



# Probing new physics

$$\Lambda_b^0 \rightarrow \Lambda_c^+ (\rightarrow \Lambda \pi^+) \tau \bar{\nu}_\tau \text{ decay}$$

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# *Motivation*

- $B \rightarrow D^{(*)} \ell \bar{\nu}$  decays being studied theoretically and experimentally for the last decade extensively and shows anomaly in LFU ratios
- To ensure if any New Physics (NP) shows in these mesonic decays we need some complimentary decays too
- One such decay is  $\Lambda_b^0 \rightarrow \Lambda_c^+ (\rightarrow \Lambda \pi^+) \ell \bar{\nu}_\tau$
- Belle and Babar has B decay results but they cannot measure b-baryons
- LHCb can and recently measured the BR for  $\Lambda_b^0 \rightarrow \Lambda_c^+ \tau \bar{\nu}_\tau$
- Using DELPHI result for  $\Lambda_b^0 \rightarrow \Lambda_c^+ \mu \bar{\nu}_\mu$ , LHCb provide LFUV ratio  $R_{\Lambda_c}$
- so high time to analyse the current status of NP operators taking all the semileptonic b-decays

# ***Hamiltonian***

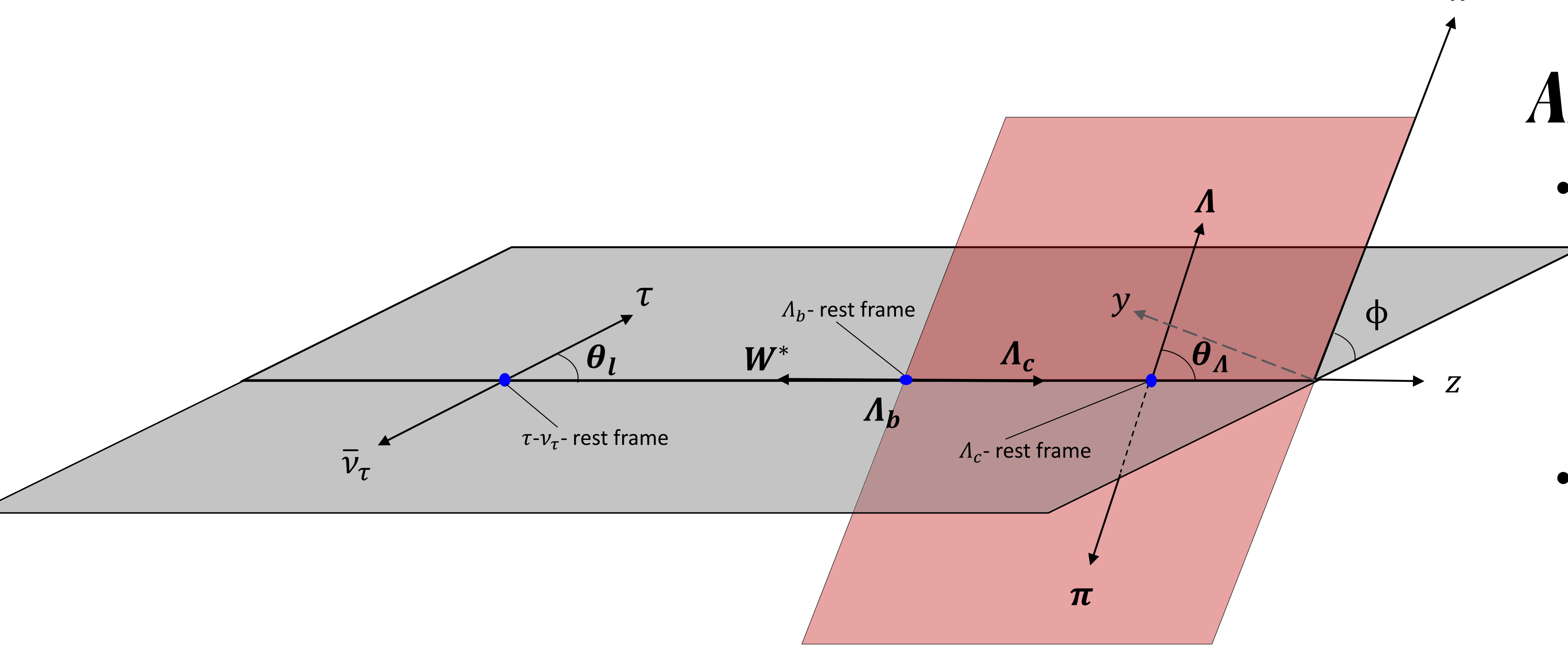
- The full hamiltonian for underlying  $b \rightarrow c\tau\bar{\nu}$

$$\mathcal{H}_{eff} = \frac{G_F V_{cb}}{\sqrt{2}} \left\{ \left[ (1 + C_{V_1}) \bar{c} \gamma_\mu (1 - \gamma_5) b + C_{V_2} \bar{c} \gamma_\mu (1 + \gamma_5) b \right] \bar{\tau} \gamma^\mu (1 - \gamma_5) \nu_\tau \right. \\ \left. + \left[ C_{S_1} \bar{c} (1 + \gamma_5) b + C_{S_2} \bar{c} (1 - \gamma_5) b \right] \bar{\tau} (1 - \gamma_5) \nu_\tau + \left[ C_T \bar{c} \sigma^{\mu\nu} (1 - \gamma_5) b \right] \bar{\tau} \sigma_{\mu\nu} (1 - \gamma_5) \nu_\tau + h.c \right\},$$

- So we have  $C_{V_1}, C_{V_2}, C_{S_1}, C_{S_2}, C_T$  as new physics operators
- taken the  $\nu$  as left-handed for all the operators

# Angular distribution

- the decay is constructed as consecutive 2-body decays:  $\Lambda_b \rightarrow \Lambda_c W^*$  then  $W^* \rightarrow \tau \bar{\nu}$  and  $\Lambda_c \rightarrow \Lambda \pi$
- the 4-fold decay distribution is given by the kinematic variables  $\theta_\ell$ ,  $\theta_\Lambda$  and azimuthal angle  $\phi$  and di-lepton mass  $q^2$
- 10 observables: 8 survives in SM



$$\frac{d\Gamma}{dq^2 d \cos \theta_\ell d \cos \theta_\Lambda d \phi} = \frac{3}{8\pi} K(q^2, \cos \theta_\ell, \cos \theta_\Lambda, \phi)$$

$$\begin{aligned} K(q^2, \cos \theta_\ell, \cos \theta_\Lambda, \phi) = & (K_{1ss} \sin^2 \theta_\ell + K_{1cc} \cos^2 \theta_\ell + K_{1c} \cos \theta_\ell) \\ & + (K_{2ss} \sin^2 \theta_\ell + K_{2cc} \cos^2 \theta_\ell + K_{2c} \cos \theta_\ell) \cos \theta_\Lambda \\ & + (K_{3sc} \sin \theta_\ell \cos \theta_\ell + K_{3s} \sin \theta_\ell) \sin \theta_\Lambda \cos \phi \\ & + (K_{4sc} \sin \theta_\ell \cos \theta_\ell + K_{4s} \sin \theta_\ell) \sin \theta_\Lambda \sin \phi. \end{aligned}$$

# *important angular observables*

- decay rate  $\frac{d\Gamma}{dq^2} = 2K_{1ss} + K_{1cc}$
- leptonic forward-backward(FB) asymmetry:  $A_{\text{FB}}^{\ell} = \frac{3}{2} \frac{K_{1c}}{2K_{1ss} + K_{1cc}}$
- FB asymmetry coming from the daughter  $\Lambda_c$  decay:  $A_{\text{FB}}^{\Lambda_c} = \frac{1}{2} \frac{2K_{2ss} + K_{2cc}}{2K_{1ss} + K_{1cc}}$
- FB asymmetry coming from the coefficient of  $\cos \theta_{\ell} \cos \theta_{\Lambda}$ :  $A_{\text{FB}}^{\Lambda_c \ell} = \frac{3}{4} \frac{K_{2c}}{2K_{1ss} + K_{1cc}}$
- the  $\tau$ -polarization asymmetry:  $P_{\tau}^{(\Lambda_c)}(q^2) = \frac{d\Gamma^{\lambda_{\tau}=1/2}/dq^2 - d\Gamma^{\lambda_{\tau}=-1/2}/dq^2}{d\Gamma/dq^2}$
- $\Lambda_c$  spin polarization asymmetry:  $P_{\Lambda_c}(q^2) = \frac{d\Gamma^{\lambda_{\Lambda_c}=1/2}/dq^2 - d\Gamma^{\lambda_{\Lambda_c}=-1/2}/dq^2}{d\Gamma/dq^2}$ .
- convexity parameter  $C_F^{\ell}(q^2) = \frac{1}{d\Gamma/dq^2} \left( \frac{d}{d(\cos \theta_l)} \right)^2 \left( \frac{d^2\Gamma}{dq^2 d \cos \theta_l} \right)$ .
- other normalised ang. observables  $\hat{K}_i = \frac{K_i}{2K_{1ss} + K_{1cc}}$  (independent of  $|V_{cb}|$ )

# Experiment results

| $R(D)$ [1] | $R(D^*)$ [1] | correlation [1] |
|------------|--------------|-----------------|
| 0.357(29)  | 0.284(12)    | -0.37           |

[1]HFLAV Collab  
2023

$$R(D)_{SM} = 0.304 \pm 0.003,$$

$$R(D^*)_{SM} = 0.258 \pm 0.012.$$

more than  $2\sigma$  taking correlation

$$F_L^{D^*} = 0.43 \pm 0.06 \pm 0.03.$$

compatible with SM

LHCb[2311.05224]

$$\mathcal{B}(\Lambda_b \rightarrow \Lambda_c \tau^- \nu_\tau) = (1.50 \pm 0.16 \pm 0.25 \pm 0.23)\%.$$

LHCb[2201.03497]

$R(D^{(*)})$  and  $R(\Lambda_c)$  has opposite directions

$$R(\Lambda_c)_{SM} = 0.330 \pm 0.010,$$

using DELPHI[2004] results on  $\mu$  mode LHCb predicts :

$$\mathcal{R}(\Lambda_c^+) = 0.242 \pm 0.026 \pm 0.040 \pm 0.059,$$

# Fit procedure

- To perform a model-independent analysis, we did the  $\chi^2$ -fit to the data with different NP Wilson coefficients  $C_k$  (all taken real):
- $V_{i,j}^{exp(th)}$  is the corresponding measured (theoretical) covariance matrix.
- the theory correlations will be between  $R(D^*)$  and  $F_L^{D^*}$ , and between  $R(\Lambda_c)$  and  $\mathcal{B}(\Lambda_b \rightarrow \Lambda_c \tau \nu)$ .

$$\chi^2(C_k) = \sum_{i,j} [\mathcal{O}_i^{th}(C_k) - \mathcal{O}_i^{exp}] (V^{exp} + V^{th})_{i,j}^{-1} [\mathcal{O}_i^{th}(C_k) - \mathcal{O}_i^{exp}].$$

- when we say 1-parameter scenario it means we take  $C_{V_1}$ ,  $C_{V_2}$  etc one at a time in addition to SM current, there are such 5 scenarios for 5 NP operators
- we have also taken 2 parameter scenario i.e. taking 2 parameter at a time.

