Exclusive b➝ c $\ell \nu$ modes as windows to New Physics

Damir Bečirević

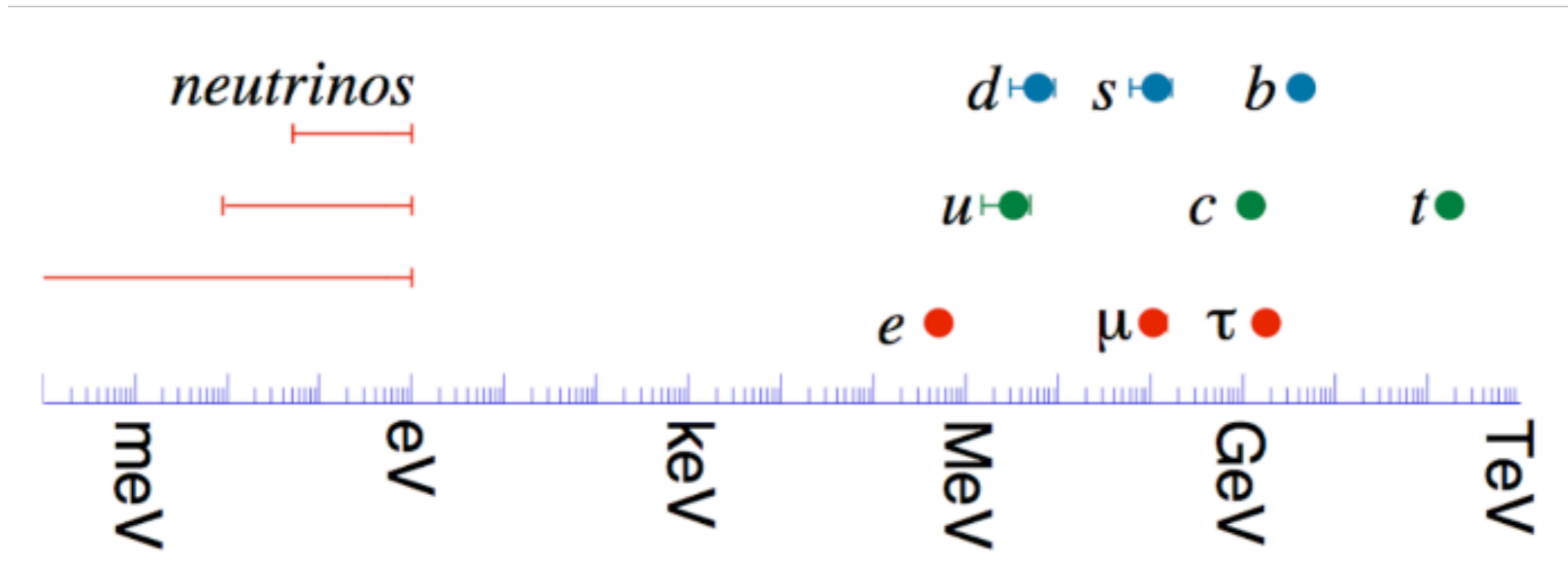*Pôle Théorie, IJCLab*
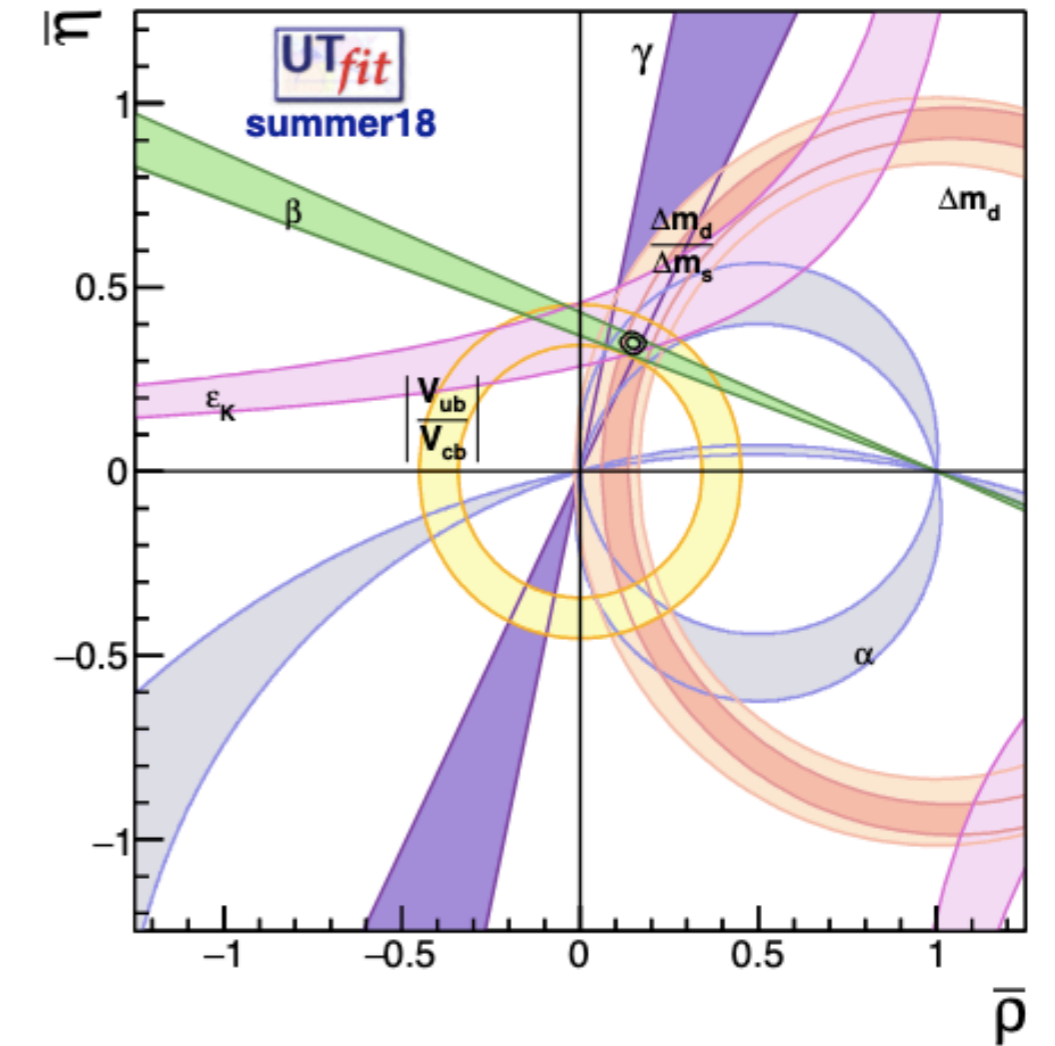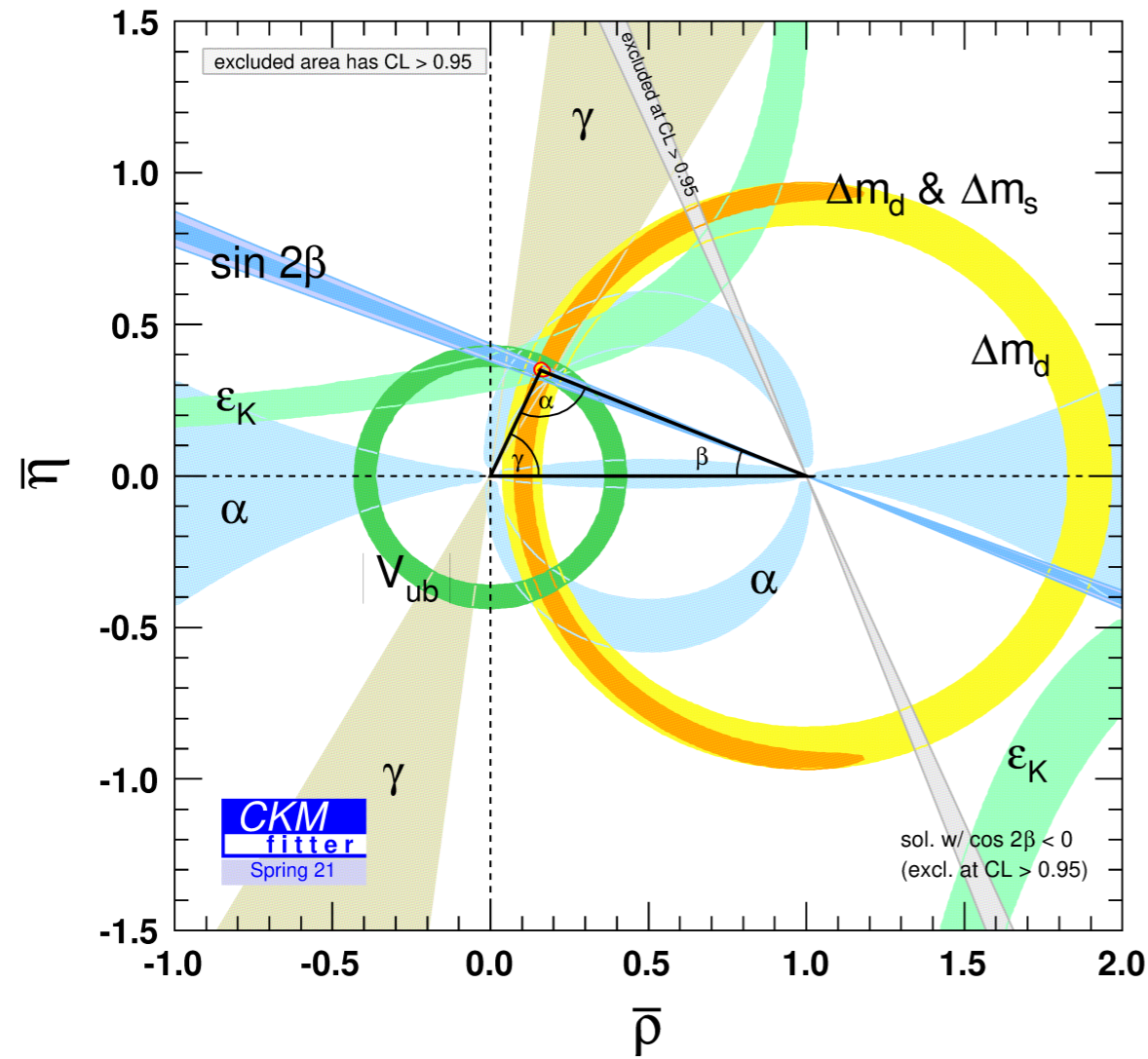*CNRS et Université Paris-Saclay*

Pisa, February 16, 2023

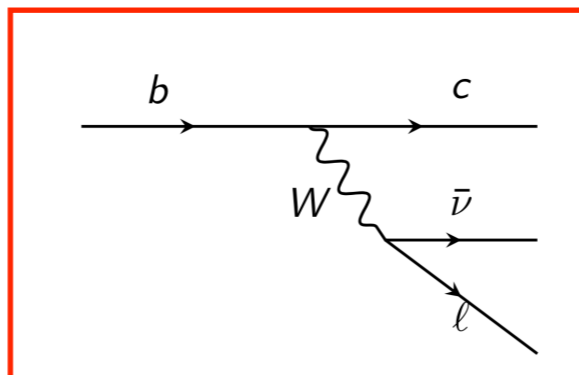based on works with F. Jaffredo, A. Le Yaouanc, and O. Sumensari

Flavor Physics

✘   Why three generations?
✘   Why such hierarchy of masses and mixing?
✘   Why so small CPV phase?
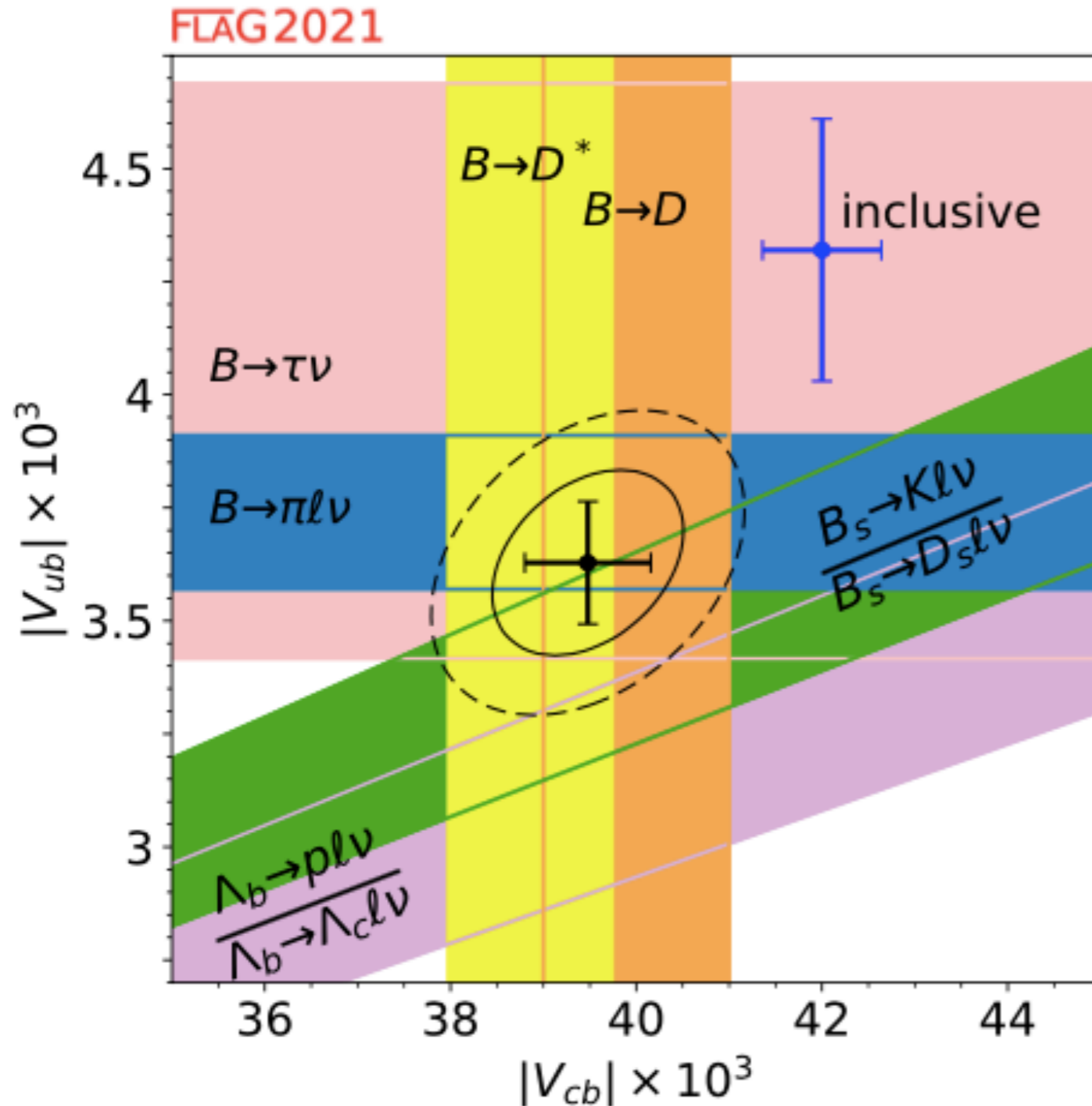
CKM-ology

✘ Still open: inclusive v exclusive V_{ub} and V_{cb}?
   Is V_{ud} well controlled? V_{us} keeps coming back (EM)…

CKM-ology - Small flavor 'anomaly'

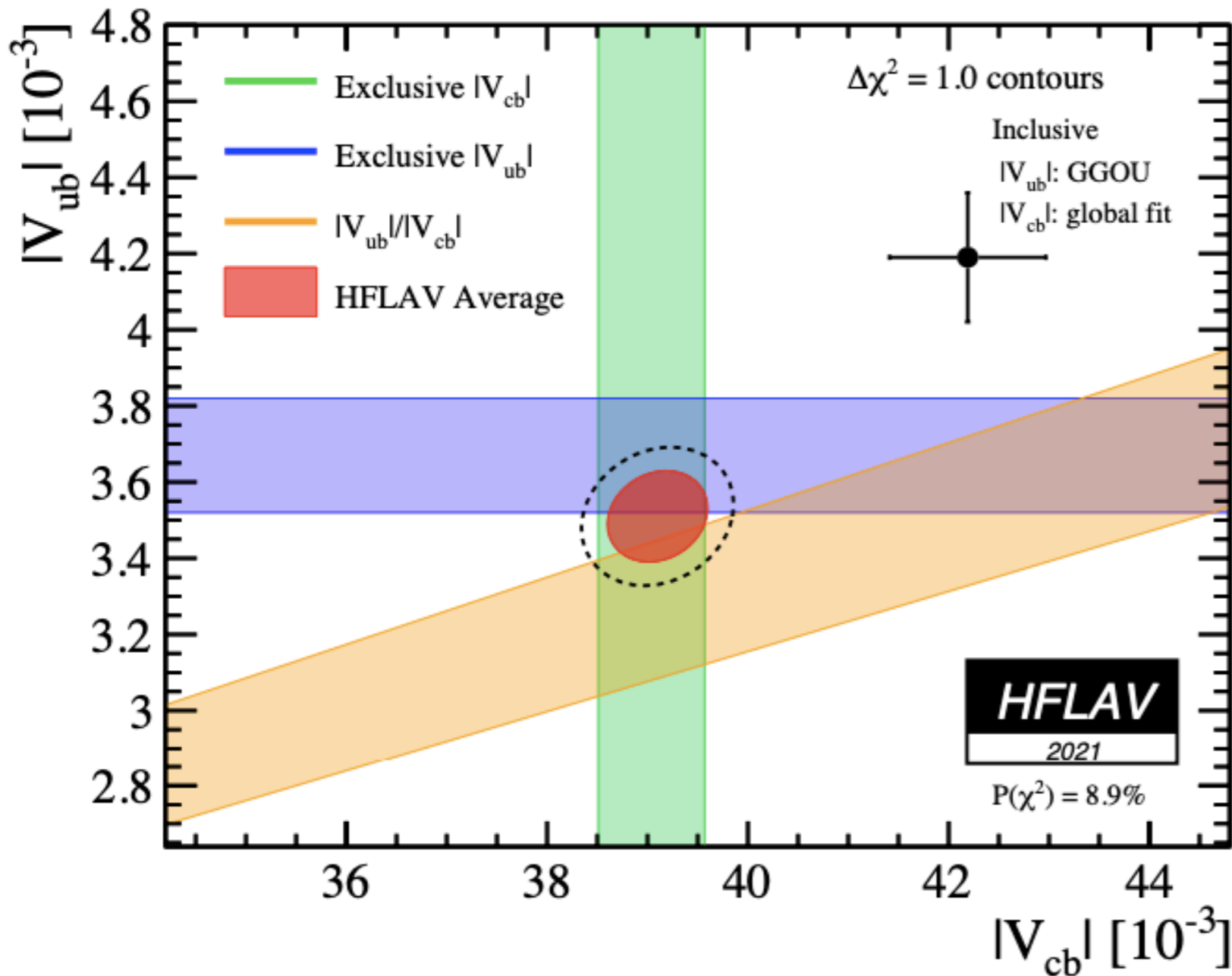✘ Still open: inclusive v exclusive V$_{ub}$ and V$_{cb}$?

✘ Belle II (excl + incl), LHCb (excl)

✘ QCD on very fine lattices
B → D and B → D* at *w=1*

✘ Nowadays probed *non-zero recoil*

2111.09849

CKM-ology - Small flavor 'anomaly'

✘ Still open: inclusive v exclusive V_{ub} and V_{cb}?

