New physics search with angular distribution of B→D*l v decay

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For l=e, mu

&

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For l=tau

Outline

Introduction

- Angular distribution and new physics search
- Form factor dependence

The impact of the new lattice data

- Fermilab and JLQCD result on the form factors
- Impacts of the lattice results

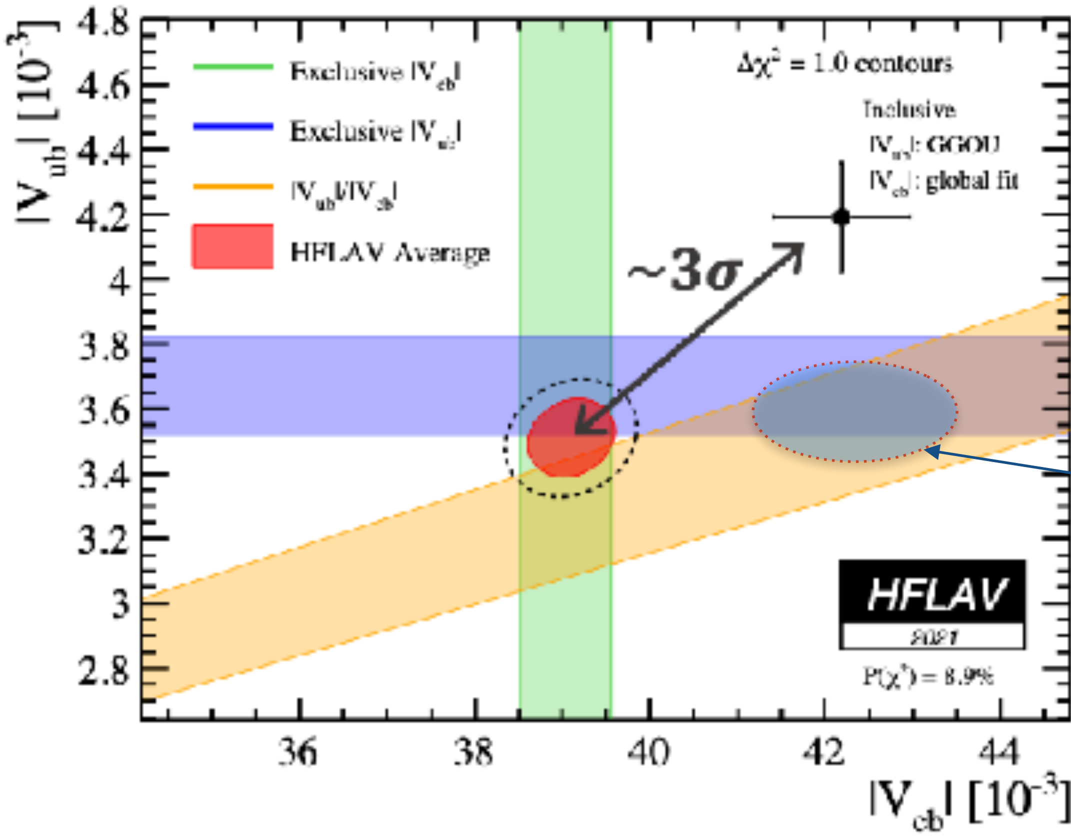
New Physics fit of experimental data including lattice data

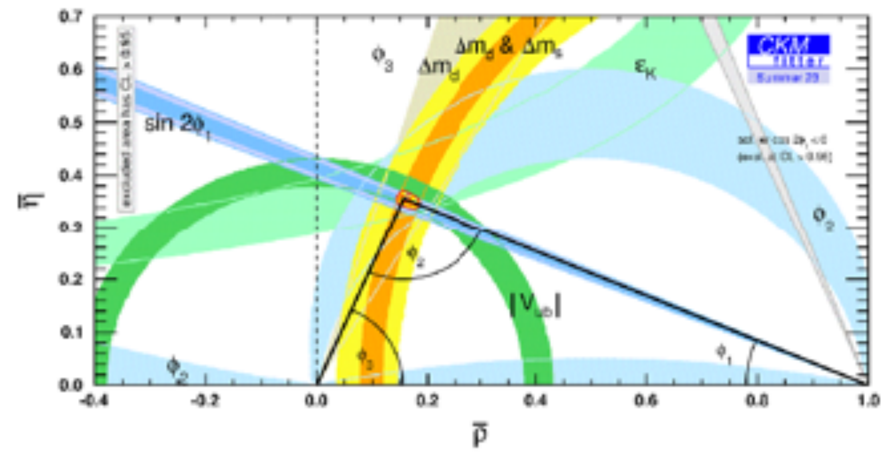
- Toy study of unbanned analysis

Conclusions

Introduction

Introduction: B→D*l ν decay (l=e,mu)





CKM constraint

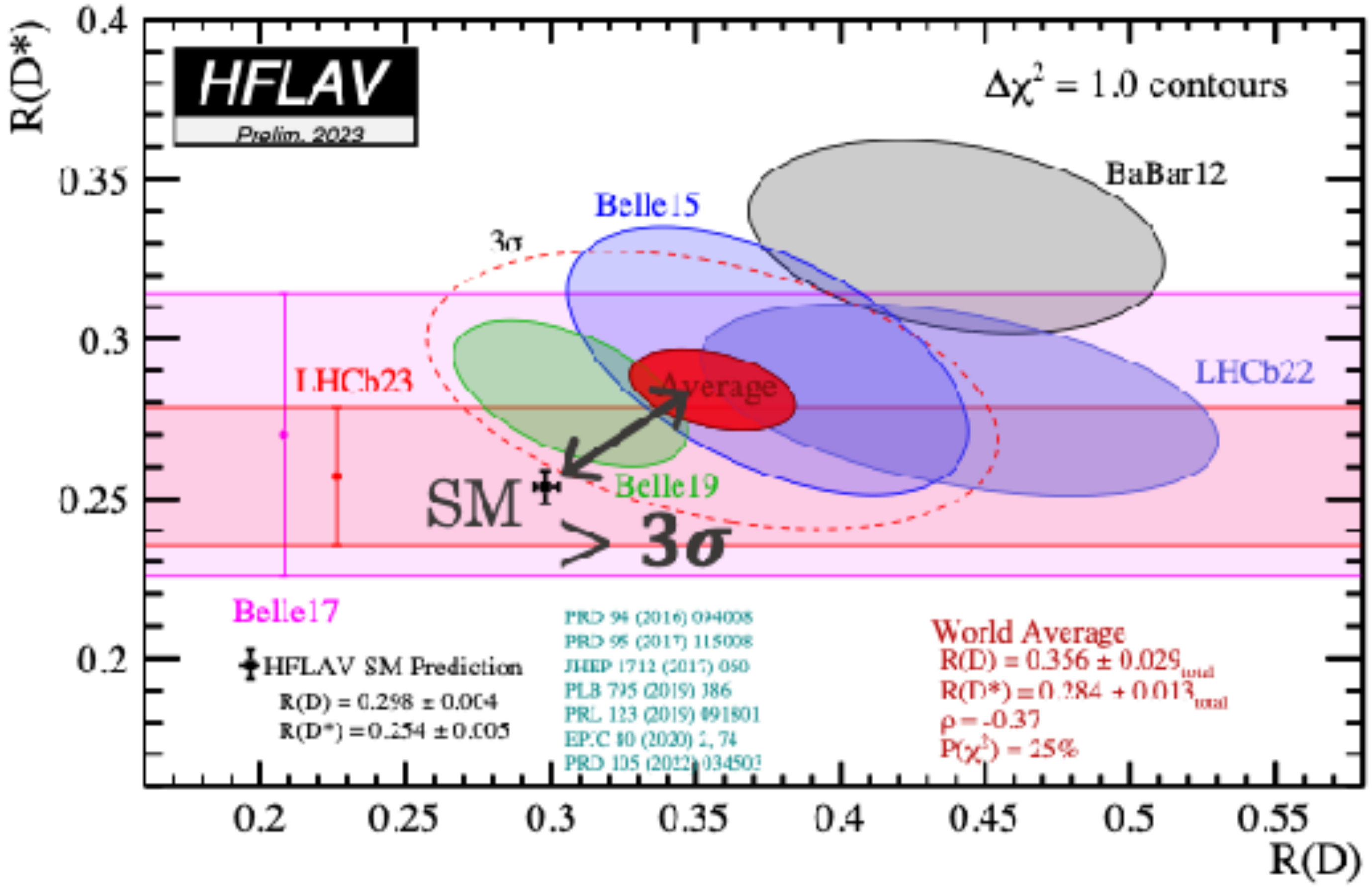
$\lvert V_{ub}\rvert$ (meas. not in the fit)	0.003601 [+0.000101 -0.000095]	0.00360 [+0.00021 -0.00022]	0.00360 [+0.00033 -0.00030]
$\lvert V_{cb}\rvert$ (meas. not in the fit)	0.04235 [+0.00074 -0.00069]	0.0424 [+0.0012 -0.0018]	0.0424 [+0.0016 -0.0023]

Vcb(-Vub) puzzle:

- The observed discrepancy between exclusive and inclusive determination of Vcb (&Vub)
- CKM goal fit points Vcb inclusive measurement: problem in Vcb exclusive???
- Difficult to judge due to hadronic uncertainties...

➠ Motivation for angular analysis!

