$B \to D^*(D\pi, D\gamma)\ell\nu$ modes and the search for new physics

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$R(D^{(*)})|_{SM}$ vs $R(D^{(*)})|_{exp}$ and $|V_{cb}|_{excl}$ vs $|V_{cb}|_{incl}$

are both tensions alive?
are they related?
how to disentangle NP effects?

F. De Fazio & PC, JHEP 1806, 082 and PRD 95, 011701(R)

Precision Era in High Energy Physics
Portoroz, April 16-19, 2019

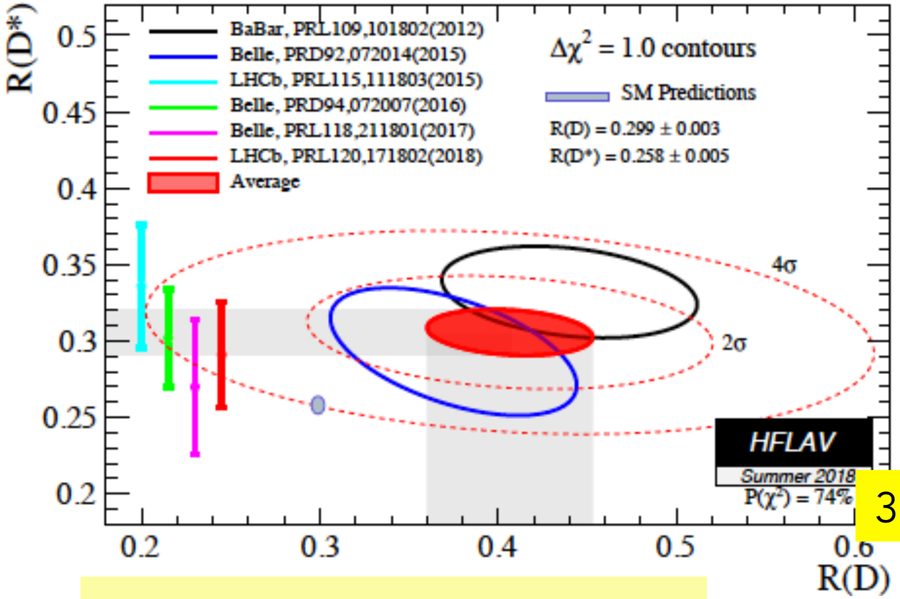
R(D(*)) & friends

$$\mathcal{R}^0(D) = \frac{\mathcal{B}(\bar{B}^0 \to D^+ \tau^- \bar{\nu}_\tau)}{\mathcal{B}(\bar{B}^0 \to D^+ \ell^- \bar{\nu}_\ell)}$$

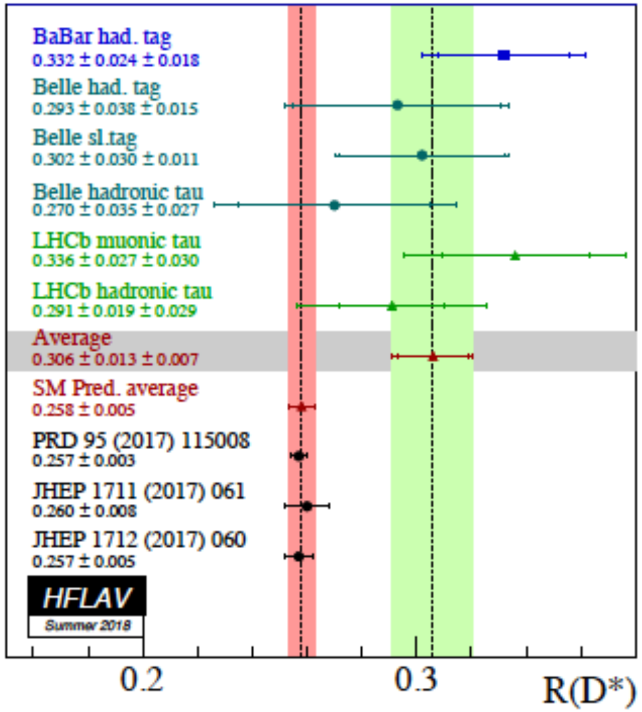
$$\mathcal{R}^0(D^*) = \frac{\mathcal{B}(\bar{B}^0 \to D^{*+} \tau^- \bar{\nu}_\tau)}{\mathcal{B}(\bar{B}^0 \to D^{*+} \ell^- \bar{\nu}_\ell)}$$

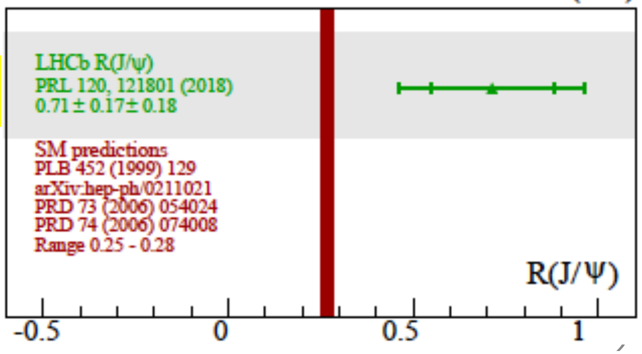
first analyzed by S. Fajfer et al.

pre-Moriond 2019



3 σ from SM





$$R(J/\psi) = \frac{\mathcal{B}(B_c^+ \to J/\psi\, \tau^+ \nu_\tau)}{\mathcal{B}(B_c^+ \to J/\psi\, \mu^+ \nu_\mu)}$$

Belle NEW (Moriond 2019, 1904.08974)

$$R(D) = 0.307 \pm 0.037 \pm 0.016$$

$$R(D^*) = 0.283 \pm 0.018 \pm 0.014$$

➔ τ/μ,e universality questioned

$|V_{cb}|_{excl}$ vs $|V_{cb}|_{incl}$

$$|V_{cb}|^{D^*}_{excl} = (39.27 \pm 0.56_{th} \pm 0.49_{exp}) \times 10^{-3}$$

$$|V_{cb}|^{D}_{excl} = (40.85 \pm 0.98) \times 10^{-3}$$

LQCD+CLN+BABAR+Belle+LHCb

CLN ↑ Caprini Lellouch Neubert

Gambino et al
Grinsten et al
Berlochner et al

$$|V_{cb}|^{D^*}_{excl} = (41.9^{+2.0}_{-1.9}) \times 10^{-3}$$

LQCD+BGL+Belle (dataset in 1701.0827)

BGL ↑ Boyd Grinstein Lebed

NEW from BABAR

$$|V_{cb}|^{D^*}_{excl} = (38.36 \pm 0.90) \times 10^{-3}$$

LQCD+BGL+BABAR (1903.10002)

$$|V_{cb}|_{incl} = (42.46 \pm 0.88) \times 10^{-3}$$

HFLAV

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issue: B to D* form factors

CLN: HQET + QCD SR

$$h_{A_1}(w) = h_{A_1}(1)\,[1 - 8\rho^2 z + (53\rho^2 - 15)z^2 - (231\rho^2 - 91)z^3]$$
$$R_1(w) = R_1(1) - 0.12(w-1) + 0.05(w-1)^2$$
$$R_2(w) = R_2(1) + 0.11(w-1) - 0.06(w-1)^2$$
$$R_0(w) = R_0(1) - 0.11(w-1) + 0.01(w-1)^2,$$

5 parameters

BGL: analiticity + crossing symm.

$$f(z) = \frac{1}{P_f(z)\phi_f(z)} \sum_{n=0}^{N} a_n z^n$$

$$\sum_{n=0}^{N} |a_n|^2 \leq 1$$

$$z = \frac{\sqrt{t_+ - t} - \sqrt{t_+ - t_0}}{\sqrt{t_+ - t} + \sqrt{t_+ - t_0}}$$

$$t_\pm = (M_B \pm M_{D^*})^2$$

$$t_0 = t_+ - \sqrt{t_+(t_+ - t_-)}$$

Blatsche factors ($B^{(n)}_c$ poles)+outer functions

parameters

$R(D^{(*)})$ and $|V_{cb}|$ puzzles are there

are they related?

R(D$^{(*)}$) consider additional operators

many talks at this worksop

example: NP scenario enhancing B to τ semileptonic modes and leaving $\tau(B_c)$ quite unaffected

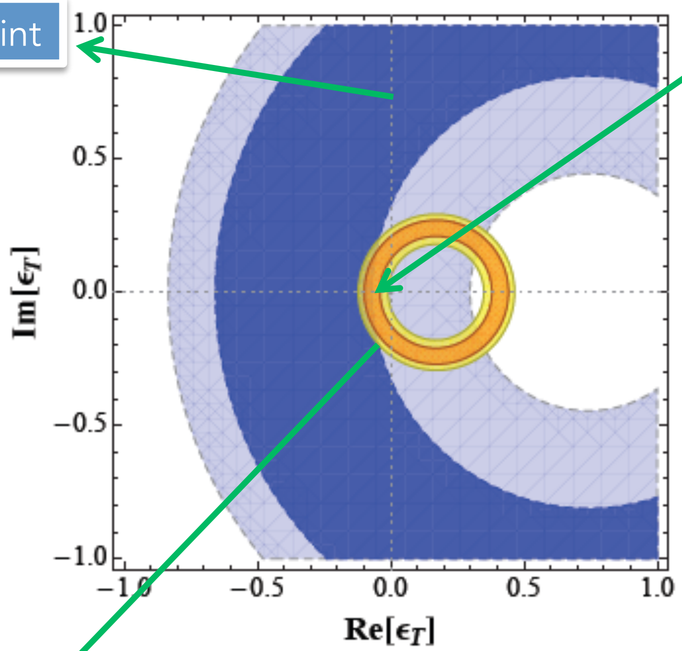
Biancofiore De Fazio PC

$$H_{eff} = H_{eff}^{SM} + H_{eff}^{NP} = \frac{G_F}{\sqrt{2}} V_{cb} \left[\bar{c}\gamma_\mu (1-\gamma_5) b \, \bar{\ell}\gamma^\mu (1-\gamma_5) \bar{\nu}_\ell + \epsilon_T^\ell \, \bar{c}\sigma_{\mu\nu}(1-\gamma_5) b \, \bar{\ell}\sigma^{\mu\nu}(1-\gamma_5)\bar{\nu}_\ell \right]$$

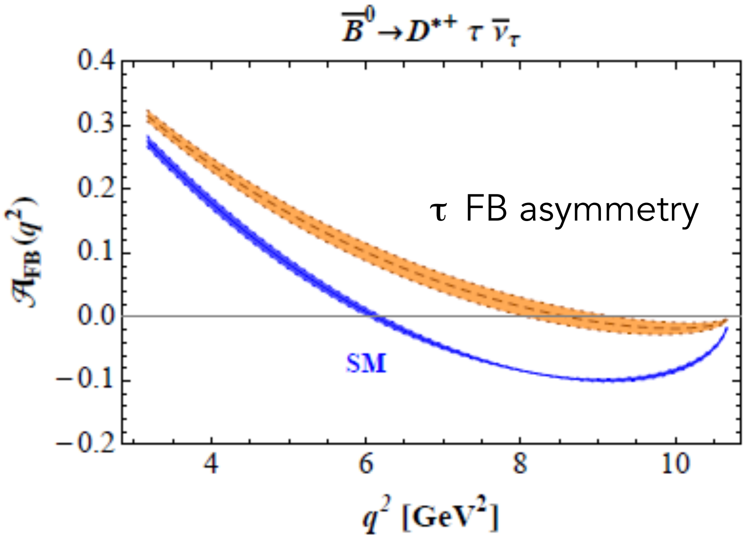
$\varepsilon_T^{\mu,e}=0$, $\varepsilon_T^{\tau} \neq 0$

common range

R(D) constraint



R(D*) constraint



SM zero ($q^2 \approx 6.15$ GeV^2) shifted to higher q^2

effects in B -> D** modes, ...

$|V_{cb}|$

Arguments against a NP option

- For H_{eff} with new four-fermion operators (S,P,T) and massless leptons, at zero recoil no interference between SM and NP contributions
- same NP effect in all modes

Crivellin Pokorski, PRL 114, 011802 (2015)

These arguments can be evaded:

- include a new operator in H_{eff} (example: tensor)
- relax the assumption that it contributes only for τ lepton
- keep non vanishing m_ℓ $\ell = e, \mu, \tau$ and $m_e \neq m_\mu$

De Fazio PC, PRD 95, 011701(R)

same NP example:

$$H_{\rm eff} = \frac{G_F}{\sqrt{2}} V_{cb} [\bar{c}\gamma_\mu (1-\gamma_5) b \bar{\ell}\gamma^\mu (1-\gamma_5) \bar{\nu}_\ell + \epsilon_T^\ell \bar{c}\sigma_{\mu\nu} (1-\gamma_5) b \bar{\ell}\sigma^{\mu\nu} (1-\gamma_5) \bar{\nu}_\ell]$$

B -> $X_c \ell \nu_\ell$

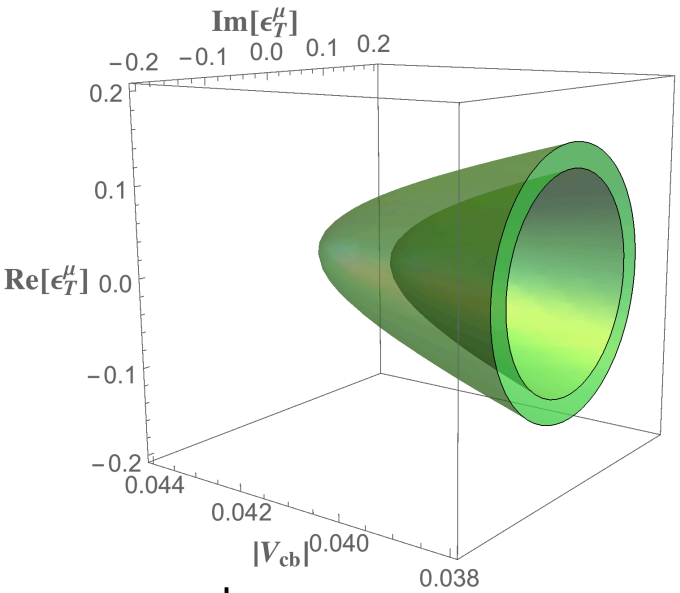
$$\Gamma = \Gamma_{SM} + |\varepsilon_T|^2 \Gamma_{NP} + \mathrm{Re}(\varepsilon_T)\Gamma_{INT}$$

