Explaining the $b \to s\ell^+\ell^-$ anomalies in Z' scenarios with top-FC/FCNC couplings and its implications for the W-boson mass shift

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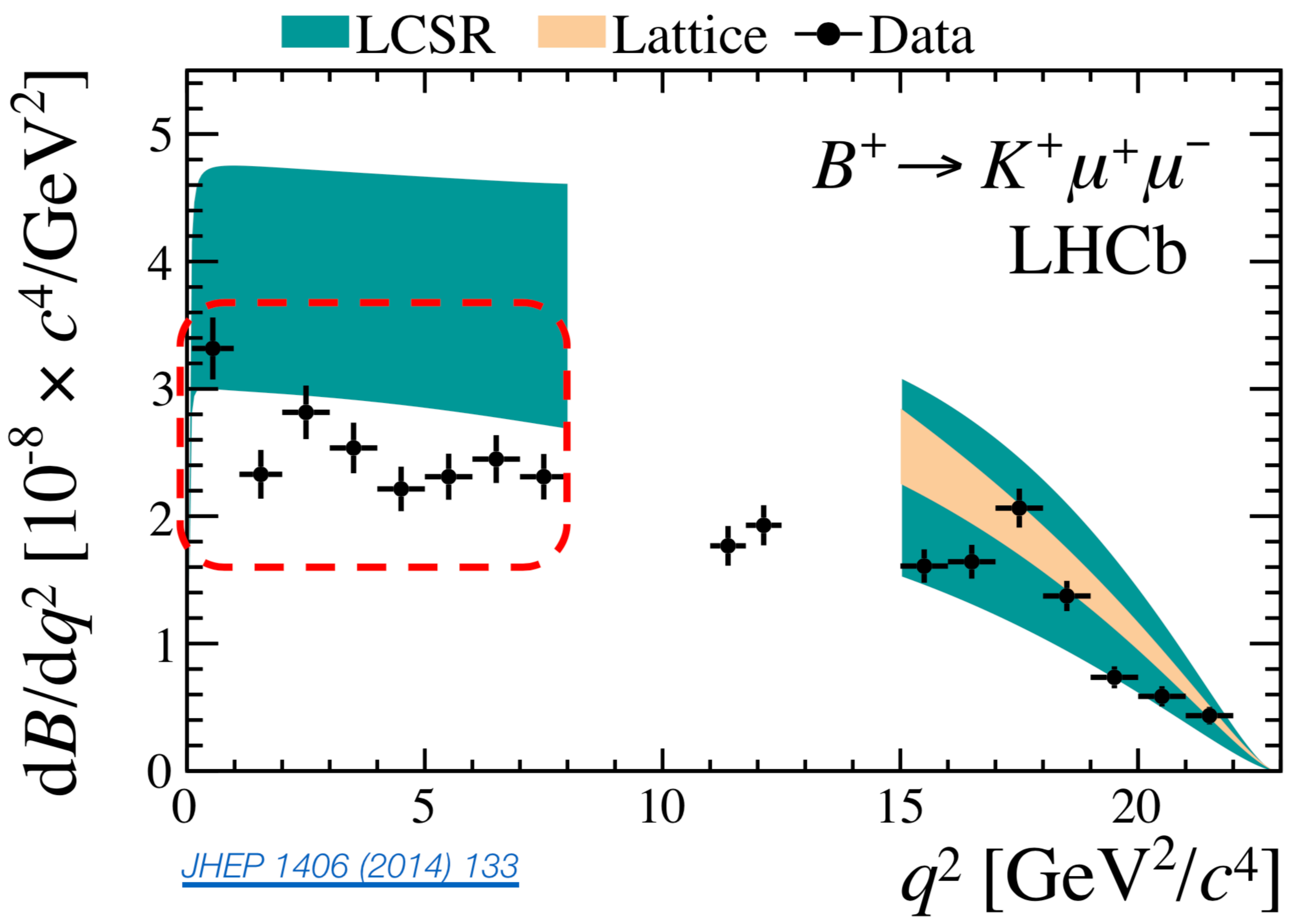
arXiv: 2112.14215，李新强，沈　萌，王东洋，杨亚东，袁兴博