Introduction: B→D*l ν decay (l=tau)

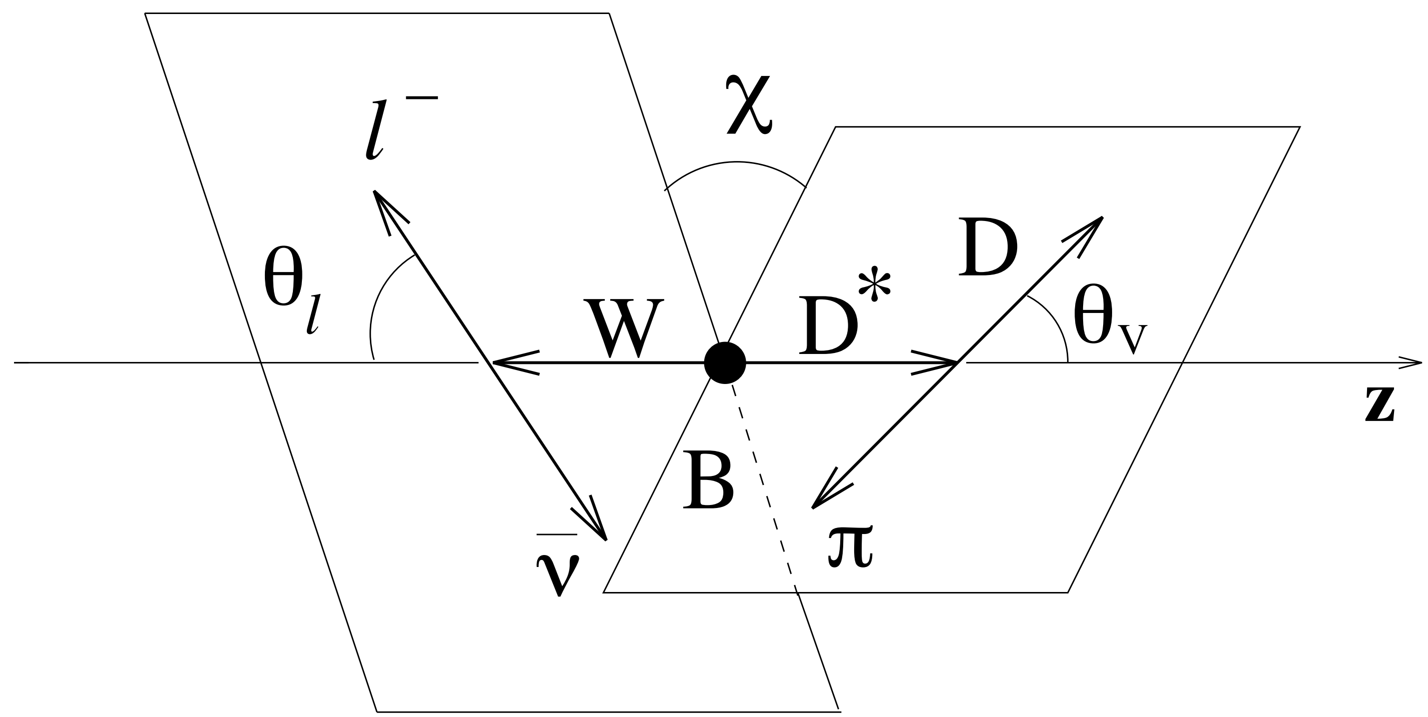


$$R(D^{(*)}) = \frac{\mathcal{B}(\bar{B} \to D^{(*)}\tau^- \bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D^{(*)}\ell^- \bar{\nu}_\ell)}, (\ell = e \text{ or } \mu)$$

R(D)-R(D*) anomaly:

- $R(D^{(*)})$ is hadronic uncertainty FREE observable
- Thus, the observed anomaly is very intriguing
- Tau decays with missing energy: challenge for experiment

Introduction: angular distribution



<u>Angular distribution is a powerful tool for new physics search:</u>

- It can probe the different Dirac structure
- Some observables are hadronic uncertainty FREE (unlike branching ratio measurement)
- Interesting challenge for experiment!

Angular analysis for |Vcb| fit (SM)

B→D*l v decay (l=e,mu): angular analysis

In SM:

$$\frac{d\Gamma(B^0 \to D^{*-}\ell^+\nu_\ell)}{dw\,d\cos\theta_\ell\,d\cos\theta_{\rm v}\,d\chi} =$$

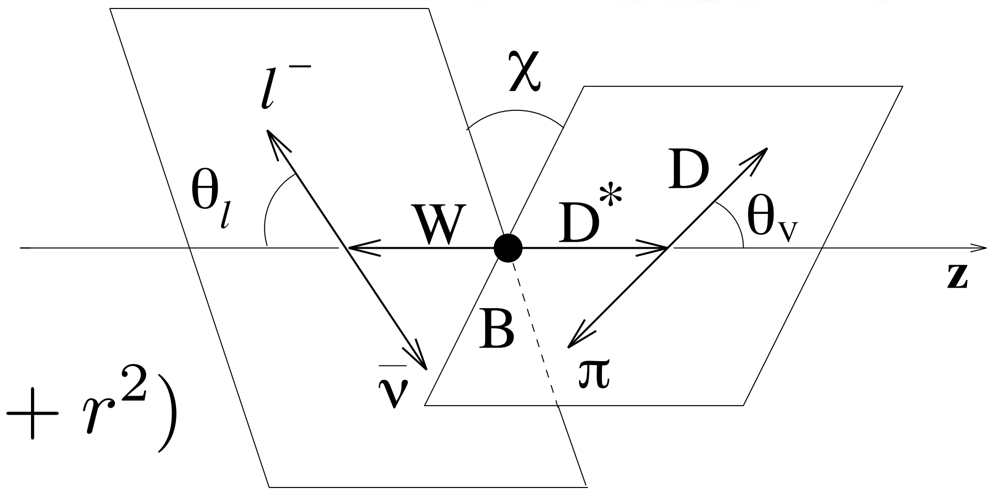
$$\frac{\eta_{\rm EW}^2 3 m_B m_{D^*}^2}{4(4\pi)^2} G_F^2 |V_{cb}|^2 \sqrt{w^2-1}(1-2wr+r^2)$$

$$\{(1-\cos\theta_\ell)^2 \sin^2\theta_{\rm v} H_+^2(w) + (1+\cos\theta_\ell)^2 \sin^2\theta_{\rm v} H_-^2(w)$$

$$+4\sin^2\theta_\ell \cos^2\theta_{\rm v} H_0^2 - 2\sin^2\theta_\ell \sin^2\theta_{\rm v} \cos 2\chi H_+(w) H_-(w)$$

$$-4\sin\theta_\ell(1-\cos\theta_\ell)\sin\theta_{\rm v}\cos\theta_{\rm v}\cos\chi H_+(w) H_0(w)$$

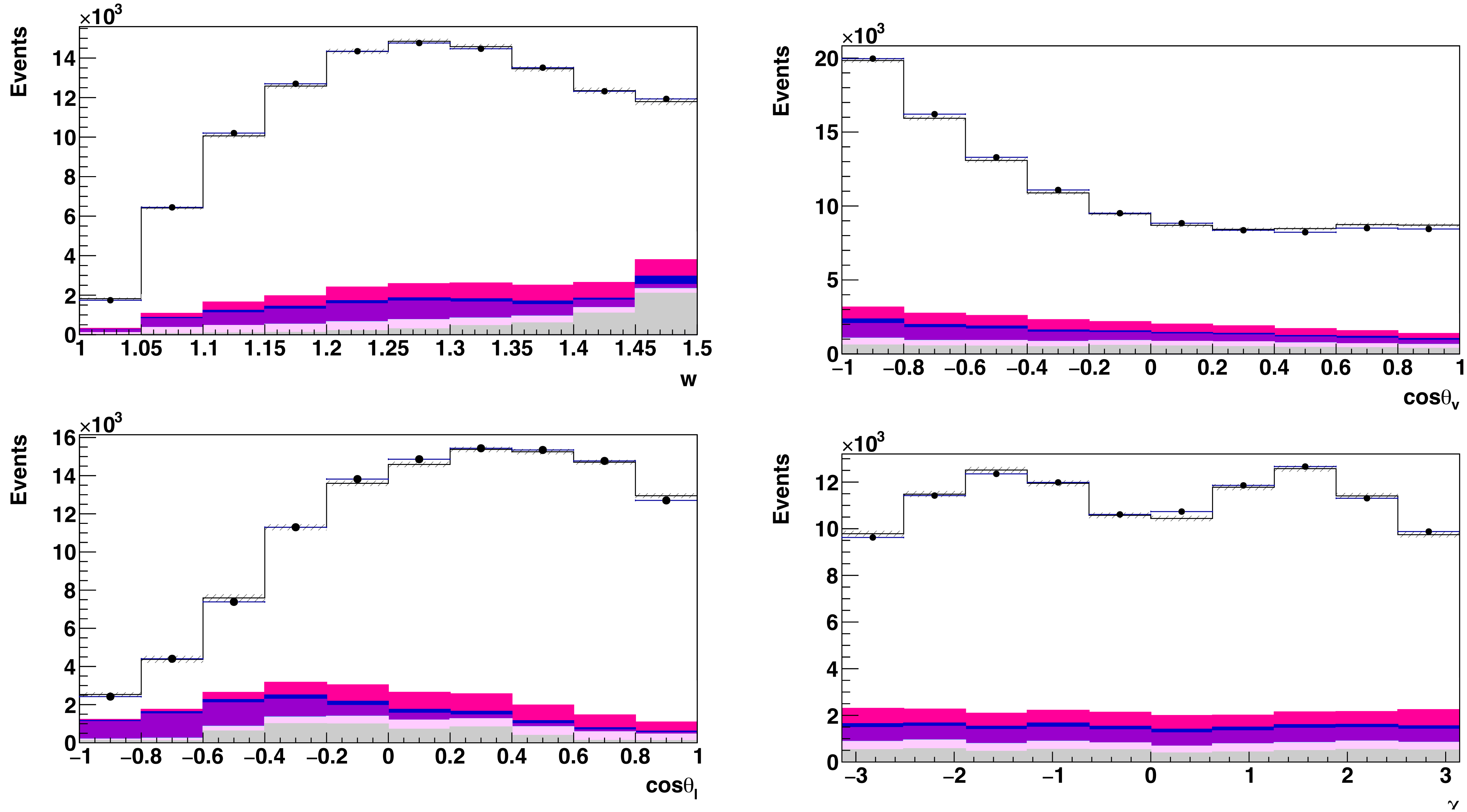
$$+4\sin\theta_\ell(1+\cos\theta_\ell)\sin\theta_{\rm v}\cos\theta_{\rm v}\cos\chi H_-(w) - H_0(w)\}$$



$$H_\pm = (M_B + M_{D^*}) A_1(q^2) \mp \frac{\sqrt{\lambda_{D^*}(q^2)}}{M_B + M_{D^*}} V(q^2)$$

$$H_0 = \frac{M_B + M_{D^*}}{2M_{D^*}\sqrt{q^2}} \left[-(M_B^2 - M_{D^*}^2 - q^2) A_1(q^2) + \frac{\lambda_{D^*}(q^2)}{(M_B + M_{D^*})^2} A_2(q^2) \right]$$

B→D*l ν decay (l=e,mu): Belle (SM) analysis



- 1 dimensional binned analysis
- SM is assumed
- Simultaneous fit of form factors and Vcb (one lattice input needed)

Belle PRD 103, ‘21

B→D*l v decay (l=e,mu): angular analysis

In SM:

$$\frac{d\Gamma(B^0 \to D^{*-}\ell^+\nu_\ell)}{dw\,d\cos\theta_\ell\,d\cos\theta_{\rm v}\,d\chi} =$$

