フレーバーアノマリーの現状とBファクトリーの未来

6 August 2024

b→cτν 理論

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

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Content

History of RD(*)

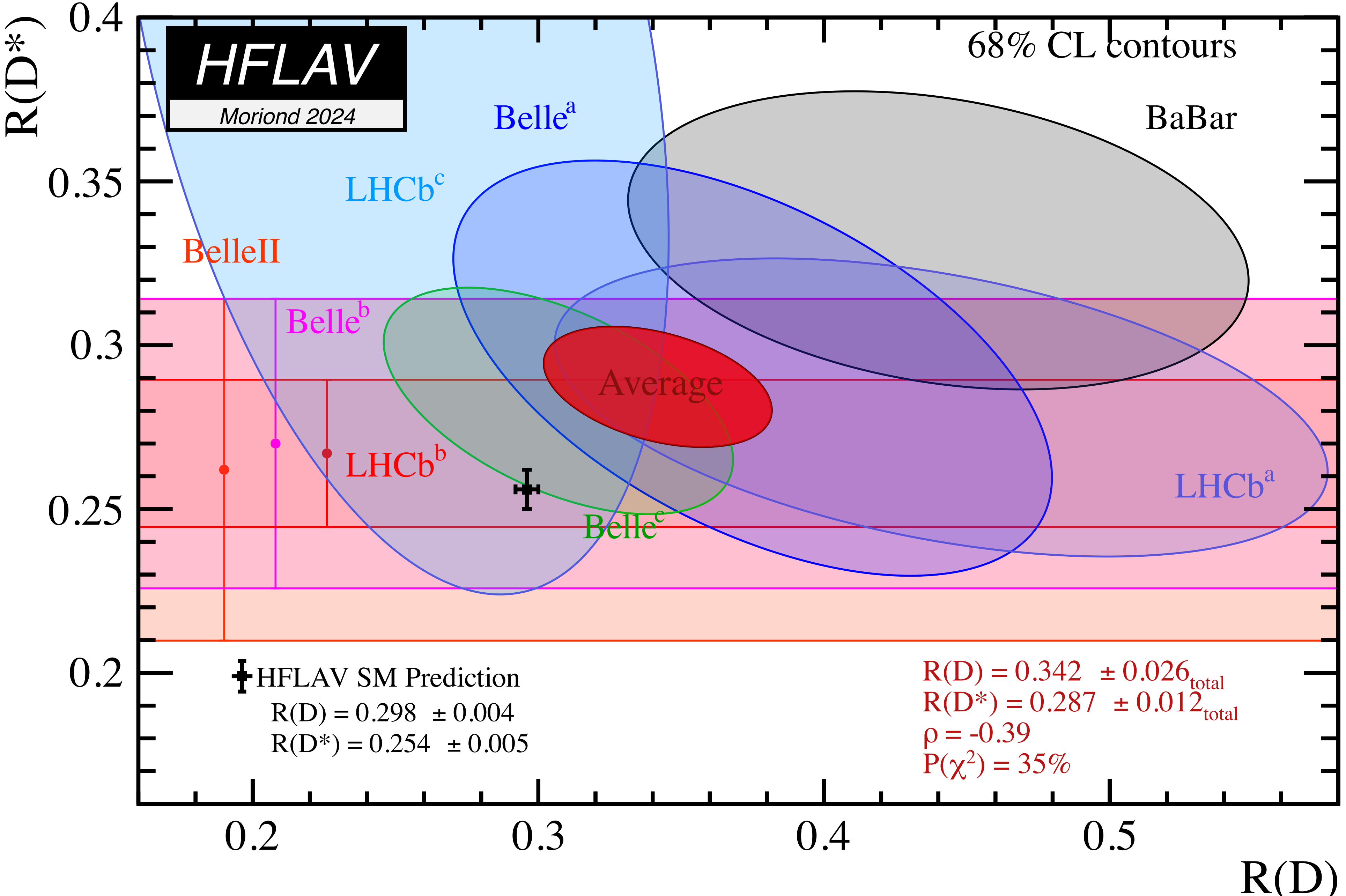
SM predictions

New Physics: status

New Physics: collider bound

New Physics: flavor signal

History of RD(*)



HFLAV (Moriond 2024)

Experiments

Preliminary reports are removed

2012: first BaBar measurement
($\tau \to l\nu\nu$, had. tag)

2015: first Belle ($\tau \to l\nu\nu$, had. tag)
first LHCb ($\tau \to \mu\nu\nu$) D* only
first HFLAV average

2016: new two Belle D* only
($\tau \to l\nu\nu$, semi-lept. tag) ($\tau \to \pi\,\nu$, had. tag)

2018: new LHCb ($\tau \to 3\pi\,\nu$) D* only

2019: Belle update 2016 with D&D*
($\tau \to l\nu\nu$, semi-lept. tag)

2023: LHCb ($\tau \to \mu\nu\nu$) update 2015 with D&D*
LHCb ($\tau \to 3\pi\,\nu$) update 2018, D* only

2024: first Belle II D* only

Theory

2008: first robust RD calc.
CLN with 2008 combined data

2012: first RD* calc.
CLN with 2010 Belle data

charged Higgs disfavored
inconsistent with BaBar

2013: leptoquark studies
possible solutions to “anomaly”

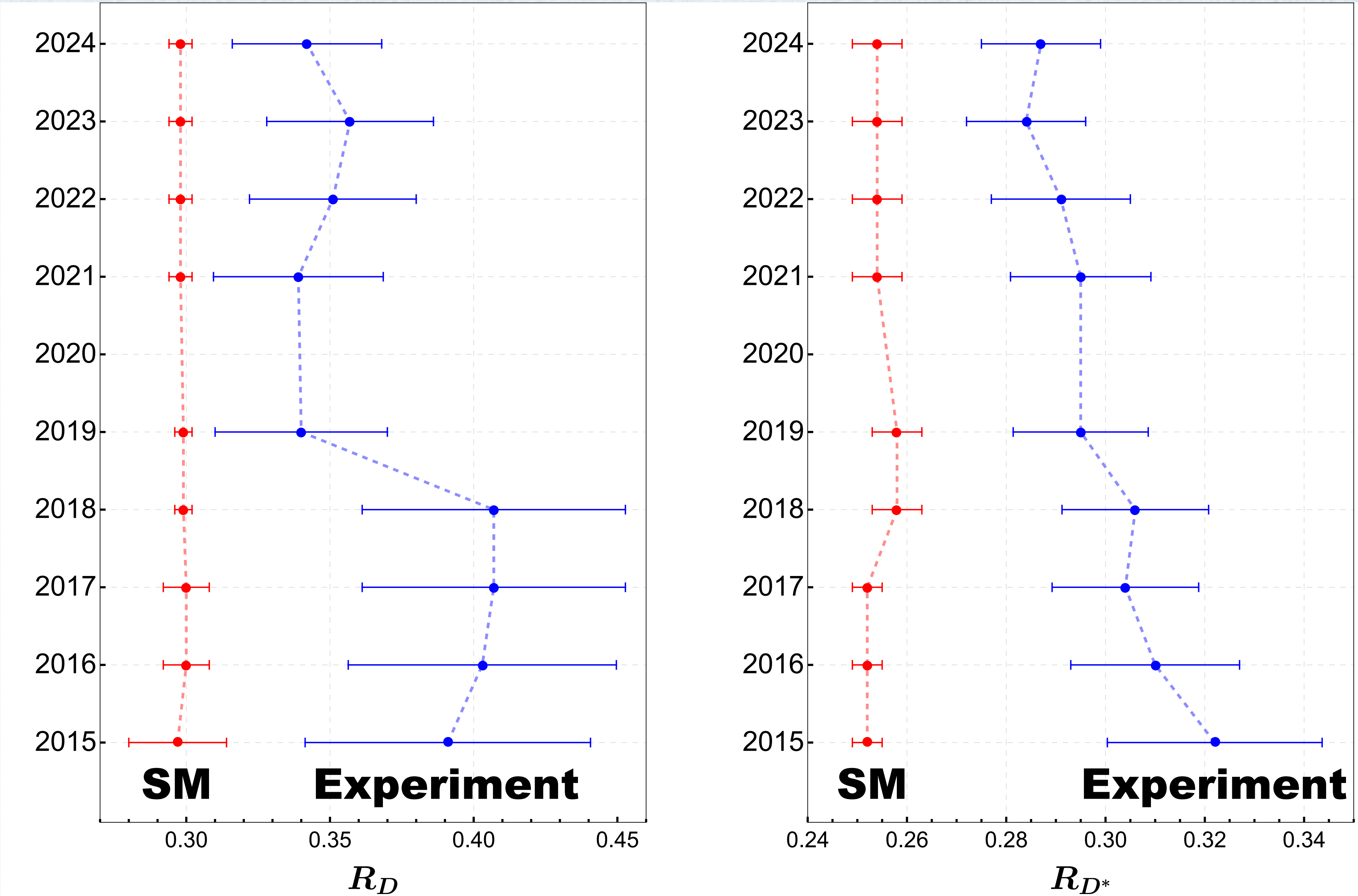
2016: first Lattice for D
BGL available for RD calc.