arXiv: 2205.02205，李新强，谢泽俊，杨亚东，袁兴博

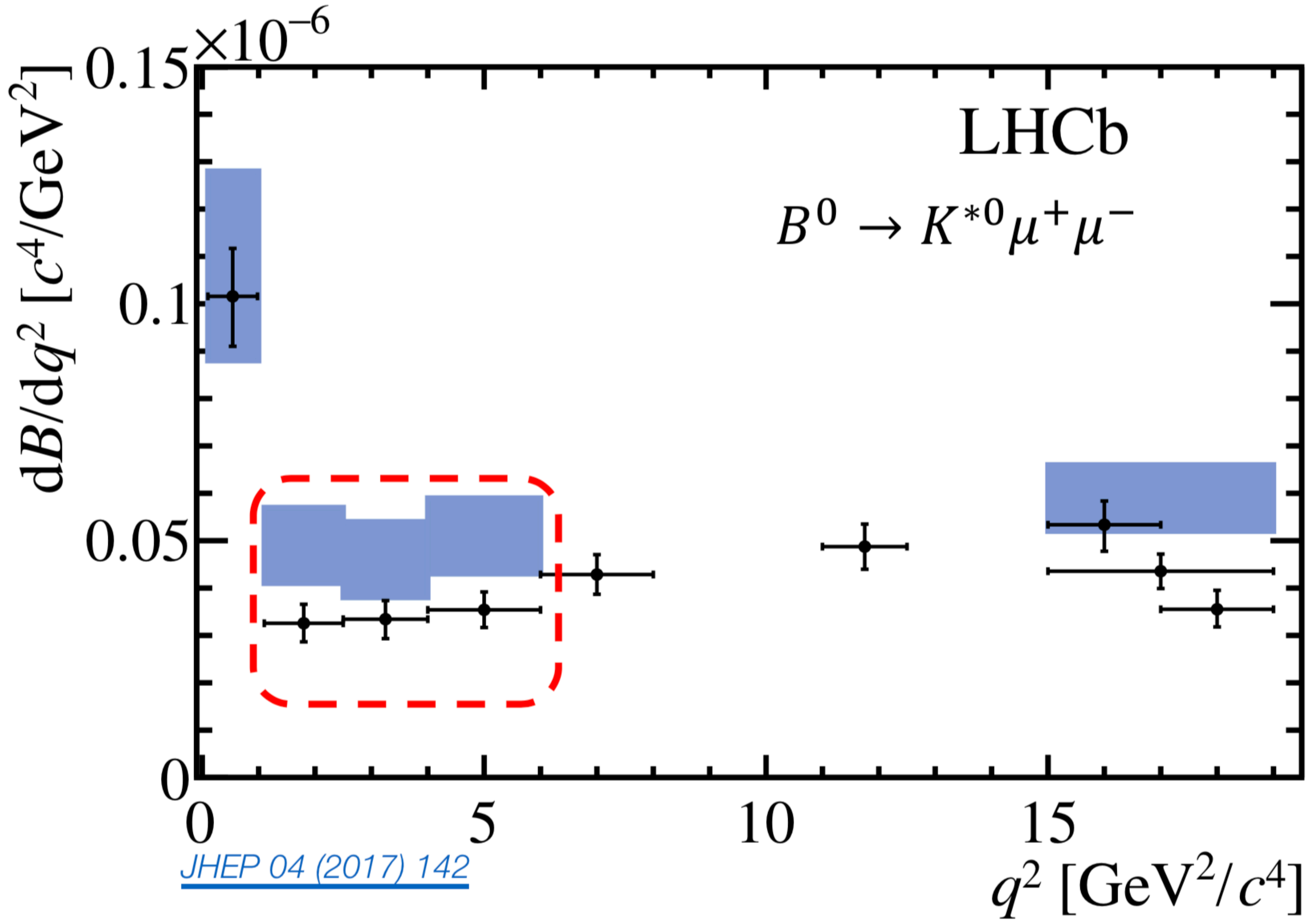
中国物理学会高能物理分会第十一届全国会员代表大会暨学术年会

辽宁师范大学，大连，2022年8月10日

$b \to s\ell\ell$ anomalies: branching ratio

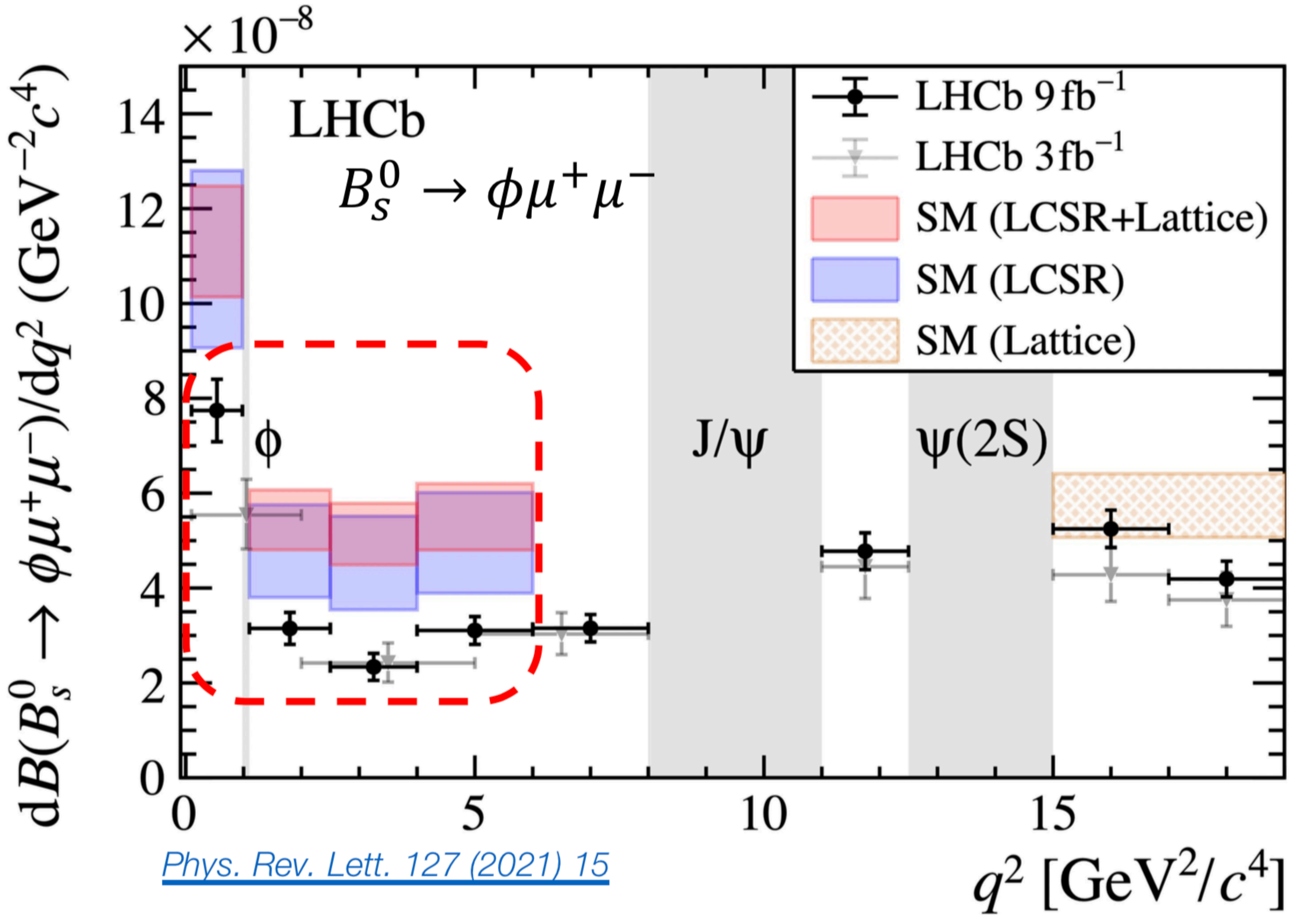


JHEP 1406 (2014) 133

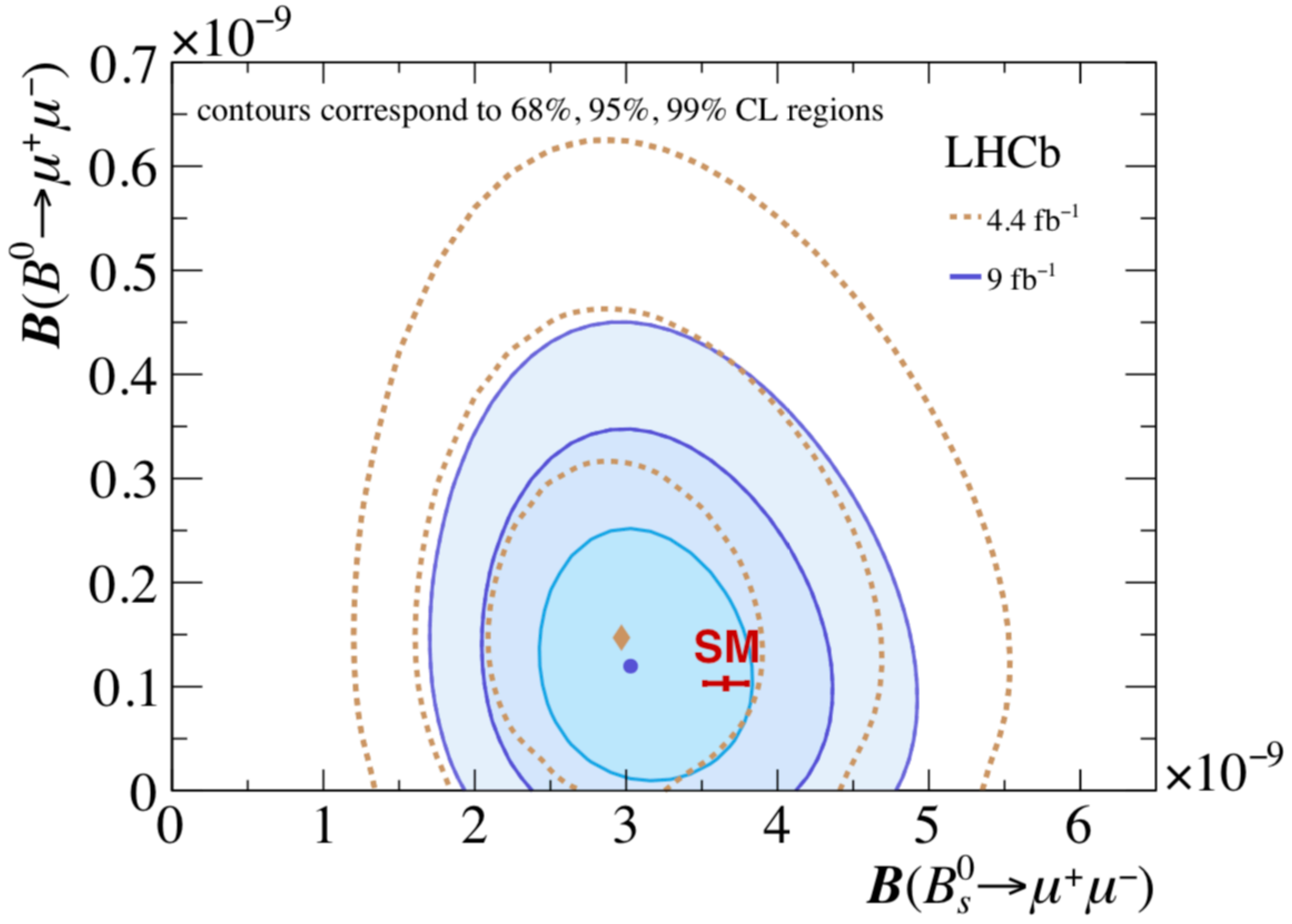


JHEP 04 (2017) 142

- **EXP below SM**
- **Low q^2**
- **Theoretical Uncertainties: 😭**

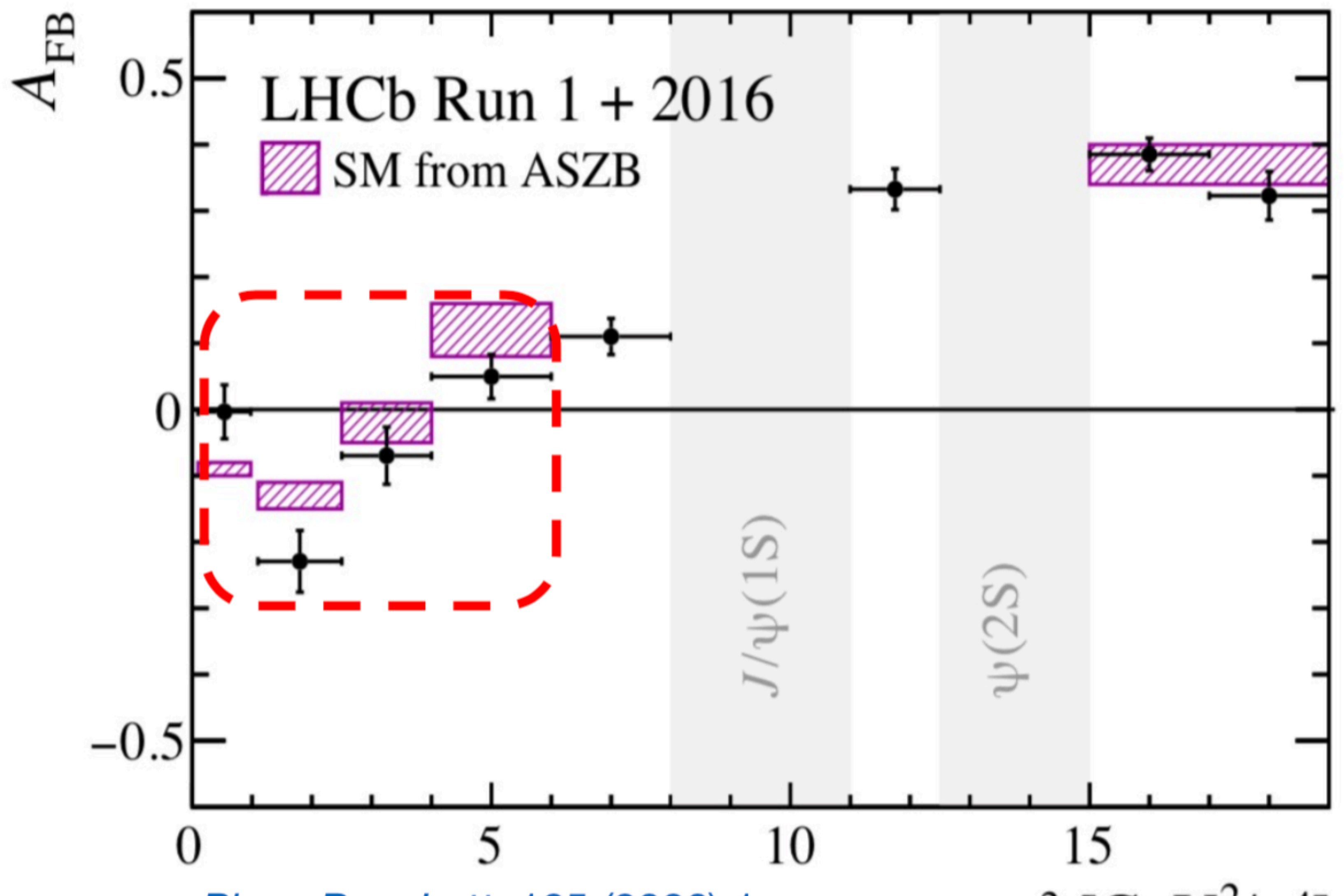


Phys. Rev. Lett. 127 (2021) 15

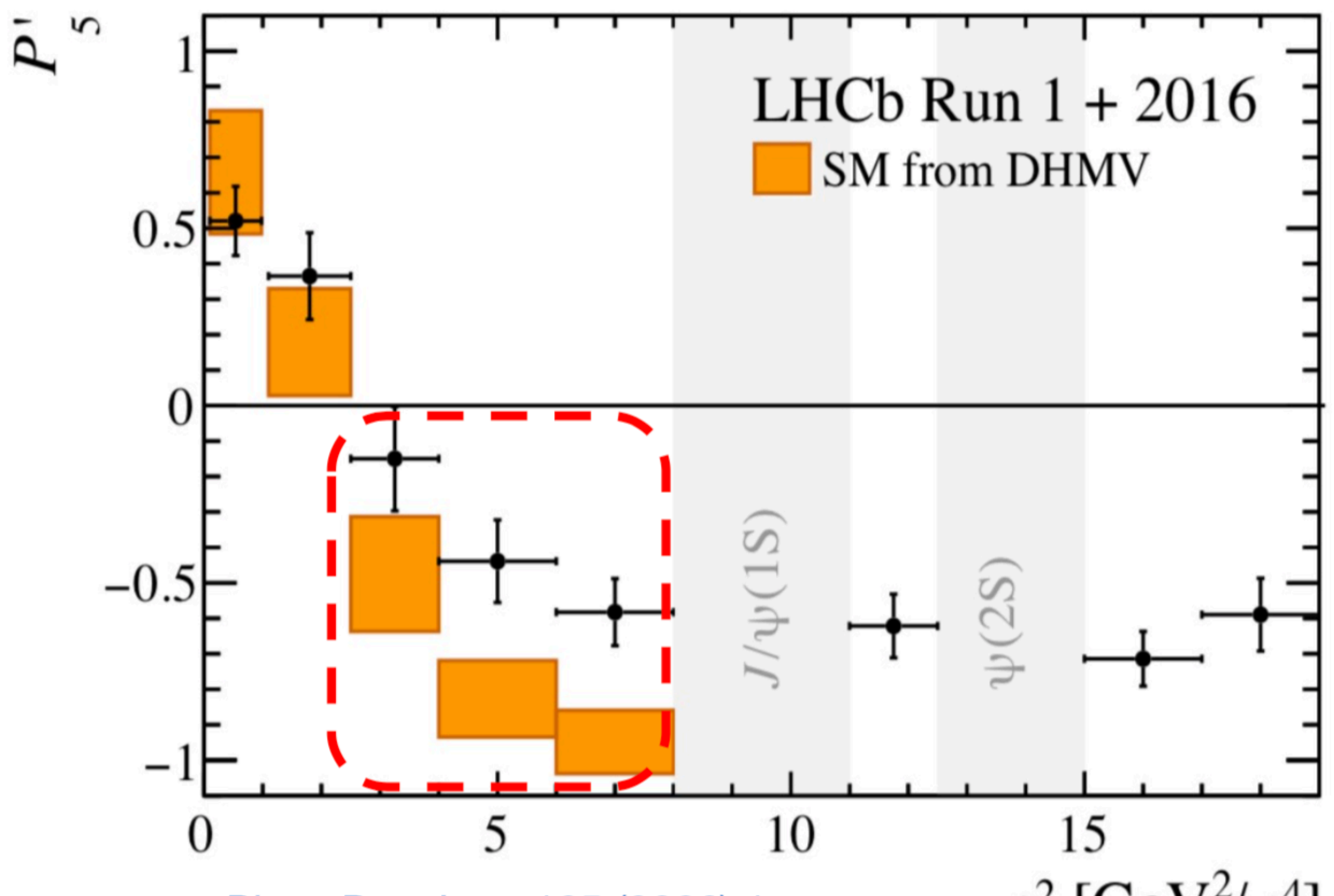


$b \to s\ell\ell$ anomalies: angular distribution

$B^0 \to K^{*0}\mu^+\mu^-$

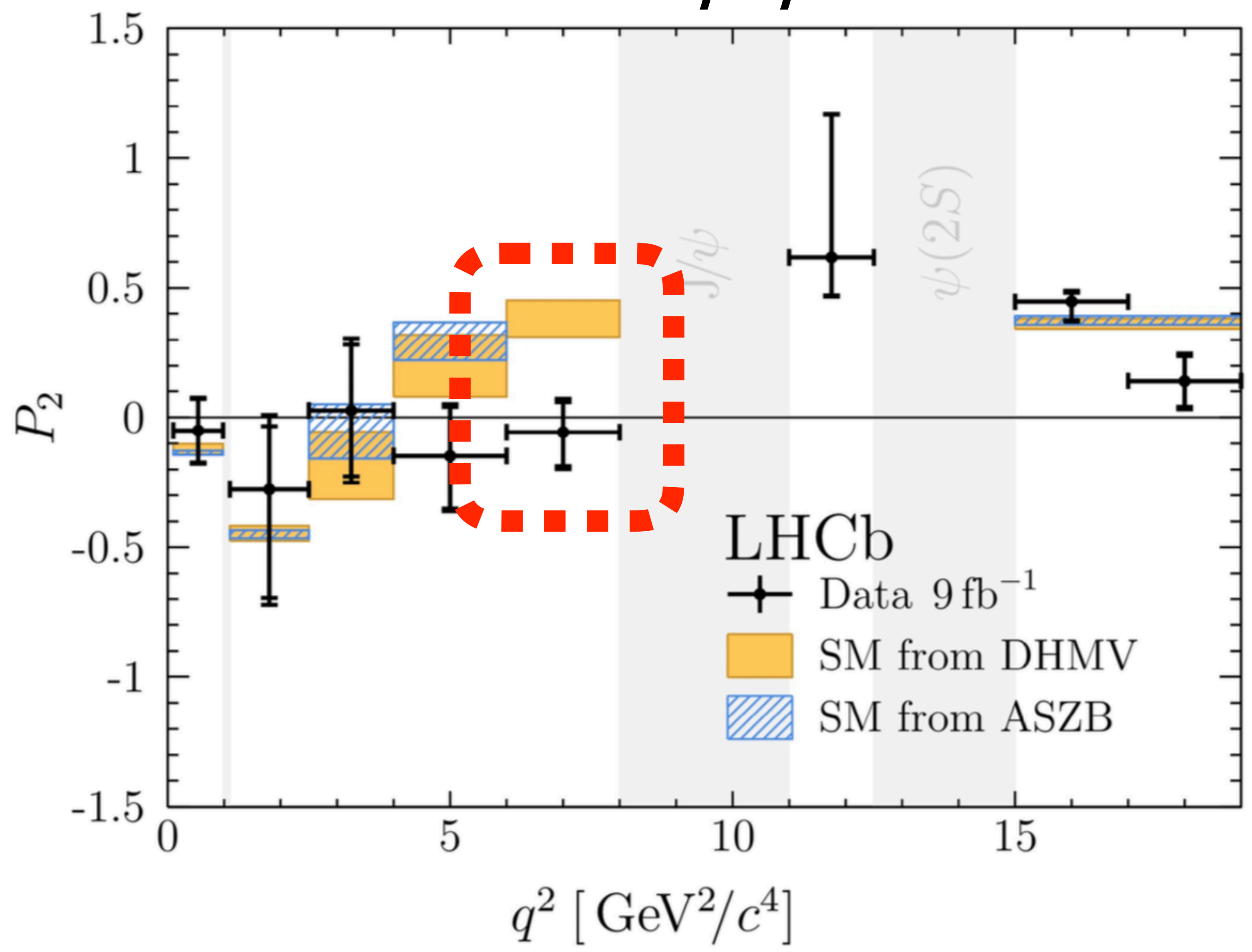


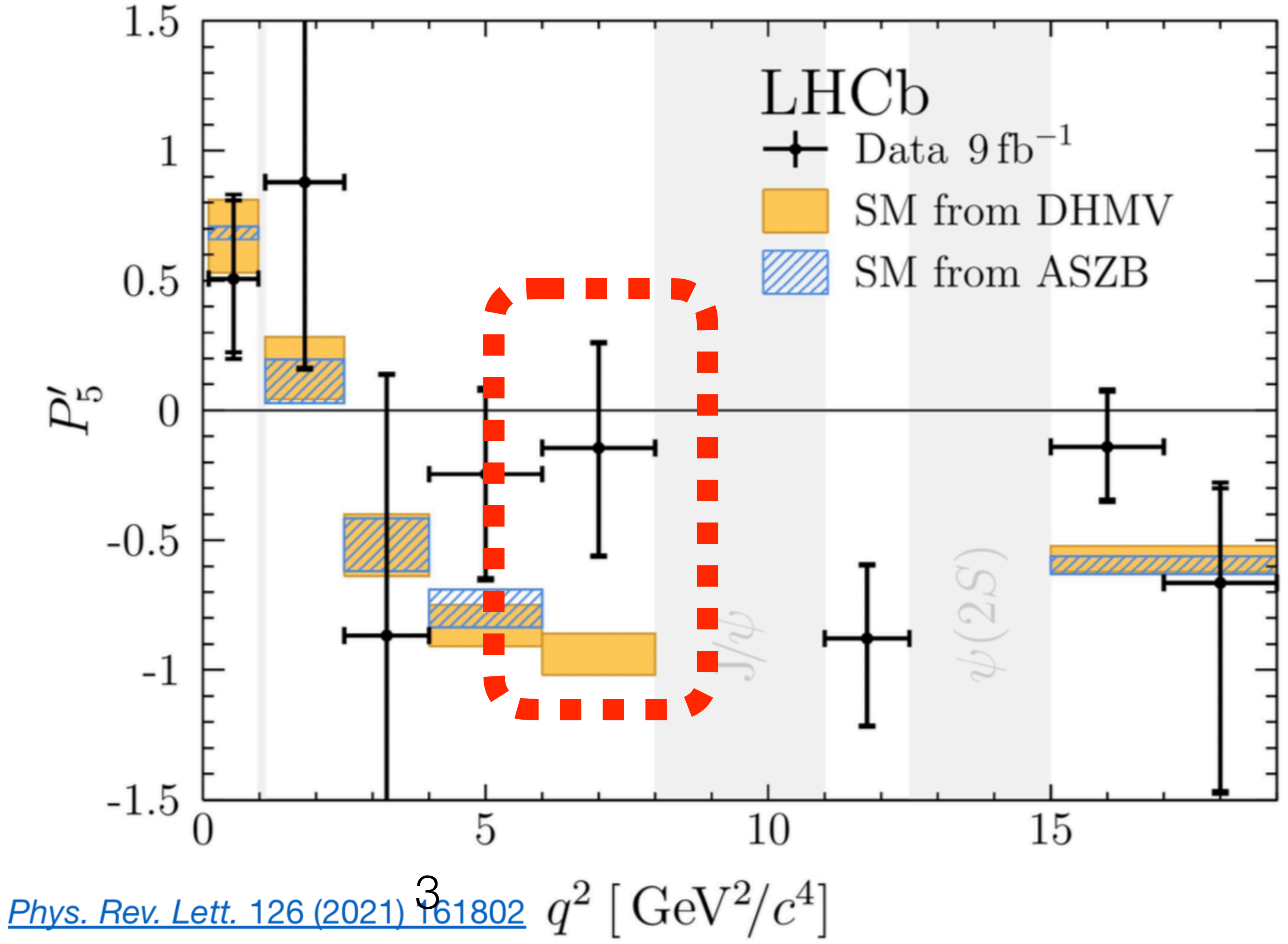
Phys. Rev. Lett. 125 (2020) 1



Phys. Rev. Lett. 125 (2020) 1

$B^+ \to K^{*+}\mu^+\mu^-$

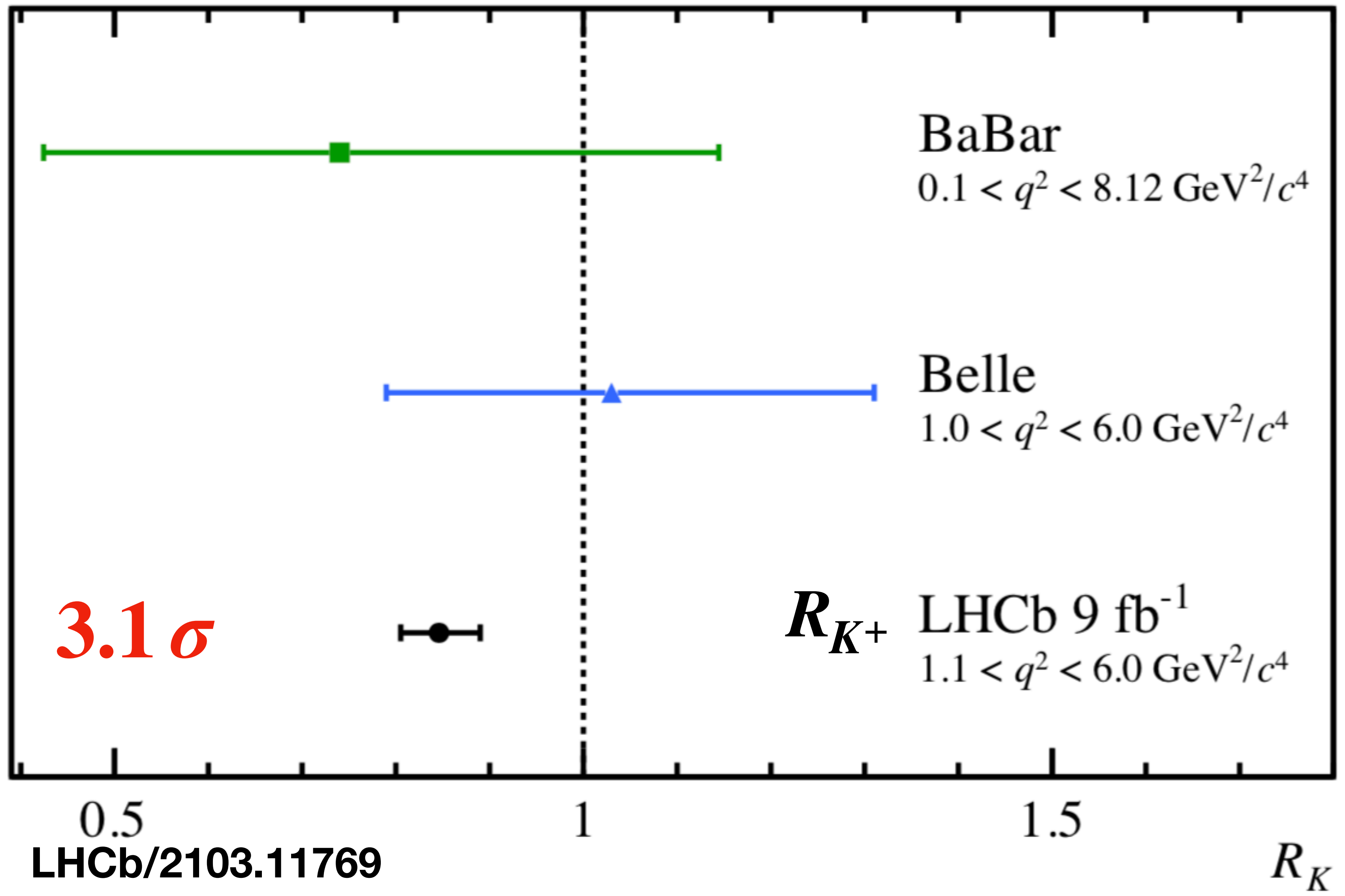




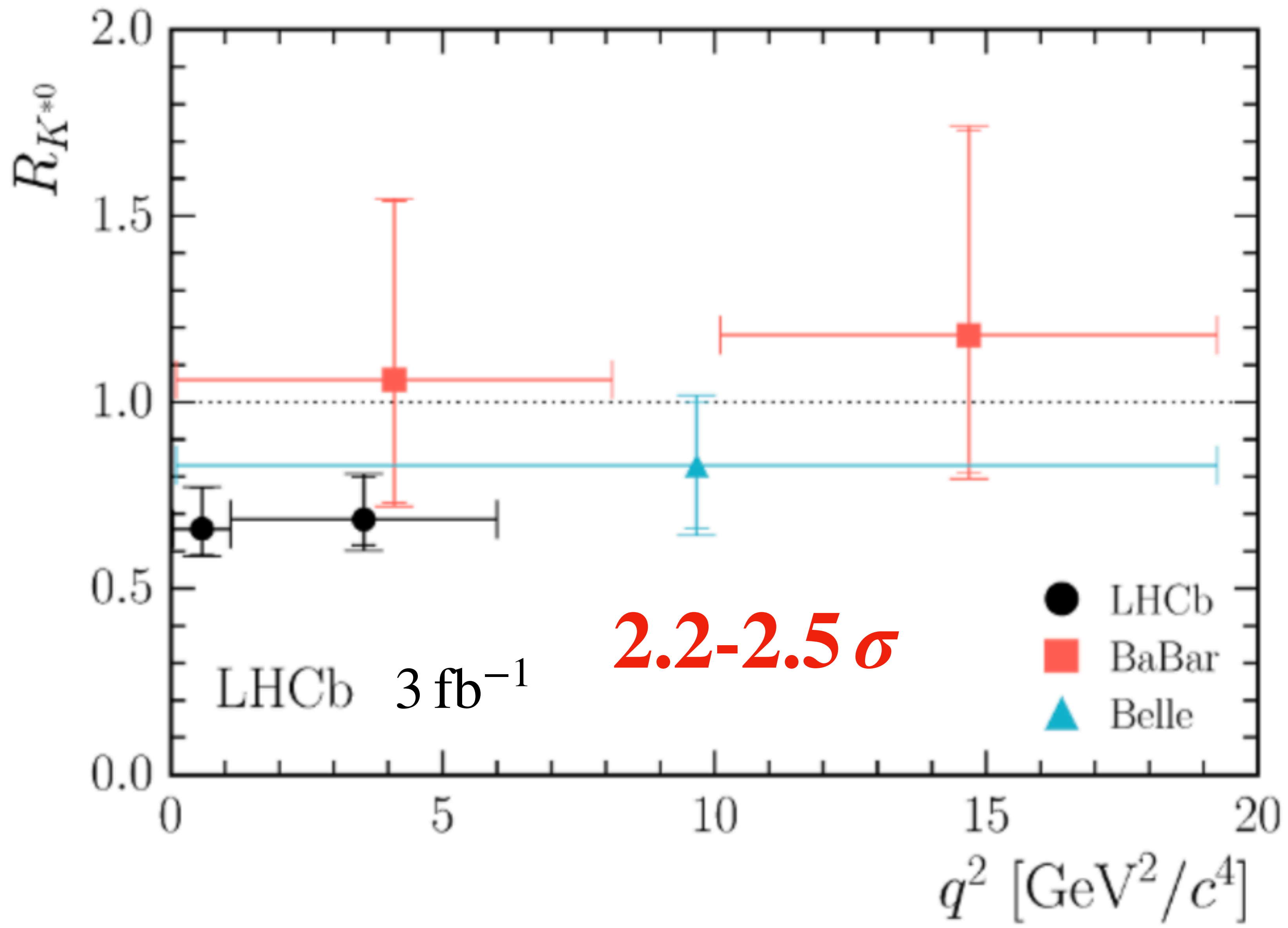
Phys. Rev. Lett. 126 (2021) 161802

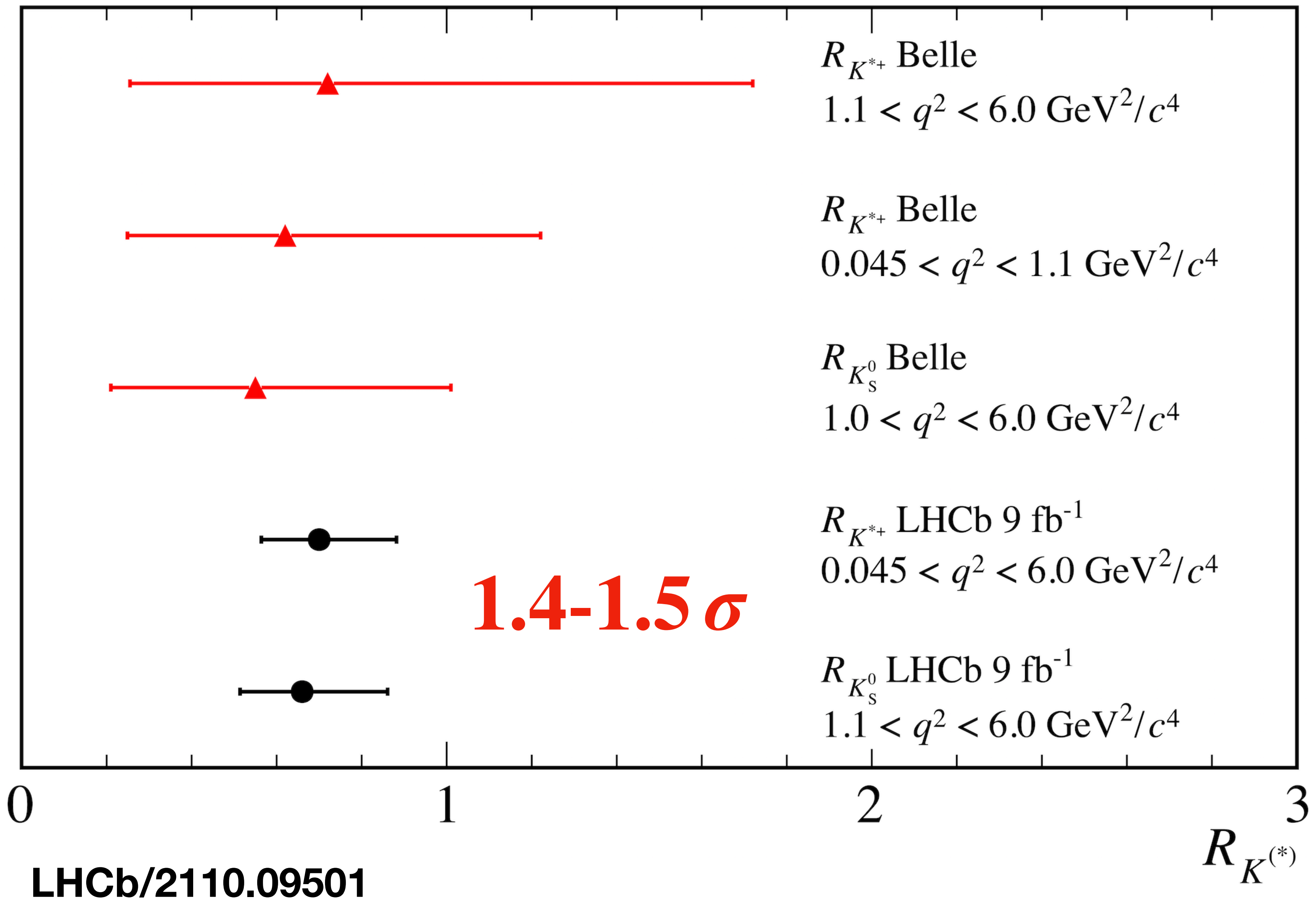
- **Similar deviations in the 2 modes**
- **Theoretical Uncertainties:**
  - **branching ratio:** 😭
  - **angular distribution:** 😢