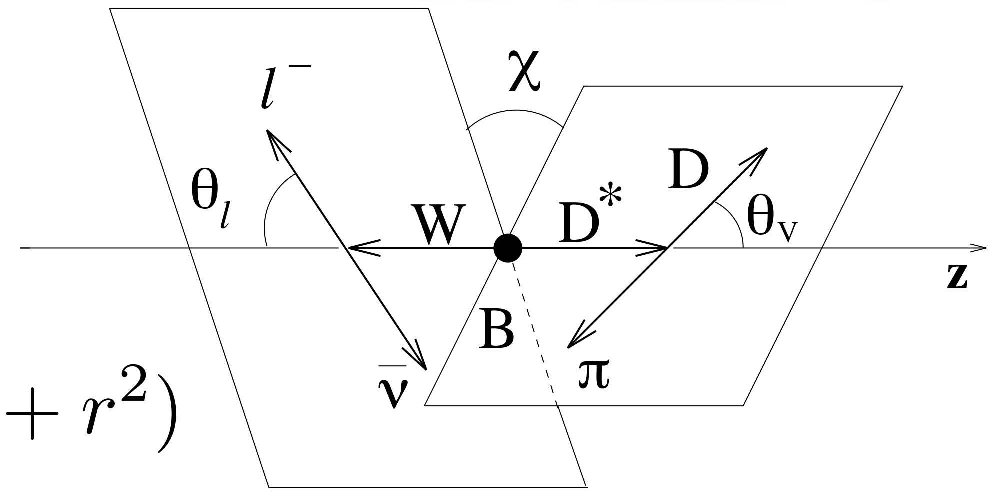
$$\frac{\eta_{\rm EW}^2 3 m_B m_{D^*}^2}{4(4\pi)^2} G_F^2 |V_{cb}|^2 \sqrt{w^2-1}(1-2wr+r^2)$$

$$\{(1-\cos\theta_\ell)^2\sin^2\theta_{\rm v} H_+^2(w) + (1+\cos\theta_\ell)^2\sin^2\theta_{\rm v} H_-^2(w)$$

$$+4\sin^2\theta_\ell\cos^2\theta_{\rm v} H_0^2 - 2\sin^2\theta_\ell\sin^2\theta_{\rm v}\cos 2\chi H_+(w)H_-(w)$$

$$-4\sin\theta_\ell(1-\cos\theta_\ell)\sin\theta_{\rm v}\cos\theta_{\rm v}\cos\chi H_+(w)H_0(w)$$

$$+4\sin\theta_\ell(1+\cos\theta_\ell)\sin\theta_{\rm v}\cos\theta_{\rm v}\cos\chi H_-(w) - H_0(w)\}$$

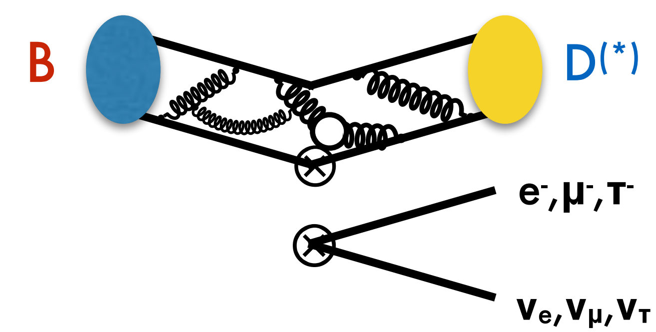


$$H_\pm = (M_B + M_{D^*})A_1(q^2) \mp \frac{\sqrt{\lambda_{D^*}(q^2)}}{M_B + M_{D^*}} V(q^2)$$

$$H_0 = \frac{M_B + M_{D^*}}{2M_{D^*}\sqrt{q^2}}\left[-(M_B^2 - M_{D^*}^2 - q^2)A_1(q^2) + \frac{\lambda_{D^*}(q^2)}{(M_B+M_{D^*})^2}A_2(q^2)\right]$$

B→D*l ν decay : hadronic form factor

- BGL parameterisation



$$g = \frac{2}{M_B + M_{D^*}} V$$

$$f = (M_B + M_{D^*}) A_1$$

$$\mathcal{F}_1 = \frac{1}{2M_{D^*}} \left[(M_B^2 - M_{D^*}^2 - q^2)(M_B + M_{D^*}) A_1 - \frac{4M_B^2 |\vec{p}_{D^*}|^2}{M_B + M_{D^*}} A_2 \right]$$

$$\mathcal{F}_2 = 2A_0$$

$$q^2 = (p_B - p_{D^*})^2$$

Boyd, Grinstein Lebed
PRD56, '97

$$w \equiv \frac{M_B^2 + M_{D^*}^2 - q^2}{2M_B M_{D^*}} \qquad z \equiv \frac{\sqrt{w+1} - \sqrt{2}}{\sqrt{w+1} + \sqrt{2}}$$

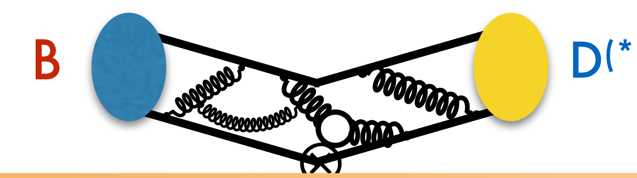
- BGL parameterisation: generic momentum expansion

$$g(z) = \frac{1}{P_{1-}(z)\phi_g(z)} \sum_{n=0}^{\infty} a_n^g z^n, \qquad f(z) = \frac{1}{P_{1+}(z)\phi_f(z)} \sum_{n=0}^{\infty} a_n^f z^n,$$

$$\mathcal{F}_1(z) = \frac{1}{P_{1+}(z)\phi_{\mathcal{F}_1}(z)} \sum_{n=0}^{\infty} a_n^{\mathcal{F}_1} z^n, \qquad \mathcal{F}_2(z) = \frac{1}{P_{0-}(z)\phi_{\mathcal{F}_2}(z)} \sum_{n=0}^{\infty} a_n^{\mathcal{F}_2} z^n,$$

B→D*l ν decay : hadronic form factor

- BGL parameterisation



$g = \frac{2}{\ldots} V$

$\mathcal{F}$

$\mathcal{F}$

- In '14, Fremilab published one form factor at w=1 limit
- In '21-'23, Femilab/JLQCD/HPQCD published 4 form factors at NON w=1 limit.

Boyd, Grins

PRD5

- BGL p

$$g(z) = \frac{1}{P_{1-}(z)\phi_g(z)} \sum_{n=0}^{\infty} a_n^g z_n, \qquad f(z) = \frac{1}{P_{1+}(z)\phi_f(z)} \sum_{n=0}^{\infty} a_n^f z^n,$$

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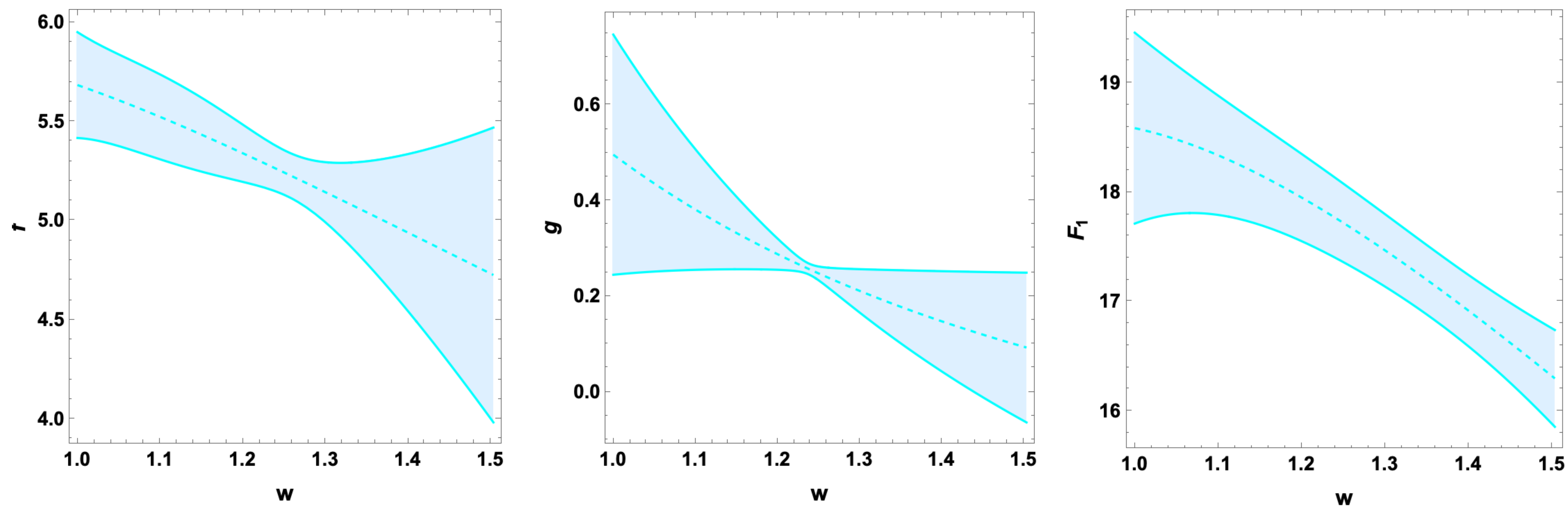
Hadronic form factor and new lattice results

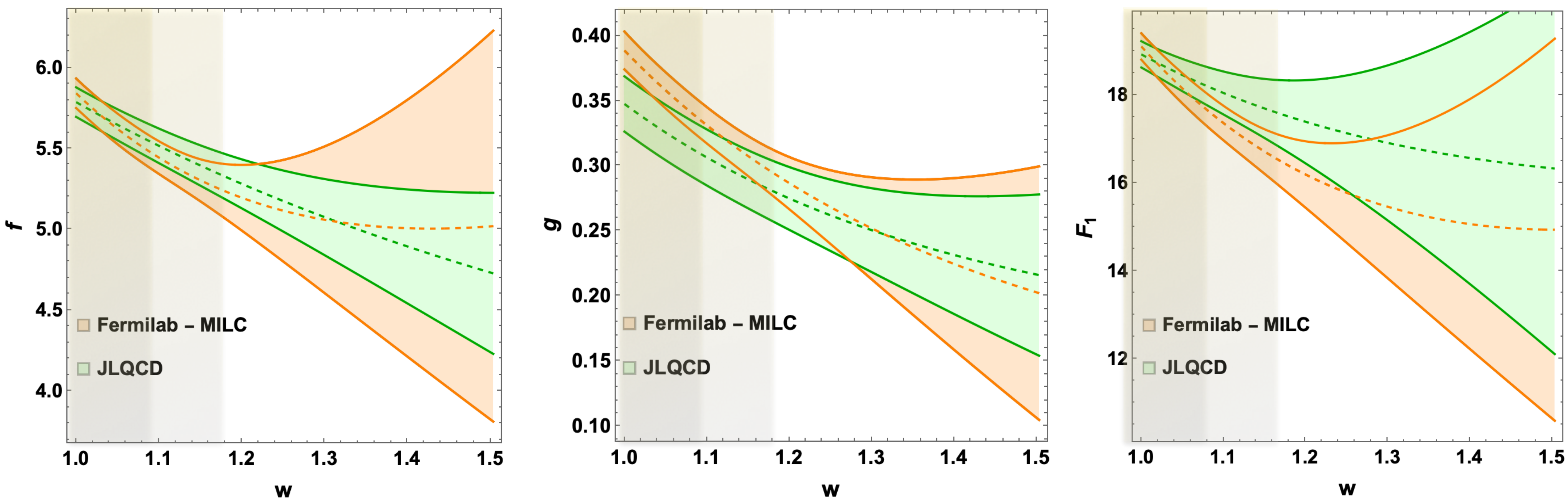
B→D*l ν decay (l=e,mu): Belle (SM) analysis