HQ expansion for $\Gamma_{SM,\ NP,\ INT}$

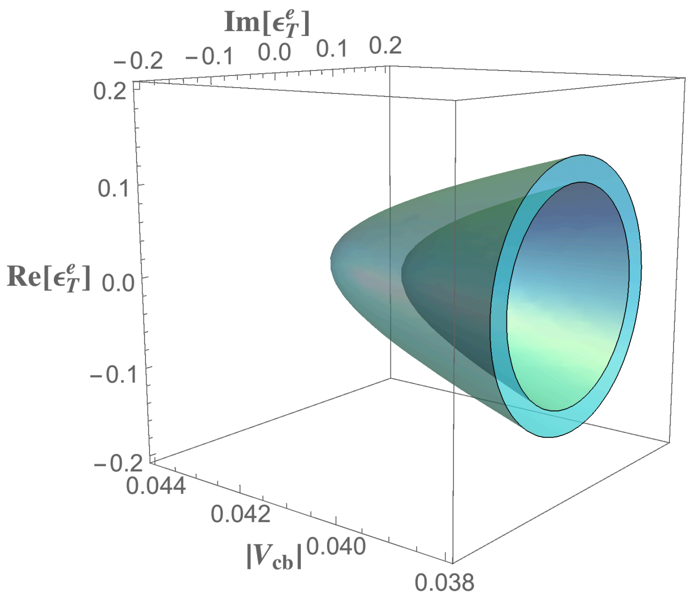
expanded in $1/m_Q$
α_s corrections in the SM term

T. Mannel

parameter space $\left(\mathrm{Re}(\varepsilon_T^\ell),\ \mathrm{Im}(\varepsilon_T^\ell),\ |V_{cb}|\right)$
input (PDG) $B(B^+ \to X_c e^+ \nu_e) = (10.8 \pm 0.4) \times 10^{-2}$



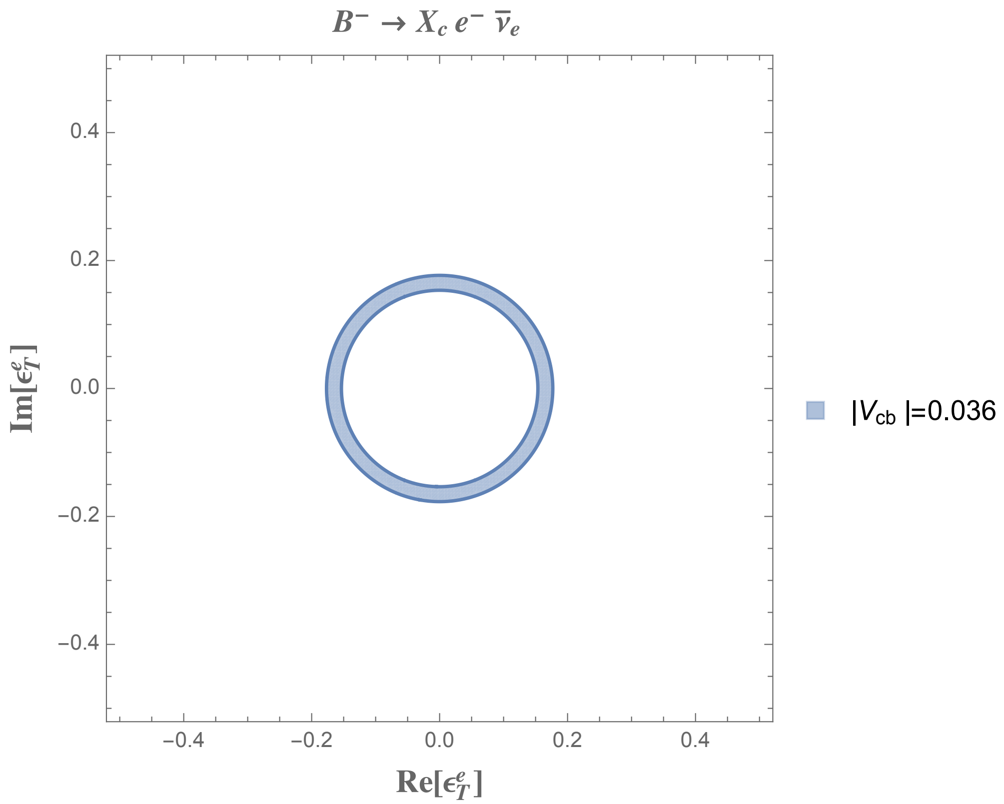
μ mode



e mode

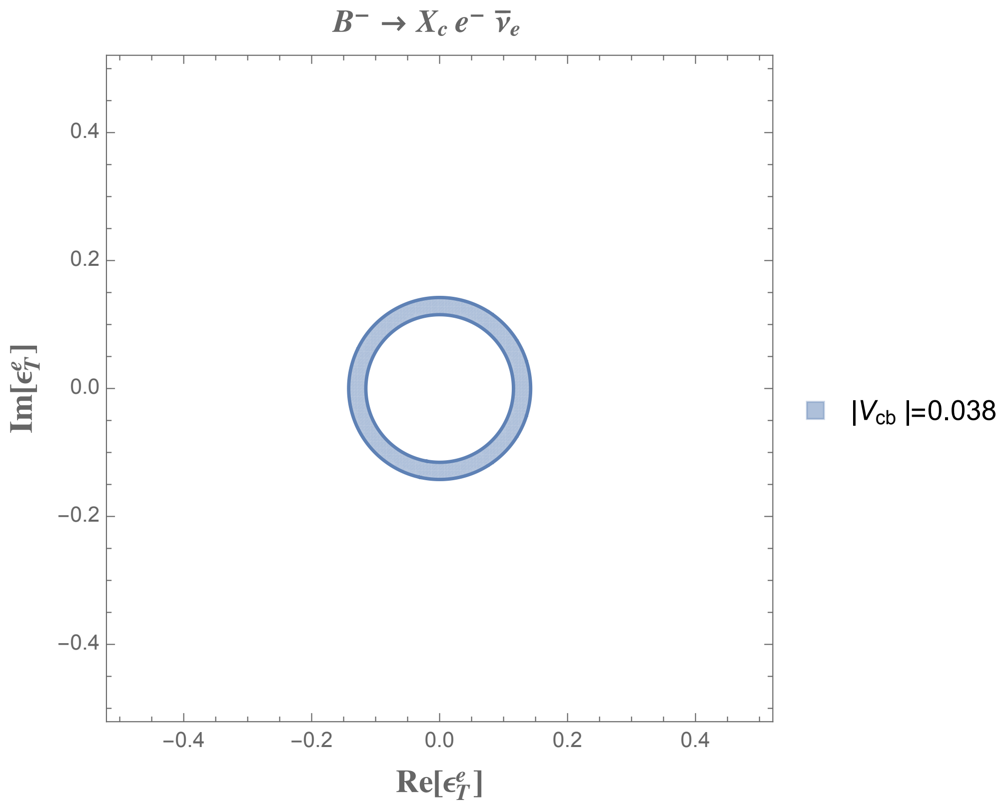
$B \to X_c\, \ell \nu_\ell$
allowed regions in parameter space

allowed ε_T^{ℓ} correlated to $|V_{cb}|$



B -> $X_c \ell \nu_\ell$ allowed regions in parameter space

allowed ε_T^ℓ correlated to $|V_{cb}|$



$B \to X_c \ell \nu_\ell$
allowed regions in parameter space

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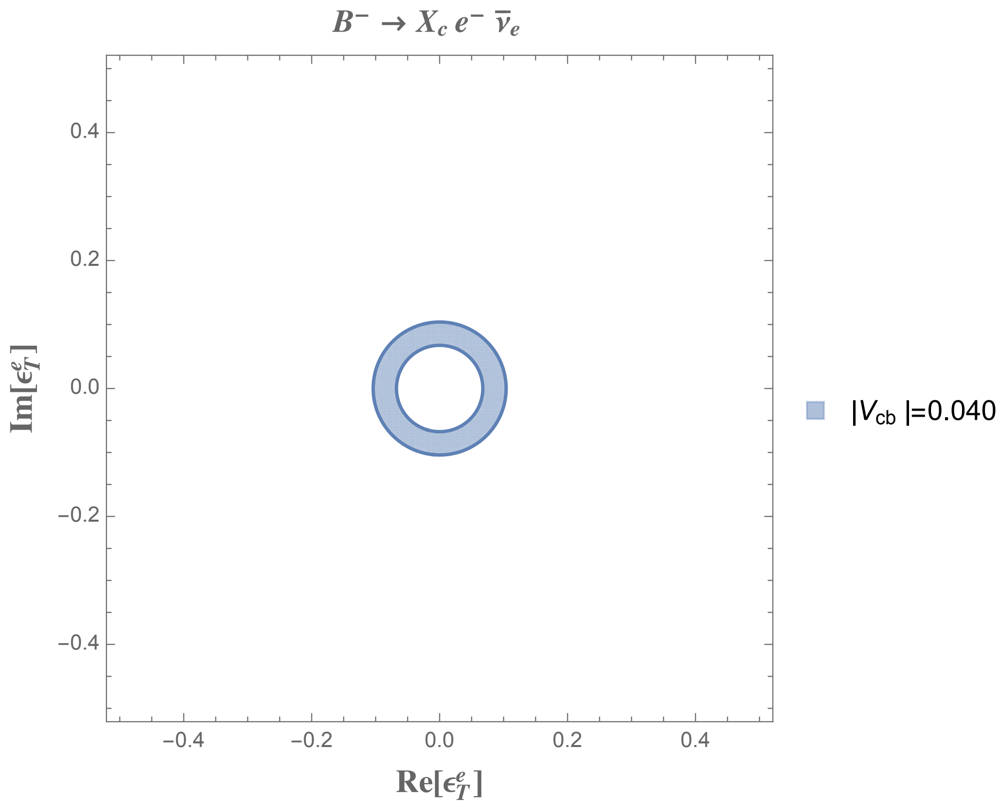
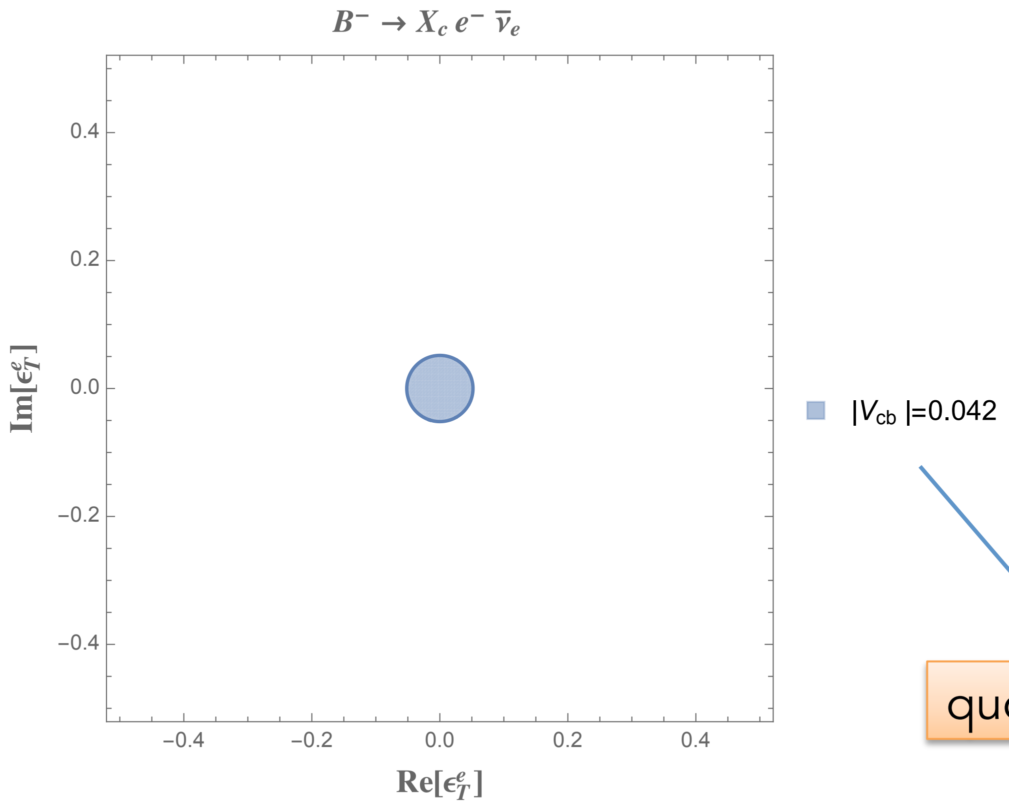