$b \to s\ell\ell$ anomalies: lepton flavour violation ratio

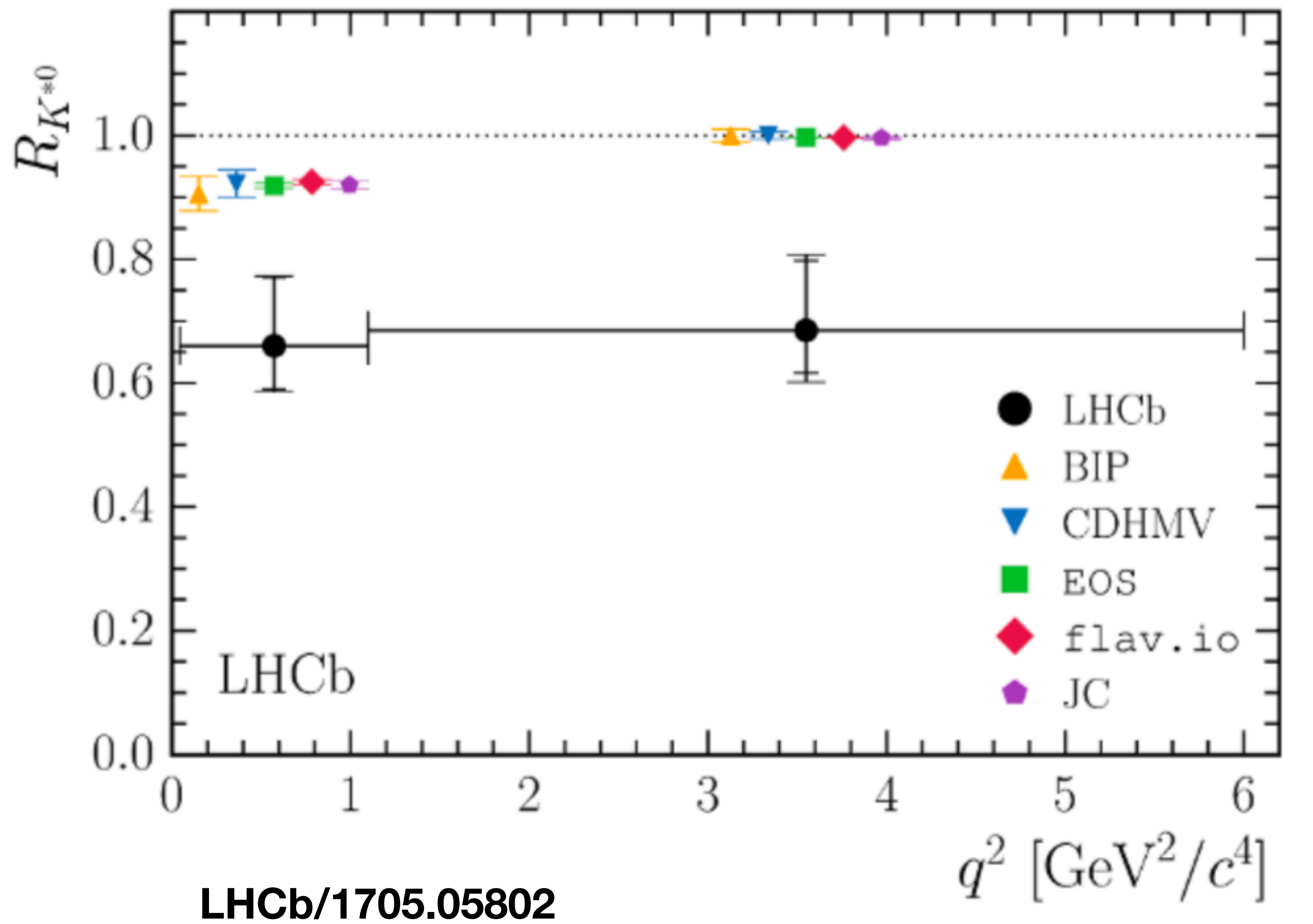


LHCb/2103.11769





LHCb/2110.09501



LHCb/1705.05802

$$R_{K^+} = \frac{\mathfrak{B}(B^+ \to K^+\mu^+\mu^-)}{\mathfrak{B}(B^+ \to K^+e^+e^-)}$$

- $R_H^{SM} \approx 1$
- **Hadronic uncertainties cancel**
- $\mathcal{O}(10^{-2})$ **QED correction**

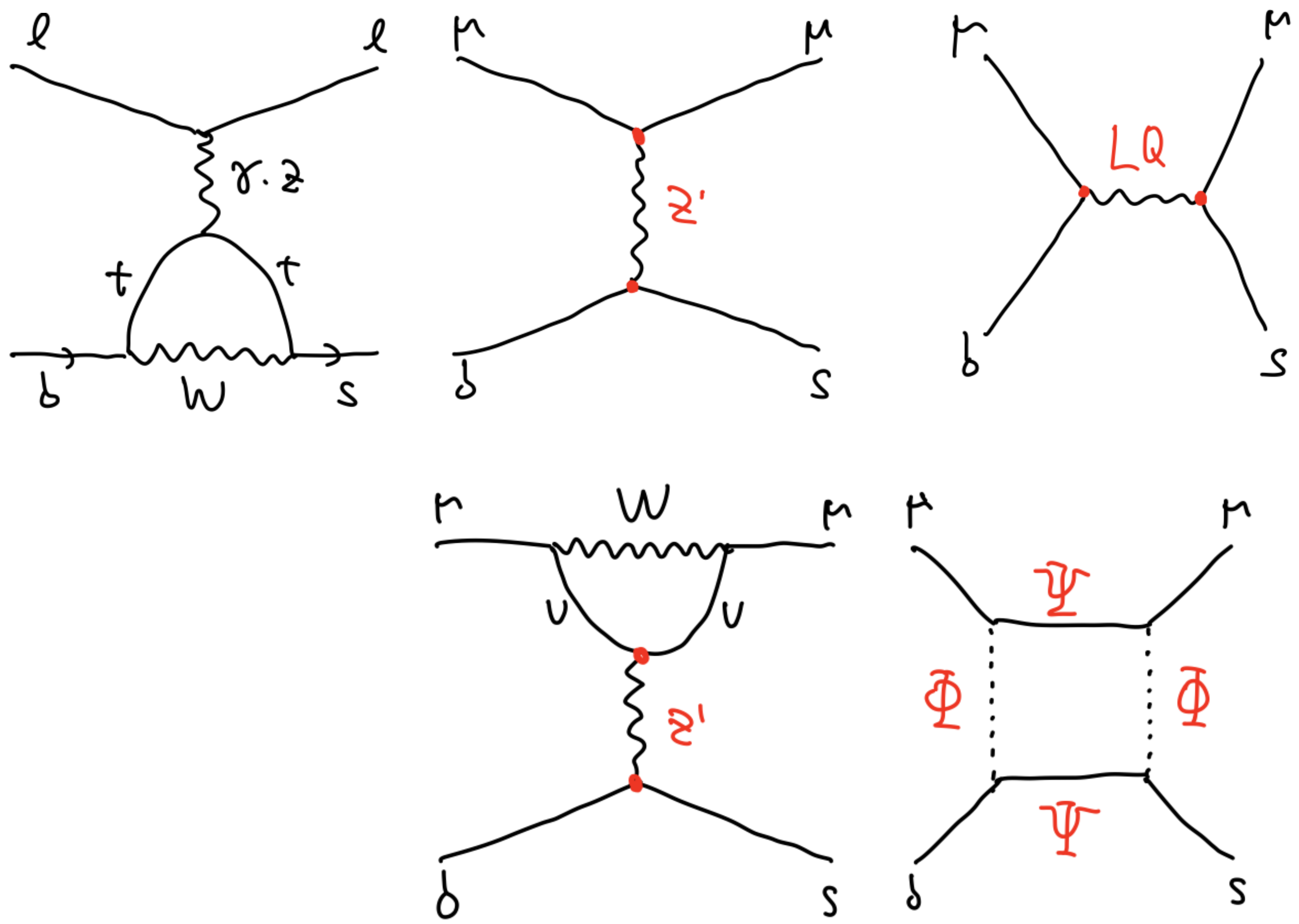
- **Theoretical Uncertainties:**
  - **branching ratio:** 😭
  - **angular distribution:** 😢
  - **LFV ratio:** 😀

deviation from unity

Physics beyond the SM

Flavour anomalies: theoretical interpretation

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



Altmannshofer, Gori, Pospelov, Yavin; 1403.1269,
Crivellin, D'Ambrosio, Heeck; 1501.00993,
Celis, Fuentes-Martin, Jung, Serodio; 1505.03079,
Crivellin, Fuentes-Martin, AG, Isidori; 1611.02703,
Alonso, Cox, Han, Yanagida; 1705.03858,
Bonilla, Modak, Srivastava, Valle; 1705.00915,
Ellis, Fairbairn, Tunney; 1705.03447;
Allanach, Davighi; 1809.01158,
Altmannshofer, Davighi, Nardecchia; 1909.02021,
Allanach; 2009.02197,
+ many more …