- we defined  $\sigma_{dev} = \left| \frac{\mathcal{O}_i^{exp} - \mathcal{O}_i^{NP}}{\sqrt{\sigma_i^2|_{exp} + \sigma_i^2|_{NP}}} \right|$

# One parameter fit

| Parameter     | One Parameter fit scenario |                     |         | $\sigma_{dev}$ (in $\sigma$ ) |          |                |
|---------------|----------------------------|---------------------|---------|-------------------------------|----------|----------------|
|               | Fit values                 | $\chi^2_{min.}/DOF$ | P-Value | $R(D)$                        | $R(D^*)$ | $R(\Lambda_c)$ |
| $Re[C_{S_1}]$ | 0.104(45)                  | 4.463/4             | 0.215   | 0.151                         | 1.355    | 1.372          |
| $Re[C_{S_2}]$ | 0.101(47)                  | 5.187/4             | 0.159   | 0.098                         | 1.709    | 1.297          |
| $Re[C_{V_1}]$ | 0.050(22)                  | 4.001/4             | 0.261   | 0.683                         | 0.048    | 1.524          |
| $Re[C_{V_2}]$ | -0.0045(339)               | 9.176/4             | 0.027   | 1.564                         | 1.029    | 1.128          |
| $Re[C_T]$     | -0.022(18)                 | 7.903/4             | 0.048   | 1.971                         | 0.343    | 1.385          |

tension b/w observable from fit and experimental data

none of the one-operator scenarios could explain all three data within  $1\sigma$

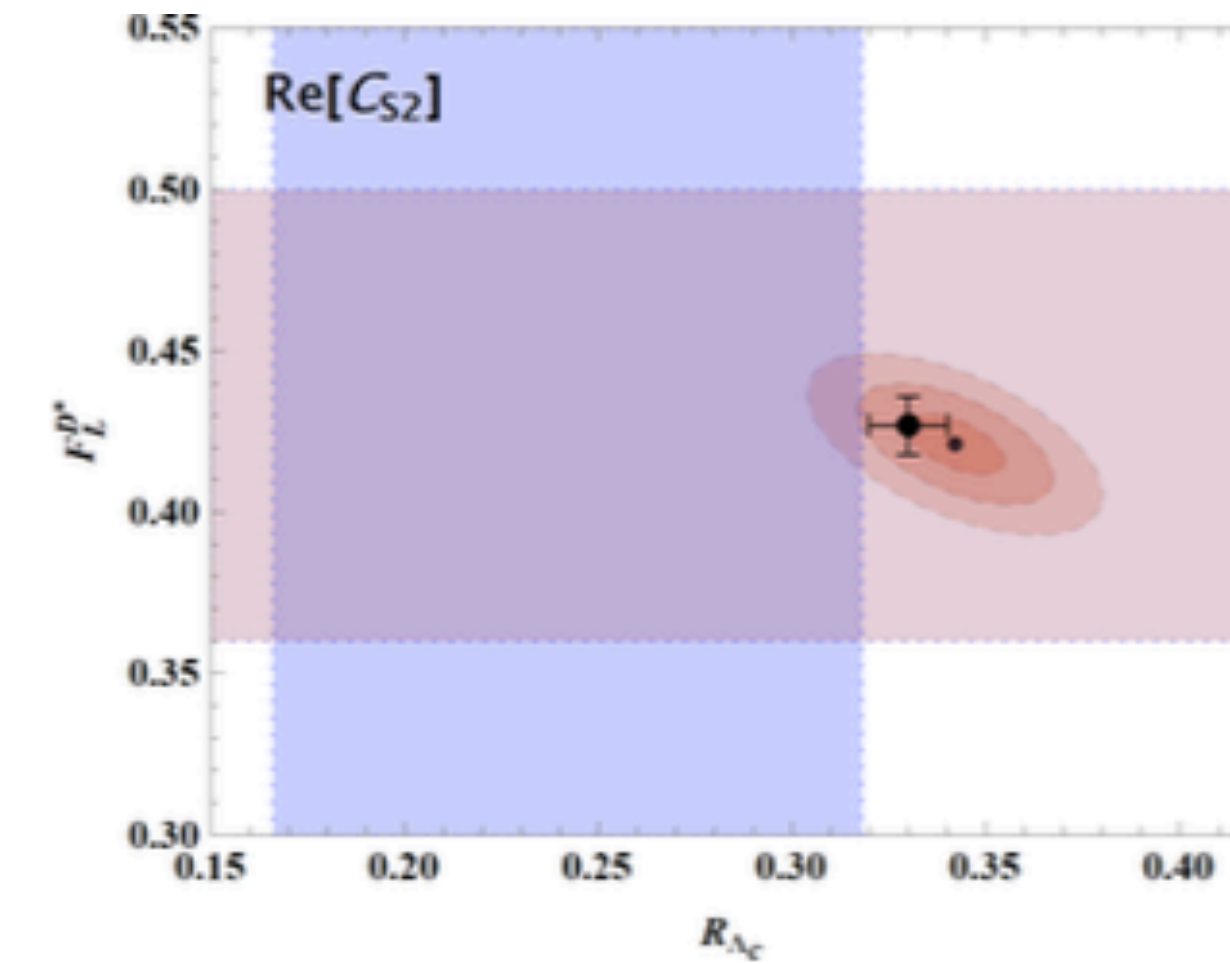
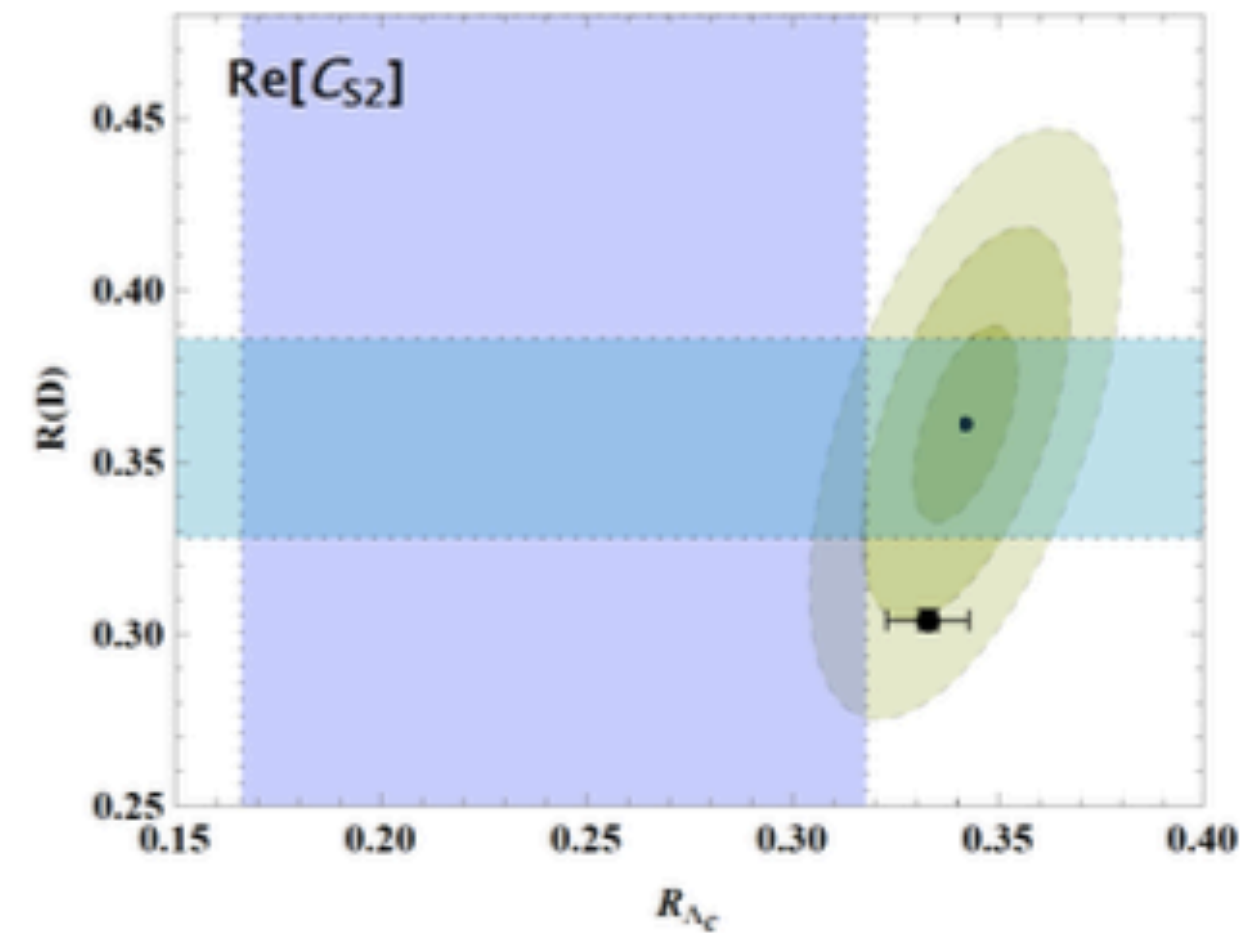
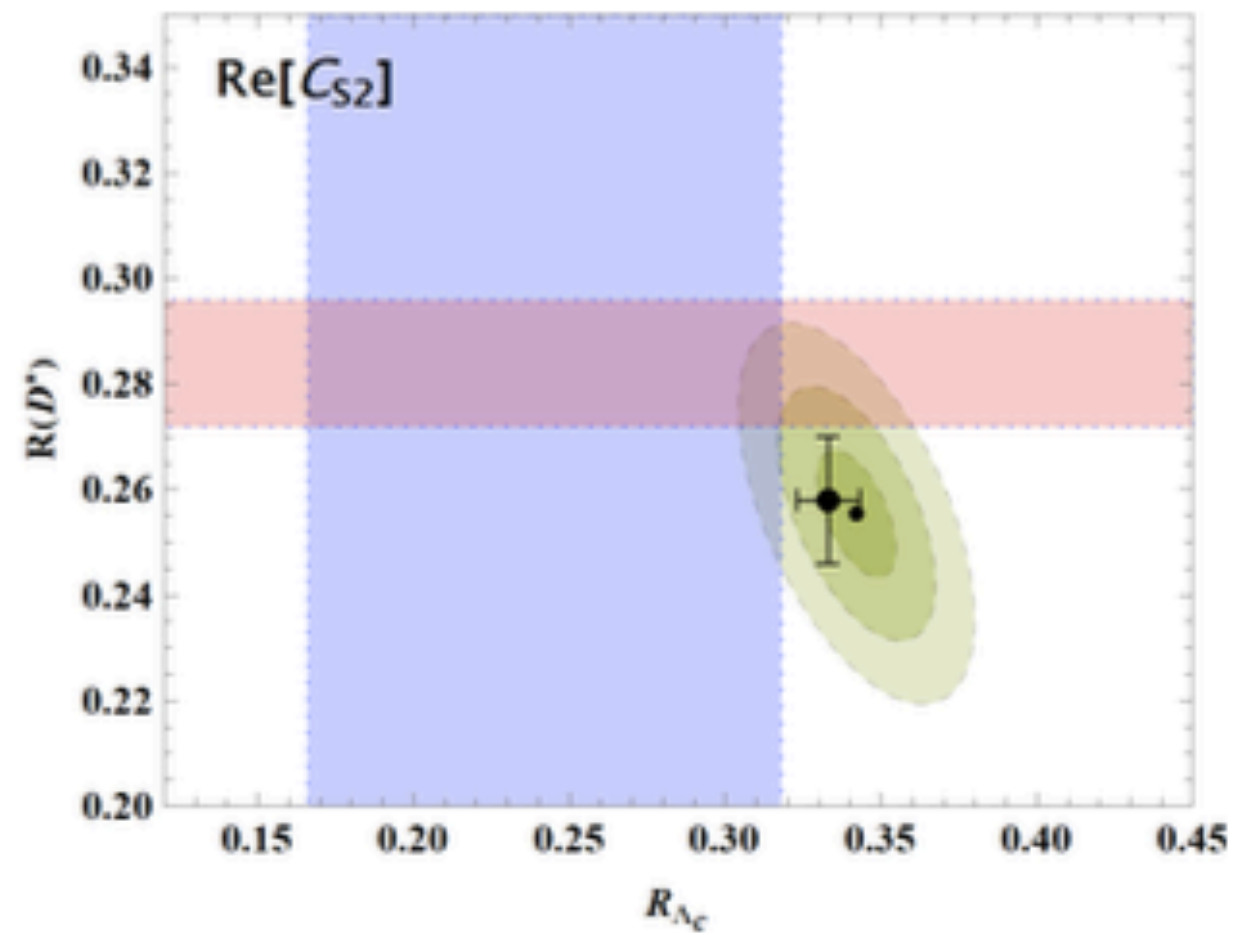
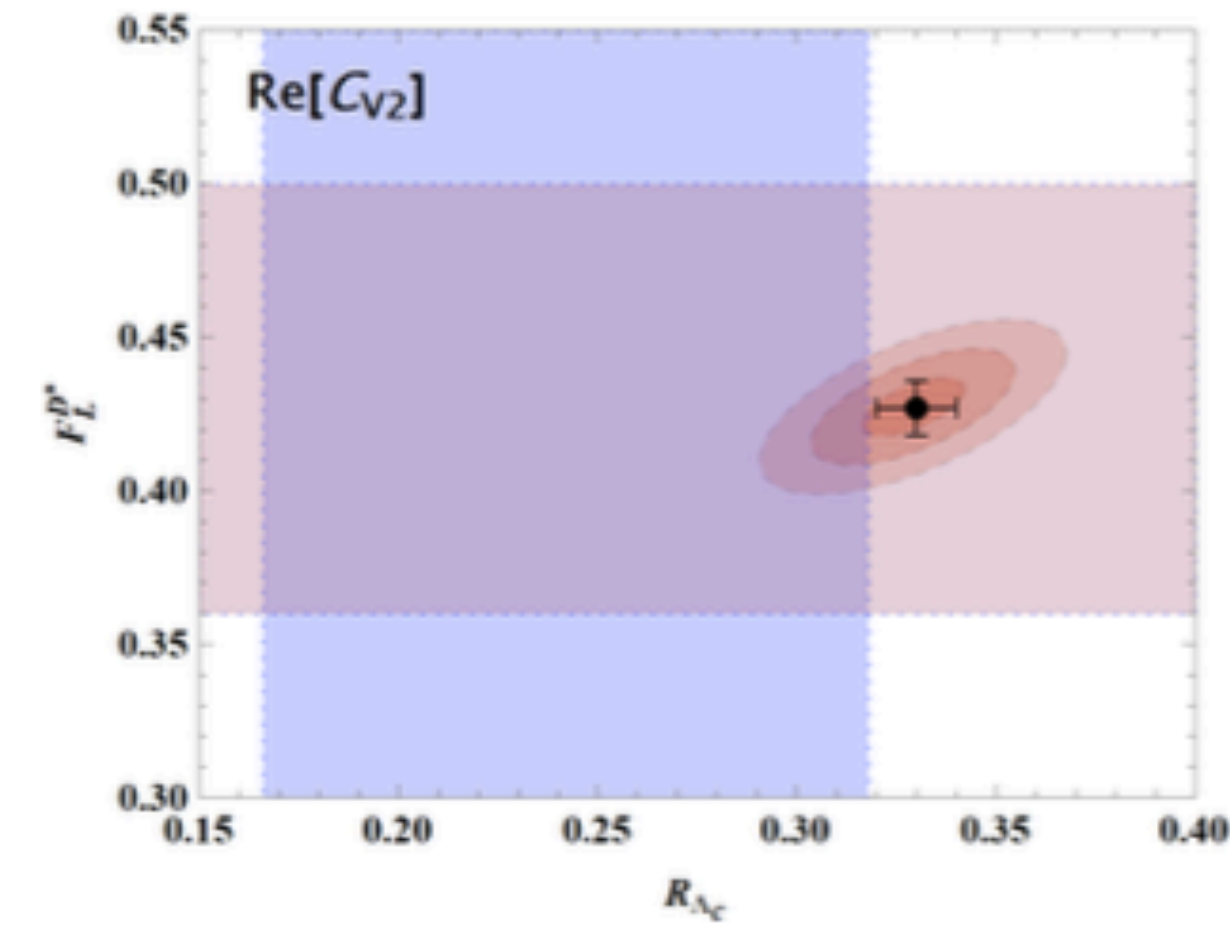
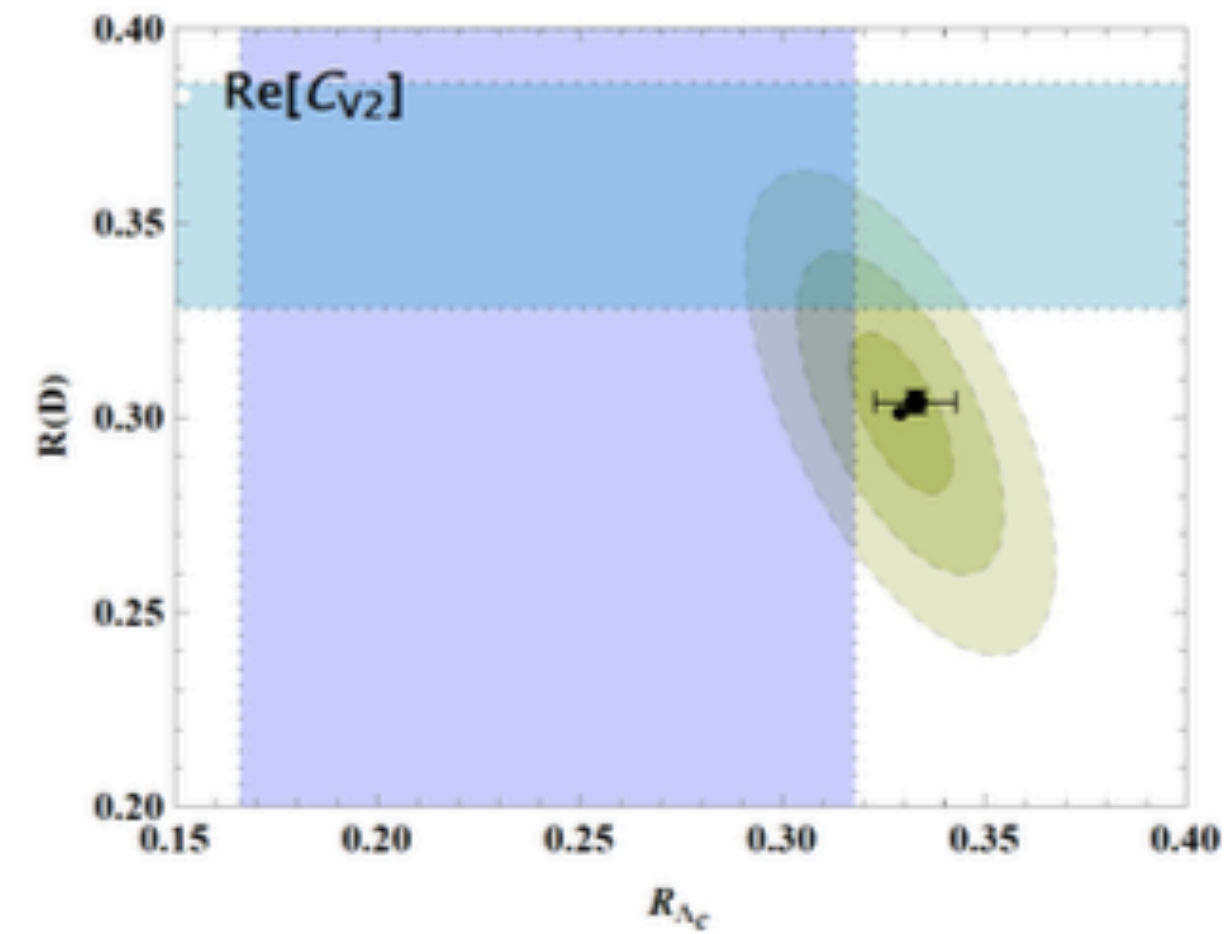
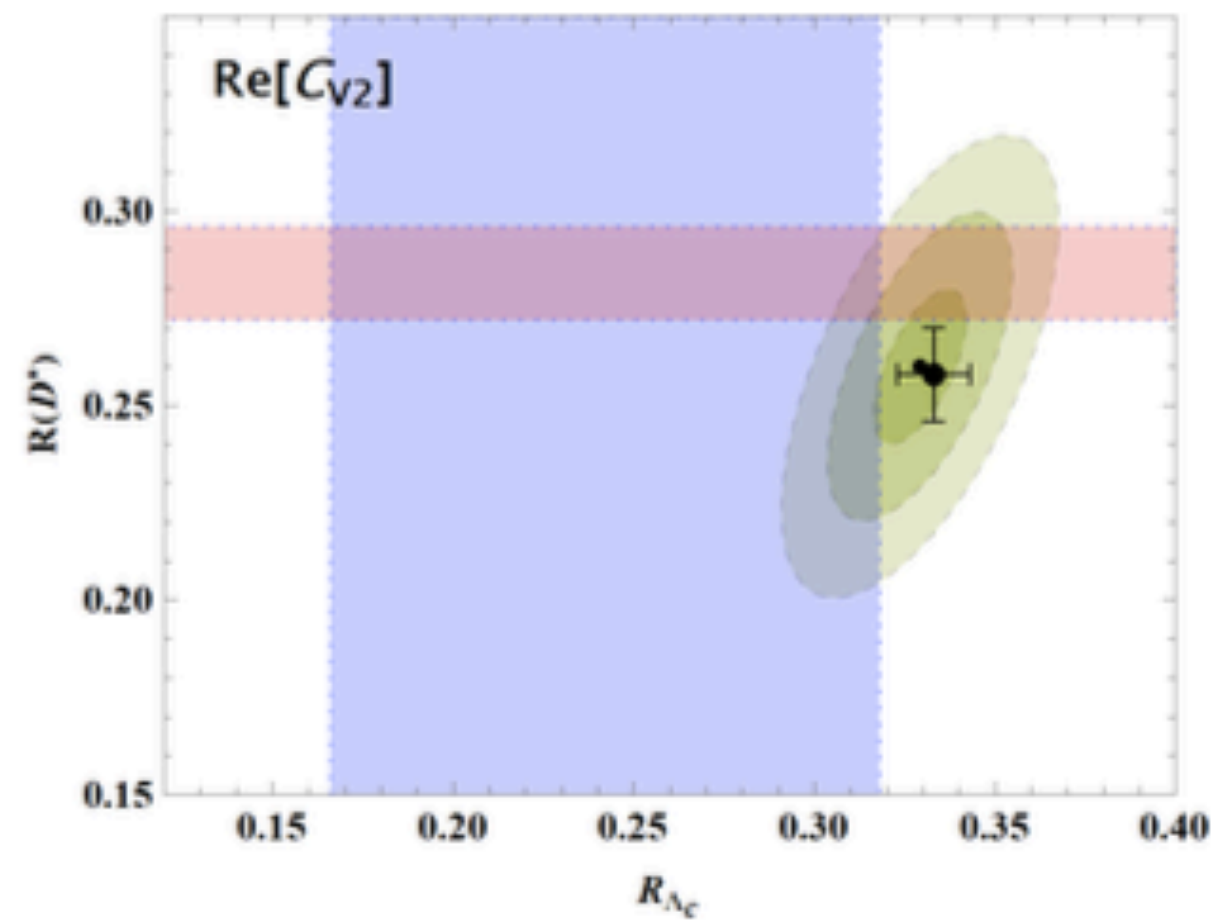
for  $C_{V_2}$ , none of the 3 data could be explained within  $1\sigma$