2017: first Lattice for D* at 0-recoil
BGL & general HQET studied

2018: first LCSR large recoil fit

2021: Non 0-recoil Lattice year
2021: FNAL-MILC
2023: JLQCD, HPQCD

HFLAV averages



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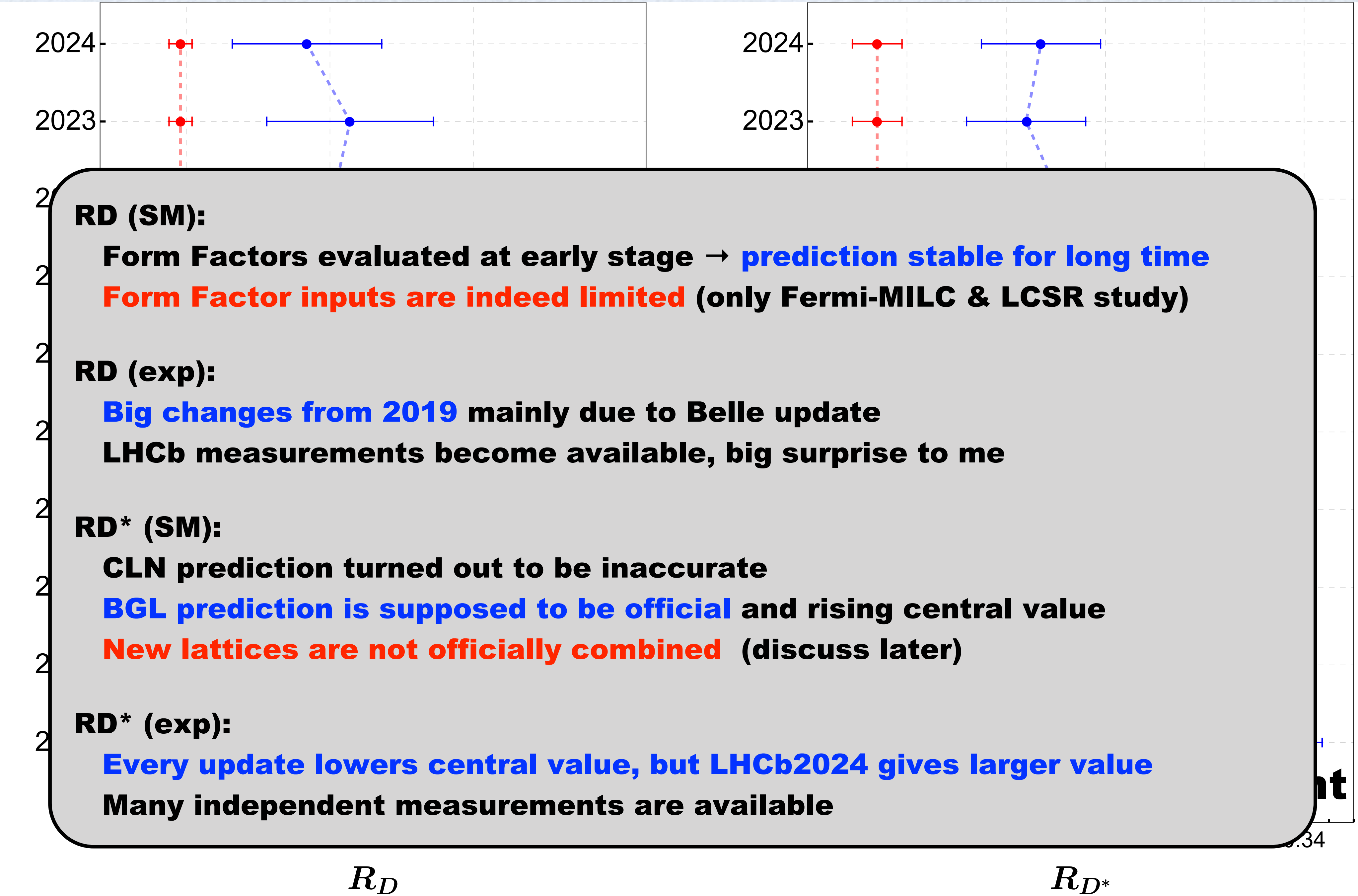

RD (SM):

Form Factors evaluated at early stage → prediction stable for long time

Form Factor inputs are indeed limited (only Fermi-MILC & LCSR study)

RD (exp):

Big changes from 2019 mainly due to Belle update

LHCb measurements become available, big surprise to me

RD* (SM):

CLN prediction turned out to be inaccurate

BGL prediction is supposed to be official and rising central value

New lattices are not officially combined (discuss later)

RD* (exp):

Every update lowers central value, but LHCb2024 gives larger value

Many independent measurements are available

SM predictions

Ingredients of FF fit

Gray analyses:
are superseded by other data,
or not provided as public data

Experimental inputs		
Belle 2015	$\bar{B} \to D\ell\bar{\nu}$	w distribution, 10 bins
Belle 2017 (full tag)	$\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}$	$(w, \theta_\ell, \theta_V, \chi)$ distributions, 40 (−3) bins
Belle 2018 (untagged)	$\bar{B}^0 \to D^{*+}e^-\bar{\nu},\ D^{*+}\mu^-\bar{\nu}$	$(w, \theta_\ell, \theta_V, \chi)$ distributions, 80 (−6) bins
BaBar 2019 (full tag)	$\bar{B} \to D^*\ell\bar{\nu}$	Data points are not provided
Belle II 2022 (untagged)	$\bar{B}^{0,+} \to D^{+,0}e^-\bar{\nu},\ D^{+,0}\mu^-\bar{\nu}$	$(w, \theta_\ell, \theta_V, \chi)$ distributions, 40 (−3) bins
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BaBar 2023	$\bar{B} \to D\ell\bar{\nu}$	Data points are not provided
Lattice		
Fermi-MILC 2014	$B \to D^*$ form factors (SM)	zero-recoil $w = 1$ point
Fermi-MILC 2016	$B \to D$ (SM)	$w = (1.00, 1.08, 1.16)$ points
HPQCD 2017	$B \to D^*$ (SM)	zero-recoil $w = 1$ point
Fermi-MILC 2021	$B \to D^*$ (SM & Tensor)	$w = (1.03, 1.10, 1.17)$ points
HPQCD 2023	$B \to D^*$ (SM & Tensor)	$q^2 = i \times q^2_{max}/3,\ i = (0, 1, 2, 3)$ points
JLQCD 2023	$B \to D^*$ (SM)	$w = (1.025,\ 1.06, 1.10)$ points
LCSR (Danny et al.)	$B \to D^{(*)}$ (SM & Tensor)	$q^2/\mathrm{GeV}^2 = (0, -5, -10, -15)$ points

Ingredients of FF fit

Gray analyses:
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B → D data points are limited and given at early stage

B → D* is in development, and "SM prediction" is messy

BaBar 2019: 0.253(5) — own BaBar 2019 with BGL + HQET

JLQCD: 0.252(22) — own Lattice

HQPCD: 0.273(15) — own Lattice
0.248(2) — own Lattice + Belle 2018

Fermi-MILC: 0.265(13) — own Lattice
0.248(1) — own Lattice + Belle 2018 + BaBar 2019

2305.11855: 0.251(1) — Fermi-MILC + JLQCD + LCSR + Belle 2018 + Belle 2023

2310.03680: 0.262(9) — Fermi-MILC + JLQCD + HPQCD + Belle 2018 + Belle 2023 + Belle II 2023 (full tag) with "Dispersive Method"

Exp	
Be	
Be	ns
Be	ns
Ba	
Be	ns
Be	bins
Be	bins
Ba	
Lat	
Fer	
Fer	
HP	
Fer	
HP	
JL	
LCS	

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HFLAV 2024 still refers SM based on 2015 - 2017

RD: 0.298(4)   RD*: 0.254(5)

➡ **needs general consensus on how to combine existing inputs**

➡ **need to check whether each FF input is reliable**

New Physics: status

Data set

FF inputs from

Lattice (2014+2016+2017) + LCSR + Belle (2017 + 2018)

FF parameterization

general HQET up to 1/mc^2 (See 2004.10208)

SM prediction: RD = 0.290(3) RD* = 0.248(1) FLD* = 0.464(3)

$\chi^2_{\rm SM} \approx 23.1$

NP fit analysis to

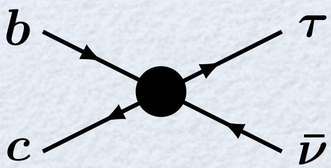
HFLAV average: RD = 0.342(26) RD* = 0.287(12) corr. = -0.39

Private average: FLD* = 0.49(5) Belle 2019 + LHCb 2023

FLD*: D* longitudinal polarization in B→D*τν

NP interpretations

NP EFT: $\mathcal{L}_X = 2\sqrt{2} G_F V_{cb} C_X^\tau (\bar{c}\,\Gamma b)(\bar{\tau}\,\Gamma' \nu)$



Solutions to the RD(*) anomaly:

$(\bar{c}\gamma^\mu P_L b)(\bar{\ell}\gamma_\mu P_L \nu)$ $\quad C_{V_L}^\tau \approx 0.08$ $\quad \text{Pull} \equiv \sqrt{\chi^2_{\text{SM}} - \chi^{2,\text{best}}_{\text{NP}}} \approx 4.8$ $\quad \left(\sqrt{\chi^2_{\text{SM}}} \approx 4.8\right)$

$(\bar{c}\gamma^\mu P_R b)(\bar{\ell}\gamma_\mu P_L \nu)$ $\quad C_{V_R}^\tau \approx 0.01 \pm i0.41$ $\quad \text{Pull} \approx 4.4$

$(\bar{c} P_L b)(\bar{\ell} P_L \nu)$ $\quad C_{S_L}^\tau \approx -0.79 \pm i0.86$ $\quad \text{Pull} \approx 4.3$

$(\bar{c} P_R b)(\bar{\ell} P_L \nu)$ $\quad C_{S_R}^\tau \approx 0.18$ $\quad \text{Pull} \approx 3.9$

$(\bar{c}\sigma^{\mu\nu} P_L b)(\bar{\ell}\sigma_{\mu\nu} P_L \nu)$ $\quad C_T^\tau \approx 0.02 \pm i0.13$ $\quad \text{Pull} \approx 4.3$

2405.06062

The situation has not been changed since HFLAV 2019

- **V_L / S_R gives the best / worst Pull**
- **V_R & S_L need very large WCs → disfavored by collider bound (see later)**
- **T is marginal, but single T operator is not usually generated (see next)**

NP scenarios

Vector boson (W'): $C^{\tau}_{V_L} \approx 0.08\,,\ \text{or}\ C^{\tau}_{V_R} \approx 0.01 \pm i0.41$