B -> $X_c\ \ell\nu_\ell$ allowed regions in parameter space

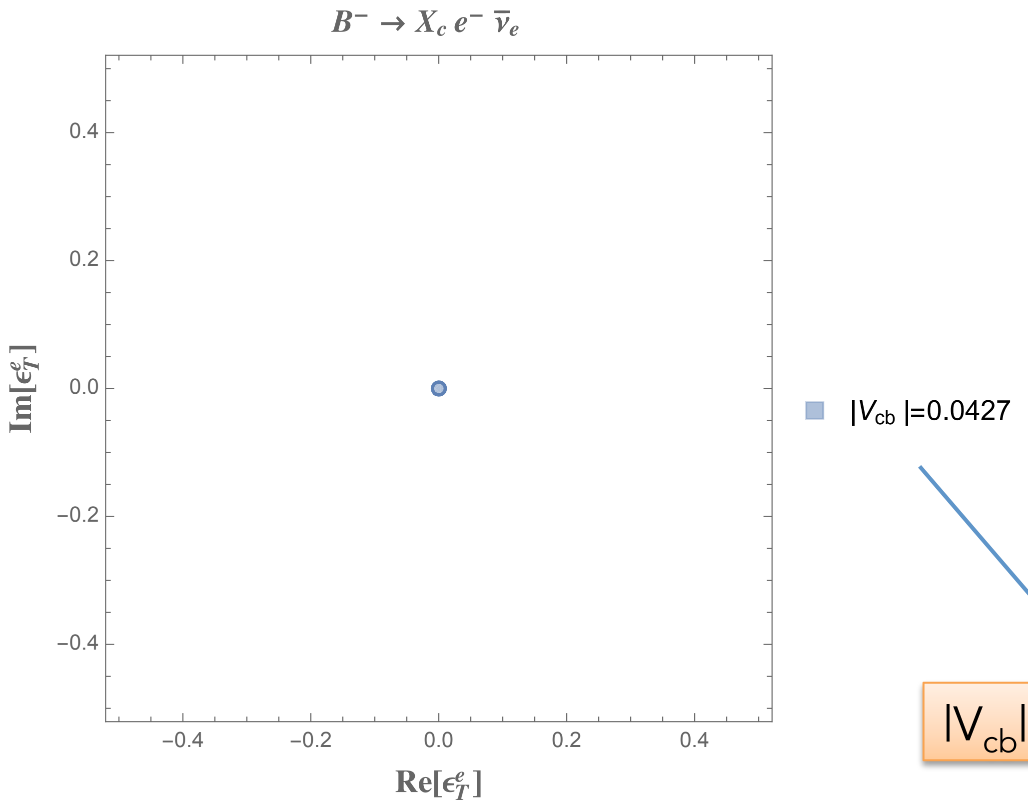
allowed ε_T^{ℓ} correlated to $|V_{cb}|$



quoted value for SM

B -> $X_c\ \ell \nu_\ell$
allowed regions in parameter space

allowed ε_T^{ℓ} correlated to $|V_{cb}|$

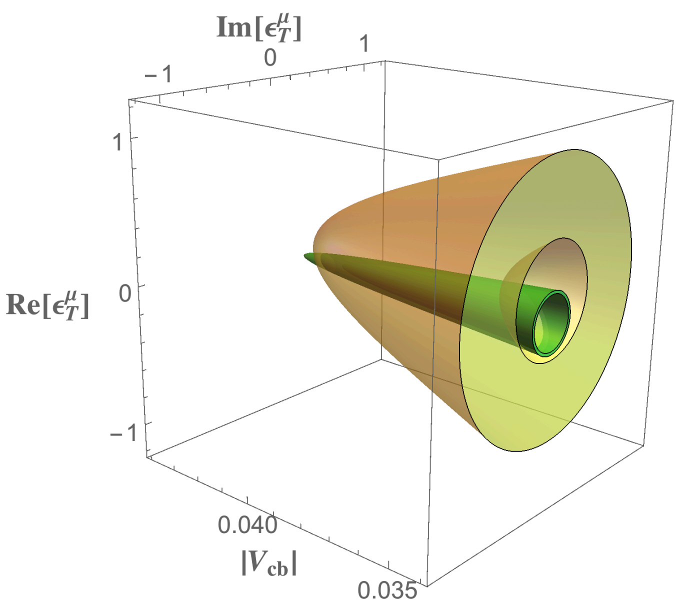


$|V_{cb}|<0.04273$

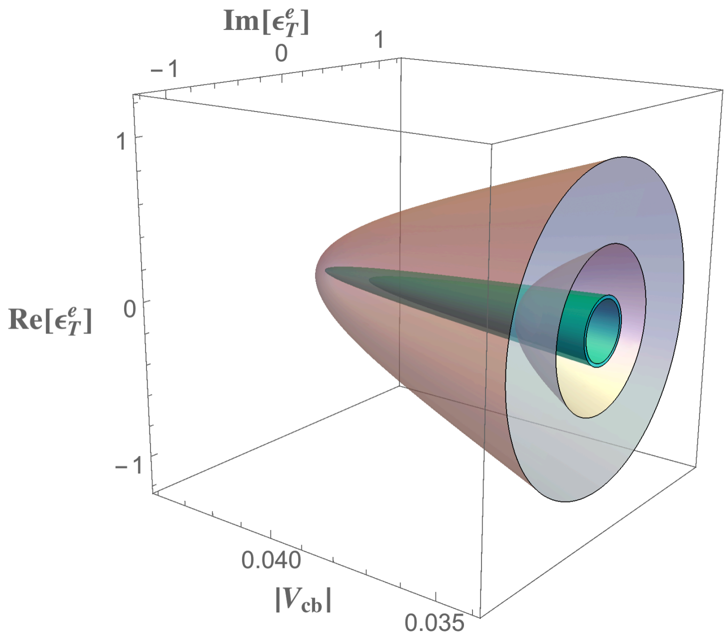
B -> D $\ell\nu_\ell$ + B -> X_c $\ell\nu_\ell$: allowed regions

$$B\left(B^+ \to \bar{D}^0 e^+ \nu_e\right) = \left(2.38 \pm 0.04 \pm 0.15\right) \times 10^{-2}$$

$$B\left(B^+ \to \bar{D}^0 \mu^+ \nu_\mu\right) = \left(2.25 \pm 0.04 \pm 0.17\right) \times 10^{-2}$$



μ mode



e mode

inner regions: inclusive
outer regions: exclusive

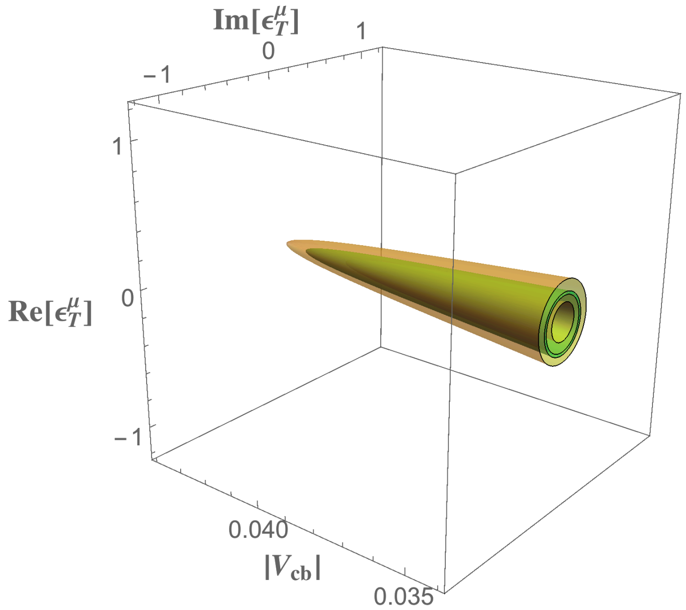
effect of the lepton mass:
the symmetry axes of the two regions do not coincide in the case of μ

B -> D* $\ell\nu_\ell$ + B -> $X_c \ell\nu_\ell$

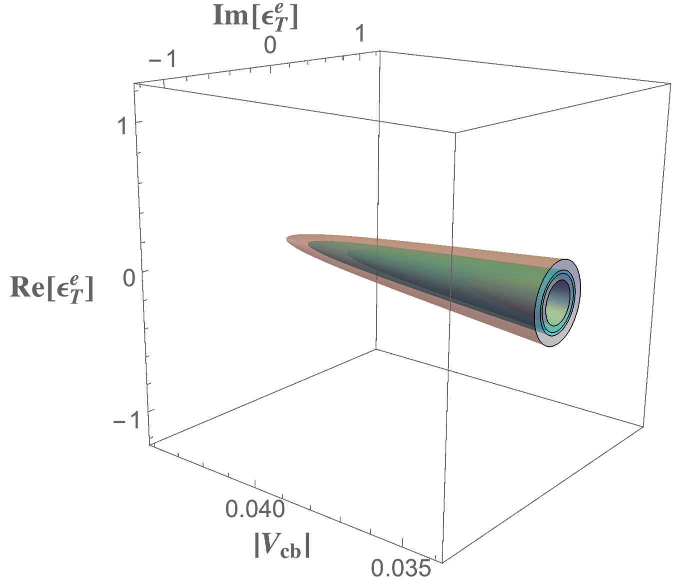
$$B\left(B^+ \to \bar{D}^{*0} e^+ \nu_e\right) = \left(5.50 \pm 0.05 \pm 0.23\right) \times 10^{-2}$$

$$B\left(B^+ \to \bar{D}^{*0} \mu^+ \nu_\mu\right) = \left(5.34 \pm 0.06 \pm 0.37\right) \times 10^{-2}$$

BABAR, PRD79, 012002 (2009)



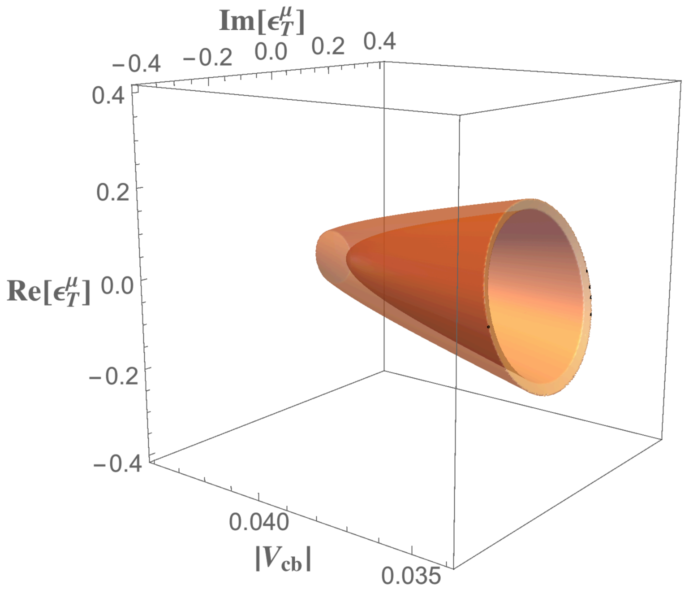
μ mode



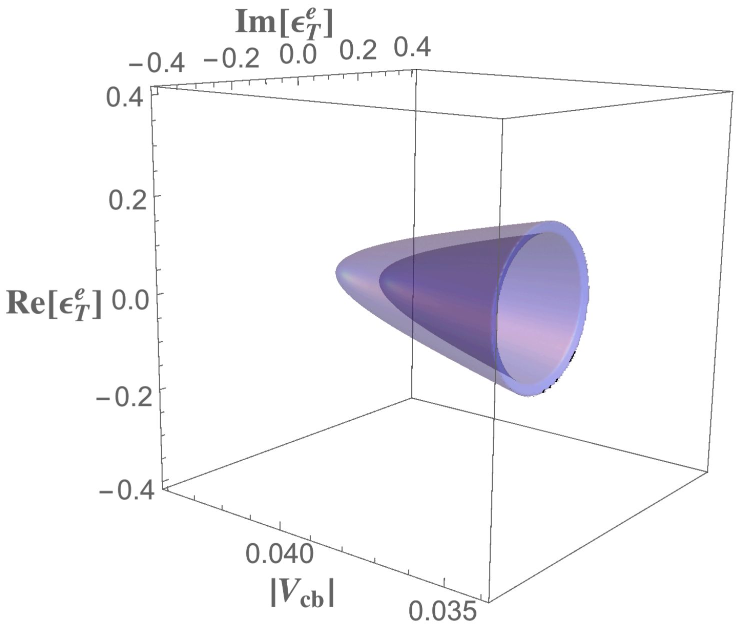
e mode

inner regions: inclusive
outer regions: exclusive

$B \to D \ell \nu_\ell$ + $B \to D^* \ell \nu_\ell$ + $B \to X_c \ell \nu_\ell$



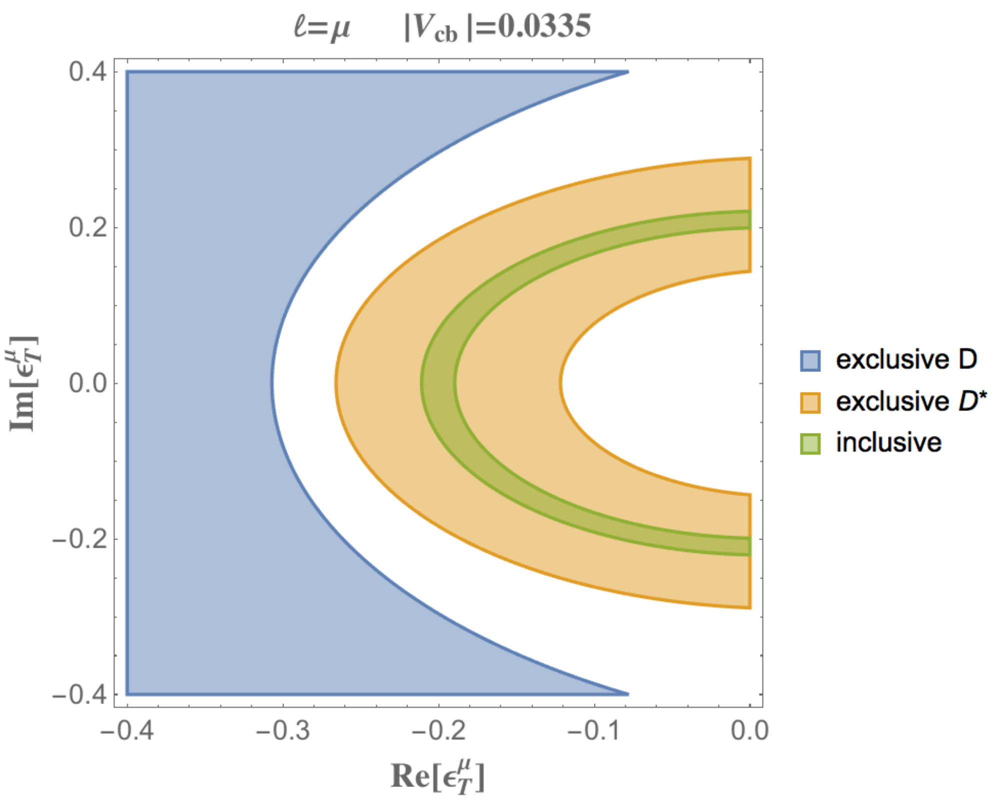
μ mode



e mode

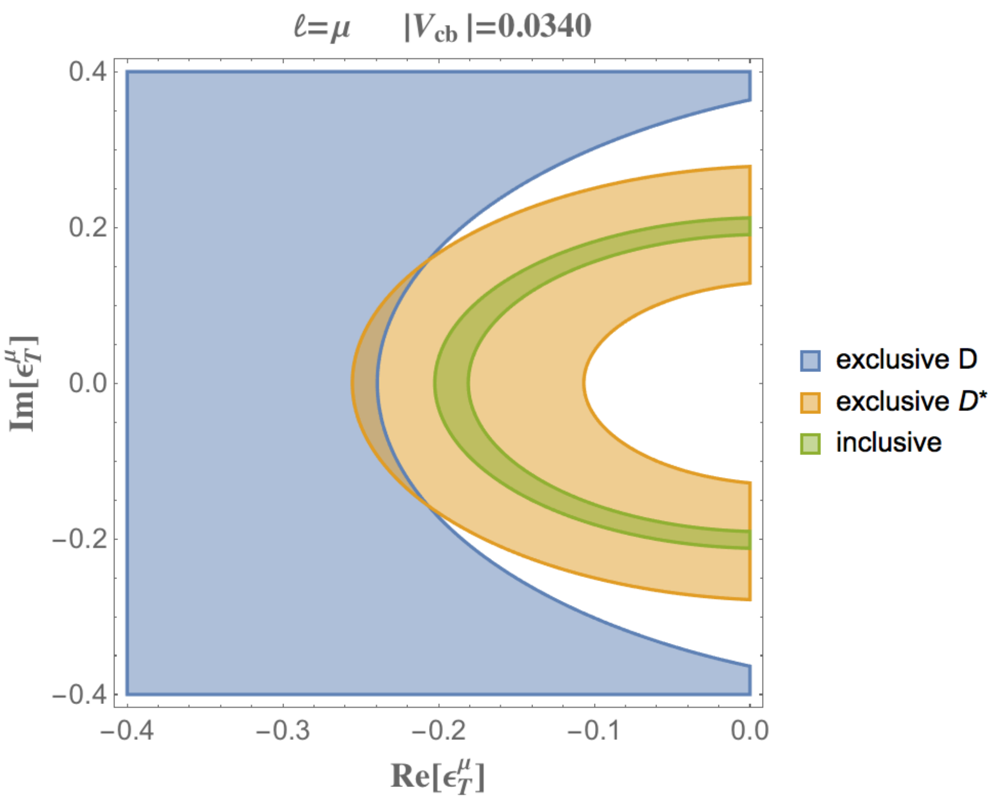
projections in the (Re ε_T, Im ε_T) plane