| Observables    | Observables Prediction( One operator scenario) |               |               |               |            | Expt. Measurement |
|----------------|--|---------------|---------------|---------------|------------|-------------------|
|                | $Re[C_{S_1}]$                                  | $Re[C_{S_2}]$ | $Re[C_{V_1}]$ | $Re[C_{V_2}]$ | $Re[C_T]$  |                   |
| $R(D)$         | 0.363(27)                                      | 0.361(29)     | 0.335(14)     | 0.301(21)     | 0.299(5)   | 0.357(29) [1]     |
| $R(D^*)$       | 0.261(12)                                      | 0.255(12)     | 0.285(17)     | 0.260(20)     | 0.276(20)  | 0.284(12) [1]     |
| $R(\Lambda_c)$ | 0.348(14)                                      | 0.342(13)     | 0.361(18)     | 0.329(13)     | 0.352(23)  | 0.242(76)[52]     |
| $F^\ell(D^*)$  | 0.433(3)                                       | 0.421(3)      | 0.427(9)      | 0.427(3)      | 0.421(6)   | 0.430(70) [53]    |
| $P^\tau(D^*)$  | -0.502(10)                                     | -0.535(9)     | -0.519(7)     | -0.519(7)     | -0.505(14) | -0.38(54) [34]    |
| $P^\tau(D)$    | 0.433(42)                                      | 0.431(45)     | 0.324(3)      | 0.324(3)      | 0.336(10)  | N.A.              |

$F_l(D^*)$  and  $P^\tau(D^*)$  can be explained comfortably in  $1\sigma$



# Correlation plot in 1 param. scenario



these 2 scenario can only explain all data within  $3\sigma$

# Two parameter scenario

mass effects for  $\tau$  ?