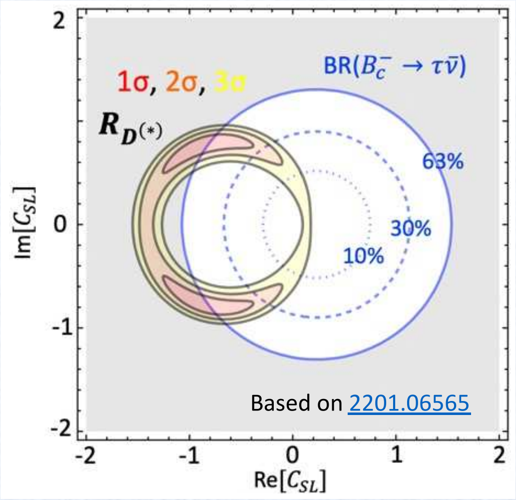
SU(2) model inevitably includes Z' that is very constrained due to tree-level FCNC

The V_L best pull implies $M_{W'}/g_{W'} \approx 3\,\text{TeV}$ ✗

Charged Higgs: $C^{\tau}_{S_L} \approx -0.79 \pm i0.86\,,\ \text{or}\ C^{\tau}_{S_R} \approx 0.18$

Typical 2HDM cannot achieve the solution ex) $C^{\text{Type II}}_{S_R} = -\tan^2\beta \frac{m_b m_\tau}{m^2_{H^\pm}} \Big/ \left(2\sqrt{2} V_{cb} G_F\right)$

General 2HDM
- needs to suppress S_R coupling due to neutral-mixing (ΔMs) ✗
- can give sizable S_L, but needs to avoid the Bc limit ✓



by Iguro

The robust constraint Br(Bc → τν) < 60% 2201.06565

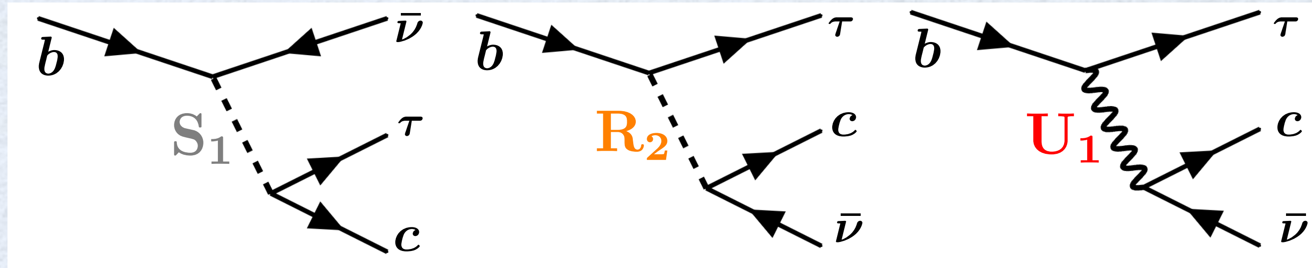
➡ Updated from the previous study of < 30%

This update significantly affects the S_L solution

➡ The S_L solution revived, but on the edge!

$$C^{\tau,\ +B_c}_{S_L} \approx -0.57 \pm i0.86 \quad (\text{Pull} \approx 4.3)$$

NP scenarios



Leptoquarks (LQ):

Three LQ bosons are capable of the RD(*) solution: S1, R2, U1 1309.0301

They have two independent and specific WCs for each

$S_1\ (\bar{3}, 1, 1/3)$ scalar: $C_{V_L},\ C_{S_L} = -4C_T$

Best Pull: $(C_{V_L},\ C_{S_L}) \approx (0.07,\ \pm i0.15)_{2D},\ (0,\ 0.18)_{1D},\ (0.08\,, 0)_{1D}$

was discussed in the context of RD-RK solution and revived these days

$R_2\ (3, 2, 7/6)$ scalar: $C_{V_R},\ C_{S_L} = +4C_T$

Best Pull: $(C_{V_R},\ C_{S_L}) \approx (\pm i0.65,\ 0.01 \mp i0.62)_{2D},\ (0,\ -0.09 \pm i0.56)_{1D}$

UV proper theory suppress $C_{V_R} \sim \frac{g_{\rm LQ}^2}{M_{\rm LQ}^2} \times \frac{v^2}{M_{\rm LQ}^2}$ **, so S_L-T solution is reliable**

$U_1\ (3, 1, 2/3)$ vector: $C_{V_L},\ C_{S_R}$

UV completion has been discussed for a long time

MFV with U(2) flavor symmetry results in $C_{S_R} = -2\, e^{I\phi}\, C_{V_L}$

Best Pull: $(\phi,\ C_{V_L}) \approx (0.08, 0.47\pi)$

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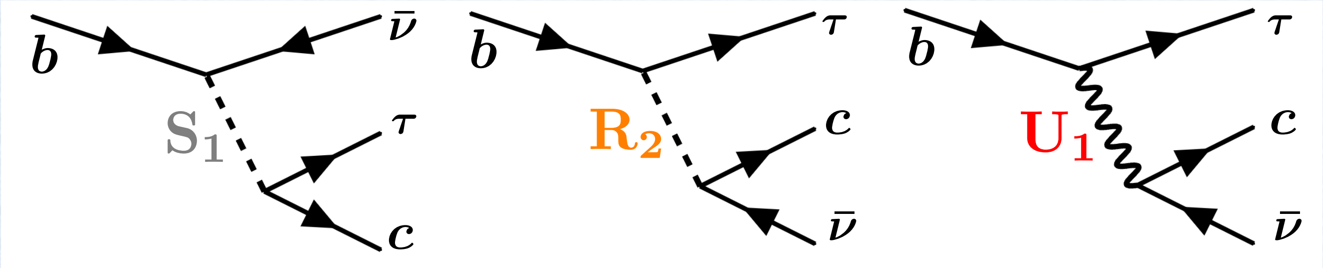
NP scenarios



Leptoquarks (LQ):

Three LQ bosons are capable of the RD(*) solution: S1, R2, U1 1309.0301

They have two independent and specific WCs for each

The situation has not been changed since HFLAV 2019

All LQ solutions are on similar Pulls → no preference

needs LQ predictions on other observables / to check collider bound (next)

2405.06062

New Physics: collider bound

Collider signals

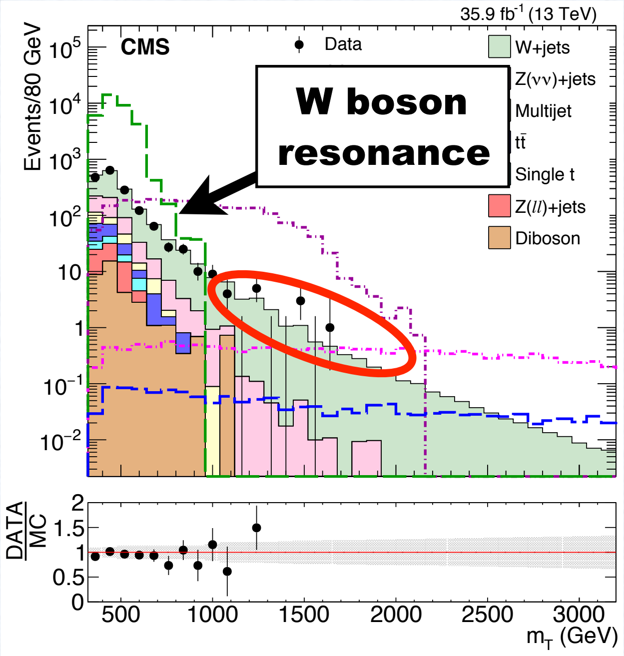
W boson resonance of τ + missing search:

Its tail can be interpreted as NP contribution responsible for the RD(*) anomaly

Minimal setup: NP effect exists only in $bc \to \tau\nu$

Vector boson scenario: $M_{W'}/g_{W'} > 1.5\,\text{TeV}$ (Minimal), $M_{W'} > 5\,\text{TeV}$ (SSM)

EFT analysis for general WCs:



$\tau^{\pm}$ + missing 1811.07920

Competitive with the RD(*) solutions that require large WCs

$$|C_{V_L}^{\text{LHC-EFT}}| < 0.32 \quad \Leftrightarrow \quad C_{V_L}^{R_{D^{(*)}}} \approx 0.08$$

$$|C_{V_R}^{\text{LHC-EFT}}| < 0.33 \quad \Leftrightarrow \quad C_{V_R}^{R_{D^{(*)}}} \approx 0.01 + i\,0.41$$

$$|C_{T}^{\text{LHC-EFT}}| < 0.20 \quad \Leftrightarrow \quad C_{T}^{R_{D^{(*)}}} \approx 0.02 + i\,0.13$$

$$|C_{S_L}^{\text{LHC-EFT}}| < 0.32 \quad \Leftrightarrow \quad |C_{S_L}^{R_{D^{(*)}},\,B_c}| \approx |-0.57 + i\,0.86| = 1.03$$

Charged Higgs (SL) is very excluded, but has an exception

➡ **tail pT < 500GeV is less sensitive to NP signal**

➡ **mass window 180GeV < mH < 400GeV is not accessible**

See poster by Iguro

Collider signals

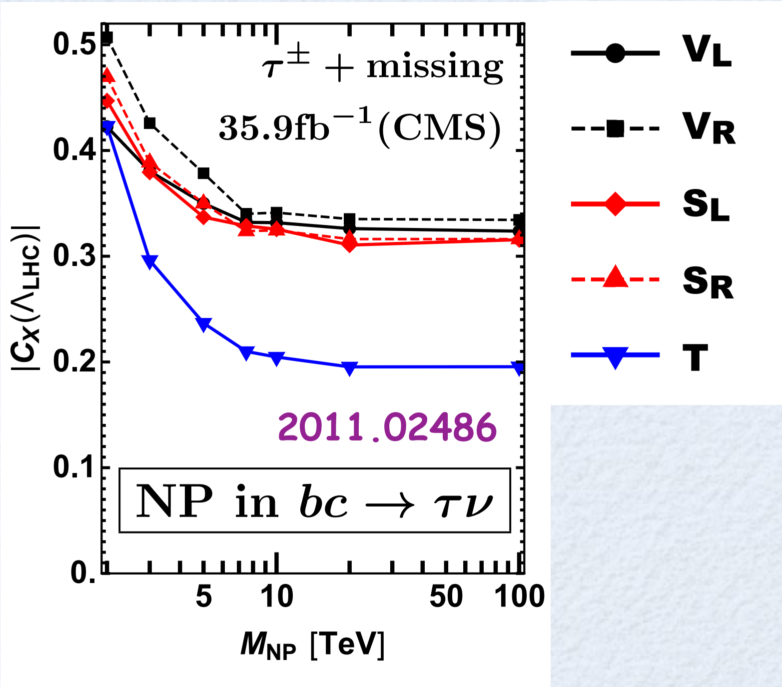
t-channel case:

2011.02486

EFT approximation is not good at high-mT

- ➡ if NP mass is close to mT bin ~ 1TeV applicable for bound
- ➡ In particular, it overestimates the signal in the case of t-channel
- ➡ Large t(<0) generates large mT and reduces the contribution

ex) $\mathcal{L}_U = h_U^{ij} \left(\bar{q}_L^i \gamma^\mu \ell_L^j \right) U_\mu + \text{h.c.} \quad \Rightarrow \quad \frac{h_U^{b\tau} \cdot h_U^{c\nu}}{t - m_{\text{LQ}}^2} \neq - \frac{h_U^{b\tau} \cdot h_U^{c\nu}}{m_{\text{LQ}}^2} \equiv C_{V_L}$



Proper bound for t-channel NP:

- ➡ 2TeV LQ: EFT bound is 40~100% overestimated
- ➡ 5TeV LQ: 10~20% overestimated
- ➡ crucial for R2 LQ solution with S_L-T operator

$$|C_{S_L}^{\text{LHC-LQ}}| < 0.80 \quad \Leftrightarrow \quad |C_{S_L}^{R_{D^{(*)}}\text{-R}_2\text{LQ}}| \approx |-0.09 + i\,0.56| = 0.57$$

Future capability:

- ➡ 3ab^-1 LHC reaches all the solutions except V_L

$$|C_T^{\text{LHC 3ab}^{-1}}| < 0.07 \quad \Leftrightarrow \quad |C_T^{R_{D^{(*)}}}| \approx 0.13$$

$$|C_{V_L}^{\text{LHC 3ab}^{-1}}| < 0.12 \quad \Leftrightarrow \quad C_{V_L}^{R_{D^{(*)}}} \approx 0.08$$

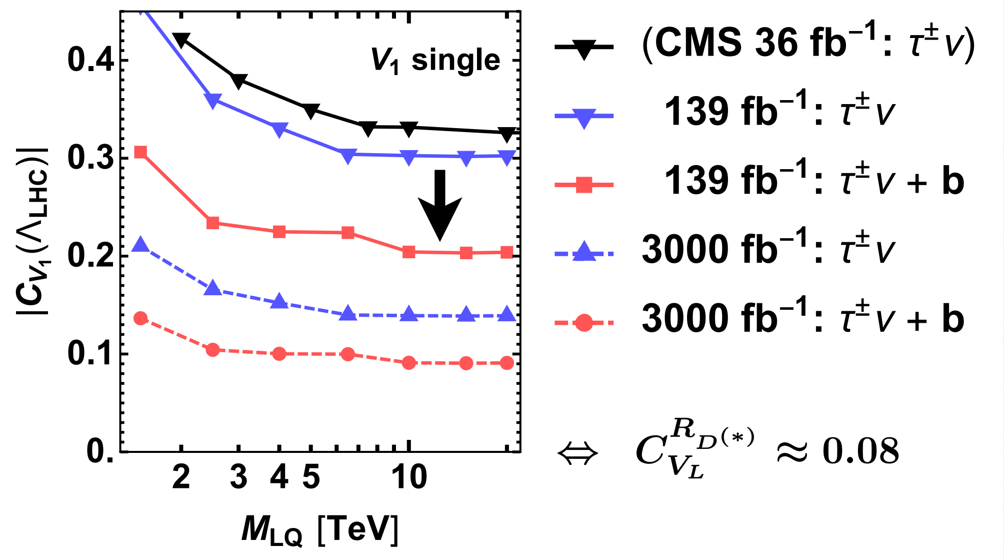
Collider signals

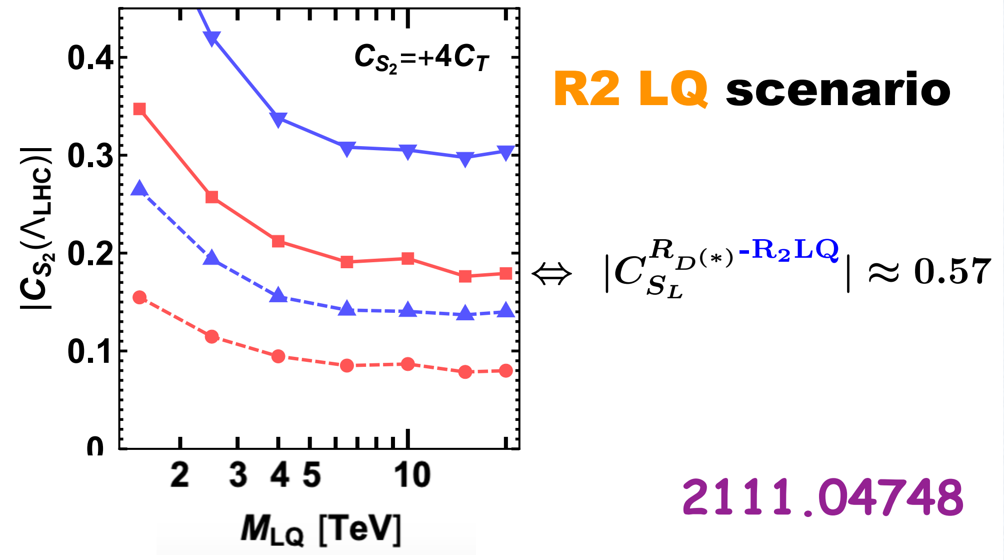
Proposal of improvement:

Requiring additional b-jet greatly improves NP sensitivity 2008.07541

➡ **comes from** $gq \to b\,\ell\,\nu \quad (q = u, c)$ **suppressed by |Vqb|^2 in the SM**

➡ **simulation shows +b search could improve the LHC bound by ~50%**





2111.04748

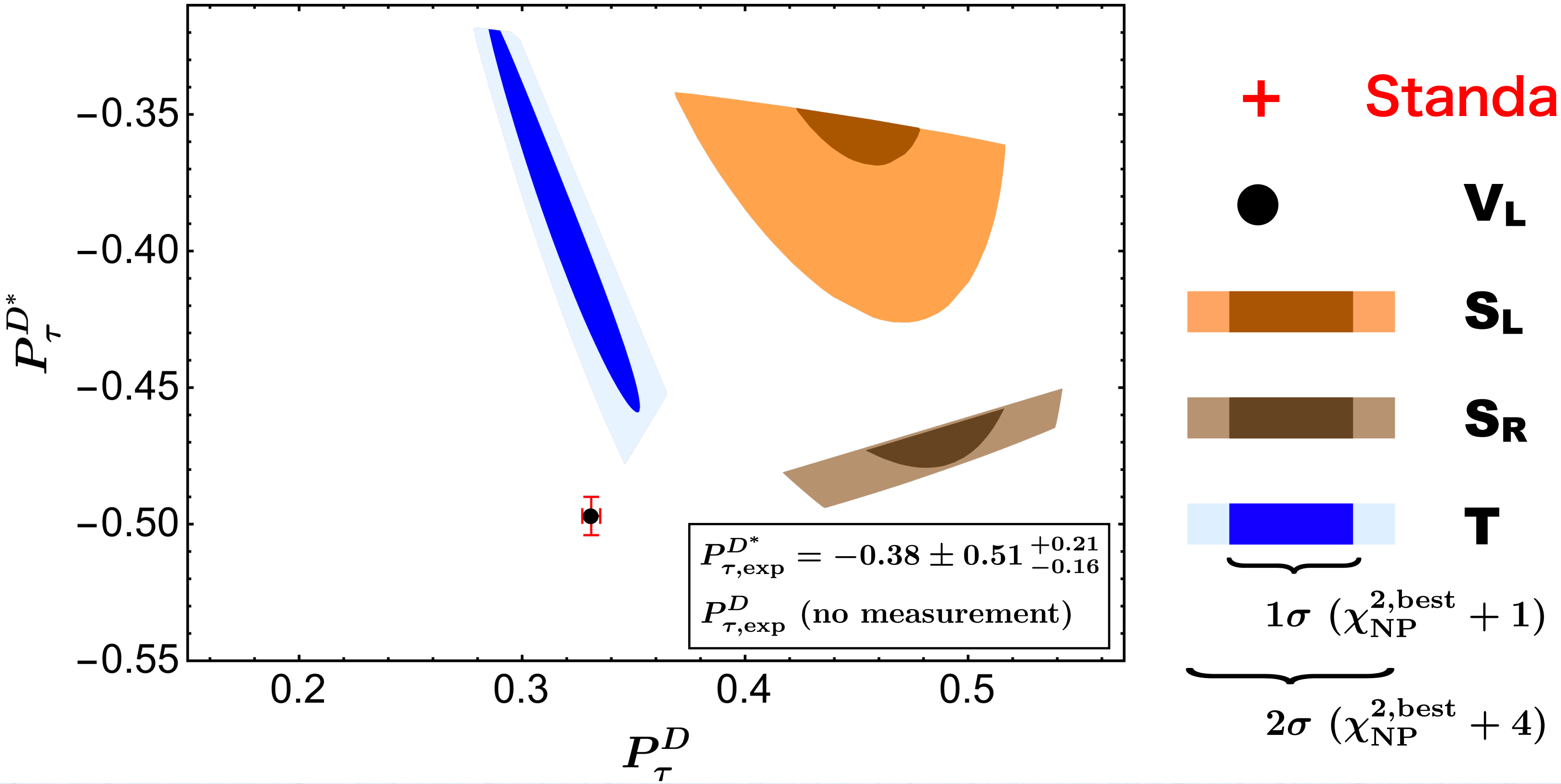
tau + b + missing search:

- **competitive with the V_L solution only with 3ab^-1**
- **can test the R2 LQ solution even with current 139 fb^-1 data**

New Physics: flavor signal

Flavor signals

Tau spin polarization:



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NP solutions for RD(*) anomaly predict distinct tau polarizations

➡ **could identify T/SL/SR solution (blue/yellow/brown)**

➡ **Current experimental measurement**

1709.00129 (Belle)

D* mode: $P^{D^*}_{\tau,\mathrm{exp}} = -0.38 \pm 0.51\ ^{+0.21}_{-0.16}$ **D mode: not measured yet**

Flavor signals

Λ_b decay:

Another R proposal from b-baryon: $R_{\Lambda_c} = \mathcal{B}(\Lambda_b \to \Lambda_c \, \tau \, \nu) \Big/ \mathcal{B}(\Lambda_b \to \Lambda_c \, \ell \, \nu)$

➡ **light lepton modes were measured by DELPHI/CDF/LHCb since 2004**

➡ **the first result for tau together with R was reported by LHCb** 2201.03497

$$R_{\Lambda_c}^{\rm LHCb} = 0.242 \pm 0.026 \pm 0.04 \pm 0.059 \quad \Leftrightarrow \quad R_{\Lambda_c}^{\rm SM} = 0.324 \pm 0.004$$

"Sum rule" has been found: 1811.09603, 1905.08253

➡ **Numerical NP formulae for the R ratios**

$$\frac{R_D}{R_D^{\rm SM}} = |1 + C_{V_L} + C_{V_R}|^2 + 1.01|C_{S_L} + C_{S_R}|^2 + 0.84|C_T|^2 + 1.49{\rm Re}[(1 + C_{V_L} + C_{V_R})(C_{S_L}^* + C_{S_R}^*)] + 1.08{\rm Re}[(1 + C_{V_L} + C_{V_R})C_T^*]$$

$$\frac{R_{D^*}}{R_{D^*}^{\rm SM}} = |1 + C_{V_L}|^2 + |C_{V_R}|^2 + 0.04|C_{S_L} - C_{S_R}|^2 + 16.0|C_T|^2 - 1.83{\rm Re}[(1 + C_{V_L})C_{V_R}^*] - 0.11{\rm Re}[(1 + C_{V_L} - C_{V_R})(C_{S_L}^* - C_{S_R}^*)] - 5.17{\rm Re}[(1 + C_{V_L})C_T^*] + 6.60{\rm Re}[C_{V_R}C_T^*] \,,$$

$$\frac{R_{\Lambda_c}}{R_{\Lambda_c}^{\rm SM}} = |1 + C_{V_L}|^2 + |C_{V_R}|^2 - 0.72\,{\rm Re}[(1 + C_{V_L})C_{V_R}^*] + 0.50\,{\rm Re}[(1 + C_{V_L})C_{S_R}^* + C_{V_R}C_{S_L}^*] + 0.33\,{\rm Re}[(1 + C_{V_L})C_{S_L}^* + C_{V_R}C_{S_R}^*] + 0.52\,{\rm Re}[C_{S_L}C_{S_R}^*] + 0.32\,(|C_{S_L}|^2 + |C_{S_R}|^2) - 3.11\,{\rm Re}[(1 + C_{V_L})C_T^*] + 4.88\,{\rm Re}[C_{V_R}C_T^*] + 10.4\,|C_T|^2 \,,$$

Flavor signals

Λ_b decay:

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R ratios are related (almost) independent of NP contributions:

$$\frac{R_{\Lambda_c}}{R_{\Lambda_c}^{\rm SM}} = (0.27 \pm 0.02)\frac{R_D}{R_D^{\rm SM}} + (0.73 \mp 0.02)\frac{R_{D^*}}{R_{D^*}^{\rm SM}} + \delta(C_X)$$

Significant point: $|\delta(C_X)| \ll 1 \quad (|C_X| < 1)$

RΛ_c that should be measured is predicted: $R_{\Lambda_c}^{\rm fit} = 0.370 \pm 0.017\big|_{R_X^{\rm SM,\ exp}} \pm (< 0.001)\big|_{\rm SR}$

➡ **inconsistent with** $R_{\Lambda_c}^{\rm LHCb} = 0.242 \pm 0.026 \pm 0.04 \pm 0.059$

➡ **potentially another problem if LHCb result is confirmed in future**

Summary

History of RD(*)

Big update in 2019 / New results 2023-24 give limited impact

SM predictions

RD: stable due to limited input / RD*: needs general consensus

New Physics: status

Several NPs give good solutions but indistinguishable

New Physics: collider bound

Charged Higgs: viable only in limited mass range (mt ~ 400GeV)

Leptoquark: viable but testable at HL-LHC or with + b jet

New Physics: flavor signal

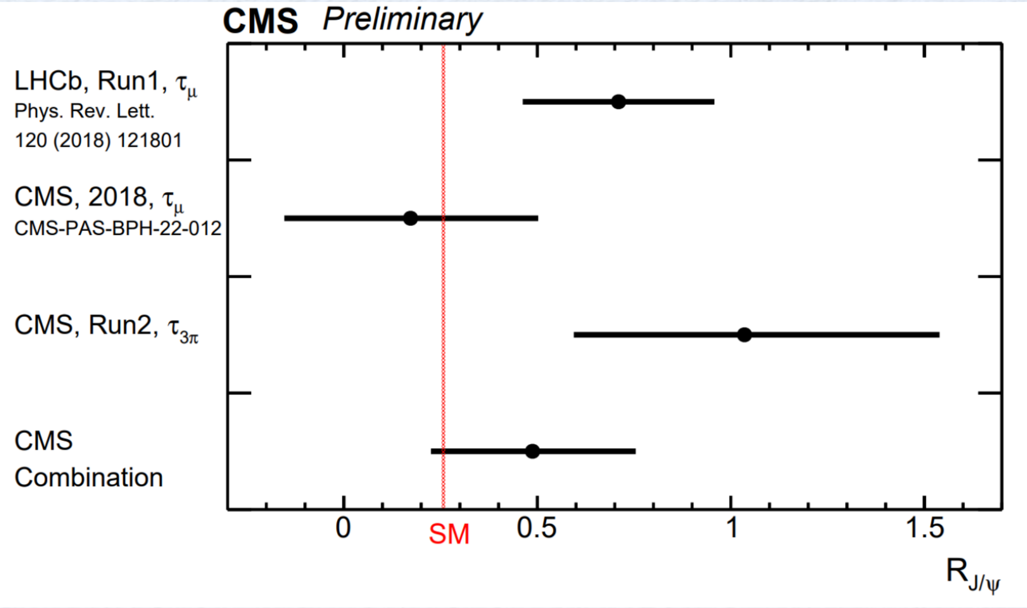
Measure tau polarization / Check $R_{\Lambda c}$ by sum rule

Backup

Flavor signals

B_c decay:

The "R" observable for Bc: $R_{J/\psi} = \mathcal{B}(B_c \to J/\psi\,\tau\,\nu)\Big/\mathcal{B}(B_c \to J/\psi\,\mu\,\nu)$



https://cms.cern/news/cms-and-quest-preferred-lepton-flavor

$\text{SM (2017)}: 0.28 \pm 0.05$ 1709.08644

$\text{SM (2019)}: 0.24 \pm 0.01$ 1901.08368

$\text{SM (2022)}: 0.258 \pm 0.004$ 2204.04357

— FF updated: 2007.06957

➡ QCD (2017) / SR (2019) / lattice (2020)

➡ deviations affected the SM value

— Strong relation with the RD*:

$$\frac{R_{J/\psi}}{R^{\rm SM}_{J/\psi}} \simeq \frac{R_{D^*}}{R^{\rm SM}_{D^*}}$$

— Consistency:

$$\frac{R^{\rm exp}_{J/\psi}}{R^{\rm SM}_{J/\psi}} - \frac{R^{\rm exp}_{D^*}}{R^{\rm SM}_{D^*}} = 1.25 \pm 0.78$$

— Private combination:

$$R^{\rm CMS+LHCb}_{J/\psi} = 0.61 \pm 0.18$$

➡ too large error to include NP fit analysis

Flavor signals

B_c lifetime:

excluded the scalar NP solution (SLL):

— **Difference in experiment/theory is room for NP contribution** hep-ph/9601249, 1611.06676

$$[\tau_{B_c}^{\rm exp} \approx 0.5{\rm ps}] \text{ vs. } [0.4{\rm ps} < \tau_{B_c}^{\rm th} < 0.7{\rm ps}] \quad \Rightarrow \quad {\rm Br}(B_c \to \underbrace{\text{induced by NP}}_{\tau\nu}) < 30\%$$

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$\tau\nu$

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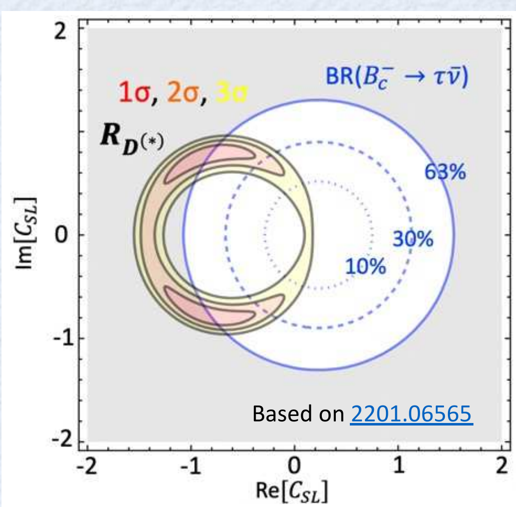
— **The present calculation (OPE) is sensitive to charm mass input**

➡ **1811.09603 pointed out a conservative bound should be <60%**

➡ **2105.02988 provides update concerning charm mass: th. could reach <1.0ps (<50%)**

➡ **theory calculation is not conclusive, need further update...**



2201.06565

— **This update significantly affects the SLL scenario**

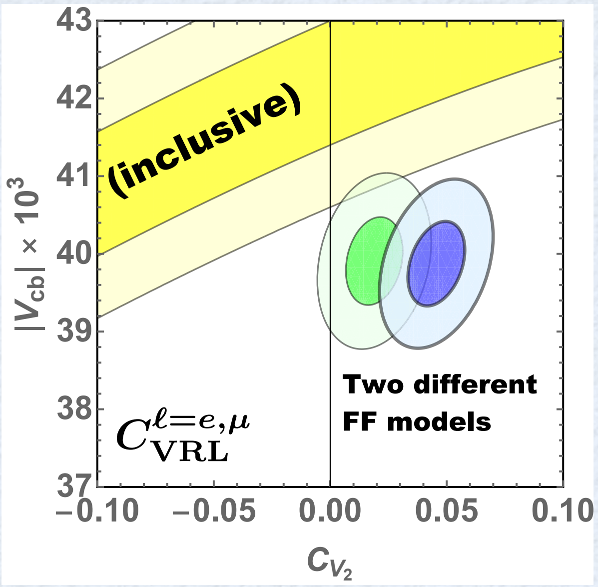
➡ **Scalar type solution revived, but on the edge!**

➡ **Type-III charged Higgs is now viable!**

➡ **Good news for several LQ scenarios as well**

NP in the light lepton modes?