- Belle data fit
- Here we don't use any lattice so no Vcb constraint
- In the plot, we scaled it with $|V_{cb}|\eta_{EW}$=0.039

Form factor	Value
$\tilde{a}_0^f$	0.000459(9)(20)
$\tilde{a}_1^f$	0.0017(13)(13)
$\tilde{a}_2^f$	−0.013(43)(32)
$\tilde{a}_0^g$	0.0016(6)(5)
$\tilde{a}_1^g$	−0.019(24)(21)
$\tilde{a}_2^g$	−0.02(17)(17)
$\tilde{a}_1^{\mathcal{F}_1}$	−0.0003(1)(1)
$\tilde{a}_2^{\mathcal{F}_1}$	−0.0028(19)(16)

B→D*l ν decay : Lattice QCD

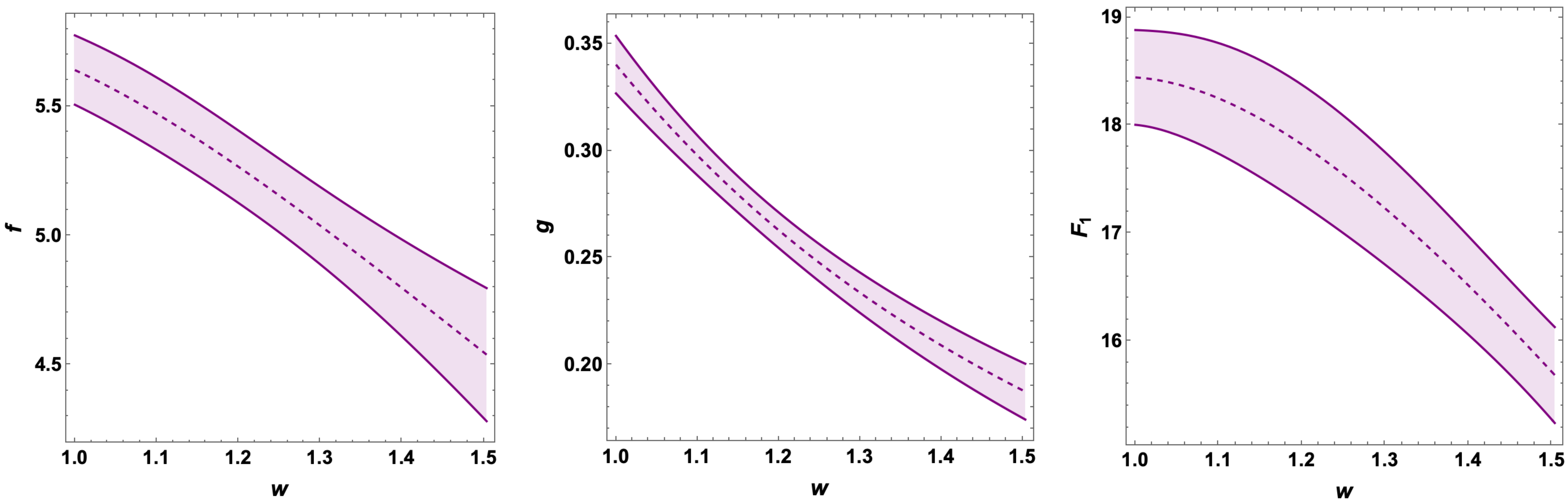


- Fremilab: w=1.03,1.10, 1.17
- JLQCD: w=1.025, 1.05, 1.10
- We extrapolate with the 2nd order BGL parameterisation

Fermilab-Milk: EPJC82, ‘22
JLQCD: arXiv:2306.05657

Form factor	JLQCD	FM
a_0^f	$0.01197(19)$	$0.01209(19)$
a_1^f	$0.020(11)$	$-0.012(20)$
a_2^f	$0.00(49)$	$0.8(14)$
a_0^g	$0.0294(18)$	$0.0329(12)$
a_1^g	$-0.057(51)$	$-0.15(10)$
a_2^g	$1.0(31)$	$0.9(55)$
$a_1^{\mathcal{F}_1}$	$0.0010(42)$	$-0.0080(38)$
$a_2^{\mathcal{F}_1}$	$0.04(21)$	$0.14(23)$

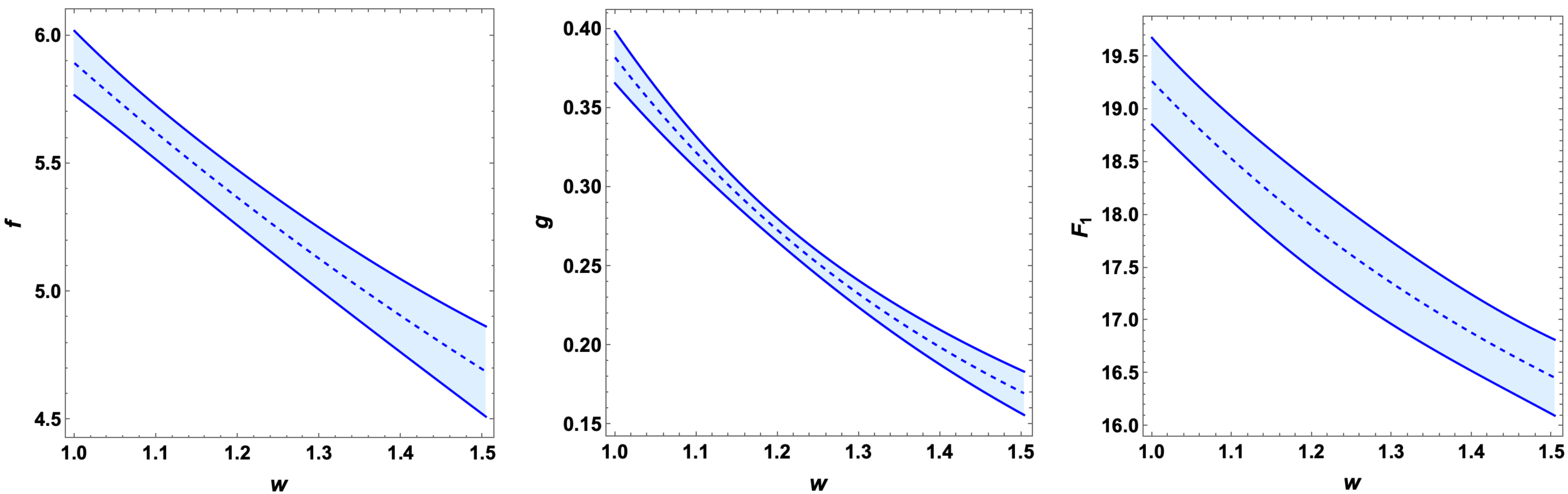
Belle (SM) data + Lattice data (JLQCD)



- Belle data + Lattice QCD combined fit
- Now we can obtain Vcb
- Two lattice results agree within the errors

Fit parameters	JLQCD	Fermilab-MILC
a_0^f	$0.01167(23)(16)$	$0.01219(17)(19)$
a_1^f	$0.0428(70)(69)$	$0.0233(54)(105)$
a_2^f	$-0.47(20)(26)$	$-0.16(12)(17)$
a_0^g	$0.02876(93)(64)$	$0.03229(99)(96)$
a_1^g	$-0.061(33)(25)$	$-0.166(35)(37)$
a_2^g	$-0.0165(80)(87)$	$-0.03(24)(22)$
$a_1^{F_1}$	$0.0089(21)(21)$	$0.0030(13)(18)$
$a_2^{F_1}$	$-0.109(44)(37)$	$0.002(26)(25)$
$\|V_{cb}\|\eta_{\rm EW}$	$0.03969(86)(67)$	$0.03892(52)(69)$

Belle (SM) data + Lattice data (Fermilab)



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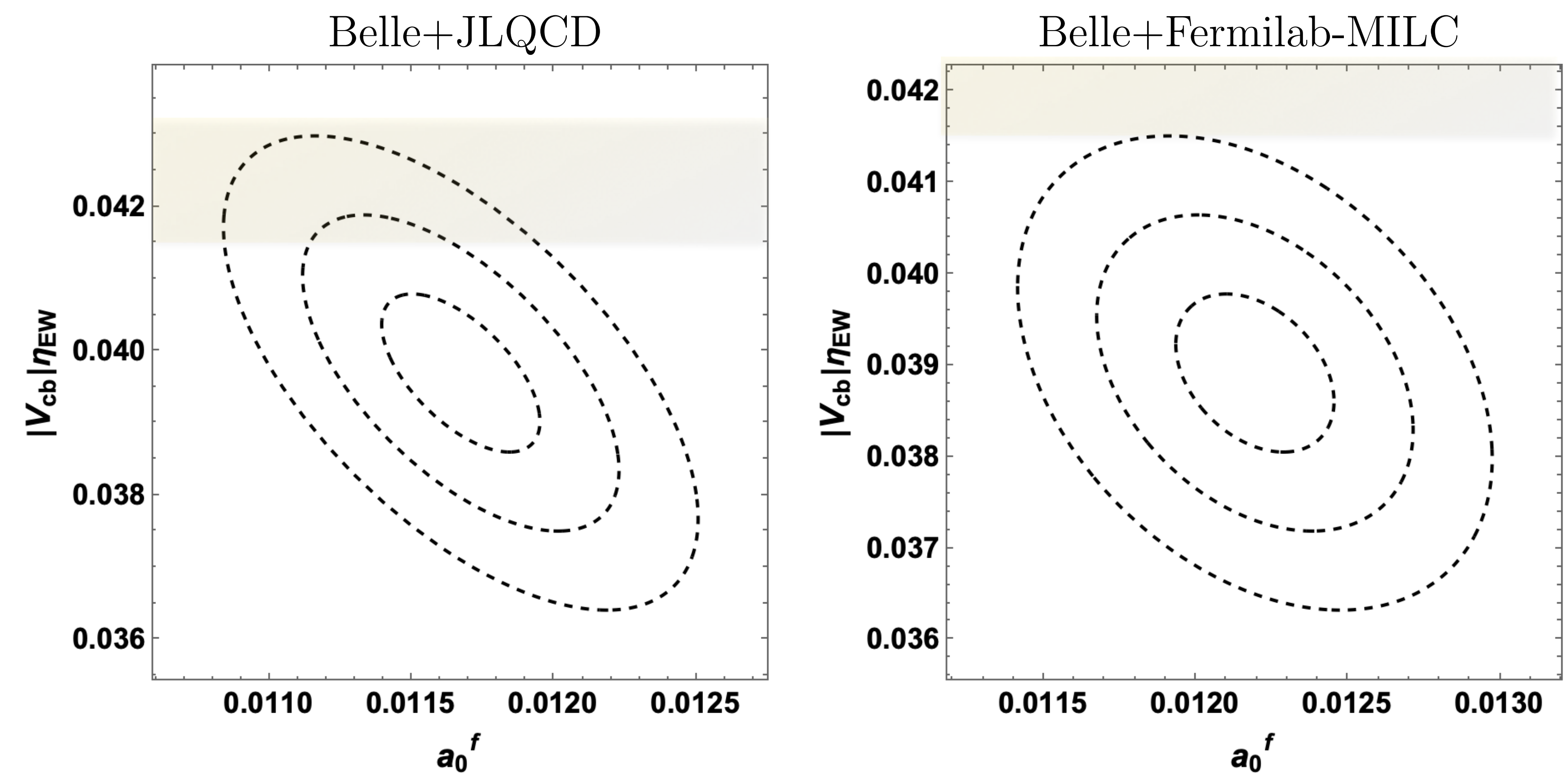
Belle (SM) data + Lattice data



- The correlation between Vcb and the form factor parameter $a_0{}^f$ is very strong.
- The JLQCD data gives a slightly higher Vcb than Fermlab data.