$$\begin{aligned}
 K_{1cc} = & N \left[ 2 \left( |H_{-\frac{1}{2},0}^{\text{SP}}|^2 + |H_{\frac{1}{2},0}^{\text{SP}}|^2 + |H_{-\frac{1}{2},-1}^{\text{VA}}|^2 + |H_{\frac{1}{2},+1}^{\text{VA}}|^2 \right) \right. \\
 & + 8 \left( |H_{-\frac{1}{2},+1,-1}^{T,-\frac{1}{2}}|^2 + |H_{\frac{1}{2},+1,-1}^{T,\frac{1}{2}}|^2 + |H_{-\frac{1}{2},t,0}^{T,-\frac{1}{2}}|^2 + |H_{\frac{1}{2},t,0}^{T,\frac{1}{2}}|^2 \right) \\
 & - 16 \text{Re} \left[ H_{-\frac{1}{2},+1,-1}^{T,-\frac{1}{2}*} H_{-\frac{1}{2},t,0}^{T,-\frac{1}{2}} + H_{\frac{1}{2},+1,-1}^{T,\frac{1}{2}*} H_{\frac{1}{2},t,0}^{T,\frac{1}{2}} \right] \\
 & + \frac{m_\ell}{\sqrt{q^2}} \left\{ \text{Re} \left[ 4 \left( H_{-\frac{1}{2},0}^{\text{SP}*} H_{-\frac{1}{2},t}^{\text{VA}} + H_{\frac{1}{2},0}^{\text{SP}*} H_{\frac{1}{2},t}^{\text{VA}} \right) \right. \right. \\
 & + 8 \left( H_{-\frac{1}{2},0}^{\text{VA}*} H_{-\frac{1}{2},t,0}^{T,-\frac{1}{2}} - H_{-\frac{1}{2},0}^{\text{VA}*} H_{-\frac{1}{2},+1,-1}^{T,-\frac{1}{2}} - H_{\frac{1}{2},0}^{\text{VA}*} H_{\frac{1}{2},+1,-1}^{T,\frac{1}{2}} + H_{\frac{1}{2},0}^{\text{VA}*} H_{\frac{1}{2},t,0}^{T,\frac{1}{2}} \right. \\
 & \left. \left. + H_{-\frac{1}{2},-1,0}^{T,\frac{1}{2}} H_{-\frac{1}{2},-1}^{\text{VA}*} - H_{\frac{1}{2},+1,0}^{T,-\frac{1}{2}} H_{\frac{1}{2},+1}^{\text{VA}*} + H_{-\frac{1}{2},-1}^{\text{VA}*} H_{-\frac{1}{2},t,-1}^{T,\frac{1}{2}} + H_{\frac{1}{2},+1}^{\text{VA}*} H_{\frac{1}{2},t,1}^{T,-\frac{1}{2}} \right) \right] \left. \right\} \\
 & + \frac{m_\ell^2}{q^2} \left\{ 2 \left( |H_{-\frac{1}{2},0}^{\text{VA}}|^2 + |H_{\frac{1}{2},0}^{\text{VA}}|^2 + |H_{-\frac{1}{2},t}^{\text{VA}}|^2 + |H_{\frac{1}{2},t}^{\text{VA}}|^2 \right) \right. \\
 & + 8 \left( |H_{-\frac{1}{2},-1,0}^{T,\frac{1}{2}}|^2 + |H_{\frac{1}{2},+1,0}^{T,-\frac{1}{2}}|^2 + |H_{-\frac{1}{2},t,-1}^{T,\frac{1}{2}}|^2 + |H_{\frac{1}{2},t,+1}^{T,-\frac{1}{2}}|^2 \right) \\
 & \left. + 16 \text{Re} \left[ H_{-\frac{1}{2},-1,0}^{T,\frac{1}{2}*} H_{-\frac{1}{2},t,-1}^{T,\frac{1}{2}} - H_{\frac{1}{2},+1,0}^{T,-\frac{1}{2}*} H_{\frac{1}{2},t,1}^{T,-\frac{1}{2}} \right] \right\}
 \end{aligned}$$

$$\begin{aligned}
 K_{1ss} = & N \left[ |H_{-\frac{1}{2},-1}^{\text{VA}}|^2 + |H_{\frac{1}{2},+1}^{\text{VA}}|^2 + 2 \left( |H_{\frac{1}{2},0}^{\text{SP}}|^2 + |H_{-\frac{1}{2},0}^{\text{SP}}|^2 + |H_{-\frac{1}{2},0}^{\text{VA}}|^2 + |H_{\frac{1}{2},0}^{\text{VA}}|^2 \right) \right. \\
 & + 4 \left( |H_{\frac{1}{2},+1,0}^{T,-\frac{1}{2}}|^2 + |H_{-\frac{1}{2},-1,0}^{T,\frac{1}{2}}|^2 + |H_{-\frac{1}{2},t,-1}^{T,\frac{1}{2}}|^2 + |H_{\frac{1}{2},t,+1}^{T,-\frac{1}{2}}|^2 \right) + 8 \text{Re} \left[ H_{-\frac{1}{2},-1,0}^{T,\frac{1}{2}*} H_{-\frac{1}{2},t,-1}^{T,\frac{1}{2}} - H_{\frac{1}{2},+1,0}^{T,-\frac{1}{2}*} H_{\frac{1}{2},t,1}^{T,-\frac{1}{2}} \right] \\
 & + \frac{m_\ell}{\sqrt{q^2}} \left\{ 4 \text{Re} \left[ H_{-\frac{1}{2},0}^{\text{SP}*} H_{-\frac{1}{2},t}^{\text{VA}} + H_{\frac{1}{2},0}^{\text{SP}*} H_{\frac{1}{2},t}^{\text{VA}} \right] \right. \\
 & + 8 \text{Re} \left[ H_{-\frac{1}{2},0}^{\text{VA}*} H_{-\frac{1}{2},t,0}^{T,-\frac{1}{2}} - H_{-\frac{1}{2},0}^{\text{VA}*} H_{-\frac{1}{2},+1,-1}^{T,-\frac{1}{2}} - H_{\frac{1}{2},0}^{\text{VA}*} H_{\frac{1}{2},+1,-1}^{T,\frac{1}{2}} \right. \\
 & + H_{\frac{1}{2},0}^{\text{VA}*} H_{\frac{1}{2},t,0}^{T,\frac{1}{2}} + H_{-\frac{1}{2},-1,0}^{T,\frac{1}{2}} H_{-\frac{1}{2},-1}^{\text{VA}*} - H_{\frac{1}{2},+1,0}^{T,-\frac{1}{2}} H_{\frac{1}{2},+1}^{\text{VA}*} \\
 & \left. \left. + H_{-\frac{1}{2},-1}^{\text{VA}*} H_{-\frac{1}{2},t,-1}^{T,\frac{1}{2}} + H_{\frac{1}{2},+1}^{\text{VA}*} H_{\frac{1}{2},t,1}^{T,-\frac{1}{2}} \right] \right\} \\
 & + \frac{m_\ell^2}{q^2} \left\{ |H_{-\frac{1}{2},-1}^{\text{VA}}|^2 + |H_{\frac{1}{2},+1}^{\text{VA}}|^2 + 2 \left( |H_{-\frac{1}{2},t}^{\text{VA}}|^2 + |H_{\frac{1}{2},t}^{\text{VA}}|^2 \right) \right.
 \end{aligned}$$

- as  $\frac{d\Gamma}{dq^2} = 2K_{1ss} + K_{1cc}$
- in the decay rate terms the interference terms between the NP are coming proportional to  $m_\ell$
- so when we take only one  $C_i$  these terms are neglected
- for  $m_\ell = m_\tau$  these terms contribute much significantly

# Two parameter scenario fit results

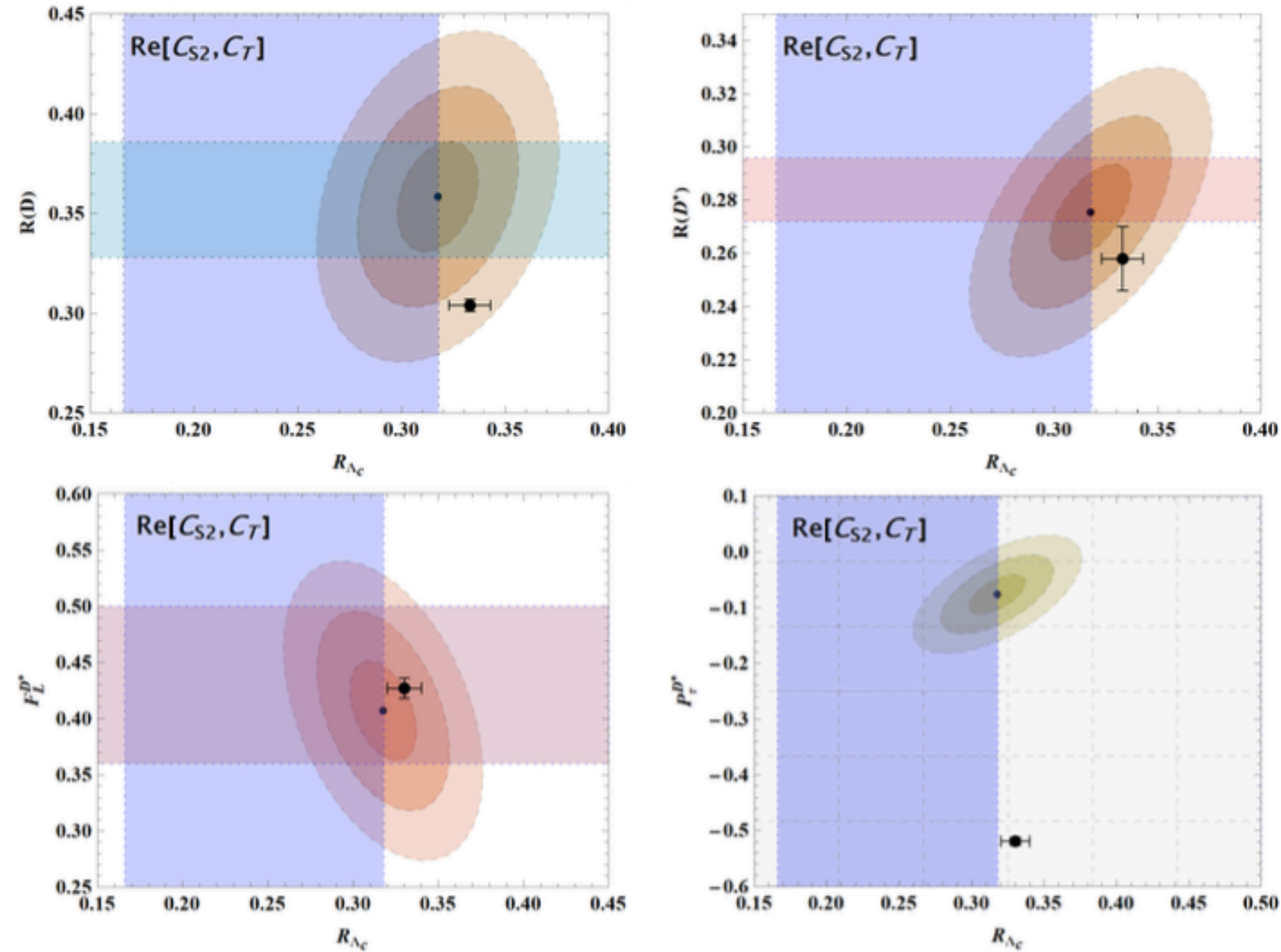
- all the 2 operator scenarios we can explain  $B \rightarrow D^{(*)}\tau^-\bar{\nu}$  observables
- the scenario with  $[\mathcal{O}_{S_2}, \mathcal{O}_T]$  is the only 2-op. scenario which could accommodate the data on  $R(\Lambda_c)$  alongside  $R(D)$ ,  $R(D^*)$ ,  $F_L^{D^*}$  within their  $1\sigma$ .
- also the best-fit scenario with largest p-value(67 %) among all others.