Simultaneous fit of FF + Vcb + NP in $B \to D^{(*)}\mu\nu\,,\ D^{(*)}e\nu$



2004.10208 (RW)

— **assuming LFU type NP in e/μ:** $C^e_X = C^\mu_X$

— **taking Belle full angular data (2017,2018) & all available theory**

— **NP can be hidden behind the Vcb measurement**

➡ **possible size is < 5% of the "SM size"** $\equiv 2\sqrt{2}G_F V_{cb}$

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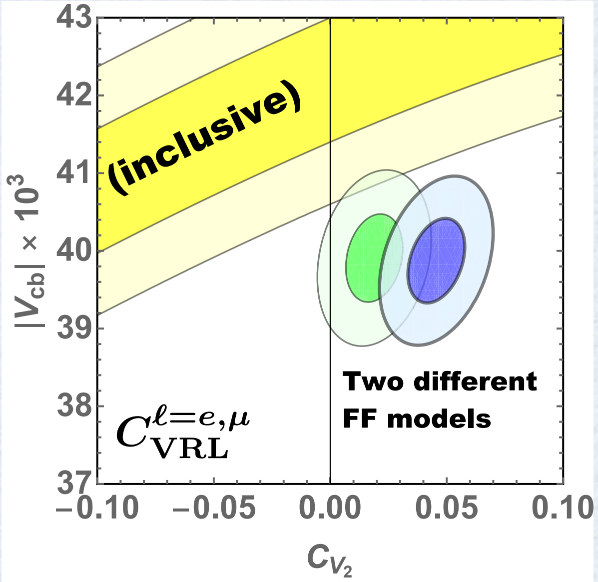

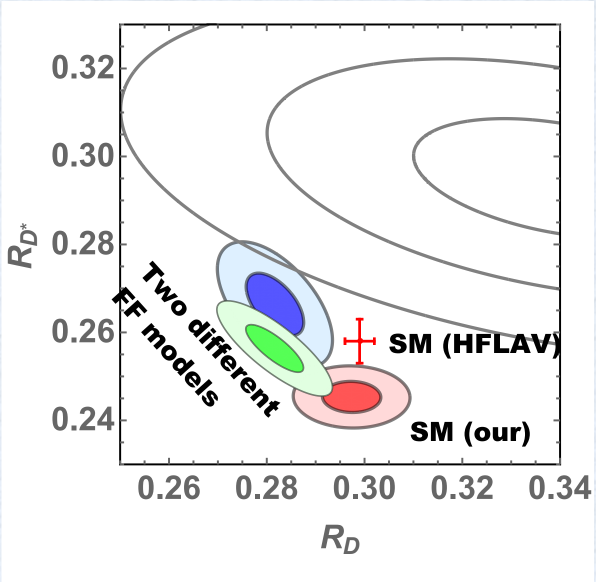

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➡ **RD* increases while RD decreases in case of VRL type NP**

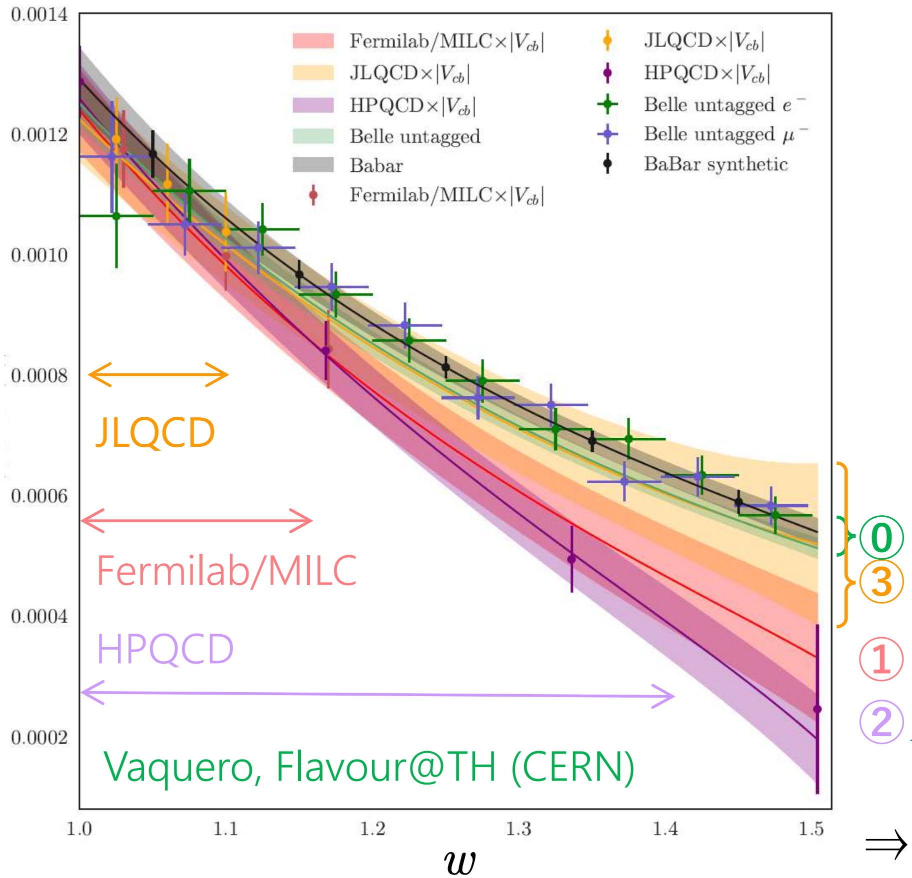
Lattice results competition

Vaquero [WG1+2] Tue 18:03

Colquhoun [WG2+3] Thu 18:50

tension on $B \to D^* \ell \nu$

$$|\eta_{EW} V_{cb} \mathcal{F}|^2 \qquad \mathcal{F}^2 \propto \left[2 \frac{1-2wr+r^2}{(1-r)^2} \left\{ 1 + \frac{w-1}{w+1} R_1^2 \right\} + \left\{ 1 + \frac{w-1}{1-r} (1-R_2) \right\}^2 \right] h_{A_1}^2 \quad R_1 = \frac{h_V}{h_{A_1}}, \quad R_2 = \frac{h_{A_3} + r h_{A_2}}{h_{A_1}}$$



⓪ Belle and BaBar data

① Fermilab/MILC : steeper slope ?

+ χ^2/dof ~ 1.5 to fit w/ exp data

② HPQCD : even steeper slope !

+ siginifcant tension with exp ($\ell = e, \mu$) at medium/large w

+ $|V_{cb}|$ = 44.2(1.8) × 10^{-3} from total Γ

③ JLQCD : good consistency w/ exp

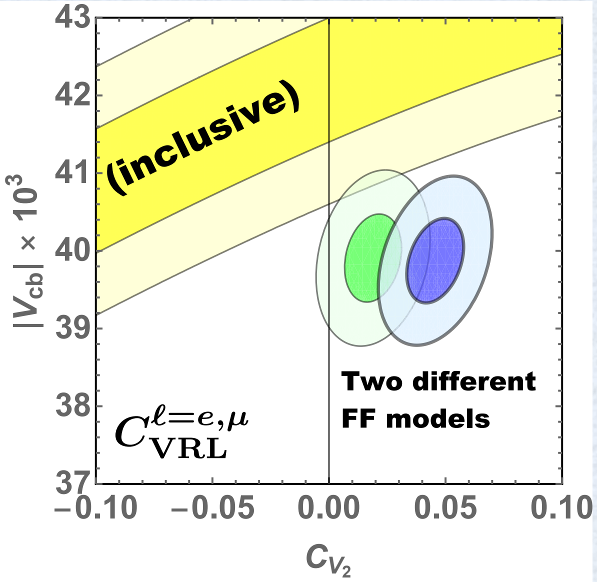
– tension on R_2 (?) [Belle 2301.07529, Jung Flavour@TH]

– small recoils [JLQCD, Fermilab/MILC] ⇔ larger ap [HPQCD]

⇒ "safe" extension to large w: JLQCD; Fermilab/MILC a^{-1}~6.6GeV

NP in the light lepton modes?