✘ Lattice, best way to go
$B \to D$ at various small *w*, but for w accessible from LQCD, a huge phase space suppression

✘ Experimentally appealing
$B \to D*$ (also *Luke theorem*)

2206.07501

CLN or BGL or…

$$\frac{d\Gamma(\overline{B} \to D^*\ell^-\overline{\nu}_\ell)}{dw} = \frac{G_F^2 m_{D^*}^3}{48\pi^3}(m_B - m_{D^*})^2 \chi(w)\eta_{EW}^2 \mathcal{F}^2(w)|V_{cb}|^2$$

$$\chi(w)\mathcal{F}^2(w) = h_{A_1}^2(w)\sqrt{w^2-1}(w+1)^2\left\{2\left[\frac{1-2wr+r^2}{(1-r)^2}\right]\left[1+R_1^2(w)\frac{w-1}{w+1}\right]+\left[1+(1-R_2(w))\frac{w-1}{1-r}\right]^2\right\}$$

$$q^2 = m_B^2 + m_{D^*}^2 - 2m_B m_{D^*}\, w \qquad\qquad r = m_{D^*}/m_B$$

$$h_{A_1}(w) = h_{A_1}(1)\left[1 - 8\rho^2 z + (53\rho^2 - 15)z^2 - (231\rho^2 - 91)z^3\right]$$

$$R_1(w) = R_1(1) - 0.12(w-1) + 0.05(w-1)^2 \qquad \text{CLN} \qquad\qquad 9712417$$
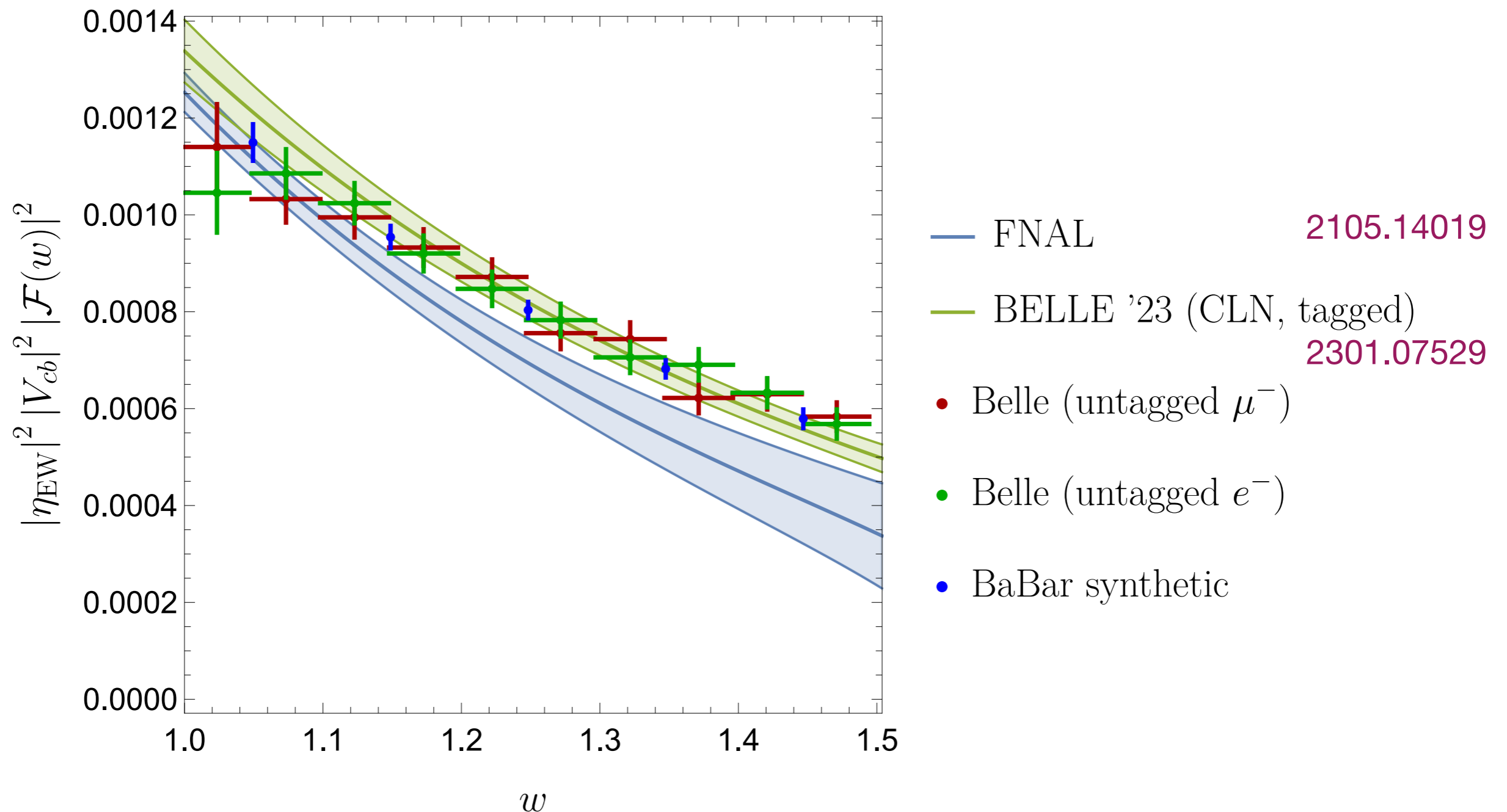
$$R_2(w) = R_2(1) + 0.11(w-1) - 0.06(w-1)^2$$

BGL 9705252
these should be fit too
and not fixed as in CLS

$$z = \frac{\sqrt{w+1} - \sqrt{2}}{\sqrt{w+1} + \sqrt{2}}$$

✘ Exp data fit very well with CLN, but eventually [with ever better precision] BGL should be the ultimate choice, if you decide to follow this route…
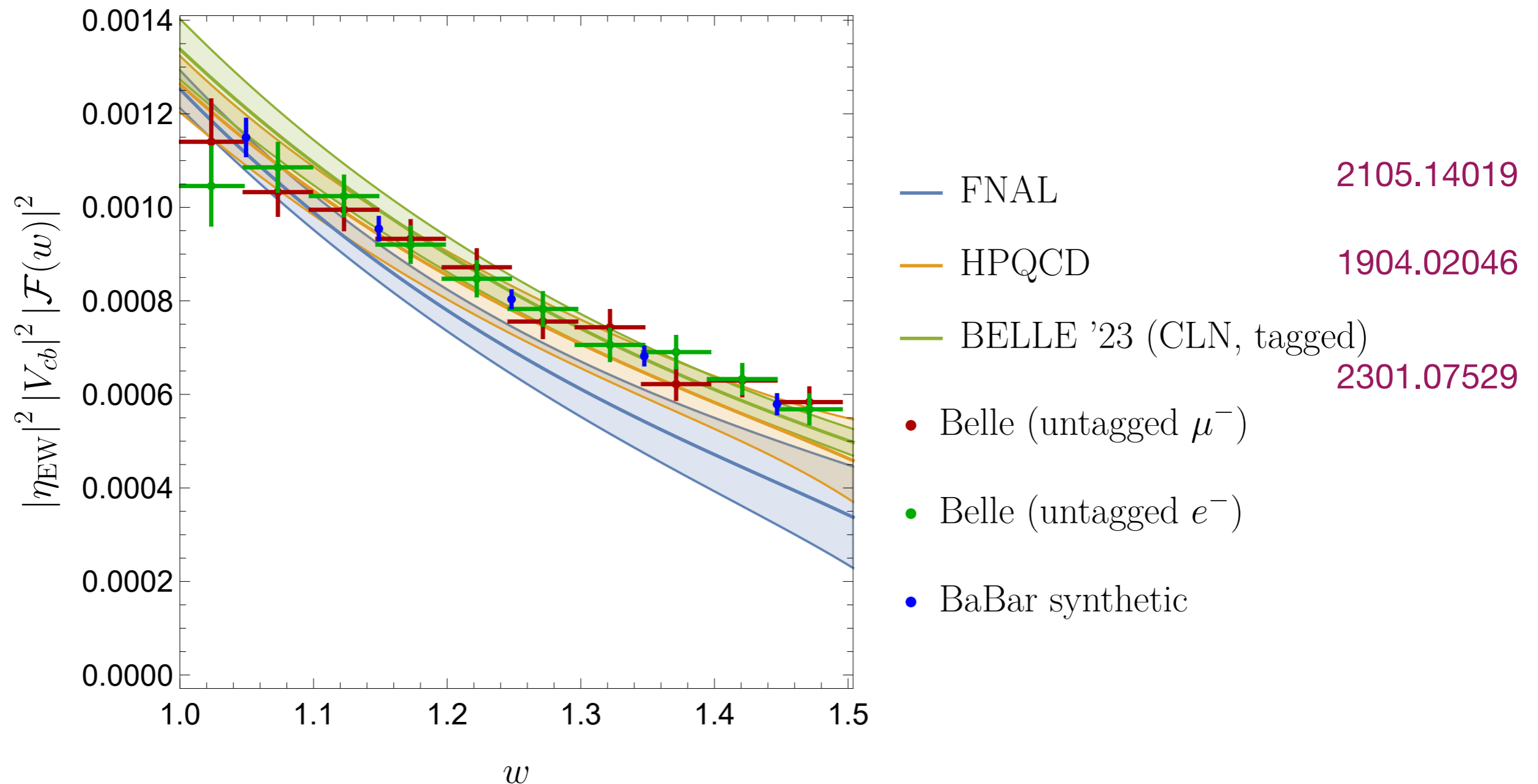
We still do not have a control over hadronic uncertainties with

$$\frac{d\mathcal{B}(B \to D^* \ell \bar{\nu})}{dq^2} = \frac{1}{2m_B m_{D^*}} \frac{d\mathcal{B}(B \to D^* \ell \bar{\nu})}{dw} \propto |V_{cb}|^2 |\mathcal{F}(w)|^2$$

Legend:
- FNAL — 2105.14019
- BELLE '23 (CLN, tagged) — 2301.07529
- Belle (untagged μ^-)
- Belle (untagged e^-)
- BaBar synthetic

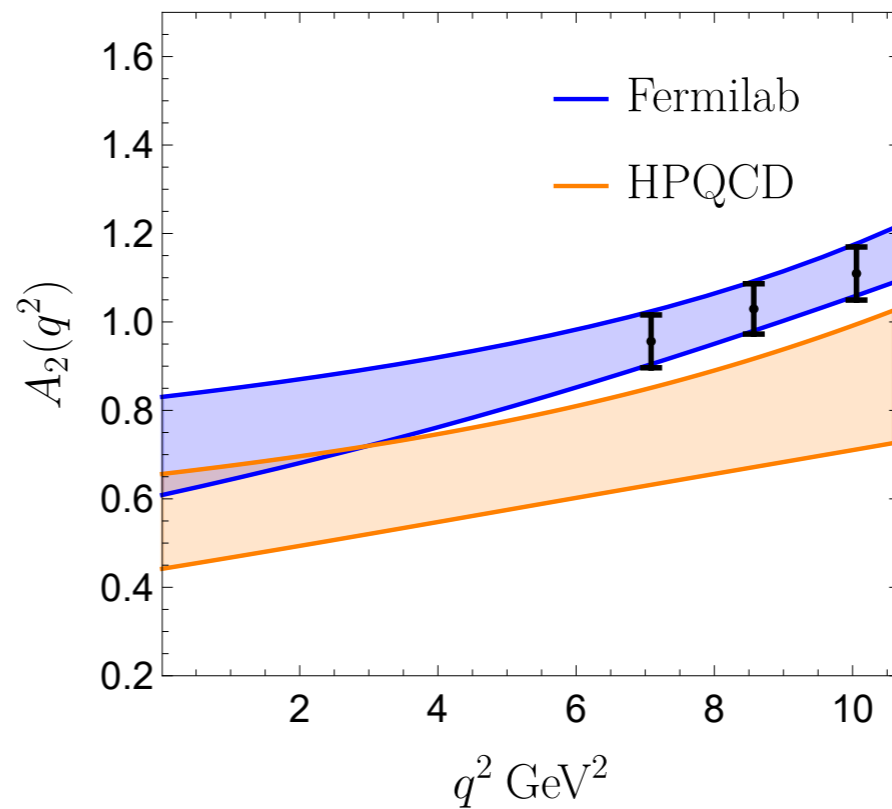Axes: $|\eta_{\mathrm{EW}}|^2 |V_{cb}|^2 |\mathcal{F}(w)|^2$ vs w

We still do not have a control over hadronic uncertainties with

$$\frac{d\mathcal{B}(B \to D^*\ell\bar{\nu})}{dq^2} = \frac{1}{2m_B m_{D^*}} \frac{d\mathcal{B}(B \to D^*\ell\bar{\nu})}{dw} \propto |V_{cb}|^2 |\mathcal{F}(w)|^2$$
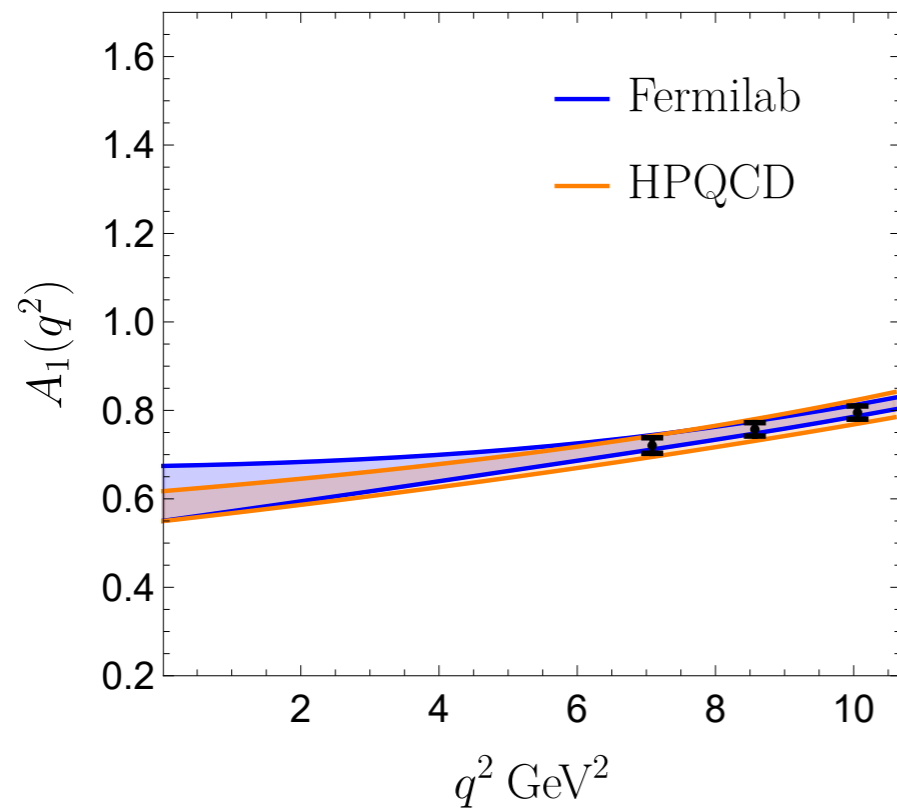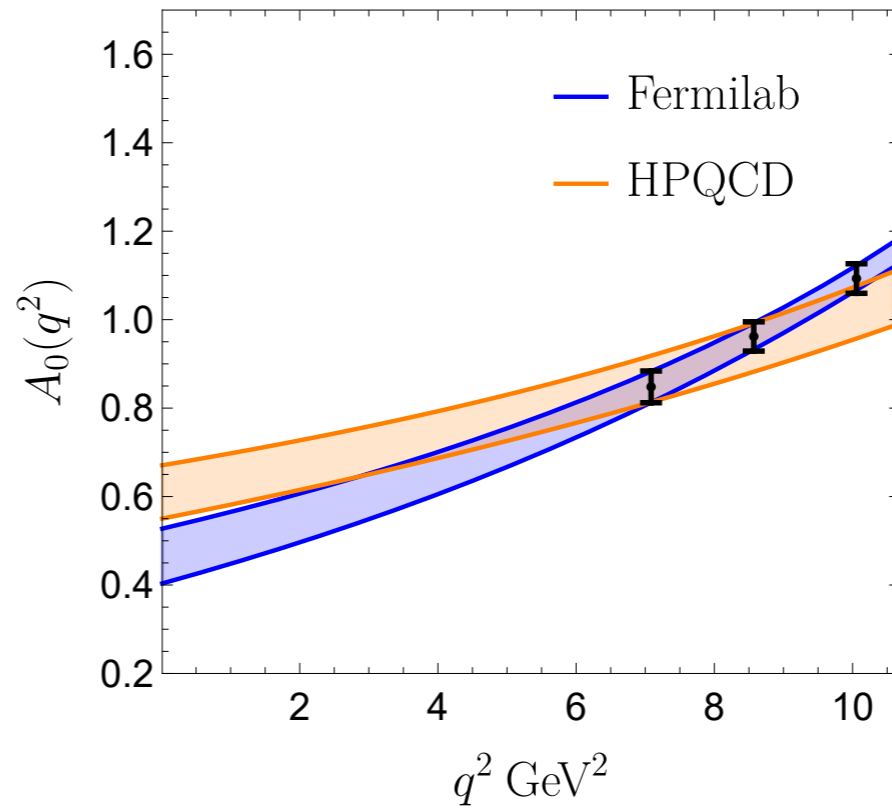

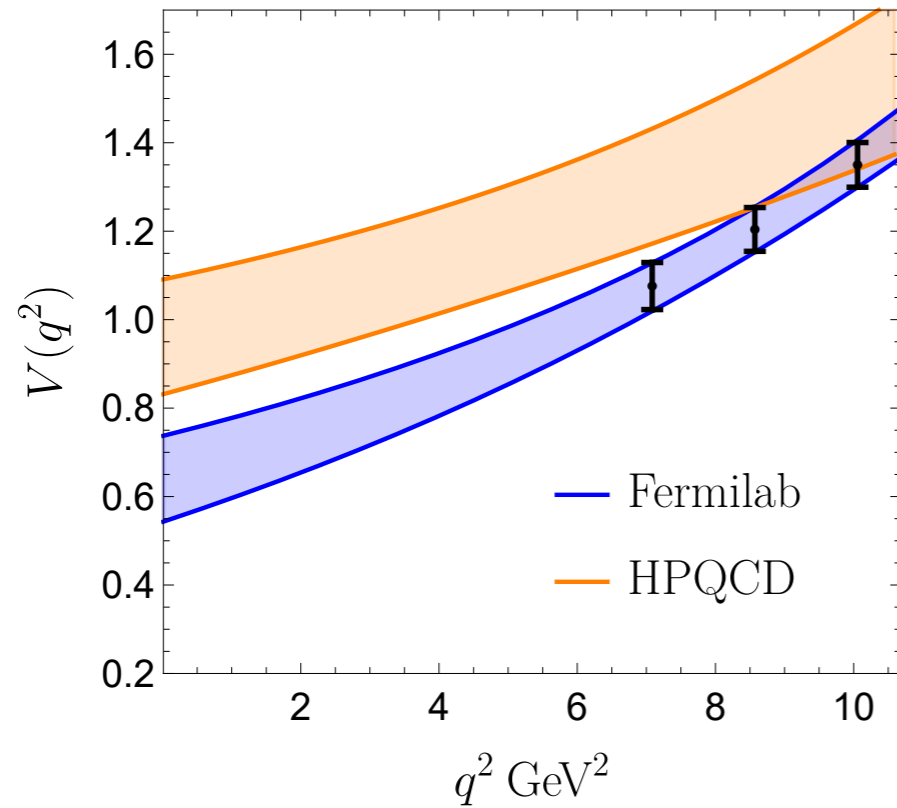FNAL — 2105.14019

HPQCD — 1904.02046

BELLE '23 (CLN, tagged) — 2301.07529

• Belle (untagged μ^-)

• Belle (untagged e^-)

• BaBar synthetic

• Assuming with HPQCD that $\mathcal{F}(w)^{B_s \to D_s^*} = \mathcal{F}(w)^{B \to D^*}$

$$B \rightarrow D^* \ell \bar{\nu}$$

2105.11433

2105.14019

$B \to D^* \ell \bar{\nu}$

Do we understand well B → D at w=1?*

$$\mathcal{F}(1) = 0.906(4)(12) \qquad (N_{\mathrm{f}} = 2 + 1) \qquad \text{1403.0635}$$

$$\mathcal{F}(1) = 0.895(10)(24) \qquad (N_{\mathrm{f}} = 2 + 1 + 1) \qquad \text{1711.1103}$$

- The value of $\mathcal{F}(1)$ seems to be too large when comparing the exclusive and inclusive semileptonics at $w = 1$.

- As if all the other $B \to D(n)$ semileptonic modes were tiny or negligible - "oversaturation".   1206.2296

- Since $|V_{cb}|\mathcal{F}(1)$ comes from fit with exp. data, a lower $\mathcal{F}(1)$ would lead to larger $|V_{cb}|$.

- Necessary to double check with $B \to D\ell\nu$.

- Lattice results for $\mathcal{F}(1)$ with different regularization would be highly welcome.