μ mode



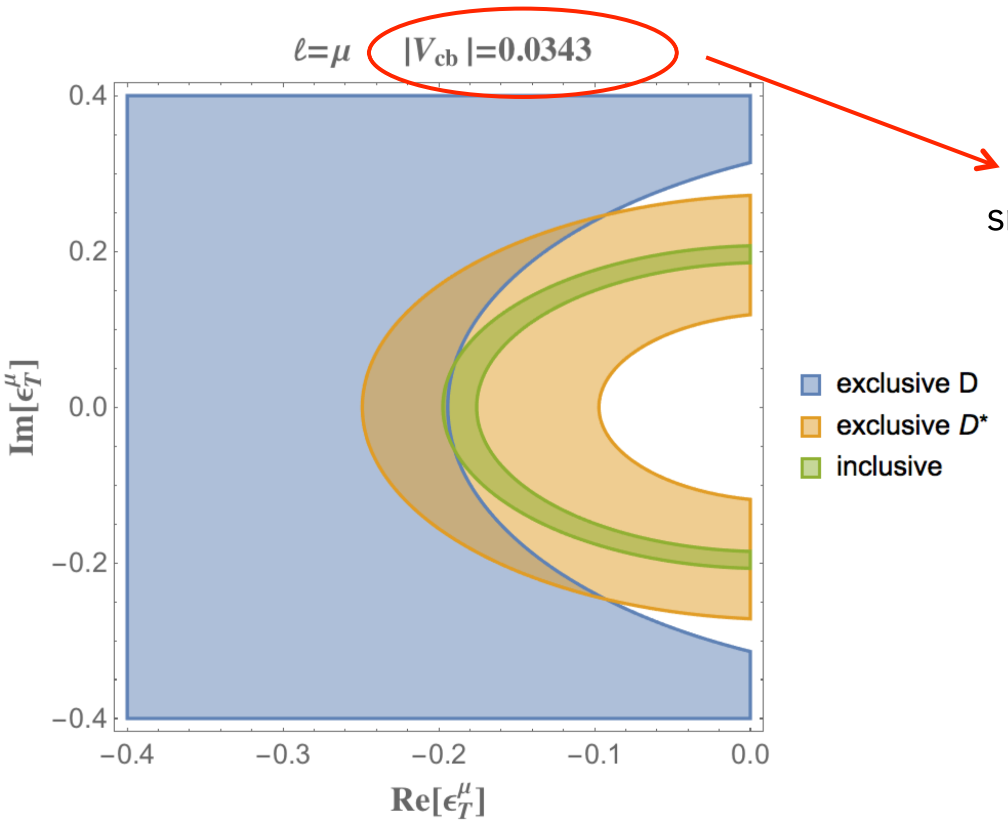
projections in the (Re ε_T, Im ε_T) plane

μ mode



projections in the (Re ε_T, Im ε_T) plane

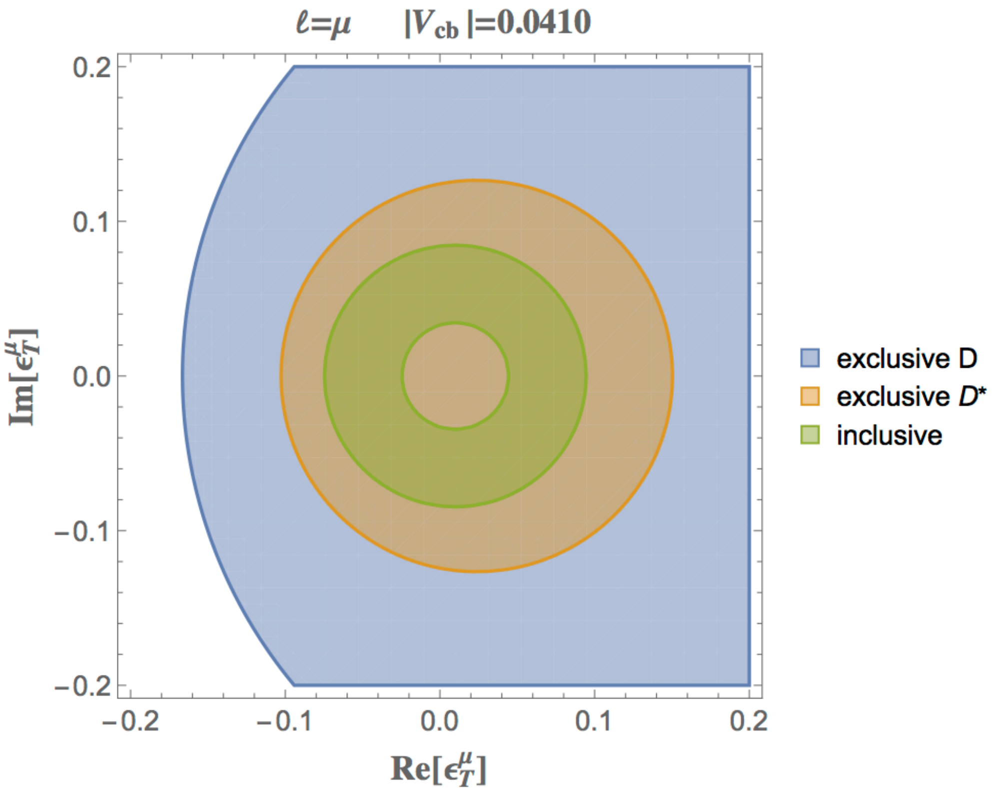
μ mode



smallest allowed value

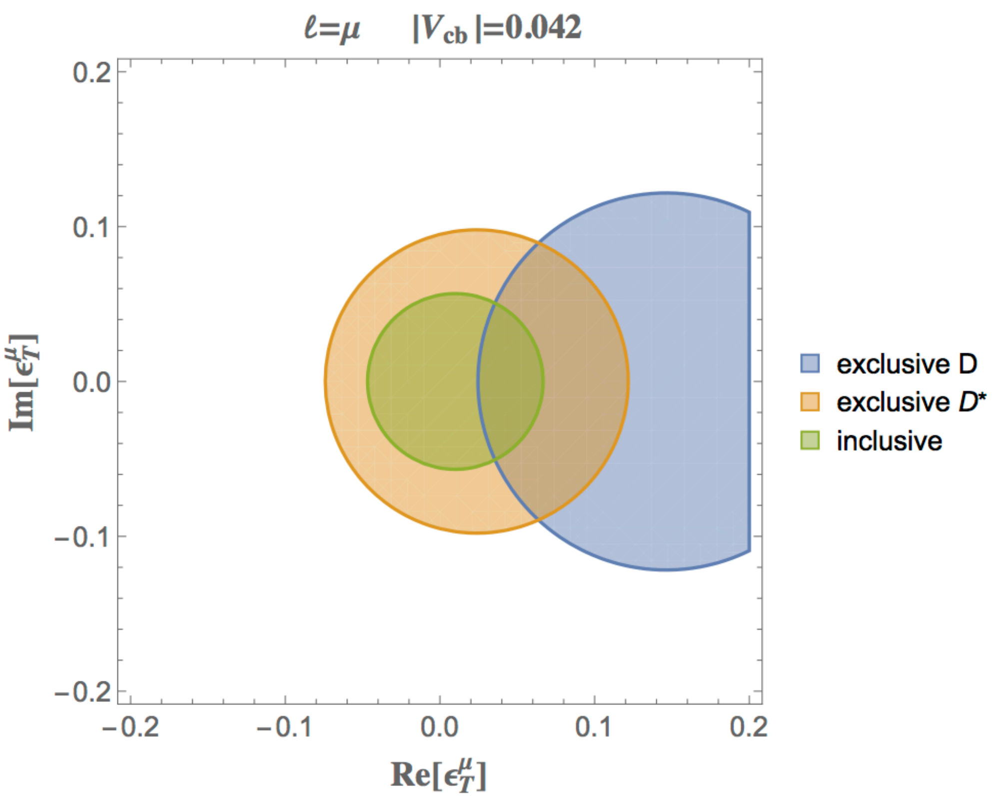
projections in the (Re ε_T, Im ε_T) plane

μ mode



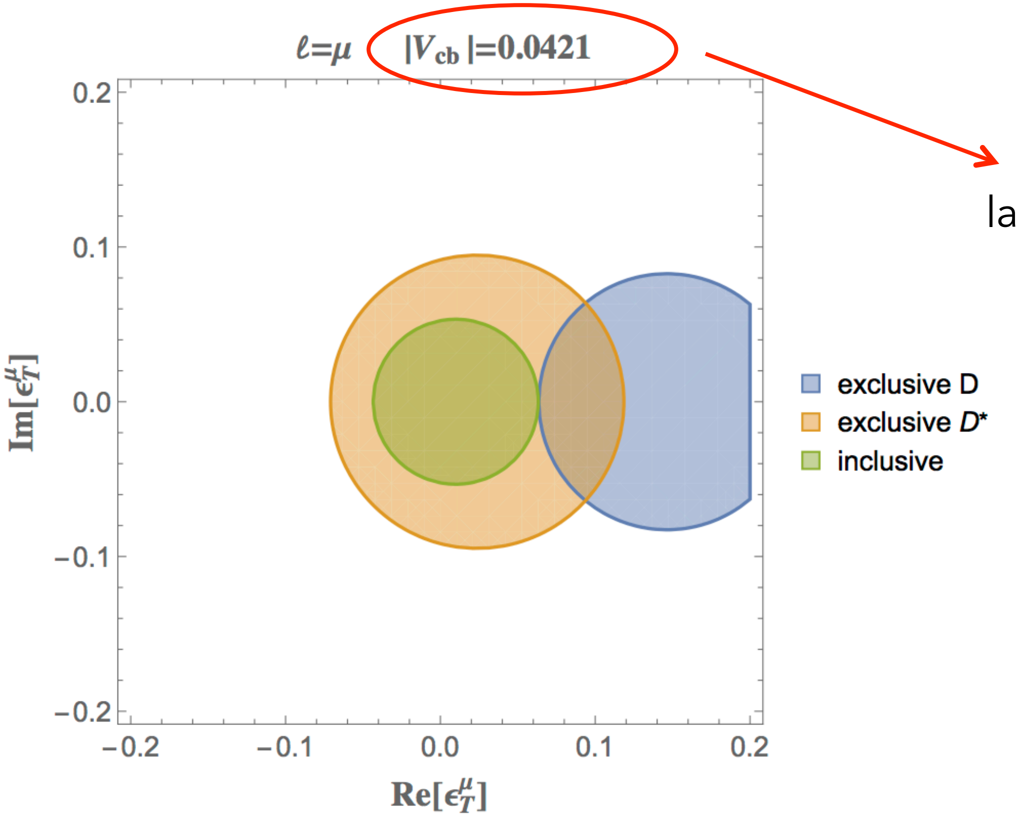
projections in the (Re ε_T, Im ε_T) plane