| 2 Operator Scenario | Two operator scenarios fit results |                   |                    | $\sigma_{dev}$ (in $\sigma$ ) |              |                    |                  |              |
|---------------------|------------------------------------|-------------------|--------------------|-------------------------------|--------------|--------------------|------------------|--------------|
|                     | WC fit results                     |                   | $\chi^2_{min}/DOF$ | P-Value                       | R(D)         | R(D <sup>*</sup> ) | R( $\Lambda_c$ ) | $F_L^{D^*}$  |
| $C_{S_1}, C_{S_2}$  | Re[ $C_{S_1}$ ]                    | -2.268(207)       | 3.432/3            | 0.330                         | 0.067        | 0.409              | 1.437            | 0.237        |
|                     | Re[ $C_{S_2}$ ]                    | 0.904(220)        |                    |                               |              |                    |                  |              |
| $C_{S_1}, C_T$      | Re[ $C_{S_1}$ ]                    | 0.098(46)         | 3.978/3            | 0.264                         | 0.038        | 0.526              | 1.494            | 0.010        |
|                     | Re[ $C_T$ ]                        | -0.014(19)        |                    |                               |              |                    |                  |              |
| $C_{S_2}, C_T$      | Re[ $C_{S_2}$ ]                    | <b>-1.255(64)</b> | <b>1.553/3</b>     | <b>0.670</b>                  | <b>0.039</b> | <b>0.391</b>       | <b>0.963</b>     | <b>0.278</b> |
|                     | Re[ $C_T$ ]                        | <b>0.226(32)</b>  |                    |                               |              |                    |                  |              |
| $C_{V_1}, C_{V_2}$  | Re[ $C_{V_1}$ ]                    | -0.978(32)        | 3.557/3            | 0.313                         | 0.113        | 0.303              | 1.503            | 0.013        |
|                     | Re[ $C_{V_2}$ ]                    | 1.055(23)         |                    |                               |              |                    |                  |              |
| $C_{V_1}, C_T$      | Re[ $C_{V_1}$ ]                    | 0.077(31)         | 2.827/3            | 0.419                         | 0.148        | 0.466              | 1.296            | 0.006        |
|                     | Re[ $C_T$ ]                        | 0.037(37)         |                    |                               |              |                    |                  |              |
| $C_{V_2}, C_T$      | Re[ $C_{V_2}$ ]                    | 0.080(53)         | 5.829/3            | 0.120                         | 0.435        | 0.560              | 1.634            | 0.389        |
|                     | Re[ $C_T$ ]                        | -0.059(28)        |                    |                               |              |                    |                  |              |
| $C_{S_1}, C_{V_1}$  | Re[ $C_{S_1}$ ]                    | 0.051(73)         | 3.534/3            | 0.316                         | 0.102        | 0.311              | 1.498            | 0.0004       |
|                     | Re[ $C_{V_1}$ ]                    | 0.033(34)         |                    |                               |              |                    |                  |              |
| $C_{S_1}, C_{V_2}$  | Re[ $C_{S_1}$ ]                    | 0.123(48)         | 3.511/3            | 0.319                         | 0.106        | 0.301              | 1.494            | 0.098        |
|                     | Re[ $C_{V_2}$ ]                    | -0.033(33)        |                    |                               |              |                    |                  |              |
| $C_{S_2}, C_{V_1}$  | Re[ $C_{S_2}$ ]                    | 0.045(65)         | 3.533/3            | 0.316                         | 0.101        | 0.311              | 1.496            | 0.079        |
|                     | Re[ $C_{V_1}$ ]                    | 0.038(29)         |                    |                               |              |                    |                  |              |
| $C_{S_2}, C_{V_2}$  | Re[ $C_{S_2}$ ]                    | 0.139(54)         | 3.474/3            | 0.324                         | 0.104        | 0.292              | 1.489            | 0.098        |
|                     | Re[ $C_{V_2}$ ]                    | -0.048(36)        |                    |                               |              |                    |                  |              |

# Prediction of Observables

| Scenarios                                | Observables/Predictions |                  |                  |                  |                  |            |
|--|-------------------------|------------------|------------------|------------------|------------------|------------|
|  | $R(D)$                  | $R(D^*)$         | $R(\Lambda_c)$   | $F_L^{D^*}$      | $P_\tau^{D^*}$   | $P_\tau^D$ |
| $\text{Re}[C_{S_1}], \text{Re}[C_{S_2}]$ | 0.354(29)               | 0.275(19)        | 0.354(19)        | 0.448(30)        | -0.463(77)       | 0.421(47)  |
| $\text{Re}[C_{S_1}], \text{Re}[C_T]$     | 0.355(29)               | 0.272(20)        | 0.361(24)        | 0.429(11)        | -0.496(14)       | 0.435(43)  |
| $\text{Re}[C_{S_2}], \text{Re}[C_T]$     | 0.359(28)               | 0.275(18)        | 0.318(19)        | 0.407(44)        | -0.076(38)       | 0.196(81)  |
| $\text{Re}[C_{V_1}], \text{Re}[C_T]$     | 0.363(29)               | 0.273(20)        | 0.345(24)        | 0.4304(90)       | -0.5319(95)      | 0.306(18)  |
| $\text{Re}[C_{V_2}], \text{Re}[C_T]$     | 0.339(29)               | 0.271(20)        | 0.374(27)        | 0.402(17)        | -0.474(28)       | 0.354(14)  |
| $\text{Re}[C_{V_1}], \text{Re}[C_{V_2}]$ | 0.352(29)               | 0.277(20)        | 0.360(18)        | 0.4291(94)       | -0.5197(66)      | 0.3238(27) |
| $\text{Re}[C_{S_1}], \text{Re}[C_{V_1}]$ | 0.353(29)               | 0.277(20)        | 0.359(19)        | 0.430(10)        | -0.511(13)       | 0.378(76)  |
| $\text{Re}[C_{S_1}], \text{Re}[C_{V_2}]$ | 0.353(29)               | 0.277(20)        | 0.359(18)        | 0.4370(100)      | -0.499(11)       | 0.455(47)  |
| $\text{Re}[C_{S_2}], \text{Re}[C_{V_1}]$ | 0.353(29)               | 0.277(20)        | 0.359(19)        | 0.4244(97)       | -0.526(12)       | 0.373(68)  |
| $\text{Re}[C_{S_2}], \text{Re}[C_{V_2}]$ | 0.353(29)               | 0.277(20)        | 0.358(18)        | 0.4231(94)       | -0.5387(92)      | 0.472(52)  |
| <b>Measurement</b>                       | <b>0.357(29)</b>        | <b>0.284(13)</b> | <b>0.242(76)</b> | <b>0.430(70)</b> | <b>-0.38(54)</b> | N.A        |

# Correlation b/w observables



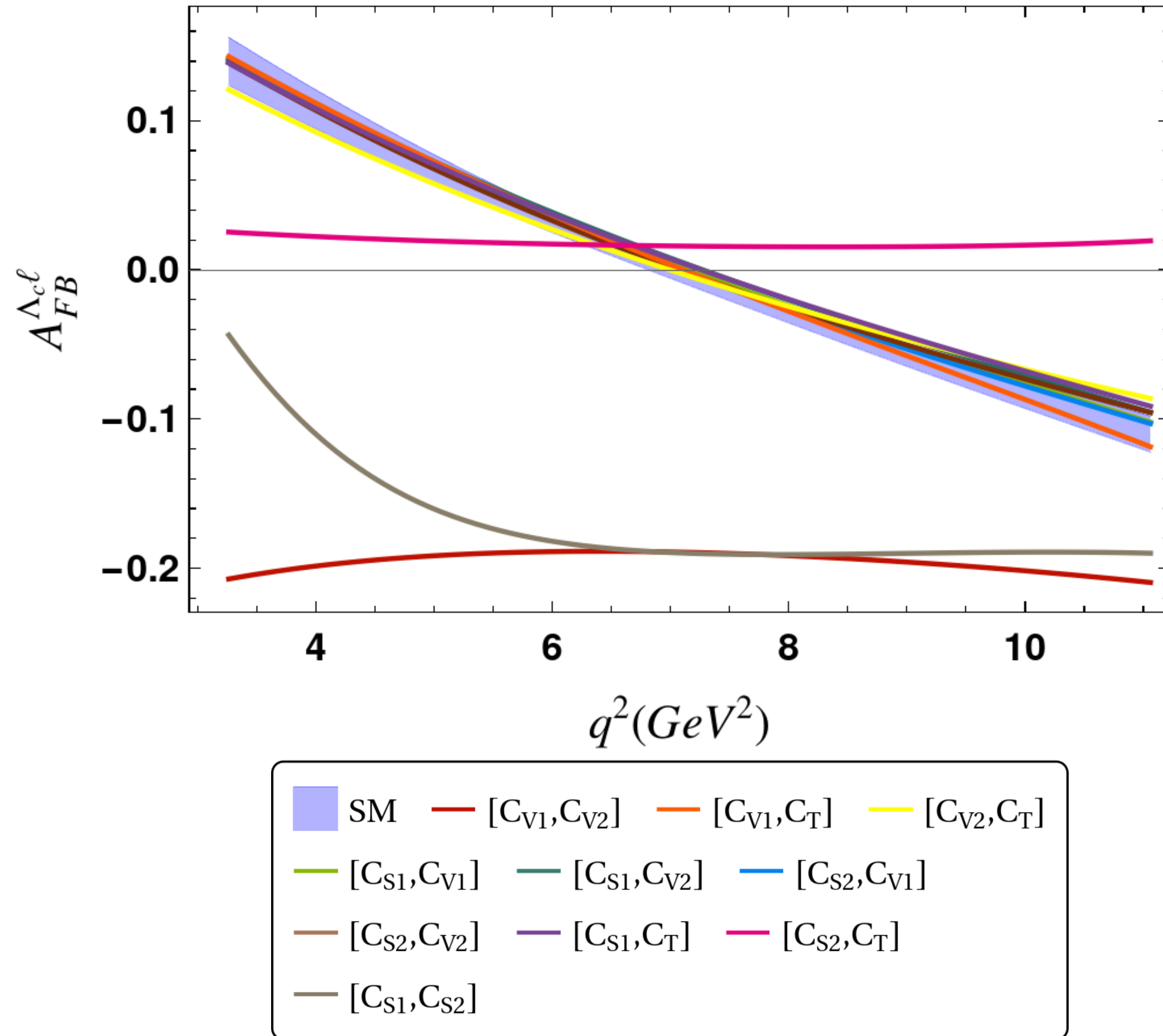
- the correlation plots indicates that we can comfortably explain  $R(D)$ ,  $R(D^*)$ ,  $R_{\Lambda_c}$  and  $F_L^{D^*}$  along with  $P_\tau^{D^*}$

# deviation for observables of $\Lambda_b \rightarrow \Lambda_c$

| Scenario             | Deviations w.r.t. SM predictions (in $\sigma$ level) |                 |                 |                 |                 |                |               |                           |                      |                 |                        |              |
|----------------------|--|-----------------|-----------------|-----------------|-----------------|----------------|---------------|---------------------------|----------------------|-----------------|------------------------|--------------|
|                      | $\hat{K}_{1cc}$                                      | $\hat{K}_{1ss}$ | $\hat{K}_{2cc}$ | $\hat{K}_{2ss}$ | $\hat{K}_{3sc}$ | $\hat{K}_{3s}$ | $A_{FB}^\ell$ | $A_{FB}^{\Lambda_c \tau}$ | $A_{FB}^{\Lambda_c}$ | $P_{\Lambda_c}$ | $P_\tau^{(\Lambda_c)}$ | $C_P^\ell$   |
| $[C_{S_1}, C_{S_2}]$ | 0.354  | 0.819           | 0.193           | 0.082           | 0.277           | <b>4.22</b>    | <b>20.051</b> | <b>9.856</b>              | 0.161                | 0.16            | 0.806                  | 0.60         |
| $[C_{S_1}, C_T]$     | 0.894  | 0.819           | 0.24            | 0.288           | 0.354           | 0.664          | 0.983         | 0.647                     | 0.364                | 0.714           | 1.574                  | 0.868        |
| $[C_{S_2}, C_T]$     | <b>3.328</b>   | <b>4.915</b>    | <b>6.209</b>    | <b>5.794</b>    | <b>2.683</b>    | <b>2.507</b>   | <b>6.116</b>  | 0.2                       | <b>7.343</b>         | <b>7.532</b>    | <b>8.831</b>           | <b>4.389</b> |
| $[C_{V_1}, C_{V_2}]$ | 0.   | 0.              | <b>13.133</b>   | <b>13.136</b>   | <b>12.021</b>   | <b>4.468</b>   | <b>19.279</b> | <b>9.753</b>              | <b>18.11</b>         | <b>70.863</b>   | 0.472                  | 0.236        |
| $[C_{V_1}, C_T]$     | 0.555  | 0.819           | 0.44            | 0.453           | 0.277           | 0.547          | 0.123         | 0.651                     | 0.602                | 1.317           | 0.451                  | 0.745        |
| $[C_{V_2}, C_T]$     | 0.447  | 0.819           | 0.901           | 0.899           | 0.832           | 0.868          | 1.057         | 0.108                     | 1.185                | 1.805           | 1.143                  | 0.589        |
| $[C_{S_1}, C_{V_1}]$ | 0.354  | 0.              | 0.              | 0.              | 0.              | 0.39           | 0.43          | 0.462                     | 0.                   | 0.              | 0.636                  | 0.217        |
| $[C_{S_1}, C_{V_2}]$ | 0.894  | 0.819           | 0.096           | 0.136           | 0.354           | 0.208          | 0.921         | 0.7                       | 0.188                | 0.786           | 1.611                  | 0.868        |
| $[C_{S_2}, C_{V_1}]$ | 0.   | 0.              | 0.064           | 0.054           | 0.              | 0.469          | 0.193         | 0.325                     | 0.081                | 0.324           | 0.572                  | 0.118        |
| $[C_{S_2}, C_{V_2}]$ | 0.894  | 0.819           | 0.354           | 0.36            | 0.354           | 0.139          | 0.064         | 0.217                     | 0.497                | 1.658           | 1.089                  | 0.759        |