Side remark: Never ending problem |V_cb|

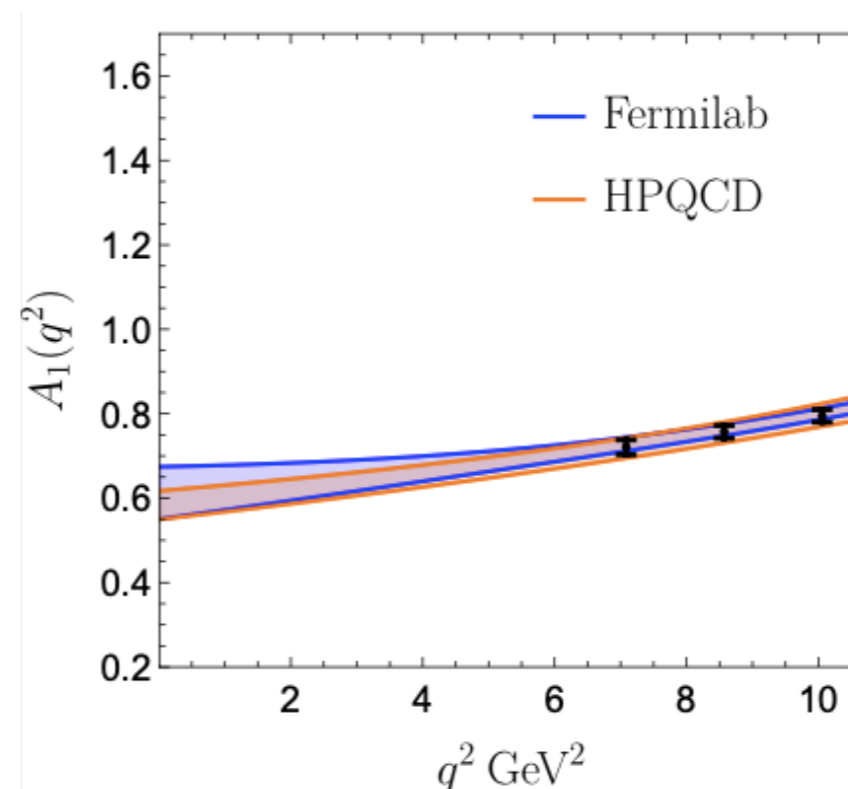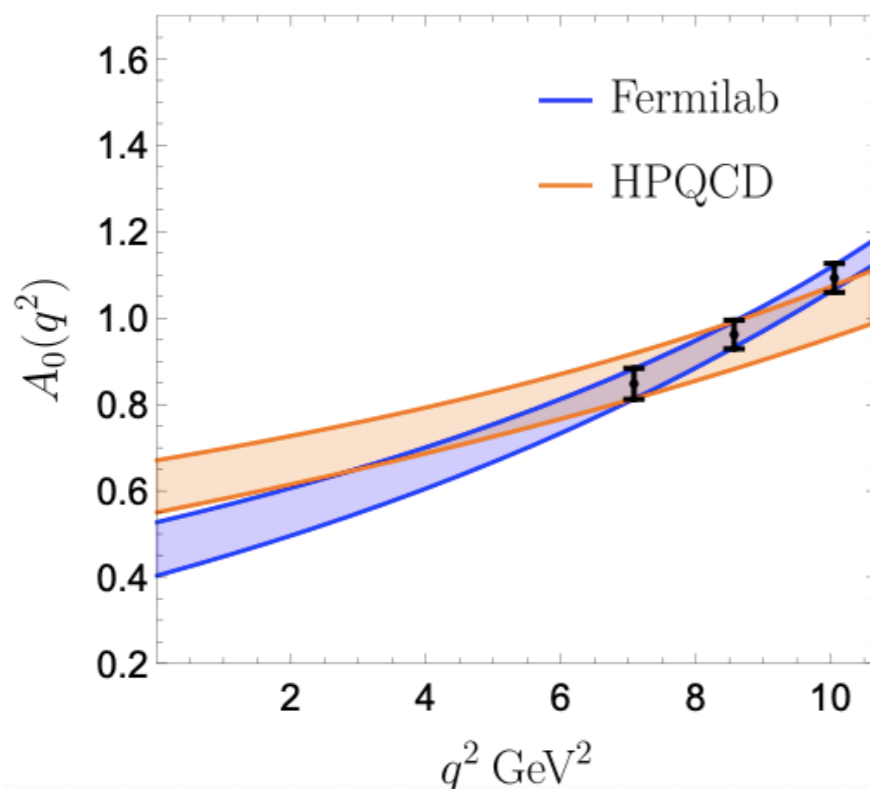There is no canonical way/parametrization that would lead to reliable |V_cb|.

Never forget that we need dynamical QCD information! Changing variables ain't gonna do it!
At least TRY various options - and cross check!

Eg1. Can we measure the slowly varying scalar helicity amplitude? (!)

Eg2. Try this!

$$\lim_{m_\ell \to 0} \frac{d\mathcal{B}(B \to D^*\ell\bar\nu)}{dq^2}\bigg|_{q^2=0} = \tau_B \frac{G_F^2 m_B^3 |V_{cb}|^2}{192\pi^3} \left(1 - \frac{m_{D^*}^2}{m_B^2}\right)^3 |A_0(0)|^2$$

2105.14019

1904.02046

Side remark: Never ending problem |V$_{cb}$|

$$\lim_{m_\ell \to 0} \frac{d\mathcal{B}(B \to D^* \ell \bar\nu)}{dq^2}\bigg|_{q^2=0} = \tau_B \frac{G_F^2 m_B^3 |V_{cb}|^2}{192\pi^3} \left(1 - \frac{m_{D^*}^2}{m_B^2}\right)^3 |A_0(0)|^2$$

- $A_0(0) = 0.47(6)^{\mathrm{FNAL}}, 0.61(6)^{\mathrm{HPQCD}}, 0.78(23)^{\text{"LCSR"}}$

  0809.0222

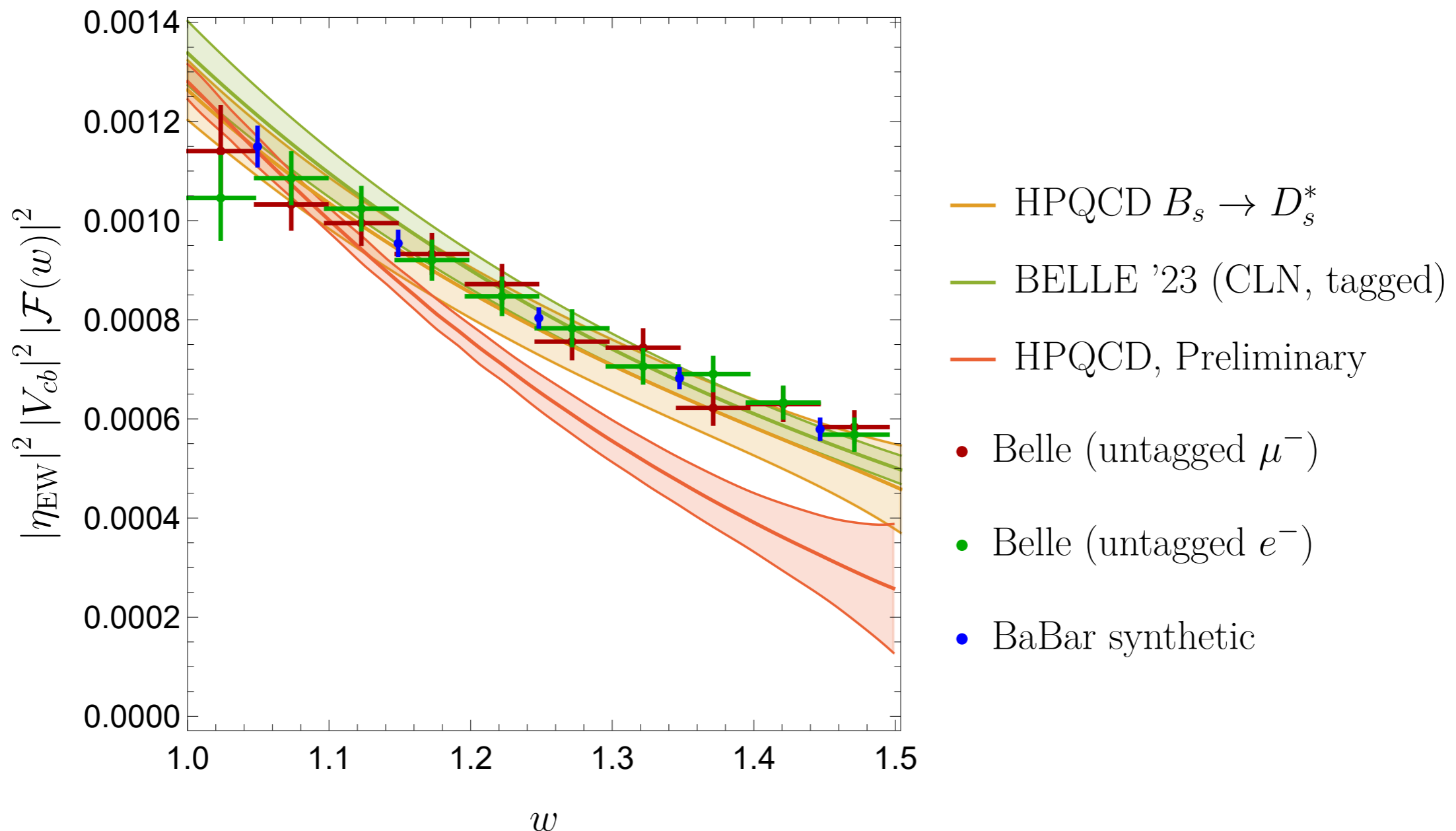- Use HFLAV results with e.g. CLN: $R_2(1) = 0.853(17) \Rightarrow R_2(w_{\max})$

  2206.07501

$$\frac{A_0(0)}{A_1(0)}\bigg|_{\mathrm{HFLAV}}^{\mathrm{CLN}} = 1.087(14) \to A_0(0) = 0.64(4)^{\mathrm{FNAL}}, 0.66(7)^{\mathrm{HPQCD}}, 0.79(22)^{\text{"LCSR"}}$$

- Use measured $\mathcal{B}(B \to D\pi^\pm)$ and $\mathcal{B}(B \to D^*\pi^\pm)$ to either check whether or not $a_1^{D\pi} = a_1^{D^*\pi}$ or to extract $A_0(m_\pi^2)/f_0(m_\pi^2)$
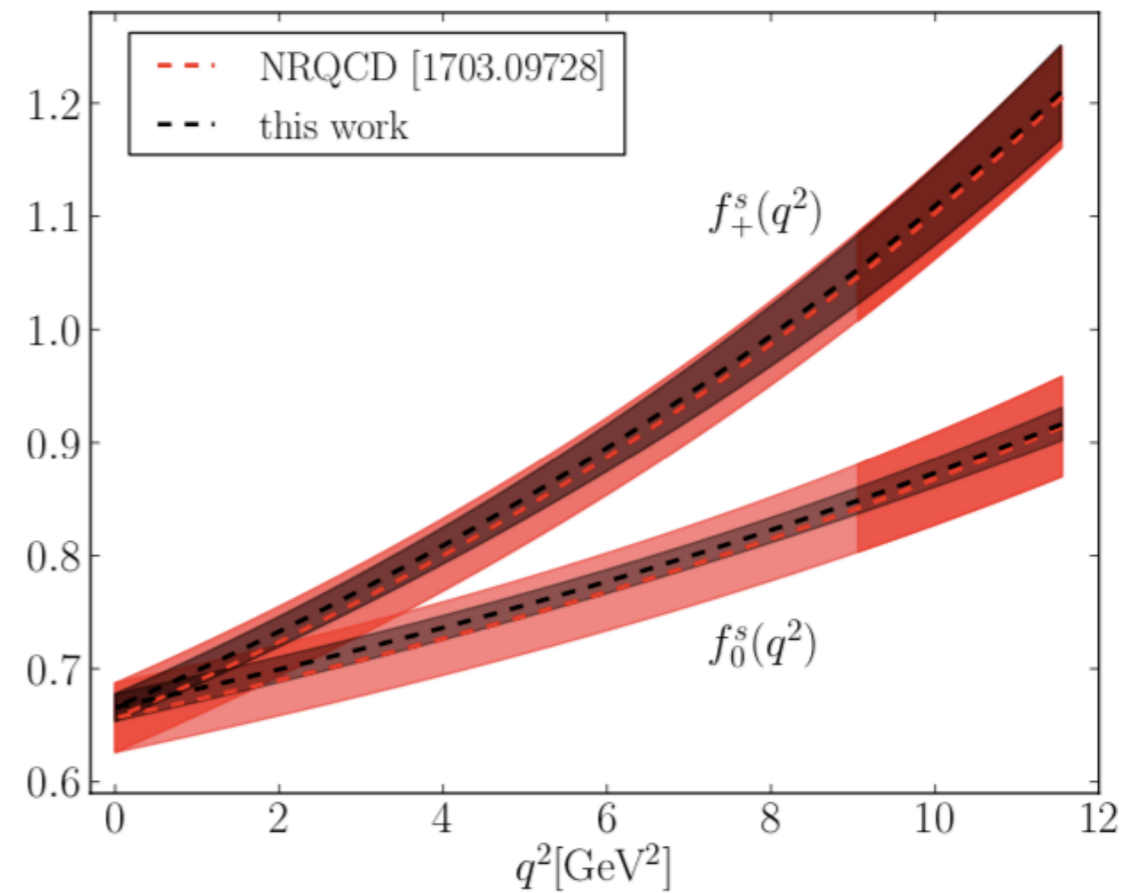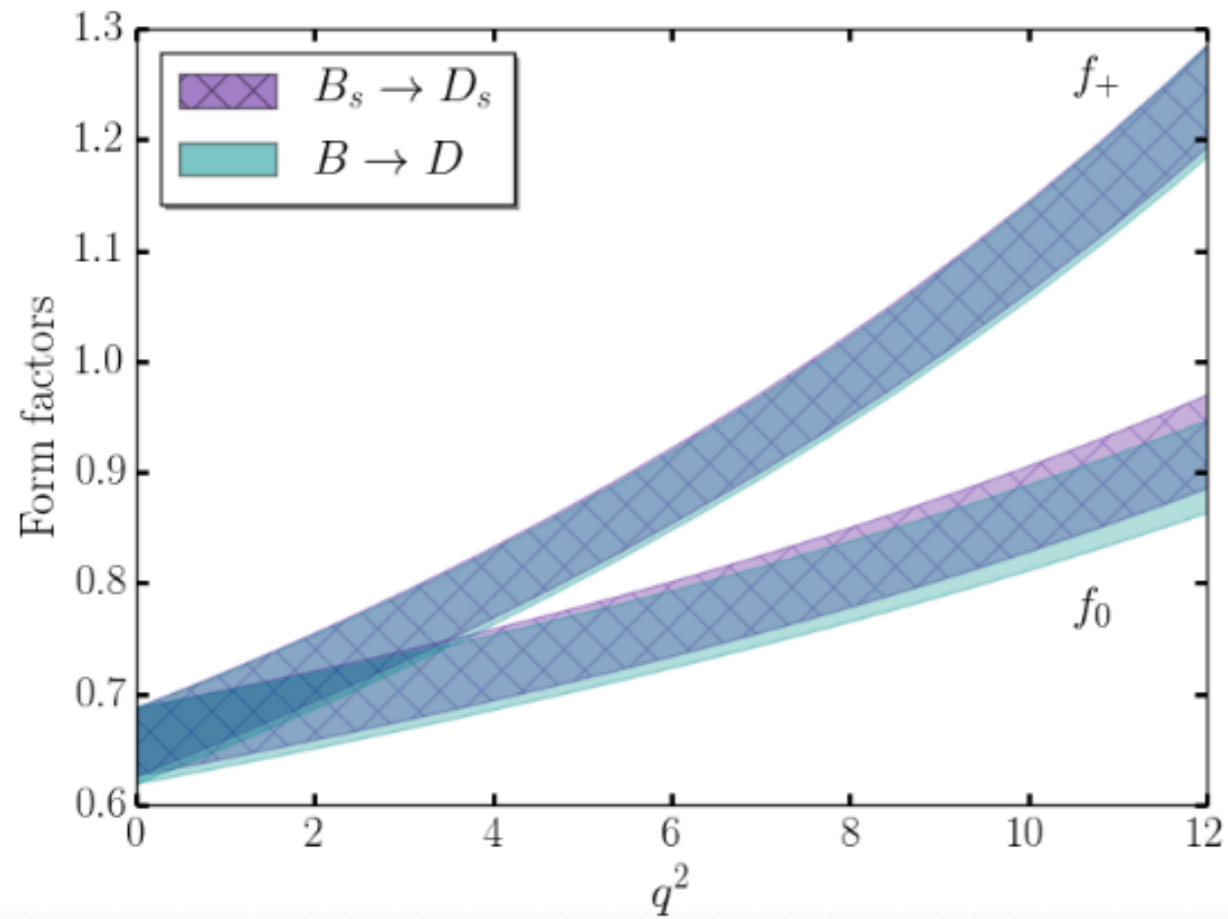 More in the paper to come.

How can we understand that?

$$\frac{d\mathcal{B}(B \to D^* \ell \bar{\nu})}{dq^2} = \frac{1}{2m_B m_{D^*}} \frac{d\mathcal{B}(B \to D^* \ell \bar{\nu})}{dw} \propto |V_{cb}|^2 |\mathcal{F}(w)|^2$$

Legend:
- —— HPQCD $B_s \to D_s^*$
- —— BELLE '23 (CLN, tagged)
- —— HPQCD, Preliminary
- • Belle (untagged μ^-)
- • Belle (untagged e^-)
- • BaBar synthetic

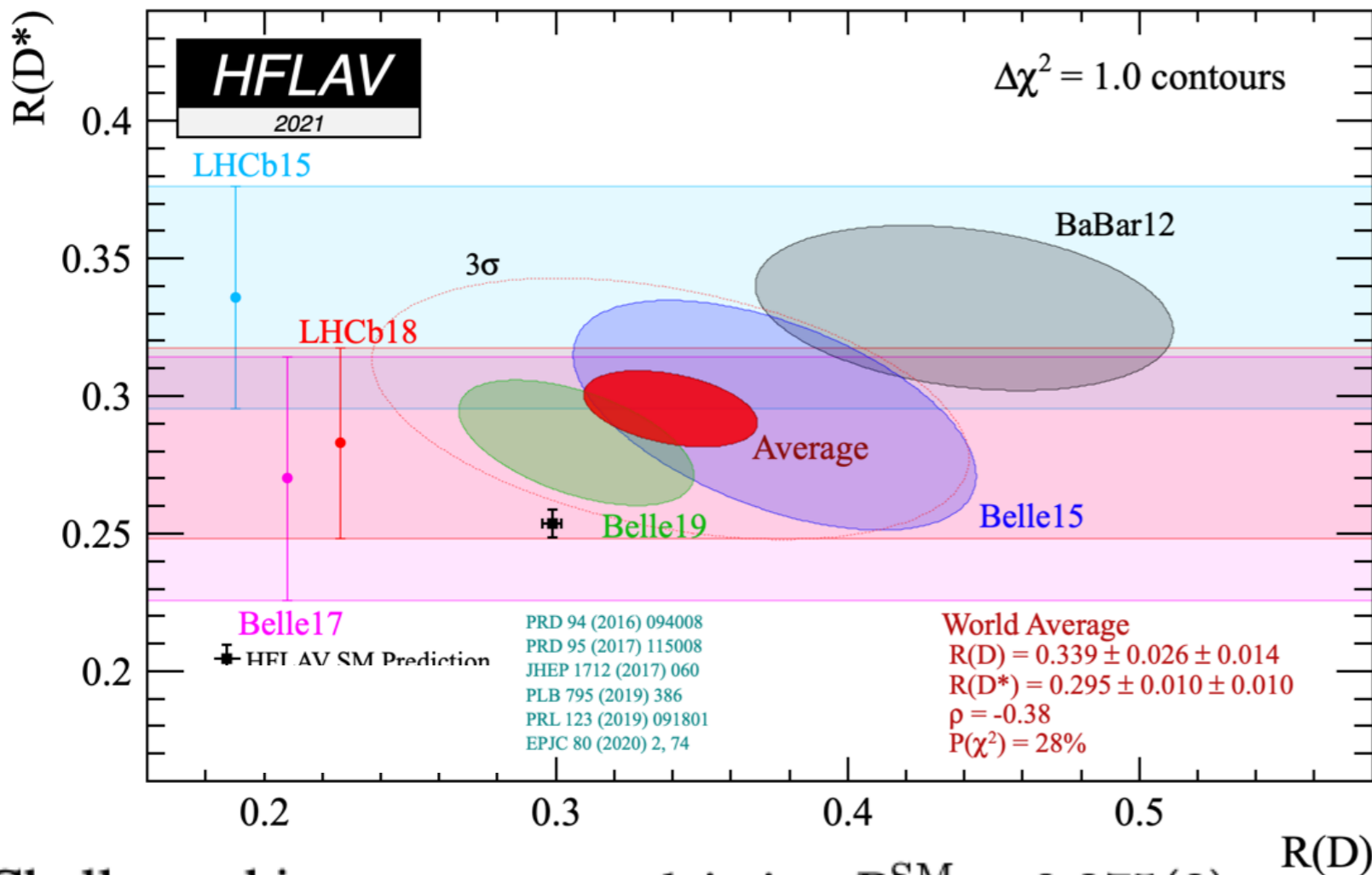Axes: vertical $|\eta_{\mathrm{EW}}|^2 |V_{cb}|^2 |\mathcal{F}(w)|^2$, horizontal w

when compared to this?