μ mode



projections in the (Re ε_T, Im ε_T) plane

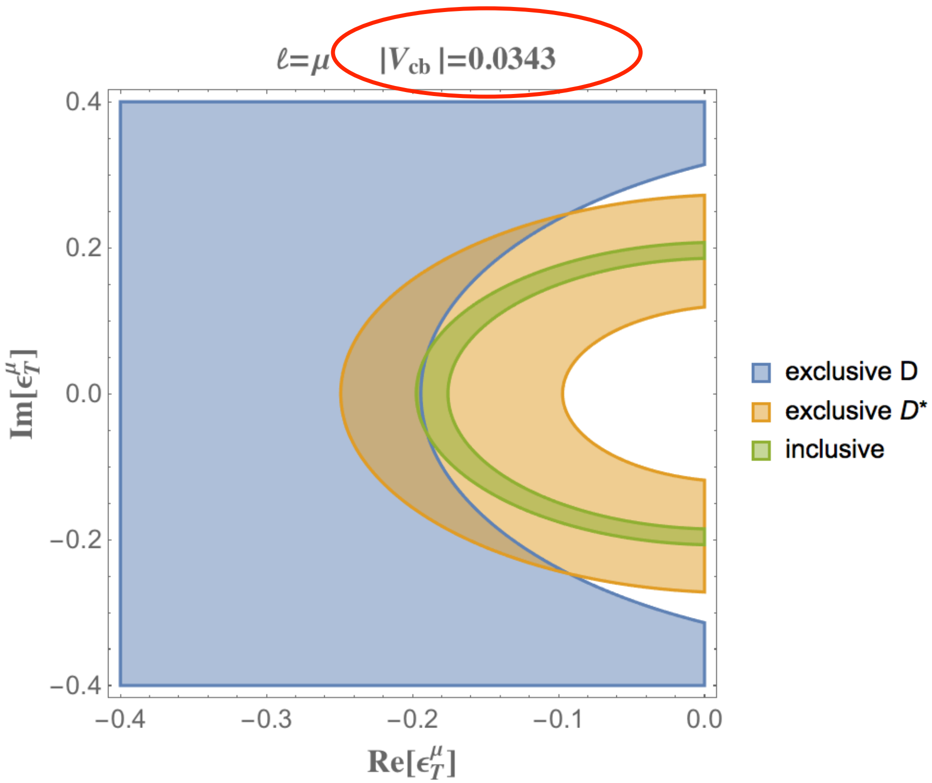
μ mode

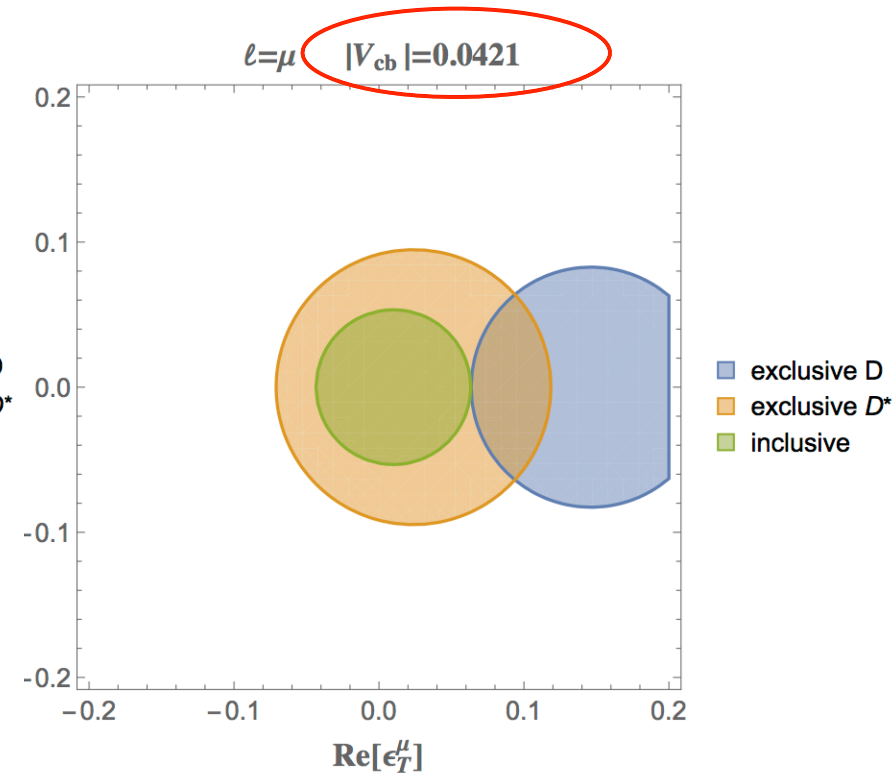


largest allowed value

projections in the (Re ε_T, Im ε_T) plane

μ mode





μ mode

$|V_{cb}| \in [0.0343, 0.0421]$

e mode

$|V_{cb}| \in [0.0360, 0.0427]$

all constraints fulfilled for $|V_{cb}| \in [0.036, 0.042]$

SM-NP interference sizable for μ

$R(D^{(*)})$ and $|V_{cb}|$ puzzles are there

a connection between them could be found

how to disentangle NP effects?
-> observables in exclusive processes

$\bar{B} \to D^*(D\pi)\ell^-\bar{\nu}_\ell$ $\bar{B} \to D^*(D\gamma)\ell^-\bar{\nu}_\ell$

De Fazio PC JHEP 1806, 082

important for $B_s \to D^*_s$

- effects of FF parametrization: BGL vs CLN
- disentangling SM from NP - example: tensor case

$$\begin{aligned}\langle D^*(p_{D^*},\epsilon)|\bar{c}\gamma_\mu(1-\gamma_5)b|\bar{B}(p_B)\rangle = & -\frac{2V(q^2)}{m_B+m_{D^*}} i\epsilon_{\mu\nu\alpha\beta}\epsilon^{*\nu}p_B^\alpha p_{D^*}^\beta \\ & -\Big\{(m_B+m_{D^*})\left[\epsilon^*_\mu - \frac{(\epsilon^*\cdot q)}{q^2}q_\mu\right]A_1(q^2) \\ & -\frac{(\epsilon^*\cdot q)}{m_B+m_{D^*}}\left[(p_B+p_{D^*})_\mu - \frac{m_B^2-m_{D^*}^2}{q^2}q_\mu\right]A_2(q^2) \\ & +(\epsilon^*\cdot q)\frac{2m_{D^*}}{q^2}q_\mu A_0(q^2)\Big\} \qquad (2.24)\end{aligned}$$

SM

$$\begin{aligned}\langle D^*(p_{D^*},\epsilon)|\bar{c}\sigma_{\mu\nu}(1-\gamma_5)b|\bar{B}(p_B)\rangle = & T_0(q^2)\frac{\epsilon^*\cdot q}{(m_B+m_{D^*})^2}\epsilon_{\mu\nu\alpha\beta}p_B^\alpha p_{D^*}^\beta + T_1(q^2)\epsilon_{\mu\nu\alpha\beta}p_B^\alpha\epsilon^{*\beta} \\ & +T_2(q^2)\epsilon_{\mu\nu\alpha\beta}p_{D^*}^\alpha\epsilon^{*\beta} \\ & +i\Big[T_3(q^2)(\epsilon^*_\mu p_{B\nu}-\epsilon^*_\nu p_{B\mu})+T_4(q^2)(\epsilon^*_\mu p_{D^*\nu}-\epsilon^*_\nu p_{D^*\mu}) \\ & +T_5(q^2)\frac{\epsilon^*\cdot q}{(m_B+m_{D^*})^2}(p_{B\mu}p_{D^*\nu}-p_{B\nu}p_{D^*\mu})\Big].\end{aligned}$$

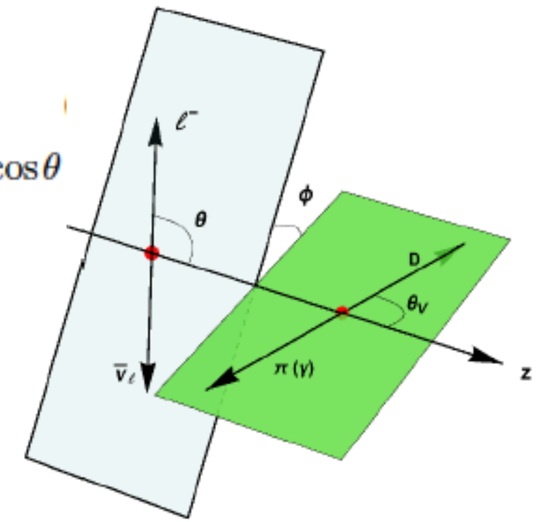
NP

$\bar{B} \to D^*(D\pi)\ell^-\bar{\nu}_\ell$ $\bar{B} \to D^*(D\gamma)\ell^-\bar{\nu}_\ell$

four dimensional decay distribution

Becirevic Fajfer et al.

$$\frac{d^4\Gamma(\bar{B}\to D^*(\to D\pi)\ell^-\bar{\nu}_\ell)}{dq^2\, d\cos\theta\, d\phi\, d\cos\theta_V} = \mathcal{N}_\pi |\vec{p}_{D^*}| \left(1-\frac{m_\ell^2}{q^2}\right)^2 \Big\{ I_{1s}^\pi \sin^2\theta_V + I_{1c}^\pi \cos^2\theta_V + \left(I_{2s}^\pi \sin^2\theta_V + I_{2c}^\pi \cos^2\theta_V\right)\cos 2\theta + I_3^\pi \sin^2\theta_V \sin^2\theta \cos 2\phi + I_4^\pi \sin 2\theta_V \sin 2\theta \cos\phi + I_5^\pi \sin 2\theta_V \sin\theta \cos\phi + \left(I_{6s}^\pi \sin^2\theta_V + I_{6c}^\pi \cos^2\theta_V\right)\cos\theta + I_7^\pi \sin 2\theta_V \sin\theta \sin\phi \Big\},$$



angular coefficients
- sensitive to FF parametrization
- some of them vanish in SM

$$\frac{d^4\Gamma(\bar{B}\to D^*(\to D\gamma)\ell^-\bar{\nu}_\ell)}{dq^2\, d\cos\theta\, d\phi\, d\cos\theta_V} = \mathcal{N}_\gamma |\vec{p}_{D^*}| \left(1-\frac{m_\ell^2}{q^2}\right)^2 \Big\{ I_{1s}^\gamma \sin^2\theta_V + I_{1c}^\gamma (3+\cos 2\theta_V) + \left(I_{2s}^\gamma \sin^2\theta_V + I_{2c}^\gamma (3+\cos 2\theta_V)\right)\cos 2\theta + I_3^\gamma \sin^2\theta_V \sin^2\theta \cos 2\phi + I_4^\gamma \sin 2\theta_V \sin 2\theta \cos\phi + I_5^\gamma \sin 2\theta_V \sin\theta \cos\phi + \left(I_{6s}^\gamma \sin^2\theta_V + I_{6c}^\gamma (3+\cos 2\theta_V)\right)\cos\theta + I_7^\gamma \sin 2\theta_V \sin\theta \sin\phi \Big\}.$$

$\bar{B} \to D^*(D\pi)\ell^-\bar{\nu}_\ell$ $\bar{B} \to D^*(D\gamma)\ell^-\bar{\nu}_\ell$

- relations between π and γ modes

$$\frac{I_{1s}^\pi}{4I_{1c}^\gamma} = \frac{I_{1c}^\pi}{2I_{1s}^\gamma} = \frac{I_{2s}^\pi}{4I_{2c}^\gamma} = \frac{I_{2c}^\pi}{2I_{2s}^\gamma} = \frac{I_{6s}^\pi}{4I_{6c}^\gamma} = \frac{I_{6c}^\pi}{2I_{6s}^\gamma} = -\frac{I_3^\pi}{2I_3^\gamma} = -\frac{I_4^\pi}{2I_4^\gamma} = -\frac{I_5^\pi}{2I_5^\gamma} = 1.$$

- fit of the experimental differential distribution ➔ angular coefficients ➔ FF

SM

$$\begin{aligned}
A_1(q^2) &= \frac{1}{4(m_B+m_{D^*})}\left\{\sqrt{\frac{4I_{1s}^\pi}{m_\ell^2+3q^2}-\frac{I_{6s}^\pi}{q^2}}+\sqrt{\frac{4I_{1s}^\pi}{m_\ell^2+3q^2}+\frac{I_{6s}^\pi}{q^2}}\right\},\\
A_2(q^2) &= \frac{(m_B+m_{D^*})}{4\lambda(m_B^2,\, m_{D^*}^2,\, q^2)}\left\{(m_B^2-m_{D^*}^2-q^2)\left[\sqrt{\frac{4I_{1s}^\pi}{m_\ell^2+3q^2}-\frac{I_{6s}^\pi}{q^2}}+\sqrt{\frac{4I_{1s}^\pi}{m_\ell^2+3q^2}+\frac{I_{6s}^\pi}{q^2}}\right]\right.\\
&\quad \left.-4\sqrt{2}m_{D^*}\sqrt{q^2}\sqrt{-\frac{I_{2c}^\pi}{q^2-m_\ell^2}}\right\},\\
V(q^2) &= \frac{(m_B+m_{D^*})}{4\lambda^{1/2}(m_B^2,\, m_{D^*}^2,\, q^2)}\left\{\sqrt{\frac{4I_{1s}^\pi}{m_\ell^2+3q^2}-\frac{I_{6s}^\pi}{q^2}}-\sqrt{\frac{4I_{1s}^\pi}{m_\ell^2+3q^2}+\frac{I_{6s}^\pi}{q^2}}\right\}, \qquad (3.8)\\
A_0(q^2) &= \frac{1}{2}\frac{\sqrt{q^2}}{\lambda^{1/2}(m_B^2,\, m_{D^*}^2,\, q^2)}\sqrt{\frac{(q^2-m_\ell^2)\,I_{1c}^\pi+(q^2+m_\ell^2)\,I_{2c}^\pi}{m_\ell^2(q^2-m_\ell^2)}}.
\end{aligned}$$

BGL vs CLN parametrization

angular coefficients -> FF ratios R_1 and R_2

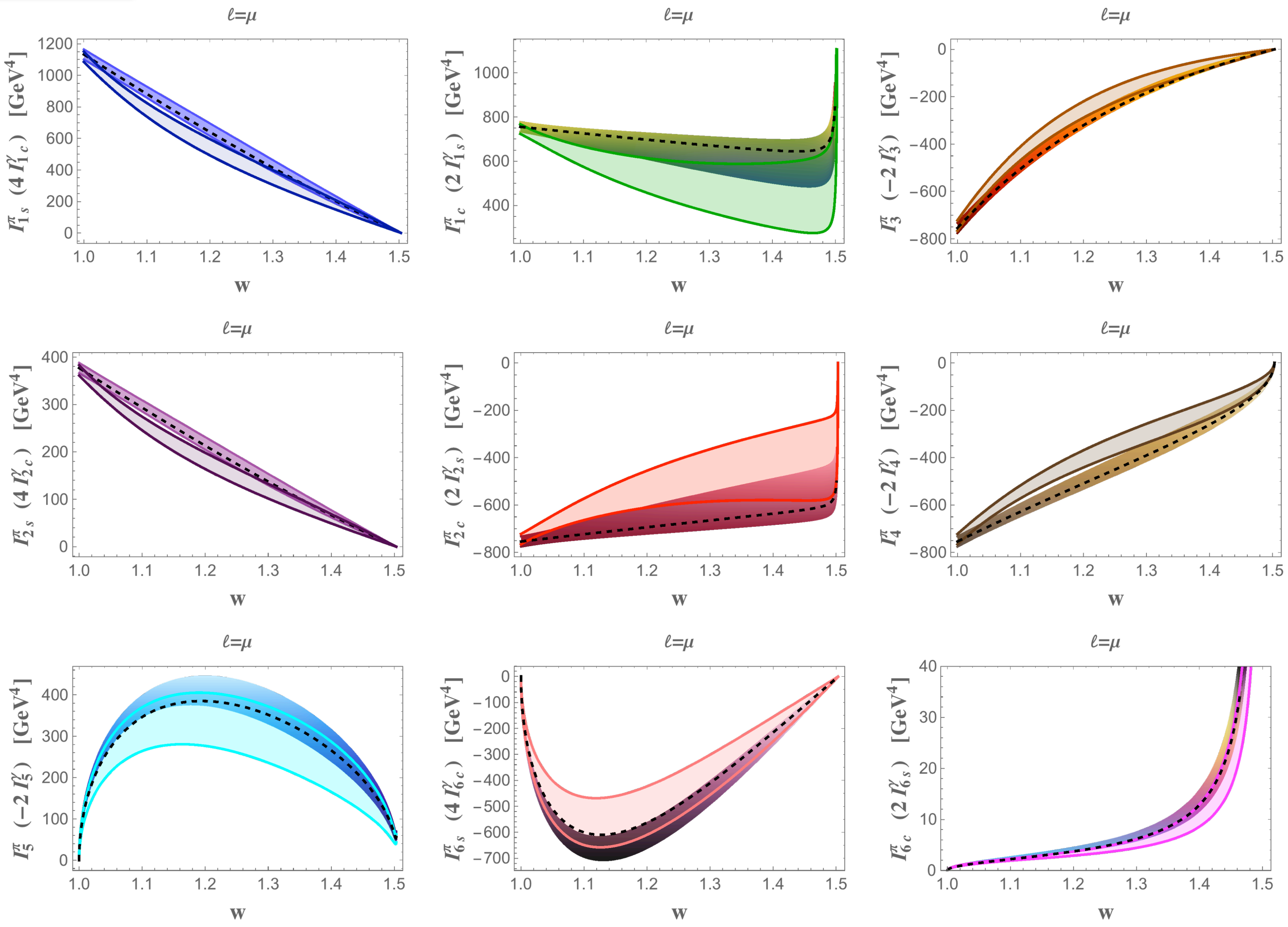
$$R_1(w) = \frac{8q^2 m_B m_{D^*}(1+w)}{(m_\ell^2+3q^2)\lambda^{1/2}(m_B^2, m_{D^*}^2, q^2)} \frac{1}{I_{6s}^\pi}\left[\sqrt{(I_{1s}^\pi)^2 - \left(\frac{m_\ell^2+3q^2}{q^2}\right)^2 \frac{(I_{6s}^\pi)^2}{16}} - I_{1s}^\pi\right],$$

