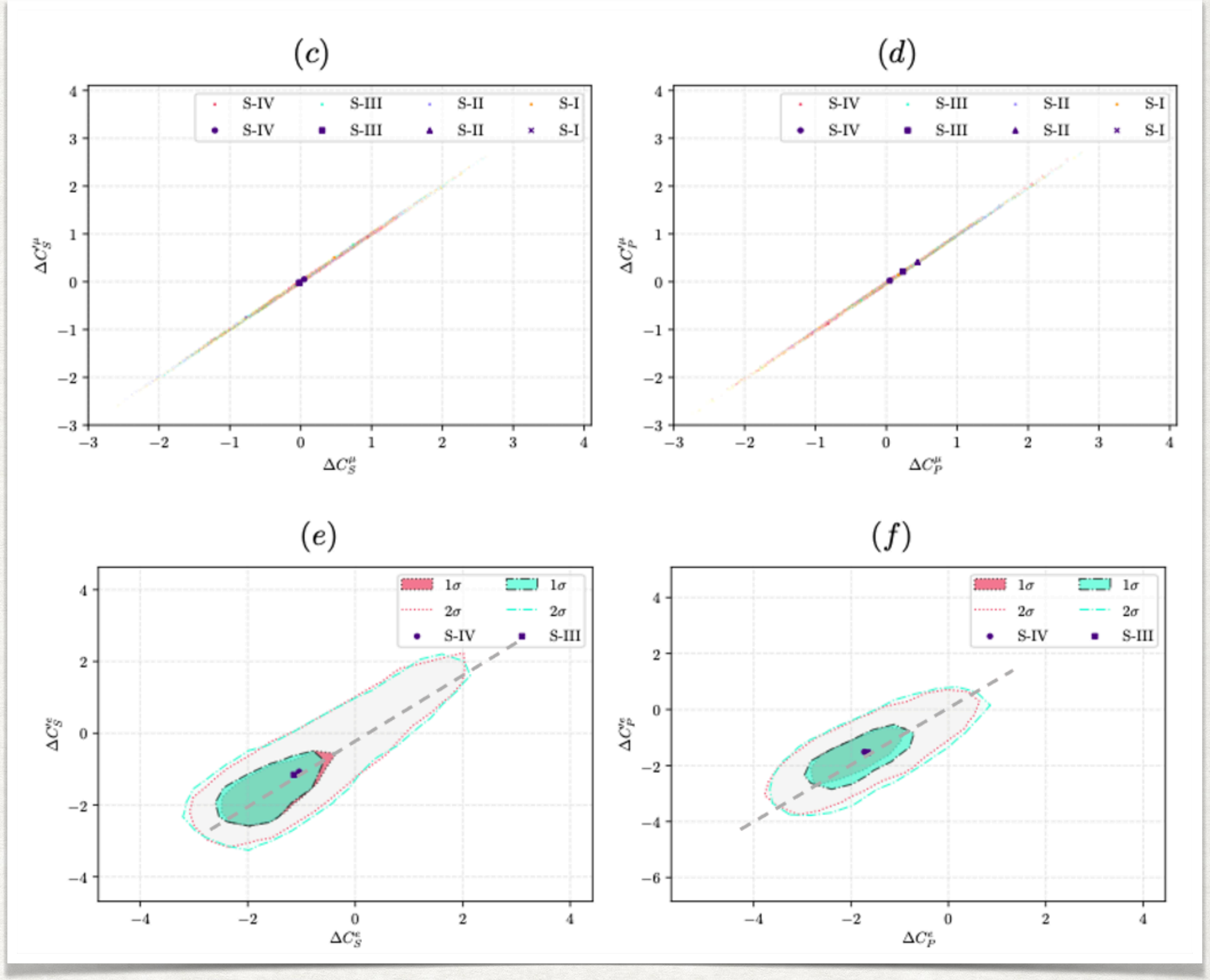



## Muon-type operator as an example

- The lepton flavor for $\Delta C_9^\mu$ is indistinguishable at $1\sigma$ level.
- All WCs are flavor identical at $2\sigma$ level