Hint of LFUV ['scare' or 'joy'] possibility to study NP effects

$$R_{D^{(*)}} = \frac{\mathcal{B}(B \to D^{(*)} \tau \bar{\nu})}{\mathcal{B}(B \to D^{(*)} \ell \bar{\nu})}\bigg|_{\ell \in (e,\mu)} \quad \& \quad R_{D^{(*)}}^{\mathrm{exp}} > R_{D^{(*)}}^{\mathrm{SM}}$$

$$R_{D^{(*)}}^{\mathrm{exp}} > R_{D^{(*)}}^{\mathrm{SM}} \quad \Rightarrow \quad \Lambda_{\mathrm{NP}} \lesssim 3 \text{ TeV}$$

HFLAV 2021

$\Delta\chi^2 = 1.0$ contours

LHCb15

3σ

BaBar12

LHCb18

Average

Belle19

Belle15

Belle17

HFLAV SM Prediction

PRD 94 (2016) 094008
PRD 95 (2017) 115008
JHEP 1712 (2017) 060
PLB 795 (2019) 386
PRL 123 (2019) 091801
EPJC 80 (2020) 2, 74

World Average
R(D) = 0.339 ± 0.026 ± 0.014
R(D*) = 0.295 ± 0.010 ± 0.010
ρ = -0.38
P(χ²) = 28%

LHCb

- $B_c \to J/\psi \, \ell \bar{\nu}$

$$R_{J/\psi}^{\mathrm{exp}} > R_{J/\psi}^{\mathrm{SM}}$$

- $\Lambda_b \to \Lambda_c \, \ell \bar{\nu}$

$$R_{\Lambda_c}^{\mathrm{exp}} \approx R_{\Lambda_c}^{\mathrm{SM}}$$
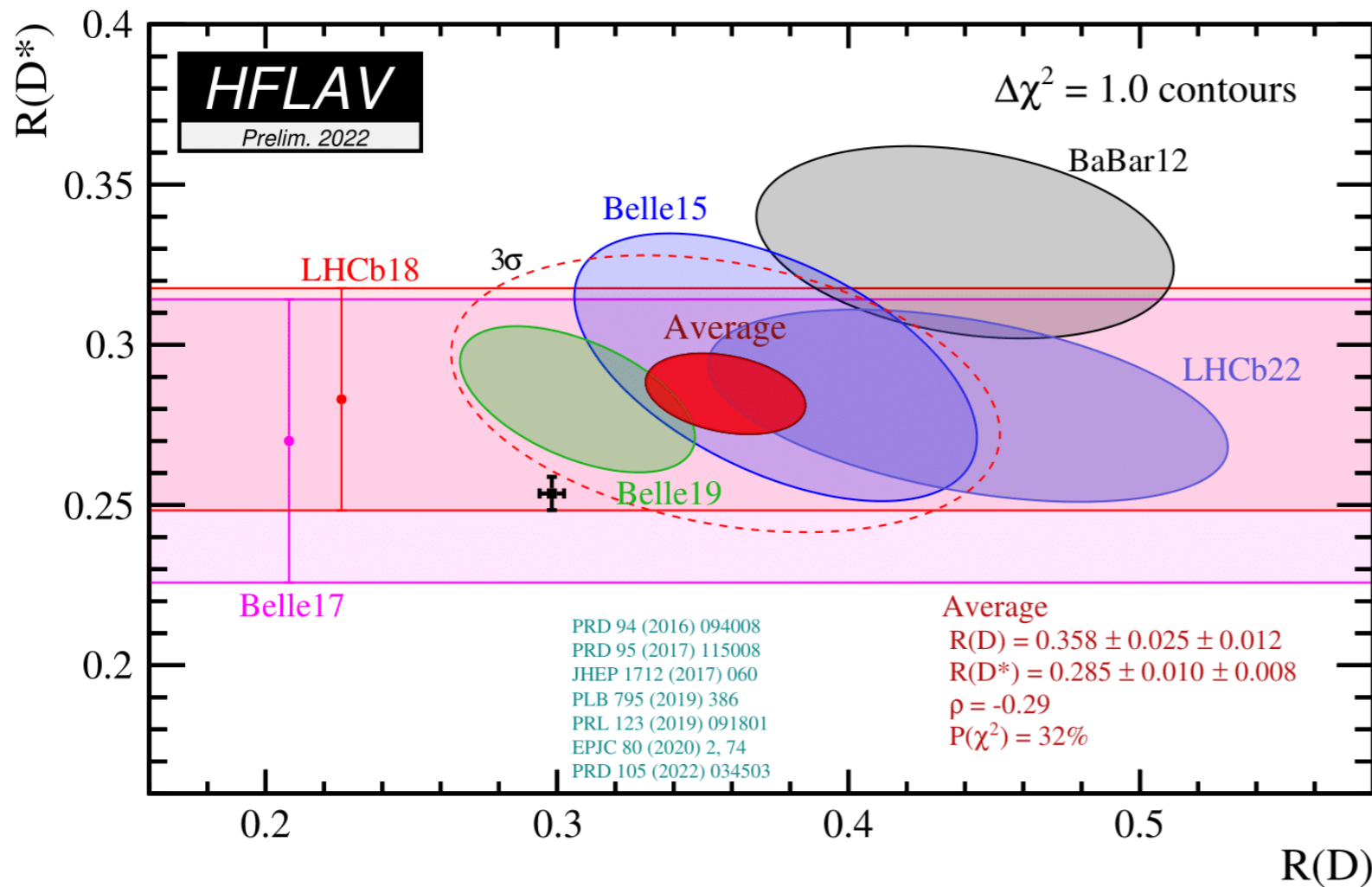
NEW and can be improved... a lot

2201.03497

Challenged in 2109.15248 claiming $R_{D^*}^{\mathrm{SM}} = 0.275(8)$

Hint of LFUV ['scare' or 'joy'] possibility to study NP effects

$$R_{D^{(*)}} = \frac{\mathcal{B}(B \to D^{(*)}\tau\bar{\nu})}{\mathcal{B}(B \to D^{(*)}\ell\bar{\nu})}_{\ell \in (e,\mu)} \qquad \& \qquad R_{D^{(*)}}^{\text{exp}} > R_{D^{(*)}}^{\text{SM}}$$

2302.02886

LHCb
- $B_c \to J/\psi \, \ell\bar{\nu}$

$$R_{J/\psi}^{\text{exp}} > R_{J/\psi}^{\text{SM}}$$

- $\Lambda_b \to \Lambda_c \, \ell\bar{\nu}$

$$R_{\Lambda_c}^{\text{exp}} \approx R_{\Lambda_c}^{\text{SM}}$$
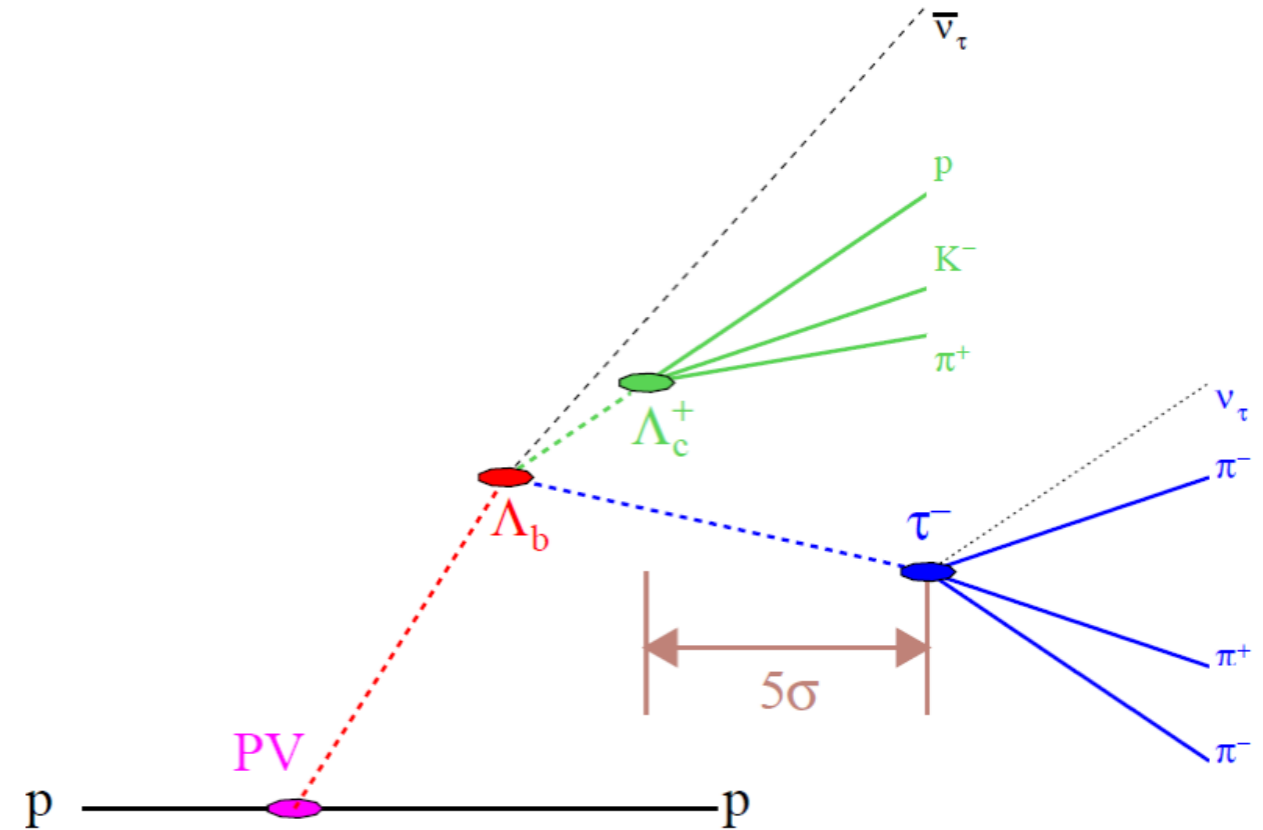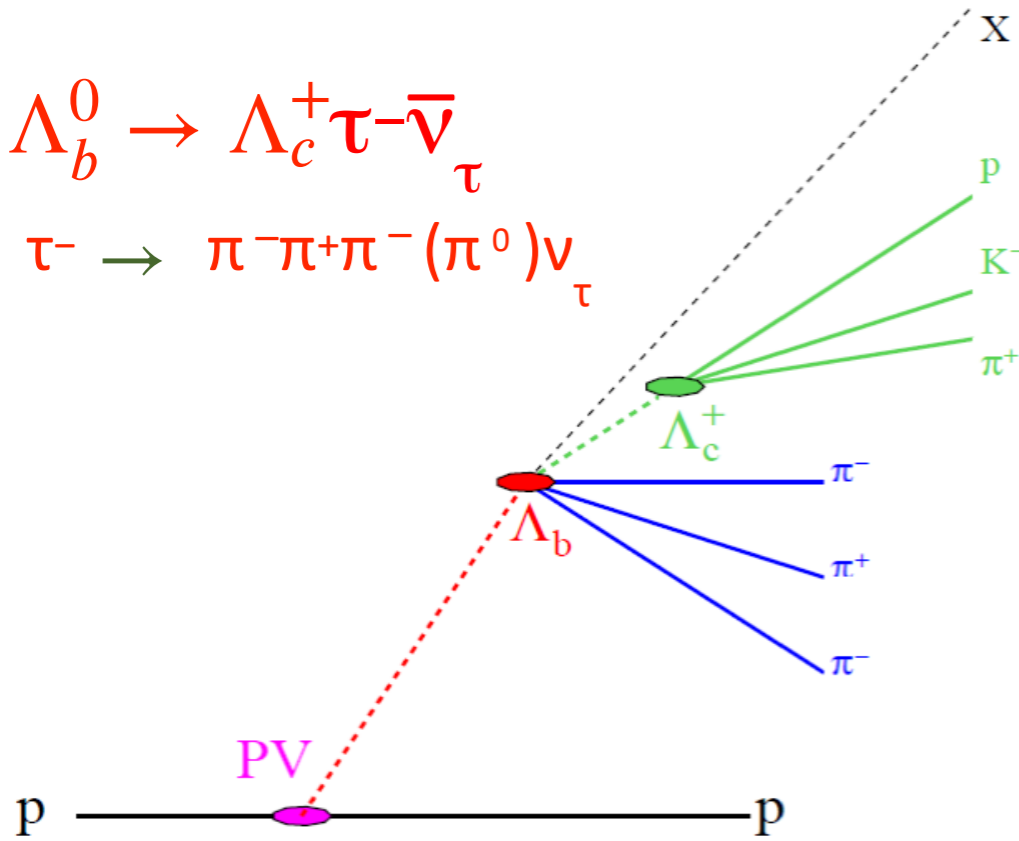
NEW and can be improved... a lot

2201.03497

A comment on R_{Λ_c}
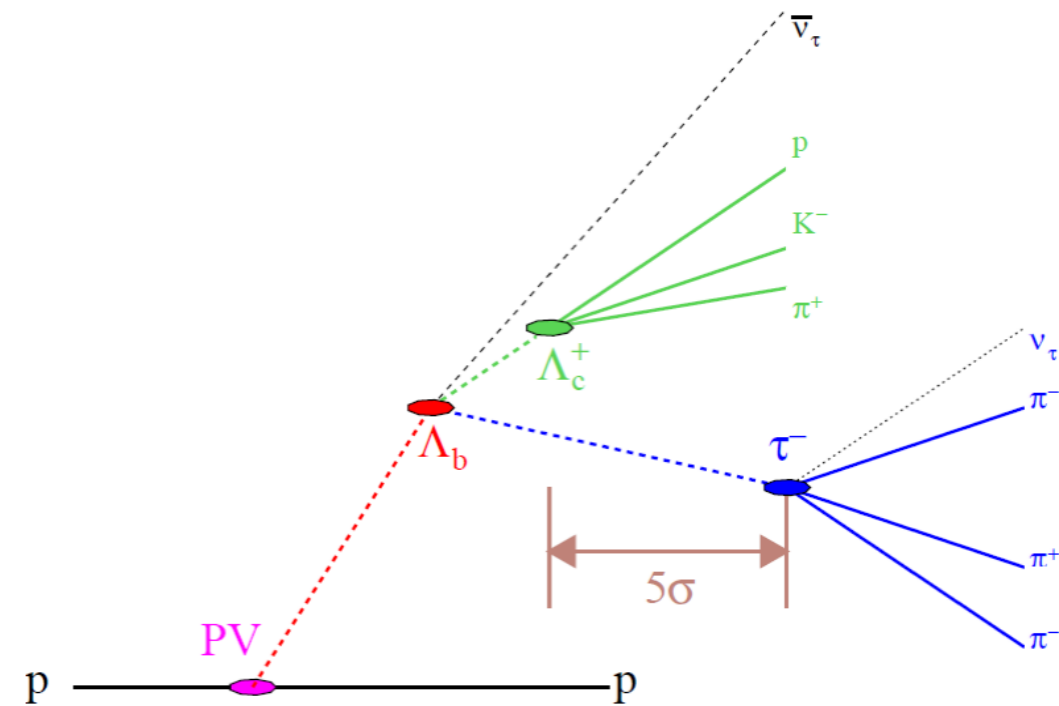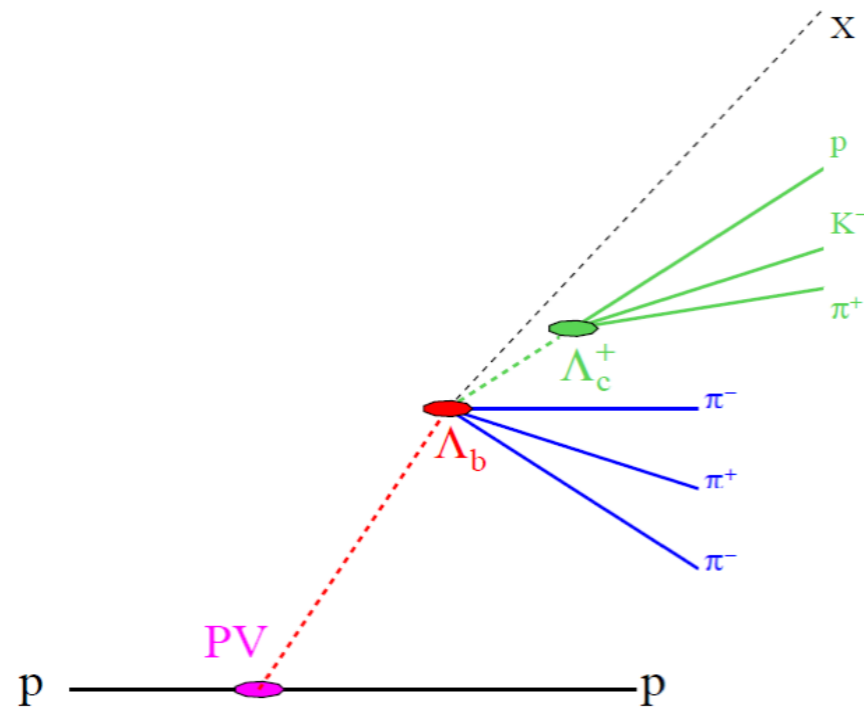
$$\Lambda_b^0 \to \Lambda_c^+ \tau^- \bar{\nu}_\tau$$

$$\tau^- \to \pi^- \pi^+ \pi^- (\pi^0) \nu_\tau$$

$$K_{\Lambda_c} = \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \tau^- \bar{\nu}_\tau)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \pi^- \pi^+ \pi^-)} = 2.46(27)(40)$$
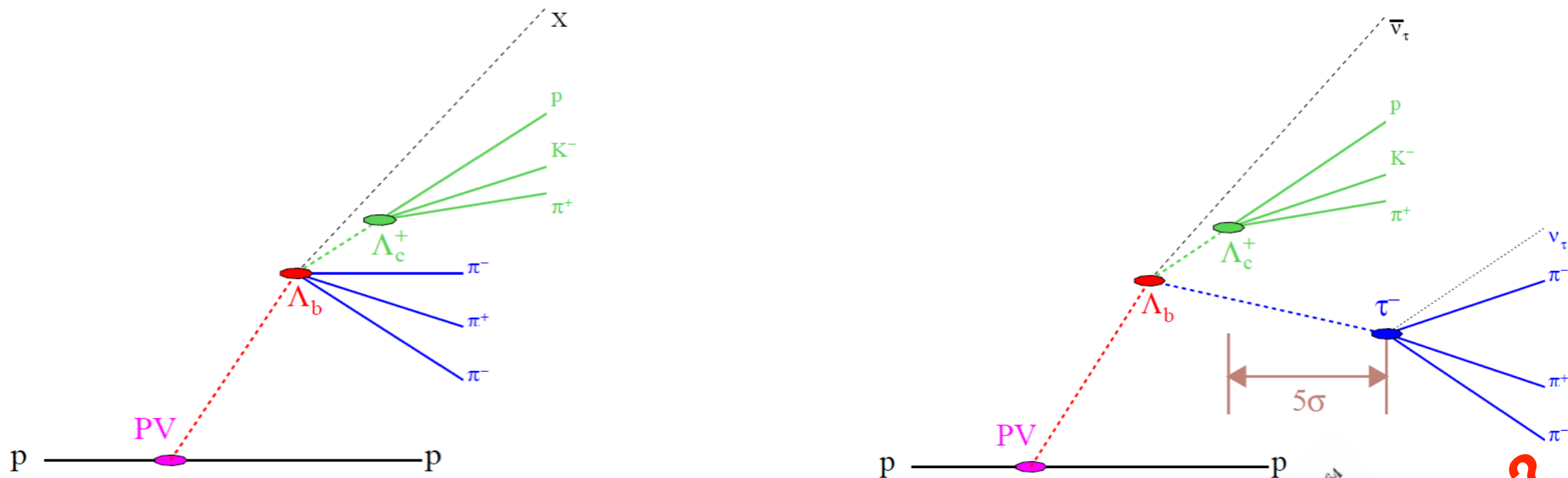
A comment on R$_{\Lambda_c}$

$$K_{\Lambda_c} = \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \tau^- \bar{\nu}_\tau)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \pi^- \pi^+ \pi^-)} = 2.46(27)(40)$$

20%

$\Gamma(\Lambda_b^0 \to \Lambda_c^+ \pi^+ \pi^- \pi^-)/\Gamma_{\text{total}}$				Γ_{35}/Γ
VALUE (10^{-3}) 14%	EVTS	DOCUMENT ID	TECN	COMMENT
7.6 ± 1.1 **OUR FIT** Error includes scale factor of 1.1.				
$14.8 \, ^{+3.8}_{-3.1} \pm 1.1$		[1] AALTONEN 2012A	CDF	$p\bar{p}$ at 1.96 TeV
		• • We do not use the following data for averages, fits, limits, etc. • •		

A comment on R_{Λ_c}

2201.03497

$$K_{\Lambda_c} = \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \tau^- \bar{\nu}_\tau)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ \pi^- \pi^+ \pi^-)} = 2.46(27)(40)$$

20%

CERN-EP-2017-164
LHCb-PAPER-2017-016
January 25, 2018

Measurement of the shape of the
differential decay
$\Lambda_b^0 \to \Lambda_c^+ \mu^- \bar{\nu}_\mu$ rate

Why not working with 1709.01920 ?