$$R_2(w) = \frac{2m_B m_{D^*}(1+w)}{\lambda(m_B^2, m_{D^*}^2, q^2)}\left[(m_B^2 - q^2 - m_{D^*}^2) + 2\sqrt{2} m_{D^*} q^2 \sqrt{-\frac{q^2}{q^2-m_\ell^2} I_{2c}^\pi \frac{1}{I_{6s}^\pi}} \left(\sqrt{\frac{4I_{1s}^\pi}{m_\ell^2+3q^2} - \frac{I_{6s}^\pi}{q^2}} - \sqrt{\frac{4I_{1s}^\pi}{m_\ell^2+3q^2} + \frac{I_{6s}^\pi}{q^2}}\right)\right].$$

$$q^2 = M_B^2 + M_{D^*}^2 - 2M_B M_{D^*} w$$

SM: BGL vs CLN
μ mode

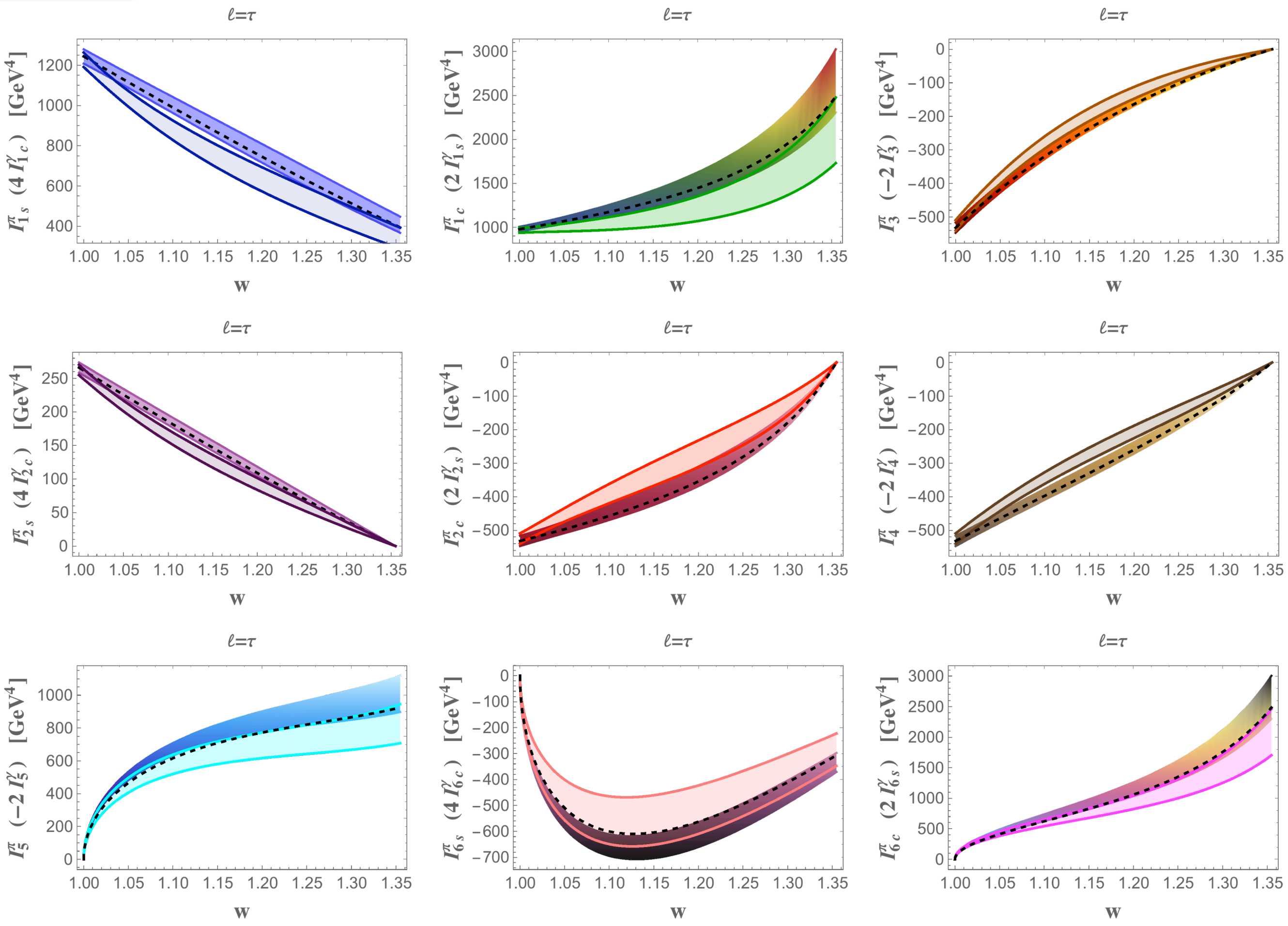
CLN: Belle parameters
BGL: parameters from Gambino et al



darker regions: CLN
lighter regions: BGL

there are coefficients more sensitive to the parametrization

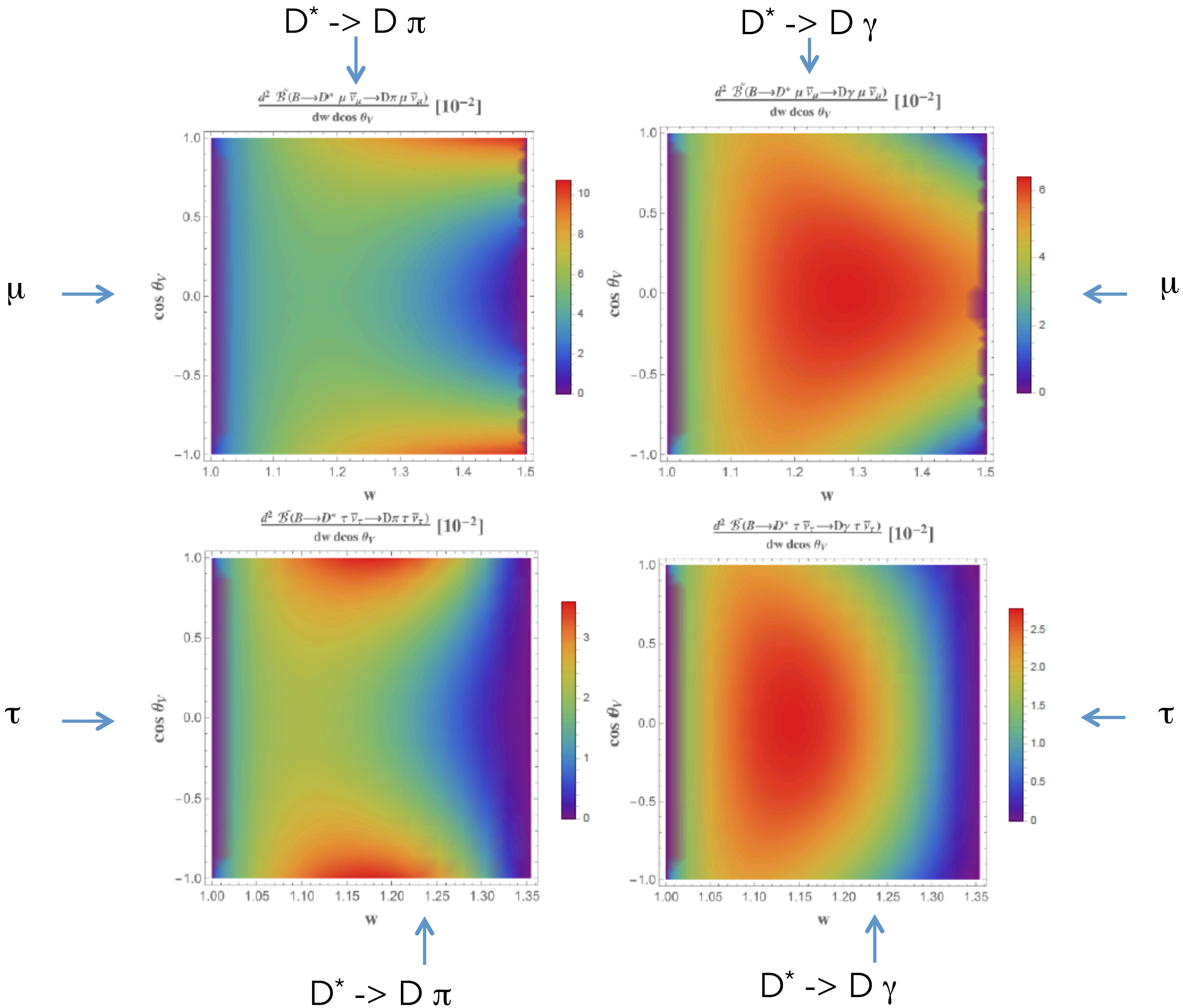
SM: BGL vs CLN
τ mode



darker regions: CLN
lighter regions: BGL

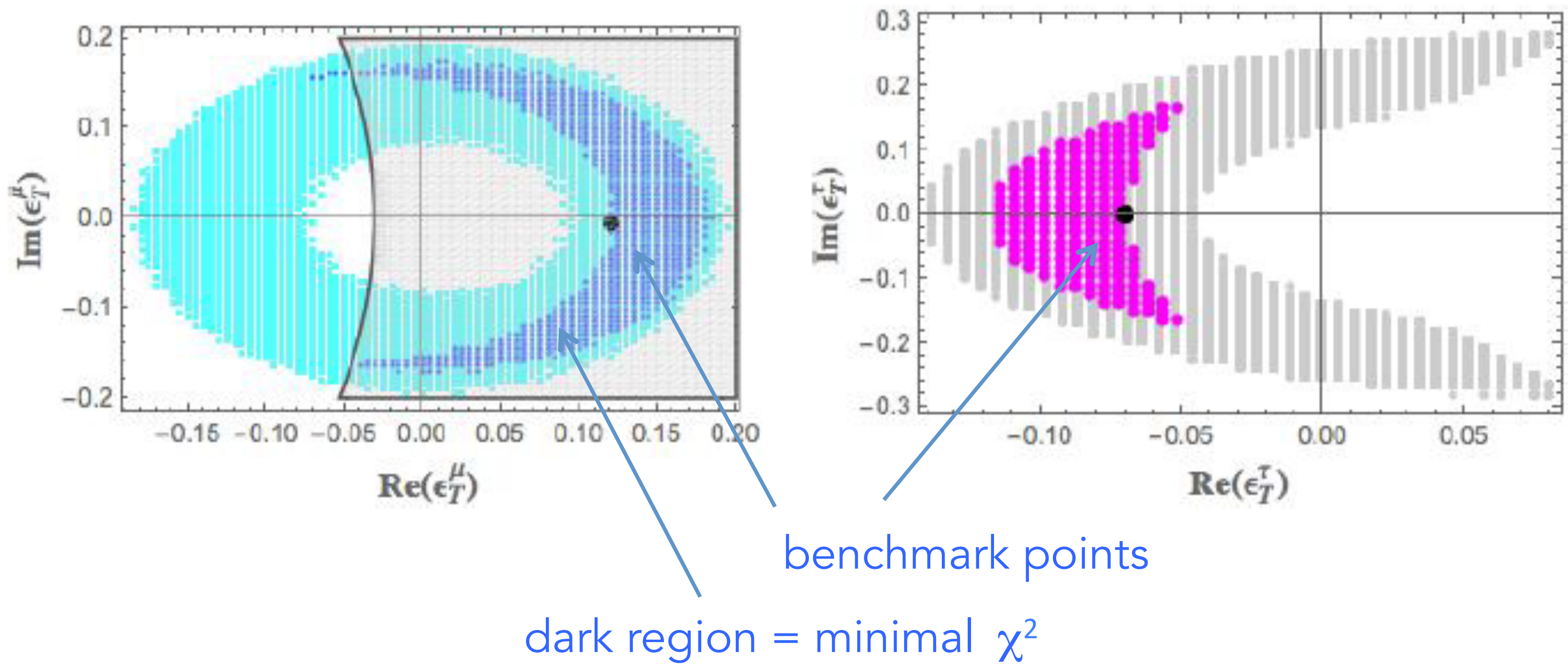
there are coefficients more sensitive to the parametrization

complementarity $D^* \to D\pi$ with $D^* \to D\gamma$



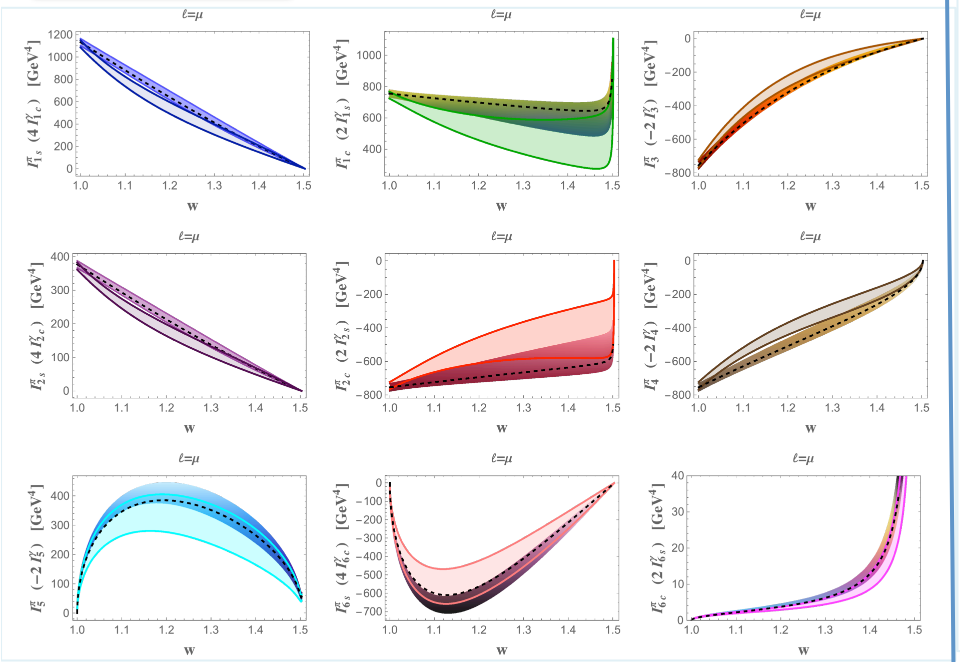
SM vs NP

- ε_T^{μ} , ε_T^{τ} non vanishing
- choose ε_T^{μ} in the region to fix the $|V_{cb}|$ tension
- determine ε_T^{τ} to reproduce R(D) & R(D*)