# OUR RESULTS (III): CHIRAL CORRELATION



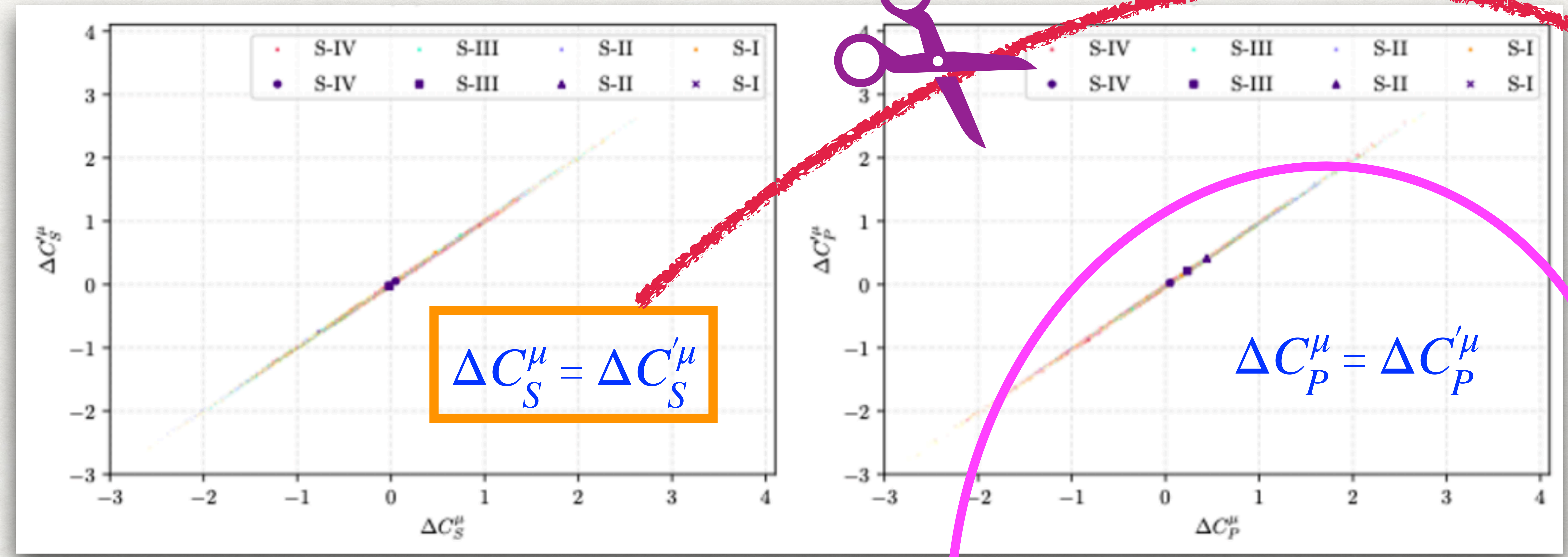




- $\Delta C_9^{\mu}$ deviates from its chiral dual one more than $2\sigma$ level, while $\Delta C_{10}^{\mu}$ is within $1\sigma$ region which is scenario dependent.
- scalar WCs have better chiral identity, and muon type is strictly respected.

# IMPLICATIONS

Two options:

- Non-SMEFT NP
- SMEFT: vanishing scalar operator




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

- SMEFT (Jenkins, Manohar and Stoffer, 1709.04486)