Fit parameters	JLQCD	Fermilab-MILC
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a_1^f	0.0428(70)(69)	0.0233(54)(105)
a_2^f	−0.47(20)(26)	−0.16(12)(17)
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$\|V_{cb}\|\eta_{\rm EW}$	0.03969(86)(67)	0.03892(52)(69)

Angular analysis for New Physics fit

B→D*l ν decay (l=e,mu): angular analysis

T. Kappor, Z.R. Huang, E.K.
arXive:2401.2401.11636

New Physics:

$$\mathcal{H}_{\rm eff} = \frac{4G_F}{\sqrt{2}} V_{cb} \sum_{\ell=e,\mu} [C^\ell_{\rm V_L} O^\ell_{\rm V_L} + C^\ell_{\rm V_R} O^\ell_{\rm V_R} + C^\ell_{\rm S} O^\ell_{\rm S} + C^\ell_{\rm P} O^\ell_{\rm P} + C^\ell_{\rm T} O^\ell_{\rm T}]$$

$$\begin{aligned}
O^\ell_{\rm V_L} &= (\bar{c}_L \gamma^\mu b_L)(\bar{\ell}_L \gamma_\mu \nu_{\ell L}) \\
O^\ell_{\rm V_R} &= (\bar{c}_R \gamma^\mu b_R)(\bar{\ell}_L \gamma_\mu \nu_{\ell L}) \\
O^\ell_{\rm S} &= (\bar{c} b)(\bar{\ell}_R \nu_{\ell L}) \\
O^\ell_{\rm P} &= (\bar{c} \gamma^5 b)(\bar{\ell}_R \nu_{\ell L}) \\
O^\ell_{\rm T} &= (\bar{c}_R \sigma^{\mu\nu} b_L)(\bar{\ell}_R \sigma_{\mu\nu} \nu_{\ell L})
\end{aligned}$$

For the l=e/mu case, only R (Right-handed), P (Pseudoscalar), T (Tensor) operators contribute

B→D*l ν decay (l=e,mu): angular analysis

New Physics:

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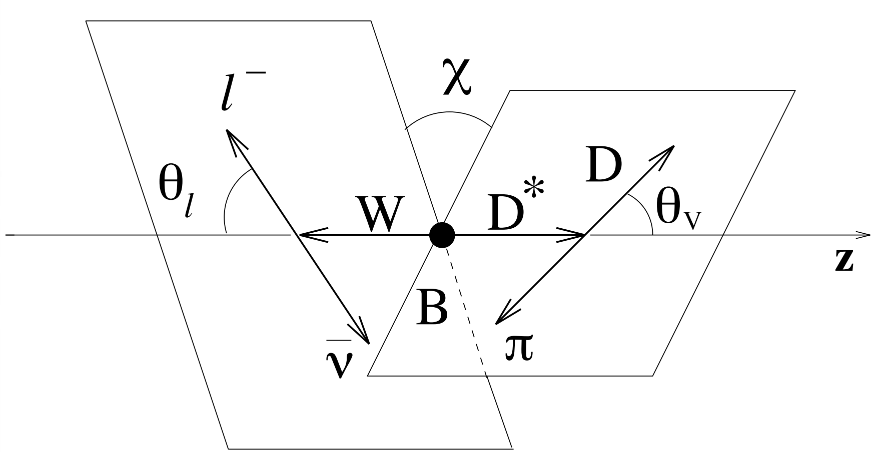
$$\frac{\mathrm{d}\Gamma(\bar{B}\to D^*(\to D\pi)\ell^-\bar{\nu}_\ell)}{\mathrm{d}w\,\mathrm{d}\cos\theta_V\,\mathrm{d}\cos\theta_\ell\,\mathrm{d}\chi} = \frac{6M_B M_{D^*}^2}{8(4\pi)^4}\sqrt{w^2-1}(1-2\,w\,r+r^2)\,G_F^2\,|V_{cb}|^2\,|\eta_{\mathrm{EW}}|^2 \times$$
$$\mathcal{B}(D^*\to D\pi)\Big\{J_{1s}\sin^2\theta_V + J_{1c}\cos^2\theta_V$$
$$+ (J_{2s}\sin^2\theta_V + J_{2c}\cos^2\theta_V)\cos 2\theta_\ell$$
$$+ J_3\sin^2\theta_V\sin^2\theta_\ell\cos 2\chi$$
$$+ J_4\sin 2\theta_V\sin 2\theta_\ell\cos\chi + J_5\sin 2\theta_V\sin\theta_\ell\cos\chi$$
$$+ (J_{6s}\sin^2\theta_V + J_{6c}\cos^2\theta_V)\cos\theta_\ell$$
$$+ J_7\sin 2\theta_V\sin\theta_\ell\sin\chi + J_8\sin 2\theta_V\sin 2\theta_\ell\sin\chi$$
$$+ J_9\sin^2\theta_V\sin^2\theta_\ell\sin 2\chi\Big\}$$



B→D*l ν decay (l=e,mu): angular analysis

New Physics:

T. Kappor, Z.R. Huang, E.K.
arXive:2401.2401.11636

J	$\lvert C_{V_L}\rvert^2$	$\lvert C_{V_R}\rvert^2$	$\mathrm{Re}[C_{V_L}C^*_{V_R}]$	$\mathrm{Im}[C_{V_L}C^*_{V_R}]$
J_{1s}	$\frac{3}{2}[(H_V^+)^2+(H_V^-)^2]$	$\frac{3}{2}[(H_V^+)^2+(H_V^-)^2]$	$-6H_V^+H_V^-$	0
J_{1c}	$2(H_V^0)^2$	$2(H_V^0)^2$	$-4(H_V^0)^2$	0
J_{2s}	$\frac{1}{2}[(H_V^+)^2+(H_V^-)^2]$	$\frac{1}{2}[(H_V^+)^2+(H_V^-)^2]$	$-2H_V^+H_V^-$	0
J_{2c}	$-2(H_V^0)^2$	$-2(H_V^0)^2$	$4(H_V^0)^2$	0
J_3	$-2H_V^+H_V^-$	$-2H_V^+H_V^-$	$2[(H_V^+)^2+(H_V^-)^2]$	0
J_4	$(H_V^+H_V^0+H_V^-H_V^0)$	$(H_V^+H_V^0+H_V^-H_V^0)$	$-2(H_V^+H_V^0+H_V^-H_V^0)$	0
J_5	$-2(H_V^+H_V^0-H_V^-H_V^0)$	$2(H_V^+H_V^0-H_V^-H_V^0)$	0	0
J_{6s}	$-2[(H_V^+)^2-(H_V^-)^2]$	$2[(H_V^+)^2-(H_V^-)^2]$	0	0
J_{6c}	0	0	0	0
J_7	0	0	0	0
J_8	0	0	0	$2(H_V^+H_V^0+H_V^-H_V^0)$
J_9	0	0	0	$-2[(H_V^+)^2-(H_V^-)^2]$

SM is C_{VL}=1. Right-handed model interferes with SM.

B→D*l ν decay (l=e,mu): angular analysis

New Physics:

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arXive:2401.2401.11636

J	$\|C_\mathrm{P}\|^2$	$\|C_\mathrm{T}\|^2$	$\mathrm{Re}[C_\mathrm{P}C_\mathrm{T}^*]$	$\mathrm{Im}[C_\mathrm{P}C_\mathrm{T}^*]$
J_{1s}	0	$8[(H_\mathrm{T}^+)^2+(H_\mathrm{T}^-)^2]$	0	0
J_{1c}	$2H_\mathrm{P}^2$	$32(H_\mathrm{T}^0)^2$	0	0
J_{2s}	0	$-8[(H_\mathrm{T}^+)^2+(H_\mathrm{T}^-)^2]$	0	0
J_{2c}	0	$32(H_\mathrm{T}^0)^2$	0	0
J_3	0	$-32H_\mathrm{T}^+H_\mathrm{T}^-$	0	0
J_4	0	$16(H_\mathrm{T}^-H_\mathrm{T}^0-H_\mathrm{T}^+H_T^0)$	0	0
J_5	0	0	$-8H_\mathrm{P}(H_\mathrm{T}^+-H_\mathrm{T}^-)$	0
J_{6s}	0	0	0	0
J_{6c}	0	0	$-32H_\mathrm{P}H_\mathrm{T}^0$	0
J_7	0	0	0	$8H_\mathrm{P}(H_\mathrm{T}^++H_\mathrm{T}^-)$
J_8	0	0	0	0
J_9	0	0	0	0

Psudoscalar and Tensor terms don't interfere with SM.