(1) Simultaneous fit of FF + Vcb + NP in $B \to D^{(*)}\mu\nu\,,\; D^{(*)}e\nu$



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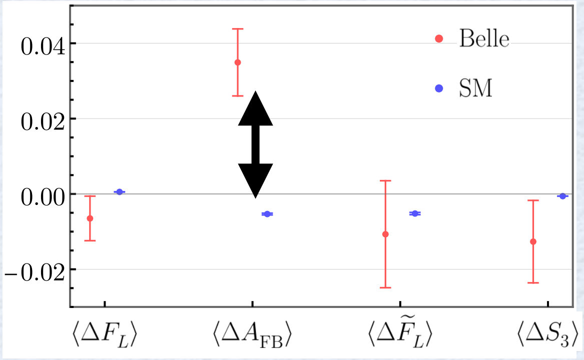

2104.02094, 2203.07189

— using Belle 2018 data, angular asymmetries can be constructed

— "anomaly" was observed in the FB asymmetry between e/μ

➡ Single NP operators difficult / Tuned NP couplings needed

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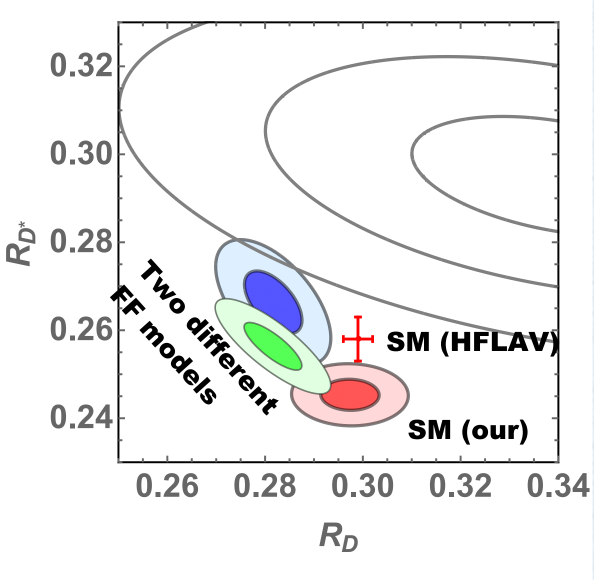

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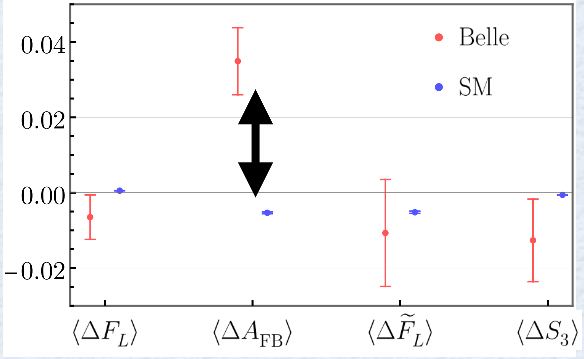

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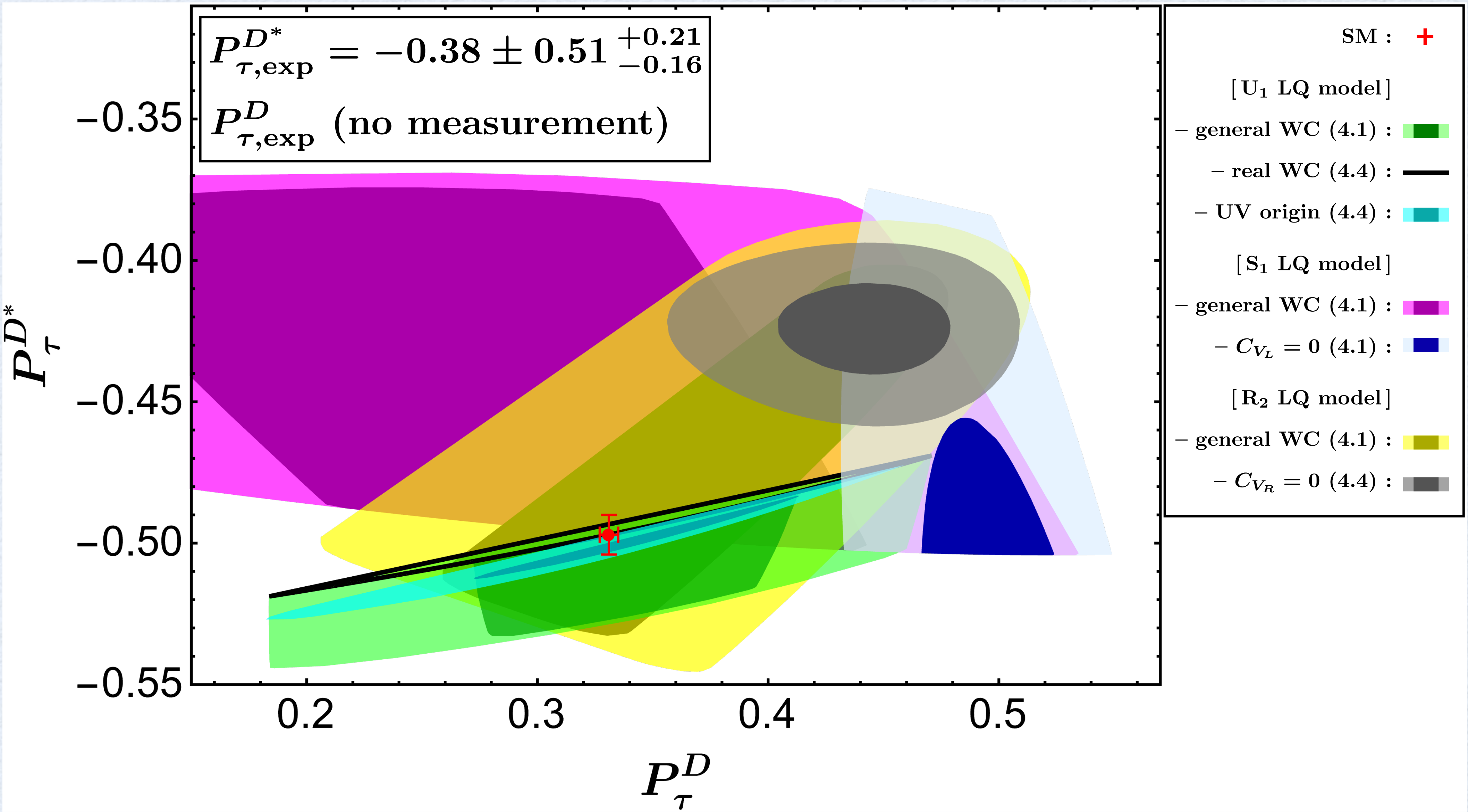
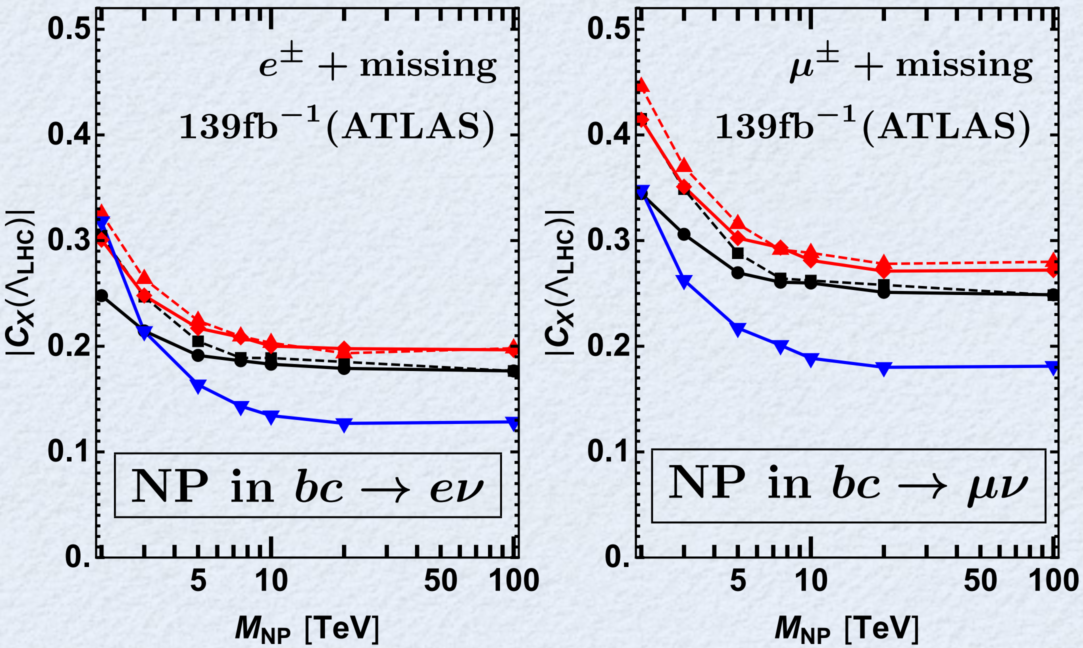
Tau Polarization for LQ scenarios



Mediator (LQ) mass dependence:



(WC definition)

V1 $2\sqrt{2}G_F V_{cb}\Big[C_{V_1}(\bar{c}\gamma^{\mu}P_L b)(\bar{\ell}\gamma_{\mu}P_L\nu)$