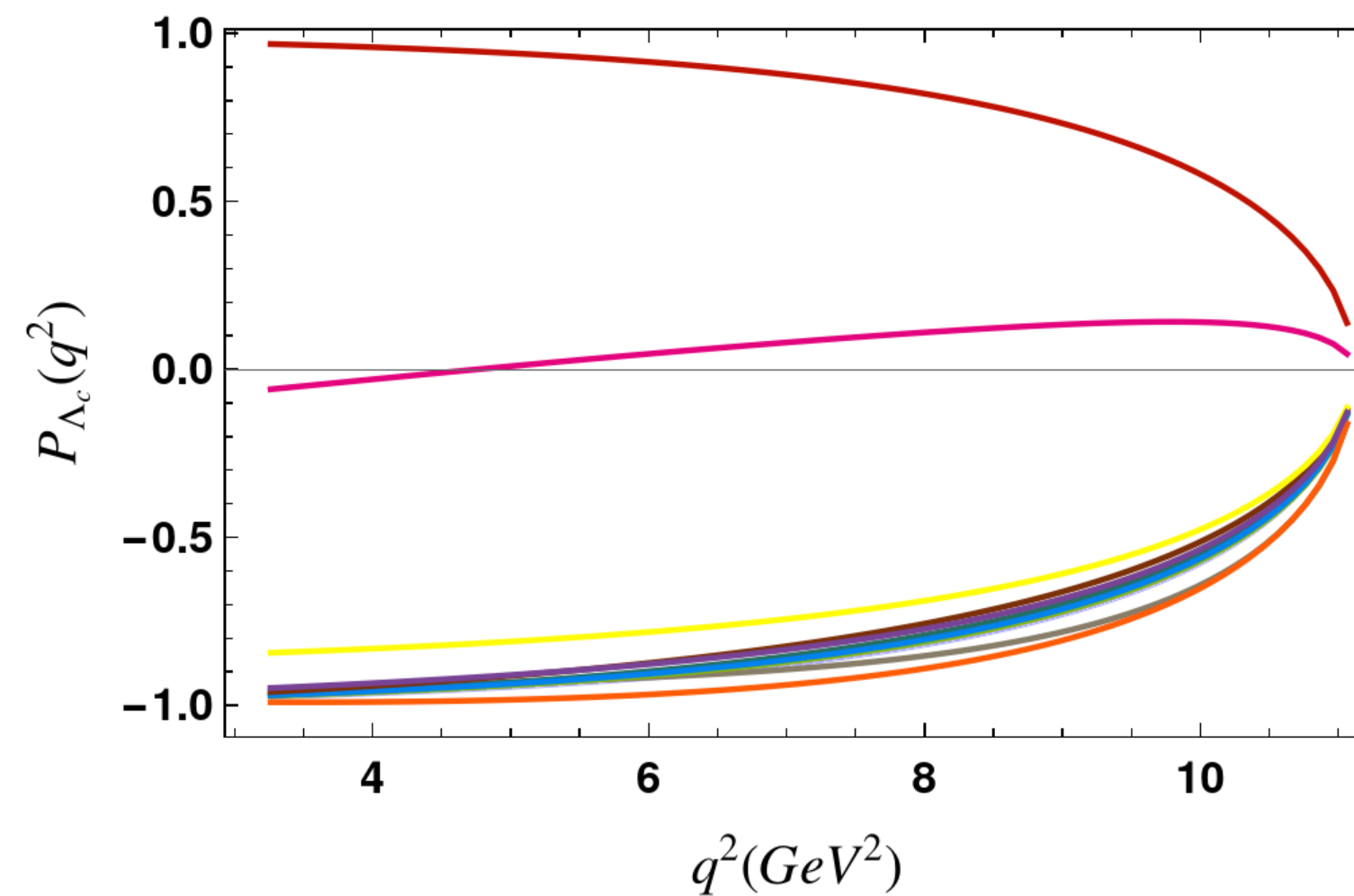
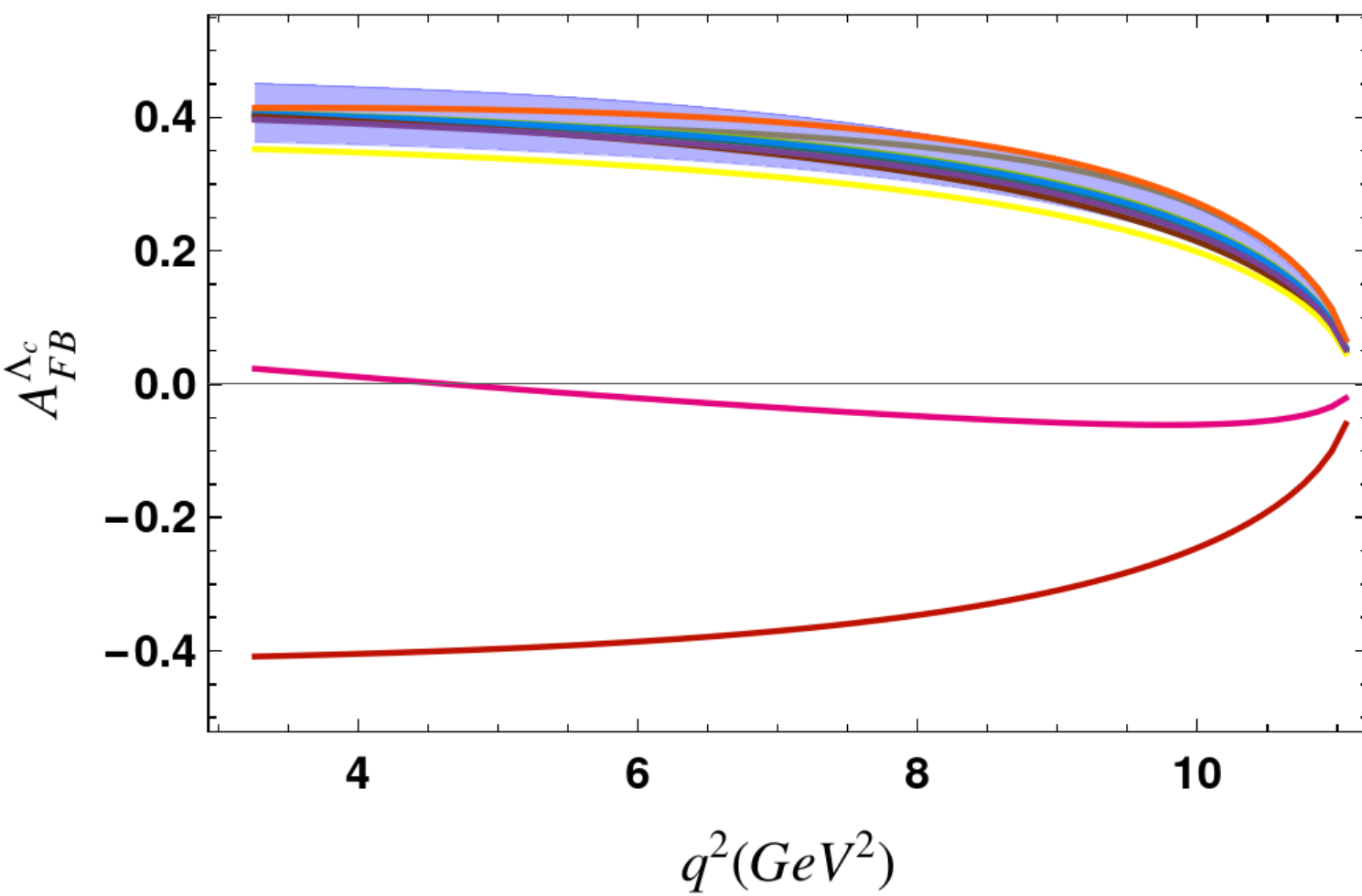
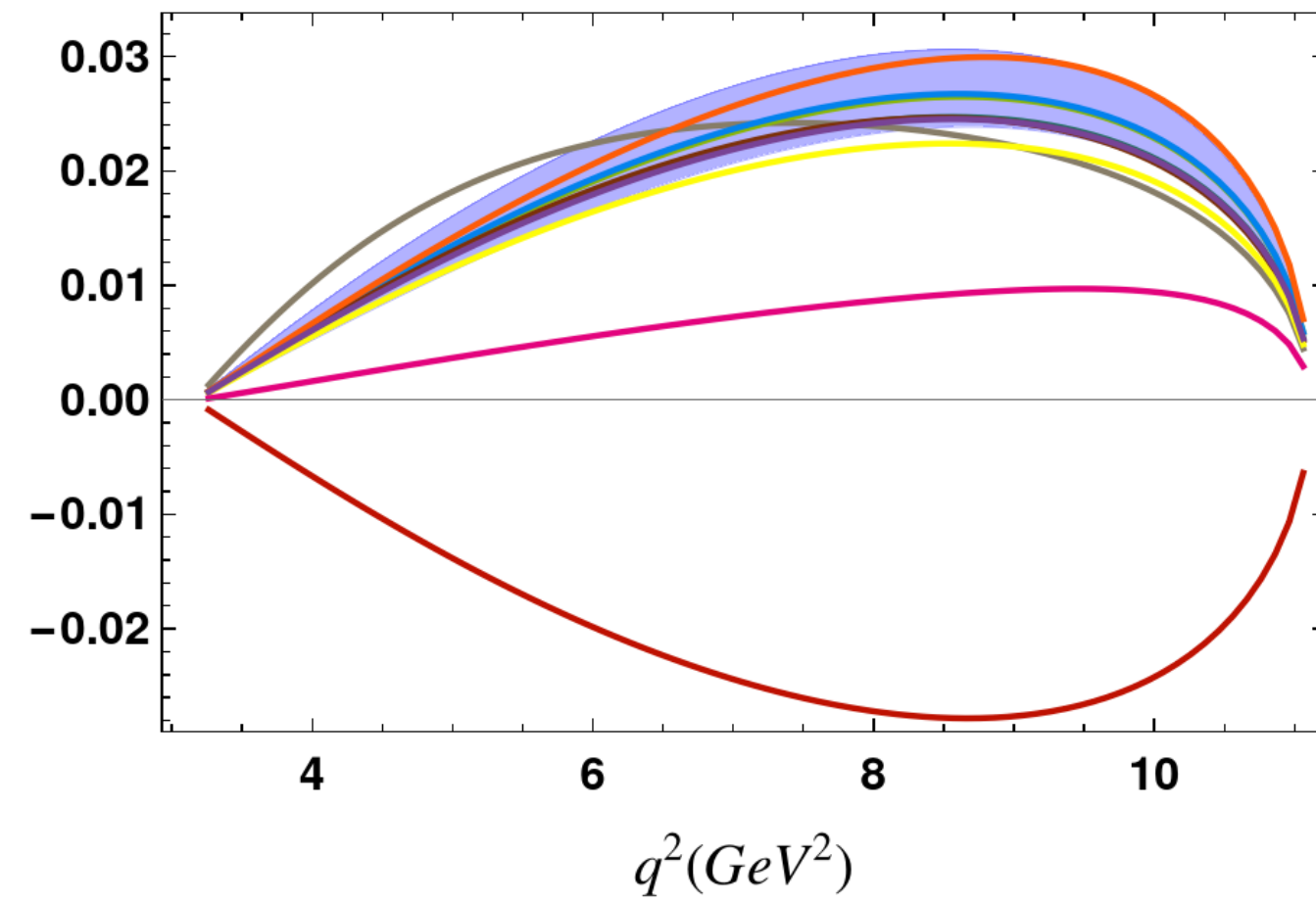
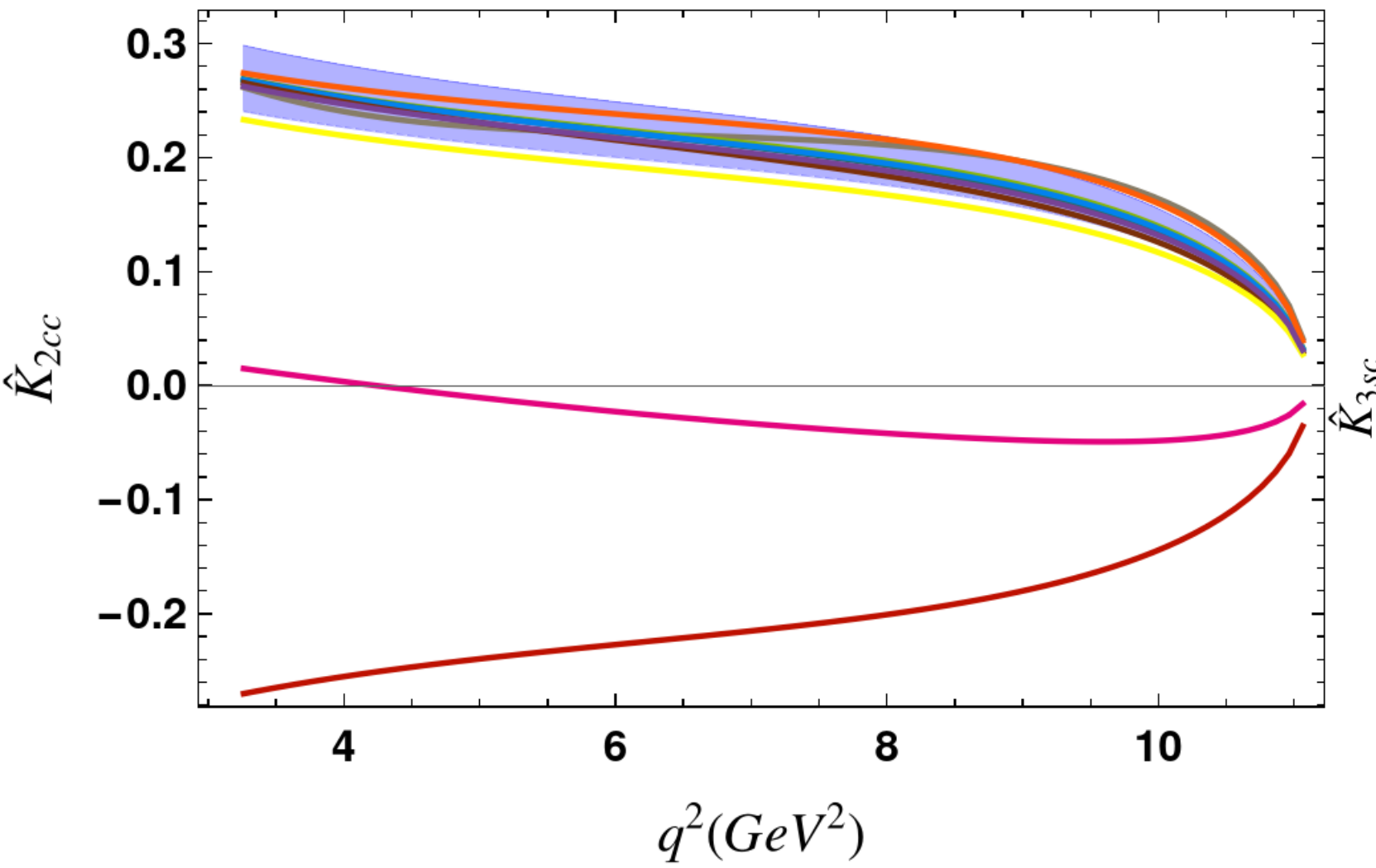
- apart from  $A_{FB}^{\Lambda_c \ell}$  all the observable show significant deviation for  $[\mathcal{O}_{S_2}, \mathcal{O}_T]$  scenario
- in  $[\mathcal{O}_{V_1}, \mathcal{O}_{V_2}]$  scenario significant deviation can be seen