$\Gamma(\Lambda_b^0 \to \Lambda_c^+ \ell^- \bar{\nu}_\ell)/\Gamma_{\text{total}}$				
VALUE 22%		DOCUMENT ID	TECN	CC
$0.062^{+0.014}_{-0.013}$	OUR FIT			
$0.050^{+0.011}_{-0.008}\,^{+0.016}_{-0.012}$		[1] ABDALLAH	2004A DLPH	$e^+ e^- \to Z$

[1] Derived from a combined likelihood and event rate fit to the distribution of the Isgur-Wise variable and using HQET. The form factor is measured to be $\rho^2 = 2.03 \pm 0.46\,^{+0.72}_{-1.00}$.
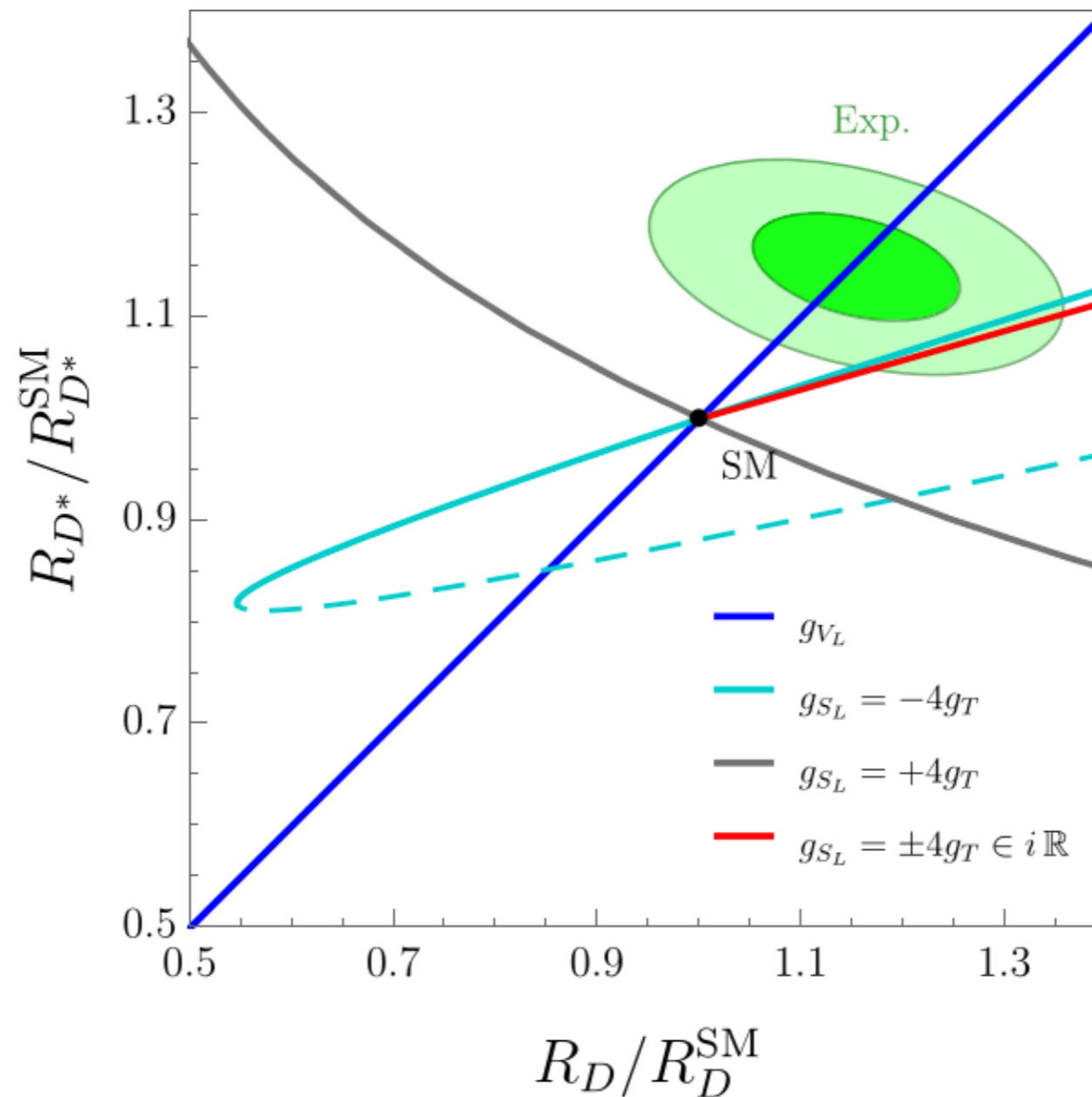
EFT - exclusive $b \rightarrow c\ell\nu$

$$\mathcal{L}_{\text{eff}} = -2\sqrt{2}G_F\, V_{cb} \Big[(1 + g_{V_L})(\bar{c}_L \gamma_\mu b_L)(\bar{\ell}_L \gamma^\mu \nu_L) + g_{V_R}\, (\bar{c}_R \gamma_\mu b_R)(\bar{\ell}_L \gamma^\mu \nu_L)$$

$$+ g_{S_R}\, (\bar{c}_L b_R)(\bar{\ell}_R \nu_L) + g_{S_L}\, (\bar{c}_R b_L)(\bar{\ell}_R \nu_L) + g_T\, (\bar{c}_R \sigma_{\mu\nu} b_L)(\bar{\ell}_R \sigma^{\mu\nu} \nu_L) \Big] + \text{h.c.}$$
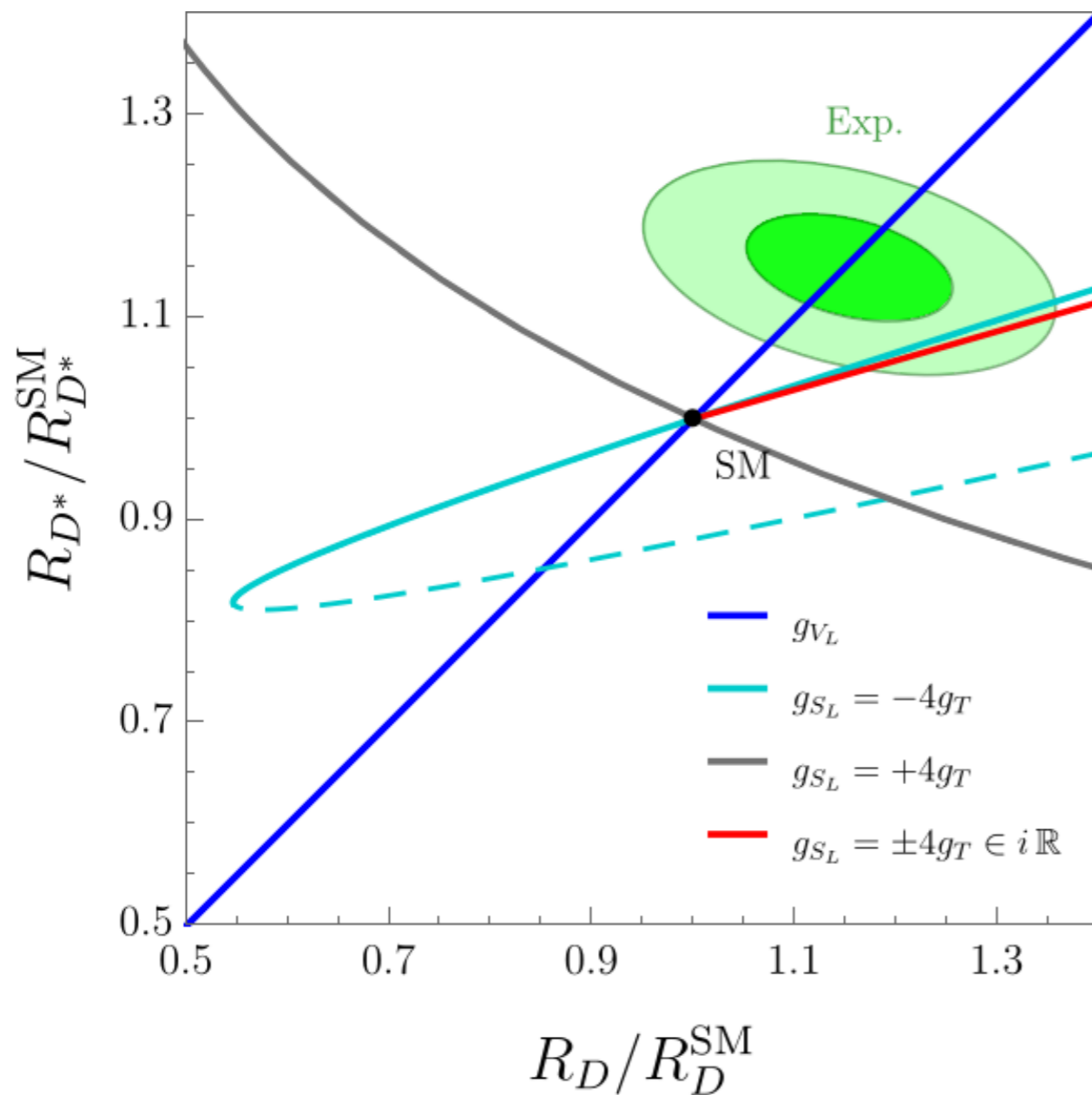
EFT - exclusive $b \to c\ell\nu$

$$\mathcal{L}_{\text{eff}} = -2\sqrt{2}G_F\,V_{cb}\Big[(1 + g_{V_L})(\bar{c}_L\gamma_\mu b_L)(\bar{\ell}_L\gamma^\mu\nu_L) + g_{V_R}\,(\bar{c}_R\gamma_\mu b_R)(\bar{\ell}_L\gamma^\mu\nu_L)$$

$$+\; g_{S_R}\,(\bar{c}_L b_R)(\bar{\ell}_R\nu_L) + g_{S_L}\,(\bar{c}_R b_L)(\bar{\ell}_R\nu_L) + g_T\,(\bar{c}_R\sigma_{\mu\nu}b_L)(\bar{\ell}_R\sigma^{\mu\nu}\nu_L)\Big] + \text{h.c.}$$

2103.12504

EFT - exclusive $b \to c\ell\nu$

$$\mathcal{L}_{\text{eff}} = -2\sqrt{2}\,G_F\,V_{cb}\Big[(1 + g_{V_L})(\bar{c}_L\gamma_\mu b_L)(\bar{\ell}_L\gamma^\mu\nu_L) + g_{V_R}\,(\bar{c}_R\gamma_\mu b_R)(\bar{\ell}_L\gamma^\mu\nu_L)$$

$$+ g_{S_R}\,(\bar{c}_L b_R)(\bar{\ell}_R\nu_L) + g_{S_L}\,(\bar{c}_R b_L)(\bar{\ell}_R\nu_L) + g_T\,(\bar{c}_R\sigma_{\mu\nu}b_L)(\bar{\ell}_R\sigma^{\mu\nu}\nu_L)\Big] + \text{h.c.}$$

Need better data and more observables to discriminate among various possibilities.

Dream goal is to confidently & simultaneously determine all NP cplgs from fit with the data.
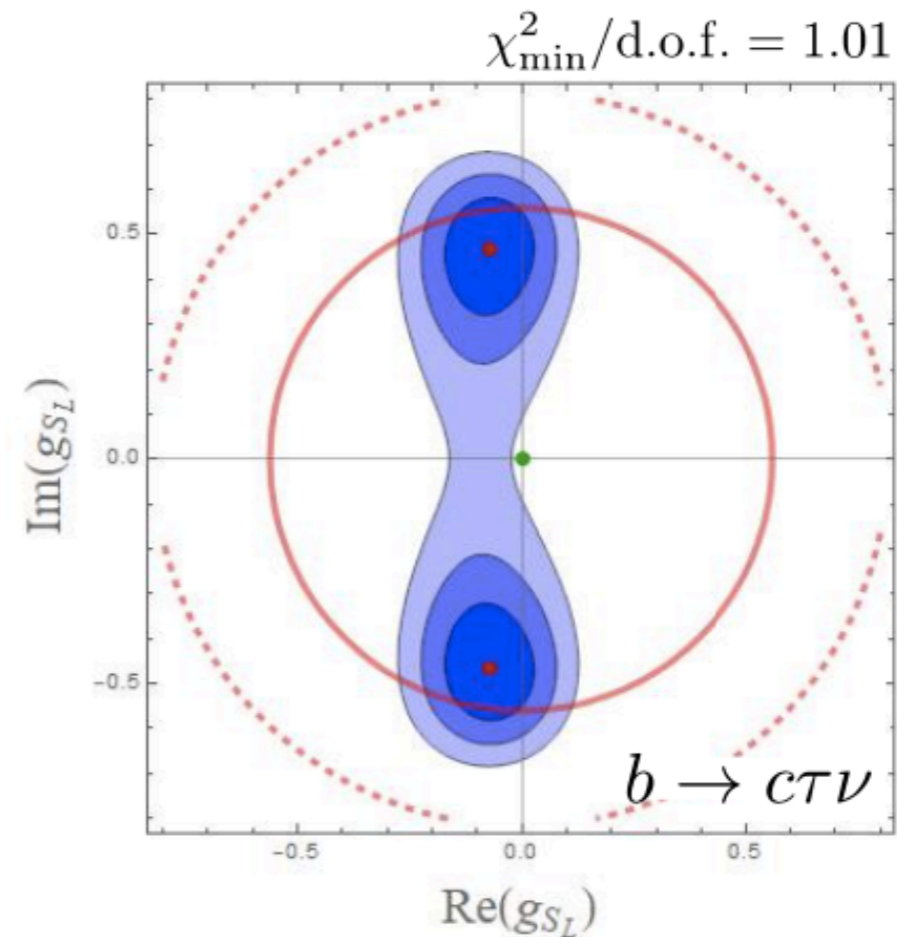
Angular distributions can help!

vast literature…

Impact of R_{Λ_c}

Wilson Coefficient	$R(D)$ and $R(D^*)$	$R(\Lambda_c)$	Combined	$\chi^2_{\min}/$d.o.f
g_{V_L}	0.084 ± 0.029	-0.15 ± 0.14	0.077 ± 0.035	$0.06 \rightarrow 1.3$
g_{S_L}	-1.47 ± 0.08	-0.53 ± 0.54	-1.45 ± 0.11	$0.5 \rightarrow 2.1$
g_T	-0.027 ± 0.011	0.13 ± 0.14	-0.026 ± 0.013	$1.2 \rightarrow 1.7$
$g_{S_L} = +4g_T \in i\mathbb{R}$	$\pm 0.49 \pm 0.10$	0.0 ± 0.39	$\pm 0.47 \pm 0.13$	$0.9 \rightarrow 1.6$
$g_{S_L} = -4g_T$	0.16 ± 0.06	0.0 ± 0.39	0.15 ± 0.07	$0.7 \rightarrow 1.0$

$\chi^2_{\min}/$d.o.f $= 0.05$

$\chi^2_{\min}/$d.o.f. $= 1.01$
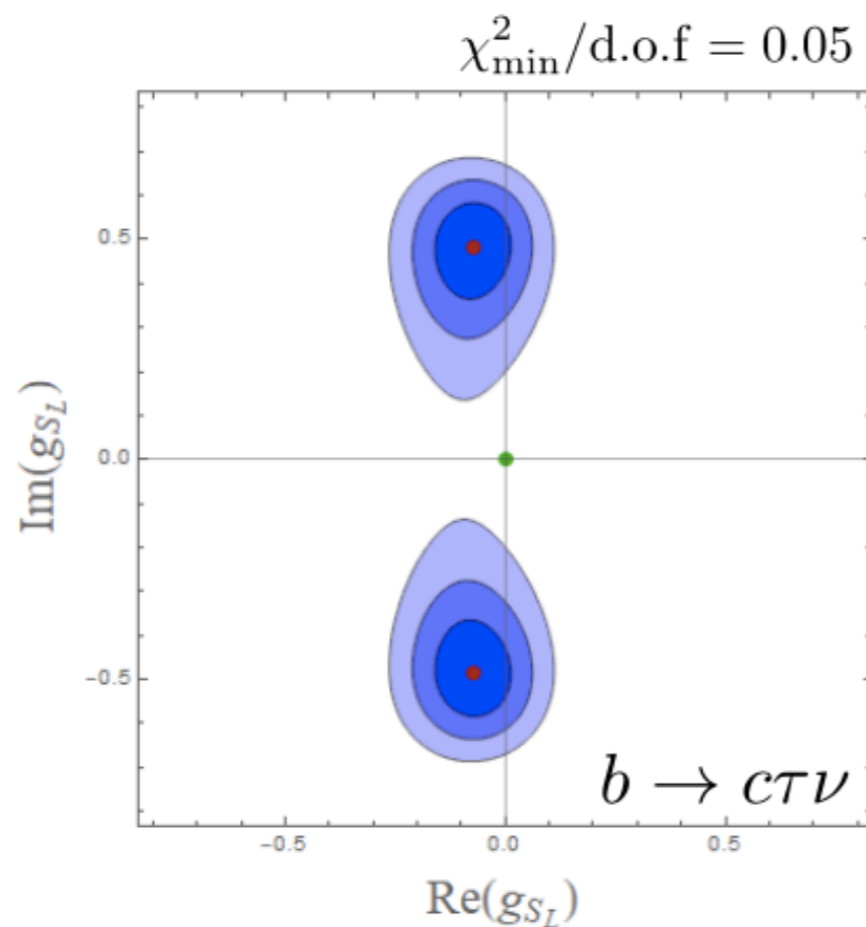
$g_{S_L} = +4g_T$

$g_{S_L} = +4g_T$

We still do not have a full/good control over hadronic uncertainties

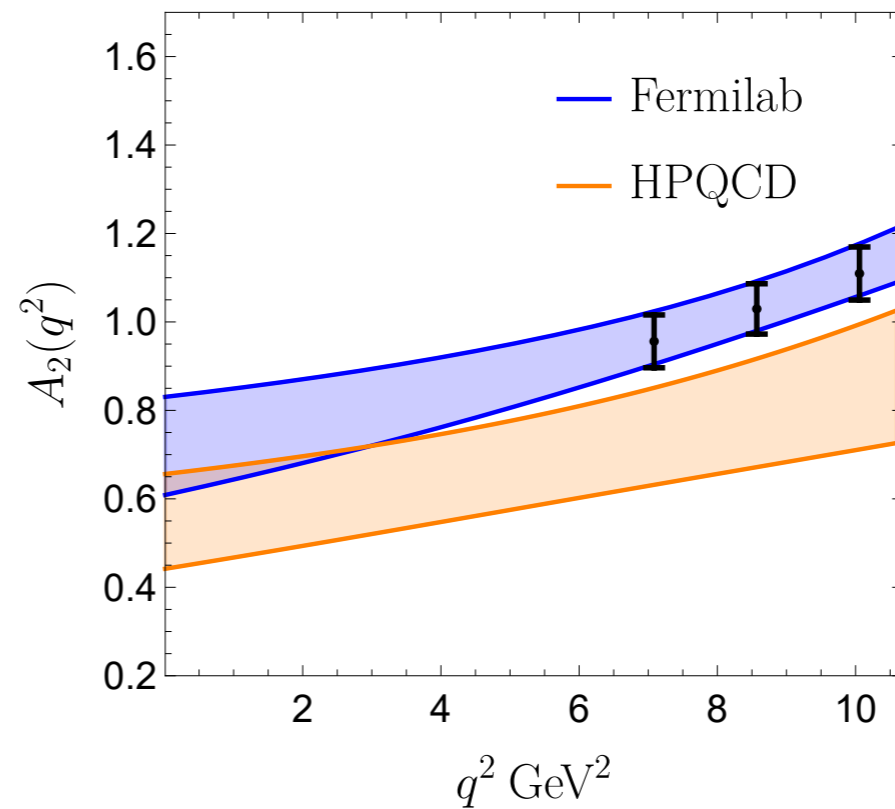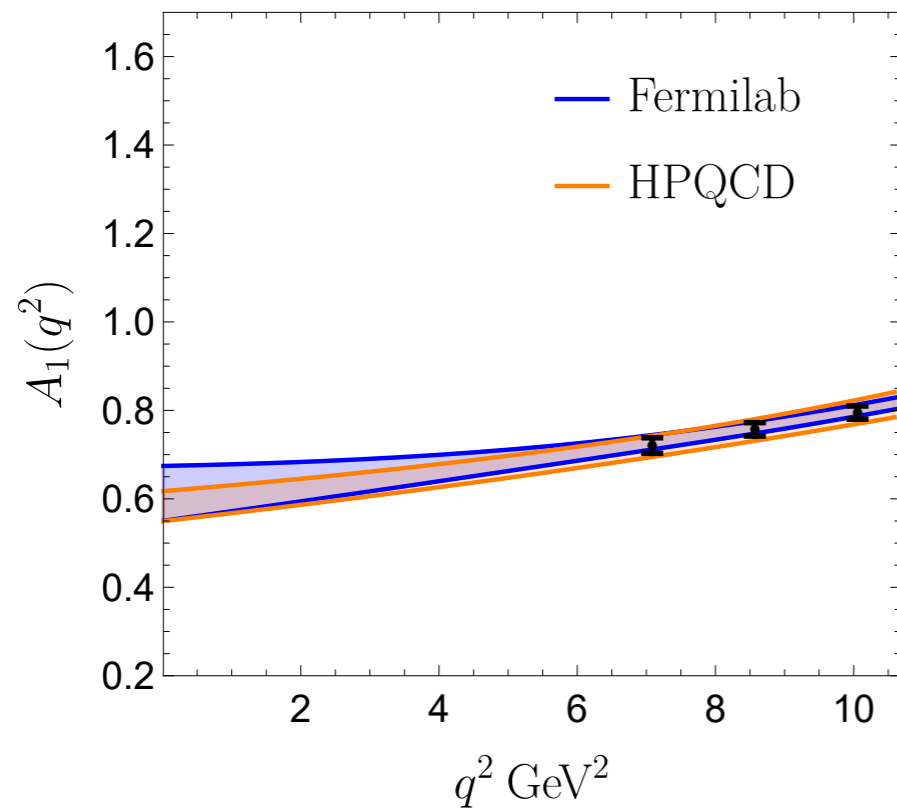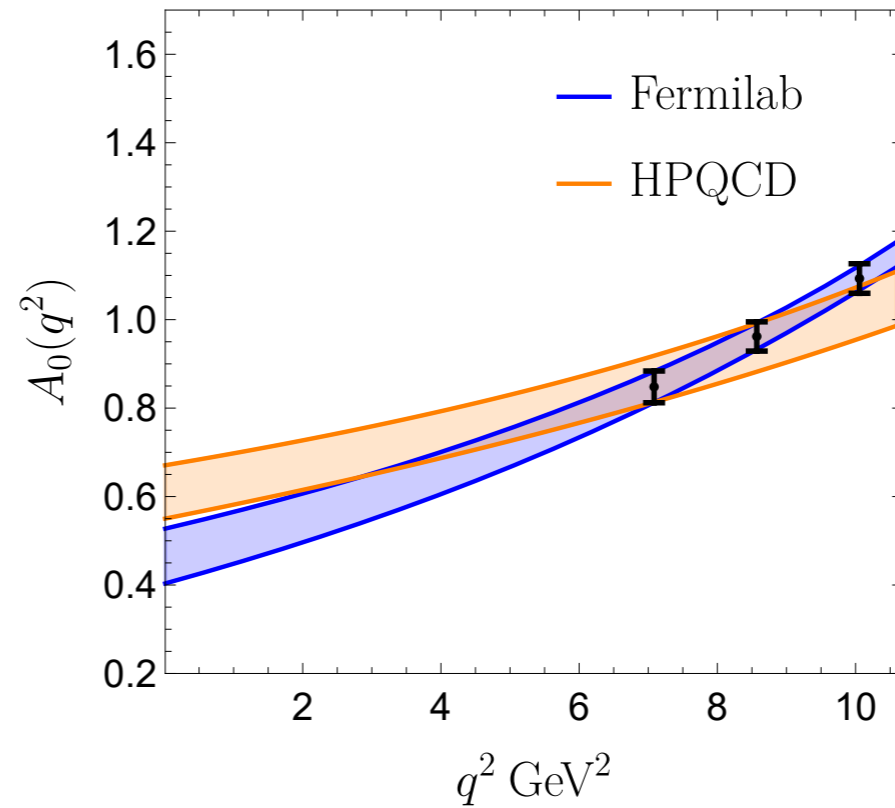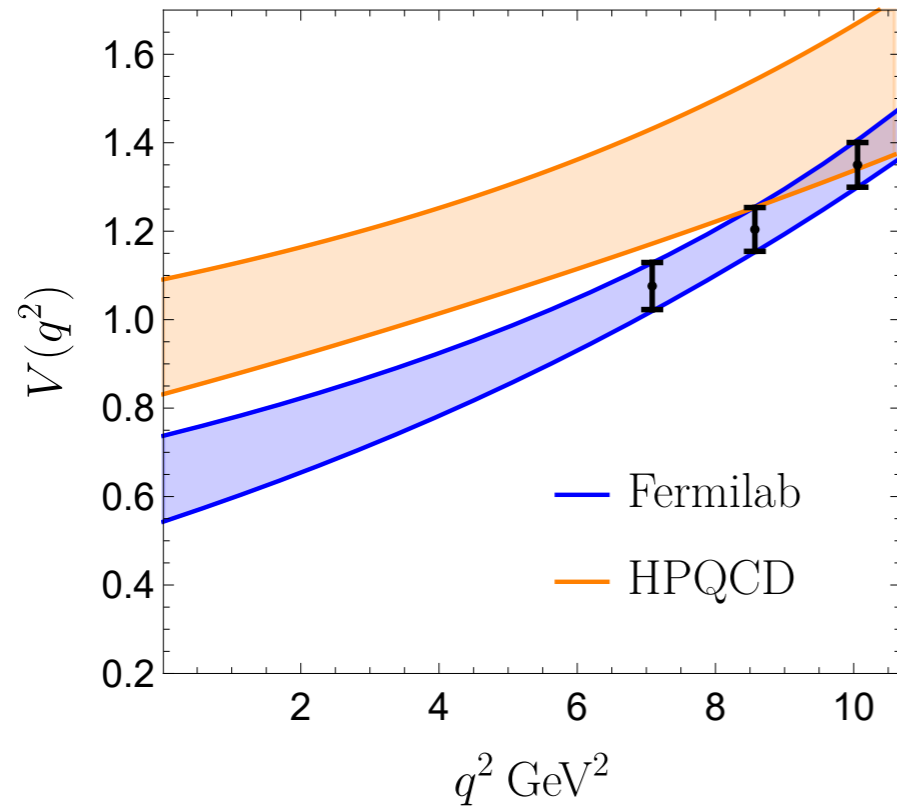| Mode	$B \to D\ell\bar{\nu}$	$B \to D^*\ell\bar{\nu}$	$\Lambda_b \to \Lambda_c\ell\bar{\nu}$
$\langle V_\mu \rangle$	2 ✓	1 ✓	3 ✓
$\langle A_\mu \rangle$		3 ✓	3 ✓
$\langle T_{\mu\nu} \rangle$	1 ✗	3 ✗	4 ✓