Toy study of new physics fit

T. Kappor, Z.R. Huang, E.K.
arXive:2401.11636

1. Generate "fake-data" with the Belle '18 fitted parameters.
2. Fit the fake-data with the theory formula including new physics parameters together with the lattice data

- 4 dimensional unbinned maximum likelihood analysis

$$\chi^2_{\rm unbinned}(\vec{a}_{\rm BGL}, V_{cb}, C_{\rm NP}) = \chi^2_{\rm angle}(\vec{a}_{\rm BGL}, C_{\rm NP}) + \chi^2_{\rm latt}(\vec{a}_{\rm BGL}) + \chi^2_{\mathcal{B}}(\vec{a}_{\rm BGL}, V_{cb}, C_{\rm NP})$$

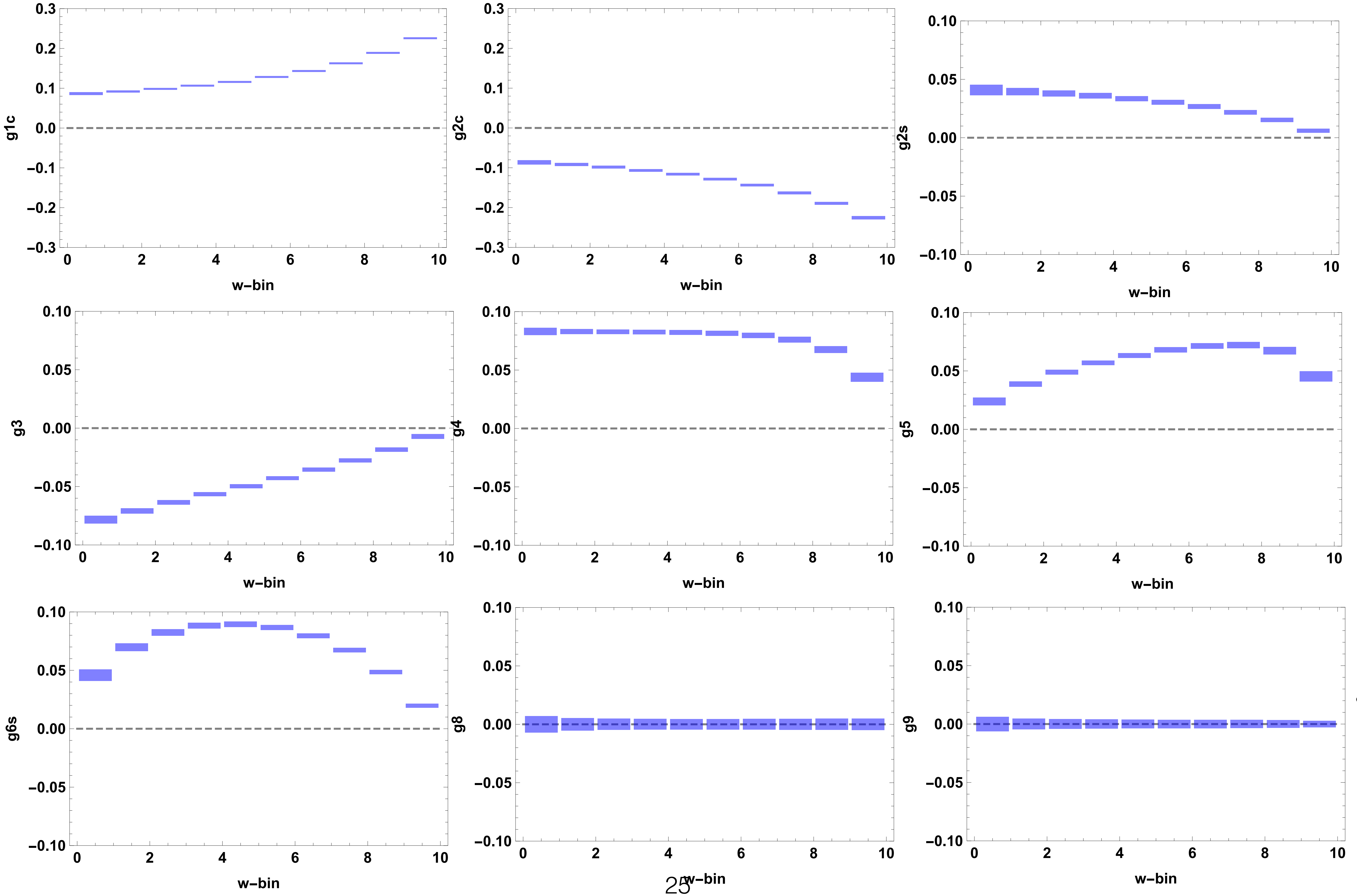
- Angular distribution and Branching ratio:

$$\chi^2_{\rm angle}(\vec{a}_{\rm BGL}, C_{\rm NP}) = \sum_{w-{\rm bin}=1}^{10} \left[N_{w-{\rm bin}} \hat{V}^{-1}_{ij} \left(\langle g_i^{\rm exp} \rangle - \langle g_i^{\rm th}(\vec{a}_{\rm BGL}, C_{\rm NP}) \rangle \right) \left(\langle g_j^{\rm exp} \rangle - \langle g_j^{\rm th}(\vec{a}_{\rm BGL}, C_{\rm NP}) \rangle \right) \right]_{w-{\rm bin}}$$

$$\chi^2_{\mathcal{B}}(\vec{a}_{\rm BGL}, V_{cb}, C_{\rm NP}) = \left(\frac{\mathcal{B}^{\rm th}(\vec{a}_{\rm BGL}, V_{cb}, C_{\rm NP}) - 0.0495}{0.0011} \right)^2$$

$$\langle g_i \rangle \equiv \frac{\langle J_i \rangle}{6\langle J_{1s} \rangle + 3\langle J_{1c} \rangle - 2\langle J_{2s} \rangle - \langle J_{2c} \rangle}$$

Fake data



Result of the Right-handed model

- Belle fake data combined with the lattice data to fit the new physics parameter C_{VR} along with SM parameter Vcb

Fit parameters	JLQCD	Fermilab-MILC
a_0^f	0.01294(20)	0.01327(20)
a_1^f	0.018(11)	−0.005(13)
a_2^f	−0.21(53)	−0.28(61)
a_0^g	0.0255(15)	0.0289(11)
a_1^g	−0.045(35)	−0.130(49)
a_2^g	0.4(11)	1.0(14)
$a_1^{\mathcal{F}_1}$	0.0061(22)	−0.0001(23)
$a_2^{\mathcal{F}_1}$	−0.095(94)	−0.05(10)
$a_0^{\mathcal{F}_2}$	0.0483(14)	0.0537(13)
$a_1^{\mathcal{F}_2}$	−0.004(50)	−0.276(62)
C_{V_R}	−0.023(34)	−0.070(23)
$\|V_{cb}\|\eta_{EW}$	0.0390(21)	0.0385(20)

Hadrons

New Physics

SM

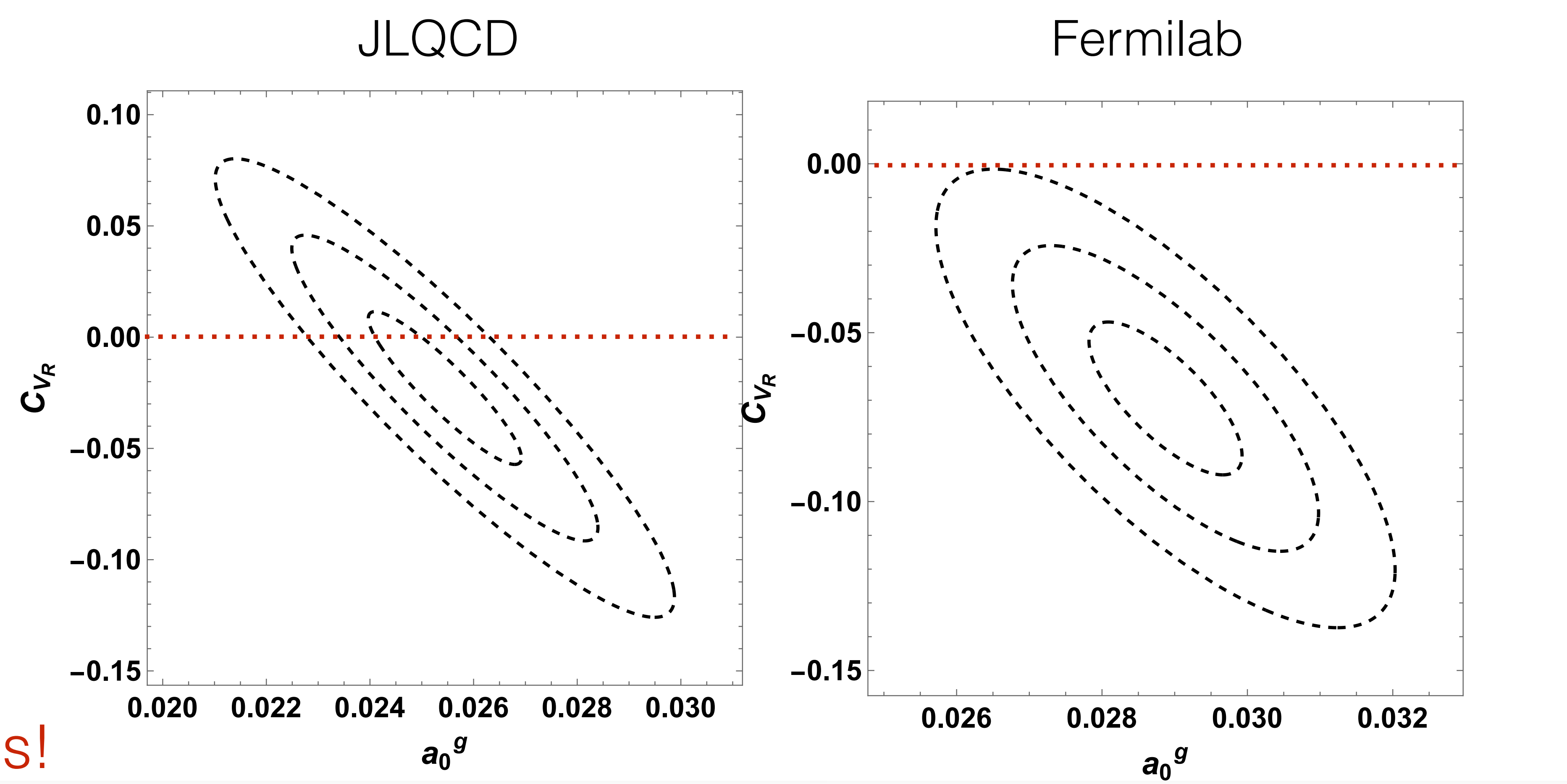
$C_{VR} \neq 0$

➠ New physics!

Now, it is important to check the correlation between the new physics parameters and hadronic parameters

Result of the Right-handed model

- Belle fake data combined with the lattice data to fit the new physics parameter C_{VR} along with SM parameter Vcb



$C_{VR} \neq 0$

➠ New physics!

Indeed, a_0^g is strongly correlated to C_{VR} : i.e. we can not distinguish the effect of these two parameters. We can see that a_0^g of JLQCD and Fermilab do not agree and that results in different values of C_{VR}

Conclusions

- Belle has been studying the angular distribution to constrain the form factors within SM.
- There are now **three lattice QCD results** on the B->D* Form Factors.
- Thus, we are **ready to move to BSM fit**!
- We performed toy study of the unbanned maximum likelihood method of Belle data to new physics models including the lattice data.
- **The observed discrepancy in Right-handed model is intriguing** and we need further investigation both from theory and experiment.
- The pseudoscalar/tensor model doesn't interfere with SM, thus, the sensitivity is lower. Nevertheless, it has very little correlation to the form factors or Vcb so it is hadronic effect FREE.