$\mu_{\rm NP}$

UV models

SMEFT: SM Effective Field Theory

$$\mathscr{L}_{\rm SMEFT} = \mathscr{L}_{\rm SM} + C_i^{\rm NP} O_i^{\rm NP}$$

$$SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$$

$$O_{\ell q}^{(1)} = (\bar{L}_p \gamma_\mu L_r)(\bar{Q}_s \gamma^\mu Q_t)$$

$\mu_{\rm EW}$

$$O_{ed}^{(1)} = (\bar{e}_p \gamma_\mu e_r)(\bar{d}_s \gamma^\mu d_t)$$

… …

LEFT: Low Energy Effective Field Theory

$$\mathscr{H}_{\rm eff} = (C_i^{\rm SM} + C_i^{\rm NP}) O_i^{\rm SM} + C_j^{\rm NP} O_j^{\rm NP} \qquad SU(3)_C \otimes U(1)_{\rm em}$$

$$O_9 = (\bar{b}\gamma^\mu P_L s)(\bar{\ell}\gamma_\mu \ell) \qquad O_{10} = (\bar{b}\gamma^\mu P_L s)(\bar{\ell}\gamma_\mu \gamma_5 \ell)$$

μ_b

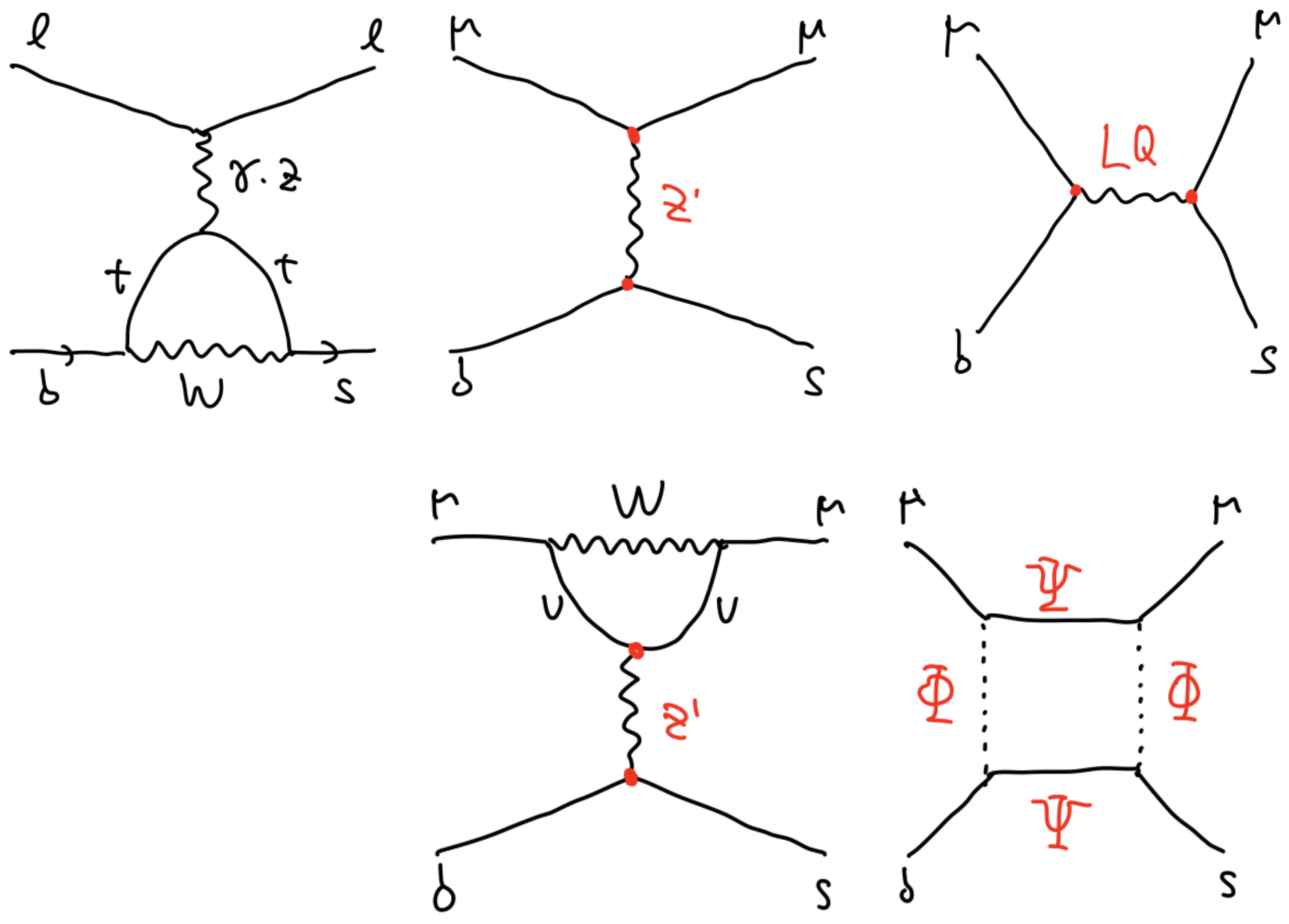
$$O_{\rm VLL} = (\bar{c}\gamma^\mu P_L b)(\bar{\tau}\gamma^\mu P_L \nu) \qquad O_{S_R} = (\bar{c}_L b_R)(\bar{\ell}_R \nu_{\tau L})$$

$$O_{\rm VRL} = (\bar{c}\gamma^\mu P_R b)(\bar{\tau}\gamma^\mu P_L \nu) \qquad O_{S_L} = (\bar{c}_R b_L)(\bar{\ell}_R \nu_{\tau L})$$

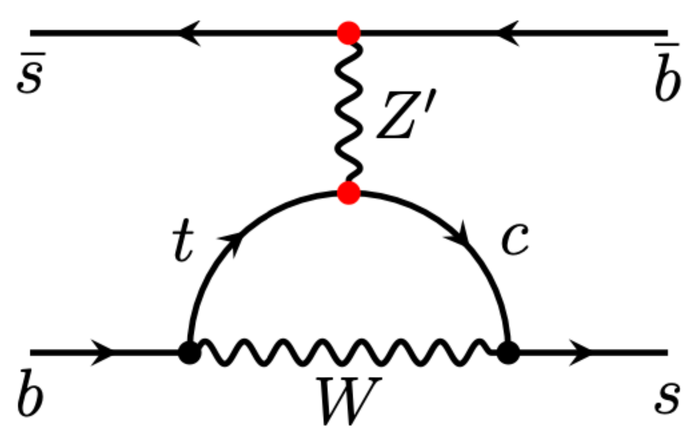
$$O_T = (\bar{c}_R \sigma^{\mu\nu} b_L)(\bar{\ell}_R \sigma_{\mu\nu} \nu_{\tau L})$$

Flavour anomalies: theoretical interpretation

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



- New possibility ?



Explain $b \to s\ell^+\ell^-$ by the NP with $t \to c$ transition ?

$\mu_{\rm NP}$

UV models

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$\mu_{\rm EW}$

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… …

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μ_b

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$$O_{\rm VRL} = (\bar{c}\gamma^\mu P_R b)(\bar{\tau}\gamma^\mu P_L \nu) \qquad O_{S_L} = (\bar{c}_R b_L)(\bar{\ell}_R \nu_{\tau L})$$

$$O_T = (\bar{c}_R \sigma^{\mu\nu} b_L)(\bar{\ell}_R \sigma_{\mu\nu} \nu_{\tau L})$$

Z' scenarios with top-FCNC couplings

Lagrangian (mass eigenstates)

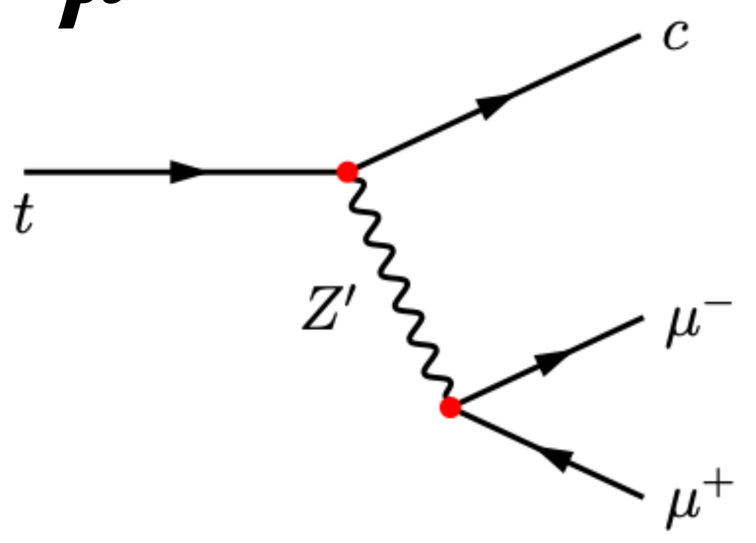
$$\mathcal{L}^{\rm I}_{Z'} = \left(X^L_{ct}\,\bar{c}\gamma^\mu P_L t\, Z'_\mu + \text{h.c.}\right) + \lambda^L_{\mu\mu}\,\bar{\mu}\gamma^\mu P_L \mu\, Z'_\mu$$

Comments

- Phenomenological scenarios (simple, but not UV complete)
- 2 parameters X^L_{ct} (complex) and $\lambda^L_{\mu\mu}$ (real)
- Right-handed $\mu^+\mu^- Z'$ interaction can be added $\Longrightarrow (g-2)_\mu$
- e^+e^-Z' instead of $\mu^+\mu^-Z'$ is also possible $\Longrightarrow$ pheno@e^+e^- collider
- $\bar{t}uZ'$ instead of $\bar{t}cZ'$ is also possible
- Models with right-handed $\bar{t}cZ'$ couplings

R. Coy, M. Frigerio, F. Mescia, O. Sumensari, EPJC 2020.
H.J. He, T.M.P. Tait, C.P. Yuan, PRD 2000
X.F. Wang, C. Du, H.J. He, PLB 2013

$t \to c\mu^+\mu^-$



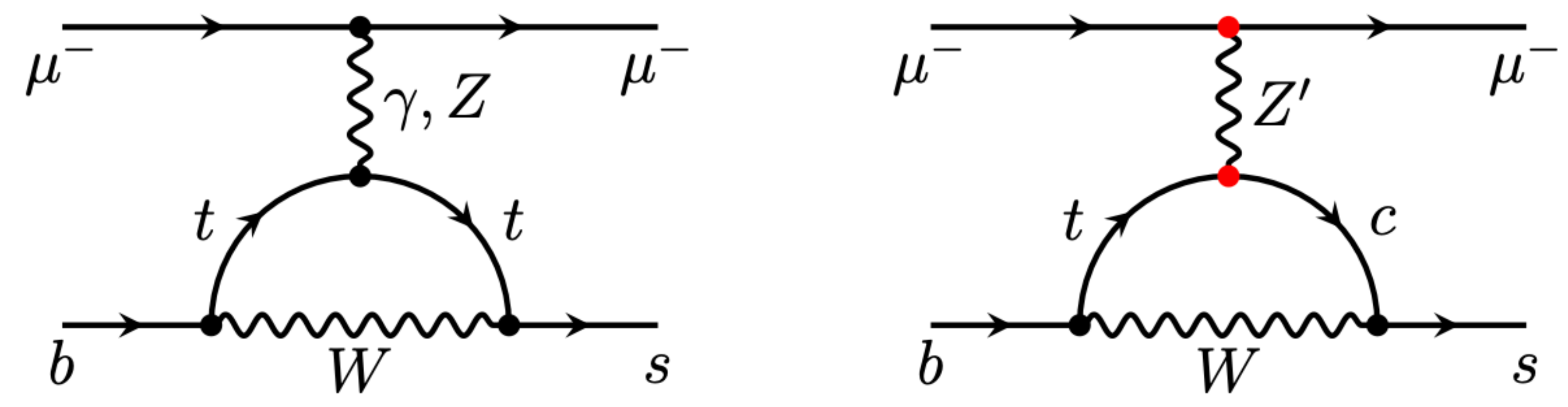
SM branching ratio ~ $\mathcal{O}(10^{-10})$

↓

clean NP signal

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

- Feynman diagram



- Effective Hamiltonian

$$\mathcal{H}_{\rm eff}^{b\to s\mu^+\mu^-} = -\frac{4G_F}{\sqrt{2}} V_{tb}V^*_{ts} \sum_{i=1}^{10} \mathcal{C}_i \mathcal{O}_i$$

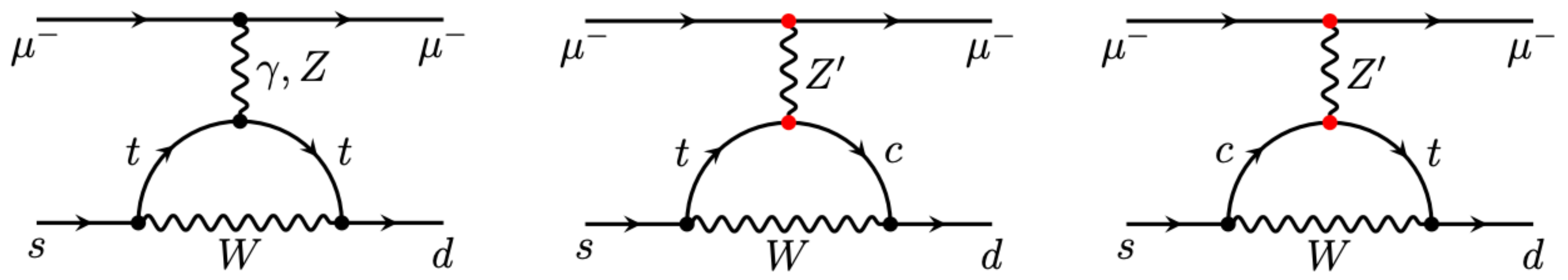
$$\mathcal{O}_{9\ell} = \frac{e^2}{16\pi^2}(\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell) \quad \mathcal{O}_{10\ell} = \frac{e^2}{16\pi^2}(\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu\gamma_5 \ell)$$

- Wilson coefficient: NP effect

$$\mathcal{C}^{\rm NP,\,I}_{9\mu} = -\mathcal{C}^{\rm NP,\,I}_{10\mu} = \frac{1}{8\sqrt{2}G_F s_W^2}\frac{V^*_{cs}}{V^*_{ts}}\frac{X^L_{ct}\lambda^L_{\mu\mu}}{m^2_{Z'}} f(x_t)$$

- enhanced by V_{cs}/V_{ts}
- favored by $b \to s\ell^+\ell^-$ global fits

$s \to d\mu^+\mu^-$



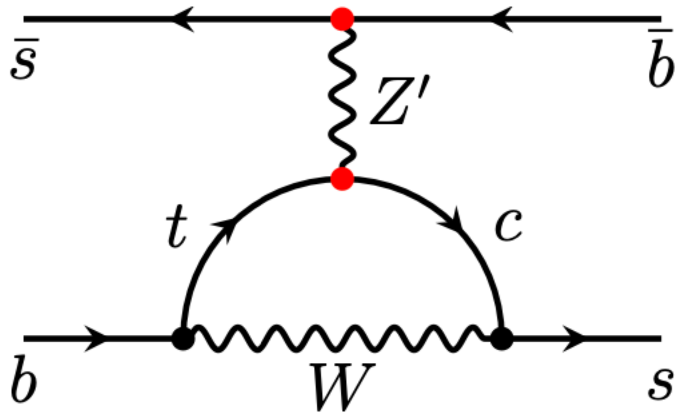
Numerical analysis: $b \to s\ell^+\ell^-$