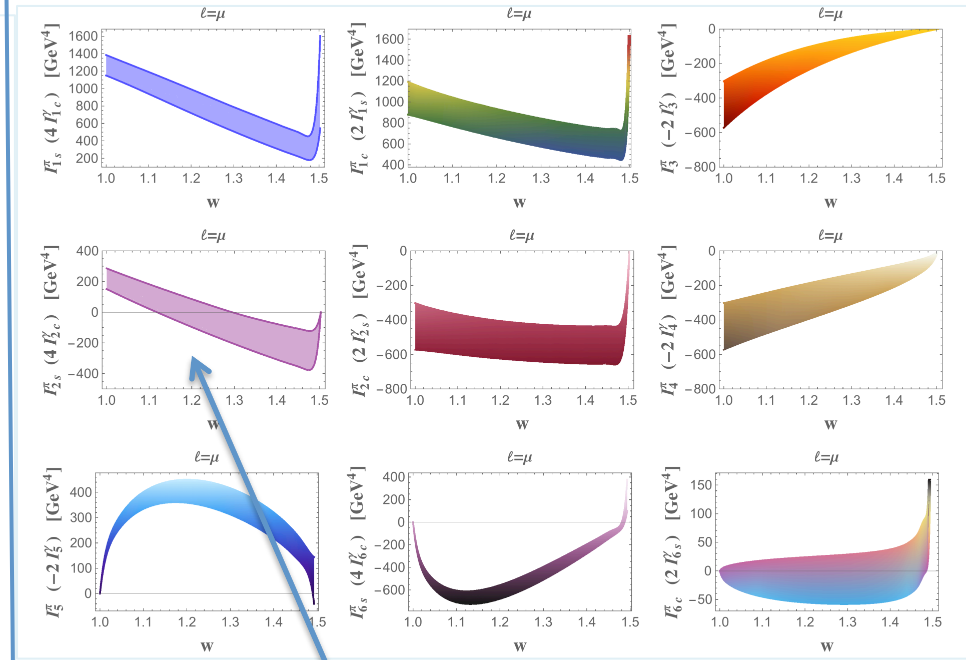


SM vs NP
μ mode

SM



NP

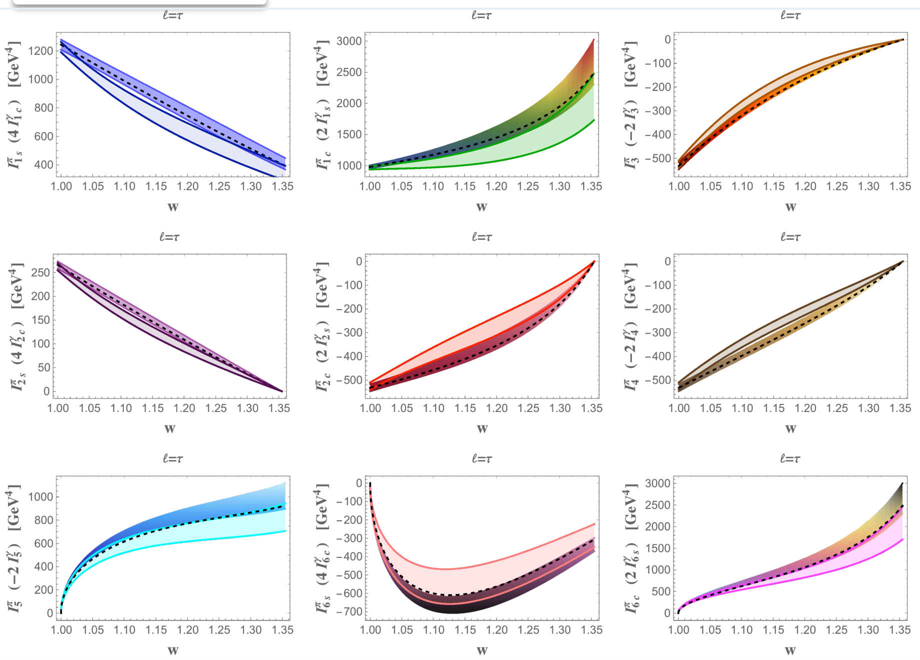


size modified in NP

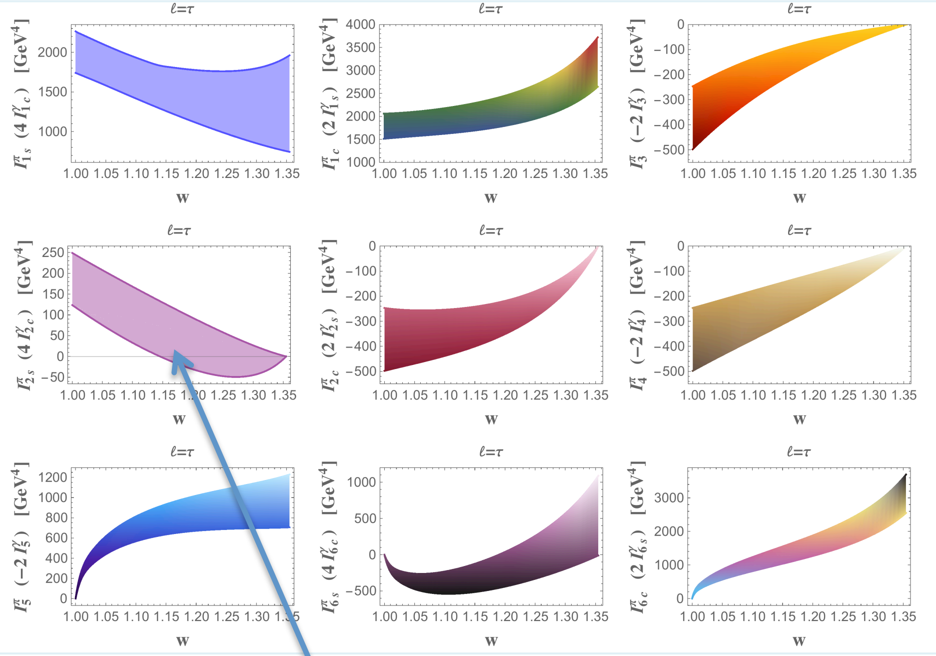
some coefficients display a zero absent in SM (I_{2s}^{π} or I_{2c}^{γ})

SM vs NP τ mode

SM

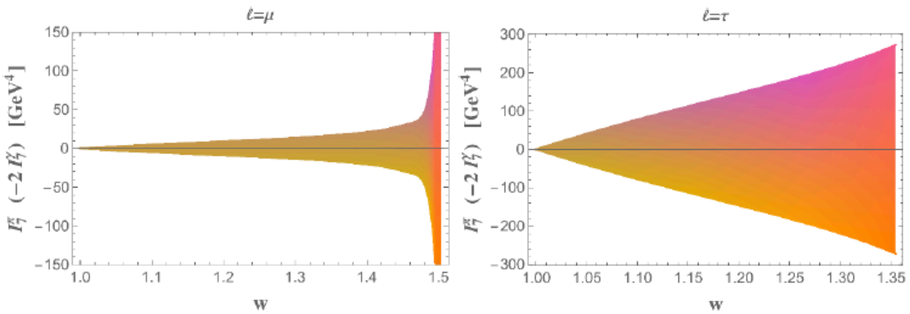


NP



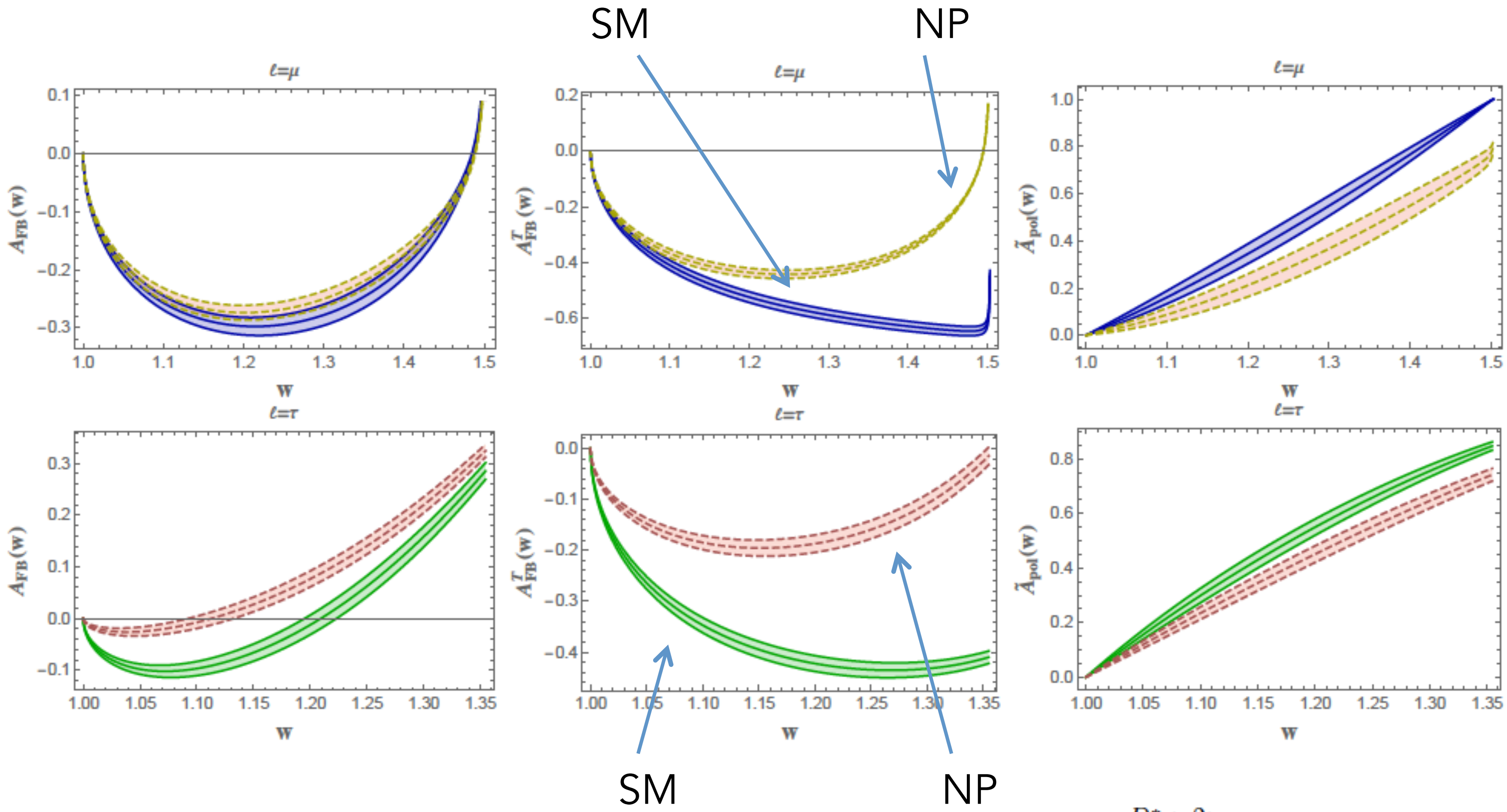
size modified in NP
some coefficients display a zero absent in SM (I_{2s}^{π} or I_{2c}^{γ})

I_7 vanishes in SM, not in NP



SM vs NP at the benchmark points

$$A_{\rm FB}(q^2) = \left[\int_0^1 dcos\,\theta\,\frac{d^2\Gamma}{dq^2 dcos\,\theta} - \int_{-1}^0 dcos\,\theta\,\frac{d^2\Gamma}{dq^2 dcos\,\theta}\right] / \frac{d\Gamma}{dq^2}\,.$$