B→D*l ν decay (l=τ): angular analysis

We use τ→μνν decay

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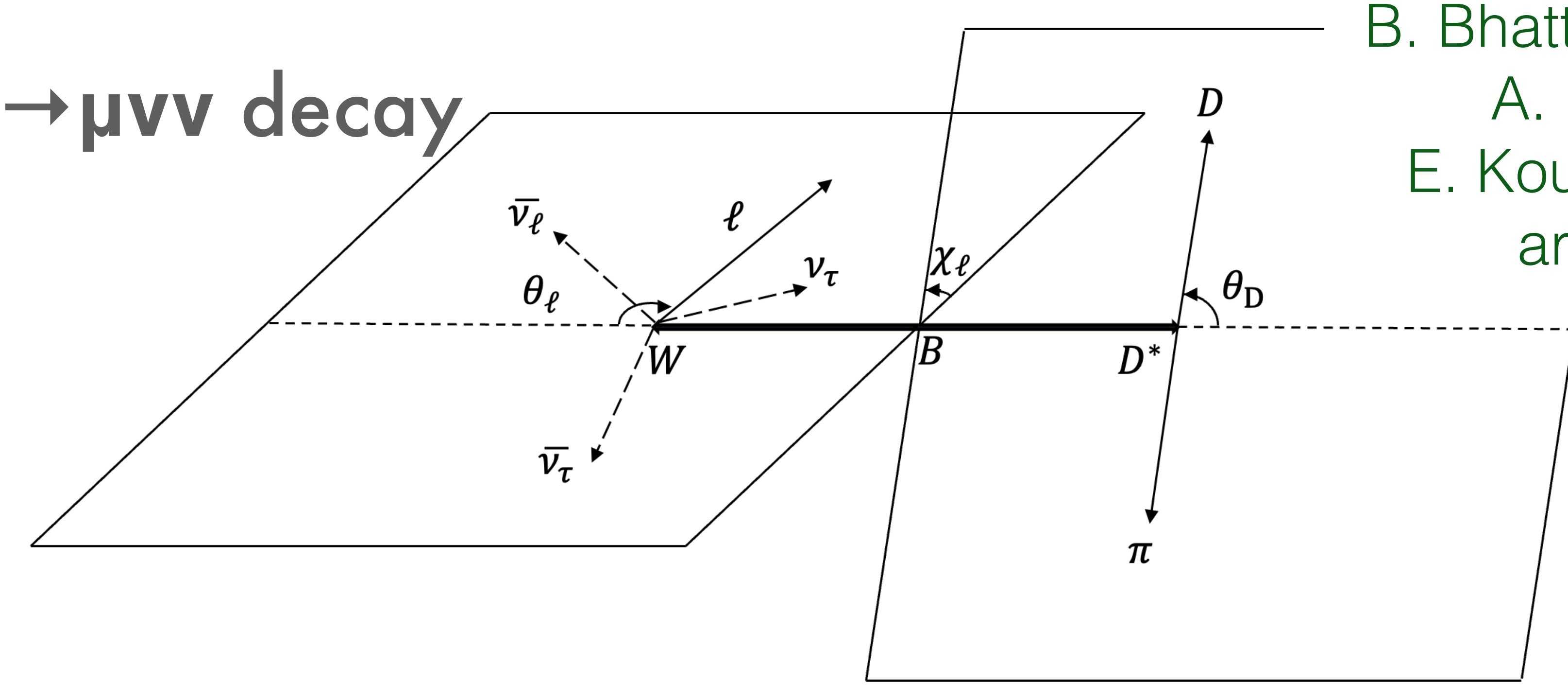

$$
\begin{aligned}
\frac{d\Gamma^{\rm r}(\bar{B}\to D^*(\to D\pi)\tau^-(\to \ell\bar{\nu}_\ell\nu_\tau)\bar{\nu}_\tau)}{dw dE_\ell d\cos\theta_D d\cos\theta_\ell d\chi_\ell} &= \frac{3G_F^2\,|V_{cb}|^2\,|\eta_{\rm EW}|^2 M_{D^*}\mathcal{B}(D^*\to D\pi)\mathcal{B}(\tau\to\ell\nu_\tau\bar{\nu}_\ell)}{16(4\pi)^5 M_B^2 M_\tau^6 |\vec{p}_D|^2} \\
&\times \frac{|\vec{p}_{D^*}(w)||\vec{p}_\tau(w)|E_\ell}{\sqrt{1+r^2-2wr}}\Big\{J^{\rm r}_{1s}\sin^2\theta_D + J^{\rm r}_{1c}\cos^2\theta_D \\
&+ (J^{\rm r}_{2s}\sin^2\theta_D + J^{\rm r}_{2c}\cos^2\theta_D)\cos 2\theta_\ell \\
&+ J^{\rm r}_3\sin^2\theta_D\sin^2\theta_\ell\cos 2\chi_\ell \\
&+ J^{\rm r}_4\sin 2\theta_D\sin 2\theta_\ell\cos\chi_\ell + J^{\rm r}_5\sin 2\theta_D\sin\theta_\ell\cos\chi_\ell \\
&+ (J^{\rm r}_{6s}\sin^2\theta_D + J^{\rm r}_{6c}\cos^2\theta_D)\cos\theta_\ell \\
&+ J^{\rm r}_7\sin 2\theta_D\sin\theta_\ell\sin\chi_\ell + J^{\rm r}_8\sin 2\theta_D\sin 2\theta_\ell\sin\chi_\ell \\
&+ J^{\rm r}_9\sin^2\theta_D\sin^2\theta_\ell\sin 2\chi_\ell\Big\},
\end{aligned}
$$

B→D*l ν decay (l=τ): angular analysis

We use τ→μνν decay

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J function	LH	LH-RH	LH-PS	LH-T
J_{1s}	$\|C^2_{V_L}\|$	$\mathrm{Re}(C_{V_L}C^*_{V_R})$	0	$\mathrm{Re}(C_{V_L}C^*_T)$
J_{1c}	$\|C^2_{V_L}\|$	$\mathrm{Re}(C_{V_L}C^*_{V_R})$	$\mathrm{Re}(C_{V_L}C^*_P)$	$\mathrm{Re}(C_{V_L}C^*_T)$
J_{2s}	$\|C^2_{V_L}\|$	$\mathrm{Re}(C_{V_L}C^*_{V_R})$	0	$\mathrm{Re}(C_{V_L}C^*_T)$
J_{2c}	$\|C^2_{V_L}\|$	$\mathrm{Re}(C_{V_L}C^*_{V_R})$	0	$\mathrm{Re}(C_{V_L}C^*_T)$
J_3	$\|C^2_{V_L}\|$	$\mathrm{Re}(C_{V_L}C^*_{V_R})$	0	$\mathrm{Re}(C_{V_L}C^*_T)$
J_4	$\|C^2_{V_L}\|$	$\mathrm{Re}(C_{V_L}C^*_{V_R})$	0	$\mathrm{Re}(C_{V_L}C^*_T)$
J_5	$\|C^2_{V_L}\|$	$\mathrm{Re}(C_{V_L}C^*_{V_R})$	$\mathrm{Re}(C_{V_L}C^*_P)$	$\mathrm{Re}(C_{V_L}C^*_T)$
J_{6s}	$\|C^2_{V_L}\|$	0	0	$\mathrm{Re}(C_{V_L}C^*_T)$
J_{6c}	$\|C^2_{V_L}\|$	$\mathrm{Re}(C_{V_L}C^*_{V_R})$	$\mathrm{Re}(C_{V_L}C^*_P)$	$\mathrm{Re}(C_{V_L}C^*_T)$
J_7	0	$\mathrm{Im}(C_{V_L}C^*_{V_R})$	$\mathrm{Im}(C_{V_L}C^*_P)$	$\mathrm{Im}(C_{V_L}C^*_T)$
J_8	0	$\mathrm{Im}(C_{V_L}C^*_{V_R})$	0	$\mathrm{Im}(C_{V_L}C^*_T)$
J_9	0	$\mathrm{Im}(C_{V_L}C^*_{V_R})$	0	$\mathrm{Im}(C_{V_L}C^*_T)$

Sensitivity study with B→D*l ν decay (l=τ): angular analysis

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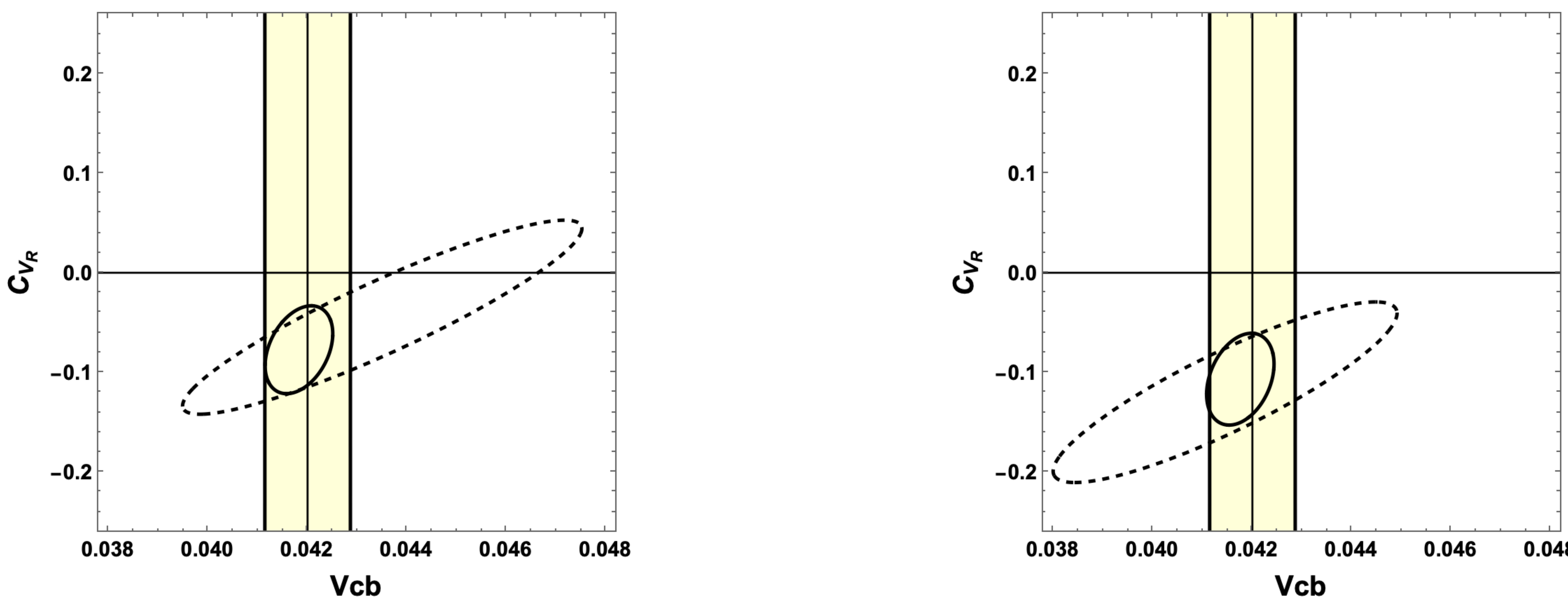
We use τ→μνν decay (2k events)



(a) $C_{V_R} - V_{cb}$ correlation plot with JLQCD lattice data

(b) $C_{V_R} - V_{cb}$ correlation plot with Fermilab-MILC lattice data

C_{VR} model can be constrained at the 7-8% level.