1503.07237   1904.02046   1503.01421

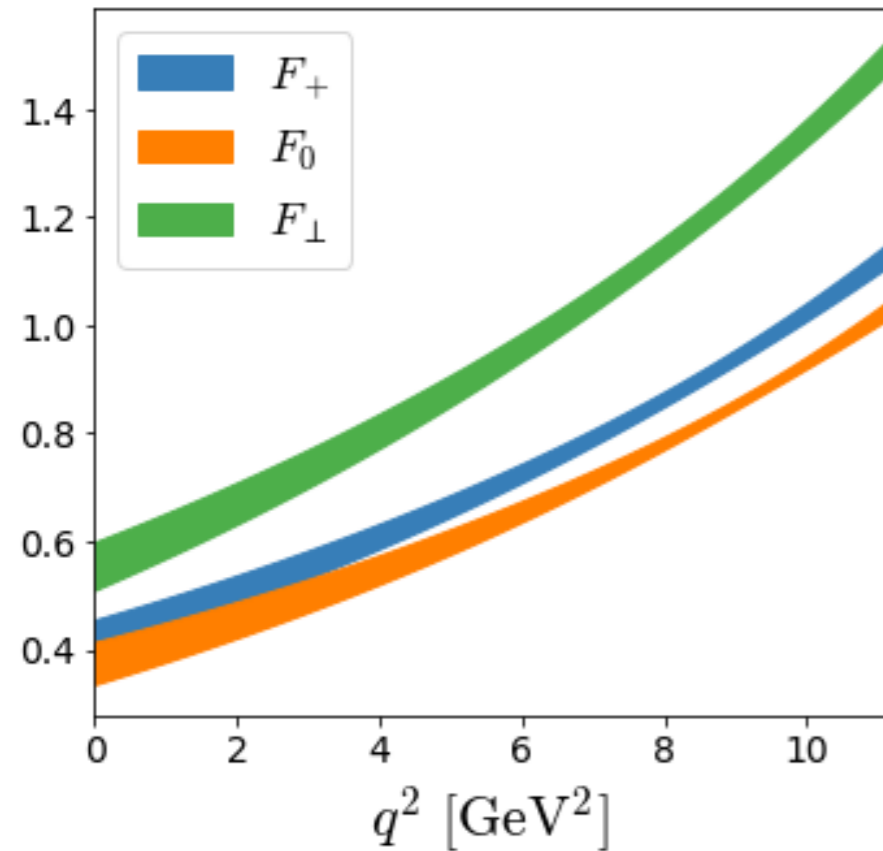1505.03925   2105.14019   1702.02243

$$B \to D^* \ell \bar{\nu}$$

2105.11433

2105.14019

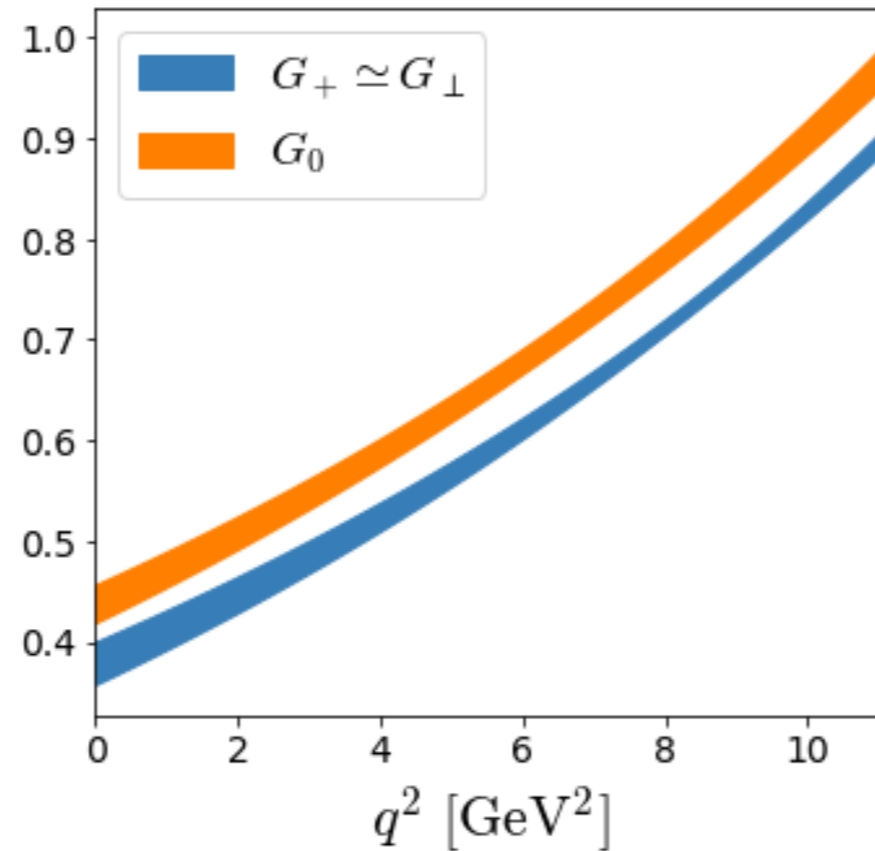$$\Lambda_b \rightarrow \Lambda_c \ell \bar{\nu}$$

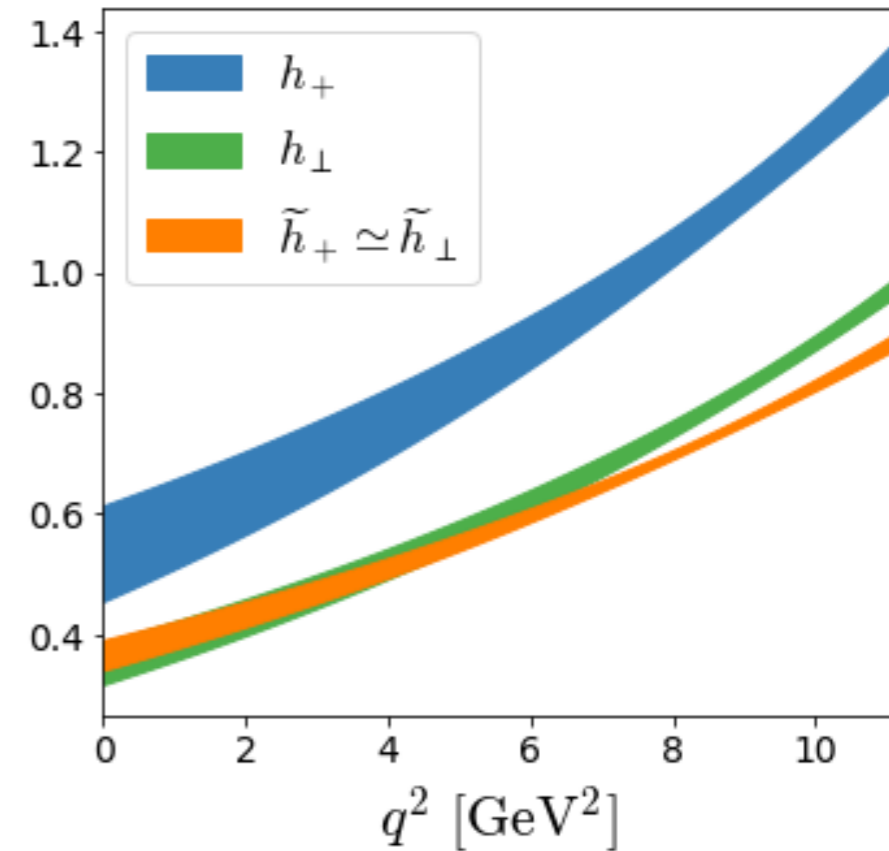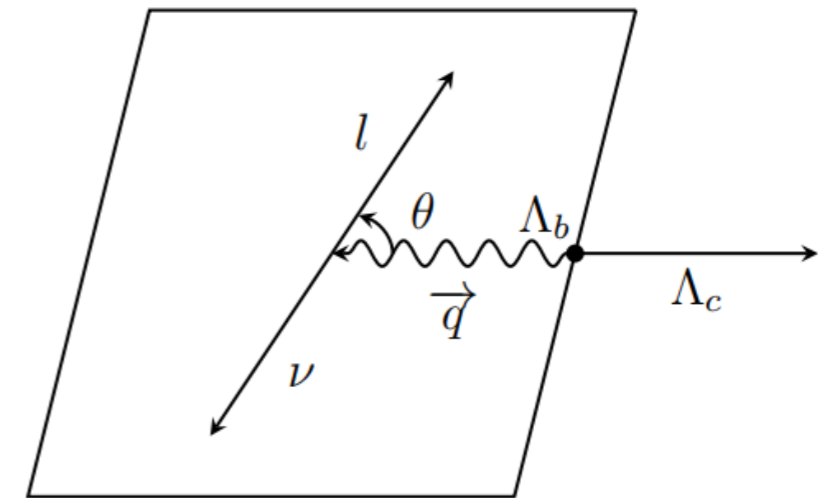$$\langle \Lambda_c | \bar{c} \gamma_\mu b | \Lambda_b \rangle \qquad \langle \Lambda_c | \bar{c} \gamma_\mu \gamma_5 b | \Lambda_b \rangle \qquad \langle \Lambda_c | \bar{c} \sigma_{\mu\nu} b | \Lambda_b \rangle$$

1503.01421

1702.02243

Keep in mind: Less than a half of available q^2's computed on the lattice. Otherwise "z-parametrization".

Angular observables can help disentangling among various NP scenarios

Many works with mesons: $\mathbf{B \to D\ell\bar{\nu}}$ $\qquad$ $\mathbf{B \to D^*\ell\bar{\nu}}$

Let us now play with baryons:

$$\frac{d^2\Gamma}{dq^2 d\cos\theta} = \frac{\sqrt{\lambda_{\Lambda_b\Lambda_c}(q^2)}}{1024\pi^3 M_{\Lambda_b}^3}\left(1 - \frac{m_l^2}{q^2}\right)\sum_{\lambda_l\lambda_b\lambda_c}\left|\mathcal{M}_{\lambda_c}^{(3)\lambda_b\lambda_l}\right|^2$$

$$\frac{d^2\Gamma(\Lambda_b \to \Lambda_c^{\lambda_c}\ell^{\lambda_l}\nu)}{dq^2 d\cos\theta} = a_{\lambda_c}^{\lambda_l}(q^2) + b_{\lambda_c}^{\lambda_l}(q^2)\cos\theta + c_{\lambda_c}^{\lambda_l}(q^2)\cos^2\theta$$

Each $a_{\lambda_c}^{\lambda_l}(q^2)$, $b_{\lambda_c}^{\lambda_l}(q^2)$, $c_{\lambda_c}^{\lambda_l}(q^2)$ is a function of kinematics, form factors and the NP couplings g_{V_L}, g_{S_L}, g_{S_R}, g_T.

12-2=10 observables

Angular observables $\quad \Lambda_b \to \Lambda_c \ell \bar{\nu}$

1907.12554   1908.02328   1909.10769   1702.02243   1502.04864   2209.13409

Three powerful observables:

○ $\quad \mathcal{A}_{\text{fb}}(q^2) = \dfrac{1}{\Gamma} \left[\displaystyle\int_0^1 - \int_{-1}^0 \right] \dfrac{d\Gamma}{d\cos\theta} d\cos\theta$

○ $\quad \mathcal{A}_{\pi/3}(q^2) = \dfrac{1}{\Gamma} \left[\displaystyle\int_0^{\pi/3} + \int_{2\pi/3}^{\pi} - \int_{\pi/3}^{2\pi/3} \right] \dfrac{d\Gamma}{d\cos\theta} \sin\theta \, d\theta$

○ $\quad \mathcal{A}_{\lambda}(q^2) = \dfrac{1}{\Gamma} \left[\dfrac{d\Gamma^+}{dq^2} - \dfrac{d\Gamma^-}{dq^2} \right]$
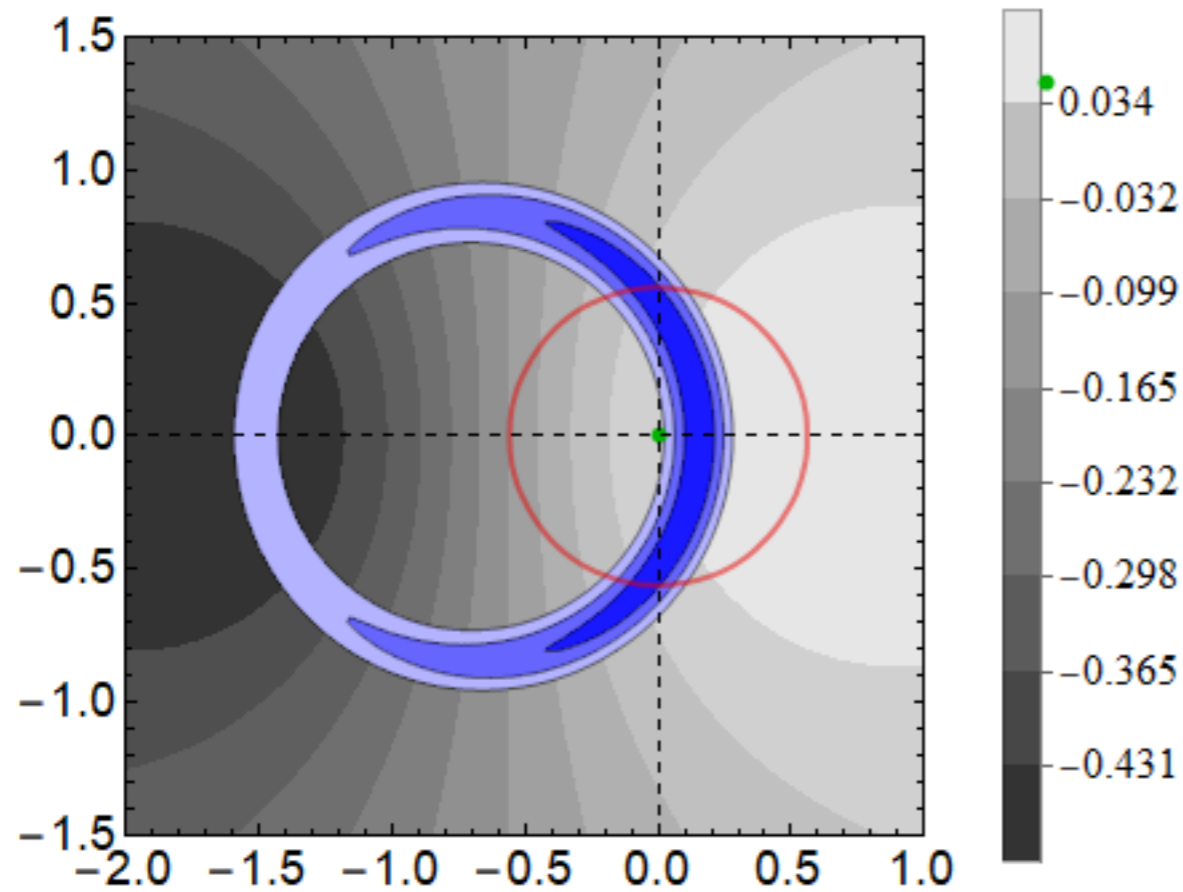
Examples:

$$U_1 : g_{V_L} \qquad R_2 : g_{S_L} = 4\, g_T \qquad S_1 : g_{S_L} = -4\, g_T$$

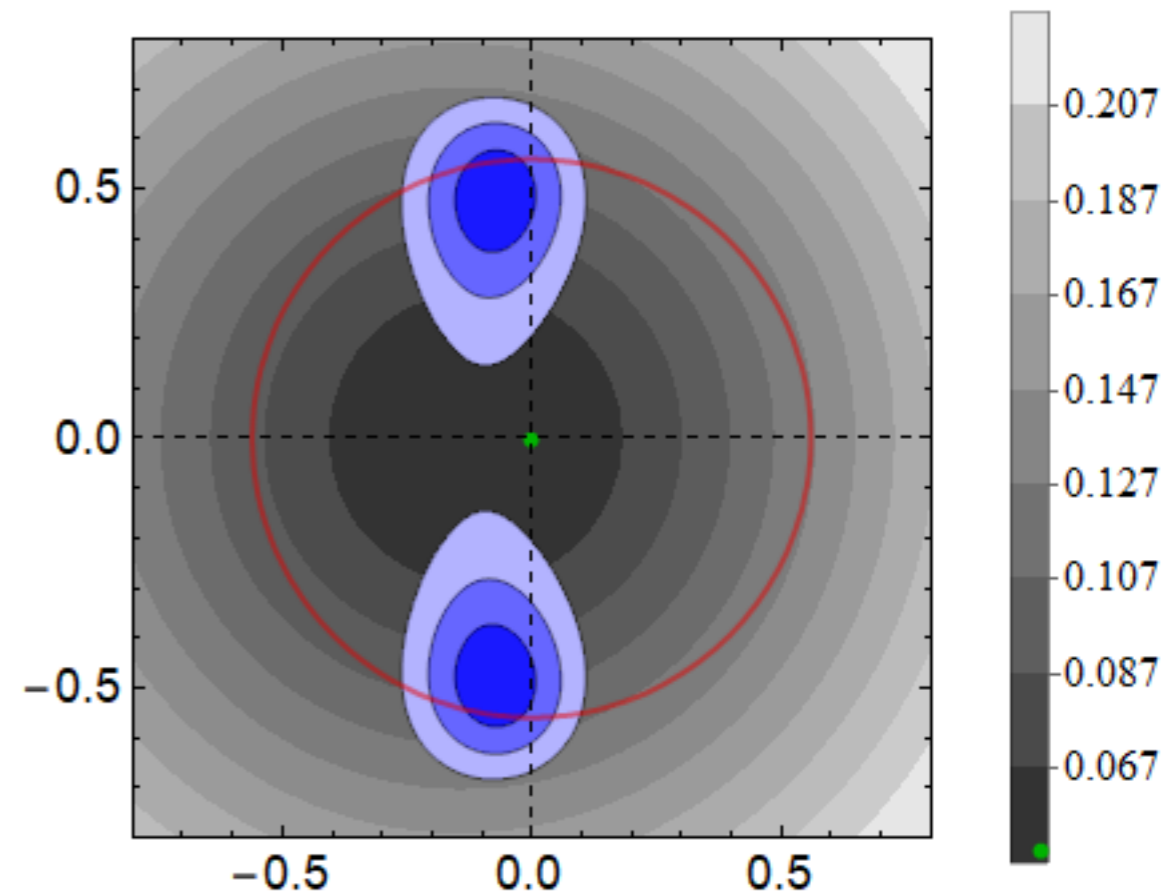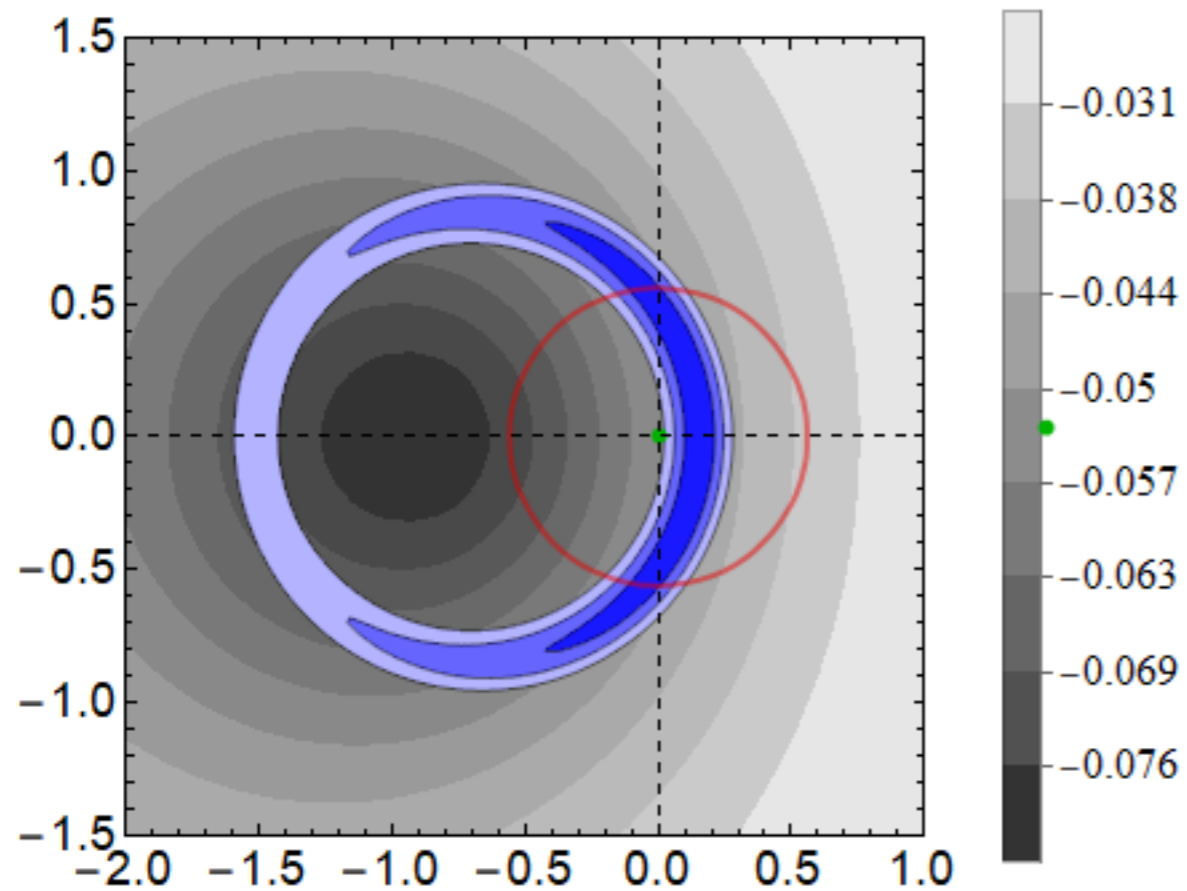# Angular observables $\Lambda_b \to \Lambda_c \ell \bar{\nu}$

2209.13409

Three powerful observables:

$$\langle \mathcal{A}_{\mathrm{fb}}^{\tau} \rangle$$

S_1 R_2

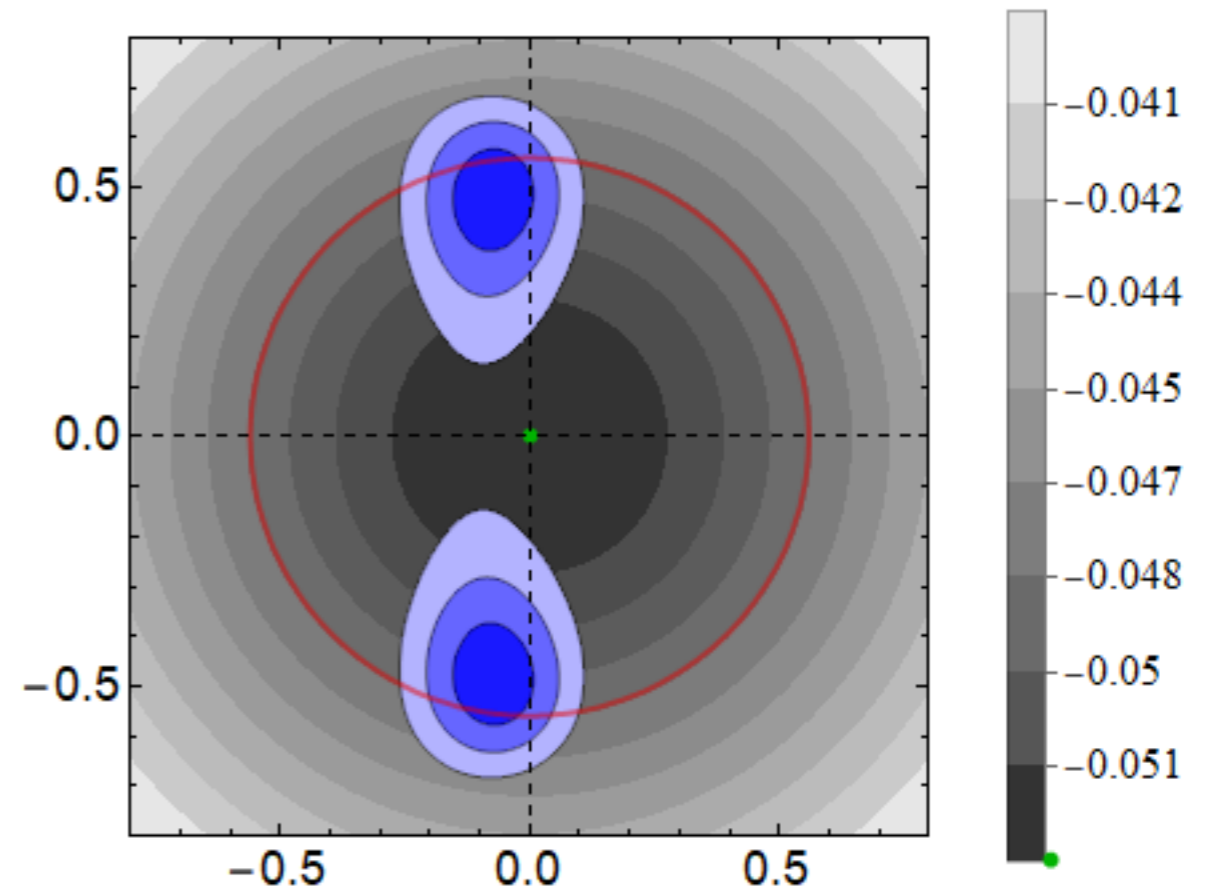# Angular observables $\quad \Lambda_b \to \Lambda_c \ell \bar{\nu}$

Three powerful observables:

$$\langle \mathcal{A}^{\tau}_{\pi/3} \rangle :$$

S_1

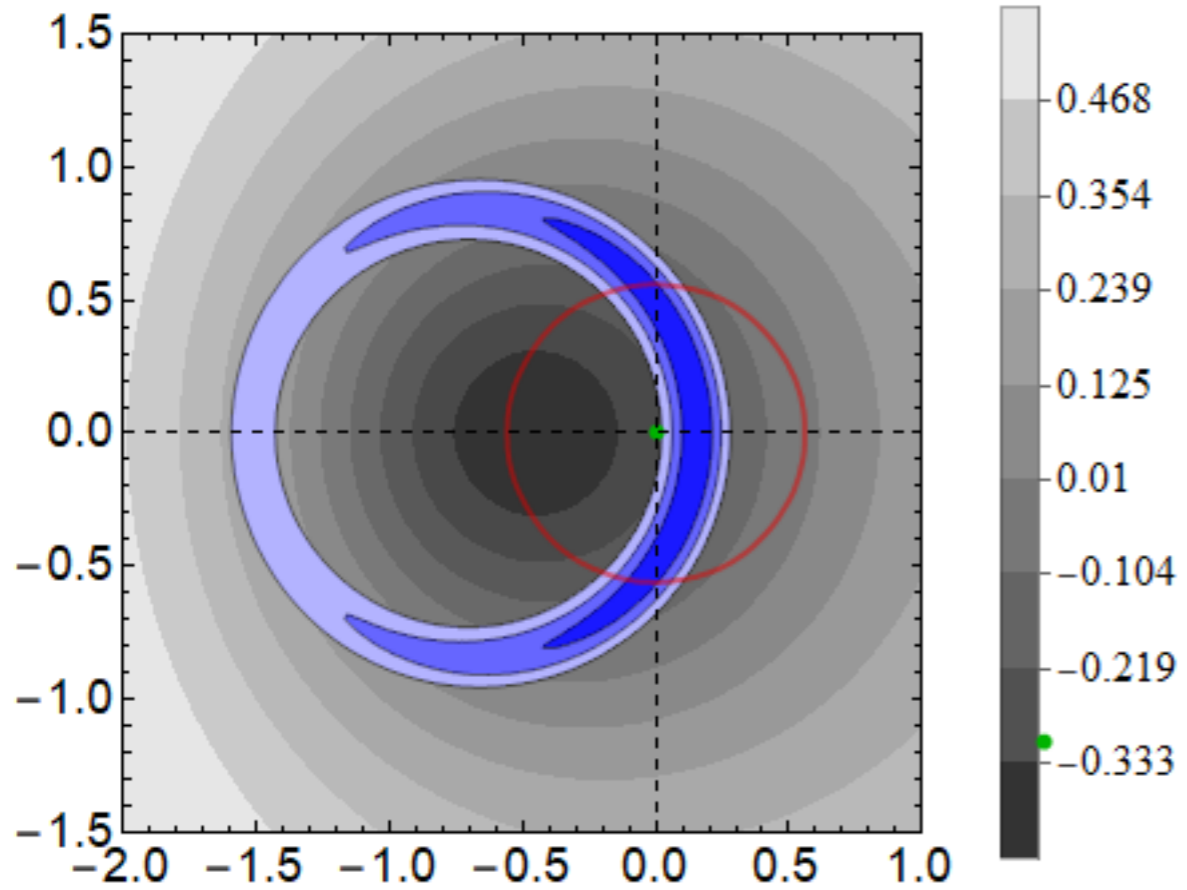R_2

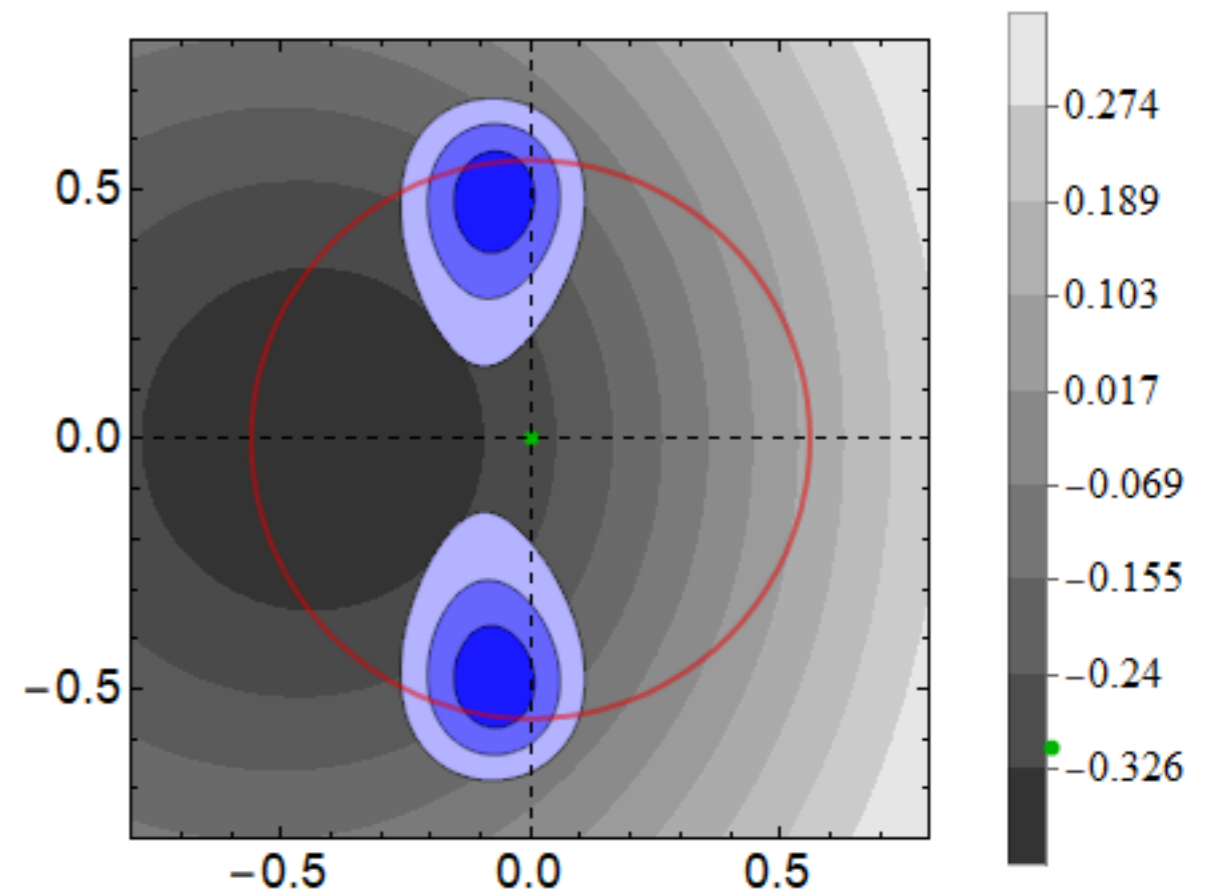# Angular observables $\Lambda_b \to \Lambda_c \ell \bar{\nu}$
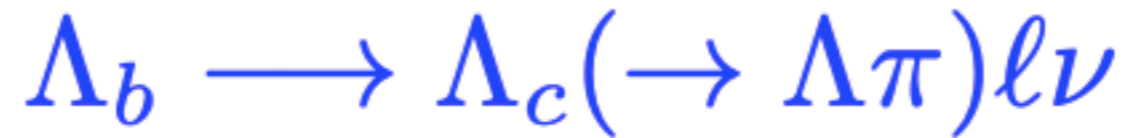
2209.13409

Three powerful observables:

$$\langle \mathcal{A}_\lambda^\tau \rangle$$

S_1

R_2

$$\Lambda_b \longrightarrow \Lambda_c(\rightarrow \Lambda\pi)\ell\nu$$

2209.13409

NB: $\mathcal{B}(\Lambda_c \rightarrow \Lambda\pi) = 1.30(7)\%$ or $\mathcal{B}(\Lambda_c \rightarrow pK_S) = 1.59(8)\%$

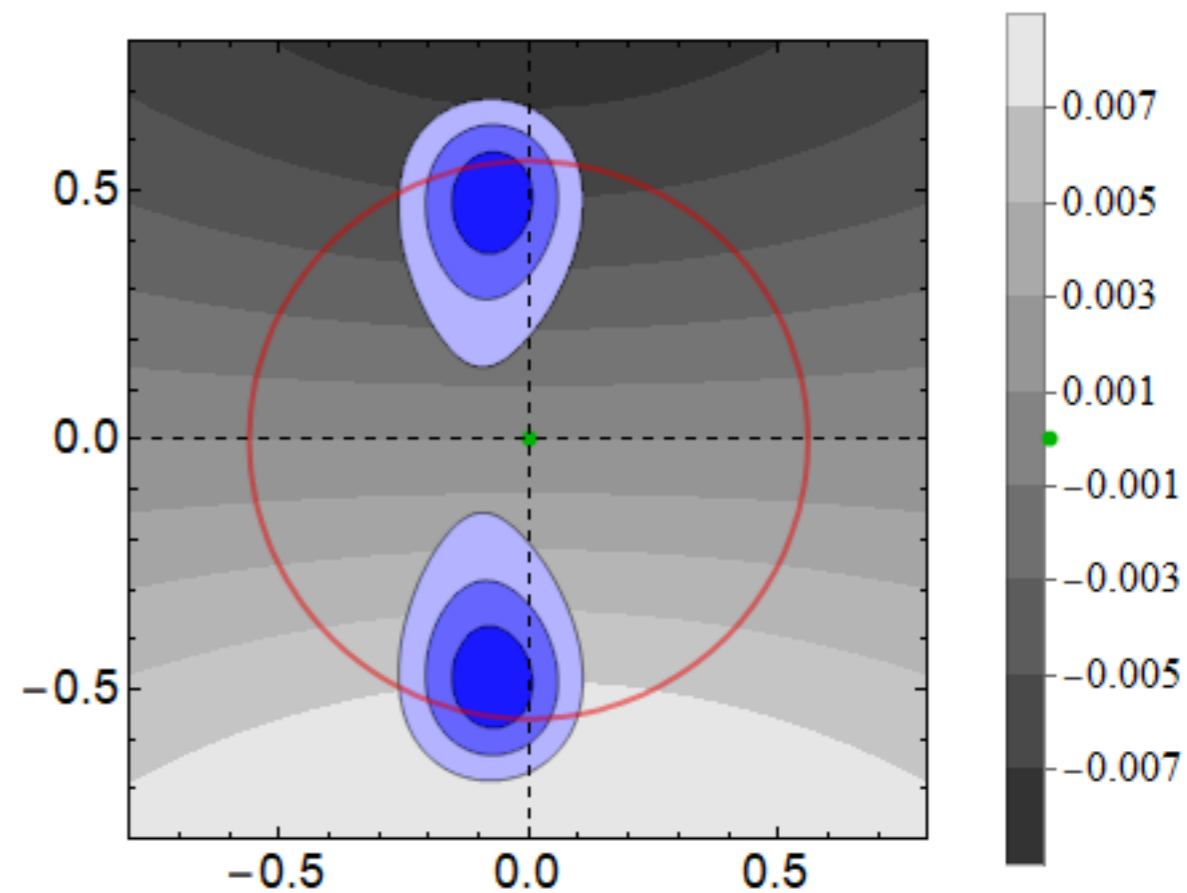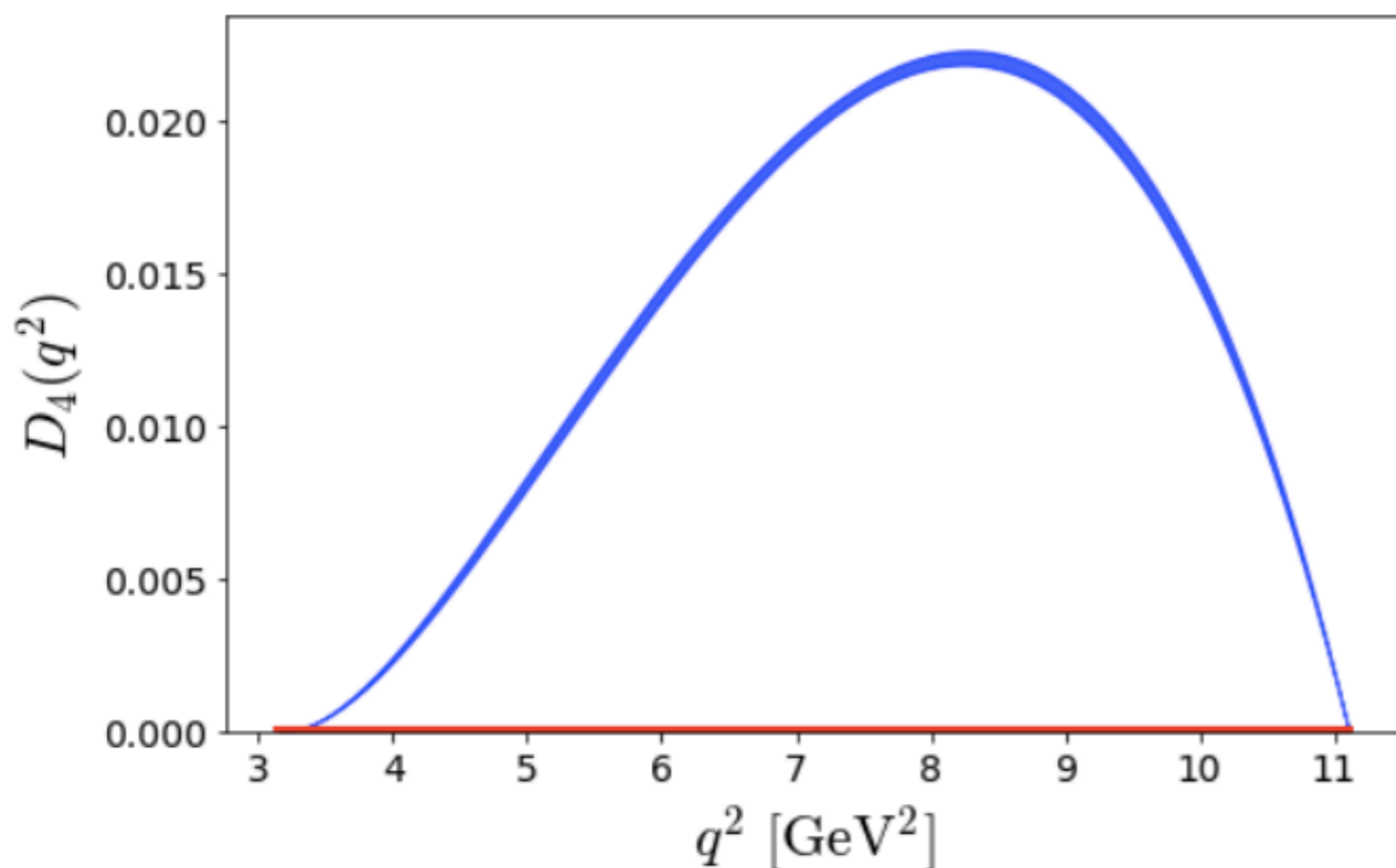Many more angular observables and checking on Im[g_X] ≠ 0