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

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

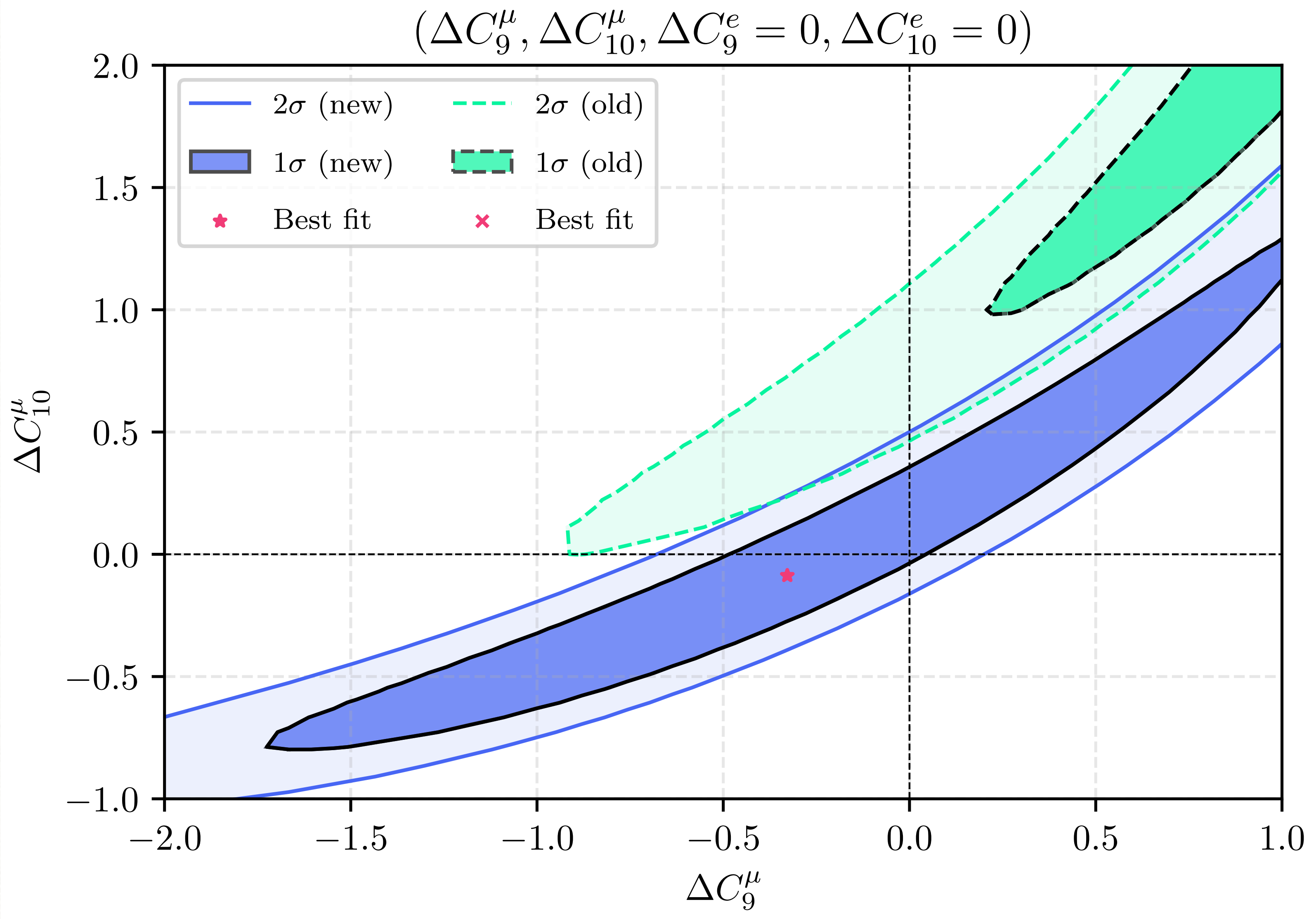
# SUMMARY

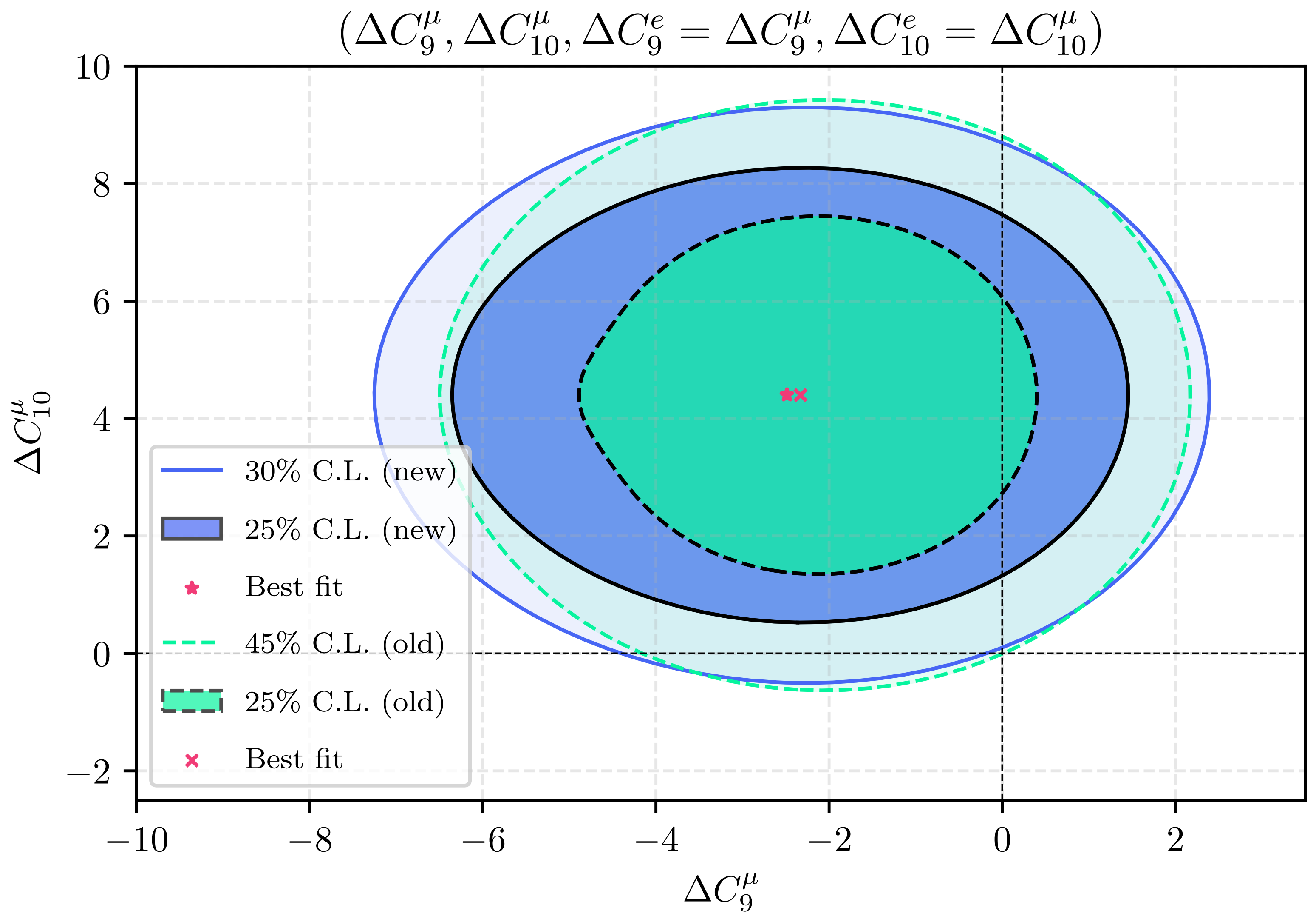
- Based on 2 datasets, global fits have been carried out in four different operator basis/scenarios, including the 20-D fit with specific lepton flavors.
- NP possibility in $b \to s$ window still exists. It turns up most likely in terms of $\Delta C_9^\mu$ , but $\Delta C_{10}^\mu$ and $\Delta C_9^e$ are also possible.
- Experimentally, CEPC may provide complementary view via $e^+e^- \to bs$ process.
- Theoretically, the obtained linear relation between scalar operator provides useful information to NP exploration: non-SMEFT or certain vanishing SMEFT operators.
- More serious studies on bottomed baryon decays are expected!