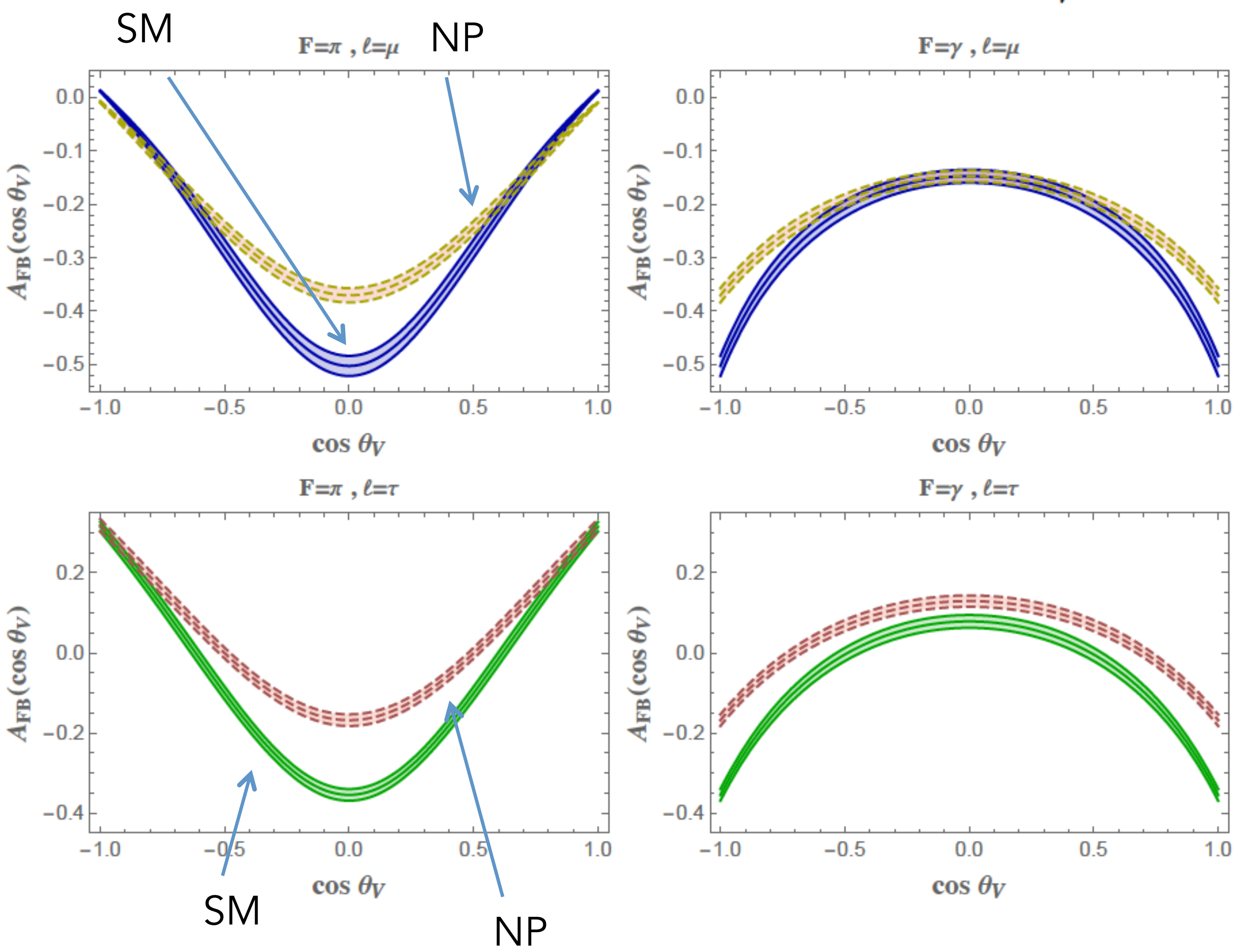


transverse A_{FB}

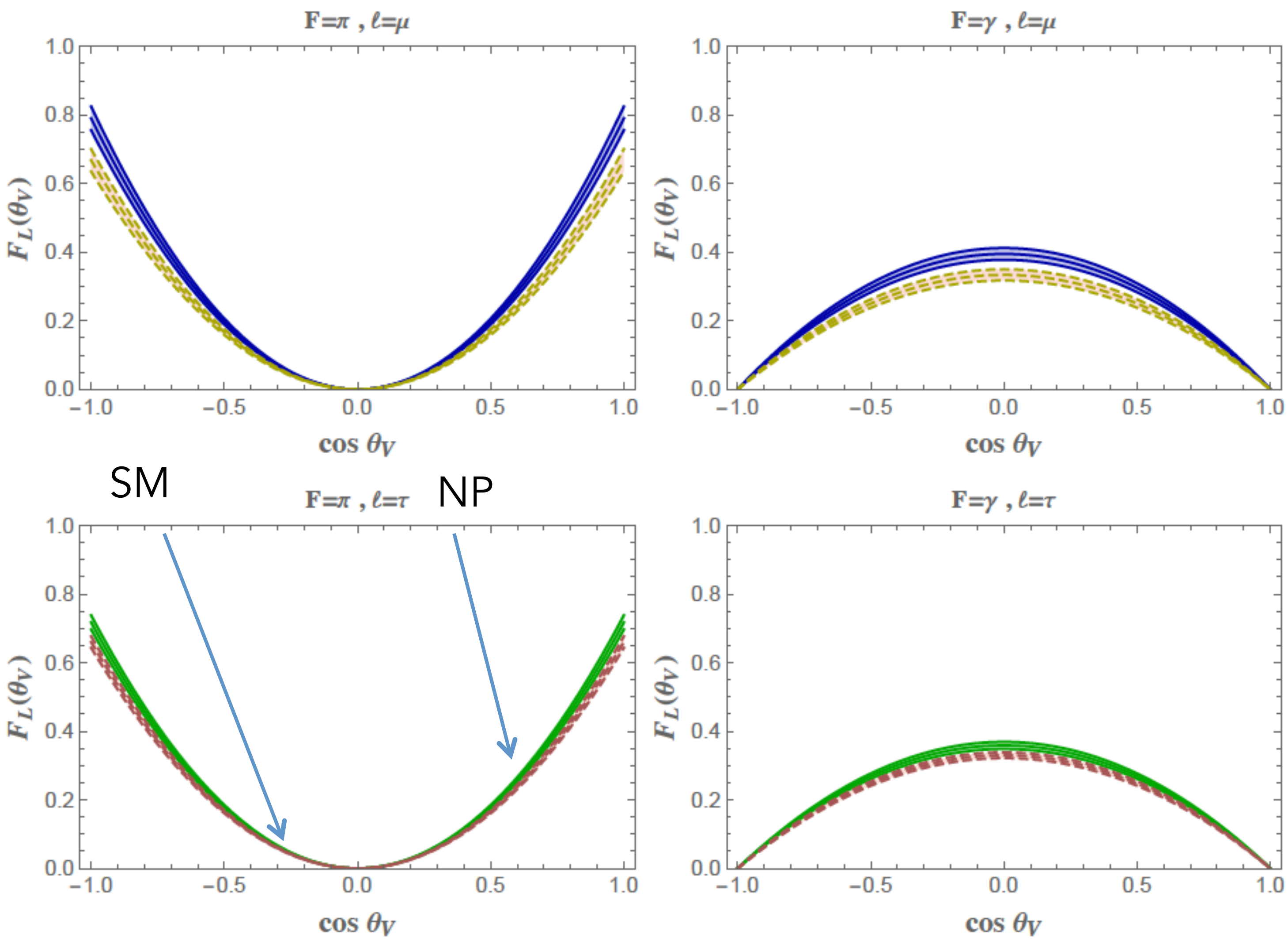
$$\frac{dA_{\rm pol}^{D^*}(q^2)}{dq^2} = 2\frac{d\Gamma_L}{dq^2} / \frac{d\Gamma_T}{dq^2} - 1\,.$$

SM vs NP at the benchmark points

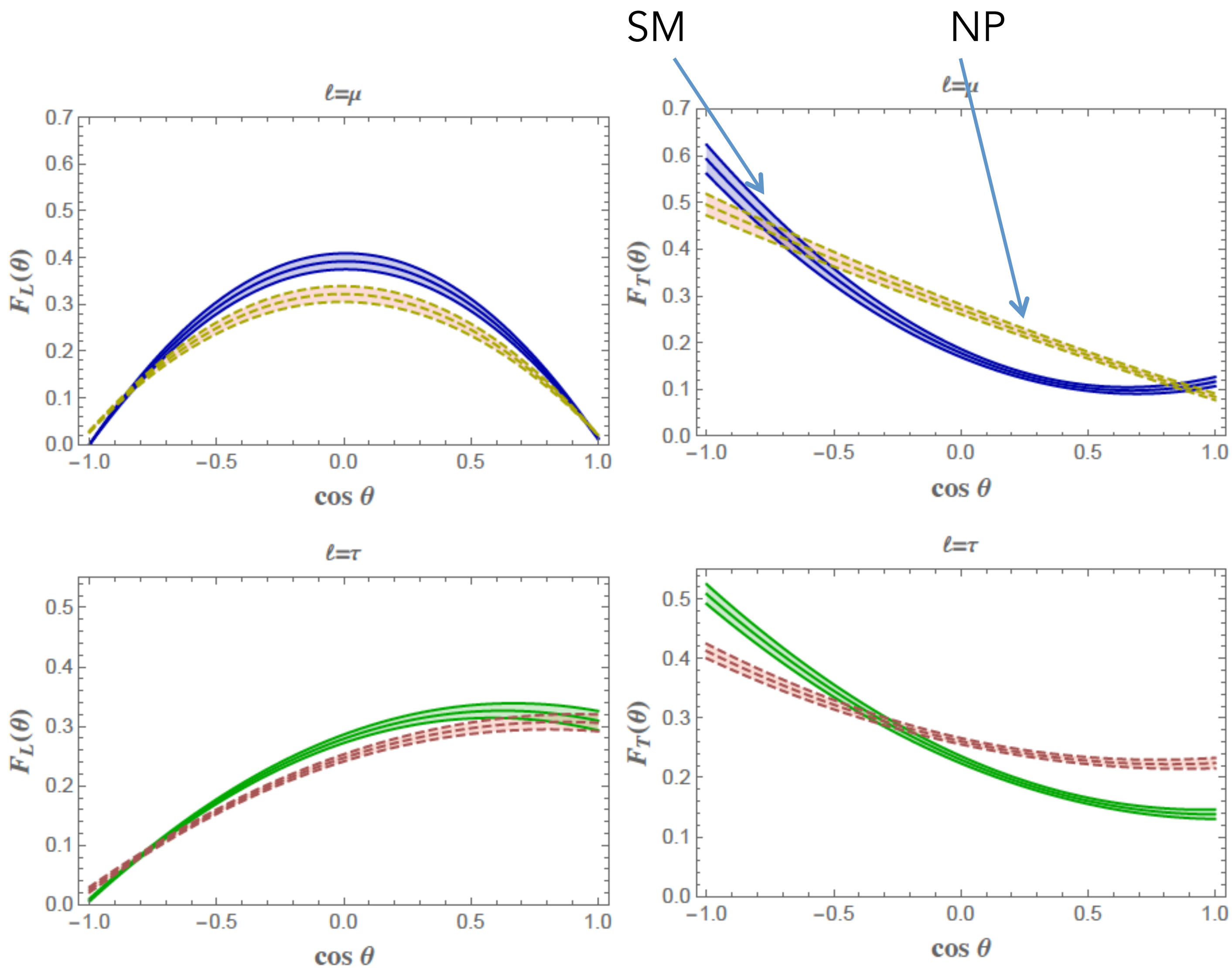
$$A_{FB}(cos\theta_V) = \frac{\left[\int_0^1 dcos\,\theta \frac{d^2\Gamma}{dcos\theta_V\, dcos\,\theta} - \int_{-1}^{0} dcos\,\theta \frac{d^2\Gamma}{dcos\theta_V\, dcos\,\theta}\right]}{\frac{d\Gamma}{dcos\theta_V}}.$$



D* polarization fractions



D* polarization fractions



tests of LFU using the angular coefficient functions

$$R_i^{\ell_1 \ell_2} = \frac{\int_{w=1}^{w_{\max}(\ell_1)} (\tilde{I}_i^{\pi}(w))_{\ell_1} dw}{\int_{w=1}^{w_{\max}(\ell_2)} (\tilde{I}_i^{\pi}(w))_{\ell_2} dw}$$

generalized by Fedele et al.

$$\tilde{I}_i = \left(1 - \frac{m_\ell^2}{q^2}\right)^2 |\vec{p}_{D^*}|_{BRF}\, I_i$$

SM

	$\ell_1 = \tau\,,\, \ell_2 = \mu$	$\ell_1 = \tau\,,\, \ell_2 = e$	$\ell_1 = \mu\,,\, \ell_2 = e$
R^π_{1s}	0.263 ± 0.006	0.262 ± 0.005	0.9957 ± 0.0001
R^π_{1c}	0.28 ± 0.02	0.28 ± 0.02	1.008 ± 0.004
R^π_{2s}	0.134 ± 0.003	0.133 ± 0.003	0.9923 ± 0.0002
R^π_{2c}	0.079 ± 0.005	0.077 ± 0.005	0.975 ± 0.002
R^π_{3}	0.153 ± 0.004	0.152 ± 0.004	0.9932 ± 0.0002
R^π_{4}	0.112 ± 0.004	0.111 ± 0.004	0.9891 ± 0.0004
R^π_{5}	0.30 ± 0.02	0.30 ± 0.02	0.999 ± 0.001
R^π_{6s}	0.197 ± 0.004	0.196 ± 0.004	0.9943 ± 0.0001
R^π_{6c}	5.90 ± 0.45	76000 ± 7000	12900 ± 200

NP

	$\ell_1 = \tau\,,\, \ell_2 = \mu$	$\ell_1 = \tau\,,\, \ell_2 = e$	$\ell_1 = \mu\,,\, \ell_2 = e$
R^π_{1s}	0.32 ± 0.01	0.304 ± 0.008	0.957 ± 0.002
R^π_{1c}	0.36 ± 0.03	0.34 ± 0.02	0.956 ± 0.003
R^π_{2s}	0.37 ± 0.02	0.38 ± 0.02	1.04 ± 0.01
R^π_{2c}	0.082 ± 0.006	0.080 ± 0.006	0.973 ± 0.002
R^π_{3}	0.183 ± 0.005	0.182 ± 0.005	0.9932 ± 0.0002
R^π_{4}	0.131 ± 0.005	0.130 ± 0.005	0.9890 ± 0.0004
R^π_{5}	0.35 ± 0.03	0.33 ± 0.03	0.96 ± 0.01
R^π_{6s}	0.150 ± 0.006	0.152 ± 0.006	1.012 ± 0.003
R^π_{6c}	-11.6 ± 1.5	-944 ± 40	81.2 ± 9.1
R^π_{7}	0	0	184 ± 2

Messages

- The $|V_{cb}|_{excl}$ vs $|V_{cb}|_{incl}$ tension still persists
- As alternative to conventional SM solutions, a NP option for it seems viable and related to $R(D^{(*)})$
- Angular coefficients in $\bar{B} \to D^*(D\pi)\ell\bar{\nu}_\ell$ 4d distribution can disentangle non SM effects
- Some angular coefficients are more sensitive to FF parametrization
- $\bar{B} \to D^*(D\pi)\ell\bar{\nu}_\ell$ $\bar{B} \to D^*(D\gamma)\ell\bar{\nu}_\ell$ complementarity can be exploited
- Precision era: importance of separate th and exp analyses for electrons and muons

} example (bullets 2–3)