...

$$\frac{d^4\Gamma^{\lambda_l}}{dq^2 d\cos\theta d\cos\theta_\Lambda d\phi} = A_1^{\lambda_l} + A_2^{\lambda_l}\cos\theta_\Lambda$$

$\mathcal{A}_{fb}$ Baryon

$$+ \left(B_1^{\lambda_l} + B_2^{\lambda_l}\cos\theta_\Lambda \right)\cos\theta$$

$\mathcal{A}_{fb}$ Lepton

$$+ \left(C_1^{\lambda_l} + C_2^{\lambda_l}\cos\theta_\Lambda \right)\cos^2\theta$$

$$+ \left(D_3^{\lambda_l}\sin\theta_\Lambda\cos\phi + D_4^{\lambda_l}\sin\theta_\Lambda\sin\phi \right)\sin\theta$$

$$+ \left(E_3^{\lambda_l}\sin\theta_\Lambda\cos\phi + E_4^{\lambda_l}\sin\theta_\Lambda\sin\phi \right)\sin\theta\cos\theta$$

$$\Lambda_b \longrightarrow \Lambda_c(\to \Lambda\pi)\ell\nu$$

NB: $\mathcal{B}(\Lambda_c \to \Lambda\pi) = 1.30(7)\%$ or $\mathcal{B}(\Lambda_c \to pK_S) = 1.59(8)\%$

Many more angular observables and checking on Im[g_X] ≠ 0

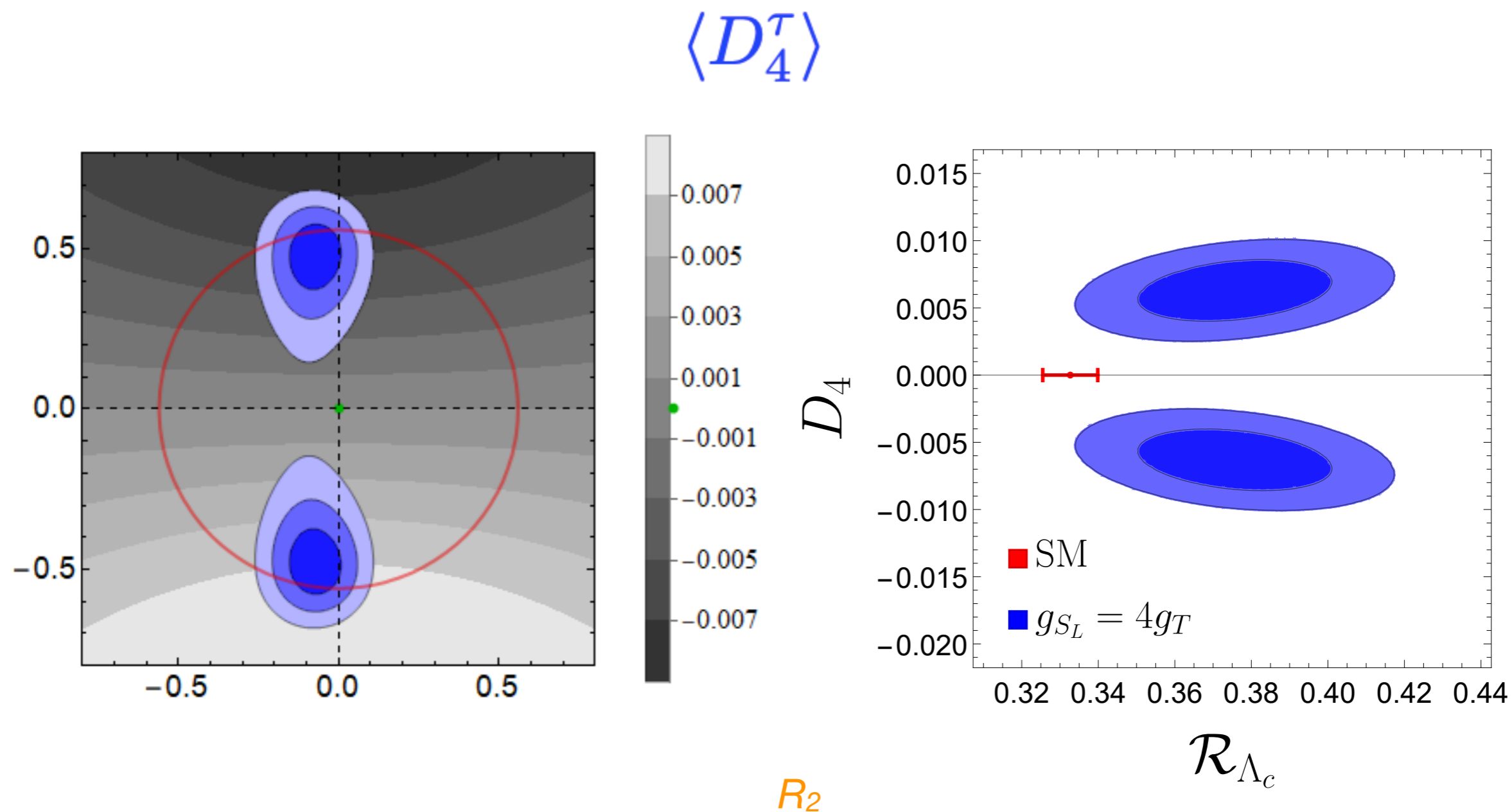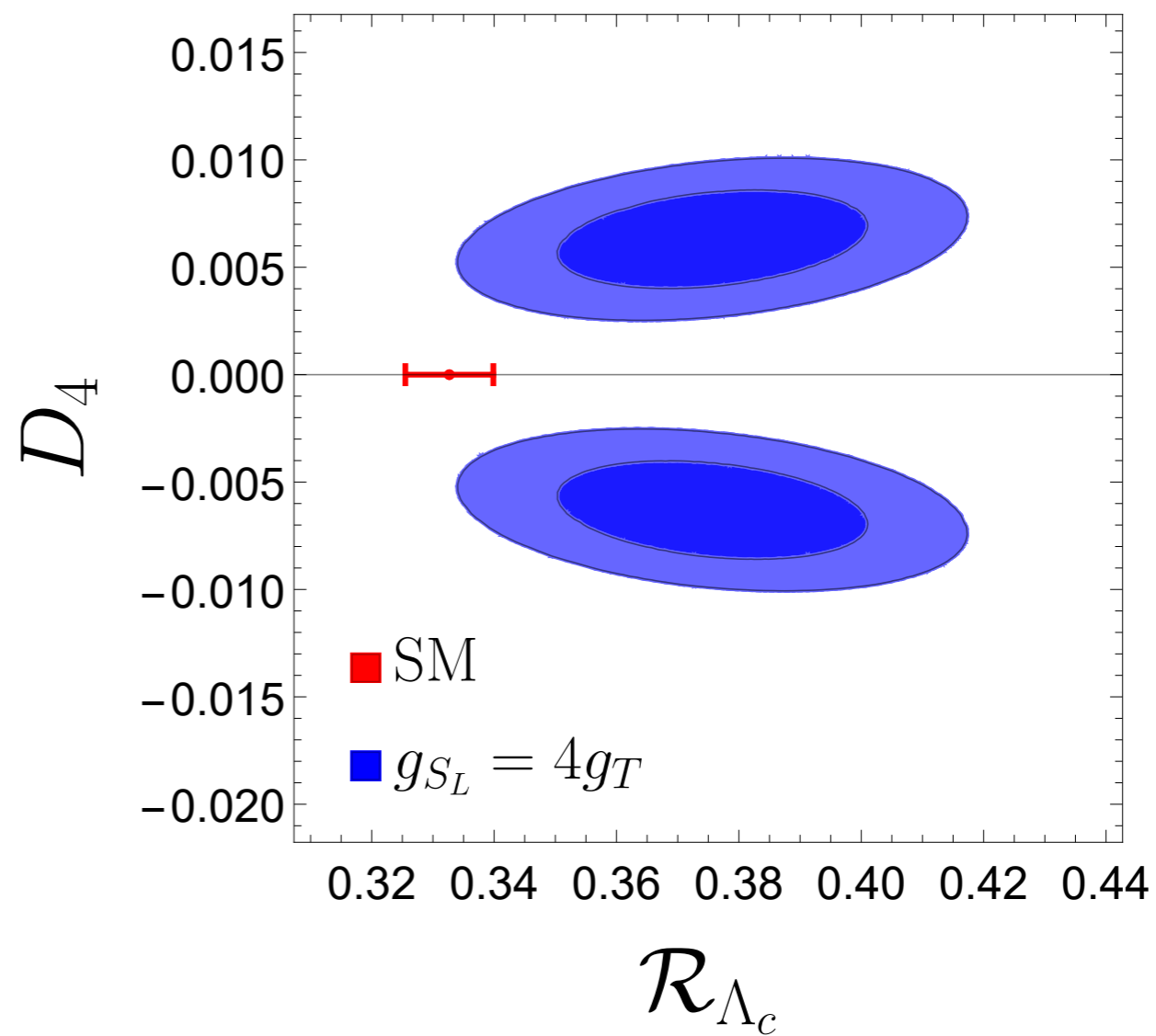$$\langle D_4^\tau \rangle$$

R_2

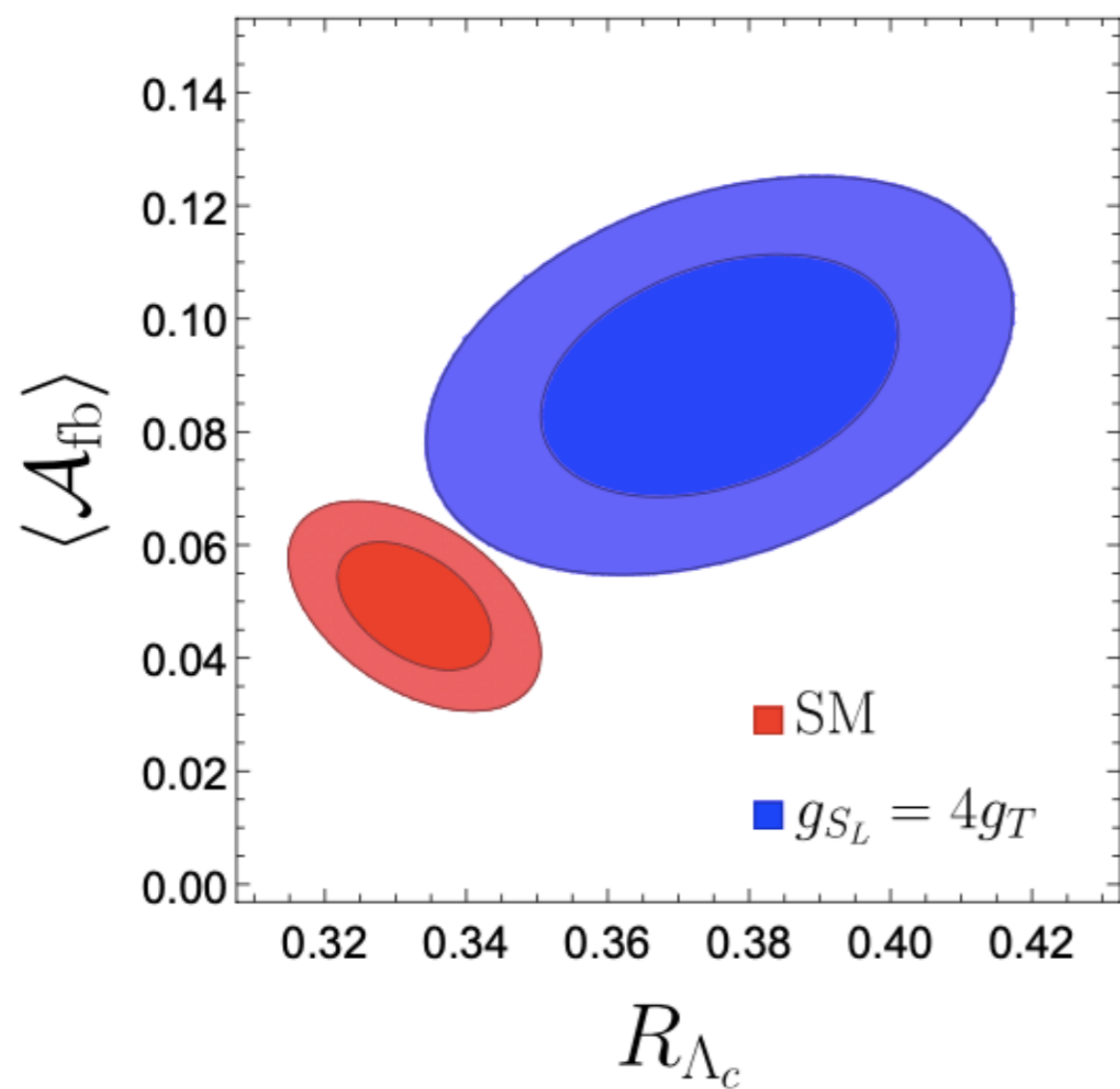$$\Lambda_b \longrightarrow \Lambda_c(\to \Lambda\pi)\ell\nu$$

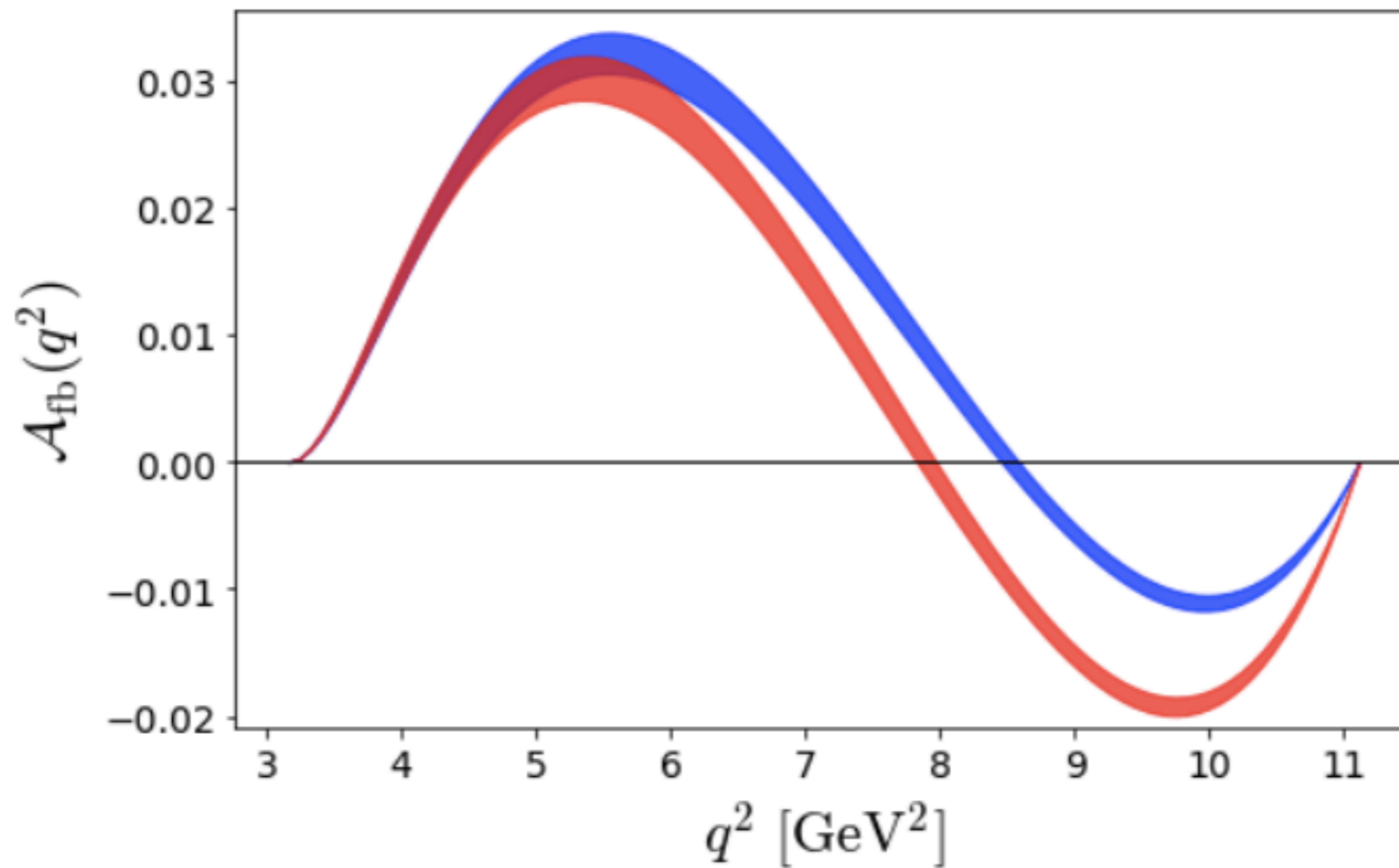Many more angular observables and checking on Im[g_X] ≠ 0

$$\langle D_4^\tau \rangle$$

R₂

$$\Lambda_b \longrightarrow \Lambda_c(\to \Lambda\pi)\ell\nu$$

R_2

$$\Lambda_b \longrightarrow \Lambda_c (\to \Lambda \pi) \ell \nu$$

And there is also this…

R_2

CONCLUDING REMARKS

- Hadronic uncertainties are with us and one should always keep in mind that nonperturbative QCD is <u>not</u> solved.

- Results from various models and SR suffer from systematics that is next-to-impossible to estimate.

- LQCD is the only good way to go but the situation is still unsatisfactory for a reliable fit with data to extract $|V_{cb}|$ and NP parameters.

- Exclusive V_{cb} should be checked on in several possible ways. [Sanity check and can be helpful for testing other ideas - e.g. factorization.]

- R_D and R_{D*} are too few observables to understand the source of LFUV. Too many NP solutions exist and could be filtered by angular $B \rightarrow D^{(*)} \tau \nu$ and $\Lambda_b \rightarrow \Lambda_c \tau \nu$ observables.

- All of the $\Lambda_b \rightarrow \Lambda_c \ell \nu$ form factors are known from LQCD in SM and BSM. LHCb showed it is possible to measure $B(\Lambda_b \rightarrow \Lambda_c \tau \nu)$. A partial angular is doable.

- There are 18 observables that can be extracted from $\Lambda_b \rightarrow \Lambda_c (\rightarrow \Lambda \pi)\tau \nu$. Even a small subset would be very helpful to discriminate among various scenarios.

- There are observables allowing to check whether or not there is a nonzero NP phase!