Global fit

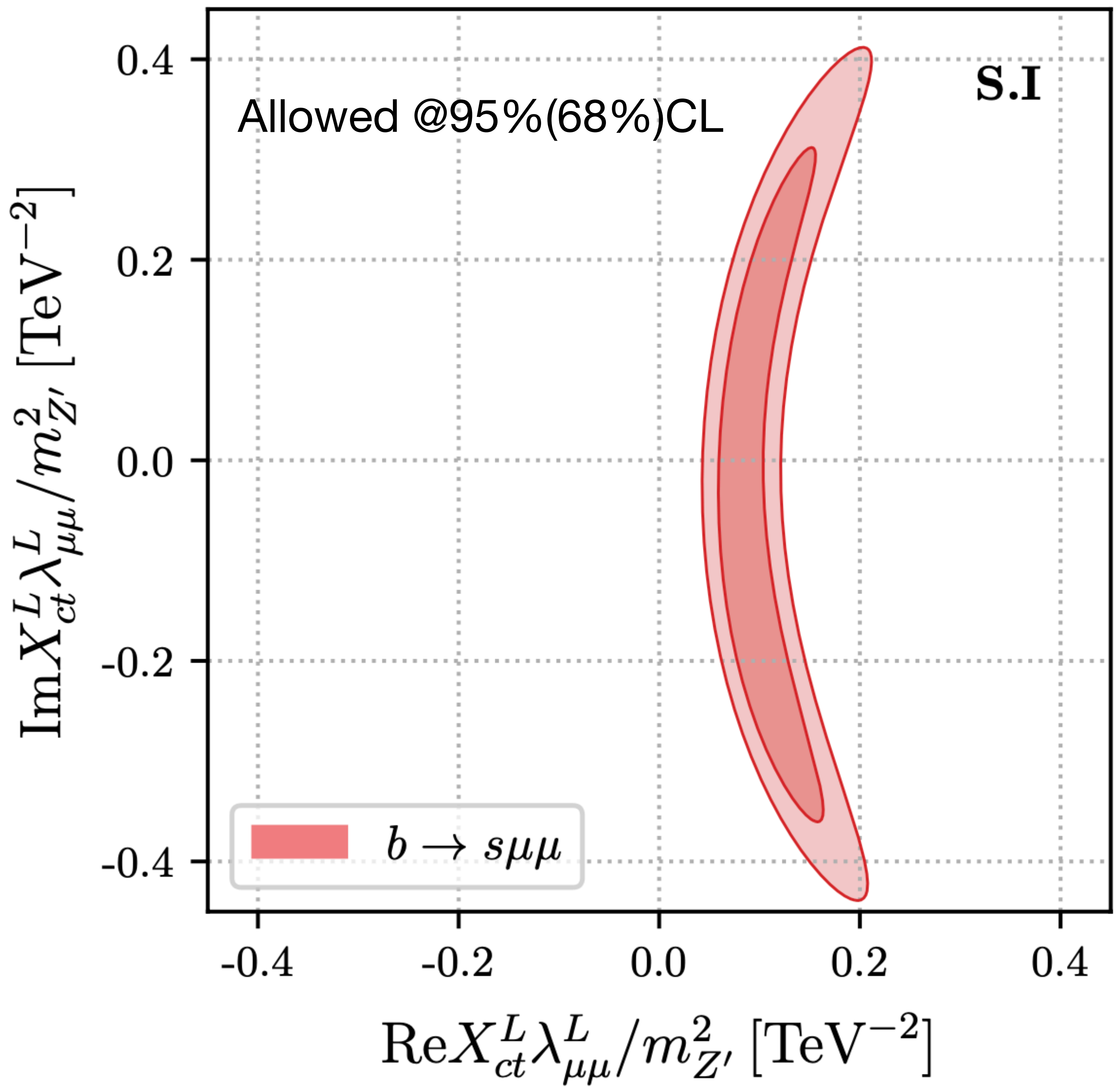
- Inclusive decays
  - $B \to X_s\gamma$
  - $B \to X_s\ell^+\ell^-$
- Exclusive leptonic decays
  - $B_{s,d} \to \ell^+\ell^-$ e.g., LHCb, PRL128 (2022)4, 041801
- Exclusive radiative/semileptonic decays
  - $B \to K^*\gamma$
  - $B^{(0,+} \to K^{(0,+)}\ell^+\ell^-$ e.g., LHCb, Nature Phys. 18 (2022) 3, 277 | PRL128(2022)19, 191802
  - $B^{(0,+} \to K^{*(0,+)}\ell^+\ell^-$ e.g., LHCb PRL126(2021), 16161802
  - $B_s \to \phi\mu^+\mu^-$ e.g., LHCb, PRL127(2021)15, 151801, JHEP11(2021)043
  - $\Lambda_b \to \Lambda\mu^+\mu^-$ e.g., LHCb JHEP 09 (2018) 146
- Including about 200 observables (almost all available measurements from BaBar, Belle, CDF, ATLAS, CMS, and LHCb)
- performed using an extended version of the package `flavio`

Parameters

$$\frac{\mathrm{Re}X^L_{ct}\lambda^L_{\mu\mu}}{m^2_{Z'}} \quad \frac{\mathrm{Im}X^L_{ct}\lambda^L_{\mu\mu}}{m^2_{Z'}} \quad \longleftarrow$$



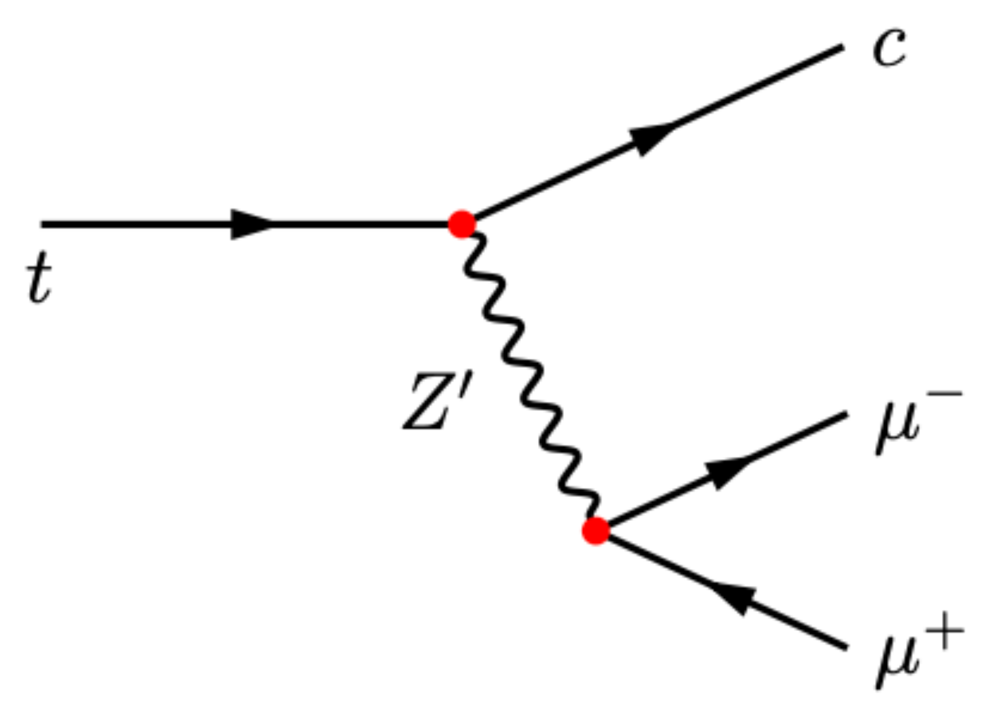
Fit result



★ can explain $b \to s\ell^+\ell^-$ anomalies at 95% CL.

★ for $m_{Z'} < \mathcal{O}(5)$ TeV, both X^L_{ct} and $\lambda^L_{\mu\mu}$ are in the perturbative region

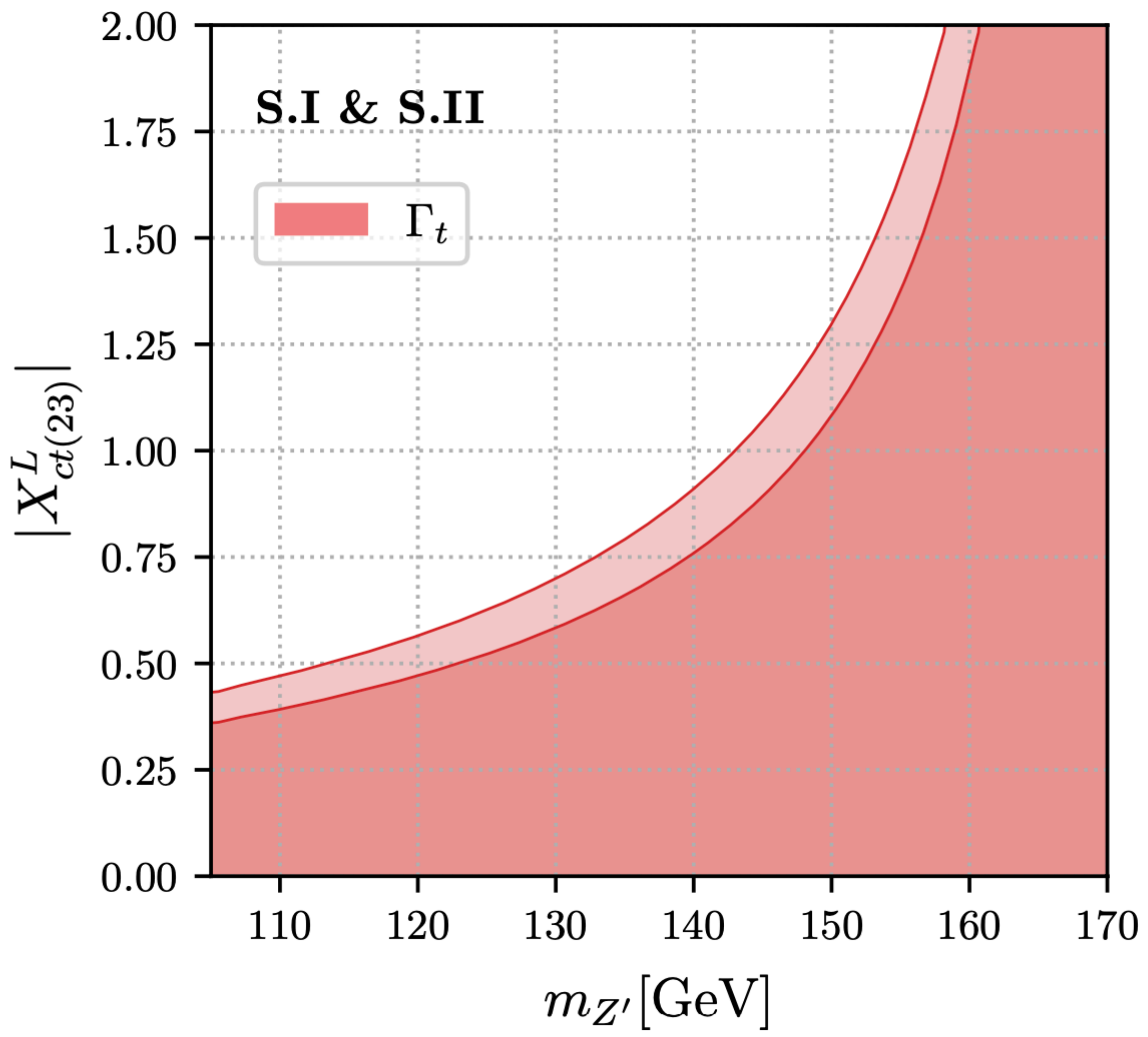
Numerical analysis: $t \to c\mu^+\mu^-$



$m_{Z'} < m_t$

- $t \to c\mu^+\mu^-$
  - Currently, no direct experimental bounds
  - LHC searches performed at the Z peak, $|m_{\mu\mu} - m_Z| < 15\,\mathrm{GeV}$ — ATLAS, JHEP07(2018)176; CMS, JHEP07(2017)003
  - Detailed analysis with the signal shape could be used to derive constraints — M. Chala, J. Santiago, and M. Spannowsky, JHEP04(2019)014
  - We concentrate on the mass region $105\,\mathrm{GeV} < m_{Z'} < m_t$
- $t \to cZ'$
  - Currently, no direct experimental bounds
  - Contribute to the top-quark width
  - $\Gamma_t^{\mathrm{SM}} = 1.3\,\mathrm{GeV}$ v.s. $\Gamma_t^{\mathrm{exp}} = 1.42^{+0.19}_{-0.15}\,\mathrm{GeV}$ leaves $\mathcal{O}(20\%)$ room for Z'

★Top-quark provides a unique constraint on the $\bar{t}cZ'$ coupling

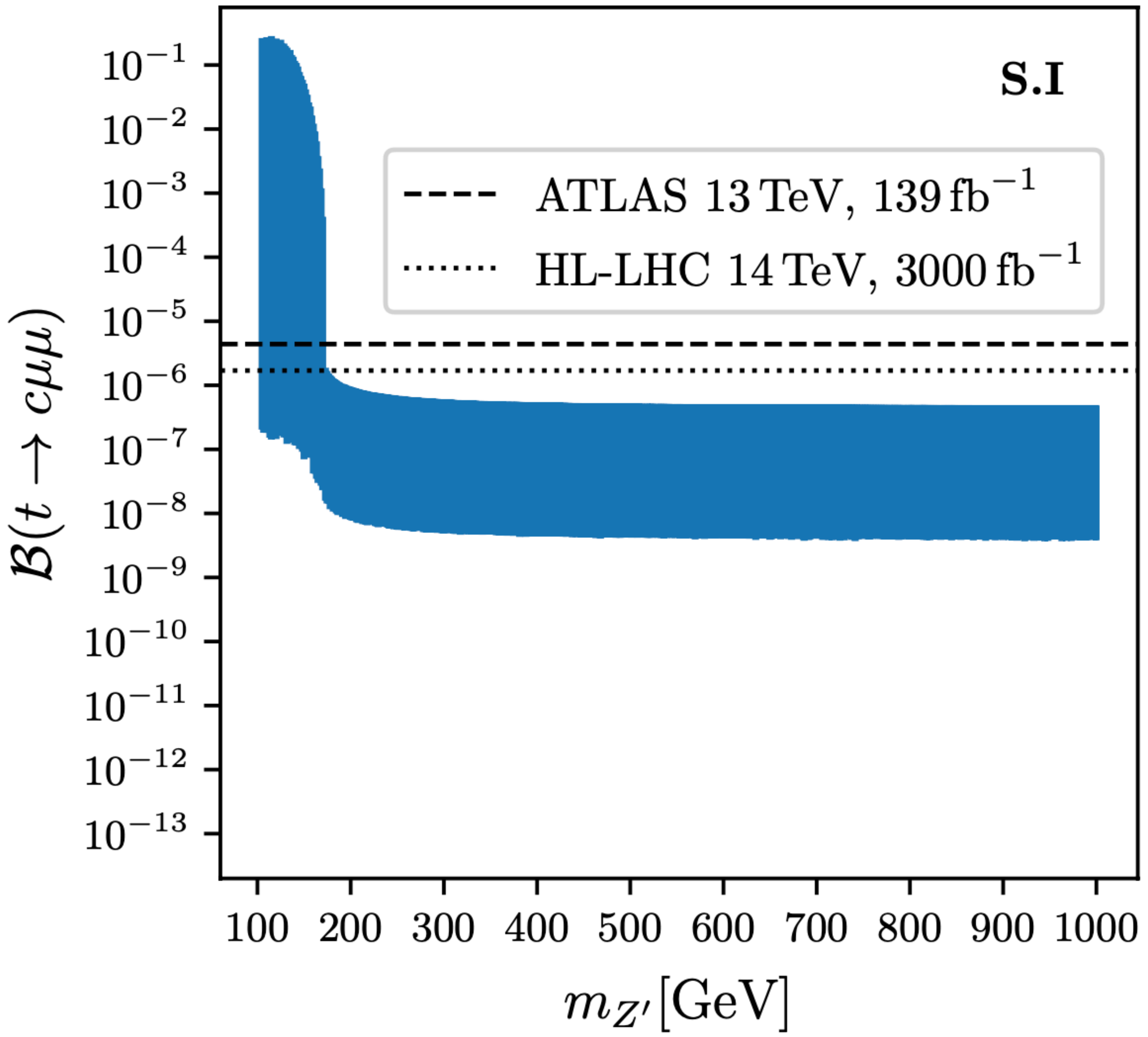


$m_{Z'} > m_t$

- $t \to c\mu^+\mu^-$
  - Currently, no direct experimental bounds
  - No constraints, similar as the $m_{Z'} < m_t$ case
- $pp \to tZ'$