# $A_{FB}^{\Lambda_c \ell}$ prediction in full $q^2$

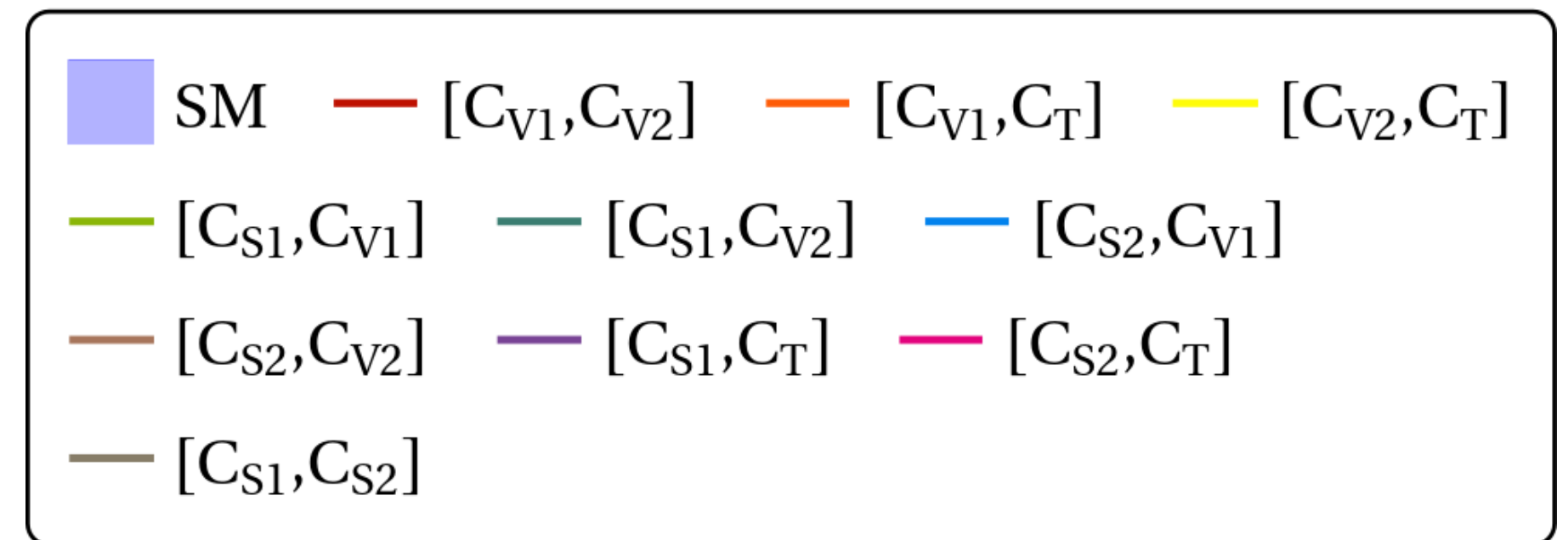


- very important observable but not discussed in literature
- in SM, zero crossing is there
- for  $[\mathcal{O}_{S_2}, \mathcal{O}_T]$  the  $q^2$  integrated  $A_{FB}^{\Lambda_c \tau}$  are consistent with the SM.
- due to a relative cancellation in high and low  $q^2$  region, the  $q^2$  integrated value becomes very small and consistent with the respective NP prediction.
- in both the high and low  $q^2$  regions, NP predictions have discrepancies with SM.
- so only  $q^2$  integrated value is not sufficient: bin predictions are needed