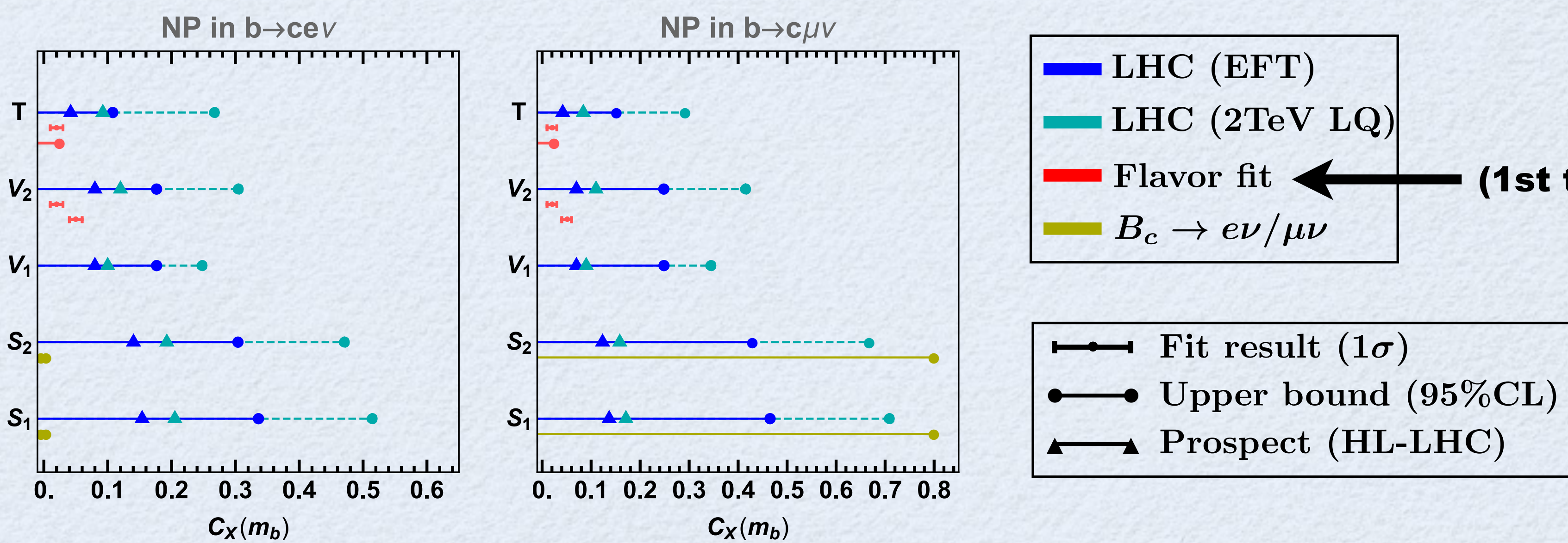
V2 $+C_{V_2}(\bar{c}\gamma^{\mu}P_R b)(\bar{\ell}\gamma_{\mu}P_L\nu)$

S1 $+C_{S_1}(\bar{c}P_R b)(\bar{\ell}P_L\nu)$

S2 $+C_{S_2}(\bar{c}P_L b)(\bar{\ell}P_L\nu)$

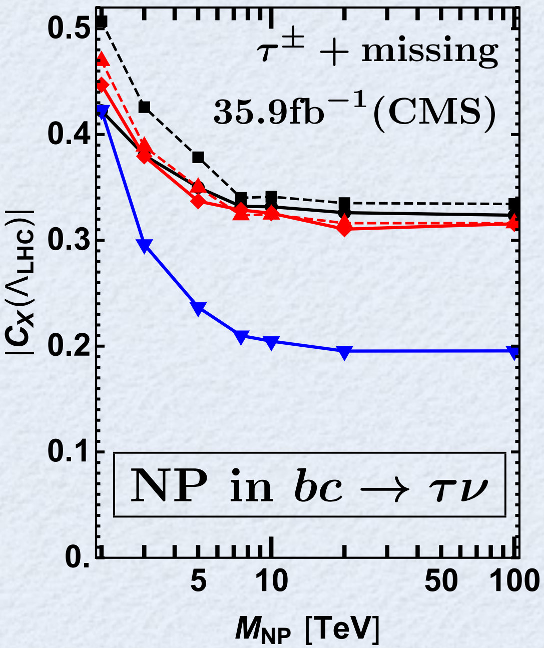
T $+C_T(\bar{c}\sigma^{\mu\nu}P_L b)(\bar{\ell}\sigma_{\mu\nu}P_L\nu)\Big]$

Impact on Flavor (Vcb+NP fit):



(1st topic)

The tau case:



EFT) $|C_T|_{\rm LHC} < 0.20$ (95%CL) $\leftrightarrow$ $|C_T|_{R_{D^{(*)}}} \approx |0.15 + i\,0.19| = 0.24$

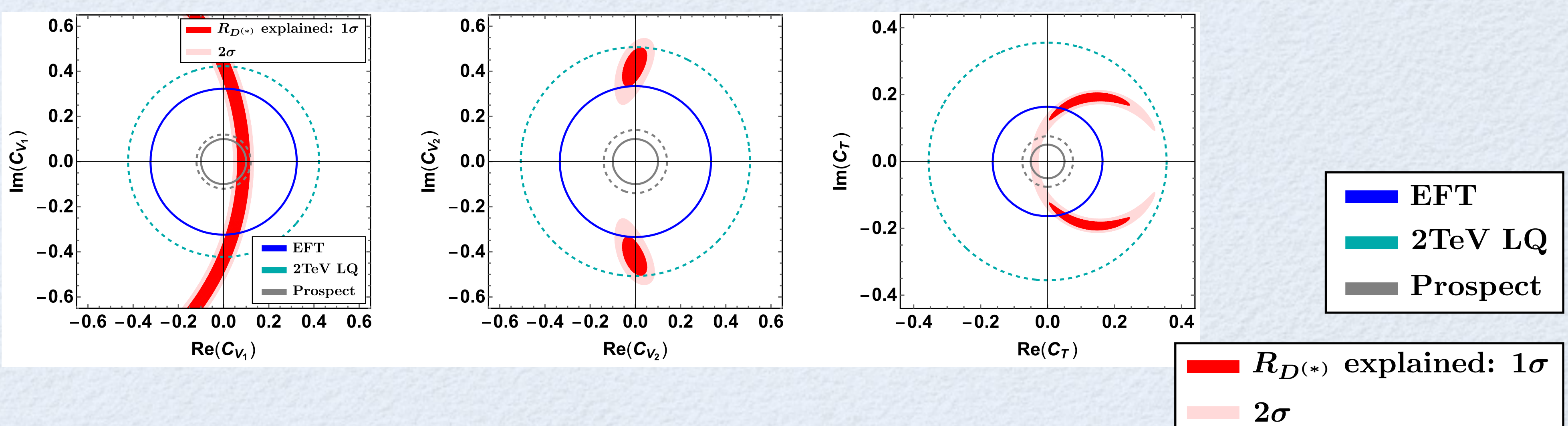
LQ) $|C_T|_{\rm LHC} < 0.42$ (95%CL)

(Summary)

2TeV LQ: EFT bound is 40~100% overestimated

5TeV LQ: 10~20% overestimated

Impact on Flavor (RD(*) anomaly):

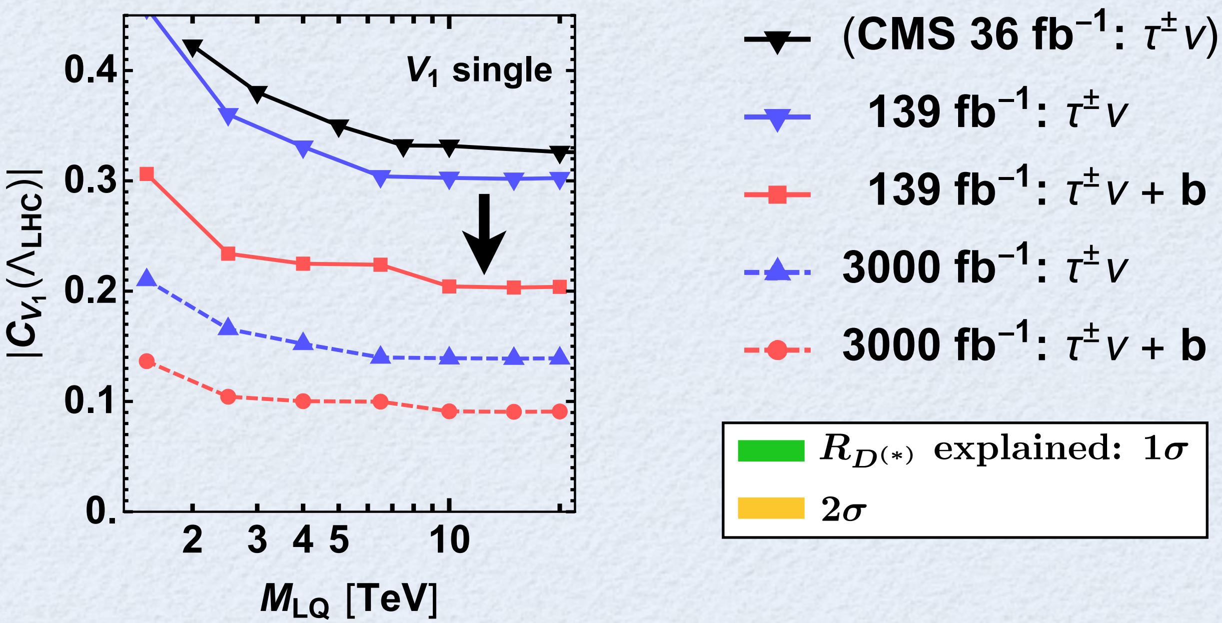


+ b-jet tag

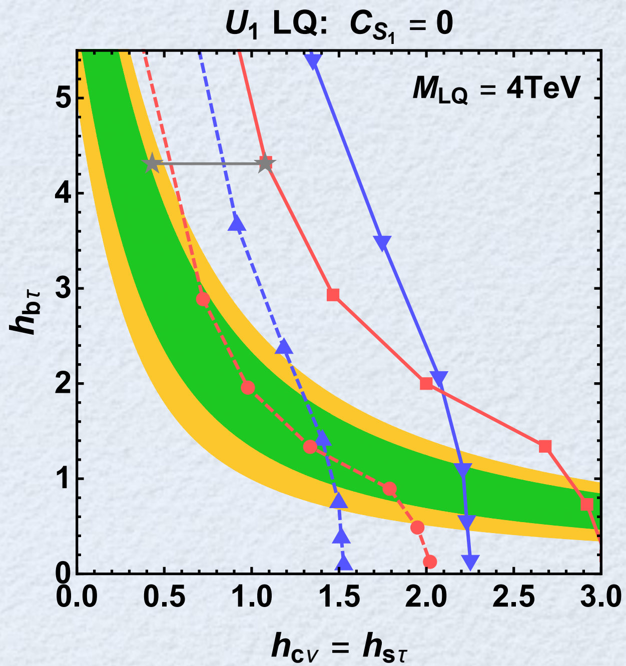
2111.104748

(BG/Signal events generated & simulated: details skipped)

Improvement ①:



Improvement ②:



Observations:

- **+b search improves the bound by ~50%**
- **+b search at HL_LHC can achieve Cx~0.1, i.e. 10% NP effect**
- **Given the LQ mass, the two couplings (not combination) are constrained**