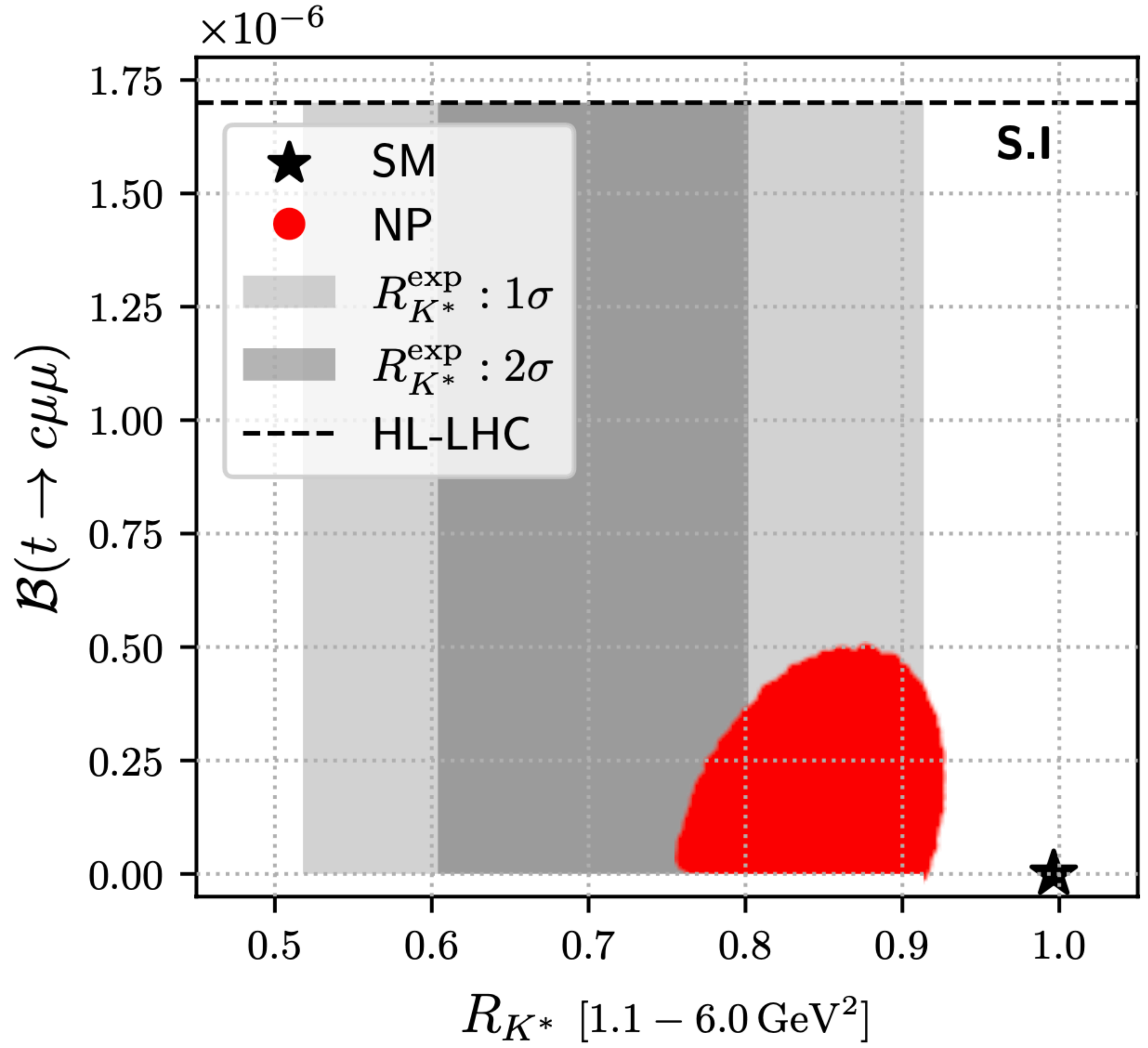
Numerical analysis: $t \to c\mu^+\mu^-$

▶ Prediction on $Br(t \to c\mu^+\mu^-)$



- Upper bound on $Br(t \to c\mu^+\mu^-)$ is estimated by the bound on $Br(t \to cZ)$ and $Br(Z \to \mu^+\mu^-) = 3.37\,\%$

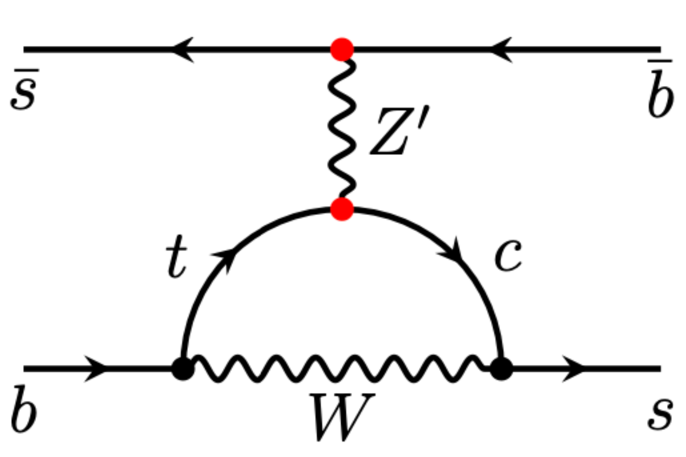
▶ Correlation for $m_{Z'} = 1\,\mathrm{TeV}$

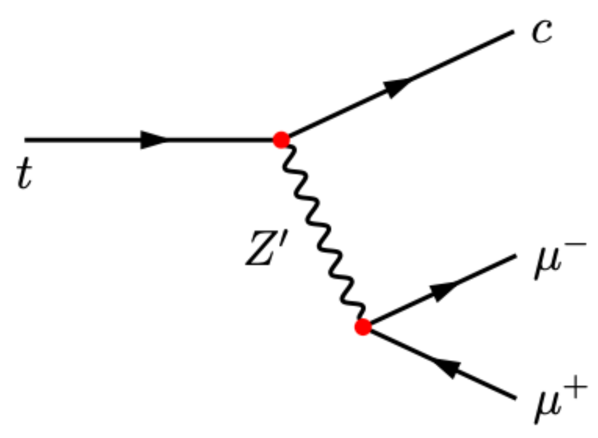


★ $m_{Z'} < m_t$: $t \to c\mu^+\mu^-$ can serve as a sensitive probe of the Z' boson

★ $m_{Z'} > m_t$: $pp \to tZ'$ reaches the sensitivity of the HL-LHC ($3000\,\mathrm{fb}^{-1}$)

- Sensitivity is $\Lambda_{tc\mu\mu} = 1.5\,\mathrm{TeV}$ from an EFT analysis Y. Afik, S. Bar-Shalom, A. Soni, and J. Wudka PRD103 (2021), no. 7 075031
- $1.4 < \Lambda_{tc\mu\mu} < 4.8\,\mathrm{TeV}$ obtained from the $b \to s\ell^+\ell^-$ global fit





Summary: Z' scenarios with top-FCNC couplings

Conclusions

- **A phenomenological Z' scenario is considered, in which a Z' couples only to $t\bar{c}$ and $\mu^+\mu^-$ with left-handed chirality**
- **The Z' effects on the $b \to s\mu^+\mu^-$ automatically induce $C_9^{\rm NP} = -C_{10}^{\rm NP}$, which is favored by the global fit**
- **The Z' scenario can address the $b \to s\mu^+\mu^-$ anomalies, which satisfying other flavour and collider constraints**
- **For $m_{Z'} < m_t$: resonance searches in $t \to c\mu^+\mu^-$ can serve as a sensitive probe of the Z' boson**
- **For $m_{Z'} > m_t$: $pp \to tZ'$ reaches the sensitivity of the HL-LHC ($3000\,{\rm fb}^{-1}$)**

Issues

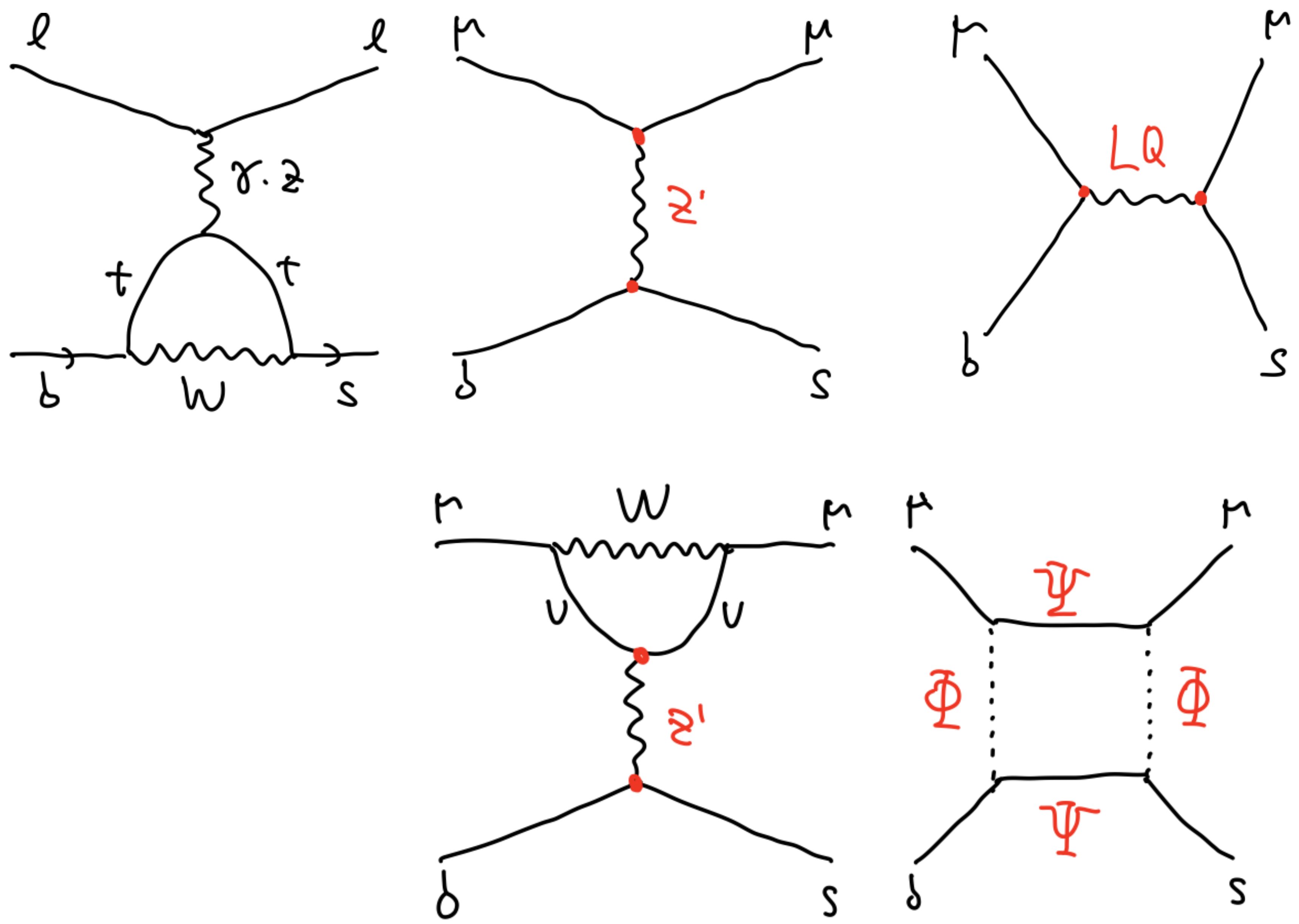
- **NOT UV complete**
- **SU(2) invariance**
  - same coupling for $\bar{b}sZ'$ (considered in our work. For $b \to s\mu^+\mu^-$, effects from $\bar{b}sZ'$ is dominated)
  - SU(2) is constructed in the interaction eigenstate. However, the rotation matrices from the interaction to the mass eigenstate are different for b_L and t_L. Therefore, the couplings of $\bar{b}sZ'$ and $\bar{t}cZ'$ could be different and should depend on the flavour structure of the UV theory.
  - In the case of a light Z' (e.g., $m_{Z'} < \mu_{\rm EW}$), the $\bar{t}cZ'$ could be an effective interaction and SU(2) can be broken

Future works

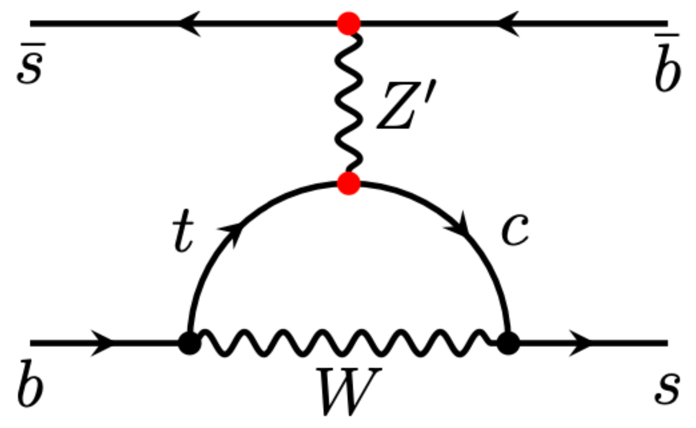
- **UV complete model | (ultra) light Z' | e^+e^-Z' | detailed collider simulation**

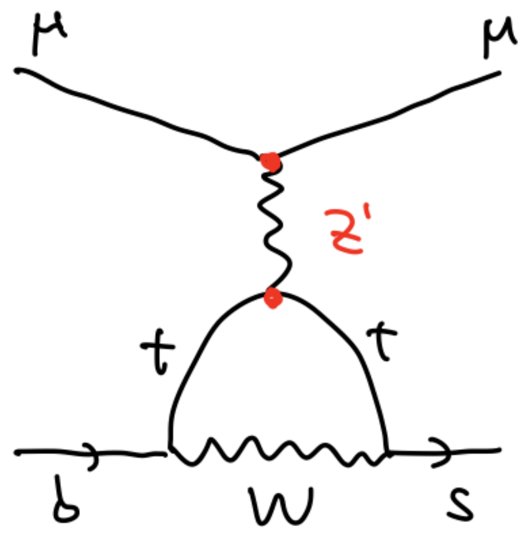
Flavour anomalies: theoretical interpretation

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



- New possibility ?





J. F. Kamenik, Y. Soreq, J. Zupan, PRD97 (3) (2018) 035002

Explain $b \to s\ell^+\ell^-$ by the NP without FCNC ?

$\mu_{\rm NP}$ — **UV models**

$\mu_{\rm EW}$

μ_b

SMEFT: SM Effective Field Theory

$$\mathcal{L}_{\rm SMEFT} = \mathcal{L}_{\rm SM} + C_i^{\rm NP} O_i^{\rm NP}$$

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$$O_{ed}^{(1)} = (\bar{e}_p \gamma_\mu e_r)(\bar{d}_s \gamma^\mu d_t)$$

… …

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$$O_{\rm VLL} = (\bar{c}\gamma^\mu P_L b)(\bar{\tau}\gamma^\mu P_L \nu) \qquad O_{S_R} = (\bar{c}_L b_R)(\bar{\ell}_R \nu_{\tau L})$$

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$$O_T = (\bar{c}_R \sigma^{\mu\nu} b_L)(\bar{\ell}_R \sigma_{\mu\nu} \nu_{\tau L})$$

Top-philic Z' model

J. F. Kamenik, Y. Soreq, J. Zupan, PRD97 (3) (2018) 035002
P. J. Fox, I. Low, Y. Zhang, JHEP 03 (2018) 074

- **Gauge group: $SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \otimes U(1)'$**
- **New fermions: vector-like top partner $U'_{L,R} \sim (3,1,2/3,q_t)$**
- **Lagrangian: quark sector**

$$\mathcal{L}_{\text{int}} = \left(\lambda_H \bar{Q}_{3L} \tilde{H} u_{3R} + \lambda_\Phi \bar{U}'_L u_{3R} \Phi + \mu \bar{U}'_L U'_R + \text{h.c.}\right) + q_t g_t \left(\bar{U}'_L \gamma^\mu U'_L + \bar{U}'_R \gamma^\mu U'_R\right) Z'_\mu,$$

- **Comments**
  - interaction eigenstates
  - Assuming only 3rd-gen SM quarks mix with the top partner
  - Vector-like top partner + Z'
- **Rotation from the interaction to the mass eigenstate**

$$\begin{pmatrix} t_L \\ T_L \end{pmatrix} = \begin{pmatrix} \cos\theta_L & -\sin\theta_L \\ \sin\theta_L & \cos\theta_L \end{pmatrix} \begin{pmatrix} u_{3L} \\ U'_L \end{pmatrix}$$

$$\begin{pmatrix} t_R \\ T_R \end{pmatrix} = \begin{pmatrix} \cos\theta_R & -\sin\theta_R \\ \sin\theta_R & \cos\theta_R \end{pmatrix} \begin{pmatrix} u_{3R} \\ U'_R \end{pmatrix}$$

mass **interaction**

$$\tan\theta_L = \frac{m_t}{m_T} \tan\theta_R$$

- **Interactions**

$$\mathcal{L}_\gamma = \frac{2}{3} e \bar{t} \not{A} t + \frac{2}{3} e \bar{T} \not{A} T\,, \tag{7}$$

$$\mathcal{L}_W = \frac{g}{\sqrt{2}} V_{td_i} \left(c_L \bar{t} \not{W} P_L d_i + s_L \bar{T} \not{W} P_L d_i\right) + \text{ h.c.}\,, \tag{8}$$

$$\mathcal{L}_Z = \frac{g}{c_W} \left(\bar{t}_L, \bar{T}_L\right) \begin{pmatrix} \frac{1}{2} c_L^2 - \frac{2}{3} s_W^2 & \frac{1}{2} s_L c_L \\ \frac{1}{2} s_L c_L & \frac{1}{2} s_L^2 - \frac{2}{3} s_W^2 \end{pmatrix} \not{Z} \begin{pmatrix} t_L \\ T_L \end{pmatrix} + \frac{g}{c_W} \left(\bar{t}_R, \bar{T}_R\right) \left(-\frac{2}{3} s_W^2\right) \not{Z} \begin{pmatrix} t_R \\ T_R \end{pmatrix}\,, \tag{9}$$

$$\mathcal{L}_{Z'} = q_t g_t \left(\bar{t}_L, \bar{T}_L\right) \begin{pmatrix} s_L^2 & -s_L c_L \\ -s_L c_L & c_L^2 \end{pmatrix} \not{Z}' \begin{pmatrix} t_L \\ T_L \end{pmatrix} + (L \to R)\,, \tag{10}$$