# Angular obs for $\Lambda_b \rightarrow \Lambda_c \tau \bar{\nu}$



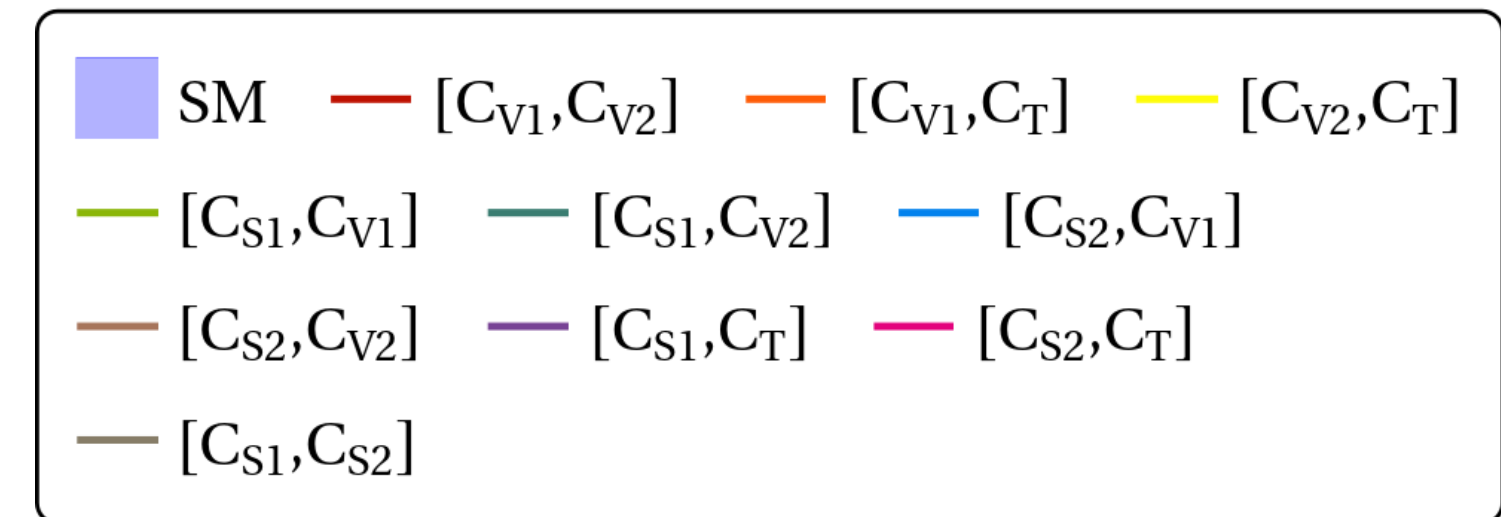
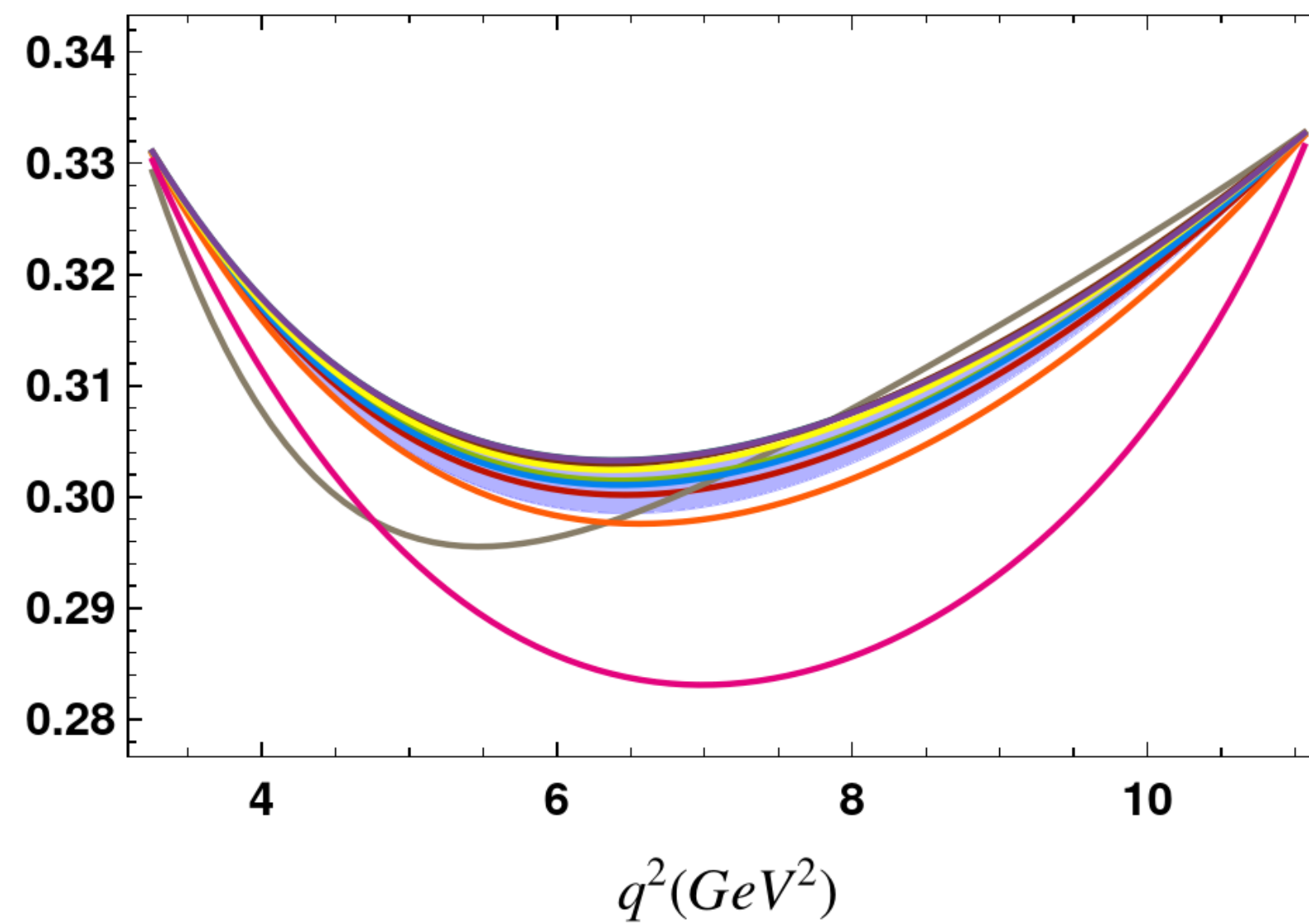
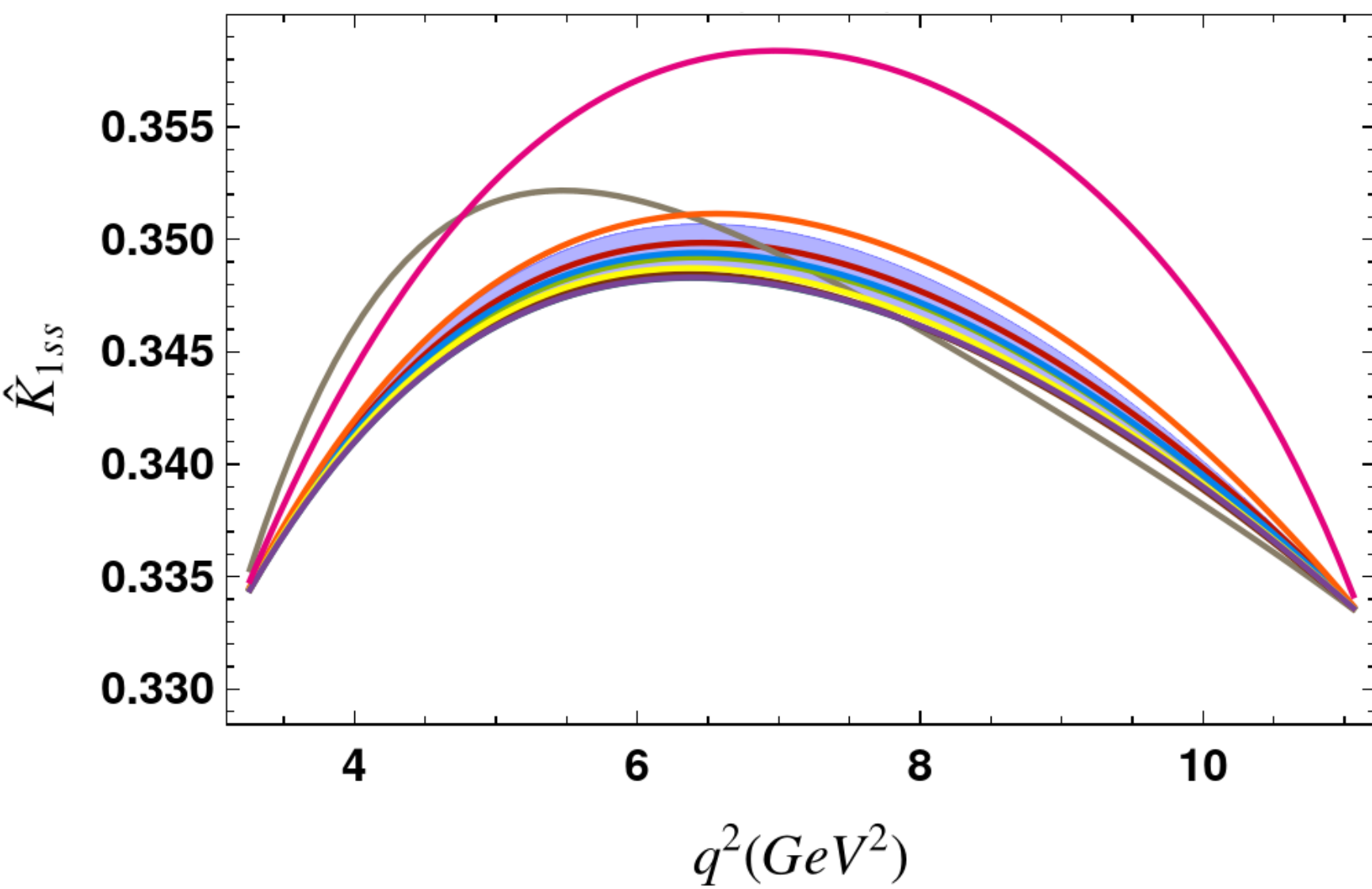
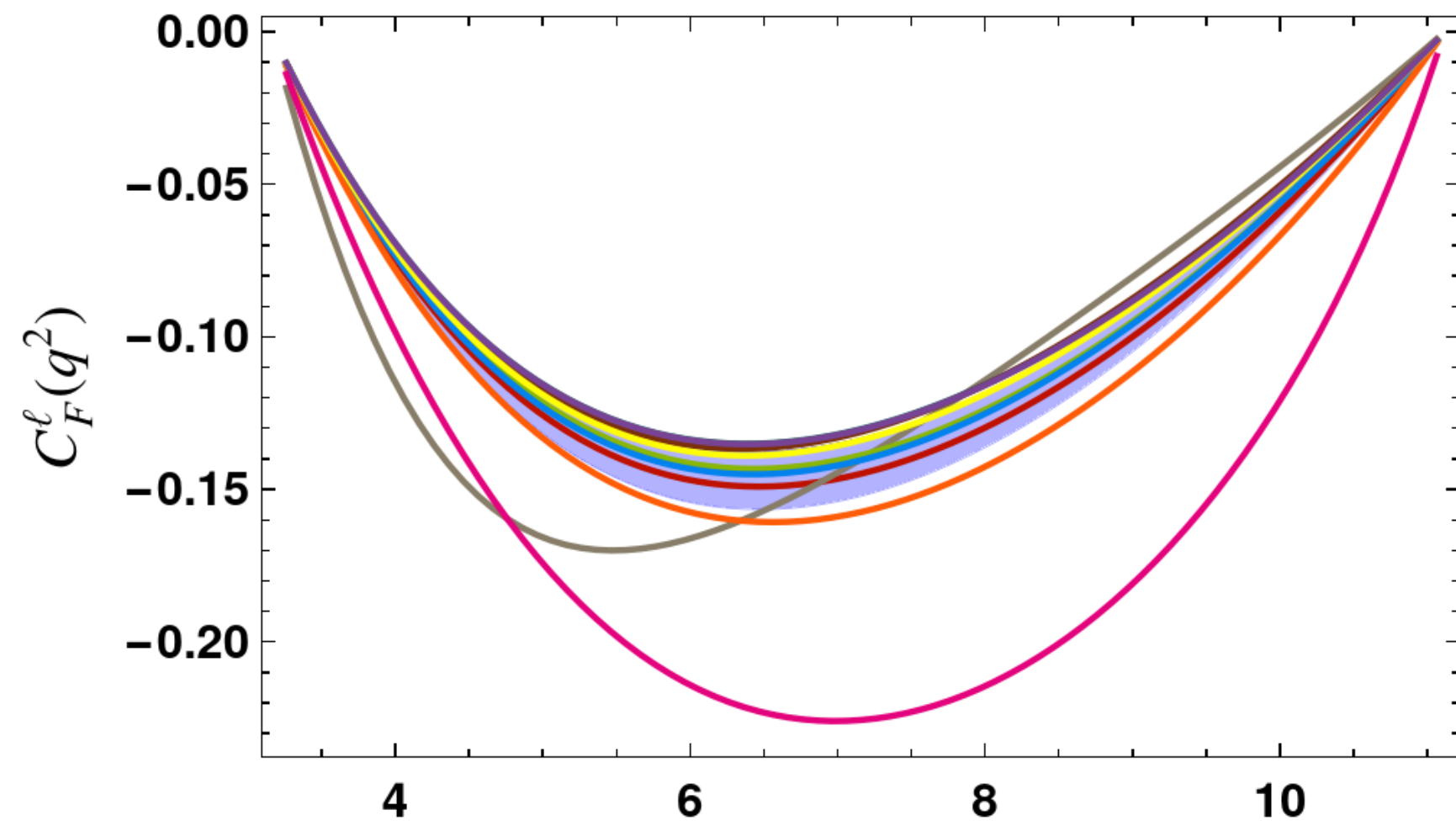
- In the scenario  $[\mathcal{O}_{V_1}, \mathcal{O}_{V_2}]$ , the predictions for  $A_{FB}^{\Lambda_c}$ ,  $P_{\Lambda_c}$ ,  $\hat{K}_{2SS}$ ,  $\hat{K}_{2CC}$  and  $\hat{K}_{3SC}$  have opposite sign of the respective SM predictions different
- for  $[\mathcal{O}_{S_2}, \mathcal{O}_T]$  they show deviation





# Observable predictions

- If the measurements show deviations only in  $C_F^\tau$ ,  $\hat{K}_{1cc}$  and  $\hat{K}_{1ss}$  this could be an indication for contributions from  $[\mathcal{O}_{S_2}, \mathcal{O}_T]$ .



# Summary

- We discussed the full 4-body angular distribution for the decay
- various asymmetric and angular observables from the angular analysis  $\Lambda_b \rightarrow \Lambda_c^+ (\rightarrow \Lambda\pi)\tau^- \bar{\nu}$  decay
- Using the available data on  $B \rightarrow D^{(*)}\ell^- \bar{\nu}$  decays and  $R(\Lambda_c)$ , we have extracted the new Wilson coefficients and noticed that only the  $C_{S_2}, C_{V_2}$  one operator scenario can explain all these data simultaneously within  $3\sigma$
- We have done the fits to data using two different operator scenarios and found that scenario  $[\mathcal{O}_{S_2}, \mathcal{O}_T]$  is the only two operator scenarios which could accommodate comfortably all the measured data simultaneously
- In the other two operator scenarios, apart from  $R(D^*)$ , we are able to explain all the other data simultaneously if we take the uncertainties of our predictions at the  $3\sigma$  level.
- We have studied the interesting correlations between the observables in different NP scenarios.
- we have also discussed the NP sensitivities of all the angular and asymmetric observables in all the two operator scenarios and found that many of them show distinguishable sensitivity to the operators  $[\mathcal{O}_{S_2}, \mathcal{O}_T]$ ,  $[\mathcal{O}_{V_1}, \mathcal{O}_{V_2}]$ .

**Thank You!**