Sensitivity study with $B \to D^* l \nu$ decay ($l=\tau$): angular analysis

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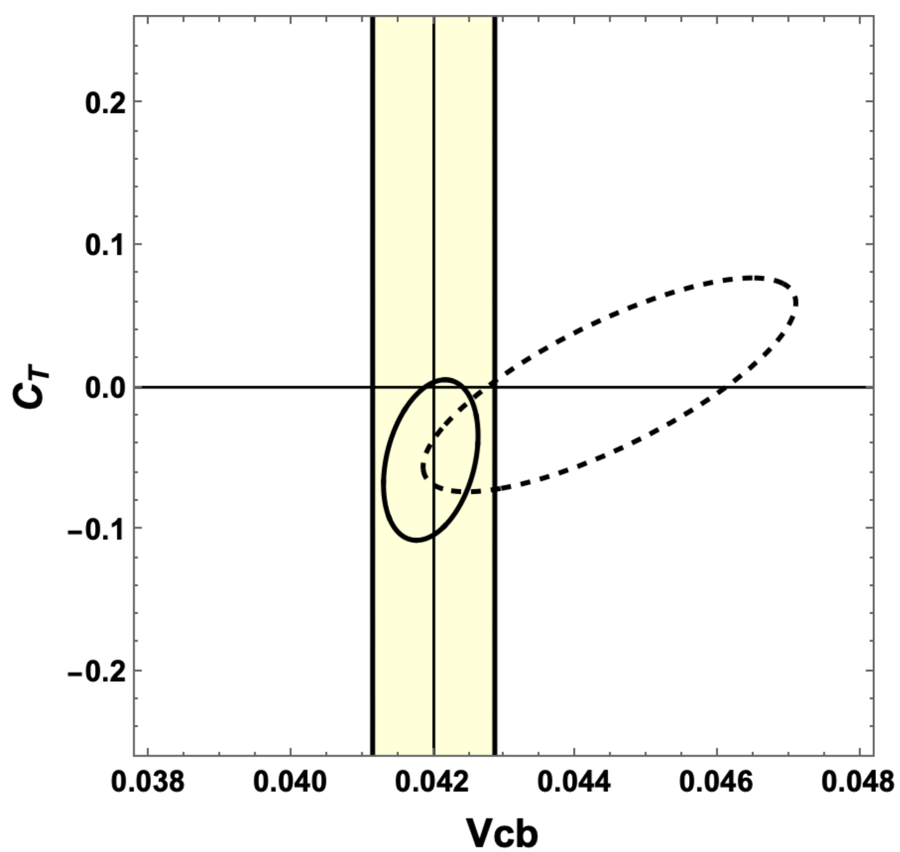
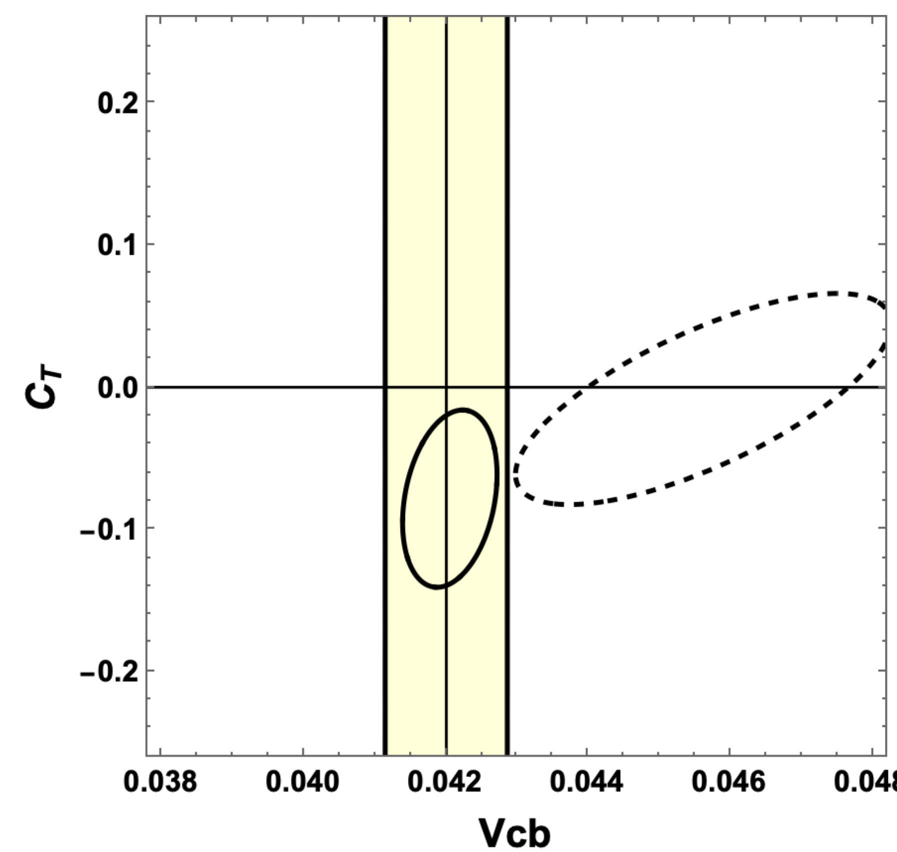
We use $\tau \to \mu\nu\nu$ decay (2k events)



(a) $C_T - V_{cb}$ correlation plot with JLQCD lattice data



(b) $C_T - V_{cb}$ correlation plot with Fermilab-MILC lattice data

Real C_T model can be constrained at the 7-8% level.

Sensitivity study with B→D*l ν decay (l=τ): angular analysis

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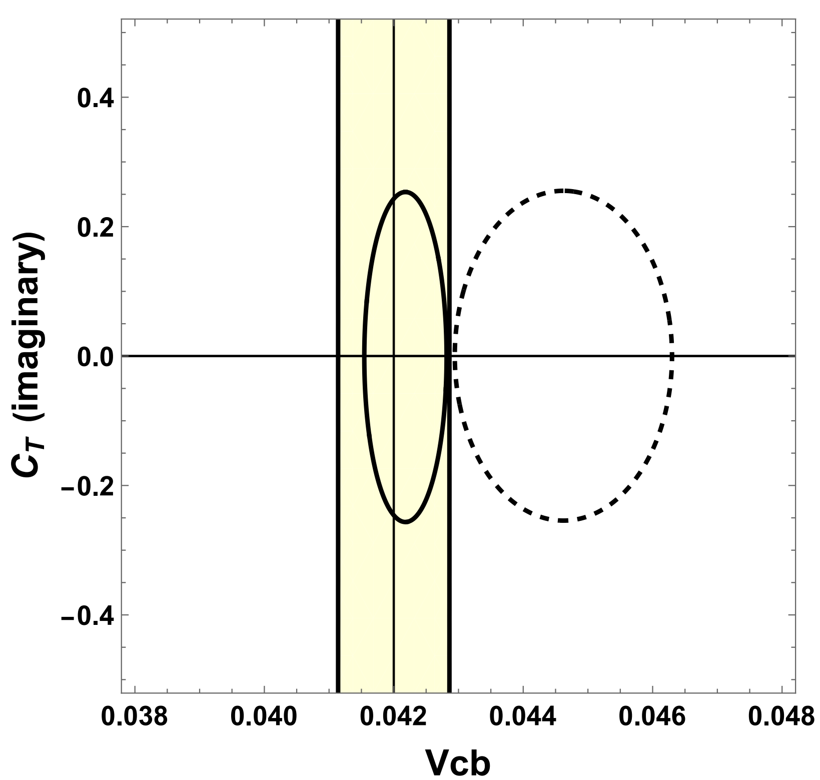
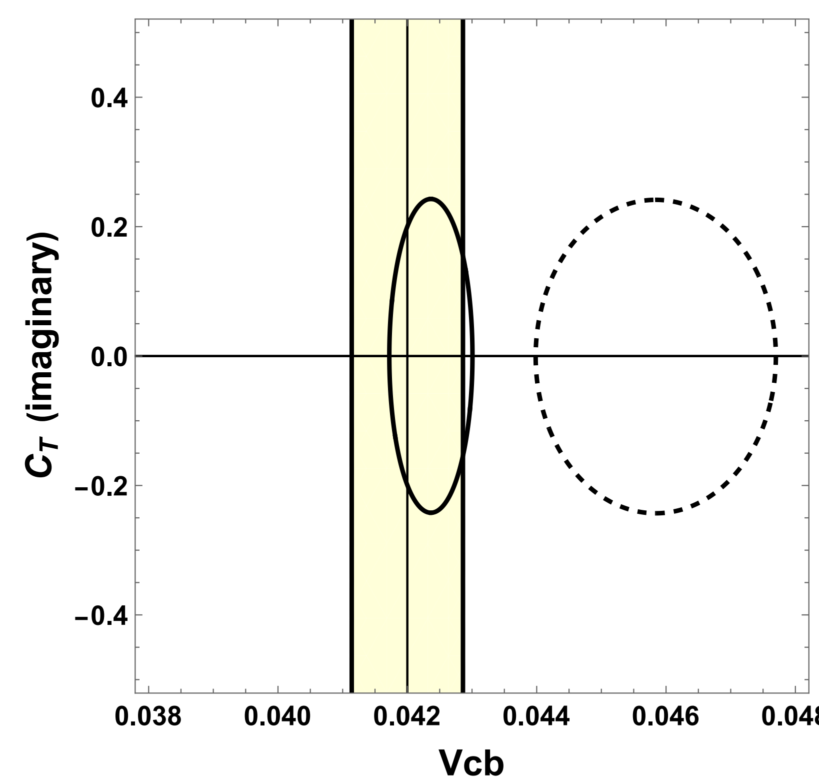
A. Datta, T. Kapoor
E. Kou, and L. Mukherjee
arXive:2411.xxxx

We use τ→μνν decay (2k events)



(c) $C_{V_R} - V_{cb}$ correlation plot with JLQCD lattice data



(d) $C_{V_R} - V_{cb}$ correlation plot with Fermilab-MILC lattice data

Imaginary C_T model can be constrained at the 20% level.

Conclusions

- The theoretical formula for the $B \to D^* \tau \nu$ ($\tau \to \mu \nu \nu$) angular distribution is derived for the first time.
- On top of the usual 3 angles and 1 momentum, the muon energy in the rest frame of W boson can be used to constraint the NP parameters.
- As $B \to D^* \tau \nu$ angular analysis not available so far, we have performed a sensitivity study using the result of Belle's $B \to D^* l \nu$ (l=e,mu) fit.
- We found that the right-handed or tensor model can be constrained at 7-8% level with ~2k events of Belle II data.