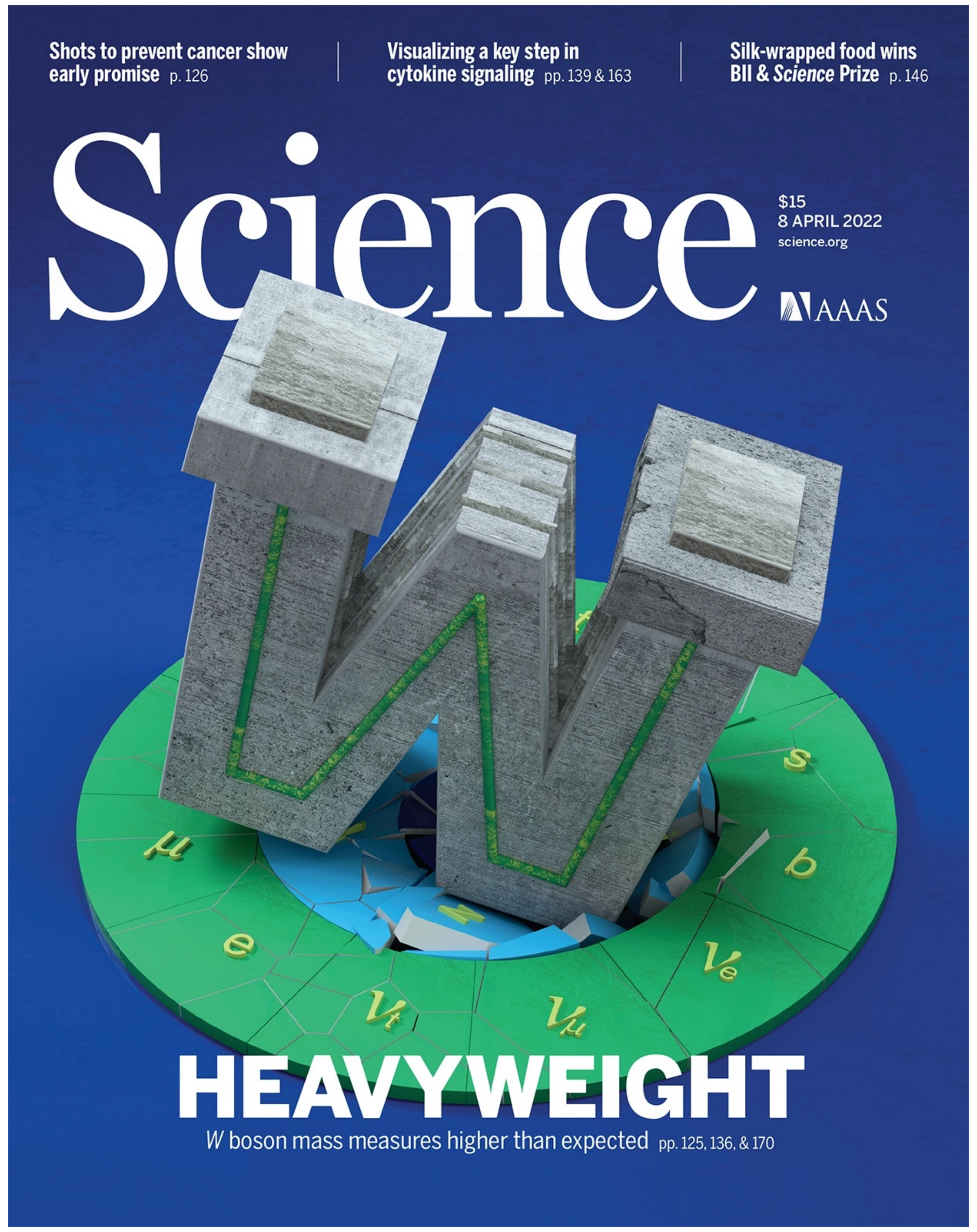
- **Lagrangian: lepton section**

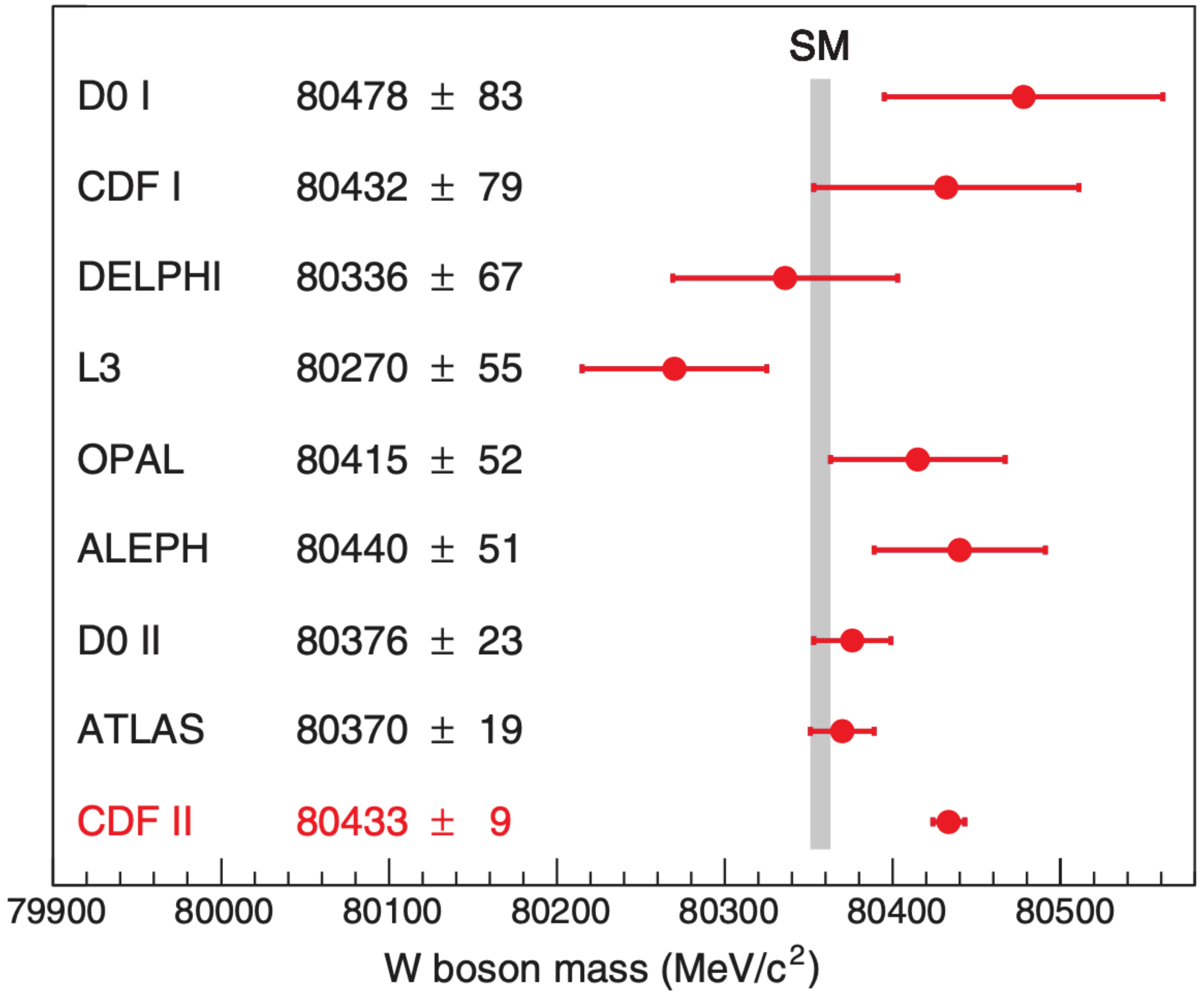
$$\mathcal{L}_\mu = \bar{\mu} \not{Z}' \left(g_\mu^L P_L + g_\mu^R P_R\right) \mu$$

- **NP parameters**

$$(\cos\theta_L,\, m_T,\, g_\mu^L,\, g_\mu^R,\, g_t,\, q_t,\, m_{Z'})$$

W-boson mass shift and oblique parameters





Global EW fit

- Most NP effects on the EW sector can be parameterized by S, T, U , e.g.,

$$\Delta m_W^2 = \frac{\alpha c_W^2 m_Z^2}{c_W^2 - s_W^2}\left[-\frac{S}{2} + c_W^2 T + \frac{c_W^2 - s_W^2}{4 s_W^2} U\right]$$

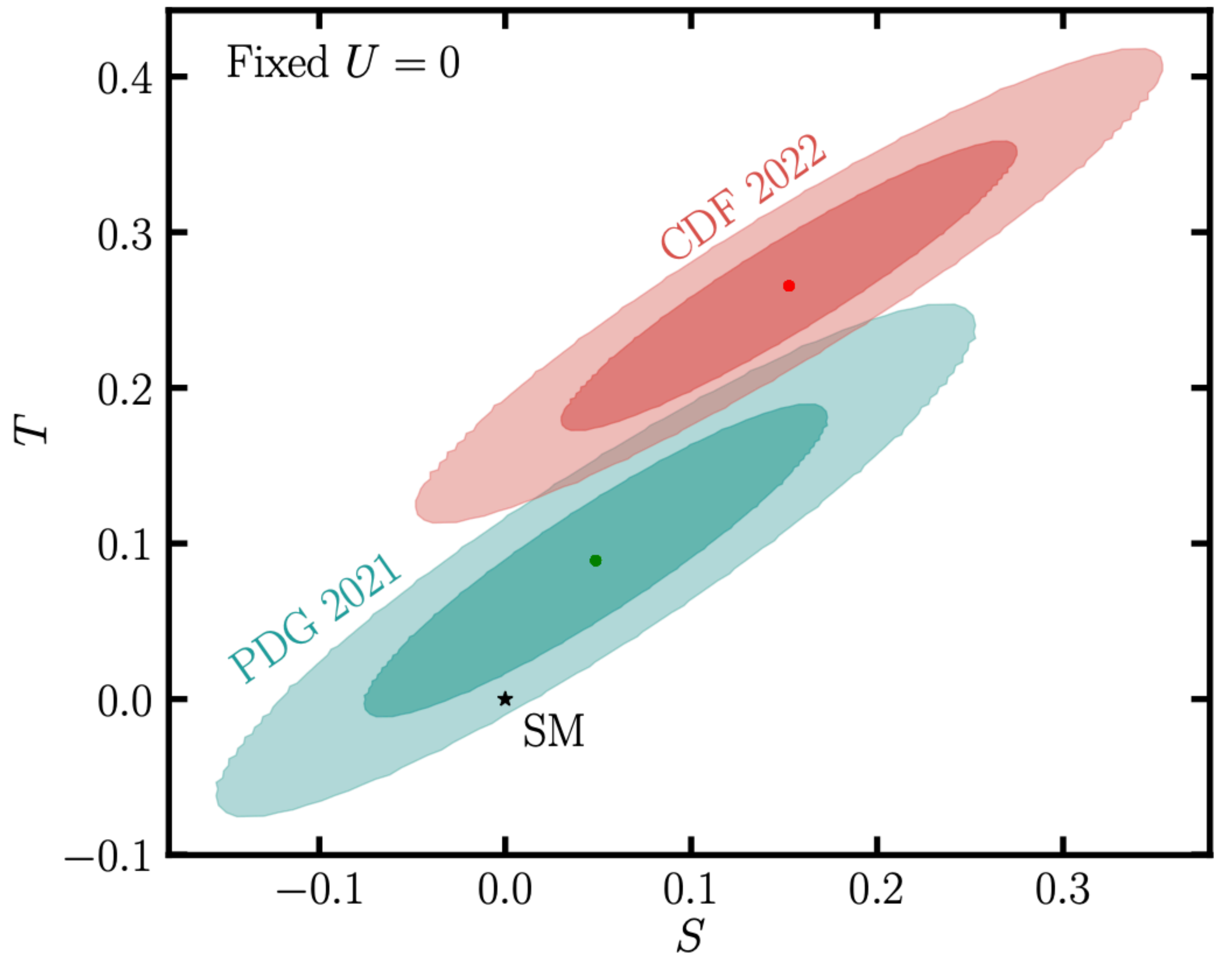
- S, T, U are related to the vacuum polarization of gauge bosons

$$S = \frac{4 s_W^2 c_W^2}{\alpha_e}\left[\frac{\Pi_{ZZ}(m_Z^2) - \Pi_{ZZ}(0)}{m_Z^2} - \frac{c_W^2 - s_W^2}{s_W c_W}\Pi'_{Z\gamma}(0) - \Pi'_{\gamma\gamma}(0)\right],$$

$$T = \frac{1}{\alpha_e}\left[\frac{\Pi_{WW}(0)}{m_W^2} - \frac{\Pi_{ZZ}(0)}{m_Z^2}\right],$$

$$U = \frac{4 s_W^2}{\alpha_e}\left[\frac{\Pi_{WW}(m_W^2) - \Pi_{WW}(0)}{m_W^2} - \frac{c_W}{s_W}\Pi'_{Z\gamma}(0) - \Pi'_{\gamma\gamma}(0)\right] - S,$$

- A global EW fit is needed to explanation of the CDF m_W shift



By Gfitter

Chih-Ting Lu, Lei Wu, Yongcheng Wu, and Bin Zhu, arXiv: 2204.03796

CDF： 80433 ± 9 GeV

PDG： 80387 ± 12 GeV

EW fit： 80357 ± 6 GeV

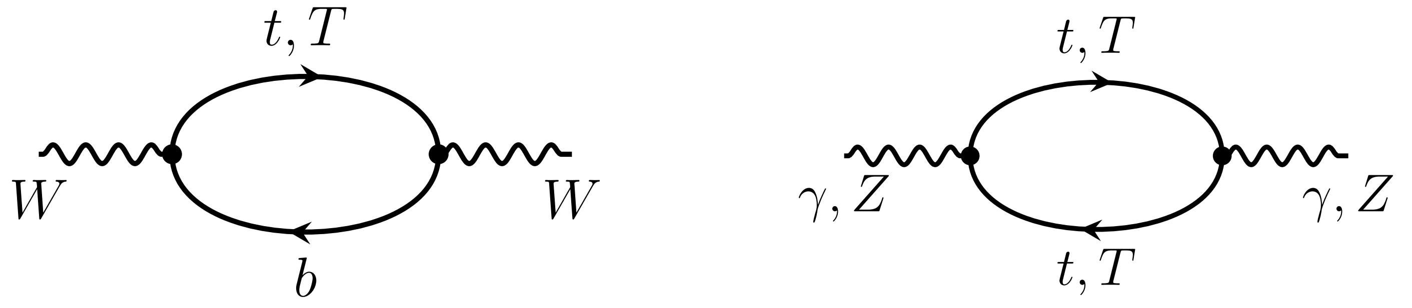
LHCb： 80354 ± 31 GeV LHCb, JHEP01(2022)036

About 7 σ deviation ! ! !