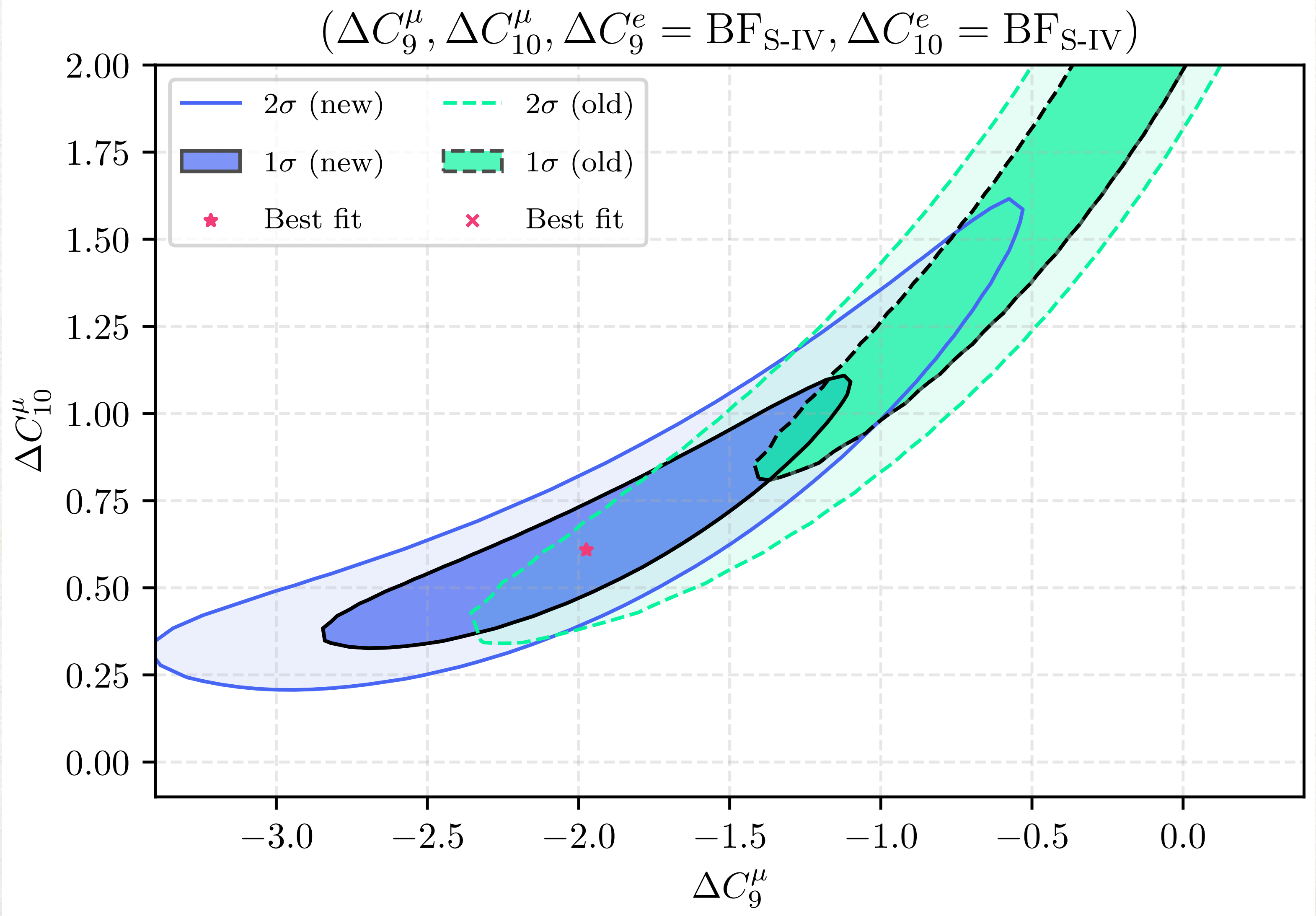
*Thank you for your attention!*

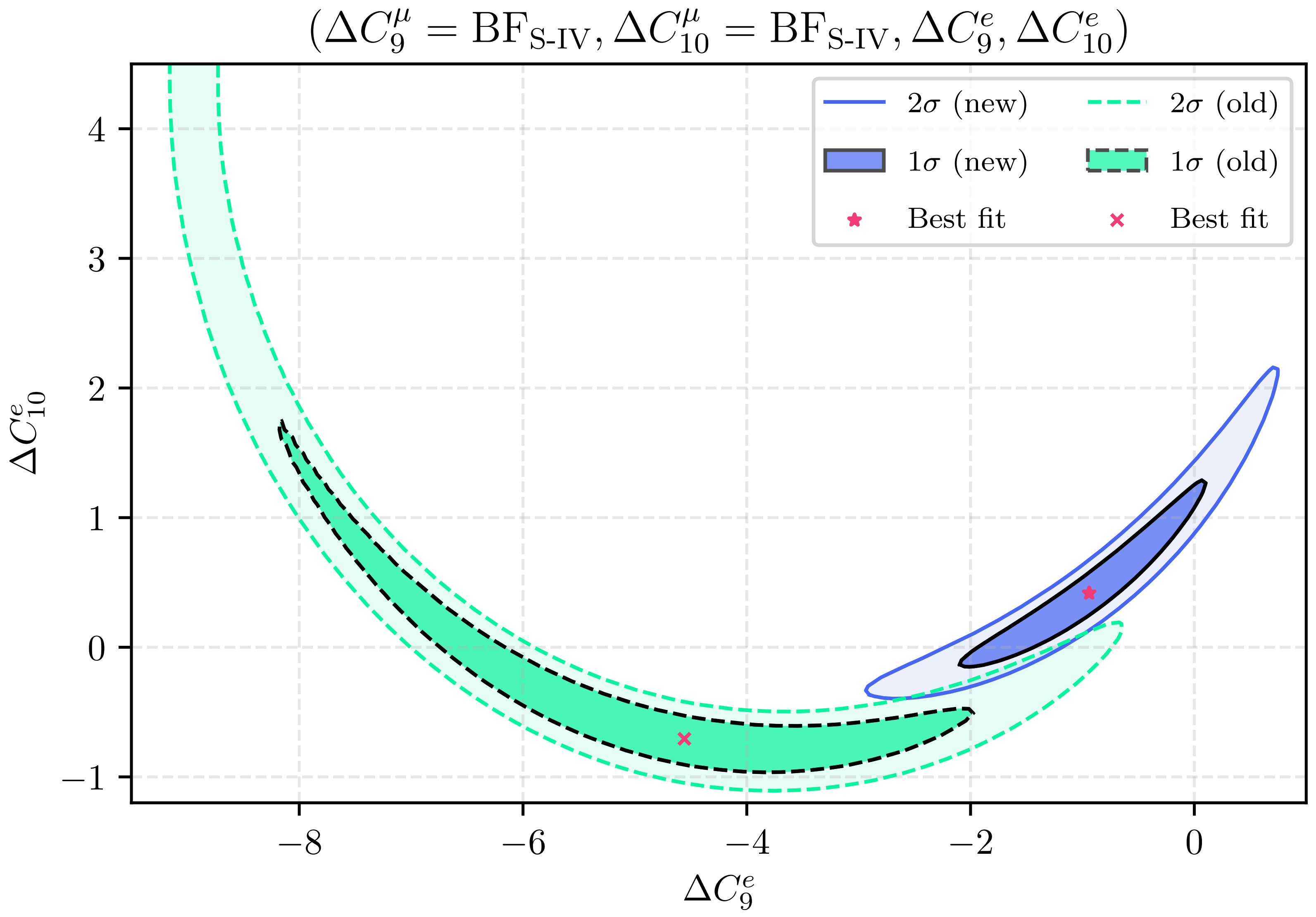
# BACKUP SLIDES

# LEPTON FLAVOR DEPENDENCE



# THE LATEST $(\Delta C_9, \Delta C_{10})$ RANGE