W-boson mass shift and oblique parameters

Explanation in top-philic Z' scenario

- NP contributions to vacuum polarizations



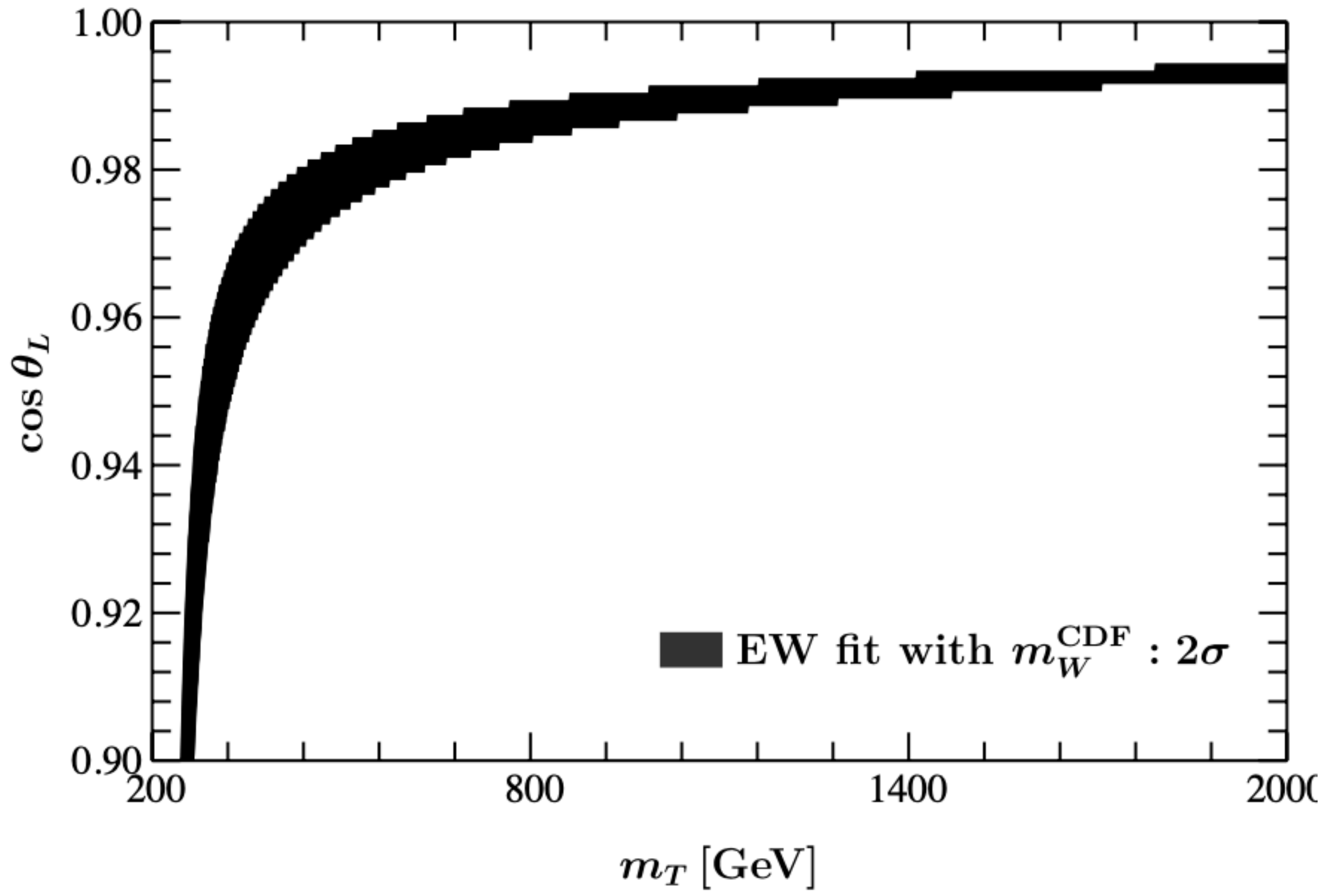
- S, T, U are affected

$$S_T = \frac{s_L^2}{12\pi}\left[K_1(y_t, y_T) + 3c_L^2 K_2(y_t, y_T)\right],$$

$$T_T = \frac{3s_L^2}{16\pi s_W^2}\left[x_T - x_t - c_L^2\left(x_T + x_t + \frac{2x_t x_T}{x_T - x_t}\ln\frac{x_t}{x_T}\right)\right]$$

$$U_T = \frac{s_L^2}{12\pi}\left[K_3(x_t, y_t) - K_3(x_T, y_T)\right] - S,$$

- Allowed parameter space



★ $m_W^{\rm CDF}$ can be explained by the top-parter effects

★ small θ_L is allowed

Global EW fit

- Most NP effects on the EW sector can be parameterized by S, T, U, e.g.,

$$\Delta m_W^2 = \frac{\alpha c_W^2 m_Z^2}{c_W^2 - s_W^2}\left[-\frac{S}{2} + c_W^2 T + \frac{c_W^2 - s_W^2}{4s_W^2}U\right]$$

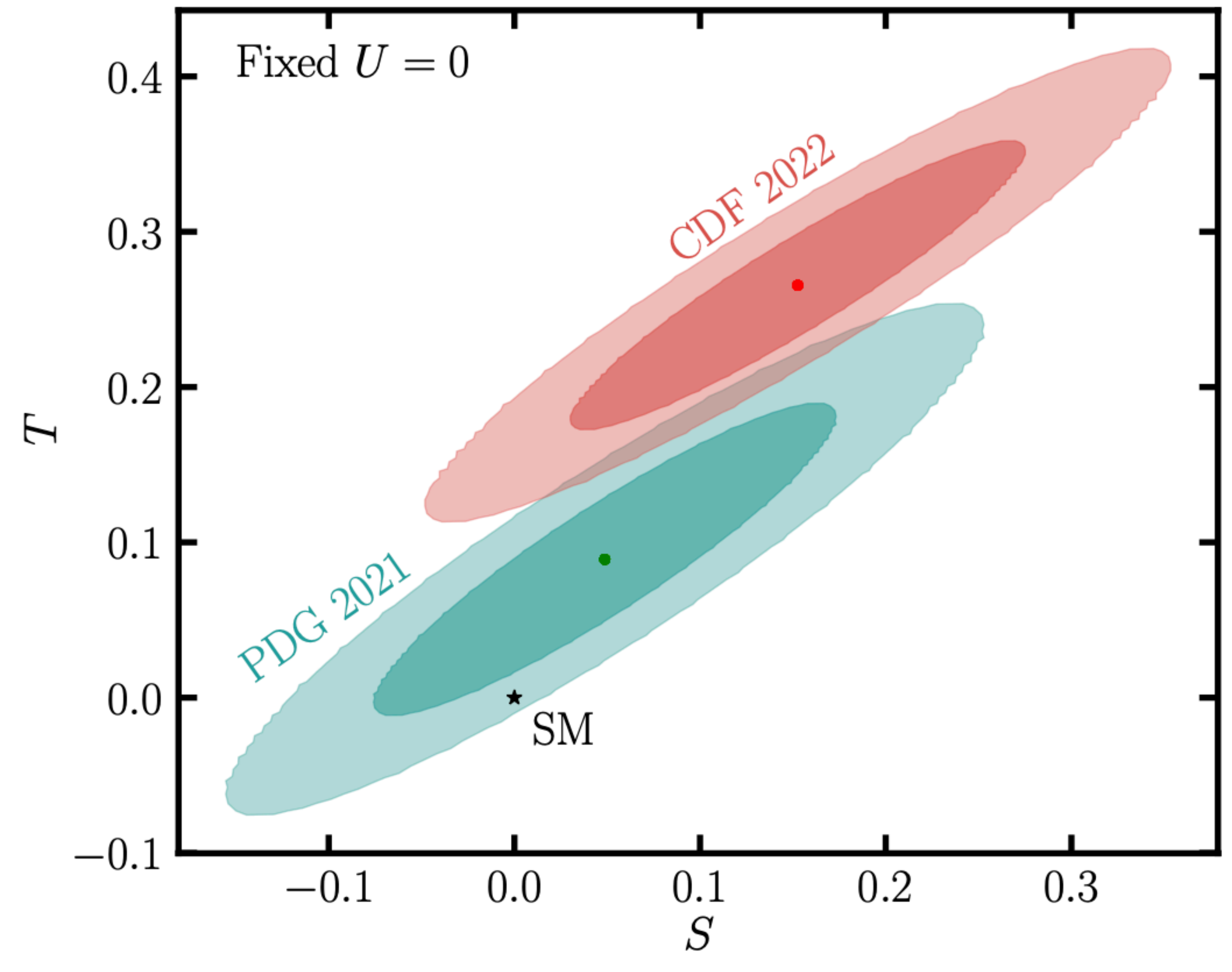
- S, T, U are related to the vacuum polarization of gauge bosons

$$S = \frac{4s_W^2 c_W^2}{\alpha_e}\left[\frac{\Pi_{ZZ}(m_Z^2) - \Pi_{ZZ}(0)}{m_Z^2} - \frac{c_W^2 - s_W^2}{s_W c_W}\Pi'_{Z\gamma}(0) - \Pi'_{\gamma\gamma}(0)\right],$$

$$T = \frac{1}{\alpha_e}\left[\frac{\Pi_{WW}(0)}{m_W^2} - \frac{\Pi_{ZZ}(0)}{m_Z^2}\right],$$

$$U = \frac{4s_W^2}{\alpha_e}\left[\frac{\Pi_{WW}(m_W^2) - \Pi_{WW}(0)}{m_W^2} - \frac{c_W}{s_W}\Pi'_{Z\gamma}(0) - \Pi'_{\gamma\gamma}(0)\right] - S,$$

- A global EW fit is needed to explanation of the CDF m_W shift

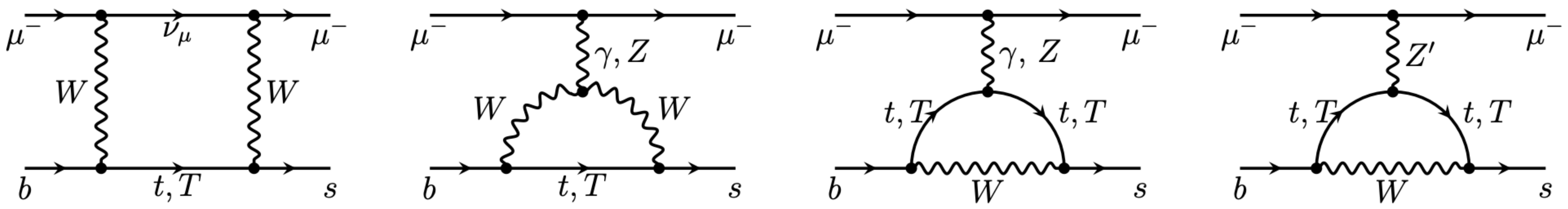


By Gfitter

Chih-Ting Lu, Lei Wu, Yongcheng Wu, and Bin Zhu, arXiv: 2204.03796

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

- **NP contributions**



- **Effective Hamiltonian**

$$\mathcal{H}_{\text{eff}} \supset -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{\alpha}{4\pi} \left(\mathcal{C}_9^\mu \mathcal{O}_9^\mu + \mathcal{C}_{10}^\mu \mathcal{O}_{10}^\mu\right) + \text{ h.c.} \,,$$

- **Wilson coefficients**

$$\mathcal{C}_9^{\text{NP}} = s_L^2 I_1 + s_L^2 \left(1 - \frac{1}{4 s_W^2}\right) \left(I_2 + c_L^2 I_3\right) + \Delta\mathcal{C}_+^{Z'}$$

$$\mathcal{C}_{10}^{\text{NP}} = \frac{s_L^2}{4 s_W^2} \left(I_2 + c_L^2 I_3\right) + \Delta\mathcal{C}_-^{Z'} \,,$$

$$\Delta\mathcal{C}_\pm^{Z'} = \frac{(g_L \pm g_R) q_t g_t}{e^2} \frac{m_W^2}{m_{Z'}^2} c_L^2 s_R^2 \left(I_4 - \frac{c_L^2}{c_R^2} I_5\right)$$

★ The W-box, γ- and Z- penguin diagrams are highly suppressed (proportional to $\sin^2\theta_L$)

★ The Z' penguins do not suffer from this suppression and may affect the $b \to s\ell^+\ell^-$ processes

- **NP parameters**

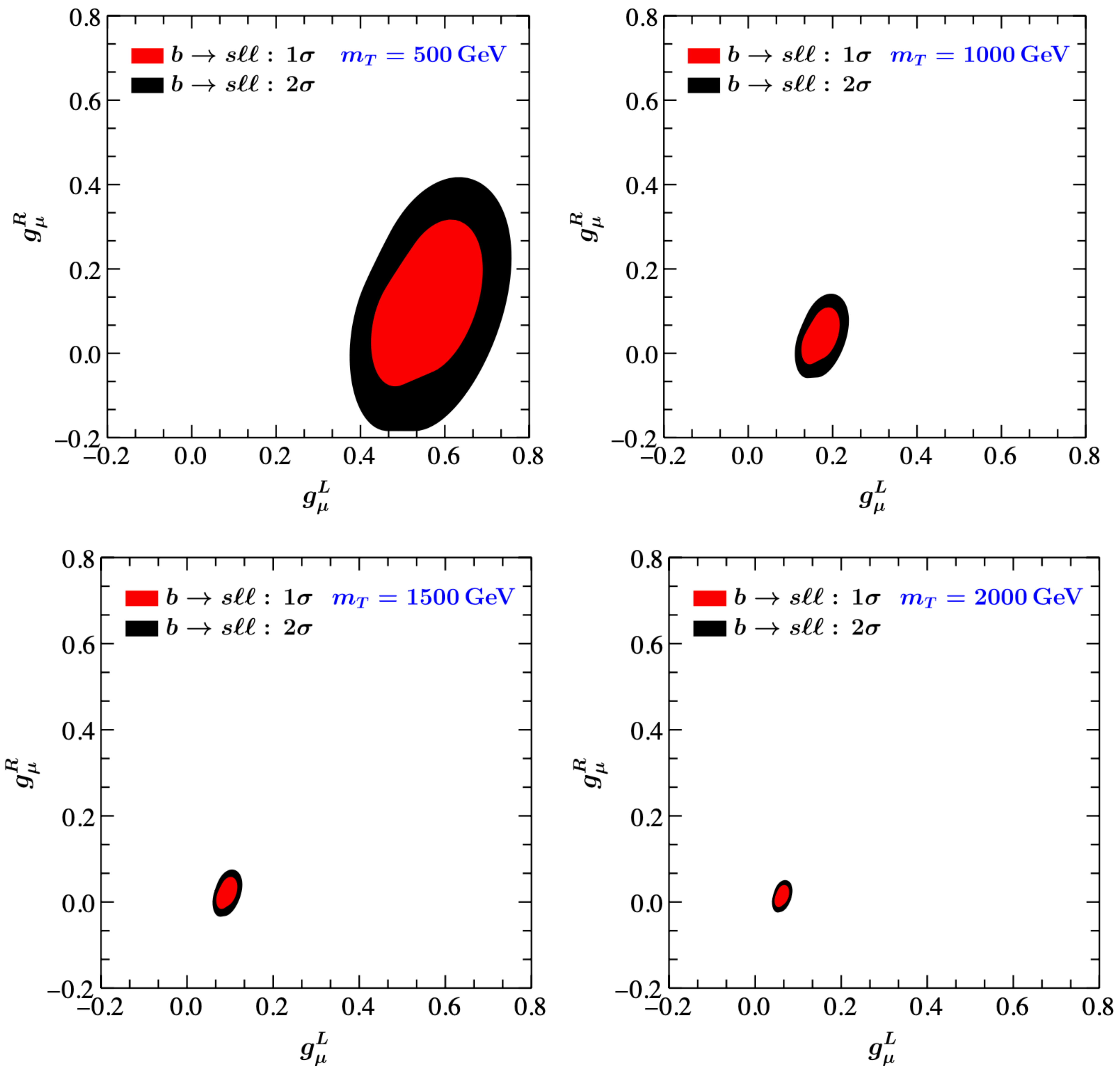
$$\left(\cos\theta_L,\, m_T,\, \frac{q_t g_t g_\mu^{L,R}}{m_{Z'}^2}\right)$$

Without loss of generality

$$q_t = 1,\; g_t = 1,\; m_{Z'} = 200\,\text{GeV}$$

$$(\cos\theta_L,\, m_T,\, g_\mu^L,\, g_\mu^R)$$

$b \to s\ell^+\ell^-$ anomalies and the CDF m_W shift



- $b \to s\ell^+\ell^-$ $(\cos\theta_L,\, m_T,\, g_\mu^L,\, g_\mu^R)$
- m_W shift $(\cos\theta_L,\, m_T)$

★ $m_W^{\rm CDF}$ and $b \to s\ell^+\ell^-$ anomalies simultaneously explained at $2\,\sigma$ level

★ the couplings are safely in the perturbative region

Constraints on $(g_\mu^L,\, g_\mu^R)$ from the $b \to s\ell^+\ell^-$ processes, in the $2\,\sigma$ allowed regions of $(\cos\theta_L,\, m_T)$ obtained from the global EW fit

Summary

Conclusions

- Oblique parameters S, T, U and Wilson coefficients C_9 and C_{10} calculated in a top-philic Z' model
- It is found that the model can simultaneously explain the CDF m_W measurement and the $b \to s\ell^+\ell^-$ anomalies

Issues

- Lepton sector is NOT UV complete
- Top partner mixing with 1st and 2nd generation is also possible — G.C. Branco et al, arXiv:2103.13409
- Z' contributions to the global EW fit is not included
- Naturalness from the top partner not discussed — J. Berger, J. Hubisz and M. Perelstein, arXiv: 1205.0013

Future works

- UV complete model | Z' contributions to EW fit | mixing with 1st and 2nd gen | Nautralness
- detailed collider simulation

谢谢